Climatology of Tropical System Rainfall in the Eastern Corn Belt

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(Manuscript received 17 April 2013, in final form 14 October 2013)

ABSTRACT

This study examines the frequency of daily rainfall totals greater than 2.54 cm (1 in.) averaged within a climate division (CD) associated with tropical systems that moved through the U.S. eastern Corn Belt region during the growing season. These occurrences are defined as "events." From 1913 to 2012, the tracks of 60 tropical systems moved over a study area that included 24 CDs—9 in Illinois, 9 in Indiana, and 6 in western Ohio. Of those 60 tropical systems, 37 were associated with events. Event risk varied through the growing season ranging from 3 events in June to 21 events in September. Decadal analysis showed an increase in the frequency of tropical systems and events during the last decade of the study (2003–12). Tropical systems were infrequent, and the timing of rainfall associated with the majority of events (i.e., September) was too late to impact corn and soybean development or yield in this region. Events had some impact on current and subsequent CD average soil moisture conditions; however, only 8 of the 37 events produced dramatic improvements in Palmer drought severity index (PDSI) values from categorical moderate to severe drought levels to near-normal conditions in the eastern Corn Belt. Those CDs that experienced a September or October event were associated with significantly higher PDSI values (+1.34) prior to the following summer than those that did not experience an event (+0.54).

1. Introduction

a. Motivation

Crop development and yields in the U.S. eastern Corn Belt are impacted by the occurrence of timely rainfall during critical parts of the growing season (Changnon and Neill 1968; Changnon and Changnon 2006; Tannura et al. 2008). Agricultural decision makers in this region are frequently confronted by regional short-term dry spells during the summer. Faced with weather conditions that negatively impact crops, many in agribusiness have questioned whether tropical systems could alleviate dry conditions and improve yields in the eastern Corn Belt (M. Tannura 2012, unpublished manuscript). Working with a regional agribusiness firm (T-Storm Weather 2012), this study sets out to develop a climatology of eastern Corn Belt–impacting tropical systems for the benefit of decision makers involved in managing weather-related risk. The applied nature of this study, which is tailored to those in agribusiness, necessitated defining three underlying goals:

1) to examine the frequency at which tropical systems occur in this region, especially those that produced 2.54 cm of precipitation or more averaged within a climate division (CD) (i.e., an event);
2) to determine the temporal and spatial variability of tropical systems and events to ascertain whether these events occurred during critical crop-growing periods; and
3) to test if events improved soil moisture levels and could end a drought in the eastern Corn Belt.

b. The extensive drought of 2012

From June to August during the 2012 growing season, most CDs in Illinois, Indiana, or Ohio met or exceeded the criteria for categorical moderate drought [i.e., Palmer drought severity index (PDSI) less than or equal to −2.00] based on the long-term PDSI [see Alley (1984)

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DOI: 10.1175/JAMC-D-13-0151.1

and Palmer (1965) for a discussion on calculating PDSI]. These abnormally dry summer conditions negatively impacted corn development and yields for 2012. November 2012 national estimates indicated that corn production was the lowest since 2006 and average yield was the lowest since 1995 (USDA 2013). These agricultural impacts were similar to those experienced in the last widespread drought that impacted the eastern Corn Belt, in 1988 (Riebsame et al. 1991). A question raised by many agricultural decision makers during the summer of 2012 was: what is the probability for a tropical storm of improving growing conditions in key corn and soybean areas of the central United States? (M. Tannura 2012, unpublished manuscript).

c. *Role of precipitation in crop development and yield*

During the summer of 2005, there was growing concern in Illinois over the potential impacts of the ongoing drought on agricultural yields (Changnon and Changnon 2006). From 1 March to 30 September 2005 total rainfall for each CD in Illinois ranged from 2 to 28 cm below normal (MRCC 2012). Despite this, corn yields for 2005 did not have major adverse effects from the drought. Changnon and Changnon (2006) suggested that this was due, in part, to bioengineering that produced corn that was drought resistant as well as the beneficial effects of well-timed rainfall from Tropical Storm Dennis in July.

Various studies have found that the optimal timing for rainfall is crop dependent. Changnon and Neill (1968) showed that rainfall between 29 June and 12 July was found to enhance corn yields more than any other period of time that was studied, and Tannura et al. (2008) illustrated that June and July rainfalls are the primary drivers of yield. Furthermore, Changnon and Changnon (2004) found that although mid-August rains in 2002 improved the soybean yield, the corn yield was unaffected. This result implies that rainfall "too late" in the summer may have no effect on one crop (i.e., corn) but may be beneficial to another crop (i.e., soybeans).

d. *Tropical systems and impacts on soil moisture conditions*

Tropical systems typically weaken over land due to decreased sensible and latent heat flux, friction, and preexisting baroclinic conditions (Evans et al. 2011; Andersen and Shepherd 2014). Overland evolution (i.e., strengthening, weakening, direction of movement, etc.) of tropical systems may depend on interactions with existing synoptic-scale features (Bosart and Lackmann 1995; Bassill and Morgan 2006), soil moisture conditions (Arndt et al. 2009; Evans et al. 2011; Andersen and Shepherd 2014), and the presence of barotropic or baroclinic

