S2 Radiometric Uncertainty Tool: review, status and future plan

Javier Gorroño

IDEAS+ L1 meeting, Davos (Switzerland),
8-9 December 2015

Introduction

- General framework
- L1 Radiometric Model chain
- Radiometric Uncertainty Contributors extraction
- Dark noise example
- Allan deviation
- Noise validation using the Allan deviation
- Calibration time exposure
- Uncertainty combination model validation
- RUT software implementation
- Project strategy

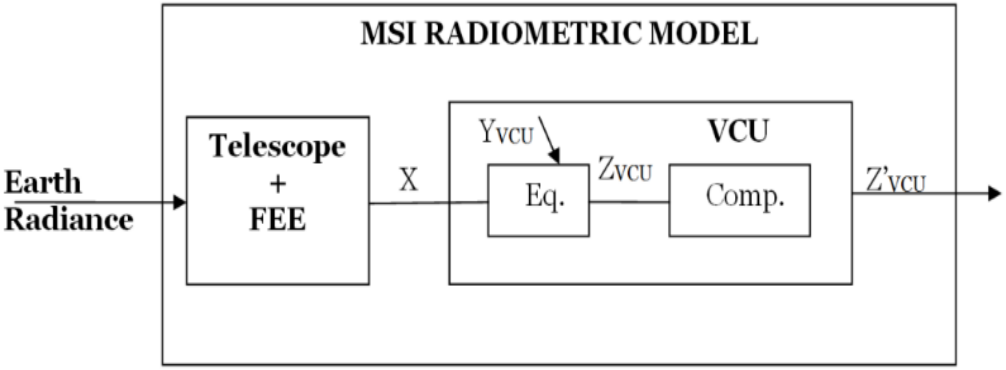
General framework

1. **Radiometric uncertainty assessment**: it brings up methodologies and theoretical concepts that can be applied to the performance and uncertainty estimation of a satellite optical sensor (e.g. Allan deviation). A conference and publication summarise most (but not only) of the work in this field so far

   Javier Gorroño ; Ferran Gascon and Nigel P. Fox" Radiometric uncertainty per pixel for the Sentinel-2 L1C products ", Proc. SPIE 9639, Sensors, Systems, and Next-Generation Satellites XIX, 96391G (October 12, 2015)

2. **Radiometric uncertainty implementation**: studies which are the best strategies to implement a tool that is operationally feasible and overcomes the associated challenges (e.g. memory solution by reading as slices).

L1 Radiometric Model chain



MSI RADIOMETRIC MODEL

Earth Radiance

Telescope + FEE

X

Y_{VCU}

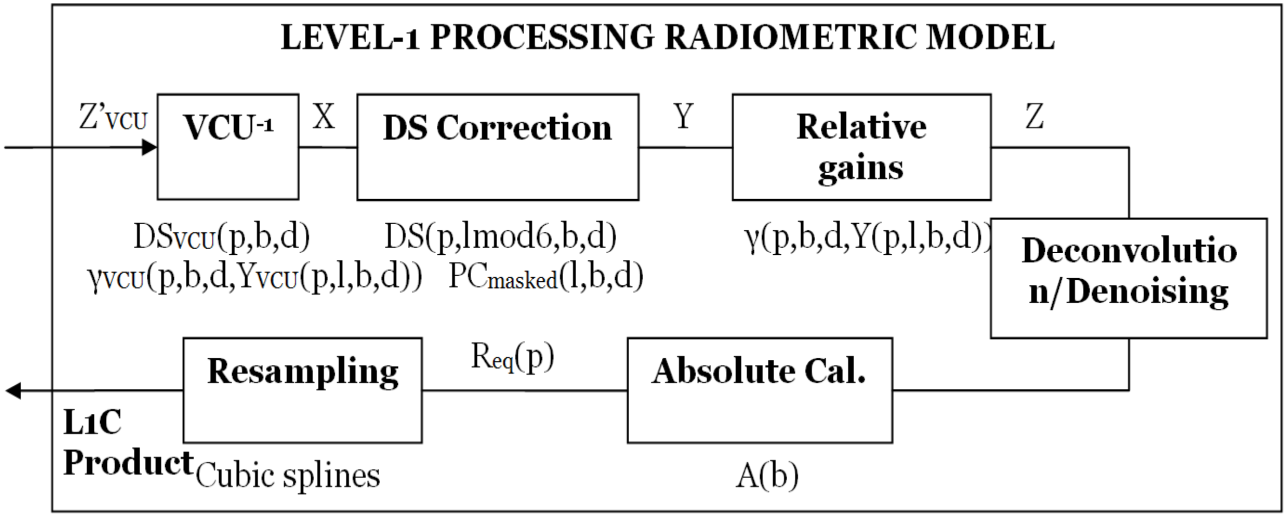
Eq.

