Evaluation of Satellite Ocean Color Data Using SIMBADA Radiometers

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The SIMBADA Project

-Originally developed by LOA, University of Lille to evaluate POLDER-derived ocean color.

-Requirements included (1) quality measurements of the basic ocean color variables, (2) low cost, and (3) capability to collect sufficient data in a wide range of environmental conditions (i.e., over the global oceans).

-This led to the SIMBAD/SIMBADA radiometer concept.

The SIMBADA Radiometer

-Portable, compact, hand-held instrument that can be operated from fixed and moving platforms at sea (e.g., ship does not need to stop).

-Measures both marine reflectance and aerosol optical thickness in spectral bands approximately 10 nm wide centered at 350, 380, 412, 443, 490, 510, 565, 620, 670, 750, and 870 nm.

-Advanced version of the SIMBAD radiometer (5 spectral bands).

-Aerosol optical thickness is obtained by viewing the Sun, and marine reflectance by viewing the ocean surface at a nadir angle of 45 degrees and a relative azimuth angle of 135 degrees.

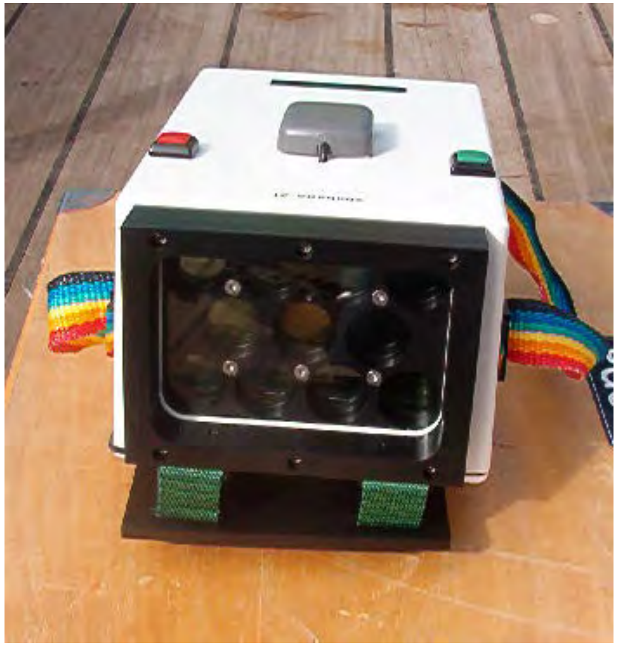
-The measurements are made through a vertical polarizer which, when viewing the surface, reduces substantially sunlight reflected in the instrument field-of-view (Fougnie et al., 1999; Deschamps et al., 2004).

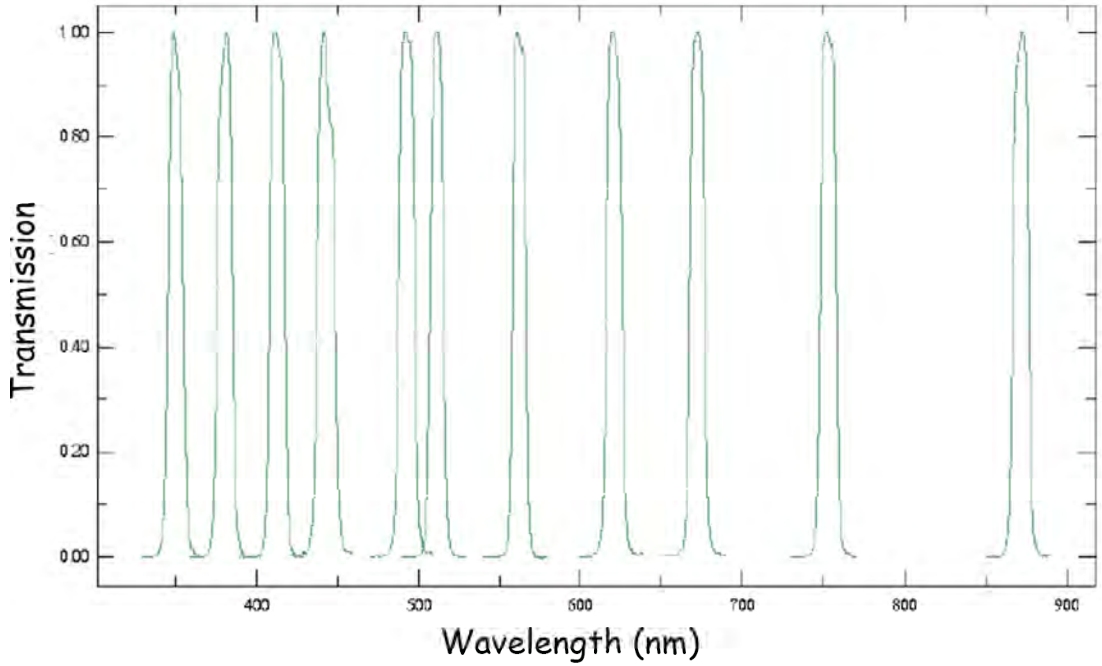
-Same optics and detectors but different electronic gains are used in Sun- and ocean-viewing modes. Field-of-view is 3 degrees.

-Measurements are made simultaneously in all the spectral bands (one collimator and detector for each band), but viewing the Sun and the ocean surface is accomplished sequentially. Frequency of measurements is 10 Hz.

-Data is only collected in clear sky situations, i.e., when satellite ocean-color retrievals are made.

