A Climatology of Springtime Dryline Position in the U.S. Great Plains Region

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ABSTRACT

A climatology of dryline frequency and location is presented based on 30 yr (1973–2002) of April, May, and June surface observations from the Great Plains region of the United States. Drylines having a horizontal specific humidity gradient greater than or equal to 3×10^{-8} m^{-1} [greater than or equal to 3 g kg^{-1} (100 km)$^{-1}$] are found to be present on 32% of the days, with the peak frequency occurring in mid- to late May. The most favored longitude of the generally meridionally oriented drylines is near $-101°$W at 0000 UTC, although the favored longitude tends to shift westward as the April–June period elapses. There is no robust suggestion of a shift in the annual mean dryline position over the period studied.

Relationships between dryline position and wind and relative humidity data at mandatory levels (e.g., 850, 700, and 500 mb) also are investigated. Dryline longitude increases with increasing westerly momentum aloft. Dryline longitude also increases with decreasing relative humidity at 850 mb, primarily at stations in the western Great Plains region, west of the climatologically favored dryline position near $-101°$. Dryline position is not as closely associated with either 850-mb relative humidity east of the climatologically favored dryline position or relative humidity in the middle troposphere.

1. Introduction and motivation

Mesoscale boundaries separating moist, maritime tropical air from dry, continental tropical air commonly develop in the western Great Plains of the United States during the warm season. These boundaries have been referred to as "dry fronts" (Fujita 1958; Miller 1959), "dewpoint fronts" (Beebe 1958), and, most popularly, "drylines" (Rhea 1966; Schaefer 1973, 1974a, 1986). The large horizontal moisture gradients associated with drylines arise from the confluence of air coming from different source regions. The moist air east of the dryline originates from the Gulf of Mexico, whereas the dry air west of the dryline originates from arid regions in northern Mexico, eastern New Mexico, and western Texas. Gradients in dewpoint temperature in the vicinity of the dryline exceeding 10 K (1 km)$^{-1}$ have been observed.[1] On other days, the gradients are more diffuse, for example, 10 K (100 km)$^{-1}$. Drylines in the U.S. Great Plains region generally are oriented meridionally, with dry (moist) air to the west (east). The fact that the north–south orientation is approximately normal to the terrain-height gradient is not a coincidence, because drylines essentially represent the intersection of the top of the maritime tropical boundary layer with the ground. For a comprehensive review of dryline morphology, formation, and propagation, and drylines worldwide, the reader is referred to Schaefer (1986).

Drylines are among the most important mesoscale boundaries in the Great Plains region during the spring and early summer, owing to the convective storms that frequently are initiated along these boundaries. For this reason, drylines and their association with convection initiation have been studied extensively over the last several decades, both observationally (e.g., Rhea 1966; Schaefer 1974a; McCarthy and Koch 1982; Bluestein et al. 1988; Ziegler and Hane 1993; Crawford and Bluestein 1997; Hane et al. 1997; Atkins et al. 1998; Ziegler and Rasmussen 1998) and with the use of numerical simulations (e.g., Schaefer 1974b; Benjamin and Carlson 1986; Ziegler et al. 1995, 1997; Shaw et al. 1997).

Curiously, only a few climatological studies of the dryline have been undertaken since the meteorological

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[1] These observations were made using instrumented automobiles during a tornado field experiment in 1999 (Pietrycha and Rasmussen 2001).

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community first became aware of the presence and importance of drylines. In Rhea's (1966) climatological investigation of thunderstorm formation with respect to drylines, he found that drylines were present on 45% of the days of his study, which included the months of April, May, and June during the 1959–62 period. Schaefer (1973) obtained a slightly lower frequency of dryline occurrence (41% of days) during the same months in a 3-yr study from 1966 to 1968, although he probably used a more restrictive dryline definition than Rhea did. Rhea (1966) required a 10°F dewpoint differential between neighboring reporting stations, whereas Schaefer (1973) required a fairly uniform dewpoint field east of the dryline, having a mean value of 50°F or more and a diurnal change in the direction of the temperature gradient. Peterson's (1983) climatological study spanned 10 yr (1970–79), but was confined to the west Texas region (from −103° to −100°W, from the Oklahoma border to the Mexican border). Peterson identified drylines on 43% of April–June days.

The purpose of this note is to establish a 30-yr climatology of the Great Plains dryline. Surface analyses from 0000 UTC during the months of April, May, and June from 1973 to 2002 are used to record the frequency of dryline occurrence and dryline position. The April–June period tends to be when drylines are most prolific in the initiation of convective storms. Furthermore, the study investigates relationships between dryline position and upper-air observations from 1200 and 0000 UTC on days on which drylines are observed.

