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The 2005 Illinois Drought

by

Kenneth E. Kunkel (editor), James R. Angel, Stanley A. Changnon, Roger Claybrooke,
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Illinois State Water Survey
A Division of the Illinois Department of Natural Resources

2006

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Abstract

Dry conditions in 2005 reached a historic level of severity in some parts of Illinois and ranked as one of the three most severe droughts in Illinois in 112 years of record. The timing of the dryness during the spring and summer, when water demand and use are high, ensured substantial impacts on agriculture and other sectors. The drought also had several unusual characteristics. The drought area was long and narrow, extending from south Texas to the Great Lakes, but within the Midwest, the drought had relatively minor impacts on states other than Illinois. A record number of remnants of hurricanes and tropical storms passed through Illinois during July, August, and September, substantially ameliorating drought conditions in portions of central and southern Illinois. Crop yields were surprisingly high in parts of the state, perhaps providing evidence of increased drought resistance in modern varieties and the benefits of timely rains.

Chapter 1. Introduction

Although drought is a natural and recurring feature of climate, the dry conditions in 2005 reached a historic level of severity in some parts of Illinois and ranked as one of the three most severe droughts in Illinois in 112 years of record. The timing of the dryness during the spring and summer, when water demand and use are high, ensured substantial impacts on agriculture and other sectors. The drought also had several unusual characteristics. First, and most prominently, the long, narrow area affected extended from south Texas to the Great Lakes. Within the Midwest, the drought had relatively minor impacts on states other than Illinois, unlike the vast majority of past severe droughts that affected large portions of the Midwest. Second, a record number of remnants of hurricanes and tropical storms passed through Illinois during July, August, and September, substantially ameliorating drought conditions in portions of central and southern Illinois. Third, crop yields were surprisingly high in parts of the state, perhaps providing evidence of increased drought resistance in modern varieties. The unusual nature of the 2005 drought prompted this study to document and provide insights into the drought's physical and atmospheric chemistry characteristics and societal impacts.

Chapter 2 provides an overview of the temporal and spatial features of precipitation and temperature anomalies during 2005, including a comparison with past major droughts. Since the early 1980s, the Illinois State Water Survey has operated a soil moisture network known worldwide for longevity and quality. Using data from this network, Chapter 3 describes the evolution of soil moisture conditions during the drought and also briefly discusses the effects on streamflows and groundwater levels. Chapter 4 describes regional climate conditions, showing the unusual spatial distribution of this drought. Chapter 5 identifies atmospheric circulation features associated with the precipitation deficiencies and explores possible connections to sea surface temperatures. The 2005 hurricane season in the North Atlantic set a record not only for the number of tropical storms and hurricanes, but also for the number of these events with direct precipitation effects on Illinois, as described in Chapter 6. Chapter 7 assesses drought impacts, particularly agricultural impacts. Atmospheric circulation anomalies that caused the drought also caused anomalies in the quantities of chemicals deposited from the atmosphere as described in Chapter 8. Finally, Chapter 9 provides a concise summary of the principal findings of the study.

Acknowledgments

The authors thank Eva Kingston for her diligent editorial work and Linda Hascall for careful page layout. This report was prepared using financial resources appropriated by the Illinois General Assembly and Governor Blagojevich to the Illinois Department of Natural Resources and the Illinois State Water Survey. Partial support also was provided by the National Oceanic and Atmospheric Administration under contract EA133E-02-CN-0027.

Chapter 2. Illinois Temperature and Precipitation Characteristics of 2005

James R. Angel and Stanley A. Changnon

Introduction

The precipitation and temperatures between January and December contributed to development and intensification of the 2005 drought. This chapter contains monthly and seasonal maps of precipitation, graphs of monthly precipitation and temperatures for Illinois and its nine climate divisions, and graphs of daily precipitation and temperature departures. Data used for these analyses were collected by the National Weather Service Cooperative Observer Network. Tables 2-1 and 2-2 summarize the more significant rankings of precipitation and temperature for 2005.

It is important to note that hydrological conditions were at or above normal going into the 2005 drought as a result of near-normal precipitation in 2004, followed by the sixth wettest January since 1895 (Figure 2-1). Average precipitation in January 2005 was 5.39 inches, 3.42 inches above the statewide 1971-2000 mean. Precipitation in February 2005 was 1.94 inches, near normal.

Dry conditions began to develop in March 2005. Statewide rainfall was only 1.65 inches (51 percent of the 1971-2000 mean): less than an inch in northern Illinois and 3 inches in far southern Illinois, with precipitation departures 1-2 inches below the 1971-2000 mean (Figure 2-2). Farmers generally responded favorably because dry conditions allowed early planting of corn. The drying trend continued in April (Figure 2-3), with rainfall 1.24 inches below the statewide 1971-2000 mean and temperatures much above the 1971-2000 mean (Table 2-2).

Rainfall deficits in May were even greater (Figure 2-4), with a statewide average of 1.70 inches (2.61 inches below the 1971-2000 mean), the fourth driest May on record. In western, central, and eastern Illinois it also was the sixth, fourth, and fifth driest May, respectively, on record. The media began to carry stories noting the drought was centered in Illinois and adjacent portions of surrounding states (Burns, 2005a).

Table 2-1. Selected Statewide Rankings of Precipitation since 1895

Period	*Rank*	*Amount (inches)*	*Departure from normal (inches)*
January	6th wettest	5.39	3.42
March	18th driest	1.65	-1.57
April	30th driest	2.59	-1.24
May	4th driest	1.70	-2.61
June	8th driest	1.94	-2.18
October	13th driest	1.26	-1.61
December	17th driest	1.23	-1.51
March-May	2nd driest	5.94	-5.42
March-June	2nd driest	7.88	-7.60
March-July	5th driest	11.01	-8.32
March-August	5th driest	14.82	-8.29
March-September	5th driest	18.43	-7.92
March-October	4th driest	19.69	-9.53
January-December	11th driest	31.48	-7.85

Table 2-2. Selected Statewide Rankings of Temperature since 1895

Period	*Rank*	*Temperature (°F)*	*Departure from normal (°F)*
January	34th warmest	29.1	+4.5
February	12th warmest	36.1	+6.0
April	15th warmest	55.2	+3.5
June	12th warmest	74.8	+3.2
January-June	13th warmest	49.1	+2.2
June-August	16th warmest	75.6	+2.2
June-November	3rd warmest	66.5	+2.9
January-December	12th warmest	53.8	+2.3

June conditions continued the dry regime with statewide average rainfall of 1.94 inches, 2.18 inches below the 1971-2000 mean (Figure 2-5), and a statewide temperature average of 74.8°F, 3.2°F above the 1971-2000 mean. Northern Illinois experienced the fifth warmest June on record. Some locations in southern Illinois received heavy rains early in June from Tropical Storm Arlene (see Chapter 6). Rainfall during March-June (Figure 2-6) was 5-9 inches below the 1971-2000 mean, the second driest such period on record. In response to the worsening conditions, Governor Blagojevich activated the Drought Response Task Force in June to monitor and respond to issues with impacts on public safety and the economy. Task Force members represent various state agencies, including the Illinois Department of Agriculture, the Illinois Environmental Protection Agency, the Illinois Department of Public Health, and the Illinois Department of Natural Resources.

July rainfall also was below normal (Figure 2-7), but the statewide average of 3.22 inches was only 0.72 inch below the 1971-2000 mean. July temperatures were slightly above normal, despite a statewide heat wave with temperatures above 90°F in mid-July that lasted 10 days (National Weather Service, July 26, 2005). July rainfall was quite variable across the state: quite low in parts of western and northern Illinois but 30 percent above the 1971-2000 mean across southern Illinois as a result of Hurricane Dennis (see Chapter 6). March-July 2005 ranked as the fifth driest such period on record, with rainfall averaging more than 8 inches below the 1971-2000 mean across the state. Furthermore, high temperatures with daily highs of 90°F or more during June and July ranged from 8 to 22 days above the 1971-2000 mean across Illinois. Thus, summer to that date was considered as hot and dry.

August rainfall was deficient in central and northeastern Illinois (Figure 2-8), but tropical storms delivered significant above normal rainfall across the southern half of Illinois. The statewide average of 3.72 inches in August was 0.03 inch above the 1971-2000 mean. Temperatures averaged 2°F above the 1971-2000 mean. Statewide, March-August rainfall totaled 14.82 inches, 8.29 inches below the 1971-2000 mean, the fifth driest such period on record.

Comparisons of the 2005 drought with past recent droughts began to appear in the media during June (Grant, 2005e). Most scientists compared the emerging 2005 drought with the 1988 drought. As summer wore on, however, scientists noted that the 2005 drought was localized and largely confined to a narrow band from south Texas across Illinois to the southern Great Lakes (see Chapter 4), unlike the 1988 drought which extended across most of the Midwest and High Plains (Riebsame et al., 1991).

Comparison of the March-August 2005 drought pattern, expressed as a percent of the 1971-2000 mean precipitation (Figure 2-9), and the March-August 1936 rainfall pattern (Figure 2-10), the driest on record, showed extensive areas with precipitation less than 60 percent of the 1971-2000 mean in both years. The more severe 1936 drought had statewide average rainfall of 11.62 inches compared to 14.82 inches in 2005. Other March-August periods since 1895 averaging less rainfall than that in 2005 included 1930 (12.55 inches), 1988 (13.03 inches), and 1914 (14.31 inches).

September rainfall was above normal (Figure 2-11), with some areas receiving 5-6 inches. Temperatures were also well above normal across Illinois and averaged 71.0°F statewide, 5.2°F above the 1971-2000 mean, the fifth warmest September on record. The northwest and northeast areas of Illinois continued to experience rainfall below average, with amounts 77 percent of the 1971-2000 mean.

Late fall and early winter typically provide an opportunity for recharge of water resources in Illinois as temperatures drop and vegetative growth ends. Statewide, precipitation in October, November, and December remained below normal, however. Precipitation was 1.26 inches in October (1.61 inches below the 1971-2000 mean), 3.23 inches in November (0.18 inches below the mean); and 1.23 inches in December (1.31 inches below the mean). As a result, the statewide deficit since March 2005 increased another 3.3 inches, making March-December 2005 the third driest such period on record, only 24.15 inches compared to the 1971-2000 mean of 35.37 inches.

Statewide Monthly Temperatures and Precipitation

Figure 2-12 illustrates statewide monthly precipitation and temperature departures in 2004 and 2005. Precipitation in 2004 was notable only in that amounts alternated between above and below normal. Overall, 2004 precipitation was 40.42 inches, 1.09 inches above the 1971-2000 mean.

Precipitation in 2005 was markedly different. Despite a wet start in January, nine of the remaining 11 months were below normal. Overall, 2005 precipitation was 31.48 inches, 7.85 inches below the 1971-2000 mean, and the 11th driest year on record.

Temperatures in 2004 were very favorable for crops. Spring temperatures were above normal and led to early planting while summer temperatures below normal reduced plant stress. Fall temperatures above normal enabled rapid maturing of crops. Temperatures continued to be above normal through winter 2004-2005. After alternating temperatures above and below normal in spring 2005, Illinois entered a June-November stretch of temperatures above normal, 2.9°F above the 1971-2000 mean, and the third warmest June-November on record. It was also the 12th warmest year on record, 53.8°F (2.0°F above the 1971-2000 mean).

Monthly Temperatures and Precipitation by Climate Division

Figure 2-13 depicts the nine climate divisions in Illinois. Each climate division is a region of similar climatic features within Illinois. Figure 2-14 illustrates monthly temperature departures (°F) from the 1971-2000 mean at each climate division. Monthly temperature patterns closely match the statewide pattern found in Figure 2-12, with most months in 2005 having temperatures above normal across the state. Temperature departures were greatest in northern and central Illinois where drought was most intense. It is fairly typical in Illinois for drought and temperatures above normal to occur together. Once surface soil moisture is depleted and crops are under stress, solar energy normally used for evaporation and transpiration instead heats the land surface, resulting in higher temperatures.

Figure 2-15 shows the 2004-2005 monthly precipitation departures (inches) from the 1971-2000 mean at each climate division. Like the statewide precipitation pattern found in Figure 2-12, some fairly significant positive and negative precipitation departures occurred in 2004, but without long-term soil moisture stress. In 2005, January precipitation was above normal across the state. It should be noted, however, that the positive departures in the northwest, northeast, and west were smaller than in other parts of the state. After a wet start, conditions became uniformly dry across all regions for the period

March-June. Beginning in July, many southern climate divisions showed moderating conditions and several months of precipitation near to above normal. Precipitation in northwestern, northeastern, and western Illinois was consistently below normal through December, however.

