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Changes Log

Version	Date	Changes
1.0	15/09/2025	Creation of the document

List of Changes

Version	Section	Answers to RID	Changes

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 <p>OPT-MPC Copernicus Sentinel Optical Mission Performance Cluster</p>	<p>OPT-MPC S2 RUT Validation report</p>	<p>Ref.: OMPC.ACR.MEM.053 Issue: 1.0 Date: 15/09/2025 Page: 1</p>
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1 Introduction

This document describes the validation report against software requirements specified in OMPC.ACR.MEM.40. Additional scientific validation is provided in Tandem analysis report [RD3].

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2 Functional tests

2.1 Input products

Input product	Processing mode	Outcome (pass/fail)
S2B_MSIL1C_20230625T110619_N0509_R137_T30UWU_20230625T114918	Full tile, all bands	pass
S2A_MSIL1C_20240505T144731_N0510_R139_T20NKG_20240505T181400	Full tile, selected bands	pass
S2A_MSIL1C_20240706T134711_N0510_R024_T22NEF_20240706T170805	AOI	pass
	Single pixel	Fail (*)
S2C_MSIL1C_20241214T044241_N9905_R033_T45QWD_20241214T063754	Check S2A/S2B/S2C compatibility	pass

(*) The single pixel mode is no longer working after the implementation of the geolocation uncertainty model. A waiver is requested for this requirement.

2.2 Outputs

Item	check	Outcome (pass/fail)
JP2 product	Opens in QGIS	pass
Png images	Visualize	pass
Relative or absolute uncertainty maps	Check if both can be generated	Fail (*)
Individual contributors	Check if can be generated	pass

(*) After discussion within the project, the production of relative uncertainty maps has been disabled. A waiver is requested for this requirement.

3 Other requirements

3.1 Installation requirements

Requirement	Check	Outcome pass/fail
Installation from gitlab	Provide gitlab url	pass
List of dependencies	Provided in the readme of gitlab page	pass
Default configuration	Default json file included in the package	pass

3.2 Implementation requirements

Requirement	Check	Outcome pass/fail
Compatible with python 3.8 or higher	Run with python 3.8 or higher	pass

3.3 Performance requirements

Requirement	Check	Outcome pass/fail
Memory requirement < 32 GB for a full tile	Run with 32GB RAM (all bands and all contributors)	pass
Processing < 1 hour for a full tile and all bands	Report run time	2 min 48 s pass

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4 Quality assessment

4.1 Introduction

In this document we report on qualitative assessment, while partial scientific validation was performed using tandem data. The present assessment checks the following points:

- Uncertainty values are reasonable, in the range of a few percent or a few digital counts (for lower input values).
- The uncertainty should be of similar order of magnitude for all spectral bands, the cirrus band B10 excepted
- Geometric uncertainty contribution should be limited to areas with sharp gradients
- No artefacts or unexpected structures should be present (visual check)

A set of four products with different types of scenes has been used:

- Desert scene
- Vegetated scene
- Water scene
- Snow scene

For each product we provide:

- Statistics of relative contribution of different error sources
- Uncertainty images for selected bands
- Scatter plot between reflectance and uncertainty

4.2 Desert Scene

S2A_MSIL1C_20241208T092401_N0511_R093_T33RZH_20241208T101914.SAFE

Desert scene is an S2A acquisition over Libya from 2024-12-08. An RGB of the scene is presented in Figure 1.

Figure 2 presents the mean uncertainty over all pixel for each band, except B10. The total uncertainty is plotted in green, while blue and orange curves represent the random and systematic component of the uncertainty. Systematic part is composed mostly by out-of-field straylight estimated at 0.3% of the mean signal, which is clearly visible in this plot. Over desert scene the mean uncertainty remains below 2%.

Figure 3 represents the relative mean contribution of random and systematic to the total uncertainty. Random contributors represent around 80% of the total uncertainty for most of the bands.

The relative mean contribution of each random component to the total random uncertainty is presented in Figure 4. For each contributor, the mean over all pixel is computed and compare to the mean random uncertainty. Each relative contribution is then summed to obtain the bar plot. In the case of band 10, the approximation over all pixels is not working perfectly leading to a total sum lower than 100%, due to high difference of contribution between pixels. For other bands it shows that the diffuser term is the leading contributor while geolocation term remains very low on a scene without sharp contrast. As an example, the Figure 5 presents the full image per-pixel uncertainties of each component of band 04.

Full images uncertainties for each band are given in Figure 6 while Figure 7 presents the scatter plot between the uncertainty in absolute unite (i.e. reflectance dimension) and the reflectance. A clear pattern is visible with a minimal value for uncertainty linked to the reflectance of the pixel. For B10 the value, both for reflectance and uncertainty, seems to be too discrete to obtain a coherent scatter plot.

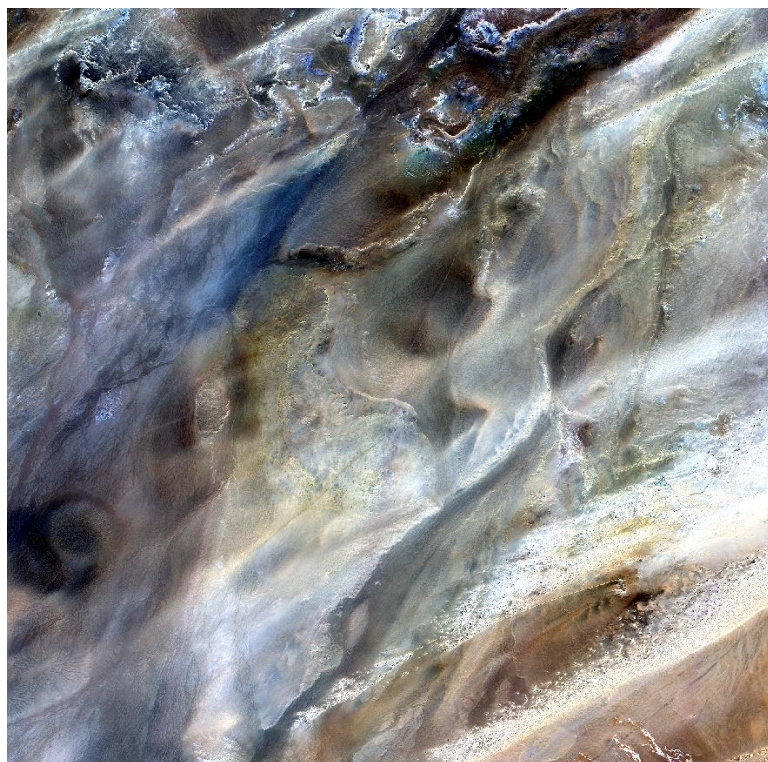


Figure 1: Desert scene RGB image

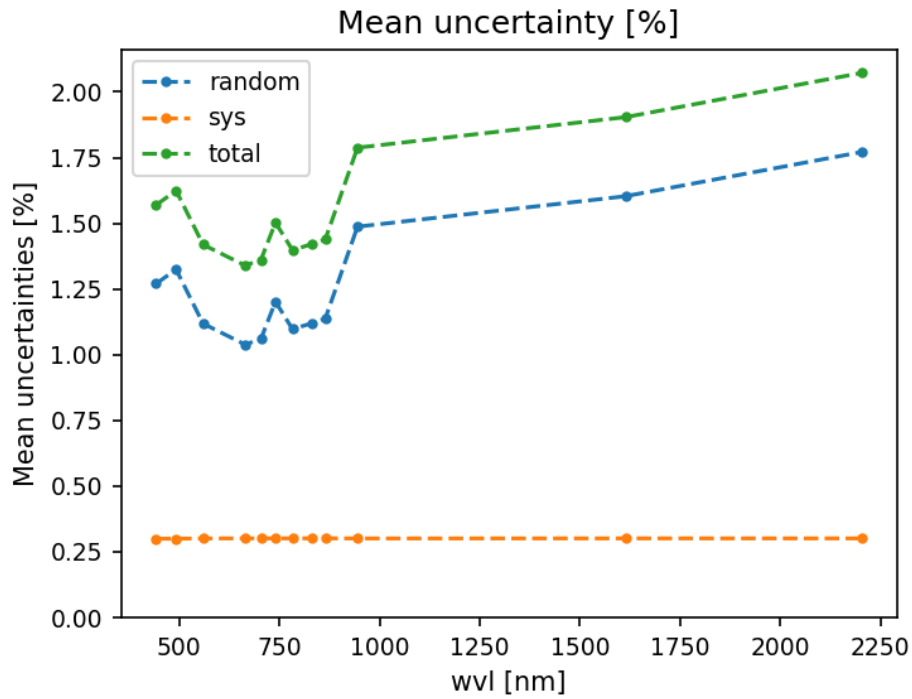


Figure 2: Desert scene mean uncertainty per band in percentage. Green is the total uncertainty, blue the random components and orange the systematics components. (B10 excluded)

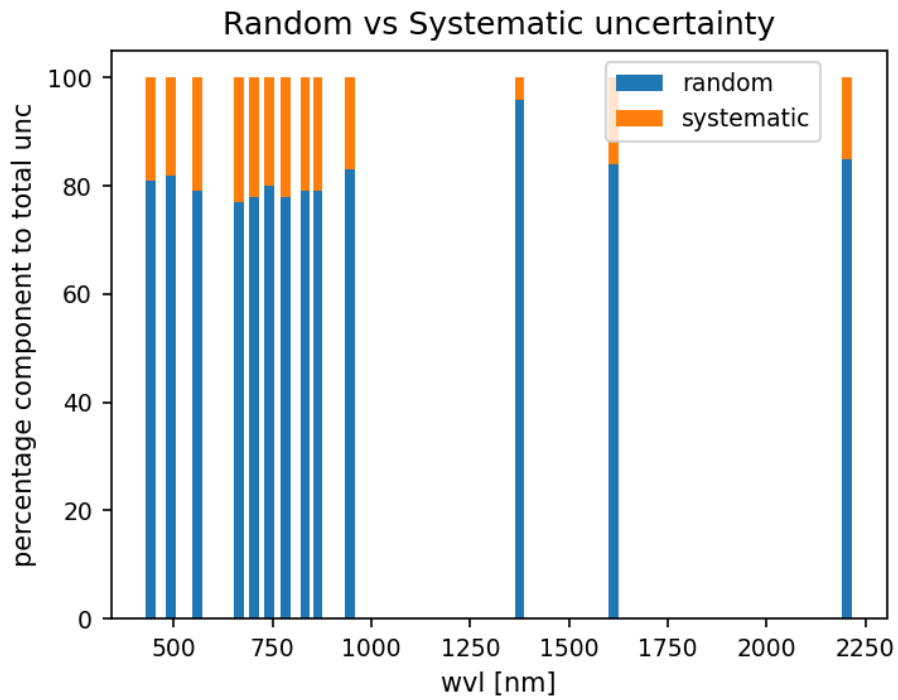


Figure 3: Desert scene random and systematic relative mean contribution to total uncertainty

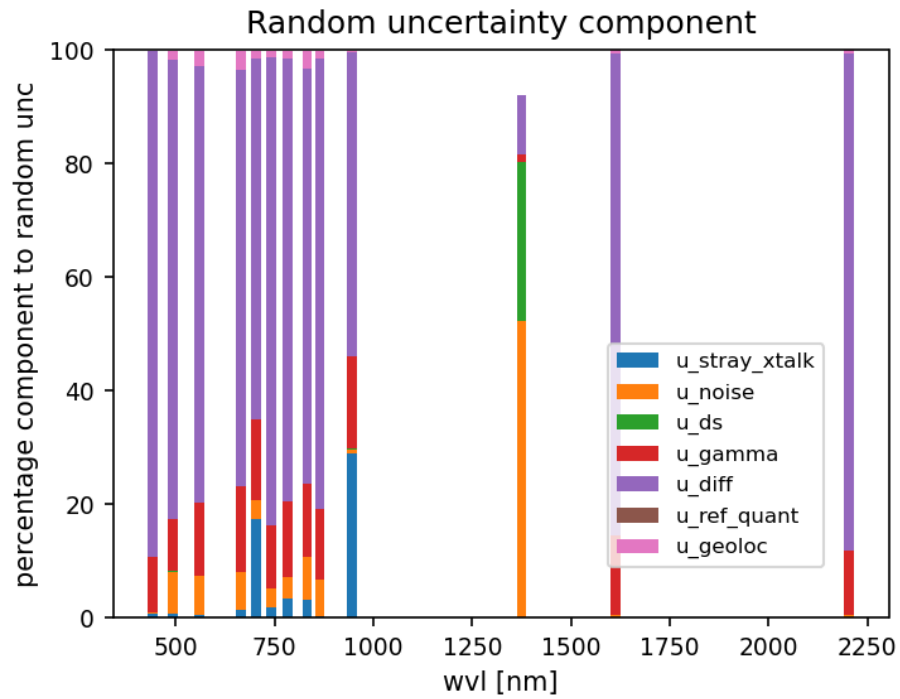


Figure 4: Desert scene random components relative mean contribution to RANDOM uncertainty. (B10 mean approximation over full-image is not 100% due to high difference of contribution between pixels)

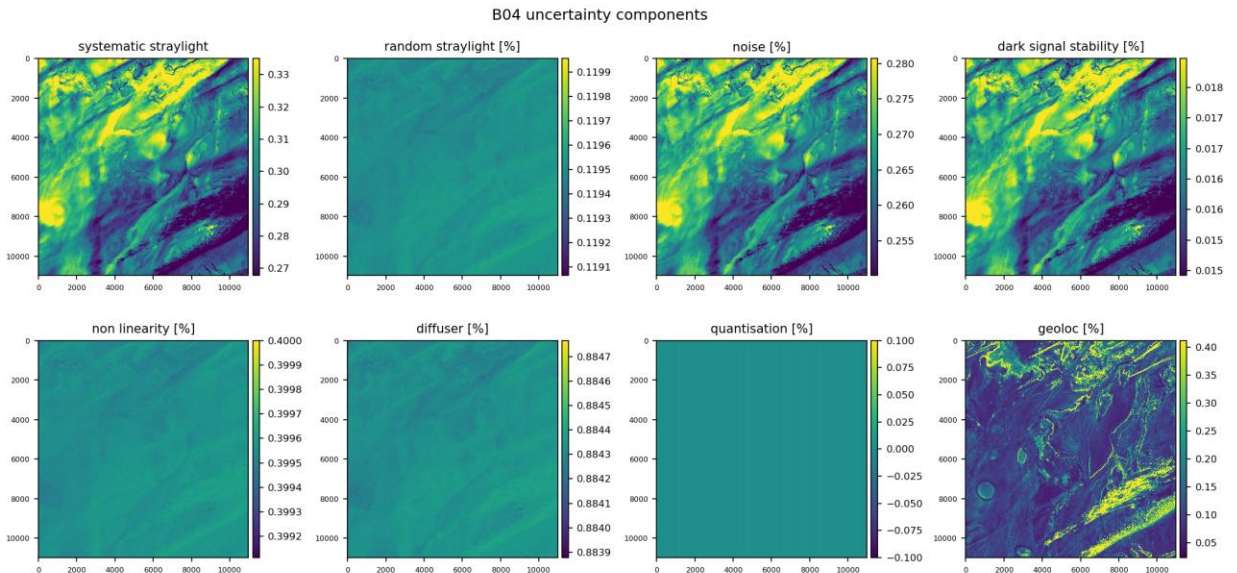
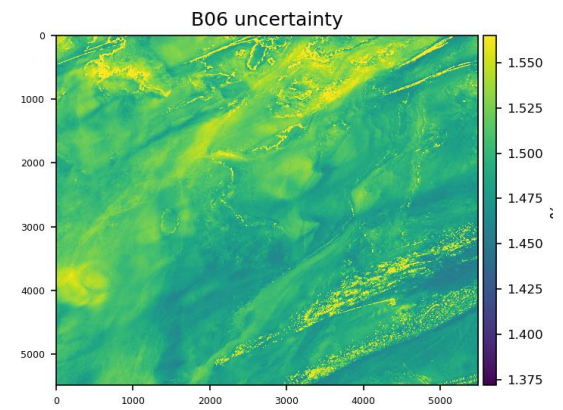
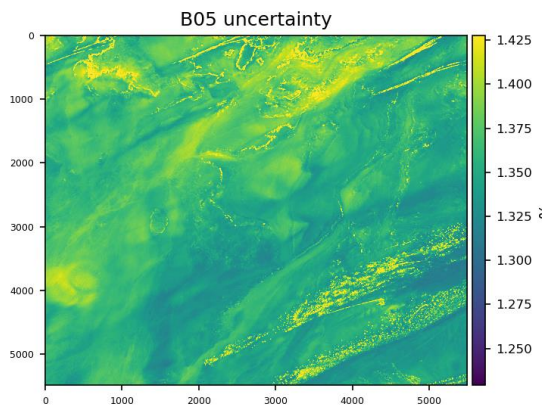
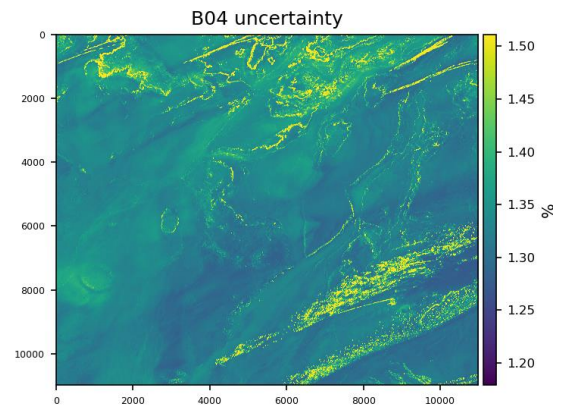
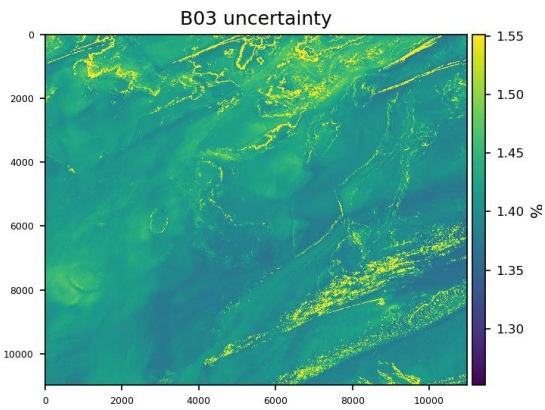
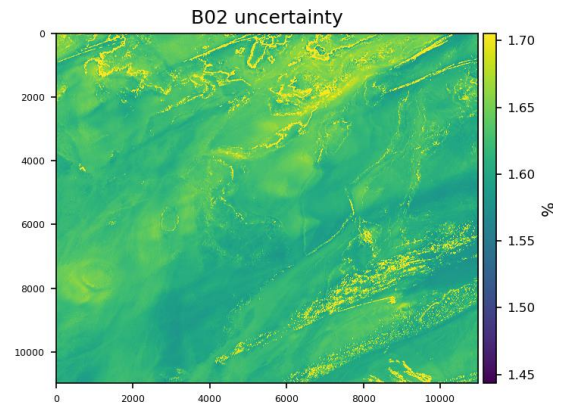
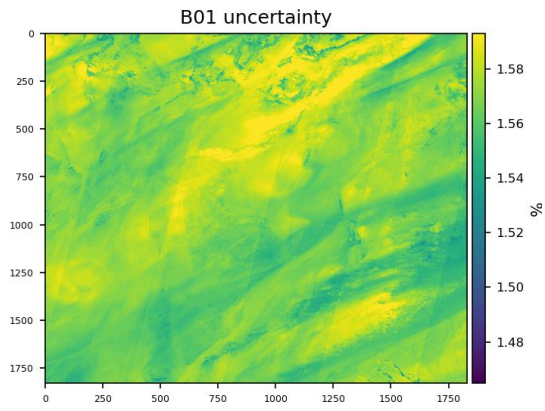
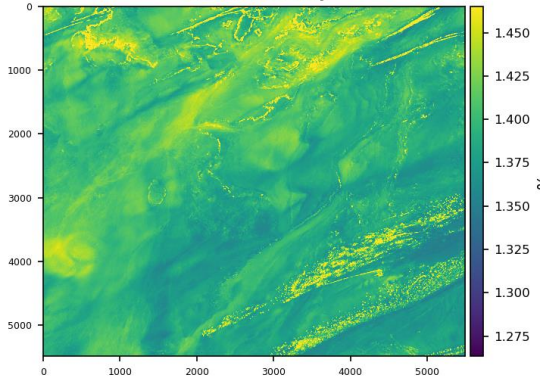


