Characteristics and Synoptic Environment of Drylines Occurring over the Higher Terrain of Southeastern Wyoming

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ABSTRACT

Commonly observed over the broadly sloped terrain of the southern Great Plains (SGP), drylines are frequent loci of warm season deep convection and have been the focus of numerous observational, theoretical, and climatological studies over last half century. In this study, a 3-yr (2010–12) analysis of the characteristics and synoptic environment of drylines occurring elsewhere, over the high terrain in southeastern Wyoming just east of the Rocky Mountains, is presented. Observed on ~11% of the days between May and August of the years examined, southeastern Wyoming drylines were often associated with large moisture gradients [5–10 g kg\(^{-1}\) (100 km)\(^{-1}\)], large horizontal virtual potential temperature differences (~2–5 K), and convergent zonal wind flow at the surface. The synoptic conditions leading to their formation and their relationship to thunderstorm activity are also explored in an effort to aid local forecasters in anticipating the development and convective impact of drylines across the region. Similarities exist between these drylines and those found over the SGP, especially with regard to their strength and close relationship to deep convection. However, the frequency at which they occur, some characteristics of their diurnal motion, and the synoptic conditions driving their formation differ noticeably.

1. Introduction

Surface boundaries separating warm, moist air originating over the Gulf of Mexico from warm, dry air originating within the semiarid climate of the southwestern United States are commonly referred to as drylines. Frequently observed during the spring and early summer along the higher elevations of the southern Great Plains (SGP), a dryline is marked chiefly by a large surface moisture gradient (Owen 1966; Schaefer 1986). Convergent surface flow (Schultz et al. 2007) and a density contrast (Ziegler and Hane 1993; Miao and Geerts 2007) may also be observed across the dryline. While the latter has led some researchers to conclude that drylines frequently behave as density currents (Ziegler and Hane 1993; Atkins et al. 1998; Geerts 2008), others have shown evidence that suggests this is not always the case (e.g., Crawford and Bluestein 1997). Moist convection, including thunderstorm formation, frequently occurs along drylines, although the mechanisms responsible for initiating such convection remain poorly understood and have been the focus of much research in recent decades (Koch and McCarthy 1982; Ziegler et al. 1997; Wakimoto and Murphey 2009). Often, these storms become severe as they may attain supercellular characteristics as a result of the highly sheared environment common near drylines (Weiss et al. 2006).

In an effort to better understand their overall behavior, some studies have taken a climatological approach and have attempted to describe SGP drylines either statistically or via the large-scale atmospheric patterns by which they are preceded (Owen 1966; Schaefer 1974b; Peterson 1983; Hoch and Markowski 2005; Schultz et al. 2007). Most of these investigations adopted slightly different approaches for how to choose and analyze the drylines. Some of these studies (e.g., Owen 1966; Hoch and Markowski 2005) chose drylines based only on a surface moisture gradient requirement, while the others were a bit more restrictive and included additional selection criteria. Depending on the approach, drylines were observed in these studies over the SGP on anywhere from 30% to 45% of days between April and June.

Only a few studies investigating drylines outside of the SGP have been published (e.g., Weston 1972; Arnup and Reeder 2007; Taylor et al. 2011). It has been

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noted for many years by researchers at the University of Wyoming and by forecasters at the National Weather Service Office in Cheyenne, Wyoming, that dryline-like surface boundaries appear in southeastern Wyoming from time to time. Recently, a case study was carried out investigating a strong dryline that formed in southeastern Wyoming during the summer of 2010 (Campbell et al. 2014). Airborne profiling Raman lidar data and flight-level data show that this dryline was sharply defined and had characteristics of a density current (Bergmaier et al. 2014). Deep convection initiated just east of this dryline, some of which became severe and produced several tornadoes in western Nebraska. The Weather Research and Forecasting (WRF) Model run with a 1-km grid spacing nicely captured the location and evolution of this dryline, as well as the convection initiation, although it moved the boundary too quickly to the east over a local ridge (Campbell et al. 2014).

Naturally, questions have arisen regarding the characteristics of drylines in southeastern Wyoming, some of which we seek to answer here. This multiyear investigation of southeastern Wyoming drylines, the first of its kind, will address the following objectives: 1) describe the general characteristics of southeastern Wyoming drylines, 2) identify their typical synoptic environment, and 3) examine aspects of their diurnal evolution and their relationship to the local initiation of deep convection. The findings will be compared with similar studies of drylines found over the SGP and may have significant local forecasting implications. For the purposes of this study, southeastern Wyoming can be loosely, and somewhat arbitrarily, defined as the region bounded to the west by the crest of the Laramie Range (LR), to the south and east by the state line, and to the north by the range of low-level radar coverage from the Weather Surveillance Radar-1988 Doppler (WSR-88D) at Cheyenne (KCYS). As will be shown, the use of radar in this study was crucial for identifying and monitoring these drylines given the sparseness of surface observations across southeastern Wyoming, a problem that often makes conventional surface analysis difficult.

The next section describes the process by which drylines were identified in southeastern Wyoming over a 3-yr period and the data that were used to analyze them. In section 3, results of the study are presented and the mean synoptic environment of southeastern Wyoming drylines is described. A comparison between these drylines and those found in the SGP is made in section 4, accompanied by a discussion on potential forecasting implications. We summarize and offer some conclusions in section 5.

