IOCS SESSION REPORT: EMERGING TECHNOLOGY FOR OCEAN COLOR

Chairs: Mike Twardowski and Griet Neukermans

Session goals: Discuss breakthrough technologies for ocean color, considerations in implementation, and associated potential for new applications in ocean color science. The focus of the session was not gaps in technology for ocean color, as this has been addressed in several recent papers and workshops.

Format: Emerging technology types were grouped into 3 categories: radiometry for cal/val, IOPs, and emerging imaging systems for ocean color. Session included at least one presentation from each technology group followed by discussion.

AGENDA	
09:30 - 09:35	Introduction to session. **Mike Twardowski** (HBOI-FAU)
09:35 – 09:50	Radiometric validation: HYPERNETS/WATERHYPERNETS next generation hyperspectral, multi-view validation system. **Kevin Ruddick** (RBINS)
09:50 – 10:00	Radiometric cal/val: HYPERNAV float. **Andrew Barnard** (SeaBird)
10:00 – 10:10	Radiometric cal/val: ProVal float. **Griet Neukermans** (LOV)
10:10 – 10:40	<u>Group Discussion</u>: Radiometric cal/val advances in support of OC missions
10:40 – 10:50	Inherent optical properties for validation: Hyperspectral bb sensor. **Wayne Slade** (Sequoia)
10:50 – 11:20	<u>Group Discussion</u>: IOP advances for validation for OC missions
11:20 – 11:35	The remote sensor and platform: A spatial light modulator imaging system for high altitude platforms. **Mike Twardowski** (HBOI-FAU)
11:35 – 12:05	<u>Group discussion</u>: Remote sensor and platform advances for OC missions
12:05 – 12:15	Summary and preparation of key messages

Summaries

The following points were made by the presenters:

Kevin Ruddick (RBINS)

1. AERONET for OC with seaprism instrument (multispectral) gives massive amounts of successful matchups
    a. Improvements needed to accommodate new satellite sensors such as Sentinel, LandSat (high spat. Res.) plus many more planned, some hyperspectral, multi-angle, polarized;
    b. Hyperspectral sensors on an AERONET OC type platform needed for spectral mismatches
2. Spectrometers are getting cheaper and smaller but not necessarily good data
3. Emerging radiometer system being developed at University of Tartu, Estonia
4. Removal of skyglint for above water radiometry also needs improvements, mainly related to polarization, and particularly waves (highest uncertainty, beyond the Cox-Monk model), sunglint flashes, skyglint does not come from only one direction, new modeling approaches -> idea: using multiple angles for pointing of the radiometers (panthyr system)
5. Panthyr system has been tested now and is robust and functional

Andrew Barnard (SeaBird)

1. HyperNAV: cal/val for PACE; hyperspectral (2nm), low noise
2. Radiance uncertainty: <4% in blue-green, 6% in red
3. 1 deployment off Hawaii, comparison with MOBY and MODIS data reveals problems in red wavelengths
4. Platforms for cal/val in remote ocean areas
5. Future work: long-term data uncertainties, assess repeatability, provide data for algorithm development and testing

Griet Neukermans (LOV)

1. ProVal: 2 sets of sensors for Ed and Lu, multispectral with chl+bb+CDOM
    a. Redundancy nice for uncertainty characterization
2. Self shading minor addressed in Monte Carlo computations
3. Drift over about 2 months was about 4%
4. Double digit matchups with OLCI
5. Next step: hyperspectral

Wayne Slade (Sequoia)

1. HyperBb: hyperspectral single angle backscatter, work in progress; LISST-VSF single wavelength multiangle scatter already commercialized
2. Move beyond the power-law spectral model for bb; with real measurements, 420-700nm, 135° scattering angle
3. Requires focusing and collimating optics (unlike, ECO-bb, bb-9), spectral linear variable filter moves linearly in front of transmitter and receiver
4. Status: lab characterization mid-April 2019 (characterization and validation with beads ongoing), takes ~10 seconds to do one scan; working on making it faster; prototype will be given to NASA this summer; commercial possible availability this year
5. LISST-VSF: 0.15-150° with linear polarization
6. Uncertainties related to the chi-factor, ambient light
7. Significant cost for specialized, complex sensor; will likely sell a small number of these instruments… how do we make a business model work?
    a. Should Sequoia pursue a centralized service model for hyperspectral bb where the community purchases the service (i.e., sensor accompanied by technician with expertise to collect high quality measurements) when these data are needed for field work?

Mike Twardowski (HBOI-FAU)

1. Fine spatial, temporal and spectral resolution is currently a critical gap for coastal areas: CubeSats have potential for addressing this gap
2. Developing CubeSat pushbroom-type imaging system with a digital micromirror device (DMD) that enables hyperspectral acquisition in a small form factor
3. Overcomes several issues with conventional CCD-based imaging systems, including SNR, interpixel nonuniformity, blooming/saturation effects over bright clouds and land, adjacency effects
4. Use of the DMD allows front end filtering to significantly reduce redundant data loading, resulting in far less data volume transmitted to the ground station; this is critical for cubesat sensors, as data transmission rates are currently ~1 Mbps. The US Navy tech demonstration division is developing optical communications that may increase that to ~120 Mbps.
5. High altitude long endurance (HALE) platforms: typically fly at 20km; these can be an airplane, linked-wing airplanes, balloons; these are new observation platforms having strong potential for ocean color science
6. Spectral resolution is adaptable, will be dependent on SNR
7. CubeSAT imager and platform are relatively cheap; need to pay for launch and for data transmission

Summary of Discussion for Radiometry

Besides the sensor systems presented, another emerging radiometric sensor system being developed is the MOBY-NET system, with focus on OC calibration for the NASA PACE mission. Another system that was mentioned was the Floating Ocean Optics Buoy (FOBY) developed in China by Liqiao Tian (Wuhan U), Zhaohua Sun (S. China Sea Inst. Of Oceanology), Qingjun Song (National Ocean Satellite Application Center), and Jun Zhao (Sun Yat-sen U) based on the approach of Lee et al. (2013) in blocking skylight glint with a cone.

