JP3J.7 **THE MOISTURE ROUTE OF PALO DURO CANYON**

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1. INTRODUCTION

Due to the significant discontinuity in elevation created by the "Caprock" Escarpment in west Texas, low-level moisture returning to that region under the influence of southeasterly flow potentially has significant interaction with that feature. The shape of the Caprock Escarpment in the central Texas panhandle is such that air confined to the lowest atmospheric levels would be "funneled" into the increasingly narrow cross-section of Palo Duro Canyon. Eventually, the air would reach the head of the canyon and lift over the escarpment, spreading onto the tabletop plains. Though the influence of the Caprock Escarpment on convective initiation is something that has interested storm chasers for decades, the problem needs further investigation for a wider variety of meteorological reasons (www.srh.noaa.gov/ama/paloduro/paloduro_front.htm). Since low-level moisture is one of the keys to other meteorological phenomena such as fog formation, it would be useful to have some indication that the idealized funneling situation described above indeed happens to some degree in the real atmosphere.

To scientifically address this issue, a vehicle-mounted mobile mesonet was employed. Measured parameters such as temperature, dewpoint, and wind speed and direction from inside the canyon could then be compared to those same parameters measured in locations outside the canyon. Figure 1 shows the regional topography, including Palo Duro Canyon.

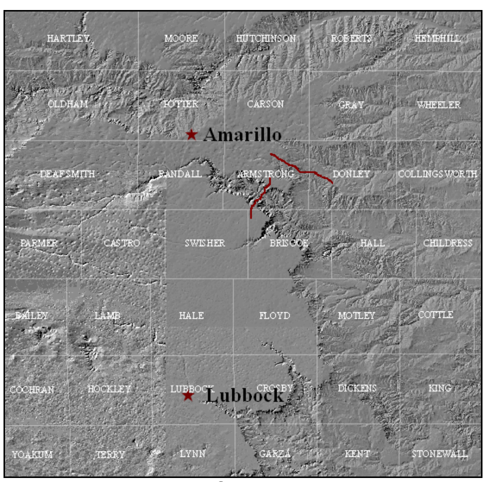

Figure 1. Topography of the Texas Panhandle. Palo Duro Canyon is just southeast of Amarillo in Randall, Armstrong, and Briscoe counties. Maroon lines are transect portions of Hwy 207 (inside canyon) and Hwy 287 (northeast of canyon).

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2. PREVIOUS WORK

Despite Palo Duro Canyon's potentially important role in local meteorology, there are few previous works that address the issue. Further, to the authors' knowledge there have been *no* attempts to take measurements inside the canyon. Gerbier (1961), while investigating lee waves in the French Alps, found that upward motion, an important factor for convection and convective initiation, is most enhanced when winds flow into a concave escarpment with a steep boundary. A multi-year Amarillo, TX radar climatology by Marshall (1980) revealed a maximum in convective activity on or near the Caprock Escarpment, with the southeastern portion of Palo Duro Canyon recording the highest number of radar echoes during the months of May and June (his Figure 10). This finding is consistent with Fankhauser (1971), who documented the lifecycle of a thunderstorm that formed on the Caprock just northeast of Palo Duro Canyon and attributed the storm's initiation to moist upslope flow along the escarpment.

Correspondence with forecasters at the National Weather Service in Amarillo, TX has indicated a suspicion amongst present-day operational meteorologists that the canyon is an important part of local weather. For example, one prominent meteorological feature in west Texas during spring time is the dryline. Eastward mixing of the dryline during the day is often a key factor in severe thunderstorm initiation. Figure 2 shows a satellite image from a day with an active dryline. From this image, one can see that the eastward propagation of the dryline has been slowed or even halted in the vicinity of Palo Duro Canyon in the Texas panhandle. A deeper moist convective boundary layer in the canyon could potentially cause this retardation, though this cannot be concluded from the image alone.

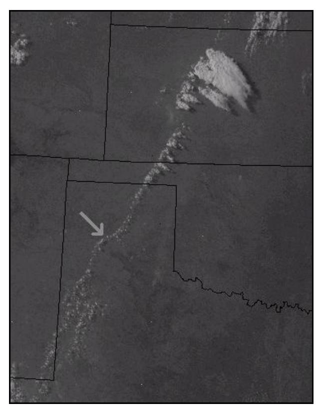

Figure 2. The eastward propagation of the dryline (indicated by the sharp line of clouds) is seemingly slowed in the vicinity of Palo Duro Canyon (indicated by arrow). Image courtesy of Robert Slattery, NWS Amarillo.

