EUMETSAT

PROGRAMME OF THE EUROPEAN UNION

Copernicus Europe's eyes on Earth

Giuseppe

Ewa Kwiatkowska, Juan Ignacio Gossn, David Dessailly
EUMETSAT

CEOS WGCV meeting, Washington DC, 30 August 2022

Giuseppe Zibordi

AERONET-OC: the main validation source for all missions

Pillar of the community: unparalleled expertise always in pursuit of scientific truth and excellence

Seminal work on System Vicarious Calibration

Community service, reviews, panels

IOCCG protocols: standards for the community

CEOS INSITU-OCR White Paper

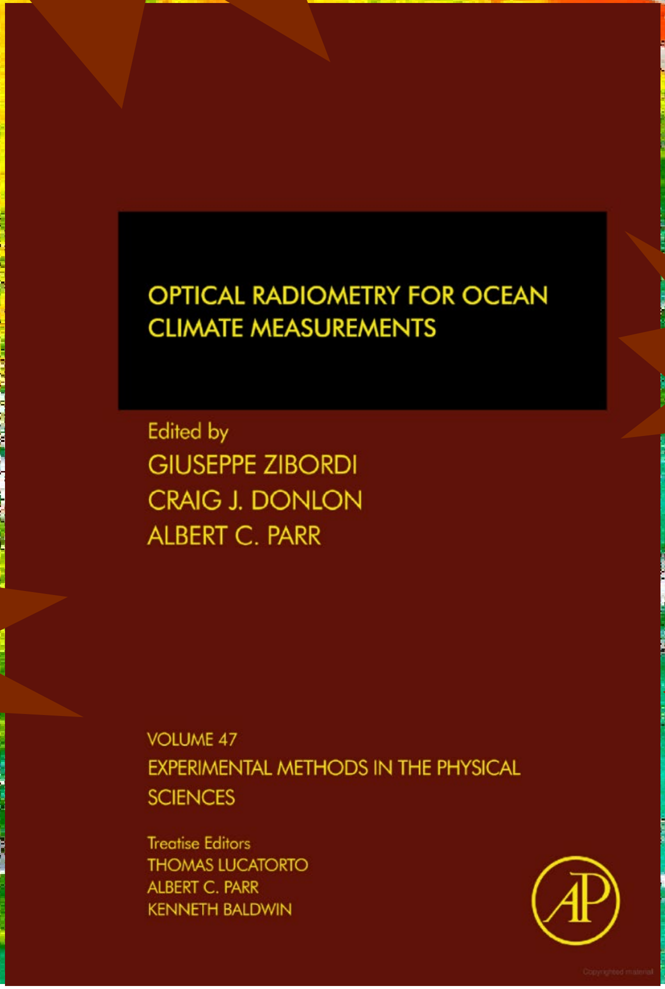
Radiometer design, calibration lab, cal/val, measurements

BiOMaP and CoASTS

Books and papers

MERIS QWG and MVT

OLCI QWG and S3VT-OC


OPTICAL RADIOMETRY FOR OCEAN CLIMATE MEASUREMENTS

Edited by
GIUSEPPE ZIBORDI
CRAIG J. DONLON
ALBERT C. PARR

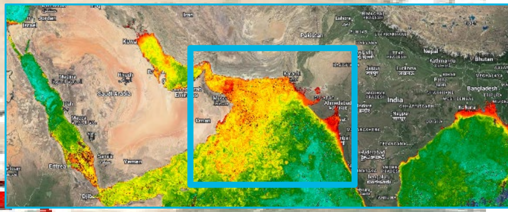
VOLUME 47
EXPERIMENTAL METHODS IN THE PHYSICAL SCIENCES

Treatise Editors
THOMAS LUCATORTO
ALBERT C. PARR
KENNETH BALDWIN

chl-a [mg/m^3] 0.02 0.06 0.13 0.25 0.5 1.0 2.0 4.0 8.0 16.0 35.0

Sentinel-3 OLCI

Ocean Colour – observing the living aquatic ecosystems



Allure of Ocean Colour

Climate

Biological Carbon Pump – oceans constitute about 50% of Earth's carbon sequestration

Aquatic phytoplankton – about 50% of Earth's primary production, fraction of the fixed Carbon is buried into the deep ocean

Ocean absorbs 20 – 30% of anthropogenic CO_2 emissions, also contributing to ocean acidification

Water Quality

Harmful Algal Blooms

Drinking water quality

Tourism and coastal communities

Eutrophication

Ecosystem status and services

Legislation, e.g. EU Water Framework Directive

Marine resources

Fisheries

Aquaculture

Coastal management / ports

Legislation, e.g. EU Marine Strategy Framework Directive

chl-a [mg/m^3] 0.02 0.06 0.13 0.25 0.5 1.0 2.0 4.0 8.0 16.0 35.0

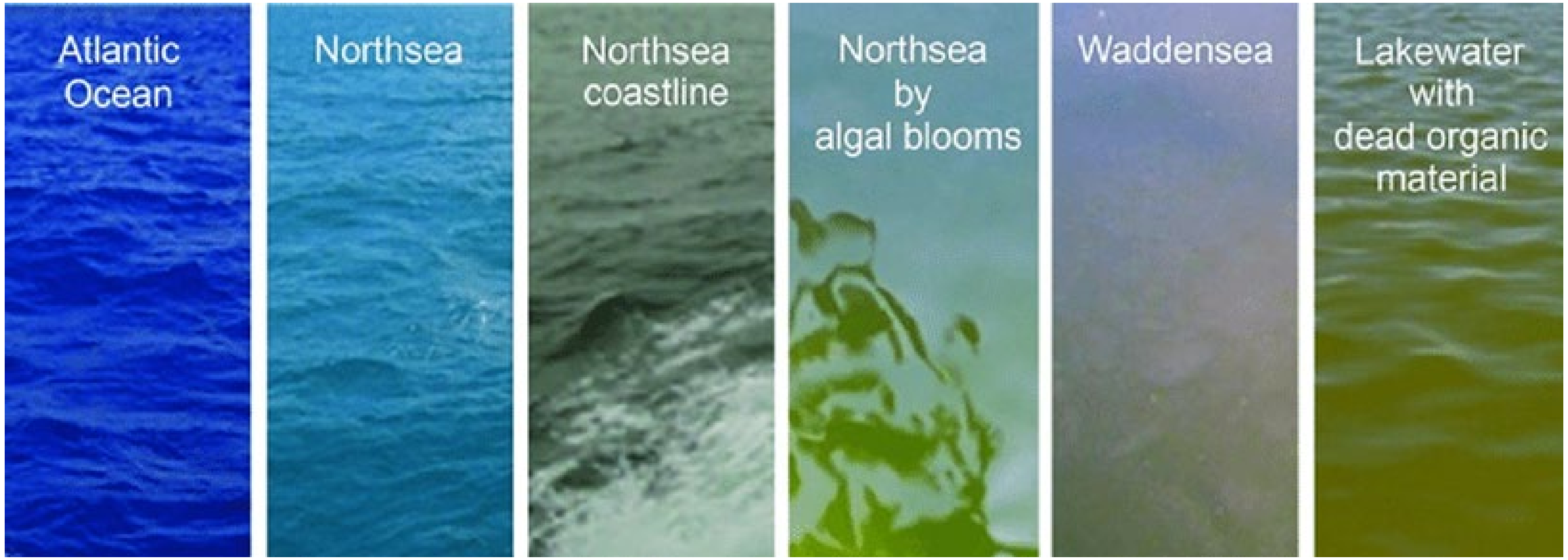
Sentinel-3 OLCI

Detection of phytoplankton concentrations from space is not easy

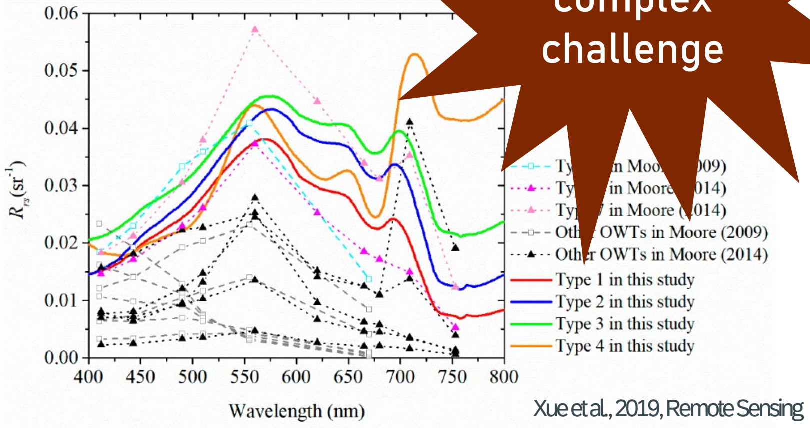
copernicus.eumetsat.int

Addressing a complex challenge

Water colour depends on concentrations of phytoplankton, coloured dissolved material and sediments

