Sentinel-2 MSI level-1 Radiometric Uncertainty Tool, status and application to tandem analysis

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S2-L1C-RUT software status

S2 L1C Radiometric Uncertainty Tool: New version available !

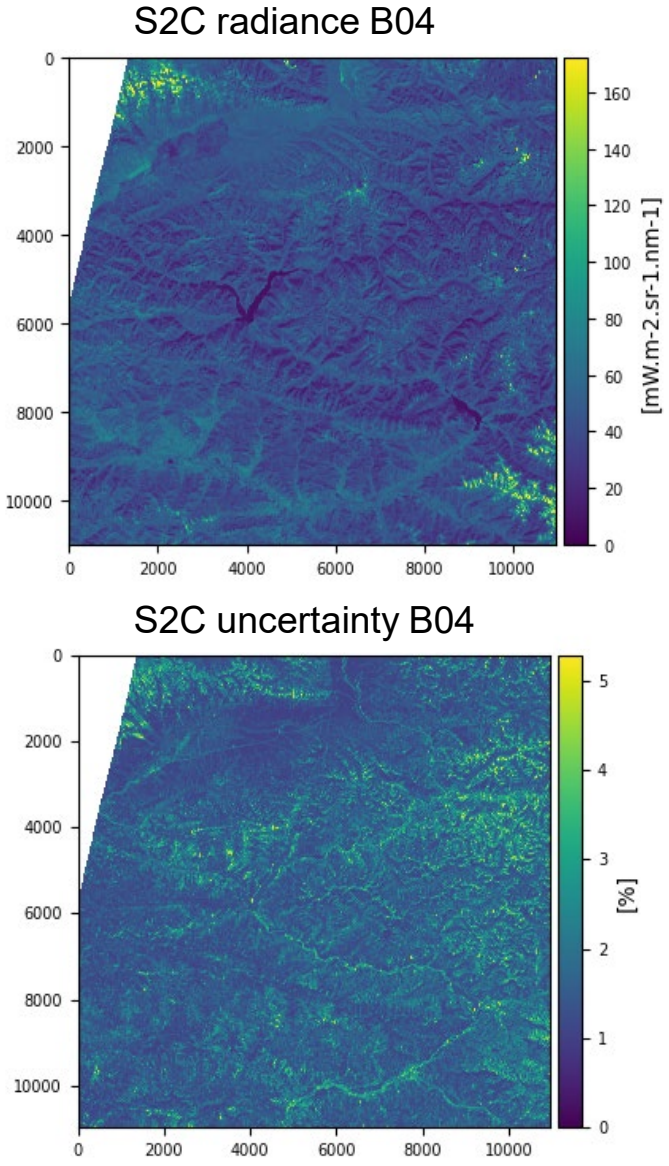
S2 RUT developed by J. Gorroño, then transferred to OPT-MPC to continue the support and the development of the tool.

S2-L1C-RUT is designed to:

- Be an offline tool that can be run directly on L1C product.
- Produce per pixel full image radiometric uncertainties representative of the L1 ground processing radiometric model.
- Be configurable with parameters for each identified error sources.
- Gives the possibility to output uncertainty per contributors.
- Run in simple python environment in command line

Code available publicly :

https://gitlab.acri-cwa.fr/opt-mpc/s2_tools/s2rut



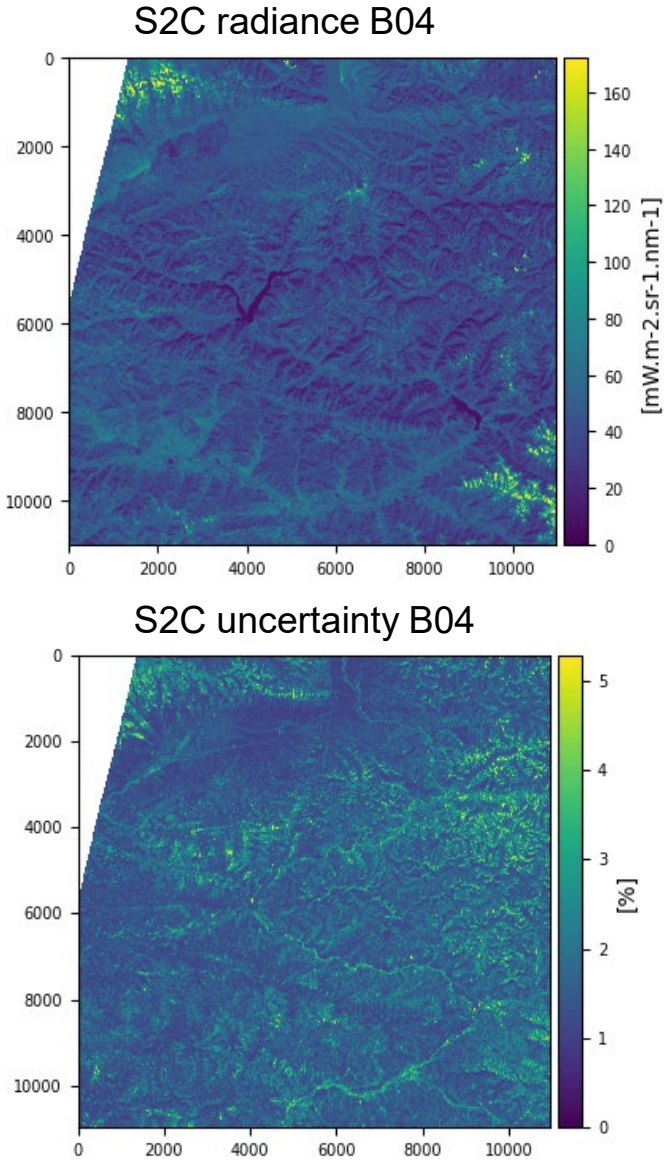
S2-L1C-RUT software status

Documentation available to public (via GitLab):

- **OMPC.ACR.MEM.41 - i1r0 - RUT Error sources analysis**: *describes all analysis made for each contributor. Most of them lead to a revision of contribution but some describe effects to complicated to be accounted in the current S2-L1C-RUT.*

- **OMPC.ACR.MEM.52 - i1r0 - S2 L1C RUT ATBD**: *describes all equations used and the processing of the uncertainties. Document seen as a complement of the "Error Source Analysis".*

- **OMPC.ACR.MEM.53 - i1r0 - S2 L1C RUT Validation report**: *software verification and validation and results analysis of 4 differents scenes. Document seen as a complement of the Tandem uncertainty analysis done in the S2C radiometric* FTO.



Contributors revision

Updated uncertainty contributors:

- **Instruments noise**: now includes the last QCC noise model.
- **Out-of-field SL**: now based on mean signal level instead of Lref.
- **Crosstalk**: revised and negligible.
- **ADC quantisation**: already accounted in QCC model.
- **Compression noise**: revised and too complex to account globally, set to negligeable.