2. Data and methods

a. Datasets

A variety of observational and gridded data were used to select and analyze drylines. Among these were level II WSR-88D base reflectivity data from KCYS, local Automated Surface Observing System (ASOS) station observations, national surface analysis charts from the Weather Prediction Center (formerly the Hydrometeorological Prediction Center), and severe storm reports from the National Climatic Data Center (NCDC) Storm Events Database. The National Centers for Environmental Prediction 32-km North American Regional Reanalysis (NARR) dataset (Mesinger et al. 2006), chosen primarily because of the quality of its assimilated historical observations and long-term consistency, was used to identify days when a dryline was likely present in southeastern Wyoming. It was also chosen without the need for high spatial resolution as the NARR was used not to resolve the strengths and precise locations of the drylines themselves, but instead only as a first guess to find days when the regional-scale surface variables suggested the possible presence of dryline-like boundaries somewhere over southeastern Wyoming. Initialized data from the 1800 UTC 12-km North American Mesoscale Forecast System (NAM), were used for the creation of higher-resolution composite maps, at 1800 UTC only. If the 1800 UTC NAM data were not available for a specific day, the 6-h forecast data from the 1200 UTC NAM were used instead. These maps, created by averaging the gridded data from all 39 cases, allowed for the assessment of typical meteorological conditions on days when southeastern Wyoming drylines formed.

b. Selection of cases

All days in May–August during the years of 2010–12 (369 days) were analyzed in an effort to identify those days in which a well-defined dryline was likely present across southeastern Wyoming. It was crucial that any prospective dryline days be analyzed manually to ensure that other boundaries possibly having characteristics similar to drylines, such as convective outflow and fronts, were not included in the final dataset. To make individual analysis more manageable, the first step was

1 Available online at http://www.ncdc.noaa.gov/nexradinv/.
2 Available online at http://mesowest.utah.edu/.
4 Available online at https://www.ncdc.noaa.gov/stormevents/.
5 Available online at http://nomads.ncdc.noaa.gov/data.php.
to narrow down the number of days in the initial dataset by removing days on which a dryline was unlikely to have occurred. This was done using surface data from two grid points within the NARR domain. These grid points, shown in Fig. 1 and separated by about 96 km, were chosen because they approximately represent the western and eastern boundaries of where one might expect a dryline to develop. The western grid point, labeled A, was situated just east of the LR crest in the NARR domain and included a weighted average of the surface wind, temperature, and humidity from along both the ridgetop and the adjacent high plains to the east (i.e., the region within the 32 km × 32 km box in Fig. 1). The LR can be a natural barrier to the westward progression of shallow, moist upslope flow from the east. While the 32-km grid spacing of the NARR dataset is not able to fully resolve the topography of the LR itself (range width is about 30 km), these two grid points were used as it was presumed that the strongest surface moisture gradients across the region would still be found between them (i.e., along or east of the range) owing to the contribution of surface observations into the NARR. The number of moisture gradients identified by the algorithm described below between gridpoints A and B was actually larger than the number of gradients found if gridpoint A was replaced with an adjacent grid point 32 km to its west or east (i.e., on the western and eastern sides of the LR, respectively). Thus, gridpoints A and B appear to be the optimal choices for this study. Days on which the following three criteria were not met between gridpoints A and B were ultimately eliminated from the final dataset:

1) the presence of a specific humidity gradient $\nabla q$, of $3 \times 10^{-8} \text{ m}^{-1} [3 \text{ g kg}^{-1} (100 \text{ km})^{-1}]$ or stronger, with the drier air to the west;
2) a virtual potential temperature difference $\Delta \theta_v$, with the warmer air to the west; and
3) convergence of the zonal wind component ($-\partial u / \partial x > 0$, with $u$ being the zonal wind and $x$ being the east–west distance).

These criteria were applied to the NARR data only at 1800 UTC [1200 local time (LT)] each day, close to when drylines are typically strongest (Owen 1966; Schaefer 1986). This particular $\nabla q$, was chosen in order to be consistent with previous dryline studies (Schaefer 1974b; Hoch and Markowski 2005; Coffer et al. 2013). The second and third criteria were chosen because they are commonly observed near drylines over the SGP (e.g., Ziegler and Hane 1993; Miao and Geerts 2007; Geerts 2008), although the second criterion also acts as a means of removing strong eastward-moving cold fronts. A total of 79 days met all three criteria, although some days with a weaker $\nabla q$, may have been removed as a result of the relatively large distance over which these gradients were calculated. Of the 85 days that satisfied the first criterion, only 6 failed to satisfy the second or third; that is, the humidity gradient, being the most restrictive criterion, generally implied potentially warmer air to the west and convergent flow across the gradient, at least at 1800 UTC.

