CEOS WGCV 41
ESA report

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Sensor Performance Product Algorithm Section

ESA report outline

- Missions status
  - Sentinel-1
  - Sentinel-2
  - Sentinel-3
  - Sentinel-5P
  - Proba-V

- Fiducial Reference Measurements Activities

Sentinel-1

Sentinel-1 full mission exploitation capacity based on the routine operations of the 2-satellite constellation
➔ gradually achieved

S1 Mission Routine Operations

S1 Mission Operations Qualification

S1A Routine Operations

S1A Operational qualification

S1A Space Segment Commissioning

S1B Space Segment Commissioning

S1A-Launch
3 April 2014

S1A IOCR
Sep 2014

1st S1A ROR
9 June 2015

S1B Launch
25 April 2016

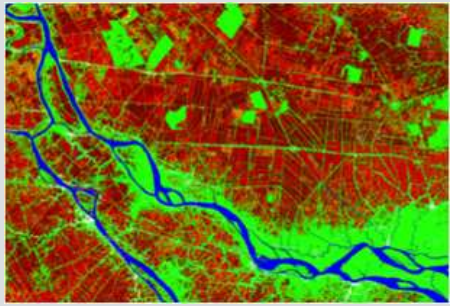
S1B IOCR
Sep 2016

S1 Mission ROR
~ early 2017

Sentinel-1 mission status

➢ Sentinel-1A **nominal routine operations continue**

- An average of **3 TB of products** is generated daily
- Support to various activations from the Copernicus Emergency Service and from the International Charter Space and Major Disasters
- Many promising results based on S1A data obtained in various application fields and from institutional, scientific, commercial players



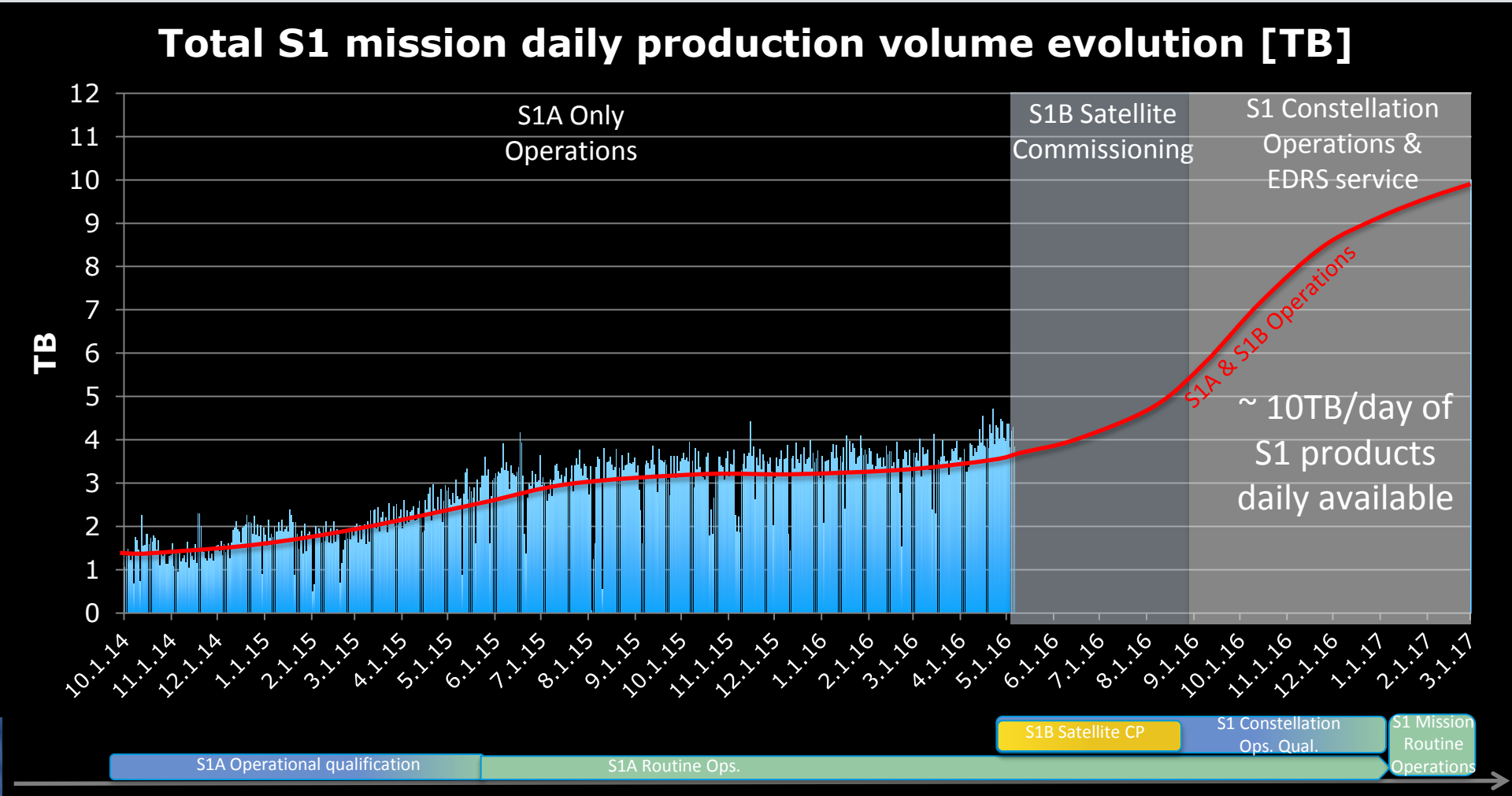
➢ Sentinel-1B **commissioning activities in-progress**

- First SAR data acquired and successfully processed less than 3 days after launch
- Commissioning activities on-going according to plans
- Start of Sentinel-1B operations after the In-Orbit Commissioning Phase Review (IOCR), planned on 14 September 2016

Sentinel-1 operations capacity evolution

S1 mission capacity will increase with S1B in operations and the integration of the EDRS service

Estimated daily volume of S1 core products in early 2017 is **10 TB / day**

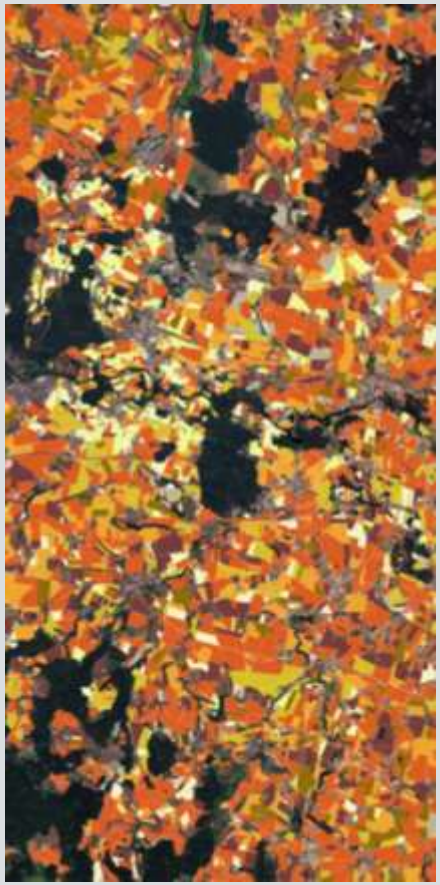


Sentinel-1

- Sentinel-1 has already proved to be a very relevant source of data for land cover monitoring

- Sentinel-1A routinely provides since end 2014 a full mapping of Europe (EU/ESA/EEA-39):
  - Every 12 days both in ascending and descending orbits, in dual polarisation VV+VH
  - In practise, depending on latitudes / swath overlaps, more frequent coverage is ensured in Europe

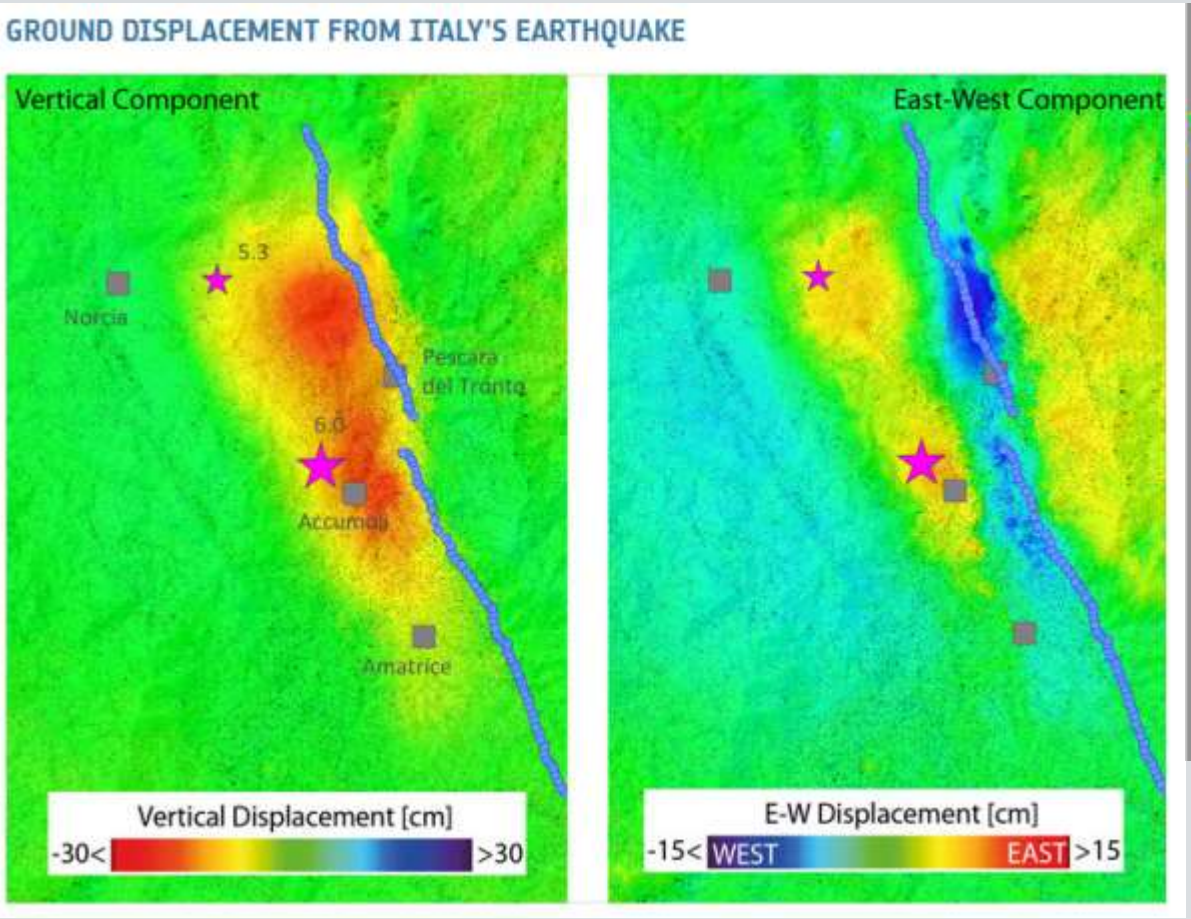
- Sentinel-1B will allow to increase this European coverage by a factor 2, ie the S1 constellation will provide a full coverage at least every 6 days, both in ascending and descending orbits

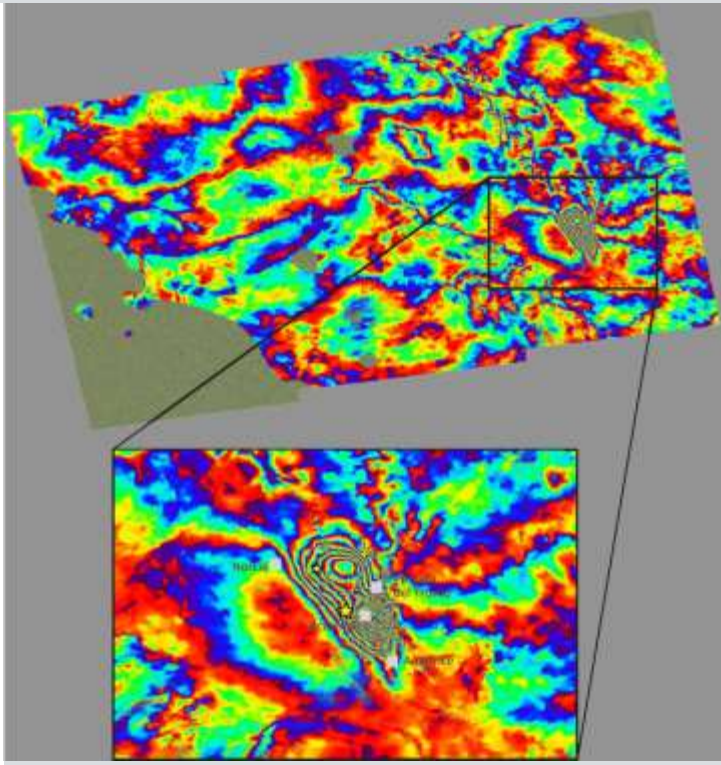


→ Dedicated presentation on Cal/Val on Wed. 7th.
Sentinel-1 SAR Constellation Instrument Calibration and Performance Verification, I. Navas-Traver et al

Sentinel-1

http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-1/Sentinel-1_provides_new_insight_into_Italy_s_earthquake

