Fidelity of Stratospheric and Upper Tropospheric Processes in CTM Simulations using GCM and Assimilated Meteorological Products

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Understanding transport processes in CTMs using assimilated met fields: An outline

Historical Perspective – problems previously encountered

New Chemistry and Transport Model (CTM) Simulations

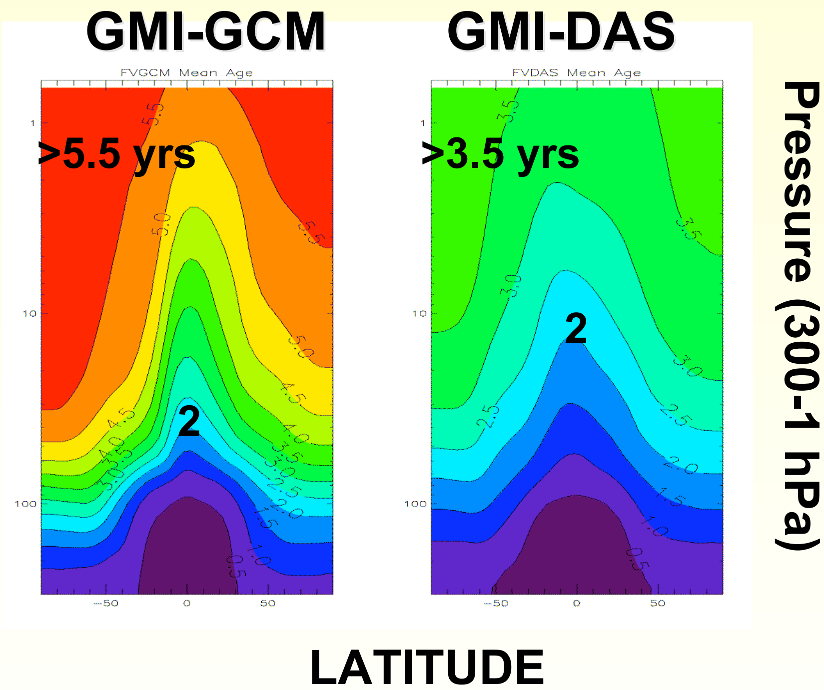
- GEOS4-Data Assimilation System (DAS)
- GEOS4-General Circulation Model (GCM) – *the parent*

Process-oriented evaluation – observations!

- Stratospheric circulation
- Transport barriers
- Interactions between the UT & Lowermost Stratosphere (LMS)

Historical perspective: age of air problems

- Both CTM simulations are 4ºx5º 28 levels (lid at 0.04 hPa)
- DAS has MUCH younger air compared to GCM

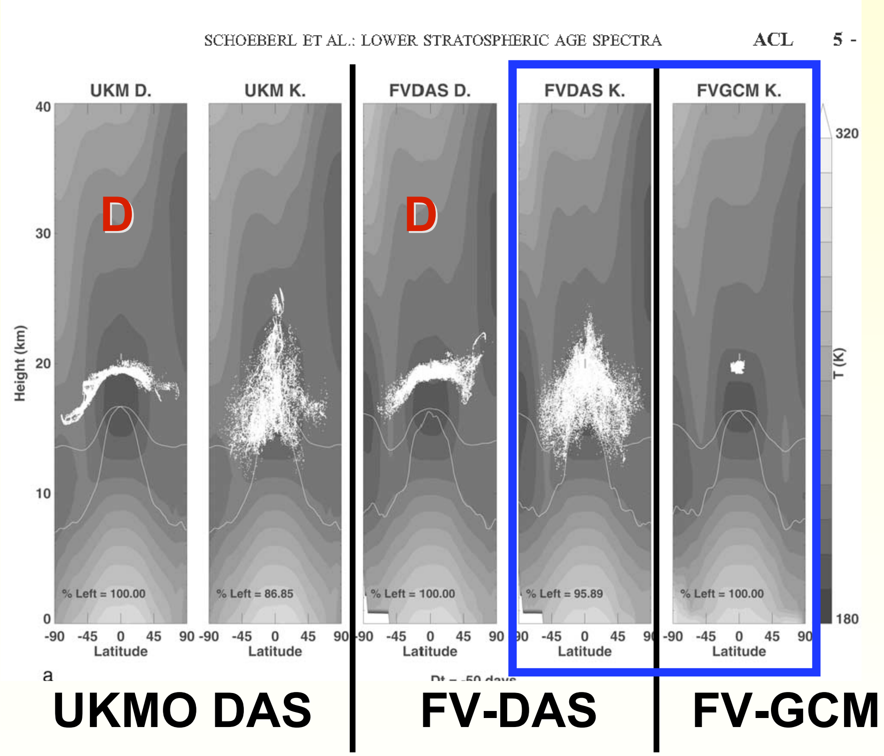


Typical DAS-CTM Problem:
residual circulation and mixing TOO FAST

Historical perspective: Noisy transport by assimilated fields

- Trajectory calculations (Schoeberl et al. [2003]) show that parcels are dispersed much too rapidly with assimilated met fields

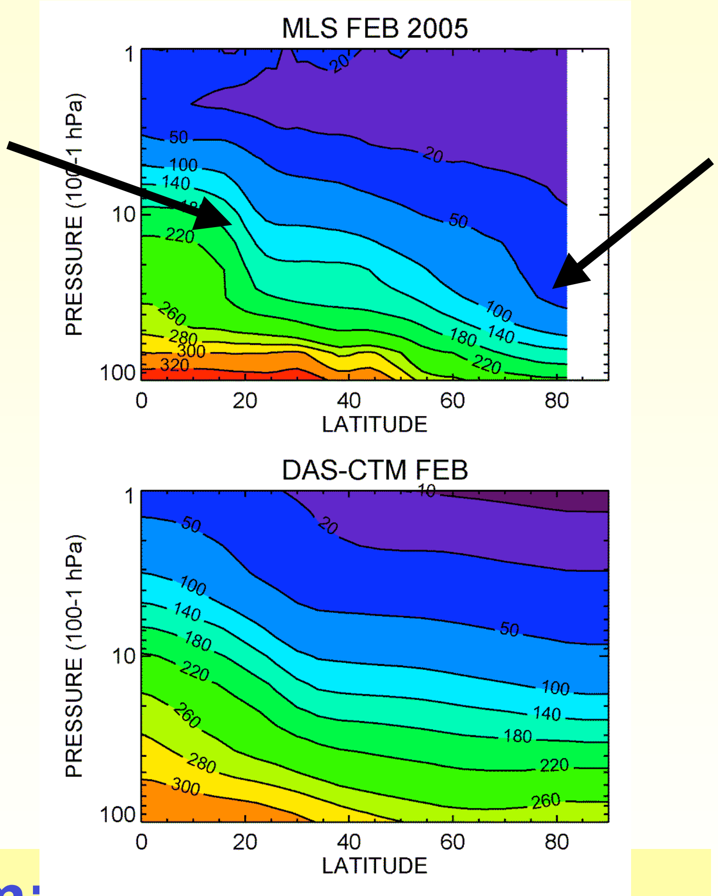
- The GCM tropical parcels (far right) have hardly dispersed after 50 days.



Note: **'Diabatic' (D) calculations (i.e. don't use noisy w field) show reduced vertical mixing, but no reduction in horizontal mixing.**

Historical perspective: Effect of transport 'noise' on N_2O

- MLS N_2O show gradients in the subtropics and high latitudes, as well as vortex descent
- DAS-CTM N_2O shows a weak subtropical gradient and little vortex isolation or descent
- **Significant consequences for other species (e.g., O_3, high ClO_x, low NO_x in the polar vortex)**



Another DAS-CTM Problem:

too much horizontal mixing across 'barriers'

The GMI 'Combo' CTM simulations

The Global Modeling Initiative (GMI) 'Combo' Model:

- 'Combo' = tropospheric + stratospheric chemical mechanism (122 species, >300 thermolytic rxns, 78 photolytic rxns)
- Lin and Rood [1996] flux form semi-Lagrangian transport
- Tropospheric processes included (e.g., wet and dry deposition, convection, boundary layer mixing, emissions)

The meteorological fields (DAS and GCM) have…

- 2^olatitude x 2.5^o longitude resolution
- 42 levels (lid at 0.015 hPa)
- ~1 km resolution below 10 hPa
- 3 hr updates (fields are 3-hr averages)

The GMI Combo-GEOS4-GCM ('Combo-GCM') simulation

- Integrated for 5-years, met fields have 1994-8 sea surface temperatures

The GMI Combo-GEOS4-DAS ('Combo-DAS') simulation

- Integrated from Feb 2004-Dec 2005

Evaluation of the Combo-GCM and Combo-DAS

The fidelity of transport processes will be evaluated with:

- AURA MLS (N_2O, O_3)
- SPURT (aircraft) (CO, O_3)*

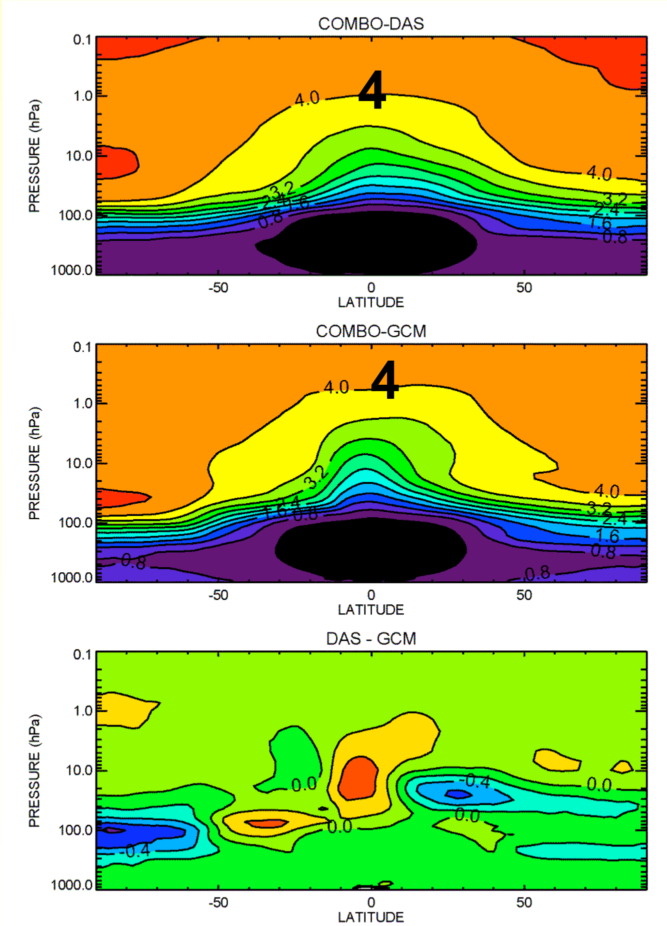
Observational analyses show which aspect of transport are well-represented by a model. (CCMVal!)

Observationally-derived diagnostics tell us:

- whether a process well-represented by the Combo-GCM is *corrupted by DAS fields*
- whether a process not well-represented by the Combo-GCM is *improved by the DAS fields*

*Thanks to Peter Hoor for making it available!!

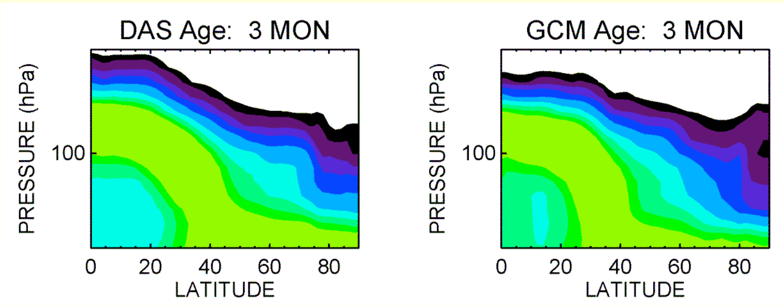
Stratospheric Circulation: Mean Age of Air



- Age of air in the Combo-DAS is quite similar to Combo-GCM
- DAS tropics are broader, indicating less tropical isolation
- DAS age is greater in the mesosphere – related to lack of tropical isolation
- 'Difference dipoles' highlight

Much of this improvement comes from the use of time averaged, rather than instantaneous, wind fields (Pawson et al, submitted, 2006).

Stratospheric Circulation: Snapshots of age tracer



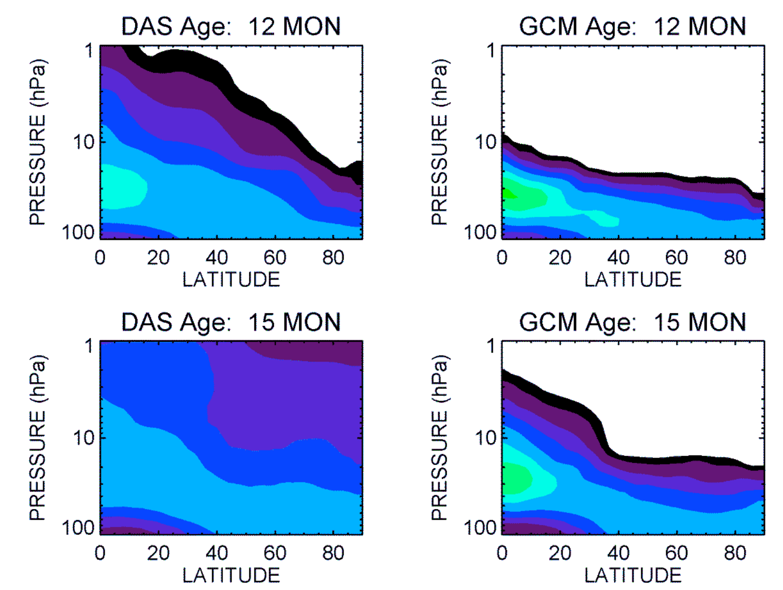
Lower Stratosphere: First 3 Months

Transport of air into the UT/LS very similar with both met fields

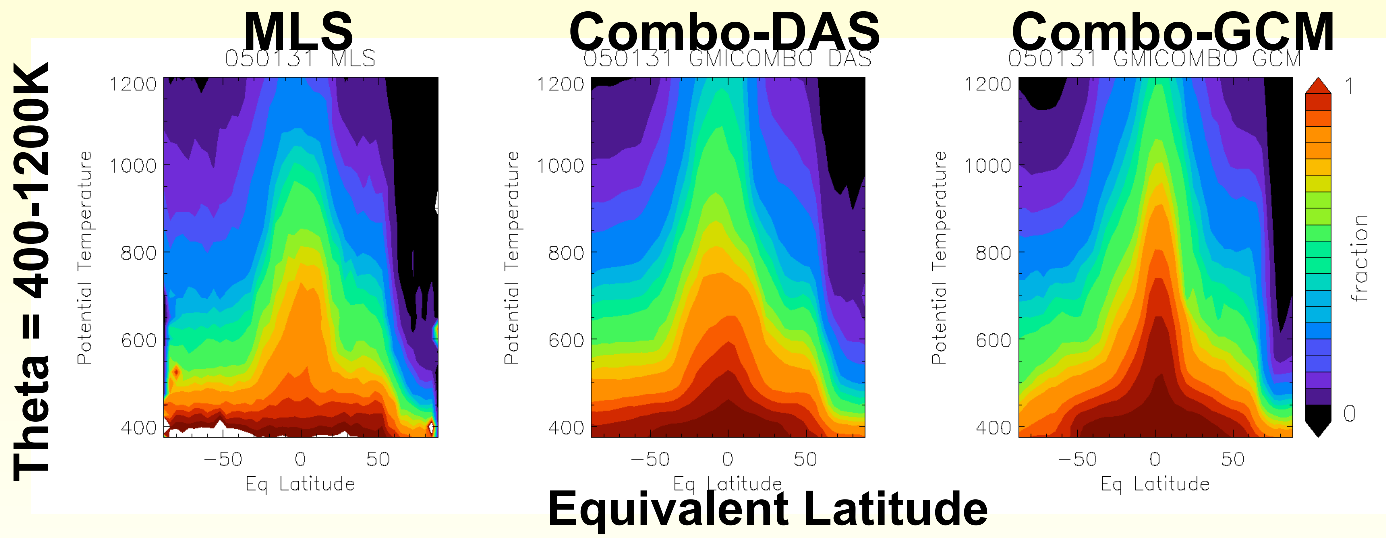
Middle Stratosphere: 1 year

DAS Tropics: air moves up much faster

DAS Extratropics: air moves poleward much faster



Stratospheric circulation: Aura MLS N_2O (January)



