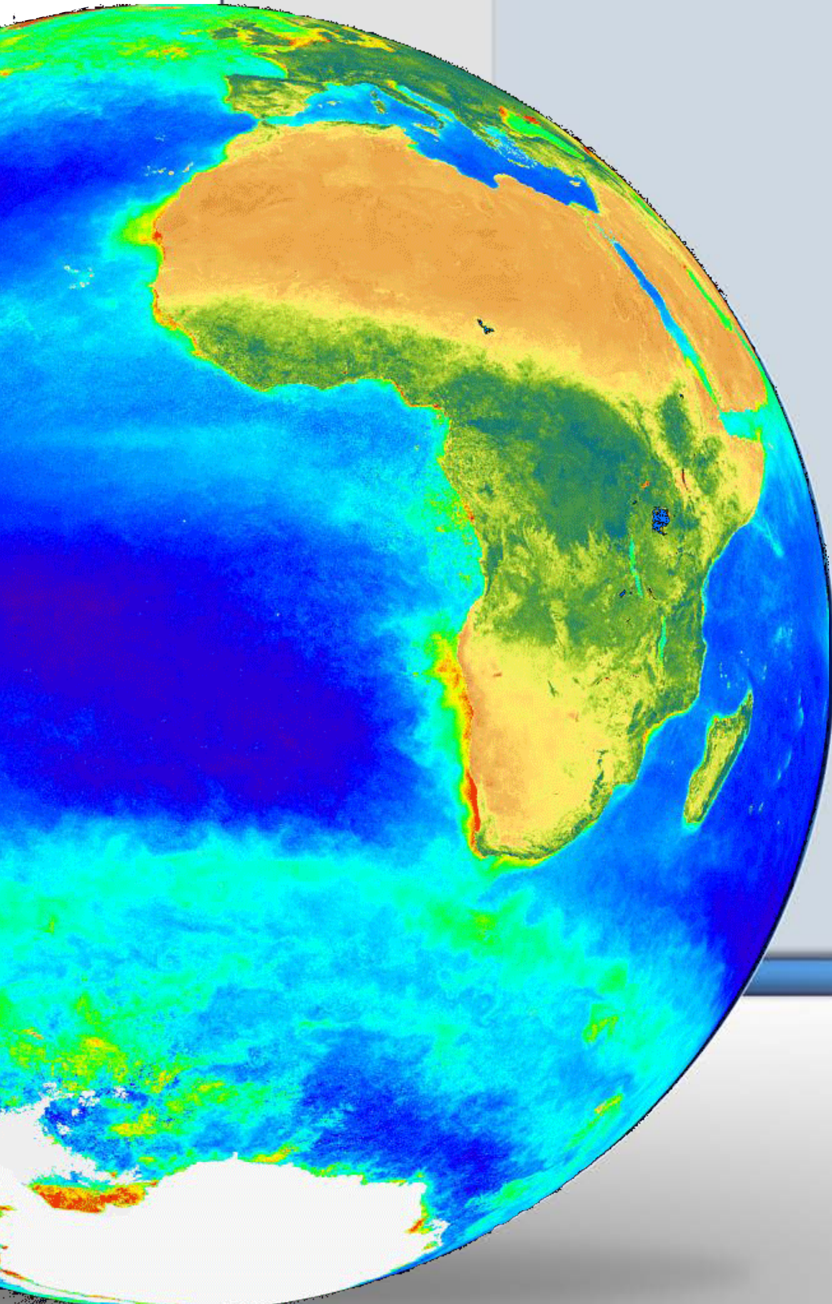


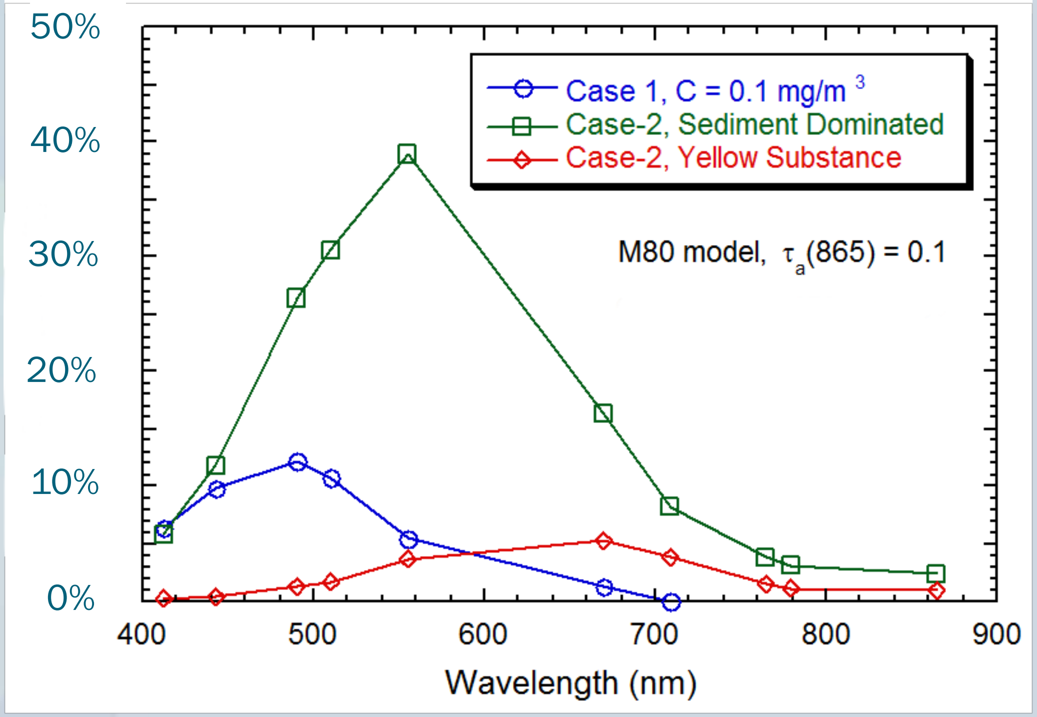
Ocean Colour: Calibration Approach

CEOS WGCV-39, May 2015

The International Ocean Colour Coordinating Group

Ocean Colour requires special calibration considerations

Percentage of ocean signal in the total measured signal



Case 1 - open ocean waters dominated by phytoplankton and their byproducts

Case 1 - the great majority of the global ocean

Ocean Colour = Weak Signal

atmosphere contributes approximately 90% of the total measured signal L_t

0.5% error in instrument calibration → 5% error in water-leaving radiances

Ocean Colour measurement requirements

Measurement requirements

water-leaving radiances / reflectances

- **5%** absolute uncertainty in blue/green (Case 1)
- **0.5%** stability per decade (GCOS)

chlorophyll concentration, C_a

- **30%** absolute uncertainty (Case 1)
- **3%** stability over a decade (GCOS)

uncertainties are present in processing algorithms, including atmospheric correction

GCOS

WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION

SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED DATA PRODUCTS FOR CLIMATE

2011 Update

Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)"

December 2011

GCOS – 154

UNITED NATIONS ENVIRONMENT PROGRAMME

INTERNATIONAL COUNCIL FOR SCIENCE

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DOCUMENT

Sentinel-3 Mission Requirements Traceability Document (MRTD)

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IOCCG Report Number 13, 2012

Mission Requirements for Future Ocean-Colour Sensors

Edited by:
Charles McClain and Gerhard Meister (NASA Goddard Space Flight Center, Greenbelt, MD, USA)

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IOCCG Report Number 14, 2013

In-flight Calibration of Satellite Ocean-Colour Sensors

Edited by:
Robert Frouin (Scripps Institution of Oceanography, La Jolla, California, USA)

Report from an IOCCG working Group on In-flight Calibration of Ocean-Colour

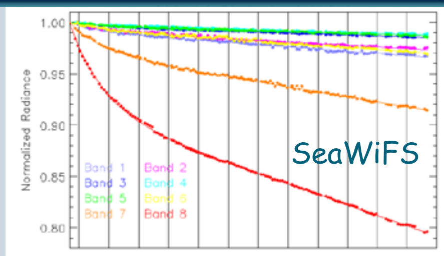
to meet the measurement requirements, L_t needs to have uncertainties **better than 0.5%**

