Central Plains Null Event of 18-19 April 2000

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The Storm Prediction Center anticipated severe weather to develop in western Kansas and Nebraska on 18-19 April 2000. While convective storms formed in Nebraska and produced hail and damaging winds, severe weather failed to develop in Kansas. Absolutely stability through much of the troposphere and dry air advection in the lower levels necessitated moisture convergence and surfaced-based forcing to produce convective storms. Surface cyclogenesis and warm frontal convergence in Nebraska provided ascent. Low inertial stability and wind speed shear in the upper troposphere enhanced convective storms as they developed in western Nebraska. Weak ascent and continued inflow of dry air at the surface and lower levels prevented convection in western Kansas. More accurate prediction of wind speed maximums throughout the troposphere and surface low and front development would have prevented the severe weather forecast for western Kansas from failing.

I. Introduction

The Storm Prediction Center (SPC) anticipated a severe weather outbreak in the Central Plains on April 18-19, 2000. The Day Two Convective Outlook issued at 18Z on 17 April centered a moderate risk of severe weather over western Kansas. It forecasted the left exit region of an upper level jet to produce surface cyclogenesis in western Kansas. This was expected to intensify a southerly nocturnal low level jet to 80kt, raising dewpoints in Kansas to the mid-60s. Also, strong mid-level flow was forecasted to steepen mid-level lapse rates, resulting in strong conditional instability. The moderate risk area shifted northwards throughout the April 18 Day One Convective Outlook, and a slight risk covered Kansas. The slight risk anticipated storm initiation with moisture convergence along a warm front and nocturnal low level jet. Two Mesoscale Discussions on April 18 anticipated deep convective initiation and possible supercell formation in western Nebraska and Kansas before 01Z on 19 April with warm front convergence and veering winds.

Severe weather developed in western and central Nebraska on 18 April, including seven reports of hail and nine reports of winds in excess of 50 mph. However, deep convection and severe weather failed to initiate in western and central Kansas. This case study will perform a dynamical and kinematic analysis of the atmosphere over western Kansas and Nebraska on this date. Rawinsonde data, surface and upper air analyses and model forecasts, vertical cross-sections, and satellite imagery will be used to investigate processes and structures throughout the depth of the troposphere. It is hypothesized that inaccurate forecasting of mesoscale variations in atmospheric vertical structure between Kansas and Nebraska led to the null event.

II. Data & Methods

Eta model data from 00Z on 18 April, 2000 through 12Z on 19 April was viewed using General Meteorology Package (GEMPAK) software and the GEMPAK interface, GARP. Maps of analyses and six-hour forecasts of jets, geopotential heights, absolute vorticity and mean sea level pressure were produced at different mandatory levels. GOES-East satellite imagery was centered on the central Plains to track the movement and evolution of cloud structures associated with the system. Archived surface plots were hand-analyzed for wind streamlines and mesoscale boundaries. Soundings from the University of Wyoming's archive for North Platte, NB, Dodge City, KS, and Topeka, KS were compared to investigate the vertical structure of the atmosphere in areas with and without severe weather development. Hand analysis of vertical distribution of mixing ratio was made by interpolating sounding data between from North Platte, NB and Dodge City, KS at 00Z on 19 April.

III. Synoptic overview

A ridge extending from middle through upper levels dominated synoptic flow in the central United States on 18-19 April. Winds at 300mb were about 25m/s (50kt) in the southern Plains and increased with latitude to reach 45m/s (90kt) in the northern Plains throughout the times of interest (Shown in Figure 1a at 18Z on 18 April). Warm, dry air from the southern and southwestern United States advected northwards in the ridge at lower levels in southwesterly flow, drawing temperatures in excess of 20 degrees Celsius at 850mb into the southern and central Plains by 18Z (Figure 1b). Lower level winds west of the warm air advection were westerly and winds east of the warm air advection were southwesterly. Confluence sharpened baroclinicity along the boundaries of the warm air advection.

An upper low moved eastward into Utah by 18Z (Figure 1a). A jet streak with winds exceeding 60kt curved south of the low into the western side of the upper ridge to the edge of the Rocky Mountains. Ageostrophic divergence on the eastern side of the encroaching upper trough promoted surface cyclogenesis over northern Colorado. Between 12Z and 18Z on 18 April a northwest-to-southeast oriented surface trough gained negative tilt into the southern and central Plains (Figure 1c). Absolute vorticity increased as the cyclone deepened through the depth of the troposphere and moved to the northeast into western Colorado and New Mexico (Figure 1d).

Upper ageostrophic divergence continued to promote surface cyclogenesis at 00Z on 19 April (Figure 2ab). Lower level convergence with the surface cyclogenesis tightened the baroclinic zone into warm and cold fronts (Figure 1c). This strengthened the thermal wind and thus increased PVA over the surface low. The surface low deepened as it moved eastward, reaching 992mb by 00Z on 19 April (Figure 1d). The surface low moved eastward over the baroclinic zone.

By 06Z on 19 April the strongest PVA by the thermal wind shifted north of the surface low into central Nebraska. The surface low filled as it moved eastward along the Nebraska-Kansas border. Weakened low level convergence decreased frontogenesis and the temperature gradient across the warm front.

IV. Mesoscale environment: A Central Plains perspective

Subsidence in the upper ridge brought calm, clear conditions to the central Plains in the early morning hours of 18 April. The ground cooled rapidly, creating a radiation inversion about 400m AGL and a nocturnal stable boundary layer (SBL) beneath. A relative minimum of dewpoint depressions stretched across Kansas into southern Nebraska in the SBL. Dewpoint depressions within the minimum ranged from 1-6°F at 06Z (Figure 3a). Fog developed in the dewpoint depression minimum in the SBL in response to radiation divergence across the top of the moist SBL and turbulent overturning (Figure 3b). Condensation of SBL moisture into fog moistened the surface. By 12Z dewpoint depressions decreased to 1-3°F in Kansas.

A line of converging surface winds from southwestern Nebraska into north-central Texas developed between 06Z and 12Z as weakly confluent flow above the boundary layer strengthened the baroclinic