3. EXPERIMENTAL SETUP

The experimental design for this project centered on the mobile mesonet equipment owned and deployed by Texas Tech University. The mobile mesonet is a vehicle roof-mounted instrument package that, with an on-board data-logger, can be connected to an in-car laptop computer via serial port for real-time data monitoring. In addition, the real-time vehicle position is logged by the mobile mesonet station via the Global Positioning System (GPS) so that the mesonet data can be transposed onto a spatial grid. Real-time data were safely monitored during the project via a custom-made laptop stand. Even though the mesonet includes its own functioning GPS, this data stream is not easily monitored in real-time. Thus, the real-time vehicle position was monitored on a high-resolution map via personal GPS and commercially-available mapping software. Additionally, the authors noted key features in the data via a personal voice-recorder throughout the field experiment to facilitate data analysis and interpretation at later dates.

To obtain adequate spatial coverage and truly investigate the local effect of the canyon, transects of the canyon were performed continuously throughout the time period when moisture advection up the canyon was evident. Fortunately, Highway 207 provides almost a direct cross-section of the southeastern portion of the canyon. Thus, a 32 km section of Highway 207 that crossed directly through the canyon was the primary transect for data collection. In some cases, a secondary option to descend into the mouth of the canyon at Palo Duro Canyon State Park was exercised. These two routes were the only available passages for data collection inside the canyon.

4. DATA COLLECTION AND QUALITY CONTROL

Data collection was at a sampling rate of 0.5 Hz, or one measurement every two seconds. Preliminary results showed that moisture values exhibited high variance. To minimize variations between neighboring data points, a five, and in some cases ten-point moving average was applied as needed to the measurements. Due to electrical interference with the sensors, random spikes in the temperature and dewpoint measurements were noted. To minimize these false readings, values that were more than 3ºC higher than the previous reading (two seconds earlier) were overwritten with the previous value.

In the absence of large vehicle accelerations, one is able to calculate a “true” wind speed and direction through vector subtraction of the vehicle speed and heading from the measured wind speed and direction. To minimize false readings caused by vehicle acceleration, and to neglect wind measurements while the vehicle was stationary, wind measurements were disregarded at vehicle speeds less than 5.1 m/s, since the greatest accelerations usually occur below this speed. Stationary measurements were disregarded because, without a flux gate compass, the vehicle heading collected from the GPS unit was erroneous, resulting in false wind readings.

5. CASE STUDIES AND ANALYSIS

April 8, 2005

The first case considered is April 8, 2005. On this date, southeasterly winds advected moisture up the canyon axis. Though the wind pattern was desirable, the moisture gradient, and therefore the moisture advection, was very weak.

Cross-sections of the canyon were taken at 1500 UTC, 1600 UTC, 2000 UTC, and 2100 UTC. Dewpoint values in these four cross-sections are overlaid on an elevation trace of the canyon along Highway 207 (Figure 3). As expected, moisture levels are meager; however, a signal of increased moisture (as much as 2ºC) is found inside the canyon. A thick deck of clouds was present over the canyon during the morning hours. As the day progressed, these stratus clouds eroded, and the coherent moisture increase within the canyon was gradually counteracted by the effects of atmospheric mixing. Consequently, dewpoint values dropped through the afternoon. Another interesting feature of note is the minima in dewpoint at all times of day coinciding with the steepest north and south-facing slopes of the canyon rim. In addition, moisture values on the north rim plains are consistently lower than values on the southern rim plains.

Throughout the experiment, temperature measurements were found to have much lower variance than dewpoint, as evident by comparing Figure 3 to Figure 4. Also, during the morning hours, there were several locations where temperature was seemingly discontinuous, one approximately correlating with the Prairie Dog Town Fork of the Red River at the base of the canyon, and one correlating with the south rim of the canyon. In addition, temperature trends across the canyon were found to completely reverse in just one hour, with the 2000 UTC transect depicting warmer temperatures on the north canyon wall and the 2100 UTC transect depicting warmer temperatures on the south canyon wall. The cause of these temperature trends is unclear, and does not completely agree with the theories of Marshall (1980), who hypothesized that additional heating on southward-facing canyon walls force higher temperatures, a cross-canyon breeze, and upward motion on the north rim of the canyon.