Z_{VCU}

VCU

Comp.

Z'_{VCU}



LEVEL-1 PROCESSING RADIOMETRIC MODEL

Z'_{VCU}

VCU-1

X

DS Correction

Y

Relative gains

Z

Deconvolution/Denoising

$DS_{VCU}(p,b,d)$

$\gamma_{VCU}(p,b,d,Y_{VCU}(p,l,b,d))$

$DS(p,l\bmod 6,b,d)$

$PC_{masked}(l,b,d)$

$\gamma(p,b,d,Y(p,l,b,d))$

Resampling

Cubic splines

$R_{eq}(p)$

Absolute Cal.

A(b)

L1C Product

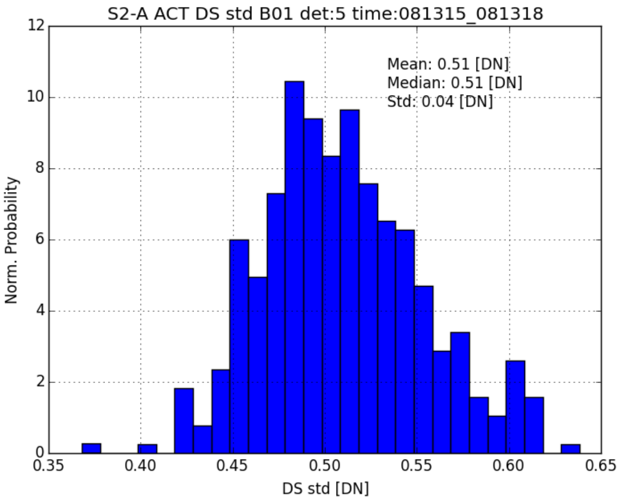
Radiometric uncertainty contributors extraction

L1B processing chain		L1C processing chain	
Contributor	**Source**	**Contributor**	**Source**
Instrument noise	$X(p,l,b,d)$	Diffuser reflectance absolute knowledge	$A(b) \rightarrow \rho_{sd}(p,\theta_{sd}(l),\varphi_{sd}(l))$
Straylight in nominal operation	$X(p,l,b,d)$	Diffuser reflectance temporal knowledge	$A(b) \rightarrow \rho_{sd}(p,\theta_{sd}(l),\varphi_{sd}(l))$
Polarisation error	$X(p,l,b,d)$	Angular diffuser knowledge-BRF effect	$A(b) \rightarrow \rho_{sd}(p,\theta_{sd}(l),\varphi_{sd}(l))$
ADC quantisation	$X(p,l,b,d)$	Instrument noise during calibration	$A(b) \rightarrow Y_{sd}(p,l,b,d)$
Compression noise	$X(p,l,b,d)$	Sun irradiance model*	$A(b) \rightarrow E_S(b)$
Dark signal knowledge	$DS(p,j,b,d)$	Angular diffuser knowledge-cosine effect	$A(b) \rightarrow cos(\theta_{Sd}(l))$
Dark signal stability	$PC_{masked}(l,b,d)$	Straylight in calibration mode - residual	$A(b) \rightarrow K_{stl}$
Non-linearity knowledge and fitting residual	$\gamma(p,b,d,Y)$	Angular observation knowledge	$cos(\theta_S(i,j))$
Non-uniformity residual	$\gamma(p,b,d,Y)$	Orthorectification uncertainty propagation	$\rho_k(i,j)$
Non-uniformity spectral residual	$\gamma(p,b,d,Y)$	Spectral knowledge	$\rho_k(i,j)$
Image quantisation	$CN_{k,NTDI}(i,j)$	Geometric knowledge	$\rho_k(i,j)$