The next step was to manually examine these 79 days to confirm that the moisture gradients were indeed associated with a dryline rather than another type of boundary. The daytime hours of 1200–0000 UTC (0600–1800 LT) were inspected to see on which of the days the following three additional requirements were satisfied by actual observations. To begin, a radar fineline must have been present over southeastern Wyoming in the KCYS WSR-88D 0.5° base reflectivity data and
persisted for at least three consecutive hours. This was the case for 66 of the 79 days. However, any finelines that originated from thunderstorm outflow were removed, as were any that may have been outflow related but whose origin was difficult to discern. Finelines often appear on radar plan position indicator displays as a thin line of relatively higher reflectivity within regions of strong convergent boundary layer flow (Wilson and Schreiber 1986; Wilson et al. 1994) and have been used in a number of previous studies to help identify the location and movement of drylines (Atkins et al. 1998; Murphey et al. 2006; Wakimoto et al. 2006; Weiss et al. 2006; Miao and Geerts 2007; Geerts 2008; Campbell et al. 2014). Drylines may not always be accompanied by a fineline, especially if occurring in the presence of weak convergent (or divergent) flow or when passive boundary layer scatterers (such as insects) are not abundant. Also, because finelines are closely tied to the depth of the boundary layer, they often become indiscernible at distances from the radar (typically about 75 km in this study) where the radar beam begins overshooting the boundary layer. This is illustrated quite well by the fact that the finelines examined in this study occurred more frequently at latitudes closer to KCYS and during the afternoon hours when the boundary layer was deepest (not shown). As a result of these limitations, drylines that were stronger near or beyond the outer fringes of low-level radar coverage, or that occurred in an environment not conducive to fineline formation, may have necessarily been excluded from the final fineline dataset used here. Next, the \( \nabla q_u \) criterion used for the NARR data \( \nabla q_u = 3 \, \text{g kg}^{-1} \, (100 \, \text{km})^{-1} \) was also required to be verified for at least 1 h by the nearest hourly ASOS observations on opposite sides of the fineline. It was not mandatory that this criterion be met at all hours during which a fineline was present, as drylines often strengthen and weaken throughout the day. Finally, any days on which the fineline was obviously associated with a larger-scale frontal boundary were removed following regional examination of high-resolution surface charts from the WPC.

All finelines visible from the KCYS WSR-88D data in this study were located within southeastern Wyoming and were denoted by a well-defined radar fineline. Any ASOS observations clearly visible from the KCYS WSR-88D data in Wyoming and were denoted by a well-defined radar fineline. Given the characteristics of these moisture boundaries established through the selection process, they are believed to be drylines and the radar finelines are assumed to represent their near-surface positions. This suggests that drylines occurred across southeastern Wyoming on at least 11% of days (39 of 369) during the period of study, although the annual number of occurrences ranged from as few as 7 in 2012 to as many as 20 in 2011.

Mean ASOS observations for each of these days, obtained only from hours during which a fineline was visible, are presented in Table 1. The 39-day mean \( \nabla q_u \) (hereafter given per 100 km) was 5.3 g kg\(^{-1}\) and most individual days (30 of 39) had a mean \( \nabla q_u \) of 3 g kg\(^{-1}\) or greater. The largest single \( \nabla q_u \) observed each day (not shown) ranged from 3.3 to 13.6 g kg\(^{-1}\) and averaged 7.1 g kg\(^{-1}\). It is likely that these gradients are underestimated given the distance between observing stations (e.g., the distance from KLAR to KCYS is \( \approx 70 \) km), as drylines often exhibit the sharpest moisture gradient over a distance of just a few kilometers or less (Staff Members 1963; Pietrycha and Rasmussen 2004; Buban et al. 2007; Ziegler et al. 2007). Observed values of \( \Delta \theta_u \) (defined as \( \theta_{u,\text{dry}} - \theta_{u,\text{moist}} \)) were positive on all days, implying the moist air was denser if the \( \theta_u \) contrast existed over a significant depth of the boundary layer. Furthermore, \( \Delta \theta_u \) was often quite large, averaging 3.5 K, which is greater in magnitude than the 1.6-K-average \( \Delta \theta_u \) (adapting the current definition of \( \Delta \theta_u \)) documented across west Texas drylines in Geerts (2008). However, in the current study the stations over which the differences

3. Results

a. General characteristics

The 39 days that survived the selection process each contained a strong surface \( q_u \) gradient over southeastern Wyoming and were denoted by a well-defined radar fineline. Any ASOS observations clearly modified by convective outflow were not included, as were those from when the fineline moved west of the WSR-88D at Laramie, Wyoming (KLAR).
were calculated were generally farther apart than in Geerts (2008), possibly accounting for some of the discrepancy. Observed daily mean surface zonal winds across these drylines were generally convergent, although on five days the winds were slightly divergent.

In previous studies, it was shown that an increase in $\nabla q_x$ generally implied a strengthening of $\Delta \theta_u$ (Geerts 2008) and zonal wind confluence (Schultz et al. 2007). Figure 2ademonstrates that these generalities also held true in this study as both $\nabla q_x$ and $\Delta \theta_u$ tended to be larger on days with stronger zonal wind convergence, and vice versa (Figs. 2b,c). The Pearson correlation coefficient $R$ ranges from 0.3 to 0.4 in each case and a two-tailed Student’s $t$ test indicated that these correlations, while not very robust, are statistically significant ($p < 0.05$). Together, they imply that a relationship exists between dryline strength (in terms of the moisture gradient) and the local surface flow and baroclinicity, consistent with conclusions reached by the two studies above.

### b. Typical synoptic environment

The composite analysis focused on variables and parameters from common surface and upper-air maps, similar to Schultz et al. (2007). At upper levels, fairly strong ridging was evident over the north-central United States at both 700 (Fig. 3a) and 500 hPa (Fig. 3b), with a relatively weak (~26 m s$^{-1}$) 250-hPa jet streak stretching across southern Idaho and northwestern Wyoming.

Table 1. Summary and mean characteristics of all 39 days included in the final dryline dataset. Numerical values shown are the daily (1500–0000 UTC) means calculated from ASOS measurements.

<table>
<thead>
<tr>
<th>Day</th>
<th>Month</th>
<th>Year</th>
<th>CI</th>
<th>Movement</th>
<th>$\nabla q_x$ [g kg$^{-1}$ (100 km)$^{-1}$]</th>
<th>$\Delta \theta_u$ (K)</th>
<th>$-\partial u/\partial x$ ($10^{-5}$ s$^{-1}$)</th>
</tr>
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<td>2010</td>
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<td>5.4</td>
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<tr>
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</tr>
<tr>
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<td>3.0</td>
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</table>
and a larger, stronger jet streak downwind of the upper-level ridge over the upper Midwest (Fig. 3c). Weak low-level warm-air advection is implied by the 700-hPa temperature pattern over the far eastern Rocky Mountains and higher terrain of southern Wyoming, where surface pressures are typically close to 700 hPa.

