GCM Data Analysis Primer

July 14, 2017

```
In [1]: import netCDF4 as nc
        import numpy as np
        import matplotlib; import pylab as plt;
        plt.rc('text', usetex=True); plt.rc('font', family='serif');
        %matplotlib inline
```

Use the netCDF4 package to load NetCDF files (*.nc). You may have to install it separately. Usage is very simple, just point nc.Dataset to the data file and tell it to read the file rather than write to it.

```
In [2]: data = nc.Dataset("MOST.001.nc","r")
```

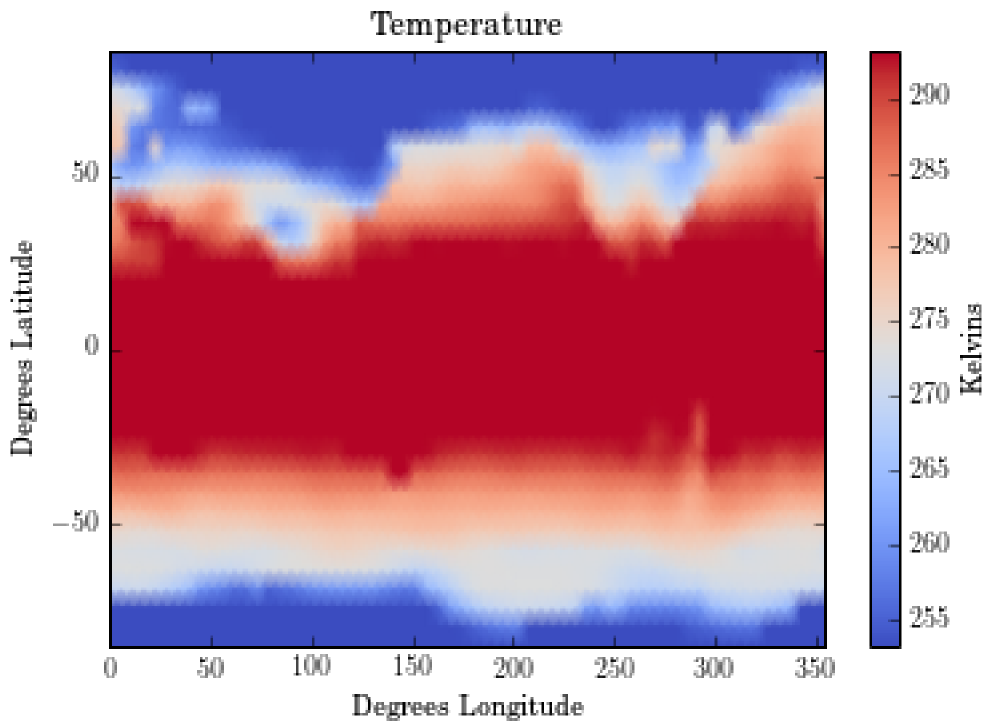
The structure of a NetCDF4 Dataset is essentially a dictionary, with a set of strings as keys, which when handed to Dataset.variables, returns array-like data.

```
In [3]: print "Code\tDimensions ([t],[z],[lat],[lon])"
        for i in data.variables:
            print i,'\t',data.variables[i][:].shape
```

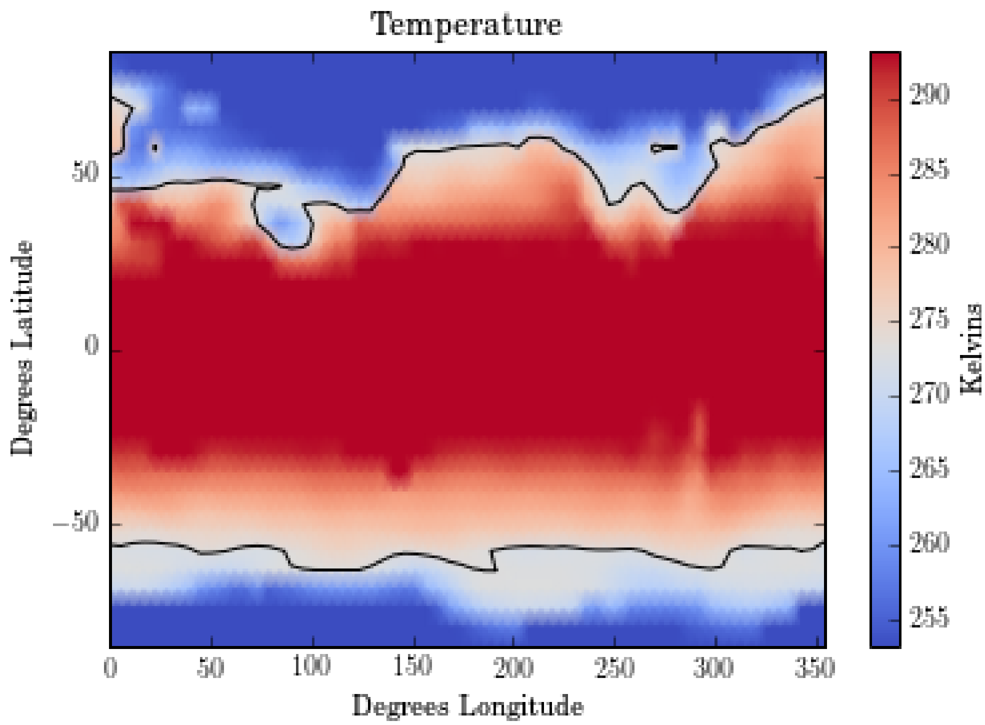
```
Code        Dimensions ([t],[z],[lat],[lon])
lon          (64,)
lat          (32,)
lev          (10,)
time          (12,)
sg          (12, 32, 64)
ta          (12, 10, 32, 64)
ua          (12, 10, 32, 64)
va          (12, 10, 32, 64)
hus          (12, 10, 32, 64)
ps          (12, 32, 64)
wap          (12, 10, 32, 64)
wa          (12, 10, 32, 64)
zeta          (12, 10, 32, 64)
ts          (12, 32, 64)
mrso          (12, 32, 64)
snd          (12, 32, 64)
prl          (12, 32, 64)
prc          (12, 32, 64)
prsn          (12, 32, 64)
hfss          (12, 32, 64)
hfls          (12, 32, 64)
stf          (12, 10, 32, 64)
psi          (12, 10, 32, 64)
psl          (12, 32, 64)
pl          (12, 32, 64)
```

```
d          (12, 10, 32, 64)
zg          (12, 10, 32, 64)
hur          (12, 10, 32, 64)
mrro          (12, 32, 64)
clw          (12, 10, 32, 64)
cl          (12, 10, 32, 64)
clt          (12, 32, 64)
tas          (12, 32, 64)
tsa          (12, 32, 64)
lsm          (12, 32, 64)
z0          (12, 32, 64)
as          (12, 32, 64)
rss          (12, 32, 64)
rls          (12, 32, 64)
rst          (12, 32, 64)
rlut          (12, 32, 64)
evap          (12, 32, 64)
rsut          (12, 32, 64)
ssru          (12, 32, 64)
stru          (12, 32, 64)
sic          (12, 32, 64)
sit          (12, 32, 64)
snm          (12, 32, 64)
sndc          (12, 32, 64)
prw          (12, 32, 64)
glac          (12, 32, 64)
spd          (12, 10, 32, 64)
pr          (12, 32, 64)
ntr          (12, 32, 64)
nbr          (12, 32, 64)
hfns          (12, 32, 64)
wfn          (12, 32, 64)
dqo3          (12, 10, 32, 64)
lwth          (12, 32, 64)
grnz          (12, 32, 64)
icez          (12, 32, 64)
netz          (12, 32, 64)
```

