FRM4SOC – Task 5
Options and approaches to the long-term vicarious adjustment of Sentinel- OLCI & MSI A/B/C and D instruments.

Lerebourg C. (ACRI-ST, France) Final Workshop

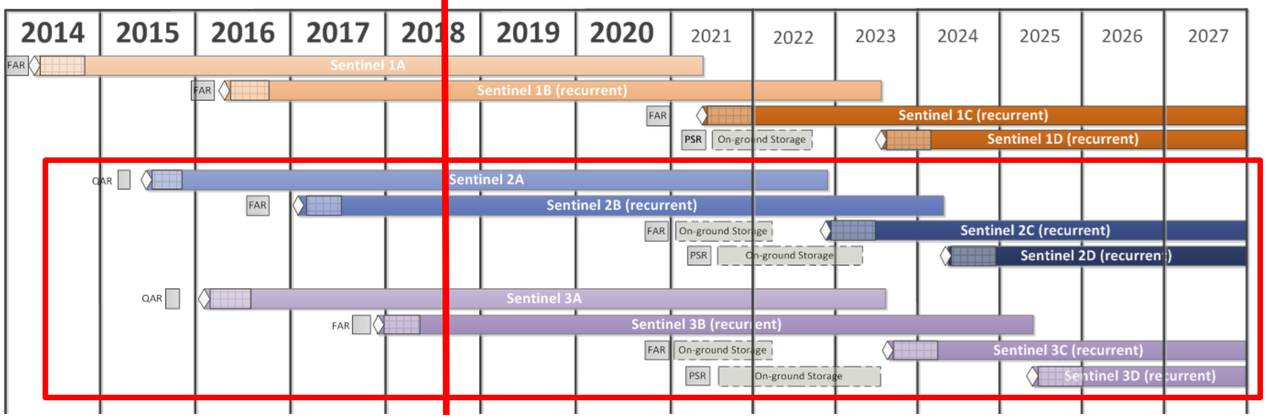
October 4-5 2018 - NPL

Work package objectives

- **The primary objective the work package was to evaluate the options for future European SVC infrastructure for the Sentinel-3 OLCI and Sentinel-2 MSI series.**
- **Workshop held in February 2017 with the international community.**
- the actual need for FRM was carefully analysed through feedback from the Space Components and downstream services.
- historical and state of the art SVC approaches were extensively reviewed to analyse their strengths and weaknesses, to document lessons learned and gather recommendations from experts in the different fields
- Reference SVC sites (BOUSSOLE and MOBY) were carefully and extensively reviewed to make sure that all aspects of SVC infrastructure was encompassed in the discussions.
- Procedures implemented to derive vicarious gains of different sensors were reviewed to make sure that all the diversity of sensor configuration and processing scheme was encompassed.
- Finally, discussions evaluated the number and location of sites, the technology and required resources for optimum OC-SVC infrastructure.
- **Reach a community consensus for future Copernicus SVC infrastructure**

Context

- **EU Copernicus program has committed for the operation of sentinel-2 and Sentinel-3 series (A, B, C and D)**



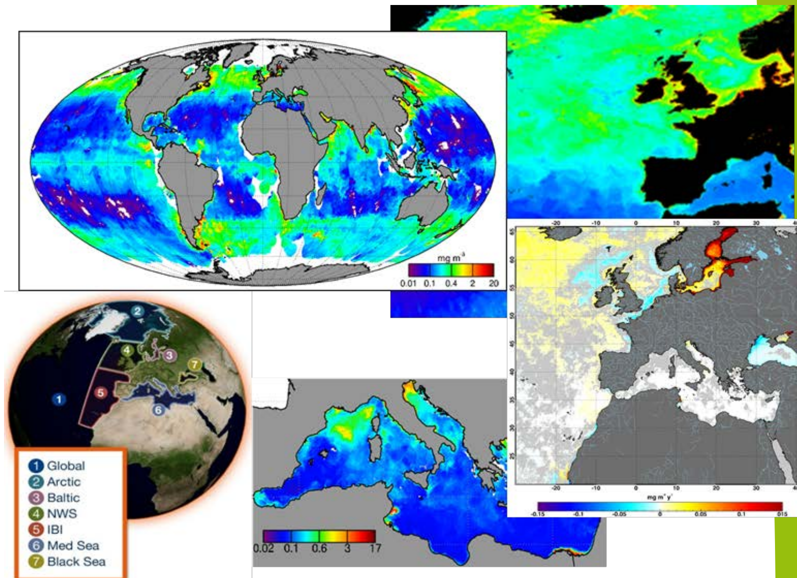
- Sentinel-2 A & B and Sentinel-3 A-B are now in orbit.
- **Among the objectives**
- Support long term scientific activities (global change, provision of Climate Data Records)
- Support monitoring service (ex CMEMS)
- Support the development of economic activities based on EO data.