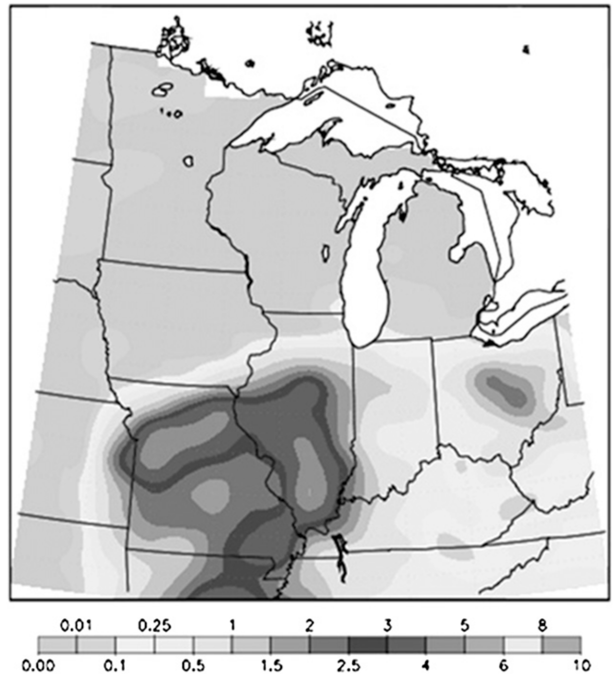

FIG. 1. The accumulated rainfall from 31 Aug to 2 Sep 2012 associated with the remnants of Hurricane Isaac. Over 2.5 in. (5.3 cm) of rain fell in areas of southern Illinois, northern Missouri, and portions of Ohio. Up to 5 in. (12.7 cm) of rain fell in southern Illinois. [This image was generated using the Midwest Regional Climate Center's MACS website (MRCC 2012).]

conditions (Bassill and Morgan 2006). Despite less-than-ideal conditions, some tropical systems can maintain some organization and continue to produce heavy rain and wind far inland (Hart and Evans 2001). Persistence of circulation over land associated with a parent tropical system is sometimes referred to as the "remnants" of a tropical system (e.g., McTaggart-Cowan et al. 2004). Within the context of this study, remnants will refer to any overland propagation of tropical systems as delineated by reanalyzed North Atlantic hurricane database (HURDAT 2) best tracks (NHC 2012).

In a study by Nogueira and Keim (2010), tropical systems, including those that affected the Corn Belt region between the months of June and October, were analyzed during the 1960–2007 period. They found that the percentage of average monthly rainfall from tropical systems in Illinois, Indiana, and Ohio for these months ranged from 0% to 20%. The largest percentage of average monthly precipitation from tropical cyclones (20%) occurs in September, when precipitation from tropical systems can range from 2.54 to 5.08 cm yr^{-1} (Nogueira and Keim 2010). Hart and Evans (2001) identified locations in the eastern Corn Belt that experienced 5 cm or more of rainfall from a tropical system. They found that this occurrence was infrequent in the

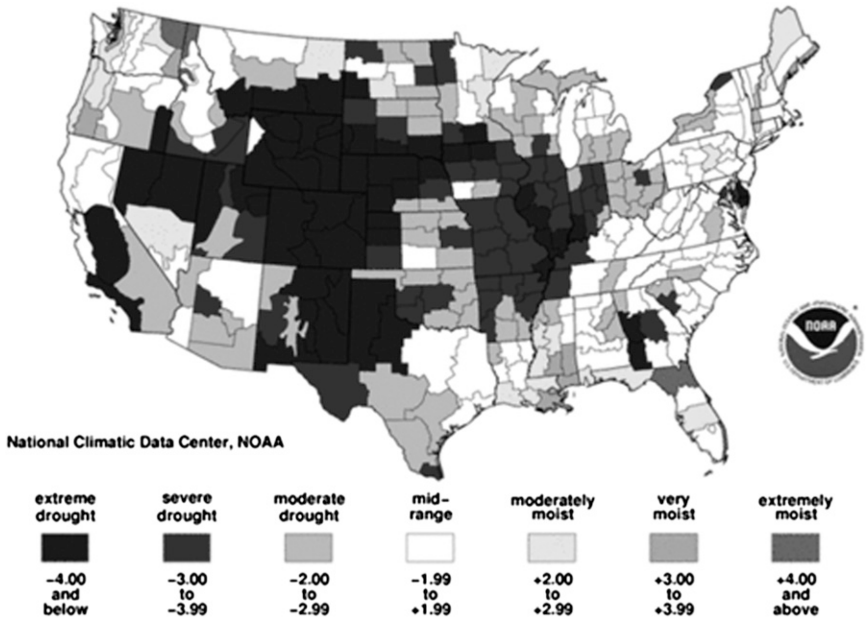

FIG. 2. PDSI values at the end of August 2012 showing at least moderate drought in each of the 24 CDs in the eastern Corn Belt study area. Illinois shows complete coverage of at least severe drought. [Image is from the National Climatic Data Center website (NCDC 2013).]

eastern Corn Belt, with a return period of 20 years or more (Hart and Evans 2001).

Late in the summer of 2012, a tropical system (Isaac) impacted areas of Illinois, Indiana, and Ohio (Fig. 1). From 30 August to 2 September 2012, Isaac produced up to 12.7 cm (5 in.) of rain in areas that were experiencing extreme drought conditions (Fig. 2), as determined by the PDSI (MRCC 2012). Following this rainfall, drought conditions were improved over much of the Corn Belt region in Illinois, Indiana, and Ohio (Fig. 3). The most dramatic improvements in CD PDSI values were found in the southern two-thirds of Illinois and Indiana (NCDC 2013).

