

AN UPDATE OF A GOME-METEOSAT METHOD FOR AEROSOL OPTICAL THICKNESS DETERMINATION AND CLASSIFICATION

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ABSTRACT

A method based on the synergy between GOME and METEOSAT data was developed to derive aerosol optical properties and thickness. Costa et al. (1999) have applied it to a desert dust outbreak that occurred in late spring 1997 over the Atlantic Ocean near the African coast.

A sensitivity study is presented on the algorithm's physical assumptions, as the ozone and water vapour vertical profiles and the type of surface considered. In addition, the radiative transfer calculations are tested by using models other than 6S. The impact that the uncertainties in METEOSAT's calibration might have on the results and the feasibility of the method is also examined.

A validation data set composed by aerosol optical thickness independent measurements is then defined using satellite (POLDER and AVHRR) and surface (AERONET) data.

1. INTRODUCTION

The interest in aerosol observations from satellite passive instrument is steadily increasing as a result of the better understanding of the key role played by aerosols within the climate system. Satellite instruments supply global observations for establishing the aerosol climatology and characterising single aerosol events.

Data from geostationary meteorological satellites, such as GOES and METEOSAT (Moulin et al., 1997) as well as from polar orbiting instruments as NOAA-AVHRR (Durkee et al., 1986; Stowe et al., 1997) have been widely used for monitoring the aerosol optical thickness (AOT) over the oceans. However, the use of such instruments for accurate aerosol quantification is problematic due to their wide spectral channels. On one hand, they do not allow for aerosol type characterisation, constraining the algorithms to the use of aerosol classes available in the literature and thus introducing significant errors in the AOT calculations. On the other hand, it is difficult to account for the surface reflectance effect as well as for gaseous presence as is the case of ozone and especially water vapour.

Costa et al. (1999) presented a method for aerosol characterisation and optical thickness retrievals, based on a synergy between polar (GOME - Global Ozone Monitoring Experiment, Burrows et al., 1999) and geostationary (METEOSAT) systems. It aims at a better exploitation of the advantages of both kind of sensors and at the same time overcome as much as possible their limitations. The application of the new algorithm that derives aerosol classes from GOME spectral measurements showed significant differences between the retrieved AOT values with respect to those obtained using fixed aerosol classes. The uncertainties in the METEOSAT VIS calibration are now taken into consideration in order to assess the significance of such differences with respect to the accuracy of the measurements.

A sensitivity study is presented for quantifying the effect of the physical assumptions on the surface reflectance and molecular vertical profiles (ozone and water vapour) on the retrieved AOT. Moreover, the performance of the radiative transfer model (Second Simulation of the Satellite Signal in the Solar Spectrum – 6S) is compared to MODTRAN-4 in terms of the AOT retrievals.

The validation is of crucial importance, a planning is presented using AOT values obtained from independent satellite, and ground based measurements. A data set from POLDER and AVHRR sensors and measurements from the ACE2 campaign and AERONET ground-based stations on chosen locations is defined.

2. DATA AND TOOLS

The sensitivity analysis is applied to the algorithm test case, corresponding to a strong desert aerosol transport between 6 and 8 June 1997 over the North Atlantic as shown in Figure 1. Hereinafter, results depicted in Figure 1 will be referred to as reference results.

