L2A-RUT: Development of uncertainty estimates for Sentinel 2 surface reflectance products

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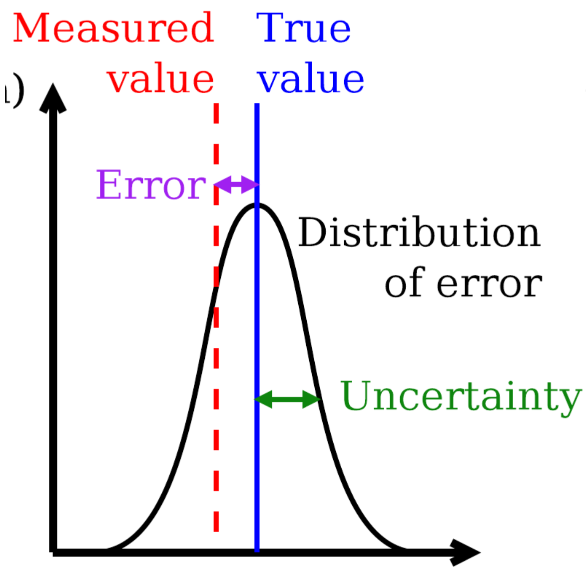
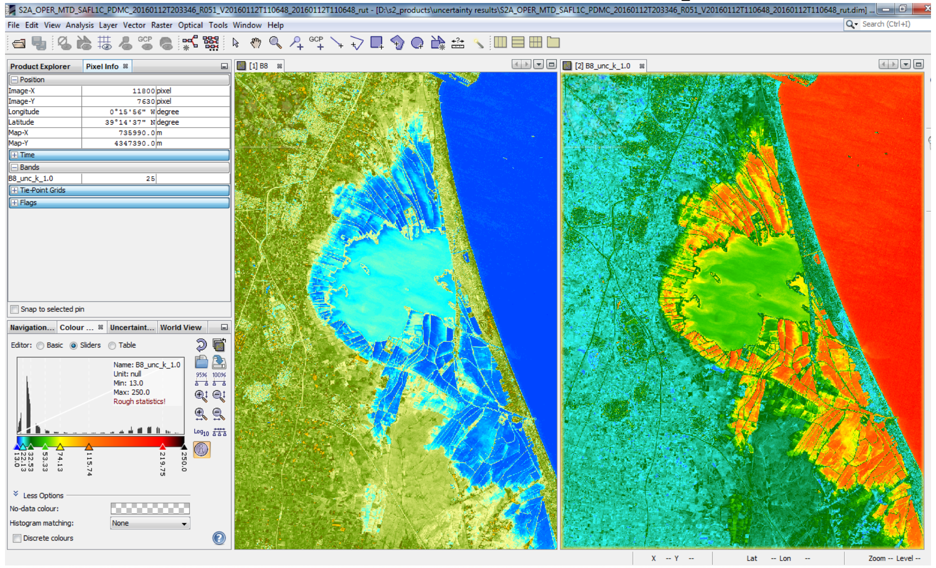
Introduction

- Uncertainty (of measurement) parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand. (GUM, JCGM 100:2008).



