National Aeronautics and Space Administration

Polar Stratopause and Tropopause Evolution: Implications for Assimilated Analyses

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with:

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http://mls.jpl.nasa.gov

- ➤ Detailed knowledge of the regions surrounding both the stratopause and tropopause is crucial to understanding climate change and ozone recovery
- ➤ Assimilation systems, e.g., ECMWF and GMAO, are providing analyses into the mesosphere, and including trace gases (especially ozone)
- ➤ Previous studies of the upper stratosphere/lower mesosphere (USLM) and upper troposphere/lower stratosphere (UTLS) have been hampered by lack of data:
  - ❖ Neither dynamical nor trace gas data have been routinely available in the USLM
  - ❖ While ground-based UTLS temperatures have been available, trace gas data on global and multi-annual scales have been scarce
- ➤ With the launch of recent satellites, e.g., the Microwave Limb Sounder (MLS) on NASA's Aura mission, the Sounding of the Atmosphere with Broadband Emission Radiometry (SABER) instrument, and the Canadian Atmospheric Chemistry Experiment-Fourier Transform Spectrometer (ACE-FTS), an unprecedented wealth of data covering the UTLS through the USLM are now available
- ➤ We show highlights of studies using these data to improve our understanding of the polar USLM and UTLS and to help assess assimilation systems
- ➤ Examples are from 2005–2006 Arctic winter, with a prolonged stratospheric sudden warming (SSW), along with comparisons with other recent winters

Temperatures:

- MLS provides near-global daily fields from the UTLS through the mesosphere (v1.5, v2.2)
- SABER provides $\sim$50–85° fields (switching hemispheres every two months) from lower stratosphere through mesosphere and in thermosphere (v1.06)
- ACE-FTS provides up to $\sim$30 profiles per day at two latitudes from UTLS through the mesosphere (v2.2)
- Ground-based data (lidar, up to $\sim$70 km; radiosonde, up to $\sim$35 km) provide high-resolution point profiles

Trace Gases:

- MLS O_3, HNO_3 (v2.2 only), H_2O and CO are useful for studying UTLS; CO and H_2O are useful tracers in USLM
- ACE-FTS CO, O_3, N_2O, HNO_3, HCl should be useful for studying UTLS; CO and H_2O for the USLM
- ACE-MAESTRO O_3 is useful for studying UTLS (v1.2)

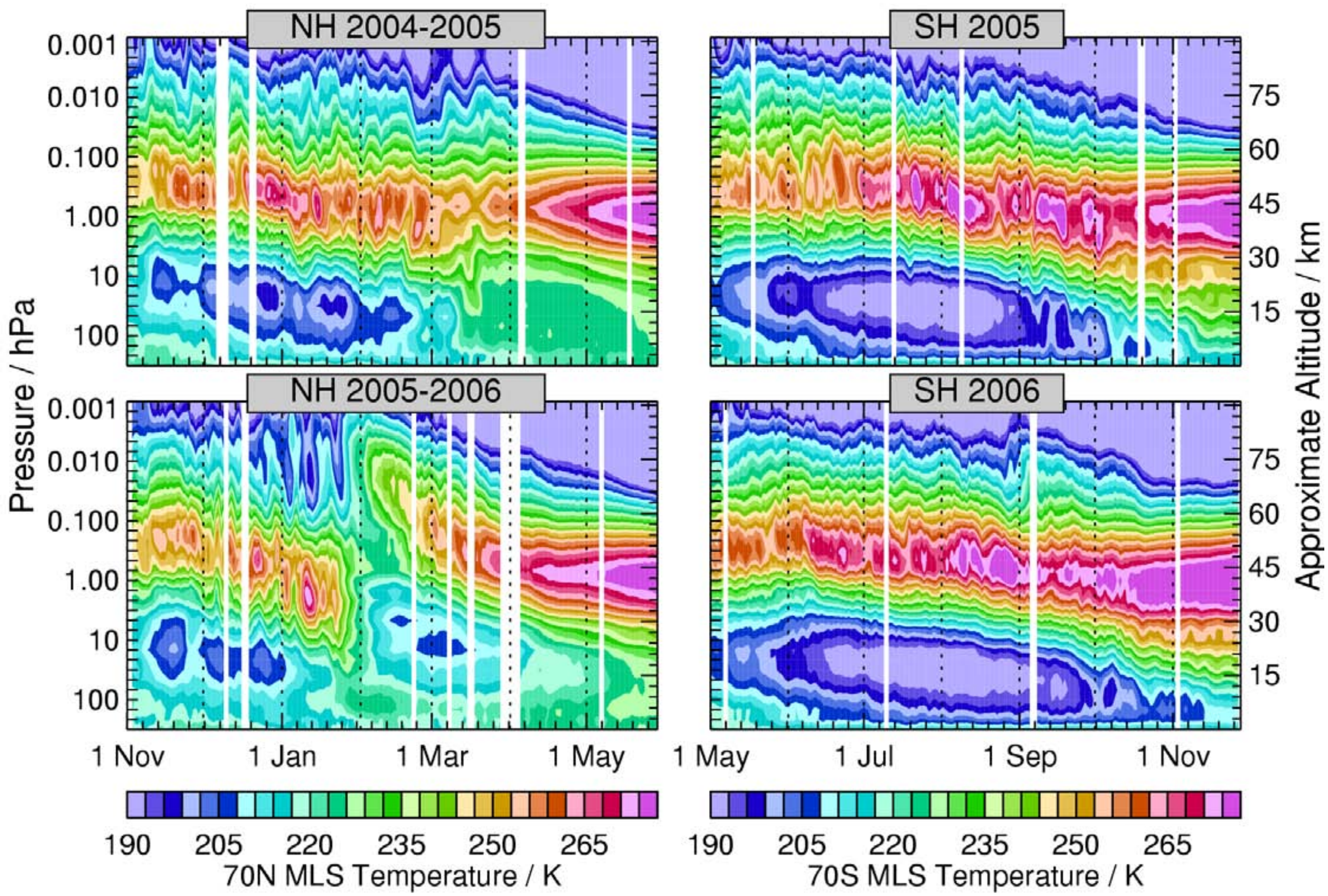
Operational Assimilation Products:

- GEOS-4: Top at 0.01 hPa, simple non-orographic GW drag scheme, $1\times1.25^\circ$ resolution
- GEOS-5: Top at 0.01 hPa, simple non-orographic GW drag scheme, $0.5\times0.67^\circ$ output fields
- ECMWF: T511/L60, 0.1 hPa top (T799/L91, 0.01 hPa top) before (after) 1 February 2006, Rayleigh friction to slow upper stratospheric jet, output used at various resolutions
- Met Office (MetO): Top near 0.1 hPa, $2.5\times3.75^\circ$ resolution ($0.375\times$ 0.5625° after 12 March 2006)

Research Products:

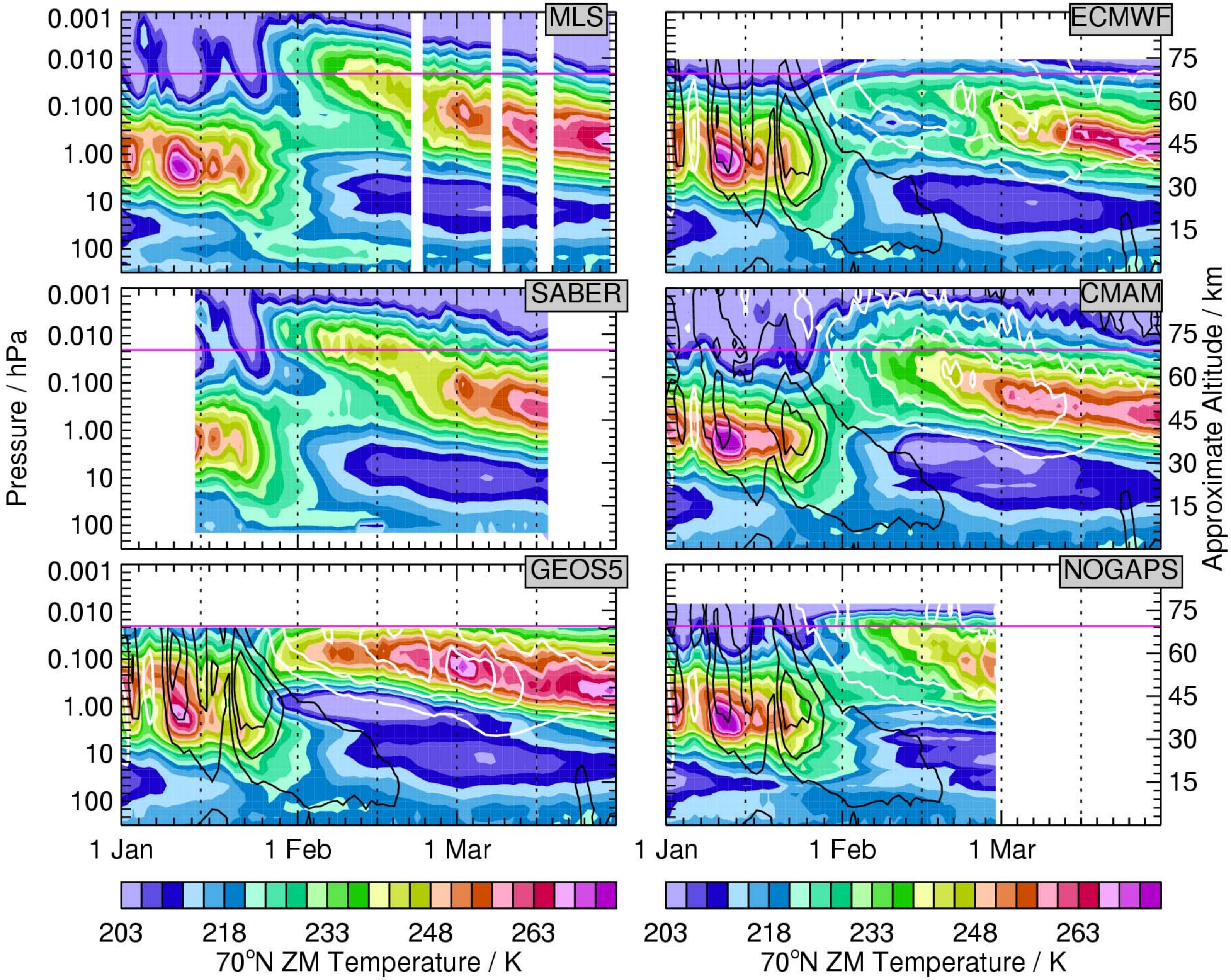
- CMAM (Details in Shuzhan Ren talk following): Very high model top, comprehensive online transport and chemistry; no chemical assimilation; $\sim3.75\times3.75^\circ$ resolution; Scinocca non-orographic gravity wave scheme
- NOGAPS-ALPHA (Details in Karl Hoppel talk following): Model top near 0.005 hPa; assimilating MLS and SABER temperatures (to 0.01 hPa) and O_3; $\sim1.5\times1.5^\circ$ resolution; Rayleigh friction in this experiment

Stratopause: Interannual and Interhemispheric Variability



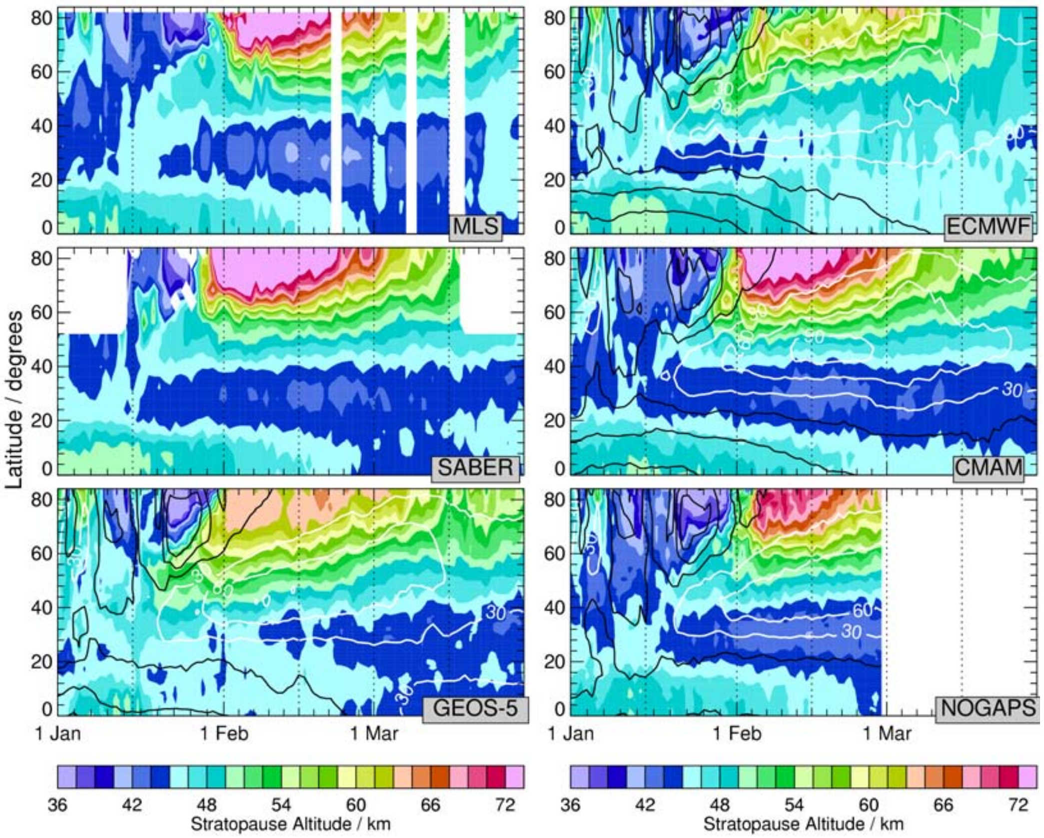
- 70° latitude MLS temperatures in past two NH and SH fall/winter/spring seasons
- "Undisturbed" winters (2004-2005 NH, SH winters) show early winter stratopause near 55 km, dropping to near 45 km by spring
- Stratopause temperatures relatively constant in undisturbed winters, slightly higher in SH, increasing in spring
- "Coldpoint" in lower stratosphere shows substantial interannual and interhemispheric variability