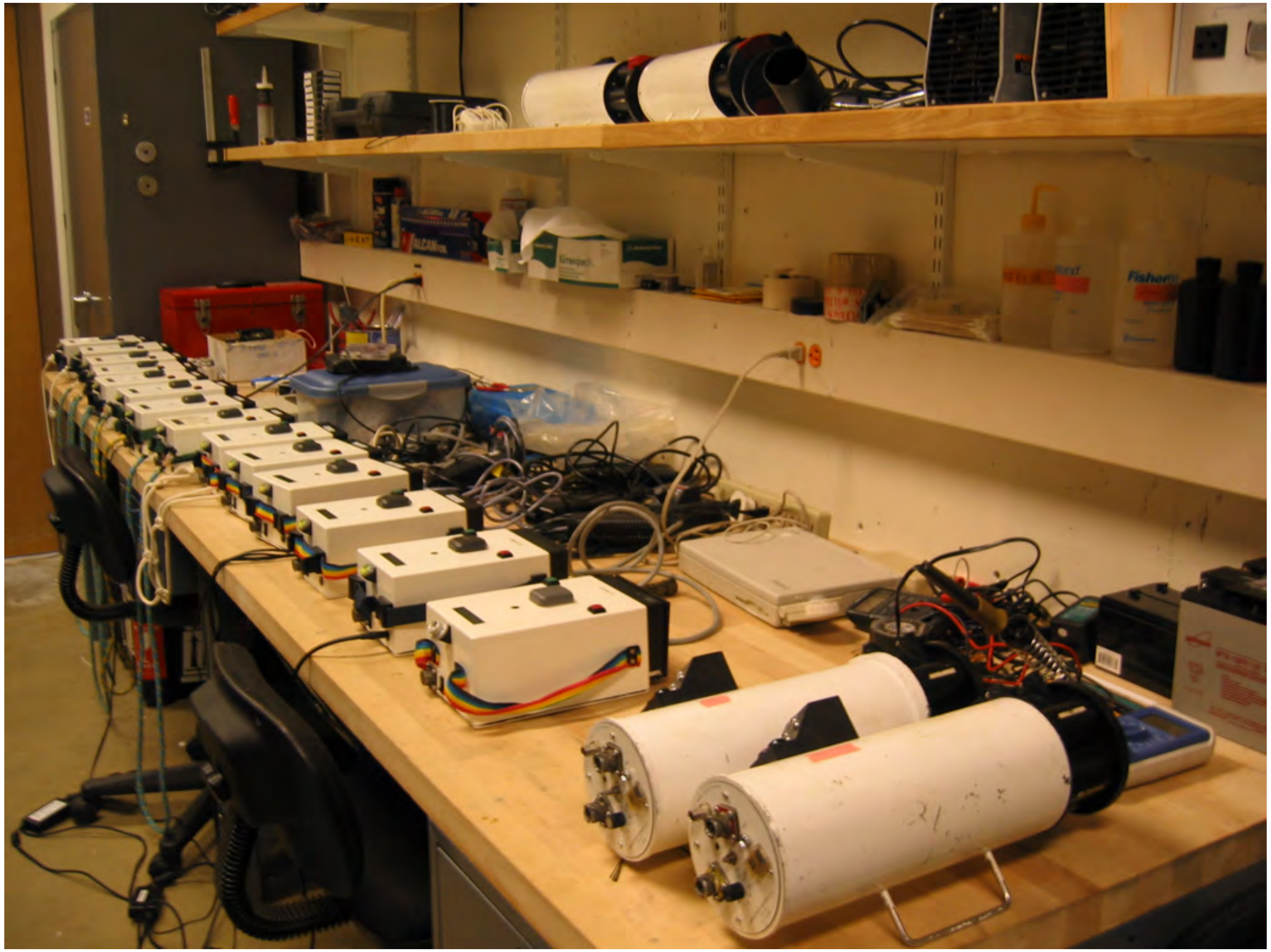
-The instrument also acquires data on viewing angles (inclinometer, magnetometer) and internal control parameters, i.e., time, geographical location (GPS), temperature, and atmospheric pressure.





The SIMBADA radiometer and its spectral bands.

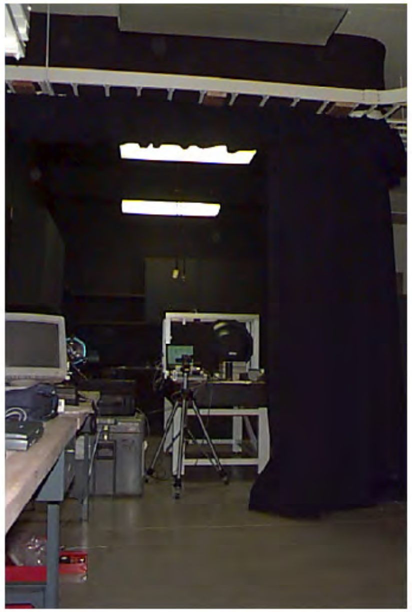
-25 radiometers were built and used to collect hundreds of data sets during research cruises of opportunity and merchant ship voyages.

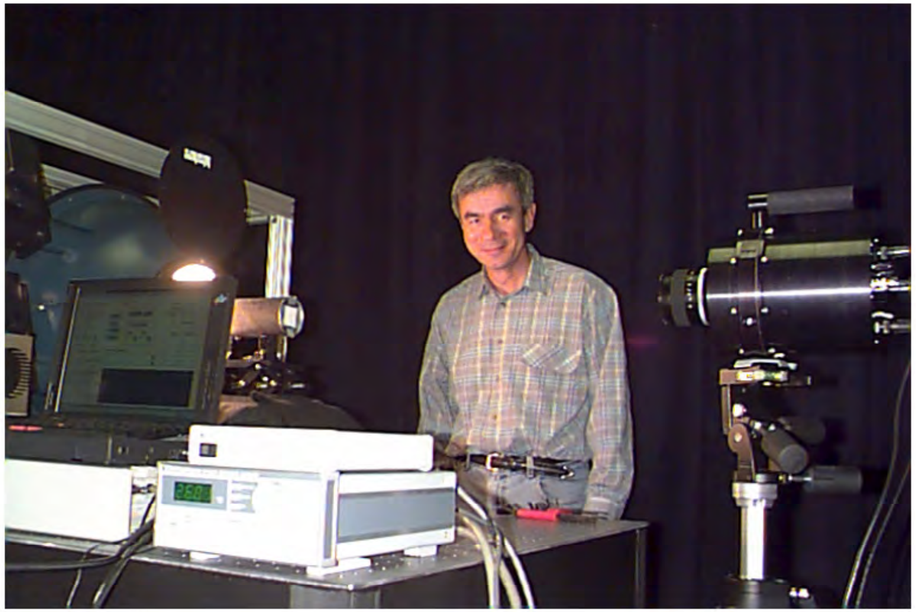


SIMBAD and SIMBADA radiometers at the Scripps Institution of Oceanography.

Radiometric Calibration

-Radiometric calibration of the instrument, including characterization of noise and detector linearity, is performed using a 0.5 m diameter integrating sphere with a 0.2 m aperture. Illumination is achieved by two (internal and external) tungsten lamps and one (external) Xenon lamp. Attenuators allow for variable radiance levels. Stability is better than 1%.

