Final Presentation

Project No IDEAS+/SER/SUB/10:
Development of a radiometric uncertainty tool for EO missions

05/07/2016, ESRIN Rome, Italy

Javier Gorroño

Index

- Introduction
  - Aim of research
  - Deliverables
- The design and implementation of a Radiometric Uncertainty Tool
  - Sentinel-2 L1 Radiometric model
  - L1 Radiometric Uncertainty contributors
  - L1 Radiometric uncertainty contributors assessment
  - Model combination and validation
  - Radiometric uncertainty software implementation
- Novel techniques for the analysis of the TOA radiometric uncertainty
- The correlation in the spatial, spectral and temporal domain of the TOA reflectance/radiance pixel measurements
- The study of the noise in-flight using the Allan deviation
- S2-RUT future versions
- Extension to other Sentinel missions
- Towards a full chain uncertainty implementation

Aim of research

The design, development and implementation of techniques to estimate the radiometric uncertainty associated the TOA radiance/reflectance factor pixel measurements of EO satellite optical instruments.

Specific goals:

- End-to-end methodology: radiometric model→ uncertainty contributors →uncertainty combination based on GUM (BIPM, IEC et al. 2008).
- Assessment of each one of the uncertainty contributors
- Validation of the combined standard uncertainty model vs. a MCM method, the impact of simplifications and the correlation between uncertainty contributors.
- The research for different software strategies to implement the tool and integrate as part of EO processing chain.
- A critical review of the metrological concepts used for the assessment of the radiometric uncertainty contributions of EO sensors in-flight.

Deliverables

<table>
<tr>
<td>NPL1 – Summary progress Report on Radiometric Performance & Uncertainty Analysis</td>
<td rowspan="2">

“Radiometric uncertainty per pixel for the Sentinel-2 L1C products ", Proc. SPIE 96391G (October 12, 2015)
Minor studies: Diffuser calibration time analysis, ICCDB comments…
Presentation at CEOS WGCV IVOS, Toulouse, 19th November 2015.
SPPA webpage 2nd version
Support to the development of S3-OLCI RUT
Radiometric uncertainty Tool: technical guide
Model validation 2nd version

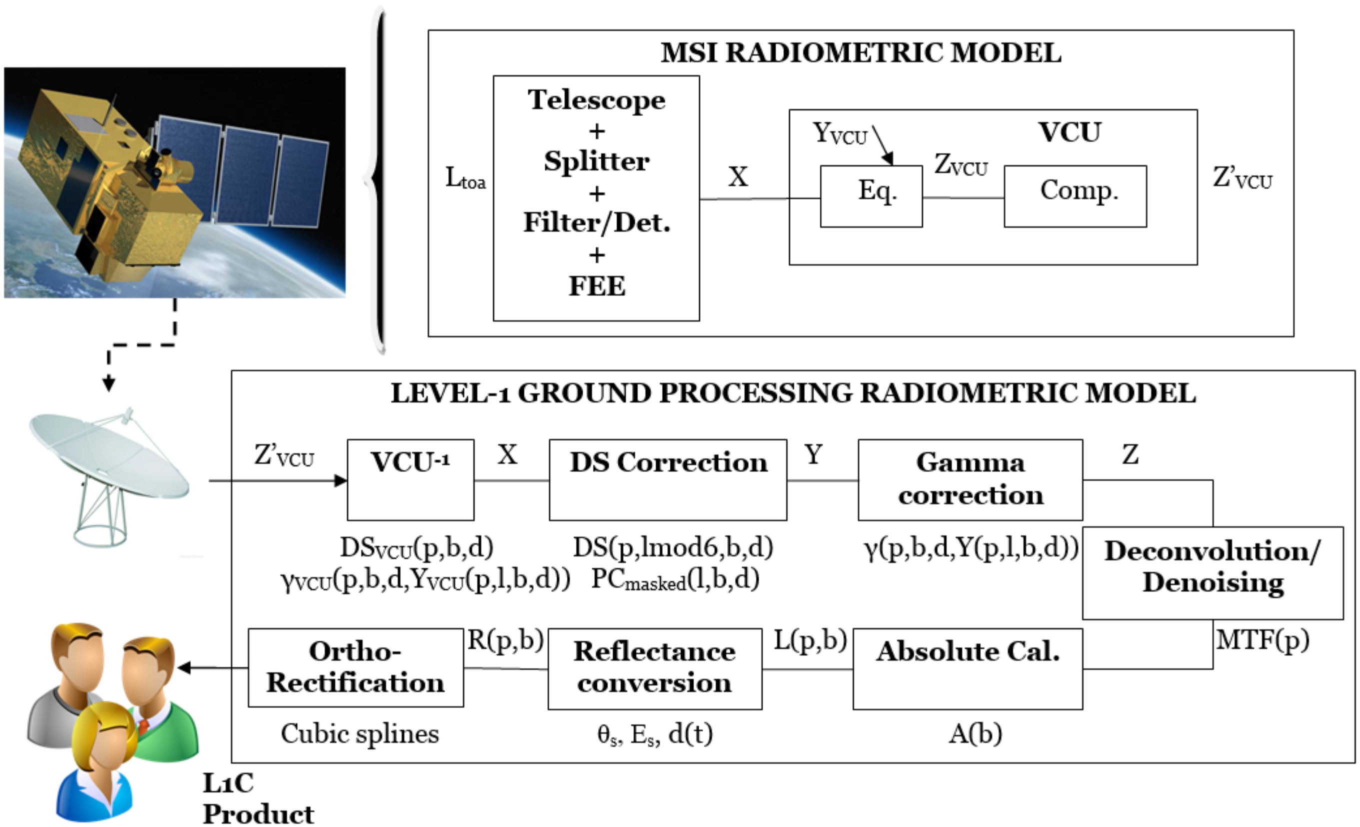
</td>
</tr>
<tr>
<td>NPL2 - Summary Progress Report on Radiometric Uncertainty Theory and Model Validation</td>
</tr>
<tr>
<td>NPL3A - Software Tool (V1)</td>
<td rowspan="3">

