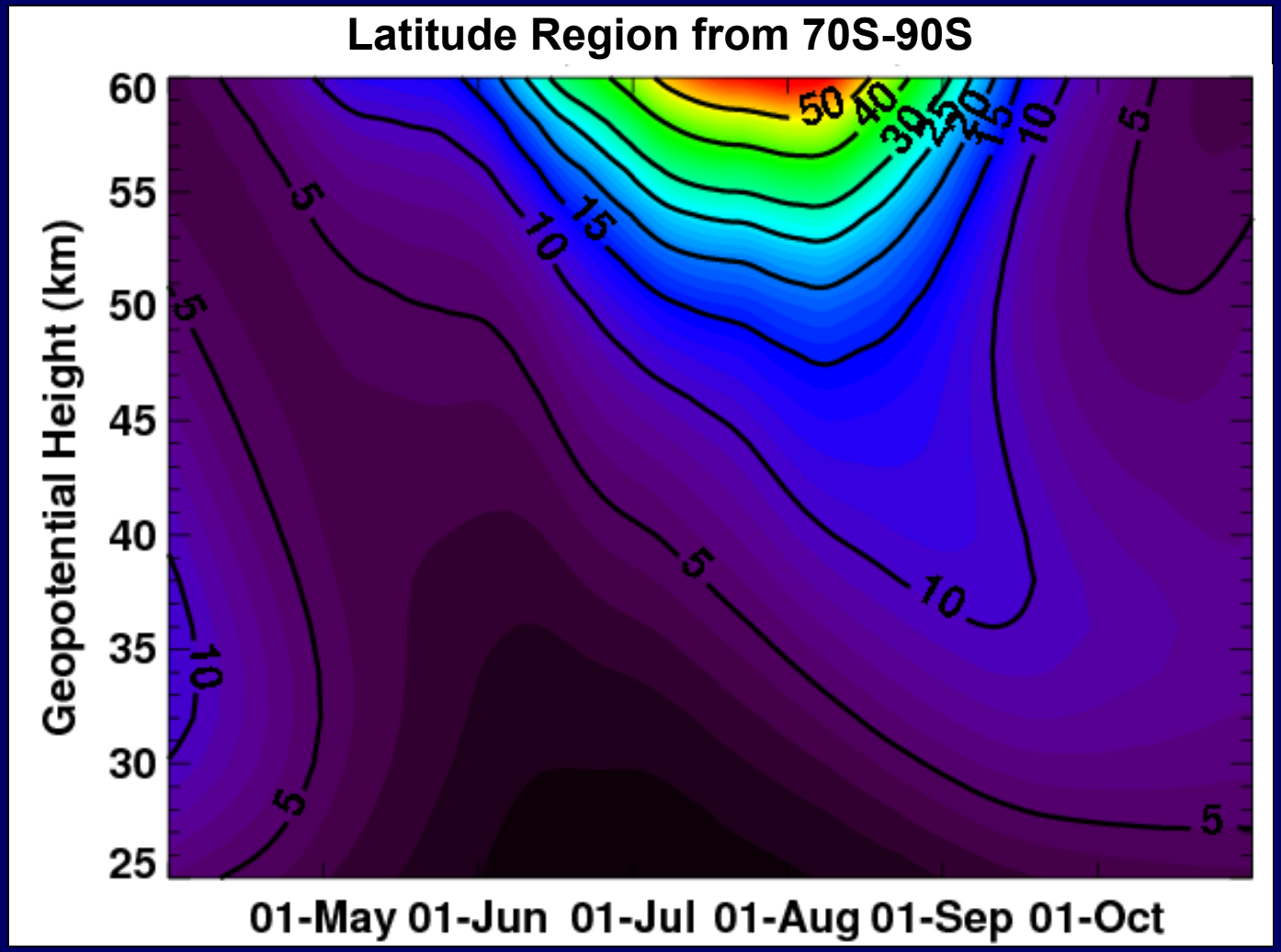
NO_x descent in the Arctic middle atmosphere in early 2009

Cora Randall, V. Lynn Harvey, David Siskind, Jeff France, Peter Bernath, Chris Boone, Kaley Walker

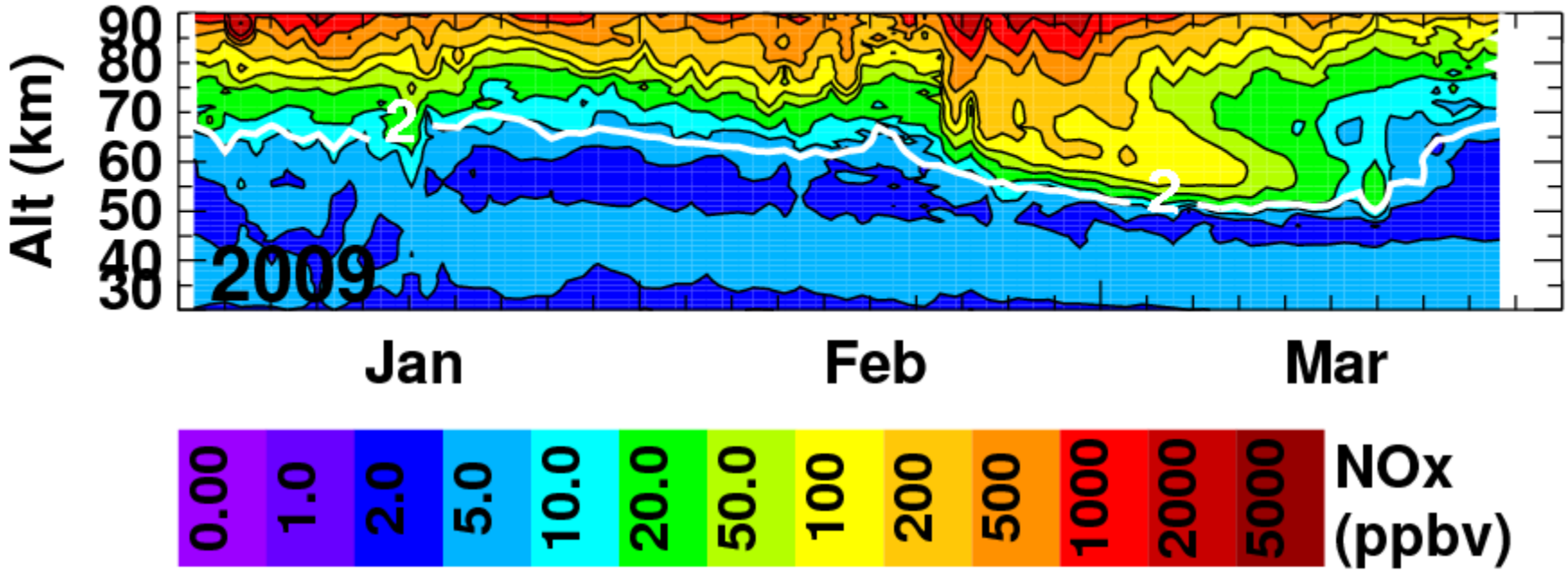
Geophys. Res. Lett., 36, L18811, doi:10.1029/2009GL039706