L1B contributor	included	L1C contributor	status
instrument noise	**y**	Diffuser reflectance abs knowledge	y
systematic out of field straylight	**y**	Diffuser reflectance temporal knowledge	y
random out of field straylight	y	Angular diffuser knowledge BRF effect	negligeable
Crosstalk	**y**	Instrument noise and dark signal in calibration	negligeable
Deconvolution residual	n	Solar irradiance model	negligeable
Polarisation Error	n	Angular diffuser knowledge cosine effect	y
ADC quantisation	**y**	Straylight in calibration mode	y
Compression noise	**negligeable**	sun to satellite distance knowledge	negligeable
Dark signal knowledge	negligeable	Angular observation knowledge—cosine effect	negligeable
Dak signal stability	y	**Orthorectification**	**partially**
Non linearity knowledge	y	**Spectral knowledge**	**n**
Non uniformity spectral residual	n	**Geometric knowledge**	**y**
L1B Image quantisation	negligeable	L1C Image quantisation	y

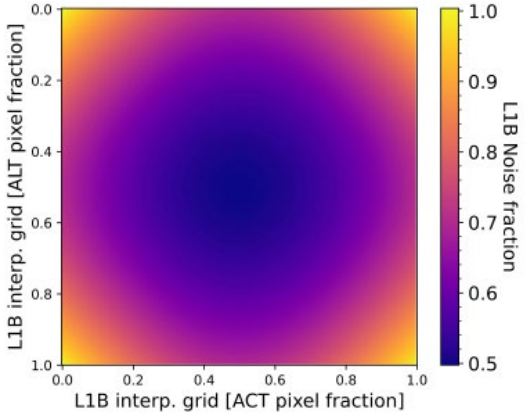
Included
Not included
Negligeable
partially
Bold = updated

Contributors revision

New contributors now included:

- **Orthorectification resampling**: L1b to L1c Resampling reduce the noise by averaging uncorrelated error, add a factor over the noise estimation.

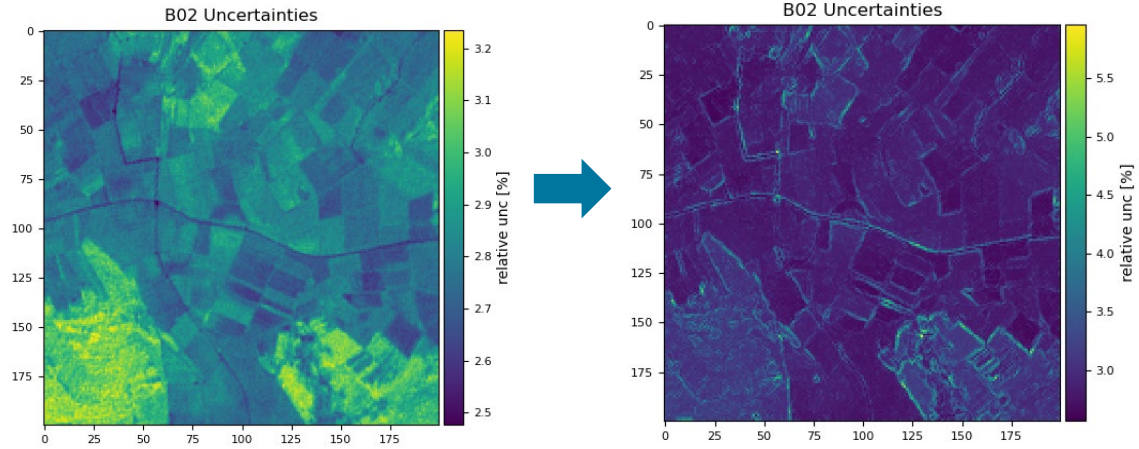
- **Geolocation error**: computed from the gradient of the image. Geolocation error is automatically set depending on the refinement status of the tile.



Monte Carlo study by J.Gorrono show a mean effect of 0.65:

$$\sigma = \mathbf{0.65}\sqrt{\alpha^2 + \beta . L}$$

Geolocation error impact high contrast features. The unc is computed from the image gradient and the geoloc error (1.5 m)

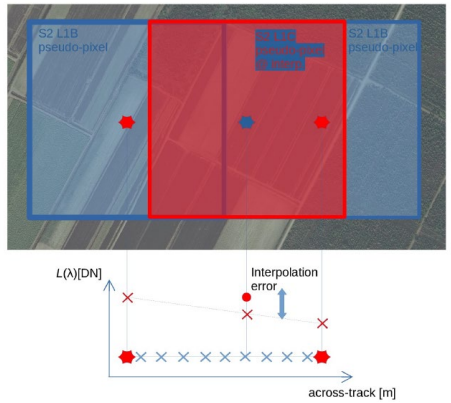


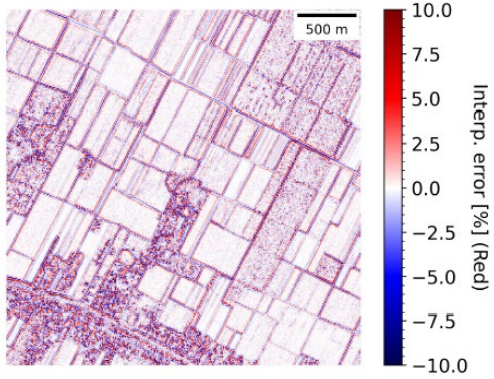
Contributors revision

More contributors with additional studies required:

- **Orthorectification interpolation error**: need a full study with high resolution images.
- **Spectral knowledge error**: analysis done by CS but results too dependent of the spectral content of the observed scenes to be generalize.
- **Straylight**: Revision of straylight error thank to moon acquisition. Analysis shows non negligeable impact within 1km of bright object. To correctly account for it a kernel straylight would be necessary

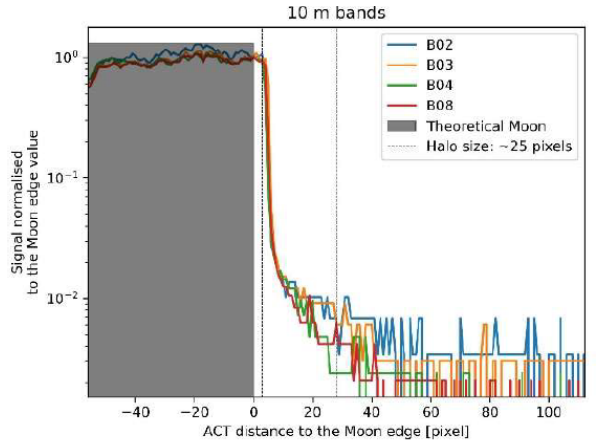
L1C interpolation also causes an increase of the error





Results from: J.Gorroño, L.Guanter, *Assessing the radiometric impact of the Sentinel 2 orthorectification process*. https://doi.org/10.1117/12.2603730

Local halo around the moon (modified dynamic)



width 20 to 30 pixels, Intensity of a few %

Courtesy of D.Rodat [CNES]

Uncertainty contributors analysis

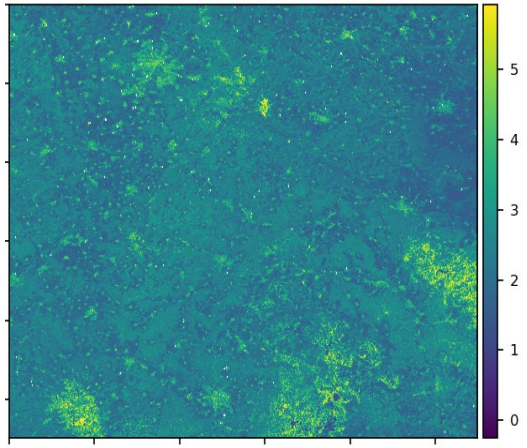
Contributors analysis: vegetated scene

Mean uncertainty per band (over a full image) and repartition between contributors

- Unc below 3% (except B10 at 9%, not plotted here)
- Out-of-field SL represents less than 20% of the total unc.