Poster presentation “Integration of the Sentinel-2 Radiometric Uncertainty Tool in the Sentinel Toolbox”, ESA Living Planet Symposium, Prague (Czech Republic) 9-13 May 2016 (includes brief case study of Albufera lake, Valencia)
Code evolution and release at: https://github.com/senbox-org/snap-rut
HTML user guide at: https://github.com/senbox-org/snap-rut
Manuscript for http://www.mdpi.com/journal/remotesensing
NOTE: due to the constrains of the peer-review process, the final form is not available yet.

</td>
</tr>
<tr>
<td>NPL4A - Software (V1) Implementation Summary Report</td>
</tr>
<tr>
<td>NPL5 - User guide including Case Studies on RUT Applications</td>
</tr>
</table>

Sentinel-2 L1 Radiometric model

- Mathematical formulation based on the instrument and L1 processing chain.



L1 Radiometric Uncertainty contributors

- Uncertainty contributions linked to the Sentinel-2 L1 radiometric model. In dark orange contributions in RUTv1. In light orange contributions with negligible impact and, in white, contributions to be included in next versions.

L1B processing chain		**L1C processing chain**	
Contributor	**Source**	**Contributor**	**Source**
Instrument noise **u_noise**	$X(p,l,b,d)$	Diffuser reflectance absolute knowledge **u_diff_abs**	$A(b) \rightarrow \rho_{sd}(p,\theta_{sd}(l),\varphi_{sd}(l))$
Out-of-field Stray-light – systematic part **u_stray_sys**	$X(p,l,b,d)$	Diffuser reflectance temporal knowledge **u_diff_temp**	$A(b) \rightarrow \rho_{sd}(p,\theta_{sd}(l),\varphi_{sd}(l))$
Out-of-field Stray-light – random part **u_stray_sys**	$X(p,l,b,d)$	Angular diffuser knowledge- BRF effect	$A(b) \rightarrow \rho_{sd}(p,\theta_{sd}(l),\varphi_{sd}(l))$
Crosstalk **u_xtalk**	$X(p,l,b,d)$	Instrument noise and dark signal during calibration	$A(b) \rightarrow Y_{sd}(p,l,b,d)$
Deconvolution residual	$X(p,l,b,d)$	Sun irradiance model	$A(b) \rightarrow E_S(b)$
Polarisation error	$X(p,l,b,d)$	Angular diffuser knowledge -cosine effect **u_diff_cos**	$A(b) \rightarrow cos(\theta_{Sd}(l))$
ADC quantisation **u_adc**	$X(p,l,b,d)$	Straylight in calibration mode – residual **u_diff_k**	$A(b) \rightarrow K_{stl}$
Compression noise	$X(p,l,b,d)$	Sun-to-satellite distance knowledge	$d(t)$
Dark signal knowledge	$DS(p,j,b,d)$	Angular observation knowledge - cosine effect	$cos(\theta_S(i,j))$
Dark signal stability **u_ds**	$PC_{masked}(l,b,d)$	Orthorectification uncertainty propagation	$\rho_k(i,j)$
