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Correlation between Tropopause Height Pressure and TOMS-Data for the EASOE-Winter 1991/1992

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Abstract

A correlation between tropopause height pressure and total ozone carried out for the period November 1991 to April 1992 indicates clearly that low values of total ozone over northern Europe can be partly explained by the persistent presence of a high tropopause. The depletion of ozone by chemical processes should have been only a few percentage of dynamical-caused effects. This findings agree well with the results published by others with regards to this winter.

1 Introduction

The ozone distribution of the Earth's atmosphere is influenced by dynamical and chemical processes. In the Northern Hemisphere dynamical processes play a more significant role than in the Southern Hemisphere. To explain variations in measured ozone column values, it is necessary to analyse the relative importance of dynamical and chemical processes. This is complicated, by the need for time consuming analysis procedures which are necessary before reliable conclusions can be drawn.

The relationship between low and high ozone values and dynamical processes is well established. Reed (1950) pointed out the role of vertical motion and horizontal advection in producing low ozone values in upper tropospheric ridges and high ozone values in upper tropospheric troughs. Since then the relationship between ozone fluctuations and various meteorological parameters have been discussed in a large number of papers (e.g. Ohring and Muench (1960), Schoeberl and Krüger (1983), Bojkov (1986), Sekiguchi (1986), Newman and Schoeberl (1986), Farrara and Mechoso (1986), Schubert and Munteanu (1988), Vaughan and Begum (1989)). In particular, during the winter 1991/1992 it was difficult to identify the chemical ozone depletion because an unusual dynamical situation over northern Europe (blocking anticyclone for almost three month) yielded to low amounts of total ozone. Extreme low values of total ozone (< 220 Dobson Units (DU)) were observed in January 1992. The January 1992 deviations from long-term January means of total ozone from TOMS-satellite were approximately − 90 DU (Naujokat et al., 1992). A comparison with long-term January means indicates strong positive height anomalies at 300 hPa (+ 32 gpdam) and strong negative temperature anomalies at 30 hPa (− 12.5 K) over northern Europe. So, in principle, both dynamical and chemical processes could have lead to the observed ozone values. Quantification, especially in this case, has been difficult.

The correlation between tropopause height pressure and total ozone which is presented in this paper should be seen in addition to recently published investigations, e.g. Farman et al. (1994) and Petzoldt et al. (1994), who discussed in detail the dynamical situation of the winter 1991/1992 and its influence on the ozone column. Farman and co-workers described the influence of the observed blocking system on the structure of the polar vortex. They pointed out that in the lower stratosphere there was a persistent collocation of the core of the jet stream with temperatures low enough to promote heterogeneous processes. On the basis of correlation between stratospheric temperature, geopotential height and ozone (column and partial pressure values), Petzoldt et al. showed that the blocking anticyclone strongly affected the distribution of ozone, producing the deep minimum in January 1992. It was shown that most of the days with total ozone columns below 235 DU are connected with tropopause temperatures below – 70 °C and 30 hPa temperatures below – 82 °C (analysis for Oslo). They concluded that anomalous low ozone columns can be attained at the edge of the polar vortex when dynamical processes in the lower and middle stratosphere interact. In other words, vertical motion plays a significant role in the amount of ozone in the vertical column, in particular during this time.

In Section 2, the data and the analysis procedures are described briefly, the results are presented in Section 3, and a conclusion is given in Section 4.

2 Data and Analysis Procedures

The ozone column data used in the present analysis derives from the Total Ozone Mapping Spectrometer (TOMS) on board of the satellite NIMBUS 7. The analyses of the European Centre for Medium Range Weather Forecast (ECMWF) were used to calculate the height of the tropopause. Both datasets originate from different sources and therefore are appropriate for empirical correlation.

The TOMS data are available on a global grid with an increment of 1.25° in longitudinal and 1.0° in latitudinal direction. This high nominal resolution is real only in low latitudes. In middle and high latitudes the resolution of the ozone data is 2.5° and 5.0°, respectively. Irregularly distributed small gaps in the data are caused by the non-uniform coverage of the Earth (NIMBUS 7 described a precessing polar orbit). The gaps occured only seldom: In the area of our interest outside the polar night region 1.2 % of the grid points were not engaged. The gaps were filled by linear spatial interpolation. No measurements were possible in the polar night region because the spectrometer employed the backscattering of sunlight to measure ozone. The investigation presented in this paper is restricted to a region 30.5 °N to 79.5 °N and 29.4 °W to 119.4 °E (cf. Figure 1), the area covered during the EASOE campaign.

