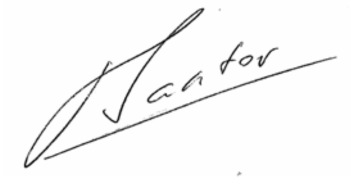
Validation Study

for ocean colour product

Short description	Validation for ocean colour
Version	1.2
Author(s) and affiliation(s)	R. SANTER 
Author(s) of the contributions	
Modification history	21.10.2008 Final version
Distribution	Brockmann Consult

Definitions, Acronyms, Abbreviations

AERONET	Aerosol RObotic NETwork (http://**aeronet**.**gsfc**.**nasa**.gov/)
AOT	Aerosol optical thickness
AU	Astronomic Unit
BOA	Bottom Of the Atmosphere
BRDF	Bi-directional Reflection Distribution Function
CalVal	Calibration Validation
CEOS WGCV	Committee on Earth Observation Satellites Working Group Calibration Validation
Chl-a	Chorphya concentration
ECMWF	European Centre for Medium range Weather Forecasting
ENVISAT	Environmental Satellite
EO	Earth Observation
ESA	European Space Agency
FOV	Field-of-View
GLI	Global Imager (Japan, ADEOS)
GMES	Global Monitoring Earth System
GS	Ground Segment
IOP	Inherent Optical Property
IVOS	Infrared and Visible Optical Sensors subgroup
LUT	Look Up Table
MERIS	Medium Resolution Imaging Spectrometer (ESA Envisat)
WRSR	Water Remote Sensing Reflectance
MOBY	Marine Optical Buoy
MODIS	Moderate-Resolution Imaging Spectroradiometer (NASA EOS)
NILU	Norsk Institutt for Luftforskning
NIR	Near Infrared (spectral region)
NN	Neural Network
NRT	Near Real Time
PAR	Photosynthesis Active Radiation
POLDER	Polarization and Directionality of the Earth's Reflectances (CNES, ADEOS)
RTC	Radiative Transfer Code
SAM	Standard aerosol models
Seabass	http://seabass.gsfc.nasa.gov/docs/Protocols_Ver4_VolVI.pdf
SeaWiFS	Sea-Viewing Wide Field-of-View Sensor (USA)
SIMBAD	
SIMBIOS	
TOA	Top Of the Atmosphere
TSM	Total Suspended Matter
VOS	Visible Optical Sensor
YS	Yellow Substance

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1. Introduction

The D13 report was mostly focussing on the calibration activities for the IVOS sensor. Calibration issues are relevant to level 0 and level 1 products. This report deals with the validation activities, and first to the ocean colour validation. Validation is a level 2 activity. Validation of upper levels can be of course related, but we will not address this issue here.

SIMBIOS is the reference on the subject. It was initialised by SeaWiFS and mainly focuses on open ocean issues in the context of global studies. We do not pretend to summarize this fundamental work. It is just a presentation of the bases of the case 1 (open ocean) water. It is also, through the fundamental aspects of the methodology, to emphasize on one hand the coherence of the approach, and in the other hand to identify the limits of a simple duplication to case 2 waters.

In the frame of application programs like GMES, it is then necessary to adjust the validation strategy of the open ocean to coastal waters. First, we have to remind that a possible validation of the atmospheric correction can be made through atmospheric measurements. The development on case 2 algorithms can be (should be) based on remote sensing reflectance, rather than on marine reflectance. That does avoid the need to convert those WRSR into marine reflectance. Therefore, the case 2 validation can be based on water leaving radiance measurements.

Flags are one possibility to make a quality control. For global study, conducted with level 3, it is possible to retain only the "good" pixels. Because the optical relative simplicity of the satellite signal over the open ocean as well as because of the scientific maturity of the algorithms, they are sufficient pixels to conduct global study. They are as well enough match-up to be selective.

For end user involves in coastal water management, the level of confidence of the products is a key issue. Therefore, the flags should be subject as well to a validation/evaluation.

2 Validation of the ocean colour missions

2.1 Basic definitions

2.1.1 Basic radiometric definitions

The incoming signal to a satellite sensor is a radiance L ($W/m^2/sr$) integrated over the spectral response S(λ). Generally, once define the equivalent radiance $L^e\,(w/m^2/sr/\mu m)$ as:

$$L^e = \frac{L}{\int_0^\infty S(\lambda)d\lambda} \quad (1)$$

in order to normalize the radiance by the filter response.

Similarly, we introduce the mean solar irradiance $E_S^e\,(w/m^2/\mu m)$:

$$E_S^e = \frac{\int_0^\infty S(\lambda)E_S(\lambda)d\lambda}{\int_0^\infty S(\lambda)d\lambda} \quad (2)$$

2.1.2 Basic geophysic definitions

The reflectance ρ is defined as the ratio between the reflected irradiance Φ_r to the incident irradiance Φ_i:

$$\rho = \frac{\phi_r}{\phi_i} \quad (3)$$

At TOA, the direction of the sun $\vec{s}_0$ is defined by the solar zenith angle θ_s and the solar azimuth angle φ_s and:

$$\phi_i = \mu_s E_S^e / d^2 \quad (4)$$

in which *d* is the Sun to Earth distance (in AU) and μ_s is the cosine of the solar zenith angle.

The TOA upwelling irradiance corresponds to the angular integration of the TOA upwelling radiance *L* according to:

$$\phi_r = \int_0^{2\pi}\int_0^1 \mu L(\mu,\varphi) d\mu d\varphi \quad (5)$$

For an isotropic radiance (L=constant), we get:

$$\phi_r = \pi L \quad (6)$$

The view direction $\vec{s}$ is defined by the view zenith angle θ_v and the view azimuth angle φ_v

By extension, we introduce the TOA bi directional reflectance as:

$$\rho^*(\vec{s},\vec{s}_0)=\pi L(\vec{s},\vec{s}_0)/(\mu_s E_s^g/d^2) \quad (7)$$

At the surface, we also define the BOA bi directional reflectance as:

$$\rho(\vec{s},\vec{s}_0)=\pi L(\vec{s},\vec{s}_0)/E_0^+ \quad (8)$$

where E_0^+ is the downwelling irradiance at the surface.

2.1.3 Ocean colour definitions

Getting the apparent water leaving radiance

The first step of the atmospheric correction is to correct from the gaseous absorption. Gaseous absorption and atmospheric scattering are generaly decoupled. From the gaseous content, it is possible to compute the gaseous transmittance T_g. The correction is applied globally on the TOA radiance L^*as:

$$L^*_{ng}=L^*/T_g \quad (9)$$

The second step is to characterize the aerosols. For ocean case 1 water, the ocean body is black. More over, below a wind speed threshold and outside of the specular direction, foam and direct sunglint contributions are negligible. We then measure L_{atm} *as* L^*_{ng}. Two pieces on information on the aerosol are obtained from two spectral bands: the aerosol type and the AOT.