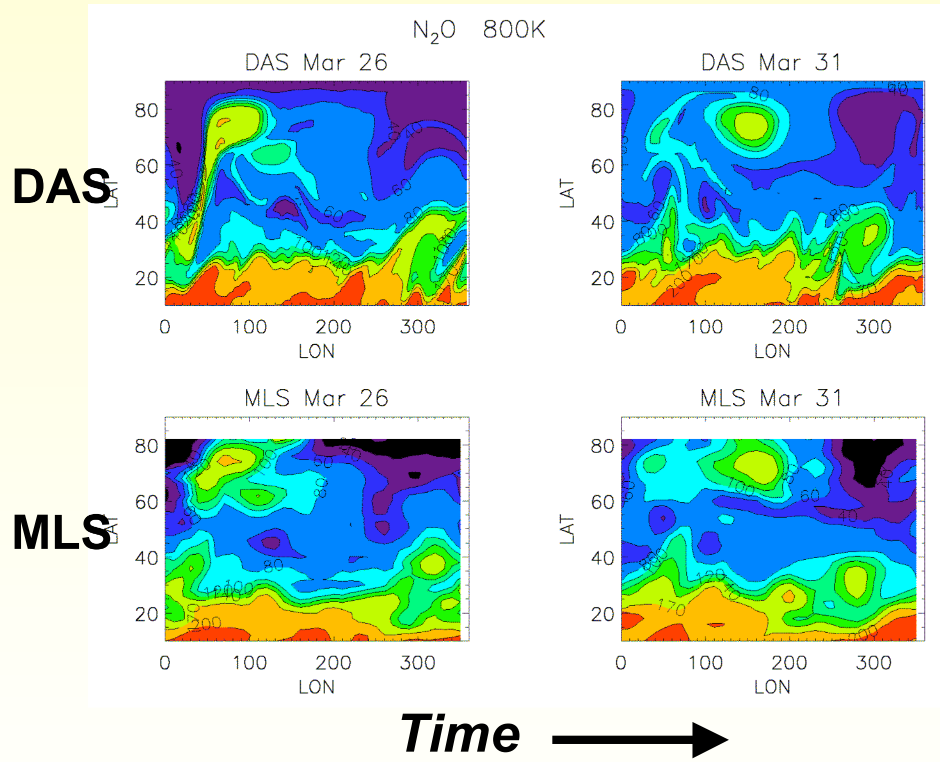
- Vortex present in DAS, not deep enough. Better in GCM
- DAS tropics broader, but more like MLS.
- GCM ascent (residual circulation) too fast.

The Combo-DAS effectively slows down the fast ascent in the GCM by strong horizontal mixing. Compensating errors?

Slow ‘Summer’ Mixing: Aura MLS N_2O Blob

26 Mar 2005, 800K:

MLS observed a large blob of subtropical air that was transported to the polar region. In the weak easterlies, the blob persisted through August.



The DAS also peeled off subtropical air and transported it to 60-80°N. What are the mixing properties in the DAS during a quiescent season in the summer middle stratosphere?

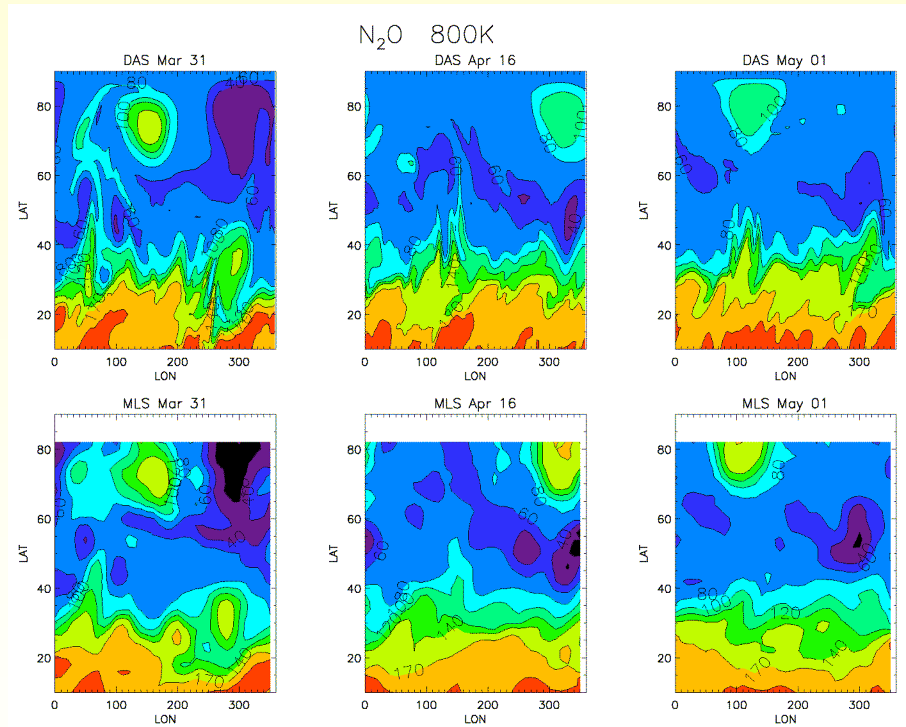
‘Summer’ Mixing: Aura MLS N_2O Blob (Apr-May)

DAS: 5 weeks after the event, the blob is still circling the pole. But, the highest subtropical values within it are not maintained.

MLS: High N_2O inside the blob persists more than 1 month after peel off from the subtropics.

DAS

MLS

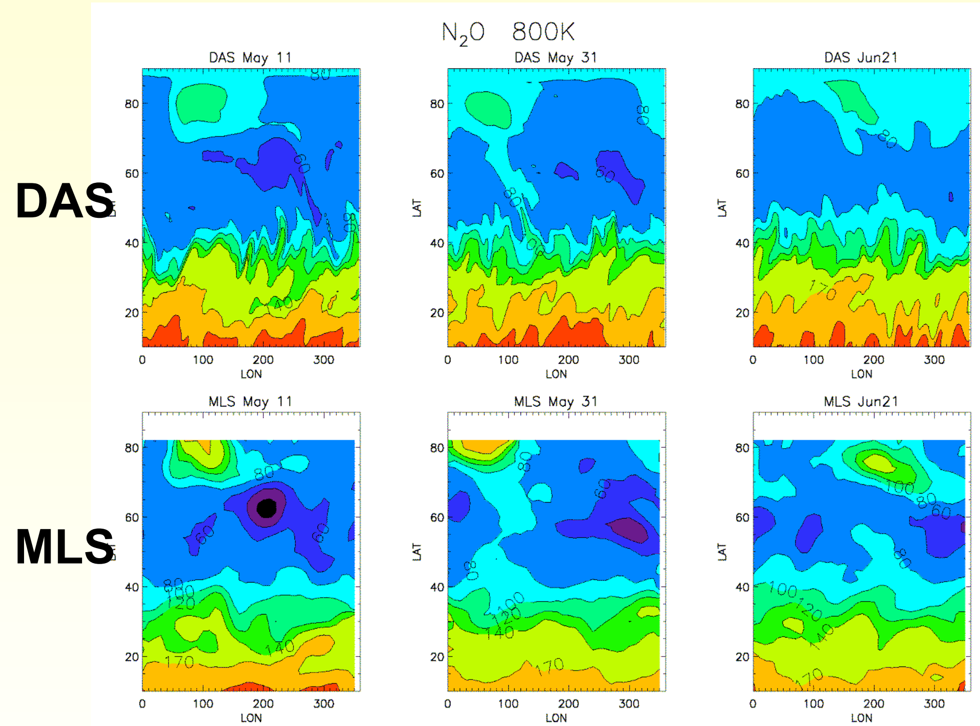


Time →

‘Summer’ Mixing: Aura MLS N_2O Blob (May-Jun)

DAS: ***Nearly 3 months after the event***, **the blob is still circling the pole. Its high subtropical values and surrounding gradients are not well maintained.**

MLS: High N_2O inside the blob has only decreased slightly after 3 months. Traces of the blob can still be found in August.



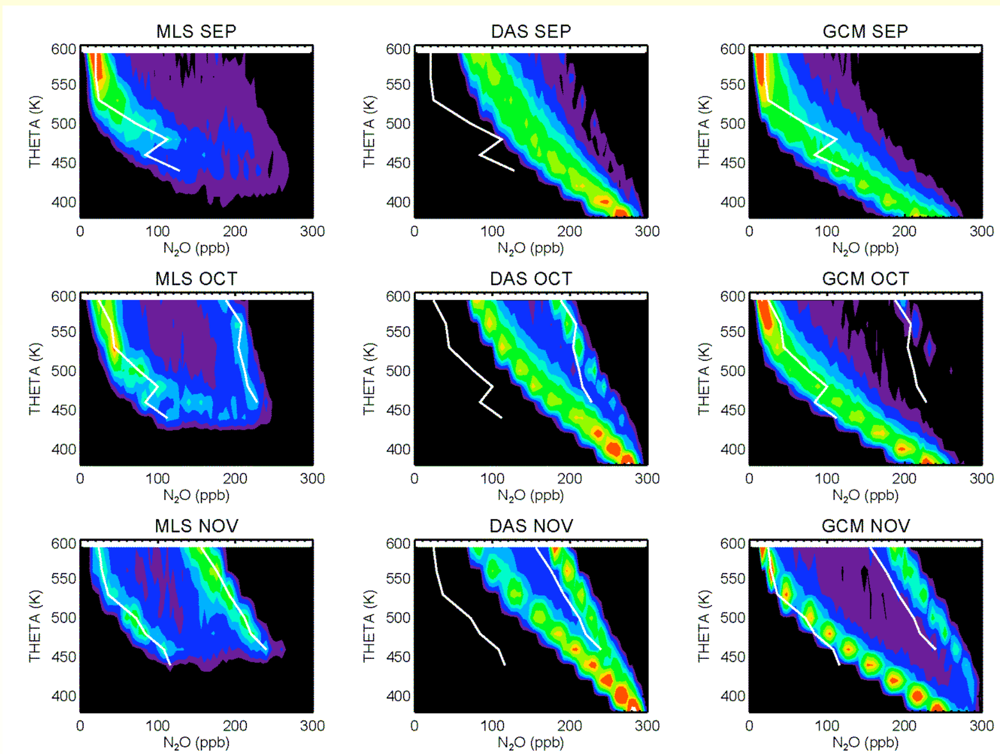
Time →

Combo-DAS has stronger mixing than implied by the MLS observations, but not so bad because the blob survives for more than 3 months!

