The importance of FRM in Ocean Colour satellite data validation for EUMETSAT

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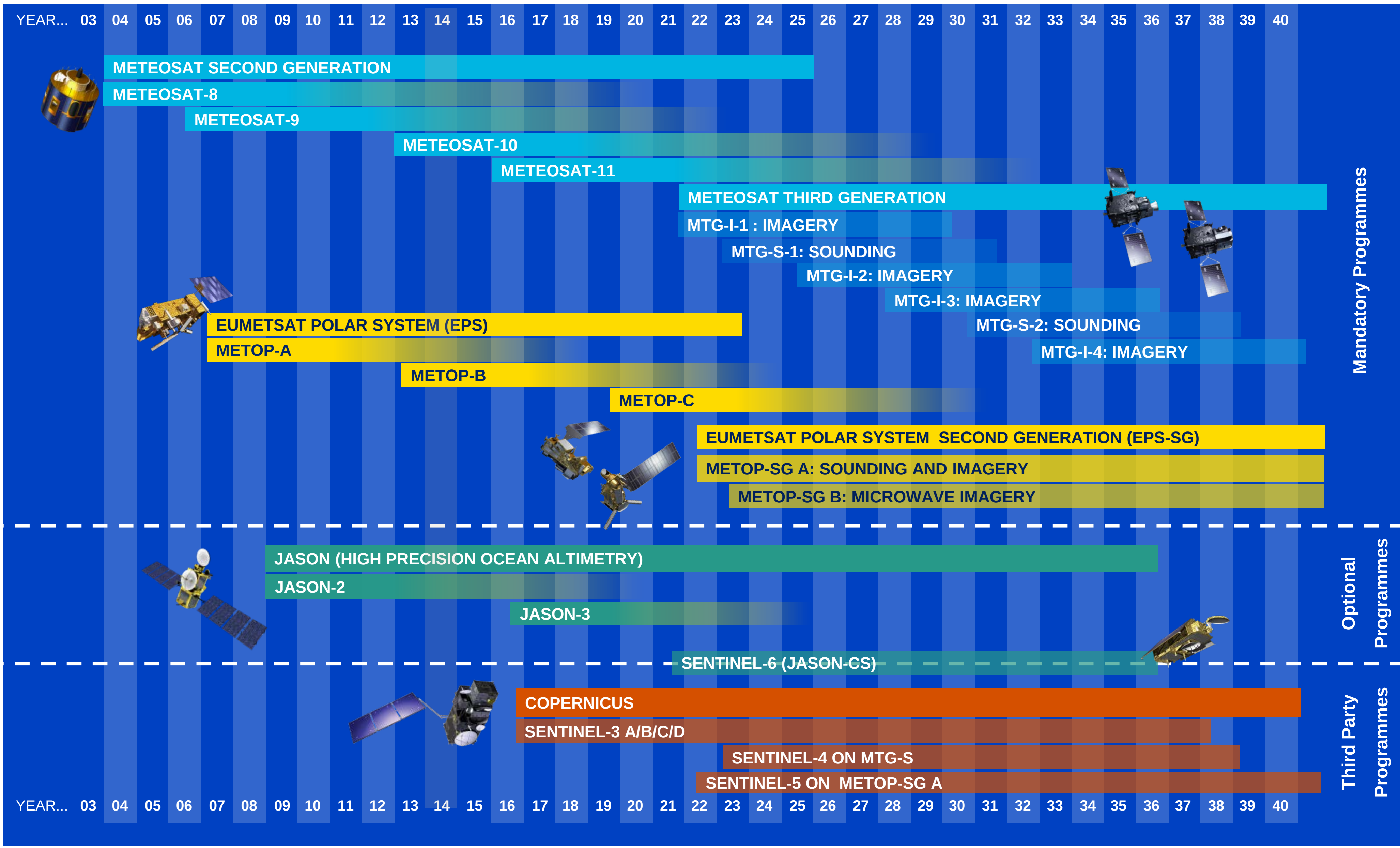
FRM4SOC Final Workshop, NPL

