Simulations of the Circulation and Transport in the Middle Atmosphere Using WACCM3.5

A. K. Smith, R. R. Garcia, D. R. Marsh, J. H. Richter

paper in preparation

Transport in the transformed Eulerian mean system

$$\overline{v}^* \equiv \overline{v} - \frac{1}{\rho_0}\frac{\partial}{\partial z}\left(\rho_0 \frac{\overline{v\prime\theta\prime}}{\overline{\theta}_z}\right)$$

$$\overline{w}^* \equiv \overline{w} + \frac{1}{acos\phi}\frac{\partial}{\partial\phi}\left(cos\phi \frac{\overline{v\prime\theta\prime}}{\overline{\theta}_z}\right)$$

The eddy correlation terms (v’θ’, etc.) have been calculated and saved in WACCM output so the residual circulation can be determined daily.

Tracer μ:

$$\frac{\partial\overline{\mu}}{\partial t} + \frac{\overline{v}^*}{a}\frac{\partial\overline{\mu}}{\partial\phi} + \overline{w}^*\frac{\partial\overline{\mu}}{\partial z} = \overline{P} - \overline{L}\overline{\mu} - \overline{L\prime\mu\prime} + \overline{X_K} + \overline{X_D} + F.$$

advection by The TEM circulation

photochemistry

eddy diffusion (GW)

