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Validation of Satellite-Derived Ocean Color: Theory and Practice

Sean W. Bailey, P. Jeremy Werdell[2], and Charles R. McClain[3]

Futuretech Corporation, Greenbelt, Maryland, USA
[2] Science Systems and Applications, Inc., Lanham, Maryland, USA
[3] NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

INTRODUCTION:

Satellite validation is the process of determining the spatial and temporal errors of a given biological or geophysical data product, including the development of match-up data sets, i.e., field observations and satellite data coincident in time and location. The primary objective of NASA's Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) Project is identifying biases between similar products generated by various ocean color missions. The utility of satellite ocean color data is strongly dependent on the validation of these data. The temporal and spatial scales of the phenomena being measured by a satellite-borne sensor, along with the resolution of the sensor, must be considered when trying to validate a data product using single in situ measurements. Once these issues are satisfactorily addressed, the benefits of satellite validation activity can be realized.

These benefits include:

1) Provide a measure of accuracy to satellite derived products to lend confidence in their scientific utility;

2) Identify conditions, either oceanic, atmospheric, or satellite specific, for which satellite derived products are invalid; and

3) Provide a consistency check to ensure that satellite calibration is correct, and to monitor long-term stability of satellite measurements.

THEORY:

The basic concept of satellite validation is quite straightforward: compare coincidentally collected satellite and *in situ* measurements. There are a number of considerations that must be taken into account in order to realize this concept. These can be categorized as satellite-, measurement-, or environment-specific.

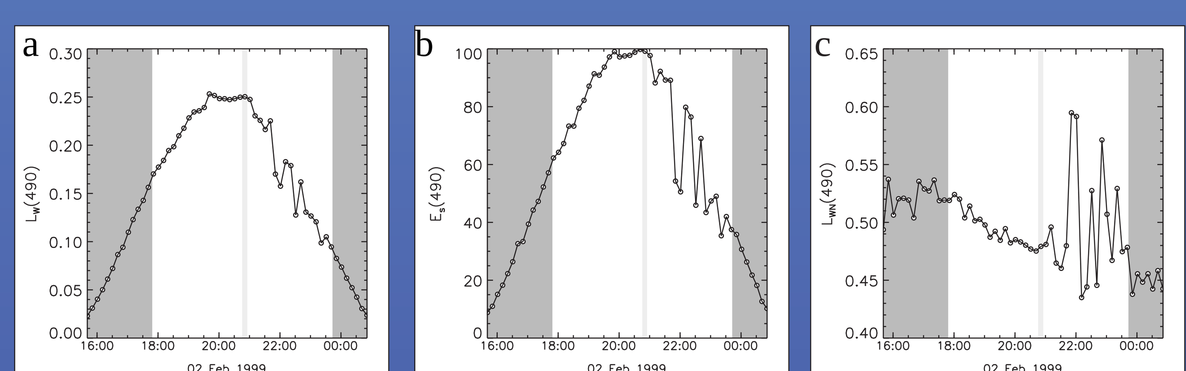

Figure 1: An example data set illustrating validation time dependent effects. These data were collected on 02 February 1999 by a Monterey Bay Aquarium Research Institute (MBARI) mooring situated at the mouth of Monterey Bay, CA. The shaded regions indicate data collected outside a +/- 3-hour window of the SeaWiFS overflight (indicated by the shaded bar at 20:50 hrs). a) Lw at 490nm, b) Es at 490nm, c) nLw at 490nm. Panel c shows that for this day, *in situ* calculated nLw's can vary by as much as 10% (ignoring outliers due to passing clouds) in the 6-hour window typical of a validation analysis.

Acknowledgments:

We would like to acknowledge Dr. Francisco Chavez of MBARI for the use of the mooring data shown in Figures 1 and 4, and Dr. William Balch, David Drapeau, Bruce Bowler, Amanda Ashe, Emily Scally, and Joaquim Goes of Bigelow Laboratory for the along-track data presented in Figure 3. We would also like to acknowledge all the SeaBASS archive contributing investigators whose data may (or may not) be depicted in the validation results shown in Figure 5. Without dedicated researchers like these, a comprehensive global satellite validation activity could not exist.

