NOTES AND CORRESPONDENCE

Structure and Evolution of Winter Cyclones in the Central United States and Their Effects on the Distribution of Precipitation. Part IV: The Evolution of a Drytrough on 8–9 March 1992

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ABSTRACT

The structure and evolution of a drytrough (i.e., a surface pressure trough that has characteristics of both a lee trough and a dryline) from the southern Great Plains to the lower Mississippi Valley are described using both observational data and outputs from a mesoscale model. An elevated zone of cold-air advection associated with a cold front aloft interacted with the drytrough over the southern Great Plains to form a structure similar to a warm occlusion. This type of structure figures importantly in a new conceptual model that has been proposed for cyclones in the central United States.

1. Introduction

Previous papers in this series have described various aspects of a cyclone that moved across the central United States from 8 to 10 March 1992. Some of the features described include the drytrough (i.e., a lee trough that also has the characteristics of a dryline) (Martin et al. 1995), a pre-drytrough rainband (Martin et al. 1995), an arctic front (Wang et al. 1995), and a severe squall line associated with a cold front aloft (CFA)[1] (Locatelli et al. 1995).

Martin et al. (1995) showed that the drytrough originated as a leeside pressure trough that formed in response to adiabatic warming induced by descending air in the lee of the Rockies. Between 0000 UTC 9 March 1992 and 1200 UTC 9 March 1992 the CFA began interacting with the drytrough, resulting in the formation of a tipped-forward zone of cold-air advection aloft in advance of a surface trough, similar to the structure of a warm occlusion (Locatelli et al. 1995). Similar structures were described by Locatelli et al. (1989), Sienkiewicz et al. (1989), Martin et al. (1990), and Steenburgh and Mass (1994).

The drytrough was instrumental in producing two significant convective rainbands located ahead of the surface position of the drytrough, namely, the pre-drytrough rainband (Martin et al. 1995) and a series of squall lines constituting a CFA râinband (Locatelli et al. 1995).

The purpose of this note is to complete the description of the 8–10 March 1992 cyclone up to 1200 UTC 9 March. We calculate the field of surface frontogenesis, and the horizontal temperature advection and adiabatic terms in the thermodynamic energy equation, in the vicinity of the drytrough as it advanced from the southern Great Plains to the lower Mississippi Valley between 1200 UTC 8 March and 1200 UTC 9 March 1992. These results provide further support for the view that the interaction of a CFA with a drytrough can change the structure of a drytrough into something resembling a warm occluded front.

2. Surface synoptic evolution

At 1200 UTC 8 March 1992 the drytrough was located in a broad region of maximum potential temperature at the surface (see Fig. 1a). For about 12 h following 1200 UTC 8 March the trough strengthened, so that by 0000 UTC 9 March there was a well-defined

[1] The term CFA refers to the leading edge of a transition zone above the surface that separates advancing cold air from warmer air. The length of the transition zone is much greater than its width, and the gradients of temperature and absolute momentum in the transition zone are much greater than in the adjacent regions. Defined in this way, CFA encompasses features ranging from regions of concentrated upper-level cold-air advection within migrating upper short-waves to bona fide upper-level frontal zones of the type discussed by Keyser and Shapiro (1986). The important dynamical characteristic that these features have in common is the occurrence of active frontogenesis in association with baroclinic zones (frontal or nonfrontal).

