WACCM simulations of the chemical response of the high-latitude middle atmosphere to solar proton events

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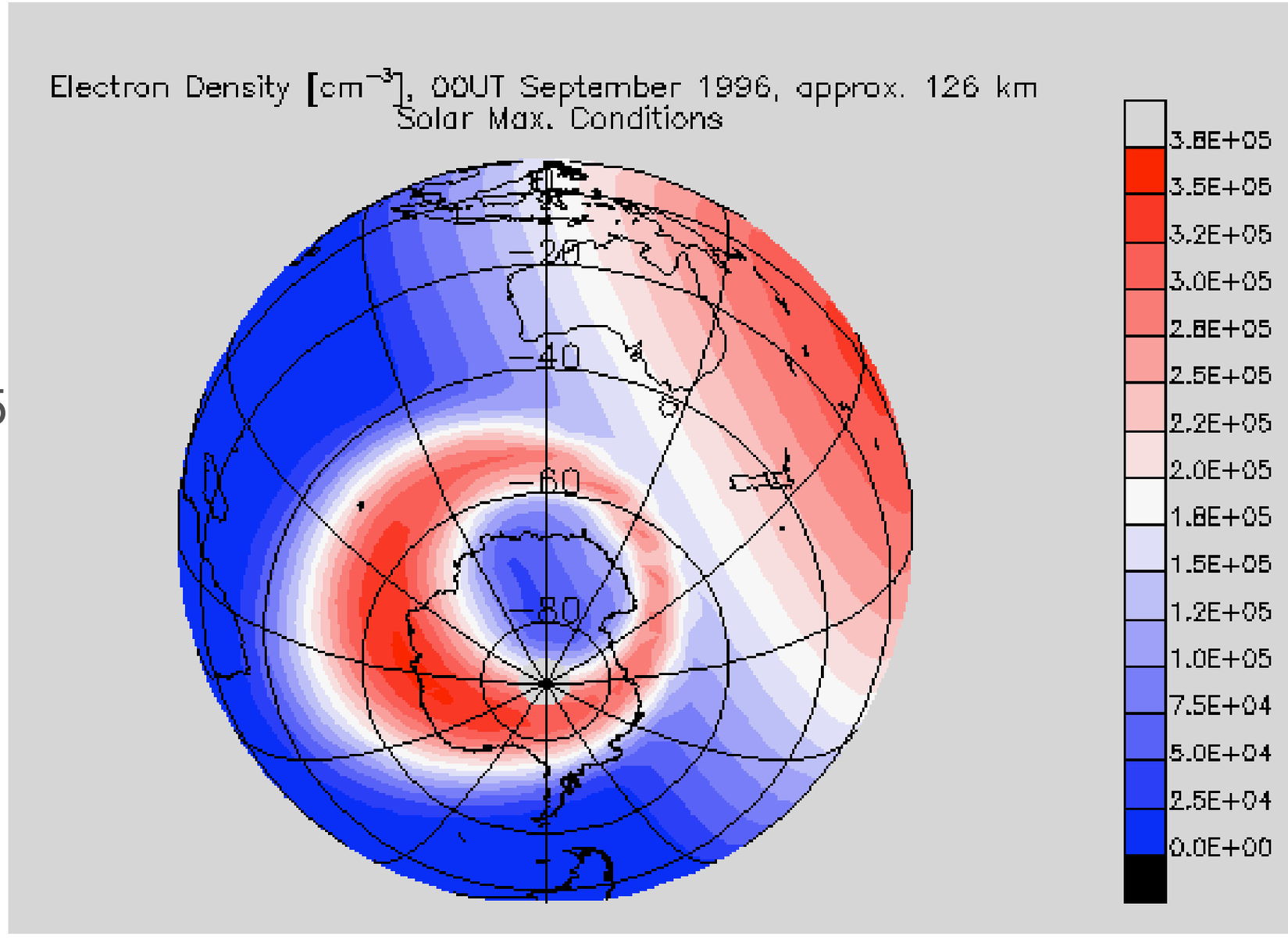
WACCM-3.5

Model Framework	Dynamics	Tracer Advection	Resolution	Chemistry	Other Processes
Extension of the NCAR Community Atmosphere Model version 3 (CAM3) Based upon CAM3.5.48	Finite Volume Dynamical Core (Lin, 2004) Fully-interactive with chemistry, i.e., consistent with model-derived, radiatively active gases: O3, CO2, CH4, N2O, H2O, CFC11, CFC12, O2, NO	Flux-form Finite Volume (Lin, 2004)	Horizontal: 1.9° x 2.5° (lat x lon) Vertical: 66 levels 0-140km < 1.0km in UTLS 1-2 km in stratosphere ~3 km in MLT	Middle Atmosphere Mechanism: 57 Species including Ox, HOx, NOx, BrOx, and ClOx Heterogeneous chemistry E-region Ion Chemistry	GW Param.: convection-, frontal-, and orographically-generated Molecular Diffusion: Banks and Kockarts, 1973 Auroral processes, including ion drag, and Joule heating LW/SW and chemical potential heating

WACCM-3.5

- WACCM modifications for the upper atmosphere:
  - Variability of solar spectrum
  - Chemical heating
  - Airglow
  - E-region ion chemistry (5 ions & electrons)
  - EUV and x-ray ionization
  - Auroral processes
    - Particle precipitation
    - Ion drag
    - Joule heating



SPE effects on chemistry in 2004/2005

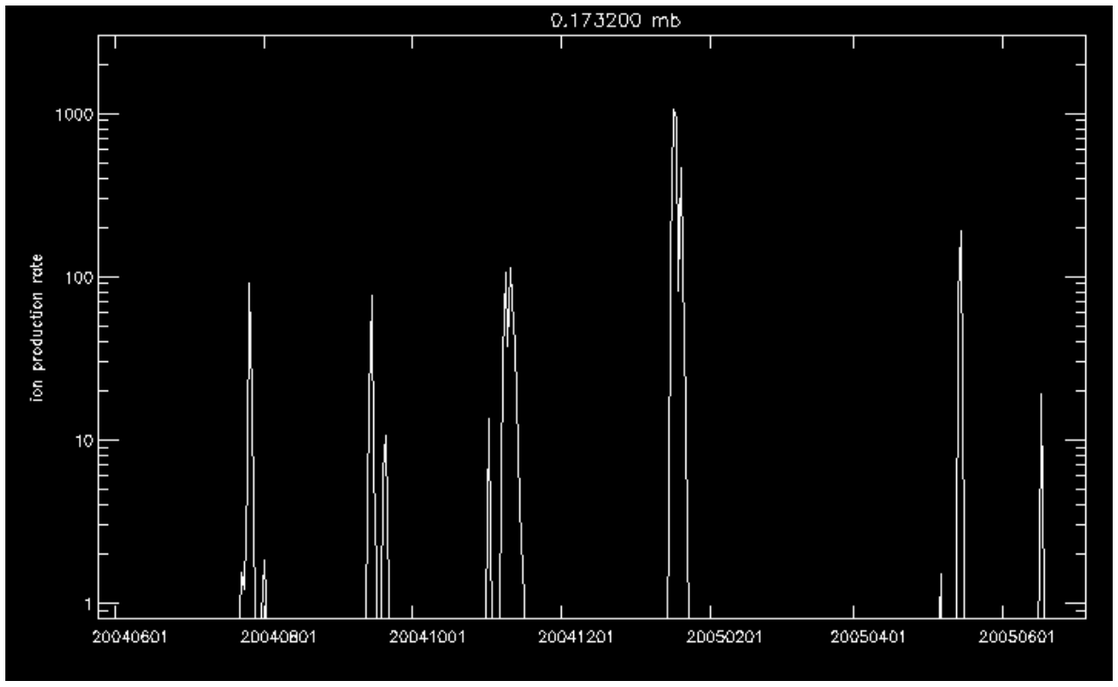
- Model / data comparisons are difficult in a free running model due to not reproducing exact dynamics

- Observations show efficiency of EPP varies strongly with strength of residual circulation and isolation of NH polar winter

- Solution: ‘nudge’ WACCM to reanalysis

  - Look at chemical effects only

SPE ionization 0.2hPa in 2004-2005



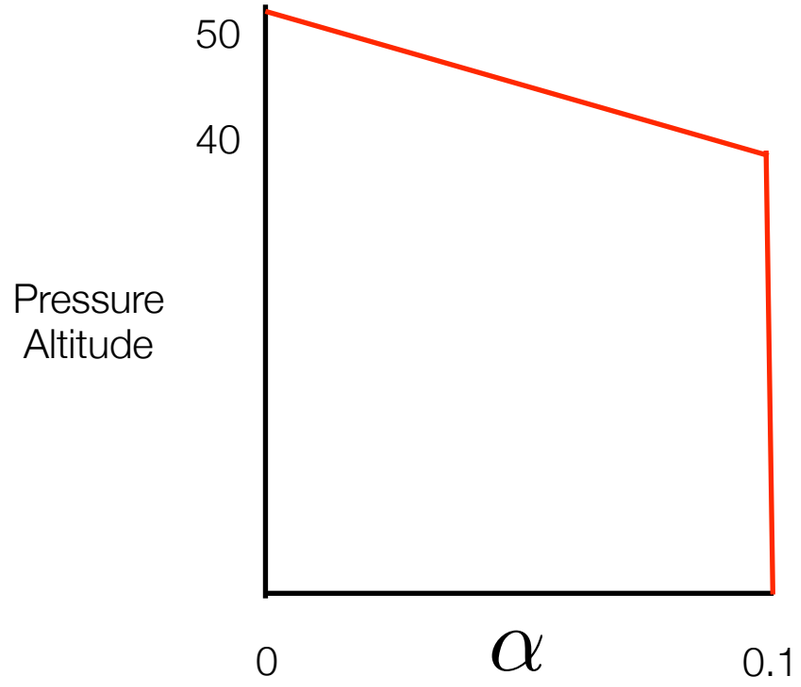
June 2004 Dec 2004 June 2005

WACCM with GEOS-5 ‘nudging’

At each time step:

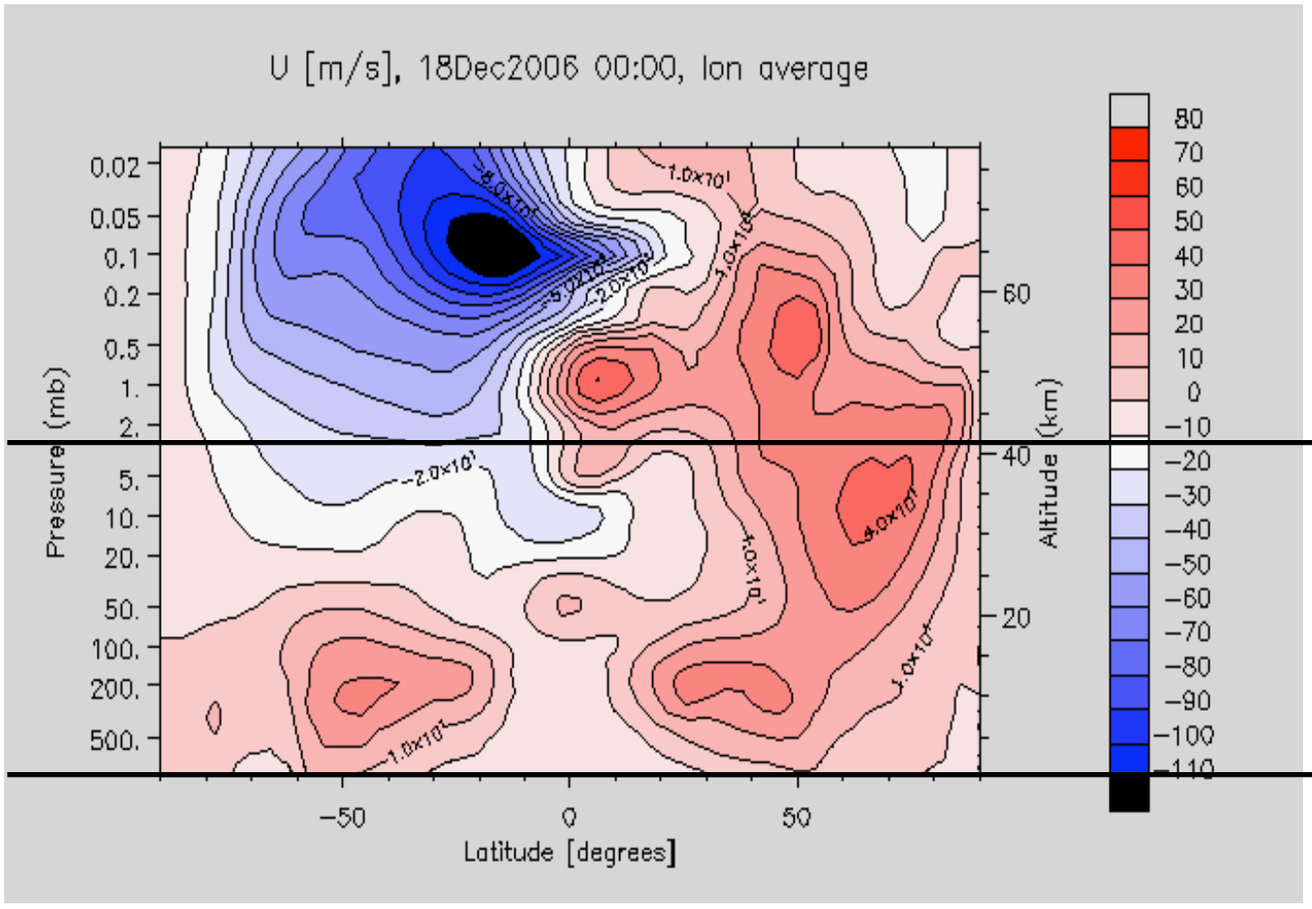
$$(u, v, T) = \alpha \times (u, v, T)_{GEOS5} + (1 - \alpha) \times (u, v, T)_{WACCM}$$