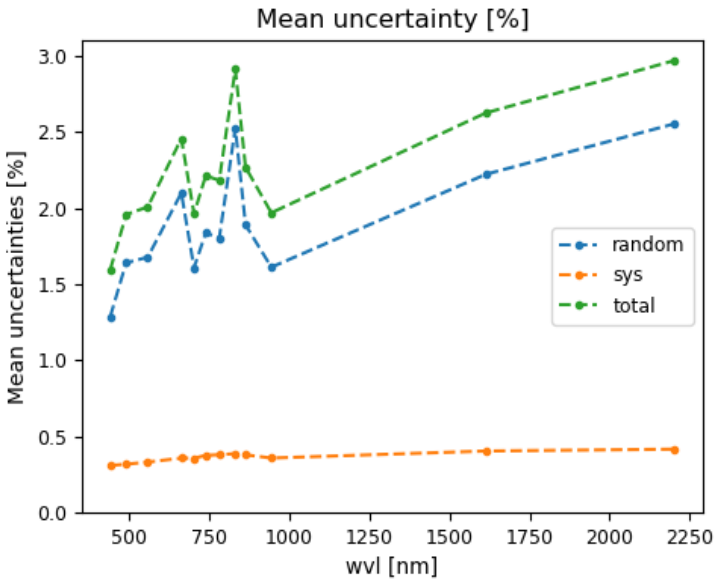
Noise contributors analysis : dominated by geoloc and diffuser