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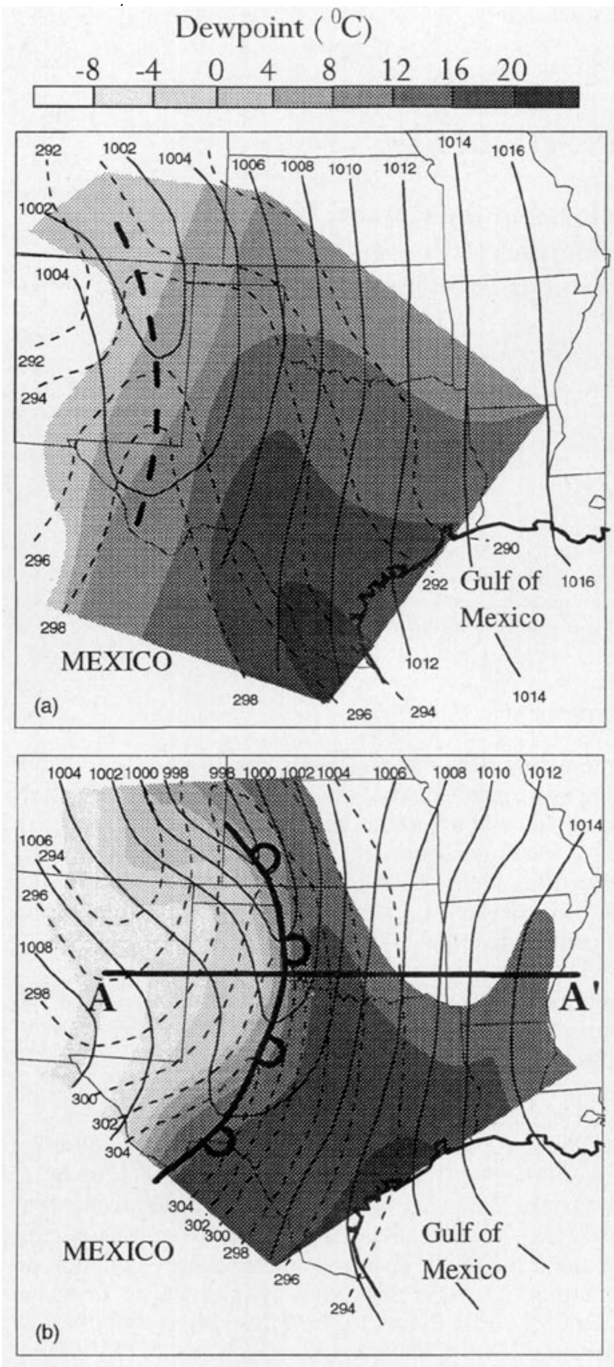

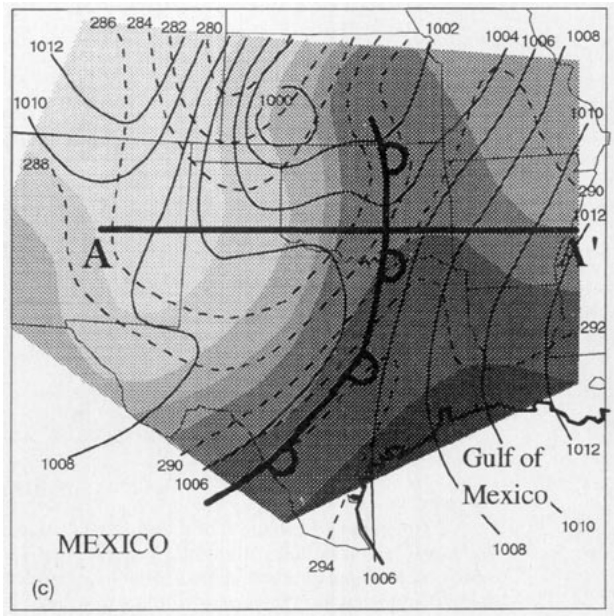

FIG. 1. (a) Surface analysis for 1200 UTC 8 March 1992. Solid lines are isobars (hPa, contoured every 2 hPa). Dashed lines are isotherms of potential temperature (K, contoured every 2 K). The heavy dashed line indicates the position of the trough determined from the surface data. The shading represents dewpoint temperatures. (b) As for (a) except for 0000 UTC 9 March 1992. The heavy scalloped line indicates the position of the drytrough. (c) As for (b) except for 1200 UTC 9 March 1992.

pressure trough at the surface stretching from the eastern Texas panhandle through western Texas (Fig. 1b). The axis of highest surface potential temperature air was coincident with the axis of the trough. This thermal structure is characteristic of leeside troughs (Carlson 1961).

