1.8 THE DEVELOPMENT OF INTENSE FRONTONGENSIS WITHIN A TROWAL

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1. INTRODUCTION

It is not uncommon for the development of heavy precipitation in the northwest quadrant of occluded mid-latitude cyclones to be associated with the development of a trough of warm air aloft (trowal). Recent examples of this connection are given in Martin (1998a, b) in which a heavy band of snowfall is shown to be associated with ascent through the trowal. Given the current availability of gridded numerical model output, identification of the trowal is routine and can alert the forecaster to the potential for heavy snow. Prior work concerning the dynamics of the occluded quadrant (Martin 1999) makes little reference to the role of frontogenesis in the trowal.

This paper will examine the development of intense frontogenesis and an associated snow band within a trowal that developed across South Dakota and Nebraska 29-30 January 2001. Section 2 will provide an overview of data used. Section 3 will give an overview of the storm. Section 4 will examine the potential vorticity and frontogenetical structure within the storm. Section 5 will provide concluding remarks.

2. DATA SOURCES

In order to examine the development of the mesoscale structure within the trowel, model data was used as it provides a dynamically consistent data set. Only the 00 h and 03 h forecast from Eta model runs initializing at 1800 UTC 29 January, 0000 UTC 30 January, 0600 UTC 30 January, and 1200 UTC 30 January 2001 were used. Grids were remapped to the CONUS 215 grid with 40 km resolution in the horizontal and 25 hPa resolution in the vertical.

Observed surface and upper air data were also used from 0000 UTC 29 January 2001 through 0000 UTC 31 January 2001. Snowfall and precipitation data were obtained from cooperative observers across South Dakota, Nebraska, North Dakota, and Minnesota.

3. STORM OVERVIEW

On 29-30 January 2001, a trowel developed across eastern South Dakota and persisted for over 12 h. Heavy snow across portions of South Dakota and Nebraska was associated with this feature. Over 50 cm of snow fell within 24 hours across the James River valley of South Dakota, with at least one location setting an all-time record for snowfall in 24 h. Accompanying the snow were winds of 5 to 15 m s^{-1} which caused significant blowing snow.

At 1200 UTC 29 January 2001, a lee cyclone was developing across western Kansas (not shown). At 850 hPa, strong warm air advection had developed across the eastern Plains. In addition, temperatures had fallen below 0°C north of the warm front (Fig. 1a). At 500 hPa, a cut-off low was located over eastern Colorado with a strong upper level front extending south of the low into central Texas (Fig 1b). At 300 hPa, there was also a cut-off circulation. To the southeast of the low, a strong jet streak was rounding the base of the trough (not shown). Winds in excess of 60 m s^{-1} were located across northern Mexico and southern Texas.

The 850 hPa low had moved to eastern Nebraska (Fig. 2a) at 0000 UTC 30 January. Implied strong warm advection continued across eastern South Dakota. At 500 hPa, a strong mid-level circulation slowly moved to the east and was centered in northeastern Kansas (Fig 2b). The mid-level cold front had rotated northeast and extended from eastern Nebraska into eastern Missouri (Fig. 2b). At 300 mb, a curved jet streak extends from Texas into eastern Iowa (not shown). Winds at the base of the trough were still in excess of 60 m s^{-1}.

The equivalent potential temperature (θ_e) at 700 hPa and 500 hPa showed ridge of high θ_e rotating around the cyclone at 0000 UTC 30 January (Fig. 3). The structure of the θ_e ridge is similar to that described by Martin (1998a) and is suggestive of moist and less stable air having wrapped around the low into eastern South Dakota and central Nebraska.

Precipitation began north of the warm front around 1200 UTC 29 January. As the trowal organized during the afternoon, a band of snow developed across eastern South Dakota. This area of snow became stationary across eastern South Dakota after 0000 UTC 30 January. Moderate to heavy snow continued for 6-12 h as the cyclone slowly moved northeast. After 1200 UTC 30 January, the band began to weaken as the trowal and cyclone progressed to the northeast.

4. DYNAMICAL PROCESSES

4.1. Frontogenesis

Around 0000 UTC 30 January, the 850 hPa frontogenesis were indicative of a warm front extending across central Minnesota and Wisconsin and a cold front

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from southeast South Dakota into eastern Iowa and Illinois. At the intersection of the two fronts, a local maximum of frontogenesis was beginning to develop (Fig. 4a). At 0600 UTC, an area of strong frontogenesis had developed across eastern South Dakota into central Minnesota (Fig. 4b). The frontogenesis continued to intensify through 1200 UTC. After 1200 UTC, the frontogenesis gradually weakened at this level as the cold air moved in and the cyclone moved to the northeast.