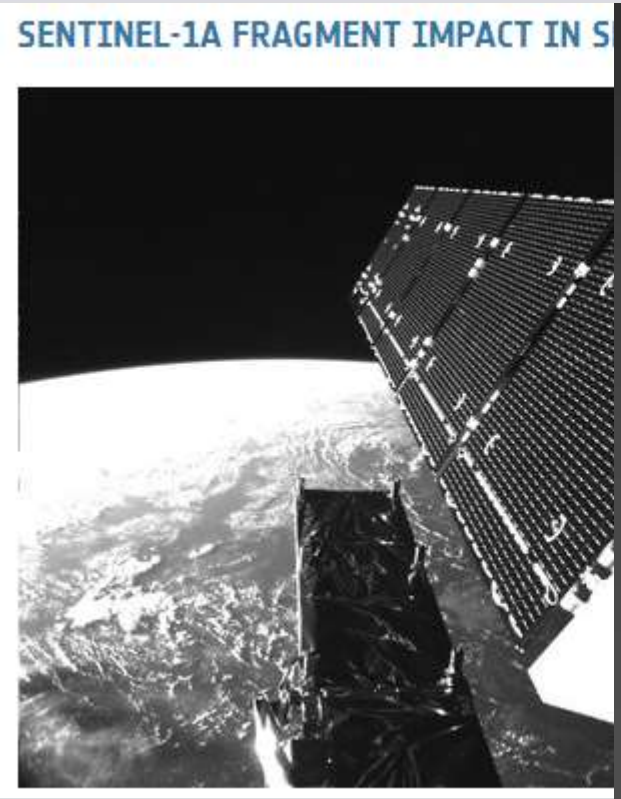


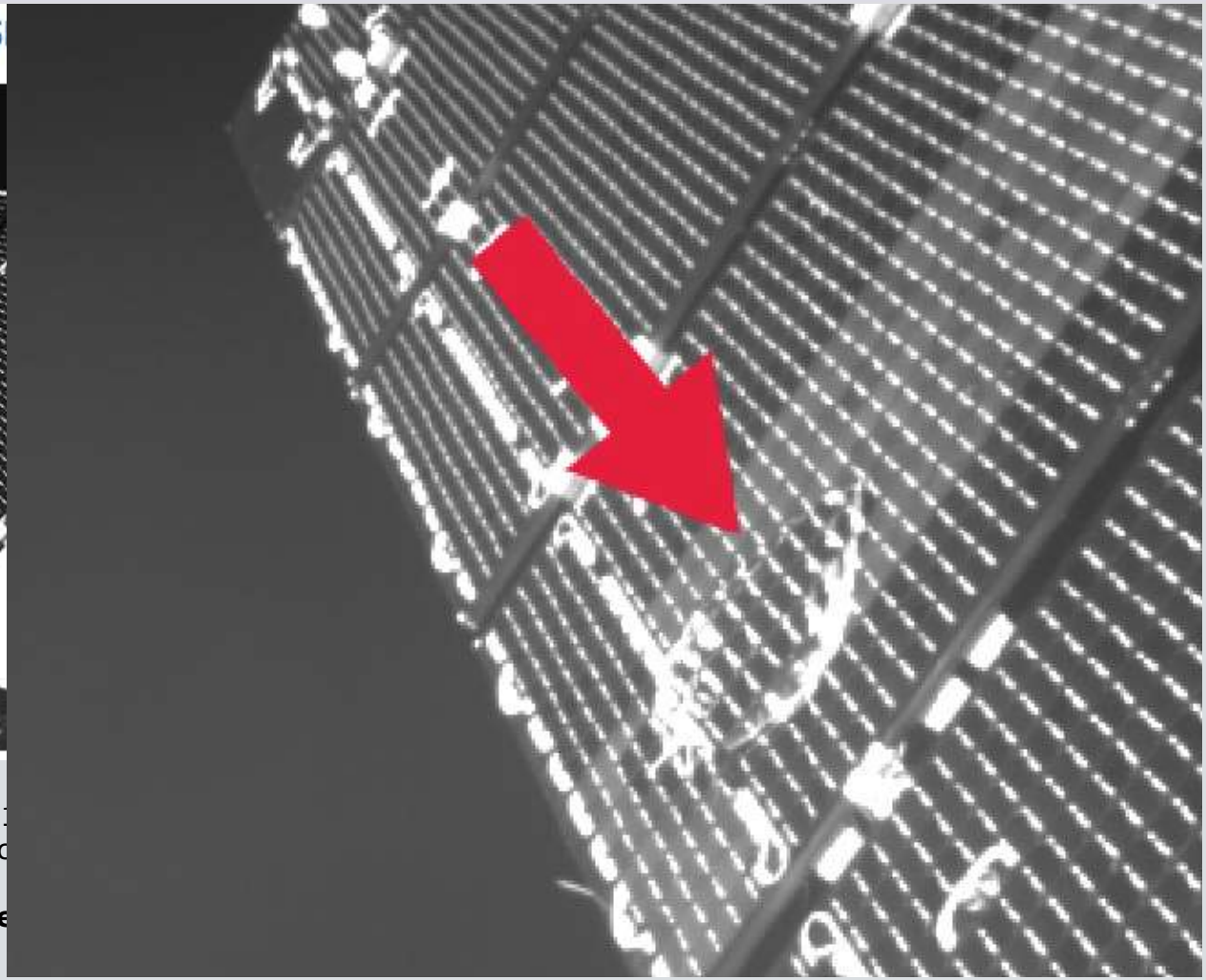


S1A and S1B before and after the 24 August 2016 earthquake: 15 August, 21 August and 27 August 2016.
The result shows vertical ground subsidence, reaching about 20 cm in correspondence to the Accumoli area, and lateral movement of up to 16 cm.
The blue line indicates the location of the fault trace

Sentinel-1 selfie

http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-1/Copernicus_Sentinel-1A_satellite_hit_by_space_particle

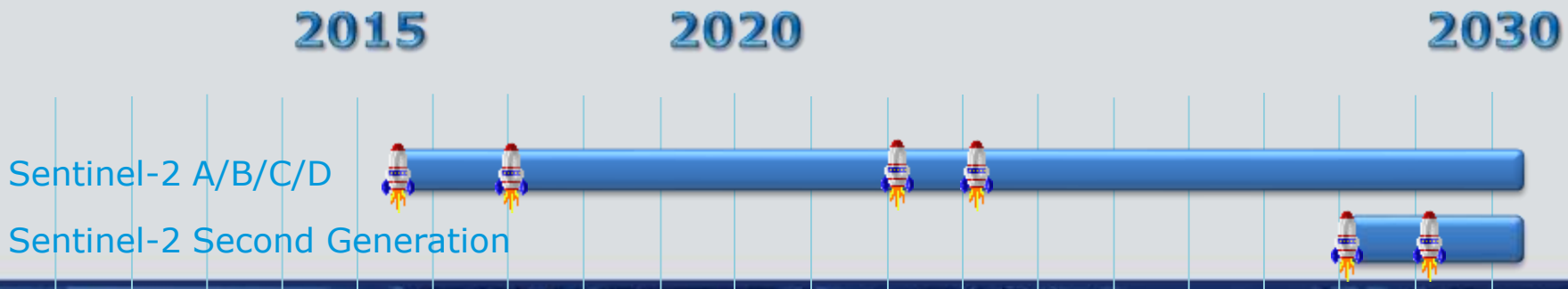




Solar panel on the Copernicus Sentinel-1
orbit on 23 August. Thanks to onboard c
affected area.
There has been no effect on the sate

Sentinel-2 : Mission Overview

- Spacecrafts: 2 operating in twin configuration
- Sentinel-2A launched on 23rd June 2015
- Orbit: Sun-synchronous at 786 km (14+3/10 revs per day), with LTDN 10:30 AM
- MultiSpectral Instrument (MSI): operating in pushbroom principle, filter based optical system
- **Spectral bands: 13 (VIS–NIR–SWIR spectral domains)**
- **Spatial resolution: 10m / 20m / 60m**
- **Swath: 290 km**



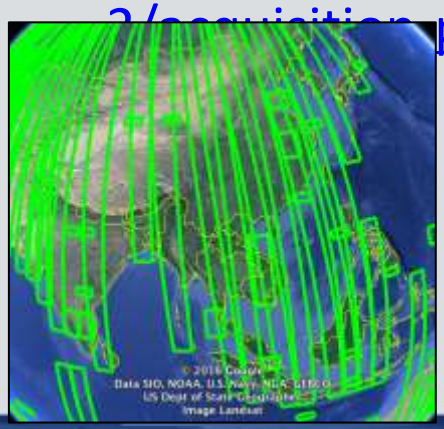
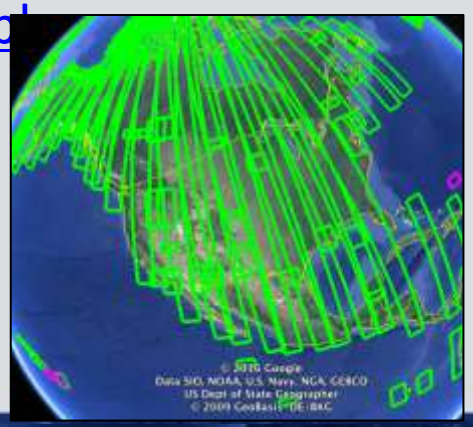
Sentinel-2 Observation scenario, acquisition plans online

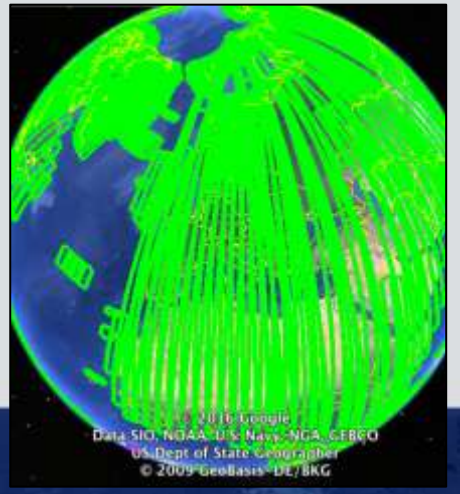
Currently observation of average ~14 min/orbit (i.e. **>80%** of average observation time in full operations)

- Systematically Europe, Greenland & Africa on every orbit = 10 days (at equator)
- The Rest of the World (RoW) wi…

Since 3 May: revisit frequency increased to 20 days Rest of World!

- Observation plan is published ahead of every repeat cycle as kml at https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2/acquisition-pl…



Sentinel-2 Products

Name	High-level Description	Production	Preservation Strategy	Volume
Level-1B	Top-of-atmosphere radiances in sensor geometry	Systematic	Long-term	~27 MB (each 25x23km^2)
Level-1C	Top-of-atmosphere reflectance in cartographic geometry	Systematic	Long-term	~500 MB (each 100x100km^2)
Level-2A	Bottom-of-atmosphere reflectances in cartographic geometry (prototype product)	On user side* (using Sentinel-2 Toolbox**)	N/A	~600 MB (each 100x100km^2)

***: Systematic global production of L2A is currently being prepared**

**: https://sentinels.copernicus.eu/web/sentinel/toolboxes/sentinel-2

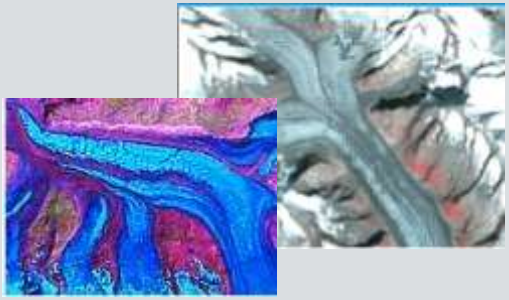
Sentinel-2A
Ever increasing range of applications

Forests & Carbon, Vegetation monitoring

Land cover classification/CORINE, IMAGE2006, IMAGE2009 etc.

Regional to Urban Applications

Emergency management

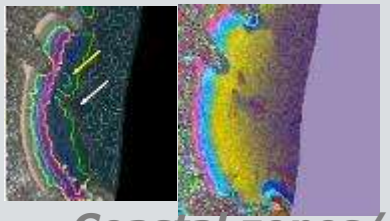


Glaciers & Ice

Global Land use & change

Geology

Coastal zones/ Water quality

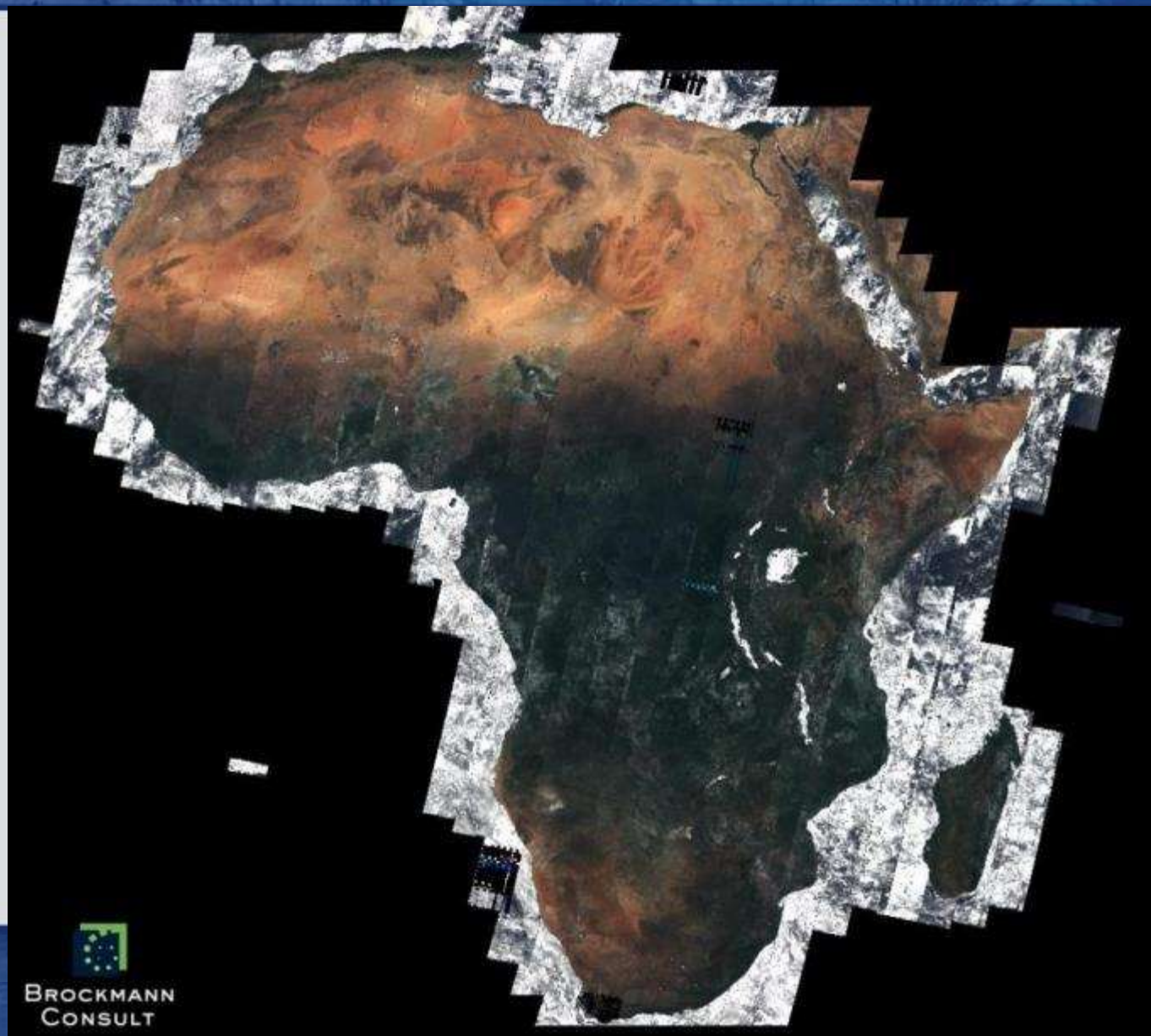


Coastal zones/ bathymetry

First CCI Land Cover Sentinel-2 TOA reflectance composite over Africa

Max-NDVI composite of TOA reflectance from all available Sentinel-2 images acquired from August 2015 to April 2016

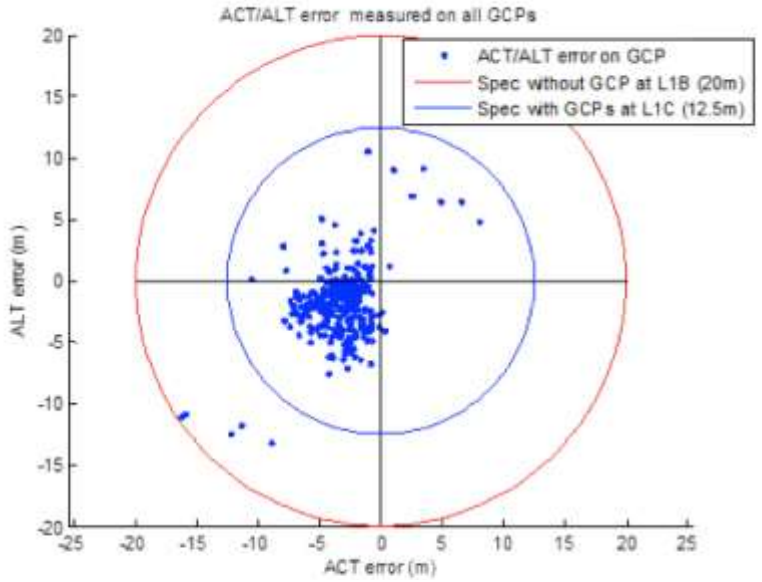
(~32 TByte of data)

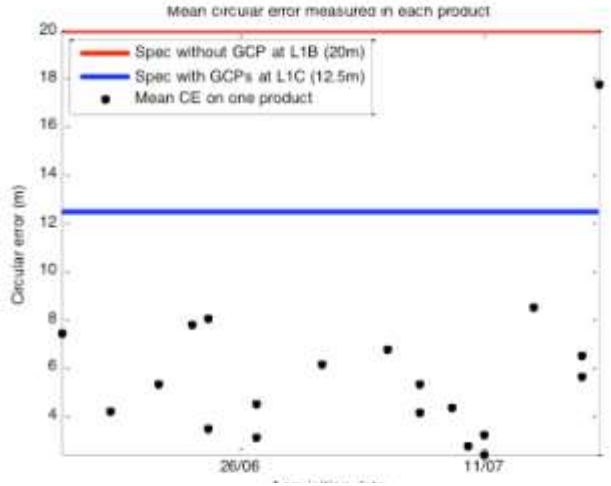


Sentinel-2A Measured Performances
L1 Geometry

Geolocation

- **Method**: Matching L1 images with perfectly geolocalized reference images (GCPs).
- **Results**: Performance analysed on 107 products including 708 GCPs.





