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OBSERVATIONAL EVIDENCE OF A TROPOPAUSE FOLD OVER BISMARCK, NORTH DAKOTA ON 10 MARCH 2005

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1. Introduction

On the morning of 10 March 2005, an interesting synoptic feature was observed over Bismarck, North Dakota. This feature, known as a tropopause fold, is a folding of the tropopause that occurs as the result of an intense jet streak. A jet streak can induce indirect circulations due to convergent and divergent patterns that result from ageostrophic motions in the jet streak (Bluestein 1993). The circulation that sets up allows stratospheric air to descend down and to the right (equatorward), under the entrance region of the jet streak, while tropospheric air ascends up and to the left (poleward – assuming the jet streak is oriented west to east with westerly flow). This can be an important process in the development of a surface cyclone (Uccellini et al. 1985).

The stratosphere is a reservoir for high potential vorticity air due to its high stability. Assuming this air descends adiabatically and that vertical motion (ω) is a maximum at some level below the extrusion point in the stratosphere, it follows that this air mass can be a large source of absolute vorticity. Using Ertel's potential vorticity equation:

$$PV = -g(\xi_\theta + f)\, \partial\Theta/\partial p$$

where PV is potential vorticity, g is gravity, $(\xi_\theta + f)$ is absolute vorticity and $-\partial\Theta/\partial p$ is static stability, as ∂p increases, $(\xi_\theta + f)$ must also increase so that potential vorticity is conserved, thus absolute vorticity increases (Holton 1992). Bluestein (1993) also demonstrated how an upper-level potential vorticity anomaly can lead to surface low development over a stationary baroclinic boundary.

A surface low pressure system may exhibit rapid intensification if a potential vorticity anomaly from a tropopause fold is advected over a developing surface low. Uccellini et al. (1985) showed that this may have been the case with the President's Day cyclone of 1979, which underwent explosive development after a tropopause fold occurred upstream of the developing system.

The fold over Bismarck was detected by pure accident. In performing the upper-air observation at this station, it was assumed that the instrument had a temperature sensor failure. The reasoning was that the observed tropopause height of 410 mb was too low (Figure 1). It was later determined through analysis of nearby upper-air sites that this feature was real. Low tropopause heights are a common occurrence with strong folding events, as they can reach heights as low as 850 mb and in some instances may include multiple tropopause boundaries (Phillip Smith, Purdue University, personal communication).

Sounding analysis along with cross sections of potential vorticity and potential temperature will be used to highlight the folding event as in Nastrom et al. (1989). The motivation for this paper is to document the fold using a North American Model (NAM) analysis (named the Eta model at the time of this event) along with surface and upper-air observations. It is not the authors' intent to perform any diagnosis on the event or to try to show the evolution of the feature. This paper is meant to be a brief review of an interesting feature that is more common than might be assumed.

2. Data

The data utilized in this case came from the Advance Weather Interactive Processing System (AWIPS) archive. AWIPS is a forecasting tool that was developed for and is used by the National Weather Service. The archived data included the 12 UTC NAM model run for 10 March 2005. Surface and upper-air observations from 12 UTC 10 March 2005 were also used.

3. Analysis

An intense surface low pressure system (Alberta clipper) was centered in northern Minnesota on 10 March 2005, 1200 UTC (Figure 2). This system was a fast moving storm and was producing very gusty winds in its wake along with a small area of snow in northeastern North Dakota (Figure 3). At this time the low pressure system was beginning to fill in and weaken.

The associated 500-mb shortwave trough was located in broad northwest flow over the Northern/Central Plains (Figure 4). A series of shortwave troughs was observed to propagate around a large persistent upper level ridge located over the western United States. Another important feature to note is the strong jet stream on the periphery of the upper level ridge (western United States) and trough (central United States) along with its associated jet streak positioned over the Central Plains (Figure 5). The aforementioned jet streak is the feature that was responsible for producing the tropopause fold, which will be examined next.

4. The Tropopause Fold

As mentioned before, upper-air soundings in the Northern Plains were indicating low tropopause heights. This is evident at surrounding locations such as International Falls, Minnesota (Figure 6) and Aberdeen, South Dakota (Figure 7). A low tropopause indicates either very cold air at lower levels as in an arctic air mass or a dynamically driven forced decent of the tropopause (jet streak forcing).

Two techniques were used to document the descent of the tropopause. Both utilized a cross section starting from a point located in northwestern Colorado and ending at a point in southwestern Ontario. The first technique employed was similar to what Nastrom et al. (1989) used in their analysis. Figure 8 is a cross section of potential temperature with height. Packing of isentropes at the top of the figure, which is indicative of stratospheric air, can be seen. A pronounced "dip" is noted over the Northern Plains. This was the location of the possible fold event.

Another cross section was made using a different technique, to confirm our suspicion that this was indeed a tropopause fold event. This technique is perhaps the best to use when searching for such a feature as it is easier to visualize the "folding" process. Figure 9 depicts both potential vorticity and the 250-mb wind speed to identify the locations of the jet streak and stratospheric air. Uccellini et al. (1985) discussed that stratospheric air contains values of potential vorticity greater than 1 potential vorticity unit (PVU). Using this definition, it is evident that stratospheric air was beginning to wrap underneath the entrance region of the jet streak – a strong signal of a tropopause fold. Further analysis (not shown) revealed that the folding of the tropopause was only present over the Northern Plains.