Statewide Daily Temperatures and Precipitation

Figure 2-16 illustrates the 2005 daily statewide precipitation (inches) and temperature departures (ºF) from the 1971-2000 mean statewide. After a wet start, statewide precipitation remained low until July-August. Besides generally small amounts during the critical March-June period, there were long stretches of more than a week with no significant precipitation at all. Notable dry periods in 2005 include early and late May, mid to late June, late July to early August, early September, and most of October. Except for generally cooler-than-normal March and May conditions, Illinois experienced several periods with temperatures much above normal during and after the growing season. In some cases, daily departures exceeded the daily normal temperature by 10°F or more. Notable warm periods include the beginning and end of June, mid-July, early August, much of September and early October, and early November.

Summary

Examination of temperature and precipitation conditions revealed several key features of the 2005 drought. Abnormally wet January conditions established ample levels of soil moisture, streamflows, and reservoir levels early in the year. This was followed by the second driest March-June on record, which resulted in rapid development of drought conditions across the state. By July, conditions in southern Illinois and parts of central Illinois had improved dramatically with timely rains from tropical storms (Chapter 6) as much of northern and western Illinois remained very dry. Temperatures during the growing season were generally above normal, with a high frequency of days with temperatures above 90°F. Data for Illinois indicate 2005 was the 11^{th} driest and 12^{th} warmest year on record with 31.48 inches of precipitation (7.75 inches below the 1971-2000 mean) and a mean temperature of 53.8ºF (2.1°F above the 1971-2000 mean), respectively.

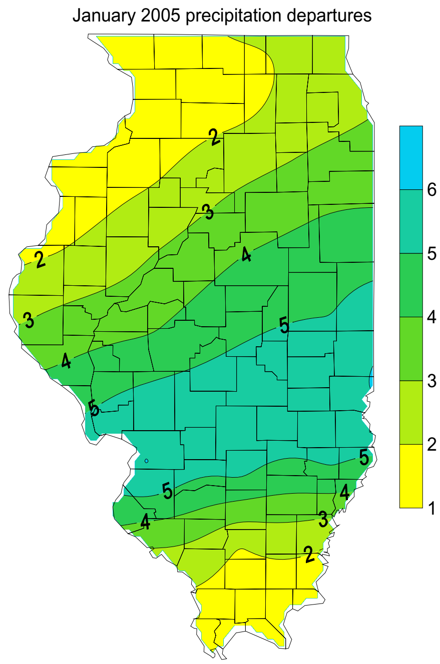


Figure 2-1. January 2005 precipitation departures from the 1971-2000 mean (inches)

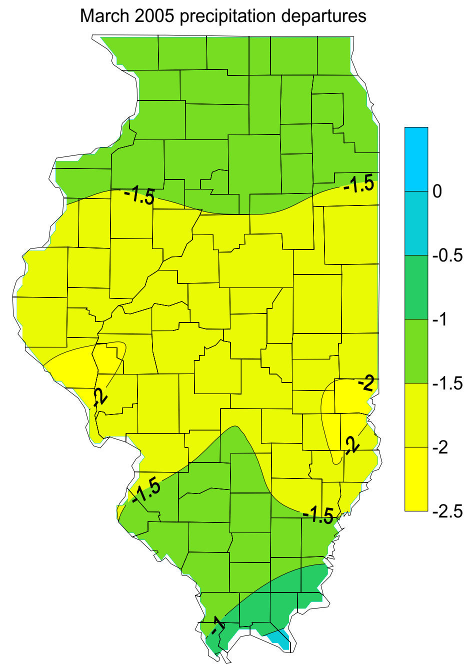


Figure 2-2. March 2005 precipitation departures from the 1971-2000 mean (inches)

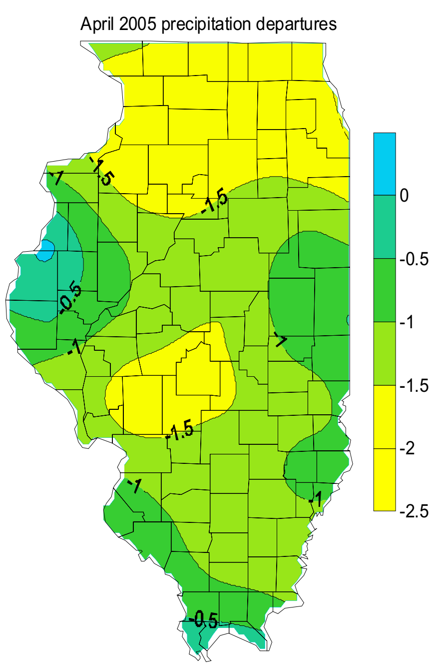


Figure 2-3. April 2005 precipitation departures from the 1971-2000 mean (inches)

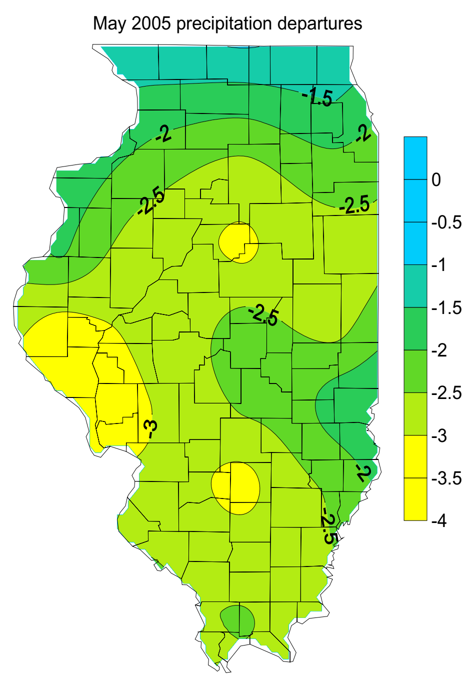


Figure 2-4. May 2005 precipitation departures from the 1971-2000 mean (inches)

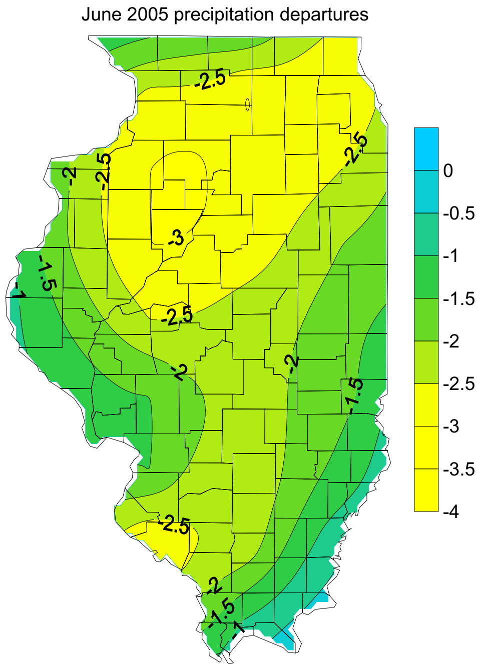


Figure 2-5. June 2005 precipitation departures from the 1971-2000 mean (inches)

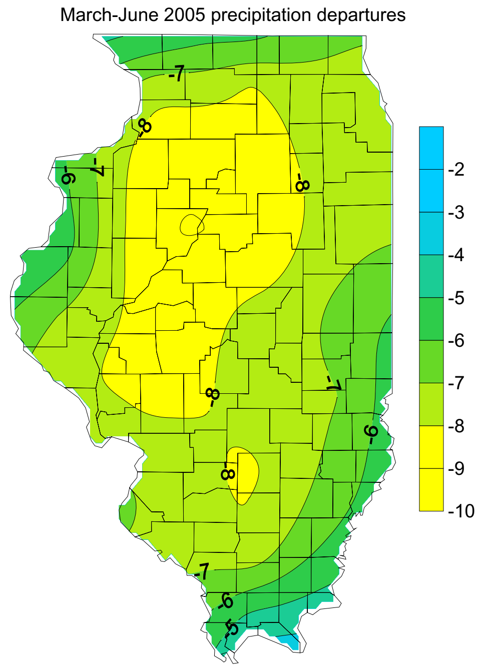


Figure 2-6. March-June 2005 precipitation departures from the 1971-2000 mean (inches)

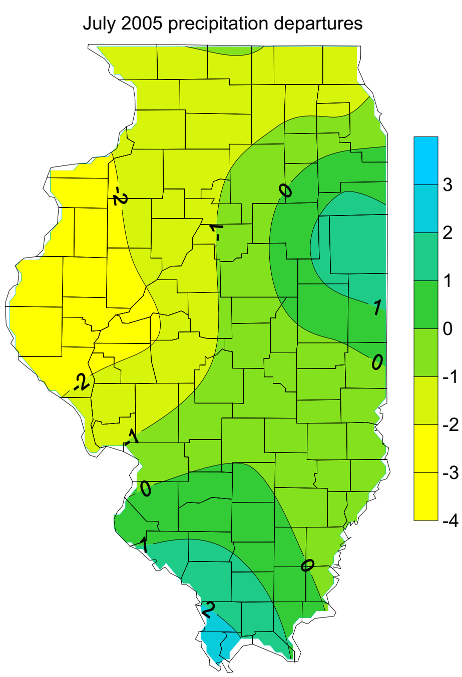


Figure 2-7. July 2005 precipitation departures from the 1971-2000 mean (inches)

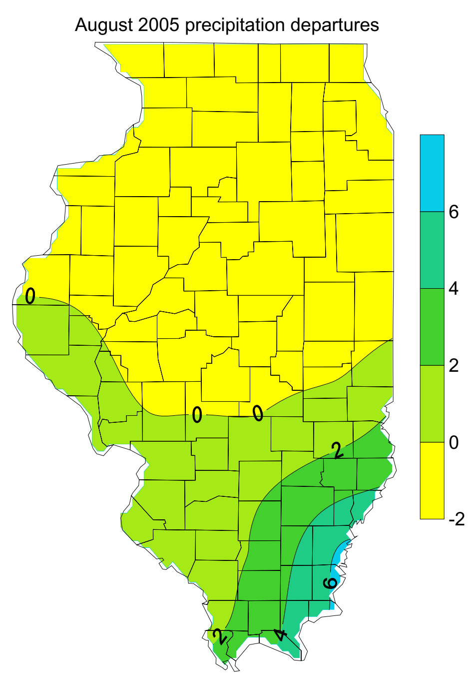


Figure 2-8. August 2005 precipitation departures from the 1971-2000 mean (inches)

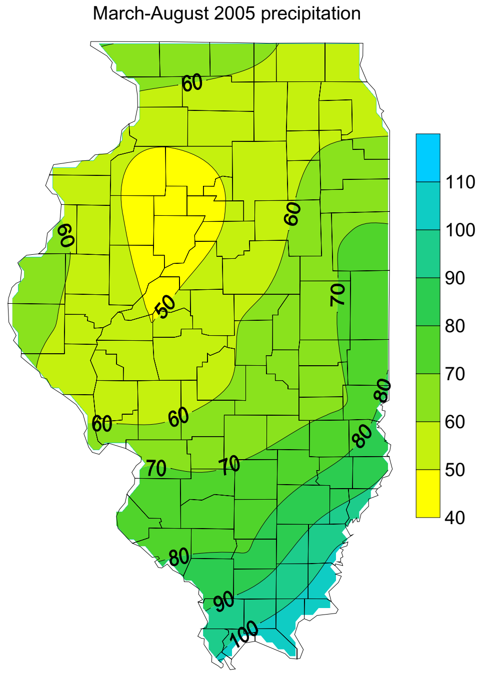


Figure 2-9. March-August 2005 precipitation (percent of the 1971-2000 mean)