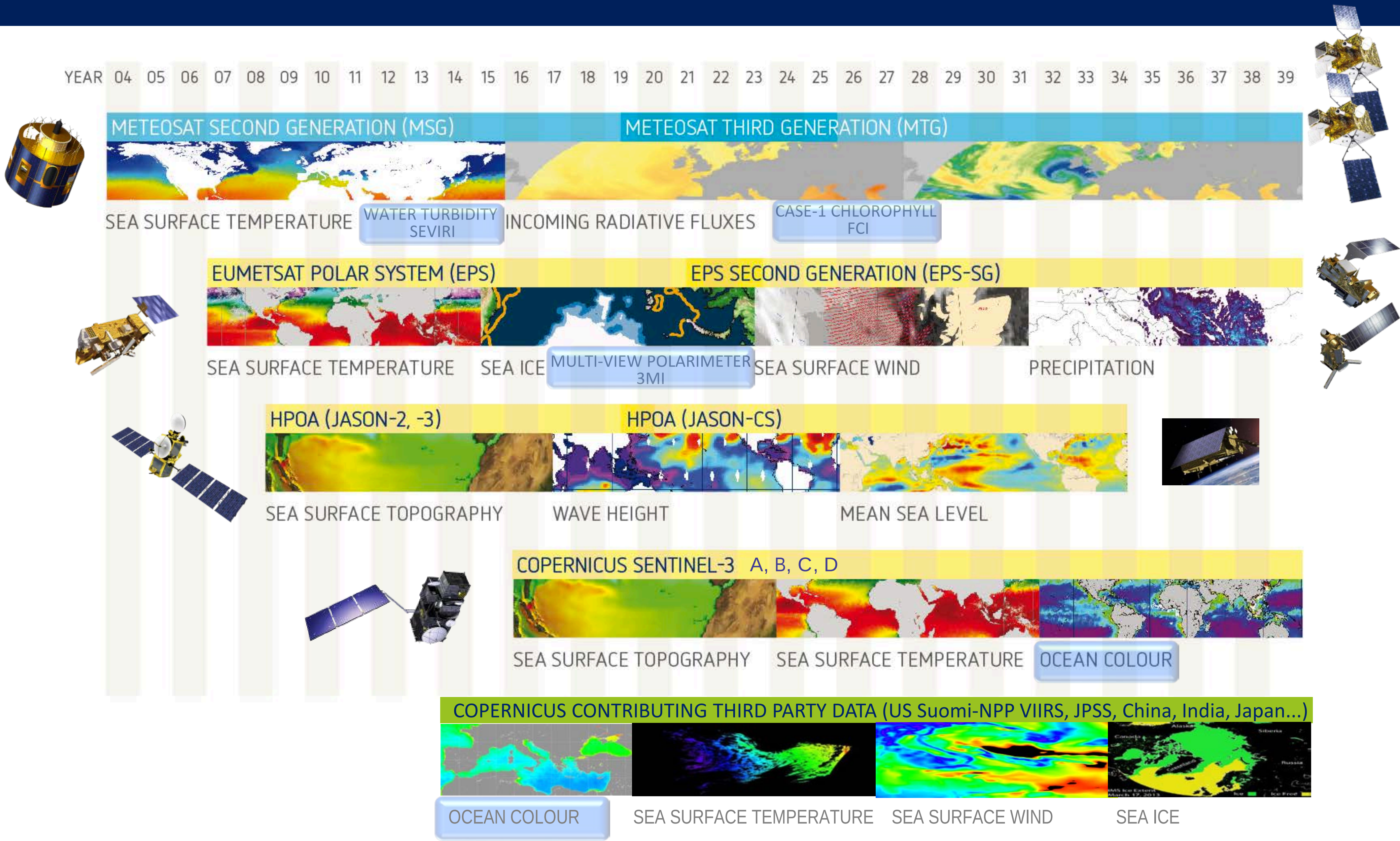
04/10/2018

EUM/RSP/DOC/18/1023841, v1C Draft, 2 October 2018

EUMETSAT operational satellite mission commitments



EUMETSAT operational satellite oceanography



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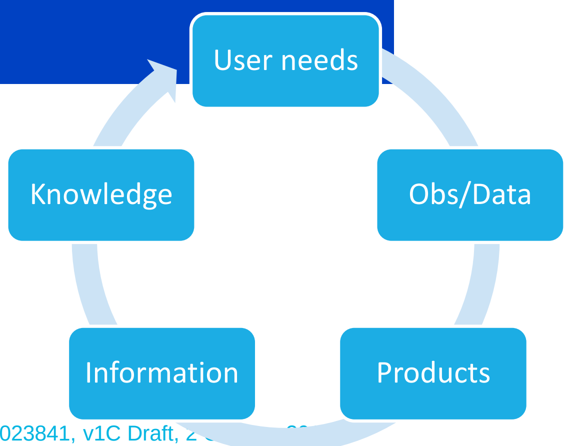
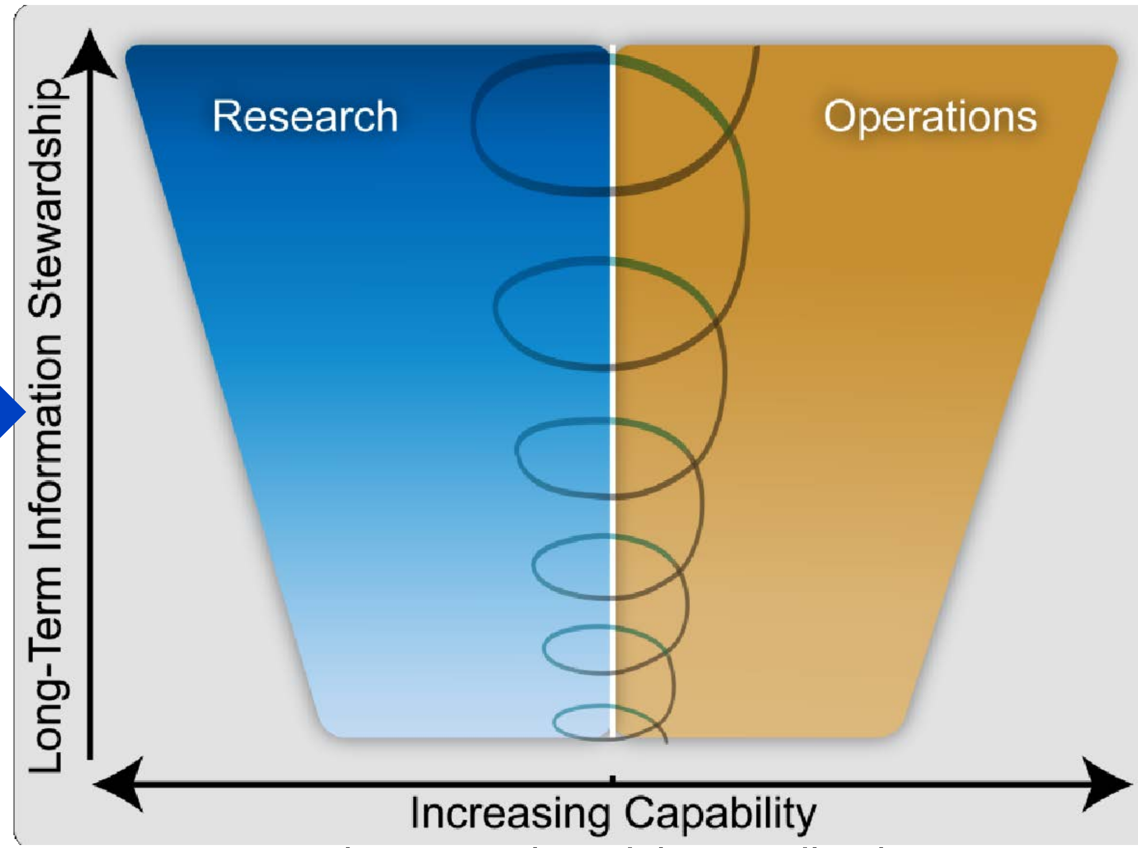
Operational satellite oceanography paradigm

OPERATIONAL:
Routine and sustained provision of accurate, consistent and fit for purpose quality data and products spanning different time-scales (NRT to climate) in support of research, applications and services…





Diverse and Evolving Applications

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CEOS OCR-VC and IOCCG INSITU-OCR White Paper

	Recommendations
Space Sensor Radiometric Calibration, Characterization and Temporal Stability	R1.1 Comprehensive pre-launch instrume calibration/characterization
	R1.2 Open access to calibration and characterization data
	R1.3 Permanent working group on satellit sensor calibration
	R1.4 Vicarious calibration
	R1.5 Support for calibration teams
	R1.6 Assess and correct for instrumen degradation
Development and Assessment of Satellite Products	R2.1 Distribution of calibrated and uncalibrated data
	R2.2 Permanent working groups on al topics
	R2.3 Product uncertainties
	R2.4 Regional bio-optical algorithms
	R2.5 Open access to source codes for processing algorithms
	R2.6 Long-term field measurement progra
	R2.7 Validation protocols
	R2.8 Level-3 data products generation
	R2.9 Ancillary data

	Recommendations
In Situ Data / Fiducial Reference Measurements	R3.1 Improving traceability of in situ measurements
	R3.2 Continuous consolidation and update of measurement protocols
	R3.3 Uncertainty budgets
Management and Support	data
	R4.2 Processing capabilities for calibration and validation activities
	R4.3 Accessibility to documentation
	R4.4 Data formats
	R4.5 Support for open source data processing and visualization

FRM (*FRM4SOC SOW, 2015*):

- documented SI traceability
- independence from the satellite geophysical retrievals
- uncertainty budget for instruments and derived measurements
- adherence to measurement protocols and community-wide management practices (measurement, processing, archive, documents etc.)
- open and free availability of measurements for independent scrutiny