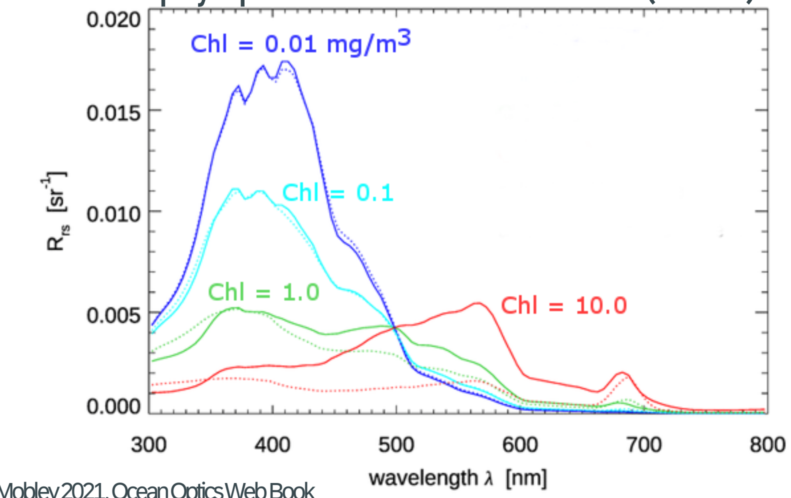


Remote sensing reflectance in complex waters, case-2 (O



Xue et al., 2019, Remote Sensing

Remote sensing reflectance in phytoplankton-dominated waters (case-1)



Mobley 2021, Ocean Optics Web Book

Detection of phytoplankton concentrations with **30 %** uncertainty in case-1 waters

⇒ requires to estimate water-leaving radiance or reflectance with the uncertainty of **5 %** in the blue and green range of the spectrum

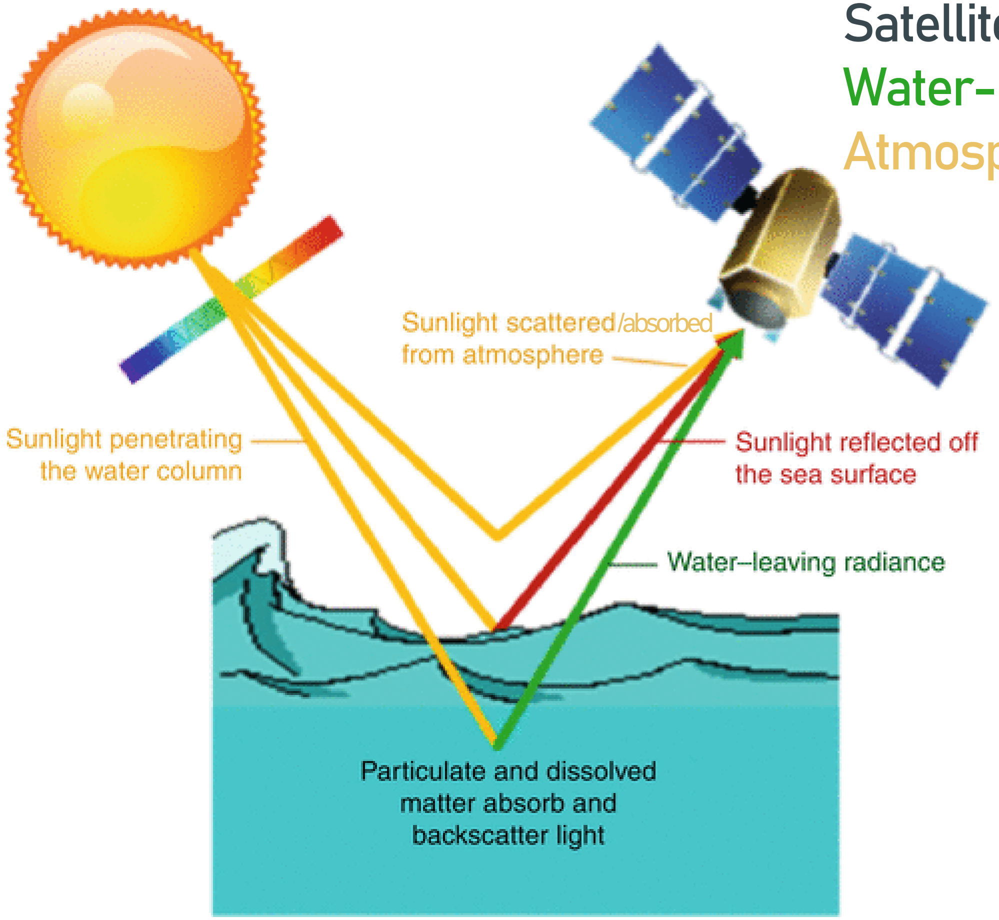
Sentinel-3 OLCI Mission Requirements

Parameter	Requirement threshold, [goal]
Marine reflectance@442nm	5.10^{-4}
Water-leaving radiance	**5%**
Chlorophyll-a – phytoplankton concentration	**30%** [10%] (case 1 waters) 70% [10%] (case 2 waters)
Photosynthetically Active Radiation	5%
Water turbidity – diffuse attenuation coeff.	5%
Sediments – total suspended matter	30% [10%] (case 1 waters) 70% [10%] (case 2 waters)
Coloured Dissolved Organic Material	50% [10%] (case 1 waters) 70% [10%] (case 2 waters)

Ocean Colour measurement – ocean is dark from space!

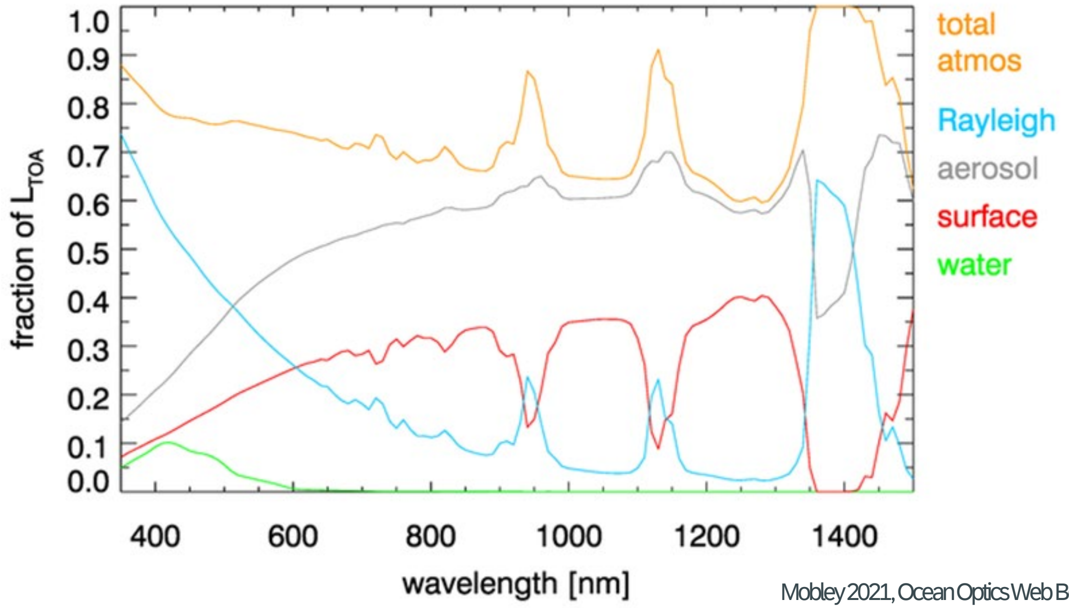
In-depth understanding of the Ocean Colour process