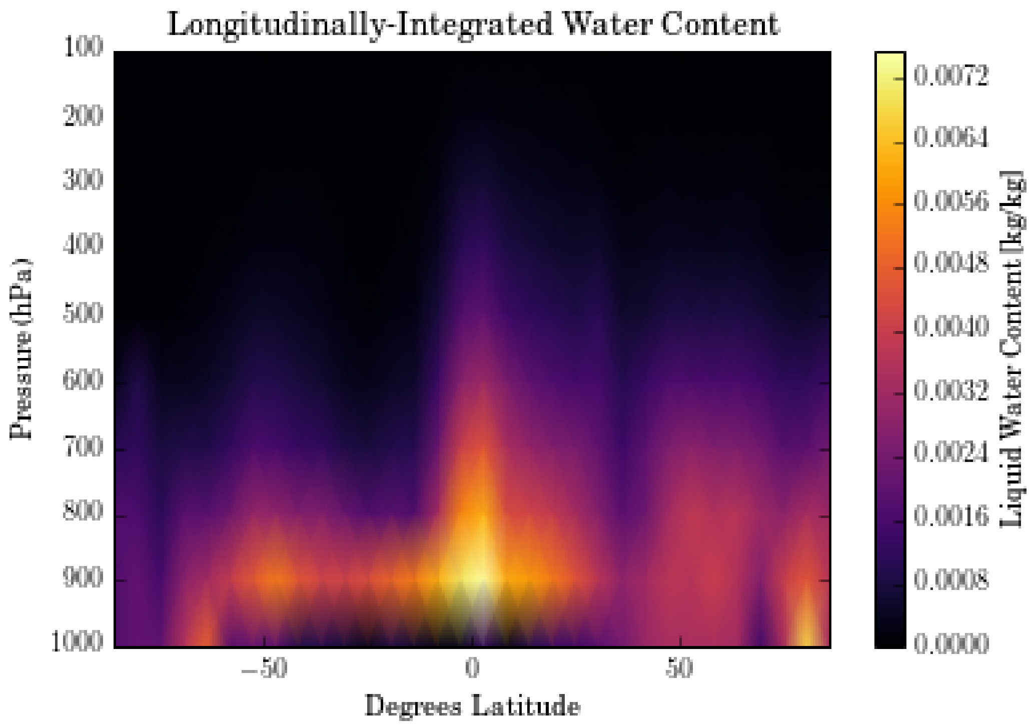
```
In [4]: lts = data.variables['lat'][:]
        lns = data.variables['lon'][:]
        lons, lats = np.meshgrid(lns,lts)
        t=plt.pcolormesh(lons,lats,data.variables['ts'][10,:],shading='Gouraud',cmap='coolwarm',vmin=25
        plt.xlabel('Degrees Longitude')
        plt.ylabel('Degrees Latitude')
        plt.title("Temperature")
        plt.ylim(np.amin(lts),np.amax(lts))
        plt.xlim(np.amin(lns),np.amax(lns))
        c=plt.colorbar(t,label='Kelvins')
```




```
In [5]: t=plt.pcolormesh(lons,lats,data.variables['ts'][10,:],shading='Gouraud',cmap='coolwarm',vmin=25
        plt.contour(lons,lats,data.variables['ts'][10,:],[273.15,],colors='k')
        plt.xlabel('Degrees Longitude')
        plt.ylabel('Degrees Latitude')
        plt.title("Temperature")
        plt.ylim(np.amin(lts),np.amax(lts))
        plt.xlim(np.amin(lns),np.amax(lns))
        c=plt.colorbar(t,label='Kelvins')
```



In [6]:
```
lvs = data.variables['lev'][:]
lats2,levs = np.meshgrid(lts,lvs)
w=plt.pcolormesh(lats2,levs,np.sum(data.variables['clw'][7,:],axis=2),shading='Gouraud',cmap='i
plt.ylabel('Pressure (hPa)')
plt.xlabel('Degrees Latitude')
plt.title("Longitudinally-Integrated Water Content")
plt.ylim(np.amin(lvs),np.amax(lvs))
plt.xlim(np.amin(lts),np.amax(lts))
c=plt.colorbar(w,label='Liquid Water Content [kg/kg]')
plt.gca().invert_yaxis()
```



It can be instructive to view the data with the proper scaling, noting that we're talking about a spherical planet. The additional Matplotlib Basemap package allows us to plot the data as a Mollweide projection. This package needs to be installed separately, on top of the existing matplotlib installation.

```
In [7]: from mpl_toolkits.basemap import Basemap
```

We also need to wrap the data–our data doesn't include both 360 degrees longitude and 0 degrees longitude, but we need it for a full Mollweide projection. So we define two functions for wrapping 2D and 3D data.

```
In [8]: def wrap2d(datd,vals):
            modf=np.zeros(datd.ndim,dtype=int)
            modf[-1]=1
            dd=np.zeros(datd.shape+modf)
            dd[:,0:datd.shape[-1]]=datd
            dd[:,datd.shape[-1]]=vals
            return dd

        def wrap3d(datd,vals):
            modf=np.zeros(datd.ndim,dtype=int)
            modf[-1]=1
            dd=np.zeros(datd.shape+modf)
            dd[:,:,0:datd.shape[-1]]=datd
            dd[:,:,datd.shape[-1]]=vals
            return dd
```

