Atmospheric correction of multi-temporal mono-directional images : VENµS level 2 algorithms applied to Formosat-2 images

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ABSTRACT - *Usually, reflectance time series in the visible or near-infrared domain, such as those provided by SPOT satellites or by wide field of view instruments (VGT, MERIS, MODIS) are degraded by two geo-physical sources of variability: 1) atmospheric effects, mainly because of aerosol scattering, difficult to correct because Aerosol Optical Properties (AOP) are highly variable in time and place, 2) directional effects, since the observed surface reflectances depend on solar and observation angles.*

The VENµS mission will provide high resolution images every second day acquired with a constant observation angle in 12 narrow spectral bands ranging from 415 nm to 910 nm .With these features, the directional effects will be considerably reduced since only solar angles will slowly vary with time. Furthermore, when reflectance time series are free from directional effects, the following properties may be applied to perform atmospheric corrections:

- aerosol optical properties vary quickly with time but slowly with location.

- reflectances vary quickly with location but slowly with time, when observed with a constant viewing angle.

In a few days period, the top of atmosphere reflectance variations are mainly due to variations of aerosol optical properties, providing a way to estimate these properties. These properties will be used in Venµs level 2 algorithms.

To develop and test Venµs atmospheric corrections, a data set partly similar to Venµs ones has been acquired thanks to Formosat-2 satellite, a Taiwanese high resolution satellite with 4 spectral bands. Images are being acquired every 3 days for a site in France, every 4 days for a site in Morocco, with constant observation angles. AERONET sun photometers measurements are available on both sites. First results and performances of the atmospheric correction method are presented in this article.

1 INTRODUCTION

Atmospheric correction is one of the key steps to obtain surface reflectances from spaceborne optical instruments working in the visible and near infrared domain. The main difficulty of this processing is the correction of the effects of atmospheric aerosols. In the visible domain, the Top Of Atmosphere (TOA) reflectance above dark targets (vegetation cover for instance) may vary by more than 100% when comparing a hazy day to a clear day. To perform accurate atmospheric corrections, knowledge of the nature and quantity of aerosols in the atmosphere is necessary.

Unfortunately, there is no operational source of measurement that provides this information on all places at all times. The most reliable system is the AERONET sun photometer network which acquires measurements from the ground at a few hundreds of sites around the world (Holben et al, 1998). But of course these sun-photometers are not available anywhere. Moreover, AERONET data often have data gaps when the sensor is being calibrated, and in all circumstances, they would only provide one measurement for the whole Venµs site, whereas the optical thickness will probably vary within the site, especially if the altitude within the image is not constant.

Venµs is a research satellite: its aim is to develop new processing algorithms, we thus decided to explore the possibility of using Venµs imagery itself to detect aerosols and correct their effect on Venµs images. Inversion of Aerosol Optical Properties (AOP) from remote sensing images is not an easy task, especially above land. The difficulty can be explained easily with equation (1), which is a first order approximation of atmospheric radiative transfer :

$$r_{TOA} = t_g.(r_{surf}.T_{atm} + r_{atm}) \qquad (1)$$

for each measurement of TOA reflectance r_{TOA} ,we have two unknowns: the surface reflectance r_{surf} and the atmospheric radiative properties T_{atm}, r_{atm} (resp. the atmospheric transmission, and the atmospheric path reflectance), t_g is the transmission of molecular gases in the atmosphere. Despite this difficulty, the inversion of AOP has been attempted using many methods that add hypotheses to determine simultaneously surface reflectance and the aerosol optical properties.

The sensors of POLDER family enable to invert aerosols thanks to measurements of light polarisation (Deuzé, 2001), but this method is not available for Venµs. Venµs is also unable to measure reflectance in many viewing directions

Second Recent Advances in Quantitative Remote Sensing. 2005. Edited by José A. Sobrino, Universitat de Valencia, Spain - ISBN: 84-370-6533-X ; 978-84-370-6533-5 - Pages 776-781

simultaneously, whereas it is used to invert AOP with the ATSR sensor family (North, 2002).

Another family of algorithms uses hypotheses on a spectral relationship between surface reflectances measured in two or more spectral bands (Remer, 2005). These methods are usually not very efficient on bright targets, and work better if a Short Wave Infrared (SWIR) band is available, but Venµs has no SWIR band. However, some interesting results have been obtained with MERIS sensor that has a set of spectral band very close to Venµs' (Guanter 2004, von Hoyningen-Huene, 2003). These methods might be used for Venµs.