Non-linearity and non-uniformity knowledge **u_gamma**	$\gamma(p,b,d,Y)$	Spectral knowledge	$\rho_k(i,j)$
Non-uniformity spectral residual	$\gamma(p,b,d,Y)$	Geometric knowledge	$\rho_k(i,j)$
L1B Image quantisation	$CN_{k,NTDI}(i,j)$	L1C Image quantisation **u_ref_quant**	$\rho_k(i,j)$

L1 Radiometric uncertainty contributors assessment

A more detailed description of each contributors can be found in the "RUT technical guide". Three main methods that can be identified in this research:

1. The pre-flight test documentation and Instrument Characterisation and Calibration DataBase (ICCDB).
2. Post-launch info and product information
3. Novel methodologies

"Proper estimation of uncertainties, rather than over-estimation, then leads to the increased probability of detecting systematic effects which may have been overlooked in the original analysis, which in turn leads to a better understanding of the practice of spectral radiometry." (Gardner 2004).

E.g. the *Out-of-Field Stray-light systematic part* is a known systematic effect (i.e. error) and not an uncertainty contributor. Assessed as 0.3% of L_{ref} (>2% in many low radiance meas.) and verified by setting a uniform source out of the FOV (0.14% of L_{ref}). Solution→ Redefine the ref. conversion

$$\rho_k(i,j) = \frac{\pi}{E_S \cdot d(t) \cdot \cos(\theta_S(i,j))} \cdot \left(\frac{CN_{k,NTDI}(i,j)}{A_{k,NTDI}} - 0.003 \cdot L_{ref} \right)$$

RUT to account for uncertainty associated with the correction.

Model combination and validation

NPL National Physical Laboratory

Brockmann Consult

- The model follows the GUM (international standard) to combine the L1 radiometric uncertainty.

$$U(R_k(i,j))[\%] = k \cdot u(R_k(i,j)) + u_{diff\_temp}(t_{stamp}) + \frac{100 \cdot A_{k,NTDI} \cdot u_{stray\_sys}}{CN_{k,NTDI}(i,j)}$$

$$u(R_k(i,j)) = \sqrt{\left(u_{ref\_quant}/\sqrt{3}\right)^2 + u_{diff}^{\,2} + u_{gamma}^{\,2} + u_{stray}^{\,2} + u_{LSB}^{\,2}}$$

- No significant correlation between contributors simplifies the combination.

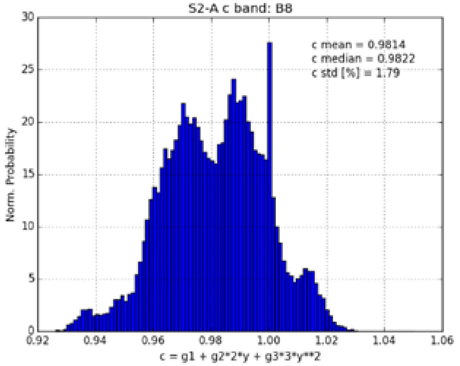
$$u_{LSB}[\%] = \sqrt{\left(\frac{100 \cdot u_{noise}}{CN_{k,NTDI}(i,j)}\right)^2 + u_{DS}^{'\,2} + u_{ADC}^{'\,2}} \qquad u_{diff}[\%] = \sqrt{u_{diff\_k}^{\,2} + u_{diff\_\cos}(t_{stamp})^2 + u_{diff\_abs}^{\,2}} \qquad u_{stray}[\%] = \sqrt{u_{stray\_rand}^{\,2} + \left(\frac{100 \cdot A_{k,NTDI} \cdot u_{x\_talk}}{CN_{k,NTDI}(i,j)}\right)^2}$$

