LAND SURFACES LEVEL 2 :

ATMOSPHERIC SCATTERING CORRECTIONS

Aim of the algorithm : Improvement of atmospheric corrections, by taking into account the surface anisotropy and performing some aerosol correction, without over-correcting the surface reflectances.

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Development of the POLDER "Land Surfaces" algorithms results from a joint effort of Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Laboratoire d'Optique Atmosphérique (LOA), and MEDIAS-FRANCE. It has been supported by CNES (Centre National d'Etudes Spatiales).

1 INTRODUCTION

After cloudy pixels are eliminated, reflectances are corrected from the effect of absorbing gazes (O2, O3 and H2O) and stratospheric aerosols.
Two main improvements have then been brought to the atmospheric scattering corrections :
- we no longer use the lambertian hypothesis for the final inversion of surface reflectances and
- we now simultaneously correct from Rayleigh scattering and partly from the scattering and absorption due to tropospheric aerosols.

2 SOLVING THE RADIATIVE TRANSFER EQUATION (RTE)

In order to solve the RTE, we need an a priori knowledge of the Bidirectional Reflectance Distribution Function (BRDF). For the first POLDER algoritm, the lambertian hypothesis was adopted : the BRDF is assumed anisotropic. In this case the surface reflectance ρ_s is linearly related to the Top Of Atmosphere reflectance ρ_{TOA}. However, amplitudes of inverted directional signatures are underestimated using this simplifying assumption. Hu et al. (1999) have shown that under various atmospheric conditions, relative error in the red and near infrared goes on average from 2 to 7% and may reach 15%.

So we decided to follow the scheme developed for MODIS Land Surfaces processing (Vermote et al., 1997) : we suppose we have an a priori knowledge of the BDRF, through a BRDF model noted ρ^m , and we slightly modify the RTE (see Vermote et al., 1997 for notations) :

$$\begin{aligned}\rho_{TOA} = \rho_{R+A} + {} & \\ & e^{-\tau/\mu v}\, e^{-\tau/\mu s}\, \rho_s + \\ & e^{-\tau/\mu v}\, t_d(\mu_s)\, \bar{\rho} + e^{-\tau/\mu s}\, t_d(\mu_v)\, \bar{\rho}' + \\ & t_d(\mu_s)\, t_d(\mu_v)\, \bar{\bar{\rho}} + T_{R+A}(\mu_s)\, T_{R+A}(\mu_v)\, S\, \bar{\bar{\rho}}^2 / (1 - S\, \bar{\bar{\rho}})\end{aligned} \qquad (a)$$

using this ρ^m :

$$\begin{aligned}\rho_{TOA} = \rho_{R+A} + {} & \\ & e^{-\tau/\mu v}\, e^{-\tau/\mu s}\, \rho_s + \\ & \rho_s\, [e^{-\tau/\mu v}\, t_d(\mu_s)\, \bar{\rho}^m/\rho_s^m + e^{-\tau/\mu s}\, t_d(\mu_v)\, \bar{\rho}'^m/\rho_s^m + \\ & t_d(\mu_s)\, t_d(\mu_v)\, \bar{\bar{\rho}}^m/\rho_s^m + \rho_s\, T_{R+A}(\mu_s)\, T_{R+A}(\mu_v)\, S\, (\bar{\bar{\rho}}^m/\rho_s^m)^2 / (1 - S\, \bar{\bar{\rho}}^m)\,]\end{aligned} \qquad (b)$$

So the $\bar{\rho}^m/\rho_s^m$, $\bar{\rho}'^m/\rho_s^m$ and $\bar{\bar{\rho}}^m/\rho_s^m$ terms of equation (b) do not depend on the unknown ρ_s, they only depend on the form of the BRDF model ρ^m and can be pre-computed, using a radiative transfer code.

We now get a second order equation :

$$\rho_{TOA} = A(\theta_s,\theta_v,\phi,z,\tau,iBRDF)\, \rho_s^2 + B(\theta_s,\theta_v,\phi,z,\tau,iBRDF)\, \rho_s + C(\theta_s,\theta_v,\phi,z,\tau) \qquad (c)$$

iBRDF representing an a priori BRDF model form.