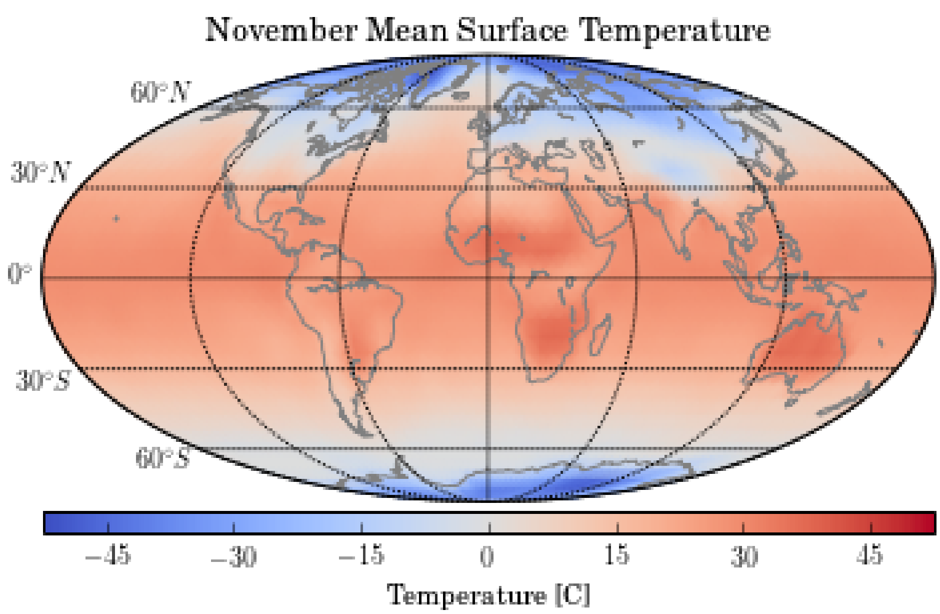
```
In [9]: latsw=wrap2d(lats,lats[:,0])
        lonsw=wrap2d(lons,360.0)
        dataw=wrap2d(data.variables['ts'][6,:],data.variables['ts'][6,:,0])
        print np.amax(dataw-273.15)
```

```
43.416619873
```

```
In [10]: names=['January','February','March','April','May','June','July','August','September','October'
```

```
In [11]: month=10
         latsw=wrap2d(lats,lats[:,0])
         lonsw=wrap2d(lons,360.0)
         dataw=wrap2d(data.variables['ts'][month,:],data.variables['ts'][month,:,0])

         maxv=np.amax(abs(dataw-273.15))
         minv=-maxv

         m = Basemap(projection='moll',lon_0=0,resolution='c')
         tm = m.pcolormesh(lonsw,latsw,dataw-273.15,shading='Gouraud',cmap='coolwarm',latlon=True,vmin=m

         m.drawcoastlines(color='gray')
         pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1])
         mr=m.drawmeridians(np.arange(-180,180.,60.))
         cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Temperature [C]")
         plt.title(names[month]+" Mean Surface Temperature")
```

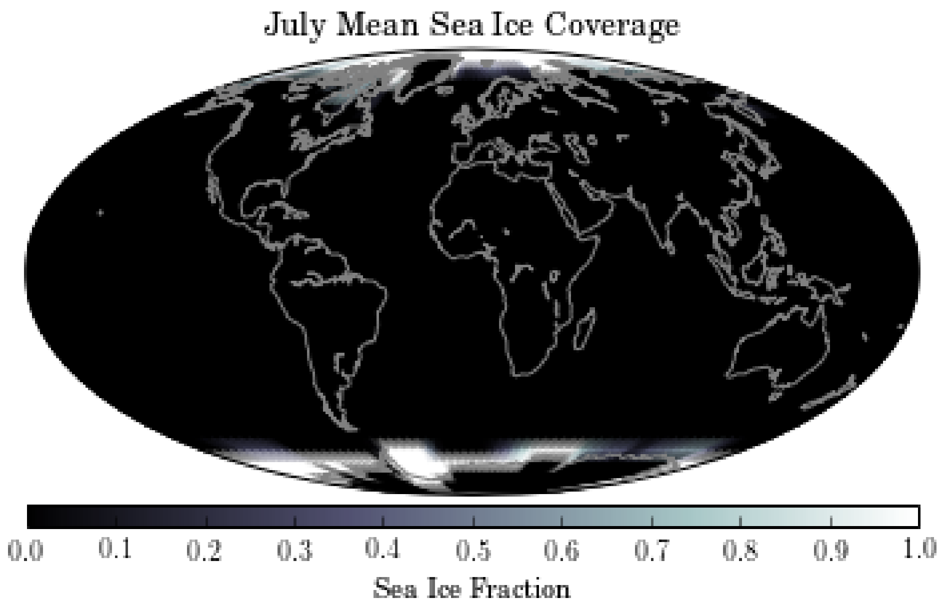
```
Out[11]: <matplotlib.text.Text at 0x7f8a53b36290>
```




```
In [12]: month=6
         latsw=wrap2d(lats,lats[:,0])
         lonsw=wrap2d(lons,360.0)
         dataw=wrap2d(data.variables['sic'][month,:],data.variables['sic'][month,:,0])
         lsm=wrap2d(data.variables['lsm'][month,:],data.variables['lsm'][month,:,0])

         m = Basemap(projection='moll',lon_0=0,resolution='c')
         tm = m.pcolormesh(lonsw,latsw,dataw,shading='Gouraud',cmap='bone',latlon=True)
         m.drawcoastlines(color='gray')
```

```
#pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1])
#mr=m.drawmeridians(np.arange(-180,180.,90.))
cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Sea Ice Fraction")
plt.title(names[month]+" Mean Sea Ice Coverage")
```

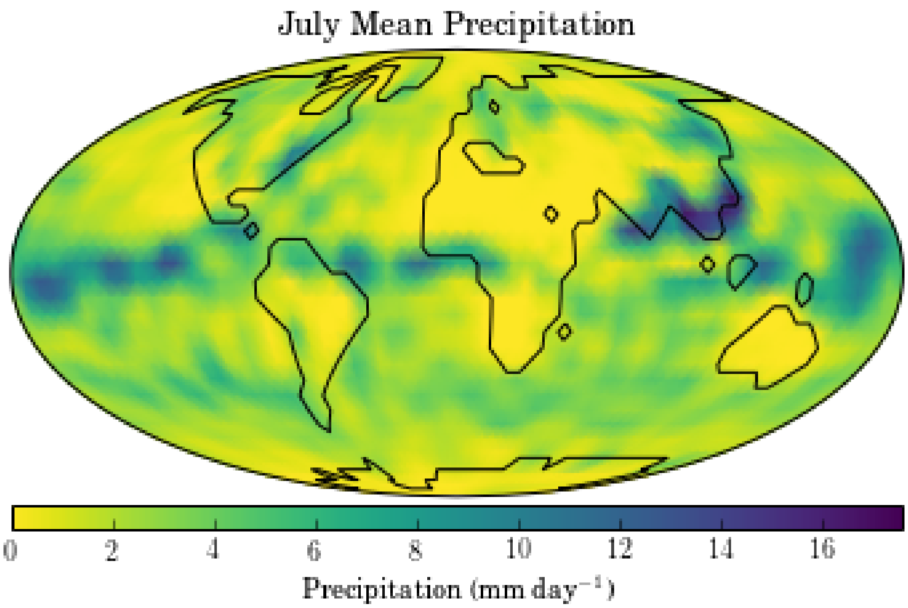
Out[12]: <matplotlib.text.Text at 0x7f8a5145d290>