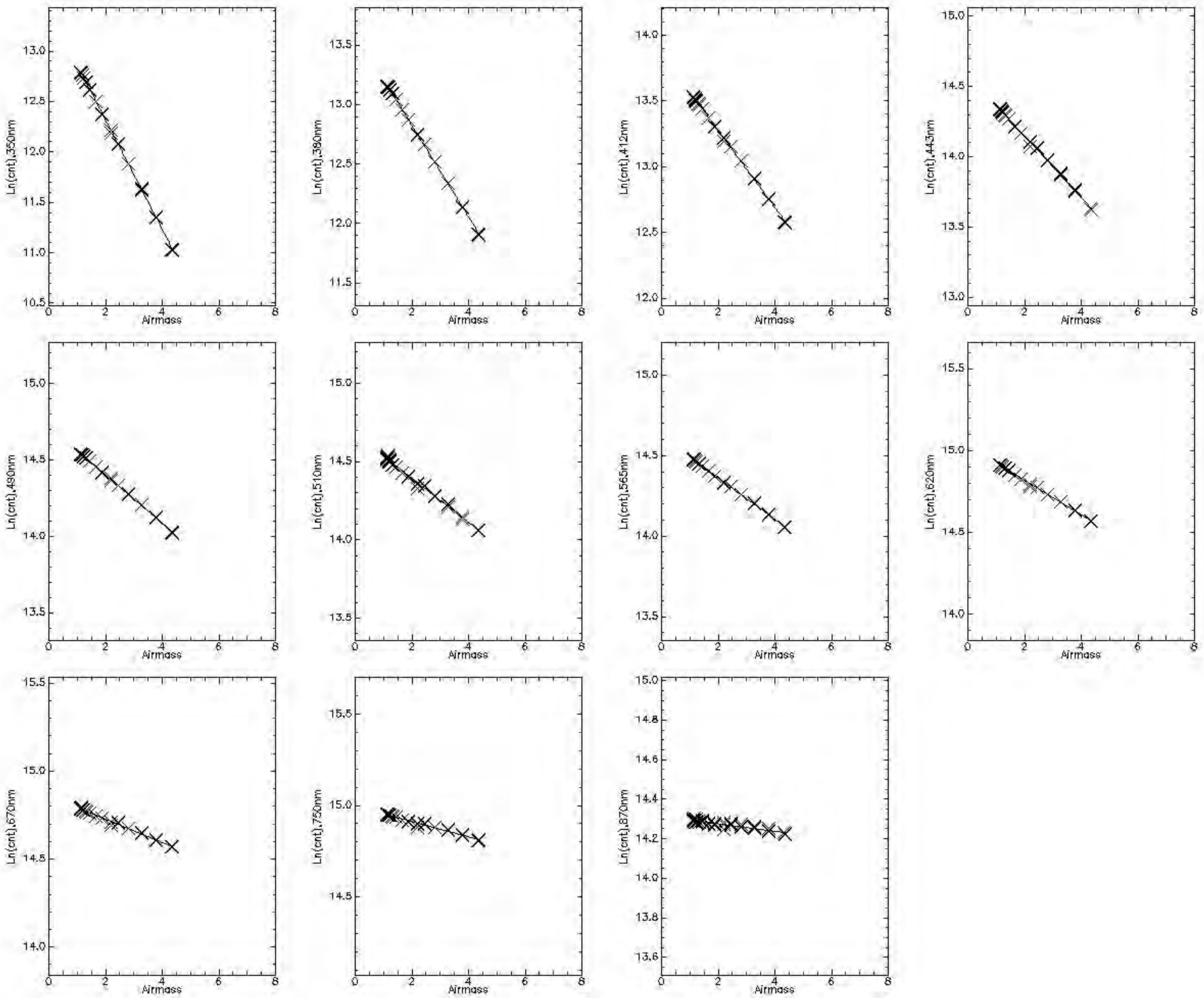




(Left) SIO radiometric calibration facility. (Right) Integrating sphere and NASA SXR-II transfer radiometer.

-The integrating sphere can only be used to calibrate the SIMBADA radiometer in ocean-viewing mode (high detector gain), because its radiance is too low for measurements in Sun-viewing mode (low detector gain).

-The calibration in Sun-viewing mode is performed in the field, on top of Mount Laguna (Stevenson's peak, 1896 m), California, using the Bouguer-Langley method.



Example of Bouguer-langley plot obtained at Stevenson's peak for SIMBADA No. 25.

Data Processing

-Processing the raw SIMBADA data into aerosol optical thickness and marine reflectance involves a number of steps and corrections (Deschamps et al., 2004; Bécu, 2004).

-The passage to aerosol optical thickness, which only uses the highest numerical counts, is straightforward. The vertical polarizer has minimum influence since direct sunlight is not polarized.

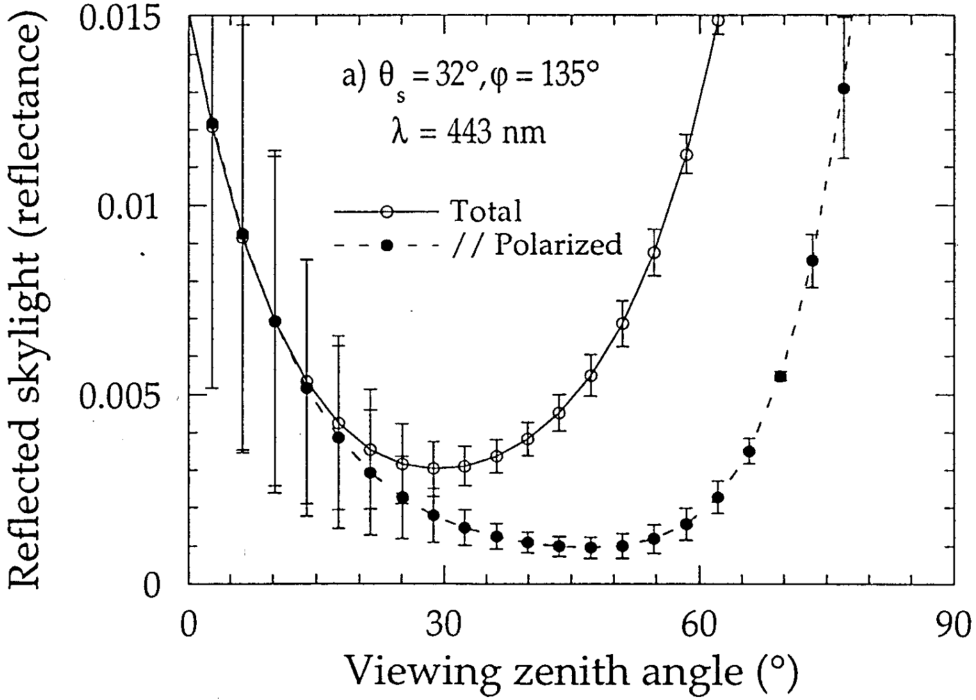
-For marine reflectance, the numerical counts, after subtraction of the dark signal, are transformed into radiance (using the calibration coefficients for ocean-viewing measurements) and reflectance (using an estimate of the downward solar irradiance).

-Downward solar irradiance is calculated as a function of solar zenith angle, aerosol optical thickness (determined from the SIMBADA measurements), and ozone amount (obtained from satellite data), which is accurate for cloudless skies.

-Only ocean surface measurements made within ±5 degrees of 45 degree nadir angle are kept, and the smallest values over a series of measurements (i.e., 100 measurements in 10 seconds) are selected.

-A correction is made for the residual skylight (the surface is not completely flat), as a function of aerosol optical thickness and type (i.e., Angström exponent), and wind speed.

-This correction, in terms of reflectance, is typically 0.0007 at 350 nm and 0.00005 at 870 nm.



Simulations of skylight reflectance (total and polarized) at 443 nm.