The 2006 SSW: Temperature Evolution

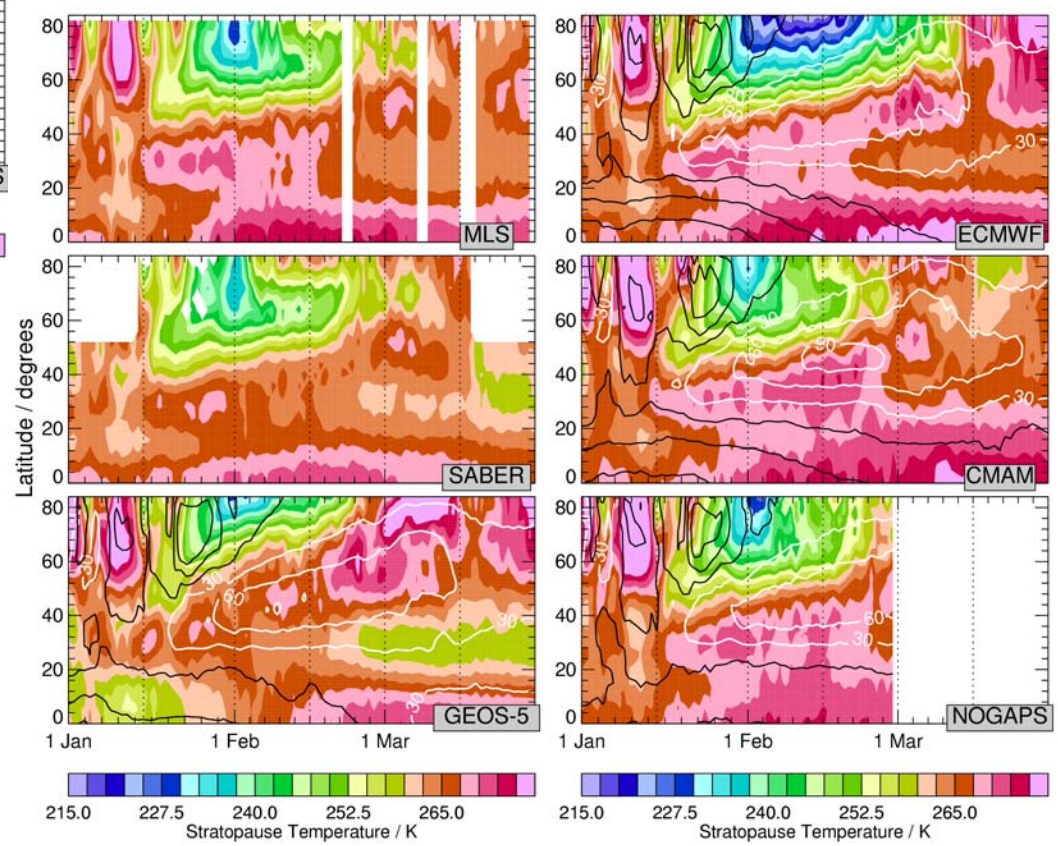


- Satellite and analysis 70°N zonal mean temperatures during 2006 SSW
- Operational analyses stratopause too low, temperature biases; research systems show improvement

The 2006 SSW: Stratopause Evolution

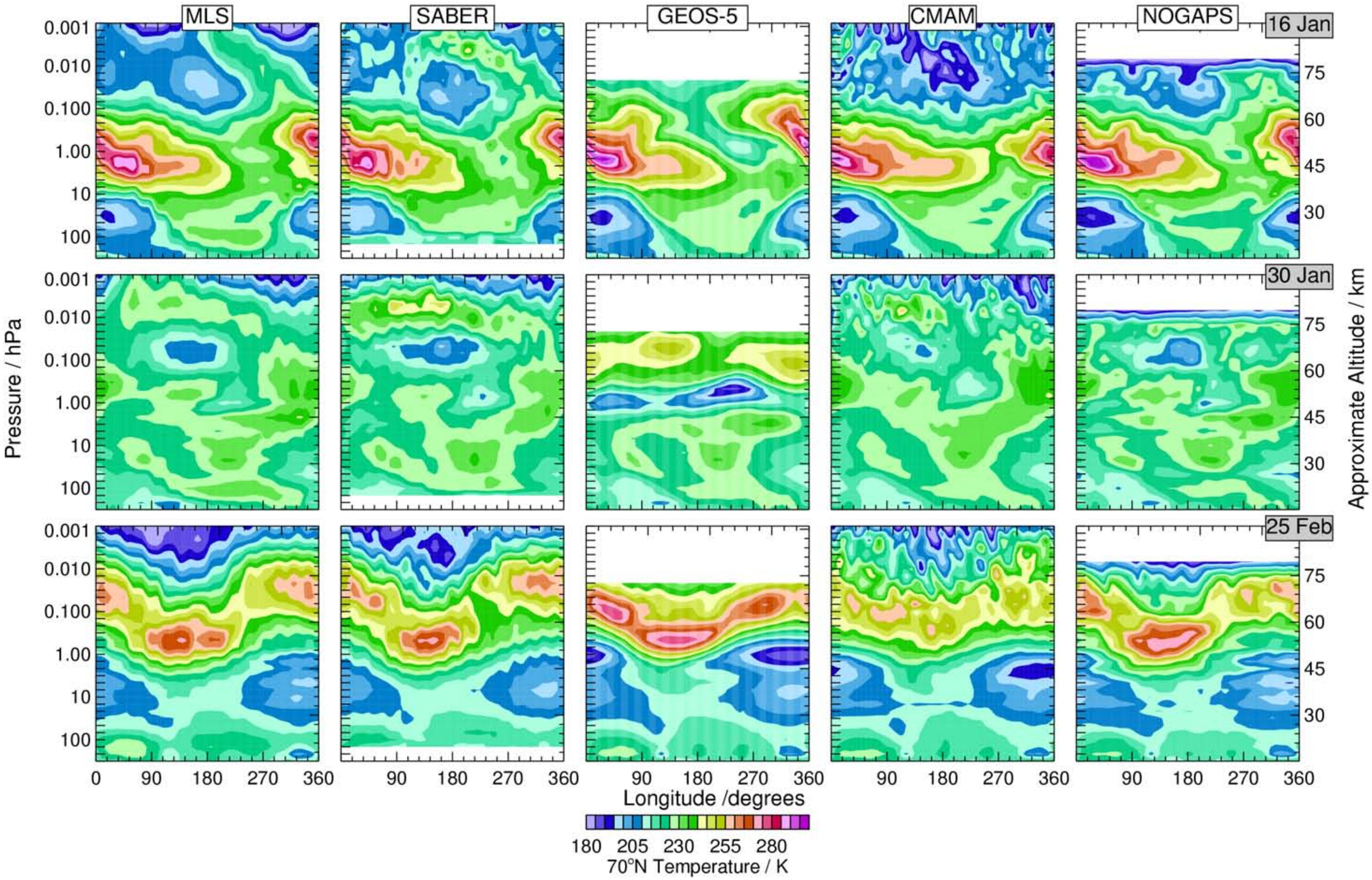


- ➤ Stratopause evolution in 2006 Arctic winter
- ➤ GEOS-5 too low, warm; ECMWF too low, cool
- ➤ Research systems show improvement



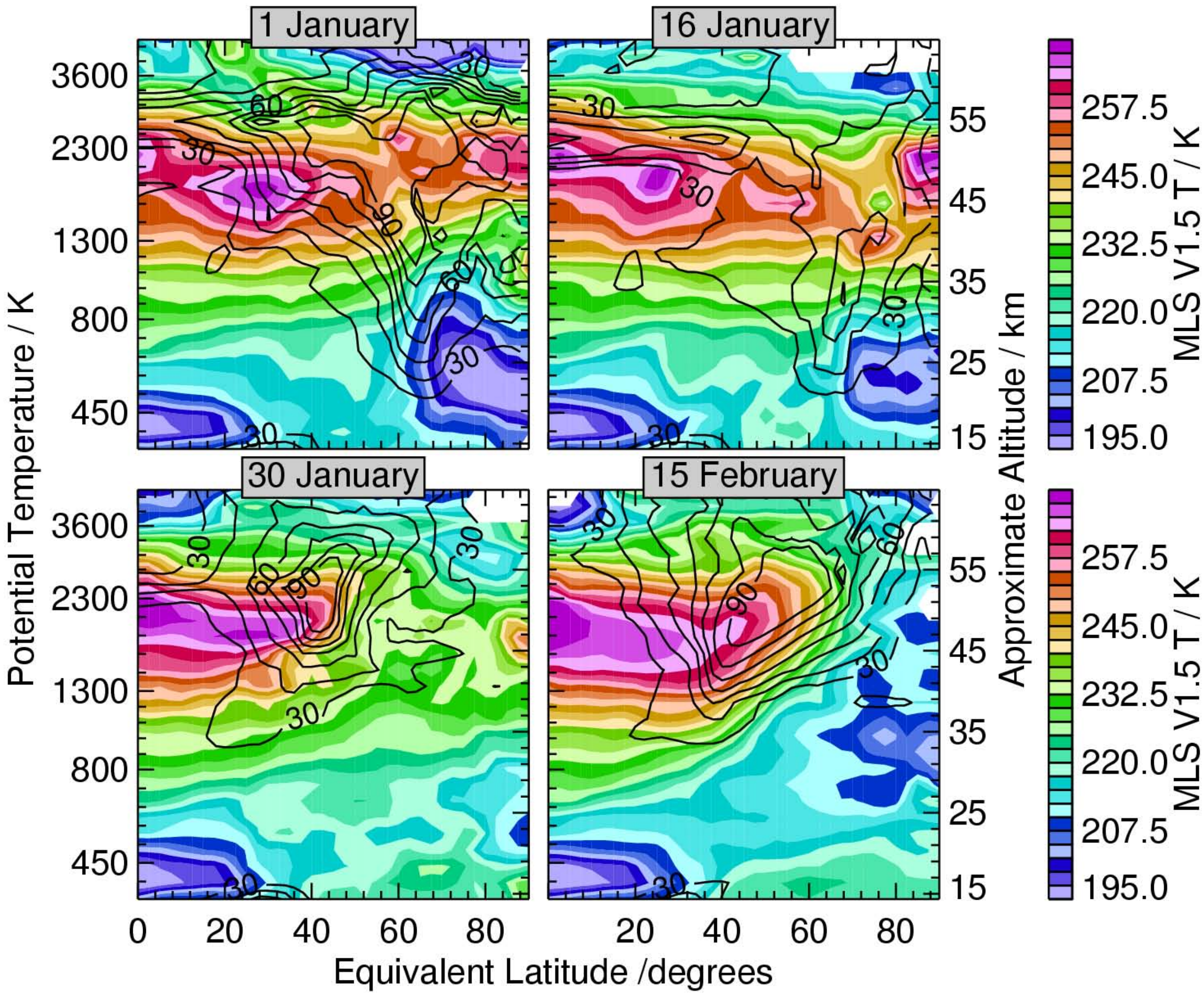
- ➤ High polar stratopause reforms pole-ward of redeveloping jet (white contours 1 hPa zonal mean wind)
- ➤ Polar stratopause separated from mid-latitude stratopause throughout (strong temperature/altitude gradients)