The importance of consistent, rigorous, and transparent approaches to calibration and characterization of radiometric sensor systems being developed globally was emphasized. A key recommendation was for all groups to adopt the protocols for calibration and characterization detailed in the Zibordi and Voss draft NASA protocols document currently available on the IOCCG website. This document is currently undergoing a period of review by the community. Another recommendation was the necessity that detailed instrument specifications, characterization and performance results be published with peer-review for all systems. If these recommendations are met, then a centralized lab for calibration and characterization of all radiometric systems should not be necessary.

With the emergence of new radiometric cal/val assets for ocean color globally, the need for developing a coordinated strategy for global calibration and validation requirements was recognized. Radiometric assets for cal/val may soon include stationary buoys (MOBY-NET, BOUSSOULE), profiling floats (HyperNAV, ProVal), and stationary above-water systems (AERONET, HYPERNETS, WATERHYPERNETS), as well as more conventional boat deployed systems for in-water and above-water radiometry. Optimal calibration and validation strategies must be developed that balance numbers and locations of specific assets with practical considerations such as cost, who pays, and possibly international restrictions in mobilizing assets. Furthermore, optimal strategies will vary depending on specific science questions of interest and/or management applications.

Summary of Discussion for IOPs

Besides the scattering sensor systems presented by Slade from Sequoia, other emerging IOP sensors discussed included the multi-wavelength backscattering sensors recently commercialized by In-situ Marine Optics, Freemantle, Australia. These devices have larger dynamic range than WET Labs ECO sensors, with quantitative bb measurements possible in extremely turbid waters. It was also noted that servicing of existing ac devices from SeaBird/WET Labs was becoming increasingly sluggish and it is rumored these devices may be discontinued entirely in the near future, creating a potential issue with disappearing technology that is critical to our community.

A key topic of discussion was finding compatibility between the community’s need for increasingly complex, expensive instrumentation with extensive capabilities (i.e., hyperspectral, multi-angle, polarization, etc) and a viable business model for the companies willing to develop these sensors. If our market can only bear the sale of a handful of these sensors, conventional commercial sales will struggle to be profitable. One thought was to use a centralized business service model, where community-certified, high quality instrumentation with experienced technician and associated protocols are hired for field efforts from the company. This model would help ensure consistent, high quality measurements are being made within the community, and the market for providing the service may be large enough to actually be profitable.

Summary of Discussion for Remote Imagers and Platforms

The point was made there is no program at NASA focused on developing capabilities for Earth observing from cubesats. While programs such as INVEST sometimes use cubesats to test remote sensing technologies before deploying on a full mission, there is no program we are aware of where the pursuit of remote sensing from high altitude platforms (i.e., stratospheric drones and LEO cubesats) to enhance current measurement capabilities for cost-effective, quantitative science IS the mission. As a general comment, imaging technology is progressing to a point where high quality ocean color measurements may soon be possible on cubesat type platforms. These platforms may address a significant current gap in high spatial (~10 m), high temporal (~hourly) frequency measurements in coastal regions with hyperspectral capabilities. Such devices could also enhance data collection at the poles. Considering the cost-effective nature of these imaging systems and platforms and the potential for broad global coverage through a constellation of such systems – as well as conflicting/tenuous political support within the US for typical NASA style ~$1B global ocean color missions – such an approach may be worth investment, at least in parallel to the global type missions. In the future, if we were able to couple a cubesat constellation with the global missions, we would increase the range of spatial and temporal resolutions sampled while enabling cross-calibration of cubesat imaging technologies with the very high quality global imagers. And if there was a gap in the future in global class ocean color imaging, our community would still have a resource to continue ocean color research.

The potential of imaging from cubesats and high altitude platforms has been recognized within the European Space Agency, resulting in a new program initiated in 2018 call phi-lab, focused on “disruptive technologies” in Earth observing such as cubesats, high altitude long endurance (HALE) platforms, Earth observing sensors for these platforms, and emerging techniques for assimilating data from these emerging technologies for science applications. The US Office of Naval Research has also started a new program for development of Earth observing sensors for cubesats, and the technology demonstration division of the US Navy, SPAWAR, has a cubesat testing program and a new program to test HALE drone platforms. A recommendation is NASA should consider investing in these types of programs in the US.

While imaging technology for compact platforms is progressing, it was pointed out that the capability to provide ocean color imagery from these platforms of adequate quality to address key science applications has yet to be demonstrated. There is a chicken and egg argument here, as without support from the major space agencies such as NASA and ESA to develop and test such technology, such a demonstration is challenging. Other funding sources currently must be leveraged. As mentioned, US ONR is now supporting development of cubesat sensors for Earth observing. Also, the Hawkeye imaging system for cubesats (UNCW) is funded by the Moore Foundation.

Cubesat platforms come with reaction wheels for fine attitude adjustment, so multi-angle views through orbit are possible, as well as periodic platform rotation for moon calibration.

It was mentioned that liability insurance is needed to deploy cubesat platforms.

Cubesats are usually piggybacked on larger mission deployments, but this can still cost US$250K according to UNCW. The ESA phi-lab has offered cubesat deployment opportunities as well and there may be cheaper deployment options in the future.