- **There is a consensus that SVC must be implemented to reach the product requirement**
- 5% uncertainty in satellite-derived ρ_w in the blue/green spectral region
- Not achievable through pre-launch or on-board calibration

- **Crucial that Copernicus secure in the long term the capacity to achieve SVC and therefore ensure EO derived product quality**

WHAT ARE THE NEEDS FOR COPERNICUS?

The operational recommendations



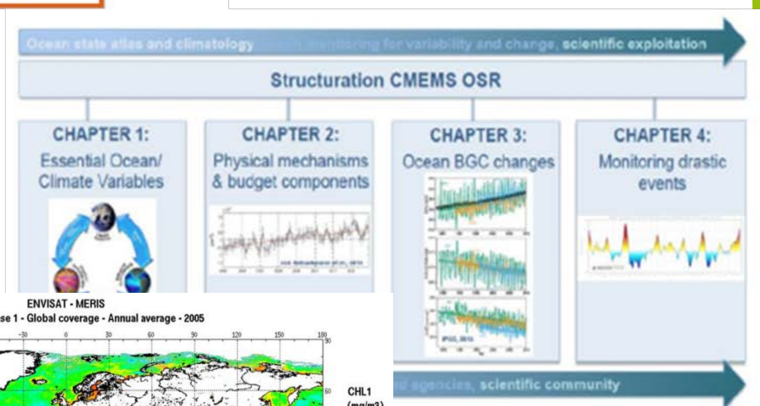
❖ Downstream service CMEMS

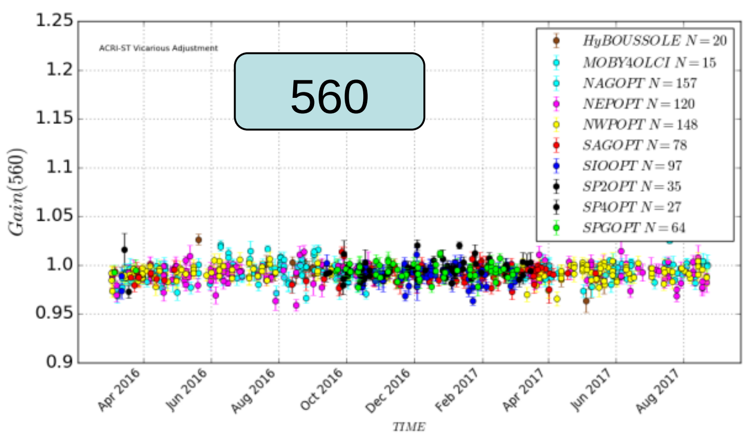
- Copernicus down stream operational services like CMEMS ingests nominal Ground Segment (PDGS) products to generate and distribute higher-level operational products (level3 and level4) to the community.
  - ✓ Sentinel nominal products quality is therefore of prime importance to CMEMS.
  - ✓ Nominal (PDGS) and CMEMS products quality will remain poor without SVC.