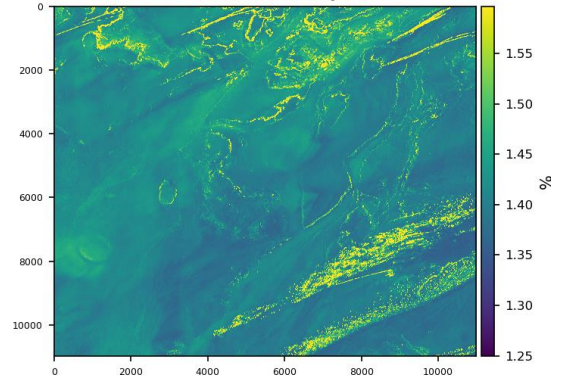
Figure 5: Desert scene, B04 components full image uncertainty in %



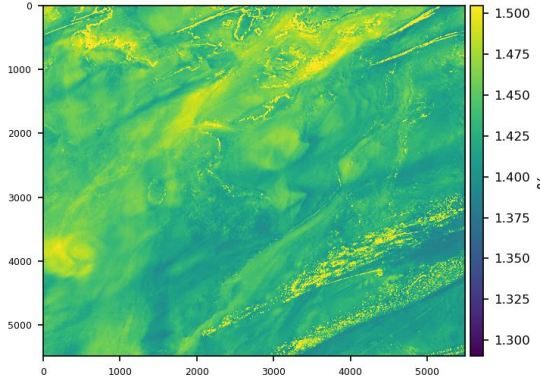
B07 uncertainty



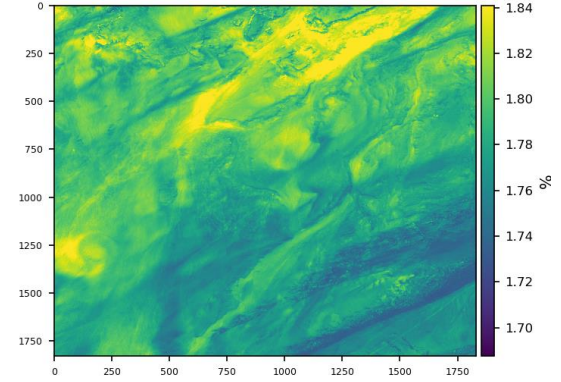
B08 uncertainty



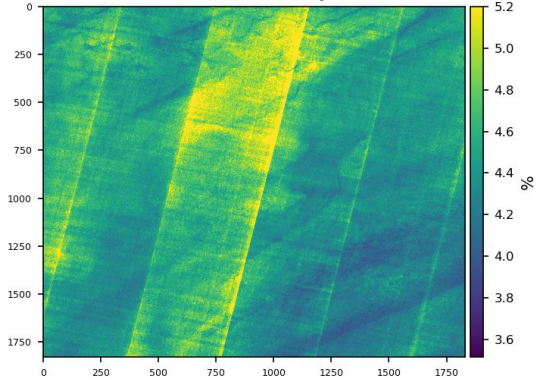
B8A uncertainty



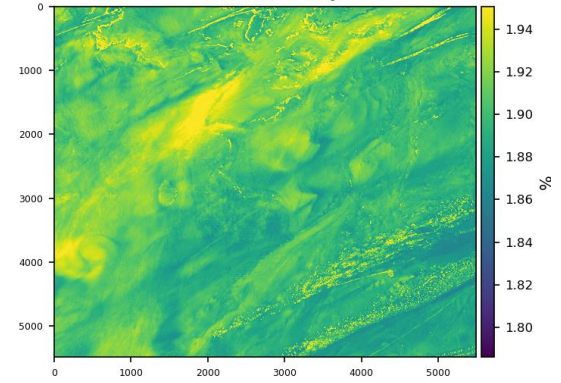
B09 uncertainty



B10 uncertainty



B11 uncertainty



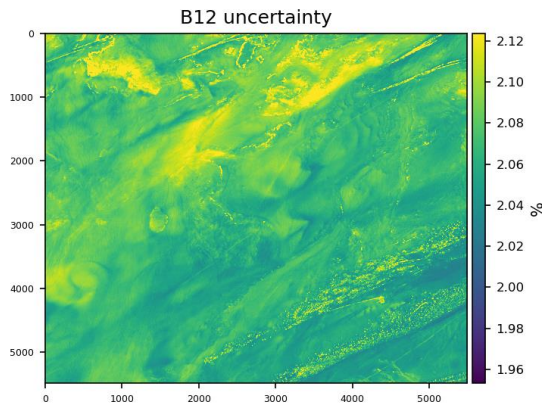
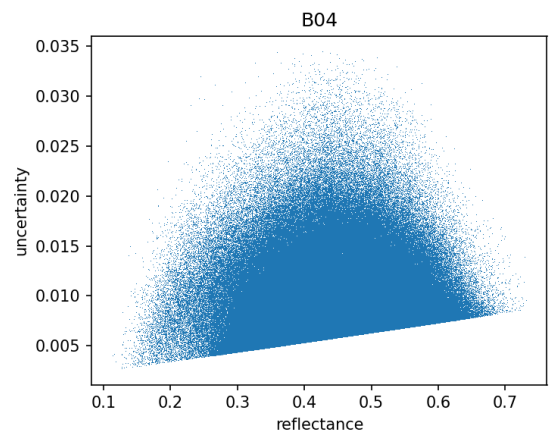
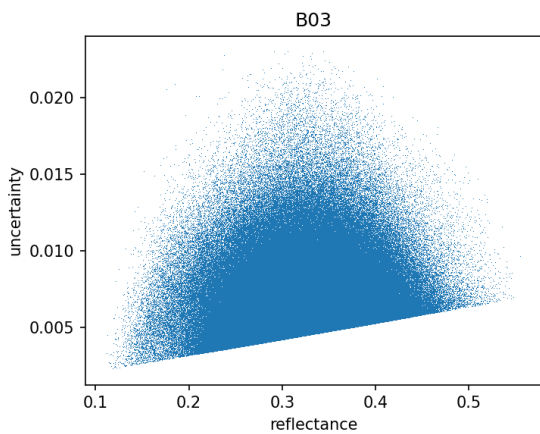
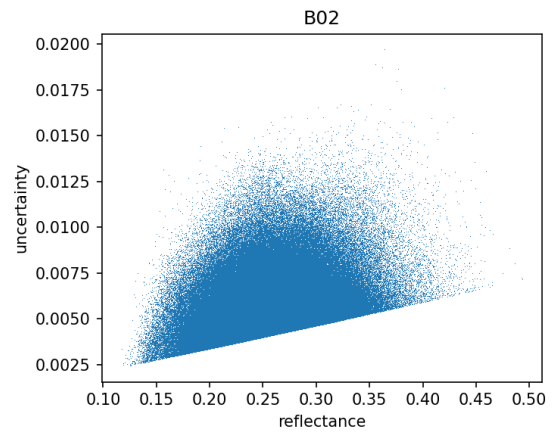
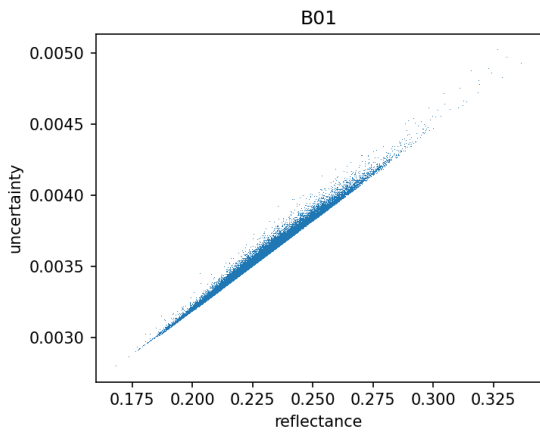
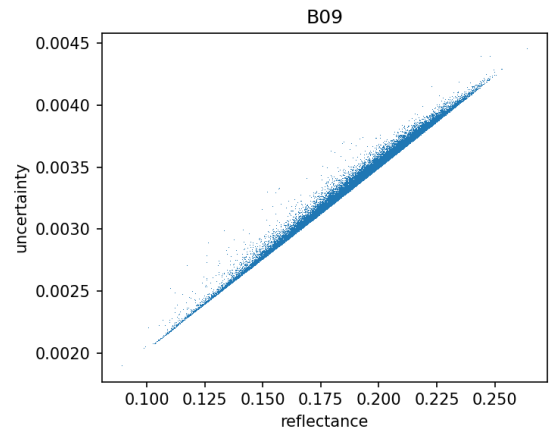
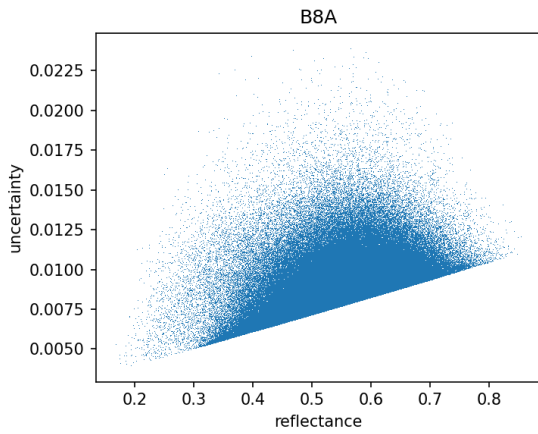
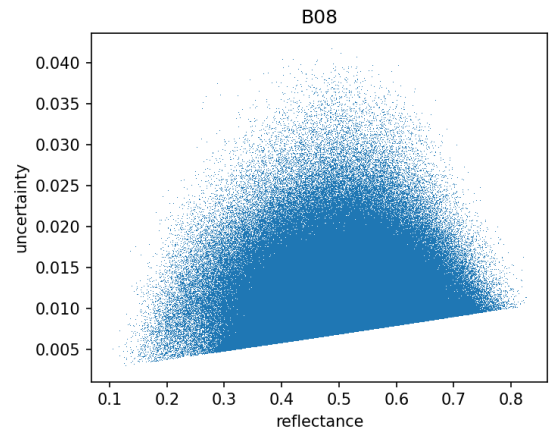
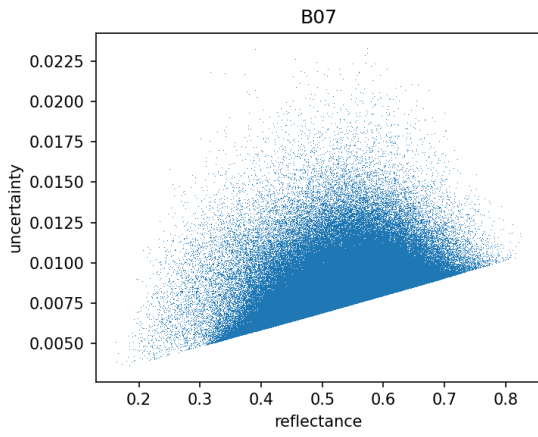
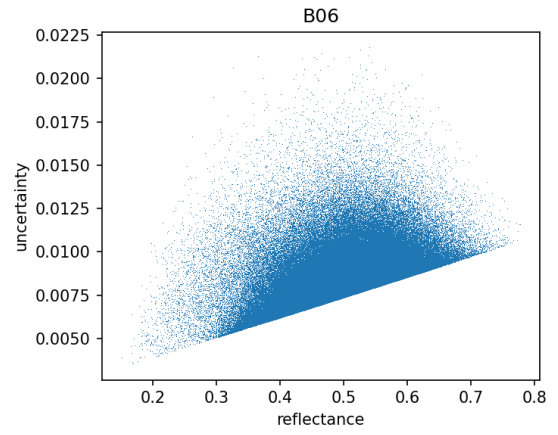
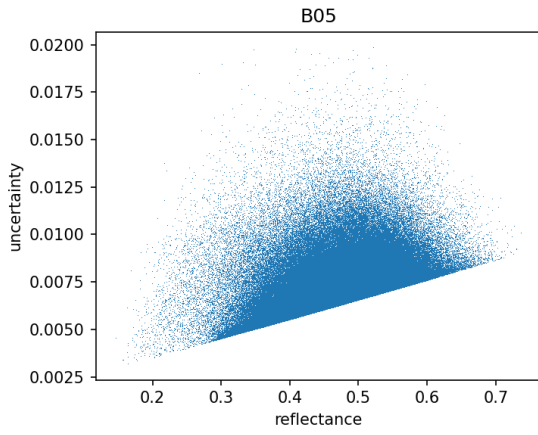


Figure 6: Desert scene per-pixel uncertainty (in %) per band. Colour scale is clipped to 98 percentile value of uncertainty to improve contrast