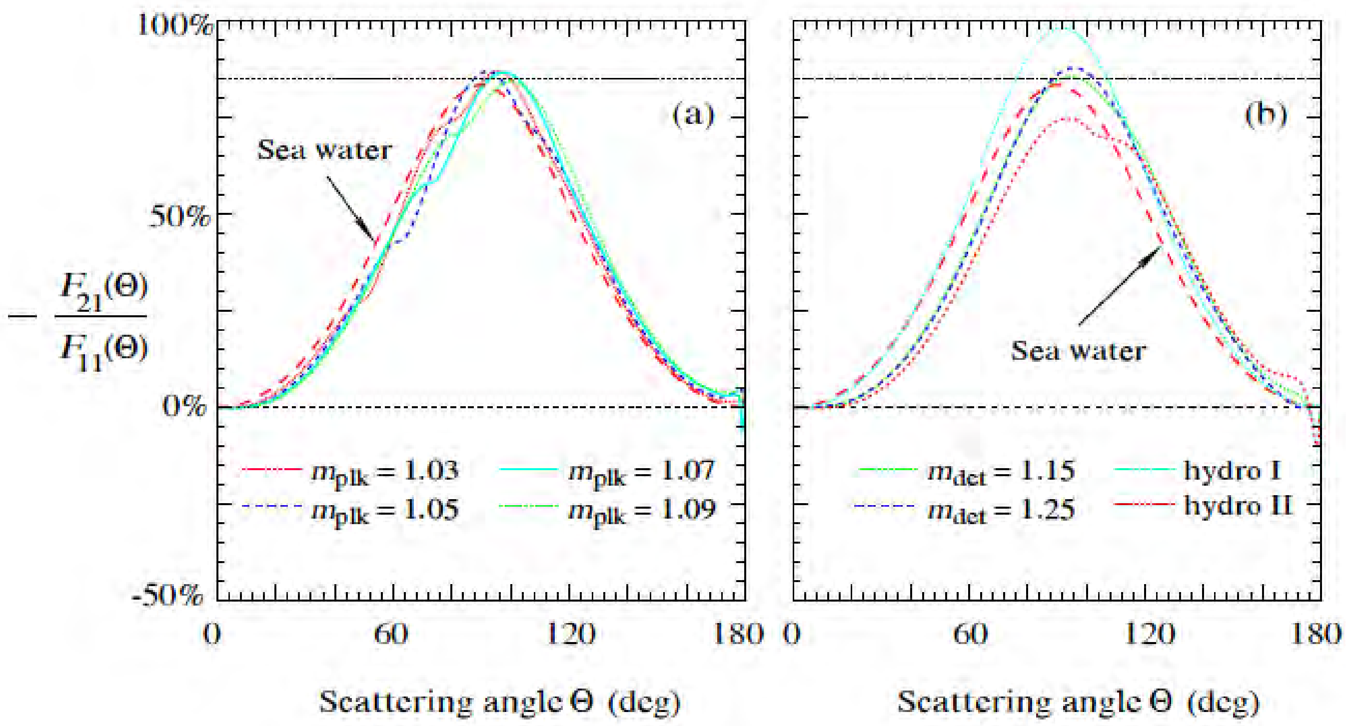
-To account for eventual contamination by whitecaps, ship reflection, (i.e., other perturbations than reflected skylight), the reflectance at 870 nm is subtracted from the reflectance in the other spectral bands.

-This assumes that the water body reflectance is null at 870 nm (a good assumption, except in very turbid waters), and that the contamination does not depend on wavelength.

-This correction is not performed when the raw reflectance at 870 nm is above 0.004. Beyond this threshold, the data are discarded.

-Finally, the polarized reflectance values are transformed into total reflectance, which includes correcting the measurements for polarization by water molecules and particles.

-The correction, relatively small at the scattering angles of interest, typically 150 degrees below water (degree of polarization is less than 15%), is performed assuming that the water body contains only molecules.



Degree of linear polarization for single scattering of unpolarized light (Chowdhary et al., 2007).

-Final marine reflectance is generally close from the raw reflectance (i.e., perturbing effects are small).

-Uncertainty budget for marine reflectance: ±0.0015 to ±0.0010 (ultraviolet to blue), ±0.0004 (green), ± 0.0002 (red).

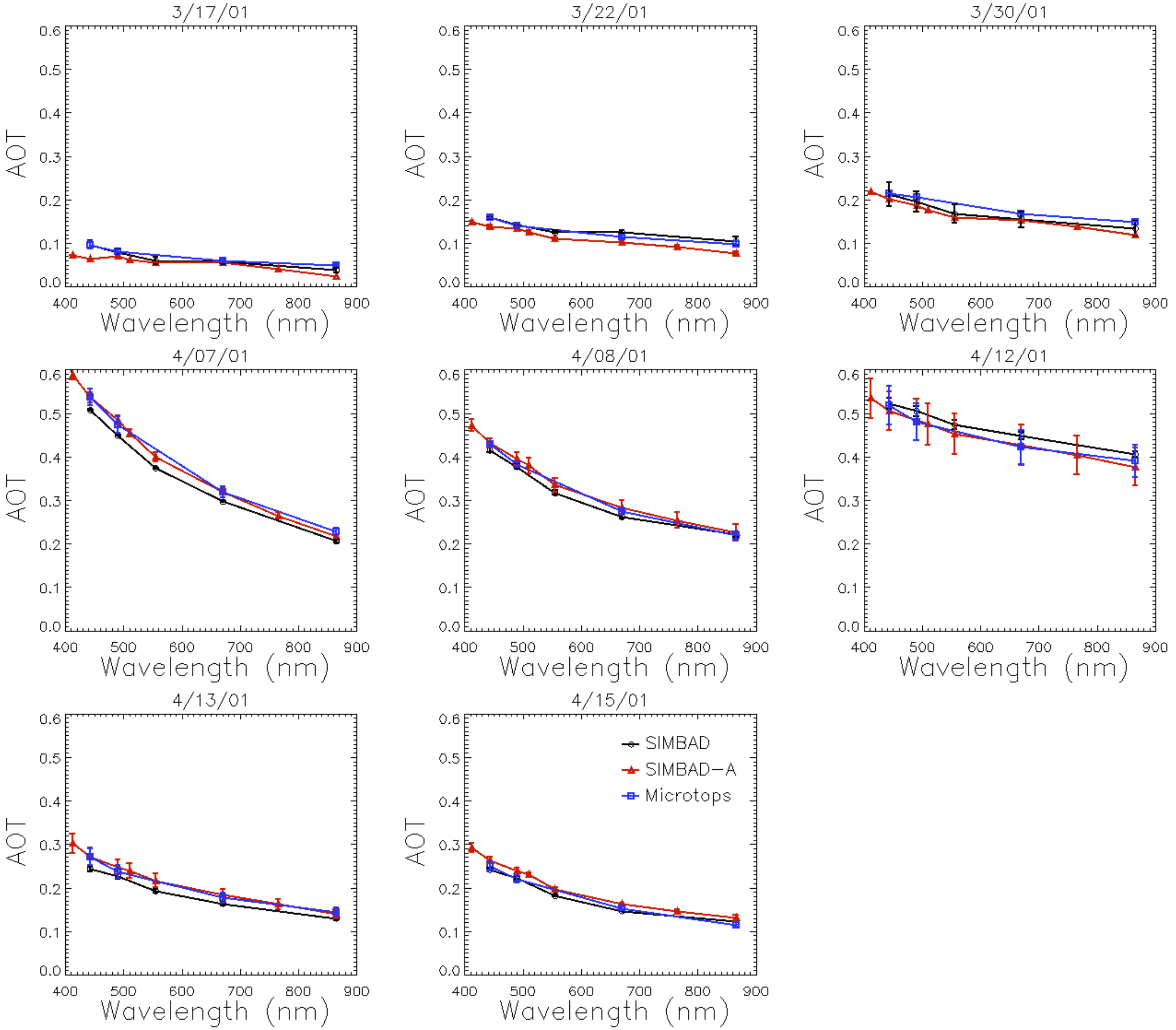
-Uncertainty budget for aerosol optical thickness: ±0.02 (ultraviolet to green), ±0.01 (red to near infrared)

