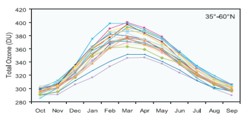
Seasonal persistence of anomalies of ozone and other trace gases in the NH stratosphere

S. Tegtmeier[1], V. E. Fioletov[1] and T. G. Shepherd[2]
[1]Environment Canada, [2]University of Toronto

Motivation

Fioletov & Shepherd: Seasonal persistence of midlatitude total ozone anomalies, 2003



Time series of midlatitude total ozone 1979 - 2000

- winter buildup and late spring/summer decline
- interannual anomalies established in winter/spring persist through the summer period

Can we find the same persistence of anomalies in the upper stratosphere where ozone is under photochemical control and has a short lifetime?

Ozone profile data sets

Merged SBUV(/2) data set

- Nearly global daily coverage with a vertical resolution of about 5 km
- monthly zonal mean zonal values
- November 1978 to December 2007
- profile ozone, layer amounts [DU] for 9 layers between 1000 - 1.6 hPa
- processed using the SBUV version 8 algorithm
- Stolarski and Frith [2005]

SAGE II data set

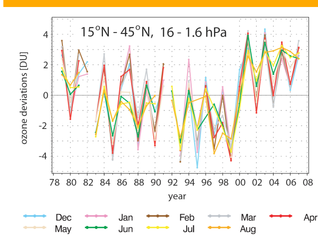
- based on solar occultation with limited spatial sampling
- January 1985 to December 2003
- ozone and NO_2 volume mixing ratio on 16 pressure levels between 700 and 0.2 hPa
- processed using the version 6.2 retrieval algorithm
- Zawodny and McCormick [1991]

HALOE data set

- based on solar occultation with limited spatial sampling
- October 1991 to August 2002
- NO_x, CH_4, H_2O, HCL and HF volume mixing ratio on 22 pressure levels between 316 and 0.1 hPa
- data set prepared by Grooß and Russell [2005]

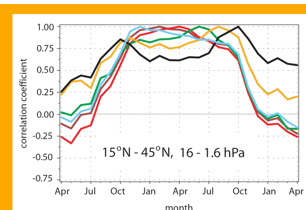
Seasonal persistence of 1.) SBUV ozone and 2.) SAGE II ozone

Analysis of partial ozone columns above 16 hPa (approximately 30 km altitude) in the latitude band 15°N-45°N reveals that negative or positive ozone anomalies in individual years persist through the entire year from November to October.



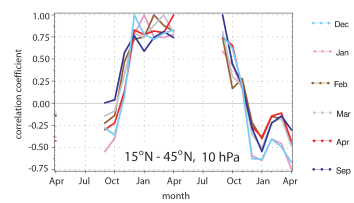
Correlation coefficients between ozone time series in individual months

This persistence of the ozone anomalies is quantified with correlation functions between the ozone time series for individual months. A strong persistence is characterized by a clear clustered structure of large correlation coefficients.

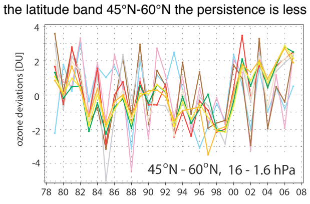


Which mechanism is responsible for the seasonal persistence of ozone anomalies above 16 hPa?

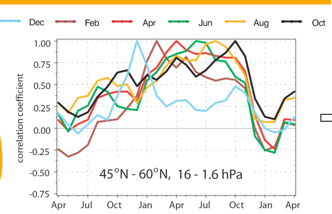
Correlation functions of SAGE II ozone volume mixing ratio at 10 hPa in the latitude band 15°N-45°N demonstrate persistence of ozone anomalies in winter and early spring and confirm observations made for the SBUV data set.



In the latitude band 45°N-60°N the persistence is less strong.



Correlation coefficients between ozone time series in individual months



Analysis of SBUV(/2) ozone data in the NH demonstrates that upper stratospheric anomalies persist from November to October of the following year. This seasonal persistence is particularly strong in the 15°N-45°N latitude belt. Analysis of SAGE II ozone demonstrates a similar persistence in winter and early spring (correlations for the summer months are not displayed because of data gaps). Correlations for the latitude band 45°N-60°N are of comparable strength in late spring and summer but less strong in winter. Which mechanism is responsible for the seasonal persistence of ozone anomalies above 16 hPa?

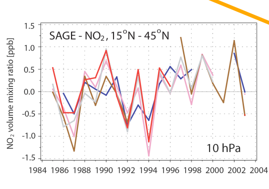
Analysis of SBUV ozone data for the lower stratosphere reveals strong persistence especially in the latitude band 45°N-60°N (not shown here). The mechanism responsible for this persistence is ozone build up in winter-spring with subsequent slow summertime photochemical relaxation of ozone.

