The 360 K Potential Temperature Surface: A New Diagnostic for Stratospheric Prediction

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Abstract

Tropospheric weather systems that are associated with extremely cold temperatures near 100 hPa can have dramatic effects on the stratosphere, especially when the cold temperatures occur below the stratospheric vortex edge. These events are associated with a large vertical flux of planetary wave activity (EP flux) that can lead to planetary wave breaking and stratospheric sudden warmings (SSW). They are often associated with low ozone, mini-hole, events. Here we use GEOS (Goddard Earth Observing System), NOGAPS-ALPHA (Navy Operational Global Atmospheric Prediction System- Advanced Level Physics High Altitude), and Met. Office analyses along with forecasted meteorological fields to examine several cold upper tropospheric temperature events and the subsequent changes forced in the stratosphere. Results show that upper tropospheric disturbances over the North Atlantic in January 2003 and January 2004 were both followed by stratospheric wave breaking in the tropics, advection of low potential vorticity (pv), tropical air over the pole, and major SSWs. A strong cold upper troposphere temperature region over the South Atlantic, associated with a large vertical EP flux also occurred prior to the major SSW in September 2002. It was found that these cold upper tropospheric temperatures are best identified by examining the heights of the 360 K potential temperature surface, which are greatly elevated in response to the cold temperatures. While typically ranging from 10-13 km, in extreme events these 360 K heights can rapidly exceed 15 km, acting as transient "moving mountains" that dynamically force the stratosphere at the lower boundary.

1. Background and Method

BACKGROUND

Stratospheric Sudden Warmings (SSWs) are generally assumed to be forced by large-scale tropospheric disturbances, such as blocking events.

However, a recent study by Taguchi (*J. Atmos. Sci.* 2008) has shown no statistically significant correlation between blocking events and SSWs.

HYPOTHESIS

Synoptic scale transient events in the troposphere may force <u>some</u> SSWs.

METHOD

We examine the tropospheric forcing of major SSW of January 2006, using local (non-zonally averaged) diagnostics, to better understand the scale and development of the tropspheric forcing. We use GEOS-4 Analyses.

2. Stratospheric Warming 2006

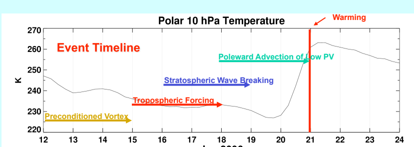
Key Elements Observed

1. **Preconditioned Vortex:** Early January polar vortex was weak and displaced off the pole.

2. **Large Amplitude Synoptic-Scale Tropospheric Disturbance:** On 16-17 January a tropospheric disturbance developed over the North Atlantic and under the polar vortex winds

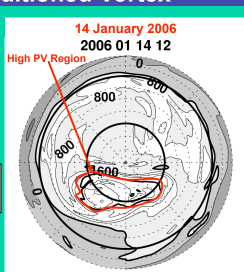
3. **Subtropical Wave Breaking:** Forcing from the tropospheric disturbance resulted in subtropical wave breaking in the mid-stratosphere.

4. **Rapid Poleward Advection of Low PV Air:** The subtropical wave breaking resulted in tropical air with low PV values being advected to the pole. Descent associated with the low PV anomaly produced the Major SSW on 21 January 2006.



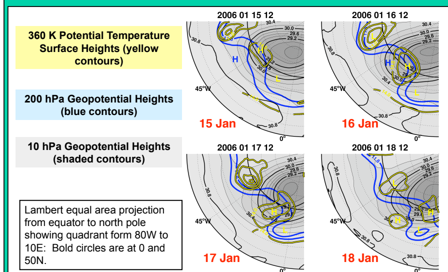
3. Preconditioned Vortex

On 14 January 2006, the mid-stratospheric (1100 K; ~10 hPa) polar vortex is well off the pole.



1100 K PV for 14 January 2006. Lambert equal area projection from equator to north pole: Bold circles are at 20N and 60N. 0 degrees longitude is at the bottom: Contour interval is 400 PVU.

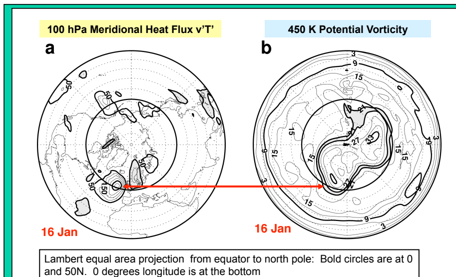
4. Tropospheric Forcing



The **360 K surface** at 50N is **over 2 km higher** than the average 360 K surface heights at that latitude.

This high 360 K surface is associated with **low ozone** (ozone mini-hole) with **record low total ozone** observed over the UK on 19 January 2006 (Kell et al., *ACP*, 2007).

The nearly 15 km peak **360 K surface height** is the **second largest** observed (40-50N) in the **1991-2006** time period.

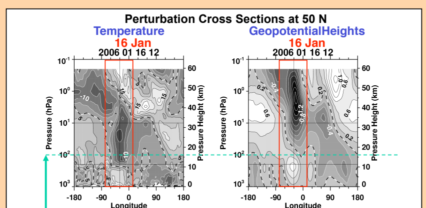


The high **360 K surface** at 50N is associated with **very cold temperatures** and **large local values of meridional heat flux**.