The third step is to sustract the atmospheric path radiance L_{atm}. L_{atm} includes the coupling term between atmospheric scattering and Fresnel reflection. The estimate of L_{atm} results from a radiative transfert code (RTC) run in which the Fresnel reflection is accounted for with a black ocean body.

The apparent contribution of the water body is:

$$L^*_w=L^*_{ng}-L_{atm} \quad (10)$$

In L^*_w, we have three contributions from:

(i) the water body
(ii) the direct sunglint
(iii) the foam.

The reflection of the sky dome is included in L_{atm}.

L^*_w is the apparent contribution at TOA. To go from TOA to BOA, we introduce the upward total transmittance $T(\mu_v)$. Following 5S, it corresponds to the ratio of the BOA irradiance to the TOA irradiance for a solar zenith angle θ_v measured over a dak surface (without Fresnel reflection). The water leaving radiance is:

$$L_w=L^*_w/T(\mu_v) \quad (11)$$

Playing with L_w

In order to fully remove the atmosphere, we now introduce the dark sky water leaving radiance:

$$L_w^{ds}=L_w/T(\mu_s) \quad (12)$$

The downwelling transmittance $T(\mu_s)$ corresponds to the ratio of the BOA irradiance to the TOA irradiance for the solar zenith angle θ_s measured over a dark surface (with the Fresnel reflection).

The introduction of the marine remote sensing reflectance ρ_w allows to remove the variation of the the TOA irradiance:

$$\rho_w(\mu_s, \mu_{s,}\phi) = \pi L_w^{ds}(\mu_s, \mu_{s,}\phi) / (\mu_s E_s^e / d^2) \quad (13)$$

ϕ is the difference in azimuth between the principal plane and the view plane. ρ_w is the geophysical output of an atmospheric correction which is based on a de-coupled atmosphere-ocean system.

Following equations (10) to (13), ρ_w is derived from ρ_{ng}^* with:

$$\rho_w = (\rho_{ng}^* - \rho_{atm}) / T(\mu_s) / T(\mu_v) \qquad (14)$$

2.2 The level 2 product

2.2.1 The products

We took two representatives of ocean colour sensors: SeaWifs (table1) is the most popular standard. Slight differences exit with MERIS, table 2.

The gaseous contents are provided by auxiliary data (surface pressure for Rayleigh scattering, ozone and water vapour for gaseous absorption). The first step to start with the level 2 is the aerosol remote sensing. The first output is the AOT in the near infrared (at 865 nm for MERIS in table 1, at 869 nm for SeaWiFS in table 2). The second input informs on the aerosol type: through the spectral dependence (between the two spectral bands devoted to this task) of

(i) the AOTs for MERIS (α, Angstroem coefficient)

(ii) the aerosol path radiance for SeaWiFS (epsilon)

The information on the aerosols is in first an information on what will be used for the atmospheric correction.

The PAR for MERIS is an instantaneous value, used in the interpretation of the fluorescence. For SeaWiFS, the PAR is provided as a mean daily value, used in primary productivity models. But the major output of the atmospheric correction is the outgoing signal from the sea, which mean that the Fresnel reflection of the sky dome has been removed.

In MERIS it is a surface reflectance (WRSR as in Eq. (13)) in the sun-sea-sensor geometry. It came from the initial conversion of the TOA radiance into reflectance. It is the choice to put in the first row a geophysical parameter. It is relevant for MERIS because of the so-called smile effect. For a given band, the solar irradiance varies with the central wavelength associated to each pixel. Therefore, it is a simplification in the delivery of the product to remove this pixel-by-pixel solar irradiance variation leaving a more stable geophysical value, a reflectance.

In SeaWiFS it is a "normalized" radiance ${}_nL_w$. Radiance as defined in Eq (12). Normalized means here that it is the radiance, as it should be measured for a sun at zenith and a nadir view. It is actually a geometrical standardisation, which requires knowing what the bi-directionality of the water body reflectance is.

The marine standard product for SeaWiFS is the chlorophyll-a concentration. This concentration is derived by standard marine algorithms, which basically relate marine reflectance and Chla concentration. The diffuse attenuation coefficient at 490nm is a derivative product from Chla. For MERIS, this class of algorithm applies to Chl_1 while Chl_2 is derived more specifically for case 2 water using a neural network inversion technique. The TSM and the YS are also outputs of this neural network.

Geophysical Parameter Name	Description	Units
Tau_869	Aerosol optical thickness at 869 nm	dimensionless
Angstrom_531	Angstrom coefficient, 531-869 nm	dimensionless
Eps_78	Epsilon at 748 and 869 nm	dimensionless
nLw_412	Normalized water-leaving radiance at 412 nm	mW·cm-2·µm-1·sr-1
nLw 443	Normalized water-leaving radiance at 443 nm	mW·cm-2·µm-1·sr-1
nLw_488	Normalized water-leaving radiance at 488 nm	mW·cm-2·µm-1·sr-1
nLw_531	Normalized water-leaving radiance at 531 nm	mW·cm-2·µm-1·sr-1
nLw_551	Normalized water-leaving radiance at 551 nm	mW·cm-2·µm-1·sr-1
nLw_667	Normalized water-leaving radiance at 667 nm	mW·cm-2·µm-1·sr-1
Chlor_a	OC3 Chlorophyll a concentration	mg·m-3
K490	Diffuse attenuation coefficient at 490nm	m-1

Table 1 : SeaWiFS standard products

Product	Unit
Aerosol optical thickness at 865 nm	Dimensionless
Angstrom coefficient, 778-869 nm	Dimensionless
Photosynthetic Available Radiation (PAR)	microEinstein.m^{-2}.s^{-1} or 10^{-6} mol.photons.m^{-2}.s^{-1}
Surface reflectance	Dimensionless
Algal pigment index 1 (Chl_1)	mg.m^{-3} or Log_{10}(mg.m^{-3})
Algal pigment index 2 (Chl_2)	mg.m^{-3} or Log_{10}(mg.m^{-3})
Total Suspended Matter (TSM)	mg.m^{-3} or Log_{10}(mg.m^{-3})
Yellow substance absorption	m^{-1} or Log_{10}(m^{-1})

Table 2: MERIS standard products

2.2.2 The flags

Tables 3 and 4 give the different flags respectively for MERIS. Basically a flag is something codes in one byte. These flags correspond to the 'ocean colour' branch. To fall in this branch, we are above water (ocean and inland following geometrical information) and under clear sky condition. There are different categories of flags when can propose to classify into:

(i) Instrument flags: they derive from engineering information (cosmetic, suspect, navigation problem), geometrical information (land flag, shallow water, sunglint), radiometric information (stray light, consolidation of the coastline,..). The validation of those flags should enter in the quality control protocol of the space agency in charge of the platform, of the instrument and of the level 0 and level 1 products.

