Observations and Modeling of the 'Frozen-In Anticyclone' in the 2005 Arctic Summer Stratosphere

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<u>Lifecycle of the Frozen-In Anticyclone (FrIAC)</u>

- Spin-up Phase (March – Early April 2005)
- Anticyclonic Phase (Mid-April – early June 2005)
- Shear Phase (early June – August 2005)

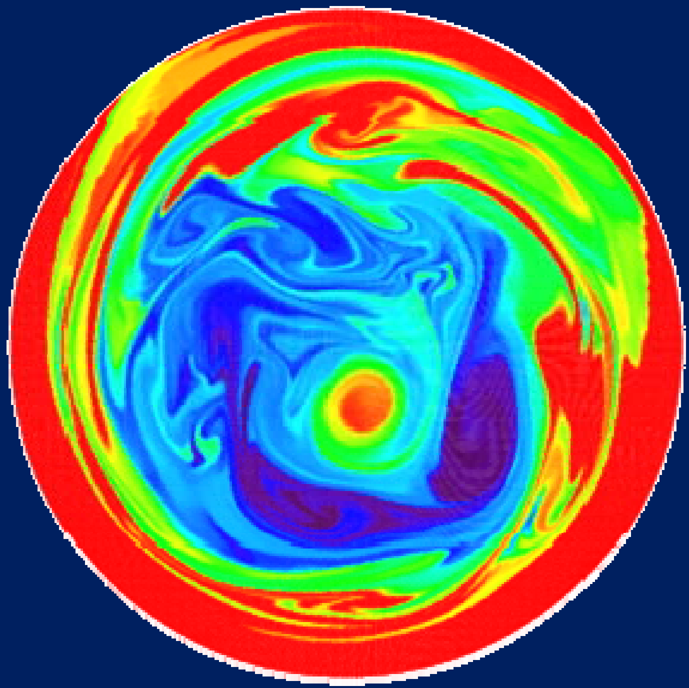
<u>Modeling with GMI</u>

- Aura4, Aura5, MERRA-Replay

<u>Modeling with "VITA"</u>

- High-resolution simulations on triangular grid

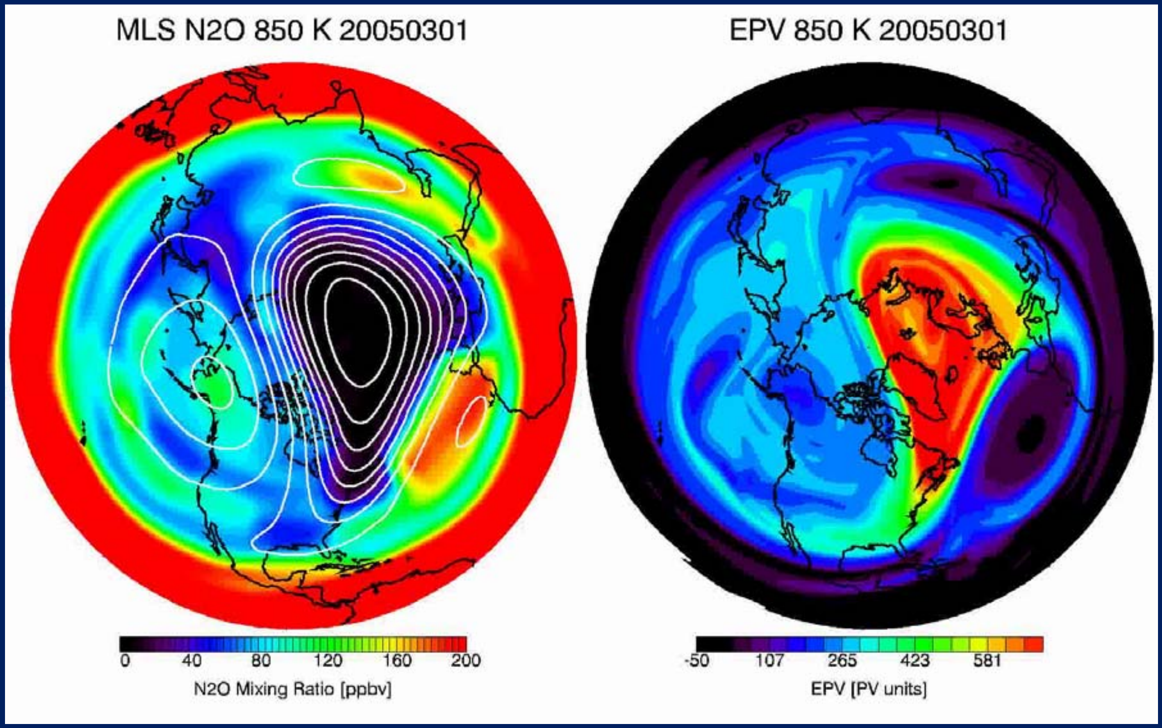
<u>Summary/Conclusions</u>



VITA N_2O at 850 K on 18 April 2005

Phase I: Spin-up of the FrIAC (Pronounced "Freak")

March – Early April 2005



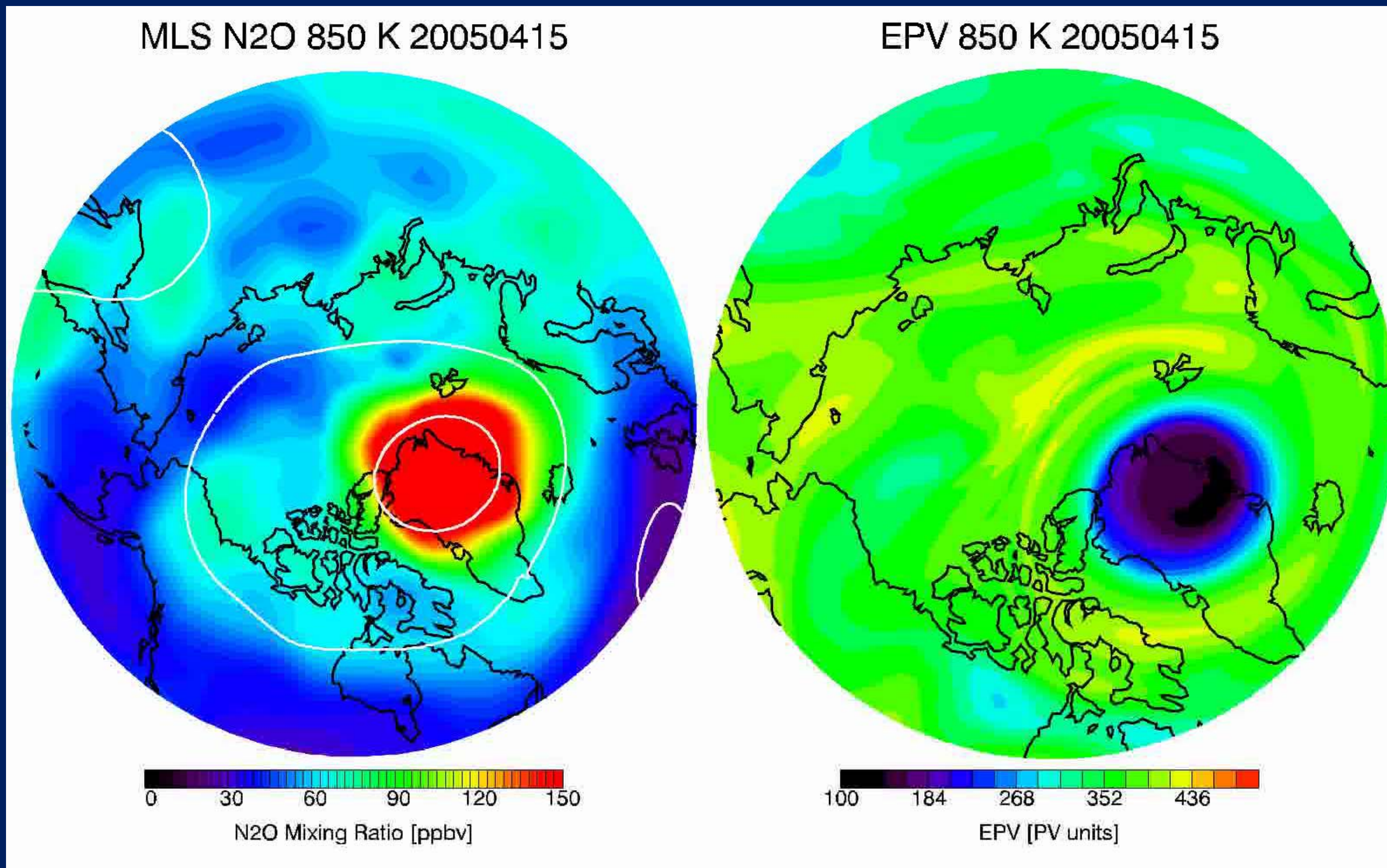
MLS N_2O and EPV at 850 K.

White lines are geopotential height at 10 hPa.