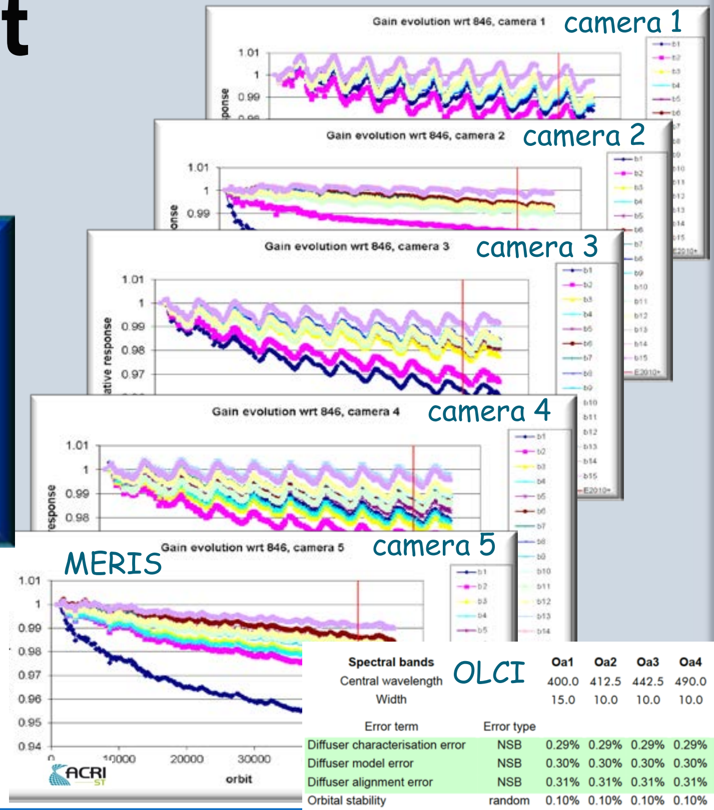
uncertainties of instrument characterization need to be even smaller, **0.2%:**
e.g. solar diffuser BRDF, straylight, polarization, detectors, mirror RVS

Direct Instrument Calibration

Sensor calibration requirements (e.g.S3 OLCI)

- **2%** pre-launch absolute radiometric uncertainty (≤ 900nm)
- **1%** inter-band radiometric uncertainty
- **no** long-term stability requirement





OLCI

Spectral bands		Oa1	Oa2	Oa3	Oa4
Central wavelength		400.0	412.5	442.5	490.0
Width		15.0	10.0	10.0	10.0
Error term	Error type				
Diffuser characterisation error	NSB	0.29%	0.29%	0.29%	0.29%
Diffuser model error	NSB	0.30%	0.30%	0.30%	0.30%
Diffuser alignment error	NSB	0.31%	0.31%	0.31%	0.31%
Orbital stability	random	0.10%	0.10%	0.10%	0.10%
Intrument ageing	SBE	0.08%	0.08%	0.08%	0.08%
Calibration straylight	NSB	0.08%	0.08%	0.08%	0.08%
Post-calibration straylight	NSB	0.20%	0.20%	0.20%	0.20%
Calibration speckle	NSB	0.10%	0.10%	0.10%	0.10%
Diffuser 1 ageing	SBE	0.05%	0.05%	0.05%	0.05%
Diffuser 2 ageing	SBE	0.24%	0.24%	0.24%	0.24%

Pre-launch – sensor is characterized / calibrated in a laboratory

On-orbit – regular radiometric & spectral calibrations track temporal changes in sensor response
– absolute calibration separated from degradation monitoring and characterization

radiometric degradation
- solar diffusers (single or dual)
- lunar calibration (lunar irradiance model)
- lamp sources

spectral calibration
- spectroradiometric calibration assembly
- erbium diffuser
- Fraunhofer lines, O_2 A-band

characterization
- solar diffuser BRDF, straylight
- polarization, detectors, mirror RVS

radiometry verification:
- Rayleigh absolute calibration
- DCC inter-calibration
- desert cross-calibration

Vicarious Instrument Calibration

Sensor calibration requirements

2% pre-launch absolute radiometric uncertainty

2% uncertainty

Absolute measurement requirements

5% absolute uncertainty in blue/green (Case 1)

<< 0.5% uncertainty

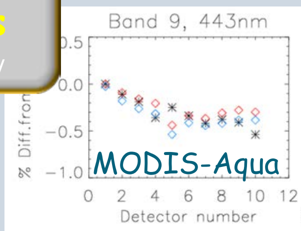
0.2% relative uncertainty

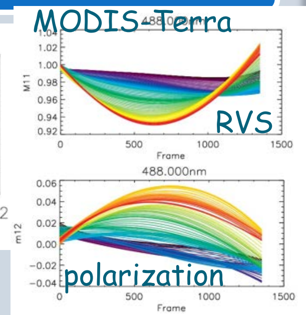
Characterization requirements

0.2% uncertainty

Vicarious Methods

* Earth-view

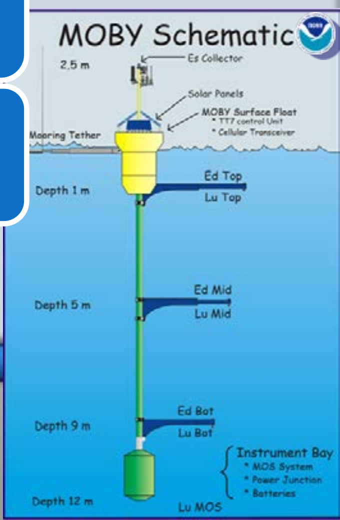




System Vicarious Calibration

* Earth-view – comparison against an independent source; single gain per band
* Calibration of the combined instrument-algorithm system