A. C. Povey and R. G. Grainger: Uncertainty estimation in satellite remote sensing, 2015

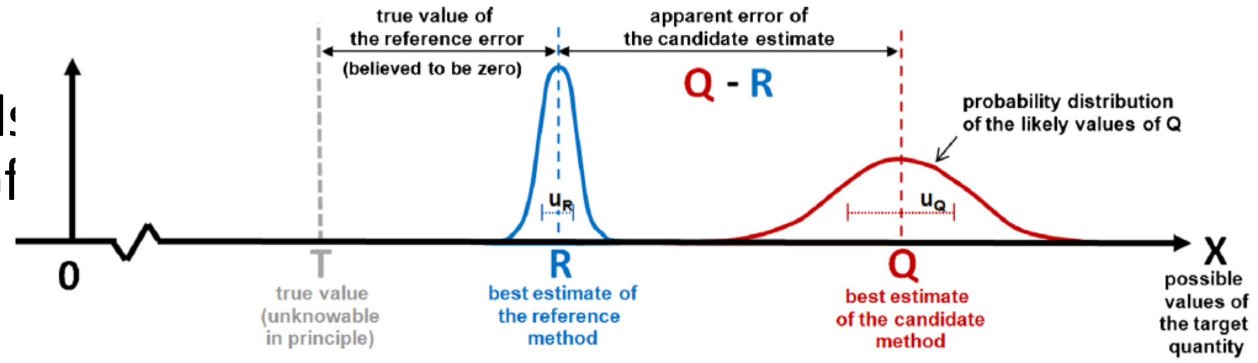
- Previous efforts have produced operational L1 (TOA reflectance) uncertainty estimates for missions such as MODIS (Xiong, Sun et al. 2005) and S2 (Gorroño, Fomferra et al. 2017).
- The aim of this project is the **development of operational per-pixel uncertainty estimates for the Sentinel 2 L2A products**.



Extracted from Gorroño et al. 2017. Screen-shot of SNAP. L1C Sentinel-2 B8 image for Albufera Lake (left) and the equivalent uncertainty k=1 (right).

Uncertainty applications

- **S2 L2A product validation.** Benchmarking and conformance testing are essential tool that quantify the socioeconomic benefits of EO data.
- **S2 L2A uncertainty propagation.** Uncertainty analysis consists of an unbroken chain of steps that assess the sources and their propagation. Pre/post launch calval, TOA reflectance, BOA reflectance, bio-physical retrieval, bio-physical model
- **Bio-geophysical retrieval.** Possibility tha users define the observation space (surfa reflectance) and potentially improve their retrievals (e.g. LAI). Applications to OE, Gaussian process, regression…



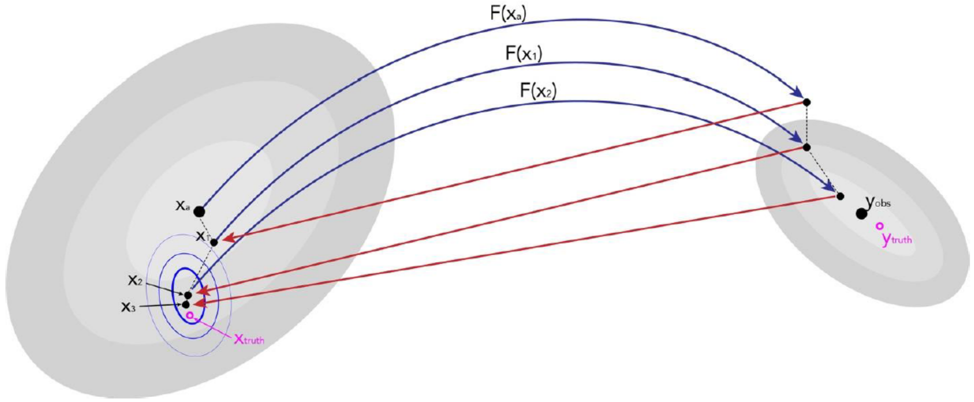
Widlowski, J. L. (2015). Conformity testing of satellite-derived quantitative surface variables. Environmental Science & Policy, 51, 149-169.

Retrieval space

(e.g. LAI, FAPAR…)

Observation space

(S2 L2A surface reflec.)

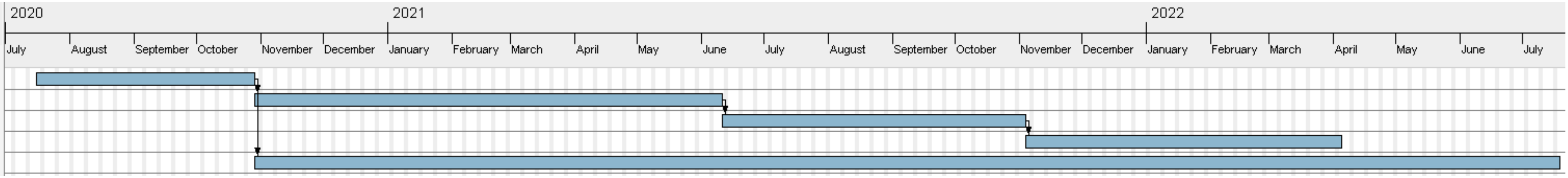


Extracted from Maahn, M., D. D. Turner, U. Löhnert, D. J. Posselt, K. Ebell, G. G. Mace, and J. M. Comstock, Optimal Estimation Retrievals and Their Uncertainties: What Every Atmospheric Scientist Should Know. Bull. Amer. Meteor. Soc.

