CHAPTER 7
SUMMARY AND CONCLUSIONS

7.1 Summary

An experiment was designed whereby many meteorological properties of the high plains dryline were observed. Instrumented 10-meter towers of the WTXM, as well as several portable towers and two NWS towers were utilized to establish a high resolution field network of observing stations. Data was collected from these stations during April and May 2002. A catalogue of the observations (shown in Appendix B) shows that several drylines translated through the experimental domain during this period. A detailed analysis was performed on the data to produce objective fields of parameters such as mixing ratio, divergence, advection and others. The analysis was then divided into two major case studies, each consisting of a period of several days where there was a nearly continuous oscillation of the dryline within the domain. Mean and variances were computed to explore differences in the parameters between the dryline and the surrounding environment, and between advancing and retreating segments of the dryline.

In some instances, observations of the dryline were also conducted by mobile mesonets. These data provided information at resolutions on the order of 100-1000 meters. Cross-dryline profiles of dewpoint, virtual and potential temperature and wind were shown from these transects and the results were in general agreement to those found by similar mobile mesonet studies (e.g., Pietrycha and Rasmussen, 2004).
Three-dimensional mesoscale model simulations were performed on each case. Two models were employed, the PSU/NCAR MM5 and the CSU/ATMET RAMS. Each model run was set up in a similar fashion, using a nested grid centered over the field experiment domain, initialized from the NECP ETA analysis fields, and used the same horizontal and vertical resolution. The forecast model fields were interpolated to the gridded observational fields, and compared using statistics such as root mean square error and the Kuiper skill score.

7.2 Conclusions

An analysis of the data shows that six complete dryline cycles (including advancing, retreating and stationary segments) were sampled in this experiment. Table 7.1 presents a summary of these drylines partitioned by segment type. This compilation of dryline data provides insights into the structure and evolution of the quiescent dryline that are only available through the utilization of a mesoscale observation network for dryline investigations. The approximately 30 kilometer spacing of the mesonetwork is less than half of the median 78 kilometer spacing of the NWS surface observing network (Morris and Janish, 1996). This spacing allowed for the identification of dryline properties such as orientation, translation speed, acceleration/deceleration, and quasi-stationary oscillations that would likely not be apparent in coarser resolution data.

Perhaps most importantly, the results demonstrate that the quiescent dryline can be accurately and objectively identified and tracked by the algorithm described in Appendix F. The following sections highlight the significant findings from the analysis.
TABLE 7.1  Summary of dryline motion observed within the domain and the subjectively analyzed average cross-dryline moisture gradient (QS – quasi-stationary). Some segments do not incorporate the entire range of dryline motion because the dryline passed outside of the domain.

<table>
<thead>
<tr>
<th>Dryline Segment</th>
<th>Motion type</th>
<th>Starting time</th>
<th>Ending time</th>
<th># of hours</th>
<th>Mixing ratio gradient (g kg$^{-1}$ 100 km$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Advancing</td>
<td>16 UTC / 11 CDT</td>
<td>19 UTC / 14 CDT</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Retreating</td>
<td>04 UTC / 23 CDT</td>
<td>10 UTC / 05 CDT</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
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<td>10 UTC / 05 CDT</td>
<td>14 UTC / 09 CDT</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>Advancing</td>
<td>14 UTC / 09 CDT</td>
<td>18 UTC / 13 CDT</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Retreating</td>
<td>11 UTC / 06 CDT</td>
<td>16 UTC / 11 CDT</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
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<td>16 UTC / 11 CDT</td>
<td>19 UTC / 14 CDT</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>Advancing</td>
<td>19 UTC / 14 CDT</td>
<td>22 UTC / 17 CDT</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>QS</td>
<td>22 UTC / 17 CDT</td>
<td>01 UTC / 20 CDT</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>Retreating</td>
<td>01 UTC / 20 CDT</td>
<td>08 UTC / 03 CDT</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
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<td>08 UTC / 03 CDT</td>
<td>14 UTC / 09 CDT</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>11</td>
<td>Advancing</td>
<td>14 UTC / 09 CDT</td>
<td>19 UTC / 14 CDT</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
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<td>19 UTC / 14 CDT</td>
<td>21 UTC / 16 CDT</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>13</td>
<td>Retreating</td>
<td>21 UTC / 16 CDT</td>
<td>06 UTC / 01 CDT</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>14</td>
<td>Advancing</td>
<td>15 UTC / 10 CDT</td>
<td>21 UTC / 16 CDT</td>
<td>6</td>
<td>10</td>
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<td>15</td>
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<td>18</td>
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<td>17 UTC / 12 CDT</td>
<td>23 UTC / 18 CDT</td>
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<td>19</td>
<td>Retreating</td>
<td>01 UTC / 20 CDT</td>
<td>10 UTC / 05 CDT</td>
<td>9</td>
<td>11</td>
</tr>
</tbody>
</table>
7.2.1 Case study results

