Chemistry-dynamics interaction in polar stratospheric ozone: Weak and strong vortex events

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1. Introduction

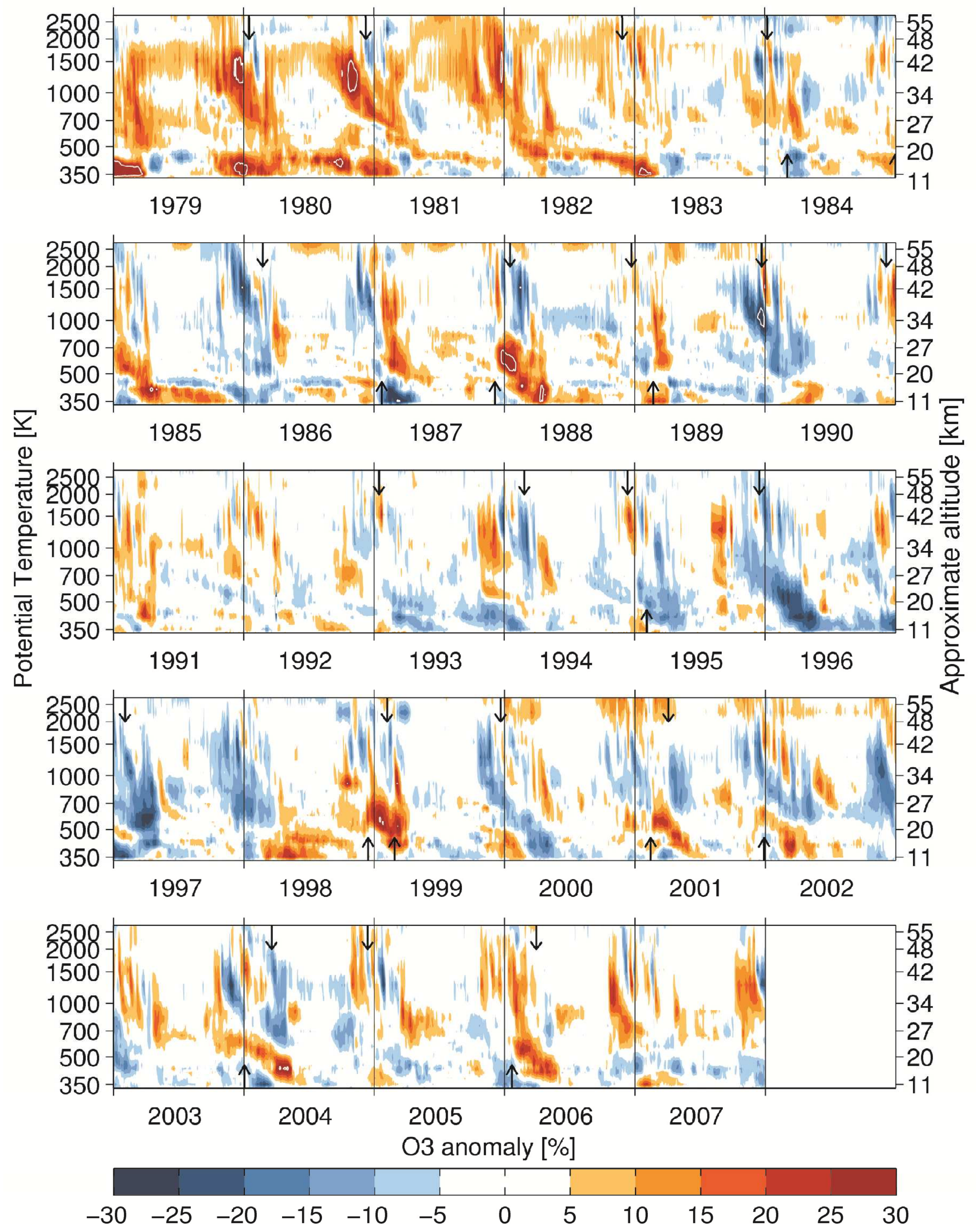
We here use a 29 year global dataset (1979-2007) of stratospheric ozone to investigate Arctic ozone variability. The data set has been generated by sequential assimilation of SBUV satellite observations in our chemistry transport model (Bremen CTM) and is described in Kiesewetter et al (2010).

