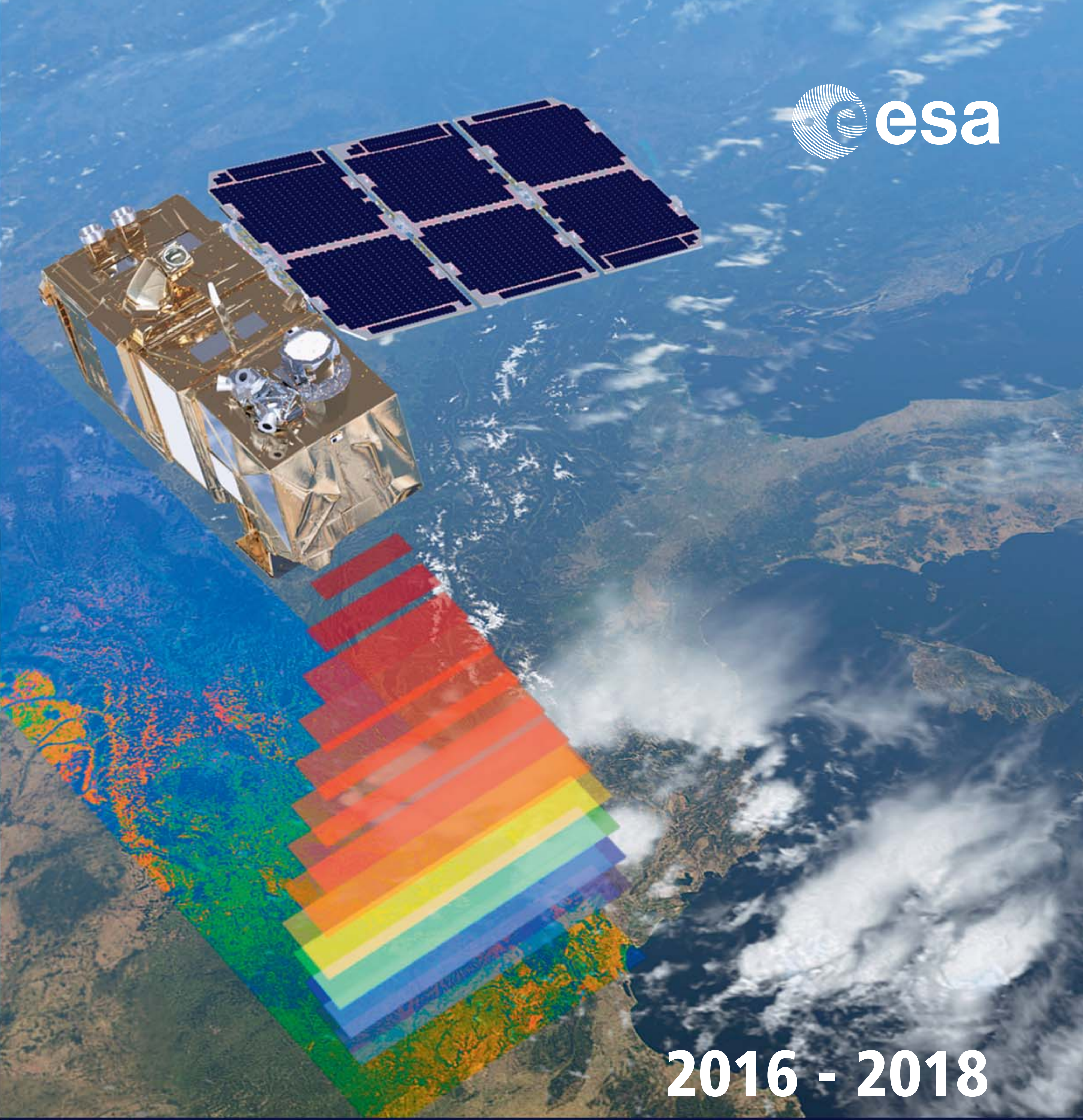


2016 - 2018

fiducial reference measurements for satellite ocean colour

→ FRM4SOC

→ FRM4SOC

The FRM4SOC project, with funding from ESA, has been structured to provide support for evaluating and improving the state of the art in ocean colour validation through a series of comparisons under the auspices of the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration & Validation and in support of the CEOS ocean colour virtual constellation. FRM4SOC also strives to help fulfil the International Ocean Colour Coordinating Group (IOCCG) in situ ocean colour radiometry white paper objectives and contribute to the relevant IOCCG working groups and task forces (e.g. the working group on uncertainties in ocean colour remote sensing and the ocean colour satellite sensor calibration task force).

