Dynamical contributions to stratospheric ozone trends in mid-latitudes

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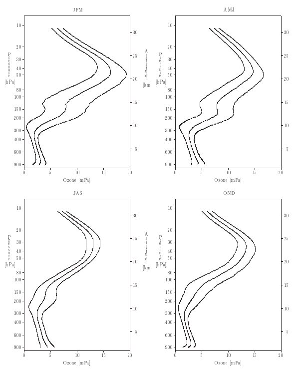


Mean ozone profiles $\pm 2\sigma$ for the four seasons at Payerne, Switzerland.

Ozone Profiles

4119 ozone profiles have been measured between 1970 and 2001 by MeteoSwiss at Payerne, Switzerland (46.80N, 6.95E, 490 a.s.l.) with a Brewer-Mast sonde.

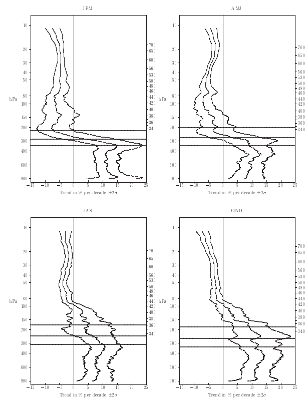
The high resolution ozone profiles are scaled with an altitude-independent factor to match total ozone measured at Arosa (200 km east of Payerne).

Ozone deviations are calculated with respect to the 30-year monthly means at 16 levels in the lower and middle stratosphere in units of the standard deviation σ.

Variability is most pronounced in winter and spring.

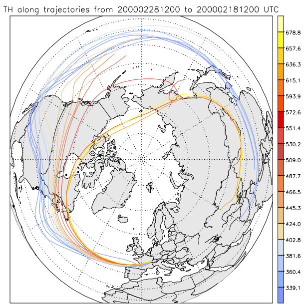
Ozone Trends

Negative ozone trends are significant (on the 95% confidence level) on altitudes higher than 120 hPa in winter and spring and above 80 hPa in summer and autumn. This is in contrast to studies considering shorter time periods, but the negative trends found in the lowest part of the stratosphere are not significant when including the last few years. For the statistical analysis we focused on winter time and divided the profiles into two stratospheric parts: the lower one with its high variability and the upper part where significant negative trends are found.



Linear ozone trends $\pm 2\sigma$ for the period 1970-2001 at Payerne, Switzerland.

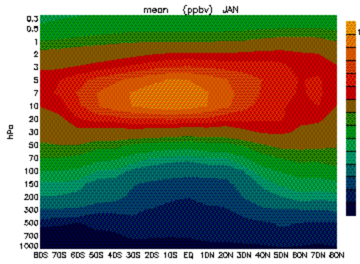
Method and Motivation



Example of 16 isentropic trajectories for 28 Feb 2000.

To determine the recent origin of air masses arriving at Payerne, 10-day backward trajectories were computed for all ozone profiles between 1970 and 2001. Trajectories were calculated on 16 isentropic surfaces between 340 and 700 K, that correspond to pressure levels between about 300 and 20 hPa and to altitudes between about 12 and 30 km. Along the isentropic trajectories longitude, latitude, pressure and potential vorticity (PV) values are obtained every 6 h. These calculations are based on wind fields from the National Centers for Environmental Prediction (NCEP) reanalysis data that are available on 17 pressure levels up to 10 hPa and with a horizontal resolution of $2.5° \times 2.5°$.

The potential role of atmospheric transport for the observed ozone variability becomes evident when the climatological global ozone distribution is considered. In the lowermost stratosphere (below 16 km, which corresponds typically to 100 hPa or 420K) it is characterized by a poleward increase, and above that level by a poleward decrease. This indicates that transport of stratospheric air for instance from the subtropics into the mid-latitudes below about 16 km is typically associated with anomalously low ozone values. The same applies for air from the polar regions above this level.