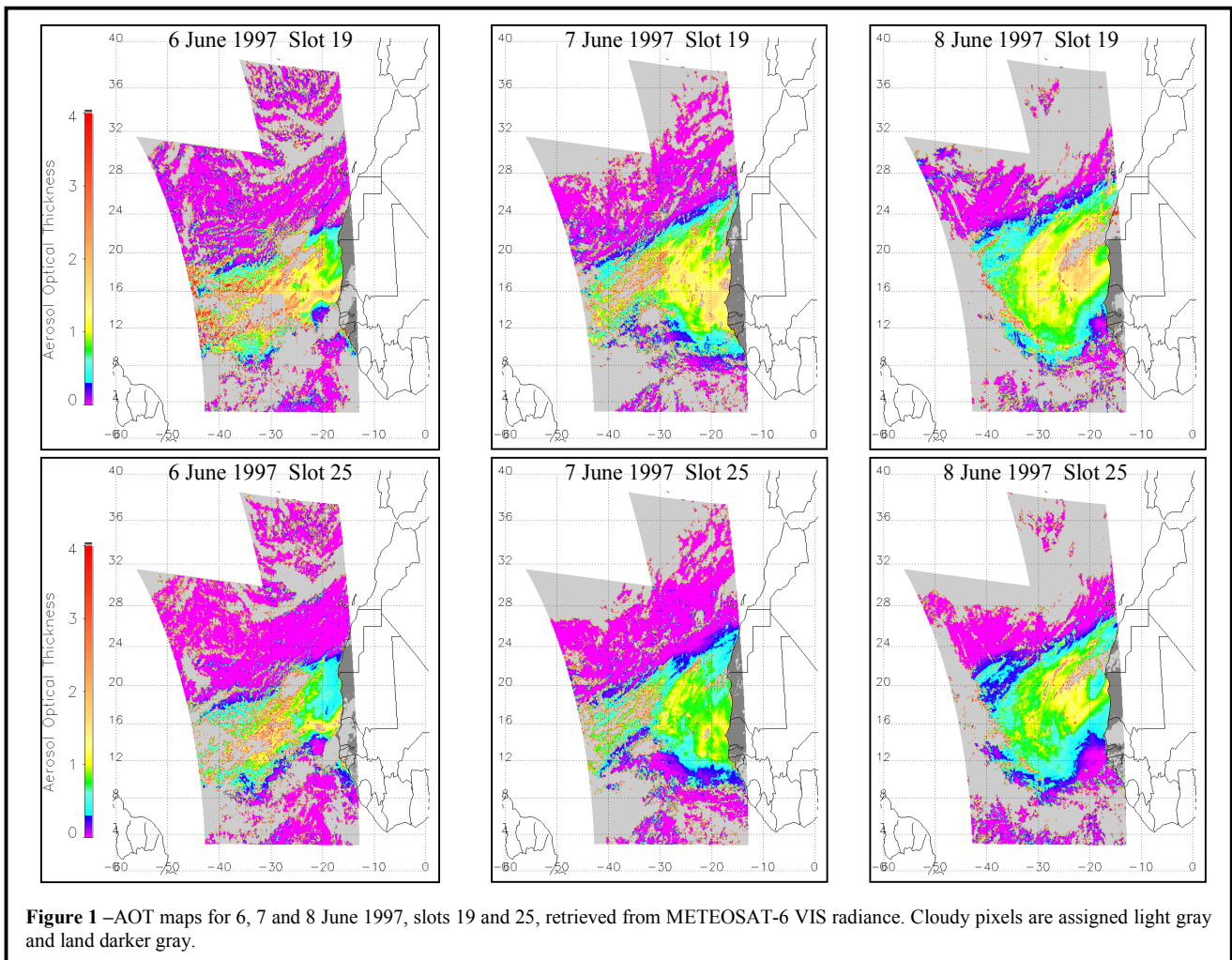
METEOSAT-6 visible and infrared full-disk data from slots 19 (0900 - 0925 UTC) and 25 (1200 - 1225 UTC) have been used for three consecutive days (6, 7 and 8 June 1997). GOME data from two orbits (113 from 6 June and 122 from 8 June 1997), temporally and spatially closest to some of the METEOSAT slots, have been used for the retrieval of aerosol optical properties.

METEOSAT pixels are classified using a statistical VIS-IR algorithm originally developed for the METEOSAT channels (Porcù and Levizzani, 1992). The method separates six different classes (water, land, broken cloud over water, broken cloud over land, cloud or, in case of problematic classification, an undetermined class). The only processed pixels are those correspondent to the ocean surface or in some cases to the undetermined class, that is usually associated with a strong aerosol event.