Throughout the day, wind direction both in and out of the canyon was generally south-southeasterly. Wind speeds (not shown) inside the canyon were consistently lower than that found on the rim plains, so an argument of increased moisture advection based on the wind speed trends alone would not necessarily hold. In the weeks following the first data collection period, a more typical spring-like pattern began to be established over the southern plains. Large-scale southeasterly flow allowed for very gradual moisture return northwestward into the Texas panhandle and eastern New Mexico, and drylines eventually became established on a near-daily basis near the Texas - New

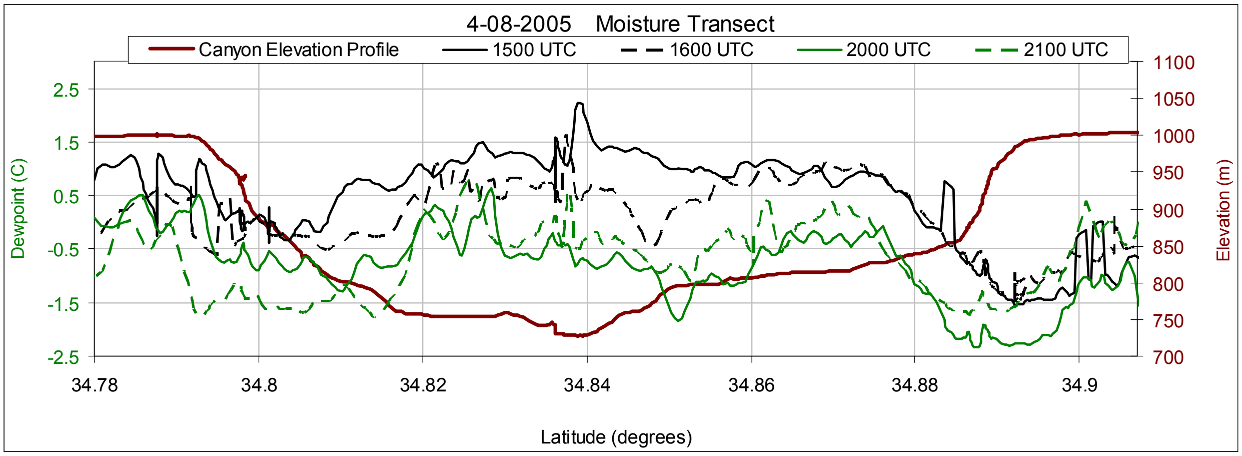

Figure 3. Five-point moving averages of dewpoint on four transects. April 08, 2005.

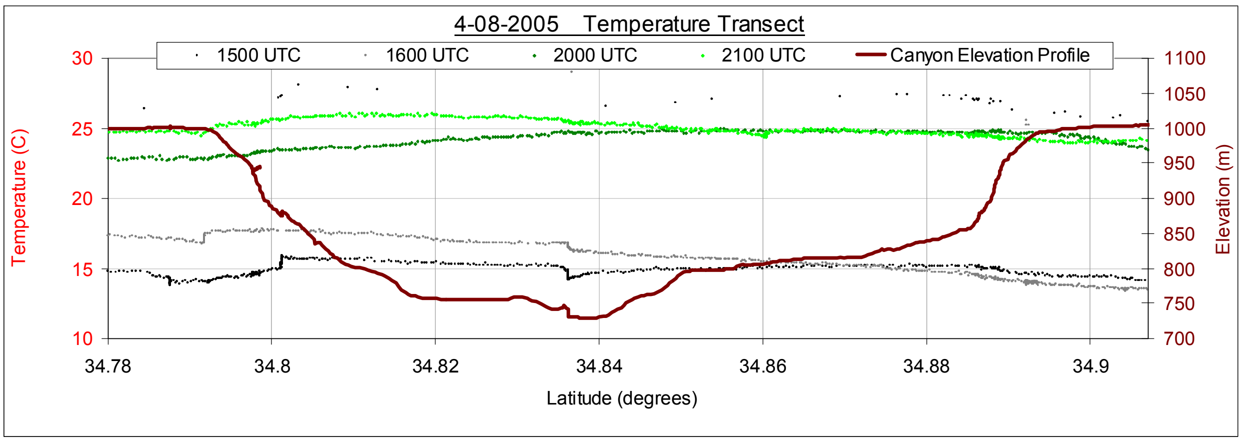

Figure 4. Temperature values on four transects. April 08, 2005.