WACCM Simulation of the EPP Indirect Effect

NO_x produced by EPP descends to the stratosphere

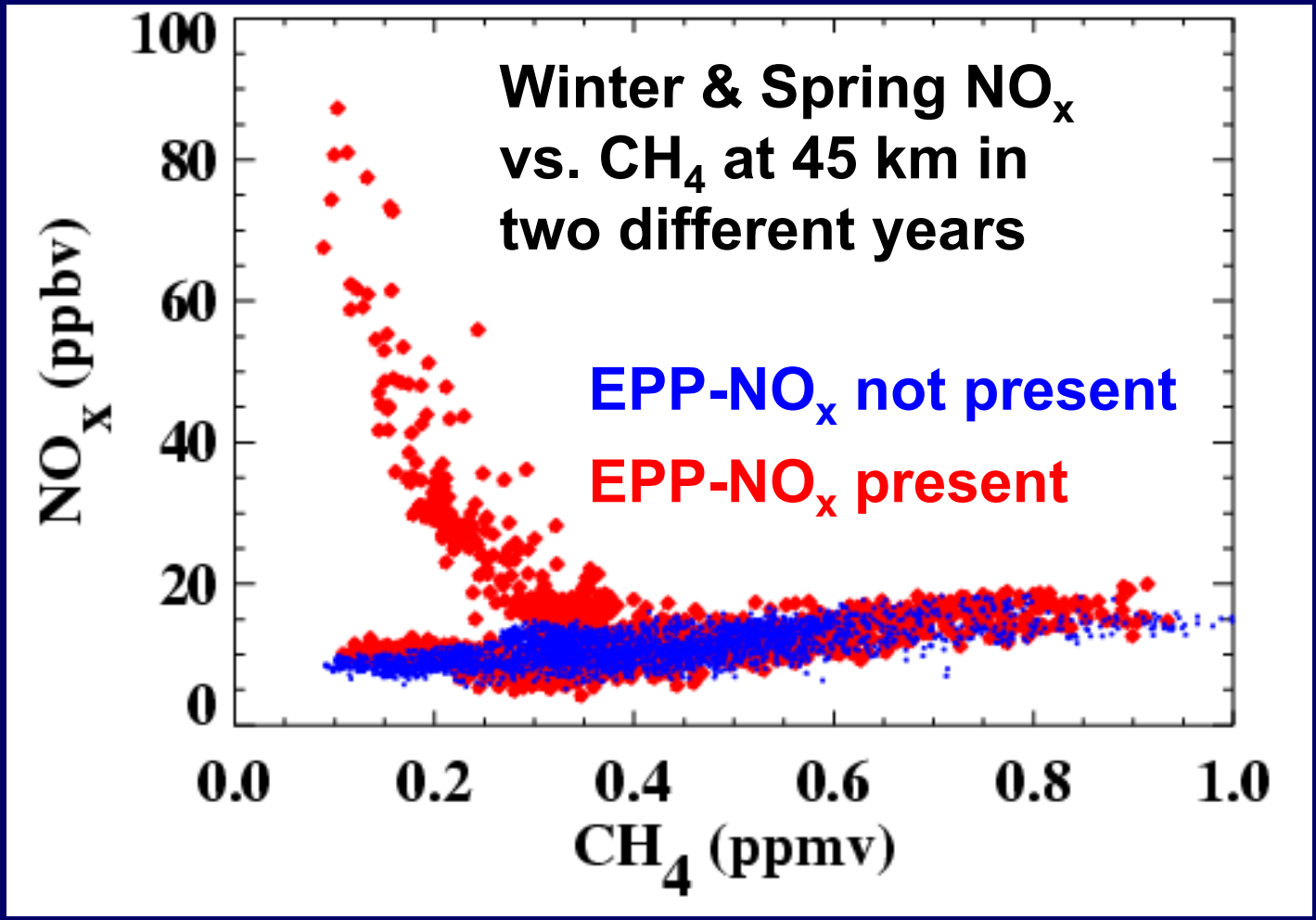


Arctic EPP-NO_x descending from the thermosphere in 2009 as observed by the Atmospheric Chemistry Experiment

