The benefits of in-line advection - Assessing the transport characteristics of the CMAM-DAS

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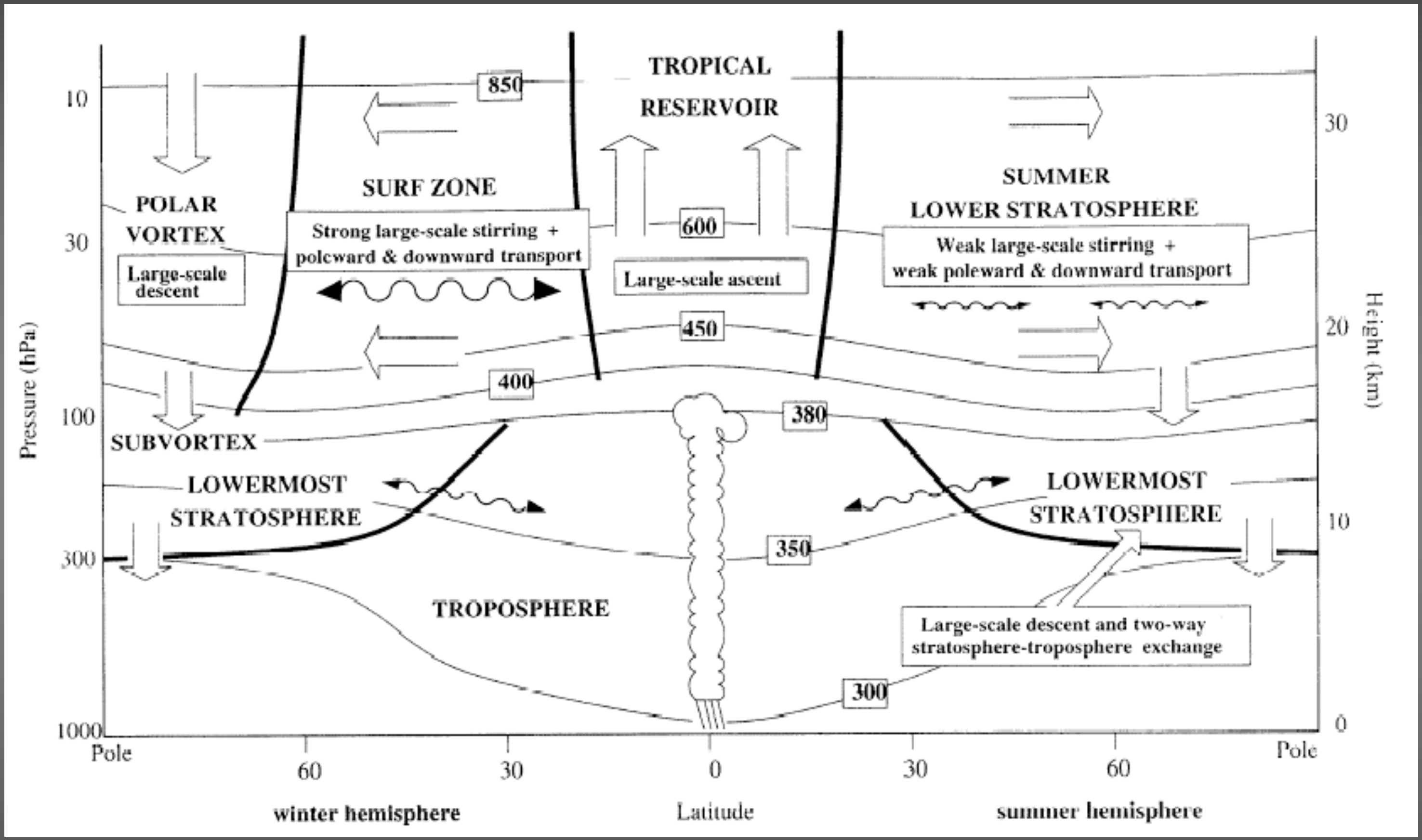
ATMOSPHERIC TRANSPORT

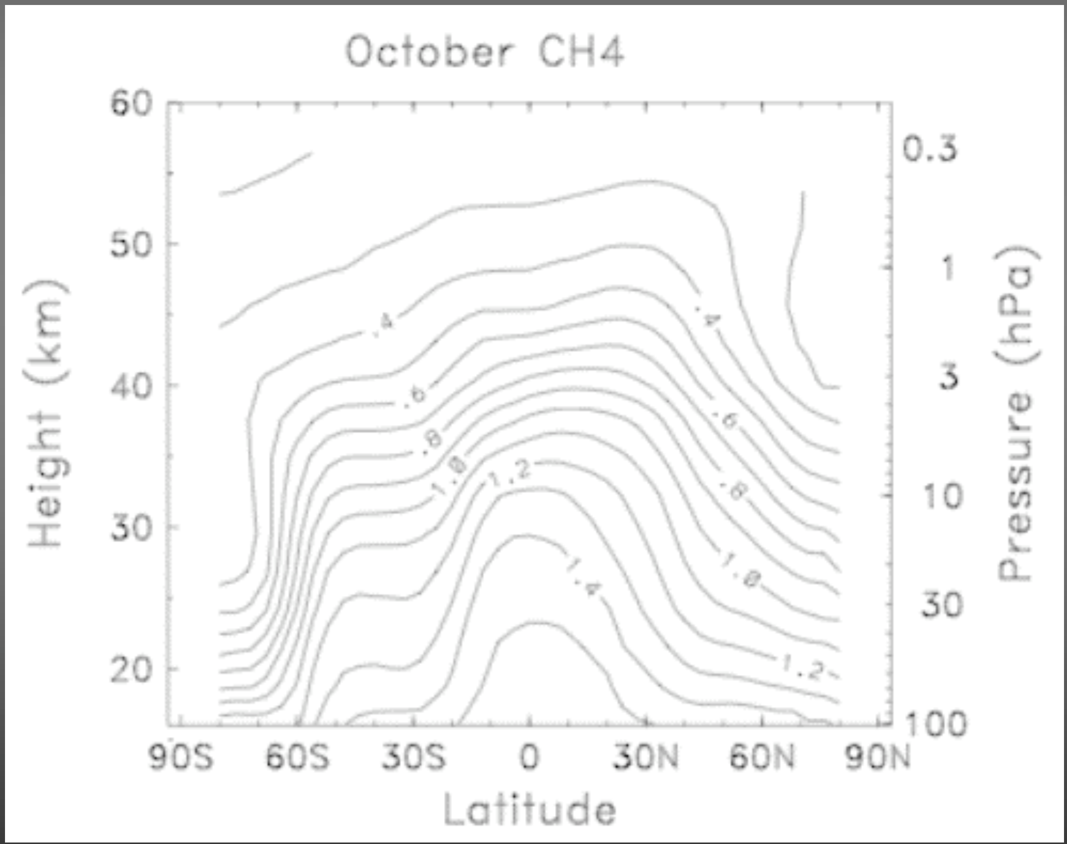


Haynes und Shuckburgh, JGR 2001

Atmospheric transport determines the distributions of radiatively active species, which feedback on climate.

RESULTING STRATOSPHERIC TRACER DISTRIBUTIONS

The CH_4 distribution immediately gives the sense of the stratospheric Brewer-Dobson circulation with ascent in the tropics and descent in the extratropics, and also reveals transport barriers.



HALOE AND CLAES latitude-height cross-section of CH_4 mixing ratio for October (in ppmv).

Randel et al., JGR 1998

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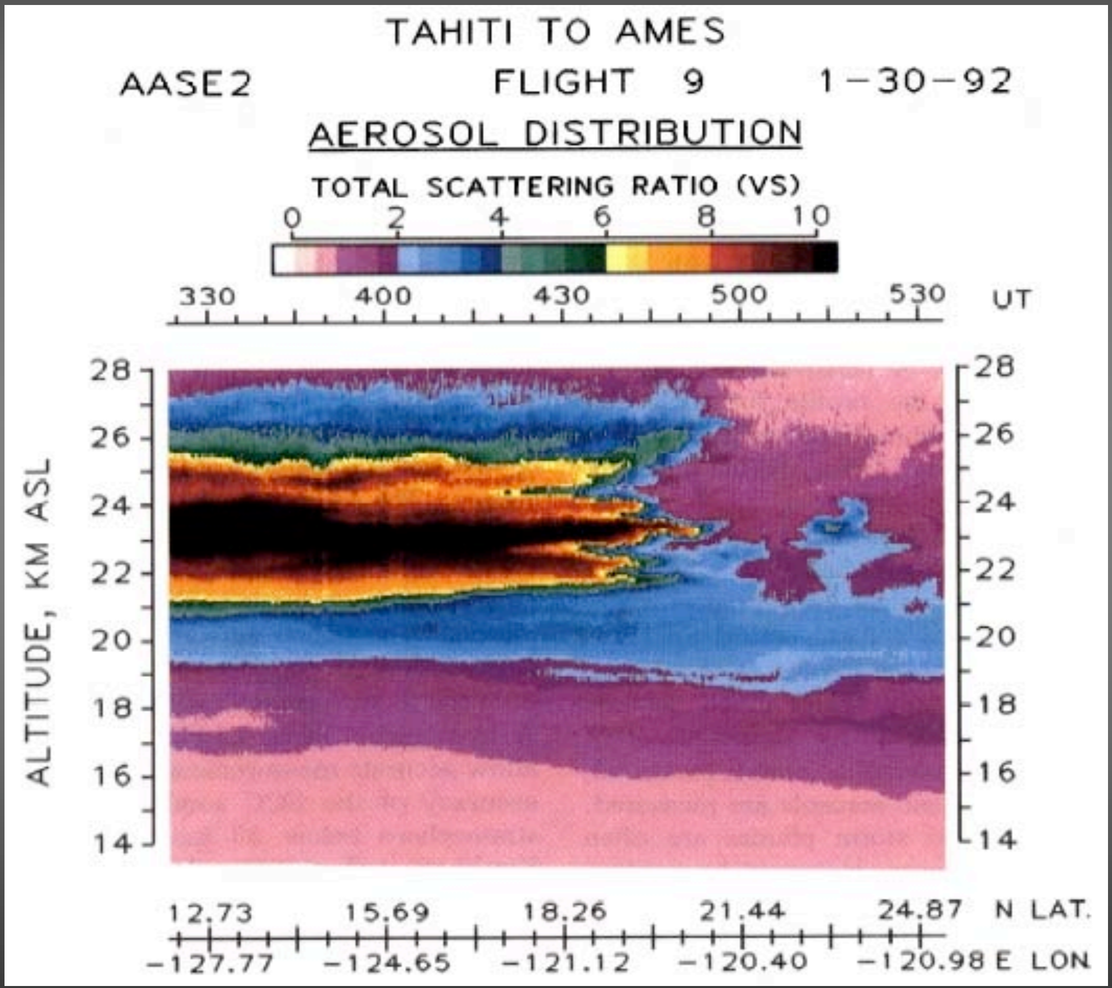
STRONG GRADIENTS ACROSS THE TROPICAL PIPE EDGES

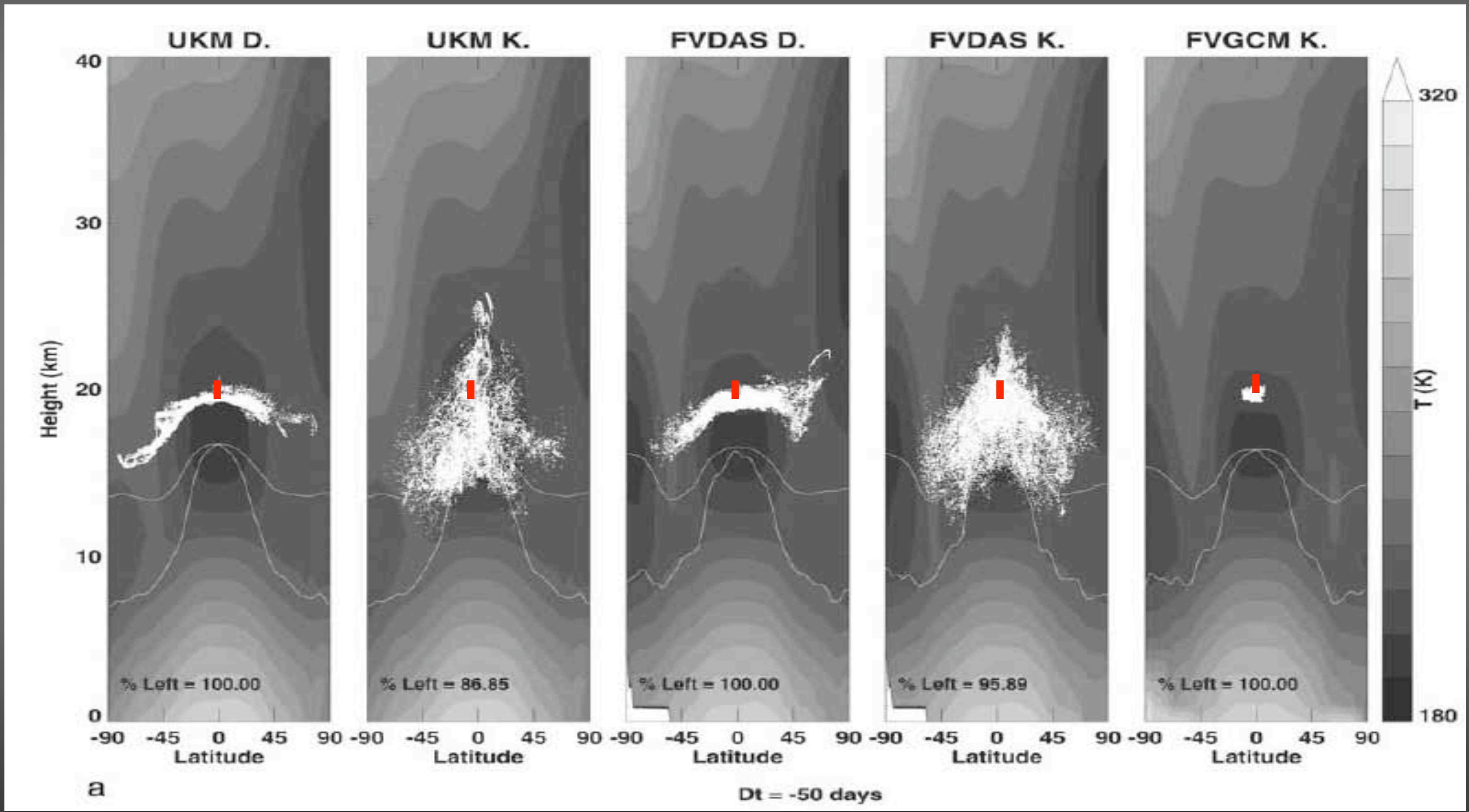


Aerosol measurements after the Mt Pinatubo volcanic eruption (measured by an airborne lidar) show rapid lateral transport in the layer between the tropical tropopause and the 'tropical pipe' mixing barrier, and strong gradient across the edge of the pipe above these heights.

