Climate Change Research: Evaluation and Policy Implications
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Total Ozone Trend Analysis from the TOMS Data

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Abstract

A multiple linear regression model was applied to describe the monthly mean Nimbus-7 and Meteor-3 TOMS column ozone data in the period November 1978 to June 1994. Year-round and monthly mean ozone trends, QBO coefficients and solar cycle coefficients were calculated with a high spatial resolution for all grid cells (1° latitude by 1.25° longitude) of the TOMS column ozone data, as well as for zonal means over the 10° latitude bands. After the eruption of Pinatubo, ozone trends became more negative (about 1% per decade) in the Tropics and the northern hemisphere.

1. Introduction

The depletion of the ozone layer has a direct influence on climate due to changes in temperature, circulation and UV -radiation. Since the early 1970s there has been an increasing interest in the assessment of atmospheric ozone data for changes related to human activity. The satellite-based instruments have the advantage of full spatial coverage. The longest continuous global satellite ozone measurements have been obtained by the TOMS instrument. TOMS ozone trends were derived for zonal mean ozone over the 10° latitude bands for November 1978 through May 1990 [1] and until the end of the 1991 [2]. In [3] the TOMS ozone trends were calculated on a monthly basis in the 10° latitude × 10° longitude blocks for the time period November 1978 to May 1990.

2. TOMS ozone dataset and model description

TOMS is a satellite-based Total Ozone Mapping Spectrometer. TOMS measures the UV sunlight, backscattered from the atmosphere at six wavelengths between 312.5 and 380 nm on a daily basis over the entire world. The sunlight in the UV is absorbed by ozone molecules in the atmosphere. Total ozone columns are calculated by fitting the ratios of the radiances of the wavelength pairs (where one wavelength is strongly absorbed by ozone while the other is only weakly absorbed) with the ratios calculated by the radiation transport model. Ozone is measured with high spatial resolution; individual measurements have been averaged into grid cells of 1° latitude × 1.25° longitude. The TOMS instrument was active on board the Nimbus-7 satellite from November 1978 until May 7 1993. Version 6 of the TOMS data set is corrected for the diffuser plate degradation and is estimated to be precise to ±1.3% (2σ) at the end of 1989 relative to the beginning of the record. A second TOMS instrument was launched on-board the Meteor-3 spacecraft in 1991. We used the ozone data after April 1993 from the Meteor-3/TOMS.

Total ozone has a strong annual variation. On interannual time scales ozone varies in response to a number of competing factors. These factors include long-term changes in the atmospheric content of anthropogenic trace gases such as the chlorofluorocarbons (CFCs), quasi-biennial oscillations (QBO) of the zonal winds in the Tropics, 11 years solar cycle, volcanically ejected trace gases and aerosols, the El Niño - Southern Oscillation (ENSO) and the solar proton events. The last two turn out to be non-significant for the determination of the long-term trends.

The temporal dependency of the ozone column can be described by the following multiple linear regression model:

$$O_3(t) = \mu(i) + \beta_T \cdot t + \beta_{QBO} \cdot X_{QBO}(t-L) + \beta_{SUN} \cdot X_{SUN}(t) + N(t)$$

