P6M.1 AN INVESTIGATION OF THE DYNAMICS OF COHERENT TROPOPAUSE DISTURBANCES USING A HIGH RESOLUTION GLOBAL MODEL

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1. INTRODUCTION

Jet streams and jet streaks play a significant role in many different aspects of synoptic and mesoscale weather systems. Recent studies have demonstrated that jet streaks are frequently associated with the superposition of large-amplitude, localized potential vorticity (PV) maxima of mesoscale dimensions with the enhanced PV gradients associated with jet streams. In many cases, these PV maxima can be interpreted dynamically as coherent monopolar vortices that are located on or near the tropopause (Meade, 2001; Pyle, 2004). An observational climatology of these vortices was recently conducted by Hakim and Canavan (2005), and a dynamical framework for their association with jet streaks has also been established (Hakim, 2000; Cunningham and Keyser, 2004). While these studies have categorized and classified coherent structures from a diagnostic and dynamical framework, the dynamical details of their life cycles (e.g., origins, sources, and sinks) have yet to be determined. The role of these coherent structures in extratropical cyclogenesis, jet streak intensification, and their interaction with smaller- and larger-scale flows, also remain to be investigated and are worthy of further examination.

To this end, the objectives of this study are to examine results of high-resolution global model data to identify coherent tropopause vortices, and to investigate the viability of simulation data as a tool for analyzing the dynamic origin and behavior of coherent tropopause vortices.

2. MODEL AND METHODOLOGY

The NCAR Community Climate Model Version 3 (Kiehl et al. 1996; CCM3) is an atmospheric general circulation model that is used for climate research. Model output was obtained at a resolution of T213 with 51 levels, and interpolated onto a 2.5-degree resolution grid with 20 isobaric levels in 50 hPa increments, which was sufficient to begin this initial study. Model output was generated and examined for one representative winter period (January through April), over 401 time steps in 6-hour increments.

Potential vorticity was calculated on each pressure level, and potential temperature was interpolated onto the 2.0 PVU surface, which was chosen to represent the dynamic tropopause (where 1 PVU = 1×10^{-6} m^2 K Kg^{-1} s^{-1}). Coherent tropopause vortices were then identified via closed potential temperature contours on the 2.0 PVU surface as described below.

Parameters for vortex identification and classification were calculated using the methodology of Hakim and Canavan (2005). A vortex core was defined as a local minimum in potential temperature within a 650 km radius, on the 2.0 PVU surface. The last closed isentrope was identified by scanning out from the vortex core along eight equally spaced radials; the last closed isentrope was defined as the potential temperature contour found closest to the vortex core where the radial gradient of potential temperature changed sign. The vortex amplitude was defined as the difference between the value of the last closed isentrope and the value of the vortex core.

Initial results for the Northern Hemisphere were examined to verify that the CCM3 is a viable model for the study of coherent tropopause vortices. Time averages of several fields were examined for comparison to observed climatology. Model results were then examined for different genesis events of coherent tropopause vortices. A basic census of coherent tropopause vortices was also conducted for this model-simulated winter period.

3. RESULTS AND DISCUSSION

An initial analysis of the CCM3 data for the Northern Hemisphere indicates that the model results are consistent with observed climatology. Time-averaged isotach maxima at 300 hPa appear

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off the east coasts of North America and Asia, as shown in Fig. 1, and the time average of PV at 300hPa, depicted in Fig. 2, shows that the highest gradients of PV are coincident with these isotach maxima.

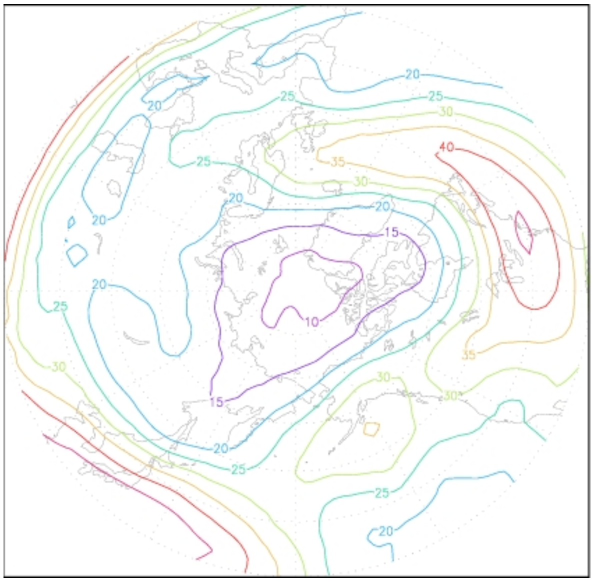

Figure 1. Time-averaged isotachs (m s^{-1}) at 300 hPa.