The project makes a fundamental contribution to the European system for monitoring the Earth (Copernicus) through its core role of working to ensure that ground-based measurements of ocean colour parameters are traceable to SI standards. This is in support of ensuring high quality and accurate Copernicus satellite mission data, in particular Sentinel-2 MSI and Sentinel-3 OLCI ocean colour products. The FRM4SOC project also contributes directly to the work of ESA and EUMETSAT to ensure that these instruments are validated in orbit.

Revealing the colour of ocean life.
Released 13/01/2016 10:49 am. © ESA/ATG medialab

Front cover photo: Colour vision for Copernicus.
Released 11/02/2015 2:42 pm. © ESA/ATG medialab

The aim of the FRM4SOC project is to establish and maintain SI traceability of Fiducial Reference Measurements (FRM) for satellite Ocean Colour Radiometry (OCR) with accompanying uncertainty budgets.

"Those responsible for studies of Earth resources, the environment, human wellbeing and related issues ensure that measurements made within their programs are in terms of well-characterized SI units so that they are reliable in the long term, are comparable world-wide and are linked to other areas of science and technology through the world's measurement system established and maintained under the Convention du Mètre."

Resolution 1 of the 20th Conférence Générale des Poids et Mesures

→ SCIENTIFIC BACKGROUND

Calibration and Validation of Satellite Ocean Colour Sensors

Accurate radiometric calibration and characterization of the individual satellite sensors is the most critical component toward achieving the goal of consistent, long-term multi-mission Ocean Colour products.

Once on-orbit, the uncertainty characteristics of the satellite instruments established during pre-launch laboratory calibration and characterization activities and the end-to-end geophysical measurement retrieval process can only be assessed via independent calibration and validation activities.

Ground Measurements

Ground measurements are essential to Ocean Colour remote sensing for:

- Vicarious adjustment of L2 products;
- Continuous assessment of OCR quality (i.e., validation of normalized water leaving radiance or the equivalent remote sensing reflectance);
- Validation of derived satellite ocean colour products (e.g., chlorophyll-a concentration);
- Development and verification of the bio-optical algorithms required for generating derived products (independent of any specific satellite mission).

Fiducial Reference Measurement

The concept of Fiducial Reference Measurements (FRM) has been established by the Sentinel-3 Validation Team (S3VT) as: "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 form of independent validation results and satellite measurement uncertainty estimation, over the entire end-to-end duration of a satellite mission."
https://earth.esa.int/web/sppa/activities

The defining mandatory characteristics for FRM are:

- FRM measurements have documented SI traceability (eg. via round-robin intercalibration of instruments) using metrology standards.
- FRM measurements are independent from the satellite geophysical retrieval process, noting the exception of L2 product vicarious adjustment that fundamentally depends on FRM ground based measurements.
- 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, published openly and adhered to by FRM instrument deployments.
- FRM measurements are openly and freely available for independent scrutiny.

The Committee for Earth Observation Satellites (CEOS) define

Calibration as "the process of quantitatively defining a system's responses to known, controlled signal inputs".

Validation, on the other hand, is "the process of assessing, by independent means, the quality [uncertainty] of the data products derived from those system outputs".

Validation is a core component of a satellite mission and should be planned for accordingly starting at the moment satellite instrument data begin to flow until the end of the mission.

VIM: International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM) states

Adjustment is "set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured".

Adjustment of a measuring system should not be confused with calibration, which is a prerequisite for adjustment.

BOUSSOLE mooring. BOUSSOLE is funded by the European Space Agency (ESA), the French Space Agency (CNES), the Institut National des Sciences de l'Univers (INSU), and benefits from logistical and staff support from the Laboratoire d'Océanographie de Villefranche (LOV), and the Observatoire Océanologique de Villefranche (OOV). 2015.
Photos: Courtesy of the LOV, David Antoine and Vincenzo Vellucci.

→ TRACEABILITY TO SI

SI provides the foundation for measurement around seven base units and a system of coherent derived units. The SI units must be stable over centuries. They must also be uniform worldwide and independent of the method used to realise the unit.