Tropopause height was evaluated from temperature fields of ECMWF analysis, using the WMO criterion, which defines the tropopause as the lowest level at which the lapse rate decreases to 2 °C/km or less, provided also the average lapse rate between this level and all higher levels within 2 km does not exceed 2 °C/km. Temperature fields are available on standard pressure levels (300, 250, 200, 150, 100 hPa) in the tropopause region. To find the tropopause, the lapse rate was calculated at the intermediate pressure levels (half levels). Then the pressure level is determined, at which the WMO criterion is fulfiled. Whenever vertical interpolation is necessary it is assumed that the variables vary linear with respect to pressure. Because of the coarse vertical resolution, this technique is a critical point. A statistical analysis yields a global mean standard deviation of 15–20 hPa for tropopause height, which is already on the subgrid scale. Therefore careful interpretation of the data is necessary. On the other hand, Hoinka et al. (1993) demonstrated a good agreement between the tropopause height calculated from ECMWF analysis and direct TEMPS observations (results of radiosonde profile measurements). Horizontally, a spectral representation of temperature in spherical harmonics up to a total wavenumber 42 (T42) was used. This corresponds to a physical resolution of approximately 4.3° (≈ 480 km). Due to the sparse distribution of observations at tropopause height (mostly resulting from measurements by radiosondes and commercial aircraft), a higher resolution would be an artifact of the ECMWF model. The horizontal resolutions of the ozone column data at mid and high latitudes (2.5°, 5.0° respectively) and of the tropopause data (T42, nominal resolution is 2.8°) are similar, which is optimal for a correlation analysis. The tropopause data are adapted to the 1.25° × 1.0° longitude latitude grid of the TOMS-data by linear interpolation. Since both grids are oversized for the real resolution of the data, this technique will have no significant effect on the correlation analysis fields. One value per day was used (at 0 : 00 UTZ) for both total ozone and tropopause pressure. No additional time or space filtering was performed on the data. Calculating a phase shift between total ozone and tropopause pressure may have proved interesting, but was not performed due to the long (24-hour) time increment.

3 Results

Charts of tropopause height pressure (in hPa) and of total ozone (in DU) for 12th and 15th January 1992 are presented in Figures 1 and 2, respectively. These data can be taken as representatives for January 1992. Large areas over middle and northern Europe were dominated by a high tropopause (Figure 1). Values of less than 180 hPa (> 12 km) were typical for the entire period from late December until early February. Occasionally, regions with very low tropopause (> 320 hPa, or < 8 km) were found in the vicinity of these areas (e.g. 12th January). These regions are linked to cyclones

