International Ocean Colour Science Meeting 2017

Advancing Global Ocean Colour Observations

Ocean Colour Vicarious Calibration

Community requirements for future infrastructures

IOCS 2017 - Breakout Workshop#3

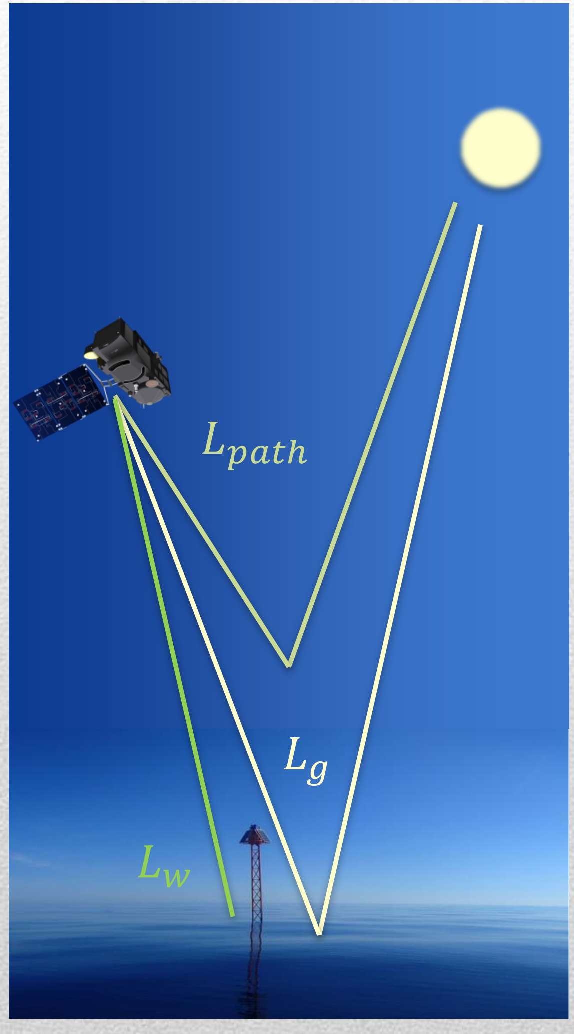
Goal of the workshop

- This workshop is a forum to discuss the **requirements** for the development & operation of future vicarious calibration infrastructures

- It is a **follow-up of the IOCS 2013 session** on System Vicarious Calibration (SVC) which expected to be *“the start for additional international actions aiming at detailing specific requirements and methods for SVC of new missions like PACE and Sentinel-3”*

- Expected outcome: **get consensus on the requirements, ensure international harmonisation and rationalise efforts for the next decades** (as part of the INSITU-OCR initiative).

Brief reminder of SVC



- Calibration of the sensor + algorithm system
- Only solution today to reach specification on Lw
- Signal modelling:

$$L_t(\lambda) = t_g(\lambda) \cdot \left(L_{path}(\lambda) + T(\lambda)L_g + t(\lambda)\mu_s C_s C_Q(\lambda) L_{wN}(\lambda)\right)$$

↓ TOA ↓ Rayleigh+aerosol ↓ Sun-glint ↓ BRDF ↓ Water

- Reconstruction of the true (targeted) signal:

From atm. corr. *Avoided* *Sea-truth*

$$L_t^t(\lambda) = t_g(\lambda) \cdot \left(L_{path}(\lambda) + T(\lambda)L_g + t(\lambda)\mu_s C_s C_Q(\lambda) L_{wN}^t(\lambda)\right)$$

- Computation of gains at pixel level $g(\lambda) = \frac{L_t^t(\lambda)}{L_t(\lambda)}$
- Averaging over mission life time: unique $\bar{g}(\lambda)$
- **Today's priority: review requirements for L_{wN}^t**

Workshop agenda

Part I: On-going activities & existing/under-development infrastructures

14:15 - 14:25 On-going SVC activities in Space agencies (EUMETSAT, ESA & NASA)
C. Mazeran (Solvo), C. Lerebourg (ACRI-ST), S. Bailey (NASA/GSFC)