The latest performance estimation, with processing baseline 02.04 deployed on 30th of May, is now 8m at 95.5% vs. 14.6m previously, well below requirements (20m at 95.5%). The performances improvement results from an improvement of the yaw pointing bias correction.

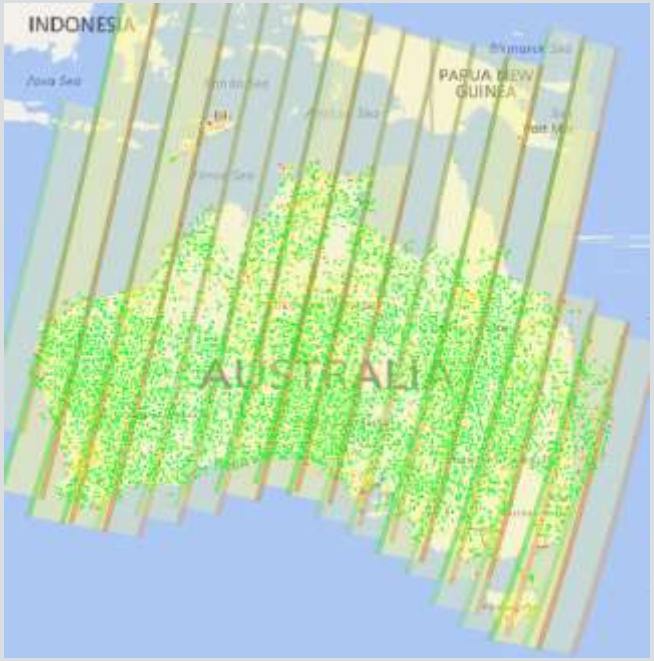
Sentinel-2A Measured Performances
L1 Geometry

Improvement using a GRI (Global Reference Image)

- **Objective**: To obtain a full repeat cycle dataset of well-localized mono-spectral Level-1B images (band 4) which will be used as reference images in the processing, allowing to: improve geolocation, ensure coherence between orbits and ensure multi-temporal registration.

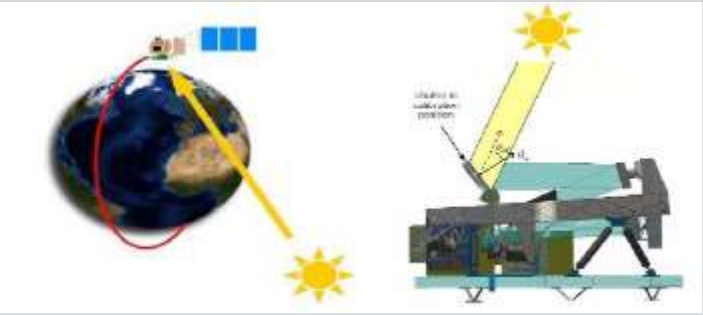
First GRI validation results

Pre-validation made internally.
Geolocation estimated to 8m CE95

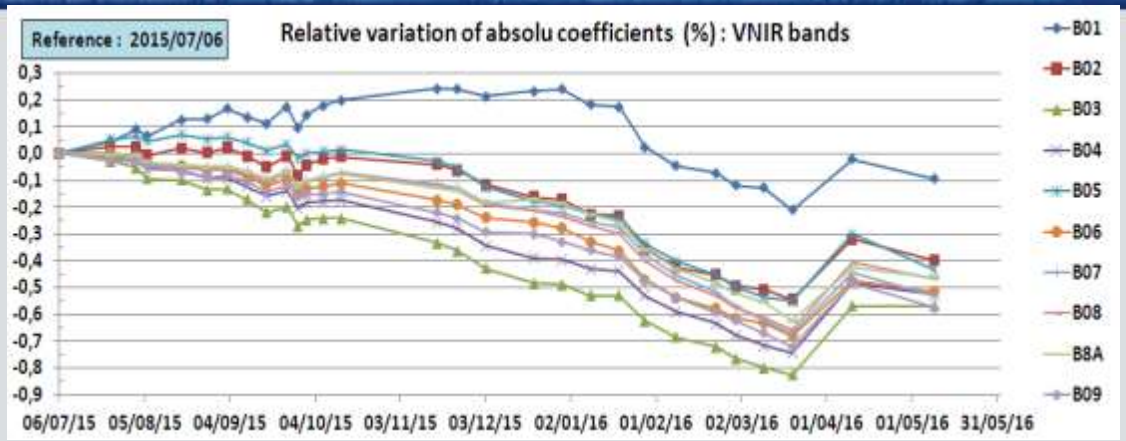


Green <7m 7m Orange <10m <10 Red >10m

Sentinel-2A Measured Performances: Radiometry

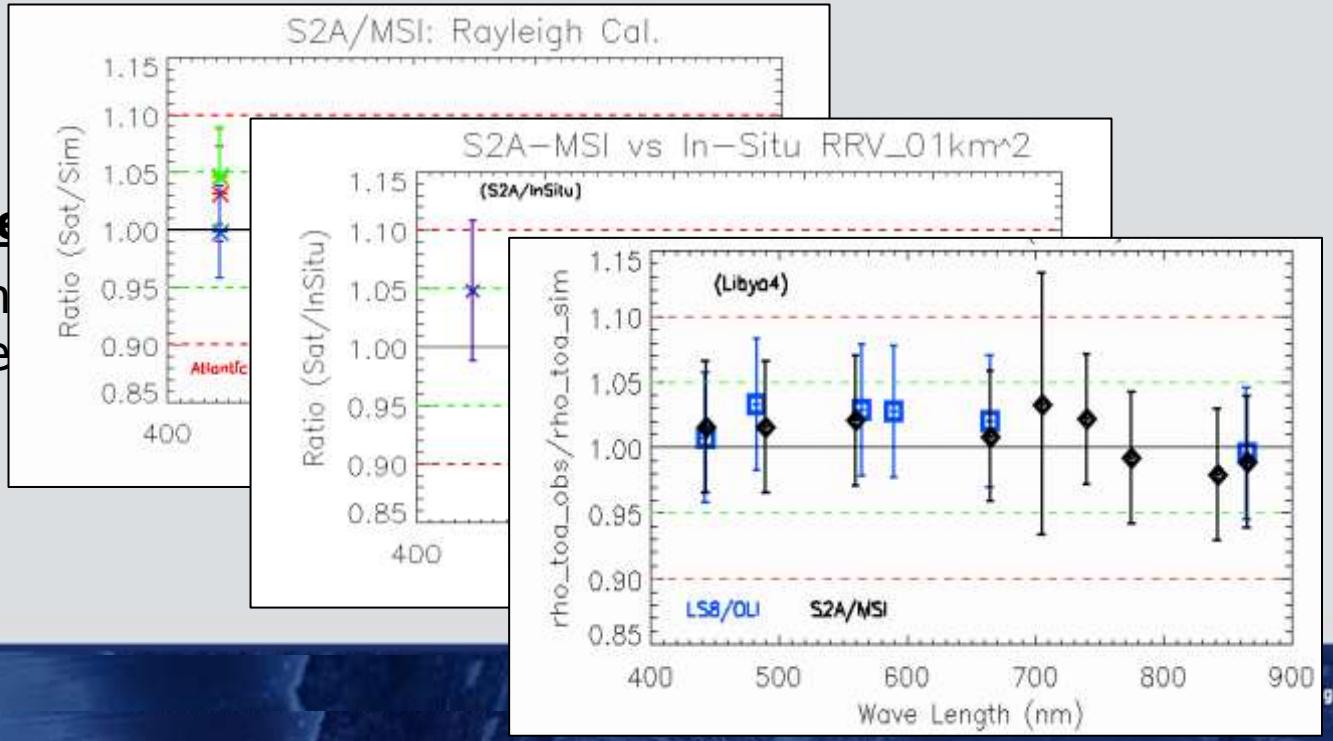


On-board sun diffuser



Absolute Radiome

- **Method**: Rayleigh measurements ove Landsat-8.



Sentinel-2A Performance summary

- **Excellent product data quality:**

Requirement	Description	Measured performance
Absolute geolocation (without ground control points)	The geo-location uncertainty shall be better than 20 m at 2σ confidence level (without Ground Control Points).	< 12.36 m at 2σ
Multi-spectral Registration	The inter-channel spatial co-registration of any two spectral bands shall be better than 0.30 of the coarser achieved spatial sampling distance of these two bands at 3σ confidence level.	< 0.26 pixel at 3σ
Absolute radiometric uncertainty	The absolute radiometric uncertainty shall be better than 5 % (goal 3%).	B1 to B9: < 5%±2%
SNR	The Signal-to-Noise Ratio (SNR) shall be higher than specified values (see Table 2.2 in this document)	All bands compliant with > 20% margin

- Next main steps:
  - GRI generation and validation on-going.
  - To complete on-going reprocessing campaign.
  - Commissioning of Sentinel-2B in Q1/Q2 2017.

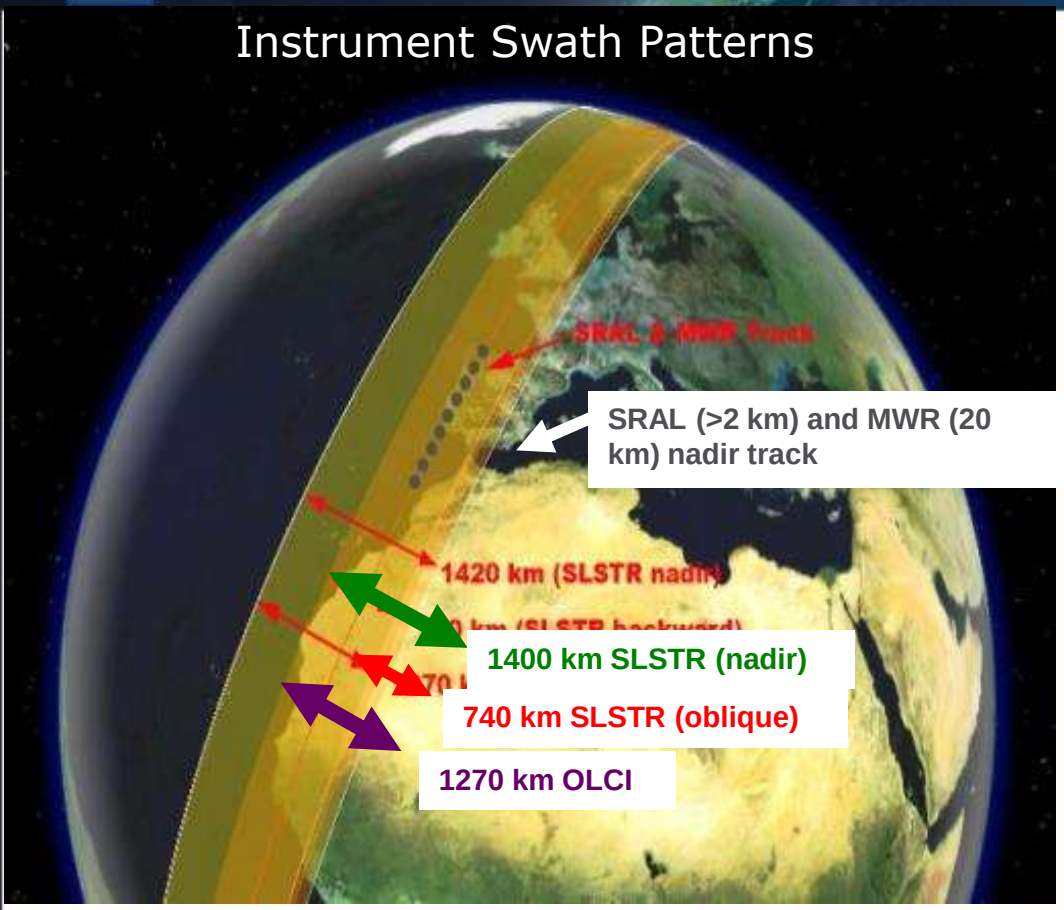
Sentinel-3: launch

Launched on a Rockot from Plesetsk, Russia, at 17:57 GMT on 16 February 2016

Sentinel-3: mission

- **Sentinel-3 A is the first of a series of 4 satellites ensuring 20 years of operational ocean and land monitoring**
- **Developed by ESA for the European Commission and co-operated by ESA/EUMETSAT**
- **The spacecrafts carry four main instruments:**
  - ✓ OLCI: Ocean and Land Colour Instrument
  - ✓ SLSTR: Sea and Land Surface Temperature Instrument
  - ✓ SRAL: SAR Radar Altimeter
  - ✓ MWR: Microwave Radiometer.
- **These are complemented by three instruments for Precise Orbit Determination (POD):**
  - ✓ DORIS: a Doppler Orbit Radio positioning system
  - ✓ GNSS: a GPS receiver, providing precise orbit determination and tracking multiple satellites simultaneously
  - ✓ LRR: to accurately locate the satellite in orbit using a Laser Retro-Reflector system.