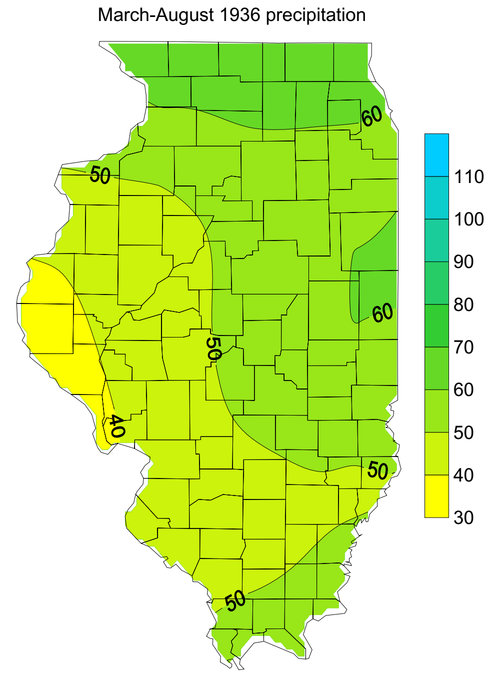


Figure 2-10. March-August 1936 precipitation (percent of the 1971-2000 mean)

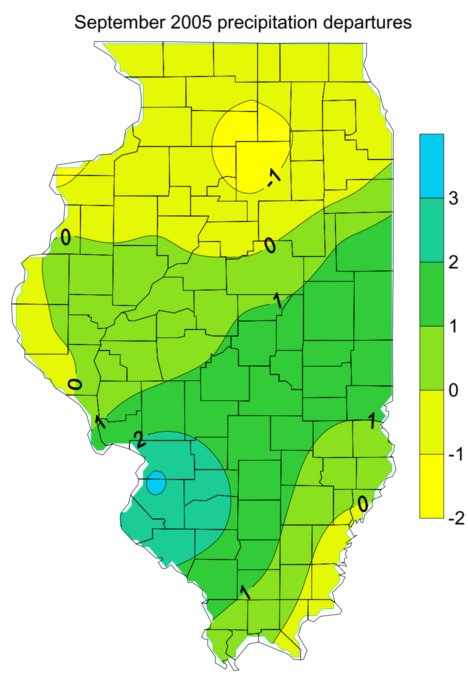
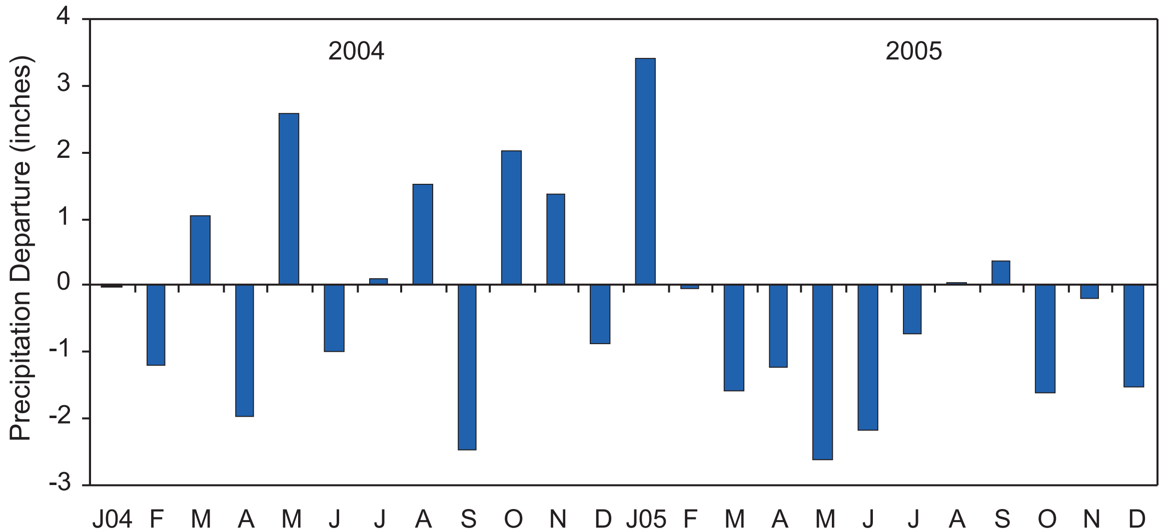


Figure 2-11. September 2005 precipitation departures from the 1971-2000 mean (inches)

a) Statewide Precipitation



b) Statewide Temperature

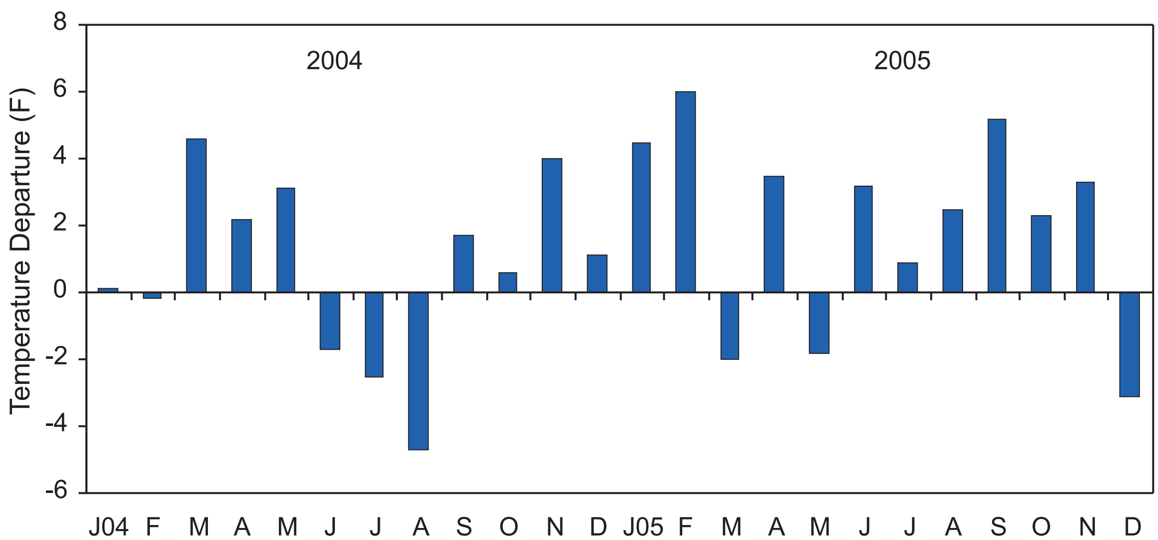


Figure 2-12. Monthly precipitation (inches) and temperature (°F) departures from the 1971-2000 mean, 2004 and 2005

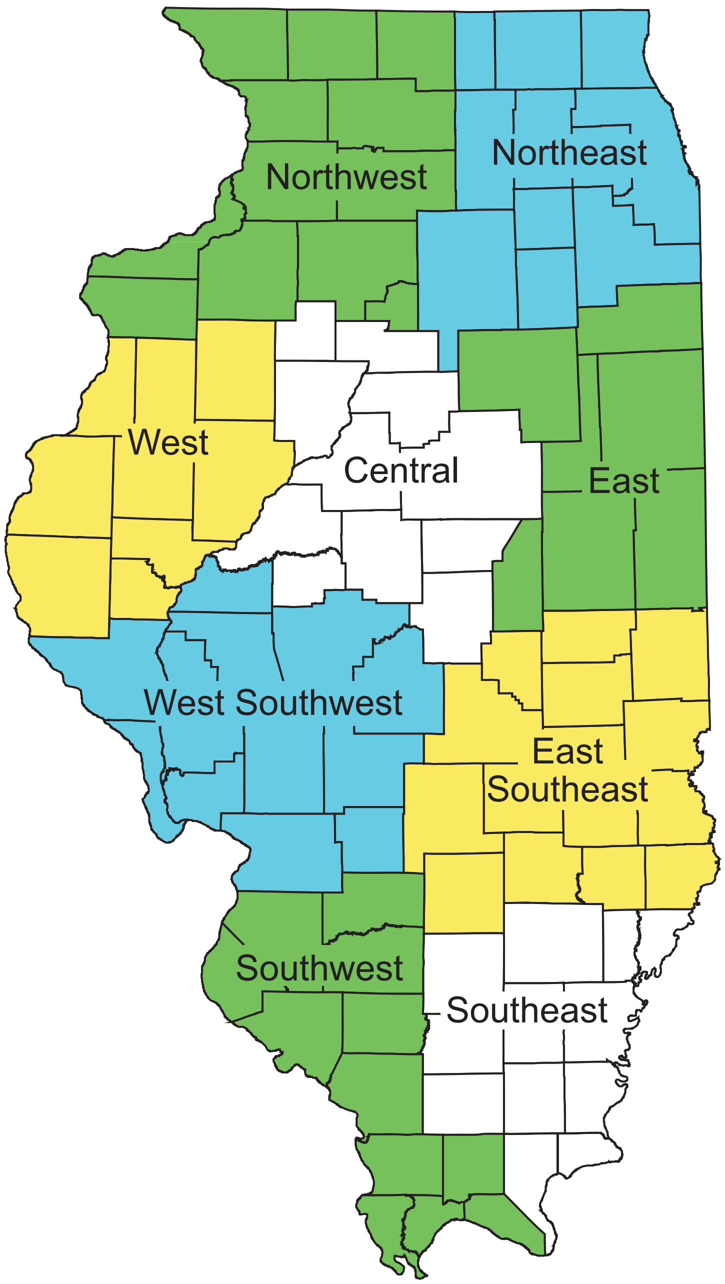


Figure 2-13. Illinois climate divisions

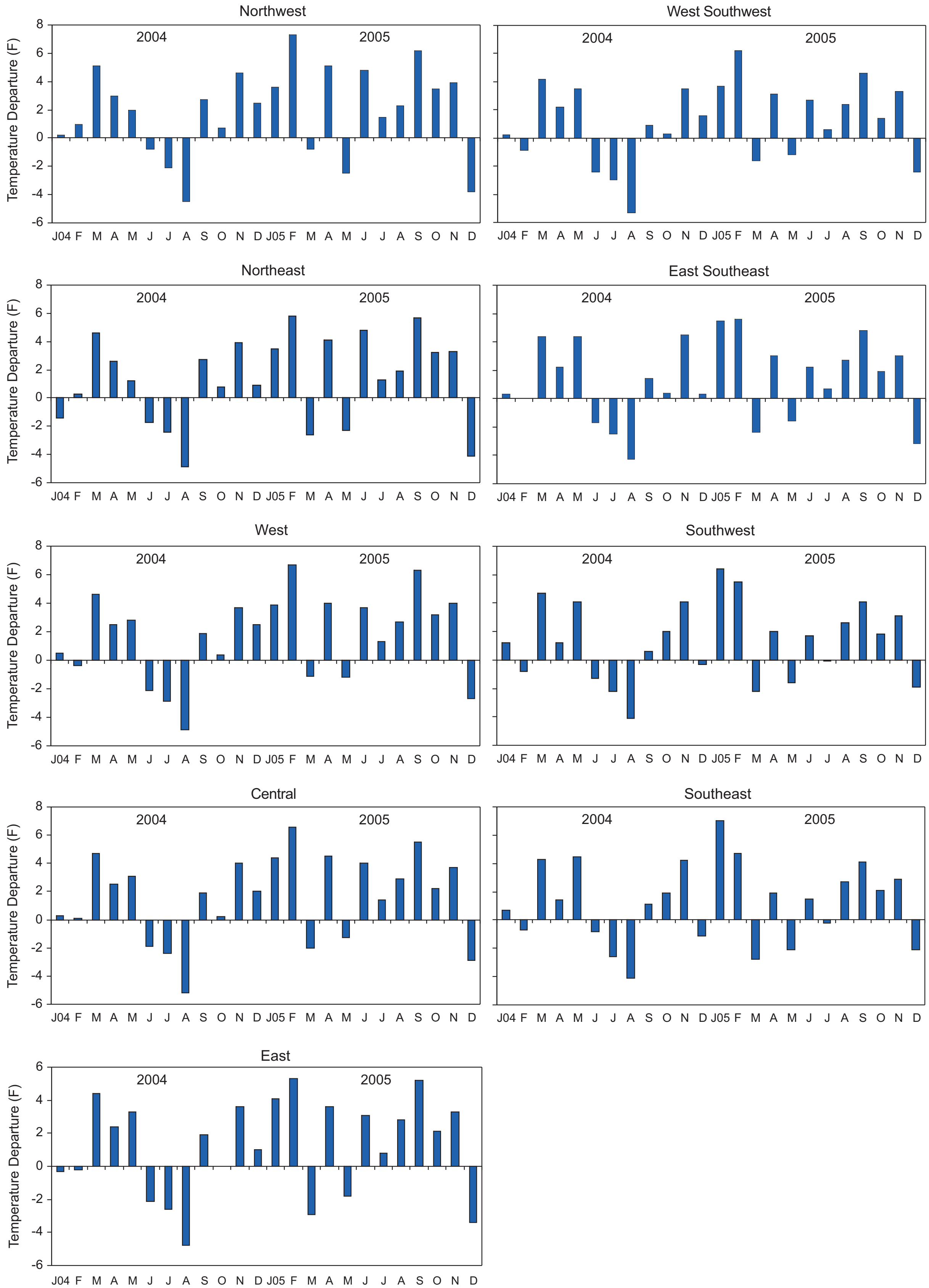


Figure 2-14. Temperature departures (°F) from the 1971-2000 mean by climate division, 2004 and 2005