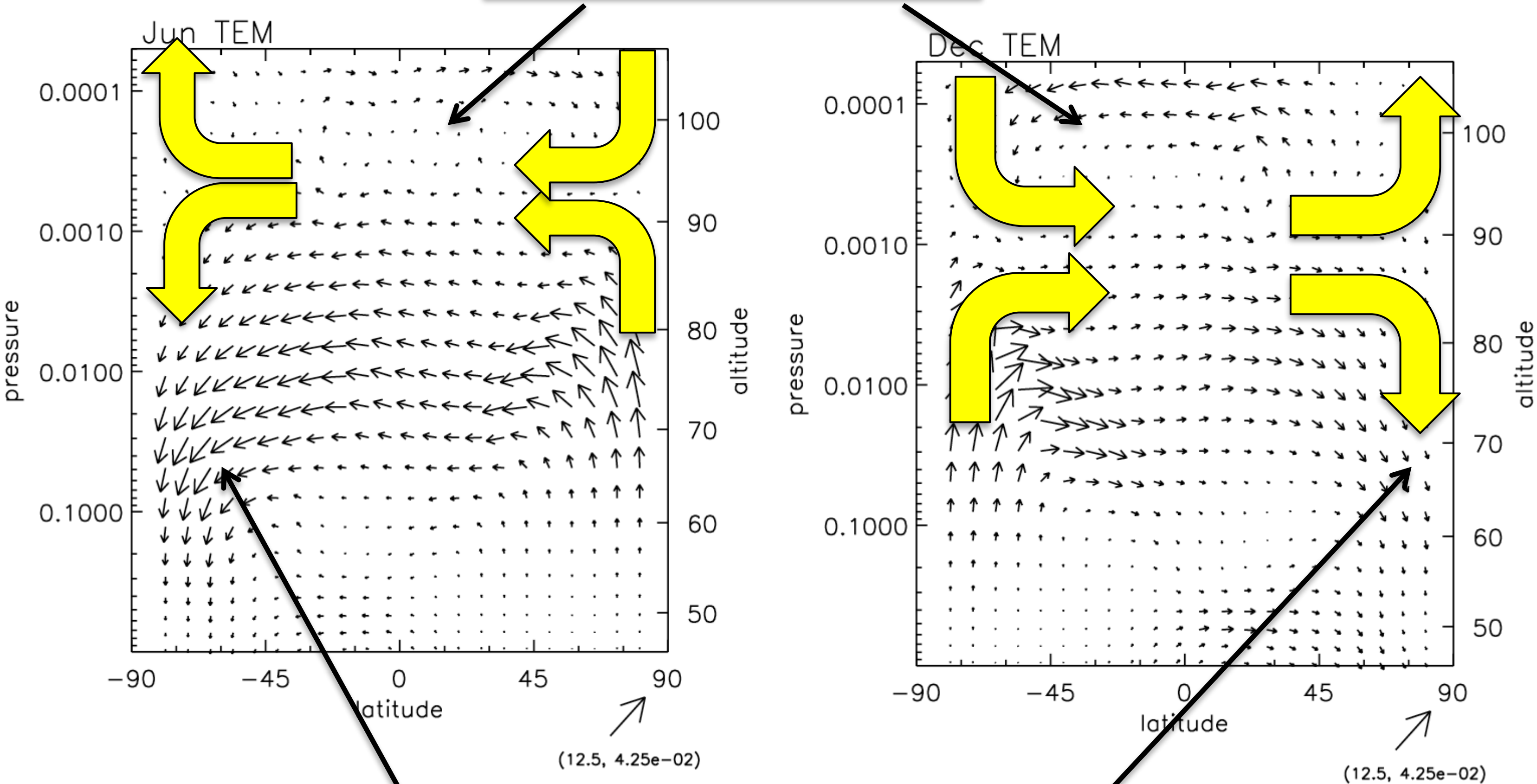
molecular diffusion

climatological v* and w* vectors at solstice

weak reversed circulation cell in MLT
- stronger in NH winter

June

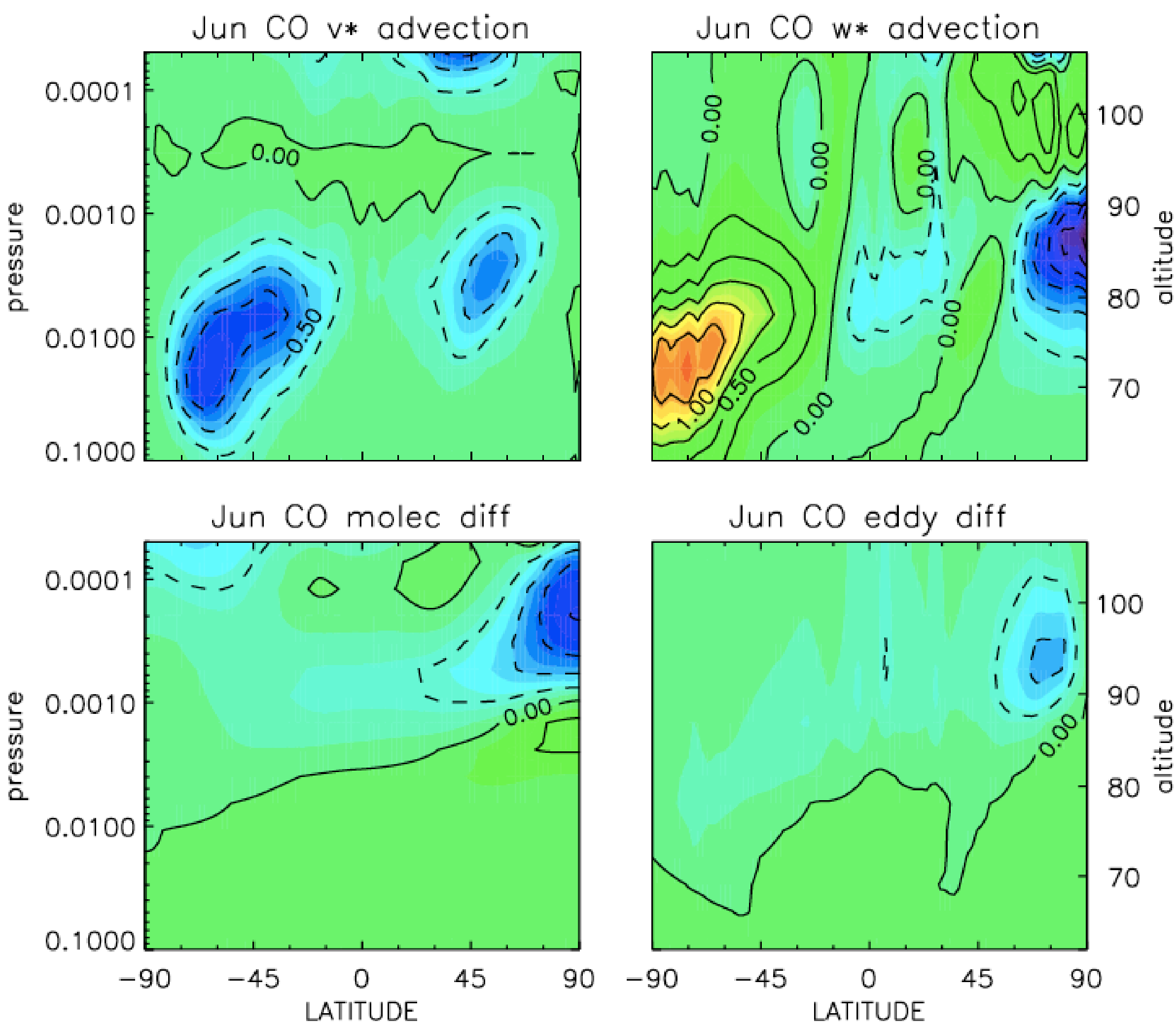
December



WINTER: SH circulation much stronger

processes that affect zonal average CO

tendency in CO due to various processes – June average



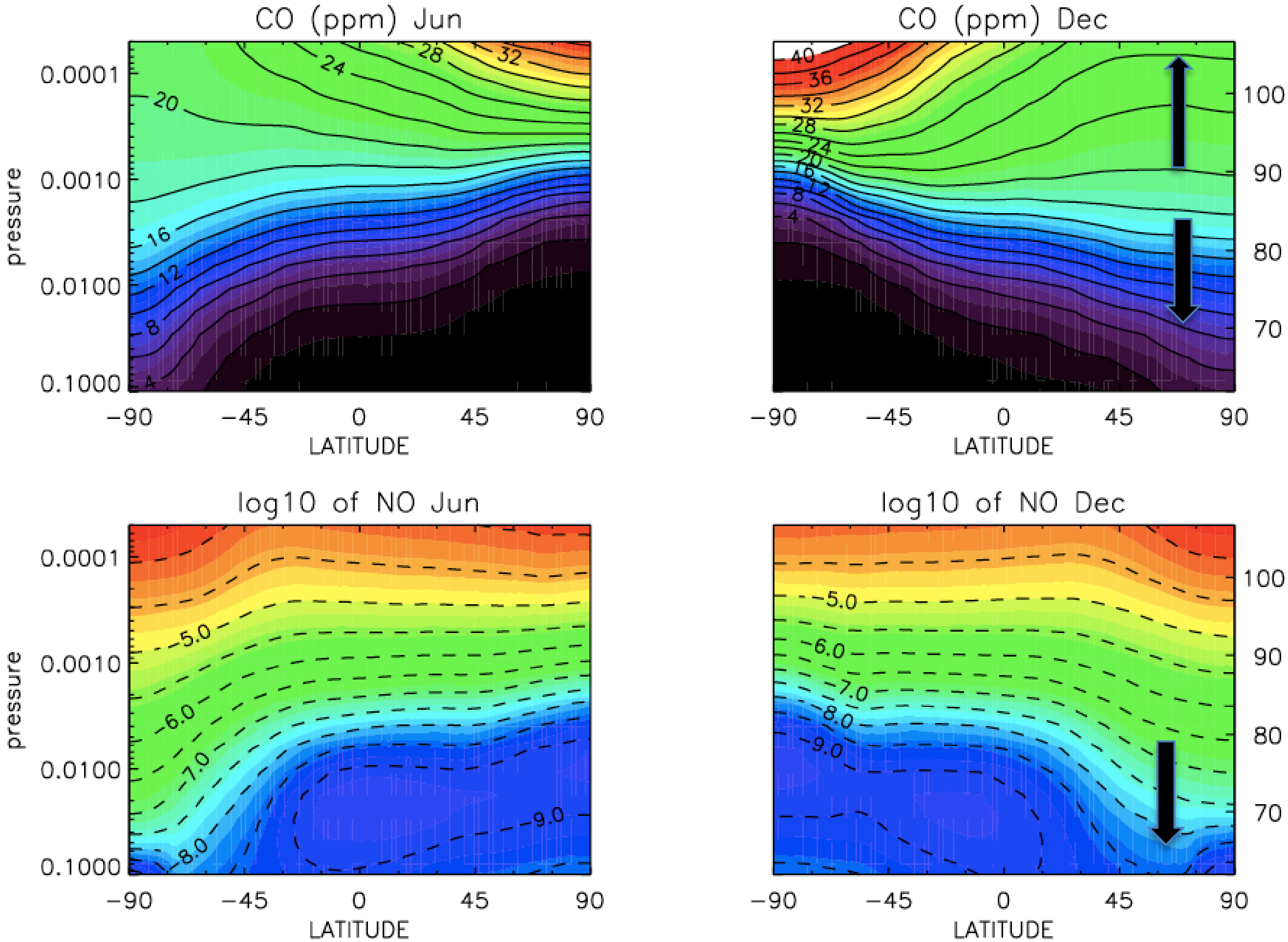
advection by TEM circulation

dominant, particularly below 90 km

molecular and eddy diffusion

eddy diffusion is weak compared to advection during solstice seasons

