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Contribution of landfalling tropical system rainfall to the hydroclimate of the eastern U.S. Corn Belt 1981–2012

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ABSTRACT

This study provides a climatology (1981–2012) of landfalling tropical systems in the eastern U.S. Corn Belt and investigates the total contribution of these storms to the monthly climatological rainfall in the Midwestern United States. The primary focus is on rainfall impacts from landfalling tropical systems on historic corn yields at the climate division and crop reporting district level. Climatologically dry to drought conditions for historic monthly observed rainfall are identified using the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Index (SPI). It was found that without landfalling tropical system rainfall, the percentage increase in climatologically dry (or drier) conditions across the domain at state climate division resolution increased from 16% up to over 200%. The study also considers the effects of climatologically wet conditions on crop yields.

Landfalling tropical system rainfall accounts for approximately 20% of the observed monthly rainfall during the tropical storm season (June–November) across the eastern U.S. Corn Belt (1981–2012). Correlation between the annual number of landfalling tropical systems and annual yield by state results in no relationship, but correlation of August monthly observed rainfall by climate division to crop reporting district annual yields has a weak to moderate, statistically significant correlation in Ohio districts 30–60 and Indiana CRD 90. ANOVA analysis suggests that landfalling tropical rainfall may actually reduce yields in some state's climate divisions/crop reporting districts while increasing yield in others. Results suggest that there is a balance between landfalling tropical storms providing sufficient rainfall or too much rainfall to be of benefit to crops. Findings aim to provide information to producers, crop advisers, risk managers and commodity groups so that seasonal hurricane forecasts can potentially be utilized in planning for above or below normal precipitation during phenologically important portions of the growing season.

1. Introduction

Tropical systems (TSs), defined here as hurricanes, tropical storms, tropical depressions, and remnant lows, that impact the tropical and subtropical latitudes of the United States primarily originate in the descending branch of the Hadley cell circulation known as the northeasterly trade winds over the Atlantic Ocean. Climatological assessment of rainfall resulting from TSs has been completed for coastal regions along the Gulf of Mexico and the East Coast of the United States (e.g., Cry (1967), Knight and Davis (2009), Nogueira and Keim (2011), LaRow (2013) and Maxwell et al. (2013)). However, less attention has been given to assessing the contribution of landfalling TSs to the eastern U.S. Corn Belt hydroclimate, especially in regards to agricultural production.

The Midwest region (i.e., the Eastern U.S. Corn Belt – in this study is defined as Wisconsin, Michigan, Illinois, Indiana, Ohio, and Kentucky) of the United States is inclusive of a vast expanse of agriculture land primarily devoted to the growth of soybean and corn. Seasonal rainfall from midlatitude weather systems and convective thunderstorms is typically sufficient for the growth of corn across much of the region. Irrigation is only readily needed in regions of sandy soils (e.g., northern Indiana, southern Michigan, and portions of Illinois), and during climatologically drier periods of the growing season. Corn reaches its critical grain-fill period during the months of August and September (depending on planting date) when heat and moisture stress within a two week window can vastly affect the yield potential of the crop (Nielsen,

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2011; Takle et al., 2014).

Hydroclimatological analyses are valuable tools allowing for a better understanding of the relationships between crop growth and precipitation in light of potential climate variability and change identified in the last several years (e.g., IPCC (2014) and Charusombat and Niyogi (2011)). As the world's largest producer of corn, the United States Corn Belt is located in a region expected to experience climate variability and change. Climate change projections indicate longer dry spells, heavier rain events, and longer growing seasons resulting from warmer days and warmer nights (Melillo et al., 2014). Being prepared to face climate change begins with understanding climate variability (e.g., anomalous warm/cold and wet/dry conditions) caused by various atmospheric phenomena. This examination of a hydroclimate region helps provide a better understanding of climate variability impacts to precipitation in the climate system, and in this case, a better understanding of climate variability in the Midwest hydroclimate from landfalling TSs.

This analysis investigates landfalling TS rainfall in the Midwest in an effort to understand its' contribution during the hurricane/tropical system season (June 1–November 30) to the Midwest rainfall budget. The period reviewed is 1981–2012 to coincide with the most recent monthly precipitation climate division normals. The normals are used to determine if observed rainfall for a given month can be classified according to the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Index (SPI) as climatologically dry up to full drought conditions.

