Sentinel-3 OLCI/SLSTR - Validation of the Radiometric Calibration for Optical Sensors

Bertrand Fougnie
Centre national d'Etudes Spatiales, 31404 Toulouse, France (@cnes.fr)

Jens Nieke, Marc Bouvet
European Space Agency, NL-2200 Noordwjik, Netherlands (@esa.int)

Véronique Bruniquel, Ludovic Bourg
ACRI-ST, 06904 Sophia Antipolis, France (@acri-st.fr)

Dave Smith
Rutherford Appleton Laboratory, OX11 Didcot, UK (@stfc.ac.uk)

Abstract : The main objective of the SENTINEL-3 mission is to measure sea surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring. The mission will provide data continuity for the ERS, Envisat and SPOT satellites. The SENTINEL-3 mission will be jointly operated by ESA and EUMETSAT to deliver operational ocean and land observation services. Sentinel-3 will make use of multiple sensing instruments to accomplish its objectives. Two of them, OLCI (Ocean and Land Colour Imager) and SLSTR (Sea and Land Surface Temperature Radiometer), are optical sensors designed to provide a continuity with Envisat's MERIS and AATSR instruments. OLCI is based on the opto-mechanical and imaging design of MERIS instrument, i.e. a push-broom imaging spectrometer with five cameras and a total swath width of 1270 km. The acquisition is made for a spatial sampling of 300m and in 21 spectral bands from 0.4 to 1.02 microns. SLSTR is based on the design of AATSR instrument, i.e. a conical scanning imaging radiometer employing the along track scanning dual view technique for a total swath of 1420km nadir (and 750km backward). The acquisition is made for a spatial sampling of 500m (VIS-SWIR) and 1000m (MWIR, TIR) and in 9 spectral bands from 0.55 to 12 microns. The first Sentinel-3A satellite will be launched in late 2015. During the commissioning phase lasting approximately 5 months, in-orbit calibration and validation activities will be conducted. Instrument will be recalibrated and recharacterized in-orbit particularly using on-board devices which include diffusers (OLCI, SLSTR) and black body (SLSTR). We present here the vicarious calibration methods that will be used in order to validate the OLCI and SLSTR radiometry for the reflective bands. It is expected to check the calibration over Rayleigh scattering, sunglint, desert sites, Antarctica, and tentatively deep convective clouds. For this, tools have been developed and/or adapted (S3ETRAC, MUSCLE). Based on these matchups, it will be possible to provide an accurate checking of absolute and interband calibrations, the trending correction, the behavior within field-of-view calibration, and more generally this will provide an evaluation of the radiometric consistency for various type of targets. The cross-calibration will also be checked with many other instruments such as MERIS, AATSR, MODIS, as well as Sentinel-2.

1. INTRODUCTION

We describe in this paper the methodology that will be used to validate once in-orbit the radiometry of the coming Sentinel-3 optical sensors, OLCI (Ocean and Land Colour Imager) and SLSTR (Sea and Land Surface Temperature Radiometer).

2. SENTINEL-3 Mission and Sensors

2.1 The Sentinel-3 Mission

The main objective of the SENTINEL-3 mission, one major piece of the European Copernicus Space program, is to measure sea surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring. The mission will provide data continuity for the ERS, Envisat and SPOT satellites. The SENTINEL-3 mission will be jointly operated by ESA and EUMETSAT to deliver operational ocean and land observation services. Sentinel-3 will make use of multiple sensing instruments to accomplish its objectives, among which altimeter, imager, and radiometer. The first Sentinel-3A satellite will be launched in late 2015 on an 815km and 27-days cycle orbit for observations at a 10:00 local equatorial crossing time. Sentinel-3B will join the same orbit in 2017 but separated by 180°. For both satellites, the nominal lifetime is 7.5 years and they will be replaced at term by Sentinel-3C and 3D satellites.