impact of TEM circulation on trace species with MLT or thermospheric source



CO (ppmv)

advection causes steep vertical gradients in summer, weaker vertical gradients in winter

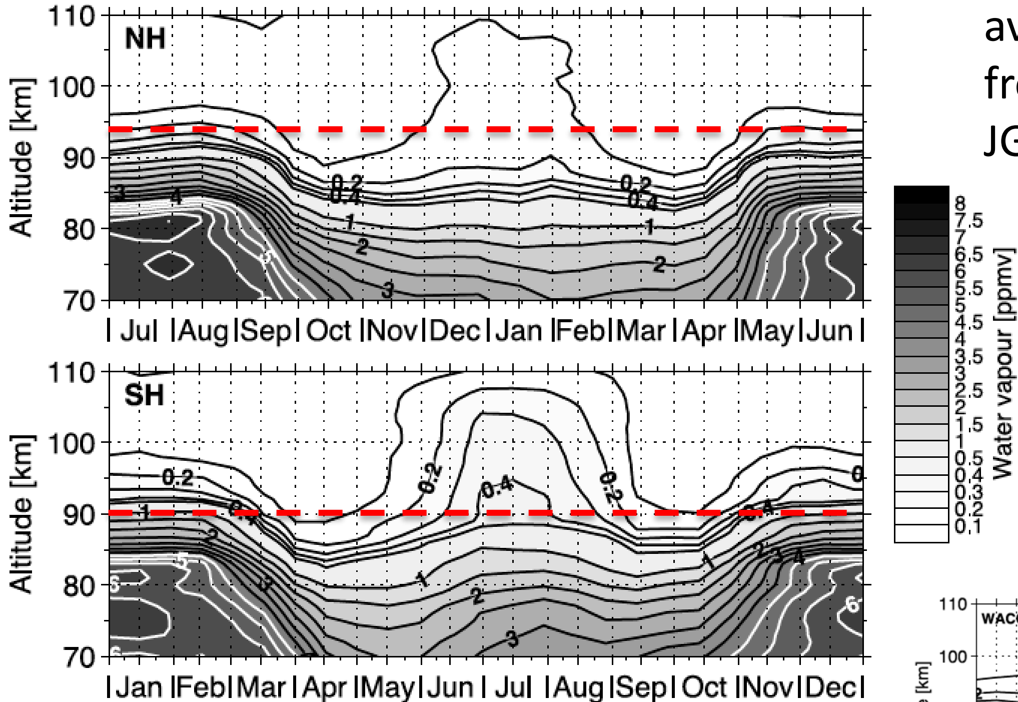
NO
(log10 of mixing ratio)

observational evidence for rising in winter polar MLT

ODIN H_2O, 2003-2007, averaged 50˚-82˚ from Lossow et al., JGR, 2009

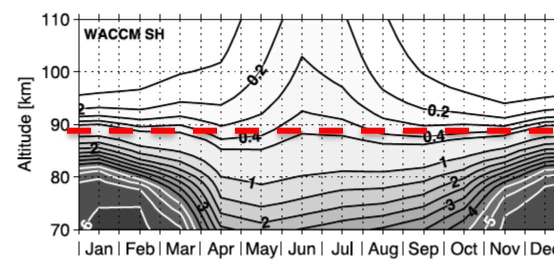
NH

SH

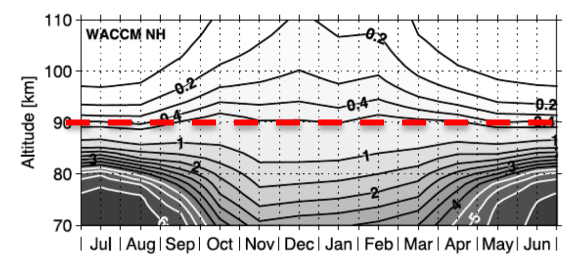


Vertical gradients are stronger in summer; weaker in winter.

