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Temporal and Spatial Distribution of the Stratospheric Aerosol Optical Thickness at 1013 nm derived from the ORA Experiment after the Pinatubo Eruption

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Abstract. In this article, we present aerosol optical thickness data, computed from the aerosol extinctions measured by the ORA experiment at 1013 nm. Temporal and latitudinal dependences are discussed for the period Aug. 1992 - May 1993. A comparison with SAGE II optical thickness data is presented, and shows good agreement.

Introduction

The ORA (occultation radiometer) experiment was launched in August 1992 onboard the European Retrievable Carrier (EURECA). The goal of the UV-visible unit developed at the Belgian Institute for Space Aeronomy was the retrieval of altitude density profiles for O_3, NO_2 and water vapour, and aerosol extinction coefficient profiles. Details of the experiment have been described elsewhere [*Arijs et al.*, 1995]. Briefly, the unit has 8 radiometric modules with a center wavelength located in the range from 385 nm to 1013 nm. During orbital occultation, each module measures the incoming light from the full solar disc, through the Earth's atmosphere. Special algorithms for the vertical and spectral inversion of the atmospheric transmittance have been developed, and validated with respect to the Stratospheric Aerosol and Gas Experiment (SAGE II) [*Fussen*, 1995; *Fussen et al.*, 1997; *Fussen et al.*, 1998] [Fussen et al., Tomography of the Earth's atmosphere by the spaceborne occultation radiometer ORA: Final inversion algorithm, submitted to *Annales Geophysicae*]. A satisfactory agreement between the two experiments was observed.

The module centered at 1013 nm fulfills a special role. At this wavelength, apart from Rayleigh scattering, only aerosol scattering contributes to the attenuation process and the aerosol extinction profiles can therefore be retrieved with a minimal inversion error.

The ORA experiment offered a unique opportunity to study the spatial and temporal dynamics of aerosols in high volcanic conditions, because the 9-month observation period (Aug. 1992 - May 1993) occured in the aftermath of the Mt. Pinatubo eruption. The optical thickness was chosen as a suitable parameter to study these variations, because it incorporates the aerosol extinction at all altitude levels.

Optical Thickness

The aerosol optical thickness is calculated as the upwards integrated extinction, with respect to a reference altitude level. Many authors [*Trepte et al.*, 1994; *Brogniez and Lenoble*, 1987; *Brogniez and Lenoble*, 1991] take this level to be 2 km above the local tropopause level. This choice is the result of two considerations. First, it is supposed to reasonably prevent the optical thickness to be affected by possible clouds. Secondly, the altitude surfaces of equal aerosol extinction roughly "follow" the global tropopause surface.

We calculated the tropopause level for every ORA event from United Kingdom Meteorological Office (UKMO) temperature profiles, using the standard definition of tropopause [*Brasseur*, 1982], but noticed a variability of several kilometers for different events at identical latitudes and months. While this variability reflects the local meteorological state, we realized that it could cause unwanted side effects in the optical thickness computation. Because of this, we preferred to use the monthly mean values of tropopause altitude. Other authors have also encountered this problem and used a similar remedy [*Brogniez and Lenoble*, 1991].

Taking this into account, the aerosol optical thickness at 1013 nm is calculated as:

$$\delta = \int_{z_{\mathrm{ref}}+2} \beta_a(z)\, dz \qquad (1)$$

with $z_{\mathrm{ref}} = z_{\mathrm{T}} + 2$ km, and z_{T} equals the local tropopause altitude level, interpolated from mean values, tabulated as function of month and latitude.

It was clear from the start of the data processing that a considerable number of the ORA extinction profiles showed abnormally high values at low altitudes. Taking into account that these outliers would distort the final geophysical processing results, we decided to remove them by applying a statistical rejection criterium. After this procedure, 4547 events were left. A first comparison of the 2274 rejected events with monthly mean cloud coverage maps obtained from the International Satellite Cloud Climatology Project (ISCCP) showed that a high probability of cloud occurrence can be associated with these events.

Further investigation revealed another suspicious behaviour. We observed a decrease in time, explained by the gradual sedimentation and dispersion of aerosols, but at the same time, the variability of the optical thickness increased. This could not have been caused by the inversion algorithm, because the same increase of variability was observed in the raw transmission signals at low altitudes. We soon realised that the effect was caused by additional light extinction by smaller subvisual clouds. The presence of such a cloud does not produce a radical cut-off in the measured signal, but introduces a modulation in the measured transmission. So the random cloud relative modulation increases with decreasing aerosol extinction and associated increasing transmission, as observed.