The radiative transfer model (RTM) used for the atmospheric radiative calculations, subject of the sensitivity analysis, is 6S (Vermote et al., 1997). Atmospheric tropical vertical profiles of pressure, temperature, concentration of water vapour and ozone are considered, as well as a lambertian ocean surface. As for the aerosol characterisation, two different groups of GOME-derived aerosol optical properties are used, one characteristic of maritime atmospheric conditions and another of desert dust (see Costa et al., 1999).

The two aforementioned aerosol classes are derived from GOME spectral reflectance measurements, assuming a tri-modal lognormal size distribution composed by a nucleation, an accumulation and a coarse mode, with the same spectral complex refractive index for the three modes. The GOME spectral reflectance is calculated in three spectral regions (0.361-0.427 μm , 0.753-0.756 μm , and 0.777-0.783 μm) for selected cloud-free ground pixels over the ocean and varying three parameters: the modal radius of the accumulation and coarse modes of the size distribution and the imaginary part of the spectral refractive index at 4 wavelengths (0.400, 0.488, 0.694 and 0.860 μm). Since the aim is to detect the spectral properties produced by varying the mentioned microphysical parameters, it has been decided to "freeze" the AOT at the same values (pixel by pixel) estimated by using exclusively GOME data and a-priori aerosol classes of Torricella et al. (1999). The variation is continued until the difference between simulations and measurements is minimised. When the fitting is satisfactory a new group of aerosol parameters representative of the actual atmospheric conditions is obtained – a GOME equivalent aerosol class. The spectral aerosol optical properties are then obtained at the four wavelengths, assuming that the particles are spherical and thus using the Mie theory.

The METEOSAT VIS radiance is simulated for METEOSAT observing geometries equally spaced by about 1° within the working scene, for 5 different AOT values (0.11, 0.22, 0.55, 1.1, 2.2) and for both aerosol type cases. Lookup tables (LUTs) are built that allow for the AOT retrieval, by applying the respective LUT according to the pixel's geographic location (the criterion was the nearest pixel where the simulation was done) and aerosol type. The selection of the aerosol class is crucial for the AOT retrieval. This was done by comparing the METEOSAT VIS radiance with simulations (solar and viewing zenith angles accounted for) obtained for an AOT of 0.3 and the GOME-derived maritime class. Till the METEOSAT VIS radiance is lower than the simulated threshold value the maritime-like type is kept, whereas the desert-like is considered in the opposite case. Figure 1 shows the maps of the retrieved AOT.



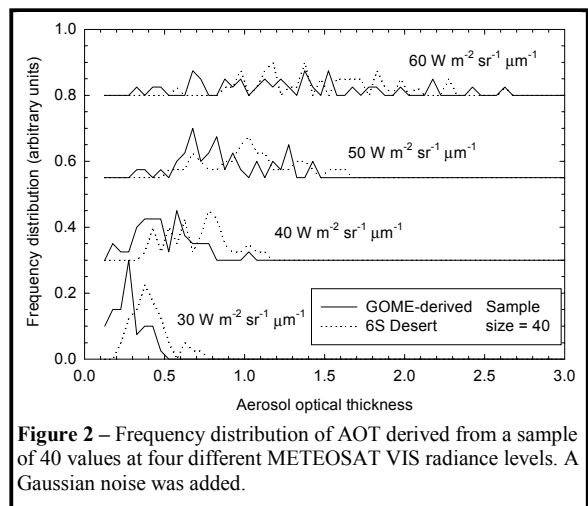
3. ANALYSIS OF RETRIEVALS

3.1. ACCURACY OF THE SATELLITE MEASUREMENTS

A statistical test is carried out to assess the significance of the differences in AOT obtained when using GOME-derived aerosol classes instead of fixed classes, with respect to the accuracy of the measurements. Generally, the compensation for systematic errors (the knowledge of the actual aerosol model) is a problem other than the random errors. In practice, there could be no point in improving the performance of the algorithm in case the accuracy of the sensor remains too low.