Grant et al., JGR 1994

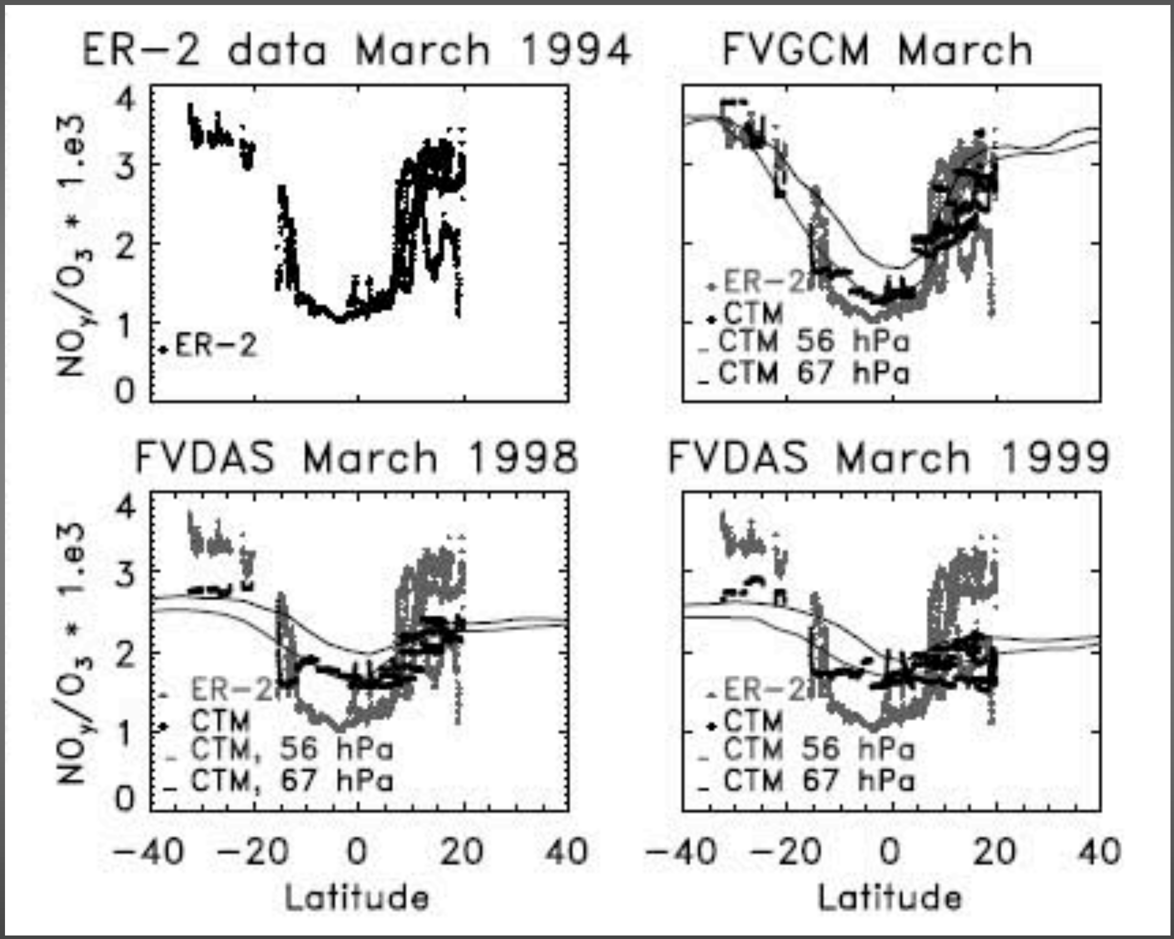
DISPERSION CHARACTERISTICS OF DAS

Backward trajectory calculations starting in the tropical region for different DAS's and a GCM. All DAS-trajectories show excessive horizontal and/or vertical dispersion.



Schoeberl et al., JGR 2003

INFLUENCE OF DISPERSION ON TRACER GRADIENTS

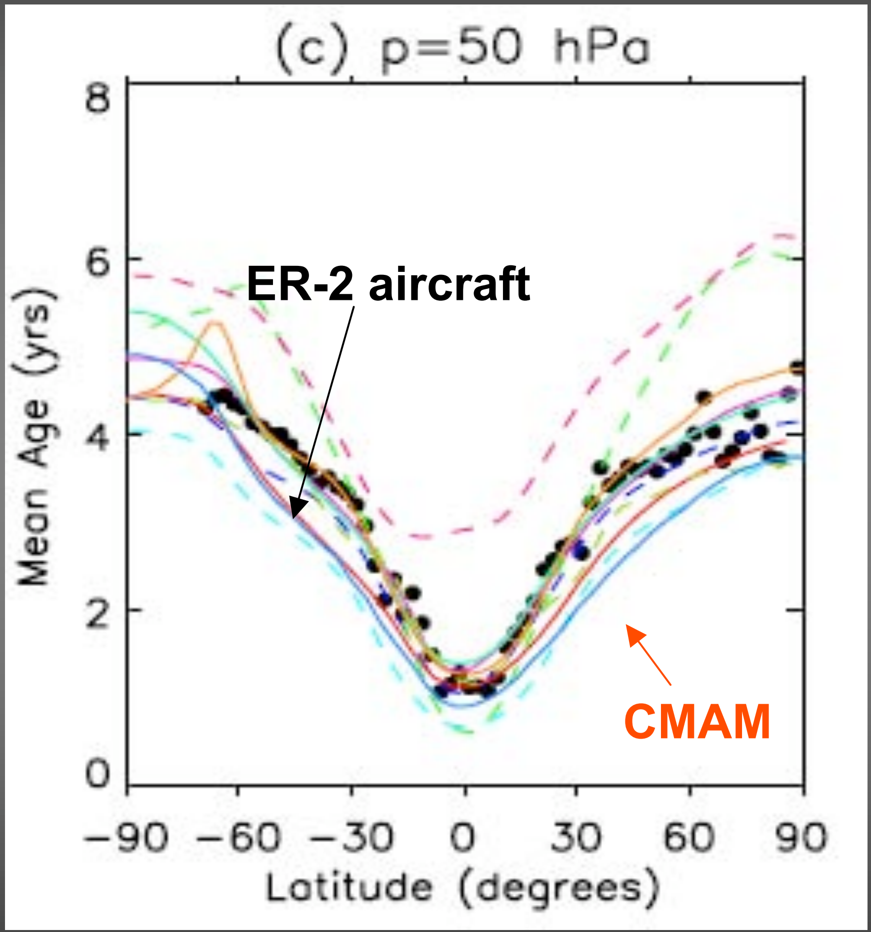


Douglass et al., JGR 2003

Shown are the meridional profiles of the NO_y-O_3 ratio from the ER-2 aircraft, a GCM and a DAS.

CTMs driven by analysed winds show excessive dispersion and cannot maintain the observed latitudinal gradients of long-lived species

AGE OF AIR IN CCMs



CCMs on the other hand, have reasonable transport, even at low resolution.

This is reflected in the results of a recent comparison between the age of air distributions of different CCMs with aircraft measurements.

Eyring et al., JGR 2006

MOTIVATION FOR THIS STUDY

Recently, some authors have suggested that a point might be reached where the intrinsic elements of data assimilation prevent certain transport applications from further improvement [Stohl et al., 2004; Rood, 2005].

While CTMs are driven off-line by analyzed wind fields sampled at a certain frequency, and often suffer from too strong dispersion, CMAM-DAS calculates advection within the model code (in-line), hence providing higher temporal resolution.

This procedure should mitigate the effects of noise and make 3D-Var analyses useable for advection of chemical species.

In this study we test this hypothesis by investigating the transport characteristics of the CMAM-DAS.

MODELS

CMAM-DAS

Based on regular Canadian Middle Atmosphere Model (v8):

→ fully coupled chemistry-climate model
→ vertically extended version of the CCCma tropospheric GCM
→ includes a comprehensive representation of the relevant physical and chemical processes in a fully interactive mode
→ 71 vertical levels, T47, roughly 3.75°

3D-Var Data-Assimilation:

→ surface observations (from land stations, ships and buoys)
→ aircraft winds, radiosondes
→ temperature, pressure, wind components, humidity, radiances:
- cloud driftwinds from geostationary satellites
- Satellite radiances from the Advanced Microwave
- Sounding Unit (AMSU), part of the Advanced TIROS
- Operational Vertical Sounder (ATOVS)
- NOAA-15 and NOAA-16

→ most observations are limited to below 10 hP (~30 km)
→ no assimilation of data in the mesosphere
→ no assimilation of chemical species yet

MODELS CONTINUED AND OBSERVATIONS

CMAM-REF:	CMAM (T48) free running reference run (over 5 years)
CMAM:	CMAM (T32) WMO Ref-2
ECMWF:	Observational and forecast fields (1°lonx2°lat)
NCEP:	Reanalyses (1979-2006)

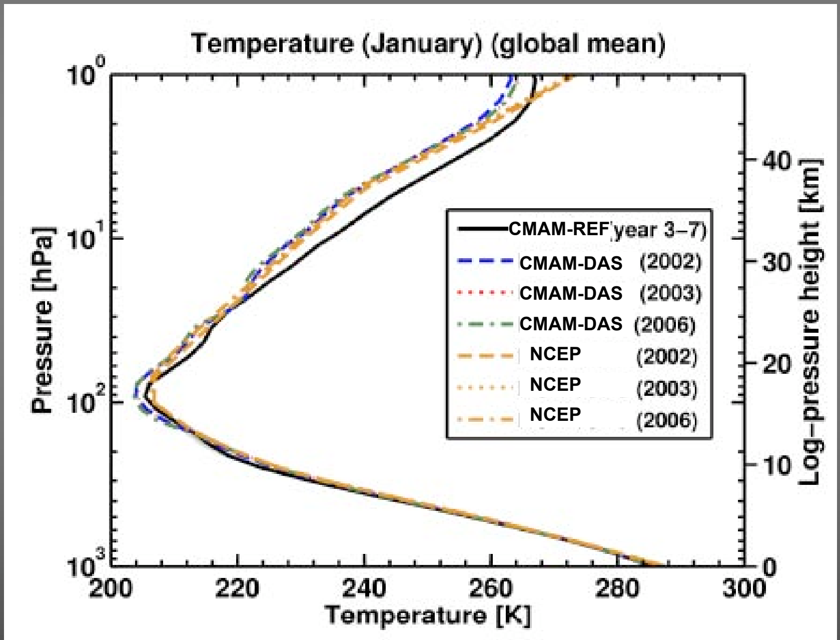
Observations:

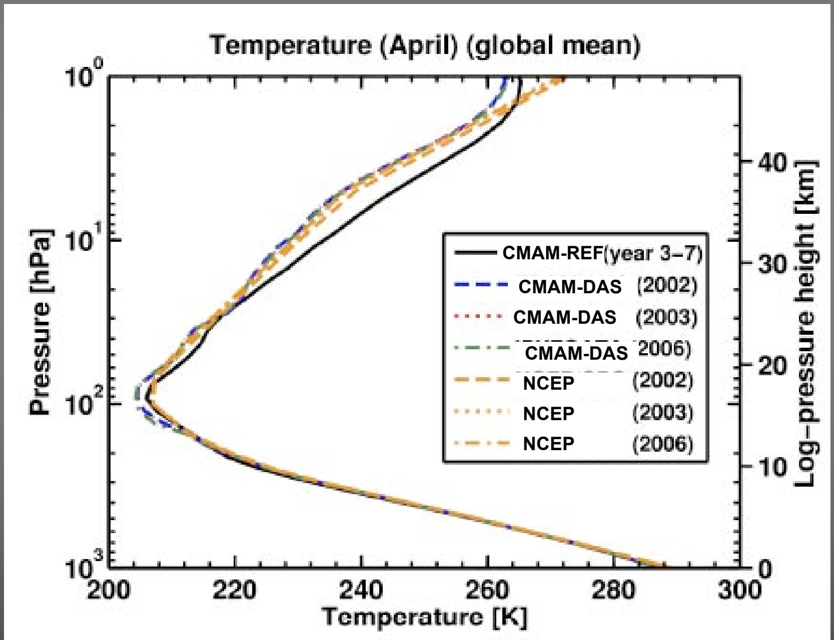
ACE-FTS satellite data:	stratosphere and mesosphere 2004-present
HALOE/UARS satellite data:	stratosphere and mesosphere 1991-2002
ER2 aircraft data:	18-20 km altitude mid 90's
SPURT aircraft data:	8-13 km altitude 2002/2003

TEMPERATURE FIELDS

GLOBAL MEAN TEMPERATURES

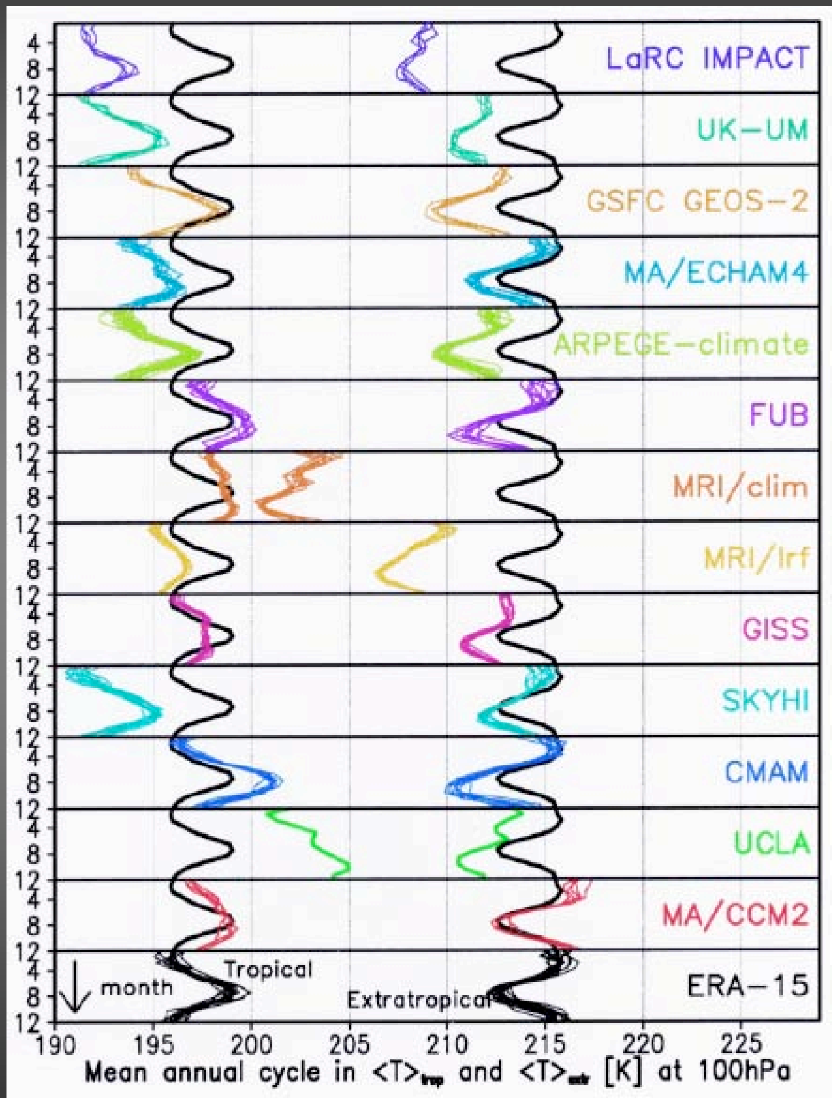
The comparison of global mean temperatures shows that data assimilation lowers the temperatures between 1 and 50 hPa, resulting in better agreement with NCEP, except at 100 hPa, where temperatures are too cold.