Plumes of higher water extend up from ~90 km during winter, both hemispheres.



WACCM H_2O for comparison



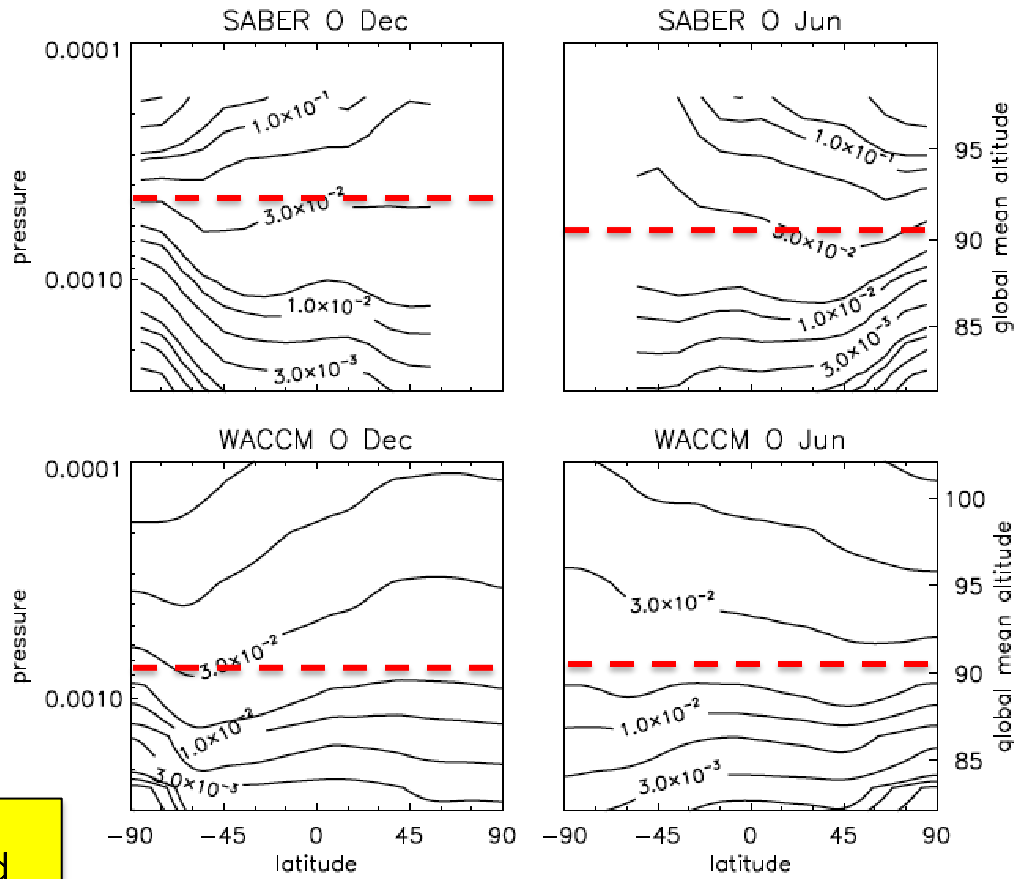
altitude of transition from summer max to winter max:
SH: WACCM and Odin at ~90 km
NH: Odin at ~94 km; WACCM at ~90 km

observational evidence for rising in winter polar MLT

SABER atomic oxygen
average over
solstice season
(60 days) for 9 years

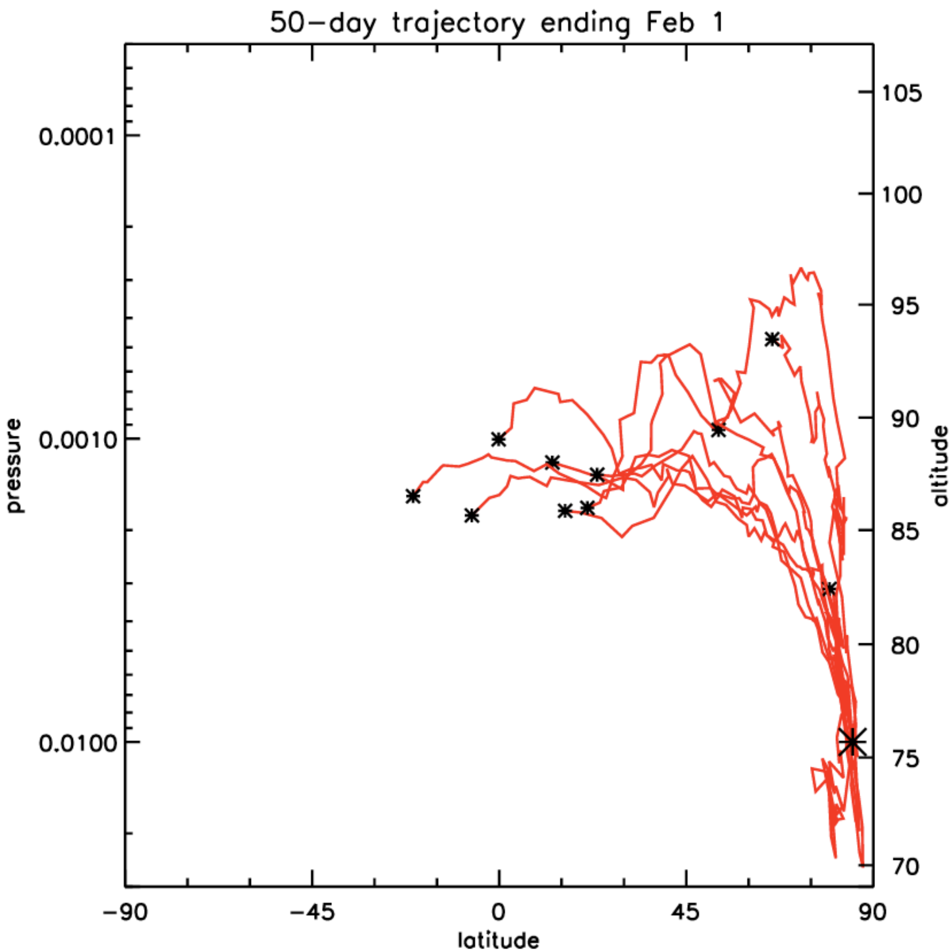
(mixing ratio)