- Normalised counts $CN_{k,NTDI(i,j)}$ obtained from pixel-level inversion using the L1C product metadata

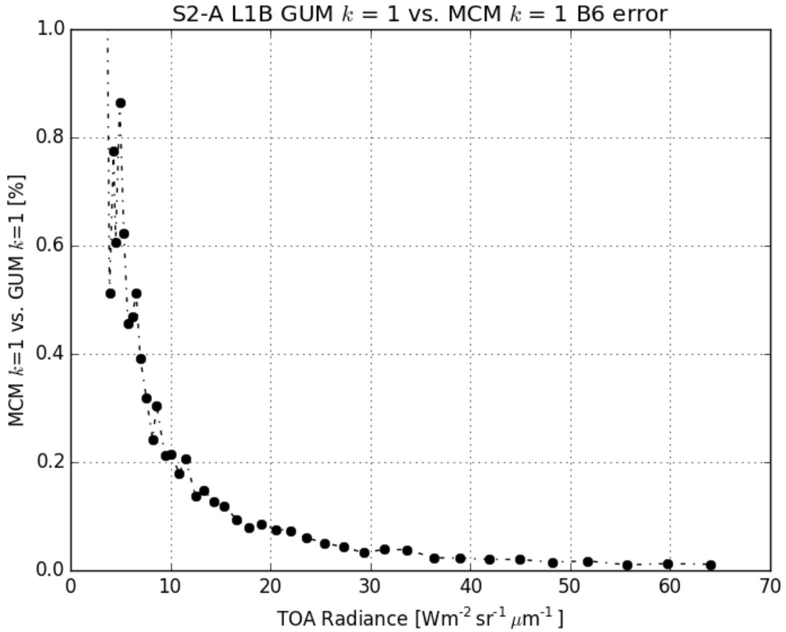
- u'_{ADC} and u'_{DS} require sensitivity coefficient c_y. Negligible→WC of 10% error of 2 contributors in the global L1 budget.

$$u'_{ADC}[\%] = \frac{100 \cdot \left(u_{ADC}/\sqrt{3}\right) \cdot c_Y}{CN_{k,NTDI}(i,j)}$$

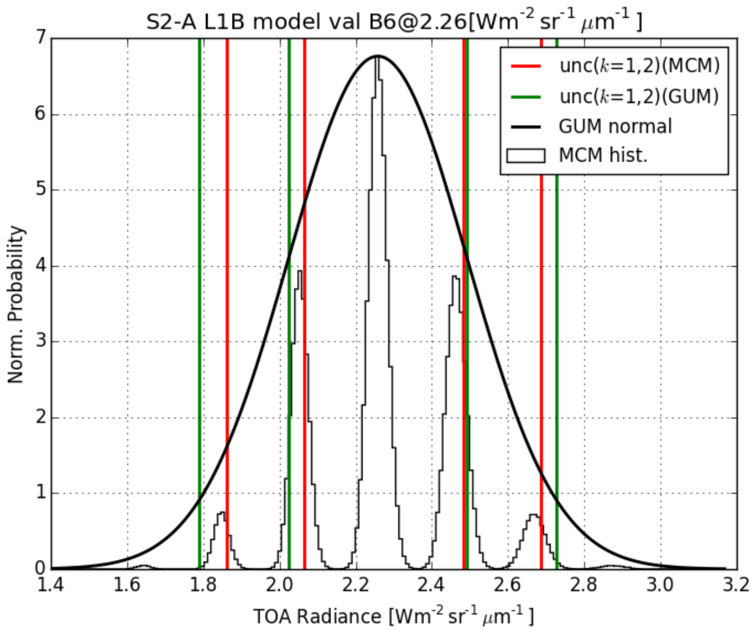
$$u'_{DS}[\%] = \frac{100 \cdot u_{DS} \cdot c_Y}{CN_{k,NTDI}(i,j)}$$