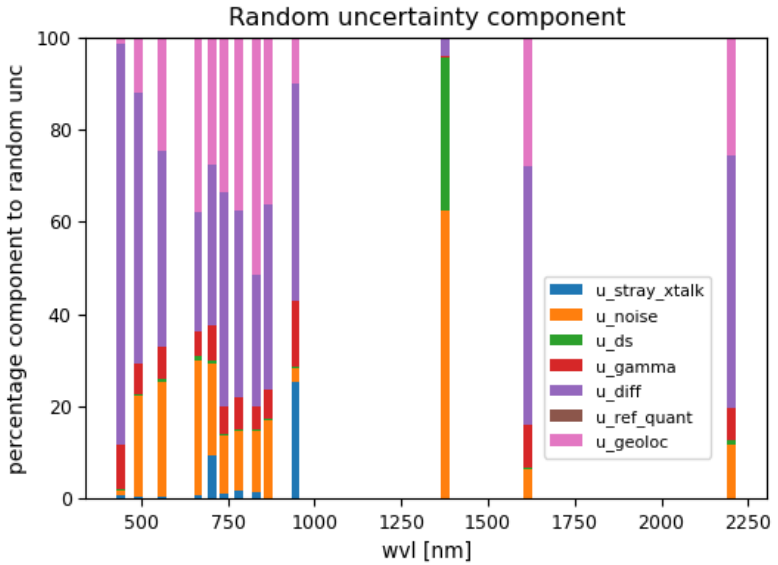
RGB of granule used

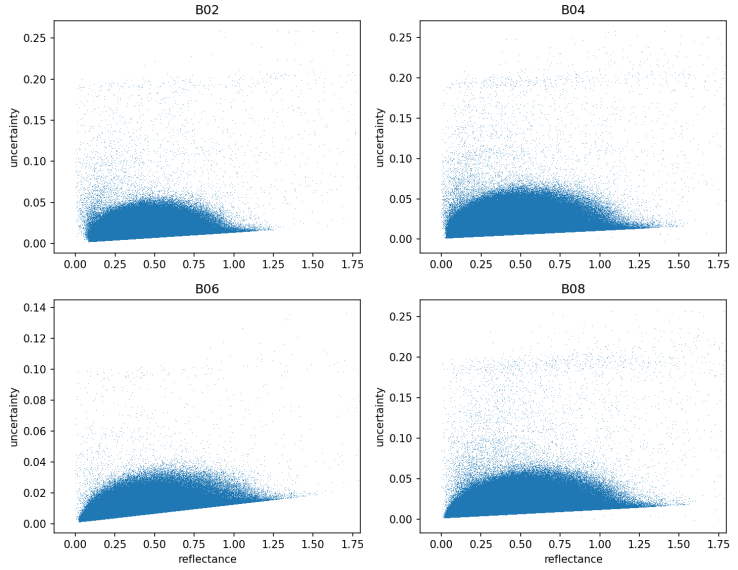


Unc [%] of B04

Scatter plot between uncertainties and reflectance



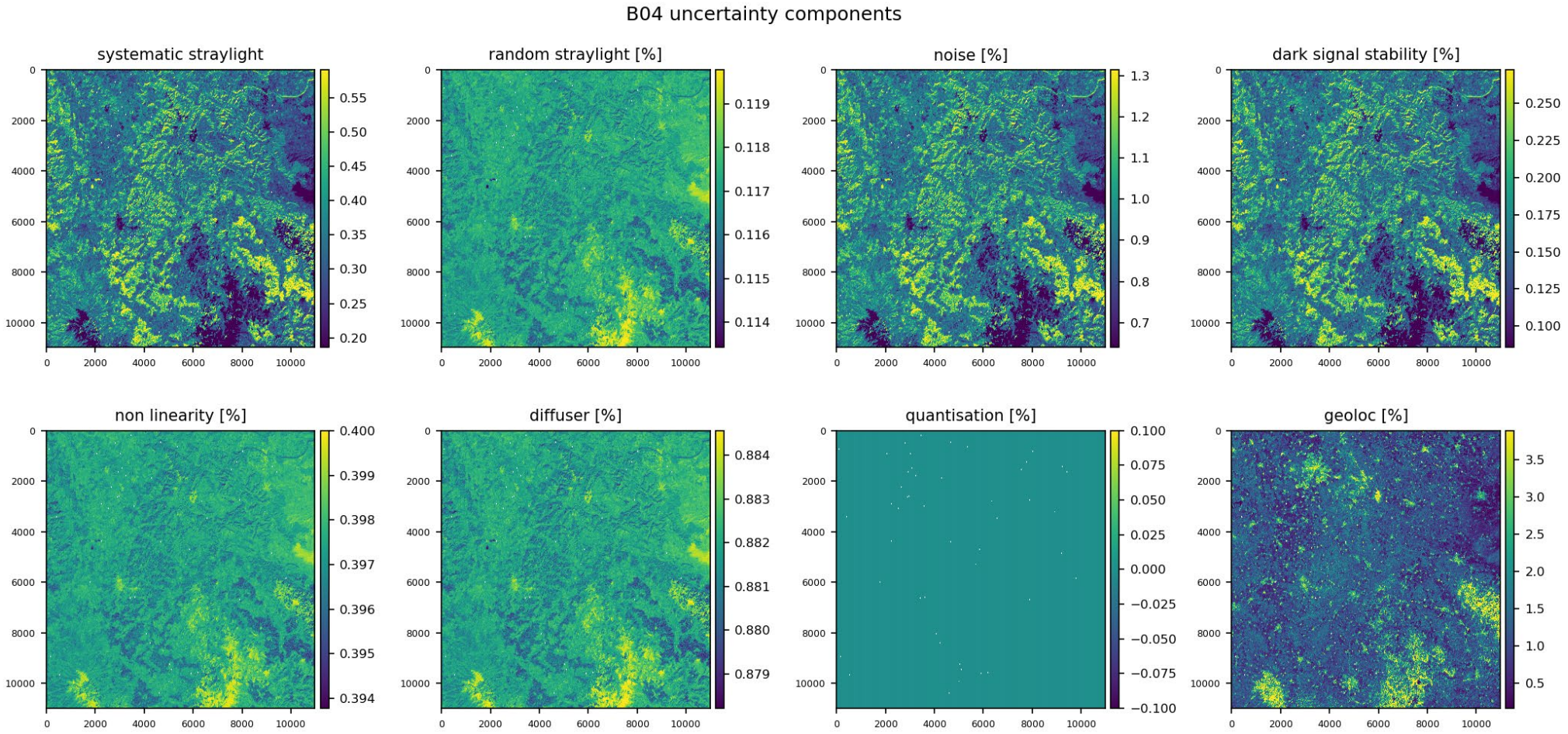




Unc vs Reflectance scatterplot

Contributors analysis: vegetated scene

Uncertainty contributor full image map

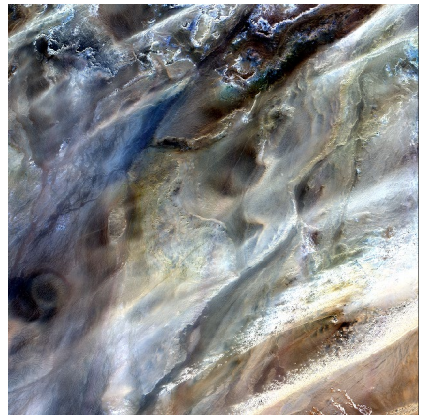


Contributors analysis: desert scene

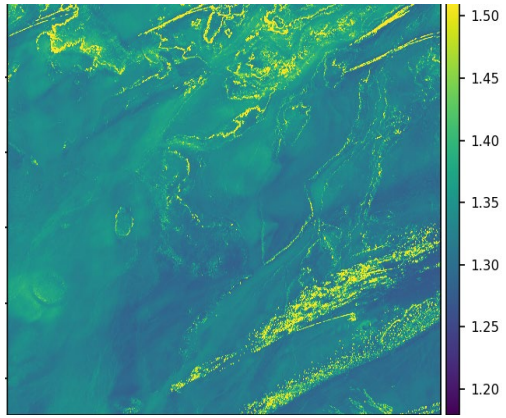
Mean uncertainty per band (over a full image) and repartition between random and systematic

- Mean unc below 2% (except for B10 at 4%).
- High mean radiance: ~130 $W.m^{-2}.sr^{-1}.\mu m^{-1}$ (Lref = 108)

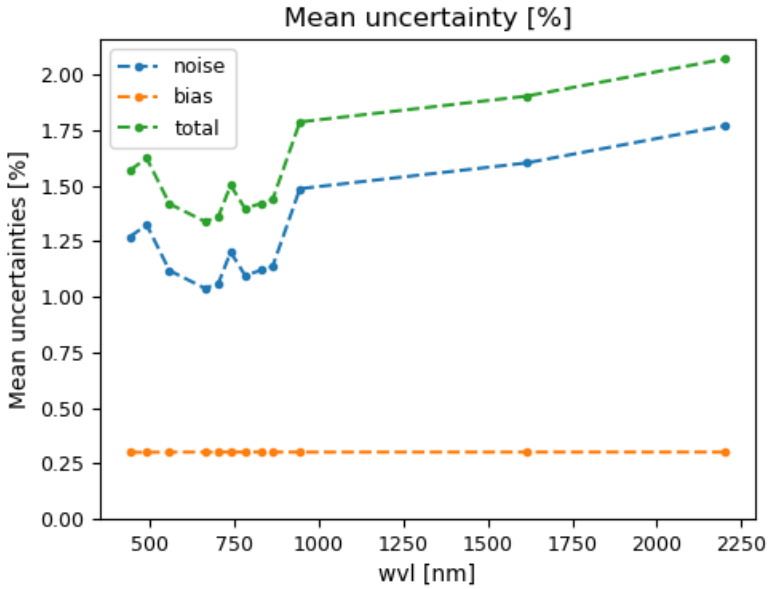
Random contributors analysis : diffusers component has a greater relative importance