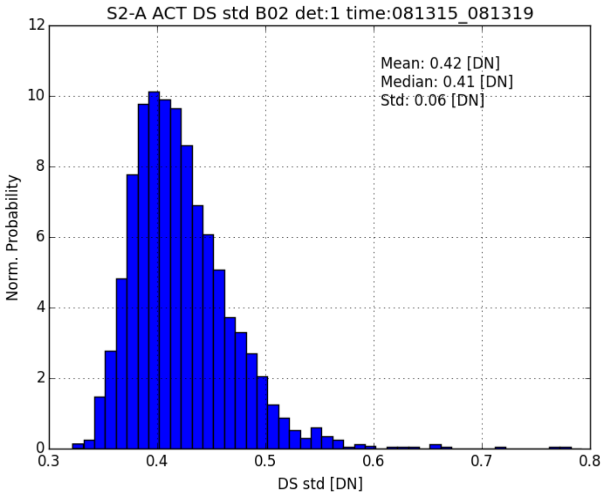
Dark noise example

1. Analysis of the standard deviation ACT the detector line.

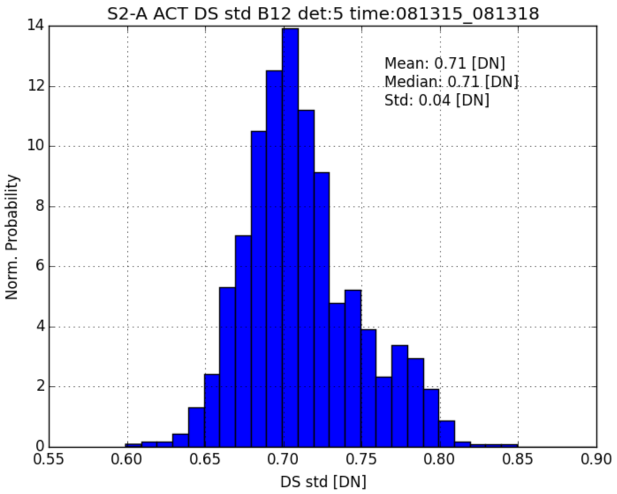
   The deviation of values ACT approximates the achievable dark signal knowledge by each pixel. Under ideal circumstances, the distribution should resemble the Poisson distribution as for the B2.


S2-A ACT DS std B01 det:5 time:081315_081318

Mean: 0.51 [DN]
Median: 0.51 [DN]
Std: 0.04 [DN]


S2-A ACT DS std B02 det:1 time:081315_081319

Mean: 0.42 [DN]
Median: 0.41 [DN]
Std: 0.06 [DN]


S2-A ACT DS std B12 det:5 time:081315_081318

Mean: 0.71 [DN]
Median: 0.71 [DN]
Std: 0.04 [DN]

2. Application of the standard deviation of the mean method.

   For 1152 samples, the application of the standard deviation of the mean to a pixel with dark noise of 0.42 LSB would results in a value of ~0.04 (0.42/√1152).

   Validation of the applicability of the concept of standard deviation of the mean.

Allan deviation

- The Allan deviation is defined as:

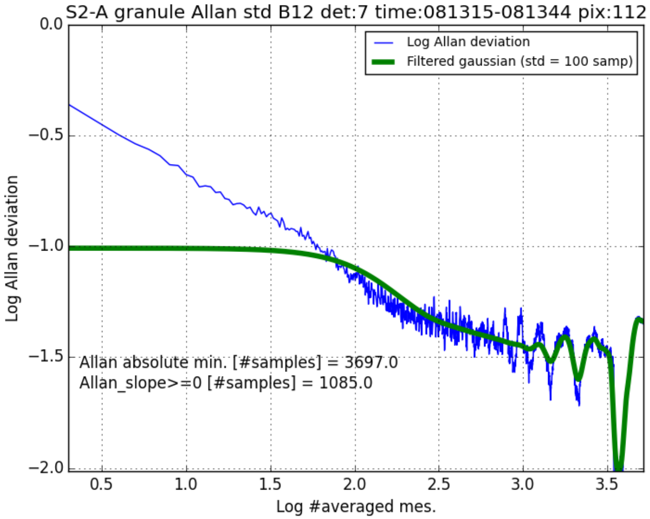
$$\sigma_y(\tau_0) = \sqrt{\frac{\sum_{i=1}^{N-1} (y_{i+1} - y_i)^2}{2 \cdot (N-1)}}$$

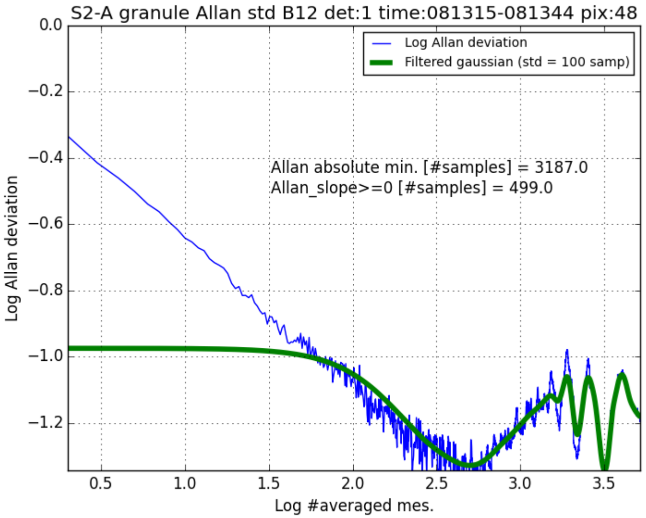
- where *N* is the number of sample bins and y_i is the average of the samples in the bin *i*.