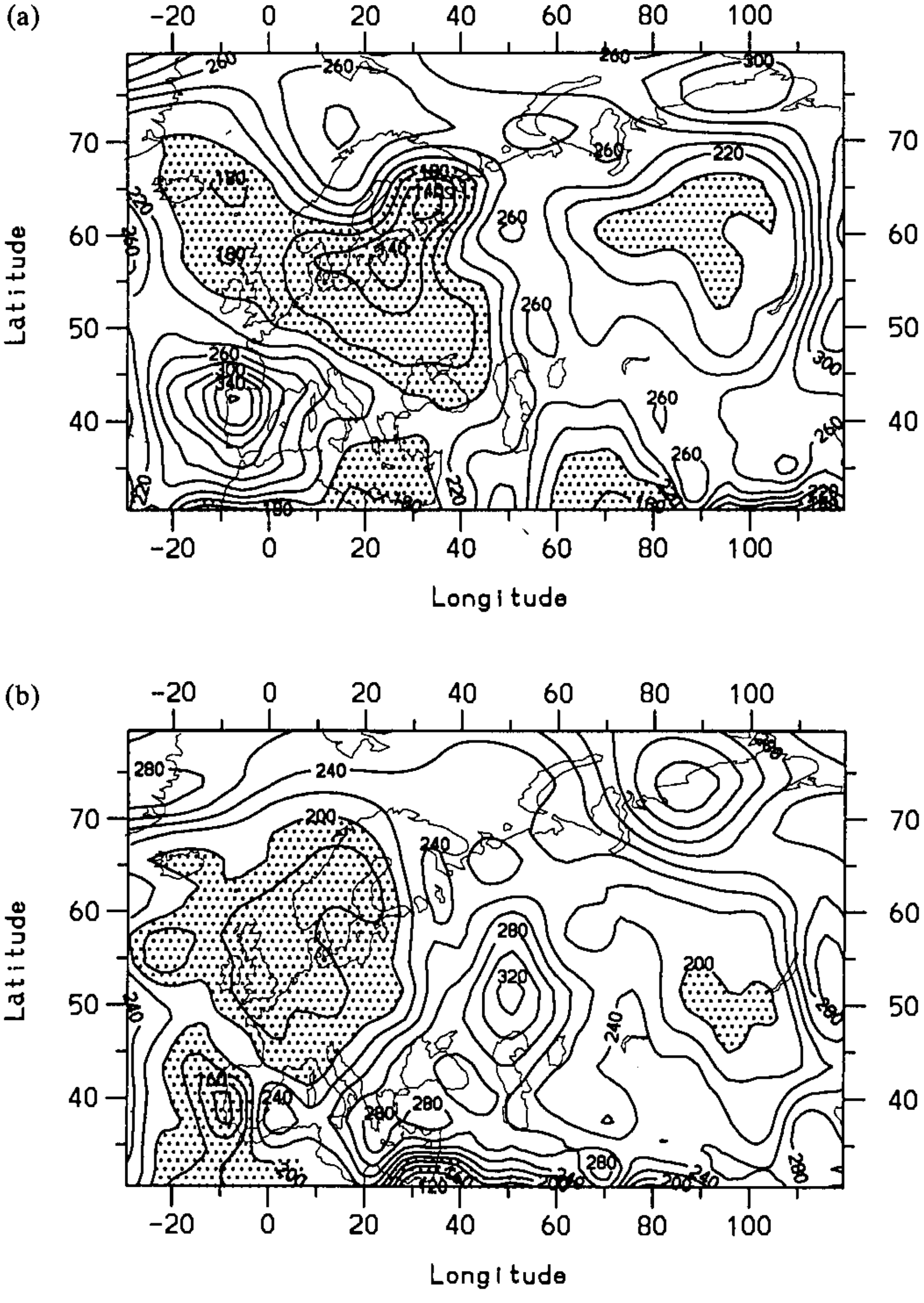

Figure 1 Charts of tropopause pressure (in hPa) from 30.5 °N to 79.5 °N and 29.4 °W to 119.4 °E for (a): 12th January 1992, and (b): 15th January 1992. Stippled regions indicate a tropopause pressure less than 200 hPa (> 11 km).

passing the blocking anticylone. Charts of total ozone (Figure 2) were restricted to the region south of 63°N, as the TOMS instrument allowed no measurements during polar night. Visual inspection indicates that low values of total ozone (< 240 DU) broadly correlate with a high tropopause. On the other hand, values of total ozone are significantly enhanced (~ 400 DU) when tropopause height is low.

The temporal correlation between tropopause height and ozone column was calculated for each grid point presented in Figure 2 for the time period of 1st November 1991 to 30th April 1992 (Figure 3). As expected, large correlations are found over northern Europe with a maximum over the Baltic Sea. To estimate the confidence limit we assumed that each time series has about 12 degrees of freedom (no autocorrelation longer than 15 days). A correlation