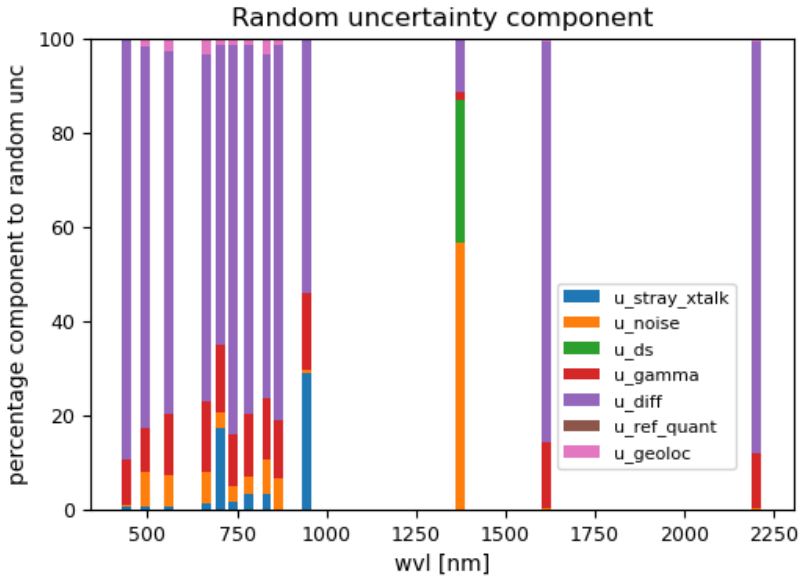


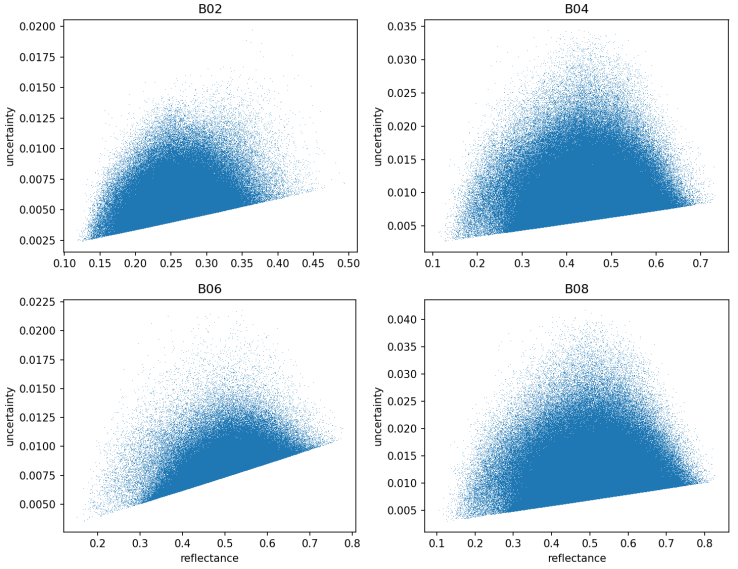
RGB of granule used



Unc [%] of B04

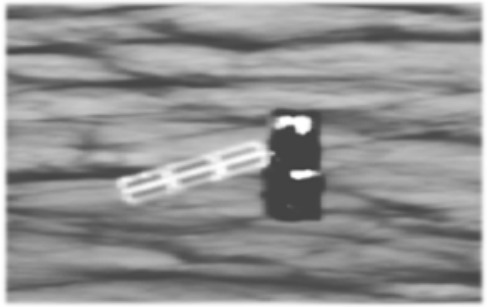






Tandem uncertainty validation

Tandem uncertainty validation



S2C seen from S2A during commissioning

Tandem between S2A and S2C from 1st November to 11th December

- Temporal separation between the 2 satellites below 30 sec
- Same ground track, altitude and viewing angles.
- Temporary configuration lasting only a few cycles

"Uncertainties validation" refers to the "Relative inter-comparison of Tandem Level-1 uncertainties" and not to the absolute validation, as usually done for L2 reflectance for example ➔ This is possible only thank to tandem data acquisitions

Based on SLSTR Methodology published by Samuel Hunt et al., from NPL.

"Comparison of the Sentinel-3A and B SLSTR Tandem Phase Data Using Metrological Principles", Remote Sens. 2020, 12, 2893.

Method was used for OLCI L1 and adapted to the recent tandem between S2A and S2C.

Metrological approach: based on analysis of the distribution of the uncertainty-normalised differences: $\varepsilon_i = \frac{\Delta L}{u(\Delta L)}$

If the variance of differences is well described by the uncertainties, the resulting distribution should follow a standard normal law (Gaussian centred on 0 with a standard deviation of 1)

- Stdev > 1 ➔ underestimation of uncertainties
- Stdev < 1 ➔ overestimation of uncertainties

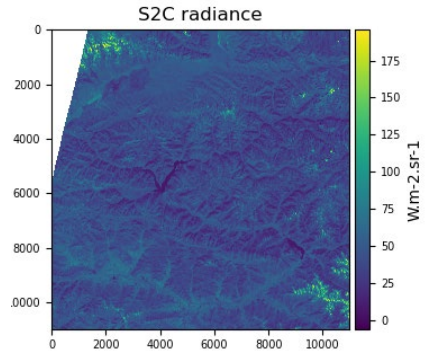
Tandem uncertainty validation

For S2 the method will be adapted as following :

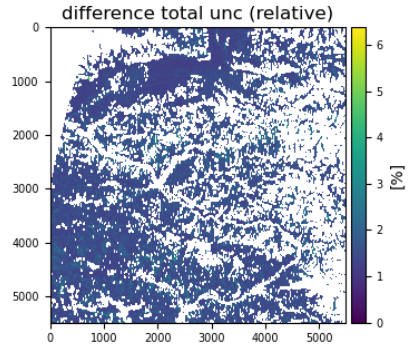
- pixel-to-pixel comparison of radiance.
- Keeping only “bare_soil” pixels from L2A classification to reduce spectral response difference.
- Water/vegetation pixels shown a strong spectral impact during the radiometric analysis and they have been discarded from the study.
- Cloud pixels move to quicky to be used safely in direct comparison
- Radiometric vicarious alignment of both satellite is performed. S2C is aligned over S2A using per bands gains computed with 4 independent method during IOC.
- Compute Uncertainty Normalised-difference (uncorrelated case) :

$$\frac{\Delta L}{u(\Delta L)} = \frac{L1_{S2A} - L1_{S2C}}{\sqrt{u^2(L1_{S2A}) + u^2(L1_{S2C})}}$$

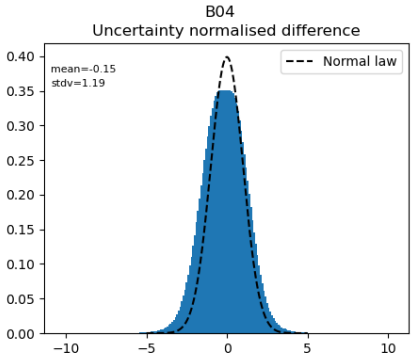
- Compare histogram of epsilon to the Normal Gaussian law
- Cumulative histogram are computed over ~100 tiles to increase the statistic per detector, allowing an independent study over the 12 detector of S2.