Mexico border. It is widely known that the dryline can be a very prominent feature in west Texas meteorology, with often very large gradients in boundary-layer moisture over short distances across this boundary. Due to the diurnal cycle of vertical mixing, this feature regularly advances eastward during the daytime hours and retreats westward during the night.

April 19-20, 2005

On April 19, the dryline had advanced eastward off the Caprock Escarpment and east of Palo Duro Canyon by 2345 UTC. Westward retreat through the canyon was anticipated through the remainder of the evening.

Transects of the canyon began at 0030 UTC , just before sunset, and were repeated at 0145 UTC, 0300 UTC, 0600 UTC, 0700 UTC, and 0800 UTC (Figure 5). In the initial transect (0030 UTC), before dryline retrogression through the canyon, there appeared to be no coherent increase in moisture inside the canyon. In fact, the moisture there was lower than on the southern rim plains. In the time before the next transect, nearly an hour was spent on the north rim plains taking stationary wind measurements. During this time, the winds clearly backed from southwesterly (typical of the dry side of the dryline) to southeasterly (typical of the moist side of the dryline), the wind speeds nearly doubled, and the dewpoint increased by about 1ºC.

The next transect, which was centered on 0145 UTC, shows a marked increase in moisture inside the canyon. During this transect, the dewpoint was measured to be approximately 8ºC higher in the canyon than on the northern rim plains where the transect began. Inside the canyon, the dewpoint had risen nearly 6ºC since the last transect, only one hour and fifteen minutes prior. On the southern rim plains, the dewpoints were again higher than those on the northern rim plains; however those values were still lower than those found at the in-canyon maximum.

This significant local in-canyon maximum was substantiated by a third cross-section temporally centered on 0300 UTC. At this time, the moisture maximum in the canyon was still clear, but the moisture on both the north and south rim plains had not begun to increase much at all, contrary to what one would expect if the dryline had truly passed to the west, as the wind field (everywhere) and moisture (in the canyon) were indicating. Transects were later performed east of the canyon to find the location of dewpoints comparable to those found in the canyon. Two transects of the dryline on Hwy 287 (Figure 1) were performed, with the dewpoint discontinuity found to be between Claude and Clarendon, TX (Figure 6).

Interestingly, Figure 6 shows that the dewpoint gradient seems to tighten up and stop its westward propagation along the steepest terrain, despite the fact that along Highway 287 the elevation change of the Caprock Escarpment is much less pronounced than areas further south. Also, the wind shift typically associated with the dewpoint discontinuity of the dryline had continued propagating westward of the moisture gradient. This observation was consistent with the wind shift and limited dewpoint increase measured on the north canyon rim.

Returning to the canyon, three more canyon transects were performed between approximately 0600 UTC and 0800 UTC. Results are shown in Figure 7.

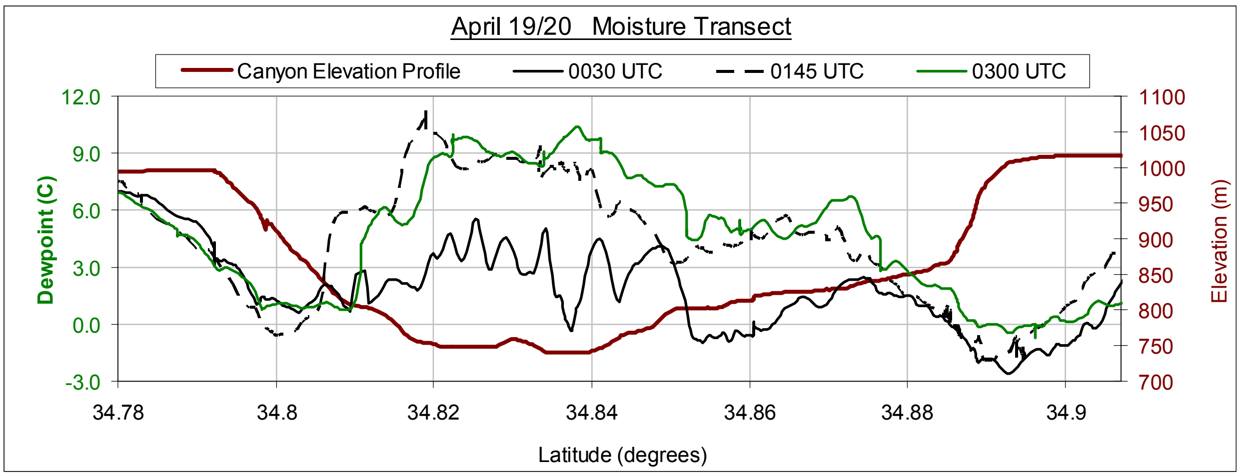

Figure 5. Five-point moving averages of moisture values on the first three transects of April 19-20, 2005.