Antarctic Descent and Mixing:
Aura MLS N_2O pdfs 62-82ºS

MLS DAS GCM

THETA = 380-600K



GCM profiles agree closely with MLS in all months.

GCM vortex is larger and longer lived.

DAS vortex did not have as much descent.

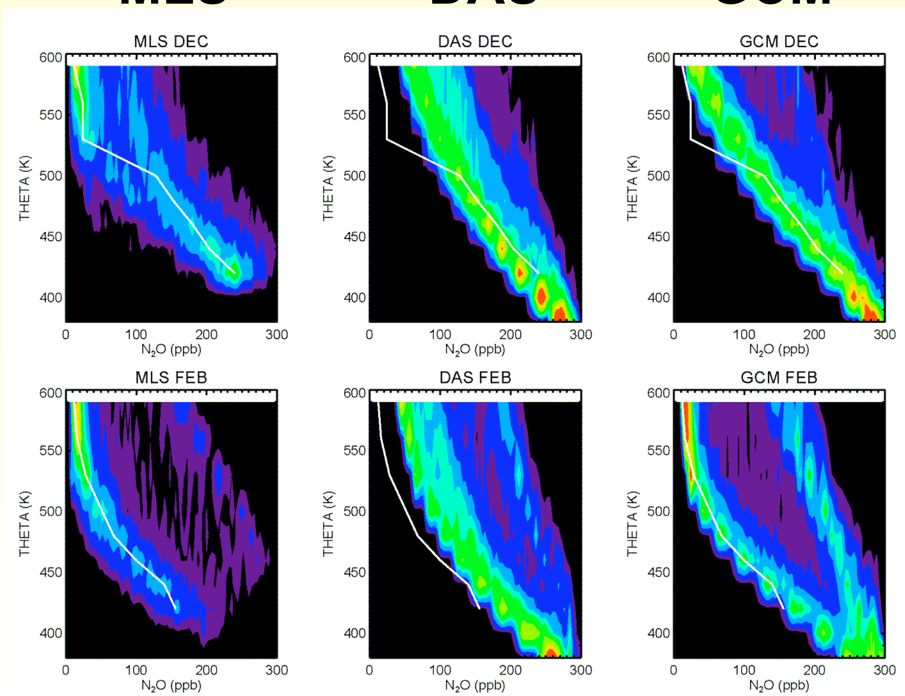
DAS vortex has a barrier, but not as strong as in GCM or MLS.

GCM is capable of getting sufficient descent during winter, AND of forming a strong barrier that prevents horizontal mixing.

Arctic Descent and Mixing:
Aura MLS N_2O pdfs 66-82ºN

THETA = 380-600K

MLS DAS GCM



December:

- θ DAS and GCM have great agreement up to 500K
- θ GCM closer to MLS above 500K

February:

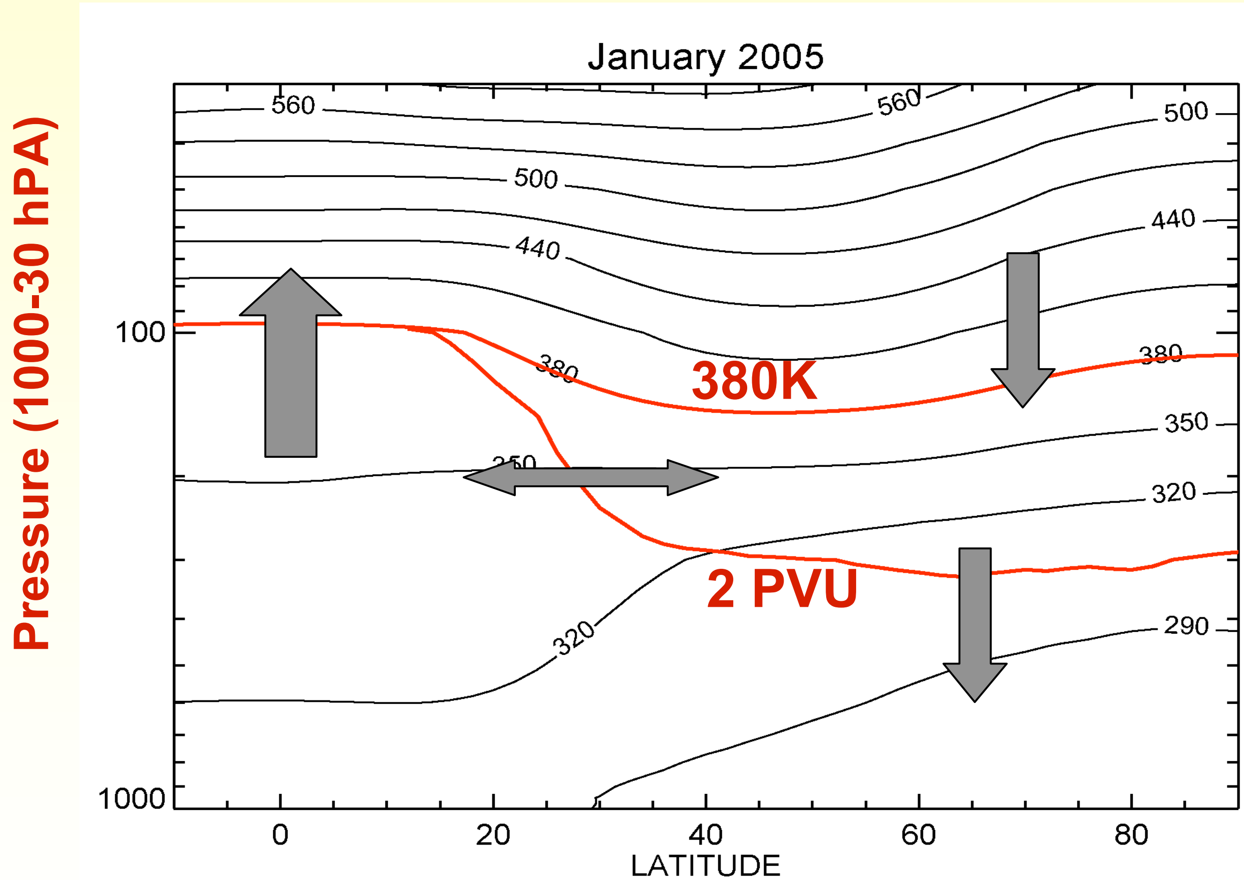
- θ GCM shows great descent and separation from the surf zone
- θ DAS doesn't show much descent; separation not as distinct

GCM is capable of getting sufficient descent during winter, AND of forming a strong barrier that prevents horizontal mixing

Recap: Stratospheric Circulation Differences

- GEOS4-DAS seems to have better (slower) residual circulation than older versions and mean age agrees with GEOS4-GCM. The use of time-averaged winds is essential.
- Age tracer shows that GEOS4-DAS met fields have 'extra' vert/horiz transport, especially in the mid/upper stratosphere. Still, they aren't terrible (e.g., subtropical blob lasts 3 months in the Arctic).
- The Combo-GCM produces a realistic vortex: sufficient descent and sufficient isolation
- The processes that form/maintain the LS polar vortex are perturbed in the DAS.

Transport Pathways in the Lowermost Stratosphere



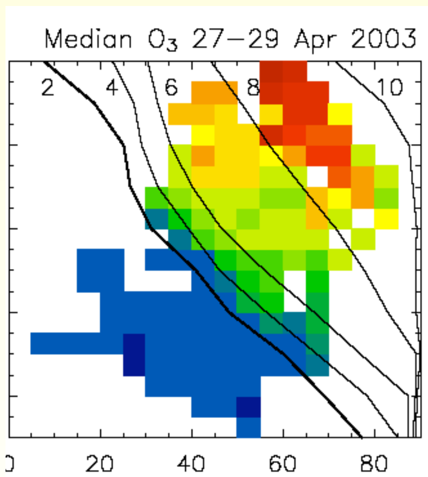
Contours are potential temperature. The boundaries of the lowermost stratosphere (RED) are the 2 PVU contour and the 380K contour

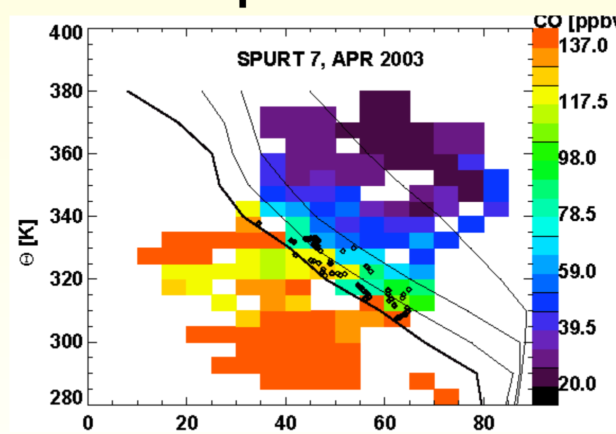
Transport in the Lowermost Stratosphere

Complementary tracers for transport diagnostics in the lowermost stratosphere: SPURT O_3 (Hegglin et al, 2006) and SPURT CO (Hoor et al, 2004).