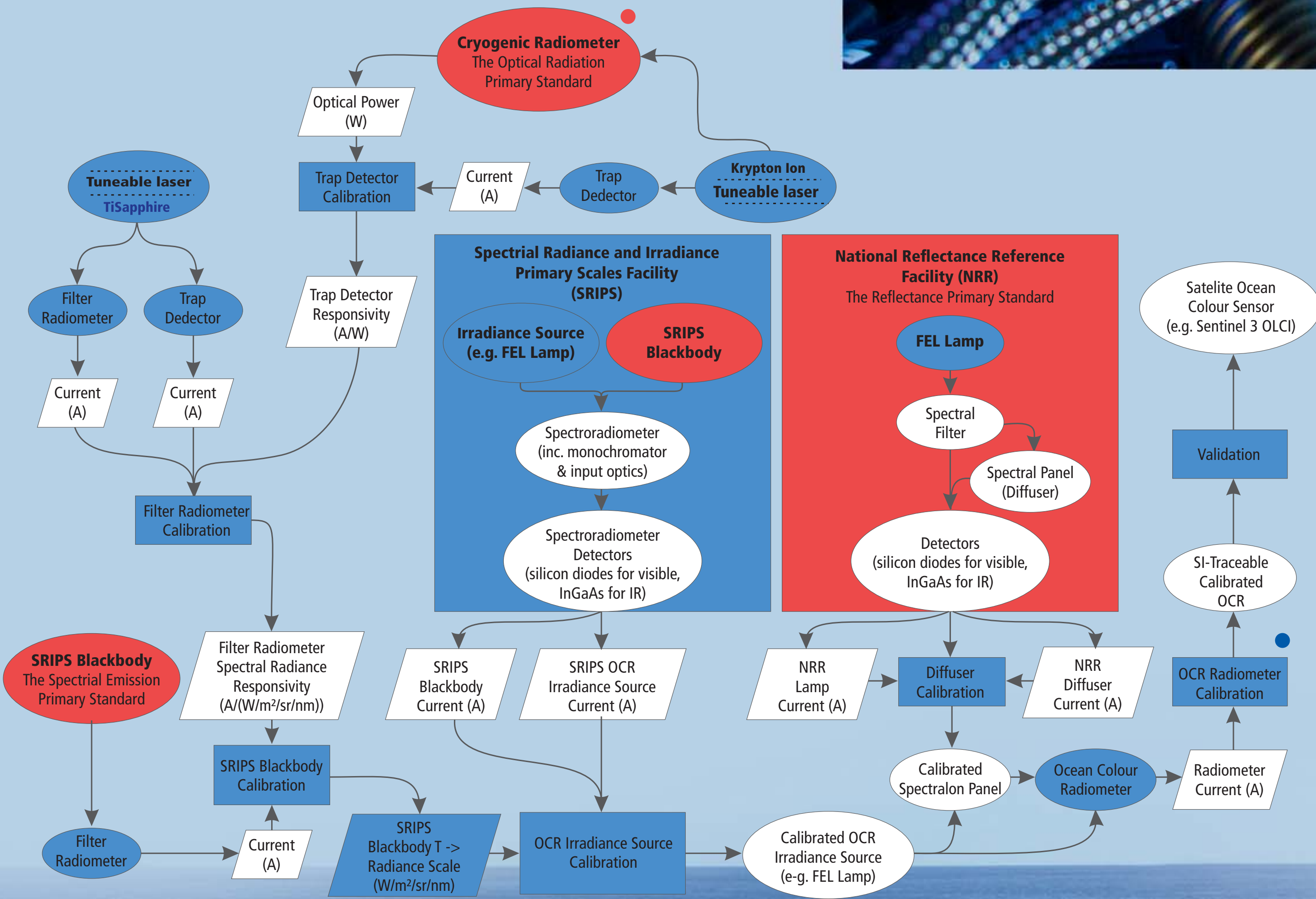
The metrological community achieves this through three technical concepts: traceability, uncertainty analysis and comparison.