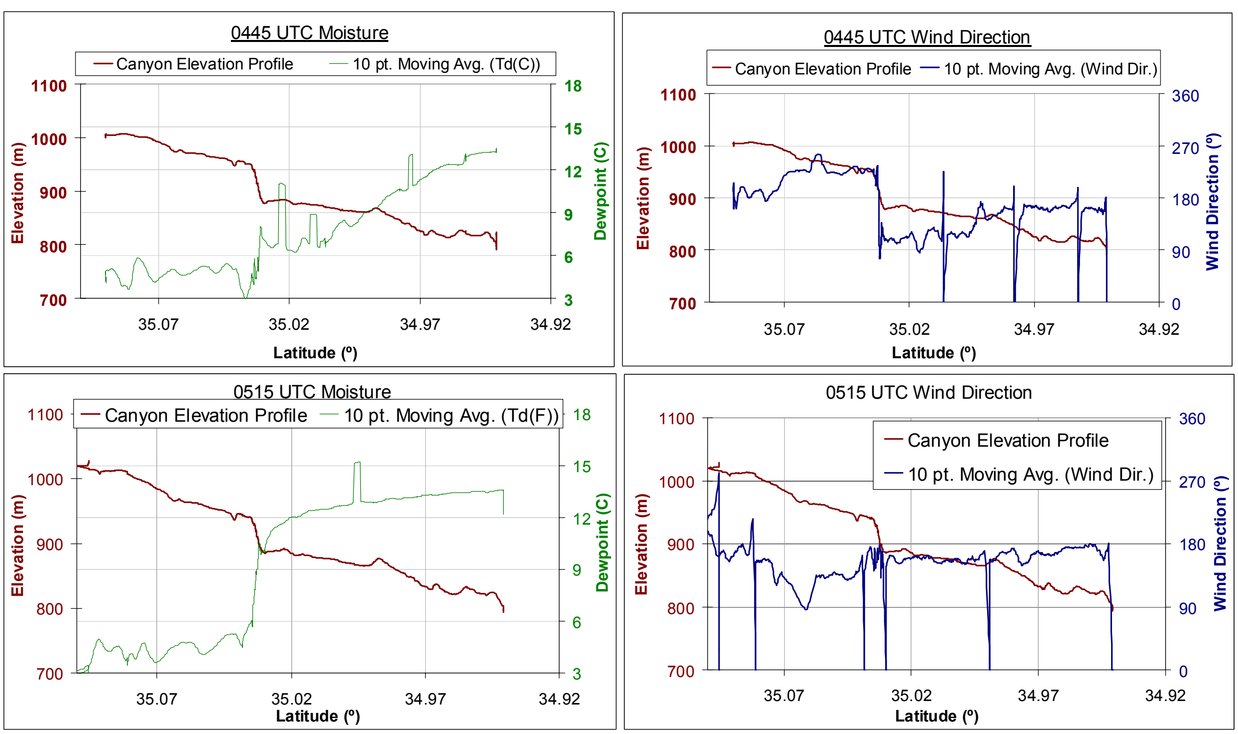

Figure 6. Dewpoint vs. elevation (left) and wind direction vs. elevation (right) on first (top figures, 0445 UTC) and second (bottom figures, 0515 UTC) dryline transect, April 19-20, 2005.