5. Summary

The objective of this small study was to confirm the presence of a tropopause fold. As mentioned earlier, tropopause folds are a source of potential vorticity in the troposphere. This high potential vorticity air can be advected over a developing surface low pressure system adding to its intensification.

Two simple techniques employed by previous researchers were utilized to determine the presence of a tropopause fold in this case. These techniques may be beneficial to the forecaster when a folding event is anticipated. Knowing the location of the fold in relation to the surface low can help in forecasting the development of the surface low.

Further research could be performed to trace the evolution of the tropopause fold, and to determine its impact on the development of the strong low pressure system that traversed the Northern Plains.

6. References

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Uccellini, L. W., and D. Keyser, K. F. Brill, and C. H. Wash, 1985: The Presidents' Day Cyclone of 18-19 February 1979: Influence of Upstream Trough Amplification and Associated Tropopause Folding on Rapid Cyclogenesis. *Mon. Wea. Rev*., **113**, 962-988.

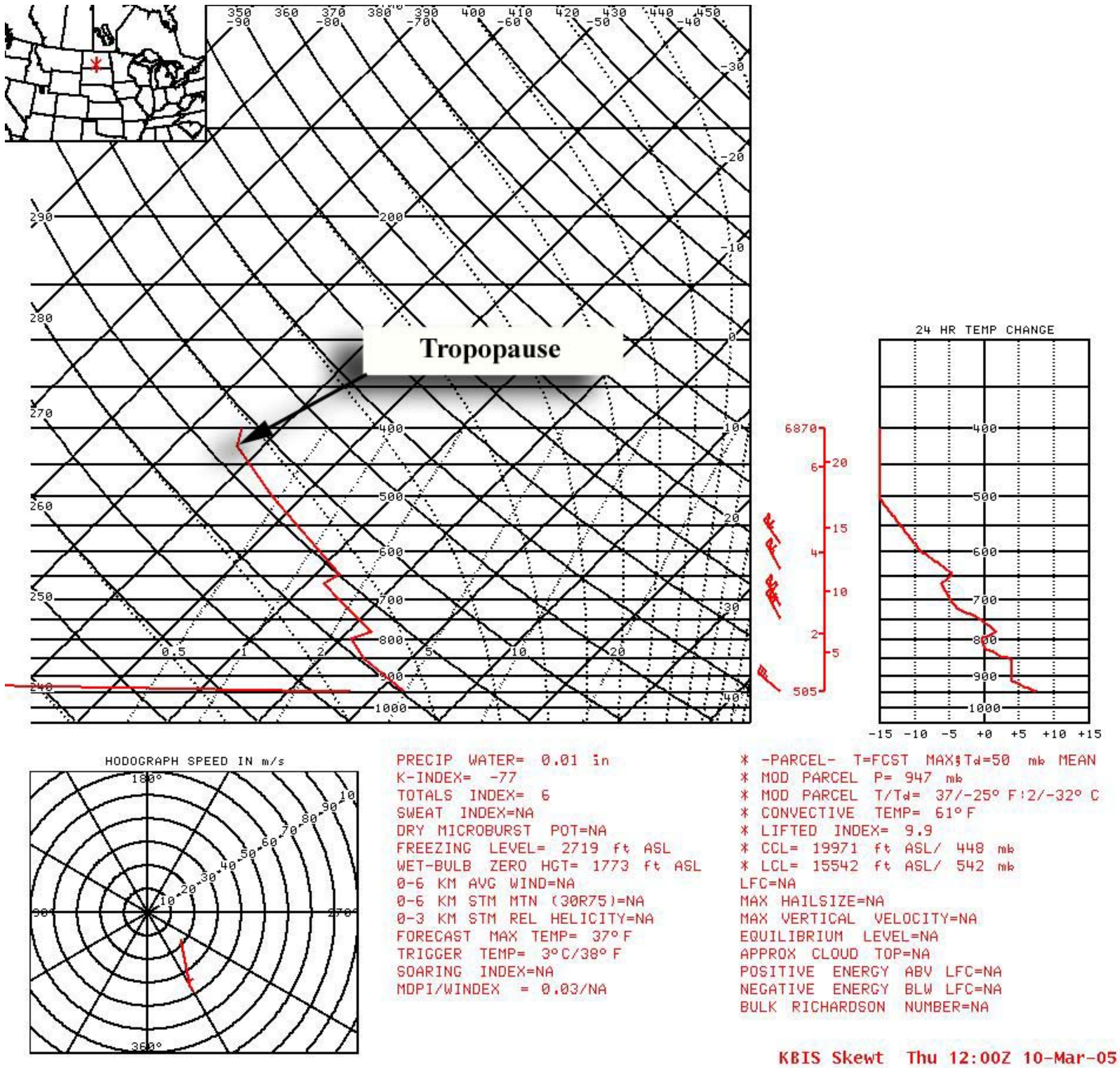

Figure 1. Upper-air sounding taken at Bismarck, ND at 12 UTC 10 March 2005. A low tropopause height is indicated at approximately 410 mb.