The hypothesis that needs to be tested is whether two samples of AOT values retrieved making use of the two different desert aerosol models can be considered as drawn from the same population, i.e. whether the average difference becomes negligible due to the high sample variances. The result depends strongly on the sample size N . Four radiance levels at fixed observing geometry and many N 's are tested. As N increases, even small systematic differences become significant. The aim is thus to find a lower limit to assess that the difference is significant at a fixed significance level (0.05).

The samples are generated by applying a Gaussian-distributed noise to selected METEOSAT VIS radiance levels. The sigma value (15% of the total signal) is determined from the estimation of the calibration errors (10% [Govaerts, 1999]) and spectral response (10% maximum, Govaerts personal



communication). Figure 2 shows the frequency distribution of the retrieved AOT at four different radiance levels for the two different desert type aerosol classes, one from the 6S code and another derived from GOME measurements. The

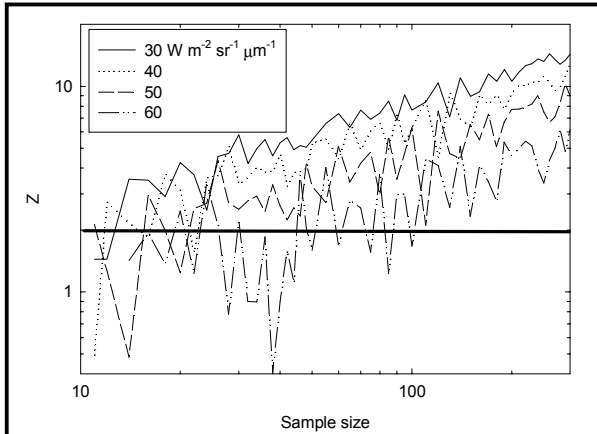


Figure 3 – Results from the Mann-Whitney U-test for different AOT samples as a function of sample size for the radiance levels of Figure 1. The 1.96 value of the normally-distributed Z variable (thick line) sets the rejection limit for the hypothesis that the two samples have been drawn from the same population, that is there are negligible differences between sample averages. The samples differ for the aerosol models used in the AOT retrieval.

Mann-Whitney U-test [Wilks, 1995; IDL, 1998] is applied to compute the statistic variable Z associated with the sum of ranks of the sample. Z is considered normally-distributed if $N > 10$. The plot of Z values against N is shown in Figure 3. The 0.05 (two-tailed probability) significance level is reached if $Z < 1.96$, otherwise the samples show significant differences. It becomes then hard to assess differences at the radiance level where the responses of the two aerosol models are identical ($60 \text{ W m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-1}$) (see Figure 6 of Costa et al., 1999). At the other radiance levels the two sample averages can be considered significantly different when N is greater than 20-25.

Since the repetition of exactly the same measurement with METEOSAT cannot be achieved, the result may be interpreted as follows: different AOT patterns in the analyzed VIS images make sense in spite of the random uncertainty in case at least few tens of pixels show similar levels of radiance and assuming the presence of quite the same aerosol type, as is the case for an intense aerosol transport event lasting several days.

3.2. SENSITIVITY TO SURFACE PARAMETERIZATION

AOT retrievals from one-channel algorithms are very sensitive to the surface reflectance (King et al., 1999). Therefore, the reference results obtained with the assumption of a lambertian ocean surface are now compared with those retrieved considering a Bidirectional Reflectance Distribution Function (BRDF) for the ocean surface, aiming at quantifying the differences between both cases. The BRDF ocean model inside 6S (Morel, 1988) was used. It takes into account wind speed and direction, ocean salinity and pigment concentration. For this purpose mean values for the considered geographical area and period are taken: wind speed of 6 m s^{-1} , wind direction of 45° , salinity of 35 ppt and pigment concentration of 0.3 mg m^{-3} . The AOT obtained in this way is confronted with the reference results (lambertian ocean surface) shown before in Figure 1 and the results are illustrated in the scatter diagram of Figure 4.

Absolute differences from reference AOT values, represented on the right axis of the diagram in Figure 4 are significant for low aerosol loads, as reported also by Mishchenko et al. (1999), whereas for the dust event differences are in general, lower than 10%. The scattering pattern of the dark points representing the differences should be tightly connected with different geometrical conditions and air masses. These arise from the use of METEOSAT slots 19 and 25 for the three days of study within the given geographical area (see Figure 1).