But Venµs satellite will have a unique feature that may be used to invert aerosols: the ability to make measurements with a 2 day revisit period, with constant viewing angles. Thanks to this feature, the TOA reflectance variations during a couple of days are mainly related to atmospheric effects. Such a property was explored with Landsat by Tanré et al, (Tanré, 1988), but it concentrated mainly on the blurring effects and not on the reflectance variations, mainly because the time lag between acquisitions was too long. The method planned for Venµs is explained in §2, and first results obtained with Formosat-2 images are shown in §3.

2 AOP INVERSION METHOD FOR VENµS

2.1 Venµs and Formosat-2 images

The Venµs mission is primarily designed for providing measurements over land surfaces. The objective is to offer the scientific community the opportunity to develop the use of high spatial and temporal resolution data.

The Venµs satellite (Dedieu et al, this conference) will provide high resolution images every second day. The resolution of Venµs products is 10m, for a field of view of 27km. The instrument delivers images in 12 narrow spectral bands ranging from 415 nm to 910 nm. 50 sites will be imaged by Venµs, for two years, starting in 2009. One important characteristic of Venµs images is that a given site will be acquired with constant observation angles, thus minimizing directional effects: only sun angles vary, but since the satellite is on a sun-synchronous orbit, the variation within a month is just a few degrees.

Formosat-2, a satellite owned by Taiwan National Space Organisation (NSPO), provides images with features very close to Venµs'. The resolution of Formosat-2 multispectral images is 8m, for a field of view of 24 km. It provides images in 4 spectral bands, centred at 488, 555, 650, 830 nm. Thanks to its orbital cycle of one day, it is able to acquire data on a given site every day, with constant observation angles.

Formosat-2 was launched in May 2004; its images can thus be used to simulate Venµs images. We have been able to obtain two data sets over two sites where an AERONET sun photometer is available. These sites have been acquired every third day during 7 to 12 months. One of the sites is situated at an irrigated agricultural site in Morocco, the other one is in France: an agricultural region of France, near Toulouse, with a mixture of winter and summer crops.

2.2 Method description

Our inversion method uses the following properties:

- the directional effects on VENµS time series are minimised, thanks to constant viewing angles. Of course, Sun angles do change with time, but may be considered constant during one or two weeks.

- the aerosol optical properties (AOP) vary quickly with time but slowly with location.

- the surface reflectance varies quickly with location but slowly with time (with exceptions that need to be detected before aerosol inversions).

As a result, any quick variation of TOA reflectance should be interpreted as due to a variation of AOP. It is thus possible to invert the AOP with the following scheme.

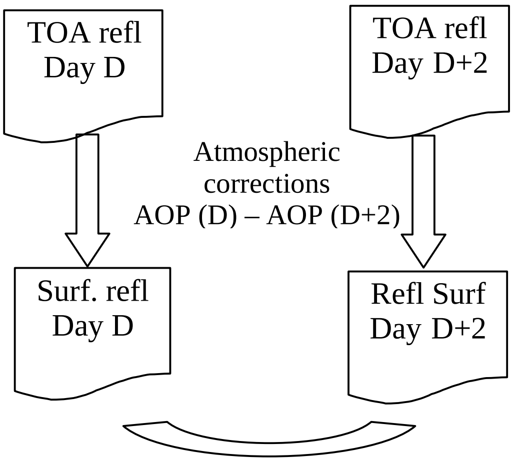

Figure 1: *Scheme of a first version of aerosol inversion cost function.*

Let us assume the Venµs acquisitions of day D and D+2 are cloud free (if it is not the case, one can use D+4 or D+6…). Within such a short duration, surface reflectances should not change: we can therefore search the AOP of day D and D+2 minimise the sum of squares of the differences of surface reflectance of day 2 and day D+2, for a neighbourhood of pixels (Figure 1). In this inversion, we have two unknowns: the AOP of D and D+2, and many equations: one equation per pixel of the neighbourhood and per spectral band. The atmospheric correction is performed using look-up tables built with the Successive Orders of Scattering (SOS) code: (Deuzé, 1998). In this first test of the method, the aerosol model is fixed, and the only parameter to estimate is the aerosol optical thickness (AOT).