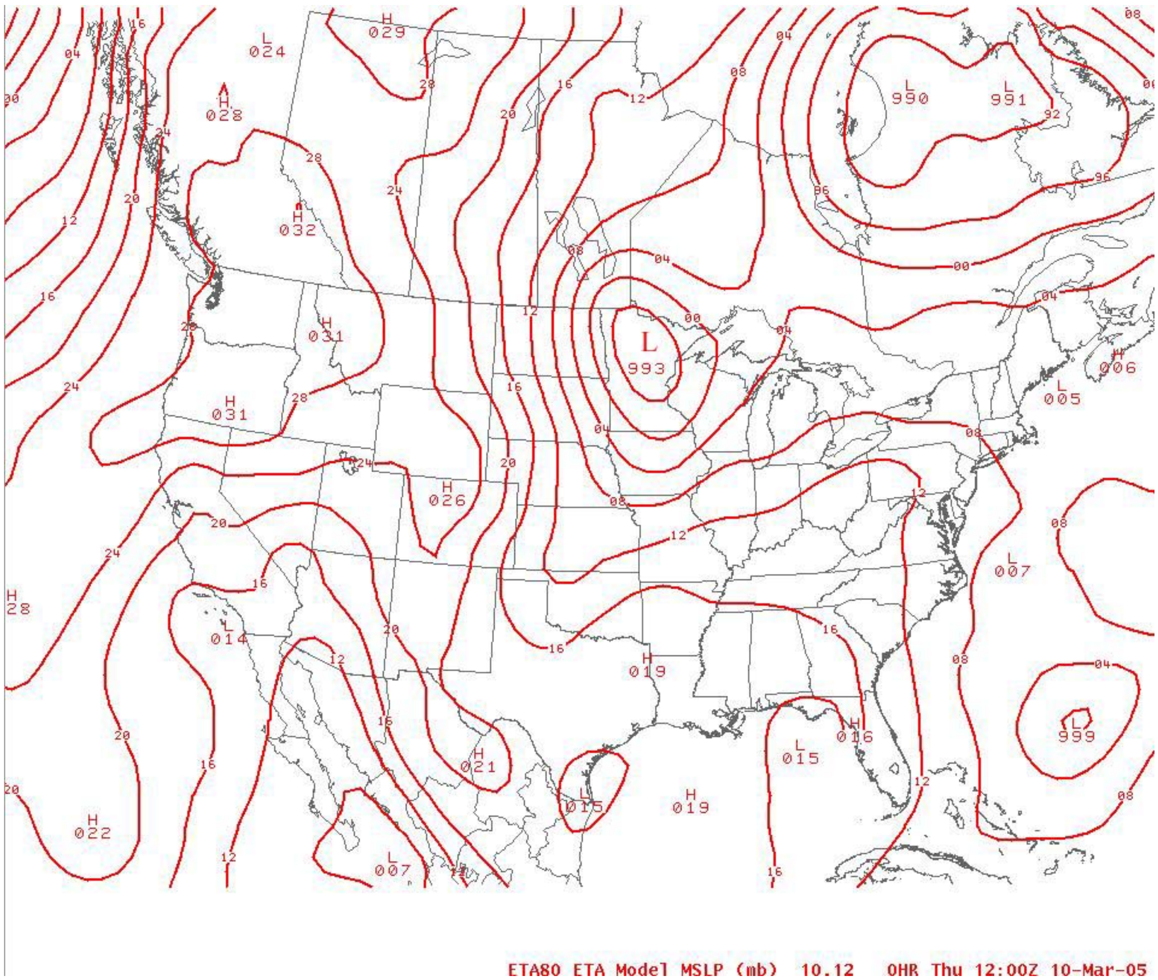

Figure 2. Mean sea level pressure analysis from 12 UTC 10 March 2005. Deep low pressure (an Alberta Clipper) is centered over northern Minnesota. North Dakota is located on the back side of the low where a very strong pressure gradient existed.