While the remnants of Hurricane Isaac produced rainfall in a region that was designated as being in categorical moderate to extreme drought, was this tropical system considered a ''drought busting'' event? Maxwell et al. (2012) examined the influence of drought-mitigating tropical cyclones in the southeastern United States during a period from 1950 to 2008 and determined that tropical cyclones ended approximately 40% of the droughts during that period in at least one CD. Applying the drought-busting tropical cyclone criteria developed by Maxwell et al. (2012), this research will examine whether remnants from tropical cyclones end moderate to severe droughts in the eastern Corn Belt.

e. *Climate division data*

CD data have proved sufficient for numerous studies that employed daily and monthly CD averages to examine short-term temporal variation over a long study period (McRoberts and Nielsen-Gammon 2011; e.g., Huff and Angel 1992; Maxwell et al. 2012, 2013). Recently, gridded climate division datasets have been created to address the weaknesses of the traditional climate division dataset (TCDD; Fenimore et al. 2011). The National Climatic Data Center has discussed a new gridded divisional dataset (GrDD) and outlined plans to make the transition from the TCDD to the GrDD by 2013 (Fenimore et al. 2011). The GrDD includes more cooperative observer network (COOP) stations than the TCCD and addresses topographic (e.g., elevation and terrain) and station variability issues (e.g., changes in the number of stations per CD; Karl et al. 1986; Guttman and Quayle 1996; Menne et al. 2009; Fenimore et al. 2011). The most notable difference between the GrDD and the TCDD, within the context of this study, is that daily climate values from dates before 1931 are station based and not based on state averages (Fenimore et al. 2011). The Midwest Regional Climate Center (MRCC) developed a similar 65-km-resolution gridded dataset and has made the data available since 1998 (J. Angel, personal communication). MRCC data are employed in this study to capture localized rain events much more effectively than the TCDD and make up an ideal daily CD dataset to use for the purposes of this study. Although MRCC precipitation data are gridded, monthly PDSI values are still taken directly from TCDD data. Thus, issues related to the statewide aggregation of data may still be apparent in data from months before 1931.

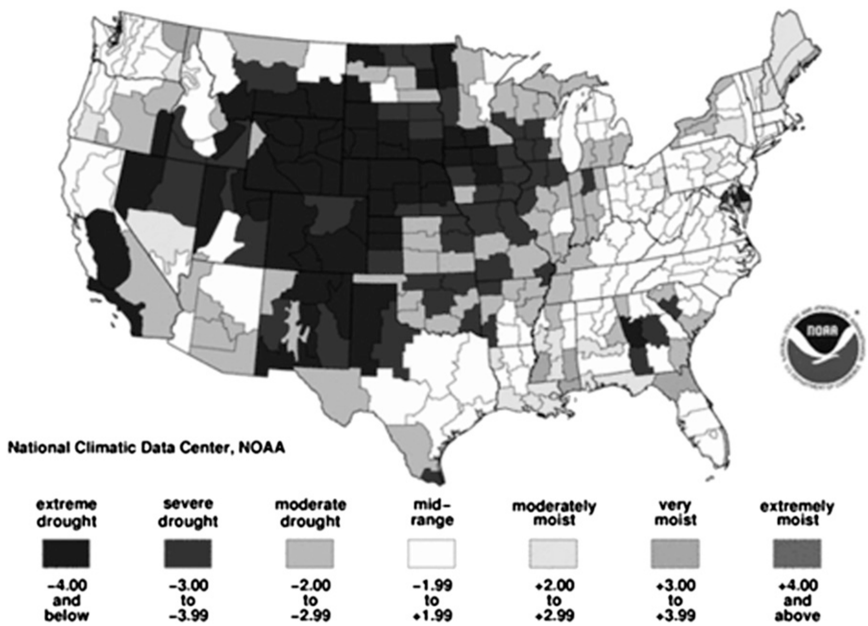

FIG. 3. PDSI values at the end of September 2012. Illinois and Indiana show improvement after the passage of Hurricane Isaac. CD 7 in southeastern Illinois improved from severe drought to midrange (i.e., normal) conditions. [Image is from the National Climatic Data Center website (NCDC 2013).]

2. Methods and data

a. Study parameters

Differentiating between frontal rainfall and tropical system rainfall has proven difficult, even in the southeastern United States (Knight and Davis 2007; Maxwell et al. 2013). Although this study does not test if a considered tropical system merges with an existing frontal boundary, this phenomenon may be important to regional rainfall amounts and agricultural applications. Therefore, this study will also consider tropical systems after their categorical transition to subtropical, tropical depression, or extratropical systems. This approach differs from the methodology of some existing studies (e.g., Nogueira and Keim 2010) to meet the unique needs of eastern Corn Belt agribusiness interests. One caveat of this approach is that nontropical system rainfall may be included in the analysis. Further event qualifiers are defined to minimize the inclusions of nontropical system rainfall.