WACCM O
for comparison



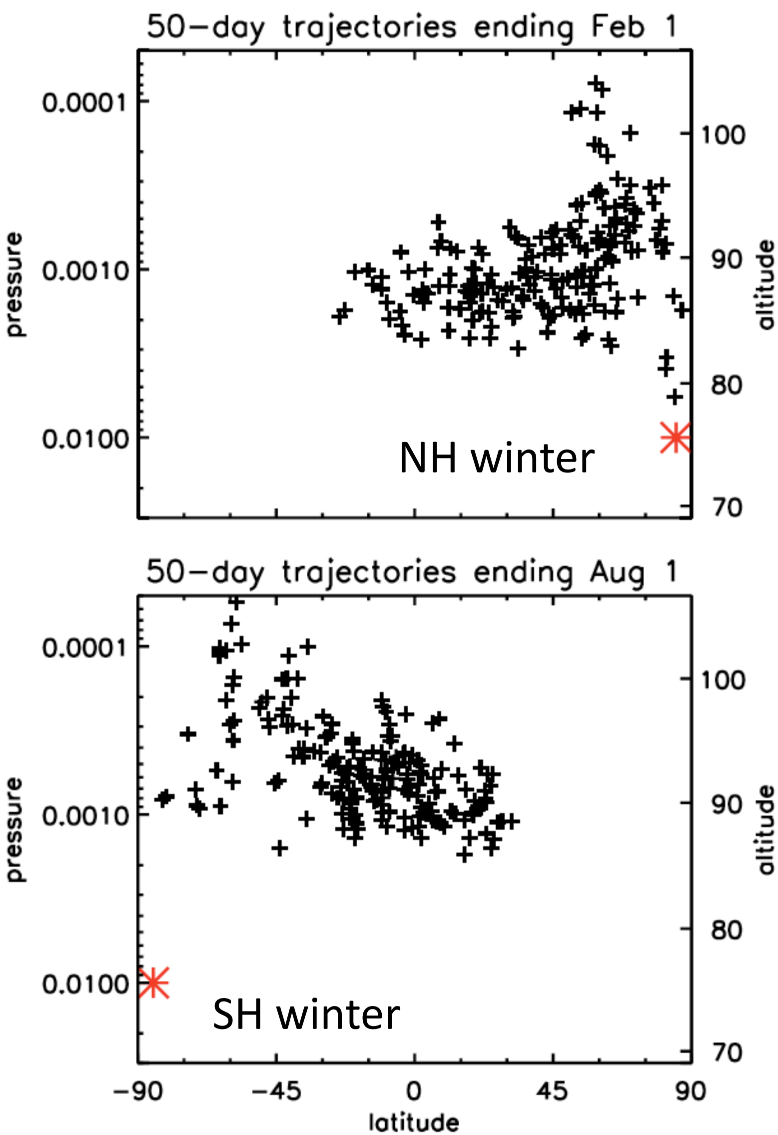
altitude of transition from upward to downward sloping contours:
June: WACCM and SABER at ~91 km
December: SABER at ~93 km; WACCM at ~91 km

origin of air parcels in winter high latitudes



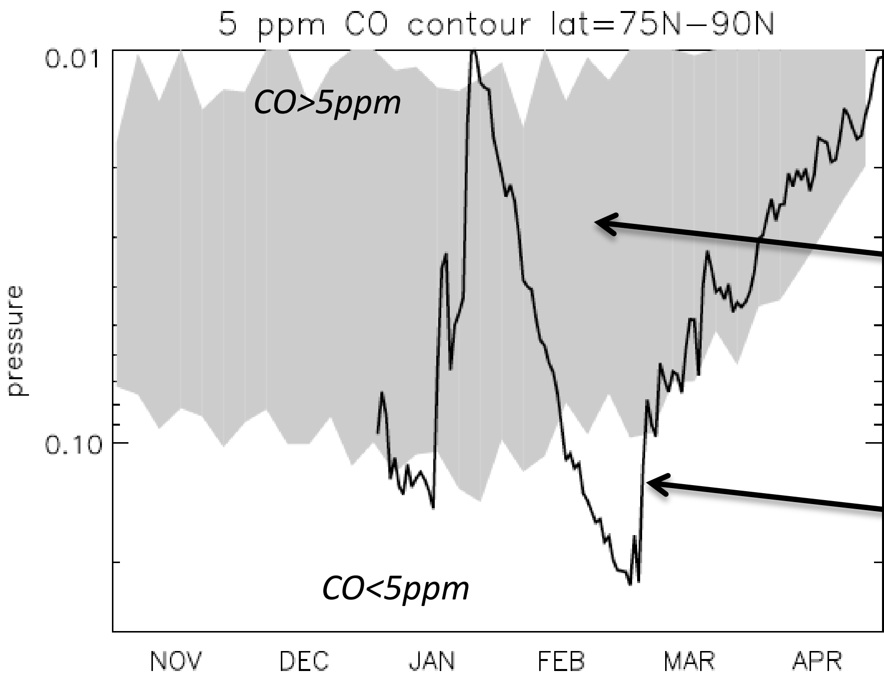
- back trajectories of air parcels calculated from daily v* and w*
- advection by TEM circulation
- end point: 0.01 hPa, 85˚N
- 50 days, ending 1 February
- 10 different years