Some results of the analyses that lend potentially greater understanding of the structure of the quiescent dryline include:

1. The dryline can be accurately and objectively identified by a combination of a range of values of the mixing ratio along with a diagnosis of the moisture gradient and advection. This dryline zone is by definition two to three grid points (20-30 km) in the east-west (or northwest to southeast in the case of the retreating dryline) direction;

2. The region associated with the identified dryline zone exhibits significantly greater mean values of moisture and mass convergence, moisture advection, and moisture gradient than the surrounding environment. The coefficients of variation of the variables also support the distinction of the dryline zone as they are significantly lower than those of the surrounding environment;

3. Several properties of the retreating dryline differ consistently and significantly from the advancing dryline segments. Moisture convergence was two to three times greater and moisture advection was approximately 1.6 times greater when associated with the retreating dryline. As repeatedly seen in the five-minute time series plots of dewpoint temperature and winds, the retreating dryline is characterized by more rapid moisture and wind direction changes at the surface than the advancing dryline. The values of mass convergence and the moisture gradient were roughly similar. Thunderstorm climatology shows that the larger values of moisture convergence and advection in association with the retreating
dryline do not relate to relatively more convective development than with the advancing dryline. Two reasons are postulated for this characteristic. First, as noted in Parsons et al (2000), the vertical slope of the retreating dryline is smaller than that of the advancing dryline. Thus it has smaller vertical motions at the dryline interface. Deep lifting of moist air is considered a necessary condition for convective development in the dryline environment. Secondly, the development of the nocturnal inversion can produce a stronger “cap” to potential convective development than was present during the day. Together, these two effects are usually sufficient to prevent lifted air parcels from reaching the LFC;

4. The data documents the distinct differences in the air mass properties on each side of the dryline, particularly in terms of moisture. The difference in dewpoint/mixing ratio was often 15 to 20 °C /4 to 9 g kg$^{-1}$ and sometimes as large as 28 °C /13 g kg$^{-1}$;

5. In the two cases examined, the quiescent drylines were determined to have similar values of the properties listed in #2. Minor differences in the observed fields and differences in dryline evolution are postulated to occur through interaction with the synoptic-scale mass and moisture fields;

6. The evolution of the drylines occurred in a similar fashion in all cycles/cases. The dryline generally moved eastward during the late morning, sometimes in discrete steps. Convergence along the advancing dryline was not large, due in part to a lack of wind confluence along the dryline. As the dryline moved into
the eastern half of the domain, it usually decelerated and often became quasi-
stationary during the late afternoon. This deceleration is attributed to the
cumulative effect of the deeper moisture profile to the east and the isallobaric
response of the wind field to the diurnal trend of lowering surface pressure over
the higher terrain to the west. Moisture convergence along the dryline typically
increases during this period. Near (but always before) the time of local sunset,
the dryline retreats westward. The retreat shows a more consistent nature with
respect to speed and moisture gradient than is shown with the advancing
dryline. Table 7.1 highlights the temporal details of the observed dryline motion
and examination reveals significant variety in the individual segments;