The 2006 SSW: Synoptic Temperature Evolution



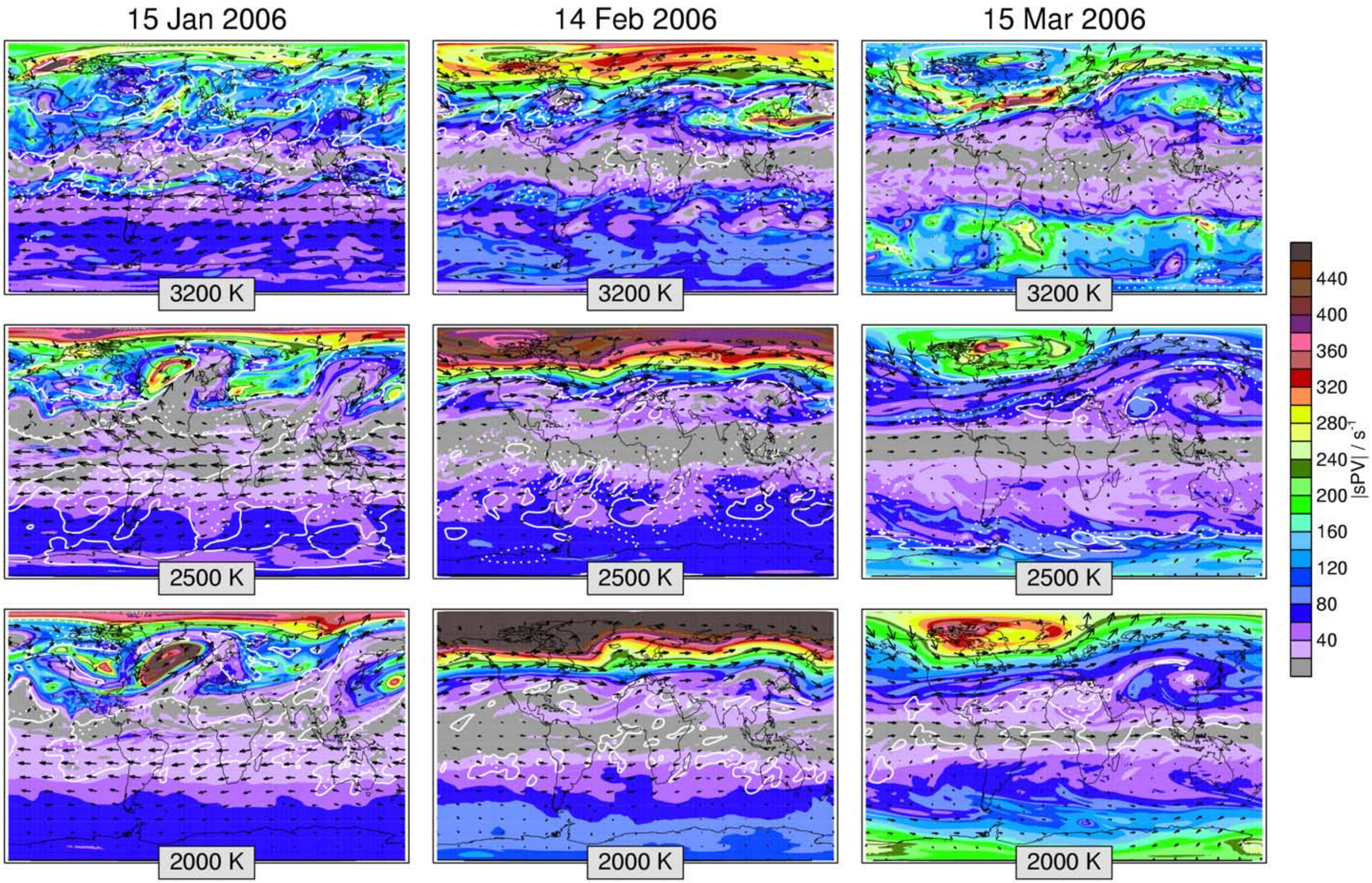
- ➤ Longitude/pressure temperature snapshots show secondary temperature maximum, stratopause separated in longitude
- ➤ CMAM and NOGAPS capture behavior on 30 January, hint of secondary temperature maximum

The 2006 SSW: Vortex and Stratopause Structure



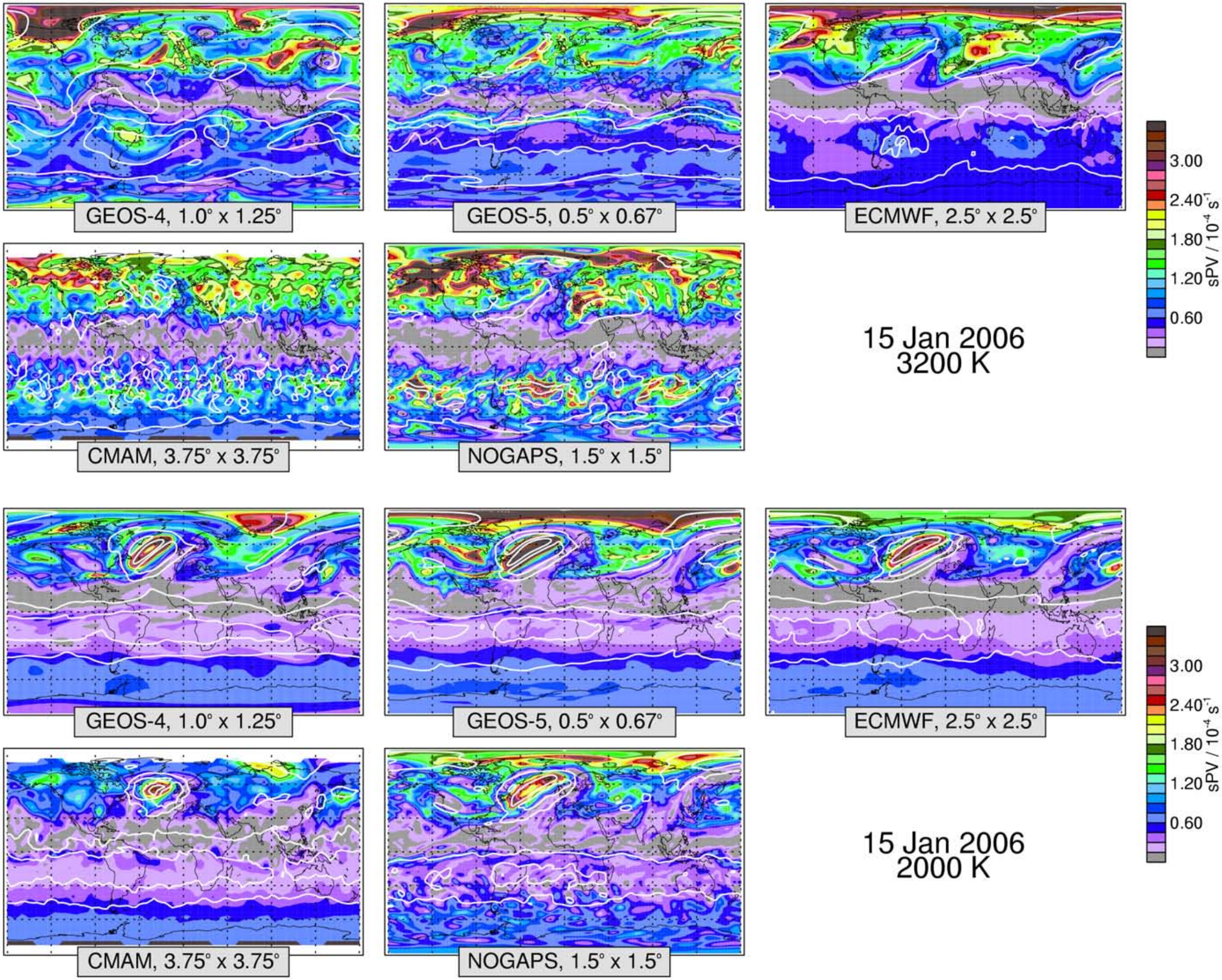
- ➤ Equivalent latitude (GEOS-4)/potential temperature sections of temperature and windspeed in 2006
- ➤ Stratopause separated across top of upper stratospheric jet throughout the SSW
- ➤ Secondary temperature maximum before SSW extends towards lower EqL across lower EqL branch of double upper stratospheric jet

The 2006 SSW: Vortex Structure

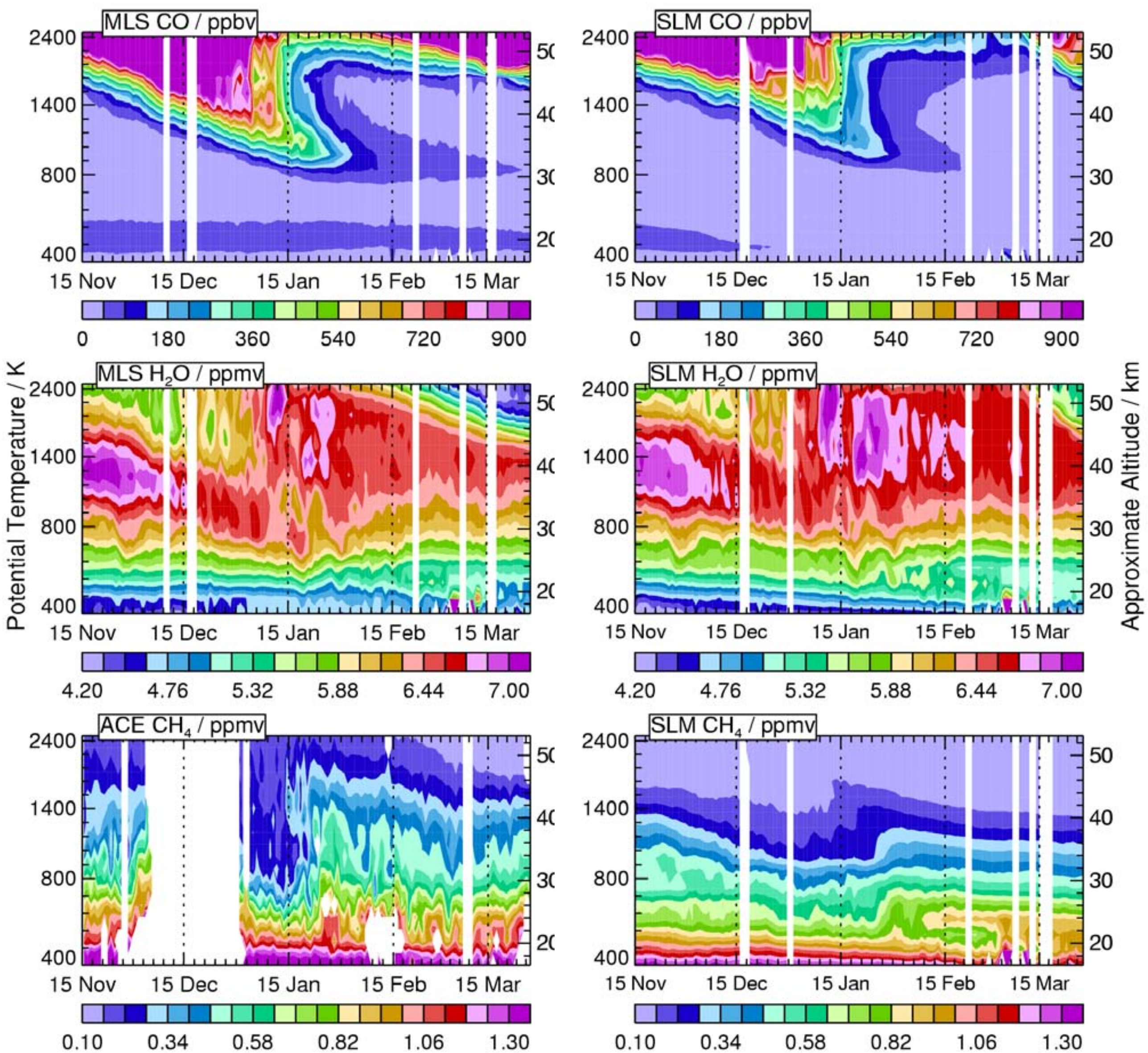


- PV across the stratopause from GEOS-5; 2000 K crossing stratopause, 2500 K and 3200 K mostly in mesosphere (static stability $\leq 4\times 10^{-4}$ s^{-2})
- 15 January, USLM vortex already broken down, reformed strongly by 14 February, decaying again by 15 March