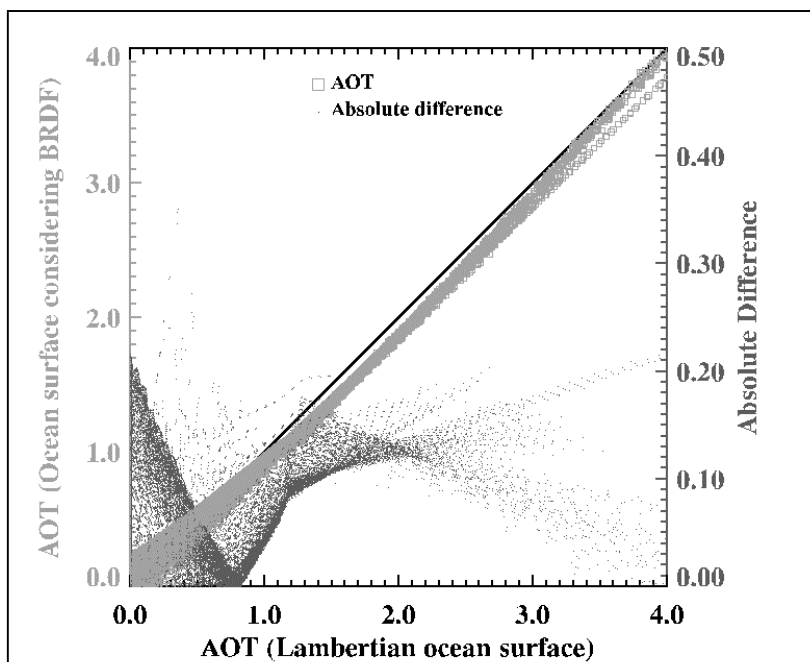
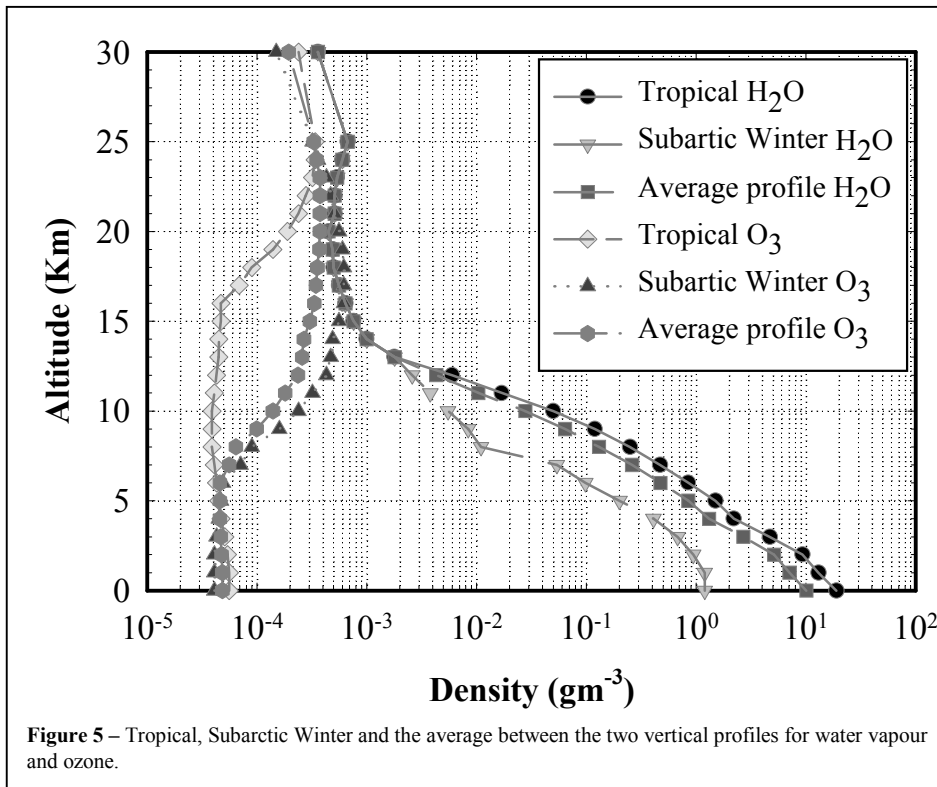


Figure 4 – Scatter diagram of the retrieved AOT considering the BRDF of the ocean surface vs the AOT retrieved for a lambertian ocean surface. The right-hand axis represents the absolute differences in AOT between both cases.

