Arctic ozone loss inferred from assimilation of EOS MLS and SBUV/2 observations

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Introduction

We present a new technique for the estimation of stratospheric ozone loss based on the assimilation of EOS MLS and SBUV/2 ozone observations in the Met Office data assimilation system (see also Jackson and Orsolini, 2008). The aim of this approach is to better account for the effect of horizontal mixing and to preserve spatial ozone loss inhomogeneities in the polar vortex.

We present results for the northern winters of 2004/5 and 2006/7. Both winters had very low Arctic lower stratospheric temperatures, with associated large ozone depletion due to heterogeneous chemistry.

Because of the potential for large ozone loss in the 2004/5 winter, many observational and model-based estimates of ozone loss for this winter have been published. These estimates have been made using a variety of methods and the size of the calculated ozone loss varies, which indicates potential difficulties with the existing methods used.

Ozone loss estimation based on data assimilation

Ozone loss is estimated by taking the difference between two near-identical assimilation runs: an assimilation run where EOS MLS and SBUV/2 ozone observations are assimilated, together with standard meteorological observations, and a reference run where the ozone data are not assimilated, and no chemical ozone loss is represented (see Figure 1 for more details). The assimilation system uses 3D-Var. Because the experiments are computationally relatively expensive, they were limited to the January - March period.

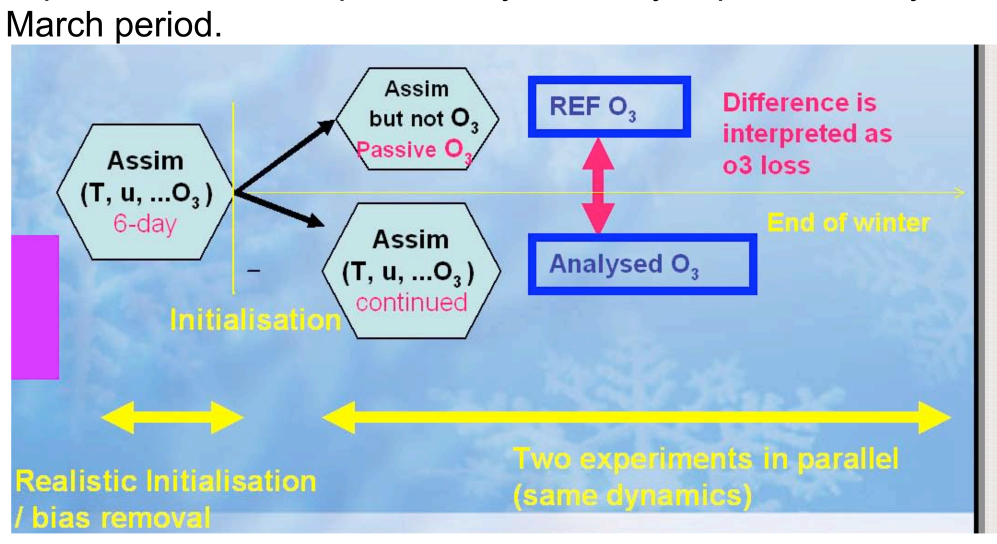

Figure 1: Schematic of ozone loss estimation method.

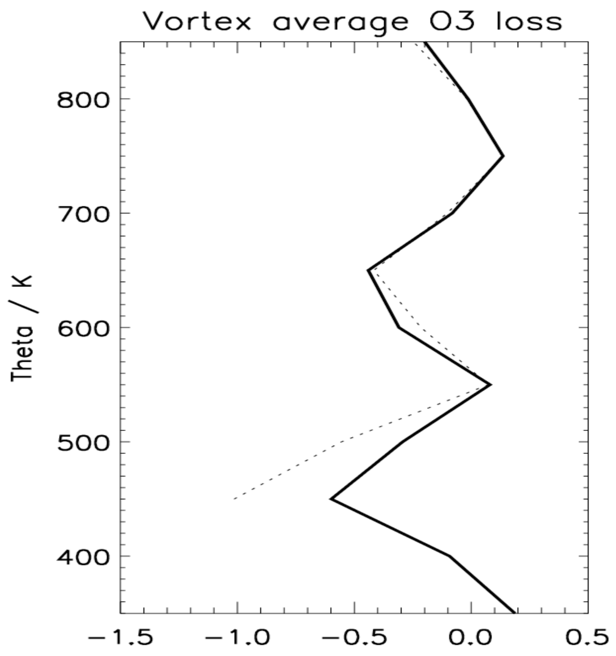

Figure 2: Average ozone loss profile for whole vortex (solid) and vortex core (dashed). Negative values indicate ozone loss. Units:ppmv. The ozone loss is shown for the 1 February - 10 March 2005 period. The vortex edge is defined using the scaled potential vorticity criterion described by Manney et al (2006).