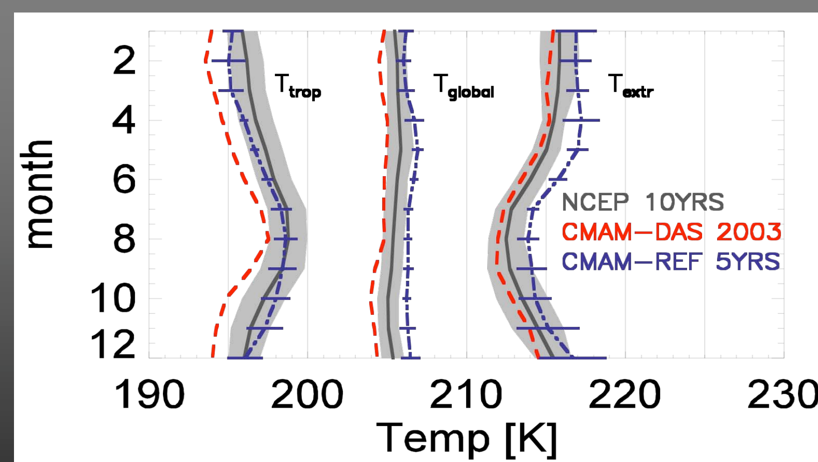
Figures courtesy Andreas Jonsson

MONTHLY MEAN TEMPERATURE CYCLE @100hPa



Annual temperature cycle at 100 hPa shows an exact compensation between the tropics and extratropics (Yulaeva et al. 1994 JAS). This feature is clearly seen in the ERA-15 data.

Data assimilation improves the seasonal temperature cycle but leads to a too strong decrease in tropical temperatures.



Pawson, BAMS 2000

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MESOSPHERE

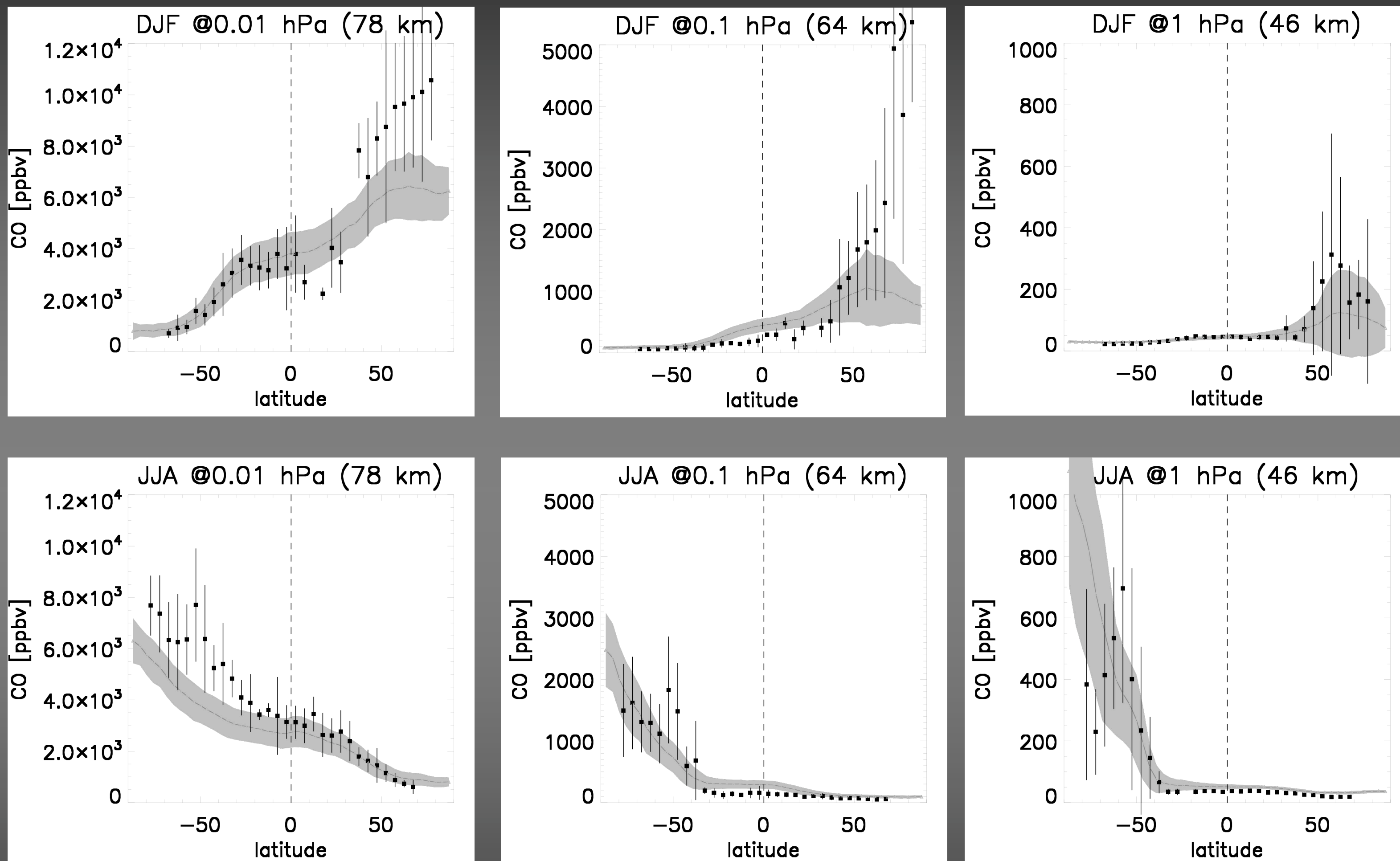
CO DISTRIBUTIONS

DJF

ACE + DAS 2006

JJA

ACE 2006 + DAS 2003



Latitudinal structures show general good agreement between ACE and CMAM-DAS, however, CO at high latitudes is too low in the NH mesosphere, and too high in the SH upper stratosphere, which might be related to the strength of downward transport.

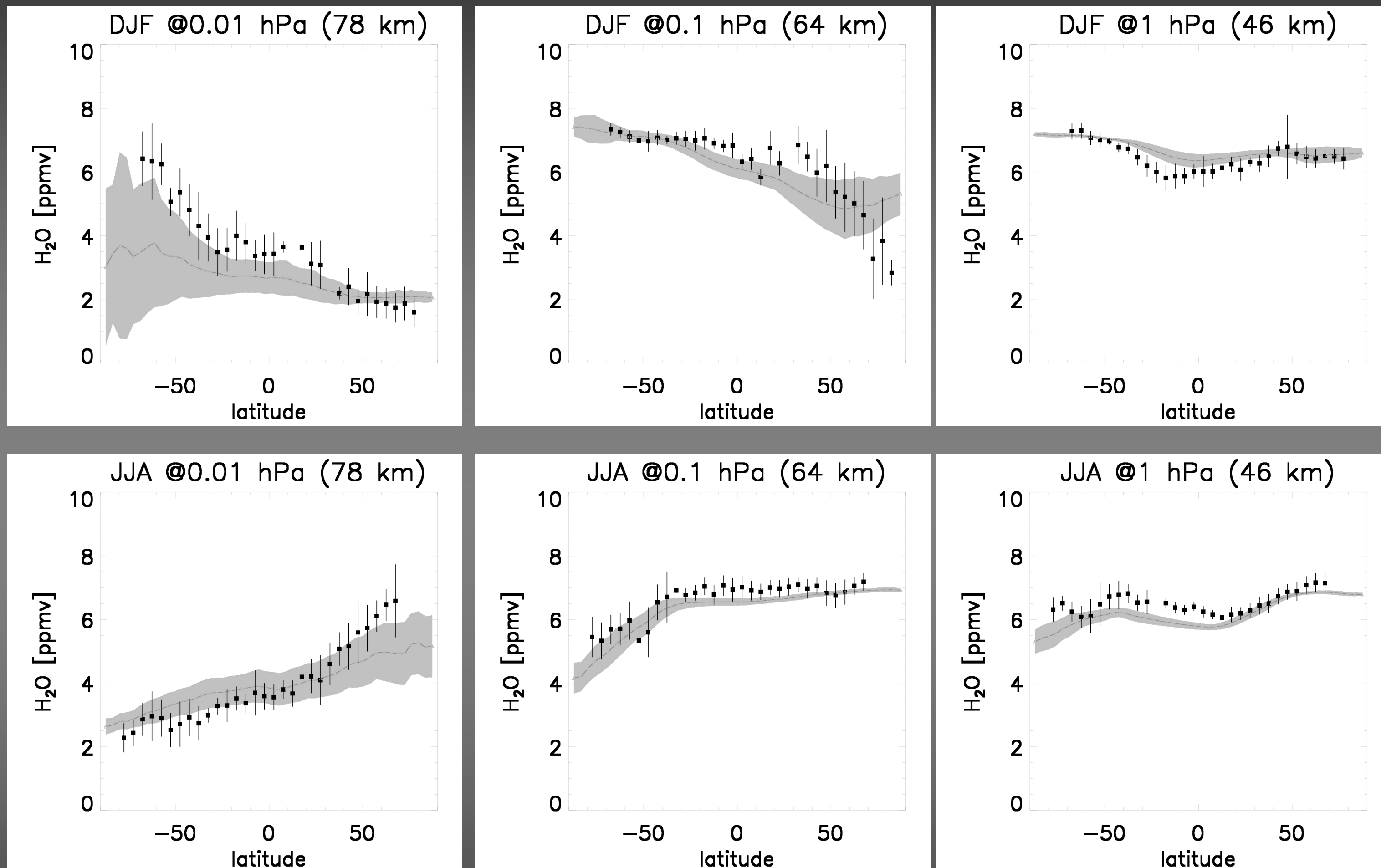
H_2O DISTRIBUTIONS

DJF

ACE + DAS 2006

JJA

ACE 2006 + DAS 2003



General good agreement between ACE and CMAM-DAS features, however, 2 ppmv were added to the CMAM-DAS prior to plotting.

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STRATOSPHERE

Meridional N_2O profiles

COMPARISON OF MERIDIONAL N_2O PROFILES

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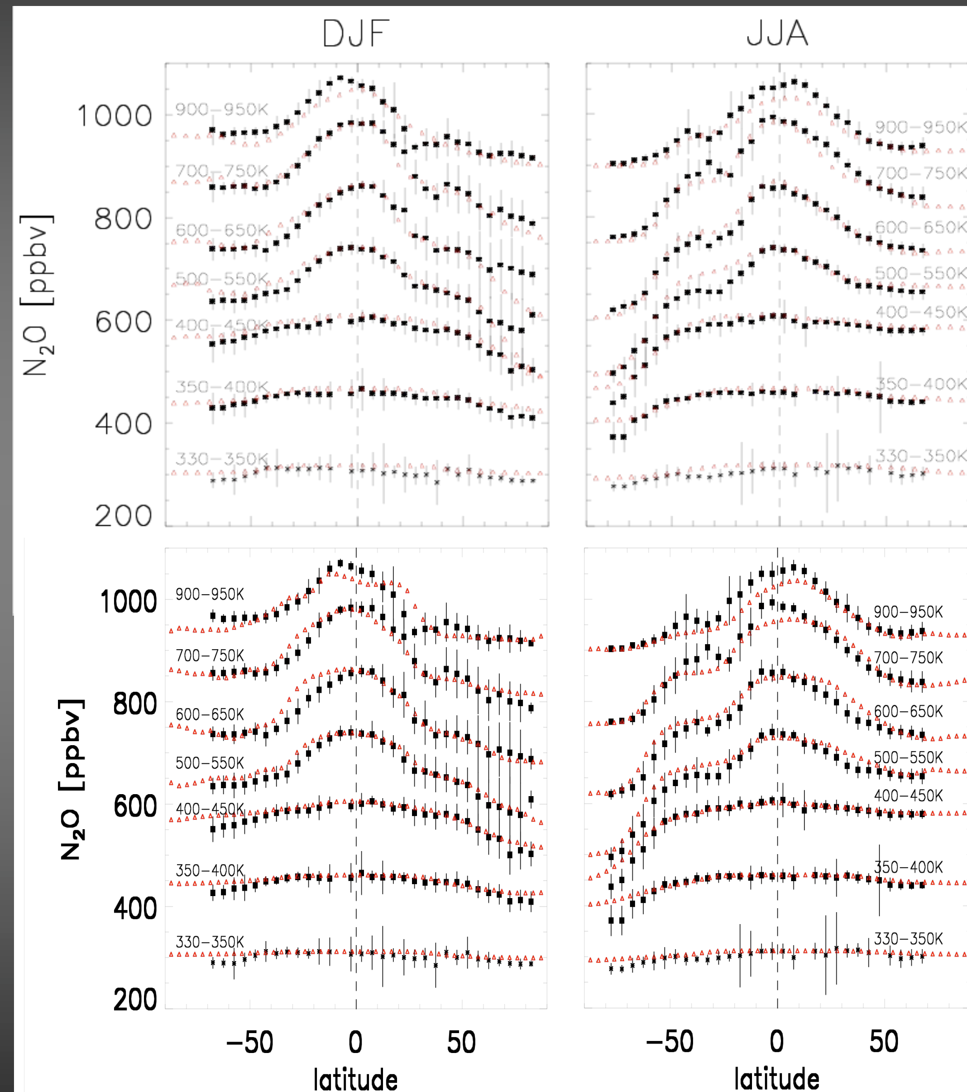
ACE and CMAM



ACE and CMAM-DAS (2002)

The gradients are well maintained, except at lowest potential temperature levels. This points towards too strong meridional transport.

