Doppler-radar observations of a prefrontal wind-shift line in the Southern Plains of the U. S.

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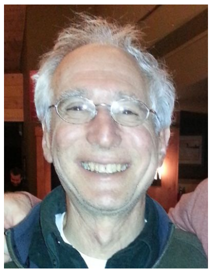

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1 Introduction

Prefrontal wind-shift lines are sometimes found in the Southern Plains of the U. S. (Hutchinson and Bluestein 1998; Schultz 2004). They are significant because *a convergent wind shift is found well in advance of the temperature gradient associated with the trailing cold front*; in most cold fronts, the wind shift is found along the leading edge of the zone of strong temperature gradient (Bluestein 1993) for reasons that can be explained by application of the geostrophic-momentum approximation of the inviscid equations of motion, the thermodynamic equation, and the continuity equation. It appears as if the interaction of orography (downslope motion in the lee of the Rocky Mountains) plays a role in disconnecting the convergence line from the front.

To the best of the authors' knowledge, the fine-scale structure of prefrontal wind-shift lines has not been studied in any detail. On 11 Nov. 2013, a prefrontal wind-shift line and trailing cold front swept across central Oklahoma. The purpose of this presentation is to describe data collected by RaXPol, a rapid-scan, polarimetric, Doppler radar (Pazmany et al. 2013), when the wind-shift line propagated through Norman, Oklahoma. Data from a nearby WSR-88D radar (KTLX) and a thermodynamic profiling system are also described.

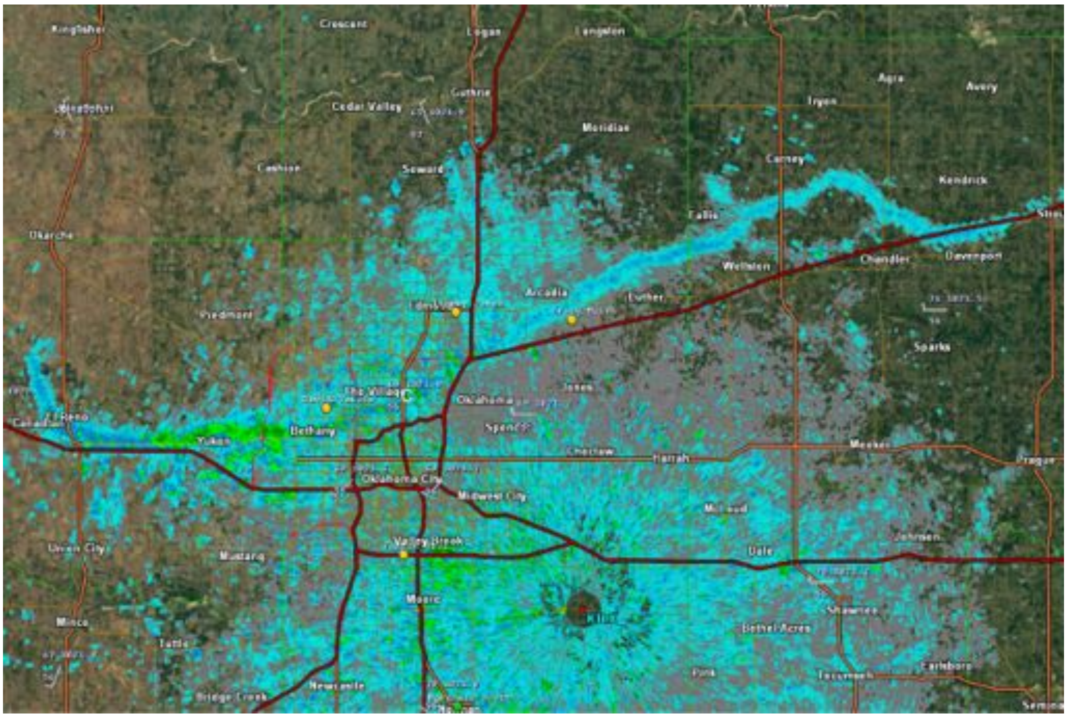

Figure 1: Radar reflectivity factor from the KTLX WSR-88D radar at 2155 UTC 11 Nov. 2013, at 0.5^0 elevation angle. The prefrontal wind-shift line is located by the fine line just passing through the northern part of the Oklahoma City area. Norman is at the southern edge of the map.