Satellite measurement, L_{TOA} [mW/m²/sr/nm]
Water-leaving radiance, L_w ~ 10%
Atmosphere and sea surface ~ 90%



Dierssen and Randolph, 2012, Earth System Monitoring

Clear water chl-a = 0.05 mg/m³, clear sky, tropical marine atmosphere
Water-leaving radiance ~ 10% in the blue and green spectral range

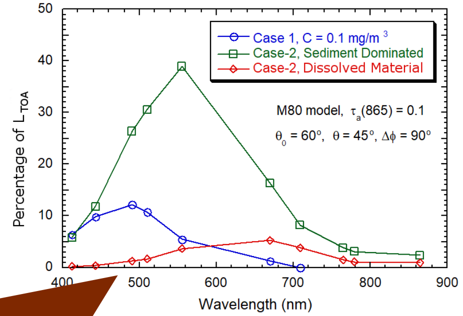


Mobley 2021, Ocean Optics Web Book

Ocean appears black from space
Water-leaving radiance is a small fraction of the total radiance measured by the satellite
Satellite instrument calibration and algorithms require the lowest possible uncertainties
The uncertainties are magnified 10-fold for water-leaving radiances

Ocean Colour requires System Vicarious Calibration (OC-SVC)

Chlorophyll requirement **30%** → Water-leaving radiance L_W requirement **5%** → Sensor TOA radiance required L_{TOA} « **0.5%** (L_W ~ 10% of L_{TOA}) → But the satellite sensor which measures L_{TOA} has an uncertainty of **2%** (e.g. S3 OLCI MRD)

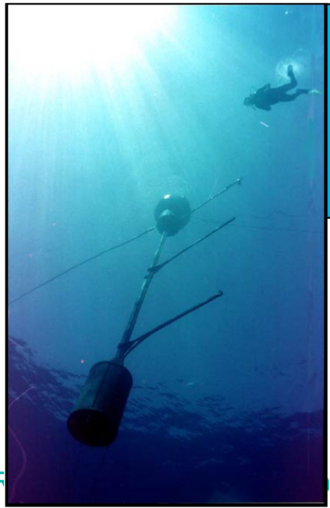


System Vicarious Calibration is a requirement for all Ocean Colour missions

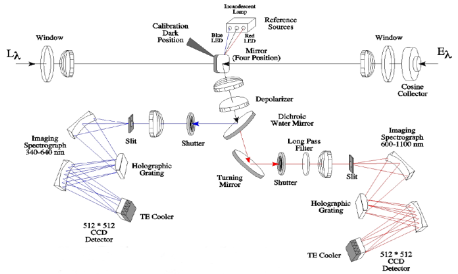
OC-SVC is the Fiducial Reference Measurement Gold Standard in Ocean Colour and the only way to meet the uncertainty requirements

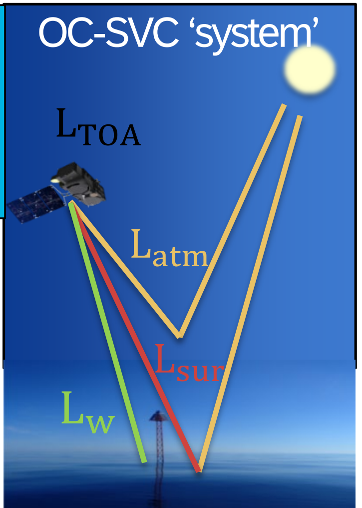
Giuseppe's seminal work on System Vicarious Calibration

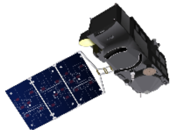
OC-SVC relies on in situ water-leaving radiance / reflectance measurements, which require SI traceability and the lowest achievable uncertainties of the complete OC-SVC 'system' process



- in-water radiometric measurement – the lowest calibration and characterisation uncertainties of the radiometer
- controlled measurement procedure – no tilting, shading or fouling; stable illumination and depth; consistent procedure implementation
- environmental conditions of the measurement – the lowest uncertainties from the water through the atmosphere and to the satellite sensor







IOCCG International Ocean Colour Coordinating Group

CEOS The Committee on Earth Observation Satellites

Sentinel-3 Cal/Val Plan OLCI-L2WLR-CV-200

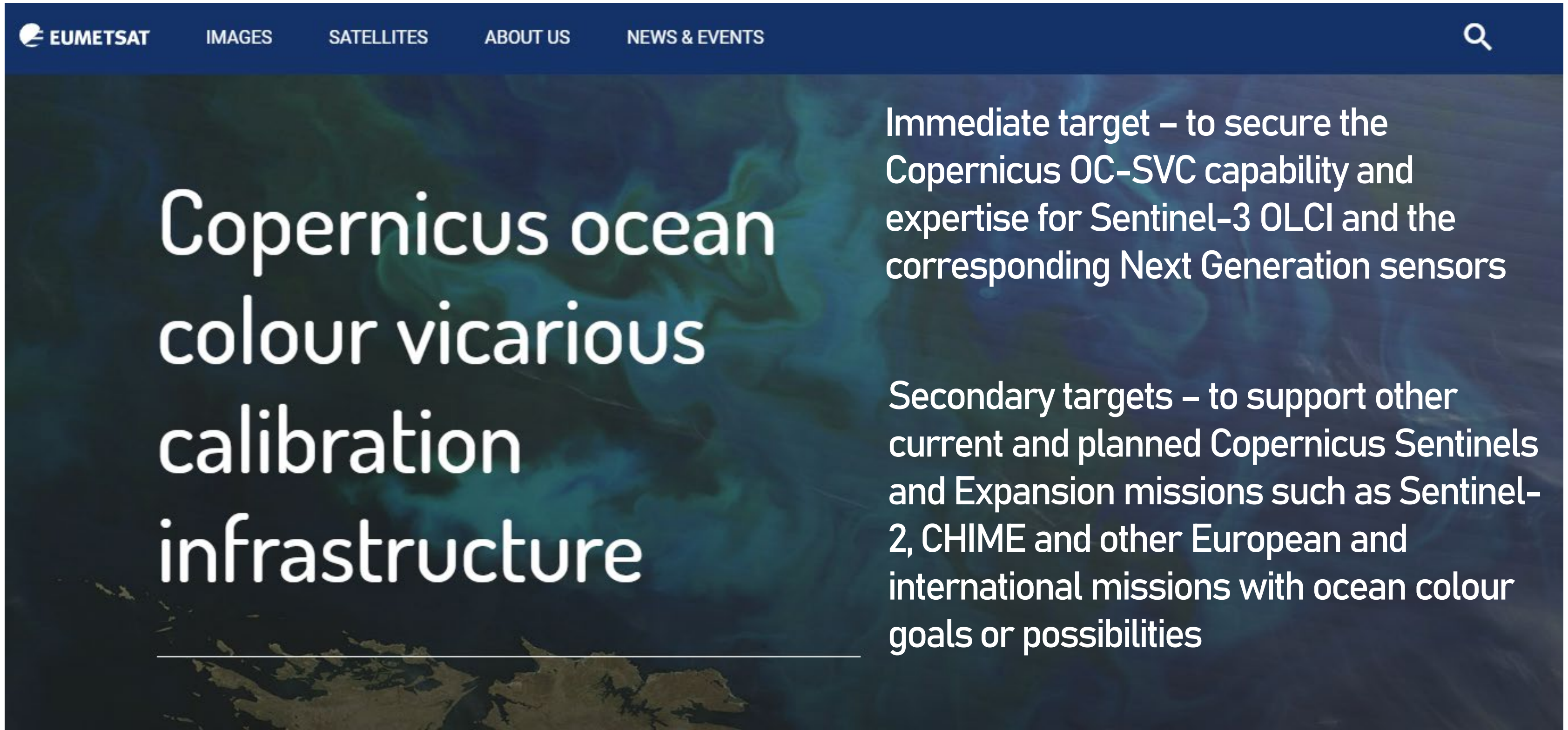
Contributions towards a potential Copernicus OC-SVC infrastructure