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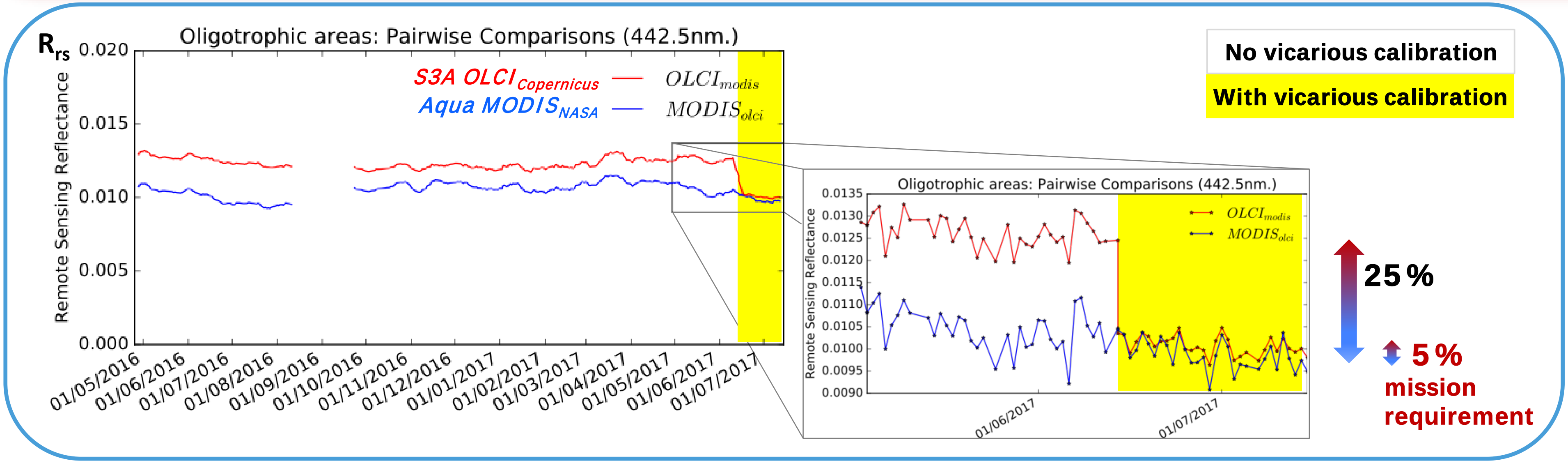
Fiducial Reference Measurements are essential for operational satellite Ocean Colour

… accurate, consistent and fit for purpose quality data and products …

- System Vicarious Calibration
- Satellite product validation
- Satellite product algorithm evolution and new products

FRM for System Vicarious Calibration – Ocean Colour requirement

- The requirement for OC-SVC is clearly defined by the ocean colour community [IOCCG 2012, CEOS INSITU-OCR White Paper 2012 → **R1.4**]
- OC-SVC is a prerequisite to meeting the operational mission requirements [S3-MRTD 2011, S3-CVP 2014]
- OC-SVC is a prerequisite to meeting the requirements of ocean colour data users and services [CMEMS and CCCS: CMEMS 2017, GCOS 2016]
- Requirement stated at ESA–FRM4SOC SVC workshop in Feb 2017 and Report



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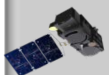
Copernicus requirements for OC-SVC infrastructure

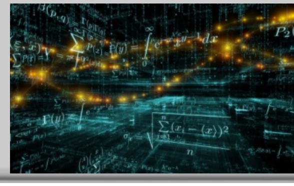
Copernicus satellites S3/OLCI, S2/MSI + Third-Party



S3A
S3B
S3C
S3D

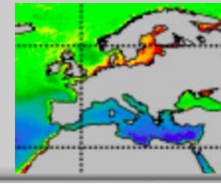
Multi-mission
20 years Copernicus data

Cal/val and
Data processing



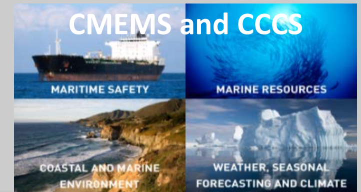
System Vicarious Calibration

Core products: radiometry ρ_w or R_{rs}

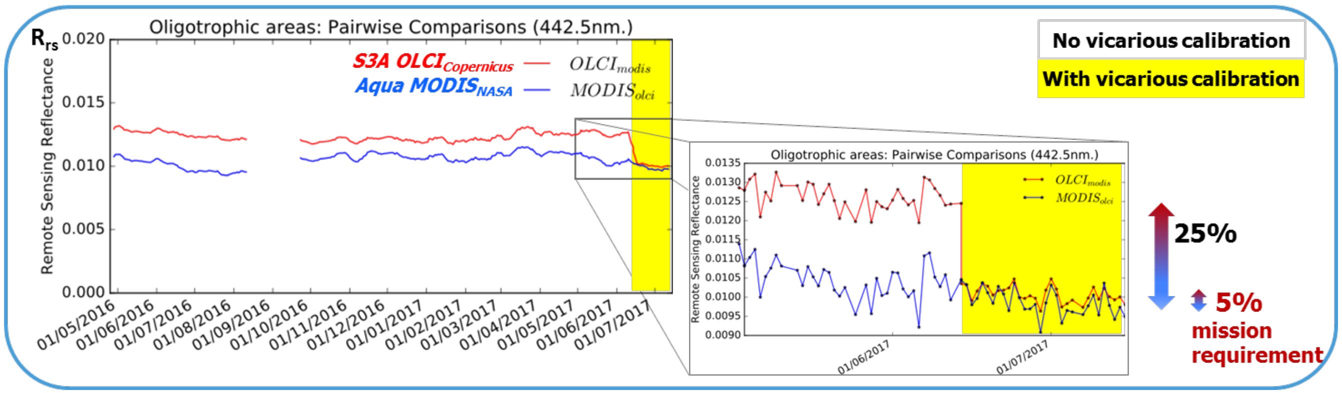


ρ_w ~ 10% of ρ_{TOA}

Applications**, services** users



Long-term ocean colour **consistent, stable, accurate**



OC-SVC must be used to meet mission accuracy requirements

OC-SVC is a pre-requisite to quality Copernicus Marine and Climate Services for aquatic biogeochemistry

Copernicus OC-SVC infrastructure must be (at least) equivalent to the existing highest quality OC-SVC FRM used across agencies

