SpacePy Documentation

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The SpacePy Team

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SpacePy is a package for Python, targeted at the space sciences, that aims to make basic data analysis, modeling and visualization easier. It builds on the capabilities of the well-known NumPy and MatPlotLib packages. Publication quality output direct from analyses is emphasized among other goals:

- Quickly obtain data
- Create publications quality plots
- Perform complicated analysis easily
- Run common empirical models
- Change coordinates effortlessly
- Harness the power of Python

The SpacePy project seeks to promote accurate and open research standards by providing an open environment for code development. In the space physics community there has long been a significant reliance on proprietary languages that restrict free transfer of data and reproducibility of results. By providing a comprehensive, open-source library of widely-used analysis and visualization tools in a free, modern and intuitive language, we hope that this reliance will be diminished.

When publishing research which used SpacePy, please provide appropriate credit to the SpacePy team via citation or acknowledgment.

To cite SpacePy in publications, use (BibTeX code): @INPROCEEDINGS{spacepy11, author = {{Morley}, S.~K. and {Koller}, J. and {Welling}, D.~T. and {Larsen}, B.~A. and {Henderson}, M.~G. and {Niehof}, J.~T.}, title = "{Spacepy - A Python-based library of tools for the space sciences}", booktitle = "{Proceedings of the 9th Python in science conference (SciPy 2010)}", year = 2011, address = {Austin, TX} }

Or to cite the code itself: @software{SpacePy, author = {{Larsen}, B.~A. and {Morley}, S.~K. and {Niehof}, J.~T. and {Welling}, D.~T.}, title = {SpacePy}, publisher = {Zenodo}, doi = {10.5281/zenodo.3252523}, url = {https://doi.org/10.5281/zenodo.3252523} }

Certain modules may provide additional citations in the `__citation__` attribute. Contact a module's author (details in the `__citation__` attribute) before publication or public presentation of analysis performed by that module, or in case of questions about the module. This allows the author to validate the analysis and receive appropriate credit for his or her work.

CHAPTER

ONE

GETTING STARTED

First steps in SpacePy and scientific Python.

1.1 Installing SpacePy

The simplest way from zero (no Python) to a working SpacePy setup is:

1. Install the Anaconda Python environment. Python 3 is strongly recommended (64-bit is recommended).
2. `pip install --upgrade spacepy`

If you already have a working Python setup, install SpacePy by:

1. `pip install --upgrade numpy`
2. `pip install --upgrade spacepy`

This will install a binary build of SpacePy if available (currently only on Windows), otherwise it will attempt to compile. It will also install most dependencies.

`numpy` must be installed first as it's required for the SpacePy build. See *Windows Installation* for important notes regarding numpy on Windows.

If you are familiar with installing Python packages, have particular preferences for managing an installation, or if the above doesn't work, refer to platform-specific instructions and the details below.

For installing the NASA CDF library to support *`pycdf`*, see the platform-specific instructions linked below.

The first time a user imports SpacePy, it automatically creates the *configuration directory*.

If you need further assistance, you can open an issue.

1.1.1 SpacePy Dependencies

SpacePy relies on several other pieces of software for complete functionality. *Installing SpacePy* links to details on installing the required software for each platform.

Unless otherwise noted, a dependency may be installed *after* SpacePy, and the new functionality will be available the next time SpacePy is imported.

Currently required versions are documented here. *Dependency version support* describes future support.

Hard Dependencies

Without these packages installed, SpacePy will not function.

Python 2.7+

Python is the core language for SpacePy. Python 3 is strongly recommended and will be required soon. See *Python 2 End of Support*.

Required to install SpacePy.

NumPy 1.10+

NumPy provides the high-performance array data structure used throughout SpacePy. Version 1.10 or later is required.

Required to install SpacePy. f2py is part of NumPy, but is sometimes packaged separately; it is required (at installation time) if `irbempy` is to be used.

Due to a numpy bug, numpy 1.15.0 is not supported. Use 1.15.1 or later.

On Python 3.9, numpy 1.18 or later is required.

dateutil

If you choose not to install *matplotlib*, dateutil 1.4 or later is required. (Installing matplotlib will fulfill this dependency.)

C compiler

If you are installing SpacePy from source, a working C compiler is required. (Not necessary for the Windows binary installer.)

Soft Dependencies

Without these packages, SpacePy will install, but certain features may not be available. Usually an ImportError means a dependency is missing.

These are simply marked as dependencies in SpacePy metadata and thus will be automatically installed when using dependency-resolving methods such as pip.

SciPy 0.11+

SciPy provides several useful scientific and numerical functions build on top of NumPy. It is highly recommended. The following modules may have limited functionality without SciPy:

- `coordinates`
- `ctrans`
- `empiricals`
- `seapy`
- `toolbox`

matplotlib 1.5.0+

matplotlib is the preferred plotting package for Python. It is highly recommended. Without it, you will not be able to effectively visualize data, and the following modules may have limited functionality or fail entirely:

- *plot*
- *poppy*
- *pybats*
- *radbelt*
- *seapy*
- *toolbox*

h5py 2.6+

h5py provides a Python interface to HDF5 files. It is required for the HDF import/export capability of *datamodel* and for use of the *omni* module.

CDF 2.7+

NASA's CDF library provides access to Common Data Format files. It is required for *pycdf*, and thus for the CDF import/export capability of *datamodel*.

Warning: Unlike the Python-based dependencies, the CDF library must be installed if pycdf support is needed; it will not be automatically installed.

Fortran compiler

If installing from source, *irbempy* requires a Fortran compiler. (This is not required for the Windows binary installer). Supported compilers are the GNU compiler `gfortran`, the older GNU compiler `g77`, and the Portland Group PGI compiler.

If *irbempy* is to be used, the Fortran compiler (and f2py) must be installed before SpacePy.

coordinates requires *irbempy* to use the IRBEM-based backend, but the new CTrans-based backend can be used without Fortran. See the *coordinates* documentation for the `use_irbem` option.

Astropy 1.0+

time requires Astropy if conversion to/from Astropy `Time` is desired.

coordinates requires Astropy if conversion to/from Astropy `SkyCoord` is desired.

Soft Dependency Summary

The following table summarizes, by SpacePy module, the functionality that is *lost* if a soft dependency is not installed. If there is nothing for a given dependency/module combination, the module is unaffected by that dependency.

Table 1: SpacePy functionality lost without soft dependencies

	CDF	Fortran compiler	h5py	matplotlib	SciPy	AstroPy
coordinates		Coords IRBEM backend (except Windows binaries)			Entire module	• from_skycoord() • to_skycoord()
ctrans					Entire module	
datamodel	• toCDF() • fromCDF() • toCDF()		• toHDF5() • fromHDF5() • toHDF5()			
empiricals					• vampolaPA() • omniFromDirectionalFlux()	
irbempy		Entire module (except Windows binaries)				
LANLstar		May be required to install ffnet.				
omni			Entire module			
plot				Entire module		
poppy				• assoc() • plot() • plot_mult() • plot_two_ppro()		
pybats				• regrid() • dgcpm • interact • kyoto • pwom • ram • rim		
				All plotting functions: • add_body()		

1.1.2 Linux Installation

Installation on Linux requires both a C and a Fortran compiler; a recent GCC is recommended (the C compiler is likely included with your distribution). On Debian and Ubuntu:

```
sudo apt-get install gfortran
```

Once this is set up, `pip install spacepy` should Just Work. If you're installing as a single user (not in a virtual environment) then add the `--user` flag.

You will also need the *NASA CDF library* to use `pycdf`.

Our recommended (but not required) Python distribution is Anaconda running 64-bit Python 3. Anaconda includes much of the scientific Python stack. Another excellent distribution is Canopy.

You may need to install the dependencies some way other than pip; for example, if you are running an earlier version of Python. The latest version of many dependencies requires Python 3.6 and pip will not install older versions to get around this. See *Dependencies via conda* and *Dependencies via system packages*.

- *Dependencies via conda*
- *Dependencies via system packages*
- *CDF*
- *Compiling*

Dependencies via conda

Installation via `pip` will automatically install most Python dependencies (but not the *NASA CDF library*). They can also be installed from conda:

```
conda install numpy scipy matplotlib h5py
```

Dependencies via system packages

SpacePy usually works with the system Python on Linux. To install dependencies via the package manager on Debian or Ubuntu:

```
sudo apt-get install python-dev python-h5py python-matplotlib python-numpy python-scipy
```

For Python 3, use:

```
sudo apt-get install python3-dev python3-h5py python3-matplotlib python3-numpy python3-
↪scipy
```

For other distributions, check *SpacePy Dependencies* and install by hand or via your package manager.

CDF

It is recommended to install the ncurses library; on Ubuntu and Debian:

```
sudo apt-get install ncurses-dev
```

Download the latest CDF library. Choose the file ending in `-dist-all.tar.gz` from the `linux` directory. Untar and cd into the resulting directory. Then build:

```
make OS=linux ENV=gnu CURSES=yes FORTRAN=no UCOPTIONS=-O2 SHARED=yes all
```

Use `CURSES=no` if the curses library is not installed. (The distribution-specific directions above will install curses.)

Install:

```
sudo make install
```

This will install the library into the default location `/usr/local/cdf`, where SpacePy can find it. If you choose to install elsewhere, see the CDF documentation, particularly the notes on the `CDF_BASE` and `CDF_LIB` environment variables. SpacePy uses these variables to find the library.

Compiling

With the dependencies installed, SpacePy can be built from source. This uses standard Python distutils. You can always get the latest source code for SpacePy from our github repository and the latest release from PyPI

Build:

```
python setup.py build
```

If this fails, specify a Fortran compiler:

```
python setup.py build --fcompiler=gnu95
```

`python setup.py build --help-fcompiler` will list options for Fortran compilers. Currently available compilers are `pg`, `gnu95`, `gnu`, `intelem`, `intel` or `none` (to skip all Fortran); `gnu95` (the GNU gfortran compiler) is recommended.

Install for one user:

```
python setup.py install --user
```

If you're using conda, installation as user isn't recommended:

```
python setup.py install
```

Or install for all users on the system:

```
sudo python setup.py install
```

If you want to build the documentation yourself (rather than using the documentation shipped with SpacePy), install sphinx and numpydoc. The easiest way is via pip:

```
pip install sphinx numpydoc
```

They are also available via conda:

```
conda install sphinx numpydoc
```

Or the package manager:

sudo apt-get install python-sphinx python-numpydoc

For Python 3:

sudo apt-get install python3-sphinx python3-numpydoc

1.1.3 MacOS Installation

The following are performed from the command line on OSX.

Installation on OSX requires a C compiler:

```
xcode-select --install
```

Our recommended (but not required) Python distribution is Anaconda running 64-bit Python 3. Anaconda includes much of the scientific Python stack. Another excellent distribution is Canopy.

Once python is installed (Anaconda assumed) install the Fortran compiler:

```
conda install gfortran_osx-64
```

Dependencies via conda and pip

Installation via `pip` will automatically install most Python dependencies (but not the *NASA CDF library*). They can also be installed from conda:

```
conda install numpy scipy matplotlib h5py
```

Once this is set up, `pip install spacepy` should just work. If you're installing as a single user (not in a virtual environment) then add the `--user` flag.

You will also need the *NASA CDF library* to use *pycdf*.

To install the latest code from the repository, rather than the latest stable release, use:

```
pip install git+https://github.com/spacepy/spacepy
```

1.1.4 Windows Installation

The SpacePy team currently provides binary "wheels" via PyPI so it can be installed on Windows without a compiler. Binaries are provided for Python 3.6 through 3.10 in 64-bit and 32-bit variants for each. `pip install spacepy` should find and install these binaries.

Our recommended (but not required) Python distribution is Anaconda running 64-bit Python 3. Anaconda includes much of the scientific Python stack. Another excellent distribution is Canopy.

You may need to install the dependencies some way other than pip; for example, if you are running an earlier version of Python. The latest version of many dependencies requires Python 3.6 and pip will not install older versions to get around this. See *Dependencies via conda*.

- *Compiling*
- *NASA CDF*
- *Dependencies via conda*
- *Standalone dependencies*
- *Developers*

Compiling

If a binary wheel is not available for your version of Python, `pip` will try to compile SpacePy. The only supported compiler is `mingw32`. Install it with:

```
conda install m2w64-gcc-fortran libpython
```

This is also required if installing from a source distribution or git checkout.

irbempy requires Fortran to compile and the only supported compiler is `gnu95`; this is the default and provided by `m2w64-gcc-fortran`.

If you have difficulties, it may be useful to reference the build scripts the SpacePy developers use.

NASA CDF

pycdf requires the NASA CDF library . Binary installers are available for Windows; be sure to pick the version that matches your Python installation. The current 32-bit version is cdf37_1_0-setup-32.exe; for 64-bit, cdf37_1_0-setup-64.exe.

This is a simple self-extracting installer that can be installed either before or after installing SpacePy.

Dependencies via conda

Installation via `pip` will automatically install most Python dependencies (but not the *NASA CDF library*). They can also be installed from conda:

```
conda install numpy scipy matplotlib h5py
```

Standalone dependencies

Most of the *SpacePy Dependencies* have Windows installers available via their pages, but `pip` or `conda` are recommended instead.

Developers

If you want to build the documentation yourself (rather than using the documentation shipped with SpacePy), install sphinx and numpydoc. The easiest way is via pip:

```
pip install sphinx numpydoc
```

They are also available via conda:

```
conda install sphinx numpydoc
```

SpacePy installs with the common Python distutils and pip.

The latest stable release is provided via PyPI To install from PyPI, make sure you have pip installed:

```
pip install --upgrade spacepy
```

If you are installing for a single user, and are not working in a virtual environment, add the `--user` flag when installing with pip.

Source releases are available from PyPI and our github. Development versions are on github.

After downloading and unpacking, run (a virtual environment, such as a conda environment, is recommended):

```
python setup.py install
```

or, to install for all users (not in a virtual environment):

```
sudo python setup.py install
```

or, to install for a single user (not in a virtual environment):

```
python setup.py install --user
```

If you do not have administrative privileges, or you will be developing for SpacePy, we strongly recommend using virtual environments.

To install in custom location, e.g.:

```
python setup.py install --home=/n/packages/lib/python
```

Installs using `setup.py` do not require setuptools.

1.2 SpacePy - A Quick Start Documentation

The SpacePy Team (Steve Morley, Josef Koller, Dan Welling, Brian Larsen, Jon Niehof, Mike Henderson)

1.2.1 Installation

See *Installing SpacePy*.

1.2.2 Toolbox - A Box Full of Tools

Contains tools that don't fit anywhere else but are, in general, quite useful. The following functions are a selection of those implemented:

- *windowMean()*: windowing mean with variable window size and overlap
- *dictree()*: pretty prints the contents of dictionaries (recursively)
- *loadpickle()*: single line convenience routine for loading Python pickles
- *savepickle()*: same as loadpickle, but for saving
- *update()*: updates the OMNI database and the leap seconds database (internet connection required)
- *tOverlap()*: find interval of overlap between two time series
- *tCommon()*: find times common to two time series
- *binHisto()*: calculate number of bins for a histogram
- *medAbsDev()*: find the median absolute deviation of a data series
- *normalize()*: normalize a data series
- `feq()`: floating point equals

Import this module as:

```
>>> import spacepy.toolbox as tb
```

Examples:

```
>>> import spacepy.toolbox as tb
>>> a = {'entry1':'val1', 'entry2':2, 'recurse1':{'one':1, 'two':2}}
>>> tb.dictree(a)
+
|____entry1
|____entry2
|____recurse1
     |____one
     |____two
>>> import numpy as np
>>> dat = np.random.random_sample(100)
>>> tb.binHisto(dat)
(0.19151723370512266, 5.0)
```

1.2.3 Time and Coordinate Transformations

Import the modules as:

```
>>> import spacepy.time as spt
>>> import spacepy.coords as spc
```

Ticktock Class

The Ticktock class provides a number of time conversion routines and is implemented as a container class built on the functionality of the Python datetime module. The following time coordinates are provided

- UTC: Coordinated Universal Time implemented as a `datetime.datetime`
- ISO: standard ISO 8601 format like `2002-10-25T14:33:59`
- TAI: International Atomic Time in units of seconds since Jan 1, 1958 (midnight) and includes leap seconds, i.e. every second has the same length
- JD: Julian Day
- MJD: Modified Julian Day
- UNX: UNIX time in seconds since Jan 1, 1970
- RDT: Rata Die Time (Gregorian Ordinal Time) in days since Jan 1, 1 AD midnight
- CDF: CDF Epoch time in milliseconds since Jan 1, year 0
- DOY: Day of Year including fractions
- leaps: Leap seconds according to ftp://maia.usno.navy.mil/ser7/tai-utc.dat

To access these time coordinates, you'll create an instance of a Ticktock class, e.g.:

```
>>> t = spt.Ticktock('2002-10-25T12:30:00', 'ISO')
```

Instead of ISO you may use any of the formats listed above. You can also use numpy arrays or lists of time points. `t` has now the class attributes:

```
>>> t.dtype = 'ISO'
>>> t.data = '2002-10-25T12:30:00'
```

FYI `t.UTC` is added automatically.

If you want to convert/add a class attribute from the list above, simply type e.g.:

```
>>> t.RTD
```

You can replace RTD with any from the list above.

You can find out how many leap seconds were used by issuing the command:

```
>>> t.getleapsecs()
```

Timedelta Class

You can add/subtract time from a Ticktock class instance by using an instance of `datetime.timedelta`:

```
>>> dt = datetime.timedelta(days=2.3)
```

Then you can add by e.g.:

```
>>> t+dt
```

Coords Class

The spatial coordinate class includes the following coordinate systems in Cartesian and spherical forms.

- GZD: (altitude, latitude, longitude) in km, deg, deg
- GEO: cartesian, Re
- GSM: cartesian, Re
- GSE: cartesian, Re
- SM: cartesian, Re
- GEI: cartesian, Re
- MAG: cartesian, Re
- SPH: same as GEO but in spherical
- RLL: radial distance, latitude, longitude, Re, deg, deg.

Create a Coords instance with spherical='sph' or cartesian='car' coordinates:

```
>>> spaco = spc.Coords([[1,2,4],[1,2,2]], 'GEO', 'car')
```

This will let you request, for example, all y-coordinates by `spaco.y` or if given in spherical coordinates by `spaco.lati`. One can transform the coordinates by `newcoord = spaco.convert('GSM', 'sph')`. This will return GSM coordinates in a spherical system. Since GSM coordinates depend on time, you'll have to add first a Ticktock vector with the name `ticks` like `spaco.ticks = spt.Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:00:00'], 'ISO')`

Unit conversion will be implemented in the future.

1.2.4 The radbelt Module

The radiation belt module currently includes a simple radial diffusion code as a class. Import the module and instatiate a radbelt object:

```
>>> import spacepy.radbelt as sprb
>>> rb = sprb.RBmodel()
```

Add a time grid for a particular period that you are interested in:

```
>>> rb.setup_ticks('2002-02-01T00:00:00', '2002-02-10T00:00:00', 0.25)
```

This will automatically lookup required geomagnetic/solar wind conditions for that period. Run the diffusion solver for that setup and plot the results:

```
>>> rb.evolve()
>>> rb.plot()
```

1.2.5 The Data Assimilation Module

This module includes data assimilation capabilities, through the assimilation class. The class assimilates data for the radiation belt model using the Ensemble Kalman Filter. The algorithm used is the SVD method presented by Evensen in 2003 (Evensen, G., Ocean dynamics, 53, pp.343–367, 2003). To compensate for model errors, three inflation algorithms are implemented. The inflation methodology is specified by the inflation argument, where the options are the following:

- inflation = 0: Add model error (perturbation for the ensemble) around model state values only where observations are available (DEFAULT).
- inflation = 1: Add model error (perturbation for the ensemble) around observation values only where observations are available.
- inflation = 2: Inflate around ensemble average for EnKF.

Prior to assimilation, a set of data values has to be specified by setting the start and end dates, and time step, using the `setup_ticks` function of the radiation belt model:

```
>>> import spacepy
>>> import datetime
>>> from spacepy import radbelt
```

```
>>> start = datetime.datetime(2002,10,23)
>>> end = datetime.datetime(2002,11,4)
>>> delta = datetime.timedelta(hours=0.5)
>>> rmod.setup_ticks(start, end, delta, dtype='UTC')
```

Once the dates and time step are specified, the data is added using the `add_PSD` function (NOTE: This requires a database available from the SpacePy team):

```
>>> rmod.add_PSD()
```

The observations are averaged over the time windows, whose interval is give by the time step. Once the dates and data are set, the assimilation is performed using the `assimilate` function:

```
>>> rmod.assimilate(inflation=1)
```

This function will add the PSDa values, which are the analysis state of the radiation belt using the observations within the dates. To plot the analysis simply use the `plot` function:

```
>>> rmod.plot(values=rmod.PSDa,clims=[-10,-6],Lmax=False,Kp=False,Dst=False)
```

Additionally, to create a summary plot of the observations use the `plot_obs` function within the radbelt module. For reference, the last closed drift shell, Dst, and Kp are all included. These can be disabled individually using the corresponding Boolean kwargs.

The clims kwarg can be used to manually set the color bar range. To use, set it equal to a two-element list containing minimum and maximum log $_{10}$ value to plot. Default action is to use [0,10] as the log $_{10}$ of the color range. This is good enough for most applications. The title of the top most plot defaults to 'Summary Plot' but can be customized using the title kwarg.

The figure object and all three axis objects (PSD axis, Dst axis, and Kp axis) are all returned to allow the user to further customize the plots as necessary. If any of the plots are excluded, None is returned in their stead.

Example:

```
>>> rmod.plot_obs(clims=[-10,-6],Lmax=False,Kp=False,Dst=False,title='Observations Plot')
```

This command would create the summary plot with a color bar range of 10^{-10} to 10^{-6}. The Lmax line, Kp and Dst values would be excluded. The title of the topmost plot (phase space density) would be set to 'Observations Plot'.

1.2.6 OMNI Module

The OMNI database is an hourly resolution, multi-source data set with coverage from November 1963; higher temporal resolution versions of the OMNI database exist, but with coverage from 1995. The primary data are near-Earth solar wind, magnetic field and plasma parameters. However, a number of modern magnetic field models require derived input parameters, and Qin and Denton (2007) have used the publicly-available OMNI database to provide a modified version of this database containing all parameters necessary for these magnetic field models. These data are available through ViRBO - the Virtual Radiation Belt Observatory.

In SpacePy this data is made available, at 1-hourly resolution, on request on first import; if not downloaded when SpacePy is first used then any attempt to import the omni module will ask the user whether they wish to download the data. Should the user require the latest data, the toolbox.update function can be used to fetch the latest files from ViRBO.

The following example fetches the OMNI data for the storms of October and November, 2003.:

```
>>> import spacepy.time as spt
>>> import spacepy.omni as om
>>> import datetime as dt
>>> st = dt.datetime(2003,10,20)
>>> en = dt.datetime(2003,12,5)
>>> delta = dt.timedelta(days=1)
>>> ticks = spt.tickrange(st, en, delta, 'UTC')
>>> data = om.get_omni(ticks)
```

data is a dictionary containing all the OMNI data, by variable, for the timestamps contained within the `Ticktock` object *ticks*. Now it is simple to plot Dst values for instance:

```
>>> import pyplot as p
>>> p.plot(ticks.eDOY, data['Dst'])
```

1.2.7 The irbempy Module

ONERA (Office National d'Etudes et Recherches Aerospatiales) initiated a well-known FORTRAN library that provides routines to compute magnetic coordinates for any location in the Earth's magnetic field, to perform coordinate conversions, to compute magnetic field vectors in geospace for a number of external field models, and to propagate satellite orbits in time. Older versions of this library were called ONERA-DESP-LIB. Recently the library has changed its name to IRBEM-LIB and is maintained by a number of different institutions.

A number of key routines in IRBEM-LIB have been made available through the module *irbempy*. Current functionality includes calls to calculate the local magnetic field vectors at any point in geospace, calculation of the magnetic mirror point for a particle of a given pitch angle (the angle between a particle's velocity vector and the magnetic field line that it immediately orbits such that a pitch angle of 90 degrees signifies gyration perpendicular to the local field) anywhere in geospace, and calculation of electron drift shells in the inner magnetosphere.:

```
>>> import spacepy.time as spt
>>> import spacepy.coordinates as spc
>>> import spacepy.irbempy as ib
>>> t = spt.Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> y = spc.Coords([[3,0,0],[2,0,0]], 'GEO', 'car')
>>> ib.get_Bfield(t,y)
>>> # {'Blocal': array([  976.42565251,  3396.25991675]),
>>> #    'Bvec': array([[ -5.01738885e-01,  -1.65104338e+02,   9.62365503e+02], [  3.
↪33497974e+02,  -5.42111173e+02,   3.33608693e+03]])}
```

One can also calculate the drift shell L* for a 90 degree pitch angle value by using:

```
>>> ib.get_Lstar(t,y, [90])
>>> # {'Bmin': array([  975.59122652,  3388.2476667 ]),
>>> #  'Bmirr': array([[  976.42565251], [ 3396.25991675]]),
>>> #  'Lm': array([[ 3.13508015], [ 2.07013638]]),
>>> #  'Lstar': array([[ 2.86958324], [ 1.95259007]]),
>>> #  'MLT': array([ 11.97222034,  12.13378624]),
>>> #  'Xj': array([[ 0.00081949], [ 0.00270321]])}
```

Other function wrapped with the IRBEM library include:

- *find_Bmirror()*
- *find_magequator()*
- *coord_trans()*

1.2.8 pyCDF - Python Access to NASA CDF Library

pycdf provides a "pythonic" interface to the NASA CDF library. It requires that the NASA CDF C-library is properly installed. The module can then be imported, e.g.:

```
>>> import spacepy.pycdf as cdf
```

To open and close a CDF file, we use the CDF class:

```
>>> cdf_file = cdf.CDF('filename.cdf')
>>> cdf_file.close()
```

CDF files, like standard Python files, act as context managers:

```
>>> with cdf.CDF('filename.cdf') as cdf_file:
>>>     #do brilliant things with cdf_file
>>> #cdf_file is automatically closed here
```

CDF files act as Python dictionaries, holding CDF variables keyed by the variable name:

```
>>> var_names = keys(cdf_file) #list of all variables
>>> for var_name in cdf_file:
>>>     print(len(cdf_file[var_name])) #number of records in each variable
>>> #list comprehensions work, too
>>> lengths = [len(cdf_file[var_name]) for var_name in cdf_file]
```

Each CDF variable acts like a numpy array, where the first dimension is the record number. Multidimensional CDF variables can be subscripted using numpy's multidimensional slice notation. Many common list operations are also implemented, where each record acts as one element of the list and can be independently deleted, inserted, etc. Creating a Python `Var` object does not read the data from disc; data are only read as they are accessed:

```
>>> epoch = cdf_file['Epoch'] #Python object created, nothing read from disc
>>> epoch[0] #time of first record in CDF (datetime object)
>>> a = epoch[...] #copy all times to list a
>>> a = epoch[-5:] #copy last five times to list a
>>> b_gse = cdf_file['B_GSE'] #B_GSE is a 1D, three-element array
>>> bz = b_gse[0,2] #Z component of first record
>>> bx = b_gse[:,0] #copy X component of all records to bx
>>> bx = cdf_file['B_GSE'][:,0] #same as above
```

1.2.9 The datamodel Module

The SpacePy datamodel module implements classes that are designed to make implementing a standard data model easy. The concepts are very similar to those used in standards like HDF5, netCDF and NASA CDF.

The basic container type is analogous to a folder (on a filesystem; HDF5 calls this a group): Here we implement this as a dictionary-like object, a `datamodel.SpaceData` object, which also carries attributes. These attributes can be considered to be global, i.e. relevant for the entire folder. The next container type is for storing data and is based on a numpy array, this class is `datamodel.dmarray` and also carries attributes. The dmarray class is analogous to an HDF5 dataset.

Guide for NASA CDF users

By definition, a NASA CDF only has a single 'layer'. That is, a CDF contains a series of records (stored variables of various types) and a set of attributes that are either global or local in scope. Thus to use SpacePy's datamodel to capture the functionality of CDF the two basic data types are all that is required, and the main constraint is that datamodel.SpaceData objects cannot be nested (more on this later, if conversion from a nested datamodel to a flat datamodel is required).

This is best illustrated with an example. Imagine representing some satellite data within a CDF – the global attributes might be the mission name and the instrument PI, the variables might be the instrument counts [n-dimensional array], timestamps[1-dimensional array and an orbit number [scalar]. Each variable will have one attribute (for this example).

```
>>> import spacepy.datamodel as dm
>>> mydata = dm.SpaceData(attrs={'MissionName': 'BigSat1'})
>>> mydata['Counts'] = dm.dmarray([[42, 69, 77], [100, 200, 250]], attrs={'Units': 'cnts/
↪s'})
>>> mydata['Epoch'] = dm.dmarray([1, 2, 3], attrs={'units': 'minutes'})
>>> mydata['OrbitNumber'] = dm.dmarray(16, attrs={'StartsFrom': 1})
>>> mydata.attrs['PI'] 'Prof. Big Shot'
```

This has now populated a structure that can map directly to a NASA CDF. To visualize our datamodel, we can use the *tree()* method, which is equivalent to `toolbox.dictree()` (which works for any dictionary-like object, including PyCDF file objects).

```
>>> mydata.tree(attrs=True)
+
:|____MissionName
:|____PI
```

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```
|____Counts
    :|____Units
|____Epoch
    :|____units
|____OrbitNumber
    :|____StartsFrom
>>> import spacepy.toolbox as tb
>>> tb.dictree(mydata, attrs=True)
+
:|____MissionName
:|____PI
|____Counts
    :|____Units
|____Epoch
    :|____units
|____OrbitNumber
    :|____StartsFrom
```

Attributes are denoted by a leading colon. The global attributes are those in the base level, and the local attributes are attached to each variable.

If we have data that has nested 'folders', allowed by HDF5 but not by NASA CDF, then how can this be represented such that the data structure can be mapped directly to a NASA CDF? The data will need to be flattened so that it is single layered. Let us now store some ephemerides in our data structure:

```
>>> mydata['Ephemeris'] = dm.SpaceData()
>>> mydata['Ephemeris']['GSM'] = dm.dmarray([[1,3,3], [1.2,4,2.5], [1.4,5,1.9]])
>>> tb.dictree(mydata, attrs=True)
+
:|____MissionName
:|____PI
|____Counts
    :|____Units
|____Ephemeris
    |____GSM
|____Epoch
    :|____units
|____OrbitNumber
    :|____StartsFrom
```

Nested dictionary-like objects is not uncommon in Python (and can be exceptionally useful for representing data, so to make this compatible with NASA CDF we call the *flatten()* method .

```
>>> mydata.flatten()
>>> tb.dictree(mydata, attrs=True)
+
:|____MissionName
:|____PI
|____Counts
    :|____Units
|____Ephemeris<--GSM
|____Epoch
    :|____units
```

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```
|____OrbitNumber
    :|____StartsFrom
```

Note that the nested SpaceData has been moved to a variable with a new name reflecting its origin. The data structure is now flat again and can be mapped directly to NASA CDF.

Converters to/from datamodel

Currently converters exist to read HDF5 and NASA CDF files directly to a SpacePy datamodel. This capability also exists for JSON-headed ASCII files (RBSP/AutoPlot-compatible). A converter from the datamodel to HDF5 is now available and a converter to NASA CDF is under development. Also under development is the reverse of the SpaceData.flatten method, so that flattened objects can be restored to their former glory.

1.2.10 Empiricals Module

The empiricals module provides access to some useful empirical models. As of SpacePy 0.1.2, the models available are:

- *getLmax()* An empirical parametrization of the L* of the last closed drift shell (Lmax)
- *getPlasmaPause()* The plasmapause location, following either Carpenter and Anderson (1992) or Moldwin et al. (2002)
- *getMPstandoff()* The magnetopause standoff location (i.e. the sub-solar point), using the Shue et al. (1997) model
- *vampolaPA()* A conversion of omnidirectional electron flux to pitch-angle dependent flux, using the $\sin^n$ model of Vampola (1996)

Each of the first three models is called by passing it a Ticktock object (see above) which then calculates the model output using the 1-hour Qin-Denton OMNI data (from the OMNI module; see above). For example:

```
>>> import spacepy.time as spt
>>> import spacepy.empiricals as emp
>>> ticks = spt.tickrange('2002-01-01T12:00:00','2002-01-04T00:00:00',.25)
```

calls *tickrange()* and makes a Ticktock object with times from midday on January 1st 2002 to midnight January 4th 2002, incremented 6-hourly:

```
>>> Lpp = emp.getPlasmaPause(ticks)
```

then returns the model plasmapause location using the default setting of the Moldwin et al. (2002) model. The Carpenter and Anderson model can be used by setting the Lpp_model keyword to 'CA1992'.

The magnetopause standoff location can be called using this syntax, or can be called for specific solar wind parameters (ram pressure, P, and IMF Bz) passed through in a Python dictionary:

```
>>> data = {'P': [2,4], 'Bz': [-2.4, -2.4]}
>>> emp.getMPstandoff(data)
>>>   # array([ 10.29156018,   8.96790412])
```

1.2.11 SeaPy - Superposed Epoch Analysis in Python

Superposed epoch analysis is a technique used to reveal consistent responses, relative to some repeatable phenomenon, in noisy data . Time series of the variables under investigation are extracted from a window around the epoch and all data at a given time relative to epoch forms the sample of events at that lag. The data at each time lag are then averaged so that fluctuations not consistent about the epoch cancel. In many superposed epoch analyses the mean of the data at each time u relative to epoch, is used to represent the central tendency. In SeaPy we calculate both the mean and the median, since the median is a more robust measure of central tendency and is less affected by departures from normality. SeaPy also calculates a measure of spread at each time relative to epoch when performing the superposed epoch analysis; the interquartile range is the default, but the median absolute deviation and bootstrapped confidence intervals of the median (or mean) are also available.

As an example we fetch OMNI data for 4 years and perform a superposed epoch analysis of the solar wind radial velocity, with a set of epoch times read from a text file:

```
>>> import datetime as dt
>>> import spacepy.seapy as sea
>>> import spacepy.omni as om
>>> import spacepy.toolbox as tb
>>> import spacepy.time as spt
>>> # now read the epochs for the analysis (the path specified is the default
>>> # install location on linux, different OS will have this elsewhere)
>>> epochs = sea.readepochs('~/.local/lib/python2.7/site-packages/spacepy/data/SEA_
↪epochs_OMNI.txt')
```

The readepochs function can handle multiple formats by a user-specified format code. ISO 8601 format is directly supported though it is not used here. The the readepochs docstring for more information. As above, we use the get_omni function to retrieve the hourly data from the OMNI module:

```
>>> ticks = spt.tickrange(dt.datetime(2005,1,1), dt.datetime(2009,1,1), dt.
↪timedelta(hours=1))
>>> omni1hr = om.get_omni(ticks)
>>> omni1hr.tree(levels=1, verbose=True)
```

```
+
|____ByIMF (spacepy.datamodel.dmarray (35065,))
|____Bz1 (spacepy.datamodel.dmarray (35065,))
|____Bz2 (spacepy.datamodel.dmarray (35065,))
|____Bz3 (spacepy.datamodel.dmarray (35065,))
|____Bz4 (spacepy.datamodel.dmarray (35065,))
|____Bz5 (spacepy.datamodel.dmarray (35065,))
|____Bz6 (spacepy.datamodel.dmarray (35065,))
|____BzIMF (spacepy.datamodel.dmarray (35065,))
|____DOY (spacepy.datamodel.dmarray (35065,))
|____Dst (spacepy.datamodel.dmarray (35065,))
|____G (spacepy.datamodel.dmarray (35065, 3))
|____Hr (spacepy.datamodel.dmarray (35065,))
|____Kp (spacepy.datamodel.dmarray (35065,))
|____Pdyn (spacepy.datamodel.dmarray (35065,))
|____Qbits (spacepy.datamodel.SpaceData [7])
|____RDT (spacepy.datamodel.dmarray (35065,))
|____UTC (spacepy.datamodel.dmarray (35065,))
|____W (spacepy.datamodel.dmarray (35065, 6))
|____Year (spacepy.datamodel.dmarray (35065,))
```

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```
|____akp3 (spacepy.datamodel.dmarray (35065,))
|____dens (spacepy.datamodel.dmarray (35065,))
```

and these data are used for the superposed epoch analysis. the temporal resolution is 1 hr and the window is +/- 3 days

```
>>> delta = dt.timedelta(hours=1)
>>> window= dt.timedelta(days=3)
>>> sevx = sea.Sea(omni1hr['velo'], omni1hr['UTC'], epochs, window, delta)
    #rather than quartiles, we calculate the 95% confidence interval on the median
>>> sevx.sea(ci=True)
>>> sevx.plot()
```

1.3 SpacePy Help

The best way to get help is to open an issue. Searching existing issues may find other people who have had similar questions. Try changing the filters (at the top) to include closed issues, as they may have been addressed.

Most modules also have a contact person listed in the docstring. These are built into in the main *SpacePy 0.3.0 documentation*, or you can view it from within Python/IPython:

```
>>> import spacepy.pycdf
>>> help(spacepy.pycdf)
>>> print(spacepy.pycdf.__contact__)
```

A web version of this documentation is currently hosted at spacepy.github.io.

1.3.1 Contributing

Contributions to SpacePy are welcome! Development is managed via our github. If you're interesting in contributing a new feature or bugfix, it is recommended to open an issue to discuss your plans. Once your code is ready, you can open a pull request. Thanks for helping to improve SpacePy!

CHAPTER

TWO

SPACEPY DOCUMENTS

Further reference material on how to use SpacePy, and examples.

2.1 SpacePy Capabilities

This page lists some capabilities of SpacePy and, in some cases, of other packages that might be of interest to SpacePy users. It is organized by topic; searching within this page is recommended. See the *module reference* for every class/function available in SpacePy, organized by module.

- *Array manipulation*
- *Coordinate Transforms*
- *File I/O*
- *Modeling*
- *Statistics*
- *Time conversions*
- *Time series analysis and correlations*
- *Visualization*

2.1.1 Array manipulation

Various `toolbox` functions are useful in manipulating NumPy arrays. `datamanager` also contains many functions for indexing arrays and manipulating them in ways that do not depend on the interpretation of their contents.

2.1.2 Coordinate Transforms

`coordinates` provides a class for transforming among most coordinate systems used in Earth magnetospheric and ionospheric physics.

It also provides generalized coordinate transforms via quaternions.

2.1.3 File I/O

pycdf provides reading and writing of NASA CDF files, with additional functionality for those with ISTP-compliant metadata.

datamodel provides easy reading and writing of HDF5 and most netCDF files. It also supports reading and writing ASCII-based data files with rich JSON metadata, supported by tools such as Autoplot.

`numpy.loadtxt()` and related functions are helpful for reading various "plain-text" files into numerical arrays.

`scipy.io.readsav()` reads IDL savesets.

`astropy.io.fits` supports FITS files.

2.1.4 Modeling

ae9ap9 supports import and visualization of data from the AE9/AP9 empirical radiation belt model.

empiricals implements several simple empirical and/or analytic models for magnetospheric and solar wind phenomena, including the plasmapause location, the Shue magnetopause model, and solar wind temperature.

pybats supports output analysis and visualization of many models compatible with the Space Weather Modeling Framework, including the BATS-R-US global MHD model and the RAM-SCB ring current model.

omni provides ready access to the OMNI near-Earth solar wind dataset, useful for model inputs.

2.1.5 Statistics

poppy **supports determining confidence intervals on** population metrics using the non-parametric bootstrap method.

2.1.6 Time conversions

time contains a class that easily allows time to be represented in, and converted among, many representations, including Python datetimes, ISO time strings, GPS time, TAI, etc.

2.1.7 Time series analysis and correlations

poppy implements association analysis to determine the relationship between point-in-time events.

seapy implements superposed epoch analysis, the statistical evaluation of the time evolution of a system relative to a set of starting epochs.

2.1.8 Visualization

plot provides tools useful in making publication-quality plots with the matplotlib toolkit.

2.2 Release Notes

This document presents user-visible changes in each release of SpacePy.

- *0.3 Series*
  - *0.3.0 (2022-04-27)*
- *0.2 Series*
  - *0.2.3 (2021-10-30)*
  - *0.2.2 (2020-12-29)*
  - *0.2.1 (2019-10-02)*
  - *0.2.0 (2019-06-22)*
- *0.1 Series*
  - *0.1.6 (2016-09-08)*
  - *0.1.5 (2014-12-23)*
  - *0.1.4 (2013-05-21)*
  - *0.1.3 (2012-06-22)*
  - *0.1.2 (2012-05-25)*
  - *0.1.1 (2011-10-31)*
  - *0.1 (2011-08-24)*

2.2.1 0.3 Series

0.3.0 (2022-04-27)

This release continues the phaseout of *Python 2* support. No Python 2 binaries are provided, and 0.3.0 will not install on Python 2 with `pip`. Installation via `setup.py` from a source distribution is still available.

This is the last release with Python 2 bugfix support. SpacePy 0.4.0 will make no attempt to maintain functionality for Python 2 and SpacePy 0.5.0 will not function without Python 3.

Windows binaries are only provided as 64-bit wheels, installable with `pip`, for Python 3.6 and later. Windows executable installers and 32-bit binaries are no longer provided.

New features

The *coordinates* module has been overhauled with a new, Python-based backend. This provides comparable performance to the existing *irbempy* backend with higher precision and reduces the dependence on Fortran. By default, irbemlib will still be built at installation time. The default backend remains IRBEM; in 0.4.0, this will switch to the new *ctrans* based backend. The new *igrf* module is part of this support but may be of interest on its own.

In accordance with a change from NASA, *pycdf* now assumes strings in CDFs are UTF-8. It will no longer raise errors on reading non-ASCII data from a CDF. See *String handling* in the pycdf documentation for details.

ae9ap9 now supports the new ephem model file format (>=1.50.001) via *parseHeader()*. The old file format is deprecated.

Deprecations and removals

HTML documentation is no longer installed with SpacePy. *help()* now opens the latest online documentation. Offline documentation are available separately (files named like `spacepy-x.y.z-doc.zip` and `spacepy-x.y.z-doc.pdf`) and as part of the source distribution (`spacepy-x.y.z.tar.gz` or `spacepy-x.y.z.zip`). These files can be downloaded from SpacePy's releases on GitHub; the source can also be found on PyPI.

`LANLstar` requires ffnet, which does not install properly with current setuptools (version 58). The SpacePy team is working on replacing this dependency, but in the meantime `LANLstar` is unsupported and will require manually installing `ffnet` and networkx.

As mentioned above, *ae9ap9* support for the old ephem model file format is deprecated.

Colourmaps have been removed from *plot*. The same colourmaps (`plasma` and `viridis`) have been available in matplotlib since at least 1.5. (Deprecated in 0.2.3.)

The old name `spectrogram` for *Spectrogram* has been removed. (Deprecated in 0.2.2.)

The `read_ram_dst` function has been removed from *ram*, as it operates on files that are no longer written by RAM-SCB. (Deprecated in 0.1.6.)

The `fix_format` function has been removed from *rim*; *Iono* can now read these files directly. (Deprecated in 0.2.2.)

The `from_dict` method of CDF attribute lists (*gAttrList()*, *zAttrList()*) has been removed. Use *clone()*, which supports cloning from dictionaries. (Deprecated in 0.1.5.)

The `feq` function has been removed from *toolbox*; use `numpy.isclose()`. (Deprecated in 0.2.2.)

Quaternion math functions have been removed from *toolbox*; they are available in *coordinates*. (Deprecated in 0.2.2.)

Dependency requirements

Due to the new backend, scipy is now required for *coordinates* (even if using the old backend). 0.11 remains the minimum version.

Since `LANLstar` is not currently supported, `ffnet` and `networkx` are no longer treated as SpacePy dependencies.

Other changes

pycdf now defaults to creating version 3 (not backward-compatible) CDFs if the backward compatible mode is not explicitly set (*set_backward()*). It still issues a warning when creating a CDF if this is not set; this warning will be removed in 0.4.0. (Warning added in 0.2.2.)

Similarly, *pycdf* defaults to TIME_TT2000 when creating a time variable or attribute without specifying a type (EPOCH or EPOCH16 are used if TT2000 isn't available). A warning is issued when doing so; this warning will be removed in 0.4.0. (Warning added in 0.2.2.)

On Windows, *pycdf* now looks in more locations for the NASA CDF library. Newer versions of the library by default install to a different location (`Program Files`). The DLL is also now placed in the `bin` directory instead of `lib`, so `bin` is searched and the value of environment variable `CDF_BIN` in addition to `lib` and `CDF_LIB`. The net effect should be to increase the chance of successfully loading the library, with a small chance of accidentally loading the wrong one.

The default data source for leapsecond files has been reverted from NASA/MODIS to the USNO, as USNO data services are back online. If present, entries in the *configuration file* will still be used instead of the default.

2.2.2 0.2 Series

0.2.3 (2021-10-30)

This is the last release of the 0.2 series and the last with full support for *Python 2*. Binary installers (including wheels) for *32-bit Windows* will also end after the 0.2 series, as will Windows installers. The only binaries for Windows will be 64-bit wheels, installable with `pip`.

New features

pycdf now supports variables with sparse records, including enabling/disabling sparse records (*sparse()*) and setting the pad value (*pad()*). Thanks Antoine Brunet.

Deprecations and removals

The colourmaps provided in the *plot* module have been deprecated. The same colourmaps have been available in matplotlib since at least 1.5, and users who do not directly import the colourmaps should see no impact.

Major bugfixes

The passing of keyword arguments from *bootHisto()* to `numpy.histogram()` and `matplotlib.pyplot.bar()` has been fixed.

The check for out-of-date leapseconds in *time* has been fixed (previously warned even when the file was up to date.)

Fixed installation on new versions of setuptools, which removed `bdist_wininst` support (#530).

The handling of library paths on Windows has been updated. This should fix situations where *irbempy* would not import on Windows with Python 3.8 or later. This did not seem to be a problem with Anaconda, but would sometimes manifest with Python from the app store or from http://python.org/ (#507)

Other changes

Modern leapsecond rules are applied from 1958-1972 rather than rounding fractional leapseconds. See *time* for full discussion of leap seconds and other conversion considerations.

The handling of the `.spacepy` directory (see *SpacePy Configuration*) has been improved. If the `SPACEPY` environment variable is used, the directory will be created. The import process also is less fragile in the case of a partially-created `.spacepy` directory or an invalid (e.g. empty) `spacepy.rc`.

0.2.2 (2020-12-29)

The 0.2 series will be the last with full support for *Python 2*; 0.2.3 will likely be the last release. Binary installers for *32-bit Windows* will also end after the 0.2 series.

New features

irbempy incorporates upstream IRBEMlib rev620. This adds IGRF13 coefficients. *coordinates* and *irbempy* now also support using all supported coordinate systems as inputs to routines; if a routine does not support an input system, it will be automatically converted.

Ticktock supports conversions to and from `astropy.time.Time`.

The following classes, functions, and methods are new:

quaternionFromMatrix(matrix[, scalarPos])	Given an input rotation matrix, return the equivalent quaternion
quaternionToMatrix(Qin[, scalarPos, normalize])	Given an input quaternion, return the equivalent rotation matrix.
rebin(data, bindata, bins[, axis, bintype, ...])	Rebin one axis of input data based on values of another array
add_arrows(lines[, n, size, style, ...])	Add directional arrows along a plotted line.
concatCDF(cdfs[, varnames, raw])	Concatenate data from multiple CDFs
nanfill(v)	Set fill values to NaN
empty_entry(f)	Check for attributes with empty string
VarBundle(var)	Collective handling of ISTP-compliant variable and its dependencies.
deltas(v)	Check DELTA variables
empty_entry(v)	Check for attributes with empty string

Deprecations and removals

pycdf now warns if creating a new CDF file without explicitly setting backward compatible or not backward compatible (*set_backward()*). The default is still to make backward-compatible CDFs, but this will change in 0.3.0. Similarly it now warns if creating a time variable without specifying a time type; the default is still to use EPOCH or EPOCH16, but this will change to TIME_TT2000 in 0.3.0.

`fix_format()` is now deprecated, as *Iono* can now read these files directly.

Quaternion math functions have been moved to *coordinates*; using the functions in *toolbox* is deprecated.

`feq()` is deprecated; numpy 1.7 added the equivalent `isclose()`.

The *spectrogram* class is now capitalized (*Spectrogram*); the old, lower-case variant is kept for compatibility but will be removed.

Dependency requirements

Not all dependencies are required for all functionality; see *SpacePy Dependencies* for full details, including what functionality is lost if a dependency is not installed.

numpy 1.10 is now required. (Many functions erroneously required it from 0.2.1, but this was not adequately documented.)

scipy 0.11 is now the minimum supported version of SciPy. (Again, this was erroneously required in 0.2.0 without appropriate documentation.)

Several dependencies without an established minimum version were tested.

As of 0.2.2, minimum supported versions of dependencies are:

- CPython 2 2.7 or CPython 3 3.2
- AstroPy 1.0
- CDF 2.7
- dateutil 1.4 (earlier may work)
- ffnet 0.7 (earlier may work)
- h5py 2.6 (earlier may work)
- matplotlib 1.5
- networkx 1.0 (earlier may work)
- numpy 1.10
- scipy 0.11

Major bugfixes

Time conversions between time systems before 1961 now use the proper number of leapseconds (0).

Many minor bugfixes.

Other changes

Data sources for leapsecond files and *omni* Qin-Denton files have been updated to provide current sources. If present, entries in the *configuration file* will still be used instead. A (configurable) warning is issued for out-of-date leapsecond files.

The representation of leap second intervals in time systems which cannot directly represent them has been changed. Formerly times such as 2008-12-31T23:59:60 were represented in e.g. UTC datetime as the the beginning of the next day, e.g. 2009-01-01T00:00:00. They are now represented by the last possible moment of the same day, e.g. 2008-12-31T23:59:59.999999. Fractional leapsecond counts are now rounded to the integer instead of truncated; this rounding is applied to the total TAI - UTC quantity not the individual increments of leap seconds. E.g successive 0.2, 0.2, 0.2 leap seconds will result in 0, 0, and 1 new leap seconds.

Similarly, leap seconds are now included in the fractional day calculation of MJD, so MJD values around a leap second may be different than in previous versions of SpacePy.

Most time systems are now converted to/from TAI rather than using datetime. This may cause small differences with previous versions of SpacePy, on order of a double precision. RDT and JD are particularly affected for dates in the modern era. Time conversions around leapseconds may also be different; in many cases they were undefined in previous versions.

now() and *today()* return times in UTC; in previous versions the value returned was local, but was treated as UTC for all conversions (and thus inaccurate.)

See *time* for full discussion of leap seconds, time resolution, and other conversion considerations.

0.2.1 (2019-10-02)

New features

The following module is new:

istp	Support for ISTP-compliant CDFs

Deprecations and removals

None

Dependency requirements

No changes to minimum dependency versions.

As of 0.2.1, the minimum versions of dependencies are:

- CPython 2 2.7 or CPython 3 3.2
- CDF 2.7
- matplotlib 1.5
- numpy 1.4
- scipy 0.10

Other dependencies have no established minimum. See *SpacePy Dependencies* for full details.

Major bugfixes

Fixed compliation of *irbempy* on several systems.

Other changes

None of note.

0.2.0 (2019-06-22)

New features

Deprecations and removals

None

Dependency requirements

Support for Python 2.6 was removed; 2.7 is the only supported version of Python 2.

As of 0.2.0, the minimum versions of dependencies are:

- CPython 2 2.6 or CPython 3 3.2
- CDF 2.7
- matplotlib 1.5
- numpy 1.4
- scipy 0.10

Other dependencies have no established minimum. See *SpacePy Dependencies* for full details.

Major bugfixes

`human_sort()` was fixed for non-numeric inputs (the normal case.) This had been broken since 0.1.6.

Many minor bugfixes as well.

Other changes

Many updates to improve ease of installation, including Windows binary wheels.

2.2.3 0.1 Series

See the CHANGELOG file in the source distribution for changes in the 0.1 release series.

0.1.6 (2016-09-08)

0.1.5 (2014-12-23)

0.1.4 (2013-05-21)

0.1.3 (2012-06-22)

0.1.2 (2012-05-25)

0.1.1 (2011-10-31)

0.1 (2011-08-24)

2.3 SpacePy Case Studies

The SpacePy team has prepared case studies showing how to reproduce the results from published papers using Python-based tools, including SpacePy. It is hoped that these extensively-documented examples will ease the transition to Python for space scientists.

Basic familiarity with programming and general computing tasks in your chosen environment is assumed, including editing text files, copying and deleting files, etc. No Python-specific knowledge is assumed, although it is recommended to at least skim the excellent Python tutorial.

2.3.1 Paulikas and Blake revisited (Reeves et al. 2011)

This case study reproduces the figures of Reeves et al. (2011), "On the relationship between relativistic electron flux and solar wind velocity: Paulikas and Blake revisited" (doi:10.1029/2010JA015735).

Setup

Create a directory to hold files for this case study. Within this directory, create subdirectories `code`, `data`, and `plots`. (Using version control on the code directory is recommended; the SpacePy team uses git.)

Obtaining energetic particle data

We require the 1.8-3.5 MeV electron flux from the LANL-GEO ESP detector, available in the paper's auxiliary material (scroll down to "Supporting information" on the paper's page. The ESP data are in Data Set S1. Save this file to the `data` directory; the filename is assumed to be `jgra20797-sup-0003-ds01.txt`.

The data file was corrupted on upload to AGU, and the code to fix it is non-trivial, so this is a good chance to learn how to run someone else's code. (*Appendix: Fixing the ESP data file* has step-by-step information on each portion of this process.) Copy all of the following and paste it into a file called `fix_esp_data.py` in the `code` directory.

```
import os.path


datadir = os.path.join('..', 'data')
in_name = os.path.join(datadir, 'jgra20797-sup-0003-ds01.txt')
out_name = os.path.join(datadir, 'jgra20797-sup-0003-ds01_FIXED.txt')
infile = open(in_name, 'r')
outfile = open(out_name, 'w')
data = infile.read()
infile.close()

data = data.replace('\r', '\n')
data = data.replace('\n\n', '\n')
data = data.split('\n')

for i in range(15):
    outfile.write(data.pop(0) + '\n')
oldline = None
for line in data:
    if line[0:2] in ['19', '20', '2']:
        if not oldline is None:
            outfile.write(oldline + '\n')
        oldline = line
    else:
        oldline += line
outfile.write(oldline + '\n')
outfile.close()
```

Now this script can be run with `python fix_esp_data.py`. It should create a file called `jgra20797-sup-0003-ds01_FIXED.txt` in the `data` directory.

File fixed, we can load and begin examining the data. Change to the `code` directory and start your Python interpreter. (IPython is recommended, but not required.)

In the following examples, do not type the leading >>>; this is the Python interpreter prompt. IPython has a different prompt that looks like `In [1]`.

```
>>> import os.path
>>> datadir = os.path.join('..', 'data')
>>> print(datadir)
../data
```

The first line imports the `os.path` module from the Python standard library. Python has a huge standard library. To keep this code organized, it is divided into many modules, and a module must be imported before it can be used. (The Python module of the week is a great way to explore the standard library.)

The second line makes a variable, `datadir`, which will contain the path of the data directory. The `os.path.join()` function provides a portable way of "gluing" together directories in a path, and will use backslashes on Windows and forward slashes on Unix. The third line then prints out the value of this variable for confirmation; note this is a Unix system.

Note that string constants in Python can use single or double quotes; we could just as well have written:

```
>>> datadir = os.path.join("..", "data")
```

or even:

```
>>> datadir = os.path.join('..', "data")
```

The full path can also be used (and this is a better case for using a variable.) For example, I am preparing this example in a directory `reeves_morley_friedel_2011` in my home directory, so I could use:

```
>>> datadir = os.path.join('home', 'jniehof', 'reeves_morley_friedel_2011',
...                        'data')
```

This very long line can be typed across two lines in Python, and because the line break happens within parentheses, a line continuation character is not required.

Returning to reading the ESP data file:

```
>>> fname = os.path.join(datadir, 'jgra20797-sup-0003-ds01_FIXED.txt')
```

creates a variable holding the full path to the fixed file.

```
>>> import numpy
```

The import statement imports any installed module, just as if it were in the standard library. Here we import the very useful numpy module, which is a prerequisite for SpacePy and useful in its own right.

```
>>> esp_fluxes = numpy.loadtxt(fname, skiprows=14, usecols=[1])
```

`loadtxt()` makes it easy to load data from a file into a numpy `ndarray`, a very useful data container. `skiprows` skips the header information, and specifying only column 1 (first column is column 0) with `usecols` will only load the fluxes for 1.8-3.5MeV. We only load the fluxes at this point because they can be represented as floats, which numpy arrays store very efficiently.

```
>>> import datetime
```

The datetime module provides Python objects which can manipulate dates and times and have some understanding of the meanings of dates, making for easy comparisons between dates, date arithmetic, and other useful features.

```
>>> convert = lambda x: datetime.datetime.strptime(x, '%Y-%m-%d')
```

This line sets up a converter to be used later. strptime() creates a datetime from a string, given a format definition (here specified as year-month-day). So:

```
>>> print(datetime.datetime.strptime('2010-01-02', '%Y-%m-%d'))
2010-01-02 00:00:00
```

lambda is a simple shortcut for a one-liner function; wherever `convert(x)` is used after the definition, it functions like `datetime.datetime.strptime(x, '%Y-%m-%d')`. This makes it easier to parse a date string without specifying the format all the time:

```
>>> print(convert('2010-01-02'))
```

This converter can be used with loadtxt():

```
>>> esp_times = numpy.loadtxt(fname, skiprows=14, usecols=[0],
...                           converters={0: convert}, dtype=numpy.object)
```

The `converters` option takes a Python dictionary. The default dtype is float, which cannot store datetimes; using `numpy.object` allows storage of any Python object.

Since it would be useful to be able to load the data without typing so many lines, create a file called `common.py` in the code directory with the following contents:

```
import datetime
import os.path

import numpy


datadir = os.path.join('..', 'data')

def load_esp():
    fname = os.path.join(datadir, 'jgra20797-sup-0003-ds01_FIXED.txt')
    esp_fluxes = numpy.loadtxt(fname, skiprows=14, usecols=[1])
    convert = lambda x: datetime.datetime.strptime(x, '%Y-%m-%d')
    esp_times = numpy.loadtxt(fname, skiprows=14, usecols=[0],
                              converters={0: convert}, dtype=numpy.object)
    return (esp_times, esp_fluxes)
```

All needed imports are at the top of the file, with one blank line between standard library imports and other imports and two blank lines after them. `datadir` is defined as a global variable, outside of the function (but notice that it is available to the `load_esp` function.)

The rest of the file defines a function which returns the dates and fluxes in a tuple. The next section shows how to use this function.

Solar Wind data and averaging

The top panel of figure 1 shows the ESP fluxes overplotted with the solar wind velocity. Fortunately, the *omni* module of SpacePy provides an interface to the hourly solar wind dataset, OMNI. *get_omni()* returns data for a particular set of times. In this case, we want hourly data, covering 1989 through 2010 (we'll cut it down to size later). *tickrange()* allows us to specify a start time, stop time, and time step.

```
>>> import spacepy.omni
>>> import spacepy.time
>>> times = spacepy.time.tickrange('1989-01-01', '2011-01-01',
...                                datetime.timedelta(hours=1))
>>> d = spacepy.omni.get_omni(times)
>>> vsw = d['velo']
>>> vsw_times = d['UTC']
```

We'll also load the esp data:

```
>>> import common
>>> esp_times, esp_flux = common.load_esp()
```

Even though we have not installed `common.py`, the `import` statement finds it because it is in the current directory.

`load_esp` returns a tuple, which can be *unpacked* into separate variables.

Now we need to produce 27-day running averages of both the flux and the solar wind speed. Fortunately there are no gaps in the time series:

```
>>> import numpy
>>> d = numpy.diff(vsw_times)
>>> print(d.min())
1:00:00
>>> print(d.max())
1:00:00
>>> d = numpy.diff(esp_times)
>>> print(d.min())
1 day, 0:00:00
>>> print(d.max())
1 day, 0:00:00
```

`numpy.diff()` returns the difference between every element of an array and the previous element. `min()` and `max()` do exactly what they sound like. So this code confirms that every time in the vsw data is on a continuous one hour cadence, and the ESP data is on a continuous one day cadence.

```
>>> import scipy.stats
>>> esp_flux_av = numpy.empty(shape=esp_flux.shape, dtype=esp_flux.dtype)
>>> for i in range(len(esp_flux_av)):
...     esp_flux_av[i] = scipy.stats.nanmean(esp_flux[max(i - 13, 0):i + 14])
```

`numpy.empty()` creates an empty array, taking the `shape` and `dtype` from the `esp_flux` array. `empty` does not initialize the data in the array, so it is essentially random junk; use `zeros()` to create an array filled with zeros.

`len()` returns the length of an array, and `range()` then iterates over each number from 0 to length minus 1, i.e. the entire array. Each element is then set to a 27-day average: from 13 days before a day's measurement through 13 days after. (Python slices do not include the last element listed; they are half-open). Note that these slices can happily run off the end of the `esp_flux` array, but we use `max()` to ensure the first index does not go negative. (Negative indices have special meaning in Python.)

`nanmean()` takes the mean of a numpy array, but skips any elements with a value of "not a number" (nan), which is often used for fill. (This is our first exposure to the `scipy` module.)

For the solar wind averaging, the times need to cover the 24 * 13.5 = 324 hours previous, and 324 hours following (non-inclusive). There is also a more efficient way than using an explicit loop:

```
>>> vsw_av = numpy.fromiter((scipy.stats.nanmean(vsw[max(0, i - 324):i + 324])
...                          for i in range(len(vsw))),
...                          count=len(vsw), dtype=vsw.dtype)
```

`fromiter()` makes a numpy array from an iterator, which is like a list except that it holds information on generating each element in a sequence rather than creating the entire sequence. `count` provides numpy with the number of elements in the output (so it can make the entire array at once); `dtype` here is just copied from the input.

The type of iterator used here is a generator expression, closely related to a list comprehension. These are among the most powerful and most difficult to understand concepts in Python. An illustrative, although not useful, example:

```
>>> for i in (x + 1 for x in range(10)):
...     print(i)
```

Here `(x + 1 for x in range(10))` is a generator expression that creates an iterator, which will return the numbers 1 through 10. At no point is the complete list of all numbers constructed, saving memory.

In our calculation of `esp_flux_av`, we created an explicit loop in Python. The generator expression used to compute `vsw_av` has no explicit loop, and the actual looping is handled in (much faster) compiled C code.

Making Figure 1

To actually plot, we need access to the `pyplot` module:

```
>>> import matplotlib.pyplot as plt
>>> plt.ion()
```

This alternate form of the import statement shouldn't be overused (it can make code harder to read by masking the origin of functions), but is conventional for matplotlib.

`ion()` turns on interactive mode so plots appear and are updated as they're created.

```
>>> plt.semilogy(esp_times, 10 ** esp_flux_av, 'b')
>>> plt.draw()
>>> plt.draw()
```

`semilogy()` creates a semilog plot, log on the Y axis. The first two arguments are a list of X and Y values; after that there are many options to specify formatting (such as the color, used here.)

The ESP fluxes are stored as the log of the flux; ** is the exponentiation operator so the (geometric!) average is plotted properly.

`draw()` draws the updated plot; sometimes it needs to be called repeatedly. Use it whenever you want the plot updated; it will not be included from here on.

```
>>> plt.xlabel('Year', weight='bold')
>>> plt.ylabel('Electron Flux\n1.8-3.5 MeV', color='blue', weight='bold')
>>> plt.ylim(1e-2, 10)
(0.01, 10)
```

`xlabel()` and `ylabel()` set the labels for the axes. Note the newline (\n) in the string for the Y label. `ylim()` sets the lower and upper limits for the Y axis; there is, of course, `xlim()` as well.

These are the simplest, although not most flexible, ways to work with plots. To produce the full Figure 1, we'll move out of interactive mode:

```
>>> plt.ioff()
>>> plt.show()
```

`ioff()` turns off interactive mode. Once interactive mode is off, `show()` displays the full plot, including controls for panning, zooming, etc. Until the plot is closed, nothing further can happen in the Python window.

```
>>> fig = plt.figure(figsize=[11, 8.5])
```

`figure()` creates a new `Figure`; the size specified here is US-letter paper, landscape orientation.

```
>>> ax = fig.add_subplot(111)
```

`add_subplot()` creates an `Axes` object, which can contain an actual plot. `111` here means that the figure will have 1 subplot and the new subplot should be in position (1, 1); more on this later.

```
>>> fluxline = ax.plot(esp_times, 10 ** esp_flux_av, 'b')
```

`plot()` puts the relevant data into the plot; again specifying a blue line. It returns a list of `Line2D` objects, which we save for later use.

```
>>> ax.set_yscale('log')
```

`set_yscale()` switches the Y axis between log and linear (`set_xscale()` for the X axis).

```
>>> ax.set_ylim(1e-2, 10)
>>> ax.set_xlabel('Year', weight='bold')
>>> ax.set_ylabel('Electron Flux\n1.8-3.5 MeV', color='b', weight='bold')
```

`set_ylim()` (and `set_xlim()`), `set_xlabel()`, and `set_ylabel()` function much as above, but operate on a particular `Axes` object.

```
>>> ax2 = ax.twinx()
```

`twinx()` establishes a second Y axis (two values twinned on one X axis) on the same plot.

```
>>> vswline = ax2.plot(vsw_times, vsw_av, 'r')
>>> ax2.set_ylim(300, 650)
>>> ax2.set_ylabel('Solar Wind Speed', color='r', rotation=270, weight='bold')
```

The resulting `Axes` object has all the methods that we've used before. Note `rotation` on `set_ylabel()` to make the text run top-to-bottom rather than bottom-to-top.

```
>>> ax.set_xlim(esp_times[0], esp_times[-1])
```

Since the solar wind data extends beyond the ESP data, this sets the X axis to match the ESP data. Note `-1` to refer to the last element of the array.

```
>>> leg = ax.legend([fluxline[0], vswline[0]], ['Flux', 'Vsw'],
...                 loc='upper left', frameon=False)
```

`legend()`, as may be expected, creates a `Legend` on the axes. The first parameter is a list of the matplotlib objects to make a legend for; since the plotting commands return these, we can pass them back in. Each plotting command returns a *list*. In this case we just take the 0th element of each list since we know there's only one line from each plotting command. The second parameter is the text used to annotate each line.

```
>>> fluxtext, vswtext = leg.get_texts()
>>> fluxtext.set_color(fluxline[0].get_color())
>>> vswtext.set_color(vswline[0].get_color())
```

The default text color is black, so we use `get_texts()` to get the `Text` objects for the annotations. Again, we know there are two (we just created the legend). Then `set_color()` sets the color based on the the existing color for each line (`get_color()`).

To see the results:

```
>>> plt.show()
```

Close the window when done. Now we want to save the output:

```
>>> fig_fname = os.path.join('..', 'plots', 'fig1a.eps')
>>> fig.savefig(fig_fname)
```

`savefig()` saves the figure, in this case as an encapsulated PostScript file (to the `plots` directory).

Let's tweak a few things. For one, there's a lot of padding around the figure, which can make it difficult to properly scale for publication. The way around this is to specify a `Bbox` (bounding box), basically the lower left and upper right corners (in inches) to include in the saved figure. Getting this right tends to be a matter of trial and error. (`get_tightbbox()` is supposed to help with this, but it doesn't quite work yet.)

```
>>> import matplotlib.transforms
>>> bob = matplotlib.transforms.Bbox([[0.52, 0.35], [10.5, 7.95]])
>>> fig.savefig(fig_fname, bbox_inches=bob, pad_inches=0.0)
```

Better, but all the text is awfully small. Once the figure is fit in the paper it'll be really small. And the font isn't that great.

```
>>> import matplotlib
>>> matplotlib.rcParams['axes.unicode_minus'] = False
>>> matplotlib.rcParams['text.usetex']= True
>>> matplotlib.rcParams['font.family'] = 'serif'
>>> matplotlib.rcParams['font.size'] = 14
>>> bob = matplotlib.transforms.Bbox([[0.4, 0.35], [10.7, 7.95]])
>>> fig.savefig(fig_fname, bbox_inches=bob, pad_inches=0.0)
```

Now the font is bigger and it's rendered using TeX, which should match the body of the paper better (assuming the paper is in LaTeX). The larger font means tweaking the bounding box. `unicode_minus` fixes a problem where negative numbers on the axis don't render properly in TeX. Matplotlib has many more options for customization.

The end result is a nice figure that can be printed full-size, put in a PDF, or included directly in a paper.

Now we need the bottom half of Figure 1. From SIDC, download the "Monthly mean total sunspot number" (`monthssn.dat`). Put it in the `data` directory.

```
>>> import bisect
>>> import datetime
>>> monthfile = os.path.join(common.datadir, 'monthssn.dat')
```

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```
>>> convert = lambda x: datetime.datetime.strptime(x, '%Y%m')
>>> ssn_data = numpy.genfromtxt(monthfile, skip_header=2400, usecols=[0, 2, 3],
...                             converters={0: convert}, dtype=numpy.object,
...                             skip_footer=24)
>>> idx = bisect.bisect_left(ssn_data[:, 0], datetime.datetime(1989, 1, 1))
>>> ssn_data = ssn_data[idx:]
>>> ssn_times = ssn_data[:, 0]
>>> ssn = numpy.asarray(ssn_data[:, 1], dtype=numpy.float64)
>>> smooth_ssn = numpy.asarray(ssn_data[:, 2], dtype=numpy.float64)
>>> ssn_times += datetime.timedelta(days=15)
```

Much of this should be familiar. `genfromtxt()` is a little more flexible than `loadtxt()`; here it allows the skipping of lines at the end as well as the beginning (skipping 200 years at the start, 2 at the end, where data are provisional.) Here we load both times and the sunspot numbers in the same command so that if any lines don't load, they will not wind up in any of the arrays.

`bisect` provides fast functions for searching in sorted data; `bisect_left()` is roughly a find-the-position-of function. Having found the position of the start of 1989, we then keep times from then on (specifying a start index without a stop index in Python means "from start to end of the list.") Note that, although `bisect` is meant to work on lists, it also works fine on numpy arrays; this is a common feature of Python known as duck typing.

We then use `asarray()` to convert the `ssn` and `smooth_ssn` columns to float arrays. Note the slice notation: `[:, 0]` means take all indices of the first dimension (line number) and only the 0th index of the second dimension (column in the line). Finally, we use `timedelta` to shift the date associated with a month from the beginning to roughly the middle of the month. Adding a scalar to an array does an element-wise addition.

```
>>> import matplotlib.figure
>>> fig = plt.figure(figsize=[11, 8.5],
...                  subplotpars=matplotlib.figure.SubplotParams(hspace=0.1))
>>> ax = fig.add_subplot(211)
```

When creating the figure this time, we use `SubplotParams` to choose a slightly smaller vertical spacing between adjacent subplots. Tweaking `SubplotParams` also provides an alternative to tweaking bounding boxes.