Experimental Verification

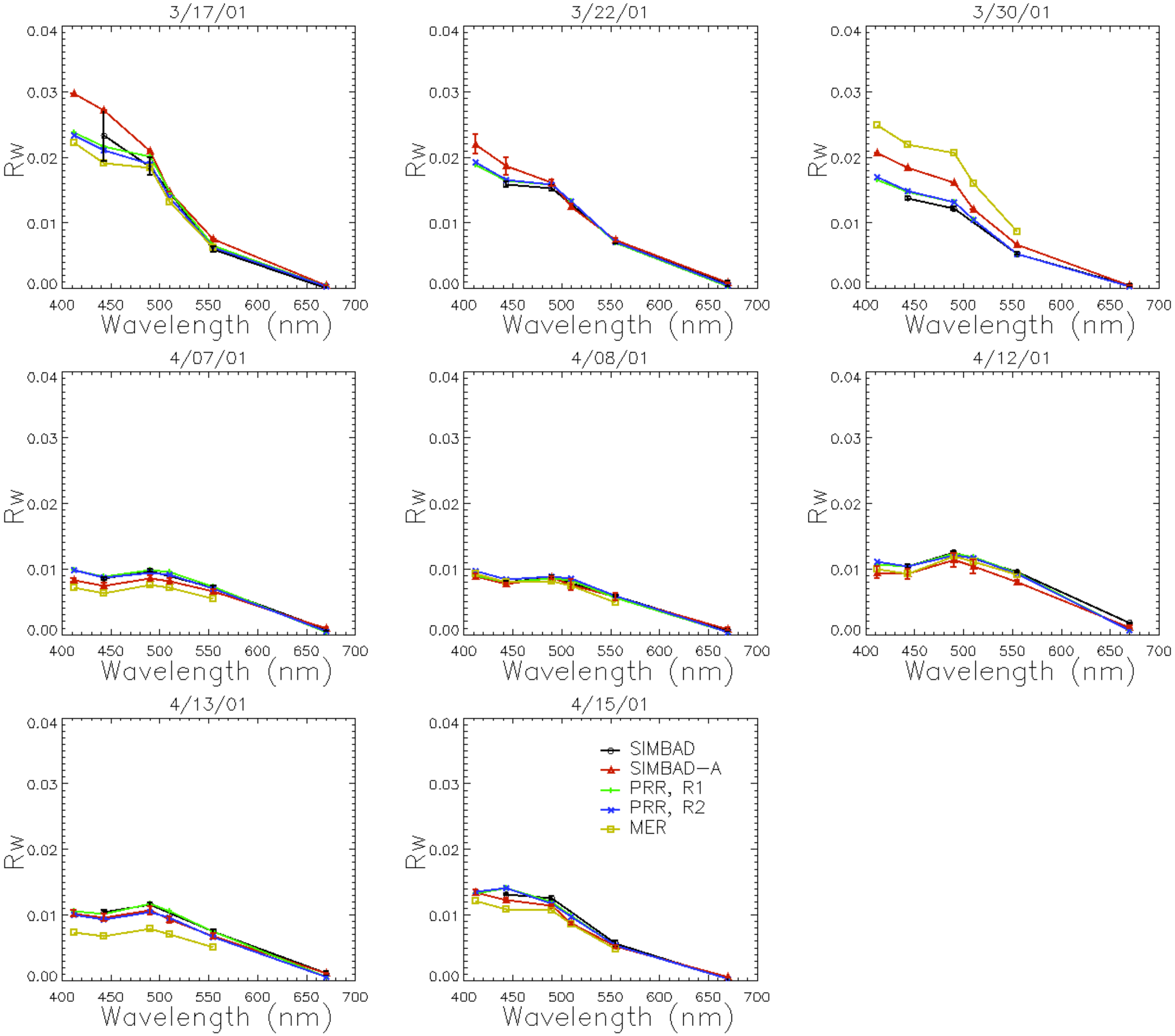
-The theoretical accuracy of the SIMBADA measurements has been evaluated experimentally in comparisons with measurements from other instruments, acquired during various campaigns.

-Such measurements were made during ACE-Asia in the Northwest Pacific Ocean and Japan Sea (March-April 2001), AOPEX in the Mediterranean Sea (July-August 2004).

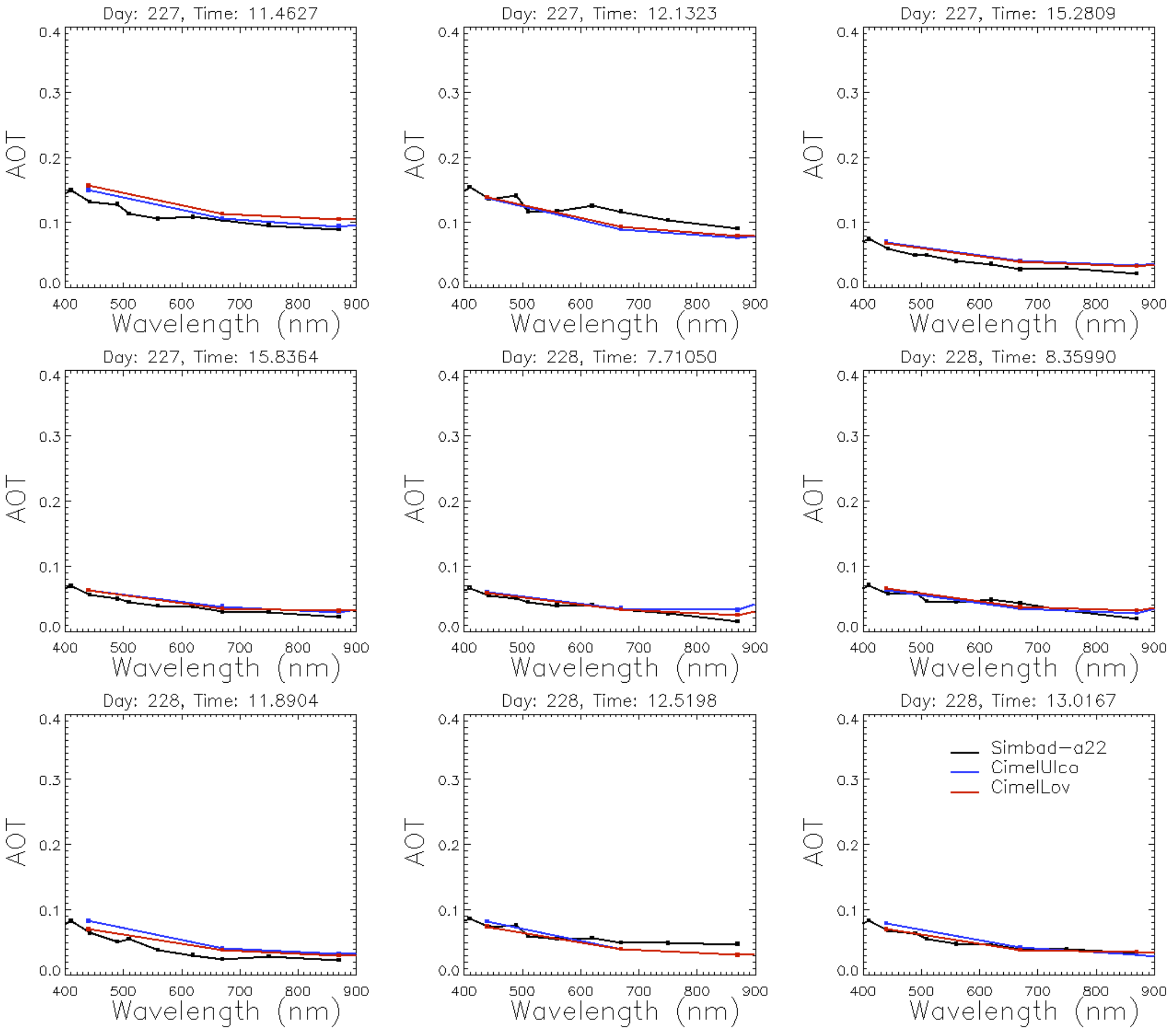
-Q factors (Morel and Mueller, 2003) were used, with the relevant geometry and chlorophyll concentration measured from filtered samples (HPLC, fluorometry), to transform, when applicable, the marine reflectance measurements into nadir values.