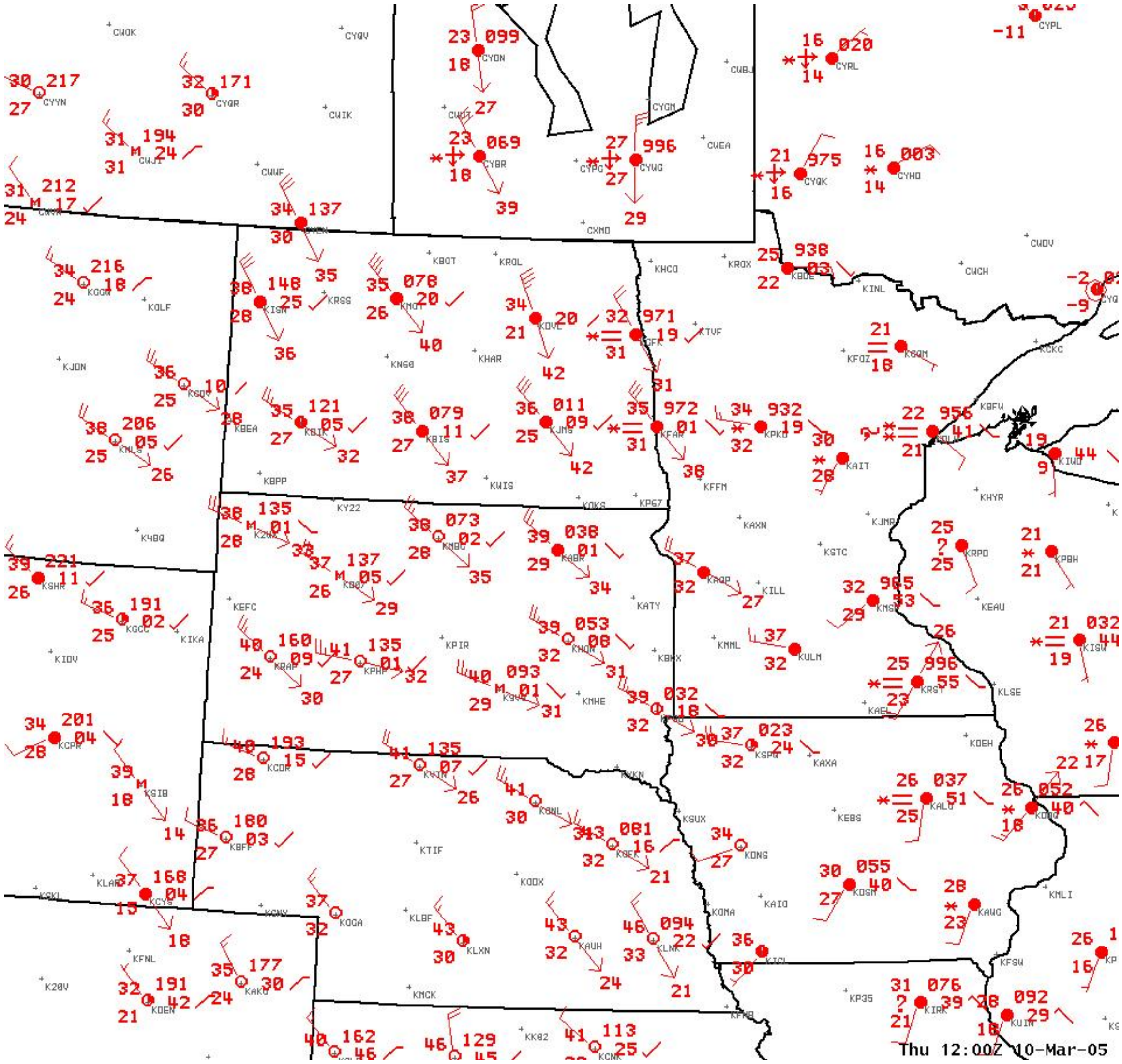

Figure 3. Surface plot from 12 UTC 10 March 2005. Very gusty winds were present over the Dakotas on the back side of the surface low. Snow was reported over northeastern North Dakota, where moderate cold air advection was present.