- Following the breakup of the 2005 Arctic winter vortex, a coherent anticyclone was advected poleward, merging with the Aleutian High.
- This anticyclone (marked by low PV, high N_2O and low H_2O) subsequently became trapped in the summer easterly flow.
- The N_2O anomaly was observed in Aura MLS data (Manney et al., GRL, 2006) over vertical range 580 – 1100 K (approx. 24-37 km)

Phase II: Anticyclonic Phase

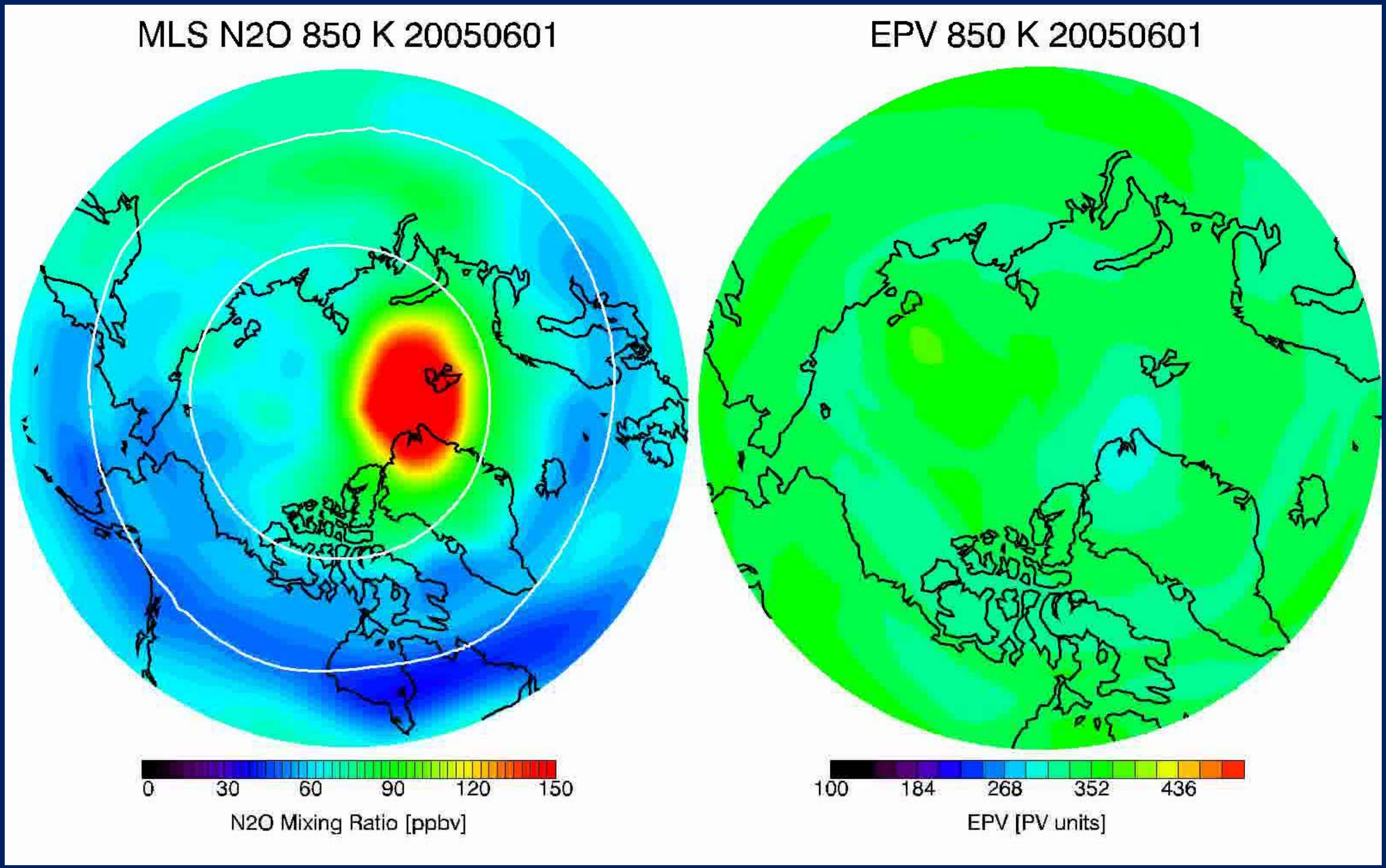
Mid-April to early-June 2005



The PV anomaly vanishes by 1 June due to radiative effects

The N_2O anomaly is relatively undiminished

Phase III: Shear Phase
Early June – August



N_2O anomaly shears in both horizontal and vertical.
Anomaly eventually homogenizes with the ambient air.

Modeling the FrIAC with GMI

<u>Aura 4</u>

- Met fields: GEOS-4 Data Assimilation System
- 2° lat x 2.5° lon x 42 levels (lid at 0.01 hPa)
- Time period: Feb. 2004 – Dec. 2006

<u>Aura 5</u>

- Met Fields: GEOS-5.1 Data Assimilation System
- 2° lat x 2.5° lon x 72 levels (lid at 0.01 hPa)

<u>Merra Replay</u>

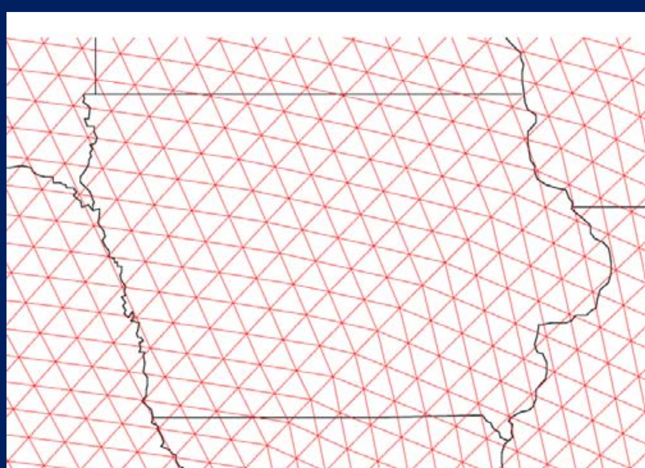
- Met Fields: MERRA
- 2° lat x 2.5° lon x 72 levels (lid at 0.01 hPa)
- “Online” constituents

Modeling the FrIAC with VITA

Van leer Icosahedral-Triangular Advection (VITA) Model

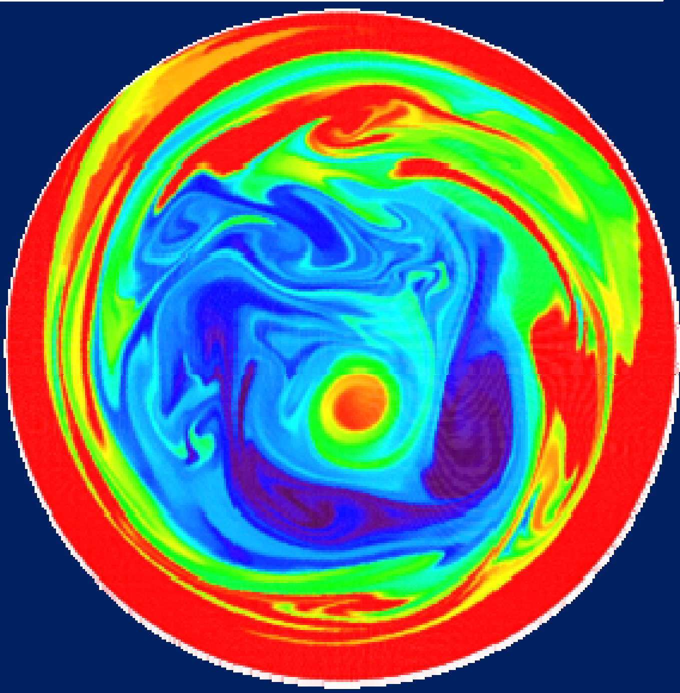
- Van leer flux limiting scheme (superbee) on triangular grid
- 983040 triangles (~20 km resolution)
- Driven with offline GEOS-5 winds
- Initialized with MLS N_2O on 580, 650, 740, 850, 960, 1100 K surfaces
- Initialized on 1 March, 1 April, 1 June