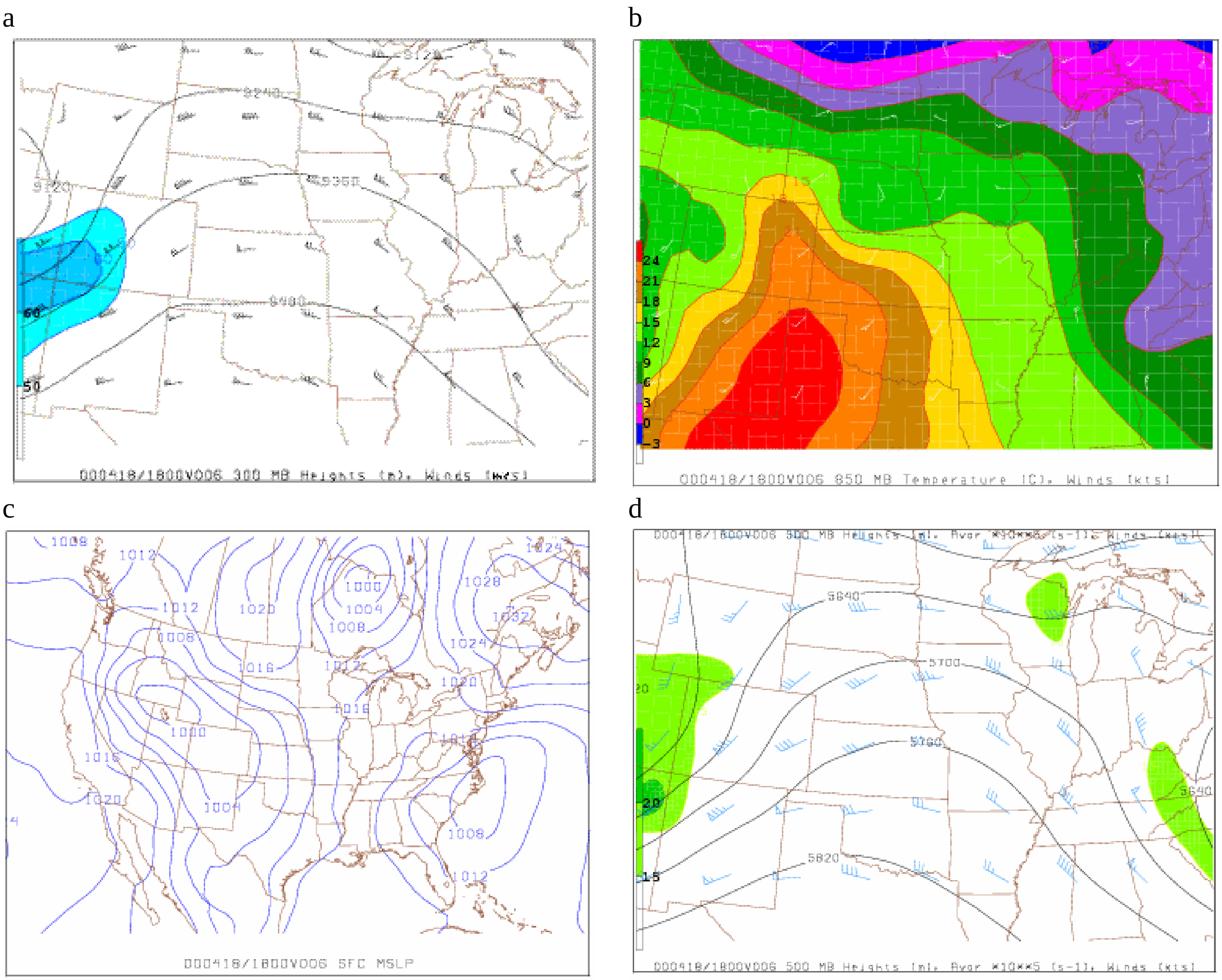


Figure 1: Eta model output initialized at 12Z on 18 April and taken at the six-hour forecast at 18Z. (a) 300mb geopotential heights and winds. Isohypses are contoured in 120m intervals. Wind barbs are in knots, and wind speeds are contoured and filled in 10kt intervals. (b) 850mb temperature and winds. Isotherms are contoured and filled in 3 degree Celsius intervals. Wind barbs are in knots. (c) Mean sea level pressure. Isobars are contoured in 4mb intervals. (d) 500mb geopotential heights, winds, and absolute vorticity. Isohypses are contoured in 60m intervals. Wind barbs are in knots. Absolute vorticity is filled in 5*10**-55 s^{-1} intervals.

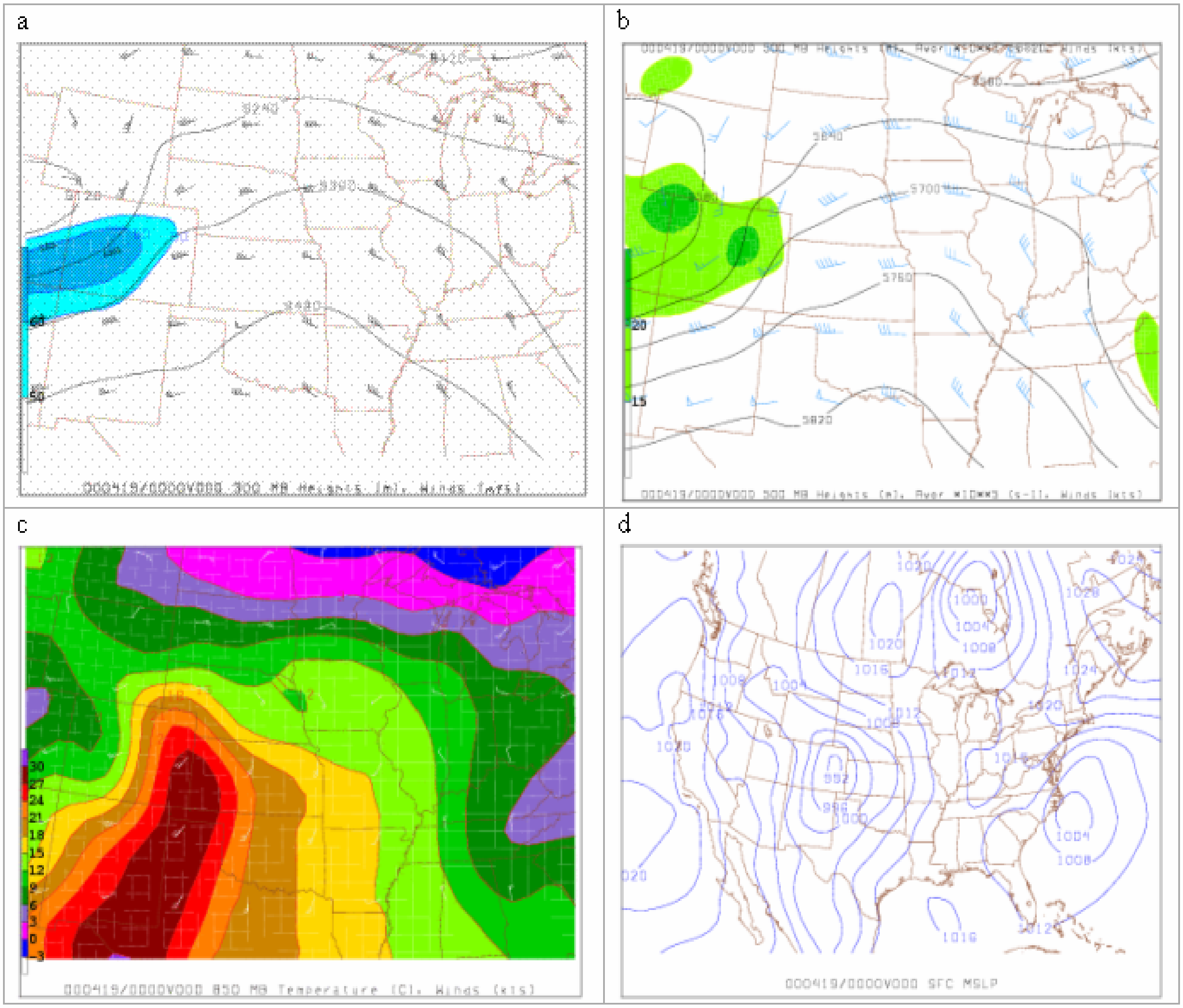


Figure 2: Eta model analyses initialized at 00Z on 19 April. (a) 300mb geopotential heights and winds. Isohypses are contoured in 120m intervals. Wind barbs are in knots, and wind speeds are contoured and filled in 10kt intervals. (b) 500mb geopotential heights, winds, and absolute vorticity. Isohypses are contoured in 60m intervals. Wind barbs are in knots. Absolute vorticity is filled in 5*10**-5 s^{-1} intervals. (c) 850mb temperature and winds. Isotherms are contoured and filled in 3 degree Celsius intervals. Wind barbs are in knots. (d) Mean sea level pressure. Isobars are contoured in 4mb intervals.

