An estimation of Arctic stratospheric ozone loss using a data assimilation method

Yvan J. Orsolini, Amund Sovde^, David Jackson*, Frode Stordal^, Ivar Isaksen^

Norwegian Institute for Air Research (NILU)
^Dept of Geosciences, University of Oslo
**UK Met Office*

SPARC, Exeter, 2010

Stratospheric O_3 Loss in the Arctic

- O_3 loss inter-annual variability is strongly influenced by dynamics: winters 2004/05, 2006/07 experienced large O loss, while major strat. warmings in 2003/04, 2005/06, 2008/09 limited extent of the cold period

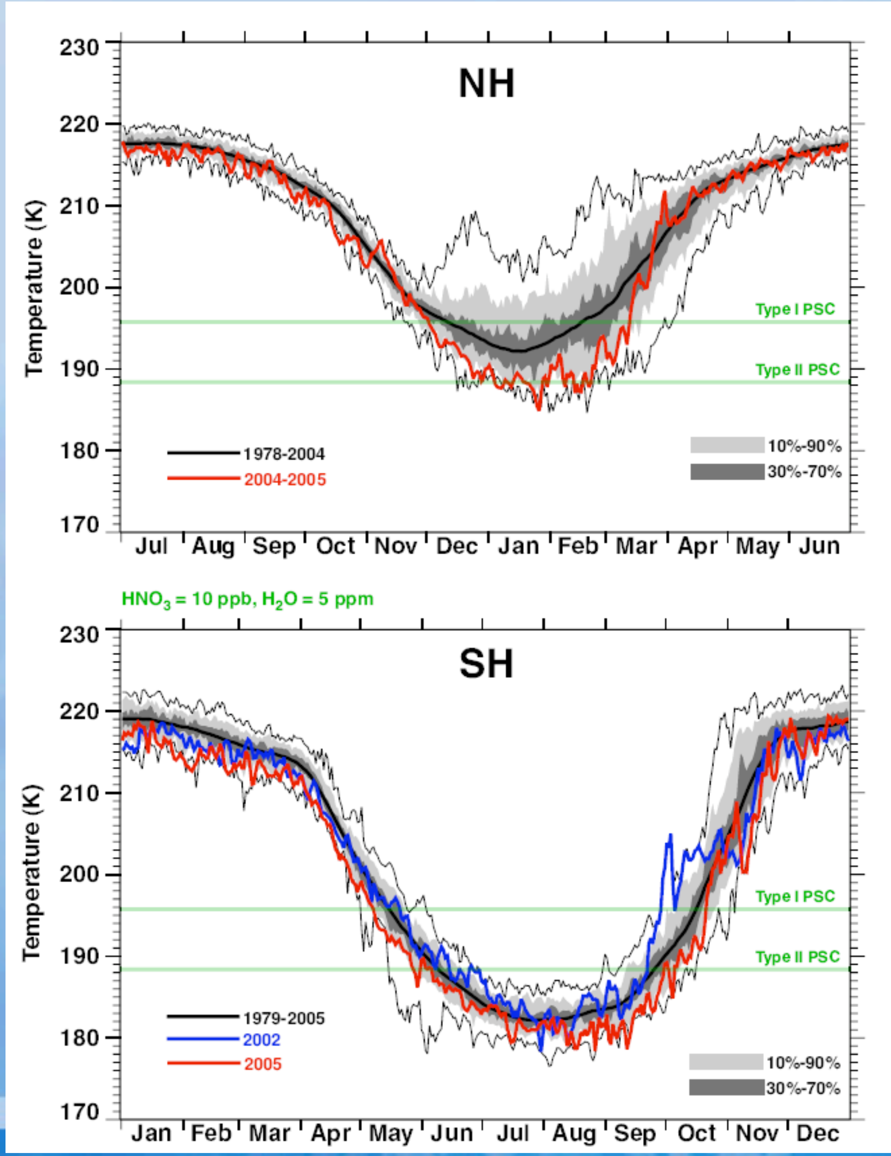
- Chemical O_3 loss estimated by a variety of methods (tracer correlations, profile descent, Lagrangian "Match" techniques, …), and with a variety of observations (balloon soundings, satellite solar occultation or microwave radiometry, …)

- Data assimilation approach to provide better quantitative estimate of O_3 loss with the aim of better accounting for the effect of horizontal mixing and preserving spatial ozone loss in-homogeneities in the polar vortex.

Recent work : El Amraoui et al. (2007), Rösevall et al. (2007;2008), Jackson and Orsolini (2008)

Stratospheric O_3 Loss in the Arctic is highly variable from winter to winter

Polar Stratospheric Temperatures : contrasting Arctic and Antarctic



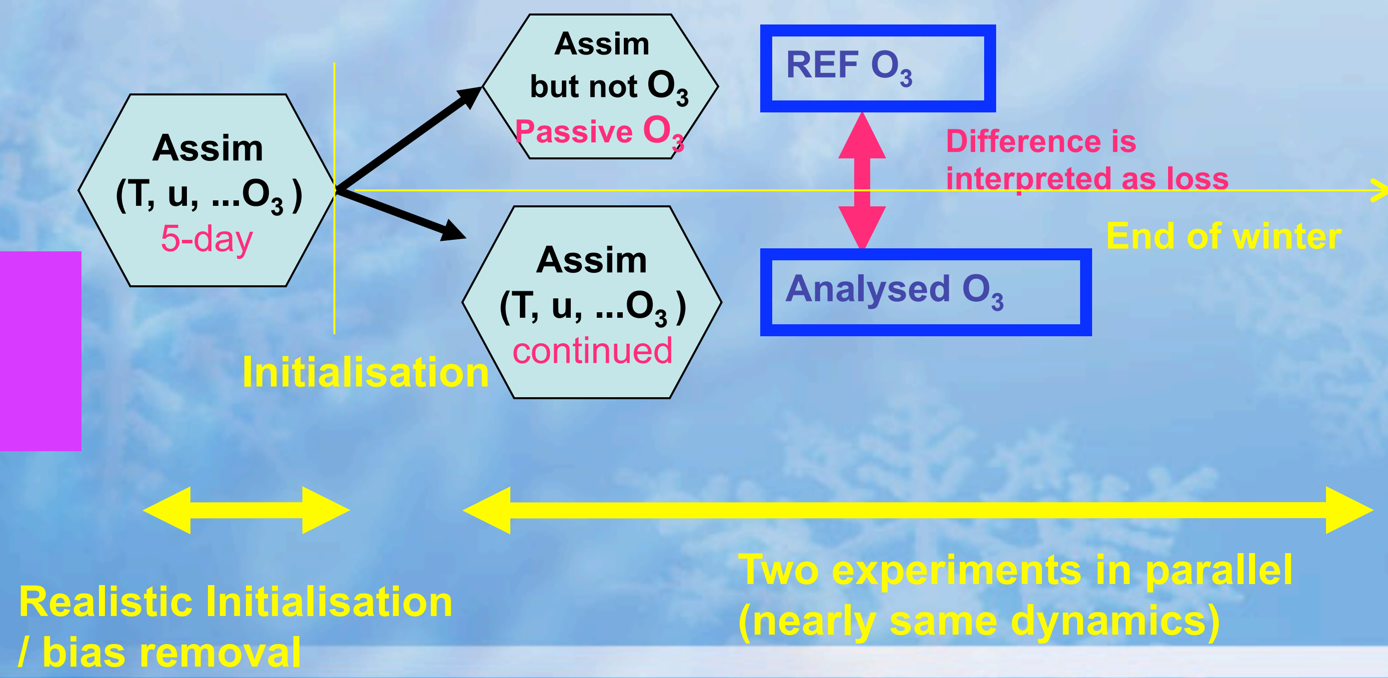
From WMO 2006 ozone assessment

Estimation of O_3 loss by DA

Jackson and Orsolini, QJRMS,2008

- **UK Met Office O_3 analyses produced by merging model O_3 and satellite O_3 observations, along with other dynamical fields (T, winds, …) in a GCM (Numerical Weather Prediction-like DA)**
- **These O_3 analyses by themselves do not allow to infer O_3 loss: one needs to design a specific experiment**
- **In addition you need to subtract a 'reference O_3' (as if transport acting on O_3 alone, in absence of O_3 -depleting chemistry)**