430 km Across

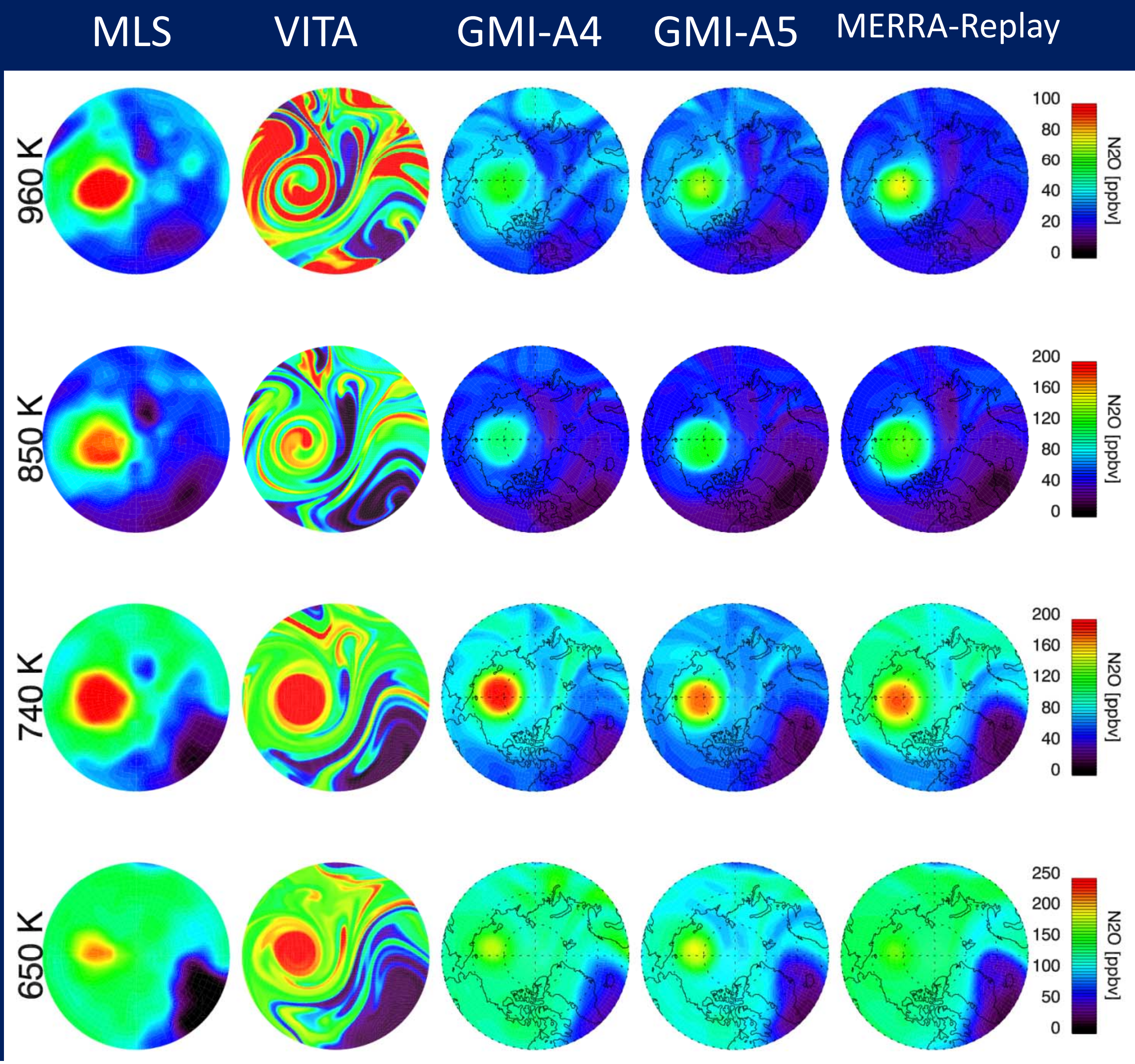


Model Grid over Iowa

VITA N_2O at 850 K on 18 April 2005



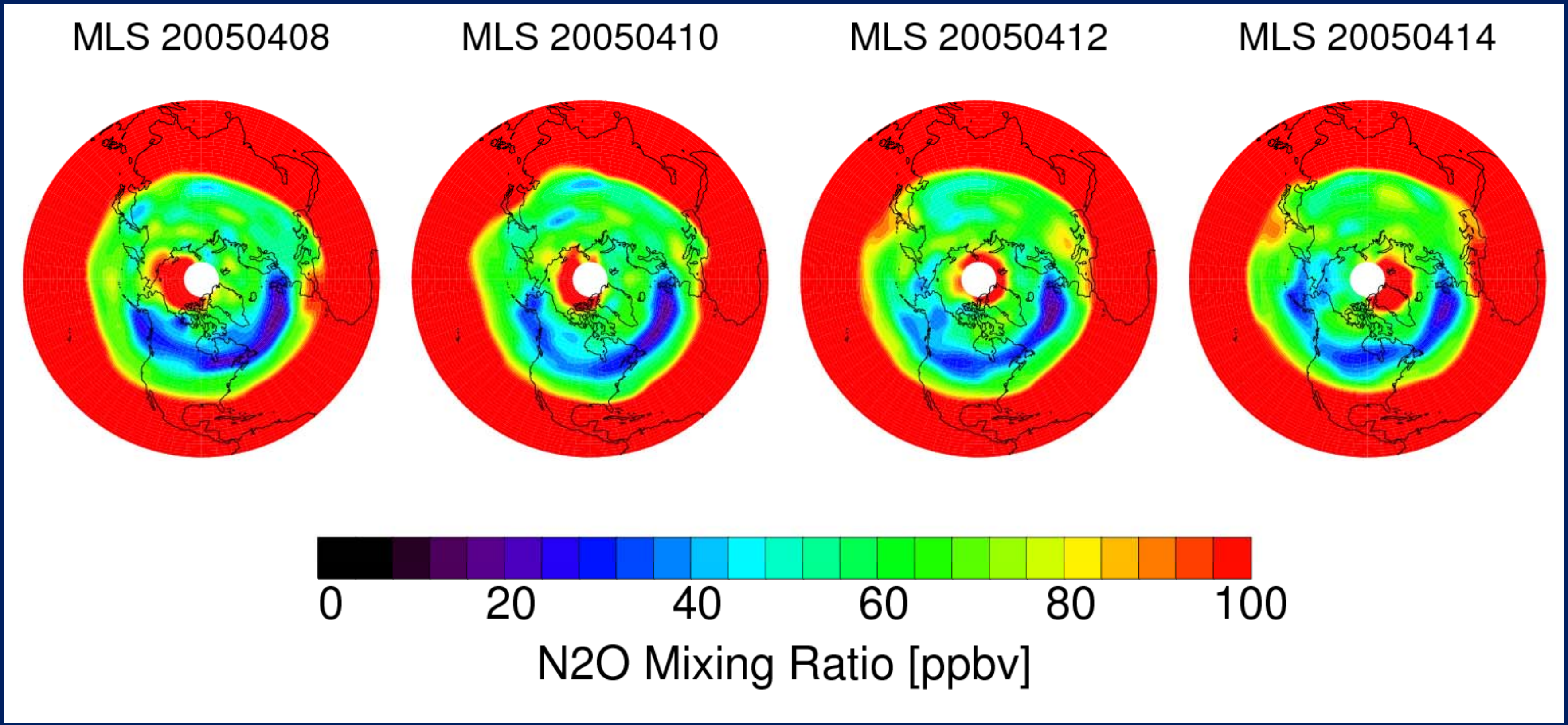
Modeling the FrIAC
Phase 1: Spin-Up (4 April 2005)



GMI :
- Produces the FrIAC at all levels
- Peak N_2O mixing ratios are smaller than MLS

VITA (init on 1 March):
- Produces FrIAC at 650 and 740 K.
- Numerous fine-scale filaments at higher levels.

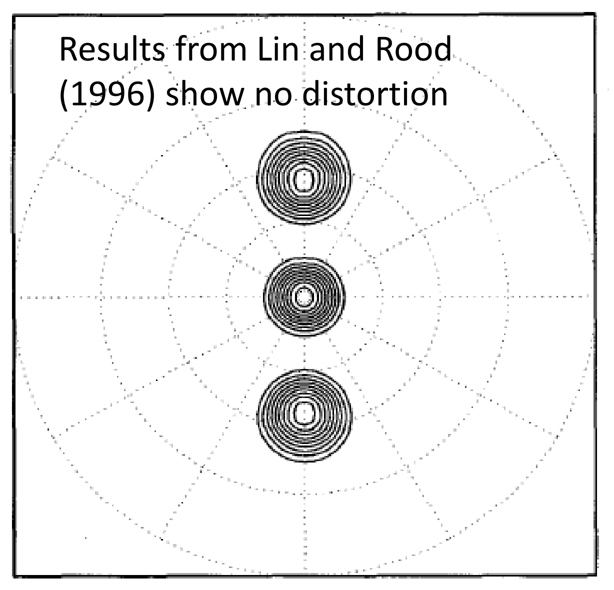
Cross-Polar Advection: 8-14 April

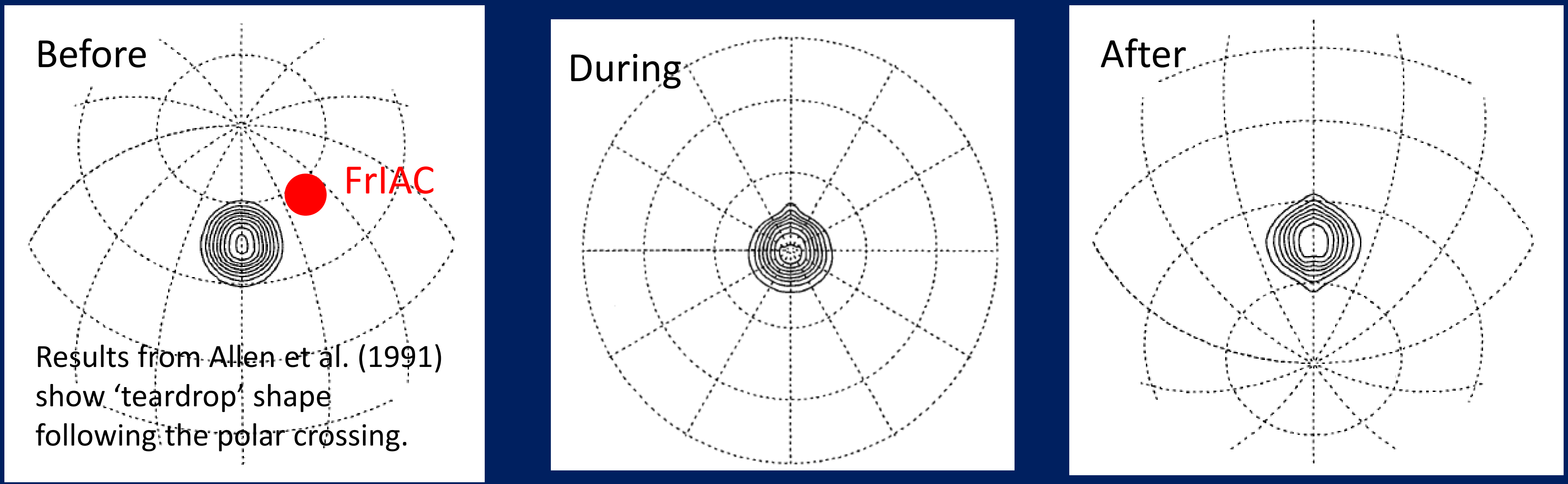


- From 8-14 April, the FrIAC crosses directly over the North Pole
- This is partially obscured in the MLS data, which only extends to 82° N
- Interesting case study of cross-polar transport.

Cross-Polar Advection in GMI

- In GMI the polar cap is forced to be well-mixed
- Tracer is homogenized in this region, thereby introducing numerical diffusion
- GMI-Combo offline has polar cap with radius of 3 latitude degrees (87-90°).
- FrIAC is smaller than standard cosine bell test case.