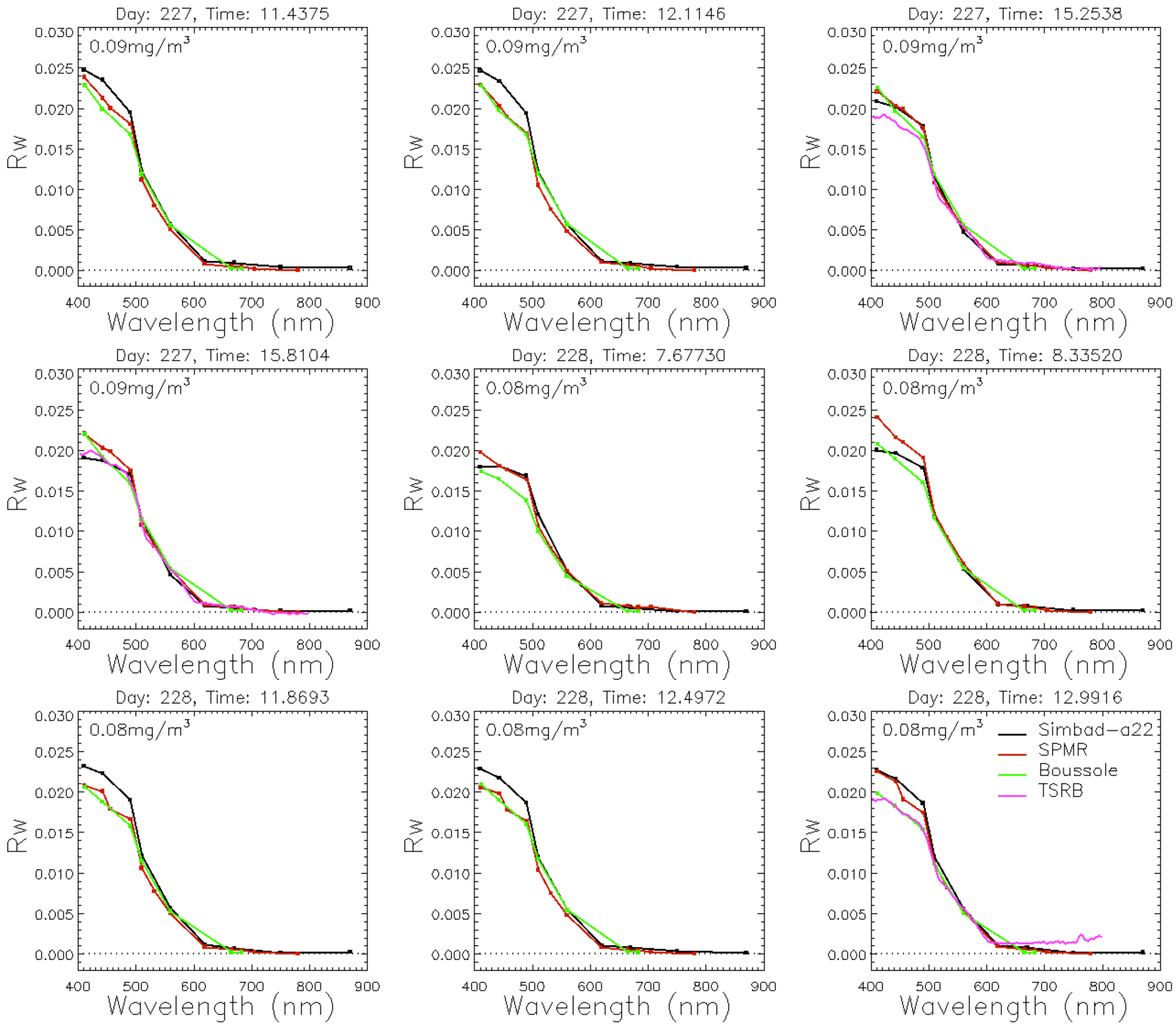
Comparison of SIMBADA, SIMBAD, and Microtops aerosol optical thickness measurements during ACE-Asia.



Comparison of SIMBADA, SIMBAD, PRR, and MER marine reflectance (R_w) measurements during ACE-Asia. PRR R_w was derived using E_s (R1) or $E_d(0\text{-})$ (R2).