OC-SVC

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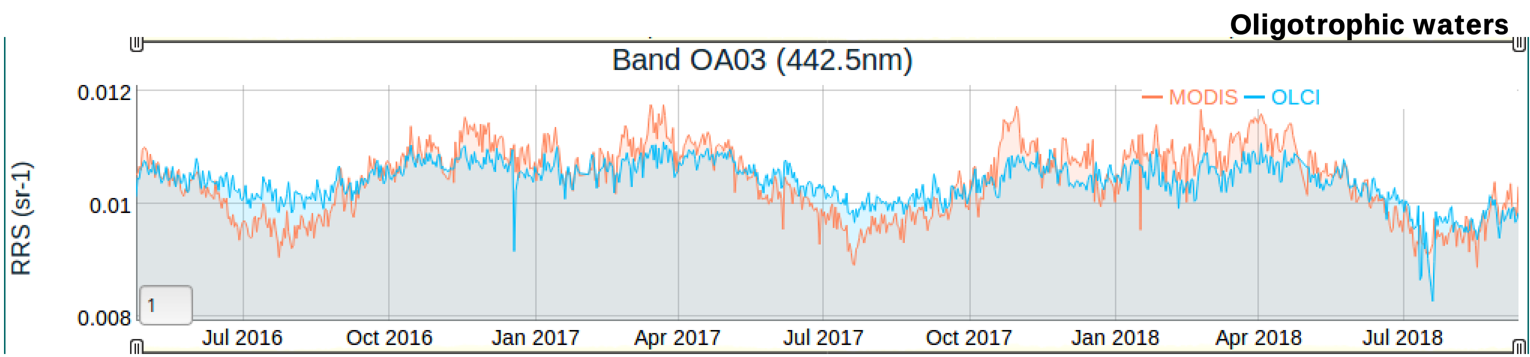
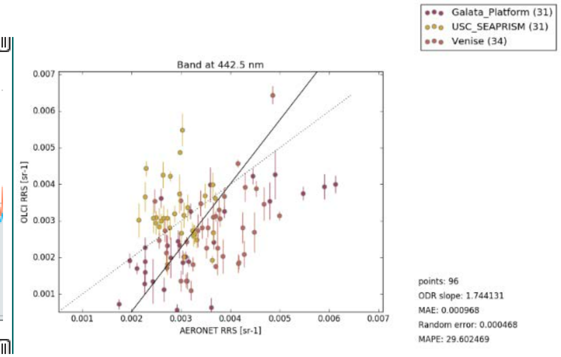
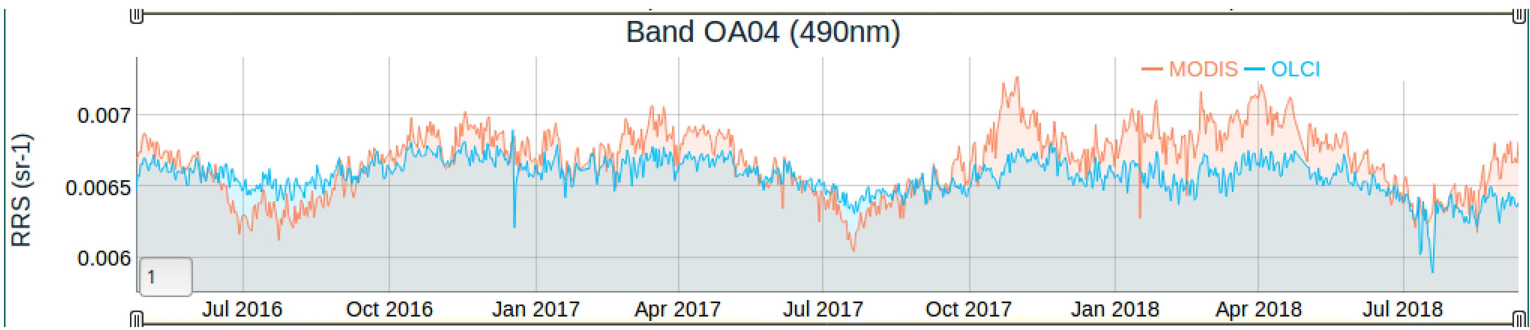
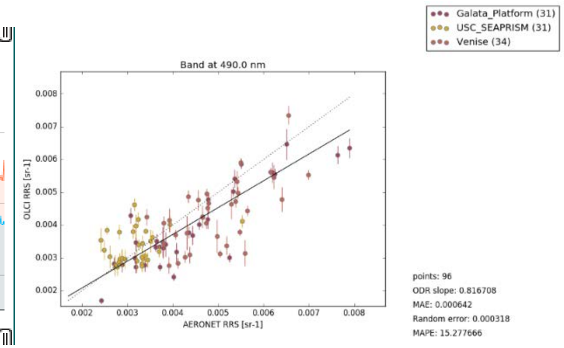
OC-SVC gains enable Sentinel-3A OLCI L2 radiometry to mostly meet mission requirements

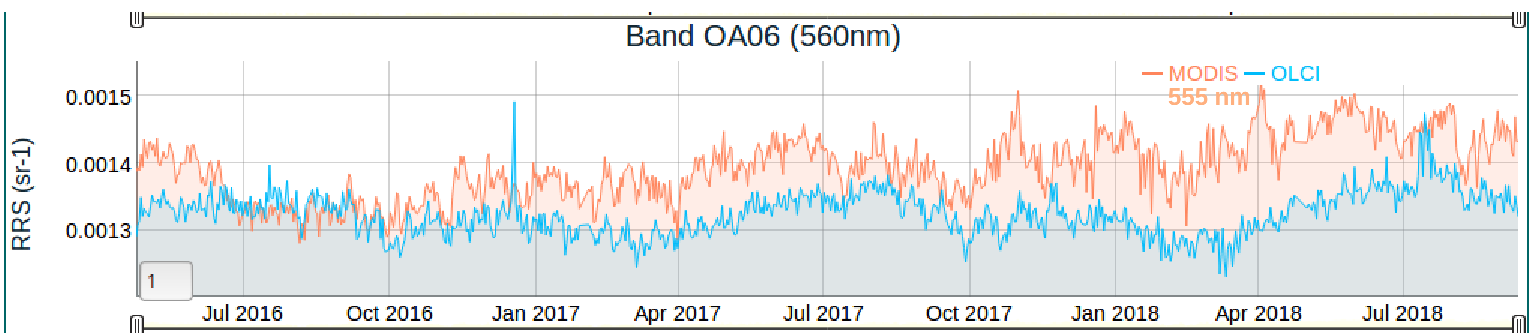
Oligotrophic waters

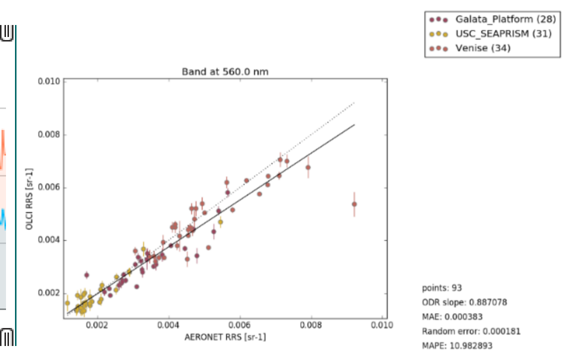










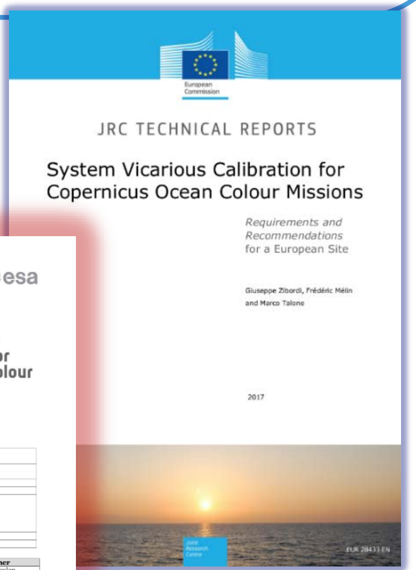


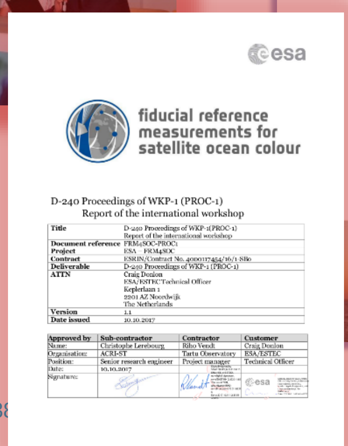
Malcolm Taberner
and Ilaria Cazzaniga

Copernicus OC-SVC development activities: critical contributions of ESA FRM4SOC, OC-SVC roadmap

Cross-agency context

- **ESA – FRM4SOC SVC workshop in Feb 2017 and Report**
- ESA – FRM4SOC radiometry protocols under IOCCG review, final workshop 4-5 October 2018
- ESA / CNES – continuous operations of BOUSSOLE
- JRC – peer-review publications, OC-SVC requirements
- NOAA – continuous operations of MOBY
- NOAA – MOBY Technology Refreshment on-going
- NASA – completing 3-year/US$8M investment in first phase of SVC development, 3 projects (UV-SWIR)
- NASA – preparing for follow-on in situ SVC competition