Sentinel-3 Instrument Swath and Satellite Orbit



Orbit type	Repeating frozen SSO
Repeat cycle	27 days (14 + 7/27 orbits/day)
LTDN	10:00
Average altitude	815 km
Inclination	98.65 deg

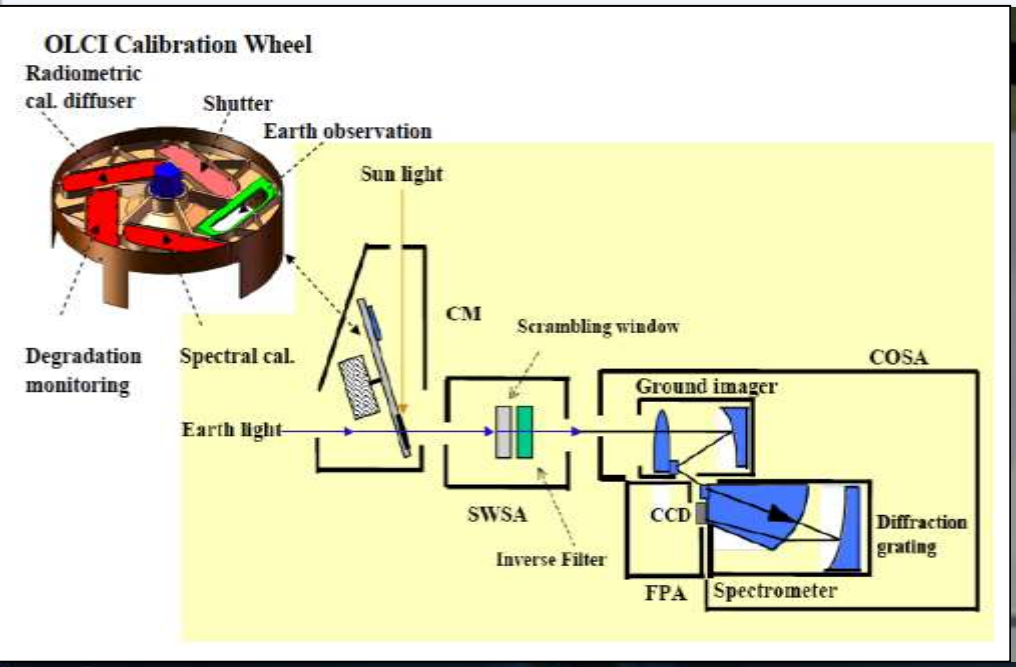
OLCI spectral/radiometric calibration

OLCI is a self-calibrating instrument using on-board diffusers:

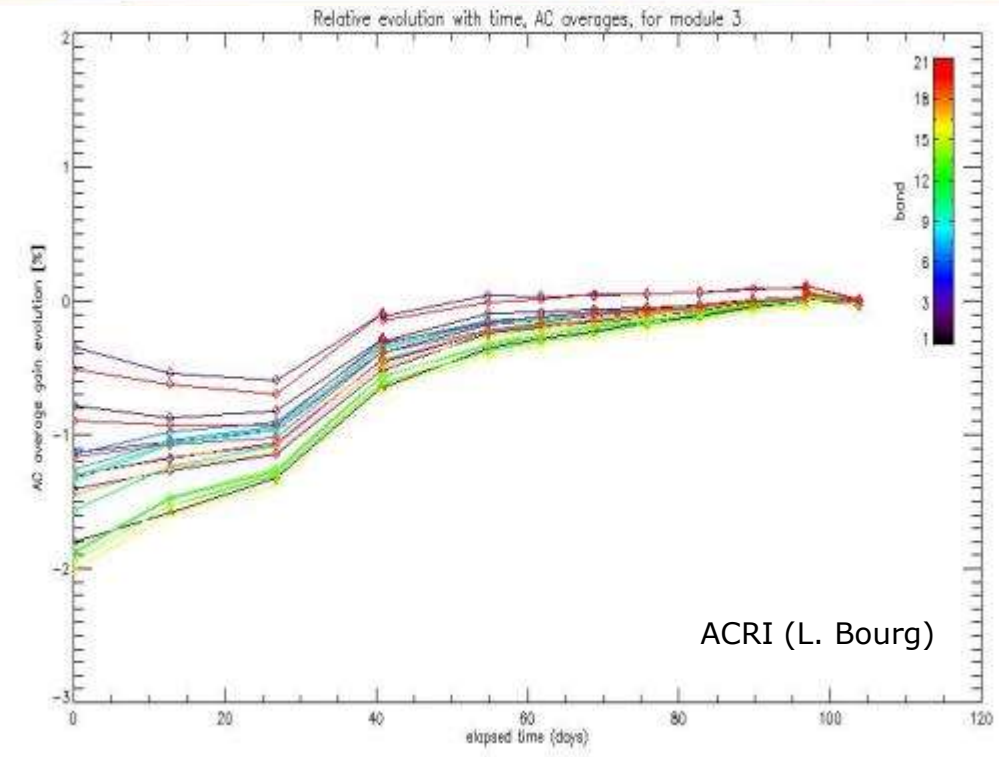
- **Every ~2 weeks routine with 1st white diffuser**

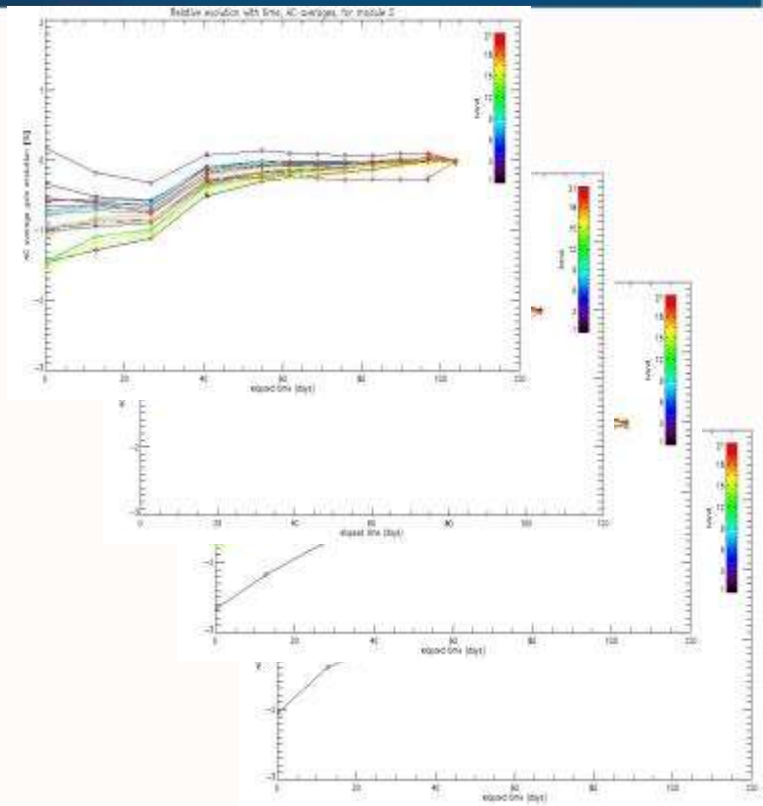
It is being changed to perform the calibration at fixed geometry (i.e about every two weeks)

- **Every ~3 months with 2nd white diffuser for ageing**
- **Spectral calibration: Erbium Doped Diffuser (for spectral calibration)**



Sentinel-3A : Radiometric gain variation from white diffuser – Mean across track gains (ACRI)



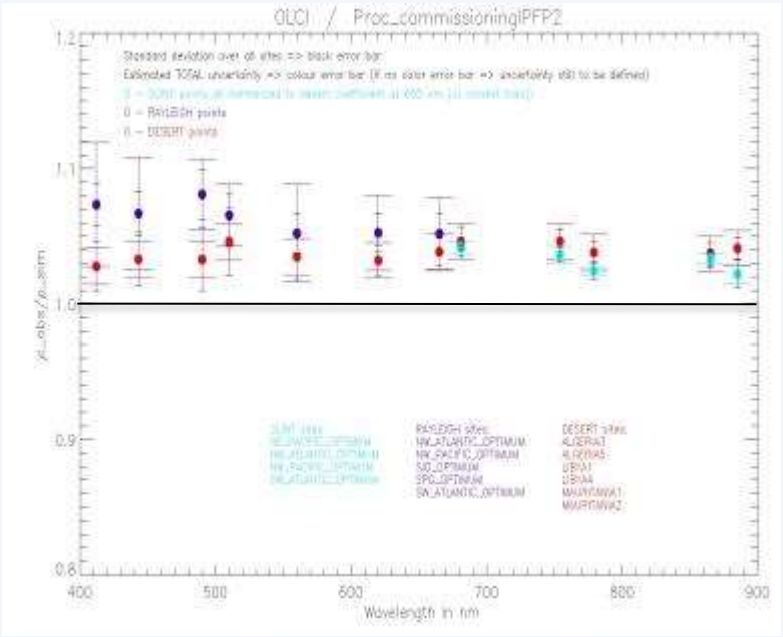


- Calibration gains show time variability believed to be related to:
  - ✓Star tracker anomaly => pointing model
  - ✓Uncertainties of diffuser BRDF model (already known from on-ground)
- Stability improves with time.

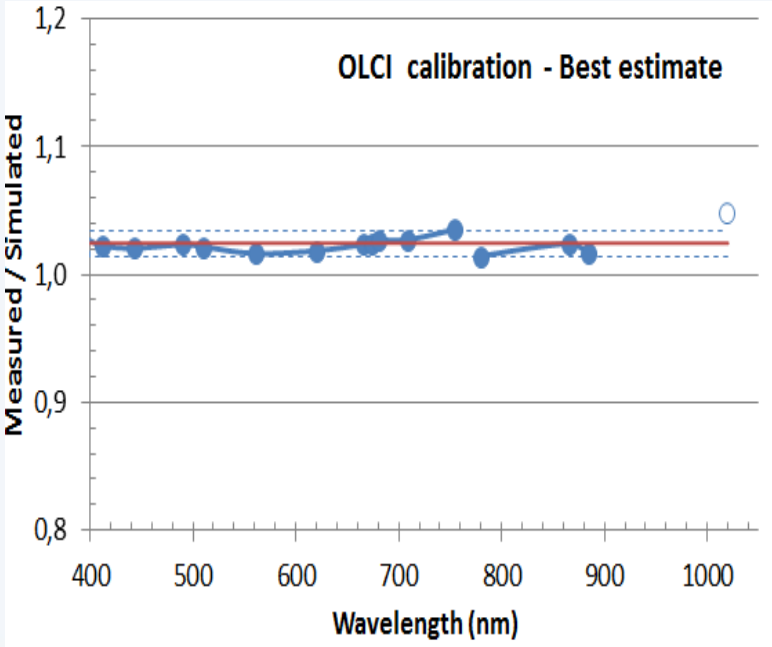
Sentinel-3A: Independent radiometric assessment

CNES (SADE/MUSCLE) and ESTEC (DIMITRI) used for independent assessment:

- **Consistent results making use of different methods / implementations**
- **Spectral consistency**
  - **OLCI radiances might be slightly higher than expected <u>but more data over longer period of time is needed</u> to confirm and monitor the evolution**

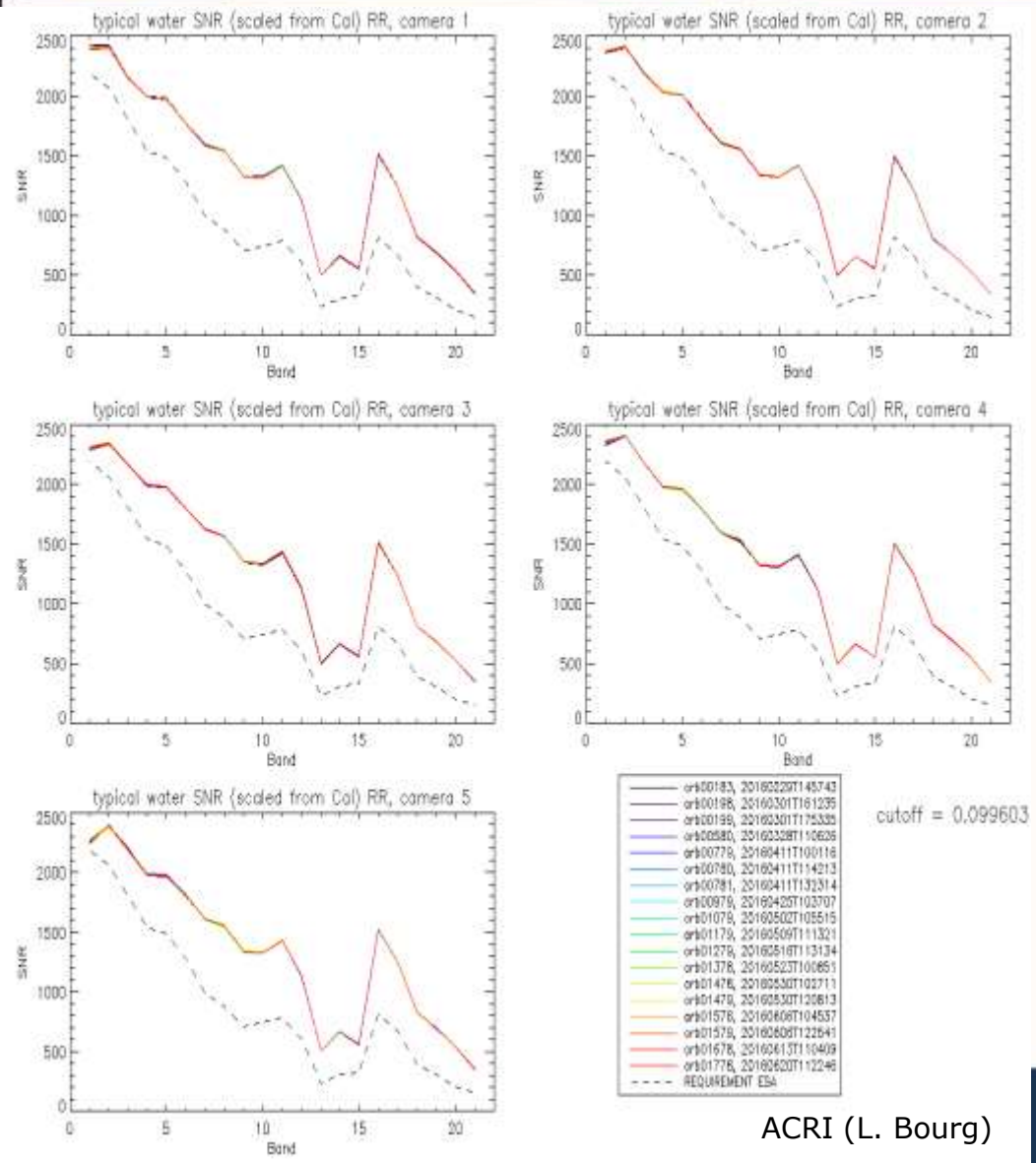


ESTEC (M. Bouvet)