(ii) Algorithm flags: they inform on the specific conditions for which the algorithm is working. They are raised before the retrieval algorithm is activated. It can be informative on the ancillary data used (continental absorbing aerosols) or on the limit of the algorithm. When two algorithms are available, it provides information on the one, which appears to be the most reliable (example: turbid waters). It is specific flags proposed by the algorithm developers. They are responsible of the documentation and of the verification of the correct functionality of those flags.

(iii) Quality flags: they are raised when the algorithm fails or/and when the quality of the product is suspicious. The ice/cloud flag is the first of them.

(iv) Geophysical flags: they are raised when the algorithm fails but because of specific biological events occurred. Therefore, they are as well informative on such events.

The above classification is quite arbitrary but can be informative on what flag to consider in validation activities? In that case, the strategy of the validation has to be defined.

- Coastline: From Level 1b
- Cosmetic: From Level 1b
- Suspect: From Level 1b
- Continental absorbing aerosol
- Dust-Like absorbing aerosol
- Turbid water
- Anomalous scattering water
- Yellow substance loaded water
- Ice or high aerosol load
- Corrected for glint
- Contaminated by glint

Table 3: The MERIS flags

ATMFAIL	Atmospheric correction failure from invalid inputs
LAND	Land (present in pixel)
BADANC	Missing ancillary data
HIGLINT	Severe Sun glint
HILT	Total radiance above knee in any band
HISATZEN	Satellite zenith angle above limit
COASTZ	Shallow water
NEGLW	Negative water-leaving radiance in any band
STRAYLIGHT	Stray light contamination
CLDICE	Clouds and/or ice
COCCOLITH	Presence of coccolithophores

TURBIDW	Turbid, case-2 water
HISOLZEN	Solar zenith angle above limit
HITAU	High aerosol concentration
LOWLW	Low water-leaving radiance at 555 nm
CHLFAIL	Chlorophyll concentration not calculable
NAVWARN	Questionable navigation (e.g. tilt change)
ABSAER	Absorbing aerosol index above threshold
TRICHO	Presence of Trichodesmium
MAXAERITER	Maximum iterations of NIR algorithm
MODGLINT	Moderate Sun glint
CHLWARN	Chlorophyll out-of-range
ATMWARN	Epsilon out-of-range
DARKPIXEL	Dark pixel (Lt - Lt < 0) for any band

Table 4: The SeaWiFS flags

2.3 The ocean case 1 validation

2.3.1 The strategy to validate the apparent optical properties

Figure 1 is a schematic representation of the validation strategy for SeaWiFs like algorithm. We put in green box the algorithm, in green ellipsoids the input-output to the algorithm. The same representation is used for the validation activities. The AOTs and their spectral dependences are directly validated from the same kind of ground-based measurements. A sun photometer, through the solar extinction measurements, gives quasi directly the AOTs. The ε coefficient can be made comparable to α.

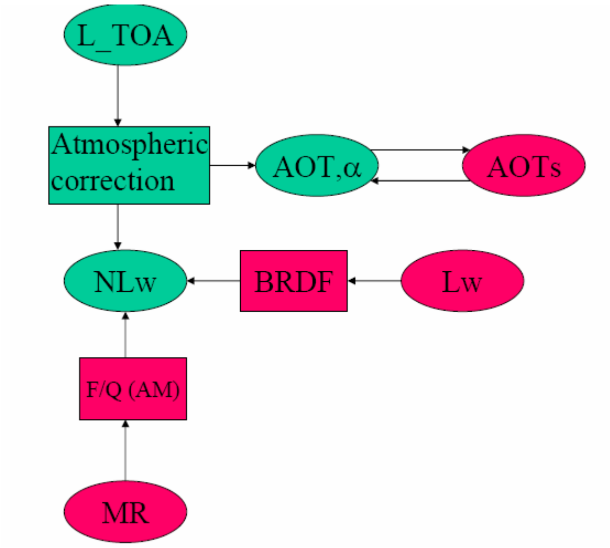


Figure 1: schematic representation of the SeaWiFS like validation

The other output of the atmospheric correction module is the normalized water leaving radiance NL_w. It can be validated using water leaving radiance measurements L_w in the same spectral bands. These L_w have to be normalised thank to a BRDF model. It is mostly validated by the measurements of marine reflectance. The conversion of the marine reflectance in NL_w is applied thank to relevant case 1 radiative transfer code computations.

There are minor changes to adapt the SeaWiS validation scheme to MERIS as illustrated in figure 2 at least for case 1 water. The validation of the aerosol model is still based on a comparison with the measured AOT. The second output of the atmospheric correction is the remote sensing reflectance in 13 spectral bands (the oxygen band 11 and the water vapour band are excluded). RSS are occasionally measured through cross measurements over a reference panel. More generally, we get water leaving radiance measurements L_w These L_w have to be corrected with a BRDF model to match the satellite sensor geometrical conditions.

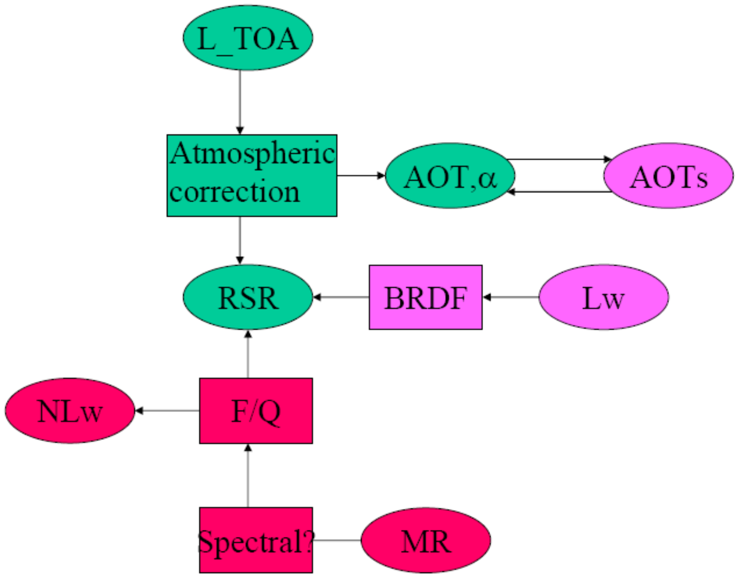


Figure 2: schematic representation of the MERIS case 1 validation

The standard validation [R. 1] relies on the measurements of the marine reflectance. Most of the instrumentation used was developed in the frame of the SeaWiFS validation. For MERIS, even if the central wavelengths of the "ocean" spectral bands are closed to the 6 one of SeaWiFS, they are some differences in the bandwidth of the filters that may be considered. GLI has quite different spectral bands compared to SeaWiFS and MERIS mainly with a band at 380 nm. The presence of a spectral band in the ultra violet for Sentinel 3 is as well an option. For case 1 water, it is not relevant to validate the WRSR in the near infrared, assumed to be null or negligible.