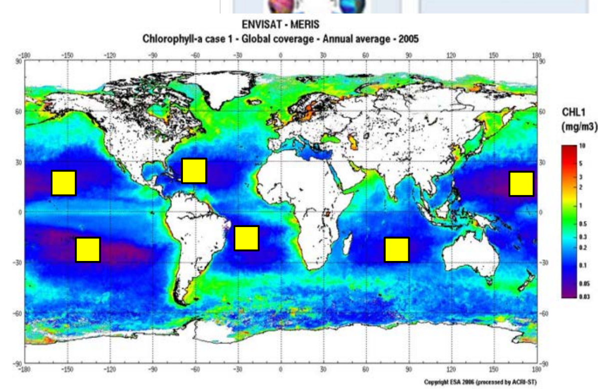
❖ Upstream service MPCs

- SVC needs to be implement prior level-2 products which is challenging for Copernicus upstream services.
- The capacity to provide high-quality products mostly relies on a timely implementation of SVC in the PDGS.
- This essentially relies on the availability of sufficient number of highly precise and accurate measurements, the so-called Fiducial Reference Measurements (FRMs) produced by SVC infrastructures.
- Needed to us Ocean Colour climatologies for S3A will probably be the same for S3B.

❖ Additional services and applications will only be developed products of sufficient quality are provided.

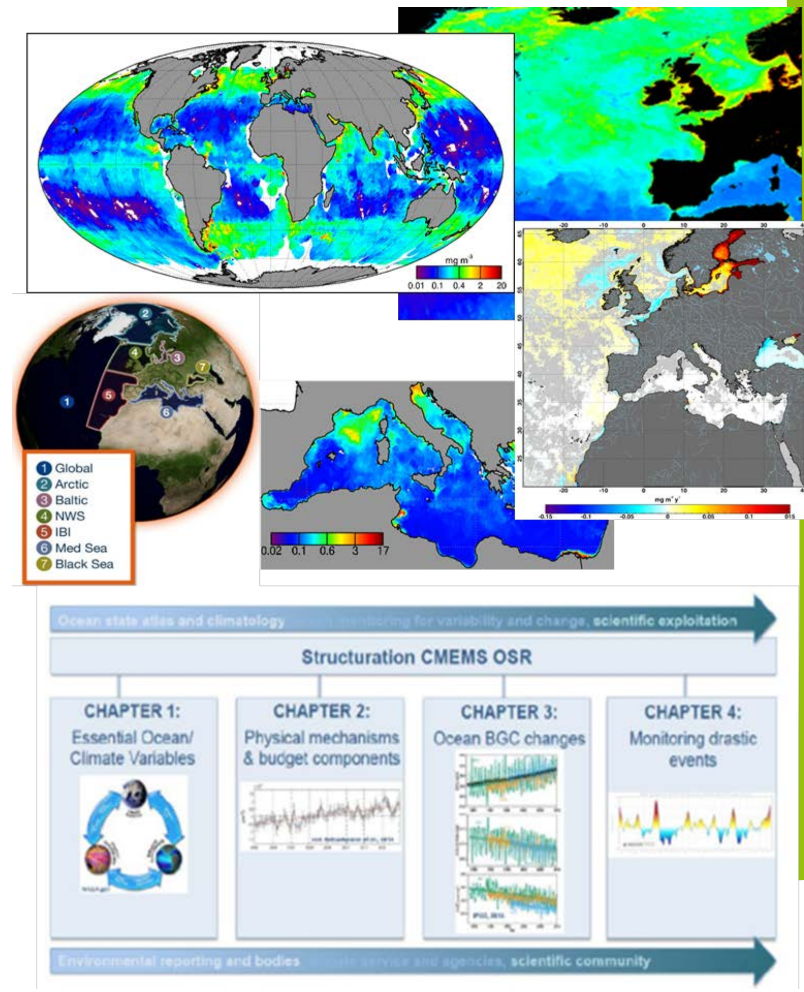






The operational recommendations

- **An operational buoy can provide between 1.5 and 2.0 high quality matchups per month for the purpose of SVC**
  - At this rate, it can take **several years before robust vicarious** gains can be derived from a single SVC infrastructure.
  - In an operational context, it would be **preferable to increase the number of operational SVC** buoys to reduce this delay.
  - It is recalled here that an SVC infrastructure will provide **many more matchups per month for data validation** and monitoring purposes, as the quality requirements are less stringent.
- **timely distribution of the SVC in situ data is important for the near-real-time OC data quality monitoring.**
- **The need to increase the availability of radiometric measurements in a large diversity of water types to perform operational satellite product validation**
  - Operational networks like AERONET-OC have proven their efficiency.
  - HYPER-NET in the future?
  - New technologies, like autonomous floats should be supported
    - ✓ to cover areas of the World's ocean that are poorly sampled
    - ✓ to support SVC in the early stages of a space mission.