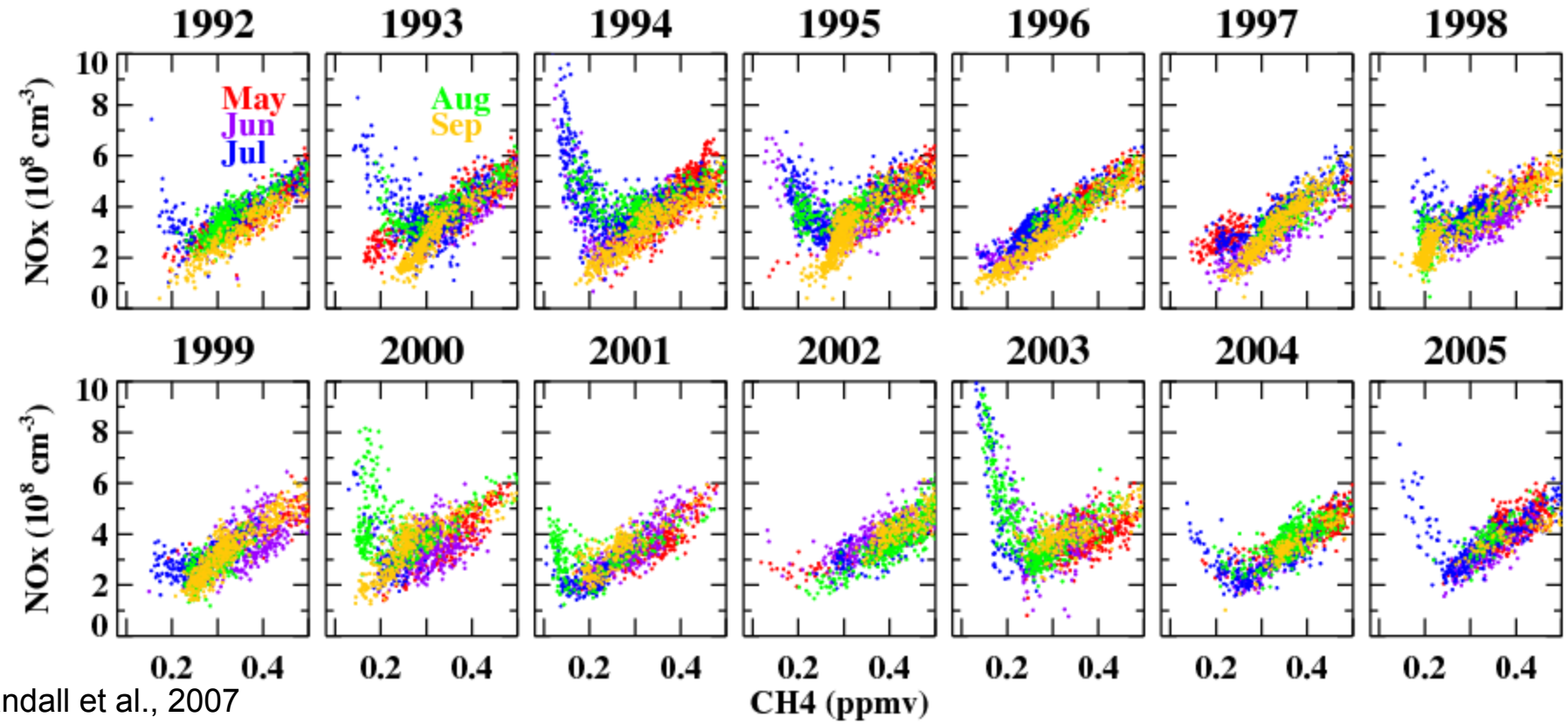


Randall et al., 2009

Historically EPP-NO_x descent identified by CH_4/NO_x anti-correlation:



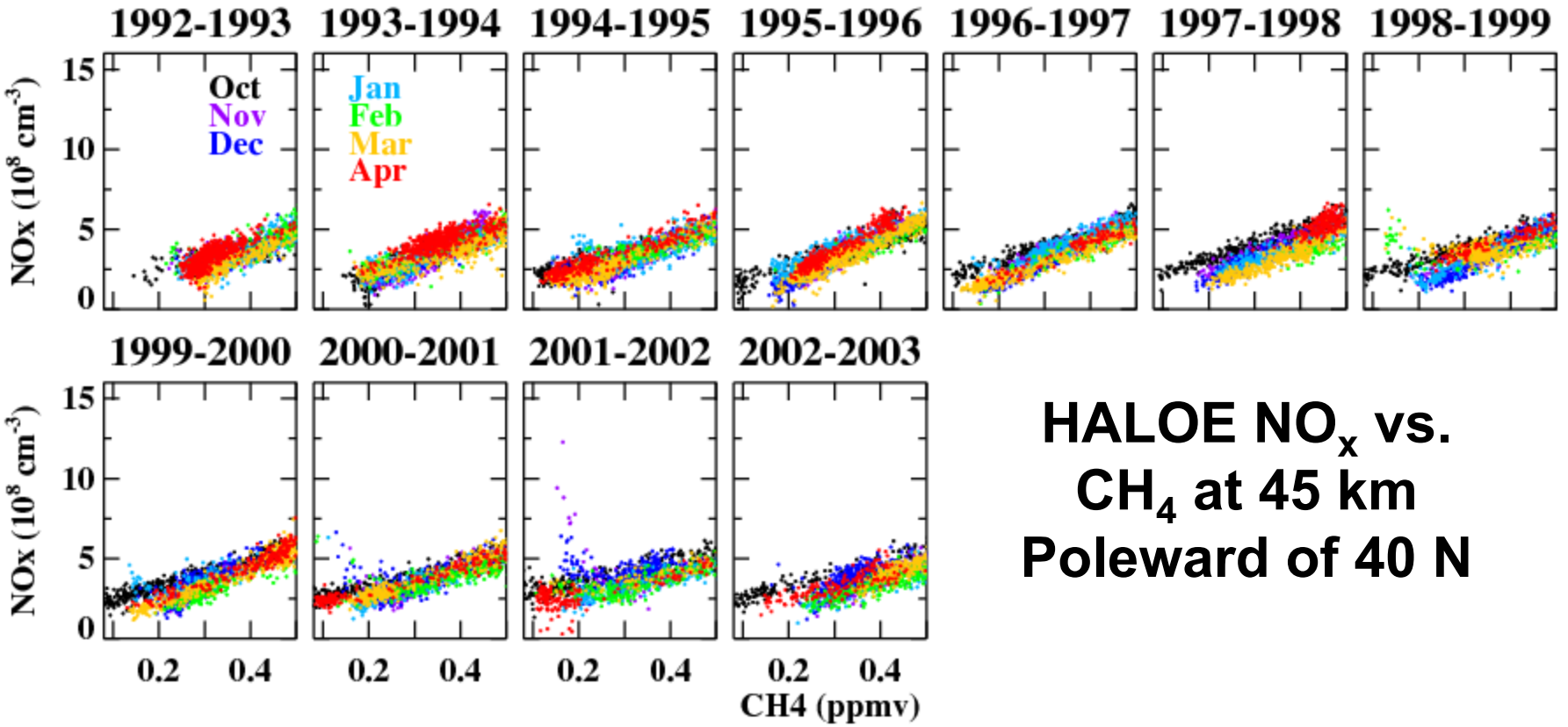
HALOE NO_x vs. CH_4 at 45 km Poleward of 40 S