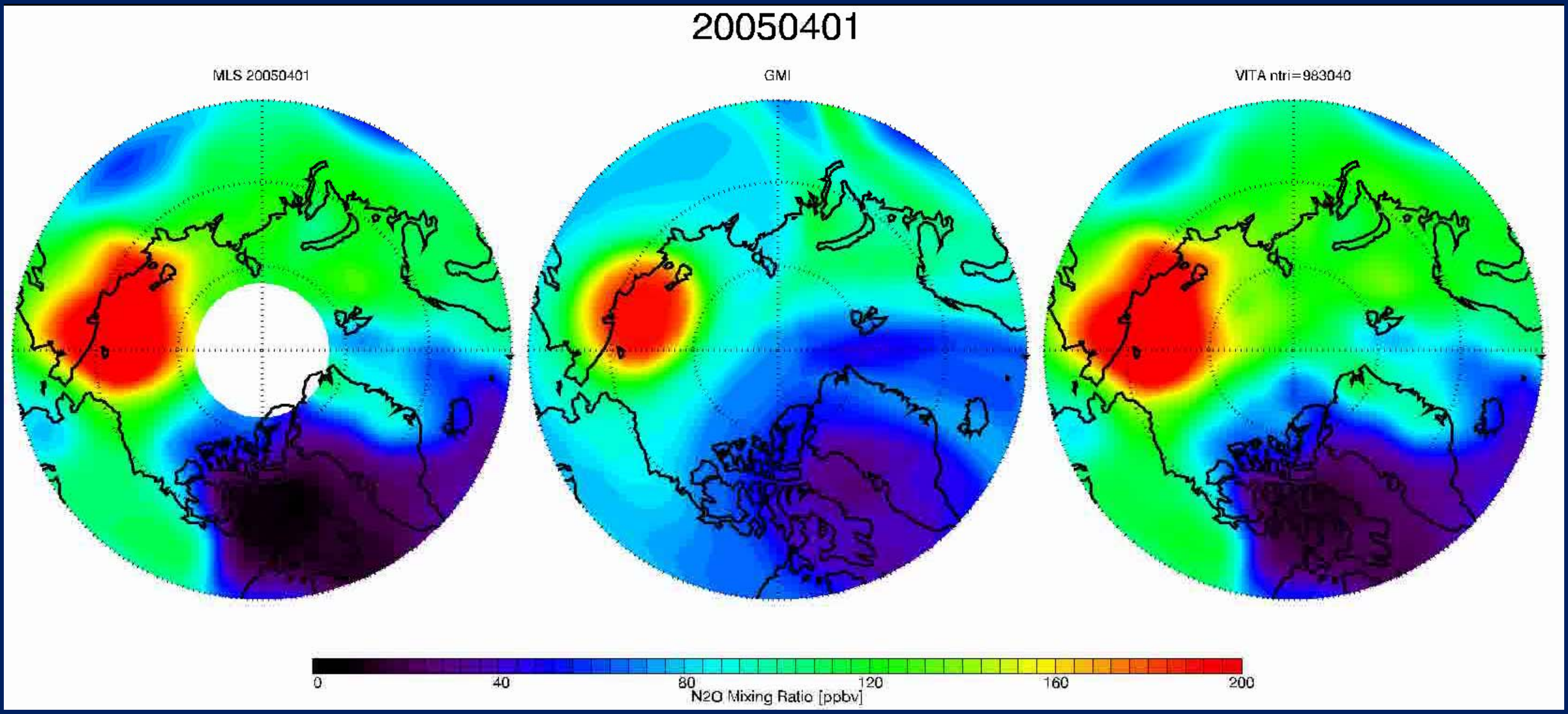




Cross-Polar Advection

(740 K shown, approximately 29 km)

MLS GMI-Aura4 VITA



Note: MLS Data not available on 5-6 April 2005

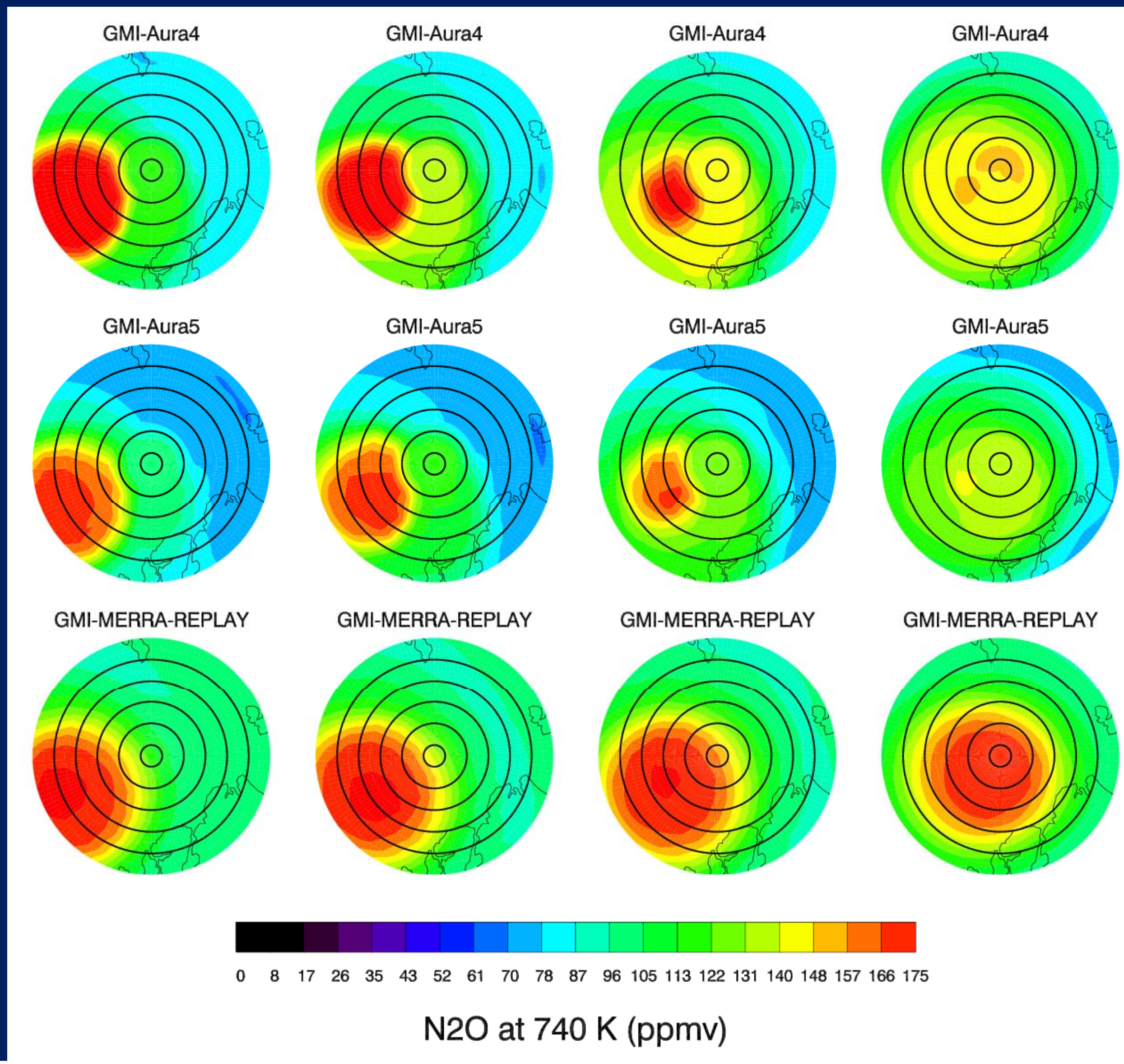
Cross-Polar Flow in GMI

8 April | 9 April | 10 April | 11 April

GMI-Aura4

GMI-Aura5

GMI-MERRA Replay



Large drop in N_2O (19% reduction of peak)

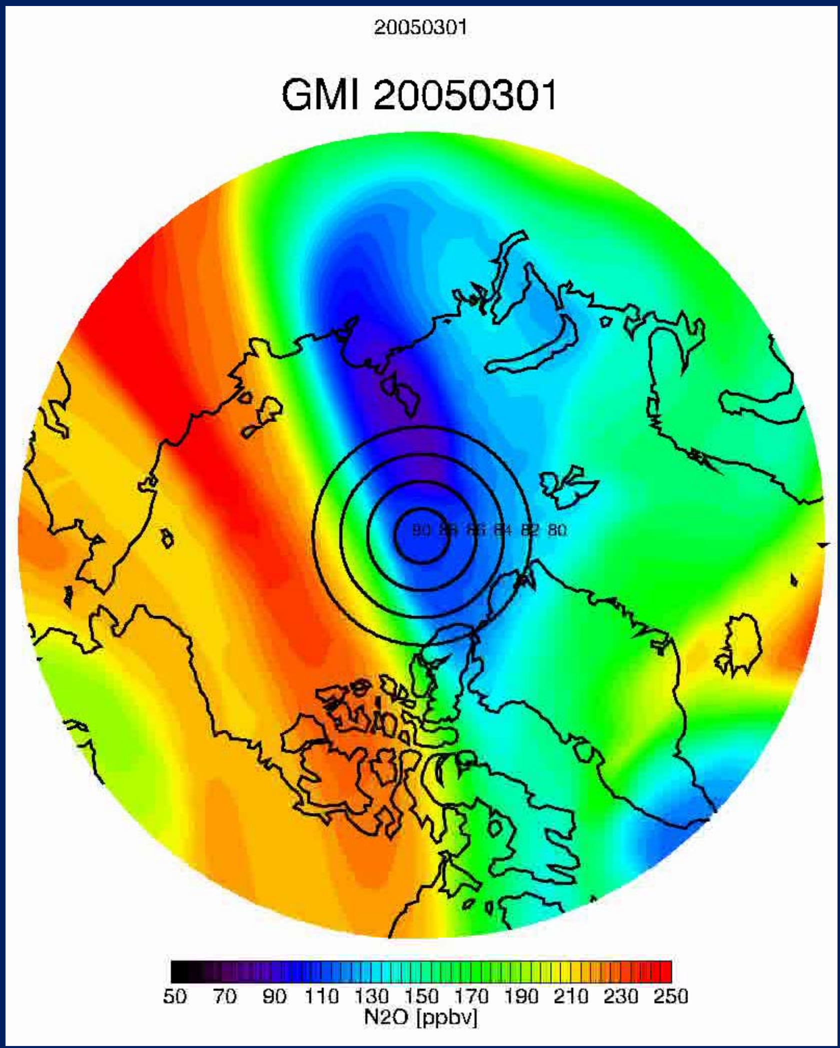
Small drop in N_2O (1% reduction of peak)