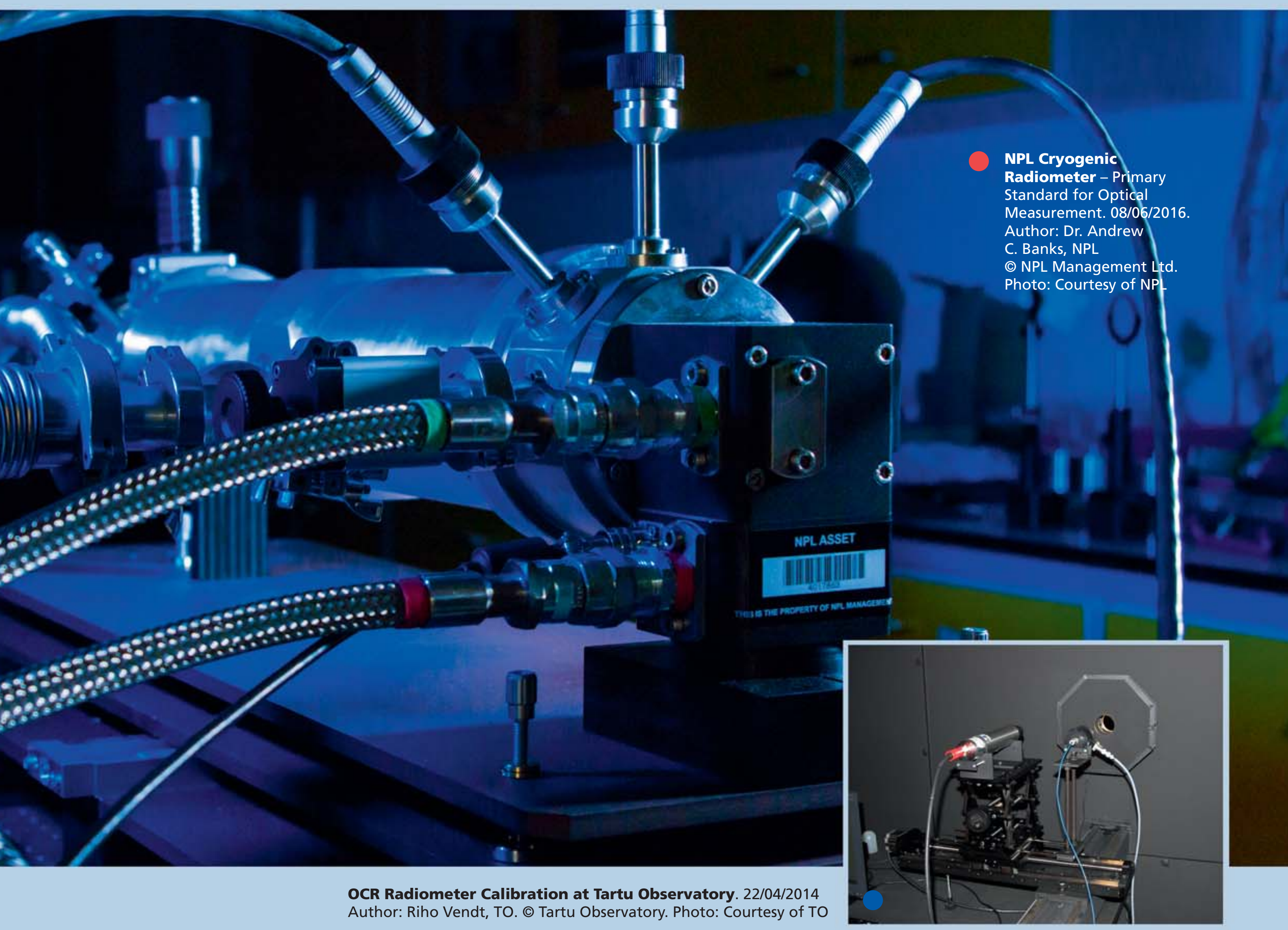
Metrological traceability is a property of a measurement that relates the measured value to a stated metrological reference through an unbroken chain of calibrations or comparisons.

Uncertainty analysis is the review of all sources of uncertainty and the propagation of that uncertainty through the traceability chain.

The traceability and uncertainty analysis at the NMIs is rigorously audited through the Mutual Recognition Arrangement, which also involves regular formal international comparisons (Woolliams et al., 2016).

For ocean colour measurements, whether they are made by satellite or in situ ocean colour radiometers, traceability to SI is achieved through an unbroken series of calibrations back to the primary standard for optical radiation: the NPL cryogenic radiometer. This traceability chain is visualized for FRM4SOC in the figure below.