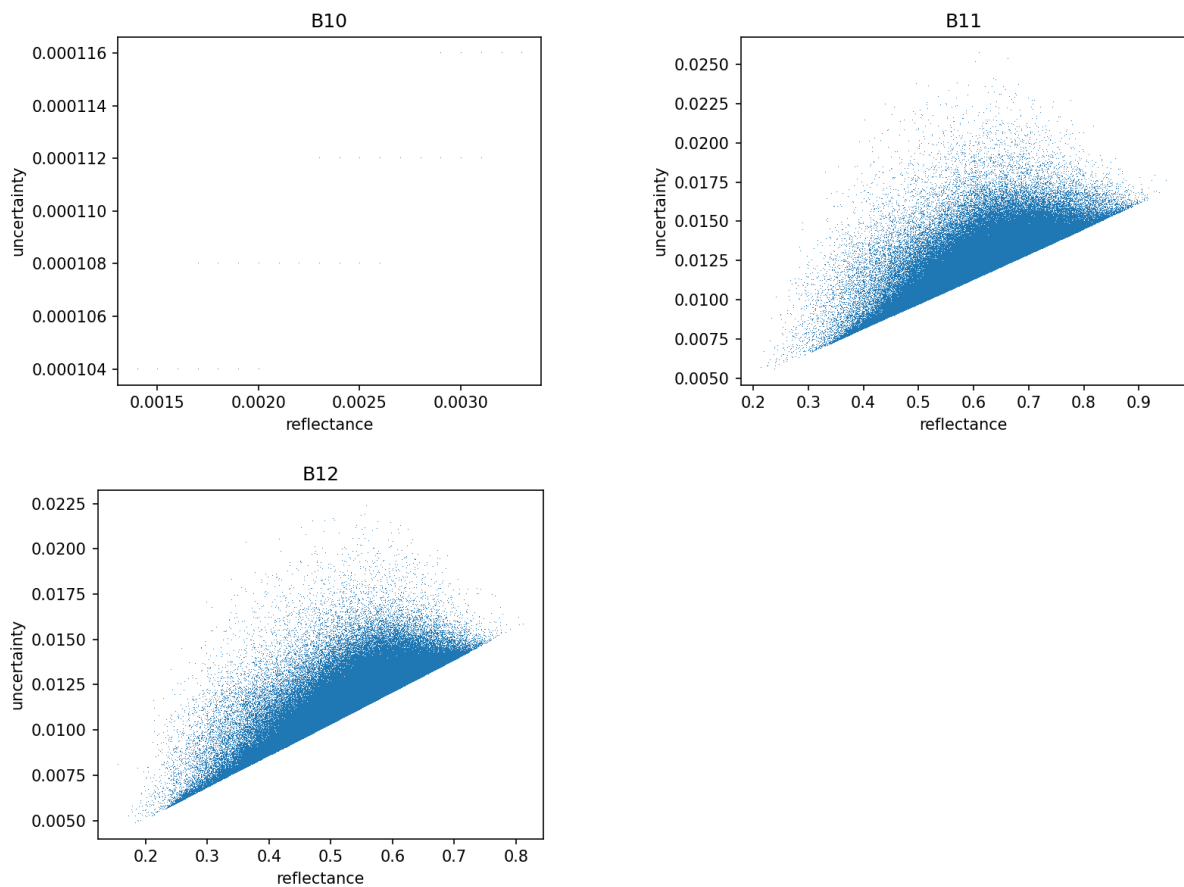


Figure 7: Desert scene, uncertainty (in absolute unit) versus reflectance scatter plot for each band

4.3 Vegetated scene

S2A_MSIL1C_20230208T103211_N0509_R108_T32UNB_20230208T141004.SAFE

Vegetated scene is an S2A acquisition over Germany from 2023-02-08. An RGB of the scene is presented in Figure 8.

Figure 9 presents the mean uncertainty over all pixel for each band, except B10. The total uncertainty is plotted in green, while blue and orange curves represent the random and systematic component of the uncertainty. Systematic part is composed mostly by out-of-field straylight estimated at 0.3% of the mean signal, which is clearly visible in this plot. Over vegetated scene the mean uncertainty remains below 3%.

Figure 10 represents the relative mean contribution of random and systematic to the total uncertainty. Random contributors represent around 80% of the total uncertainty for most of the bands.

The relative mean contribution of each random component to the total random uncertainty is presented in Figure 11. For each contributor, the mean over all pixel is computed and compare to the mean random uncertainty. Each relative contribution is then summed to obtain the bar plot. In the case of band 10, the approximation over all pixels is not working perfectly leading to a total sum lower than 100%, due to high difference of contribution between pixels. For other bands it shows that the diffuser remains a major contributor, but noise and geolocation terms are no longer negligible (in comparison to the same analysis on desert scene). The geolocation uncertainties are mostly impacting the high contrast feature of the scene, as the edge of road and fields. As an example, the Figure 12 presents the full image per-pixel uncertainties of each component of band 04.

Full images uncertainties for each band are given in Figure 13 while Figure 14 presents the scatter plot between the uncertainty in absolute unite (i.e. reflectance dimension) and the reflectance. A clear pattern is visible with a minimal value for uncertainty linked to the reflectance of the pixel. The vegetated scene presents a very large range of reflectances, with a mean value rather low but with very reflective pixel reaching a reflectance above 2, this example show very well that uncertainties do not reach outlier physical values, even if they reach very high percentage of low radiance pixel. For B10 the value, both for reflectance and uncertainty, seems to be too discrete to obtain a coherent scatter plot.



Figure 8: Vegetated scene RGB image

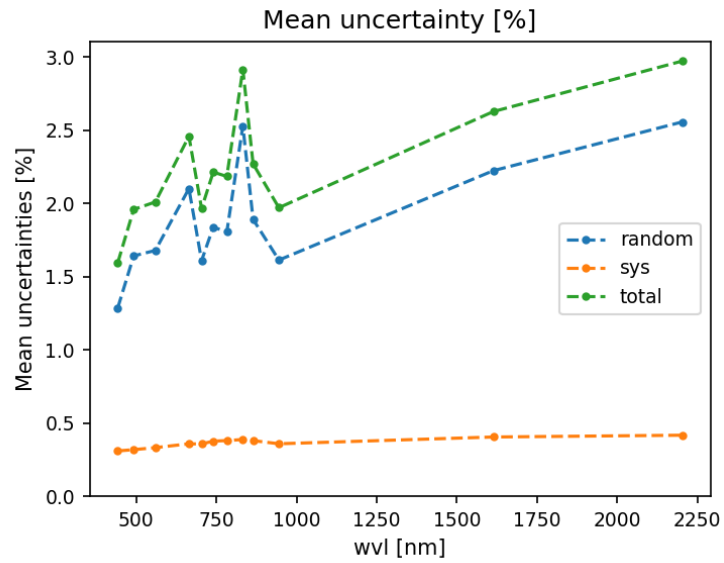


Figure 9: Vegetated scene mean uncertainty per band in percentage. Green is the total uncertainty, blue the random components and orange the systematics components. (B10 excluded)

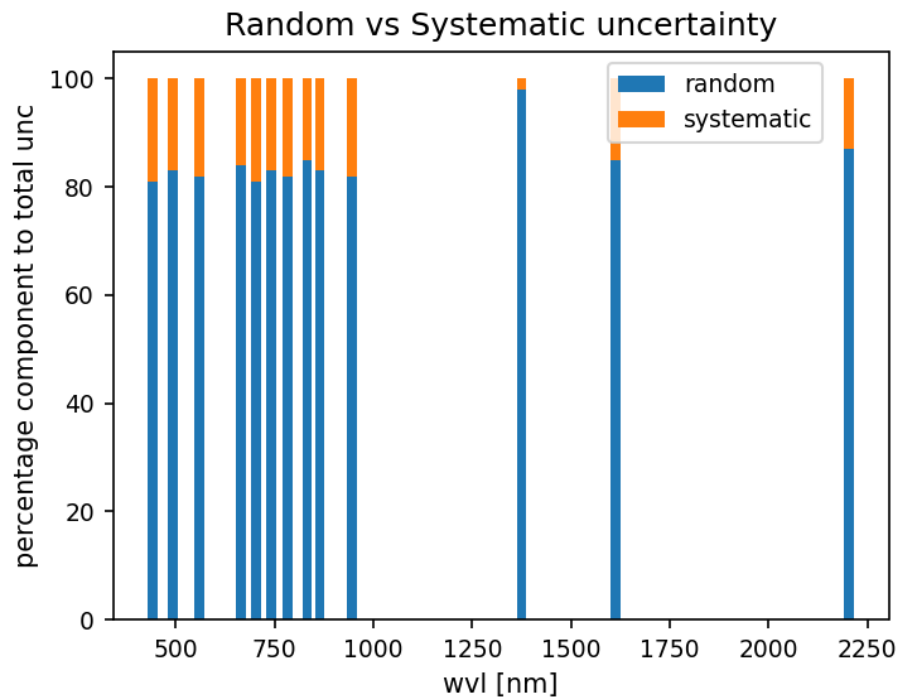


Figure 10: vegetated scene random and systematic relative mean contribution to total uncertainty

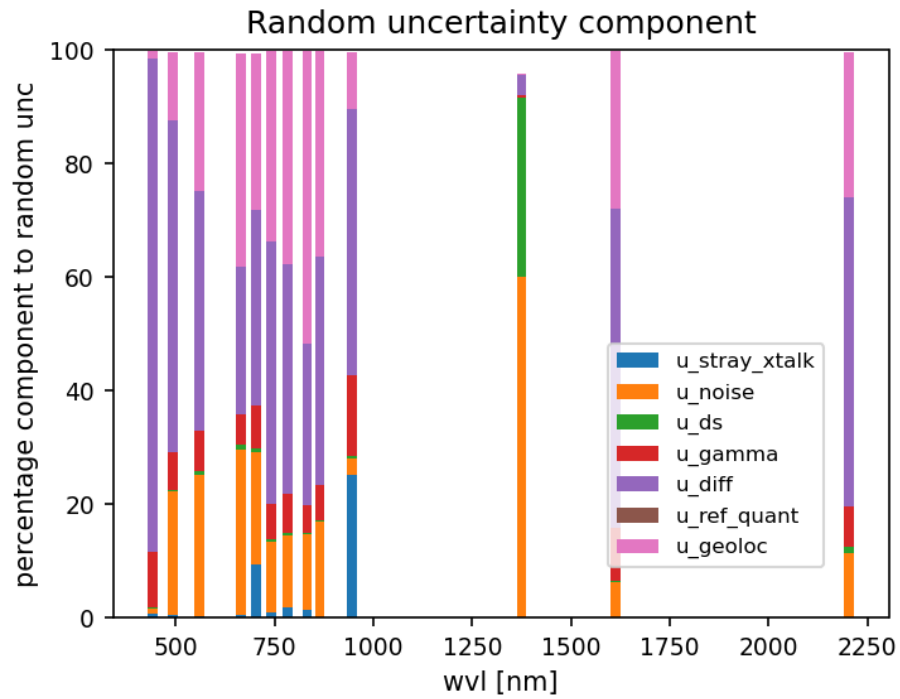


Figure 11: Vegetated scene random components relative mean contribution to RANDOM uncertainty. (B10 mean approximation over full-image is not 100% due to high difference of contribution between pixels)

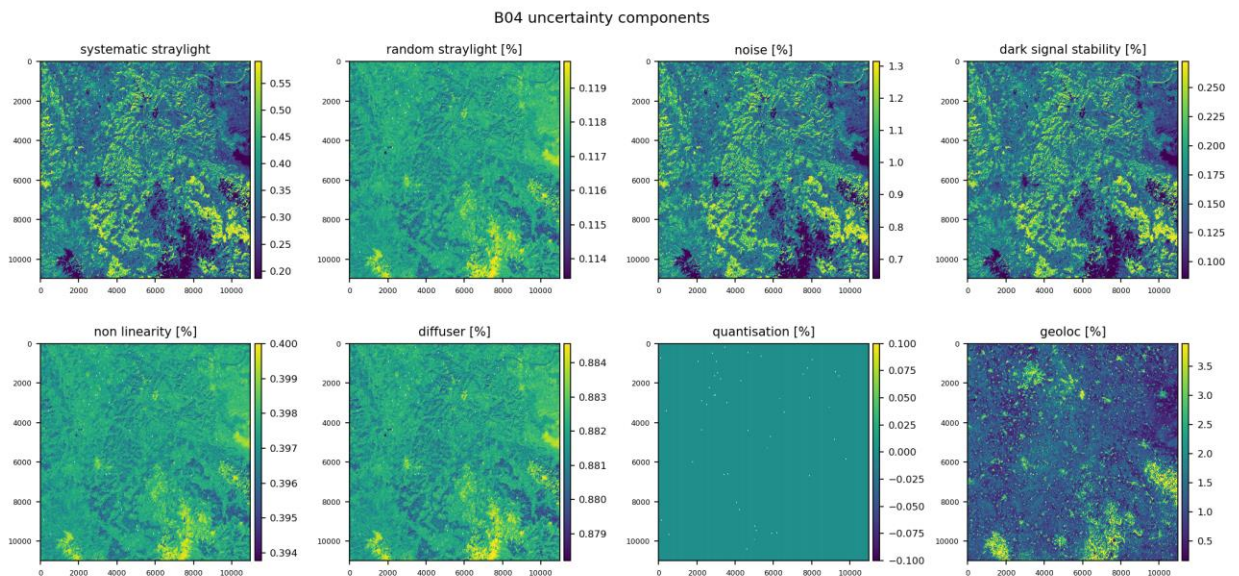
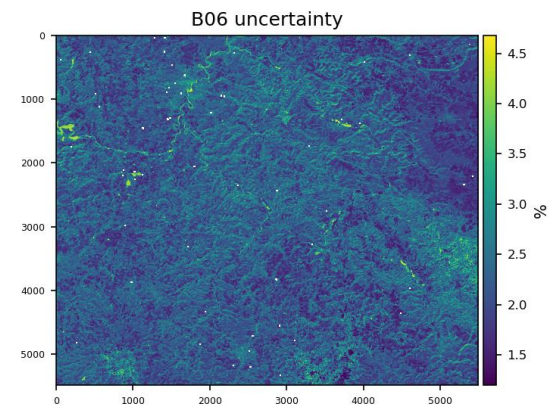
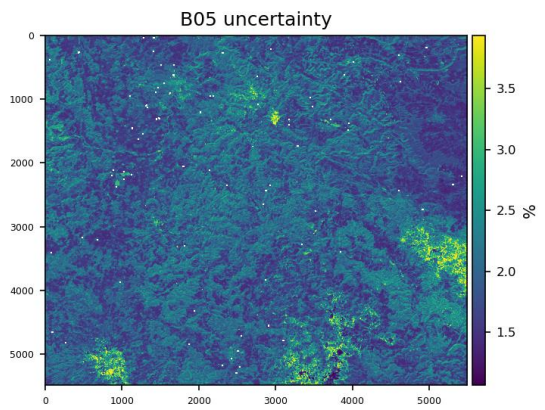
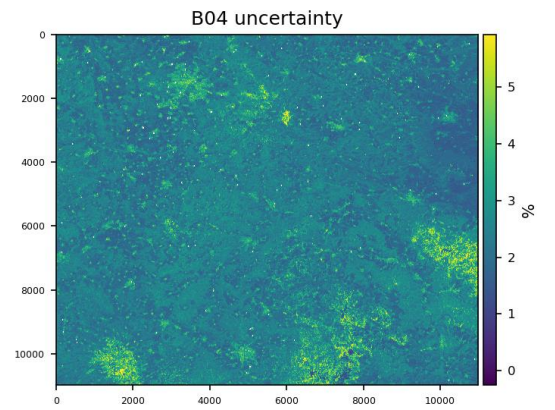
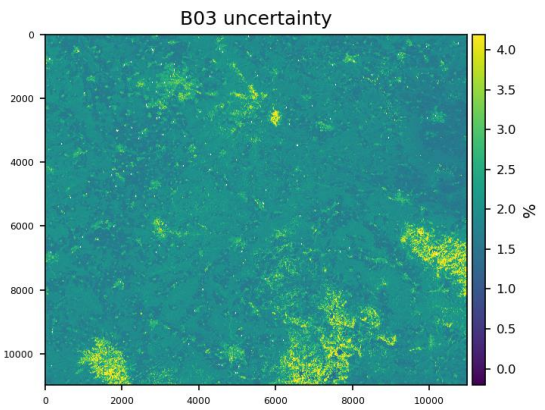
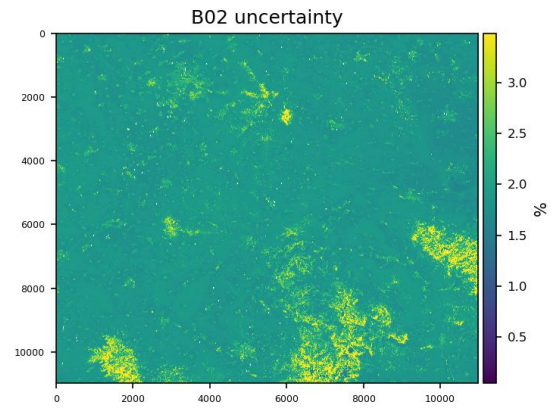
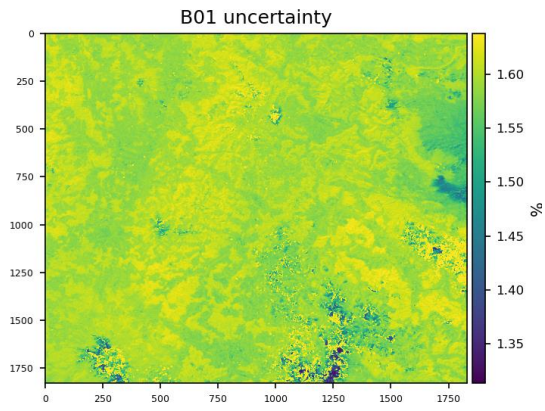
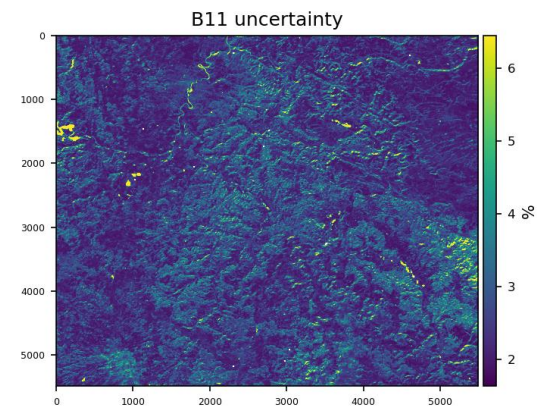
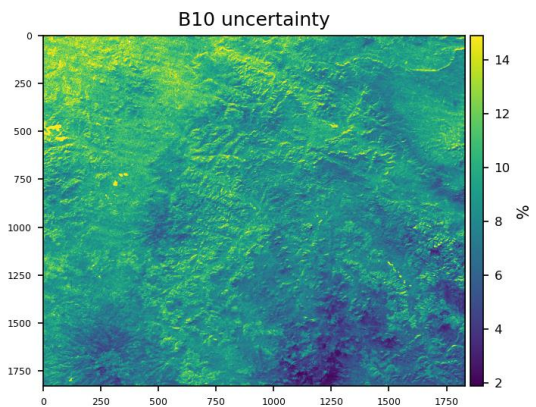
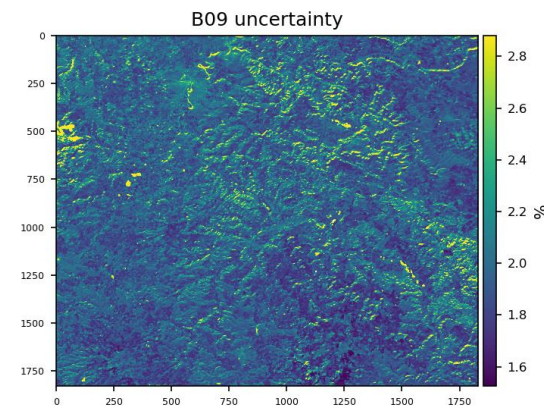
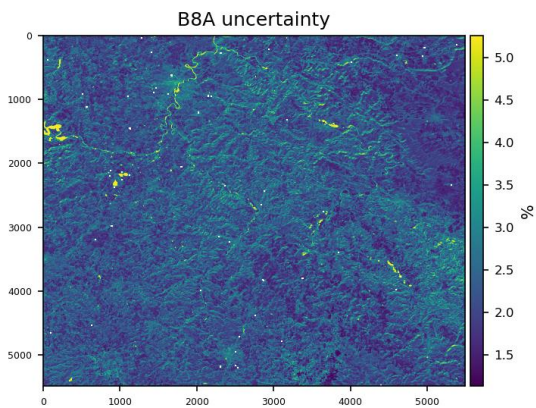
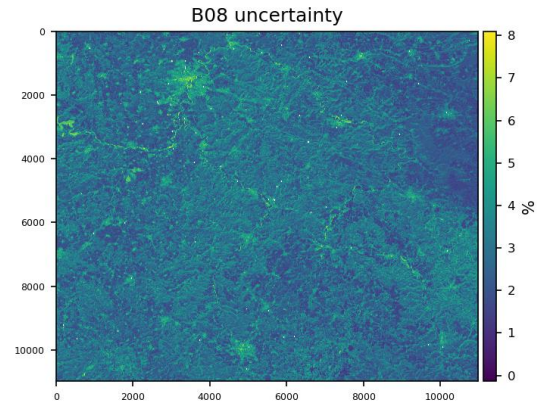
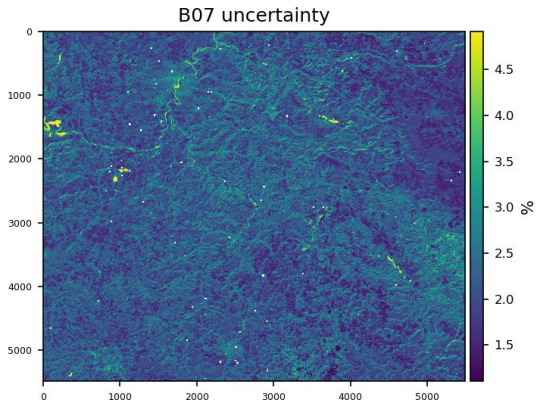