2.2 Sentinel-3 Optical Sensors

Two of the Sentinel-3 sensors are optical sensors : OLCI, for Ocean and Land Colour Imager, and SLSTR, for Sea and Land Surface Temperature Radiometer. These instruments are designed to provide continuity with Envisat's MERIS and AATSR instruments respectively. OLCI is based on the opto-mechanical and imaging design of MERIS instrument, i.e. a push-broom imaging spectrometer with five cameras and a total swath width of 1270 km.[(1)] The acquisition is made for a spatial sampling of 300m and in 21 spectral bands from 0.4 to 1.02 microns. SLSTR is based on the design of AATSR instrument, i.e. a conical scanning imaging radiometer employing the along track scanning dual view technique for a total swath of 1420km nadir (and 750km backward).[(2)] The acquisition is made for a spatial sampling of 500m (VIS-SWIR) and 1000m (MWIR, TIR) and in 9 spectral bands from 0.55 to 12 microns.

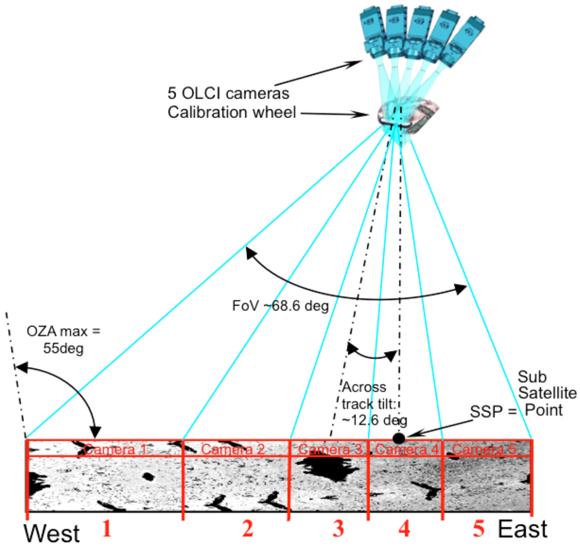

Figure 1. OLCI viewing configuration (cross-track)

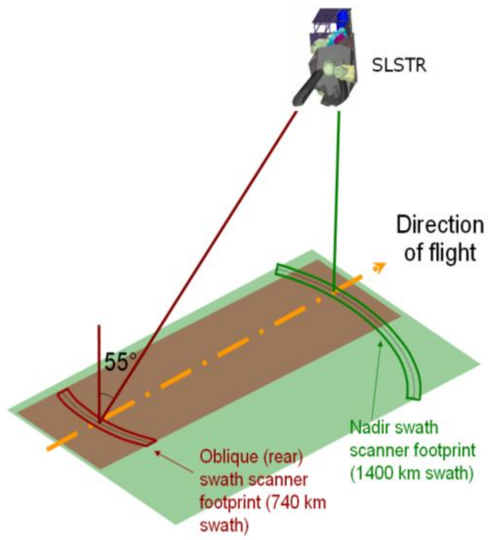

Figure 2. SLSTR viewing acquisition (2 scans)

2.3 Nominal calibration

OLCI and SLSTR will be equipped with on-board calibration devices. These calibration supplies are similar to those of MERIS and AATSR which were crucial to reach a high level of radiometric quality.

For OLCI, one calibration wheel is placed in front of the instrument in order to view, alternatively to the Earth view, one spectral diffuser, one nominal calibration diffuser, and one degradation monitoring diffuser. The spectral diffuser is made by an Erbium-doped “pink” panel which will be used, as for MERIS, to check the spectrometer spectral response and if necessary to determine the adjustment of the spectral bands.[(3)] The nominal diffuser, made by an optical PTFE panel, will be used every 2 weeks to check the calibration within the field-of-view, and adjust the absolute reflectance-based calibration.[(4)]The secondary diffuser, identical to the nominal one, will be used every 3 months to monitor the degradation of the nominal diffuser.[(4)]

For SLSTR, and as it was done for AATSR, a VISCAL calibration unit will be used every orbit to calibrate and monitor the reflective bands.[(5)] The diffuser is made with the same material as for the OLCI diffuser. Thermal bands will be calibrated for every scan using two black bodies, hot and cold, at about 305°K and 265°K respectively.[(5)]

3. VALIDATION OF THE RADIOMETRY

Even if the nominal calibration will perform a high level of accuracy, it is very useful to perform additional checking of the radiometry through alternative methods in order to identify as soon as possible anomalies or errors, but also more generally to help the setting of the in-flight characterization. Analyse the radiometry using different approaches is a good way to try to isolate signatures that could be not accessible through the nominal calibration. The validation proposed here is a direct heritage of the activity conducted on MERIS[(6)]. It is based on the combination of various vicarious methods using natural targets. The approach is statistic. Vicarious methods proposed here are now very experienced on many Earth Observing sensors such as MERIS, POLDER, PARASOL, MODIS, SeaWiFS, Végétation, Landsat, Pleiades…