Copernicus OC-SVC Roadmap

1. Requirements
2. Preliminary Design, Project Plan and Costing
3. Technical Definition, Specifications, Detailed Design
4. Development, Testing and Demonstration in the Field
5. Operations

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EUMETSAT OC-SVC Copernicus Roadmap contributions
❶ Requirements for Copernicus OC-SVC infrastructure

Main outcomes:

- Document with 60+ requirements
- Methodology for an end-to-end OC-SVC uncertainty budget


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Requirements for Copernicus OC-VCAL Infrastructure

Ref: SOLVO/EUM/16/VCA/D8
Issue: 1.2
Date: 2017-07-31
Page: 1/91

Requirements for Copernicus Ocean Colour Vicarious Calibration Infrastructure

31st July 2017

Study funded by the European Commission and EUMETSAT under contract EUM/CO/16/4600001772/EJK

Uncertainty source	rel_unc(400) rand.	rel_unc(400) syst.
In situ Lw measurement		
Spectral resolution		0.50%
Spectral calibration		0.10%
Stray-light		0.75%
Radiometric calibration & stability		2.00%
Angular response		
Immersion factor	0.25%	
Thermal stability	0.30%	
Dark current		
Polarisation sensivity	0.20%	
Non-linearity response		0.10%
Noise characterisation		
Environ. conditions (like-to-like rule)	0.50%	
Shading		0.25%
Tilting & BRDF	0.30%	
Depth-extrapolation	1.00%	1.00%
Surface propagation	0.25%	
Data reduction	2.10%	
Spare line for other effects		
otal uncertainty on in situ Lw	2.45%	2.43%
ncertainty on in situ Lw (rand. + syst)	3.45%	

International consensus:

- Formal review by 10 experts from CMEMS, CNRS, ESA, JAXA, JRC, KIOST, NASA, NIST, NOAA, NPL
- Open reviews during 2 conferences
- IOCCG endorsement

- Solvo (France)
- RBINS (Belgium)
- Brockmman Consult (Germany)
- University of Miami (US)

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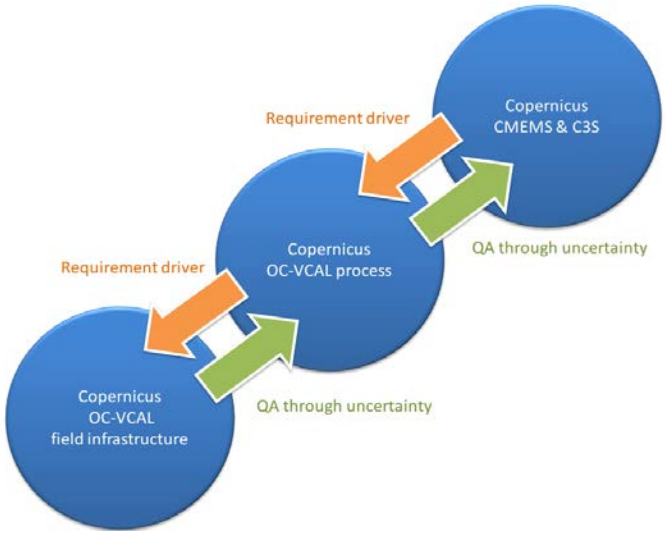
❶ Requirements for Copernicus OC-SVC infrastructure Approach for requirement engineering

I. Sound understanding of the OC-SVC process



1. Required quality (CMEMS, climate studies…)
2. Requirements on the SVC process (spaceborne sensor, method…)
3. Requirements on the field infrastructure (radiometer…)
4. Requirement on the data processing (quality control…)
5. Requirement on the operations & services (field operation…)

II. Uncertainty budget based on metrology principles (GUM - Guide to the expression of Uncertainty in Measurement)

$$u(g)^2 = \left(\frac{t_g t \mu_s C_s C_Q L_{wN}^t}{L_t}\right)^2 \left[\left(\frac{u(L_{wN}^t)}{L_{wN}^t}\right)^2 + \left(\frac{u(C_Q)}{C_Q}\right)^2 + \left(\frac{u(t)}{t}\right)^2\right.$$

$$u(\bar{g})^2 = \left(\frac{u_{rand}(g)}{\sqrt{N}}\right)^2 + u_{syst}(g)^2$$

III. Applying lessons-learned

MOBY & BOUSSOLE experience
International Ocean Colour community

Existing infrastructures provide guidance

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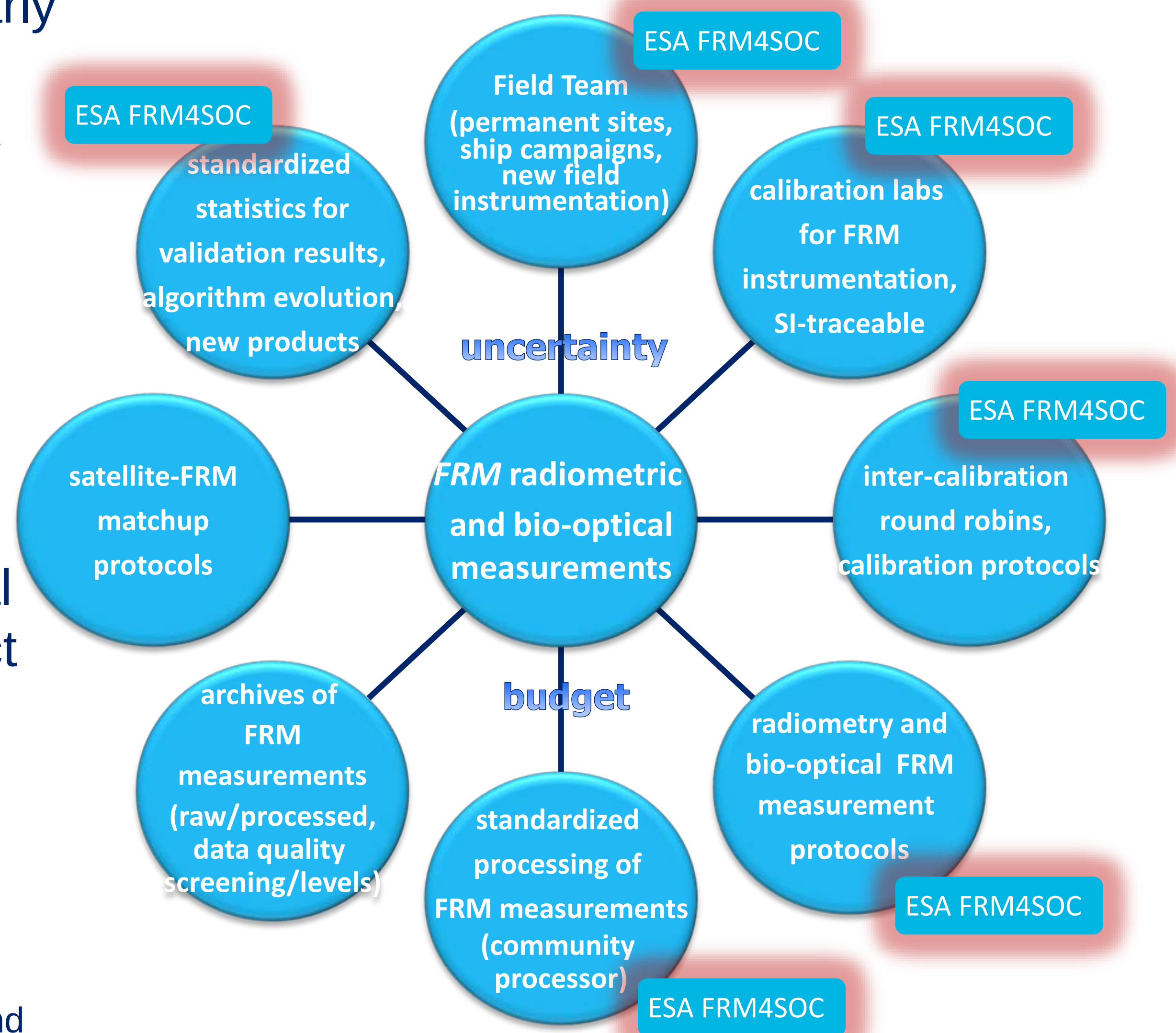
EUMETSAT OC-SVC Copernicus Roadmap contributions
➋ OC-SVC Preliminary Design, Project Plan and Costing