2 Description of the data

A fine-line of reflectivity associated with a prefrontal wind-shift line was apparent on the KTLX WSR-88D radar as it approached the northern side of Oklahoma City (Fig. 1). From Fig. 2 it is seen that this wind-shift line was not associated with any significant horizontal temperature gradient and the wind speeds were relatively weak. The actual cold front, as marked by the leading edge of a strong horizontal temperature gradient and a sudden increase in wind speed, but with no significant change in wind direction, was located ~ 100 km to the northwest.

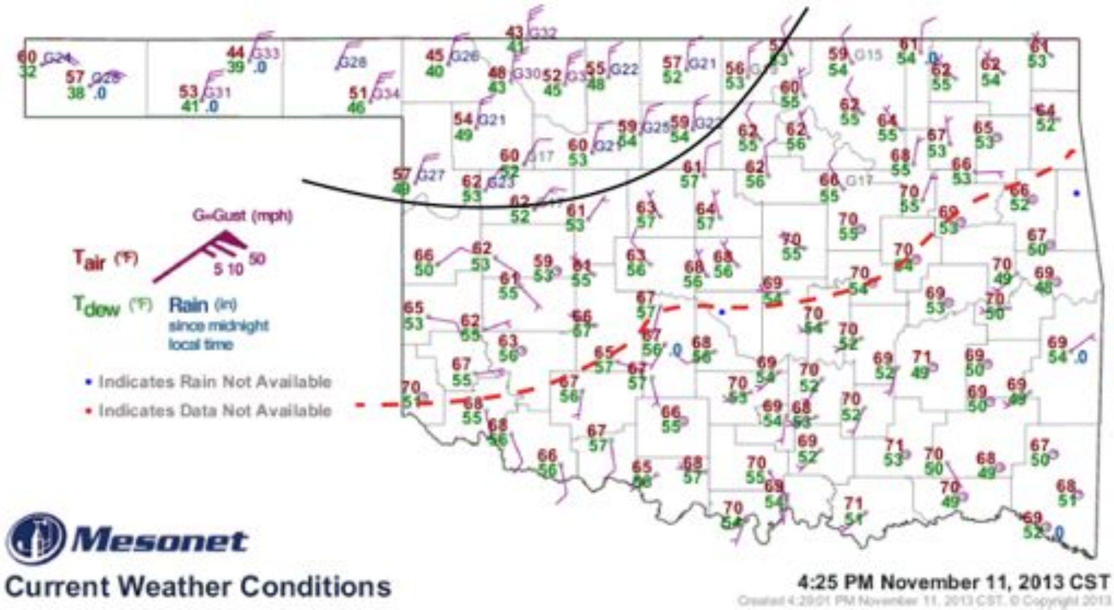

Figure 2: Surface conditions at sites in the Oklahoma Mesonet at 2225 UTC 11 Nov. 2013. Temperature and dew point are plotted in ^{0}F. Wind is plotted in mph, with whole barb = 10 mph, half barb = 5 mph, and small barb < 5 mph. Solid blue line marks the approximate location of the front; dashed red line marks the approximate location of the pre-frontal wind-shift line.