Between 1200 UTC 8 March and 0000 UTC 9 March, horizontal confluence associated with the trough produced an intense gradient in dewpoint across the trough (Fig. 1b). [See Fig. 14 in Martin et al. (1995) for the complete station reports.] Thus, the developing surface lee trough became a boundary between very moist air to the east and extremely dry air to the west. This is the classic signature of the dryline (Schaefer 1986). Since the surface trough acquired the characteristics of both a lee trough and a dryline, we refer to it as a *drytrough* (Martin et al. 1995).

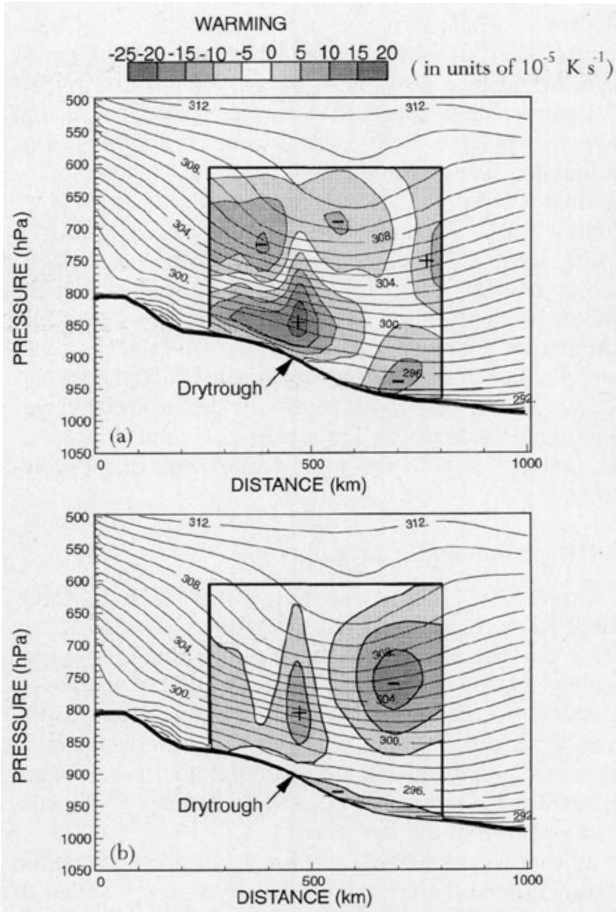

FIG. 2. (a) Cross section of potential temperature lines (K, contoured every 2 K) at 1200 UTC 8 March 1992 from the MM4 model simulation along line *AA′* in Fig. 1b. The inset box, which is in the vicinity of the drytrough, shows warming at the time of this cross section from the contributions of both the horizontal temperature advection and the adiabatic terms of the thermodynamic energy equation. (b) As for (a) except the inset shows warming only for the adiabatic term.

By 1200 UTC 9 March 1992 the drytrough had advanced eastward into central Oklahoma and Texas (Fig. 1c), but the surface pressure trough weakened considerably over this 12-h period. The thermal structure of the drytrough at the surface also changed during this period. The axis of highest potential temperature air was no longer coincident with the drytrough at the surface; instead this feature had shifted to the east, with the drytrough marking the leading edge of a cold baroclinic zone at the surface. In addition, the gradient in moisture across the drytrough had become weaker, so that the dryline characteristics were less pronounced (Fig. 1c).