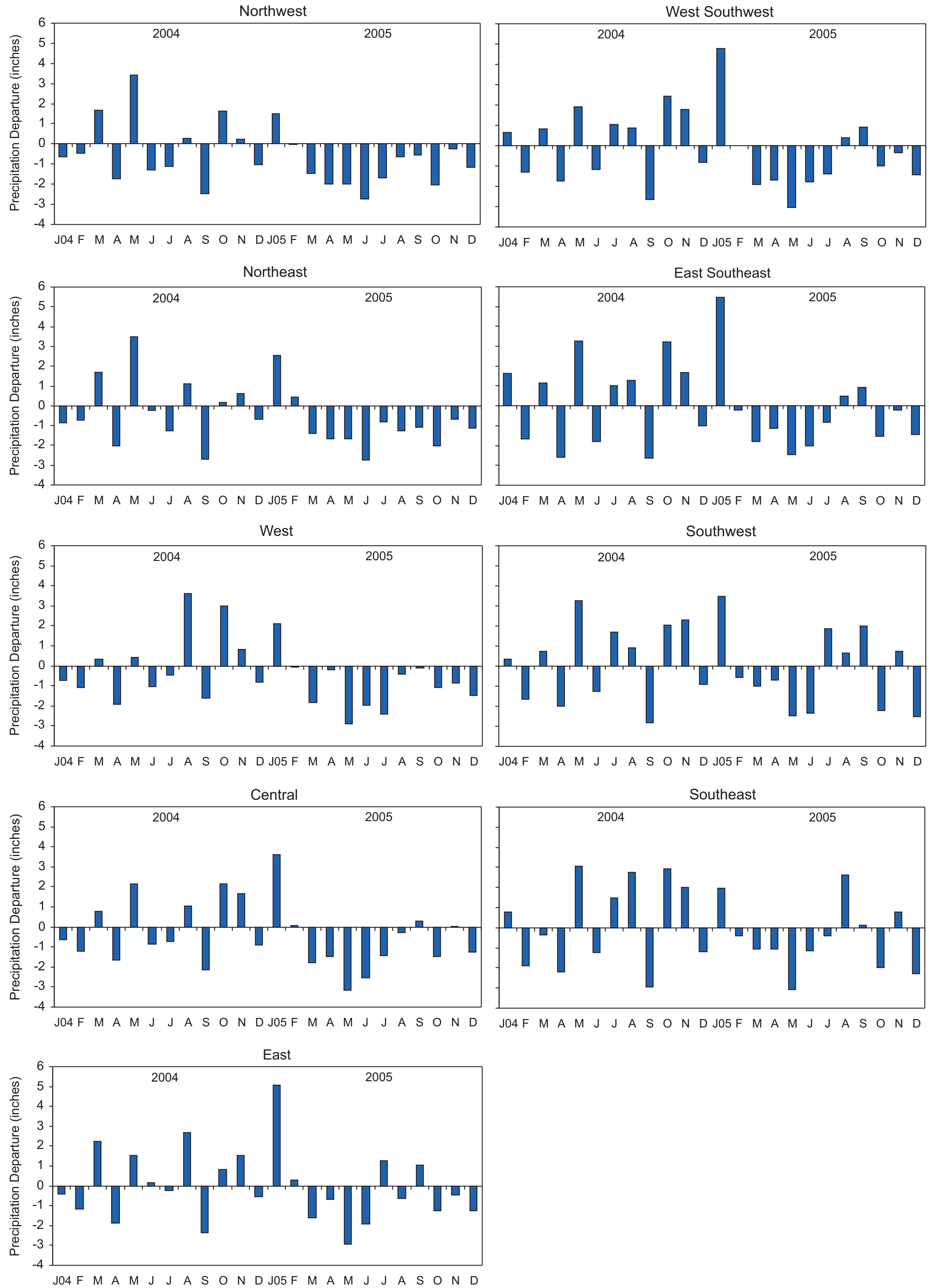


Figure 2-15. Precipitation departures (inches) from the 1971-2000 mean by climate division, 2004 and 2005

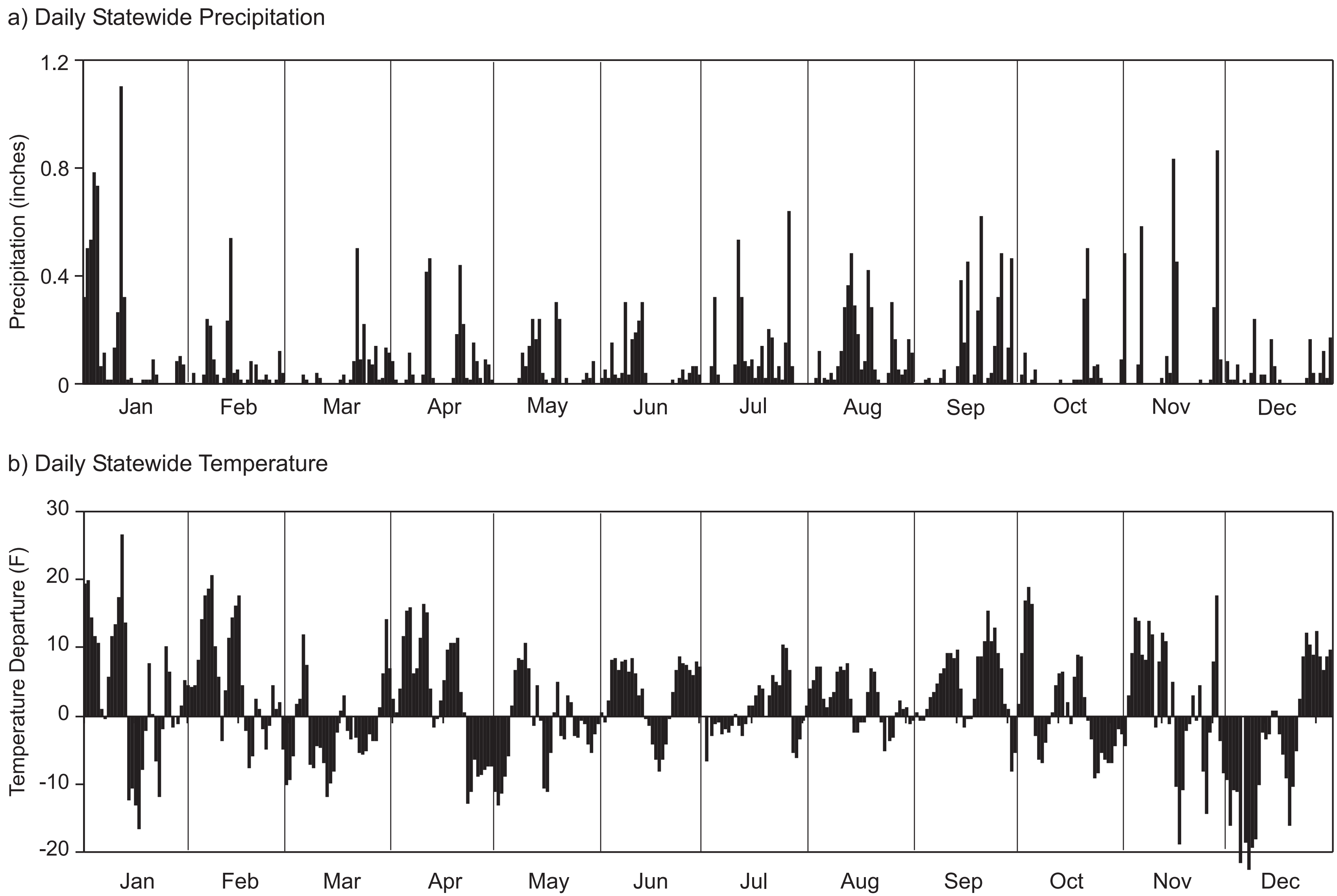


Figure 2-16. a) Daily precipitation (inches) and b) temperature departures (°F) from the 1971-2000 mean for 2005.

Chapter 3. Physical Effects on Illinois' Water Resources

Robert W. Scott and Stanley A. Changnon

Introduction

The Illinois State Water Survey (ISWS) regularly collects and archives data on soil moisture, streamflow, reservoir levels, and shallow groundwater depths. This information forms the basis for a monthly ISWS report on water resources, the *Illinois Water and Climate Summary (IWCS)*. Long-term analyses and tracking of these data help scientists understand the impacts and extent of Illinois droughts and floods.

Soil moisture data have been collected at 17 sites across Illinois since 1983. At all but one location, these sites roughly coincide with stations in the automated Illinois Climate Network (ICN), also operated by the ISWS. Through 2004, soil moisture was measured manually with a Troxler 3220 series neutron probe at 11 levels between the surface and a depth of 79 inches within a vertically aligned access tube placed under a sod-covered surface. Measurements were taken near the end of every month and also near mid-month during the growing season (March-September), totalling19 observations annually. Beginning in 2000, installation of Stevens-Vitel Hydra II continuous soil moisture sensors began at each ICN site, designed to replace the neutron probe measurements. Under this new system, individual sensors were placed at 6 levels under sod, 2-60 inches deep, connected to the ICN data logger, and automatically polled for information once each hour. After a 4-year comparative period, in December 2004, neutron probe observations were terminated at nine sites, but maintained at eight locations where the neutron probe observations were located some distance from the ICN tower, perhaps within a different soil profile. Thus, soil moisture observations in 2005 were collected using a combination of both data platform types.

Drought impacts on streamflows were assessed using provisional flow data collected by the U. S. Geological Survey (USGS) and posted on its Web sites. These provisional data are compared to long-term streamflow records to determine the ranking and percentiles related to the flows that have occurred during the same time period in other years. Drought impacts on shallow groundwater levels were assessed from data routinely collected by the ISWS. The ISWS operates a network of 17 shallow groundwater monitoring wells (water table wells) sited in rural locations across the state. The selected wells are remote from pumping stations in order to assess short- and long-term trends in water table levels under natural conditions. These data are obtained from paper chart recording equipment and are extracted monthly during site visits.

State-Averaged Soil Moisture

Monthly departures from normal soil moisture statewide within the top 40 in. of soil are shown from January 2004-December 2005 (Figure 3-1). The time series shows a rapid response of soil moisture from more typical conditions in 2004 to a much drier condition that began in March 2005. In general, each month with above average precipitation in 2004 (Figure 2-12) also had a concomitant increase in soil moisture. Likewise, months with below average precipitation nearly always were identified with below normal soil moisture. However, the impacts on soil moisture of much larger monthly precipitation deficits during the drought appeared to be delayed by one month. That is, the largest soil moisture deficit (June 2005) occurred a month after the largest precipitation deficit, and the start of soil moisture recovery in August 2005 occurred a month after the first month with near average rainfall.

Monthly data after July 2005 showed continued dryness, but not as severe. Statewide soils remained dry through the following fall and winter, but on a lesser scale than was observed in late spring and early summer.

Evolution of Soil Moisture Spatial Patterns during 2005 Drought

Figures 3-2 to 3-6 show spatial patterns for five months, May to September 2005, respectively. Data displayed represent values at the start of each month within four layers of the soil profile, expressed as percent of the 1985-1995 mean. By May 1 (Figure 3-2), two months of precipitation deficits had reduced soil moisture in most locations below normal levels. Spotty rains across parts of Illinois just prior to data collection resulted in scattered wet areas, but overall dryness was developing across much of the state. Moist conditions within deeper layers in southern Illinois appeared to reflect residual effects from heavier rains over the October 2004-January 2005 period. As the precipitation deficit continued, by June 1 (Figure 3-3), top layers had dried substantially, not only from lack of rain, but from increased seasonal surface evaporation as well. By July 1 (Figure 3-4), soil moisture was depleted across most of Illinois, except in areas where heavy rain events just prior to observations moistened soils near the surface. In general, broad areas of Illinois were characterized by very dry soils that were expanding into deeper layers.