Randall et al., 2007

HALOE data show that EPP-NO_x descends to the stratosphere in the SH in most years

Through 2002-2003, HALOE data show much less descending EPP-NO_x in the NH



HALOE NO_x vs. CH_4 at 45 km Poleward of 40 N

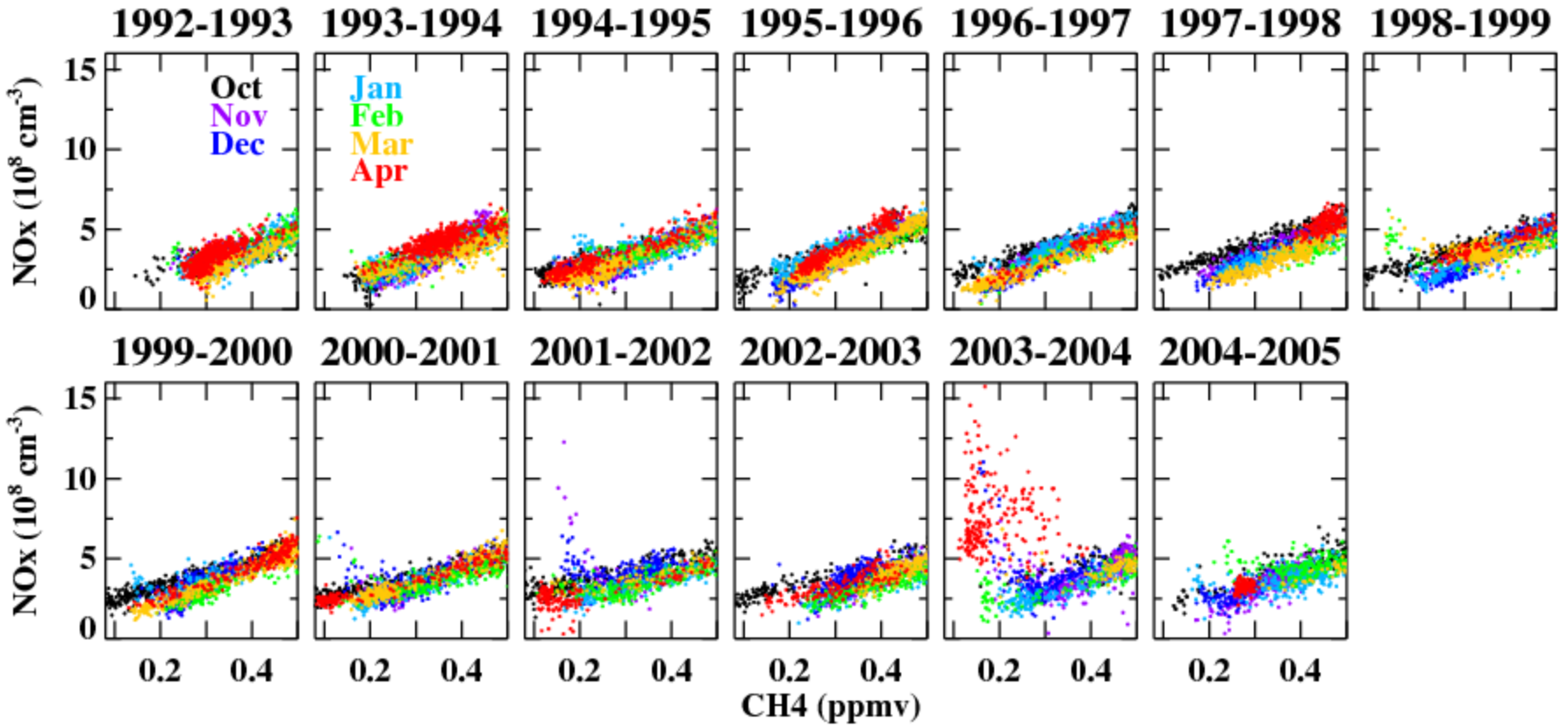
Until 2004, EPP-NO_x was thought to perturb the SH stratosphere much more than NH.