European Commission

Giuseppe on the Copernicus OC-SVC Expert Review Board

Within the Copernicus framework, EUMETSAT manages OC-SVC infrastructure development activities for the Copernicus Programme on behalf of the European Commission

Goals - to achieve the best OC-SVC infrastructure for the upcoming 20 years for the benefit of the Copernicus Programme and to strengthen Europe's autonomy for the calibration of the relevant Sentinels



Immediate target – to secure the Copernicus OC-SVC capability and expertise for Sentinel-3 OLCI and the corresponding Next Generation sensors

Secondary targets – to support other current and planned Copernicus Sentinels and Expansion missions such as Sentinel-2, CHIME and other European and international missions with ocean colour goals or possibilities

Roadmap (subject to EC decision at each Phase)

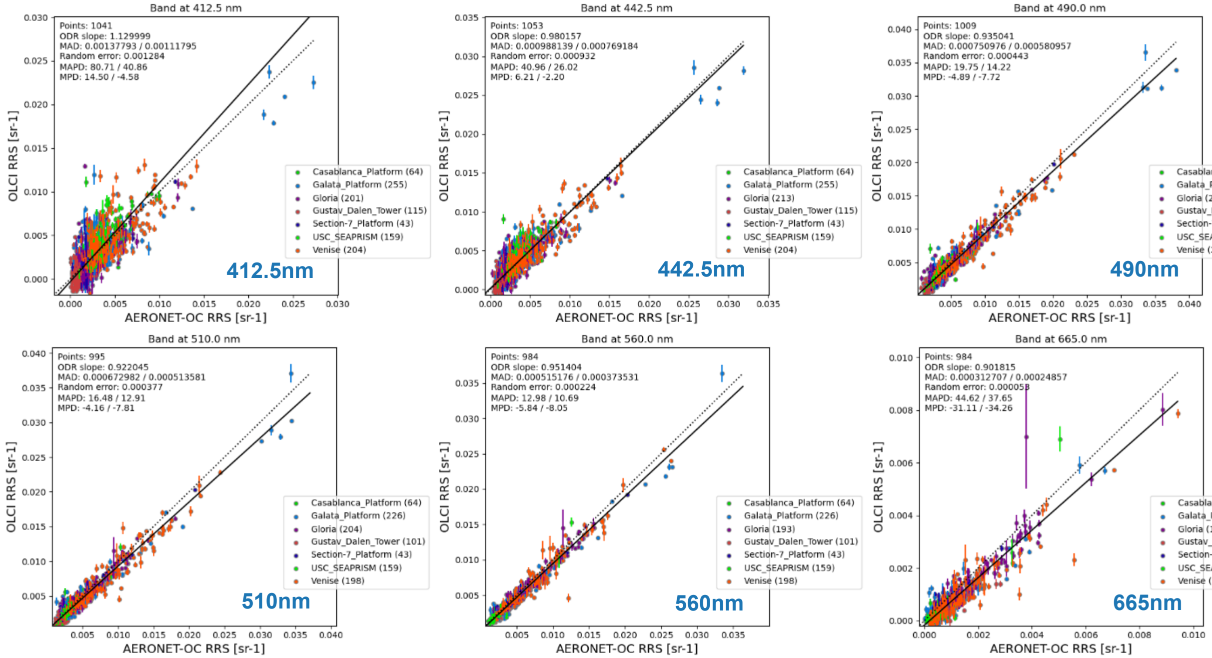
1. Scientific, Technical, Operational Requirements (completed)
2. Preliminary Design, Project Plan and Costing (completed)
3. Infrastructure Location (completed)
4. Engineering Design, Detailed Technical Definition, Specifications
5. Development, Testing and Demonstration in the Field
6. Operations

https://www.eumetsat.int/OC-SVC

AERONET-OC is the major validation source for S3 OLCI

AERONET-OC are the only operationally and openly available Fiducial Reference Measurements for validation of Ocean Colour missions

OLCI-A



OLCI-A previous status

- Residual water reflectance non-compliances

Collection-3 status

- Significant impact in the blue bands with more accurate spectral shape

https://www.eumetsat.int/media/47794

- AERONET-OC data courtesy of AERONET-OC PIs, JRC Giuseppe Zibordi, and NASA
- Sentinel-3 OLCI Collection-3 Report: (https://www.eumetsat.int/media/47794)