By August 1 (Figure 3-5), timely rains had ameliorated some dryness in upper layers, but these were insufficient to percolate downward very far as plant roots near the surface layers continued to extract moisture. Thus, dryness in deeper layers expanded. This pattern persisted into September (Figure 3-6). Even as crop moisture needs and surface evaporation began to wane seasonally, the entire soil moisture profile in the top 72 in. was largely depleted, especially in a north-south band from central to northeastern Illinois. At the same time, a few sites in southern and western Illinois had responded to increased precipitation from the passage of several tropical systems (see Chapter 6).

The DeKalb site (DeKalb County) in northern Illinois exhibited some of the driest conditions during the drought. Observations at that site were made with continuous sensors. Hourly, March through December 2005, time series at the six monitoring levels (Figure 3-7) show temporal development of dry soils (water fraction by volume) as a function of depth. Analyses of these continuous data revealed rapid temporal responses to precipitation occurrence and deficits poorly detected by the far less frequent neutron probe observations.

March 2005 values show small downward trends at the 2- and 8-inch levels, with a slightly greater drop at 4 inches Beginning in April, a significant downward trend was observed in all three levels nearest the surface. Moisture content decreased quickly during this period with quite noticeable episodes of short-term recharge due to precipitation events. As would be expected, these recharge episodes were more substantial in the 2-inch level and progressively diminished (and were not always observed) at 4 and 8 inches.

Beginning slowly in March, but accelerating in May, soil moisture declined at the 20-inch level. Near the end of the first week in June, a substantial downward moisture trend commenced at 40 inches. The sensor at the deepest (60-inch) level detected no impact of the drought until mid-June, more than 3 months after the beginning of reduced precipitation, followed by a slow steady decrease in moisture into September.

By the end of October, all levels were near their lowest readings for the year. Starting in mid-November, sensors at the top three levels began to observe sustained soil moisture recovery, while soils at the remaining levels maintained their lowest moisture readings through the end of 2005. It should be noted that the top (2-inch) level showed significant variability during December, perhaps due to freezing soils at that level, a condition that yields a different response with these continuous sensors, thus, yielding less trustworthy values. As a final note, it is unclear why certain soil depths remained wetter than others (e.g., at 20 inches from July-November values). The situation may be due to the soil type/texture profile at the site and the fractured or impervious nature of the soil with depth, a quite site-specific situation. Further exploration of such features was beyond the scope of this report.

Evolution of Surface and Groundwater Levels during 2005 Drought

Shallow groundwater (water-table) levels were above average at the end of March 2005, but by the end of May, levels statewide were below average May levels by 1.1 feet (Figure 3-8). Levels fell slightly more during June and July, becoming 1.2 feet below the monthly average at the end of June and 1.5 feet below average by the end of July. At the end of August, groundwater levels were below the August average by 1.1 feet. Water levels in some wells fell a foot during August. Continued dryness, especially the cumulative effect of the drought, resulted in further declines during fall and early winter. By December 2005, shallow groundwater levels averaged more than 3 feet below the period-of-record mean for December.

Averaged streamflows across Illinois (Figure 3-9) were near to above the period-of-record median at the end of February 2005; however, by the end of May, most rivers in Illinois were experiencing median flows normal below, generally 20 percent lower than the median. Period-of-record mean flows much below normal existed on June 1 on the Iroquois River, Salt Creek, and the Illinois River (at Valley City). By the end of July, most river flows in Illinois were much below normal (25 percent of period-of-record mean flows). Only the Cache River (in far southern Illinois) had a normal flow (ISWS, 2005). Many river flows in central Illinois were only 10 percent of the period-of-record mean, including those on the Spoon, La Moine, Mackinaw, Sangamon, Macoupin, Kaskaskia (at Vandalia), and Little Wabash Rivers. Low flows on the Little Wabash and Kishwaukee Rivers rated as once in 10-year events. The flow of the Illinois River at Valley City was the lowest July flow on record with records dating back to 1940 [6455 cubic feet per second (cfs) vs. the normal 21,580 cfs]. Streamflow conditions in August reflected those in July, although flows in southern Illinois had become normal (Figure 3-9). Dry conditions in Illinois did not create any serious decreases in the flows of the Mississippi and Ohio Rivers. Late August-September rains in central and southern Illinois brought streamflows there to near normal levels, but rivers in northern Illinois, including the Rock, Pecatonica, and Green Rivers, remained at levels well below normal through the end of 2005.

Reservoir levels at the end of July reflected low streamflows, a foot or more below period-of-record mean levels at water-supply lakes in central and south-central Illinois: Bloomington, Carlinville, Highland, Mattoon, Pana, Paris, Pittsfield, Salem and Sparta (ISWS, 2005). No reservoirs showed levels at period-of-record mean or higher. Most water-supply reservoirs at the end of August showed decreases of 0.2 to 1 foot from levels for the previous month. A few locales with supply concerns, including Decatur, sought other sources of water. Several reservoirs in southern Illinois showed slight increases in levels at the end of August. Late August and September rains from Hurricanes Katrina and Rita brought reservoir levels up in central and southern Illinois within a foot or two below period-of-record means by the end of September.

Summary

Spatial and temporal decreases in soil moisture near the surface occurred soon after the precipitation deficit began in March, while decreases in deeper layers were delayed and occurred at a slower pace with less amplitude. Recovery to higher levels was observed in upper soil layers by year's end, while deeper layers in central and northeastern Illinois remained at their lowest moisture values for the year. This sustained dryness eventually affected streamflows, reservoir levels, and groundwater levels. All fell to levels below normal by late spring and generally maintained this position throughout 2005, although some regional variations were observed with near normal conditions in southern Illinois in the latter part of the year.

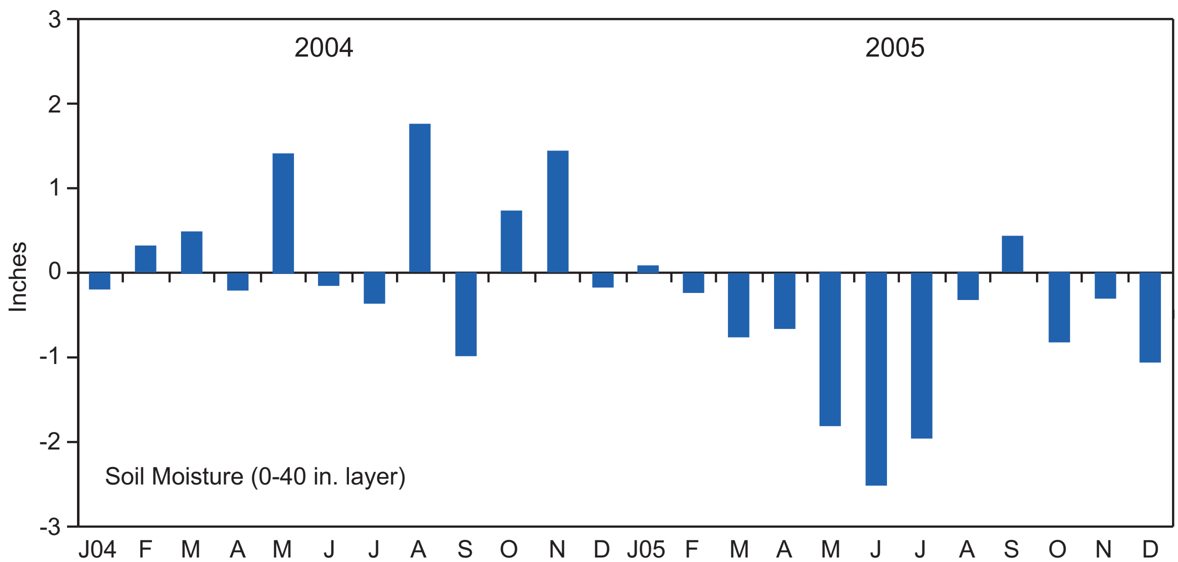


Figure 3-1. Monthly soil moisture departures within the top 40 inches of soil (inches) from the 1985-1995 mean, averaged for all soil moisture sites, January 2004 - December 2005

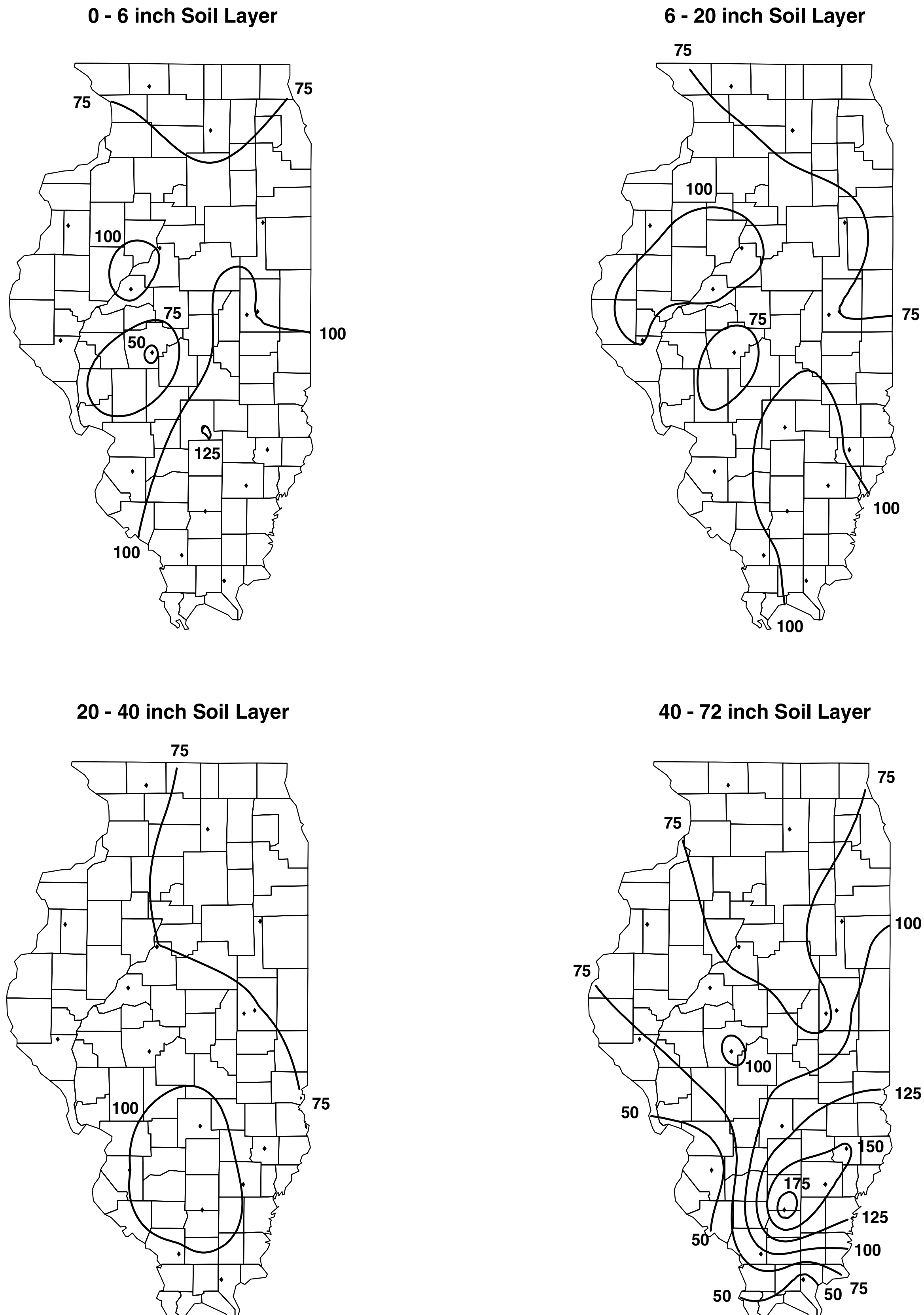


Figure 3-2. Soil moisture expressed as percent of the 1985-1995 monthly means for May 1, 2005