Even if this method uses relative variations of reflectance, it is able to determine absolute values when the reflectance of the pixels used for the inversion are not constant. This may be understood with the example on Figure 2. On the image of November 21st, a higher optical thickness causes an increase of surface reflectance, but this increase is different depending on the surface reflectance of the pixel. The differences in reflectance increase due to aerosols are use to invert the absolute value of the AOP.

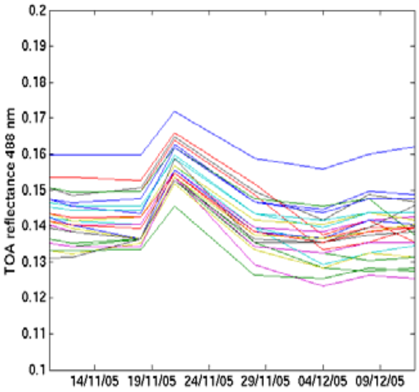

Figure 2: *Variations of TOA reflectance in Formosat-2 blue band as a function of time, each curve corresponds to a different pixel in an agricultural site in Morocco. For a few pixels, reflectance variations are due to the ploughing of some parcels. But the sudden variation of the reflectance of all pixels on November 21st is due to a higher aerosol optical thickness.*

However, when two successive acquisitions are obtained with nearly identical AOP, our method is undetermined, since, if TOA reflectances of day D and D+2 are identical, of course, any value of the optical thickness will deliver identical surface reflectances. (See Figure 3)

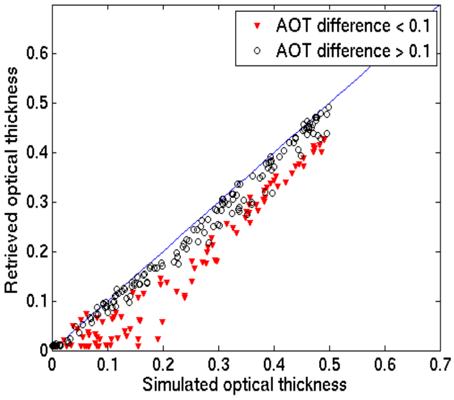

Figure 3 : *Inversion of Aerosol Optical Thickness (AOT) with simulated data. 200 days of top of atmosphere reflectances have been simulated with random AOT and a constant aerosol model. The inversion of the AOT with the scheme on Fig 2 is correct when the difference of AOT for two successive days is greater than 0.1.*

To cope with this problem, we have somewhat complicated the cost function (Figure 4) : we search for AOP of day D and D+2 in order to minimise the differences between surface reflectances of day D and D+2 as in Figure 1, and also the differences with an a priori knowledge of surface reflectances. The a-priori reflectance comes from a previous iteration of this algorithm, for instance with day D-2 and D. If the AOP of day D and D+2 are different, the method works as shown previously, if not, the use of the a priori reflectance still enables to invert the optical thickness.

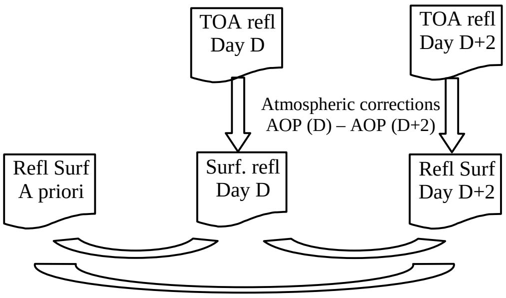

Figure 4 : *Scheme of the current version of aerosol inversion cost function.*

The initial a-priori surface reflectance is obtained by applying atmospheric corrections to the first image of the time series with an arbitrary optical thickness. We have verified that the algorithm converges after a few dates.