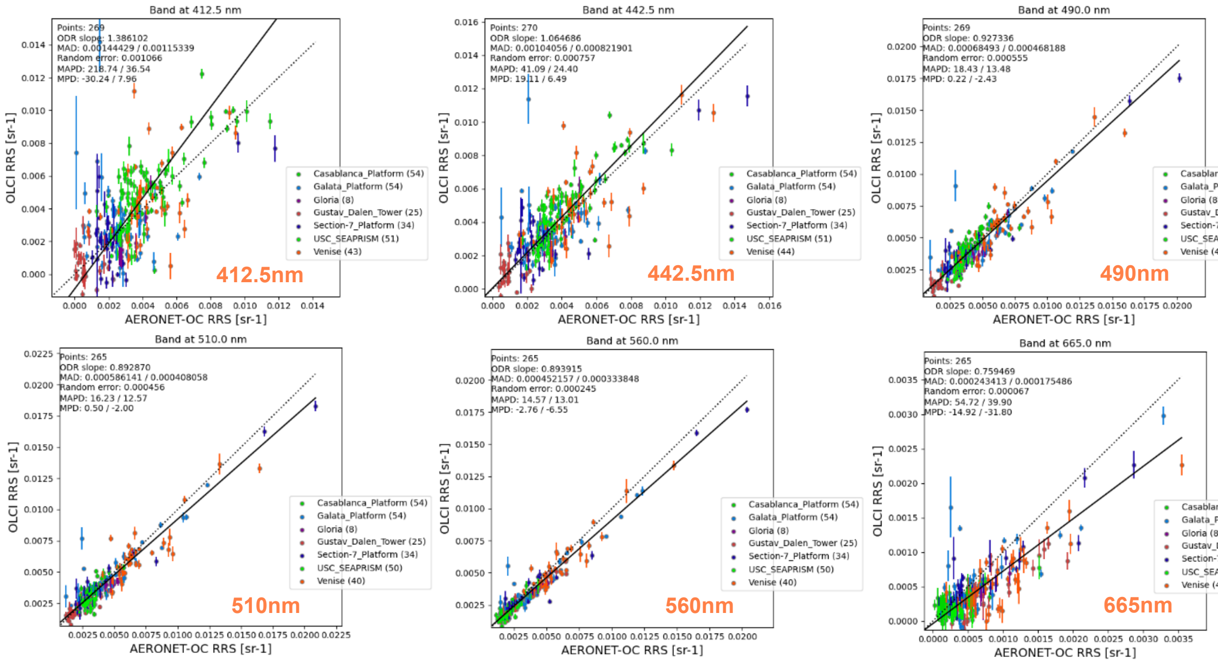
OLCI-B previous status

- Water reflectance full non-compliance, no OC-SVC applied

Collection-3 status

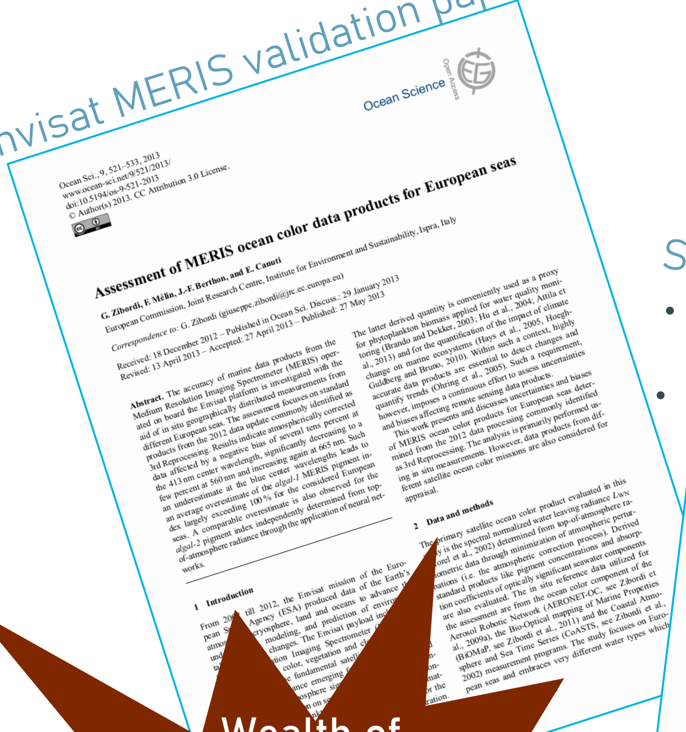
- Significant reduction of positive biases which were observed before
- Performance of OLCI-A and OLCI-B is now highly consistent

OLCI-B



AERONET-OC contributions

Envisat MERIS validation papers


Ocean Science

Ocean Sci., 9, 521–533, 2013
www.ocean-sci.net/9/521/2013/
doi:10.5194/os-9-521-2013
© Author(s) 2013. CC Attribution 3.0 License.

Assessment of MERIS ocean color data products for European seas

G. Zibordi, F. Mélin, J.-F. Berthon, and E. Canuti

European Commission, Joint Research Centre, Institute for Environment and Sustainability, Ispra, Italy

S3 OLCI Collection-3 L2 validation

- Zibordi *et al.*, 2022, RSE: https://doi.org/10.1016/j.rse.2022.112911
- Cazzaniga *et al.*, 2022, IEEE GRSL: https://doi.org/10.1109/LGRS.2021.3136291


Remote Sensing of Environment 272 (2022) 112911

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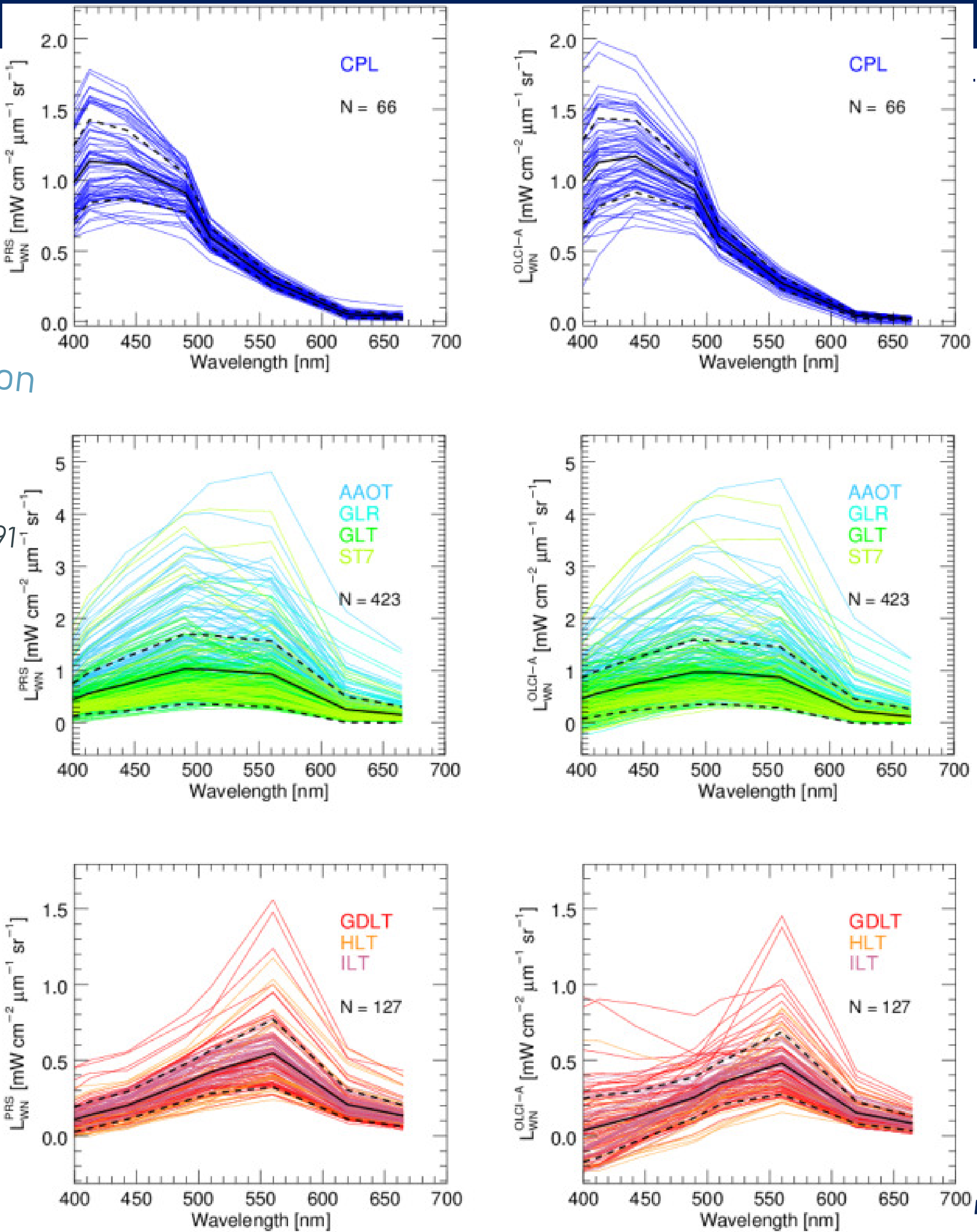
journal homepage: www.elsevier.com/locate/rse

Assessment of OLCI-A and OLCI-B radiometric data products across European seas

Giuseppe Zibordi, Ewa Kwiatkowska, Frédéric Mélin, Marco Talone, Ilaria Cazzaniga, David Dessailly, Juan Ignacio Gossn

Wealth of AERONET-OC validation contributions from Giuseppe and the community

AERONET-OC | Collection-3 OLCI-A



Clear oligotrophic and mesotrophic waters

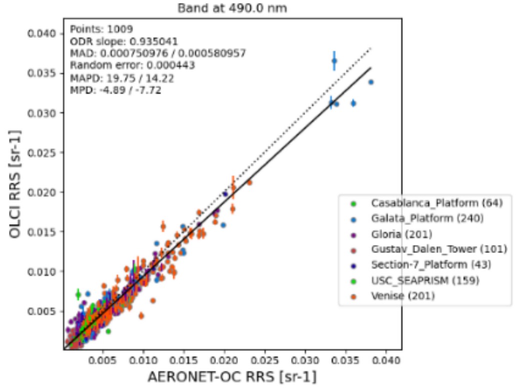
Generic complex waters with moderate concentrations of sediments and CDOM