The Midwest is selected as the study area because of its contribution to crop production in the United States. Research efforts to determine the contribution of TS rainfall to seasonal rainfall in the United States were completed over the last several years for coastal regions (e.g., Corbosiero et al. (2009), Knight and Davis (2009), LaRow (2013), Maxwell et al. (2013), Nogueira and Keim (2011), Rodgers et al. (2001), and Cry (1967)), however, the Midwest Region and impacts to agricultural production is an area with limited research. Many TSs have traversed far inland impacting the Midwest during the growing season such as Tropical Storm Arlene, Hurricane Katrina, and Hurricane Rita in 2005. Rippey (2010) shows a possible link between corn yield and Atlantic tropical cyclone activity/inactivity in an assessment of the Pacific Decadal Oscillation (PDO) and El Niño-Southern Oscillation (ENSO), which shows that the number of landfalling TSs may influence crop yields. This study further investigates the conjecture that landfalling TSs serve an important role in the Midwest hydroclimate as related to agriculture.

In addition to the aforementioned studies, Haberlie et al. (2014) recently reported an analysis of TS rainfall in the Eastern Corn Belt similar in intent to this work, but differing in tools, methodology, classification of landfalling TSs, and scope of influence on the Midwest hydroclimate. The primary difference between Haberlie et al. (2014) and this study is that Haberlie et al. (2014) identify the role of landfalling TSs entering the Midwest as “drought-busting events” based on the storm producing a specific precipitation threshold value and the storm's ability to alleviate drought conditions. The drought of 2012 serves as the catalyst for their investigation. In contrast, this study investigates monthly precipitation conditions with and without landfalling TSs affecting Midwest rainfall. The primary goal here is to assess the total climatological contribution of landfalling TS-based monthly rainfall to the climatological normal and the impact this rainfall has on crop production during the hurricane/tropical system season (June–November). The unique ability to ascertain the contribution of landfalling TSs to historic observed Midwest rainfall, and comparing that to the climatological normal rainfall allows the determination of whether landfalling TSs benefit or hinder eastern U. S. Corn Belt crop production. Whether the rainfall is beneficial or harmful to crop production will depend on antecedent soil moisture conditions from any previous rainfall events. Tropical Storm Bill (June 2015) is a good example of what this study aims to highlight by completing a landfalling TS climatology in the Midwest that includes historic yield data. Tropical Storm Bill (2015) provided drought relief in Texas and Oklahoma but brought two to six inches of precipitation across Missouri, Illinois, Indiana, and Ohio of which Illinois, Indiana, and Ohio saw their wettest June on record (1895–2015) (Kellner, 2015). As of July 14, 2015, projections of yield loss due to flooded fields was estimated at $740 million for Indiana (Sites, 2015).

Understanding the total contribution of landfalling TS rainfall in the Midwest and its impact to crop production is linked because of the inherent nature of crop production and soil moisture used by crops for plant growth. Kam et al. (2013) highlight regional impacts of tropical cyclones on soil moisture and drought for the Eastern United States demonstrating their contribution to drought relief across the region depending on antecedent climatological conditions (i.e., severity/type of drought). However, the study does not align findings with historic yield data. Maxwell et al. (2012) highlight the role of tropical cyclones in drought amelioration in Florida, Georgia, and the Carolinas, but also does not investigate observed rainfall alongside historic yield data. Based on this study that includes historic corn yield data, the authors suggest that a timely release of a hurricane season forecast could help identify the potential of landfalling TS rainfall ending a dry spell or drought in the Midwest, or forewarn producers of a wet spell so that they can adjust tile drainage. This type of information (i.e., potential to end a drought or bring anomalously wet conditions) is expected to help agricultural producers, risk managers, and commodity groups make informed decisions related to crop production when a hurricane season outlook is available.

2. Tropical system climatology 1981–2012

Historic seasonal TS maps for the Atlantic Basin are collected from the NOAA National Hurricane Center (NHC) data archive (http://www.nhc.noaa.gov/data/#annual). A total of 116 TSs made landfall in the Continental United States (CONUS) with only 28 entering the Midwest domain. Fig. 1 shows total landfalling TSs affecting the Midwest from1981 to 2012. Annually, 2005 is the year with the highest number of named TSs (28) in the Atlantic Basin, and is also the year with highest number of landfalling TSs affecting the Midwest (5). The years 1982–1984, 1986, 1987, 1990, 1991, 1993, 1997–2000, 2007, 2009, and 2010, experienced no landfalling Midwest TSs, but this is not to say landfalling TSs did not occur outside the Midwest domain. The Midwest averages less than one landfalling TS per year (0.85 a year; median value of 1). The most active month for landfalling TSs affecting the Midwest is September, with 13 TSs impacting the region 1981–2012 (Fig. 2). If a TS affecting the Midwest straddled two months, it was assigned to the month during which it spent the most time, and if the TS equally spanned two months, it was assigned the month the TS made landfall. Out of the six-state domain, Ohio and Kentucky are the states that were most affected by landfalling TSs during 1981–2012. Over the time period, 23 landfalling TSs affecting the Midwest contributed to observed rainfall in these states, followed by the state of Indiana with 17, Illinois with 16, and Wisconsin with 4. The average time a TS spent in the domain is 45.8 h (median value of 44.5 h).