Combine DA with passive O_3 subtraction method



UKMO assimilation system

- **3D-var version of the operational Met Office assimilation system**
- **Semi-lagrangian transport**
- **O_3 assimilation is univariate (no feedback onto other variables like winds or temperature)**
- **Background error covariances from ECMWF data**
- **Parametrisation of O_3 photochemistry (Cariolle scheme) as an on/off option.**
- ***No heterogeneous chemistry :*** **O_3 analyses *constrained by the dense set of MLS observations***
- **Model resolution: 2.5 lat x 3.75 lon; 50 levels, up to 63 km**
- **Special simulations for case studies:**
  - **winter 2004/05: FEB 1 – MAR 10**
  - **winter 2006/07: JAN 10 – MAR 10**
  - **winter 2009/10: (planned) (“Reconcile” aircraft campaigns)**

Some issues with passive O_3

- "Reference" O_3 is a passive tracer (e.g. Harris et al., 2002; Singleton et al., 2005)

- But gas phase NO_x-related loss/production can be important:

  - ✓ Mid-stratospheric loss, followed by transport downwards
  - ✓ Lower-stratospheric loss when vortex is very distorted (e.g. March 2007)
  - ✓ Transport out of low -latitude production region (ozone gain)

- Our DA-method (as currently implemented) infers O_3 total loss due to both PSCs and NO_x

Satellite Data

EOS – Microwave Limb Sounder on AURA (NASA-JPL)

- **profiles from 215-0.46 hPa with vertical resolution ~ 3km**
- **along track resolution of 165km**
- **global coverage**
- **Data version V1.51, later switched to V2.2**

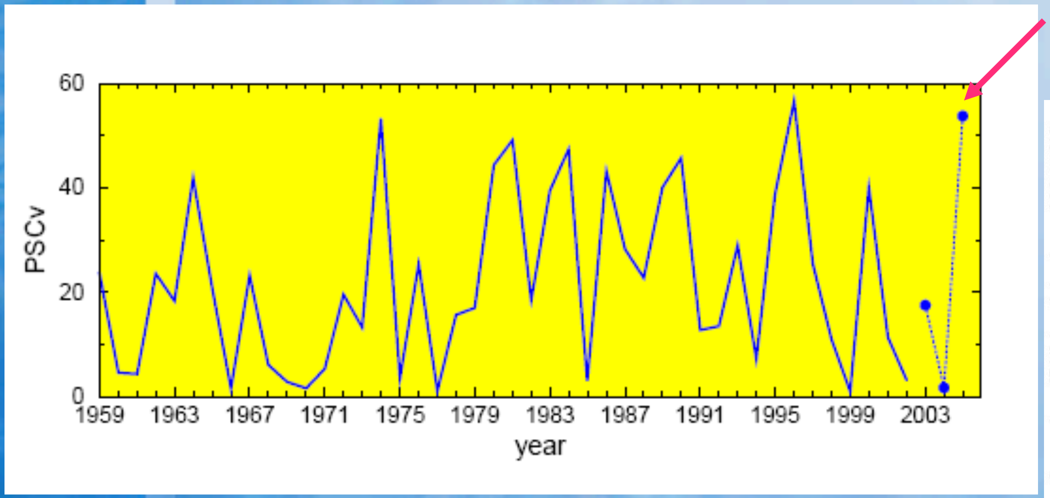
SBUV

- **Nadir viewing, low vertical resolution (1000-16, 16-8, 8-4, 4-2, 2-1 and 1-0.1 hPa layers)**
- **horizontal resolution ~ 200 km. No observations in polar night**
- **available in near real time from NOAA operational satellites**

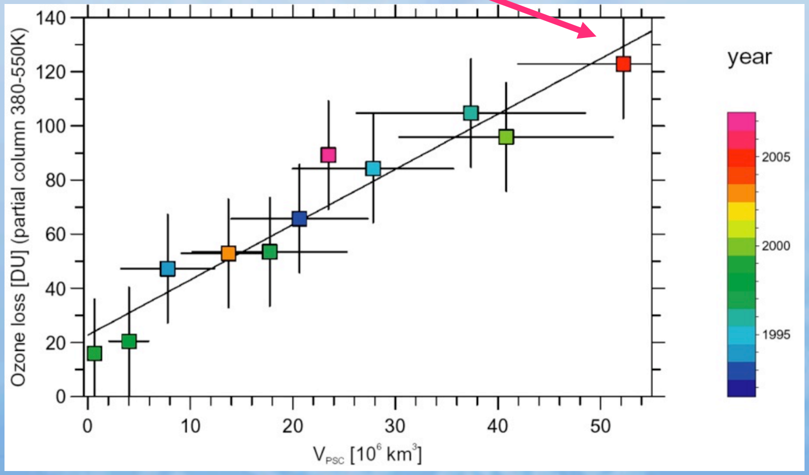
The meteorology of the 2004/05 winter

- **Arctic lower stratospheric temperatures were exceptionally cold during the winter 2004/05, and PSC volume was large**
- **On January 26, type-II PSCs were in fact observed for the first time in 15 years of observations above Spitzbergen (79N) (Maturilli et al., 2006)**
- **Arctic O_3 depletion was large, particularly in terms of column O_3**

2004/05



PSC volume (DJF) from ERA-40 (mill. sq. km)

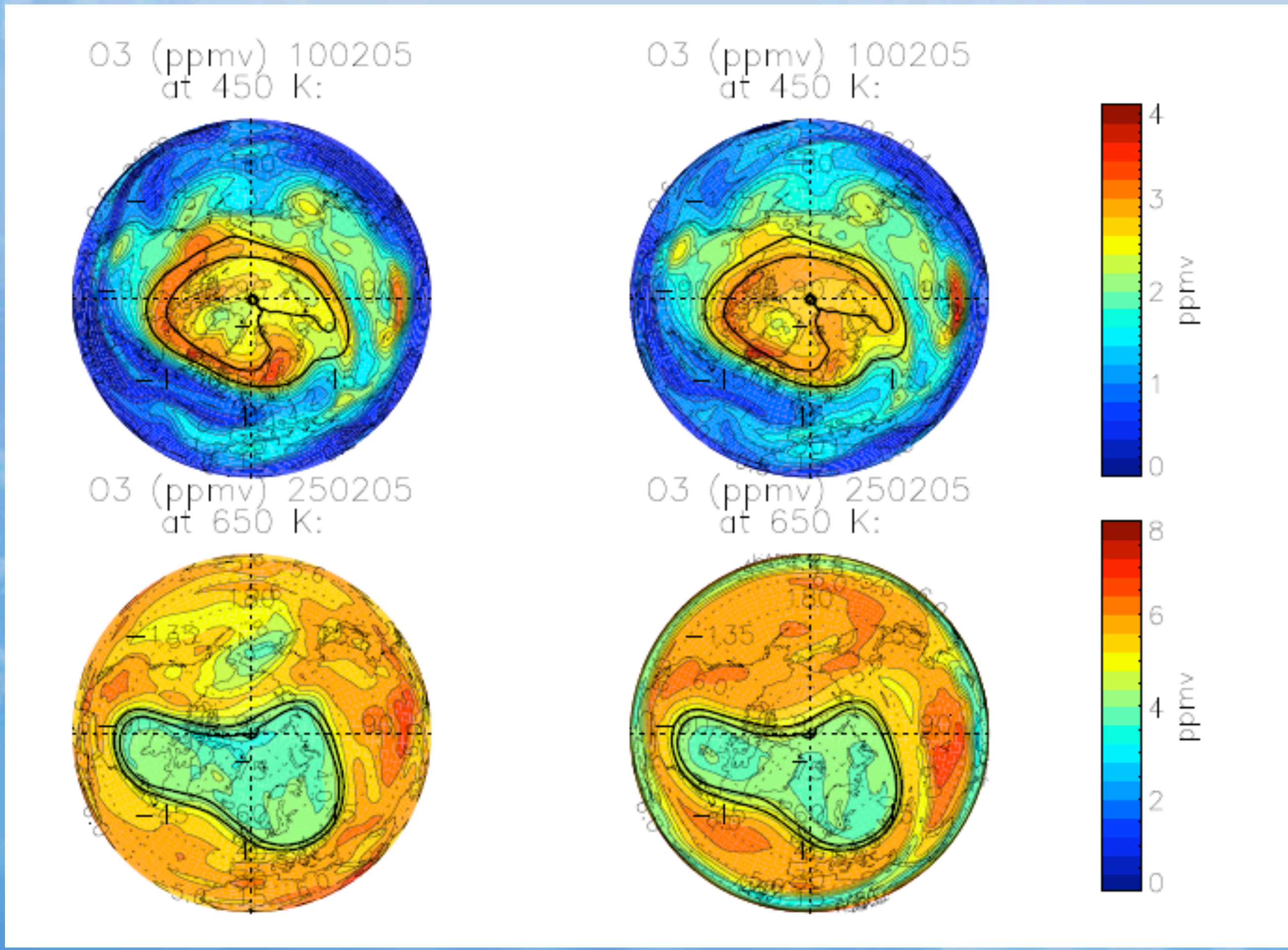


PSC volume is central in Arctic O3 loss studies : compact, near-linear relation with winter O3 loss (Rex et al., 2004)