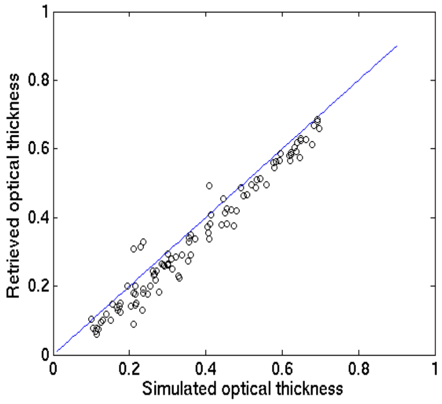

Figure 5 *: Results with same simulations as for Figure 3, but with the cost function described in Figure 4. Convergence is obtained for the 5th image (values before convergence are above the identity line.*

3 RESULTS WITH FORMOSAT-2 DATA

Our method has been applied to Formosat-2 time series. For this, Formosat-2 images have been sub-sampled to 100m in order to avoid noise and registration errors, and a neighbourhood of 7*7 low resolution pixels has been used to invert the optical thickness of aerosols. For the moment, we use only Formosat-2 488nm spectral band, because this band is the most sensitive to aerosol effects, and because surface reflectance in this band are much more stable with time than for the other bands. The aerosol model is supposed constant for all the sites and all the dates. We have used a log normal size distribution with a modal radius of 0.7 and a refraction index of 1.44-0.03i, ie some sort of a continental model.

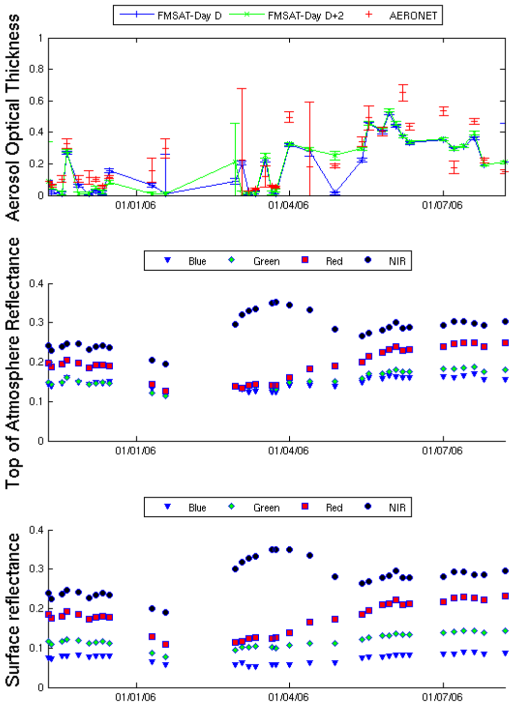

Figure 6 : *results of aerosol optical thickness estimation as a function of time for a neighbourhood of pixels in Morocco Formosat-2 time series (a fallow). From top to bottom : 1) Retrieved optical thickness when the date is used as day D (blue) or D+2 (green), compared to optical thickness derived from AERONET (red). 2) Top of atmosphere reflectance for all Formosat-2 channels, 3) surface reflectance for all Formosat-2 channels*

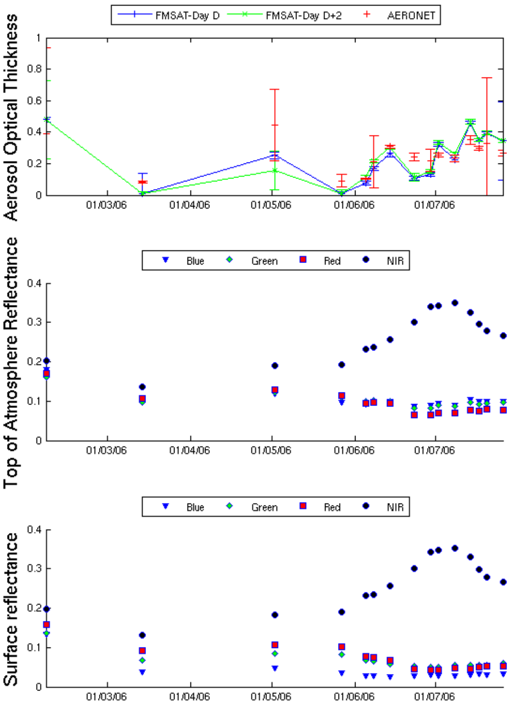

Figure 7 : *Same as Fig 6 for the site near Toulouse. The pixel depicted corresponds to a summer crop.*

Fig 6, 7 and 8 show a pretty good agreement between AERONET measurements of aerosol optical thickness (AOT) and our measurements using Formosat-2. Moreover, for a given date, the aerosol estimates obtained when the date is used as day D or day D+2 are also very consistent. The TOA reflectances time series are already very smooth, thanks to the absence of directional effects, but, after correction, the smoothness of reflectances is nicely enhanced for the blue and green spectral bands, somewhat enhanced for the red band, whereas the near infra-red band smoothness is not much affected by our correction, because the atmosphere is much more transparent at that wavelength.