- EUMETSAT ITT closed on 4 June 2018
- Two proposals have been selected:
  - Laboratoire d'Océanographie de Villefrance (LOV, France) with Hellenic Centre for Marine Research, ACRI-ST, NPL, Uni Tartu, CIMEL
  - Consiglio Nazionale delle Ricerche (CNR, Italy) with AEQUORA, ENEA and SOLVO
- Study kick-offs in October 2018
- Study duration: 12 months
- Study reviews will involve external experts, in particular ESA & JRC
- Following step: selection of the Copernicus OC-SVC design and ➌Technical Definition, Specifications, Detailed Design

FRM for Satellite Product Validation, Algorithm Evolution & New Products – Ocean Colour requirement

- The requirement for FRM is clearly defined by the ocean colour community [CEOS INSITU-OCR White Paper 2012 → **R3**]
- FRMs give evidence about the quality of ocean colour products and data services
- FRMs provide empirical knowledge to develop bio-optical models for algorithm and product development
- FRMs are critical to establish
  - SI-traceable L2 product validation
  - L2 algorithm evolution (now particularly for complex waters)
  - New L2 products requested by CMEMS and other users



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EUMETSAT satellite product validation activities

Independent validation evidence

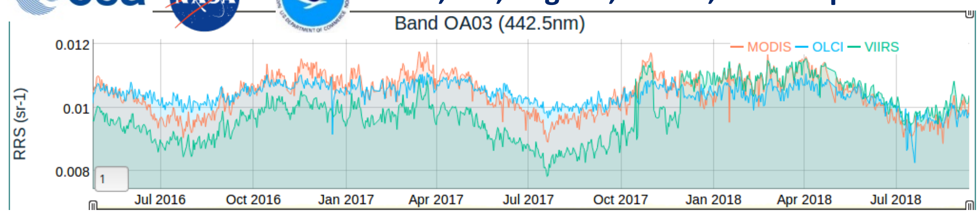
S3VT

"to engage world-class validation expertise and activities to complement Sentinel-3 routine validation and ensure the best possible outcomes for the Sentinel-3 Mission"

Routine operational validation

Inter-comparisons against other missions and climatologies

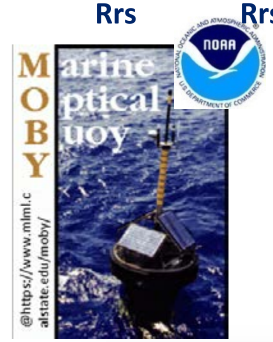
Rrs, Chl, adg443, Kd490, aerosol products



Inter-comparisons against qualified in situ measurements

Rrs

Rrs



Rrs, Chl, TSM, adg443, Kd490

esa

cnes

cnrs

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Example: importance of radiometry (and bio-optical) FRM measurement protocols/data processing protocols

- Uncertainty budget is dependent on the used protocol, FRM uncertainty protocol is needed
- Awareness is needed of protocol's impact on measurements and hence OC products

In situ measured Rrs values

Values are different for different measurement and processing methods

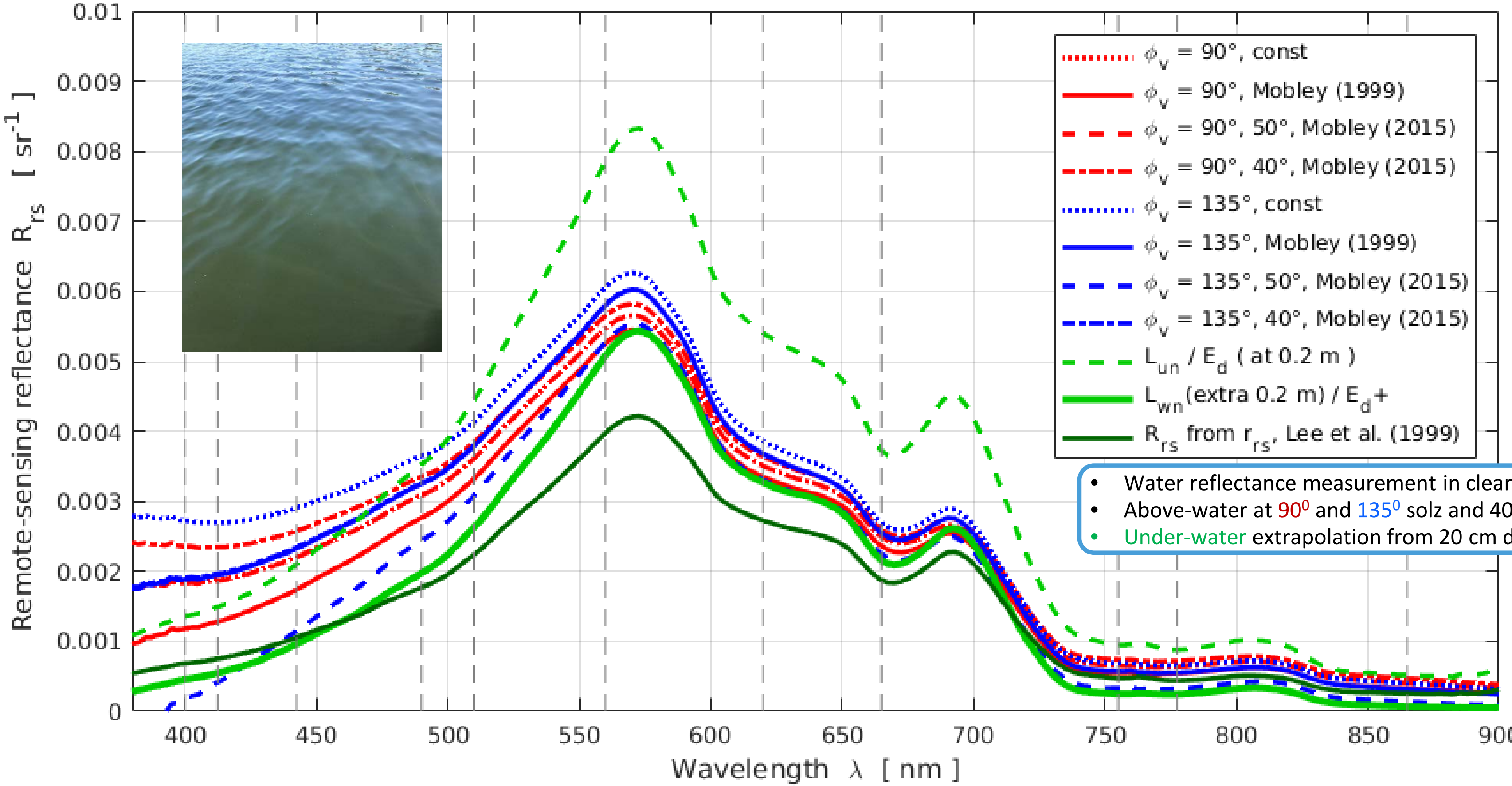
- surface reflectance factor, sun/viewing geometry, extrapolation to surface, BRDF, normalization, etc.