Figure 12: Vegetated scene, B04 components full image uncertainty in %





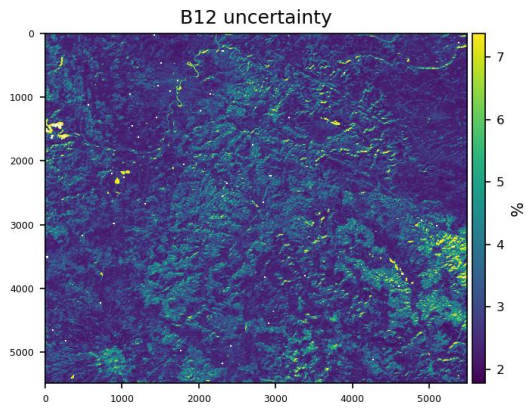
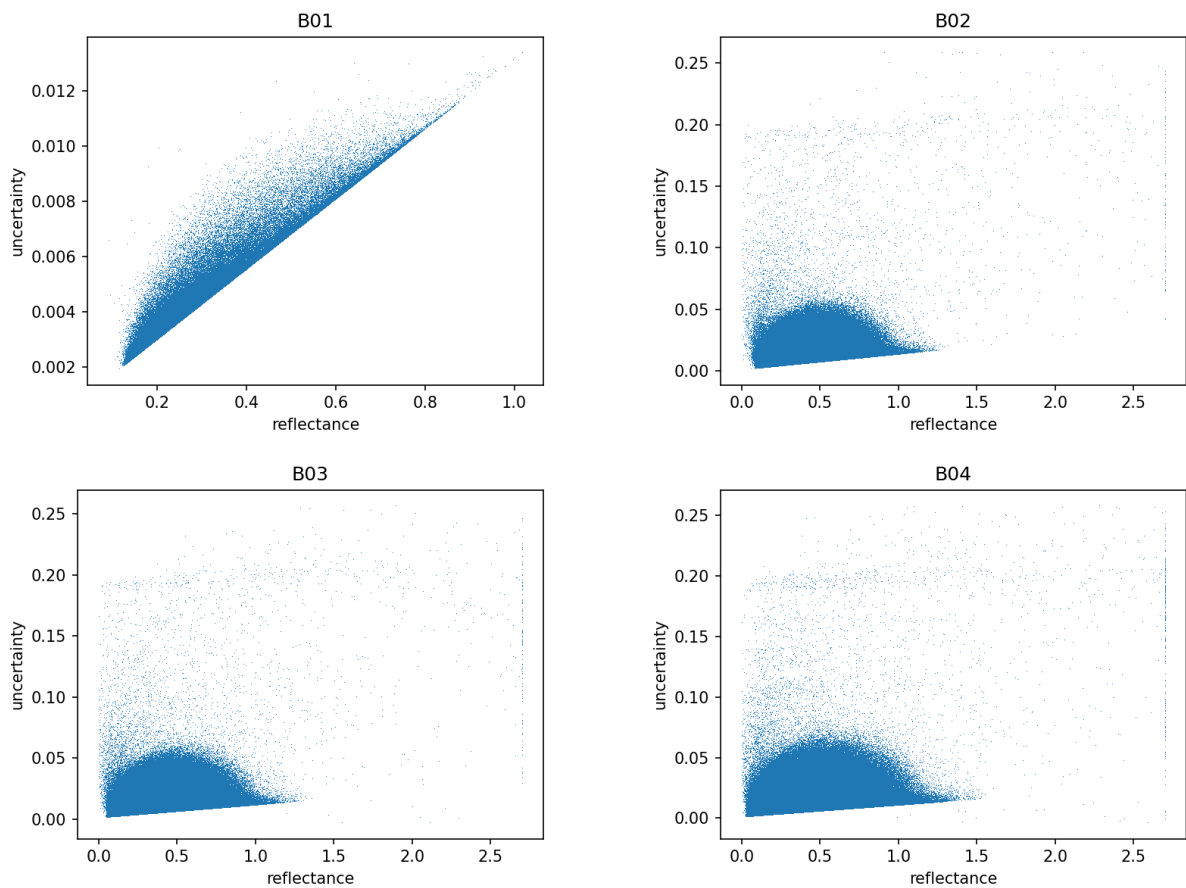
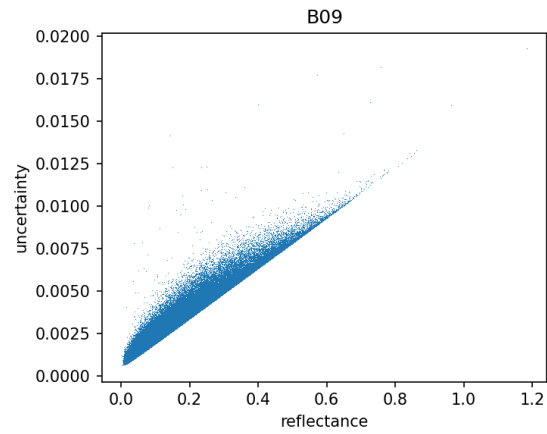
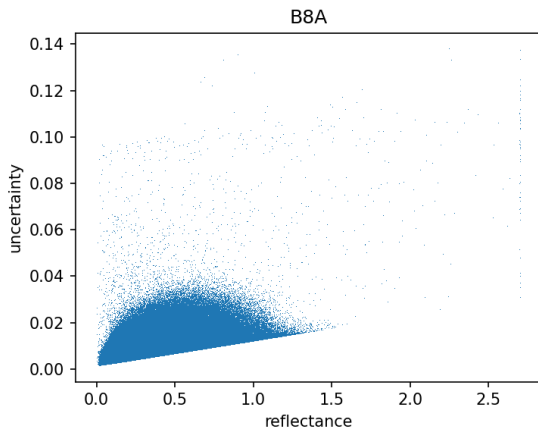
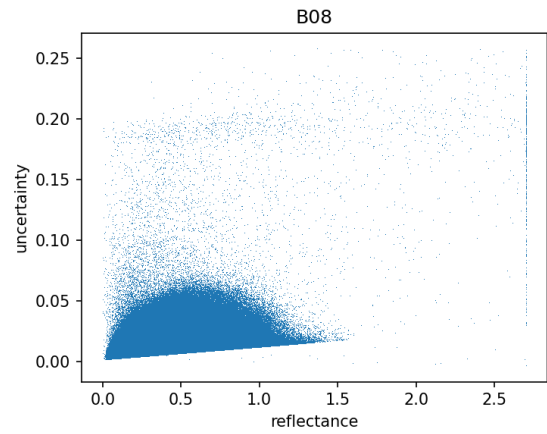
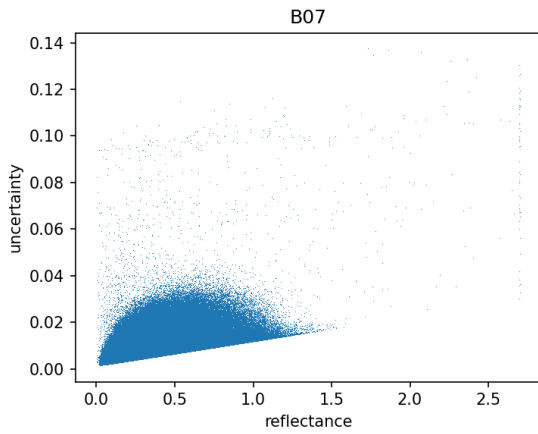
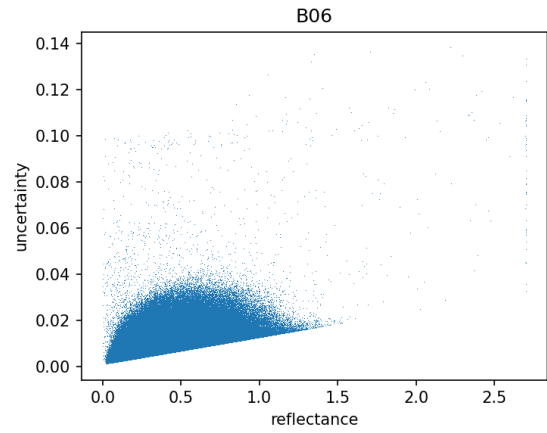
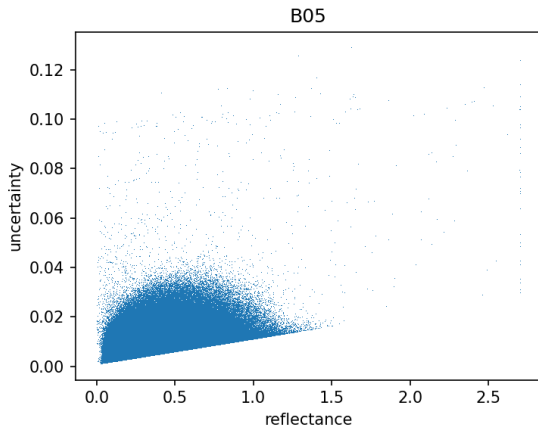


Figure 13: vegetated scene per-pixel uncertainty (in %) per band. Colour scale is clipped to 98 percentile value of uncertainty to improve contrast





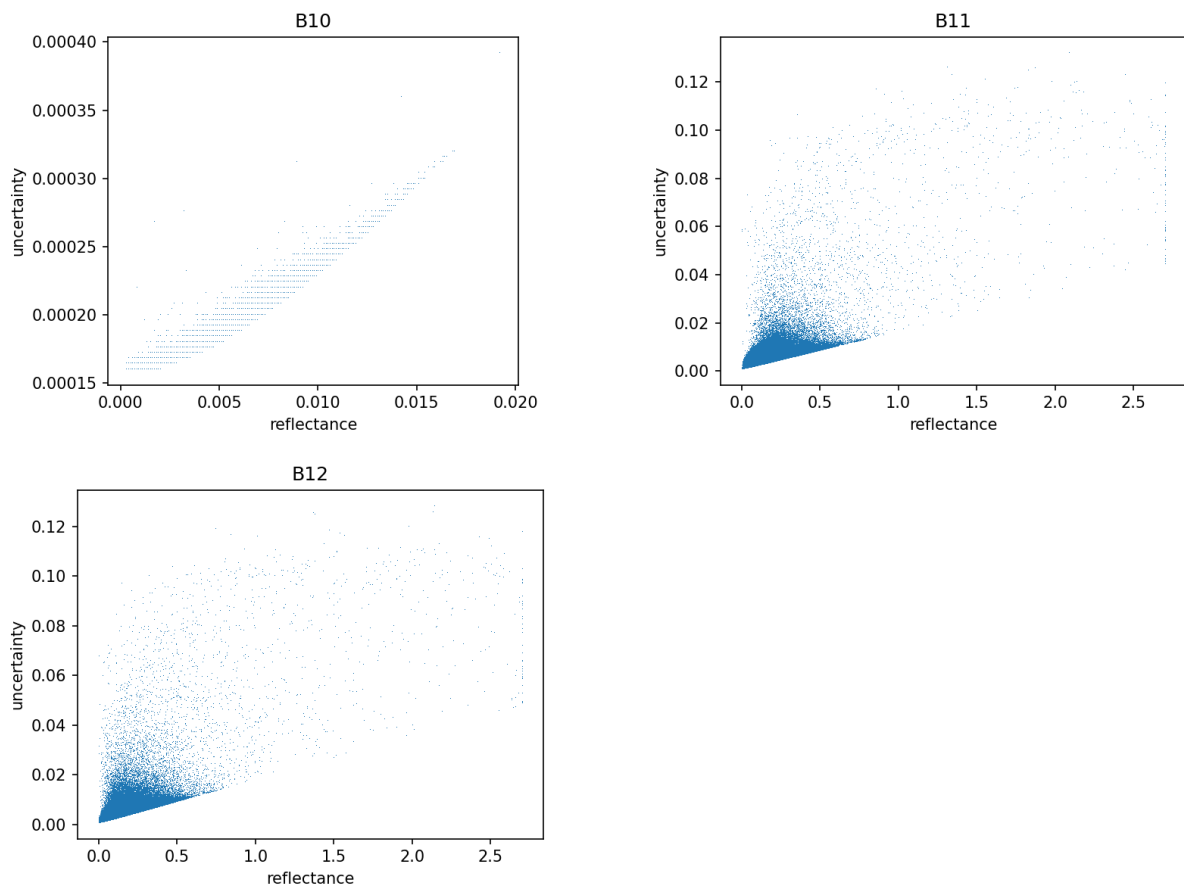


Figure 14: Vegetated scene, uncertainty (in absolute unit) versus reflectance scatter plot for each band

4.4 Water scene

S2A_MSIL1C_20241112T021931_N0511_R003_T51PVS_20241112T041208.SAFE

Water scene is an S2A acquisition over Philippine from 2024-11-12. An RGB of the scene is presented in Figure 15.