Meanwhile, the accompanying surface pattern was dominated by a very broad high pressure region over the eastern half of the country and a weak leeside low centered over northeastern Wyoming and extending down into northern Colorado (Fig. 4a), all of which coincided well with the position of the upper-level ridge and the low-level temperature advection pattern. The positions of these surface features, and in particular the pressure gradient, implied southeasterly low-level geostrophic flow over the central plains. The 10-m wind vectors in

![Figure 2](https://journals.ametsoc.org/waf/article-pdf/30/6/1733/4665015/waf-d-15-0061_1.pdf)

![Figure 3](https://journals.ametsoc.org/waf/article-pdf/30/6/1733/4665015/waf-d-15-0061_1.pdf)
Fig. 4a support this, as they were primarily out of the south-southeast over this region. This flow, which was moist (Fig. 4b), gradually ascended the sloping terrain of the high plains into southeastern Wyoming, where it encountered drier westerly (i.e., downslope) flow exiting the Rocky Mountains (hereafter, the Rockies). These converging air masses, well illustrated by the surface zonal wind field, led to the presence of a sharp surface $q_v$ gradient over eastern Wyoming and north-central Colorado (Fig. 4b). In concert with the ASOS observations, the eastern air mass tended to be cooler (in terms of $\theta_v$) and thus perhaps denser, on average, than the air mass to the west (Fig. 4c).

Composite vertical cross sections over southeastern Wyoming—along the 41.5°N parallel—show the mean vertical structure of the moist layer (Fig. 5a) and zonal wind field (Fig. 5b) near these converging air masses. The moist layer depicted in Fig. 5a, to the lower right where the isohumes and isentropes are tightly packed, was shallow—on the order of 1000–1500 m deep (assuming 1 hPa ≈ 10 m in the vertical)—and capped by an inversion. In this case, the moist layer extended as far west as the eastern slopes of the LR (shown in Figs. 5a,b) but did not progress past the range crest. The apparent slope of the inversion from the ground up to the east was not steep, as seen in some studies of individual drylines (e.g., Campbell et al. 2014), but was more broad as a result of the averaging. The region of surface convergence seen in Fig. 5b, near where one might expect the dryline to exist, was not collocated with the strongest surface moisture gradient in Fig. 5a but rather farther east. The structure of the isentropes over the Laramie Range, westerly flow over the ridgetop (near 700 hPa; cf. Fig. 3a), and the presence of near-surface downslope flow on the lee side of the ridge suggest that lee convergence processes (Banta 1984, 1986) may have partially contributed to the development and movement of the moisture gradient.

As a point of comparison, the moist layer farther south—along the 40.5°N parallel—over the steeper terrain of the Colorado Front Range (FR; shown in Figs. 5c, d) exhibited similar vertical structure and depth but remained highly stratified and horizontal as it met the higher mountainsides (Fig. 5c). Furthermore, the low-level easterly flow progressed all the way up the eastern slopes of the FR before being impeded by the terrain near 800 hPa (Fig. 5d). In fact, a maximum in easterly flow was present at the base of the mountain range. Here, the boundary separating westerly and easterly flow appears to have correlated well with the top of the moist layer.

While a variety of upper-air and surface patterns contributed to these mean synoptic conditions, a qualitative analysis of the individual days (not shown)
revealed that the patterns on roughly 22 of the 39 days were similar, in terms of the locations of the 500-hPa ridge and surface high or low, to the 39-day mean. Of the remaining 17 days, 11 could perhaps be considered synoptically active, with a strong surface low moving across the Rockies from the Pacific Northwest and highly amplified flow aloft. The last six days were characterized by a broad region of high pressure sitting over the western half of the United States and relatively weak flow aloft.

Fig. 5. The 39-day composite vertical cross sections at 1800 UTC over southeastern Wyoming (41.5°N) and northern Colorado (40.5°N), from 12-km NAM data. The two-dimensional plane-parallel wind (m s⁻¹; vectors) and θₑ (K; black contours) are shown in addition to (a),(c) the vertical distribution of qₑ (g kg⁻¹; color filled above 6 g kg⁻¹, dashed contours below 6 g kg⁻¹) and (b),(d) the zonal wind magnitude (m s⁻¹; color filled, red is easterly and blue is westerly). MB refers to the Medicine Bow mountain range, LR refers to the Laramie Range, and FR refers to the Front Range. The longitude of KCYS in (a),(b) is also shown by the red arrow. In (a)–(d), west (east) is to the left (right).
c. Diurnal characteristics and dryline movement

An illustration of hour-by-hour horizontal fineline structure from 1500 to 0000 UTC is given in Fig. 6. Each solid line represents the mean fineline location at a specific hour while the dashed lines on either side represent the corresponding longitudinal standard deviations. It is evident that the finelines were predominantly oriented near the 105.3°W meridian throughout most of the period, along the eastern flanks of the LR (consistent with Fig. 5). There does, however, appear to have been some diurnal variability in fineline location, particularly near and just north of the Wyoming–Colorado state line. Here, the finelines tended to propagate westward after 1800 UTC, in some cases west of the LR, as indicated by the standard deviation lines. The distance of the standard deviation lines from their respective mean finelines also reveals that the day-to-day meridional fineline variability tended to be greater in southeastern Wyoming than in Colorado. From about 40.0° to 40.8°N, the mean finelines appear to have remained locked to the higher terrain of the FR (near 105.5°W). The standard deviations here were relatively small, suggesting that these southern fineline segments were typically observed near the same location each day and propagated only short distances up and down the slopes of the FR. A possible explanation for these fineline differences is given in section 4.