Maps of O_3 in FEB 2005

assimilated O3 reference O3

▪Low values both in the vortex (450K) and also outside the vortex (650K)

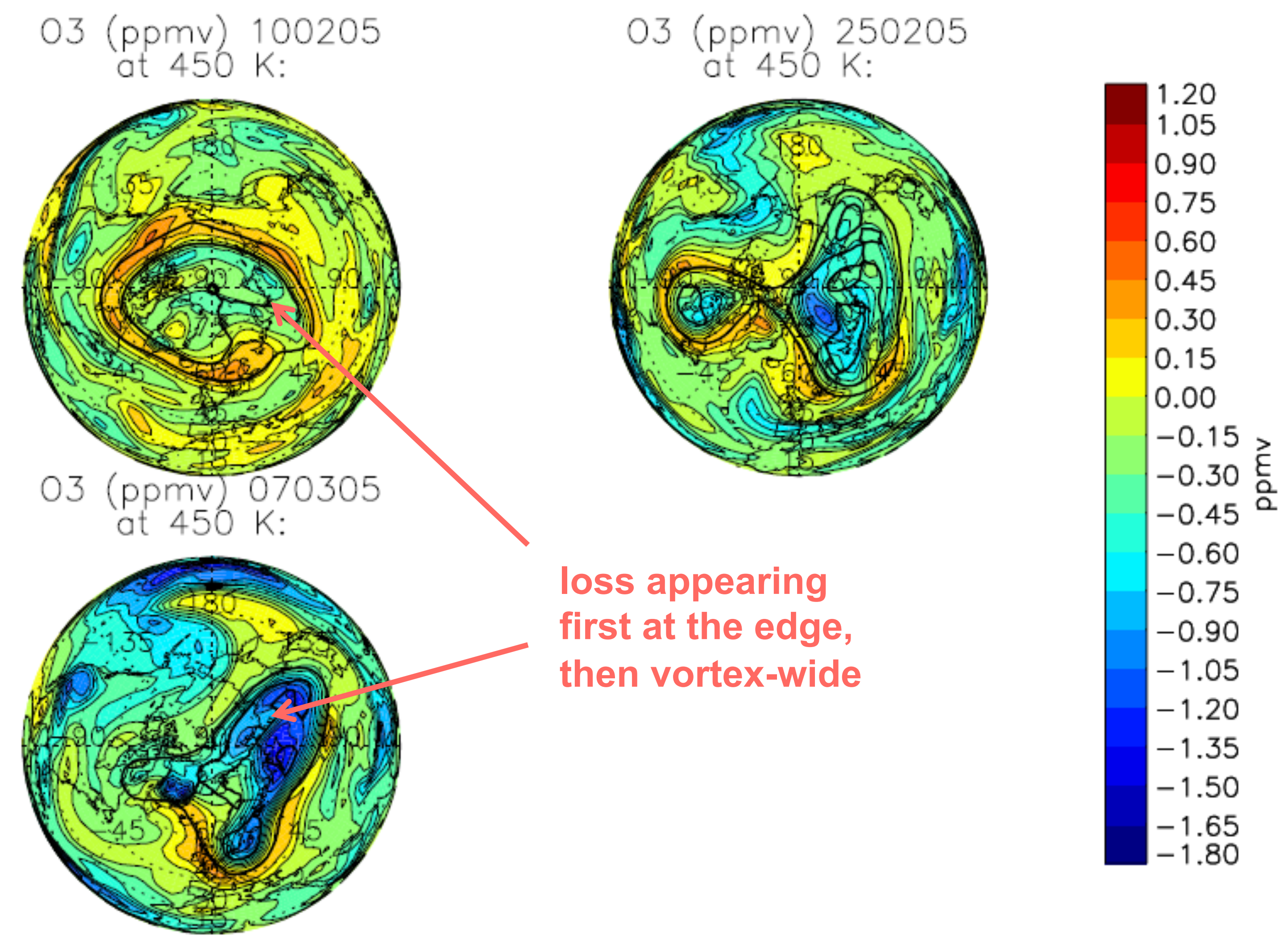


450K
FEB 10

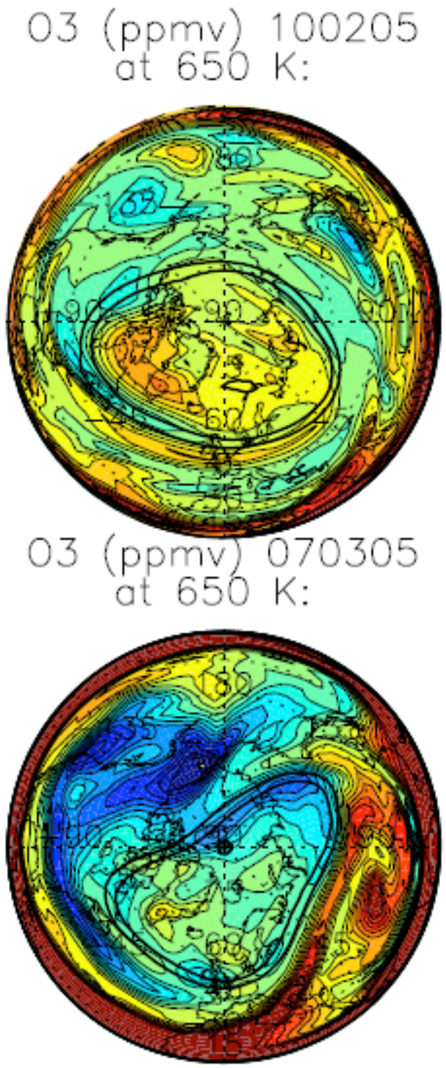
650K
FEB 25

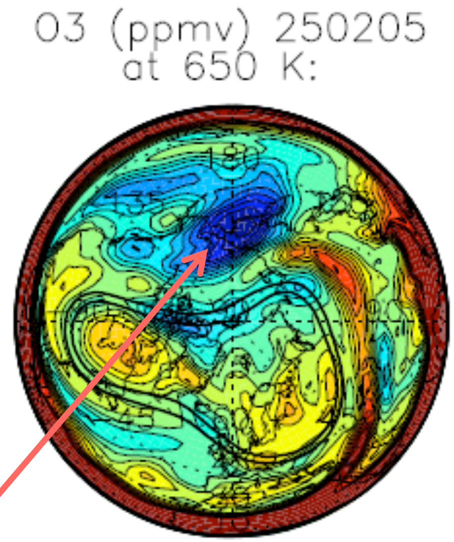
Contours denote vortex edge (sPV =1.6, and 2.2)

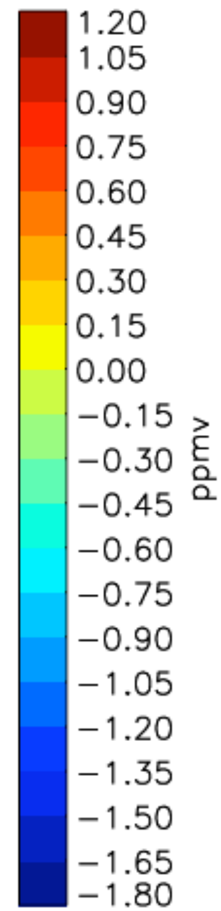
Maps of O_3 loss in FEB-MAR 2005 (450K)



Maps of O_3 loss in FEB-MAR 2005 (650K)