origin of air parcels for all runs, all years



- trajectory origin points
- all trajectories end at 0.01 hPa and 85˚ on the specified calendar date
- SH air originates at higher altitude & lower latitudes
- air parcels come down directly from the winter polar thermosphere only in very few years in either hemisphere

closer look at an active NH winter



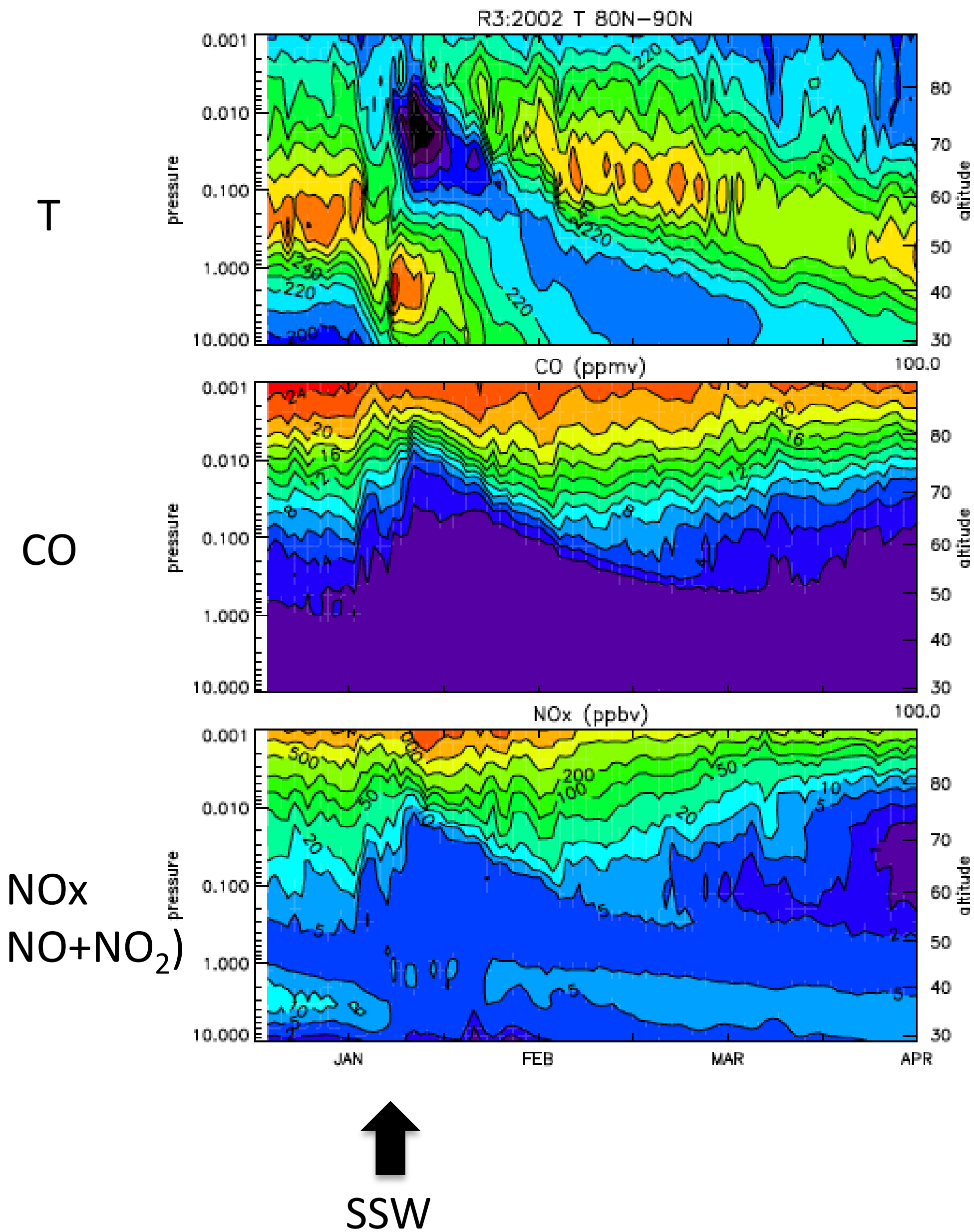
location of the 5 ppm CO contour

latitudes 75˚N-90˚N

all winters except this case (187 cases)

this case

time series for the case-study winter (R3:2002)



- latitude: 80˚-90˚N
- sudden warming (SSW) in January followed by elevated stratopause
- CO and NOx: decrease during SSW and then steady increase for ~ 40 days
- magnitude of WACCM CO perturbations similar to observations in 2004, 2006, 2009
- WACCM NOx perturbations below 80 km are smaller than observed in 2004, 2006, 2009

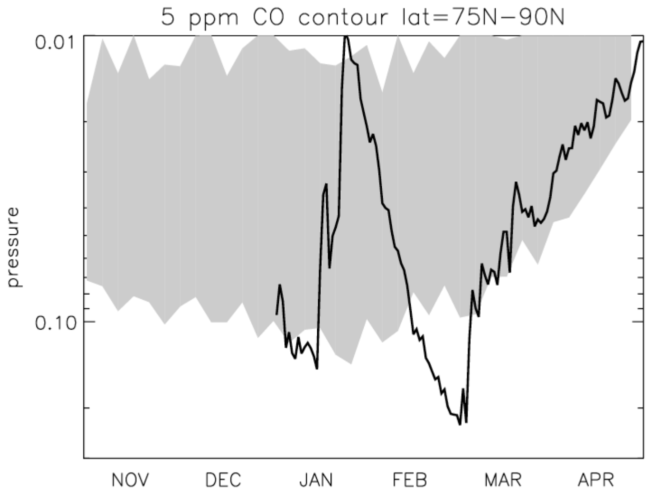
<u>observations of perturbed composition:</u>