COMPARISON OF MERIDIONAL PROFILES O3

DAS WS TORONTO 2007

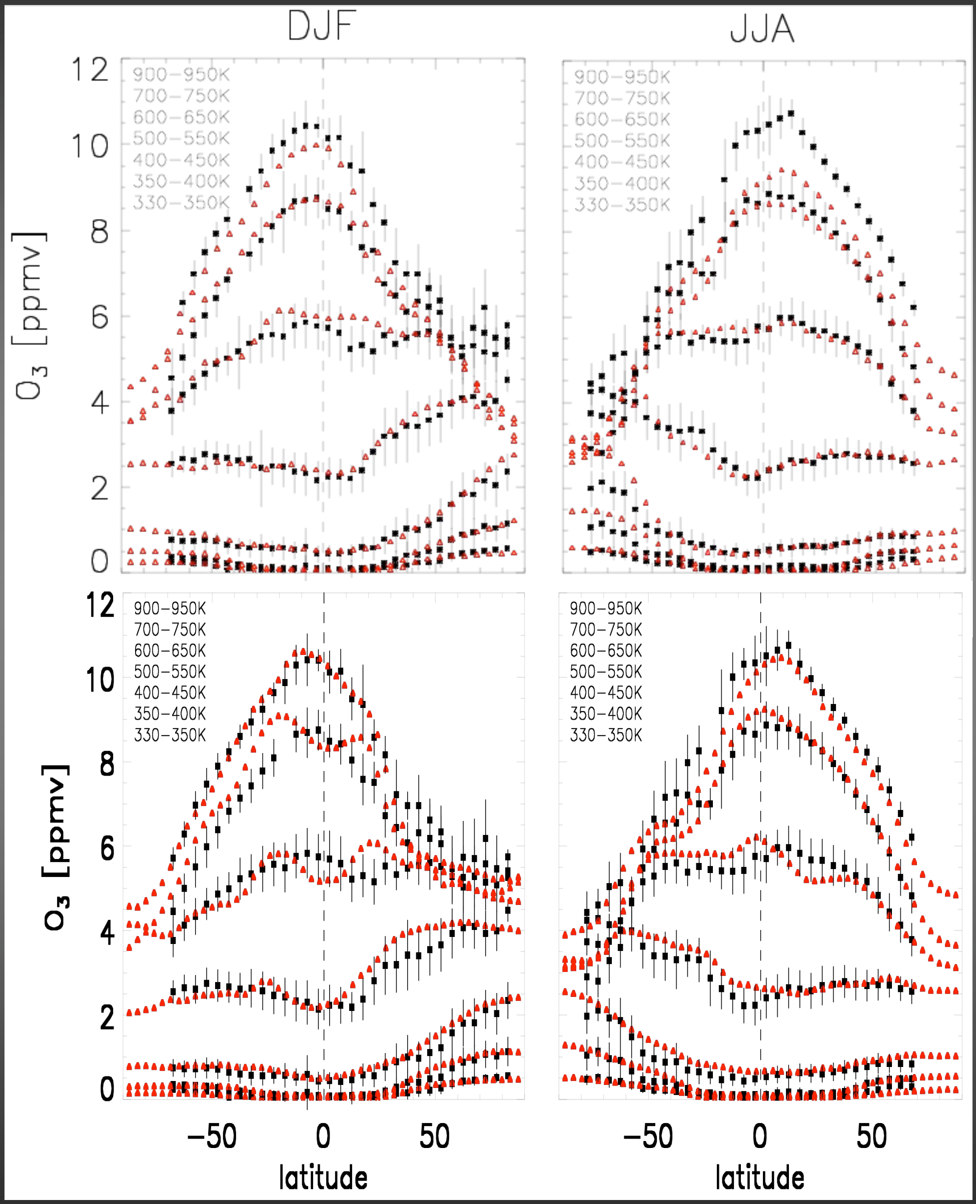
ACE and CMAM

Good agreement between model and observations, except JJA potential temperature level of 900-950 K which exhibits low-bias.

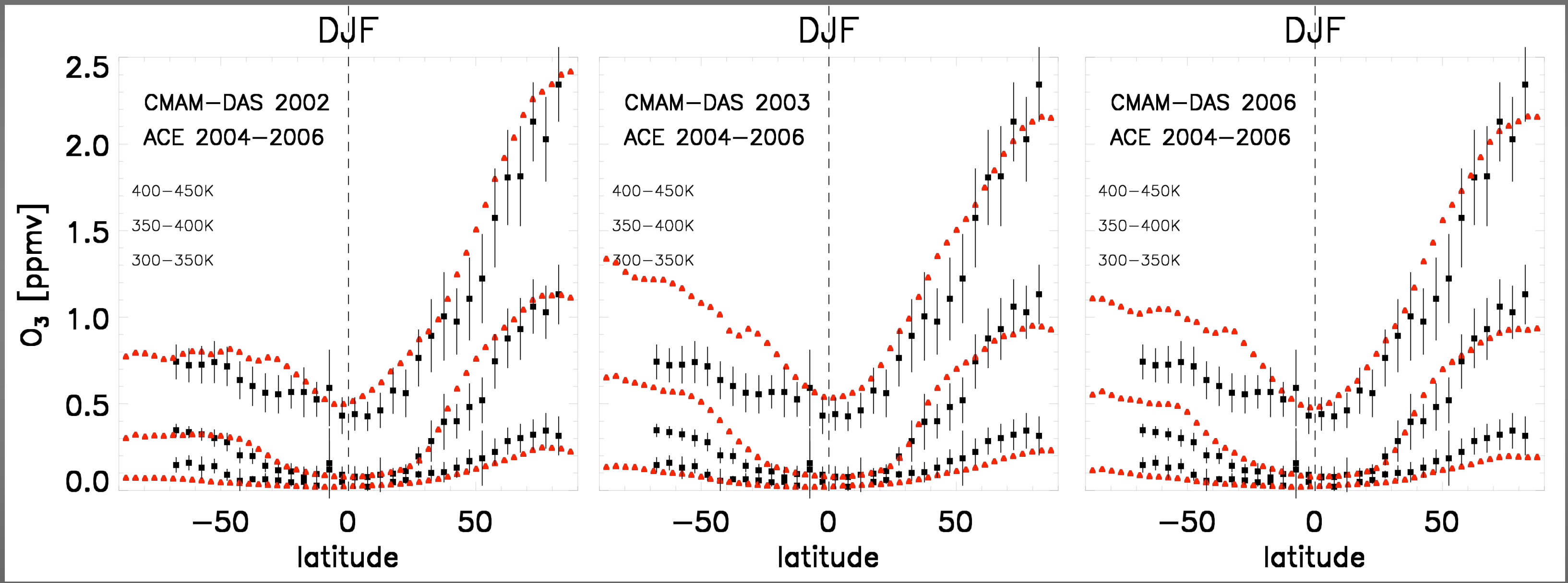
ACE and CMAM-DAS (2002)

CMAM-DAS shows double peak in tracer meridional profile within the tropical pipe.

CMAM-DAS shows more structure than expected from ACE.

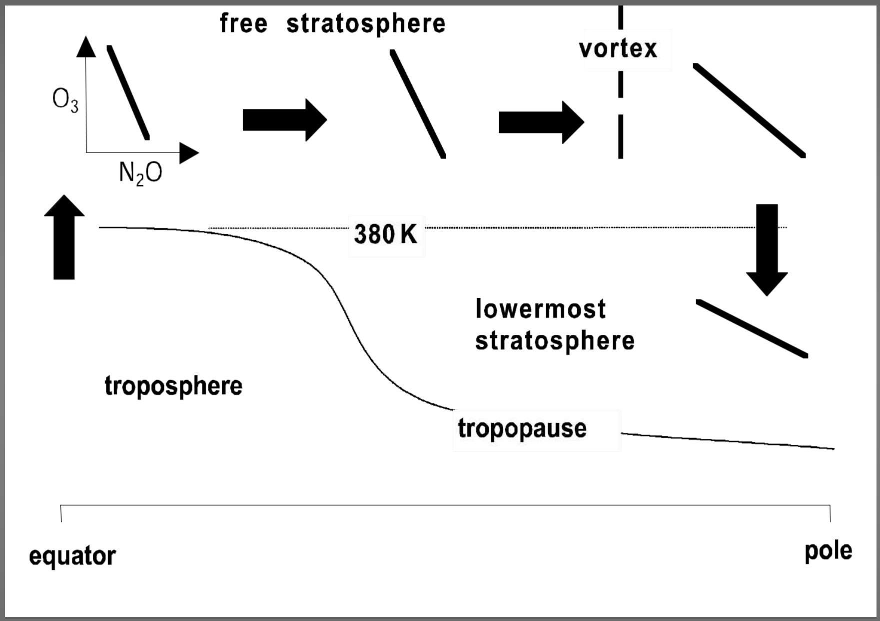


LOWER STRATOSPHERE:
AFTER SPINUP TIME, OZONE IS TOO HIGH

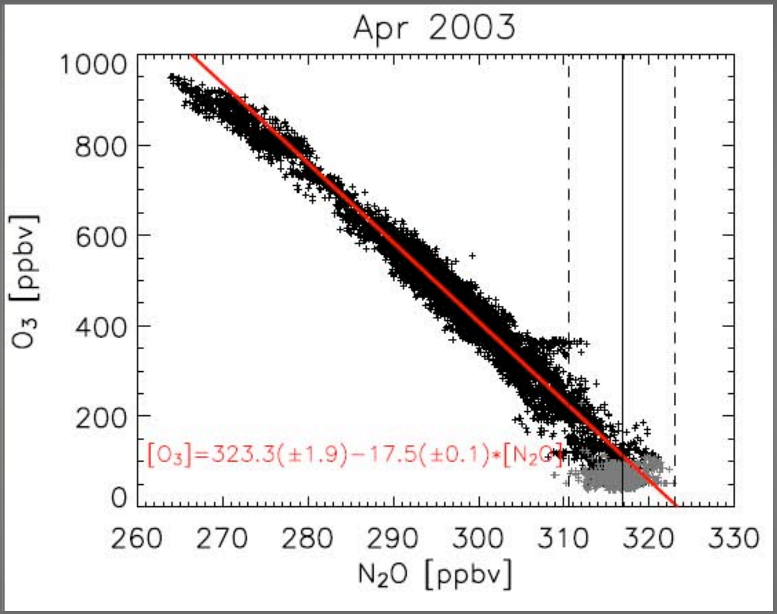


See presentation of Gloria Manney!

O3-N2O SLOPES AS A DIAGNOSTIC FOR TRANSPORT AND CHEMISTRY



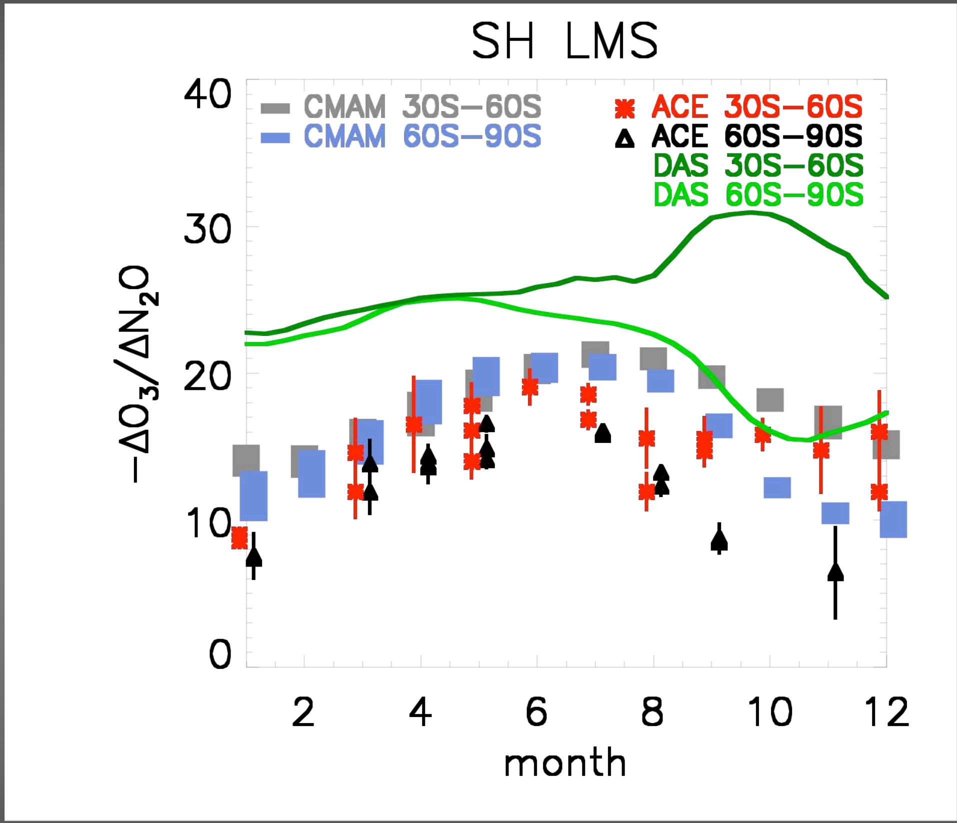
Bregman et al., JGR 2000



Hegglin et al., ACP 2006

The O_3-N_2O correlation slopes are an indicator for the chemical age of air. Large negative slopes indicate young air masses with rather tropical origin, small negative slopes aged air masses of stratospheric origin.

THE SEASONAL CYCLE OF O3-N2O SLOPES IN THE SH



Freely adapted from Hegglin and Shepherd, JGR accepted.

The seasonal cycle of the DAS indicates way too young air masses.

The separation between the midlatitudinal and polar branches is mainly due to chemical ozone loss.