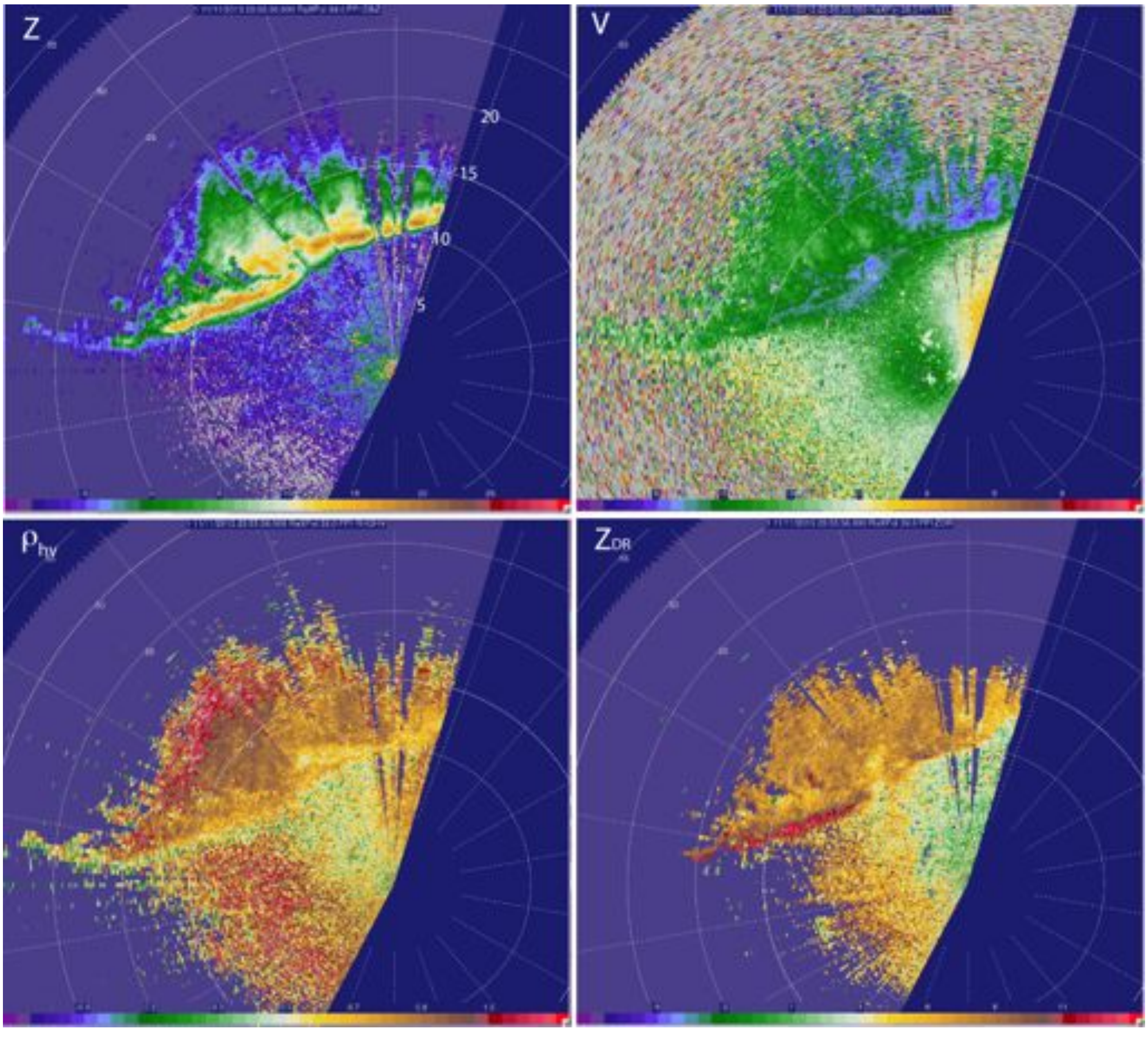

Figure 3: PPIs from RaXPol at 2355 UTC 11 Nov. 2013 for (top left) radar reflectivity factor Z (dBZ), (top right) Doppler velocity V (m s^{-1}), (bottom left) co-polar correlation coefficient ρ_{hv}, and (bottom right) differential reflectivity Z_{DR} (dB). The prefrontal wind-shift line is about 10 km to the northwest of Norman. Range markers are shown every 5 km.