Initial granule S2C tile

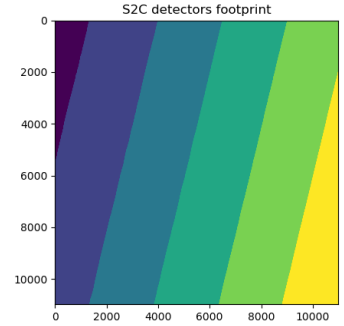


Filtered total uncertainty from S2A & S2C



Epsilon ratio histogram, to be cumulated with other tiles

Tandem uncertainty validation



S2-MSI results

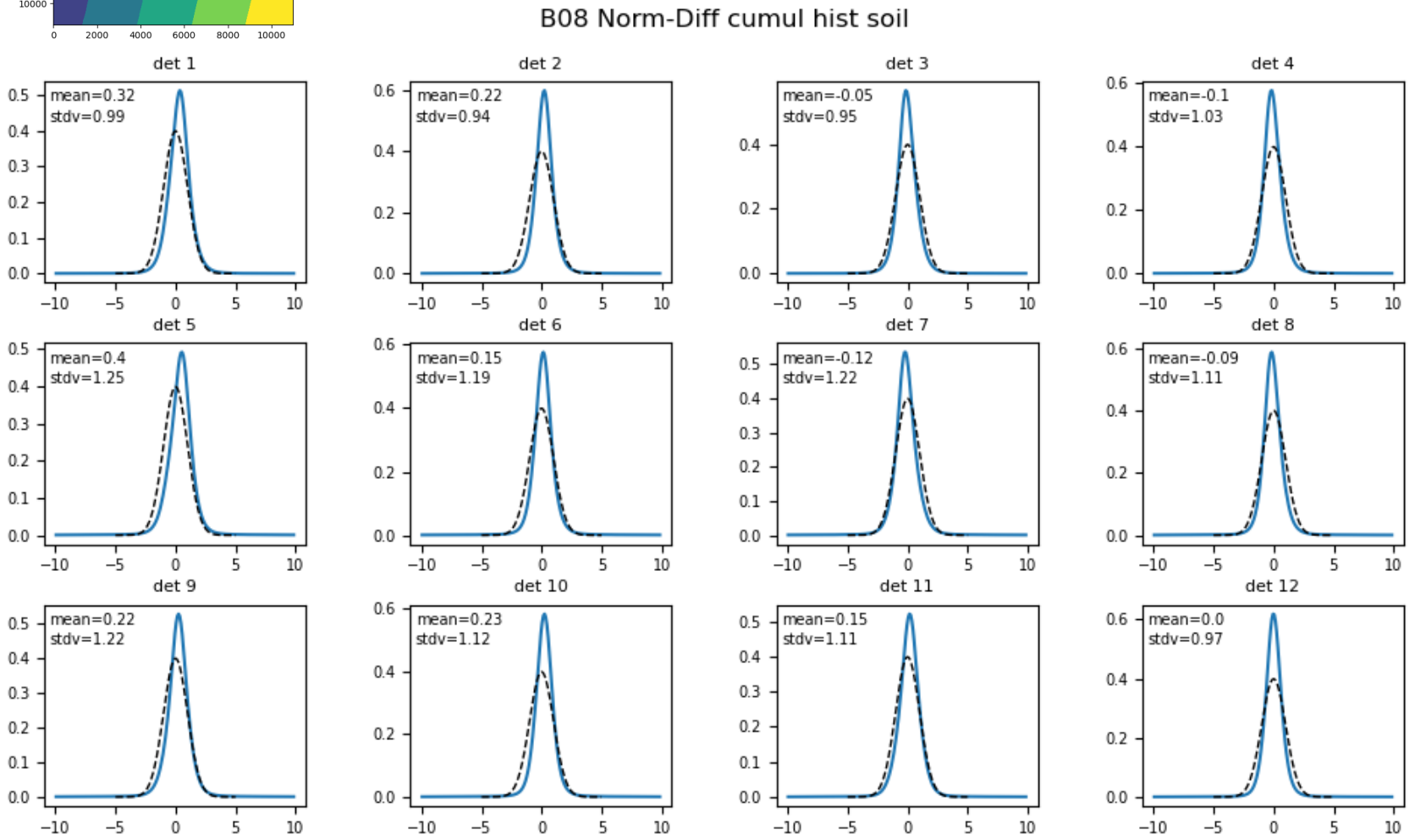
Typical results obtain for a given band per detector, after aggregation of ~100 tiles (~1 billion pixels per detector) :

Normalised histogram vs expected Gaussian Law.

Shape of the distribution:

- Almost perfectly centred on 0, meaning that 2 sensors are well aligned
- Standard deviation around 1.
- Fairly Gaussian shape: sometime slightly too narrow with an over-representation of small difference.

➔ **Mean and standard deviation computed over each detector**



Tandem uncertainty validation

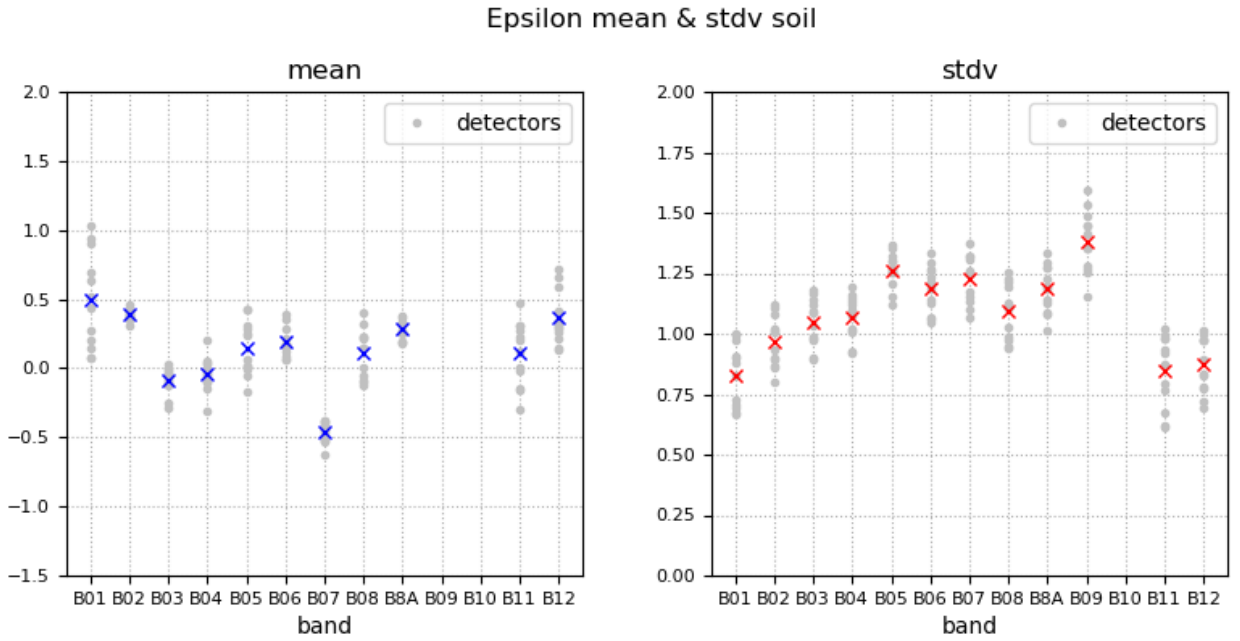
Mean & stdev of distribution computed from each detector and each period

Independent days of data has been studied and aggregated separately, 6 different period:

2024-11-01	2024-11-06
2024-11-02	2024-11-07
2024-11-03 to 05	2024-12-12

Mean of distribution centred on 0 for all bands (except B09 & B10)

- **radiometric alignment is well performed!**
- Highest residual bias for B01 & B02 which is consistent with radiometric alignment study: tandem method was giving higher gain than 3 other methods.
- B09 (945.1 nm) issue with water vapour leading to remaining bias
- B10 (1375 nm) is excluded from the study, method requires specific adaptation on this band