[R. 1] D. K. Clark, H. R. Gordon, K. J. Voss, Y. Ge, W. Broenkow, and C. Trees, "Validation of atmospheric correction over oceans," J. Geophys. Res. **102,** 17209–17217 (1997).

2.3.2 The vicarious calibration of the water leaving radiance

A vicarious radiometric calibration is based on the prediction of the TOA radiance. The output of the atmospheric correction is a water leaving radiance (or a WRSR). This vicarious calibration is based on the prediction (measurement) of the water leaving radiance. It falls in the validation activities because it is based on the use of a level 2 product. The objective is to apply gain factors g_L to the regular radiometric calibration coefficients. These gains factors reflect a vicarious calibration of the integrated instrument-atmospheric correction system.

The general principles [R. 2] of this vicarious calibration are the followings:

(i) The inter temporal radiometric calibration is known. It is the case for SeaWiFS thanks to the moon and MERIS can rely on the on board calibration. This assumption is not necessary but removes the temporal dimension of the adjustment.

(ii) It is a case 1 water calibration. The water body is dark in the NIR. The radiometric calibration is assumed to be correct at 865 nm. The gain factor g_L at 865 nm is set to one. These arbitrary setting may have a small impact on the retrieval of the AOT_865 but not on the atmospheric correction.

(iii) The maritime aerosol model is assumed. The AOT is determined at 865 nm. Knowing the model, the atmospheric correction can be applied to get the water leaving radiance (or a WRSR) in all the spectral bands.

(iv) For each band, the radiometric calibration is corrected by g_L to force the agreement between satellite and in situ water leaving radiance.

This protocol has been applied to SeaWiFS using MOBY data. Of course, it possible to imagine modifications to this protocol. For example, the gain factor g_L at 865 nm and 778 nm can be set to one. It relies then to a good inter band calibration between 865 nm and 778 nm. The regular atmospheric correction can be applied, including the selection of the aerosol type.

The L_w vicarious calibration relies on optical in situ measurements of the ocean colour. It can be as well prediction of L_w through measurements of Chl-a [R. 3].

[R. 2] H. R. Gordon, "In-orbit calibration strategy for ocean color sensors," Remote Sens. Environ. **63,** 265–278 (1998).

[R. 3] P. Jeremy Werdell, Sean W. Bailey,1 Bryan A. Franz,1 André Morel,2 and Charles R. McClain1. On-orbit vicarious calibration of ocean color sensors using an ocean surface reflectance model 2007 _ Vol. 46, No. 23 _ APPLIED OPTICS

2.3.3 The data base for the atmospheric parameter

The first step of the atmospheric correction is the correction of the gaseous absorption. For observations in the atmospheric windows (spectral regions for which we can simply correct from the gaseous absorption or neglect it). The meteorological data are the first characterization of the atmosphere. They are generally provided by meteorological office and attached as auxiliary data in the satellite products. In situ data of the barometric pressure, of the relative humidity and of the ozone content may be used for validation.

The aerosol product is directly validated thanks to the AOT. These AOT are in first determined from the CIMEL stations of the AERONET network [R. 4]., used in the validation of POLDER and MODIS. Complementary in the open ocean, aerosol optical thickness and type will be measured from merchant and research ships using solar radiometers. For example, SIMBAD radiometers have been used extensively for the calibration and validation of POLDER and SeaWiFS[R. 5].

One parameter derived from the atmosphere characterization is the PAR. An experimental validation of the MERIS PAR has been conducted thanks to in situ measurement of the solar irradiance at sea[R. 6].

[R. 4] Holben, B., T. Eck, I. Slutsker, D. Tanré, J.-P. Buis, A. Setzer, E. Vermote, J. Reagan, Y. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak, and A. Smirnov, A federated instrument network and data archive for aerosol characterization, *Remote Sen. Environ*., **66**, 1-16, 1998.

[R. 5] Deschamps

[R. 6] Bouvet M., MERIS Photosynthetically Available Radiation: a product quality assessment, MAVT, 2006

2.3.4 The validation of the ocean IOPs and products

As a standard, we will use the globcolor project, http://www.globcolour.info/.

- Fully normalised water leaving radiances

The fully normalized water leaving radiance ${}_{fn}L_w$ is defined as the normalized (incident solar irradiance of 1) radiance observed at nadir for a sun at zenith. It is still considered above water, without direct sunglint and after correction of the Fresnel reflection of the sky dome.

The basic measurement is the marine reflectance $R(0^-)$, and the conversion equation is:

$$L_{wn} = \Re\, F_0 \frac{R(0^-)}{Q} \qquad (15)$$

Q is the ratio of the upwelling irradiance to the upwelling radiance at nadir (equal to π for a totally diffuse radiance distribution), and $\Re$ describes the combined reflection and refraction effects that occur as downward irradiance and upward radiance propagate through the air-sea interface. A standard value $\Re$ of is 0.529, which is valid when the solar zenith angle and wind speed are not too large. Conveniently, Morel *et al.* [R. 7] describe both Q spectrally as a function of *Chl-a* and solar zenith angle, using a series of lookup tables (LUT; available at http://www.obs-vlfr.fr/_morel). The bi-directional correction requires modelling the BRDF of the oceanic body, with, for the case 1 water, the knowledge of the Chla concentration.

[R. 7] A. Morel, D. Antoine, and B. Gentili, "Bidirectional reflectance of oceanic waters: accounting for Raman emission and varying particle scattering phase function," Appl. Opt. **41,** 6289–6306 (2002).

- Relative excess of radiance at 555 nm

Knowing the Chla concentration for case 1 water, it is possible to predict the water leaving radiance at 550 nm. EL550 gives the relative excess of radiance at 555 nm as a case 1 /case 2 classification.

- Chlorophyll-a

- Coloured dissolved and detrital organic materials (CDM)

CDM is the coloured dissolved and detrital organic materials (m^{-1}) available from MERIS.

- Diffuse attenuation coefficient (Kd(490))

Kd(490) is the diffuse attenuation coefficient at 490 nm (m-1). It is one indicator of the turbidity of the water column. The merged Kd(490) is computed directly from the merged CHL1,

- Particulate back-scattering coefficient (b_{bp}) and Total Suspended Matter (TSM)

b_{bp} is the particulate back-scattering coefficient at the reference wavelength λ_0 = 443nm (in m^{-1}). The TSM in standard MERIS L2 product is calculated using the case 2 water neural network. The assumption of the neural network is that there is a constant ratio between total particulate scattering (BP) and particulate back-scattering (BBP): BBP/BP = 0.015. TSM as dry weight of all water constituents is then calculated as TSM (g.m-3) = 1.73*BP.

