Spatial Patterns of Global Total Ozone Trends 1995-2009

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APPLIED REMOTE SENSING CLUSTER

Abstract

The stratospheric ozone layer is affected by a variety of factors including natural fluctuations, as well as the emission of ozone depleting substances (ODSs). Although the Montreal Protocol now controls the production and release of ODSs, the timing of ozone recovery is still unclear.
Global long-term observations with space-borne instruments are essential to monitor the further evolution of the ozone layer, they are supplementary to well-maintained ground-based measurements, and they provide the basis for the evaluation of numerical models describing atmospheric processes.

For this study total ozone columns from three European satellite sensors GOME/ERS-2, SCIAMACHY/ENVISAT, and GOME-2/METOP-A are merged into a self-consistent data record starting in 1995. Global ozone trends are then estimated by applying a linear regression model to the time series.
A slightly positive significant trend was found from the last 14 years for the northern hemisphere with distinct regional patterns, which agree very well with a second satellite-based data record. Results are also compared to ground-based observations and Chemistry Climate Model simulations.

GOME-type Total Ozone – Essential Climate Variable

GOME, SCIAMACHY, and GOME-2 (launched in 1995, 2002, and 2006, respectively) are passive remote sensing instruments providing global amounts and distributions of atmospheric trace gases such as ozone or NO_2. In order to establish a homogeneous long-term time series an optimized merging algorithm has been developed. The individual ozone measurements are averaged to 1°x1° monthly means and differences among the instruments are analysed carefully. They are mainly due to differences in temporal and spatial sampling, cloud correction, as well as calibration and degradation effects. They depend on latitude, season and time. Because of its excellent long-term stability compared to ground data, the GOME data record was used as a reference standard, and correction factors for SCIAMACHY and GOME-2 have been calculated as a function of latitude and time during overlap periods. Dotted lines in Fig. 1 denote the original uncorrected data, and solid lines denote the adjusted and combined data. A detailed description can be found in **[1]**.

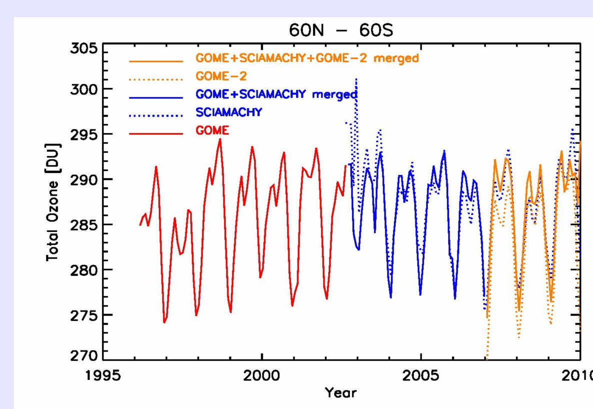


Fig. 1: GOME/SCIAMACHY/GOME-2 merged total ozone 1995-2009

Ozone Anomalies 1980-2040

Fig. 2 shows ozone anomalies from 1980-2040 for four latitude bands: the global mean, northern and southern mid latitudes, and tropics for four different data sets: the new European GTO-ECV ozone data record, the Merged Ozone Data set (MOD) provided by NASA **[2]**, and two Chemistry Climate Model simulations: E39C-A **[3]** provided by DLR and UMUKCA-UCAM **[4]** provided by University of Cambridge. Both satellite data sets agree very well during their 14 years overlap period. Large negative values in NH mid latitudes 1991-1994 are due to the Mount Pinatubo eruption. The long-term behaviour of both model simulations is similar, although differences may be large on short time scales. Both simulations predict a greenhouse-gas induced "super-recovery" at the end of the 21st century.