We selected 24 eastern Corn Belt CDs (Illinois CDs 1–9, Indiana CDs 1–9, and western Ohio CDs 1, 2, 4, 5, 8, and 9; Fig. 4) for this study because they were areas with long-term high soybean and corn production (Figs. 5 and 6; M. Tannura 2012, unpublished manuscript). To capture tropical system rainfall in these CDs, a circular buffer was created with a radius of 3 decimal degrees centered on the centroid of each CD polygon. A radius of 3 decimal degrees was chosen to be representative of the mean tropical system radius in the Atlantic basin (Merrill 1984). From these buffers, a rectangular area, representative of the northern, western, eastern, and southern extremes of buffers centered on each CD centroid, was generated to identify a region where remnants from a tropical system could potentially impact precipitation amounts in an eastern Corn Belt CD based solely on available best-track data of each tropical system

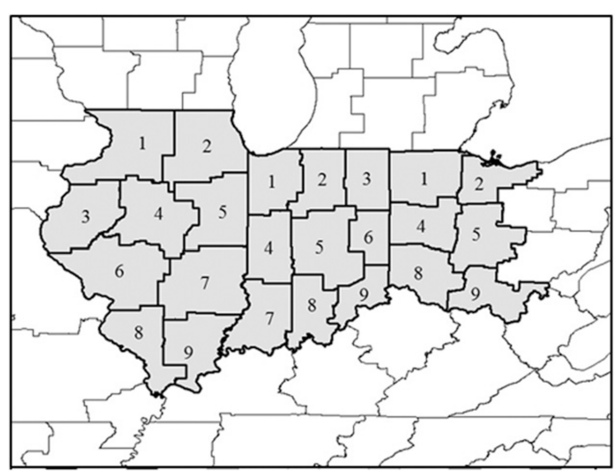

FIG. 4. Illinois, Indiana, and Ohio CDs that are within the study area. These CDs represent areas that experience occasional tropical system rainfall and have widespread agricultural land use. High corn and soybean production is common within these CDs.

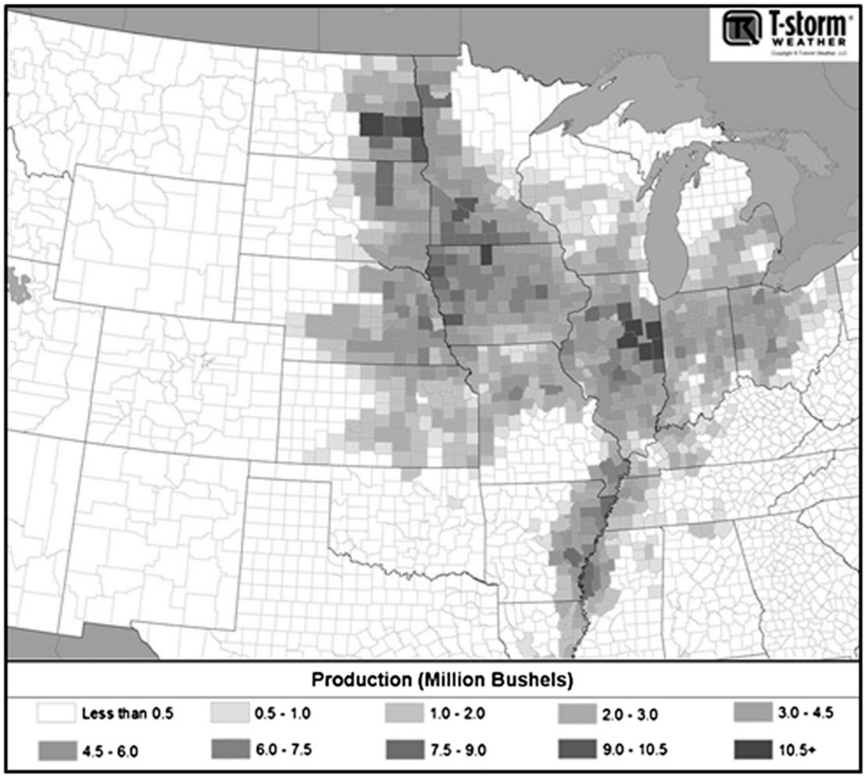

FIG. 5. Mean soybean production during 2006–10 for the United States by county. Areal soybean production maxima can be seen in east-central Illinois and portions of eastern North Dakota, which are denoted by a clustering of darker-shaded counties. [The image was generated by T-Storm Weather (T-Storm Weather 2012; NASS 2012).]

(Fig. 7). Only tropical systems affecting the rectangular study area between 1913 and 2012 will be considered. The 100-yr study period was chosen as the ideal range for agribusiness applications (M. Tannura 2012, unpublished manuscript).

b. HURDAT2

To develop a database of named tropical systems entering the eastern Corn Belt buffer region (Fig. 7), the National Hurricane Center (NHC) HURDAT2 (NHC 2012) was examined (Landsea et al. 2004). HURDAT2 spatially displays every tropical storm track for each year, identifying the location of transitional intensity information and dates of impact. The NHC's data archive of annual Atlantic basin best-track seasonal maps each year dating from 1913 through 2012 were examined and the year, name, and range of regional dates were noted for each tropical system associated with a track that intersected or was completely contained by the study area buffer.