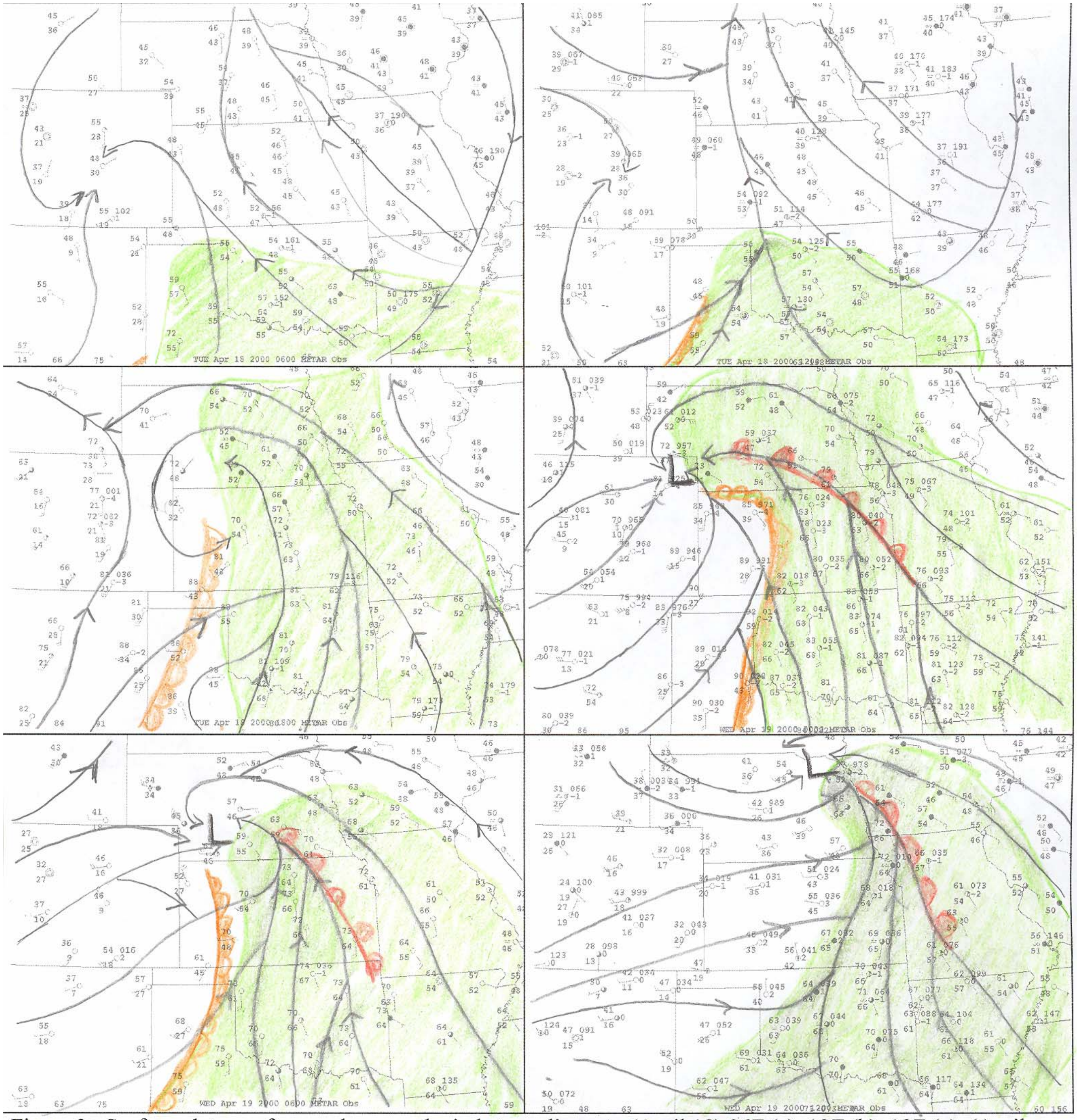


Figure 3: Surface plots, surface analyses, and wind streamlines at: (April 18) 06Z (a); 12Z (b); 18Z (c); (April 19) 00Z (d); 06Z (e). Surface boundary symbols follow standard conventions.

zone stretching from Oklahoma into southwestern Kansas. Surface winds ahead of the line were southeasterly and southwesterly behind the axis. A 3-5°F gradient in both surface temperature and dewpoint also marked the convergence. The southern portion of the convergence axis was about 240km east of a dryline in the Texas panhandle.

Surface cyclogenesis produced by upper level ageostrophic divergence moved into eastern Colorado by 18Z (Figure 3c). Surface flow into the region of cyclogenesis tightened the surface temperature and dewpoint gradients across the lower level baroclinic zone to about 10°C. This increased frontogenesis at 1000mb, converting the baroclinic zone into a warm front stretching from extreme southeastern Wyoming into southeastern Kansas (Figure 4a). Gulf moisture flowed northward ahead of the warm front, reaching into northern Nebraska by 18Z. Warm, dry air with high static stability continued to advect from the southern United States northeastwards behind the front.

By 00Z on 19 April frontogenesis maximized to 36°C$m^{-1}s^{-1}$ and deepened to 850mb as a surface low developed in northeastern Colorado near Akron (Figure 4bc). The Texas dryline moved northward in response to flow around the low (Figure 3d). Moist Gulf air ahead of the warm front curved cyclonically north of the surface low to cover Nebraska with surface dewpoints in excess of 50°F. Surface temperatures ahead of the front ranged from the low to mid-60s in Nebraska to the upper 70s and lower 80s in eastern Kansas. Behind the front, temperatures reached the upper 80s and low 90s with dewpoints ranging from the middle 20s into the lower 30s.

Eastward movement of the surface low across the Kansas-Nebraska border pushed the moist Gulf air rapidly from the central Plains between 00Z and 12Z as westerly flow advected dry air from the Rocky Mountains to the central Plains (Figure 3def). Soundings taken within the dry air reported mixing ratios below 2g/kg at 700mb and a distinct EML structure to about 525mb. This decreased temperature and dewpoint gradients across the warm front. Frontogenesis consequently decreased by 06Z at both 1000mb and 850mb.

Movement and evolution of the surface low and warm front can be tracked by infrared satellite imagery (Figure 5). The north-south oriented boundary through central Kansas and Nebraska between moist air and dry air had thin clouds to the east and mostly cloud-free air to its west. The dry air in lower levels and absolute stability prevented cumulus from developing west of the boundary. A circular mass of low clouds moved to the northeast ahead of the warm front. This area was enhanced by ascent with the surface low. The upper low was marked by a larger circular area of colder cirrus clouds. These clouds were convective, and storms with heavy precipitation formed within the cloud mass between 21Z and 22Z on 18 April. By 00Z on 19 April these clouds entered western Nebraska, producing severe weather.

The following sections will detail sounding data at three locations in the central Plains during 18-19 April. Dodge City, KS was in the dry, stable air behind the warm front. North Platte, NB was in the region of surface cyclogenesis and had a boundary layer moistened by Gulf air advection. Topeka, KS was ahead of the warm front in moist air advection.

a. Dodge City, KS sounding

At 00Z on 18 April a subsidence inversion capped a dry mixed layer at 850mb (Figure 6a). Winds decreased from about 15kt in the mixed layer to about 5kt in the inversion layer. They were weak throughout the depth of the troposphere, with a speed maximum of 70kt at 200mb. The troposphere was very dry and absolutely stable. This prevented free convection.