Then we create a subplot with the information that there will be 2 rows, 1 column, and this is the first subplot. Now everything acting on ax, above, can be repeated, although we skip setting the xlabel since only the bottom axis will be labeled.

```
>>> fluxline = ax.plot(esp_times, 10 ** esp_flux_av, 'b')
>>> ax.set_yscale('log')
>>> ax.set_ylim(1e-2, 10)
>>> ax.set_ylabel('Electron Flux\n1.8-3.5 MeV', color='b', weight='bold')
>>> ax2 = ax.twinx()
>>> vswline = ax2.plot(vsw_times, vsw_av, 'r')
>>> ax2.set_ylim(300, 650)
>>> ax2.set_ylabel('Solar Wind Speed', color='r', rotation=270, weight='bold')
>>> ax.set_xlim(esp_times[0], esp_times[-1])
>>> leg = ax.legend([fluxline[0], vswline[0]], ['Flux', 'Vsw'],
...                 loc='upper left', frameon=False)
>>> fluxtext, vswtext = leg.get_texts()
>>> fluxtext.set_color(fluxline[0].get_color())
>>> vswtext.set_color(vswline[0].get_color())
```

Then we move on to adding the solar wind:

```
>>> ax3 = fig.add_subplot(212, sharex=ax)
```

This adds another subplot, the second in the 2x1 array. Its x axis is shared with the existing `ax`. (This is poorly documented; see this example)

```
>>> plt.setp(ax.get_xticklabels(), visible=False)
>>> plt.setp(ax2.get_xticklabels(), visible=False)
```

`setp()` sets a property. `get_xticklabels()` returns all the tick labels (`Text`) for the x axis; `setp` then sets `visible` to `False` for all of them. This hides the labeling on the axis for the upper subfigure.

```
>>> ax3.set_xlabel('Year', weight='bold')
>>> ax3.set_ylabel('Sunspot Number', weight='bold')
>>> smoothline = ax3.plot(ssn_times, smooth_ssn, lw=2.0, color='k')
>>> ssnline = ax3.plot(ssn_times, ssn, color='k', linestyle='dotted')
```

There is nothing new here except for the specifications of `linewidth` and `linestyle`; see `plot()` for details. Note `k` as the abbreviation for black (to avoid confusion with blue.)

```
>>> leg2 = ax3.legend([ssnline[0], smoothline[0]],
...                   ['Sunspot Number', 'Smoothed SSN'],
...                   loc='upper right', frameon=False)
>>> ax3.set_ylim(0, 200)
>>> ax3.set_xlim(esp_times[0], esp_times[-1])
```

```
>>> fig_fname = os.path.join('..', 'plots', 'fig1.eps')
>>> fig.savefig(fig_fname, bbox_inches=bob, pad_inches=0.0)
```

All of this has been seen for the top half of figure 1.

Following is the complete code to reproduce Figure 1.

```
import bisect
import datetime
import os.path

import common
import matplotlib
import matplotlib.figure
import matplotlib.pyplot as plt
import matplotlib.transforms
import numpy
import scipy
import scipy.stats
import spacepy.omni
import spacepy.time


matplotlib.rcParams['axes.unicode_minus'] = False
matplotlib.rcParams['text.usetex']= True
matplotlib.rcParams['font.family'] = 'serif'
matplotlib.rcParams['font.size'] = 14
bob = matplotlib.transforms.Bbox([[0.4, 0.35], [10.7, 7.95]])
```

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```
times = spacepy.time.tickrange('1989-01-01', '2011-01-01',
                               datetime.timedelta(hours=1))
d = spacepy.omni.get_omni(times)
vsw = d['velo']
vsw_times = d['UTC']
esp_times, esp_flux = common.load_esp()
esp_flux_av = numpy.empty(shape=esp_flux.shape, dtype=esp_flux.dtype)
for i in range(len(esp_flux_av)):
    esp_flux_av[i] = scipy.stats.nanmean(esp_flux[max(i - 13, 0):i + 14])
vsw_av = numpy.fromiter((scipy.stats.nanmean(vsw[max(0, i - 324):i + 324])
                         for i in range(len(vsw))),
                        count=len(vsw), dtype=vsw.dtype)
monthfile = os.path.join(common.datadir, 'monthssn.dat')
convert = lambda x: datetime.datetime.strptime(x, '%Y%m')
ssn_data = numpy.genfromtxt(monthfile, skip_header=2400, usecols=[0, 2, 3],
                            converters={0: convert}, dtype=numpy.object,
                            skip_footer=24)
idx = bisect.bisect_left(ssn_data[:, 0], datetime.datetime(1989, 1, 1))
ssn_data = ssn_data[idx:]
ssn_times = ssn_data[:, 0]
ssn = numpy.asarray(ssn_data[:, 1], dtype=numpy.float64)
smooth_ssn = numpy.asarray(ssn_data[:, 2], dtype=numpy.float64)
ssn_times += datetime.timedelta(days=15)

fig = plt.figure(figsize=[11, 8.5],
                 subplotpars=matplotlib.figure.SubplotParams(hspace=0.1))
ax = fig.add_subplot(211)
fluxline = ax.plot(esp_times, 10 ** esp_flux_av, 'b')
ax.set_yscale('log')
ax.set_ylim(1e-2, 10)
ax.set_ylabel('Electron Flux\n1.8-3.5 MeV', color='b', weight='bold')
ax2 = ax.twinx()
vswline = ax2.plot(vsw_times, vsw_av, 'r')
ax2.set_ylim(300, 650)
ax2.set_ylabel('Solar Wind Speed', color='r', rotation=270, weight='bold')
ax.set_xlim(esp_times[0], esp_times[-1])
leg = ax.legend([fluxline[0], vswline[0]], ['Flux', 'Vsw'],
                loc='upper left', frameon=False)
fluxtext, vswtext = leg.get_texts()
fluxtext.set_color(fluxline[0].get_color())
vswtext.set_color(vswline[0].get_color())

ax3 = fig.add_subplot(212, sharex=ax)
plt.setp(ax.get_xticklabels(), visible=False)
plt.setp(ax2.get_xticklabels(), visible=False)
ax3.set_xlabel('Year', weight='bold')
ax3.set_ylabel('Sunspot Number', weight='bold')
smoothline = ax3.plot(ssn_times, smooth_ssn, lw=2.0, color='k')
ssnline = ax3.plot(ssn_times, ssn, color='k', linestyle='dotted')
leg2 = ax3.legend([ssnline[0], smoothline[0]],
                  ['Sunspot Number', 'Smoothed SSN'],
                  loc='upper right', frameon=False)
```

(continues on next page)

(continued from previous page)

```
ax3.set_ylim(0, 200)
ax3.set_xlim(esp_times[0], esp_times[-1])

fig_fname = os.path.join('..', 'plots', 'fig1.eps')
fig.savefig(fig_fname, bbox_inches=bob, pad_inches=0.0)
```

Appendix: Fixing the ESP data file

This appendix provides a detailed explanation of the script that fixes the ESP data file.

First set up a variable to hold the location of the data, as above:

```
>>> import os.path
>>> datadir = os.path.join('..', 'data')
```

Examining the data file, it is clear that something is odd: lines appear to have been broken inappropriately; for example, the data for 1989-10-12 are split across two lines. So the first task is to fix this file, first opening the original (broken) file and an output (fixed) file:

```
>>> in_name = os.path.join(datadir, 'jgra20797-sup-0003-ds01.txt')
>>> out_name = os.path.join(datadir, 'jgra20797-sup-0003-ds01_FIXED.txt')
>>> infile = open(in_name, 'r')
>>> outfile = open(out_name, 'w')
```

These lines `open()` the original file for reading (`r`), and a new file for writing (`w`). Note that opening a file for writing will destroy any existing contents.

The file happens to contain a mixture of carriage returns and proper newlines, so to begin all the carriage returns need to be rewritten as newlines:

```
>>> data = infile.read()
>>> infile.close()
>>> data = data.replace('\r', '\n')
>>> data = data.replace('\n\n', '\n')
```

`read()` reads *all* data from the file at once, so this is not recommended for large files. In this case it makes things easier. Once the data are read, `close()` the file. Calling the `replace()` method on `data` replaces all instances of the first parameter (`'\r'`) with the second (`'\n'`). `\r` is the special code indicating a carriage return; `\n`, a newline. For a literal backslash, use `\\`. Once the carriage returns have been replaced with newlines, a second round of replacement eliminates duplicates.

Now that the line endings have been cleaned up, it's time to rejoin the erroneously split lines. First copy over the 15 lines of header verbatim:

```
>>> data = data.split('\n')
>>> for i in range(15):
...     outfile.write(data.pop(0) + '\n')
```

`split()` splits a string into a list, with the split between elements happening wherever the provided parameter occurs. A simple example:

```
>>> foo = 'a.b.c'.split('.')
>>> print(foo)
['a', 'b', 'c']
```

The splitting character is not present in the output.

The advantage of a list is that it makes it easy to access individual elements: >>> print(foo[1]) b

The first element of a Python list is numbered zero.

`range()` returns a list of numbers, starting from 0, with the parameter specifying how many elements are in the list:

```
>>> print(range(5))
[0, 1, 2, 3, 4]
```

The last number is 4 (not 5 as might be expected), but there are 5 elements in the list.

The for executes the following indented statement once for every element in the `in` list:

```
>>> for i in ['a', 'b', 'c']:
...     print i
a
b
c
```

Indentation is significant in Python! Normally indents are four spaces and the tab key will do the job. (In the above example, you may need to hit enter twice after the print statement, the second to terminate the indentation.)

pop returns one element from a list, and deletes it from the list. Using `0` pops off the first element, and `write()` writes a string to a file. + can be used to concatenate two strings together. Since `split()` removed the newlines, they need to be readded.

So this little block of code splits the data into a list on newlines and, repeating fifteen times, takes the first element of that list and writes it, with a newline, to the output. Now `data` contains only the actual lines of data.

```
>>> oldline = None
>>> for line in data:
...     if line[0:2] in ['19', '20', '2']:
...         if not oldline is None:
...             outfile.write(oldline + '\n')
...         oldline = line
...     else:
...         oldline += line
>>> outfile.write(oldline + '\n')
>>> outfile.close()
```

`None` is a special Python value specifically indicating nothing; it's used here to mark the first time around the loop.

`line[0:2]` gets the first two characters in the string *line*, and the `in` operator compares the resulting string to see if it is present in the following list. This will return `True` if the line begins with `19` or `20`. The if statement executes the following indented block if the condition is True. So, if this is True, the previous line probably ended properly and it can be written out. First there is an additional check that this isn't the first time around the loop, and then the *previous* line (which we know ended cleanly) is written out. The currently-read line then becomes the new "previous" line.

The `2` is a special case: if the line is less than two characters long, `line[0:2]` will return the entire line, and it so happens that these cases always correspond to the previous line being whole.

If this test fails, everything under `else` is executed. Here the assumption is that the previous line didn't end cleanly and the current line is actually a continuation of it, so the current line is appended to the previous. `a += b` is a shortcut for `a = a + b`.

Once the loop terminates, the last line is written out, and the file closed.

2.4 Publication List

The following publications have been prepared using SpacePy. If you have published a paper using SpacePy, contact the SpacePy team to be added to this list. Please also provide a citation or acknowledgment, as appropriate, in your paper.

2.4.1 Papers using SpacePy

Peer-reviewed papers

- Gieseler, J., P. Oleynik, H. Hietala, R. Vainio, H.-P. Hedman, J. Peltonen, A. Punkkinen, R. Punkkinen, T. Säntti, E. Hæggström, J. Praks, P. Niemelä, B. Riwanto, N. Jovanovic, and M. R. Mughal (2020), Radiation monitor RADMON aboard Aalto-1 CubeSat: First results, Adv. Space Res., 66 (1), 52-65, doi:10.1016/j.asr.2019.11.023.
- Jordanova, V. K., Y. Yu, J. T. Niehof, R. M. Skoug, G. D. Reeves, C. A. Kletzing, J. F. Fennell, and H. E. Spence (2014), Simulations of inner magnetosphere dynamics with an expanded RAM-SCB model and comparisons with Van Allen Probes observations, Geopys. Res. Lett., 41 (8), 2687-2695, doi:10.1002/2014GL059533.
- Niehof, J. T., S. K. Morley, and R. H. W. Friedel (2012), Association of cusp energetic ions with geomagnetic storms and substorms, Ann. Geophys., 30 (12), 1633-1643, doi:10.5194/angeo-30-1633-2012.
- Turner, D. L., V. Angelopoulos, Y. Shprits, A. Kellerman, P. Cruce and D. Larson (2012), Radial distributions of equatorial phase space density for outer radiation belt electrons, Geophys. Res. Lett., 39, L09101, doi:10.1029/2012GL051722.
- Welling, D. T. and A. J. Ridley (2010), Exploring sources of magnetospheric plasma using multispecies MHD, Journal of Geophysical Research, 115, 4201, doi:10.1029/2009JA014596.
- Morley, S. K., R. H. W. Friedel, E. L. Spanswick, G. D. Reeves, J. T. Steinberg, J. Koller, T. Cayton and E. Noveroske (2010), Dropouts of the outer electron radiation belt in response to solar wind stream interfaces: Global Positioning System observations, Proceedings of the Royal Society A, doi:10.1098/rspa.2010.0078.

Other publications and presentations

- Niehof, J. T. and S. K. Morley (2012), Determining the significance of associations between two series of discrete events: bootstrap methods, Tech Report LA-14453, Los Alamos National Laboratory, Los Alamos, NM, doi:10.2172/1035497.

2.4.2 Papers about SpacePy

Peer-reviewed papers

- Morley, S. K., D. T. Welling, J. Koller, B. A. Larsen, M. G. Henderson and J. Niehof (2010), SpacePy - A Python-based library of tools for the space sciences, Proceedings of the 9th Python in Science Conference (SciPy 2010), presented in Austin, TX, June 30 - July 1, 2010 pdf. full proceedings

Other publications and presentations

- Niehof, J. T., M. G. Henderson, J. Koller, B. A. Larsen, S. Morley, D. T. Welling, Y. Yu (2012), Space Science with the SpacePy Toolkit, Abstract IN53C-1746 presented at 2012 Fall Meeting, AGU, San Francisco, Calif., 3-7 Dec. (pdf)
- The SpacePy Developer Team (2010), SpacePy - Python-Based of Tools for the Space Science Community, A Tri-Fold pdf.
- Morley, S. K., D. T. Welling, J. Koller, B. A. Larsen, M. G. Henderson (2010), SpacePy - Data Analysis and Visualization Tools for the Space Sciences, presented at GEM 2010 Summer Workshop, Snowmass, CO, June 20-25. (pdf)

2.5 Python 2 End of Support

Python 3 is fully supported by SpacePy and used in daily work by the SpacePy team.

On January 1, 2020, Python 2 reached end of life. Most of the scientific Python stack has committed to ending Python 2 support by 2020. This includes numpy.

As a result, the SpacePy team will phase out Python 2 support over the course of 2020 and early 2021. This process is managed through SpacePy issue 26.

2.5.1 0.2 series: full support

The last release of the SpacePy 0.2 series will be 0.2.3, by the end of 2020. This will be the last release where all functionality works with Python 2 and that has binary installers provided for Python 2. 0.2 will *not* be supported past this release (this will not be a "long-term support" release.)

2.5.2 0.3 series: no feature support

Starting with 0.3.0 in early 2021, the SpacePy team will:

- Provide no prebuilt packages for Python 2. We will attempt to ensure the last 0.2.x version will still install from pip on Python 2.
- Allow new features that do not support Python 2 as long as they do not break existing functionality.
- Provide no workarounds for dependencies that no longer support Python 2.

SpacePy 0.3.x will still function on Python 2 for those who install "by hand".

2.5.3 0.4 series: no bugfix support

Starting with 0.4.0, no later than mid-2021, the SpacePy team will provide no fixes for bugs that cannot be reproduced on Python 3.

SpacePy 0.4.x will still function on Python 2 for those who install "by hand".

2.5.4 0.5 series: remove support

Starting with 0.5.0, mid-2021, SpacePy developers will begin removing code that exists only to support Python 2. SpacePy 0.5.x will not function on Python 2.

Release 0.3.0

Doc generation date Apr 27, 2022

2.6 SpacePy Configuration

SpacePy has a few tunable options that can be altered through the `spacepy.rc` configuration file. All options have defaults which will be used if not specified in the configuration file. These defaults are usually fine for most people and may change between SpacePy releases, so we do not recommend changing the configuration file without substantial reason.

`spacepy.rc` lives in the per-user SpacePy directory, called `.spacepy`. You can find this directory by:

```
>>> import spacepy
>>> spacepy.DOT_FLN
'/home/username/.spacepy'
```

On Unix-like operating systems, it is in a user's home directory; on Windows, in the user's Documents and Settings folder. If it doesn't exist, this directory (and `spacepy.rc`) is automatically created when SpacePy is imported.

`spacepy.rc` has an INI-style format, parsed by `ConfigParser`. It contains a single section, `[spacepy]`.

- *The spacepy directory*
- *Available configuration options*
- *Developer documentation*

2.6.1 The spacepy directory

If you prefer a different location for the SpacePy directory, set the environment variable `$SPACEPY` to a location of your choice. For example, with a `csh`, or `tcsh` you would:

```
setenv SPACEPY /a/different/dir
```

for the `bash` shell you would:

```
export SPACEPY=/a/different/dir
```

If `$SPACEPY` is not an absolute path, it is treated as relative to the working directory at the time of import. In particular, that means if it is defined as an empty string (rather than an undefined variable), `.spacepy` is made directly in the current directory. Home directory references (~) are expanded via `expanduser()`.

If you change the default location, make sure you add the environment variable `$SPACEPY` to your `.cshrc`, `.tcshrc`, or `.bashrc` script. If this directory does not exist, it will be created.

The actual `.spacepy` directory is made inside the directory specified by `$SPACEPY`.

This directory contains the configuration file and also SpacePy-related data, which can be updated with *`update()`*.

2.6.2 Available configuration options

enable_deprecation_warning SpacePy raises `DeprecationWarning` when deprecated functions are called. Starting in Python 2.7, these are ignored. SpacePy adds a warnings filter to force display of deprecation warnings from SpacePy the first time a deprecated function is called. Set this option to False to retain the default Python behavior. (See `warnings` module for details on custom warning filters.)

enable_old_data_warning SpacePy maintains certain databases from external sources, notably the leapsecond database used by *time*. By default `UserWarning` is issued if the leap second database is out of date. Set this option to False to suppress this warning (and warnings about out-of-date data which may be added in the future.)

keepalive True to attempt to use HTTP keepalives when downloading data in *update()* (default). This is faster when downloading many small files but may be fragile (e.g. if a proxy server is required). Set to False for a more robust and flexible, but slower, codepath.

leapsec_url URL of the leapsecond database used by time conversions. *update()* will download from the URL. The default should almost always be acceptable.

ncpus Number of CPUs to use for computations that can be multithreaded/multiprocessed. By default, they will use the number of CPUs reported by `multiprocessing.cpu_count()`. You may wish to set this to a lower number if you need to reserve other processors on your machine.

notice True to display the SpacePy license and other information on import (default); False to omit.

omni2_url URL containing the OMNI2 data. *update()* will download from the URL. The default should almost always be acceptable.

qindenton_url URL containing Qin-Denton packaging of OMNI data as as single file. *update()* will download from the URL. The default should almost always be acceptable.

qd_daily_url URL containing Qin-Denton packaging of OMNI data in daily files, supplemental to `qindenton_url`. *update()* will download from the URL. The default should almost always be acceptable.

psddata_url URL containing PSD data. *update()* will download from the URL if requested. The default should almost always be acceptable.

support_notice True to display a notice on import if not a release version of SpacePy (default); False to omit. Those regularly installing from git instead of a release may want to set this to False.

user_agent User Agent for network access. If this is set, *update()* will use this User Agent string on all HTTP requests. Normally leaving this unset should be fine.

2.6.3 Developer documentation

`spacepy.rc` is loaded into a dictionary (`spacepy.config`) by SpacePy's main `__init__.py`. All options from the `[spacepy]` section are loaded, with no developer intervention needed. Each key is the option's name; the associated value is the option's value. To specify a default, add to the `defaults` dictionary at the top of `_read_config`; each default, if not overridden by the config file, will be included in the config dict. Values are assumed to be strings. The `caster` dictionary is keyed by option name; the value for each key is a function to be applied to the value with the same key to produce a different type from a string.

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For additions or fixes to this page, contact the SpacePy Team at Los Alamos.

2.7 SpacePy Scripts

Some scripts using SpacePy are included in the `scripts` directory of the source distribution. At the moment they are not installed by the installer.

2.7.1 istp_checks.py

Checks for various ISTP compliance issues in a file and prints any issues found. This script is supplemental to the checker included with the ISTP skeleton editor; it primarily checks for errors that the skeleton editor does not.

Badly noncompliant files generally result in the error "Test x did not complete". This means the test crashed due to some failure in the assumptions about the CDF structure. Please run the individual test to get a traceback and open an issue.

This is just a thin wrapper to *spacepy.pycdf.istp.FileChecks.all()*; that documentation (plus other methods in the class) describes the actual checks.

cdffile
: Name of the CDF file to check (required)

CHAPTER

THREE

DEVELOPER GUIDE

For those developing SpacePy, plus tips for all Python developers.

3.1 Writing Pythonic Code

Code is often described as "Pythonic" or "not Pythonic" (with the implication that "Pythonic" is better.) The description is often applied to refer to code that reflects best practices which have emerged from the Python community and have become almost second nature to experienced programmers.

Reading lots of Python code (particularly from well-respected long maintained community projects) is the best way to develop this sense, but some principles are described here.

3.1.1 Good coding practice

Familiarity with modern coding practices that apply across most languages is a good start:

- Compact but descriptive names for variables, functions, etc.
- Succinct comments where necessary
- Encapsulation of data and abstraction through functions and classes
- Use of existing libraries rather than reimplementing

3.1.2 Using language features

Where Python or its standard library provides a means of accomplishing a task, it is generally preferred to use that means rather than reimplementing the wheel. The canonical example is using list comprehensions rather than for loops to transform a list:

```
>>> newlist = [i + 1 for i in oldlist]
```

not:

```
>>> newlist = []
>>> for i in range(len(oldlist)):
...     newlist.append(oldlist[i] + 1)
```

Note there are several non-Pythonic ways to perform this task.

For those not familiar with the features of the lanaguage and the standard library, this does represent a barrier to entry. However once that knowledge is built, using the features of the language makes one's intention much more clear. It often also results in shorter code that is easier to comprehend.

See several examples in *SpacePy Python Programming Tips*.

3.1.3 Idiom and communication

Because "code is more often read than written," anything that improves clarity is beneficial. A list comprehension and a for loop may have the same result, but the use of a list comprehension immediately makes it apparent to the reader that the code is intended to create a new list based on some element-by-element translation of the input list. It is a pattern with a common solution, and sticking to the common solution helps make the pattern apparent so the reader of the code understands the underlying problem.

Generally this choice of the common way is referred to as "idiomatic Python." This can be expanded to conventions such as the use of "self" as the first argument in instance methods, even though such choice is generally free.

3.1.4 Further Reading

A web search for "pythonic" will give a wealth of opinions. These references are a good starting point.

- Python Style Guide (PEP 8)
- Zen of Python (PEP 20)
- What is Pythonic?
- Examples of idiomatic and nonidiomatic Python
- Idomatic Python from Wikibooks

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3.2 SpacePy Python Programming Tips

One often hears that interpreted languages are too slow for whatever task someone needs to do. In many cases this belief is unfounded. As the time spent programming and debugging in an interpreted language is of far less than for a compiled language, the programmer has more time to identify bottlenecks in the code and optimize it where necessary. This page is dedicated to that idea, providing examples of code speedup and best practices.

One often neglected way to speed up development time is to use established libraries, and the time spent finding existing code that does what you want can be more productive than trying to write and optimize your own algorithms. We recommend exploring the SpacePy documentation, as well as taking the time to learn some of the vast functionality already in numpy and the Python standard library.

- *Basic examples*
- *Lists, for loops, and arrays*
- *Zip*
- *External links*

3.2.1 Basic examples

Though there are some similarities, Python does not look like (or work like) Matlab or IDL. As (most of us) are, or have been, Matlab or IDL programmers, we have to rethink how we do things – what is efficient in one language may not be the most efficient in another. One truth that Python shares with these other languages, however, is that if you are using a for loop there is likely to be a faster way…

Take the simple case of a large data array where you want to add one to each element. Here wa show four of the possible ways to do this, and by using a profiling tool, we can show that the speeds of the different methods can vary substantially.

Create the data

```
>>> data = range(10000000)
```

The most C-like way is just a straight up for loop

```
>>> for i in range(len(data)):
>>>     data[i] += 1
```

This is 6 function calls in 2.590 CPU seconds (from `cProfile`)

The next, more Pythonic, way is with a list comprehension

```
>>> data = [val+1 for val in data]
```

This is 4 function calls in 1.643 CPU seconds (~1.6x)

Next we introduce numpy and change our list to an array then add one

```
>>> data = np.asarray(data)
>>> data += 1
```

This is 6 function calls in 1.959 CPU seconds (~1.3x), better than the for loop but worse than the list comprehension

Next we do this the *right* way and just create it in numpy and never leave

```
>>> data = np.arange(10000000)
>>> data += 1
```

this is 4 function calls in 0.049 CPU seconds (~53x).

While this is a really simple example it shows the basic premise, if you need to work with numpy, start in numpy and stay in numpy. This will usually be true for array-based manipulations.

If in doubt, and speed is not a major consideration, use the most human-readable form. This will make your code more maintainable and encourage its use by others.

3.2.2 Lists, for loops, and arrays

This example teaches the lesson that most advanced IDL or Matlab programmers already know; do everything in arrays and never use a for loop if there is another choice. The language has optimized array manipulation and it is unlikely that you will find a faster way with your own code.

The following bit of code takes in a series of coordinates, computes their displacement, and drops the largest 100 of them.

This is how the code started out, Shell_x0_y0_z0 is an Nx3 numpy array, ShellCenter is a 3 element list or array, and Num_Pts_Removed is the number of points to drop:

```
import numpy as np
def SortRemove_HighFluxPts_(Shell_x0_y0_z0, ShellCenter, Num_Pts_Removed):
    #Sort the Shell Points based on radial distance (Flux prop to 1/R^2) and remove Num_
↪Pts_Removed points with the highest flux
    Num_Pts_Removed = np.abs(Num_Pts_Removed)  #make sure the number is positive
    #Generate an array of radial distances of points from origin
    R = []
    for xyz in Shell_x0_y0_z0:
        R.append(1/np.linalg.norm(xyz + ShellCenter)) #Flux prop to 1/r^2, but don't need␣
↪the ^2
    R = np.asarray(R)
    ARG = np.argsort(R)   # array of sorted indies based on flux in 1st column
    Shell_x0_y0_z0 = np.take(Shell_x0_y0_z0, ARG, axis = 0)  # sort based on index order
    return Shell_x0_y0_z0[:-Num_Pts_Removed,:]   #remove last points that have the
↪"anomalously" high flux
```

A cProfile of this yields a lot of time spent just in the function itself; this is the for loop (list comprehension is a little faster but not much in this case):

```
Tue Jun 14 10:10:56 2011    SortRemove_HighFluxPts_.prof

         700009 function calls in 4.209 seconds

   Ordered by: cumulative time
   List reduced from 14 to 10 due to restriction <10>

   ncalls  tottime  percall  cumtime  percall filename:lineno(function)
        1    0.002    0.002    4.209    4.209 <string>:1(<module>)
        1    2.638    2.638    4.207    4.207 test1.py:235(SortRemove_HighFluxPts_)
   100000    0.952    0.000    1.529    0.000 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/linalg/linalg.py:1840(norm)
   100001    0.099    0.000    0.240    0.000 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/core/numeric.py:167(asarray)
   100000    0.229    0.000    0.229    0.000 {method 'reduce' of 'numpy.ufunc' objects}
   100001    0.141    0.000    0.141    0.000 {numpy.core.multiarray.array}
   100000    0.082    0.000    0.082    0.000 {method 'ravel' of 'numpy.ndarray' objects}
   100000    0.042    0.000    0.042    0.000 {method 'conj' of 'numpy.ndarray' objects}
   100000    0.016    0.000    0.016    0.000 {method 'append' of 'list' objects}
        1    0.000    0.000    0.005    0.005 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/core/fromnumeric.py:45(take)
```

Simply moving the addition outside the for-loop gives a factor of 2.3 speedup. We believe that the difference arising from moving the addition lets numpy (which works primarily in C) operate once only. This massively reduces the calling overhead as array operations are done as for loops in C, and not in element-wise in python:

```
def SortRemove_HighFluxPts_(Shell_x0_y0_z0, ShellCenter, Num_Pts_Removed):
    #Sort the Shell Points based on radial distance (Flux prop to 1/R^2) and remove Num_
↪Pts_Removed points with the highest flux
    Num_Pts_Removed = np.abs(Num_Pts_Removed)  #make sure the number is positive
    #Generate an array of radial distances of points from origin
    R = []
    Shell_xyz = Shell_x0_y0_z0 + ShellCenter
    for xyz in Shell_xyz:
```

(continues on next page)

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```
        R.append(1/np.linalg.norm(xyz)) #Flux prop to 1/r^2, but don't need the ^2
    R = np.asarray(R)
    ARG = np.argsort(R)   # array of sorted indies based on flux in 1st column
    Shell_x0_y0_z0 = np.take(Shell_x0_y0_z0, ARG, axis = 0)  # sort based on index order
    return Shell_x0_y0_z0[:-Num_Pts_Removed,:]   #remove last points that have the
↪"anomalously" high flux
```

A quick profile:

```
Tue Jun 14 10:18:39 2011    SortRemove_HighFluxPts_.prof

         700009 function calls in 1.802 seconds

   Ordered by: cumulative time
   List reduced from 14 to 10 due to restriction <10>

   ncalls  tottime  percall  cumtime  percall filename:lineno(function)
        1    0.001    0.001    1.802    1.802 <string>:1(<module>)
        1    0.402    0.402    1.801    1.801 test1.py:235(SortRemove_HighFluxPts_)
   100000    0.862    0.000    1.361    0.000 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/linalg/linalg.py:1840(norm)
   100000    0.207    0.000    0.207    0.000 {method 'reduce' of 'numpy.ufunc' objects}
   100001    0.080    0.000    0.199    0.000 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/core/numeric.py:167(asarray)
   100001    0.120    0.000    0.120    0.000 {numpy.core.multiarray.array}
   100000    0.067    0.000    0.067    0.000 {method 'ravel' of 'numpy.ndarray' objects}
   100000    0.041    0.000    0.041    0.000 {method 'conj' of 'numpy.ndarray' objects}
   100000    0.014    0.000    0.014    0.000 {method 'append' of 'list' objects}
        1    0.000    0.000    0.005    0.005 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/core/fromnumeric.py:45(take)
```

A closer look here reveals that all of this can be done on the arrays without the for loop (or list comprehension):

```
def SortRemove_HighFluxPts_(Shell_x0_y0_z0, ShellCenter, Num_Pts_Removed):
    #Sort the Shell Points based on radial distance (Flux prop to 1/R^2) and remove #␣
↪points with the highest flux
    Num_Pts_Removed = np.abs(Num_Pts_Removed)  #make sure the number is positive
    #Generate an array of radial distances of points from origin
    R = 1 / np.sum((Shell_x0_y0_z0 + ShellCenter) ** 2, 1)
    ARG = np.argsort(R)   # array of sorted indies based on flux in 1st column
    Shell_x0_y0_z0 = np.take(Shell_x0_y0_z0, ARG, axis = 0)  # sort based on index order
    return Shell_x0_y0_z0[:-Num_Pts_Removed,:]   #remove last points that have the
↪"anomalously" high flux
```

The answer is exactly the same and comparing to the initial version of this code we have managed a speedup of 382x:

```
Tue Jun 14 10:21:54 2011    SortRemove_HighFluxPts_.prof

         10 function calls in 0.011 seconds

   Ordered by: cumulative time

   ncalls  tottime  percall  cumtime  percall filename:lineno(function)
```

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```
        1    0.000    0.000    0.011    0.011 <string>:1(<module>)
        1    0.002    0.002    0.011    0.011 test1.py:236(SortRemove_HighFluxPts_)
        1    0.000    0.000    0.004    0.004 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/core/fromnumeric.
↪py:598(argsort)
        1    0.004    0.004    0.004    0.004 {method 'argsort' of 'numpy.ndarray'␣
↪objects}
        1    0.000    0.000    0.003    0.003 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/core/fromnumeric.py:45(take)
        1    0.003    0.003    0.003    0.003 {method 'take' of 'numpy.ndarray' objects}
        1    0.000    0.000    0.002    0.002 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/core/fromnumeric.py:1379(sum)
        1    0.002    0.002    0.002    0.002 {method 'sum' of 'numpy.ndarray' objects}
        1    0.000    0.000    0.000    0.000 {isinstance}
        1    0.000    0.000    0.000    0.000 {method 'disable' of '_lsprof.Profiler'␣
↪objects}
```

In summary, when working on arrays it's worth taking the time to think about whether you can get the results you need without for-loops or list comprehensions. The small amount of development time will likely be recouped very quickly.

3.2.3 Zip

The `zip()` function is extremely useful, but it is really slow. If you find yourself using it on large amounts of data then significant time-savings might be achieved by re-writing your code to make the `zip()` operation unnecessary. A good alternative, if you do need the functionality of `zip()`, is in `itertools.izip()`. This is far more efficient as it builds an interator.

This example generates N points, evenly distributed on the unit sphere centered at (0,0,0) using the "Golden Spiral" method.

The original code:

```
import numpy as np
def PointsOnSphere(N):
# Generate evenly distributed N points on the unit sphere centered at (0,0,0)
# Uses "Golden Spiral" method
    x0 = np.array((N,), dtype= float)
    y0 = np.array((N,), dtype= float)
    z0 = np.array((N,), dtype= float)
    phi = (1 + np.sqrt(5)) / 2. # the golden ratio
    long_incr = 2.0*np.pi / phi # how much to increment the longitude
    dz = 2.0 / float(N)    # a unit sphere has diameter 2
    bands = np.arange(0, N, 1) # each band will have one point placed on it
    z0 = bands * dz - 1 + (dz/2)  # the z location of each band/point
    r = np.sqrt(1 - z0*z0)    # the radius can be directly determined from height
    az = bands * long_incr # the azimuth where to place the point
    x0 = r * np.cos(az)
    y0 = r * np.sin(az)
    x0_y0_z0 = np.array(zip(x0,y0,z0))     #combine into 3 column (x,y,z) file
    return (x0_y0_z0)
```

Profiling this with `cProfile` shows that a lot of time is spent in `zip()`:

```
Tue Jun 14 09:54:41 2011    PointsOnSphere.prof

         9 function calls in 8.132 seconds

   Ordered by: cumulative time

   ncalls  tottime  percall  cumtime  percall filename:lineno(function)
        1    0.010    0.010    8.132    8.132 <string>:1(<module>)
        1    0.470    0.470    8.122    8.122 test1.py:192(PointsOnSphere)
        4    6.993    1.748    6.993    1.748 {numpy.core.multiarray.array}
        1    0.654    0.654    0.654    0.654 {zip}
        1    0.005    0.005    0.005    0.005 {numpy.core.multiarray.arange}
        1    0.000    0.000    0.000    0.000 {method 'disable' of '_lsprof.Profiler'␣
↪objects}
```

So lets try and do a few simple rewrites to make this faster. Using numpy.vstack is the first one that came to mind. The change here is to replace building up the array from the elements made by `zip()` to just concatenating the arrays we already have:

```
def PointsOnSphere(N):
# Generate evenly distributed N points on the unit sphere centered at (0,0,0)
# Uses "Golden Spiral" method
    x0 = np.array((N,), dtype= float)
    y0 = np.array((N,), dtype= float)
    z0 = np.array((N,), dtype= float)
    phi = (1 + np.sqrt(5)) / 2. # the golden ratio
    long_incr = 2.0*np.pi / phi # how much to increment the longitude
    dz = 2.0 / float(N)    # a unit sphere has diameter 2
    bands = np.arange(0, N, 1) # each band will have one point placed on it
    z0 = bands * dz - 1 + (dz/2)  # the z location of each band/point
    r = np.sqrt(1 - z0*z0)    # the radius can be directly determined from height
    az = bands * long_incr # the azimuth where to place the point
    x0 = r * np.cos(az)
    y0 = r * np.sin(az)
    x0_y0_z0 = np.vstack((x0, y0, z0)).transpose()
    return (x0_y0_z0)
```

Profiling this with `cProfile` one can see that this is now fast enough for me, no more work to do. We picked up a 48x speed increase, I'm sure this can still be made better and let the SpacePy team know if you rewrite it and it will be included:

```
Tue Jun 14 09:57:41 2011    PointsOnSphere.prof

         32 function calls in 0.168 seconds

   Ordered by: cumulative time
   List reduced from 13 to 10 due to restriction <10>

   ncalls  tottime  percall  cumtime  percall filename:lineno(function)
        1    0.010    0.010    0.168    0.168 <string>:1(<module>)
        1    0.123    0.123    0.159    0.159 test1.py:217(PointsOnSphere)
        1    0.000    0.000    0.034    0.034 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/core/shape_base.py:177(vstack)
```

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```
        1    0.034    0.034    0.034    0.034 {numpy.core.multiarray.concatenate}
        1    0.002    0.002    0.002    0.002 {numpy.core.multiarray.arange}
        1    0.000    0.000    0.000    0.000 {map}
        3    0.000    0.000    0.000    0.000 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/core/shape_base.py:58(atleast_
↪2d)
        6    0.000    0.000    0.000    0.000 {numpy.core.multiarray.array}
        3    0.000    0.000    0.000    0.000 /opt/local/Library/Frameworks/Python.
↪framework/Versions/2.7/lib/python2.7/site-packages/numpy/core/numeric.
↪py:237(asanyarray)
        1    0.000    0.000    0.000    0.000 {method 'transpose' of 'numpy.ndarray'␣
↪objects}
```

3.2.4 External links

To learn about NumPy from a MatLab user's perspective

- NumPy for MatLab users
- Mathesaurus

And if you're coming from an IDL, or R, background

- Mathesaurus

Here is a collection of links that serve as a decent reference for Python and speed

- PythonSpeed PerformanceTips
- scipy array tip sheet
- Python Tips, Tricks, and Hacks

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For additions or fixes to this page contact the SpacePy team at Los Alamos.

3.3 Dependency version support

SpacePy will occasionally drop support for old versions of *dependencies*. Failures with older versions will not be treated as SpacePy bugs. Dependency support is based on these principles:

1. SpacePy supports released versions of a dependency that meet a minimum version requirement; there is no maximum supported version.
2. Support for old versions of dependencies will be dropped only for reason, e.g. if a new version is required to support a new feature or fix a bug. Maintenance of convoluted workarounds is included in this category.
3. Support will be maintained for versions included in the second-most-recent Ubuntu Long Term Support (LTS) release, e.g. upon release of Ubuntu 20.04 LTS, support will be maintained for at least the versions in 18.04 LTS
4. Support will also be maintained for Python and NumPy versions in the spirit of NEP 29.

    1. A SpacePy release will support at least all minor versions of Python released in the prior 42 months, and at least the two latest minor versions.
    2. SpacePy will support all minor versions of NumPy and, where possible, other Python dependencies released in the prior 24 months, and at least the three latest minor versions.
    3. Non-Python dependencies that use a similar versioning system will be supported similarly where possible.
    4. This support is based on minor releases (x.y.0), not subsequent subminor releases (x.y.z for the same x.y). Where x.y.0 is supported, so is x.y.z for all z.
    5. All versions of all dependencies and all combinations thereof will *not* necessarily be tested in continuous integration.
5. No support will be provided for conflicting versions of dependencies. E.g. SciPy 1.4 requires NumPy 1.13. Although SpacePy supports SciPy 1.4 and Numpy 1.6, it contains no workarounds for using them in that combination.
6. Support for a particular version of a dependency does not imply a commitment to work around bugs in that version.
7. Support for even earlier versions will be maintained as necessary for Python 2 compatibility as long as *Python 2 support* is maintained.
8. A release of SpacePy that requires new dependency versions will always have a subminor version of 0, e.g. if the release that follows 0.5.2 requires updated dependencies, it will be numbered 0.6.0.
9. The commit that requires a newer version of a dependency must also update the `requirements.txt`, *SpacePy Dependencies*, and the table below. The commit message must include the reason for the dependency requirement.

Regardless of minimum requirements, using the latest stable version of a package is generally preferred. The minimum supported version for SpacePy may not be recommended for other reasons (e.g. bug fixes or improved features elsewhere in the package.)

This table summarizes the versions to be supported according to the above policy, as well as the minimum version currently supported by SpacePy. Where available, the dependency name links to its version history. The oldest version supported according to this policy is in **bold**.

Table 1: SpacePy dependency versions (2021/9/16)

Dependency	Current Release	Ubuntu 18.04LTS	Ubuntu 20.04LTS	NEP 29 (42/24 mo.)	NEP 29 (2/3 minor versions)	SpacePy current minimum
CPython	3.9.7 (2021/8/30)	**3.6.5** (2018/2/5)	3.8.2 (2020/2/24)	3.7.0 (2018/6/27)	3.8.0 (2019/10/14)	3.2.0 (2011/2/20) or 2.7.0 (2010/7/3)
AstroPy	4.3.1 (2021/8/11)	**2.0.4** (2018/2/6)	4.0 (2019/2/16)	3.2 (2019/6/14)	4.1 (2020/10/21)	1.0 (2015/2/18)
CDF	3.8.0.1 (2020/7/7)	N/A	N/A	3.8.0 (2019/10/27)	**3.6.0** (2015/2/5)	2.7.0 (1999/9/27)
dateutil	2.8.2 (2021/7/8)	2.6.1 (2017/7/10)	2.7.3 (2018/5/9)	2.8.0 (2019/2/5)	**2.6.0** (2016/11/8)	tested from 1.4 (2008/2/27)
h5py	3.4.0 (2021/8/3)	**2.7.1** (2017/9/1)	2.10.0 (2019/9/6)	3.0.0 (2020/10/30)	3.2.0 (2021/3/3)	tested from 2.6 (2017/3/18)
matplotlib	3.4.3 (2021/8/12)	**2.1.1** (2017/12/9)	3.1.2 (2019/12/4)	3.2.0 (2020/3/3)	3.2.0 (2020/3/3)	1.5.0 (2015/10/29)
numpy	1.21.2 (2021/8/15)	**1.13.3** (2017/7/6)	1.16.5 (2019/8/27)	1.18.0 (2019/12/22)	1.19.0 (2020/1/20)	1.10.0 (2015/10/5)
scipy	1.7.1 (2021/8/1)	**0.19.1** (2017/6/23)	1.3.3 (2019/11/23)	1.4.0 (2019/12/16)	1.5.0 (2020/6/21)	0.11.0 (2012/9/24)

3.4 Documentation Standard

SpacePy aims to be a high quality product, and as such we (the SpacePy Team) encourage a a high degree of uniformity in the documentation across included modules. If you are contributing to SpacePy, or hope to, please take the time to make your code compliant with the documentation standard.

SpacePy uses Sphinx to generate its documentation. This allows most of the documentation to be built from docstrings in the code, with additional information being provided in reStructured Text files. This allows easy generation of high-quality, searchable HTML documentation.

In addition to Sphinx, SpacePy uses the following extensions:

- 'sphinx.ext.autodoc'
- 'sphinx.ext.doctest"
- 'sphinx.ext.intersphinx'
- 'sphinx.ext.todo'
- 'sphinx.ext.imgmath' (falls back to 'sphinx.ext.pngmath' if imgmath is not available)
- 'sphinx.ext.ifconfig'
- 'sphinx.ext.viewcode'
- 'numpydoc'
- 'sphinx.ext.inheritance_diagram'
- 'sphinx.ext.autosummary'

- 'sphinx.ext.extlinks'

3.4.1 So what do I need to do in my code?

Since we are using the 'numpydoc' extension there are fixed headings that may appear in your documentation block. There are a few things to note: * No other headings can appear in your docstrings * Most reStructuredText commands cannot appear in your docstrings either (e.g. .. Note:) * Since 'numpydoc' is not well documented, the best way of finding out what you can do in your docstrings is to look at the source for the SpacePy documentation or the numpy documentation.

Allowed headings

Always use

- Parameters
- Returns

Use as needed

- Attributes
- Raises
- Warns
- Other Parameters
- See Also
- Notes
- Warnings
- References
- Examples
- Methods

No need to use

- Summary
- Extended Summary
- index

Do not use

- Signature

Examples

- Use them, but they must be fully stand alone; the user should be able to type the exact code in the example and it should work as shown (doctest can help with this)

3.4.2 Function Example

This code from toolbox shows what a function should look like in your code

```
def logspace(min, max, num, **kwargs):
    """
    Returns log spaced bins.  Same as numpy logspace except the min and max␣
↪are the ,min and max
    not log10(min) and log10(max)

    Parameters
    ==========
    min : float
        minimum value
    max : float
        maximum value
    num : integer
        number of log spaced bins

    Other Parameters
    ================
    kwargs : dict
        additional keywords passed into matplotlib.dates.num2date

    Returns
    =======
    out : array
        log spaced bins from min to max in a numpy array

    Notes
    =====
    This function works on both numbers and datetime objects

    Examples
    ========
    >>> import spacepy.toolbox as tb
    >>> tb.logspace(1, 100, 5)
    array([   1.        ,    3.16227766,   10.        ,   31.6227766 ,  100.  ␣
↪     ])
    """
    from numpy import logspace, log10
    if isinstance(min, datetime.datetime):
        from matplotlib.dates import date2num, num2date
        return num2date(logspace(log10(date2num(min)), log10(date2num(max)),␣
↪num, **kwargs))
    else:
        return logspace(log10(min), log10(max), num, **kwargs)
```

Which then renders as:

spacepy.toolbox.**logspace**(*min*, *max*, *num*, ***kwargs*)

Returns log-spaced bins. Same as numpy.logspace except the min and max are the min and max not log10(min) and log10(max)

Parameters

min [float] minimum value

max [float] maximum value

num [integer] number of log spaced bins

Returns

out [array] log-spaced bins from min to max in a numpy array

Other Parameters

kwargs [dict] additional keywords passed into matplotlib.dates.num2date

See also:

geomspace

linspace

Notes

This function works on both numbers and datetime objects

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.logspace(1, 100, 5)
array([   1.        ,    3.16227766,   10.        ,   31.6227766 ,  100.  ␣
↪     ])
```

3.5 Unit tests

- *The spacepy_testing module*
  - *Classes*
  - *Functions*
  - *Data*

3.5.1 The spacepy_testing module

The `spacepy_testing` module contains utilities for assistance with testing SpacePy. It is not installed as part of SpacePy and is thus only importable from the unit test scripts themselves (which are in the same directory). All unit test scripts import this module, and should do so before importing any spacepy modules to ensure pathing is correct.

On import, *add_build_to_path()* is run so that the `build` directory is added to the Python search path. This means the tests run against the latest build, not the installed version. Remove the build directory to run against the installed version instead. The build directory does not completely separate out Python versions, so removing the build directory (and rebuilding) is recommended when switching Python versions.

Build the package before running the tests:

```
python setup.py build
```


- *Classes*
- *Functions*
- *Data*

Classes

assertWarns(test[, action, message, ...])	Tests that a warning is raised.
assertDoesntWarn(test[, action, message, ...])	Tests that a warning is not raised.

spacepy_testing.assertWarns

class spacepy_testing.**assertWarns**(*test*, *action='always'*, *message=''*, *category=<class 'Warning'>*, *module=''*, *lineno=0*)

Tests that a warning is raised.

Use as a context manager. Code within the context manager block will be executed and, on exit from the block, all warnings issued during execution of the block will be checked to see if the warning specified was issued.

assertWarns requires that the matched warning be issued *exactly once* within the context manager, or the test function will fail (whether the warning was issued not at all, or multiple times). assertDoesntWarn requires that matched warnings are not issued at all.

All other warnings are issued as normal, although the warning will not be shown (e.g. printed) until the exit of the context manager. If code within the context manager issues an exception, the test for warnings will be skipped (test failure will not be issued), and all warnings shown before the exception propagates up the stack.

The parameters determining which warning to match are for the code referenced in the warning, not necessarily the code being warned. E.g. if code calls a deprecated function, and the deprecated function issues a `DeprecationWarning`, what is matched may be the code in the deprecated function, not the caller; see the `stacklevel` parameter to warn() for how this may be changed.

Parameters

test [unittest.TestCase] The test case from which this is being called, almost always `self` (so the fail() method is available).

action [{'always', `None`, 'default', 'error', 'ignore', 'module',]

'once'}

Unless `None`, a warning filter matching the specified warning will be added to the filter before executing the block. 'always' (default) is generally recommended to make sure the tested warning will be raised. If 'always' is specified, on Python 2 the log of previously-issued warnings will be edited to work around a Python bug. In this case using `module` is strongly recommended to minimize the impact of this editing. This filter will be removed on completion of the block.

message [str, optional] Regular expression to match the start of warning message. Default is to match all.

category [type, optional] Matches if the warning is an instance of this type or a subclass. Default is the base *Warning* type (matches all warnings).

module [str, optional] Regular expression to match the start of the name of the module from which the warning is issued. This is primarily used in setting up the warnings filter; matching the module to determine if the desired warning was issued is based on filename and may not work for modules built into the interpreter. Default is to match all.

lineno [int, optional] Line number from which the warning was issued. This is rarely useful since it will change from version to version. Default (0) will match all lines.

See also:

`warnings.filterwarnings` The `action`, `message`, `category`, `module`, and `lineno` parameters are based on the filter specifications.

Examples

This class is primarily useful as part of a test suite, and cannot be easily demonstrated through interactive examples. See the tests of it in `test_testing.py` and its usage throughout the test suite.

spacepy_testing.assertDoesntWarn

class spacepy_testing.**assertDoesntWarn**(*test*, *action='always'*, *message=''*, *category=<class 'Warning'>*, *module=''*, *lineno=0*)

Tests that a warning is not raised.

Use as a context manager. Code within the context manager block will be executed and, on exit from the block, all warnings issued during execution of the block will be checked to see if the warning specified was issued.

assertWarns requires that the matched warning be issued *exactly once* within the context manager, or the test function will fail (whether the warning was issued not at all, or multiple times). *assertDoesntWarn* requires that matched warnings are not issued at all.

All other warnings are issued as normal, although the warning will not be shown (e.g. printed) until the exit of the context manager. If code within the context manager issues an exception, the test for warnings will be skipped (test failure will not be issued), and all warnings shown before the exception propagates up the stack.

The parameters determining which warning to match are for the code referenced in the warning, not necessarily the code being warned. E.g. if code calls a deprecated function, and the deprecated function issues a `DeprecationWarning`, what is matched may be the code in the deprecated function, not the caller; see the `stacklevel` parameter to `warn()` for how this may be changed.

Parameters

test [unittest.TestCase] The test case from which this is being called, almost always `self` (so the `fail()` method is available).

action [{'always', `None`, 'default', 'error', 'ignore', 'module',]

'once'}

Unless `None`, a warning filter matching the specified warning will be added to the filter before executing the block. 'always' (default) is generally recommended to make sure the tested warning will be raised. If 'always' is specified, on Python 2 the log of previously-issued warnings will be edited to work around a Python bug. In this case using `module` is strongly

recommended to minimize the impact of this editing. This filter will be removed on completion of the block.

message [str, optional] Regular expression to match the start of warning message. Default is to match all.

category [type, optional] Matches if the warning is an instance of this type or a subclass. Default is the base *Warning* type (matches all warnings).

module [str, optional] Regular expression to match the start of the name of the module from which the warning is issued. This is primarily used in setting up the warnings filter; matching the module to determine if the desired warning was issued is based on filename and may not work for modules built into the interpreter. Default is to match all.

lineno [int, optional] Line number from which the warning was issued. This is rarely useful since it will change from version to version. Default (0) will match all lines.

See also:

`warnings.filterwarnings` The `action`, `message`, `category`, `module`, and `lineno` parameters are based on the filter specifications.

Examples

This class is primarily useful as part of a test suite, and cannot be easily demonstrated through interactive examples. See the tests of it in `test_testing.py` and its usage throughout the test suite.

Functions

add_build_to_path()	Adds the python build directory to the search path.

spacepy_testing.add_build_to_path

spacepy_testing.**add_build_to_path**()

Adds the python build directory to the search path.

Locates the build directory in the same repository as this test module and adds the (version-specific) library directories to the Python module search path, so the unit tests can be run against the built instead of installed version.

This is run on import of this module.

Data

datadir	Directory containing unit test data
testsdir	Directory containing the unit test scripts

spacepy_testing.datadir

spacepy_testing.**datadir = '/home/jtniehof/scm/spacepy/tests/data'**
Directory containing unit test data

spacepy_testing.testsdir

spacepy_testing.**testsdir = '/home/jtniehof/scm/spacepy/tests'**
Directory containing the unit test scripts

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3.6 Continuous Integration

SpacePy uses GitHub Actions for continuous integration. Most of the relevant information is checked into the repository: the configuration file CI.yml manages the CI process, which ultimately runs the unit tests. However a few elements of the setup are not in the repository and are documented here. This may be useful if this ever has to be set up in the future, or if you want to run SpacePy CI tests on your fork before opening a pull request.

- *Initial run*
- *Merging rules*
- *Rerunning CI on a PR*
- *Cacheing*
- *Usage*

3.6.1 Initial run

A workflow cannot be run until it has been run once against the default branch (`master`). This makes it somewhat hard to test the workflow before merging; in SpacePy this was handled by merging a tiny workflow first (PR 496).

Once this first run has been made, updated versions of the workflow can be run from topic branches. It will show up under the `Actions` tab of a repository and the branch to use can be selected. It is also possible to specify a branch by using the REST API; you will need an access token with `workflow` scope.

3.6.2 Merging rules

PRs require CI to pass before merging; this is managed with a branch protection rule (`Settings` from the tab at the top of a repository, `Branches` from the left menu.) The relevant choices is "Require status checks to pass before merging." Every variant of the unit testing job (`test (2.7, ubuntu-18.04...` etc.) will be in the list of checks; leave these alone and select only the `All tests` job. The name of this won't change and it will always depend on *all* the jobs in the workflow. "Require branches to be up to date" should *not* be selected; this encourages merging rather than our preferred rebase, and the tests will run against a (temporary) merge regardless.

3.6.3 Rerunning CI on a PR

There is no way to manually trigger a workflow run on a pull request. SpacePy's CI workflow is set up to trigger the workflow when a PR is marked ready for review, so one way to force a run is to mark the PR as a draft, and then as ready again.

Note that a PR will not trigger the CI if there is a merge conflict.

3.6.4 Cacheing

Dependencies for CI are stored in two caches: one for all pip dependencies, and one for the NASA CDF library. This minimizes CI time use for building dependencies.

Caches expire weekly (the week begins at 00 Monday, UTC). Caches can also be force-expired by incrementing the versions in `ci.yml` for the pip and/or CDF cache. Unfortunately this does require pushing a commit.

3.6.5 Usage

SpacePy administrators can view the usage minutes, storage (for caches), etc. on our billing page.

Release 0.3.0

Doc generation date Apr 27, 2022

CHAPTER

FOUR

SPACEPY MODULE REFERENCE

Description of all functions within SpacePy, by module.

4.1 spacepy - main SpacePy module

SpacePy: Space Science Tools for Python

SpacePy is a package of tools primarily aimed at the space science community. This __init__.py file sets the parameters for import statements.

If running the ipython shell, simply type '?' after any command for help. ipython also offers tab completion, so hitting tab after '<module name>.' will list all available functions, classes and variables.

Detailed HTML documentation is available online by typing:

```
>>> spacepy.help()
```

Most functionality is in spacepy's submodules. Each module has specific help available:

Submodules

coordinates	Implementation of Coords class functions for coordinate transformations
data_assimilation	
datamodel	The datamodel classes constitute a data model implementation meant to mirror the functionality of the data model output from pycdf, though implemented slightly differently.
empiricals	Module with some useful empirical models (plasmapause, magnetopause, Lmax)
irbempy	module wrapper for irbem_lib Reference for this library https://sourceforge.net/projects/irbem/ D.
omni	Tools to read and process omni data (Qin-Denton, etc.)
poppy	PoPPy -- Point Processes in Python.
pybats	PyBats! An open source Python-based interface for reading, manipulating, and visualizing BATS-R-US and SWMF output.

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Table 1 – continued from previous page

pycdf	This package provides a Python interface to the Common Data Format (CDF) library used for many NASA missions, available at http://cdf.gsfc.nasa.gov/.
radbelt	Functions supporting radiation belt diffusion codes
seapy	SeaPy -- Superposed Epoch in Python.
time	Time conversion, manipulation and implementation of Ticktock class
toolbox	Toolbox of various functions and generic utilities.
ae9ap9	Module for reading and dealing with AE9AP9 data files.

Functions

deprecated(version, message[, docstring])	Decorator to deprecate a function/method
help()	Launches web browser with SpacePy documentation

spacepy.**deprecated**(*version*, *message*, *docstring=None*)

Decorator to deprecate a function/method

Modifies a function so that calls to it raise `DeprecationWarning` and the docstring has a deprecation note added in accordance with numpydoc format

Parameters

version [str] What is the first version where this was deprecated?

message [str] Message to include in the deprecation warning and in the docstring.

Other Parameters

docstring [str] New in version 0.2.2.

If specified, `docstring` will be added to the modified function's docstring instead of `message` (which will only be used in the deprecation warning.) It can be a multi-line string (separated with `\n`). It will be indented to match the existing docstring.

Notes

On Python 2, the deprecated function's signature won't be preserved. The function will work but will not have proper argument names listed in e.g. `help`.

This warning will show as coming from SpacePy, not the deprecated function.

Examples

```
>>> import spacepy
>>> @spacepy.deprecated('0.2.1', 'Use a different function instead',
...                     docstring='A different function is better\n'
...                               'because of reasons xyz')
... def foo(x):
...     '''This is a test function
...
...     It may do many useful things.
```

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```
...     '''
...     return x + 1
>>> help(foo)
Help on function foo in module __main__:
foo(x)
    This is a test function
    .. deprecated:: 0.2.1
       A different function is better
       because of reasons xyz
    It may do many useful things.
>>> foo(2)
DeprecationWarning: Use a different function instead
3
```

spacepy.**help**()
Launches web browser with SpacePy documentation

Online help is always for the latest release of SpacePy.

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4.2 ae9ap9 - Handle AE9/AP9 data files

Module for reading and dealing with AE9AP9 data files.

See https://www.vdl.afrl.af.mil/programs/ae9ap9/ to download the model. This is not a AE9AP9 runner.

Authors: Brian Larsen, Steve Morley Institution: Los Alamos National Laboratory Contact: balarsen@lanl.gov

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This module provides a convenient class for handling data from AE9/AP9 (and legacy models provided by the software).

Class

Ae9Data(*args, **kwargs)	Dictionary-like container for AE9/AP9/SPM data, derived from SpacePy's datamodel

4.2.1 spacepy.ae9ap9.Ae9Data

class spacepy.ae9ap9.**Ae9Data**(**args*, ***kwargs*)
Dictionary-like container for AE9/AP9/SPM data, derived from SpacePy's datamodel

To inspect the variables within this class, use the tree method. To export the data to a CDF, HDF5 or JSON-headed ASCII file use the relevant "to" method (toCDF, toHDF5, toJSONheadedASCII).

getLm([alpha, model])	Calculate McIlwain L for the imported AE9/AP9 run and add to object
plotOrbit([timerange, coord_sys, landscape, ...])	Plot X-Y and X-Z projections of satellite orbit in requested coordinate system

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Table 4 – continued from previous page

plotSummary([timerange, coord_sys, ...])	Generate summary plot of AE9/AP9/SPM data loaded
plotSpectrogram([ecol, pvars])	Plot a spectrogram of the flux along the requested orbit, as a function of Lm and time
setUnits([per])	Set units of energy and flux/fluence

getLm(*alpha=[90]*, *model='T89'*)
Calculate McIlwain L for the imported AE9/AP9 run and add to object

plotOrbit(*timerange=None*, *coord_sys=None*, *landscape=True*, *fig_target=None*)
Plot X-Y and X-Z projections of satellite orbit in requested coordinate system

plotSummary(*timerange=None*, *coord_sys=None*, *fig_target=None*, *spec=False*, *orbit_params=(False, True)*, ***kwargs*)
Generate summary plot of AE9/AP9/SPM data loaded

spec : if True, plot spectrogram instead of flux/fluence lineplot, requires 'ecol' keyword

plotSpectrogram(*ecol=0*, *pvars=None*, ***kwargs*)
Plot a spectrogram of the flux along the requested orbit, as a function of Lm and time

Other Parameters

zlim [list] 2-element list with upper and lower bounds for color scale

colorbar_label [string] text to appear next to colorbar (default is 'Flux' plus the units)

ylabel [string] text to label y-axis (default is 'Lm' plus the field model name)

title [string] text to appear above spectrogram (default is climatology model name, data type and energy)

pvars [list] list of plotting variable names in order [Epoch-like (X axis), Flux-like (Z axis), Energy (Index var for Flux-like)]

ylim [list] 2-element list with upper and lower bounds for y axis

setUnits(*per=None*)
Set units of energy and flux/fluence

If keyword 'per' is set to None, this method reports the units currently set. To set energy in MeV and flux/fluence in 'per MeV', set 'per=MeV'. Valid options are 'eV', 'keV', 'Mev' and 'GeV'.

Other Parameters

per [string (optional)] Energy units for both energy and flux/fluence

Though the class is derived from SpacePy's SpaceData, the class also provides several methods targeted at the AE9/AP9 output. Additional functions for working with the data are provided.

Functions

readFile(fname[, comments])	read a model generated file into a datamodel.SpaceData object
parseHeader(fname)	given an AE9AP9 output test file parse the header and return the information in a dictionary

4.2.2 spacepy.ae9ap9.readFile

spacepy.ae9ap9.**readFile**(*fname*, *comments='#'*)
read a model generated file into a datamodel.SpaceData object

Parameters

fname [str] filename of the file

Returns

out [*SpaceData*] Data contained in the file

Other Parameters

comments [str (optional)] String that is the comments in the data file

Examples

```
>>> from spacepy import ae9ap9
>>> ae9ap9.readFile('ephem_sat.dat').tree(verbose=1)
+
|____Epoch (spacepy.datamodel.dmarray (121,))
|____Coords (spacepy.datamodel.dmarray (121, 3))
|____MJD (spacepy.datamodel.dmarray (121,))
|____posComp (spacepy.datamodel.dmarray (3,))
```

4.2.3 spacepy.ae9ap9.parseHeader

spacepy.ae9ap9.**parseHeader**(*fname*)
given an AE9AP9 output test file parse the header and return the information in a dictionary

Changed in version 0.3.0.

The underlying AE9AP9 model changed the ephem file format and this reader was updated to match. Reading the old format will issue DeprecationWarning.

Parameters

fname [str] filename of the file

Returns

out [dict] Dictionary of the header information in the file

4.3 coordinates - module for coordinate transforms

Implementation of Coords class functions for coordinate transformations

The coordinate systems supported by this module cover the most commonly used geophysical and magnetospheric systems. The naming conventions can follow the names used by the popular IRBEM library, but for inertial systems we use a more consistent, fine-grained naming convention that clarifies the different systems.

- **ECI2000** Earth-centered Inertial, J2000 epoch
- **ECIMOD** Earth-centered Inertial, mean-of-date

- **ECITOD** Earth-centered Inertial, true-of-date
- **GEI** Geocentric Equatorial Inertial (IRBEM approximation of TOD)
- **GSM** Geocentric Solar Magnetospheric
- **GSE** Geocentric Solar Ecliptic
- **SM** Solar Magnetic
- **MAG** Geomagnetic Coordinate System (aka CDMAG)
- **GEO** Geocentric geographic, aka Earth-centered Earth-fixed
- **GDZ** Geodetic coordinates

By convention *all* systems are treated as natively Cartesian except geodetic (GDZ), which is defined in [altitude, latitude, longitude] where altitude is relative to a reference ellipsoid. Similarly, distance units are assumed to be Earth radii (Re) in all systems except GDZ, where altitude is given in km. Conversions to GDZ will output altitude in km regardless of the input distance units and conversions from GDZ will output in Re regardless of input units. In all other cases, the distance units will be preserved.

Changed in version 0.3.0.

The new CTrans backend was added, which includes support for the names `ECI2000`, `ECIMOD`, `ECITOD`, and `CDMAG`. With the exception of `ECIMOD`, these can be used with the existing IRBEM backend, and will be converted to their closest equivalents.

4.3.1 Notes on differences between representations

IRBEM's coordinate transformations are low-accuracy and were written for a library with a driving philosophy of speed and robustness as priorities. The coordinate transformations are therefore approximate. Further, most of the geophysical systems (e.g., GSE, SM) are derived from an inertial system. It is standard practice to use ECIMOD as this system. However, IRBEM does not currently make ECIMOD available as one of its inertial systems. IRBEM's default inertial system (called GEI) is consistent with an approximation of ECITOD. Hence there will be small differences between IRBEM's transformations and those using SpacePy's CTrans backend. Further sources of difference include: IRBEM uses a low-order approximation to the sidereal time and other parameters; the calculation of the Earth-Sun vector differs between the representations; the definitions of an Earth radius differ (SpacePy = 6378.137km; IRBEM = 6371.2 km). SpacePy's in-built representation is higher accuracy and is comprehensively tested, including tests for consistency with other high accuracy packages such as LANLGeoMag and AstroPy. However, for use cases where the required precision is of order 1 percent the output can be considered equivalent.

4.3.2 Setting options for coordinate transformation

The backend for coordinate transformations can be provided at instantiation of a *Coords* object using a keyword argument. However, for convenience and flexibility the options can be set at the module level. Configurable options include the backend used (*irbempy* or SpacePy's *ctrans*) and the reference ellipsoid (only configurable for the SpacePy backend). A warning will be raised if the backend is not set (either through the defaults or the keyword argument). The final configurable option (`itol`) is the maximum separation, in seconds, for which the coordinate transformations will not be recalculated. To force all transformations to use an exact transform for the time, set `itol` to zero. Values between 10s and 60s are recommended for speed while also preserving accuracy, though different applications will require different accuracies. For example, assuming this module has been imported as `spc`, to set the SpacePy backend as the default and set `itol` to 5 seconds:

```
>>> spc.DEFAULTS.set_values(use_irbem=False, itol=5)
```

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Classes

Coords(data, dtype, carsph, [units, ticks, ...)	A class holding spatial coordinates and enabling transformation between coordinate systems.

4.3.3 spacepy.coordinates.Coords

class spacepy.coordinates.**Coords**(*data*, *dtype*, *carsph*[, *units*, *ticks*, *use_irbem*])

A class holding spatial coordinates and enabling transformation between coordinate systems. Coordinates can be stored as Cartesian or spherical and units are assumed to be Re (distance) and degrees (angle)

Note: Although other units may be specified and will be carried through, most functions throughout SpacePy assume distances in Re and angles in degrees, regardless of specified units.

By default, coordinate transforms are based on the IRBEM library; its manual may prove useful. SpacePy also provides a framework for accurate coordinate transformations. This can be used by setting the *use_irbem* flag to False. In a future release of SpacePy this will become the default method. For a good reference on heliospheric and magnetospheric coordinate systems, see Franz & Harper, "Heliospheric Coordinate Systems", Planet. Space Sci., 50, pp 217-233, 2002 (https://doi.org/10.1016/S0032-0633(01)00119-2).

Parameters

data [list or ndarray, dim = (n,3)] coordinate points [X,Y,Z] or [rad, lat, lon]

dtype [string] coordinate system; supported systems are defined in module-level documentation. Common systems include GEO, GSE, GSM, SM, MAG, ECIMOD

carsph [string] Cartesian or spherical, 'car' or 'sph'

units [list of strings, optional] standard are ['Re', 'Re', 'Re'] or ['Re', 'deg', 'deg'] depending on the carsph content. See note.

ticks [Ticktock instance, optional] used for coordinate transformations (see a.convert)

use_irbem [bool] New in version 0.3.0.

Set to True to use IRBEM for coordinate transforms (current default). Otherwise use SpacePy's coordinate transform library.

Returns

out [Coords instance] instance with a.data, a.carsph, etc.

See also:

spacepy.coordinates.DEFAULTS

spacepy.time.Ticktock

Examples

```
>>> from spacepy import coordinates as coord
>>> cvals = coord.Coords([[1,2,4],[1,2,2]], 'GEO', 'car')
>>> cvals.x  # returns all x coordinates
array([1, 1])
>>> from spacepy.time import Ticktock
>>> cvals.ticks = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:00:00'], 'ISO') #␣
↪add ticks
>>> newcoord = cvals.convert('GSM', 'sph')
>>> newcoord
```

append(other)	Append another Coords instance to the current one
convert(returntype, returncarsph)	Create a new Coords instance with new coordinate types
from_skycoord(skycoord[, use_irbem])	Create a Coords instance from an Astropy SkyCoord instance

append(*other*)

Append another Coords instance to the current one

Parameters

other [Coords instance] Coords instance to append

convert(*returntype*, *returncarsph*)

Create a new Coords instance with new coordinate types

Parameters

returntype [string] coordinate system, see module level documentation for supported systems

returncarsph [string] coordinate type, possible 'car' for Cartesian and 'sph' for spherical

Returns

out [Coords object] Coords object in the new coordinate system

Examples

```
>>> from spacepy.coordinates import Coords
>>> y = Coords([[1,2,4],[1,2,2]], 'GEO', 'car')
>>> from spacepy.time import Ticktock
>>> y.ticks = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:00:00'], 'ISO')
>>> x = y.convert('SM','car')
>>> x
Coords( [[ 0.81134097  2.6493305   3.6500375 ]
 [ 0.92060408  2.30678864  1.68262126]] ), dtype=SM,car, units=['Re', 'Re', 'Re
↪']
```

classmethod from_skycoord(*skycoord*, *use_irbem=None*)

Create a Coords instance from an Astropy SkyCoord instance

Parameters

skycoord [*astropy.coordinates.SkyCoord*] The coordinate to be converted

Returns

out [Coords instance] The converted coordinate

Notes

This method requires Astropy to be installed.

This method uses the GEO coordinate frame as the common frame between the two libraries.

`to_skycoord()`
Create an Astropy SkyCoord instance based on this instance

Returns

out [*astropy.coordinates.SkyCoord*] This coordinate as an Astropy SkyCoord

Notes

This method requires Astropy to be installed.

This method uses the GEO coordinate frame as the common frame between the two libraries.

Functions

car2sph(car_in)	Coordinate transformation from Cartesian to spherical
sph2car(sph_in)	Coordinate transformation from spherical to Cartesian
quaternionRotateVector(Qin, Vin[, ...])	Given quaternions and vectors, return the vectors rotated by the quaternions
quaternionNormalize(Qin[, scalarPos])	Given an input quaternion (or array of quaternions), return the unit quaternion
quaternionMultiply(Qin1, Qin2[, scalarPos])	Given quaternions, return the product, i.e. Qin1*Qin2.
quaternionConjugate(Qin[, scalarPos])	Given an input quaternion (or array of quaternions), return the conjugate
quaternionFromMatrix(matrix[, scalarPos])	Given an input rotation matrix, return the equivalent quaternion
quaternionToMatrix(Qin[, scalarPos, normalize])	Given an input quaternion, return the equivalent rotation matrix.