4. CALIBRATION METHODS AND MEASUREMENTS

4.1 Inter-Calibration and trending over desert sites

Pseudo-invariant calibration sites, especially desert sites, are fully relevant for cross-calibration and monitoring. The method was recently described in Lachérade et al. (2013).[(7)] The idea is to use desert sites selected for their stability with time, their spatial homogeneity, and their favourable clear sky conditions. Twenty desert sites in Africa and Arabia are considered. In a statistical approach, all possible observations from 2 sensors are matched when they correspond to the same viewing geometries, but not necessarily the same acquisition date. Then, for each pair of measurements and starting from the reference sensor, the surface reflectance spectrum is derived after an atmospheric correction step. Afterward, top-of-atmosphere (TOA) reflectances are computed for the sensor to calibrate, considering for each band the corresponding spectral response. The comparison to the real measurement provides the calibration estimation. The typical accuracy is estimated to about 1-2%, but may strongly depend on spectral bands and consistency of the matchup dataset.[(7)-(8)]

OLCI and SLSTR data will be collected over these 20 desert sites. After a dedicated cloud screening, TOA reflectances will be spatially averaged over the site. This pre-processing first step will be performed by a devoted tool called S3ETRAC.[(9)] Data will be inserted into the SADE database and processed using the MUSCLE toolbox. Through desert sites, it will be possible to cross-calibrate OLCI with SLSTR, but also OLCI with MERIS, SLSTR with AATSR, OLCI with MSI (Sentinel-2 sensor), and many other combinations.

4.2 Inter-Calibration and trending over snowy sites

Other pseudo-invariant calibration sites can be found on snowy surfaces. Among them, some sites are very relevant for calibration in Antarctica. The so-called Dome sites provide very interesting geophysical properties.[(10)] For polar orbiting sensors, they can be viewed many times a day. The only limitation is the period of observation which is reduced to only 3 months a year. The same methodology will be used as for desert sites, i.e. geometrical matching and spectral interpolation as described in Lachérade et al. (2013).[(7)] OLCI and SLSTR data will be collected over 4 sites around Dome-C and processed as for desert sites.

4.3 Absolute calibration over Rayleigh scattering

This method considered since early nineties is since then in permanent improvement.[(11)-(12)] The principle is to observe for atmospheric molecular scattering over dark surface, i.e. the oceanic surface. Consequently, a very careful selection has to be perform in order to discard acquisitions corresponding to turbid atmospheric conditions (aerosol load greater than the background level), as well as turbid oceanic conditions (no whitecap, stable and homogeneous oligotrophic waters according Fougnie et al., 2010).[(13)] In such conditions, the signal observed from bands 410 to 670nm is composed by about 90% of Rayleigh scattering which is very accurately predictable. Other contributors are the oceanic surface, the aerosol background (using NIR band), and gaseous absorption. The typical accuracy of the method is estimated at about 2-3%, but may depend on various parameters and on the considered spectral band. This method is a statistical approach and appears to be a very good way to validate at a global spatial and temporal scale the final vicarious adjustment using in-situ measurements which is still required for ocean color applications.

OLCI and SLSTR data will be collected over 6 main oceanic sites. After a dedicated cloud screening, TOA reflectances will be spatially undersampled to a 7x7km² resolution. This pre-processing first step will be performed by S3ETRAC and data will be inserted on SADE then processed by MUSCLE.

4.4 Inter-band calibration over sunglint

This method was initially developed for POLDER and VEGETATION calibrations (Hagolle et al., 1999 and 2004).[(14)] The approach is to use the sunglint reflectance as a white contribution to intercalibrate all bands, from blue to SWIR bands. One spectral band is considered as reference to estimate the sunglint contribution. Other contributions are, like for Rayleigh calibration, the molecular scattering and some other minor contributors (marine reflectance, gas, background aerosol). The major interest of this method is the ability to efficiently propagate the calibration of one visible band (e.g. band 670nm) to all other bands, and particularly NIR and SWIR bands which are crucial for ocean color atmospheric corrections. The typical accuracy is close to 1%.