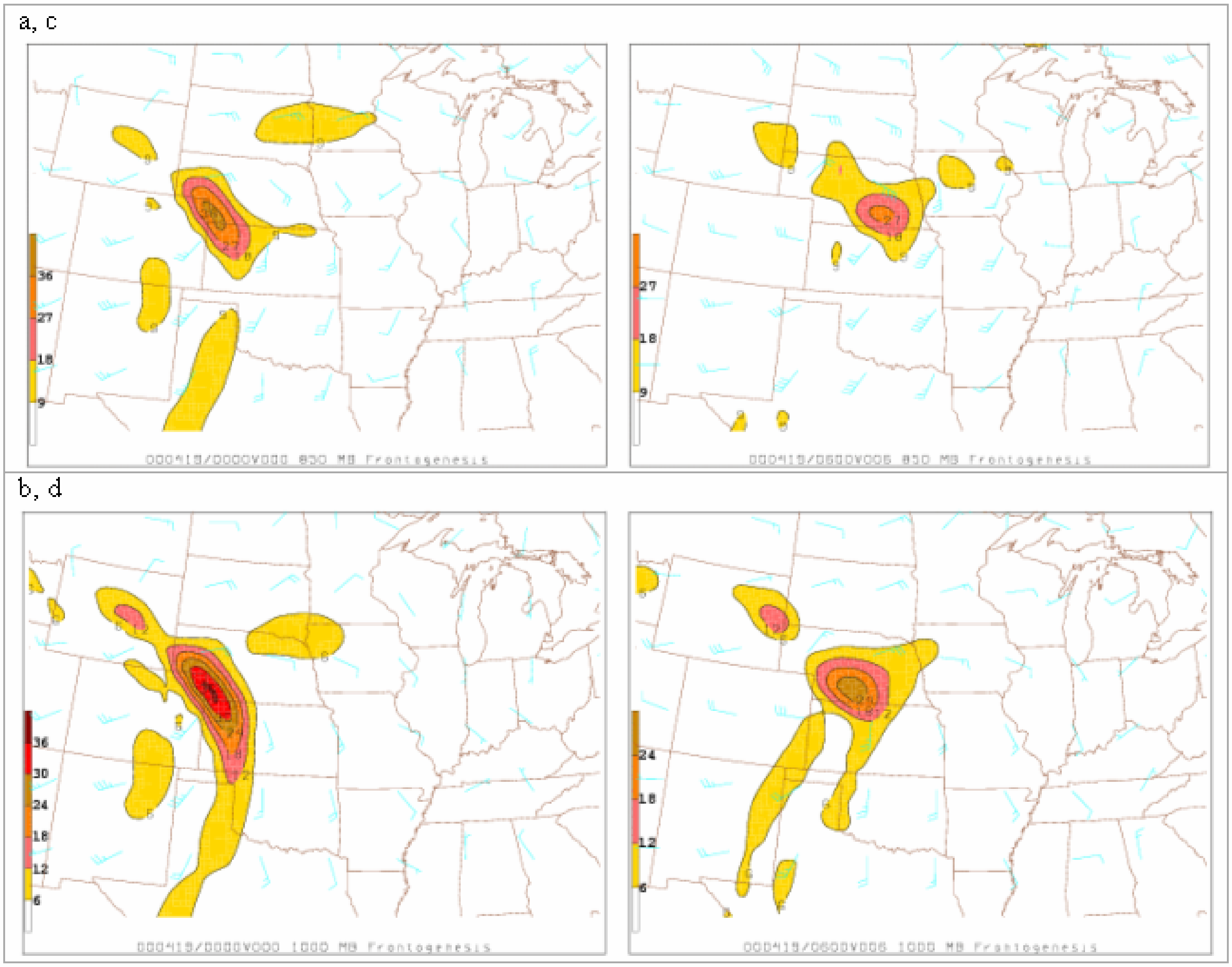


Figure 4: Positive frontogenesis derived from Eta model data initialized at 00Z on 19 April. (a) 850mb positive frontogenesis at 00Z. Isopleths of frontogenesis are contoured and filled in 9°$Cm^{-1}s^{-1}$ intervals. (b) 1000mb positive frontogenesis at 00Z. Isopleths of frontogenesis are contoured and filled in 6°$Cm^{-1}s^{-1}$ intervals. (c) 850mb positive frontogenesis from the six-hour forecast at 06Z. Isopleths of frontogenesis are contoured and filled in 9°$Cm^{-1}s^{-1}$ intervals. (d) 1000mb positive frontogenesis from the six-hour forecast at 06Z. Isopleths of frontogenesis are contoured and filled in 6°$Cm^{-1}s^{-1}$ intervals.

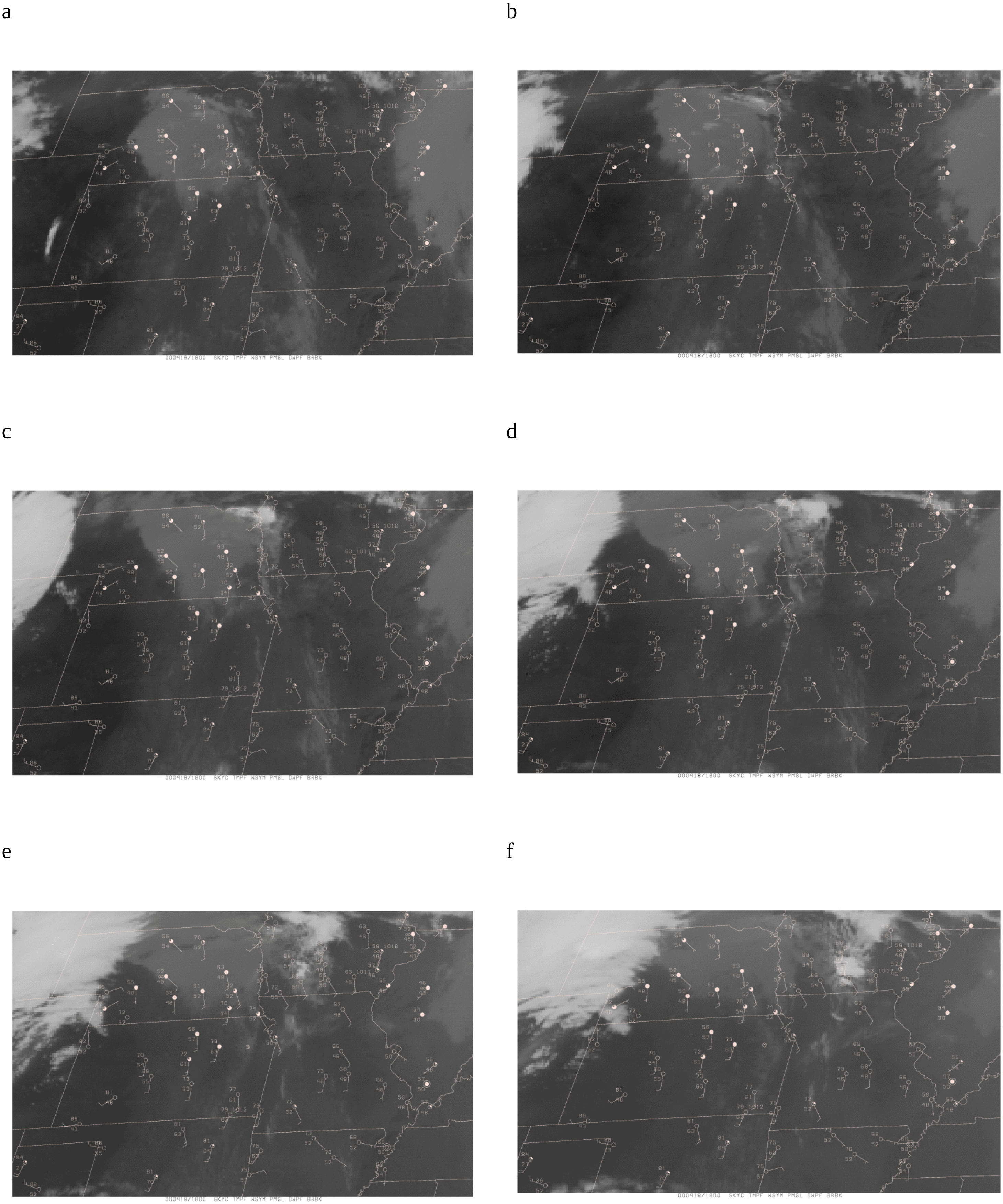
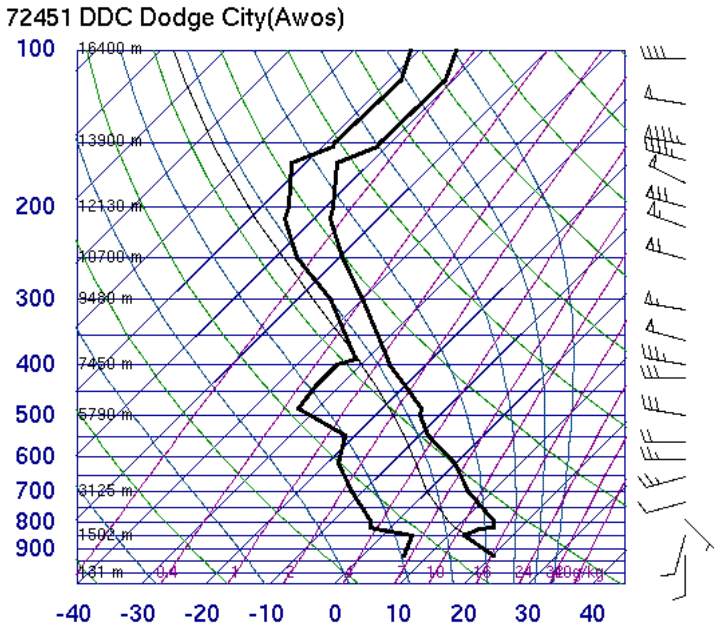


Figure 5: GOES-East 10.7 micron infrared channel satellite imagery centered over the central Plains on 18 April at: (a) 1815Z; (b) 1915Z; (c) 2015Z; (d) 2115Z; (e) 2215Z; and (f) 2315Z.