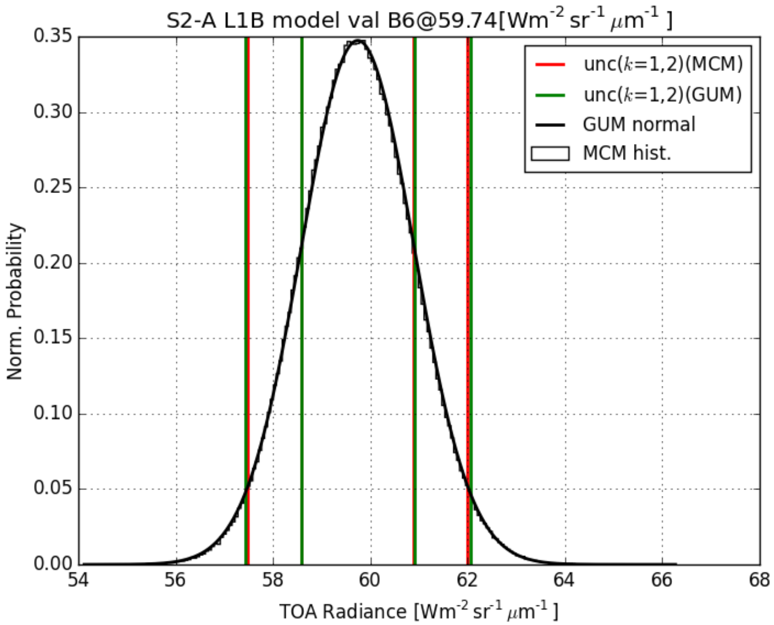


Model combination and validation



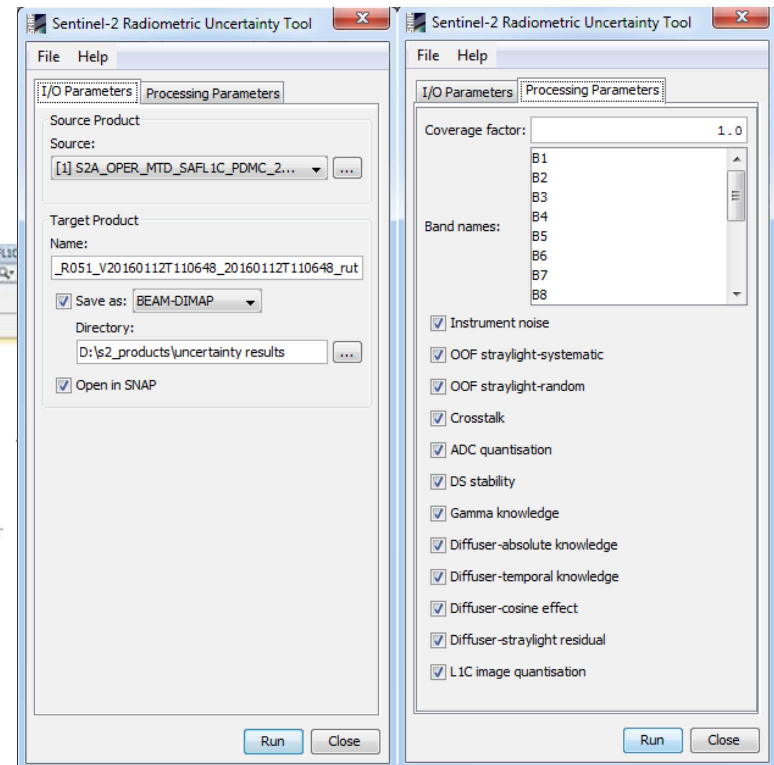
Comparison to the Monte-Carlo method determined the validity of the central limit theorem. At low radiance values, unstable distribution due to quantisation

