CORRELATION BETWEEN TOMS AEROSOL INDEX AND THE ASTRONOMICAL EXTINCTION

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ABSTRACT

We combined aerosol index measurements of TOMS/Nimbus-7 and Earth Probe observations with CAMC visual extinction over La Palma from 1984 to 1997, to investigate the possibility to calibrate TOMS data in terms of astronomical extinction.

The results show that the correlation of the two sets of data is quite good for extinction values greater than about Av = 0.2 mag./airmass. A detailed analysis reveals that the satellite aerosol index is indeed sensitive to the desert dust, but does not show evidence of the extinction contribution of the volcanic smoke due to the Mt. Pinatubo eruption which affected astronomical observations in 1992-1993.

This calibrated aerosol index is then used to investigate the number and distribution of dusty events over the astronomical site of Oukaimeden, Morocco. We find a remarkable correlation of the extinction over the two sites.

Finally we study the long term variability of the extinction over the region including Oukaimeden and La Palma, and we conclude that there is some correlation with the Northern Atlantic Oscillation.

1. INTRODUCTION

The atmospheric extinction is an important parameter for an astronomical site. The extinction directly affects the observations reducing the available radiation, but the most relevant effect on the quality of the astronomical data is the variation of the extinction across the sky and in the course of the observation night. In the optical window, the extinction is usually dominated by Rayleigh scattering due to particles which are small compared to the wavelength of the radiation, typically the molecules of the atmosphere. The Rayleigh scattering decreases with the altitude, but is rather constant in a given site. Larger particles (dust and aerosol) can occasionally contribute to increase the extinction over an astronomical site when the meteorological conditions advect them to high altitude. Vast regions of the Earth can be covered by giant dust clouds originated from desert areas. The West of Sahara desert as well as most of the tropical region of the Atlantic Ocean is often over flown by dust clouds pumped from the inner Sahara mainly during the summer.

The transport of the Saharan dust has been of great interest in the recent years because of the possible connections with the transport of microorganisms and toxic chemicals across the Atlantic (Griffin et al., 2002). There is also some evidence that the amount of transported dust is correlated to the Northern Atlantic Oscillation (NAO) (Moulin et al., 1997, Chiappello and Moulin, 2002). There are several papers attempting to calibrate satellite data, in particular TOMS data which cover more than a decade, into dust optical thickness (Hsu et al., 1999) according to its physical properties (Torres et al., 1998).

From the astronomical point of view it is highly interesting to calibrate TOMS data into the more commonly used astronomical visual extinction. With the present paper we describe the calibration correlating TOMS data to the visual extinction measured by the Carlsberg Automatic Meridian Circle Telescope (CAMC) since 1984. The public CAMC database has been used to estimate the extinction over the astronomical site of Oukaimeden, Morocco. In Section 2 we present the data, in Section 3 the calibration, and in Section 4 we discuss the results.

2. DATA SOURCES: TOMS/NIMBUS-7 SATELLITE AND CAMC GROUND BASED OBSERVATIONS

The TOMS (Total Ozone Mapping Spectrometer) records used in this work are based on two satellites: Nimbus7 TOMS for 1978-1993 and Earth Probe TOMS for 1996-2002. For these two instruments, the aerosol index (AI) was determined using respectively the 340/331 nm (channel A) and 380/360 nm (channel B) wavelengths for NIMBUS-7, and Earth Probe. Therefore, the aerosol index is defined as:

$$AI = -100\left[\log(I_A / I_B)_{mes} - \log(I_A / I_B)_{\mathrm{mod}}\right] \quad \textbf{(1)}$$

Where the indices $_{mes}$ and $_{mod}$ refer to the measured and modeled radiance for pure Rayleigh scattering, respectively. AI is positive for absorbing aerosols (e.g. dust and smoke particles) and negative for non-absorbing aerosols (e.g. sulfates) (Herman et al., 1997; Torres et al., 1998).