- slope of *log(σy(samp)*) vs. the *log(samp)* type of noise:
  - -0.5 white Gaussian noise (e.g. thermal noise)
  - ~0 noise floor (e.g. 1/f noise or RTS noise)
  - slope >0 represent a long-term drift (e.g. sun angle)

Noise validation using Allan deviation

- Why using this?: in the frequency and temporal domain the noise types cannot be effectively disentangled.
- Example: if I have a noise of 1% can I say that 10000 samples will reduce it to 0.01%? (are all the samples uncorrelated?)





- Several applications:

  Automatic detection of failing pixels

  Optimisation of dark and abs. cal. Diffuser signal frames (see next)

  Evolution of random vs. systematic noise in-flight

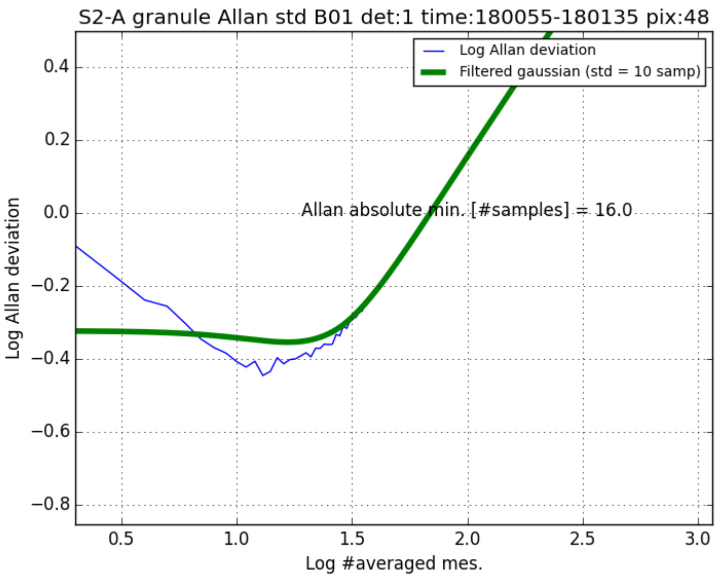
Calibration time exposure

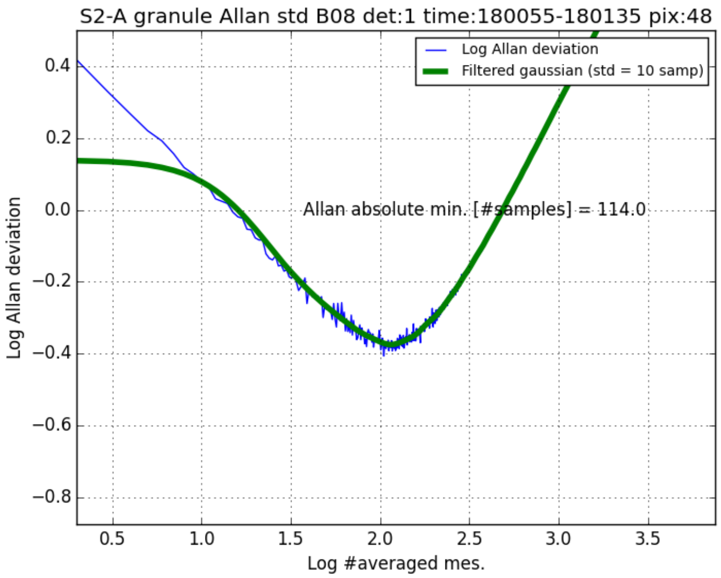
- Objective: a step-by-step methodology to assess the optimum number of diffuser samples in terms of uncertainty (absolute, relative and temp)

1. **Absolute uncertainty [A(b)]→** limit provided by the Allan deviation. The concept needs to be applied to the angular corrected samples.

$$A(b) = \frac{1}{N_p \cdot N_l \cdot N_d} \cdot \sum_{p,l,d} \frac{\pi \cdot d_{sun}^2 \cdot Y_{sd}(p,l,b,d)}{K_{slt} \cdot \rho(p,\theta_{sd}(l),\varphi_{sd}(l)) \cdot E_{sun}(b) \cdot \cos\theta_{sd}(l)}$$

Following advise from ESA, this information has been passed to the S2 MPC. Example here on the raw diffuser samples→