Cross-Polar Advection (N_2O at 50 hPa)

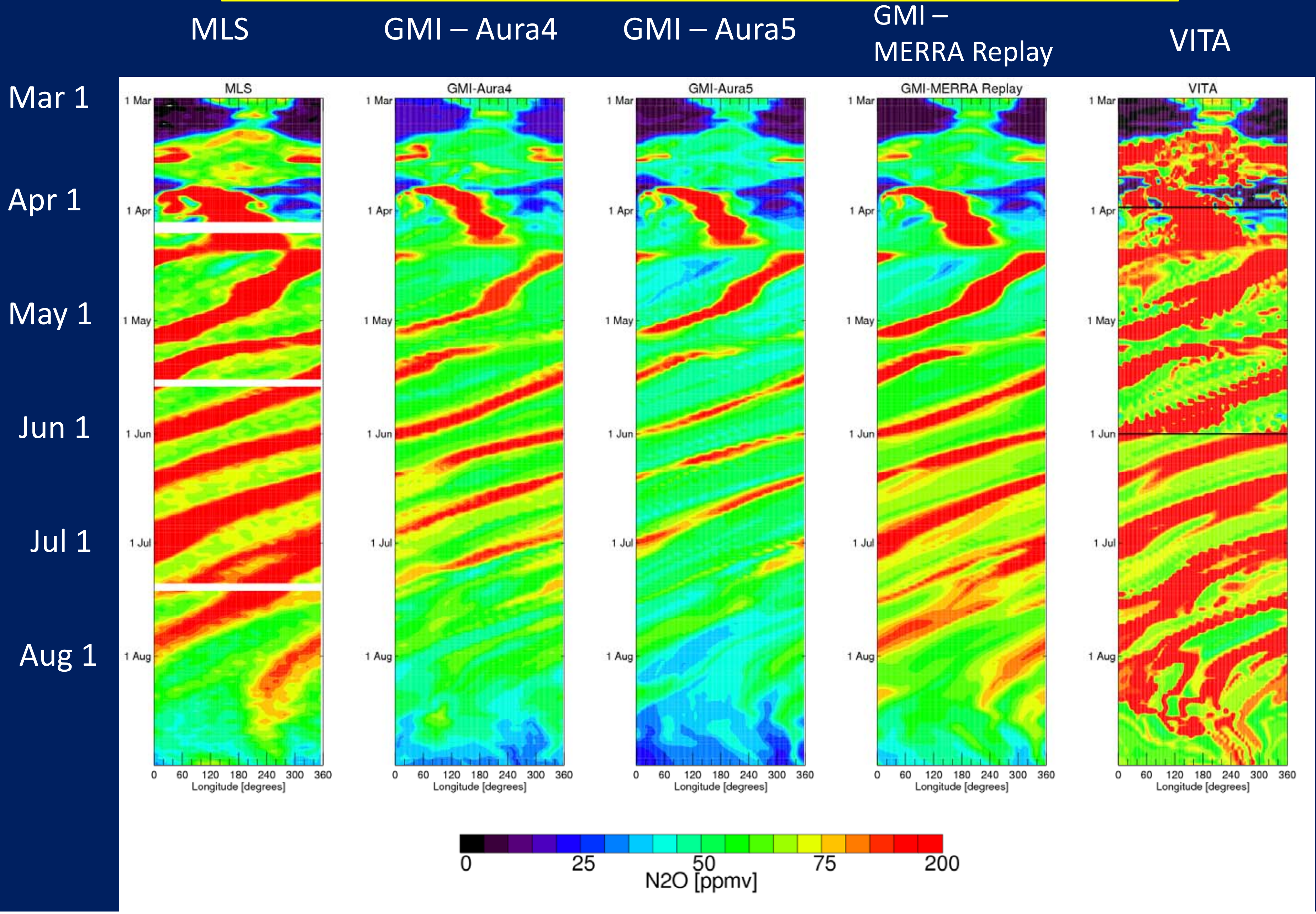
The polar mixing will be important whenever cross-polar flow is accompanied by strong tracer gradients. How often does this happen?

GMI-Aura4 from March-May 2005 at 10 hPa shows numerous polar crossings during the winter-to-summer transition.

Each time a strong gradient crosses the pole significant diffusion occurs.



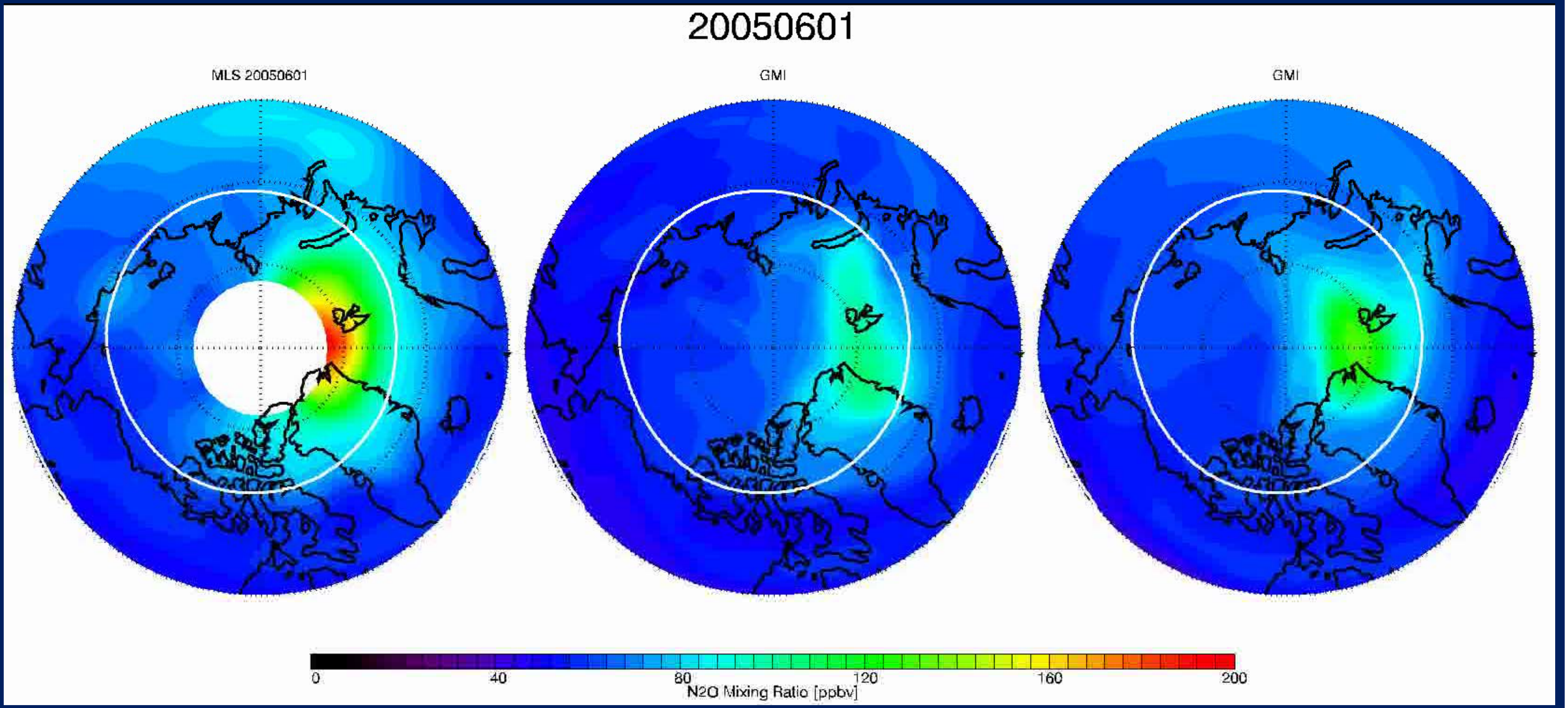
Longitude vs. Time Plots at 850 K, 78° N



Shearing Phase (Early June – August)

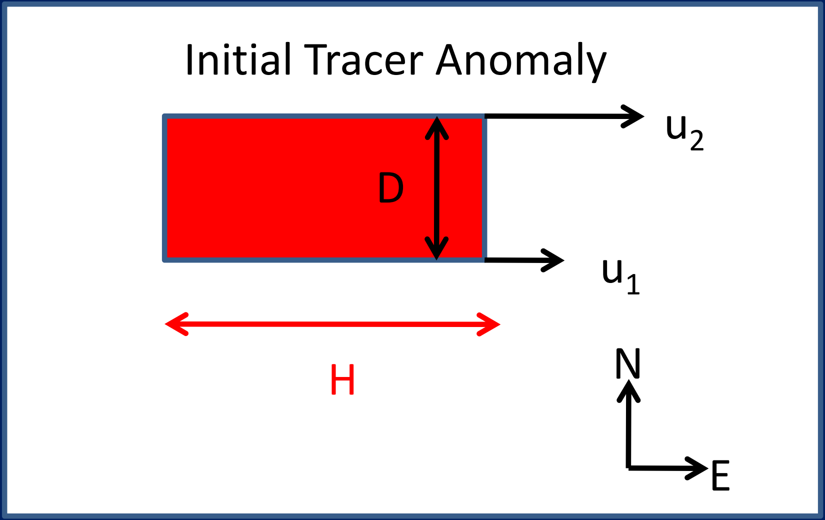
Simulations at 850 K, 1 June – 31 August 2005