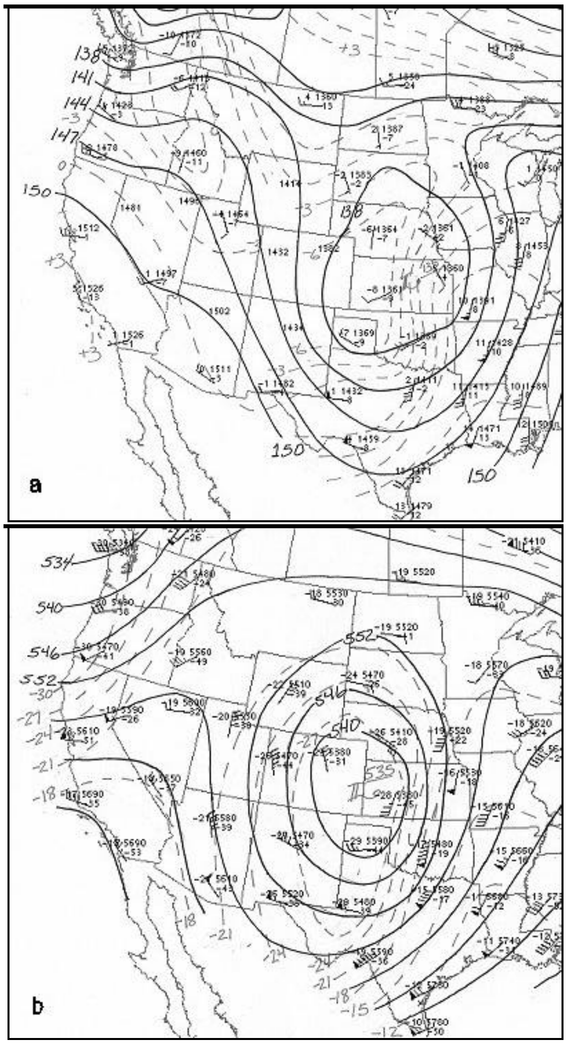

Fig. 1. Subjective analysis of a) 850 hPa and b) 500 hPa at 1200 UTC 29 January 2002. Temperatures, dashed lines every 3°C. Height, solid lines every 3 dm (6 dm) at 850 hPa (500 hPa).

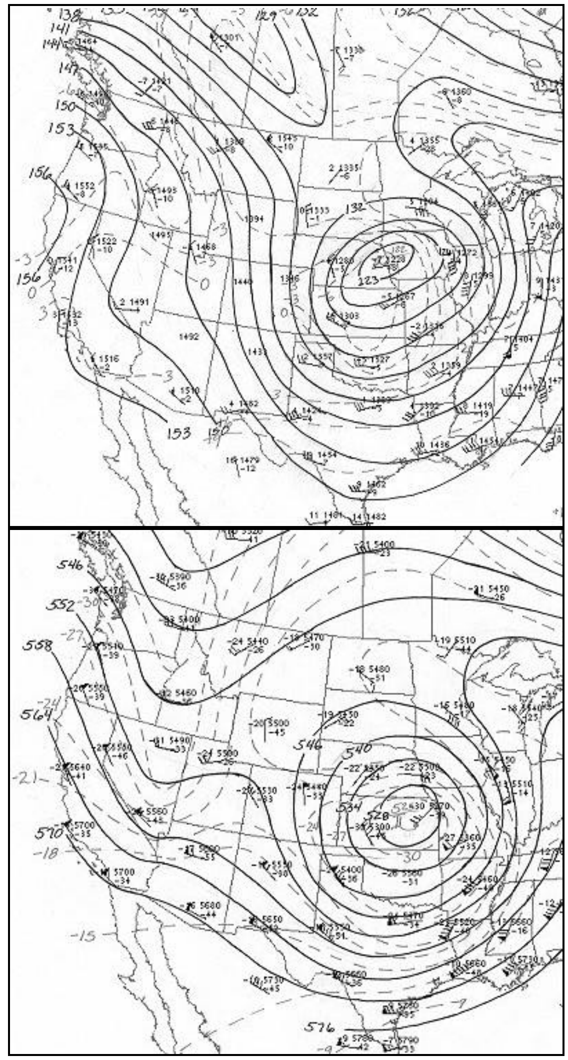

Fig. 2. As in Fig. 1 except for 0000 UTC 30 January 2001.