$$N(t) = \Phi \cdot N(t-1) + \varepsilon(t)$$

where O_3 is the monthly mean ozone, t the time in months, $\mu(i)$ a seasonal term for the ith month of the year (i=1,2,...,12); $X_{QBO}(t)$ is the Singapore (2° N) 30 mbar zonal wind representing the tropical QBO, L the optimum phase lag between $X_{QBO}(t)$ and $O_3(t)$, X_{SUN} the solar 10.7 cm flux used as a proxy for the ultraviolet solar irradiance; N(t) is a residual noise term, modelled as a first-order autoregressive process because there is a month-to-month correlation in ozone values; $\varepsilon(t)$ is a residual uncorrelated series with the mean equal to zero, although the variance of $\varepsilon(t)$ depends on the month $[\sigma^2(t)=\sigma^2(t-12)]$; β_T, β_{QBO} and β_{SUN} are, respectively, the linear trend, QBO and solar cycle coefficients to be determined by least squares regression. The monthly mean ozone values are used because of their relative independence, the daily data strongly correlated within the month. To determine the monthly coefficients and seasonal term, 12 monthly models were first solved. Then the year-round model was fitted by a weighted estimation procedure (to account for different variability of ozone in different months), with weights for each month inversely proportional to the estimated monthly variances of the residual noise. In both cases, the initial application of the model yielded the estimation for N(t-1); the coefficients were determined in the second application of the model. Calculations were made with a high spatial resolution for all grid cells (1° latitude × 1.25° longitude) of the TOMS column ozone data, as well as for zonal means over the 10° latitude bands. The Singapore 30-mbar wind values were lagged to produce maximum positive correlation with the ozone time series in each latitude band.

3. Results and discussion

Zonal means of the TOMS monthly mean ozone over the 10° latitude bands were fit with the model described above. For the latitude bands centred at 75°N, 85°N, 75°S and 85°S, there are some missing values as the satellite could not observe ozone over the polar region at night. Zonal means were calculated only in the latitudes 70°S-70°N. For the zonal mean ozone in this region, year-round and monthly ozone trends, QBO coefficients and solar cycle coefficients, together with their standard errors, were calculated. Ozone trends were calculated separately for the period before the eruption of the Pinatubo volcano in June 1991. The results are in good agreement with the previous calculations [2]. Calculations were then repeated for the time period through June 1994. The ozone trend is not significant (at the 2σ error level) in the Tropics from 30°S to 30°N before Pinatubo and from 10°S to 10°N for the update through June 1994. The trend becomes negative and its absolute value increases as we move along the latitude towards both poles, faster in the southern hemisphere. The ozone trend has a strong seasonal variation depending on latitude. In Table 1 the year-round trends, the minimum and maximum monthly trends are listed for the latitude bands centred at 55°N (the Netherlands is situated in this area) and 65°S for the time period before the eruption of Pinatubo and for an update through June 1994. After the eruption of Pinatubo ozone trends became more negative (about 1% per decade) in the Tropics and the northern hemisphere. The rise in ozone depletion is due, at least in part, to the cumulative effect of heterogeneous chemistry occurring on enhanced aerosol surfaces in the Pinatubo cloud; radiative and dynamical perturbations could induce reductions in the Tropics [4].

Table 1
Total ozone trend estimates for the latitude bands centred at 55°N and 65°S (% per decade)

	Year-round trend		Minimum monthly trend		Maximum monthly trend	
	05/1991	06/1994	05/1991	06/1994	05/1991	06/1994
55°N	-3.5±1.4	-4.4±1.4	-6.0±3.1 February	-8.2±2.4 February	-2.3±1.8 August	-2.9±1.5 August
65°S	-7.2±1.8	-6.8±1.6	-19.8±4.9 October	-20.8±4.6 October	-4.6±2.4 February	-4.8±1.9 February

Year-round and monthly mean ozone trends, QBO coefficients and solar cycle coefficients were calculated with a high spatial resolution for all grid cells (1° latitude × 1.25° longitude) of the TOMS column ozone data. Figure 1 (upper part) shows the year-round total ozone trends worldwide. In addition to latitude and seasonal dependency, it is possible to see the longitudinal dependency of ozone depletion and its geographical location. Strong ozone depletion occurs in the high latitudes of the southern hemisphere and near the south pole, the area corresponding to the Antarctic ozone hole appearing from September to November. The monthly trends for this period show strong ozone depletion (more than 10% per decade) almost the whole area south of 60°S. The ozone depletion reaches its maximum in October, when trends in the polar region are about 30% per decade and those above the most southern part of South America and the Falkland Islands are about 10% per decade. The high negative trend area moves northwest in November. Year-round ozone trends are significantly negative in the northern hemisphere above 30°N, reaching absolute values of up to 6% per decade. The maximum negative year-round trends in this area apply to above the UK, south of Norway and Sweden and some northern parts of Russia. An example of the monthly ozone trends for March is shown in Figure 1 (lower part). Here, we see a fairly strong longitudinal dependency of ozone trends in the northern hemisphere. The areas above the UK, northern France, Benelux, northern part of Scandinavia and large parts of Russia have large absolute trend values equal to about 10% per decade and more. At the same time there is a region between the coasts of Canada and Greenland at about the same latitude where a trend is almost non-significant.

