An Airborne Raman Lidar and Modeling Study of a Dryline and Convection Initiation Over the High Plains of Southeast Wyoming

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Drylines in Southeast Wyoming

Typically considered a Southern Great Plains (SGP) phenomenon, drylines are frequently associated with the initiation of deep convection during the spring and early summer months. Thunderstorms that form along a dryline often become severe and occasionally produce tornadoes. Various processes have been identified as playing some role in the movement and stength of drylines. However, clear explanations of the mechanisms responsible for convection initiation along drylines remain elusive.

Drylines have been observed in other parts of the world as well, albeit much less frequently than those in the SGP. A recent study, presented here, offers evidence of the first documented case of a dryline occurring in southeast Wyoming (SE WY). The frequency of these occurrences is not well-known, but preliminary results of an ongoing climatology study at the University of Wyoming suggest that drylines are observed in SE WY on ~10-15 days per year from May-August, with dryline-related convection seen on more than half of those days.

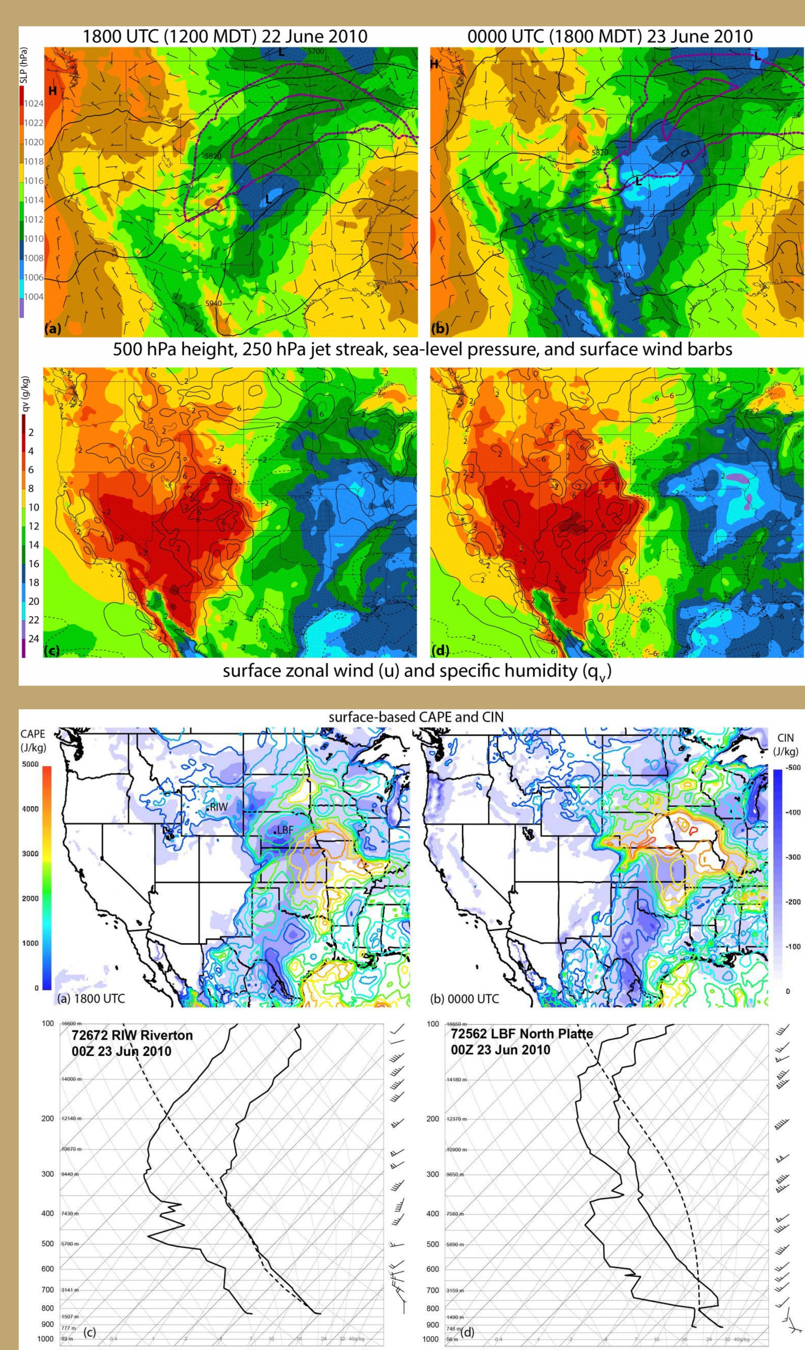
The purpose of this present study is 1) to describe the characteristics and evolution of a SE WY dryline using observations and high-resolution WRF model output, and 2) to examine the fine-scale vertical structure of this dryline by means of an airborne Raman lidar and elucidate the fine-scale dynamics which led to convection initiation. The first set of objectives are set to be published in a paper by Campbell et al. (2013)[1], while the Raman lidar results are currently being refined and will be part of a future paper.

