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ESA Sentinel-2 Radiometric Uncertainty Tool

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{ Level 2 }

Executive summary

Sentinel-2 will provide high-resolution optical imagery in the 10-60 metre spatial resolution range for applications including urban planning, disaster management and agriculture as part of the ESA Sentinel programme. As part of the drive towards greater distribution of Quality Indicators (QI) on Earth Observation (EO) data products the ESA funded Sentinel-2 Radiometric Uncertainty Analysis Tool (S2-RUT) has been created. The S2-RUT allows users to generate uncertainty images associated with the orthorectified TOA reflectance (level 1C) products which are based on a radiometric model of the instrument and ground processing as well as an assessment of the main uncertainty sources and their combination.

The ESA Sentinel-2 (S2 hereafter) mission will be the second in a five part programme of satellites, known as the Sentinels, dedicated to the European Earth Observation Copernicus programme. The S2 mission will provide high-resolution optical observations over global terrestrial and coastal surfaces in 13 VNIR bands with spatial resolutions of 10 m, 20 m and 60 m as well as a short revisit time and a wide field of view (290 km).

For applications requiring the measured radiance values (or derivatives thereof, i.e. anything beyond qualitative information), an appropriate uncertainty value should accompany the measured value. The Sentinel-2 Radiometric Uncertainty Tool (S2-RUT) has been designed to generate radiometric uncertainty values per-pixel for S2 level 1C products to address this need. The S2-RUT is documented and defined according to the QA4EO guidelines; this means that the authors have created a mathematical model based on the radiometry of S2 Multispectral Instrument (MSI) and the ground processing chain. The main uncertainty contributions are parameterised and combined according to the law of the propagation of uncertainties defined by the Guide to the expression of Uncertainty in Measurement (GUM).

The S2-RUT software program reads the S2 level 1C image and any input arguments the user has selected (e.g. a specific band). The uncertainty analysis provides a set of uncertainty contributor values for each band at the minimum, reference and maximum MSI radiance range. These values and other metadata such as the confidence level are stored as an XML and provided as an input to the S2-RUT. The tool interpolates each uncertainty contribution over the whole radiance range. Then, the radiance level of each pixel determines its associated uncertainty value. This process is repeated for the rest of contributors which are combined to provide the level 1C uncertainty. The final uncertainty image is coded in JPEG-2000 along with metadata associated with the uncertainty calculation, which are provided as output.

The S2-RUT is applicable to end-users and data providers/processors alike. For the latter, the calculations can be considered as the base for uncertainty assessments in higher level products. Similarly, the end-users will benefit from being able to quantify the quality of the input dataset for their specific application.

The S2-RUT software design and uncertainty analysis were commissioned and funded by the European Space Agency (ESA).

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Uncertainty analysis

The MSI on-board Sentinel-2 collects and translates the radiance reflected off the Earth into a quantized signal, stored as a digital number (DN). The signal is compressed and equalised by a Video Compression Unit (VCU) and sent to a ground station. On the ground, the signal is decompressed and inversion of the equalisation is applied to recover the original signal. Following this, dark signal and non-linearity corrections are applied to each pixel, followed by conversion to top-of-atmosphere (TOA) radiances via the absolute calibration coefficients.

From each of these steps it is then possible to identify and quantify the main uncertainty contributions. At an instrument level the authors identified several sources of uncertainty such as stray-light and electrical crosstalk. At a processing level, the authors assessed the decompression as a deterministic process with a negligible uncertainty associated. The accuracy and stability of the dark signal was also factored into the uncertainty budget. Finally, the non-linearity and absolute calibration coefficients were characterised and quantified based on the associated uncertainty with the pre-flight diffuser calibration and the uncertainty associated with the on-board calibration measurement.

Through characterisation of the uncertainty components, a resulting uncertainty value is calculated following the GUM guidelines. However, the S2-RUT assumes the processes behind the uncertainty estimates are uncorrelated; it is noted that this is unlikely and future revisions will include its impact. In addition, the uncertainty contributors have been characterised based on the radiance level and spectral band. It is known that they are dependent on other parameters such as the detector, time and the positions of the pixel in the field-of-view. Future iterations will broaden the analysis to cover these factors.

Figure 1 shows an example of the reflectance uncertainty image (bottom) associated with the S2-L1C product (top). This example is based on a S2 simulated product. The figure shows that there is a significant variation in pixel uncertainty across the image. Similarly, the inverse relationship between the reflectance in the above and the uncertainty given in the lower image can be seen.

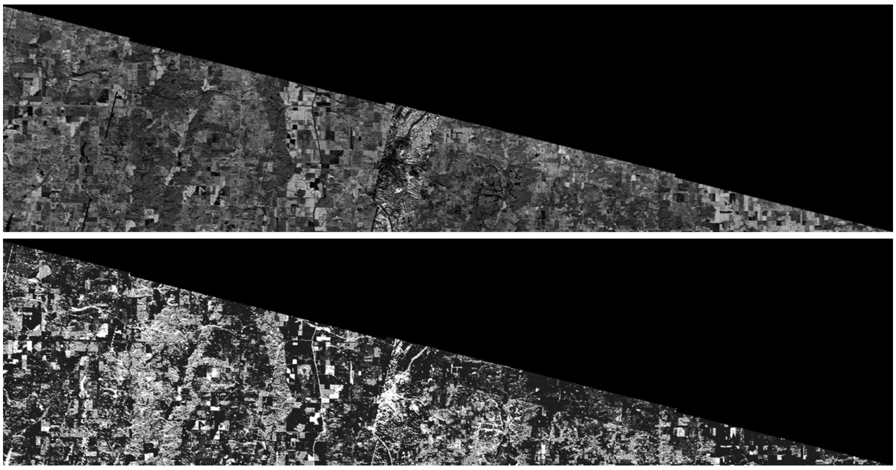

Figure 1. (Top) S2 L1-C Reflectance image from band 9 of a simulated product and (bottom) the resultant reflectance uncertainty image.

Known assumptions:

- The processes contributing to the uncertainty budget are uncorrelated (to be revised).
- Characterisation is on-going (e.g. stray-light in nominal mode likely to be corrected and optical crosstalk to be reassessed in future updates).
- Assessment at Level 1B taking into account the individual detector dependence and the subsequent propagation to Level 1C resampled and orthorectified products.

For more information on the S2-RUT please contact Ferran Gascon (ferran.gascon@esa.int); for more information on QA4EO please contact the QA4EO Secretariat (niall.origo@qa4eo.org)