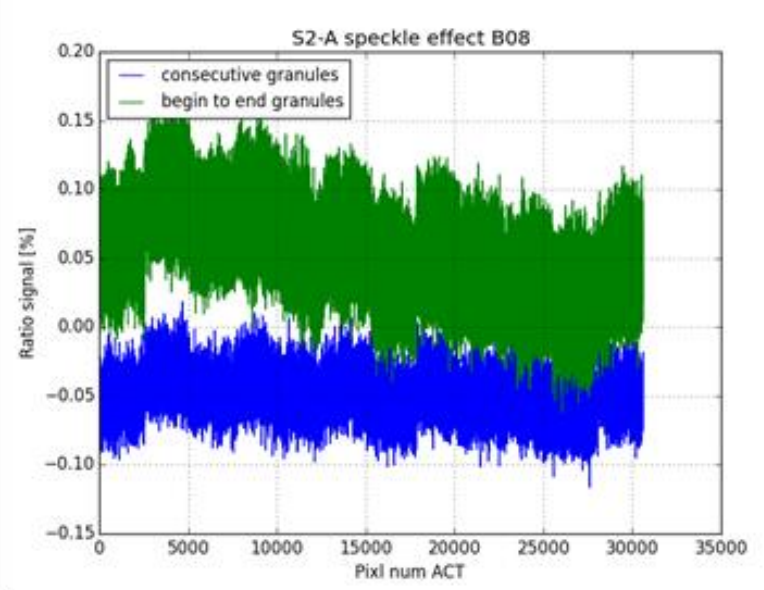

S2-A granule Allan std B01 det:1 time:180055-180135 pix:48


S2-A granule Allan std B08 det:1 time:180055-180135 pix:48

Calibration time exposure

2. **Relative uncertainty (Relative gains (γ))→** limit provided by averaging through angular motion: speckle or diffuser knowledge reduction. Initial application of the Speckle noise concept as in:

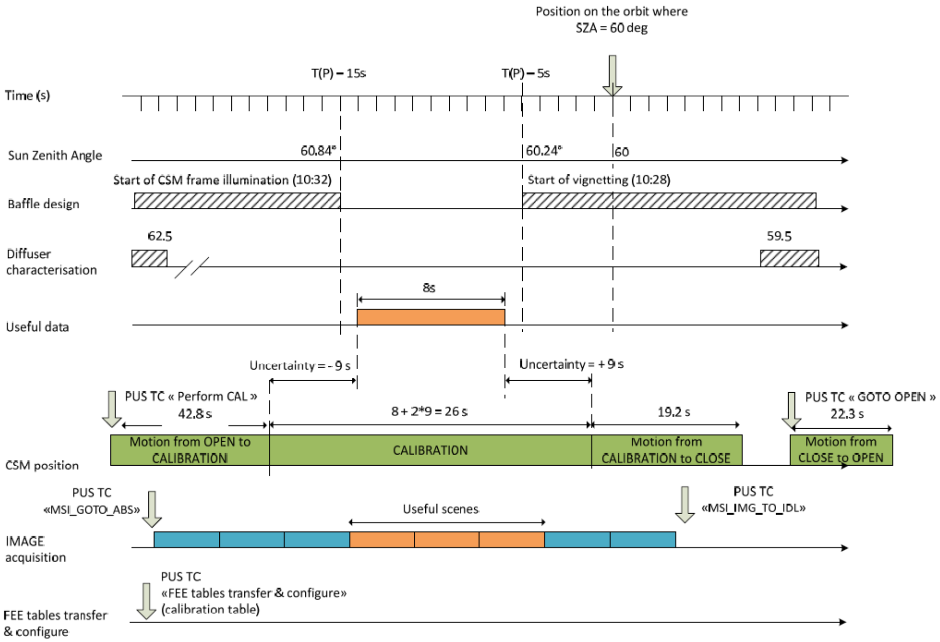
Otter, Gerard, et al. "Enhancement of Diffusers BRDF Accuracy." *ESA Special Publication*. Vol. 621. 2006.



Requirements for relative gains and absolute calibration exposure set the useful calibration time but the mechanism introduces further constraints in the calibration exposure.

Calibration time exposure

3. Temporal uncertainty [CSM mechanism]:



- Most of the diffuser exposure is related to the open/close of the diffuser (5.8s) and orbit uncertainty (18s). The useful calibration time is 8s→ a reduction of it has a limited impact in the degradation rate.
- Best degradation rate strategy for S2 mission is a minimisation of the number of calibration.
- This general methodology can be applied to other optical sensors.

