Validation of Satellite-Derived Ocean Color: Theory and Practice

Sean W. Bailey, P. Jeremy Werdell², and Charles R. McClain³

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 accuracy of all ocean color products. The increasing temporal and spatial redundancy of ocean color measurements over the past decade has led to an explosion of interest in the validation of ocean color products. The need for a principled, systematic approach to validation is clear. The primary objectives of validation, relative to the generation of ocean color products, are: (1) to evaluate the performance of ocean color products generated by various instruments or derived algorithms; (2) to compare the spatial and temporal scales of the phenomena being measured by a satellite sensor with those of similar measurements taken in situ at the same time and location; (3) to determine if the satellite measurements can be atmospherically corrected and if so, what are the assumptions and uncertainties associated with this process; and (4) to demonstrate, through comparison of in situ measurements and satellite images, that a particular pixel in the satellite image can be correlated with a particular pixel in the in situ measurement (i.e., that the in situ measurement was in fact taken in the footprint of the satellite image).

The primary objectives of validation are best met through the use of a systematic validation methodology. The key components of this methodology include: (1) the development of a comprehensive database of in situ measurements; (2) the selection of in situ measurements that are coincident and comparable to satellite measurements; (3) the development of rigorous validation techniques; and (4) the implementation of a systematic validation methodology.

Satellite validation requires a comprehensive database of in situ measurements. The database should include measurements of ocean color at a range of scales, from point measurements to large-scale surveys. The database should also include measurements of ocean color at a range of times, from real-time measurements to long-term time series.

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THEORY:

The basic concept of satellite validation is quite straightforward: compare simultaneously collected satellite and in situ measurements. However, there are a number of considerations that must be taken into account in order to realize this concept. These can be categorized as satellite-specific, measurement-specific, spatial/temporal match, and in situ-specific.

Measurement-specific:
1. Accuracy: While in situ measurements are sometimes referred to as reference measurements, they rarely provide absolute truth. The errors associated with in situ measurements must be adequately characterized and understood when evaluating validation results.
2. Convenience: The applicability of in situ measurements towards validation of a satellite product strongly depends on the time the measurement was collected relative to the time the satellite image was acquired. The acceptable time difference is dependent on the stability of the phytoplankton primary productivity.

Spatial/temporal match:
1. Coincidence: Satellite and in situ measurements must be coincident in time and location. The primary objective of validation is to compare the spatial and temporal scales of the phenomena being measured by a satellite sensor with those of similar measurements taken in situ at the same time and location. The primary objective of validation is to compare the spatial and temporal scales of the phenomena being measured by a satellite sensor with those of similar measurements taken in situ at the same time and location.

In situ-specific:
1. Measurement accuracy: Absolute truth. The errors associated with in situ measurements must be adequately characterized and understood when evaluating validation results.
2. Spatial/temporal match: Satellites and in situ measurements must be coincident in time and location.

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 located at the mouth of Monterey Bay, CA. The shaded region indicates data collected outside a ±2.5-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 SLw/a can vary by as much as 10% (depending on weather due to passing clouds) in the 6-hour window typical of a validation analysis.

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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 front region.

Figure 3: Plots showing in situ and satellite-derived chlorophyll for each point along the transect in Figure 2. The solid black line with diamonds are the in situ data. The circles are the satellite data, black for the corresponding pixel, green for a 3x3 pixel 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 match, particularly for dynamic regions.

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 rolloff can occur in water-leaving radiance outside a ±2.5 hour window of local noon.

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.