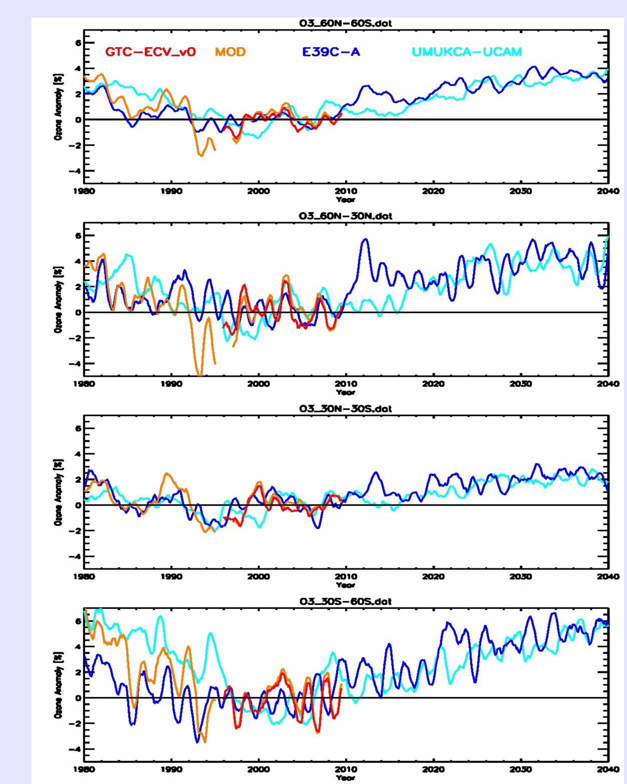


Fig. 2: Ozone Anomalies 1980-2040

Global Total Ozone Trends 1995-2009

Trends are estimated using a typical linear regression model including the overall mean, the seasonal cycle, the quasi-biennial-oscillation (at 30 and 50hPa), the solar cycle, and a linear trend term.
Global trend patterns for GTO-ECV (left) and NASA/MOD data record (right) are shown in Fig. 3. Both patterns are similar and they reveal small significant positive trends in the northern hemisphere between 10°-40°N and for parts of the Euro-Atlantic sector. Trends in the southern hemisphere are statistically not significant (see also Fig. 4, top right panel). Longitudinal structures indicate the influence of changes in the dynamical structure of the atmosphere on ozone trends.

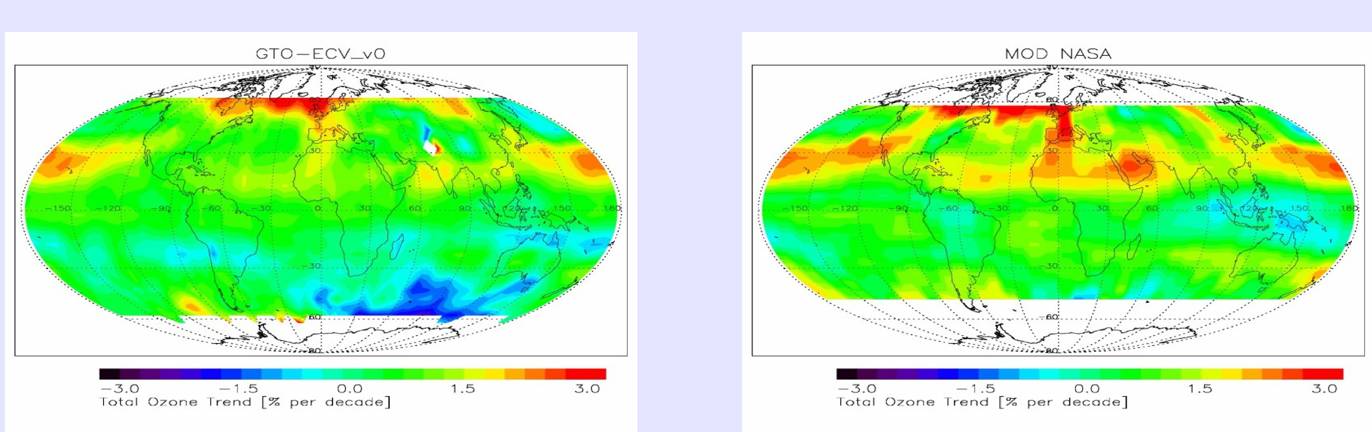
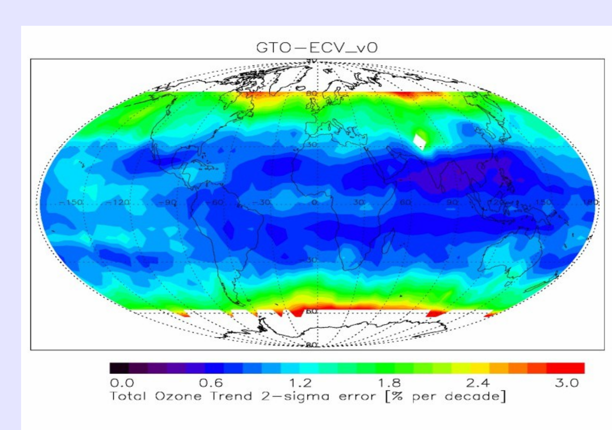
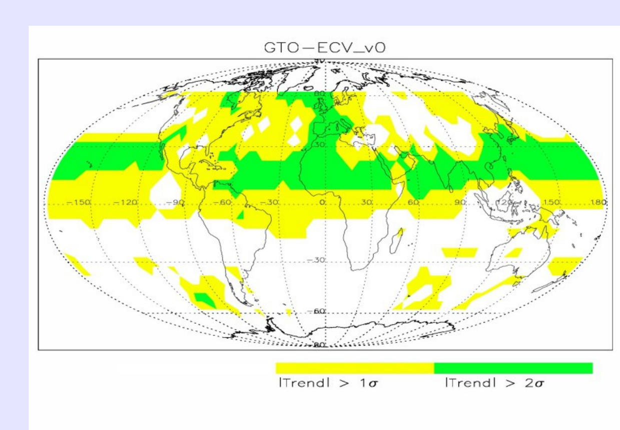


