What controls the inter-annual variabilty of Arctic ozone?

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Introduction

Understanding the processes that control the inter-annual variability of Arctic total ozone during winter and spring is important to predict how the ozone layer will evolve in the coming decades. It is now well accepted that high latitude total ozone during spring is largely controlled by the flux of planetary-scale waves into the stratosphere during mid-winter, as measured by the Eliassen-Palm (EP) flux. E.g., years with low wave activity during mid-winter exhibit reduced poleward and downward ozone transport, enhanced confinement of air masses at high latitudes and low temperatures that favour chemical ozone destruction.

Here we now show that the inter-annual variability of Arctic total ozone during March is highly correlated with high latitude ozone in the mid-stratosphere during the previous summer and autumn. This raises the question of what controls the stratospheric inter-annual variability during winter and spring.

Inter-annual variability in polar ozone

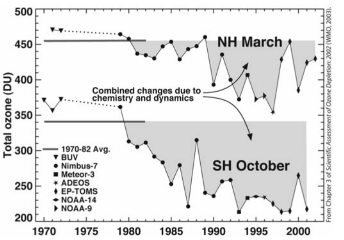

Fig 1. Stratospheric ozone has shown large decreases over past decades at high latitudes of both hemispheres as a result of changes in chemistry (most importantly anthropogenic emission of ozone depleting substances) and dynamics. There is a large inter-annual variability in Arctic ozone that is related to inter-annual variability in the meteorological conditions.

Polar ozone controlled by EP flux?

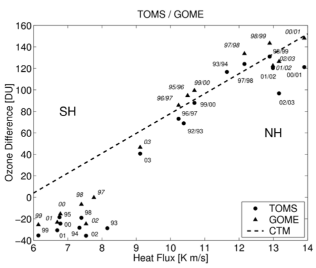

Fig 2. Relation between winter averaged heat flux (vertical component of EP flux) at 100 hPa and total ozone increase between September and March (NH) or March and September (SH). The dashed line shows the relation for a CTM without polar chemistry.

Because the planetary waves originate from the troposphere it is sometimes more or less tacitly assumed that stratospheric variability is controlled by the troposphere below.

March polar ozone related to ozone in prior November?

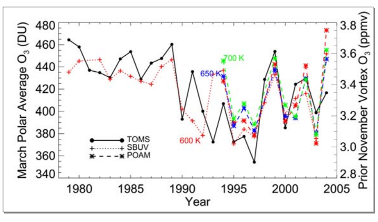

Fig 3 The relation between Arctic total ozone in March from TOMS observations (black line) and mid-stratospheric (~25–30 km altitude) ozone inside the polar vortex during the previous November from SBUV and POAM observations (coloured lines).
From Kawa et al. (2005).

Ozone Sonde Observations

Ozone sonde observations at Ny-Ålesund

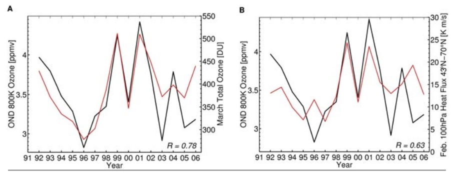

Fig. 4. (A) The relation between Arctic total ozone in March and mid-stratospheric ozone during the previous October-December at 800K (about 30km altitude) from ozone sondes at Ny-Ålesund.

(B) The relation between the EP flux during February and 800K ozone during the previous October-December.

From Sinnhuber et al. (2006).

Summertime ozone as a predictor for March total ozone

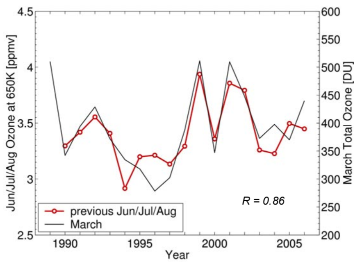

Fig. 5. Ozone sonde observations at Ny-Ålesund show that the inter-annual variability of March total ozone is closely correlated with mid-stratospheric ozone during the previous July-August, about 9 months in before!

Ozone sondes: Comparison with other data

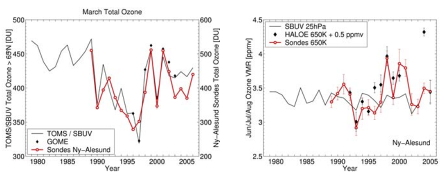

Fig 6. (Left) The comparison between Ny-Ålesund sondes and TOMS shows that the inter-annual variability of total ozone at Ny-Ålesund is representative for the Arctic in general. **(Right)** Ozone anomalies at 650K from ozone sondes are supported by HALOE observations (although there is a substantial bias of 0.5ppmv), but not present in SBUV data.

Development of ozone anomalies

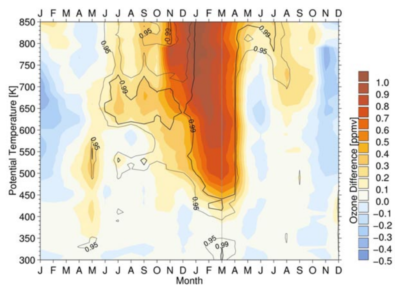

Fig. 7. Stratospheric ozone differences between years with March total ozone above and below average.

Years with high total ozone during March exhibit already anomalously high ozone during the previous summer to autumn period and stay high throughout the winter. Black contour lines show statistical significance.

Impact on Surface Weather ?

Arctic Oscillation

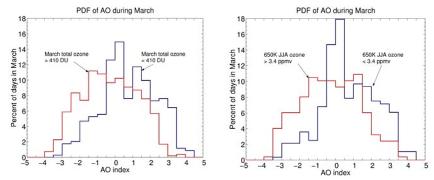

Fig 8. (Left) Probability density function of the Arctic Oscillation during March (AO, the Northern Annular Mode at the surface) for years with TOMS Arctic total ozone during March above (>410 DU) and below (<410 DU) average. **(Right)** Probability density function of the AO during March, seperated into years with ozone at Ny-Ålesund during June-August at 650K below (<3.4ppmv) and above (>3.4ppmv) average.

Outlook: Data Assimilation

In order to further investigate the observed correlations over the polar winter we started to create a long-term data set of winter-time polar ozone by assimilation of SBUV(/2) satellite observations into our chemcal transport model. First preliminary results are shown below.

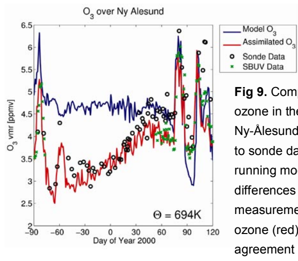

Fig 9. Comparison of assimilated ozone in the mid-stratosphere over Ny-Ålesund during winter 1999/2000 to sonde data. While the free-running model (blue) shows large differences to the sonde measurements, the assimilated ozone (red) is in much better agreement to the independent sonde measurements, even though SBUV data are not available near Ny-Ålesund during most of the winter.

Conclusions

- Arctic total ozone in March is correlated with anomalies in stratospheric ozone several month before. Moreover, the mid-winter EP flux is apparently correlated with summer to autumn ozone anomalies.
- Years with high ozone during summer are typically associated with high total ozone during the following March and a higher probability of finding the Arctic Oscillation in its low phase, and vice versa.
- The link between stratospheric ozone during summer and autumn and atmospheric dynamics during winter and total ozone during March is not clear at present. This unexpected finding raises the question of what controls the stratospheric inter-annual variability during winter.
- The observed correlation may offer a perspective to predict total ozone and stratospheric dynamics several month in advance.
- In order to further investigate the observed correlations we are currently performing a long-term data assimilation of SBUV(/2) ozone observations into a chemical transport model.

References

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