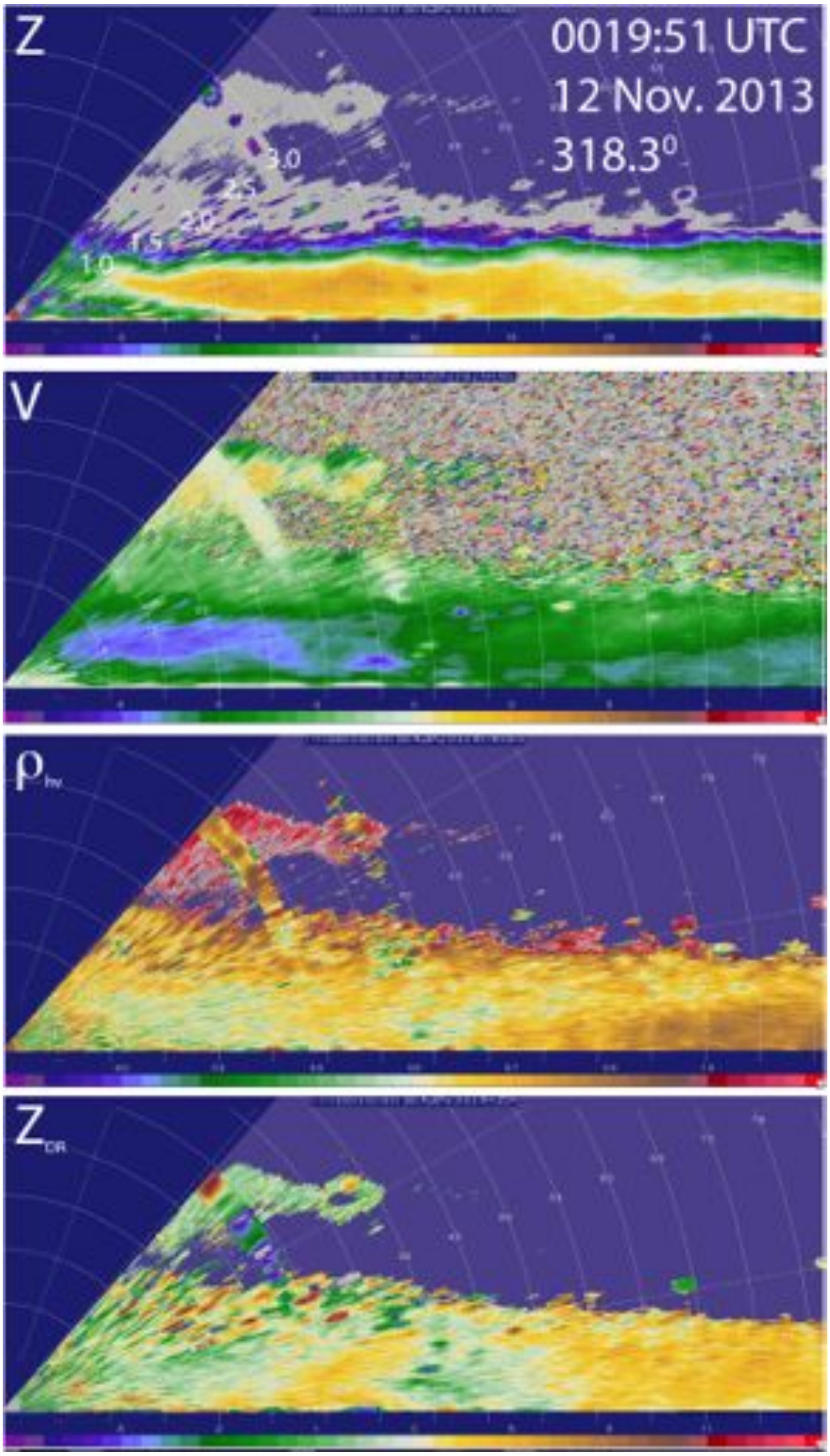

Figure 4: RHIs (vertical cross sections) from RaXPol through the prefrontal wind-shift line at 0019:51 UTC 12 Nov. 2013, looking to the northwest (318.3^0) from the radar site in Norman, Oklahoma, just before it passed by; (top panel) radar reflectivity factor Z (dBZ), (second panel) Doppler velocity V (m s^{-1}), (third panel) co-polar cross-correlation coefficient ρ_{hv}, (bottom panel/fourth panel) differential reflectivity (Z_{DR}). Range markers are shown every 0.5 km.