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3.3. SENSITIVITY TO ATMOSPHERIC VERTICAL PROFILES

Figure 5 represents several types of atmospheric vertical profiles for water vapour and ozone. The Tropical and Subarctic Winter are standard profiles from 6S,



whereas the average vertical profiles are calculated as the mean between both atmospheric types. The Tropical ozone total column is 0.278 atm cm and the Subarctic Winter 0.376 atm cm. As for the water vapour total column, the values for the Tropical and Subarctic Winter are respectively 5.12×10^3 and 5.18×10^2 atm cm.

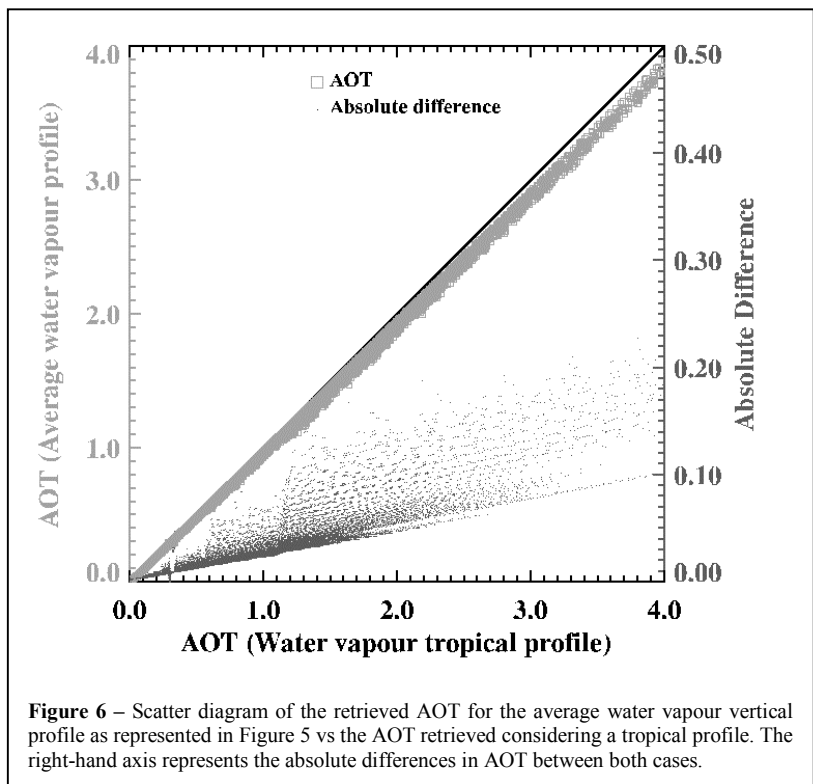
The reference results depicted in Figure 1 are obtained considering the Tropical atmospheric vertical profile of 6S. These results are now compared with those retrieved considering the average vertical profiles. Applied average water vapour and ozone vertical profiles may represent extreme conditions for the