A cross-section was taken perpendicular to the front - from Williston North Dakota (ISN) to St. Louis Missouri (STL) (Fig. 5). The cross-section shows that this frontogenesis was associated with the movement of the mid-level cold front into the area. The cold dome moved to the north and the vertical slope of the isentropes increased across eastern South Dakota. There was also horizontal deformation across this area (not shown). The wind field then acted on this thermal gradient and frontogenesis developed across the area. Unlike the case described by Martin (1998b), the frontogenesis was along the cold front instead of the warm front.

4.2 Potential Vorticity

Potential vorticity was calculated in the 450-350 hPa layer. While PV is not conserved in adiabatic flow, it provides a way to track the potential vorticity anomaly. The cut-off low, described in section 3, was associated with a potential vorticity anomaly (Fig. 6). Again, in contrast to the case documented by Martin (1998a), in which the PV anomaly was an extension from the northern reservoir and produced a "treble clef" configuration, the potential vorticity anomaly was isolated from the northern reservoir of PV. As this PV anomaly slowly moved to the northeast, the cold pool underneath the anomaly moved with it. The leading edge of this cold pool was the cold front observed above 850 hPa.

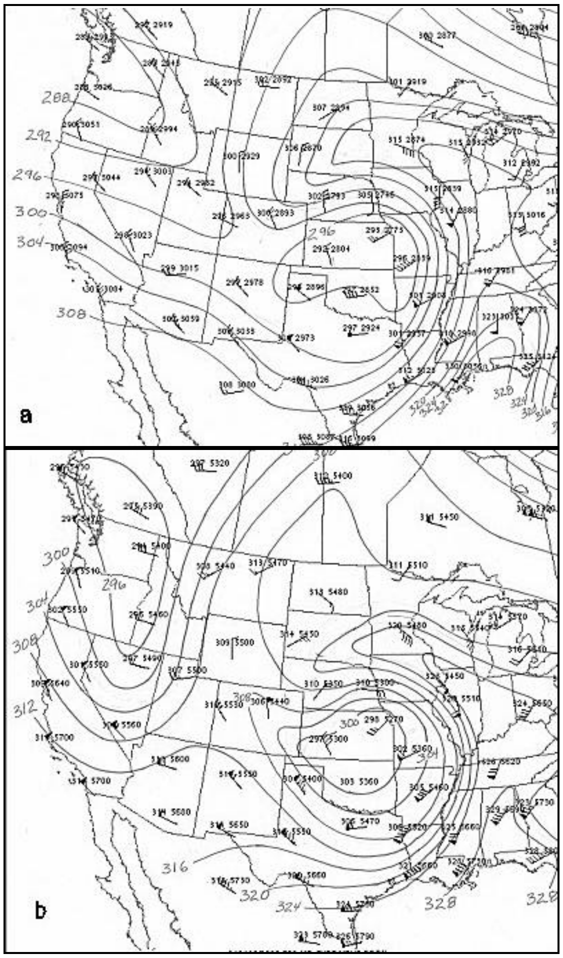

Fig. 3. Subjective analysis of a) 700 hPa and b) 500 hPa equivalent potential temperature at 0000 UTC 30 January 2001. Contours are every 4°K.

Martin (1998a) showed that the treble clef tropopause PV structure provides a sufficient condition for asserting the presence of a warm occluded thermal structure (i.e. a trowal) in the underlying troposphere. He also showed that such a structure tends to favor frontogenesis along the warm frontal portion of the warm occluded structure. Thus, heavy precipitation in the trowal was found north and west of the trowal axis in his case. The present case, involving an isolated tropopause PV feature in association with a trowal, favors frontogenesis along the cold frontal portion of the occluded thermal structure with a resultant distribution of heavy precipitation on the south and east side of the trowal axis.

5. CONCLUDING REMARKS

The trowal on 29-30 January 2001 was unique from other cases thus far presented in the literature. Rather than observing a treble clef shape to the tropopause-level potential vorticity, this PV anomaly was isolated from the northern reservoir. This distribution of PV favors frontogenesis along the cold front instead of along the warm front resulting in a precipitation distribution to the south and east side of the trowal axis.

The frontogenesis within the trowal in this case developed as the cold pool associated with the PV anomaly moved toward the mid-level deformation zone. The thermal gradient became oriented with the axis of dilatation and resulted in rapid development of frontogenesis within the trowal. Given the characteristically weaker stratification within the trowal, the response to the frontogenetical forcing was the production of a narrow, long-lived band of intense snowfall.

We suggest that the nature of the tropopause-level PV anomaly associated with a given warm occluded cyclone may provide significant guidance concerning the mesoscale distribution of heavy precipitation in the occluded quadrant of cyclones.