c. Event selection

To determine whether each selected tropical system would be considered an event, average daily CD precipitation values were examined. The MRCC has developed a gridded daily-averaged CD precipitation dataset that exists on the MRCC Applied Climate Systems (MACS) database (MRCC 2012). These data were used to examine daily precipitation totals associated with the identified tropical systems. If an average of 2.54 cm or greater of precipitation fell in 24 h in at least one CD in the eastern Corn Belt during the growing season (June–October), that storm was then labeled as an event. In each CD, general windows of consecutive days during the period when the tropical system was within the buffer region were checked for each tropical system to ensure a comprehensive sample of possible events. The mean amount of time a tropical system was in the eastern Corn Belt buffer was 22.1 h and ranged from 6 to 144 h with a median of 18 h. Thus, window length was typically 1 day but was as high as 7 days.

d. Soil moisture conditions

To understand the impacts that tropical system events had on soil moisture and drought conditions, the CD monthly values of the PDSI, obtained through the MACS database, were examined. The PDSI (Palmer 1965) is sufficient for quantifying long-term drought severity and since it is cumulative, month-to-month

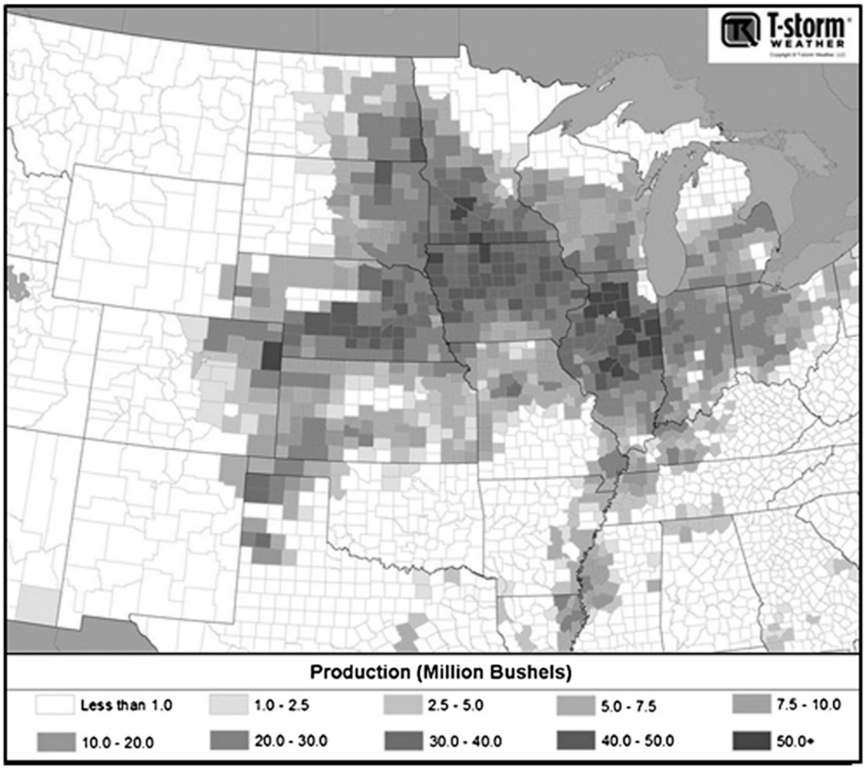

FIG. 6. Mean corn production during 2006–10 for the United States by county. High corn production exists in much of Illinois, Indiana and Ohio including an areal maximum in northern Illinois, which is denoted by a clustering of darker-shaded counties. [The image was generated T-Storm Weather (T-Storm Weather 2012; NASS 2012).]

variability (e.g., worsening or improving) in PDSI values could be explained by the occurrence of unusual weather patterns (i.e., a tropical system; Maxwell et al. 2012, 2013). To compare PDSI values of the month prior to event (PE) and the month of the event (E), E needs to be defined. If an event's dates ranged over a period of 2 months, E was identified as the month having more event dates than the previous/following month depending on the dates of occurrence. For example, the remnants of Hurricane Isaac entered the region on 31 August 2012, exited on 3 September 2012, and produced events on 1 and 2 September. With the greatest number of event days falling in September, August was considered PE and September was therefore considered E. Based on these criteria, the E–PE difference was used to describe changes in soil moisture conditions associated with the occurrence of an event. In the identified events, the mean E–PE difference was computed for those CDs that experienced an event and those that did not experience an event. These average differences were compared, using the t-test statistic, to determine if event CDs experienced a greater change in PDSI than CDs that did not experience an event. Furthermore, to explore if late-season tropical system rainfall had an effect on the next season's soil moisture conditions, PDSI values for the month prior to the growing season (May) were examined for the year following each September or October event. Means for event CD PDSI and nonevent CD PDSI were calculated and a t-test statistic was computed to determine if event CDs had significantly higher PDSI (i.e., wetter conditions) values entering the growing season the following year when compared to nonevent CDs' PDSI values.

3. Results

Over the 100-yr (1913–2012) period, a total of 60 tropical systems entered the eastern Corn Belt buffer region, with 37 events impacting at least one CD with 2.54 cm or greater of precipitation within 24 h (Table 1). Thus, 62% of the tropical systems entering the buffer region produced a heavy amount of precipitation (i.e., an event) in at least one CD. The frequency of tropical systems and events varied throughout the 100-yr period (Fig. 8). The decadal-mean number of tropical systems entering the Corn Belt region for the first nine decades was 5.2.

FIG. 7. Rectangular buffer containing the eastern Corn Belt. Using the HURDAT2 (NHC 2012) best tracks, this buffer region was used as a selection criterion for which tropical systems were analyzed. Any tropical system with a 6-h best track that intersected or was completely contained within the buffer boundary was considered in this study.