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The cause for this cloud modulation at stratospheric altitudes is of course the large field of view of the ORA optical modules. Two kilometers above tropopause altitude, the instrument is still capable of viewing tropospheric clouds. The only remaining option was to augment the reference altitude level. Finally, we used $z_{\mathrm{ref}} = z_{\mathrm{T}} + 6$ km, because the cloud modulation in the optical thickness disappeared at this altitude. For comparison, the results are shown together with the SAGE II data in Fig. 1. Clearly visible are the modulations in time, caused by the latitudinal movement. The general agreement is fair, although ORA seems to exhibit a plateau during the first period of the mission. Note however, that such kind of plateau has also been clearly observed for SAGE II just before this period [*Russell et al.*, 1996]. The plateau is probably not visible in the depicted SAGE data, due to a low sample density.

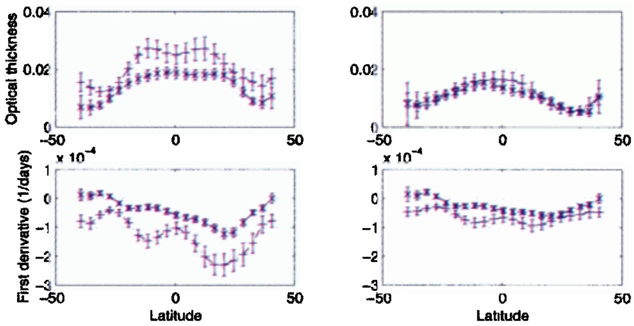


Figure 2. Fitted aerosol optical thickness (top) and first derivative (bottom) as function of latitude, evaluated at $d = 100$ days (left, Nov. 19, 1992), and $d = 200$ days (right, Feb. 27, 1993), for ORA (1013 nm, x-signs) and SAGE II (1020 nm, +-signs).

Results and Interpretation

Using the calculated optical thickness for all 4547 occultation events, we investigated the temporal and latitudinal aerosol variations. We have divided the total ORA latitude range (-45° to 45°) into 5° bins, with the central bin centered around 0°. The temporal bin size was taken to be 3 days. For every bin, we calculated the mean optical thickness and the standard deviation. The reason for this binning procedure is the non-uniform sample density in latitude and time, which may lead to unwanted bias.

The temporal variations were modelled by a simple exponential form, to describe the aerosol sedimentation and dispersion:

$$\delta(\phi, d) = A(\phi)\exp(-d/d_0(\phi)) \qquad (2)$$

where d equals the elapsed days since the start of the ORA mission (Aug. 12, 1992), d_0 a relaxation time related to the speed of the aerosol sedimentation, and ϕ the latitude. To ensure that A and d_0 have a reasonable smoothness as function of latitude, we used two independent Legendre expansions over the latitude range $\phi = (-90°, 90°)$:

$$A(\phi) = \sum_{i=0}^{n_1} a_i P_i(\phi) \qquad (3)$$

$$\frac{1}{d_0(\phi)} = \sum_{i=0}^{n_2} b_i P_i(\phi) \qquad (4)$$

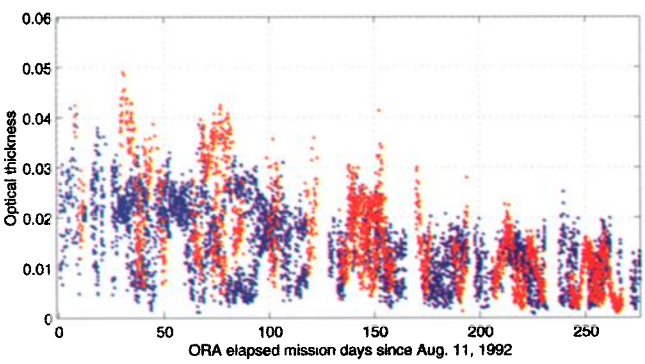


Figure 1. Optical thickness at subsequent occultation events for ORA (blue, 1013 nm) and SAGE II (red, 1020 nm), calculated from $z_T + 6$ km upwards, as function of time.

These two equations, together with the logarithm of Eq. 2, lead to a linear least squares problem. Investigation of the solution covariance matrix (calculated with $n_1 = n_2 = 10$) indicates that A and d_0 remain quite correlated due to the restricted temporal range. Instead, we present the fitted optical thickness and the first time derivative of the optical thickness, evaluated at $d = 100$ and $d = 200$ days, in Fig. 2.