2.3.5 The data base for the water parameters

This review is not exhaustive and based on information available on internet. Table 3 is a first attempt to list the relevant web site and indicate how to get access.

Web address	Contact	Data policy
http://wdc-d.coi.gov.cn/english/exm/enr4.htm		Registered people
http://wood.jhuapl.edu/wood/	Jeffrey H. Smart smartjh1@jhuapl.edu	open
http://seabass.gsfc.nasa.gov/		Registered people
http://www.research.plymouth.ac.uk/casix /		Registered people

Table 3: Ocean colour database

2.3.6 The validation and the flags and vice versa

There are different issues:

(i) What flags are subject to validation?

(ii) Do we validate the products when a flag is raised?

The classification is generally conducted on a pixel-by-pixel basis. A simple visual inspection of the image allows accessing the quality of some of the "instrument" flags: coastline, glint,… For the quality flag, the cloud/ice flag validation results from a visual inspection as well. This visual inspection can be conducted on specific spectral bands: for example the 761 nm/753 nm ratio for MERIS provides, through the oxygen transmittance, a good evidence of the presence of cirrus clouds. The use of thermal bands is of course a plus. For the geophysical flags, visual inspection and likelihood may help for validation as for example for the presence of coccolithophores

When a flag is raised, and if the product exists, the non-validation of a product should be the rule. But it is useful to investigate the resistance of the algorithm to the phenomena described by the flags. For example, the validation of the cloud flag can be made on meteorological basis thanks to specialized classification algorithm. But the response of the algorithm to the presence of a detected thin cloud can be correct. In other word, a flag is product oriented and the validation of the flag should be in line.

2.3.7 The spatio temporal correspondence between satellite data and in situ measurements.

As an example, we took the case of the MERIS validation, [R. 10], which follows the IOCCG recommendations:

The whole MERIS archive is scanned to search products corresponding to in situ acquisition. Extraction is achieved on 5 × 5 RR pixels around the site. The match up is selected if and only if all the following conditions are satisfied (most of them taken from [R. 11]):

• Difference in time between MERIS and the in situ measurement doesn't exceed 3 hours.

• At least 50% of the pixels in the box are not flagged as land or cloud or medium_glint or ice_haze or PCD_1_13 or PCD_19. The last two flags correspond to a failure in the atmospheric correction and thus depend highly on the algorithm itself. However their inclusion is recommended by [R. 11].

• For a given wavelength: The mean and standard deviation of water-leaving reflectance over non-flagged pixel is first evaluated, and then filtered.

[R. 10] C. Mazeran, 2007, Quality Control methodology for validating Ocean Atmospheric Correction, Internal report, ACRI ST.

[R. 11] S. W. Bailey and P. J. Werdell. A multi-sensor approach for the on-orbit validation of ocean color satellite data products. Remote Sensing of Environment, 102:12_23, 2006.

2.4 The ocean case 2 validation

2.4.1 The strategy to validate the apparent optical properties

The ocean case 1 validation is consistent with the different modules of the algorithm:

(i) The Chl-a retrieval is based on semi empirical algorithm developed from marine reflectance and Chl-a concentration.

(ii) The marine reflectance are converted into normalized water leaving radiance (or WRSR) with the same set of equations than the one used to transform the level 2 into a marine reflectance.

(iii) The atmospheric correction is “calibrated” on in situ measurement of marine reflectance.

The situation for the coastal water is very different:

(i) The retrieval of the water composition is based on the use of the WRSR. Therefore, it is relevant to validate these WRSR with measurements of the water leaving radiance.

(ii) The maritime model with high meteorological visibilities is not likely to occur in coastal areas. The validation of the AOTs remains relevant to validate the aerosol model but appears insufficient to access on the quality of the atmospheric correction.

(iii) The atmospheric correction relies on standard aerosol models and they corresponding optical properties. The aerosol IOPs have to be validated. This validation can be only based on a statistical approach and can be conducted regardless of satellite imagery.

(iv) The large spatio temporal variability of the coastal ocean renders difficult to realize "good" match up.

(v) The ocean colour algorithm relies on water IOPs that appear more variable than for the open ocean. The optical characterization of case 2 waters is needed to validate the standard IOPs used in the algorithms.

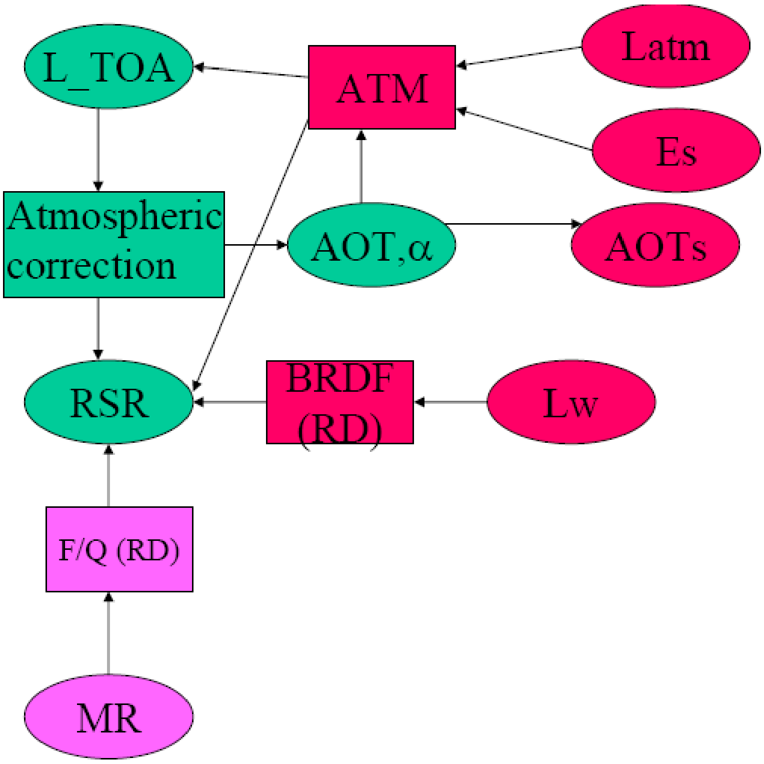


Figure 3: schematic representation of the case2 validation

Figure 3 is a schematic representation of the case 2 validation:

(i) The aerosol product is still the AOT_865 and the Angstroem coefficient with a classical validation using surface based solar extinction measurements.

(ii) Complementary to that, it is important to validate the atmospheric transmittance thanks to irradiance measurements E_s. The validation of the atmospheric path radiance L_{atm} (or ρ_{atm}) is required. Having measured the atmospheric functions, equation (14) can be used to derived the remote sensing water reflectance.