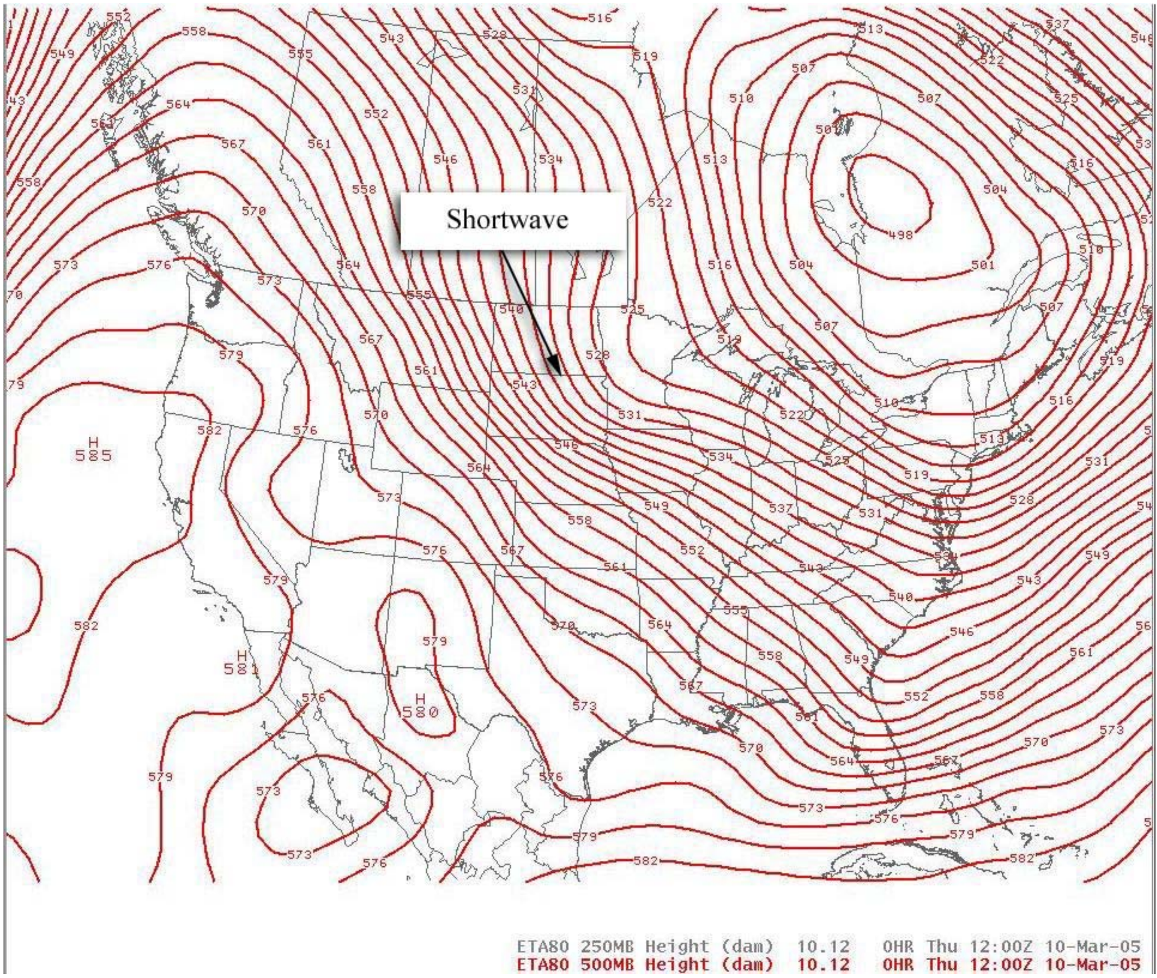

Figure 4. An analysis of 500-mb height at 12 UTC 10 March 2005. A shortwave trough is indicated propagating on the downstream periphery of the long wave ridge over the western U.S.

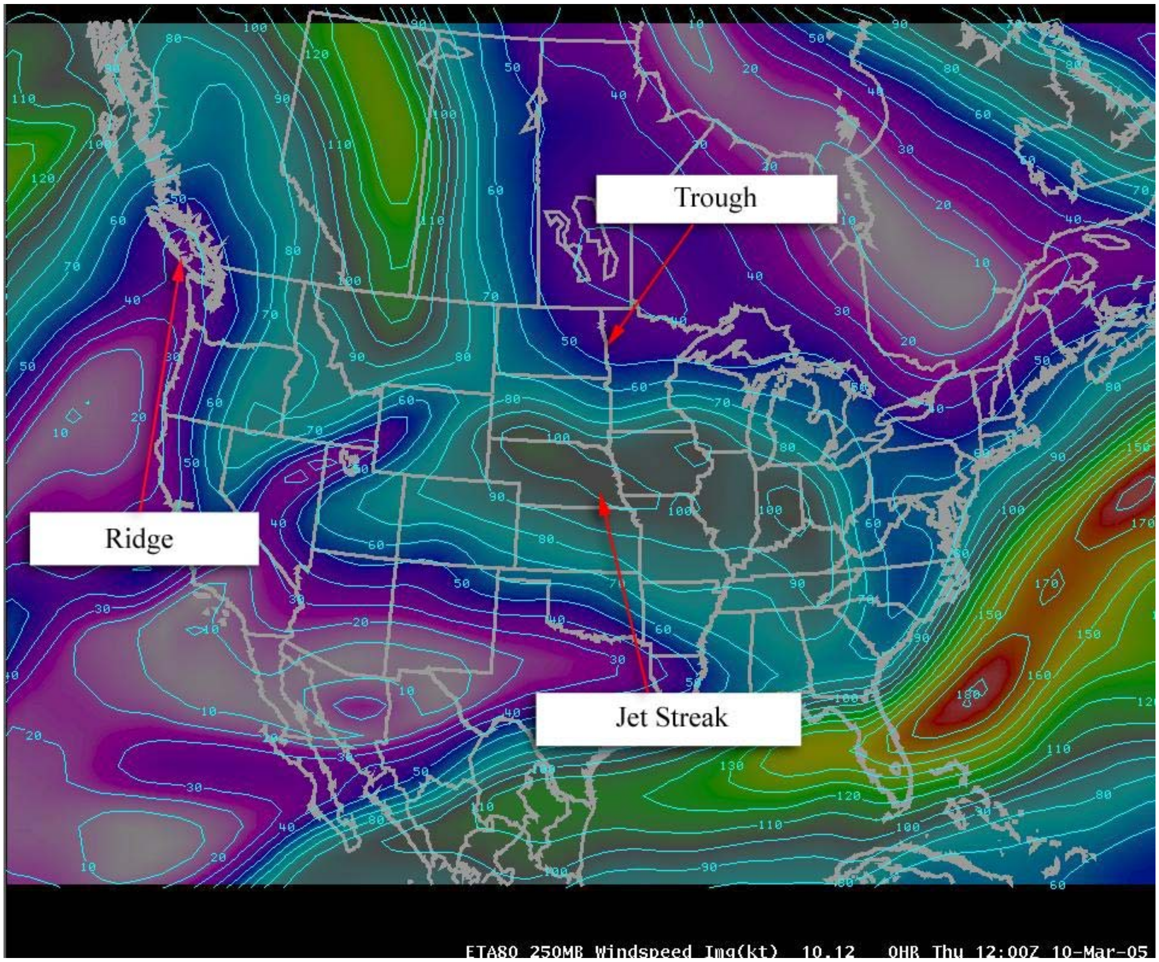

Figure 5. An analysis of the 200-mb wind speed at 12 UTC 10 March 2005 (knots). Indicated in the figure is the position of the jet stream as well as shortwave trough and ridge locations. A strong jet streak was located over the Central Plains from Nebraska to Kentucky. The jet streak had propagated southward from North Dakota as the trough moved southeast by this time. This jet streak was responsible for the tropopause fold event.