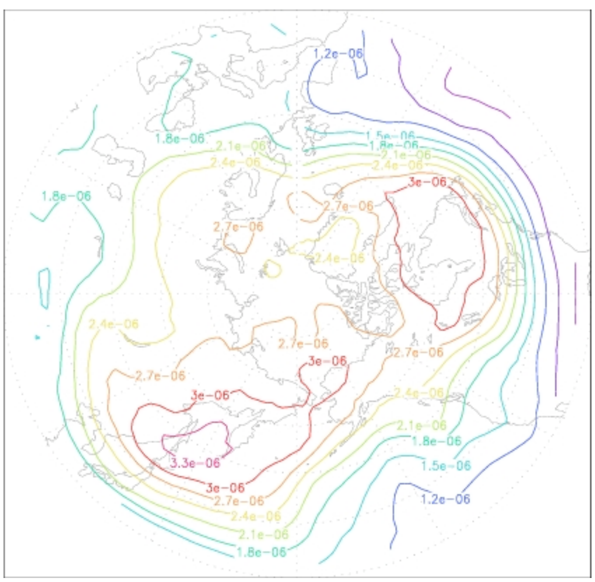

Figure 2. Time-averaged PV (K Kg^{-1} m^2 s^{-1}) at 300 hPa.

The time mean of potential temperature on the 2.0 PVU surface, shown in Fig. 3, reveals the strongest gradients of potential temperature off the east coasts of both North America and Asia, in the vicinity of the climatological jet locations, again consistent with theory and observed climatology.

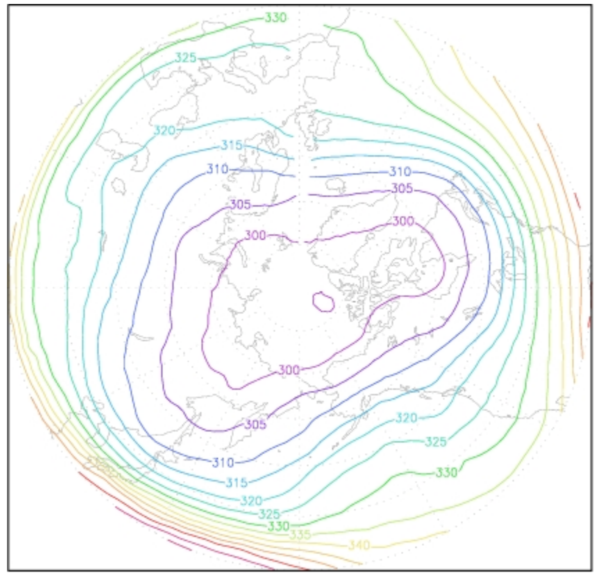

Figure 3. Time-averaged potential temperature (K) on the 2.0 PVU surface.

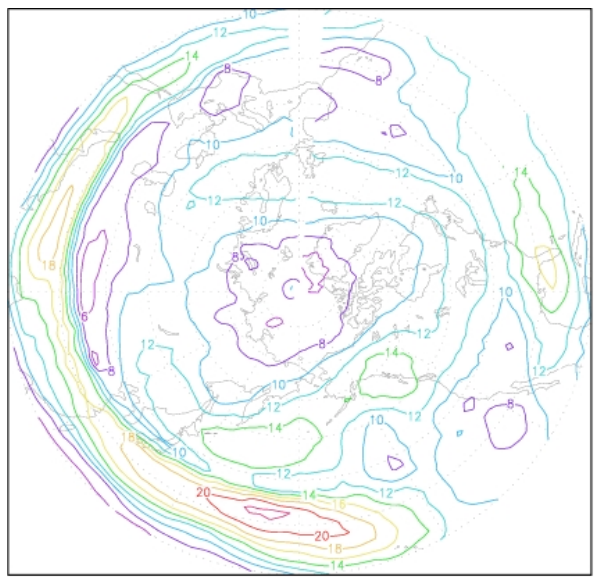

Figure 4. Standard deviation of potential temperature (K) on the 2.0 PVU surface.

The standard deviation of potential temperature on the 2.0 PVU surface (Fig. 4) indicates regions of significant variability in the typical winter storm track regions. Less significant but still notable variability is found poleward of the climatological storm tracks, in the vicinity of the Aleutian Islands, and again near the Alaska–Yukon border, with values of 12 K or higher.