In [13]:
```
month=6
```

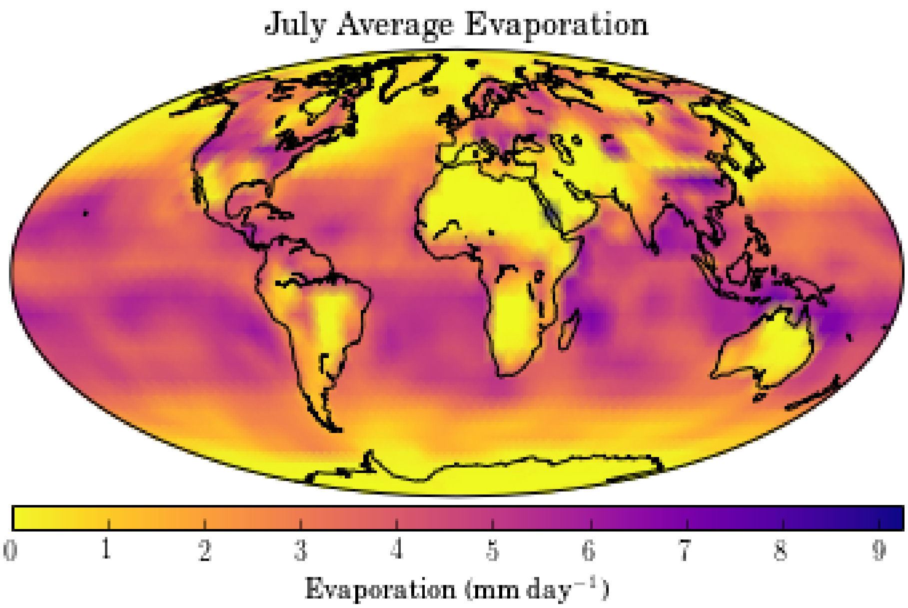
In [14]:
```
latsw=wrap2d(lats,lats[:,0])
lonsw=wrap2d(lons,360.0)
dataw=wrap2d(data.variables['pr'][month,:],data.variables['pr'][month,:,0])

m = Basemap(projection='moll',lon_0=0,resolution='c')
tm = m.pcolormesh(lonsw,latsw,(dataw)*8.64e7,shading='Gouraud',cmap='viridis_r',latlon=True)#,
continent = m.contour(lonsw,latsw,lsm,[0.5,],colors='k',latlon=True,zorder=3)
#m.drawcoastlines()
#pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1])
#mr=m.drawmeridians(np.arange(-180,180.,90.))
cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Precipitation (mm day$^{-1}$)")
plt.title(names[month]+" Mean Precipitation")
```

Out[14]: <matplotlib.text.Text at 0x7f8a510bdc90>

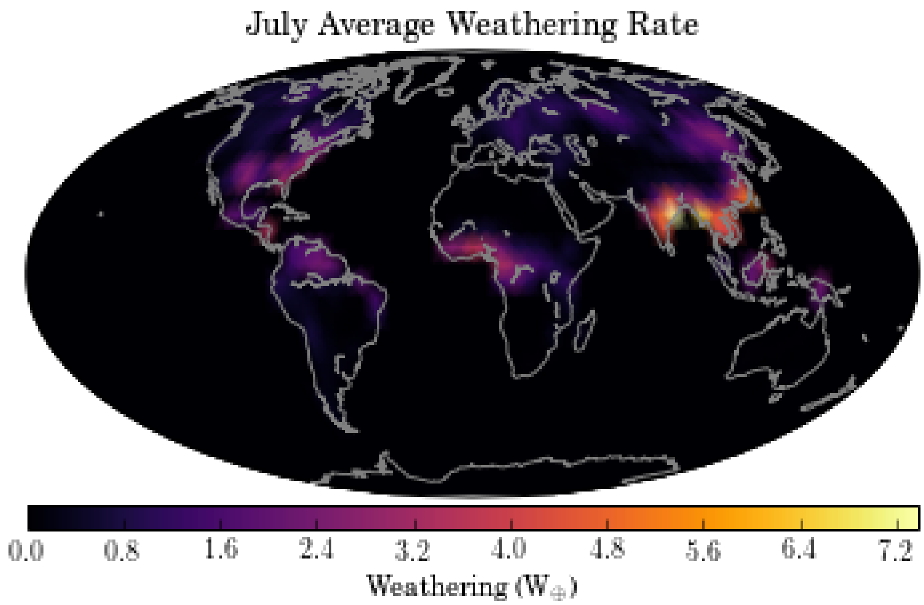


In [15]:
```
dataw=wrap2d(data.variables['evap'][month,:],data.variables['evap'][month,:,0])

m = Basemap(projection='moll',lon_0=0,resolution='c')
tm = m.pcolormesh(lonsw,latsw,-dataw*8.64e7,shading='Gouraud',cmap='plasma_r',latlon=True)
#continent = m.contour(lonsw,latsw,lsm,[0.5,],colors='lightgray',latlon=True,zorder=3)
m.drawcoastlines()
#pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1])
#mr=m.drawmeridians(np.arange(-180,180.,90.))
cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Evaporation (mm day$^{-1}$)")
plt.title(names[month]+" Average Evaporation")
```

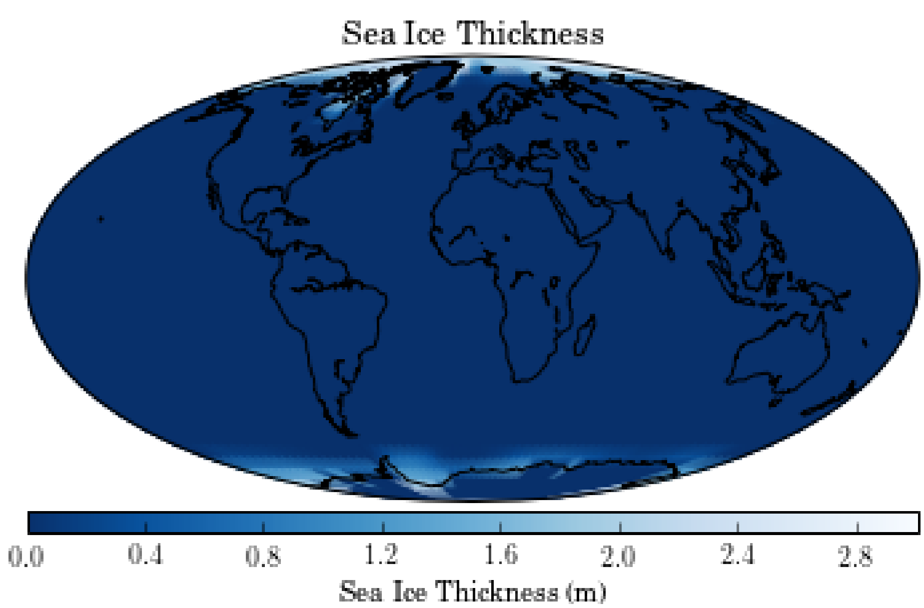
Out[15]:
```
<matplotlib.text.Text at 0x7f8a51189c50>
```




```
In [16]: dataw=wrap2d(data.variables['lwth'][month,:],data.variables['lwth'][month,:,0])

         m = Basemap(projection='moll',lon_0=0,resolution='c')
         tm = m.pcolormesh(lonsw,latsw,dataw,shading='Gouraud',cmap='inferno',latlon=True)
         #continent = m.contour(lonsw,latsw,lsm,[0.5,],colors='lightgray',latlon=True,zorder=3)
         m.drawcoastlines(color='gray')
         #pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1])
         #mr=m.drawmeridians(np.arange(-180,180.,90.))
         cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Weathering (W$_\oplus$)")
         plt.title(names[month]+" Average Weathering Rate")

Out[16]: <matplotlib.text.Text at 0x7f8a51003390>
```