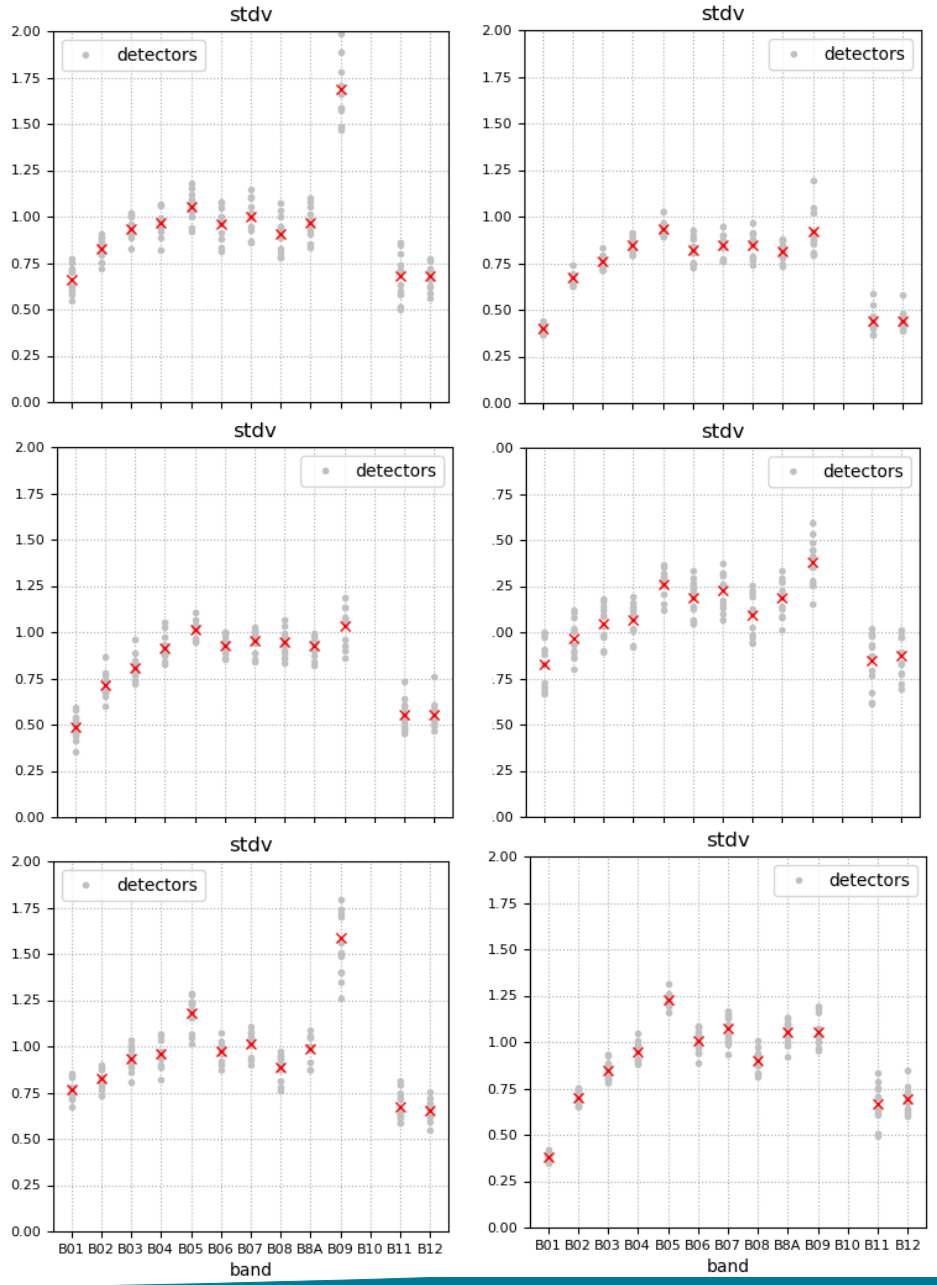


Averaged "mean" and "stdev" over all detector for a given period

Tandem uncertainty validation

Standard deviation of distribution in function of the bands:

- Very repeatable results between independent periods
- B03 to B08A (559.8 to 864.7 nm) : close to 1 , small variation between periods but overall good representation of uncertainties
- B01, B11 & B12: systematic lowest stdv values indicates an overestimation of uncertainties
- B09: high variation from days to days, possibly link to the presence/absence of water vapour in the day of acquisition.
- Clear spectral pattern from B01 (443 nm) to B05 (704 nm) possibly link to partial correlation not fully accounted for, especially regarding the diffuser absolute knowledge. This contribution seems correlated between sensors, but the analysis assumes uncorrelated uncertainties between S2A & S2C.
- If contribution is in fact correlated, it would lead to an overestimation of uncertainties, but this is yet to be investigated and confirmed.



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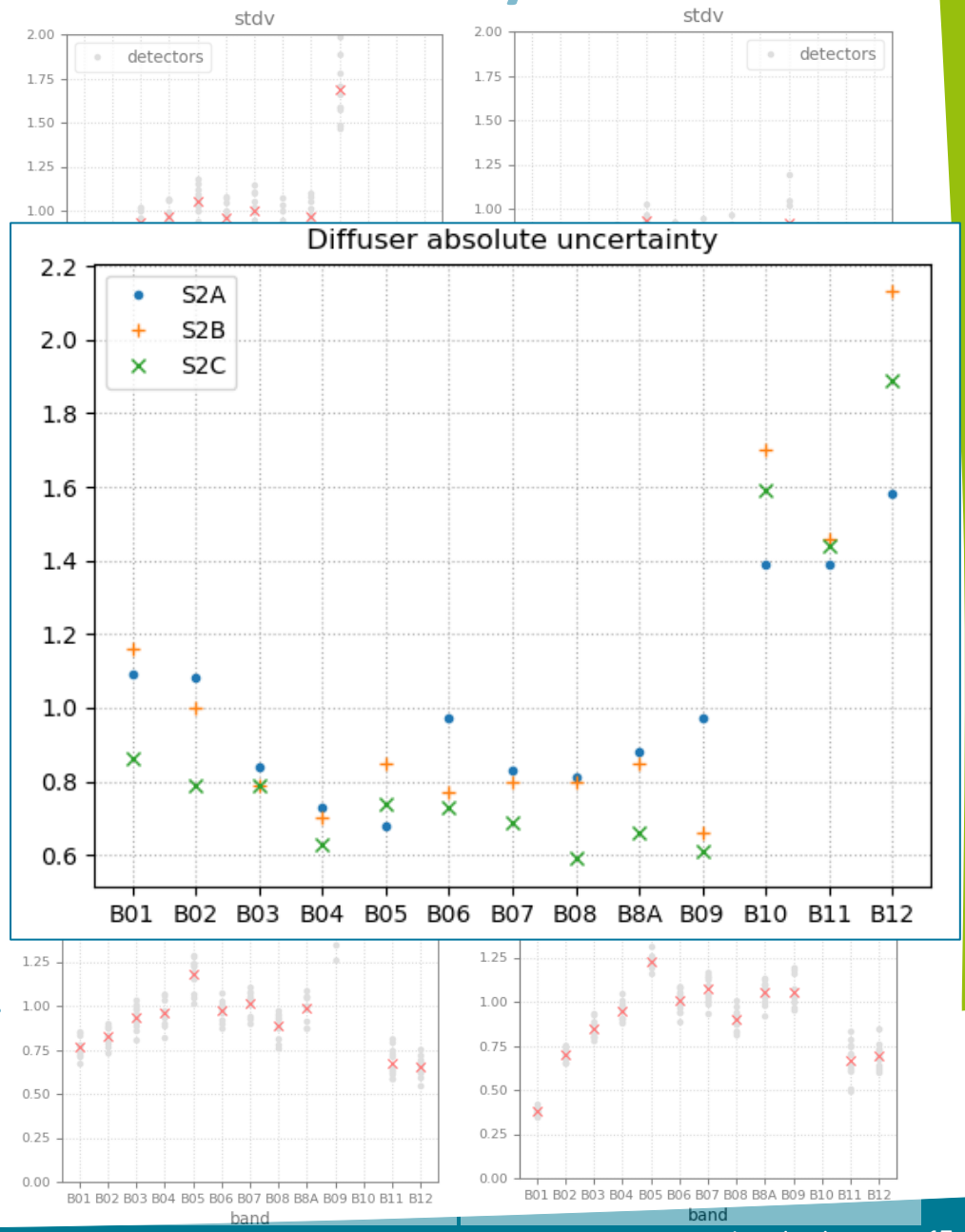