2. Analysis methods

Surface observations at 0000 UTC during the months of April, May, and June from 1973 to 2002, were systematically examined for the presence of drylines. Only conventional surface observations [e.g., surface airways observations (SAOs), Automated Surface Observing Systems (ASOSs)] are included. The drylines included in this study are defined as confluent boundaries separating a dry, continental, tropical air mass from a much more humid air mass (either a maritime tropical or a substantially modified continental polar air mass). The horizontal specific humidity gradient is required to be at least $3 \times 10^{-8}\ \mathrm{m}^{-1}$ [$3\ \mathrm{g\ kg}^{-1}\ (100\ \mathrm{km})^{-1}$], as resolved by objective analyses of conventional, synoptic-scale surface observations. The objective analyses of specific humidity are produced using the two-pass Barnes (1964) technique recommended by Koch et al. (1983), which enhances the convergence of the analyses to the observations. The shape of the scheme's response function is determined by the observation density, as in Koch et al. (1983). Gradients of specific humidity were preferred over gradients of dewpoint temperature, given the conservation properties of the former. Gradients in station pressure along sloping terrain surfaces give rise to dewpoint gradients, even if the specific humidity field is horizontally homogeneous.

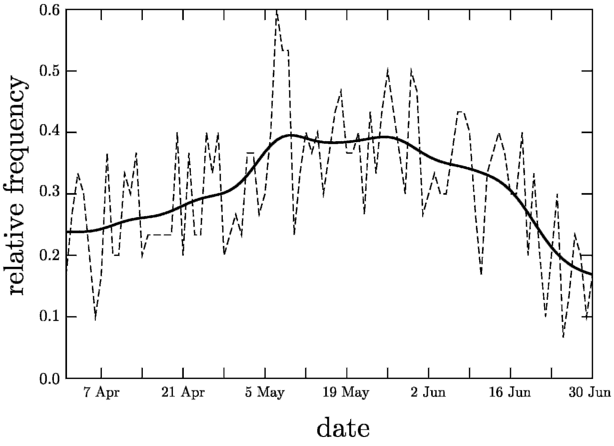

FIG. 1. Fraction of Apr, May, and Jun days during the 1973–2002 period on which a dryline was observed at 0000 UTC. The dashed (solid) trace is the raw (smoothed) average.

In the U.S. Great Plains region, drylines tend to be oriented meridionally. Occasionally, drylines deviate from a north–south orientation by as much as 30°, especially in proximity to bulges or waves along the dryline (Tegtmeier 1974; Schaefer 1986). Herein, the longitude of the dryline on a given day was defined as the *easternmost* longitude of the zone of a large horizontal specific humidity gradient defining the dryline. We estimate that the density of the surface observations (average station separation is approximately 125 km) allows us to determine dryline positions to within approximately 0.5° (less than the average station spacing owing to the irregular distribution of observing stations).

In Figs. 1–4, both raw and smoothed results are presented. The smoothed results are obtained from the application of a Gaussian smoother to the raw results. Each datum defining a smoothed trace represents a weighted average of the data defining the raw trace, whereby the weight w assigned to each datum in the raw trace is

$$w = \exp\left[-\left(\frac{|n|}{\kappa}\right)^{2}\right], \tag{1}$$

where n is the number of data points in the trace between the raw and smoothed observation, and κ governs the shape of the response function associated with the Gaussian smoother. For the smoothed traces shown in Figs. 1–4, the arbitrary choice of $\kappa = 5$ seemed to

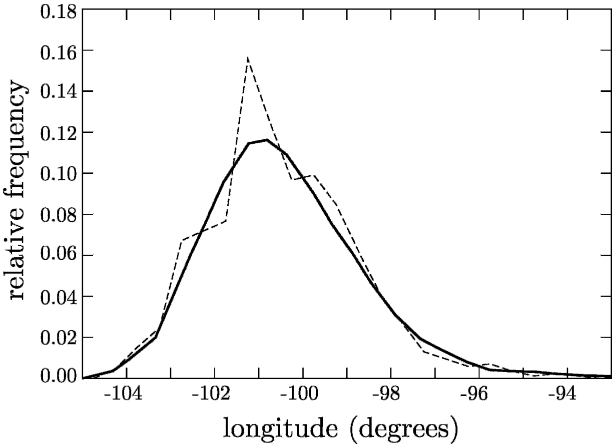

FIG. 2. Relative frequency of dryline longitude at 0000 UTC during the months of Apr, May, and Jun for the 1973–2002 period. The dashed (solid) trace is the raw (smoothed) average. Each datum along the traces represents a 0.5°-wide bin.