Helmholtz-Zentrum Geesthacht

Zentrum für Material- und Küstenforschung

Courtesy of Martin Hieronymi

Lake in Germany (Suesser See), 29/08/2017, 08:00 - 13:00 UTC



- Water reflectance measurement in clear sky, calm wind conditions
- Above-water at 90^0 and 135^0 solz and 40^0 and 50^0 senz
- Under-water extrapolation from 20 cm depth

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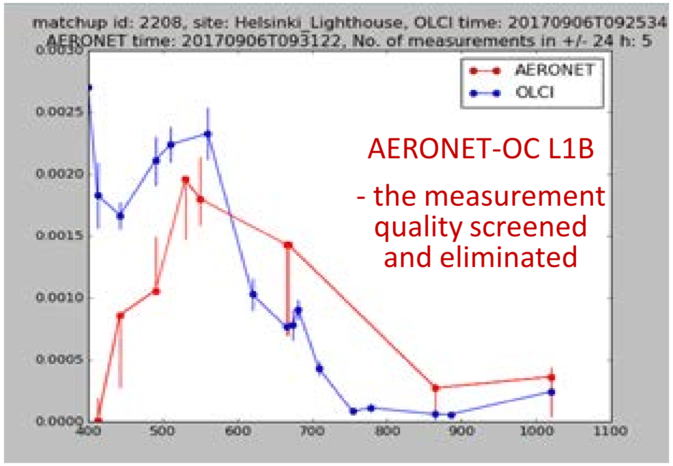
Example: importance of standardized FRM processing, auxiliary measurements, and quality screening

Standardized AERONET-OC measurements

AERONET L2 data quality screening eliminate bad L1.5 measurements
EUMETSAT internal screening also eliminates bad measurements through:

- Spectral Angle Mapper (spectral shape criterion)
- measurement 24-hour variability criterion

JRC EUROPEAN COMMISSION

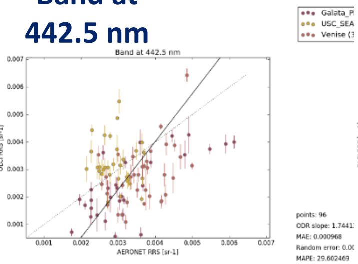


EUMETSAT additional corrections:

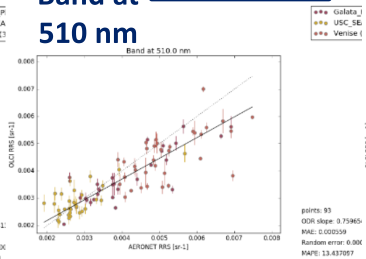
- f/Q full BRDF normalization (Talone *et al.*, 2017; Morel *et al.*, 2002)
- Band shifting to OLCI wavelengths (Melin *et al.*, 2015; Lee *et al.*, 2009)

Band-shifting!

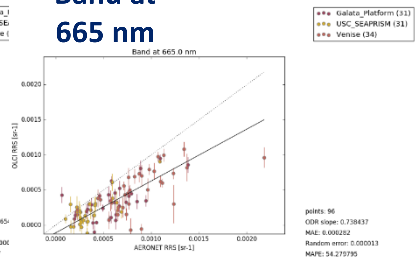
Band at 442.5 nm



Band at 510 nm



Band at 665 nm



Generic in situ Rrs measurements

- Different wavelengths
- Multi- / hyper-spectral
- Above / Below water
- Single/multiple cast
- Different formats
- Multiple casts in same/ different files
- Sample depth
- Spectrum along columns/ rows?
- Any correction applied?

SeaBASS

Above water
Required:
L_w/E_s or
Rrs and E_s

Below water
Required:
L_u, E_s and E_d

Exclusion criteria:
$|E_{s,meas} - E_{s,est}| > 25\%$
$z_1 > 5$ m
Instability Flag:
E_s stability $(E_{s,MAX} - E_{s,min}) > 10\% \, E_{s,MAX}$

- Correction for E_s variability along time
- E_d binned to 1 m interval along depth
- K_d and K_{lu} from exp. fitting of E_d and L_u E_d along depth (0:10m] or (0:20m] if K < 0 m-1
- $E_d(0\text{-}) = E_d(z_m) * \exp(K_d * z_m)$ and $L_u(0\text{-}) = L_u(z_m) * \exp(K_u * z_m)$, where $z_m = z_1 + 0.5$
- **Rrs** $= E_d(0\text{-}) / L_u(0\text{-})$
- $E_{s,est} = E_d(0\text{-}) / t_d$

Courtesy of
Ilaria Cazzaniga

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Example: importance of FRM-quality measurements and auxiliary data for algorithm development

Most algorithm evolution and product development activities require simultaneous measurements of radiometry and bio-optical (and/or atmospheric) parameters

OLCI adaptation of Chlorophyll Index Algorithm by Hu *et al*., 2012

Required

HPLC measurements, or

selected fluorometrically/spectrophotometrically derived chl-a values

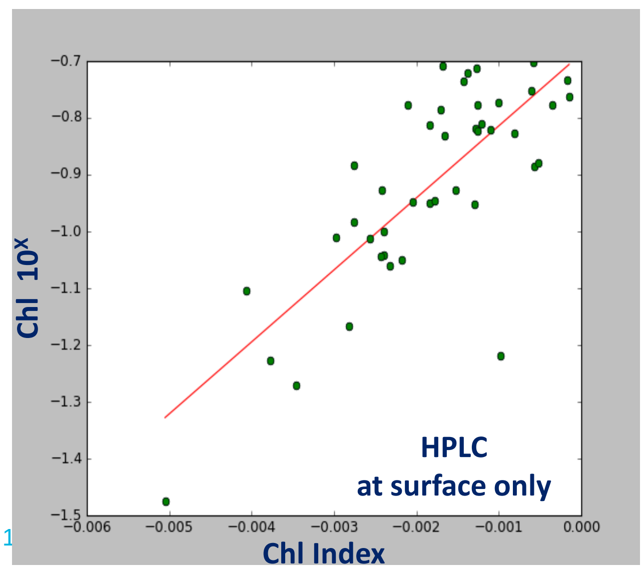
simultaneous Rrs measurements at 442.5, 560, and 665 nm