OLCI and SLSTR data will be collected over 6 main oceanic sites. A dedicated cloud screening will be applied on the Reduced Resolution TOA reflectances. This pre-processing first step will be performed by S3ETRAC, inserted on SADE then processed by MUSCLE.

4.5 Other calibration methods

Data would be also collected over deep convective clouds targets (DCC) a very powerful calibration target that can be sometimes assimilated to a white diffuser plate placed at the top-of-atmosphere in front of the instrument as described in Fougnie and Bach (2009).[(15)] The cloud screening and pre-processing could be made through S3ETRAC, SADE and MUSCLE even if the development are not currently made.

5. RADIOMETRIC ASPECT TO BE ANALYZED

What can be learned through these combination of statistical vicarious calibration methods ? We provide here a non-exhaustive list of radiometric aspect that will be covered through these methods.

5.1 Trending of the radiometric sensitivity

Month after month, a collection of data will be collected and it will become possible to check the consistency of the radiometry with time. If the calibration trending is well corrected through the nominal calibration and processing, the time series would show a perfectly stable radiometry. This aspect can be assessed through desert sites as show hereafter for the MERIS example.

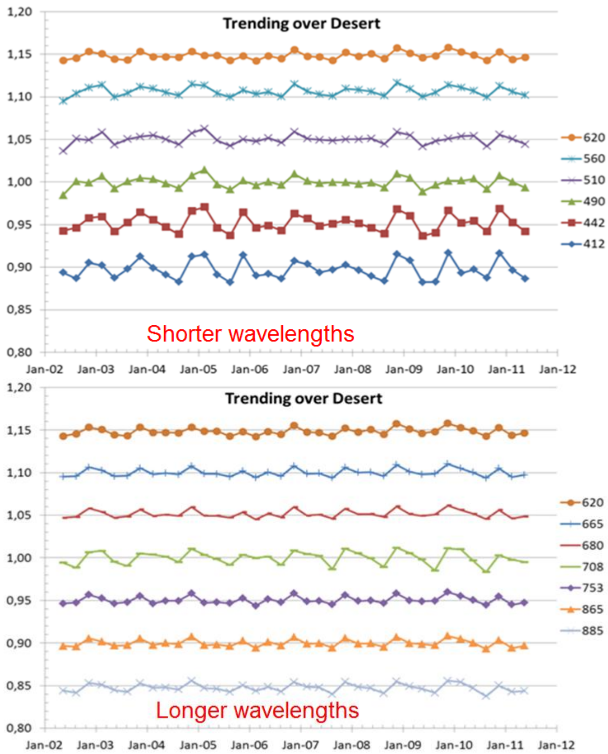

Figure 3. Time series of calibration over desert sites for all MERIS bands. Series are shifted up/down for clarity.

5.2 Trending of the interband calibration

If degradation occurs in the sensor, it is highly unlikely that all bands vary with exactly the same trend. As a consequence, the interband calibration will change with time. This would be corrected through the nominal calibration. But calibration over natural targets is sometimes very efficient in term of inter-band estimation. As a consequence, check or estimate the interband trending is a proxy to the absolute trending.

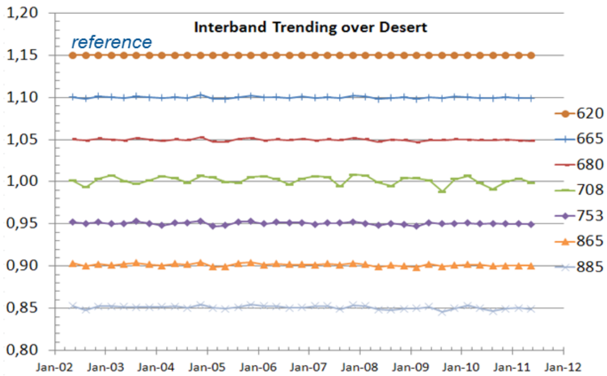

Figure 4. Time series of the inter-band calibration calculated over desert sites for near infrared MERIS bands using the 620nm as the reference band.

As shown here for desert sites, the interband time series for MERIS, computed over desert sites, becomes nearly perfectly stable with a very small month-to-month variation (here about 0.1-0.2% for near infrared bands). This result can be checked using other method as for instance the calibration over sunglint. The result is not so nice as for desert, but it is a fully independent way to validate the consistency.