The site of Carlsberg Automatic Meridian Circle (CAMC) is located in the Observatorio del Roque de los Muchachos (ORM, 17º 52' 57" West, 28º 45' 36" North, 2326m a.s.l, La Palma Island, Canaries, Spain). From 1984 to 1997 the atmospheric extinction (AE) was measured using observations through the Johnson V filter (551 nm) in units of magnitude per airmass (mag/airmass). In Figure 1, we present the extracted TOMS aerosol index (top) and the CAMC V astronomical extinction (down).

3. TOMS AEROSOL INDEX AND CAMC ASTRONOMICAL EXTINCTION CORRELATION

The set of TOMS aerosol index was produced using the TOMS pixel closest to the ORM astronomical observatory within a 1ºx1º latitude-longitude box. In order to obtain a straightforward interpretation of the comparison between TOMS aerosol index and the atmospheric extinction, we use only the same days in our analysis. Only the aerosol data corresponding to a significant absorption were used, with a threshold arbitrarily set at AI>0.7. The threshold for the selected dusty events for the astronomical extinction was set to AE>0.2 mag/airmass according to Guerrero et al. (1998). Finally, we notice on Figure 1 that there is no sign of violent fluctuations of the aerosol index while, following the Mt. Pinatubo June 1991 eruption, the effect of the plume of volcanic ashes on the astronomical extinction is clearly visible (Guerrero et al., 1998). For this reason, the Pinatubo period was removed from the calibration set.

Figure 2 presents the correlation of the calibrated Nimbus7 data vs. the astronomical extinction over La Palma. The linear fit gives a correlation coefficient 0.75 and the following relation:

$$AE = AI * 0.16 + 0.14 \quad \textbf{(2)}$$

Where AE is astronomical extinction and AI is the aerosol index. A comparative analysis of TOMS data over the ESO Observatory of La Silla in Northern Chile was conducted with the same criteria. No dusty events were detected, confirming that the desert dust does not affect the transmission of the atmosphere in this area.

4. RESULTS AND DISCUSSION

We present in Figure 3 (right) the monthly variation of the extinction derived from TOMS/Nimbus7 daily AI records, compared to the monthly average astronomical extinction measured during clear nights by CAMC at ORM. The correlation between both derived and measured monthly average extinction sets is presented in Figure 3 (left) with a correlation coefficient 0.78 and a slope of 0.96.
Such figures demonstrate the possibility to extract astronomical extinction from the TOMS aerosol index data as long as no major volcanic event is involved. This confirms the results of previous studies comparing TOMS aerosol index to aerosol optical thickness measured with a solar photometer (Hsu et al., 1999 and Chiapello and Moulin, 2002).

In the frame of the characterization the potential of the Moroccan Oukaïmeden station as an astronomical Observatory ($31^{o}12'$ North; $7^{o}52'$ West, 2700m a.s.l), it has been regularly compared to the closest international ORM Observatory (Jabiri et al., 2000) as well as to all IRIS (International Research of the Interior of the Sun) sites (Siher et al., 2002). As part of this comparison, we extend the statistical study of airborne aerosol density to Oukaïmeden. In Figure 4, we present the monthly number of dusty events in the period 1978-1993 for both Oukaïmeden and ORM. We notice that this number is larger for Oukaïmeden than ORM while the average AI is smaller for Oukaïmeden than ORM as shown in Figure 5. In Figure 6, we plot the extinction derived from TOMS/Nimbus7 AI with the same equation (2) for both Oukaïmeden and ORM, using the closest TOMS pixel. In principle the AI depends not only on the nature of the dust but also on its cruising altitude. It would therefore be important for very high accuracy data to confirm the validity of the ORM calibration for characterizing other sites in the area. Nevertheless, the results of our two different test sets (La Silla and ORM) give confidence that, in a first approximation, we can extrapolate the equation (2) to different sites for deriving qualitative assessments. Figure 7 shows the histogram of dusty events above Oukaïmeden and ORM.