$\alpha = 0.1$

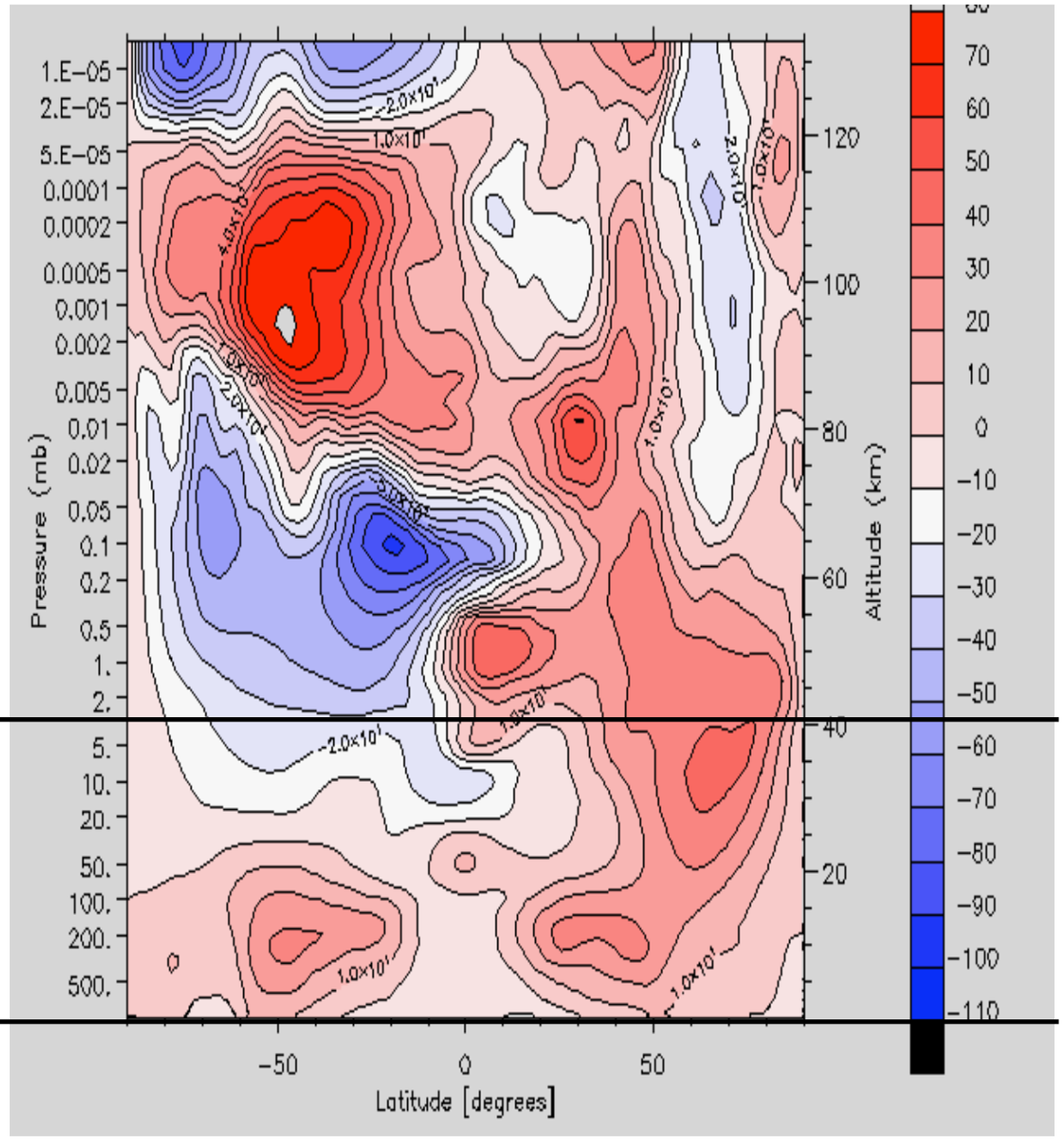


Zonal wind Dec 18, 2008

GEOS5



WACCM



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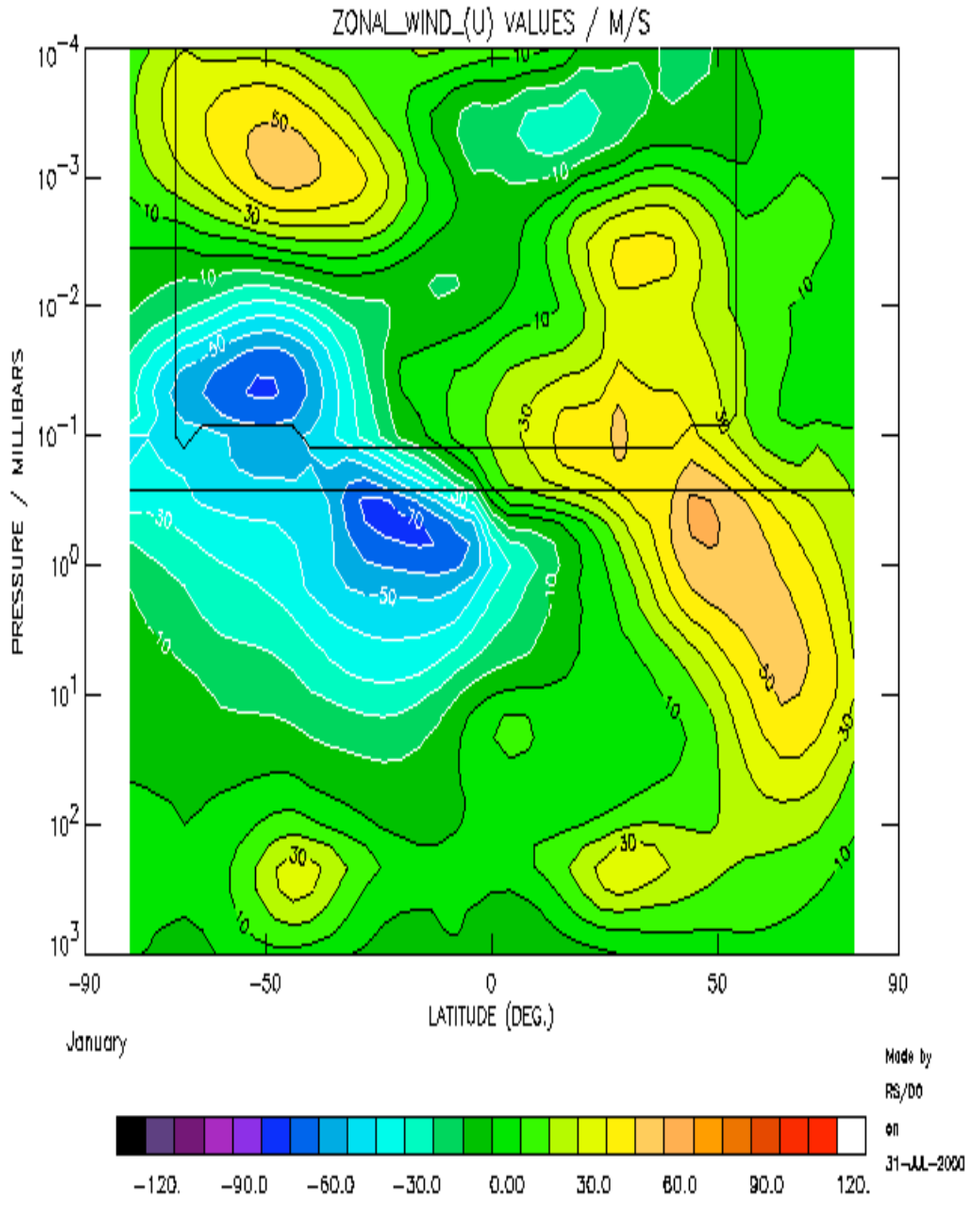
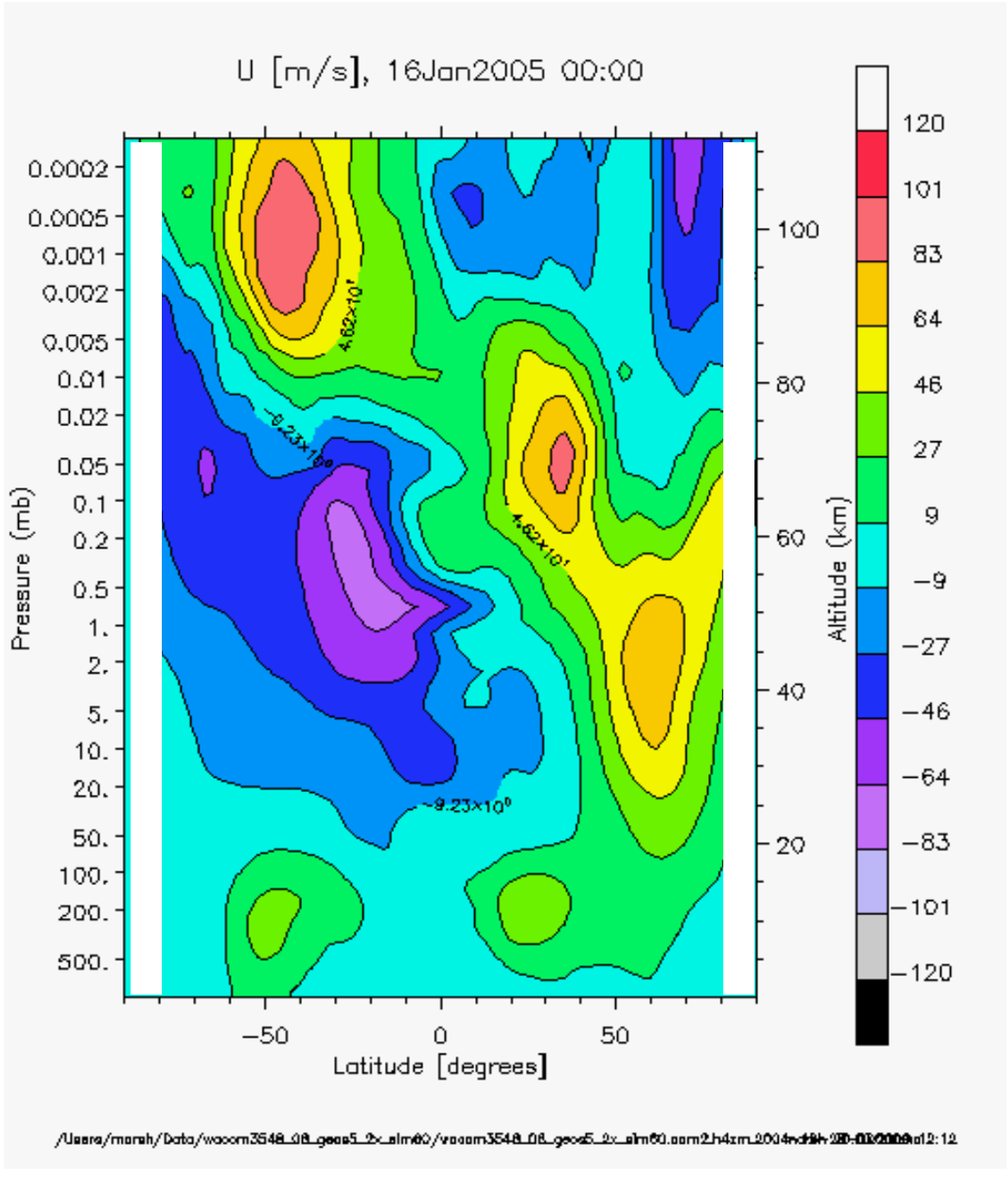
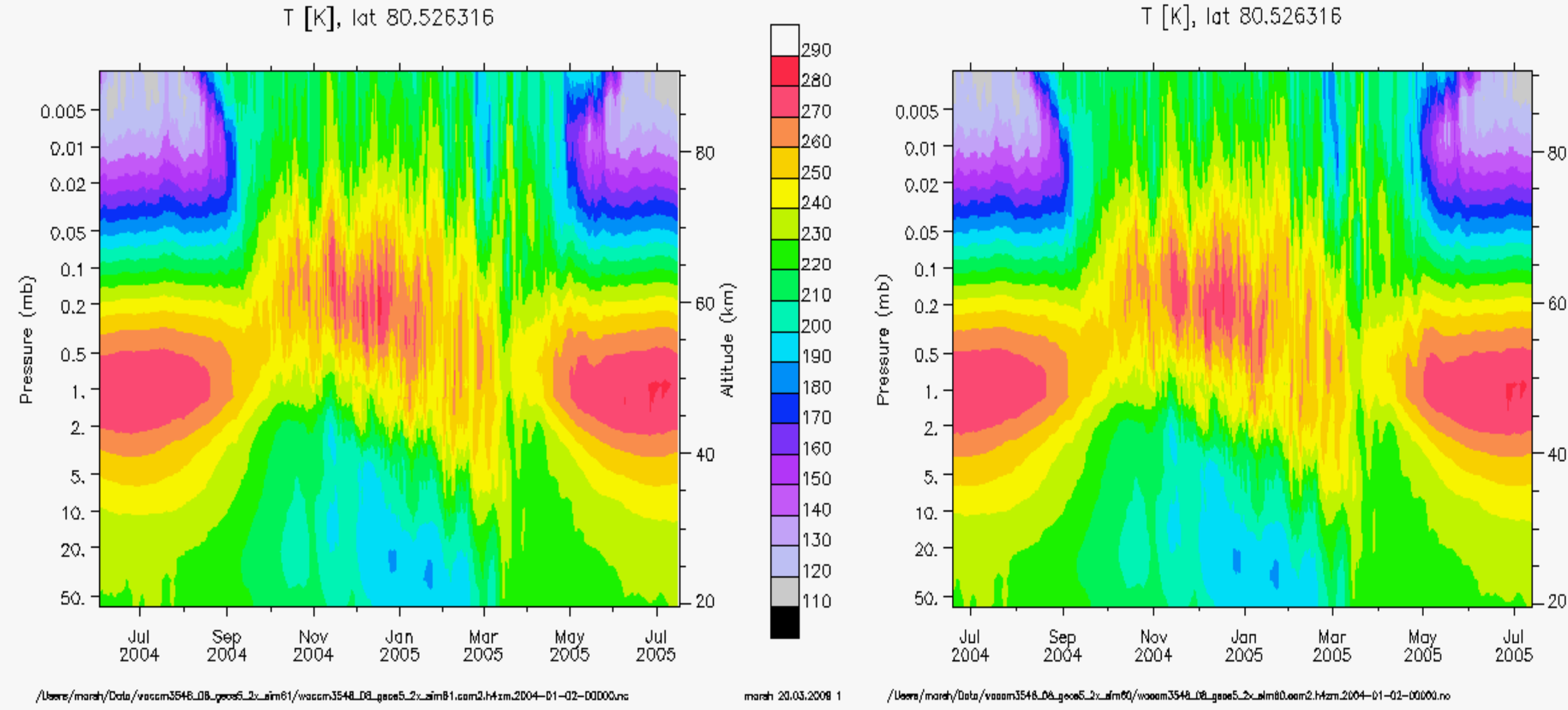
Comparison to UARS Reference Atmosphere

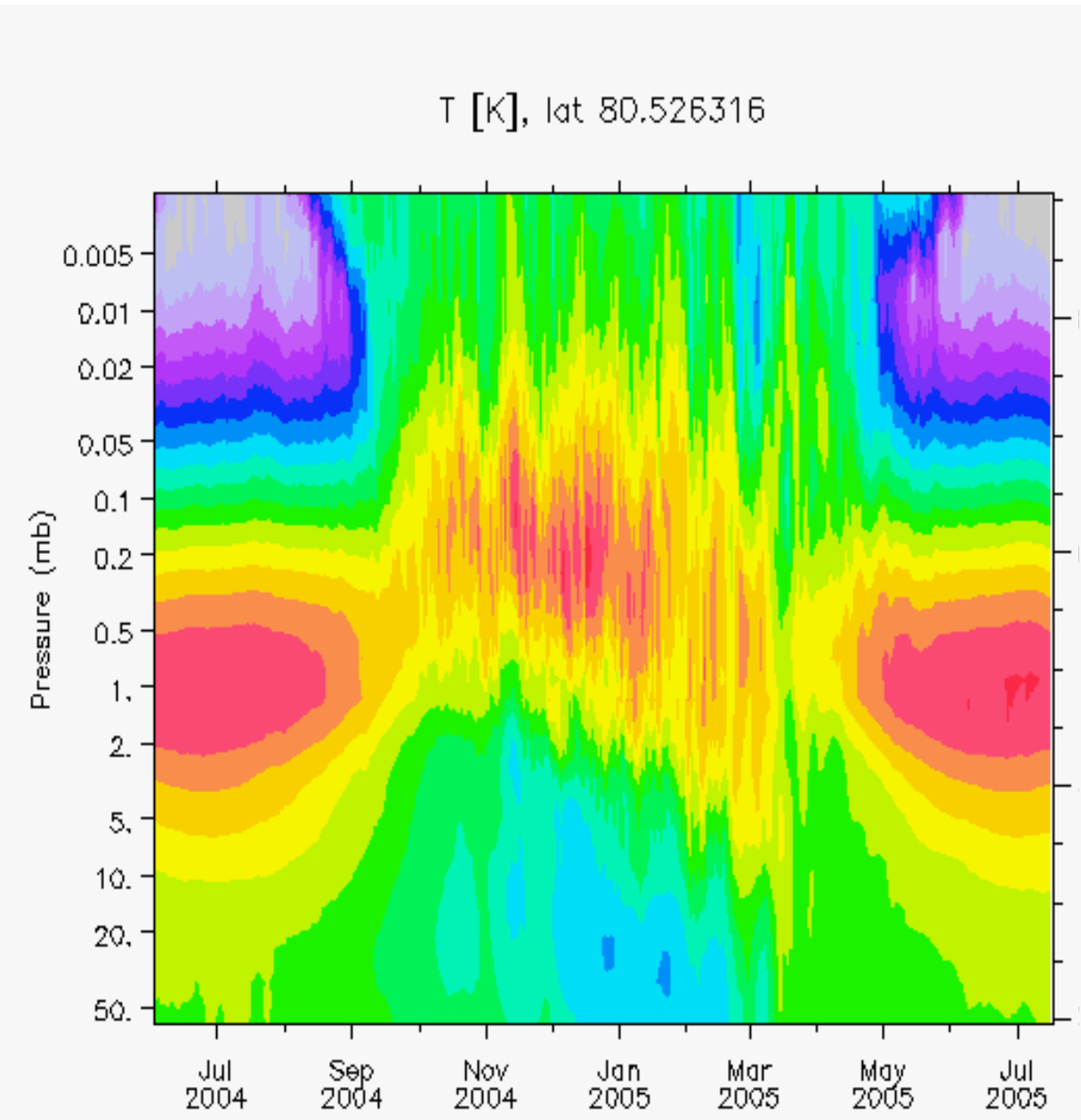


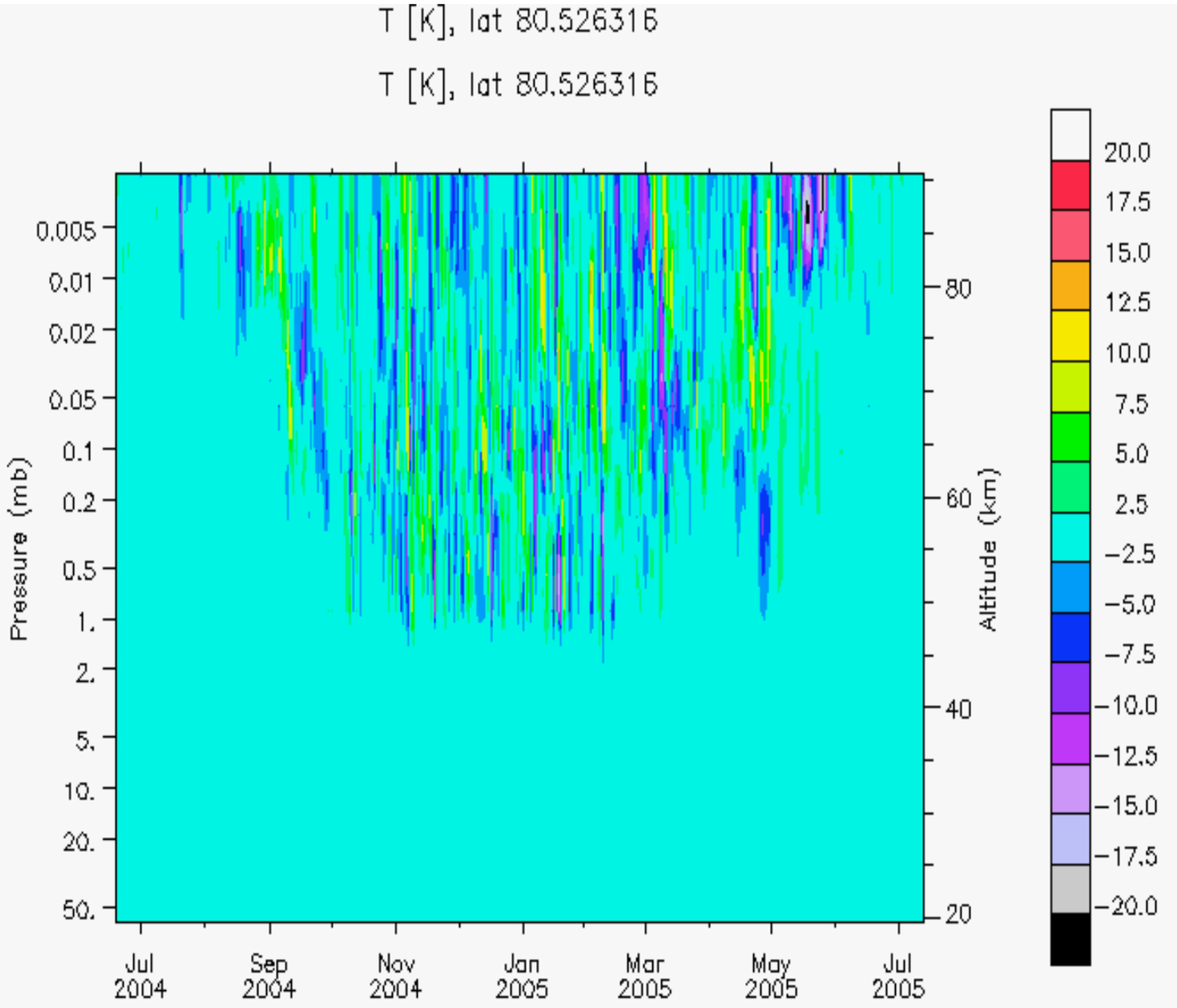


Zonal-mean temperature 80.5°N

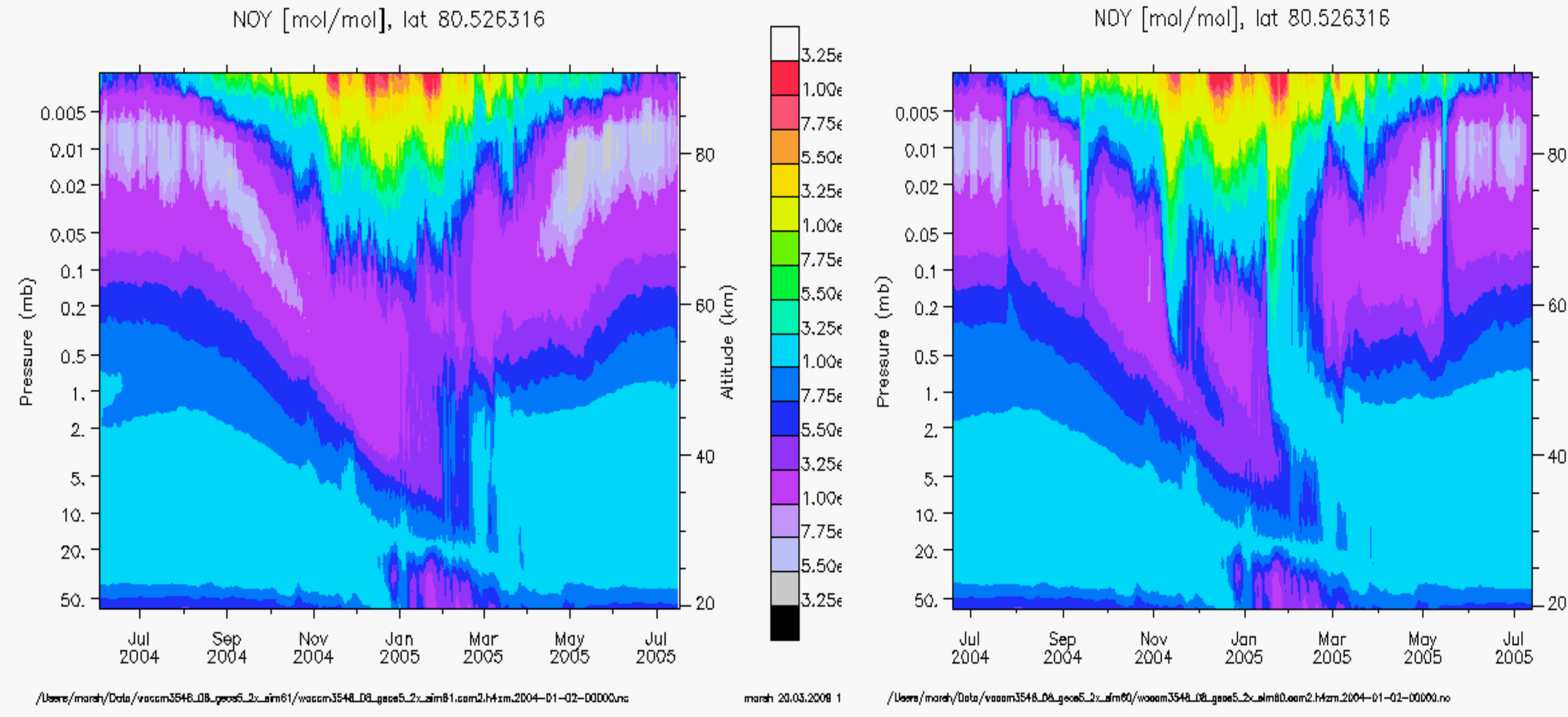


Zonal-mean temperature 80.5°N





Zonal-mean NOy 80.5°N



NOy (=N+NO+NO_2+NO_3+N_2O_5+HNO_3+HO_2NO_2+$ClONO_2$+$BrONO_2$)