High CDOM concentration waters

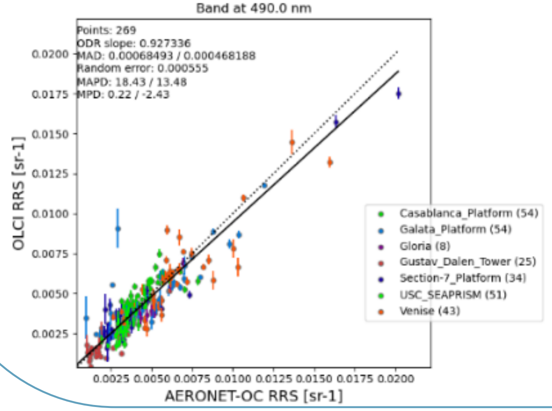
Giuseppe's support to OLCI algorithm and processing validation

S3 OLCI-A and OLCI-B: With OC-SVC, OLCI Collection-3 reprocessed and operational data

With OC-SVC: OLCI-A 490 nm vs AERONET-OC
Blue/green bands within Mission Requirements or just above (complex waters, case-2) < 8%



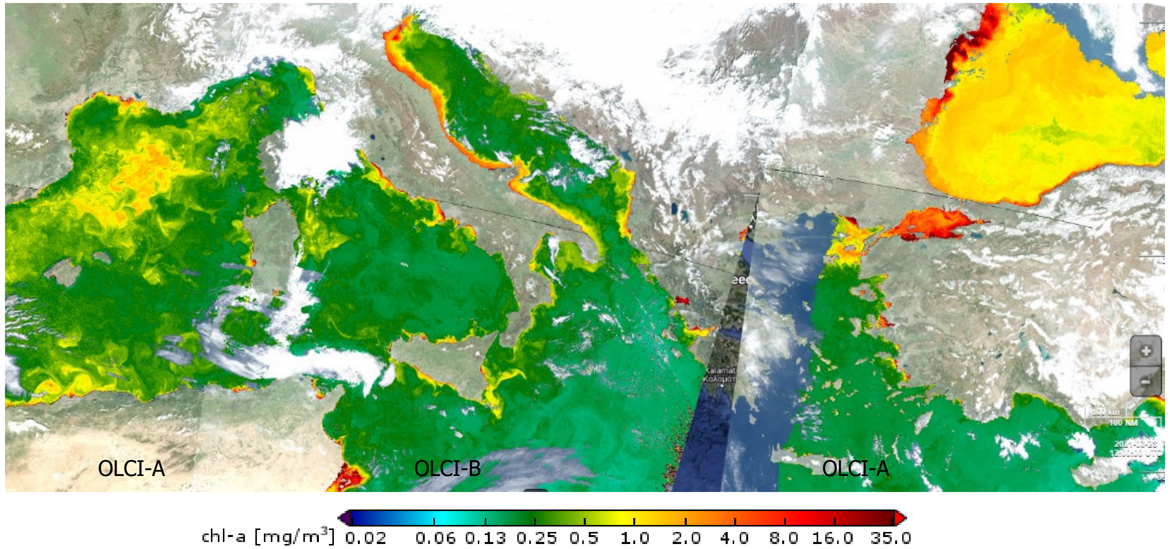
With OC-SVC: OLCI-B 490 nm vs AERONET-OC
Blue/green bands within Mission Requirements or just above (complex waters, case-2) < 8%



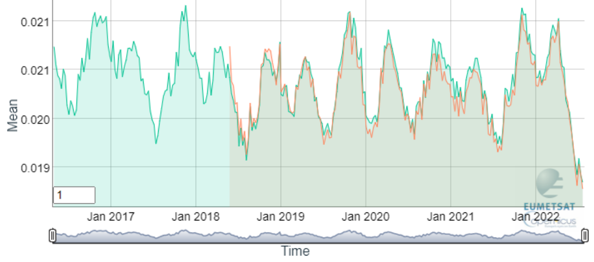
Copernicus Europe's eyes on Earth — Copernicus Marine Service

CMEMS: Merged OLCI-A and OLCI-B Ocean Colour 300 m products are distributed from May 2021 (Collection-3) thanks to the excellent consistency between OLCI-A and -B as a result of the OC-SVC

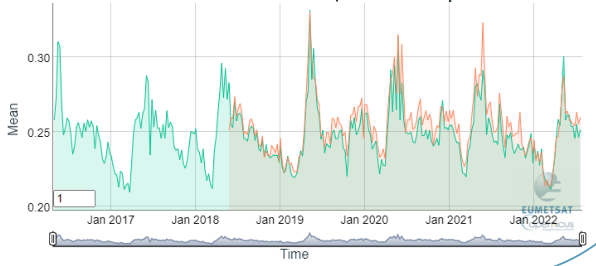
With OC-SVC: Merged OLCI-A and OLCI-B chlorophyll concentrations, 28 March 2021



With OC-SVC: OLCI-A and OLCI-B water reflectance at 490 nm time series, oligotrophic waters



With OC-SVC: OLCI-A and OLCI-B chlorophyll concentration time series, mesotrophic waters



- AERONET-OC data courtesy of AERONET-OC PIs, JRC Giuseppe Zibordi, and NASA
- Robust OC-SVC process: OC-SVC gains were derived independently for both sensors (OC-SVC tool)
- Good agreement with third party missions, e.g. MODIS-Aqua courtesy of NASA
- Sentinel-3 OLCI Collection-3 Report: (https://www.eumetsat.int/media/47794)

Community's capacity to collect FRM-quality measurements

Ideas from the meeting discussions
MERIS Validation Team meeting
Tartu Observatory, EST, 2015

esa

- **50K is the cost of the in situ matchups – from the ships**
- Old protocols: mix of methods and protocols – review the protocols
- Use one instrument – do it just for this instrument, create a standard, do not accommodate everybody
- Protocols include in situ data processing protocols, consider which raw data are needed to be delivered to enable future reprocessings
- Instrument characterization – needs to be peer-reviewed (critical)
- Community processor – to include all the new findings for the class, low level data, quality control and uncertainties, characterisation of instruments from this class, specific data format
- Calibration database – information about individual instruments
- What needs to be characterized for all instruments in the class?
- What needs to be characterized for each instrument individually?
- E.g. Network for TRiOS
- For each network one needs a leader, someone who can take a long-term commitment
- Need to involve the metrology institute – quantum leap in absolute calibration and characterization
- Manufactures should calibrate their instruments to a specific factor, e.g. ISO international standard, so that when people get their sensor have the certainty they are calibrated – enforce this on the manufacturers
- Create the framework and structure for the activity and start filling the gaps

European Space Agency

FRM4SOC Phase 1 2016 – 2019

- Funded and coordinated by ESA
- In a series of several other FRM projects, https://frm4soc.org

FRM4SOC Phase 2 objective

Develop foundations for operational implementation of the FRM principles by the Ocean Colour community

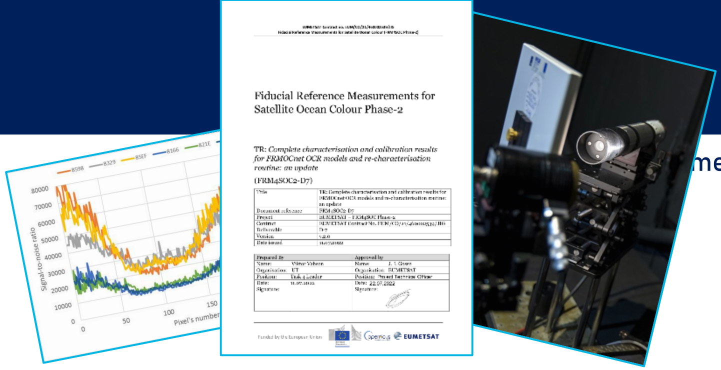
Discussions with Giuseppe are always inspirational: origins for FRM4SOC-2