WHAT IS THE STATUS?

Current SVC status

- **For the time being, ESA and EUMETSAT can rely on MOBY and BOUSSOLE for S3 OLCI SVC.**
- **MOBY is so far the only fully operational buoy on which we can rely for SVC.**
  - ✓ It has more than 20 years experience in sensor calibration and characterisation through strong involvement of NMIs (NIST).
  - ✓ It can rely on secured funding to ensure hardware purchase, system maintenance, risk mitigation and staff salaries.
- **BOUSSOLE is technically operational yet it does not have secured funding in the long term**
- This system has proven its potential for SVC in the MERIS 3rd and 4th data reprocessing.
- Great efforts and investments have been made to consolidate
  - ✓ the end-to-end uncertainty budgets,
  - ✓ full instrument characterization and
  - ✓ full environmental quantifications on the final uncertainty budget through collaboration with NMIs (NPL).
- BOUSSOLE in addition to its SVC capacity has a unique potential for data validation and bio-optical research and is deployed in case 1 waters offering a chlorophyll seasonal dynamic.

- **Neither MOBY nor BOUSSOLE are directly supported by Copernicus.**

- **In a Copernicus perspective, there is therefore no control on SVC and consequently a risk regarding its capacity in implement SVC**

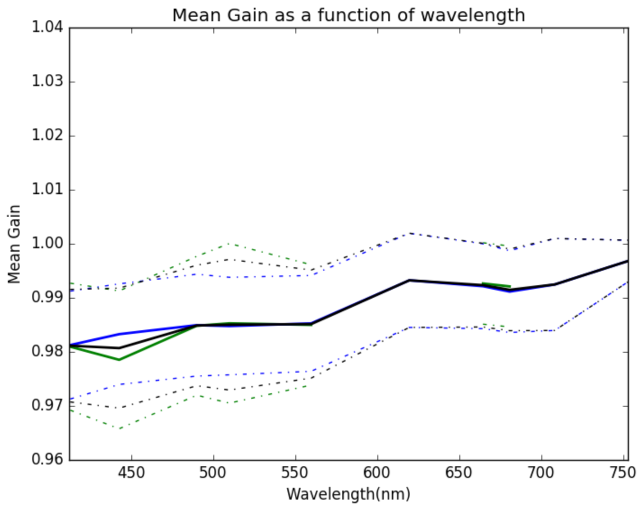


Figure 1: MERIS 4th reprocessing vicarious gains: BOUSSOLE (green), MOBY (blue) and final interpolated gains (black).

OUTCOME OF THE DISCUSSIONS AND REQUIREMENTS FOR SVC

- Metrology
- Instrumentation
- Location
- Maintenance and operation

- Vicarious gains computation

Metrological recommendations

❖ **Metrological aspects were at the centre of discussion as it is essential that the future SVC infrastructure, as well as future validation systems, achieve SI traceability.**

1. **How many sites to be considered**
   1. From a purely metrological perspective, several SVC sites would be preferable.
   2. At least 3 SVC sites would be necessary to ensure the robustness and redundancy.

2. **It is specified by NMIs that the SVC systems could be different in terms of instrumentation and infrastructure providing they are equivalent.**
   1. How to formally define equivalence (in the metrological sense) between SVCs is still an open question
   2. It was acknowledged that using data from different sites to derive vicarious calibration gains is not trivial.