Satellite-specific:

1) *Resolution* - The spatial and temporal resolutions of a satellite-borne sensor needs to be considered when evaluating validation results.

2) *Pixel averaging* - The 'box' used for determining the satellite retrieval can range from a single pixel to a full scene. Increasing the box size may reduce noise, but at the same time reduces the effective resolution of the sensor.

3) *Algorithms* - An important concept for consideration when making comparisons for the sake of validation is that the satellite product being evaluated is a derived product. An understanding of the algorithms involved in the retrieval of the satellite product is essential.

3) *Comparability* - Differences in the quantity measured by an *in situ* instrument and that derived by satellite observations need to be considered. For example, an in situ radiometer may measure upwelled radiance at 488nm with a 10nm band pass, while the satellite sensor measures 490nm with a 20nm band pass.

Measurement-specific:

1) *Measurement accuracy* - While in situ measurements are sometimes referred to as 'ground' or 'sea' truth measurements, they rarely provide absolute truth. The errors associated with an in situ measurement must be adequately characterized and considered when evaluating validation results.

2) *Coincidence* - The applicability of an in situ measurement towards validation of a satellite product strongly depends on the time the measurement was collected relative to the time the satellite imaged the *in situ* location. The acceptable time difference is dependent on the stability of the geophysical parameter being compared (Figure 1).

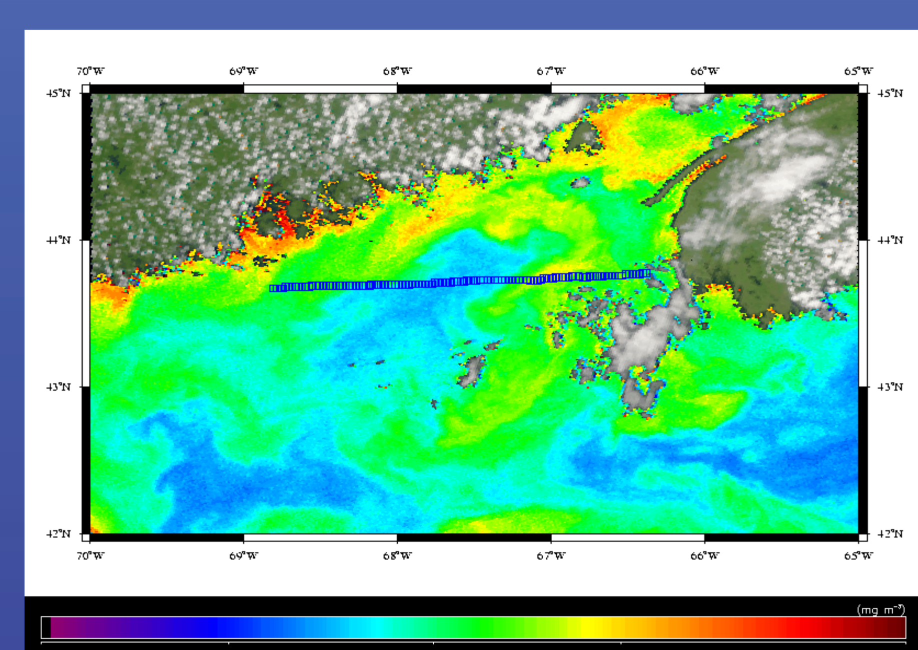

Figure 2: SeaWiFS image of the Gulf of Maine on 20 June 2000. The blue line is transect of flow-through data measured by Bigelow Laboratory. Notice that just past the midpoint of the transect, the cruise tracks along a chlorophyll frontal region.

Environment-specific:

1) *Phenomenal scales* - When validating remote sensors with *in situ* measurements, it is possible to overlook the difference in the scales of what is measured. The phenomena to be most cognizant of are those that fall in scale between what is measured by the *in situ* instrument and those measured by the satellite sensor (Figures 2 and 3).