PARTICLE DISPERSION @ 420K

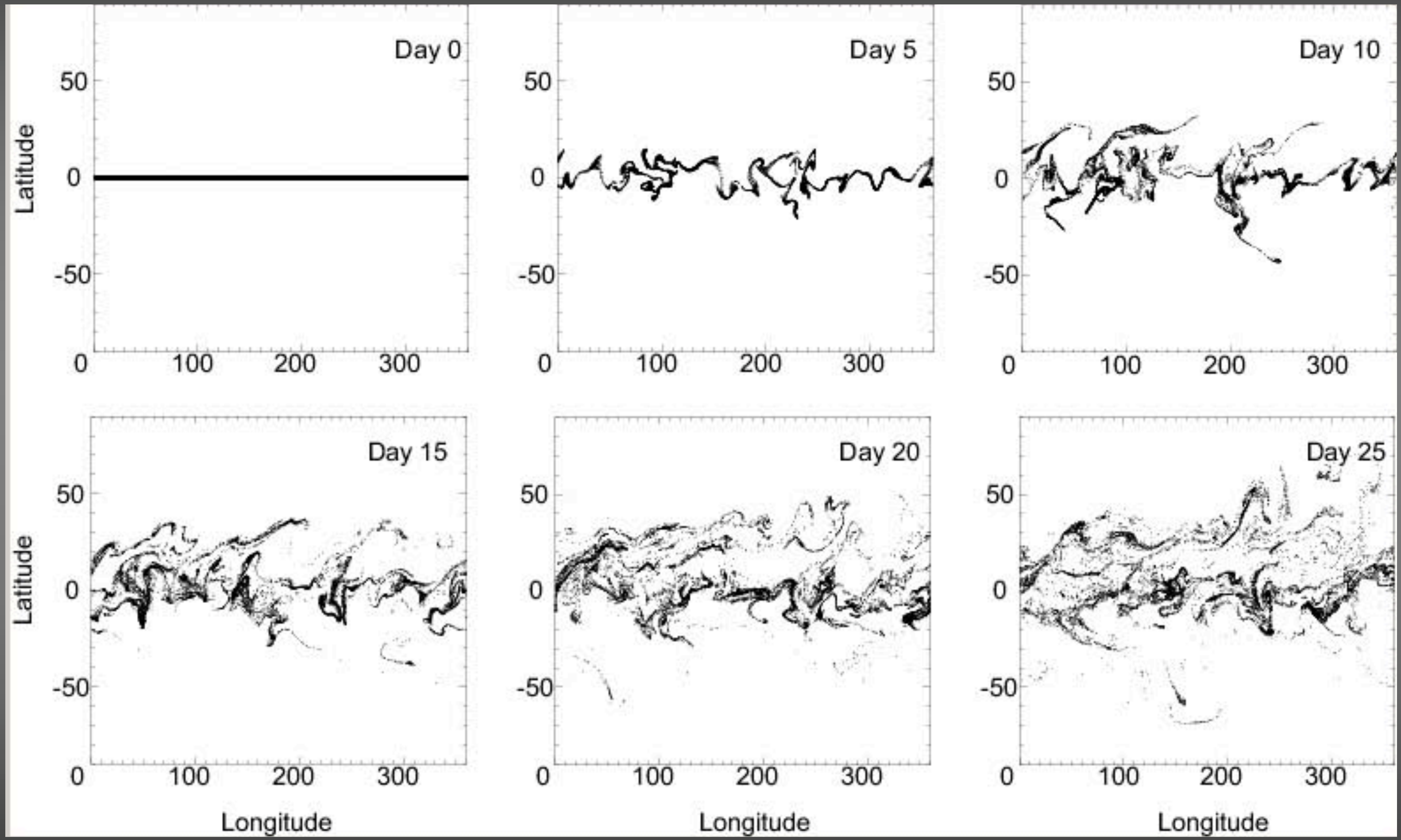


Figure courtesy Diane Pendlebury

PARTICLE DISPERSION @ 480K

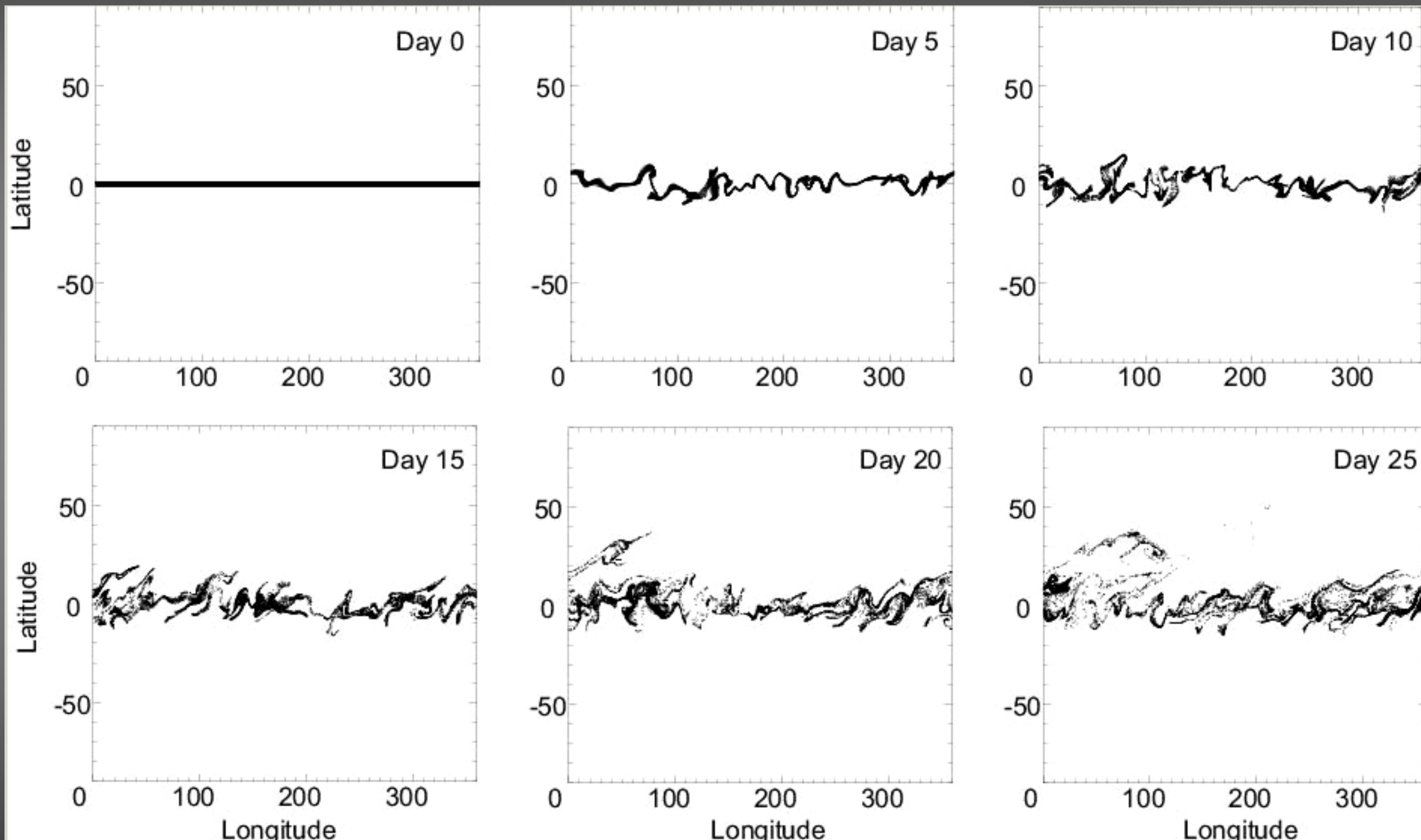


Figure courtesy Diane Pendlebury

PARTICLE DISPERSION CALCULATIONS
30 DAY FORWARD TRAJECTORIES WITH CMAM-DAS JAN

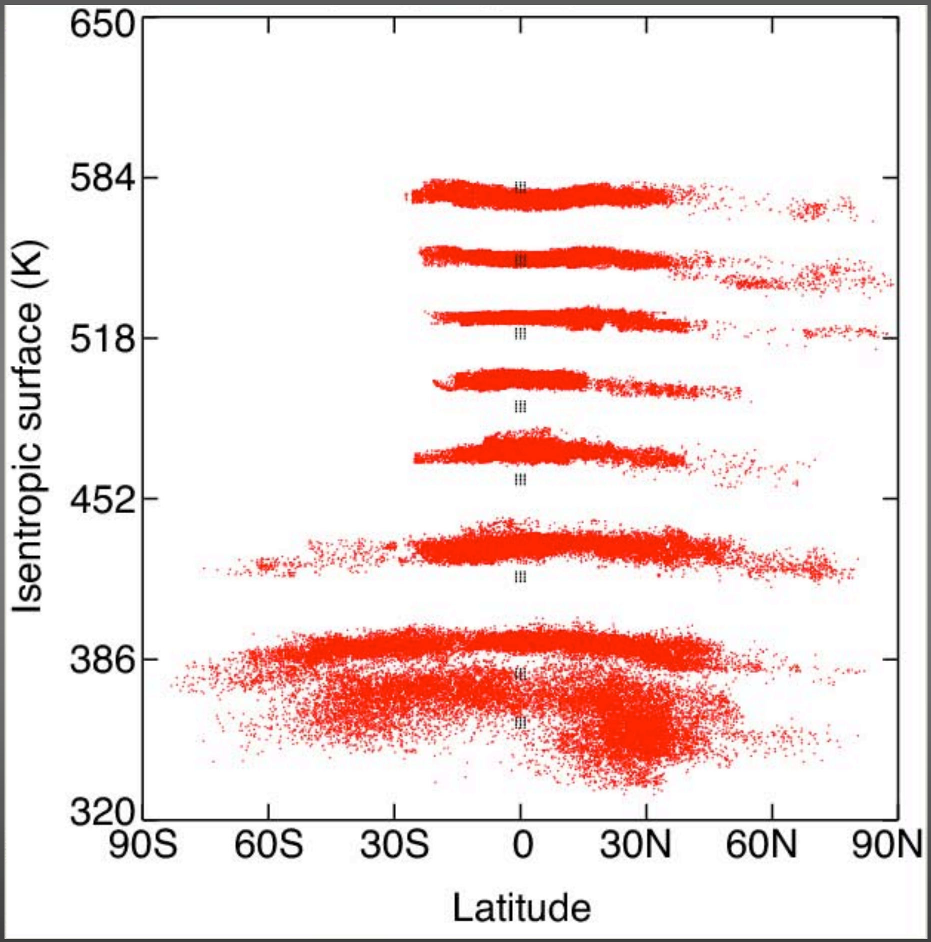
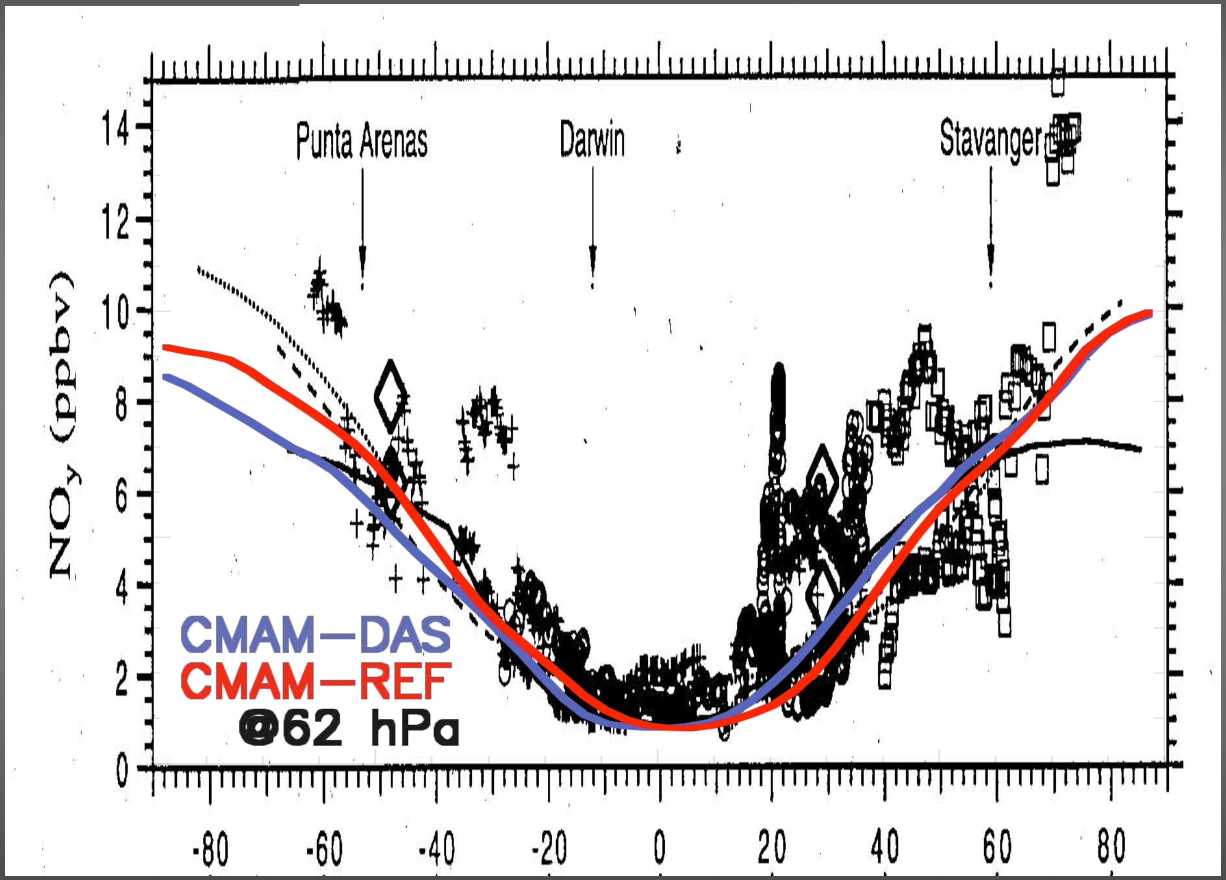


Figure courtesy Diane Pendlebury

Forward trajectories started on different potential temperature levels (360, 380, 420, 460, 500, 520, 540, 580 K).

Strong meridional transport to midlatitudes, between 420 and 460 the tropical pipe finally starts to be confined (better in the SH).

TRACER GRADIENTS AT THE SUBTROPICAL EDGE – NO_y



Murphy et al., JGR 98

ER-2 aircraft data, for March 2003, from Murphy et al. (JGR 1998)

Latitudinal gradients of NO_y are well maintained not only in the CMAM but in the CMAM-DAS.

This results from the in-line advection in CMAM-DAS

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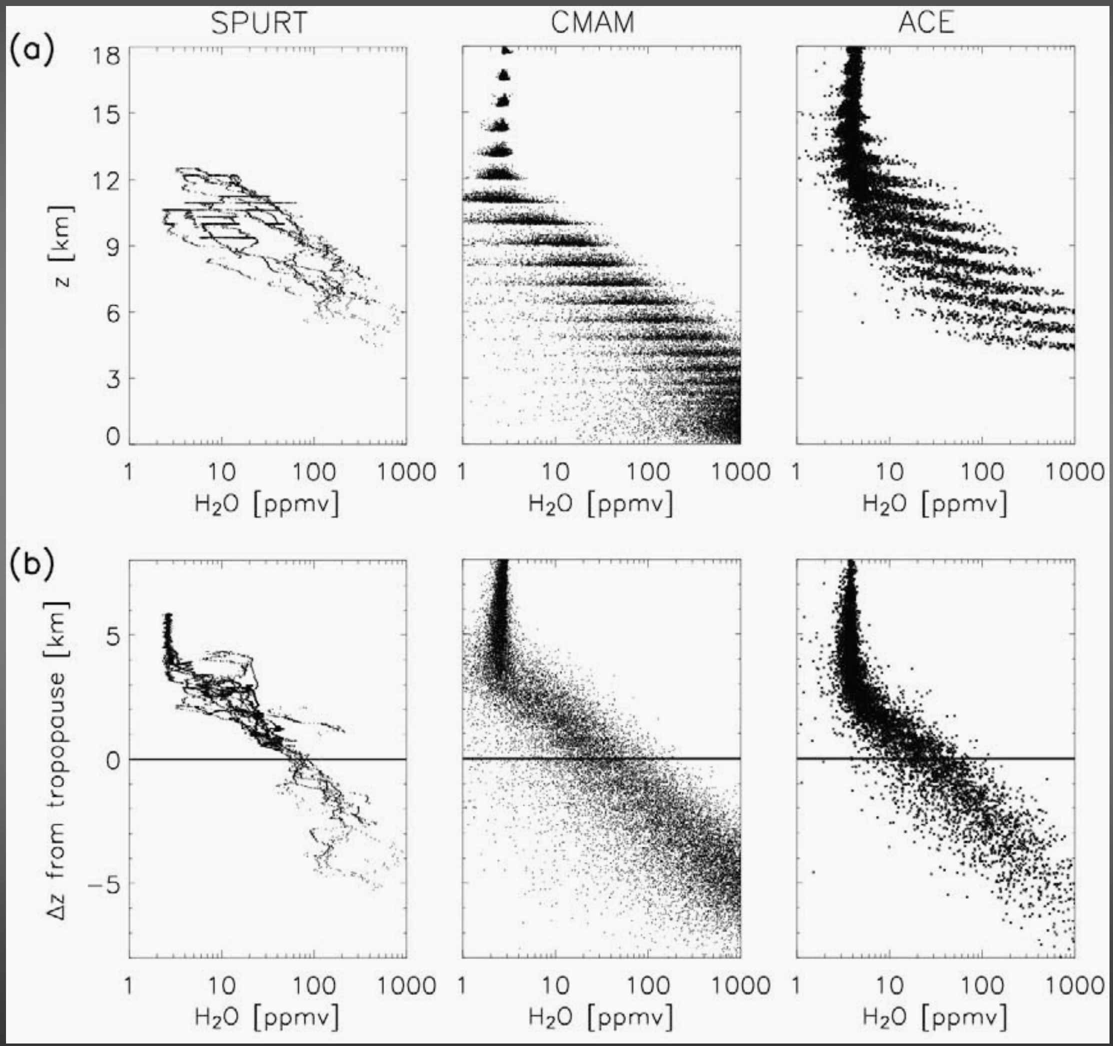
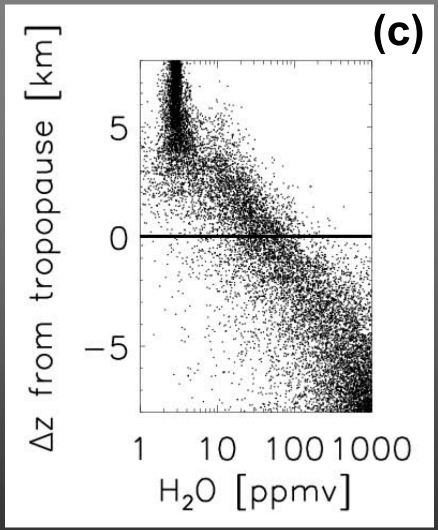
LOWER STRATOSPHERE/UPPER TROPOSPHERE