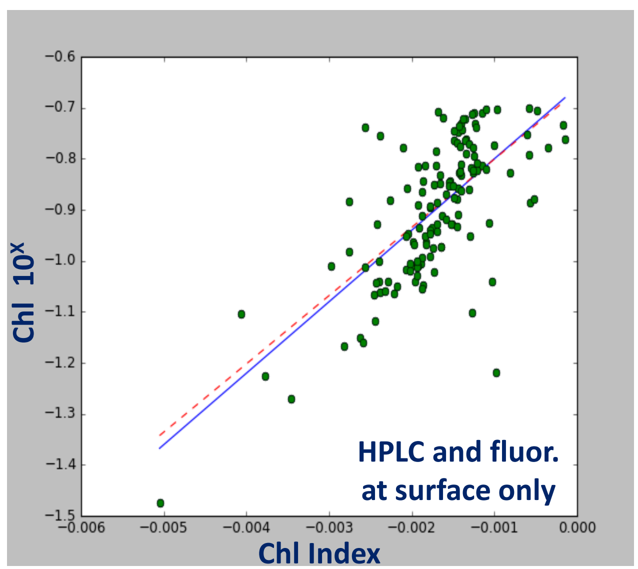
Chlorophyll measurement requirements

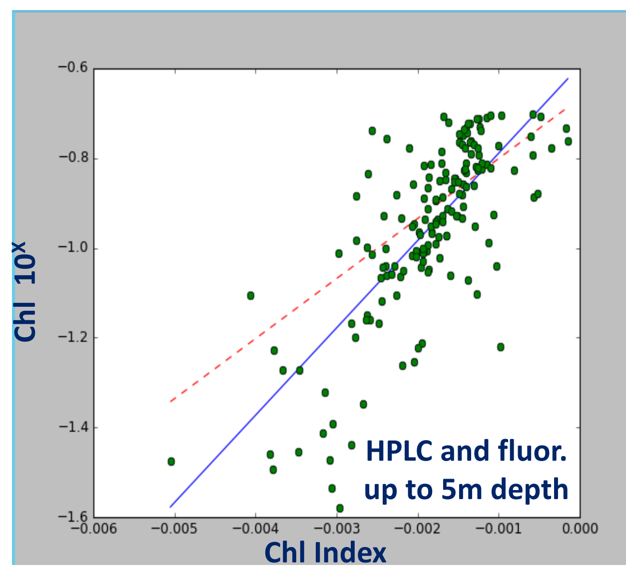
- Optically weighted along depth using:
  - *Kd(490)* previously estimated or
  - $Kd(490) = 0.0166 + 0.07242[chl]^{0.68955}$
  - $\langle chla \rangle = \frac{\sum e^{-2k_d z}\, chla(z)}{\sum e^{-2k_d z}}$
- Measurement at minimum depth is recorded but discarded if depth is deeper than 5 m

SeaBASS

Courtesy of
Ilaria Cazzaniga







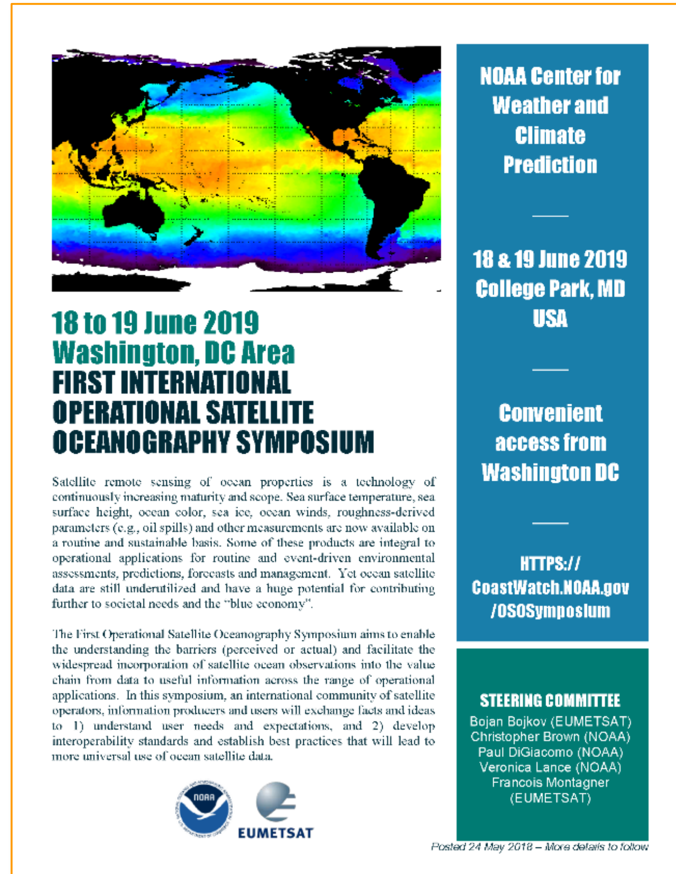
Conclusions

- EUMETSAT goal is to routinely and sustainably deliver accurate, consistent and fit-for-purpose quality Ocean Colour data and products spanning time-scales from NRT to climate in support of research, applications and services
- The FRM-quality of radiometric and bio-optical measurements is essential to achieve the accuracy, consistency and fit-for-purpose quality of satellite data services
- EUMETSAT continues supporting the Copernicus OC-SVC Roadmap – two preliminary design studies are starting
- FRM4SOC has made a major contribution in support of the Copernicus OC-SVC infrastructure activities
- FRM4SOC has defined strategies, protocols and best practices for FRMs for satellite product validation and algorithm development that should be
  - implemented by the community, e.g. S3VT-OC
  - continued and expanded to bio-optical measurements like IOPs, Chl etc.
  - sustained all throughout the lifetime of the Copernicus Ocean Colour missions

The First Operational Satellite Oceanography Symposium

18 - 19 June 2019
NOAA, Washington, DC

- *Aims to*
  - enable the understanding the barriers (perceived or actual) and
  - facilitate the widespread incorporation of satellite ocean observations into the value chain from data to useful information across the range of operational applications
- *Satellite operators, information producers and users will exchange facts and ideas to*
  - understand user needs and expectations
  - develop interoperability standards and establish best practices that will lead to more universal use of ocean satellite data
  - training sessions to facilitate use of products will also be offered



18 to 19 June 2019
Washington, DC Area
FIRST INTERNATIONAL OPERATIONAL SATELLITE OCEANOGRAPHY SYMPOSIUM

Satellite remote sensing of ocean properties is a technology of continuously increasing maturity and scope. Sea surface temperature, sea surface height, ocean color, sea ice, ocean winds, roughness-derived parameters (e.g., oil spills) and other measurements are now available on a routine and sustainable basis. Some of these products are integral to operational applications for routine and event-driven environmental assessments, predictions, forecasts and management. Yet ocean satellite data are still underutilized and have a huge potential for contributing further to societal needs and the "blue economy".

The First Operational Satellite Oceanography Symposium aims to enable the understanding the barriers (perceived or actual) and facilitate the widespread incorporation of satellite ocean observations into the value chain from data to useful information across the range of operational applications. In this symposium, an international community of satellite operators, information producers and users will exchange facts and ideas to 1) understand user needs and expectations, and 2) develop interoperability standards and establish best practices that will lead to more universal use of ocean satellite data.

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NOAA Center for Weather and Climate Prediction

18 & 19 June 2019
College Park, MD
USA

Convenient access from Washington DC

HTTPS://
CoastWatch.NOAA.gov
/OSOSymposium

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Posted 24 May 2018 – More details to follow