Fig. 3: Global Total Ozone Trends 1995-2009 from GTO-ECV (left) and MOD (right)





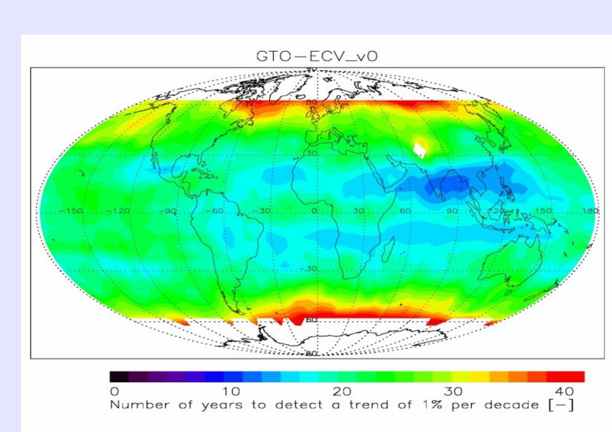


Fig. 4: top left panel: 2-sigma error of regression; top right panel: green areas denote statistically significant trends; and bottom left panel: theoretical estimation of number of years which is required to detect a trend of 1% per decade (at 95% confidence level). In the tropics the amount of GTO-ECV data available already is sufficient, but additional years of measurements are needed to reach the same confidence level for the middle latitudes or polar regions.

Chemistry Climate Model Simulations

The time period for trend estimation using model simulations has been extended by 20 years. Linear trends for 1995-2029 are shown in Fig. 5. Significant positive trends are found for the middle latitudes of the northern and southern hemisphere. Longitudinal patterns indicate the influence of changes in the dynamical structure of the atmosphere on ozone.

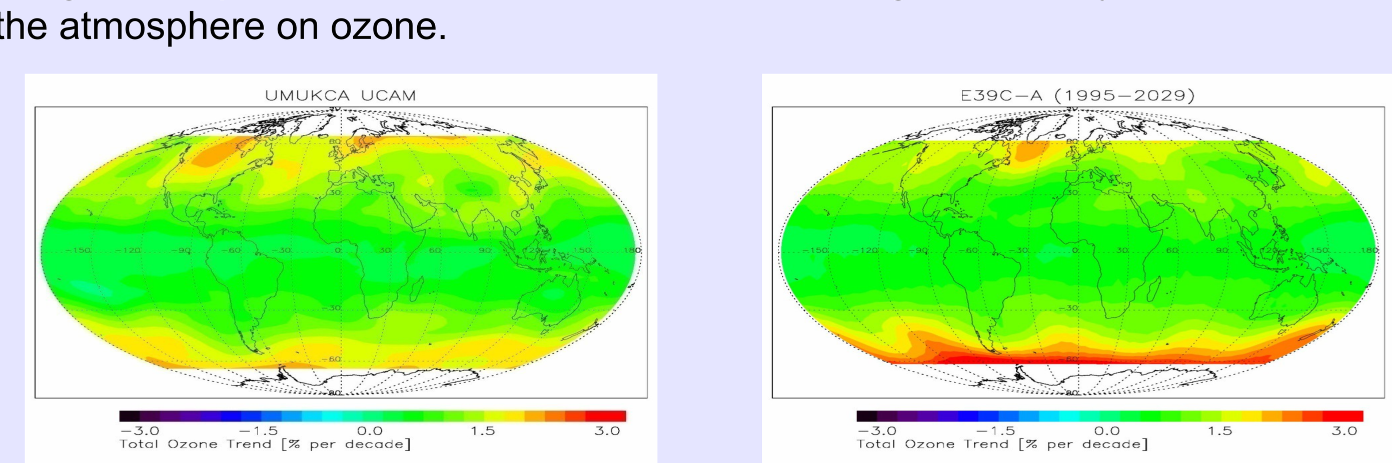


Fig. 5: Predicted Total Ozone Trends 1995-2029 from UMUKCA-UCAM (left) and E39C-A (right) model simulations

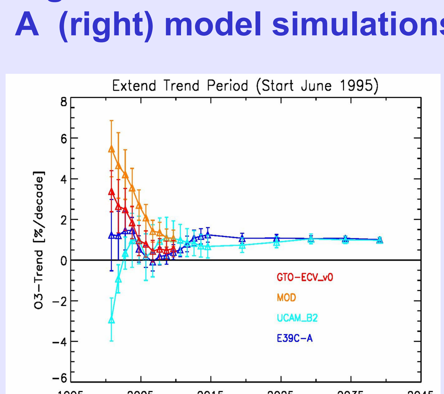


Fig. 6: Trends for all data sets and different fit periods

Fig. 6 shows total ozone trends for the global mean (60°N-60°S) for both satellite data records and model simulations for different fit periods (start date is always 1995). The first data point corresponds to a fit period from 1995 to Dec. 2001. Large positive trends found for the satellite time series for short fit periods are due to the influence of the solar cycle, which was maximum in 2002. The Cambridge model does not include the solar cycle. Both models predict a linear trend of 1% per decade for the period 1995-2040.