The 2006 SSW: Vortex Structure

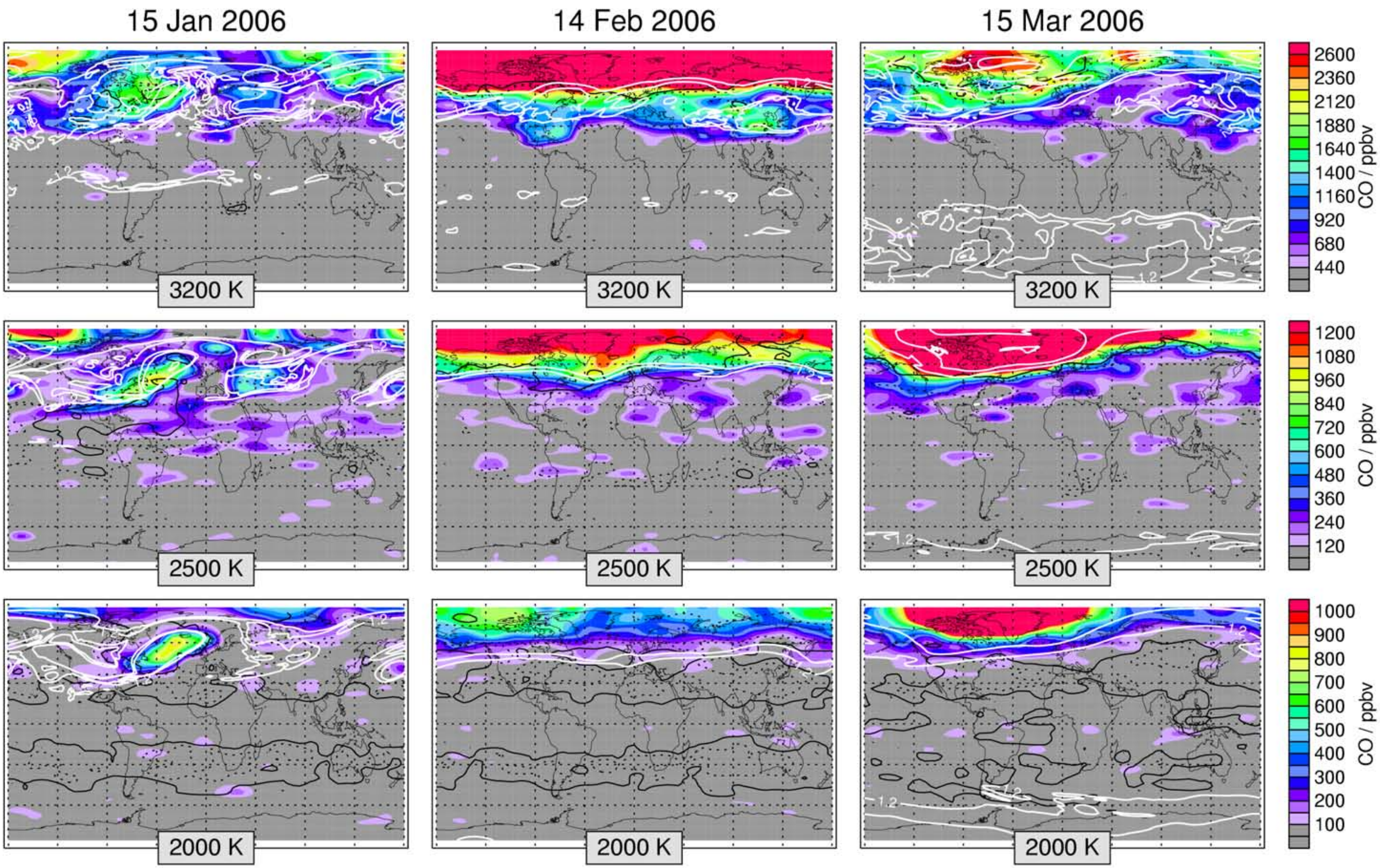


The 2006 SSW: Vortex Transport



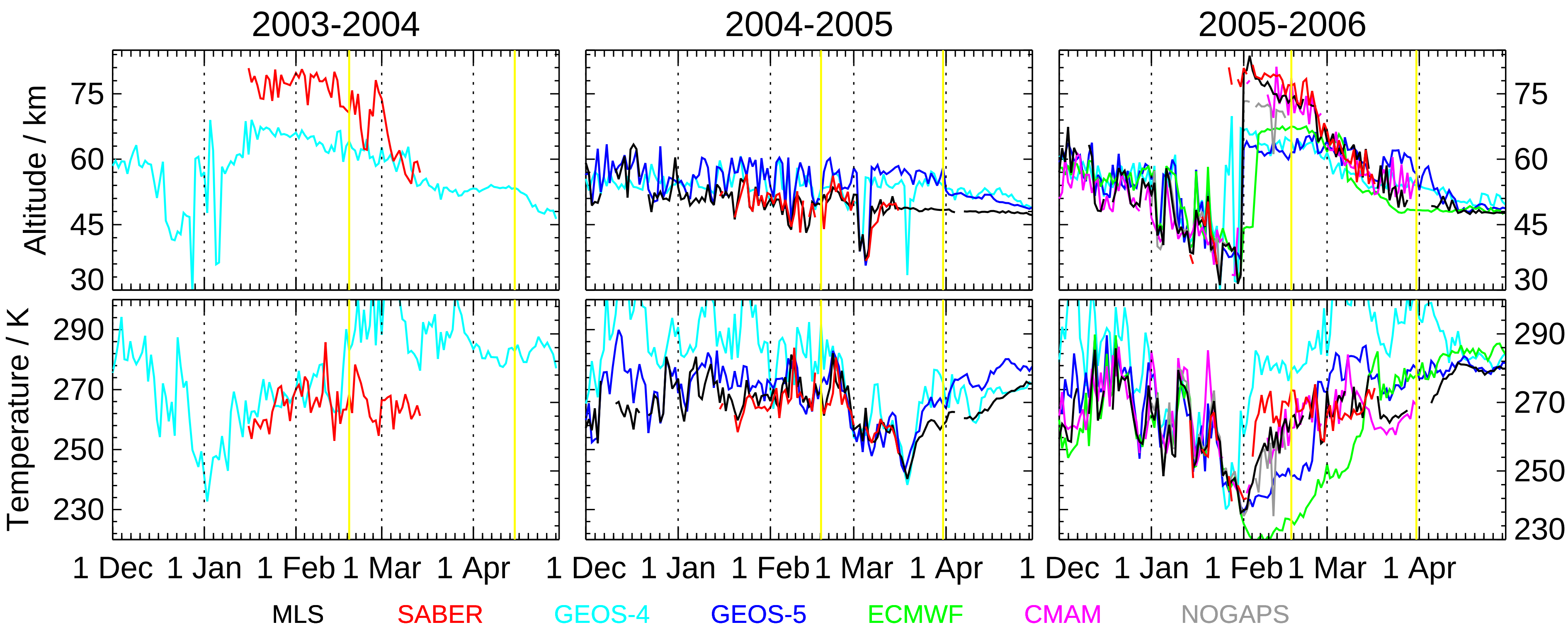
- "Vortex-average" (left) MLS CO & H_2O, ACE-FTS CH_4, in 2005-2006 NH winter and (right) SLIMCAT CTM fields
- Major warming destroys confined descent signature
- Strong USLM vortex quickly reforms in early February
- "Replay" of descent of mesospheric air into reforming vortex echoes behavior in fall
- Comparison of observed trace gases with assimilated winds/PV and transport model results can help evaluate assimilation systems
- SLIMCAT runs using ECMWF winds show some discrepancies

The 2006 SSW: Vortex Structure and Transport



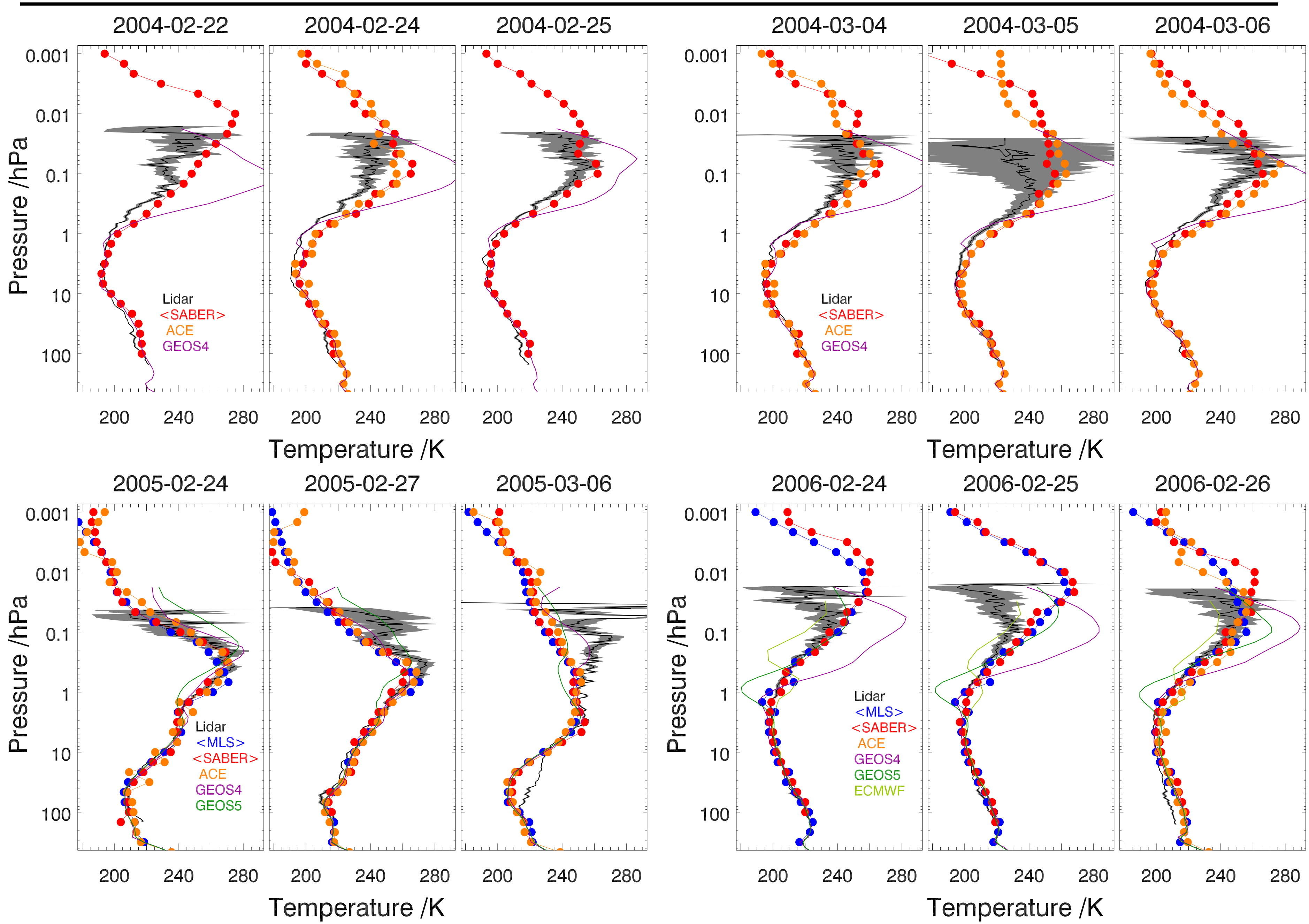
- ➤ MLS trace gas maps (e.g., CO) compared with PV (GEOS-5) here can help evaluate assimilation quality in USLM
- ➤ Correlations better at 2000 and 2500 K, large scale features correlate well even at 3200 K