14:25 – 14:35 Overview and status of the HYPERNAV concept
Andrew Barnard (Sea-Bird Scientific)

14:35 – 14:45 Overview and status of the HARPOONS concept
Sean Bailey on behalf of Carlos Del Castillo (NASA/GSFC)

14:45 – 14:55 Overview and status of the MOBY-NET concept
Kenneth Voss (University of Miami)

14:55 – 15:05 Overview and status of the BOUSSOLE concept
David Antoine (CNRS-LOV & Curtin University)

Part II: Discussion on requirements for any future SVC programme

15:05 – 16:00 High level scientific and technical requirements (key aspects)

16:00 – 16:30 Operational requirements

16:30 – 16:50 Programmatic steps and international activities

16:50 – 17:00 Conclusion: coordinated message to IOCS

Part I: On-going activities & existing/under-development infrastructures

On-going SVC activity at EUMETSAT

- EUMETSAT is responsible for operating the Copernicus Sentinel-3 satellites, with ESA support, and delivering the marine data

- For SVC, the goal is to plan and develop the infrastructure required for decades of upcoming Copernicus Ocean Colour operations

- First step: on-going study “**Requirements for Copernicus Ocean Colour Vicarious Calibration Infrastructure” (OC-VCAL)**
  - Clear justification of SVC for Copernicus missions
  - Listing of SVC science and high-level technical requirements
  - Listing of SVC operational and service requirements

- Next step: ITT to define a preliminary design

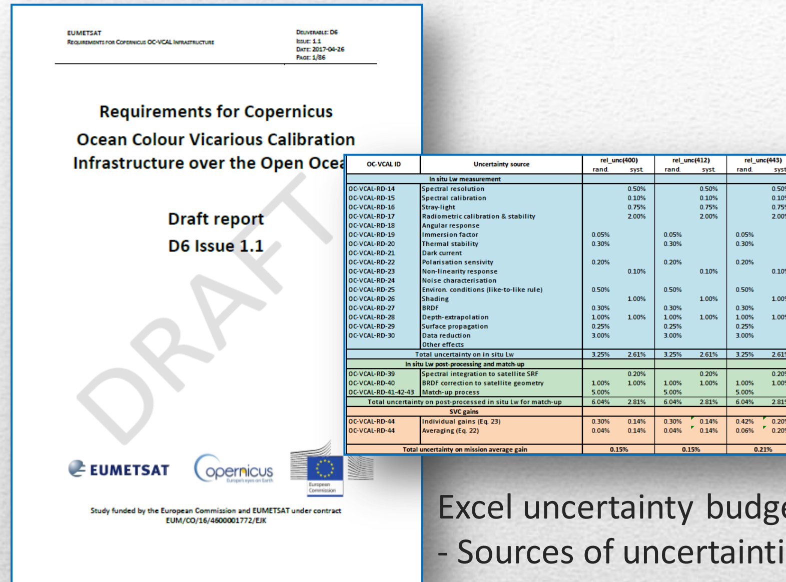
European Commission

Copernicus Europe's eyes on Earth

EUMETSAT

On-going SVC activity at EUMETSAT

- **Requirement report to be delivered to the European Commission in July 2017**
- **International Expert Review Team :**
  - Agnieszka Bialek (cc. Nigel Fox) (NPL) – metrology
  - Bryan Franz (NASA) – vicarious calibration method
  - Carol Johnson (NIST) – metrology, MOBY calibration
  - Craig Donlon (ESA) – FRM4SOC
  - David Antoine (LOV) – in situ infrastructure BOUSSOLE
  - Giuseppe Zibordi (JRC) – in situ infrastructures
  - Hiroshi Murakami (JAXA) – space instruments
  - Menghua Wang (NOAA) – atmospheric correction
  - Vittorio Brando (CMEMS) – Copernicus marine service
  - Young Je Park (KIOST) – operational requirements
- **Two reviews associated with international workshops:**
  - ESA FRM4SOC workshop (21-23 Feb 2017)
  - This IOCS 2017 session



