<u>Splinter Session 2</u>: Advances in Atmospheric Correction of Satellite Ocean-Color Imagery

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During the past decade major improvements to atmospheric correction of satellite ocean-color imagery have been made. They allow one to deal effectively with absorbing aerosols, sun glint, thin clouds, adjacency effects, and highly turbid waters, and to attach uncertainties to the retrieved marine reflectance. The proposed techniques do not rely solely on observations in the red and near infrared, the approach currently used for processing data from ocean-color missions, but include information from other spectral regions. Some techniques also exploit the bidirectional and polarization properties of sunlight reflected by the ocean-atmosphere system. The inversion is semi-empirical, physical, or statistical, and tools of various complexities are used, such as principal component analysis and neural networks. The session was organized to discuss the new techniques, including advantages and limitations, and their potential for operational processing of ocean-color imagery from next-generation sensors.

<u>Objectives</u>

- To review advances in atmospheric correction.
- To identify areas/issues that still need improvements.
- To examine whether planned sensors have the capabilities to exploit the advances and improvements.
- To discuss mechanisms to value/assess the new algorithms, in the context of operational processing and continuity versus innovation.

The session included three talks followed by a general discussion:

(1) Atmospheric correction over turbid waters (C. Jamet);
(2) Aerosol determination with emphasis on aerosol absorption (S. Bailey); and
(3) Atmospheric correction in the presence of Sun glint, thin clouds, and adjacency effects (R. Frouin).

<u>Recent Advances</u>

Many approaches have been investigated to account for non-negligible marine reflectance in the near infrared. They consider spatial homogeneity for the spectral ratio of the aerosol and water reflectance in the red and near infrared or for the aerosol type, defined in a nearby non-turbid area. They also use iteratively a bio-optical model, exploit differences in the spectral shape of the aerosol and marine reflectance, or make use of observations in the short-wave infrared, where the ocean is black, even in the most turbid situations.

Regarding aerosol determination, new aerosol models, based on observation of optical properties measured at island and coastal sites have been used. To deal with absorbing aerosols, spectral matching or spectral optimization methods have been proposed, that include information in spectral bands sensitive to aerosol absorption. In other methods, absorbing aerosols are detected by using a constraint on expected values of marine reflectance, and the set of aerosol models to choose from is selected accordingly. The coupling between aerosol absorption and scattering, which depends on viewing geometry, is also exploited to correct, using multi-angle observations, the spectral extrapolation to the visible of scattering properties observed in the near infrared.

New algorithms, in which the perturbing signal, smooth spectrally, is approximated by a low-order polynomial or a few eigenvectors, as well as powerful nonlinear regression techniques (e.g., neural networks), have shown great potential to deal with imagery contaminated by Sun glint, thin clouds, and adjacency effects. The inverse ocean color problem has also been investigated in a Bayesian context, with the solution expressed in the form of a probability distribution from which expected value and covariance can be computed. This provides not only an estimate of the marine reflectance, but also a measure of uncertainty.

<u>Question/Issues and Recommendations</u>

1. How significant are the advances? What aspects still require improvements: Aerosol model determination, bio-optical modeling in the near infrared, dealing with imagery gaps? What Strategy to adopt?

- The new techniques proposed are robust in situations of absorbing aerosols, Sun glint, thin clouds, and adjacency effects, generally ignored in the standard processing of ocean-color imagery, are robust, and their performance against in situ measurements is comparable to the performance of standard techniques. Retrieved marine reflectance under Sun glint and thin clouds exhibits continuity with adjacent estimates in clear conditions. Application of these techniques is expected to increase significantly the spatial coverage of ocean-color products. But further evaluation is necessary.

- Cloud screening (small clouds, shadows), often an issue in coastal waters, should be linked to atmospheric correction.

- Even with recent advances, large gaps still exist in ocean-color products. More attention/ effort should be placed by agencies on this problem –generating long-time series is not just lining up ocean color missions (e.g., combining observations and modeling).

- Aerosol model determination is useful to at least constrain the ill-posed inverse ocean-color problem, but errors may be too large to compute the perturbing signal with sufficient accuracy, i.e., it is desirable to estimate the perturbing signal more directly. Yet aerosol information is required for studies of aerosol/ocean interactions (e.g., iron fertilization).

- Aerosol altitude is an essential variable to compute atmospheric effects at ocean color wavelengths, especially in the presence of absorbing aerosols (but even if they are not absorbing).

- Absorption by hydrosols becomes important in the near infrared in the case of very turbid waters, and needs to be determined. Better bio-optical models in the near infrared are needed.

2. Do planned sensors have the capabilities to exploit the advances? What are the implications for future ocean color sensor/mission design?

- Planned sensors generally have the required spectral capability (measurements from ultraviolet to shortwave infrared), but it is recommended to complement spectral measurements by multi-angular and multi-polarized instruments, at least to constrain the range of possible solutions. Also high spectral resolution is recommended in specific spectral regions, such as the oxygen A-band. Measuring NO_2 is definitely needed to perform accurate atmospheric correction in coastal zone.

- Synergy between instruments/missions should be considered, in particular OLCI (visible NIR) and SLSTR (SWIR) (1b or 1c co-registered).

- New techniques suggest sensors should not saturate over Sun glint and clouds, and that it may not be necessary to tilt them, but strategy should keep continuity while allowing improvements based on gained knowledge.

3. How to value the new techniques? Are they mature enough for operational processing? How to integrate advances and new capabilities for climate change detection?

- Efforts should be made by space agencies to make the new techniques more visible and accessible, e.g., via inter-comparison activities, implementation in SeaDAS for evaluation/feedback, etc. (requires resources and dedicated programs).

- Parallel processing lines with standard and improved schemes, that may be targeted to specific products in view of accuracy, may help to understand advantages and limitations of individual techniques and define the quality of final products and allow for continuity. This approach should be considered by space agencies to maximize the investment made in the development of new techniques and to yield more accurate ocean-color products. Yet, several processing lines may be confusing to users.