7. A graph of each dryline segment summarized in Table 7.1 reveals several
important characteristics of each segment (Figure 7.1). The graph shows that
the advancing segments are generally of shorter duration than retreating
segments (6.8 hours versus 8.67 hours on average). Quasi-stationary segments
show the most variation in duration. Quasi-stationary segments in the morning
are generally longer than those in the afternoon. The fact that the first two
advancing drylines in Case One went farther east than the others may be related
to a greater westerly wind component at 850 hPa as evidenced by the 12 UTC
Midland soundings (refer to Figures 4.1b and 4.2b). It is noted that the precise
evolution of several advancing cases are incomplete due to the diurnal
oscillation carrying the dryline beyond the study area (specifically, segments
“A1”, “A4”, and “A18”), thus their total duration was estimated.
Figure 7.1 Graph of the duration of dryline segments in relation to local time of day (CDT equals UTC minus five hours). The shaded region represents the nighttime hours. Approximate average sunrise and sunset times for both cases are 7:00 a.m. CDT and 8:30 p.m. CDT respectively. The advancing dryline segment is indicated by the red line with crosses. The retreating segment is indicated by a blue line with circles. The quasi-stationary segment is indicated by a plain black line. The “A”, “R”, and “S” refer to advancing, retreating, and quasi-stationary segments respectively. Please refer to Table 7.1 for more information on each segment.
8. The mesoscale analysis highlights the existence of discontinuous, multiple steps of moisture decrease in conjunction with the advancing dryline. This corroborates previous research such as Hane (2003) and Weiss et al. (2004);

9. In general terms this work lent a degree of validation of current conceptual models of the dryline. The mechanisms for dryline propagation, widely attributed to vertical turbulent mixing for the advancing dryline and a combination of rapid stabilization of the boundary layer west of the dryline after the loss of insolation and the westward component of wind along and east of the dryline associated with the low-level jet, are both at least partially corroborated by the behavior shown by drylines in this experiment;

10. Mobile mesonet observations documented cross-dryline gradients of moisture on the order of 8 °C/200 meters. The results compare favorably with the maximum gradient observed by Pietrycha and Rasmussen (2004) of 10 °C/185 meters. Little evidence of a virtual temperature gradient was found. High frequency (5- to 10-minute) oscillations were evident in the data, however no attempt was made to discover the qualities or mechanisms for these oscillations.

7.2.2 Model results

1. Initial model fields, created by interpolating the ETA model analysis, accurately reflected the state of the atmosphere at the beginning of the simulations;

2. The accuracy of both the MM5 and RAMS forecast positions of the dryline decreased considerably after the first 12-18 hours;
3. The MM5 model, while failing to predict the precise temporal evolution of the dryline, was successful in predicting the trend of the dryline oscillation through the domain more accurately than the RAMS model. In both cases, the MM5 mixed the second dryline cycle eastward too quickly during the late morning hours. The MM5 also stopped the eastward advance and started the westward retreat in the evening too quickly. In case study one, the MM5 did not accurately portray the extent of the westward retreat of the dryline while in case two, the MM5 brought the retreating dryline back too far west;

4. In case one, the MM5 underforecast the magnitude of the moisture return associated with the retreating dryline by 2-5 g kg\(^{-1}\). In case two, the difference between the model forecast and observations was negligible;

5. In both case studies, the RAMS model significantly overforecast the eastward displacement of the advancing dryline and underforecast the strength and duration of the moisture return associated with the retreating dryline;

6. Comparisons of potential temperature showed that the RAMS did not predict the evening northwest to southeast temperature gradient manifested in the observations. Since the uneven heating reflected by this gradient causes an isallobaric wind that plays an important role in retarding the eastward progression of the dryline, this deficiency partially explains why the RAMS poorly simulated the dryline’s retreat. The MM5 more accurately depicts the temperature gradient but in case two is too cool at 0 UTC. This inaccuracy
coincided with an overestimate of the amount of surface moisture across the domain.