22 June 2010 Overview

The synoptic environment on 22 June 2010 can be ascertained from the figures below. A surface low pressure center was situated near the Colorado-Kansas border at 18 UTC with persistent southerly flow over much of the southern and central plains and a prevailing southwesterly wind over the intermountain west. A 500-hPa shortwave was present over the western U.S. with a 250-hPa jet streak (>50 m s-1) located above the northern plains.

The specific humidity field reveals a rather sharp moisture gradient from SE WY down through eastern Colorado in conjunction with a rapid west-east transition of the zonal wind from positive to negative, implicit of convergent zonal flow. Low values of CAPE (<1000 J kg^{-1}) and large convective inhibition (-200 to -300 J kg $^{-1}$) were present at this time over SE WY and much of the high plains just east of the Rocky Mountains.

Several important changes had occurred by 00 UTC on 23 June. First, northwest displacement and strengthening of the surface low (attributed to diurnal surface heating) was evident. Second, the specific humidity gradient had amplified due to increased zonal convergent flow north of the low and was strongest in SE WY. Third, an increase in CAPE was seen locally across SE WY while a large tongue of significant CAPE (>3000 J kg^{-1}) had emerged over northeastern Colorado. This, along with a broad weakening of CIN across the region, led to gradual destabilization and isolated thunderstorm development in SE WY and western Nebraska. Overall, it appears that the conditions under which the dryline formed on this day could be characterized as "synoptically-active", wherein the large-scale environment drives the evolution of the dryline.



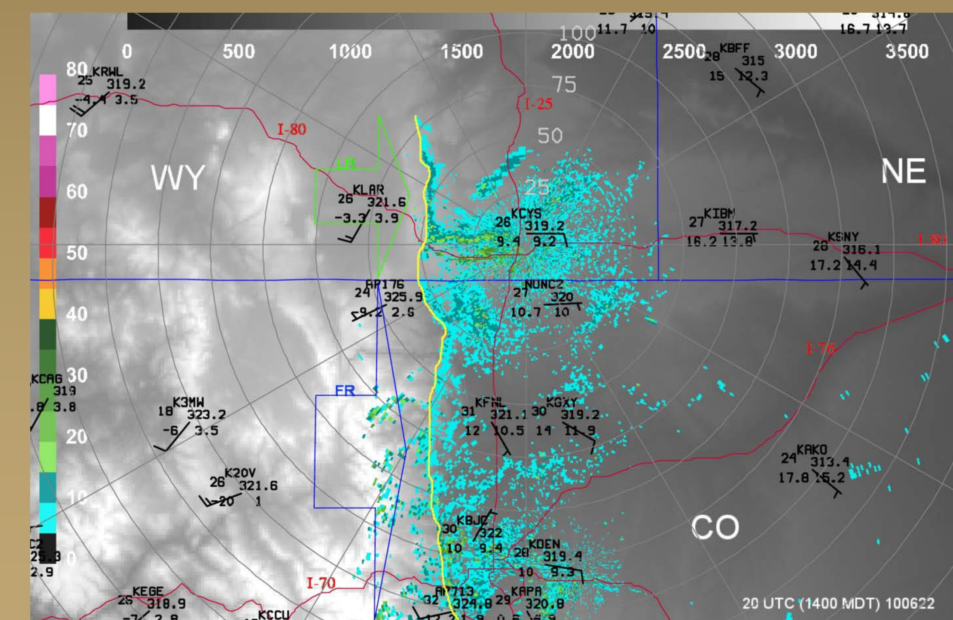
12-km NAM output, initialized at both 18 and 00 UTC