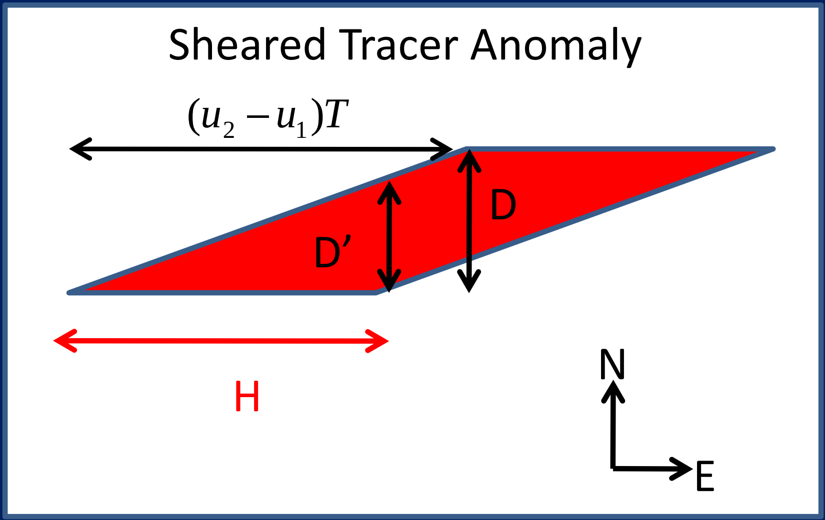
MLS | GMI – Aura 4 | GMI – MERRA Replay



Note: the Aura5 run does about the same as the Aura4 run during this period.

Time Scale for Horizontal Shear (assuming zero strain rate)





Put a rectangle into a shear that varies linearly with latitude.

Determine the lateral scale of the sheared feature via:

$$\frac{D'}{D} = \frac{H}{(u_2 - u_1)T}$$

$$D' = \frac{HD}{\frac{du}{d\phi}DT} = \frac{H}{\frac{du}{d\phi}T}$$

H = 100 °lon
du/dϕ = 0.5 °lon/day/°lat

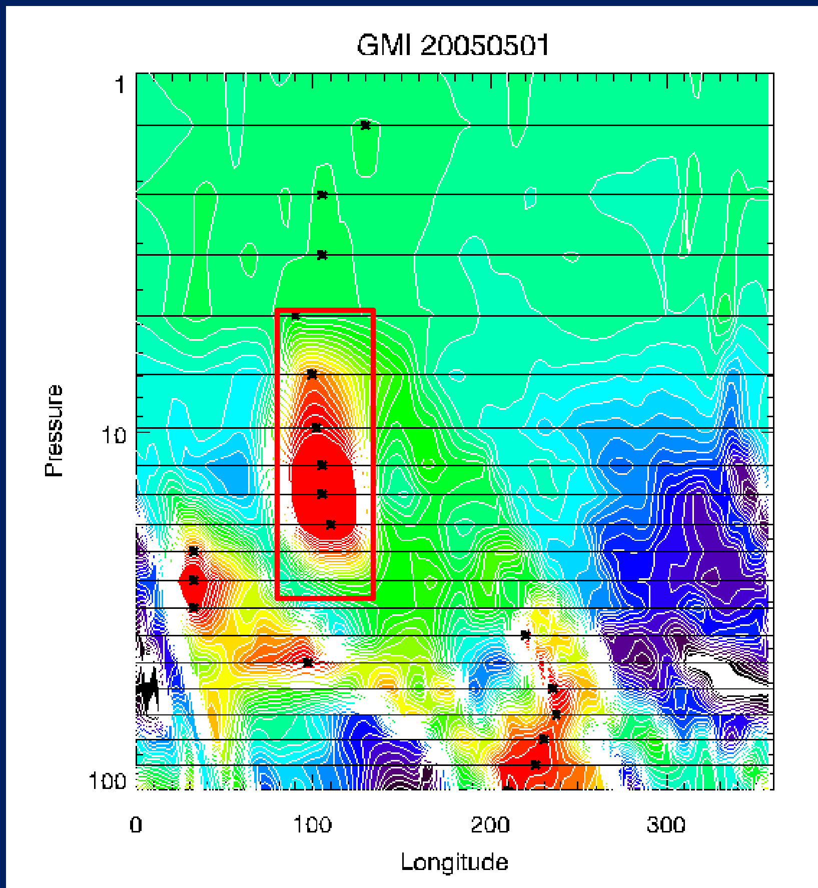
What would be time for lateral scale to reduce to 2.0 °lat (GMI Resolution)?
T ~ 100 days (~3 months)

GMI Should be able to resolve the horizontal scale of the feature for a couple months (in absence of strain).

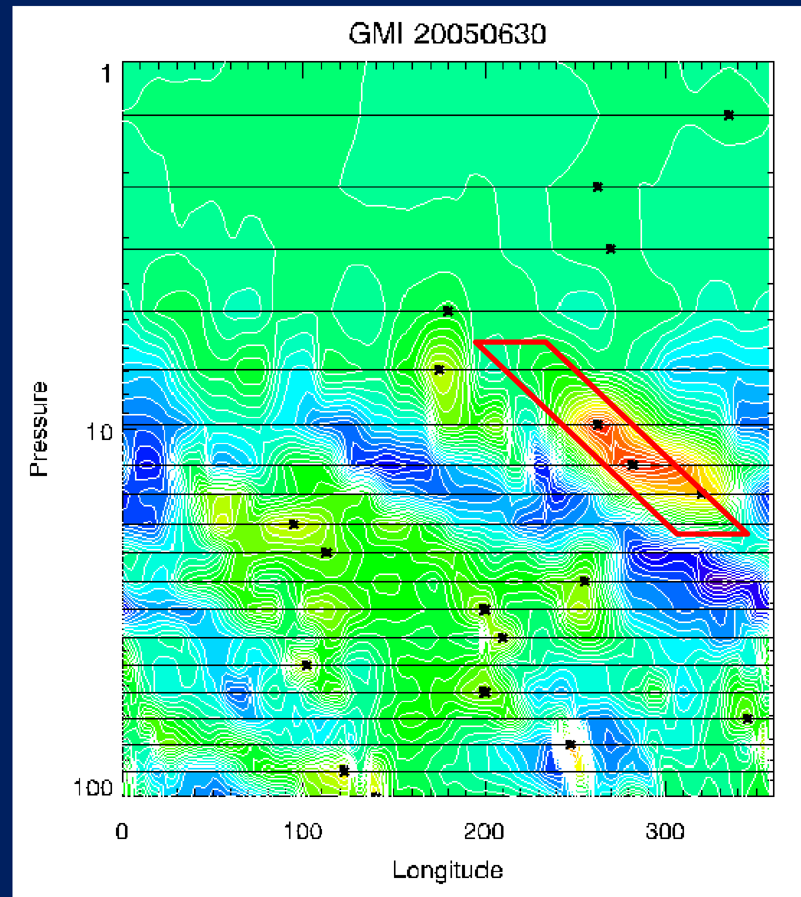
Vertical Tilting of N_2O Anomaly

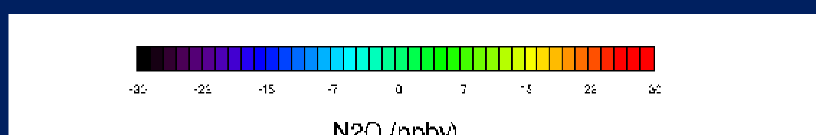
GMI Aura4 N_2O at 74° N (deviation from the zonal mean)

1 May 2005 (Anomaly is vertically Upright)



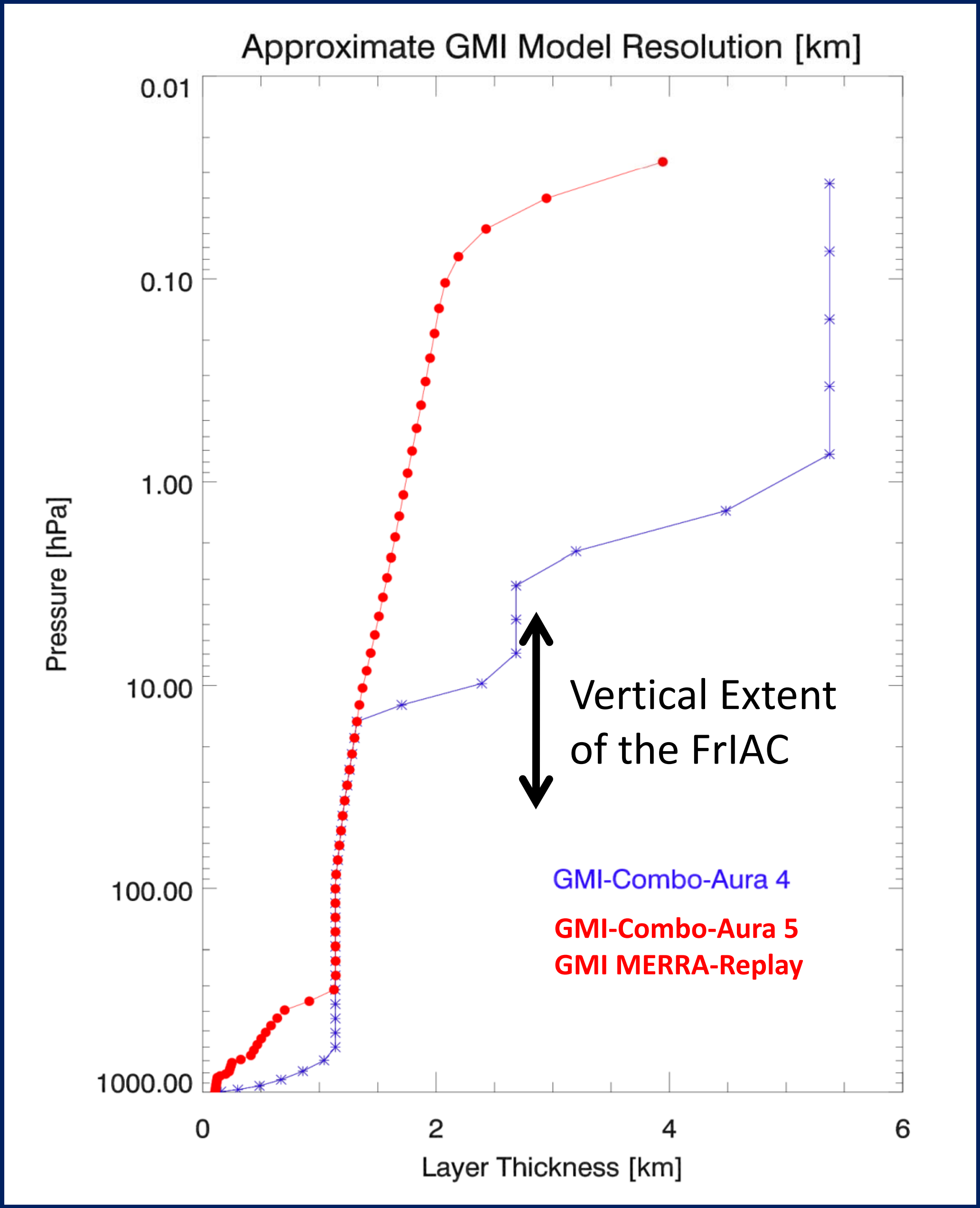
30 June 2005 (Anomaly is tilted)