EUMETSAT
Requirements for Copernicus OC-VCAL Infrastructure

Deliverable: D6
Issue: 1.1
Date: 2017-04-26
Page: 1/86

Requirements for Copernicus Ocean Colour Vicarious Calibration Infrastructure over the Open Ocea[n]

Draft report
D6 Issue 1.1

DRAFT

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

OC-VCAL ID	Uncertainty source	rel_unc(400) rand.	rel_unc(400) syst.	rel_unc(412) rand.	rel_unc(412) syst.	rel_unc(443) rand.	rel_unc(443) syst.
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OC-VCAL-RD-16	Stray-light		0.75%		0.75%		0.75%
OC-VCAL-RD-17	Radiometric calibration & stability		2.00%		2.00%		2.00%
OC-VCAL-RD-18	Angular response						
OC-VCAL-RD-19	Immersion factor	0.05%		0.05%		0.05%	
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OC-VCAL-RD-21	Dark current						
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OC-VCAL-RD-29	Surface propagation	0.25%		0.25%		0.25%	
OC-VCAL-RD-30	Data reduction	3.00%		3.00%		3.00%	
	Other effects						
Total uncertainty on in situ Lw		3.25%	2.61%	3.25%	2.61%	3.25%	2.61%
In situ Lw post-processing and match-up							
OC-VCAL-RD-39	Spectral integration to satellite SRF		0.20%		0.20%		0.20%
OC-VCAL-RD-40	BRDF correction to satellite geometry	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
OC-VCAL-RD-41-42-43	Match-up process	5.00%		5.00%		5.00%	
Total uncertainty on post-processed in situ Lw for match-up		6.04%	2.81%	6.04%	2.81%	6.04%	2.81%
SVC gains							
OC-VCAL-RD-44	Individual gains (Eq. 23)	0.30%	0.14%	0.30%	0.14%	0.42%	0.20%
OC-VCAL-RD-44	Averaging (Eq. 22)	0.04%	0.14%	0.04%	0.14%	0.06%	0.20%
Total uncertainty on mission average gain		0.15%		0.15%		0.21%	

Excel uncertainty budget:
- Sources of uncertainties
- Examples of values

- **Today's discussion: agree on the approach and key requirements**

- **Any feedback welcome after this meeting**: constant.mazeran@solvo.fr ewa.kwiatkowska@eumetsat.fr

On-going activity at ESA: FRM4SOC

fiducial reference measurements for satellite ocean colour

https://frm4soc.org

- ***Overall objective***
  - *To establish and maintain SI traceability of Fiducial Reference Measurements (FRM) for satellite ocean colour radiometry (OCR) with accompanying uncertainty budgets.*
- ***Activities***
  - Revision of measurement protocols and procedure
  - Lab. and field inter-comparison exercises
  - **Workshop on vicarious adjustment (Feb. 2017):**
    - *Options for future European satellite OCR vicarious adjustment infrastructure (including approaches and value for money) for the Sentinel-3 OLCI and Sentinel-2 MSI A/B/C and D instruments*
    - **Context**: SVC is essential to make the best out of S2 and S3 missions and ensure the required product quality for the next 20 years
    - **Workshop objectives:** Gather the international community to review approaches, operation, maintenance, address the in situ challenges, conclude with a consensus on the way forward

On-going activity at ESA: FRM4SOC

fiducial reference measurements for satellite ocean colour

https://frm4soc.org

- ***Workshop conclusions (report under preparation):***
  - Key component: metrological foundation with 'hands-on' involvement of NMIs at all stages of development and operations
  - Increased effort on sensor characterisation, consolidation of uncertainty budgets
  - At least two SVC sites in Europe:
    - In priority, BOUSSOLE should be maintained and strengthened (more than 15 years expertise, long and valuable time series…)
    - A second site should be created, possibly in Eastern Med. A MOBY-net system could be envisaged.
  - In complement for larger CalVal purposes:
    - Autonomous radiometric systems (ProVals/HyperNav) should be encouraged in support of CalVal activities. These systems should follow FRM guide lines for SI-traceability and uncertainty budgets.
    - AERONET-OC as a proven system should be maintained and further developed