Figure 16 presents the mean uncertainty over all pixel for each band, except B10. The total uncertainty is plotted in green, while blue and orange curves represent the random and systematic component of the uncertainty. Systematic part is composed mostly by out-of-field straylight estimated at 0.3% of the mean signal, which is clearly visible in this plot. Over water scene the mean uncertainty remains below 3% for visible bands and increase up to 4% in the SWIR.

Figure 17 represents the relative mean contribution of random and systematic to the total uncertainty. Random contributors represent around 80% of the total uncertainty for most of the bands.

The relative mean contribution of each random component to the total random uncertainty is presented in Figure 18. For each contributor, the mean over all pixel is computed and compare to the mean random uncertainty. Each relative contribution is then summed to obtain the bar plot. In the case of band 9 and 10, the approximation over all pixels is not working perfectly leading to a total sum lower than 100%, due to high difference of contribution between pixels. For other bands it shows that if the diffuser remains a major contributor in the blue bands, the noise contributor becomes predominant for higher wavelength. As an example, the Figure 19 presents the full image per-pixel uncertainties of each component of band 04.

Full images uncertainties for each band are given in Figure 20 while Figure 21 presents the scatter plot between the uncertainty in absolute unite (i.e. reflectance dimension) and the reflectance. A clear pattern is visible with a minimal value for uncertainty linked to the reflectance of the pixel. For B10 the value, both for reflectance and uncertainty, seems to be too discrete to obtain a coherent scatter plot.

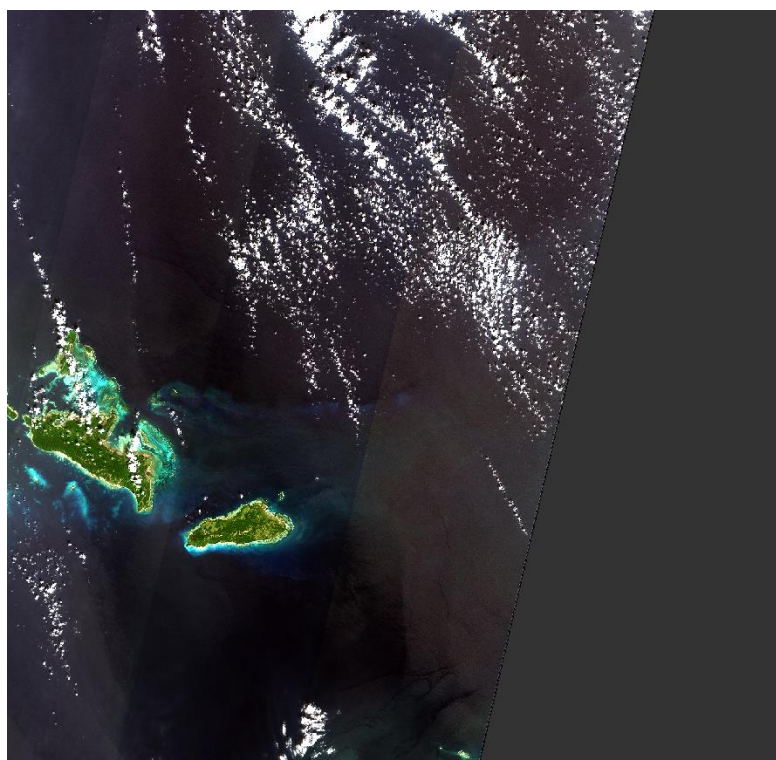


Figure 15: Water scene RGB image

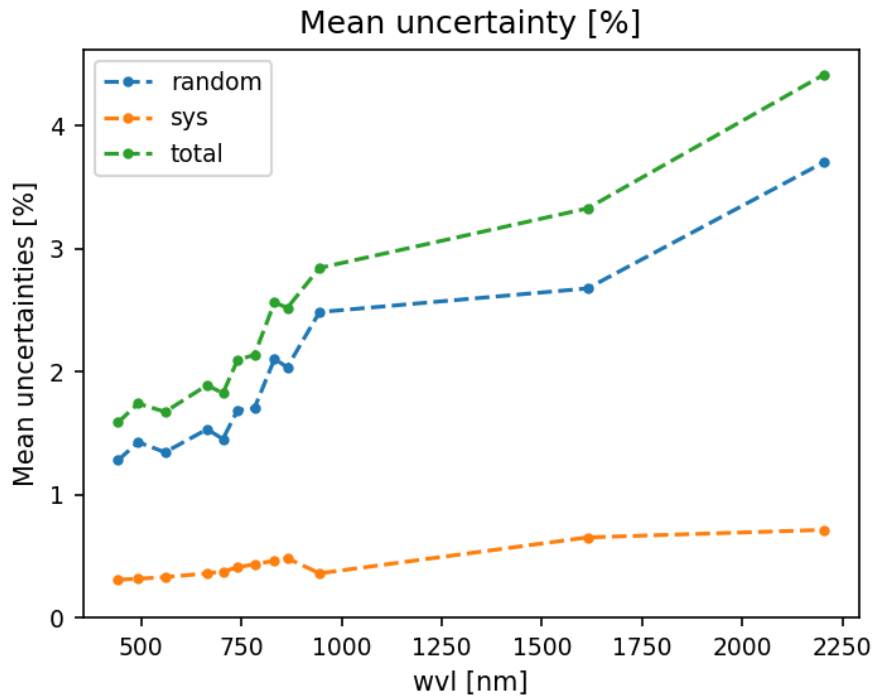


Figure 16: water scene mean uncertainty per band in percentage. Green is the total uncertainty, blue the random components and orange the systematics components. (B10 excluded)

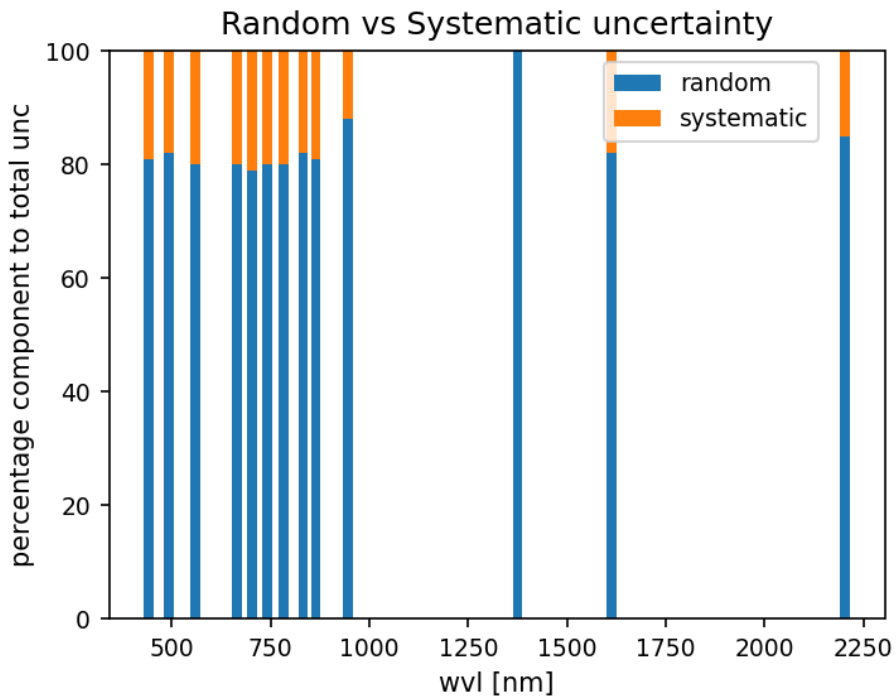


Figure 17: water scene random and systematic relative mean contribution to total uncertainty

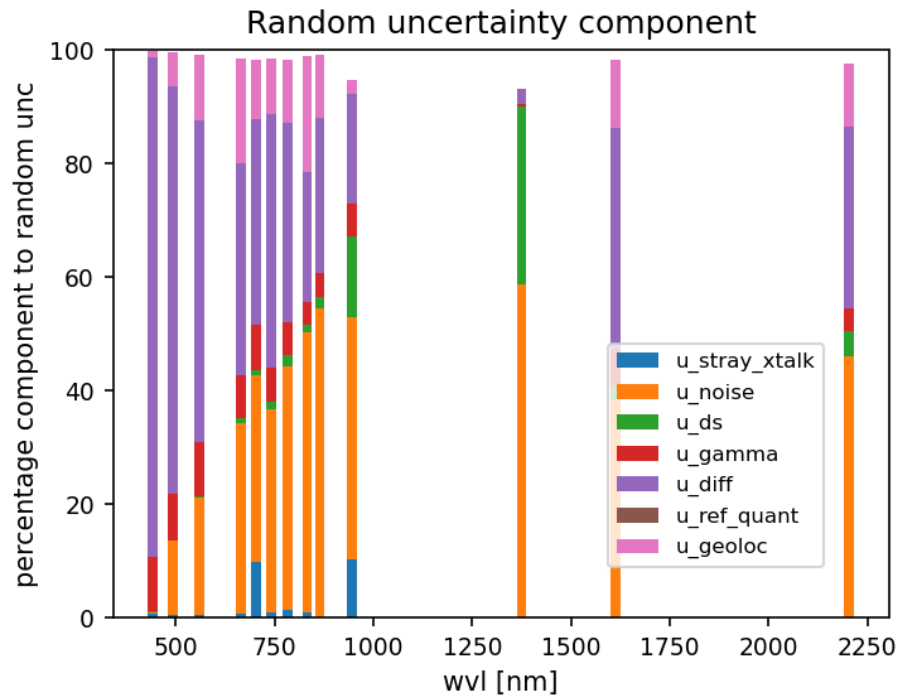


Figure 18: water scene random components relative mean contribution to RANDOM uncertainty. (B09 & B10 mean approximation over full-image is not 100% due to high difference of contribution between pixels)

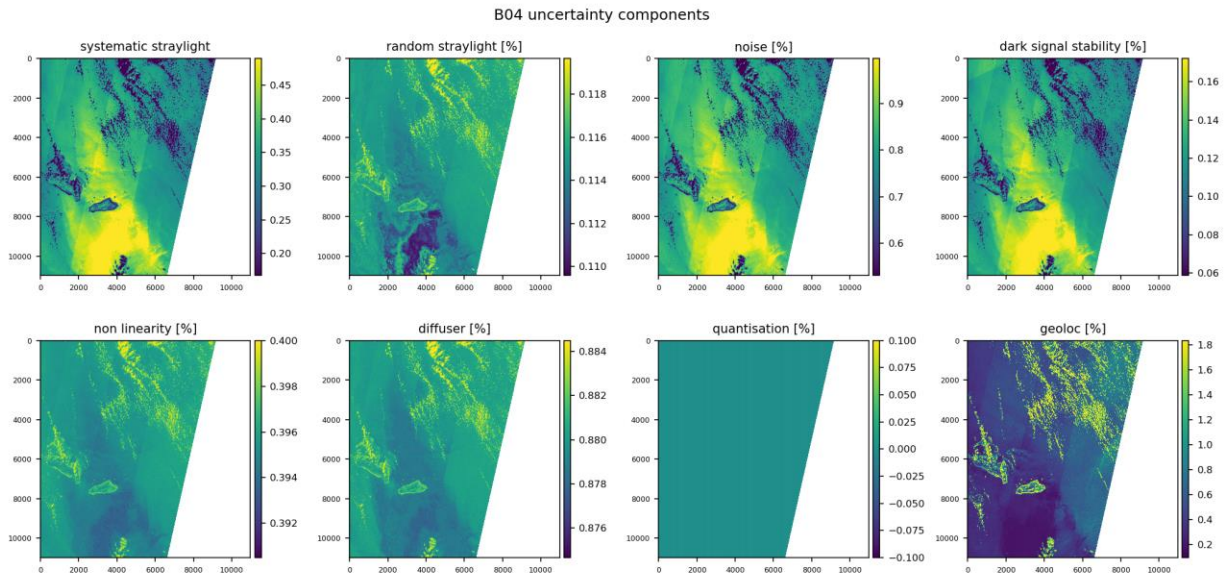
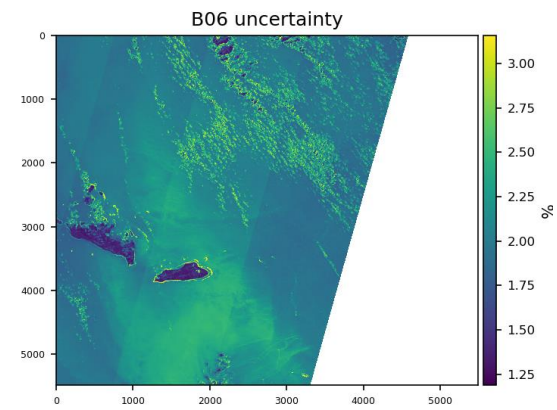
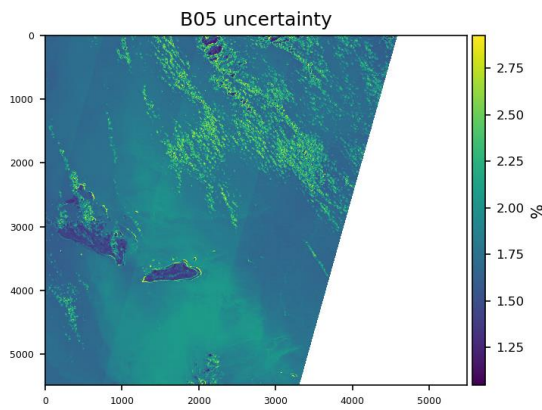
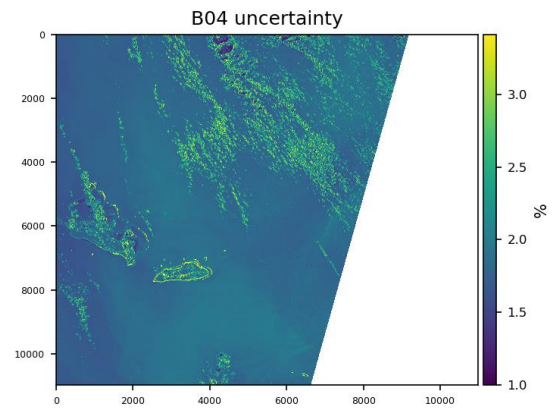
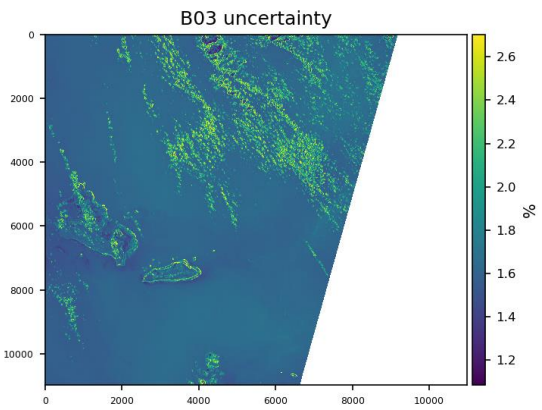
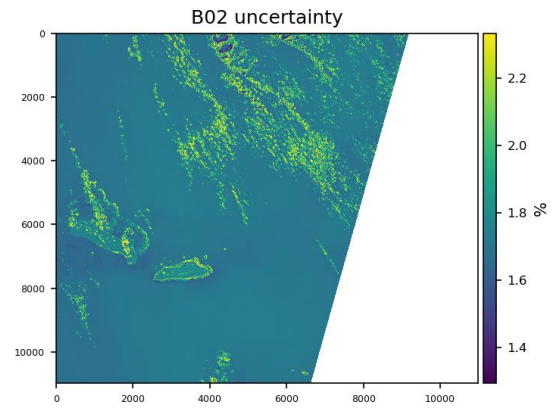
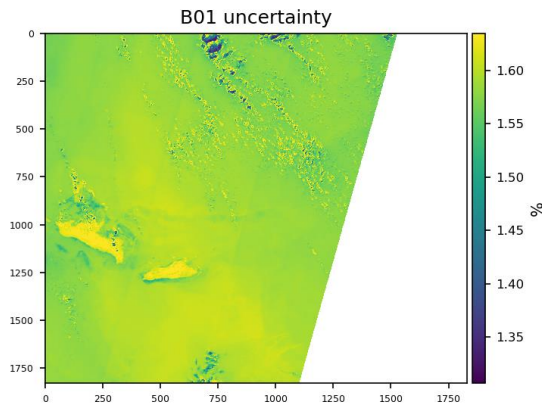
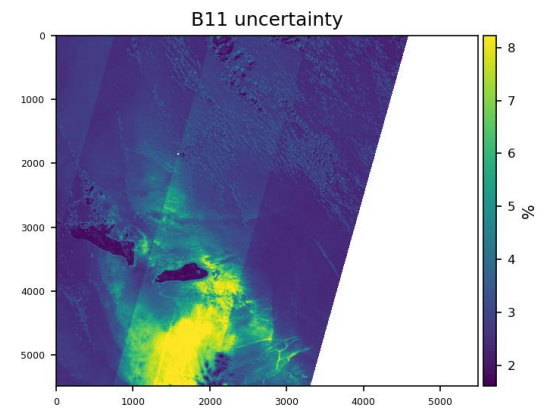
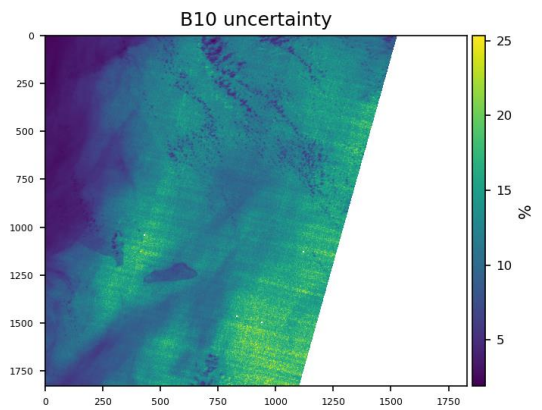
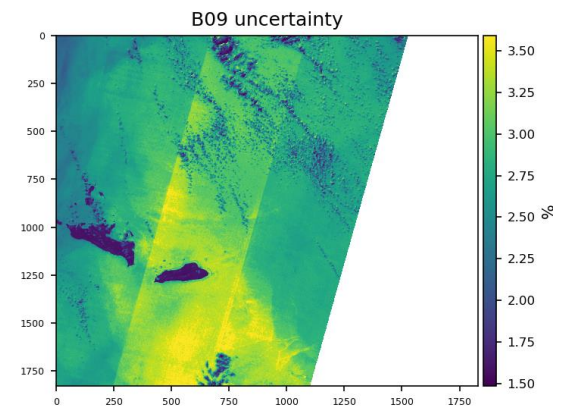
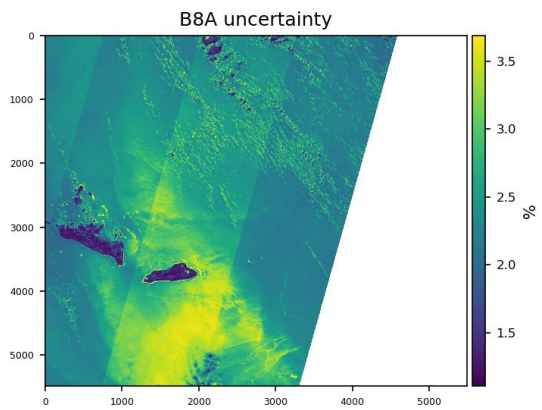
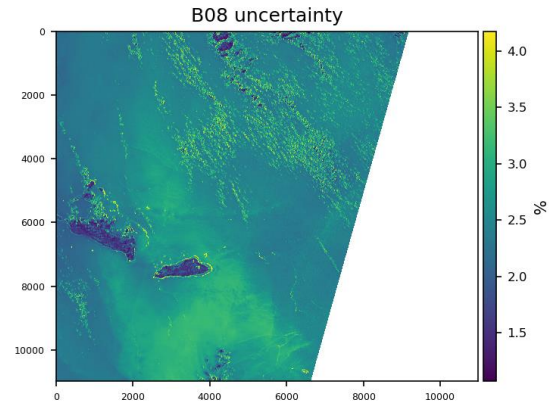
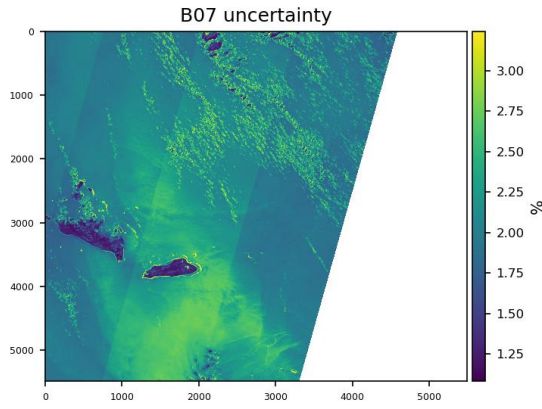