April CO

Theta, 280-380K





Equivalent Latitude

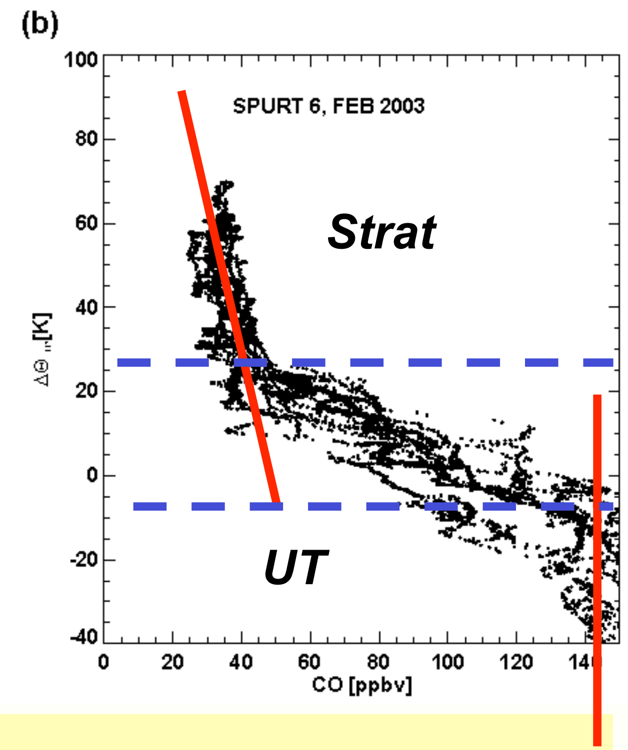
CO - tropospheric source – a good tracer of tropospheric air.
O_3 - stratospheric source – a good tracer of stratospheric air.
CO and O_3 isopleths follow PV contours near the tropopause.

Stratosphere-Troposphere interaction: Constant thickness of the mixed region

Results from Hoor et al (2004):

- **SPURT CO is plotted as a function of height in potential temperature from the dynamical tropopause ("Delta Theta").**

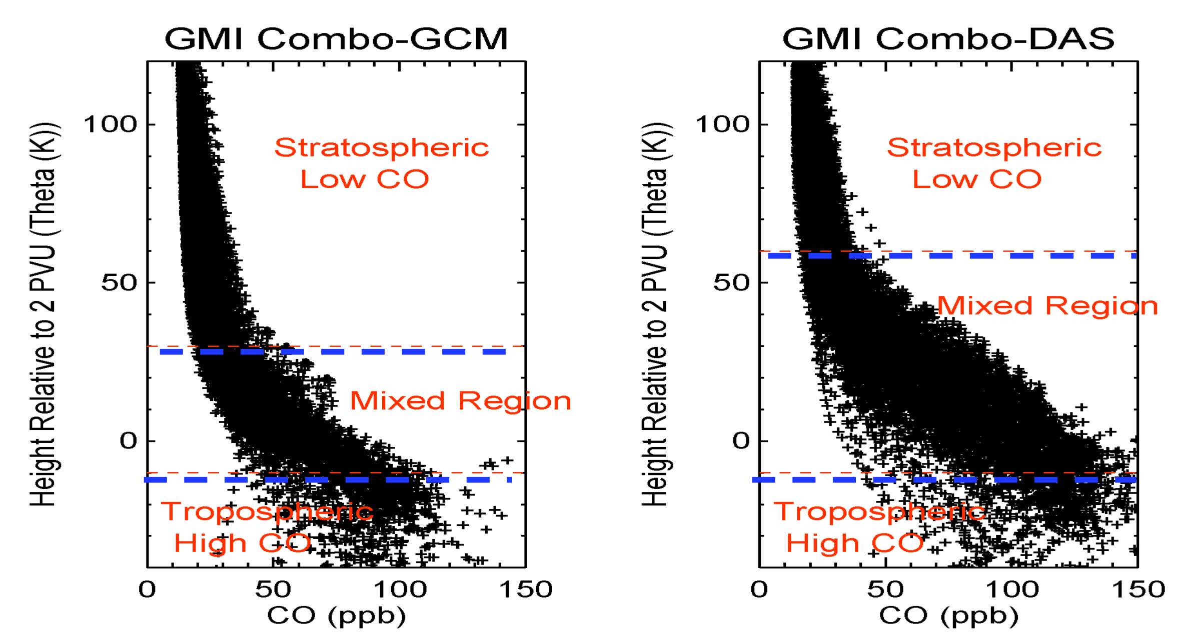
- **Variability in CO profiles is minimized in a coordinate that references the dynamical tropopause (e.g., 2 PVU).**



Red lines show the CO-Delta Theta relationship in 'unmixed' troposphere or stratosphere. Blue dashed lines indicate the mixed region in the lowermost stratosphere influenced by the troposphere.

The Mixed Region in Combo-GCM and Combo-DAS

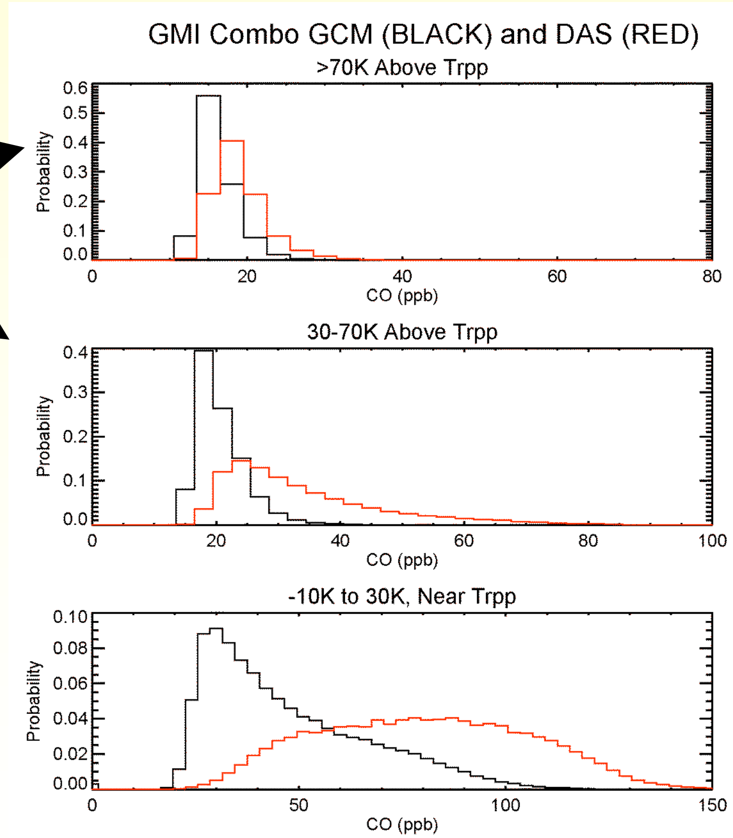
The thickness of the GCM mixed layer is very close to the same as SPURT, but the DAS is much thicker.



If we examine the distribution of CO values within different layers, the degree of tropospheric influence is better illustrated.