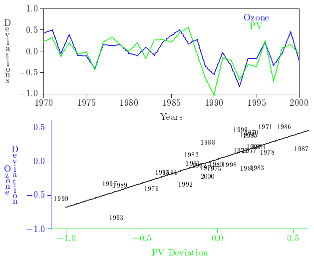


Zonally averaged ozone distribution for January 1980 - 1991

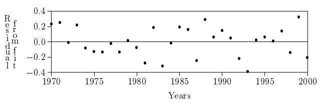
from J.P.F Fortuin and H. Kelder, J. Geoph. Res., vol. 103, 1998

Ozone and Potential Vorticity

Ozone and PV are very well correlated on altitudes between 12 and 17 km:



No change in Ozone-PV relationship:



Ozone and PV deviation time series for JFM between 340 and 440 K

340K - 440K

The climatological potential vorticity (PV) distribution on isentropic surfaces shows high PV values in the polar region and low values in the (sub)tropics and thus PV can also provide information about the origin of air masses arriving at the measurement site.

Similarly to the ozone deviations PV deviations are calculated in units of standard deviation from the 32 years PV average on the different isentropic levels.

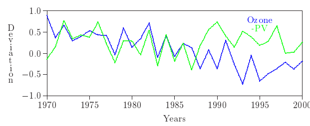
The region between 340K and 440K makes the major contribution to total ozone. There is a significant positive correlation between PV and ozone, as expected from climatological ozone distribution. The good correlation between PV and ozone is also evident in the scatter diagram of PV and ozone deviations. The residuals to the fitted line show no trend and this indicates that there is no change in time of the robust PV-ozone relationship.

460K - 700K

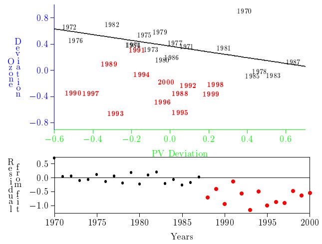
In comparison to the lowermost stratosphere the correlations between ozone and PV deviations are expected to change their sign because of the reversal of the meridional gradient in the climatological ozone distribution above 460 K. On these altitudes a negative trend in ozone is found, whereas the PV deviations do not significantly increase or decrease with time. First only the years 1970-1987 are considered, where ozone and PV deviations are significantly negatively correlated as expected.

From the late 1980s onwards, ozone values are systematically lower than the fit to the years 1970 - 1987 would suggest. As there is no significant (positive or negative) trend in mean PV values, the ozone changes at these altitudes cannot simply be ascribed to systematical changes in the frequency of transport of ozone rich or poor air to mid-latitudes.

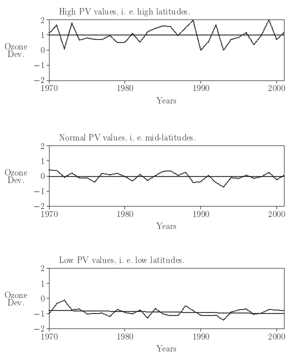
Ozone and PV are anti-correlated on altitudes between 17 and 30 km only up to 1987:



Ozone values of the late 1980s and the 1990s are systematically lower than expected:



Ozone and PV deviation time series for JFM between 460 and 700 K



To gain insight into the temporal ozone changes associated with air masses from different origins, every ozone value was classified according to its trajectory's mean PV value: class P (Polar origin) for mean PV values exceeding 120 % of the 32-year monthly mean, class M (Mid-latitude origin) for 80 % to 120 % and class S (Subtropic origin) for less than 80 %.

Mid-latitude ozone variability at altitudes between 340-440 K is mainly controlled by the varying origin of the air masses and not in first place by chemistry. For the time period 1970-2001 sounding data from Payerne show no significant decrease for this layer.

The amount of ozone (represented by the deviation from the seasonal mean in units of the respective standard deviation) changed significantly in all three classes. The negative trends are most pronounced for high and low PV values and smaller, but still significant, for the PV range in between. This reveals that the observed negative ozone trends in mid-latitudes are strongly influenced by the decrease of ozone in the polar and subtropical regions. The strongest decrease is found for air masses of polar origin, and this indicates the impact of the increasing chemical ozone destruction in polar regions on mid-latitude ozone through large-scale transport.

Ozone trends in high PV regions (Arctic) and low PV regions (subtropics) are responsible for about 50% of the negative ozone trends at mid-latitudes on altitudes between 17 and 30 km.