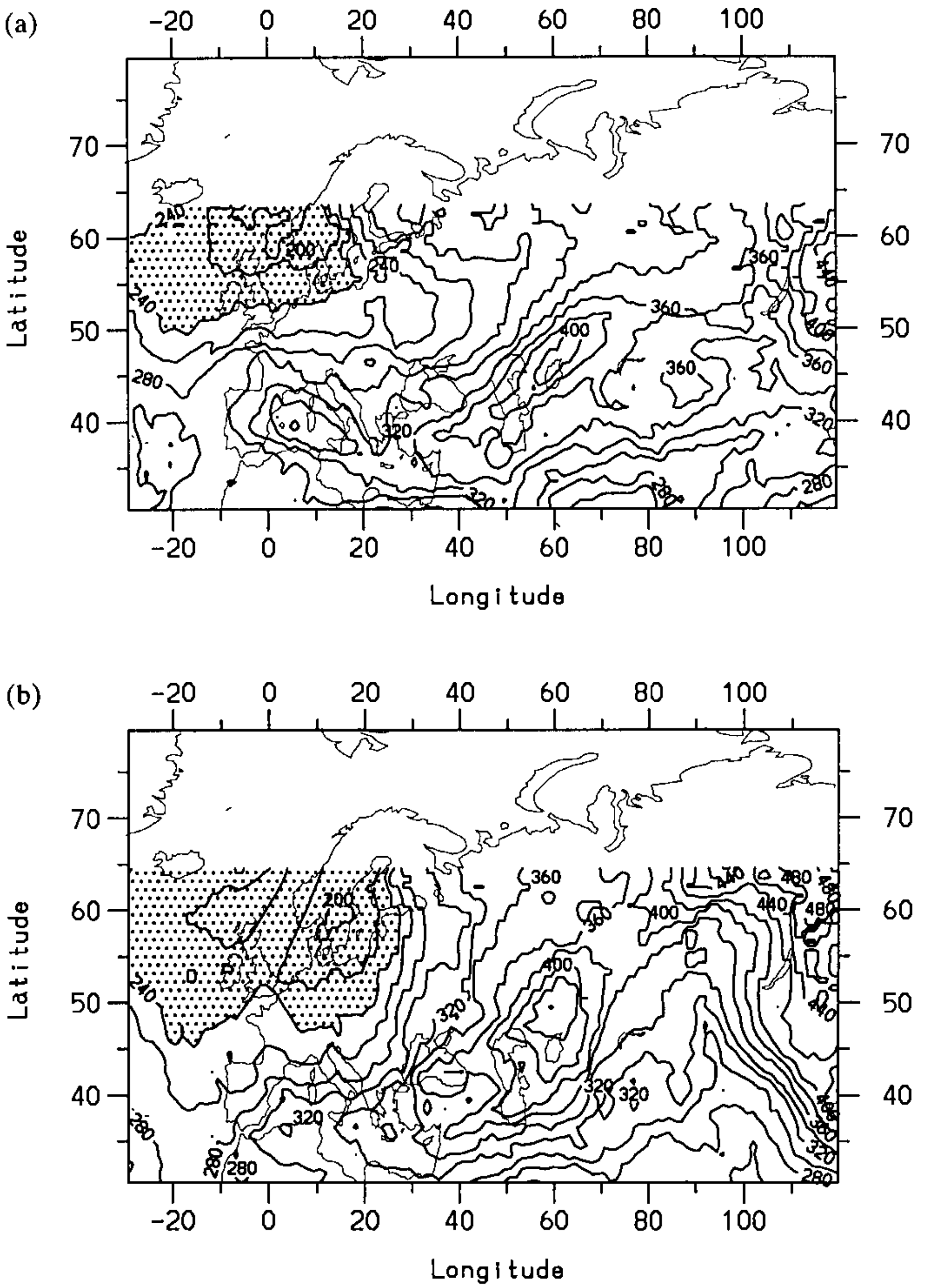

Figure 2 As Figure 1, but for total ozone (in DU). Stippled regions indicate total ozone values less than 240 DU.

coefficient of 0.6 (stippled regions in Figure 3) is then found to be significant on a confidence level of 98 %.

In order to get an additional impression of the link between the tropopause height and total ozone, the time development of both data series at a single gridpoint centred in the region of high correlation (55.5 °N, 15.6 °E) are presented in Figure 4. It clearly indicates the relationship of total ozone and tropopause pressure, in particular that rather low tropopause height pressure values observed in January over northern Europe are correlated with anomalous low values of total ozone. While the tropopause pressure is highly variable over the whole time period, the values of total ozone are following quite well. Nevertheless, it also points to the limitation of an isolated view of tropopause height against total ozone: The strong increase of total ozone after 7th February is not accompanied by a similar strong increase in tropopause height