Explanation:

- Stable SH vortex efficiently funnels mesospheric air to stratosphere
- Unstable NH vortex allows NO_x transport to sunlit latitudes before descent can occur

In 2004 the picture began to change...

The EPP IE in the NH in 2004 was unprecedented

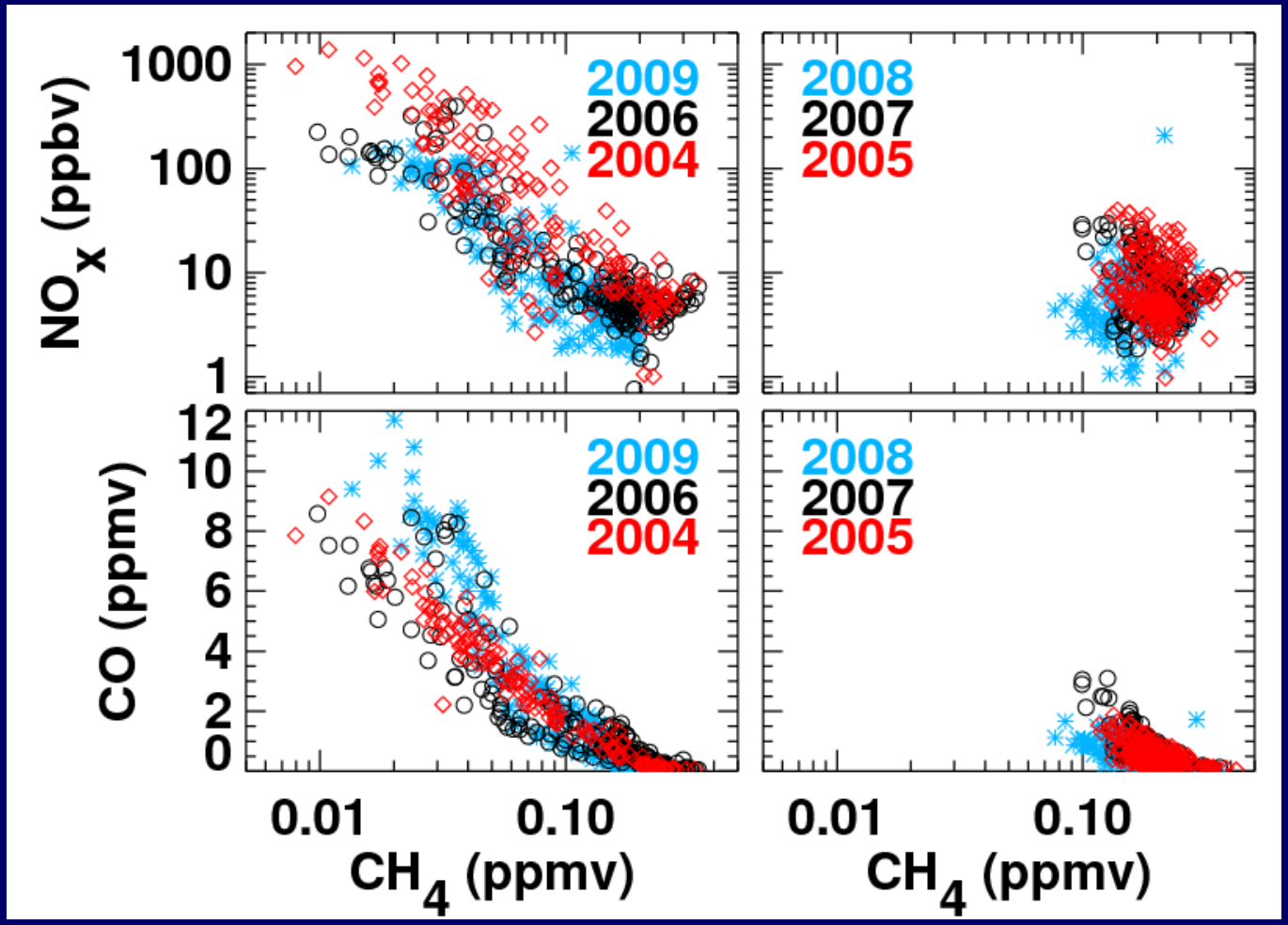


Unusual EPP: Halloween storms

Unusual Meteorology: Extraordinary recovery from strat warming – strong vortex & enhanced descent in mesosphere