4.3.4 spacepy.coordinates.car2sph

spacepy.coordinates.**car2sph**(*car_in*)
Coordinate transformation from Cartesian to spherical

Parameters

- car_in (list or ndarray) [coordinate points in (n,3) shape with n coordinate points in] units of [Re, Re, Re] = [x,y,z]

Returns

- results (ndarray) [values after conversion to spherical coordinates in] radius, latitude, longitude in units of [Re, deg, deg]

See also:

sph2car

Examples

```
>>> sph2car([1,45,0])
array([ 0.70710678,  0.        ,  0.70710678])
```

4.3.5 spacepy.coordinates.sph2car

spacepy.coordinates.**sph2car**(*sph_in*)

Coordinate transformation from spherical to Cartesian

Parameters

- sph_in (list or ndarray) [coordinate points in (n,3) shape with n coordinate points in] units of [Re, deg, deg] = [r, latitude, longitude]

Returns

- results (ndarray) [values after conversion to cartesian coordinates x,y,z]

See also:

car2sph

Examples

```
>>> sph2car([1,45,45])
array([ 0.5       ,  0.5       ,  0.70710678])
```

4.3.6 spacepy.coordinates.quaternionRotateVector

spacepy.coordinates.**quaternionRotateVector**(*Qin*, *Vin*, *scalarPos='last'*, *normalize=True*)

Given quaternions and vectors, return the vectors rotated by the quaternions

Parameters

Qin [array_like] input quaternion to rotate by

Vin [array-like] input vector to rotate

Returns

out [array_like] rotated vector

See also:

quaternionMultiply

Examples

```
>>> import spacepy.coordinates
>>> import numpy as np
>>> vec = [1, 0, 0]
>>> quat_wijk = [np.sin(np.pi/4), 0, np.sin(np.pi/4), 0.0]
>>> quat_ijkw = [0.0, np.sin(np.pi/4), 0, np.sin(np.pi/4)]
>>> spacepy.coordinates.quaternionRotateVector(quat_ijkw, vec)
array([ 0.,  0., -1.])
>>> spacepy.coordinates.quaternionRotateVector(
...     quat_wijk, vec, scalarPos='first')
array([ 0.,  0., -1.])
```

4.3.7 spacepy.coordinates.quaternionNormalize

spacepy.coordinates.**quaternionNormalize**(*Qin*, *scalarPos='last'*)

Given an input quaternion (or array of quaternions), return the unit quaternion

Parameters

vec [array_like] input quaternion to normalize

Returns

out [array_like] normalized quaternion

Examples

```
>>> import spacepy.coordinates
>>> spacepy.coordinates.quaternionNormalize([0.707, 0, 0.707, 0.2])
array([ 0.69337122,  0.        ,  0.69337122,  0.19614462])
```

4.3.8 spacepy.coordinates.quaternionMultiply

spacepy.coordinates.**quaternionMultiply**(*Qin1*, *Qin2*, *scalarPos='last'*)

Given quaternions, return the product, i.e. Qin1*Qin2

Parameters

Qin1 [array_like] input quaternion, first position

Qin2 [array-like] input quaternion, second position

Returns

out [array_like] quaternion product

Examples

```
>>> import spacepy.coordinates
>>> import numpy as np
>>> vecX = [1, 0, 0] #shared X-axis
>>> vecZ = [0, 0, 1] #unshared, but similar, Z-axis
>>> quat_eci_to_gsm = [-0.05395384,  0.07589845, -0.15172533,  0.98402634]
>>> quat_eci_to_gse = [ 0.20016056,  0.03445775, -0.16611386,  0.96496352]
>>> quat_gsm_to_eci = spacepy.coordinates.quaternionConjugate(
...     quat_eci_to_gsm)
>>> quat_gse_to_gsm = spacepy.coordinates.quaternionMultiply(
...     quat_gsm_to_eci, quat_eci_to_gse)
>>> spacepy.coordinates.quaternionRotateVector(quat_gse_to_gsm, vecX)
array([  1.00000000e+00,   1.06536725e-09,  -1.16892107e-08])
>>> spacepy.coordinates.quaternionRotateVector(quat_gse_to_gsm, vecZ)
array([  1.06802834e-08,  -4.95669027e-01,   8.68511494e-01])
```

4.3.9 spacepy.coordinates.quaternionConjugate

spacepy.coordinates.**quaternionConjugate**(*Qin*, *scalarPos='last'*)

Given an input quaternion (or array of quaternions), return the conjugate

Parameters

Qin [array_like] input quaternion to conjugate

Returns

out [array_like] conjugate quaternion

See also:

quaternionMultiply

Examples

```
>>> import spacepy.coordinates
>>> spacepy.coordinates.quaternionConjugate(
...     [0.707, 0, 0.707, 0.2], scalarPos='last')
array([-0.707, -0.   , -0.707,  0.2  ])
```

4.3.10 spacepy.coordinates.quaternionFromMatrix

spacepy.coordinates.**quaternionFromMatrix**(*matrix*, *scalarPos='last'*)

Given an input rotation matrix, return the equivalent quaternion

The output has one fewer axis than the input (the last axis) and the shape is otherwise unchanged, allowing multi-dimensional matrix input.

Parameters

matrix [array_like] input rotation matrix or array of matrices

Returns

out [array_like] Quaternions representing the same rotation as the input rotation matrices.

Other Parameters

scalarPos [str] Location of the scalar component of the output quaternion, either 'last' (default) or 'first'.

Raises

NotImplementedError for invalid values of `scalarPos`

ValueError for inputs which are obviously not valid 3D rotation matrices or arrays thereof: if the size doesn't end in (3, 3), if the matrix is not orthogonal, or not a proper rotation.

See also:

quaternionToMatrix

Notes

New in version 0.2.2.

No attempt is made to resolve the sign ambiguity; in particular, conversions of very similar matrices may result in equivalent quaternions with the opposite sign. This may have implications for interpolating a sequence of quaternions.

The conversion of a rotation matrix to a quaternion suffers from some of the same disadvantages inherent to rotation matrices, such as potential numerical instabilities. Working in quaternion space as much as possible is recommended.

There are several algorithms; the most well-known algorithm for this conversion is Shepperd's[1], although the many "rediscoveries" indicate it is not sufficiently well-known. This function uses the method of Bar-Itzhack[2] (version 3), which should be resistant to small errors in the rotation matrix. As a result, the input checking is quite coarse and will likely accept many matrices that do not represent valid rotations.

Also potentially of interest, although not implemented here, is Sarabandi and Thomas[3].

References

Examples

```
>>> import spacepy.coordinates
>>> spacepy.coordinates.quaternionFromMatrix(
...     [[ 0.,  0.,  1.],
...      [ 1.,  0.,  0.],
...      [ 0.,  1.,  0.]])
array([0.5, 0.5, 0.5, 0.5])
```

[1] S.W. Shepperd, "Quaternion from rotation matrix," Journal of Guidance and Control, Vol. 1, No. 3, pp. 223-224, 1978, doi:10.2514/3.55767b

[2] I. Y. Bar-Itzhack, "New method for extracting the quaternion from a rotation matrix", AIAA Journal of Guidance, Control and Dynamics, 23 (6): 1085–1087, doi:10.2514/2.4654

[3] S. Sarabandi and F. Thomas, "Accurate Computation of Quaternions from Rotation Matrices", In: Lenarcic J., Parenti-Castelli V. (eds) Advances in Robot Kinematics 2018, Springer. doi:10.1007/978-3-319-93188-3_5

4.3.11 spacepy.coordinates.quaternionToMatrix

spacepy.coordinates.**quaternionToMatrix**(*Qin*, *scalarPos='last'*, *normalize=True*)

Given an input quaternion, return the equivalent rotation matrix.

The output has one more axis than the input (the last axis) and the shape is otherwise unchanged, allowing multi-dimensional quaternion input.

Parameters

Qin [array_like] input quaternion or array of quaternions, must be normalized.

Returns

out [array_like] Rotation matrix

Other Parameters

scalarPos [str] Location of the scalar component of the input quaternion, either 'last' (default) or 'first'.

normalize [True] Normalize input quaternions before conversion (default). If False, raises error for non-normalized.

Raises

NotImplementedError for invalid values of `scalarPos`.

ValueError for inputs which are not valid normalized quaternions or arrays thereof: if the size doesn't end in (4), if the quaternion is not normalized and `normalize` is False.

See also:

quaternionFromMatrix

Notes

New in version 0.2.2.

Implementation of the Euler–Rodrigues formula.

Examples

```
>>> import spacepy.coordinates
>>> spacepy.coordinates.quaternionToMatrix([0.5, 0.5, 0.5, 0.5])
array([[ 0.,  0.,  1.],
       [ 1.,  0.,  0.],
       [ 0.,  1.,  0.]])
```

4.4 ctrans - Coordinate transformation backend

CTrans: Module for backend coordinate transformations in SpacePy

This module is primarily intended to provide a backend for the standard `Coords` class rather than direct use, and the interface is subject to change.

The `CTrans` class calculates all of the necessary information to convert between different coordinate systems *at a single time*. By using `Coords` the handling of multiple times is built in, and the calling syntax is backwards compatible with the legacy IRBEM-backed coordinate transforms.

Coordinate systems supported by this module can broadly be described by two categories. The first category is a broad set of Earth-centered coordinate systems that are specified by astronomical parameters. If we consider the International Celestial Reference Frame to be our starting point, then taking the origin as the center of the Earth instead of the solar barycenter gives us the International Terrestrial Reference Frame (ITRF). All coordinate systems described here are right-handed Cartesian systems, except geodetic.

Systems and their relationships:

- **ECI2000: Earth-Centered Inertial, J2000 epoch** This system can be considered equivalent to the ITRF, to within 10s of milliarcseconds. The z-axis is aligned with the mean celestial pole at the J2000 epoch. The x-axis is aligned with the mean equinox at the J2000 epoch. The y-axis completes and lies in the plane of the celestial equator.
- **ECIMOD: Earth-Centered Inertial, Mean-of-Date** This system accounts for precession between the J2000 epoch and the date of interest: The coordinate system is time-dependent. The system is defined similarly to ECI2000, but uses the mean equinox and mean equator of the date of interest.
- **ECITOD: Earth-Centered Inertial, True-of-Date** This system builds on ECIMOD and accounts for the nutation (the short- period perturbations on the precession). This system is therefore considered to use the true equator and true equinox of date.
- **GSE: Geocentric Solar Ecliptic** This system is not inertial. It is Earth-centered, with the x-axis pointing towards the Sun. The y-axis lies in the mean ecliptic plane of date, pointing in the anti-orbit direction. The z-axis is parallel to the mean ecliptic pole.
- **GEO: Geocentric Geographic** This system is not inertial. It is Earth-Centered and Earth-Fixed (also called ECEF), so that the coordinates of a point fixed on (or relative to) the surface of the Earth do not change. The x-axis lies in the Earth's equatorial plane (zero latitude) and intersects the Prime Meridian (zero longitude; Greenwich, UK). The z-axis points to True North (which is roughly aligned with the instantaneous rotation axis).
- **GDZ: Geodetic** This system is not inertial and is defined in terms of altitude above a reference ellipsoid, the geodetic latitude, and geodetic longitude. Geodetic longitude is identical to GEO longitude. Both the altitude and latitude depend on the ellipsoid used. While geodetic latitude is close to geographic latitude, they are not the same. The default here is to use the WGS84 reference ellipsoid.

The remaining coordinate systems are also reference to Earth's magnetic field. Different versions of these systems exist, but the most common (and those given here) use a centered dipole axis.

- **GSM: Geocentric Solar Magnetospheric** This system is similar to GSE, but is defined such that the centered dipole lies in the x-z plane. As in all of these systems, z is positive northward. The y-axis is thus perpendicular to both the Sun-Earth line and the centered dipole axis (of date, defined using the first 3 coefficients of the IGRF/DGRF). GSM is therefore a rotation about the x-axis from the GSE system.
- **SM: Solar Magnetic** The z-axis is aligned with the centered dipole axis of date (positive northward), and the y-axis is perpendicular to both the Sun-Earth line and the dipole axis. As with GSE and GSM, y is positive in the anti-orbit direction. The x-axis therefore is not aligned with the Sun-Earth line and SM is a rotation about the y-axis from the GSM system.

- **CDMAG: Geomagnetic** This is a geomagnetic analog of the GEO system. The z-axis is aligned with the centered dipole axis of date. The y-axis is perpendicular to to both the dipole axis and True North, i.e., y is the cross product of the z-axis of the GEO system with the dipole axis. The x-axis completes.

4.4.1 Classes

CTrans(ctime[, ephmodel, pnmodel, eop])	Coordinate transformation class for a single instance in time
Ellipsoid([name, A, iFlat])	Ellipsoid definition class for geodetic coordinates

spacepy.ctrans.CTrans

class spacepy.ctrans.**CTrans**(*ctime*, *ephmodel=None*, *pnmodel=None*, *eop=False*)

Coordinate transformation class for a single instance in time

A general coordinate conversion routine, which takes a numpy array (Nx3) of Cartesian vectors along with the names of the input and output coordinate systems and returns an array of the converted coordinates.

Parameters

ctime [(spacepy.time.Ticktock, datetime, float, string)] Input time stamp. Must have one time only. Accepted input formats

Returns

out [CTrans] instance with self.convert, etc.

Other Parameters

ephmodel [str, optional] Select ephemerides model (e.g., for determining Sun direction). Currently only 'LGMDEFAULT' is supported, for consistency with LANLGeoMag implementation.

pnmodel [str, optional] Select precession/nutation model set. Options are: 'IAU82' (default), and 'IAU00'.

eop [bool, optional] Use Earth Orientation Parameters

See also:

spacepy.coordinates.Coords

Notes

New in version 0.3.0.

Methods

calcTimes([recalc])	Calculate time in systems required to set up coordinate transforms
calcOrbitParams([recalc])	Calculate Earth orbit parameters needed for coordinate transforms
calcCoreTransforms([recalc])	Calculate core coordinate transform matrices
calcMagTransforms([recalc])	Calculate geophysical coordinate systems
convert(vec, sys_in, sys_out[, defaults])	Convert an input vector between two coordinate systems
getEOP([useEOP])	Get/set Earth Orientation Parameters
gmst()	Calculate Greenwich Mean Sidereal Time

calcTimes(*recalc=False*, ***kwargs*)
Calculate time in systems required to set up coordinate transforms

Sets Julian Date and Julian centuries in UTC, TAI, UT1, and TT systems.

Parameters

recalc [bool, optional] If True, recalculate the times for coordinate transformation. Default is False.

calcOrbitParams(*recalc=False*)
Calculate Earth orbit parameters needed for coordinate transforms

Calculates Earth's orbital parameters required for defining coordinate system transformations, such as orbital eccentricity, the obliquity of the ecliptic, anomalies, and precession angles.

Parameters

recalc [bool, optional] If True, recalculate the orbital parameters for coordinate transformation. Default is False.

calcCoreTransforms(*recalc=False*)
Calculate core coordinate transform matrices

These coordinate systems do not require information about Earth's magnetic field. The systems are: Earth-Centered Inertial, J2000 (ECI2000) Earth-Centered Inertial, Mean-of-date (ECIMOD) Earth-Centered Inertial, True-of-date (ECITOD) Geocentric Solar Ecliptic (GSE) Geocentric Geographic (GEO)

Parameters

recalc [bool, optional] If True, recalculate the core (non-magnetic) coordinate transformations. Default is False.

calcMagTransforms(*recalc=False*)
Calculate geophysical coordinate systems

Calculate transforms for coordinate systems requiring magnetic field information.

These are: Solar Magnetic (SM) Geocentric Solar Magnetospheric (GSM) Geomagnetic, centered dipole (CDMAG)

Parameters

recalc [bool, optional] If True, recalculate the core (non-magnetic) coordinate transformations. Default is False.

convert(*vec*, *sys_in*, *sys_out*, *defaults=None*)
Convert an input vector between two coordinate systems

Parameters

vec [array-like] Input 3-vector (can be an array of input 3-vectors) to convert. E.g., for 2D input the array must be like [[x1, y1, z1], [x2, y2, z2]]

sys_in [str] String name for initial coordinate system. For supported systems, see module level documentation.

sys_out [str] String name for target coordinate system. For supported systems, see module level documentation.

Other Parameters

defaults [namedtuple or None] Named tuple containing default settings passed from Coordinates module

`getEOP`(*useEOP=False*)
Get/set Earth Orientation Parameters

Parameters

useEOP [bool] If True, use Earth Orientation Parameters. Default False.

Notes

Currently Earth Orientation Parameters are all set to zero. Use is not yet supported.

`gmst`()
Calculate Greenwich Mean Sidereal Time

Notes

The formulation used to calculate GMST is selected using the status of the 'pnmodel' variable in the CTrans object attributes.

spacepy.ctrans.Ellipsoid

`class` spacepy.ctrans.`Ellipsoid`(*name='WGS84'*, *A=6378.137*, *iFlat=298.257223563*)
Ellipsoid definition class for geodetic coordinates

Returns

out [Ellipsoid] Ellipsoid instance storing all relevant paramters for geodetic conversion

Other Parameters

name [str] Name for ellipsoid, stored in attrs of returned Ellipsoid instance. Default is 'WGS84'

A [float] Semi-major axis (equatorial radius) of ellipsoid in km. Default is 6378.137km (WGS84_A)

iFlat [float] Inverse flattening of ellipsoid. Default is WGS84 value of 298.257223563.

Notes

New in version 0.3.0.

4.4.2 Functions

convert_multitime(coords, ticks, sys_in, sys_out)	Convert coordinates for N times, where N >= 1
gdz_to_geo(gdzvec[, units, geoid])	Convert geodetic (GDZ) coordinates to geocentric geographic
geo_to_gdz(geovec[, units, geoid])	Convert geocentric geographic (cartesian GEO) to geodetic (spherical GDZ)
geo_to_rll(geovec[, units, geoid])	Calculate RLL from geocentric geographic (GEO) coordinates
rll_to_geo(rllvec[, units, geoid])	Calculate geocentric geographic (GEO) from RLL coordinates

spacepy.ctrans.convert_multitime

spacepy.ctrans.**convert_multitime**(*coords*, *ticks*, *sys_in*, *sys_out*, *defaults=None*, *itol=None*)

Convert coordinates for N times, where N >= 1

Parameters

coords [array-like] Coordinates as Nx3 array. Cartesian assumed unless input system is gedetic.

ticks [spacepy.time.Ticktock] Times for each element of coords. Must contain either N times or 1 time.

sys_in [str] Name of input coordinate system.

sys_out [str] Name of output coordinate system.

Other Parameters

defaults [namedtuple or None] Named tuple with parameters from coordinates module

itol [float] Time tolerance, in seconds, for using a unique set of conversions. Default is 1. Supplying a defaults namedtuple (i.e., if routine is called by spacepy.cooordinates.Coords.convert) will override this value.

spacepy.ctrans.gdz_to_geo

spacepy.ctrans.**gdz_to_geo**(*gdzvec*, *units='km'*, *geoid={'1mE2': 0.9933056200098587, 'A': 6378.137, 'A2': 40680631.59076899, 'A2mB2': 272331.60610755533, 'B': 6356.752314245179, 'B2': 40408299.98466144, 'E2': 0.006694379990141316 5, 'E4': 4.481472345240445e-05, 'EP2': 0.006739496742276451 4, 'Flat': 0.0033528106647474805, 'iFlat': 298.257223563}*)

Convert geodetic (GDZ) coordinates to geocentric geographic

Parameters

gdzvec [array-like] Nx3 array of geodetic altitude, latitude, longitude (in specified units)

Returns

out [numpy.ndarray] Nx3 array of geocentric geographic x, y, z coordinates

Other Parameters

units [str] Units for input geodetic altitude. Options are 'km' or 'Re'. Default is 'km'. Output units will be the same as input units.

geoid [spacepy.ctrans.Ellipsoid] Instance of a reference ellipsoid to use for geodetic conversion. Default is WGS84.

Notes

New in version 0.3.0.

spacepy.ctrans.geo_to_gdz

spacepy.ctrans.**geo_to_gdz**(*geovec*, *units='km'*, *geoid={'1mE2': 0.9933056200098587, 'A': 6378.137, 'A2': 40680631.59076899, 'A2mB2': 272331.60610755533, 'B': 6356.752314245179, 'B2': 40408299.98466144, 'E2': 0.006694379990141316 5, 'E4': 4.481472345240445e-05, 'EP2': 0.006739496742276451 4, 'Flat': 0.003352810664747480 5, 'iFlat': 298.257223563}*)

Convert geocentric geographic (cartesian GEO) to geodetic (spherical GDZ)

Uses Heikkinen's exact solution[1], see Zhu et al. [#Zhu] for details.

Parameters

geovec [array-like] Nx3 array (or array-like) of geocentric geographic [x, y, z] coordinates

Returns

out [numpy.ndarray] Nx3 array of geodetic altitude, latitude, and longitude

Notes

New in version 0.3.0.

References

spacepy.ctrans.geo_to_rll

spacepy.ctrans.**geo_to_rll**(*geovec*, *units='km'*, *geoid={'1mE2': 0.9933056200098587, 'A': 6378.137, 'A2': 40680631.59076899, 'A2mB2': 272331.60610755533, 'B': 6356.752314245179, 'B2': 40408299.98466144, 'E2': 0.006694379990141316 5, 'E4': 4.481472345240445e-05, 'EP2': 0.006739496742276451 4, 'Flat': 0.003352810664747480 5, 'iFlat': 298.257223563}*)

Calculate RLL from geocentric geographic (GEO) coordinates

Parameters

geovec [array-like] Nx3 array of geographic radius, latitude, longitude (in specified units)

Returns

rllvec [numpy.ndarray] Nx3 array of [distance from Earth's center, geodetic latitude, geodetic longitude]

[1] Heikkinen, M., "Geschlossene formeln zur berechnung raumlicher geodatischer koordinaten aus rechtwinkligen koordinaten", Z. Vermess., vol. 107, pp. 207-211, 1982.

Other Parameters

units [str] Units for input geodetic altitude. Options are 'km' or 'Re'. Default is 'km'. Output units will be the same as input units.

geoid [spacepy.ctrans.Ellipsoid] Instance of a reference ellipsoid to use for geodetic conversion. Default is WGS84.

Notes

New in version 0.3.0.

spacepy.ctrans.rll_to_geo

spacepy.ctrans.**rll_to_geo**(*rllvec*, *units='km'*, *geoid={'1mE2': 0.9933056200098587, 'A': 6378.137, 'A2': 40680631.59076899, 'A2mB2': 272331.60610755533, 'B': 6356.752314245179, 'B2': 40408299.98466144, 'E2': 0.006694379990141316 5, 'E4': 4.481472345240445e-05, 'EP2': 0.00673949674227645 14, 'Flat': 0.003352810664747480 5, 'iFlat': 298.257223563}*)

Calculate geocentric geographic (GEO) from RLL coordinates

Parameters

rllvec [array-like] Nx3 array of geocentric radius, geodetic latitude, geodetic longitude (in specified units)

Returns

geoarr [numpy.ndarray] Nx3 array of [altitude, geodetic latitude, geodetic longitude]

Other Parameters

units [str] Units for input geocentric radii. Options are 'km' or 'Re'. Default is 'km'. Output units will be the same as input units.

geoid [spacepy.ctrans.Ellipsoid] Instance of a reference ellipsoid to use for geodetic conversion. Default is WGS84.

Notes

New in version 0.3.0.

4.4.3 Submodules

iau80n	IAU 1980 Nutation model

spacepy.ctrans.iau80n

IAU 1980 Nutation model

Functions

nutation(TT_JC, const[, nTerms])	Calculate dPsi and dEps for IAU80 nutation model

spacepy.ctrans.iau80n.nutation

spacepy.ctrans.iau80n.**nutation**(*TT_JC*, *const*, *nTerms=106*)
Calculate dPsi and dEps for IAU80 nutation model

Data

coeff80	IAU 1980 nutation coefficients

spacepy.ctrans.iau80n.coeff80

spacepy.ctrans.iau80n.**coeff80** = **array**([[0.00000e+00, 0.00000e+00, 0.00000e+00,
0.00000e+00, 1.00000e+00, -1.71996e+05, -1.74200e+02, 9.20250e+04, 8.90000e+00], [
0.00000e+00, 0.00000e+00, 0.00000e+00, 0.00000e+00, 2.00000e+00, 2.06200e+03,
2.00000e-01, -8.95000e+02, 5.00000e-01], [-2.00000e+00, 0.00000e+00, 2.00000e+00,
0.00000e+00, 1.00000e+00, 4.60000e+01, 0.00000e+00, -2.40000e+01, 0.00000e+00], [
2.00000e+00, 0.00000e+00, -2.00000e+00, 0.00000e+00, 0.00000e+00, 1.10000e+01,
0.00000e+00, 0.00000e+00, 0.00000e+00], [-2.00000e+00, 0.00000e+00, 2.00000e+00,
0.00000e+00, 2.00000e+00, -3.00000e+00, 0.00000e+00, 1.00000e+00, 0.00000e+00], [
1.00000e+00, -1.00000e+00, 0.00000e+00, -1.00000e+00, 0.00000e+00, -3.00000e+00,
0.00000e+00, 0.00000e+00, 0.00000e+00], [0.00000e+00, -2.00000e+00, 2.00000e+00,
-2.00000e+00, 1.00000e+00, -2.00000e+00, 0.00000e+00, 1.00000e+00, 0.00000e+00], [
2.00000e+00, 0.00000e+00, -2.00000e+00, 0.00000e+00, 1.00000e+00, 1.00000e+00,
0.00000e+00, 0.00000e+00, 0.00000e+00], [0.00000e+00, 0.00000e+00, 2.00000e+00,
-2.00000e+00, 2.00000e+00, -1.31870e+04, -1.60000e+00, 5.73600e+03, -3.10000e+00], [
0.00000e+00, 1.00000e+00, 0.00000e+00, 0.00000e+00, 0.00000e+00, 1.42600e+03,
-3.40000e+00, 5.40000e+01, -1.00000e-01], [0.00000e+00, 1.00000e+00, 2.00000e+00,
-2.00000e+00, 2.00000e+00, -5.17000e+02, 1.20000e+00, 2.24000e+02, -6.00000e-01], [
0.00000e+00, -1.00000e+00, 2.00000e+00, -2.00000e+00, 2.00000e+00, 2.17000e+02,
-5.00000e-01, -9.50000e+01, 3.00000e-01], [0.00000e+00, 0.00000e+00, 2.00000e+00,
-2.00000e+00, 1.00000e+00, 1.29000e+02, 1.00000e-01, -7.00000e+01, 0.00000e+00], [
2.00000e+00, 0.00000e+00, 0.00000e+00, -2.00000e+00, 0.00000e+00, 4.80000e+01,
0.00000e+00, 1.00000e+00, 0.00000e+00], [0.00000e+00, 0.00000e+00, 2.00000e+00,
-2.00000e+00, 0.00000e+00, -2.20000e+01, 0.00000e+00, 0.00000e+00, 0.00000e+00], [
0.00000e+00, 2.00000e+00, 0.00000e+00, 0.00000e+00, 0.00000e+00, 1.70000e+01,
-1.00000e-01, 0.00000e+00, 0.00000e+00], [0.00000e+00, 1.00000e+00, 0.00000e+00,
0.00000e+00, 1.00000e+00, -1.50000e+01, 0.00000e+00, 9.00000e+00, 0.00000e+00], [
0.00000e+00, 2.00000e+00, 2.00000e+00, -2.00000e+00, 2.00000e+00, -1.60000e+01,
1.00000e-01, 7.00000e+00, 0.00000e+00], [0.00000e+00, -1.00000e+00, 0.00000e+00,
0.00000e+00, 1.00000e+00, -1.20000e+01, 0.00000e+00, 6.00000e+00, 0.00000e+00],
[-2.00000e+00, 0.00000e+00, 0.00000e+00, 2.00000e+00, 1.00000e+00, -6.00000e+00,
0.00000e+00, 3.00000e+00, 0.00000e+00], [0.00000e+00, -1.00000e+00, 2.00000e+00,
-2.00000e+00, 1.00000e+00, -5.00000e+00, 0.00000e+00, 3.00000e+00, 0.00000e+00], [
2.00000e+00, 0.00000e+00, 0.00000e+00, -2.00000e+00, 1.00000e+00, 4.00000e+00,
0.00000e+00, -2.00000e+00, 0.00000e+00], [0.00000e+00, 1.00000e+00, 2.00000e+00,
-2.00000e+00, 1.00000e+00, 4.00000e+00, 0.00000e+00, -2.00000e+00, 0.00000e+00], [
1.00000e+00, 0.00000e+00, 0.00000e+00, -1.00000e+00, 0.00000e+00, -4.00000e+00,
0.00000e+00, 0.00000e+00, 0.00000e+00], [2.00000e+00, 1.00000e+00, 0.00000e+00,
-2.00000e+00, 0.00000e+00, 1.00000e+00, 0.00000e+00, 0.00000e+00, 0.00000e+00], [
0.00000e+00, 0.00000e+00, -2.00000e+00, 2.00000e+00, 1.00000e+00, 1.00000e+00,
0.00000e+00, 0.00000e+00, 0.00000e+00], [0.00000e+00, 1.00000e+00, -2.00000e+00,
2.00000e+00, 0.00000e+00, -1.00000e+00, 0.00000e+00, 0.00000e+00, 0.00000e+00], [
0.00000e+00, 1.00000e+00, 0.00000e+00, 0.00000e+00, 2.00000e+00, 1.00000e+00,
0.00000e+00, 0.00000e+00, 0.00000e+00], [-1.00000e+00, 0.00000e+00, 0.00000e+00,
1.00000e+00, 1.00000e+00, 1.00000e+00, 0.00000e+00, 0.00000e+00, 0.00000e+00], [
0.00000e+00, 1.00000e+00, 2.00000e+00, -2.00000e+00, 0.00000e+00, -1.00000e+00,
0.00000e+00, 0.00000e+00, 0.00000e+00], [0.00000e+00, 0.00000e+00, 2.00000e+00,
0.00000e+00, 2.00000e+00, -2.27400e+03, -2.00000e-01, 9.77000e+02, -5.00000e-01], [
1.00000e+00, 0.00000e+00, 0.00000e+00, 0.00000e+00, 0.00000e+00, 7.12000e+02,
1.00000e-01, -7.00000e+00, 0.00000e+00], [0.00000e+00, 0.00000e+00, 2.00000e+00,
0.00000e+00, 1.00000e+00, -3.86000e+02, -4.00000e-01, 2.00000e+02, 0.00000e+00], [
1.00000e+00, 0.00000e+00, 2.00000e+00, 0.00000e+00, 2.00000e+00, -3.01000e+02,
0.00000e+00, 1.29000e+02, -1.00000e-01], [1.00000e+00, 0.00000e+00, 0.00000e+00,
-2.00000e+00, 0.00000e+00, -1.58000e+02, 0.00000e+00, -1.00000e+00, 0.00000e+00],
[-1.00000e+00, 0.00000e+00, 2.00000e+00, 0.00000e+00, 2.00000e+00, 1.23000e+02,
0.00000e+00, -5.30000e+01, 0.00000e+00], [0.00000e+00, 0.00000e+00, 0.00000e+00,
2.00000e+00, 0.00000e+00, 6.30000e+01, 0.00000e+00, -2.00000e+00, 0.00000e+00], [
1.00000e+00, 0.00000e+00, 0.00000e+00, 0.00000e+00, 1.00000e+00, 6.30000e+01,
1.00000e-01, -3.30000e+01, 0.00000e+00], [-1.00000e+00, 0.00000e+00, 0.00000e+00,

4.5 datamanager - easy access to and manipulation of data

The datamanager classes and functions are useful for locating the correct data file for a particular day and manipulating data and subsets in a generic way.

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4.5.1 About datamanager

4.5.2 Examples

Examples go here

Classes

DataManager(directories, file_fmt[, ...])	THIS CLASS IS NOT YET COMPLETE, doesn't do much useful.

Functions

apply_index(data, idx)	Apply an array of indices to data.
array_interleave(array1, array2, idx)	Create an array containing all elements of both array1 and array2
axis_index(shape[, axis])	Returns array of indices along axis, for all other axes
flatten_idx(idx[, axis])	Convert multidimensional index into index on flattened array.
insert_fill(times, data[, fillval, tol, ...])	Populate gaps in data with fill.
rebin(data, bindata, bins[, axis, bintype, ...])	Rebin one axis of input data based on values of another array
rev_index(idx[, axis])	From an index, return an index that reverses the action of that index
values_to_steps(array[, axis])	Transform values along an axis to their order in a unique sequence.

class spacepy.datamanager.**DataManager**(*directories*, *file_fmt*, *descend=False*, *period=None*)

THIS CLASS IS NOT YET COMPLETE, doesn't do much useful.

Will have to do something that allows the config file to specify regex and other things, and then just the directory to be changed (since regex, etc.

Parameters

directories [list] A list of directories that might contain the data

file_fmt [string] Regular expression that matches the files desired. Will also recognize strftime parameters %w %d %m %y %Y %H %M %s %j %U %W, all zero-pad. https://docs.

python.org/2/library/datetime.html#strftime-strptime-behavior Can have subdirectory reference, but separator should be unix-style, with no leading slash.

period [string] Size of file; can be a number followed by one of d, m, y, H, M, s. Anything else is assumed to be "irregular" and files treated as if there are neither gaps nor overlaps in the sequence. If not specified, will be assumed to match one count of the smallest unit in the format string.

files_matching(*dt=None*)

Return all the files matching this file format

Parameters

dt [datetime] Optional; if specified, match only files for this date.

Returns

out [generator] Iterates over every file matching the format specified at creation. Note this is specified in native path format!

get_filename(*dt*)

Returns the filename corresponding to a particular point in time

spacepy.datamanager.**apply_index**(*data*, *idx*)

Apply an array of indices to data.

Most useful in dealing with the output from `numpy.argsort()`, and best explained by the example.

Parameters

data [array] Input data, at least two dimensional. The 0th dimension is treated as a "time" or "record" dimension.

idx [sequence] 2D index to apply to the import data. The 0th dimension must be the same size as `data`'s 0th dimension. Dimension 1 must be the same size as one other dimension in data (the first match found is used); this is referred to as the "index dimension."

Returns

data [sequence] View of `data`, with index applied. For each index of the 0th dimension, the values along the index dimension are obtained by applying the value of `idx` at the same index in the 0th dimension. This is repeated across any other dimensions in `data`.

> **Warning:** No guarantee is made whether the returned data is a copy of the input data. Modifying values in the input may change the values of the input. Call `copy()` if a copy is required.

Raises

ValueError [if can't match the shape of data and indices]

Examples

Assume `flux` is a 3D array of fluxes, with a value for each of time, pitch angle, and energy. Assume energy is not necessarily constant in time, nor is ordered in the energy dimension. If `energy` is a 2D array of the energies as a function of energy step for each time, then the following will sort the flux at each time and pitch angle in energy order.

```
>>> idx = numpy.argsort(energy, axis=1)
>>> flux_sorted = spacepy.datamanager.apply_index(flux, idx)
```

spacepy.datamanager.**array_interleave**(*array1*, *array2*, *idx*)

Create an array containing all elements of both array1 and array2

`idx` is an index on the output array which indicates which elements will be populated from `array1`, i.e., `out[idx] == array1` (in order.) The other elements of `out` will be filled, in order, from `array2`.

Parameters

array1 [array] Input data.

array2 [array] Input data. Must have same number of dimensions as `array1`, and all dimensions except the zeroth must also have the same length.

idx [array] A 1D array of indices on the zeroth dimension of the output array. Must have the same length as the zeroth dimension of `array1`.

Returns

out [array] All elements from `array1` and `array2`, interleaved according to `idx`.

Examples

```
>>> import numpy
>>> import spacepy.datamanager
>>> a = numpy.array([10, 20, 30])
>>> b = numpy.array([1, 2])
>>> idx = numpy.array([1, 2, 4])
>>> spacepy.datamanager.array_interleave(a, b, idx)
array([ 1, 10, 20,  2, 30])
```

spacepy.datamanager.**axis_index**(*shape*, *axis=- 1*)

Returns array of indices along axis, for all other axes

Parameters

shape [tuple] Shape of the output array

Returns

idx [array] An array of indices. The value of each element is that element's index along `axis`.

Other Parameters

axis [int] Axis along which to return indices, defaults to the last axis.

See also:

`numpy.mgrid` This function is a special case

Examples

For a shape of `(i, j, k, l)` and `axis` = -1, `idx[i, j, k, :] = range(l)` for all `i`, `j`, `k`.

Similarly, for the same shape and `axis = 1`, `idx[i, :, k, l] = range(j)` for all `i`, `k`, `l`.

```
>>> import numpy
>>> import spacepy.datamanager
>>> spacepy.datamanager.axis_index((5, 3))
array([[0, 1, 2],
       [0, 1, 2],
       [0, 1, 2],
       [0, 1, 2],
       [0, 1, 2]])
>>> spacepy.datamanager.axis_index((5, 3), 0)
    array([[0, 0, 0],
           [1, 1, 1],
           [2, 2, 2],
           [3, 3, 3],
           [4, 4, 4]])
```

spacepy.datamanager.**flatten_idx**(*idx*, *axis=- 1*)

Convert multidimensional index into index on flattened array.

Convert a multidimensional index, that is values along a particular axis, so that it can derefence the flattened array properly. Note this is not the same as `ravel_multi_index()`.

Parameters

idx [array] Input index, i.e. a list of elements along a particular axis, in the style of `argsort()`.

Returns

flat [array] A 1D array of indices suitable for indexing the flat version of the array

Other Parameters

axis [int] Axis along which `idx` operates, defaults to the last axis.

See also:

apply_index

Examples

```
>>> import numpy
>>> import spacepy.datamanager
>>> data = numpy.array([[3, 1, 2], [3, 2, 1]])
>>> idx = numpy.argsort(data, -1)
>>> idx_flat = spacepy.datamanager.flatten_idx(idx)
>>> data.ravel() #flat array
array([3, 1, 2, 3, 2, 1])
>>> idx_flat #indices into the flat array
array([1, 2, 0, 5, 4, 3])
>>> data.ravel()[idx_flat] #index applied to the flat array
array([1, 2, 3, 1, 2, 3])
```

spacepy.datamanager.**insert_fill**(*times*, *data*, *fillval=nan*, *tol=1.5*, *absolute=None*, *doTimes=True*)
Populate gaps in data with fill.

Continuous data are often treated differently from discontinuous data, e.g., matplotlib will draw lines connecting data points but break the line at fill. Often data will be irregularly sampled but also contain large gaps that are not explicitly marked as fill. This function adds a single record of explicit fill to each gap, defined as places where the spacing between input times is a certain multiple of the median spacing.

Parameters

times [sequence] Values representing when the data were taken. Must be one-dimensional, i.e., each value must be scalar. Not modified

data [sequence] Input data.

Returns

times, data [tuple of sequence] Copies of input times and data, fill added in gaps (`doTimes` True)

data [sequence] Copy of input data, with fill added in gaps (`doTimes` False)

Other Parameters

fillval Fill value, same type as `data`. Default is `numpy.nan`. If scalar, will be repeated to match the shape of `data` (minus the time axis).

Note: The default value of `nan` will not produce good results with integer input.

---

tol [float] Tolerance. A single fill value is inserted between adjacent values where the spacing in `times` is strictly greater than `tol` times the median of the spacing across all `times`. The inserted time for fill is halfway between the time on each side. (Default 1.5)

absolute An absolute value for maximum spacing, of a type that would result from a difference in `times`. If specified, `tol` is ignored and any gap strictly larger than `absolute` will have fill inserted.

doTimes [boolean] If True (default), will return a tuple of the times (with new values inserted for the fill records) and the data with new fill values. If False, will only return the data – useful for applying fill to multiple arrays of data on the same timebase.

Raises

ValueError [if can't identify the time axis of data] Try using `numpy.rollaxis()` to put the time axis first in both `data` and `times`.

Examples

This example shows simple hourly data with a gap, populated with fill. Note that only a single fill value is inserted, to break the sequence of valid data rather than trying to match the existing cadence.

```
>>> import datetime
>>> import numpy
>>> import spacepy.datamanager
>>> t = [datetime.datetime(2012, 1, 1, 0),
         datetime.datetime(2012, 1, 1, 1),
         datetime.datetime(2012, 1, 1, 2),
         datetime.datetime(2012, 1, 1, 5),
```

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```
         datetime.datetime(2012, 1, 1, 6)]
>>> temp = [30.0, 28, 27, 32, 35]
>>> filled_t, filled_temp = spacepy.datamanager.insert_fill(t, temp)
>>> filled_t
array([datetime.datetime(2012, 1, 1, 0, 0),
       datetime.datetime(2012, 1, 1, 1, 0),
       datetime.datetime(2012, 1, 1, 2, 0),
       datetime.datetime(2012, 1, 1, 3, 30),
       datetime.datetime(2012, 1, 1, 5, 0),
       datetime.datetime(2012, 1, 1, 6, 0)], dtype=object)
>>> filled_temp
array([ 30.,  28.,  27.,  nan,  32.,  35.])
```

This example plots "gappy" data with and without explicit fill values.

```
>>> import matplotlib.pyplot as plt
>>> import numpy
>>> import spacepy.datamanager
>>> x = numpy.append(numpy.arange(0, 6, 0.1), numpy.arange(12, 18, 0.1))
>>> y = numpy.sin(x)
>>> xf, yf = spacepy.datamanager.insert_fill(x, y)
>>> fig = plt.figure()
>>> ax0 = fig.add_subplot(211)
>>> ax0.plot(x, y)
>>> ax1 = fig.add_subplot(212)
>>> ax1.plot(xf, yf)
>>> plt.show()
```

spacepy.datamanager.**rebin**(*data*, *bindata*, *bins*, *axis=- 1*, *bintype='mean'*, *weights=None*, *clip=False*, *bindatadelta=None*)

Rebin one axis of input data based on values of another array

This is clearest with an example. Consider a flux as a function of time, energy, and the look direction of a detector (could be multiple detectors, or spin sectors.) The flux is then 3-D, dimensioned Nt x Ne x Nl. Now consider that each look direction has an associated pitch angle that is a function of time and thus stored in an array Nt x Nl. Then this function will redimension the flux into pitch angle bins (rather than tags.)

So consider the PA bins to have dimension Np + 1 (because it represents the edges, the number of bins is one less than the dimension.) Then the output will be dimensioned Nt x Ne x Np.

`bindata` must be same or lesser dimensionality than `data`. Any axes which are present must be either of size 1, or the same size as `data`. So for `data` 100x5x20, `bindata` may be 100x5x20, or 100, or 100x1x20, but not 100x20x5. This function will insert axes of size 1 as needed to match dimensionality.

Parameters

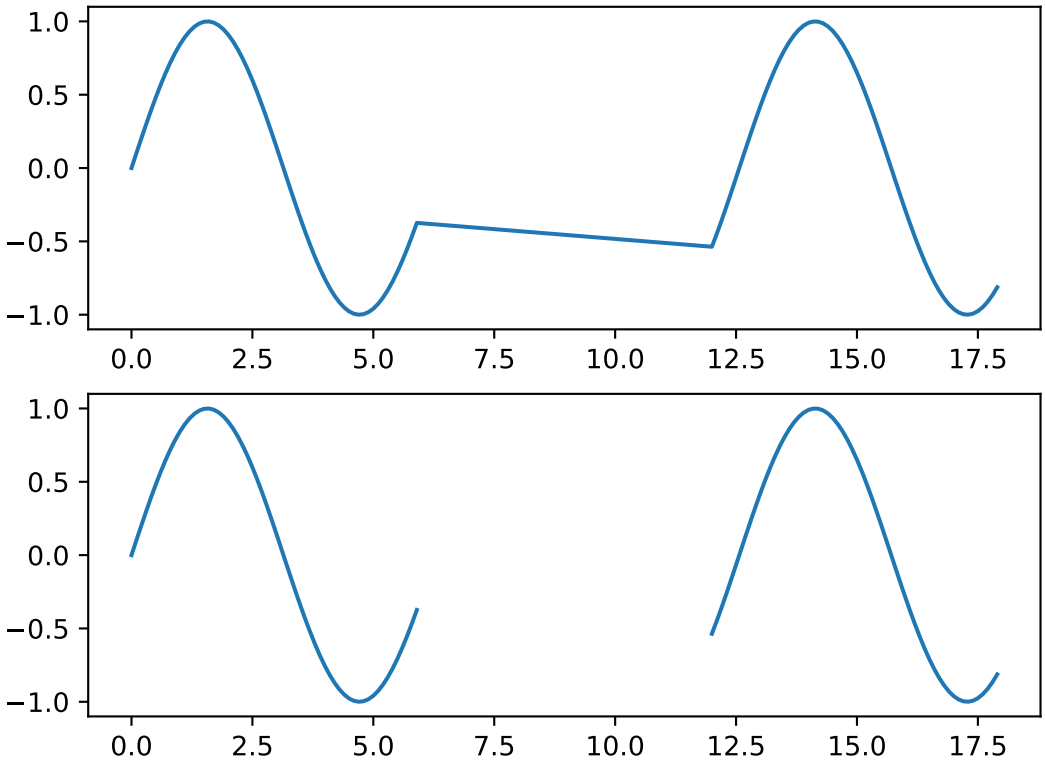
data [ndarray] N-dimensional array of data to be rebinned. `nan` are ignored.

bindata [ndarray] M-dimensional (M<=N) array of values to be compared to the bins.

bins [ndarray] 1-D array of bin edges. Output dimension will be this size minus 1. Any values in `bindata` that don't fall in the bins will be omitted from the output. (See `clip` to change this behavior).

Returns

ndarray `data` with one axis redimensioned, from its original dimension to the bin dimension.


1.0
0.5
0.0
−0.5
−1.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
1.0
0.5
0.0
−0.5
−1.0
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5

Other Parameters

axis [int] Axis of *data* to rebin. This axis will disappear in the output and be replaced with an axis of the size of `bins` less one. (Default -1, last axis)

bintype [str]

Type of rebinning to perform:

mean Return the mean of all values in the bin (default)

unc Return the quadrature mean of all values in the bin, for propagating uncertainty

count Return the count of values that fall in each bin.

weights [ndarray] Relative weight of each sample in `bindata`. Must be same shape as `bindata`. Purely relative, i.e. the output is only affected based on the total of `weights` if `bintype` is `count`. Note if `weights` is specified, `count` returns the sum of the weights, not the count of individual samples.

clip [boolean] Clip data to the bins. If true, all input data will be assigned a bin and data outside the range of the bin edges will be assigned to the extreme bins. If false (default), input data outside the bin ranges will be ignored.

bindatadelta [ndarray] By default, the `bindata` are treated as point values. If `bindatadelta` is specified, it is treated as the half-width of the `bindata`, allowing a single input value to be split between output bins. Must be scalar, or same shape as *bindata*. Note that input values are not weighted by the bin width, but by number of input values or by `weights`. (Combining `weights` with `bindatadelta` is not comprehensively tested.)

Examples

Consider a particle flux distribution that's a function of energy and pitch angle. For simplicity, assume that the energy dependence is a simple power law and the pitch angle dependence is Gaussian, with a peak whose position oscillates in time over a period of about one hour. This is fairly non-physical but illustrative.

First making the relevant imports:

```
>>> import matplotlib.pyplot
>>> import numpy
>>> import spacepy.datamanager
>>> import spacepy.plot
```

The functional form of the flux is then:

```
>>> def j(e, t, a):
...     return e ** -2 * (1 / (90 * numpy.sqrt(2 * numpy.pi))) \
...     * numpy.exp(
...         -0.5 * ((a - 90 + 90 * numpy.sin(t / 573.)) / 90.) ** 2)
```

Illustrating the flux at one energy as a function of pitch angle:

```
>>> times = numpy.arange(0., 7200, 5)
>>> alpha = numpy.arange(0, 181., 2)
# Add a dimension so the flux is a 2D array
>>> flux = j(1., numpy.expand_dims(times, 1),
...          numpy.expand_dims(alpha, 0))
>>> spacepy.plot.simpleSpectrogram(times, alpha, flux, cb=False,
```

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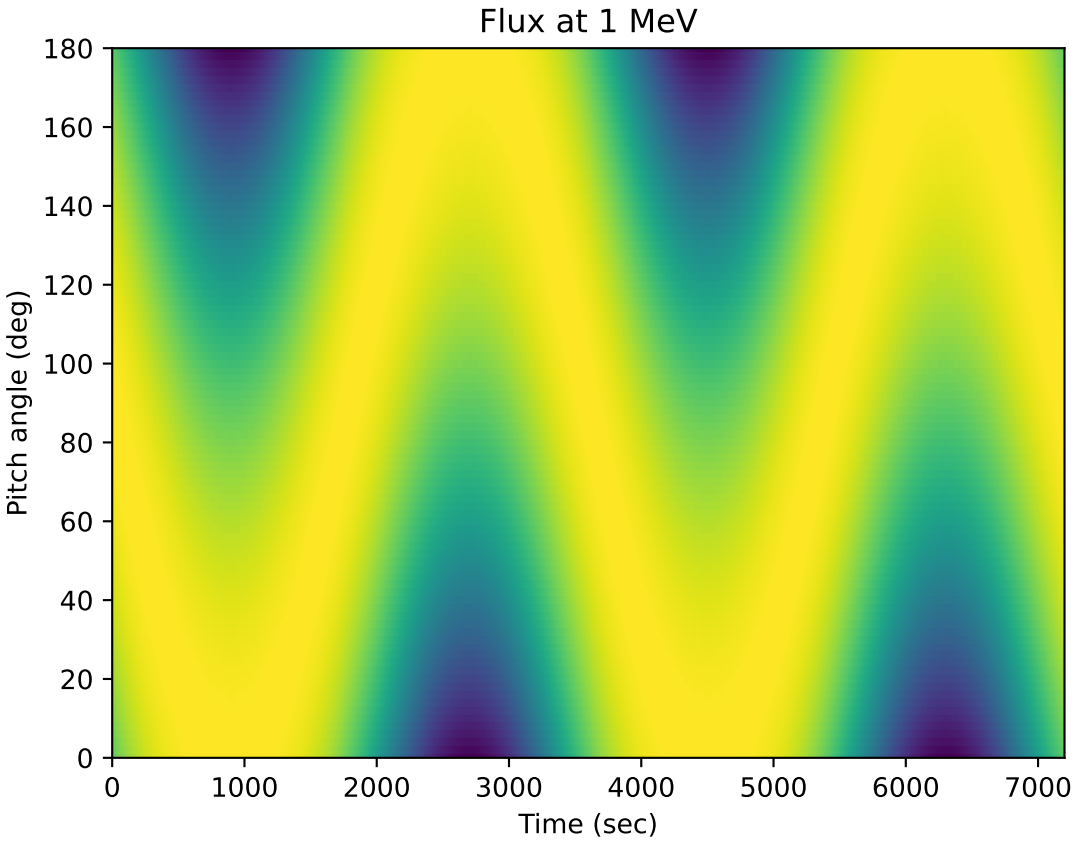
```
...                                 ylog=False)
>>> matplotlib.pyplot.ylabel('Pitch angle (deg)')
>>> matplotlib.pyplot.xlabel('Time (sec)')
>>> matplotlib.pyplot.title('Flux at 1 MeV')
```



Or the flux at one pitch angle as a function of energy:

```
>>> energies = numpy.logspace(0, 3, 50)
>>> flux = j(numpy.expand_dims(energies, 0),
...          numpy.expand_dims(times, 1), 90.)
>>> spacepy.plot.simpleSpectrogram(times, energies, flux, cb=False)
>>> matplotlib.pyplot.ylabel('Energy (MeV)')
>>> matplotlib.pyplot.xlabel('Time (sec)')
>>> matplotlib.pyplot.title('Flux at 90 degrees')
```

The measurement is usually not aligned with a pitch angle grid, and the detector pointing in pitch angle space usually varies with time. Taking a very simple case of eight detectors that sweep through pitch angle space in an organized fashion at ten degrees per minute, the measured pitch angle as a function of detector and time is:

```
>>> def pa(d, t):
...     return (d * 22.5 + t * (2 * (d % 2) - 1)) % 180
>>> lines = matplotlib.pyplot.plot(
```

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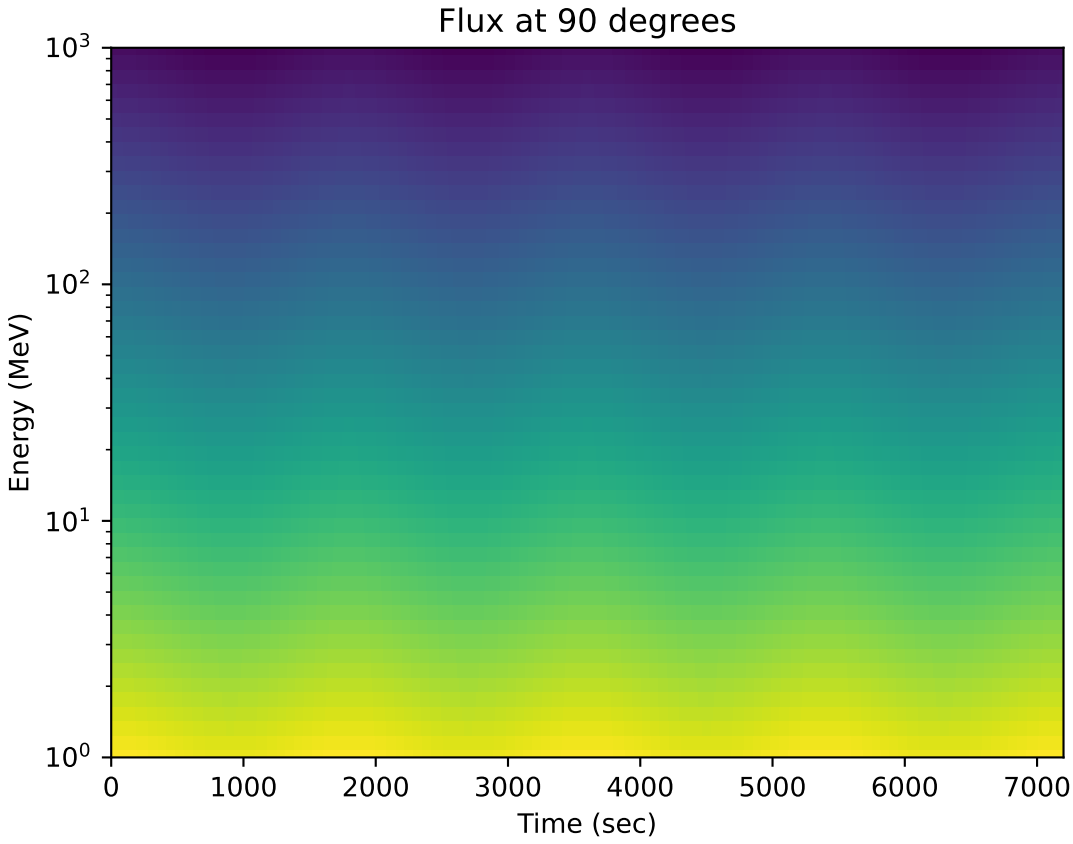
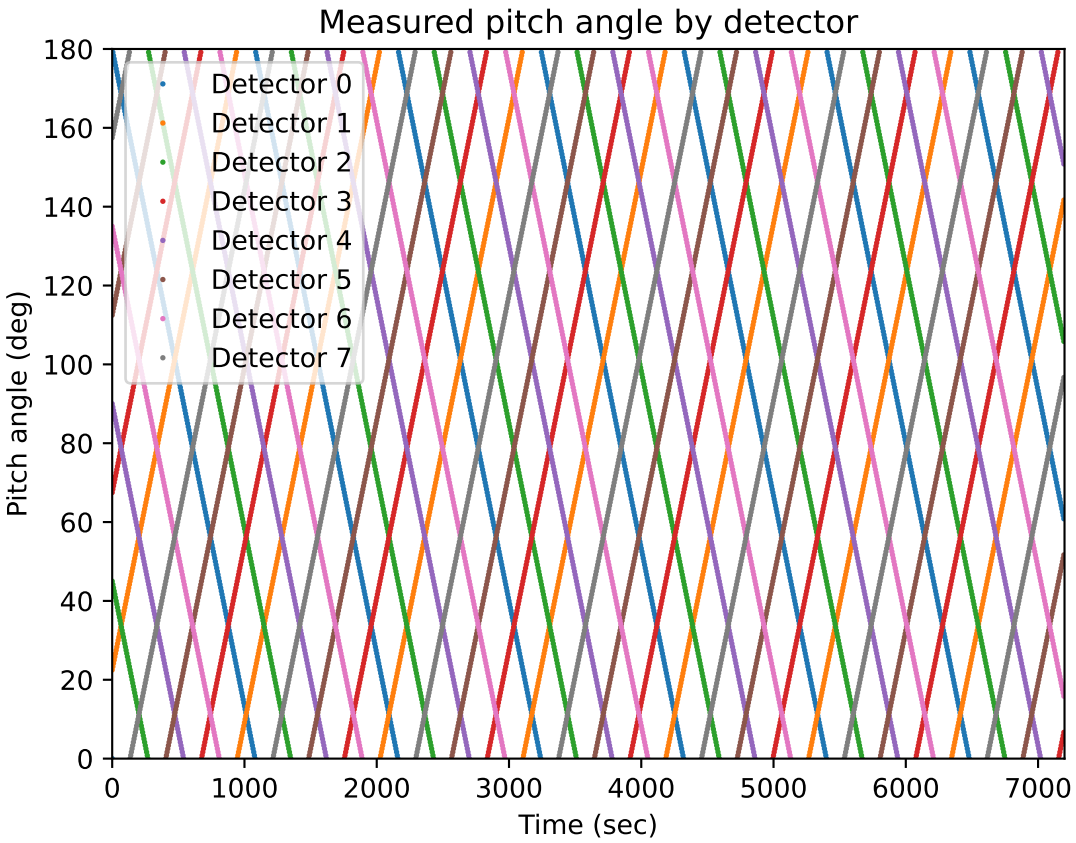

Flux at 90 degrees
10^3
10^2
10^1
10^0
Energy (MeV)
0
1000
2000
3000
4000
5000
6000
7000
Time (sec)

(continued from previous page)

```
...     times, pa(numpy.arange(8).reshape(1, -1), times.reshape(-1, 1)),
...     marker='o', ms=1, linestyle='')
>>> matplotlib.pyplot.legend(lines,
...     ['Detector {}'.format(i) for i in range(4)], loc='best')
>>> matplotlib.pyplot.xlabel('Time (sec)')
>>> matplotlib.pyplot.ylabel('Pitch angle (deg)')
>>> matplotlib.pyplot.title('Measured pitch angle by detector')
```

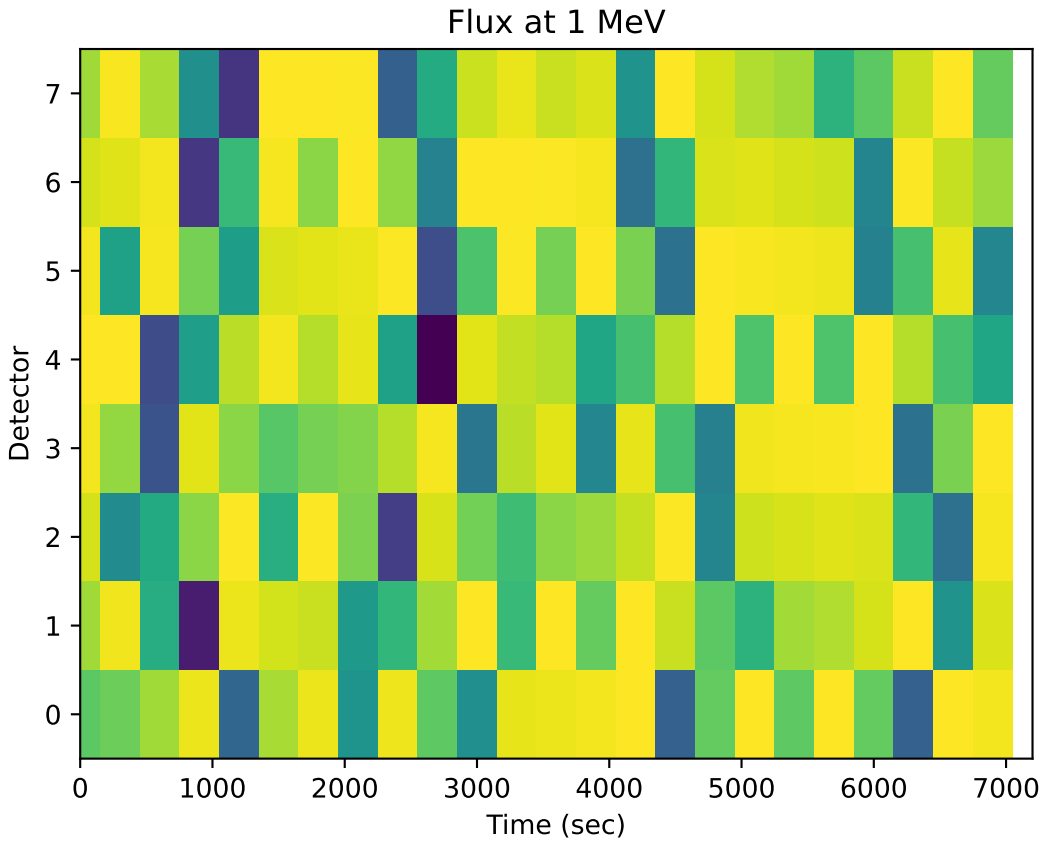


Assuming a coarser measurement in time and energy than used to illustrate the distribution above, the measured flux as a function of time, detector, and energy is constructed:

```
>>> times = numpy.arange(0., 7200, 300) #5 min cadence
>>> alpha = pa(numpy.arange(8).reshape(1, -1), times.reshape(-1, 1))
>>> energies = numpy.logspace(0, 3, 10) #10 energy channels (3/decade)
# Every dimension (t, detector, e) gets its own numpy axis
>>> flux = j(numpy.reshape(energies, (1, 1, -1)),
             numpy.reshape(times, (-1, 1, 1)),
             numpy.expand_dims(alpha, -1))
>>> flux.shape
(24, 8, 10)
```

The flux at an energy as a function of detector is not very useful:

```
>>> spacepy.plot.simpleSpectrogram(times, numpy.arange(8),
...                                flux[..., 0], cb=False, ylog=False)
>>> matplotlib.pyplot.ylabel('Detector')
>>> matplotlib.pyplot.xlabel('Time (sec)')
>>> matplotlib.pyplot.title('Flux at 1 MeV')
```



As a function of energy for one detector, the energy dependence is apparent but time and pitch angle effects are confounded:

```
>>> spacepy.plot.simpleSpectrogram(times, energies, flux[:, 0, :],
...                                cb=False)
>>> matplotlib.pyplot.ylabel('Energy (MeV)')
>>> matplotlib.pyplot.xlabel('Time (sec)')
>>> matplotlib.pyplot.title('Flux in detector 0')
```

What is needed is to recover the array of flux dimensioned by time, pitch angle, and energy, with appropriate pitch angle bins. The assumption is that the pitch angle as a function of time and detector is measured and thus the `alpha` array is available. Using that array, `rebin` can change flux from time, detector, energy bins to time, pitch angle, energy bins. The axis 1 changes from a detector dimension to pitch angle:

```
>>> pa_bins = numpy.arange(0, 181, 36)
>>> flux_by_pa = spacepy.datamanager.rebin(
...     flux, alpha, pa_bins, axis=1)
```

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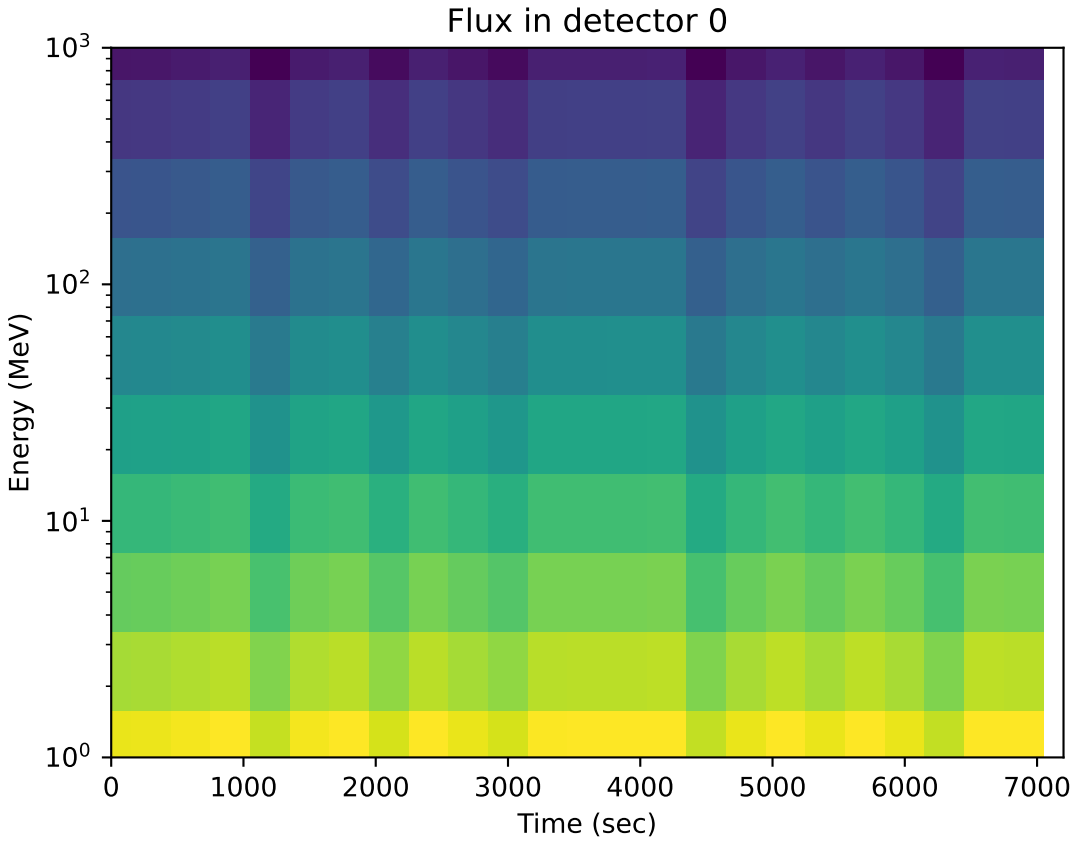
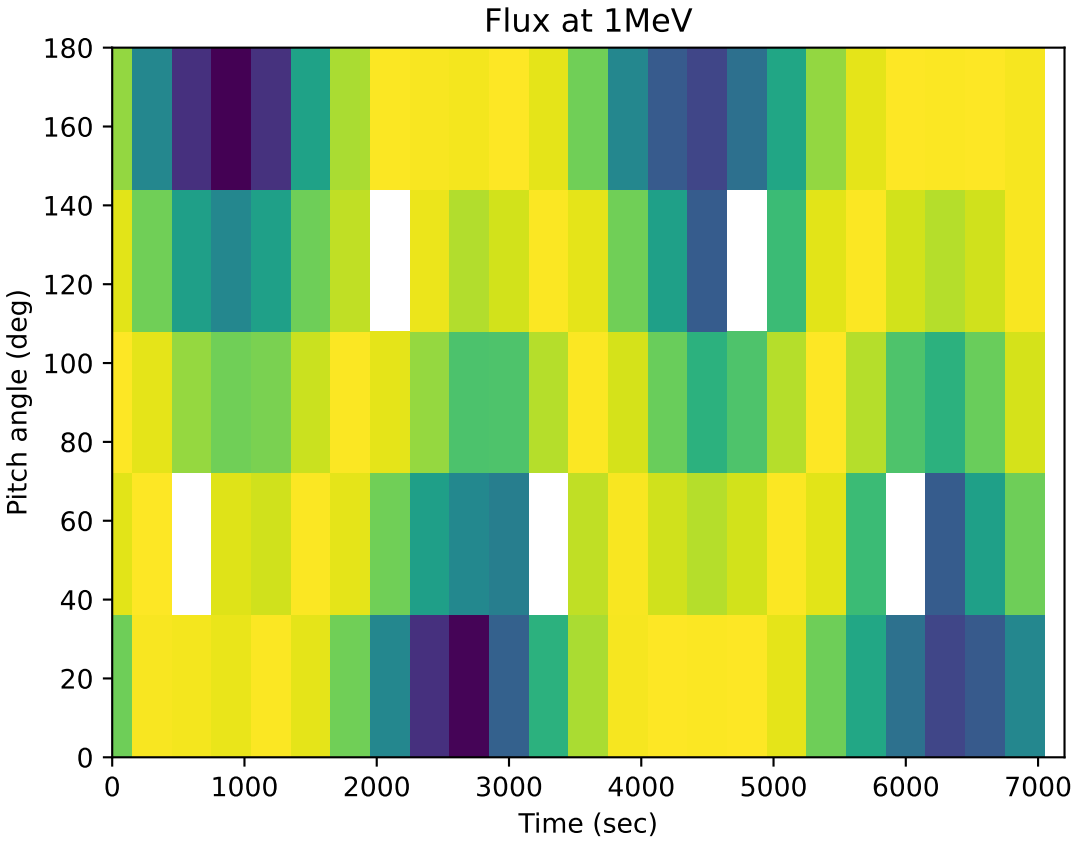

Flux in detector 0
10^3
10^2
10^1
10^0
Energy (MeV)
0
1000
2000
3000
4000
5000
6000
7000
Time (sec)

(continued from previous page)

```
>>> flux_by_pa.shape
(24, 6, 10)
```

This can then be visualized. The pitch angle coverage is not perfect, but the original shape of the distribution is apparent, and further analysis can be performed on the regular pitch angle grid:

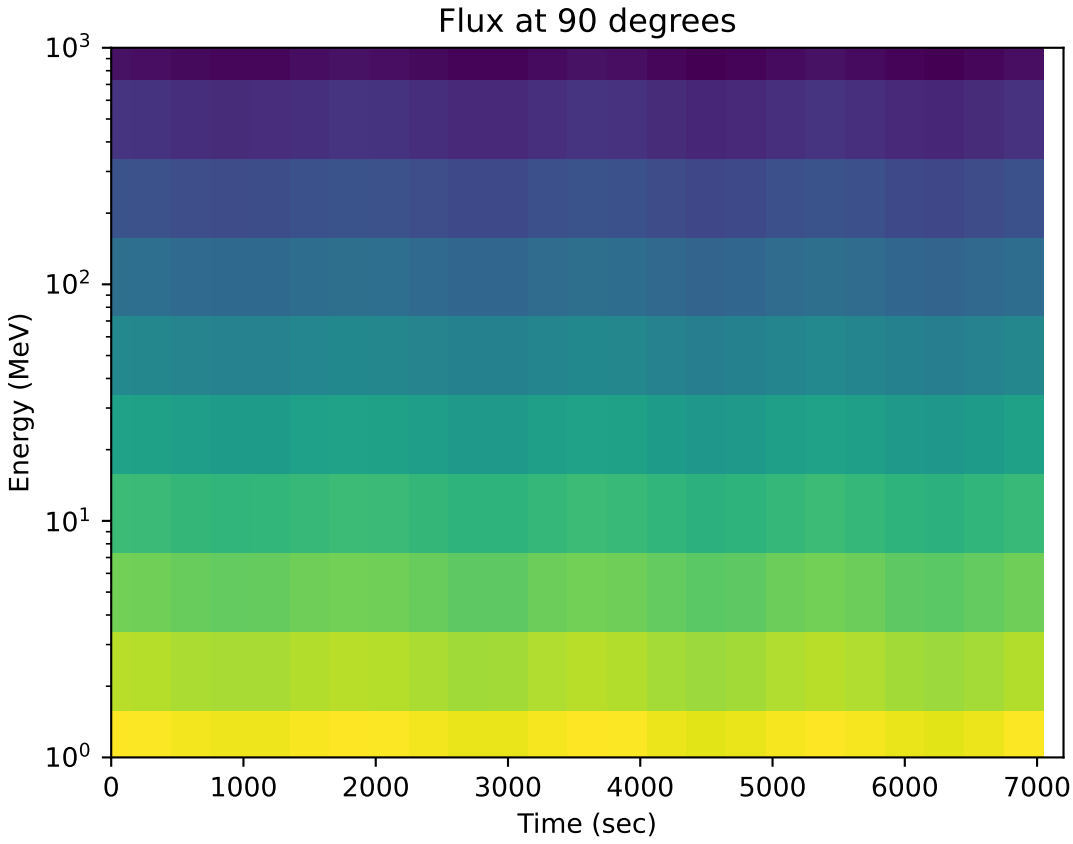
```
>>> spacepy.plot.simpleSpectrogram(times, pa_bins, flux_by_pa[..., 0],
...                                cb=False, ylog=False)
>>> matplotlib.pyplot.ylabel('Pitch angle (deg)')
>>> matplotlib.pyplot.xlabel('Time (sec)')
>>> matplotlib.pyplot.title('Flux at 1MeV')
```



Or by energy:

```
>>> spacepy.plot.simpleSpectrogram(times, energies, flux_by_pa[:, 2, :],
...                                cb=False)
>>> matplotlib.pyplot.ylabel('Energy (MeV)')
>>> matplotlib.pyplot.xlabel('Time (sec)')
>>> matplotlib.pyplot.title('Flux at 90 degrees')
```

`rebin` can be used for higher dimension data, if the pitch angle itself depends on energy (e.g. if an energy sweep takes substantial time), and to propagate uncertainties through the rebinning. It can also be used to rebin on the time axis, e.g. for transforming time base.


Flux at 90 degrees
10^3
10^2
10^1
10^0
Energy (MeV)
0
1000
2000
3000
4000
5000
6000
7000
Time (sec)

spacepy.datamanager.**rev_index**(*idx*, *axis=- 1*)

From an index, return an index that reverses the action of that index

Essentially, `a[idx][rev_index(idx)] == a`

Note: This becomes more complicated in multiple dimensions, due to the vagaries of applying a multidimensional index.

Parameters

idx [array] Indices onto an array, often the output of `argsort()`.

Returns

rev_idx [array] Indices that, when applied to an array after `idx`, will return the original array (before the application of `idx`).

Other Parameters

axis [int] Axis along which to return indices, defaults to the last axis.

See also:

apply_index

Examples

```
>>> import numpy
>>> import spacepy.datamanager
>>> data = numpy.array([7, 2, 4, 6, 3])
>>> idx = numpy.argsort(data)
>>> data[idx] #sorted
array([2, 3, 4, 6, 7])
>>> data[idx][spacepy.datamanager.rev_index(idx)] #original
array([7, 2, 4, 6, 3])
```

spacepy.datamanager.**values_to_steps**(*array*, *axis=- 1*)

Transform values along an axis to their order in a unique sequence.

Useful in, e.g., converting a list of energies to their steps.

Parameters

array [array] Input data.

Returns

steps [array] An array, the same size as `array`, with values along `axis` corresponding to the position of the value in `array` in a unique, sorted, set of the values in `array` along that axis. Differs from `argsort()` in that identical values will have identical step numbers in the output.

Other Parameters

axis [int] Axis along which to find the steps.

Examples

```
>>> import numpy
>>> import spacepy.datamanager
>>> data = [[10., 12., 11., 9., 10., 12., 11., 9.],
            [10., 12., 11., 9., 14., 16., 15., 13.]]
>>> spacepy.datamanager.values_to_steps(data)
array([[1, 3, 2, 0, 1, 3, 2, 0],
       [1, 3, 2, 0, 5, 7, 6, 4]])
```

4.6 datamodel - easy to use general data model

The datamodel classes constitute a data model implementation meant to mirror the functionality of the data model output from pycdf, though implemented slightly differently.

This contains the following classes:

- *dmarray* - numpy arrays that support .attrs for information about the data
- *SpaceData* - base class that extends dict, to be extended by others

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4.6.1 About datamodel

The SpacePy datamodel module implements classes that are designed to make implementing a standard data model easy. The concepts are very similar to those used in standards like HDF5, netCDF and NASA CDF.

The basic container type is analogous to a folder (on a filesystem; HDF5 calls this a group): Here we implement this as a dictionary-like object, a datamodel.SpaceData object, which also carries attributes. These attributes can be considered to be global, i.e. relevant for the entire folder. The next container type is for storing data and is based on a numpy array, this class is datamodel.dmarray and also carries attributes. The dmarray class is analogous to an HDF5 dataset.

In fact, HDF5 can be loaded directly into a SpacePy datamodel, carrying across all attributes, using the function fromHDF5:

```
>>> import spacepy.datamodel as dm
>>> data = dm.fromHDF5('test.h5')
```

Functions are also available to directly load data and metadata into a SpacePy datamodel from NASA CDF as well as JSON-headed ASCII. Writers also exist to output a SpacePy datamodel directly to HDF5 or JSON-headed ASCII. See `datamodel.fromCDF()`, `datamodel.readJSONheadedASCII()`, `datamodel.toHDF5()`, and `datamodel.toJSONheadedASCII()` for more details.

4.6.2 Examples

Imagine representing some satellite data within the global attributes might be the mission name and the instrument PI, the variables might be the instrument counts [n-dimensional array], timestamps[1-dimensional array and an orbit number [scalar]. Each variable will have one attribute (for this example).