Project plan

- The work is split into:
  - WP1: Review of S2 L1C uncertainty estimates
  - WP2: Atmospheric correction uncertainty: 2.1 propagation and 2.2. validation
  - WP3: Auxiliary retrieval uncertainty
  - WP4: Prototype implementation of S2 L2A uncertainty estimates in Sen2Cor
- The plan is to split the two-year project into two releases:
  - **Beta release** (goal summer 2021): Solid framework in order to work towards further versions (targeted to specific users not for full distribution).
  - **Pre-operational release** (goal summer 2022). A version that includes most of the planned features, a detailed science validation and a basic software validation. Intended for Sen2Cor release and PDGS integration.

Name	Begin date	End date
WP 1	16/07/2020	28/10/2020
WP 2.1	29/10/2020	10/06/2021
WP 2.2	11/06/2021	03/11/2021
WP 3	04/11/2021	04/04/2022
WP 4	29/10/2020	18/07/2022

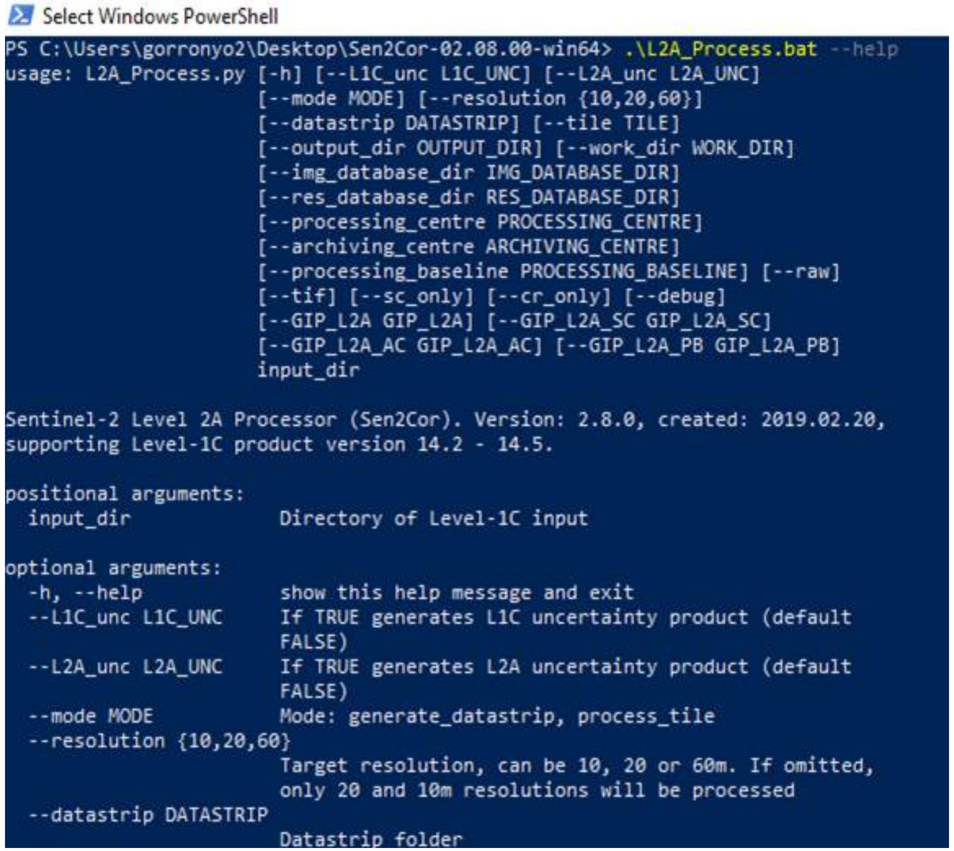


Sen2Cor and the L2A product

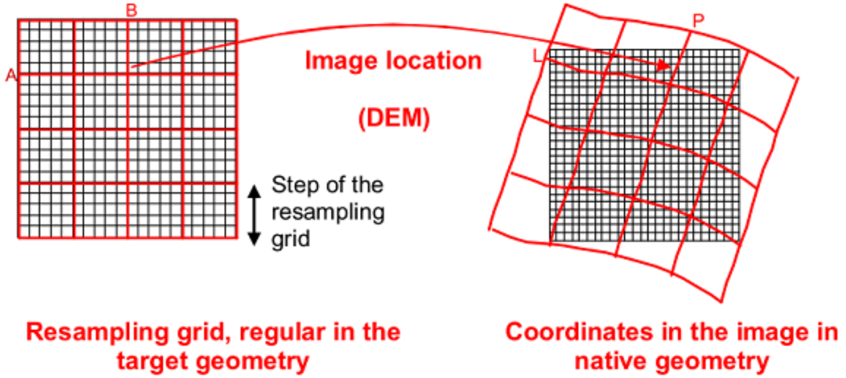
- L2A operational processor generates surface reflectance products from L1C input. Processor available to users at S2 Toolbox or standalone Sen2Cor version.
