IOCS 2019
Final report and Recommendations for
Breakout Workshop 3. High temporal/spatial resolution applications

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Objective:
This breakout workshop provided a forum to address key observational gaps and technological challenges for high quality and high spatial-, temporal-, spectral- resolution remote sensing of short-term and spatially complex processes in open ocean and coastal, estuarine, ice edge and inland aquatic environments. Among the main objectives of the workshop was to discuss how existing, or planned, high resolution remote sensing technologies can be utilized in the study of open ocean and aquatic margin systems, identify how these observations can support applications/science end-users and stakeholders, and determine what still must be developed.

Key Recommendations:

- **Science and end-user communities are seeking high temporal, high spatial resolution, hyperspectral satellite observations (H4D, CEOS report, etc.). How is trade space resolved under current paradigm of ESA, NASA, and NOAA, that are focused on global missions?**
- **Given formal interactions with end-user groups, revisit time is the most critical aspect in the trade space, and that temporal resolution must be adequate to resolve processes that change on a sub-daily time step.**
- **A constellation of ~ 15 m (baseline) to 30 m (threshold) resolution sensors with as high as possible radiometric performance and 8 to 15 nm contiguous spectral bands (VIS-NIR-SWIR) would serve a wide range of applications in inland and nearshore coastal waters as well as shallow coastal and coral reef environments.**
- **Inter-consistency in observations and products is challenging and requires dedicated effort. Yet, satellite ocean color products that combine high quality, high spatial, high temporal, and high spectral characteristics may only be attainable through multi-source remote sensing data fusion methods. We recommend that space agencies coordinate mission development, from formulation to operations, and pre-launch calibration to facilitate multi-source data fusion and minimize potential differences in products.**

Requirements and priorities:

- For aquatic ecosystems (with exclusion of optically deep oceans and very large inland water bodies) temporal, spectral and spatial resolution were all identified at the workshop as the core sensor priorities; radiometric resolution and range and temporal resolution needs to be as high as is technologically and financially possible.
- SBG VSWIR data volume is estimated to be ~18TB/day, the magnitude of which concerned some workshop attendees. However, many current and near-future technology approaches can help cope: on-board processing, per ecosystem or large scene area spectral band settings, on board programming and processing, cloud and HPC should be able to cope with automated routines though.
- Emphasis was placed on currently existing inconsistencies within the ocean colour community regarding the terminology and definition of "low", "medium" and "high" spatial-, spectral-, temporal-, radiometric- resolution for aquatic environments. Workshop participants recommended that these terms are defined and used consistently across environments, application concepts, and areas of expertise.

- The inland/estuarine aquatic ecosystems community has been extremely productive at opportunistically using satellite sensors not originally designed for addressing aquatic/ocean science and application questions. Although this increases the cost effectiveness of satellite missions, workshop participants recommended that as a community we adequately report on the limitations of this approach and we make explicit what we would gain with increased spectral, spatial, temporal resolution and particularly radiometric quality.

Spatial & Temporal Resolution Requirements and Recommendations

- One hour repeat coverage e.g. (GOCI; GOCI-2) is adequate to resolve most (but not all) relevant coastal processes. Such resolution is needed to capture diurnal growth processes, and trajectories of colored substances.
- ~15 to 17 m spatial resolution was discussed as the ideal compromise for global coverage and covering enough lakes, rivers, delta's, estuaries, lagoons, as well as suitable for seagrass, macro-algae and coral reefs. A spatial resolution of ~25-30m was discussed as threshold.
- Assume 1km sufficient for ocean, but not necessarily true —> when/where sufficient to go from low 1 km or 300 m to higher spatial resolution. Currently the switch is from 300 to 30 m (Sentinel-3 to Landsat) and then to Sentinel-2 at 10, 20 and 60 m spatial resolution.
- Should a system of EO satellites for aquatic ecosystems all have the same specifications, or should we aim for a mix (multi, hyper, fine to medium spatial resolution)?
- Scale of spatial heterogeneity for coral/seagrass/macro-algae/benthic micro-algae/macrophytes/mangroves/rocky reefs etc: vs ecosystem scale 2m versus ecosystem scale mapping at ~15 to 17 m and ~30m)
- Participants emphasize that there will be many cases where the suggested resolution requirements are not adequate for the size of the water body, the complexity of the suite of constituents, or frequency of the process. We do not know how these inadequacies would accumulate to affect our knowledge of global processes (e.g. global productivity).

Spectral Resolution Requirements and Recommendations

- +/- 40 to 50 multispectral bands required or hyperspectral at ~ 5-to 8 nm average resolution over range of 380-1000 (for optical systems) and 1000-1400 for SWIR
- +/- 40 to 50 multispectral bands required or hyperspectral at ~ 5 to 8 nm resolution over 380-820 nm, 16 to 20 nm 820-1000 nm; 16-20 nm in SWIR.

End-user requirements

- In the inland waters, near coastal, coastal and seagrass/macro-algae/coral reef environments the end-user requirements are highly diverse (mainly due to the scale of the ecosystems and the management boundaries) , which has been an obstacle for getting dedicated sensors designed, built and launched. Workshop participants highlighted that many grey literature report and inventories exist (sensor studies and proposals, H2020 projects, state and national government level reports, etc.). It is recommended to unearth all these reports and to do a meta-analysis and publish this in the international peer reviewed literature. Such consolidated end user requirements across continents and use cases would be very beneficial. This could flow through to a globally accepted science and applications traceability matrix.

Science Community ideas:

- The EO science community would greatly benefit from a simulated dataset (e.g. contain such aspects as global, high spatial, high spectral, high radiometric, high temporal (hourly- to daily) as well as optically deep and optically shallow environments with both homogeneous and heterogeneous substratum types, representative for LEO polar and equatorial and geostationary orbits.

- Study how to Include vertical resolution (e.g., lidar or stereophotogrammetrical approaches or inversion approaches) in water column
- Study benefit and disadvantages of spatial and spectral blending: multiple spatial and/or spectral resolution from the same sensor (e.g., Landsat) or a suite of sensors, including World View V, Sentinel-2 and Landsat. This emphasizes the need for coordinated mission developments from formulation to operations.
- Geostationary satellite ocean color sensors could go down to 50 m spatial resolution. More studies are needed to explore whether a swarm of polar LEO or 4-6 geostationary high spatial resolution sensors, or a combination of these approaches would result in optimal observing system architecture and increased cost effectiveness.
- The adjacency effect vs. spatial resolution is an area where more research needs to be done; the physics say adjacency is not only a function of distance from the land boundary but also it depends on environmental conditions (e.g., aerosol optical thickness, aerosol height, topography, land cover). Ranging from 5 Landsat pixels to 5 MODIS pixels: this apparent contradiction requires dedicate research.

Relevant publications

- CEOS feasibility study 2018 (http://ceos.org/document_management/Publications/Feasibility-Study-for-an-Aquatic-Ecosystem-EOS-v.2-hi-res_05April2018.pdf)