Figure 19: water scene, B04 components full image uncertainty in %





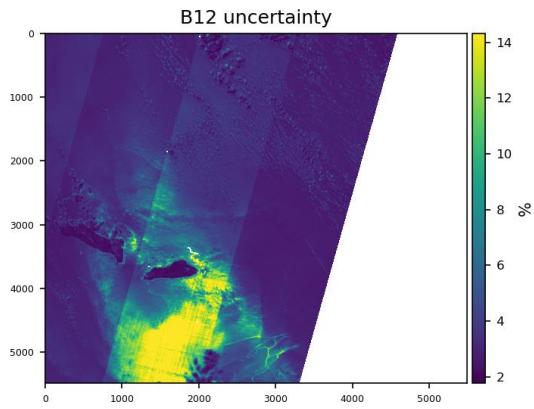
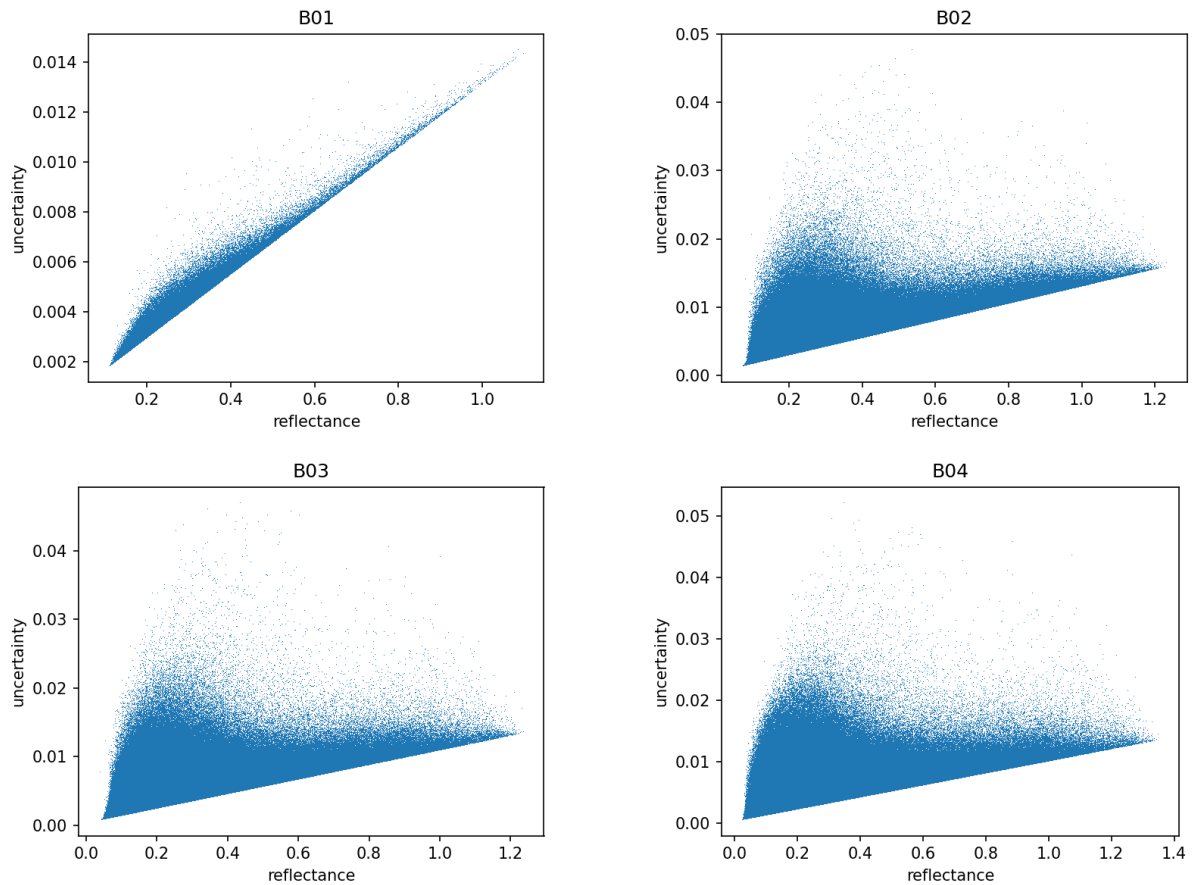
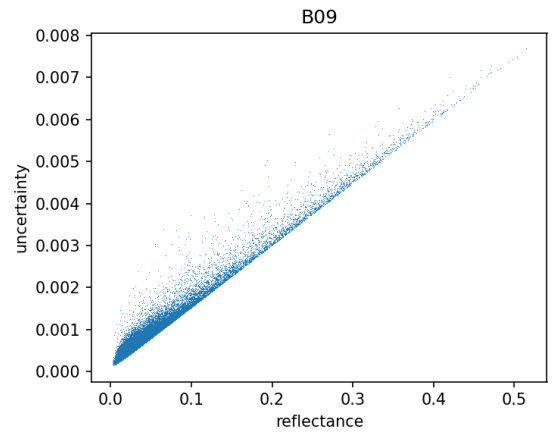
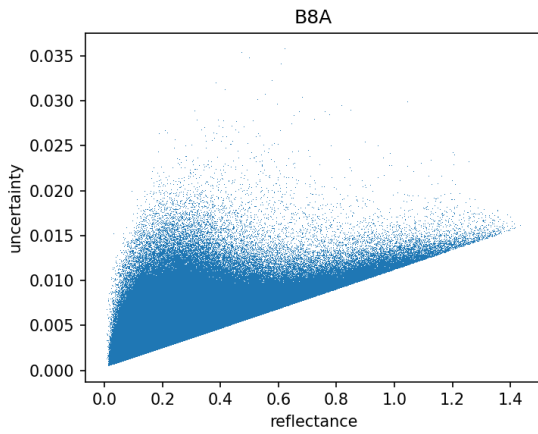
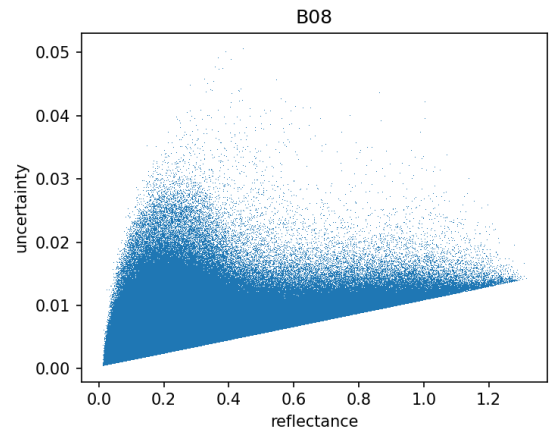
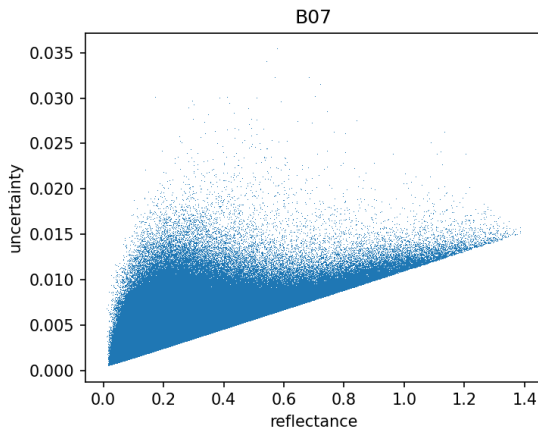
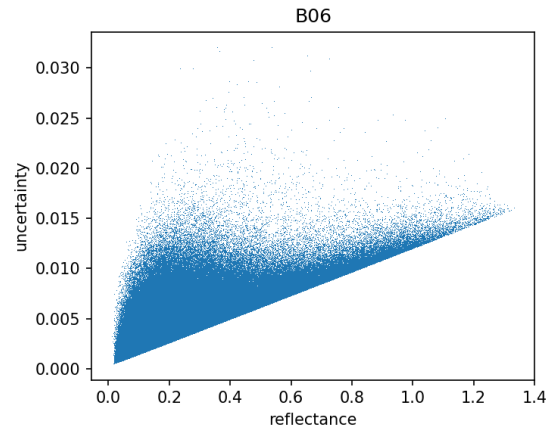
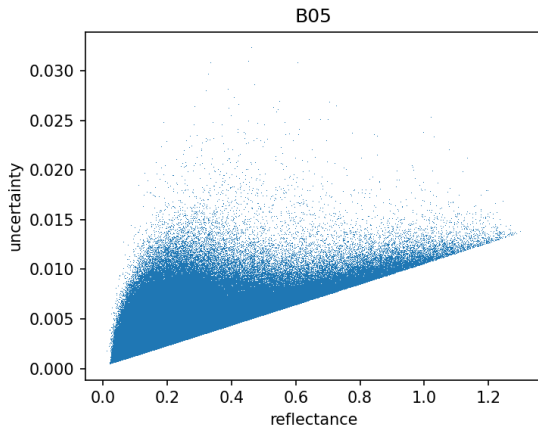


Figure 20: water scene per-pixel uncertainty (in %) per band. Colour scale is clipped to 98 percentile value of uncertainty to improve contrast





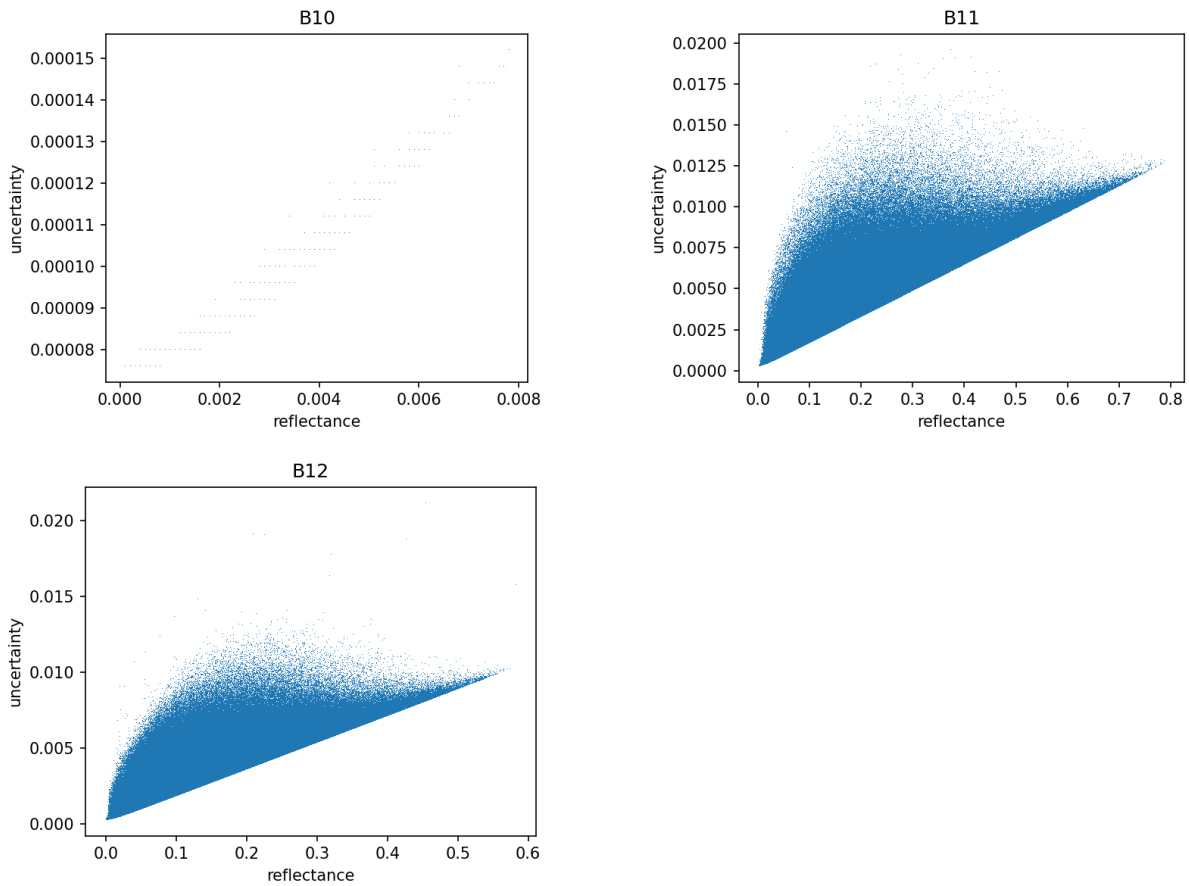


Figure 21: water scene, uncertainty (in absolute unit) versus reflectance scatter plot for each band

4.5 Snow scene

S2A_MSIL1C_20250115T052151_N0511_R062_T44SPC_20250115T061803.SAFE

Snow scene is an S2A acquisition over Tibet from 2025-01-15. An RGB of the scene is presented in Figure 22.

Figure 23 presents the mean uncertainty over all pixel for each band, except B10. The total uncertainty is plotted in green, while blue and orange curves represent the random and systematic component of the uncertainty. Systematic part is composed mostly by out-of-field straylight estimated at 0.3% of the mean signal, which is clearly visible in this plot. Over snow scene the mean uncertainty remains below 3% for all the bands

Figure 24 represents the relative mean contribution of random and systematic to the total uncertainty. Random contributors represent around 80% of the total uncertainty for most of the bands.

The relative mean contribution of each random component to the total random uncertainty is presented in Figure 25. For each contributor, the mean over all pixel is computed and compare to the mean random uncertainty. Each relative contribution is then summed to obtain the bar plot. It shows that if the diffuser and geolocation are 2 major contributors. As an example, the Figure 26 presents the full image per-pixel uncertainties of each component of band 04.