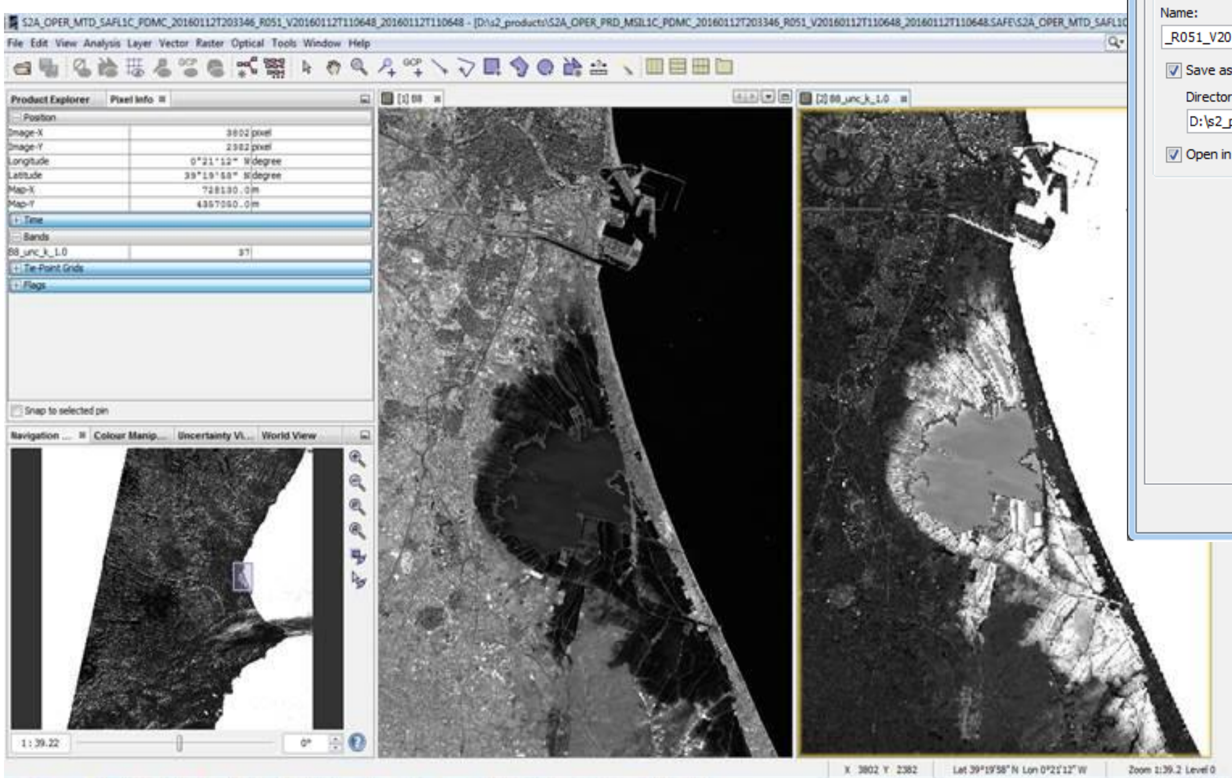




Radiometric uncertainty software implementation

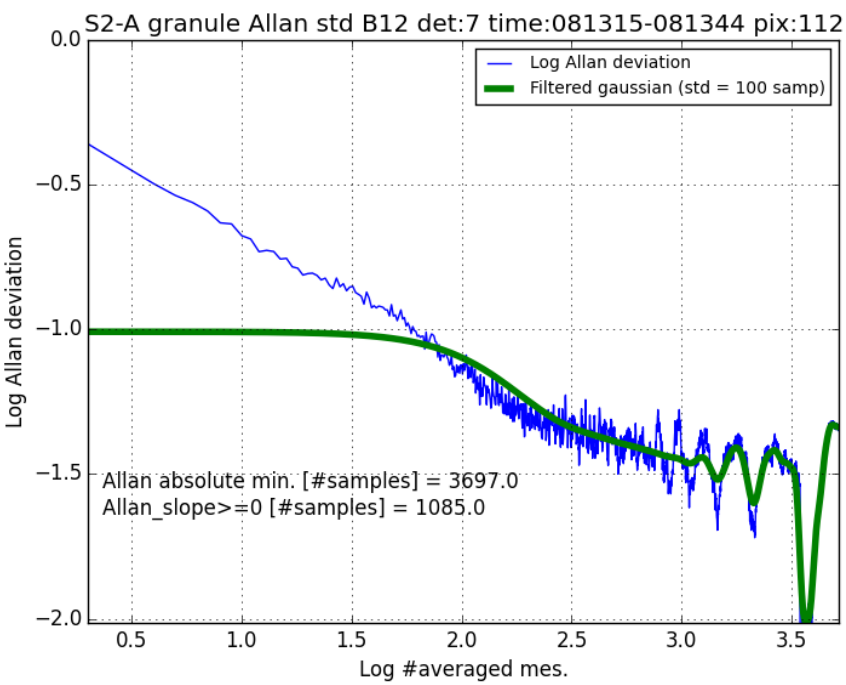
- Fully operational tool. Available for download as a plugin or to build it: https://github.com/senbox-org/snap-rut
- HTML help integrated as part of the tool