In particular, we investigate ozone anomalies that arise as a consequence of large dynamical anomalies (weak and strong vortex events). Sensitivity calculations with the unconstrained CTM are used to estimate the contributions of dynamics and chemistry to the formation of these anomalies.

2. Arctic ozone anomalies

We use the assimilated data set to investigate Arctic ozone variability.

↓ **Fig. 1.** Arctic ozone anomalies (deviations from the annual cycle) > 70N equivalent latitude in the assimilated data set: Large patterns of alternating descending ozone anomalies with remarkable lifetimes. Some ozone anomalies appear related to strong dynamical anomalies indicated as arrows (↑ … weak vortex events, ↓ … strong vortex events)



3a. Ozone anomalies and NAM

3b. Extreme phases of the NAM: Vortex events

The Northern Annular Mode (NAM) is the dominant pattern of atmospheric variability in the NH. It plays an important role for Arctic O3 variability:

↓ **Fig. 2.** Correlation of Arctic O3 anomalies to the NAM index, both at ~24km. Positive NAM phases induce negative O3 anomalies and vice versa. For equivalent latitude O3, the anticorrelation is weaker and delayed by 10 days.

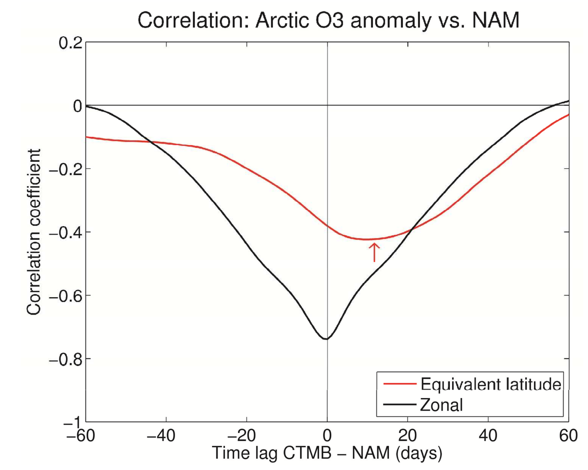


Fig. 3: O3 anomaly (zonal mean 70-90N)

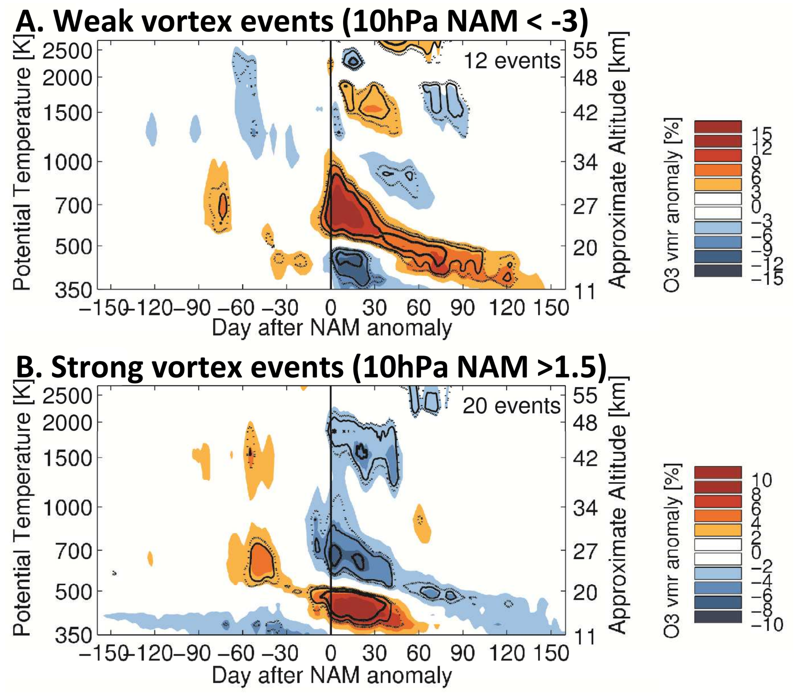
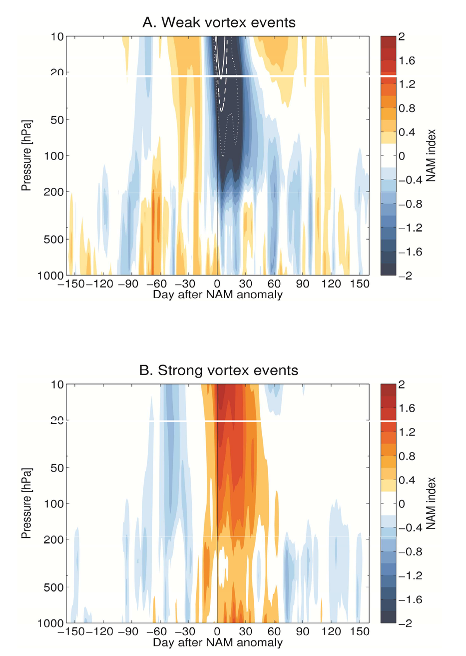