On-going activity at ESA: FRM4SOC

fiducial reference measurements for satellite ocean colour

https://frm4soc.org

- ***An IOCCG working group on vicarious calibration has been created and will benefit from the on-going activities (FRM4SOC, OC-VCAL, ROSES …)***
  - http://ioccg.org/group/vicarious-adjustment/
  - **Co-chairs:**
    - Christophe Lerebourg, ACRI-ST, France
    - Carol Johnson, NIST, USA
    - Ewa Kwiatkowska, EUMETSAT, Germany
  - **Members:**
    - David Antoine, Curtin University, Australia
    - Ken Voss, University of Miami, USA
    - Nigel Fox, NPL, UK
    - Marlon Lewis, Dalhousie University, Canada
    - Bryan Franz, NASA GSFC, USA
    - Hiroshi Murakami, JAXA, Japan
    - Sean Bailey, NASA GSFC, USA
    - Andrew Banks, NPL, UK
    - Craig Donlon, ESA/ESTEC, Netherlands
    - Constant Mazeran , Solvo, France
    - Emmanuel Boss, University of Maine, USA

On-going activity at NASA

- **ROSES 2014 - Ocean Color Remote Sensing Vicarious (In Situ) Calibration Instruments**
  - Solicited proposals for the development of in situ instrumentation explicitly for vicarious calibration of satellite-based ocean color remote sensors
  - 3 proposals selected (presentations to follow)
  - 3-year award – ending this FY
  - A follow-on has yet to be announced
- **PACE Project Science Office has been focusing a lot of attention on overall measurement uncertainties, including the development of a complete uncertainty budget**

Part II: Discussion on community requirements for any future SVC programme

High level scientific and technical requirements

15:05 – 15:25 Approach to define requirements (uncertainty, stability)

15:25 – 15:45 Requirements on the SVC process and site

15:45 – 16:00 Sources of uncertainty and example of quantified budget

What approach to define requirements?

1. Requirements on the SVC infrastructure are driven by the **uncertainty budget of the gains (e.g. to reach 0.5% TOA)**
   - Requirements are **not directly** defined by applications
   - Existing infrastructures provide **guidance**

2. Justification for the gain uncertainty (e.g. 0.5% TOA) are driven by requirements on OC products:
   - **Open ocean, climate applications**: 5% on Lw in the blue
   - **Coastal applications**: unknown. Effort should focus on AC

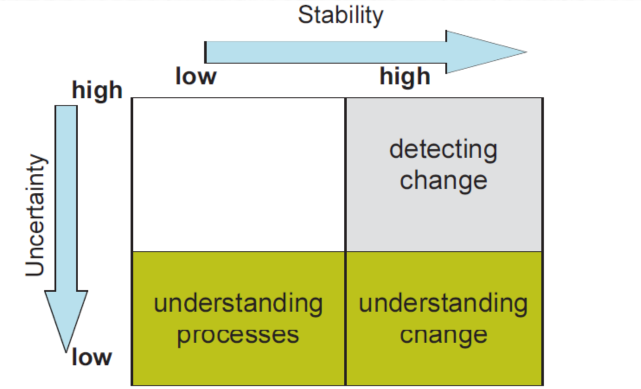
3. Focus on **System** Vicarious Calibration and on **standard** atmospheric correction (Gordon & Wang)

$\frac{u(\overline{L_w^{cal}})}{\overline{L_w^{cal}}} = u(\bar{g}) / \left(\frac{t_g t_{up} \overline{L_w^{cal}}}{L_t} \right)$ → 5% for L_w with tL_w/L_t=10% requires u($\bar{g}$)=0.5%

What quality required in OCR?