Uncertainty Combination Model validation

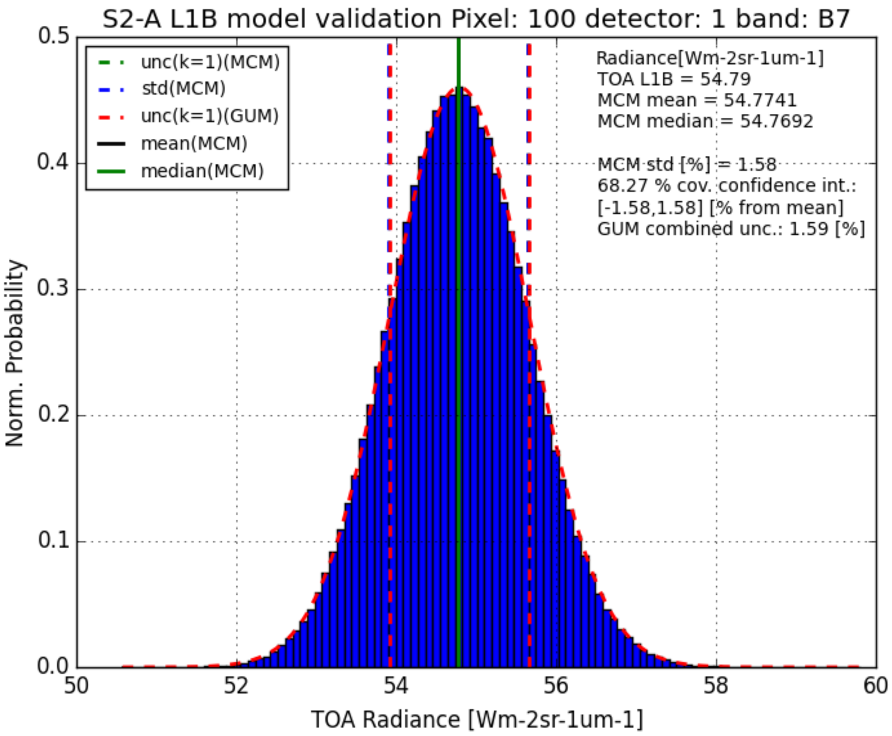
- L1B model covering the main uncertainty contributions.

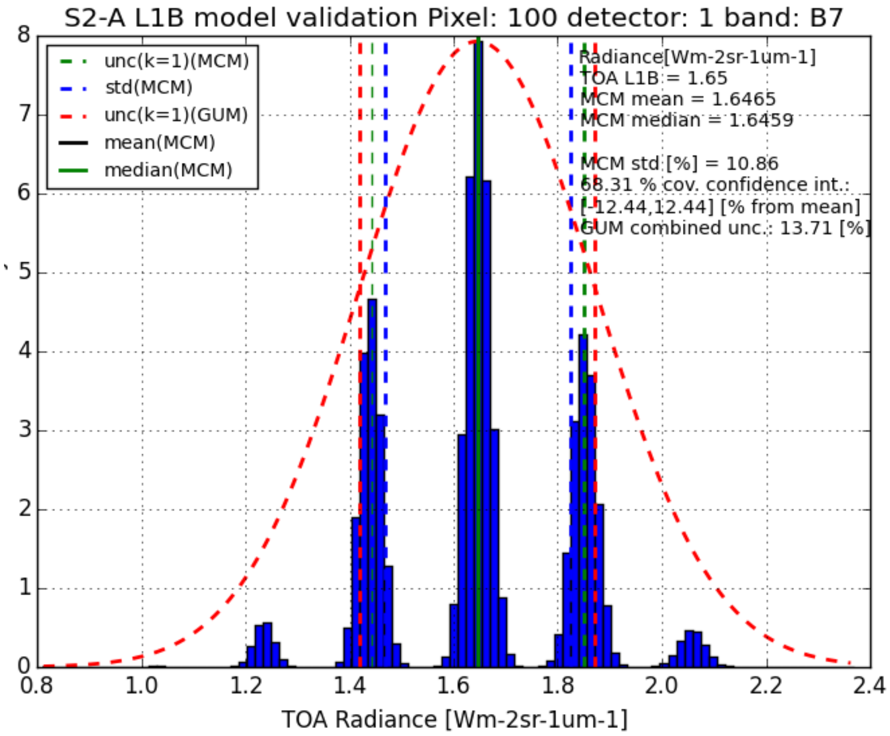
Uncertainty contributions	Value	Distribution type	Divisor
Instrument noise	As in noise model	Gaussian	**1**
Dark signal knowledge	±0.05LSB	Gaussian	**1**
Dark signal stability	±0.1LSB VNIR, ±0.24LSB B10, ±0.12 LSB B11, ±0.16LSB B12.	Rectangular	**√3**
Relative gains accuracy	Extracted from the ICCDB [%]	Gaussian	**1**
ADC Quantisation	±0.5LSB	Rectangular	**√3**
Diffuser uncertainty	As provided by CSL [%]	Gaussian	**1**
Diffuser ageing	±1% B1-B2, ±0.6% B3, ±0.4%B4-B5, ±0.2%B6-B12	Rectangular	**√3**
Diffuser angle knowledge	±0.4%	Gaussian	**1**
Kstl residual	±0.3%	Rectangular	**√3**
Z truncation	**±0.5LSB**	**Rectangular**	**√3**