- Produces a pixel classification map: cloud, cloud shadows, vegetation…
- Atmospheric correction (TOA to BOA reflectance):
    - based on ATCOR and a large LUT using LibRadTran.
    - AOT can be derived using DDV method.
    - WV retrieval using APDA method.
    - Topographic effects corrected if accurate DEM.

<u>Implementation strategy</u>

- L2A-RUT running in parallel to Sen2Cor (subroutine).
- Multiple implementation strategies: PDGS, user-side…
- Simplified interface. e.g. *--L2A_unc True*



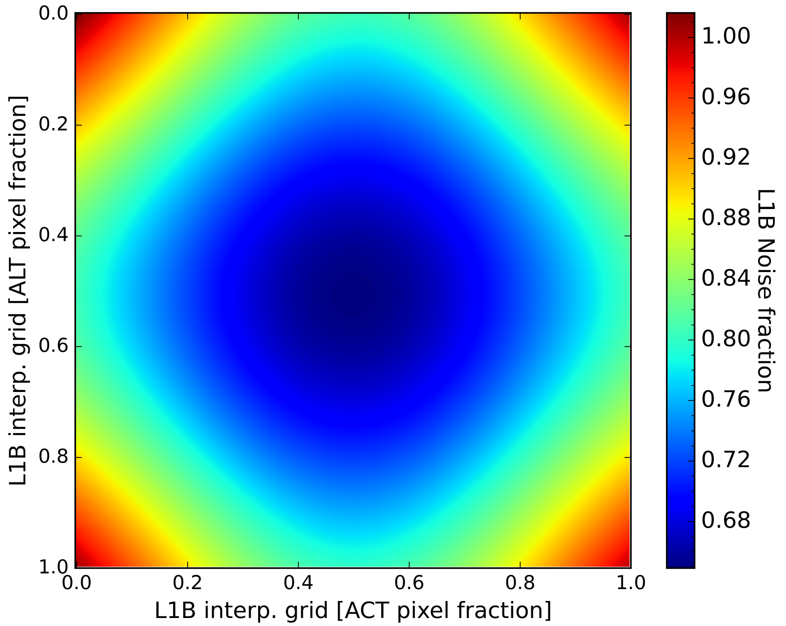
Orthorectification radiometric uncertainty



- The orthorectification process involves a geometric and radiometric transformation of the L1B observations (focal plane) into L1C orthoimage (in UTM coordinates).
- Radiometric transformation includes a resampling (interpolation or fitting)
- S2 resampling:
  - B-spline of cubic order
  - 4x4 pixel kernel.
  - surface fitting with a cost function (defined by a smoothing factor)
- Three main considerations at a radiometric level:
  - Noise improvement
  - Interpolation accuracy
  - Covariance impact