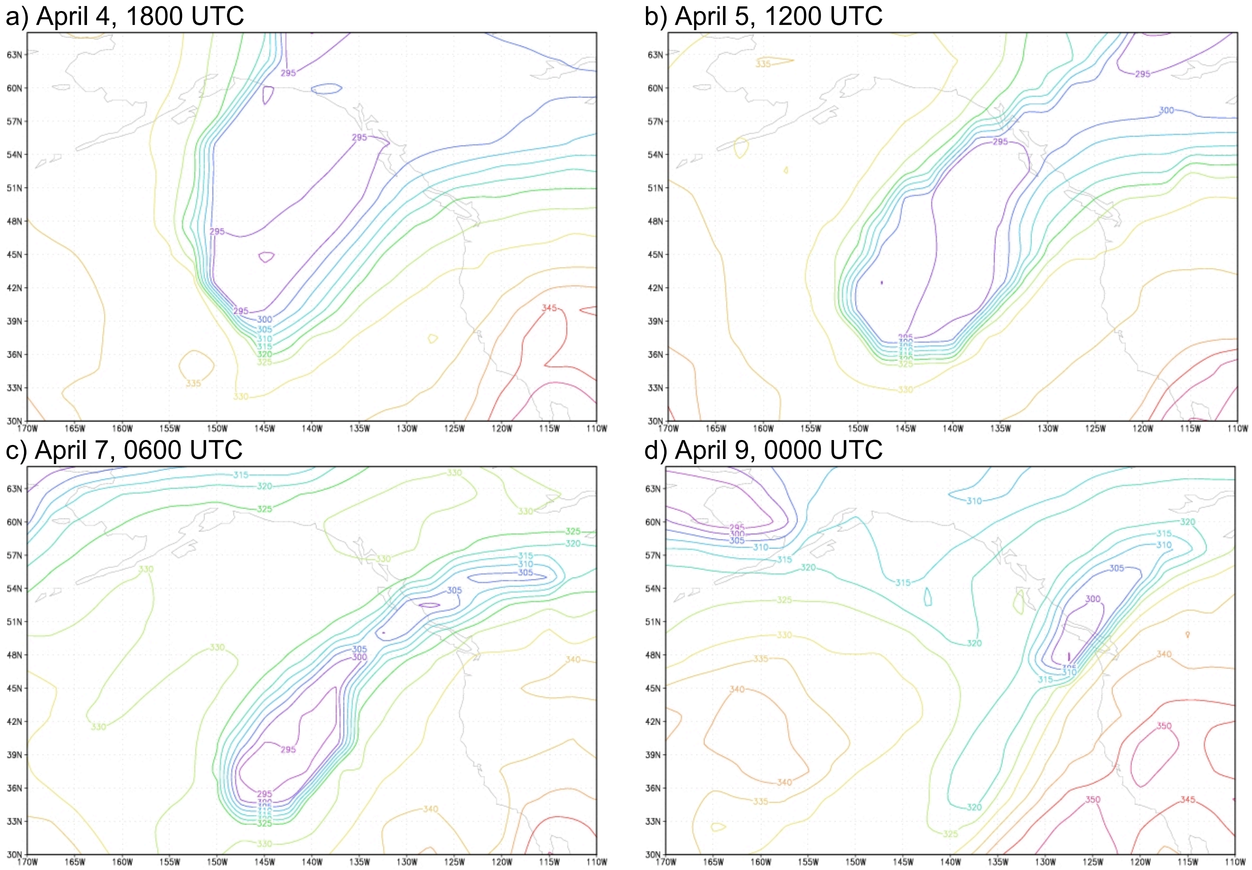

Figure 5. Potential temperature (K) on the 2.0 PVU surface. April 4, 1800 UTC - April 9, 0000 UTC. The figure depicts a trough fracture resulting in a closed coherent tropopause vortex.