VERTICAL PROFILES RELATIVE TO THE TROPOPAUSE (midlatitudes)



CMAM-DAS (2003)



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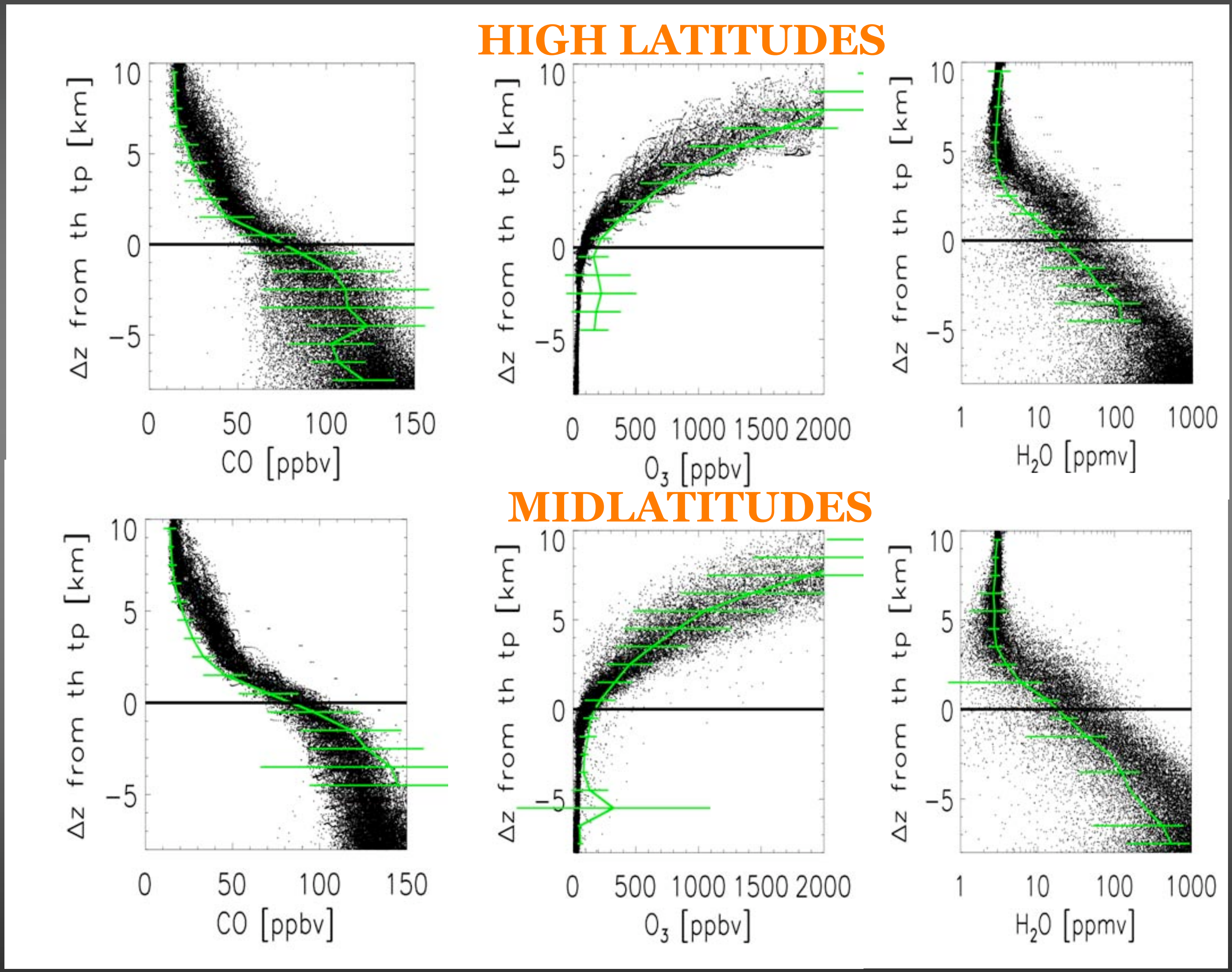
CMAM-DAS AND ACE O3, CO, AND H2O VERTICAL PROFILES



Again plus 1.5 ppmv for the CMAM-DAS H_2O values!

CMAM-DAS January 03.

ACE 2004-2006.

NH UTLS.

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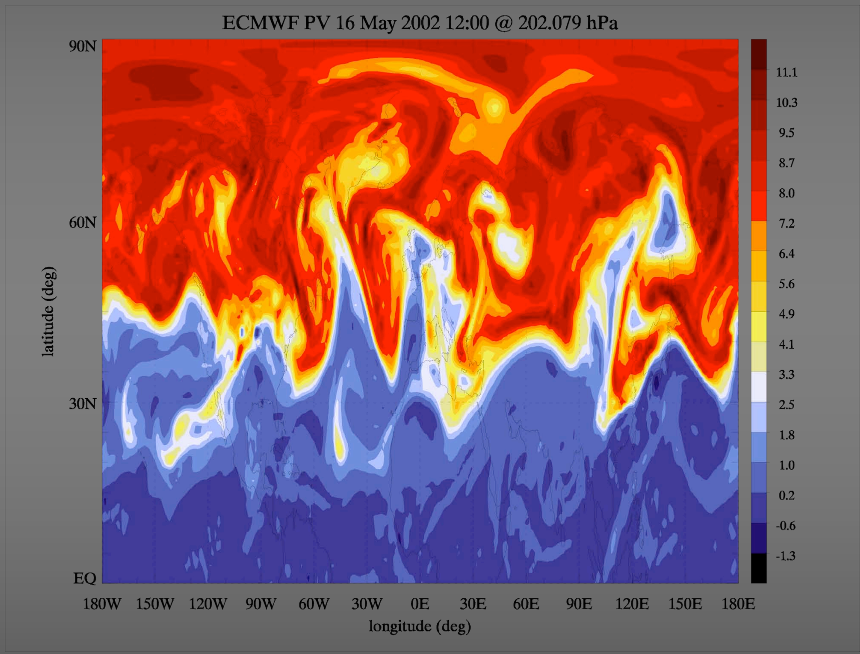
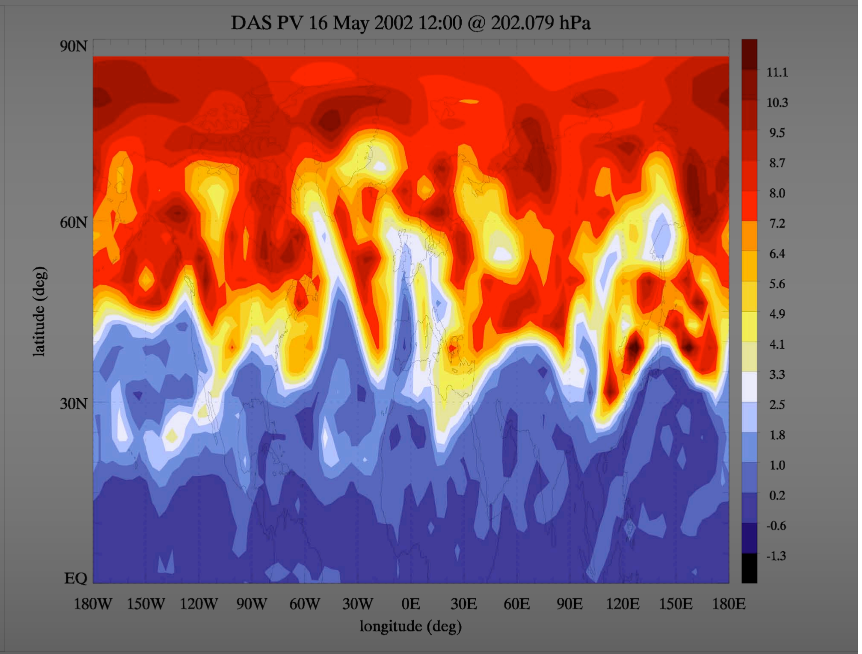
POTENTIAL VORTICITY @ 202 hPa FOR MAY 16 2002 12:00

ECMWF



CMAM-DAS



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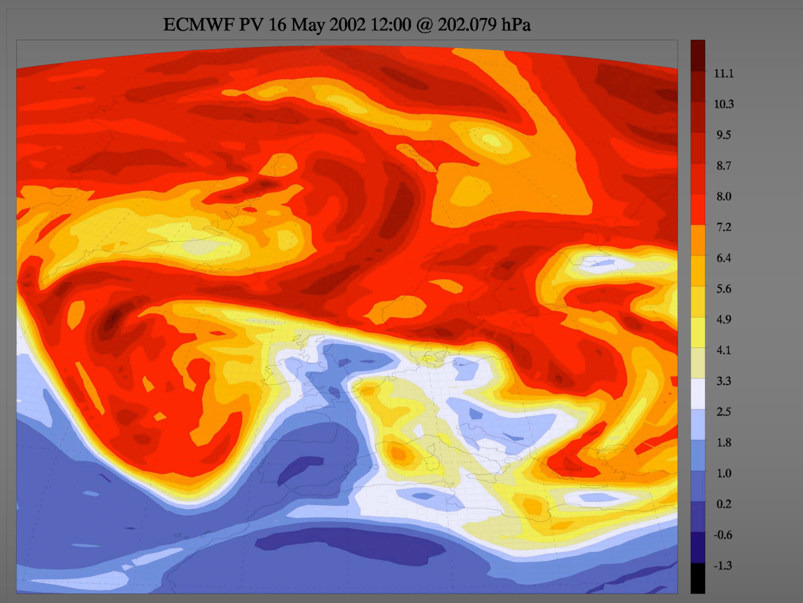
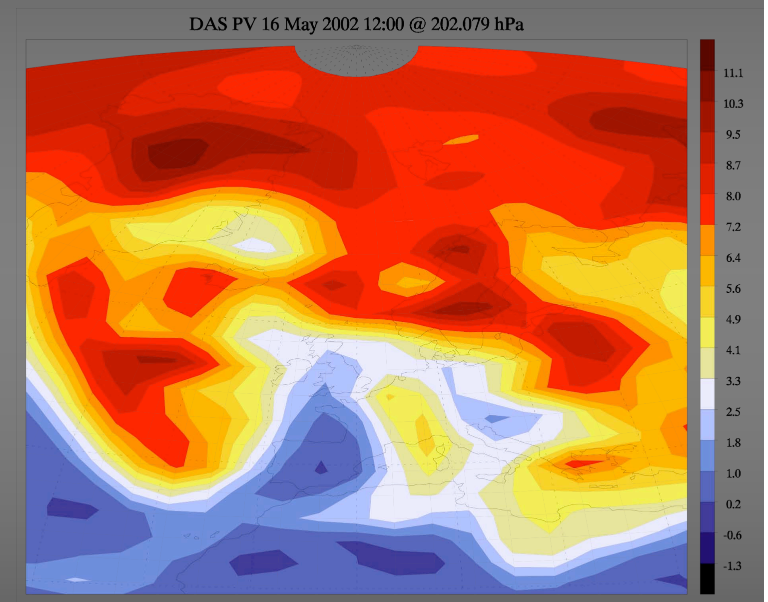
ZOOM ON PV OVER EUROPE @ 2002 hPa ON MAY 16 2002 12:00