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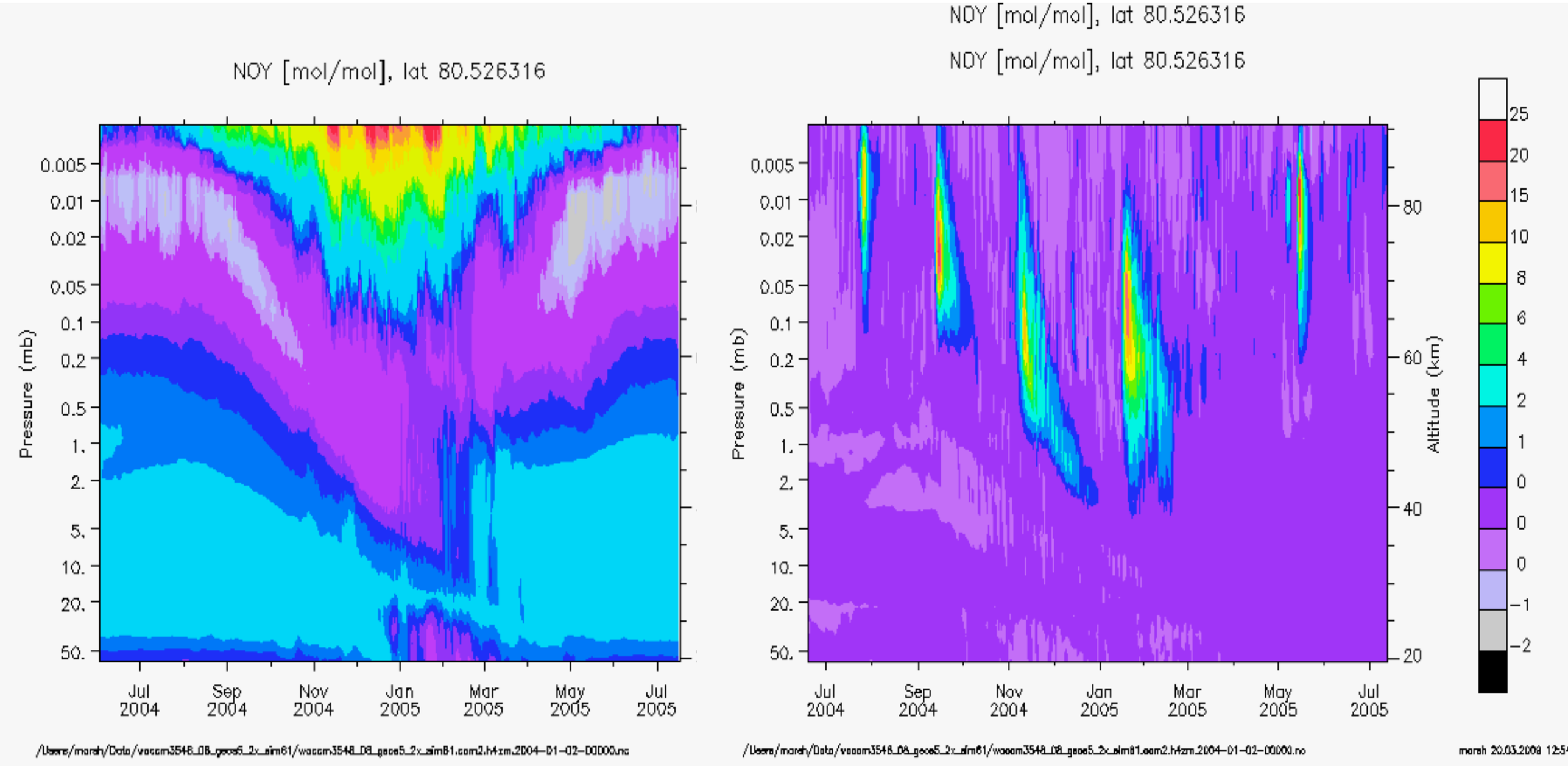
Zonal-mean NOy 80.5°N



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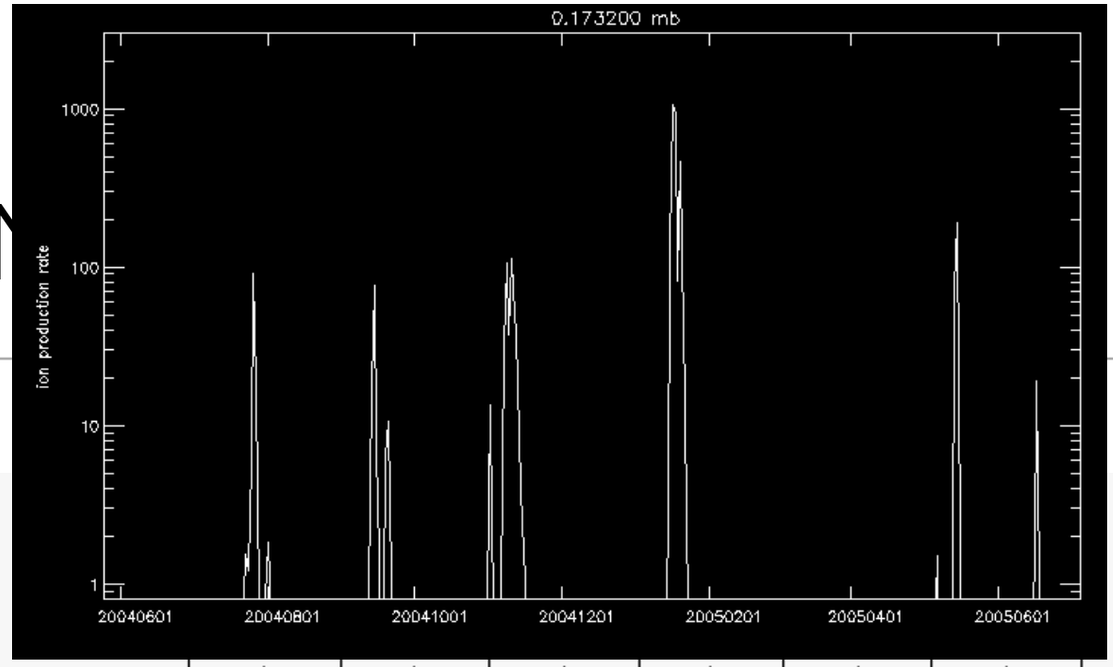
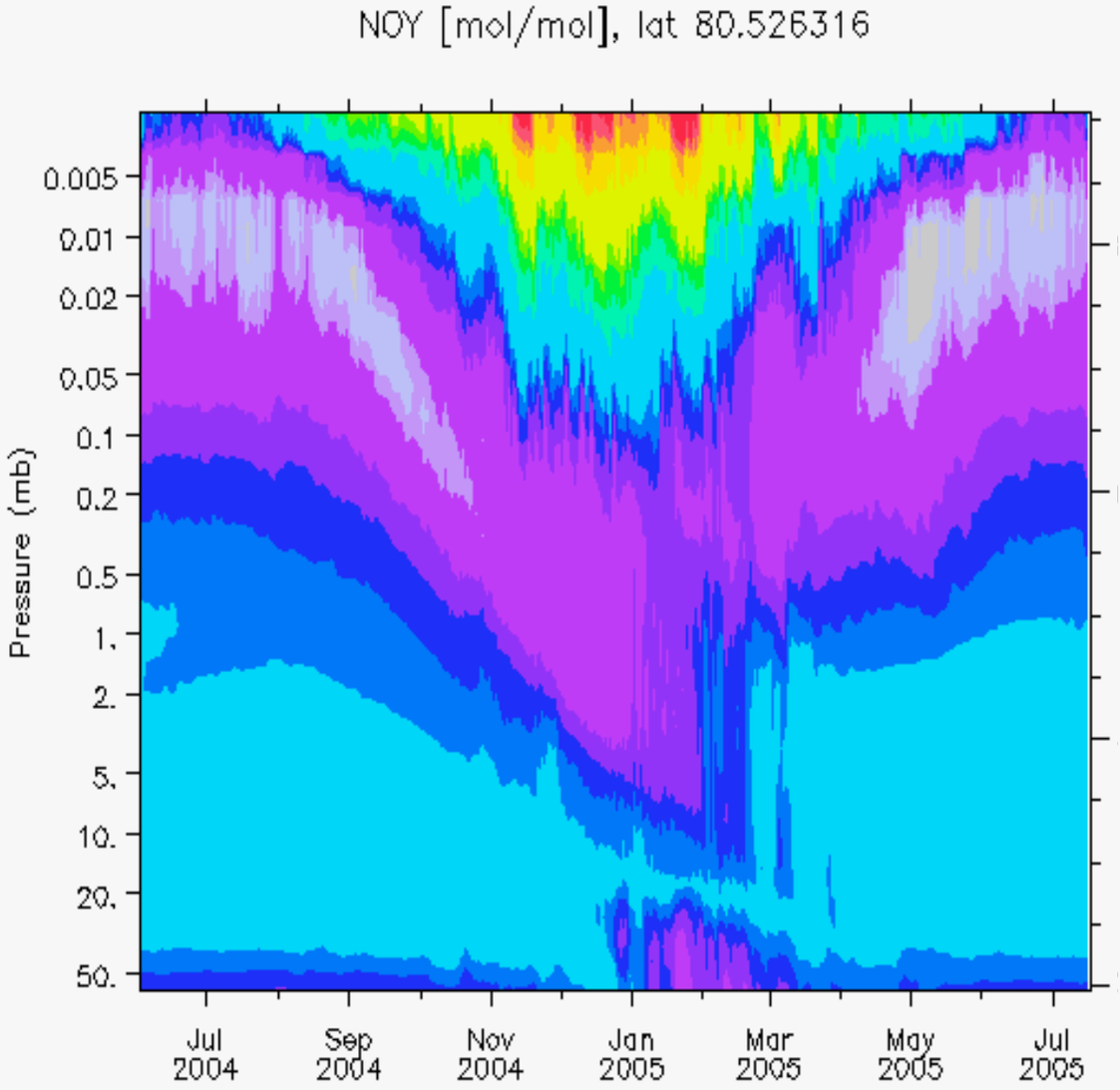
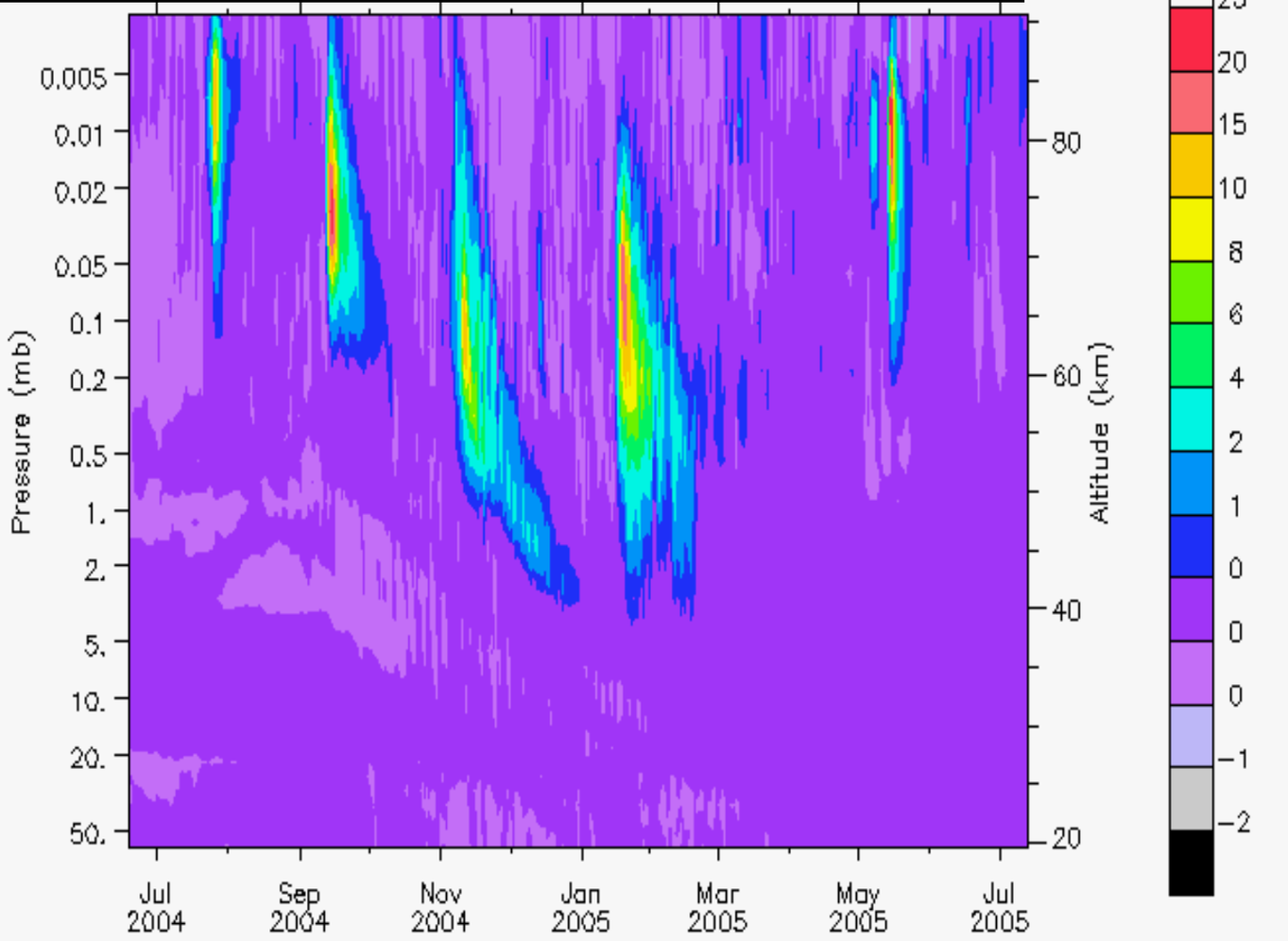
Zonal-mean NOy 80.5°N







NOy (=N+NO+NO_2+NO_3+N_2O_5+HNO_3+HO_2NO_2+$ClONO_2$+$BrONO_2$)