Surface and Radar Observations

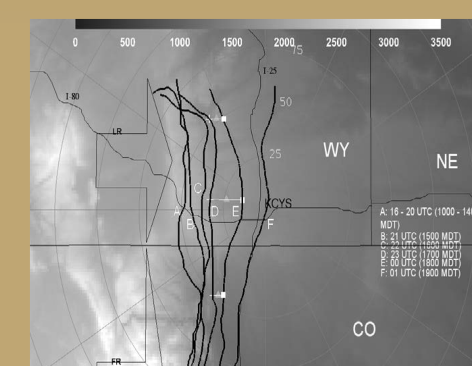
Surface observations and radar imagery are often used to identify drylines and monitor their motion. Dewpoint and wind measurements help reveal moisture gradients and regions of convergence, respectively. Radar can be used to locate radar finelines, or "thinlines", which signify surface boundaries where insects have congregated under convergent flow. Drylines are frequently seen on radar by means of a radar fineline.

Analyses of local surface data and radar reflectivity from the Cheyenne, WY (CYS) WSR-88D radar on 22 June 2010 yielded the following observations:

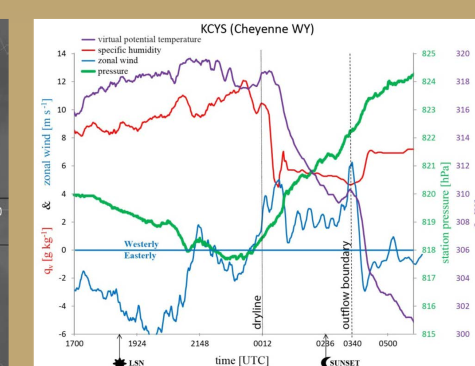
- A north-to-south oriented radar fineline was visible west of CYS and nearly parallel to the Laramie Range at 20 UTC
- From 20-01 UTC the fineline shifted eastward, passing through CYS at around 00 UTC
- A dramatic drop in specific humidity and a shift in the zonal wind from easterly to westerly was at seen at CYS during the dryline passage



CYS reflectivity and station observations at 20 UTC



Hourly analysis of radar fineline locations (isochrones)

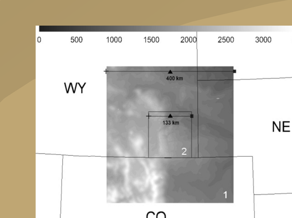


Station time series at CYS from 17-06 UTC

WRF Model Results

A non-hydrostatic simulation from the Weather Research and Forecasting (WRF-ARW) model was used to better understand some of the fine-scale aspects of the dryline, its evolution, and convection initiation. The model was configured as follows:

- Two domains (see figure to the right), with resolutions of 4-km and 1-km, respectively
- Initialized by 12-km NAM data every 3 hours
- Hourly output from 12 UTC (22 June) to 03 UTC (23 June)



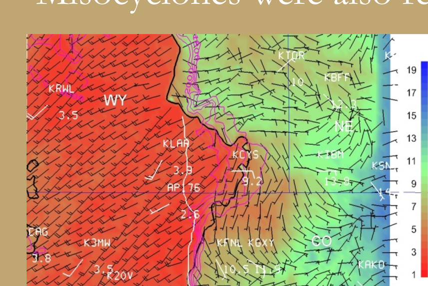
WRF domains

Other aspects of the configuration are provided in the table to the right. Detailed analysis of both the 4-km and 1-km domains allow for several comments to be made:

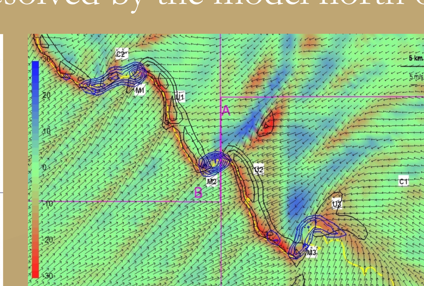
Specification	Selection(s)
Basic Equations	3D; nonhydrostatic
Vertical Levels	40
Turbulence and Mixing	Evaluates 2nd order diffusion term
Turbulence Closure	Horizontal Smagorinksy
Microphysics	Thompson graupel/high resolution scheme
Longwave Radiation	Rapid Radiative Transfer Model
Shortwave Radiation	Dudhia scheme (ptop > 50 hPa)
Surface Layer	MM5 Monin-Obukhov scheme
Land Surface	Unified Noah land-surface model
Planetary Boundary Layer	Yonsei University Scheme
Cumulus Parameterization	None
Lateral Boundaries	Domain 1: Specified ; Domain 2: Interactive
Model Initialization	12-km NAM Model
	Lambert Conformal
Model Output	Hourly: 12 UTC (06/22) - 03 UTC (06/23)