3 DETERMINING A PRIORI BRDF MODELS FORMS

Each level 3 monthly synthesis of the first POLDER processing has produced global maps of the three coefficients of the Roujean model (Roujean et al., 1992). Hence we have at our disposal a unique BRDF database. So we have resolved to apply a data reduction to this database in order to extract a few number of BRDF-form prototypes. We used ACTS (N. Viovy, 2000), a software specialised in the classification of satellite data, using a k-means-like algorithm. We analysed the eight months of POLDER level 3 products and thus determined three great types : one quasi-isotropic model, standing for desert and snow, one for developed forests and one last for intermediate vegetations. How these prototypes are used is explained is section 5.

4 TAKING INTO ACCOUNT TROPOSPHERIC AEROSOLS

The three coefficients of equation (c) also depend on the optical thickness, including two components : Rayleigh and tropospheric aerosols.

Detection of aerosols over land surfaces is a very complex problem and POLDER is one of the few instruments who have the capacity to deliver aerosol information over land ; its original inversion method, based on polarisation, is not limited to Dark Dense Vegetation targets.

As we are now very confident in the POLDER retrieved aerosol optical thickness, we may consider using it to perform some correction of the tropospheric aerosols signal. Deuzé et al. (2001) have shown that the aerosol inversion algorithm is particularly sensitive to fine aerosols particles, only because they are polarising. These aerosols are mainly anthropogenic (Tanré et al., 2001), issued from biomass-burning and industrial pollution. On the contrary, this algorithm does not detect coarse particles, such as Saharan dust, because they do not polarise enough.

Our aim is to perform some aerosol correction, without taking the risk of over correcting the reflectances. As a consequence, the correction will be significant only for large aerosol load. For this purpose, we will use the aerosol optical thickness estimation based on a fixed aerosol model that displays a large polarized phase function. Because the inversion is based on the polarized reflectance, this model tends to generate an optical thickness estimate that is in the low range of possible values.

Choosing a fixed model

As we wanted a realistic model, we were very interested in the Dubovik models (Dubovik et al., 2002), which are inverted from AERONET measurements. Mainly dealing with vegetation we prefered a biomass-burning model : we chose the African Savanna model ; this model answers the constraints we had fixed of being polarising and absorbing and furthermore, according to Eck et al (2001), 80% of the remote-sensed fires take place in tropics and for the great majority in the African Savanna.

As Dubovik models are dynamic and we needed a completely determined one to compute the three coefficients of equation (c), we fixed tau440 = 0.5 and synthesised the fixed model with the following parameters :

Distribution

Parameters	Fixed model
r fine mode (µm)	0.08199
σ fine mode	0.174
N fine mode (particles / μm^2)	12.6504830
fraction fine mode	0.99979557
r coarse mode (µm)	0.72272
σ coarse mode	0.317
N coarse mode (particles / μm^2)	0.0025867
fraction coarse mode	0.00020443
r min (µm)	**0.05**
r max (µm)	15.0
ANGSTRÖM COEFFICIENT	2.10

Refractive index n and scattering albedo ω0

Parameters	Fixed model
n 443 nm	1.51 – i 0.021
n 670 nm	1.51 – i 0.021
n 865 nm	1.51 – i 0.021
ω0 443 nm	0.88
ω0 670 nm	0.84
ω0 865 nm	0.80

5 IMPLEMENTATION

As we cannot possibly include radiative transfer computations in the processing line because it would take to much CPU time, we have to use look-up tables.

Tables for coefficients A, B, C of equation (c) are computed using radiative transfer code 6S (Vermote et al., 1997). For each of the five wavelengths (443, 565, 670, 765 and 865 nm), dimensions are the following ones :

Angles	Minimum (degrees)	Maximum (degrees)	Step (degrees)	Number of values
ϕ	0	180	5	NB_PHI = 37
θv	0	80	5	NB_THETAV = 17
θs	0	75	5	NB_THETAS = 16

Optical thickness	Minimum	Maximum	Step	Number of values
τ865	0	0.5	0.05	NB_TAU = 11

(In the end, maximum should be equal to 1.)

BRDF Class	Minimum	Maximum	Step	Number of values
iBRDF	1	4	1	NB_BRDF = 4

NB_BRDF stands for the three BRDF model form prototypes plus the isotropic form.