The Mixed Region in the Lowermost Stratosphere: CO distributions at and above the tropopause

Spring (MAM)



Should be purely stratospheric

This is the mixed layer according to SPURT data

DAS and GCM about the same

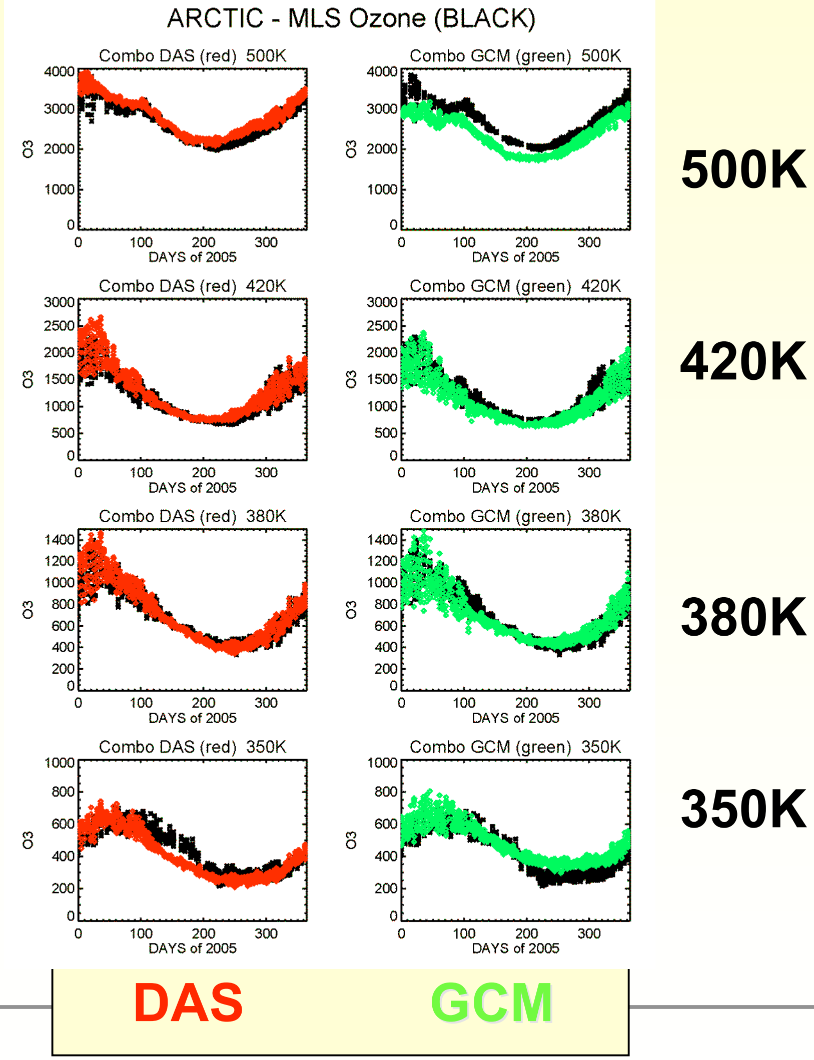
GCM is stratospheric, but DAS has tropo influence.

Both show tropo influence, but DAS shows greater influence.

MLS O_3 annual cycles in the UT and LS: Arctic (60-80ºN)

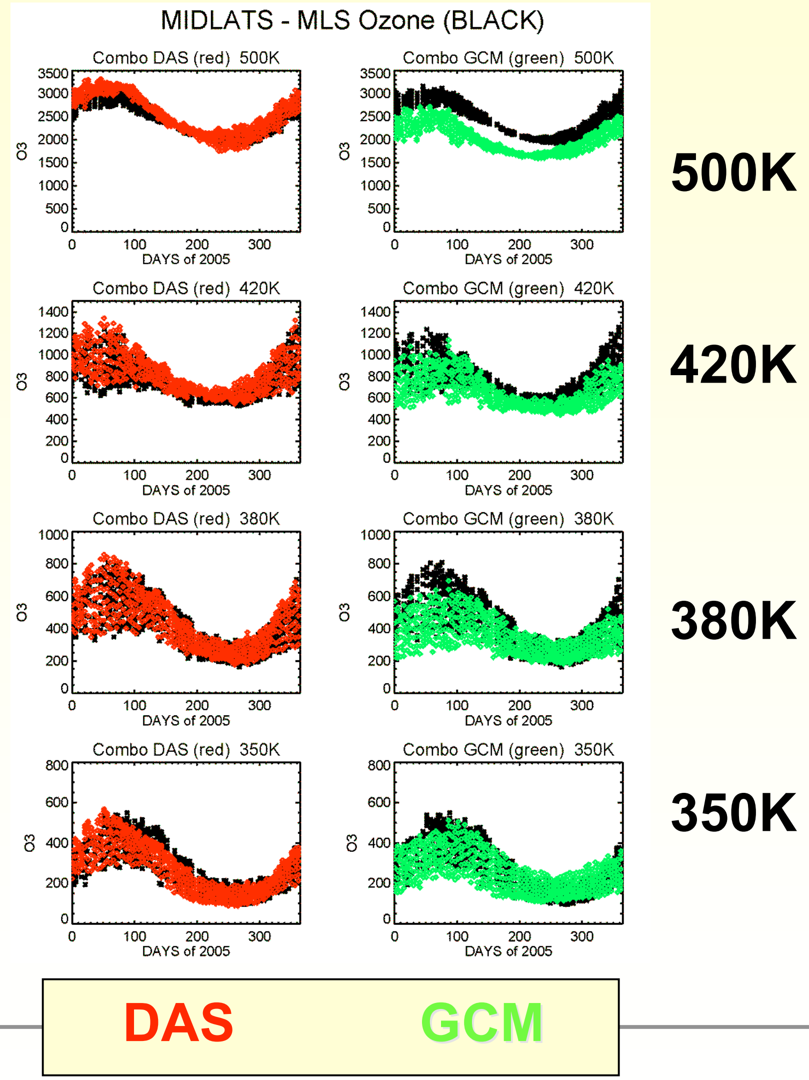
GCM and DAS agree extremely well with MLS O_3 data in the Arctic, including variability.

Data assimilation does not appear to perturb the GCM's seasonal cycle of polar ozone transport in the lower stratosphere.



MLS O_3 annual cycles in the UT and LS: Midlatitudes

The Combo-DAS agrees better with MLS O_3 data at all lower stratospheric levels. Even the variability is excellent.



Data assimilation not only does not appear to perturb the midlatitude seasonal cycle, but it seems to improve of the GCM O_3 cycle. (Is this a case of compensating errors?

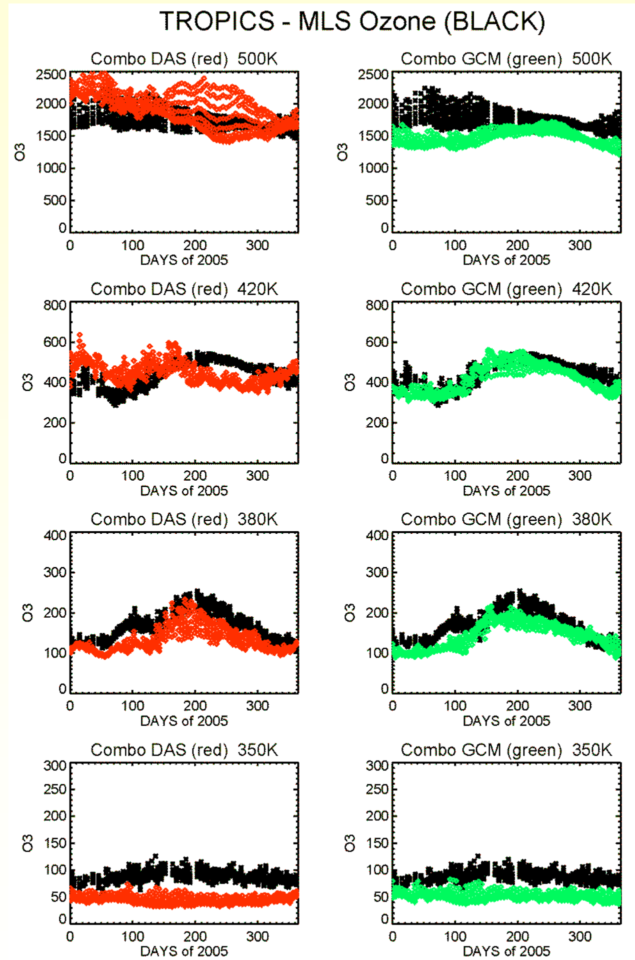
MLS O_3 annual cycles in the UT and LS: Tropics

At 500K, the GCM does not capture high O3 in winter. In the DAS, the variability goes wild. Temperatures but few winds assimilated in the tropics.

The GCM captures the cycle at 420K, but the DAS perturbs it.

Seasonal cycle is captured at 380K.

The DAS and GCM are nearly identical in the UT, both a little low compared to MLS.