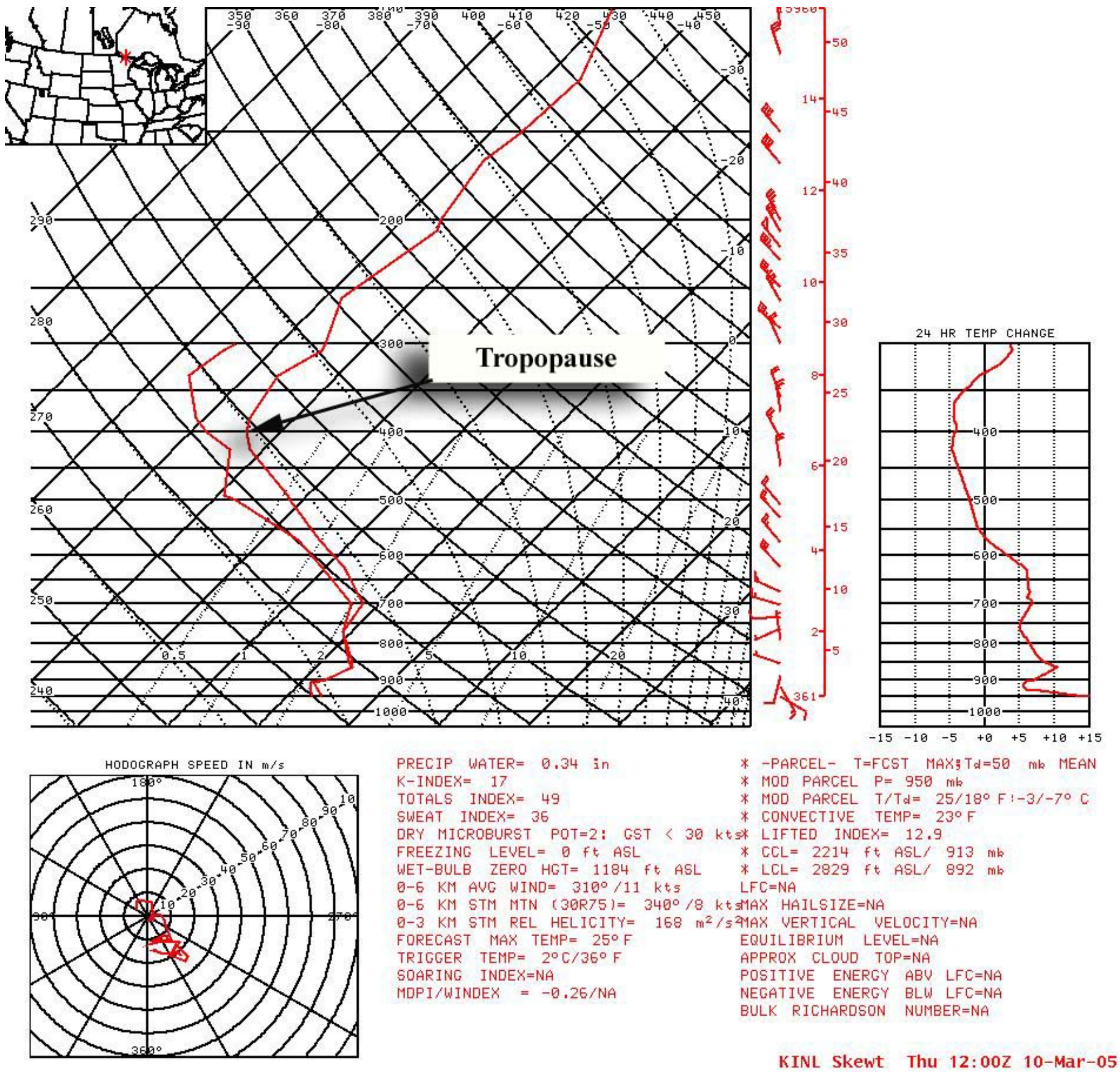

Figure 6. Upper-air sounding taken at International Falls, MN at 1200 UTC 10 March 2005. Evident is the low tropopause of 400 mb.