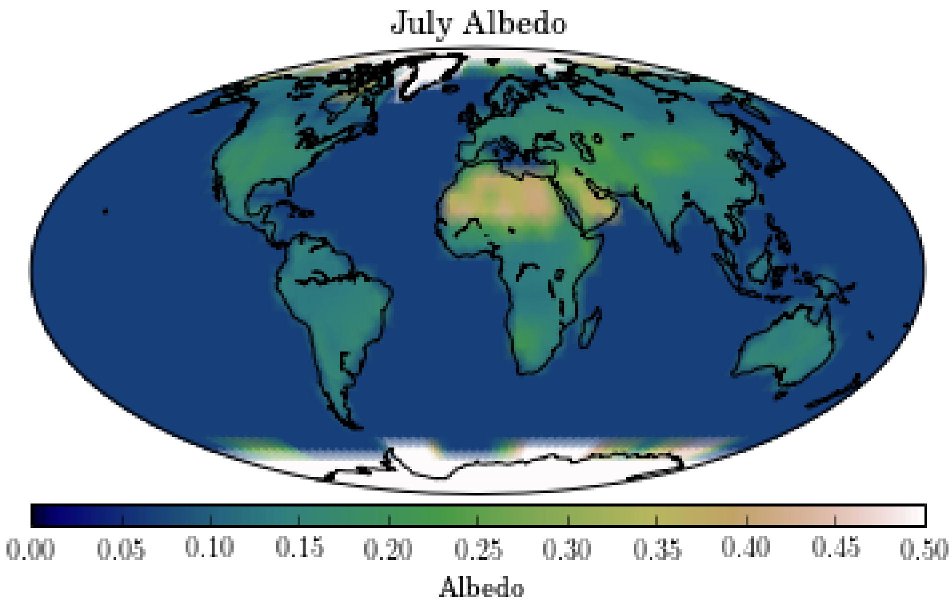



```
In [17]: dataw=wrap2d(data.variables['sit'][month,:],data.variables['sit'][month,:,0])

         m = Basemap(projection='moll',lon_0=0,resolution='c')
         tm = m.pcolormesh(lonsw,latsw,dataw,shading='Gouraud',cmap='Blues_r',latlon=True)
         m.drawcoastlines()
         #pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1])
         #mr=m.drawmeridians(np.arange(-180,180.,90.))
         cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Sea Ice Thickness (m)")
         plt.title("Sea Ice Thickness")

Out[17]: <matplotlib.text.Text at 0x7f8a50c9b2d0>
```



In [18]:
```
dataw=wrap2d(data.variables['as'][month,:],data.variables['as'][month,:,0])

m = Basemap(projection='moll',lon_0=0,resolution='c')
tm = m.pcolormesh(lonsw,latsw,dataw,shading='Gouraud',cmap='gist_earth',latlon=True,vmin=0,vma
#continent = m.contour(lonsw,latsw,lsm,[0.5,],colors='lightgray',latlon=True,zorder=3)
m.drawcoastlines()
#pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1])
#mr=m.drawmeridians(np.arange(-180,180.,90.))
cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Albedo")
plt.title(names[month]+" Albedo")
```

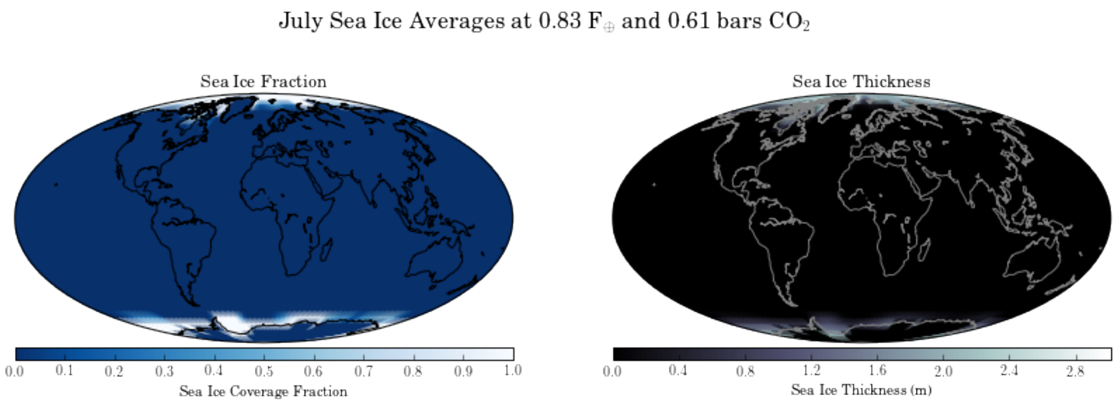
Out[18]: <matplotlib.text.Text at 0x7f8a50fe8110>



In [19]:
```
f,axarr = plt.subplots(1,2,figsize=(14,4.5))
f.suptitle(names[month]+" Sea Ice Averages at 0.83 F$_\oplus$ and 0.61 bars CO$_2$",fontsize=1

datac=wrap2d(data.variables['sic'][month,:],data.variables['sic'][month,:,0])

m = Basemap(projection='moll',lon_0=0,resolution='c',ax=axarr[0])
tm = m.pcolormesh(lonsw,latsw,datac,shading='Gouraud',cmap='Blues_r',latlon=True)
m.drawcoastlines()
#pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1])
#mr=m.drawmeridians(np.arange(-180,180.,90.))
cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Sea Ice Coverage Fraction")
axarr[0].set_title("Sea Ice Fraction")

dataw=wrap2d(data.variables['sit'][month,:],data.variables['sit'][month,:,0])
```

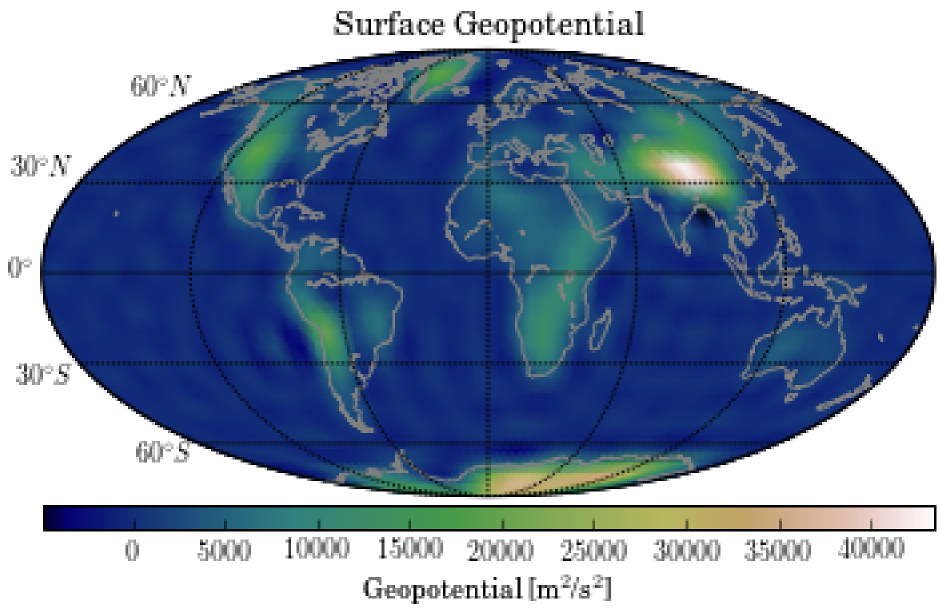
```
m2 = Basemap(projection='moll',lon_0=0,resolution='c',ax=axarr[1])
tm2 = m2.pcolormesh(lonsw,latsw,dataw,shading='Gouraud',cmap='bone',latlon=True)
m2.drawcoastlines(color='gray')
#pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1])
#mr=m.drawmeridians(np.arange(-180,180.,90.))
cb2 = m2.colorbar(tm2,"bottom", size="5%", pad="2%",label="Sea Ice Thickness (m)")
axarr[1].set_title("Sea Ice Thickness")
```