Funke et al, ACP, 2009

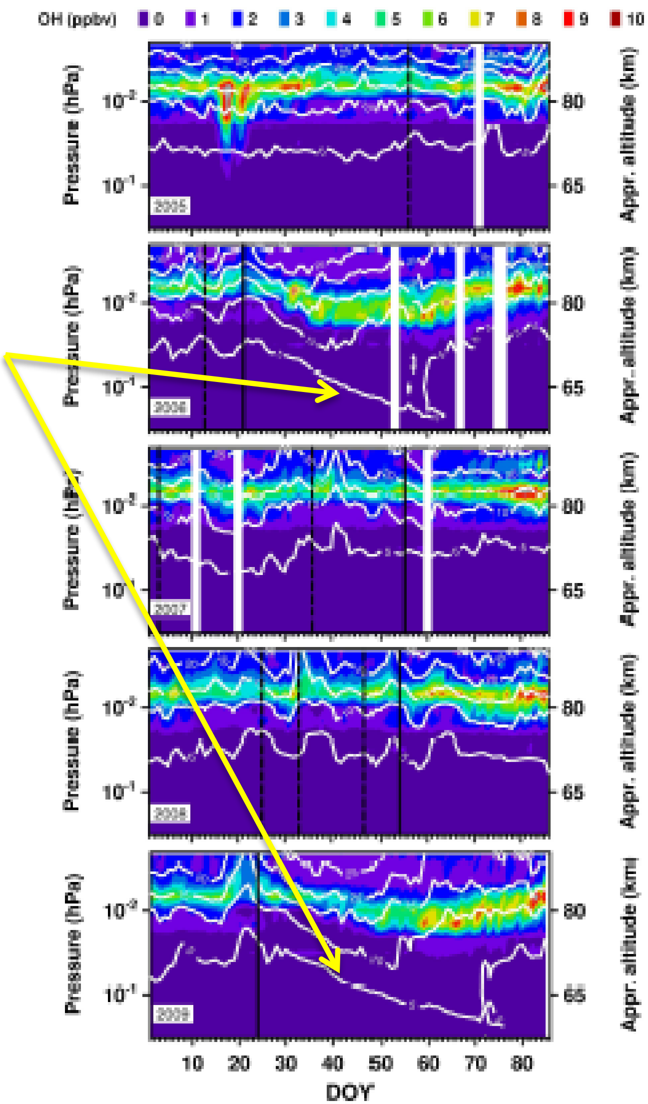
Damiani et al., ACP, 2010

Randall et al., GRL, 2009

compare CO with recent active winters



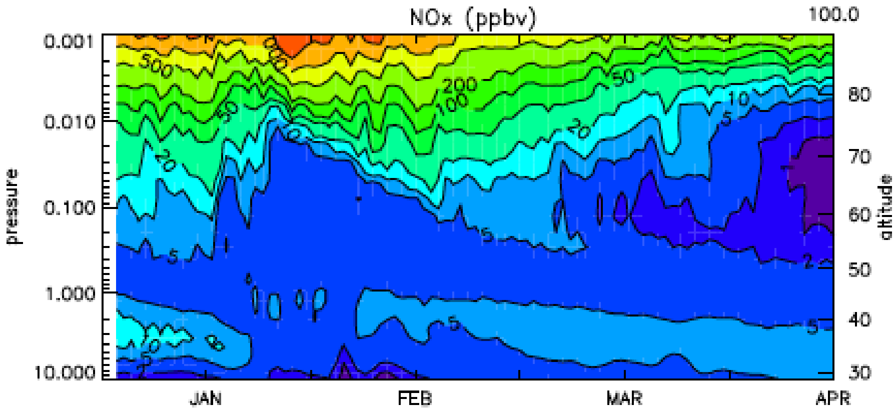
MLS observations
5 ppm contour
of CO (white)



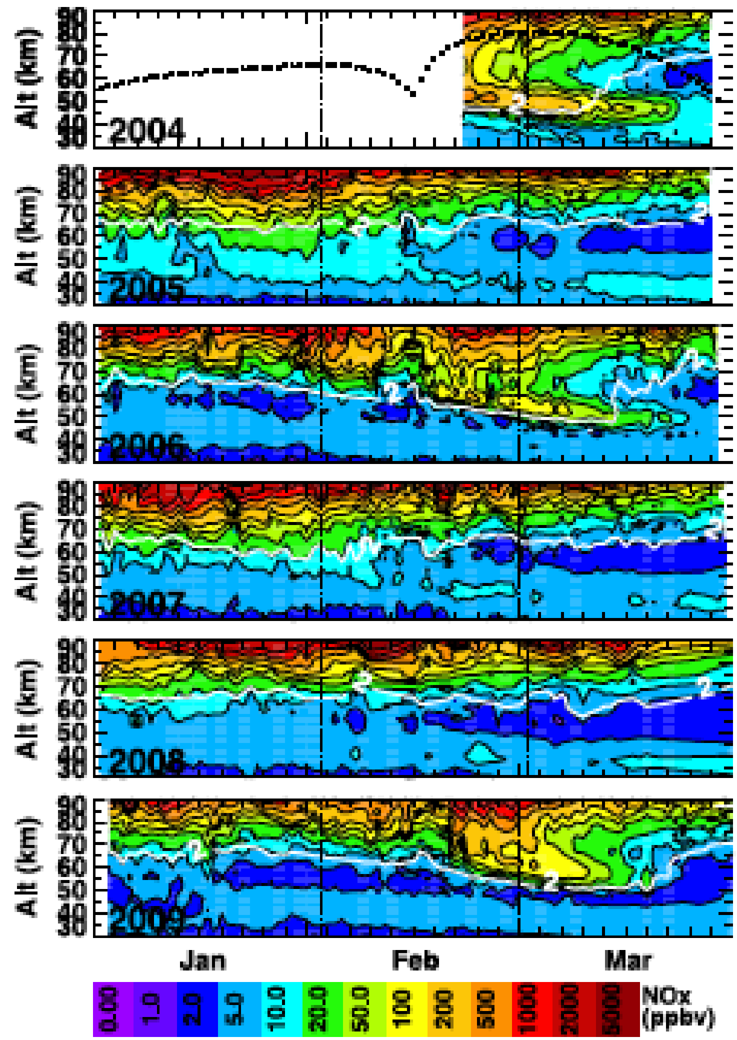
5 ppm of CO seen at ~0.2 hPa in MLS observations and WACCM