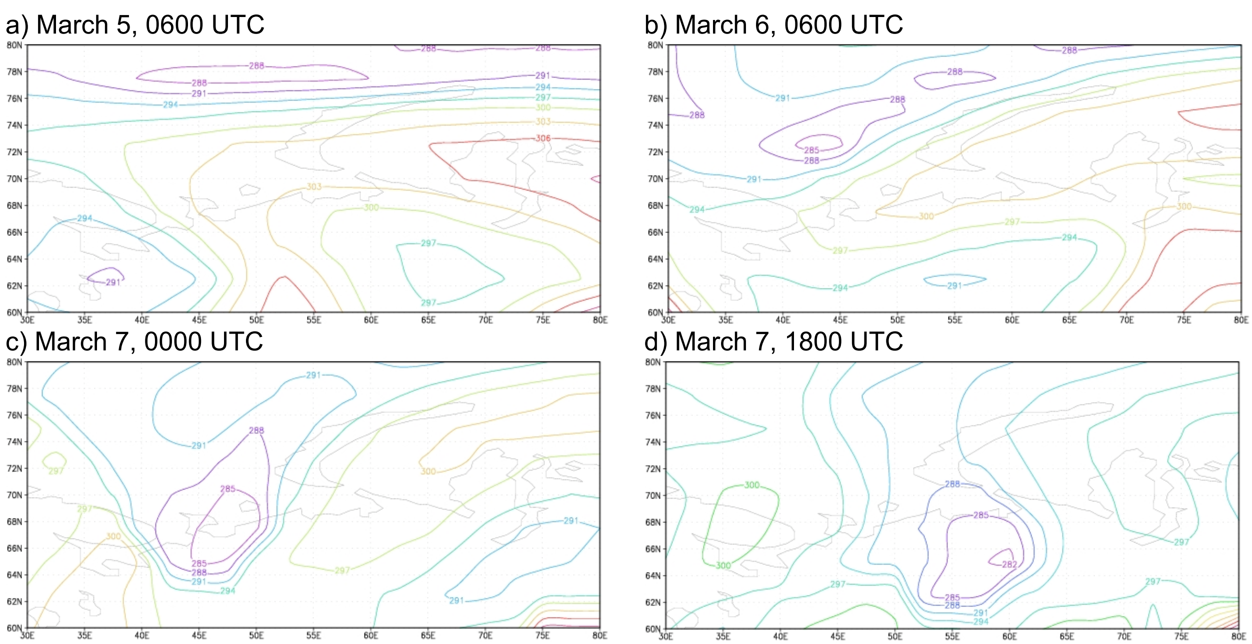

Figure 6. Potential temperature (K) on the 2.0 PVU surface. March 5, 0600 UTC – March 7, 1800 UTC. The figure depicts the genesis and intensification of a coherent tropopause vortex.

a) Cross-section through 65N

b) Cross-section through 57.5E

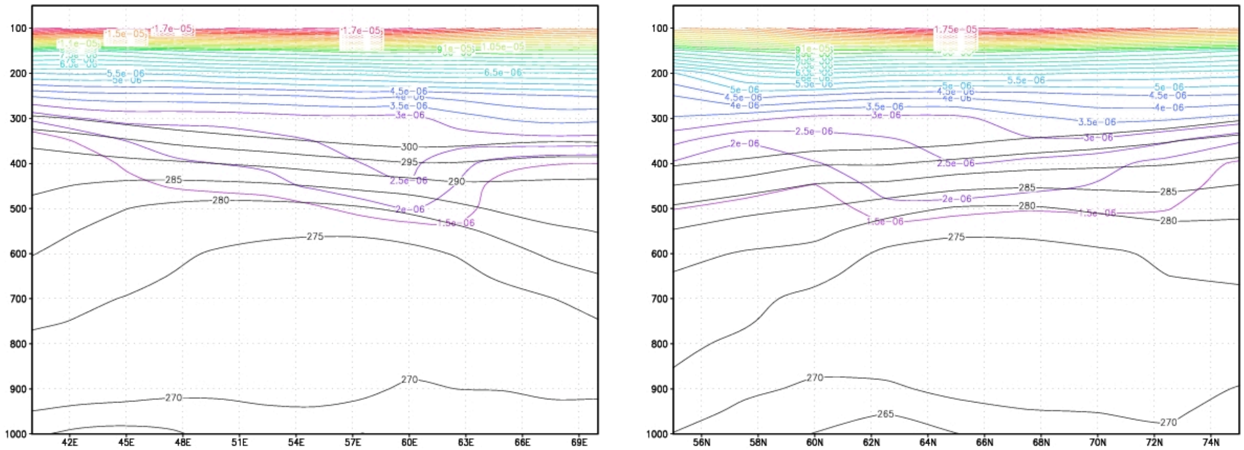

Figure 7. Height-distance cross-sections of potential temperature (K) and PV (Kg^{-1} K m^2 s^{-1}) through 65N (figure 7a) and through 57.5E (figure 7b). Contours of potential temperature are plotted to a maximum of 300 K in an interval of 5 K. Contours of PV are plotted from a minimum of 1.5×10^{6} Kg^{-1} K m^2 s^{-1} in an interval of 0.5×10^{6} Kg^{-1} K m^2 s^{-1}. Vertical coordinate is in hPa.

Detailed exploration of these secondary regions in the model data reveals several instances of potential temperature minima that are bounded by closed potential temperature contours. The existence of these potential temperature minima on the 2.0 PVU surface is indicative of materially closed regions, or coherent vortices on the dynamic tropopause.