The high meridional **heat flux** region at 100 hPa develops **under** the lower stratospheric vortex winds, as seen in the **450 K PV**.

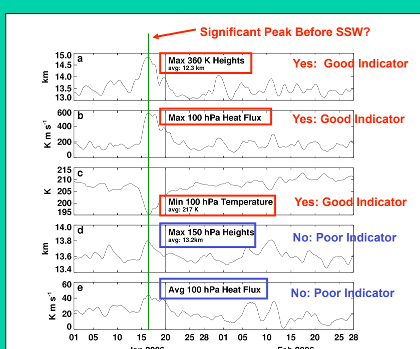
The high values of meridional heat flux and upward displaced 360 K surface occurring under the vortex edge implies a **strong upward flux of wave activity**.

5. UT/LS Structure



Note: Strong Temperature, Weak Geopotential Height Perturbations at 100 hPa

6. Tropospheric Forcing (Indicators)



Time Series at 50 N for January and February 2006

Simple Diagnostics for Local UT Disturbances:

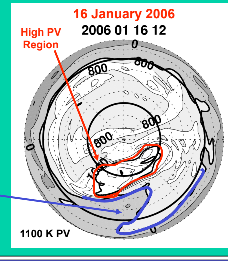
50 N is approximately under the polar vortex edge.

Search for the maximum value of 360 K surface height at 50 N at each time to create time series. Use same procedure for heat flux and 150 hPa geopotential heights. Search for minimum 100 hPa temperatures at 50 N. Compare with zonally averaged heat flux.

7. Subtropical Wave Breaking

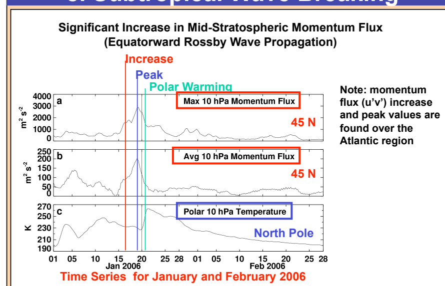
Mid-stratospheric vortex rotates eastward with tropospheric forcing.

Change in vortex orientation implies an increase in the horizontal momentum flux u'v'; implying equatorward Rossby wave propagation.



Lambert equal area projection from equator to north pole: Bold circles are at 20N and 60N. 0 degrees longitude is at the bottom: Contour interval is 400 PVU.

8. Subtropical Wave Breaking

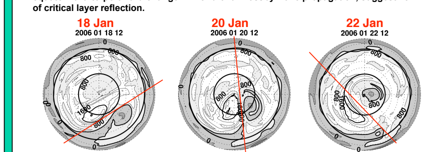


Note: momentum flux (u'v') increase and peak values are found over the Atlantic region

9. Poleward Advection

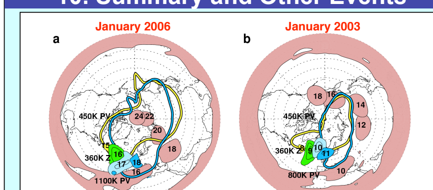
PV at 1100 K (~10 hPa)

Note change in orientation of the vortex (red line) → change in momentum flux → equatorward-to-poleward change in meridional Rossby wave propagation, suggestive of critical layer reflection.



Lambert equal area from equator to north pole: Bold circles are at 20N and 60N. 0 degrees longitude is at bottom: Contour interval is 400 PVU

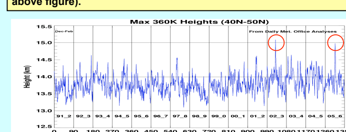
10. Summary and Other Events



360 K Surface on 15,16,17, and 18 January 2006 (yellow, green, light blue, and blue areas)
450 K PV on 15 and 18 Jan (yellow and blue contours)
1100 K pv on 16,18,20,22, and 24 Jan (brown areas)

360 K Surface on 8,9,10, and 11 January 2003 (yellow, green, light blue, and blue areas)
450 K PV on 9 and 11 Jan (yellow and blue contours)
1100 K pv on 10,12,14,16, and 18 Jan (brown areas)

Major SSW of January 2003 (18 Jan 2003) was similar to January 2006 SSW (see above figure).



1991-2006 NH Winters:

2003 and 2006 forcing events have strongest signals

Major SSW of September 2002 was also similar to January 2006 SSW:

Rapid synoptic-scale UT/LT development under polar vortex associated with large local upward EP flux, followed by subtropical wave breaking, although subsequent dynamics become more complex in this case.

Conclusions

1. The January 2006 major SSW was forced by a **synoptic-scale system** in the troposphere that amplified in the UT/LS as it moved under the polar vortex.
2. The height of the **360K potential temperature** surface below the LS vortex winds is an excellent indicator of the forcing on the stratosphere for this type of tropospheric disturbance. 100 hPa Temperature and heat flux below the vortex winds are also good indicators of the forcing on the stratosphere.
3. The 100-200 hPa geopotential heights are not a good indicator of the tropospheric forcing of the stratosphere because the cold core system is changing from high geopotential heights below 100-200 hPa to low geopotential heights above 100-200 hPa, making geopotential height perturbations relatively small near 100 hPa for this type of system. Mechanistic model that use upper tropospheric geopotential heights for their lower boundary forcing may under predict the strength of these events.
4. Other major SSWs, such as the January 2003 warming (and the September 2002 warming), show similar synoptic-scale tropospheric forcing.