(iii) The output is the water leaving radiance (or WRSR) in the sensor geometry. The priority to the water leaving radiance is given for MERIS because the NN uses them as input. It is better to have a WRSR in the sensor geometry because it is the intrinsic output of the atmospheric correction scheme. The validation of the atmospheric correction can (should?) be done using water leaving radiance measurements with a correction of the BRDF between the two geometries of acquisitions. A case 2 BRDF model should be available . This BRDF model should be consistent with the level 2 algorithm (in the BRDF box, RD stands for Rolland Doerffer who will implement this tool in the calval portal).

(iv) Of course marine reflectance measurements are still relevant. The factor *f/Q* is applied to get normalized water leaving radiance. This *f/Q* should be consistent with the level 2 algorithm. It is recommended to de-normalise the normalized water leaving radiance to get the WRSR in the sensor geometry.

(v) The water leaving radiance should be measured as well in the NIR to validate a case 1 water remote sensing or to evaluate the performance of an AC correction scheme over case 2 water (BPAC for example).

2.4.2 An atmospheric validation of the atmospheric correction

The standard validation of the aerosol model can be done though the comparison on the AOTs between satellite derived values and surface based measurements. To validate the aerosol product, once can use the AOTs in the NIR in order to compare AOT_865 and α. The retrieval of the AOT in the blue is a good indicator than the extrapolation of ρ_{aer} is correctly done from the NIR to the blue.

The gaseous absorption correction is not subject to validation simply because the gas content (ie, the ozone) is provided in the auxiliary data file and because the formulation of the correction is consensual.

A more relevant validation consist in examining all the atmospheric functions involved in the atmospheric correction. According to §2.1.3, a full validation of the AC requires to validate the atmospheric function: ρ_{atm} , $\mathrm{T}(\mu_s),\mathrm{T}(\mu_v)$.

Validation of the atmospheric path reflectance in the NIR: aerosol remote sensing

The validation of ρ_{atm} is possible in the NIR over case 1 water because ρ^* corresponds to ρ_{atm} . The surface (direct sunglint, foam) or the water body (case 1) contribution should be negligible or these different terms should be accurately corrected.

ρ^* in the NIR is used to determine the aerosol model, therefore this approach is more a validation of the aerosol model than a validation of the AC.

The full validation of ρ_{atm} requires first having sky radiance measurements in a twin geometry to the space sensor which can associate the same scattering angle Θ.

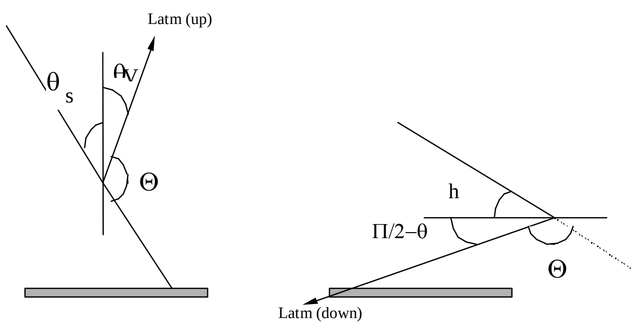


Figure 4: Twin geometry on the atmospheric path radiance between space and ground based measurements.

There are few circumstances for which this association can be realized simultaneously. At the time of the satellite over pass, the solar zenith angle should be large enough to realize the correspondence. Most of the time it is not and this validation strategy can only applied on stable days. The way to control this requirement is to use the AOT measurements and to check the stability of α as an indicator of the stability of the aerosol model.

At a first order neglecting the multiple scattering and the coupling between scattering and Fresnel reflection, we have

$$L_{atm}^{u} = \frac{\mu_v^d L_{atm}^d}{\mu_v^u} \qquad (16)$$

Equation (16) reflects that L_{atm} is proportional to the phase function which is the same for the twin geometries.

In order to make the association more accurate, we can introduce a corrective factor *f* to account for the multiple scattering and the coupling between scattering and Fresnel reflection:

$$L_{atm}^{u} = f\,\frac{\mu_v^d L_{atm}^d}{\mu_v^u} \qquad (17)$$

A radiative transfer code is ran twice to compute this corrective factor *f* with as input:

(i) the geometrical conditions

(ii) the surface pressure for the Rayleigh

(iii) the Angstroem coefficient α to select an aerosol model. This aerosol model can be selected among the standard aerosol models used in the AC module of the sensor ground segment.

(iv) The AOTs at the respective time for the two measurements.

(v) The wind speed to include a rough ocean surface.

At the end, in the two NIR bands (likely 775 nm and 865 nm) the predicted L_{atm} is compared to the measured one.

Validation of the atmospheric path reflectance in the visible: AC

This time, ρ^* does not correspond to ρ_{atm} and ρ_{atm} is not a product. Therefore we need to reconstruct the ρ_{atm} used in the AC. The aerosol product is not informative enough to reconstruct as it is used except if the agency provided an open source which allows to do it.

Validation of the atmospheric transmittance

The total down welling transmittance is defined as:

$$\mathrm{T}(\mu_s) = E_0^{\downarrow}(\mu_s) / \mu_s E_s \quad (18)$$

The down welling irradiance at the surface $E_0^{\downarrow}(\mu_s)$ is a routine measurement. If $\mathrm{T}(\mu_s)$ is validated, then once can believe that $\mathrm{T}(\mu_v)$ as well. $\mathrm{T}(\mu_v)$ is equivalent to $\mathrm{T}(\mu_s)$ following the principle of reciprocity, exception of the coupling between Fresnel reflection and scattering, which is a second order term.

The down welling irradiance is measured the day long and with a good approximation, the Log of the transmittance is proportional to the air mass. Therefore, $\mathrm{T}(\mu_v)$ can be experimentally derived.

Unfortunately, we need again to know the transmittances used in the ground segment.

NB: the PAR is a level 2 product which can be validated through the measurement of $E_0^{\downarrow}(\lambda,\mu_s)$.

Combine atmospheric reflectance and transmittances: validation of WRSR

The above experimental determination of ρ_{atm} , $T(\mu_s), T(\mu_v)$ and the application of equation (14) provides an experimental determination of ρ_w .

This validation is direct when the atmospheric function are determined in the same spectral bands. If not, a spectral interpolation (integration) has to be done. This spectral integration follows common standard:

(i) remove the Rayleigh contribution.

(ii) interpolate the aerosol contribution on a log scale.

Matching the signal at 865 nm

We started by the validation at 865 nm. The discrepancy between the satellite measurement and the prediction reflects, within the error bars, possible disagreements on

(i) the aerosol single scattering albedo.

(ii) the aerosol phase function.

(iii) the residual contribution of the water (foam, sunglint).

(iv) numerical differences.