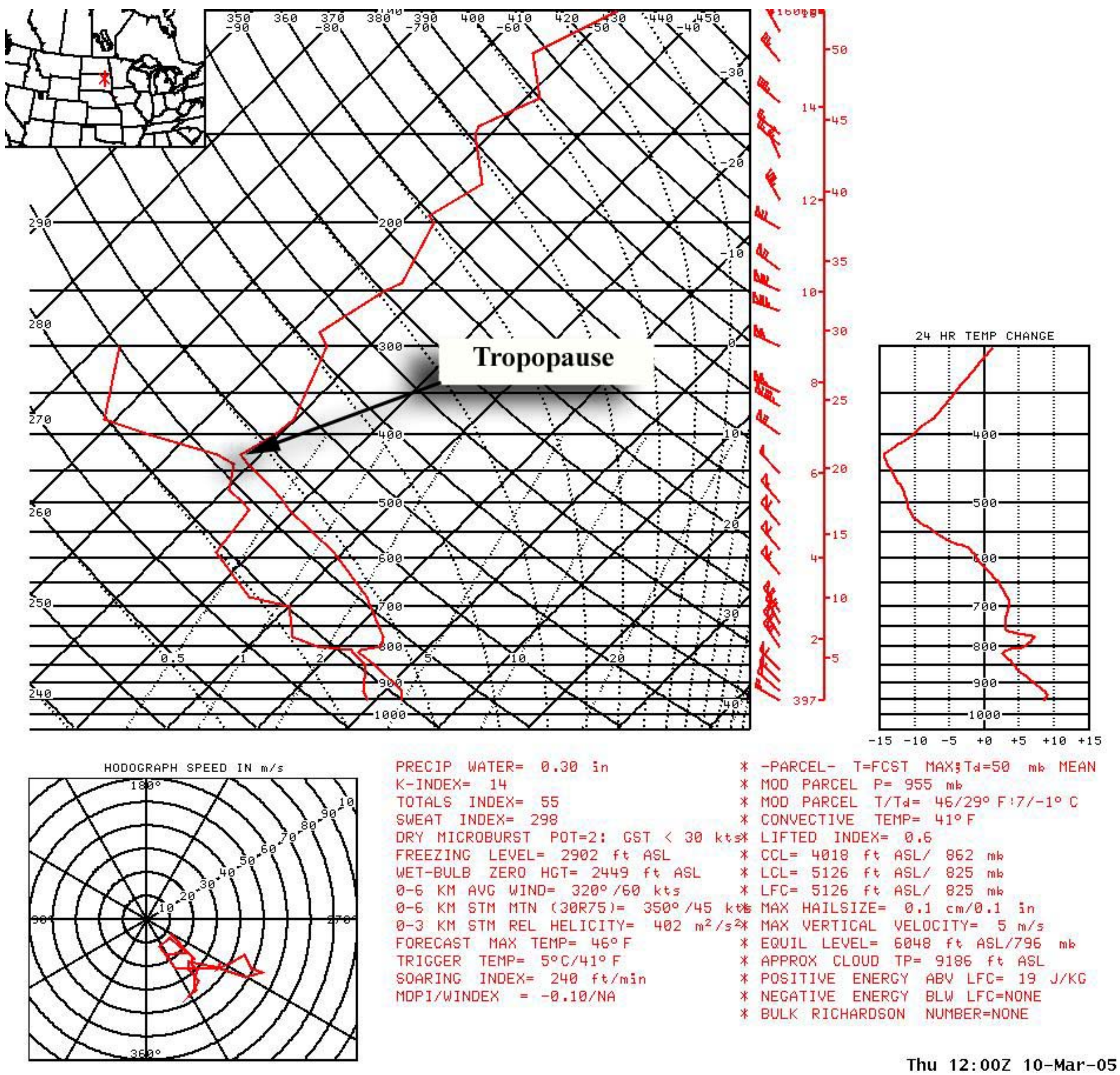

Figure 7. Upper-air sounding taken at Aberdeen, SD at 1200 UTC 10 March 2005. A low tropopause of 425 mb is evident, as indicated.