Full images uncertainties for each band are given in Figure 27 while Figure 28 presents the scatter plot between the uncertainty in absolute unite (i.e. reflectance dimension) and the reflectance. A clear pattern is visible with a minimal value for uncertainty linked to the reflectance of the pixel. This scene being at a higher altitude than other test scene, the B10 value are less impacted by water vapour. The range of reflectance value is wider, and the associated uncertainty is no impacted by the discretization. The B10 scatter plot appears coherent with other bands.

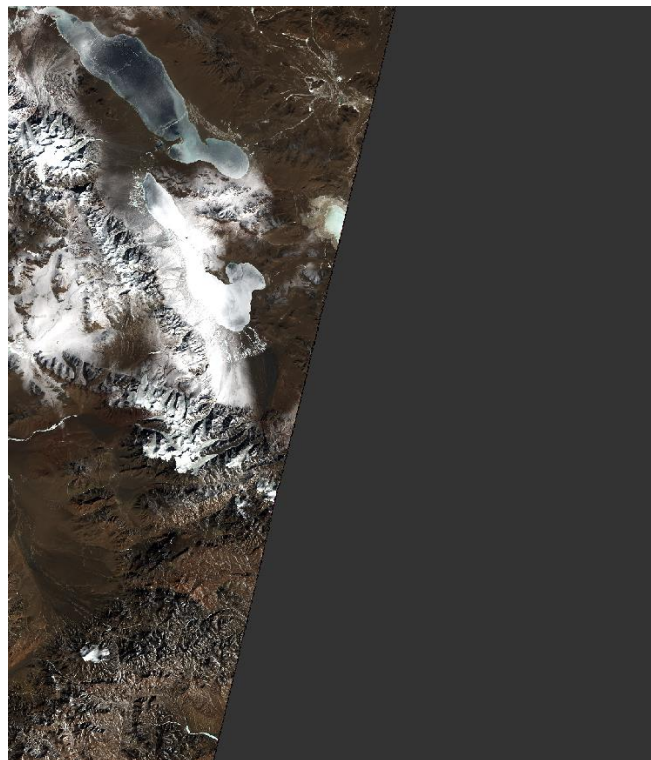


Figure 22: Snow scene RGB image

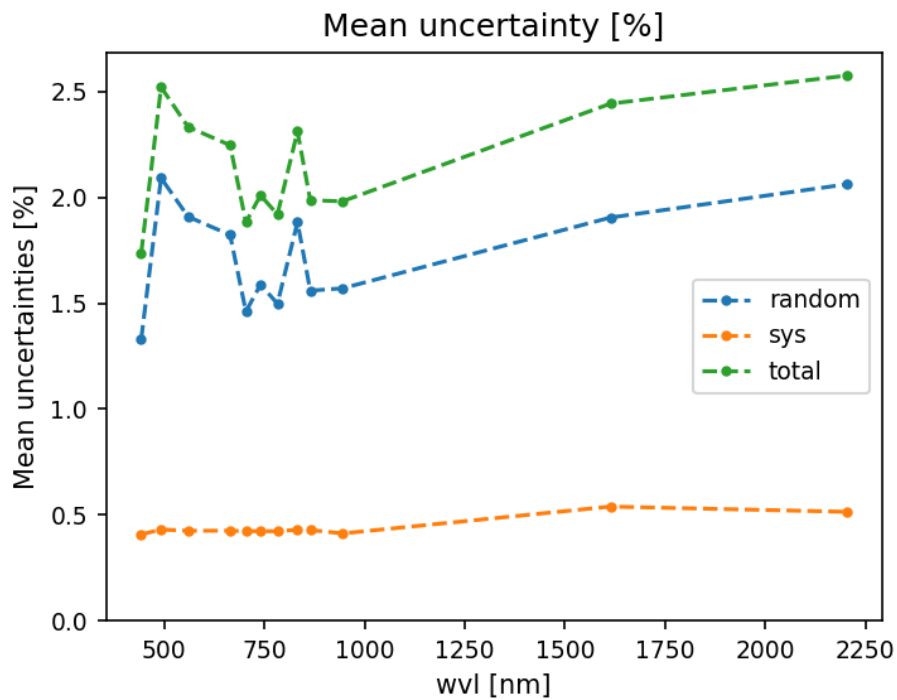


Figure 23: snow scene mean uncertainty per band in percentage. Green is the total uncertainty, blue the random components and orange the systematics components. (B10 excluded)

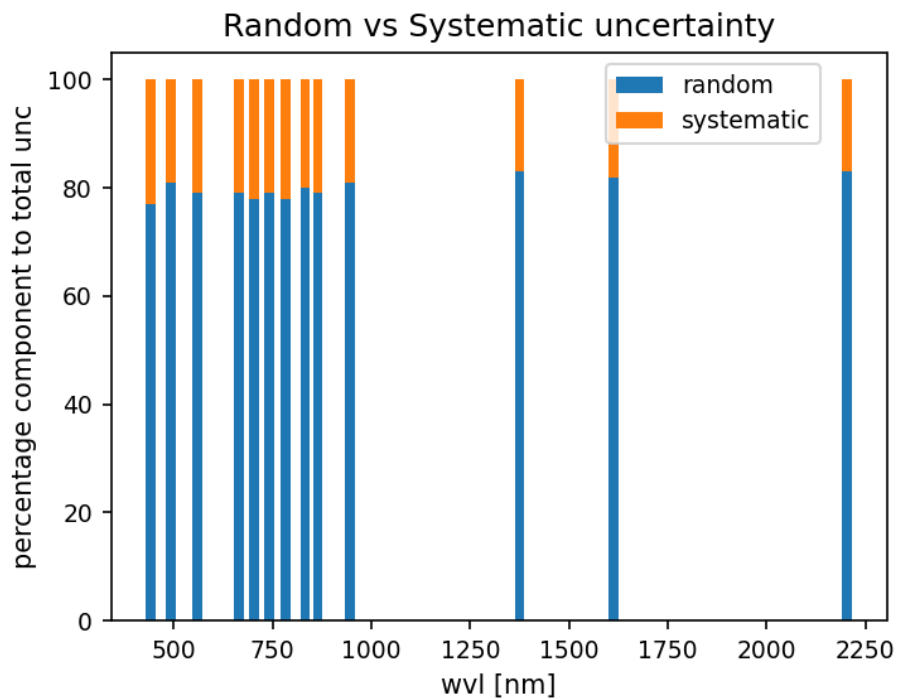


Figure 24: snow scene random and systematic relative mean contribution to total uncertainty

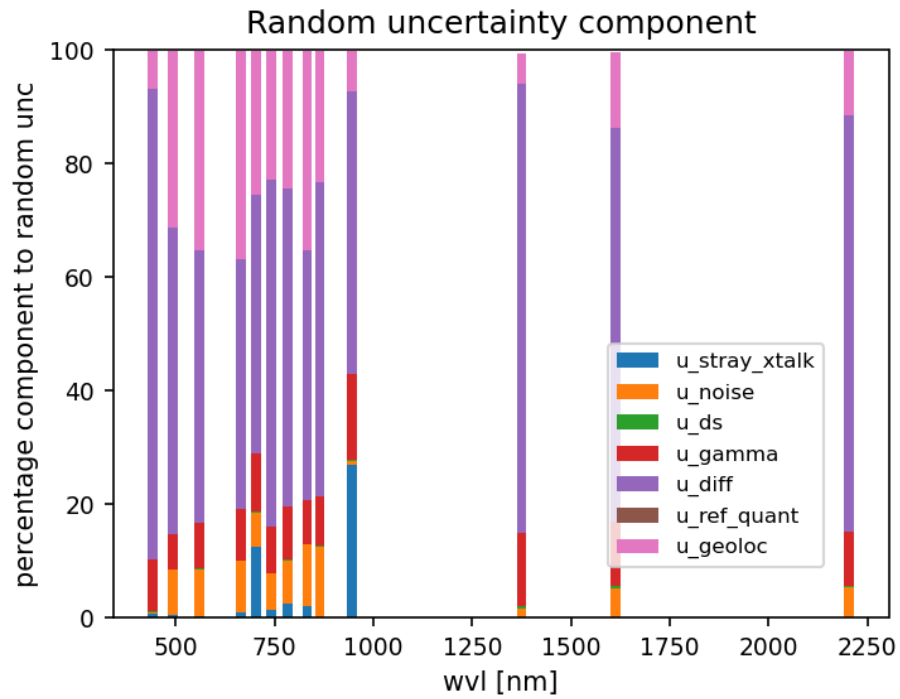


Figure 25: snow scene random components relative mean contribution to RANDOM uncertainty.

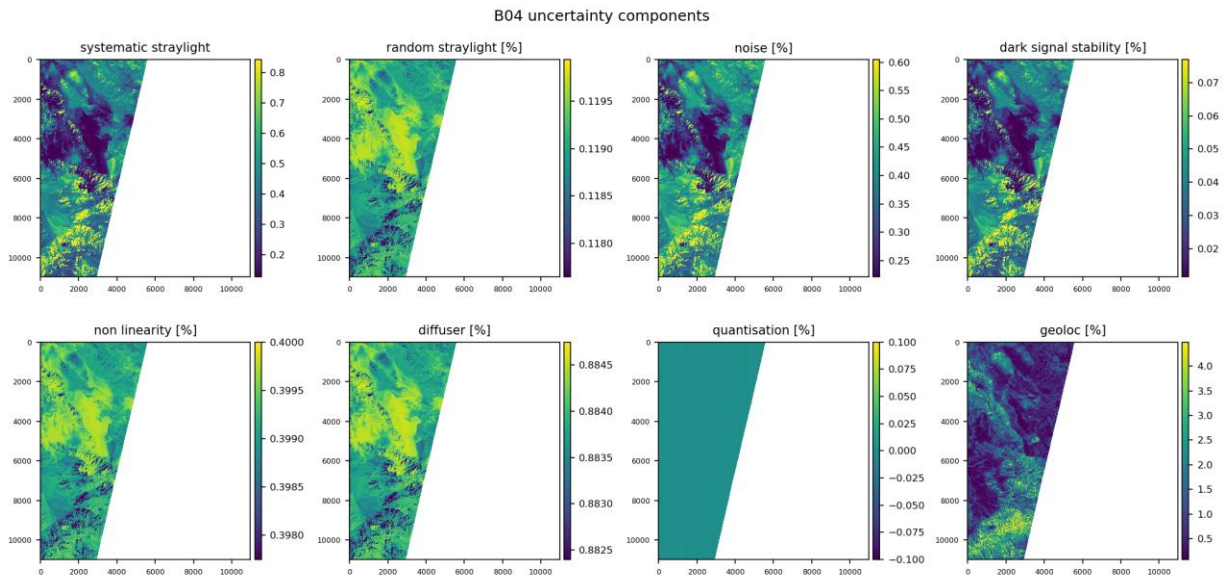
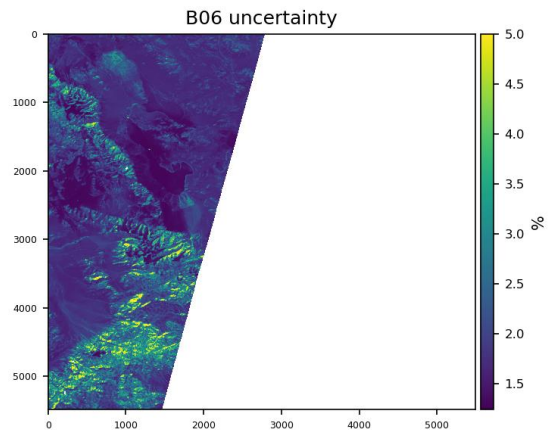
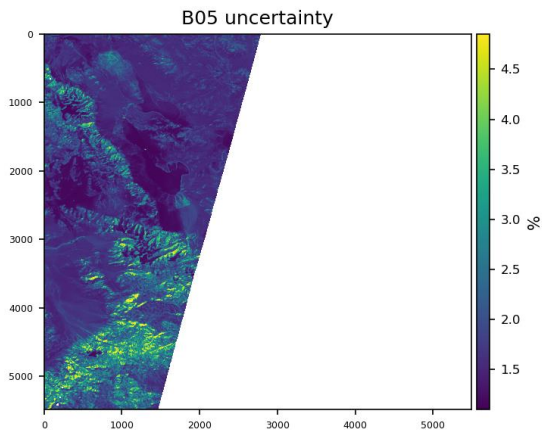
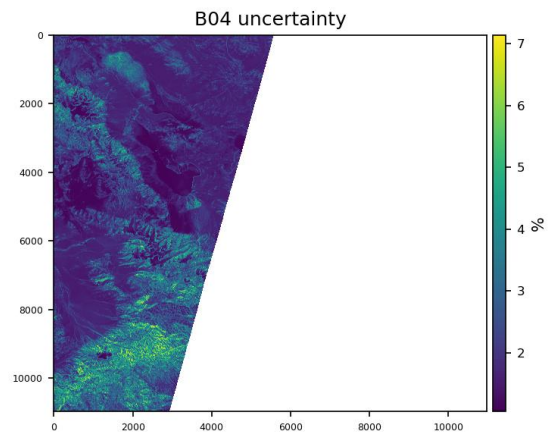
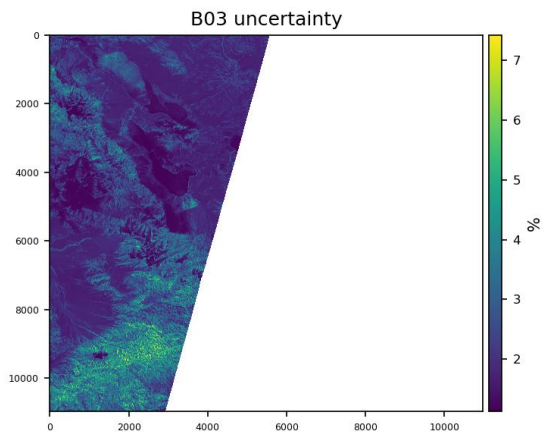
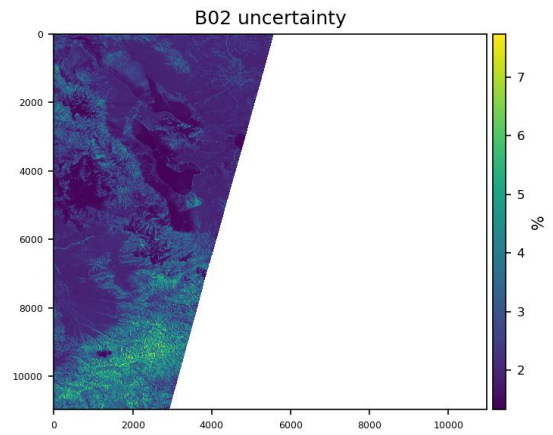
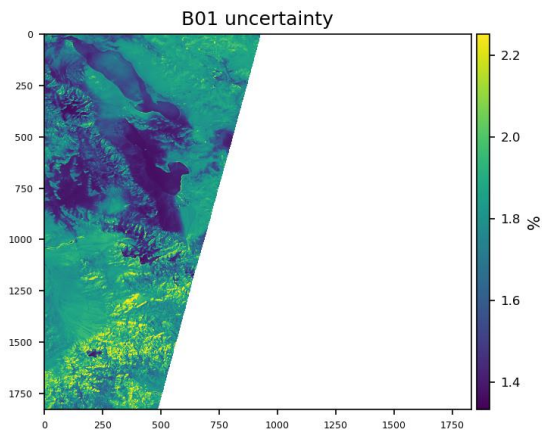
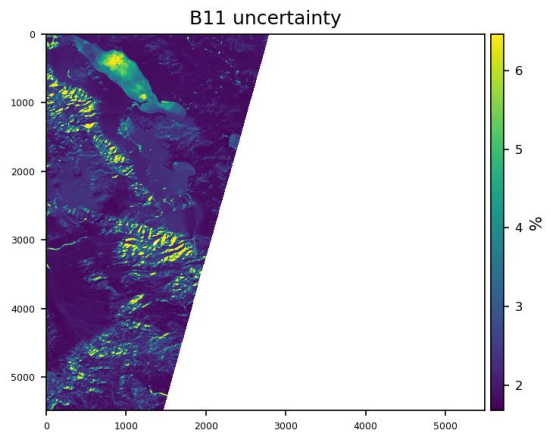
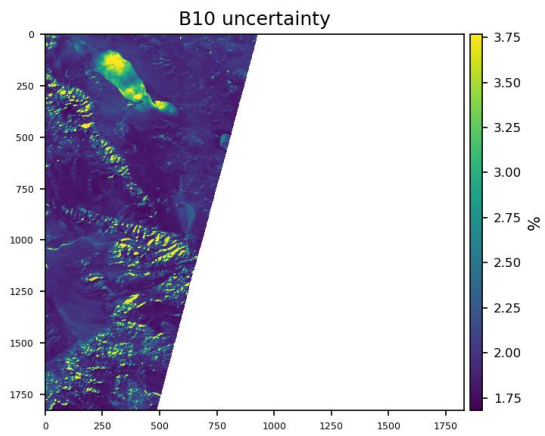
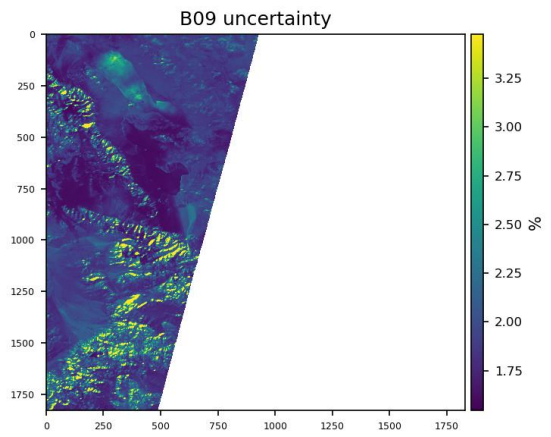
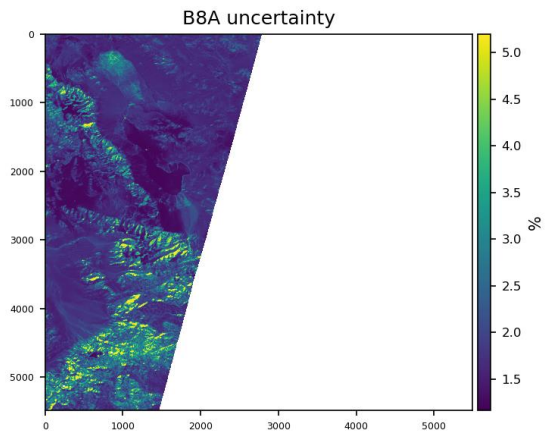
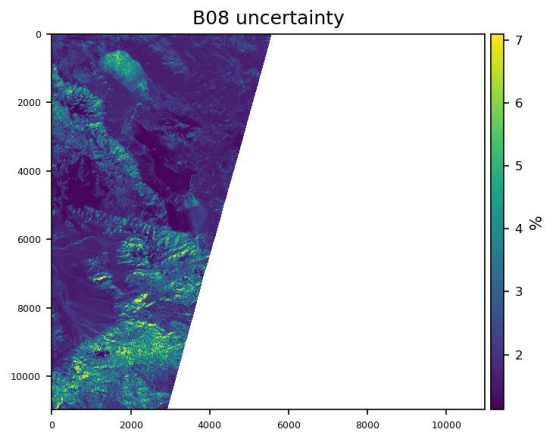
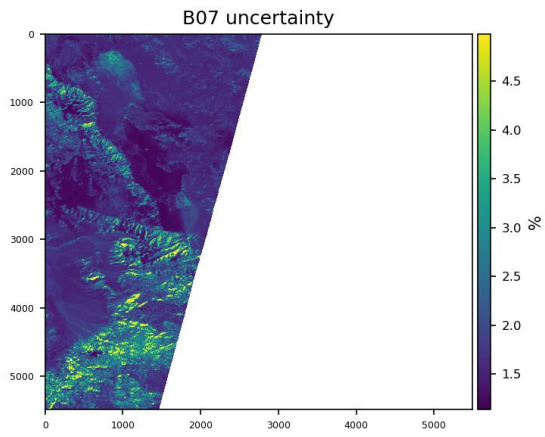