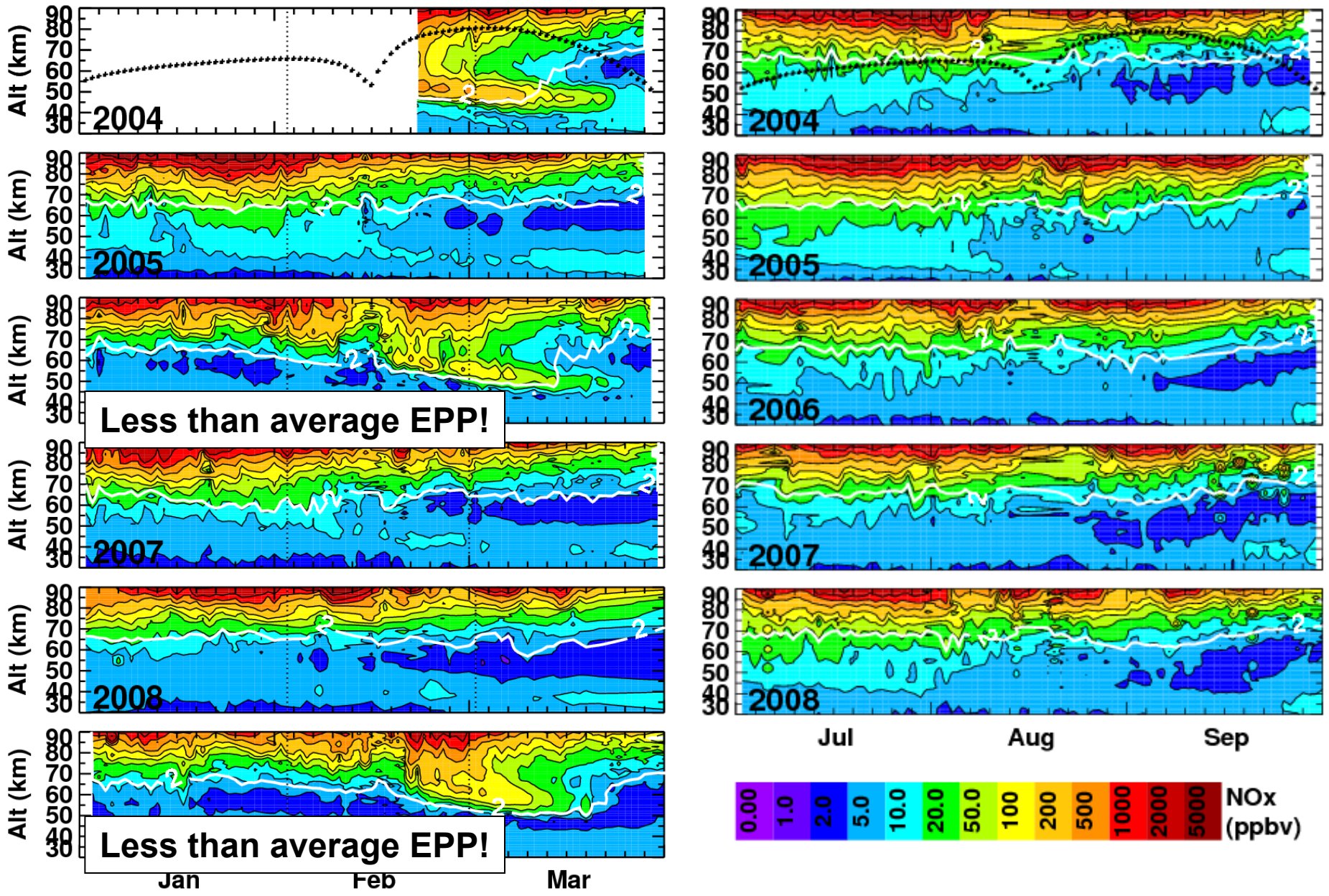
Natarajan, Clilverd, Seppälä, Randall, Rinsland, Orsolini, Verronen, Löpez-Puertas, Hauchecorne, Degenstein, Jackman, Rohen, Semeniuk....