On a practical point of view in the AC scheme, this discrepancy on the atmospheric reflectance at 865 nm, between the satellite ρ_{atm}^{*} and the simulation ρ_{atm}^{sim} , is attributed to an extra contribution of the aerosol scattering with:

$$d\rho_{aer}^{865} = \rho_{atm}^{*} - \rho_{atm}^{sim} \qquad (19)$$

Equation (19) assumes that the Rayleigh contribution is computed in the same way in the GS and in the validation procedure.

The aerosol reflectance ρ_{aer}^{sim} can be derived in each spectral band *j* as:

$$\rho_{aer}^{j} = \rho_{atm}^{sim,j} - \rho_{R}^{sim,j} \qquad (20)$$

Assuming than $d\rho_{aer}^{j}$ has the same spectral dependence than ρ_{aer}^{j} , we have:

$$d\rho_{aer}^{j} = \rho_{aer}^{j} \; d\rho_{aer}^{865} / \rho_{aer}^{865} \qquad (21)$$

The satellite TOA reflectance in the visible band *j* is corrected from $d\rho_{aer}^{j}$. Then equation (14) is used to provide an experimental determination of ρ_w .

2.4.3 The water leaving radiance

AERONET has been extended to support marine applications. This new network component called AERONET – Ocean Color (AERONET-OC), figure 5, provides the additional capability of measuring the radiance emerging from the sea (i.e., water-leaving radiance) with modified sun-photometers installed on offshore platforms like lighthouses, oceanographic and oil towers. AERONET-OC is instrumental in satellite ocean colour validation activities through standardized measurements a) performed at different sites with a single measuring system and protocol, b) calibrated with an identical reference source and method, and c) processed with the same code.

The in situ measurement of the water leaving radiance L_w can be compared to the satellite derived value if:

- (i) same location
- (ii) same time
- (iii) same spectral band
- (iv) same viewing geometry
- (v) after correction of the Fresnel reflection of the sky dome.

NB1: The contribution of the sky dome reflection to L_w can be an output of the RTC in the L_{atm} computation.

What are the specificities of the case 2 water:

(i) The spectral behaviour of the WRSR can be more complex. Because the spectral band of the in situ radiometer may be not the same than for the satellite sensor, the spectral matching can be a problem. An extensive database of high spectral measurements can be the mean to evaluate the spectral matching. One straightforward initiative for MERIS should be to refer to the standard water IOPs used to train the NN. By consistency, the spectral matching can be used by any statistical method between the WRSR in the MERIS bands on one hand and the *in situ* radiometer on the other.

(ii) A BRDF model has to be used to move from the in- situ geometry to the satellite geometry. One straightforward initiative for MERIS should be to refer to the standard water IOPs used to train the NN. By consistency, the spectral matching can be used by any statistical method between *in situ* and MERIS geometries.

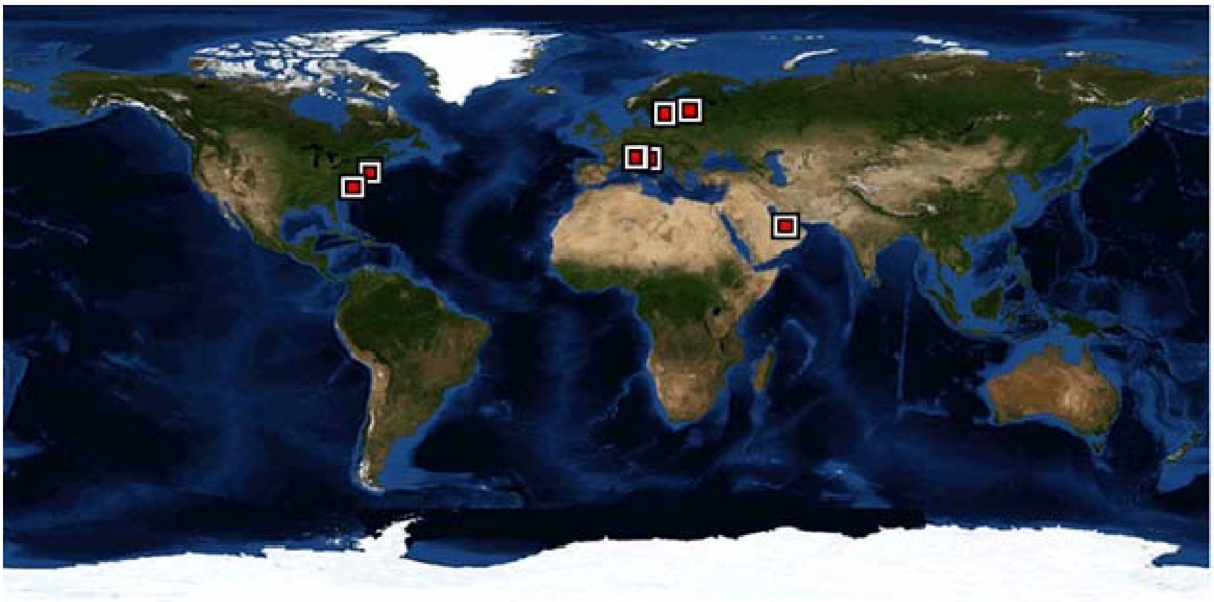


Figure 5: The localisation of the CIMEL radiometers in the AERONET "ocean colour" network.

2.4.4 The spatio temporal correspondence between satellite data and in situ measurements.

The traditional 1D formulation

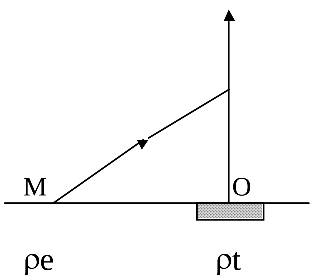
Case 2 and/or coastal waters require reconsidering the spatio-temporal matching between satellite and *in situ* data for the two environmental compartments: atmosphere and ocean.

For the atmosphere, they are enough radiometers to quantify the variation of the aerosol IOPs with time. The temporal variation of the AOTs can even be translated into error bars on the WRSR retrieval. For the spatial variability, it can be checked between close radiometers (Osteende and Dunkerque are within 40 km distance). The spatial homogeneity can be tested as well on the satellite imagery in the NIR bands (865 nm) for medium turbid waters. At the end, the same selection (3 hours, 5*5 FR pixels) that over the open ocean can be approved after a first check using AERONET data.

For the coastal ocean, the answer is not obvious because strongly related to the hydro dynamical conditions.

The 2D formulation: the adjacency effects

The WRSR is measured in point O. This signal is viewed on the direct path but also in the diffuse path, from the point M in the vicinity as illustrated below.



The AC scheme is conducted assuming that the surface is homogeneous. It may be the case for the open ocean but not for coastal waters. Actually, only a fraction of the ground based measurement of WRSR at surface corresponds to the level 2 WRSR. This fraction correspond to the ratio between the direct transmittance and the total transmittance (computed for a dark surface).