If we include the last decade (2003–12), which produced the highest number of tropical systems (13) in the past century, the average number of tropical systems increases from 5.2 to 6.0 (15% increase). The entire study period exhibits interdecadal variance, with a range of from 1 (1933–42) to 9 (2003–12) events per decade and an average of 3.7 events per decade. When the 2003–12 decade is removed (which experienced nearly double the number of events of any previous decade), the mean decreases by 19%, producing a decadal average of 3.1 events.

Seasonally, the greatest number of the events occurred in September (Fig. 9), with a total of 21 events (56.7% of the total 37 events occurring during the 100-yr period), which is similar to what Nogueira and Keim (2010) reported. June experienced the fewest events, with three (8.1%) of the total number of events. The monthly return periods for a tropical system entering the eastern Corn Belt buffer region and producing an event are as follows: once in 5 years in September, once in 20 years in October, once in 25 years in August and July, and once in 33 years in June.

Of the 60 tropical systems, 23 did not create an event; however, the number of CDs impacted by any one event exhibited a great deal of variability (Fig. 10). Out of a total of 37 events, 11 events affected 1 or 2 CDs, 12 events affected 6–8 CDs, and 8 events affected 10 or more CDs. This shows while approximately 29.7% of the events only affected 1 or 2 CDs, 21.6% of the events were spatially large, impacting more than 40% of all CDs in the study region. However, on average, the total number of CDs affected by any one event was 5.7 (23.7% of the 24 CDs).

To examine the frequency of events spatially across the eastern Corn Belt, the number of events experienced during the 100-yr period was determined for each CD (Fig. 11). CD 6 in east-central Indiana and CD 5 in east-central Illinois experienced the highest numbers of events (12 out of 37 events or 32.4%). On the other hand, the northwestern regions of Illinois and Ohio were impacted by the lowest number of events (6 out of 37 events or 16.2%). In general, the southern two-thirds of each state experienced more events although no obvious pattern was discernible across the three-state region.

The PDSI difference between monthly values of E and PE were calculated for the 24 CDs in the 34 events [since 2 events occurring in the same month happened three times (October 1923, September 1932, September 2004), the number of PE and E months is 34 and not 37]. The average E–PE difference for CDs that experienced an event was +1.06, while that average difference was −0.06 for those CDs that did not experience an event (during 1 of the 34 E months). The mean difference between those CDs that experienced an event and those that did not was approximately 1.13, a statistically significant difference using a 95% confidence interval ($p < 0.0001$). PDSI values for May of the year following each September or October event were examined to determine if there was a significant difference between the PDSI values for event and nonevent CDs entering the subsequent growing season. The average PDSI value in May of the following year was +1.34 for event CDs and +0.54 for nonevent CDs. The difference between the means (0.8) was statistically significant using a 95% confidence interval ($p < 0.0001$).

Using the drought-buster approach developed by Maxwell et al. (2012), where a CD has a PDSI value of less than or equal to −2.00 for PE and the PDSI improves to a value of greater than or equal to −0.49 for E, 8 out of 37 events (21.6%) in the eastern Corn Belt met the criteria for drought-buster status in at least one CD. The drought-buster events in this study were storm 3 (1932), storm 8 (1932), storm 2 (1941), Carla (1961), Betsy (1965), Gilbert (1988), Opal (1995), and Isaac (2012). When considering the benefits of a drought buster on agriculture, the timeliness of occurrence is critical. The eight events occurred in September or October, when rainfall is less crucial for crop development or yields. These storms, however, could have contributed to an autumnal recharge of soil moisture.

TABLE 1. List of each of the 60 tropical systems that entered the eastern Corn Belt buffer from 1913 to 2012. Included are the names of the systems, the dates that they were within the buffer, the CDs (if any) that experienced an event from the system, and the total number of CD events produced by each system. Storm information is from the HURDAT2 best tracks from NHC (2012).