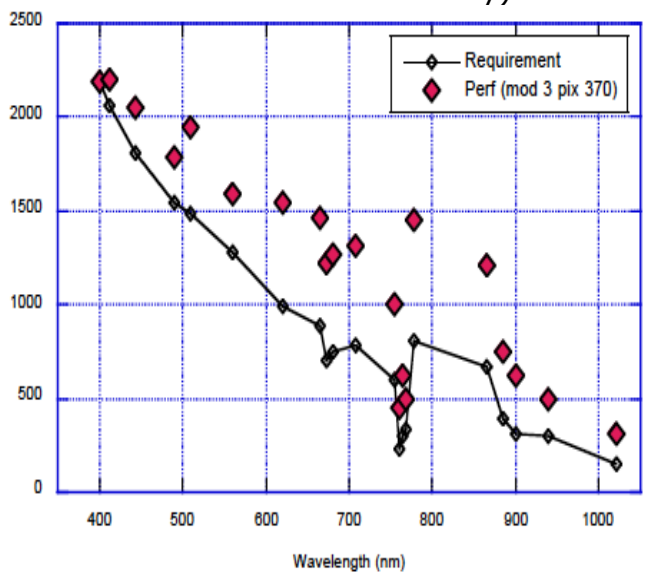
CNES (B. Fougnie)

Signal-to-Noise Ratio (SNR)



ACRI (L. Bourg)

- SNR performance are scaled down from L_{cal} to typical water radiance (L_{ref}) with 2 different methods.
- Results compliant, downscaling to be confirmed by ongoing analysis of EO images



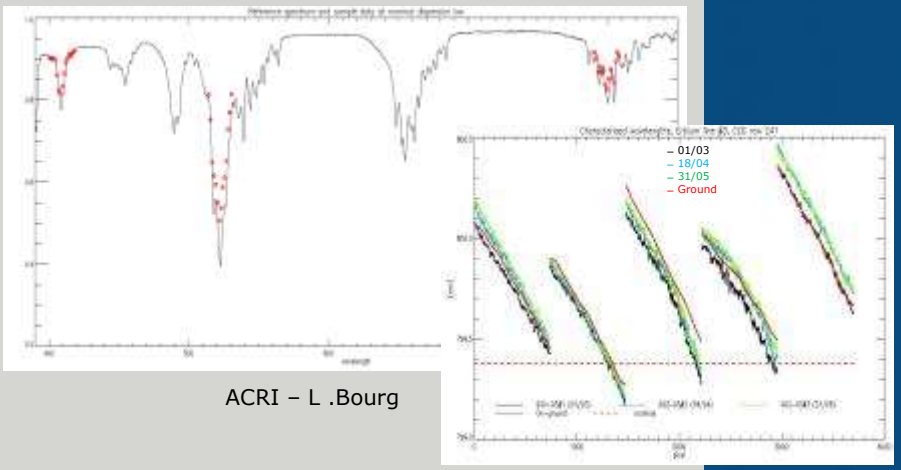
ESTEC (J.-L. Bezy)

OLCI in-flight spectral calibration

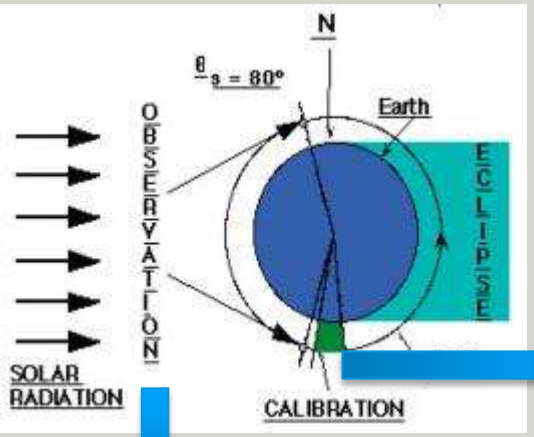
spectral calibration is established using**:**

- The on-board Erbium Doped Diffuser,
- Fraunhofer Lines (for validation),
- Oxygen O2A (for validation).

doping material Erbium absorption spectrum



ACRI – L .Bourg

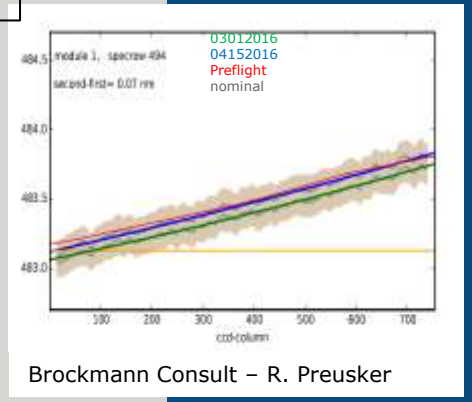


"Pink" Diffuser Measurements

Acquisitions scenario:
Orbit n = Diffuser-1 Cal (Band setting j)
Orbit n+1 = Diffuser-Er (Band setting j)

Fraunhofer lines on non-doped diffuser

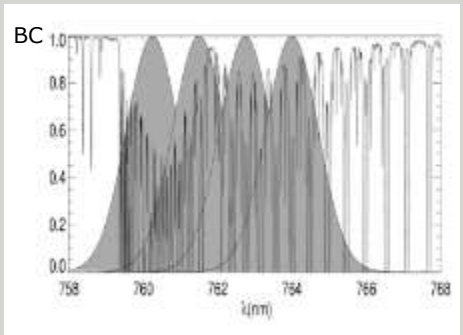
White Diffuser Measurements

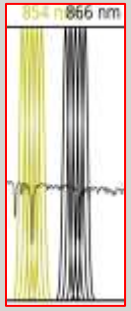


Brockmann Consult – R. Preusker

Measurements over Natural target

O2A spectrum



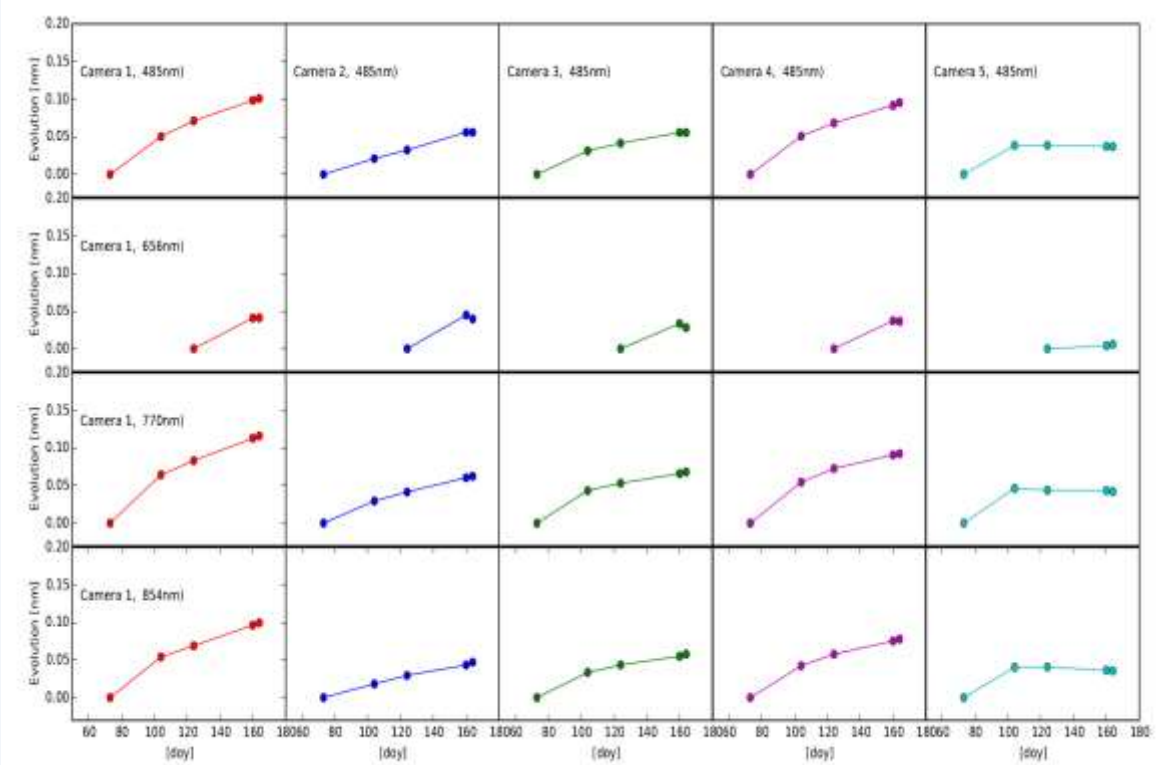


OLCI was programmed in a way to observe the O2A absorption features over bright Earth targets

In flight spectral calibration results

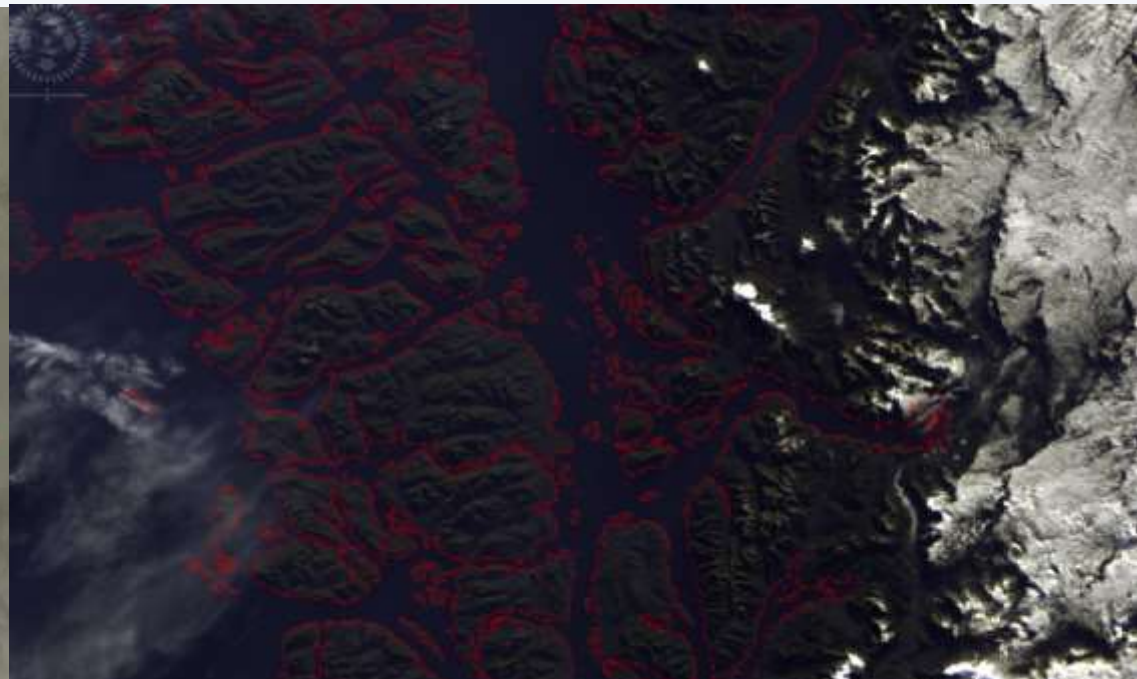
- **Pre-flight characterisation confirmed in-flight (<0.15nm)**
- **Small temporal trends since beginning of the mission (comparable to MERIS)**
- **Spectrally fully compliant**

Brockmann Consult – R. Preusker



In flight geometric calibration results

- After early mission pointing issues were fixed (e.g.: star tracker software), OLCI spatial feature matching with a Landsat reference imagettes database led to a first geometric calibration resulting into approximately sub-pixel accuracies. More data needed to fit a thermo-elastic model (seasonal variations) and further improve the calibration.



SLSTR First Im

Sentinel-3 SLSTR First Image over Egypt **03/03/2016**

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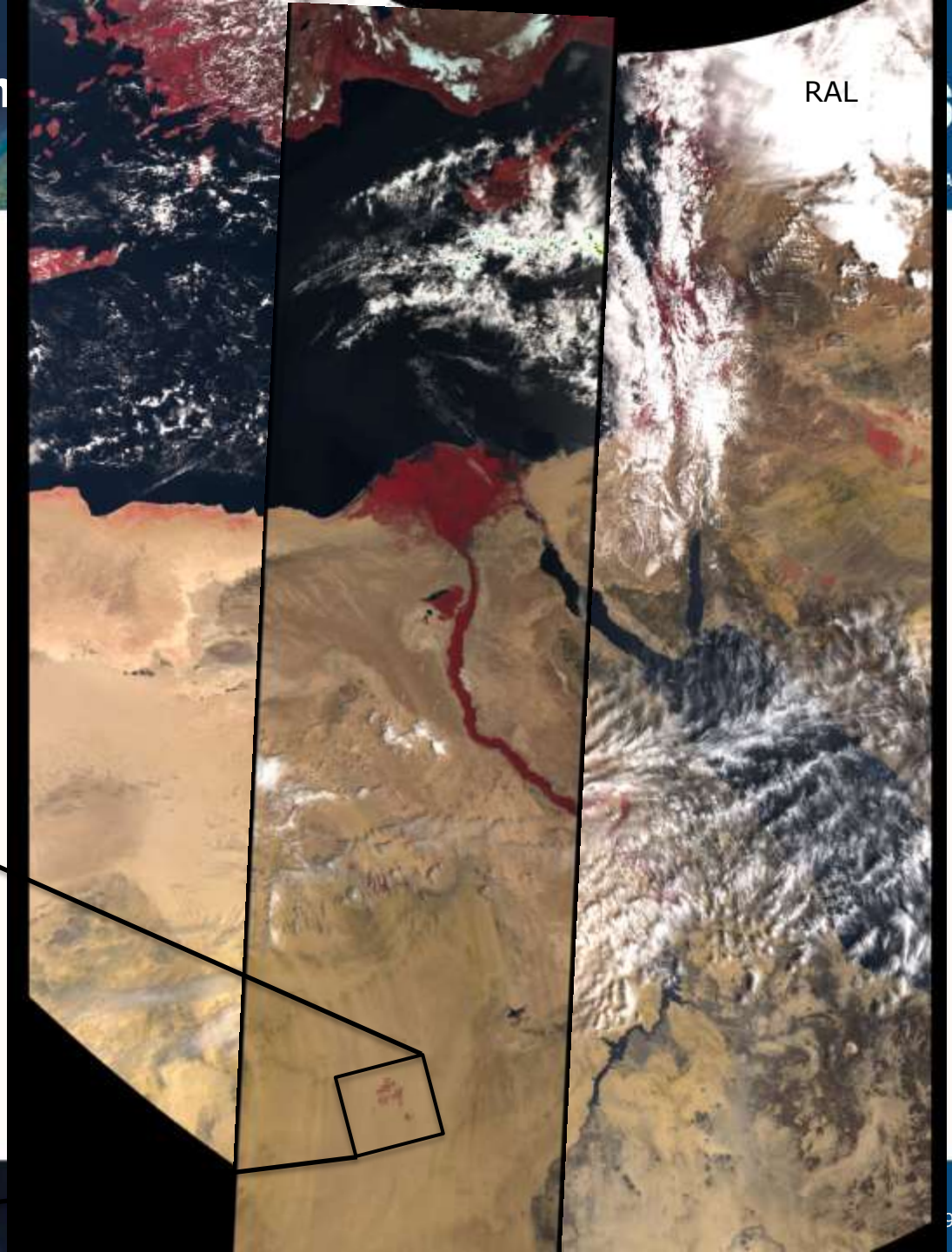
Last AATSR image over Egypt **07/04/2012**