4

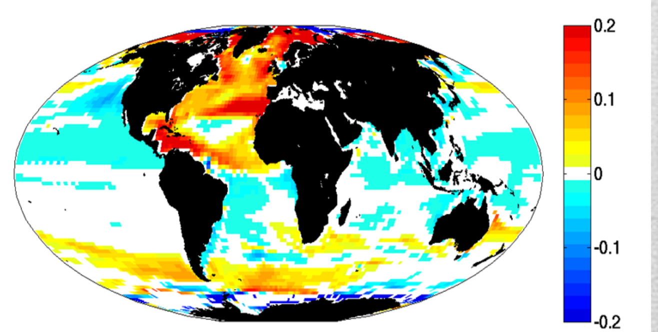
- **Commonly accepted radiometric uncertainty requirement** for CDRs: 5% (k=1) in the blue-green for open ocean (Gordon 1987, GCOS 2011)



Uncertainty and stability requirement for CDR. From Ohring et al. 2004

5

- Long-term stability is key attribute for CDRs, but **which requirement on stability?**
  - 0.5% per decade from GOCS 2011
  - 1% from Ohring et al. 2004: "*somewhat arbitrary*" by simple rule of "1/5"
  - Predicted change from numerical model (S. Dutkiewicz): 1% per decade for most of the ocean



Predicted change in rrs(475) per year [%] over the 21st century. From Dutkiewicz 2016

6

- **What metric to assess stability?**
  - Ohring 2004: *Stability is measured by the maximum excursion of the short-term-average measured value of a variable under identical conditions over a decade*
  - Zibordi et al. 2015: $\left(\sigma_{\bar{g}}/\bar{g}\right)/\sqrt{N_y}$

What requirements on the SVC process?

7

- **What justification in the Level-1 calibration for one unique $\overline{g}(\lambda)$?**
  - Characterisation and monitoring of sensor SRF (including out-of-band)
  - Correction for ageing. Use of lunar or on-board device for verification.
  - Across-track relative calibration. E.g. OLCI on-board diffuser and BRDF characterisation; what for scanner?
  - Non-linearity correction

8

- **What requirement on the L_w^t in the VIS, in terms of SVC process?**
  - Choice of water type (meso/oligo) only driven by the uncertainty budget

$$\sigma_g = \sqrt{\left(\frac{\sigma_{L_{wN}^t}}{L_{wN}^t}\right)^2 + \left(\frac{\sigma_{C_Q}}{C_Q}\right)^2} \frac{t_g t \mu_s C_s C_Q L_{wN}^t}{L_t}$$

Mesotrophic waters may minimize L_w^t / L_t but increase $\sigma_{L_w^t}$ and σ_{C_Q}

  - Calibration in radiance or reflectance: use of L_{wN}^t or $L_{wN}^t / E_s^t * F_0$?

9

- **How to evaluate various SVC options? Assess global impact of SVC?**
  - Need high-quality validation dataset (Fiducial Reference Measurements)

What requirements at the SVC site?

- **Assuming a low uncertainty in L_w^t is achieved (cf. full unc. budget):**
  - **Temporal stability?** *An ideal external calibration source is one that is nearly constant in time and able to be viewed from different orbit configurations* (Ohring 2004)
  - **Spatial homogeneity?** To be assess by in situ measurements
  - **Characterisation of water IOPs?** Depth-extrapolation, BRDF correction

10

- **What atmospheric measurement (used for site selection & QC)?**
  - Need characterisation by dedicated space mission for aerosol (not OC mission) + field measurement (LIDAR, AERONET) at least during one year
  - During operation, monthly measurement of AOT(λ)

11

- **Can multiple sites be used? What requirement on the "super-site"?**
  - Redundancy is recommended from a metrology point of view (weighted average gains) + limit impact of any failure + maximise # of match-ups
  - Requirements: strict equivalence in terms of uncertainty, traceability, protocols, observation conditions. Statistical proof of equivalence of gains

12

Sources of uncertainty

- **Completeness of the uncertainty sources?**

In situ radiometer (Lw)