Noise improvement

- **Montecarlo approach**: Uncorrelated gaussian noise is propagated through the B-spline interpolation at different potential positions in the grid.
- **Empirical approach**: ratio between the noise variance (or SNR) at collocated L1B and L1C images using a Discrete Cosine Transform over near-homogeneous areas.
- Ratios Montecarlo: max=1.02, min=0.64, mean=0.78
- Ratios Empirical: 0.5-0.75 approx. Mean per band over different sites 0.6-0.65.
- Higher ratio in MonteCarlo with zero smoothing (i.e. interpolation)-->S2 L1C products including a surface fitting?which level of smoothing?

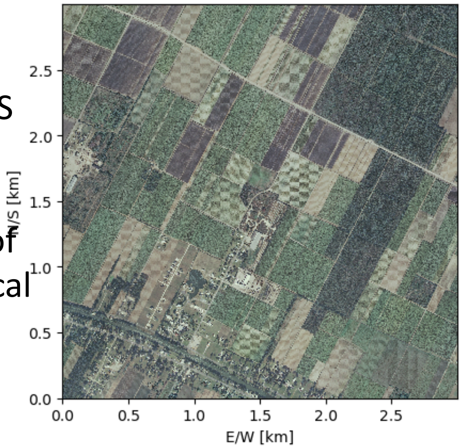


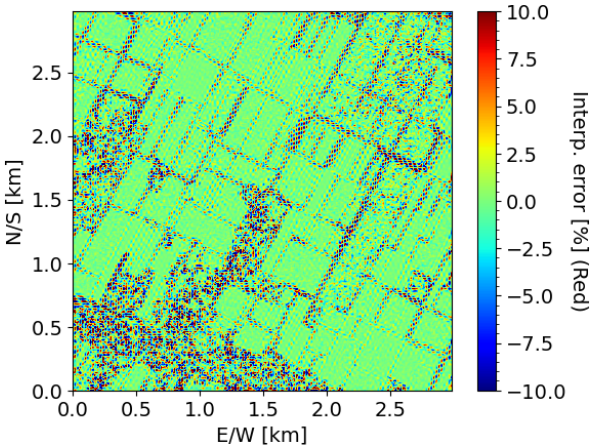
Libya-1	B2	B3	B4	B5	B6	B7	B8	B8A	B11	B12
SNR_{L1B}^{ALT}	190	242	306	408	331	442	251	273	742	598
$SNR_{L1C}^{N/S}$	301	400	503	589	614	632	446	446	1263	1090
Ratio	0.63	0.61	0.61	0.69	0.54	0.70	0.56	0.61	0.59	0.55
SNR_{L1B}^{ACT}	179	244	296	365	363	327	256	274	650	574
$SNR_{L1C}^{E/W}$	266	349	437	541	496	509	354	386	895	913
Ratio	0.68	0.70	0.68	0.67	0.73	0.64	0.72	0.71	0.73	0.63