NIR calibration	oceanic gyres, e.g. South Pacific Gyre
VIS calibration	*in situ* SI-calibrated source, < 4% uncertainty, hyperspectral




Contents lists available at ScienceDirect

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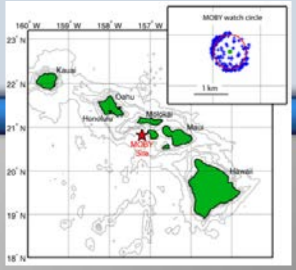
System vicarious calibration for ocean color climate change applications: Requirements for in situ data

Giuseppe Zibordi, Frédéric Mélin, Kenneth J. Voss, B. Carol Johnson, Bryan A. Franz, Ewa Kwiatkowska, Jean-Paul Huot, Menghua Wang, David Antoine



PACE Threshold Ocean Mission Science Traceability Matrix (STM)

Science Questions

No.	Science Question
1	What are the standing stocks, compositions, and productivity of ocean ecosystems? How and why are they changing?
2	How and why are ocean biogeochemical cycles changing? How do they influence the Earth system?
3	What are the material exchanges between land & ocean? How do they influence coastal ecosystems and biogeochemistry? How are they changing?
4	How do aerosols influence ocean ecosystems & biogeochemical cycles? How do ocean biological & photochemical processes affect the atmosphere?
5	How do physical ocean processes affect ocean ecosystems & biogeochemistry? How do ocean biological processes influence ocean physics?
6	What is the distribution of both harmful and beneficial algal blooms and how is their appearance and demise related to environmental forcings? How are these events changing?
7	How do changes in critical ocean ecosystem services affect human health and welfare? How do human activities affect ocean ecosystems and the services they provide? What science-based management strategies need to be implemented to sustain our health and well-being?

Approach

Approach	Maps to Science Question
Quantify phytoplankton biomass, pigments, optical properties, key groups (functional/HABS), & estimate productivity using bio-optical models, chlorophyll fluorescence, & ancillary physical properties (e.g., SST, MLD)	1, 4, 2, 5, 3, 6
Measure particulate &dissolved carbon pools, their characteristics & optical properties	2, 3
Quantify ocean photobiochemical & photobiological processes	2, 4
Estimate particle abundance, size distribution (PSD), & characteristics	1, 3
Assimilate PACE observations in ocean biogeochemical model fields to evaluate key properties (e.g., air-sea CO_2 flux, carbon export, pH, etc.)	2, 4
Compare PACE observations with field- and model data of biological properties, land-ocean exchange, physical properties (e.g., winds, SST, SSH), and circulation (ML dynamics, horizontal divergence, etc)	3, 4, 5, 6
Combine PACE ocean & atmosphere observations with models to evaluate ecosystem-atmosphere interactions	4
Assess ocean radiant heating and feedbacks	5
Conduct field sea-truth measurements & modeling to validate retrievals from the pelagic to near-shore environments	1, 4, 2, 5, 3, 6
Link science, operational, & resource management communities. Communicate social, economic, & management impacts of PACE science. Implement strong education & capacity building programs.	7