There was also variability in the mean ASOS observations throughout the analysis period. As seen in Fig. 7, \( \nabla q_v \) (dashed green line) strengthened to about 5.5 g kg\(^{-1}\) by 1800 UTC and then decreased to less than 4.5 g kg\(^{-1}\) by 0000 UTC. The \( \Delta \theta_v \) (solid red line) pattern was similar, reaching its maximum early at 1600 UTC before decreasing throughout the afternoon. However, the zonal wind convergence (solid blue line) strengthened throughout the afternoon by almost an order of magnitude to a maximum at 0000 UTC, when \( \nabla q_v \) and \( \Delta \theta_v \) were relatively small.

To examine the diurnal propagation of southeastern Wyoming drylines, all 39 finelines were categorized as either westward moving, eastward moving, or stationary (cf. Table 1). The category in which a fineline was placed was determined arbitrarily by noting its average beginning and ending longitudes. When a fineline’s average ending longitude was more than 0.1° west (east) of its average beginning longitude, the fineline was deemed to have been westward (eastward) moving. If the longitudes differed by 0.1° or less, the fineline was considered stationary. Using this method, 15 finelines were classified as westward moving, 9 as eastward moving, and 15 as stationary.

Out of curiosity, the 1600–0000 UTC hourly surface wind observations from KCYS, KLAR, and Kimball, Nebraska (KIBM), were examined for each of these cases to see if there was any relationship between the regional-scale wind flow across southeastern Wyoming and dryline propagation. The regional mean zonal wind \( U \) (defined as the hourly average of all three stations) for westward-moving, eastward-moving, and stationary dryline days is presented in Fig. 8a. A sign reversal of \( U \) was typical during the afternoons of days with westward-moving drylines, with the flow shifting from westerly (positive) to easterly (negative). In contrast, \( U \) became more positive by midafternoon on days with eastward-moving drylines and was overall relatively weak on days with stationary drylines.

An alternative perspective is given by Figs. 8b–d, where the mean zonal wind—broken down by individual station—is shown for the various modes of dryline movement. Here, it becomes more evident that the
movement of the drylines in this study appears to have been related to the relative strengths of the westerly and easterly winds on either side of the dryline. For instance, drylines tended to propagate westward when the westerly flow at KLAR became weaker in magnitude during the afternoon than the easterly flow at KIBM (Fig. 8b). Eastward propagation was typically accompanied by a strengthening of the westerlies at KLAR during the afternoon, which overwhelmed the weaker easterlies at KIBM (Fig. 8c). The winds at these two stations were more balanced on days with stationary drylines (Fig. 8d).

In all three of these cases, an estimate of the 1800, 2100, and 0000 UTC mean 700-hPa zonal wind over the LR, obtained from gridpoint A (cf. section 2) in the 3-hourly NARR data, is shown by the black dots. They indicate that the 700-hPa zonal winds were westerly for all modes of dryline movement, but strongest for days on which the dryline moved eastward (Fig. 8c). Also, these winds tended to be close in magnitude to the surface winds at KLAR, implying that the 700-hPa layer was within the well-mixed boundary layer west of the dryline.

d. Influence on local convection initiation

To describe the relationship between southeastern Wyoming drylines and local thunderstorm formation, KCYS WSR-88D reflectivity data were once again examined on each of the dryline days in search of cases where deep convection initiation (CI) occurred near the dryline (i.e., the radar fineline), and where the convection appeared to be initiated by the dryline itself. CI is defined here, and elsewhere (e.g., Campbell et al. 2014), as the first occurrence of a cell with radar echoes of 40 dBZ or greater. These days were classified as “CI” days, while days on which deep convection did not occur were classified as “NO CI” days. On CI days, the time and location of the first occurrence of a deep convective cell was recorded. It was found that CI occurred on 21 of the 39 days (54%) over a rather widespread area, typically east of the crest of the Laramie Range (Fig. 9a). The mean location and time of CI were 41.3°N, 105.0°W (i.e., about 30 km northwest of KCYS) and ~1930 UTC (1330 LT), respectively. CI that occurred later in the day also tended to be observed farther east (see time next to each red dot in Fig. 9a). In all cases, CI occurred along or east of the observed fineline, often within 20 km (about 60% of the time) and almost always within 40 km (Fig. 9b). The average distance that convection initiated from the fineline was ~21 km. These results are in agreement with findings from both Owen (1966) and Ziegler and Rasmussen (1998), where it was shown that the frequency of moist convection initiation (in the form of new radar echoes and cumulus clouds, respectively) tended to peak just east of drylines.