WRF configuration

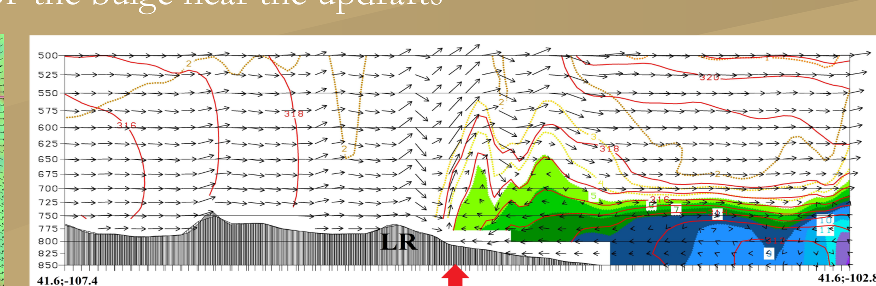
- The simulated dryline exhibited an eastward bulge over the higher terrain of the Cheyenne Ridge at 20 UTC, resulting in it being much farther east than the observed dryline
- The vertical extent of the simulated dryline is fairly shallow at 20 UTC, near the time of convection initiation. The leading edge of the dryline, however, is quite steep and exhibits a strong gradient in both specific humidity and virtual potential temperature
- Strong updrafts were found on the north side of the bulge where dryline convergence was greatest. These updrafts were co-located with the intersection of the dryline and horizontal convective rolls (HCRs). Misocyclones were also resolved by the model north of the bulge near the updrafts



Domain 1 specific humidity (colored), surface winds, station observations, 20 UTC dryline position (black line), 16-20 UTC average dryline position (white line), and terrain (purple contours)

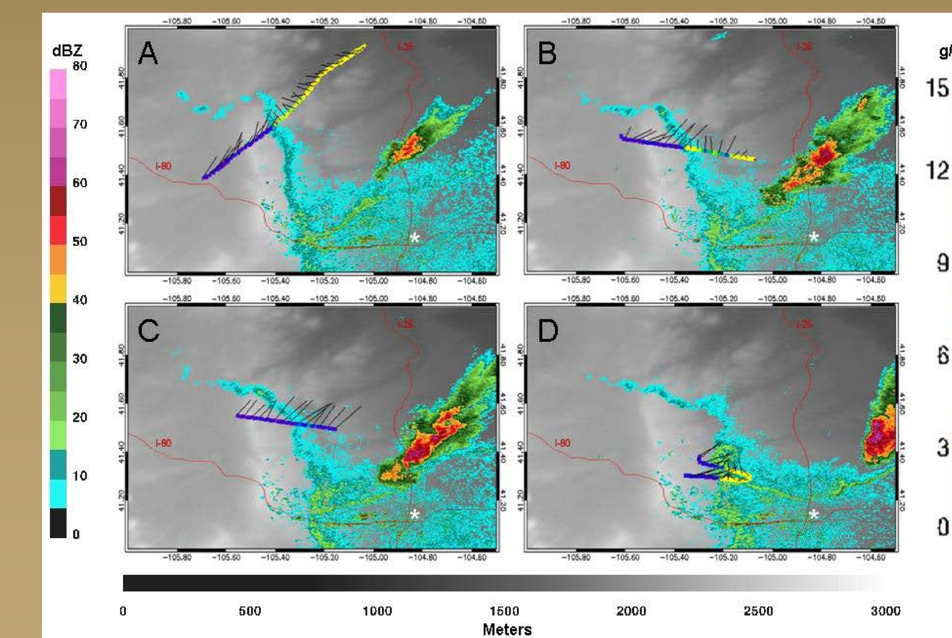


Domain 2 moisture convergence (colored), surface winds, vertical velocity (black contours), and vertical vorticity (blue contours) at 19 UTC



Domain 1 cross section of the dryline at 20 UTC along the 41.6° parallel. Specific humidity (colored), virtual potential temperature (red contours), and vector tangential winds are shown with LR referring to the Laramie Range. The red arrow corresponds to the dryline location