3. **End-to-end uncertainty budgets must be derived by careful analyses of the different steps**

$$R_{rs}(t,\lambda) = \frac{L_w(t,\lambda)}{E_S(t,\lambda)}$$

$$R_{rs} = \frac{\overline{L_{u4}} f_{cal} f_{s4} \exp\left[z_4 \left(\frac{-\ln\left(\overline{L_{u9}} f_{cal} f_{s9} / \overline{L_{u4}} f_{cal} f_{s4}\right)}{z_9 - z_4} \right) \right] f_H f_{\rho n}}{\overline{E_s} f_{cal} f_{cos} f_{tilt} f_{dir} + (1 - f_{dir}) \overline{E_s} f_{cal}}$$

4. **The uncertainty of the derived gains must also be carefully evaluated.**

5. **The specific aspect of uncertainty requirement for SVC is addressed in the OC-VCAL final report (Mazeran et al., 2017).**

6. **Such practices should be encouraged not only for SVC infrastructures but also for OCR measurements used for validation. ➔ part of FRM4SOC broader objectives**

Instrumentation

Spectral range

- For SVC purposes in situ radiometers should **hyperspectral and cover the 400 to 700nm** to suite multi mission needs of current and planned OCR sensors.
  - ✓ NIR and SWIR bands (>700nm) FRM are not required for SVC
  - ✓ performing accurate measurements between 600 and 700nm is still challenging.

Spectral resolution.

- Zibordi et al (2017) have a published a detailed analysis of the impact of the spectral resolution and derived requirements for SVC needs.
- spectral resolution **better than 3nm for an OLCI like sensor**.
- Additionally, Zibordi et al (2017) argued that using Lw rather than Rrs also increases requirements to less than 1nm spectral resolution.

Instrument characterisation

- To fulfil SVC needs, radiometers must be fully characterised and regularly calibrated.
- Several sets of instruments must be within the SVC package to ensure continuity of the system when the instruments are in post deployment maintenance.
- A detailed list of SVC requirements for instrument characterisation is available in OC-VCAL report (Mazeran et al 2017)

Ancillary data

- ✓ Inherent Optical Properties (IOP ; Transmissometers, backscattering meters,)
- ✓ Absorption meter should be considered but the current technology might not be yet adapted.
- ✓ Chlorophyll fluorescence should also be monitored.
- ✓ Meteorological and oceanographic data must be collected for quality control purpose.
- ✓ wind speed and direction
- ✓ atmospheric pressure
- ✓ wave high etc.
- ✓ Ideally, spectral Aerosol Optical Thickness (AOT) should be measured.

Infrastructure location

Historical requirements for SVC site location where defined by Gordon (1998).

- a location with **maximum number of cloud free days per year**.
  - Local climatology should be taken into account with regards to overpass time.
  - Morning or afternoon overpass can have significant cloudiness condition differences due to morning haze or afternoon evaporation.
- The **atmosphere should be clear with dominant marine aerosol types of AOT lower than 0.1** and no absorbing aerosols to reduce uncertainties on atmospheric correction.
  - Consequently the SVC site should not be located along the coast or in an area dominated by continental atmosphere.
- The **water body should be spatially homogenous** so that a point measurement can reasonably be assumed representative of a satellite pixel or macropixel.
- The SVC site should be **located in oligotrophic to mesotrophic waters** in order to maximize the Lw signal in the blue/green region of the spectrum
- The SVC site should additional be in
  - an **area of low sea state** not necessarily easily achieved in open ocean conditions
  - on low current to limit tilt and
  - **low wind** to limit white caps formation and probability of sun glint due to surface roughness.
- The SVC site should preferably be **located in low latitudes to reduce the variability in solar zenith angle** and therefore reduce uncertainties in atmospheric corrections.