Year	Name	Regional dates	IL CDs	IN CDs	OH CDs	Total No. of CDs
1915	2	20–22 Aug	4–9	3, 4, 7	4	10
1915	4	5–6 Sep				0
1915	6	1 Oct				0
1916	14	19 Oct	2			1
1920	3	23 Sep				0
1923	8	17 Oct	2, 4–9	1, 2, 4, 5, 7, 8		13
1923	9	18–19 Oct	2, 5, 7, 9	1, 4		6
1926	1	31 Jul–2 Aug	5	3, 5, 6, 9	8	6
1928	2	16–17 Aug				0
1932	3	2–4 Sep	9	2–9	1	10
1932	8	20–21 Sep		6	8	2
1932	11	18 Oct				0
1934	1	18 Jun				0
1940	2	11 Aug				0
1940	3	13–14 Aug				0
1941	2	24–25 Sep	2–4, 6			4
1942	1	23 Aug				0
1947	4	21 Sep	1	7		2
1948	5	5–6 Sep	8, 9			2
1949	2	28 Aug				0
1949	10	6 Oct	1, 4, 5, 7			4
1950	Baker	1 Sep	7, 8	3, 4	1, 2	6
1953	3	2–3 Sep				0
1955	Connie	14 Aug				0
1955	5	29 Aug	3			1
1957	Audrey	28–29 Jun	5–7	2, 3, 6, 9	1, 2, 4, 5	11
1959	Gracie	30 Sep–1 Oct			5	1
1960	1	27–28 Jun				0
1960	Ethel	17 Sep	5			1
1961	Carla	13–14 Sep	1–6	1		7
1965	Betsy	11–12 Sep	8, 9	7–9	5, 8, 9	8
1968	Candy	25–26 Jun	1–5, 7–9	1–3		11
1969	Camille	19–20 Aug				0
1970	Becky	23 Jul				0
1975	Eloise	24 Sep			9	1
1979	Bob	12–14 Jul	1	4–9		7
1979	Claudette	28–29 Jul	7, 8	5, 6		4
1979	Frederic	14 Sep		6, 8, 9	2, 4, 5, 8, 9	8
1985	Elena	4 Sep				0
1986	Bonnie	28 Jun				0
1988	Gilbert	19 Sep		2, 3		2
1989	Hugo	22 Sep			9	1
1994	Beryl	17 Aug				0
1995	Erin	5–6 Aug		6–9	4, 5, 8, 9	8
1995	Opal	5–6 Oct		6, 9	1, 2, 4, 5, 8	7
2001	Barry	7–8 Aug				0
2002	Isidore	27 Sep			2, 4, 5, 8	4
2003	Bill	2 Jul				0
2003	Isabel	19 Sep				0
2004	Frances	8–9 Sep			2, 5, 9	3
2004	Ivan	17 Sep			9	1
2005	Arlene	12–14 Jun	9	4–8		6
2005	Cindy	7 Jul				0
2005	Dennis	11–17 Jul	8, 9	5		3
2005	Katrina	30–31 Aug	9	5–9	1, 2, 4, 5, 8, 9	12
2005	Rita	25–26 Sep	7	1–6	1, 2, 4	10
2008	Fay	27–28 Aug				0
2008	Gustav	4–5 Sep	2–6	1		6
2008	Ike	14–15 Sep	1–6	1, 2		8
2012	Isaac	31 Aug–3 Sep	3–9	7, 9	5	10

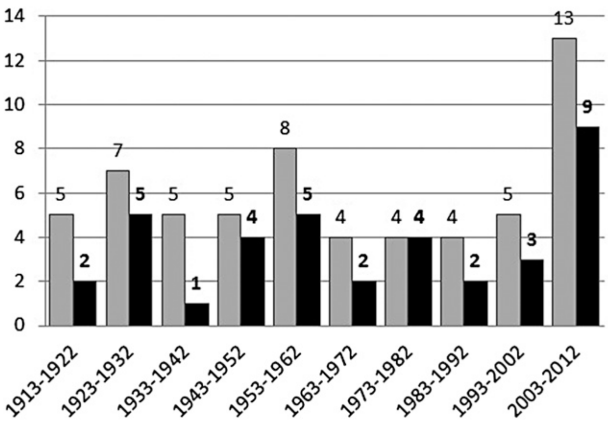

FIG. 8. Decadal frequency of total numbers of tropical systems (gray) and tropical systems that produced events (black). The *y* axis represents frequency and the *x* axis represents the decade. The most recent decade produced over twice the decadal mean of both storms and events for the region.

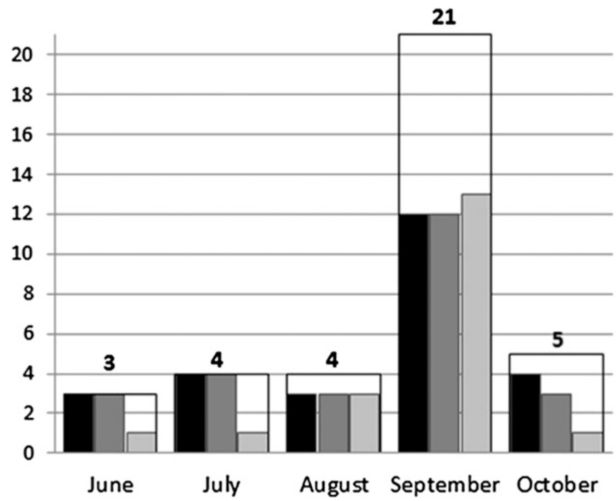

FIG. 9. Number of events per month for each state. The number of events for Illinois (black), Indiana (gray), and Ohio (light gray) are displayed for June–October from 1913 to 2012. Total events are represented by the open bar. It is possible for events to happen in one state and not the other during the same time period and this explains why September has a much higher total event count than any individual state. Conversely, months like July show that both Illinois and Indiana have been affected by all four events in July during the 100-yr period.

Furthermore, no drought busters occurred before 1932. This may be due to the methods by which PDSI was calculated for months before 1931.

4. Conclusions

The number of tropical system tracks that entered the region encompassing the eastern Corn Belt over the 100-yr (1913–2012) study period was 60; 37 of these tropical systems produced a CD daily-average precipitation amount of 2.54 cm or more in at least 1 of the 24 CDs in the region. During the first 90 years of the study, the number of tropical systems and events (decadal averages of 5.2 and 3.1 respectively) ranged from 4 to 8 tropical systems and from 1 to 5 events per decade. In the last decade (2003–12), 13 tropical storms and 9 events occurred. On average an event occurs once every 2.7 years and sometimes during the growing season. However, the risk varies dramatically through the season, ranging from approximately once in 5 years for September to once in 33 years for June. Importantly, only 11 out of the 37 (29.7%) events occurred in the key corn and soybean development months of June–August and had a return period of 9.1 years. These results suggest that remnants from tropical events should not be counted on to help crop development in the vast majority of years.