Lidar Transects

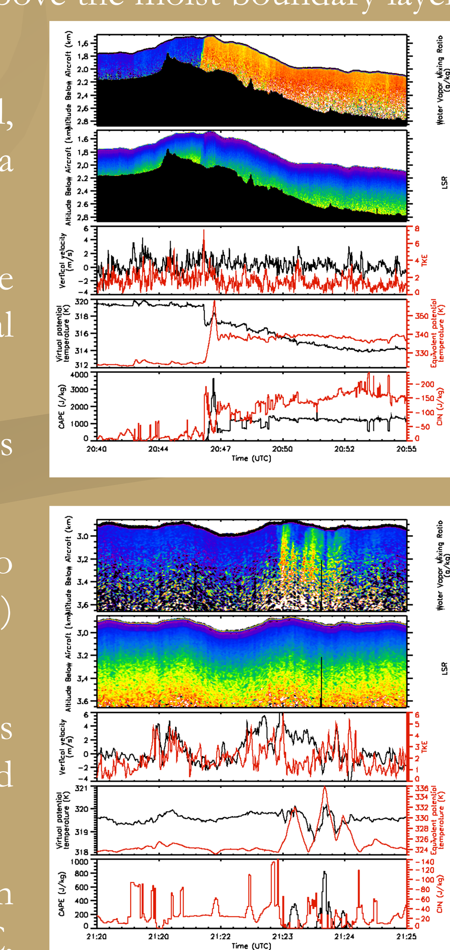


Four different UWKA flight legs (A-D) overlaid on CYS reflectivity. Flight tracks are colored by flight-level specific humidity measurements and black lines are flight-level wind vectors

A ~2.5 hour flight (1946-2212 UTC) over the dryline to the northwest of Cheyenne was also completed on this day by the University of Wyoming King Air (UWKA) during which flight-level and airborne Raman lidar data were collected. Some preliminary results will be presented here while a full analysis will be carried out in a future follow-up paper to Campbell et al. (2013).

A number of flight legs transected the dryline during the flight period, with four of them shown in the figure to the left. None of the legs intersected deep convection, although on at least a few occasions the aircraft flew beneath cumulus clouds near the dryline. The bottom two figures show downward-pointing Raman lidar data and relevant flight-level measurements from two legs different altitudes, within the moist boundary layer at ~500 m AGL (leg A) and above the moist boundary layer at ~1500 m AGL (leg C). Several comments can be made:

- The transition across the dryline was both very abrupt quite vertical, with mixing ratios increasing from ~4 g kg^{-1} to 10-12 g kg^{-1} over a very short distance, perhaps only several kilometers
- The most buoyant and unstable parcels were located just east of the dryline where there was a peak in both equivalent potential temperature and CAPE (along with a local minimum in CIN)
- Vertical motion on both sides of the dryline (during Leg A) appears dominated by boundary layer turbulence
- Above the moist boundary layer (Leg C) local maxima in mixing ratio almost reach flight level, indicative of moist updrafts (plumes) penetrating into the free atmosphere
- These plumes coincide with relatively large vertical velocities (>3 m s^{-1}) and have thermodynamic properties (lower θ_v and CAPE > 0) consistent with that of the moist boundary layer below
- It would be within moist plumes such as these where parcels attain their LCL, leading to convection initiation, and possibly their LFC, allowing deep convection to ensue



Raman lidar and flight-level data from flight legs A (top) and C (bottom)

Summary

The work shown here presents some of the results from the first detailed investigation of a dryline occurring in SE WY. Evidence was provided demonstrating that this boundary clearly was a dryline, exhibiting characteristics found in other drylines over the SGP. High-resolution modeling data suggested that HCRs and misocyclones likely played a key role in the deepening of the moist boundary layer and subsequent initiation of deep convection near the dryline. Data from an airborne Raman lidar revealed detailed information regarding the vertical structure of the dryline and the moist plumes which had broken into the free atmosphere just to the east.

More investigation into the characteristics and evolution of SE WY drylines would be of great benefit to local forecasters as they seek to understand when, where, and how these drylines form. A climatological study at the University of Wyoming is currently looking into some of these issues, but further examination in the form of case studies or field projects is probably necessary if we hope to fully understand these phenomena and how they differ from the drylines of the SGP.

1 Campbell, P. C., B. Geerts, and P. T. Bergmaier, 2013: A dryline in southeast Wyoming. Part I: Multi-scale analysis using observations and modeling on 22 June 2010. *Accepted to Mon. Wea. Rev.*