DAS WS TORONTO 2007

ECMWF



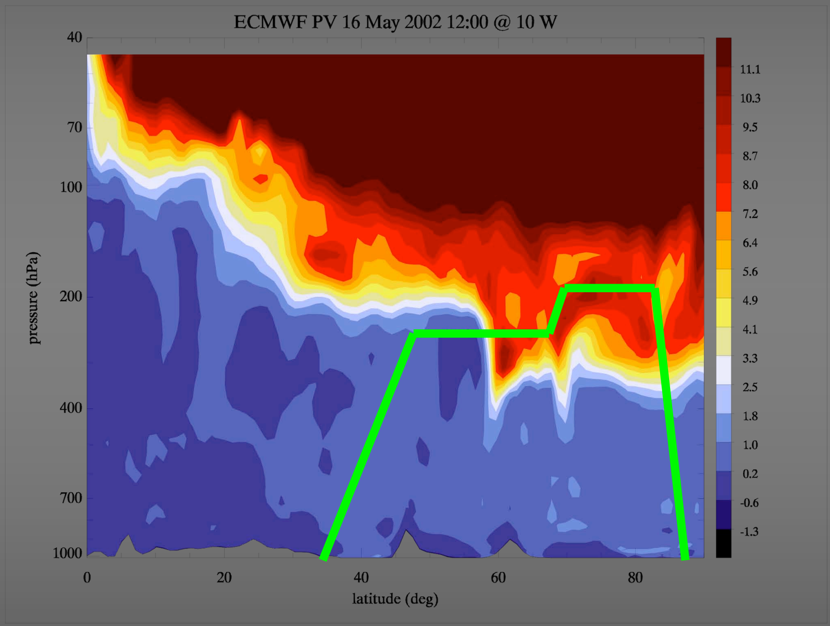
CMAM-DAS



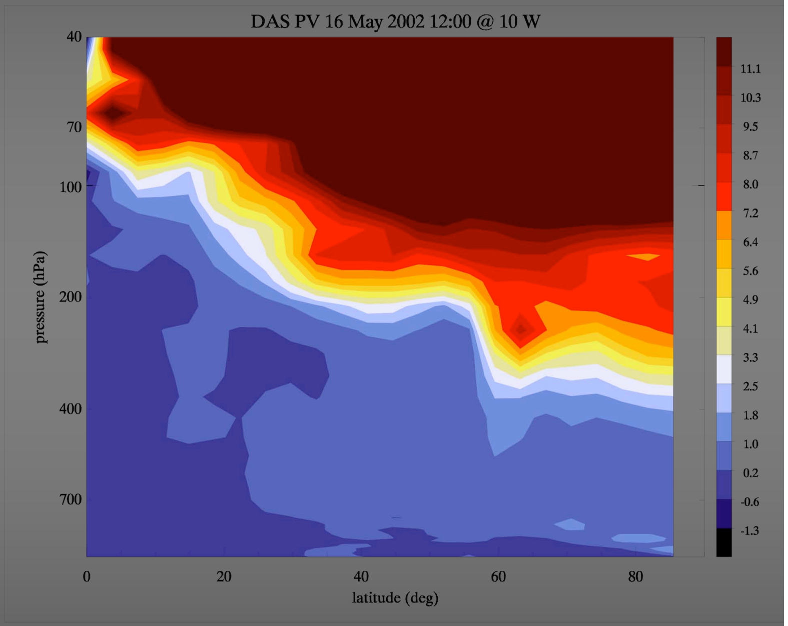
DAS WS TORONTO 2007

VERTICAL CROSS SECTION OF PV @ 10°W May 16 2002 12:00

ECMWF

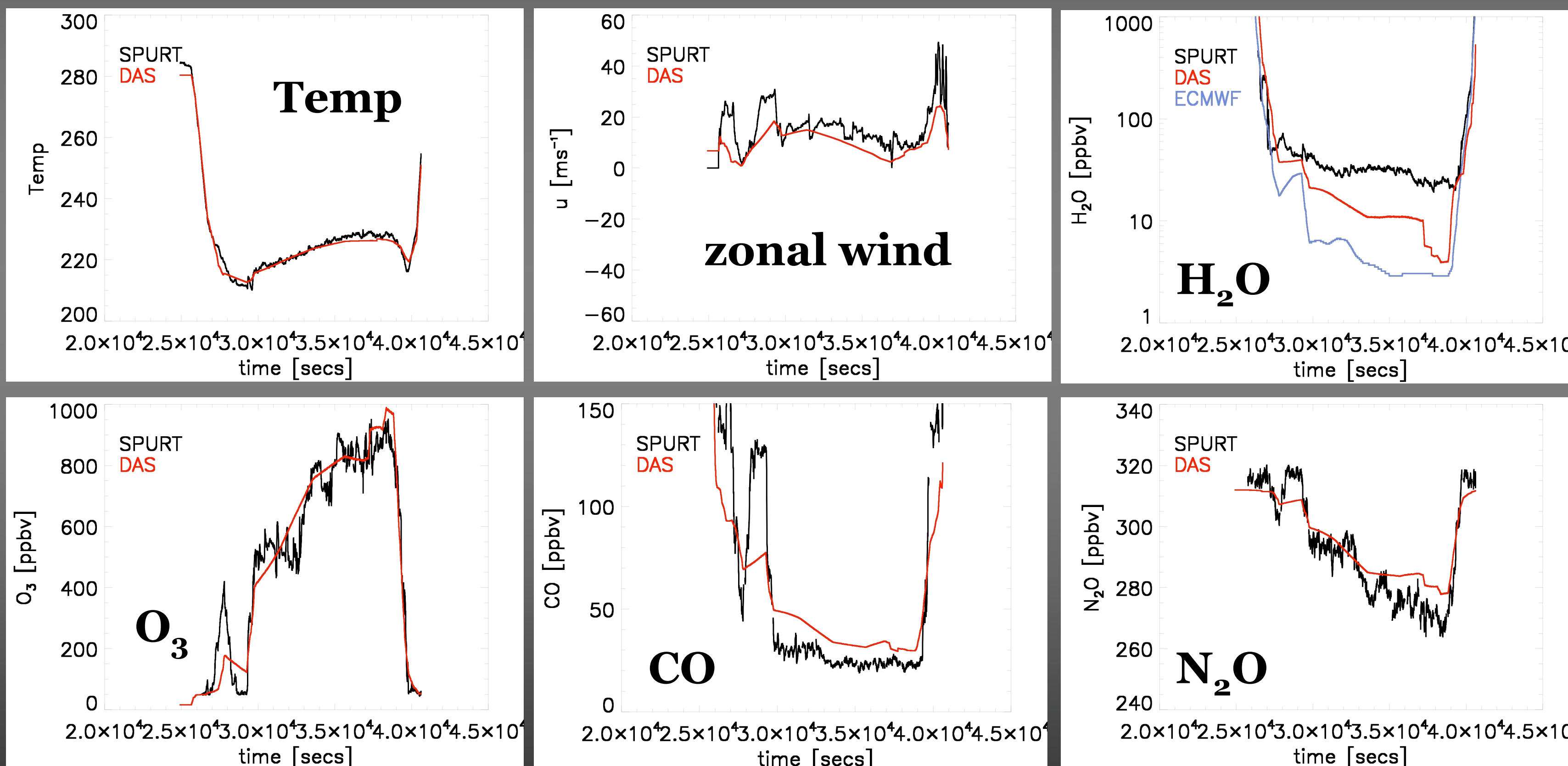


CMAM-DAS



IN-SITU COMPARISON SPURT AIRCRAFT AND CMAM-DAS

CMAM-DAS and SPURT aircraft data for 27 April 2003. Except H_2O the DAS captures most of the relevant features.



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SUMMARY

In general, the CMAM-DAS compares well with both, the free running CMAM and observations, except for H_2O which shows a low bias of around 2 ppmv.

Seasonal features in mesospheric tracer distributions are well reproduced in the CMAM-DAS, indicating the coupling between the stratosphere and the mesosphere is appropriate.

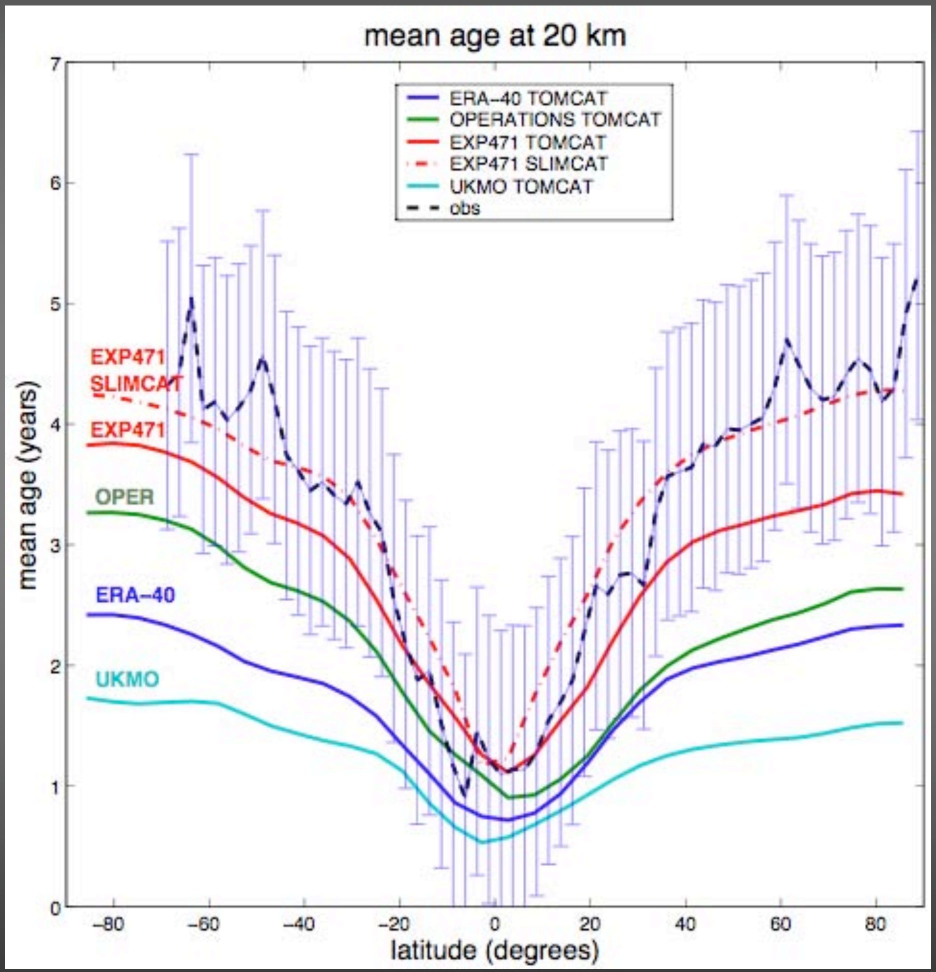
We also showed a clear improvement in upper stratospheric O_3 due to corrected temperatures compared to the free running CMAM.

The comparisons with the ACE-FTS satellite data and ER-2 aircraft measurements show that mixing barriers are well represented and latitudinal gradients in N_2O, NO_y, and O_3 are mostly retained in the CMAM-DAS.

However, some issues remain between 380 and 430 K, where transport to the Southern hemisphere seems to be too strong.

We conclude that in-line advection mitigates the effects of noise in data-assimilation systems, makes 3D-Var analyses useable for advection of chemical species, and hence represents a way ahead in order to improve tracer transport in DAS.

IMPACT ON THE MEAN AGE OF AIR DISTRIBUTION



Mean age of air at 20 km altitude from TOMCAT and SLIMCAT CTM calculations using different ECMWF and UKMO analyses for the year 2000, as indicated.

Age of air from DAS-driven CTMs usually looked pretty bad; but there have been some recent improvements.

Monge-Sanz et al., GRL 2007

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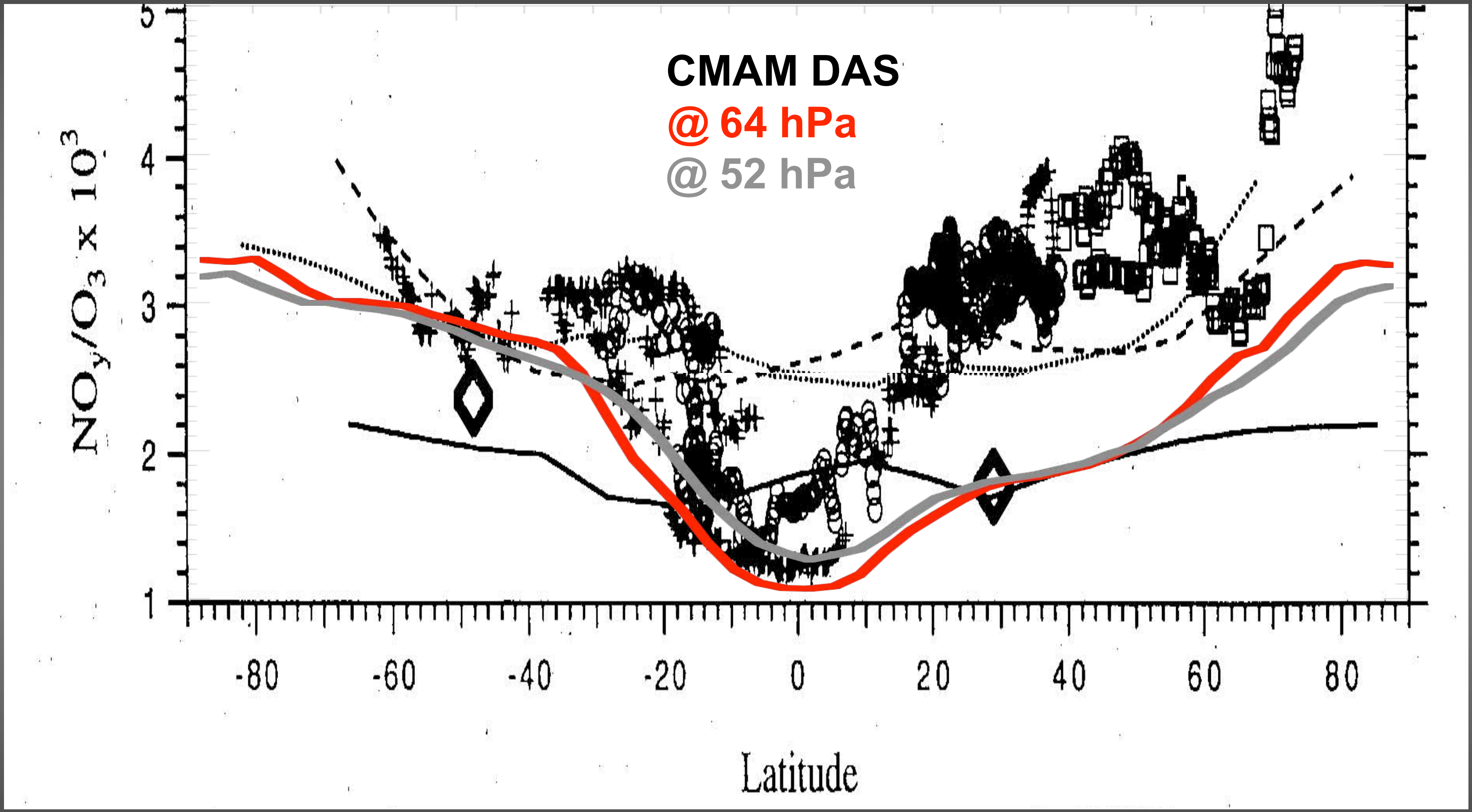
TRACER GRADIENTS AT THE SUBTROPICAL EDGE – NO_y/O_3



Freely adapted after Murphy et al., JGR 98

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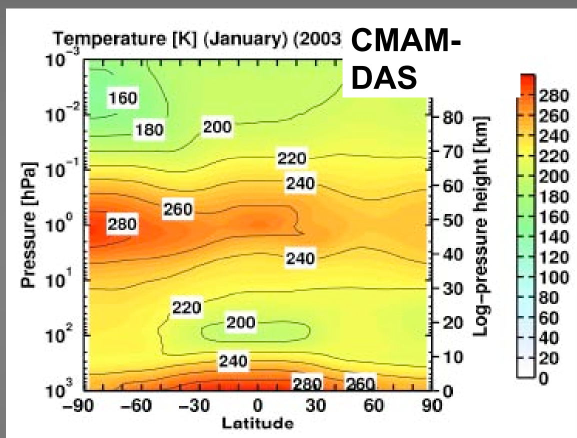
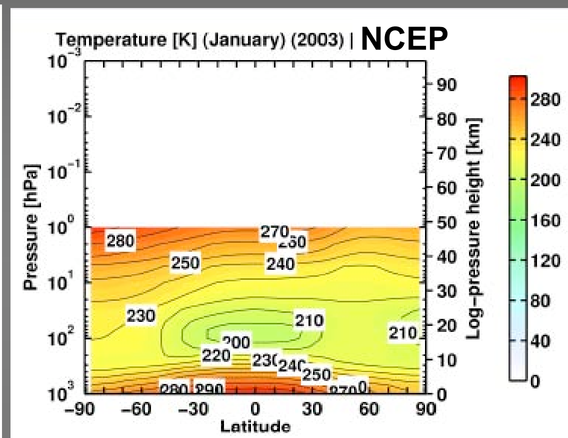
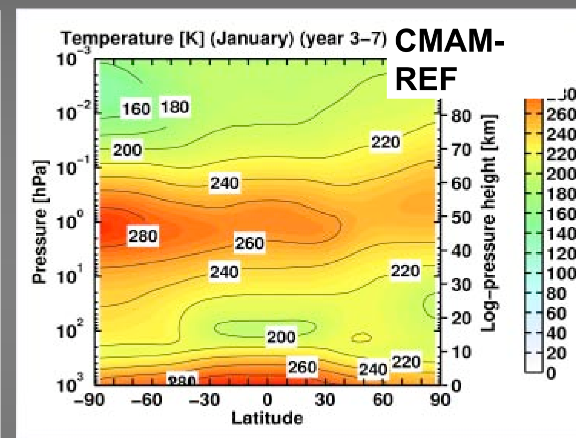
ZONAL MEAN TEMPERATURES

