Ocean Carbon from Space Workshop

Dissolved Organic Carbon from space

Session Summary:

Dissolved Organic Carbon (DOC) is ubiquitous in the ocean and represents a large carbon reservoir equivalent in size to the atmospheric CO_2 pool, and roughly two hundred times larger than that of marine biomass. Marine DOC is also a dynamic carbon component that fulfills important biogeochemical and ecological functions and connects terrestrial landscapes, freshwater and marine ecosystems and the atmosphere. Having the ability to continuously and accurately quantify DOC stocks and fluxes in the ocean is critical to our understanding of the global role of DOC and its susceptibility to change. In recent years, optical techniques and synoptic earth observations have opened new doors to achieve this objective on a global scale. The session on "Dissolved Organic Carbon from Space" provided an overview of current efforts aimed at improving our ability to detect DOC concentrations and its dynamics in the global surface ocean from ocean color remote sensing. Presentations and posters showcased the results of new approaches applied to ocean color (mainly empirical: e.g., linear regressions, artificial neural network algorithm, random forest classification, gradient boosting) to estimate DOC concentration in the global ocean using single or multiple regressors including remote-sensing reflectance, as well as remotely sensed CDOM absorption coefficients, sea-surface salinity, and chlorophyll-a concentration, and modelled mixed layer depth. Presentations also highlighted the limitations of current ocean color satellites and explained how upcoming geostationary satellites such as NASA Geostationary Littoral Imaging and Monitoring Radiometer (GLIMR) will provide the temporal sampling (e.g., hours) needed to facilitate the quantification of accurate DOC fluxes across the boundaries of the coastal ocean. Finally, presentations also highlighted the need for improved modeling of the processes regulating the relationship between DOC concentration and CDOM absorption coefficients in the ocean (e.g., photobleaching), which compromise our ability to retrieve DOC from ocean color.

Recommendations for the DOC workshop session:

The presentations and discussions carried out at the end of the session led to recommendations related to four different themes:

1. Temporal coverage of the coastal ocean: Accurate estimates of DOC stocks and fluxes in dynamic and heterogenous coastal environments are limited by the temporal coverage of

existing ocean-color satellites. Current satellites offer revisit times of about 5 times per week, at best. More appropriate revisit times for coastal waters would need to be an order of magnitude higher (e.g., 3-5 times per day) to facilitate the accurate estimation of DOC fluxes across the boundaries of coastal systems. Geostationary sensors such as the upcoming NASA GLIMR (Launch expected in 2027) will help address this issue in coastal environments of the continental USA and in targeted regions of coastal South America (e.g., Amazon River outflow, Orinoco River Outflow) by providing multiple observations per day, at ~300-m resolution. Reflectances from GLIMR will also be hyperspectral (10-nm resolution) across the UV-NIR range (340 -1040 nm) and will therefore provide the opportunity for improved accuracy of DOC concentration retrievals. We recommend continuing efforts towards deploying additional geostationary satellites to improve the temporal coverage of other coastal regions around the world.