a



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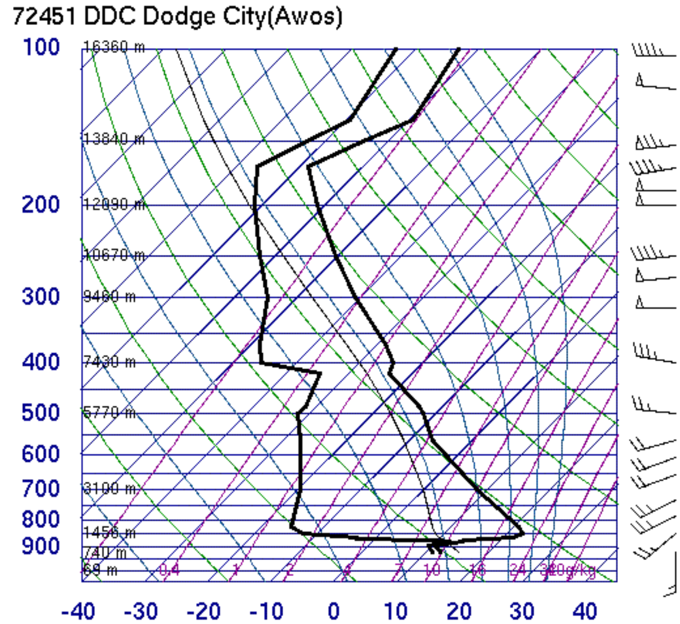

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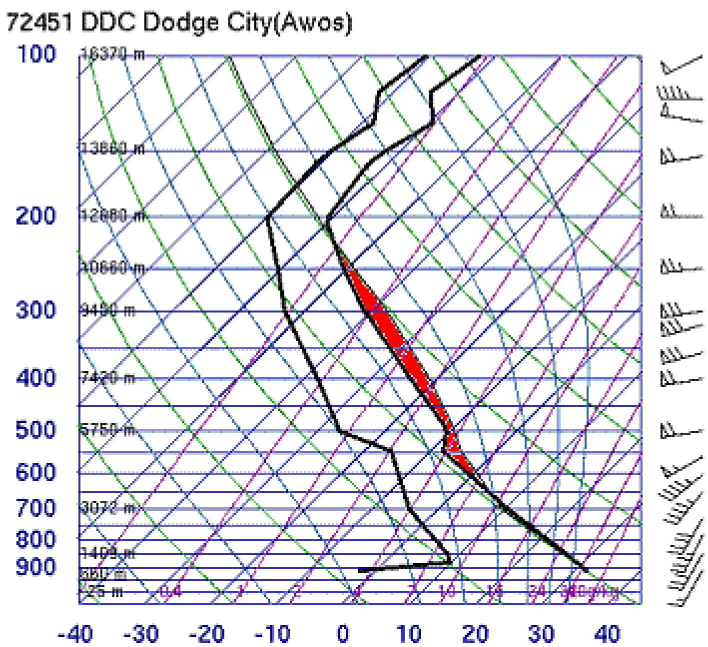


Figure 6: Soundings taken at Dodge City, KS (DDC) at: 00Z on 18April (a); 12Z (b); and 00Z on 19 April (c). CAPE is shaded in red in panel c.

By 12Z a strong radiation developed at 900mb under clear skies. Southerly flow at the surface moistened the nocturnal SBL beneath the inversion and fog developed. An elevated mixed layer (EML) with a nearly dry adiabatic lapse rate extended from the inversion to about 525mb. The lapse rate above the EML was less steep and maintained absolutely stability. The wind speed maximum shifted above the tropopause, and speeds between 400mb and the tropopause decreased nearly uniformly by 10kt from their speeds at 00Z.

Winds were approximately westerly throughout the depth of the free troposphere at 12Z. In the following 12 hours, winds below 525mb backed to become southwesterly and strengthened from 20-25kts to 40-45kts (Figure 6c). Speeds between 525mb and the tropopause roughly doubled, with a maximum of 70kt near 300mb. This produced a unidirectional and nearly constant wind profile in the lowest 5km. Such a vertical wind profile promotes downward mixing (Shapiro and Keyser 1990). Dry air from the EML mixed downward, joining the boundary layer with the free troposphere and producing a nearly dry adiabatic lapse rate. Erosion of the EML structure created a generally uniform dewpoint lapse rate through the troposphere. Surface temperature rose from 12°C at 12Z to 32°C under the influence of solar heating (after fog dissipation), downward mixing of warm EML air, and warm air advection from the southern and southwestern United States. An enhanced shallow layer of very dry air near the surface produced a surface dewpoint of -3°C. The enhanced dry surface layer and very warm temperature produced an LCL at roughly 630mb and an LFC at 600mb. Weak mid-level lapse rates in the middle and upper troposphere reduced surface-based CAPE to 650J/kg.

b. North Platte, NB

The 00Z sounding on 18 April was similar to the 12Z sounding on the same day at Dodge City (compare Figure 7a to Figure 6a). A unidirectional wind profile of westerly winds of about 20kt through the lowest 5km promoted downward mixing. Dry air from the EML mixed downward, producing of a dry adiabatic lapse rate and joining of the boundary layer with the free troposphere. The surface dewpoint was about 0°C. The warm, dry surface produced a surface-based LCL at about 600mb. Weak mid-level lapse rates produced an absolutely stable atmosphere above 525mb, preventing an LFC. Winds were westerly throughout the troposphere and maximized at 84kt near 200mb.

By 12Z a nocturnal SBL formed to separate the lower troposphere from the free atmosphere. A moist layer of fog formed in the SBL under a dry inversion layer at about 800mb (Figure 7b). This deep inversion layer was itself capped by an EML extending from 700mb to 525mb. Winds in the EML and SBL backed from their directions at 00Z to become southerly near the surface and southwesterly with height. The upper wind speed maximum shifted upwards to about 200mb, and winds through the free troposphere remained westerly above 500mb. Lapse rates above the EML weakened to maintain absolute stability.

A special 18Z sounding was made at North Platte on 18 April (Figure 7c). By 18Z the fog dissipated and a shallow mixed layer developed below 825mb. The fog and moisture advection around the low raised the surface dewpoint to about 10°C. The EML lowered, capping the mixed layer with a strong inversion. Winds within the EML veered relative to their directions at 12Z in flow around the approaching surface low. This abruptly sheared profile was less conducive to mixing warm air downward than was the wind profile at 00Z. The surface temperature lowered to about 13°C. The atmosphere was still absolutely stable, and a very dry layer developed between 500mb and 300mb. Despite a surface-based LCL at the inversion level, no LFC was