Figures courtesy Andreas Jonsson



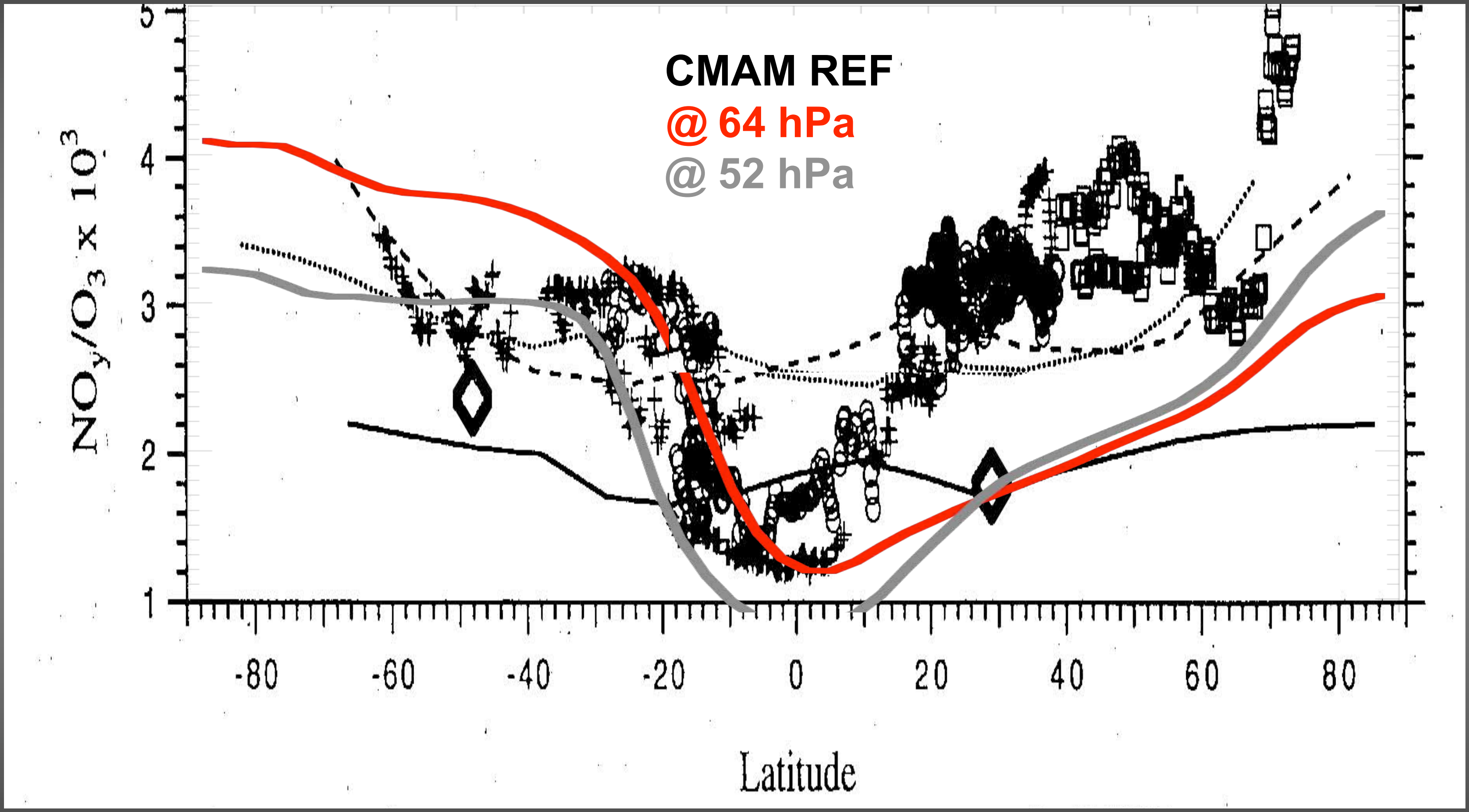




Zonal mean temperatures of CMAM-DAS and CMAM-REF compare well with NCEP.

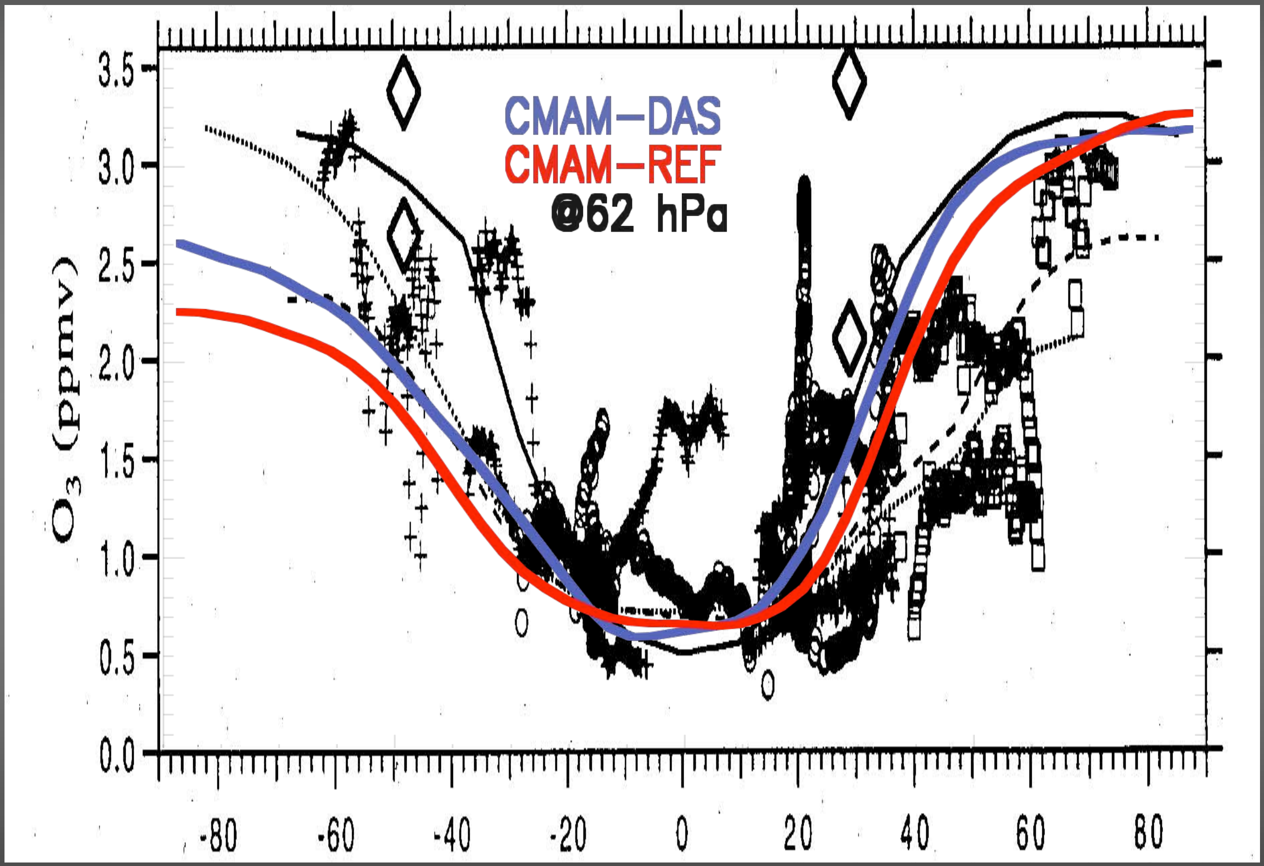
Data assimilation In general cools the extratropical region.

TRACER GRADIENTS AT THE SUBTROPICAL EDGE – NO_y/O_3



Murphy et al., JGR 98

TRACER GRADIENTS AT THE SUBTROPICAL EDGE – O_3



Murphy et al., JGR 98

CMAM-DAS and ER-2 aircraft data (Murphy et al. JGR 1998), for March 2003, and CMAM-REF for March of 4 years.

Well maintained gradients as seen for NO_y.

COMPARISON OF MERIDIONAL N_2O PROFILES

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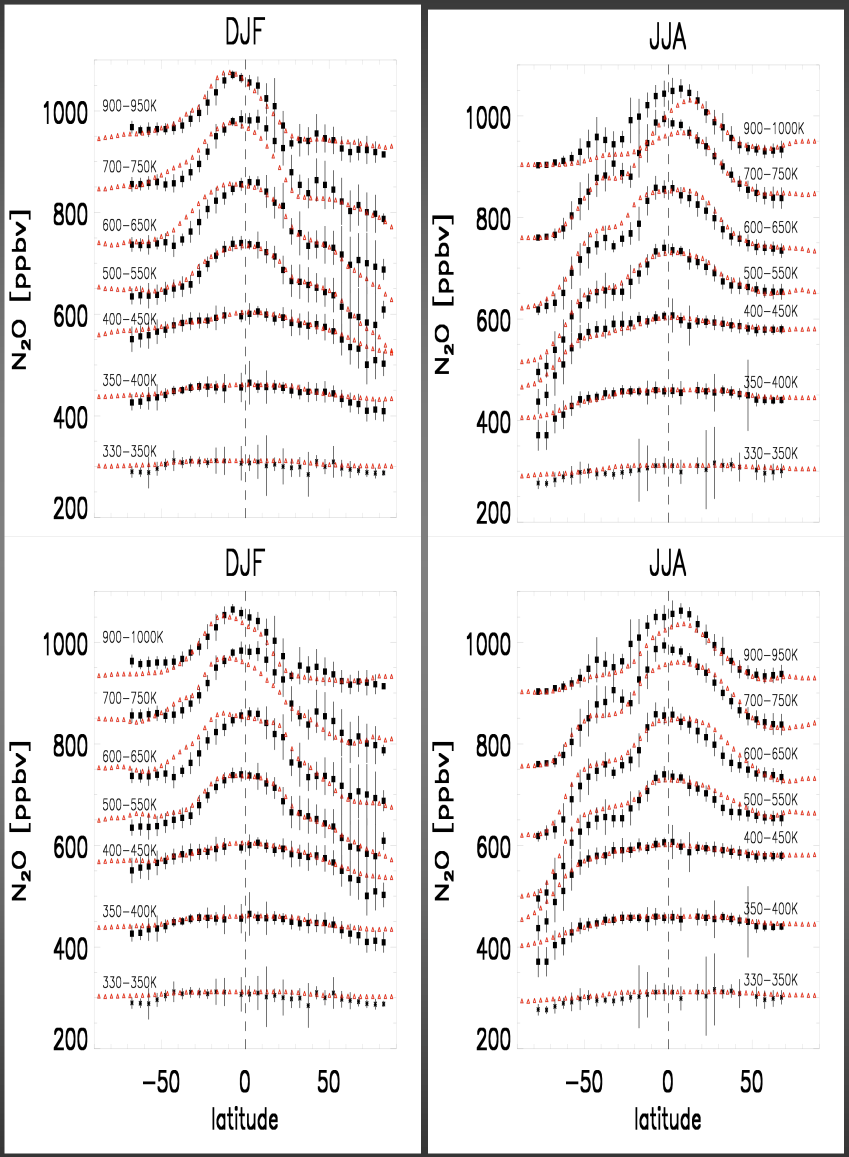
ACE and CMAM-DAS (2003)



ACE and CMAM-DAS (2006)

While DJF looks well in both years, JJA 2003 does show unrealistic structures in the tropical region and SH midlatitudes.

COMPARISON OF MERIDIONAL O_3 PROFILES

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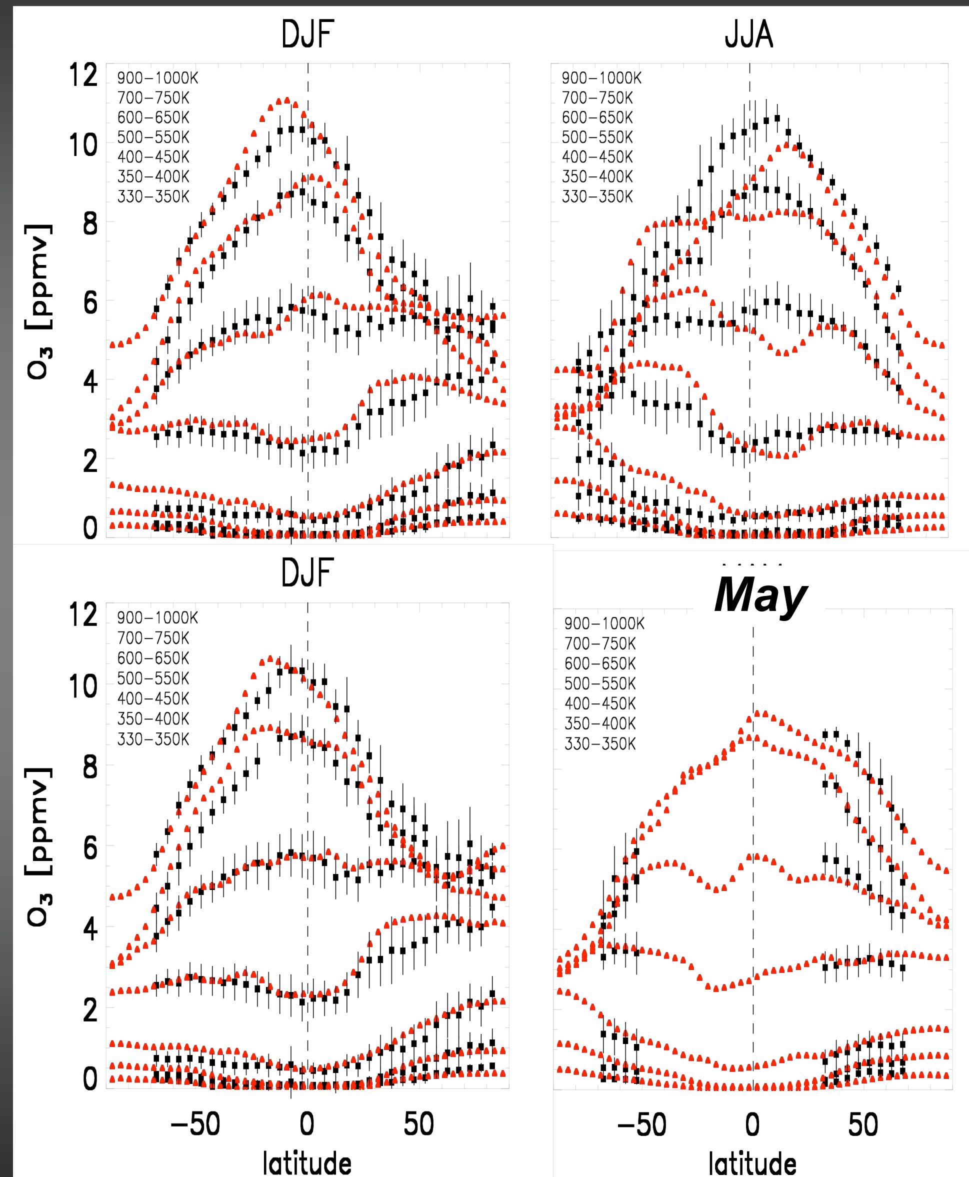
ACE and CMAM-DAS (2003)

ACE and CMAM-DAS (2006)



While DJF looks well in both years, JJA 2003 does show unrealistic structures in the tropical region and SH midlatitudes.