Figure 26: snow scene, B04 components full image uncertainty in %





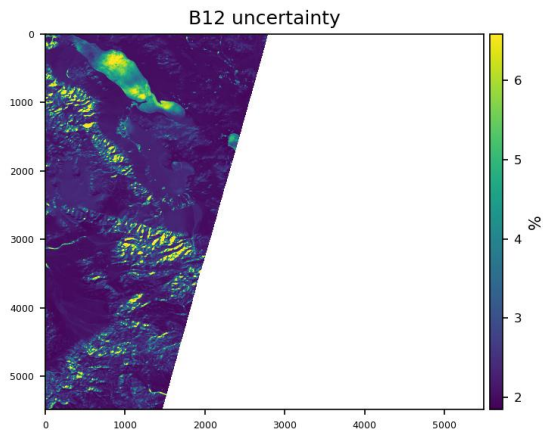
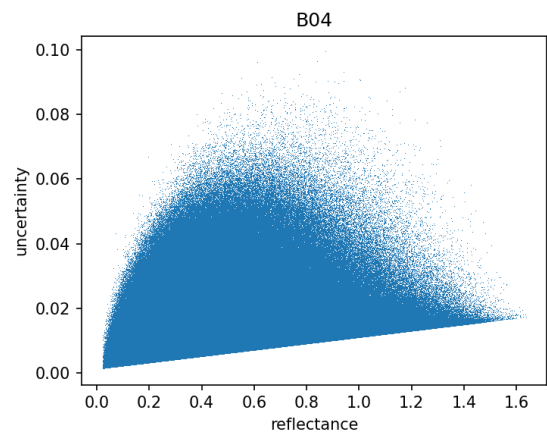
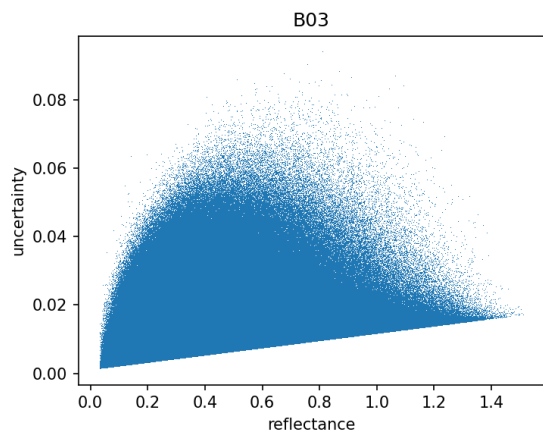
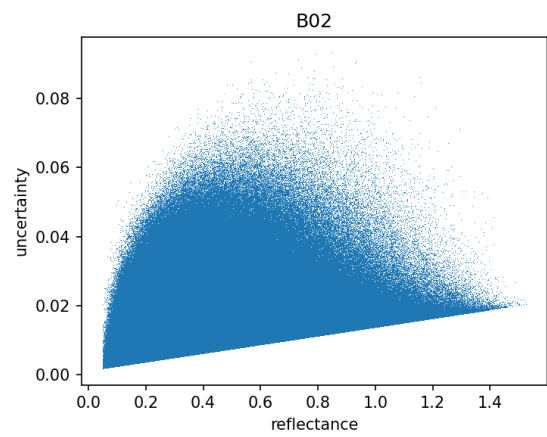
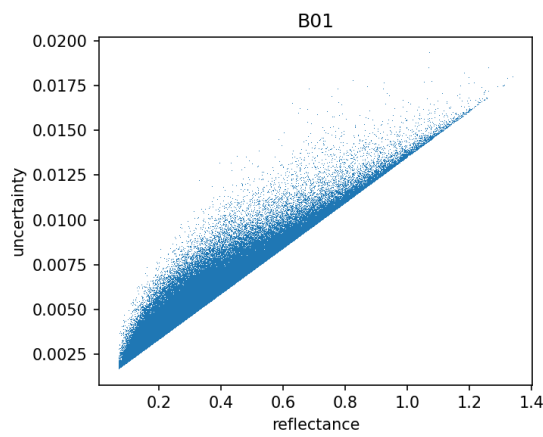
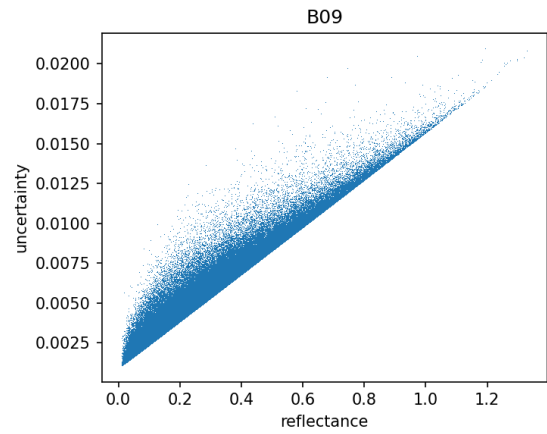
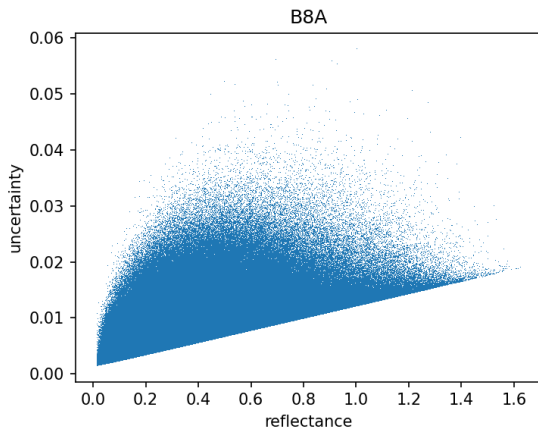
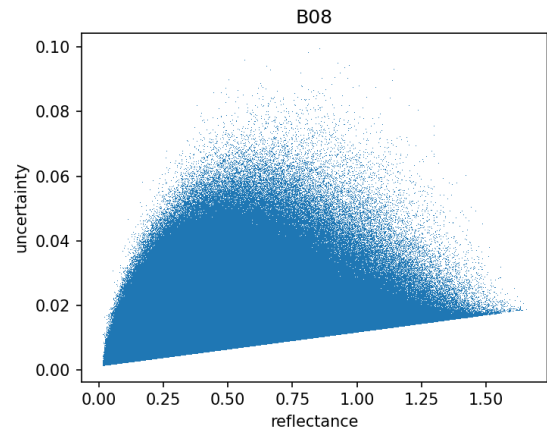
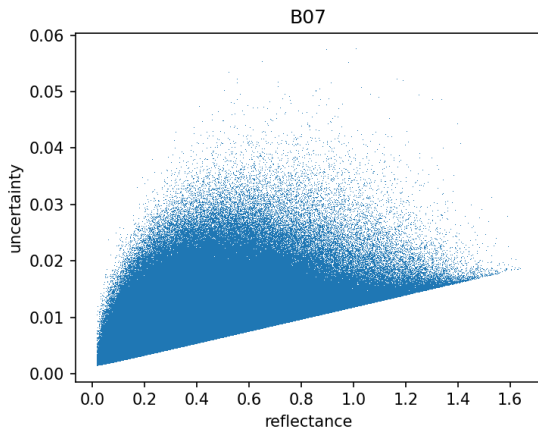
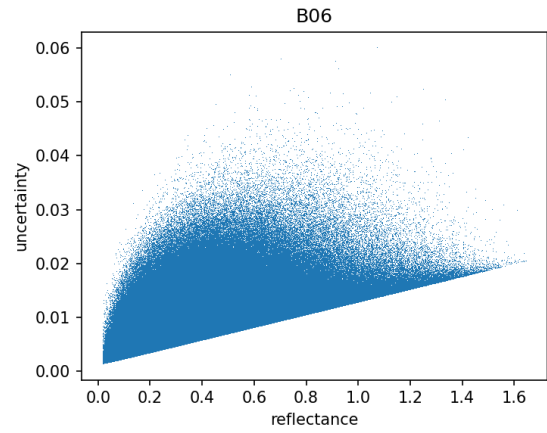
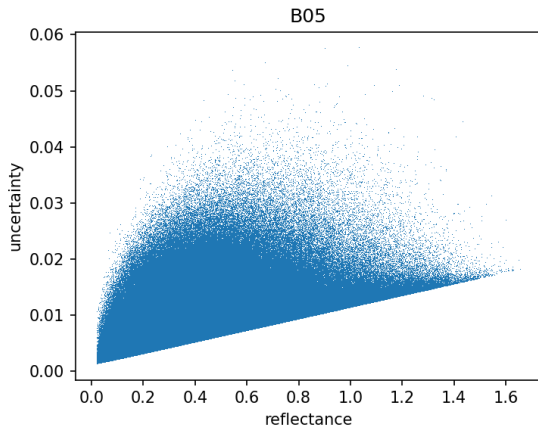


Figure 27: snow scene per-pixel uncertainty (in %) per band. Colour scale is clipped to 98 percentile value of uncertainty to improve contrast





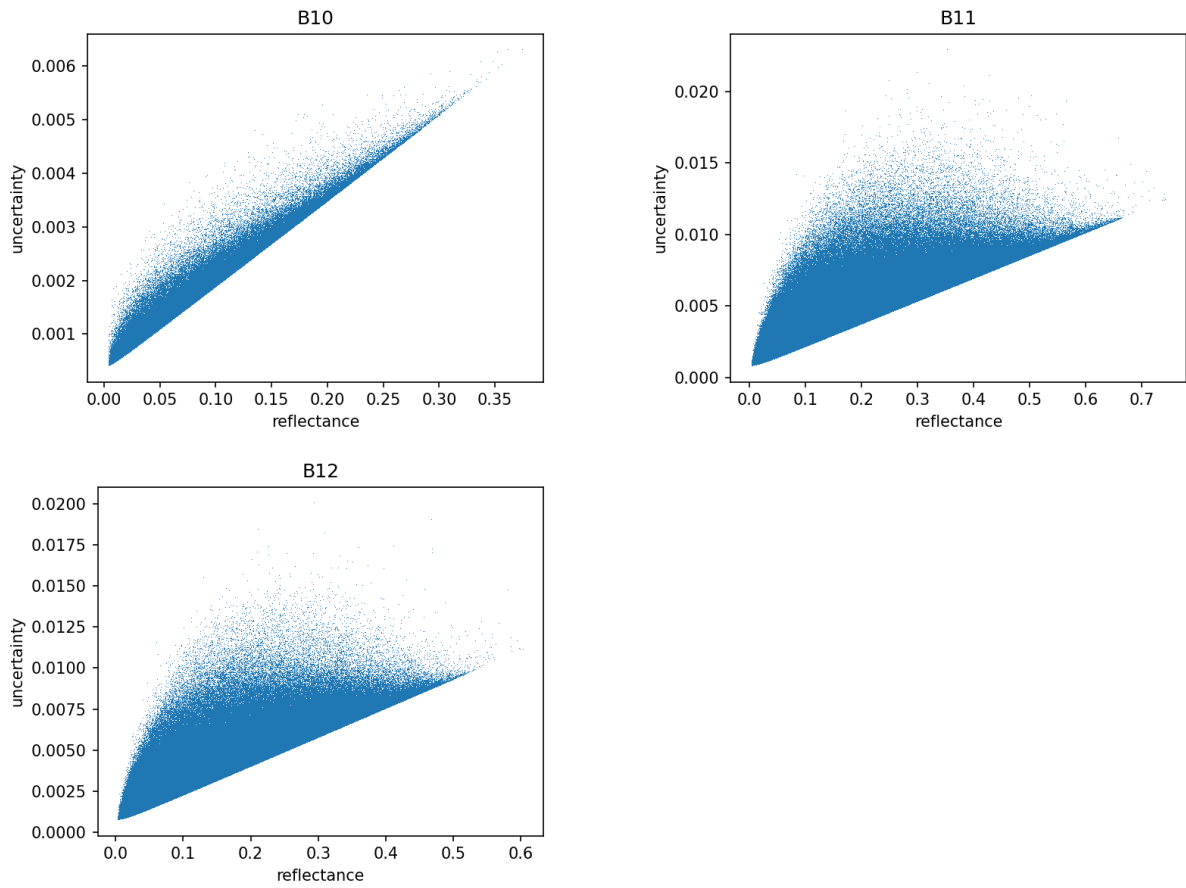


Figure 28: snow scene, uncertainty (in absolute unit) versus reflectance scatter plot for each band

 <p>OPT-MPC</p>	<p>OPT-MPC</p> <p>S2 RUT Validation report</p>	<p>Ref.: OMPC.ACR.MEM.053</p> <p>Issue: 1.0</p> <p>Date: 15/09/2025</p> <p>Page: 37</p>
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5 Conclusion

The verification and validation campaign confirmed the validity of the proposed RUT software.

Two software requirements initially formulated in the specification are no longer fulfilled due to evolution of the design. The other requirements were all verified independently.

The quality assessment performed on various types of scenes confirms that the results are in line with the expected outcome and present no visual defects. This quality assessment is complemented by the quantitative validation performed on S2A/S2C tandem data [RD3].

	<p>OPT-MPC</p> <p>S2 RUT Validation report</p>	<p>Ref.: OMPC.ACR.MEM.053 Issue: 1.0 Date: 15/09/2025 Page: 38</p>
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6 References

[RD1]	<p>Gorroño, J.; Fomferra, N.; Peters, M.; Gascon, F.; Underwood, C.I.; Fox, N.P.; Kirches, G.; Brockmann, C. A Radiometric Uncertainty Tool for the Sentinel 2 Mission. Remote Sens. 2017, 9, 178. https://doi.org/10.3390/rs9020178</p>
[RD2]	<p>Gorroño, J.; Banks, A.; Gascon, F.; Fox, N.P.; Underwood, C.I. Novel techniques for the analysis of the TOA radiometric uncertainty. Proc. SPIE 2016. https://doi.org/10.1117/12.2240391</p>
[RD3]	<p>OMPC.ACR.047, S2A-C Tandem uncertainty validation, i1r0, 13/06/2025</p>

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