Fiducial Reference Measurements for Satellite Ocean Colour

FRM4SOC Phase 2 2021 – 2023, options for 2024 and 2025

- Funded by the EC and coordinated by EUMETSAT
- https://frm4soc2.eumetsat.int/ EUMETSAT

1. Initially focus on the two most common Ocean Colour hyperspectral radiometer classes



metsat.int

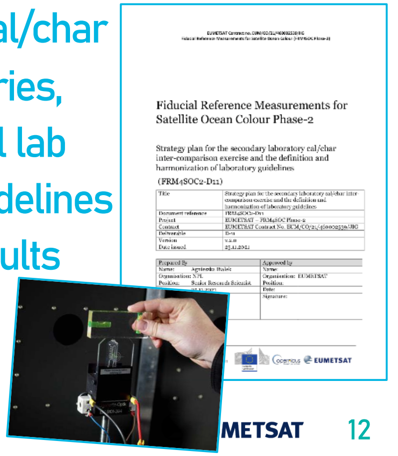
2. Fully characterise the two Ocean Colour radiometer classes

(issue recommendations to instrument manufacturers)

Parameter	Scope	Before initial use	Re-cal/char	D-2 requirement
1. Absolute calibration for radiometric responsivity	individual	required	1 year	IR1
2. Long term stability	individual	required	after every calibration	IR1
3. Stray light and out of band response	individual	required	3 – 5 years	IR2
4. Immersion factor (irradiance)	individual	required for under-water	after fore-optics modification	-
4b.Immersion factor (radiance)	individual/class-specific	required for under-water	after fore-optics modification	-
5. Angular response of irradiance sensors in air	individual	required	after fore-optics modification	IR3
6. Response angle (FOV) of radiance sensors in air	class-specific	recommended	after fore-optics modification	-
7. Non-linearity	class-specific	recommended	after repair in workshop	IR4
8. Accuracy of integration times	class-specific	recommended	after repair in workshop	IR4
9. Dark signal	individual	required	1 year	IR7
10. Thermal responsivity	class-specific	recommended	after repair in workshop	IR5
11. Polarisation sensitivity	class-specific	recommended	after repair in workshop	IR6
[illegible]ral response	TBD	TBD	TBD	IR8
[illegible]elength scale	class-specific	recommended	after fore-optics modification	IR9
[illegible] Signal-to-noise ratio	individual	recommended	1 year	-
15. Pressure effects	TBD	TBD	TBD	-

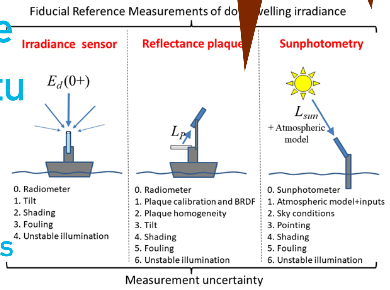
3. Provide community guidelines on radiometer cal/char schedules

4. Develop radiometer cal/char guidelines for laboratories, include an international lab exercise to test the guidelines and inter-compare results



5. Provide prescriptive and detailed FRM in situ measurement procedures

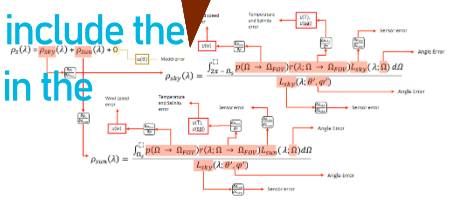
(following from the IOCCG protocols and FRM4SOC-1 experience)



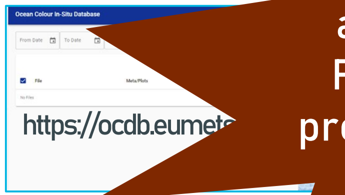
6. Develop a community processor for in situ radiometric measurements

(cooperating with NASA on HyperInSPACE)

7. Develop a complete end-to-end uncertainty budget for the instruments and the measurements, include the uncertainty calculations in the community processor



8. Adapt and maintain Ocean Colour In-Situ Database OCDB



9. Review and test the developed procedures, guidelines and tools: a field experiment, an international workshop, Expert Review Board

Giuseppe's contributions are fundamental to FRM4SOC-2: IOCCG protocols, lab cal/char, data processing

Giuseppe on the Copernicus FRM4SOC-2 Expert Review Board

Contributions to international cooperation

IOCCG
International
Ocean Colour
Coordinating Group

Scientific working group... / ... forces: 20 Report...

Capacity building:
training courses, on-line resources

Internat... Ocean C... Meeting...

INSITU-OCR White Paper

International Network for Sensor Inter-comparison and Uncertainty assessment for Ocean Color Radiometry (INSITU-OCR)

Working toward consistency and accuracy in the development of essential climate variables from multiple missions

Executive Summary
The Ocean Color Radiometry - Virtual Constellation (OCR-VC) developed in the context of the Committee on Earth Observation Satellites (CEOS), aims at producing sustained data records of well calibrated and validated satellite ocean color radiometry to assess the impact of climatic changes on coastal and open sea waters. Within this framework, the *International Network for Sensor Inter-comparison and Uncertainty Assessment for Ocean Color Radiometry* (INSITU-OCR) initiative aims at integrating and rationalizing inter-agency efforts on satellite sensor inter-comparisons and uncertainty assessment for remote sensing products with particular emphasis on requirements addressing the generation of Ocean Color Essential Climate Variables (ECV) as proposed by the Global Climate Observing System (GCOS). Under the guidance of the International Ocean Color Coordinating Group (IOCCG), representatives of Space Agencies and Institutions supporting INSITU-OCR agreed on a series of recommendations on activities critical to ensure high accuracy and consistency among products from present and future ocean color missions. Those recommendations, as consolidated here, call for thoughtful consideration by Space Agencies contributing to OCR-VC in view of achieving the final goal of developing consistent long-term Climate Data Records. Key recommendations address: i. space sensor radiometric calibration, characterization and temporal stability; ii. development and assessment of satellite products; iii. *in situ* data generation and handling; iv. information management and support. Special consideration is given to traceability, application and accessibility of the necessary *in situ* measurements, which are a fundamental element of any ocean color mission.

Agency Representatives
- EC/JRC – Zibordi (co-lead): giuseppe.zibordi@jrc.ec.europa.eu
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CEOS The Committee on Earth Observation Satellites

June 8, 2012

CEOS
The Committee on Earth Observation Satellites

Ocean Colour Radiometry – Virtual Constellation
Cooperations: WGClimate, WGCV, WGCapD
IOCCG - associate member of CEOS

OCR-VC

Climate
- OCR is Essential Climate Variable defined by GCOS
- OCR Climate Data Records contribution to the WGClimate ECV inventory

Carbon
- Aquatic Carbon is a major component of the Earth System with respect to carbon cycling and carbon sequestration (carbon stocks, sources/sinks, fluxes; methods and uncertainties)
- "Aquatic Carbon From Space" – international workshop (ESA), Earth Science Reviews special issue in December 2022, development of CEOS Aquatic Carbon Strategy White Paper

Water Quality
- OCR provides major EO variables for Water Quality applications
- IOCCG report 'Earth Observations in Support of Global Water Quality Monitoring' coordinated with "CEOS Feasibility Study on Satellite Missions/Instruments Focused on Water Quality Measurements" in the frame of "CEOS Strategy for Water Observations from Space"