NPL Cryogenic Radiometer – Primary Standard for Optical Measurement. 08/06/2016. Author: Dr. Andrew C. Banks, NPL

Photo: Courtesy of NPL

OCR Radiometer Calibration at Tartu Observatory. 22/04/2014
Author: Riho Vendt, TO. Photo: Courtesy of TO

→ THE IMPORTANCE OF UNCERTAINTY BUDGETS

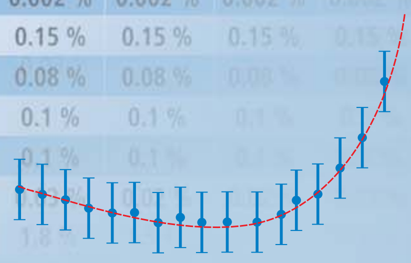
All measurements are imperfect and have errors that can be of a random nature (i.e. noise on charge coupled device detectors) or of a systematic nature.

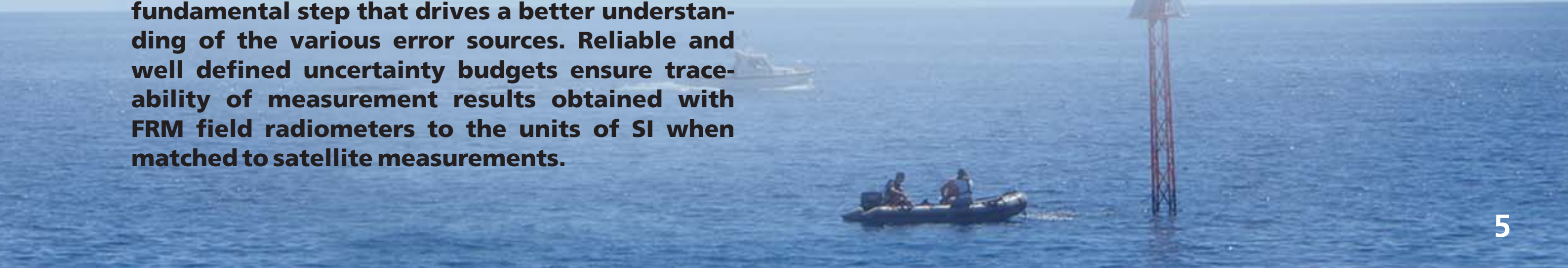
Uncertainties arise due to many aspects that can be generally grouped into the following primary categories:

- Instrument measurement uncertainty: those relating to instrument hardware,
- Retrieval/algorithm uncertainty: those relating to derived quantities,
- Application uncertainty: those relating to a specific application,
- Unknown: those uncertainties that are "unknown".

Establishing an uncertainty budget for FRM is a fundamental step that drives a better understanding of the various error sources. Reliable and well defined uncertainty budgets ensure traceability of measurement results obtained with FRM field radiometers to the units of SI when matched to satellite measurements.

UNCERTAINITY COMPONENTS	SELECTED SPECTRAL BANDS OF THE SENTINEL 3 OLCI SENSOR			
	400 nm	442.5 nm	490 nm	560 nm
FEL standard lamp irradiance	0.78 %	0.61 %	0.61 %	0.61 %
Interpolation of irradiance	0.2 %	0.2 %	0.2 %	0.2 %
Lamp ageing	0.28 %	0.28 %	0.28 %	0.28 %
Shunt	0.002 %	0.002 %	0.002 %	0.002 %
Lamp current	0.15 %	0.15 %	0.15 %	0.15 %
Distance lamp - sensor	0.08 %	0.08 %	0.08 %	[illegible]
Alignment of lamp position	0.1 %	0.1 %	0.1 %	[illegible]
Alignment of radiometer	0.1 %	0.1 %	[illegible]	[illegible]
Temperature variability	[illegible]	[illegible]	[illegible]	[illegible]
Expanded uncertainity, k=2	1.8 %	[illegible]	[illegible]	[illegible]





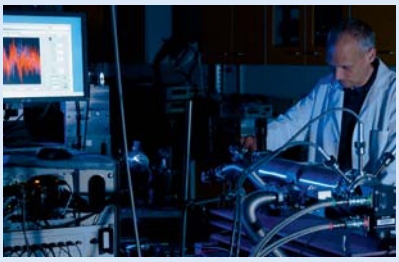
→ ACTIVITIES

To achieve its goal, FRM4SOC consortium will organize a set of activities including workshops (WKP), laboratory (LCE) and in situ (FICE) inter-comparison experiments. You will find below the schedule of these events. More details can be found on **https://frm4soc.org.**