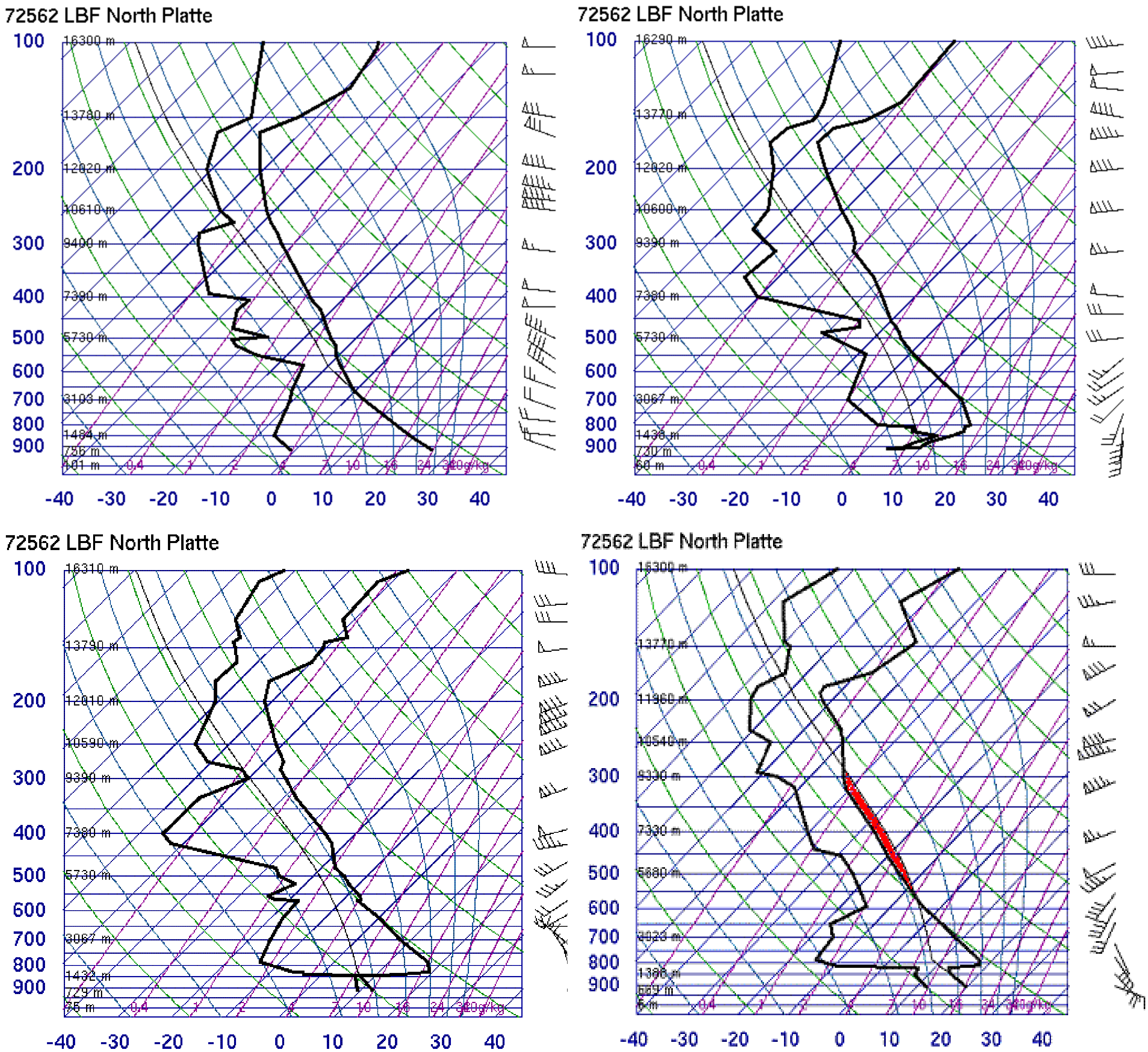


Figure 7: Soundings taken at North Platte, NB (LBF) at: 00Z on 18April (a); 12Z (b); 18Z (c); and 00Z on 19 April (d). CAPE is shaded in red in panel d.

reached. Winds above the EML became west-southwesterly with the speed maximum remaining near 200mb.

The mixed layer dried by 00Z on 19 April as surface temperature rose from 12°C to 20°C (Figure 7d). The dry layer between 500mb and 300mb mixed downward, creating a more uniform dewpoint lapse rate above the EML. As the surface low advanced eastward winds in the lowest 3km became southeasterly and veered with height to become westerly by 6km. This produced a deep-layer shear of about 32kts. Warming of the surface created a LFC at 570mb and CAPE of 364J/kg in the middle and upper troposphere. The Bulk Richardson Number was 3.33. Maximum wind speeds in the upper troposphere deepened to about 85kt at 300mb, and increased to 95kt near 250mb.

c. Topeka, KS

At 00Z on 18 April a dry boundary layer with weak disorganized winds was capped at about 900mb (Figure 8a). The troposphere was uniformly dry and warm and absolutely stable. West-northwesterly winds in the free troposphere reached a speed maximum of nearly 80kt at about 250mb.

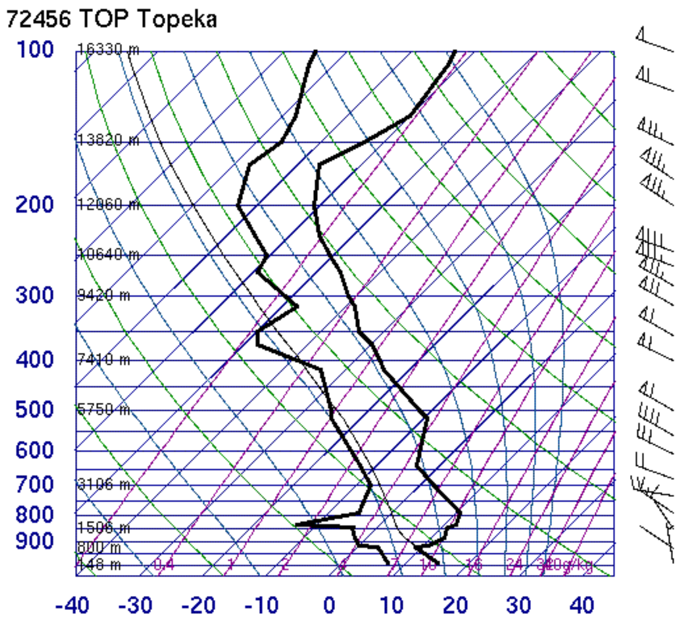
At 12Z on 18 April a fog layer extended from the surface to 825mb (Figure 8b). Winds within the fog were disorganized and weak, possibly indicative of turbulent overturning. Dry air with a weak EML structure between 825mb and 700mb capped the fog layer. A shallow mid-level temperature lapse rate maintained absolute stability above the fog layer as the free troposphere continued to lose moisture. Winds between 400mb and the tropopause decreased from their speeds at 00Z by about 10-15kt.

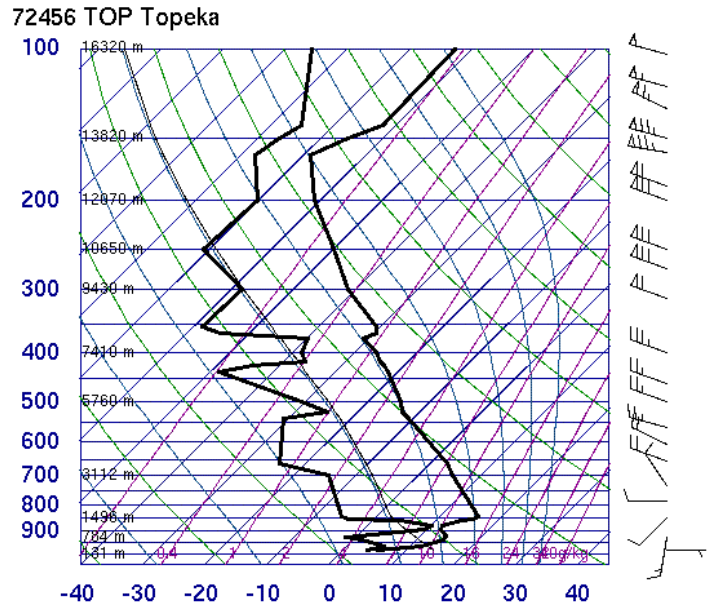
At 00Z on 19 April a deep mixed layer developed as Gulf air moved northward and solar insolation increased despite thing clouds (Figure 8c). The mixed layer was capped at 800mb by an EML. A second EML extended from 600mb to 525mb. The LCL was at 825mb and the LFC at 810mb. These were separated by -5J/kg of convective inhibition at the boundary layer inversion. Winds veered with height to produce deep-layer shear of 28kts. Surface-based CAPE of 2000J/kg and veering winds produced a Bulk Richardson Number (BRN) of about 28. Wind speeds in the upper troposphere remained roughly the same as at 12Z.

V. Discussion and Conclusions

Air across the central Plains was absolutely stable and very dry through much of the depth of the troposphere. Upper level forcing of ascent was also very weak. This necessitated low level forcing and moistening of the boundary layer to produce severe weather. While severe weather was anticipated in both western Kansas and Nebraska, these conditions were only met in Nebraska.