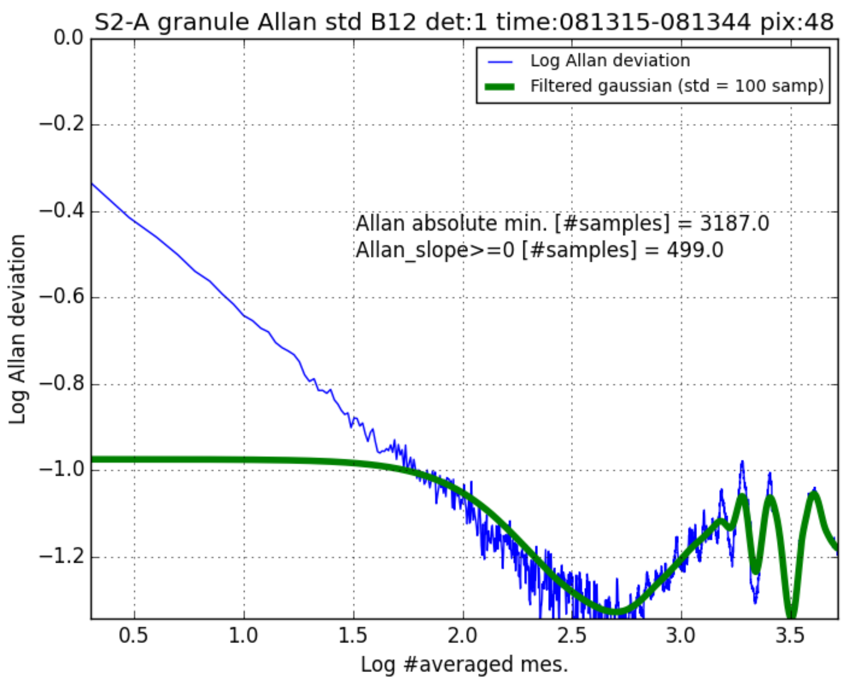




The study of the noise in-flight using the Allan deviation

- Application of the Allan deviation to the S2 dark samples showed that depending on the pixel and band, the number of uncorrelated samples varies. Potential uses
  1. Optimise pixel averaging (standard deviation of the mean validation)
  2. Study the differences and evolution of the pixel noise
  3. Internal/external measurement contingencies (e.g. temperature drift)





S2-RUT future versions

- Software consolidation
  - Move to one tile process and adapt to new product changes
  - Read of sun angular grid and rest of masks (e.g. defective pixels)
  - Further memory optimisation
  - Embedding the uncertainty in the S2 L1C product
  - Etc.