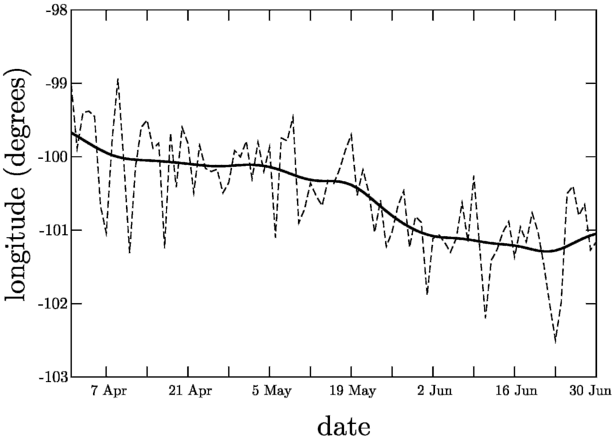

FIG. 4. Thirty-year-averaged (1973–2002) 0000 UTC dryline longitude vs days during the months of Apr, May, and Jun. The dashed (solid) trace is the raw (smoothed) average.

produce more realistic traces while preserving potentially important signals.

3. Climatology of dryline position

In the 30-yr period from 1973 to 2002, drylines were observed on 869 days during the April–June period (32% of the days). The relative frequency of dryline occurrence has a broad peak in mid- to late May (Fig. 1), when drylines have been observed on more than 40% of the days, depending on the exact date. Dryline frequency decreases in late June, when only approximately 20% of the days had identifiable drylines. We speculate that the late June dryline frequency decrease may be due, in part, to the onset of the summer monsoon in the western United States, which occasionally begins in late June. The summer monsoon would tend to be associated with a moistening of the typical source regions of continental tropical air, thereby weakening the moisture gradient in the favored dryline formation regions downstream.

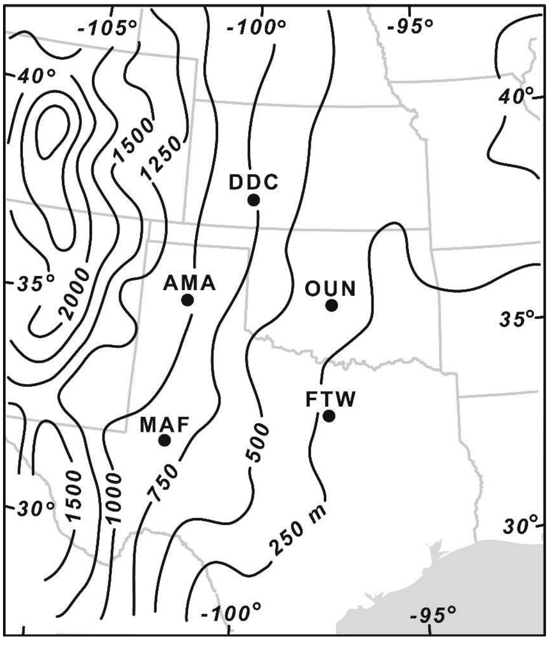

FIG. 3. Smoothed terrain elevation in the U.S. Great Plains region (contours are drawn every 250 m). The Norman, OK (OUN), Amarillo, TX (AMA), Dodge City, KS (DDC), Midland, TX (MAF), and Fort Worth, TX (FTW), sounding stations also are indicated.

The longitudinal distribution of 0000 UTC dryline positions has a well-defined peak near −101°W longitude (Fig. 2). This longitude is basically where the topography of the plains most rapidly increases from east to west (Fig. 3; between roughly 33° and 37°N latitude, the elevation increase is actually much more dramatic than depicted in the smoothed elevation contours of Fig. 3). This finding is not surprising, given that surface drylines mark the intersection with the ground of the top of the moist layer, to which the dry front terminology also has been applied (Jones and Bannon 2002). The frequency of dryline observations decreases approximately exponentially in both the east and west directions from the peak near −101°W.