Extreme Arctic Winters: Stratopause Evolution



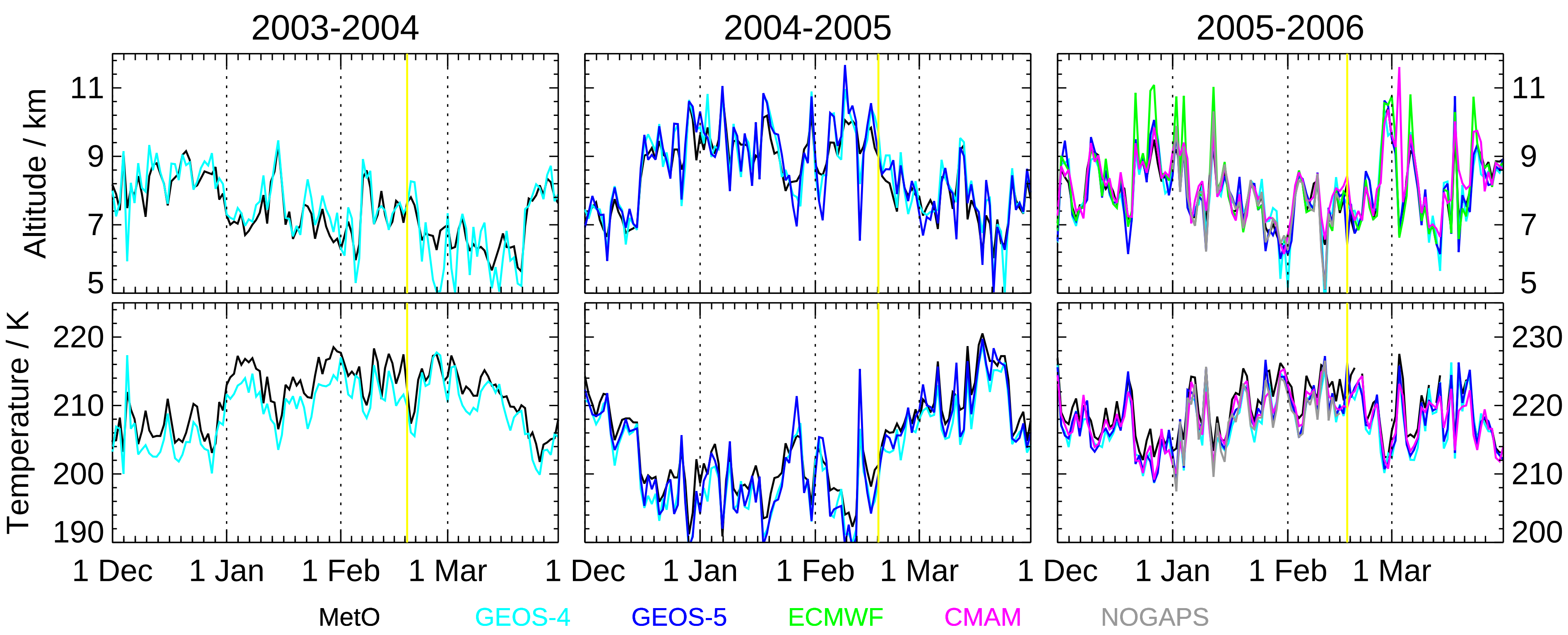
- ACE validation campaigns have been conducted at Eureka (80°N, 86°W; details in Kaley Walker and Kim Strong talks later today) during the past four Arctic late winters (yellow lines)
- Evolution of stratopause at Eureka in MLS, SABER data and assimilated analyses
- Behavior during prolonged SSW in 2004 similar to that in 2006
- Analyses capture stratopause altitude well in 2004-2005, and prior to vortex (and warm stratopause layer) breakdown in 2005-2006
- High temperature bias at stratopause in GEOS-4 alleviated in GEOS-5
- CMAM and NOGAPS-ALPHA show large improvement over operational analyses in altitude and temperature of stratopause after 2006 SSW

Extreme Arctic Winters: Lidar/Satellite/Analysis Comparisons



- Eureka lidar profiles compared with satellite data and assimilated analyses
- Lidar stratopause too low/cool February 2004 and 2006, slightly warm in 2005

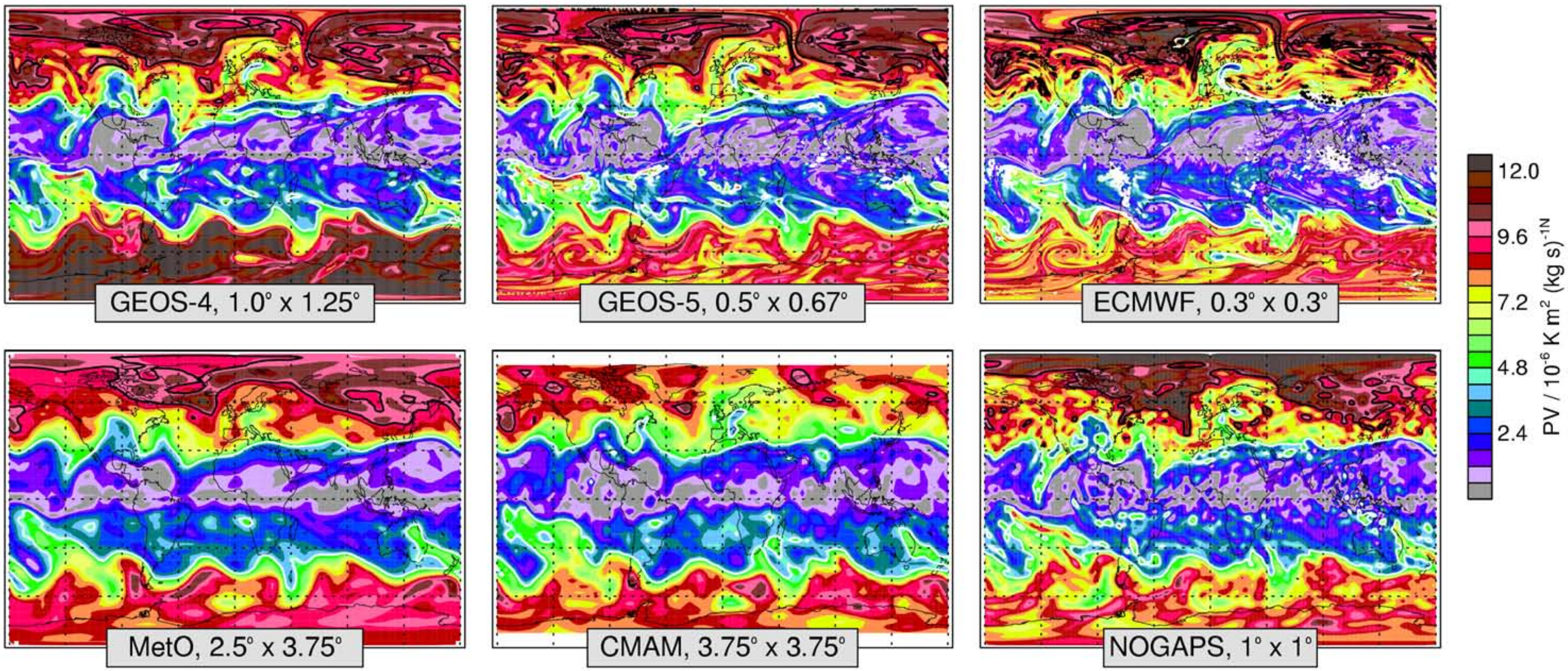
Extreme Arctic Winters: Tropopause Variability



- Dynamical tropopause at Eureka from analyses shows quite good agreement – expected since all are tied to radiosondes (including that at Eureka weather station)
- Tropopause altitude increases/temperature decreases during winter months (late December–late February) in 2004-2005 (cold winter)
- More constant in disturbed winters, but altitude decreases/temperature increases slightly during SSWs

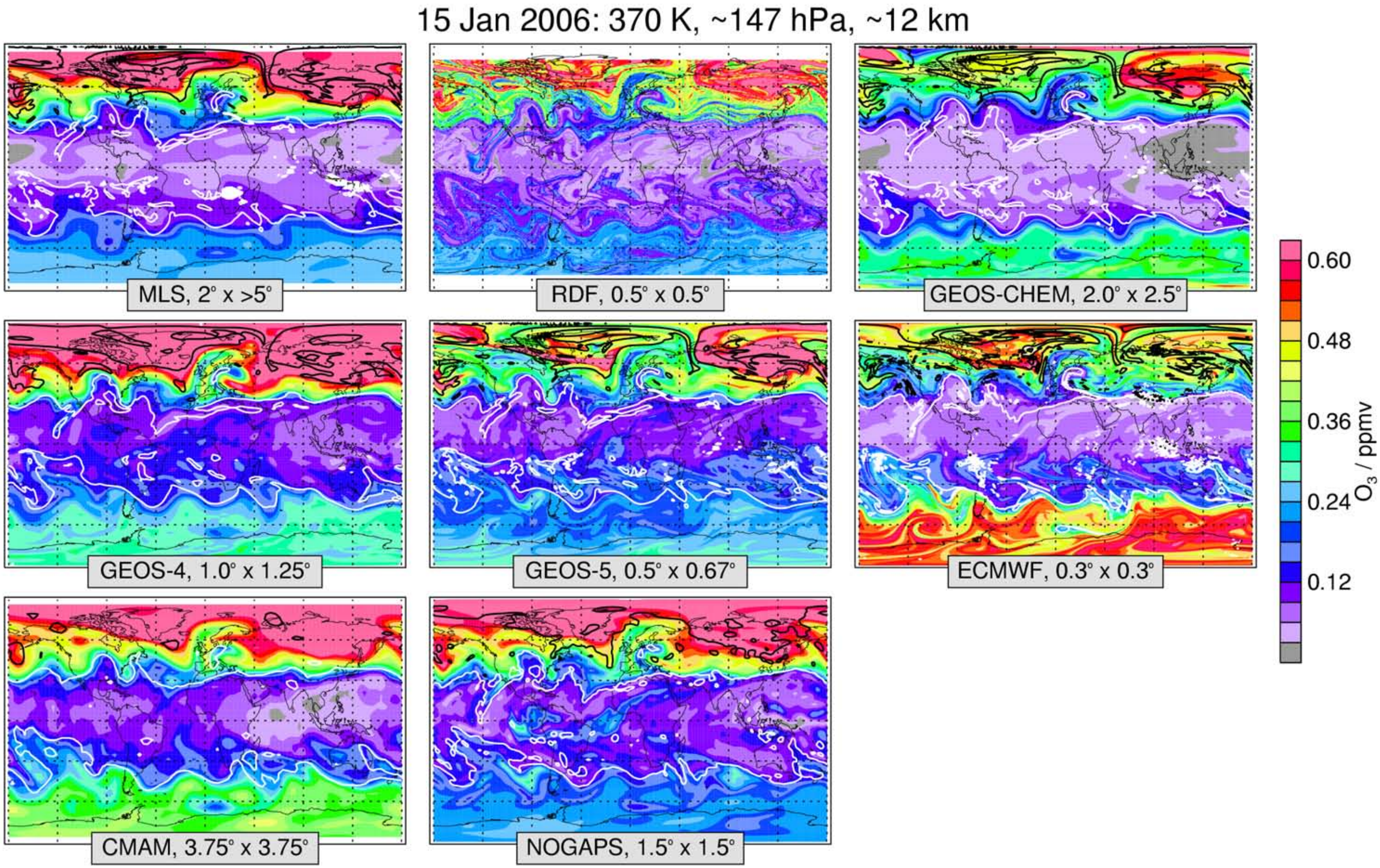
Tropopause/Subvortex Structure and Transport

15 Jan 2006: 370 K, ~147 hPa, ~12 km



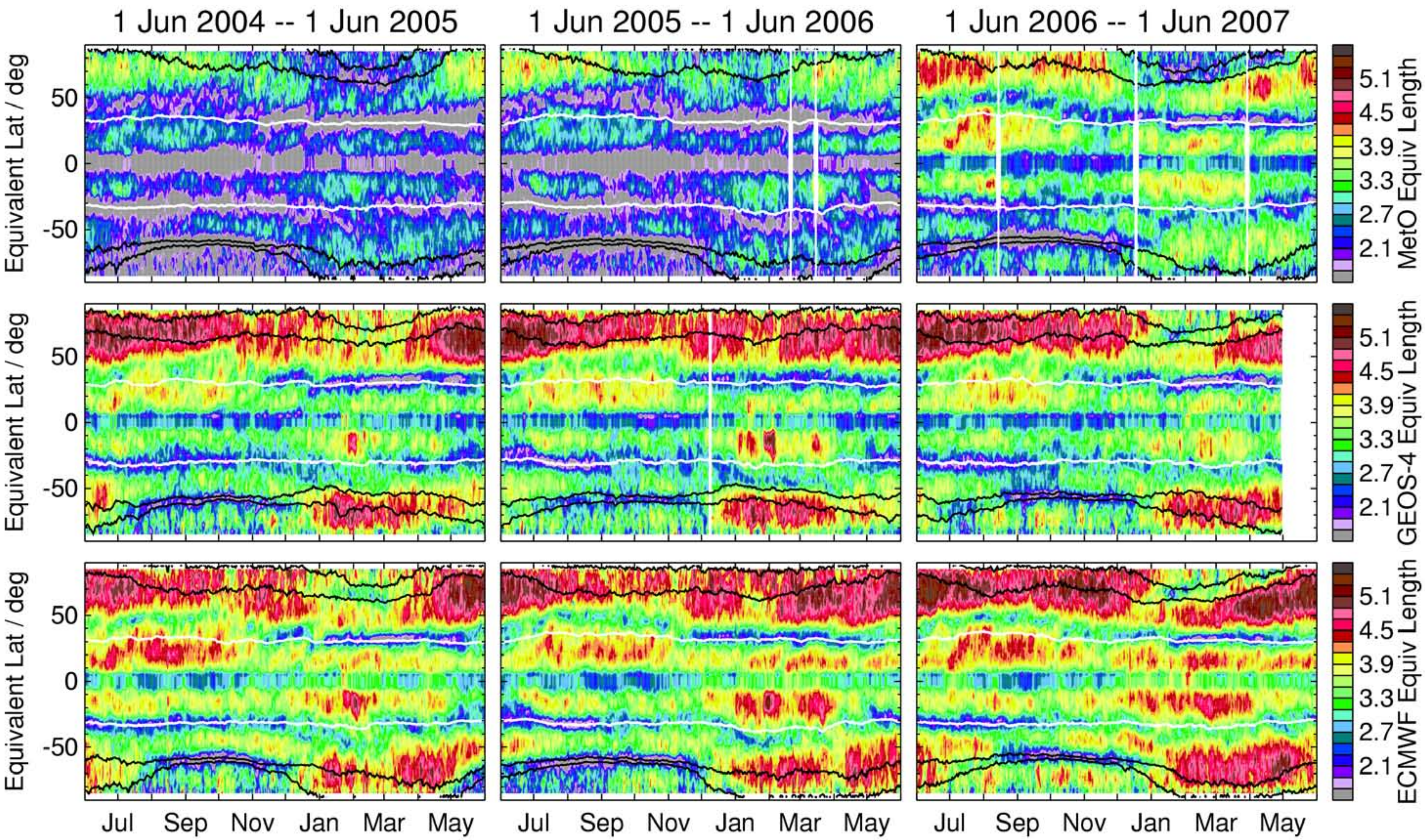
- ➤ Tropopause-level PV (white contour 4.5 PVU, near top of tropopause region) shows large-scale biases between analyses
- ➤ Small-scale features agree well, depending on resolution (e.g., intrusions of low-latitude/tropospheric air near 0° longitude in both hemispheres, and near 90°W in NH; streamer of high-latitude/stratospheric air over Australia)