Finally, we report that the zonal mean ozone seasonal term described above was compared with the ozone values calculated with the 2D Cambridge/RIVM stratosphere model. A good overall agreement was found.

4. References

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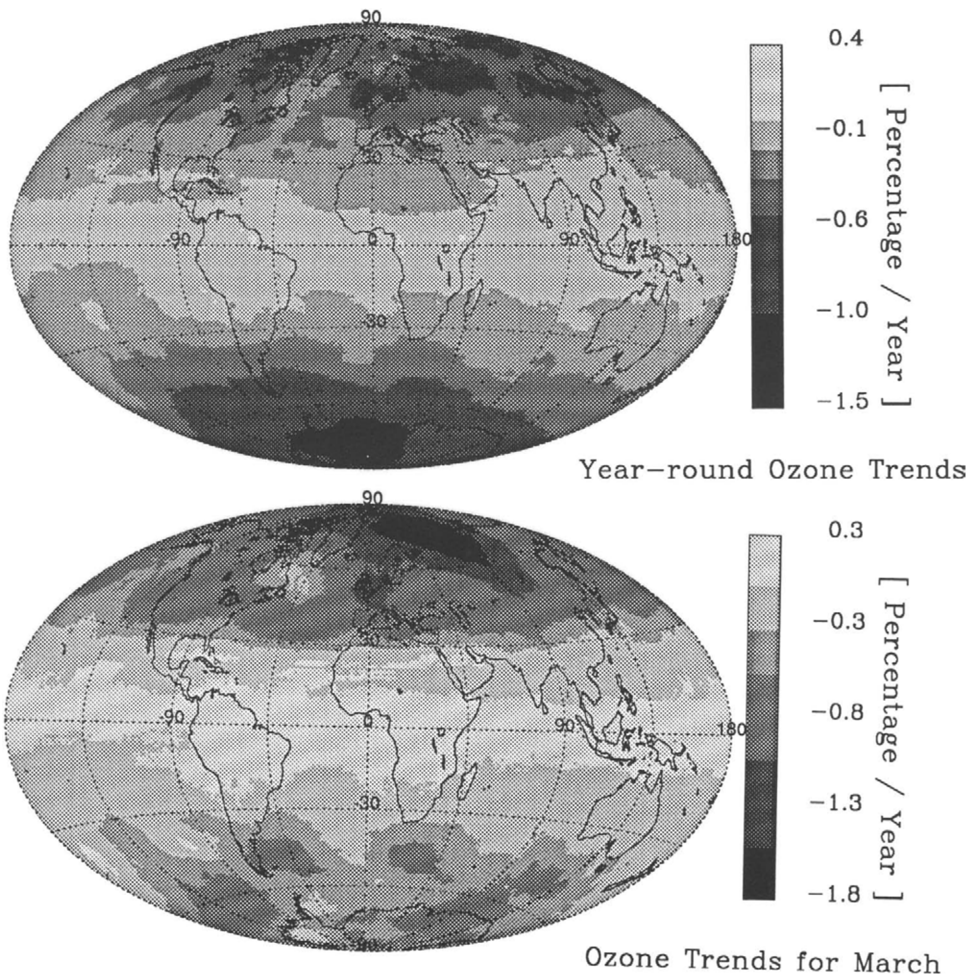

Figure 1. The year-round (upper part) and the monthly ozone trends for March (lower part).