Ozone loss estimates

2004/5: Figure 2 shows two peaks in the ozone loss: 0.6 ppmv at 450 K and 0.4 ppmv at 650 K. The loss at 450 K is similar to or smaller than results from other studies:

- 0.6-0.9 ppmv (Rosevall et al, 2007)
- 0.8 ppmv (Grooss and Muller, 2007)
- 1.2 ppmv (Singleton et al, 2007)
- When combined with results from other studies that estimate ozone loss occurring outside our assimilation period, we get an estimate of 0.8-1.2 ppmv for ozone loss from early January to early March 2005.

Figure 3 shows that the ozone loss at 450 K is initiated in the periphery of the vortex core, and becomes progressively more homogeneous in the vortex. Positive values at the vortex edge exist because transport errors in the reference run smear out the collar of high ozone around the vortex edge (this is much less of a problem in the assimilation run). The smearing impacts ozone loss estimates. Figure 2 shows that at 450 K the ozone loss estimate is ~0.4 ppmv higher if only the vortex core is considered.

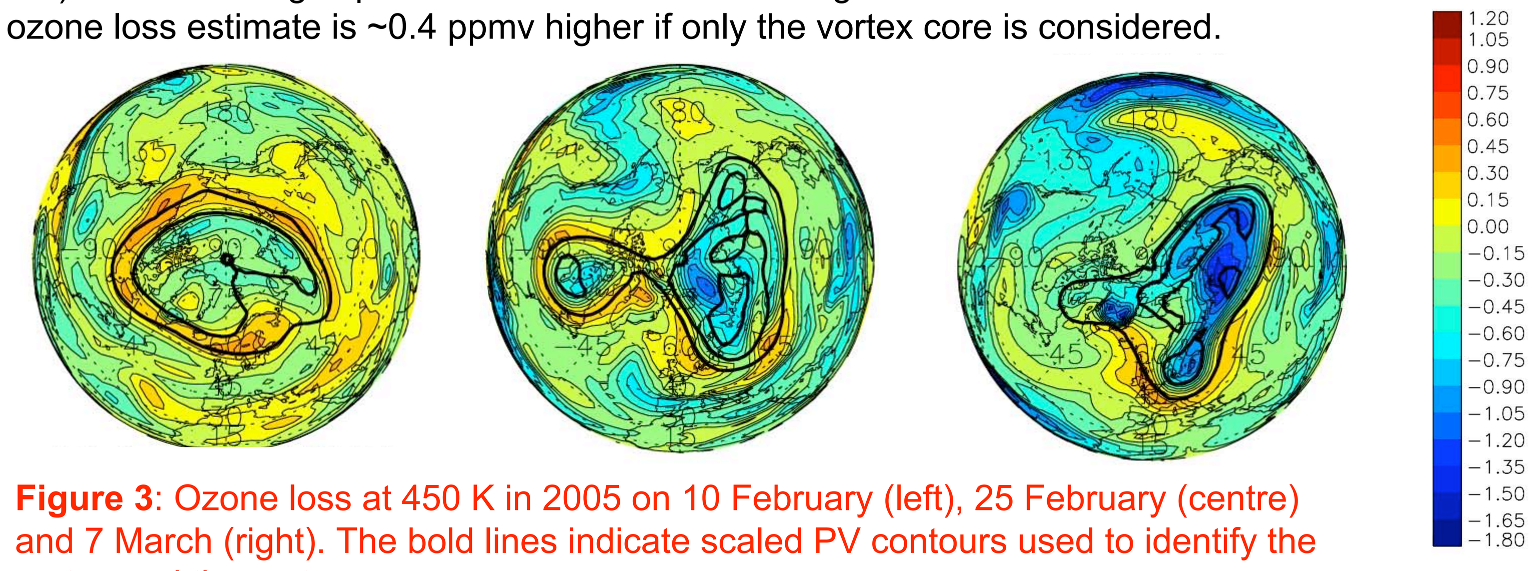

Figure 3: Ozone loss at 450 K in 2005 on 10 February (left), 25 February (centre) and 7 March (right). The bold lines indicate scaled PV contours used to identify the vortex and the vortex core.