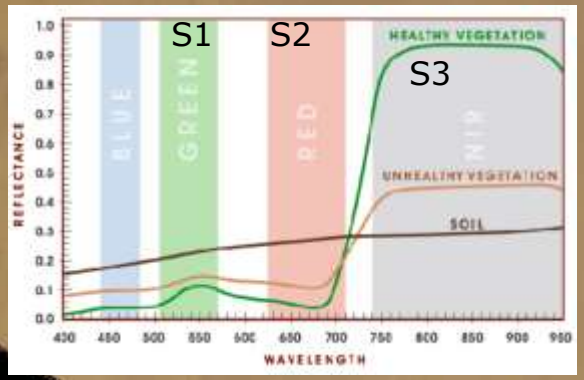


Google Image

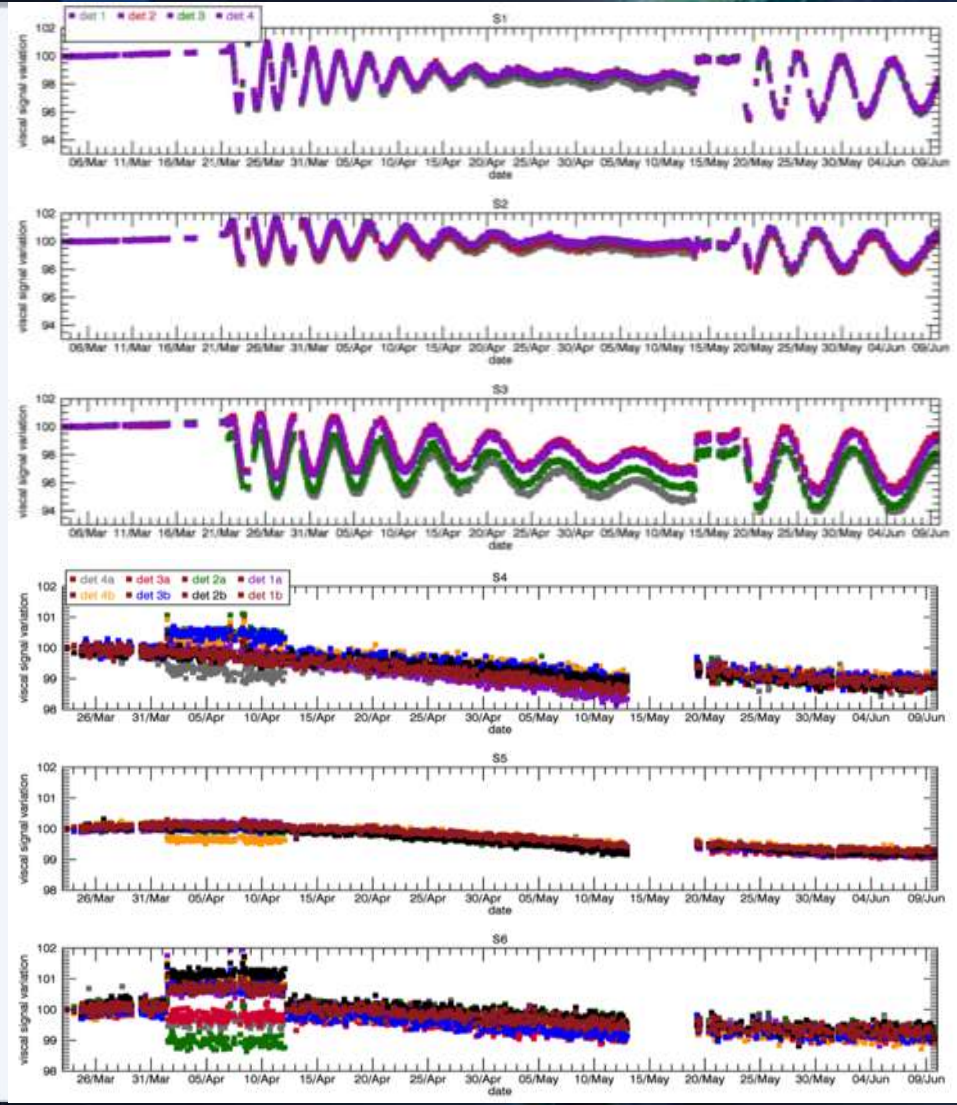
SLSTR 0.5km Spatial Resolution (VIS channels) in 2106

Large irrigation fields in the desert
(healthy vegetation appears in red)

Google
Image



VIS-SWIR radiometric monitoring based on VISCAL

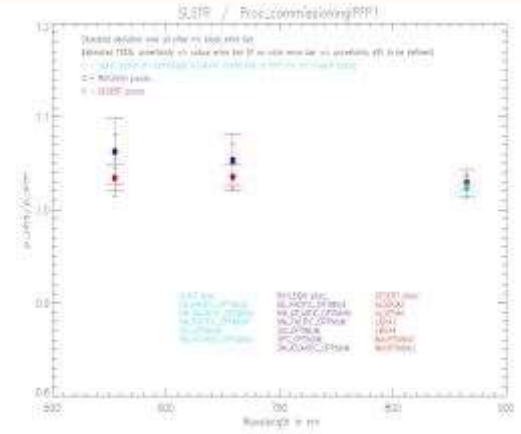


- VISCAL (white diffuser) is illuminated once per orbit
- Oscillations in VIS channels caused by build up of water ice on VIS relay optics
- Same behaviour as seen on ATSR-2, AATSR
- VISCAL measurements are used to account for the long term instrument sensitivity changes (and short term changes due to the water ice contamination)

Radiometric calibration

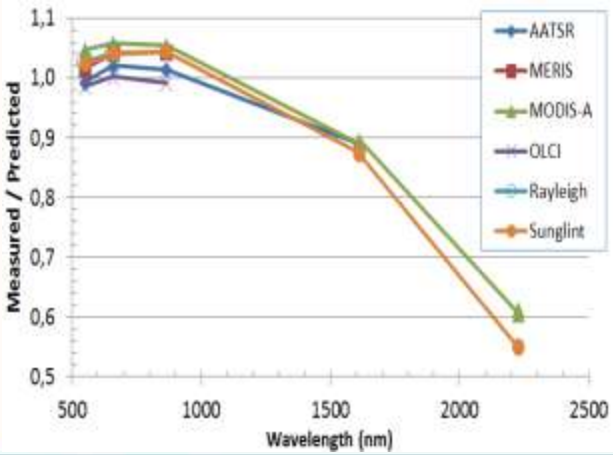
- Vicarious methodologies using stable reference sites (e.g. SADE, DIMITRI) revealed a very good spectral consistency in the VIS and a possible ~+3% bias (wrt MERIS/MODIS-A) in the VIS
- Radiometric issue in the SWIR (~-10 % at 1.6 µm and ~-40% at 2.2 µm). The issue is strongly suspected to be linked to the pre-flight calibration

---> Investigation on-going. Current status shows about 10% in SWIR

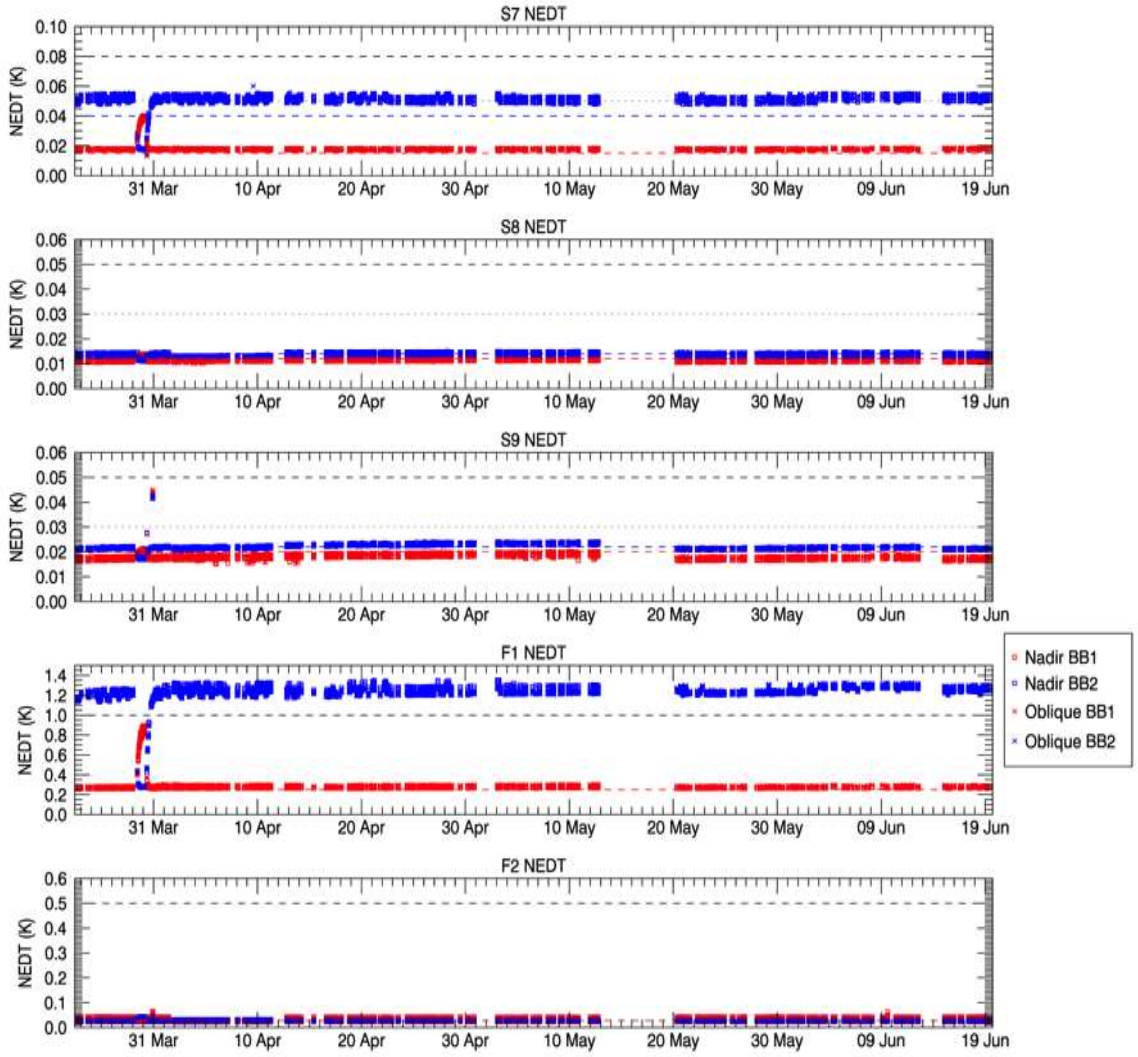


ESTEC (M. Bouvet)

CNES (B. Fougnie)



TIR Performance – Radiometric Noise



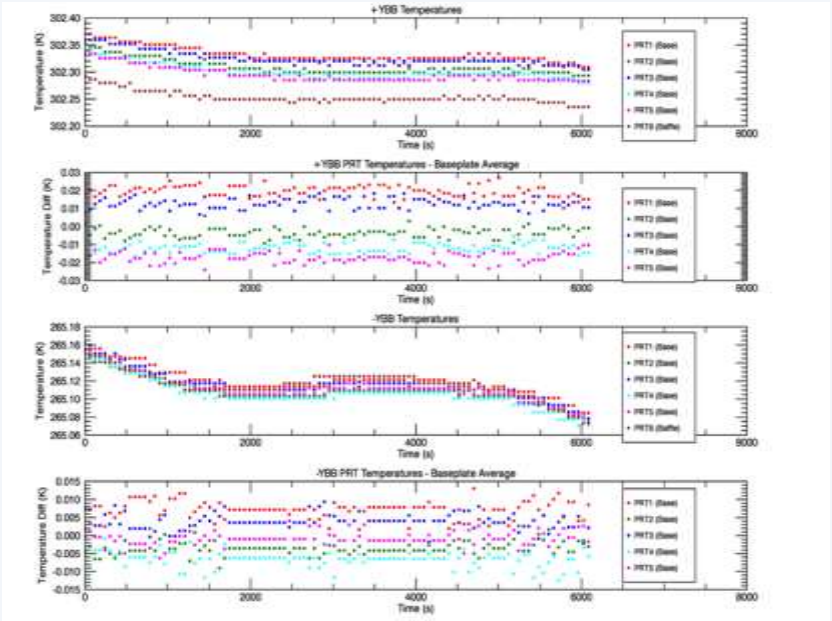
NEDT values agree with pre-launch calibration and are well within specification,

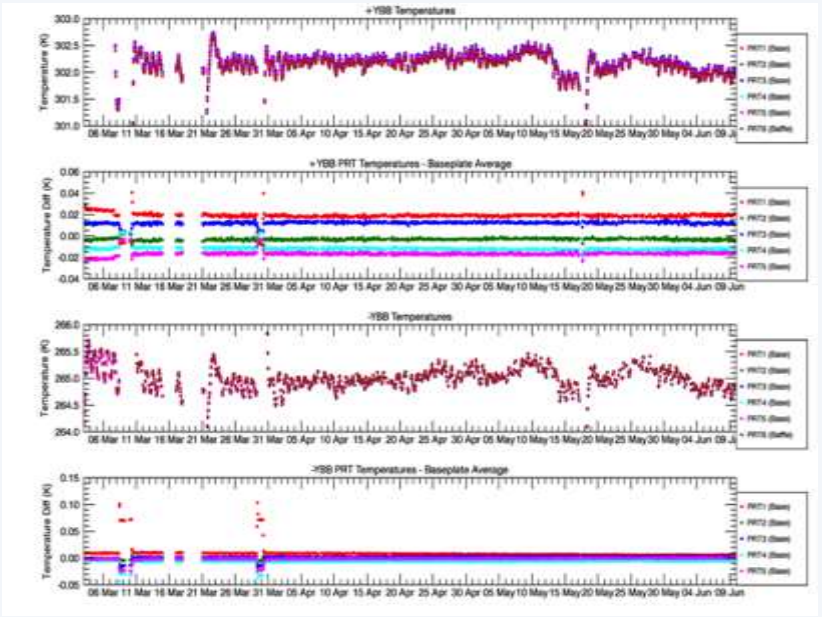
Good initial long term stability,

No effects on performance due to the build up of water ice have been observed.

TIR radiometric calibration

- TIR calibration is based on 2 black bodies ('cold' and 'warm' to cover dynamic range)
- Both black bodies temperature show good orbital stability< 0.1K
- Gradients on black body plates in nominal configuration are stable.