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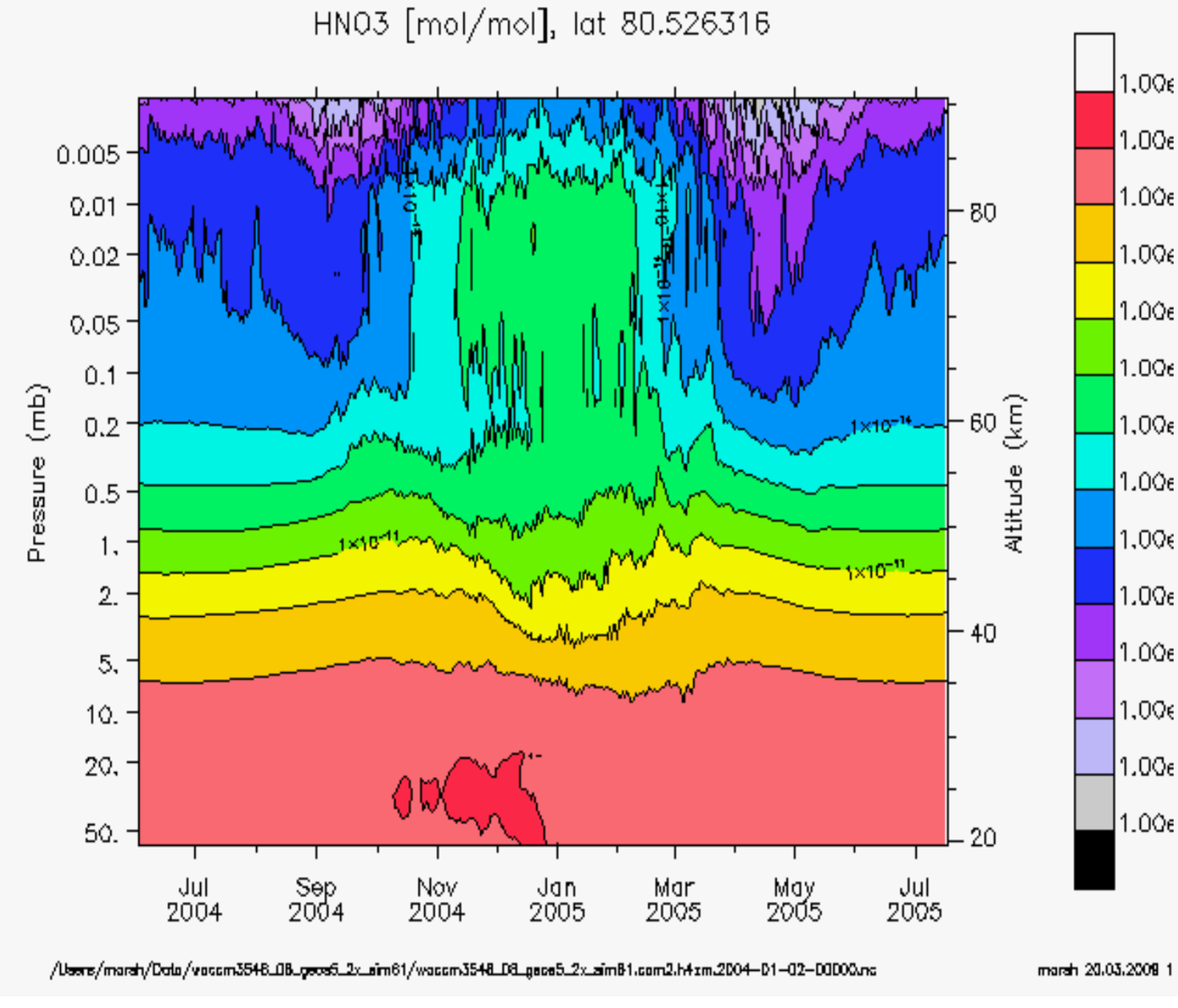
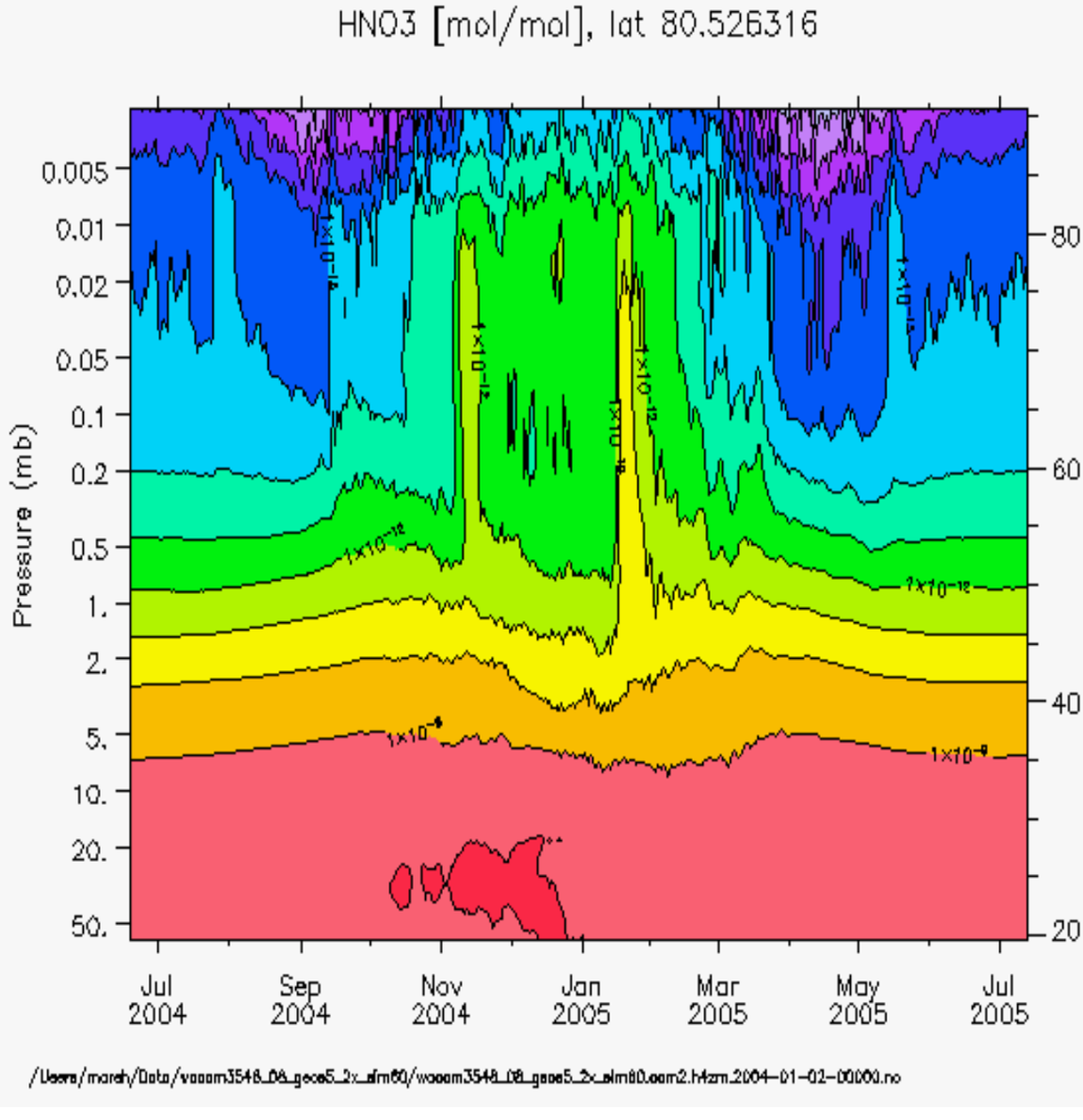
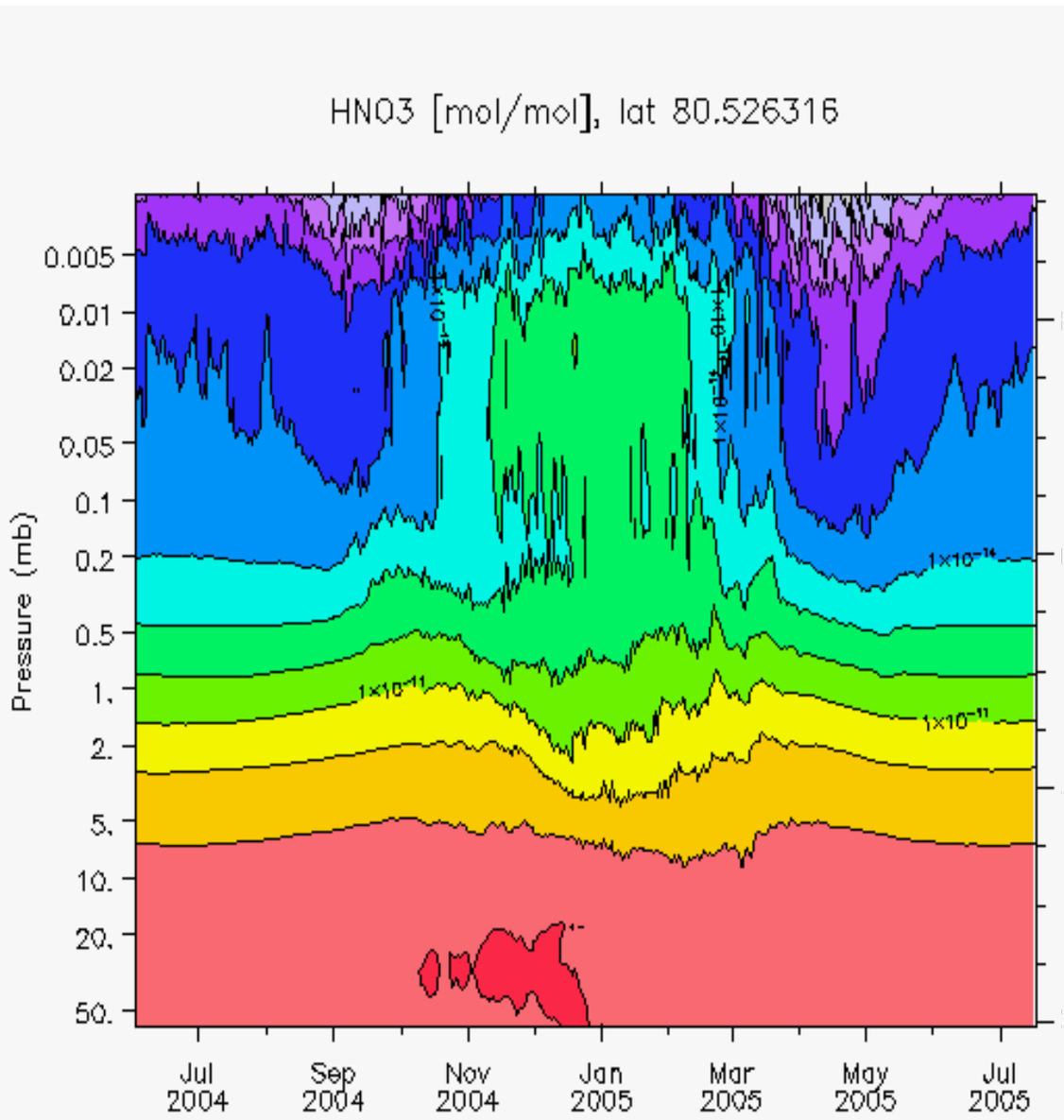
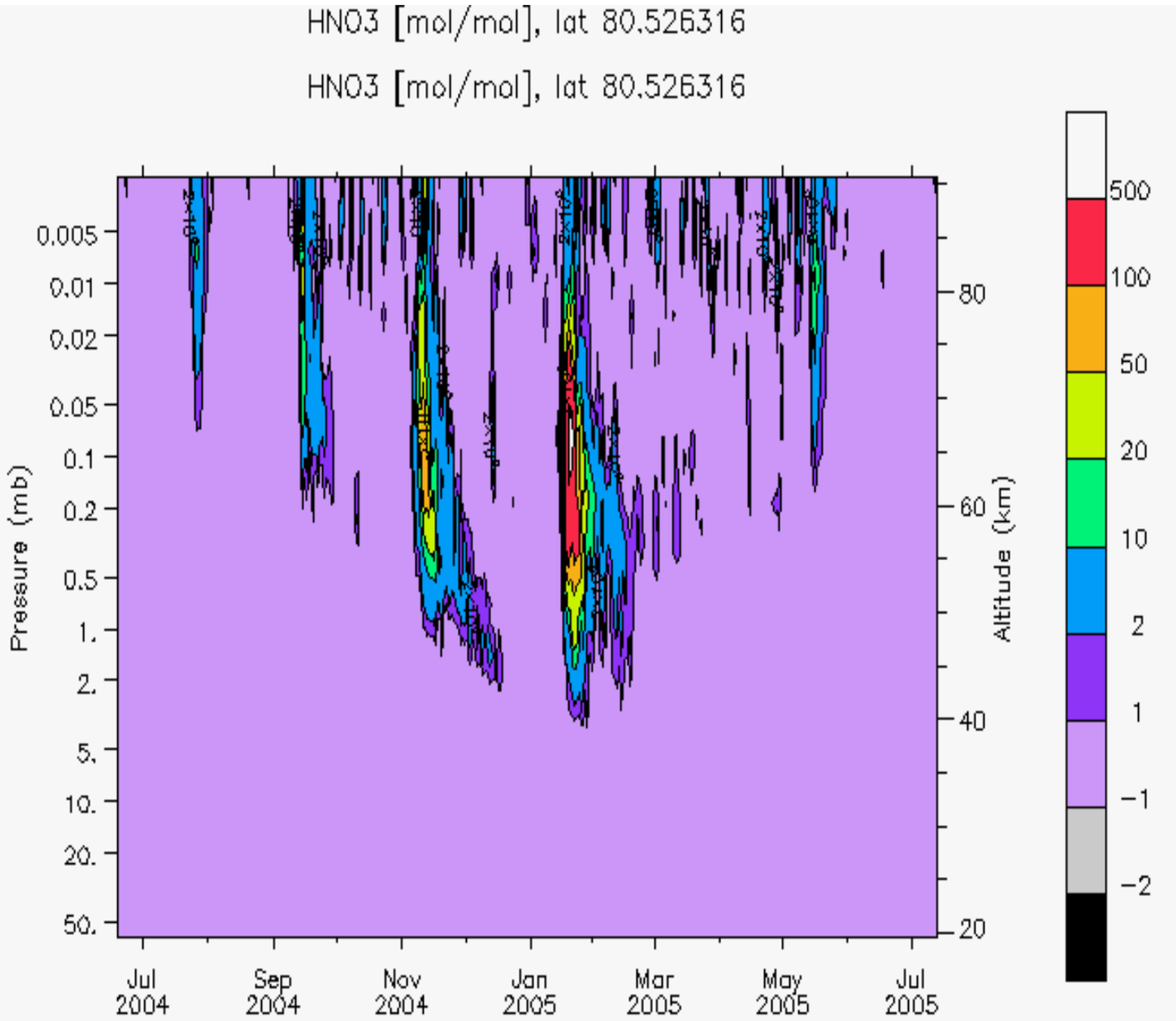
Zonal-mean HNO_3 80.5°N