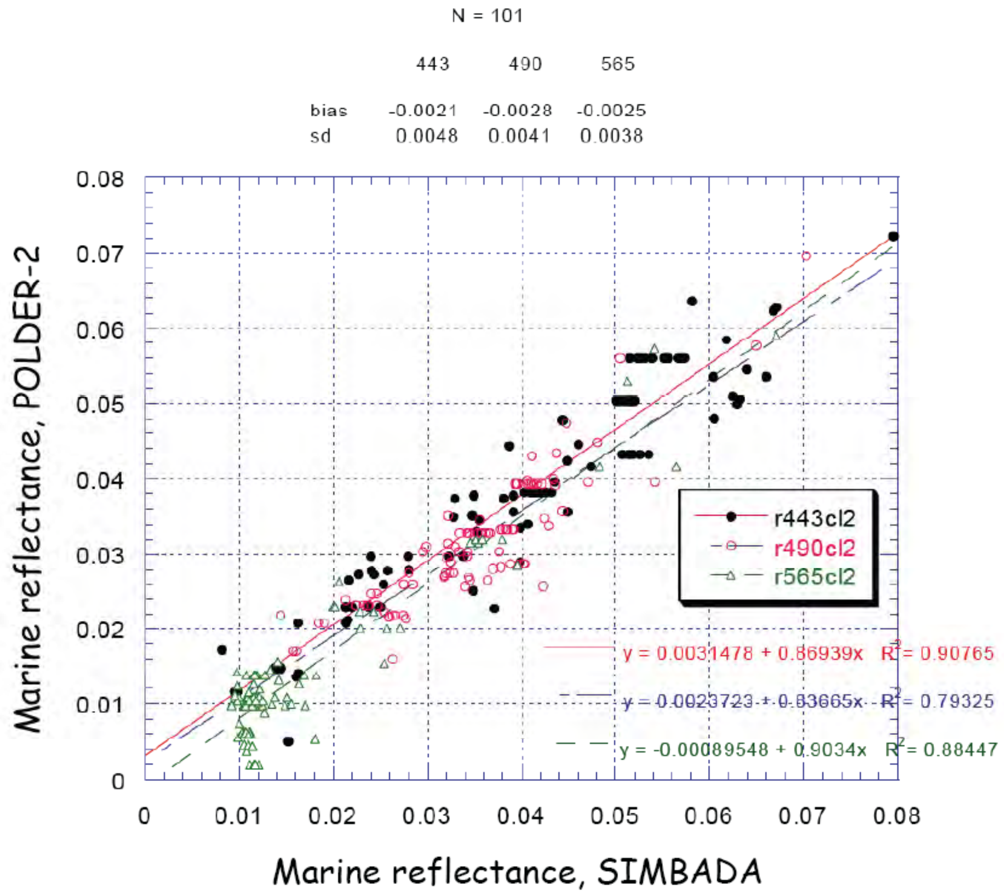
Comparison of SIMBADA and CIMEL aerosol optical thickness during AOPEX (ship at the BOUSSOLE site).



Comparison of SIMBADA, SPMR, Boussole, and TSRB marine reflectance (R_w) during AOPEX (ship at the BOUSSOLE site).