![Fig. 8. Diurnal change in the 39-day mean hourly 10-m zonal wind component (i.e., u) across the southeastern Wyoming region from 1600 to 0000 UTC. In (a) the regional mean (i.e., U) of all three ASOS stations (KLAR, KCYS, and KIBM) is shown for westward-moving, eastward-moving, and stationary dryline days. A station-by-station breakdown of the mean u is then shown for (b) westward-moving, (c) eastward-moving, and (d) stationary dryline days. For reference, the mean u at 700 hPa from the 1800, 2100, and 0000 UTC NARR data is represented in (b)–(d) by the black dots. These were obtained from the grid point near the crest of the LR (i.e., gridpoint A from the dryline selection process described in section 2).](https://journals.ametsoc.org/waf/article-pdf/30/6/1733/4665015/waf-d-15-0061_1.pdf)
The drylines examined in this study were occasionally associated with severe weather. Severe storm reports [i.e., tornadoes, hail ≥1-in. diameter, and thunderstorm winds ≥50 knots (kt; where 1 kt = 0.51 m s\(^{-1}\))] from eastern Wyoming, western Nebraska, and northern Colorado, archived in the NCDC Storm Events Database, were analyzed for the occurrence of severe weather events associated with thunderstorms initiated along southeastern Wyoming drylines. A total of 70 severe weather events were reported, spread out over 7 of the 21 days. These include five weak tornadoes (on three days), all rated as category 0 on the enhanced Fujita scale (EF0), which were reported in eastern Wyoming or western Nebraska. There were also 60 hail reports (on all seven days) and five severe wind reports (on three days), with a maximum hail diameter and wind speed of 4 in. (≈10 cm) and 80 kt (≈41 m s\(^{-1}\)), respectively. On a handful of occasions, thunderstorms that were not initiated along the dryline but instead developed farther west (e.g., over south-central Wyoming) also generated severe weather as they propagated eastward across southeastern Wyoming, sometimes intensifying upon encountering the dryline. A casual analysis of radar and surface data suggests that most of these storms were probably initiated orographically or in association with an approaching frontal boundary. Because these storms were not initiated by the dryline itself, any severe weather events they produced were not included in this analysis.

A comparison of the 1800 UTC NAM mean upper-level and surface environments on CI and NO CI days (not shown) revealed that, for the most part, the conditions on both types of days did not differ significantly from each other and were actually quite similar to the 39-day composites shown in Figs. 3 and 4. On the other hand, the local convective potential, as indicated by the NAM surface-based convective available potential energy (CAPE; Figs. 10a,b) and convective inhibition (CIN; Figs. 10c,d), tells a different story. Near the Wyoming–Nebraska state line, CAPE ranged from 1200 to 1400 J kg\(^{-1}\) on CI days as opposed to 800 to 1200 J kg\(^{-1}\) on NO CI days. The former was accompanied by a broad area of large CIN (≈−100 J kg\(^{-1}\)) to the east over Nebraska and Kansas. There, deep convection was greatly suppressed. However, CIN on both CI and NO CI days was quite comparable across much of southeastern Wyoming and smaller in magnitude (from −20 to −60 J kg\(^{-1}\)). This is consistent with previous work that found that CIN often approaches zero just east of the dryline, whether CI occurs or not (e.g., Owen 1966; Ziegler and Rasmussen 1998). Furthermore, a small amount of CAPE (400–600 J kg\(^{-1}\)) was present on CI days across western parts of southeastern Wyoming where CIN was close to zero. Here, even just several hundred joules per kilogram of CAPE in the presence of weak inhibition would perhaps have been enough to lead to CI. As CI tended to occur after 1800 UTC on these days, another hour or two of surface heating may have completely eroded CIN locally near the dryline and maximized CAPE, allowing deep convection to ensue. While other factors such as lift and entrainment are perhaps more important in regulating CI than CAPE and CIN (Ziegler and Rasmussen 1998; Lock and Houston 2014), the contrast between CI and NO CI days shown in Fig. 10 implies that CAPE and CIN nonetheless corresponded well with the development of deep convection in this study.

Observed surface conditions across the fineline on CI and NO CI days, with exception to \(V_{\text{dry}}\), were quite similar and nearly mirrored the 39-day means. Drylines
that eventually led to CI tended to have a much larger average $\nabla q_v$ ($6.1 \text{ g kg}^{-1}$), owing to deeper moisture over the eastern high plains (not shown), than drylines that did not ($4.3 \text{ g kg}^{-1}$). This is not all that surprising given that, all else being equal, larger low-level moisture content will generally lead to greater atmospheric instability. It is perhaps surprising, however, that the larger $q_v$ gradient on CI days was not accompanied by stronger zonal wind convergence as suggested by the trend in Fig. 2a (although the convergence values for both CI and NO CI cases approximately equaled the 39-day average of $\approx 4.2 \times 10^{-4} \text{s}^{-1}$). Schultz et al. (2007) suggested that, while they observed a similar correlation between the cross-dryline moisture difference and zonal wind convergence on the synoptic scale (which they termed dryline intensity and dryline confluence, respectively), some stronger drylines in their dataset probably formed under synoptically quiescent conditions and were dominated by vertical mixing, which in turn may have diluted any weak confluence present in the synoptic flow. They also made the point that confluence may have still been present across these stronger drylines on spatial scales too small to be resolved by the widely spaced surface stations. Ultimately, this matter is outside the scope of the current study.

4. Discussion

To understand the nature of drylines that occur in southeastern Wyoming, it is perhaps wise to begin by viewing them in light of what we already know about these features. Much of our current understanding stems from decades of research focusing on drylines in the SGP, and it has become apparent that the drylines observed in this study demonstrated characteristics similar to those found to the south. Yet there were also some noticeable differences.