3. Evolution of the vertical structure of the drytrough

To investigate changes in the vertical structure of the drytrough, output from the Pennsylvania State University–National Center for Atmospheric Research (NCAR) MM4 mesoscale model (Anthes and Warner 1978; Anthes et al. 1987) were used to construct a series of vertical cross sections through the line *AA′* in Fig. 1b. The version of the model we used included a high-resolution planetary boundary layer (Blackadar 1979; Zhang and Anthes 1982) and prognostic equations for water vapor, cloud water, and rainwater. The terrain was represented by actual heights on a 0.5° × 0.5° latitude–longitude grid. The domain contained 61 × 61 grid points with a grid size of 45 km centered at 40°N, 96°W. The model atmosphere was divided into 23 layers from the surface to 50 hPa, and a sigma vertical coordinate system was used. The model was initialized using National Meteorological Center (NMC, now referred to as the National Centers for Environmental Prediction) gridded data as a "first guess" field,

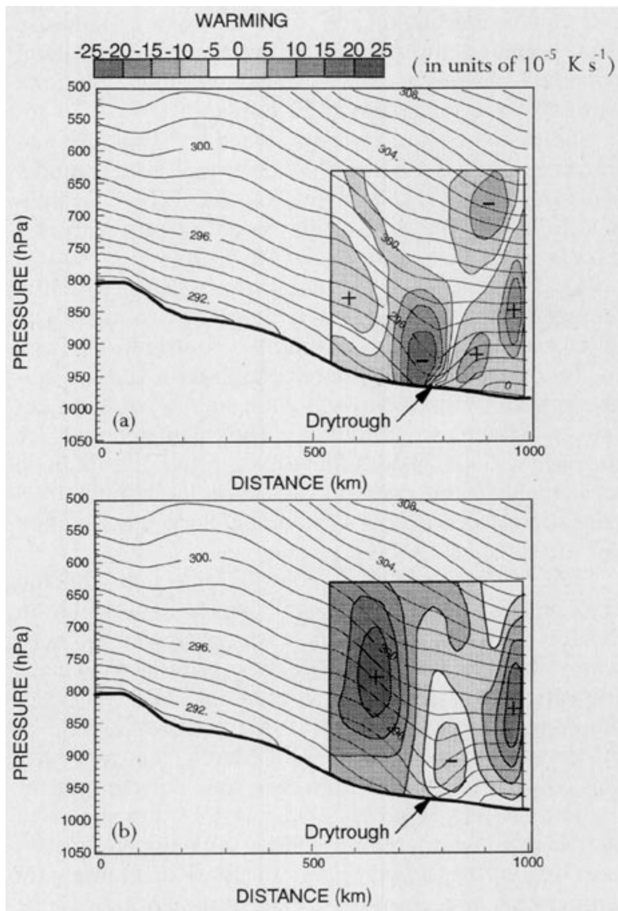

FIG. 3. (a) Cross section of potential temperature lines (K, contoured every 2 K) at 1200 UTC 9 March 1992 from the MM4 model simulation along line *AA′* in Fig. 1c. The inset box, which is in the vicinity of the drytrough, shows warming at the time of this cross section from the contributions of both the horizontal temperature advection and the adiabatic terms of the thermodynamic energy equation. (b) As for (a) except the inset shows warming only for the adiabatic term.

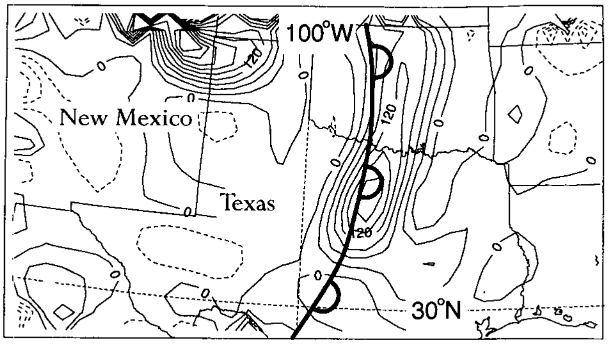

FIG. 4. Surface frontogenesis values (10^{-11} K m^{-1} s^{-1}, contoured every 30 × 10^{-11} K m^{-1} s^{-1}) from the MM4 model simulation valid at 1200 UTC 9 March 1992. The heavy scalloped line indicates the position of the drytrough determined from the MM4 model simulation.

supplemented by NMC and global operational surface and rawinsonde data, and snow cover and land-use data, prepared and maintained by NCAR. The lateral boundary conditions were linearly interpolated in time using observational data at 12-h intervals.