ACE NO_x, CH_4, CO at 55 km, Jan-Mar, Poleward of 50N

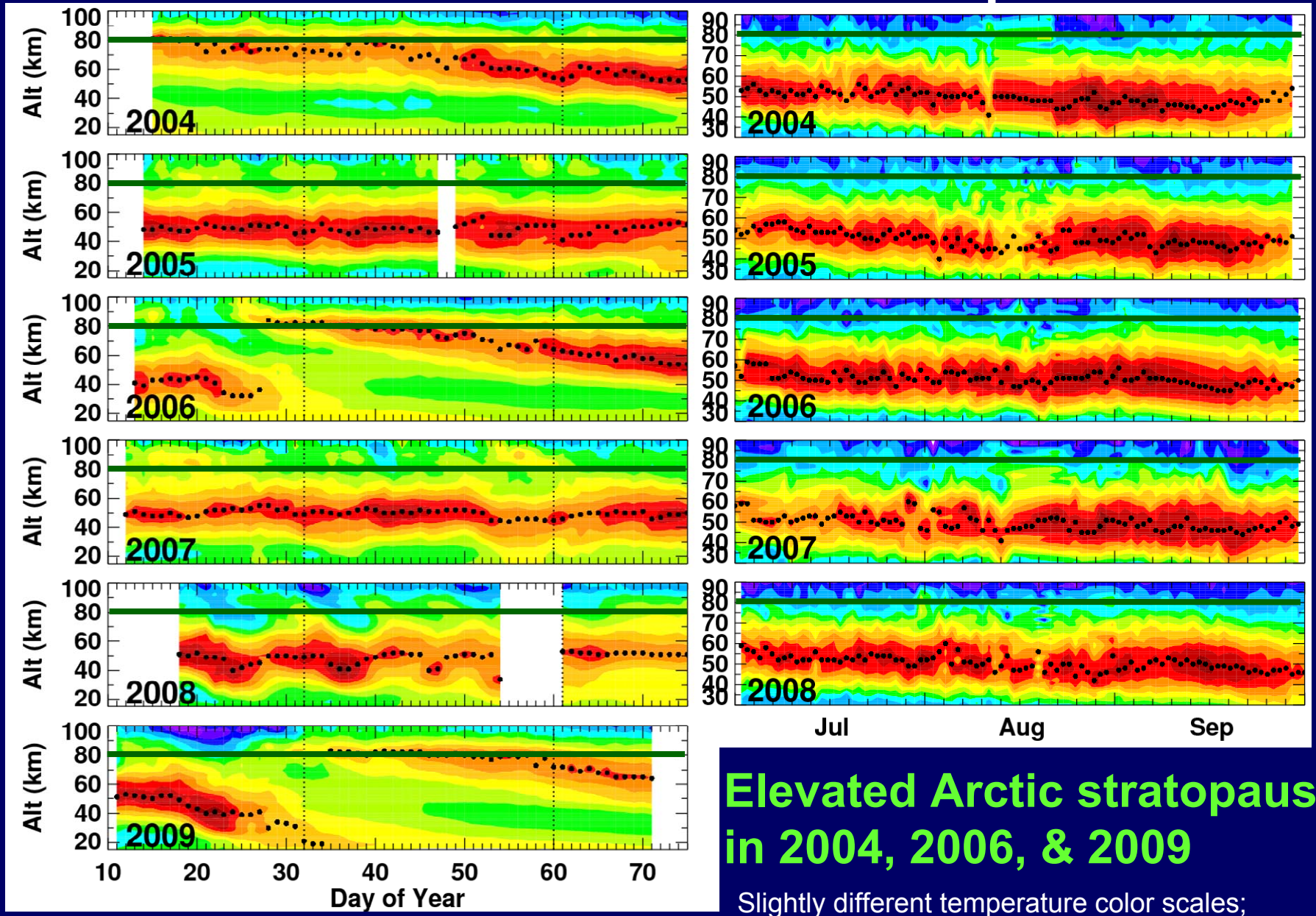


- 2005, 2007, 2008 similar to previous years
- 2004, 2006, 2009 indicate significant descent of EPP-NO_x
- Less mixing in 2004 (tighter CH_4/CO correlation)

NORTH ACE NO_x 2004 – 2009 SOUTH



NORTH SABER & ACE Polar Temp SOUTH

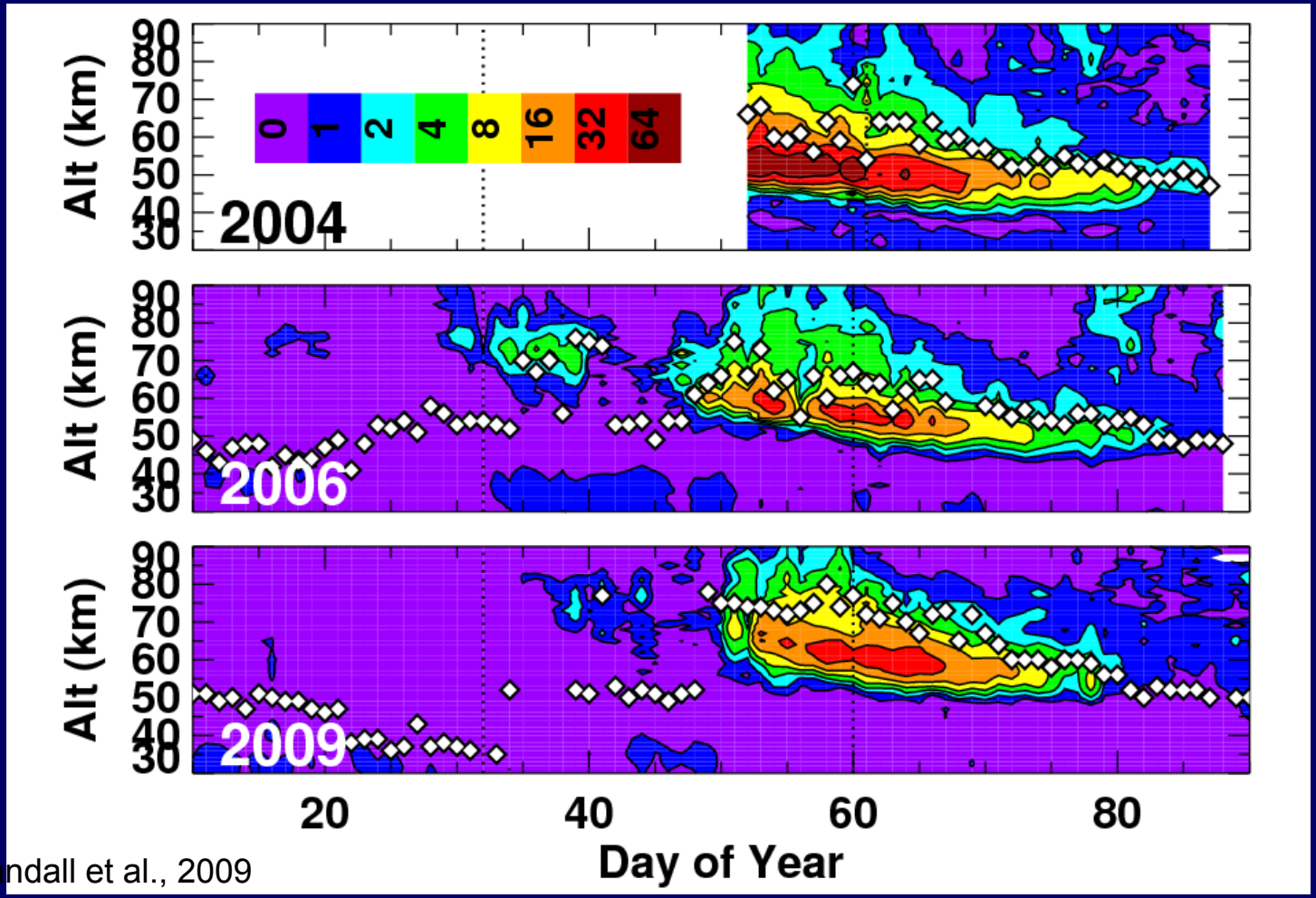


Elevated Arctic stratopause in 2004, 2006, & 2009

Slightly different temperature color scales; range from ~170K-270K (blue-red).

Thanks to Jeff France for SABER data

Ratio of observed NO_x in 2004, 2006, & 2009 to average NO_x in 2005, 2007, & 2008



Randall et al., 2009

NO_x enhancements coincide with elevated stratopause, which indicates enhanced descent at 70-80 km

Why do we get so much NO_x descending to the stratosphere in 2006 & 2009, when EPP itself was so low?