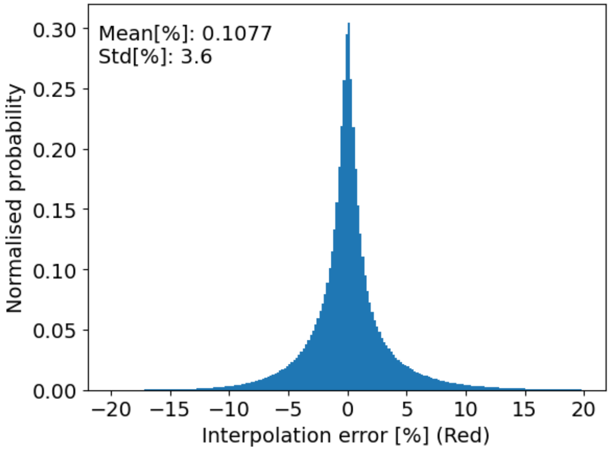
Interpolation accuracy

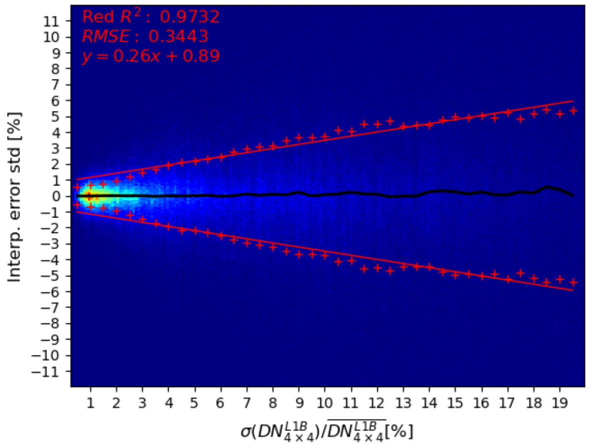
- Systematic error: difference interpolated value with real scene.
- Real case cannot be known but simulated using orthoimages.
- The error can be obtained for any potential position in the image. The result is an interpolation accuracy map.
- Challenging implementation in the RUT:
  - Provide a abs. mean error over many images (see error distribution)
  - Produce a simple regression against (see example) against slope, std, hessian…

3 × 3 km area selected from orthoimage USGS Orthoimage F2909010NW. Image courtesy of the U.S. Geological Survey.