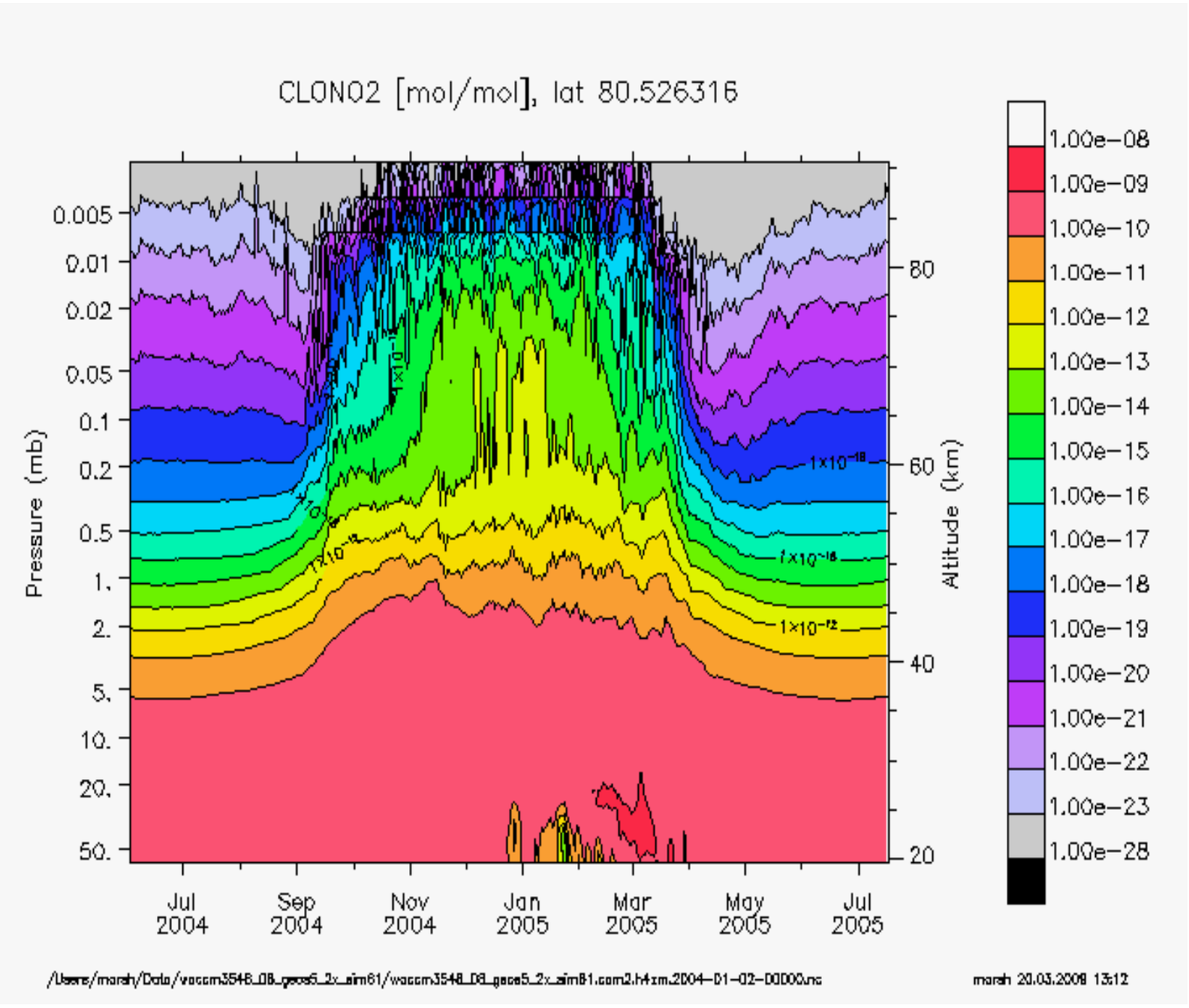


Zonal-mean HNO_3 80.5°N

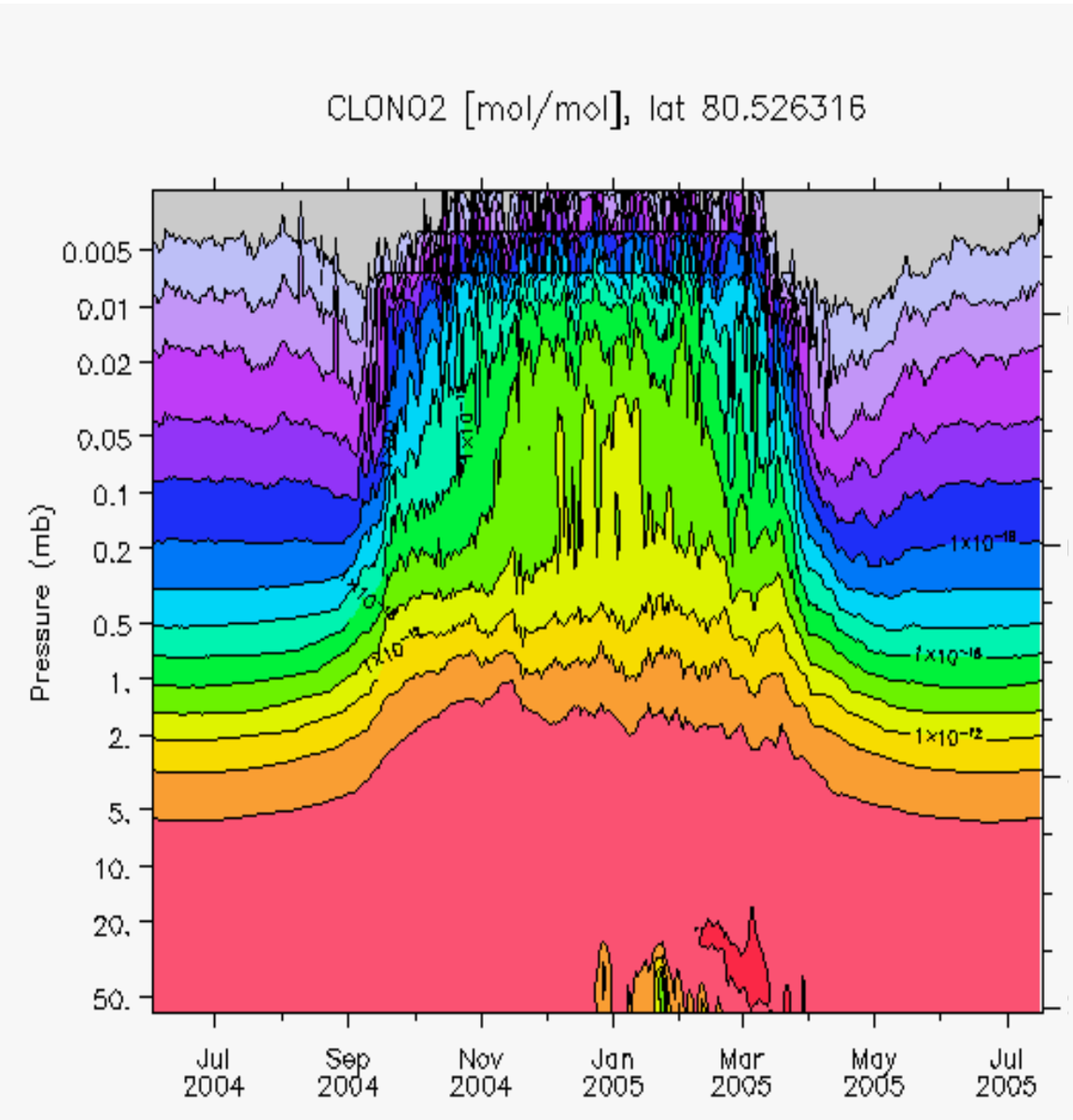


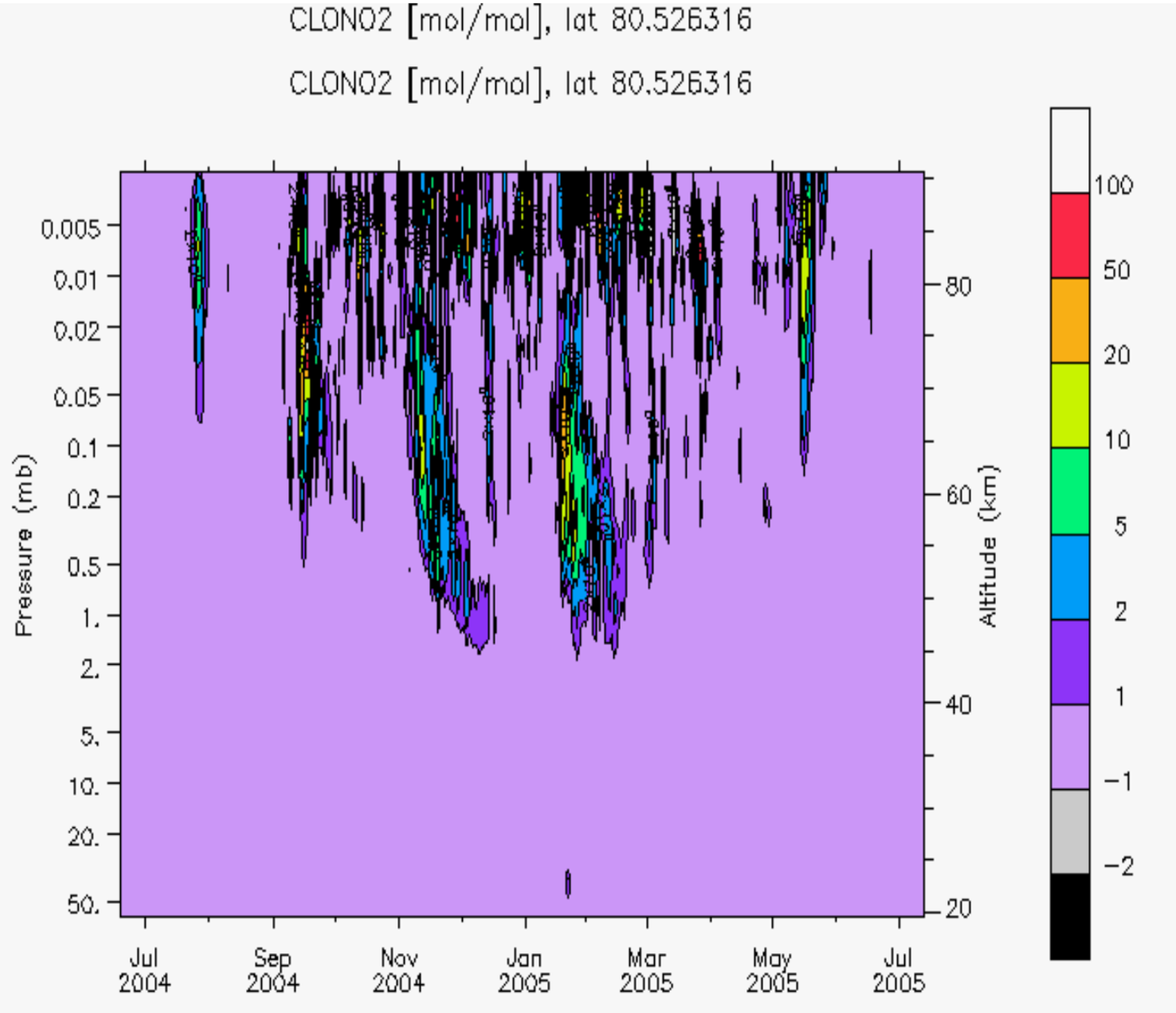


Zonal-mean $ClONO_2$ 80.5°N

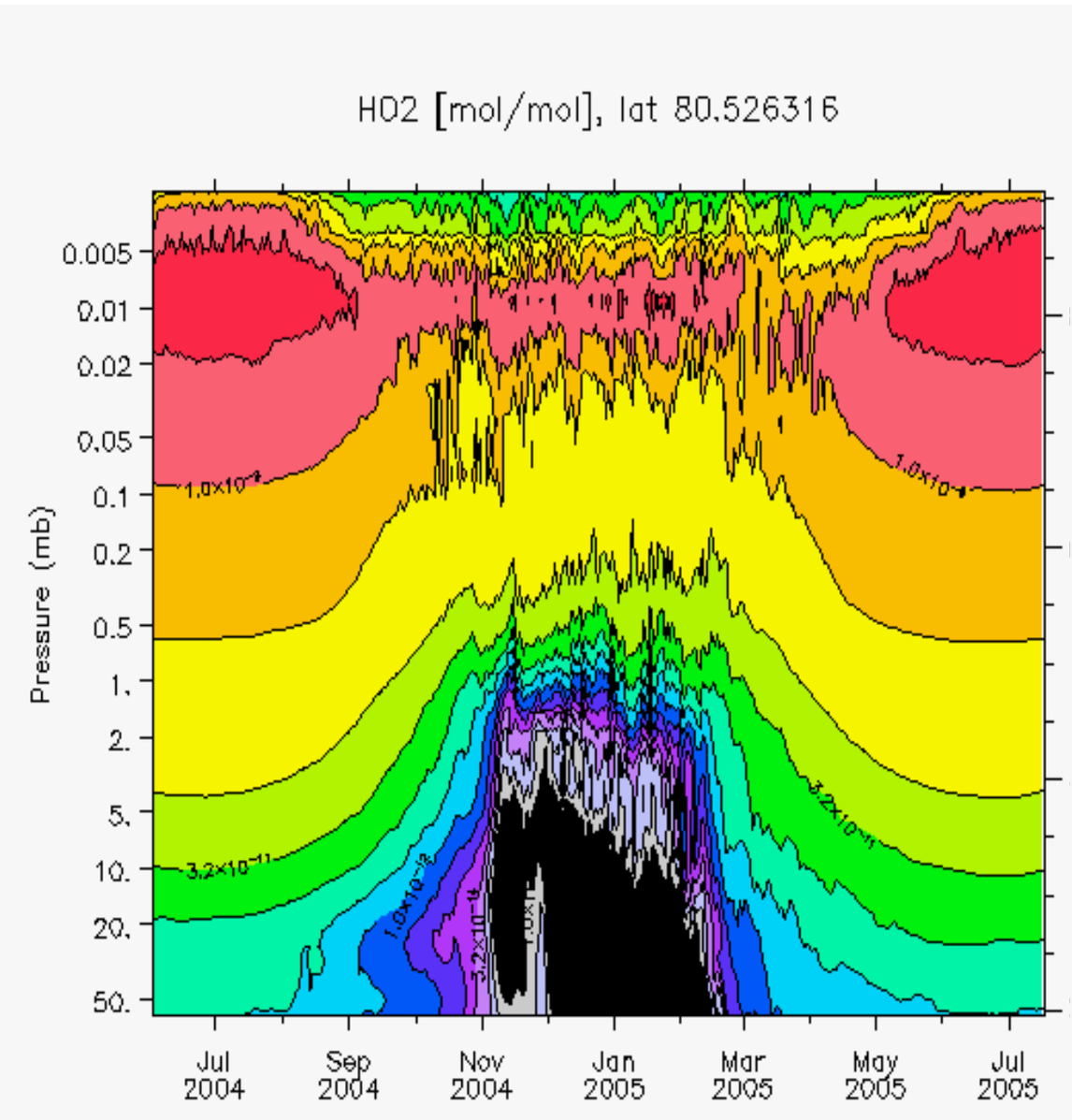


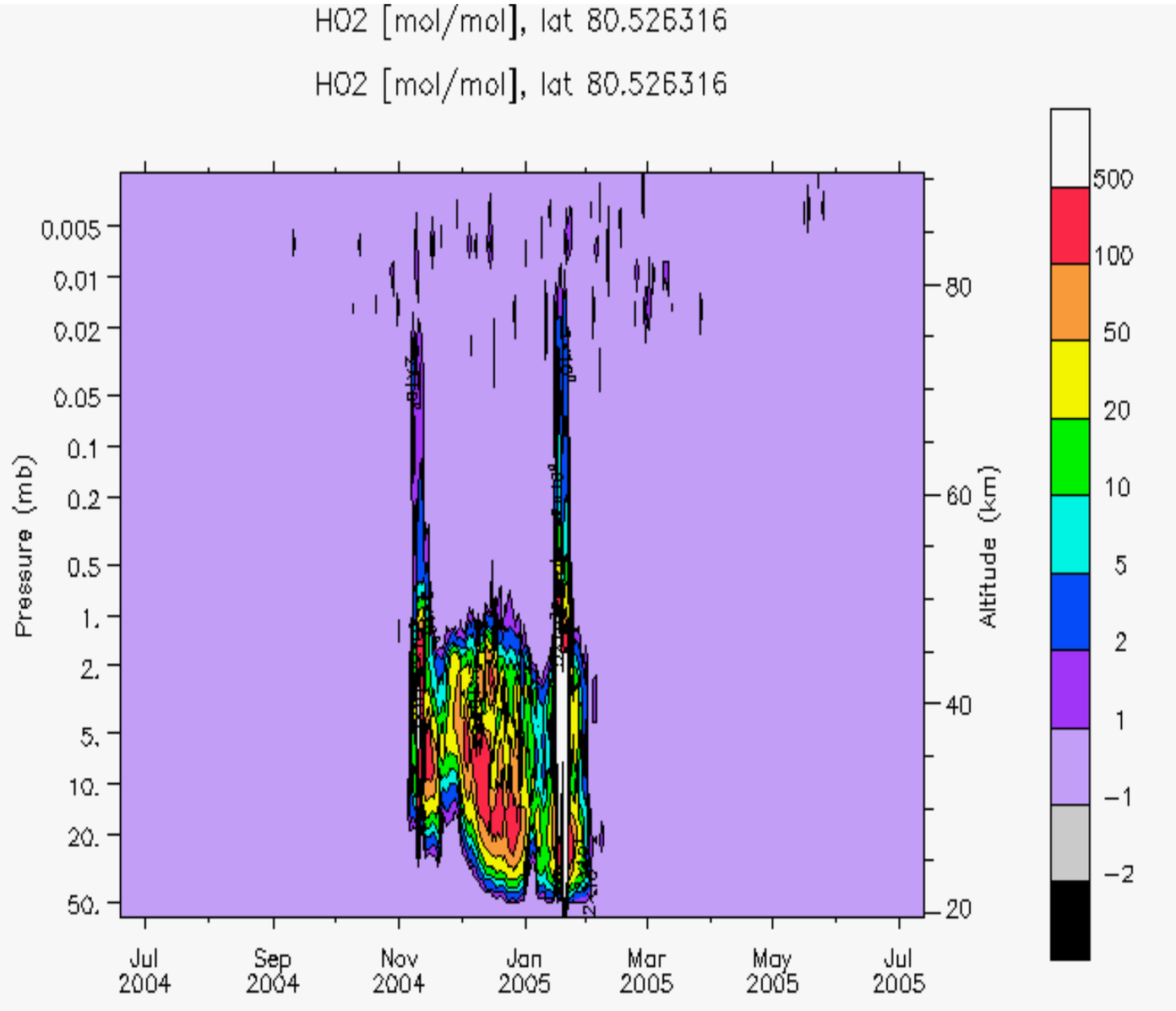
Zonal-mean $ClONO_2$ 80.5°N



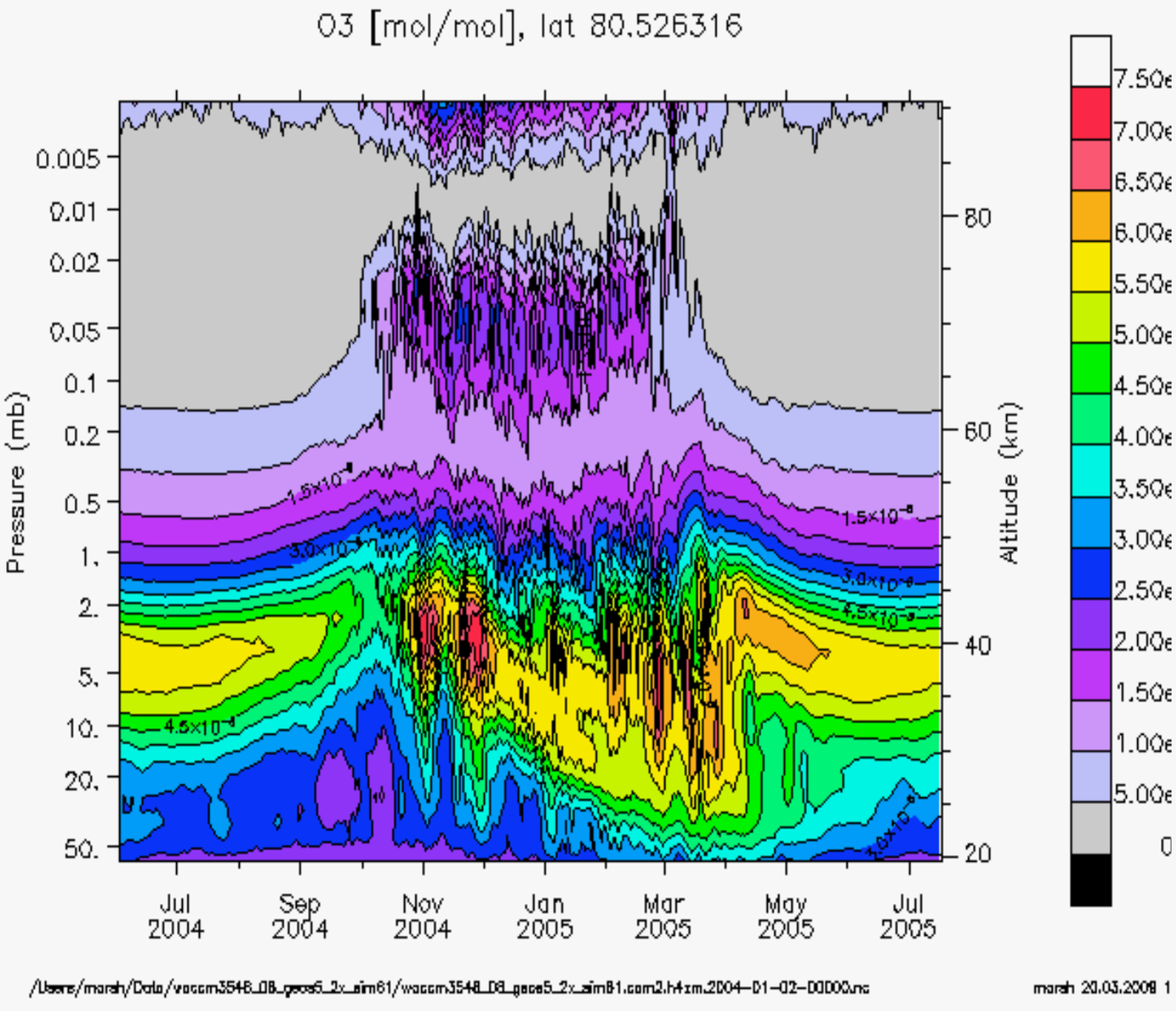


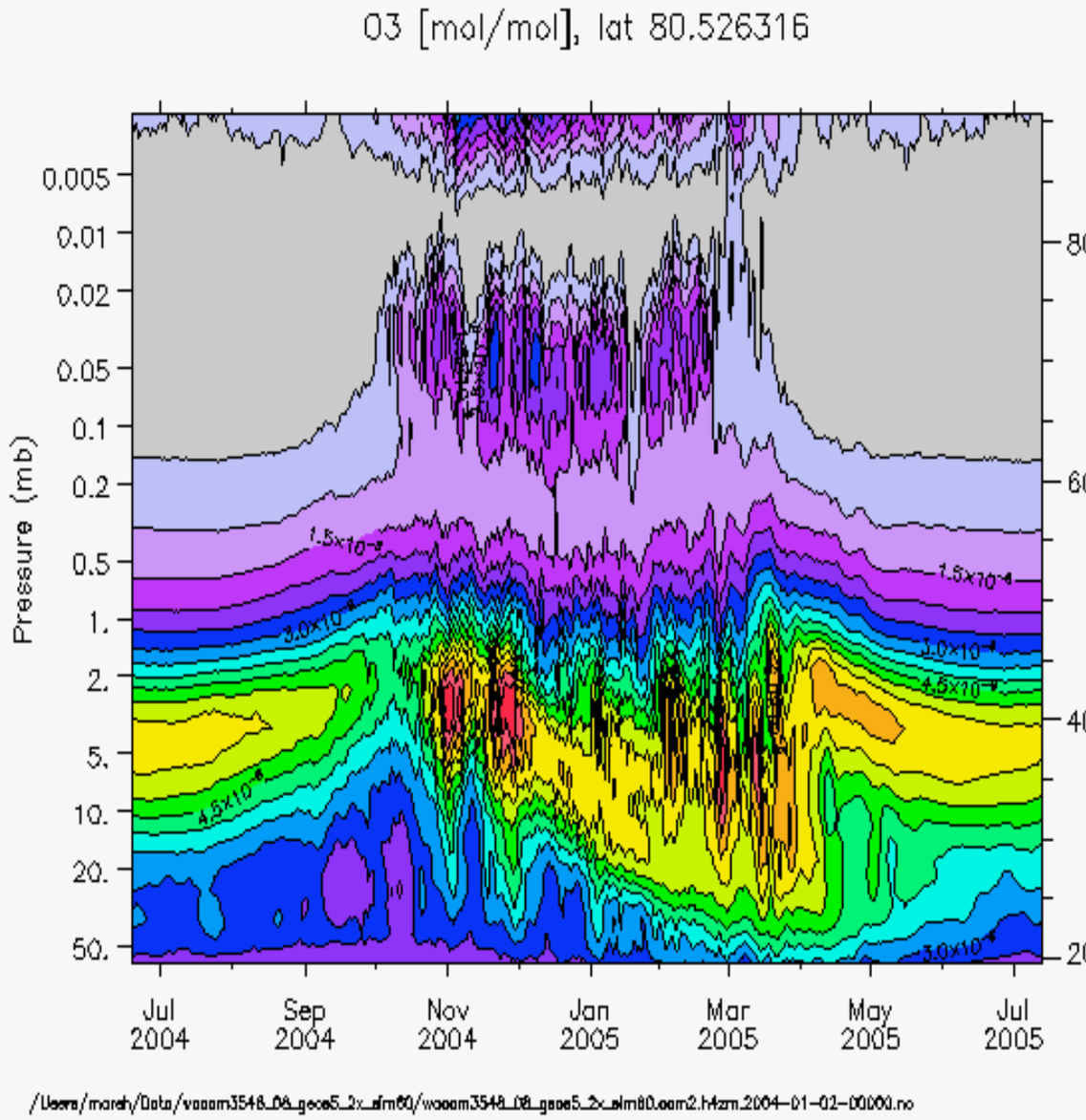
Zonal-mean HO_2 80.5°N



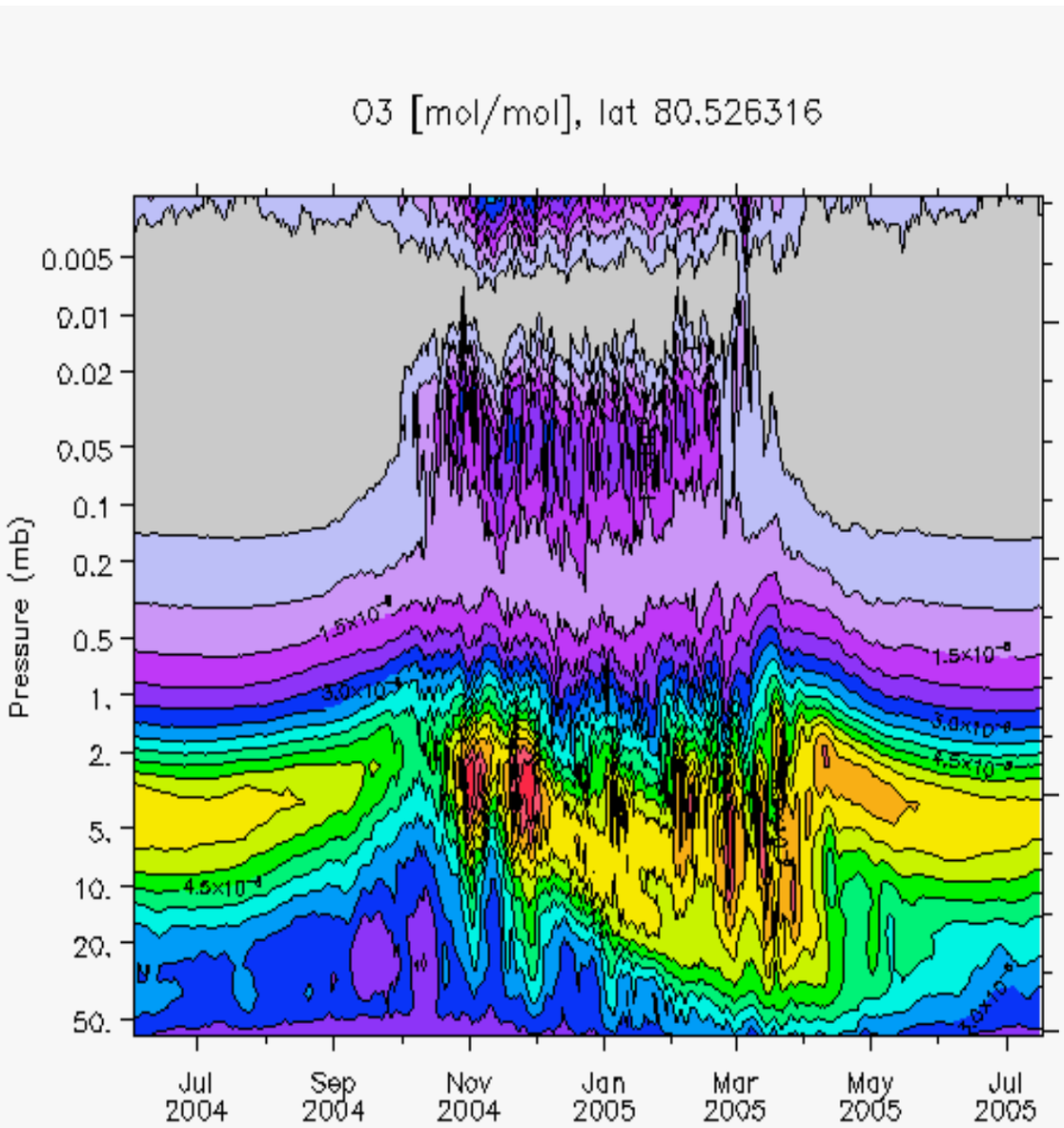


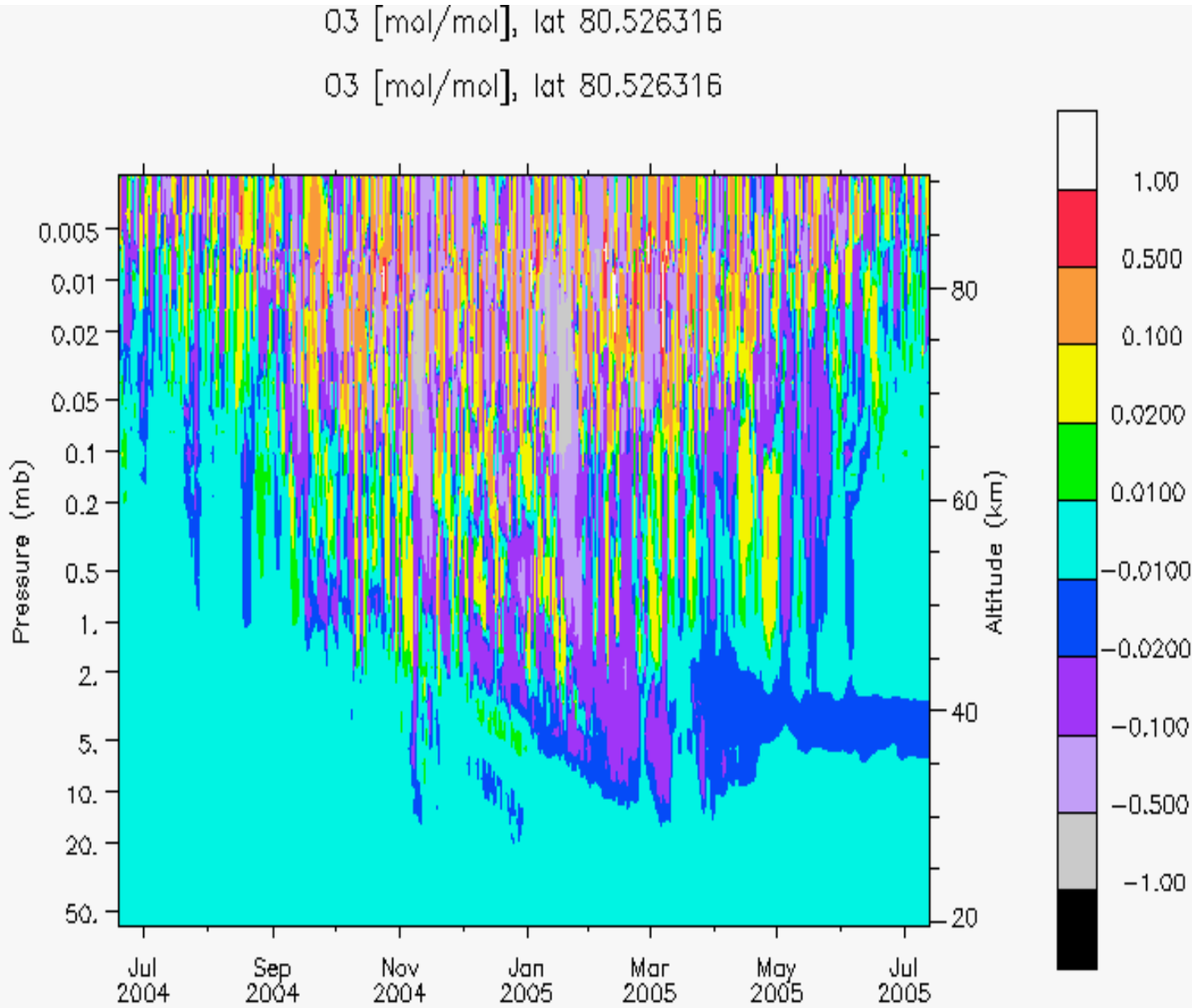
Zonal-mean O_3 80.5°N



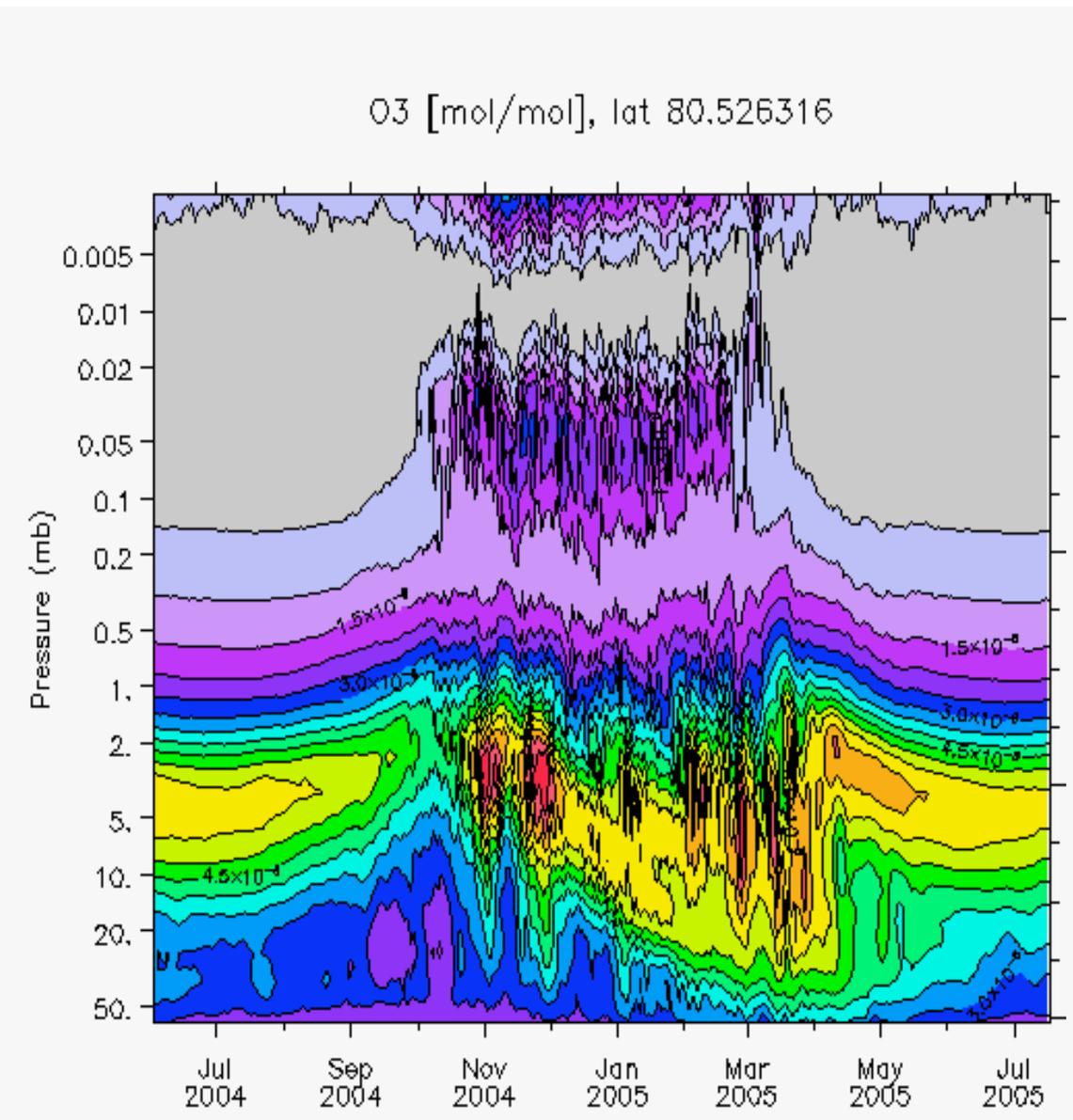


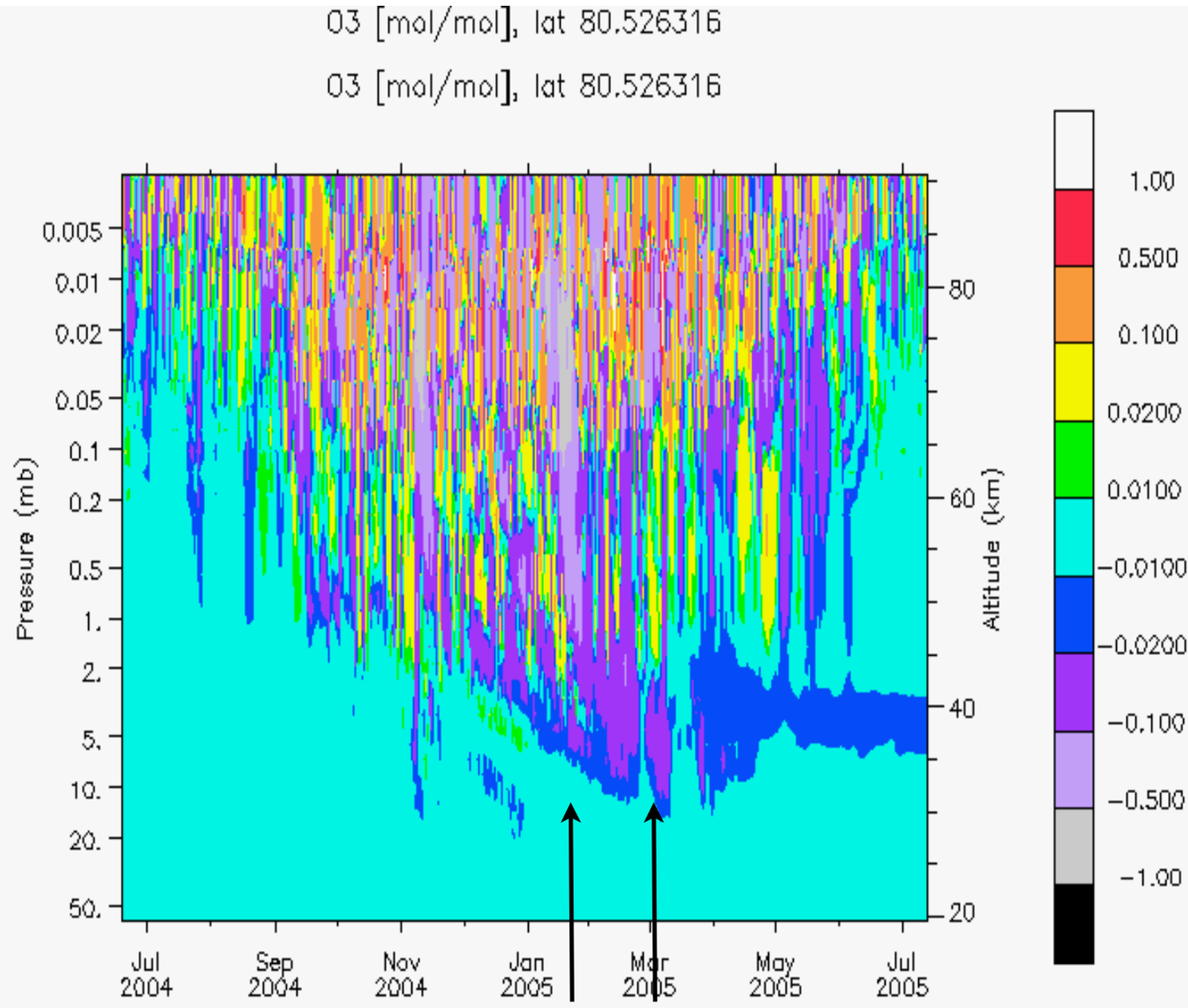
Zonal-mean O_3 80.5°N



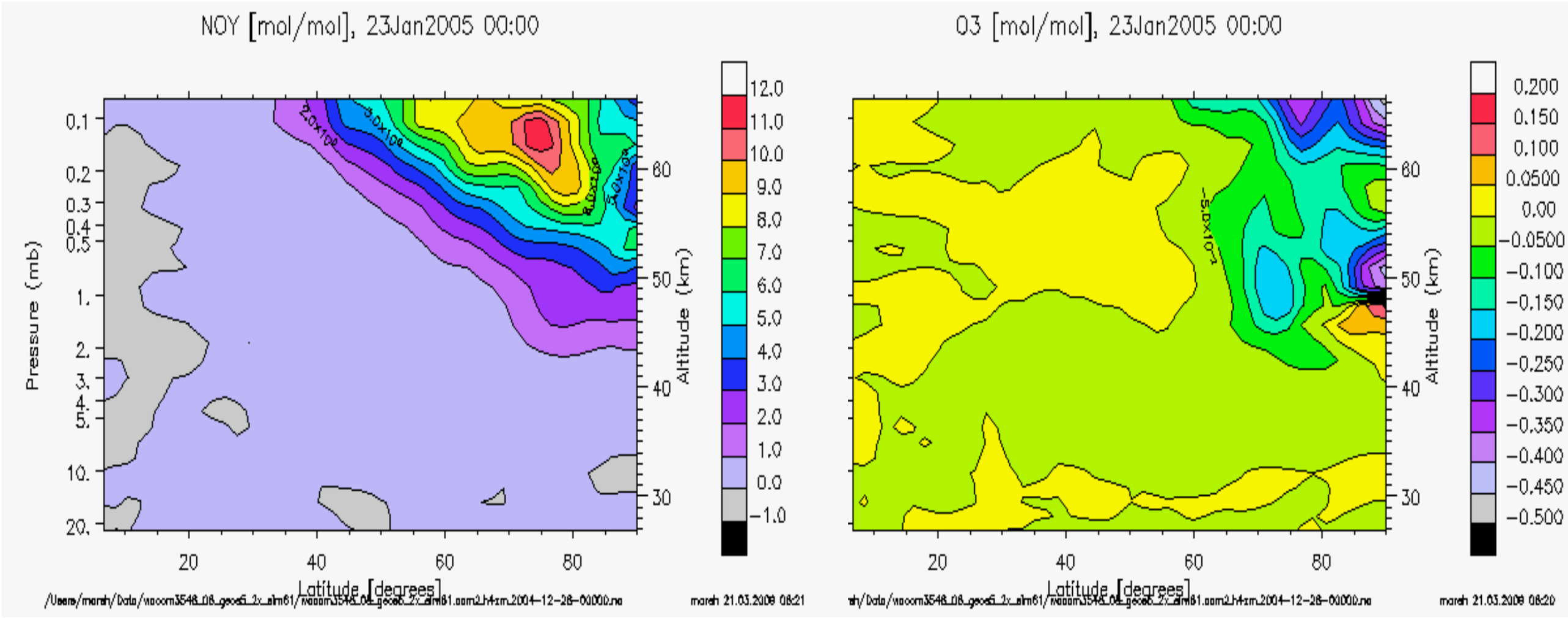


Zonal-mean O_3 80.5°N