Lw post-processing and match-up

Gain computation

OC-VCAL ID	Uncertainty source
In situ Lw measurement	
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Uncertainty budget - Example

- **Examples to be discussed**
  - Random and systematic components in the averaging: $\sigma_{\bar{g}}^2 = \left(\frac{\sigma_g^{rand}}{\sqrt{N}}\right)^2 + \left(\sigma_g^{syst}\right)^2$

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Total uncertainty on mission average gain		**0.15%**		**0.15%**		**0.21%**	

In this example:

$\frac{t_g t C_Q L_w^t}{L_t}$=5% at 400, 412

= 7% at 443

Operational requirements

16:00 – 16:10 Field operation and maintenance

16:10 – 16:20 Data access and timelines

16:20 – 16:30 Service operation & science

Field operation & maintenance

15
- **What rotation?**
  - Frequency of rotation of 4 to 6 months (max)
  - Maybe limited to some component of the structure
  - Continuity between deployment

16
- **What routine maintenance?**
  - Divers for cleaning and checking anomalous measurements

17
- **What autonomous field operation?**
  - Store all measured data (optical + platform + environmental)
  - Continuous transmission to the lab

Data access and timelines

18
- **What access?**
  - Data publicly and freely available on a website
  - Documentation on measurement protocols, field operation, quality level
  - Raw data, Lw data, history of calibration
  - Automated graph
  - Open source code to process raw data to Lw
  - Rigorous version management system
  - Levels of data quality (cf. AERONET-OC)
  - Different levels of uncertainty depending on levels of data quality
  - Sampling strategy programmed according to LEO/GEO acquisition

19
- **What latency?**
  - For early phase of mission: quick delivery (one week)
  - With reduced quality for NRT monitoring: daily or weekly
  - With highest quality for SVC (after post-calibration): after several months

Service operation & science

20

- **What type of operation is required?**
  - **Operational component** for SVC. For Copernicus: rely on Service Level Agreement (SLA)
  - **Evolutionary and science component**. Research activity possibly funded by other programmes

21

- **What requirements to run a sustainable SVC service?**
  - Service aligned on the mission lifetime (e.g. Copernicus)
  - Long-term funding. Cost driven by the characterisation, calibration and maintenance, not the equipment.
  - Contingency funding in case of emergency
  - Sustainable team with demonstrated experience, training, redundancy of PI
  - Joint development and operation with a NMI

Programmatic steps and international activities

16:30 – 16:40 International harmonisation

16:40 – 16:50 Programmatic steps

International harmonisation

22

- **What could be the required actions for international harmonisation?**
  - Link with CEOS and IOCCG, in particular INSITU-OCR
  - Create an IOCCG task force and or Working Group
  - Harmonisation in infrastructure? Intercomparison in Lu measurement with a dedicated transfer instrument (with similar radiometric quality)
  - Harmonised protocols
  - Consistent uncertainty budget assessment (metrology)
  - Data and code sharing
  - Training