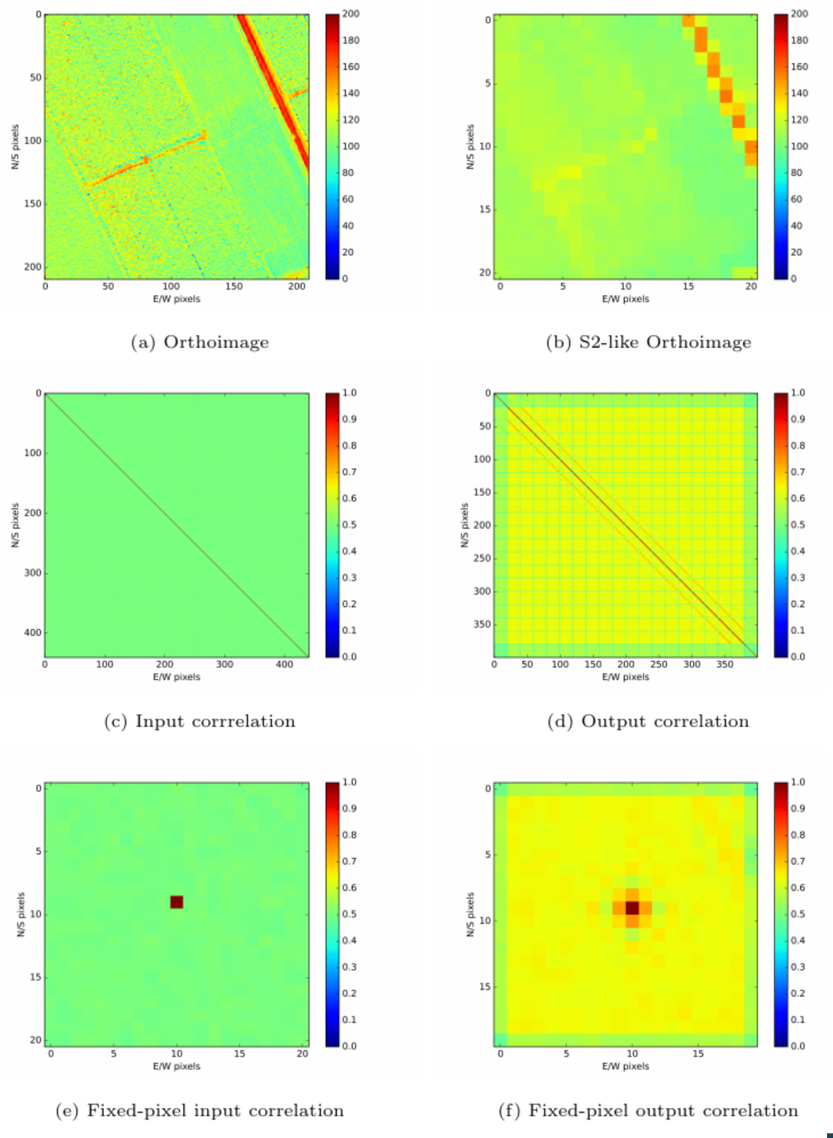






Covariance impact

- Correlation between pixels increases as the raw measurements are processed though the chain. Simplified example:
  1. 210×210 1-metre pixels from the same orthoimage are selected (see a)).
  2. This image is binned into 10-m pixels that simulates 21×21 L1B pixels(see b)).
  3. Uncertainty is simulated (1% noise + 1% sys. calibration) resulting in a correlation of 0.5(see c) and e))
  4. In an iterative mode, the samples are propagated through a B-spline interpolation (see d) and f) for example in the centre of the grid)

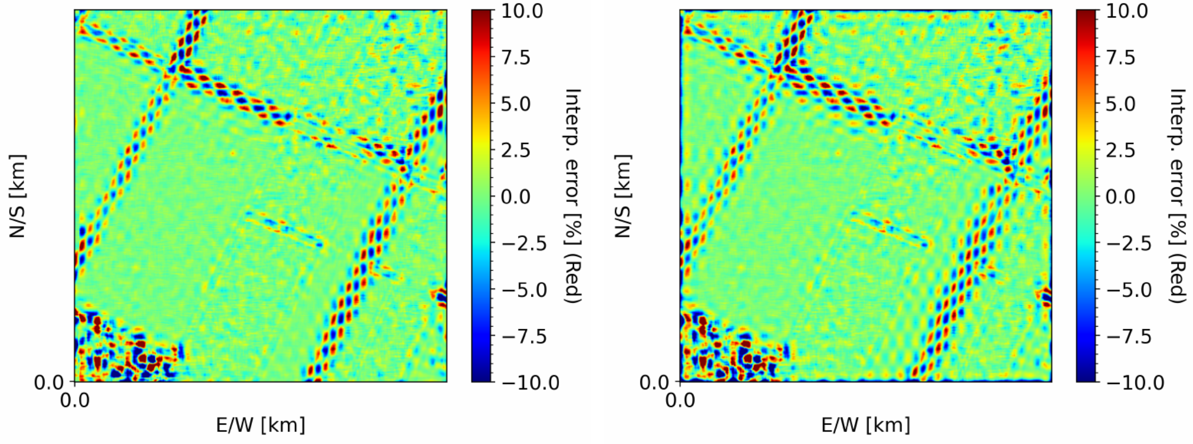


- Generally, the correlation increases and, locally, the correlation is perturbed by the interpolation kernel.

Considerations for the interpolation of S2 NG

- Option 1: *dynamic smoothing factor*. The use of this fitting in a dynamic mode linked to the instrument noise (α and β metadata noise parameters).

- Option 2: *gaussian process regression*.
  + propagates noise and covariance
  - computationally intensive
  ? defining a method to account for systematic error.



(a) Red B-spline (b) Red GPR

Figure 9: Interpolation error map of results using 10m spatial resolution with a B-spline interpolation and a GPR with 1% noise in the priors.

Conclusions and Future work

- WP1 study has been focused on the radiometric changes through an orthorectification.
  1. Detailed study of the noise change, interpolation accuracy and covariance.
  2. Consideration of alternative interpolation methods for S2 NG.
  3. strategies for its implementation in the L2A-RUT
- RUT development
  - Currently, studying the Sen2Cor code and defining a preliminary design
  - Need an implementation and communication strategy that explains the upcoming product. E.g. uncertainty is not a proxy for noise!!!!
- Deliverables
  1. Manuscript under internal review: "A radiometric uncertainty analysis of the Sentinel 2 orthorectification"
  2. Code: working on L2A-RUT with the aim beta release (summer 2021)
  3. Technical note/conference: ATBD and userguide of L2A-RUT (summer 2021).

Thank you

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