Damiani et al, ACP 2010

compare NOx with recent active winters



ACE observations of NOx

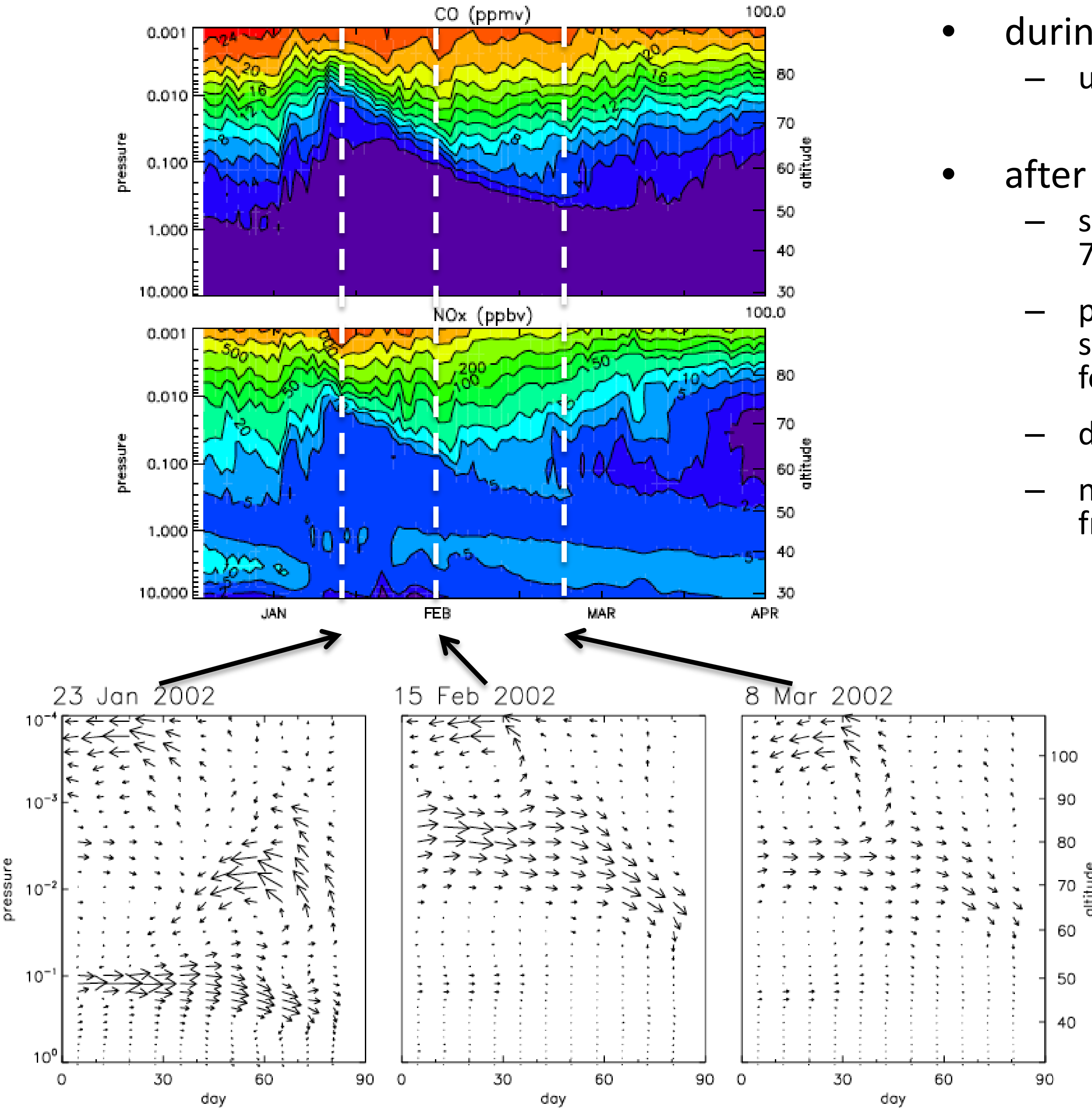


ACE sees NOx of 100 ppb down to ~55 km in 2006 and 2009

In WACCM, 100 ppb occurs only above ~70 km.

Randall et al, GRL 2009

TEM circulation for this active winter



- during SSW
  - upwelling in polar mesosphere
- after SSW
  - strong steady poleward flow at 70-90 km
  - poleward, downward flow strongest in the weeks following the warming
  - downwelling in polar region
  - no indication of sustained flow from the polar thermosphere

WACCM transport in the winter MLT

- For most years, polar downward transported air comes from upper mesosphere, mid-low latitudes.
- The mean transport is upward to the thermosphere from the winter upper mesosphere.
- Even during years with disturbed dynamics and enhanced middle atmosphere CO and NO_x, the bulk of the descending air originates in the mesosphere at middle latitudes, not the polar thermosphere.
- WACCM NH poleward winter TEM flow may be too low in altitude.
- WACCM underestimates transport of NOx into the lower mesosphere – may be associated with the altitude of the circulation cell.