Tropopause/Subvortex Structure and Transport



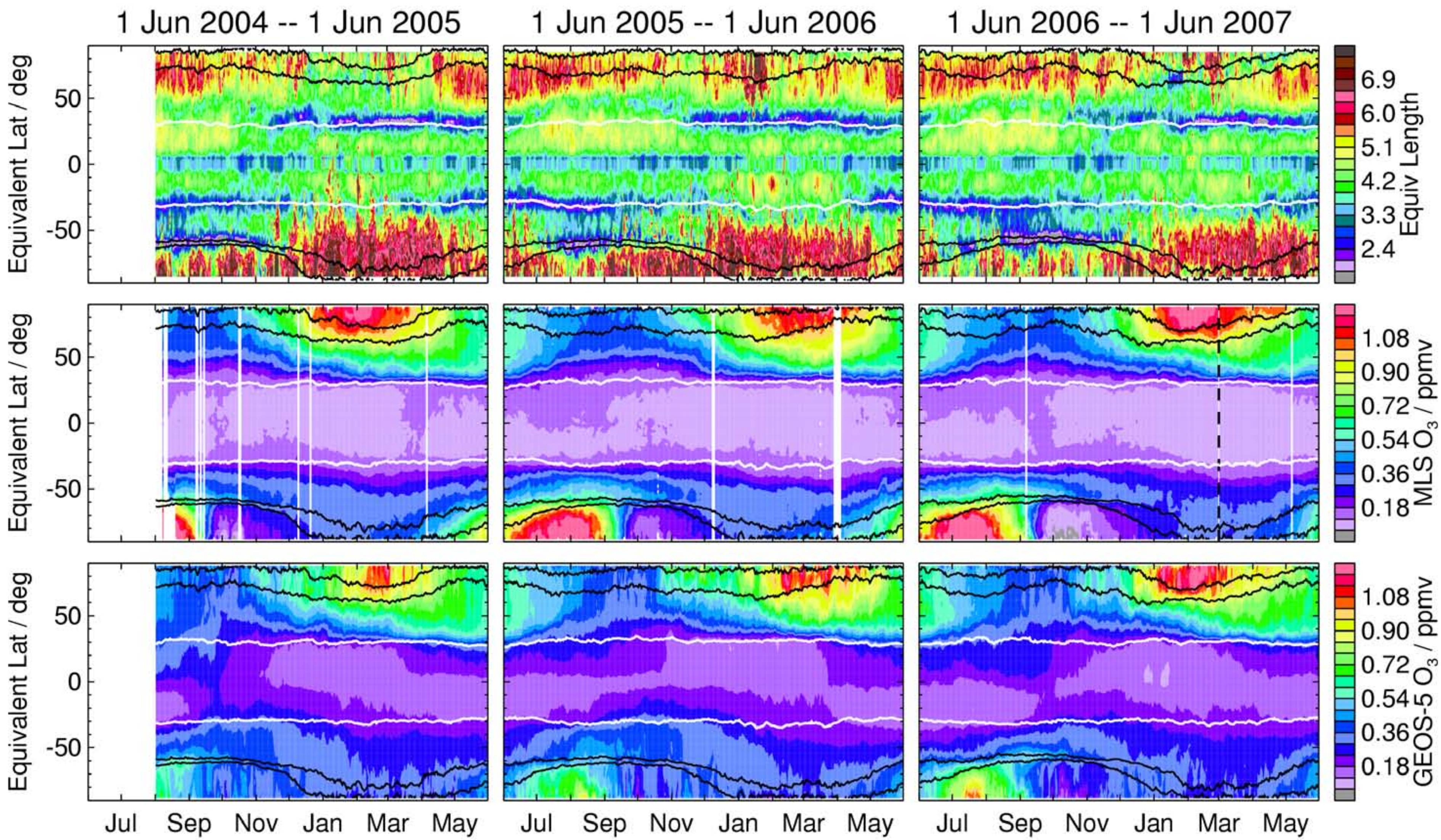
- Tropopause-level MLS ozone compared with transport models (RDF, simple reverse trajectory model, GEOS-5 winds; GEOS-CHEM, full 3D tropospheric CTM, GEOS-4 winds) and ozone from assimilation systems

Tropopause/Subvortex Structure, Annual Cycle



- ➤ K_{eff} (Equivalent Length) from Met Office, GEOS-4 and ECMWF PV; low values indicate transport barriers, high values, mixing regions
- ➤ Good agreement in location and evolution of tropopause and SH subvortex transport barriers
- ➤ Values depend on resolution, e.g., change in MetO values in 2006-2007

Tropopause/Subvortex Transport, Annual Cycle



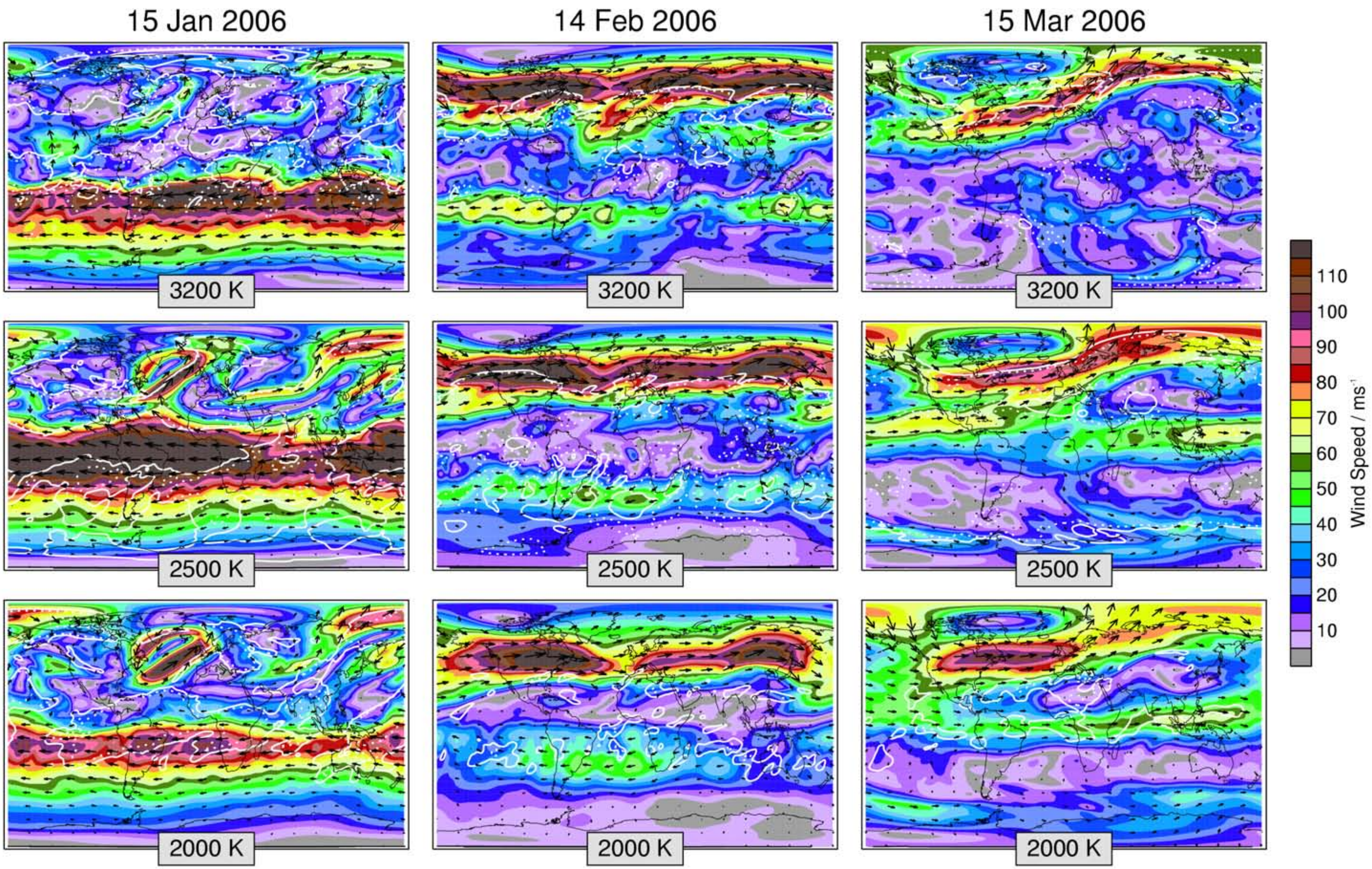
- ➤ Transport barriers in K_{eff} (from GEOS-5 PV, "noisy" near poles) compared with MLS and GEOS-5 ozone
- ➤ Good agreement with strong ozone gradients, mixing out of subvortex in spring
- ➤ Evidence of quasi-isentropic STE and interannual variability therein

- New satellite datasets from MLS, ACE and SABER provide unprecedented opportunities for detailed study of the stratopause and tropopause regions
- Examples shown here illustrate:
  - Breakdown of the warm stratopause layer during the 2006 SSW, with subsequent reformation of very high stratopause
  - Failure of operational analyses to capture stratopause evolution during 2006 SSW, and improvements in research systems
  - Temperature evolution in the high Arctic in recent extreme winters
  - Interannual/interhemispheric variability in stratopause evolution
  - Transport near stratopause/tropopause in MLS data, and relationships to assimilated PV and winds
  - Comparisons of ozone from MLS, transport models, and assimilation systems
  - Tropopause transport barriers and ozone evolution
- The continuation of these, and other, studies will result in improved understanding of the stratopause and tropopause regions and allow detailed assessments needed to improve assimilation systems

- Material on stratopause evolution during 2006 SSW in satellite data and analyses adapted from Manney et al., The Evolution of the Stratopause During the 2006 Major Warming: Satellite Data and Assimilated Meteorological Analyses, submitted to JGR, available at http://mls.jpl.nasa.gov