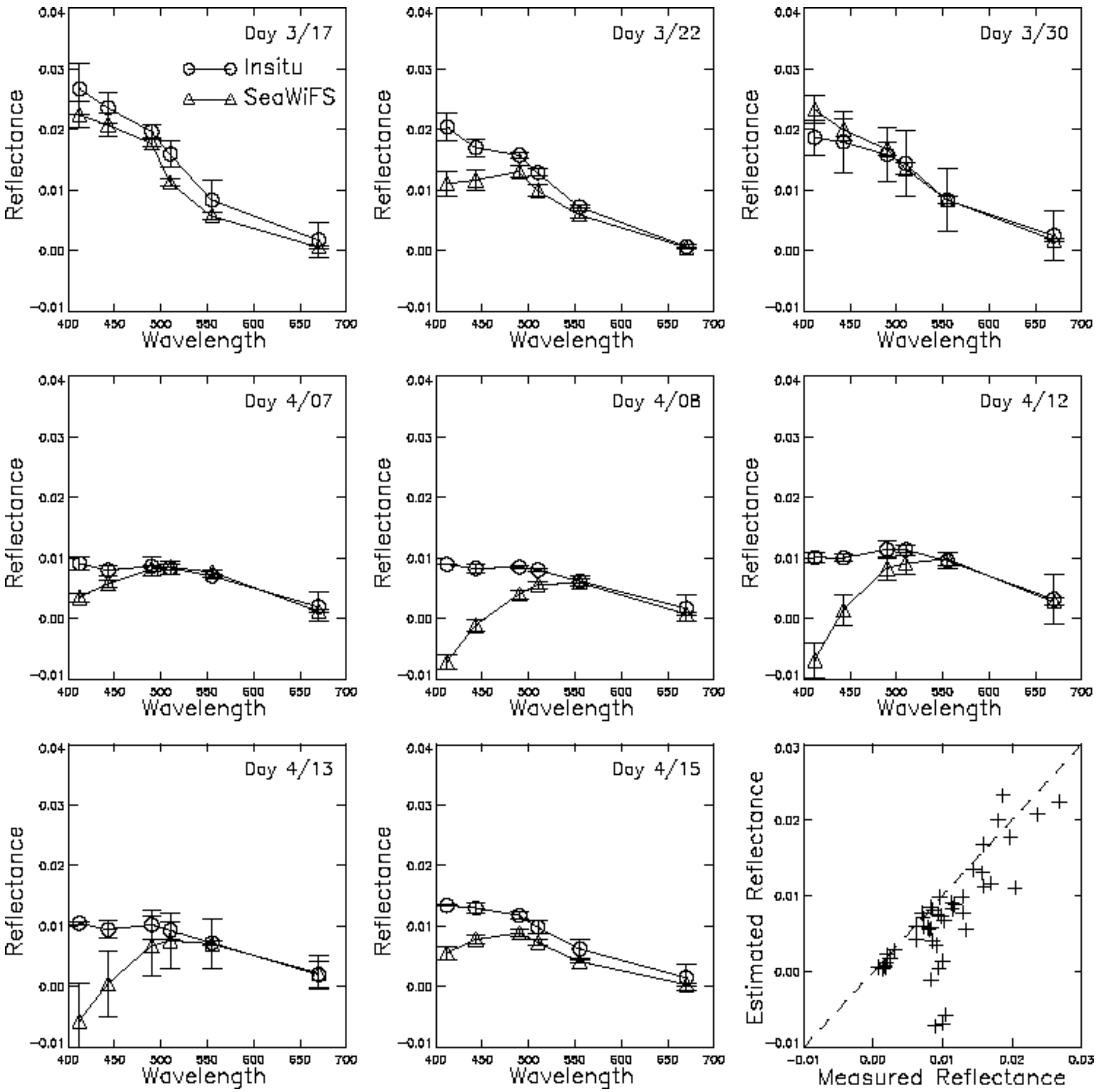
Applications

- POLDER-2: Evaluation of marine reflectance



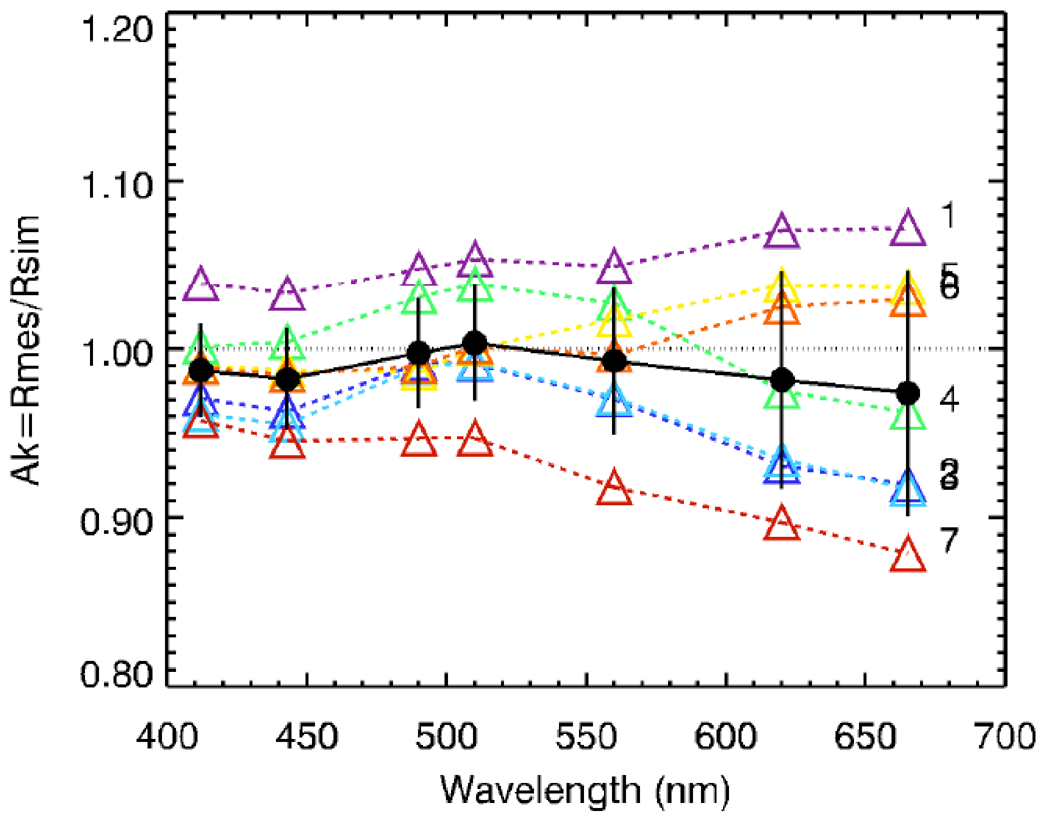
Comparison of the marine reflectance, $\pi L_w/E_d$, estimated by POLDER-2 and measured by SIMBADA. (After Nicolas et al., 2005.)

-SeaWiFS: Evaluation of marine reflectance



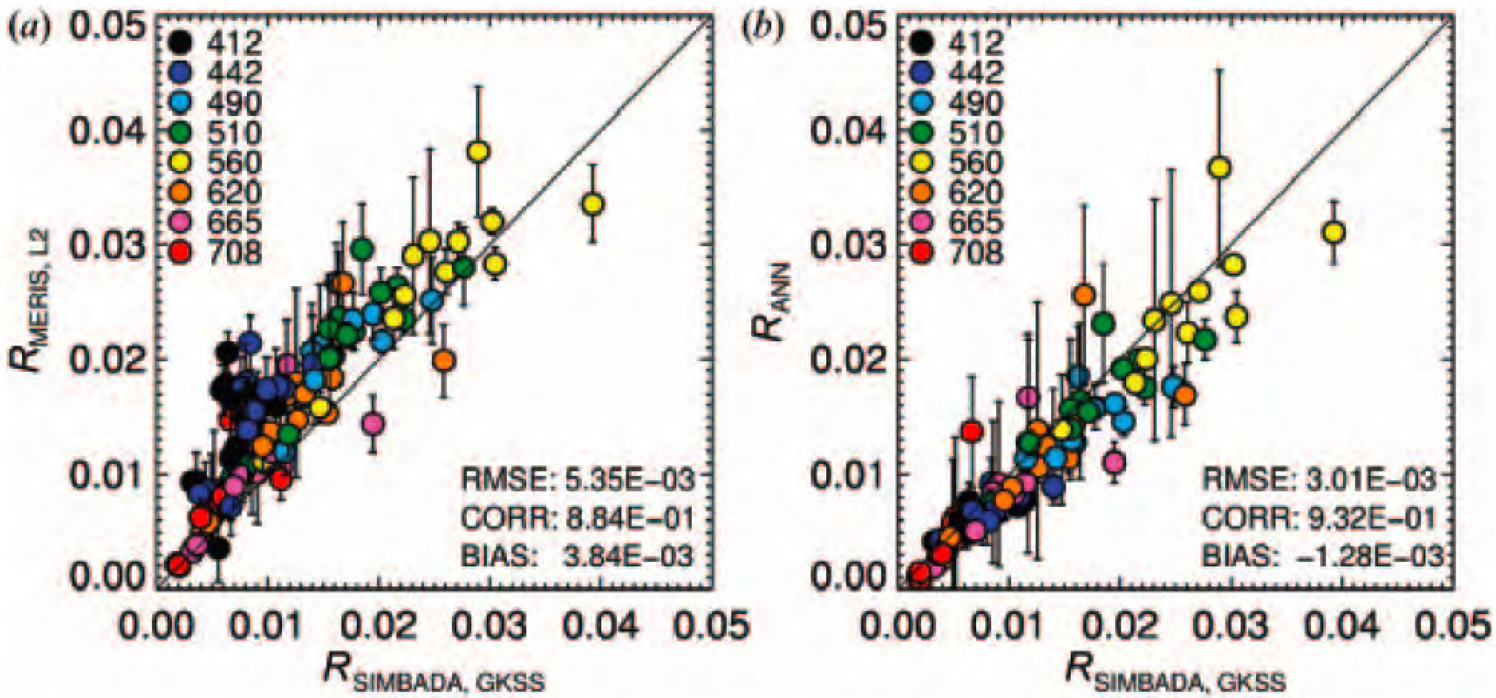
Comparison of the marine reflectance, $\pi L_w/E_d$, estimated by SeaWiFS and measured by SIMBADA during ACE-Asia.

-MERIS: Evaluation of radiometric calibration



Evaluation of the MERIS radiometric calibration from SIMBADA measurements. (After Nicolas et al., 2002.)

-MERIS: Evaluation of marine reflectance



Comparison of MERIS marine reflectance derived by the standard algorithm (a) and by the ANN algorithm (b) with SIMBADA measurements. (After Shroeder et al., 2007.)

Summary

-SIMBADA project has proven useful to check the calibration of ocean-color sensors and evaluate ocean-color products (e.g., provided 75% of all cal/val data for GLI, Murakami et al., 2006).

-Complements MOBY, BOUSSOLE, and AERONET-OC (allows sampling of the global oceans).

-Improvements can be made, e.g., taking into account the aerosol model in the calculation of downward solar irradiance, correcting for polarization by hydrosols, and estimating the marine reflectance at 870 nm (extension to highly turbid waters).

-Data were collected from 1994 to about 2006 (support from CNES and NASA). Instruments need to be refurbished, re-characterized, and calibrated for continued data collection.

-Future developments:

(1) measuring downward solar irradiance will be measured by an external irradiance sensor, with the data acquired by the SIMBADA radiometer via radio waves, allowing marine reflectance measurements under cloudy skies.

(2) measuring chlorophyll fluorescence by differential absorption in the oxygen B-band.