OCR-VC Deliverables

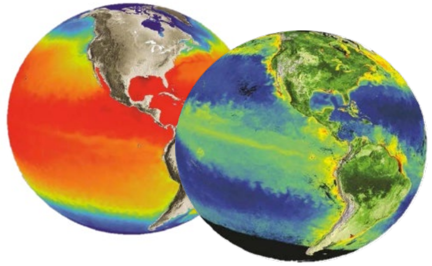
CEOS INSITU-OCR White Paper implementation

New Technologies
- Geostationary OCR
- Hyperspectral OCR
- Polarimetry, Lidar

Giuseppe's leadership: always provides measurable and tangible benefits to the community

Into next generation operational Ocean Colour, climate and services

copernicus.eumetsat.int

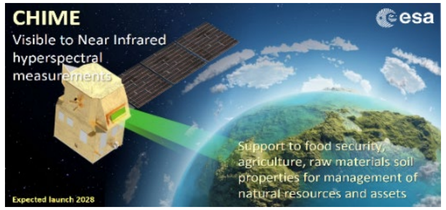


Copernicus Sentinel-3 Next Generation Optical is in Phase 0 and moving to Phase A in 2023

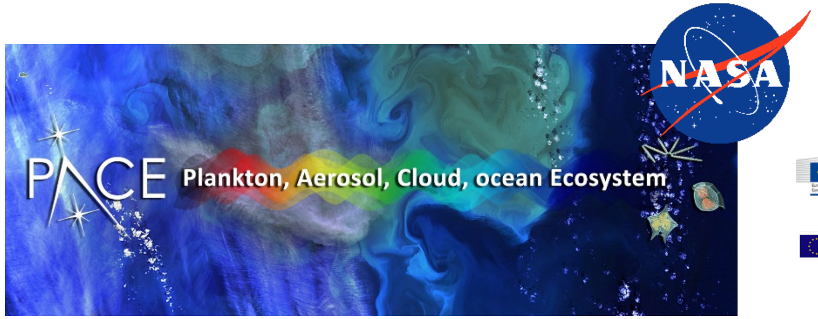
Enhanced Continuity: potential enhanced spectral capabilities and spatial resolution

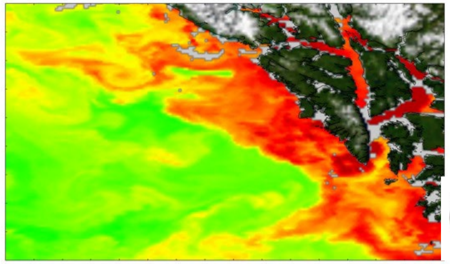
Relevant Ocean Colour Copernicus Next Generation and Expansion Missions

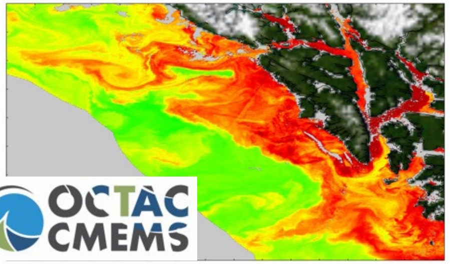
- *Sentinel-2 Next Generation*
- *CHIME (Copernicus Hyperspectral Imaging Mission)*
- *FLEX ESA's Earth Explorer*



Giuseppe's contributions are impactful and leave a lasting legacy!







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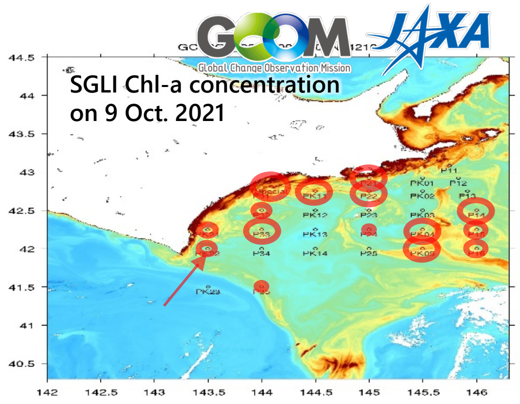

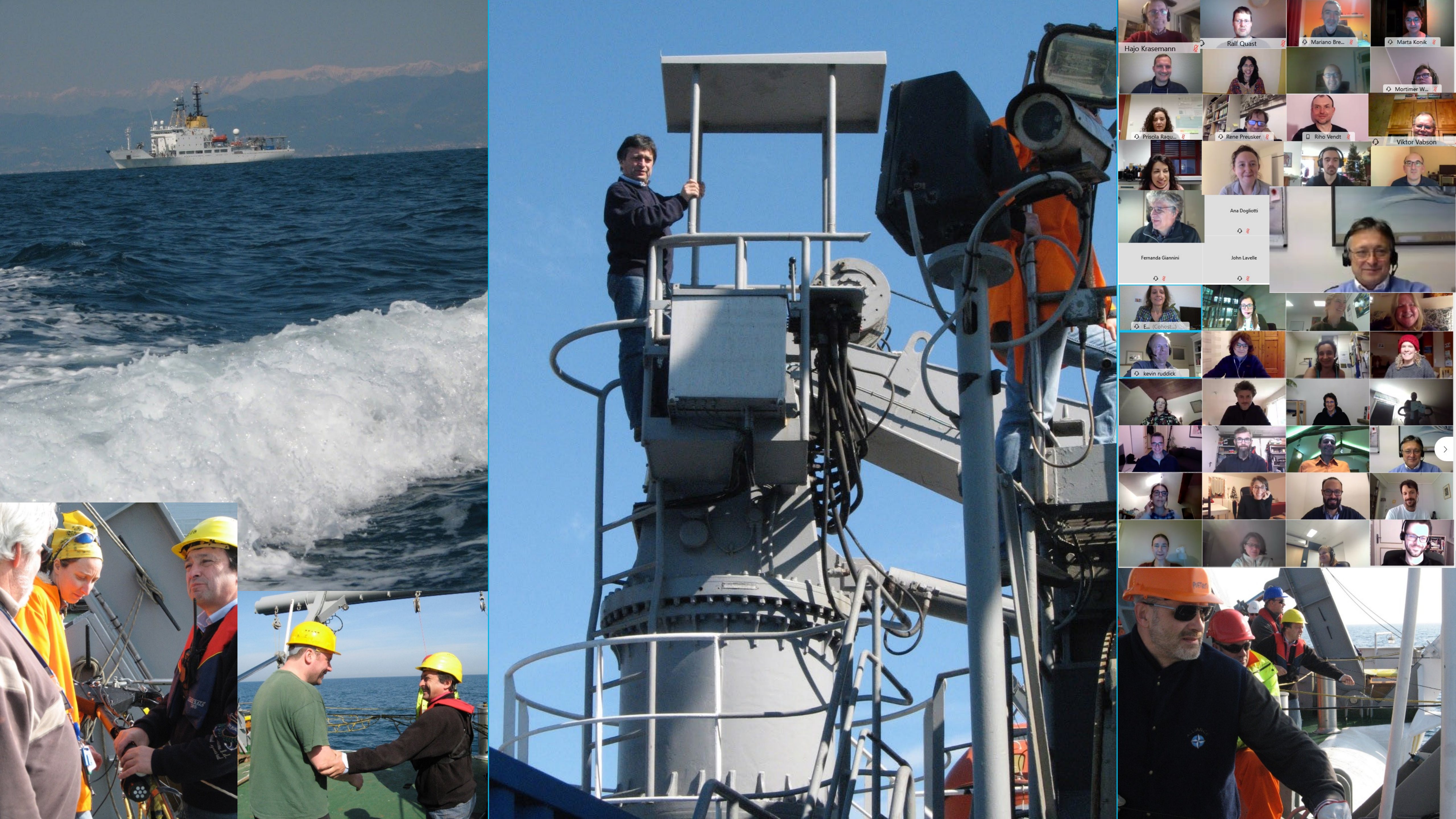
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Ralf Quast
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