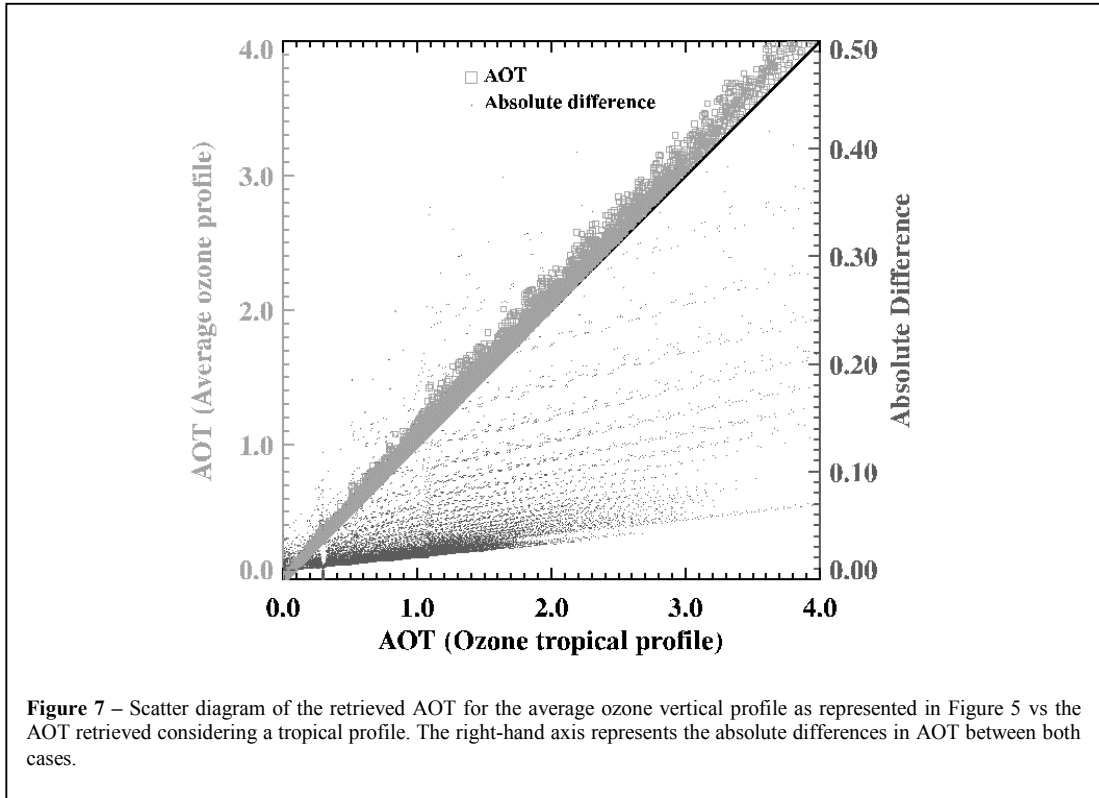
considered geographical area, therefore the resulting differences represent the upper limit for real atmospheric conditions. The next two Figures report the differences in AOT values when considering a different atmospheric vertical characterisation, respectively for water vapour and ozone. Results correspond to METEOSAT slots 19 and 25 for the three days study.

Absolute difference between the AOT reference value and that retrieved with the average water vapour profile reported on the right-hand axis of the diagram in Figure 6 are clearly lower than 0.2.

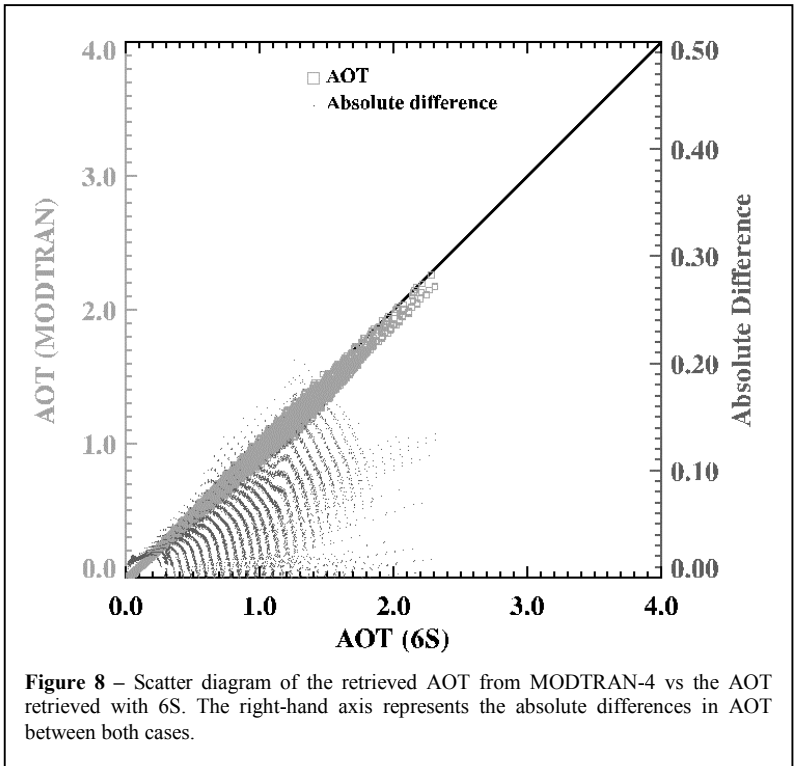
The results obtained with the average ozone profile are depicted in Figure 7. Although there are some cases with absolute differences slightly greater than 0.2, the majority of the points that represent the absolute difference fall under the 0.2 border, as in the water vapour case. Absolute differences from reference AOT values (calculated with water vapour and ozone Tropical profile) are less than 10%, for the majority of the cases.