In Figure 8, we present the yearly variations of the Northern Atlantic Oscillation (NAO) index as defined by Hurrell et al. (1995) from the difference between normalized sea-level atmospheric pressures between Lisbon, Portugal and Stykkisholmur, Iceland.
The NAO index shows some correlation with the winter TOMS aerosol index depending on the averaging area. We obtain the best correlation coefficients choosing 10x10 degree latitude – longitude windows centered on La Palma and Oukaïmeden, respectively (r=0.49 in the 23º-33ºN x 23º-12ºW box and r=0.31 in the 26º-36ºN x 13º-2ºW box). This lower correlation over Oukaïmeden can be related to the fact that the NAO effect is more important on the Sahara dust transport towards the West than to the North.

5. CONCLUSIONS

We analyzed TOMS/Nimbus7 and Earth Probe data and compared to CAMC telescope extinction measurements. The main results are the TOMS/Nimbus7 data can be used to assess the V astronomical extinction due to desert dust above a minimum threshold of about AE = 0.2 mag/airmass (AI = 0.7). The sites of ORM and Oukaïmeden show similar trends. We verified that, with possibly a few exceptions, there are no days significantly degraded by desert dust at La Silla in Chile when using the same criteria, in a good agreement with astronomical data.
There is some weak correlation between the winter average AI (or number of winter dusty events) and the Northern Atlantic Oscillation (NAO) index over La Palma and Oukaïmeden.
We note that the correlation of Earth probe data (not used in this paper) with the astronomical visual extinction is not as tight as when using Nimbus7 data. We need a more detailed analysis to check the reason for this dispersion.

ACKNOWLEDGMENTS

This research has been supported by the European Southern Observatory. We thank the TOMS group at NASA Goddard Space Flight Center for making available the TOMS data and the CAMC team for the astronomical extinction data.