WKP-1 21 - 23 FEBRUARY 2017

Location: ESA/ESRIN, Frascati, Italy
Event: ESA international workshop "Options for future European satellite OCR vicarious adjustment infrastructure for the Sentinel-3 OLCI and Sentinel-2 MSI series"
Contact: **Christophe Lerebourg**
christophe.lerebourg@acri-st.fr

LCE-1 3 - 7 APRIL 2017



Location: NPL, Teddington, UK
Event: SI-traceable Laboratory inter-comparison experiment for FRM OCR and reference irradiance/radiance calibration targets. Verification of reference irradiance and radiance sources.
Contact: **Andrew Banks**
andrew.banks@npl.co.uk

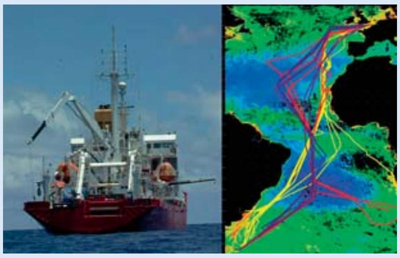
LCE-2 8 - 13 MAY 2017

Location: Tartu Observatory, Tõravere, Estonia
Event: SI-traceable Laboratory inter-comparison experiment for FRM OCR and reference irradiance/radiance calibration targets. Verification of FRM OCR.
Contact: **Joel Kuusk**
joel.kuusk@to.ee

FICE AAOT JUNE - JULY 2017

Location: Gulf of Venice, Italy
Event: Fiducial Inter-Comparison Experiment for Sentinel-3 at the Acqua Alta Oceanographic Tower (AAOT)
Contact: **Gavin Tilstone**
ghti@pml.ac.uk

FICE AMT SEPT- OCT 2017



Location: Atlantic Meridional Transect
Event: Fiducial Inter-Comparison Experiment at the Atlantic Meridional Transect (AMT)
Contact: **Gavin Tilstone**
ghti@pml.ac.uk

WKP-2 AUGUST 2018

Location: NPL, UK
Event: Final Workshop
Contact: **Andrew Banks**
andrew.banks@npl.co.uk

The core action of the Fiducial Reference Measurements for Satellite Ocean Colour - FRM4SOC project - is to ensure that ground-based measurements of ocean colour parameters are traceable to SI standards in support of ensuring high quality and accurate Sentinel-2 MSI and Sentinel-3 OLCI products.

ESRIN. Released 20/09/2005 11:43 am © ESA
NPL Cryogenic Radiometer – Primary Standard for Optical Measurement wide view with technical scientist Florian Graber. 08/06/2016. Author: Dr. Andrew C. Banks, NPL. © NPL Management Ltd. Photo: Courtesy of NPL
View from satellite ESTCube-1 to Estonia. © ESTCube-1 team. Photo: Courtesy of TO.
AMT cruises are conducted between UK & South Atlantic on a NERC ship. © PML
Aqua Alta Oceanographic Tower. Released 26/04/2006 5:04 pm. © Joint Research Centre.
Meeting at NPL. © NPL Management Ltd. Photo: Courtesy of NPL

Measuring downwelling irradiance. © RBINS. ▶

→ PARTNERS

EUROPEAN SPACE AGENCY

Craig Donlon, ESA
craig.donlon@esa.int
Principal Scientist for Oceans and Ice
http://www.esa.int/ESA

The European Space Agency (ESA) is Europe's gateway to space. Its mission is to shape the development of Europe's space capability and ensure that investment in space continues to deliver benefits to the citizens of Europe and the world.

ESA is an international organisation with 22 Member States. By coordinating the financial and intellectual resources of its members, it can undertake programmes and activities far beyond the scope of any single European country.

FRM4SOC kick-off meeting in ESA/ESTEC. 05/27/2016 © Tartu Observatory.

TARTU OBSERVATORY, Estonia

Riho Vendt, TO
riho.vendt@to.ee
https://to.ee
https://frm4soc.org

Having 200+ years of experience in space research, Tartu Observatory (TO) is the leading centre of astronomical research in Estonia, also possessing an internationally acknowledged competence in remote sensing of natural environment. Tartu Observatory research strategy brings together scientific and public goals. Here meet the high competence of internationally recognized senior researchers with splendid enthusiasm of young scientists to find solutions for new challenging research questions. This enables to respond to the challenges that modern technology, political situation and economic needs create.