- Fully automatised. Relies on the pre-flight calibration results.
- Compares the GUM approach to the Monte-carlo to understand the impact of non-linear processes e.g. quantisation, relative gains…
- Phase 2: Extension to L1C. Interpolation propagation

Uncertainty Combination Model validation

- Why this analysis?
  1. sets up a threshold and validity of the GUM *combined standard uncertainty*
  2. Alternative for the cases where GUM is not applicable





RUT software implementation

Reading:

L1C images as slices of several rows and all columns for all the 13 bands at the same time with a certain level of overlapping between each slice. Flexibility of the JPEG2000 + Python SNAP library.

Why? Three reasons:

1. Lower memory consumption.
2. Neighbourhood pixels accessible. E.g. disregard each one of the 12 modules
3. Inter-spectral information available.

RUT software implementation

Required information:

- Metadata parameters extraction (e.g. noise model)
- Consultation of quality mask (e.g. defective pixel)
- Other values are not in the L1C product must be appended in the tool

Output:

- Uncertainty values 1 byte→ 0%-25.4% step of 0.1%
- Second byte optional → systematic/random separation, warning flags (e.g. polarisation) etc.
- Result modifies the L1C → Uncertainty folder per tile

Evolution towards a QA band with uncertainty information

RUT Software implementation

National Physical Laboratory

- Github has been opened

  https://github.com/senbox-org/snap-rut
- SNAP Hackathon attendance on 15th-16th October
- Snap library fully included to read and write the S2 bands. Example how can be used:.

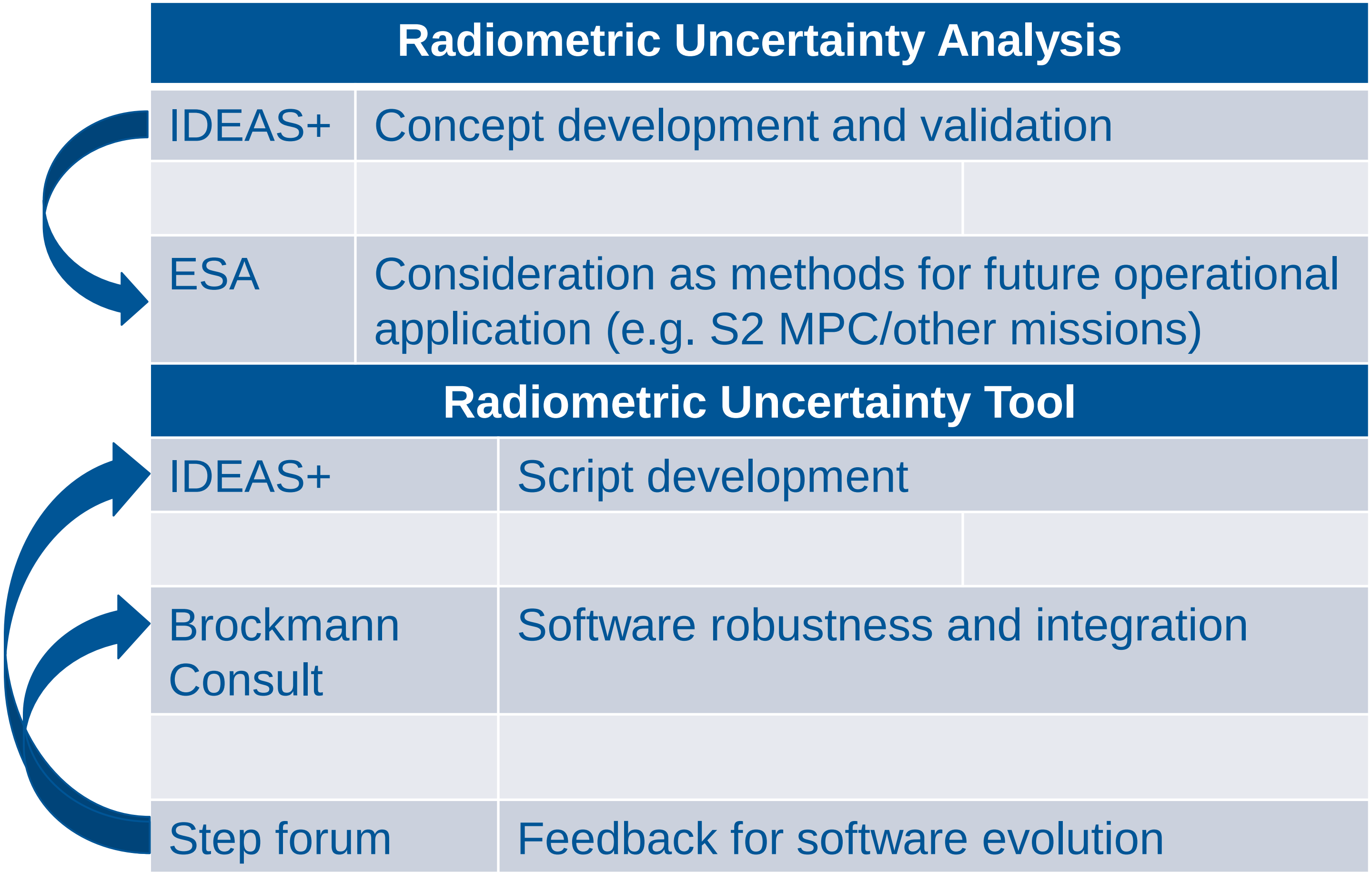
```
import snappy #it includes all the methods to readout and so on.
prod = snappy.ProductIO.readProduct('D:\s2_products\S2A_OPER_PRD_MSIL1C_PDMC_20150820T085706_R051_V20150815T110427_20150815T110427.SAFE/S2A_OPER_MTD_SAFL1C_PDMC_20150820T085706_R051_V20150815T110427_20150815T110427.xml')

names = ['B01','B02','B03','B04','B05','B06','B07','B8A','B09','B10','B11','B12']
datachunk = []
data = np.zeros(2000) #you need to predefine your ROI

for i in names:
    band = prod.getBand(i)
    band.readPixels(10000,10000,200,10,data) #readRasterData(int offsetX, int offsetY, int width, int height)
    data.reshape(200,10)#it brings back a uni-dimensional. you need reshape
    datachunk.append(data)
```