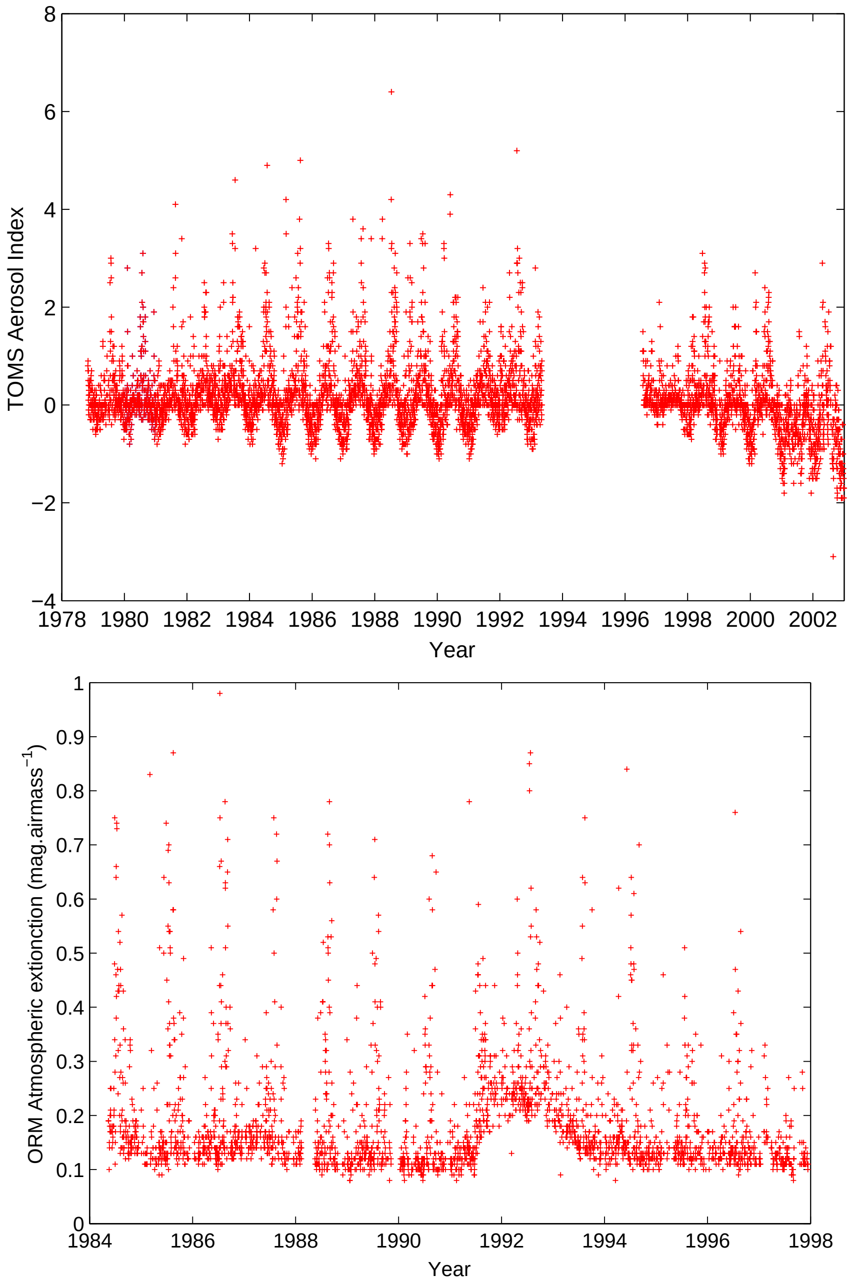

Figure 1: Available Database: TOMS aerosol index (AI, top) and ORM astronomical extinction (AE, down)

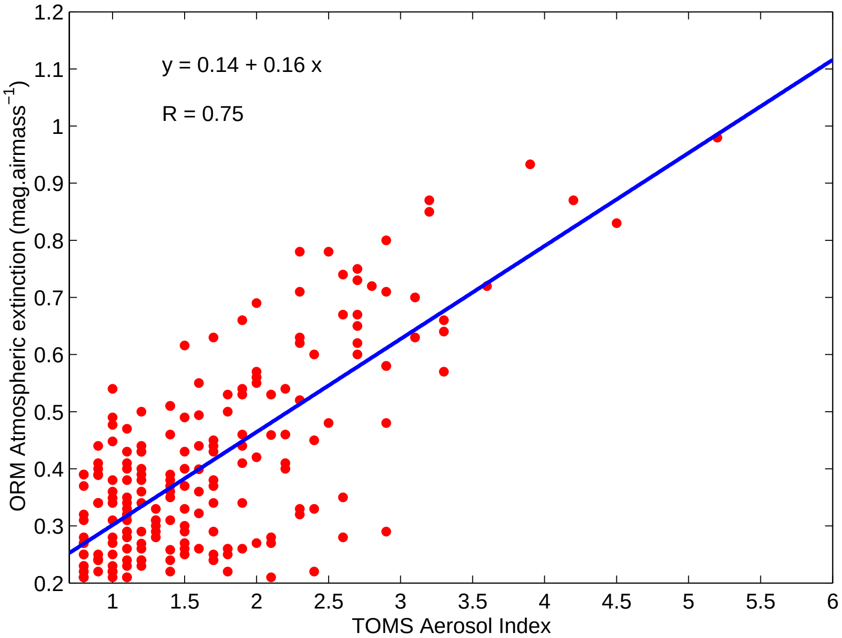

Figure 2: Correlation of TOMS/Nimbus7 AI with ORM AE during summertime dusty events (AI>0.7 and AE >0.2)