To begin with the similarities, large moisture gradients are known to occur in association with SGP drylines, especially under strong synoptic forcing (Schultz et al. 2007). The moisture gradients associated with southeastern Wyoming drylines were often quite large as well, as $\nabla q_v$ averaged $5.3 \text{ g kg}^{-1}$. This corresponds to a dewpoint gradient of about $16.5^\circ \text{C}$ ($30^\circ \text{F}$) over the same distance, assuming the measurements were taken from KLAR and KCYS and that the air at

![Expanded view over the Wyoming–Colorado–Nebraska tristate region of the 1800 UTC surface-based mean CAPE and CIN on (a),(c) CI and (b),(d) NO CI days, according to 12-km NAM data. The southeastern Wyoming region is approximated by the thick black box.](http://journals.ametsoc.org/waf/article-pdf/30/6/1733/4665015/waf-d-15-0061_1.pdf)
KCYS had a rather modest dewpoint of 10°C. This dewpoint gradient is much larger, perhaps by nearly an order of magnitude, than the mean summertime climatological dewpoint gradient (Dodd 1965; Schaefer 1974b) that is often present along the eastern slopes of the Rockies. Thus, it is clear that these moisture gradients were not only large, but they must have existed as a result of processes associated with the prevailing large- and regional-scale atmospheric flow, and not simply as a consequence of the presence of higher terrain.

Deep convection also occasionally occurred along these drylines, leading to a number of severe weather events including a few tornadoes. The average straight-line distance of about 20 km between the location of CI and the dryline-related fineline suggests that, before reaching their level of free convection, air parcels lifted either at or in the vicinity of the dryline were carried eastward by westerly momentum aloft. Furthermore, surface $\nabla q_y$ and convective parameters like CAPE and CIN appeared to correlate well with CI, although the latter two have not been confirmed with observations.

Regarding differences, southeastern Wyoming drylines were much more infrequent than their SGP counterparts, occurring on only $\sim 11\%$ of days from May to August. Drylines in the SGP have been documented as occurring on more than 40% of days, although these studies typically only looked for drylines over the shorter 3-month period from April to June (e.g., Owen 1966; Schaefer 1974b). Drylines in southeastern Wyoming also tended to be more difficult to observe and analyze, primarily because surface data across the region are sparse and low-level radar coverage becomes rather poor at distances greater than 75 km from KCYS. Over the SGP, the lack of sufficient surface data and radar coverage is much less of an issue. The presence of the west Texas Mesonet (Schroeder et al. 2005) and the Oklahoma Mesonet (Brock et al. 1995), in addition to the conventional ASOS stations, provides a relatively dense network of surface observations across prime dryline territory. WSR-88D coverage is also better over the SGP than in southeastern Wyoming, if fineline analysis is desired.

Perhaps one of the more significant differences deals with the synoptic patterns under which southeastern Wyoming drylines formed. The primary synoptic feature present at 1800 UTC on the days in this study was a broad high over the eastern United States that helped drive the large-scale southeasterly flow over the central plains, ushering moist, unstable air into western Nebraska and southeastern Wyoming. Figure 11a, which is based on the 39-day composites from Figs. 3, 4, and 5, illustrates this mean surface pattern schematically. The basic premise is that the moist southeasterly flow is strong enough on these days to progress as far north as

![Figure 11](http://journals.ametsoc.org/waf/article-pdf/30/6/1733/4665015/waf-d-15-0061_1.pdf)

**FIG. 11.** Schematic showing the typical synoptic pattern over the CONUS for (a) southeastern Wyoming drylines (based on Figs. 3, 4) and (b) strong drylines over the SGP as described by Schultz et al. (2007). The dryline is represented by the scalloped brown line, fronts by their conventional symbols, and large-scale dry (moist) airflow by the yellow (red) arrows. The letter L (H) is the surface low (high), and the dashed black lines are 500-hPa height contours. The low in (b) is shown to be deepening by the dotted pressure contours encircling it.

Wyoming and as far west as the eastern slopes of the Rockies, where it encounters drier westerlies descending off the higher terrain. Where these two air masses meet is where the dryline tends to develop, with smaller-scale processes influencing its strength and movement.

The synoptic conditions frequently driving the formation and evolution of SGP drylines differ from what was just described. Schultz et al. (2007) found that synoptic conditions during SGP drylines tend to vary, depending on whether the dryline is weak or strong. Strong drylines are often accompanied by a surface low pressure center, supported by an approaching upper-level shortwave, that develops in the morning to the lee of the southern Rockies and intensifies during the day. The
associated cyclonic flow brings warm, dry air from the deserts in the Southwest and warm, moist air from the Gulf of Mexico together somewhere over the SGP where a dryline develops (Fig. 11b). Weaker drylines, on the other hand, are usually dominated by small-scale vertical mixing and are typically associated with a weaker lee surface low, weaker low-level flow, and less upper-level support. Yet in both cases the presence of a lee surface low tends to be the primary synoptic factor governing the regional-scale wind flow and moisture field near drylines over the SGP.

The influence of the nearby Rockies must be considered when analyzing the evolution of southeastern Wyoming drylines. For the present study, in Colorado—where the FR is quite high and steep—the moist air mass was able to surge westward up against the eastern slopes where it subsequently became impeded (cf. Figs. 5c,d). Its western edge remained confined to these slopes and any westerly momentum coming off the Rockies tended to flow over the moist air. Lee convergence processes (Banta 1984, 1986), forced by surface heating of the elevated terrain and the mixing down of ridgetop westerlies, may have been responsible for the appearance of the quasi-stationary radar fineline during the day (cf. Fig. 6). We suspect that these southern fineline segments were not driven by dryline dynamics given their apparent connection to the steep terrain and lack of eastward diurnal movement onto the high plains. The moisture gradients that accompanied the finelines here instead delineated the top of the stratified shallow moist air mass (i.e., the inversion) that had nudged up against, or become blocked by, the steep mountainsides.