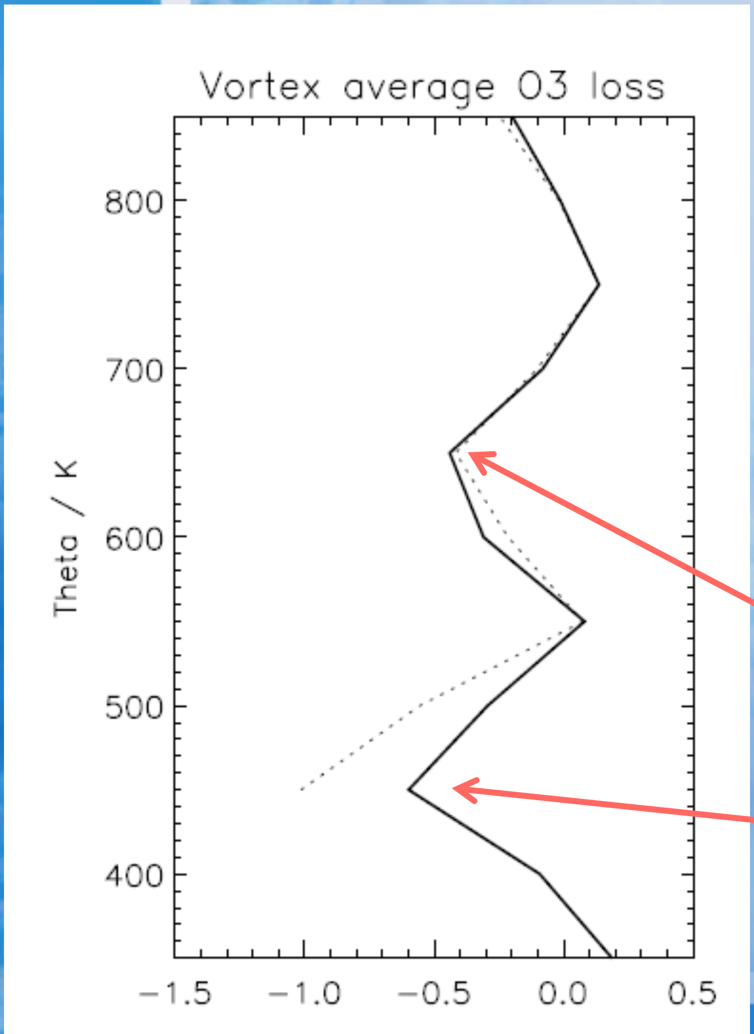


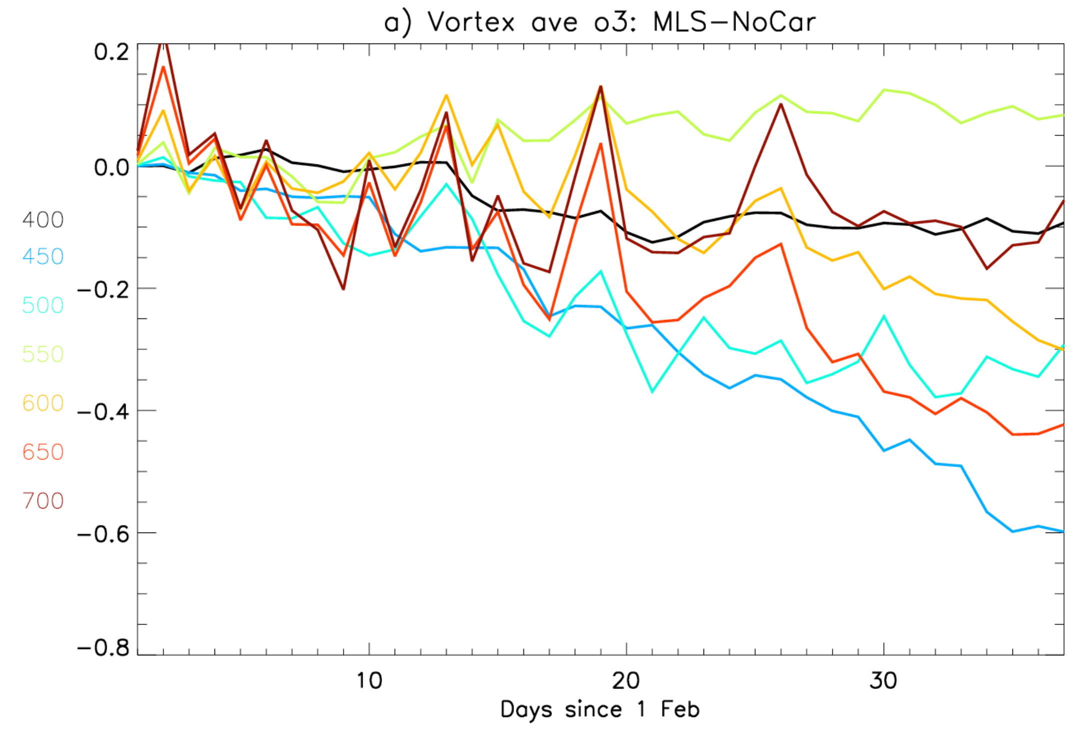


- Loss is stronger outside the vortex, in Aleutian Antyclone (Low Ozone Pockets)

Low Ozone Pockets (Manney et al., 1995; Harvey et al., 2004)

Vortex-averaged O_3 loss





Double-peaked loss profile

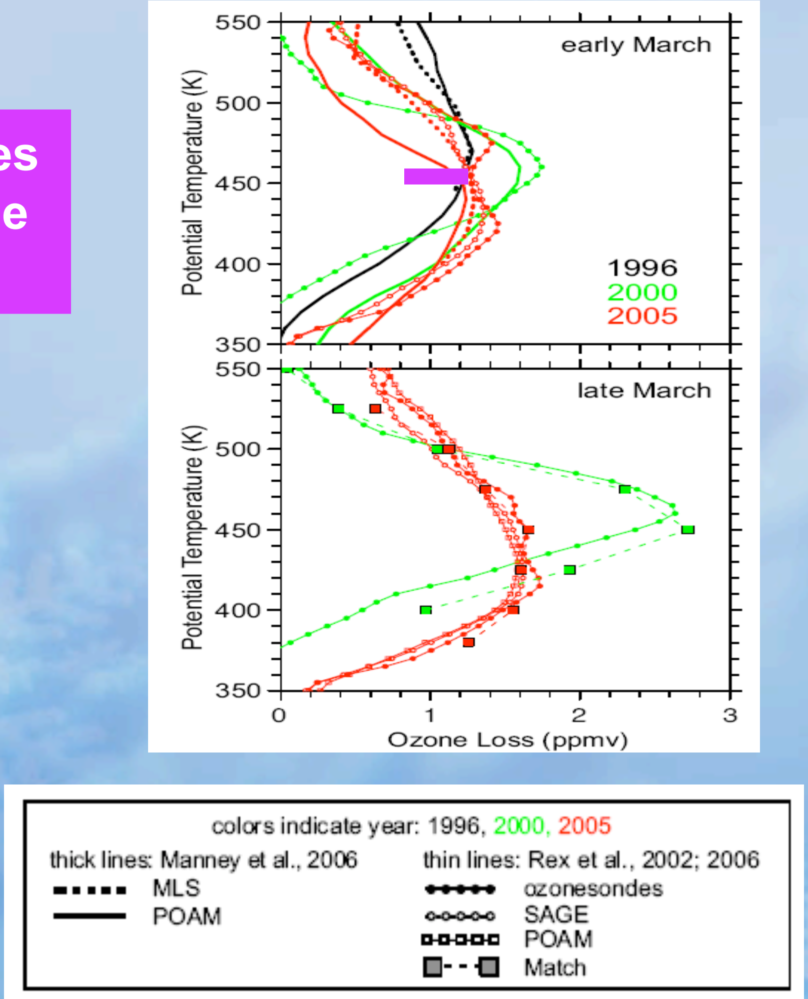
Upper level (650K):
O_3 loss : ~ -0.4 ppmv

Low level (450K):
O_3 loss : ~ -0.6 ppmv

Dashed line : vortex core

Comparison of vortex-averaged loss estimates (WMO-2006)

Our estimate proves to be slightly on the <u>conservative side</u>



Source : WMO 2006

Potential issues with the DA method of O_3 loss inference

Effect of data gaps in 2004/05 study

- Bias in analyses after periods of missing data, but only few occurrences in MLS dataset

Quality of the “reference O3”

- Quality of transported, passive O3

2006/07 case study: Comparison of assimilated O_3 and inferred loss with MLS, and with CTM (U. Oslo CTM-2)

EOS – Microwave Limb Sounder
- **Data version V2.2**
- **Standard MLS pressure levels**

UK Met Office assimilation
- **Assimilated O3 (ASSIM), "Reference O3" (UK REF)**
- **UKMO winds**

U of Oslo CTM-2
- **Comprehensive strat. chemistry model**
- **T24, l60 up to 0.1 hPa**
- **Heterogeneous chemistry on PSCs, aerosols**
- **ECMWF 3-hourly winds (12h-forecast from analyses)**
- **IFS cycle 36**
- **Winter simulations (from Jan 1, 2007) spun up with multi-annual low resolution run**

Simulations with CTM (U. Oslo CTM-2)