As the surface low moved eastward along the Kansas-Nebraska border, frontogenesis tightened a low level baroclinic zone and strengthened when the baroclinicity had moved from western into central Kansas. Frontogenesis forced upward vertical motion. Fog across Kansas inhibited mixing and convergence at the warm front; this was not the case in Nebraska. The fog cooled the surface and lower levels by blocking solar insolation. Surface temperatures in Kansas rose due to warm air advection rather than solar heating and turbulent mixing. Fog evidences a calm atmosphere—not conducive to frontogenesis. Gulf moisture advected in flow around the low to the east of the warm front. Moist air curled cyclonically into the boundary layer in Nebraska while most of Kansas had very dry air at the surface from the southwestern United States. Formation of thing clouds and a low cloud mass in the moist air hindered solar insolation in Nebraska relative to Kansas during the peak hours of solar heating, creating conditional





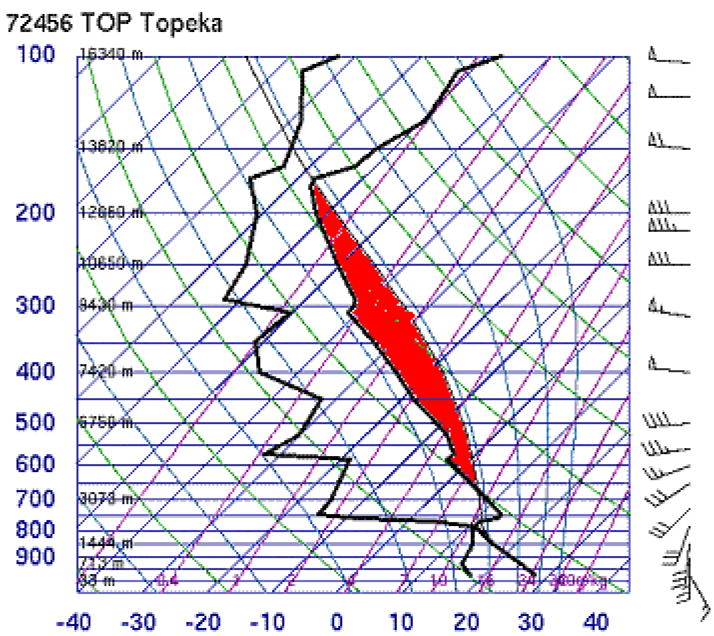


Figure 8: Soundings taken at Topeka, KN (TOP) at: 00Z on 18April (a); 12Z (b); and 00Z on 19 April (c). CAPE is shaded in red in panel c.

instability. Figure 9 idealizes the conditions over Kansas and Nebraska.

Figure 10 compares cross-sections through the warm front in northwestern Kansas and southwestern Nebraska at 18Z on 18 April and 00Z on 19 April. In each case and at each time step, a well-mixed boundary layer was ahead of the warm front in Gulf air advection. Analysis of dewpoints and dewpoint depressions shows that this was a moist mixed layer. A downward sloping area of isentropes near the center of each figure represents the frontal boundary. Convergence at the warm front in Nebraska was much more vigorous than in Kansas, as evidenced by more densely packed isentropes sloping from the mid-troposphere to the flat isentropic pattern of the mixed layer. By 00Z on 19 April this transition is virtually absent in Kansas, giving way instead to a broad, deep layer of warm dry air.

Figure 11 is a cross-section of wind speed between North Platte, NB and Dodge City, KS at 00Z on 19 April. A speed maximum of 95kt between 300mb and 200mb over North Platte provided upper level wind shear that enhanced storm development by drawing outflow from storm tops away from the storms. This allows CAPE to be almost completely used by storm growth. The jet was mesoscale, as other soundings around North Platte did not show this feature. The upper ridge added to removal of storm outflow with its associated low inertial stability. Wind speeds over Kansas rose steadily with height, with a weak maximum between 400mb and 300mb over Dodge City. This evidences calm flow within the upper ridge.

Comparison of sounding data among Topeka, Dodge City, and North Platte emphasizes differences in atmospheric conditions over Kansas and Nebraska. The 00Z on 19 April sounding at Topeka, KS was very favorable for severe weather development, including supercells. However, a lack of lower level forcing sufficient to break the convective cap prevented development. The 00Z sounding at North Platte, NB was less favorable for severe weather development. However, greater lower level forcing by the warm front and surface low allowed severe weather to initiate.

The SPC anticipated strong upper level flow, formation of a nocturnal low level jet, surface cyclogenesis in Kansas, and warm frontal wind and moisture convergence to force deep convection and severe weather development in western Kansas. These expectations, however, were not met by actual synoptic scale and mesoscale dynamics. An absolutely stable atmosphere for much of the time domain hindered convection. Upper level flow through a ridge was very weak over the central Plains, and the upper level jet remained over the Rocky Mountains. While surface cyclogenesis formed on the western side of the upper ridge it moved northward of the predicted track. This drew low level Gulf moisture into Nebraska while dry air advected into western Kansas. Absence of a nocturnal low level jet allowed dry advection to continue unchecked. Early morning radiation fog inhibited solar insolation and warm frontal convergence in Kansas. A mesoscale wind maximum in western Nebraska and low inertial stability in the upper ridge enhanced storm development in Nebraska by removing outflow at the level of storm tops. Better forecasting of these parameters would have improved the accuracy of the severe weather outlook for western Kansas on 18-19 April 2000.

VI. References

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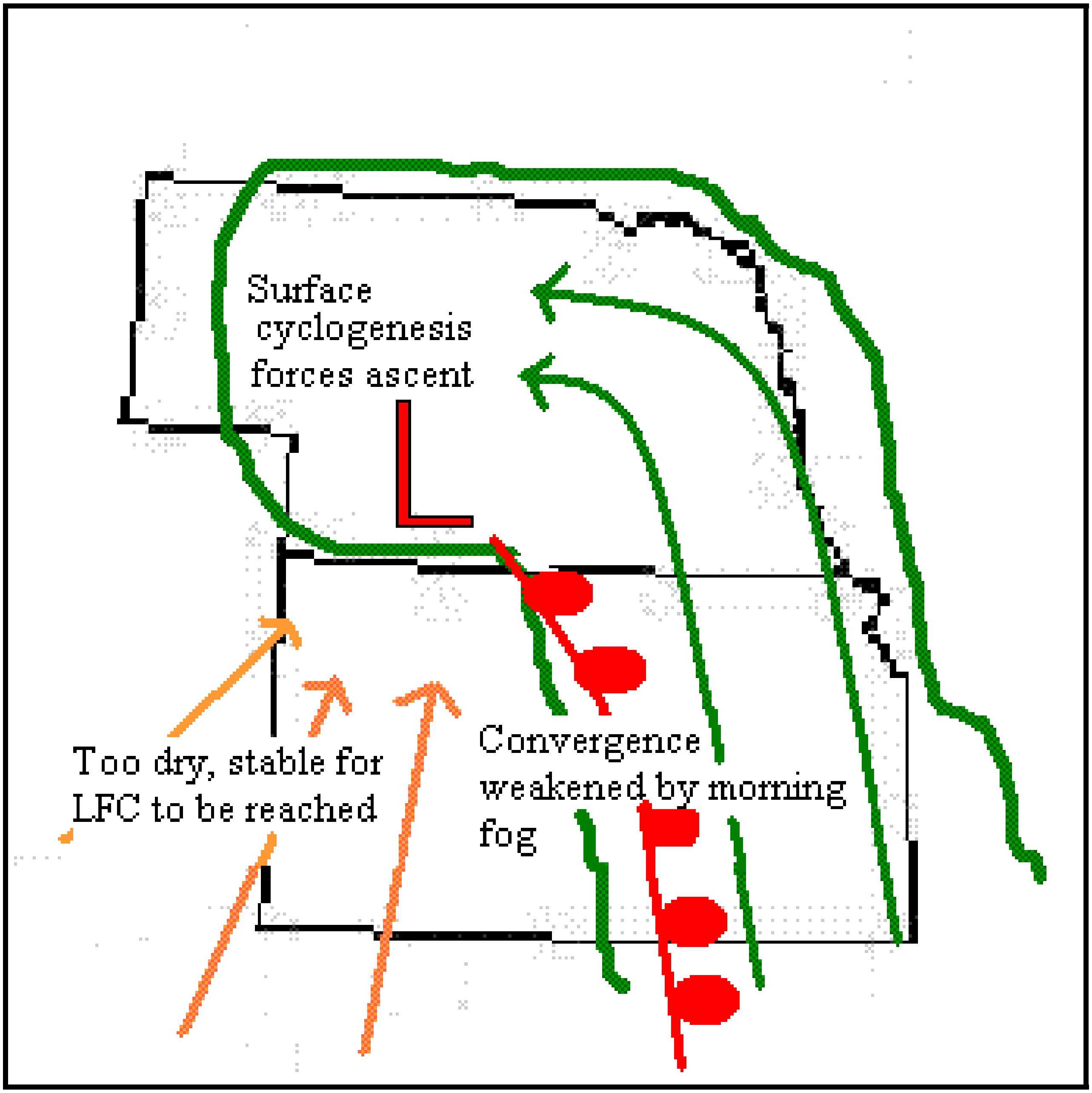

Figure 9: Summary of surface conditions and forcings in Kansas and Nebraska during the case. Surface boundary symbols follow standard conventions.