Programmatic steps

23

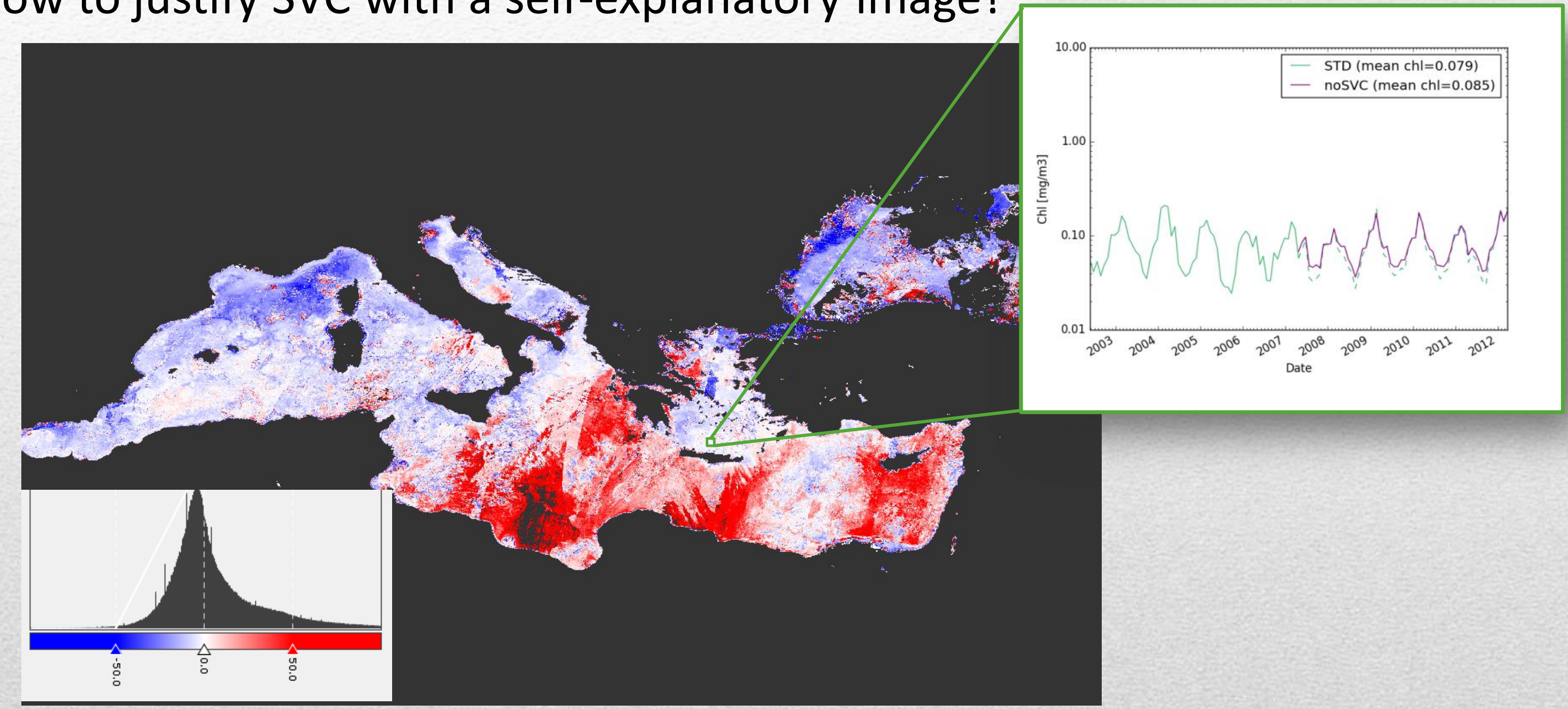
- **In US: next steps after the ROSES call?**
- **In Asia and Oceania:**
  - Plans for GOCI-II (KIOST)?
  - Plans for the Kavaratti buoy in Arabian Sea (ISRO)?
  - Buoy off Australia?
- **In Europe:**
  - **Conclusions of FRM4SOC workshop:**
    - Two sites in Europe, including BOUSSOLE
    - Long-term investment is critical (initial purchase and installation but also adequate funding for on-going operations in terms of updates/ upgrades, maintenance, and consistent staffing that develops and retains expertise
  - **What should be the next steps towards a SVC programme?**
    - Step1: Scientific, technical and operational requirements (EUMETSAT report)
    - Step2: Preliminary design, project plan and costing
    - Step 3: Technical definition, specifications, detailed design
    - Step 4: Development, testing and demonstration in the field
    - Step 5: Operation

Conclusion

Message to decision-makers

24

- How to justify SVC with a self-explanatory image?



Impact of vicarious calibration on chlorophyll-a concentration, as measured by MERIS over the Med Sea in April 2008. The relative change (in %) is due to disabling vicarious calibration.

Coordinated message to IOCS

- **Goal:** identify ONE highest priority for SVC, captured in a single sentence, to be discussed during the final IOCS Q&A session with space agencies

- **Suggestion:**

25 Main priority for operational SVC is to ensure sustainable resources (people and infrastructure) along the complete lifetime of current and future OC missions