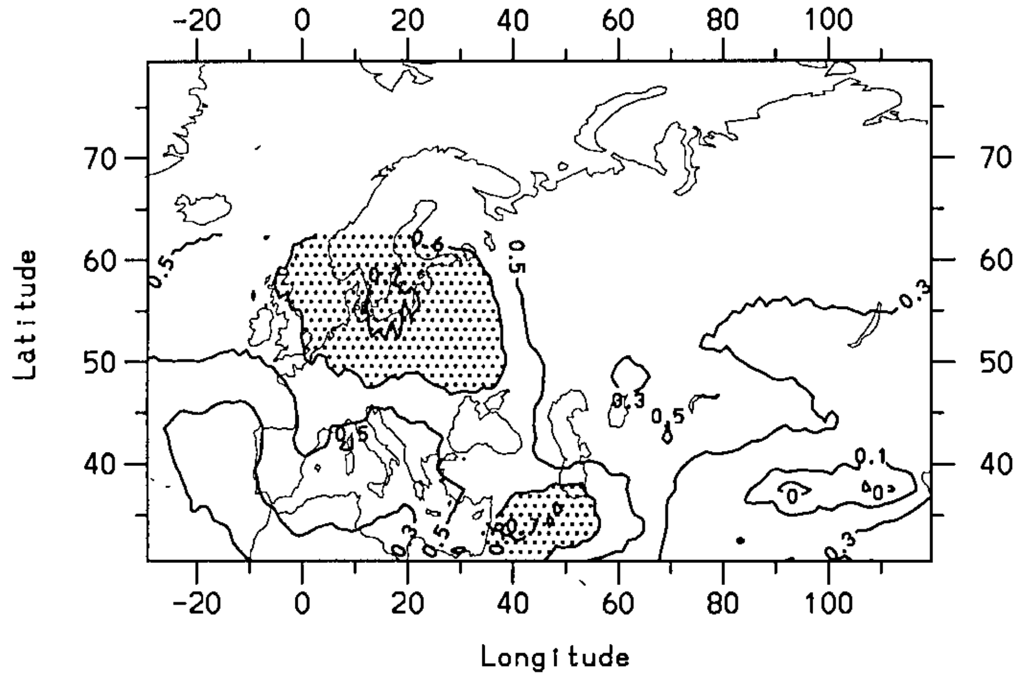

Figure 3 Correlation in time of anomaly between total ozone and tropopause pressure from 1st November 1991 to 30th April, 1992. Stippled regions indicate correlation coefficients greater 0.6.

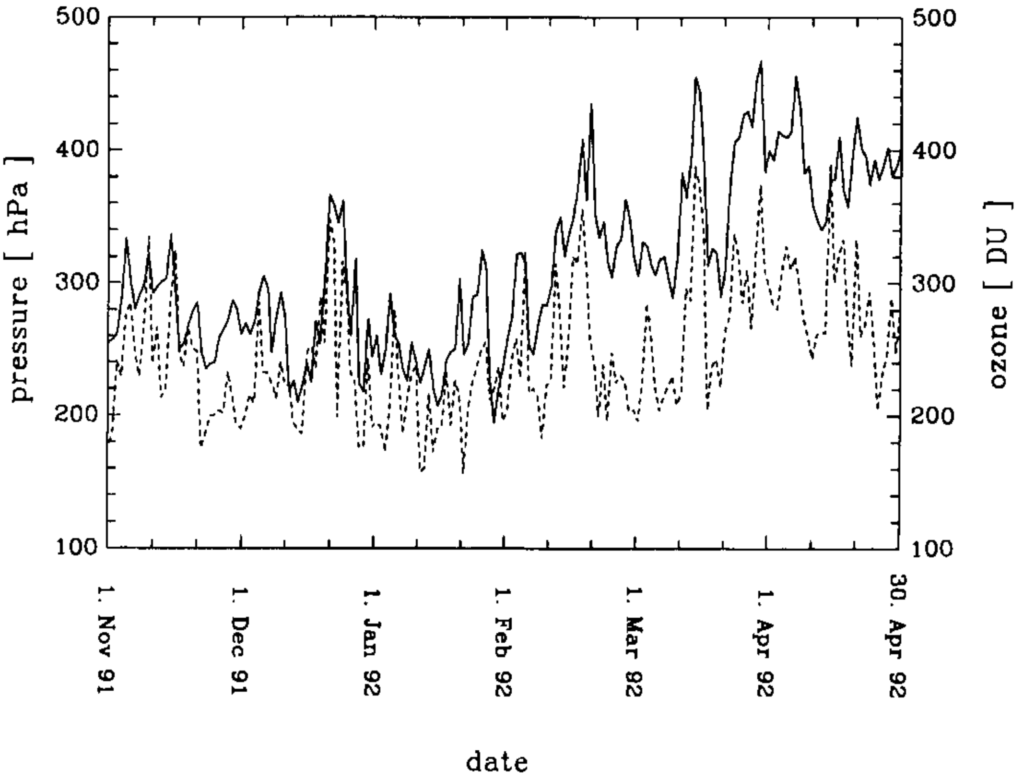

Figure 4 Time development of total ozone (in DU, full line) and tropopause pressure (in hPa, dashed line) for gridpoint 55.5 °N, 15.6 °E.

pressure, indicating that other (dynamical) processes have yield to this effect (Petzoldt et al., 1994). For example, the influence of differential advection in the lower stratosphere during winter and spring, which cannot be reflected in this type of correlation, further contributes to ozone column variability.