OLCI/SLSTR Conclusions

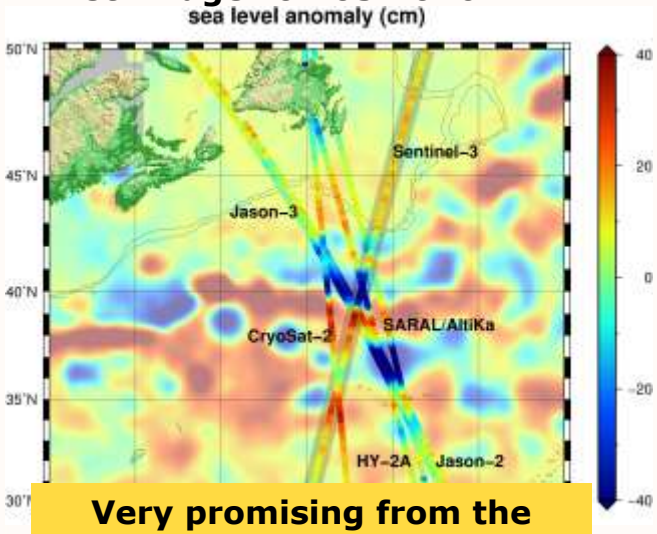
- **OLCI and SLSTR SNR is compliant with specification**
- **OLCI Calibration gains show time variability**
  - ✓ Partly related to star tracker anomaly and uncertainties of BRDF model (already known from on-ground)
  - ✓ Stability seems to improve with time
- **OLCI Vicarious calibration shows spectrally/spatially/dynamically consistent results, however a ~+3% bias.**
  - ⇒ Actions are in place to further investigate this point (e.g., yaw maneuvers to characterize BRDF diffuser in flight and perform calibrations at fixed geometry, periodic noise correction in ground processing) during next phase.
- **SLSTR Radiometric calibration will require longer period monitoring**
- **SLSTR TIR Radiometric Noise**
  - ✓ NEDTs agree with pre-launch data and within specification
- **SLSTR TIR Radiometric Gains and Offsets**
  - ✓ Black body signals provide 'continuous' measurement of dark signals and the instrument is within specification
  - ✓ Show good orbital stability
- **Black Body Calibration System fully functional**
  - ✓ Absolute accuracy:
    - Difference in measured counts between the two black bodies during cross over test suggest calibration accuracy < 0.2K => compliance. Seems confirmed by IASI SNOs.
- **Geometric calibration is ongoing with the prospect of delivering sub-pixel accuracy. Long term monitoring needed to derive thermo-elastic model.**

OLCI/SLSTR Data availability

- IOCR – In Orbit Commissioning Phase Review – was completed in July 2016
- Level 1B data will be released in September 2016
- Level 2 validation is on going
- Level 2 data release planned for the end of 2016
  - **Marine Product distributed by EUMETSAT**
  - **Land Product distributed by ESA**
- "New" product – Global Aerosol and Fire Radiative Power Products will be distributed by mid-2017.
- Sentinel-3 Validation Team Meeting will take place 22-24 November 2016 at ESRIN

S-3 Surface Topography Mission (STM)

"First Image" 01.03.2016

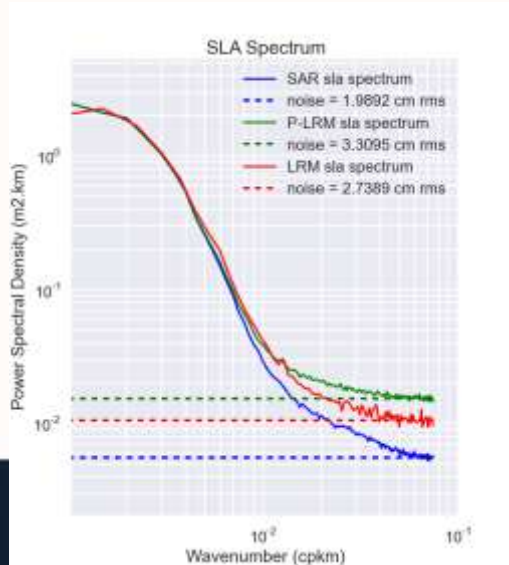


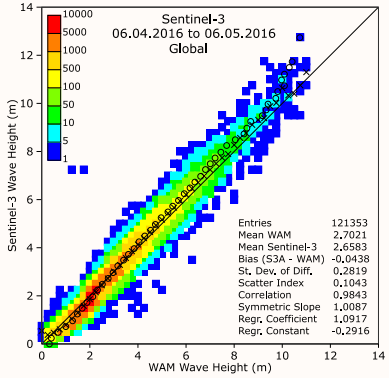
Very promising from the first SRAL measurements !

S-3A STM status:

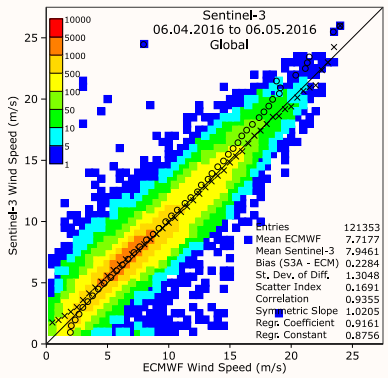
- Overall status of the mission sensors and science products is good
- L1 data operationally qualified
- Overall L2 data quality is already good over the ocean
- Additional assessment of L2 data and corrections of anomalies in ground processor is requested before L2 data release to the user community
- **Expected official L1 & L2 data release in Q3 2016**

Reduced noise in SAR mode vs LRM as expected
➔ Improved spectral information content for SLA at ocean mesoscale



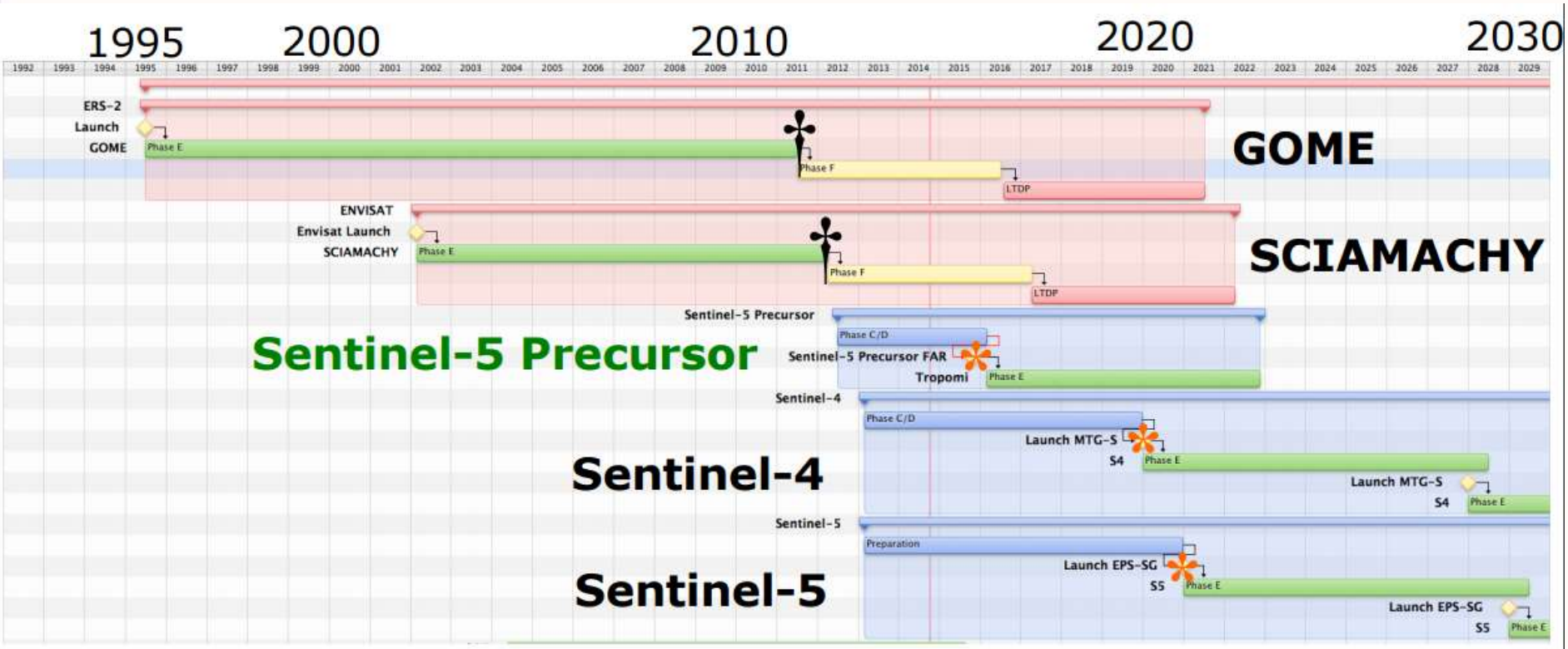


SWH is quite GOOD
(Needs slight fine-tuning)



Wind Speed looks OK
(Except for few outliers)

Sentinel-5P



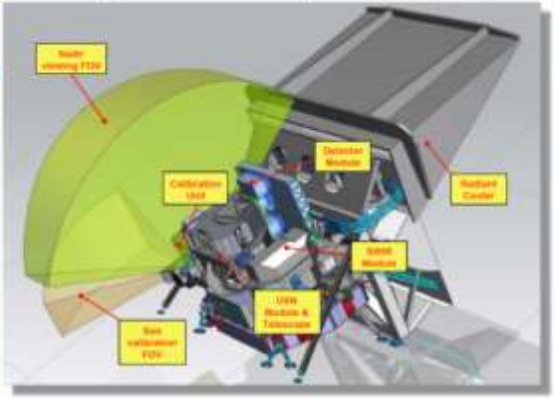
- S5p is narrowing the gap between Envisat and Sentinel-5
- Towards 40 years of similar atmospheric composition observations!

Sentinel-5P

- The ESA Sentinel-5 Precursor (S5P) is a pre-operational mission focussing on global observations of the atmospheric composition for Air Quality and Climate.
- The TROPOspheric Monitoring Instrument (TROPOMI) is the payload of the S-5P mission and is jointly developed by The Netherlands and ESA.
- The planned launch date for S5P is **Q1/2017** with 7 year design lifetime.
- Background mission with global daily coverage.

TROPOMI

- UV-VIS-NIR-SSWIR push-broom grating spectrometer.
- Spectral range: 270-500 nm, 675-775 nm, 2305-2385 nm
- Spectral Resolution: 0.25-1.1 nm
- Observation Mode: Nadir, global daily coverage, ground pixel 7x7km^2 at nadir
- Orbit: Sun synchronous, 824 km, 13:30 hr dayside equator crossing time.



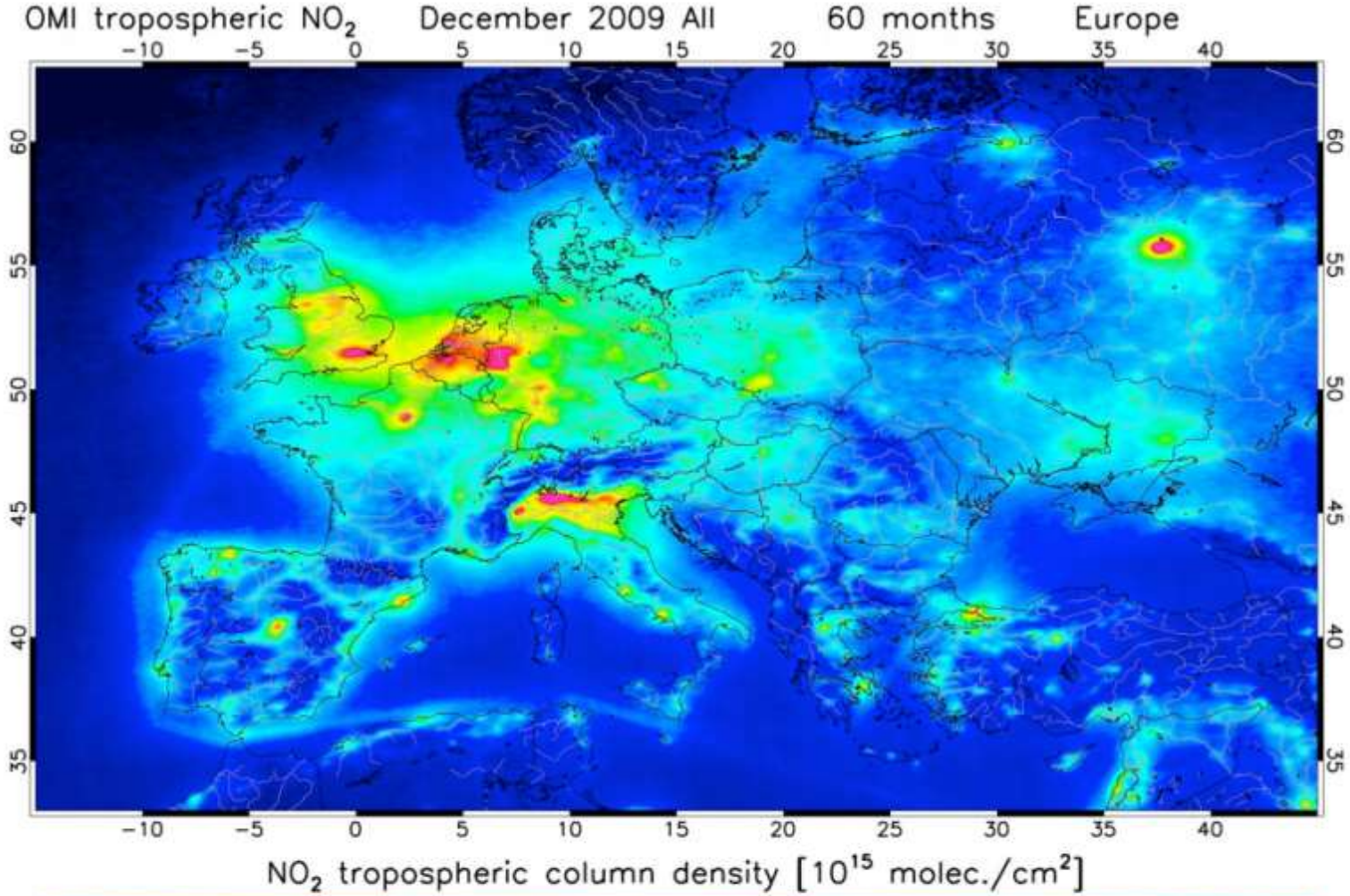
CONTRIBUTION TO Copernicus

- O_3: total and tropospheric column, profile
- NO_2: tropospheric and total column
- CO: total column
- SO_2: total column
- CH_4: total column
- Aerosol: absorbing index, type, optical depth
- H_2O: tropospheric column
- H_2O: total column
- BrO: total column

