Validation Study for land product

Short description	Validation for land product
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	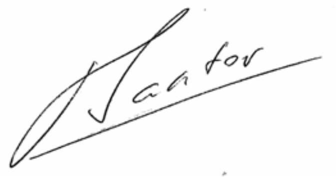
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Definitions, Acronyms, Abbreviations

AATSR	
AERONET	Aerosol RObotic NETwork (http://**aeronet**.**gsfc**.**nasa**.gov/)
AOT	Aerosol optical thickness
ARVI	Atmospheric Resistant Visible Index
AVHRR	Advance Very High Resolution Radiometer
BOA	Bottom Of the Atmosphere
BRDF	Bi-directional Reflection Distribution Function
CalVal	Calibration Validation
DDV	Dense Dark Vegetation
DEM	Digital Elevation Model
GLI	Global Imager (Japan, ADEOS)
LAI	Infrared and Visible Optical Sensors subgroup
LANDSAT	
MERIS	Medium Resolution Imaging Spectrometer (ESA Envisat)
METEOSAT	
MIR	Medium Infra Red (spectral region)
MGVI	MERIS Global Vegetation Index
MODIS	Moderate-Resolution Imaging Spectroradiometer (NASA EOS)
MODLAND	
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared (spectral region)
POLDER	Polarization and Directionality of the Earth's Reflectances (CNES, ADEOS)
SEVERI	
SPOT	Satellite Probatoire pour l'Observation de la Terre
TOA	Top Of the Atmosphere
TOMS	Total Ozone Mapping Sensor
VI	Vegetation Index

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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 land product validation. Validation is a level 2 activity. Validation of upper levels can be of course related, but we will not address this issue here.

We started in §2 by the optical parameters with the definition at level 1 (TOA) and how to get the BOA reflectance first through the aerosol remote sensing and second through the atmospheric correction. This section 2 presents similarities with the ocean branch.

The validation, in §3, first report the strategy to validate the atmospheric correction and the evaluation of the aerosol product participates to it. The definition of the bio-geophysical products can be specific for one mission. For MODIS, MODLAND is the reference on the subject.

2. The land optical products

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 and the view azimuth angle

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.

One important point to underline is that the estimate (or measurement) of E_0^+ is conducted for an horizontal surface. Therefore, equation (8) only applies to horizontal surface.

2.2 Getting the surface reflectance

Correct from the gaseous absorption

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 gaseous transmittance is computed on the direct to direct path. It is relevant for the ozone absorption which takes place in the stratosphere. It is reasonnable for others atmospheric absorbants in the NIR or MIR because in these spectral regions the land is bright enough to emphazise the direct to direct contribution.

Correct from the Rayleigh scattering

The second step is to remove the Rayleigh contribution. The inputs are the barometric pressure, generaly provided at sea level) and the elevation (provides by a DEM) to correct for.

For MERIS, http://envisat.esa.int/instruments/meris/pdf/atbd_2_15.pdf, the so-called surface reflectance is actually a « bottom of Rayleigh reflectance » because only the Rayleigh scattering is accounted for in the atmospheric correction scheme.

Characterize the aerosols: an aerosol product

Thanks to the addition of new spectral bands, mainly in the blue (MODIS,MERIS,POLDER,...), there are potentialities to remote sense the aerosols over land and therefore to achieve atmospheric correction. The surface reflectance is a level 2 product proposed by several missions (MODIS,POLDER,MERIS). These atmospheric corrections are less accurate than over the ocean due to the real difficulties to remote sense the aerosols mainly on a pixel basis.

For specific pixels and in dedicated spectral bands, the land can appear dark. Even so, the surface reflectance level is of the order of magnetide of the aerosol reflectance one. The aerosol remote sensing over land is a difficult task and a short cut is to rely on an aerosol climatology which provides standard values of the aerosol models. Therefore, once can used these standard models to achieve the atmospheric correction. Alternatively, based on a priori knowledge on these standard aerosol models, you can use spectral indices which are built to be resistant to the presence of the aerosols. It is the case of the ARVI.

The aerosol remote sensing requires to know the residual contribution of the surface. It is restricted to specific pixels in specific spectral bands. The dense dark vegetation (DDV) is one popular candidate which offers to be quite dark in the blue and to some extend in the red. But an universal DDV model does not exist and LUTs of DDV reflectance have to be built.

More over, a strict concept of DDV pixels only concern a small percentage of pixels. This DDV concept needs to be extended to “less dark” pixels.In order to apply the atmospheric correction on a pixel by pixel basis, once needs to extend the aerosol product to all the land pixels using any interpolation numerical technique.