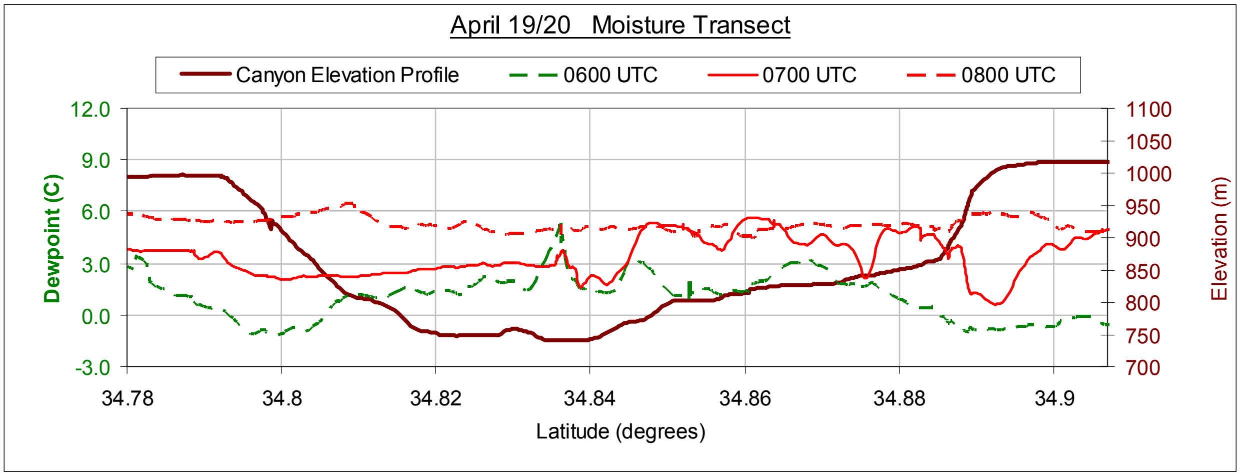

Figure 7. Five-point moving averages of moisture values on the last three transects of April 19-20, 2005.

The dewpoint maximum within the canyon had completely disappeared by these times. The wind fields provide no insight into the rapid reduction in dewpoint in the canyon.

Figure 8 shows surface wind vectors from the mobile mesonet from five transects of the canyon, spanning the time of appearance and disappearance of the high moisture values. Note in Figure 8a that the winds are southwesterly both inside the canyon and out, indicative of typical conditions on the dry side of the dryline. However, in the next transect and throughout the rest of the data collection period, winds inside the canyon turn mostly southeasterly, indicative of the moist airmass impinging upon the canyon. Meanwhile, winds outside the canyon maintain a westerly component. Oddly, the southeasterly winds inside the canyon persist after the moisture maximum disappears (Figure 8d,e). If the winds in the canyon had been found to shift back to the southwest, an argument could be made that the moist airmass penetrated the canyon and then quickly retreated. However, this does not appear to be the case, and the wind field does not explain why the elevation of dewpoint values inside the canyon is only temporary.

Of additional note from the transects is the continuation of pronounced local minima in dewpoint at both the north and south canyon wall. Interestingly, this feature, which had been present in all April 8 transects (Figure 3), continued to be present in the April 19-20 transects until just after midnight (Figures 5, 7). The dewpoint field became nearly homogeneous across the domain due to increased moisture advection from the southwest, where the dryline had retreated more rapidly and yielded a source for southwesterly moisture advection by the nocturnal low-level jet.

Temperature traces from April 19-20 (Figure 9) show discontinuities similar to those found on April 8 (Figure 4). However, the discontinuities were much more pronounced for this case, at times more than a 3ºC increase in just a few hundred meters. These microscale discontinuities, which in this case were present in every post-sunset transect, are not local maxima or minima, but near-discontinuities between regions of nearly constant temperature. It was verified that these features were not caused by instrument error, as they were not present in any data taken outside the canyon.

Finally, just before sunset (0030 UTC transect) temperatures at the north rim wall were nearly 2.8ºC warmer than those at the southern rim, a finding consistent with the hypotheses of Marshall (1980).

6. CONCLUSION

The role of Palo Duro Canyon as a mechanism for moisture concentration and a route for moisture transportation in West Texas has been investigated in two distinct meteorological cases. Each case showed evidence that higher quantities of moisture can be found inside the canyon, but the sample set is too small at this point to make conclusions with confidence. Hopefully, this work will be a solid foundation for future study, perhaps involving additional observing platforms to compliment the mobile mesonet.

7. ACKNOWLEDGEMENTS

Many thanks to those already involved in collaboration, including Robert Slattery, Jason Jordan, Matthew Kramar, and Roland Nunez from the NWS Amarillo, and Rolando Vega from the Texas Tech Wind Science and Engineering Research Center. Thanks to Dr. Doug Smith for providing additional funding for research equipment, and to Dr. John Schroeder and Brian Hirth for allowing use of the mobile mesonet equipment. This work is made possible through funding provided by the NSF to the IGERT program at the Texas Tech University Wind Science and Engineering Research Center.