2) *'Out of Bounds' conditions* - Atmospheric correction algorithms, sophisticated as they are, cannot account for all environmental conditions which may be encountered. The limitations of the algorithms need to be understood, and environmental conditions need to be known, so that validation results can be interpreted correctly.

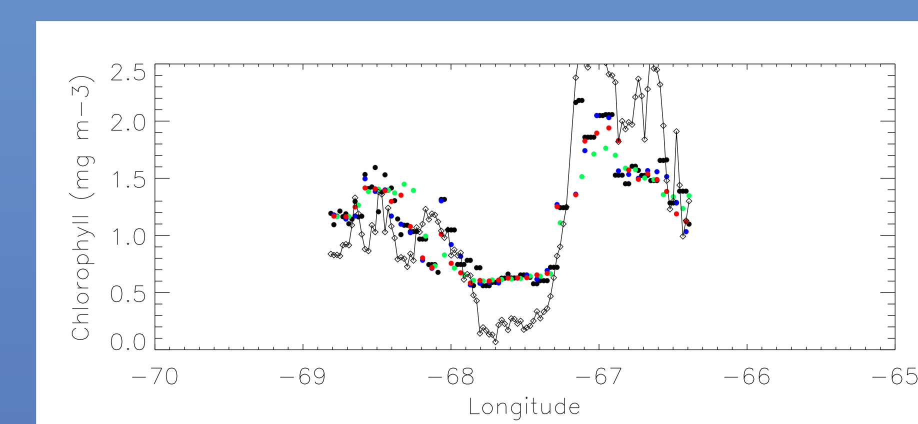

Figure 3 : Plots showing in situ and satellite-derived chlorophyll for each point along the transect line in Figure 2. The solid black line with diamond points are the in situ data. The circles are the satellite data; black for the corresponding pixel, green for a 3x3pixel box, red for a 5x5 pixel box, and blue for a 7x7 pixel box. Notice that the size of the box chosen can affect the resulting validation matchup, particularly for dynamic regions.

PRACTICE:

Gathering data:

In order to validate a satellite data product, *in situ* data must be available. To facilitate the validation process, the SIMBIOS project, in conjunction with the SeaWiFS Project, has developed a database of radiometric and phytoplankton pigment data, and other oceanographic and atmospheric data: the SeaWiFS Biooptical Archive and Storage System (SeaBASS).

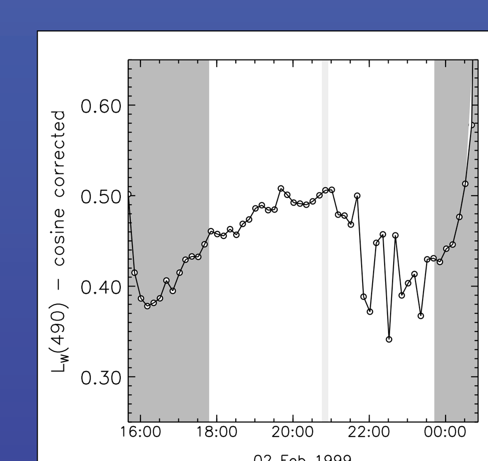

Figure 4: Data from Figure 1 are replotted after normalization to the cosine of the solar zenith angle. This figure illustrates that even with cosine normalization, considerable roll-off can occur in water-leaving radiances outside a ±2.5 hour window of local noon.

Spatial/Temporal match:

Once the data sets are in hand, the *in situ* data need to be matched to the corresponding satellite data both spatially and temporally. The spatial match is straightforward. Determine whichpixel in the satellite image matches the *in situ* location. The data within a predetermined box around the matched pixel are then extracted. A sensitivity study on a set of nearly 250 in situ points demonstrated that an acceptable box size is 5x5 pixels (assuming ~ 1km resolution). An acceptable time difference for radiometric measurements has been determined to be ±2.5 to 3 hours (Figure 4).