Here the uncertainty calculation can start

Project strategy



Radiometric Uncertainty Analysis	
IDEAS+	Concept development and validation
ESA	Consideration as methods for future operational application (e.g. S2 MPC/other missions)
Radiometric Uncertainty Tool	
IDEAS+	Script development
Brockmann Consult	Software robustness and integration
Step forum	Feedback for software evolution

Project strategy

Project outputs	Situation and proposal
NPL 2A- Summary Progress Report on Radiometric Uncertainty Theory and Model Validation [interim] June 2015	• *Radiometric uncertainty per pixel for the Sentinel-2 L1C products ", Proc. SPIE 96391G (October 12, 2015)* • Diffuser calibration time analysis • ICCDB comments • Presentation at CEOS WGCV IVOS, Toulouse, 19th November 2015. • SPPA webpage
NPL1 – Summary progress Report on Radiometric Performance & Uncertainty Analysis June 2016	***Part in phase 1 and in phase 2 proposal*** *The continuance of the work with one-by-one issues. E.g.:* *1. Upgrade of the model validation to L1C. Impact of a cubic interpolation vs. Lagrange in the radiometric uncertainty* *2. Detailed analysis of the spectral knowledge by using parallel processing.* *3. Algorithms and concepts for second uncertainty image byte* *Delivered as publications/conferences*
NPL 2 - Summary Progress Report on radiometric uncertainty and model validation Aug 2016	

Project strategy

Project outputs	**Situation and proposal**
NPL3A - Software Tool (V1) Dec 2015	Constant upgrade on Github with all required information. Expected consolidated v1 in March 2016.
NPL4A - Software (V1) Implementation Summary Report Jan 2016	Paper and presentation “Integration of the Sentinel-2 Radiometric Uncertainty Tool in the Sentinel Toolbox”, Prague (Czech Republic) 9-13 May 2016
NPL 3 – Software Tool (V2) (Jan 2017)	***phase 2 proposal*** • *Feedback from users* • *Evolution in the implementation of second byte of ‘uncertainty image’* • *Refinement of implementation and integration of more complex uncertainty contributors*
NPL4 - Software (V2) Implementation Summary Report Feb 2017	
NPL5 - User guide including Case Studies on RUT Applications (Jun 2017)	