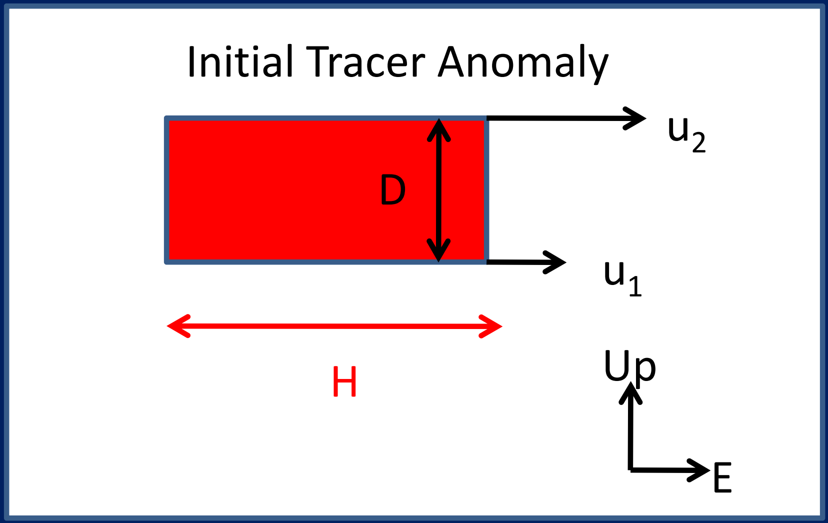


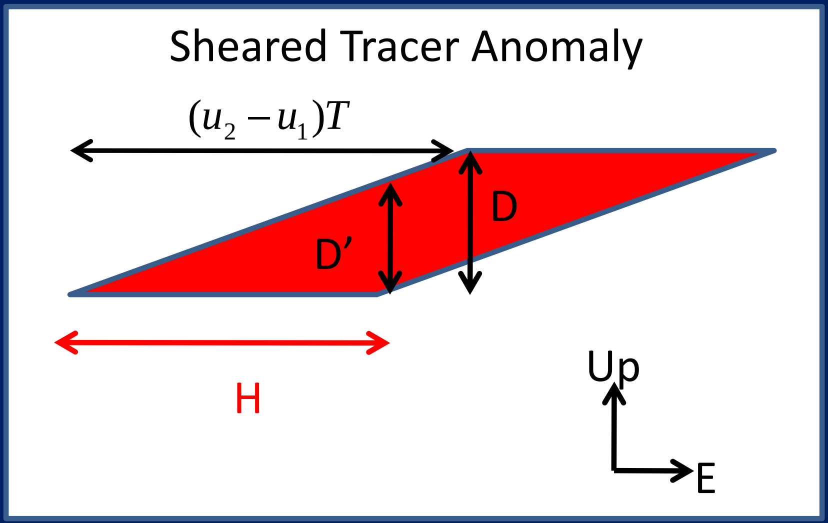
GMI Vertical Resolution

- In the Aura4 run, the vertical resolution varies over the top and bottom half of the FrIAC.
  - ~2.7 km above 7 hPa
  - ~1.1 km below 15 hPa
- The Aura5 and MERRA-Replay provide more uniform vertical resolution



Time Scale for Vertical Shear (assuming zero strain rate)





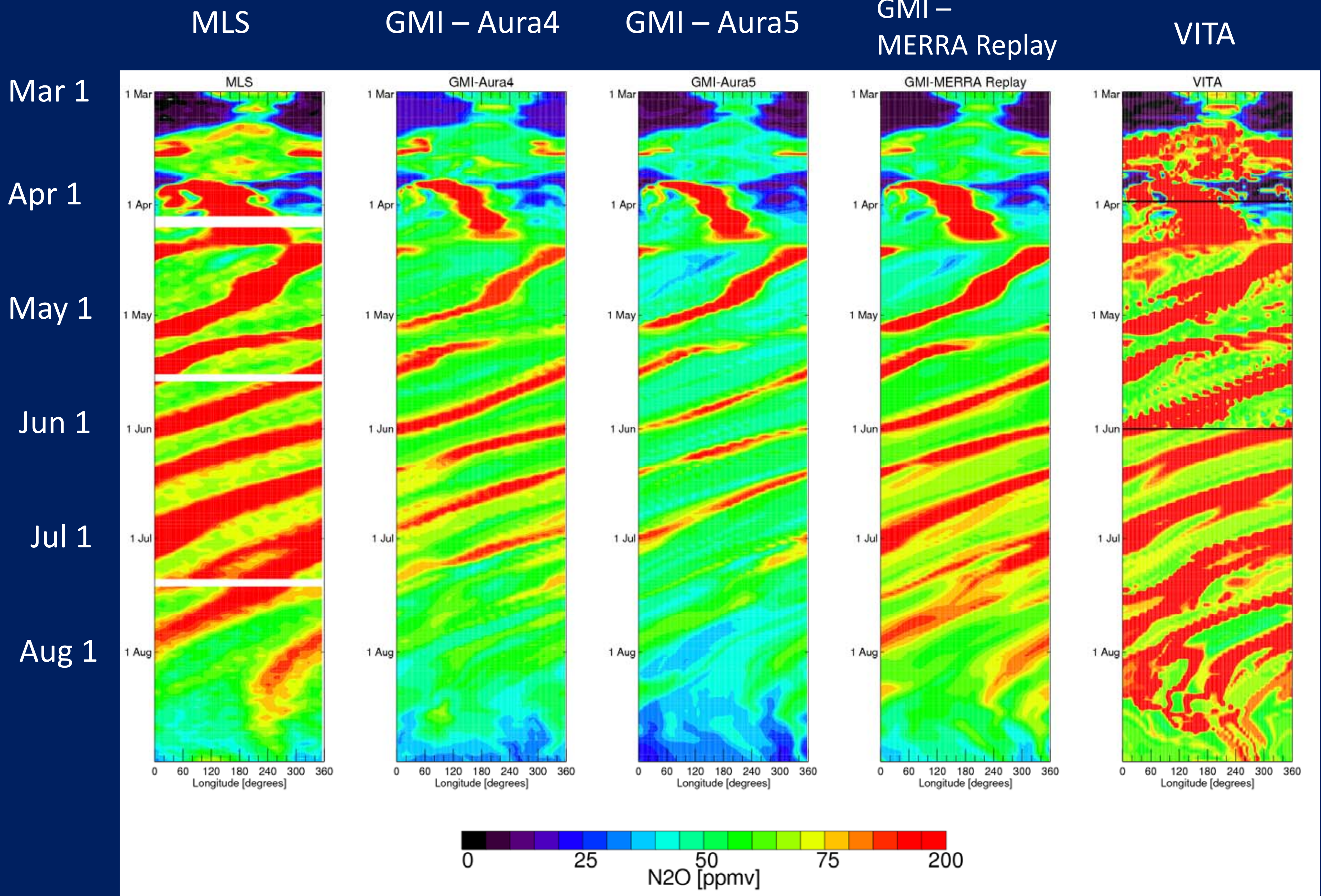
$$D' = \frac{HD}{\frac{du}{dz}DT} = \frac{H}{\frac{du}{dz}T}$$