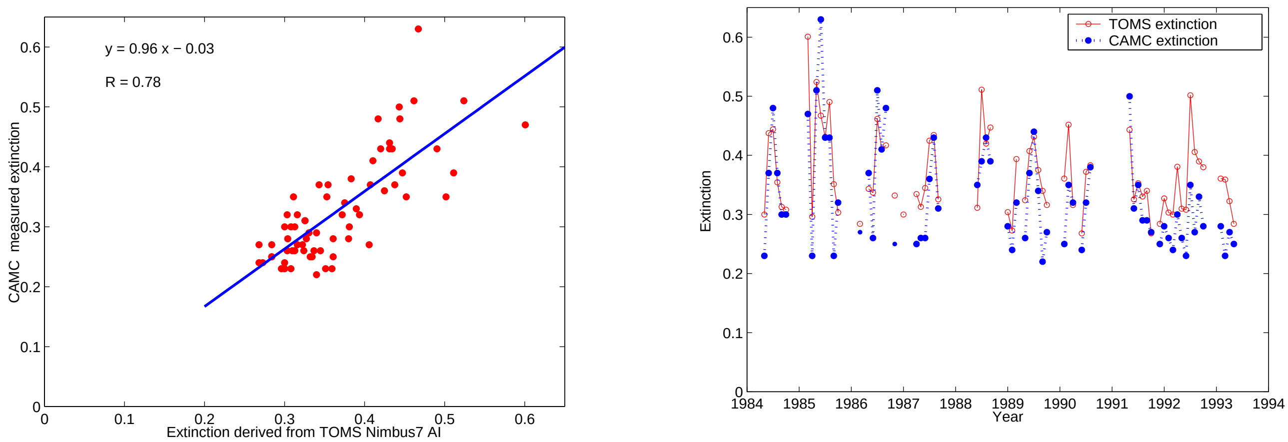

Figure 3: Correlation (left) between the monthly average extinctions (right) derived from TOMS/Nimbus7 AI using Eq.2 and the astronomical extinction measured at ORM

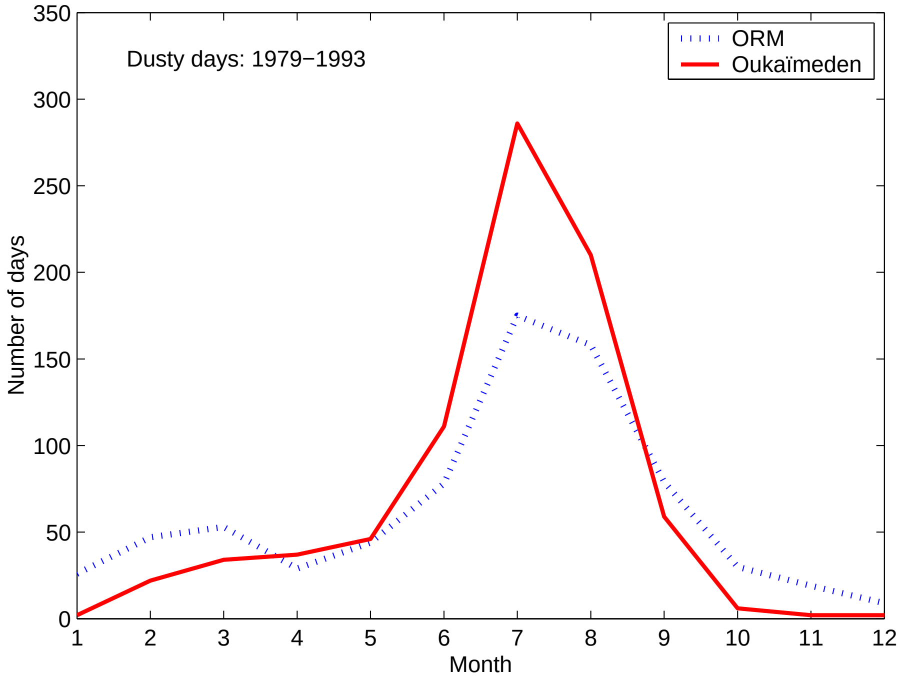

Figure 4: Monthly average TOMS/Nimbus7 dusty events over ORM and Oukaïmeden in the period 1978-1993