Sentinel-5P

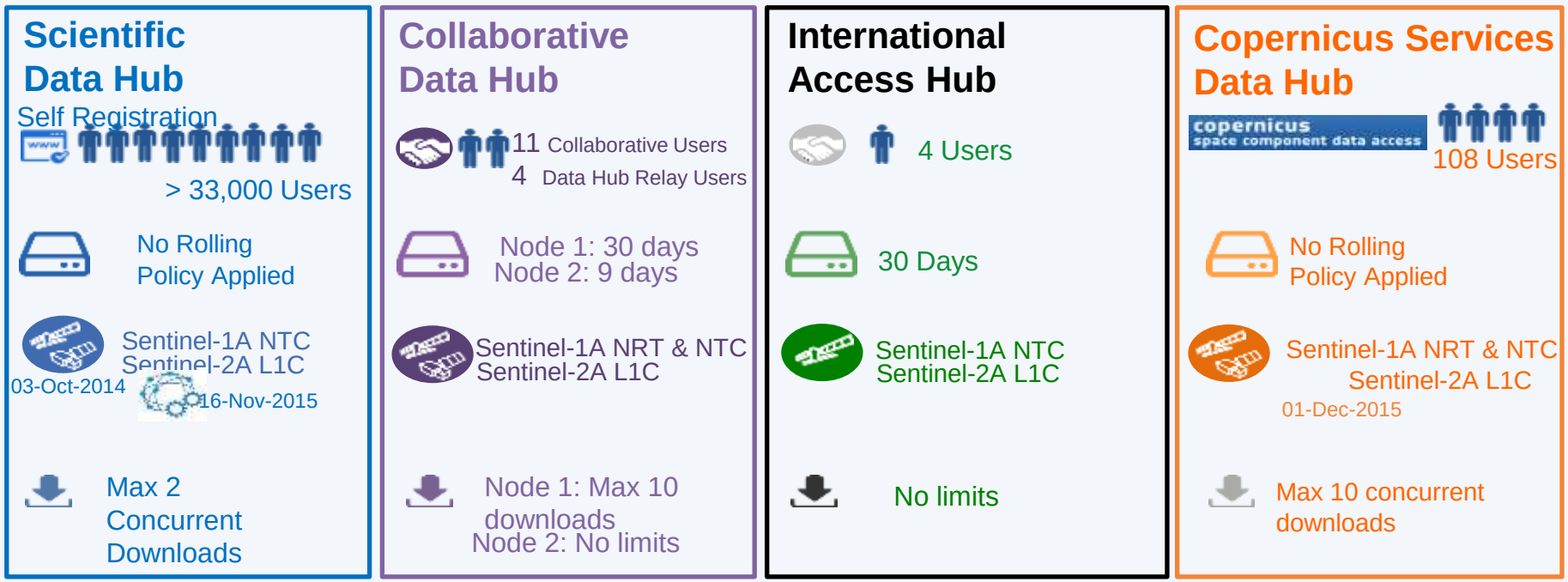
Parameter	Data Product	Vertical Resolution	Accuracy	Precision
Ozone 	Ozone Profile	6 km	10-30%	10%
	Total Ozone	total column	3.5-5%	1.6-2.5%
	Tropospheric Ozone	trop column		
NO_2 	Stratospheric NO_2	strat column	<10%	0.5e15
	Tropospheric NO_2	trop column	25-50%	0.7e15
SO_2 	SO_2 enhanced	total column	30%	0.15-0.3 (0.06-0.12) DU
	Total SO_2	total column	30-50%	1-3 (0.4-1.2) DU
Formaldehyde 	Total HCHO	total column	40-80%	1.2e16 (4e15)
CO 	Total CO	total column	15%	<10%
Methane 	Total CH_4	total column	1.5%	1%
Cloud 	Cloud Fraction	total column	<20%	0.05
	Albedo (Optical Thickness)	total column	<20%	0.05 (10)
	Cloud Height (Pressure)	total column	<20%	<0.5 km (<30hPa)
	SNPP VIIRS Cloud data			
Aerosol 	Aerosol Layer Height	total column	<100hPa	<50hPa
	Aerosol Type	total column	~1 AAI	<0.1 AAI

Sentinel-5P


OMI tropospheric NO_2 December 2009 All 60 months Europe
−10 −5 0 5 10 15 20 25 30 35 40
60 55 50 45 40 35
NO_2 tropospheric column density [10^{15} molec./cm^2]
0.00 0.50 1.00 2.00 3.00 4.00 5.00 7.00 10.0 15.0
Image credits:
Geert Vinken (TU/e) and Folkert Boersma (KNMI)

SENTINEL Data Policy

- **EU Copernicus Regulation: full, open and free data policy, defining responsibilities for ESA and EUMETSAT and overall financial envelope**
- **ESA Copernicus data access is ensuring that all Sentinels core products are accessible to all users online**
  - Any user can **self-register** at **sentinels.copernicus.eu**



Proba-V Mission Status, Calibration, Products and Applications

Mission

- ✓ Launched on 7 May 2013 for 5 years
- ✓ Global daily vegetation monitoring
- ✓ Spectral bands: Blue, Red, NIR, SWIR
- ✓ Operations running very smoothly

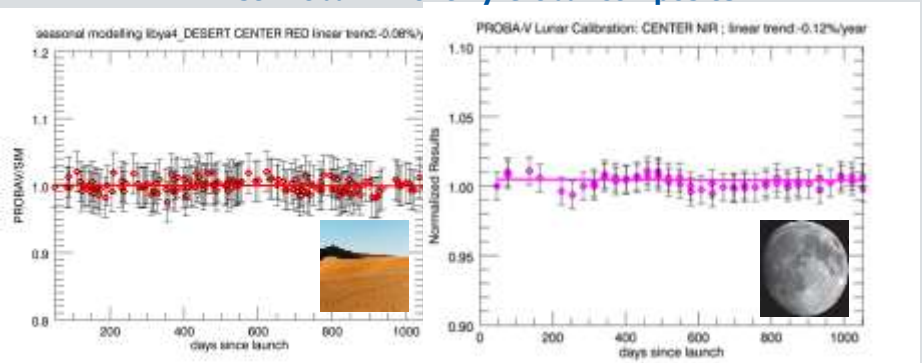
Calibration

- ✓ Radiometry (vicarious) better than 5% with 3% stability
- ✓ Geometry better than 60m with GCP

Products and Applications

- ✓ Composites TOA, TOC (1, 5, 10 days) delivered to users at 1km, 333m, 100m
- ✓ Reprocessing on-going mainly to improve cloud screening
- ✓ Increasing number of users for a wide range of applications (land and water)
- ✓ Large interest in 100m data (5 days revisit) for crop monitoring and LCLU

First Proba-V Monthly Global composite



Radiometric stability monitoring with desert and moon

100m data for agriculture and inland water monitoring

Proba-V Consistency, Continuity and Data Exploitation

Consistency and Continuity

- ✓ Primary source of data to Copernicus Global Land for retrieval of biophysical variables: FAPAR, Fcover, LAI, …
- ✓ Consistency with VGT demonstrated
- ✓ Crucial for seamless transition from SPOT-VGT archive to S3A+B

Data Exploitation

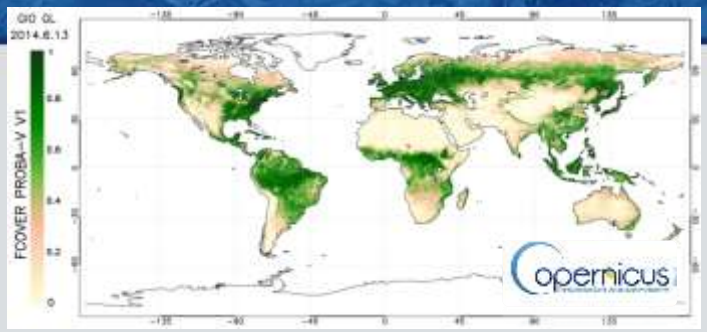
- ✓ Mission Exploitation Platform (MEP) for accessing full VGT+PV archive

https://proba-v-mep.esa.int

- ✓ Projects on-going exploiting 100m for LC and coastal water applications

Cloud detection Round Robin

- ✓ Started in Feb 2016 (1 year)
- ✓ 9 Research Institutes
- ✓ Various techniques: NN, Bayesian, …
- ✓ Validation data: representative large set of visually classified pixels



Copernicus *Fcover* global NRT from Proba-V

Mission Exploitation Platform (MEP) concept and web site

Cloud Round Robin: Validation dataset with PixBox

Fiducial Reference Measurements - FRM

What are FRM ?

Fiducial Reference Measurements (FRM) are (Donlon, S3VT meeting):

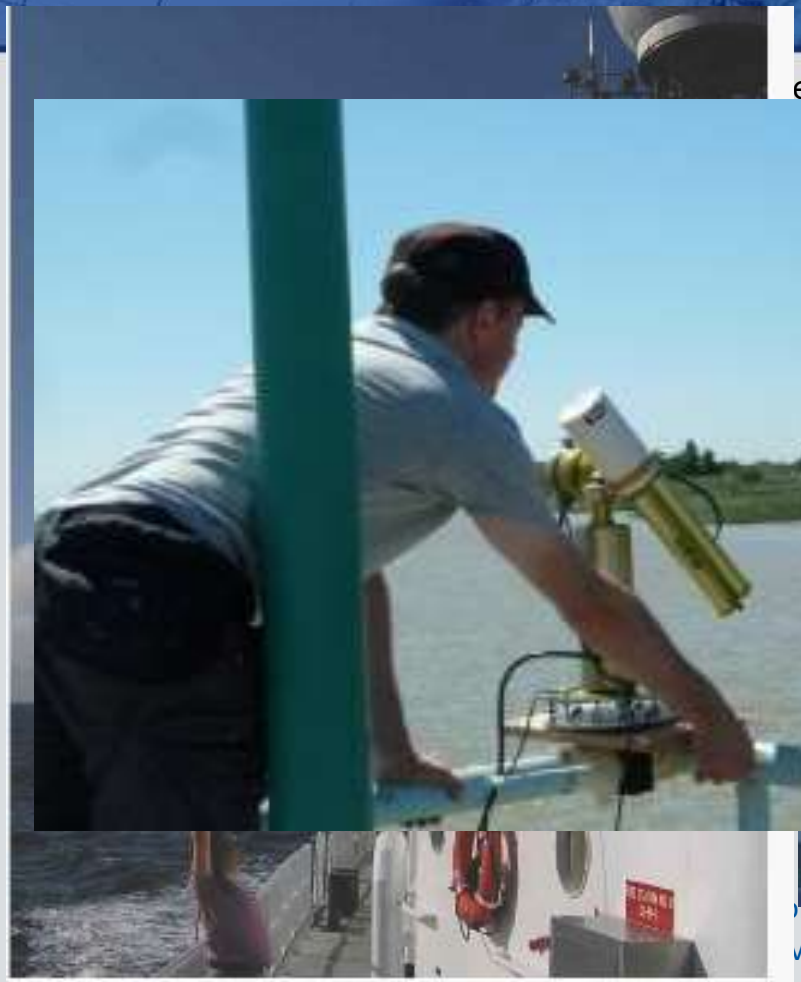
- the suite of independent ground measurements
- that provide the maximum Return On Investment (ROI) for a satellite mission
- by delivering, to users,
- the required confidence in data products,
- in the from of independent validation results and satellite measurement uncertainty estimation,
- over the entire end-to-end duration of a satellite mission.

The defining mandatory characteristics of an FRM are:

- FRM measurements have documented SI traceability via round-robin inter-calibration of instruments.
- FRM measurements are independent from the satellite retrieval process.
- An uncertainty budget for all FRM instruments and derived measurements is available and maintained.
- FRM measurement protocols and community-wide management practices (measurement, processing, archive, documents etc.) are defined and adhered to.

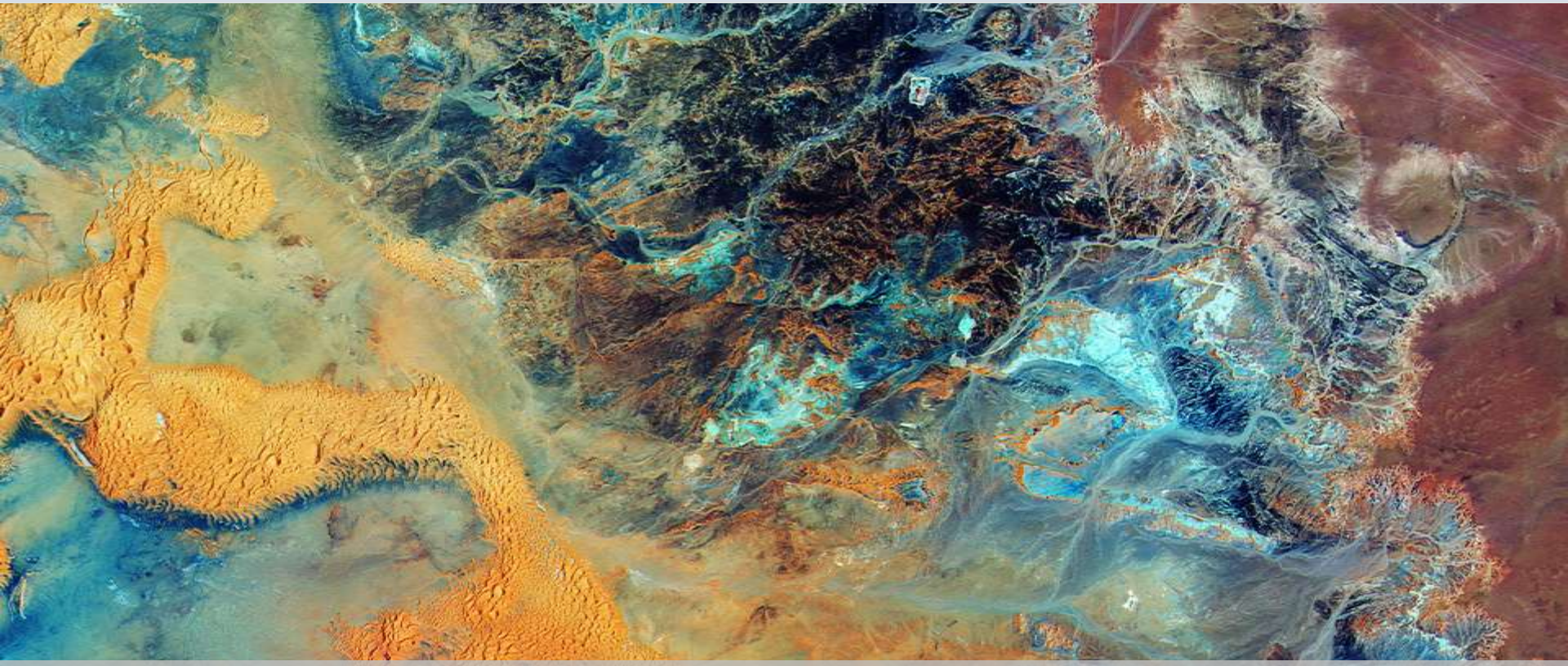
→ FRM allow a proper understanding of the validation results and FRM comparison between Validation measurements

FRM4 activities



At Sea Comparison of 3 radioameters (R/V Walton Smith, University of Miami) (Credit: P. Minnett)

THANK YOU



Further information available at:

http://sentinels.copernicus.eu
https://earth.esa.int/web/sppa/activities