Out[19]: <matplotlib.text.Text at 0x7f8a509f64d0>



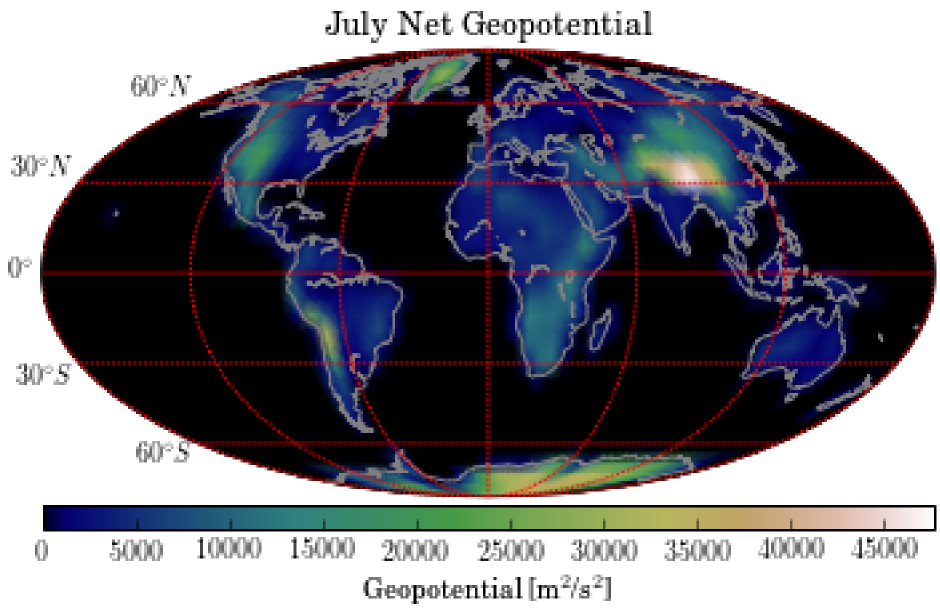

```
In [20]: dataw=wrap2d(data.variables['sg'][month,:],data.variables['sg'][month,:,0])

m = Basemap(projection='moll',lon_0=0,resolution='c')
tm = m.pcolormesh(lonsw,latsw,dataw,shading='Gouraud',cmap='gist_earth',latlon=True)
#continent = m.contour(lonsw,latsw,lsm,[0.5,],colors='lightgray',latlon=True,zorder=3)
m.drawcoastlines(color='gray')
pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1])
mr=m.drawmeridians(np.arange(-180,180.,60.))
cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Geopotential [m$^2$/s$^2$]")
plt.title("Surface Geopotential")
```

Out[20]: <matplotlib.text.Text at 0x7f8a5040be50>



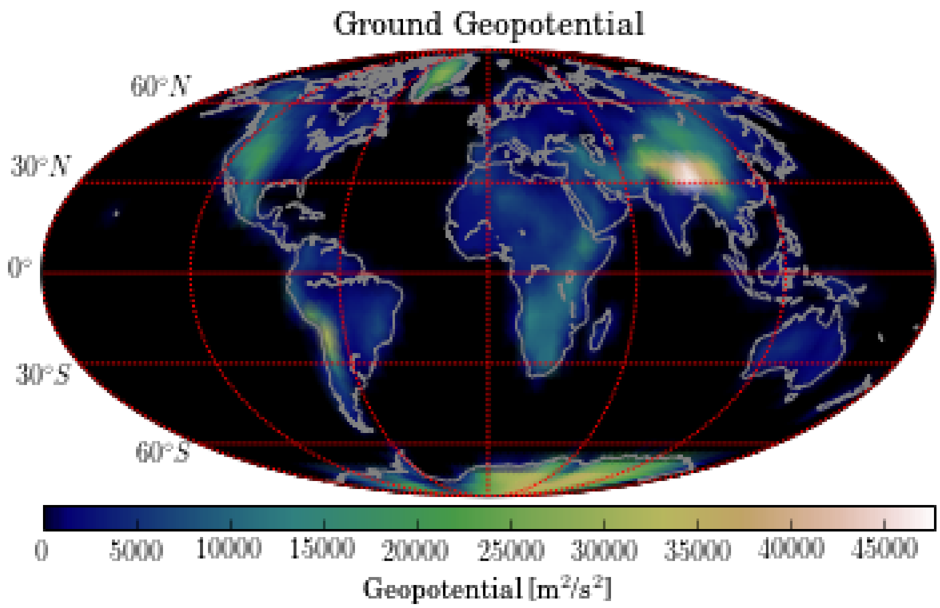
In [21]:
```
dataw=wrap2d(data.variables['netz'][month,:],data.variables['netz'][month,:,0])

m = Basemap(projection='moll',lon_0=0,resolution='c')
tm = m.pcolormesh(lonsw,latsw,dataw,shading='Gouraud',cmap='gist_earth',latlon=True)
#continent = m.contour(lonsw,latsw,lsm,[0.5,],colors='lightgray',latlon=True,zorder=3)
m.drawcoastlines(color='gray')
pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1],color='r')
mr=m.drawmeridians(np.arange(-180,180.,60.),color='r')
cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Geopotential [m$^2$/s$^2$]")
plt.title(names[month]+" Net Geopotential")
```