Exclusion criteria:

Taking into consideration the theoretical basis of validation addressed earlier, a number of exclusion criteria have been determined to be necessary for a meaningful validation. These include:

1) *Minimum number of valid pixels:* At least 50% of the non-land pixels in the defined 5x5 box must be unflagged. The following flags (or their equivalent) considered are:

Land
Cloud/Ice
Sun glint
Stray light
Shallow water
Turbid water
High aerosol concentration
Atmospheric correction algorithm failure
Product algorithm failure / algorithm out-of-bounds
Large satellite zenith angle
Large solar zenith angle

2) *Duplicate in situ data reduction:* Duplicate measurements are reduced either by elimination or averaging. This includes along-track measurements where a number of measurements may be taken within the footprint of a single satellite pixel or match-up 'box'.

3) *Large coefficient of variation:* Satellite matchups with a large variation between pixels in the defined box are eliminated from consideration. This ensures that frontal regions or other anomalies (e.g., cloud edge effects) do not bias the validation results.

The validation technique described here has been successfully applied to SeaWiFS, OCTS, MOS and MODIS (Figure 5).

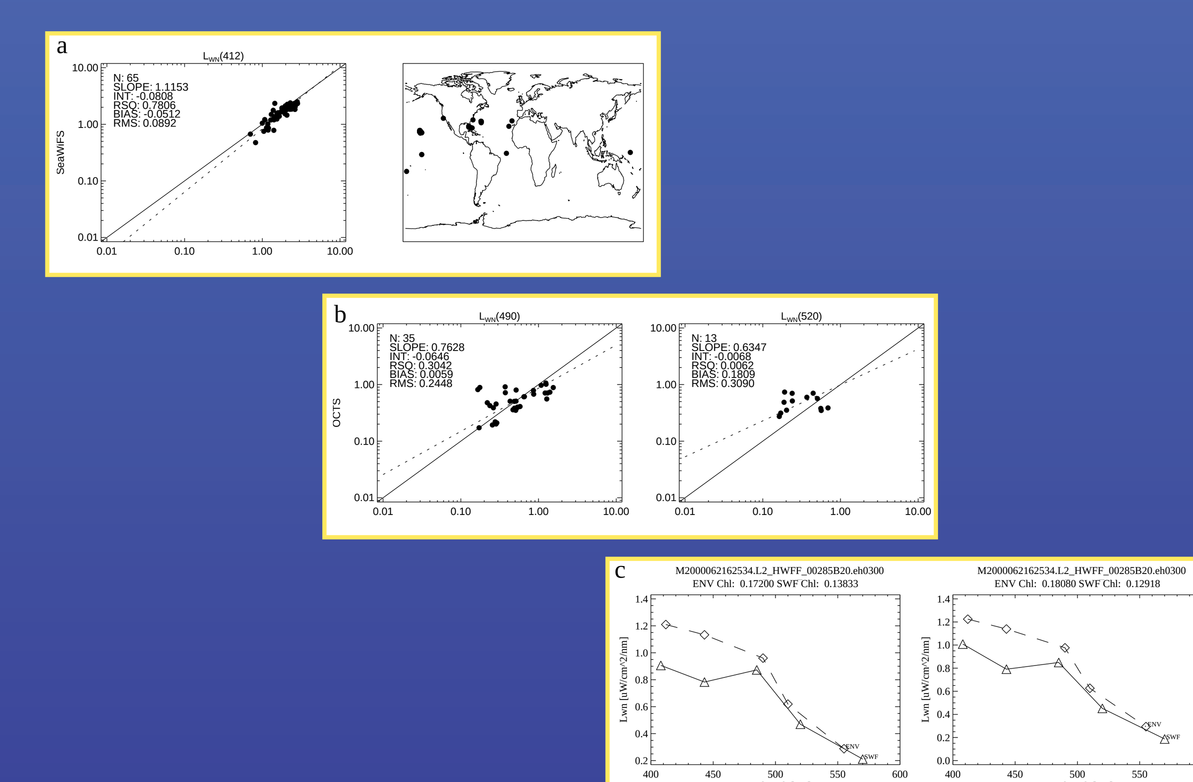

Figure 5: Validation results from various satellite sensors: a) SeaWiFS - global validation results with map, b) OCTS - global validation results and c) MOS - spectral comparison validation.