January 23, 2005



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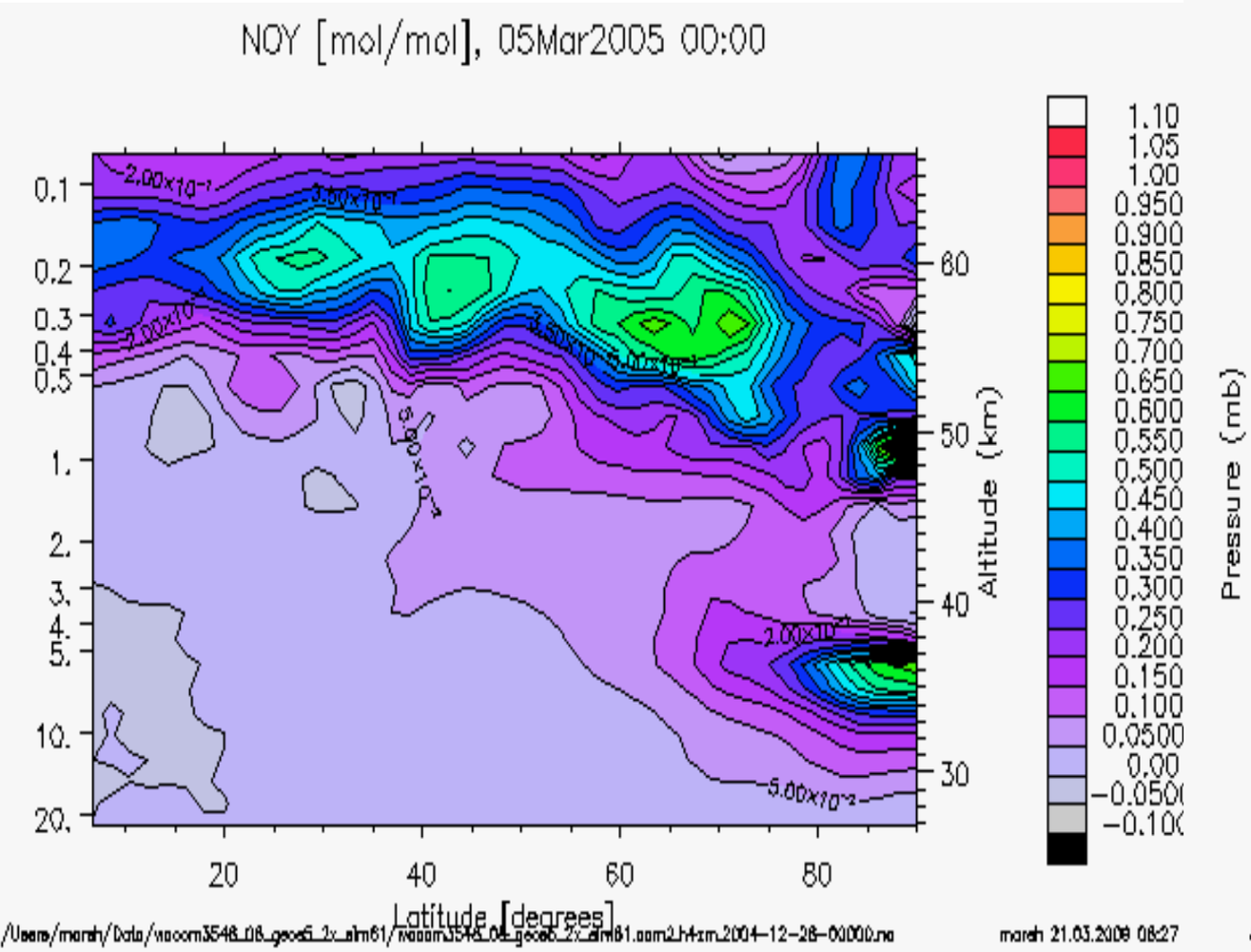
March 5, 2005


NOY [mol/mol], 05Mar2005 00:00
Pressure (mb)
Altitude (km)
Latitude [degrees]
1.10
1.05
1.00
0.950
0.900
0.850
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.0500
0.00
−0.050(
−0.10(
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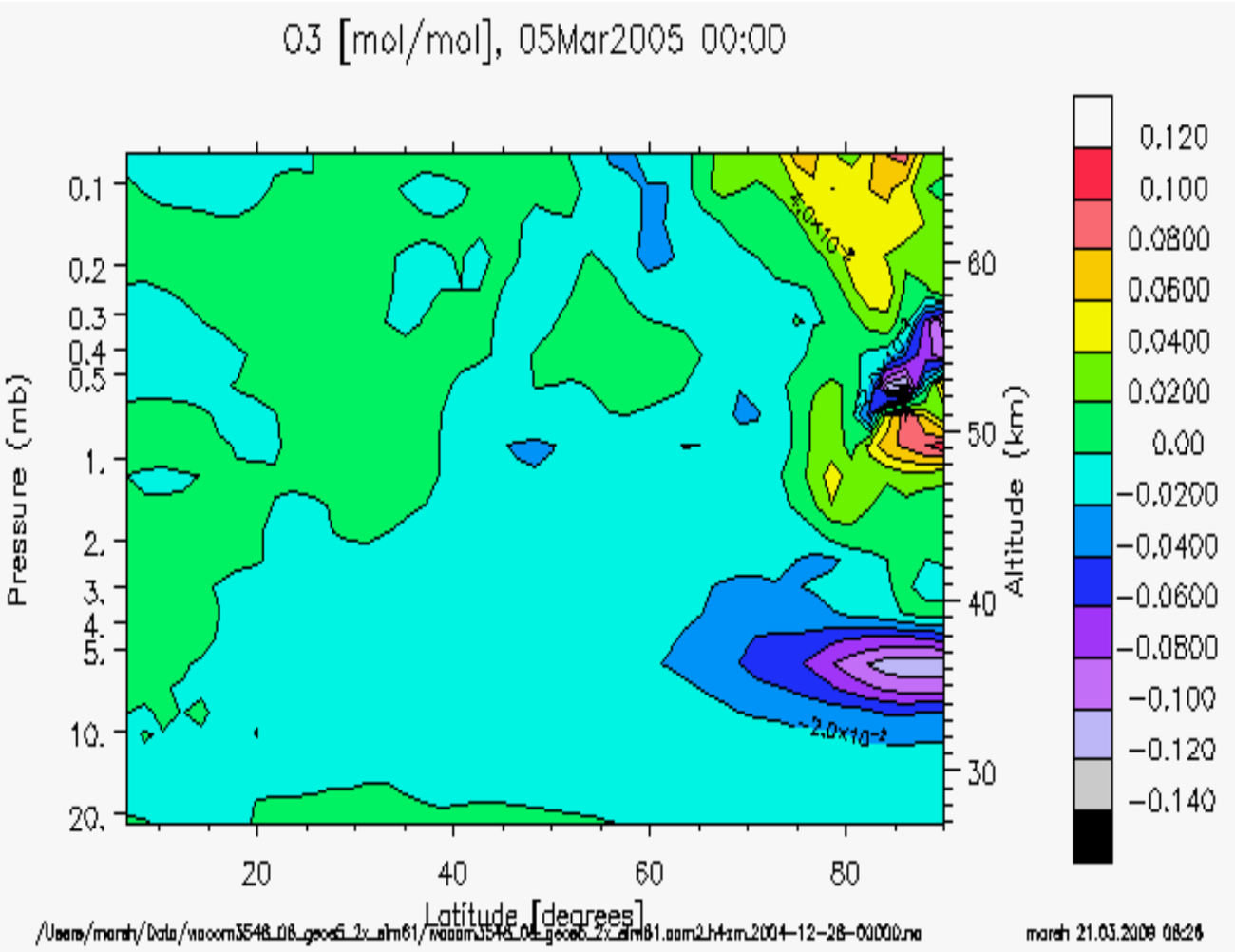
O3 [mol/mol], 05Mar2005 00:00
Pressure (mb)
Altitude (km)
Latitude [degrees]
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0.100
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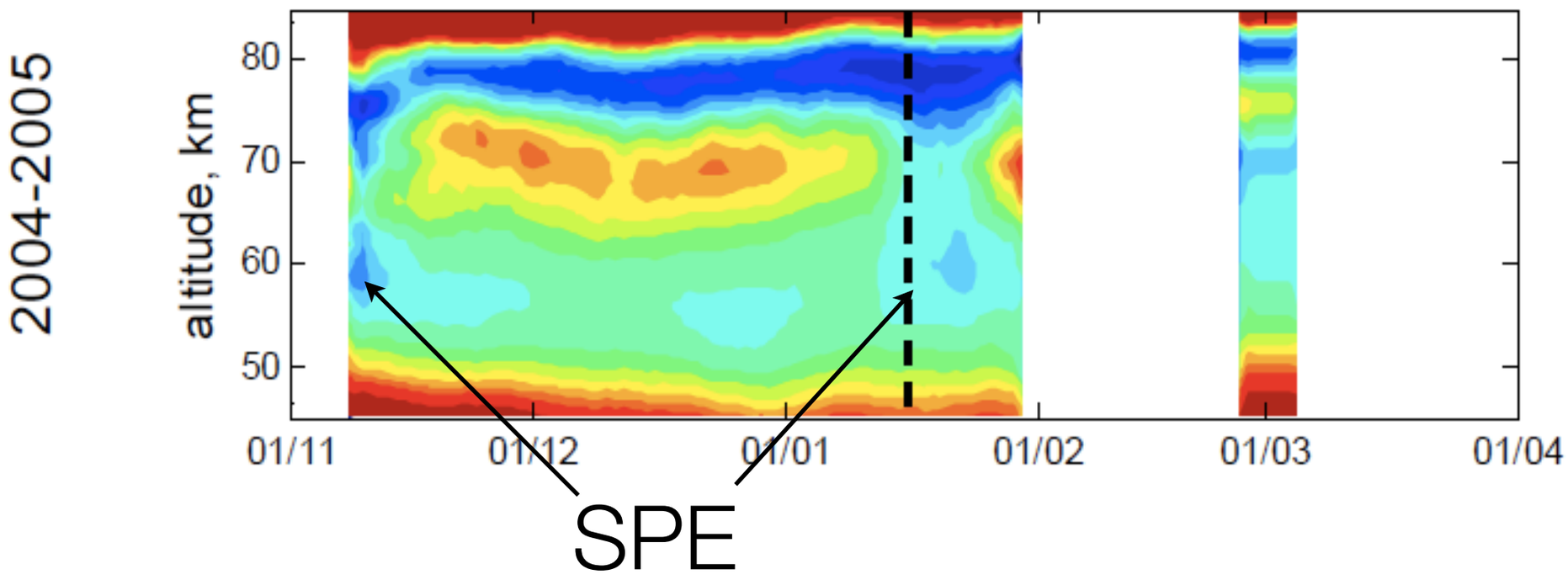
Atmos. Chem. Phys. Discuss., 9, 6597–6615, 2009