Out[21]:
```
<matplotlib.text.Text at 0x7f8a50541150>
```

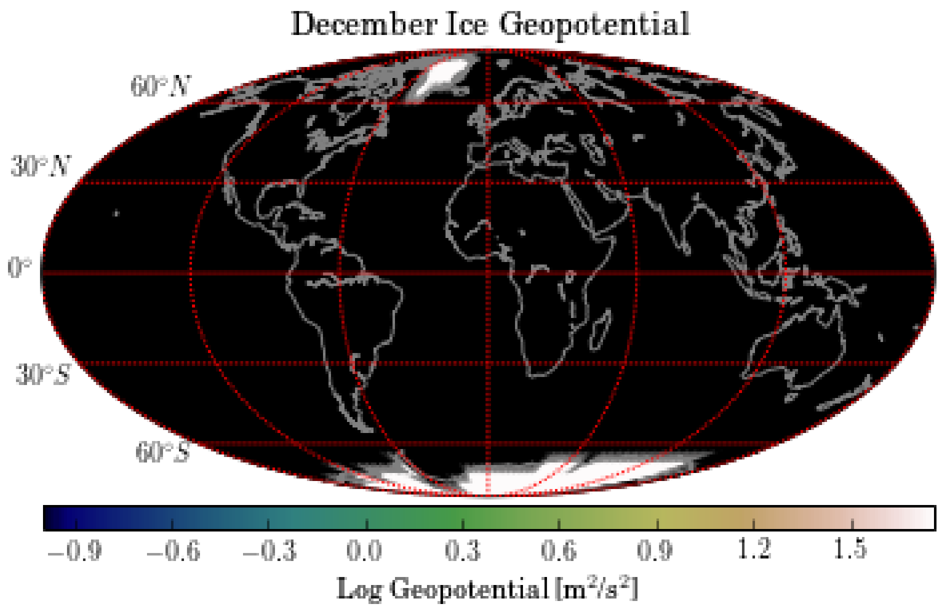


In [22]:
```
dataw=wrap2d(data.variables['grnz'][month,:],data.variables['grnz'][month,:,0])

m = Basemap(projection='moll',lon_0=0,resolution='c')
tm = m.pcolormesh(lonsw,latsw,dataw,shading='Gouraud',cmap='gist_earth',latlon=True)
#continent = m.contour(lonsw,latsw,lsm,[0.5,],colors='lightgray',latlon=True,zorder=3)
m.drawcoastlines(color='gray')
pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1],color='r')
mr=m.drawmeridians(np.arange(-180,180.,60.),color='r')
cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Geopotential [m$^2$/s$^2$]")
plt.title("Ground Geopotential")
```

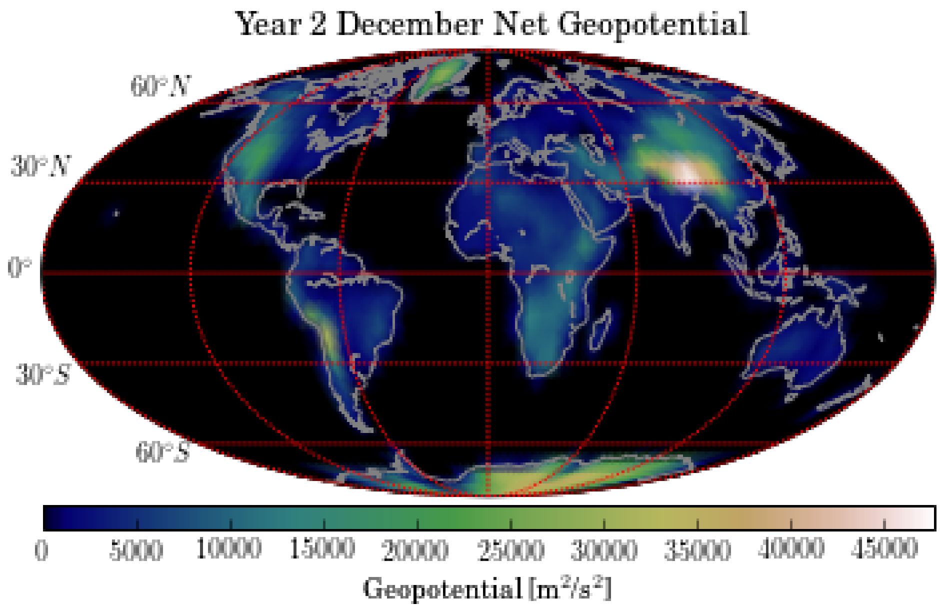
Out[22]:
```
<matplotlib.text.Text at 0x7f8a4a0bbdd0>
```




```
In [23]: month=11
         dataw=wrap2d(data.variables['icez'][month,:],data.variables['icez'][month,:,0])

         m = Basemap(projection='moll',lon_0=0,resolution='c')
         tm = m.pcolormesh(lonsw,latsw,np.log10(np.maximum(dataw,0.1)),shading='Gouraud',cmap='gist_ear
         #continent = m.contour(lonsw,latsw,lsm,[0.5,],colors='lightgray',latlon=True,zorder=3)
         m.drawcoastlines(color='gray')
         pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1],color='r')
         mr=m.drawmeridians(np.arange(-180,180.,60.),color='r')
         cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Log Geopotential [m$^2$/s$^2$]")
         plt.title(names[month]+" Ice Geopotential")

Out[23]: <matplotlib.text.Text at 0x7f8a49964a90>
```

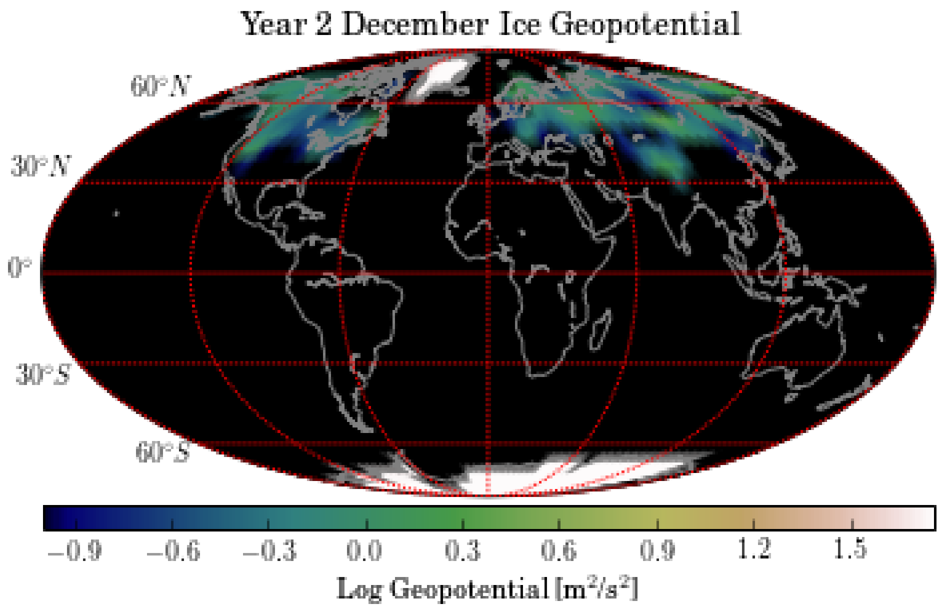



```
In [24]: data2 = nc.Dataset("MOST.002.nc","r")

In [25]: dataw=wrap2d(data2.variables['netz'][month,:],data2.variables['netz'][month,:,0])

         m = Basemap(projection='moll',lon_0=0,resolution='c')
         tm = m.pcolormesh(lonsw,latsw,dataw,shading='Gouraud',cmap='gist_earth',latlon=True)
         #continent = m.contour(lonsw,latsw,lsm,[0.5,],colors='lightgray',latlon=True,zorder=3)
         m.drawcoastlines(color='gray')
         pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1],color='r')
         mr=m.drawmeridians(np.arange(-180,180.,60.),color='r')
         cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Geopotential [m$^2$/s$^2$]")
         plt.title("Year 2 "+names[month]+" Net Geopotential")

Out[25]: <matplotlib.text.Text at 0x7f8a500974d0>
```