Fig. 4: NAM index

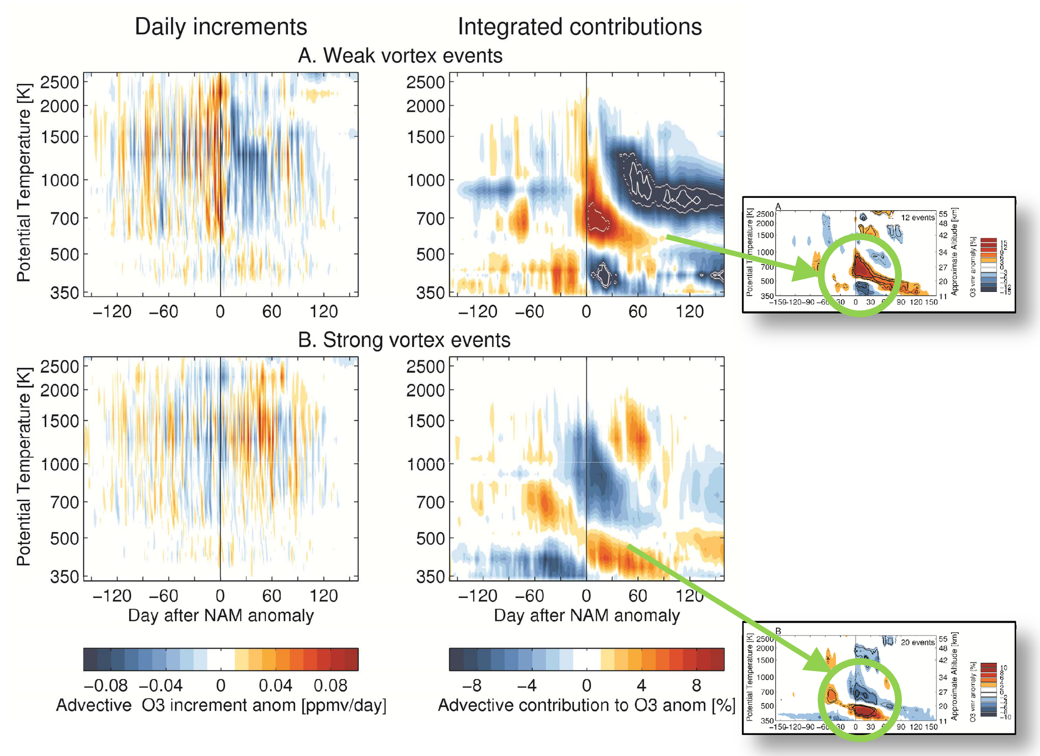


← **Fig. 3.** Strong excursions of the NAM phase, known as **weak (A) and strong (B) vortex events**, induce large O3 anomalies that remain visible for 5 months, far longer than the NAM anomaly itself (**Fig. 4 →**).

The shape of these O3 anomalies is caused by chemistry-dynamics interaction: See box 4 below.

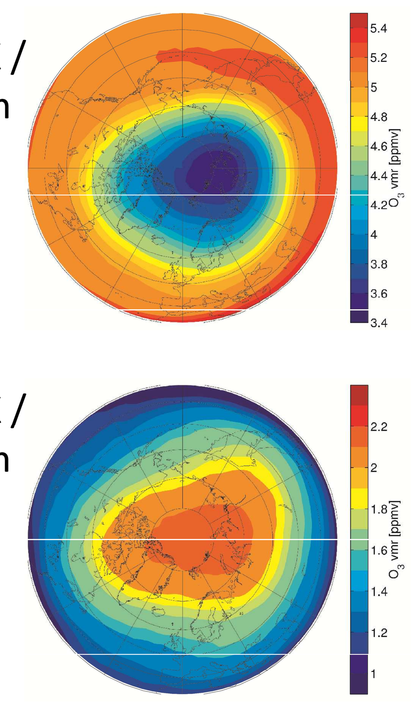
4. Explaining the shape of NAM-related ozone anomalies