The ozone loss near 650 K was also reported in Grooss and Muller (2007), but they report a higher value (around 0.6 ppmv). However, the upper-level depletion is actually much stronger outside the vortex in the Aleutian anticyclone, where ozone is lower than the ambient value (Figure 4). Such a feature is likely to be a 'low-ozone pocket' (e.g. Harvey et al, 2004). The ozone depletion at these levels is likely driven by the NOx catalytic cycle (Konopka et al, 2007). This result shows that an advantage of our technique is that it can identify ozone loss both inside and outside the polar vortex.

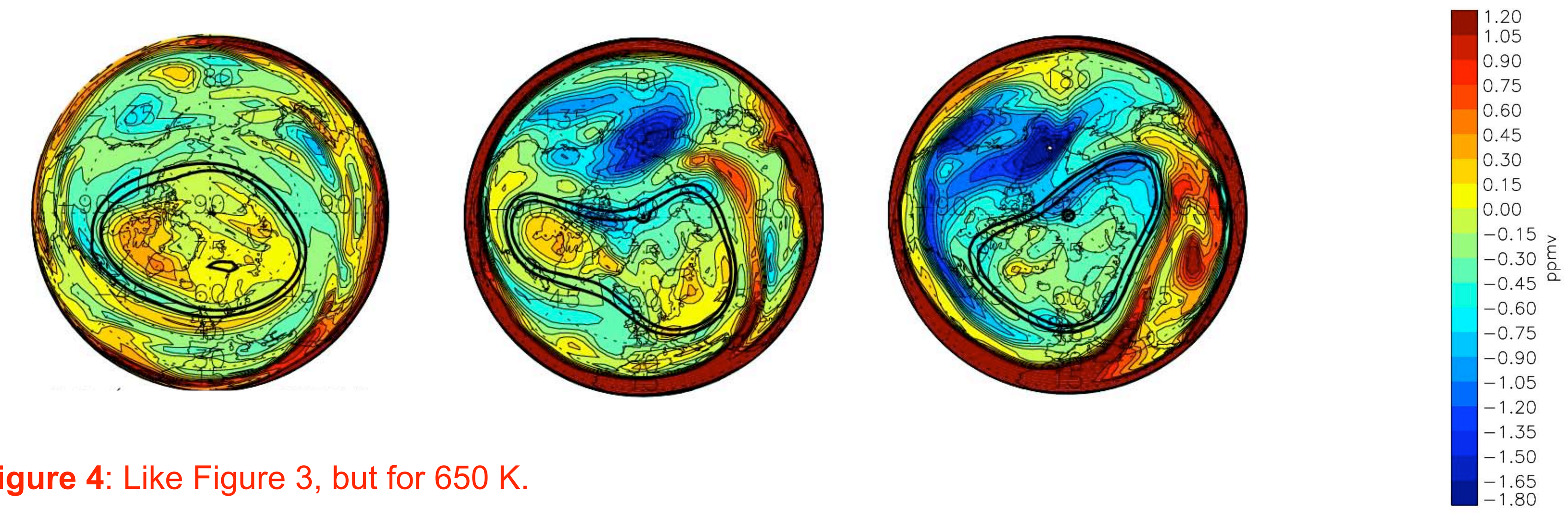

Figure 4: Like Figure 3, but for 650 K.

2006/7: Figure 5a shows an ozone loss pattern similar to 2004/5 with maxima at 450 K (~0.7 ppmv) and 650 K (~0.8 ppmv). The daily ozone loss (Figure 5b) shows that at 450 K most of the ozone loss occurs in February, in agreement with other studies (e.g. F.Goutail et al, pers. comm.). Maps of ozone loss at 450 K show a similar pattern to 2004/5, but at 650 K there is less evidence of low ozone 'pockets' outside the vortex.