7. Model predictions of station pressure were compared with the observations and showed a distinct tendency to exaggerate the pressure gradient along the Caprock Escarpment. This is most likely due to the utilization of terrain-following vertical coordinates in the simulations that introduce inaccuracies in the vicinity of large elevation gradients. Increasing the vertical resolution in the lowest model levels may help to mitigate this error;

8. In case study two, in which the environment was characterized by having greater low-level moisture, both models showed slightly more skill with the dryline forecast than with the first case. Atmospheric wind profile differences obviously existed in each case, which are hypothesized to have a large influence on the forecasted dryline motion;

9. Some of the procedures used in this study to compare mesoscale model forecasts with real world observations may prove useful in future studies. In particular, the establishment of a matching observation and model objective analysis field allows for direct comparison of a wide variety of meteorological parameters and derived fields.

7.3 Recommendations

This work has resulted in the establishment of some benchmark values for certain meteorological parameters associated with drylines at this scale. Since the WTXM is
almost certainly to be utilized for future dryline studies, comparisons with these results may be of benefit. Future studies may also benefit from the following specific recommendations:

1. A primary deficiency of this dataset is the lack of data above the 10-meter AGL level outside of model output and the upper-air observations at Amarillo and Midland. This deficiency effectively limited the analysis of the dryline to within (or close to) the surface layer, without examining potentially important variations in dryline structure that occur as the boundary layer evolves between the stable nocturnal boundary layer and the daytime convectively mixed layer. A sequence of meteorological soundings as well as Doppler radar, lidar and other remote sensing technologies may be utilized during dryline passage to investigate the differences in vertical structure between the advancing and retreating drylines;

2. A mesoscale climatology of the dryline, partitioned into active and quiescent events, using the five minute observations from the West Texas Mesonet should be undertaken;

3. Many of the results obtained for the quiescent dryline are not expected to hold true for the synoptically-active dryline. A companion study to investigate comparative statistics for the active dryline is suggested;

4. An examination of the relative vorticity field would be useful to investigate areas of upward motion along the dryline and the link to convective development;

5. A dense network of observing stations with high temporal resolution may be used to conduct research on the properties of along-dryline waves. Additionally, the
Richter and Hane (2004) hypothesis that the downdraft portion of horizontal convective rolls intersecting the dryline may be the source of dryline waves should be investigated.

6. A dense array of stations, positioned along a Caprock Escarpment, may help to understand the role this topographic feature plays in dryline evolution.

7. Given the hypothesis that discontinuous dryline steps are related to differences in surface heating, an experiment may be designed to relate surface fluxes to mixed layer growth.

8. This study suggests that increased horizontal resolution of a model is not sufficient to increase the accuracy of dryline forecasts. An experiment might be designed to investigate how the forecast skill varies with horizontal resolution.

9. There is a wide array of options in configuration of numerical simulations that can be used in conjunction with dryline investigations. These can be divided into three main areas: land-air interaction, model resolution, and model physics.

    Land-air interactions include: soil models, land-surface models, topography resolution, land-use, vegetation types and moisture. One might also include parameterizations of the surface and boundary layers, such as albedo, aerodynamic roughness length and surface fluxes. This study used simple land-air schemes and high-resolution topography in the inner grid. Certainly, more sophisticated land-air schemes might have a strong influence on forecast dryline evolution.
While this study used high horizontal resolution, it used a typical vertical resolution. The settings for both models roughly corresponded to a 10 hPa resolution in the boundary layer, decreasing to near 50 hPa at higher altitudes. Both the RAMS and the MM5 are capable of higher vertical resolution. Higher resolution, particularly close to the surface, should provide better results.

There are many different options for model physics, ranging from PBL and radiation schemes to precipitation physics and cumulus parameterization schemes. Evaluating the merits of any combination of options was beyond the scope of this work and certainly a prospective avenue for future study.

Finally, future modeling work should also concentrate on the potential of observation nudging using the WTXM. Both models have the capability to perform four-dimensional data assimilation (FDDA). Chang and Conder (2004) conducted FDDA experiments using the MM5 and WTXM data. Their preliminary results showed little impact on the mass and moisture forecast fields, but further studies are encouraged.