2. Relationship between CDOM and DOC in the global ocean: The remote sensing of DOC in the surface ocean is facilitated by the detection of its optical proxy: chromophoric dissolved organic matter (CDOM). Specifically, the detection of DOC from space relies on the optical detection of CDOM absorption coefficients, $a_g(\lambda)$, from remote-sensing reflectance, followed by the estimation of DOC from $a_g(\lambda)$. Strong relationships between DOC concentration and $a_g(\lambda)$ have been observed repeatedly in the coastal ocean, where the dilution of terrigenous inputs exert a dominant control on dissolved organic matter dynamics. However, this relationship tends to be variable seasonally and across coastal systems. Furthermore, the dynamics of CDOM and DOC are largely decoupled in the open ocean, making the accurate remote sensing of DOC concentration challenging in much of the ocean. We therefore need an improved understanding and ability to constrain the relationship between DOC and CDOM absorption coefficients across the global ocean and seasons. We recommend the community work towards improving this understanding through a combination of the following efforts:
    1. Improved empirical approaches to constrain the variability between CDOM and DOC in the ocean: In river-influenced coastal systems, the spectral slope coefficient, $S_{275-295}$ has been shown to be a useful parameter to constrain the variability between CDOM and DOC. It has also been shown that this parameter can be retrieved empirically with reasonable accuracy from ocean color, therefore providing a means to improve DOC retrievals. In the rest of the ocean (e.g., open ocean, upwelling regions), however, the relationship between DOC and CDOM is less well understood can constrained. Future studies could look into developing similar approaches for other regions of the ocean.
    2. Improved mechanistic models of the processes regulating the relationship between CDOM and DOC: Recent efforts have been quantifying the effects of photobleaching on CDOM absorption coefficient spectra, which in turn, can improve our ability to constrain the relationship between CDOM and DOC in the global ocean. Similar efforts should be conducted for other processes such as the marine biological production of DOC. A quantitative understanding of these processes is also critical to understand the influence of climate-driven change on the relationship between CDOM and DOC.
    3. This effort could benefit from continuous efforts to acquire high-quality field measurements of DOC and CDOM across different seasons and marine environments. Many field data sets include measurements of CDOM absorption coefficients but lack DOC measurements. It should be noted, however, that while many labs have the

capability to measure CDOM, much fewer labs can measure DOC. Coordinated efforts should therefore be considered to ensure that CDOM and DOC are measured together as often as possible. We also recommend that these measurements are collected alongside comprehensive suites of inherent and apparent optical properties, biogeochemical properties, and subsurface measurements, to facilitate the development of improved algorithms

3. <u>Identification of DOC source and reactivity in the ocean:</u>
   It is often desirable to identify specific pools of DOC of different source and reactivity to better understand and quantify the cycling, fate, and impacts of DOC in the ocean. This is particularly true for the coastal ocean. Fluorescence excitation-emission matrix has often been used as an optical indicator of DOM origin and reactivity in in-situ samples. Here, we recommend the community puts efforts towards assessing whether the fluorescence of DOC/CDOM originating from specific sources (e.g., riverine, effluent) can have a measurable influence on remote-sensing reflectance. Upcoming hyperspectral sensors such GLIMR, PRISMA, PACE will provide improved signal-to-noise ratio, atmospheric corrections, as well as enhanced spectral information in the UV-visible range that could facilitate better detection of the fluorescence signature of certain pools of DOC/CDOM. Such efforts can be facilitated with radiative transfer simulations (e.g., Hydrolight). However, these simulations would require a better quantitative knowledge of the fluorescence quantum yield matrix of DOC/CDOM and how it varies with specific DOM sources.

   Active remote-sensing approaches based on laser-induced fluorescence could also potentially facilitate the sourcing of DOM in the surface ocean. Airborne laser-based measurements of DOM have been used in the past, but these only used a single excitation-emission wavelength pair and were used to specifically measure DOC. The use of multiple carefully chosen excitation-emission wavelength combinations could potentially help identify specific pools of DOM with unique fluorescence signatures.

4. <u>Sub-surface measurements of DOC:</u>
   The remote sensing of CDOM/DOC has been limited to surface measurements, and the variability of CDOM/DOC with depth is generally assumed or estimated using empirical approaches (e.g., neural networks) trained with field observations. In situ measurements from autonomous platforms like Bio-argo equipped with DOM-fluorescence sensors can provide valuable information about the depth-dependency of DOM in the ocean. Recently, projects such as AEOLUS COLOR (CDOM-proxy retrieval from aeOLusObseRvations), have focused on developing UV-lidar-based techniques to retrieve sub-surface information about CDOM in the ocean. The ESA AEOLUS mission is a UV-lidar (355 nm) mission originally designed for the retrieval of atmospheric properties, but the UV capabilities of this active sensor provides an opportunity to retrieve in-water properties of CDOM. We recommend that the community continue to explore original ideas to improve the detection of CDOM and DOC below the surface.