References:

[1] Loyola, D., Coldewey-Egbers, M., Dameris, M., Garny, H., Stenke, A., van Roozendael, M., Lerot, C., Balis, D., and Koukouli, M., "***Global long-term monitoring of the ozone layer – a prerequisite for predictions***", International Journal of Remote Sensing, Vol. 30, Nos. 15-16, pp.4295-4318, 2009.

[2] available from URL: http://acdb-ext.gsfc.nasa.gov/Data_services/merged/

[3] Stenke, A., Dameris, M., Grewe, V. and Garny, H., "***Implications of Lagrangian transport for coupled chemistry-climate simulations***", Atmos. Chem. Phys., Vol. 9, pp. 5489-5504, 2009.

[4] Morgenstern, O., Braesicke, P., O'Connor, F.M., Bushell, A.C., Johnson, C.E., Osprey, S.M., and Pyle, J.A., "***Evaluation of the new UKCA climate-composition model – Part 1: The stratosphere***", Geosci. Model Dev., Vol. 2, pp. 43-57, 2009.

Comparison to Ground-Based Data

Linear trends 1995-2009 for 5° zonal averages are estimated and presented in Fig. 7. Satellite as well as simulated data exhibit similar latitudinal structures, but regions of significance are slightly different. Trends obtained from ground stations show large variations among the zonal bands.

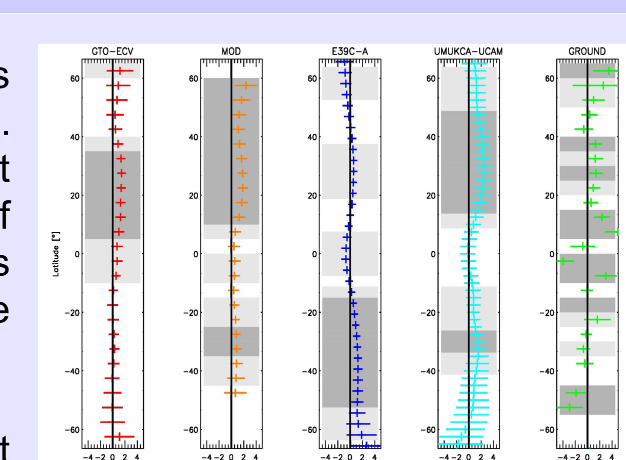


Fig. 7: Zonal mean trends 1995-2009 for different data sets. From left to right: GTO-ECV, NASA/MOD, E39C-A, UMUKCA-UCAM, and Dobson/Brewer ground-based observations. Grey-shaded areas denote statistically significant trends.

Fig. 8 shows a comparison of ozone trends at all individual ground stations with trends at the corresponding GTO-ECV grid points.

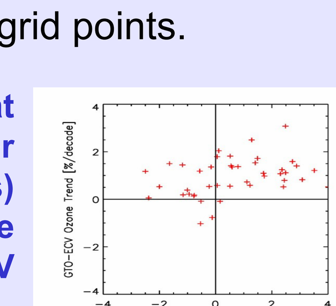


Fig. 8: Total ozone trends at all individual Dobson/Brewer ground stations (x-axis) compared to trends at the corresponding GTO-ECV grid points (y-axis)

Conclusions

This work presents a global total ozone trend analysis using a homogeneous self-consistent long-term data record called GOME-type Total Ozone – Essential Climate Variable (GTO-ECV) with fourteen years of measurements merged from three European satellite sensors GOME, SCIAMACHY, and GOME-2. A global slightly positive trend of ~1% per decade since June 1995 was found for the northern hemisphere, with marked longitudinal patterns. They indicate the influence of changes in the dynamical structure of the atmosphere due to climate change on ozone trends in addition to changes caused by the reduced amount of ozone depleting substances as result of the Montreal Protocol. Trends in the southern hemisphere are statistically not significant. These results agree very well with a second independent satellite data set MOD provided by NASA. Longitudinal patterns in long-term trends from 1995-2029 are also found for two Chemistry-Climate Model simulations. This work will be extended in the framework of ESA's Climate Change Initiative, and it is also planned to include the ozone products from the upcoming satellite missions GOME-2 on Metop-B (start 2012) and the Sentinel 5 precursor (start 2014).

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