H = 2875 km (~100 °lon at 75 N)
du/dz = 0.0.0004 1/s

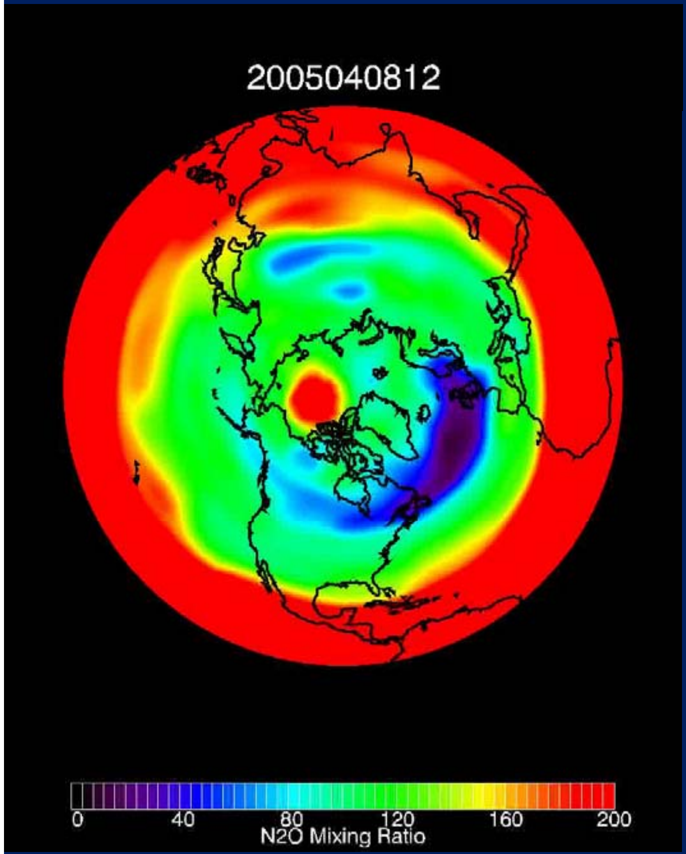
What would be the time for vertical scale to reduce to 2.7 km?
T ~ 31 days (1 month)

What would be the time for vertical scale to reduce to 1.1 km?
T ~ 75 days

Longitude vs. Time Plots at 850 K, 78° N



Summary/Conclusions

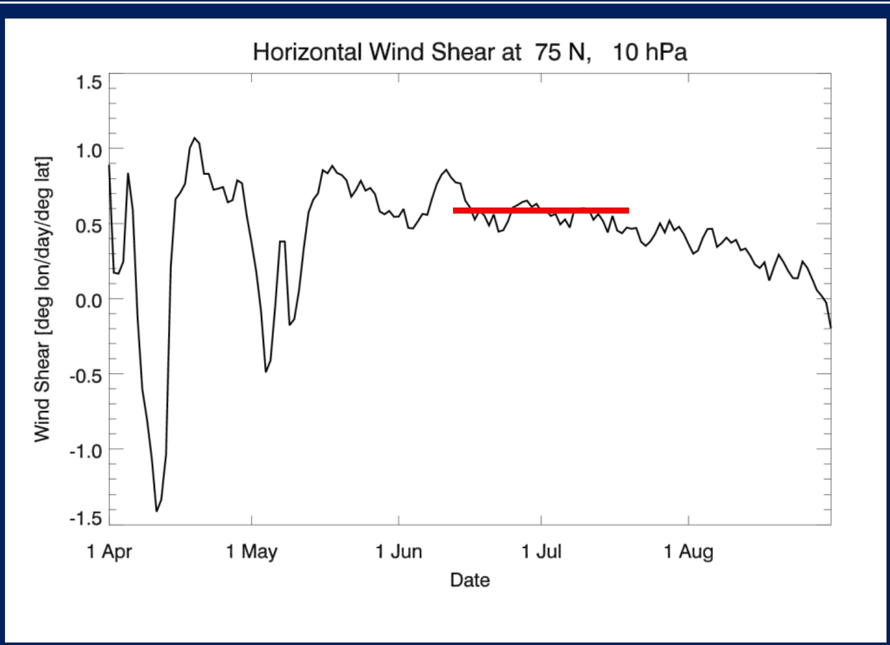


- **Spin-up**
  - GMI establishes the N_2O anomaly at all levels.
  - Peak N_2O values are too low.
- **Polar Transport**
  - GMI-Aura4 and Aura5 show too much mixing as N_2O anomaly crosses the pole
  - MERRA-Replay does much better job
  - Likely due to size of polar cap
- **Shearing phase**
  - Aura4 and Aura5 runs lose the anomaly about a month too soon.
  - MERRA-Replay does better.
  - Likely due to better vertical resolution and/or (on-line) transport scheme in MERRA-Replay.

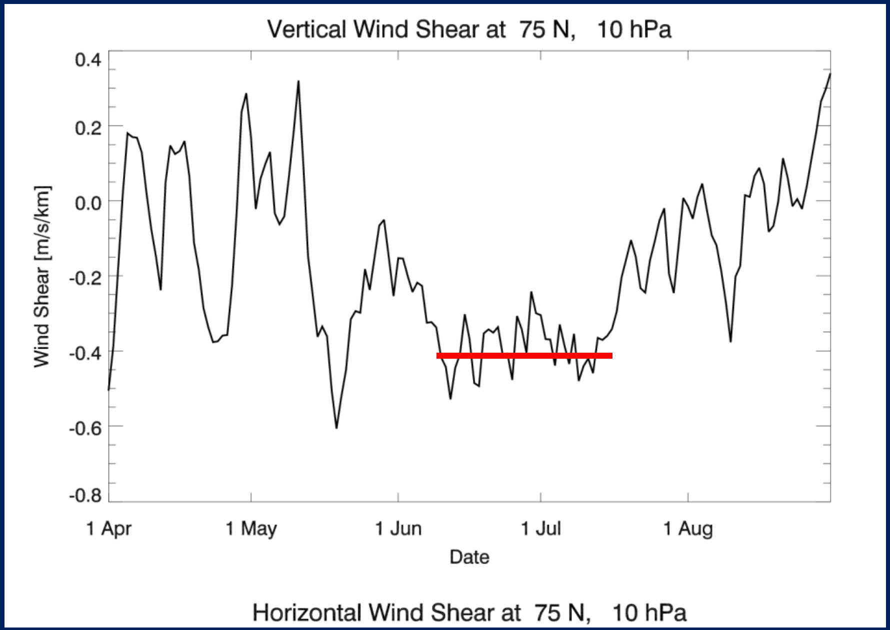
Extras

Shearing-Phase: early June - August

- Wind shears in both vertical and horizontal are rather weak in the summer easterly stratosphere.
- However, acting on long time-scales (weeks to months), these can cause significant distortion of an initially quasi-circular anomaly.



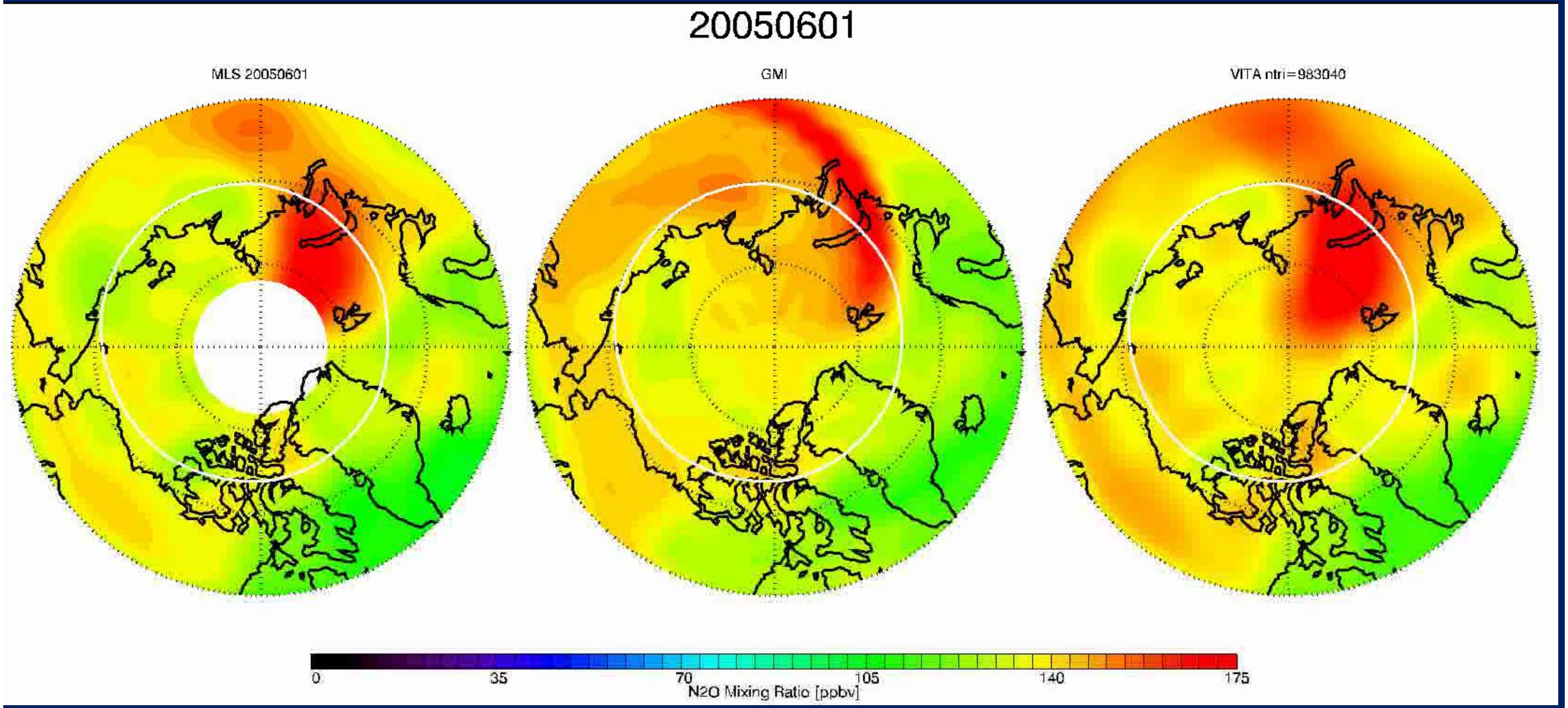
Horizontal Shear in Angular Velocity
~O(0.5 °lon/day/°lat)



Vertical Shear in Zonal Wind
~O(0.4 m/s/km = 0.0004 1/s)

Simulations at 650 K, 1 June – 31 August 2005

MLS GMI – Aura4 VITA



Tracer structure appears to last longer in GMI at 650 K than at 850 K, consistent with better vertical resolution.