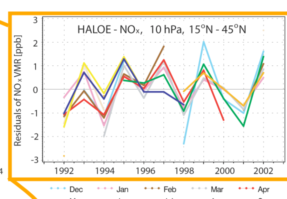
Seasonal persistence of NO_2 (SAGE II) and NO_x (HALOE)

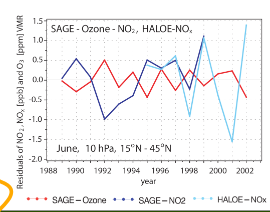
We found a strong seasonal persistence of ozone anomalies in the subtropical and midlatitude upper stratosphere. Because of the short lifetime of O_x in this region, it is not possible for the memory to reside in the ozone itself.

Winter-spring upper stratospheric extratropical ozone anomalies have been attributed to NO_2 anomalies induced by the effect of the QBO on the dynamical forcing of the BDC [Zawodny and McCormick, 1991; Chipperfield et al., 1994]

We hypothesize that transport-induced NO_y persist through the autumn to autumn time frame and that this is the mechanism responsible for the seasonal persistence of upper stratospheric ozone anomalies







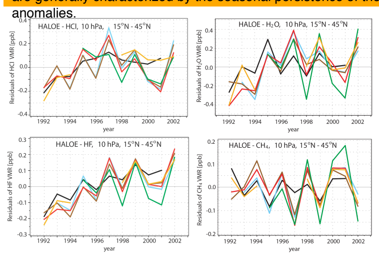
Year-to-year variability of SAGE II NO_2 for 15°N-45°N at 10 hPa illustrates the persistence of NO_2 anomalies during winter and spring. Because of data gaps we can not analyze the behavior after April.

HALOE NO_x anomalies for 15°-45° equivalent latitude at 10 hPa clearly persist from winter through spring and summer until the following autumn.

An additional test of our hypothesize confirms that NO_2 and ozone anomalies are negatively correlated during summer

Persistence of long-lived trace gases (HALOE)

A final test of our hypothesis shows that long-lived trace gases in the upper stratosphere are generally characterized by the seasonal persistence of their interannual anomalies.



HALOE HCl, HF, H_2O and CH_4 anomalies averaged over 15°-45° equivalent latitude at 10 hPa establish during late autumn/early winter and then persist through the whole spring and summer. In October the magnitude of the anomalies decreases and November (not shown here) is a transitional month where the anomalies of the next winter start to build up.

Frith and Stolarski (2005), Merged Profile Ozone Data from the SBUV/SBUV2 Series of Instruments, American Geophysical Union, Fall Meeting 2005, San Francisco
Grooß and Russell (2005), A stratospheric climatology for O_3, H_2O, CH_4, NO_x, HCl and HF derived from HALOE measurements, *Atmos. Chem. Phys., 5*, 2797-2807.
Zawodny and McCormick (1991), Stratospheric Aerosol and Gas Experiment II measurements of the quasi-biennial oscillations in ozone and nitrogen dioxide, *J. Geophys. Res.*, *96*, 9371-9377.
Chipperfield et al. (1994), A two-dimensional model study of the QBO signal in SAGE II NO_2 and O_3, *Geophys. Res. Lett.*, *21*, 589–592.

Summary

Ozone anomalies in the extratropical upper stratosphere show a very strong seasonal persistence. The mechanism responsible for the persistence of ozone anomalies is the persistence of transport-induced wintertime anomalies in NO_y which perturb ozone through NO_x chemistry. Evidence for this mechanism is provided based on the analysis of SAGE II NO_2 and HALOE NO_x data and by the analysis of other long-lived trace gases which show the same seasonal persistence.

One practical application of ozone anomaly persistence is that ozone values in spring, summer, and autumn can be predicted already in winter and early spring. This is demonstrated in the Figure below for the SBUV(/2) time series of ozone anomalies (1970-2007, 15°N-45°N, 16-1.6 hPa). The ozone time series is shown as a black line and the March ozone values are highlighted as red dots. The blue line shows a reconstruction of the original time series which is based on the March ozone. For nearly all the years the full seasonal cycle of the ozone deviations can be reconstructed based on just a single value for that year. These prediction capabilities are highly seasonal: it is possible to predict September ozone deviation 9 months ahead based on the values in the previous December, but December values can't be accurately predicted from the previous September values which are just 3 months away. This shows that seasonal persistence is a completely distinct phenomenon from dependence on some slowly varying external factor such as the QBO.