500K

420K

380K

350K

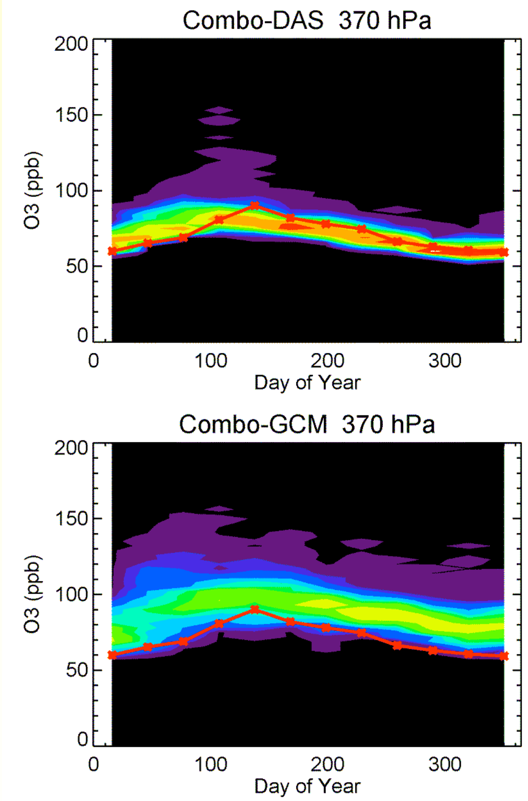
DAS **GCM**

Stratospheric influence on the troposphere: O_3 at 370 hPA, 50-80ºN

DAS met fields are known for too strong residual circulation, but…

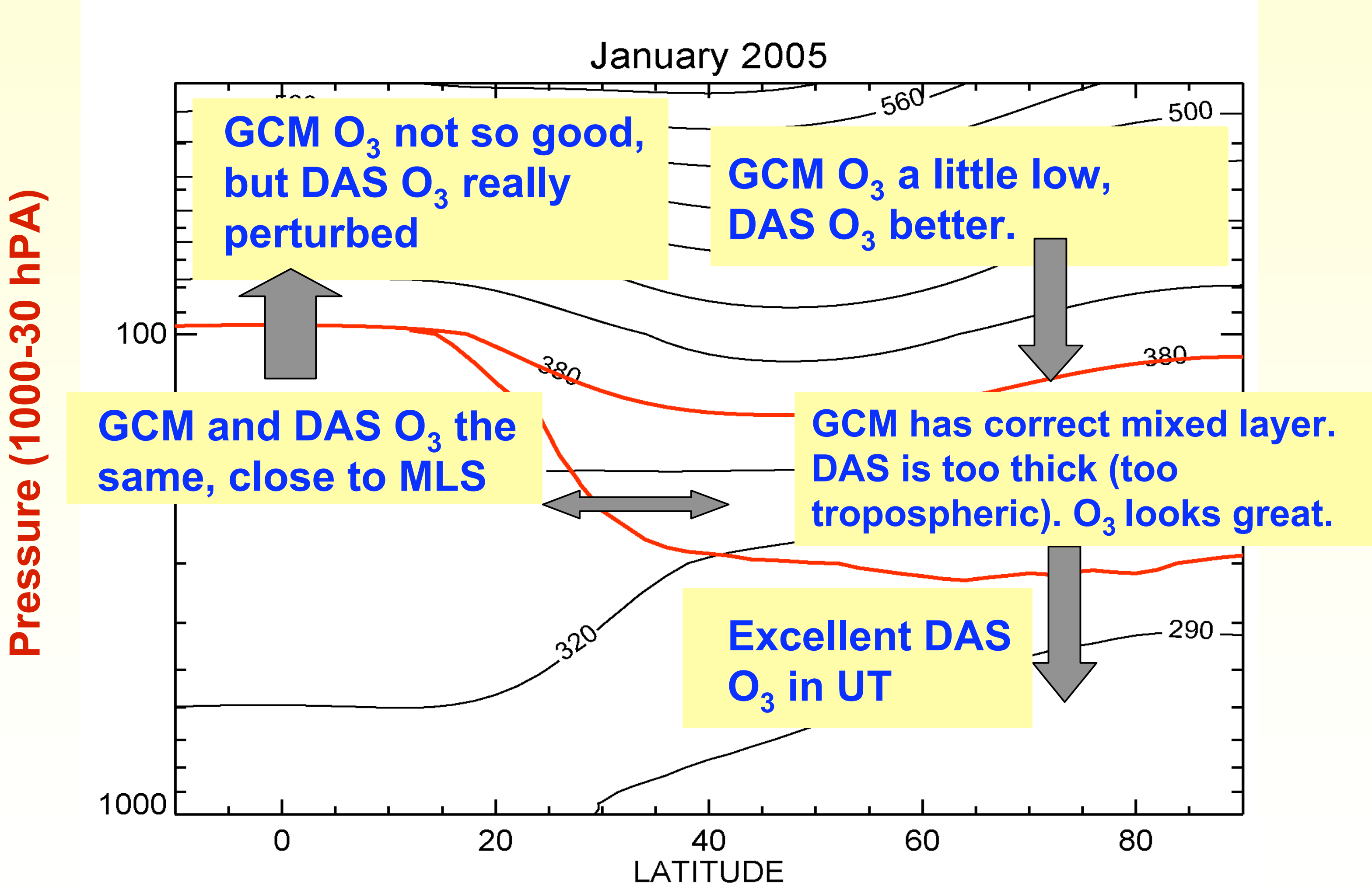
The Combo-GCM shows *greater* stratospheric influence in the UT than the Combo-DAS. It has 20-30% more O_3 all year.

This is consistent with the stronger tropospheric influence above the tropopause seen in the Combo-DAS.



Monthly averaged O_3 from stations 50-80ºN (370 hPa) is shown as a heavy red line. **The Combo-DAS shows excellent agreement with the station data.**

Summary of DAS Transport in the UT/LMS



Summary:

CTM Simulations with GEOS4-DAS met fields:

What are they suitable for?

For the Combo-DAS, the evidence shows

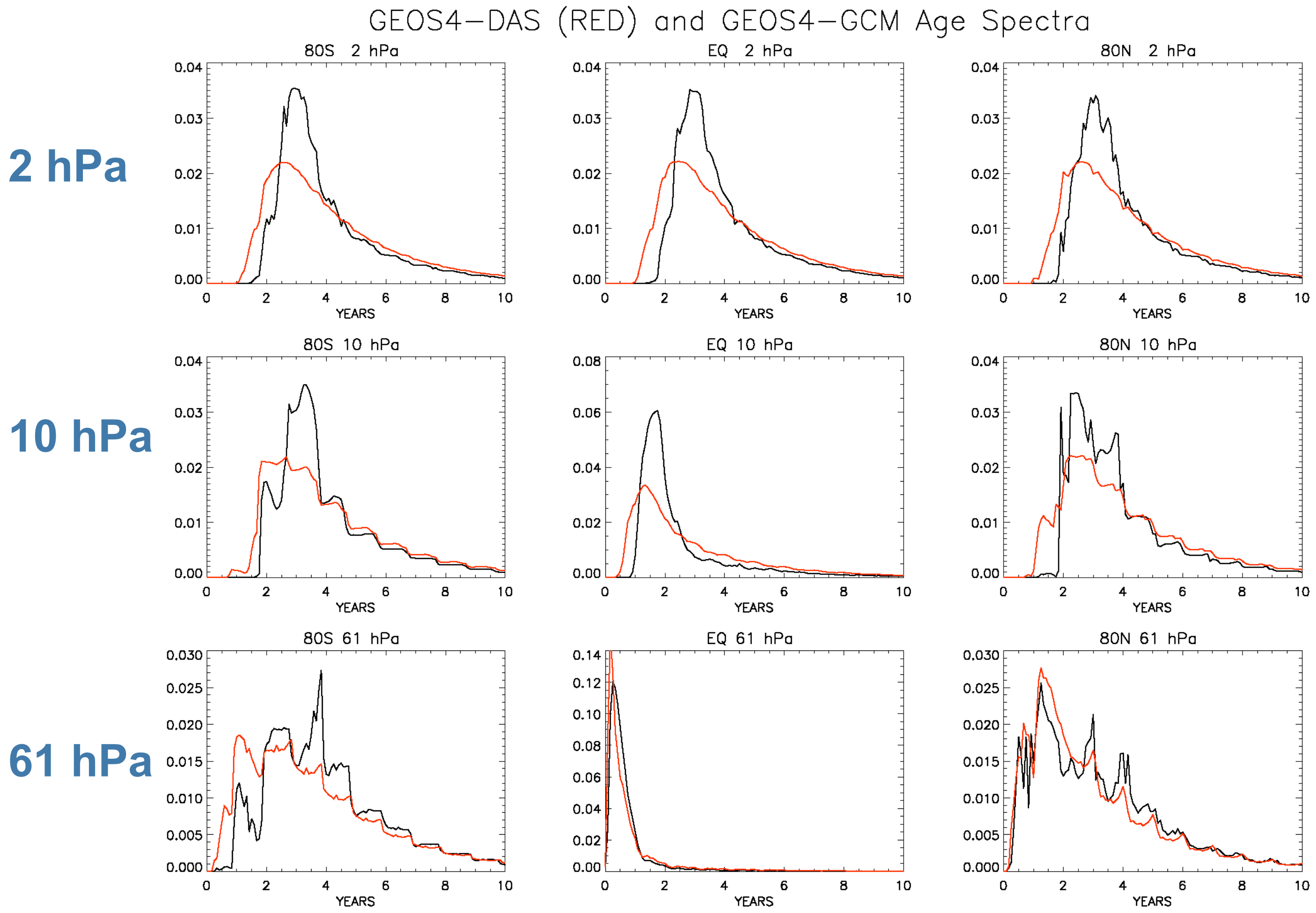
- some vortex isolation
- blob survival for 3 months
- mean age similar to GCM

indicates that CTM simulations with time-averaged wind fields are less dispersive than older CTM-DAS simulations. They should be useful for simulations of many months.