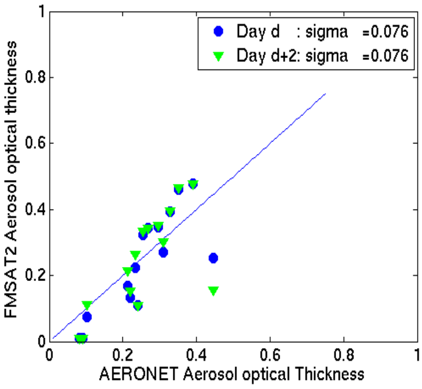

Figure 8 *shows the comparison of optical thicknesses derived by our method and by the AEROSNET instrument, for the site near Toulouse. The standard deviation is below 0.1, which was our aim initially*.

4. CONCLUSIONS

We have developed a very new method to invert aerosol optical properties from high resolution images with a high revisit frequency and constant observation angles. This method has been tested on two different time series of Formosat-2 images, and the results shows a good agreement with in-situ measurements of AERONET. The reflectances after atmospheric correction are much smoother than the TOA reflectances, at least for the visible channels. This method is going to be implemented in Venµs level 2 operational algorithm, but it may also be worth trying to apply it to other satellites with a high revisit frequency and constant observations angles: for instance, the weather geostationary satellites and POLDER 2 have these features.

5. REFERENCES

1 G. Dedieu, A. Karnieli, O. Hagolle, H. Jeanjean, F. Cabot, P. Ferrier, Y. Yaniv, VENµS: A joint Israel-French Earth Observation scientific mission with High spatial and temporal resolution capabilities, this conference, 2006

2 Holben, B. N., T. F. Eck, I. Slutsker, D. Tanre, J. P. Buis, A. Setzer, E. Vermote, J. A. Reagan, Y. J. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak, and A. Smirnov,: AERONET-A federated instrument network and data archive for aerosol characterization. Remote Sensing of Environment, 66, (1), 1-16, 1998

3 North, P.R.J. (2002), Estimation of aerosol opacity and land surface bidirectional reflectance from ATSR-2 dual-angle imagery:operationand method and validation, J. Geophys. Res., 107(D12)

4 Luis Guanter, Marıa Del Carmen Gonzalez, and Jose Moreno : Retrieval of Land surface reflectance and Albedo from MERIS data, , in Proc. of the 2004 Envisat & ERS Symposium, Salzburg, Austria 6-10 September 2004 (ESA SP-572, April 2005)

5 Remer, L. A., Y. J. Kaufman, D. Tanre, S. Mattoo, D. A. Chu, J. V. Martins, R. R. Li, C. Ichoku, R. C. Levy, R. G. Kleidman, T. F. Eck, E. Vermote, and B. N. Holben: The MODIS aerosol algorithm, products and validation. J. Atmos. Sci., 62, 947-973, 2005

6 Deuzé, J. L.; Bréon, F. M.; Devaux, C.; Goloub, P.; Herman, M.; Lafrance, B.; Maignan, F.; Marchand, A.; Nadal, F.; Perry, G.; Tanré, D : Remote sensing of aerosols over land surfaces from POLDER-ADEOS-1 polarized measurements, Journal of Geophysical Research, Volume 106, Issue D5, p. 4913-4926, 2001

7 von Hoyningen-Huene, W.; Freitag, M.; Burrows, J. B. : Retrieval of aerosol optical thickness over land surfaces from top-of-atmosphere radiancen, Journal of Geophysical Research (Atmospheres), Volume 108, Issue D9, pp. AAC 2-1,2003

8 D. Tanré, C, Devaux; M. Herman, P Y; Deschamps, Estimation of Saharan aerosol optical thickness from blurring effects in Thematic Mapper data, 1988 Journal of Geophysical Research. Vol. 93, pp. 15955-15964.

9 J. L. Deuzé, M. Herman, and R. Santer, Fourier series expansion of the transfer equation in the atmosphere-ocean system, J. Quant. Spectrosc. Radiat. Transf., vol. 41, no. 6, pp. 483-494, 1988.

6 ACKNOWLEDGEMENTS

AERONET sun photometer network, SPOT-IMAGE and NSPO for Formosat-2 data.