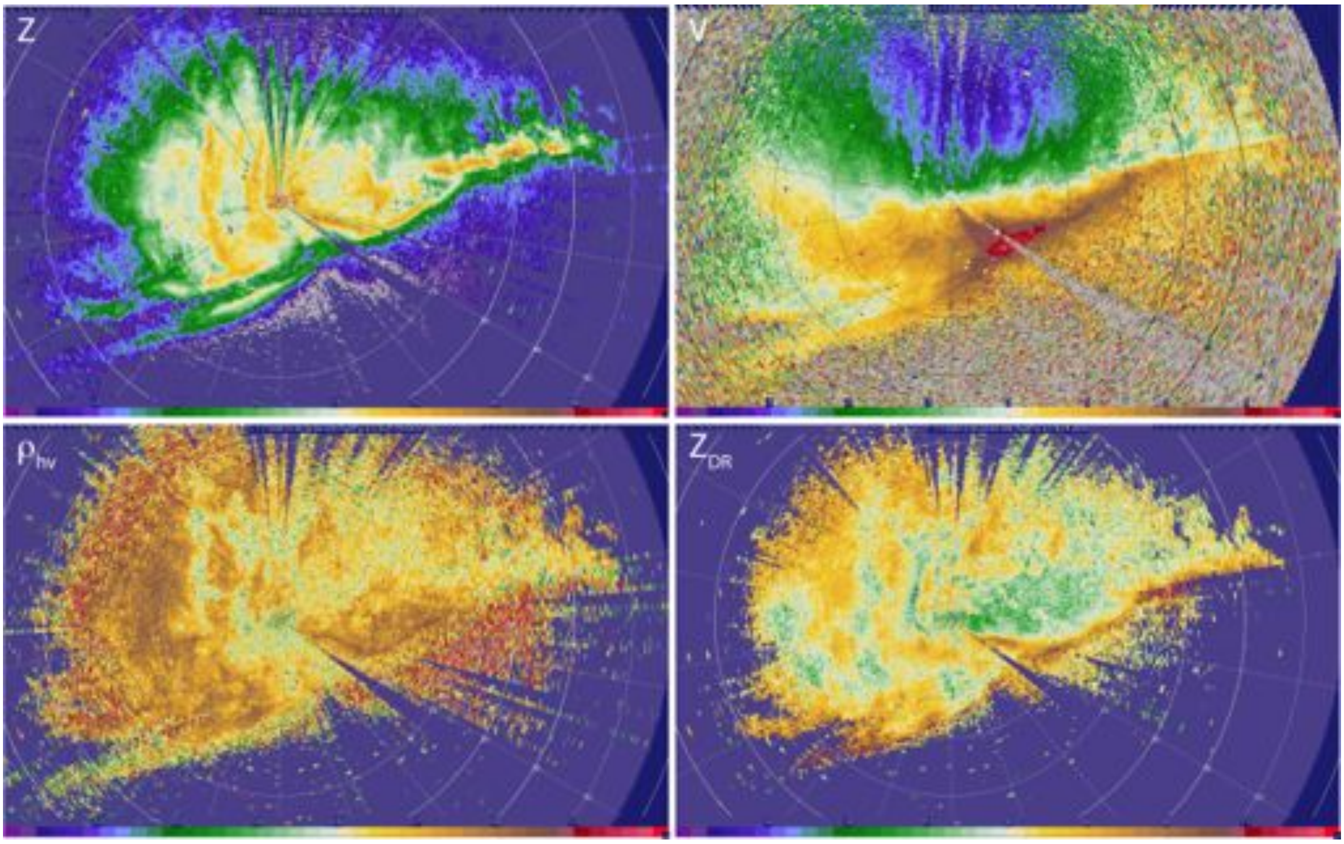

Figure 5: As in Fig. 3, but after the prefrontal wind-shift line had passed by the radar, at 0033:54 UTC 12 Nov. 2013.

Figs. 3 and 5 show the fine-scale radar reflectivity, Doppler velocity, and polarimetric fields associated with the prefrontal wind-shift line based on RaXPol data; Fig. 4 shows the vertical cross-section of these fields from an RHI (range-height indicator) cutting across the prefrontal wind-shift line. The fine line marks the prefrontal wind-shift line, along which there is radial convergence. No precipitation was reported or otherwise observed as the fine line passed by. It is postulated that the enhancement of reflectivity at the wind-shift line was caused to a large extent by insects, or birds feeding on insects caught in the convergence zone (Harper 1958), since at least in the southwestern portion of the line, the co-polar cross-correlation coefficient ρ_{hv} was relatively low, while the differential reflectivity Z_{DR} was relatively high (Mueller and Larkin 1985; Christian and Wakimoto 1989; Achtemeier 1991; Wilson et al. 1994; Martin and Shapiro 2007). From studies at S-band, it has been found that radar return from insects have higher Z_{DR} than birds, but radar return from birds have much higher differential phase than insects (Zhang et al. 2005a,b; Zrnić and Ryzhkov 1998). In addition, return from insects is associated with relatively high Z_{DR} when the radar beam is normal to the motion of the insects. If the insects are moving to the south-southeast along with the prefrontal wind-shift line, then Z_{DR} should be relatively high along the fine line, as is observed in Fig. 3 northwest of the radar and in 5 both south and east of the radar. Radar echoes from birds are often more granular appearing than radar echoes from insects.

From the vertical cross section (Fig. 4), it is noteworthy that there is an elevated jet with a southward component and an elevated zone of enhanced reflectivity. In most density currents, similar jets are not as elevated. From Fig. 2, recall that there was no significant temperature gradient at the surface, at the prefrontal wind-shift line. It is therefore hypothesized that this particular prefrontal wind-shift line behaved like an "intrusion" rather than a typical density current (Ungarish 2010) (Fig. 6).