This aerosol remote sensing is generaly confined to a directionnal reflectance measument in the blue and in the red. Of course, some sensors offer a “plus”:

(i) Better selection of the DDV reflectance using correlative measurements in the MIR (MODIS)

(ii) Multidirectionnal views (MISR, POLDER)

(iii) Polarization (POLDER)

(iv) UV spectral bands (GLI, TOMS)

Atmospheric correction

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}. The estimate of L_{atm} results from a radiative transfert code (RTC) run with a black land surface.

The apparent contribution of the land surface is:

$$L_s^* = L_{ng}^* - L_{atm} \quad (10)$$

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. The surface leaving radiance is:

$$L_s = L_s^* / T(\mu_v) \quad (11)$$

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

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

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

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

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

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

Characterize the aerosols using a land surface reflectance model

The land surface reflectance is modelized. A library (or an analytical formulation) of surface reflectance models is available. The same library is generated with aerosol standard models. The game is not the same:

(i) It is a multi spectral approach using spectral band for which the surface is bright.

(ii) It is on a pixel by pixel basis.

(iii) The outputs of this global approach are the aerosol model and the surface reflectance.

The quality of the retrieval depends upon the use of these retrieved surface reflectance. It can be level 2 product (biophysical parameters: FAPAR, LAI,…) or land classification. Therefore, the validation should reflect in priority the quality of the final product. The aerosol model and the surface reflectance are intermediaite break points.

2.3 Validation of the atmospheric corrections

Validate the aerosol product

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.

Most of the time, the atmospheric correction is a derived product from the aerosol remote sensing. Therefore, the validation of the atmospheric correction is limited to the validation of the aerosol product.

Vermote E., El Saleous N. Z. and Justice C. O., Atmospheric correction of MODIS data in the visible to middle infrared: first results**:** Remote Sensing of Environment, 83: 97-111.

Validate the surface reflectance

A regular level 2 product is the surface reflectance. Validation of the surface reflectance is a difficult task which needs first to combine at the time of overpass a representative sampling of the surface reflectance at the pixel size. It also needs to account for the difference in geometry between satellite and ground based measurements. On a practical point of view a validation strategy can be only relevant for high spatial resolution sensors which allows to collect representative samples of the surface reflectance at nadir, which is the common view geometry of high spatial resolution sensors.

One difficulty with this validation is for heterogeneous surface is the contamination by the so-called adjacency effects.

Validate the atmospheric functions

The atmospheric correction, based on the 6S formulation, requires the knowledge of L_{atm} and $T(\mu)$. By definition $T(\mu)$ is directly comparable to the total irradiance at the surface which can measured accurately. The sky radiance measurements can be used to validate L_{atm} at least when the scattering angle Θ of the satellite observation can be reached from the ground based observations; i.e. Θ >150°.

3 The land biophysical products and associated validation

3.1 The standard daily

As we already pointed out, the atmospheric correction is less critical over the land than over the ocean. That the reason while a first set of level 2 products have been derived from the level 1 TOA radiance (or reflectance) or even from the level 0 (digital counts). Different spectral indices have been used (see http://hyperdaac.webthing.com/html/rsvegfaq.txt for an extensive review). The most popular of it is the Normalized Difference Vegetation Index :

$$NDVI=(NIR-red)/(NIR+red) \quad (14)$$

The validation of the TOA spectral indices is a calibration activity. It is mostly radiometric and more specifically an interband calibration. For the MERIC MTIC, the quality of the product also depends on the spectral calibration: MTCI requires a correction of the so-called smile effect.

For MODIS, analyses from various field and flux tower validation campaigns indicate good agreement of VI values with land surface biophysical properties for most biomes, and the correlation across sensors (AVHRR, Landsat, SPOT, etc...) is very strong.

Gao X., Huete A. R., and Didan K. Multisensor comparisons and validation of MODIS vegetation indices at the semiarid Jornada Experimental Range. IEEE Transactions on Geoscience & Remote Sensing, 41(10):2368-2381

To account for the atmospheric effect, a set of spectral indices has been conceived to be less sensitive the presence of the atmosphere (ARVI,). On the MERIS vegetated pixels, (http://envisat.esa.int/instruments/meris/pdf/atbd_mgvi_jrc.pdf),TOAVI or MERIS Global Vegetation Index (MGVI) is estimated in two steps. First, the information contained in the blue band at 442 nm is combined with that in the bands at 681 and 865 nm traditionally used to monitor vegetation, in order to generate "rectified channels" at these latter two wavelengths. The "rectification" is done in such a way as to minimise the difference between those rectified channels and the spectral reflectance that would be measured at the top of the canopy under a standard geometry of illumination and observation. The proposed algorithm assumes that ratios of polynomials are appropriate to generate both the "rectified channels" and the final spectral index, MGVI.