According to the census procedure described in Section 2, a total of 14208 vortex cores were found. The average vortex core had a value of approximately 308 K, and the average vortex amplitude was approximately 4.6 K.

Subjective examination of model data reveals two apparent types of formation of these coherent tropopause vortices. The first type of vortex formation is a more frequent case of the fracture of a deep trough. In these cases, the trough base pulls equatorward from the main trough body and breaks off to form a closed vortex. In this first type of vortex formation, the time derivative of the potential temperature of the vortex core remains nearly constant, indicating an essentially adiabatic process. The second type of vortex formation, which is less frequent, involves the genesis and amplification of a vortex within a cold-air filament or trough. In this second case, the time derivative of the potential temperature of the vortex core is negative, suggesting that diabatic processes are important for the intensification of this type of vortex.

A trough fracture event leading to the development of a coherent tropopause vortex is depicted in Fig. 5a through Fig. 5d. A diabatic vortex growth event is depicted in Fig. 6a through Fig. 6d. Cross sections of the vortex shown in Fig. 6 are shown in Fig. 7.

The cross sections of Fig. 7 clearly indicate the intersection of potential temperature and PV contours, which are material surfaces under adiabatic and frictionless conditions. The tropopause in these cross-sections is found at a comparatively low height of nearly 550 hPa. In Fig. 7b, potential temperature contours resemble a strong, upper-level PV anomaly. Cooling near the surface is also evident in both Fig. 7a and Fig. 7b. The evolution of this feature appears to be diabatic in nature, since the time-derivative of potential temperature on the 2.0 PVU surface is negative.

4. DISCUSSION AND FUTURE RESEARCH

Model output from the NCAR CCM3 was examined for a representative winter period of January through April. Time-averaged isotachs and PV at 300 hPa were computed in order to gain insight into the behavior of jet maxima in association with the PV field. Analysis of model results clearly indicates time-mean wind maxima off the coasts of Eastern North America and Asia. These wind maxima are consistent with observed climatological storm tracks. Time-averaged PV at 300 hPa shows the highest mean PV gradients in the vicinity of the time-mean wind maxima, according to expectations. These summary observations of model output are also consistent with observed climatology.

The CCM3 also generates what appear to be localized PV maxima that are located on the poleward side of jet streaks. These PV maxima are indicative of coherent tropopause vortices; and they behave in a similar manner to those documented by Pyle (2004).

In order to analyze more rigorously coherent tropopause vortices with CCM3, potential temperature was calculated and interpolated onto the 2.0 PVU surface, selected to represent the dynamic tropopause. Examination of potential temperature on this surface indicates the existence of transient local potential temperature minima, with several closed contours surrounding the minima. These closed contours represent closed material contours within which fluid parcels are bound in an adiabatic framework, and are indicative of coherent vortices on the dynamic tropopause. The CCM3 depicts the identity and behavior of these coherent vortices in a similar manner to recent observational studies.

Examination of the time-mean potential temperature interpolated onto the 2.0 PVU surface indicates sharp gradients in potential temperature located in the vicinity of the climatological storm tracks, and also with the isotach maxima found in the time mean. These results are again consistent with both climatology and theory. The standard deviation of potential temperature on the 2.0 PVU surface indicates the highest variability over the West Pacific storm track, and to a lesser extent over the Western Atlantic storm track region. Sub-maxima in variability are found on the poleward side of the major storm tracks.

Subjective observation of these regions indicates the presence of several coherent vortices, as evidenced by closed potential temperature contours about a potential temperature minimum. Two types of vortex origins were observed subjectively. The first type of vortex origin is found in a typical trough fracture event, where the trough base digs equatorward and breaks to form a closed vortex. This first type of vortex formation appears to be essentially adiabatic in nature. The second type of vortex origin is found in the growth of a vortex core over time within a larger cold pool. In the second type of case, a vortex core develops and gradually intensifies, evidenced by decreasing potential temperature values of the vortex core, and an increasing number of potential temperature contours enclosing the vortex core.

Further examination of the model results will include an objective tracking methodology for coherent tropopause vortices, in order to quantify objectively the sources and sinks of coherent vortices. Further insight may be gained by examining the frequency distribution of coherent vortices, and a formal analysis of scale interactions may also yield considerable insight into the relationships between coherent tropopause disturbances and jet streams, jet streaks, cyclogenesis, and the general circulation.

From a general perspective, the NCAR CCM3 yields results that are consistent with observation and theory. These results indicate that the CCM3 can be used to gain further insight into the dynamics of life cycles of coherent tropopause disturbances, their association with cyclogenesis, and their role in the general circulation.

5. REFERENCES

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