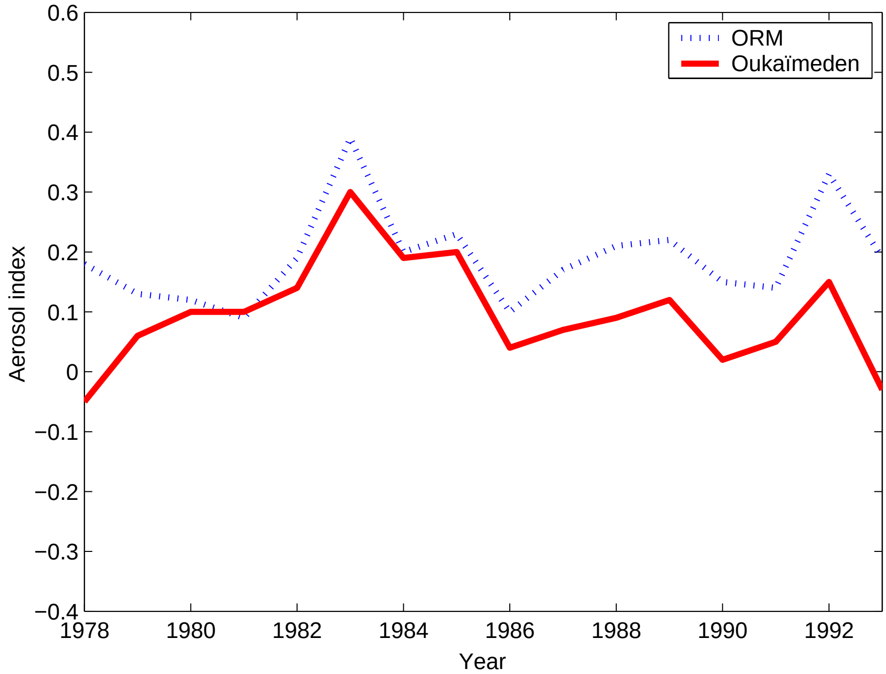

Figure 5: Yearly average TOMS/Nimbus7 aerosol index over ORM and Oukaïmeden

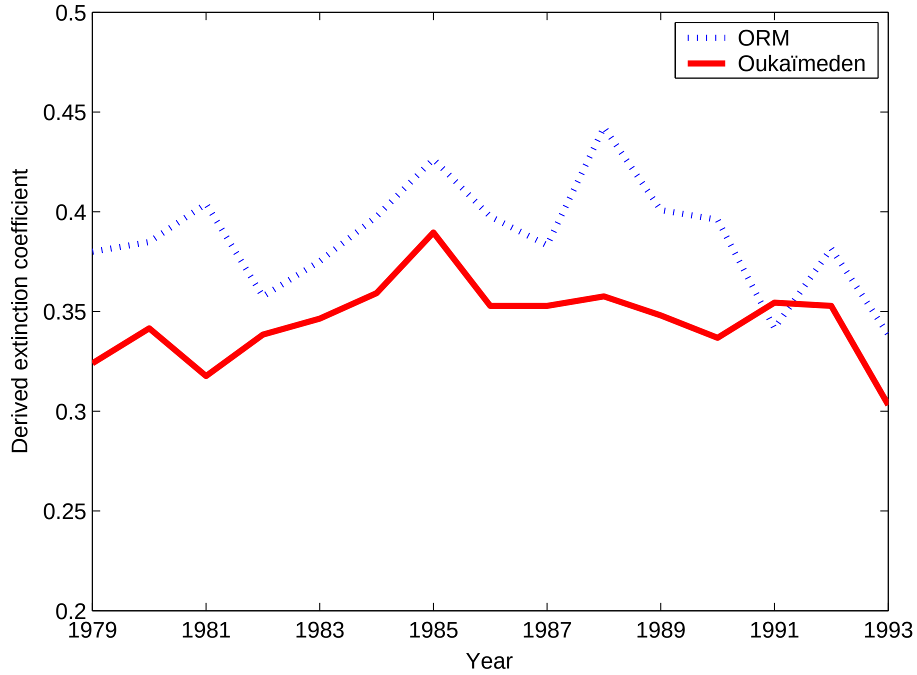

Figure 6: Comparison of the yearly average extinction derived from TOMS/Nimbus7 AI over ORM and Oukaïmeden using Eq.2