In this study we have made no attempt to distinguish between "quiescent" dryline cases (e.g., those in which the dryline is observed to undergo a diurnal, zonal vacillation) and "dynamic" dryline cases (e.g., those in which dryline motion is dominated by large-scale dynamical processes). Although it is difficult to make such distinctions objectively, virtually all dryline passages

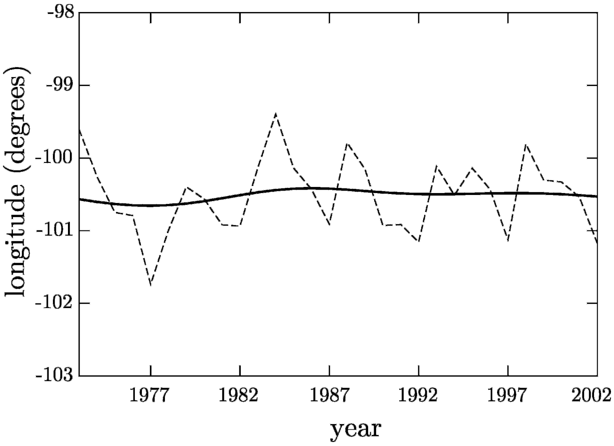

FIG. 5. Apr–Jun average 0000 UTC dryline longitude vs the year during the period of 1973–2002. The dashed (solid) trace is the raw (smoothed) average.

east of roughly −97°W longitude are associated with migrating cyclones.

The 0000 UTC dryline position drifts westward as the spring progresses. On 1 April, the 30-yr-averaged dryline longitude is near −99°W. By the last week in June, the 30-yr-average position ranges from −102.6° to −100.4°W (Fig. 4). The 30-yr mean April–June dryline longitude has no trend toward the east or west (Fig. 5). This particular result is slightly unexpected, based on casual recollections of the late-day dryline position that have been provided to us by forecasters over the years. Some had surmised that increasing agricultural land use, particularly west of −100°W, had increased the low-level humidity, thereby leading to an increasingly western mean dryline position in time. Dryline formation and propagation have been shown in idealized numerical simulations to be sensitive to soil moisture (e.g., Ziegler et al. 1995; Shaw et al. 1997), which is partly a function of land use and vegetation.

4. Relationships between dryline position and upper-air observations

Sounding observations from 1200 and 0000 UTC also were compared to 0000 UTC dryline positions (cf. Fig. 3 for sounding station locations).[2] Not surprisingly, significant negative correlations (from −0.25 to −0.50) exist between dryline longitude and the relative humidity observed at 850 mb at 0000 UTC (Table 1). It is also not surprising that the magnitude of the correlations is not as large that at 1200 UTC (Table 2). Interestingly, the magnitude of the correlation between the dryline longitude and 850-mb relative humidity tends to increase with decreasing longitude, especially for 1200 UTC upper-air observations (e.g., the correlation is −0.42 at Midland, Texas, and −0.15 at Norman, Oklahoma). In fact, there is little association between the dryline position and 850-mb relative humidity at 1200 UTC at stations east of the dryline's climatologically favored longitude. Furthermore, the relationship between the dryline longitude and relative humidity generally decreases with height. At 500 mb, 0000 (1200) UTC correlations between the relative humidity and dryline longitude at the upper-air stations that were surveyed range from −0.04 to −0.25 (from −0.14 to 0.01).

Dryline longitude generally increased with increasing westerly momentum between 850 and 500 mb (Tables 1 and 2). This relationship is somewhat better defined when 0000 UTC dryline positions are compared to 0000 UTC upper-air observations, rather than to 1200 UTC upper-air observations. These observations lead us to hypothesize that the westward drift of mean dryline position from April to June (Fig. 4) may be due, in part, to the weakening of westerly momentum at the latitudes at which drylines typically are observed as the polar jet stream retreats northward.

Another curious finding is the relatively large negative correlation between dryline longitude and the 850-mb meridional wind, at sounding stations on the "High Plains" (i.e., west of approximately −100°W). For example, at Dodge City, Amarillo, Texas, and Midland, the correlations range from −0.24 to −0.49 (Tables 1 and 2). The magnitude of the 850-mb meridional wind, which is virtually always southerly on dryline days, is closely tied to the presence of the low-level jets that are routinely observed in the plains region. Low-level jets, which may arise from a variety of mechanisms (Stensrud 1996 provides a comprehensive review), are well known for their ability to rapidly advect moisture northward from the Gulf of Mexico. Thus, the axis of the richest boundary layer moisture tends to be located not far from the axis of the low-level jet, if one exists. It follows that one possibility for these relatively large negative correlations is that anomalously fast low-level wind speeds at these stations may indicate that the axis of the richest boundary layer moisture also is unusually far to the west. Thus, the dryline might not be expected to propagate as far to the east during the day. It is perhaps noteworthy that the correlations have larger magnitudes at 1200 rather than 0000 UTC at Amarillo and Midland. This enhancement of the statistical relationship might be due to the tendency for low-level jets

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[2] The statistics for the Fort Worth, Texas, sounding station include soundings from nearby Stephenville, Texas, where soundings were launched until 1995.

