Vicarious radiometric calibration of satellite ocean colour sensors
Étalonnage radiométrique indirect des capteurs satellite couleur de l'océan

Laboratoire d'Océanographie, Observatoire Océanologique de Villefranche-sur-mer, France

Authors: David Antoine and Malik Chami

Abstract

The basic principle of the so-called vicarious calibration of ocean colour satellite observations is first briefly recalled. A new method is then presented, which is providing elements for this vicarious calibration, starting from sun-photometer ground measurements of sky radiances and degree of polarisation, and based on a neural network approach for the inversion of these measurements in terms of aerosol optical properties.

Résumé

Le principe des étalonnages radiométriques indirects des observations satellitaires de la couleur de l'océan est brièvement rappelé. Une nouvelle méthode est ensuite présentée, qui fournit des éléments pour cet étalonnage à partir des mesures réalisées au sol par un photomètre mesurant les luminances du ciel ainsi que leur taux de polarisation. Cette méthode utilise les techniques neuronales pour réaliser l'inversion de ces mesures en terme de propriétés optiques et physico-chimiques des aérosols, qui sont des paramètres importants dans ces techniques d'étalonnage indirect.

A great care and specific efforts are devoted to the pre-launch characterisation and radiometric calibration of satellite sensors, and in particular of ocean colour satellite sensors. Some of these instruments are as well equipped with a series of devices that are designed to permanently monitor the possible changes with time of their radiometric response, as a possible consequence of the stress during launch and then of their exposure to the space environment. In the case of the ESA Medium Resolution Imaging Spectrometer (MERIS), these devices are spectralon diffusers, one of which being mostly kept unexposed to solar radiation and used on a monthly basis to monitor the degradation of the other one that is used for calibration at each orbit.

It is now acknowledged, however, that this direct radiometric calibration alone is not sufficient to ensure the production of ocean colour products of the desired accuracy, i.e., water-leaving radiances within an error of about 5% in the blue for an oligotrophic ocean. The use of onboard devices must be accompanied by so-called vicarious calibration activities. Two main pathways for this indirect calibration exist and are summarised below. They are as well particularly critical for those sensors that are not equipped with the devices mentioned above (e.g., the POLDER and PARASOL instruments).

One technique consists in forcing the satellite-derived water-leaving radiances to agree with a set of in situ-derived water-leaving radiances. A set of vicarious calibration coefficients is therefore obtained, which is applied to the Top-of-atmosphere (TOA) total radiances measured by the sensor. The second procedure, which is also an indirect calibration, is sometimes referred to as a vicarious radiometric calibration, and consists in simulating the TOA signal that the sensor should measure under certain conditions, and to compare it to the measured signal.

Inconveniences of the first type of vicarious calibration is that it is dependent upon the procedure used for the atmospheric correction of the TOA observations. The advantage of this technique is, however, and besides the fact that atmospheric measurements are not needed, that the marine signals delivered by several sensors that use different atmospheric correction algorithms can be cross-calibrated provided that the same set of *in situ* water-leaving radiances is used as a reference to perform the vicarious calibration. This is presently the case, for instance, for the NASA SeaWiFS and MODIS sensors.

Inconveniences of the vicarious radiometric calibration is that it requires a set of *in situ* measurements that is difficult to collect. Indeed, in addition to the in-water measurements of the water-leaving radiances, this data set must include : sea state and atmospheric pressure, ozone concentration, aerosol optical thickness, aerosol type, and even aerosol vertical profile if the aerosols reveal to be absorbing. Incidentally, when these measurements are not available and are replaced by mean, reasonably guessed, values, the technique comes down to the so-called "Rayleigh calibration" (or "calibration over the Rayleigh"), also used for MERIS.

If this data set is successfully assembled, the great advantage of the vicarious radiometric calibration is that it is independent of the atmospheric correction algorithms, so that the TOA signals of various sensors can be cross-calibrated. Then it is up to any user to apply its preferred atmospheric correction to these TOA signals.

The greatest difficulty of the vicarious radiometric calibration lies in the estimation of the aerosol optical thickness, phase function, and single scattering albedo. These parameters are accessible through the inversion of sun photometer measurements, yet uncertainties inevitably occur when applying such methods, for instance because of multiple scattering, of perturbations from the ground reflectance, of uncertainties in the photometer calibration. This article briefly presents the features of a new inversion algorithm that has been developed in particular to provide the necessary inputs to the vicarious radiometric calibration of the MERIS sensor.

The technique is based on the use of a neural network inversion algorithm, specifically designed to retrieve the aerosol complex refractive index from ground-based measurements of sky radiances and degree of polarisation. These measurements are collected with an automatic scanning sky and sun photometer (part of the AERONET international photometer network), which has been installed at the semaphore premises of cap Ferrat, France, on the Mediterranean coast, in the frame of the BOUSSOLE project (a project supported by CNES and ESA and aiming in particular at calibration and validation of ocean colour satellite observations). The specific feature of the method, which uses spectral radiances measured in the principal plane in order to include large scattering angles, lies in the use of the degree of polarisation as an additional physical constraint to improve the retrieval of the aerosols characteristics. Then, these characteristics are used as inputs to the radiometric vicarious calibration of ocean colour sensors. The degree of polarisation is exploited by the NN as a physical constraint that helps to converge toward a realistic solution of an inherently ill-posed inverse problem. The degree of polarisation also provides information on the composition of the particles.