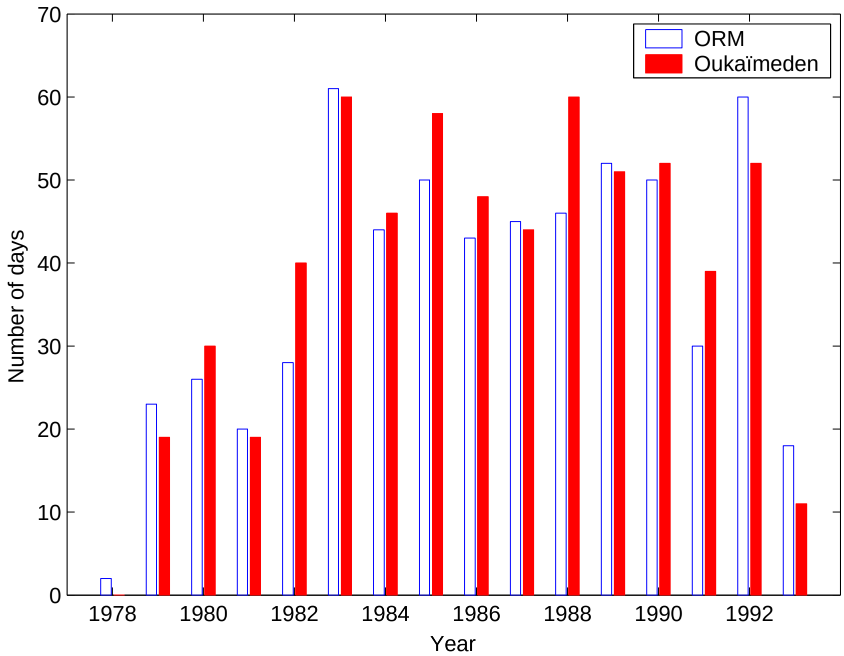

Figure 7: Long term evolution of the yearly frequency of dusty events over La Palma and over Oukaïmeden

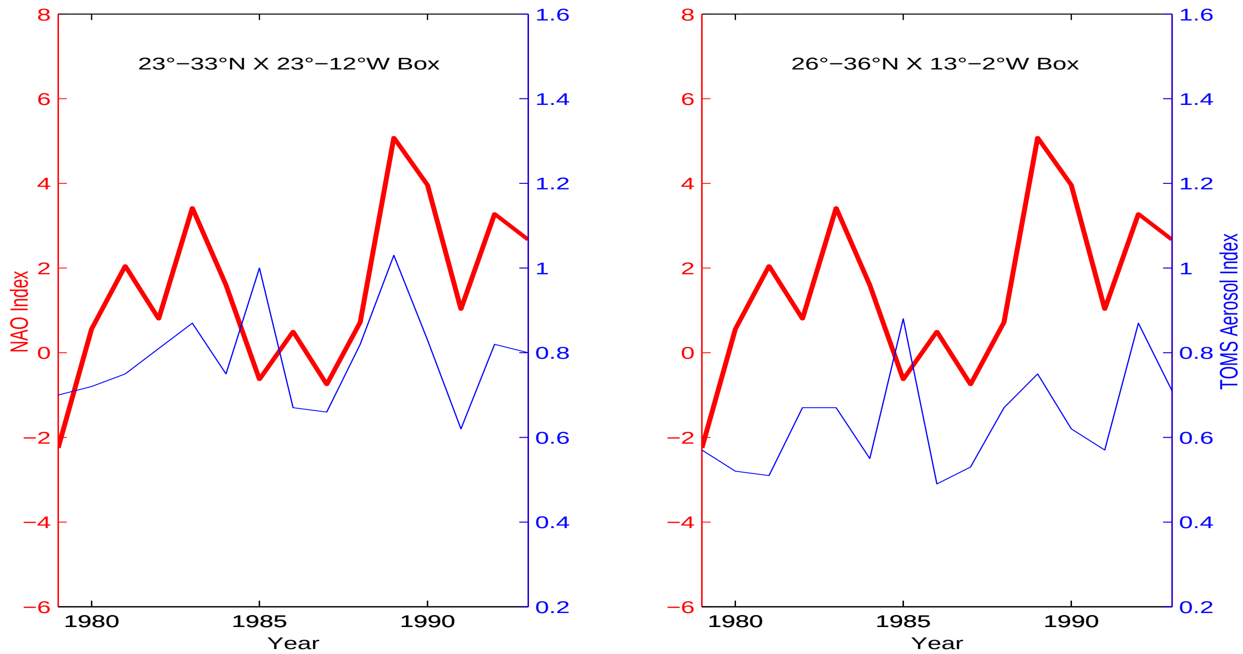

Figure 8: Comparison between the NAO index (bold continuous line) and the mean aerosol index above ORM (left) and above Oukaïmeden (right)

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