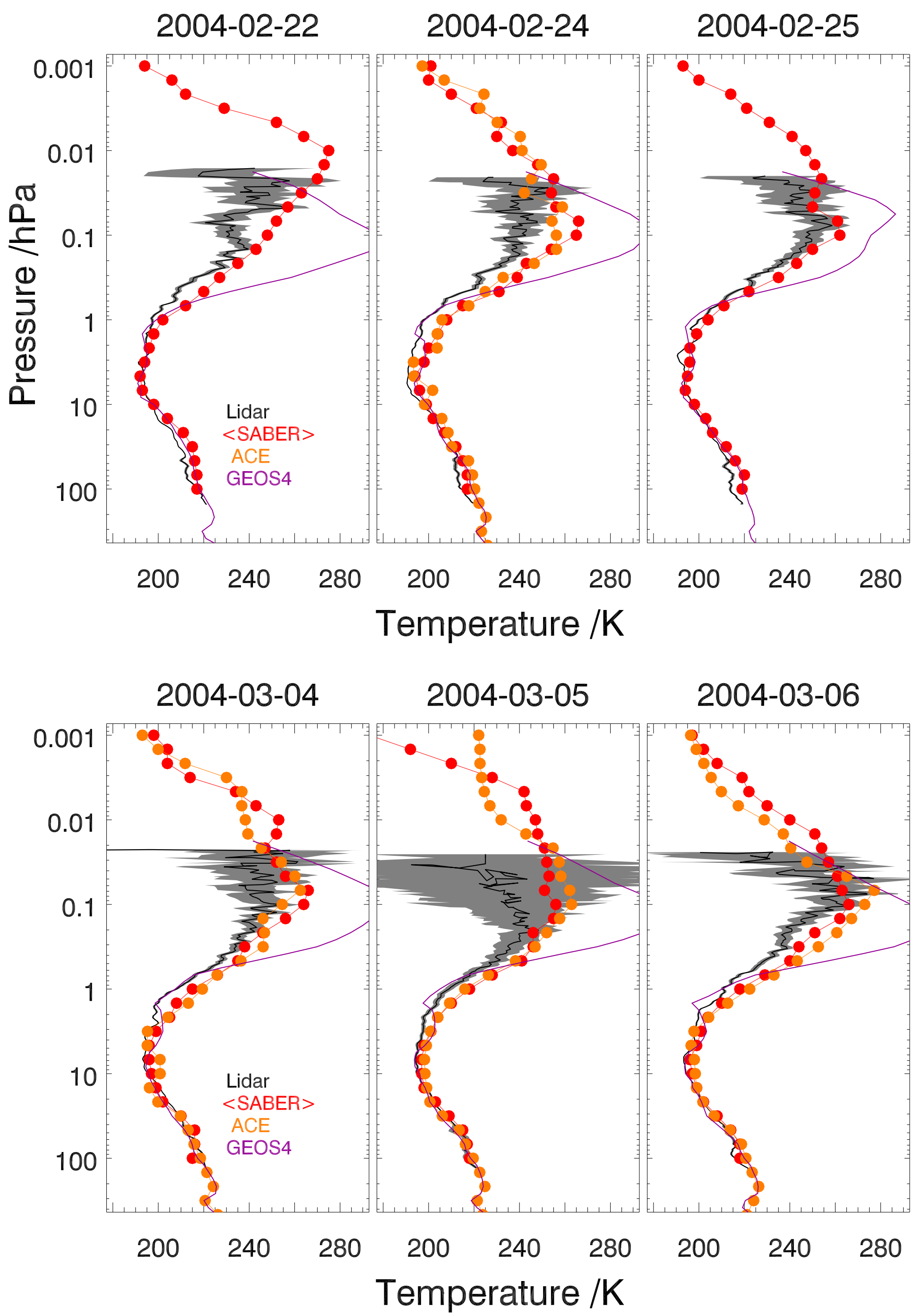
- Material on conditions at Eureka in extreme Arctic winters adapted from Manney et al., The High Arctic in Extreme Winters: Vortex, Temperature, and MLS Trace Gas Evolution, ACPD, 7, 10,235–10,285

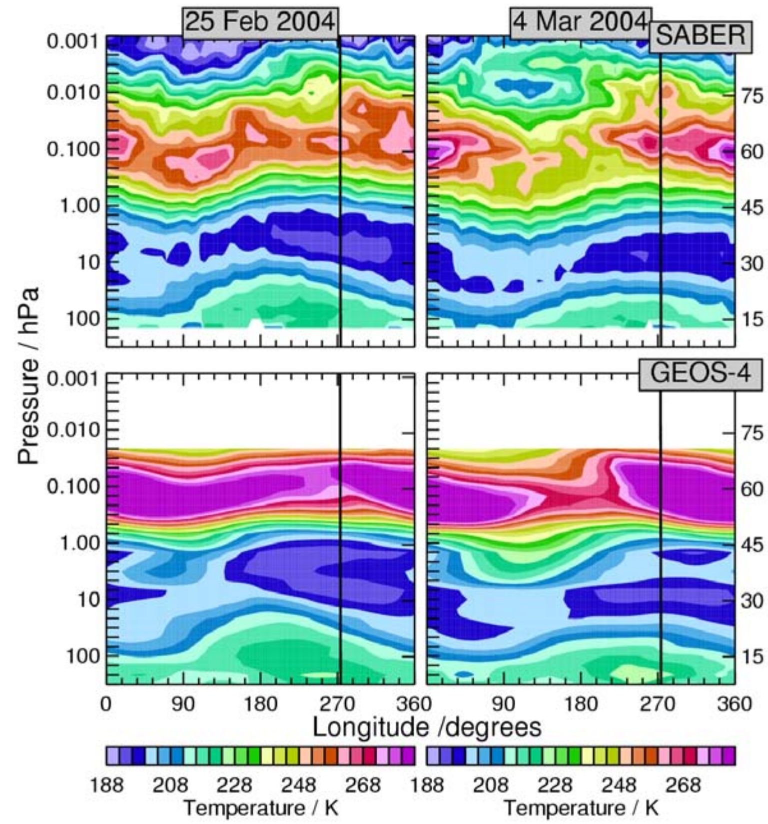
The 2006 SSW: Vortex Structure and Transport



- ➤ USLM Windspeed shows continuing close relation between strong jet and strong PV gradient (previous page) regions
- ➤ Jet structure becomes more complex across the stratopause

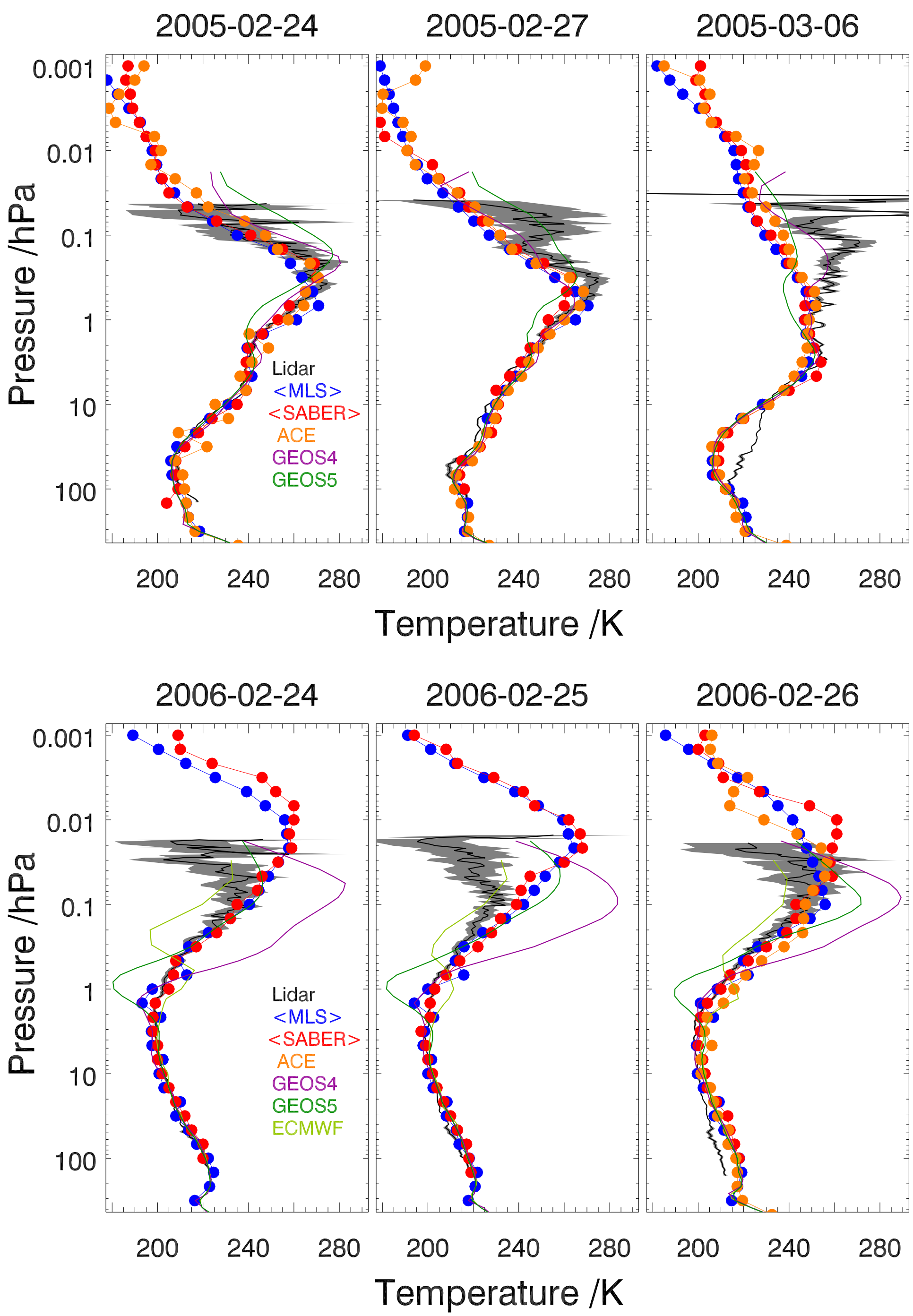
Extreme Arctic Winters: Lidar/Satellite/Analysis Comparisons

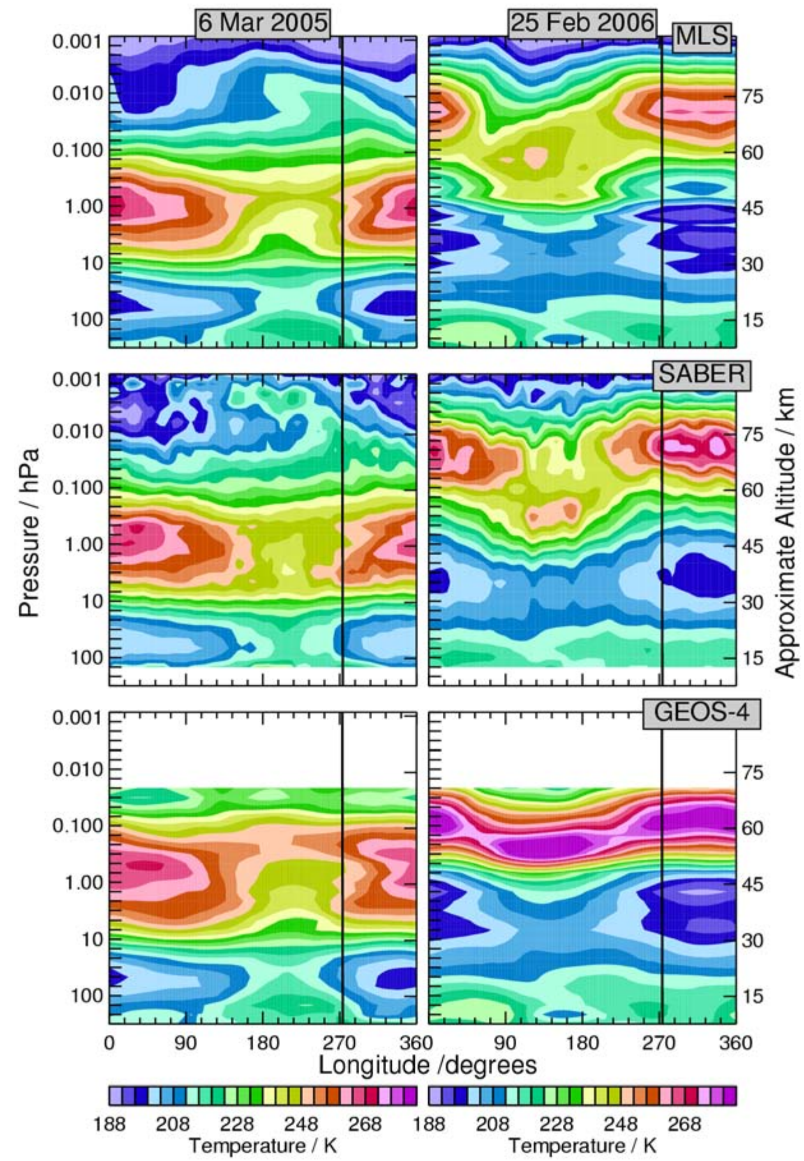




- ➤ Eureka lidar profiles compared with satellite data and assimilated analyses
- ➤ Lidar stratopause too low/cool on several days in February 2004
- ➤ Some differences in small-scale features appear related to atmospheric variability (e.g., February dates, 4 March)