It is unclear why the spatial pattern of event frequency, shown in Fig. 11, exists. One conceivable explanation is that predecessor rain events (PREs, Galarneau et al. 2010), ahead of the tropical system center of circulation, may have produced heavy-enough precipitation to complement rainfall associated with the main tropical system rain shield over a 24-h period. This is unresolvable with the daily climate averages used in this study. Seven tropical systems selected for this study were documented as producing PREs in Galarneau et al. (2010) from 1995 to 2008, including Opal (1995), Isabel (2003), Frances (2004), Dennis (2005), Katrina (2005), Rita (2005), and Ike (2008). All seven tropical systems mentioned in the study eventually produced events in the study area and represented 41% of all tropical systems and 58% of all events during this period. Although

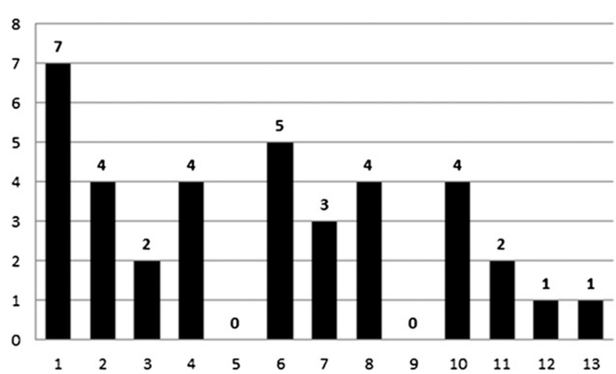

FIG. 10. Distribution of the number of CDs that experienced an event by any single tropical system that was analyzed. For example, six CDs experienced an event during five tropical system passages and one CD experienced an event during seven tropical system passages.

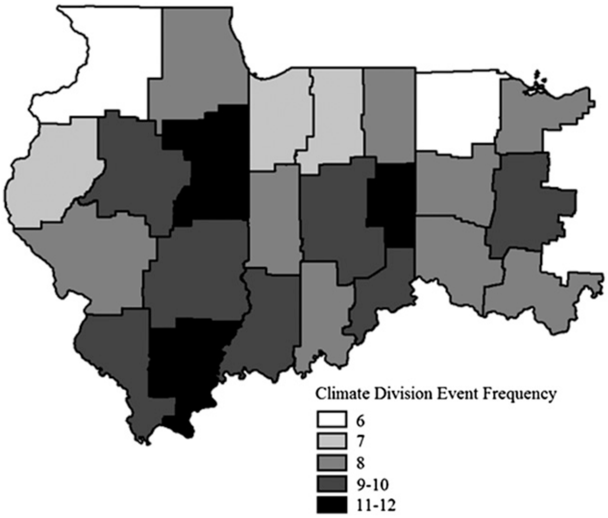

FIG. 11. Total number of event occurrences for each CD in the eastern Corn Belt study area. Illinois CD 5 and Indiana CD 6 have the largest numbers of event occurrences (12) and Ohio CD 1 and Illinois CD 1 have the fewest event occurrences (6).

Galarneau et al. (2010) only mention Ike (2008) as producing a PRE that affected Illinois, Indiana, or Ohio, the criteria for PRE identification mention that there must be a clear separation between the tropical cyclone rain shield and the PRE rainband. It is possible that the same mechanisms involved in producing PREs when the tropical system was farther south produced heavier rainbands that were connected to the rain shield when the systems moved north. This could also explain the variability in the number of CD events (Fig. 10) produced by each system. Validation of this assumption would require an in-depth study and the authors present this possibility as conjecture. Sampling issues could also account for the spatial pattern, and a larger number of tropical systems and events could smooth the pattern.

Monthly PDSI values for the period before and after each tropical system were examined for the 24 CDs that make up the eastern Corn Belt. When examining the difference between the monthly PDSI value after the event and before the event, those CDs that experienced an event (i.e., a daily average of 2.54 cm or more of precipitation) had a 1.13 greater increase in average PDSI value than those CDs that did not experience an event. Only 8 of 37 events (21.6%) had at least one CD experience an increase in PDSI value from less than −2.00 to a value greater than −0.50 [“drought buster”; Maxwell et al. (2012)]. These eight events occurred in September or October, generally beyond the period when critical crop development occurs for corn or soybeans. However, when comparing event CD to non-event CD PDSI values in May of the year following a September or October event, the CDs that experienced an event had significantly higher PDSI values. This suggests that events may result in more favorable soil moisture conditions entering the growing season the following year.

Tropical systems that infrequently migrate into the eastern Corn Belt often produce useful (>2.54 cm day^{-1}) rainfall in many areas. Because the timing of most of these events is beyond the critical growth stages for corn and soybeans, this rainfall rarely alleviates the drought impacts on eventual yield. However, when events do occur, they may have a positive impact on soil moisture conditions at the beginning of the following year’s growing season.

Acknowledgments. The authors thank Stephen Strader for his editorial input and Andrei Bouwmeester for his work in the undergraduate class that led to the inception of this paper. The authors also thank two anonymous reviewers for their helpful input that resulted in a much improved manuscript.

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