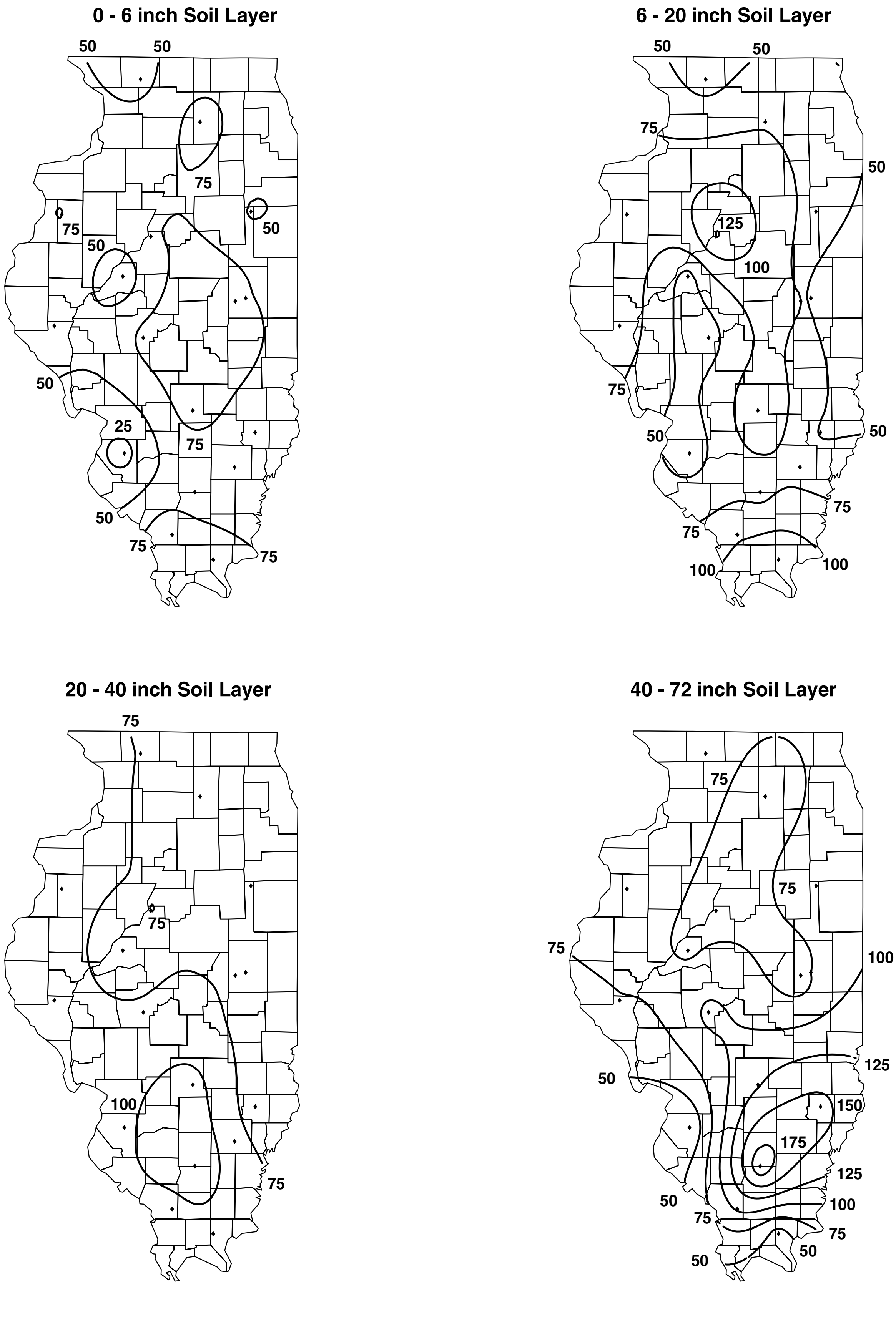


Figure 3-3. Soil moisture expressed as percent of the 1985-1995 monthly means for June 1, 2005

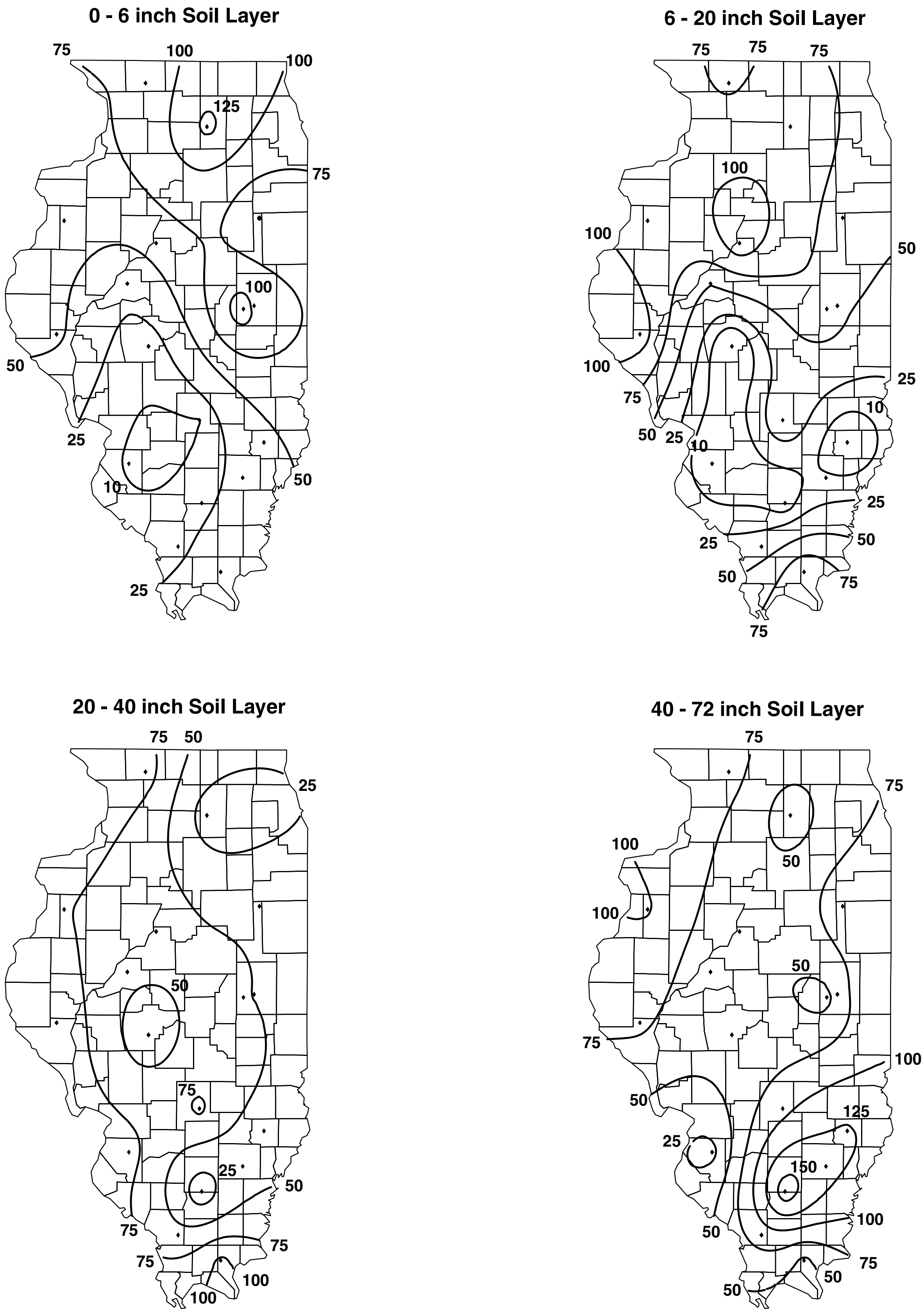


Figure 3-4. Soil moisture expressed as percent of the 1985-1995 monthly means for July 1, 2005

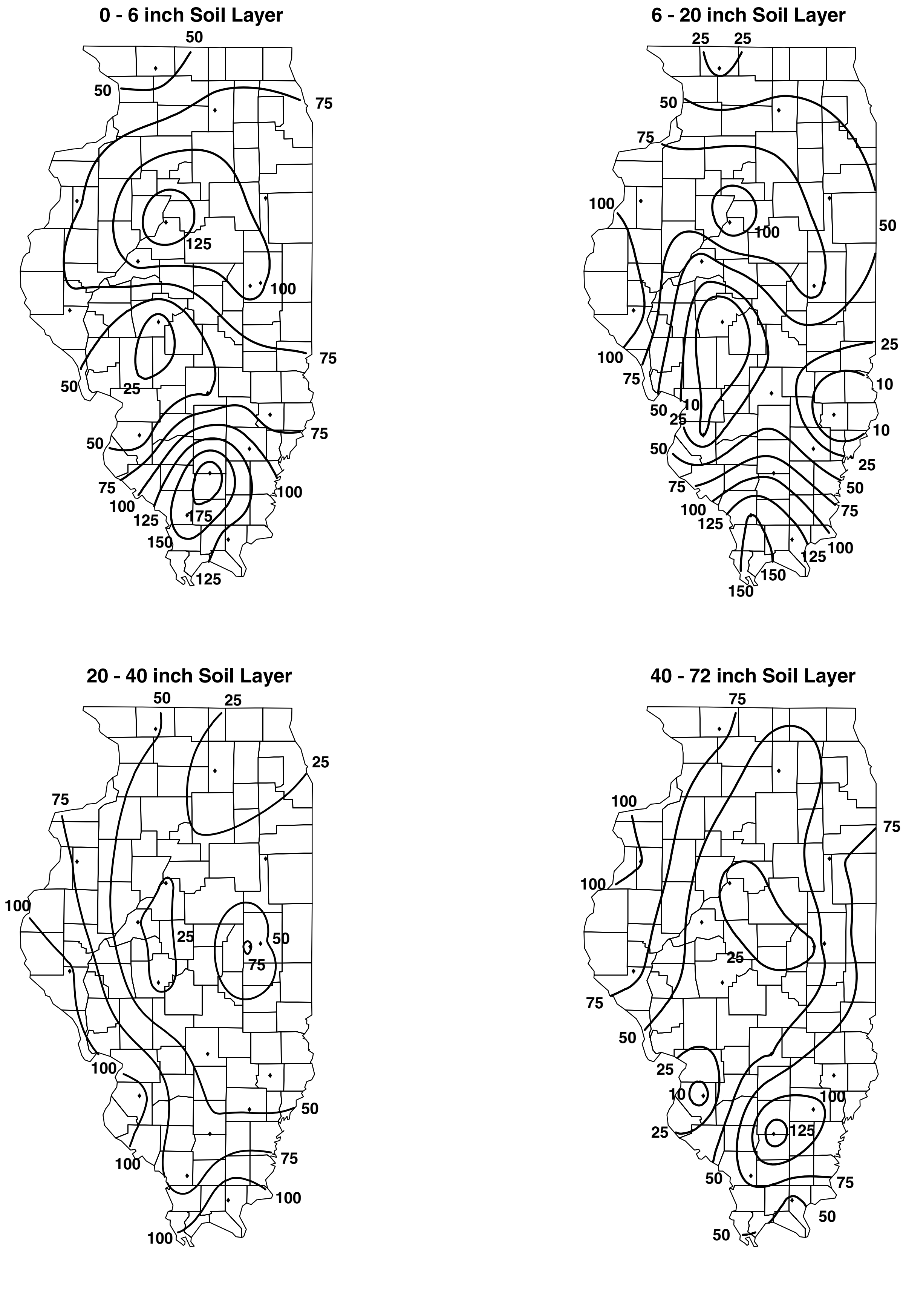


Figure 3-5. Soil moisture expressed as percent of the 1985-1995 monthly means for August 1, 2005