4a. Anomalies in meridional ozone transport



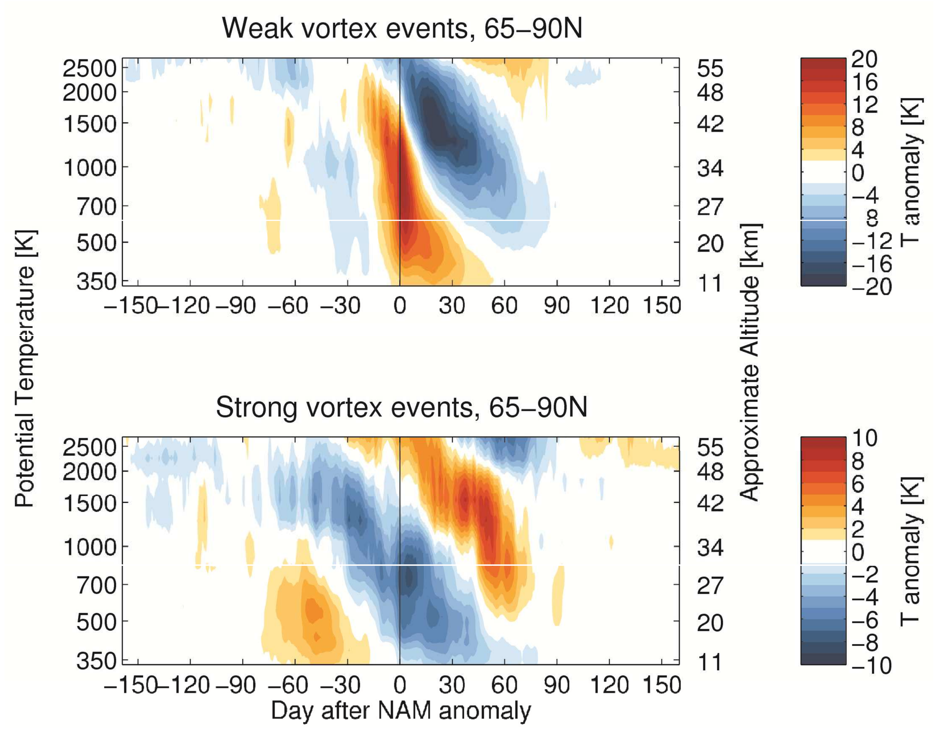
← **Fig. 5.** Vortex events are characterized by large anomalies in meridional transport (increased for weak vortex events, de-creased for strong vortex events). These transport anomalies are responsible for the initial shape of the ozone anomalies.

→ **Fig. 6.** The reversal of the transport effect around 500K / 20km is caused by the reversal of the meridional ozone gradient in this altitude. More (less) mixing leads to a positive (negative) O3 anomaly above this level and a negative (positive) O3 anomaly below.



4b. Temperature anomalies and their effects: Chemistry-dynamics interaction

Fig.7. T anomalies around vortex events



← **Fig. 7.** Vortex events also coincide with large temperature anomalies.

→ **Figs. 8 & 9**: These T anomalies induce chemical effects on ozone by shifting gas-phase reaction equilibria in the upper stratosphere (Fig. 8), and modifying the occurrence of PSCs and Cl activation in the lower stratosphere (Fig. 9)