www.atmos-chem-phys-discuss.net/9/6597/2009/

Atmospheric Chemistry and Physics Discussions

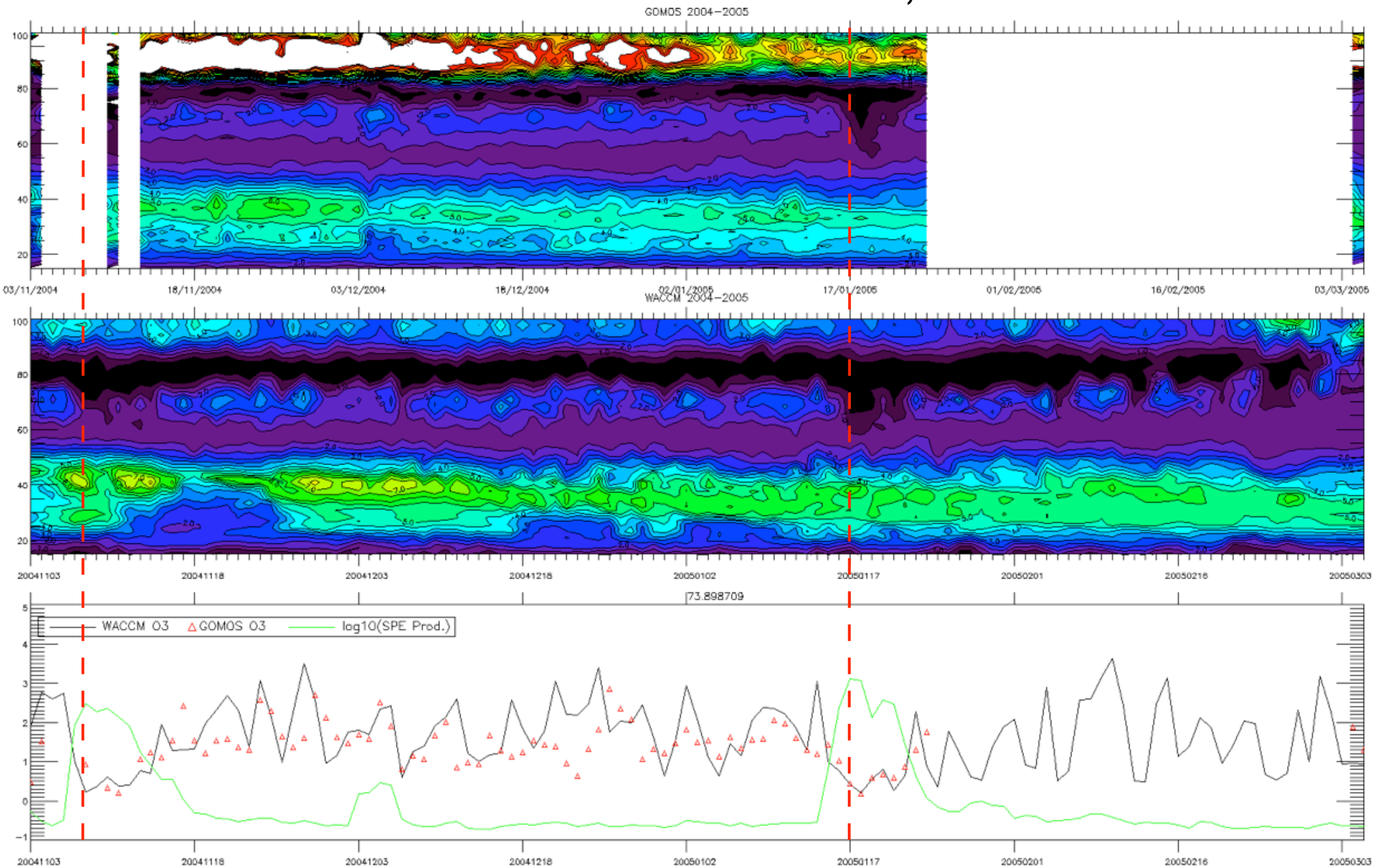
This discussion paper is/has been under review for the journal *Atmospheric Chemistry and Physics (ACP)*. Please refer to the corresponding final paper in *ACP* if available.

Spatio-temporal observations of tertiary ozone maximum

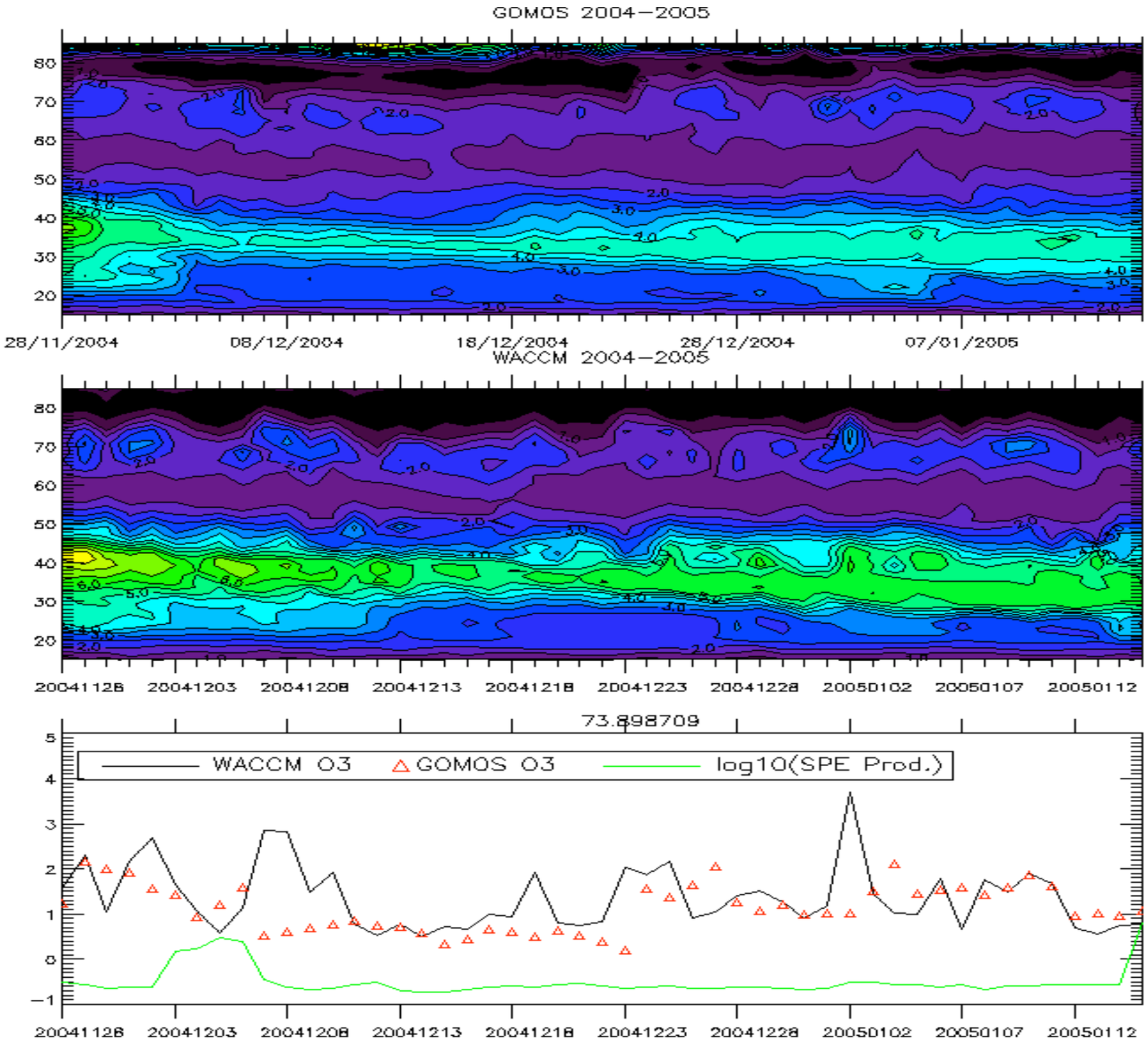
V. F. Sofieva[1], E. Kyrölä[1], P. T. Verronen[1], A. Seppälä[1], J. Tamminen[1], D. R. Marsh[2], A. K. Smith[2], J.-L. Bertaux[3], A. Hauchecorne[3], F. Dalaudier[3], D. Fussen[4], F. Vanhellemont[4], O. Fanton d'Andon[5], G. Barrot[5], M. Guirlet[5], T. Fehr[6], and L. Saavedra[6]