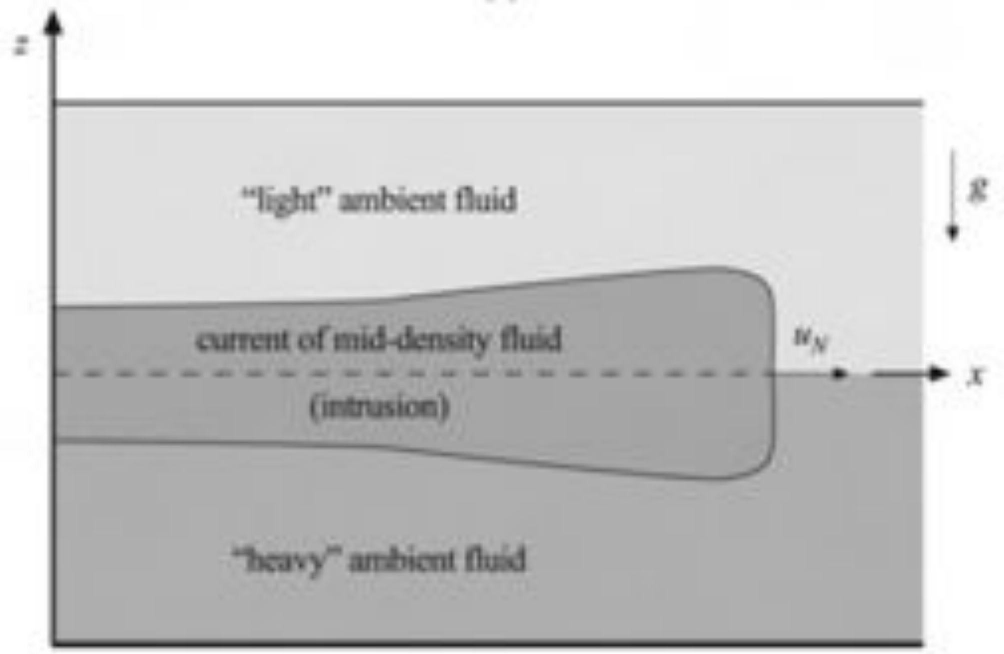

Figure 6: Idealized conceptual model of a gravity-current configuration in which there is an "intrusion" of a "mixed" fluid in a sharply stratified atmosphere (from Ungarish 2010, p. 6). U_N is the speed of the intrusion normal to its leading edge, in the +x direction.

More evidence supporting the lack of baroclinicity at the surface until the front passes by is found in Fig. 7, in which it is seen that there is little change in temperature when the surface wind direction changes near 0000 UTC as the prefrontal wind-shift line passes. However, several hours later the temperature suddenly falls more rapidly while the wind speed suddenly increases.

The sounding released before the prefrontal wind-shift line passed (Fig. 8) shows that near the surface the air is dry-adiabatically stratified, indicating substantial vertical mixing and/or surface heating. The AERI (Turner and Loehnert 2014) soundings show an elevated temperature gradient, but none at the surface, consistent with an intrusion (Fig. 6). The retrievals are valid for regions of both clear air and clouds. Most of the temperature fall occurred above ~ 250 m AGL. There may have been a brief temperature rise ~ 200 – 400 m AGL when the prefrontal wind-shift line passed by, but data were not available during the passage. If the temperature did indeed rise at this time, then it might have been a result of vertical mixing. *The in situ* measurement at the Oklahoma Mesonet site did not record any temperature rise at the prefrontal wind-shift line passed by, but there could have been a rise above the surface. The lowest cloud base dropped ~ 500 m after the passage of the prefrontal wind-shift line.