Fig. 8: T effects on ozone via gas phase chemistry

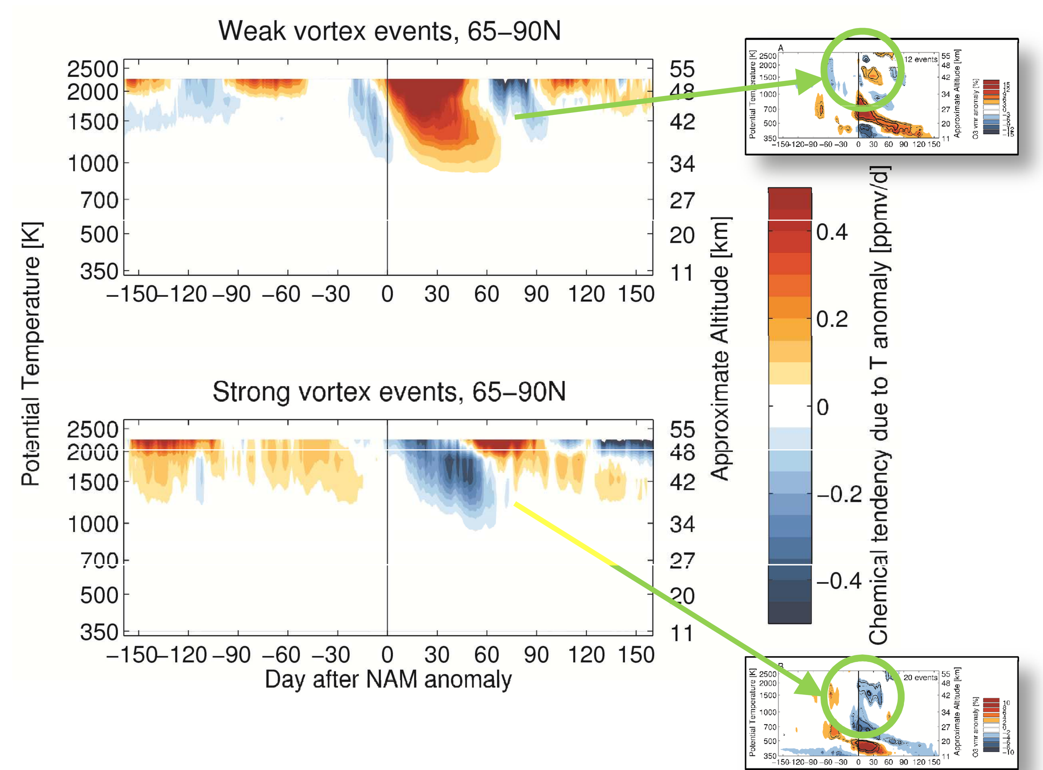
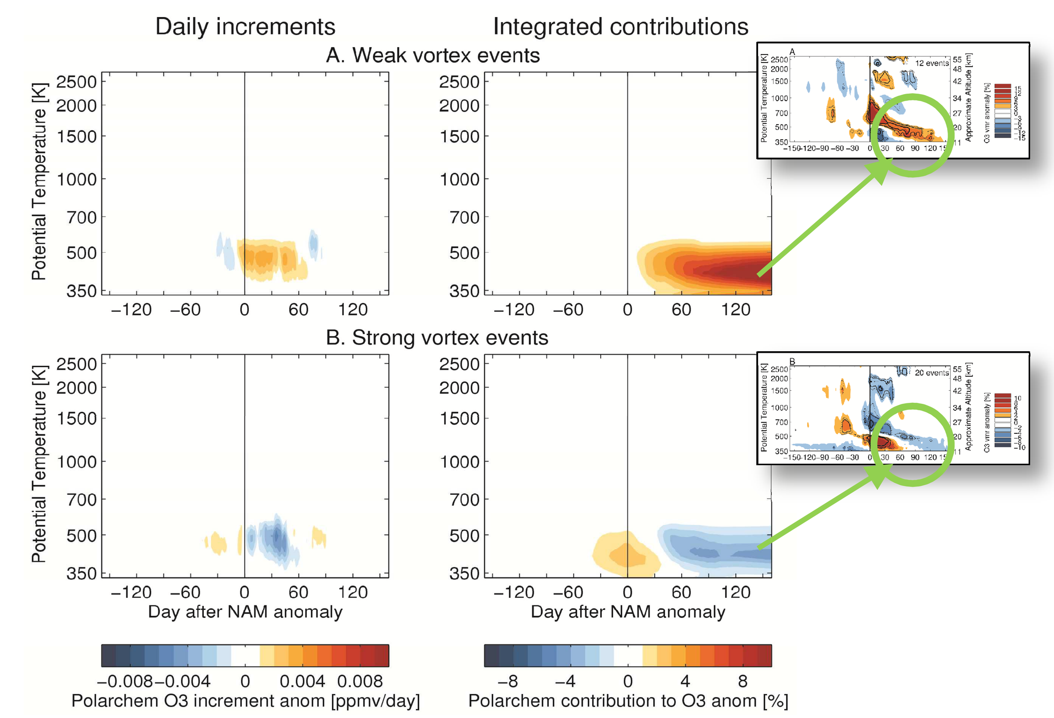
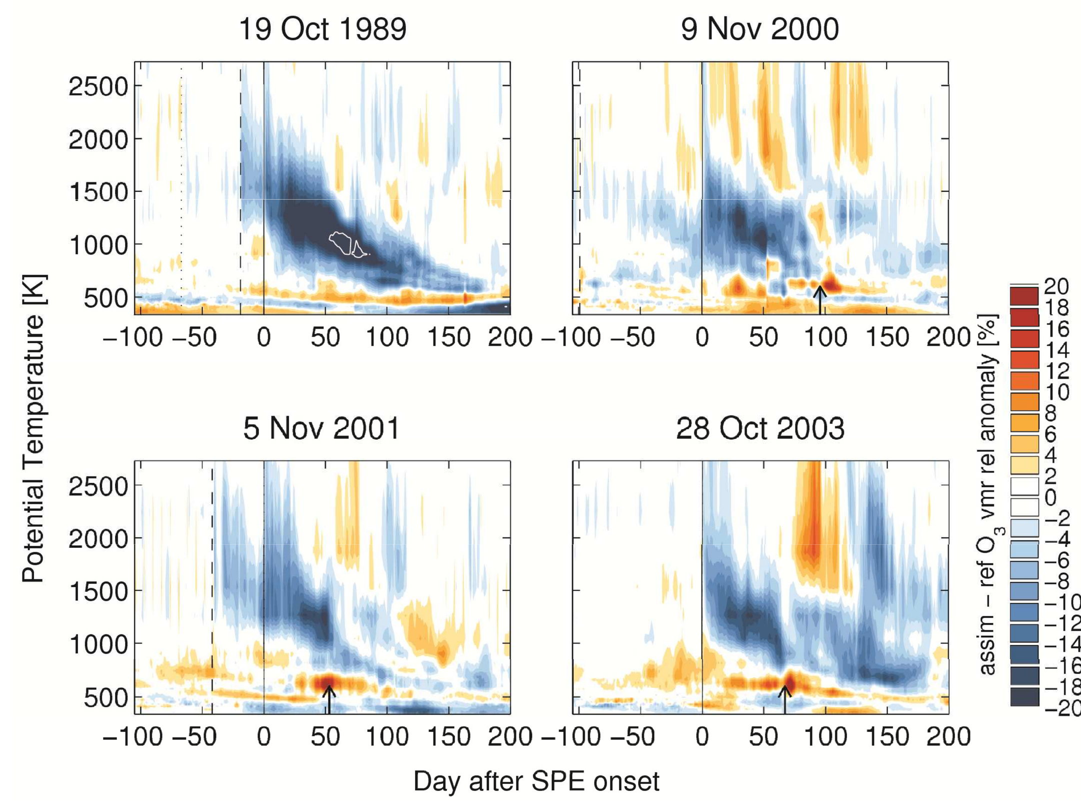


Fig. 9. Effects on ozone via heterogeneous polar chemistry



5. Example: Effects on SPE-related ozone anomalies

↓ **Fig. 10.** Solar proton events lead to strong negative ozone anomalies caused by the formation of HO_x and NO_x radicals in the upper stratosphere and mesosphere. These ozone anomalies are well visible in our data set in the wake of four of the largest SPEs during recent decades. However, the evolution of the ozone anomaly is different in different winters, related to the occurrence of weak vortex events in three of four winters (indicated by ↑).



6. Conclusions

- Weak and strong vortex events induce large anomalies in Arctic ozone, which survive far longer than the dynamical anomaly (NAM excursion) itself.
- The characteristic shape can be explained as a result of transport anomalies as well as chemical effects of temperature anomalies.
- As an example, we show that the different residence times of solar-proton induced ozone anomalies are a result of vortex events in the corresponding winters.

Reference Kiesewetter, G., B.-M. Sinnhuber, M. Vountas, M. Weber, and J. P. Burrows, A long-term stratospheric ozone data set from assimilation of satellite observations: High-latitude ozone anomalies, J. Geophys. Res., 115, D10307, 2010