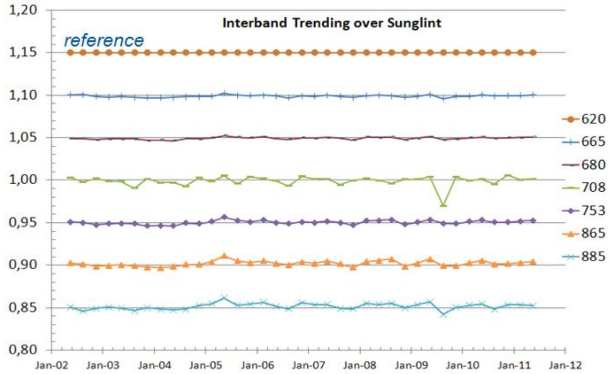

Figure 5. Time series of the inter-band calibration calculated over sunglint for near infrared MERIS bands using the 620nm as the reference band.

As shown by Fougnie and Bach (2009)[15], it could be foreseen better result based on the use of deep convective clouds. This will be hopefully implemented for OLCI.

5.3 Calibration within the field-of-view

Calibration methods provide data that were acquired for many different part of the field-of-view of the instrument, pixel, detector or camera number. If results are analysed versus the viewing angle, it is possible to check the radiometric consistency.

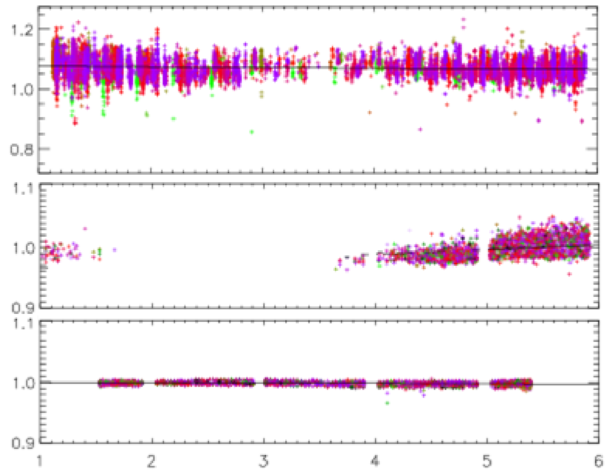

Figure 6. Calibration versus the camera/pixel number for the MERIS band at 620nm, as seen by desert sites (up), Rayleigh scattering (middle), and clouds (bottom).

It is crucial to check that every calibration method is able to observe the same behaviour, and if not, to understand why. This could be the sign of a radiometric inaccuracy on the system (of course after a double checking that there is no processing error).

5.4 Interband calibration

Whatever the absolute calibration, it is very useful to check the spectral radiometric consistency between all bands. This is possible through desert sites or sunglint as shown here based on MERIS and MODIS examples.

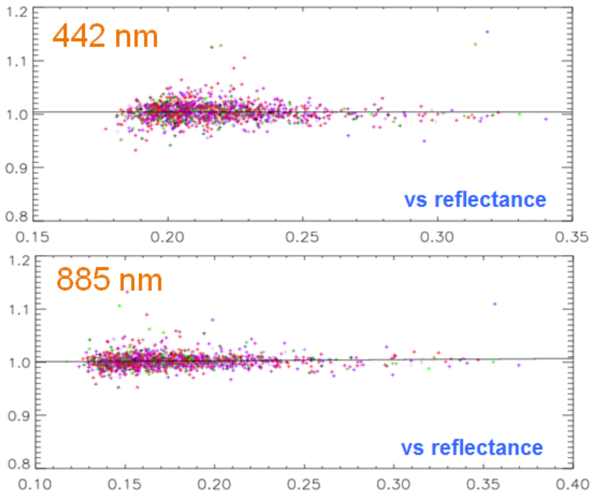

Figure 7. Interband calibration versus the observed reflectance for the MERIS bands at 442 (up) and 885nm (bottom) as seen over sunglint assuming the 620nm band as reference.