TABLE 1. Linear correlation coefficients between 0000 UTC dryline longitude and selected 0000 UTC upper-air observations at Amarillo, TX (AMA); Dodge City, KS (DDC); Fort Worth, TX (FTW); Midland, TX (MAF); and Norman, OK (OUN). The zonal and meridional wind components are u and v, respectively, and the relative humidity is RH. The subscripts 850, 700, and 500 refer to the pressure levels.

	u_{850}	v_{850}	RH_{850}	u_{700}	v_{700}	RH_{700}	u_{500}	v_{500}	RH_{500}
AMA	0.49	−0.33	−0.37	0.31	−0.22	−0.22	0.33	−0.05	−0.14
DDC	0.36	−0.35	−0.26	0.17	−0.14	−0.01	0.26	0.02	−0.04
FTW	0.53	−0.01	−0.38	0.51	0.16	−0.13	0.44	0.23	−0.12
MAF	0.56	−0.35	−0.50	0.40	0.01	−0.28	0.39	0.01	−0.18
OUN	0.42	0.02	−0.25	0.48	0.13	−0.23	0.46	0.21	−0.25

to peak in the early morning hours, because of the inertial wind oscillation that is initiated by the cessation of vertical mixing within the boundary layer near sunset (Blackadar 1957).

5. Summary

This note has presented a climatology of dryline observations in the Great Plains region of the United States during the months of April, May, and June from 1973 to 2002. Some relationships between dryline location and upper-air data obtained from the rawinsonde network also were examined. Our study permits the following conclusions:

1) The frequency of dryline observations has a broad peak in mid- to late May, when drylines are observed on more than 40% of the days; the frequency of dryline observations decreases to ~20% of days by late June.
2) The distribution of dryline longitudes at 0000 UTC has a prominent peak near −101°W, which approximately coincides with a relative maximum in the longitudinal elevation gradient.
3) Drylines are observed increasingly farther west, on average, as the April–June period progresses.
4) The mean annual longitude of drylines has not shifted appreciably during the 1973–2002 period.
5) The longitude at which drylines are observed at 0000 UTC tends to increase with increasing westerly momentum in the lower to middle troposphere; the longitude tends to decrease with increasing southerly winds at 850 mb that are west of the climatologically favored dryline location near −101°W.
6) The longitude at which drylines are observed at 0000 UTC tends to increase with decreasing relative humidity at 850 mb; this relationship is strongest for the westernmost upper-air observations made on the Plains, as well as for 0000 rather than 1200 UTC upper-air observations.
7) There is little association between the middle tropospheric relative humidity and dryline position.

The results obtained herein were acquired with relative ease compared to the more difficult challenges of improving our understanding of the precise dynamical roles of drylines in producing vertical motion, and the complex interactions between drylines and their environments, such as boundary layer convective cells, gravity waves, along-dryline moisture heterogeneities, and even the synoptic scale. Large gains in our understanding of the precise dynamical role of drylines in convection initiation likely await answers to many of these unresolved questions. We are encouraged by the prospects of resolving some of these issues in the near future by way of innovative new observations and steadily improving numerical models.

Acknowledgments. This study was motivated by conversations with Dr. Erik Rasmussen (Cooperative Institute for Mesoscale Meteorological Studies). We also thank Ben Root (Penn State Department of Meteorology) for providing computing assistance, as well as the two anonymous reviewers.

TABLE 2. As in Table 1, but for selected 1200 UTC upper-air observations at Amarillo, TX (AMA); Dodge City, KS (DDC); Fort Worth, TX (FTW); Midland, TX (MAF); and Norman, OK (OUN).

	u_{850}	v_{850}	RH_{850}	u_{700}	v_{700}	RH_{700}	u_{500}	v_{500}	RH_{500}
AMA	0.28	−0.38	−0.33	0.42	−0.01	−0.12	0.41	0.23	−0.11
DDC	−0.01	−0.24	−0.18	0.17	0.09	−0.09	0.26	0.26	0.01
FTW	0.45	0.11	−0.17	0.42	0.10	−0.16	0.38	0.23	−0.02
MAF	0.55	−0.49	−0.42	0.51	0.09	−0.12	0.43	0.24	−0.14
OUN	0.33	0.14	−0.15	0.44	0.17	−0.17	0.41	0.24	−0.01

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