Measurement Requirements

- water leaving radiance at 5 nm resolution from 350 to 800 nm
- 10 to 40 nm wide atmospheric correction bands at 350, 820 (or 940), 865, 1240, 1640, and 2130 nm
- characterization of instrument performance changes to ±0.2% in first 3 years & for remaining duration of the mission
- monthly characterization of instrument spectral drift to 0.3 nm accuracy
- daily measurement of dark current & a calibration target/source with its degradation known to ~0.2%
- Prelaunch characterization of linearity, RVVA, polarization sensitivity, radiometric & spectral temperature sensitivity, high contrast resolution, saturation, saturation recovery, crosstalk, radiometric & band-to-band stability, bidirectional reflectance distribution, & relative spectral response
- overall instrument artifact contribution to TOA radiance of < 0.5%
- image striping to < 0.1% in calibrated top-of-atmosphere radiances
- crosstalk contribution to radiance uncertainties of 0.1% at L_{typ}
- polarization sensitivity ≤ 1%
- knowledge of polarization sensitivity to ≤ 0.2%
- no detector saturation for any science measurement bands at L_{max}
- RVVA of < 5% for entire view angle range & < 0.5% for view angles differing by less than 1°
- Stray light contamination for the instrument < 0.2% of L_{typ} 3 pixels away from a cloud
- Out-of-band contamination < 0.01 for all multispectral channels
- Radiance-to-counts characterized to 0.1% over full dynamic range
- Global spatial coverage of 1 km x 1 km (±0.1 km) along-track
- Multiple daily observations at high latitudes
- View zenith angles not exceeding ±60°
- Standard marine atmosphere, clear-water $[r_w(l)]_N$ retrieval with accuracy of max[5% , 0.001] over the wavelength range 400 – 710 nm
- SNR at L_{typ} for 1 km^2 aggregate bands of 1000 from 360 to 710 nm; 300 @ 350 nm; 600 @ NIR bands; 250, 180, and 15 @ 1240, 1640, & 2130 nm
- Absolute calibration to 2% pre-launch and 5% on-orbit (before vicarious calibration)
- 3 hour data latency and direct broadcast of aggregate spectral bands
- Simultaneity of 0.02 second

Implementation Requirements

Vicarious Calibration: Ground-based R_{rs} data for evaluating post-launch instrument gains. Features: (1) Spectral range = 350 - 900 nm at ≤ 3 nm resolution, (2) Spectral accuracies ≤ 5%, (3) Spectral stability ≤ 1%, (4) Deploy = 1 yr prelaunch through mission lifetime, (5) Gain standard errors to ≤ 0.2% in 1 yr post-launch, (6) Maintenance & deploy centrally organized, & (7) Routine field campaigns to verify data quality & evaluate uncertainties

Product Validation: Field radiometric & biogeochemical data over broad possible dynamic range to evaluate PACE science products. Features: (1) Competed & revolving Ocean Science Teams, (2) PACE-supported field campaigns (2 per year), (3) Permanent/public archive with all supporting data

Ocean Biogeochemistry-Ecosystem Modeling

- Expand model capabilities by assimilating expanded PACE retrieved properties, such as NPP, IOPs, & phytoplankton groups & PSD's
- Extend PACE science to key fluxes: e.g., export, CO_2, land-ocean exchange

Platform Reqmts.

2-day global coverage to solar zenith angle of 75°

Sun-synchronous polar orbit with equatorial crossing time between 11:00 and 1:00

Maintain orbit to ±10 minutes over mission lifetime

Mitigation of sun glint

Mission lifetime of 5 years

Storage and download of full spectral and spatial data

Monthly lunar observations at constant phase angle through Earth observing port

System-level pointing accuracy of 2 IFOV and knowledge equivalent to 0.1 IFOV over the full range of viewing geometries

System-level pointing jitter accuracy of 0.01 IFOV or less between any adjacent spatial samples

Spatial band-to-band registration of 80% of one IFOV between any two bands, without resampling

Other Needs

Capability to reprocess full data set 1 – 2 times annually

Ancillary data sets from models missions, or field observations:

Measurement Requirements
(1) Ozone
(2) Water vapor
(3) Surface wind velocity and barometric pressure
(4) NO_2

Science Requirements
(1) SST
(2) SSH
(3) PAR
(4) UV
(5) MLD
(6) CO_2
(7) pH
(8) Ocean circulation
(9) Aerosol deposition
(10) run-off loading in coastal zone

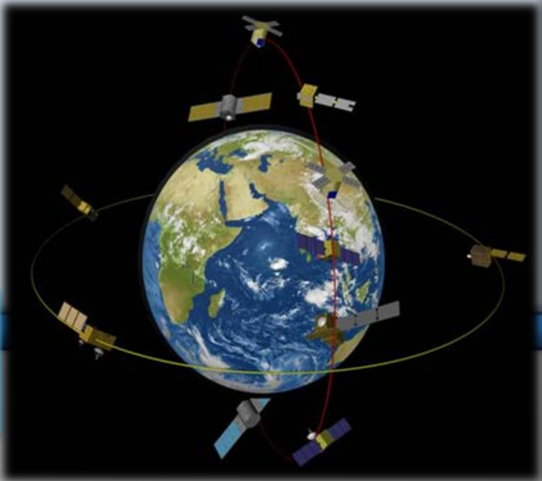
Ocean Colour Calibration within OCR-VC

OCR-VC established by IOCCG to provide **a long time series of calibrated ocean colour radiances** from measurements obtained from multiple satellites