Barrier formation is essential for realistic stratospheric circulation. Good barriers are necessary for polar chemistry. Vortex descent and isolation are better represented by the Combo-GCM. Long-term simulations, e.g. assessments, are more sensibly conducted with GCM met fields.

The Combo-GCM has a very realistic O_3 simulation in the UT/LMS, and so does the Combo-DAS!! Both models are suitable for studying composition, chemistry, and transport in this region.

Age Spectra at 80S, EQ, and 80N: GEOS4-GCM(black) and GEOS4-DAS (red)



Barrier Formation: Aura MLS N_2O Gradients

500K (~50 hPa):

θ GCM captures seasonal cycle of gradients well in the subtropics and polar regions.

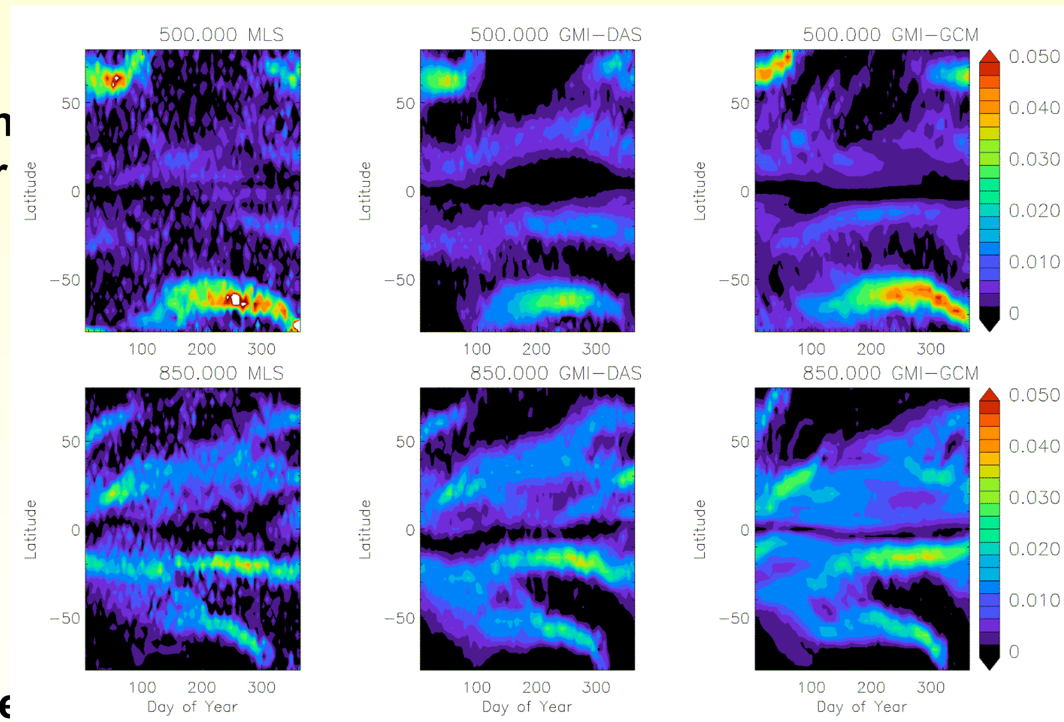
θ DAS vortex barriers are weak but subtropics too strong!

850K (~10 hPa):

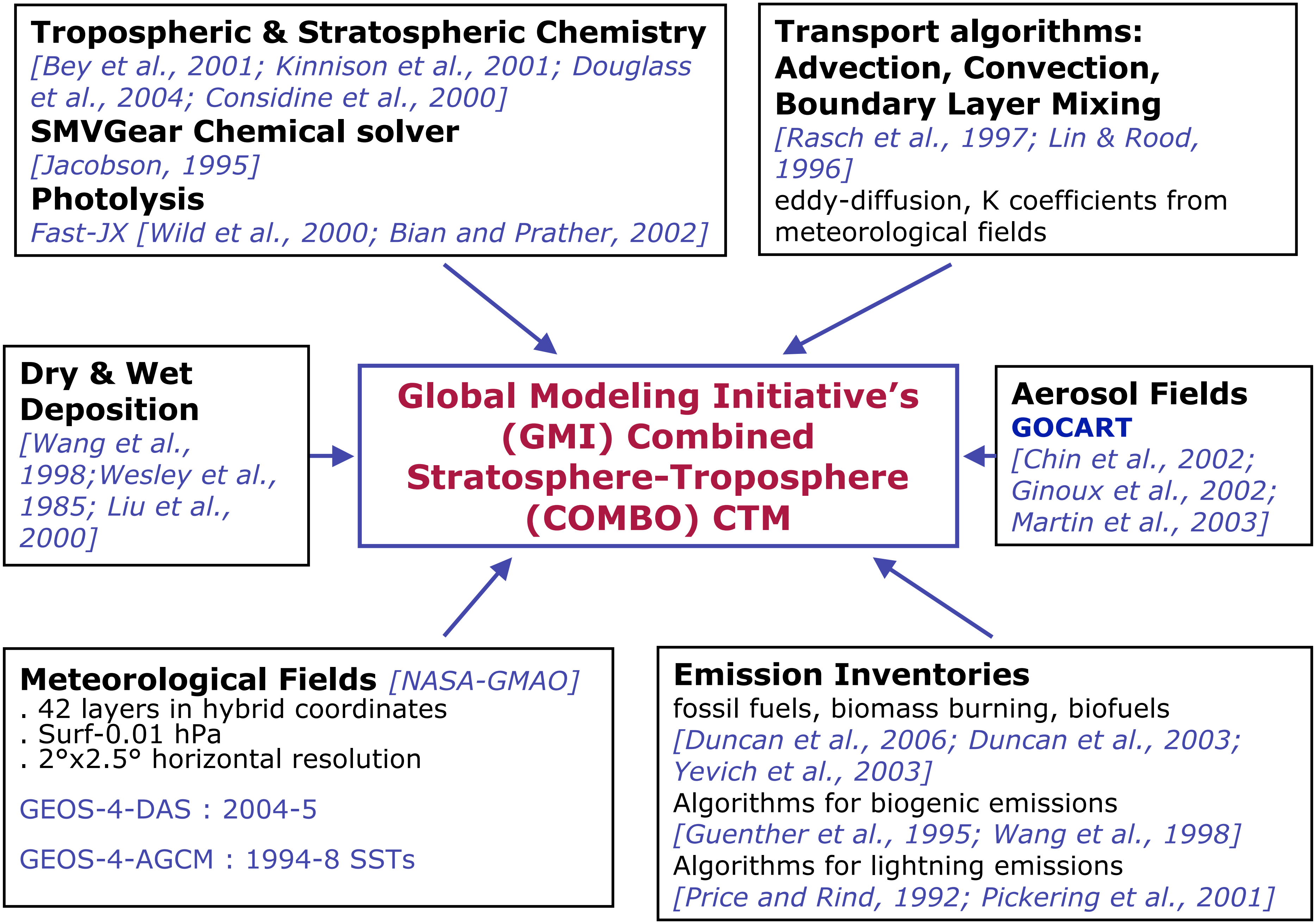
θ DAS and GCM very similar

θ DAS subtropics are more like MLS!

MLS DAS GCM



Both simulations capture the observed patterns of transport barriers. The GCM tropics are too narrow but are improved in the DAS.


Tropospheric & Stratospheric Chemistry
[Bey et al., 2001; Kinnison et al., 2001; Douglass et al., 2004; Considine et al., 2000]
SMVGear Chemical solver
[Jacobson, 1995]
Photolysis
Fast-JX [Wild et al., 2000; Bian and Prather, 2002]
Transport algorithms: Advection, Convection, Boundary Layer Mixing
[Rasch et al., 1997; Lin & Rood, 1996]
eddy-diffusion, K coefficients from meteorological fields
Dry & Wet Deposition
[Wang et al., 1998;Wesley et al., 1985; Liu et al., 2000]
Global Modeling Initiative's (GMI) Combined Stratosphere-Troposphere (COMBO) CTM
Aerosol Fields
GOCART
[Chin et al., 2002; Ginoux et al., 2002; Martin et al., 2003]
Meteorological Fields [NASA-GMAO]
. 42 layers in hybrid coordinates
. Surf-0.01 hPa
. 2°x2.5° horizontal resolution
GEOS-4-DAS : 2004-5
GEOS-4-AGCM : 1994-8 SSTs
Emission Inventories
fossil fuels, biomass burning, biofuels
[Duncan et al., 2006; Duncan et al., 2003; Yevich et al., 2003]
Algorithms for biogenic emissions
[Guenther et al., 1995; Wang et al., 1998]
Algorithms for lightning emissions
[Price and Rind, 1992; Pickering et al., 2001]