We did compute in table 3 this ratio at 412 nm for 3 view zenith angles and 4 AOTS (0,0.2,0.4,0.8 at 550 nm). The continental aerosol model is used. The first case is the Rayleigh case, the last case correspond to the limit value of the AC process for MERIS.

AOT/VZA(°)	6.5	28.8	73.3
0.000	88.3	86.7	61.9
0.244	70.4	70.4	29.3
0.449	58.1	54.2	15.3
0.859	39.5	35.1	4.1

Table 5:Direct to total transmittance ratio at 412 nm in percent for 3 VZA. The AOTs are given at 412 nm.

Let us say that the two first columns are representative for MERIS. AOT_550=0.2 is the standard value in coastal areas. 30 percent of what we observed from space do not correspond to the viewed target. It goes to more than 60 percent for an OAT_550=0.8.

Disregard the last column which may correspond to the edge of the image for Sentinel 3!

Equation (22) give the ratio between:

(i) the true apparent WRSR (weighted by the atmospheric transmittances in the upward path). Here, the reflectance of the target ρ_t is weighted by the direct transmittance $\exp(-\delta/\mu_v)$ while the mean reflectance of the environment $<\rho>$ is weighted by the diffuse transmittance $t_d(\mu_v)$.

(ii) The apparent WRSR as it happens for an homogeneous scene of reflectance

$$R = \left(\rho_t \exp(-\delta/\mu_v) + \langle\rho\rangle t_d(\mu_v)\right) / (\rho_t T(\mu_v)) \qquad (22)$$

We use this ratio and the RTC run of table 5, to evaluate the relative error causes by ignoring the adjacency effect at 412 nm. The target as 0.03 reflectance and the mean reflectance of the environment is 0.02. What is given in table 6 is in percent the negative bias which occurs when the AC ignores the adjacency effect (the target reflectance is darker than it should be by the reported relative value.

AOT/VZA(°)	6.5	28.8	73.3
0.000	3.9	4.4	12.7
0.244	9.9	9.9	23.6
0.449	14.0	15.3	28.2
0.859	20.2	21.6	32.0

Table 6:Relative bias at 412 nm (see table 5 for conditions).

The recommendation in terms of algorithm is clear:

(i) process regular level 2.

(ii) test if an adjacency effect correction is needed. A simple threshold (TBD) should combine the direct to total ratio with the difference of the WRSR for a given pixel to the mean WRSR in it vicinity.

(iii) If required, apply an adjacency effect correction. The inputs to this correction are the regular aerosol product and WRSR. The 6S formalism can be used.

The recommendation in terms of validation of the existing algorithm is:

(iv) Measure WRSR.

(v) The same test than above is needed. A simple threshold (TBD) should combine the direct to total ratio with the difference of the WRSR for a given pixel to the mean WRSR in it vicinity.

(vi) If required apply, an adjacency effect correction. The inputs to this correction are the regular aerosol product and the measured WRSR. The 6S formalism can be used.

In coastal water, we suppose that the adjacency effects coming from the land are negligible (it requires a adjacency effects simulator).

2.4.5 The validation of the ocean colour algorithm

The classical approach

The traditional approach is the match up between satellite and in situ measurements of ocean colour products and to validate step by step the algorithm.

Do we need satellite measurements?

Another approach is to decouple the validation of the atmospheric correction from the validation of the ocean colour algorithm. What are the arguments:

(i) The state of the art of the atmospheric correction over coastal water is not fully mature. Therefore, why to validate the interpretation of the ocean colour with wrong WRSR?

(ii) Once can believe that the validation of the atmospheric correction can be made by atmospheric measurements. The spatio temporal stability of the atmosphere is certainly stronger than for the ocean.

(iii) It is possible to collect simultaneously WRSR and in water measurements of Chla, SM and YS absorption.

2.4.6 Break points for validation

Break points are not products but they should be produced consistently with the implemented inversion routines.

The atmospheric scattering function

The aerosol product and the information you should be able to derive from the ground based measurements are AOT, ρ_{atm}, $T(\mu_s), T(\mu_v)$. Two alternatives:

(i) These quantities can be printed out. It is the case where GS software packages are available to public like for Seadass. ESA should be able to provide them on demand for MERIS using MEGS.

(ii) From the level 2 aerosol product, the users has the tool to generate the GS values of AOT, ρ_{atm}, $T(\mu_s), T(\mu_v)$. It has to be consistent with the level 2 algorithm, therefore, algorithms developers may provide the relevant software and attached LUTs.

The sky dome reflection

It is to validate the different methods proposed to remove the reflection of the sky dome during water leaving radiance measurements. Again, he has to be consistent with the algorithm; therefore, algorithm developers may provide the relevant software and attached LUTs.

BRDF model

The different conversion between reflectance and radiance, between marine and water leaving measurements should follows the protocols used in the GS. It is the role of the Space Agencies to provide relevant information and tools.

3. Conclusion and perspectives

Because the state of the art is mature for the validation of the ocean colour for case 1 water, this report just summarizes it and provides links to some validation sites. For ocean case 1, the one dimension retrieval of the chlorophyll content is based on a well defined path: chl-a_MR_normalized water leaving radiance.

We tried here to address the specificities of the validation of case 2 waters. First of all, the complexity of the inverse problem imposes new inversion techniques with a multi spectral approach. These inversed techniques can be applied on the bi directional WRSR which are therefore the natural outputs of the AC scheme. The MR and the water leaving radiance remains the basic in situ measurements but once need to define the protocol to transform those in situ measurements into WRSR. This protocol needs to be fully consistent with the inversion procedure of the WRSR. On a practical point of view, the new inversed techniques are trained with synthetic data. This synthetic data are outputs of RTCs feed with standard IOPs of the water body. The conversion of in situ measurements to WRSR in the satellite geometrical conditions should be based on the production of the algorithm synthetic data. Relevant tools havr to be made available by the algorithm developers.

In coastal areas, the aerosols are more unpredictable as the results of the presence of multiple sources of different origins. Complementary to the standard validation based on surface reflectance, we propose a validation protocol based on the validation of the different atmospheric functions used in the AC scheme. Clearly the key element of the AC is the aerosol path radiance L_{aer} in the visible. The measurement of the AOT can not be related to L_{aer} with no ambiguity because of the acknowledge of the aerosol phase function. More over, the need to use sky radiance measurements at the same scattering angle than the satellite measurement imposes to use automatic atmospheric stations as for AERONET and certainly the AERONET ocean colour network is a good opportunity. This approach needs to be validated by comparison to standard surface reflectance approach. Once validated, a clear protocol needs to be issued and relevant tools to be developed.

The validation of the ocean colour algorithm for case 2 waters is another issue. It can be conducted irregardless of satellite overpasses based on the collection of WRSR combines to in water measurements of the IOPs and/or constituents.