The Sharpness of the Winter Polar Tropopause in GEOS-5 Analyses

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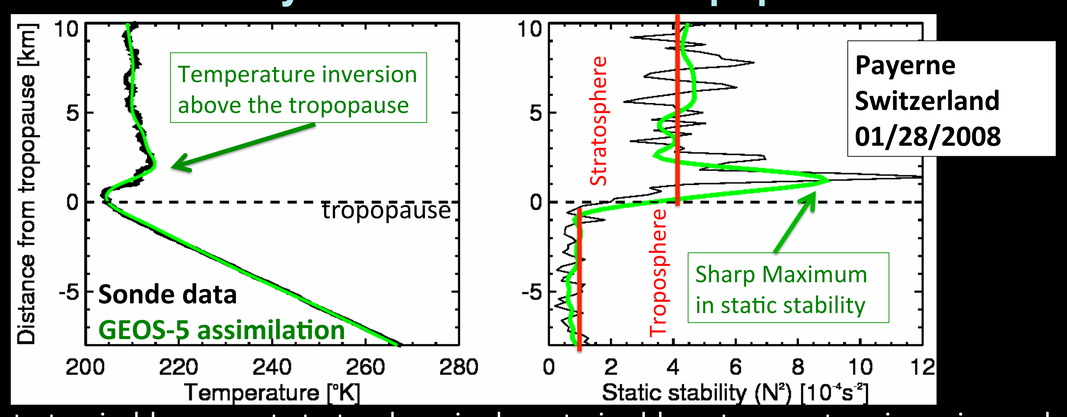
Introduction

Stability structure near the tropopause



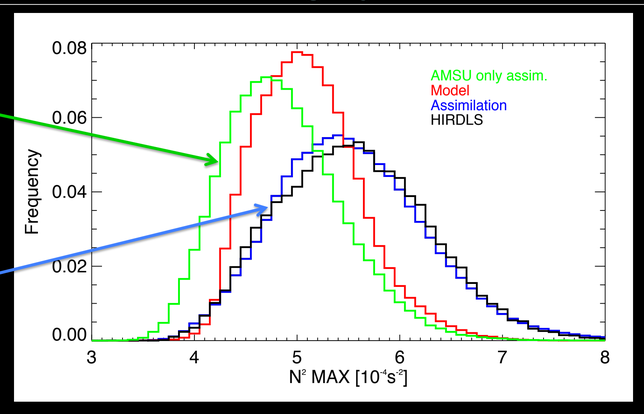
The extratropical lowermost stratosphere is characterized by a temperature inversion and a sharp maximum in static stability in a shallow layer directly above the thermal tropopause. The feature, referred to as the tropopause inversion layer (TIL), is present in all seasons and shows in the global zonal average in tropopause-based coordinates.

Older data assimilation systems were unable to represent the TIL correctly due to excessive vertical smoothing. However, more recent analyses generate realistic temperature and static stability profiles near the tropopause, which are in good agreement with independent high-resolution data, such as from radiosonde observations. This motivates the use of reanalysis data sets in scientific studies of the TIL.

Sensitivity to the observing system

The TIL in the AMSU-only is weaker than in the model

Full assimilation reproduces the distribution of N^2 reported by HIRDLS very well



Distributions of maximum N^2 between in the 3 km layer above the tropopause from High Resolution Dynamics Limb Sounder (HIRDLS on NASA's Aura satellite), full assimilation, free-running model and AMSU-only assimilation, 45°N - 75°N

These data withholding experiments show that the full assimilation experiment, which uses high spectral resolution AIRS data leads to the best agreement with observations. The use of hyperspectral radiance data and conventional observations is critical for the correct representation of near-tropopause static stability in assimilation.

Objective

We study the static stability structure of the polar tropopause during a major sudden stratospheric warming (SSW) event that occurred in January 2009. Major SSW events are large-scale disturbances of the wintertime polar circulation in the stratosphere, characterized by a weakening of the zonal winds over the pole and a reversal of the meridional temperature gradient.

Several studies done in the past few years noted that static stability of the polar tropopause increases during the onset of SSWs, leading to a sharper TIL in the northern high latitudes but the phenomenon has not yet been studied in detail.