Tandem uncertainty analysis

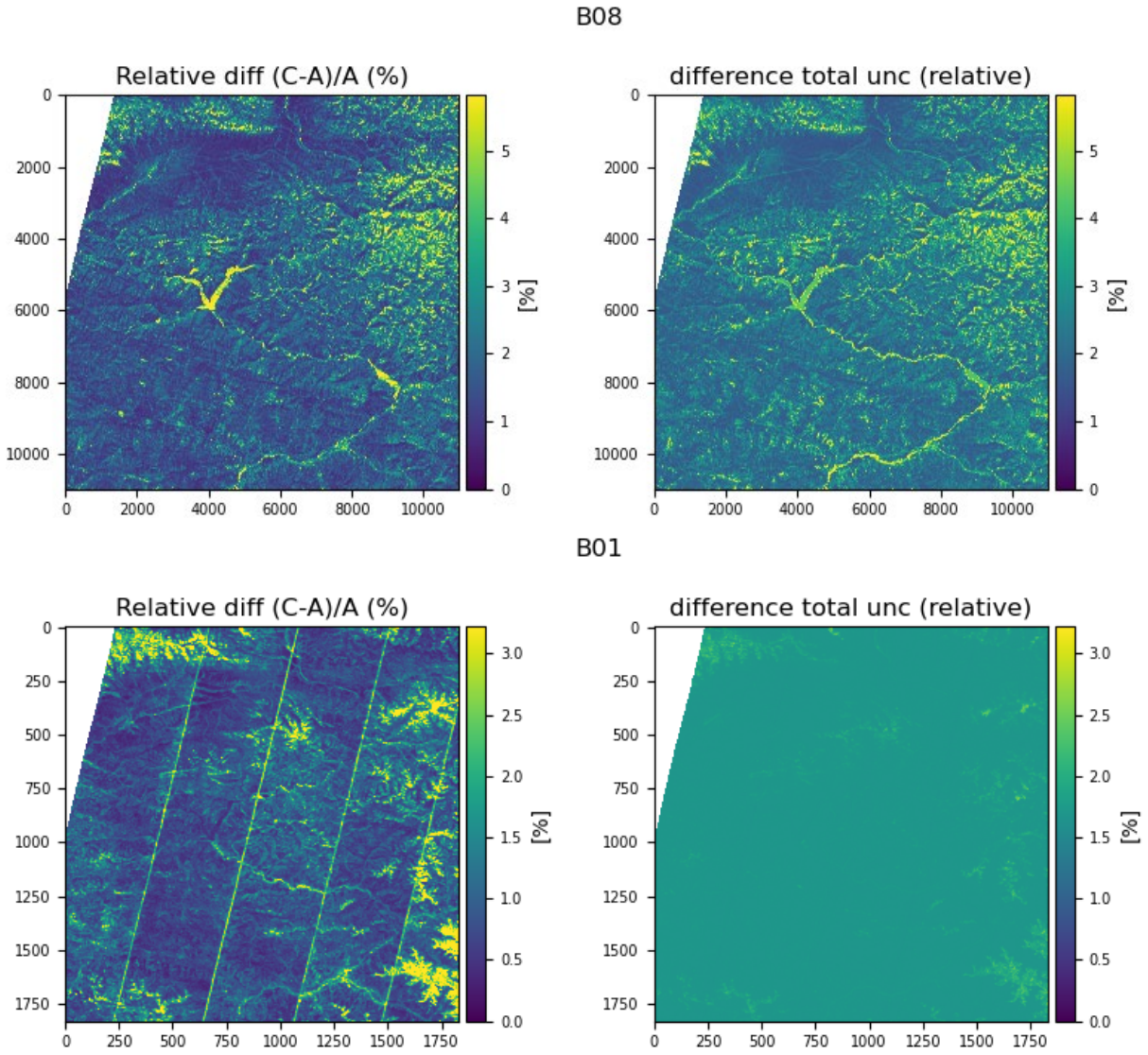
Visual comparison of absolute relative difference with the total uncertainty over a tile confirm the global analysis.

B08 (favourable case):

- Uncertainties catch the relative difference of the scene.
- Overestimation of uncertainties over low differences and underestimation over high differences. Might be due to a non-optimized geometric calibration for tandem data. This can be redone on re-processed data later.

B01 (not-so-favourable case)

- Uncertainty almost constant over image, does not catch the scene contrast
- Consistent with a “diffuser term” over-estimated over the full FoV for this band.



Conclusion

Conclusion

- Sentinel 2 MSI now has a new tool for computing uncertainty over full-image, the S2-L1C-RUT. The tool allows to produce L1 uncertainties from any L1C data.
- The tandem analysis showed that the overall uncertainty products appears to be consistent with instruments differences. Even if some partial correlation of diffuser term can have an impact on some bands (ex: B01)
- Tandem phases was very useful to characterize sensors and offers a unique opportunity to inter-compare uncertainties.

Limitation

- Offline tool: starting from L1C data necessary imposes some simplification, and some contributors must be considered globally instead of locally.
- Correlation: depending on the use cases of the uncertainties the partially known correlation can make the propagation of uncertainty very difficult.

OPT-MPC

Copernicus Sentinel

Optical Mission Performance Cluster

ACRI ST

Thank you for listening.