1. Stratospheric Warming: Equator-to-pole T gradient reverses → Zonal wind reverses direction

2. Planetary waves cannot propagate upward so upper stratosphere & lower mesosphere cools

3. Causes reformation of very strong upper vortex and westerly winds

4. Gravity waves with westward phase speed preferentially propagate to the mesosphere

5. Westerly zonal wind slows → induces poleward meridional wind to balance pressure gradient & Coriolis

6. Leads to enhanced descent in the polar mesosphere
   - Brings down more NO_x
   - Adiabatic compression results in elevated stratopause

Why did we get such impressive stratospheric warmings and recovery in 2004, 2006, & 2009 ?
We don't know.

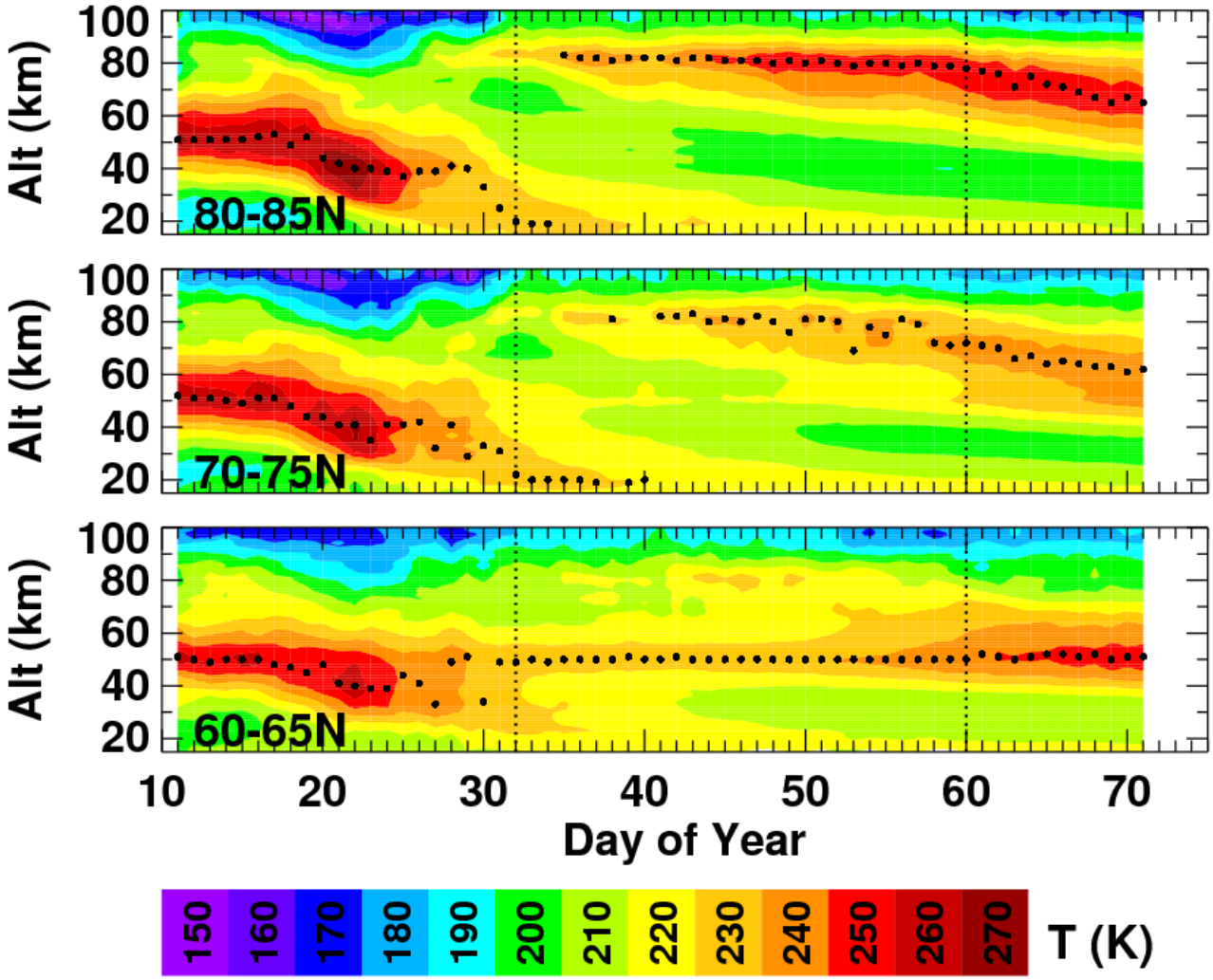
Maybe climate change, but still speculative

- Although 2004, 2006, and 2009 were highly unusual, the frequency of SSW seems to be increasing (~1 per year since 1999, ~once every two years in previous half-century)

- Models predict more variability with climate change, so extremes might occur more often

- Models inconclusive with regard to frequency & strength of SSWs

A caution regarding available data....



SABER shows 2009 stratopause only elevated poleward of 70ºN

Solar occultation instruments have limited sampling

MIPAS & GOMOS just since 2002

ISAMS & CLAES 1991-1993

LIMS 1978-1979

ERA-40 Temperatures up to ~50 km since 1957

Conclusions

- 2009 is now the third year on record since 2004 with extraordinary meteorology & large EPP IE in NH
- Large EPP IE in 2006 & 2009, with very low EPP, emphasizes importance of dynamics
- Results contribute to growing body of evidence that the 2003 Halloween storms were *not* responsible for the exceptional stratospheric NO_x enhancements the following spring
- Caution is warranted regarding climate implications, but speculation is tempting:

  IF the dynamics in 2004, 2006, & 2009 are becoming the norm rather than the exception, stratospheric NO_x enhancements such as those seen in 2004 will become much more prevalent.

Thanks very much!