```
>>> import spacepy.datamodel as dm
>>> mydata = dm.SpaceData(attrs={'MissionName': 'BigSat1'})
>>> mydata['Counts'] = dm.dmarray([[42, 69, 77], [100, 200, 250]], attrs={'Units': 'cnts/
↪s'})
>>> mydata['Epoch'] = dm.dmarray([1, 2, 3], attrs={'units': 'minutes'})
>>> mydata['OrbitNumber'] = dm.dmarray(16, attrs={'StartsFrom': 1})
>>> mydata.attrs['PI'] 'Prof. Big Shot'
```

This has now populated a structure that can map directly to a NASA CDF, HDF5 or JSON-headed ASCII file. To visualize our datamodel, we can use tree method (which can be applied to any dictionary-like object using *dictree()*).

```
>>> mydata.tree(attrs=True)
```

```
+
:|____MissionName
:|____PI
|____Counts
     :|____Units
|____Epoch
     :|____units
|____OrbitNumber
     :|____StartsFrom
```

4.6.3 Guide for NASA CDF users

By definition, a NASA CDF only has a single 'layer'. That is, a CDF contains a series of records (stored variables of various types) and a set of attributes that are either global or local in scope. Thus to use SpacePy's datamodel to capture the functionality of CDF the two basic data types are all that is required, and the main constraint is that datamodel.SpaceData objects cannot be nested (more on this later, if conversion from a nested datamodel to a flat datamodel is required).

Opening a CDF and working directly with the contents can be easily done using the PyCDF module, however, if you wish to load the entire contents of a CDF directly into a datamodel (complete with attributes) the following will make life easier:

```
>>> import spacepy.datamodel as dm
>>> data = dm.fromCDF('inFile.cdf')
```

4.6.4 A quick guide to JSON-headed ASCII

In many cases it is preferred to have a human-readable ASCII file, rather than a binary file like CDF or HDF5. To make it easier to carry all the same metadata that is available in HDF5 or CDF we have developed an ASCII data storage format that encodes the metadata using JSON (JavaScript Object Notation). This notation supports two basic datatypes: key/value collections (like a SpaceData) and ordered lists (which can represent arrays). JSON is human-readable, but if large arrays are stored in metadata is quickly becomes difficult to read. For this reason we use JSON to encode the metadata (usually smaller datasets) and store the data in a standard flat-ASCII format. The metadata is provided as a header that describes the contents of the file.

To use JSON for storing only metadata associated with the data to be written to an ASCII file a minimal metadata standard must be implemented. We use the following attribute names: DIMENSION and START_COLUMN. We also recommend using the NASA ISTP metadata standard to assign attribute names. The biggest limitation of flat ASCII is that sensibly formatting datasets of more than 2-dimensions (i.e. ranks greater than 2) is not possible. For this reason if you have datasets of rank 3 or greater then we recommend using HDF5. If text is absolutely required then it is possible to encode multi-dimensional arrays in the JSON metadata, but this is not recommended.

This format is best understood by illustration. The following example builds a toy SpacePy datamodel and writes it to a JSON-headed ASCII file. The contents of the file are then shown.

```
>>> import spacepy.datamodel as dm
>>> data = dm.SpaceData()
>>> data.attrs['Global'] = 'A global attribute'
>>> data['Var1'] = dm.dmarray([1,2,3,4,5], attrs={'Local1': 'A local attribute'})
>>> data['Var2'] = dm.dmarray([[8,9],[9,1],[3,4],[8,9],[7,8]])
>>> data['MVar'] = dm.dmarray([7.8], attrs={'Note': 'Metadata'})
>>> dm.toJSONheadedASCII('outFile.txt', data, depend0='Var1', order=['Var1'])
#Note that not all field names are required, those not given will be listed
#alphabetically after those that are specified
```

The file looks like:

```
#{
#    "MVar": {
#        "Note": "Metadata",
#        "VALUES": [7.8]
#    },
#    "Global": "A global attribute",
#    "Var1": {
#        "Local1": "A local attribute",
#        "DIMENSION": [1],
#        "START_COLUMN": 0
#    },
#    "Var2": {
#        "DIMENSION": [2],
#        "START_COLUMN": 2
#    }
#}
1 8 9
2 9 1
3 3 4
4 8 9
5 7 8
```

Classes

SpaceData(*args, **kwargs)	Datamodel class extending dict by adding attributes.
dmarray(input_array[, attrs, dtype])	Container for data within a SpaceData object
DMWarning	Warnings class for datamodel, subclassed so it can be set to always

4.6.5 spacepy.datamodel.SpaceData

class spacepy.datamodel.**SpaceData**(**args*, ***kwargs*)

Datamodel class extending dict by adding attributes.

flatten()	Method to collapse datamodel to one level deep
tree(**kwargs)	Print the contents of the SpaceData object in a visual tree

flatten()

Method to collapse datamodel to one level deep

Examples

```
>>> import spacepy.datamodel as dm
>>> import spacepy.toolbox as tb
>>> a = dm.SpaceData()
>>> a['1'] = dm.SpaceData(dog = 5, pig = dm.SpaceData(fish=dm.SpaceData(a='carp
↪', b='perch')))
>>> a['4'] = dm.SpaceData(cat = 'kitty')
>>> a['5'] = 4
>>> a.tree()
+
|____1
     |____dog
     |____pig
          |____fish
               |____a
               |____b
|____4
     |____cat
|____5
```

```
>>> b = dm.flatten(a)
>>> b.tree()
+
|____1<--dog
|____1<--pig<--fish<--a
|____1<--pig<--fish<--b
|____4<--cat
|____5
```

```
>>> a.flatten()
>>> a.tree()
+
|____1<--dog
|____1<--pig<--fish<--a
|____1<--pig<--fish<--b
|____4<--cat
|____5
```

tree(***kwargs*)

Print the contents of the SpaceData object in a visual tree

Other Parameters

verbose [boolean (optional)] print more info

spaces [string (optional)] string will added for every line

levels [integer (optional)] number of levels to recurse through (True means all)

attrs [boolean (optional)] display information for attributes

See also:

toolbox.dictree

Examples

```
>>> import spacepy.datamodel as dm
>>> import spacepy.toolbox as tb
>>> a = dm.SpaceData()
>>> a['1'] = dm.SpaceData(dog = 5)
>>> a['4'] = dm.SpaceData(cat = 'kitty')
>>> a['5'] = 4
>>> a.tree()
+
|____1
     |____dog
|____4
     |____cat
|____5
```

4.6.6 spacepy.datamodel.dmarray

class spacepy.datamodel.**dmarray**(*input_array*, *attrs=None*, *dtype=None*)

Container for data within a SpaceData object

Raises

NameError raised is the request name was not added to the allowed attributes list

Examples

```
>>> import spacepy.datamodel as datamodel
>>> position = datamodel.dmarray([1,2,3], attrs={'coord_system':'GSM'})
>>> position
dmarray([1, 2, 3])
>>> position.attrs
{'coord_system': 'GSM'}a
```

The dmarray, like a numpy ndarray, is versatile and can store any datatype; dmarrays are not just for arrays.

```
>>> name = datamodel.dmarray('TestName')
dmarray('TestName')
```

To extract the string (or scalar quantity), use the tolist method

```
>>> name.tolist()
'TestName'
```

addAttribute(name[, value])	Method to add an attribute to a dmarray equivalent to a = datamodel.dmarray([1,2,3]) a.Allowed_Attributes = a.Allowed_Attributes + ['blabla']

addAttribute(*name*, *value=None*)
Method to add an attribute to a dmarray equivalent to a = datamodel.dmarray([1,2,3]) a.Allowed_Attributes = a.Allowed_Attributes + ['blabla']

4.6.7 spacepy.datamodel.DMWarning

class spacepy.datamodel.**DMWarning**
Warnings class for datamodel, subclassed so it can be set to always

Functions

convertKeysToStr(SDobject)	
createISTPattrs(datatype[, ndims, vartype, ...])	Return set of unpopulated attributes for ISTP compliant variable
dmcopy(dobj)	Generic copy utility to return a copy of a (datamodel) object
dmfilled(shape[, fillval, dtype, order, attrs])	Return a new dmarray of given shape and type, filled with a specified value (default=0).
flatten(dobj)	Collapse datamodel to one level deep
fromCDF(fname, **kwargs)	Create a SpacePy datamodel representation of a NASA CDF file
fromHDF5(fname, **kwargs)	Create a SpacePy datamodel representation of an HDF5 file or netCDF4 file which is HDF5 compliant

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fromRecArray(recarr)	Takes a numpy recarray and returns each field as a dmarray in a SpaceData container
toCDF(fname, SDobject, **kwargs)	Create a CDF file from a SpacePy datamodel representation
toHDF5(fname, SDobject, **kwargs)	Create an HDF5 file from a SpacePy datamodel representation
toHTML(fname, SDobject[, attrs, varLinks, ...])	Create an HTML dump of the structure of a spacedata
toJSONheadedASCII(fname, insd[, metadata, ...])	Write JSON-headed ASCII file of data with metadata from SpaceData object
toRecArray(sdo)	Takes a SpaceData and creates a numpy recarray
unflatten(dobj[, marker])	Collapse datamodel to one level deep
readJSONMetadata(fname, **kwargs)	Read JSON metadata from an ASCII data file
readJSONheadedASCII(fname[, mdata, comment, ...])	read JSON-headed ASCII data files into a SpacePy datamodel
resample(data[, time, winsize, overlap, ...])	resample a SpaceData to a new time interval
writeJSONMetadata(fname, insd[, depend0, ...])	Scrape metadata from SpaceData object and make a JSON header

4.6.8 spacepy.datamodel.convertKeysToStr

spacepy.datamodel.**convertKeysToStr**(*SDobject*)

4.6.9 spacepy.datamodel.createISTPattrs

spacepy.datamodel.**createISTPattrs**(*datatype*, *ndims=1*, *vartype=None*, *units=' '*, *NRV=False*)

Return set of unpopulated attributes for ISTP compliant variable

Parameters

datatype [{'data', 'support_data', 'metadata'}] datatype of variable to create metadata for.

ndims [int] number of dimensions, default=1

vartype [{'float', 'char', 'int', 'epoch', 'tt2000'}] The type of the variable, default=float

units [str] The units of the variable, default=' '

NRV [bool] Is the variable NRV (non-record varying), default=False

Returns

attrs [dict] dictionary of attributes for the variable

Examples

```
>>> import spacepy.datamodel as dm
>>> dm.createISTPattrs('data', ndims=2, vartype='float', units='MeV')
{'CATDESC': '',
 'DISPLAY_TYPE': 'spectrogram',
 'FIELDNAM': '',
 'FILLVAL': -1e+31,
 'FORMAT': 'F18.6',
 'LABLAXIS': '',
```

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```
 'SI_CONVERSION': ' > ',
 'UNITS': 'MeV',
 'VALIDMIN': '',
 'VALIDMAX': '',
 'VAR_TYPE': 'data',
 'DEPEND_0': 'Epoch',
 'DEPEND_1': ''}
```

4.6.10 spacepy.datamodel.dmcopy

spacepy.datamodel.**dmcopy**(*dobj*)

Generic copy utility to return a copy of a (datamodel) object

Parameters

dobj [object] object to return a copy of

Returns

copy_obj: object (same type as input) copy of input oibject

Examples

```
>>> import spacepy.datamodel as dm
>>> dat = dm.dmarray([2,3], attrs={'units': 'T'})
>>> dat1 = dm.dmcopy(dat)
>>> dat1.attrs['copy': True]
>>> dat is dat1
False
>>> dat1.attrs
{'copy': True, 'units': 'T'}
>>> dat.attrs
{'units': 'T'}
```

4.6.11 spacepy.datamodel.dmfilled

spacepy.datamodel.**dmfilled**(*shape*, *fillval=0*, *dtype=None*, *order='C'*, *attrs=None*)

Return a new dmarray of given shape and type, filled with a specified value (default=0).

See also:

numpy.ones

Examples

```
>>> import spacepy.datamodel as dm
>>> dm.dmfilled(5, attrs={'units': 'nT'})
dmarray([ 0.,  0.,  0.,  0.,  0.])
```

```
>>> dm.dmfilled((5,), fillval=1, dtype=np.int)
dmarray([1, 1, 1, 1, 1])
```

```
>>> dm.dmfilled((2, 1), fillval=np.nan)
dmarray([[ nan],
       [ nan]])
```

```
>>> a = dm.dmfilled((2, 1), np.nan, attrs={'units': 'nT'})
>>> a
dmarray([[ nan],
       [ nan]])
>>> a.attrs
{'units': 'nT'}
```

4.6.12 spacepy.datamodel.flatten

spacepy.datamodel.**flatten**(*dobj*)

Collapse datamodel to one level deep

See also:

unflatten

SpaceData.flatten

Examples

```
>>> import spacepy.datamodel as dm
>>> import spacepy.toolbox as tb
>>> a = dm.SpaceData()
>>> a['1'] = dm.SpaceData(dog = 5, pig = dm.SpaceData(fish=dm.SpaceData(a='carp', b=
↪'perch')))
>>> a['4'] = dm.SpaceData(cat = 'kitty')
>>> a['5'] = 4
>>> a.tree()
+
|____1
     |____dog
     |____pig
          |____fish
               |____a
               |____b
|____4
     |____cat
|____5
```

```
>>> b = dm.flatten(a)
>>> b.tree()
+
|____1<--dog
|____1<--pig<--fish<--a
|____1<--pig<--fish<--b
|____4<--cat
|____5
```

```
>>> a.flatten()
>>> a.tree()
+
|____1<--dog
|____1<--pig<--fish<--a
|____1<--pig<--fish<--b
|____4<--cat
|____5
```

4.6.13 spacepy.datamodel.fromCDF

spacepy.datamodel.**fromCDF**(*fname*, ***kwargs*)

Create a SpacePy datamodel representation of a NASA CDF file

Parameters

file [string] the name of the cdf file to be loaded into a datamodel

Returns

out [spacepy.datamodel.SpaceData] SpaceData with associated attributes and variables in dmarrays

See also:

spacepy.pycdf.CDF.copy

Examples

```
>>> import spacepy.datamodel as dm
>>> data = dm.fromCDF('test.cdf')
```

4.6.14 spacepy.datamodel.fromHDF5

spacepy.datamodel.**fromHDF5**(*fname*, ***kwargs*)

Create a SpacePy datamodel representation of an HDF5 file or netCDF4 file which is HDF5 compliant

Parameters

file [string] the name of the HDF5/netCDF4 file to be loaded into a datamodel

Returns

out [spacepy.datamodel.SpaceData] SpaceData with associated attributes and variables in dmarrays

Notes

Zero-sized datasets will break in h5py. This is kluged by returning a dmarray containing a None.

This function is expected to work with any HDF5-compliant files, including netCDF4 (not netCDF3) and MatLab save files from v7.3 or later, but some datatypes are not supported, e.g., non-string vlen datatypes, and will raise a warning.

Examples

```
>>> import spacepy.datamodel as dm
>>> data = dm.fromHDF5('test.hdf')
```

4.6.15 spacepy.datamodel.fromRecArray

spacepy.datamodel.**fromRecArray**(*recarr*)

Takes a numpy recarray and returns each field as a dmarray in a SpaceData container

Parameters

recarr [numpy record array] object to parse into SpaceData container

Returns

sd: spacepy.datamodel.SpaceData dict-like containing arrays of named records in recarr

Examples

```
>>> import numpy as np
>>> import spacepy.datamodel as dm
>>> x = np.array([(1.0, 2), (3.0, 4)], dtype=[('x', float), ('y', int)])
>>> print(x, x.dtype)
array([(1.0, 2), (3.0, 4)], dtype=[('x', '<f8'), ('y', '<i4')])
>>> sd = dm.fromRecArray(x)
>>> sd.tree(verbose=1)
+
|____x (spacepy.datamodel.dmarray (2,))
|____y (spacepy.datamodel.dmarray (2,))
```

4.6.16 spacepy.datamodel.toCDF

spacepy.datamodel.**toCDF**(*fname*, *SDobject*, ***kwargs*)

Create a CDF file from a SpacePy datamodel representation

Parameters

fname [str] Filename to write to

SDobject [spacepy.datamodel.SpaceData] SpaceData with associated attributes and variables in dmarrays

Returns

None

Other Parameters

skeleton [str (optional)] create new CDF from a skeleton file (default '')

flatten [bool (optional)] flatten incoming datamodel - if SpaceData objects are nested (default False)

overwrite [bool (optional)] allow overwrite of an existing target file (default False)

autoNRV [bool (optional)] attempt automatic identification of non-record varying entries in CDF

backward [bool (optional)] create CDF in backward-compatible format (default is v3+ compatibility only)

TT2000 [bool (optional)] write variables beginning with 'Epoch' as datatype CDF_TT2000 (default is automatic selection of EPOCH or EPOCH16)

verbose [bool (optional)] verbosity flag

4.6.17 spacepy.datamodel.toHDF5

spacepy.datamodel.**toHDF5**(*fname*, *SDobject*, ***kwargs*)

Create an HDF5 file from a SpacePy datamodel representation

Parameters

fname [str] Filename to write to

SDobject [spacepy.datamodel.SpaceData] SpaceData with associated attributes and variables in dmarrays

Returns

None

Other Parameters

overwrite [bool (optional)] allow overwrite of an existing target file (default True)

mode [str (optional)] HDF5 file open mode (a, w, r) (default 'a')

compression [str (optional)] compress all the variables using this method (default None) (gzip, shuffle, fletcher32, szip, lzf)

compression_opts [str (optional)] options to the compression, see h5py documentation for more details

Examples

```
>>> import spacepy.datamodel as dm
>>> a = dm.SpaceData()
>>> a['data'] = dm.dmarray(range(100000), dtype=float)
>>> dm.toHDF5('test_gzip.h5', a, overwrite=True, compression='gzip')
>>> dm.toHDF5('test.h5', a, overwrite=True)
>>> # test_gzip.h5 was 118k, test.h5 was 785k
```

4.6.18 spacepy.datamodel.toHTML

spacepy.datamodel.**toHTML**(*fname*, *SDobject*, *attrs=()*, *varLinks=False*, *linkFormat=None*, *echo=False*, *tableTag='<table border="1">'*)

Create an HTML dump of the structure of a spacedata

Parameters

fname [str] Filename to write to

SDobject [spacepy.datamodel.SpaceData] SpaceData with associated attributes and variables in dmarrays

Other Parameters

overwrite [bool (optional)] allow overwrite of an existing target file (default True)

mode [str (optional)] HDF5 file open mode (a, w, r) (default 'a')

echo [bool] echo the html to the screen

varLinks [bool] make the variable name a link to a stub page

4.6.19 spacepy.datamodel.toJSONheadedASCII

spacepy.datamodel.**toJSONheadedASCII**(*fname*, *insd*, *metadata=None*, *depend0=None*, *order=None*, ***kwargs*)

Write JSON-headed ASCII file of data with metadata from SpaceData object

Parameters

fname [str] Filename to write to (can also use a file-like object) None can be given in conjunction with the returnString keyword to skip writing output

insd [spacepy.datamodel.SpaceData] SpaceData with associated attributes and variables in dmarrays

Returns

None

Other Parameters

depend0 [str (optional)] variable name to use to indicate parameter on which other data depend (e.g. Time)

order [list (optional)] list of key names in order of start column in output JSON file

metadata: str or file-like (optional) filename with JSON header to use (or file-like with JSON metadata)

delimiter: str delimiter to use in ASCII output (default is whitespace), for tab, use ' '

Examples

```
>>> import spacepy.datamodel as dm
>>> data = dm.SpaceData()
>>> data.attrs['Global'] = 'A global attribute'
>>> data['Var1'] = dm.dmarray([1,2,3,4,5], attrs={'Local1': 'A local attribute'})
>>> data['Var2'] = dm.dmarray([[8,9],[9,1],[3,4],[8,9],[7,8]])
>>> data['MVar'] = dm.dmarray([7.8], attrs={'Note': 'Metadata'})
>>> dm.toJSONheadedASCII('outFile.txt', data, depend0='Var1', order=['Var1'])
#Note that not all field names are required, those not given will be listed
#alphabetically after those that are specified
```

4.6.20 spacepy.datamodel.toRecArray

spacepy.datamodel.**toRecArray**(*sdo*)

Takes a SpaceData and creates a numpy recarray

Parameters

sdo [SpaceData] SpaceData to change to a numpy recarray

Returns

recarr: numpy record array numpy.recarray object with the same values (attributes are lost)

Examples

```
>>> import numpy as np
>>> import spacepy.datamodel as dm
>>> sd = dm.SpaceData()
>>> sd['x'] = dm.dmarray([1.0, 2.0])
>>> sd['y'] = dm.dmarray([2,4])
>>> sd.tree(verbose=1)
+
|____x (spacepy.datamodel.dmarray (2,))
|____y (spacepy.datamodel.dmarray (2,))
>>> ra = dm.toRecArray(sd)
>>> print(ra, ra.dtype)
[(2, 1.0) (4, 2.0)] (numpy.record, [('y', '<i8'), ('x', '<f8')])
```

4.6.21 spacepy.datamodel.unflatten

spacepy.datamodel.**unflatten**(*dobj*, *marker='<--'*)

Collapse datamodel to one level deep

Examples

```
>>> import spacepy.datamodel as dm
>>> import spacepy.toolbox as tb
>>> a = dm.SpaceData()
>>> a['1'] = dm.SpaceData(dog = 5, pig = dm.SpaceData(fish=dm.SpaceData(a='carp', b=
↪'perch')))
>>> a['4'] = dm.SpaceData(cat = 'kitty')
>>> a['5'] = 4
>>> a.tree()
+
|____1
     |____dog
     |____pig
          |____fish
               |____a
               |____b
|____4
     |____cat
|____5
```

```
>>> b = dm.flatten(a)
>>> b.tree()
+
|____1<--dog
|____1<--pig<--fish<--a
|____1<--pig<--fish<--b
|____4<--cat
|____5
```

```
>>> c = dm.unflatten(b)
>>> c.tree()
+
|____1
     |____dog
     |____pig
          |____fish
               |____a
               |____b
|____4
     |____cat
|____5
```

4.6.22 spacepy.datamodel.readJSONMetadata

spacepy.datamodel.**readJSONMetadata**(*fname*, ***kwargs*)
Read JSON metadata from an ASCII data file

Parameters

fname [str] Filename to read metadata from

Returns

mdata: spacepy.datamodel.SpaceData SpaceData with the metadata from the file

Other Parameters

verbose [bool (optional)] set verbose output so metadata tree prints on read (default False)

4.6.23 spacepy.datamodel.readJSONheadedASCII

spacepy.datamodel.**readJSONheadedASCII**(*fname*, *mdata=None*, *comment='#'*, *convert=False*, *restrict=None*)
read JSON-headed ASCII data files into a SpacePy datamodel

Parameters

fname [str or list] Filename(s) to read data from

Returns

mdata: spacepy.datamodel.SpaceData SpaceData with the data and metadata from the file

Other Parameters

mdata [spacepy.datamodel.SpaceData (optional)] supply metadata object, otherwise is read from fname (default None)

comment: str (optional) comment string in file to be read; lines starting with comment are ignored (default '#')

convert: bool or dict-like (optional) If True, uses common names to try conversion from string. If a dict- like then uses the functions specified as the dict values to convert each element of 'key' to a non-string

restrict: list of strings (optional) If present, restrict the variables stored to only those on this list

4.6.24 spacepy.datamodel.resample

spacepy.datamodel.**resample**(*data*, *time=[]*, *winsize=0*, *overlap=0*, *st_time=None*, *outtimename='Epoch'*)
resample a SpaceData to a new time interval

Parameters

data [SpaceData or dmarray] SpaceData with data to resample or dmarray with data to resample, variables can only be 1d or 2d, if time is specified only variables the same length as time are resampled, otherwise only variables with length equal to the longest length are resampled

time [array-like] dmarray of times the correspond to the data

winsize [datetime.timedelta] Time frame to average the data over

overlap [datetime.timedelta] Overlap in the moving average

st_time [datetime.datetime] Starting time for the resample, if not specified the time of the first data point is used (see spacepy.toolbox.windowMean)

Returns

ans [SpaceData] Resampled data, included keys are in the input keys (with the data caveats above) and Epoch which contains the output time

Examples

```
>>> import datetime
>>> import spacepy.datamodel as dm
>>> a = dm.SpaceData()
>>> a.attrs['foo'] = 'bar'
>>> a['a'] = dm.dmarray(range(10*2)).reshape(10,2)
>>> a['b'] = dm.dmarray(range(10)) + 4
>>> a['c'] = dm.dmarray(range(3)) + 10
>>> times = [datetime.datetime(2010, 1, 1) + datetime.timedelta(hours=i) for i in␣
↪range(10)]
>>> out = dm.resample(a, times, winsize=datetime.timedelta(hours=2),␣
↪overlap=datetime.timedelta(hours=0))
>>> out.tree(verbose=1, attrs=1)
# +
# :|____foo (str [3])
# |____Epoch (spacepy.datamodel.dmarray (4,))
# |____a (spacepy.datamodel.dmarray (4, 2))
# :|____DEPEND_0 (str [5])
#
# Things to note:
#    - attributes are preserved
#    - the output variables have their DEPEND_0 changed to Epoch (or outtimename)
#    - each dimension of a 2d array is resampled individually
```

4.6.25 spacepy.datamodel.writeJSONMetadata

spacepy.datamodel.**writeJSONMetadata**(*fname*, *insd*, *depend0=None*, *order=None*, *verbose=False*, *returnString=False*)

Scrape metadata from SpaceData object and make a JSON header

Parameters

fname [str] Filename to write to (can also use a file-like object) None can be given in conjunction with the returnString keyword to skip writing output

insd [spacepy.datamodel.SpaceData] SpaceData with associated attributes and variables in dmarrays

Returns

None (unless returnString keyword is True)

Other Parameters

depend0 [str (optional)] variable name to use to indicate parameter on which other data depend (e.g. Time)

order [list (optional)] list of key names in order of start column in output JSON file

verbose: bool (optional) verbose output

returnString: bool (optional) return JSON header as string instead of returning None

4.7 data assimilation - data assimilation module

Classes

ensemble([ensembles])	Ensemble-based data assimilation subroutines for the Radiation Belt Model

4.7.1 spacepy.data_assimilation.ensemble

class spacepy.data_assimilation.**ensemble**(*ensembles=50*)

Ensemble-based data assimilation subroutines for the Radiation Belt Model

EnKF(A, Psi, Inn, HAp)	analysis subroutine after code example in Evensen 2003 this will take the prepared matrices and calculate the analysis most efficiently, A will be returned
EnKF_oneobs(A, Psi, Inn, HAp)	analysis subroutine for a single observations with the EnKF.
add_model_error(model, A, PSDdata)	this routine will add a standard error to the ensemble states
add_model_error_obs(model, A, Lobs, y)	this routine will add a standard error to the ensemble states
getHA(model, Lobs, A)	compute HA provided L vector of observations and ensemble matrix A
getHAprime(HA)	calculate ensemble perturbation of HA HA' = HA-HA_mean
getHPH(Lobs, Pfxx)	compute HPH
getInnovation(y, Psi, HA)	compute innovation ensemble D'
getperturb(model, y)	compute perturbations of observational vector

EnKF(*A*, *Psi*, *Inn*, *HAp*)

analysis subroutine after code example in Evensen 2003 this will take the prepared matrices and calculate the analysis most efficiently, A will be returned

Parameters

A

Psi

Inn

HAp

Returns

out []

EnKF_oneobs(*A*, *Psi*, *Inn*, *HAp*)
analysis subroutine for a single observations with the EnKF. This is a special case.

Parameters

A

Psi

Inn

HAp

Returns

out []

add_model_error(*model*, *A*, *PSDdata*)
this routine will add a standard error to the ensemble states

Parameters

model

A

PSDdata

Returns

out []

add_model_error_obs(*model*, *A*, *Lobs*, *y*)
this routine will add a standard error to the ensemble states

Parameters

model

A

Lobs

y

Returns

out []

getHA(*model*, *Lobs*, *A*)
compute HA provided L vector of observations and ensemble matrix A

Parameters

model

Lobs

A

Returns

out []

getHAprime(*HA*)
calculate ensemble perturbation of HA HA' = HA-HA_mean

Parameters

HA

Returns

out []

`getHPH`(*Lobs*, *Pfxx*)
compute HPH

Parameters

Lobs

Pfxx

Returns

out

`getInnovation`(*y*, *Psi*, *HA*)
compute innovation ensemble D'

Parameters

y

Psi

HA

Returns

out []

`getperturb`(*model*, *y*)
compute perturbations of observational vector

Parameters

model

y

Returns

out []

Functions

average_window(PSDdata, Lgrid)	combine observations on same L shell in
getobs4window(dd, Tnow)	get observations in time window [Tnow - Twindow, Tnow] from all satellites lumped together into one y vector
output(init, result)	write results to file and be done
forecast(Tnow+Twindow)	
assimilate_JK(dd)	this version is currently not working main function to assimilate all data provided in init
addmodelerror_old2(dd, A, y, L)	this routine will add a standard error to the ensemble states
addmodelerror_old(dd, A, y, L)	this routine will add a standard error to the ensemble states

4.7.2 spacepy.data_assimilation.average_window

spacepy.data_assimilation.**average_window**(*PSDdata*, *Lgrid*)
combine observations on same L shell in

Parameters

model

PSDdata

HAp

Returns

out []

4.7.3 spacepy.data_assimilation.getobs4window

spacepy.data_assimilation.**getobs4window**(*dd*, *Tnow*)
get observations in time window [Tnow - Twindow, Tnow] from all satellites lumped together into one y vector

Parameters

model

PSDdata

HAp

Returns

out []

4.7.4 spacepy.data_assimilation.output

spacepy.data_assimilation.**output**(*init*, *result*)
write results to file and be done

Parameters

model

PSDdata

HAp

Returns

out []

4.7.5 spacepy.data_assimilation.forecast

spacepy.data_assimilation.**forecast**(*Tnow+Twindow*)

4.7.6 spacepy.data_assimilation.assimilate_JK

spacepy.data_assimilation.**assimilate_JK**(*dd*)

this version is currently not working main function to assimilate all data provided in init

Parameters

model

PSDdata

HAp

Returns

out []

4.7.7 spacepy.data_assimilation.addmodelerror_old2

spacepy.data_assimilation.**addmodelerror_old2**(*dd*, *A*, *y*, *L*)

this routine will add a standard error to the ensemble states

4.7.8 spacepy.data_assimilation.addmodelerror_old

spacepy.data_assimilation.**addmodelerror_old**(*dd*, *A*, *y*, *L*)

this routine will add a standard error to the ensemble states

4.8 empiricals - module with heliospheric empirical modules

Module with some useful empirical models (plasmapause, magnetopause, Lmax)

Authors: Steve Morley, Josef Koller Institution: Los Alamos National Laboratory Contact: smorley@lanl.gov

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getDststar(ticks[, model, dbase])	Calculate the pressure-corrected Dst index, Dst*
getExpectedSWTemp(velo[, model, units])	Return the expected solar wind temperature based on the bulk velocity
getLmax(ticks[, model, dbase])	calculate a simple empirical model for Lmax - last closed drift-shell
getMagnetopause(ticks[, LTs, dbase])	Calculates the Shue et al. (1997) position in equatorial plane.
getMPstandoff(ticks[, dbase, alpha])	Calculates the Shue et al. (1997) subsolar magnetopause radius.
getPlasmaPause(ticks[, model, LT, omnivals])	Plasmapause location model(s)
getSolarProtonSpectra([norm, gamma, E0, ...])	Returns a SpaceData with energy and fluence spectra of solar particle events

continues on next page

Table 24 – continued from previous page

getSolarRotation(ticks[, rtype, fp, reverse])	Calculates solar rotation number (Carrington or Bartels) for a given date/time
getVampolaOrder(L)	Empirical lookup of power for sin^n pitch angle model from Vampola (1996)
omniFromDirectionalFlux(fluxarr, alphas[, norm])	Calculate omnidirectional flux [(s cm^2 kev)^-1] from directional flux [(s sr cm^2 keV)^-1] array
vampolaPA(omniflux, **kwargs)	Pitch angle model of sin^n form

4.8.1 spacepy.empiricals.getDststar

spacepy.empiricals.**getDststar**(*ticks*, *model='OBrien'*, *dbase='QDhourly'*)

Calculate the pressure-corrected Dst index, Dst*

We need to add in the references to the models here!

Parameters

ticks [spacepy.time.Ticktock] TickTock object of desired times (will be interpolated from hourly OMNI data) OR dictionary including 'Pdyn' and 'Dst' keys where data are lists or arrays and Dst is in [nT], and Pdyn is in [nPa]

Returns

out [float] Dst* - the pressure corrected Dst index from OMNI [nT]

Examples

Coefficients are applied to the standard formulation e.g. Burton et al., 1975 of Dst* = Dst - b*sqrt(Pdyn) + c The default is the O'Brien and McPherron model (2002). Other options are Burton et al. (1975) and Borovsky and Denton (2010)

```
>>> import spacepy.time as spt
>>> import spacepy.omni as om
>>> import spacepy.empiricals as emp
>>> ticks = spt.tickrange('2000-10-16T00:00:00', '2000-10-31T12:00:00', 1/24.)
>>> dststar = emp.getDststar(ticks)
>>> dststar[0]
-21.317220132108943
```

User-determined coefficients can also be supplied as a two-element list or tuple of the form (b,c), e.g.

```
>>> dststar = emp.getDststar(ticks, model=(2,11)) #b is extreme driving from O'Brien
```

We have chosen the OBrien model as the default here as this was rigorously determined from a very long data set and is pertinent to most conditions. It is, however, the most conservative correction. Additionally, Siscoe, McPherron and Jordanova (2005) argue that the pressure contribution to Dst diminishes during magnetic storms.

To show the relative differences, run the following example:

```
>>> import matplotlib.pyplot as plt
>>> params = [('Burton','k-'), ('OBrien','r-'), ('Borovsky','b-')]
>>> for model, col in params:
        dststar = getDststar(ticks, model=model)
        plt.plot(ticks.UTC, dststar, col)
```

4.8.2 spacepy.empiricals.getExpectedSWTemp

spacepy.empiricals.**getExpectedSWTemp**(*velo*, *model='XB15'*, *units='K'*)

Return the expected solar wind temperature based on the bulk velocity

The formulations used by this function are those given by, L87 – Lopez, R.E., J. Geophys. Res., 92, 11189-11194, 1987 BS06 – Borovsky, J.E. and J.T. Steinberg, Geophysical Monograph Series 167, 59-76, 2006 XB15 – Xu, F. and J.E. Borovsky, J. Geophys. Res., 120, 70-100, 2015

Parameters

velo [array-like] Array like of solar wind bulk velocity values [km/s]

model [str [optional]] Name of model to use. Valid choices are L87, BS06 and XB15. Default is XB15

units [str [optional]] Units for output temperature, options are eV or K. Default is Kelvin [K]

Returns

Texp [array-like] The expected solar wind temperature given the bulk velocity [K] or [eV]

4.8.3 spacepy.empiricals.getLmax

spacepy.empiricals.**getLmax**(*ticks*, *model='JKemp'*, *dbase='QDhourly'*)

calculate a simple empirical model for Lmax - last closed drift-shell

Uses the parametrized Lmax from: Koller and Morley (2010) 'Magnetopause shadowing effects for radiation belt models during high-speed solar wind streams' American Geophysical Union, Fall Meeting 2010, abstract #SM13A-1787

Parameters

ticks [spacepy.time.Ticktock] Ticktock object of desired times

model [string, optional] 'JKemp' (default - empirical model of J. Koller)

Returns

out [np.ndarray] Lmax - L* of last closed drift shell

Examples

```
>>> from spacepy.empiricals import getLmax
>>> import spacepy.time as st
>>> import datetime
>>> ticks = st.tickrange(datetime.datetime(2000, 1, 1), datetime.datetime(2000, 1,␣
↪3), deltadays=1)
array([ 7.4928412,  8.3585632,  8.6463423])
```

4.8.4 spacepy.empiricals.getMagnetopause

spacepy.empiricals.**getMagnetopause**(*ticks*, *LTs=None*, *dbase='QDhourly'*)

Calculates the Shue et al. (1997) position in equatorial plane

Shue et al. (1997), A new functional form to study the solar wind control of the magnetopause size and shape, J. Geophys. Res., 102(A5), 9497–9511, doi:10.1029/97JA00196.

Parameters

ticks [spacepy.time.Ticktock] TickTock object of desired times (will be interpolated from hourly OMNI data) OR dictionary of form {'P': [], 'Bz': []} Where P is SW ram pressure [nPa] and Bz is IMF Bz (GSM) [nT]

LTs [array-like] Array-like of local times for evaluating the magnetopause model. Default is 6 LT to 18 LT in steps of 20 minutes.

Returns

out [array] NxMx2 array of magnetopause positions [Re] N is number of timesteps, M is number of local times. The 2 positions are the X_GSE and Y_GSE positions of the magnetopause

Examples

```
>>> import spacepy.time as spt
>>> import spacepy.empiricals as emp
>>> ticks = spt.Ticktock(['2002-01-01T12:00:00','2002-01-04T00:00:00'])
>>> localtimes = [13,12,11]
>>> emp.getMagnetopause(ticks, LTs=localtimes)
array([[[ 10.27674331,  -2.75364507],
    [ 10.52909163,   0.        ],
    [ 10.27674331,   2.75364507]],
   [[ 10.91791834,  -2.9254474 ],
    [ 11.18712131,   0.        ],
    [ 10.91791834,   2.9254474 ]]])
>>> emp.getMPstandoff(ticks) #should give same result as getMagnetopause for 12LT
array([ 10.52909163,  11.18712131])
```

To plot the magnetopause: >>> import numpy as np >>> import spacepy.plot as splot >>> import matplotlib.pyplot as plt >>> localtimes = np.arange(5, 19.1, 0.5) >>> mp_pos = emp.getMagnetopause(ticks, localtimes) >>> plt.plot(mp_pos[0,:,0], mp_pos[0,:,1]) >>> ax1 = plt.gca() >>> ax1.set_xlim([-5,20]) >>> ax1.set_xlabel('X$_{GSE}$ [R$_E$]') >>> ax1.set_ylabel('Y$_{GSE}$ [R$_E$]') >>> splot.dual_half_circle(ax=ax1) >>> ax1.axes.set_aspect('equal')

4.8.5 spacepy.empiricals.getMPstandoff

spacepy.empiricals.**getMPstandoff**(*ticks*, *dbase='QDhourly'*, *alpha=[]*)

Calculates the Shue et al. (1997) subsolar magnetopause radius

Shue et al. (1997), A new functional form to study the solar wind control of the magnetopause size and shape, J. Geophys. Res., 102(A5), 9497–9511, doi:10.1029/97JA00196.

Parameters

ticks [spacepy.time.Ticktock] TickTock object of desired times (will be interpolated from hourly OMNI data) OR dictionary of form {'P': [], 'Bz': []} Where P is SW ram pressure [nPa] and Bz is IMF Bz (GSM) [nT]

alpha [list] Used as an optional return value to obtain the flaring angles. To use, assign an empty list and pass to this function through the keyword argument. The list will be modified in place, adding the flaring angles for each time step.

Returns

out [float] Magnetopause (sub-solar point) standoff distance [Re]

Examples

```
>>> import spacepy.time as spt
>>> import spacepy.empiricals as emp
>>> ticks = spt.tickrange('2002-01-01T12:00:00','2002-01-04T00:00:00',.25)
>>> emp.getMPstandoff(ticks)
array([ 10.57319537,  10.91327764,  10.75086873,  10.77577207,
     9.78180261,  11.0374474 ,  11.4065    ,  11.27555451,
    11.47988573,  11.8202582 ,  11.23834814])
>>> data = {'P': [2,4], 'Bz': [-2.4, -2.4]}
>>> emp.getMPstandoff(data)
array([ 9.96096838,  8.96790412])
```

4.8.6 spacepy.empiricals.getPlasmaPause

spacepy.empiricals.**getPlasmaPause**(*ticks*, *model='M2002'*, *LT='all'*, *omnivals=None*)

Plasmapause location model(s)

CA1992 – Carpenter, D. L., and R. R. Anderson, An ISEE/whistler model of equatorial electron density in the magnetosphere, J. Geophys. Res., 97, 1097, 1992. M2002 – Moldwin, M. B., L. Downward, H. K. Rassoul, R. Amin, and R. R. Anderson, A new model of the location of the plasmapause: CRRES results, J. Geophys. Res., 107(A11), 1339, doi:10.1029/2001JA009211, 2002. RT1970 – Rycroft, M. J., and J. O. Thomas, The magnetospheric plasmapause and the electron density trough at the alouette i orbit, Planetary and Space Science, 18(1), 65-80, 1970

Parameters

ticks [spacepy.time.Ticktock] TickTock object of desired times

Lpp_model [string, optional] 'CA1992' or 'M2002' (default) CA1992 returns the Carpenter and Anderson model, M2002 returns the Moldwin et al. model

LT [int, float] requested local time sector, 'all' is valid option

omnivals [spacepy.datamodel.SpaceData, dict] dict-like containing UTC (datetimes) and Kp keys

Returns

out [float] Plasmapause radius in Earth radii

Warns

RuntimeWarning If the CA1992 model is called with LT as it is not implemented

Examples

```
>>> import spacepy.time as spt
>>> import spacepy.empiricals as emp
>>> ticks = spt.tickrange('2002-01-01T12:00:00','2002-01-04T00:00:00',.25)
>>> emp.getPlasmaPause(ticks)
array([ 6.42140002,  6.42140002,  6.42140002,  6.42140002,  6.42140002,
    6.42140002,  6.42140002,  6.26859998,  5.772     ,  5.6574    ,
    5.6574    ])
```

4.8.7 spacepy.empiricals.getSolarProtonSpectra

spacepy.empiricals.**getSolarProtonSpectra**(*norm=32000000.0*, *gamma=- 0.96*, *E0=15.0*, *Emin=0.1*, *Emax=600*, *nsteps=100*)

Returns a SpaceData with energy and fluence spectra of solar particle events

The formulation follows that of: Ellison and Ramaty ApJ 298: 400-408, 1985 dJ/dE = K^{-gamma}exp(-E/E0)

and the defualt values are the 10/16/2003 SEP event of: Mewaldt, R. A., et al. (2005), J. Geophys. Res., 110, A09S18, doi:10.1029/2005JA011038.

Returns

data [dm.SpaceData] SpaceData with the energy and fluence values

Other Parameters

norm [float] Normilization factor for the intensity of the SEP event

gamma [float] Power law index

E0 [float] Expoential scaling factor

Emin [float] Minimum energy for fit

Emax [float] Maximum energy for fit

nsteps [int] The number of log spaced energy steps to return

4.8.8 spacepy.empiricals.getSolarRotation

spacepy.empiricals.**getSolarRotation**(*ticks*, *rtype='carrington'*, *fp=False*, *reverse=False*)

Calculates solar rotation number (Carrington or Bartels) for a given date/time

Parameters

ticks [spacepy.time.Ticktock or datetime.datetime]

Returns

rnumber [integer or array] Carrington (or Bartels) rotation number

4.8.9 spacepy.empiricals.getVampolaOrder

spacepy.empiricals.**getVampolaOrder**(*L*)

Empirical lookup of power for sin^n pitch angle model from Vampola (1996)

Vampola, A.L. Outer zone energetic electron environment update, Final Report of ESA/ESTEC/WMA/P.O. 151351, ESA-ESTEC, Noordwijk, The Netherlands, 1996.

Parameters

L [arraylike or float]

Returns

order [array] coefficient for sin^n model corresponding to McIlwain L (computed for OP77?)

Examples

Apply Vampola pitch angle model at L=[4, 6.6]

```
>>> from spacepy.empiricals import vampolaPA, getVampolaOrder
>>> order = getVampolaOrder([4,6.6])
>>> order
array([ 3.095 ,  1.6402])
>>> vampolaPA([3000, 3000], alpha=[45, 90], order=order)
(array([[ 140.08798878,  192.33572182],
    [ 409.49143136,  339.57417256]]), [45, 90])
```

4.8.10 spacepy.empiricals.omniFromDirectionalFlux

spacepy.empiricals.**omniFromDirectionalFlux**(*fluxarr*, *alphas*, *norm=True*)

Calculate omnidirectional flux [(s cm^2 kev)^-1] from directional flux [(s sr cm^2 keV)^-1] array

J = 2.pi integ(j sin(a) da) If kwarg 'norm' is True (default), the omni flux is normalized by 4.pi to make it per steradian, in line with the PRBEM guidelines

Parameters

fluxarr [arraylike] Array of directional flux values

alphas [arraylike] Array of pitch angles corresponding to fluxarr

Returns

omniflux [float] Omnidirectional flux value

Examples

Roundtrip from omni flux, to directional flux (Vampola model), integrate to get back to omni flux.

```
>>> from spacepy.empiricals import vampolaPA, omniFromDirectionalFlux
>>> dir_flux, pa  = vampolaPA(3000, alpha=range(0,181,2), order=4)
>>> dir_flux[:10], pa[:10]
(array([  0.00000000e+00,   6.64032473e-04,   1.05986545e-02,
      5.34380898e-02,   1.67932162e-01,   4.06999226e-01,
      8.36427502e-01,   1.53325140e+00,   2.58383611e+00,
```

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```
      4.08170975e+00]), [0, 2, 4, 6, 8, 10, 12, 14, 16, 18])
>>> omniFromDirectionalFlux(dir_flux, pa, norm=False)
3000.0000008112293
```

Calculate "spin-averaged" flux, giving answer per steradian

```
>>> omniFromDirectionalFlux(dir_flux, pa, norm=True)
238.73241470239859
```

4.8.11 spacepy.empiricals.vampolaPA

spacepy.empiricals.**vampolaPA**(*omniflux*, ***kwargs*)

Pitch angle model of sin^n form

Parameters

omniflux [arraylike or float] omnidirectional number flux data

order [integer or float (optional)] order of sin^n functional form for distribution (default=2)

alphas [arraylike (optional)] pitch angles at which to evaluate the differential number flux (default is 5 to 90 degrees in 36 steps)

Returns

dnflux [array] differential number flux corresponding to pitch angles alphas

alphas [array] pitch angles at which the differential number flux was evaluated

Notes

Directional number flux integrated over pitch angle from 0 to 90 degrees is a factor of 4*pi lower than omnidirectional number flux.

Examples

Omnidirectional number flux of [3000, 6000]

```
>>> from spacepy.empiricals import vampolaPA
>>> vampolaPA(3000, alpha=[45, 90])
(array([ 179.04931098,  358.09862196]), [45, 90])
>>> data, pas = vampolaPA([3000, 6000], alpha=[45, 90])
>>> pas
[45, 90]
>>> data
array([[ 179.04931098,  358.09862196],
   [ 358.09862196,  716.19724391]])
```

4.9 igrf - IGRF magnetic field model

International Geomagnetic Reference Field model

This module is intended primarily to support *coordinates* rather than for direct end use, and the interface is subject to change.

4.9.1 Classes

IGRFCoefficients([fname])	Read and store IGRF coefficients from data file
IGRF()	International Geomagnetic Reference Field model

spacepy.igrf.IGRFCoefficients

class spacepy.igrf.**IGRFCoefficients**(*fname=None*)

Read and store IGRF coefficients from data file

Other Parameters

fname [str, optional] Filename to read from; defaults from the .spacepy data directory.

spacepy.igrf.IGRF

class spacepy.igrf.**IGRF**

International Geomagnetic Reference Field model

Notes

New in version 0.3.0.

Methods

calcDipoleAxis()	Calculates dipole axis for initialized time.
initialize(time[, limits])	Initialize model state to a particular time.

Data

—

calcDipoleAxis()

Calculates dipole axis for initialized time.

Populates *moment* and *dipole*.

initialize(*time*, *limits='warn'*)

Initialize model state to a particular time.

Parameters

time [datetime] Time for which to initialize the model

Other Parameters

limits [str, optional] Set to `warn` to warn about out-of-range times (default); any other value to error.

dipole
Characteristics of dipole (dict).

moment
Dipole moments (dict).

4.10 irbempy - Python interface to irbem/ONERA library

module wrapper for irbem_lib Reference for this library https://sourceforge.net/projects/irbem/ D. Boscher, S. Bourdarie, P. O'Brien, T. Guild, IRBEM library V4.3, 2004-2008

Most functions in this module use an options list to define the models used and the settings that define the quality level of the result. The options list is a 5-element list and is defined as follows.

4.10.1 Options

- 1st element: 0 - don't compute L* or phi ; 1 - compute L*; 2- compute phi
- **2nd element: 0 - initialize IGRF field once per year (year.5);** n - n is the frequency (in days) starting on January 1st of each year (i.e. if options(2nd element)=15 then IGRF will be updated on the following days of the year: 1, 15, 30, 45 ...)
- **3rd element: resolution to compute L* (0 to 9) where 0 is the recomended value to ensure a** good ratio precision/computation time (i.e. an error of ~2% at L=6). The higher the value the better will be the precision, the longer will be the computing time. Generally there is not much improvement for values larger than 4. Note that this parameter defines the integration step (theta) along the field line such as dtheta=(2pi)/(720*[options(3rd element)+1])
- **4th element: resolution to compute L* (0 to 9). The higher the value the better will be** the precision, the longer will be the computing time. It is recommended to use 0 (usually sufficient) unless L* is not computed on a LEO orbit. For LEO orbit higher values are recommended. Note that this parameter defines the integration step (phi) along the drift shell such as dphi=(2pi)/(25*[options(4th element)+1])
- **5th element: allows to select an internal magnetic field model (default is set to IGRF)**
  - 0 = IGRF
  - 1 = Eccentric tilted dipole
  - 2 = Jensen&Cain 1960
  - 3 = GSFC 12/66 updated to 1970
  - 4 = User-defined model (Default: Centred dipole + uniform [Dungey open model])
  - 5 = Centred dipole

The routines also require specification of the external magnetic field model. The default is the Tsyganenko 2001 storm-time model. The external model is always specified using the extMag keyword and the following options exist.

4.10.2 extMag

- '0' = No external field model
- 'MEAD' = Mead and Fairfield
- 'T87SHORT' = Tsyganenko 1987 short (inner magnetosphere)
- 'T87LONG' = Tsyganenko 1987 long (valid in extended tail region)
- 'T89' = Tsyganenko 1989
- 'OPQUIET' = Olsen-Pfitzer static model for quiet conditions
- 'OPDYN' = Olsen-Pfitzer static model for active conditions
- 'T96' = Tsyganenko 1996
- 'OSTA' = Ostapenko and Maltsev
- 'T01QUIET' = Tsyganenko 2001 model for quiet conditions
- 'T01STORM' = Tsyganenko 2001 model for active conditions
- 'T05' = Tsyganenko and Sitnov 2005 model
- 'ALEX' = Alexeev model
- 'TS07' = Tsyganenko and Sitnov 2007 model

4.10.3 Authors

Josef Koller, Steve Morley

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This module provides a Python interface to the IRBEM library

Reference for this library https://sourceforge.net/projects/irbem/

D. Boscher, S. Bourdarie, P. O'Brien, T. Guild, IRBEM library V4.3, 2004-2008

Authors: Josef Koller, Steve Morley

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get_AEP8(energy, loci[, model, fluxtype, ...])	will return the flux from the AE8-AP8 model
get_Bfield(ticks, loci[, extMag, options, ...])	call get_bfield in irbem lib and return a dictionary with the B-field vector and strenght.
get_Lm(ticks, loci, alpha[, extMag, intMag, ...])	Return the MacIlwain L value for a given location, time and model
get_Lstar(ticks, loci[, alpha, extMag, ...])	This will call make_lstar1 or make_lstar_shell_splitting_1 from the irbem library and will lookup omni values for given time if not provided (optional).
find_Bmirror(ticks, loci, alpha[, extMag, ...])	call find_mirror_point from irbem library and return a dictionary with values for Blocal, Bmirr and the GEO (cartesian) coordinates of the mirror point
find_footpoint(ticks, loci[, extMag, ...])	call find_foot_point1 from irbem library and return a dictionary with values for Bmin and the GEO (cartesian) coordinates of the magnetic equator

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Table 28 – continued from previous page

find_magequator(ticks, loci[, extMag, ...])	call find_magequator from irbem library and return a dictionary with values for Bmin and the GEO (cartesian) coordinates of the magnetic equator
car2sph(CARin)	coordinate transformation from cartesian to spherical
sph2car(SPHin)	coordinate transformation from spherical to cartesian
coord_trans(loci, returntype, returncarsph)	thin layer to call coor_trans1 from irbem lib this will convert between systems GDZ, GEO, GSM, GSE, SM, GEI, MAG, SPH, RLL
get_sysaxes(dtype, carsph)	will return the sysaxes according to the irbem library
get_dtype(sysaxes)	will return the coordinate system type as string
prep_irbem([ticks, loci, alpha, extMag, ...])	Prepare inputs for direct IRBEM-LIB calls.

4.10.4 spacepy.irbempy.get_AEP8

spacepy.irbempy.**get_AEP8**(*energy*, *loci*, *model='min'*, *fluxtype='diff'*, *particles='e'*)
will return the flux from the AE8-AP8 model

Parameters

- **energy (float)** [center energy in MeV; if fluxtype=RANGE, then needs to be a list [Emin, Emax]]
- **loci (Coords)** [a Coords instance with the location inside the magnetosphere] optional instead of a Coords instance, one can also provide a list with [BBo, L] combination
- **model (str)** [MIN or MAX for solar cycle dependence]
- **fluxtype (str)** [DIFF, RANGE, INT are possible types]
- **particles (str): e or p or electrons or protons**

Returns

- **float** [flux from AE8/AP8 model]

Examples

```
>>> spacepy.irbempy.get_aep8()
```

```
>>> import spacepy.time as spt
>>> import spacepy.coordinates as spc
>>> import spacepy.irbempy as ib
>>> t = spt.Ticktock(['2017-02-02T12:00:00'], 'ISO')
>>> y = spc.Coords([3,0,0], 'GEO', 'car')
>>> y.ticks = t
>>> energy = 1.0 #MeV
>>> ib.get_AEP8(energy, y, model='max')
1932209.4427359989
```

4.10.5 spacepy.irbempy.get_Bfield

spacepy.irbempy.**get_Bfield**(*ticks*, *loci*, *extMag='T01STORM'*, *options=[1, 0, 0, 0, 0]*, *omnivals=None*)
call get_bfield in irbem lib and return a dictionary with the B-field vector and strenght.

Parameters

- ticks (Ticktock class) [containing time information]

- loci (Coords class) [containing spatial information]

- extMag (string) [optional; will choose the external magnetic field model] possible values ['0', 'MEAD', 'T87SHORT', 'T87LONG', 'T89', 'OPQUIET', 'OPDYN', 'T96', 'OSTA', 'T01QUIET', 'T01STORM', 'T05', 'ALEX', 'TS07']

- options (optional list or array of integers length=5) [explained in Lstar]

- omni values as dictionary (optional) [if not provided, will use lookup table]

- (see Lstar documentation for further explanation)

Returns

- results (dictionary) [containing keys: Bvec, and Blocal]

See also:

get_Lstar, *find_Bmirror*, *find_magequator*

Examples

```
>>> import spacepy.time as spt
>>> import spacepy.coordinates as spc
>>> import spacepy.irbempy as ib
>>> t = spt.Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> y = spc.Coords([[3,0,0],[2,0,0]], 'GEO', 'car')
>>> ib.get_Bfield(t,y)
{'Blocal': array([  976.42565251,  3396.25991675]),
   'Bvec': array([[ -5.01738885e-01,  -1.65104338e+02,   9.62365503e+02],
   [  3.33497974e+02,  -5.42111173e+02,   3.33608693e+03]])}
```

4.10.6 spacepy.irbempy.get_Lm

spacepy.irbempy.**get_Lm**(*ticks*, *loci*, *alpha*, *extMag='T01STORM'*, *intMag='IGRF'*, *IGRFset=0*, *omnivals=None*)
Return the MacIlwain L value for a given location, time and model

Parameters

- ticks (Ticktock class) [containing time information]

- loci (Coords class) [containing spatial information]

- alpha (list or ndarray) [pitch angles in degrees]

- extMag (string) [optional; will choose the external magnetic field model] possible values ['0', 'MEAD', 'T87SHORT', 'T87LONG', 'T89', 'OPQUIET', 'OPDYN', 'T96', 'OSTA', 'T01QUIET', 'T01STORM', 'T05', 'ALEX', 'TS07']

- **intMag (string)** [optional: select the internal field model] possible values ['IGRF','EDIP','JC','GSFC','DUN','CDIP'] For full details see get_Lstar

- **omni values as dictionary (optional)** [if not provided, will use lookup table]

Returns

- **results (dictionary)** [containing keys: Lm, Bmin, Blocal (or Bmirr), Xj, MLT] if pitch angles provided in "alpha" then drift shells are calculated and "Bmirr" is returned if not provided, then "Blocal" at spacecraft is returned. A negative value for Lm indicates the field line is closed but particles are lost to the atmosphere; the absolute value indicates the L value.

4.10.7 spacepy.irbempy.get_Lstar

spacepy.irbempy.**get_Lstar**(*ticks*, *loci*, *alpha=90*, *extMag='T01STORM'*, *options=[1, 0, 0, 0, 0]*, *omnivals=None*, *landi2lstar=False*)

This will call make_lstar1 or make_lstar_shell_splitting_1 from the irbem library and will lookup omni values for given time if not provided (optional). If pitch angles are provided, drift shell splitting will be calculated and "Bmirr" will be returned. If they are not provided, then no drift shell splitting is calculated and "Blocal" is returned.

Parameters

- **ticks (Ticktock class)** [containing time information]

- **loci (Coords class)** [containing spatial information]

- **alpha (list or ndarray)** [optional pitch angles in degrees (default is 90);] if provided will calculate shell splitting; max 25 values

- **extMag (string)** [optional; will choose the external magnetic field model] possible values ['0', 'MEAD', 'T87SHORT', 'T87LONG', 'T89', 'OPQUIET', 'OPDYN', 'T96', 'OSTA', 'T01QUIET', 'T01STORM', 'T05', 'ALEX', 'TS07']

- **options (optional list or array of integers length=5)** [explained below]

- **omni values as dictionary (optional)** [if not provided, will use lookup table]

- **landi2lstar** [if True, will use the faster landi2lstar routine if possible. This] routine can only be used with OPQUIET+IGRF magnetic field models.

Returns

- **results (dictionary)** [containing keys: Lm, Lstar, Bmin, Blocal (or Bmirr), Xj, MLT] if pitch angles provided in "alpha" then drift shells are calculated and "Bmirr" is returned if not provided, then "Blocal" at spacecraft is returned. A negative value for Lm indicates the field line is closed but particles are lost to the atmosphere; the absolute value indicates the L value. A negative value for Lstar indicates the field line is closed but particles are lost to the atmosphere before completing a drift orbit; the absolute value indicates the drift shell.

Notes

External Field

- 0 : no external field
- MEAD : Mead & Fairfield [1975] (uses 0<=Kp<=9 - Valid for rGEO<=17. Re)
- T87SHORT: Tsyganenko short [1987] (uses 0<=Kp<=9 - Valid for rGEO<=30. Re)
- T87LONG : Tsyganenko long [1987] (uses 0<=Kp<=9 - Valid for rGEO<=70. Re)
- T89 : Tsyganenko [1989] (uses 0<=Kp<=9 - Valid for rGEO<=70. Re)
- OPQUIET : Olson & Pfitzer quiet [1977] (default - Valid for rGEO<=15. Re)
- **OPDYN** [Olson & Pfitzer dynamic [1988] (uses 5.<=dens<=50., 300.<=velo<=500.,] - 100.<=Dst<=20. - Valid for rGEO<=60. Re)
- **T96** [Tsyganenko [1996] (uses -100.<=Dst (nT)<=20., 0.5<=Pdyn (nPa)<10.,] abs(ByIMF) (nT)<1=0., abs(BzIMF) (nT)<=10. - Valid for rGEO<=40. Re)
- **OSTA** [Ostapenko & Maltsev [1997] (uses dst,Pdyn,BzIMF, Kp)] T01QUIET: Tsyganenko [2002a,b] (uses -50.<Dst (nT)<20., 0.5<Pdyn (nPa)<=5., abs(ByIMF) (nT)<=5., abs(BzIMF) (nT)<=5., 0.<=G1<=10., 0.<=G2<=10. - Valid for xGSM>=-15. Re)
- **T01STORM: Tsyganenko, Singer & Kasper [2003] storm (uses Dst, Pdyn, ByIMF, BzIMF, G2, G3 -** there is no upper or lower limit for those inputs - Valid for xGSM>=-15. Re)
- **T05** [Tsyganenko & Sitnov [2005] storm (uses Dst, Pdyn, ByIMF, BzIMF,] W1, W2, W3, W4, W5, W6 - no upper or lower limit for inputs - Valid for xGSM>=-15. Re)

OMNI contents

- Kp: value of Kp as in OMNI2 files but has to be double instead of integer type
- Dst: Dst index (nT)
- dens: Solar Wind density (cm-3)
- velo: Solar Wind velocity (km/s)
- Pdyn: Solar Wind dynamic pressure (nPa)
- ByIMF: GSM y component of IMF mag. field (nT)
- BzIMF: GSM z component of IMF mag. field (nT)
- **G1: G1=< Vsw*(Bperp/40)2/(1+Bperp/40)*sin3(theta/2) > where the <> mean an average over the** previous 1 hour, Vsw is the solar wind speed, Bperp is the transverse IMF component (GSM) and theta it's clock angle.
- **G2: G2=< a*Vsw*Bs > where the <> mean an average over the previous 1 hour,** Vsw is solar wind speed, Bs=|IMF Bz| when IMF Bz < 0 and Bs=0 when IMF Bz > 0, a=0.005.
- **G3: G3=< Vsw*Dsw*Bs /2000.> where the <> mean an average over the previous 1 hour,** Vsw is the solar wind speed, Dsw is the solar wind density, Bs=|IMF Bz| when IMF Bz < 0 and Bs=0 when IMF Bz > 0.
- W1 - W6: see definition in (JGR-A, v.110(A3), 2005.) (PDF 1.2MB)
- AL: the auroral index

Options

- 1st element: 0 - don't compute L* or phi ; 1 - compute L*; 2- compute phi

- **2nd element: 0 - initialize IGRF field once per year (year.5);** n - n is the frequency (in days) starting on January 1st of each year (i.e. if options(2nd element)=15 then IGRF will be updated on the following days of the year: 1, 15, 30, 45 ...)
- **3rd element: resolution to compute L* (0 to 9) where 0 is the recomended value to ensure a** good ratio precision/computation time (i.e. an error of ~2% at L=6). The higher the value the better will be the precision, the longer will be the computing time. Generally there is not much improvement for values larger than 4. Note that this parameter defines the integration step (theta) along the field line such as dtheta=(2pi)/(720*[options(3rd element)+1])
- **4th element: resolution to compute L* (0 to 9). The higher the value the better will be** the precision, the longer will be the computing time. It is recommended to use 0 (usually sufficient) unless L* is not computed on a LEO orbit. For LEO orbit higher values are recommended. Note that this parameter defines the integration step (phi) along the drift shell such as dphi=(2pi)/(25*[options(4th element)+1])
- **5th element: allows to select an internal magnetic field model (default is set to IGRF)**
  - 0 = IGRF
  - 1 = Eccentric tilted dipole
  - 2 = Jensen&Cain 1960
  - 3 = GSFC 12/66 updated to 1970
  - 4 = User-defined model (Default: Centred dipole + uniform [Dungey open model])
  - 5 = Centred dipole

Examples

```
>>> t = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> y = Coords([[3,0,0],[2,0,0]], 'GEO', 'car')
>>> spacepy.irbempy.Lstar(t,y)
{'Blocal': array([ 1020.40493286,  3446.08845227]),
    'Bmin': array([ 1019.98404311,  3437.63865243]),
    'Lm': array([ 3.08948304,  2.06022102]),
    'Lstar': array([ 2.97684043,  1.97868577]),
    'MLT': array([ 23.5728333 ,  23.57287944]),
    'Xj': array([ 0.00112884,  0.00286955])}
```

4.10.8 spacepy.irbempy.find_Bmirror

spacepy.irbempy.**find_Bmirror**(*ticks*, *loci*, *alpha*, *extMag='T01STORM'*, *options=[1, 0, 0, 0, 0]*, *omnivals=None*)

call find_mirror_point from irbem library and return a dictionary with values for Blocal, Bmirr and the GEO (cartesian) coordinates of the mirror point

Parameters

ticks [Ticktock class] containing time information

loci [Coords class] containing spatial information

alpha [array-like] containing the pitch angles

extMag [str] optional; will choose the external magnetic field model possible values ['0', 'MEAD', 'T87SHORT', 'T87LONG', 'T89', OPQUIET', 'OPDYN', 'T96', 'OSTA', 'T01QUIET', 'T01STORM', 'T05', 'ALEX', 'TS07']

options [array-like (optional)] length=5 : explained in Lstar

omnivals [dict (optional)] if not provided, will use lookup table (see get_Lstar documentation for further explanation)

Returns

results [dictionary] containing keys: Blocal, Bmirr, GEOcar

See also:

get_Lstar, *get_Bfield*, *find_magequator*

Examples

```
>>> t = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> y = Coords([[3,0,0],[2,0,0]], 'GEO', 'car')
>>> ib.find_Bmirror(t,y,[90,80,60,10])
{'Blocal': array([ 0.,  0.]),
 'Bmirr': array([ 0.,  0.]),
 'loci': Coords( [[ NaN  NaN  NaN]
 [ NaN  NaN  NaN]] ), dtype=GEO,car, units=['Re', 'Re', 'Re']}
```

4.10.9 spacepy.irbempy.find_footpoint

spacepy.irbempy.**find_footpoint**(*ticks*, *loci*, *extMag='T01STORM'*, *options=[1, 0, 3, 0, 0]*, *hemi='same'*, *alt=100*, *omnivals=None*)

call find_foot_point1 from irbem library and return a dictionary with values for Bmin and the GEO (cartesian) coordinates of the magnetic equator

Parameters

- ticks (Ticktock class) [containing time information]

- loci (Coords class) [containing spatial information]

- extMag (string) [optional; will choose the external magnetic field model] possible values ['0', 'MEAD', 'T87SHORT', 'T87LONG', 'T89', 'OPQUIET', 'OPDYN', 'T96', 'OSTA', 'T01QUIET', 'T01STORM', 'T05', 'ALEX', 'TS07']

- options (optional list or array of integers length=5) [explained in Lstar]

- omni values as dictionary (optional) [if not provided, will use lookup table]

- (see Lstar documentation for further explanation)

- hemi (string) [optional (valid cases are 'same', 'other', 'north' or 'south')] will set the target hemisphere for tracing the footpoint

- alt (numeric) [optional keyword to set stop height [km] of fieldline trace (default 100km)]

Returns

- results (spacepy.datamodel.SpaceData) [containing keys] Bfoot - Magnitude of B-field at footpoint [nT] loci - Coords instance with GDZ coordinates of the magnetic footpoint [alt, lat, lon] Bfootvec - Components of B-field at footpoint in cartesian GEO coordinates [nT]

See also:

get_Lstar, *get_Bfield*, find_Bmirr, *find_magequator*

Examples

```
>>> t = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> y = Coords([[3,0,0],[3,0,0]], 'GEO', 'car')
>>> spacepy.irbempy.find_footpoint(t, y)
{'Bfoot': array([ 47559.04643444,  47542.84688657]),
 'Bfootvec': array([[-38428.07217246,   4497.31549786, -27657.19291928],
       [-38419.08514332,   4501.45390964, -27641.14866517]]),
 'loci': Coords( [[ 99.31443778  55.71415787 -10.21888955]
 [ 99.99397026  55.70716296 -10.22797462]] ), dtype=GDZ,sph, units=['km', 'deg',
↪'deg']}
```

4.10.10 spacepy.irbempy.find_magequator

spacepy.irbempy.**find_magequator**(*ticks*, *loci*, *extMag='T01STORM'*, *options=[1, 0, 0, 0, 0]*, *omnivals=None*)
call find_magequator from irbem library and return a dictionary with values for Bmin and the GEO (cartesian) coordinates of the magnetic equator

Parameters

- **ticks (Ticktock class)** [containing time information]
- **loci (Coords class)** [containing spatial information]
- **extMag (string)** [optional; will choose the external magnetic field model] possible values ['0', 'MEAD', 'T87SHORT', 'T87LONG', 'T89', 'OPQUIET', 'OPDYN', 'T96', 'OSTA', 'T01QUIET', 'T01STORM', 'T05', 'ALEX', 'TS07']
- **options (optional list or array of integers length=5)** [explained in Lstar]
- **omni values as dictionary (optional)** [if not provided, will use lookup table]
- **(see Lstar documentation for further explanation)**

Returns

- **results (dictionary)** [containing keys: Bmin, Coords instance with GEO coordinates of] the magnetic equator

See also:

get_Lstar, *get_Bfield*, find_Bmirr

Examples