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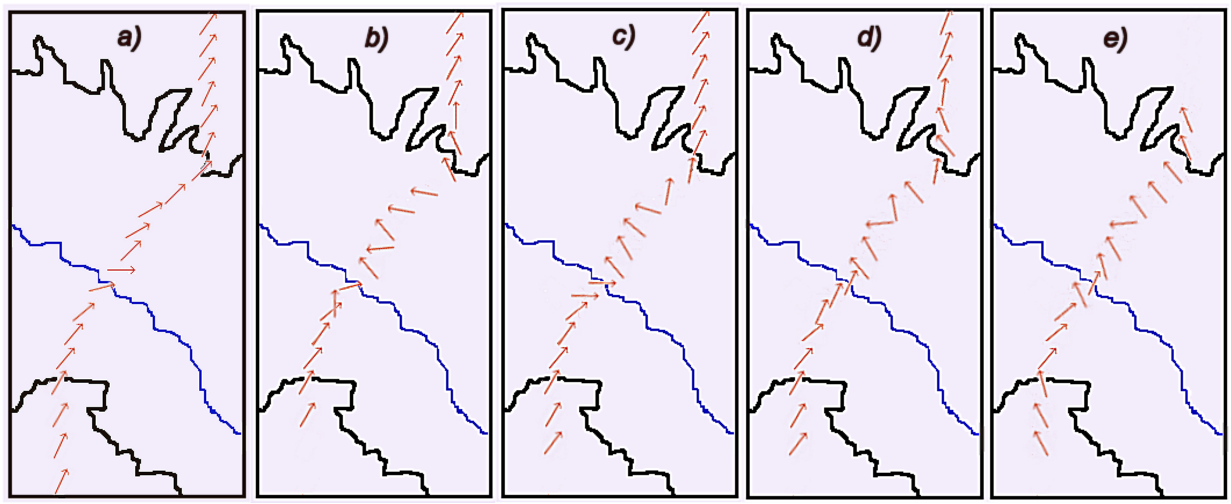

Figure 8. Measured wind direction throughout the canyon at a) 0030 UTC, b) 0145 UTC, c) 0300 UTC, d) 0600 UTC, and e) 0700 UTC on April 19-20. Black line represents approximate location of caprock; blue line represents the Prairie Dog Town Fork of the Red River.

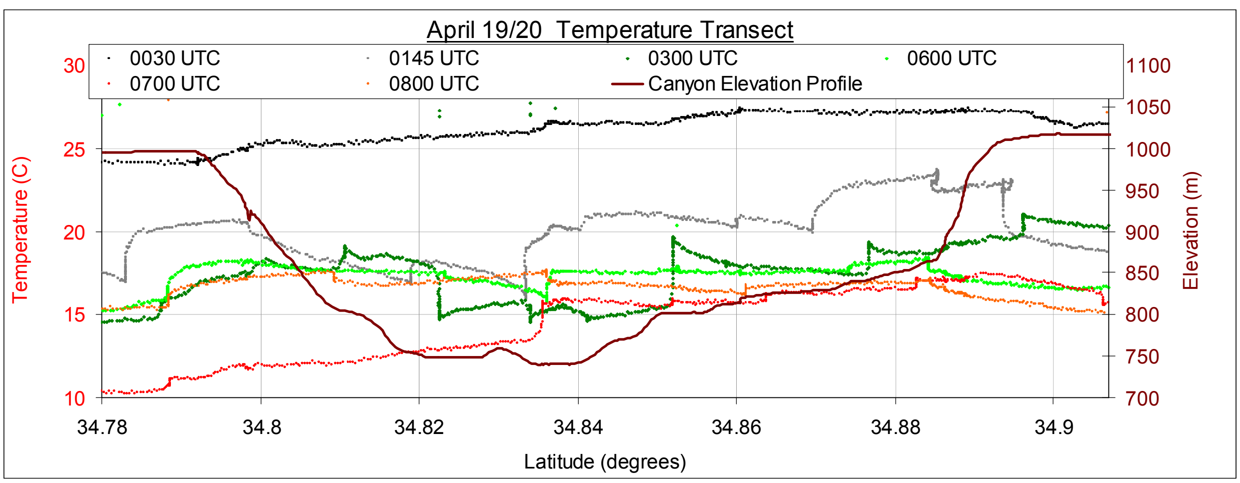

Figure 9. Temperature values on six transects. April 19-20, 2005.