Main building of Tartu Observatory.
08/09/2012. Author: Kalju Annuk. © Tartu Observatory. Photo: Courtesy of TO.

NATIONAL PHYSICAL LABORATORY, UK

Andrew Banks, NPL
andrew.banks@npl.co.uk
http://www.npl.co.uk/

The National Physical Laboratory (NPL) is the United Kingdom's national metrology institute, an internationally respected and independent centre of excellence in research, development and knowledge transfer in measurement. NPL continues to pioneer technologies and the application of these into new sectors. In Earth Observation (EO), NPL has taken a leading role in establishing a strong connection between metrology and EO; e.g. many primary optical radiometric techniques now being used throughout the world were pioneered at NPL, including the development of the primary standard, the cryogenic radiometer.

NPL has also been developing best practice guidance in conjunction with the EO community for detailed but generic Cal/Val activities, with specific organisations for particular measurement issues, and more generally in developing guidelines to support the Quality Assurance Framework for Earth Observation (QA4EO), which is gradually being adopted by ESA and other space agencies.

Main building of National Physical Laboratory. © NPL Management Ltd. Photo: Courtesy of NPL

PLYMOUTH MARINE LABORATORY, UK

Gavin Tilstone, PML
ghti@pml.ac.uk
http://www.pml.ac.uk/

Plymouth Marine Laboratory (PML) is an independent, impartial provider of scientific research and contract services relating to the marine environment.

PML has world-class research capacity in global Earth Observation, ecosystem modelling, and marine ecosystem functioning. Its core research programme contributes to the issues of climate change, marine pollution and sustainability. PML's research is highly innovative, relevant and applicable, feeding into national and international marine and coastal programmes in anticipation of societal needs.

PML has a long history of Earth Observation applications, software development and data processing for national, European Commission and ESA projects. Activities range from scientific research and development (algorithms, models, etc.) to reprocessing/reanalysis, and from near real-time and climate-quality/delayed-mode data provision to cutting-edge large scale data distribution and visualisation.

Main building of Plymouth Marine Laboratory. © PML

ROYAL BELGIAN INSTITUTE FOR NATURAL SCIENCES, Belgium

Kevin Ruddick
kruddick@naturalsciences.be
http://odnature.naturalsciences.be/remsem/index

The Royal Belgian Institute for Natural Sciences (RBINS) is a Belgian Federal Government Scientific Establishment. The RBINS Remote Sensing and Ecosystem Modelling (REMSEM) is carrying out scientific research and analysis in the field of marine ecosystems to improve the long term scientific basis for management of the marine ecosystems.

The team has 20 years' experience in the development of algorithms for the processing of ocean colour data (including atmospheric correction) and in the validation and exploitation of satellite-derived products with particular expertise in turbid coastal waters.

RBINS has been making measurements of Ocean Colour radiometry since 2001 using a three-sensor abovewater TRIOS system and was a de facto leader of this methodology, termed "MUMM_TRIOS", within the MERIS Validation Team.

Muséum des Sciences naturelles de Belgique (entrée). From Wikimedia Commons, the free media repository under Creative Commons Attribution-Share Alike 1.0 Generic license.

ACRI-ST, France

Christopher Lerebourg, ACRI-ST
christophe.Lerebourg@acri-st.fr
http://www.acri-st.fr/

ACRI-ST is a member of the ACRI Group established in 1989, comprising companies providing services from satellite remote sensing, ocean & land surveys to hydraulic civil engineering through environmental research Computational Fluid Dynamics and dynamic similitude.

ACRI-ST has more than twenty-five years of experience in Cal/Val for Earth Observations missions. They built up their expertise particularly on MERIS/ENVISAT. They have further confirmed this expertise and ACRI is now a key expert in the frame of Sentinel-2 and Sentinel-3 mission performance centres.

ACRI-ST is a supplier to space agencies (simulation of space-based sensors; operational chains development; processing, archiving and mission performance centres) and develops/operates environmental Copernicus services to end users.

ACRI head office in Sophia Antipolis, France. ©ACRi-ST

Setting up radiometers on the Research Vessel Belgica. 09/07/2015© RBINS

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