```
>>> t = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> y = Coords([[3,0,0],[2,0,0]], 'GEO', 'car')
>>> op.find_magequator(t,y)
{'Bmin': array([  945.63652413,  3373.64496167]),
    'loci': Coords( [[ 2.99938371  0.00534151 -0.03213603]
    [ 2.00298822 -0.0073077   0.04584859]] ), dtype=GEO,car, units=['Re', 'Re', 'Re
↪']}
```

4.10.11 spacepy.irbempy.car2sph

spacepy.irbempy.**car2sph**(*CARin*)

coordinate transformation from cartesian to spherical

Deprecated since version 0.2.3: use *spacepy.coordinates.car2sph()*

Parameters

- CARin (list or ndarray) [coordinate points in (n,3) shape with n coordinate points in] units of [Re, Re, Re] = [x,y,z]

Returns

- results (ndarray) [values after conversion to spherical coordinates in] radius, latitude, longitude in units of [Re, deg, deg]

See also:

sph2car

Examples

```
>>> sph2car([1,45,0])
array([ 0.70710678,  0.        ,  0.70710678])
```

4.10.12 spacepy.irbempy.sph2car

spacepy.irbempy.**sph2car**(*SPHin*)

coordinate transformation from spherical to cartesian

Deprecated since version 0.2.3: use *spacepy.coordinates.sph2car()*

Parameters

- SPHin (list or ndarray) [coordinate points in (n,3) shape with n coordinate points in] units of [Re, deg, deg] = [r, latitude, longitude]

Returns

- results (ndarray) [values after conversion to cartesian coordinates x,y,z]

See also:

car2sph

Examples

```
>>> sph2car([1,45,45])
array([ 0.5       ,  0.5       ,  0.70710678])
```

4.10.13 spacepy.irbempy.coord_trans

spacepy.irbempy.**coord_trans**(*loci*, *returntype*, *returncarsph*)

thin layer to call coor_trans1 from irbem lib this will convert between systems GDZ, GEO, GSM, GSE, SM, GEI, MAG, SPH, RLL

Parameters

- loci (Coords instance) [containing coordinate information, can contain n points]

- returntype (str) [describing system as GDZ, GEO, GSM, GSE, SM, GEI, MAG, SPH, RLL]

- returncarsph (str) [cartesian or spherical units 'car', 'sph']

Returns

- xout (ndarray) [values after transformation in (n,3) dimensions]

See also:

sph2car, *car2sph*

Examples

```
>>> c = Coords([[3,0,0],[2,0,0]], 'GEO', 'car')
>>> c.ticks = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> coord_trans(c, 'GSM', 'car')
array([[ 2.8639301 , -0.01848784,  0.89306361],
[ 1.9124434 ,  0.07209424,  0.58082929]])
```

4.10.14 spacepy.irbempy.get_sysaxes

spacepy.irbempy.**get_sysaxes**(*dtype*, *carsph*)

will return the sysaxes according to the irbem library

Deprecated since version 0.2.3: use *spacepy.coordinates.SYSAXES_TYPES*

Parameters

- dtype (str) [coordinate system, possible values: GDZ, GEO, GSM, GSE, SM,] GEI, MAG, SPH, RLL

- carsph (str) [cartesian or spherical, possible values: 'sph', 'car']

Returns

- sysaxes (int) [value after oner_desp library from 0-8 (or None if not available)]

See also:

get_dtype

Examples

```
>>> get_sysaxes('GSM', 'car')
2
```

4.10.15 spacepy.irbempy.get_dtype

spacepy.irbempy.**get_dtype**(*sysaxes*)

will return the coordinate system type as string

Parameters

- sysaxes (int) [number according to the irbem, possible values: 0-8]

Returns

- dtype (str) [coordinate system GDZ, GEO, GSM, GSE, SM, GEI, MAG, SPH, RLL]

- carsph (str) [cartesian or spherical 'car', 'sph']

See also:

get_sysaxes

Examples

```
>>> get_dtype(3)
('GSE', 'car')
```

4.10.16 spacepy.irbempy.prep_irbem

spacepy.irbempy.**prep_irbem**(*ticks=None*, *loci=None*, *alpha=[]*, *extMag='T01STORM'*, *options=[1, 0, 0, 0, 0]*, *omnivals=None*)

Prepare inputs for direct IRBEM-LIB calls. Not expected to be called by the user.

4.11 omni - module to read and process NASA OMNIWEB data

Tools to read and process omni data (Qin-Denton, etc.)

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4.11.1 About omni

The omni module primarily manages the hourly OMNI2 and Qin-Denton data, which are sourced from the Virtual Radiation Belt Observatory (ViRBO), who maintain these data sources. The data can be kept up-to-date in SpacePy using the *update()* function in the *spacepy.toolbox* module.

The OMNI2 data combines data from a variety of satellites that sample the solar wind (notably ACE and Wind), and propagates the data to Earth's bow shock nose. The Qin-Denton data is derived from the OMNI2 data and is designed for providing input to the Tsyganenko magnetic field models. The later Tsyganenko magnetic field models require subsidiary parameters (G- and W-parameters) that are pre-calculated in the Qin-Denton data. Further, the Qin-Denton data contains no data gaps – all gaps are filled (for details on the gap filling, see the paper by Qin et al..)

4.11.2 Advanced features

Higher resolution data, or custom data sources, can also be managed/accessed with this module, although this is considered an advanced use for this module. This is achieved using custom names for the dbase keyword in get_omni, which must be defined in the SpacePy configuration file (for a user-install on linux, this is ~/.spacepy/spacepy.rc; see *SpacePy Configuration*). An example of the formatting required is

qd1min: /usr/somedir/QinDenton/YYYY/QinDenton_YYYYMMDD_1min.txt

In this example the custom data source name is qd1min. Wildcard substitutions can be made for the year (YYYY), month (MM) and day (DD). Future updates will give more flexibility in data storage model, but currently we assume that all custom data sources follow a convention in which the data files are daily, and the files are organized into folders by year. The year, month and day must all be specified in the filename.

Currently there are some restrictions on the data format for custom data sources. The stored data must currently be stored as JSON-headed ASCII. If data conversions are required, then a valid dictionary of conversion functions must be supplied via the convert keyword argument. See *readJSONheadedASCII()* for details. Additionally, by default this will interpolate the data to the requested time ticks. To return only the actual recorded data values for the specified time range set the keyword argument interp to False.

get_omni(ticks[, dbase])	Returns Qin-Denton OMNI values, interpolated to any time-base from a default hourly resolution
omnirange([dbase])	Returns datetimes giving start and end times in the OMNI/Qin-Denton data

4.11.3 spacepy.omni.get_omni

spacepy.omni.**get_omni**(*ticks*, *dbase='QDhourly'*, ***kwargs*)

Returns Qin-Denton OMNI values, interpolated to any time-base from a default hourly resolution

The update function in toolbox retrieves all available hourly Qin-Denton data, and this function accesses that and interpolates to the given times, returning the OMNI values as a SpaceData (dict-like) with Kp, Dst, dens, velo, Pdyn, ByIMF, BzIMF, G1, G2, G3, etc. (see also http://www.dartmouth.edu/~rdenton/magpar/index.html and http://www.agu.org/pubs/crossref/2007/2006SW000296.shtml)

Parameters

ticks [Ticktock class or array-like of datetimes] time values for desired output

dbase [str (optional)] Select data source, options are 'QDhourly', 'OMNI2hourly', 'Merged-hourly' Note - Custom data sources can be specified in the spacepy config file as described in the module documentation.

Returns

out [spacepy.datamodel.SpaceData] containing all Qin-Denton values at times given by ticks

Notes

Note about Qbits: If the status variable is 2, the quantity you are using is fairly well determined. If it is 1, the value has some connection to measured values, but is not directly measured. These values are still better than just using an average value, but not as good as those with the status variable equal to 2. If the status variable is 0, the quantity is based on average quantities, and the values listed are no better than an average value. The lower the status variable, the less confident you should be in the value.

Examples

```
>>> import spacepy.time as spt
>>> import spacepy.omni as om
>>> ticks = spt.Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:10:00'], 'ISO')
>>> d = om.get_omni(ticks)
>>> d.tree(levels=1)
+
|____ByIMF
|____Bz1
|____Bz2
|____Bz3
|____Bz4
|____Bz5
|____Bz6
|____BzIMF
|____DOY
|____Dst
|____G1
|____G2
|____G3
|____Hr
|____Kp
|____Pdyn
|____Qbits
|____RDT
|____UTC
|____W1
|____W2
|____W3
|____W4
|____W5
|____W6
|____Year
|____akp3
|____dens
|____ticks
|____velo
```

4.11.4 spacepy.omni.omnirange

spacepy.omni.**omnirange**(*dbase='QDhourly'*)

Returns datetimes giving start and end times in the OMNI/Qin-Denton data

The update function in toolbox retrieves all available hourly Qin-Denton data, and this function accesses that and looks up the start and end times, returning them as datetime objects.

Parameters

dbase [string (optional)] name of omni database to check. Currently 'QDhourly' and 'OMNI2hourly'

Returns

omnirange [tuple] containing two datetimes giving the start and end times of the available data

Examples

```
>>> import spacepy.omni as om
>>> om.omnirange()
(datetime.datetime(1963, 1, 1, 0, 0), datetime.datetime(2011, 11, 30, 23, 0))
>>> om.omnirange(dbase='OMNI2hourly')
(datetime.datetime(1963, 1, 1, 0, 0), datetime.datetime(2011, 11, 30, 23, 0))
```

4.12 plot - Plot, various specialized plotting functions and associated utilities

plot: SpacePy plotting routines

This package aims to make getting publication ready plots easier. It provides classes and functions for different types of plot (e.g. Spectrogram, levelPlot), for helping make plots more cleanly (e.g. set_target, dual_half_circle), and for making plots convey information more cleanly, with less effort (e.g. applySmartTimeTicks, style).

This plot module now provides style sheets. For most standard plotting we recommend the *default* style sheet (aka *spacepy*). To auto-apply the default plot style the following should be added to your spacepy.rc file:

```
apply_plot_styles: True
```

Different plot types may not work well with this style, so we have provided alternatives. For polar plots, spectrograms, or anything with larger blocks of color, it may be better to use one of the alternatives:

```
import spacepy.plot as splot
splot.style('altgrid') # inverts background from default so it's white
splot.style('polar') # designed for filled polar plots
splot.revert_style() # put the style back to matplotlib defaults
```

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add_logo(img[, fig, pos, margin])	Add an image (logo) to one corner of a plot.
annotate_xaxis(txt[, ax])	Write text in-line and to the right of the x-axis tick labels

continues on next page

Table 30 – continued from previous page

applySmartTimeTicks(ax, time[, dolimit, dolabel])	Given an axis *ax* and a list/array of datetime objects, *time*, use the smartTimeTicks function to build smart time ticks and then immediately apply them to the given axis.
available([returnvals])	List the available plot styles provided by spacepy.plot
collapse_vertical(combine[, others, leave_axis])	Collapse the vertical spacing between two or more subplots.
dual_half_circle([center, radius, ...])	Plot two half circles to a plot with the specified face colors and rotation.
levelPlot(data[, var, time, levels, target, ...])	Draw a step-plot with up to 5 levels following a color cycle (e.g.
plot(*args, **kwargs)	Convenience wrapper for matplotlib's plot function
revert_style()	Revert plot style settings to those in use prior to importing spacepy.plot
set_target(target[, figsize, loc, polar])	Given a *target* on which to plot a figure, determine if that *target* is **None** or a matplotlib figure or axes object.
shared_ylabel(axes, txt, *args, **kwargs)	Create a ylabel that spans several subplots
solarRotationPlot(ticks, data[, targ_ax, ...])	Plots a 1-D time series as a Carrington or Bartels plot
Spectrogram(data, **kwargs)	This class rebins data to produce a 2D data map that can be plotted as a spectrogram
style([look, cmap])	Apply SpacePy's matplotlib style settings from a known style sheet.
timestamp([position, size, draw, strnow, ...])	print a timestamp on the current plot, vertical lower right
add_arrows(lines[, n, size, style, ...])	Add directional arrows along a plotted line.

4.12.1 spacepy.plot.add_logo

spacepy.plot.**add_logo**(*img*, *fig=None*, *pos='br'*, *margin=0.05*)

Add an image (logo) to one corner of a plot.

The provided image will be placed in a corner of the plot and sized to maintain its aspect ratio and be as large as possible without overlapping any existing elements of the figure. Thus this should be the last call in constructing a figure.

Parameters

img [str or numpy.ndarray] The image to place on the figure. If a string, assumed to be a filename to be read with imread(); if a numpy array, assumed to be the image itself (in a simliar format).

Returns

(axes, axesimg) [tuple of Axes and AxesImage] The Axes object created to hold the iamge, and the AxesImage object for the image itself.

Other Parameters

fig [matplotlib.figure.Figure] The figure on which to place the logo; if not specified, the gcf() function will be used.

pos [str] The position to place the logo. br: bottom right; bl: bottom left; tl: top left; tr: top right

margin [float] Margin to include on each side of figure, as a fraction of the larger dimension of the figure (width or height). Default is 0.05 (5%).

Notes

Calls `draw()` to ensure locations are up to date.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> ax0 = fig.add_subplot(211)
>>> ax0.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D at 0x00000000>]
>>> ax1 = fig.add_subplot(212)
>>> ax1.plot([1, 2, 3], [2, 1, 2])
[<matplotlib.lines.Line2D at 0x00000000>]
>>> spacepy.plot.utils.add_logo('logo.png', fig)
(<matplotlib.axes.Axes at 0x00000000>,
 <matplotlib.image.AxesImage at 0x00000000>)
```

4.12.2 spacepy.plot.annotate_xaxis

spacepy.plot.**annotate_xaxis**(*txt*, *ax=None*)

Write text in-line and to the right of the x-axis tick labels

Annotates the x axis of an `Axes` object with text placed in-line with the tick labels and immediately to the right of the last label. This is formatted to match the existing tick marks.

Parameters

txt [str] The annotation text.

Returns

out [matplotlib.text.Text] The `Text` object for the annotation.

Other Parameters

ax [matplotlib.axes.Axes] The axes to annotate; if not specified, the `gca()` function will be used.

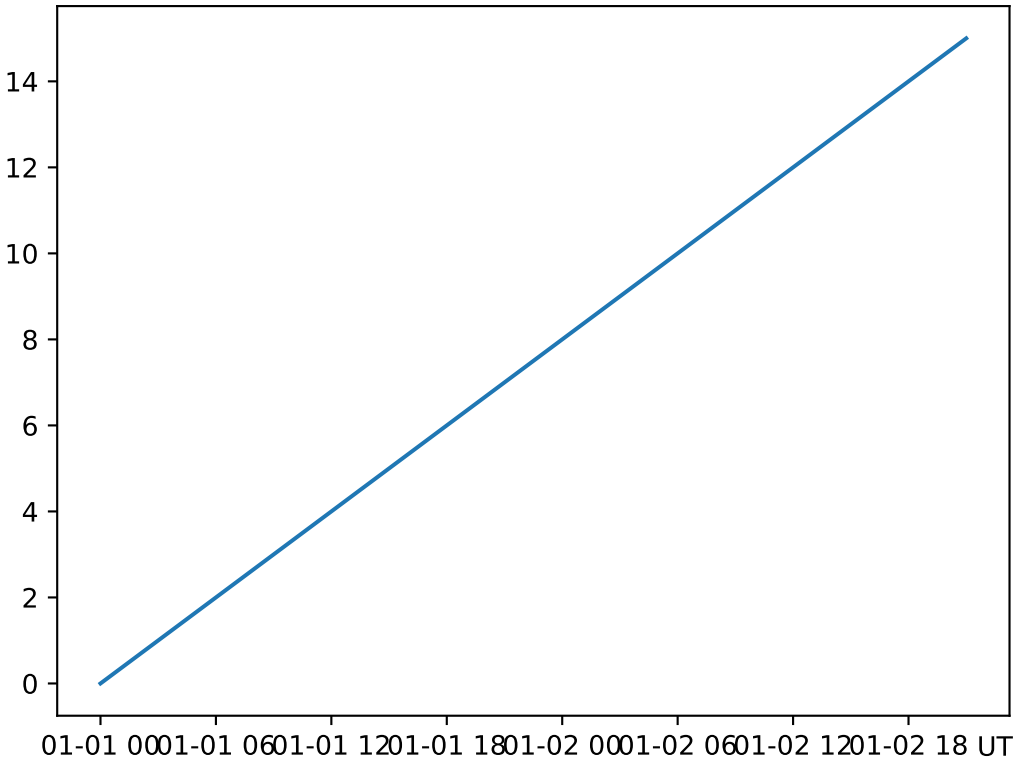
Notes

The annotation is placed *immediately* to the right of the last tick label. Generally the first character of `txt` should be a space to allow some room.

Calls `draw()` to ensure tick marker locations are up to date.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> import datetime
>>> times = [datetime.datetime(2010, 1, 1) + datetime.timedelta(hours=i)
...     for i in range(0, 48, 3)]
>>> plt.plot(times, range(16))
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> spacepy.plot.utils.annotate_xaxis(' UT') #mark that times are UT
<matplotlib.text.Text object at 0x0000000>
```



4.12.3 spacepy.plot.applySmartTimeTicks

spacepy.plot.**applySmartTimeTicks**(*ax*, *time*, *dolimit=True*, *dolabel=False*)

Given an axis *ax* and a list/array of datetime objects, *time*, use the smartTimeTicks function to build smart time ticks and then immediately apply them to the given axis. The first and last elements of the time list will be used as bounds for the x-axis range.

The range of the *time* input value will be used to set the limits of the x-axis as well. Set kwarg 'dolimit' to False to override this behavior.

Parameters

ax [matplotlib.pyplot.Axes] A matplotlib Axis object.

time [list] list of datetime objects

dolimit [boolean (optional)] The range of the *time* input value will be used to set the limits of the x-axis as well. Setting this overrides this behavior.

dolabel [boolean (optional)] Sets autolabeling of the time axis with "Time from" time[0]

See also:

`smartTimeTicks`

4.12.4 spacepy.plot.available

`spacepy.plot.`**`available`**(*returnvals=False*)

List the available plot styles provided by spacepy.plot

Note that some of the available styles have multiple aliases. To apply an available style, use *spacepy.plot.style*.

4.12.5 spacepy.plot.collapse_vertical

`spacepy.plot.`**`collapse_vertical`**(*combine*, *others=()*, *leave_axis=False*)

Collapse the vertical spacing between two or more subplots.

Useful for a multi-panel plot where most subplots should have space between them but several adjacent ones should not (i.e., appear as a single plot.) This function will remove all the vertical space between the subplots listed in `combine` and redistribute the space between all of the subplots in both `combine` and `others` in proportion to their current size, so that the relative size of the subplots does not change.

Parameters

combine [sequence] The `Axes` objects (i.e. subplots) which should be placed together with no vertical space.

Other Parameters

others [sequence] The `Axes` objects (i.e. subplots) which will keep their vertical spacing, but will be expanded with the space taken away from between the elements of `combine`.

leave_axis [bool] If set to true, will leave the axis lines and tick marks between the collapsed subplots. By default, the axis line ("spine") is removed so the two subplots appear as one.

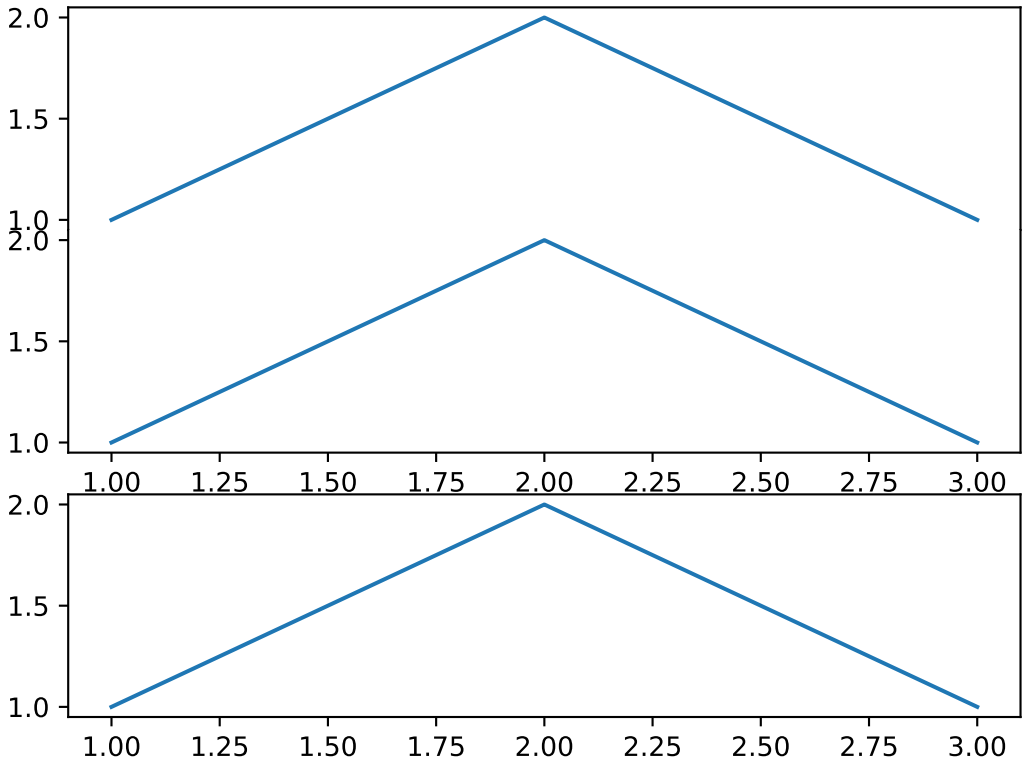
Notes

This function can be fairly fragile and should only be used for fairly simple layouts, e.g., a one-column multi-row plot stack.

This may require some clean-up of the y axis labels, as they are likely to overlap.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> #Make three stacked subplots
>>> ax0 = fig.add_subplot(311)
>>> ax1 = fig.add_subplot(312)
>>> ax2 = fig.add_subplot(313)
>>> ax0.plot([1, 2, 3], [1, 2, 1]) #just make some lines
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> ax1.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> ax2.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> #Collapse space between top two plots, leave bottom one alone
>>> spacepy.plot.utils.collapse_vertical([ax0, ax1], [ax2])
```



4.12.6 spacepy.plot.dual_half_circle

spacepy.plot.**dual_half_circle**(*center=(0, 0)*, *radius=1.0*, *sun_direction='right'*, *ax=None*, *colors=('w', 'k')*, ***kwargs*)

Plot two half circles to a plot with the specified face colors and rotation. This is normal to use to denote the sun direction in magnetospheric science plots.

Returns

out [tuple] Tuple of the two wedge objects

Other Parameters

center [array-like, 2 elements] Center in data coordinates of the circles, default (0,0)

radius [float] Radius of the circles, defualt 1.0

sun_direction [string or float] The rotation direction of the first (white) circle. Options are ['down', 'down right', 'right', 'up left', 'up right', 'up', 'down left', 'left'] or an angle in degrees counter-clockwise from up. Default right.

ax [matplotlib.axes] Axis to plot the circles on.

colors [array-like, 2 elements] The two colors for the circle fill. The First number is the light and second is the dark.

****kwargs** [other keywords] Other keywords to pass to matplotlib.patches.Wedge

Examples

```
>>> import spacepy.plot
>>> spacepy.plot.dual_half_circle()
```

4.12.7 spacepy.plot.levelPlot

spacepy.plot.**levelPlot**(*data*, *var=None*, *time=None*, *levels=(3, 5)*, *target=None*, *colors=None*, ***kwargs*)

Draw a step-plot with up to 5 levels following a color cycle (e.g. Kp index "stoplight")

Parameters

data [array-like, or dict-like] Data for plotting. If dict-like, the key providing an array-like to plot must be given to var keyword argument.

Returns

binned [tuple] Tuple of the binned data and bins

Other Parameters

var [string] Name of key in dict-like input that contains data

time [array-like or string] Name of key in dict-like that contains time, or arraylike of datetimes

levels [array-like, up to 5 levels] Breaks between levels in data that should be shown as distinct colors

target [figure or axes] Target axes or figure window

colors [array-like] Colors to use for the color sequence (if insufficient colors, will use as a cycle)

****kwargs** [other keywords] Other keywords to pass to spacepy.toolbox.binHisto

Examples

```
>>> import spacepy.plot as splot
>>> import spacepy.time as spt
>>> import spacepy.omni as om
>>> tt = spt.tickrange('2012/09/28','2012/10/2', 3/24.)
>>> omni = om.get_omni(tt)
>>> splot.levelPlot(omni, var='Kp', time='UTC', colors=['seagreen', 'orange',
↪'crimson'])
```

4.12.8 spacepy.plot.plot

spacepy.plot.**plot**(**args*, ***kwargs*)

Convenience wrapper for matplotlib's plot function

As with matplotlib's plot function, *args* is a variable length argument, allowing for multiple *x*, *y* pairs, each with optional format string. For full details, see matplotlib.pyplot.plot

Other Parameters

smartTimeTicks [boolean] If True then use applySmartTimeTicks to set x-axis labeling

figsize [array-like, 2 elements] Set figure size directly on call to plot, (width, height)

****kwargs** [other keywords] Other keywords to pass to matplotlib.pyplot.plot

4.12.9 spacepy.plot.revert_style

spacepy.plot.**revert_style**()

Revert plot style settings to those in use prior to importing spacepy.plot

4.12.10 spacepy.plot.set_target

spacepy.plot.**set_target**(*target*, *figsize=None*, *loc=None*, *polar=False*)

Given a *target* on which to plot a figure, determine if that *target* is **None** or a matplotlib figure or axes object. Based on the type of *target*, a figure and/or axes will be either located or generated. Both the figure and axes objects are returned to the caller for further manipulation. This is used in nearly all *add_plot*-type methods.

Parameters

target [object] The object on which plotting will happen.

Returns

fig [object] A matplotlib figure object on which to plot.

ax [object] A matplotlib subplot object on which to plot.

Other Parameters

figsize [tuple] A two-item tuple/list giving the dimensions of the figure, in inches. Defaults to Matplotlib defaults.

loc [integer] The subplot triple that specifies the location of the axes object. Defaults to matplotlib default (111).

polar [bool] Set the axes object to polar coodinates. Defaults to **False**.

Examples

```
>>> import matplotlib.pyplot as plt
>>> from spacepy.pybats import set_target
>>> fig = plt.figure()
>>> fig, ax = set_target(target=fig, loc=211)
```

4.12.11 spacepy.plot.shared_ylabel

spacepy.plot.**shared_ylabel**(*axes*, *txt*, **args*, ***kwargs*)

Create a ylabel that spans several subplots

Useful for a multi-panel plot where several subplots have the same units/quantities on the y axis.

Parameters

axes [list] The `Axes` objects (i.e. subplots) which should share a single label

txt [str] The label to place in the middle of all the *axes* objects.

Returns

out [matplotlib.text.Text] The `Text` object for the label.

Other Parameters

Additional arguments and keywords are passed through to

:meth:`~matplotlib.axes.Axes.set_ylabel`

Notes

This function can be fairly fragile and should only be used for fairly simple layouts, e.g., a one-column multi-row plot stack.

The label is associated with the bottommost subplot in `axes`.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> #Make three stacked subplots
>>> ax0 = fig.add_subplot(311)
>>> ax1 = fig.add_subplot(312)
>>> ax2 = fig.add_subplot(313)
>>> ax0.plot([1, 2, 3], [1, 2, 1]) #just make some lines
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> ax1.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> ax2.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> #Create a green label across all three axes
>>> spacepy.plot.utils.shared_ylabel([ax0, ax1, ax2],
... 'this is a very long label that spans all three axes', color='g')
```

4.12.12 spacepy.plot.solarRotationPlot

spacepy.plot.**solarRotationPlot**(*ticks*, *data*, *targ_ax=None*, *rtype='bartels'*, *nbins=27*)
Plots a 1-D time series as a Carrington or Bartels plot

4.12.13 spacepy.plot.Spectrogram

spacepy.plot.**Spectrogram**(*data*, ***kwargs*)
This class rebins data to produce a 2D data map that can be plotted as a spectrogram

It is meant to be used on arbitrary data series. The first series "x" is plotted on the abscissa and second series "y" is plotted on the ordinate and the third series "z" is plotted in color.

The series are not passed in independently but instead inside a *SpaceData* container.

Parameters

data [*SpaceData*] The data for the spectrogram, the variables to be used default to "Epoch" for x, "Energy" for y, and "Flux" for z. Other names are specified using the 'variables' keyword. All keywords override .attrs contents.

Other Parameters

variables [list] keyword containing the names of the variables to use for the spectrogram the list is a list of the SpaceData keys in x, y, z, order

bins [list] if the name "bins" is not specified in the .attrs of the dmarray variable this specifies the bins for each variable in a [[xbins], [ybins]] format

xlim [list] if the name "lim" is not specified in the .attrs of the dmarray variable this specifies the limit for the x variable [xlow, xhigh]

ylim [list] if the name "lim" is not specified in the .attrs of the dmarray variable this specifies the limit for the y variable [ylow, yhigh]

zlim [list] if the name "lim" is not specified in the .attrs of the dmarray variable this specifies the limit for the z variable [zlow, zhigh]

extended_out [bool (optional)] if this is True add more information to the output data model (default True)

Notes

Helper routines are planned to facilitate the creation of the SpaceData container if the data are not in the format.

Examples

```
>>> import spacepy.datamodel as dm
>>> import numpy as np
>>> import spacepy.plot as splot
>>> sd = dm.SpaceData()
>>> sd['radius'] = dm.dmarray(2*np.sin(np.linspace(0,30,500))+4, attrs={'units':'km
↪'})
>>> sd['day_of_year'] = dm.dmarray(np.linspace(74,77,500))
>>> sd['1D_dataset'] = dm.dmarray(np.random.normal(10,3,500)*sd['radius'])
```

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```
>>> spec = splot.Spectrogram(sd, variables=['day_of_year', 'radius', '1D_dataset'])
>>> ax = spec.plot()
```

plot([target, loc, figsize])	Plot the spectrogram

4.12.14 spacepy.plot.style

spacepy.plot.**style**(*look=None*, *cmap='plasma'*)

Apply SpacePy's matplotlib style settings from a known style sheet.

Parameters

look [str]

Name of style. For a list of available style names, see `spacepy.plot.available`.

4.12.15 spacepy.plot.timestamp

spacepy.plot.**timestamp**(*position=(1.003, 0.01)*, *size='xx-small'*, *draw=True*, *strnow=None*, *rotation='vertical'*, *ax=None*, ***kwargs*)

print a timestamp on the current plot, vertical lower right

Parameters

position [list] position for the timestamp

size [string (optional)] text size

draw [Boolean (optional)] call draw to make sure it appears

kwargs [keywords] other keywords to axis.annotate

Examples

```
>>> import spacepy.plot.utils
>>> from pylab import plot, arange
>>> plot(arange(11))
[<matplotlib.lines.Line2D object at 0x49072b0>]
>>> spacepy.plot.utils.timestamp()
```

4.12.16 spacepy.plot.add_arrows

spacepy.plot.**add_arrows**(*lines*, *n=3*, *size=12*, *style='->'*, *dorestrict=False*, *positions=False*)

Add directional arrows along a plotted line. Useful for plotting flow lines, magnetic field lines, or other directional traces.

lines can be either `Line2D`, a list or tuple of lines, or a `LineCollection` object.

For each line, arrows will be added using `annotate()`. Arrows will be spread evenly over the line using the number of points in the line as the metric for spacing. For example, if a line has 120 points and 3 arrows are requested, an arrow will be added at point number 30, 60, and 90. Arrow color and alpha is obtained from the parent line.

Parameters

lines [Line2D, a list/tuple, or LineCollection] A single line or group of lines on which to place the arrows. Arrows inherent color and transparency (alpha) from the line on which they are placed.

Returns

None

Other Parameters

n [integer] Number of arrows to add to each line; defaults to 3.

size [integer] The size of the arrows in points. Defaults to 12.

style [string] Set the style of the arrow via ArrowStyle, e.g. '->' (default) or '-|>'

dorestrict [boolean] If True (default), only points along the line within the current limits of the axes will be considered when distributing arrows.

positions [Nx2 array] N must be the number of lines provided via the argument *lines*. If provided, only one arrow will be placed per line. *positions* sets the explicit location of each arrow for each line as X-Y space in Axes coordinates.

Notes

The algorithm works by dividing the line in to *n*+1 segments and placing an arrow between each segment, endpoints excluded. Arrows span the shortest distance possible, i.e., two adjacent points along a line. For lines that are long spatially but sparse in points, the arrows will have long tails that may extend beyond axes bounds. For explicit positions, the arrow is placed at the point on the curve closest to that position and the exact position is not always attainable. A maximum number of arrows equal to one-half of the number of points in a line per line will be created, so not all lines will receive *n* arrows.

Examples

```
>>> import matplotlib.pyplot as plt
>>> import numpy as np
>>> x = np.arange(1, 10, .01)
>>> y = np.sin(x)
>>> line = plt.plot(x,y)
>>> add_arrows(line, n=15, style='-|>')
```

Most of the functionality in the plot module is made available directly through the *plot* namespace. However, the plot module does contain several submodules listed below

carrington	Module for plotting data by Carrington or Bartels rotation
spectrogram	Create and plot generic 'spectrograms' for space science.
utils	Utility routines for plotting and related activities

4.12.17 spacepy.plot.carrington

Module for plotting data by Carrington or Bartels rotation

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4.12.18 spacepy.plot.spectrogram

Create and plot generic 'spectrograms' for space science. This is not a signal processing routine and does not apply Fourier transforms (or similar) to the data. The functionality provided here is the binning (and averaging) of multi-dimensional to provide a 2D output map of some quantity as a function of two parameters. An example would be particle data from a satellite mission: electron flux, at a given energy, can be binned as a function of both time and McIlwain L, then plotted as a 2D color-map, colloquially known as a spectrogram.

In many other settings 'spectrogram' refers to a transform of data from the time domain to the frequency domain, and the subsequent plotting of some quantity (e.g., power spectral density) as a function of time and frequency. To approximate this functionality for, e.g., time-series magnetic field data you would first calculate a the power spectral density and then use *Spectrogram* to rebin the data for visualization.

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Class

Spectrogram(data, **kwargs)	This class rebins data to produce a 2D data map that can be plotted as a spectrogram

spacepy.plot.spectrogram.Spectrogram

class spacepy.plot.spectrogram.**Spectrogram**(*data*, ***kwargs*)

This class rebins data to produce a 2D data map that can be plotted as a spectrogram

It is meant to be used on arbitrary data series. The first series "x" is plotted on the abscissa and second series "y" is plotted on the ordinate and the third series "z" is plotted in color.

The series are not passed in independently but instead inside a *SpaceData* container.

Parameters

data [*SpaceData*] The data for the spectrogram, the variables to be used default to "Epoch" for x, "Energy" for y, and "Flux" for z. Other names are specified using the 'variables' keyword. All keywords override .attrs contents.

Other Parameters

variables [list] keyword containing the names of the variables to use for the spectrogram the list is a list of the SpaceData keys in x, y, z, order

bins [list] if the name "bins" is not specified in the .attrs of the dmarray variable this specifies the bins for each variable in a [[xbins], [ybins]] format

xlim [list] if the name "lim" is not specified in the .attrs of the dmarray variable this specifies the limit for the x variable [xlow, xhigh]

ylim [list] if the name "lim" is not specified in the .attrs of the dmarray variable this specifies the limit for the y variable [ylow, yhigh]

zlim [list] if the name "lim" is not specified in the .attrs of the dmarray variable this specifies the limit for the z variable [zlow, zhigh]

extended_out [bool (optional)] if this is True add more information to the output data model (default True)

Notes

Helper routines are planned to facilitate the creation of the SpaceData container if the data are not in the format.

Examples

```
>>> import spacepy.datamodel as dm
>>> import numpy as np
>>> import spacepy.plot as splot
>>> sd = dm.SpaceData()
>>> sd['radius'] = dm.dmarray(2*np.sin(np.linspace(0,30,500))+4, attrs={'units':'km
↪'})
>>> sd['day_of_year'] = dm.dmarray(np.linspace(74,77,500))
>>> sd['1D_dataset'] = dm.dmarray(np.random.normal(10,3,500)*sd['radius'])
>>> spec = splot.Spectrogram(sd, variables=['day_of_year', 'radius', '1D_dataset'])
>>> ax = spec.plot()
```

plot([target, loc, figsize])	Plot the spectrogram

plot(*target=None*, *loc=111*, *figsize=None*, ***kwargs*)

Plot the spectrogram

Other Parameters

title [str] plot title (default '')

xlabel [str] x axis label (default '')

ylabel [str] y axis label (default '')

colorbar_label [str] colorbar label (default '')

DateFormatter [matplotlib.dates.DateFormatter] The formatting to use on the dates on the x-axis (default matplotlib.dates.DateFormatter("%d %b %Y"))

zlog [bool] plot the z variable on a log scale (default True)

cmap [matplotlib Colormap] colormap instance to use

colorbar [bool] plot the colorbar (default True)

axis [matplotlib axis object] axis to plot the spectrogram to

zlim [np.array] array like 2 element that overrides (interior) the spectrogram zlim (default Spectrogram.specSettings['zlim'])

figsize [tuple (optional)] tuple of size to pass to figure(), None does the default

Function

simpleSpectrogram(*args, **kwargs)	Plot a spectrogram given Z or X,Y,Z.

spacepy.plot.spectrogram.simpleSpectrogram

spacepy.plot.spectrogram.**simpleSpectrogram**(**args*, ***kwargs*)

Plot a spectrogram given Z or X,Y,Z. This is a wrapper around pcolormesh() that can handle Y being a 2d array of time dependent bins. Like in the Van Allen Probes HOPE and MagEIS data files.

Parameters

***args** [1 or 3 arraylike] Call Signatures:

simpleSpectrogram(Z, **kwargs) simpleSpectrogram(X, Y, Z, **kwargs)

Returns

ax [matplotlib.axes._subplots.AxesSubplot] Matplotlib axes object that the plot is on

Other Parameters

zlog [bool] Plot the color with a log colorbar (default: True)

ylog [bool] Plot the Y axis with a log scale (default: True)

alpha [scalar (0-1)] The alpha blending value (default: None)

cmap [string] The name of the colormap to use (default: system default)

vmin [float] Minimum color value (default: Z.min(), if log non-zero min)

vmax [float] Maximum color value (default: Z.max())

ax [matplotlib.axes] Axes to plot the spectrogram on (default: None - new axes)

cb [bool] Plot a colorbar (default: True)

cbtitle [string] Label to go on the colorbar (default: None)

4.12.19 spacepy.plot.utils

Utility routines for plotting and related activities

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Classes

EventClicker([ax, n_phases, interval, ...])	Presents a provided figure (normally a time series) and provides an interface to mark events shown in the plot.

spacepy.plot.utils.EventClicker

class spacepy.plot.utils.**EventClicker**(*ax=None*, *n_phases=1*, *interval=None*, *auto_interval=None*, *auto_scale=True*, *ymin=None*, *ymax=None*, *line=None*)

Presents a provided figure (normally a time series) and provides an interface to mark events shown in the plot. The user interface is explained in *analyze()* and results are returned by *get_events()*

Other Parameters

ax [maplotlib.axes.AxesSubplot] The subplot to display and grab data from. If not provided, the current subplot is grabbed from gca() (Lookup of the current subplot is done when *analyze()* is called.)

n_phases [int (optional, default 1)] number of phases to an event, i.e. number of subevents to mark. E.g. for a storm where one wants the onset and the minimum, set n_phases to 2 and double click on the onset, then minimum, and then the next double-click will be onset of the next storm.

interval [(optional)] Size of the X window to show. This should be in units that can be added to/subtracted from individual elements of x (e.g. timedelta if x is a series of datetime.) Defaults to showing the entire plot.

auto_interval [boolean (optional)] Automatically adjust interval based on the average distance between selected events. Default is True if interval is not specified; False if interval is specified.

auto_scale [boolean (optional, default True):] Automatically adjust the Y axis to match the data as the X axis is panned.

ymin [(optional, default None)] If auto_scale is True, the bottom of the autoscaled Y axis will never be above ymin (i.e. ymin will always be shown on the plot). This prevents the autoscaling from blowing up very small features in mostly flat portions of the plot. The user can still manually zoom in past this point. The autoscaler will always zoom out to show the data.

ymax [(optional, default None)] Similar to ymin, but the top of the Y axis will never be below ymax.

line [matplotlib.lines.Line2D (optional)] Specify the matplotlib line object to use for autoscaling the Y axis. If this is not specified, the first line object on the provided subplot will be used. This should usually be correct.

Examples

```
>>> import spacepy.plot.utils
>>> import numpy
>>> import matplotlib.pyplot as plt
>>> x = numpy.arange(630) / 100.0 * numpy.pi
>>> y = numpy.sin(x)
>>> clicker = spacepy.plot.utils.EventClicker(
... n_phases=2, #Two picks per event
... interval=numpy.pi * 2) #Display one cycle at a time
>>> plt.plot(x, y)
>>> clicker.analyze() #Double-click on max and min of each cycle; close
>>> e = clicker.get_events()
>>> peaks = e[:, 0, 0] #x value of event starts
>>> peaks -= 2 * numpy.pi * numpy.floor(peaks / (2 * numpy.pi)) #mod 2pi
>>> max(numpy.abs(peaks - numpy.pi / 2)) < 0.2 #Peaks should be near pi/2
True
>>> troughs = e[:, 1, 0] #x value of event ends
>>> troughs -= 2 * numpy.pi * numpy.floor(troughs / (2 * numpy.pi))
>>> max(numpy.abs(troughs - 3 * numpy.pi / 2)) < 0.2 #troughs near 3pi/2
True
>>> d = clicker.get_events_data() #snap-to-data of events
>>> peakvals = d[:, 0, 1] #y value, snapped near peaks
>>> max(peakvals) <= 1.0 #should peak at 1
True
>>> min(peakvals) > 0.9 #should click near 1
True
>>> troughvals = d[:, 1, 1] #y value, snapped near peaks
>>> max(troughvals) <= -0.9 #should click near -1
True
>>> min(troughvals) <= -1.0 #should bottom-out at -1
True
```

```
>>> import spacepy.plot.utils
>>> import spacepy.time
>>> import datetime
>>> import matplotlib.pyplot as plt
>>> import numpy
>>> t = spacepy.time.tickrange('2019-01-01', #get a range of days
...                            '2019-12-31',
...                            deltadays=datetime.timedelta(days=1))
>>> y = numpy.linspace(0, 100, 1001)
>>> seconds = t.TAI - t.TAI[0]
>>> seconds = numpy.asarray(seconds) #normal ndarray so reshape (in meshgrid) works
>>> tt, yy = numpy.meshgrid(seconds, y) #use TAI to get seconds
>>> z = 1 + (numpy.exp(-(yy - 20)**2 / 625) #something like a spectrogram
...          * numpy.sin(1e-7 * numpy.pi**2 * tt)**2) #pi*1e7 seconds per year
>>> plt.pcolormesh(t.UTC, y, z)
>>> clicker = spacepy.plot.utils.EventClicker(n_phases=1)
>>> clicker.analyze() #double-click on center of peak; close
>>> events = clicker.get_events() #returns an array of the things clicked
>>> len(events) == 10 #10 if you click on the centers, including the last one
True
```

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```
>>> clicker.get_events_data() is None #should be nothing
True
```

analyze()	Displays the figure provided and allows the user to select events.
get_events()	Get back the list of events.
get_events_data()	Get a list of events, "snapped" to the data.

analyze()
Displays the figure provided and allows the user to select events.

All matplot lib controls for zooming, panning, etc. the figure remain active.

Double left click Mark this point as an event phase. One-phase events are the simplest: they occur at a particular time. Two-phase events have two times associated with them; an example is any event with a distinct start and stop time. In that case, the first double-click would mark the beginning, the second one, the end; the next double-click would mark the beginning of the next event. Each phase of an event is annotated with a vertical line on the plot; the color and line style is the same for all events, but different for each phase.

After marking the final phase of an event, the X axis will scroll and zoom to place that phase near the left of the screeen and include one full interval of data (as defined in the constructor). The Y axis will be scaled to cover the data in that X range.

Double right click or delete button Remove the last marked event phase. If an entire event (i.e., the first phase of an event) is removed, the X axis will be scrolled left to the previous event and the Y axis will be scaled to cover the data in the new range.

Space bar Scroll the X axis by one interval. Y axis will be scaled to cover the data.

When finished, close the figure window (if necessary) and call *get_events()* to get the list of events.

get_events()
Get back the list of events.

Call after *analyze()*.

Returns

out [array] 3-D array of (x, y) values clicked on. Shape is (n_events, n_phases, 2), i.e. indexed by event number, then phase of the event, then (x, y).

get_events_data()
Get a list of events, "snapped" to the data.

For each point selected as a phase of an event, selects the point from the original data which is closest to the clicked point. Distance from point to data is calculated based on the screen distance, not in data coordinates.

Note that this snaps to data points, not to the closest point on the line between points.

Call after *analyze()*.

Returns

out [array] 3-D array of (x, y) values in the data which are closest to each point clicked on. Shape is (n_events, n_phases, 2), i.e. indexed by event number, then phase of the event, then (x, y).

Functions

add_logo(img[, fig, pos, margin])	Add an image (logo) to one corner of a plot.
annotate_xaxis(txt[, ax])	Write text in-line and to the right of the x-axis tick labels
applySmartTimeTicks(ax, time[, dolimit, dolabel])	Given an axis *ax* and a list/array of datetime objects, *time*, use the smartTimeTicks function to build smart time ticks and then immediately apply them to the given axis.
collapse_vertical(combine[, others, leave_axis])	Collapse the vertical spacing between two or more subplots.
printfig(fignum[, saveonly, pngonly, clean, ...])	save current figure to file and call lpr (print).
set_target(target[, figsize, loc, polar])	Given a *target* on which to plot a figure, determine if that *target* is **None** or a matplotlib figure or axes object.
shared_ylabel(axes, txt, *args, **kwargs)	Create a ylabel that spans several subplots
show_used([fig])	Show the areas of a figure which are used/occupied by plot elements.
smartTimeTicks(time)	Returns major ticks, minor ticks and format for time-based plots
timestamp([position, size, draw, strnow, ...])	print a timestamp on the current plot, vertical lower right
add_arrows(lines[, n, size, style, ...])	Add directional arrows along a plotted line.

spacepy.plot.utils.add_logo

spacepy.plot.utils.**add_logo**(*img*, *fig=None*, *pos='br'*, *margin=0.05*)

Add an image (logo) to one corner of a plot.

The provided image will be placed in a corner of the plot and sized to maintain its aspect ratio and be as large as possible without overlapping any existing elements of the figure. Thus this should be the last call in constructing a figure.

Parameters

img [str or numpy.ndarray] The image to place on the figure. If a string, assumed to be a filename to be read with `imread()`; if a numpy array, assumed to be the image itself (in a simliar format).

Returns

(axes, axesimg) [tuple of Axes and AxesImage] The `Axes` object created to hold the iamge, and the `AxesImage` object for the image itself.

Other Parameters

fig [matplotlib.figure.Figure] The figure on which to place the logo; if not specified, the `gcf()` function will be used.

pos [str] The position to place the logo. br: bottom right; bl: bottom left; tl: top left; tr: top right

margin [float] Margin to include on each side of figure, as a fraction of the larger dimension of the figure (width or height). Default is 0.05 (5%).

Notes

Calls `draw()` to ensure locations are up to date.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> ax0 = fig.add_subplot(211)
>>> ax0.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D at 0x00000000>]
>>> ax1 = fig.add_subplot(212)
>>> ax1.plot([1, 2, 3], [2, 1, 2])
[<matplotlib.lines.Line2D at 0x00000000>]
>>> spacepy.plot.utils.add_logo('logo.png', fig)
(<matplotlib.axes.Axes at 0x00000000>,
 <matplotlib.image.AxesImage at 0x00000000>)
```

spacepy.plot.utils.annotate_xaxis

spacepy.plot.utils.**annotate_xaxis**(*txt*, *ax=None*)

Write text in-line and to the right of the x-axis tick labels

Annotates the x axis of an `Axes` object with text placed in-line with the tick labels and immediately to the right of the last label. This is formatted to match the existing tick marks.

Parameters

txt [str] The annotation text.

Returns

out [matplotlib.text.Text] The `Text` object for the annotation.

Other Parameters

ax [matplotlib.axes.Axes] The axes to annotate; if not specified, the `gca()` function will be used.

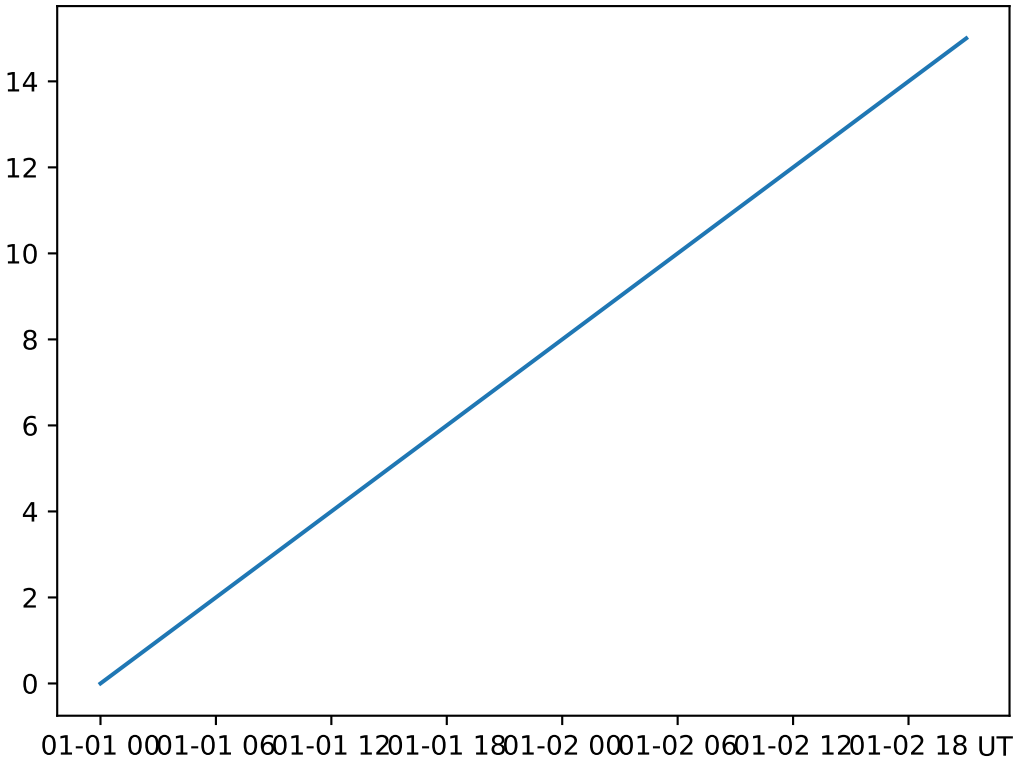
Notes

The annotation is placed *immediately* to the right of the last tick label. Generally the first character of `txt` should be a space to allow some room.

Calls `draw()` to ensure tick marker locations are up to date.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> import datetime
>>> times = [datetime.datetime(2010, 1, 1) + datetime.timedelta(hours=i)
...     for i in range(0, 48, 3)]
>>> plt.plot(times, range(16))
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> spacepy.plot.utils.annotate_xaxis(' UT') #mark that times are UT
<matplotlib.text.Text object at 0x0000000>
```



spacepy.plot.utils.applySmartTimeTicks

spacepy.plot.utils.**applySmartTimeTicks**(*ax*, *time*, *dolimit=True*, *dolabel=False*)

Given an axis *ax* and a list/array of datetime objects, *time*, use the smartTimeTicks function to build smart time ticks and then immediately apply them to the given axis. The first and last elements of the time list will be used as bounds for the x-axis range.

The range of the *time* input value will be used to set the limits of the x-axis as well. Set kwarg 'dolimit' to False to override this behavior.

Parameters

ax [matplotlib.pyplot.Axes] A matplotlib Axis object.

time [list] list of datetime objects

dolimit [boolean (optional)] The range of the *time* input value will be used to set the limits of the x-axis as well. Setting this overrides this behavior.

dolabel [boolean (optional)] Sets autolabeling of the time axis with "Time from" time[0]

See also:

smartTimeTicks

spacepy.plot.utils.collapse_vertical

spacepy.plot.utils.**collapse_vertical**(*combine*, *others=()*, *leave_axis=False*)

Collapse the vertical spacing between two or more subplots.

Useful for a multi-panel plot where most subplots should have space between them but several adjacent ones should not (i.e., appear as a single plot.) This function will remove all the vertical space between the subplots listed in `combine` and redistribute the space between all of the subplots in both `combine` and `others` in proportion to their current size, so that the relative size of the subplots does not change.

Parameters

combine [sequence] The `Axes` objects (i.e. subplots) which should be placed together with no vertical space.

Other Parameters

others [sequence] The `Axes` objects (i.e. subplots) which will keep their vertical spacing, but will be expanded with the space taken away from between the elements of `combine`.

leave_axis [bool] If set to true, will leave the axis lines and tick marks between the collapsed subplots. By default, the axis line ("spine") is removed so the two subplots appear as one.

Notes

This function can be fairly fragile and should only be used for fairly simple layouts, e.g., a one-column multi-row plot stack.

This may require some clean-up of the y axis labels, as they are likely to overlap.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> #Make three stacked subplots
>>> ax0 = fig.add_subplot(311)
>>> ax1 = fig.add_subplot(312)
>>> ax2 = fig.add_subplot(313)
>>> ax0.plot([1, 2, 3], [1, 2, 1]) #just make some lines
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> ax1.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
```

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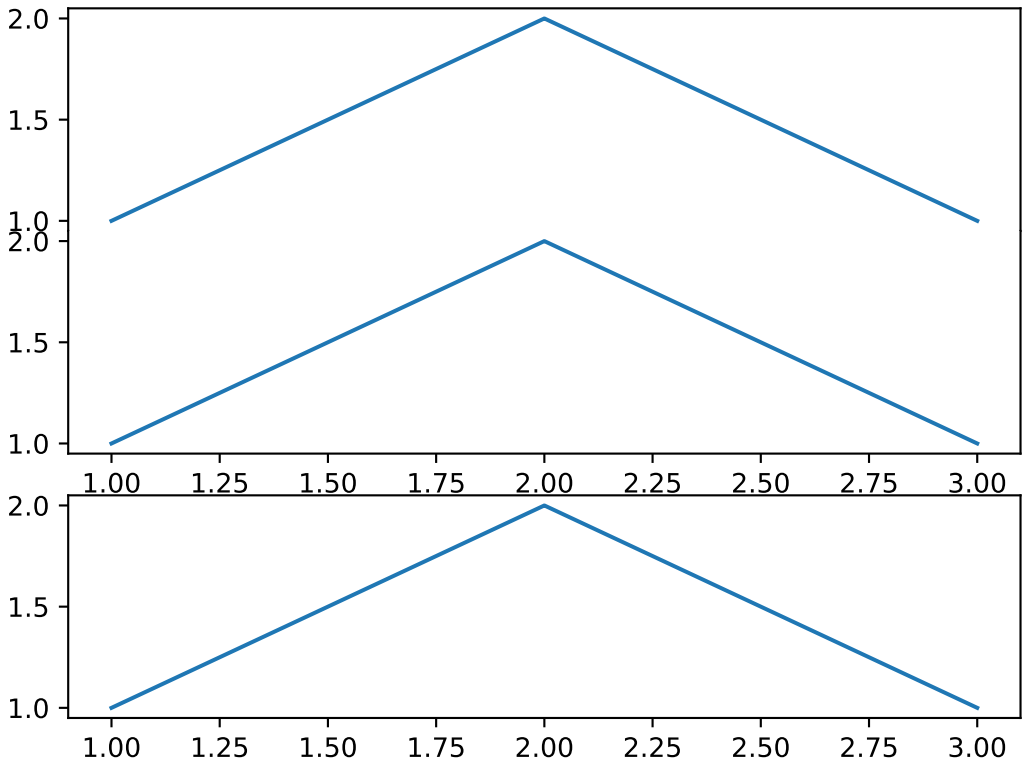
```
>>> ax2.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> #Collapse space between top two plots, leave bottom one alone
>>> spacepy.plot.utils.collapse_vertical([ax0, ax1], [ax2])
```



spacepy.plot.utils.printfig

spacepy.plot.utils.**printfig**(*fignum*, *saveonly=False*, *pngonly=False*, *clean=False*, *filename=None*)

save current figure to file and call lpr (print).

This routine will create a total of 3 files (png, ps and c.png) in the current working directory with a sequence number attached. Also, a time stamp and the location of the file will be imprinted on the figure. The file ending with c.png is clean and no directory or time stamp are attached (good for PowerPoint presentations).

Parameters

fignum [integer] matplotlib figure number

saveonly [boolean (optional)] True (don't print and save only to file) False (print and save)

pngolny [boolean (optional)] True (only save png files and print png directly) False (print ps file, and generate png, ps; can be slow)

clean [boolean (optional)] True (print and save only clean files without directory info) False (print and save directory location as well)

filename [string (optional)] None (If specified then the filename is set and code does not use the sequence number)

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> p = plt.plot([1,2,3],[2,3,2])
>>> spacepy.plot.utils.printfig(1, pngonly=True, saveonly=True)
```

spacepy.plot.utils.set_target

spacepy.plot.utils.**set_target**(*target*, *figsize=None*, *loc=None*, *polar=False*)

Given a *target* on which to plot a figure, determine if that *target* is **None** or a matplotlib figure or axes object. Based on the type of *target*, a figure and/or axes will be either located or generated. Both the figure and axes objects are returned to the caller for further manipulation. This is used in nearly all *add_plot*-type methods.

Parameters

target [object] The object on which plotting will happen.

Returns

fig [object] A matplotlib figure object on which to plot.

ax [object] A matplotlib subplot object on which to plot.

Other Parameters

figsize [tuple] A two-item tuple/list giving the dimensions of the figure, in inches. Defaults to Matplotlib defaults.

loc [integer] The subplot triple that specifies the location of the axes object. Defaults to matplotlib default (111).

polar [bool] Set the axes object to polar coodinates. Defaults to **False**.

Examples

```
>>> import matplotlib.pyplot as plt
>>> from spacepy.pybats import set_target
>>> fig = plt.figure()
>>> fig, ax = set_target(target=fig, loc=211)
```

spacepy.plot.utils.shared_ylabel

spacepy.plot.utils.**shared_ylabel**(*axes*, *txt*, **args*, ***kwargs*)

Create a ylabel that spans several subplots

Useful for a multi-panel plot where several subplots have the same units/quantities on the y axis.

Parameters

axes [list] The `Axes` objects (i.e. subplots) which should share a single label

txt [str] The label to place in the middle of all the *axes* objects.

Returns

out [matplotlib.text.Text] The `Text` object for the label.

Other Parameters

Additional arguments and keywords are passed through to

:meth:`~matplotlib.axes.Axes.set_ylabel`

Notes

This function can be fairly fragile and should only be used for fairly simple layouts, e.g., a one-column multi-row plot stack.

The label is associated with the bottommost subplot in `axes`.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> #Make three stacked subplots
>>> ax0 = fig.add_subplot(311)
>>> ax1 = fig.add_subplot(312)
>>> ax2 = fig.add_subplot(313)
>>> ax0.plot([1, 2, 3], [1, 2, 1]) #just make some lines
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> ax1.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> ax2.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D object at 0x0000000>]
>>> #Create a green label across all three axes
>>> spacepy.plot.utils.shared_ylabel([ax0, ax1, ax2],
... 'this is a very long label that spans all three axes', color='g')
```

spacepy.plot.utils.show_used

spacepy.plot.utils.**show_used**(*fig=None*)

Show the areas of a figure which are used/occupied by plot elements.

This function will overplot each element of a plot with a rectangle showing the full bounds of that element, to see for example the margins and such used by a text label.

Returns

boxes [list of Rectangle] The `Rectangle` objects used for the overplot.

Other Parameters

fig [matplotlib.figure.Figure] The figure to mark up; if not specified, the `gcf()` function will be used.

Notes

Calls `draw()` to ensure locations are up to date.

Examples

```
>>> import spacepy.plot.utils
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> ax0 = fig.add_subplot(211)
>>> ax0.plot([1, 2, 3], [1, 2, 1])
[<matplotlib.lines.Line2D at 0x00000000>]
>>> ax1 = fig.add_subplot(212)
>>> ax1.plot([1, 2, 3], [2, 1, 2])
[<matplotlib.lines.Line2D at 0x00000000>]
>>> spacepy.plot.utils.show_used(fig)
[<matplotlib.patches.Rectangle at 0x0000000>,
 <matplotlib.patches.Rectangle at 0x0000000>,
 <matplotlib.patches.Rectangle at 0x0000000>,
 <matplotlib.patches.Rectangle at 0x0000000>,
 <matplotlib.patches.Rectangle at 0x0000000>,
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 <matplotlib.patches.Rectangle at 0x0000000>,
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```

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```
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
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<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>,
<matplotlib.patches.Rectangle at 0x0000000>]
```

spacepy.plot.utils.smartTimeTicks

spacepy.plot.utils.**smartTimeTicks**(*time*)

Returns major ticks, minor ticks and format for time-based plots

smartTimeTicks takes a list of datetime objects and uses the range to calculate the best tick spacing and format. Returned to the user is a tuple containing the major tick locator, minor tick locator, and a format string – all necessary to apply the ticks to an axis.

It is suggested that, unless the user explicitly needs this info, to use the convenience function applySmartTimeTicks to place the ticks directly on a given axis.

Parameters

time [list] list of datetime objects

Returns

out [tuple] tuple of Mtick - major ticks, mtick - minor ticks, fmt - format

See also:

applySmartTimeTicks

spacepy.plot.utils.timestamp

spacepy.plot.utils.**timestamp**(*position=(1.003, 0.01)*, *size='xx-small'*, *draw=True*, *strnow=None*, *rotation='vertical'*, *ax=None*, ***kwargs*)

print a timestamp on the current plot, vertical lower right

Parameters

position [list] position for the timestamp

size [string (optional)] text size

draw [Boolean (optional)] call draw to make sure it appears

kwargs [keywords] other keywords to axis.annotate

Examples

```
>>> import spacepy.plot.utils
>>> from pylab import plot, arange
>>> plot(arange(11))
[<matplotlib.lines.Line2D object at 0x49072b0>]
>>> spacepy.plot.utils.timestamp()
```

spacepy.plot.utils.add_arrows

spacepy.plot.utils.**add_arrows**(*lines*, *n=3*, *size=12*, *style='->'*, *dorestrict=False*, *positions=False*)

Add directional arrows along a plotted line. Useful for plotting flow lines, magnetic field lines, or other directional traces.

lines can be either `Line2D`, a list or tuple of lines, or a `LineCollection` object.

For each line, arrows will be added using `annotate()`. Arrows will be spread evenly over the line using the number of points in the line as the metric for spacing. For example, if a line has 120 points and 3 arrows are requested, an arrow will be added at point number 30, 60, and 90. Arrow color and alpha is obtained from the parent line.

Parameters

lines [`Line2D`, a list/tuple, or `LineCollection`] A single line or group of lines on which to place the arrows. Arrows inherent color and transparency (alpha) from the line on which they are placed.

Returns

None

Other Parameters

n [integer] Number of arrows to add to each line; defaults to 3.

size [integer] The size of the arrows in points. Defaults to 12.

style [string] Set the style of the arrow via `ArrowStyle`, e.g. '->' (default) or '-|>'

dorestrict [boolean] If True (default), only points along the line within the current limits of the axes will be considered when distributing arrows.

positions [Nx2 array] N must be the number of lines provided via the argument *lines*. If provided, only one arrow will be placed per line. *positions* sets the explicit location of each arrow for each line as X-Y space in Axes coordinates.

Notes

The algorithm works by dividing the line in to *n*+1 segments and placing an arrow between each segment, endpoints excluded. Arrows span the shortest distance possible, i.e., two adjacent points along a line. For lines that are long spatially but sparse in points, the arrows will have long tails that may extend beyond axes bounds. For explicit positions, the arrow is placed at the point on the curve closest to that position and the exact position is not always attainable. A maximum number of arrows equal to one-half of the number of points in a line per line will be created, so not all lines will receive *n* arrows.

Examples

```
>>> import matplotlib.pyplot as plt
>>> import numpy as np
>>> x = np.arange(1, 10, .01)
>>> y = np.sin(x)
>>> line = plt.plot(x,y)
>>> add_arrows(line, n=15, style='-|>')
```

4.13 PoPPy - Point Processes in Python

PoPPy – Point Processes in Python.

This module contains point process class types and a variety of functions for association analysis. The routines given here grew from work presented by Morley and Freeman (Geophysical Research Letters, 34, L08104, doi:10.1029/2006GL028891, 2007), which were originally written in IDL. This module is intended for application to discrete time series of events to assess statistical association between the series and to calculate confidence limits. Any mis-application or mis-interpretation by the user is the user's own fault.

```
>>> import datetime as dt
>>> import spacepy.time as spt
```

Since association analysis is rather computationally expensive, this example shows timing.

```
>>> t0 = dt.datetime.now()
>>> onsets = spt.Ticktock(onset_epochs, 'CDF')
>>> ticksR1 = spt.Ticktock(tr_list, 'CDF')
```

Each instance must be initialized

```
>>> lags = [dt.timedelta(minutes=n) for n in range(-400,401,2)]
>>> halfwindow = dt.timedelta(minutes=10)
>>> pp1 = poppy.PPro(onsets.UTC, ticksR1.UTC, lags, halfwindow)
```

To perform association analysis

```
>>> pp1.assoc()
Starting association analysis
calculating association for series of length [3494, 1323] at 401 lags
>>> t1 = dt.datetime.now()
>>> print("Elapsed:  " + str(t1-t0))
Elapsed:  0:35:46.927138
```

Note that for calculating associations between long series at a large number of lags is SLOW!!

To plot

```
>>> pp1.plot(dpi=80)
Error: No confidence intervals to plot - skipping
```

To add 95% confidence limits (using 4000 bootstrap samples)

```
>>> pp1.aa_ci(95, n_boots=4000)
```

The plot method will then add the 95% confidence intervals as a semi- transparent patch.

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Classes

PPro(process1, process2[, lags, winhalf, ...])	PoPPy point process object

4.13.1 spacepy.poppy.PPro

class spacepy.poppy.**PPro**(*process1*, *process2*, *lags=None*, *winhalf=None*, *verbose=False*)

PoPPy point process object

Initialize object with series1 and series2. These should be timeseries of events, given as lists, arrays, or lists of datetime objects. Includes method to perform association analysis of input series

Output can be nicely plotted with *plot()*.

aa_ci(inter[, n_boots, seed])	Get bootstrap confidence intervals for association number
assoc([u, h])	Perform association analysis on input series
assoc_mult(windows[, inter, n_boots, seed])	Association analysis w/confidence interval on multiple windows
plot([figsize, dpi, asympt, show, norm, ...])	Create basic plot of association analysis.
plot_mult(windows, data[, min, max, ...])	Plots a 2D function of window size and lag
swap()	Swaps process 1 and process 2

aa_ci(*inter*, *n_boots=1000*, *seed=None*)

Get bootstrap confidence intervals for association number

Requires input of desired confidence interval, e.g.:

```
>>> obj.aa_ci(95)
```

Upper and lower confidence limits are added to *ci*.

After calling, *conf_above* will contain the confidence (in percent) that the association number at that lag is *above* the asymptotic association number. (The confidence of being below is 100 - conf_above) For minor variations in conf_above to be meaningful, a *large* number of bootstraps is required. (Rougly, 1000 to be meaningful to the nearest percent; 10000 to be meaningful to a tenth of a percent.) A conf_above of 100 usually indicates an insufficient sample size to resolve, *not* perfect certainty.

Note also that a 95% chance of being above indicates an exclusion from the *90%* confidence interval!

Parameters

inter [float] percentage confidence interval to calculate

n_boots [int, optional] number of bootstrap iterations to run

seed [int, optional] seed for the random number generator. If not specified, Python code will use numpy's RNG and its current seed; C code will seed from the clock.

> **Warning:** If `seed` is specified, results may not be reproducible between systems with different sizes for C long type. Note that 64-bit Windows uses a 32-bit long and so results will be the same between 64 and 32-bit Windows, but not between 64-bit Windows and other 64-bit operating systems. If `seed` is not specified, results are not reproducible anyhow.

`assoc`(*u=None*, *h=None*)
Perform association analysis on input series

Parameters

u [list, optional] the time lags to use

h association window half-width, same type as process1

`assoc_mult`(*windows*, *inter=95*, *n_boots=1000*, *seed=None*)
Association analysis w/confidence interval on multiple windows

Using the time sequence and lags stored in this object, perform full association analysis, including bootstrapping of confidence intervals, for every listed window half-size

Parameters

windows [sequence] window half-size for each analysis

inter [float, optional] desired confidence interval, default 95

n_boots [int, optional] number of bootstrap iterations, default 1000

seed [int, optional] Random number generator seed. It is STRONGLY recommended not to specify (i.e. leave None) to permit multithreading.

Returns

out [three numpy array] Three numpy arrays, (windows x lags), containing (in order) low values of confidence interval, high values of ci, percentage confidence above the asymptotic association number

> **Warning:** This function is likely to take a LOT of time.

`ci`
Contains the upper and lower confidence limits for the association number as a function of lag. The first element is the array of lower limits; the second, the array of upper limits. Not available until after calling *aa_ci()*.

`conf_above`
Contains the confidence that the association number, as a function of lag, is above the asymptotic association number. (The confidence of being below is 100 - `conf_above`.) Not available until after calling *aa_ci()*.

`plot`(*figsize=None*, *dpi=80*, *asympt=True*, *show=True*, *norm=True*, *xlabel='Time lag'*, *xscale=None*, *ylabel=None*, *title=None*, *transparent=True*)
Create basic plot of association analysis.

Uses object attributes created by *assoc()* and, optionally, *aa_ci()*.

Parameters

figsize [, optional] passed through to matplotlib.pyplot.figure

dpi [int, optional] passed through to matplotlib.pyplot.figure

asympt [boolean, optional] True to overplot the line of asymptotic association number

show [boolean, optional] Show the plot? (if false, will create without showing)

norm [boolean, optional] Normalize plot to the asymptotic association number

title [string, optional] label/title for the plot

xlabel [string, optional] label to put on the X axis of the resulting plot

xscale [float, optional] scale x-axis by this factor (e.g. 60.0 to convert seconds to minutes)

ylabel [string, optional] label to put on the Y axis of the resulting plot

transparent [boolean, optional] make c.i. patch transparent (default)

plot_mult(*windows*, *data*, *min=None*, *max=None*, *cbar_label=None*, *figsize=None*, *dpi=80*, *xlabel='Lag'*, *ylabel='Window Size'*)

Plots a 2D function of window size and lag

Parameters

windows [list] list of window sizes (y axis)

data [list] list of data, dimensioned (windows x lags)

min [float, optional] clip L{data} to this minimum value

max [float, optional] clip L{data} to this maximum value

swap()

Swaps process 1 and process 2

Functions

plot_two_ppro(pprodata, pproref[, ratio, ...])	Overplots two PPro objects
boots_ci(data, n, inter, func[, seed, ...])	Construct bootstrap confidence interval
value_percentile(sequence, target)	Find the percentile of a particular value in a sequence

4.13.2 spacepy.poppy.plot_two_ppro

spacepy.poppy.**plot_two_ppro**(*pprodata*, *pproref*, *ratio=None*, *norm=False*, *title=None*, *xscale=None*, *figsize=None*, *dpi=80*, *ylim=[None, None]*, *log=False*, *xticks=None*, *yticks=None*)

Overplots two PPro objects

Parameters

pprodata [PPro] first point process to plot (in blue)

pproref [PPro] second process to plot (in red)

ratio [float] multiply L{pprodata} by this ratio before plotting, useful for comparing processes of different magnitude

norm [boolean] normalize everything to L{pproref}, i.e. the association number for L{pproref} will always plot as 1.

title [string] title to put on the plot

xscale [float] scale x-axis by this factor (e.g. 60.0 to convert seconds to minutes)

figsize passed through to matplotlib.pyplot.figure

dpi [int] passed through to matplotlib.pyplot.figure

ylim [list] [minimum, maximum] values of y for the axis

log [bollean] True for a log plot

xticks [sequence or float] if provided, a list of tickmarks for the X axis

yticks [sequance or float] if provided, a list of tickmarks for the Y axis

4.13.3 spacepy.poppy.boots_ci

spacepy.poppy.**boots_ci**(*data*, *n*, *inter*, *func*, *seed=None*, *target=None*, *sample_size=None*, *usepy=False*, *nretvals=1*)

Construct bootstrap confidence interval

The bootstrap is a statistical tool that uses multiple samples derived from the original data (called surrogates) to estimate a parameter of the population from which the sample was drawn. This assumes that the sample is randomly drawn and hence is representative of the underlying distribution. The benefit of the bootstrap is that it is non-parametric and can be applied in situations where there is reasonable doubt about the characteristics of the underlying distribution. This routine uses the boot- strap for its most common application - the estimation of confidence intervals.