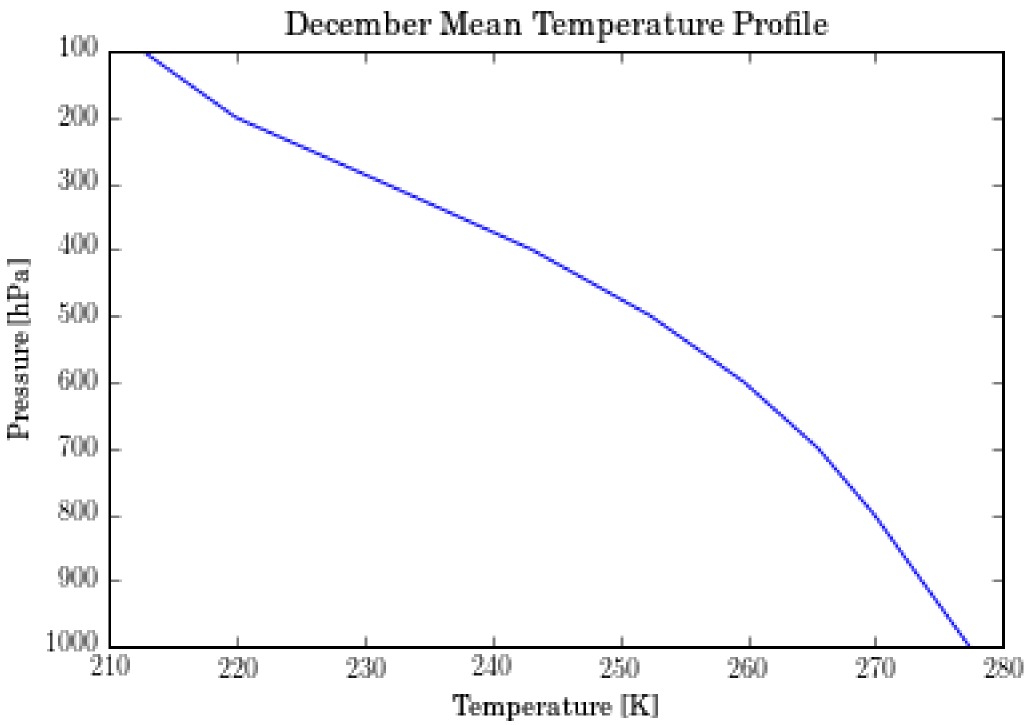


In [26]:
```
dataw=wrap2d(data2.variables['icez'][month,:],data2.variables['icez'][month,:,0])

m = Basemap(projection='moll',lon_0=0,resolution='c')
tm = m.pcolormesh(lonsw,latsw,np.log10(np.maximum(dataw,0.1)),shading='Gouraud',cmap='gist_ear
#continent = m.contour(lonsw,latsw,lsm,[0.5,],colors='lightgray',latlon=True,zorder=3)
m.drawcoastlines(color='gray')
pr=m.drawparallels(np.arange(-90.,120.,30.),labels=[1,0,0,1],color='r')
mr=m.drawmeridians(np.arange(-180,180.,60.),color='r')
cb = m.colorbar(tm,"bottom", size="5%", pad="2%",label="Log Geopotential [m$^2$/s$^2$]")
plt.title("Year 2 "+names[month]+" Ice Geopotential")
```

Out[26]:
```
<matplotlib.text.Text at 0x7f8a50225dd0>
```



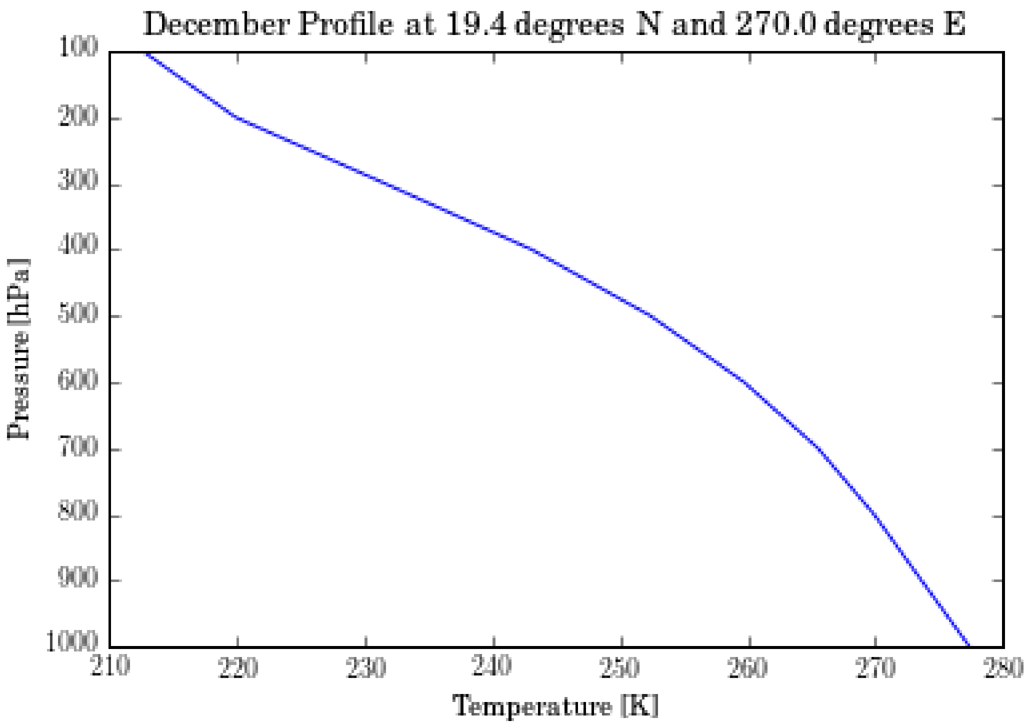

```
In [27]: data.variables['lev'][:]

Out[27]: array([  100.,    200.,    300.,    400.,    500.,    600.,    700.,    800.,
                  900.,   1000.])

In [28]: pressure = data.variables['lev'][:]
         meantemp = np.mean(data.variables['ta'][month,:],axis=(1,2))

In [29]: plt.plot(meantemp,pressure)
         plt.xlabel('Temperature [K]')
         plt.ylabel('Pressure [hPa]')
         plt.gca().invert_yaxis()
         plt.title(names[month]+' Mean Temperature Profile')

Out[29]: <matplotlib.text.Text at 0x7f8a4beeb4d0>
```




```
In [30]: localtemp = data.variables['ta'][month,:,12,48]
```

```
In [31]: plt.plot(meantemp,pressure)
         plt.xlabel('Temperature [K]')
         plt.ylabel('Pressure [hPa]')
         plt.gca().invert_yaxis()
         plt.title(names[month]+' Profile at %3.1f degrees N'%data.variables['lat'][12]+' and %3.1f deg
```

```
Out[31]: <matplotlib.text.Text at 0x7f8a491234d0>
```


December Profile at 19.4 degrees N and 270.0 degrees E
Pressure [hPa]
100
200
300
400
500
600
700
800
900
1000
210
220
230
240
250
260
270
280
Temperature [K]

```
In [ ]:
```