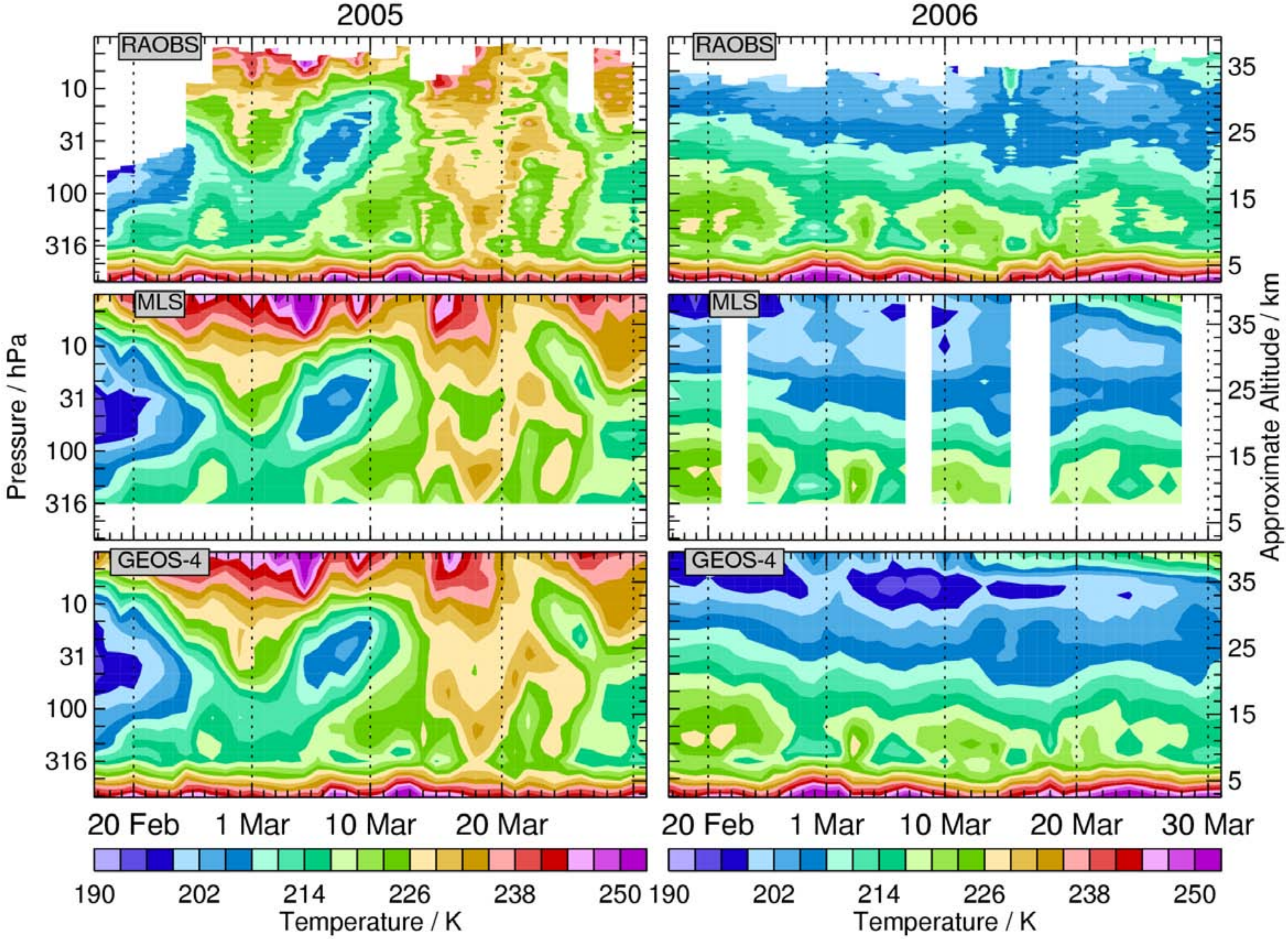
Extreme Arctic Winters: Lidar/Satellite/Analysis Comparisons





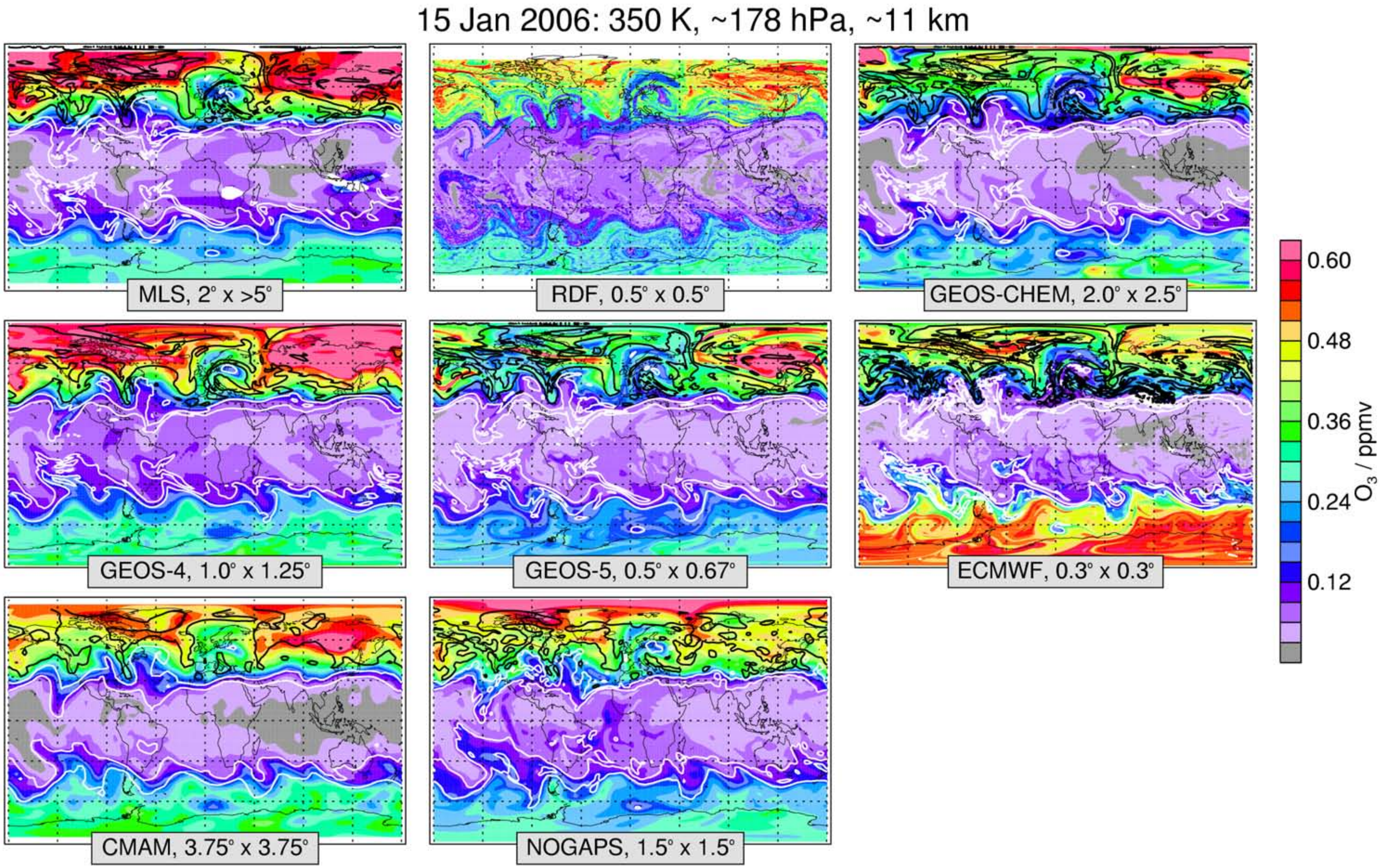
- Lidar stratopause too low/cool in 2006, slightly warm in 2005
- 6 March 2005 shows variability related to atmospheric conditions

Extreme Arctic Winters: Radiosonde & Satellite Temperatures



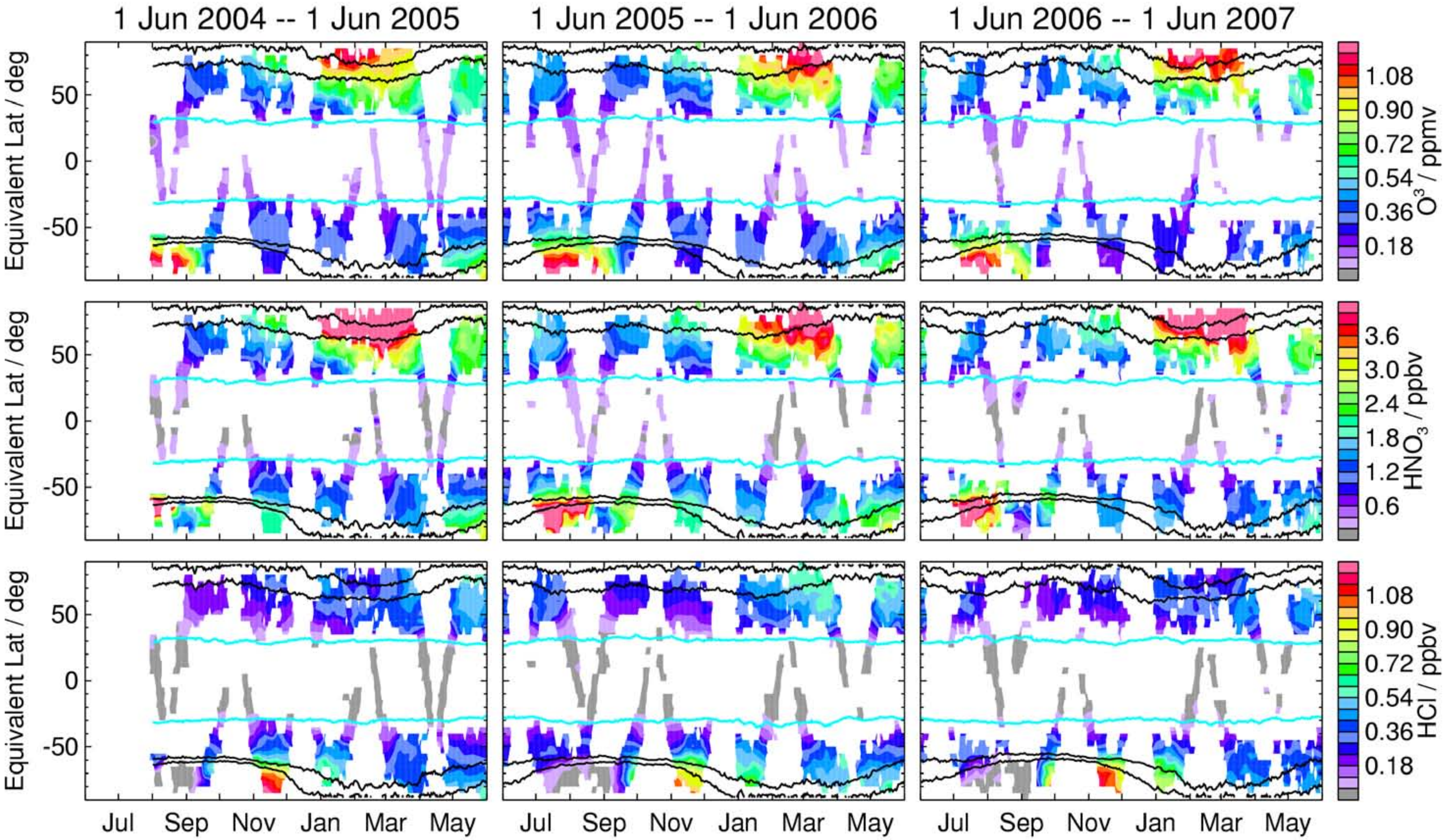
- ➤ Radiosonde, MLS and GEOS-4 temperatures during Eureka campaigns
- ➤ Analyses (e.g., GEOS-4) tied to radiosondes, so good agreement expected
- ➤ Temperature tropopause is shallow minimum near 300-400 hPa, but "coldpoint" is much higher – near 100-50 hPa in 2005, and near/above 10 hPa in 2006

Tropopause/Subvortex Structure and Transport



- Tropopause-level MLS ozone compared with transport models (RDF, simple reverse trajectory model, GEOS-5 winds; GEOS-CHEM, full 3D tropospheric CTM, GEOS-4 winds) and ozone from assimilation systems

Tropopause/Subvortex Structure and Transport, Annual Cycle



- Trace gases (O_3, HNO_3 and HCl) from ACE-FTS in the UTLS
- Sparse coverage, but show similar evolution to MLS O_3
- Other tracers (e.g., N_2O) from ACE-FTS may be useful in this region