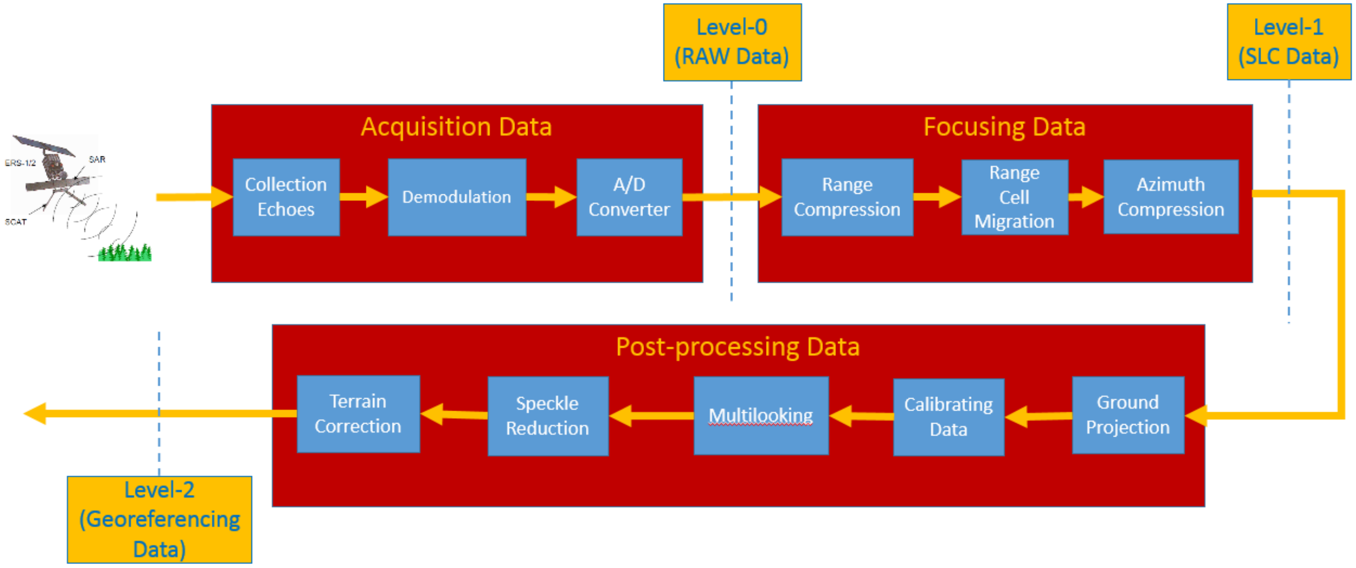
- Study and potential integration of novel uncertainty contributors: orthorectification, spectral response knowledge, polarisation…

- The investigation of the pixel covariance in the spatial, spectral and temporal domain.

Extension to other Sentinel missions

- Code and implementation structure is reusable for several EO missions.

- Extending to other Sentinel missions:
  This project supported the development of S3 OLCI uncertainty estimates.
  NPL project in the definition of SAR products uncertainty with S1 as example.

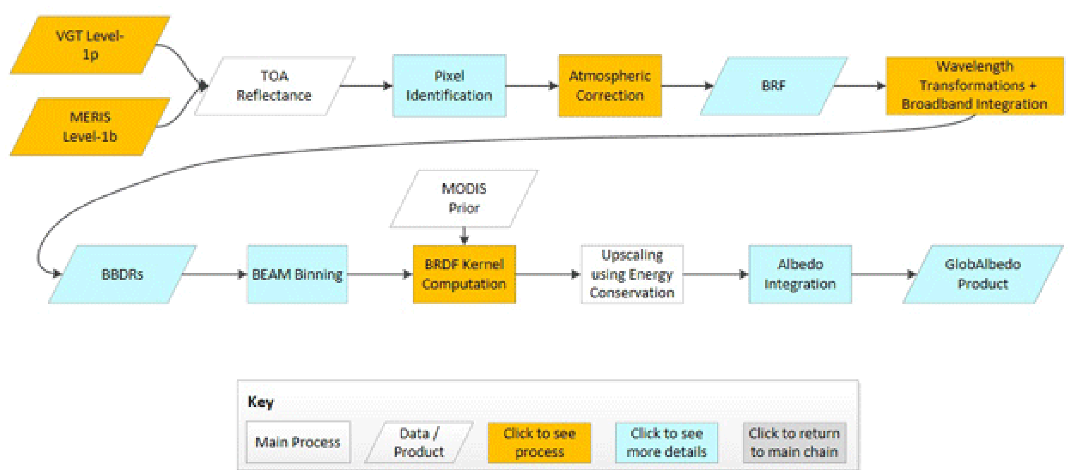


Towards a full chain uncertainty implementation

- TOA radiometric uncertainty per pixel is the first step that triggers questions as:
  Which is the uncertainty in a ROI?
  Which is the uncertainty in a L2 product?...

- ESA Projects as S2RadVal require the evaluation of an uncertainty in a ROI.

- Long-term goal: full implementation of uncertainty at any processing level and pixel combination. http://www.qa4ecv.eu/




Thanks
Questions?