Method: an application of the MERRA-2 reanalysis

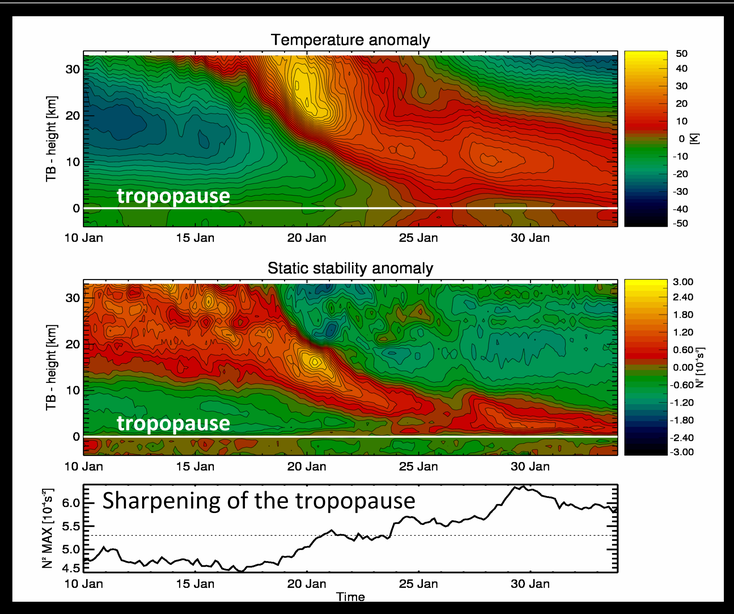
Modern Era Retrospective Analysis for research and Applications - 2 (MERRA-2) is the latest soon-to-be released reanalysis of the satellite are data produced by NASA's GMAO.

Features of MERRA-2 relevant to this study:

- **High vertical resolution data**
  - ✓ All available hyperspectral radiance data
  - ✓ GPS radio occultation observations
  - ✓ Radiosonde and aircraft measurements
- **Model**
  - ✓ State of the art Ganymede GCM on a cubed sphere grid
  - ✓ Vertical resolution is ~1 km in the lower stratosphere

Main Results

The evolution of temperature and static stability during a sudden stratospheric warming event (2009)

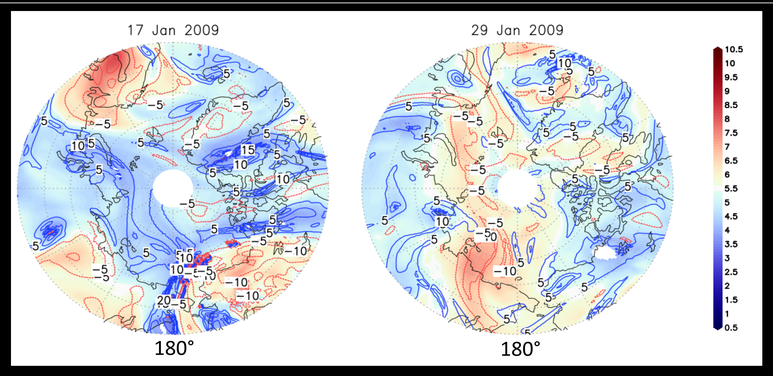


Top two panels: Evolution of 75°N-90°N averaged temperature and static stability (N^2) anomalies during the 2009 sudden stratospheric warming event. The anomalies are calculated by subtracting the 25 day mean from the area averaged quantities. Bottom: time series of maximum N^2 in the 3 km layer above the tropopause.

Associated with the SSW is a descent of positive temperature anomalies in the northern high latitudes. Consistently, increased static stability develops along the lower edge of the temperature disturbance and reaches the tropopause within several days from the beginning of the SSW.

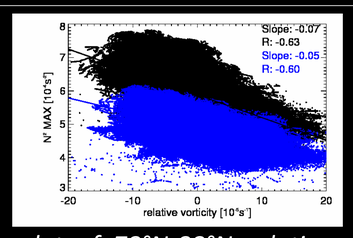
The maximum static stability in a shallow layer above the tropopause increases by over $1\times10^{-4}s^{-1}$ (>20 %).

The sharpness of the tropopause and upper tropospheric circulation



The 60°N-86°N spatial distributions of N^2 maximum in the northern high latitudes on two selected days before (left) and after (right) the warming occurred (colors). Overlaid are the contours of relative vorticity at the tropopause. Regions of cyclonic and anticyclonic circulation are shown as blue and red contours, respectively. The units of relative vorticity are $10^{-5}s^{-1}$.

Consistent with previous studies [*Wirth* 2004] we find that anticyclonic circulation at the tropopause favors high static stability directly above: the distribution of N^2 maximum is highly anticorrelated with relative vorticity. This remains true under SSW conditions.



Scatter plot of 78°N-88°N relative vorticity at the tropopause vs. the maximum static stability in the 3 km layer above the tropopause for 15 days before (blue) and 15 days after the onset of the SSW (black).

Summary and ongoing work

- **This MERRA-2 study confirms that static stability in the lowermost polar stratosphere increases during stratospheric sudden warming events**
- **Assimilation of hyperspectral data is critical – older reanalysis did not reproduce the near-tropopause stability structure correctly**
- **Work in progress:**
  - **Detailed scientific analysis of processes involved**
  - **Potential impacts on the high-latitude winter circulation in the troposphere**

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MERRA-2