Farther north over southeastern Wyoming, blocking of the moist air mass was less of an issue as the LR is not nearly as high, nor as steep, as the FR. This was confirmed by the fact that a number of finelines propagated west of the LR, which cannot be explained by lee convergence. However, finelines also propagated well east of the LR from time to time, onto the high plains near and east of KCYS. Such movement is more reminiscent of general dryline behavior over the SGP (Schaefer 1974b). These differences, in light of the large moisture gradients and vertical structure of the moist layer, lend credence to the notion that the boundaries observed over southeastern Wyoming had characteristics more common to drylines. Even so, it is still possible that lee convergence over the LR may have contributed to the formation and initial propagation of some southeastern Wyoming drylines during the morning hours, especially those that formed along the slopes of the range itself. For instance, prior to 1800 UTC the mean fineline over southeastern Wyoming moved eastward down the slopes of the LR (lightest blue lines in Fig. 6), presumably as a consequence of differential mixing between the two air masses. The mixing processes associated with both lee convergence and drylines are dynamically similar, although the former does not require a humidity gradient. Ultimately, distinguishing between the two processes given the available data is difficult and outside the realm of this study. The authors offer this discussion on lee convergence merely as a conceptual aid for understanding how southeastern Wyoming dryline evolution may be influenced by terrain-related processes.

As we have seen, some drylines in southeastern Wyoming propagated westward throughout the afternoon. This was rather surprising, as drylines over the SGP tend to propagate eastward during the afternoon and westward beginning in the evening (Schaefer 1974a, 1986). The analysis provided by Fig. 8 suggested that southeastern Wyoming dryline movement was related to hour-by-hour changes in regional-scale surface flow. Specifically, the mean zonal winds tended to exhibit a westerly to easterly shift on afternoons when the dryline moved westward. This perhaps implies an additional terrain influence as the shift in winds on these days may have resulted from the development or strengthening of a very weak lee trough to the east of the FR, which would have induced a strengthening of easterly flow to the north in Wyoming. This was observed by Campbell et al. (2014), although the dryline in that study moved eastward throughout the afternoon. Ultimately, the possible influence of a lee trough is rather speculative and investigation of the mechanism responsible for this shift in winds is beyond the scope of the current study. Closer examination of the diurnal changes in the small-scale pressure and wind fields across this region would be necessary to gain a better understanding of what is driving the flow across southeastern Wyoming.

A number of these findings have implications for local forecasters. The information presented here regarding the typical synoptic environment of southeastern Wyoming drylines and the possible influence of lee convergence processes should help forecasters better anticipate days where dryline formation in southeastern Wyoming is favorable, although to what degree these conditions depart from the monthly or seasonal means remains uncertain. Additionally, awareness of the surface moisture and instability differences that apparently exist between CI and NO CI days may provide increased confidence to local forecasters when trying to predict the likelihood of deep convection on days when these drylines do form.

5. Summary and conclusions

The main objectives of this study have been to describe the general characteristics of southeastern
Southeastern Wyoming drylines were typically observed between May and August from 2010 to 2012. The key findings are as follows:

- A dryline was present on ~11% of days between the hours of 1200–0000 UTC, accompanied by a mean surface $V_{Cq}$ much larger than the mean summertime climatological moisture gradient present along the eastern slopes of the Rockies. In all cases the average $\theta_v$ was larger in the dry air west of the dryline, implying the moist air was likely denser. The average surface zonal wind across the dryline was generally convergent.

- The typical synoptic environment of southeastern Wyoming drylines at 1800 UTC was largely defined by a very broad region of surface high pressure over the Midwest, strong upper-level ridging over the north-central United States, large-scale moist southeasterly flow at the surface over the central plains, and drier westerly flow over the high terrain of the Rockies. These conditions led to a sharp surface moisture gradient and fairly strong zonal wind convergence over southeastern Wyoming and northern Colorado.

- The presence of both convergent radar finelines and strong moisture gradients over southeastern Wyoming was similar to drylines in the SGP, although it is possible that lee convergence processes may have contributed to the initial formation and eastward movement of some southeastern Wyoming drylines during the late morning hours. It is suggested that the quasi-stationary finelines observed farther south along the eastern slopes of the Colorado FR formed primarily as a result of lee convergence and were not part of a dryline.

- Southeastern Wyoming drylines were typically observed near the 105.5°W meridian, which runs along the eastern slopes of the LR, and often remained stationary or moved westward throughout the afternoon. Drylines tended to propagate westward during the afternoon when the easterly flow over the high plains became stronger than the westerly flow over the elevated terrain to the west, or remained stationary when the flow on both sides was nearly balanced. Eastward-moving drylines, while fewer in number, tended to occur in the presence of strengthening westerly flow throughout the afternoon to the west. The mechanisms responsible for the evolution of the regional wind field on these days were not explored.

- Deep convection initiated near the dryline on just over half of the days in the study, typically during the early afternoon (~1330 LT) and often within 20 km of the dryline. On one-third of these days with CI, thunderstorms became severe. Days on which deep convection occurred were typically associated with greater instability throughout southeastern Wyoming and a stronger moisture gradient across the dryline.

These findings suggest that southeastern Wyoming drylines are often quite similar to SGP drylines with regard to their moisture contrast, baroclinic nature, and propensity to be frequent loci for deep convection. On the other hand, they are less common and more local than SGP drylines, and seem to differ with regard to their characteristic synoptic environment and in some aspects of their diurnal movement. Future work investigating anomalies within the southeastern Wyoming dryline synoptic environment would be very helpful for understanding the degree to which these conditions are unique, if at all, and if these conditions differ drastically enough from the monthly or seasonal mean to be easily recognized by forecasters.

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REFERENCES