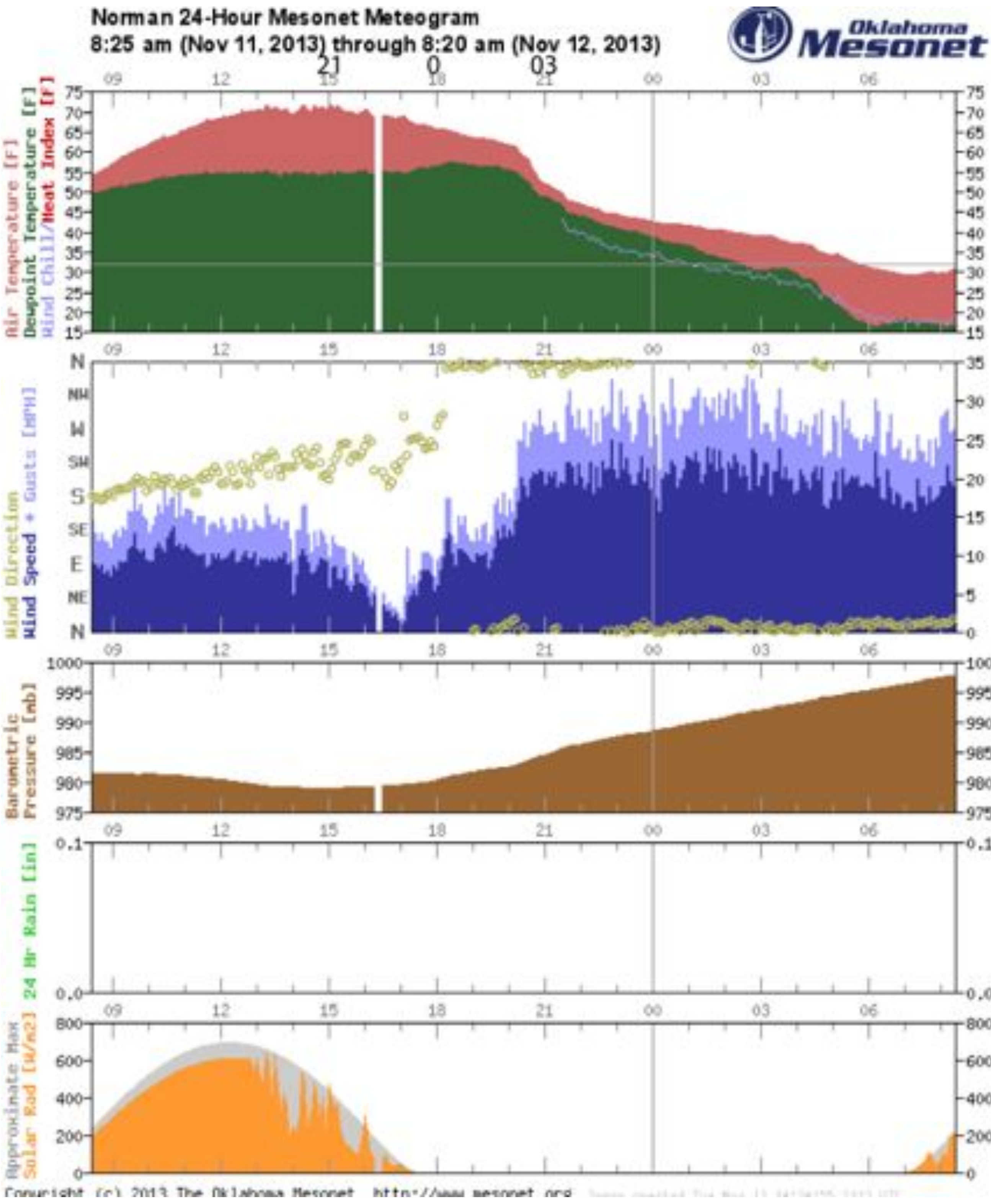

Figure 7: Meteogram from Norman, Oklahoma between 09 LST 11 Nov. 2013 and 12 LST 12 Nov. 2013. The prefrontal wind-shift line passed by the Oklahoma Mesonet site about 18 LST 11 Nov. 2013, or about 00 UTC 12 Nov. 2013 and the cold front passed by at about 20 LST, or about 02 UTC. The Mesonet site is located to the north-northwest of where the radar was located.