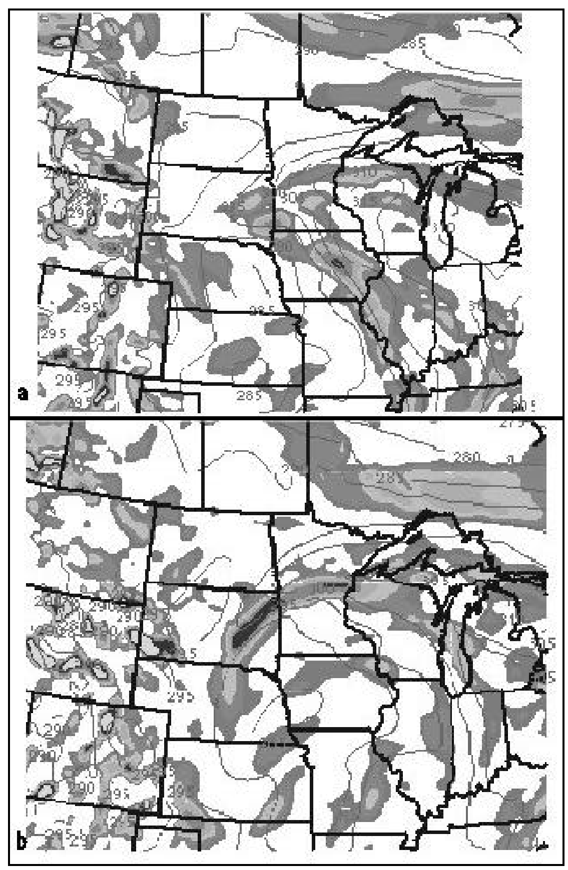

Fig. 4. 850 hPa Pettersen frontogenesis (> 0 shaded) and equivalent potential temperature (solid lines every 5°K(at a) 0000 UTC 30 January 2001 and b) 0600 UTC 30 January 2001.

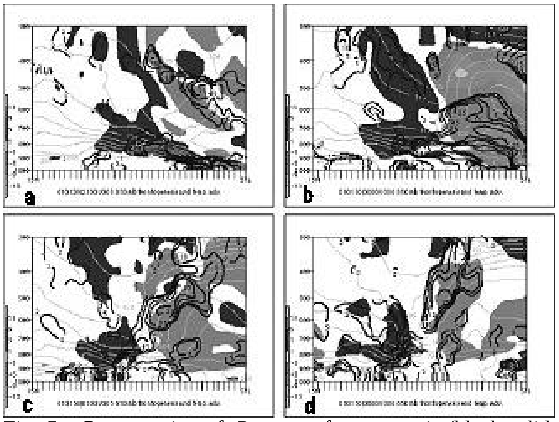

Fig. 5. Cross-section of Pettersen frontogenesis (black solid lines > 0), equivalent potential temperature (gray lines every 5°K), and temperature advection (warm advection dark shading, cold advection gray shading). A) 2100 UTC 29 January, b) 0000 UTC 30 January, c) 0300 UTC 30 January, and d) 0600 UTC 30 January 2001.

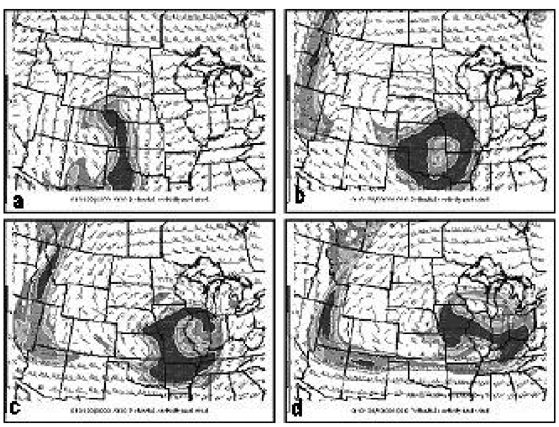

Fig. 6. 450-350 hPa potential vorticity (> 0.5 PVU shaded) and mean layer wind. A) 1200 UTC 29 January, b) 0000 UTC 30 January, c) 0600 UTC 30 January, and d) 1200 UTC 30 January.

REFERENCES

Martin, J. E., 1998a: The structure and evolution of a continental winter cyclone. Part I: Frontal Structure and the Occlusion Process. *Mon. Wea. Rev*., **126**, 303-328.

Martin, J. E., 1998b: The structure and evolution of a continental winter cyclone. Part II: Frontal forcing of an extreme snow event. *Mon. Wea. Rev*., **126**, 329-348.

Martin, J. E., 1999: Quasi-geostrophic forcing for ascent in the occluded quadrant of cyclones and the trowal airstream. *Mon. Wea. Rev*., **127**, 70-88.