Goals of the OCR-VC

1) To ensure the continuity of the ocean colour time series – Climate Data Record (CDR) / Essential Climate Variables (ECVs)
2) **To provide high quality data sets** through a concerted inter-agency effort on activities relating to sensor inter-comparison (**INSITU-OCR**)
3) Data harmonization, support implementation of ECVs
4) Facilitate timely and easy access to data (user interface)
5) Capacity building and outreach

All space agencies on the IOCCG Committee contribute to the OCR-VC



Motivation for the calibration task force

INSITU-OCR White Paper

International Network for Sensor Inter-comparison and Uncertainty Assessment for Ocean Colour Radiometry produced a White Paper with recommendations on:

- space sensor radiometric calibration, characterization and temporal stability
- development and assessment of satellite products
- in situ data generation and handling
- information management and support

Task Force on ECV Assessment

Provides guidance on the generation of better, long-term OCR climate data records

Task Force on Satellite Sensor Calibration

Facilitates collaboration to maximize the accuracy and stability of OCR data records from individual missions

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

- **R1.3 Permanent working group on satellite sensor calibration**

To facilitate collaboration between sensor calibration teams, a joint satellite calibration working group should be formed including members from all relevant ocean color sensor teams. This working group would focus on instrument

Goal of the calibration task force

Mission Statement

Provide a framework for active and hands-on collaboration among instrument calibration and characterization experts from Agencies engaged in the OCR-VC initiative.

The collaboration focuses on calibration needs specific to ocean-colour measurements and has the objective

- to maximize the accuracy and temporal and spatial stability of OCR records from individual missions for the purpose of climate, research and operational applications
- to facilitate the implementation of the pre-launch and on-orbit sensor calibration and characterization recommendations within respective Agencies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Edited by:
Charles McClain and Gerhard Meister (NASA Goddard Space Flight Center, Greenbelt, MD, USA)

Task force affiliation, scope, reporting

Scope

- Ocean colour satellite instrument calibration and characterization, pre-launch and on-orbit
- System vicarious calibration is not in the scope of this task force

Affiliation

- Joint IOCCG and CEOS OCR-VC activity (in response to OCR-VC White Paper)
- Aim to be recognized by CEOS WGCV IVOS, with direct links and adoption of IVOS guidelines relevant to ocean colour

Reporting

- Reporting to IOCCG and CEOS OCR-VC (INSITU-OCR project office)
- Reporting to CEOS WGCV IVOS when suitable
- Reporting of recommendations, results, to individual missions (e.g. S3OLCI QWG)

Permanent task force structure

Long-term structure

Terms of Reference supplemented by an annual program of work

IOCCG website

http://www.ioccg.org/groups/Calib_TF.html

Meetings

- Dedicated splinter sessions during the IOCS meetings
- Piggybacking on ocean colour community meetings (e.g. S3VT)
- Hands-on activities (e.g. SD BRDF, yaw maneuvers)
- Representation to meetings of CEOS WGCV IVOS
- Representation to meetings of GSICS (e.g. lunar calibration)
- Next meeting: Satellite Instrument Pre- and Post-Launch Calibration III, IOCS, June 2015, San Francisco

Chair and membership

Chairs

Ewa Kwiatkowska (EUMETSAT), Gerhard Meister (NASA GSFC), Bertrand Fougnie (CNES)

Membership

- Proposed by the Space Agencies in agreement with the Chairs
- Expertise required: hands-on experience in ocean colour instrument design, characterization, calibration, and calibration validation; pre-launch and on-orbit

Colleagues actively involved in the meetings up to date

Ludovic Bourg, ACRI-ST
Seongick Cho, KIOST
Prakash Chauhan, ISRO
Steven Delwart, ESA
Gene Eplee, NASA
Bertrand Fougnie, CNES
Xianqiang He, 2nd Ins. Oceanography
Tim Hewison, EUMETSAT
Ewa Kwiatkowska, EUMETSAT

Constant Mazeran, SOLVO
Gerhard Meister, NASA
Hiroshi Murakami, JAXA
Samir Pal, ISRO
Frederick Patt, NASA
Junqiang Sun, NOAA
Menghua Wang, NOAA
Xiaoxiong (Jack) Xiong, NASA
Giuseppe Zibordi, JRC