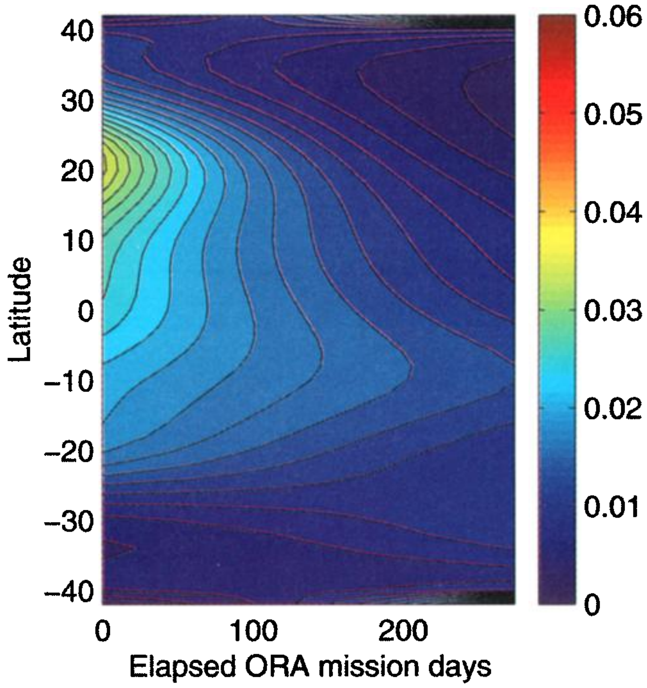
On Plate 1, we can observe the time decay of the optical thickness for both ORA and SAGE II as function of latitude. The rather large differences at the beginning of the time range have to be interpreted with caution, because of the low amount of SAGE II measurements. A broad maximum can be seen at all times between 20°S and 20°N, conform with other measurements and climatologies [*Trepte et al.*, 1994; *Long and Stowe*, 1994; *Hitchman et al.*, 1994; *Mergenthaler et al.*, 1995]. This is caused by the existence of a tropical aerosol reservoir, maintained by the mean upwards movement of the Brewer-Dobson circulation, and that is periodically enhanced by the Quasi-Biennial Oscillation (QBO) during the easterly shear phase [*Trepte et al.*, 1993].

There is a distinct zonal asymmetry at the beginning of the ORA mission, with a peak value at 20°N. This structure was also measured by SAGE II, CLAES [*Mergenthaler et al.*, 1995]and AVHRR [*Long and Stowe*, 1994]. It is likely to be a seasonal effect caused by enhanced lifting from the tropical reservoir on the summer hemisphere side, or removal of aerosol-rich air and injection of aerosol-poor air from the winter hemisphere extratropics [*Hitchman et al.*, 1994]. The asymmetry reverses towards the end of the mission, resulting in the apparently faster decay at 20°N, as can be seen on the minima in the first derivative in Fig. 2.

Conclusion

The ORA optical thickness was calculated with respect to the tropopause altitude + 6 km, and was compared to the SAGE II data. A good agreement was observed, and the measured asymmetry was confirmed by other measurements. This shows that quality aerosol data can be retrieved from a very low-cost instrument. Furthermore, it means that the ORA data can be used as a valuable addition to existing data sets, because the ORA experiment had a much larger sample density in the considered latitude range, compared with SAGE II.

We are presently investigating the evolution of the aerosol spectral dependence of the extinction coefficients and the



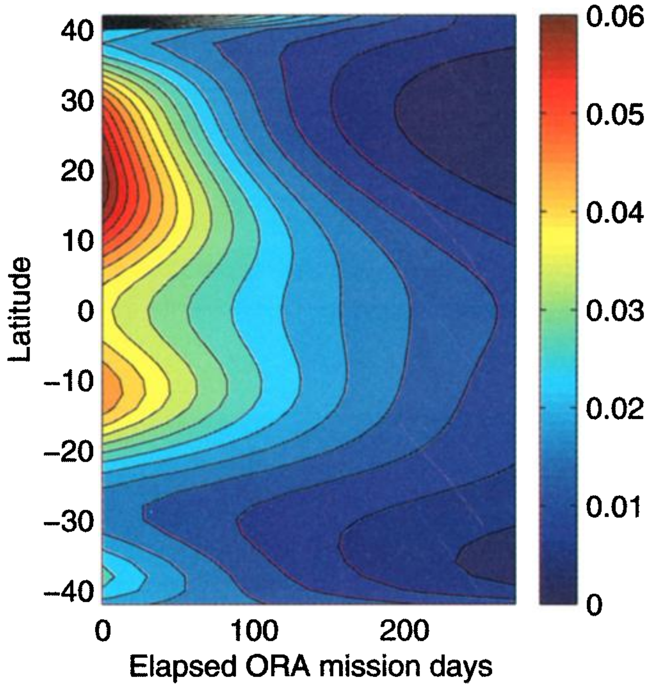


Plate 1. Fitted aerosol optical thickness as function of time and latitude. Left: ORA (1013 nm). Right: SAGE II (1020 nm).

related aerosol microphysical properties. This will be the subject of a forthcoming publication.

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