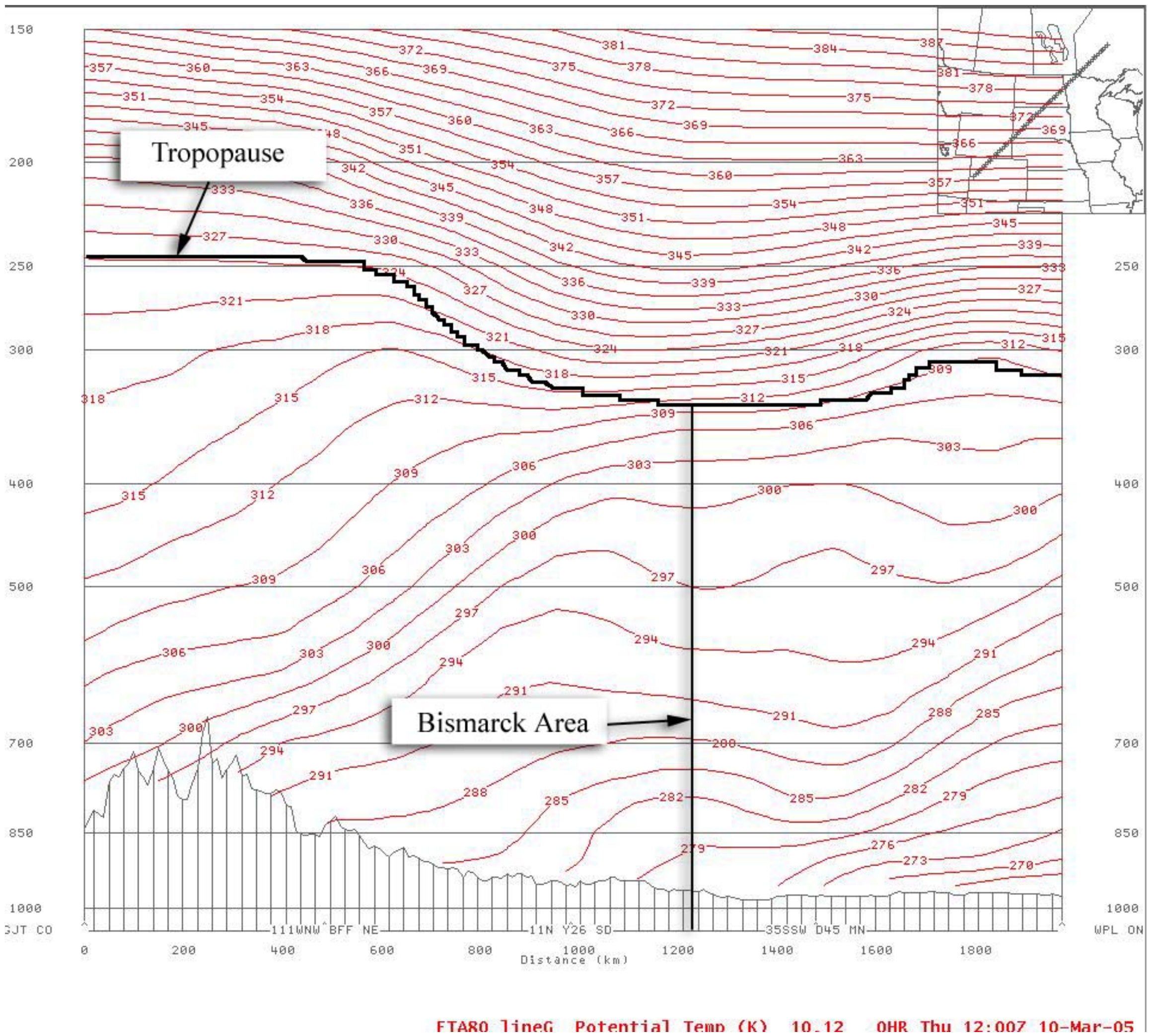

Figure 8. Vertical cross section of potential temperature along a line from northwestern Colorado to western Ontario at 1200 UTC 10 March 2005. The tropopause is indicated by the start of the strong gradient of isotherms. Also evident is the “dipping” of the tropopause over the area near Bismarck, ND.

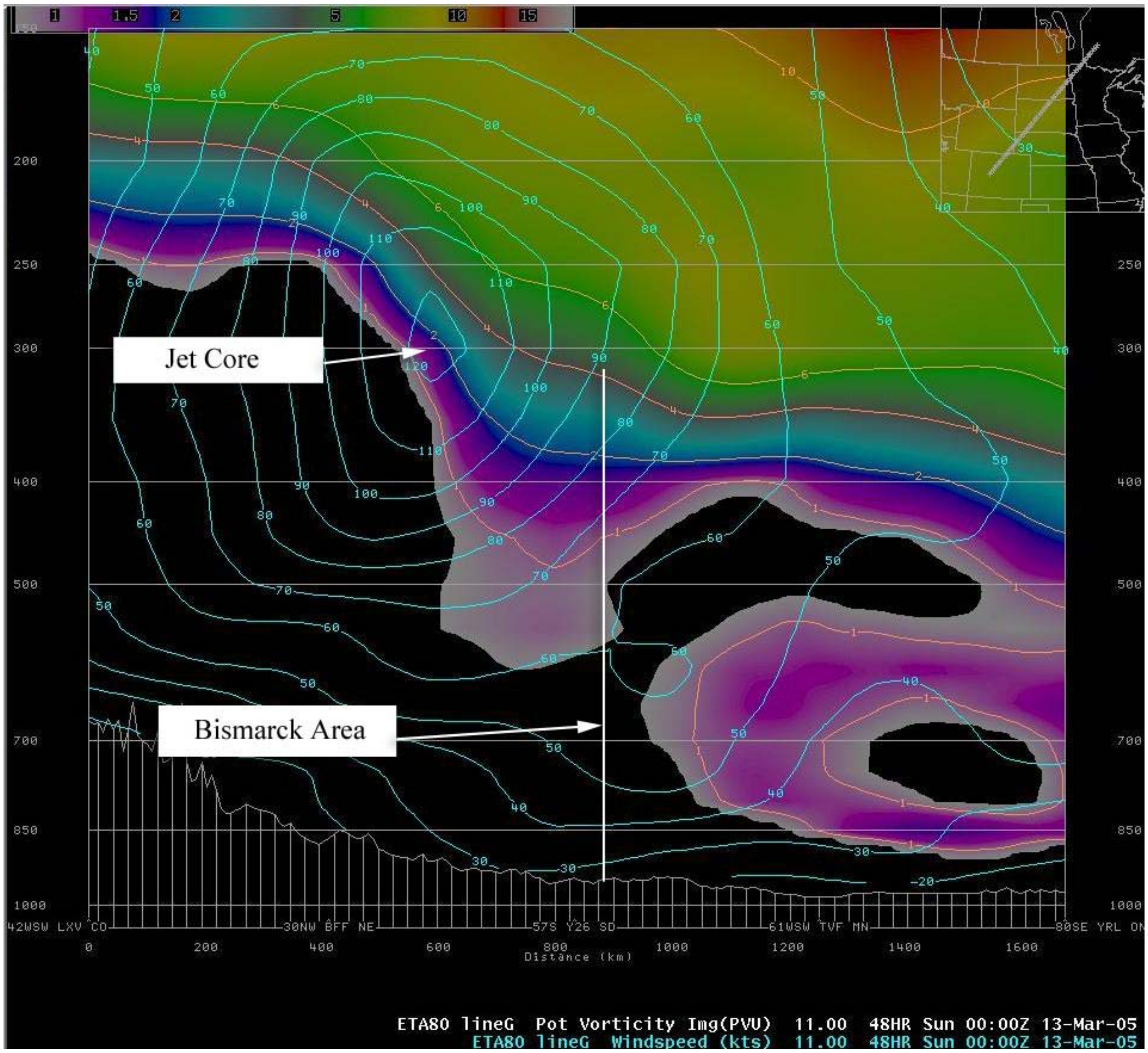

Figure 9. Cross section of 250-mb wind speed and potential vorticity along the same path as the previous cross section. The jet stream flow is out of the page or to the southeast. Potential vorticity of 1 PVU or greater is indicative of stratospheric air. Cleary visible is the “wrapping” of stratospheric air underneath the back of the jet streak in the area of Bismarck, ND.