4 Conclusion

The correlation of tropopause height pressure and total ozone, which is a useful technique which can be applied to large data sets with a certain measure of success, should be seen in addition to other analyses, for example those presented by Farman et al. (1994) and Petzoldt et al. (1994), it should provide some supplementary information. It is obvious, a straight foreward correlation of tropopause height and total ozone provides only a rough guide to the degree of influence of dynamical processes on the ozone column. It does not actually tell one anything precise, but it can be taken as a working basis for a comparison with other winters, which probably show different ozone columns for tropopause heights similar to those observed in January 1992. An isolated consideration of the tropopause to investigate the dynamical induced behaviour of total ozone does not yield to reliable results. Large scale processes in the stratosphere (i.e. effects of planetary waves) have also strong impact on the ozone column.

The analysis of winter 1991/1992 presented in this paper and also those of Farman et al. (1994) and Petzoldt et al. (1994) clearly indicate that dynamical processes play a dominant role in producing anomalous low ozone values. This has also been found by others analysing the chemistry of this winter (e.g. Lefevre et al., 1994). The depletion of ozone by chemical processes is only a few percentage of that resulting from dynamical effects.

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References

Bojkov, R. D., 1986: The 1979–1985 ozone decline in the antarctic as reflected in ground based observations, Geophys. Res. Lett. **13**, 1236–1239.

Farman, J. C., A. O'Neill, and *R. Swinbank*, 1994: The dynamics of the arctic polar vortex during the EASOE campaign, Geophys. Res. Lett. **21**, 1195–1198.

Farrara, J. D. and *C. R. Mechoso*, 1986: An observational study of the final warming in the southern hemisphere stratosphere, Geophys. Res. Lett. **13**, 1232–1235.

Hoinka, K. P., M. E. Reinhardt, and *W. Metz*, 1993: North atlantic air traffic within the lower stratosphere: Cruising times and corresponding emissions, J. Geophys. Res. **98**, 23113–23131.

Lefevre, F., G. P. Brasseur, I. Folkins, A. K. Smith, and *P. Simon*, 1994: Chemistry of the 1991–1992 stratospheric winter: Three-dimensional model simulations, J. Geophys. Res. **99**, 8183-8195.

Naujokat, B., K. Petzoldt, K. Labitzke, R. Lenschow, B. Rajewski, M. Wiesner, and *R.-C. Wohlfart*, 1992: The stratospheric winter 1991/92: The winter of the European Arctic Stratospheric Ozone Experiment, Supplement of the Berliner Wetterkarte, SO18/92.

Newman, P. A. and *M. R. Schoeberl*, 1986: October antarctic temperature and total ozone trends from 1979–1985, Geophys. Res. Lett. **13**, 1206–1209.

Ohring, G., and *H. S. Muench*, 1960: Relationships between ozone and meteorological parameters in the lower stratosphere, J. Meteorol. **17**, 195–206.

Petzoldt, K., B. Naujokat, and *K. Neugebohren*, 1994: Correlation between stratospheric temperature, total ozone, and tropospheric weather systems, Geophys. Res. Lett. **21**, 1203–1206.

Reed, R. J., 1950: The role of vertical motions in ozone-weather relationships, J. Meteorol. **7**, 263–267.

Schoeberl, M. R. and *A. J. Krueger*, 1983: Medium scale disturbances in total ozone during southern hemisphere summer, Bull. Amer. Meteor. Soc. **64**, 1358–1365.

Schubert, S. D. and *M.-J. Munteanu*, 1988: An analysis of tropopause pressure and total ozone correlations, Mon. Wea. Rev. **116**, 569–582.

Sekiguchi, Y., 1986: Antarctic ozone changes correlated to the stratosphere temperature field, Geophys. Res. Lett. **13**, 1202–1205.

Vaughan, G. and *D. A. Begum*, 1989: Correlation between total ozone and potential vorticity, in Bojkov R. D. and Fabian P. (Eds.): Ozone in the atmosphere, Hampton, VA, A. Deepak Publishing, 91–94.