Kaufman, Y. J., Tanre, D. (1992) "Atmospherically resistant vegetation index (ARVI) for EOS-MODIS, in _Proc. IEEE Int. Geosci. and Remote Sensing Symp. '92_, IEEE, New York, 261-270.

3.2 The multi view sensor

One useful piece of information on the structure of the canopy is the bi –directional reflectance function (BRDF). This function has been originally derived in the past from time composite using sensors on polar platforms such AVHRR. Different sensors have multi angular possibilities. POLDER (http://smsc.cnes.fr/POLDER/A_produits_scie.htm) provides directional surface reflectances at 443, 565, 670, 765 and 865 nm. MISR offers also the possibility to derive the BRDF. To some extend, AATSR thanks to it dual view may give information on the BRDF.

Geo stationary sensors such as METEOSAT with SEVERI can be used thanks to the daily cycle of the solar illumination.

Bicheron, P, and M. Leroy, Bidirectional reflectance distribution function signatures of major biomes observed from space, Journal of Geophysical Research, 105 , 26,669-26,681, 2000.

Diner D. J. et al, Multi-angle Imaging SpectroRadiometer (MISR) Level 2 Surface Retrieval. (http://www-misr.jpl.nasa.gov).

3.3 The composite product

The presence of clouds is the first obvious limitation to land remote sensing. The composite products may first be used to access to the land properties under clear sky.

As already mentioned, the properties of the land surface present a better time stability of the atmosphere (mainly of the aerosols). The presence of aerosols smooth the spectral behaviour. Therefore, clear days should correspond to the maximum value of a given spectral index. The MODIS Vegetation Index is retrieved using a state-of-the-art compositing method. This method is MODIS-specific and uses product quality flags and a constrained view angle to determine the maximum value. For most cloud- and snow-free, low aerosol load pixels, the VI values are very reliable. The VI product is particularly dependent upon coherent inter-band (blue, red and NIR) atmospheric correction and thus may be unstable over extreme bright or dark surfaces.

3.4 The land surface biophysical properties

From the spectral indices, once can derived biophysical properties. The most popular are the LAI (Leaf area index) and the FAPAR(Fraction of Absorbed Photosynthesis Active Radiation). The FAPAR can be instantaneous or daily as it is for the marine PAR.

Most of the time, the spectral indices are used to predict the biophysical parameters. Therefore validation of the spectral indices consist in the ability to correctly predict FAPAR and/or LAI . For example, MGVI is used to predict the FAPAR:

(http://fapar.jrc.it/WWW/Data/Pages/FAPAR_Projects/FAPAR_ESA/FAPAR_ESA.php).

Validation at has been achieved for the LAI and FPAR product. Field measurements from 29 sites, representative of major global vegetation types, were regressed against corresponding MODIS LAI pixel values, with a resulting R2 value of 0.87 and an RMSE of 0.66. An extensive review is available for MODIS at http://landval.gsfc.nasa.gov/

Rasmus Fensholt, Inge Sandholt, Michael Schultz Rasmussen, Evaluation of MODIS LAI, fAPAR and the relation between fAPAR and NDVI in a semi-arid environment using in situ measurements Remote Sensing of Environment 91 (2004) 490-507

Fred Huemmrich, Jeff Privete, Mukufute Mukelabai, Ranga Myneni, Yuri Knyazikhin.Time-series validation of MODIS land biophysical products in a Kalahari woodland, Africa . International Journal of Remote Sensing, Vol. 26, No. 19, 10 October 2005, 4381-4398

Bin Tan, Jiannan Hu, Ping Zhang, Dong Huang, and Nikolay Shabanov .Validation of Moderate Resolution Imaging Spectroradiometer leaf area index product in croplands of Alpilles, France . JGR, VOL. 110, D01107, doi:10.1029/2004JD004860, 2005

Yujie Wang, Curtis E. Woodcock, Wolfgang Buermann, Pauline Stenberg, Pekka Voipio, Heikki Smolander, Tuomas Häme, Yuhong Tian, Jiannan Hu, Yuri Knyazikhin, Ranga B. Myneni .Evaluation of the MODIS LAI algorithm at a coniferous forest site in Finland Remote Sensing of Environment 91 (2004) 114-127.