Accordingly, higher accuracy is ensured by the use of latitudinal- and seasonal-dependent atmospheric profiles.





3.4. SENSITIVITY TO THE RADIATIVE TRANSFER MODEL



6S RTM was used. Its performance is now compared with MODTRAN (Berk et. al, 1998). The model is set to use DISORT discrete ordinates multiple scattering algorithm with 8 streams. The atmospheric gas and aerosol as well as the surface characterisation are the same used to obtain the reference results (see section 2.). Accordingly, differences are exclusively due to the different RTM used.

The AOT obtained from both models are plotted against each other on the diagram of Figure 8. Results refer to METEOSAT slot 25 for the three days study. The right-hand axis represents the absolute differences, which are variable but in general lower than 0.2. The scattering pattern of the differences should be once more related to different geometrical conditions and air masses.

4. VALIDATION

The algorithm developed to use GOME and METEOSAT data in a synergic way (Costa et. al, 1999) aims at the aerosol characterisation from the combined GOME and METEOSAT, as well as radiative transfer calculations. Results from selected episodes are now planned for validation purposes, for the period between June and July 1997. The next table summarises the validation plan.

	Platform	Source	Data	Scope	Period
Data to be validated	Satellite	METEOSAT	AOT over the ocean	Validation of the results for selected episodes	June-July 1997
		GOME	AOT over the ocean Aerosol Optical Properties	Validation of the results for selected episodes	June-July 1997
Validation Data Set	Satellite	AVHRR	AOT over the ocean	Check METEOSAT derived AOT	June-July 1997
		POLDER	AOT over the ocean Angstrom coefficient	Check METEOSAT derived AOT	June 1997
	Ground Based	ACE2	AOT and Aerosol Optical Properties	Check GOME derived Aerosol Optical Properties hourly	June-July 1997
		AERONET	AOT and Aerosol Optical Properties	Check GOME derived Aerosol Optical Properties Hourly	June-July 1997

Table 1 – Summary of the validation plan.

5. CONCLUSIONS

The differences in AOT using GOME-derived aerosol properties over the a-priori fixed classes are now demonstrated to be significant in most of the cases with respect to the accuracy of the METEOSAT measurements. This stresses the improvement introduced by the new method.

Absolute AOT differences using the ocean BRDF from reference values (lambertian ocean surface) are not negligible for background aerosol situations. For higher aerosol loads a lambertian ocean can be considered a reasonable approximation to the real ocean surface.

As for the a-priori input of water vapour and ozone total column data and vertical profiles, higher accuracy in the AOT retrievals is achieved using at least latitudinal- and seasonal- dependent atmospheric profiles, if co-located data are not available.

The impact of changing the RTM (from 6S to MODTRAN-4) seems to be irrelevant: absolute AOT differences have been computed and are generally less than 10%.

Further work is now planned to compare results with other independent AOT measurements specified in the validation proposed data set.

6. ACKNOWLEDGMENTS

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