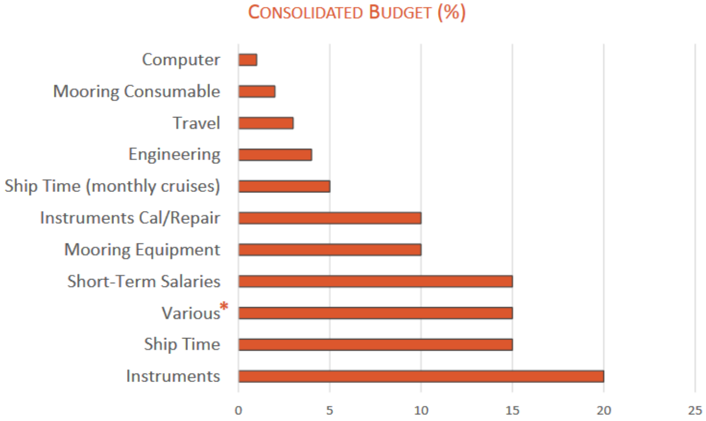
In addition to the environmental conditions, practical considerations also have to be taken into account:

- SVC sites should be in the **vicinity of a harbour** to facilitate logistic.
  - Regular “light weight” cruises are indeed mandatory for instrument and infrastructure maintenance
  - and occasional “heavy weight” cruise will take place for platform turn-over.
- Also importantly, the SVC site should be
  - **within GSM range** to ensure NRT data transfer
  - and **outside of commercial roots or recreational area** to avoid accidents or vandalism.

Maintenance and operation

Maintenance

- **Routine maintenance is a fundamental point of an operational infrastructure.**
  - MOBY has two identical systems that are deployed for a 3 to 4 month period and maintained alternatively.
  - BOUSSOLE performs
    - ✓ a bi-annual rotation of the instruments of the buoy as well as monthly cruises where optical measurements are performed, water sampled for biogeochemical analysis (chlorophyll monitoring in the first place) and optical head cleaned up.
  - 4 to 6 month instrumentation rotation has proven to be sufficient for BOUSSOLE and MOBY
- **Maintaining the expertise and therefore securing the human resources must be a priority.**

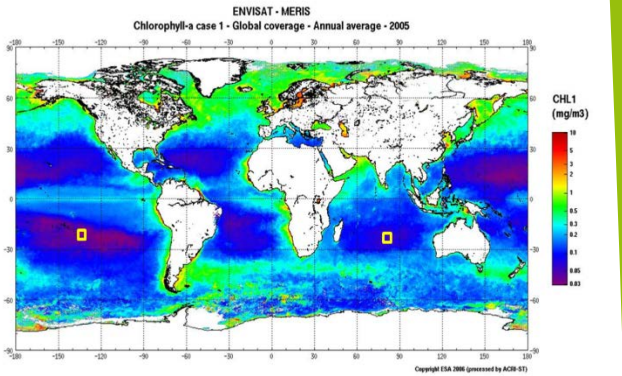


Operation

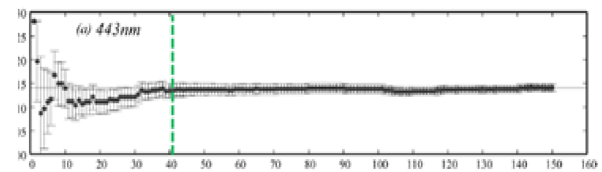
- **For traceability reason, it is recommended that:**
  - Data acquired should be publically available together with instrument calibration history
  - Measurement protocols and data processing source codes should be publically available
  - Finalized FRM should be publically available together with uncertainty budgets.
- **Delay for data delivery depends on the operational need and the mission needs.**
  - In commissioning phase a week between data acquisition and data distribution shall be a target
  - while monthly updates would be sufficient in routine operation.

Gain computation

- **Several SVC Gain computation procedure have been presented during the WS.**
- MERIS, MODIS, GOCI follow the historical methodology defined by Franz et al. (2007)
  - ✓ Base on SIO and/or SPG for the NIR,
  - ✓ MOBY and/or BOUSSOLE for visible bands
- Exception for GOCI which has neither SOI/SPG nor MOBY/BOUSSOLE in its FOV.