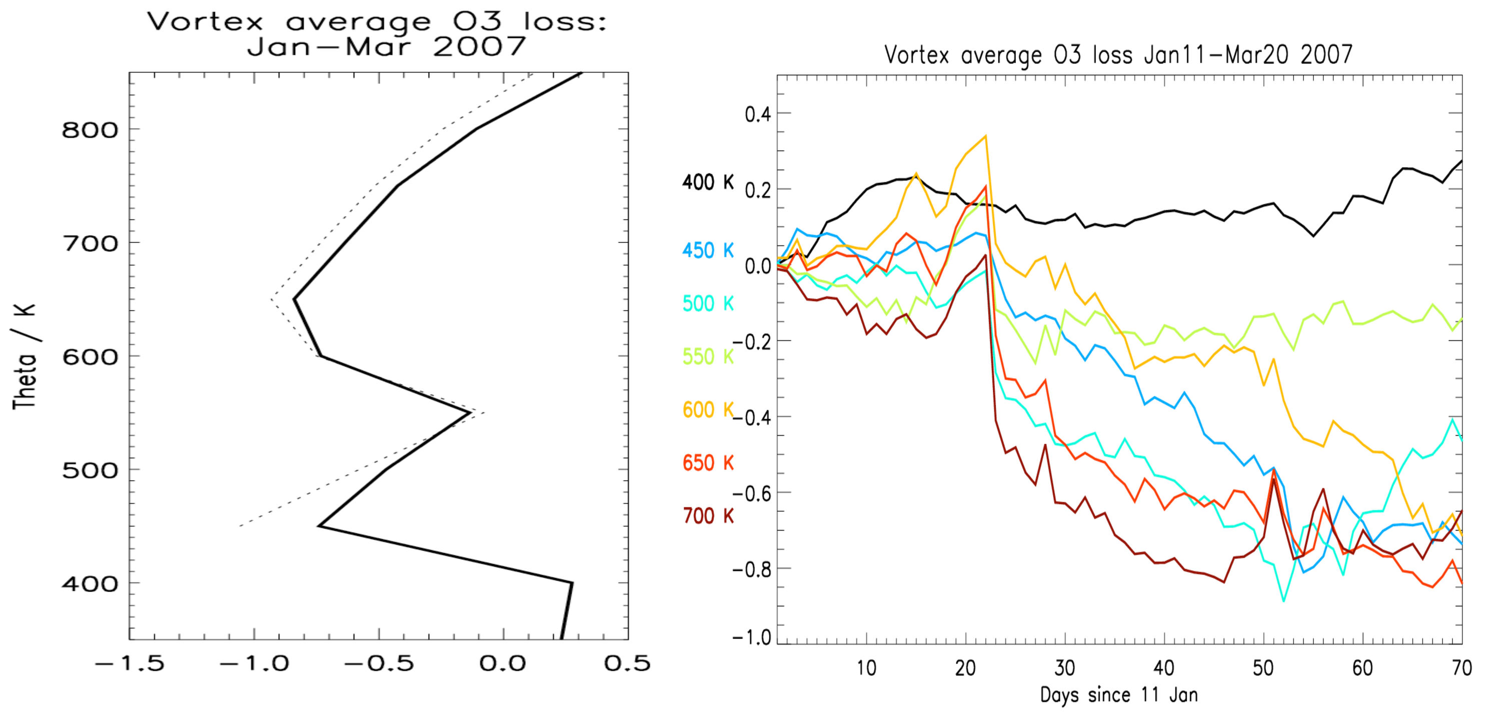

Figure 5: a) (left) like Figure 2, but for ozone loss between 11 January and 20 March 2007. b) (right) daily ozone loss between 11 January and 20 March 2007 for selected levels between 400 and 700 K.

Discussion

There are several **factors which could cause errors in other methods** used to infer ozone loss:

- CTMs can produce diverging ozone loss estimates due to the specific treatment of stratospheric chemistry or transport.
- The representativeness of sparse measurements for vortex-averaged quantities may account for some discrepancies. Transport of low-ozone extra-vortex air into the vortex at low levels could also contribute to the inaccuracy of profile descent methods.
- Estimation based on model reference ozone can lead to uncertainties if the ozone is not properly initialised, or if biases in satellite and reference ozone fields are not properly accounted for. (this may explain the larger ozone loss estimate found by Singleton et al (2007)).

Our approach has many strengths, including the avoidance, or mitigation, of the above problems, e.g.:

- Elimination of biases: if we assume that many biases in the analysis are present in both assimilation and reference runs, then these are eliminated when a difference between these runs is taken.
- Minimising errors in the representation of ozone chemistry by confronting our analyses with observations.
- Reducing transport errors via data assimilation in both assimilation and reference runs. Better representation of mixing across the vortex edge and identification of ozone loss outside the vortex.

Issues still to be addressed include potential errors arising from the interplay between model transport errors and the ozone transport implicit in the assimilated ozone data. Jackson (2007) showed that the assimilation of EOS MLS ozone observations can counteract many of the ozone assimilation errors related to inaccurate model transport. This is a particular issue in the lower stratosphere (e.g. Figures 2 and 3).
In conclusion, the technique we have used to estimate ozone loss is very promising. Future studies using this technique will benefit from the fact that the ozone assimilation is part of an assimilation system which is constantly evolving and where the better description of model and observation errors is an ongoing requirement.

References

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