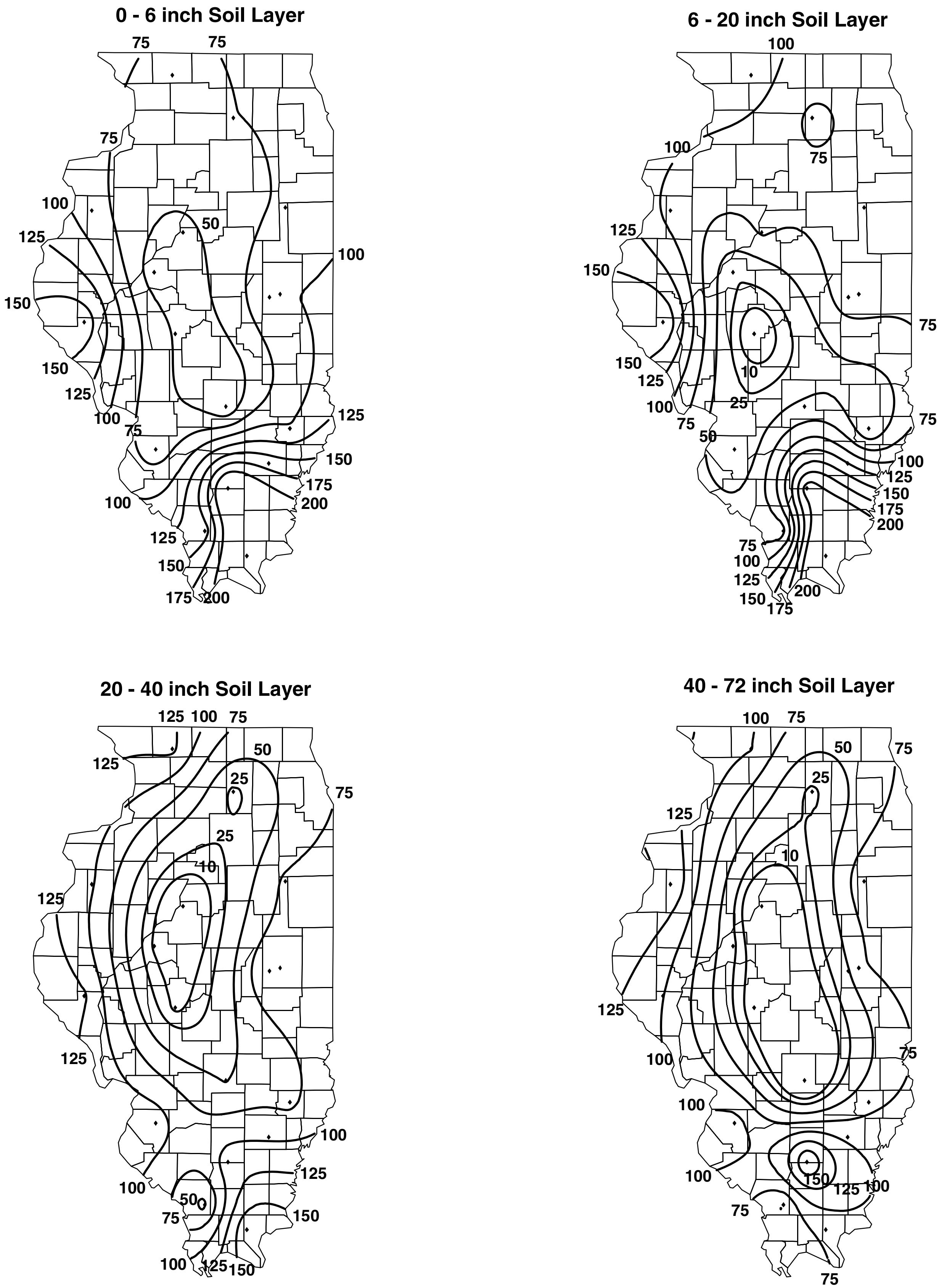


Figure 3-6. Soil moisture expressed as percent of the 1985-1995 monthly means for September 1, 2005

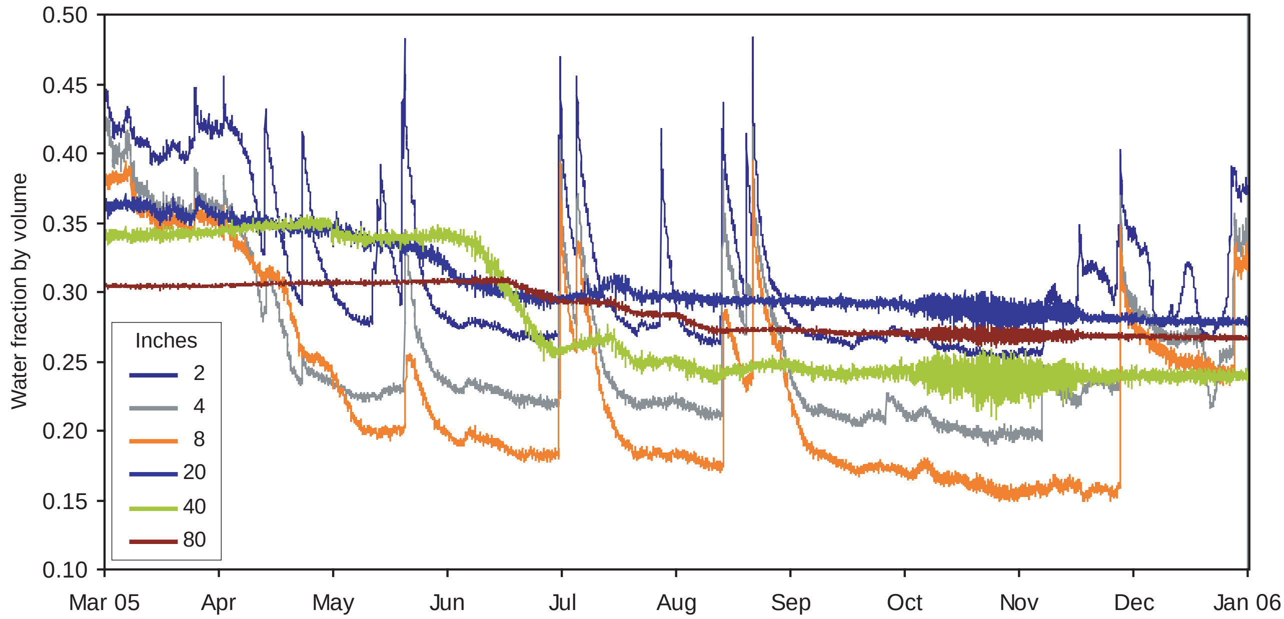


Figure 3-7. Hourly soil moisture at 6 levels under sod at DeKalb, Illinois, March-December 2005

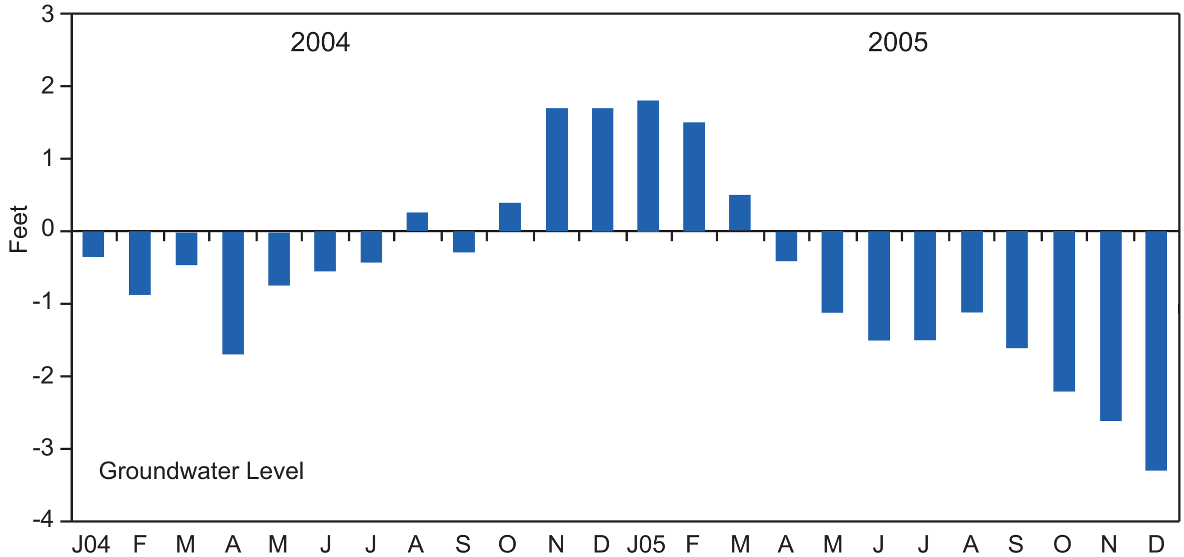


Figure 3-8. Shallow groundwater-level deviation (feet) from the period-of-record mean, averaged for 17 stations from the WARM network, January 2004 - December 2005

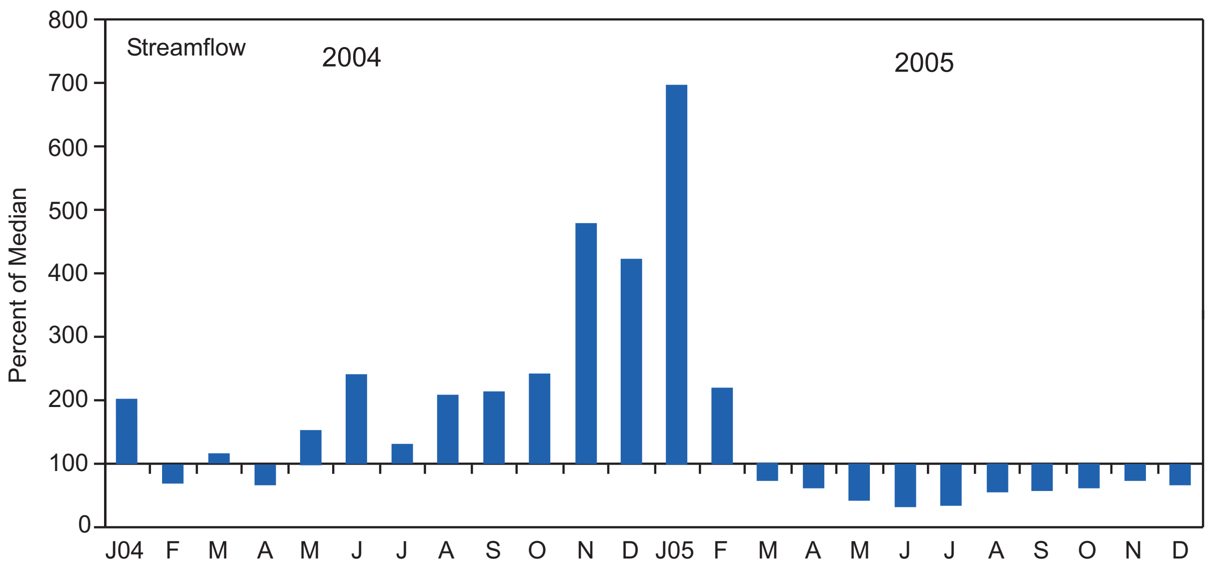


Figure 3-9. Streamline expressed as percent of the period-of-record median averaged for 26 Illinois gaging stations from the USGS network, January 2004 - December 2005

Chapter 4. Regional Analysis of the 2005 Drought

Michael Palecki and Steven D. Hilberg

Introduction

The development and evolution of drought in Illinois occurred in the context of the Midwest region and the United States. At the beginning of 2005, drought was not a concern in the central United States, while much of the western United States was enduring a severe multi-year drought. However, heavy precipitation during the winter alleviated much of the drought in the West, and the same weather systems brought copious precipitation to Illinois and the Midwest. Thus, there were virtually no abnormally dry areas in the Midwest even after the dry month of March 2005. The *U.S. Drought Monitor* (USDM) is a map product produced weekly by a consortium of federal agencies for the purpose of representing the drought status across the country (Svoboda et al., 2002). The current map can be accessed at http://www.drought.unl.edu/dm/monitor.html, and a link to an archive of these maps is also on the same page. It was not until April 12, 2005 that some abnormal dryness was apparent in the region on the USDM map, beginning where Michigan, Indiana, and Ohio converge (Figure 4-1, April 12). As represented on the USDM maps (Figure 4-1), abnormal dryness spread during April, and by May 10, abnormal dryness was widespread across the central Midwest (yellow on the USDM map), with some moderate drought (light brown on the USDM map) present near Lake Michigan (Figure 4-1, May 10). At that point, drought development accelerated, leading to the establishment of moderate drought in Illinois by the end of May (Figure 4-1, May 24). In mid-June moderate drought extended all the way from the Upper Peninsula of Michigan to the Gulf Coast of Texas (Figure 4-1, June 21), creating a fairly narrow but extensive band of drought that bisected Illinois from north to south. Some areas of severe drought (brown on the USDM map) were present in central-north Illinois and Texas through Arkansas into southern Missouri.