The model accurately reproduced the structure and movement of the CFA and the drytrough over a model run from 1200 UTC 8 March to 1200 UTC 9 March. A detailed comparison of the model results with real data is given by Martin et al. (1995).

We describe here two such cross sections: potential temperature and Eulerian warming (or cooling). The latter was calculated by adding the contributions from the horizontal temperature advection term and the adiabatic term in the thermodynamic energy equation expressed in isobaric coordinates. The calculated rates are the instantaneous values for temperature. The adiabatic term includes the vertical advection of temperature. Diabatic effects are not considered since precipitation did not form along the drytrough.

Figure 2a shows that at 1200 UTC 8 March 1992 the drytrough was located beneath a region of warming in the lower troposphere, which was produced by both warm-air advection and adiabatic warming. However, inspection of Fig. 2b shows that the adiabatic term dominated the warming above the surface position of the drytrough. By 1200 UTC 9 March, the drytrough was coincident with the transition zone between warming and cooling (Fig. 3a). The cross section shown in Fig. 3a indicates that this transition zone tipped forward with height. Inspection of Fig. 3b shows that horizontal temperature advection is now the dominant term since the adiabatic term is weaker and has the opposite sign to the combined terms in the vicinity of the surface position of the drytrough.

While the drytrough was over the steeper sloping region of the Great Plains, it was located beneath a broad region of maximum potential temperature that extended up to 500 hPa. Between 0000 and 1200 UTC 9 March 1992, the region of maximum potential temperature became shallower and more narrowly focused over the surface position of the drytrough.

Figure 4 shows the field of surface frontogenesis that was interpolated from a frontogenesis field that was calculated using potential temperature in isobaric coordinates from the model simulation for 1200 UTC 9 March 1992. Frontogenesis calculations include the tilting term. (The slight difference in the positions of the drytrough in Fig. 1c and Fig. 4 is because Fig. 1c shows an analysis of data and Fig. 4 shows a model simulation.) Two notable regions of frontogenesis can be seen: one aligned north–south across Oklahoma and Texas, which was associated with the drytrough, and another in the northern Texas panhandle and New Mexico associated with the southwestern end of an arctic front.

4. Discussion and conclusions

From 1200 UTC 8 March until 1200 UTC 9 March 1992 a drytrough traversed the southern United States from eastern New Mexico to the lower Mississippi Valley. Martin et al. (1995) and Locatelli et al. (1995) showed that the structure of this drytrough was instrumental in producing a pre-drytrough rainband and a series of squall lines that constituted a CFA rainband. Both of these rainbands were located ahead of the surface position of the drytrough.

Locatelli et al. (1995) previously established that the interaction of the CFA with the drytrough resulted in the formation of a tipped-forward zone of cold-air advection aloft in advance of a surface trough. In this note we have shown that from 1200 UTC 8 March to 0000 UTC 9 March 1992, which was prior to the interaction of the drytrough with CFA, the drytrough was a leeside pressure trough characterized by adiabatic warming, but with a moisture gradient that increased in time (see Figs. 1a,b and Fig. 2). By 0000 UTC 9 March the drytrough had both trough and dryline characteristics. During the interaction of the CFA with the drytrough (between 0000 UTC 9 March and 1200 UTC 9 March 1992), the drytrough moved eastward toward the Mississippi Valley. By 1200 UTC 9 March the adiabatic warming and the dryline characteristics associated with the drytrough had weakened, and the drytrough had become the locus of a frontogenetic transition zone between cold and warm air advection that sloped forward with height, similar to a warm occlusion (Figs. 3 and 4).