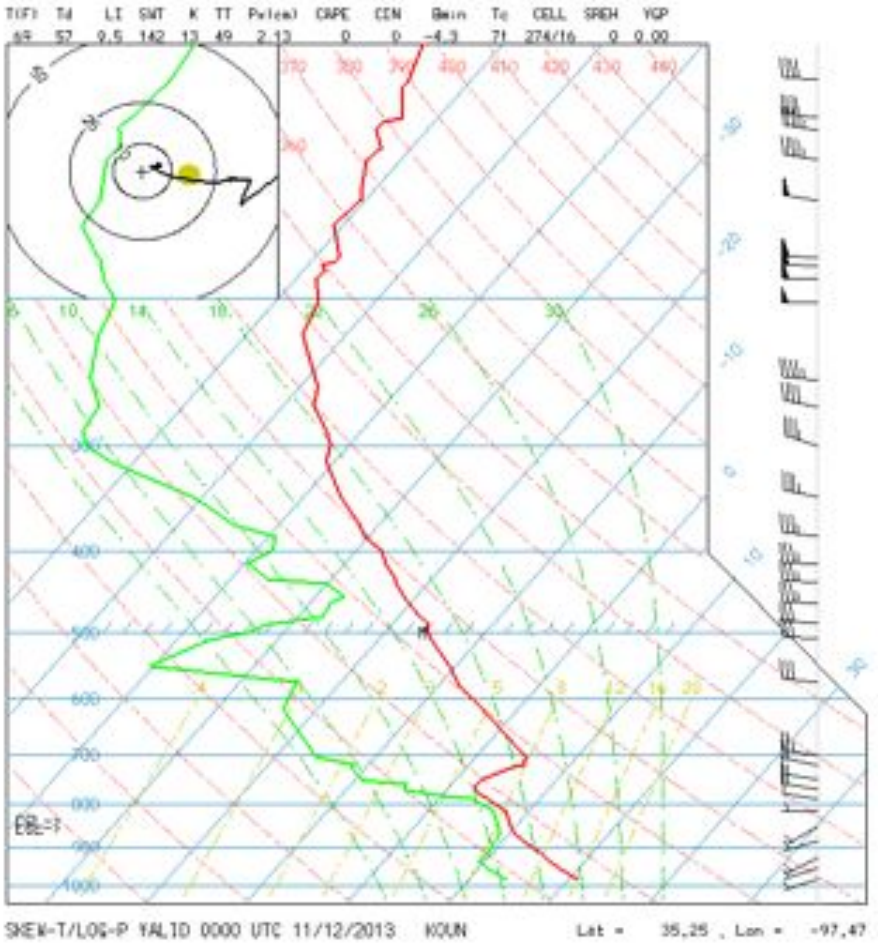

Figure 8: Sounding released at Norman, Oklahoma about 2315 UTC, before the prefrontal wind-shift line had passed by the rawinsonde site at the National Weather Center, which is located to the south of the Norman Mesonet site and west of where the radar was deployed.

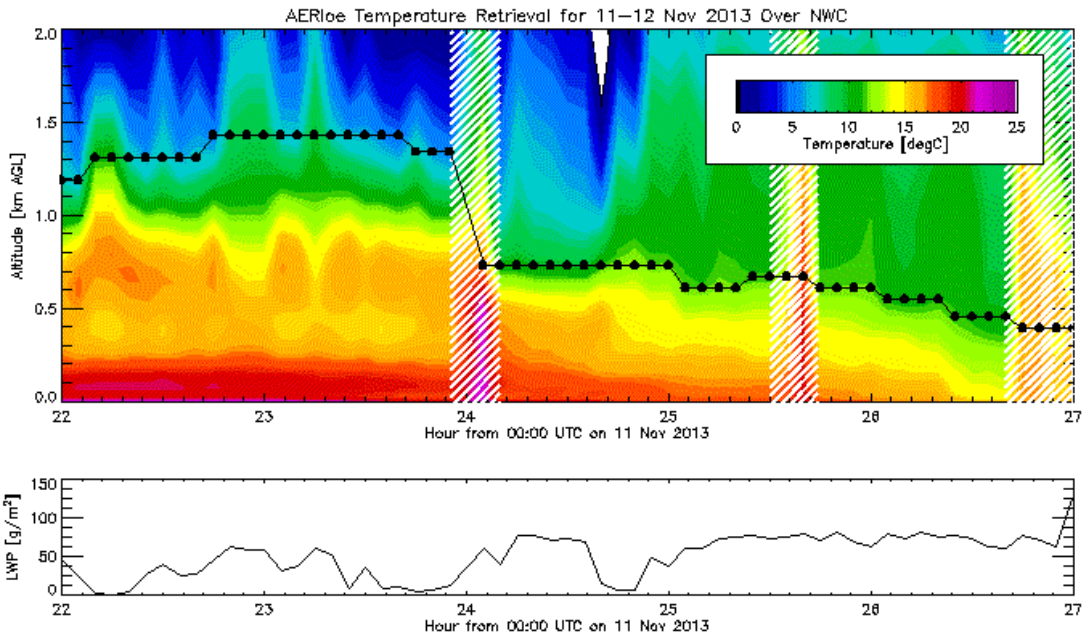

Figure 9: (top panel) AERI temperature as a function of height (km AGL) and time (hours from 0000 UTC on 11 Nov. 2013). The black line connecting the black dots represents the height of cloud base (km AGL) as a function of time. The white, hashed areas denote regions where the thermodynamic retrieval was not valid. (bottom panel) Liquid water path (g m^{-2}), the vertical integral of liquid water content from the surface to the top of the atmosphere, as a function of time

3 Summary and conclusions

It is believed that this study is the first attempt to further our understanding of the dynamics and structure of prefrontal wind-shift lines based on fine-scale measurements. The use of a high-resolution, mobile, polarimetric, Doppler radar and a thermodynamic profiling system are important components of such a study. Preliminary findings indicate that the prefrontal wind-shift line behaved like an intrusion, rather than a typical density current. Why this is so remains to be explained. In addition, the polarimetric data indicate that the fine line of enhanced reflectivity in the convergence zone is more likely caused by insects, which are typically associated with higher values of differential reflectivity, than by birds.

Acknowledgments

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