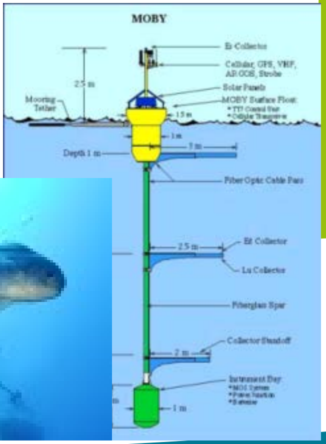


- **Being assumed that all required efforts have been made in the generation of OCR time series. The following recommendations were made for the computation of SVC gains.**
- In situ measurements must be converted into sensors acquisition geometry➔ BRDF correction
  - ✓ Uncertainty related to this conversion must be carefully quantified.
- In the matchup generation, time difference between in situ acquisition and satellite overpass shall be minimized.
  - ✓ On a system like BOUSSOLE, typical difference is less than 15minutes.
  - ✓ This reinforces the need for spatially homogeneous SVC sites to reduce uncertainty linked to time differences.
- Macropixels use to compute SVC gains shall be screened for cloud, glint, haze, white caps, high chlorophyll etc over a large area while the SVC gain itself is computed on a smaller macropixel to reduce adjacency effects.
  - ✓ In the past (Franz et al. (2007) as recommended to screen over a 15x15 macropixel while the gains itself is computed over a 5x5 macropixel.
- The minimum of SVC matchups is determined by the convergence of accumulated mean gains as described in (Franz et al., 2007)
  - ✓ in practise at least two years of data are needed to achieve stable gains. Experience with OLCI has proven that even using both BOUSSOLE and MOBY, 2 years were not enough to derive stable gains.



(from Franz et al., 2007).

- Vicarious gains shall be provided with an uncertainty budget.
- ➔ Problem of the early stages of the mission. OLCI-A used BOUSSOLE, MOBY and climatologies to ensure SVC implementation prior public release of Level-2 products.
- ➔ Copernicus should consider alternative sources of FRM during Commissioning (ProVal, HyperNav?)



Conclusion of the workshop
The community consensus

- **Current status is that neither MOBY nor BOUSSOLE are directly supported by Copernicus.**
- Copernicus therefore has no control of its capacity to perform SVC in the long term.
- Assuming that MOBY infrastructure is secured in the long term, there was a consensus that two operational SVC sites should be maintained by Copernicus
  - ✓ **redundancy** of operational systems (services , CEOS)
  - ✓ From a purely metrological perspective, multiple systems are recommended to **ensure robustness** of SVC
  - ✓ Copernicus operations (CMEMS, MPCs, Ground segments) have stressed the need for more SVC sites
  - ✓ Maintaining two sites in Europe will also **secure the existing expertise, knowledge and knowhow** in the long term
- **For the development of these two proposed Copernicus operational SVC sites, building upon existing systems and expertise (namely BOUSSOLE and MOBY) would be more cost effective. Consequently, the final community recommendation for SVC development within the framework of Copernicus is:**
- To maintain BOUSSOLE in the long term and upgrade it to full operational status for SVC purposes and also
- support the development and long term operation of a second new European infrastructure in a suitable location to ensure operational redundancy.
  - ✓ As was implemented for MOBY, and now for BOUSSOLE, for any SVC infrastructure a good metrological foundation with 'hands-on' involvement of National Metrological Institutes (NMIs) at all stages of development and operation is a key component.
  - ✓ In situ radiometry should be hyperspectral, high resolution, high quality, and of an SI-traceable FRM nature, with a full uncertainty budget and regular SI-traceable calibration.

- For the second SVC infrastructure, Zibordi et al. (2017) have provided a detailed analysis of potential sites for SVC.
  - ✓ the results of initial studies point out that a site located in the **Eastern Mediterranean Sea would represent a good candidate**, although other option was excluded.
  - ✓ A MOBY-Net system, that includes a transportable modular optical system was suggested for the new site.
  - ✓ It would offers a technologically proven system within a realistic timeframe for Copernicus needs and it would reinforces collaboration between experts

- **➔ Thing are moving forward:**
- Preliminary design of the Copernicus Ocean Colour Vicarious Calibration Project: Infrastructure, Project Planning and Costing (Phase A & B)