1st simulation: full chemistry (FULL)
2nd simulation: PSC-chemistry off (NoPSC)
3rd simulation: passive O3 tracer (PASS)

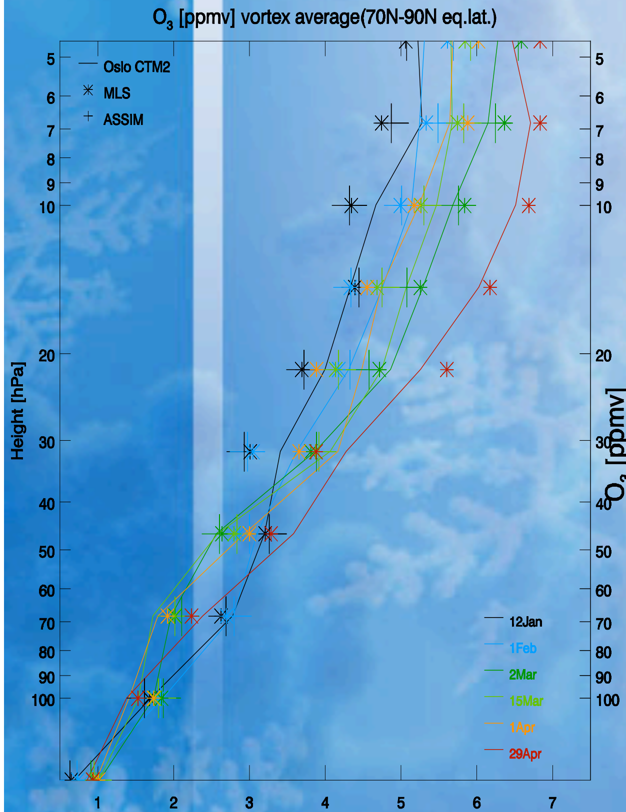
4th simulation: transport assessment : initial UKMO “Reference O3” transported by CTM-2 (UK PASS)

✓Sampled like MLS (eg. geolocation and within hour)
(~300 profiles in the vortex per day)

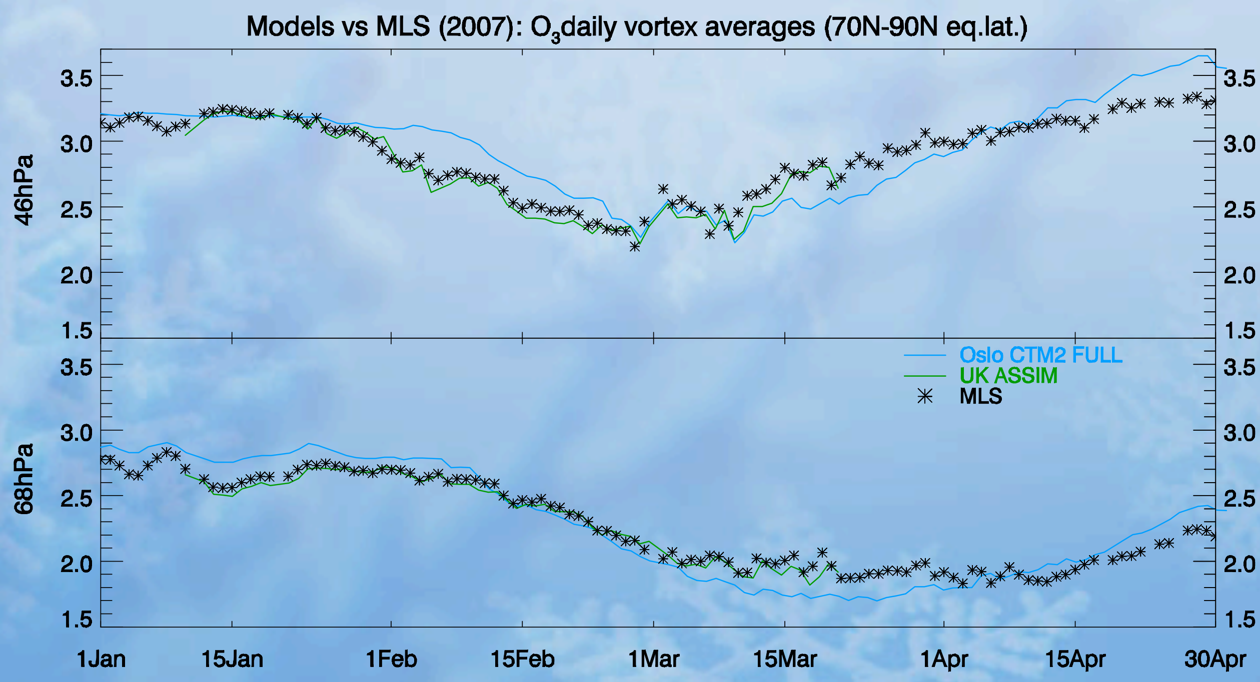
✓Vortex edge defined as 70N in equiv latitude

Evaluation of O_3 : vortex-averaged assim. - CTM - MLS

- Excellent agreement between MLS and UKMO analyses, indicating the high quality of the O3 analyses.
- Abundance of MLS observations constrains assimilation against the underlying model
- Good agreement of CTM2 with MLS too