Parameters

data [array like] data to bootstrap

n [int] number of surrogate series to select, i.e. number of bootstrap iterations.

inter [numerical] desired percentage confidence interval

func [callable] Function to apply to each surrogate series

sample_size [int] number of samples in the surrogate series, default length of L{data}. This will change the statistical properties of the bootstrap and should only be used for good reason!

seed [int] Optional seed for the random number generator. If not specified, numpy generator will not be reseeded; C generator will be seeded from the clock.

target [same as data] a 'target' value. If specified, will also calculate percentage confidence of being at or above this value.

nretvals [int] number of return values from input function

Returns

out [sequence of float] inter percent confidence interval on value derived from func applied to the population sampled by data. If target is specified, also the percentage confidence of being above that value.

Examples

```
>>> data, n = numpy.random.lognormal(mean=5.1, sigma=0.3, size=3000), 4000.
>>> myfunc = lambda x: numpy.median(x)
>>> ci_low, ci_high = poppy.boots_ci(data, n, 95, myfunc)
>>> ci_low, numpy.median(data), ci_high
(163.96354196633686, 165.2393331896551, 166.60491435416566) iter. 1
... repeat
(162.50379144492726, 164.15218265100233, 165.42840588032755) iter. 2
```

For comparison

```
>>> data = numpy.random.lognormal(mean=5.1, sigma=0.3, size=90000)
>>> numpy.median(data)
163.83888237895815
```

Note that the true value of the desired quantity may lie outside the 95% confidence interval one time in 20 realizations. This occurred for the first iteration here.

For the lognormal distribution, the median is found exactly by taking the exponential of the "mean" parameter. Thus here, the theoretical median is 164.022 (6 s.f.) and this is well captured by the above bootstrap confidence interval.

4.13.4 spacepy.poppy.value_percentile

spacepy.poppy.**value_percentile**(*sequence*, *target*)

Find the percentile of a particular value in a sequence

Parameters

sequence [sequence] a sequence of values, sorted in ascending order

target [same type as sequence] a target value

Returns

out [float] the percentile of target in sequence

4.14 PyBats - SWMF & BATS-R-US Analysis Tools

PyBats! An open source Python-based interface for reading, manipulating, and visualizing BATS-R-US and SWMF output. For more information on the SWMF, please visit the Center for Space Environment Modeling.

4.14.1 Introduction

At its most fundamental level, PyBats provides access to output files written by the Space Weather Modeling Framework and the codes contained within. The key task performed by PyBats is loading simulation data into a Spacepy data model object so that the user can move on to the important tasks of analyzing and visualizing the values. The secondary goal of PyBats is to make common tasks performed with these data as easy as possible. The result is that most SWMF output can be opened and visualized using only a few lines of code. Many complicated tasks, such as field line integration, is included as well.

4.14.2 Organization

Many output files in the SWMF share a common format. Objects to handle broad formats like these are found in the base module. The base module has classes to handle SWMF *input* files, as well.

The rest of the classes are organized by code, i.e. classes and functions specifically relevant to BATS-R-US can be found in *spacepy.pybats.bats*. Whenever a certain code included in the SWMF requires a independent class or a subclass from the PyBats base module, it will receive its own submodule.

4.14.3 Conventions and Prefixes

Nearly every class in PyBats inherits from *spacepy.datamodel.SpaceData*, so it is important for users to understand how to employ and explore SpaceData objects. There are a few exceptions, so always pay close attention to the docstrings and examples. Legacy code that does not adhere to this pattern is slowly being brought up-to-date with each release.

Visualization methods have two prefixes: *plot_* and *add_*. Whenever a method begins with *plot_*, a quick-look product will be created that is not highly- configurable. These methods are meant to yeild either simple diagnostic plots or static, often-used products. There are few methods that use this prefix. The prefix *add_* is always followed by *plot_type*; it indicates a plotting method that is highly configurable and meant to be combined with other *add_*-like methods and matplotlib commands.

Common calculations, such as calculating Alfven wave speeds of MHD results, are strewn about PyBats' classes. They are always given the method prefix *calc_*, i.e. *calc_alfven*. Methods called *calc_all* will search for all class methods with the *calc_* prefix and call them.

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4.14.4 Submodules

There are submodules for most models included within the SWMF. The classes and methods contained within are code-specific, yielding power and convenience at the cost of flexibility. A few of the submodules are helper modules- they are not code specific, but rather provide functionality not related to an SWMF-included code.

bats	A PyBats module for handling input, output, and visualization of binary SWMF output files taylored to BATS-R-US-type data.
dgcpm	The PyBats submodule for handling input and output for the Dynamic Global Core Plasma Model (DGCPM), a plasmasphere module of the SWMF.
dipole	Some functions for the generation of a dipole field.
gitm	PyBats submodule for handling input/output for the Global Ionosphere-Thermosphere Model (GITM), one of the choices for the UA module in the SWMF.
kyoto	kyoto is a tool set for obtaining and handling geomagnetic indices stored at the Kyoto World Data Center (WDC) website.
pwom	PyBats submodule for handling input/output for the Polar Wind Outflow Model (PWOM), one of the choices for the PW module in the SWMF.
ram	A module for reading, handling, and plotting RAM-SCB output.
rim	Classes, functions, and methods for reading, writing, and plotting output from the Ridley Ionosphere Model (RIM) and the similar legacy code, Ridley Serial.
trace2d	A set of routines for fast field line tracing.

spacepy.pybats.bats

A PyBats module for handling input, output, and visualization of binary SWMF output files taylored to BATS-R-US-type data.

Classes

BatsLog(filename[, starttime, keep_case])	A specialized version of *LogFile* that includes special methods for plotting common BATS-R-US log file values, such as D$_{ST}$.
Stream(bats, xstart, ystart, xfield, yfield)	A class for streamlines.
Bats2d(filename, *args, **kwargs)	A child class of `IdlFile` tailored to 2D BATS-R-US output.
Mag(nlines, time[, gmvars, ievars])	A container for data from a single BATS-R-US virtual magnetometer.
MagFile(filename[, ie_name, find_ie])	BATS-R-US magnetometer files are powerful tools for both research and operations.
GeoIndexFile(filename[, keep_case])	Geomagnetic Index files are a specialized BATS-R-US output that contain geomagnetic indices calculated from simulated ground-based magnetometers.
VirtSat(*args, **kwargs)	A *spacepy.pybats.LogFile* object tailored to virtual satellite output; includes special satellite-specific plotting methods.

spacepy.pybats.bats.BatsLog

class spacepy.pybats.bats.**BatsLog**(*filename*, *starttime=(2000, 1, 1, 0, 0, 0)*, *keep_case=True*, **args*, ***kwargs*)

A specialized version of *LogFile* that includes special methods for plotting common BATS-R-US log file values, such as D$_{ST}$.

add_dst_quicklook([target, loc, plot_obs, ...])	Create a quick-look plot of Dst (if variable present in file) and compare against observations.

add_dst_quicklook(*target=None*, *loc=111*, *plot_obs=False*, *epoch=None*, *add_legend=True*, *plot_sym=False*, *dstvar=None*, *obs_kwargs={'c': 'k', 'ls': '--'}*, ***kwargs*)

Create a quick-look plot of Dst (if variable present in file) and compare against observations.

Like all *add_* * methods in Pybats, the *target* kwarg determines where to place the plot. If kwarg *target* is **None** (default), a new figure is generated from scratch. If *target* is a matplotlib Figure object, a new axis is created to fill that figure at subplot location *loc* (defaults to 111). If target is a matplotlib Axes object, the plot is placed into that axis at subplot location *loc*.

With newer versions of BATS-R-US, new dst-like variables are included, named 'dst', 'dst-sm', 'dstflx', etc. This subroutine will attempt to first use 'dst-sm' as it is calculated consistently with observations. If not found, 'dst' is used. Users may choose which value to use via the *dstvar* kwarg.

Observed Dst and SYM-H is automatically fetched from the Kyoto World Data Center via the *spacepy.pybats.kyoto* module. The associated `spacepy.pybats.kyoto.KyotoDst` or `spacepy.pybats.kyoto.KyotoSym` object, which holds the observed Dst/SYM-H, is stored as *self.obs_dst* for future use. The observed line can be customized via the *obs_kwargs* kwarg, which is a dictionary of plotting keyword arguments.

If kwarg *epoch* is set to a datetime object, a vertical dashed line will be placed at that time.

The figure and axes objects are returned to the user.

spacepy.pybats.bats.Stream

class spacepy.pybats.bats.**Stream**(*bats*, *xstart*, *ystart*, *xfield*, *yfield*, *style='mag'*, *type='streamline'*, *method='rk4'*, *var_list='all'*, *extract=False*, *maxPoints=20000*, **args*, ***kwargs*)

A class for streamlines. Contains all of the information about the streamline, including extracted variables.

Upon instantiation, the object will trace through the vector field determined by the "[x/y]field" values and the Bats object "bats".

Parameters

bats [Bats] *Bats2d* object through which to trace.

xstart [float] X value of location to start the trace.

ystart [float] Y value of location to start the trace.

xfield [str] Name of variable in `bats` which contains X values of the field

yfield [str] Name of variable in `bats` which contains Y values of the field

Other Parameters

style [str] Sets line style, including colors. See *set_style()* for details. (Default 'mag')

type [str] (Default 'streamline')

method [str] Integration method. The default is Runge-Kutta 4 ('rk4') which gives a good blend of speed and accuracy. See the test functions in *trace2d* for more info. The other option is a simple Euler's method approach ('eul'). (Default 'rk4')

extract [bool] (Default: False) Extract variables along stream trace and save within object.

maxPoints [int] (Default : 20000) Maximum number of integration steps to take.

var_list [string or sequence of strings] (Default : 'all') List of values to extract from *dataset*. Defaults to 'all', for all values within *bats*.

Notes

Methods

set_style(style)	Set the line style either using a simple matplotlib-type style string or using a preset style type.
treetrace(bats[, maxPoints])	Trace through the vector field using the quad tree.
trace(bats)	Trace through the vector field.
plot(ax, *args, **kwargs)	Add streamline to axes object "ax".

set_style(*style*)

Set the line style either using a simple matplotlib-type style string or using a preset style type. Current types include:

'mag' [treat line as a magnetic field line. Closed lines are] white, other lines are black.

treetrace(*bats*, *maxPoints=20000*)
Trace through the vector field using the quad tree.

trace(*bats*)
Trace through the vector field.

plot(*ax*, **args*, ***kwargs*)
Add streamline to axes object "ax".

spacepy.pybats.bats.Bats2d

class spacepy.pybats.bats.**Bats2d**(*filename*, **args*, ***kwargs*)
A child class of `IdlFile` tailored to 2D BATS-R-US output.

spacepy.pybats.bats.Mag

class spacepy.pybats.bats.**Mag**(*nlines*, *time*, *gmvars=()*, *ievars=()*, **args*, ***kwargs*)
A container for data from a single BATS-R-US virtual magnetometer. These work just like a typical *spacepy.pybats.PbData* object. Beyond raw magnetometer data, additional values are calculated and stored, including total pertubations (the sum of all global and ionospheric pertubations as measured by the magnetometer). Users will be interested in methods `add_comp_plot()` and `calc_dbdt()`.

Instantiation is best done through :class: *spacepy.pybats.MagFile* objects, which load and parse organize many virtual magnetometers from a single output file into a single object. However, they can be created manually, though painfully. Users must instantiate by handing the new object the number of lines that will be parsed (rather, the number of data points that will be needed), a time vector, and (optionally) the list of variables coming from the GM and IE module. While the latter two are keyword arguments, at least one should be provided. Next, the arrays whose keys were given by the *gmvars* and *ievars* keyword arguments in the instantiation step can either be filled manually or by using the `parse_gmline()` and `parse_ieline()` methods to parse lines of ascii data from a magnetometer output file. Finally, the `recalc()` method should be called to calculate total perturbation.

spacepy.pybats.bats.MagFile

class spacepy.pybats.bats.**MagFile**(*filename*, *ie_name=None*, *find_ie=False*, **args*, ***kwargs*)
BATS-R-US magnetometer files are powerful tools for both research and operations. *MagFile* objects open, parse, and visualize such output.

The $delta B$ calculated by the SWMF requires two components: GM (BATSRUS) and IE (Ridley_serial). The data is spread across two files: GM_mag*.dat and IE_mag*.dat. The former contains $delta B$ caused by gap-region (i.e., inside the inner boundary) FACs and the changing global field. The latter contains the $delta B$ caused by Pederson and Hall currents in the ionosphere. *MagFile* objects can open one or both of these files at a time; when both are opened, the total $delta B$ is calculated and made available to the user.

Usage:

```
>>> # Open up the GM magnetometer file only.
>>> obj = spacepy.pybats.bats.MagFile('GM_file.mag')
>>>
>>> # Open up both the GM and IE file [LEGACY SWMF ONLY]
>>> obj = spacepy.pybats.bats.MagFile('GM_file.mag', 'IE_file.mag')
>>>
>>> # Open up the GM magnetometer file; search for the IE file.
>>> obj = spacepy.pybats.bats.MagFile('GM_file.mag', find_ie=True)
```

Note that the **find_ie** kwarg uses a simple search assuming the data remain in a typical SWMF-output organizational tree (i.e., if the results of a simulation are in folder *results*, the GM magnetometer file can be found in *results/GM/* or *results/GM/IO2/* while the IE file can be found in *results/IE/* or *results/IE/ionosphere/*). It will also search the present working directory. This method is not robust; the user must take care to ensure that the two files correspond to each other.

spacepy.pybats.bats.GeoIndexFile

class spacepy.pybats.bats.**GeoIndexFile**(*filename*, *keep_case=True*, **args*, ***kwargs*)

Geomagnetic Index files are a specialized BATS-R-US output that contain geomagnetic indices calculated from simulated ground-based magnetometers. Currently, the only index instituted is Kp through the faKe_p setup. Future work will expand the system to include Dst, AE, etc.

GeoIndFiles are a specialized subclass of pybats.LogFile. It includes additional methods to quickly visualize the output, perform data-model comparisons, and more.

spacepy.pybats.bats.VirtSat

class spacepy.pybats.bats.**VirtSat**(**args*, ***kwargs*)

A *spacepy.pybats.LogFile* object tailored to virtual satellite output; includes special satellite-specific plotting methods.

spacepy.pybats.dgcpm

The PyBats submodule for handling input and output for the Dynamic Global Core Plasma Model (DGCPM), a plasmasphere module of the SWMF.

spacepy.pybats.dipole

Some functions for the generation of a dipole field.

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spacepy.pybats.gitm

PyBats submodule for handling input/output for the Global Ionosphere-Thermosphere Model (GITM), one of the choices for the UA module in the SWMF.

spacepy.pybats.kyoto

kyoto is a tool set for obtaining and handling geomagnetic indices stored at the Kyoto World Data Center (WDC) website. Indices can be loaded from file or fetched from the web.

Instantiation of objects from this module should be done through the constructor functions `fetch()` and `load()`. Use help on these objects for more information.

spacepy.pybats.pwom

PyBats submodule for handling input/output for the Polar Wind Outflow Model (PWOM), one of the choices for the PW module in the SWMF.

spacepy.pybats.ram

A module for reading, handling, and plotting RAM-SCB output.

spacepy.pybats.rim

Classes, functions, and methods for reading, writing, and plotting output from the Ridley Ionosphere Model (RIM) and the similar legacy code, Ridley Serial.

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Classes

Iono(infile, *args, **kwargs)	A class for handling 2D output from the Ridley Ionosphere Model.
OvalDebugFile(infile, *args, **kwargs)	The auroral oval calculations in RIM may spit out special debug files that are extremely useful.

spacepy.pybats.rim.Iono

class spacepy.pybats.rim.**Iono**(*infile*, **args*, ***kwargs*)

A class for handling 2D output from the Ridley Ionosphere Model. Instantiate an object as follows:

```
>>> iono = rim.Iono('filename.idl')
```

...where filename.idl is the name of a RIM 2D output file.

spacepy.pybats.rim.OvalDebugFile

class spacepy.pybats.rim.**OvalDebugFile**(*infile*, **args*, ***kwargs*)

The auroral oval calculations in RIM may spit out special debug files that are extremely useful. This class handles reading and plotting the data contained within those files.

Functions

get_iono_cb([ct_name])	Several custom colorbars used by RIM and AMIE have become standard when visualizing data from these models.
tex_label(varname)	Many variable names used in the Ridley Ionosphere Model look much better in LaTeX format with their proper Greek letters.

spacepy.pybats.rim.get_iono_cb

spacepy.pybats.rim.**get_iono_cb**(*ct_name='bwr'*)

Several custom colorbars used by RIM and AMIE have become standard when visualizing data from these models. These are 'blue_white_red' and 'white_red', used for data that have positive and negative values and for data that have only positive values, respectively. This function builds and returns these colorbars when called with the initials of the color table name as the only argument.

Other Parameters

ct_name [str] Select the color table. Can be 'bwr' for blue-white-red or 'wr' for white-red. Defaults to 'bwr'.

Examples

```
>>> bwr_map = get_iono_cb('bwr')
>>> wr_map  = get_iono_cb('wr')
```

spacepy.pybats.rim.tex_label

spacepy.pybats.rim.**tex_label**(*varname*)

Many variable names used in the Ridley Ionosphere Model look much better in LaTeX format with their proper Greek letters. This function takes a variable name, and if it is recognized, returns a properly formatted string that uses MatPlotLib's MathText functionality to display the proper characters. If it is not recognized, the varname is returned.

Parameters

varname [string] The variable to convert to a LaTeX label.

Examples

>>>tex_label('n_phi') 'Phi_{Ionosphere}' >>>tex_label('Not Recognized') 'Not Recognized'

spacepy.pybats.trace2d

A set of routines for fast field line tracing. "Number crunching" is performed in C for speed.

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4.14.5 Top-Level Classes & Functions

Top-level PyBats classes handle common-format input and output from the SWMF and are very flexible. However, they do little beyond open files for the user.

There are several functions found in the top-level module. These are mostly convenience functions for customizing plots.

Classes

IdlFile(filename[, iframe, header, keep_case])	**Parameters**
ImfInput([filename, load, npoints])	A class to read, write, manipulate, and visualize solar wind upstream input files for SWMF simulations.
LogFile(filename[, starttime, keep_case])	An object to read and handle SWMF-type logfiles.
NgdcIndex([filename, load])	Many models incorporated into the SWMF rely on National Geophysical Data Center (NGDC) provided index files (especially F10.7 and Kp).
PbData(*args, **kwargs)	The base class for all PyBats data container classes.
SatOrbit([filename])	An class to load, read, write, and handle BATS-R-US satellite orbit input files.

spacepy.pybats.IdlFile

class spacepy.pybats.**IdlFile**(*filename*, *iframe=0*, *header='units'*, *keep_case=True*, **args*, ***kwargs*)

Parameters

filename [string] A *.out or *.outs SWMF output file name.

Other Parameters

header [str or **None**] Determine how to interpret the additional header information. Defaults to 'units'.

keep_case [boolean] If set to True, the case of variable names will be preserved. If set to False, variable names will be set to all lower case.

Notes

PyBats assumes little endian byte ordering because this is what most machines use. However, there is an autodetect feature such that, if PyBats doesn't make sense of the first read (a record length entry, or RecLen), it will proceed using big endian ordering. If this doesn't work, the error will manifest itself through the "struct" package as an "unpack requires a string of argument length 'X'".

spacepy.pybats.ImfInput

class spacepy.pybats.**ImfInput**(*filename=False*, *load=True*, *npoints=0*, **args*, ***kwargs*)

A class to read, write, manipulate, and visualize solar wind upstream input files for SWMF simulations. More about such files can be found in the SWMF/BATS-R-US documentation for the #SOLARWINDFILE command.

Creating an *ImfInput* object is simple:

```
>>> from spacepy import pybats
>>> obj=pybats.ImfInput(filename='test.dat', load=True)
```

Upon instantiation, if *filename* is a valid file AND kwarg *load* is set to boolean True, the contents of *filename* are loaded into the object and no other work needs to be done.

If *filename* is False or *load* is False, a blank `ImfInput file` is created for the user to manipulate. The user can set the time array and the associated data values (see *obj.attrs['var']* for a list) to any values desired and use the

method *obj.write()* to dump the contents to an SWMF formatted input file. See the documentation for the write method for more details.

Like most *pybats* objects, you may interact with *ImfInput* objects as if they were specialized dictionaries. Access data like so:

```
>>> obj.keys()
['bx', 'by', 'bz', 'vx', 'vy', 'vz', 'rho', 'temp']
>>> density=obj['rho']
```

Adding new data entries is equally simple so long as you have the values and the name for the values:

```
>>> import numpy as np
>>> v = np.sqrt(obj['vx']**2 + obj['vy']**2 + obj['vz']**2)
>>> obj['v']=v
```

Kwarg	Description
filename	Set the input/output file name.
load	Read file upon instantiation? Defaults to **True**
npoints	For empty data sets, sets number of points (default is 0)

spacepy.pybats.LogFile

class spacepy.pybats.**LogFile**(*filename*, *starttime=(2000, 1, 1, 0, 0, 0)*, *keep_case=True*, **args*, ***kwargs*)

An object to read and handle SWMF-type logfiles.

LogFile objects read and hold all information in an SWMF ascii time-varying logfile. The file is read upon instantiation. Many SWMF codes produce flat ascii files that can be read by this class; the most frequently used ones have their own classes that inherit from this.

See *spacepy.pybats.PbData* for information on how to explore data contained within the returned object.

Usage: >>>data = spacepy.pybats.LogFile('filename.log')

kwarg	Description
starttime	Manually set the start time of the data.

Time is handled by Python's datetime package. Given that time may or may not be given in the logfile, there are three options for how time is returned:

1. if the full date and time are listed in the file, `self['time']` is an array of datetime objects corresponding to the entries. The starttime kwarg is ignored.

2. If only the runtime (seconds from start of simulation) is given, self['time'] is an array of datetime objects that starts from the given *starttime* kwarg which defaults to 1/1/1 00:00UT.

3. If neither of the above are given, the time is assumed to advance one second per line starting from either the starttime kwarg or from 2000/1/1 00:00UT + the first iteration (if given in file.) As you can imagine, this is sketchy at best.

This time issue is output dependent: some SWMF models place the full date and time into the log by default while others will almost never include the full date and time. The variable `self['runtime']` contains the more generic seconds from simulation start values.

Example usage:

```
>>> import spacepy.pybats as pb
>>> import pylab as plt
>>> import datetime as dt
>>> time1 = dt.datetime(2009,11,30,9,0)
>>> file1 = pb.logfile('satfile_n0000000.dat', starttime=time1)
>>> plt.plot(file1['time'], file1['dst'])
```

spacepy.pybats.NgdcIndex

class spacepy.pybats.**NgdcIndex**(*filename=None*, *load=True*, **args*, ***kwargs*)

Many models incorporated into the SWMF rely on National Geophysical Data Center (NGDC) provided index files (especially F10.7 and Kp). These files, albeit simple ascii, have a unique format and expansive header that can be cumbersome to handle. Data files can be obtained from http://spidr.ngdc.noaa.gov .

NgdcIndex objects aid in reading, creating, and visualizing these files.

Creating an *NgdcIndex* object is simple:

```
>>> from spacepy import pybats
>>> obj=pybats.NgdcIndex(filename='ngdc_example.dat')
```

Upon instantiation, if *filename* is a valid file AND kwarg *load* is set to boolean True, the contents of *filename* are loaded into the object and no other work needs to be done.

If *filename* is False or *load* is False, a blank *NgdcIndex* is created for the user to manipulate. The user can set the time array and the ssociated data values to any values desired and use the method *obj.write()* to dump the contents to an NGDC formatted input file. See the documentation for the write method for more details.

This class is a work-in-progress. It is especially tuned for SWMF-needs and cannot be considered a general function for the handling of generic NGDC files.

Kwarg	Description
filename	Set the input/output file name.
load	Read file upon instantiation? Defaults to **True**

spacepy.pybats.PbData

class spacepy.pybats.**PbData**(**args*, ***kwargs*)

The base class for all PyBats data container classes. Inherits from *spacepy.datamodel.SpaceData* but has additional methods for quickly exploring an SWMF dataset.

Just like *spacepy.datamodel.SpaceData* objects, *PbData* objects work just like dictionaries except they have special **attr** dictionary attributes for both the top-level object and most values. This means that the following syntax can be used to explore a generic *PbData* object:

>>>print obj.keys() >>>print obj.attrs >>>value = obj[key]

Printing *PbData* objects will produce a tree of contents and attributes; calling `self.listunits()` will print all values that have the 'units' attribute and the associated units. Hence, it is often most instructive to use the following two lines to quickly learn a *PbData*'s contents:

>>>print obj >>>obj.listunits()

PbData is the main organizational tool for Pybats datasets, so the information here is applicable to nearly all Pybats classes.

spacepy.pybats.SatOrbit

class spacepy.pybats.**SatOrbit**(*filename=None*, **args*, ***kwargs*)

An class to load, read, write, and handle BATS-R-US satellite orbit input files. These files are used to fly virtual satellites through the MHD domain. Note that the output files should be handled by the *LogFile* and not this satorbit object. The object's required and always present attributes are:

Attribute	Description
head	A list of header lines for the file that contain comments.
coor	The three-letter code (see SWMF doc) of the coord system.
file	Location of the file to read/write.

The object should always have the following two data keys:

Key	Description
time	A list or numpy vector of datetime objects
xyz	A 3 x len(time) numpy array of x,y,z coordinates associated with the time vector.

A "blank" instantiation will create an empty object for the user to fill. This is desired if the user wants to create a new orbit, either from data or from scratch, and save it in a properly formatted file. Here's an example with a "stationary probe" type orbit where the attributes are filled and then dropped to file:

```
>>> from spacepy.pybats import SatOrbit
>>> import datetime as dt
>>> import numpy as np
>>> sat = SatOrbit()
>>> sat['time'] = [ dt.datetime(2000,1,1), dt.datetime(2000,1,2) ]
>>> pos = np.zeros( (3,2) )
>>> pos[:,0]=[6.6, 0, 0]
>>> pos[:,1]=[6.6, 0, 0]
>>> sat['xyz'] = pos
>>> sat.attrs['coor'] = 'SMG'
>>> sat.attrs['file'] = 'noon_probe.dat'
>>> sat.write()
```

If instantiated with a file name, the name is loaded into the object. For example,

```
>>> sat=SatOrbit('a_sat_orbit_file.dat')
```

...will populate all fields with the data in *a_sat_orbit_file.dat*.

Functions

add_body(ax[, rad, facecolor, show_planet, ...])	Creates a circle of radius=self.attrs['rbody'] and returns the MatPlotLib Ellipse patch object for plotting.
add_planet(ax[, rad, ang, add_night, zorder])	Creates a circle of `radius=self.para['rbody']` and returns the MatPlotLib Ellipse patch object for plotting.
parse_tecvars(line)	Parse the VARIABLES line from a TecPlot-formatted ascii data file.

spacepy.pybats.add_body

spacepy.pybats.**add_body**(*ax*, *rad=2.5*, *facecolor='lightgrey'*, *show_planet=True*, *ang=0.0*, *add_night=True*, *zorder=1000*, ***extra_kwargs*)

Creates a circle of radius=self.attrs['rbody'] and returns the MatPlotLib Ellipse patch object for plotting. If an axis is specified using the "ax" keyword, the patch is added to the plot. Default color is light grey; extra keywords are handed to the Ellipse generator function.

Because the body is rarely the size of the planet at the center of the modeling domain, add_planet is automatically called. This can be negated by using the show_planet kwarg.

Parameters

ax [Matplotlib Axes object] Set the axes on which to place planet.

Other Parameters

rad [float] Set radius of the inner boundary. Defaults to 2.5.

facecolor [string] Set color of face of inner boundary circle via Matplotlib color selectors (name, hex, etc.) Defaults to 'lightgrey'.

show_planet [boolean] Turns on/off planet indicator inside inner boundary. Defaults to **True**

ang [float] Set the rotation of the day-night terminator from the y-axis, in degrees. Defaults to zero (terminator is aligned with Y-axis.)

add_night [boolean] Add night hemisphere. Defaults to **True**

zorder [int] Set the matplotlib zorder of the patch to set how other plot elements order with the inner boundary patch. Defaults to 1000. If a planet is added, it is given a zorder of *zorder*+5.

spacepy.pybats.add_planet

spacepy.pybats.**add_planet**(*ax*, *rad=1.0*, *ang=0.0*, *add_night=True*, *zorder=1000*, ***extra_kwargs*)

Creates a circle of `radius=self.para['rbody']` and returns the MatPlotLib Ellipse patch object for plotting. If an axis is specified using the *ax* keyword, the patch is added to the plot.

Unlike the add_body method, the circle is colored half white (dayside) and half black (nightside) to coincide with the direction of the sun. Additionally, because the size of the planet is not intrinsically known to the MHD file, the kwarg "rad", defaulting to 1.0, sets the size of the planet. *add_night* can turn off this behavior.

Extra keywords are handed to the Ellipse generator function.

Parameters

ax [Matplotlib Axes object] Set the axes on which to place planet.

Other Parameters

rad [float] Set radius of planet. Defaults to 1.

ang [float] Set the rotation of the day-night terminator from the y-axis, in degrees. Defaults to zero (terminator is aligned with Y-axis.)

add_night [boolean] Add night hemisphere. Defaults to **True**

zorder [int] Set the matplotlib zorder of the patch to set how other plot elements order with the inner boundary patch. Defaults to 1000, nightside patch is given zorder of *zorder+5*.

spacepy.pybats.parse_tecvars

spacepy.pybats.**parse_tecvars**(*line*)
Parse the VARIABLES line from a TecPlot-formatted ascii data file. Create a list of name-unit tuples for each variable.

4.15 pycdf - Python interface to CDF files

This package provides a Python interface to the Common Data Format (CDF) library used for many NASA missions, available at http://cdf.gsfc.nasa.gov/. It is targeted at Python 2.6+ and should work without change on either Python 2 or Python 3.

The interface is intended to be 'pythonic' rather than reproducing the C interface. To open or close a CDF and access its variables, see the *CDF* class. Accessing data within the variables is via the *Var* class. The *lib* object provides access to some routines that affect the functionality of the library in general. The *const* module contains constants useful for accessing the underlying library.

The CDF C library must be properly installed in order to use this package. The CDF distribution provides scripts meant to be called in a user's login scripts, `definitions.B` for bash and `definitions.C` for C-shell derivatives. (See the installation instructions which come with the CDF library.) These will set environment variables specifying the location of the library; pycdf will respect these variables if they are set. Otherwise it will search the standard system library path and the default installation locations for the CDF library.

If pycdf has trouble finding the library, try setting `CDF_LIB` before importing the module, e.g. if the library is in `CDF/lib` in the user's home directory:

```
>>> import os
>>> os.environ["CDF_LIB"] = "~/CDF/lib"
>>> from spacepy import pycdf
```

If this works, make the environment setting permanent. Note that on OSX, using plists to set the environment may not carry over to Python terminal sessions; use `.cshrc` or `.bashrc` instead.

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4.15.1 Contents

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- *Classes*
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- *Data*

Create a CDF

This example presents the entire sequence of creating a CDF and populating it with some data; the parts are explained individually below.

```
>>> from spacepy import pycdf
>>> import datetime
>>> time = [datetime.datetime(2000, 10, 1, 1, val) for val in range(60)]
>>> import numpy as np
>>> data = np.random.random_sample(len(time))
>>> cdf = pycdf.CDF('MyCDF.cdf', '')
>>> cdf['Epoch'] = time
>>> cdf['data'] = data
>>> cdf.attrs['Author'] = 'John Doe'
>>> cdf.attrs['CreateDate'] = datetime.datetime.now()
>>> cdf['data'].attrs['units'] = 'MeV'
>>> cdf.close()
```

Import the pycdf module.

```
>>> from spacepy import pycdf
```

Make a data set of `datetime`. These will be converted into CDF_TIME_TT2000 types.

```
>>> import datetime
>>> # make a dataset every minute for a hour
>>> time = [datetime.datetime(2000, 10, 1, 1, val) for val in range(60)]
```

Warning: If you create a CDF in backwards compatibility mode (using *set_backward()*), then `datetime` objects are degraded to CDF_EPOCH (millisecond resolution), not CDF_EPOCH16 (microsecond resolution). Use *new()* to specify a data type.

Create some random data.

```
>>> import numpy as np
>>> data = np.random.random_sample(len(time))
```

Create a new empty CDF. The empty string, ‘’, is the name of the CDF to use as a master; given an empty string, an empty CDF will be created, rather than copying from a master CDF. If a master is used, data in the master will be copied to the new CDF.

```
>>> cdf = pycdf.CDF('MyCDF.cdf', '')
```

Note: You cannot create a new CDF with a name that already exists on disk. It will throw a `NameError`

To put data into a CDF, assign it directly to an element of the CDF. CDF objects behave like Python dictionaries.

```
>>> # put time into CDF variable Epoch
>>> cdf['Epoch'] = time
>>> # and the same with data (the smallest data type that fits the data is used by␣
↪default)
>>> cdf['data'] = data
```

Adding attributes is done similarly. CDF attributes are also treated as dictionaries.

```
>>> # add some attributes to the CDF and the data
>>> cdf.attrs['Author'] = 'John Doe'
>>> cdf.attrs['CreateDate'] = datetime.datetime.now()
>>> cdf['data'].attrs['units'] = 'MeV'
```

Closing the CDF ensures the new data are written to disk:

```
>>> cdf.close()
```

CDF files, like standard Python files, act as context managers

```
>>> with cdf.CDF('filename.cdf', '') as cdf_file:
...     #do brilliant things with cdf_file
>>> #cdf_file is automatically closed here
```

Read a CDF

Reading a CDF is very similar: the CDF object behaves like a dictionary. The file is only accessed when data are requested. A full example using the above CDF:

```
>>> from spacepy import pycdf
>>> cdf = pycdf.CDF('MyCDF.cdf')
>>> print(cdf)
    Epoch: CDF_TIME_TT2000 [60]
    data: CDF_FLOAT [60]
>>> cdf['data'][4]
    0.8609974384307861
>>> data = cdf['data'][...] # don't forget the [...]
>>> cdf_dat = cdf.copy()
>>> cdf_dat.keys()
    ['Epoch', 'data']
>>> cdf.close()
```

Again import the pycdf module

```
>>> from spacepy import pycdf
```

Then open the CDF, this looks the same and creation, but without mention of a master CDF.

```
>>> cdf = pycdf.CDF('MyCDF.cdf')
```

The default `__str__()` and `__repr__()` behavior explains the contents, type, and size but not the data.

```
>>> print(cdf)
    Epoch: CDF_TIME_TT2000 [60]
    data: CDF_FLOAT [60]
```

To access the data one has to request specific elements of the variable, similar to a Python list.

```
>>> cdf['data'][4]
    0.8609974384307861
>>> data = cdf['data'][...] # don't forget the [...]
```

CDF.copy() will return the entire contents of a CDF, including attributes, as a *SpaceData* object:

```
>>> cdf_dat = cdf.copy()
```

Since CDF objects behave like dictionaries they have a `keys()` method and iterations are over the names in `keys()`

```
>>> cdf_dat.keys()
    ['Epoch', 'data']
```

Close the CDF when finished:

```
>>> cdf.close()
```

Modify a CDF

An example modifying the CDF created above:

```
>>> from spacepy import pycdf
>>> cdf = pycdf.CDF('MyCDF.cdf')
>>> cdf.readonly(False)
    False
>>> cdf['newVar'] = [1.0, 2.0]
>>> print(cdf)
    Epoch: CDF_TIME_TT2000 [60]
    data: CDF_FLOAT [60]
    newVar: CDF_FLOAT [2]
>>> cdf.close()
```

As before, each step in this example will now be individually explained. Existing CDF files are opened in read-only mode and must be set to read-write before modification:

```
>>> cdf.readonly(False)
    False
```

Then new variables can be added:

```
>>> cdf['newVar'] = [1.0, 2.0]
```

Or contents can be changed:

```
>>> cdf['data'][0] = 8675309
```

You can write all new data to an existing variable, leaving the variable type, dimensionality, and attributes unchanged:

```
>>> cdf['Epoch'][...] = [datetime.datetime(2010, 10, 1, 1, val)
...     for val in range(60)]
```

This is the common usage when using a CDF file containing all the variables and attributes but no data, sometimes called a "master CDF". Although the `[...]` makes this explicit (writing new records not a new variable), the same syntax as for a new variable can also be used:

```
>>> # Either create a new variable or overwrite data in existing
>>> cdf['Epoch'] = [datetime.datetime(2010, 10, 1, 1, val)
...     for val in range(60)]
```

The new variables appear immediately:

```
>>> print(cdf)
    Epoch: CDF_TIME_TT2000 [60]
    data: CDF_FLOAT [60]
    newVar: CDF_FLOAT [2]
```

Closing the CDF ensures changes are written to disk:

```
>>> cdf.close()
```

Non record-varying

Non record-varying (NRV) variables are usually used for data that does not vary with time, such as the energy channels for an instrument.

NRV variables need to be created with *CDF.new()*, specifying the keyword 'recVary' as False.

```
>>> from spacepy import pycdf
>>> cdf = pycdf.CDF('MyCDF2.cdf', '')
>>> cdf.new('data2', [1], recVary=False)
    <Var:
    CDF_BYTE [1] NRV
    >
>>> cdf['data2'][...]
    [1]
```

Slicing and indexing

Subsets of data in a variable can be easily referenced with Python's slicing and indexing notation.

This example uses `bisect` to read a subset of the data from the hourly data file created in earlier examples.

```
>>> from spacepy import pycdf
>>> cdf = pycdf.CDF('MyCDF.cdf')
>>> start = datetime.datetime(2000, 10, 1, 1, 9)
>>> stop = datetime.datetime(2000, 10, 1, 1, 35)
>>> import bisect
>>> start_ind = bisect.bisect_left(cdf['Epoch'], start)
>>> stop_ind = bisect.bisect_left(cdf['Epoch'], stop)
>>> # then grab the data we want
```

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```
>>> time = cdf['Epoch'][start_ind:stop_ind]
>>> data = cdf['data'][start_ind:stop_ind]
>>> cdf.close()
```

The *Var* documentation has several additional examples.

String handling

Changed in version 0.3.0.

Prior to SpacePy 0.3.0, pycdf treated all strings as ASCII-encoded, and would raise errors when writing or reading strings that were not valid ASCII.

Per the NASA CDF library, variable and attribute names must be in ASCII. The contents of `CDF_CHAR` and `CDF_UCHAR` were redefined to be UTF-8 as of CDF 3.8.1. As of SpacePy 0.3.0, pycdf treats all `CHAR` variables with a default encoding of UTF-8. This is true regardless of the version of the underlying CDF library.

UTF-8 is a variable-length encoding, so the number of elements in the variable may not correspond to the number of characters if data are not restricted to the ASCII range.

A different encoding can be specified with the `encoding` argument to `open` and this encoding will be used on all reads and writes to that file. Opening a CDF read-write with `encoding` other than `utf-8` or `ascii` will issue a warning.

Writing strings which cannot be represented in the desired encoding will raise an error. When reading from a CDF, characters which cannot be decoded will be replaced with the Unicode "replacement character" U+FFFD, which usually displays as a question mark.

It is always possible to write raw bytes data to a variable, if it is desired to use a different encoding for one time. For arrays of data, this will usually involve `numpy.char.encode()`:

```
>>> cdf['Variable'] = data.encode('latin-1')
>>> cdf['Variable'] = numpy.char.encode(data, encoding='latin-1')
```

All encoding and decoding can also be skipped using the *raw_var()* method to access a variable; however, without encoding, only `bytes` can be written to string variables.

Access to CDF constants and the C library

Constants defined in cdf.h and occasionally useful in accessing CDFs are available in the *const* module.

The underlying C library is represented by the *lib* variable.

Classes

CDF(pathname[, masterpath, create, ...])	Python object representing a CDF file.
Var(cdf_file, var_name, *args)	A CDF variable.
gAttrList(cdf_file[, special_entry])	Object representing *all* the gAttributes in a CDF.
zAttrList(zvar)	Object representing *all* the zAttributes in a zVariable.
zAttr(cdf_file, attr_name[, create])	zAttribute for zVariables within a CDF.
gAttr(cdf_file, attr_name[, create])	Global Attribute for a CDF
AttrList(cdf_file[, special_entry])	Object representing a list of attributes.
Attr(cdf_file, attr_name[, create])	An attribute, g or z, for a CDF

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Library([libpath, library])	Abstraction of the base CDF C library and its state.
CDFCopy(cdf)	A dictionary-like copy of all data and attributes in a *CDF*
VarCopy(zVar)	A list-like copy of the data and attributes in a *Var*
CDFError(status)	Raised for an error in the CDF library.
CDFException(status)	Base class for errors or warnings in the CDF library.
CDFWarning(status)	Used for a warning in the CDF library.
EpochError	Used for errors in epoch routines

spacepy.pycdf.CDF

class spacepy.pycdf.**CDF**(*pathname*, *masterpath=None*, *create=None*, *readonly=None*, *encoding='utf-8'*)

Python object representing a CDF file.

Open or create a CDF file by creating an object of this class.

Parameters

pathname [string] name of the file to open or create

masterpath [string] name of the master CDF file to use in creating a new file. If not provided, an existing file is opened; if provided but evaluates to `False` (e.g., `''`), an empty new CDF is created.

create [bool] Create a new CDF even if masterpath isn't provided

readonly [bool] Open the CDF read-only. Default True if opening an existing CDF; False if creating a new one. A readonly CDF with many variables may be slow to close on CDF library versions before 3.8.1. See *readonly()*.

encoding [str, optional] Text encoding to use when reading and writing strings. Default `'utf-8'`.

Raises

CDFError if CDF library reports an error

Warns

CDFWarning if CDF library reports a warning and interpreter is set to error on warnings.

Examples

Open a CDF by creating a CDF object, e.g.:

```
>>> cdffile = pycdf.CDF('cdf_filename.cdf')
```

Be sure to *close()* or *save()* when done.

Note: Existing CDF files are opened read-only by default, see *readonly()* to change.

CDF supports the with keyword, like other file objects, so:

```
>>> with pycdf.CDF('cdf_filename.cdf') as cdffile:
...     #do brilliant things with the CDF
```

will open the CDF, execute the indented statements, and close the CDF when finished or when an error occurs. The python docs include more detail on this 'context manager' ability.

CDF objects behave like a python dictionary, where the keys are names of variables in the CDF, and the values, *Var* objects. As a dictionary, they are also iterable and it is easy to loop over all of the variables in a file. Some examples:

1. List the names of all variables in the open CDF `cdffile`:

```
>>> cdffile.keys()
>>> for k in cdffile: #Alternate
...     print(k)
```

2. Get a *Var* object for the variable named `Epoch`:

```
>>> epoch = cdffile['Epoch']
```

3. Determine if a CDF contains a variable named `B_GSE`:

```
>>> if 'B_GSE' in cdffile:
...     print('B_GSE is in the file')
... else:
...     print('B_GSE is not in the file')
```

4. Find how many variables are in the file:

```
>>> print(len(cdffile))
```

5. Delete the variable `Epoch` from the open CDF file `cdffile`:

```
>>> del cdffile['Epoch']
```

6. Display a summary of variables and types in open CDF file `cdffile`:

```
>>> print(cdffile)
```

7. Open the CDF named `cdf_filename.cdf`, read *all* the data from all variables into dictionary `data`, and close it when done or if an error occurs:

```
>>> with pycdf.CDF('cdf_filename.cdf') as cdffile:
...     data = cdffile.copy()
```

This last example can be very inefficient as it reads the entire CDF. Normally it's better to treat the CDF as a dictionary and access only the data needed, which will be pulled transparently from disc. See *Var* for more subtle examples.

Potentially useful dictionary methods and related functions:

- in
- keys
- `len()`
- list comprehensions
- `sorted()`
- *dictree()*

The CDF user's guide section 2.2 has more background information on CDF files.

The *attrs* Python attribute acts as a dictionary referencing CDF attributes (do not confuse the two); all the dictionary methods above also work on the attribute dictionary. See *gAttrList* for more on the dictionary of global attributes.

Creating a new CDF from a master (skeleton) CDF has similar syntax to opening one:

```
>>> cdffile = pycdf.CDF('cdf_filename.cdf', 'master_cdf_filename.cdf')
```

This creates and opens `cdf_filename.cdf` as a copy of `master_cdf_filename.cdf`.

Using a skeleton CDF is recommended over making a CDF entirely from scratch, but this is possible by specifying a blank master:

```
>>> cdffile = pycdf.CDF('cdf_filename.cdf', '')
```

When CDFs are created in this way, they are opened read-write, see *readonly()* to change.

By default, new CDFs (without a master) are created in version 2 (backward-compatible) format. To create a version 3 CDF, use *Library.set_backward()*:

```
>>> pycdf.lib.set_backward(False)
>>> cdffile = pycdf.CDF('cdf_filename.cdf', '')
```

Add variables by direct assignment, which will automatically set type and dimension based on the data provided:

```
>>> cdffile['new_variable_name'] = [1, 2, 3, 4]
```

or, if more control is needed over the type and dimensions, use *new()*.

Although it is supported to assign Var objects to Python variables for convenience, there are some minor pitfalls that can arise when changing a CDF that will not affect most users. This is only a concern when assigning a zVar object to a Python variable, changing the CDF through some other variable, and then trying to use the zVar object via the originally assigned variable.

Deleting a variable:

```
>>> var = cdffile['Var1']
>>> del cdffile['Var1']
>>> var[0] #fail, no such variable
```

Renaming a variable:

```
>>> var = cdffile['Var1']
>>> cdffile['Var1'].rename('Var2')
>>> var[0] #fail, no such variable
```

Renaming via the same variable works:

```
>>> var = cdffile['Var1']
>>> var.rename('Var2')
>>> var[0] #succeeds, aware of new name
```

Deleting a variable and then creating another variable with the same name may lead to some surprises:

```
>>> var = cdffile['Var1']
>>> var[...] = [1, 2, 3, 4]
>>> del cdffile['Var1']
>>> cdffile.new('Var1', data=[5, 6, 7, 8]
>>> var[...]
[5, 6, 7, 8]
```

attr_num(attrname)	Get the attribute number and scope by attribute name
attrs	Global attributes for this CDF in a dict-like format.
add_attr_to_cache(attrname, num, scope)	Add an attribute to the name-to-number cache
add_to_cache(varname, num)	Add a variable to the name-to-number cache
checksum([new_val])	Set or check the checksum status of this CDF.
clear_attr_from_cache(attrname)	Mark an attribute deleted in the name-to-number cache
clear_from_cache(varname)	Mark a variable deleted in the name-to-number cache
clone(zVar[, name, data])	Clone a zVariable (from another CDF or this) into this CDF
close()	Closes the CDF file
col_major([new_col])	Finds the majority of this CDF file
compress([comptype, param])	Set or check the compression of this CDF
copy()	Make a copy of all data and attributes in this CDF
from_data(filename, sd)	Create a new CDF file from a SpaceData object or similar
new(name[, data, type, recVary, dimVarys, ...])	Create a new zVariable in this CDF
raw_var(name)	Get a "raw" *Var* object.
readonly([ro])	Sets or check the readonly status of this CDF
save()	Saves the CDF file but leaves it open.
var_num(varname)	Get the variable number of a particular variable name
version()	Get version of library that created this CDF

attrs
Global attributes for this CDF in a dict-like format. See *gAttrList* for details.

backward
True if this CDF was created in backward-compatible mode (for opening with CDF library before 3.x)

add_to_cache(*varname*, *num*)
Add a variable to the name-to-number cache

This maintains a cache of name-to-number mappings for zVariables to keep from having to query the CDF library constantly. It's mostly an internal function.

Parameters

varname [bytes] name of the zVariable. Not this is NOT a string in Python 3!

num [int] number of the variable

add_attr_to_cache(*attrname*, *num*, *scope*)
Add an attribute to the name-to-number cache

This maintains a cache of name-to-number mappings for attributes to keep from having to query the CDF library constantly. It's mostly an internal function.

Parameters

varname [bytes] name of the zVariable. Not this is NOT a string in Python 3!

num [int] number of the variable

scope [bool] True if global scope; False if variable scope.

`attr_num`(*attrname*)
Get the attribute number and scope by attribute name

This maintains a cache of name-to-number mappings for attributes to keep from having to query the CDF library constantly. It's mostly an internal function.

Parameters

attrname [bytes] name of the attribute. Not this is NOT a string in Python 3!

Returns

out [tuple] attribute number, scope (True for global) of this attribute

Raises

CDFError [if attribute is not found]

`checksum`(*new_val=None*)
Set or check the checksum status of this CDF. If checksums are enabled, the checksum will be verified every time the file is opened.

Returns

out [boolean] True if the checksum is enabled or False if disabled

Other Parameters

new_val [boolean] True to enable checksum, False to disable, or leave out to simply check.

`clear_from_cache`(*varname*)
Mark a variable deleted in the name-to-number cache

Will remove a variable, and all variables with higher numbers, from the variable cache.

Does NOT delete the variable!

This maintains a cache of name-to-number mappings for zVariables to keep from having to query the CDF library constantly. It's mostly an internal function.

Parameters

varname [bytes] name of the zVariable. Not this is NOT a string in Python 3!

`clear_attr_from_cache`(*attrname*)
Mark an attribute deleted in the name-to-number cache

Will remove an attribute, and all attributes with higher numbers, from the attribute cache.

Does NOT delete the variable!

This maintains a cache of name-to-number mappings for attributes to keep from having to query the CDF library constantly. It's mostly an internal function.

Parameters

attrname [bytes] name of the attribute. Not this is NOT a string in Python 3!

`clone`(*zVar*, *name=None*, *data=True*)
Clone a zVariable (from another CDF or this) into this CDF

Parameters

zVar [*Var*] variable to clone

Returns

out [*Var*] The newly-created zVar in this CDF

Other Parameters

name [str] Name of the new variable (default: name of the original)

data [boolean (optional)] Copy data, or only type, dimensions, variance, attributes? (default: True, copy data as well)

`close()`
Closes the CDF file

Although called on object destruction (`__del__()`), to ensure all data are saved, the user should explicitly call *close()* or *save()*.

Raises

CDFError [if CDF library reports an error]

Warns

CDFWarning [if CDF library reports a warning]

`col_major(new_col=None)`
Finds the majority of this CDF file

Returns

out [boolean] True if column-major, false if row-major

Other Parameters

new_col [boolean] Specify True to change to column-major, False to change to row major, or do not specify to check the majority rather than changing it. (default is check only)

`compress(comptype=None, param=None)`
Set or check the compression of this CDF

Sets compression on entire *file*, not per-variable.

See section 2.6 of the CDF user's guide for more information on compression.

Returns

out [tuple] (comptype, param) currently in effect

Other Parameters

comptype [ctypes.c_long] type of compression to change to, see CDF C reference manual section 4.10. Constants for this parameter are in *const*. If not specified, will not change compression.

param [ctypes.c_long] Compression parameter, see CDF CRM 4.10 and *const*. If not specified, will choose reasonable default (5 for gzip; other types have only one possible parameter.)

See also:

Var.compress()

Examples

Set file `cdffile` to gzip compression, compression level 9:

```
>>> cdffile.compress(pycdf.const.GZIP_COMPRESSION, 9)
```

`copy`()
Make a copy of all data and attributes in this CDF

Returns

out [*CDFCopy*] *SpaceData*-like object of all data

`classmethod from_data`(*filename*, *sd*)
Create a new CDF file from a SpaceData object or similar

The CDF named `filename` is created, opened, filled with the contents of `sd` (including attributes), and closed.

`sd` should be a dictionary-like object; each key will be made into a variable name. An attribute called `attrs`, if it exists, will be made into global attributes for the CDF.

Each value of `sd` should be array-like and will be used as the contents of the variable; an attribute called `attrs`, if it exists, will be made into attributes for that variable.

Parameters

filename [string] name of the file to create

sd [spacepy.datamodel.SpaceData] data to put in the CDF. This structure cannot be nested, i.e., it must contain only *dmarray* and no `Spacedata` objects.

`new`(*name*, *data=None*, *type=None*, *recVary=None*, *dimVarys=None*, *dims=None*, *n_elements=None*, *compress=None*, *compress_param=None*, *sparse=None*, *pad=None*)
Create a new zVariable in this CDF

Note: Either `data` or `type` must be specified. If type is not specified, it is guessed from `data`.

This creates a new variable. If using a "master CDF" with existing variables and no records, simply assign the new data to the variable, or the "whole variable" slice:

```
>>> cdf['ExistingVariable'] = data
>>> cdf['ExistingVariable'][...] = data
```

Parameters

name [str] name of the new variable

Returns

out [*Var*] the newly-created zVariable

Other Parameters

data data to store in the new variable. If this has a an `attrs` attribute (e.g., *dmarray*), it will be used to populate attributes of the new variable. Similarly the CDF type, record variance, etc. will, by default, be taken from *data* if it is a *VarCopy*. This can be overridden by specifying other keywords.

type [ctypes.c_long] CDF type of the variable, from *const*. See section 2.5 of the CDF user's guide for more information on CDF data types.

recVary [boolean] record variance of the variable (default True)

dimVarys [list of boolean] dimension variance of each dimension, default True for all dimensions.

dims [list of int] size of each dimension of this variable, default zero-dimensional. Note this is the dimensionality as defined by CDF, i.e., for record-varying variables it excludes the leading record dimension. See *Var*.

n_elements [int] number of elements, should be 1 except for CDF_CHAR, for which it's the length of the string.

compress [ctypes.c_long] Compression to apply to this variable, default None. See *Var.compress()*.

compress_param [ctypes.c_long] Compression parameter if compression used; reasonable default is chosen. See *Var.compress()*.

sparse [ctypes.c_long] New in version 0.2.3.

Sparse records type for this variable, default None (no sparse records). See *Var.sparse()*.

pad New in version 0.2.3.

Pad value for this variable, default None (do not set). See *Var.pad()*.

Raises

ValueError [if neither data nor sufficient typing information] is provided.

Warns

DeprecationWarning if no type is provided and data is datetime, warn that a default type was chosen (usually TIME_TT2000).

Changed in version 0.3.0: Before 0.3.0 (when the default changed from EPOCH/EPOCH16 to TIME_TT2000), this warned that the default would change.

New in version 0.2.3.

Notes

Any given data may be representable by a range of CDF types; if the type is not specified, pycdf will guess which the CDF types which can represent this data. This breaks down to:

1. If input data is a numpy array, match the type of that array
2. Proper kind (numerical, string, time)
3. Proper range (stores highest and lowest number provided)
4. Sufficient resolution (EPOCH16 or TIME_TT2000 required if datetime has microseconds or below.)

If more than one value satisfies the requirements, types are returned in preferred order:

1. Type that matches precision of data first, then
2. integer type before float type, then
3. Smallest type first, then
4. signed type first, then

5. specifically-named (CDF_BYTE) vs. generically named (CDF_INT1)

TIME_TT2000 is always the preferred time type if it is available. Otherwise, EPOCH_16 is preferred over EPOCH if `data` specifies below the millisecond level (rule 1), but otherwise EPOCH is preferred (rule 2).

Changed in version 0.3.0: Before 0.3.0, EPOCH or EPOCH_16 were used if not specified. Now TIME_TT2000 is always the preferred type.

For floats, four-byte is preferred unless eight-byte is required:

1. absolute values between 0 and 3e-39
2. absolute values greater than 1.7e38

This will switch to an eight-byte double in some cases where four bytes would be sufficient for IEEE 754 encoding, but where DEC formats would require eight.

raw_var(*name*)
Get a "raw" *Var* object.

Normally a *Var* will perform translation of values for certain types (to/from Unicode for CHAR variables on Py3k, and to/from datetime for all time types). A "raw" object does not perform this translation, on read or write.

This does *not* affect the data on disk, and in fact it is possible to maintain multiple Python objects with access to the same zVariable.

Parameters

name [str] name or number of the zVariable

readonly(*ro=None*)
Sets or check the readonly status of this CDF

If the CDF has been changed since opening, setting readonly mode will have no effect.

Note: Before version 3.8.1 of the NASA CDF library, closing a CDF that has been opened readonly, or setting readonly False, may take a substantial amount of time if there are many variables in the CDF, as a (potentially large) cache needs to be cleared. If upgrading to a newer CDF library is not possible, specifying `readonly=False` when opening the file is an option. However, this may make some reading operations slower.

Returns

out [Boolean] True if CDF is read-only, else False

Other Parameters

ro [Boolean] True to set the CDF readonly, False to set it read/write, or leave out to check only.

Raises

CDFError [if bad mode is set]

save()
Saves the CDF file but leaves it open.

If closing the CDF, *close()* is sufficient; there is no need to call *save()* before *close()*.

Note: Relies on an undocumented call of the CDF C library, which is also used in the Java interface.

Raises

CDFError [if CDF library reports an error]

Warns

CDFWarning [if CDF library reports a warning]

`var_num`(*varname*)
Get the variable number of a particular variable name

This maintains a cache of name-to-number mappings for zVariables to keep from having to query the CDF library constantly. It's mostly an internal function.

Parameters

varname [bytes] name of the zVariable. Not this is NOT a string in Python 3!

Returns

out [int] Variable number of this zvariable.

Raises

CDFError [if variable is not found]

`version`()
Get version of library that created this CDF

Returns

out [tuple] version of CDF library, in form (version, release, increment)

spacepy.pycdf.Var

`class` spacepy.pycdf.`Var`(*cdf_file*, *var_name*, **args*)
A CDF variable.

This object does not directly store the data from the CDF; rather, it provides access to the data in a format that much like a Python list or numpy `ndarray`. General list information is available in the python docs: 1, 2, 3.

The CDF user's guide, section 2.3, provides background on variables.

Note: Not intended to be created directly; use methods of *CDF* to gain access to a variable.

A record-varying variable's data are viewed as a hypercube of dimensions n_dims+1 (the extra dimension is the record number). They are indexed in row-major fashion, i.e. the last index changes most frequently / is contiguous in memory. If the CDF is column-major, the data are transformed to row-major before return.

Non record-varying variables are similar, but do not have the extra dimension of record number.

Variables can be subscripted by a multidimensional index to return the data. Indices are in row-major order with the first dimension representing the record number. If the CDF is column major, the data are reordered to row major. Each dimension is specified by standard Python slice notation, with dimensions separated by commas. The ellipsis fills in any missing dimensions with full slices. The returned data are lists; Python represents multidimensional arrays as nested lists. The innermost set of lists represents contiguous data.

Note: numpy 'fancy indexing' is *not* supported.

Degenerate dimensions are 'collapsed', i.e. no list of only one element will be returned if a single subscript is specified instead of a range. (To avoid this, specify a slice like 1:2, which starts with 1 and ends before 2).

Two special cases:

1. requesting a single-dimension slice for a record-varying variable will return all data for that record number (or those record numbers) for that variable.
2. Requests for multi-dimensional variables may skip the record-number dimension and simply specify the slice on the array itself. In that case, the slice of the array will be returned for all records.

In the event of ambiguity (e.g., single-dimension slice on a one-dimensional variable), case 1 takes priority. Otherwise, mismatch between the number of dimensions specified in the slice and the number of dimensions in the variable will cause an `IndexError` to be thrown.

This all sounds very complicated but it is essentially attempting to do the 'right thing' for a range of slices.

An unusual case is scalar (zero-dimensional) non-record-varying variables. Clearly they cannot be subscripted normally. In this case, use the `[...]` syntax meaning 'access all data.':

```
>>> from spacepy import pycdf
>>> testcdf = pycdf.CDF('test.cdf', '')
>>> variable = testcdf.new('variable', recVary=False,
...     type=pycdf.const.CDF_INT4)
>>> variable[...] = 10
>>> variable
<Var:
CDF_INT4 [] NRV
>
>>> variable[...]
10
```

Reading any empty non-record-varying variable will return an empty with the same *number* of dimensions, but all dimensions will be of zero length. The scalar is, again, a special case: due to the inability to have a numpy array which is both zero-dimensional and empty, reading an NRV scalar variable with no data will return an empty one-dimensional array. This is really not recommended.

Variables with no records (RV) or no data (NRV) are considered to be "false"; those with records or data written are considered to be "true", allowing for an easy check of data existence:

```
>>> if testcdf['variable']:
>>>     # do things that require data to exist
```

As a list type, variables are also iterable; iterating over a variable returns a single complete record at a time.

This is all clearer with examples. Consider a variable `B_GSM`, with three elements per record (x, y, z components) and fifty records in the CDF. Then:

1. `B_GSM[0, 1]` is the y component of the first record.
2. `B_GSM[10, :]` is a three-element list, containing x, y, and z components of the 11th record. As a shortcut, if only one dimension is specified, it is assumed to be the record number, so this could also be written `B_GSM[10]`.
3. `B_GSM[...]` reads all data for `B_GSM` and returns it as a fifty-element list, each element itself being a three-element list of x, y, z components.

Multidimensional example: consider fluxes stored as a function of pitch angle and energy. Such a variable may be called Flux and stored as a two-dimensional array, with the first dimension representing (say) ten energy steps and the second, eighteen pitch angle bins (ten degrees wide, centered from 5 to 175 degrees). Assume 100 records stored in the CDF (i.e. 100 different times).

1. `Flux[4]` is a list of ten elements, one per energy step, each element being a list of 18 fluxes, one per pitch bin. All are taken from the fifth record in the CDF.
2. `Flux[4, :, 0:4]` is the same record, all energies, but only the first four pitch bins (roughly, field-aligned).
3. `Flux[..., 0:4]` is a 100-element list (one per record), each element being a ten-element list (one per energy step), each containing fluxes for the first four pitch bins.

This slicing notation is very flexible and allows reading specifically the desired data from the CDF.

Note: The C CDF library allows reading records which have not been written to a file, returning a pad value. pycdf checks the size of a variable and will raise *IndexError* for most attempts to read past the end, except for variables with sparse records. If these checks fail, a value is returned with a warning `VIRTUAL_RECORD_DATA`. Please open an issue if this occurs for variables without sparse records. See pg. 39 and following of the CDF User's Guide for more on virtual records.

All data are, on read, converted to appropriate Python data types; EPOCH, EPOCH16, and TIME_TT2000 types are converted to `datetime`. Data are returned in numpy arrays.

Note: Although pycdf supports TIME_TT2000 variables, the Python `datetime` object does not support leap seconds. Thus, on read, any seconds past 59 are truncated to 59.999999 (59 seconds, 999 milliseconds, 999 microseconds).

Potentially useful list methods and related functions:

- count
- in
- index
- len
- list comprehensions
- sorted

The topic of array majority can be very confusing; good background material is available at IDL Array Storage and Indexing. In brief, *regardless of the majority stored in the CDF*, pycdf will always present the data in the native Python majority, row-major order, also known as C order. This is the default order in NumPy. However, packages that render image data may expect it in column-major order. If the axes seem 'swapped' this is likely the reason.

The *attrs* Python attribute acts as a dictionary referencing zAttributes (do not confuse the two); all the dictionary methods above also work on the attribute dictionary. See *zAttrList* for more on the dictionary of attributes.

With writing, as with reading, every attempt has been made to match the behavior of Python lists. You can write one record, many records, or even certain elements of all records. There is one restriction: only the record dimension (i.e. dimension 0) can be resized by write, as all records in a variable must have the same dimensions. Similarly, only whole records can be deleted.

Note: Unusual error messages on writing data usually mean that pycdf is unable to interpret the data as a regular array of a single type matching the type and shape of the variable being written. A 5x4 array is supported; an irregular array where one row has five columns and a different row has six columns is not. Error messages of this type include:

- `Data must be well-formed, regular array of number, string, or datetime`
- `setting an array element with a sequence.`
- `shape mismatch: objects cannot be broadcast to a single shape`

For these examples, assume Flux has 100 records and dimensions [2, 3].

Rewrite the first record without changing the rest:

```
>>> Flux[0] = [[1, 2, 3], [4, 5, 6]]
```

Writes a new first record and delete all the rest:

```
>>> Flux[...] = [[1, 2, 3], [4, 5, 6]]
```

Write a new record in the last position and add a new record after:

```
>>> Flux[99:] = [[[1, 2, 3], [4, 5, 6]],
...              [[11, 12, 13], [14, 15, 16]]]
```

Insert two new records between the current number 5 and 6:

```
>>> Flux[5:6] = [[[1, 2, 3], [4, 5, 6]],  [[11, 12, 13],
...               [14, 15, 16]]]
```

This operation can be quite slow, as it requires reading and rewriting the entire variable. (CDF does not directly support record insertion.)

Change the first element of the first two records but leave other elements alone:

```
>>> Flux[0:2, 0, 0] = [1, 2]
```

Remove the first record:

```
>>> del Flux[0]
```

Removes record 5 (the sixth):

```
>>> del Flux[5]
```

Due to the need to work around a bug in the CDF library, this operation can be quite slow.

Delete *all data* from `Flux`, but leave the variable definition intact:

```
>>> del Flux[...]
```

Note: Variables using sparse records do not support insertion and only support deletion of a single record at a time. See *sparse()* and section 2.3.12 of the CDF user's guide for more information on sparse records.

Note: Although this interface only directly supports zVariables, zMode is set on opening the CDF so rVars appear as zVars. See p.24 of the CDF user's guide; pyCDF uses zMode 2.

attrs	zAttributes for this zVariable in a dict-like format.
compress([comptype, param])	Set or check the compression of this variable
copy()	Copies all data and attributes from this variable
dtype	Provide the numpy dtype equivalent to the CDF type of this variable.
dv([new_dv])	Gets or sets dimension variance of each dimension of variable.
insert(index, data)	Inserts a *single* record before an index
name()	Returns the name of this variable
nelems()	Number of elements for each value in this variable
pad([value])	Gets or sets this variable's pad value.
rename(new_name)	Renames this variable
rv([new_rv])	Gets or sets whether this variable has record variance
shape	Provides the numpy array-like shape of this variable.
sparse([sparsetype])	Gets or sets this variable's sparse records mode.
type([new_type])	Returns or sets the CDF type of this variable

attrs
zAttributes for this zVariable in a dict-like format. See *zAttrList* for details.

compress(*comptype=None*, *param=None*)
Set or check the compression of this variable

Compression may not be changeable on variables with data already written; even deleting the data may not permit the change.

See section 2.6 of the CDF user's guide for more information on compression.

Returns

out [tuple] the (comptype, param) currently in effect

Other Parameters

comptype [ctypes.c_long] type of compression to change to, see CDF C reference manual section 4.10. Constants for this parameter are in *const*. If not specified, will not change compression.

param [ctypes.c_long] Compression parameter, see CDF CRM 4.10 and *const*. If not specified, will choose reasonable default (5 for gzip; other types have only one possible parameter.)

copy()
Copies all data and attributes from this variable

Returns

out [*VarCopy*] list of all data in record order

dtype
Provide the numpy dtype equivalent to the CDF type of this variable.

Data from this variable will be returned in numpy arrays of this type.

See also:

type

dv(*new_dv=None*)
Gets or sets dimension variance of each dimension of variable.

If the variance is unknown, True is assumed (this replicates the apparent behavior of the CDF library on variable creation).

Parameters

new_dv [list of boolean] Each element True to change that dimension to dimension variance, False to change to not dimension variance. (Unspecified to simply check variance.)

Returns

out [list of boolean] True if that dimension has variance, else false.

insert(*index*, *data*)
Inserts a *single* record before an index

Parameters

index [int] index before which to insert the new record

data the record to insert

name()
Returns the name of this variable

Returns

out [str] variable's name

nelems()
Number of elements for each value in this variable

This is the length of strings for CHAR and UCHAR, should be 1 otherwise.

Returns

int length of strings

pad(*value=None*)
Gets or sets this variable's pad value.

See section 2.3.20 of the CDF user's guide for more information on pad values.

Returns

out [] Current pad value for this variable. `None` if it has never been set. This rarely happens; the pad value is usually set by the CDF library on variable creation.

Other Parameters

value If specified, should be an appropriate pad value. If not specified, the pad value will not be set or changed.

Notes

New in version 0.2.3.

rename(*new_name*)
Renames this variable

Parameters

new_name [str] the new name for this variable

rv(*new_rv=None*)
Gets or sets whether this variable has record variance

If the variance is unknown, True is assumed (this replicates the apparent behavior of the CDF library on variable creation).

Returns

out [Boolean] True if record varying, False if NRV

Other Parameters

new_rv [boolean] True to change to record variance, False to change to NRV, unspecified to simply check variance.

shape
Provides the numpy array-like shape of this variable.

Returns a tuple; first element is number of records (RV variable only) And the rest provide the dimensionality of the variable.

Note: Assigning to this attribute will not change the shape.

---

sparse(*sparsetype=None*)
Gets or sets this variable's sparse records mode.

Sparse records mode may not be changeable on variables with data already written; even deleting the data may not permit the change.

See section 2.3.12 of the CDF user's guide for more information on sparse records.

Returns

out [ctypes.c_long] Sparse record mode for this variable.

Other Parameters

sparsetype [ctypes.c_long] If specified, should be a sparse record mode from *const*; see also CDF C reference manual section 4.11.1. If not specified, the sparse record mode for this variable will not change.

Notes

New in version 0.2.3.

type(*new_type=None*)
Returns or sets the CDF type of this variable

Parameters

new_type [ctypes.c_long] the new type from *const*

Returns

out [int] CDF type

spacepy.pycdf.gAttrList

class spacepy.pycdf.**gAttrList**(*cdf_file*, *special_entry=None*)
Object representing *all* the gAttributes in a CDF.

Normally accessed as an attribute of an open *CDF*:

```
>>> global_attribs = cdffile.attrs
```

Appears as a dictionary: keys are attribute names; each value is an attribute represented by a *gAttr* object. To access the global attribute TEXT:

```
>>> text_attr = cdffile.attrs['TEXT']
```

See also:

AttrList

spacepy.pycdf.zAttrList

class spacepy.pycdf.**zAttrList**(*zvar*)
Object representing *all* the zAttributes in a zVariable.

Normally accessed as an attribute of a *Var* in an open CDF:

```
>>> epoch_attribs = cdffile['Epoch'].attrs
```

Appears as a dictionary: keys are attribute names, values are the value of the zEntry associated with the appropriate zVariable. Each vAttribute in a CDF may only have a *single* entry associated with each variable. The entry may be a string, a single numerical value, or a series of numerical values. Entries with multiple values are returned as an entire list; direct access to the individual elements is not possible.

Example: finding the first dependency of (ISTP-compliant) variable `Flux`:

```
>>> print cdffile['Flux'].attrs['DEPEND_0']
```

zAttributes are shared among zVariables, one zEntry allowed per zVariable. (pyCDF hides this detail.) Deleting the last zEntry for a zAttribute will delete the underlying zAttribute.

zEntries are created and destroyed by the usual dict methods on the zAttrlist:

```
>>> epoch_attribs['new_entry'] = [1, 2, 4] #assign a list to new zEntry
>>> del epoch_attribs['new_entry'] #delete the zEntry
```

The type of the zEntry is guessed from data provided. The type is chosen to match the data; subject to that constraint, it will try to match (in order):

1. existing zEntry corresponding to this zVar
2. other zEntries in this zAttribute
3. the type of this zVar
4. data-matching constraints described in *CDF.new()*

See also:

AttrList

spacepy.pycdf.zAttr

class spacepy.pycdf.**zAttr**(*cdf_file*, *attr_name*, *create=False*)
zAttribute for zVariables within a CDF.

Warning: Because zAttributes are shared across all variables in a CDF, directly manipulating them may have unexpected consequences. It is safest to operate on zEntries via *zAttrList*.

Note: When accessing a zAttr, pyCDF exposes only the zEntry corresponding to the associated zVariable.

See also:

Attr

spacepy.pycdf.gAttr

class spacepy.pycdf.**gAttr**(*cdf_file*, *attr_name*, *create=False*)
Global Attribute for a CDF

Represents a CDF attribute, providing access to the gEntries in a format that looks like a Python list. General list information is available in the python docs: 1, 2, 3.

Normally accessed by providing a key to a *gAttrList*:

```
>>> attribute = cdffile.attrs['attribute_name']
>>> first_gentry = attribute[0]
```

Each element of the list is a single gEntry of the appropriate type. The index to the elements is the gEntry number.

A gEntry may be either a single string or a 1D array of numerical type. Entries of numerical type (everything but CDF_CHAR and CDF_UCHAR) with a single element are returned as scalars; multiple-element entries are returned as a list. No provision is made for accessing below the entry level; the whole list is returned at once (but Python's slicing syntax can be used to extract individual items from that list.)

Multi-dimensional slicing is *not* supported; an entry with multiple elements will have all elements returned (and can thus be sliced itself). Example:

```
>>> first_three = attribute[5, 0:3] #will fail
>>> first_three = attribute[5][0:3] #first three elements of 5th Entry
```

gEntries are *not* necessarily contiguous; a gAttribute may have an entry 0 and entry 2 without an entry 1. `len()` will return the *number* of gEntries; use *max_idx()* to find the highest defined gEntry number and *has_entry()* to determine if a particular gEntry number exists. Iterating over all entries is also supported:

```
>>> entrylist = [entry for entry in attribute]
```

Deleting gEntries will leave a "hole":

```
>>> attribute[0:3] = [1, 2, 3]
>>> del attribute[1]
>>> attribute.has_entry(1)
False
>>> attribute.has_entry(2)
True
>>> print attribute[0:3]
[1, None, 3]
```

Multi-element slices over nonexistent gEntries will return `None` where no entry exists. Single-element indices for nonexistent gEntries will raise `IndexError`. Assigning `None` to a gEntry will delete it.

When assigning to a gEntry, the type is chosen to match the data; subject to that constraint, it will try to match (in order):

1. existing gEntry of the same number in this gAttribute
2. other gEntries in this gAttribute
3. data-matching constraints described in *CDF.new()*.

See also:

Attr

spacepy.pycdf.AttrList

class spacepy.pycdf.**AttrList**(*cdf_file*, *special_entry=None*)

Object representing a list of attributes.

> **Warning:** This class should not be used directly, but only via its subclasses, *gAttrList* and *zAttrList*. Methods listed here are safe to use from the subclasses.

clone(master[, name, new_name])	Clones another attribute list, or one attribute from it, into this list.
copy()	Create a copy of this attribute list
new(name[, data, type])	Create a new Attr in this AttrList
rename(old_name, new_name)	Rename an attribute in this list

clone(*master*, *name=None*, *new_name=None*)
Clones another attribute list, or one attribute from it, into this list.

Parameters

master [AttrList] the attribute list to copy from. This can be any dict-like object.

Other Parameters

name [str (optional)] name of attribute to clone (default: clone entire list)

new_name [str (optional)] name of the new attribute, default `name`

copy()
Create a copy of this attribute list

Returns

out [dict] copy of the entries for all attributes in this list

new(*name*, *data=None*, *type=None*)
Create a new Attr in this AttrList

Parameters

name [str] name of the new Attribute

Other Parameters

data data to put into the first entry in the new Attribute

type CDF type of the first entry from *const*. Only used if data are specified.

Raises

KeyError [if the name already exists in this list]

rename(*old_name*, *new_name*)
Rename an attribute in this list

Renaming a zAttribute renames it for *all* zVariables in this CDF!

Parameters

old_name [str] the current name of the attribute

new_name [str] the new name of the attribute

spacepy.pycdf.Attr

class spacepy.pycdf.**Attr**(*cdf_file*, *attr_name*, *create=False*)
An attribute, g or z, for a CDF

> **Warning:** This class should not be used directly, but only in its subclasses, *gAttr* and *zAttr*. The methods listed here are safe to use in the subclasses.

Represents a CDF attribute, providing access to the Entries in a format that looks like a Python list. General list information is available in the python docs: 1, 2, 3.

An introduction to CDF attributes can be found in section 2.4 of the CDF user's guide.

Each element of the list is a single Entry of the appropriate type. The index to the elements is the Entry number.

Multi-dimensional slicing is *not* supported; an Entry with multiple elements will have all elements returned (and can thus be sliced itself). Example:

```
>>> first_three = attribute[5, 0:3] #will fail
>>> first_three = attribute[5][0:3] #first three elements of 5th Entry
```

append(data)	Add an entry to end of attribute
has_entry(number)	Check if this attribute has a particular Entry number
insert(index, data)	Insert an entry at a particular number
max_idx()	Maximum index of Entries for this Attr
new(data[, type, number])	Create a new Entry in this Attribute
number()	Find the attribute number for this attribute
rename(new_name)	Rename this attribute
type(number[, new_type])	Find or change the CDF type of a particular Entry number

append(*data*)
Add an entry to end of attribute

Puts entry after last defined entry (does not fill gaps)

Parameters

data data for the new entry

has_entry(*number*)
Check if this attribute has a particular Entry number

Parameters

number [int] number of Entry to check or change

Returns

out [bool] True if `number` is a valid entry number; False if not

insert(*index*, *data*)
Insert an entry at a particular number

Inserts entry at particular number while moving all subsequent entries to one entry number later. Does not close gaps.

Parameters

index [int] index where to put the new entry

data data for the new entry

max_idx()
Maximum index of Entries for this Attr

Returns

out [int] maximum Entry number

new(*data*, *type=None*, *number=None*)
Create a new Entry in this Attribute

Note: If `number` is provided and an Entry with that number already exists, it will be overwritten.

Parameters

data data to put in the Entry

Other Parameters

type [int] type of the new Entry, from *const* (otherwise guessed from data)

number [int] Entry number to write, default is lowest available number.

number()
Find the attribute number for this attribute

Returns

out [int] attribute number

rename(*new_name*)
Rename this attribute

Renaming a zAttribute renames it for *all* zVariables in this CDF!

Parameters

new_name [str] the new name of the attribute

type(*number*, *new_type=None*)
Find or change the CDF type of a particular Entry number

Parameters

number [int] number of Entry to check or change

Returns

out [int] CDF variable type, see *const*

Other Parameters

new_type type to change this Entry to, from *const*. Omit to only check type.

Notes

If changing types, old and new must be equivalent, see CDF User's Guide section 2.5.5 pg. 57

spacepy.pycdf.Library

class spacepy.pycdf.**Library**(*libpath=None*, *library=None*)
Abstraction of the base CDF C library and its state.

Not normally intended for end-user use. An instance of this class is created at package load time as the *lib* variable, providing access to the underlying C library if necessary. The CDF library itself is described in section 2.1 of the CDF user's guide, as well as the CDF C reference manual.

Calling the C library directly requires knowledge of ctypes.

Instantiating this object loads the C library, see *pycdf - Python interface to CDF files* docs for details.

call(*args, **kwargs)	Call the CDF internal interface
check_status(status[, ignore])	Raise exception or warning based on return status of CDF call

continues on next page

Table 56 – continued from previous page

datetime_to_epoch(dt)	Converts a Python datetime to a CDF Epoch value
datetime_to_epoch16(dt)	Converts a Python datetime to a CDF Epoch16 value
datetime_to_tt2000(dt)	Converts a Python datetime to a CDF TT2000 value
epoch_to_datetime(epoch)	Converts a CDF epoch value to a datetime
epoch_to_epoch16(epoch)	Converts a CDF EPOCH to a CDF EPOCH16 value
epoch_to_num(epoch)	Convert CDF EPOCH to matplotlib number.
epoch_to_tt2000(epoch)	Converts a CDF EPOCH to a CDF TT2000 value
epoch16_to_datetime(epoch0, epoch1)	Converts a CDF epoch16 value to a datetime
epoch16_to_epoch(epoch16)	Converts a CDF EPOCH16 to a CDF EPOCH value
epoch16_to_tt2000(epoch0, epoch1)	Converts a CDF epoch16 value to TT2000
get_minmax(cdftype)	Find minimum, maximum possible value based on CDF type.
set_backward([backward])	Set backward compatibility mode for new CDFs
tt2000_to_datetime(tt2000)	Converts a CDF TT2000 value to a datetime
tt2000_to_epoch(tt2000)	Converts a CDF TT2000 value to a CDF EPOCH
tt2000_to_epoch16(tt2000)	Converts a CDF TT2000 value to a CDF EPOCH16

call(**args*, ***kwargs*)
Call the CDF internal interface

Passes all parameters directly through to the CDFlib routine of the CDF library's C internal interface. Checks the return value with *check_status()*.

Terminal NULL is automatically added to args.

Parameters

args [various, see ctypes] Passed directly to the CDF library interface. Useful constants are defined in the const module.

Returns

out [int] CDF status from the library

Other Parameters

ignore [sequence of CDF statuses] sequence of CDF statuses to ignore. If any of these is returned by CDF library, any related warnings or exceptions will *not* be raised.

Raises

CDFError [if CDF library reports an error]

Warns

CDFWarning [if CDF library reports a warning]

check_status(*status*, *ignore=()*)
Raise exception or warning based on return status of CDF call

Parameters

status [int] status returned by the C library

Returns

out [int] status (unchanged)

Other Parameters

ignore [sequence of ctypes.c_long] CDF statuses to ignore. If any of these is returned by CDF library, any related warnings or exceptions will *not* be raised. (Default none).

Raises

CDFError [if status < CDF_WARN, indicating an error]

Warns

CDFWarning [if CDF_WARN <= status < CDF_OK, indicating a warning.]

`datetime_to_epoch`(*dt*)
Converts a Python datetime to a CDF Epoch value

Parameters

dt [`datetime.datetime`] date and time to convert

Returns

out [float] epoch corresponding to dt

See also:

v_datetime_to_epoch

`datetime_to_epoch16`(*dt*)
Converts a Python datetime to a CDF Epoch16 value

Parameters

dt [`datetime.datetime`] date and time to convert

Returns

out [list of float] epoch16 corresponding to dt

See also:

v_datetime_to_epoch16

`datetime_to_tt2000`(*dt*)
Converts a Python datetime to a CDF TT2000 value

Parameters

dt [`datetime.datetime`] date and time to convert

Returns

out [int] tt2000 corresponding to dt

See also:

v_datetime_to_tt2000

`epoch_to_datetime`(*epoch*)
Converts a CDF epoch value to a datetime

Parameters

epoch [float] epoch value from CDF

Returns

out [`datetime.datetime`] date and time corresponding to epoch. Invalid values are set to usual epoch invalid value, i.e. last moment of year 9999.

See also:

v_epoch_to_datetime

epoch_to_epoch16(*epoch*)
Converts a CDF EPOCH to a CDF EPOCH16 value

Parameters

epoch [double] EPOCH to convert. Lists and numpy arrays are acceptable.

Returns

out [(double, double)] EPOCH16 corresponding to epoch

epoch_to_num(*epoch*)
Convert CDF EPOCH to matplotlib number.

Same output as `date2num()` and useful for plotting large data sets without converting the times through datetime.

Parameters

epoch [double] EPOCH to convert. Lists and numpy arrays are acceptable.

Returns

out [double] Floating point number representing days since matplotlib epoch (usually 0001-01-01 as day 1, or 1970-01-01 as day 0).

See also:

`matplotlib.dates.date2num`, `matplotlib.dates.num2date`

Notes

This number is not portable between versions of matplotlib. The returned value is for the installed version of matplotlib. If matplotlib is not found, the returned value is for matplotlib 3.2 and earlier.

epoch_to_tt2000(*epoch*)
Converts a CDF EPOCH to a CDF TT2000 value

Parameters

epoch [double] EPOCH to convert

Returns

out [int] tt2000 corresponding to epoch

See also:

v_epoch_to_tt2000

epoch16_to_datetime(*epoch0*, *epoch1*)
Converts a CDF epoch16 value to a datetime

Note: The call signature has changed since SpacePy 0.1.2. Formerly this method took a single argument with two values; now it requires two arguments (one for each value). To convert existing code, replace `epoch16_to_datetime(epoch)` with `epoch16_to_datetime(*epoch)`.

Parameters

epoch0 [float] epoch16 value from CDF, first half

epoch1 [float] epoch16 value from CDF, second half

Returns

out [datetime.datetime] date and time corresponding to epoch. Invalid values are set to usual epoch invalid value, i.e. last moment of year 9999.

Raises

EpochError [if input invalid]

See also:

v_epoch16_to_datetime

epoch16_to_epoch(*epoch16*)
Converts a CDF EPOCH16 to a CDF EPOCH value

Parameters

epoch16 [(double, double)] EPOCH16 to convert. Lists and numpy arrays are acceptable. LAST dimension should be 2: the two pairs of EPOCH16

Returns

out [double] EPOCH corresponding to epoch16

epoch16_to_tt2000(*epoch0*, *epoch1*)
Converts a CDF epoch16 value to TT2000

Note: Because TT2000 does not support picoseconds, the picoseconds value in epoch is ignored (i.e., truncated.)

Parameters

epoch0 [float] epoch16 value from CDF, first half

epoch1 [float] epoch16 value from CDF, second half

Returns

out [long] TT2000 corresponding to epoch.

Raises

EpochError [if input invalid]

See also:

v_epoch16_to_tt2000

get_minmax(*cdftype*)
Find minimum, maximum possible value based on CDF type.

This returns the processed value (e.g. datetimes for Epoch types) because comparisons to EPOCH16s are otherwise difficult.

Parameters

cdftype [int] CDF type number from *const*

Returns

out [tuple] minimum, maximum value supported by type (of type matching the CDF type).

Raises

ValueError [if can't match the type]

`set_backward`(*backward=True*)
Set backward compatibility mode for new CDFs

Unless backward compatible mode is set, CDF files created by the version 3 library can not be read by V2. pycdf does not set backward compatible mode by default.

Changed in version 0.3.0: Before 0.3.0, pycdf set backward compatible mode on import.

Parameters

backward [boolean] Set backward compatible mode if True; clear it if False.

Raises

ValueError [if backward=False and underlying CDF library is V2]

`supports_int8`
True if this library supports INT8 and TIME_TT2000 types; else False.

`tt2000_to_datetime`(*tt2000*)
Converts a CDF TT2000 value to a datetime

Note: Although TT2000 values support leapseconds, Python's datetime object does not. Any times after 23:59:59.999999 will be truncated to 23:59:59.999999.

Parameters

tt2000 [int] TT2000 value from CDF

Returns

out [`datetime.datetime`] date and time corresponding to epoch. Invalid values are set to usual epoch invalid value, i.e. last moment of year 9999.

Raises

EpochError [if input invalid]

See also:

`v_tt2000_to_datetime`

`tt2000_to_epoch`(*tt2000*)
Converts a CDF TT2000 value to a CDF EPOCH

Note: Although TT2000 values support leapseconds, CDF EPOCH values do not. Times during leapseconds are rounded up to beginning of the next day.

Parameters

tt2000 [int] TT2000 value from CDF

Returns

out [double] EPOCH corresponding to the TT2000 input time

Raises

EpochError [if input invalid]

See also:

v_tt2000_to_epoch

tt2000_to_epoch16(*tt2000*)
Converts a CDF TT2000 value to a CDF EPOCH16

Note: Although TT2000 values support leapseconds, CDF EPOCH16 values do not. Times during leapseconds are rounded up to beginning of the next day.

Parameters

tt2000 [int] TT2000 value from CDF

Returns

out [double, double] EPOCH16 corresponding to the TT2000 input time

Raises

EpochError [if input invalid]

See also:

v_tt2000_to_epoch16

v_datetime_to_epoch(*datetime*)
A vectorized version of *datetime_to_epoch()* which takes a numpy array of datetimes as input and returns an array of epochs.

v_datetime_to_epoch16(*datetime*)
A vectorized version of *datetime_to_epoch16()* which takes a numpy array of datetimes as input and returns an array of epoch16.

v_datetime_to_tt2000(*datetime*)
A vectorized version of *datetime_to_tt2000()* which takes a numpy array of datetimes as input and returns an array of TT2000.

v_epoch_to_datetime(*epoch*)
A vectorized version of *epoch_to_datetime()* which takes a numpy array of epochs as input and returns an array of datetimes.

v_epoch_to_tt2000(*epoch*)
A vectorized version of *epoch_to_tt2000()* which takes a numpy array of epochs as input and returns an array of tt2000s.

v_epoch16_to_datetime(*epoch0*, *epoch1*)
A vectorized version of *epoch16_to_datetime()* which takes a numpy array of epoch16 as input and returns an array of datetimes. An epoch16 is a pair of doubles; the input array's last dimension must be two (and the returned array will have one fewer dimension).

v_epoch16_to_tt2000(*epoch16*)
A vectorized version of *epoch16_to_tt2000()* which takes a numpy array of epoch16 as input and returns an array of tt2000s. An epoch16 is a pair of doubles; the input array's last dimension must be two (and the returned array will have one fewer dimension).

v_tt2000_to_datetime(*tt2000*)
A vectorized version of *tt2000_to_datetime()* which takes a numpy array of tt2000 as input and returns an array of datetimes.

v_tt2000_to_epoch(*tt2000*)
A vectorized version of *tt2000_to_epoch()* which takes a numpy array of tt2000 as input and returns an array of epochs.

v_tt2000_to_epoch16(*tt2000*)
A vectorized version of *tt2000_to_epoch16()* which takes a numpy array of tt2000 as input and returns an array of epoch16.

libpath
The path where pycdf found the CDF C library, potentially useful in debugging. If this contains just the name of a file (with no path information), then the system linker found the library for pycdf. On Linux, `ldconfig -p` may be useful for displaying the system's library resolution.

version
Version of the CDF library, (version, release, increment, subincrement)

spacepy.pycdf.CDFCopy

class spacepy.pycdf.**CDFCopy**(*cdf*)
A dictionary-like copy of all data and attributes in a *CDF*

Data are *VarCopy* objects, keyed by variable name. CDF attributes are in *attrs*. (I.e., data are accessed much like from a *CDF*).

Do not instantiate this class directly; use *copy()* on an existing *CDF*.

Examples

```
>>> from spacepy import pycdf
>>> with pycdf.CDF('test.cdf') as cdffile:
...     data = cdffile.copy()
```

attrs
Python dictionary containing attributes copied from the CDF.

spacepy.pycdf.VarCopy

class spacepy.pycdf.**VarCopy**(*zVar*)
A list-like copy of the data and attributes in a *Var*

Data are in the list elements. CDF attributes are in a dict, accessed through *attrs*. (I.e., data and attributes are accessed like in a *Var*.)

Do not instantiate this class directly; use *copy()* on an existing *Var*.

Several methods provide access to details about how the original variable was constructed. This is mostly for making it easier to reproduce the variable by passing it to *new()*. Operations that e.g. change the dimensionality of the copy may make this (or any) metadata out of date; see *set()* to update.

compress(*args, **kwargs)	Gets compression of the variable this was copied from.
dv()	Gets dimension variance of the variable this was copied from.
nelems()	Gets number of elements of the variable this was copied from.
pad()	Gets pad value of the copied variable.
rv()	Gets record variance of the variable this was copied from.
set(key, value)	Set CDF metadata
sparse()	Gets sparse records mode of the copied variable.
type()	Returns CDF type of the variable this was copied from.

attrs
Python dictionary containing attributes copied from the zVar

compress(**args*, ***kwargs*)
Gets compression of the variable this was copied from.

For details on CDF compression, see *spacepy.pycdf.Var.compress()*.

If any arguments are specified, calls `numpy.ndarray.compress()` instead (as the names conflict)

Returns

tuple compression type, parameter currently in effect.

dv()
Gets dimension variance of the variable this was copied from.

Each dimension other than the record dimension may either vary or not.

Returns

list of boolean True if that dimension has variance, else False

nelems()
Gets number of elements of the variable this was copied from.

This is usually 1 except for strings, where it is the length of the string.

Returns

int Number of elements in parent variable

pad()
Gets pad value of the copied variable.

This copy does *not* preserve which records were written, i.e. the entire copy is read, including pad values, and the pad values are treated as real data (if, e.g. writing to another CDF).

For details on padding, see *spacepy.pycdf.Var.pad()*.

Returns

various Pad value, matching type of the variable.

Notes

New in version 0.2.3.

rv()
Gets record variance of the variable this was copied from.

Returns

boolean True if parent variable was record varying, False if NRV

set(*key*, *value*)
Set CDF metadata

Set the metadata describing the original variable this was copied from. Can be used to update the metadata if transformation of the copy has made it out of date (e.g. by removing dimensions.) There is very little checking done and this function should only be used with care.

Parameters

key [str] Which metadata to set; this matches the name of the method used to retrieve it (e.g. use `type` to set the CDF type, which is returned by *type()*).

value Value to assign to *key*.

sparse()
Gets sparse records mode of the copied variable.

This copy does *not* preserve which records were written, i.e. the entire copy is read, including pad values, and the pad values are treated as real data (if, e.g. writing to another CDF).

For details on sparse records, see *spacepy.pycdf.Var.sparse()*.

Returns

ctypes.c_long Sparse record type

Notes

New in version 0.2.3.

type()
Returns CDF type of the variable this was copied from.

Returns

int CDF type

spacepy.pycdf.CDFError

class spacepy.pycdf.**CDFError**(*status*)
Raised for an error in the CDF library.

spacepy.pycdf.CDFException

class spacepy.pycdf.**CDFException**(*status*)
Base class for errors or warnings in the CDF library.

Not normally used directly, but in subclasses *CDFError* and *CDFWarning*.

Error messages provided by this class are looked up from the underlying C library.

spacepy.pycdf.CDFWarning

class spacepy.pycdf.**CDFWarning**(*status*)
Used for a warning in the CDF library.

spacepy.pycdf.EpochError

class spacepy.pycdf.**EpochError**
Used for errors in epoch routines

Functions

concatCDF(cdfs[, varnames, raw])	Concatenate data from multiple CDFs

spacepy.pycdf.concatCDF

spacepy.pycdf.**concatCDF**(*cdfs*, *varnames=None*, *raw=False*)
Concatenate data from multiple CDFs

Reads data from all specified CDFs in order and returns as if they were from a single CDF. The assumption is that the CDFs all have the same structure (same variables, each with the same dimensions and variance.)

Parameters

cdfs [list of *Var*] Open CDFs, will be read from in order. Must be a list (cannot be an iterable, as all files need to be open).

varnames [list of str] Names of variables to read (default: all variables in first CDF)

raw [bool] If True, read variables as raw (don't convert epochs, etc.) Default False.

Returns

SpaceData data concatenated from each CDF, with all attributes from first. Non-record-varying data is also only from first, and record variance is only checked on the first!

Examples

Read all data from all CDFs in the current directory. Note that CDFs are closed when their variable goes out of scope.

```
>>> import glob
>>> import spacepy.pycdf
>>> data = spacepy.pycdf.concatCDF([
...     spacepy.pycdf.CDF(f) for f in glob.glob('*.cdf')])
```

Submodules

const	Various constants defined in cdf.h and used in pycdf.
istp	Support for ISTP-compliant CDFs

spacepy.pycdf.const

Various constants defined in cdf.h and used in pycdf. Most constants referred to in the CDF manuals are provided by this module. E.g., to create a CDF and add a variable of type EPOCH:

```
>>> from spacepy import pycdf
>>> cdf = pycdf.CDF('new.cdf', '')
>>> cdf.new('epoch', type=pycdf.const.CDF_EPOCH)
```

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spacepy.pycdf.istp

Support for ISTP-compliant CDFs

The ISTP metadata standard specifies the interpretation of the attributes in a CDF to describe relationships between the variables and their physical interpretation.

This module supports that subset of CDFs.

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Classes

FileChecks()	ISTP compliance checks for a CDF file.
VarBundle(var)	Collective handling of ISTP-compliant variable and its dependencies.
VariableChecks()	ISTP compliance checks for a single variable.

spacepy.pycdf.istp.FileChecks

class spacepy.pycdf.istp.**FileChecks**

ISTP compliance checks for a CDF file.

Checks a file's compliance with ISTP standards. This mostly performs checks that are not currently performed by the ISTP skeleton editor. All tests return a list, one error string for every noncompliance found (empty list if compliant). *all()* will perform all tests and concatenate all errors.

all(f[, catch])	Perform all variable and file-level tests
empty_entry(f)	Check for attributes with empty string
filename(f)	Compare filename to global attributes
time_monoton(f)	Checks that times are monotonic
times(f)	Compare filename to times

classmethod all(*f*, *catch=False*)

Perform all variable and file-level tests

In addition to calling every test in this class, will also call *VariableChecks.all()* for every variable in the file.

Parameters

f [*CDF*] Open CDF file to check

catch [bool] Catch exceptions in tests (default False). If True, any exceptions in subtests will result in an addition to the validation failures of the form "Test x did not complete." Calling the individual test will reveal the full traceback.

Returns

list of str Description of each validation failure.

Examples

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> f = spacepy.pycdf.CDF('foo.cdf', create=True)
>>> v = f.new('Var', data=[1, 2, 3])
>>> spacepy.pycdf.istp.FileChecks.all(f)
['No Logical_source in global attrs.',
'No Logical_file_id in global attrs.',
'Cannot parse date from filename foo.cdf.',
'Var: No FIELDNAM attribute.']
```

classmethod empty_entry(*f*)

Check for attributes with empty string

Checks global attributes for this variable for any entries consisting of an empty string. These should be replaced with a single space.

Parameters

f [*CDF*] Open CDF file to check

Returns

list of str Description of each validation failure.

classmethod filename(*f*)

Compare filename to global attributes

Check global attribute Logical_file_id and Logical_source for consistency with CDF filename.

Parameters

f [*CDF*] Open CDF file to check

Returns

list of str Description of each validation failure.

classmethod time_monoton(*f*)

Checks that times are monotonic

Check that all Epoch variables are monotonically increasing.

Parameters

f [*CDF*] Open CDF file to check

Returns

list of str Description of each validation failure.

classmethod times(*f*)

Compare filename to times

Check that all Epoch variables only contain times matching filename.

Parameters

f [*CDF*] Open CDF file to check

Returns

list of str Description of each validation failure.

Notes

This function assumes daily files and should be extended based on the File_naming_convention global attribute (which itself is another good check to have.)

spacepy.pycdf.istp.VarBundle

class spacepy.pycdf.istp.**VarBundle**(*var*)

Collective handling of ISTP-compliant variable and its dependencies.

Representation of an ISTP-compliant variable bundled together with its dependencies to enable aggregate operations. Normally used to copy a subset of data from one CDF to another by chaining operations.

Unusual or indecipherable error messages may indicate an ISTP compliance issue; see *VariableChecks* for some checks.

Parameters

var [*Var*] Variable to process

Examples

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> #https://rbsp-ect.newmexicoconsortium.org/data_pub/rbspa/hope/level3/pitchangle/
↪2012/
>>> infile = spacepy.pycdf.CDF('rbspa_rel04_ect-hope-PA-L3_20121201_v7.1.0.cdf')
>>> infile['FPDU']
<Var:
CDF_FLOAT [3228, 11, 72]
>
>>> infile['FPDU'].attrs
<zAttrList:
CATDESC: HOPE differential proton flux [CDF_CHAR]
DEPEND_0: Epoch_Ion [CDF_CHAR]
DEPEND_1: PITCH_ANGLE [CDF_CHAR]
DEPEND_2: HOPE_ENERGY_Ion [CDF_CHAR]
...
>
>>> b = spacepy.pycdf.istp.VarBundle(infile['FPDU'])
>>> outfile = spacepy.pycdf.CDF('output.cdf', create=True)
>>> b.slice(1, 2, single=True).output(outfile)
<VarBundle:
FPDU: CDF_FLOAT [3228, 72]
Epoch_Ion: CDF_EPOCH [3228]
    Epoch_Ion_DELTA: CDF_REAL4 [3228]
PITCH_ANGLE: CDF_FLOAT ---
    Pitch_LABL: CDF_CHAR*5 ---
HOPE_ENERGY_Ion: CDF_FLOAT [3228, 72]
    ENERGY_Ion_DELTA: CDF_FLOAT [3228, 72]
    Energy_LABL: CDF_CHAR*3 [72] NRV
>
>>> outfile['FPDU']
<Var:
CDF_FLOAT [3228, 72]
>
>>> outfile['FPDU'].attrs
<zAttrList:
CATDESC: HOPE differential proton flux [CDF_CHAR]
```

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```
DEPEND_0: Epoch_Ion [CDF_CHAR]
DEPEND_1: HOPE_ENERGY_Ion [CDF_CHAR]
...
>
>>> outfile.close()
>>> infile.close()
```

mean(dim)	Take the mean of a dimension.
operations()	Operations of this bundle
output(output[, suffix])	Output the variables as modified
slice(dim[, start, stop, step, single])	Slice on a single dimension
sum(dim)	Sum across a dimension.
variables()	Description of variable output from the bundle

mean(*dim*)

Take the mean of a dimension.

Take mean of the main variable of the bundle across the given dimension. That dimension disappears from the output and dependencies (including their uncertainties) are assumed to be constant across the summed dimension. The uncertainty of the main variable, if any, is appropriately propagated.

Invalid values are excluded fromthe mean. This does not work well for variables that define multiple VALIDMIN/VALIDMAX based on position within a dimension; the smallest VALIDMIN/largest VALIDMAX rather than the position-specific value.

Averaging occurs after slicing, to allow averaging of a subset of a dimension. A single element slice (which removes the dimension) is incompatible with averaging over that dimension.

There is not currently a way to "undo" a mean; create a new bundle instead.

Parameters

dim [int] CDF dimension to average. This is the dimension as specified in the CDF (0-base for RV variables, 1-base for NRV) and does not change with successive slicing or summing. This must be a positive number (no support for e.g. -1 for last dimension.)

Returns

VarBundle This bundle, for method chaining. This is not a copy: the original object is updated.

Examples

See the *VarBundle* examples for creating output.

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> infile = spacepy.pycdf.CDF('rbspa_rel04_ect-hope-PA-L3_20121201_v7.1.0.cdf')
>>> b = spacepy.pycdf.istp.VarBundle(infile['Counts_P'])
>>> #Average over dimension 1 (pitch angle)
>>> b.mean(1)
>>> #Get a new bundle (without the previous sum)
>>> b = spacepy.pycdf.istp.VarBundle(infile['Counts_P'])
>>> #Average over first 10 elements of dimension 2 (energy bins)
```

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```
>>> b.slice(2, 0, 10).mean(2)
>>> infile.close()
```

output(*output*, *suffix=None*)
Output the variables as modified

Parameters

output [*CDF*] Output CDF to receive the new data.

suffix [str] Suffix to append to the name of any variables that are changed for the output. This allows the output to contain multiple variables derived from the same input variable. The main variable and its DELTA variables will always have the suffix applied. Any dependencies will have the suffix applied only if they have changed from the input CDF (e.g. from slicing.)

Returns

VarBundle This bundle, for method chaining.

Examples

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> infile = spacepy.pycdf.CDF('rbspa_rel04_ect-hope-PA-L3_20121201_v7.1.0.cdf')
>>> b = spacepy.pycdf.istp.VarBundle(infile['FPDU'])
>>> outfile = spacepy.pycdf.CDF('output.cdf', create=True)
>>> #Output the low energy half in one variable
>>> b.slice(2, 0, 36).output(outfile, suffix='_LoE')
>>> #And the high energy half in another variable
>>> b.slice(2, 36, 72).output(outfile, suffix='_HiE')
>>> outfile.close()
>>> infile.close()
```

operations()
Operations of this bundle

Provides information describing the operations this bundle would perform.

Returns

list Each element is a tuple: first element is a string with the name of the operation (i.e. method of *VarBundle*), next is also a tuple of positional arguments, and finally a dict of keyword arguments.

Examples

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> infile = spacepy.pycdf.CDF('rbspa_rel04_ect-hope-PA-L3_20121201_v7.1.0.cdf')
>>> b = spacepy.pycdf.istp.VarBundle(infile['FPDU'])
>>> b.slice(1, 2, single=True).operations()
  [('slice', (1, 2), {'single': True})]
>>> #Apply same operations to a different variable
```

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```
>>> b2 = spacepy.pycdf.istp.VarBundle(infile['FEDU'])
>>> for op, args, kwargs in b2.operations():
...     getattr(b2, op)(*args, **kwargs)
```

slice(*dim*, *start=None*, *stop=None*, *step=None*, *single=False*)

Slice on a single dimension

Selects subset of a dimension to include in the output. Slicing is done with reference to the dimensions of the main variable and the corresponding dimensions of all other variables are sliced similarly. The first non-record dimension of the variable is always 1; 0 is the record dimension (and is ignored for NRV variables). Multiple slices can be applied to select subsets of multiple dimensions; however, if one dimension is indexed multiple times, only the last one in the chain takes effect.

Interpretation of the slice parameters is like normal Python slicing, including the ability to use negative values, etc.

Passing in only a dimension "resets" the slice to include the entire dimension.

Parameters

dim [int] CDF dimension to slice on. This is the dimension as specified in the CDF (0-base for RV variables, 1-base for NRV) and does not change with successive slicing. Each dimension can only be sliced once.

single [bool] Treat `start` as a single index and return only that index (reducing dimensionality of the data by one.)

start [int] Index of first element of `dim` to include in the output. This can also be a sequence of indices to include, in which case `stop` and `step` must not be specified. This can be substantially slower than specifying `stop` and `step`.

stop [int] Index of first element of `dim` to exclude from the output.

step [int] Increment between elements to include in the output.

Returns

VarBundle This bundle, for method chaining. This is not a copy: the original object is updated.

Examples

See the *VarBundle* examples for creating output from the slices.

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> infile = spacepy.pycdf.CDF('rbspa_rel04_ect-hope-PA-L3_20121201_v7.1.0.cdf')
>>> b = spacepy.pycdf.istp.VarBundle(infile['FPDU'])
>>> #Select index 2 from axis 1
>>> b.slice(1, 2, single=True)
>>> #Select from index 5 to end for axis 2, keeping index 2 from axis 1
>>> b.slice(2, 5)
>>> #Select 10 through 15 on axis 2, but all of axis 1
>>> b.slice(1).slice(2, 10, 15)
>>> #Select just record 5 and 10
>>> b.slice(2).slice(0, [5, 10])
>>> infile.close()
```

sum(*dim*)

Sum across a dimension.

Total the main variable of the bundle across the given dimension. That dimension disappears from the output and dependencies (including their uncertainties) are assumed to be constant across the summed dimension. The uncertainty of the main variable, if any, is appropriately propagated (quadrature sum.)

An invalid value for any element summed over will result in a fill value on the output. This does not work well for variables that define multiple VALIDMIN/VALIDMAX based on position within a dimension; the smallest VALIDMIN/largest VALIDMAX rather than the position-specific value.

Summing occurs after slicing, to allow summing of a subset of a dimension. A single element slice (which removes the dimension) is incompatible with summing over that dimension.

There is not currently a way to "undo" a sum; create a new bundle instead.

Parameters

dim [int] CDF dimension to total. This is the dimension as specified in the CDF (0-base for RV variables, 1-base for NRV) and does not change with successive slicing or summing. This must be a positive number (no support for e.g. -1 for last dimension.)

Returns

VarBundle This bundle, for method chaining. This is not a copy: the original object is updated.

Examples

See the *VarBundle* examples for creating output.

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> infile = spacepy.pycdf.CDF('rbspa_rel04_ect-hope-PA-L3_20121201_v7.1.0.cdf')
>>> b = spacepy.pycdf.istp.VarBundle(infile['Counts_P'])
>>> #Total over dimension 1 (pitch angle)
>>> b.sum(1)
>>> #Get a new bundle (without the previous sum)
>>> b = spacepy.pycdf.istp.VarBundle(infile['Counts_P'])
>>> #Total over first 10 elements of dimension 2 (energy bins)
>>> b.slice(2, 0, 10).sum(2)
>>> infile.close()
```

variables()

Description of variable output from the bundle

Provides information describing the variables output from the bundle

Returns

list Each element is a list-of-tuples. The list corresponds to a dimension of the master var: first the master var itself, then the uncertainties and labels associated with each dimension. Each element of these sublists is then a tuple of variable name and shape on the output (itself a tuple). If a variable isn't included in the output (sliced away), its shape will be `None`.

Examples

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> infile = spacepy.pycdf.CDF('rbspa_rel04_ect-hope-PA-L3_20121201_v7.1.0.cdf')
>>> b = spacepy.pycdf.istp.VarBundle(infile['FPDU'])
>>> b.slice(1, 2, single=True).variables()
[[('FPDU', (100, 72))],
 [('Epoch_Ion', (100,)), ('Epoch_Ion_DELTA', (100,))],
 [('PITCH_ANGLE', None), ('Pitch_LABL', None)],
 [('HOPE_ENERGY_Ion', (100, 72)),
  ('ENERGY_Ion_DELTA', (100, 72)),
  ('Energy_LABL', (72,))]]
```

spacepy.pycdf.istp.VariableChecks

class spacepy.pycdf.istp.**VariableChecks**

ISTP compliance checks for a single variable.

Checks a variable's compliance with ISTP standards. This mostly performs checks that are not currently performed by the ISTP skeleton editor. All tests return a list, one error string for every noncompliance found (empty list if compliant). *all()* will perform all tests and concatenate all errors.

all(v[, catch])	Perform all variable tests
deltas(v)	Check DELTA variables
depends(v)	Checks that DELTA, DEPEND, and LABL_PTR variables exist
depsize(v)	Checks that DEPEND has same shape as that dim
empty_entry(v)	Check for attributes with empty string
fieldnam(v)	Check that FIELDNAM attribute matches variable name.
fillval(v)	Check for FILLVAL presence, type, value
recordcount(v)	Check that the DEPEND_0 has same record count as variable
validdisplaytype(v)	Check that plottype matches dimensions.
validrange(v)	Check that all values are within VALIDMIN/VALIDMAX, or FILLVAL
validscale(v)	Check SCALEMIN<=SCALEMAX, and both in range for CDF datatype.

classmethod all(*v*, *catch=False*)

Perform all variable tests

Parameters

v [*Var*] Variable to check

catch [bool] Catch exceptions in tests (default False). If True, any exceptions in subtests will result in an addition to the validation failures of the form "Test x did not complete." Calling the individual test will reveal the full traceback.

Returns

list of str Description of each validation failure.

Examples

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> f = spacepy.pycdf.CDF('foo.cdf', create=True)
>>> v = f.new('Var', data=[1, 2, 3])
>>> spacepy.pycdf.istp.VariableChecks.all(v)
['No FIELDNAM attribute.']
```

classmethod deltas(*v*)

Check DELTA variables

Check that variables specified in the variable attributes for DELTA match the type, size, and units of this variable.

Parameters

v [*Var*] Variable to check

Returns

list of str Description of each validation failure.

classmethod depends(*v*)

Checks that DELTA, DEPEND, and LABL_PTR variables exist

Check that variables specified in the variable attributes for DELTA, DEPEND, and LABL_PTR exist in the CDF.

Parameters

v [*Var*] Variable to check

Returns

list of str Description of each validation failure.

classmethod depsize(*v*)

Checks that DEPEND has same shape as that dim

Compares the size of variables specified in the variable attributes for DEPEND and compares to the size of the corresponding dimension in this variable.

Parameters

v [*Var*] Variable to check

Returns

list of str Description of each validation failure.

classmethod empty_entry(*v*)

Check for attributes with empty string

Checks attributes for this variable for any entries consisting of an empty string. These should be replaced with a single space.

Parameters

v [*Var*] Variable to check

Returns

list of str Description of each validation failure.

classmethod fieldnam(*v*)
Check that FIELDNAM attribute matches variable name.

Compare FIELDNAM attribute to the variable name; fail validation if they don't match.

Parameters

v [*Var*] Variable to check

Returns

list of str Description of each validation failure.

classmethod fillval(*v*)
Check for FILLVAL presence, type, value

Checks variable for existence of FILLVAL attribute and makes sure it is the same type as variable and matches ISTP value.

Parameters

v [*Var*] Variable to check

Returns

list of str Description of each validation failure.

See also:

spacepy.pycdf.istp.fillval Automatic setting of this value.

classmethod recordcount(*v*)
Check that the DEPEND_0 has same record count as variable

Checks the record count of the variable specified in the variable attribute for DEPEND_0 and compares to the record count for this variable.

Parameters

v [*Var*] Variable to check

Returns

list of str Description of each validation failure.

classmethod validdisplaytype(*v*)
Check that plottype matches dimensions.

Check DISPLAYTYPE of this variable and makes sure it is reasonable for the variable dimensions.

Parameters

v [*Var*] Variable to check

Returns

list of str Description of each validation failure.

classmethod validrange(*v*)
Check that all values are within VALIDMIN/VALIDMAX, or FILLVAL

Compare all values of this variable to VALIDMIN and `VALIDMAX`; fails validation if any values are below VALIDMIN or above `VALIDMAX` unless equal to FILLVAL.

Parameters

v [*Var*] Variable to check

Returns

list of str Description of each validation failure.

classmethod validscale(*v*)

Check SCALEMIN<=SCALEMAX, and both in range for CDF datatype.

Compares SCALEMIN to `SCALEMAX` to make sure it isn't larger and both are within range of the variable CDF datatype.

Parameters

v [*Var*] Variable to check

Returns

list of str Description of each validation failure.

Functions

fillval(v[, ret])	Set ISTP-compliant FILLVAL on a variable
format(v[, use_scaleminmax, dryrun])	Set ISTP-compliant FORMAT on a variable
nanfill(v)	Set fill values to NaN

spacepy.pycdf.istp.fillval

spacepy.pycdf.istp.**fillval**(*v*, *ret=False*)

Set ISTP-compliant FILLVAL on a variable

Sets or returns a CDF variable's FILLVAL attribute to the value required by ISTP (based on variable type).

Parameters

v [*Var*] CDF variable to update

Returns

various If `ret` is True, returns the correct value for variable type (which may be of various Python types). Otherwise sets the value and returns `None`.

Other Parameters

ret [boolean] If True, return the value instead of setting it (Default False, set).

Examples

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> f = spacepy.pycdf.CDF('foo.cdf', create=True)
>>> v = f.new('Var', data=[1, 2, 3])
>>> spacepy.pycdf.istp.fillval(v)
>>> v.attrs['FILLVAL']
-128
```

spacepy.pycdf.istp.format

spacepy.pycdf.istp.**format**(*v*, *use_scaleminmax=False*, *dryrun=False*)
Set ISTP-compliant FORMAT on a variable

Sets a CDF variable's FORMAT attribute, which provides a Fortran-like format string that should be useable for printing any valid value in the variable. Sets according to the VALIDMIN/VALIDMAX attributes (or, optionally, SCALEMIN/SCALEMAX) if present, otherwise uses the full range of the type.

Parameters

v [*Var*] Variable to update

use_scaleminmax [bool, optional] Use SCALEMIN/MAX instead of VALIDMIN/MAX (default False). Note: istpchecks may complain about result.

dryrun [bool, optional] Print the decided format to stdout instead of modifying the CDF (for use in command-line debugging) (default False).

Examples

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> f = spacepy.pycdf.CDF('foo.cdf', create=True)
>>> v = f.new('Var', data=[1, 2, 3])
>>> spacepy.pycdf.istp.format(v)
>>> v.attrs['FORMAT']
'I4'
```

spacepy.pycdf.istp.nanfill

spacepy.pycdf.istp.**nanfill**(*v*)
Set fill values to NaN

Finds all values which are equal to `FILLVAL`, greater than `VALIDMAX`, or less than `VALIDMIN`, and replace with `NaN` (not-a-number). This is an update-in-place operation; does not return a copy.

Assumes a single value for `VALIDMIN`, `VALIDMAX`, `FILLVAL` (although if the attribute is not present, will simply assume no restriction.)

Only applicable to floating-point types. Best applied to a *VarCopy* or *dmarray* rather than *Var*. Updating a variable in a CDF requires one write per changed value, and also will result in a CDF that is no longer ISTP compliant.

Because of floating-point comparison, the matching to `FILLVAL` may fail.

Parameters

v [*Var* or *dmarray*] CDF variable, data, or copy to update

Examples

```
>>> import spacepy.pycdf
>>> import spacepy.pycdf.istp
>>> f = spacepy.pycdf.CDF('foo.cdf', create=True)
>>> v = f.new('Var', data=[1, 2, 3, -1e31])
>>> spacepy.pycdf.istp.fillval(v)
>>> data = v.copy()
>>> data
VarCopy([1., 2., 3., -1.e31], dtype=float32)
>>> spacepy.pycdf.istp.nanfill(data)
>>> data
VarCopy([1., 2., 3., nan], dtype=float32)
```

Data

spacepy.pycdf.**lib**
Module global *Library* object.

Initalized at *pycdf* load time so all classes have ready access to the CDF library and a common state. E.g:

```
>>> from spacepy import pycdf
>>> pycdf.lib.version
    (3, 3, 0, ' ')
```

4.16 radbelt - Functions supporting radiation belt diffusion codes

Functions supporting radiation belt diffusion codes

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Classes

RBmodel([grid, NL, const_kp])	1-D Radial diffusion class

4.16.1 spacepy.radbelt.RBmodel

class spacepy.radbelt.**RBmodel**(*grid='L'*, *NL=91*, *const_kp=False*)
1-D Radial diffusion class

This module contains a class for performing and visualizing 1-D radial diffusion simulations of the radiation belts.

Here is an example using the default settings of the model. Each instance must be initialized with (assuming import radbelt as rb):

```
>>> rmod = rb.RBmodel()
```

Next, set the start time, end time, and the size of the timestep:

```
>>> import datetime
>>> start = datetime.datetime(2003,10,14)
>>> end = datetime.datetime(2003,12,26)
>>> delta = datetime.timedelta(hours=1)
>>> rmod.setup_ticks(start, end, delta, dtype='UTC')
```

Now, run the model over the entire time range using the evolve method:

```
>>> rmod.evolve()
```

Finally, visualize the results:

```
>>> rmod.plot_summary()
```

Gaussian_source()	Gaussian source term added to radiation belt model.
add_Lmax(Lmax_model)	add last closed drift shell Lmax
add_Lpp(Lpp_model)	add last closed drift shell Lmax
add_PSD_obs([time, PSD, Lstar, satlist])	add PSD observations
add_PSD_twin([dt, Lt])	add observations from PSD database using the ticks list the arguments are the following:
add_omni([keylist])	add omni data to instance according to the tickrange in ticks
add_source([source, A, mu, sigma])	add source parameters A, mu, and sigma for the Gaussian source function
assimilate([method, inflation])	Assimilates data for the radiation belt model using the Ensemble Kalman Filter.
evolve()	calculate the diffusion in L at constant mu,K coordinates
get_DLL(Lgrid, params[, DLL_model])	Calculate DLL as a simple power law function (alpha*L**Bbta) using alpha/beta values from popular models found in the literature and chosen with the kwarg "DLL_model".
plot([Lmax, Lpp, Kp, Dst, clims, title, values])	Create a summary plot of the RadBelt object distribution function.
plot_obs([Lmax, Lpp, Kp, Dst, clims, title, ...])	Create a summary plot of the observations.
set_lgrid([NL])	Using NL grid points, create grid in L.
setup_ticks(start, end, delta[, dtype])	Add time information to the simulation by specifying a start and end time, timestep, and time type (optional).

Gaussian_source()

Gaussian source term added to radiation belt model. The source term is given by the equation:

S = A exp{-(L-mu)^2/(2*sigma^2)}

with A=10^(-8), mu=5.0, and sigma=0.5 as default values

add_Lmax(*Lmax_model*)

add last closed drift shell Lmax

add_Lpp(*Lpp_model*)

add last closed drift shell Lmax

add_PSD_obs(*time=None*, *PSD=None*, *Lstar=None*, *satlist=None*)
add PSD observations

Parameters

time [Ticktock datetime array] array of observation times

PSD [list of numpy arrays] PSD observational data for each time. Each entry in the list is a numpy array with the observations for the corresponding time

Lstar [list of numpy arrays] Lstar location of each PSD observations. Each entry in the list is a numpy array with the location of the observations for the corresponding time

satlist [list of satellite names]

Returns

out [list of dicts] Information of the observational data, where each entry contains the observations and locations of observations for each time specified in the time array. Each list entry is a dictionary with the following information:

Ticks [Ticktock array] time of observations

Lstar [numpy array] location of observations

PSD [numpy array] PSD observation values

sat [list of strings] satellite names

MU [scalar value] Mu value for the observations

K [scalar value] K value for the observations

add_PSD_twin(*dt=0*, *Lt=1*)
add observations from PSD database using the ticks list the arguments are the following:

dt = observation time delta in seconds Lt = observation space delta

add_omni(*keylist=None*)
add omni data to instance according to the tickrange in ticks

add_source(*source=True*, *A=1e-08*, *mu=5.0*, *sigma=0.5*)
add source parameters A, mu, and sigma for the Gaussian source function

assimilate(*method='EnKF'*, *inflation=0*)
Assimilates data for the radiation belt model using the Ensemble Kalman Filter. The algorithm used is the SVD method presented by Evensen in 2003 (Evensen, G., Ocean dynamics, 53, pp.343–367, 2003). To compensate for model errors, three inflation algorithms are implemented. The inflation methodology is specified by the 'inflation' argument, and the options are the following:

inflation == 0: Add model error (perturbation for the ensemble) around model state values only where observations are available (DEFAULT).

inflation == 1: Add model error (perturbation for the ensemble) around observation values only where observations are available.

inflation == 2: Inflate around ensemble average for EnKF.

Prior to assimilation, a set of data values has to be speficied by setting the start and end dates, and time step, using the setup_ticks funcion of the radiation belt model:

```
>>> import spacepy
>>> import datetime
>>> from spacepy import radbelt
```

```
>>> start = datetime.datetime(2002,10,23)
>>> end = datetime.datetime(2002,11,4)
>>> delta = datetime.timedelta(hours=0.5)
>>> rmod.setup_ticks(start, end, delta, dtype='UTC')
```

Once the dates and time step are specified, the data is added using the add_PSD function:

```
>>> rmod.add_PSD()
```

The observations are averaged over the time windows, whose interval is give by the time step.

Once the dates and data are set, the assimiation is performed using the 'assimilate' function:

```
>>> rmod.assimilate(inflation=1)
```

This function will add the PSDa values, which are the analysis state of the radiation belt using the observations within the dates. To plot the analysis simply use the plot funtion:

```
>>> rmod.plot(values=rmod.PSDa,clims=[-10,-6],Lmax=False,Kp=False,Dst=False)
```

evolve()
calculate the diffusion in L at constant mu,K coordinates

get_DLL(*Lgrid*, *params*, *DLL_model='BA2000'*)
Calculate DLL as a simple power law function (alpha*L**Bbta) using alpha/beta values from popular models found in the literature and chosen with the kwarg "DLL_model".

The calculated DLL is returned, as is the alpha and beta values used in the calculationp.

The output DLL is in units of units/day.

plot(*Lmax=True*, *Lpp=False*, *Kp=True*, *Dst=True*, *clims=[0, 10]*, *title=None*, *values=None*)
Create a summary plot of the RadBelt object distribution function. For reference, the last closed drift shell, Dst, and Kp are all included. These can be disabled individually using the corresponding Boolean kwargs.

The clims kwarg can be used to manually set the color bar range. To use, set it equal to a two-element list containing minimum and maximum Log_10 value to plot. Default action is to use [0,10] as the log_10 of the color range. This is good enough for most applications.

The title of the top most plot defaults to 'Summary Plot' but can be customized using the title kwarg.

The figure object and all three axis objects (PSD axis, Dst axis, and Kp axis) are all returned to allow the user to further customize the plots as necessary. If any of the plots are excluded, None is returned in their stead.

Examples

```
>>> rb.plot(Lmax=False, Kp=False, clims=[2,10], title='Good work!')
```

This command would create the summary plot with a color bar range of 100 to 10^10. The Lmax line and Kp values would be excluded. The title of the topmost plot (phase space density) would be set to 'Good work!'.

plot_obs(*Lmax=True*, *Lpp=False*, *Kp=True*, *Dst=True*, *clims=[0, 10]*, *title=None*, *values=None*)
Create a summary plot of the observations. For reference, the last closed drift shell, Dst, and Kp are all included. These can be disabled individually using the corresponding boolean kwargs.

The clims kwarg can be used to manually set the color bar range. To use, set it equal to a two-element list containing minimum and maximum Log_10 value to plot. Default action is to use [0,10] as the log_10 of the color range. This is good enough for most applications.

The title of the top most plot defaults to 'Summary Plot' but can be customized using the title kwarg.

The figure object and all three axis objects (PSD axis, Dst axis, and Kp axis) are all returned to allow the user to further customize the plots as necessary. If any of the plots are excluded, None is returned in their stead.

Examples

```
>>> rb.plot_obs(Lmax=False, Kp=False, clims=[2,10], title='Observations Plot')
```

This command would create the summary plot with a color bar range of 100 to 10^10. The Lmax line and Kp values would be excluded. The title of the topmost plot (phase space density) would be set to 'Good work!'.

set_lgrid(*NL=91*)
Using NL grid points, create grid in L. Default number of points is 91 (dL=0.1).

setup_ticks(*start*, *end*, *delta*, *dtype='ISO'*)
Add time information to the simulation by specifying a start and end time, timestep, and time type (optional).

Examples

```
>>> start = datetime.datetime(2003,10,14)
>>> end = datetime.datetime(2003,12,26)
>>> delta = datetime.timedelta(hours=1)
>>> rmod.setup_ticks(start, end, delta, dtype='UTC')
```

Functions

get_modelop_L(f, L, Dm_old, Dm_new, Dp_old, ...)	Advance the distribution function, f, discretized into the Lgrid, L, forward in time by a timestep, Tdelta.
diff_LL(r, grid, f, Tdelta, Telapsed[, params])	calculate the diffusion in L at constant mu,K coordinates time units
get_local_accel(Lgrid, params[, SRC_model])	calculate the diffusion coefficient D_LL

4.16.2 spacepy.radbelt.get_modelop_L

spacepy.radbelt.**get_modelop_L**(*f*, *L*, *Dm_old*, *Dm_new*, *Dp_old*, *Dp_new*, *Tdelta*, *NL*)
Advance the distribution function, f, discretized into the Lgrid, L, forward in time by a timestep, Tdelta. The off-grid current and next diffusion coefficients, D[m,p]_[old,new] will be used. The number of grid points is set by NL.

This function performs the same calculation as the C-based code, spacepy.lib.solve_cnp. This code is very slow and should only be used when the C code fails to compile.

4.16.3 spacepy.radbelt.diff_LL

spacepy.radbelt.**diff_LL**(*r*, *grid*, *f*, *Tdelta*, *Telapsed*, *params=None*)
calculate the diffusion in L at constant mu,K coordinates time units

4.16.4 spacepy.radbelt.get_local_accel

spacepy.radbelt.**get_local_accel**(*Lgrid*, *params*, *SRC_model='JK1'*)
calculate the diffusion coefficient D_LL

4.17 SeaPy - Superposed Epoch in Python

SeaPy – Superposed Epoch in Python.

This module contains superposed epoch class types and a variety of functions for using on superposed epoch objects. Each instance must be initialized with (assuming import seapy as se):

```
>>> obj = se.Sea(data, times, epochs)
```

To perform a superposed epoch analysis

```
>>> obj.sea()
```

To plot

```
>>> obj.plot()
```

If multiple SeaPy objects exist, these can be combined into a single object

```
>>> objdict = seadict([obj1, obj2],['obj1name','obj2name'])
```

and then used to create a multipanel plot

```
>>> multisea(objdict)
```

For two-dimensional superposed epoch analyses, initialize an Sea2d() instance

```
>>> obj = se.Sea2d(data, times, epochs, y=[4., 12.])
```

All object methods are the same as for the 1D object. Also, the multisea() function should accept both 1D and 2D objects, even mixed together. Currently, the plot() method is recommended for 2D SEA.

–++– By Steve Morley –++–

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Classes

Sea(data, times, epochs[, window, delta, ...])	SeaPy Superposed epoch analysis object
Sea2d(data, times, epochs[, window, delta, ...])	SeaPy 2D Superposed epoch analysis object

4.17.1 spacepy.seapy.Sea

class spacepy.seapy.**Sea**(*data*, *times*, *epochs*, *window=3.0*, *delta=1.0*, *verbose=True*)

SeaPy Superposed epoch analysis object

Initialize object with data, times, epochs, window (half-width) and delta (optional). 'times' and epochs should be in some useful format Includes method to perform superposed epoch analysis of input data series

Parameters

data [array_like] list or array of data

times [array_like] list of datetime objects (or list of serial times)

epochs [array_like] list of datetime objects (or serial times) for zero epochs in SEA

window [datetime.timedelta] size of the half-window for the SEA (can also be given as serial time)

delta [datetime.timedelta] resolution of the input data series, which must be uniform (can also be given as serial time)

Notes

Output can be nicely plotted with *plot()*, or for multiple objects use the *multisea()* function

sea(**kwargs)	Method called to perform superposed epoch analysis on data in object.
plot([xquan, yquan, xunits, yunits, ...])	Method called to create basic plot of superposed epoch analysis.

sea(***kwargs*)

Method called to perform superposed epoch analysis on data in object.

Uses object attributes obj.data, obj.times, obj.epochs, obj.delta, obj.window, all of which must be available on instantiation.

Other Parameters

storedata [boolean] saves matrix of epoch windows as obj.datacube (default = False)

quartiles [list] calculates the quartiles as the upper and lower bounds (and is default);

ci [float] will find the bootstrapped confidence intervals of ci_quan at the ci percent level (default=95)

mad [float] will use +/- the median absolute deviation for the bounds;

ci_quan [string] can be set to 'median' (default) or 'mean'

Notes

A basic plot can be raised with `plot()`

plot(*xquan='Time Since Epoch'*, *yquan=''*, *xunits=''*, *yunits=''*, *epochline=True*, *usrlimy=[]*, *show=True*, *target=None*, *loc=111*, *figsize=None*, *dpi=None*, *transparent=True*, *color='#7F7FFF'*)
Method called to create basic plot of superposed epoch analysis.

Parameters

Uses object attributes created by the obj.sea() method.

Other Parameters

xquan [str] (default = 'Time since epoch') - x-axis label.

yquan [str] default None - yaxus label

xunits [str] (default = None) - x-axis units.

yunits [str] (default = None) - y-axis units.

epochline [boolean] (default = True) - put vertical line at zero epoch.

usrlimy [list] (default = []) - override automatic y-limits on plot.

transparent [boolean] (default True): make patch for low/high bounds transparent

color [str] Color to use for the patch if not transparent. (default #7F7FFF, a medium blue)

Notes

If both quan and units are supplied, axis label will read 'Quantity Entered By User [Units]'

4.17.2 spacepy.seapy.Sea2d

class spacepy.seapy.**Sea2d**(*data*, *times*, *epochs*, *window=3.0*, *delta=1.0*, *verbose=False*, *y=[]*)
SeaPy 2D Superposed epoch analysis object

Initialize object with data (n element vector), times(y*n array), epochs, window (half-width), delta (optional), and y (two-element vector with max and min of y;optional) 'times' and epochs should be in some useful format Includes method to perform superposed epoch analysis of input data series

Parameters

data [array_like] 2-D array of data (0th dimension is quantity y, 1st dimension is time)

times [array_like] list of datetime objects (or list of serial times)

epochs [array_like] list of datetime objects (or serial times) for zero epochs in SEA

window [datetime.timedelta] size of the half-window for the SEA (can also be given as serial time)

delta [datetime.timedelta] resolution of the input data series, which must be uniform (can also be given as serial time)

Notes

Output can be nicely plotted with *plot()*, or for multiple objects use the *multisea()* function

sea([storedata, quartiles, ci, mad, ...])	Perform 2D superposed epoch analysis on data in object
plot([xquan, yquan, xunits, yunits, zunits, ...])	Method called to create basic plot of 2D superposed epoch analysis.

sea(*storedata=False*, *quartiles=True*, *ci=False*, *mad=False*, *ci_quan='median'*, *nmask=1*, ***kwargs*)
Perform 2D superposed epoch analysis on data in object

Uses object attributes obj.data, obj.times, obj.epochs, obj.delta, obj.window, all of which must be available on instantiation.

Other Parameters

storedata [boolean] saves matrix of epoch windows as obj.datacube (default = False)

quartiles [list] calculates the inter-quartile range to show the spread (and is default);

ci [float] will find the bootstrapped confidence interval (and requires ci_quan to be set)

mad [float] will use the median absolute deviation for the spread;

ci_quan [string] can be set to 'median' or 'mean'

Notes

A basic plot can be raised with *plot()*

plot(*xquan='Time Since Epoch'*, *yquan=''*, *xunits=''*, *yunits=''*, *zunits=''*, *epochline=True*, *usrlimy=[]*, *show=True*, *zlog=True*, *figsize=None*, *dpi=300*)
Method called to create basic plot of 2D superposed epoch analysis.

Uses object attributes created by *sea()*.

Other Parameters

x(y)quan [str] x(y)-axis label. (default = 'Time since epoch' (None))

x(y/z)units [str] x(y/z)-axis units. (default = None (None))

epochline [boolean] put vertical line at zero epoch. (default = True)

usrlimy [list] override automatic y-limits on plot. (default = [])

show [boolean] shows plot; set to false to output plot object to variable (default = True)

figsize [tuple] (width, height) in inches

dpi [int] figure resolution in dots per inch (default=300)

Notes

If both quan and units are supplied, axis label will read 'Quantity Entered By User [Units]'

Functions

seadict(objlist, namelist)	Function to create dictionary of SeaPy.Sea objects.
multisea(dictobj[, n_cols, epochline, ...])	Function to create multipanel plot of superposed epoch analyses.
readepochs(fname[, iso, isofmt])	Read epochs from text file assuming YYYY MM DD hh mm ss format
sea_signif(obj1, obj2[, test, show, xquan, ...])	Test for similarity between distributions at each lag in two 1-D SEAs

4.17.3 spacepy.seapy.seadict

spacepy.seapy.**seadict**(*objlist*, *namelist*)

Function to create dictionary of SeaPy.Sea objects.

Parameters

- objlist: List of Sea objects.

- namelist: List of variable labels for input objects.

Other Parameters

namelist = List containing names for y-axes.

4.17.4 spacepy.seapy.multisea

spacepy.seapy.**multisea**(*dictobj*, *n_cols=1*, *epochline=True*, *usrlimx=[]*, *usrlimy=[]*, *xunits=''*, *show=True*, *zunits=''*, *zlog=True*, *figsize=None*)

Function to create multipanel plot of superposed epoch analyses.

Parameters

Dictionary of Sea objects (from superposedepoch.seadict()).

Returns

Plot of input object median and bounds (ci, mad, quartiles - see sea()).

If keyword 'show' is False, output is a plot object.

Other Parameters

- epochline (default = True) - put vertical line at zero epoch.

- usrlimy (default = []) - override automatic y-limits on plot (same for all plots).

- show (default = True) - shows plot; set to false to output plot object to variable

- x/zunits - Units for labeling x and z axes, if required

- figsize - tuple of (width, height) in inches

- dpi (default=300) - figure resolution in dots per inch

- n_cols - Number of columns: not yet implemented.

4.17.5 spacepy.seapy.readepochs

spacepy.seapy.**readepochs**(*fname*, *iso=False*, *isofmt='%Y-%m-%dT%H:%M:%S'*)

Read epochs from text file assuming YYYY MM DD hh mm ss format

Parameters

Filename (include path)

Returns

epochs (type=list)

Other Parameters

iso (default = False), read in ISO date format

isofmt (default is YYYY-mm-ddTHH:MM:SS, code is %Y-%m-%dT%H:%M:%S)

4.17.6 spacepy.seapy.sea_signif

spacepy.seapy.**sea_signif**(*obj1*, *obj2*, *test='KS'*, *show=True*, *xquan='Time Since Epoch'*, *yquan=''*, *xunits=''*, *yunits=''*, *epochline=True*, *usrlimy=[]*)

Test for similarity between distributions at each lag in two 1-D SEAs

Parameters

obj1 [Sea] First instance for comparison

obj2 [Sea] Second instance for comparison

Other Parameters

test (default = 'KS') Test to apply at each lag: KS is 2-smaple Kolmogorov-Smirnov; U is Mann-Whitney U-test

show (default = True)

xquan (default = 'Time since epoch' (None)) - x-axis label.

yquan (default = 'Time since epoch' (None)) - y-axis label.

xunits (default = None (None)) - x-axis units.

yunits (default = None (None)) - y-axis units.

epochline (default = True) - put vertical line at zero epoch.

usrlimy (default = []) - override automatic y-limits on plot.

Examples

```
>>> obj1 = seapy.Sea(data1, times1, epochs1)
>>> obj2 = seapy.Sea(data2, times2, epochs2)
>>> obj1.sea(storedata=True)
>>> obj2.sea(storedata=True)
>>> seapy.sea_signif(obj1, obj2)
```

4.18 time - Time conversion, manipulation and implementation of Ticktock class

Time conversion, manipulation and implementation of Ticktock class

4.18.1 Notes

The handling of time, in particular the conversions between representations, can be more complicated than it seems on the surface. This can result in some surprising behavior, particularly when requiring second-level accuracy and converting between time systems outside of the period 1972 to present. It is strongly recommended to use TAI if transferring times between SpacePy and other libraries. TAI has a consistent, unambiguous definition and no discontinuities.

Some time systems (e.g. the UTC representation via datetime) cannot represent times during a leapsecond. SpacePy represents all these times as the latest representable time in the day, e.g.:

```
>>> spacepy.time.Ticktock('2008-12-31T23:59:60').UTC[0]
datetime.datetime(2008, 12, 31, 23, 59, 59, 999999)
```

Conversions between continuous time representations (e.g. TAI), leap second aware representations (e.g. ISO timestrings), and those that ignore leap seconds (e.g. UTC datetime, Unix time) are well-defined between the introduction of the leap second system to UTC in 1972 and the present. For systems that cannot represent leap seconds, the leap second moment is considered not to exist. For example, from 23:59:59 on 2008-12-31 to 00:00:00 on 2009-01-01 is two seconds, but only represents a one-second increment in Unix time. Details are also discussed in the individual time representations.

UTC times more than six months in the future are not well-defined, since the schedule of leap second insertion is not known in advance. SpacePy performs conversions assuming there are no leapseconds after those which have been announced by IERS.

Between 1960 and 1972, UTC was defined by means of fractional leap seconds and a varying-length second. From 1958 (when UTC was set equal to TAI) and 1972, SpacePy treats UTC time similar to after 1972, with a consistent second the same length of the SI second, and applying a full leap second before the beginning of January and July if UTC - UT1 exceeded 0.4s. The difference with other methods of calculating UTC is less than half a second.

Changed in version 0.2.3: The application of post-1972 rules to 1958-1927 is new in 0.2.3. Before, SpacePy applied leap seconds wherever there was an entry in the USNO record of TAI-UTC, rounding fractional total leap second counts to the integer (0.5 rounds up). The UTC second was still treated as the same length as the SI second (i.e., rate changed were not applied.) This resulted in the application of six leap seconds at the beginning of 1972. The discrepancy with other means of calculating TAI-UTC was as much as five seconds by the end of this period.

Changed in version 0.2.2: Before 0.2.2, SpacePy truncated fractional leapseconds rather than rounding.

Before 1958, UTC is not defined. SpacePy assumes days of constant length 86400 seconds, equal to the SI second. This is almost guaranteed to be wrong; for times well out of the space era, it is strongly recommended to work consistently in either a continuous time system (e.g. TAI) or a day-based system (e.g. JD).

SpacePy assumes dates including and after 1582-10-15 to be in the Gregorian calendar and dates including and before 1582-10-04 to be Julian. 10-05 through 10-14 do not exist. This change is ignored for continuously-running non leap second aware timebases: CDF and RDT.

See the *Ticktock* documentation and its various `get` functions for more details on the exact definitions of time systems used by SpacePy.

4.18.2 Examples:

```
>>> import spacepy.time as spt
>>> import datetime as dt
```

Day of year calculations

```
>>> dts = spt.doy2date([2002]*4, range(186,190), dtobj=True)
>>> dts
[datetime.datetime(2002, 7, 5, 0, 0),
datetime.datetime(2002, 7, 6, 0, 0),
datetime.datetime(2002, 7, 7, 0, 0),
datetime.datetime(2002, 7, 8, 0, 0)]
```

```
>>> dts = spt.Ticktock(dts,'UTC')
>>> dts.DOY
array([ 186.,  187.,  188.,  189.])
```

Ticktock object creation

```
>>> isodates = ['2009-12-01T12:00:00', '2009-12-04T00:00:00', '2009-12-06T12:00:00']
>>> dts = spt.Ticktock(isodates, 'ISO')
```

OR

```
>>> dtdates = [dt.datetime(2009,12,1,12), dt.datetime(2009,12,4), dt.datetime(2009,12,6,
↪12)]
>>> dts = spt.Ticktock(dtdates, 'UTC')
```

ISO time formatting

```
>>> dts = spt.tickrange('2009-12-01T12:00:00','2009-12-06T12:00:00',2.5)
```

OR

```
>>> dts = spt.tickrange(dt.datetime(2009,12,1,12),dt.datetime(2009,12,6,12),     dt.
↪timedelta(days=2, hours=12))
```

```
>>> dts
Ticktock( ['2009-12-01T12:00:00', '2009-12-04T00:00:00', '2009-12-06T12:00:00'] ),␣
↪dtype=ISO
```

```
>>> dts.isoformat()
Current ISO output format is %Y-%m-%dT%H:%M:%S
Options are: [('seconds', '%Y-%m-%dT%H:%M:%S'), ('microseconds', '%Y-%m-%dT%H:%M:%S.%f')]
```

```
>>> dts.isoformat('microseconds')
>>> dts.ISO
['2009-12-01T12:00:00.000000',
 '2009-12-04T00:00:00.000000',
 '2009-12-06T12:00:00.000000']
```

Time manipulation

```
>>> new_dts = dts + tdelt
>>> new_dts.UTC
[datetime.datetime(2009, 12, 2, 18, 0),
 datetime.datetime(2009, 12, 5, 6, 0),
 datetime.datetime(2009, 12, 7, 18, 0)]
```

Other time formats

```
>>> dts.RDT  # Gregorian ordinal time
array([ 733742.5,  733745. ,  733747.5])
```

```
>>> dts.GPS # GPS time
array([  9.43704015e+08,   9.43920015e+08,   9.44136015e+08])
```

```
>>> dts.JD # Julian day
array([ 2455167. ,  2455169.5,  2455172. ])
```

And so on.

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Classes

Ticktock(data, dtype)	Ticktock class holding various time coordinate systems (TAI, UTC, ISO, JD, MJD, UNX, RDT, CDF, DOY, eDOY, APT)

4.18.3 spacepy.time.Ticktock

class spacepy.time.**Ticktock**(*data*, *dtype*)

Ticktock class holding various time coordinate systems (TAI, UTC, ISO, JD, MJD, UNX, RDT, CDF, DOY, eDOY, APT)

Possible input data types:

ISO ISO standard format like '2002-02-25T12:20:30'

UTC datetime object with UTC time

TAI Elapsed seconds since 1958-1-1 (includes leap seconds)

UNX Elapsed seconds since 1970-1-1 ignoring leapseconds (all days have 86400 secs).

JD Julian days elapsed

MJD Modified Julian days

RDT Rata Die days elapsed since 0001-1-1

CDF CDF Epoch type: float milliseconds since 0000-1-1 ignoring leapseconds

APT AstroPy `Time`. Requires AstroPy 1.0. (New in version 0.2.2.)

Possible output data types: All those listed above, plus:

DOY Integer day of year, starts with day 1

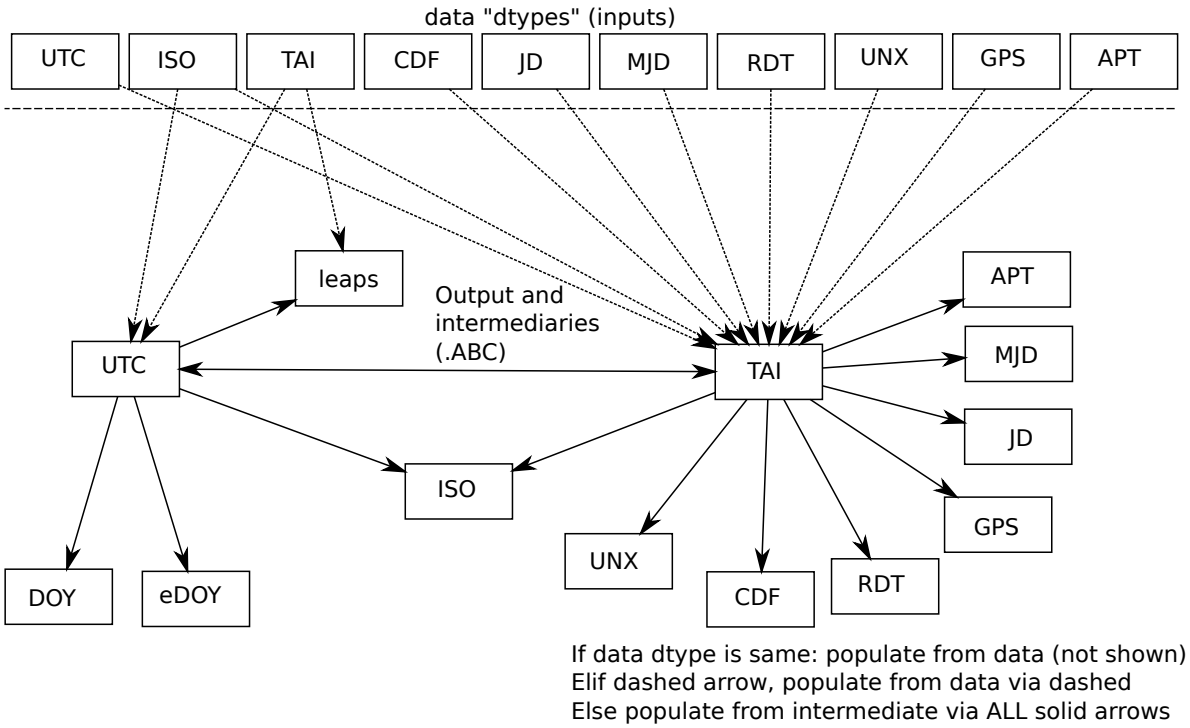
eDOY Fractional day of year, starts at day 0

It is strongly recommended to access various time systems via the attributes listed above, as in the examples. They will be calculated automatically if necessary. Using the `get` methods will force a recalculation.

The original input data will always be available as the `data` attribute.

Changed in version 0.2.2: In earlier versions of SpacePy, most values were derived from the `datetime`-based `UTC` representation. This did not properly handle leap seconds in many cases. Now most are derived from `TAI` (exceptions being `DOY` and `eDOY`). In addition to differences around actual leap seconds, this may result in small differences between versions of SpacePy, with relative magnitude on the order of the resolution of a 64-bit float (2e-16). For times in the modern era, this is about 50 microseconds (us) for `JD`, 15 us for `CDF`, 1.5 us for `RDT`, 1 us for `MJD`, and 360 *nanoseconds* for `TAI`.

The relationships between parameters and how they are calculated are listed in the `get` methods and illustrated below.



Parameters

data [array_like (int, datetime, float, string)] time stamp

dtype [string {*CDF*, *ISO*, *UTC*, *TAI*, *UNX*, *JD*, *MJD*, *RDT*, *APT*} or function] data type for data, if a function it must convert input time format to Python datetime

Returns

out [Ticktock] instance with self.data, self.dtype, self.UTC etc

Other Parameters

isoformat [str, optional] New in version 0.2.2.

Format string used for parsing and outputting ISO format. Input is not forced to be in this format; it is tried first, and other common formats tried if parsing fails. Because of this, if ISO input is in a consistent format, specifying this can speed up the input parsing. Can be changed on existing `Ticktock` with *isoformat()* method. Default `'%Y-%m-%dT%H:%M:%S'`.

See also:

`datetime.datetime.strptime`, *isoformat*

Notes

UTC data type is implemented as Python datetime, which cannot represent leap seconds. The time within a leap second is regarded as not happening.

The CDF data type is the older CDF_EPOCH time type, not the newer CDF_TIME_TT2000. It similarly cannot represent leap seconds. Year 0 is considered a leap year.

Examples

```
>>> x = Ticktock([2452331.0142361112, 2452332.0142361112], 'JD')
>>> x.ISO
dmarray(['2002-02-25T12:20:30', '2002-02-26T12:20:30'], dtype='|S19')
>>> x.DOY # Day of year
dmarray([ 56.,  57.])
>>> y = Ticktock(['01-01-2013', '20-03-2013'], lambda x: datetime.datetime.
↪strptime(x, '%d-%m-%Y'))
>>> y.UTC
dmarray([2013-01-01 00:00:00, 2013-03-20 00:00:00], dtype=object)
>>> y.DOY # Day of year
dmarray([  1.,  79.])
```

append(other)	Will be called when another Ticktock instance has to be appended to the current one
argsort()	This will return the indices that would sort the Ticktock values
convert(dtype)	convert a Ticktock instance into a new time coordinate system provided in dtype
getAPT()	a.APT or a.getAPT()
getCDF()	a.getCDF() or a.CDF
getDOY()	a.DOY or a.getDOY()
getGPS()	a.GPS or a.getGPS()
getISO()	a.ISO or a.getISO()
getJD()	a.JD or a.getJD()
getMJD()	a.MJD or a.getMJD()
getRDT()	a.RDT or a.RDT()

continues on next page

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getTAI()	a.TAI or a.getTAI()
getUNX()	a.UNX or a.getUNX()
getUTC()	a.UTC or a.getUTC()
geteDOY()	a.eDOY or a.geteDOY()
getleapsecs()	a.leaps or a.getleapsecs()
isoformat(b, attrib)	This changes the self._isofmt attribute by and subsequently this function will update the ISO attribute.
now()	Create Ticktock with the current UTC time.
sort()	This will sort the Ticktock values in place based on the values in *data*.
today()	Create Ticktock with the current UTC date and time set to 00:00:00
update_items(attrib)	After changing the self.data attribute by either __setitem__ or __add__ etc this function will update all other attributes.

append(*other*)
Will be called when another Ticktock instance has to be appended to the current one

Parameters

other [Ticktock] other (Ticktock instance)

argsort()
This will return the indices that would sort the Ticktock values

Returns

out [list] indices that would sort the Ticktock values

Other Parameters

kind [str, optional] Sort algorithm to use, default 'quicksort'.

Changed in version 0.2.2: Default is now 'quicksort' to match numpy default; previously was 'mergesort'.

See also:

argsort, numpy.argsort

convert(*dtype*)
convert a Ticktock instance into a new time coordinate system provided in dtype

Parameters

dtype [string] data type for new system, possible values are {*CDF*, *ISO*, *UTC*, *TAI*, *UNX*, *JD*, *MJD*, *RDT*}

Returns

out [Ticktock] Ticktock instance with new time coordinates

See also:

CDF

ISO

UTC

Examples

```
>>> a = Ticktock(['2002-02-02T12:00:00', '2002-02-02T12:00:00'], 'ISO')
>>> s = a.convert('TAI')
>>> type(s)
<class 'time.Ticktock'>
>>> s
Ticktock( [1391342432 1391342432] ), dtype=TAI
```

getAPT()

a.APT or a.getAPT()

Return AstroPy time object.

Always recalculates from the current value of `TAI`, which will be created if necessary.

Updates the `APT` attribute.

Returns

out [astropy.time.Time] AstroPy Time object

See also:

getUTC, *getUNX*, *getRDT*, *getJD*, *getMJD*, *getCDF*, *getISO*, *getDOY*, *geteDOY*

getGPS

Notes

New in version 0.2.2.

Requires AstroPy 1.0. The returned value will be on the `tai` scale in `gps` format (unless the *Ticktock* was created from a `Time` object, in which case it will be the original input.) See the `astropy.time` docs for conversion to other scales and formats.

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.APT
<Time object: scale='tai' format='gps' value=696686413.0>
```

getCDF()

a.getCDF() or a.CDF

Return CDF Epoch time which is milliseconds since 0000-1-1 at 00:00:00.000. "Year zero" is a convention chosen by NSSDC to measure epoch values. This date is more commonly referred to as 1 BC and is considered a leap year.