The warm occlusion-like structure described here is an important component of a new conceptual model for cyclones in the central United States proposed by Hobbs et al. (1996).

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REFERENCES

Anthes, R. A., and T. T. Warner, 1978: Development of hydrodynamic models suitable for air pollution and other meso-meteorological studies. *Mon. Wea. Rev.,* **106,** 1045–1078.

——, E.-Y. Hsie, and Y.-H. Kuo, 1987: Description of the Penn State/NCAR Mesoscale Model Version (MM4). NCAR Tech. Note NCAR/TN-282+STR, 66 pp.

Blackadar, A. K., 1979: High resolution models of the planetary boundary layer. *Advances in Environmental Science and Engineering,* Vol. 1, Pffafflin and Zeigler, Eds., Gordon and Breach, 50–85.

Carlson, T. N., 1961: Lee side frontogenesis in the Rocky Mountains. *Mon. Wea. Rev.,* **89,** 163–172.

Hobbs, P. V., J. D. Locatelli, and J. E. Martin, 1996: A new conceptual model for cyclones generated in the lee of the Rocky Mountains. *Bull. Amer. Meteor. Soc.,* **77,** 1169–1178.

Keyser, D., and M. A. Shapiro, 1986: A review of the structure and dynamics of upper level frontal zones. *Mon. Wea. Rev.,* **114,** 452–499.

Locatelli, J. D., J. M. Sienkiewicz, and P. V. Hobbs, 1989: Organization and structure of clouds and precipitation on the mid-Atlantic coast of the United States. Part I: Synoptic evolution of a frontal system from the Rockies to the Atlantic Coast. *J. Atmos. Sci.,* **46,** 1327–1348.

——, J. E. Martin, J. A. Castle, and P. V. Hobbs, 1995: Structure and evolution of winter cyclones in the central United States and their effects on the distribution of precipitation. Part III: The development of a squall line associated with weak cold frontogenesis aloft. *Mon. Wea. Rev.,* **123,** 2641–2662.

Martin, J. E., J. D. Locatelli, and P. V. Hobbs, 1990: Organization and structure of clouds and precipitation on the mid-Atlantic coast of the United States. Part III: The evolution of a middle-tropospheric cold front. *Mon. Wea. Rev.,* **118,** 195–217.

——, ——, ——, P.-Y. Wang, and J. A. Castle, 1995: Structure and evolution of winter cyclones in the central United States and their effects on the distribution of precipitation. Part I: A synoptic-scale rainband associated with a dryline and lee trough. *Mon. Wea. Rev.,* **123,** 241–264.

Schaefer, J. T., 1986: The dryline. *Mesoscale Meteorology and Forecasting,* P. Ray, Ed., American Meteorological Society, 549–570.

Sienkiewicz, J. M., J. D. Locatelli, P. V. Hobbs, and B. Geerts, 1989: Organization and structure of clouds and precipitation on the mid-Atlantic coast of the United States. Part II: The mesoscale and microscale structure of some frontal rainbands. *J. Atmos. Sci.,* **46,** 1349–1364.

Steenburgh, W. J., and C. F. Mass, 1994: The structure and evolution of a simulated Rocky Mountain lee trough. *Mon. Wea. Rev.,* **122,** 2740–2761.

Wang, P.-Y., J. E. Martin, J. D. Locatelli, and P. V. Hobbs, 1995: Structure and evolution of winter cyclones in the central United States and their effects on the distribution of precipitation. Part II: Arctic fronts. *Mon. Wea. Rev.,* **123,** 1328–1344.

Zhang, D.-L., and R. A. Anthes, 1982: A high-resolution model of the planetary boundary layer: Sensitivity tests and comparisons with SESAME-79 data. *J. Appl. Meteor.,* **21,** 1594–1609.