The neural network (NN) has been trained with synthetic “pseudo data” generated through radiative transfer simulations, including a realistic noise modelling, and the algorithm has been tested on real data for the retrieval of the optical thickness and the Angström exponent. The optical depth is estimated with an accuracy of ±0.02, which is similar to the uncertainty commonly admitted for ground based measurements, and the Angström exponent is retrieved with a 5% error. The algorithm has been as well applied to the sky radiances collected by the sun photometer to get the aerosol refractive index. The performance of the retrieval is evaluated *a posteriori* by reconstructing the radiance and degree of polarisation with a radiative transfer model (illustration below).

The proposed algorithm has been used for providing some vicarious calibration points in the near infrared for MERIS. The preliminary results exhibit an uncertainty of calibration < 5% that is within requirements. Additional points are collected as the MERIS data distribution progressively improves, and will be also collected for the POLDER-II instrument and the future PARASOL mission. The same method will similarly be applied to the visible bands of these sensors, where the atmospheric signal has to be summed up to the marine signal (reflectance), the latter being measured at sea with in-water radiometers, either deployed from ships or installed onto a buoy that was specifically designed for that purpose.

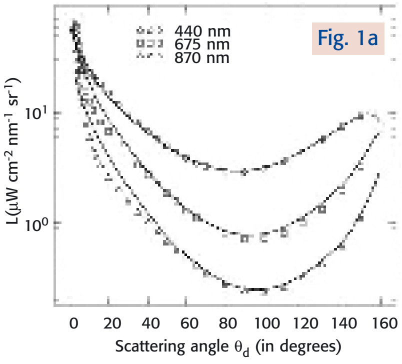
Fig. 1a

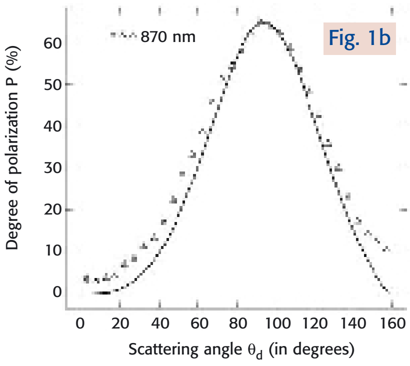
Fig. 1b

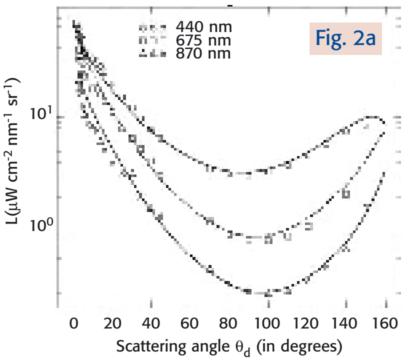
Fig. 2a

Figures 1a and 1b show a comparison between measurements of the sky radiances in the principal plane (the vertical plane containing the sun and the photometer), as collected by the photometer installed at the “cap Ferrat” (different symbols are for the three wavelengths as indicated), and the same quantity as derived through the use of radiative transfer calculations that make use of aerosol models (curves). Figure 1a is for the situation of July 11, 2002, and Figure 1b is for September 7, 2002. In both cases, the aerosol model that is used is defined on the one hand by a particle size distribution following a Junge law, and, on the other hand, by a complex refractive index.
Figures 2a and 2b show the degree of polarisation, again either as measured (symbols) or as computed (curves). These tests thus make it possible to determine, on a case-per-case basis, which is the aerosol model to use in order to best reproduce the signal at the top of the atmosphere, for a given geometry, and then to match this simulated signal to the signal measured by a given ocean colour sensor. The other parameters needed in the computations are easier to accurately determine : they are the atmospheric pressure, the integrated ozone content, the wind speed that determines the roughness of the sea surface, and finally the marine signal if the calculation is carried out in the visible part of the spectrum (there is no marine signal in the near infra-red for offshore waters of the “Case 1”, where optical properties are essentially driven by phytoplanton).

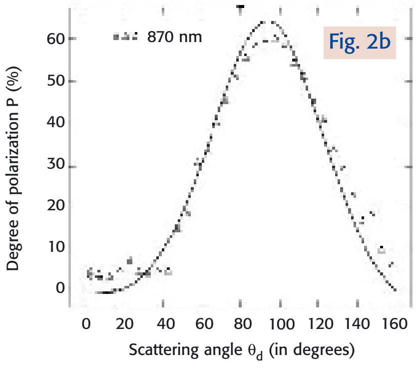
Fig. 2b