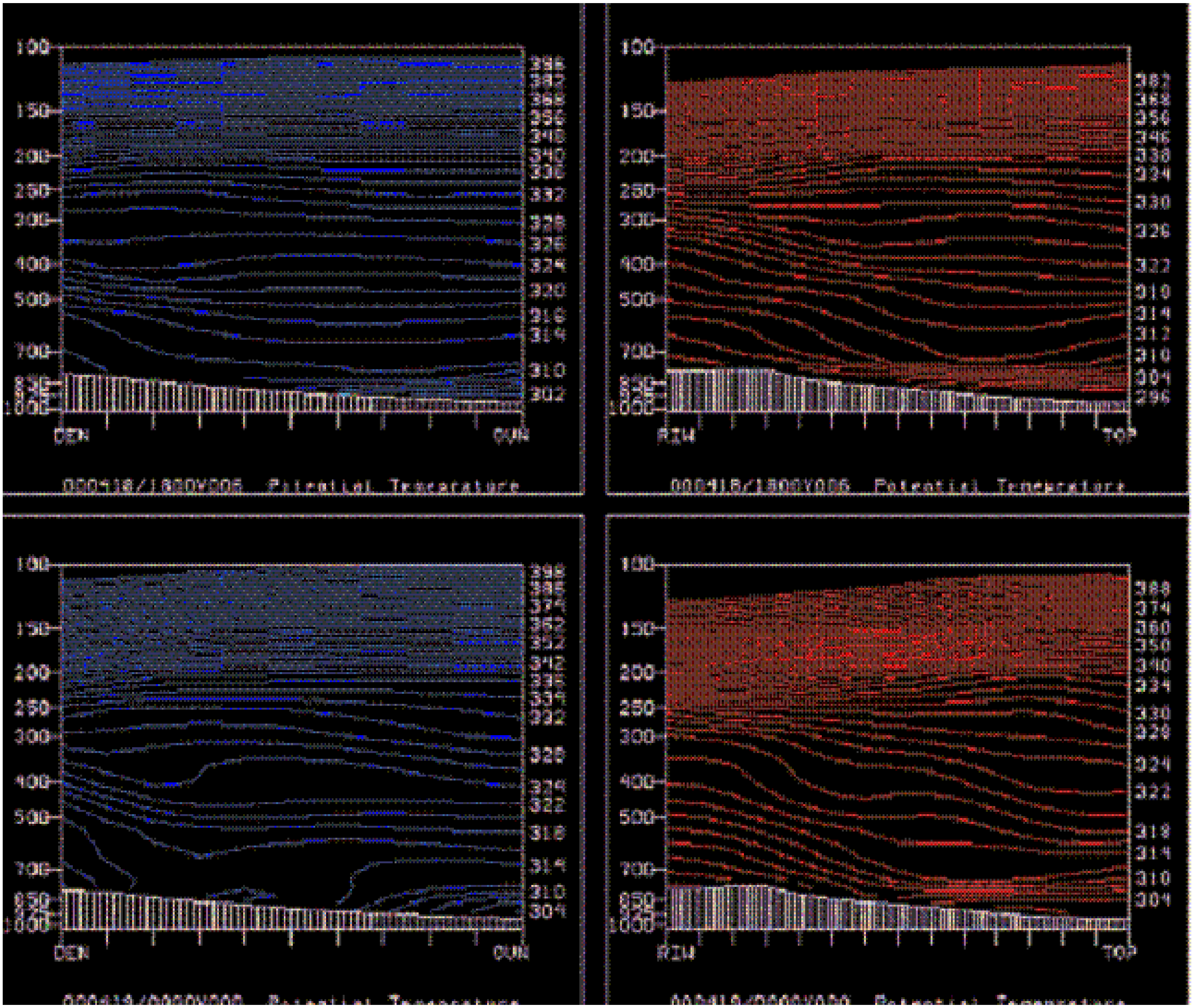

Figure 10: Vertical cross-sections of potential temperature taken from Eta model data. Isentropoes are contoured in 4K intervals. (top left) Potential temperature at 18Z on 18 April between Denver, CO (DEN) and Norman, OK (OUN). Values taken from the six-hour forecast of the Eta model initialized at 12Z on 18 April. (top right) Potential temperature at 18Z on 18 April between Riverton, WY (RIW) and Topeka, KN (TOP). (bottom left) Potential temperature at 00Z on 19 April between DEN and OUN. Values taken from the 00Z 19 April Eta model analysis. (bottom right) Potential temperature at 00Z on 19 April between RIW and TOP.

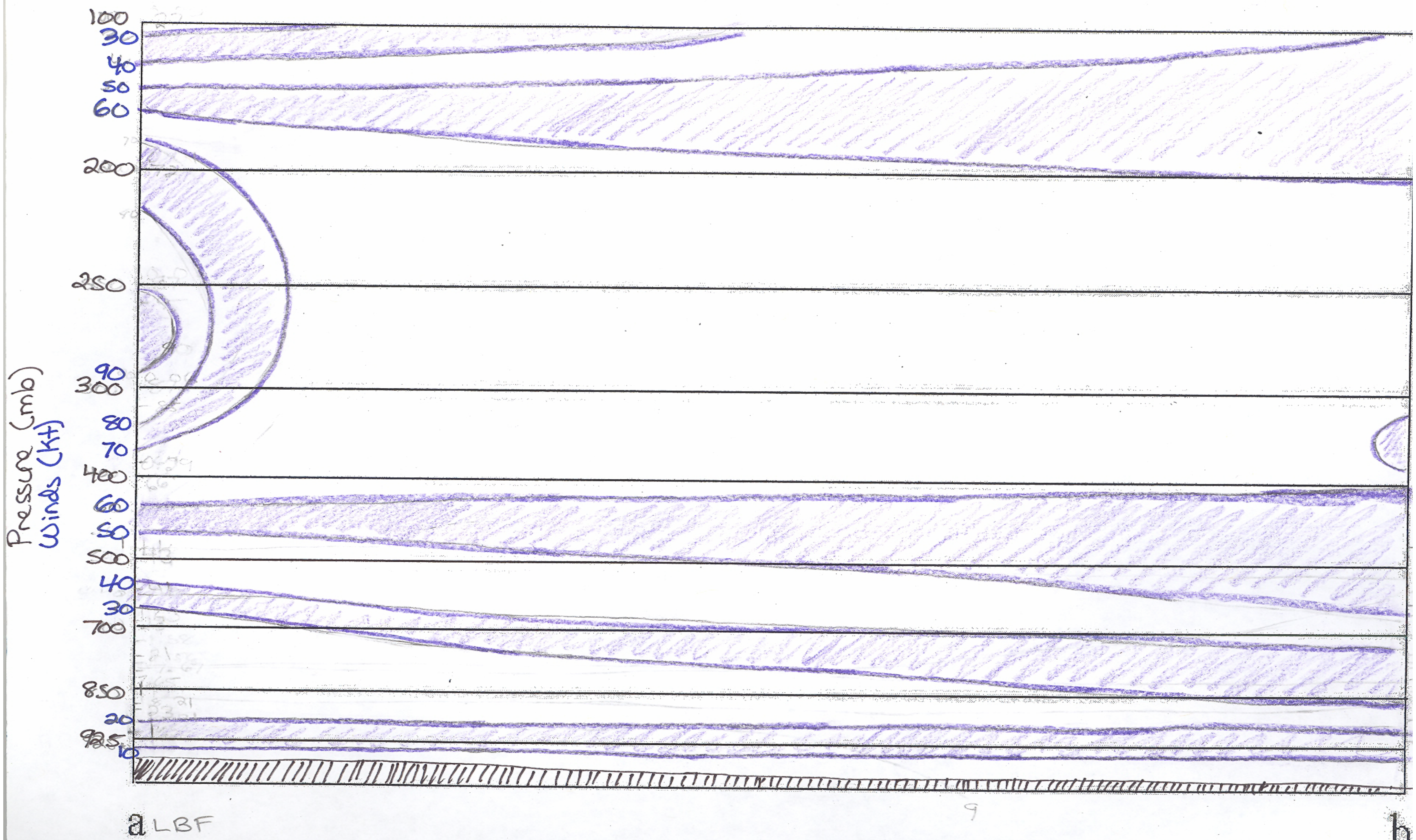

Figure 11: Vertical cross-section of wind speeds interpolated between North Platte, NB (LBF) and Dodge City, KS (DDC) at 00Z on 19 April.