Altitude	Minimum (km)	Maximum (km)	Step (km)	Number of values
z443	0	6	3	NB_Z443 = 3
z565	0	5	5	NB_Z565 = 2
z670	0	5	5	NB_Z670 = 2
z765	0	0	0	NB_Z765 = 1
z865	0	0	0	NB_Z865 = 1

Processing is decomposed in 4 steps :

1. Selecting iBRDF : First, we have to determine which a priori BRDF form we may attribute to the considered pixel. We use a simple directional criterion :

- We perfom a first inversion of the surface reflectances using the lambertian hypothesis, at 865 nm, because this wavelength provides the larger amplitude in reflectance.

- Considering we thus dispose of a BRDF section, we search among the three predefined BRDF forms which one would provide the nearest form for the same section (using a least-squares criterion) ; iBRDF stands for this nearest BRDF form.

2. Estimating τ865 : Among the aerosol models base is our fixed model. The aerosol inversion algorithm computes an optimal optical thickness for each model. So, for our own atmospheric corrections needs, we use this optimal τ865, computed for our fixed model.

3. We perform a multi-linear interpolation of tables A, B and C for dimensions other than iBRDF.

4. We may now extract the positive root of equation (c), which finally gives us ρ_s :
$\rho_s = (- B + \mathrm{sqrt}\ (B^2 - 4\ A\ (C - \rho_{TOA})) / (2\ A)$

6 REFERENCES

J.L. Deuzé, F.M. Bréon, C. Devaux, P. Goloub, M. Herman, B. Lafrance, F. Maignan, A. Marchand, F. Nadal, G. Perry and D. Tanré, Remote sensing of aerosols over land surfaces from POLDER-ADEOS-1 polarized measurements, *J. Geophys. Res.-Atmos* **106** (D5) : 4913-4926 (2001)

O. Dubovik, B. N. Holben, T. F. Eck, A. Smirnov, Y. J. Kaufman, M. D. King, D. Tanré and I. Slutsker, Variability of Absorption and Optical Properties of Key Aerosol Types Observed in Worldwide Locations, *Journal of the Atmospheric Sciences* **59** : 590-608 (2002)

T. F. Eck, B. N. Holben, D. E. Ward, O. Dubovik, J.S. Reid, A. Smirnov, M. M. Mukelabai, N.C. Hsu, N. T. O'Neill, and I. Slutsker, Characterization of the optical properties of biomass burning aerosols in Zambia during the 1997 ZIBBEE field campaign, *J. Geophys. Res.* **106** (D4) : 3425-3448 (2001)

B. Hu, W. Lucht, and A.H. Strahler, The Interrelationship of Atmospheric Correction of Reflectances and Surface BRDF Retrieval : A Sensitivity Study, *IEEE Trans. Geosci. Remote Sensing* **37** (2) : 724-738 (1999)

M. Leroy, Deuzé J.L, F.M. Bréon, O. Hautecoeur, M. Herman, J.C. Buriez, D. Tanré, Bouffies S., P. Chazette P. and J.L. Roujean, Retrieval of atmospheric properties and surface bidirectional reflectances over the land from POLDER, *J. Geophys. Res.*, **102** (D4) : 17023-17037 (1997)

J.L. Roujean, M. Leroy and P.Y. Deschamps, A Bidirectional Reflectance Model of the Earth's Surface for the Correction of Remote Sensing Data, *J. Geophys. Res.*, **97** (D18) : 20455-20468 (1992)

D. Tanré, F.M. Bréon, J.L. Deuzé, M. Herman, P. Goloub, F. Nadal and A. Marchand, Global observation of anthropogenic aerosols from satellite, *Geophys. Res. Lett*, **28** (24) : 4555-4558 (2001)

E.F. Vermote, N. El Saleous, C.O. Justice, Y.J. Kaufman, J.L. Privette, L. Remer, J.C. Roger, and D. Tanré, Atmospheric correction of visible to middle-infrared EOS-MODIS data over land surfaces : Background, operational algorithm and validation, *J. Geophys. Res.* **102** (D14) : 17131-17141 (1997)

E. F. Vermote, D. Tanré, J.L. Deuzé, M. Herman, J.J. Morcrette, Second Simulation of the Satellite Signal in the Solar Spectrum, 6S : An Overview, *IEEE Transactions On Geoscience And Remote Sensing* **35** (3) : 675-686 (1997)

N. Viovy, Automatic Classification of Time Series (ACTS) : a new clustering method for remote sensing time series, *Int. J. Remote Sensing*, **21** (6 & 7) : 1537-1560 (2000)