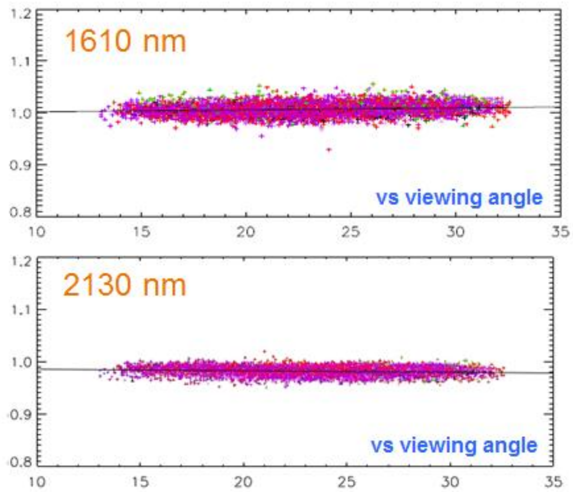

Figure 8. Interband calibration versus the observed reflectance for the MODIS bands at 1610 (up) and 2130nm (bottom) as seen over sunglint assuming the 670nm band as reference.

It will possible to check the interband calibration over the whole reflective spectral domain. In addition, as shown by Fougnie and Bach (2009)[15], it could be foreseen better result for the visible and near-infrared bands based on the use of deep convective clouds. This will be hopefully implemented for OLCI.

5.5 Consistency between sensors

The consistency between various sensors is sometimes crucial for many applications. It is also a precious information to evaluate the radiometric gaps that may exist between sensors. Pseudo-invariant calibration sites are very convenient and it will possible to evaluate the cross-calibration over desert and snowy sites. This evaluation will be done between Sentinel-3 optical instruments, i.e. between OLCI and SLSTR, but also with MERIS and AATSR in order to contribute to the continuity with historical Envisat missions. Other references will be used, such as MODIS. It will be also possible to check consistency between Sentinel-2/MSI and Sentinel-3 sensors in a more general Copernicus framework.

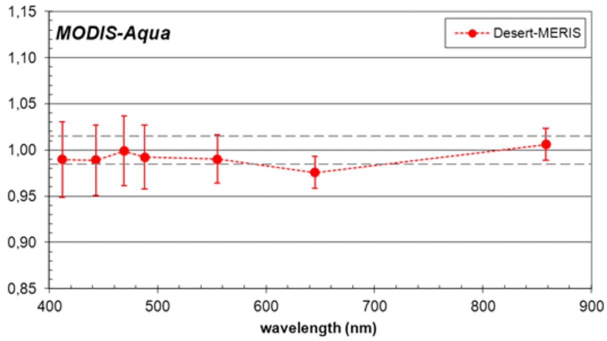

Figure 9. Cross-calibration between MODIS-Aqua and MERIS as a function of wavelength computed over desert sites.

5.6 Absolute calibration

Finally, the adjustment of the absolute calibration can be investigated through a combined analysis or results from all methods. Even if the accuracy of individual method is not good enough to be able to conclude, the synergic use of all methods could provide confidence on the overall absolute calibration or provide useful information to propose a readjustment.

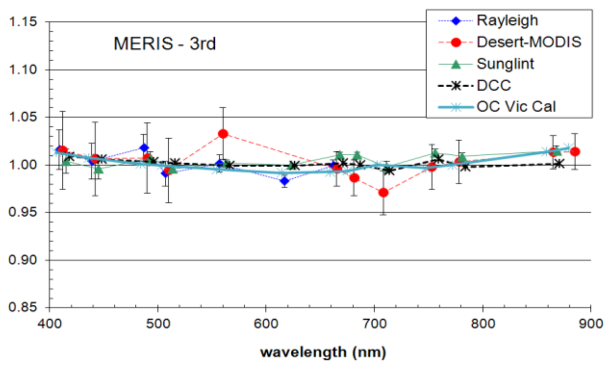

Figure 10. Summary of results obtained through various methods, Rayleigh, desert, sunglint, clouds, in the case of the MERIS 3rd reprocessing. Ocean color system vicarious calibration based on in-situ measurements is also provided for comparison.

6. CONCLUSION

A strategy is proposed to validate the radiometry for the Sentinel-3 optical sensors. The approach is based on the combination of various calibration methods using on natural targets. These methods were developed and already experienced on various sensors. Sentinel-3 data will be extracted through a S3ETRAC tool, inserted on the SADE data base, then processed on the MUSCLE calibration environment. Various radiometric aspects will be analysed, such as interband calibration and tending, calibration within the filed-of-view, absolute calibration and trending. Other radiometric behaviours, such as straylight, linearity, saturation… could be more indirectly analysed because of their specific signatures on calibration matchups.

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