The CDF date/time calculations do not take into account the change to the Gregorian calendar or leap seconds, and cannot be directly converted into Julian date/times.

Returns `data` if it was provided in CDF; otherwise always recalculates from the current value of `TAI`, which will be created if necessary.

Updates the `CDF` attribute.

Returns

out [numpy array] milliseconds since 0000-01-01T00:00:00 assuming no discontinuities.

See also:

getUTC

getUNX

getRDT

getJD

getMJD

getISO

getTAI

getDOY

geteDOY

getAPT

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.CDF
array([  6.31798704e+13])
```

getDOY()

a.DOY or a.getDOY()

extract DOY (days since January 1st of given year)

Always recalculates from the current value of UTC, which will be created if necessary.

Updates the DOY attribute.

Returns

out [numpy array] day of the year

See also:

getUTC

getUNX

getRDT

getJD

getMJD

getISO

getTAI

getDOY

geteDOY

getAPT

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.DOY
array([ 33])
```

getGPS()

a.GPS or a.getGPS()

Return seconds since the GPS epoch (1980-1-6T00:00 UT)

Always recalculates from the current value of TAI, which will be created if necessary.

Updates the GPS attribute.

Returns

out [numpy array] elapsed secs since 1980-1-6. Leap seconds are counted; i.e. there are no discontinuities.

See also:

getUTC, *getUNX*, *getRDT*, *getJD*, *getMJD*, *getCDF*, *getISO*, *getDOY*, *geteDOY*

getAPT

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.GPS
dmarray([6.96686413e+08])
```

getISO()

a.ISO or a.getISO()

convert dtype data into ISO string

Always recalculates from the current value of UTC, which will be created if necessary. Applies leapsecond correction based on TAI, also created as necessary.

Updates the ISO attribute.

Returns

out [list of strings] date in ISO format

See also:

getUTC, *getUNX*, *getRDT*, *getJD*, *getMJD*, *getCDF*, *getTAI*, *getDOY*, *geteDOY*

getAPT

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.ISO
dmarray(['2002-02-02T12:00:00'])
```

getJD()

a.JD or a.getJD()

convert dtype data into Julian Date (JD)

Returns `data` if it was provided in JD; otherwise always recalculates from the current value of `TAI`, which will be created if necessary.

Updates the `JD` attribute.

Returns

out [numpy array] elapsed days since 4713 BCE 01-01T12:00

See also:

getUTC

getUNX

getRDT

getJD

getMJD

getISO

getTAI

getDOY

geteDOY

getAPT

Notes

This is based on the UTC day, defined as JD(UTC), per the recommendation of IAU General Assembly XXIII resolution B1. Julian days with leapseconds are 86401 seconds long and each second is a smaller fraction of the day. Note this "stretching" is across the *Julian* Day, noon to noon.

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.JD
array([ 2452308.])
```

getMJD()

a.MJD or a.getMJD()

convert dtype data into MJD (modified Julian date)

Returns `data` if it was provided in MJD; otherwise always recalculates from the current value of `TAI` which will be created if necessary.

Updates the `MJD` attribute.

Returns

out [numpy array] elapsed days since 1858-11-17T00:00 (Julian date of 1858-11-17T12:00 was 2 400 000)

See also:

getUTC, *getUNX*, *getRDT*, *getJD*, *getISO*, *getCDF*, *getTAI*, *getDOY*, *geteDOY*

getAPT

Notes

This is based on the UTC day, defined as JD(UTC) - 2 400 000.5, per the recommendation of IAU General Assembly XXIII resolution B1. Julian days with leapseconds are 86401 seconds long and each second is a smaller fraction of the day. Note this "stretching" is across the *Julian* Day not the MJD, so it will affect the last half of the MJD before the leap second and the first half of the following MJD, so that MJD is always JD - 2 400 000.5 This also means that the MJD following a leap second does not begin exactly at midnight.

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.MJD
array([ 52307.5])
>>> a = Ticktock('2009-01-01T00:00:00', 'ISO')
>>> a.MJD
array([ 54832.00000579])
```

getRDT()

a.RDT or a.RDT()

convert dtype data into Rata Die (lat.) Time, or elapsed days counting 0001-01-01 as day 1. This is a naive conversion: it ignores the existence of leapseconds for fractional days and ignores the conversion from Julian to Gregorian calendar, i.e. it assumes Gregorian calendar infinitely into the past.

Returns `data` if it was provided in RDT; otherwise always recalculates from the current value of `TAI`, which will be created if necessary.

Updates the `RDT` attribute.

Returns

out [numpy array] elapsed days counting 1/1/1 as day 1.

See also:

getUTC, *getUNX*, *getISO*, *getJD*, *getMJD*, *getCDF*, *getTAI*, *getDOY*, *geteDOY*

getAPT

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.RDT
array([ 730883.5])
```

getTAI()

a.TAI or a.getTAI()

return TAI (International Atomic Time), elapsed secs since 1958-1-1 (leap seconds are counted.) Ticktock's handling of TAI and UTC conversions treats the UTC second as always equal in length to the SI second (and thus TAI), ignoring frequency changes and fractional leap seconds from 1958 through 1972, i.e. the UTC to TAI offset is always treated as an integer, truncated (not rounded) from the value at the most recent leap second (or fraction thereof).

Return value comes from (in priority order):

1. If `data` was provided in TAI, returns `data`.
2. Else recalculates directly from `data` if it was provided in APT, CDF, GPS, ISO, JD, MJD, RDT, or UNX.
3. Else calculates from current value of `UTC`, which will be created if necessary.

Updates the `TAI` attribute; will also create the `UTC` and `ISO` attributes from `data` if input is in `ISO` (but will not overwrite an existing `ISO` or `UTC`). This is for efficiency, as computation from ISO requires calculating UTC and makes creating a formatted ISO string easy.

Returns

out [numpy array] TAI as seconds since 1958-1-1.

See also:

getUTC, *getUNX*, *getRDT*, *getJD*, *getMJD*, *getCDF*, *getISO*, *getDOY*, *geteDOY*

getAPT

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.TAI
array([1391342432])
```

getUNX()

a.UNX or a.getUNX()

convert dtype data into Unix Time (Posix Time) seconds since 1970-1-1 (not counting leap seconds)

Returns `data` if it was provided in UNX; otherwise always recalculates from the current value of `TAI`, which will be created if necessary.

Updates the `UNX` attribute.

Returns

out [numpy array] elapsed secs since 1970-1-1 (not counting leap secs)

See also:

getUTC, *getISO*, *getRDT*, *getJD*, *getMJD*, *getCDF*, *getTAI*, *getDOY*, *geteDOY*

getAPT

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.UNX
array([  1.01265120e+09])
```

getUTC()

a.UTC or a.getUTC()

convert dtype data into UTC object a la datetime()

Return value comes from (in priority order):

1. If `data` was provided in UTC, returns `data`.
2. Else recalculates directly from `data` if it was provided in ISO.
3. Else calculates from current value of `TAI`, which will be created if necessary. (`data` is TAI, GPS, JD, MJD, RDT, CDF, UNX)).

Updates the `UTC` attribute.

Returns

out [list of datetime objects] datetime object in UTC time

See also:

getISO, *getUNX*, *getRDT*, *getJD*, *getMJD*, *getCDF*, *getTAI*, *getDOY*, *geteDOY*

getAPT

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.UTC
[datetime.datetime(2002, 2, 2, 12, 0)]
```

geteDOY()

a.eDOY or a.geteDOY()

extract eDOY (elapsed days since midnight January 1st of given year)

Always recalculates from the current value of `UTC`, which will be created if necessary.

Updates the `eDOY` attribute.

Returns

out [numpy array] days elapsed since midnight bbedJan. 1st

See also:

getUTC

getUNX

getRDT

getJD

getMJD

getISO

getTAI

getDOY

geteDOY

getAPT

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.eDOY
array([ 32.5])
```

getleapsecs()

a.leaps or a.getleapsecs()

retrieve leapseconds from lookup table, used in getTAI

Always recalculates from current value of `TAI` if `data` is dtype `TAI`, otherwise from the current value of `UTC`, which will be created if necessary.

Updates the `leaps` attribute.

Returns

out [numpy array] leap seconds

See also:

getTAI

Examples

```
>>> a = Ticktock('2002-02-02T12:00:00', 'ISO')
>>> a.leaps
array([32])
```

isoformat(*b*, *attrib*)

This changes the self._isofmt attribute by and subsequently this function will update the ISO attribute.

Parameters

fmt [string, optional]

classmethod now()

Create Ticktock with the current UTC time.

Equivalent to datetime.utcnow()

Changed in version 0.2.2: This now returns a UTC time; previously it returned a Ticktock UTC object, but in the local timezone, which made all conversions incorrect.

Returns

out [ticktock] Ticktock object with the current time, equivalent to datetime.utcnow()

See also:

`datetime.datetime.now`, `datetime.datetime.utcnow`

`sort()`

This will sort the Ticktock values in place based on the values in *data*. If you need a stable sort use kind='mergesort'

Other Parameters

kind [str] Sort algorithm to use, default 'quicksort'.

See also:

`argsort`, `numpy.argsort`

`classmethod today()`

Create Ticktock with the current UTC date and time set to 00:00:00

Similar to date.today() with time included but in UTC and with the time included (zero hours, minutes, seconds)

Changed in version 0.2.2: This now returns the UTC day; previously it returned a Ticktock UTC object, but in the local timezone, which made all conversions incorrect.

Returns

out [ticktock] Ticktock object with the current UTC day

See also:

`datetime.date.today`

`update_items(`*attrib*`)`

After changing the self.data attribute by either __setitem__ or __add__ etc this function will update all other attributes. This function is called automatically in __add__, __init__, and __setitem__.

Parameters

attrib [str] attribute that was updated; update others from this

Other Parameters

cls [type] Deprecated since version 0.2.2: Class is now taken from the `self` of the bound instance.

Class to use for finding possible attributes; now ignored.

See also:

`spacepy.Ticktock.__setitem__`

`spacepy.Ticktock.__add__`

`spacepy.Ticktock.__sub__`

Functions

dtstr2iso(dtstr[, fmt])	Convert a datetime string to a standard format
doy2date(year, doy[, dtobj, flAns])	convert integer day-of-year doy into a month and day after http://pleac.sourceforge.net/pleac_python/datesandtimes.html
leapyear(year[, numdays])	return an array of boolean leap year, a lot faster than the mod method that is normally seen
randomDate(dt1, dt2[, N, tzinfo, sorted])	Return a (or many) random datetimes between two given dates
sec2hms(sec[, rounding, days, dtobj])	Convert seconds of day to hours, minutes, seconds
tickrange(start, end, deltadays[, dtype])	return a Ticktock range given the start, end, and delta

4.18.4 spacepy.time.dtstr2iso

spacepy.time.**dtstr2iso**(*dtstr*, *fmt='%Y-%m-%dT%H:%M:%S'*)

Convert a datetime string to a standard format

Attempts to maintain leap second representation while converting time strings to the specified format (by default, ISO8601-like.) Only handles a single positive leap second; negative leap seconds require no special handling and policy is for UTC-UT1 not to exceed 0.9.

Parameters

dtstr [sequence of str] Date + time representation, format is fairly open.

Returns

isostr [array of str] Representation of *dtstr* formatted according to *fmt*. Always a new sequence even if contents are identical to *dtstr*.

UTC [array of datetime.datetime] The closest-possible rendering of UTC time before or equal to *dtstr*.

offset [array of int] Amount (in microseconds) to add to *UTC* to get the real time.

Other Parameters

fmt [str, optional] Format appropriate for `strftime()` for rendering the output time.

4.18.5 spacepy.time.doy2date

spacepy.time.**doy2date**(*year*, *doy*, *dtobj=False*, *flAns=False*)

convert integer day-of-year doy into a month and day after http://pleac.sourceforge.net/pleac_python/datesandtimes.html

Parameters

year [int or array of int] year

doy [int or array of int] day of year

Returns

month [int or array of int] month as integer number

day [int or array of int] as integer number

See also:

Ticktock.getDOY

Examples

```
>>> month, day = doy2date(2002, 186)
>>> dts = doy2date([2002]*4, range(186,190), dtobj=True)
```

4.18.6 spacepy.time.leapyear

spacepy.time.**leapyear**(*year*, *numdays=False*)

return an array of boolean leap year, a lot faster than the mod method that is normally seen

Parameters

year [array_like] array of years

numdays [boolean (optional)] optionally return the number of days in the year

Returns

out [numpy array] an array of boolean leap year, or array of number of days

Examples

```
>>> import numpy
>>> import spacepy.time
>>> spacepy.time.leapyear(numpy.arange(15)+1998)
[False, False,  True, False, False, False,  True, False, False,
      False,  True, False, False, False,  True]
```

4.18.7 spacepy.time.randomDate

spacepy.time.**randomDate**(*dt1*, *dt2*, *N=1*, *tzinfo=False*, *sorted=False*)

Return a (or many) random datetimes between two given dates

Convention used is dt1 <= rand < dt2. Leap second times will not be returned.

Parameters

dt1 [datetime.datetime] start date for the the random date

dt2 [datetime.datetime] stop date for the the random date

Returns

out [datetime.datetime or numpy.ndarray of datetime.datetime] the new time for the next call to EventTimer

Other Parameters

N [int (optional)] the number of random dates to generate (defualt=1)

tzinfo [bool (optional)] maintain the tzinfo of the input datetimes (default=False)

sorted [bool (optional)] return the times sorted (default=False)

4.18.8 spacepy.time.sec2hms

spacepy.time.**sec2hms**(*sec*, *rounding=True*, *days=False*, *dtobj=False*)
Convert seconds of day to hours, minutes, seconds

Parameters

sec [float] Seconds of day

Returns

out [[hours, minutes, seconds] or datetime.timedelta]

Other Parameters

rounding [boolean] set for integer seconds

days [boolean] set to wrap around day (i.e. modulo 86400)

dtobj [boolean] set to return a timedelta object

4.18.9 spacepy.time.tickrange

spacepy.time.**tickrange**(*start*, *end*, *deltadays*, *dtype=None*)
return a Ticktock range given the start, end, and delta

Parameters

start [string or number] start time (ISO standard string and UTC/datetime do not require a dtype)

end [string or number] last possible time in series (excluded unless end=start+n*step for integer n)

deltadays [float or timedelta] step in units of days (float); or datetime timedelta object

dtype [string (optional)] data type for start, end; e.g. ISO, UTC, RTD, etc. see Ticktock for all options

Returns

out [Ticktock instance] ticks

See also:

Ticktock

Examples

```
>>> ticks = st.tickrange('2002-02-01T00:00:00', '2002-02-10T00:00:00', deltadays =␣
↪1)
>>> ticks
Ticktock( ['2002-02-01T00:00:00', '2002-02-02T00:00:00', '2002-02-03T00:00:00',
'2002-02-04T00:00:00'] , dtype=ISO)
```

4.19 toolbox - Toolbox of various functions and generic utilities

Toolbox of various functions and generic utilities.

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- *Array binning*
- *Array creation*
- *Array searching and masking*
- *Other functions*
- *Multithreading and multiprocessing*
- *System tools*

4.19.1 Array binning

arraybin(array, bins)	Split a sequence into subsequences based on value.
bin_center_to_edges(centers)	Convert a list of bin centers to their edges
bin_edges_to_center(edges)	Convert a list of bin edges to their centers
binHisto(data[, verbose])	Calculates bin width and number of bins for histogram using Freedman-Diaconis rule, if rule fails, defaults to square-root method

spacepy.toolbox.arraybin

spacepy.toolbox.**arraybin**(*array*, *bins*)

Split a sequence into subsequences based on value.

Given a sequence of values and a sequence of values representing the division between bins, return the indices grouped by bin.

Parameters

array [array_like] the input sequence to slice, must be sorted in ascending order

bins [array_like]

dividing lines between bins. Number of bins is len(bins)+1, value that exactly equal a dividing value are assigned to the higher bin

Returns

out [list] indices for each bin (list of lists)

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.arraybin(range(10), [4.2])
[[0, 1, 2, 3, 4], [5, 6, 7, 8, 9]]
```

spacepy.toolbox.bin_center_to_edges

spacepy.toolbox.**bin_center_to_edges**(*centers*)

Convert a list of bin centers to their edges

Given a list of center values for a set of bins, finds the start and end value for each bin. (start of bin n+1 is assumed to be end of bin n). Useful for e.g. matplotlib.pyplot.pcolor.

Edge between bins n and n+1 is arithmetic mean of the center of n and n+1; edge below bin 0 and above last bin are established to make these bins symmetric about their center value.

Parameters

centers [list] list of center values for bins

Returns

out [list] list of edges for bins

note: returned list will be one element longer than centers

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.bin_center_to_edges([1,2,3])
[0.5, 1.5, 2.5, 3.5]
```

spacepy.toolbox.bin_edges_to_center

spacepy.toolbox.**bin_edges_to_center**(*edges*)

Convert a list of bin edges to their centers

Given a list of edge values for a set of bins, finds the center of each bin. (start of bin n+1 is assumed to be end of bin n).

Center of bin n is arithmetic mean of the edges of the adjacent bins.

Parameters

edges [list] list of edge values for bins

Returns

out [numpy.ndarray] array of centers for bins

note: returned array will be one element shorter than edges

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.bin_center_to_edges([1,2,3])
[0.5, 1.5, 2.5, 3.5]
```

spacepy.toolbox.binHisto

spacepy.toolbox.**binHisto**(*data*, *verbose=False*)

Calculates bin width and number of bins for histogram using Freedman-Diaconis rule, if rule fails, defaults to square-root method

The Freedman-Diaconis method is detailed in: Freedman, D., and P. Diaconis (1981), On the histogram as a density estimator: L2 theory, Z. Wahrscheinlichkeitstheor. Verw. Geb., 57, 453–476

and is also described by: Wilks, D. S. (2006), Statistical Methods in the Atmospheric Sciences, 2nd ed.

Parameters

data [array_like] list/array of data values

verbose [boolean (optional)] print out some more information

Returns

out [tuple] calculated width of bins using F-D rule, number of bins (nearest integer) to use for histogram

See also:

`matplotlib.pyplot.hist`

Examples

```
>>> import numpy, spacepy
>>> import matplotlib.pyplot as plt
>>> numpy.random.seed(8675301)
>>> data = numpy.random.randn(1000)
>>> binw, nbins = spacepy.toolbox.binHisto(data)
>>> print(nbins)
19
>>> p = plt.hist(data, bins=nbins, histtype='step', density=True)
```

4.19.2 Array creation

dist_to_list(func, length[, min, max])	Convert a probability distribution function to a list of values
geomspace(start[, ratio, stop, num])	Returns geometrically spaced numbers.
linspace(min, max, num, **kwargs)	Returns linear-spaced bins.
logspace(min, max, num, **kwargs)	Returns log-spaced bins.

spacepy.toolbox.dist_to_list

spacepy.toolbox.**dist_to_list**(*func*, *length*, *min=None*, *max=None*)
Convert a probability distribution function to a list of values

This is a deterministic way to produce a known-length list of values matching a certain probability distribution. It is likely to be a closer match to the distribution function than a random sampling from the distribution.

Parameters

func [callable]

function to call for each possible value, returning probability density at that value (does not need to be normalized.)

length [int] number of elements to return

min [float] minimum value to possibly include

max [float] maximum value to possibly include

Examples

```
>>> import matplotlib
>>> import numpy
>>> import spacepy.toolbox as tb
>>> gauss = lambda x: math.exp(-(x ** 2) / (2 * 5 ** 2)) / (5 * math.sqrt(2 * math.
↪pi))
>>> vals = tb.dist_to_list(gauss, 1000, -numpy.inf, numpy.inf)
>>> print vals[0]
-16.45263...
>>> p1 = matplotlib.pyplot.hist(vals, bins=[i - 10 for i in range(21)], facecolor=
↪'green')
>>> matplotlib.pyplot.hold(True)
>>> x = [i / 100.0 - 10.0 for i in range(2001)]
>>> p2 = matplotlib.pyplot.plot(x, [gauss(i) * 1000 for i in x], 'red')
>>> matplotlib.pyplot.draw()
```

spacepy.toolbox.geomspace

spacepy.toolbox.**geomspace**(*start*, *ratio=None*, *stop=False*, *num=50*)
Returns geometrically spaced numbers.

Parameters

start [float] The starting value of the sequence.

ratio [float (optional)] The ratio between subsequent points

stop [float (optional)] End value, if this is selected *num* is overridden

num [int (optional)] Number of samples to generate. Default is 50.

Returns

seq [array] geometrically spaced sequence

See also:

linspace

logspace

Examples

To get a geometric progression between 0.01 and 3 in 10 steps

```
>>> import spacepy.toolbox as tb
>>> tb.geomspace(0.01, stop=3, num=10)
[0.01,
 0.018846716378431192,
 0.035519871824902655,
 0.066943295008216955,
 0.12616612944575134,
 0.23778172582285118,
 0.44814047465571644,
 0.84459764235318191,
 1.5917892219322083,
 2.9999999999999996]
```

To get a geometric progression with a specified ratio, say 10

```
>>> import spacepy.toolbox as tb
>>> tb.geomspace(0.01, ratio=10, num=5)
[0.01, 0.10000000000000001, 1.0, 10.0, 100.0]
```

spacepy.toolbox.linspace

spacepy.toolbox.**linspace**(*min*, *max*, *num*, ***kwargs*)

Returns linear-spaced bins. Same as numpy.linspace except works with datetime and is faster

Parameters

min [float, datetime] minimum value

max [float, datetime] maximum value

num [integer] number of linear spaced bins

Returns

out [array] linear-spaced bins from min to max in a numpy array

Other Parameters

kwargs [dict] additional keywords passed into matplotlib.dates.num2date

See also:

geomspace

logspace

Notes

This function works on both numbers and datetime objects

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.linspace(1, 10, 4)
array([  1.,   4.,   7.,  10.])
```

spacepy.toolbox.logspace

spacepy.toolbox.**logspace**(*min*, *max*, *num*, ***kwargs*)

Returns log-spaced bins. Same as numpy.logspace except the min and max are the min and max not log10(min) and log10(max)

Parameters

min [float] minimum value

max [float] maximum value

num [integer] number of log spaced bins

Returns

out [array] log-spaced bins from min to max in a numpy array

Other Parameters

kwargs [dict] additional keywords passed into matplotlib.dates.num2date

See also:

geomspace

linspace

Notes

This function works on both numbers and datetime objects

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.logspace(1, 100, 5)
array([   1.        ,    3.16227766,   10.        ,   31.6227766 ,  100.        ])
```

4.19.3 Array searching and masking

interweave(a, b)	given two array-like variables interweave them together.
isview(array1[, array2])	Returns if an object is a view of another object.
tCommon(ts1, ts2[, mask_only])	Finds the elements in a list of datetime objects present in another
tOverlap(ts1, ts2, *args, **kwargs)	Finds the overlapping elements in two lists of datetime objects
tOverlapHalf(ts1, ts2[, presort])	Find overlapping elements in two lists of datetime objects

spacepy.toolbox.interweave

spacepy.toolbox.**interweave**(*a*, *b*)

given two array-like variables interweave them together. Discussed here: http://stackoverflow.com/questions/5347065/interweaving-two-numpy-arrays

Parameters

a [array-like] first array

b [array-like] second array

Returns

out [numpy.ndarray] interweaved array

spacepy.toolbox.isview

spacepy.toolbox.**isview**(*array1*, *array2=None*)

Returns if an object is a view of another object. More precisely if one array argument is specified True is returned is the arrays owns its data. If two arrays arguments are specified a tuple is returned of if the first array owns its data and the the second if they point at the same memory location

Parameters

array1 [numpy.ndarray] array to query if it owns its data

Returns

out [bool or tuple] If one array is specified bool is returned, True is the array owns its data. If two arrays are specified a tuple where the second element is a bool of if the array point at the same memory location

Other Parameters

array2 [object (optional)] array to query if array1 is a view of this object at the specified memory location

Examples

import numpy import spacepy.toolbox as tb a = numpy.arange(100) b = a[0:10] tb.isview(a) # False tb.isview(b) # True tb.isview(b, a) # (True, True) tb.isview(b, b) # (True, True) # the conditions are met and numpy cannot tell this

spacepy.toolbox.tCommon

spacepy.toolbox.**tCommon**(*ts1*, *ts2*, *mask_only=True*)

Finds the elements in a list of datetime objects present in another

Parameters

ts1 [list or array-like] first set of datetime objects

ts2 [list or array-like] second set of datetime objects

Returns

out [tuple] Two element tuple of truth tables (of 1 present in 2, & vice versa)

See also:

tOverlapHalf

tOverlap

Examples

```
>>> import spacepy.toolbox as tb
>>> import numpy as np
>>> import datetime as dt
>>> ts1 = np.array([dt.datetime(2001,3,10)+dt.timedelta(hours=a) for a in␣
↪range(20)])
>>> ts2 = np.array([dt.datetime(2001,3,10,2)+dt.timedelta(hours=a*0.5) for a in␣
↪range(20)])
>>> common_inds = tb.tCommon(ts1, ts2)
>>> common_inds[0] #mask of values in ts1 common with ts2
array([False, False,  True,  True,  True,  True,  True,  True,  True,
        True,  True,  True, False, False, False, False, False, False,
       False, False], dtype=bool)
>>> ts2[common_inds[1]] #values of ts2 also in ts1
```

The latter can be found more simply by setting the mask_only keyword to False

```
>>> common_vals = tb.tCommon(ts1, ts2, mask_only=False)
>>> common_vals[1]
array([2001-03-10 02:00:00, 2001-03-10 03:00:00, 2001-03-10 04:00:00,
       2001-03-10 05:00:00, 2001-03-10 06:00:00, 2001-03-10 07:00:00,
       2001-03-10 08:00:00, 2001-03-10 09:00:00, 2001-03-10 10:00:00,
       2001-03-10 11:00:00], dtype=object)
```

spacepy.toolbox.tOverlap

spacepy.toolbox.**tOverlap**(*ts1*, *ts2*, **args*, ***kwargs*)

Finds the overlapping elements in two lists of datetime objects

Parameters

ts1 [datetime] first set of datetime object

ts2 [datetime] datatime object

args additional arguments passed to tOverlapHalf

Returns

out [list] indices of ts1 within interval of ts2, & vice versa

See also:

tOverlapHalf

tCommon

Examples

Given two series of datetime objects, event_dates and omni['Time']:

```
>>> import spacepy.toolbox as tb
>>> from spacepy import omni
>>> import datetime
>>> event_dates = st.tickrange(datetime.datetime(2000, 1, 1), datetime.
↪datetime(2000, 10, 1), deltadays=3)
>>> onni_dates = st.tickrange(datetime.datetime(2000, 1, 1), datetime.datetime(2000,
↪ 10, 1), deltadays=0.5)
>>> omni = omni.get_omni(onni_dates)
>>> [einds,oinds] = tb.tOverlap(event_dates, omni['ticks'])
>>> omni_time = omni['ticks'][oinds[0]:oinds[-1]+1]
>>> print omni_time
[datetime.datetime(2000, 1, 1, 0, 0), datetime.datetime(2000, 1, 1, 12, 0),
... , datetime.datetime(2000, 9, 30, 0, 0)]
```

spacepy.toolbox.tOverlapHalf

spacepy.toolbox.**tOverlapHalf**(*ts1*, *ts2*, *presort=False*)

Find overlapping elements in two lists of datetime objects

This is one-half of tOverlap, i.e. it finds only occurrences where ts2 exists within the bounds of ts1, or the second element returned by tOverlap.

Parameters

ts1 [list] first set of datetime object

ts2 [list] datatime object

presort [bool]

Set to use a faster algorithm which assumes ts1 and ts2 are both sorted in ascending order. This speeds up the overlap comparison by about 50x, so it is worth sorting the list if one sort can be done for many calls to tOverlap

Returns

out [list] indices of ts2 within interval of ts1

note: Returns empty list if no overlap found

See also:

tOverlap

tCommon

4.19.4 Other functions

assemble(fln_pattern, outfln[, sortkey, verbose])	assembles all pickled files matching fln_pattern into single file and save as outfln.
bootHisto(data[, inter, n, seed, plot, ...])	Bootstrap confidence intervals for a histogram.
dictree(in_dict[, verbose, spaces, levels, ...])	pretty print a dictionary tree
eventTimer(Event, Time1)	Times an event then prints out the time and the name of the event, nice for debugging and seeing that the code is progressing
getNamedPath(name)	Return the full path of a parent directory with name as the leaf
human_sort(l)	Sort the given list in the way that humans expect.
hypot(*args)	compute the N-dimensional hypot of an iterable or many arguments
indsFromXrange(inxrange)	return the start and end indices implied by an xrange, useful when xrange is zero-length
interpol(newx, x, y[, wrap])	1-D linear interpolation with interpolation of hours/longitude
intsolve(func, value[, start, stop, maxit])	Find the function input such that definite integral is desired value.
medAbsDev(series[, scale])	Calculate median absolute deviation of a given input series
mlt2rad(mlt[, midnight])	Convert mlt values to radians for polar plotting transform mlt angles to radians from -pi to pi referenced from noon by default
normalize(vec[, low, high])	Given an input vector normalize the vector to a given range
pmm(*args)	print min and max of input arrays
poisson_fit(data[, initial, method])	Fit a Poisson distribution to data using the method and initial guess provided.
rad2mlt(rad[, midnight])	Convert radians values to mlt transform radians from -pi to pi to mlt referenced from noon by default
windowMean(data[, time, winsize, overlap, ...])	Windowing mean function, window overlap is user defined

spacepy.toolbox.assemble

spacepy.toolbox.**assemble**(*fln_pattern*, *outfln*, *sortkey='ticks'*, *verbose=True*)

assembles all pickled files matching fln_pattern into single file and save as outfln. Pattern may contain simple shell-style wildcards *? a la fnmatch file will be assembled along time axis given by Ticktock (key: 'ticks') in dictionary If sortkey = None, then nothing will be sorted

Parameters

fln_pattern [string] pattern to match filenames

outfln [string] filename to save combined files to

Returns

out [dict] dictionary with combined values

Examples

```
>>> import spacepy.toolbox as tb
>>> a, b, c = {'ticks':[1,2,3]}, {'ticks':[4,5,6]}, {'ticks':[7,8,9]}
>>> tb.savepickle('input_files_2001.pkl', a)
>>> tb.savepickle('input_files_2002.pkl', b)
>>> tb.savepickle('input_files_2004.pkl', c)
>>> a = tb.assemble('input_files_*.pkl', 'combined_input.pkl')
('adding ', 'input_files_2001.pkl')
('adding ', 'input_files_2002.pkl')
('adding ', 'input_files_2004.pkl')
('\n writing: ', 'combined_input.pkl')
>>> print(a)
{'ticks': array([1, 2, 3, 4, 5, 6, 7, 8, 9])}
```

spacepy.toolbox.bootHisto

spacepy.toolbox.**bootHisto**(*data*, *inter=90.0*, *n=1000*, *seed=None*, *plot=False*, *target=None*, *figsize=None*, *loc=None*, ***kwargs*)

Bootstrap confidence intervals for a histogram.

All other keyword arguments are passed to `numpy.histogram()` or `matplotlib.pyplot.bar()`.

Changed in version 0.2.3: This argument pass-through did not work in earlier versions of SpacePy.

Parameters

data [array_like] list/array of data values

inter [float (optional; default 90)] percentage confidence interval to return. Default 90% (i.e. lower CI will be 5% and upper will be 95%)

n [int (optional; default 1000)] number of bootstrap iterations

seed [int (optional)] Optional seed for the random number generator. If not specified; numpy generator will not be reseeded.

plot [bool (optional)] Plot the result. Plots if True or `target`, `figsize`, or `loc` specified.

target [(optional)] Target on which to plot the figure (figure or axes). See *spacepy.plot.utils.set_target()* for details.

figsize [tuple (optional)] Passed to *spacepy.plot.utils.set_target()*.

loc [int (optional)] Passed to *spacepy.plot.utils.set_target()*.

Returns

out [tuple] tuple of bin_edges, low, high, sample[, bars]. Where `bin_edges` is the edges of the bins used; `low` is the histogram with the value for each bin from the bottom of that bin's confidence interval; `high` similarly for the top; `sample` is the histogram of the input sample without resampling. If plotting, also returned is `bars`, the container object returned from matplotlib.

See also:

binHisto

plot.utils.set_target

numpy.histogram

matplotlib.pyplot.hist

Notes

New in version 0.2.1.

The confidence intervals are calculated for each bin individually and thus the resulting low/high histograms may not have actually occurred in the calculation from the surrogates. If using a probability density histogram, this can have "interesting" implications for interpretation.

Examples

```
>>> import numpy.random
>>> import spacepy.toolbox
>>> numpy.random.seed(0)
>>> data = numpy.random.randn(1000)
>>> bin_edges, low, high, sample, bars = spacepy.toolbox.bootHisto(
...     data, plot=True)
```

spacepy.toolbox.dictree

spacepy.toolbox.**dictree**(*in_dict*, *verbose=False*, *spaces=None*, *levels=True*, *attrs=False*, ***kwargs*)

pretty print a dictionary tree

Parameters

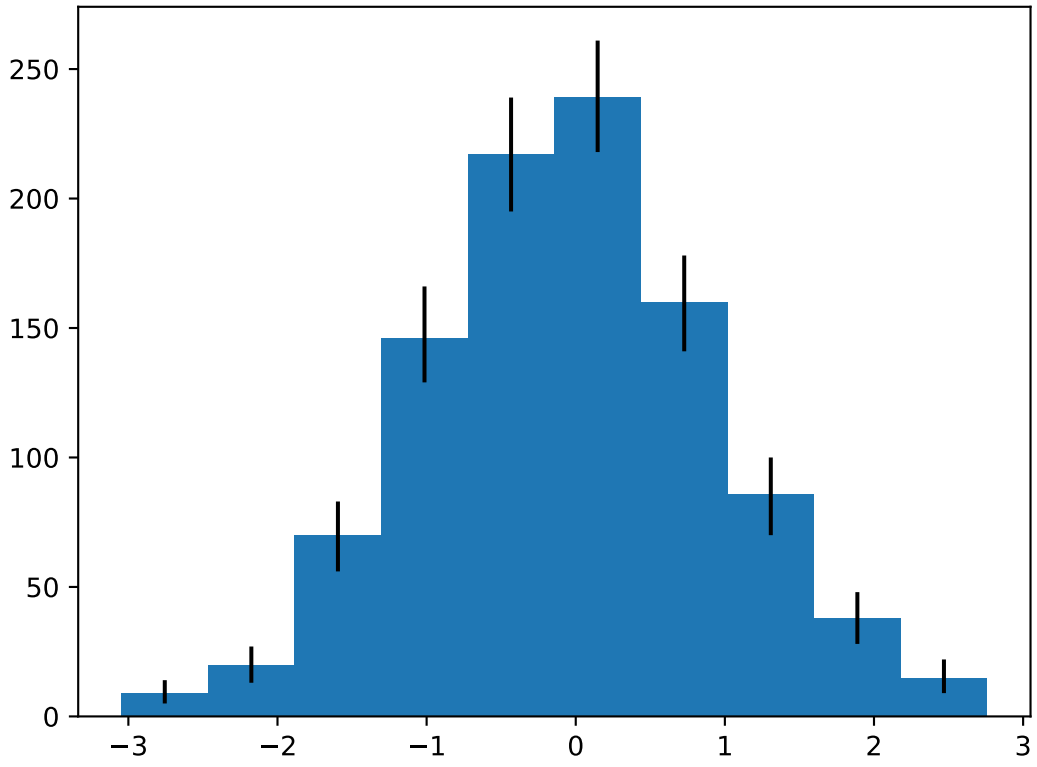
in_dict [dict] a complex dictionary (with substructures)

verbose [boolean (optional)] print more info

spaces [string (optional)] string will added for every line

levels [integer (optional)] number of levels to recurse through (True means all)

attrs [boolean (optional)] display information for attributes


250
200
150
100
50
0
−3
−2
−1
0
1
2
3

Examples

```
>>> import spacepy.toolbox as tb
>>> d = {'grade':{'level1':[4,5,6], 'level2':[2,3,4]}, 'name':['Mary', 'John',
↪'Chris']}
>>> tb.dictree(d)
+
|____grade
     |____level1
     |____level2
|____name
```

More complicated example using a datamodel:

```
>>> from spacepy import datamodel
>>> counts = datamodel.dmarray([2,4,6], attrs={'units': 'cts/s'})
>>> data = {'counts': counts, 'PI': 'Dr Zog'}
>>> tb.dictree(data)
+
|____PI
|____counts
>>> tb.dictree(data, attrs=True, verbose=True)
+
|____PI (str [6])
|____counts (spacepy.datamodel.dmarray (3,))
    :|____units (str [5])
```

Attributes of, e.g., a CDF or a datamodel type object (obj.attrs) are denoted by a colon.

spacepy.toolbox.eventTimer

spacepy.toolbox.**eventTimer**(*Event*, *Time1*)

Times an event then prints out the time and the name of the event, nice for debugging and seeing that the code is progressing

Parameters

Event [str] Name of the event, string is printed out by function

Time1 [time.time] the time to difference in the function

Returns

Time2 [time.time] the new time for the next call to EventTimer

Examples

```
>>> import spacepy.toolbox as tb
>>> import time
>>> t1 = time.time()
>>> t1 = tb.eventTimer('Test event finished', t1)
('4.40', 'Test event finished')
```

spacepy.toolbox.getNamedPath

spacepy.toolbox.**getNamedPath**(*name*)
Return the full path of a parent directory with name as the leaf

Parameters

name [string] the name of the parent directory to locate

Examples

Run from a directory /mnt/projects/dream/bin/Ephem with 'dream' as the name, this function would return '/mnt/projects/dream'

spacepy.toolbox.human_sort

spacepy.toolbox.**human_sort**(*l*)
Sort the given list in the way that humans expect. http://www.codinghorror.com/blog/2007/12/sorting-for-humans-natural-sort-order.html

Parameters

l [list] list of objects to human sort

Returns

out [list] sorted list

Examples

```
>>> import spacepy.toolbox as tb
>>> dat = ['r1.txt', 'r10.txt', 'r2.txt']
>>> dat.sort()
>>> print dat
['r1.txt', 'r10.txt', 'r2.txt']
>>> tb.human_sort(dat)
['r1.txt', 'r2.txt', 'r10.txt']
```

spacepy.toolbox.hypot

spacepy.toolbox.**hypot**(**args*)
compute the N-dimensional hypot of an iterable or many arguments

Parameters

args [many numbers or array-like] array like or many inputs to compute from

Returns

out [float] N-dimensional hypot of a number

Notes

This function has a complicated speed function.

- if a numpy array of floats is input this is passed off to C
- if iterables are passed in they are made into numpy arrays and comptaton is done local
- if many scalar agruments are passed in calculation is done in a loop

For max speed:

- **<20 elements expand them into scalars**

```
>>> tb.hypot(*vals)
>>> tb.hypot(vals[0], vals[1]...) #alternate
```

- >20 elements premake them into a numpy array of doubles

Examples

```
>>> from spacepy import toolbox as tb
>>> print tb.hypot([3,4])
5.0
>>> print tb.hypot(3,4)
5.0
>>> # Benchmark ####
>>> from spacepy import toolbox as tb
>>> import numpy as np
>>> import timeit
>>> num_list = []
>>> num_np = []
>>> num_np_double = []
>>> num_scalar = []
>>> tot = 500
>>> for num in tb.logspace(1, tot, 10):
>>>     print num
>>>     num_list.append(timeit.timeit(stmt='tb.hypot(a)',
                        setup='from spacepy import toolbox as tb;
                        import numpy as np; a = [3]*{0}'.format(int(num)),␣
↪number=10000))
>>>     num_np.append(timeit.timeit(stmt='tb.hypot(a)',
                       setup='from spacepy import toolbox as tb;
                       import numpy as np; a = np.asarray([3]*{0})'.format(int(num)),
↪ number=10000))
>>>     num_scalar.append(timeit.timeit(stmt='tb.hypot(*a)',
                          setup='from spacepy import toolbox as tb;
                          import numpy as np; a = [3]*{0}'.format(int(num)),␣
↪number=10000))
>>> from pylab import *
>>> loglog(tb.logspace(1, tot, 10),  num_list, lw=2, label='list')
>>> loglog(tb.logspace(1, tot, 10),  num_np, lw=2, label='numpy->ctypes')
>>> loglog(tb.logspace(1, tot, 10),  num_scalar, lw=2, label='scalar')
>>> legend(shadow=True, fancybox=1, loc='upper left')
>>> title('Different hypot times for 10000 runs')
```

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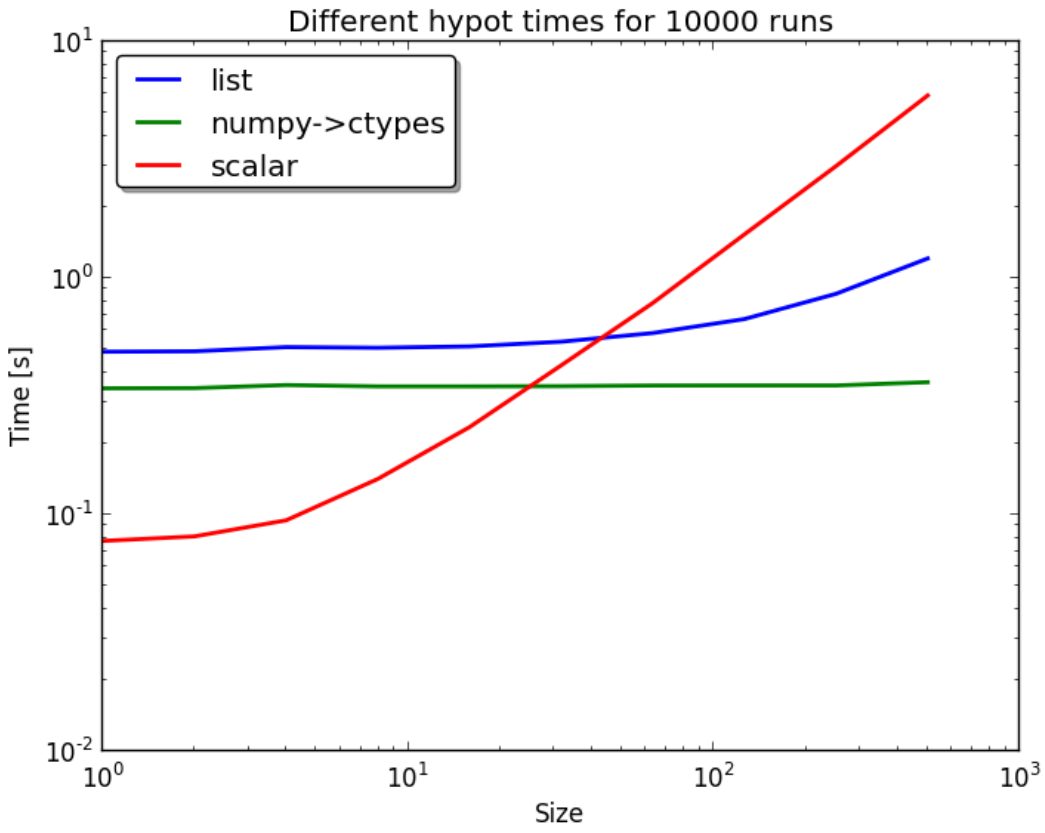
```
>>> ylabel('Time [s]')
>>> xlabel('Size')
```



spacepy.toolbox.indsFromXrange

spacepy.toolbox.**indsFromXrange**(*inxrange*)

return the start and end indices implied by an xrange, useful when xrange is zero-length

Parameters

inxrange [xrange] input xrange object to parse

Returns

list of int List of start, stop indices in the xrange. The return value is not defined if a stride is specified or if stop is before start (but will work when stop equals start).

Examples

```
>>> import spacepy.toolbox as tb
>>> foo = xrange(23, 39)
>>> foo[0]
23
>>> tb.indsFromXrange(foo)
[23, 39]
>>> foo1 = xrange(23, 23)
>>> tb.indsFromXrange(foo) #indexing won't work in this case
[23, 23]
```

spacepy.toolbox.interpol

spacepy.toolbox.**interpol**(*newx*, *x*, *y*, *wrap=None*, ***kwargs*)

1-D linear interpolation with interpolation of hours/longitude

Parameters

newx [array_like] x values where we want the interpolated values

x [array_like] x values of the original data (must be monotonically increasing or wrapping)

y [array_like] y values of the original data

wrap [string, optional] for continuous x data that wraps in y at 'hours' (24), 'longitude' (360), or arbitrary value (int, float)

kwargs [dict] additional keywords, currently accepts baddata that sets baddata for masked arrays

Returns

out [numpy.masked_array] interpolated data values for new abscissa values

Examples

For a simple interpolation

```
>>> import spacepy.toolbox as tb
>>> import numpy
>>> x = numpy.arange(10)
>>> y = numpy.arange(10)
>>> tb.interpol(numpy.arange(5)+0.5, x, y)
array([ 0.5,  1.5,  2.5,  3.5,  4.5])
```

To use the wrap functionality, without the wrap keyword you get the wrong answer

```
>>> y = range(24)*2
>>> x = range(len(y))
>>> tb.interpol([1.5, 10.5, 23.5], x, y, wrap='hour').compressed() # compress␣
↪removed the masked array
array([  1.5,  10.5,  23.5])
>>> tb.interpol([1.5, 10.5, 23.5], x, y)
array([  1.5,  10.5,  11.5])
```

spacepy.toolbox.intsolve

spacepy.toolbox.**intsolve**(*func*, *value*, *start=None*, *stop=None*, *maxit=1000*)

Find the function input such that definite integral is desired value.

Given a function, integrate from an (optional) start point until the integral reached a desired value, and return the end point of the integration.

Parameters

func [callable] function to integrate, must take single parameter

value [float] desired final value of the integral

start [float (optional)] value at which to start integration, default -Infinity

stop [float (optional)] value at which to stop integration, default +Infinity

maxit [integer] maximum number of iterations

Returns

out [float] x such that the integral of L{func} from L{start} to x is L{value}

Note: Assumes func is everywhere positive, otherwise solution may be multi-valued.

spacepy.toolbox.medAbsDev

spacepy.toolbox.**medAbsDev**(*series*, *scale=False*)

Calculate median absolute deviation of a given input series

Median absolute deviation (MAD) is a robust and resistant measure of the spread of a sample (same purpose as standard deviation). The MAD is preferred to the inter-quartile range as the inter-quartile range only shows 50% of the data whereas the MAD uses all data but remains robust and resistant. See e.g. Wilks, Statistical methods for the Atmospheric Sciences, 1995, Ch. 3. For additional details on the scaling, see Rousseeuw and Croux, J. Amer. Stat. Assoc., 88 (424), pp. 1273-1283, 1993.

Parameters

series [array_like] the input data series

Returns

out [float] the median absolute deviation

Other Parameters

scale [bool] if True (default: False), scale to standard deviation of a normal distribution

Examples

Find the median absolute deviation of a data set. Here we use the log- normal distribution fitted to the population of sawtooth intervals, see Morley and Henderson, Comment, Geophysical Research Letters, 2009.

```
>>> import numpy
>>> import spacepy.toolbox as tb
>>> numpy.random.seed(8675301)
>>> data = numpy.random.lognormal(mean=5.1458, sigma=0.302313, size=30)
>>> print data
array([ 181.28078923,  131.18152745, ... , 141.15455416, 160.88972791])
```

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```
>>> tb.medAbsDev(data)
28.346646721370192
```

note This implementation is robust to presence of NaNs

spacepy.toolbox.mlt2rad

spacepy.toolbox.**mlt2rad**(*mlt*, *midnight=False*)

Convert mlt values to radians for polar plotting transform mlt angles to radians from -pi to pi referenced from noon by default

Parameters

mlt [numpy array] array of mlt values

midnight [boolean (optional)] reference to midnight instead of noon

Returns

out [numpy array] array of radians

See also:

rad2mlt

Examples

```
>>> from numpy import array
>>> mlt2rad(array([3,6,9,14,22]))
array([-2.35619449, -1.57079633, -0.78539816,  0.52359878,  2.61799388])
```

spacepy.toolbox.normalize

spacepy.toolbox.**normalize**(*vec*, *low=0.0*, *high=1.0*)

Given an input vector normalize the vector to a given range

Parameters

vec [array_like] input vector to normalize

low [float] minimum value to scale to, default 0.0

high [float] maximum value to scale to, default 1.0

Returns

out [array_like] normalized vector

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.normalize([1,2,3])
[0.0, 0.5, 1.0]
```

spacepy.toolbox.pmm

spacepy.toolbox.**pmm**(**args*)

print min and max of input arrays

Parameters

a [array-like] arbitrary number of input arrays (or lists)

Returns

out [list] list of min, max for each array

Examples

```
>>> import spacepy.toolbox as tb
>>> from numpy import arange
>>> tb.pmm(arange(10), arange(10)+3)
[[0, 9], [3, 12]]
```

spacepy.toolbox.poisson_fit

spacepy.toolbox.**poisson_fit**(*data*, *initial=None*, *method='Powell'*)

Fit a Poisson distribution to data using the method and initial guess provided.

Parameters

data [array-like] Data to fit a Poisson distribution to.

initial [int or None] initial guess for the fit, if None np.median(data) is used

method [str] method passed to scipy.optimize.minimize, default='Powell'

Returns

result [scipy.optimize.optimize.OptimizeResult] Resulting fit results from scipy.optimize, answer is result.x, user should likely round.

Examples

```
>>> import spacepy.toolbox as tb
>>> from scipy.stats import poisson
>>> import matplotlib.pyplot as plt
>>> import numpy as np
>>> data = poisson.rvs(20, size=1000)
>>> res = tb.poisson_fit(data)
>>> print(res.x)
```

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```
19.718000038769095
>>> xvals = np.arange(0, np.max(data)+5)
>>> plt.hist(data, bins=xvals, normed=True)
>>> plt.plot(xvals, poisson.pmf(xvals, np.round(res.x)))
```

spacepy.toolbox.rad2mlt

spacepy.toolbox.**rad2mlt**(*rad*, *midnight=False*)

Convert radians values to mlt transform radians from -pi to pi to mlt referenced from noon by default

Parameters

rad [numpy array] array of radian values

midnight [boolean (optional)] reference to midnight instead of noon

Returns

out [numpy array] array of mlt values

See also:

mlt2rad

Examples

```
>>> rad2mlt(array([0,pi, pi/2.]))
array([ 12.,  24.,  18.])
```

spacepy.toolbox.windowMean

spacepy.toolbox.**windowMean**(*data*, *time=[]*, *winsize=0*, *overlap=0*, *st_time=None*, *op=<function mean>*)

Windowing mean function, window overlap is user defined

Parameters

data [array_like] 1D series of points

time [list (optional)] series of timestamps, optional (format as numeric or datetime) For non-overlapping windows set overlap to zero.

winsize [integer or datetime.timedelta (optional)] window size

overlap [integer or datetime.timedelta (optional)] amount of window overlap

st_time [datetime.datetime (optional)] for time-based averaging, a start-time other than the first point can be specified

op [callable (optional)] the operator to be called, default numpy.mean

Returns

out [tuple] the windowed mean of the data, and an associated reference time vector

Examples

For non-overlapping windows set overlap to zero. e.g. (time-based averaging) Given a data set of 100 points at hourly resolution (with the time tick in the middle of the sample), the daily average of this, with half-overlapping windows is calculated:

```
>>> import spacepy.toolbox as tb
>>> from datetime import datetime, timedelta
>>> wsize = datetime.timedelta(days=1)
>>> olap = datetime.timedelta(hours=12)
>>> data = [10, 20]*50
>>> time = [datetime.datetime(2001,1,1) + datetime.timedelta(hours=n, minutes = 30)␣
↪for n in range(100)]
>>> outdata, outtime = tb.windowMean(data, time, winsize=wsize, overlap=olap, st_
↪time=datetime.datetime(2001,1,1))
>>> outdata, outtime
([15.0, 15.0, 15.0, 15.0, 15.0, 15.0, 15.0],
 [datetime.datetime(2001, 1, 1, 12, 0),
  datetime.datetime(2001, 1, 2, 0, 0),
  datetime.datetime(2001, 1, 2, 12, 0),
  datetime.datetime(2001, 1, 3, 0, 0),
  datetime.datetime(2001, 1, 3, 12, 0),
  datetime.datetime(2001, 1, 4, 0, 0),
  datetime.datetime(2001, 1, 4, 12, 0)])
```

When using time-based averaging, ensure that the time tick corresponds to the middle of the time-bin to which the data apply. That is, if the data are hourly, say for 00:00-01:00, then the time applied should be 00:30. If this is not done, unexpected behaviour can result.

e.g. (pointwise averaging),

```
>>> outdata, outtime = tb.windowMean(data, winsize=24, overlap=12)
>>> outdata, outtime
([15.0, 15.0, 15.0, 15.0, 15.0, 15.0, 15.0], [12.0, 24.0, 36.0, 48.0, 60.0, 72.0,␣
↪84.0])
```

where winsize and overlap are numeric, in this example the window size is 24 points (as the data are hourly) and the overlap is 12 points (a half day). The output vectors start at winsize/2 and end at N-(winsize/2), the output time vector is basically a reference to the nth point in the original series.

note This is a quick and dirty function - it is NOT optimized, at all.

4.19.5 Multithreading and multiprocessing

thread_job(job_size, thread_count, target, ...)	Split a job into subjobs and run a thread for each
thread_map(target, iterable[, thread_count])	Apply a function to every element of a list, in separate threads

spacepy.toolbox.thread_job

spacepy.toolbox.**thread_job**(*job_size*, *thread_count*, *target*, **args*, ***kwargs*)

Split a job into subjobs and run a thread for each

Each thread spawned will call L{target} to handle a slice of the job.

This is only useful if a job:

1. Can be split into completely independent subjobs
2. Relies heavily on code that does not use the Python GIL, e.g. numpy or ctypes code
3. Does not return a value. Either pass in a list/array to hold the result, or see L{thread_map}

Parameters

job_size [int] Total size of the job. Often this is an array size.

thread_count [int]

Number of threads to spawn. If =0 or None, will spawn as many threads as there are cores available on the system. (Each hyperthreading core counts as 2.) Generally this is the Right Thing to do. If NEGATIVE, will spawn abs(thread_count) threads, but will run them sequentially rather than in parallel; useful for debugging.

target [callable]

Python callable (generally a function, may also be an imported ctypes function) to run in each thread. The *last* two positional arguments passed in will be a "start" and a "subjob size," respectively; frequently this will be the start index and the number of elements to process in an array.

args [sequence]

Arguments to pass to L{target}. If L{target} is an instance method, self must be explicitly passed in. start and subjob_size will be appended.

kwargs [dict] keyword arguments to pass to L{target}.

Examples

squaring 100 million numbers:

```
>>> import numpy
>>> import spacepy.toolbox as tb
>>> numpy.random.seed(8675301)
>>> a = numpy.random.randint(0, 100, [100000000])
>>> b = numpy.empty([100000000], dtype='int64')
>>> def targ(in_array, out_array, start, count):                out_array[start:start␣
↪+ count] = in_array[start:start + count] ** 2
>>> tb.thread_job(len(a), 0, targ, a, b)
>>> print(b[0:5])
[2704 7225  196 1521   36]
```

This example:

- Defines a target function, which will be called for each thread. It is usually necessary to define a simple "wrapper" function like this to provide the correct call signature.

- The target function receives inputs C{in_array} and C{out_array}, which are not touched directly by C{thread_job} but are passed through in the call. In this case, C{a} gets passed as C{in_array} and C{b} as C{out_array}
- The target function also receives the start and number of elements it needs to process. For each thread where the target is called, these numbers are different.

spacepy.toolbox.thread_map

spacepy.toolbox.**thread_map**(*target*, *iterable*, *thread_count=None*, **args*, ***kwargs*)

Apply a function to every element of a list, in separate threads

Interface is similar to multiprocessing.map, except it runs in threads

This is made largely obsolete in python3 by from concurrent import futures

Parameters

target [callable]

Python callable to run on each element of iterable. For each call, an element of iterable is appended to args and both args and kwargs are passed through. Note that this means the iterable element is always the *last* positional argument; this allows the specification of self as the first argument for method calls.

iterable [iterable] elements to pass to each call of L{target}

args [sequence]

arguments to pass to target before each element of iterable

thread_count [integer] Number of threads to spawn; see L{thread_job}.

kwargs [dict] keyword arguments to pass to L{target}.

Returns

out [list] return values of L{target} for each item from L{iterable}

Examples

find totals of several arrays

```
>>> import numpy
>>> from spacepy import toolbox
>>> inputs = range(100)
>>> totals = toolbox.thread_map(numpy.sum, inputs)
>>> print(totals[0], totals[50], totals[99])
(0, 50, 99)
```

```
>>> # in python3
>>> from concurrent import futures
>>> with futures.ThreadPoolExecutor(max_workers=4) as executor:
...:     for ans in executor.map(numpy.sum, [0,50,99]):
...:         print ans
#0
#50
#99
```

4.19.6 System tools

do_with_timeout(timeout, target, *args, **kwargs)	Execute a function (or method) with a timeout.
get_url(url[, outfile, reporthook, cached, ...])	Read data from a URL
loadpickle(fln)	load a pickle and return content as dictionary
progressbar(count, blocksize, totalsize[, text])	print a progress bar with urllib.urlretrieve reporthook functionality
query_yes_no(question[, default])	Ask a yes/no question via raw_input() and return their answer.
savepickle(fln, dict[, compress])	save dictionary variable dict to a pickle with filename fln
timeout_check_call(timeout, *args, **kwargs)	Call a subprocess with a timeout.
TimeoutError	Raised when a time-limited process times out
update([all, QDomni, omni, omni2, leapsecs, ...])	Download and update local database for omni, leapsecs etc

spacepy.toolbox.do_with_timeout

spacepy.toolbox.**do_with_timeout**(*timeout*, *target*, **args*, ***kwargs*)

Execute a function (or method) with a timeout.

Call the function (or method) `target`, with arguments `args` and keyword arguments `kwargs`. Normally return the return value from `target`, but if `target` takes more than `timeout` seconds to execute, raises `TimeoutError`.

Note: This is, at best, a blunt instrument. Exceptions from `target` may not propagate properly (tracebacks will be hard to follow.) The function which failed to time out may continue to execute until the interpreter exits; trapping the TimeoutError and continuing normally is not recommended.

Parameters

timeout [float] Timeout, in seconds.

target [callable]

Python callable (generally a function, may also be an imported ctypes function) to run.

args [sequence] Arguments to pass to `target`.

kwargs [dict] keyword arguments to pass to `target`.

Returns

out [] return value of `target`

Raises

TimeoutError [If `target` does not return in `timeout` seconds.]

Examples

```
>>> import spacepy.toolbox as tb
>>> import time
>>> def time_me_out():
...     time.sleep(5)
>>> tb.do_with_timeout(0.5, time_me_out) #raises TimeoutError
```

spacepy.toolbox.get_url

spacepy.toolbox.**get_url**(*url*, *outfile=None*, *reporthook=None*, *cached=False*, *keepalive=False*, *conn=None*)
Read data from a URL

Open an HTTP URL, honoring the user agent as specified in the SpacePy config file. Returns the data, optionally also writing out to a file.

This is similar to the deprecated `urlretrieve`.

Parameters

url [str] The URL to open

outfile [str (optional)] Full path to file to write data to

reporthook [callable (optional)] Function for reporting progress; takes arguments of block count, block size, and total size.

cached [bool (optional)] Compare modification time of the URL to the modification time of `outfile`; do not retrieve (and return None) unless the URL is newer than the file.

keepalive [bool (optional)] Attempt to keep the connection open to retrieve more URLs. The return becomes a tuple of (data, conn) to return the connection used so it can be used again. This mode does not support proxies. (Default False)

conn [http.client.HTTPConnection (optional)] An established http connection (HTTPS is also okay) to use with `keepalive`. If not provided, will attempt to make a connection.

Returns

bytes The HTTP data from the server.

See also:

progressbar

Notes

This function honors proxy settings as described in `urllib.request.getproxies()`. Cryptic error messages (such as `Network is unreachable`) may indicate that proxy settings should be defined as appropriate for your environment (e.g. with `HTTP_PROXY` or `HTTPS_PROXY` environment variables).

spacepy.toolbox.loadpickle

spacepy.toolbox.**loadpickle**(*fln*)
load a pickle and return content as dictionary

Parameters

fln [string] filename

Returns

out [dict] dictionary with content from file

See also:

savepickle

Examples

note: If fln is not found, but the same filename with '.gz' is found, will attempt to open the .gz as a gzipped file.

```
>>> d = loadpickle('test.pbin')
```

spacepy.toolbox.progressbar

spacepy.toolbox.**progressbar**(*count*, *blocksize*, *totalsize*, *text='Download Progress'*)
print a progress bar with urllib.urlretrieve reporthook functionality

Examples

```
>>> import spacepy.toolbox as tb
>>> import urllib
>>> urllib.urlretrieve(config['psddata_url'], PSDdata_fname, reporthook=tb.
↪progressbar)
```

spacepy.toolbox.query_yes_no

spacepy.toolbox.**query_yes_no**(*question*, *default='yes'*)
Ask a yes/no question via raw_input() and return their answer.

"question" is a string that is presented to the user. "default" is the presumed answer if the user just hits <Enter>. It must be "yes" (the default), "no" or None (meaning an answer is required of the user).

The "answer" return value is one of "yes" or "no".

Parameters

question [string] the question to ask

default [string (optional)]

Returns

out [string] answer ('yes' or 'no')

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.query_yes_no('Ready to go?')
Ready to go? [Y/n] y
'yes'
```

spacepy.toolbox.savepickle

spacepy.toolbox.**savepickle**(*fln*, *dict*, *compress=None*)

save dictionary variable dict to a pickle with filename fln

Parameters

fln [string] filename

dict [dict] container with stuff

compress [bool]

write as a gzip-compressed file (.gz will be added to `fln`). If not specified, defaults to uncompressed, unless the compressed file exists and the uncompressed does not.

See also:

loadpickle

Examples

```
>>> d = {'grade':[1,2,3], 'name':['Mary', 'John', 'Chris']}
>>> savepickle('test.pbin', d)
```

spacepy.toolbox.timeout_check_call

spacepy.toolbox.**timeout_check_call**(*timeout*, **args*, ***kwargs*)

Call a subprocess with a timeout.

Like `subprocess.check_call()`, but will terminate the process and raise *TimeoutError* if it runs for too long.

This will only terminate the single process started; any child processes will remain running (this has implications for, say, spawing shells.)

Parameters

timeout [float] Timeout, in seconds. Fractions are acceptable but the resolution is of order 100ms.

args [sequence] Arguments passed through to `subprocess.Popen`

kwargs [dict] keyword arguments to pass to `subprocess.Popen`

Returns

out [int] 0 on successful completion

Raises

TimeoutError [If subprocess does not return in `timeout` seconds.]

CalledProcessError [if command has non-zero exit status]

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.timeout_check_call(1, 'sleep 30', shell=True) #raises TimeoutError
```

spacepy.toolbox.TimeoutError

exception spacepy.toolbox.**TimeoutError**

Raised when a time-limited process times out

spacepy.toolbox.update

spacepy.toolbox.**update**(*all=True*, *QDomni=False*, *omni=False*, *omni2=False*, *leapsecs=False*, *PSDdata=False*, *cached=True*)

Download and update local database for omni, leapsecs etc

Web access is via *get_url()*; notes there may be helpful in debugging errors. See also the `keepalive` configuration option.

Parameters

all [boolean (optional)] if True, update OMNI2, Qin-Denton and leapsecs

omni [boolean (optional)] if True. update only omni (Qin-Denton)

omni2 [boolean (optional)] if True, update only original OMNI2

QDomni [boolean (optional)] if True, update OMNI2 and Qin-Denton

leapsecs [boolean (optional)] if True, update only leapseconds

cached [boolean (optional)] Only update files if timestamp on server is newer than timestamp on local file (default). Set False to always download files.

Returns

out [string] data directory where things are saved

See also:

get_url

Examples

```
>>> import spacepy.toolbox as tb
>>> tb.update(omni=True)
```

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