O3 vs. height, at key dates



Green: UKMO fields Light Blue: CTM2 fields

Time evolution at 46hPa and 68 hPa

Evaluation of O3 : assim. Vs. model

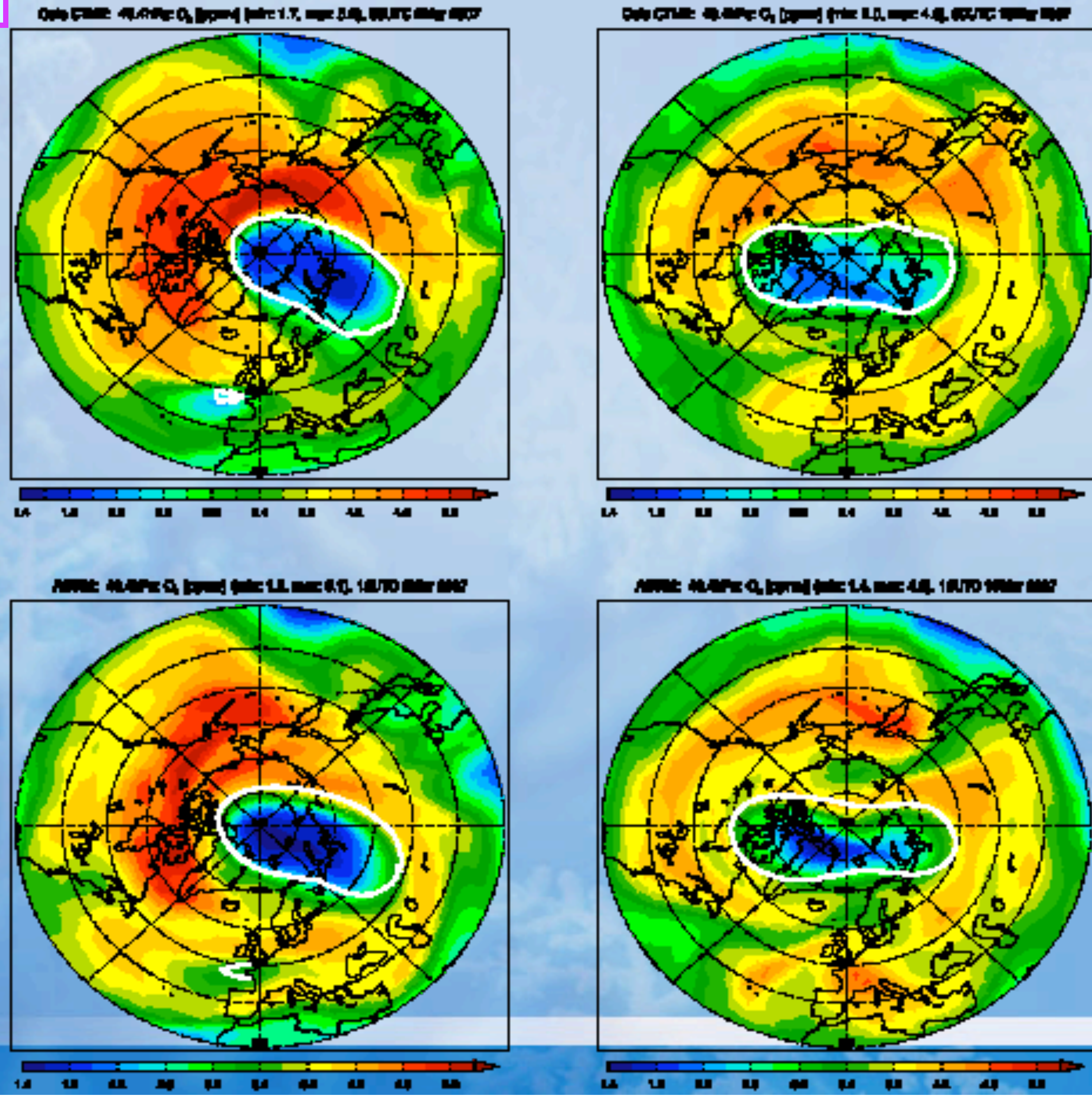
46hPa

2 MAR 2007

15 MAR 2007

CTM2 FULL

Assim



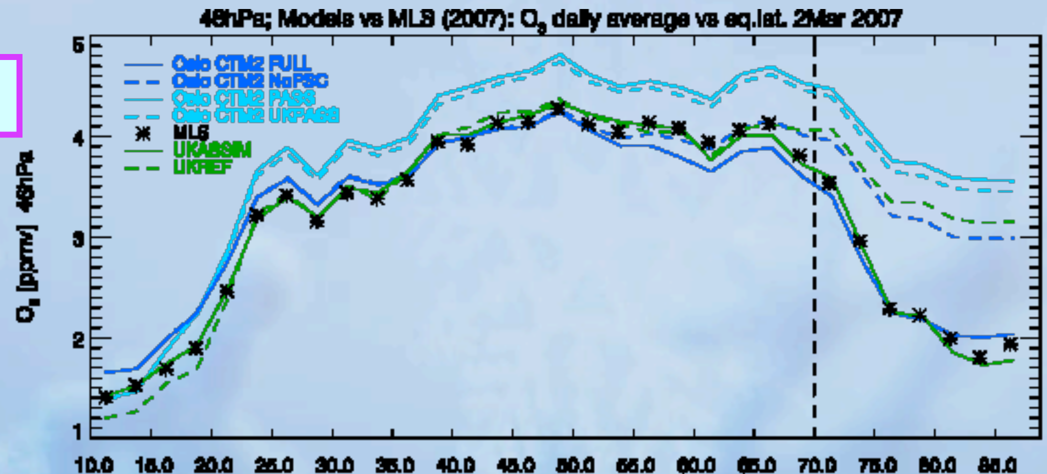
- *Overestimates assimilation outside the vortex*
- *Horizontal transport similar, despite, e.g., weaker intrusion over Far East*
- *Underestimates in the vortex on 15 MAR*

White contour denote vortex edge (70eqlat)

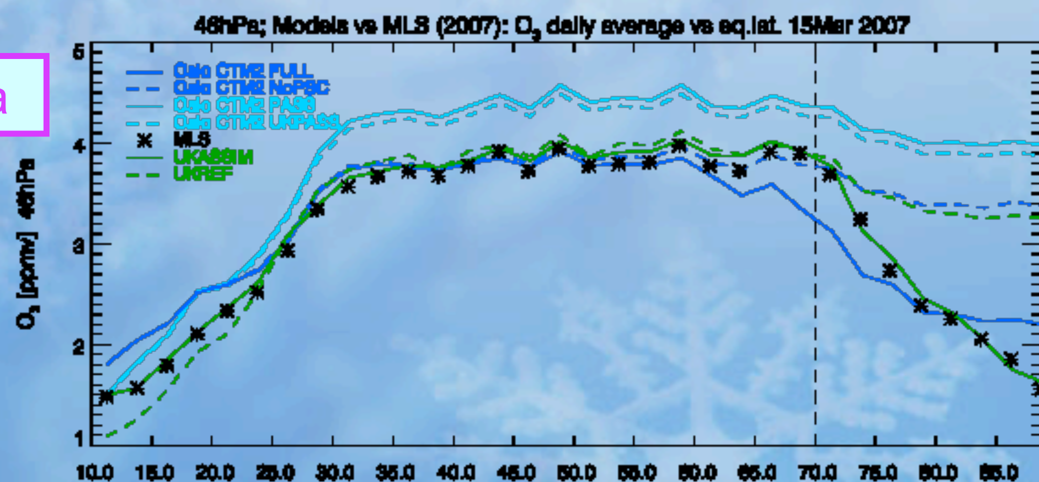
Evaluation of O3 : assim. Vs. model

Meridional profiles (in equiv. Lat)

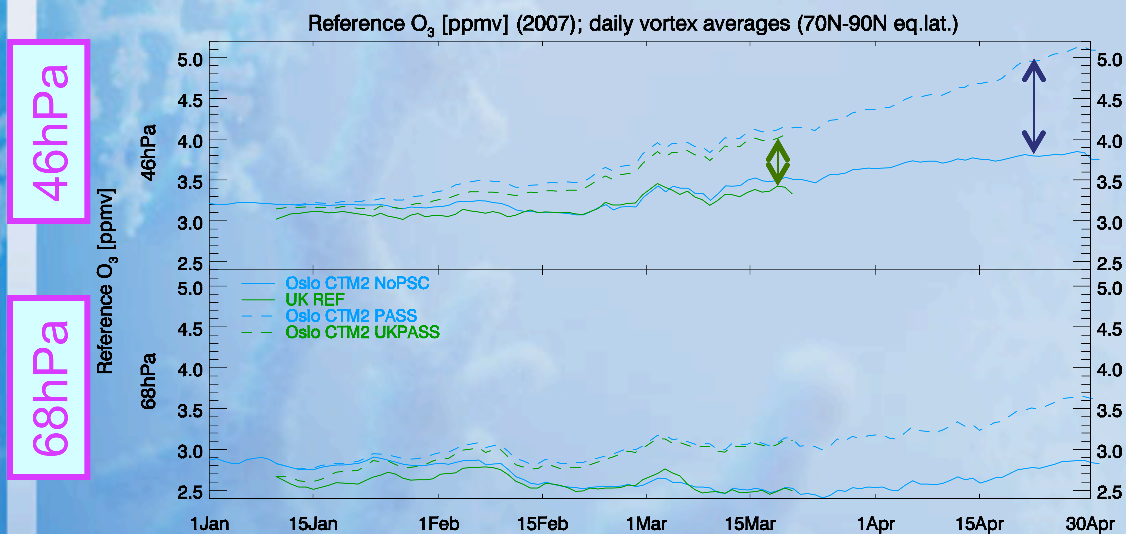
MAR 2, 2007: 46hPa



MAR 15, 2007: 46hPa



Evaluation of Reference O3: assim. vs. model



- **UKREF vs UKPASS:**

  difference due to transport UKMO or ECMWF (in CTM2)

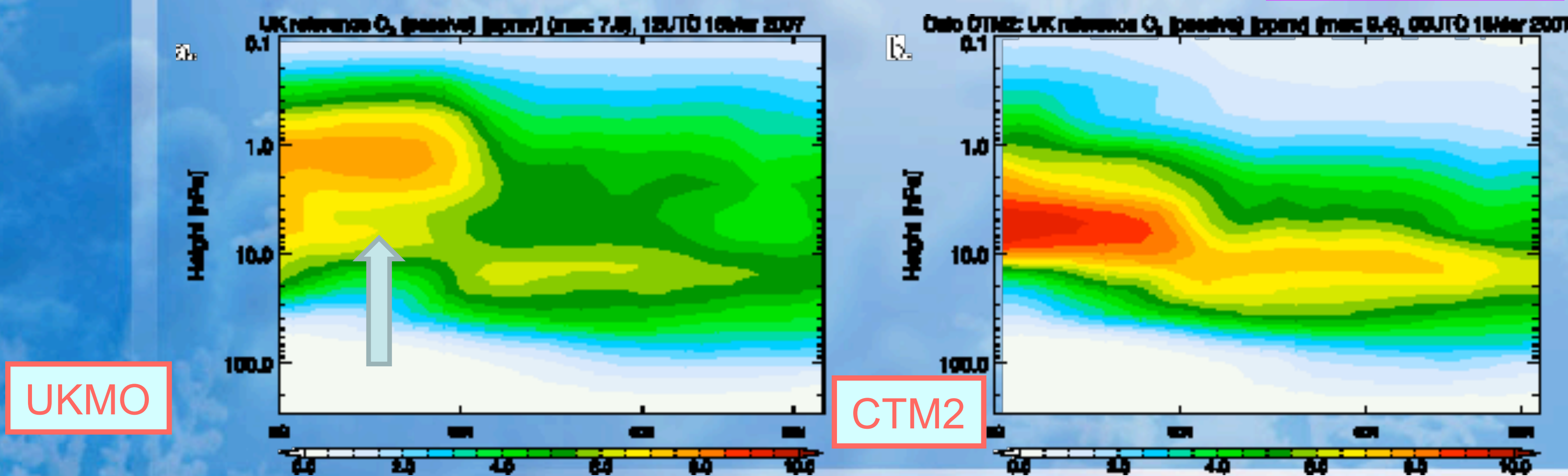
(winds+numerical scheme)