3 November 2004 - 3 March 2005, 70°N



28 November 2004 - 12 January 2005, 85°N



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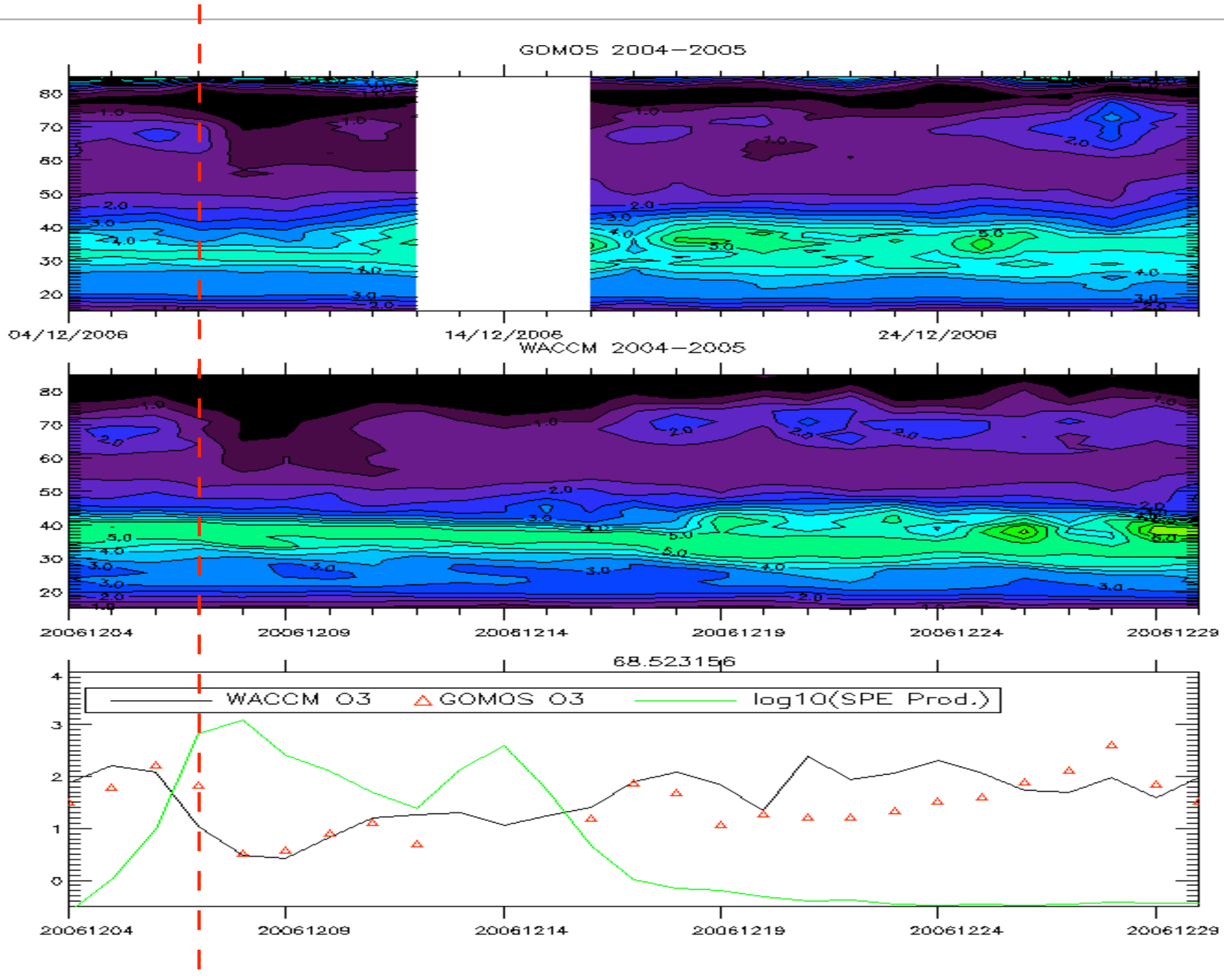
4-29 December 2006



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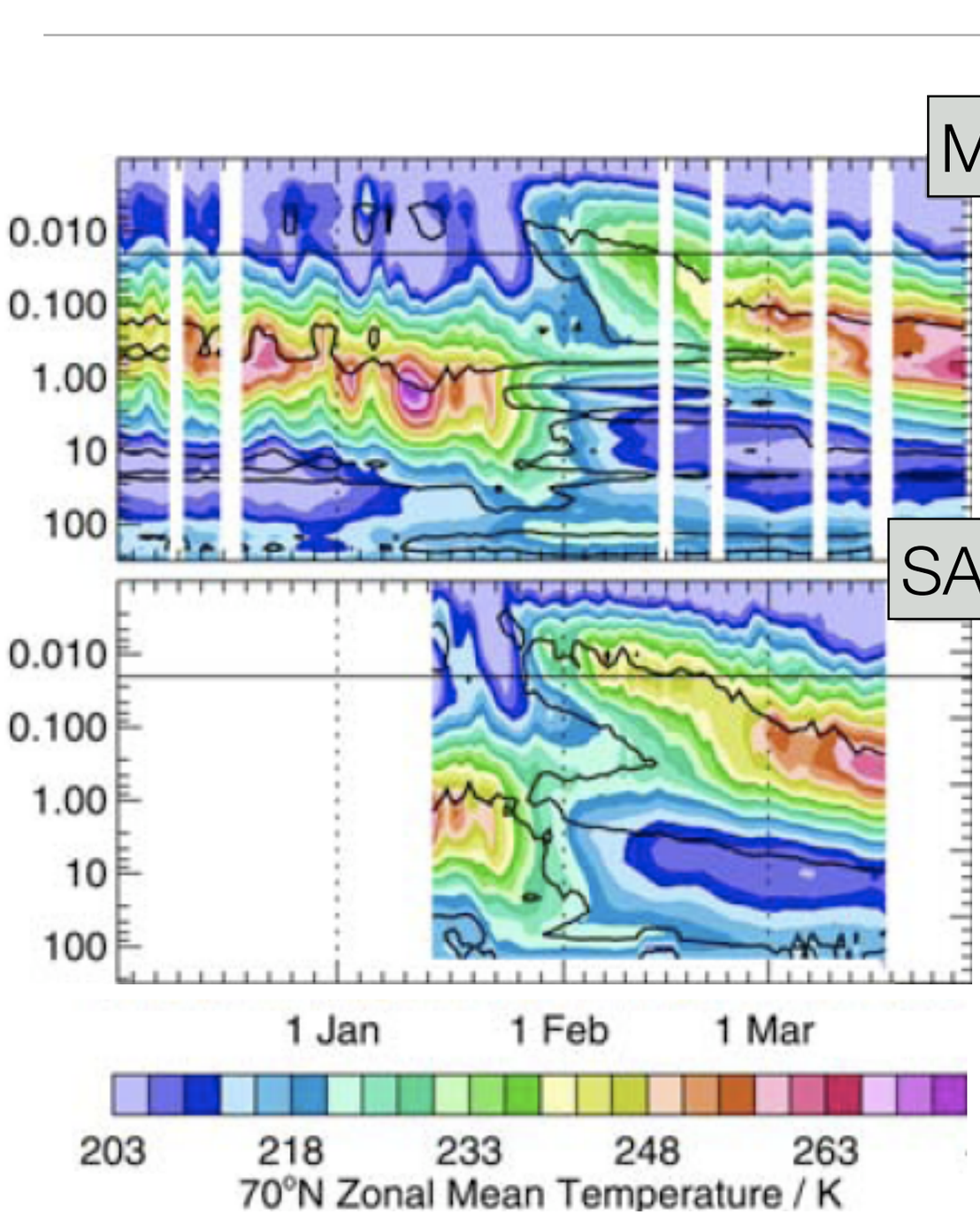
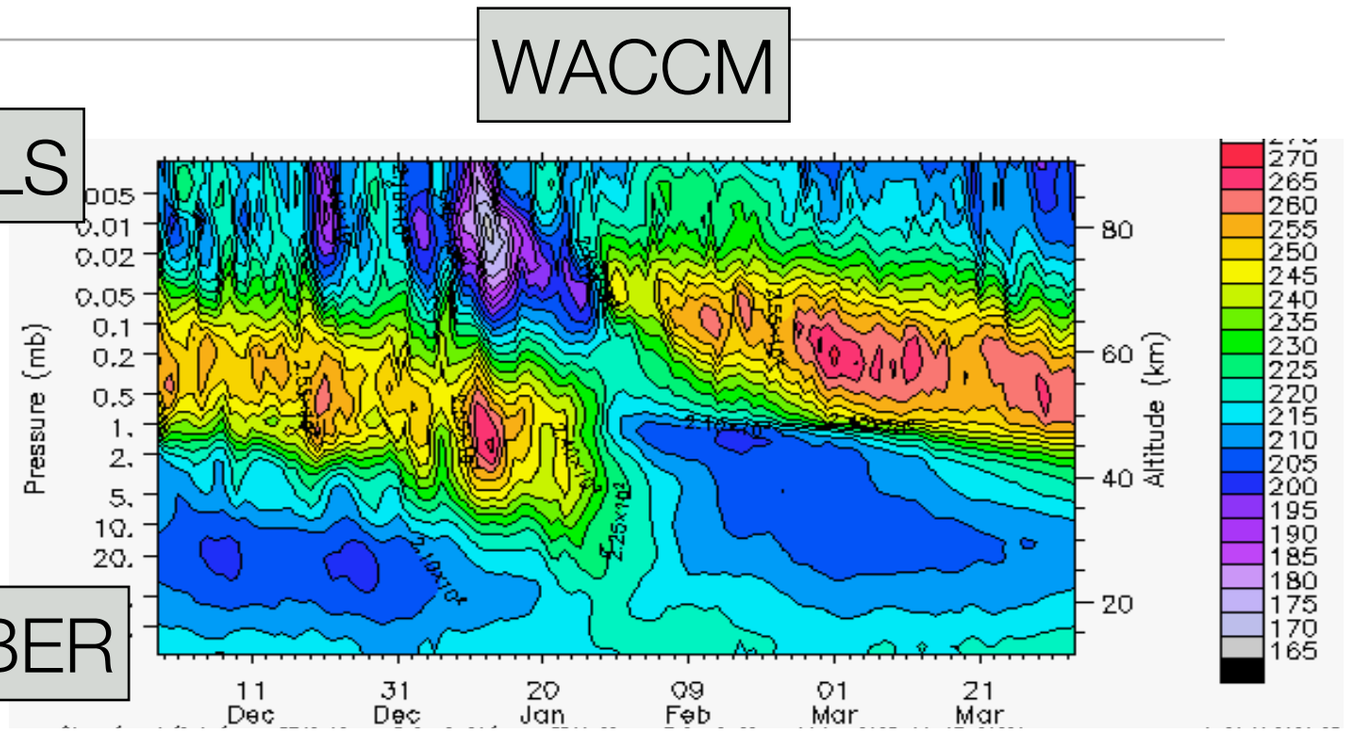
2006 Major warming

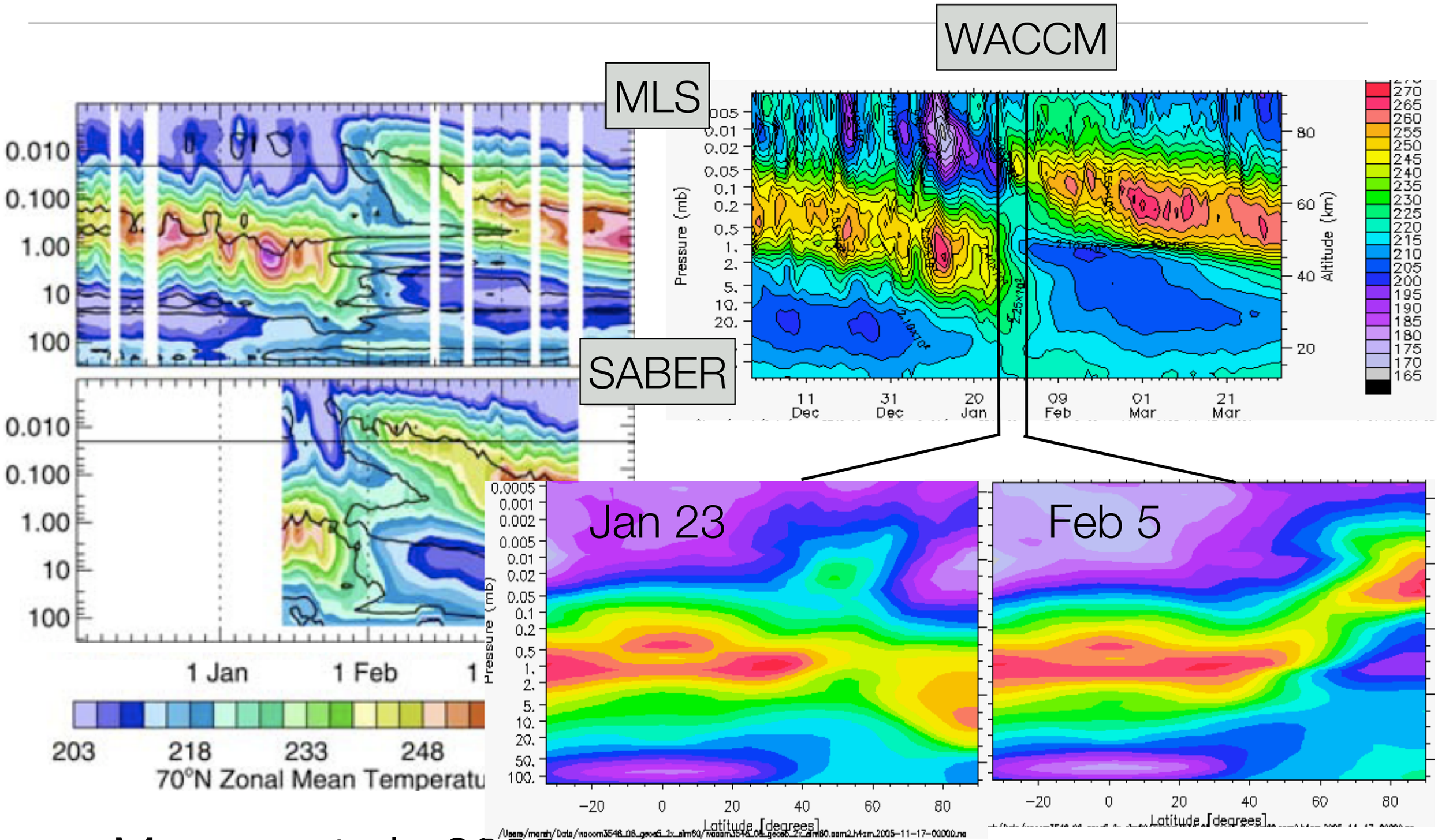
2006 Major Warming





Manney et al., 2008

2006 Major Warming



Manney et al., 2008

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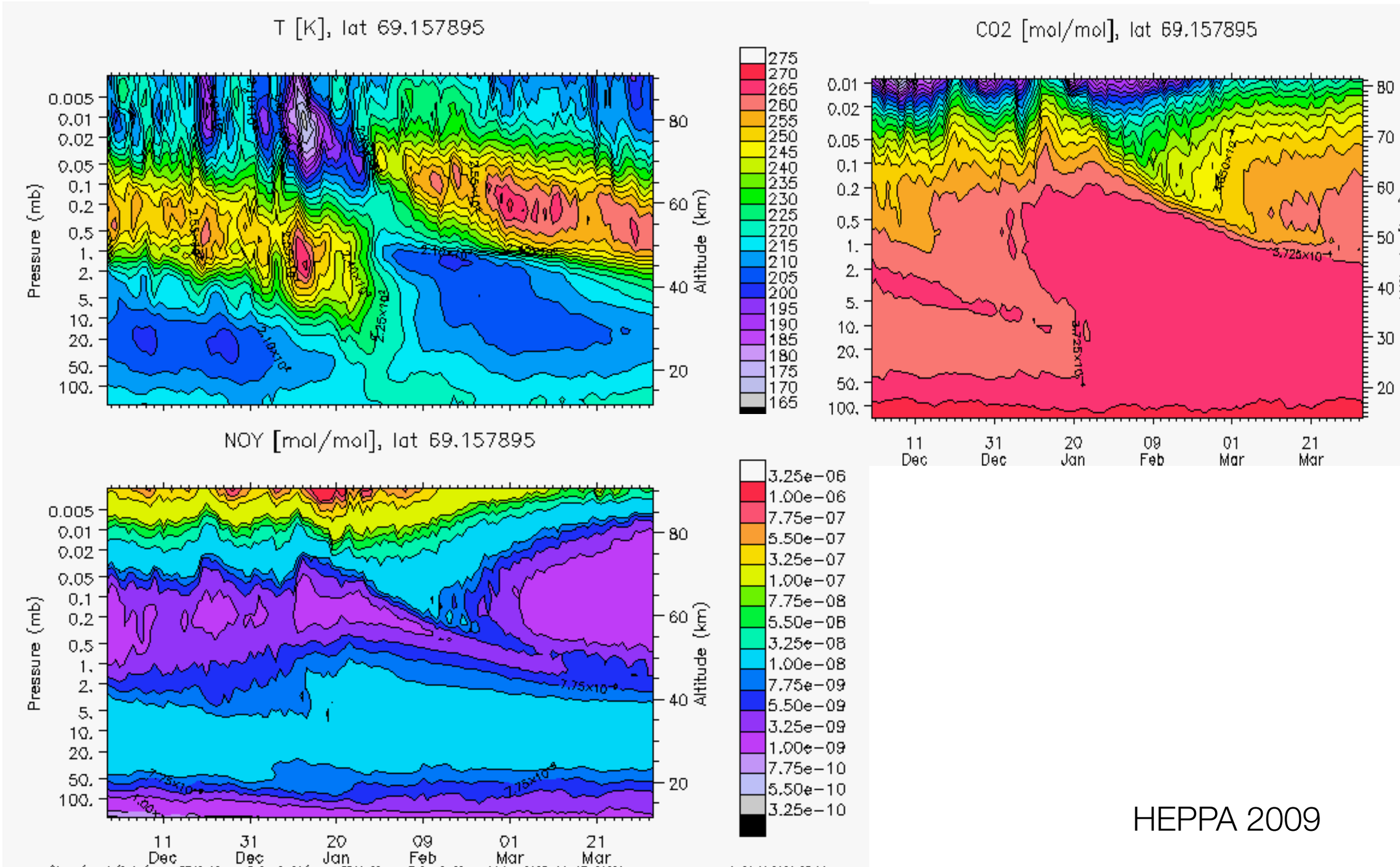
2006 Major Warming



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Summary

- SPEs produce large changes in NOy, HNO_3, $ClONO_2$, and HOx
- Able to reproduce GOMOS observed effect on ozone tertiary maximum
- Persistent ozone changes 10-15% in the stratosphere
- 2006 Major warming induced descent significantly enhanced NOy

Thank you