Too fast Brewer-Dobson in UKMO (Monge-Sanz, 2007)

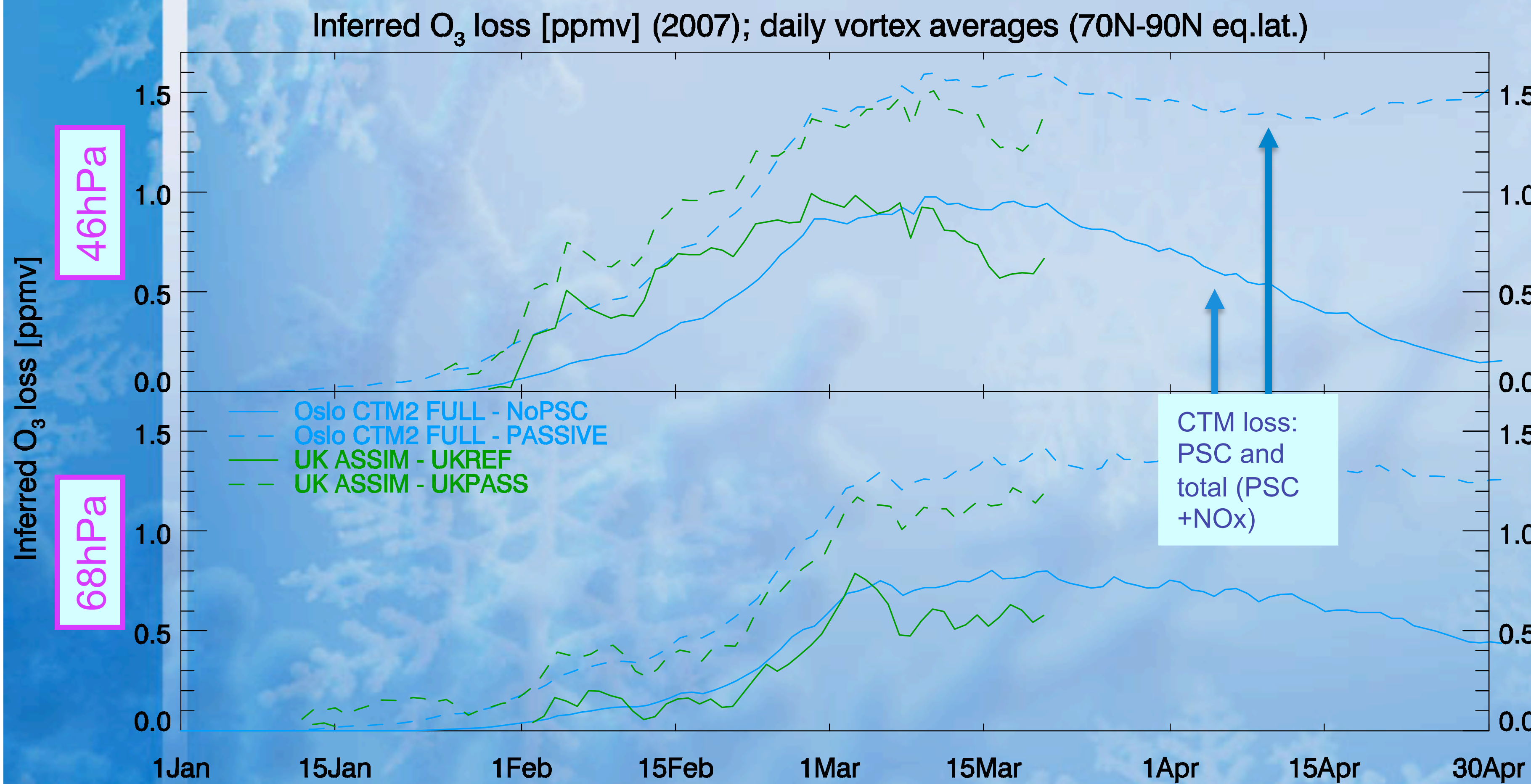
- **NoPSC vs PASS**

  Importance of NOx effect in CTM

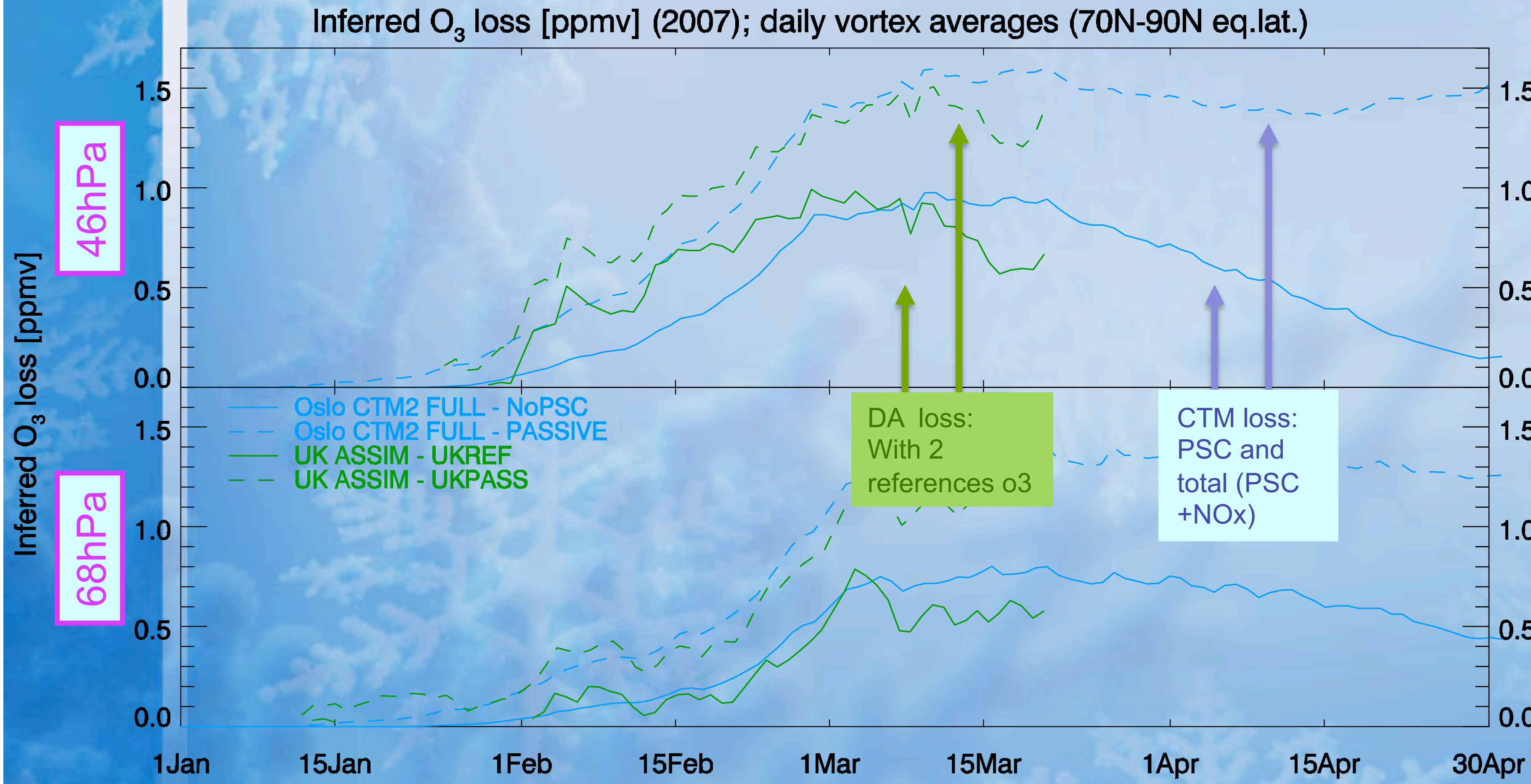
15 MAR 2007



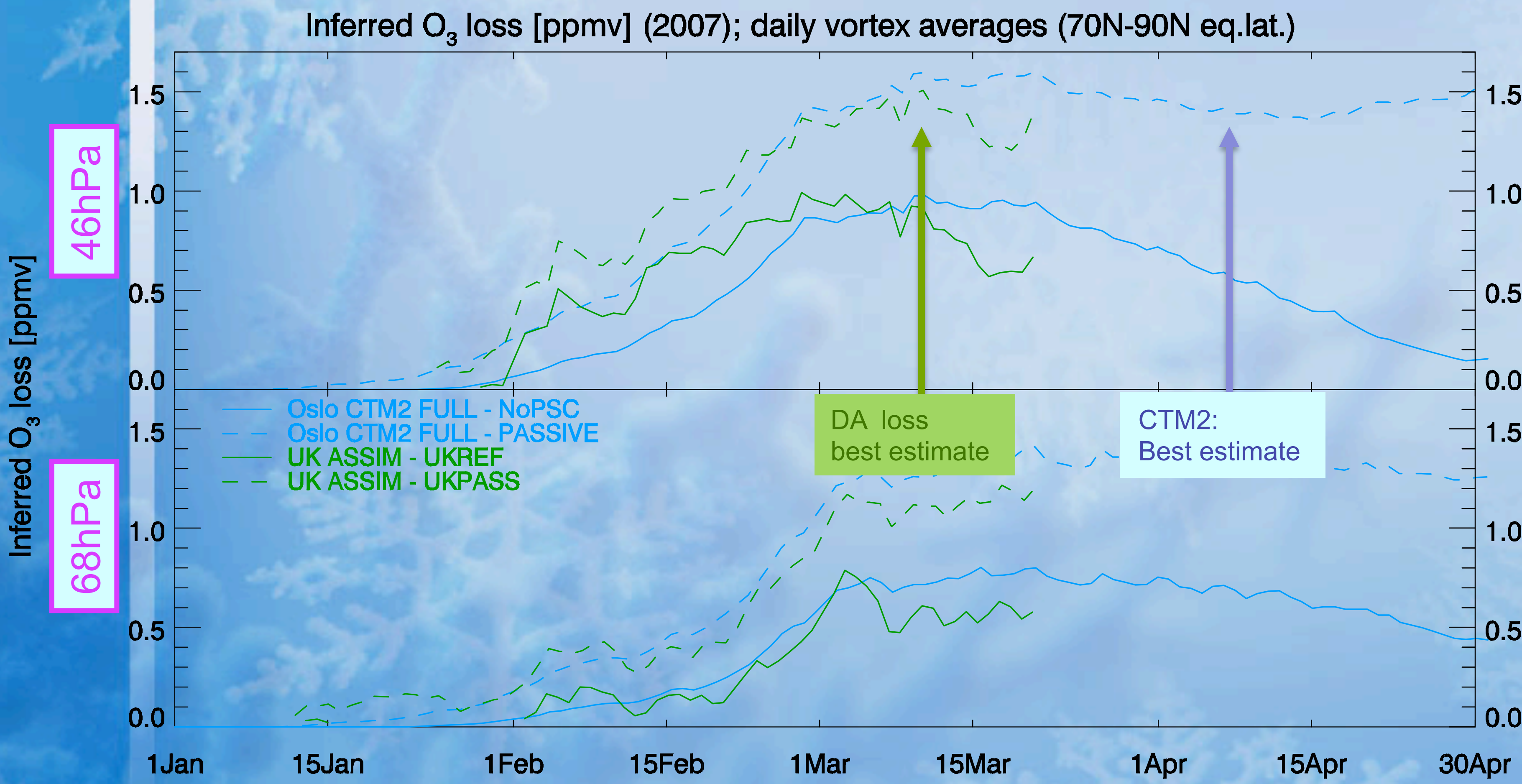
Evaluation of O3 loss: Assim method vs. CTM2 model



Evaluation of O3 loss: Assim method vs. CTM2 model

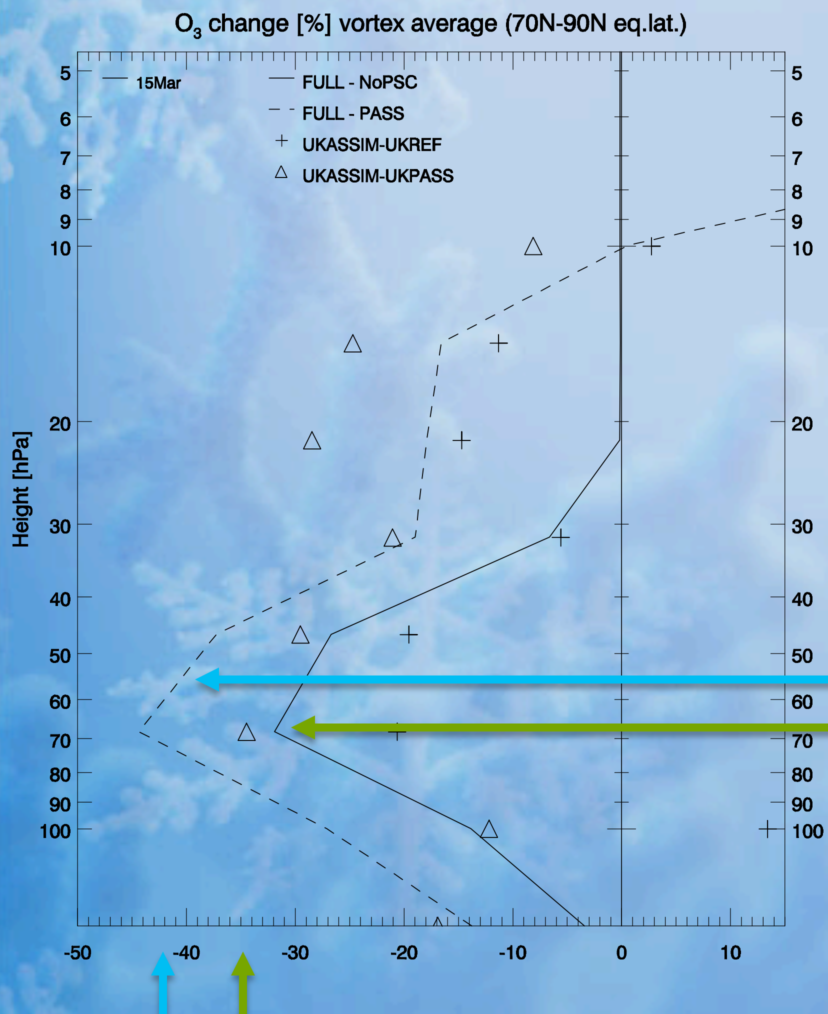


Evaluation of O3 loss: Assim method vs. CTM2 model



Good agreement on timing (peak loss in mid-March) and magnitude (peak loss of around 1.5 ppm)

Evaluation of O3 loss: DA method vs. CTM2 model



Good agreement on level of maximum loss (around 70hPa)

CTM2:
Best total loss estimate (dash)

DA:
best total loss **e**stimate (triangles)

35 to 45%

Two independent data assimilation studies provide O_3 loss estimates that are in good agreement, in both winters

Rosevall et al. (GRL, 2008) based on a CTM-like approach: assimilation of either Odin/SMR and/or MLS with isentropic CTM using ECMWF analyses

Jackson and Orsolini (QJRMS, 2008) based on GCM-like (NWP-like) assimilation using passive subtraction and MLS data

Conclusions 1

- We have developed a NWP-like assimilation method to estimate polar O_3 loss, using MLS and SBUV observations.

- Case studies in winter 2004/05 and 2006/07

- We brought refinement to the DA-method by considering transport issues for the ”Reference O_3”, making the DA-method less conservative than before.

- In the O_3 assimilation, dense and frequent MLS observations correct erroneous model transport, maintaining sharp O_3 horizontal gradients.

Conclusions 2

- Double-peaked O_3 loss profile in both winters: NO_X–related loss is important at upper levels (40% of total loss in 2006/07) (see Grooss et al., 2007)

- Next, we plan to investigate the winter 2009/10 for interpreting RECONCILE Arctic campaigns. Future refinements might include use of a new ozone variable to better represent mixing at vortex edge

Publications

Jackson D.R., Y. J. Orsolini, Estimation of Arctic ozone loss in winter 2004/05 based on assimilation of EOS MLS observations, Quart. J. of the Roy. Meteor. Soc, 134, 1833-1841, 2008.

Sovde, O. A., Y. J. Orsolini, D. Jackson, F. Stordal, and I.S.A. Isaksen, Estimation of Arctic ozone loss in the winter 2006/07 using a chemical transport model and data assimilation, submitted to Q. J. R. Meteor. Soc, May 2010.