Drought amelioration occurred during June in the Ohio River valley, especially in Indiana where the remnants of Tropical Storm Arlene dropped copious rains (Figure 4-1, June 21). But the core drought area from northern Illinois to Arkansas received little relief. Thus, by July 5, 2005, dryness and warmth intensified drought to extreme levels (red on the USDM map, Figure 4-1). An extreme drought is expected to occur only 2-5 percent of the time and is therefore a rare event. The coverage of extreme drought reached its greatest extent in the Midwest during early August 2005 (Figure 4-1, August 9). Despite some drought amelioration in southeastern Missouri, southern Illinois, and the Ohio River valley due to the remnants of Hurricane Dennis passing through in mid-July, a wide band of extreme drought extended from southeastern Wisconsin to central Missouri, and then resumed further south in Arkansas and Texas. Considerable regional recovery due to convective rains and Hurricane Katrina remnants occurred in August, and marked improvements were observed through eastern Illinois and the Ohio River valley in September from Hurricane Rita remnants. By October, a gap in the previously continuous drought band had formed in Missouri, with extreme drought holding on in northern Illinois, and only a small area of severe drought in Texas (Figure 4-1, October 11).

However, the improvement ended there, and severe to extreme drought was maintained through the end of 2005 in Illinois and Iowa, while a drought of historic proportions developed in the southern portion of the drought band in Arkansas, Oklahoma, and Texas (Figure 4-1, December 27). In the remainder of this chapter, the precipitation anomalies responsible for the evolution of regional drought and the resulting soil moisture deficits will be examined.

Precipitation on a Large Scale

In examining the total precipitation anomaly for 2005, the western United States, the Southeast, and the Northeast were wet, while central U.S. regions received well below normal rain totals. The large annual deficits occurred despite widespread flooding rains that impacted Illinois and the Midwest during January, with January to February precipitation surpluses reaching 4-8 inches over a large area (Figure 4-2a). Excluding January and February and focusing on the period March to December 2005, negative precipitation anomalies reached more than 15 inches in the northern Illinois drought area, and more than 21 inches in the south-central U.S. drought region (Texas, Oklahoma, Arkansas, and Louisiana). Most of the overall precipitation deficit in northern Illinois was achieved during spring (Figure 4-2b) and summer (Figure 4-2c). Drought in the south-central U.S. region eased during the summer, but greatly intensified during the last four months of the year (Figure 4-2d). A large portion of the rain that fell in the Ohio River valley, southern Illinois, southeastern Missouri, and points south and east of this arc resulted from the four tropical systems (detailed in Chapter 6). Otherwise, the drought region would have extended much further to the east.

Focusing on the Midwest, monthly precipitation percentage-of-normal maps show a shifting pattern from month to month (Figure 4-3), with only the northern portion of Illinois being well below normal in almost every month from March to November 2005. During the spring months, areas receiving less than 50 percent of normal precipitation (orange in Figure 4-3) were quite extensive from southern Missouri to southern Michigan, including much of Illinois. In June, there was a substantial flow of moisture into weather systems in the western Midwest, and remnants of Tropical Storm Arlene advected copious moisture into western Kentucky, Indiana, and lower Michigan, leaving only Illinois significantly below normal in precipitation. In fact, in the precipitation maps for July, August, and September, the paths of tropical systems are also quite apparent: Hurricane Dennis moisture was largely responsible for the above normal swath from southeastern Missouri to southern Michigan in the July precipitation percent-of-normal map; Hurricane Katrina contributed greatly to a wide swath of 200 percent of normal precipitation for August through the Ohio River valley; and Hurricane Rita left a similar swath a bit further north across Missouri, Illinois, Indiana, and Ohio on the September map (Figure 4-3). Other substantial outbreaks of convective precipitation used Gulf moisture but were not associated with a tropical storm, including storms drenching much of Missouri in August, and active weather systems moving through the northern Midwest in September, October, and November. This resulted in considerable drought amelioration north and east of Illinois and through Missouri but largely missed the core drought area in northern Illinois.

A comparison of weekly cumulative precipitation deficits between the northwestern Illinois climate division (CD 1) and the southeastern Missouri climate division (CD 5) illustrates the lack of recovery in the former versus substantial recovery in the latter. In northwestern Illinois (Figure 4-4a), precipitation anomalies were negative, causing the cumulative deficit to rapidly increase to nearly 9 inches by the end of June. The southeastern Missouri precipitation deficit (Figure 4-4b) reached 8 inches by this time too. Both divisions were characterized by severe to extreme drought status on July 5 (Figure 4-1). The evolution was quite different following this date. As southeastern Missouri received precipitation from Hurricane Dennis in July, convective outbreaks and Hurricane Katrina in August, and Hurricane Rita in September, the cumulative deficit was reduced to only about 3 inches by early October. A few wet weeks in late November allowed this area to recover from a dry October, although deficits increased again toward the end of the year. In northwestern Illinois, the precipitation deficit accumulation paused in July and August, but no recovery was evident. Deficits worsened from late August to late October, and maintained their lowest level until the end of the year. Therefore, northwestern Illinois remained in extreme drought status through the end of the year.

Integrated Drought Measure: Modeled Soil Moisture during 2005

Computer models of soil moisture integrate data on the antecedent moisture conditions, precipitation deficits, and air temperature anomalies to provide an estimate of short to intermediate time scale drought status during the growing season. In a sense, modeled soil moisture is a measure of potential impacts on crops due to climate anomalies. Such models are useful for examining conditions on a multistate scale because there are no regional or national networks of soil moisture observations. The particular model illustrated here is a simple "bucket" soil moisture model (Huang et al., 1996) produced daily by the Climate Prediction Center (CPC). During its development, this model was verified by comparison with soil moisture observations made in Illinois during the period 1984-1991. The model was found to simulate well the soil moisture climatology and interannual variability in Illinois. Current maps can be found at http://www.cpc.ncep.noaa.gov/soilmst/.

At the end of January 2005, soil moisture levels were well above normal across the future drought region from Texas to Michigan (Figure 4-5a). After a normal February and very dry March and April, however, a tremendous decline in soil moisture levels afflicted the same region, leaving western and northern portions of the Midwest with below normal soil moisture levels (Figure 4-5b). This is actually not harmful for crops at this time of year, and, in fact, provides dry and firm surfaces for farm tractors, facilitating crop planting.

As dryness persisted into May, though, concern rose regarding soil moisture reserves for summer crop growth in Missouri and Illinois. Soil moisture levels declined over a vast central U.S. region leading to a broad area of dry soils from Texas and Louisiana to Wisconsin and Michigan. This time period corresponds to the establishment of abnormally dry status over most of the central United States on the USDM map (Figure 4-1).

A combination of existing soil moisture at lower levels and some timely rains, however, allowed reasonable germination and early development of row crops that could send roots down faster than the soil layers were drying. Crops planted later did not fare as well.

In June, above normal temperatures and below normal precipitation over Illinois and eastern Missouri further dried soils in this area. To the west, convective storms brought considerable rain and relieved drought conditions, moistening soils west of the drought axis. While precipitation from Tropical Storm Arlene reduced deficits over Indiana, soil moisture deficits continued to intensify in Illinois, eastern Missouri, and points south during June (Figure 4-5c). Crops had very serious problems in Missouri, where soils do not hold as much plant-available water as in Illinois and Iowa, and more quickly reached the wilting point. Nonirrigated poor or sandy soils in Illinois had similar crop problems.

In July, drought conditions reached their nadir in northern Illinois, even as improvements were evident elsewhere. For example, soil moisture in northern Illinois and southeastern Missouri started the month at a similar level of deficit, but tremendous improvement occurred in the latter area due to the remnants of Hurricane Dennis for several days around the southern tip of Illinois. By the end of July, the driest soils of Illinois had been cut off from the driest soils in the Arkansas-Louisiana-Texas region, and the two drought centers would remain separated through the end of 2005.

Even more improvement in central United States soil moisture was evident during August. Substantial convective outbreaks brought large amounts of rain from the Texas Panhandle through Missouri, and remnants of Hurricane Katrina saturated soils along the Mississippi River into the southern Midwest

(Figure 4-6a). Despite the August dryness in northern Illinois, soybeans did achieve near-normal yields due to some timely rains and very deep soil moisture not accounted for in the CPC model. However, Lake Michigan water levels began to decline to a point lower than the previous year. The band of driest soils expanded from northern Illinois into southern Iowa during September (Figure 4-6b). There were modest improvements in southern and east-central Illinois soils due to the remnants of Hurricane Rita.

During August and September, dryness was intensifying in the Mid-Atlantic region even as conditions improved in Illinois. This period of East Coast soil dryness, however, was quite short lived. As tropical systems and coastal extratropical cyclones brought enormous flooding rains to the area during October, soil moisture anomalies were reversed, especially in the Northeast. On the other hand, moisture was blocked again from entering the central U.S. region resulting in very rapid soil moisture deficit increases in the southern drought area. Soils remained dry in northern Illinois and Iowa during late fall and early winter, when soil moisture recharge is very important for preparing the soil for the next growing season. The soil moisture deficit remained stable in the Illinois-Iowa region through the end of the year (Figure 4-6c), while drying intensified in the south-central U.S. region. Soil moisture deficits increased greatly in Texas, Oklahoma, and Arkansas from the end of October to mid-January 2006 (Figure 4-6c), reaching the first percentile (1 in 100 chance) in a wide area. The soils of Missouri dried again, with drought expanding into the state from both the southwest and the northeast. Most of Kentucky missed both Hurricanes Katrina and Rita, and consequently was also much drier at the end of 2005.

Integrated Drought Measure: Pasture Conditions during 2005

While most of the states in the Midwest were affected by the drought to some degree, Illinois and Missouri felt the brunt of the drought both in terms of the areal extent and severity. A time series representing general growing conditions was constructed using weekly pasture condition as a proxy. The pasture condition data were collected from the United States Department of Agriculture *Weekly Weather and Crop Bulletins*. These reports are statewide estimates of the condition of crops in five categories: "Very Poor", "Poor", Fair", "Good", and "Excellent". In Illinois, approximately 17.5 percent of the total land area is rural grassland, with the highest percentage in the northern and west-central portions of the state. This is also the region of Illinois where drought was most severe. Evolution and progress of the drought from mid-May through the end of September are given as the percentages of pasture in very poor (VP) and poor (P) conditions (Figure 4-7).

Pasture conditions declined gradually in Illinois, with the 35 percent VP/P level not reached until about the last week of June (Figure 4-7a). Pasture conditions in Missouri declined more rapidly during May, rising from only 9 percent VP/P to 35 percent VP/P by the end of the first week in June (Figure 4-7b). Both Missouri and Illinois had abundant winter season precipitation in 2004-2005, and both states received similar levels of precipitation during March and April 2005 (58 percent of normal in Illinois, 61 percent of normal in Missouri.). Average temperatures were also very similar during this period. The reason for the more rapid decline in pasture conditions in Missouri versus Illinois is not clear but could be due to the differences in soil types.

Pasture conditions in both states steadily worsened until mid-August, reaching 83 percent VP/P in both Illinois and Missouri during the week ending August 14. There was some slight improvement in Illinois pasture conditions the last week of July due to heavy rain associated with a slow-moving cold front in the heart of the drought-affected area. In Missouri, drought intensity and extent as depicted by the *U.S. Drought Monitor* peaked on August 9 (Figure 4-1), and from this point on pasture conditions began to improve in both states through the end of the month. Pasture improvements continued in Illinois through the first week in September, largely as a result of rain from Hurricane Katrina in the southeastern third of the state. Heavy thunderstorms (not associated with any tropical systems) brought more relief to western and central Missouri the last week of August. Pasture conditions briefly worsened in both states with the report ending September 11 due to lack of rain the first 10 days of the month. Dry, sunny conditions and low moisture reserves were reflected in an increase of 15 percent in VP/P coverage in Illinois, while the Missouri increase was only 4 percent. With the onset of fall weather favorable for cool season grasses, and the occurrence of near-normal rainfall in September, pasture conditions steadily improved through early October.

Summary

The drought zone in Illinois was a core area of a much larger regional drought in 2005. While northern Illinois was one of the driest areas, considerable drought was felt at various times all the way from Canada to the Gulf of Mexico, though the drought was never widespread in an east-west dimension. At the end of 2005, severe and extreme drought affected a region of the Corn Belt centered on northern Illinois and southern Iowa, and also afflicted a much larger area of Texas, Oklahoma, Arkansas, and southwestern Missouri. The soil moisture levels were not only low in the modeled surface layers but also were greatly depleted in lower subsoil layers.

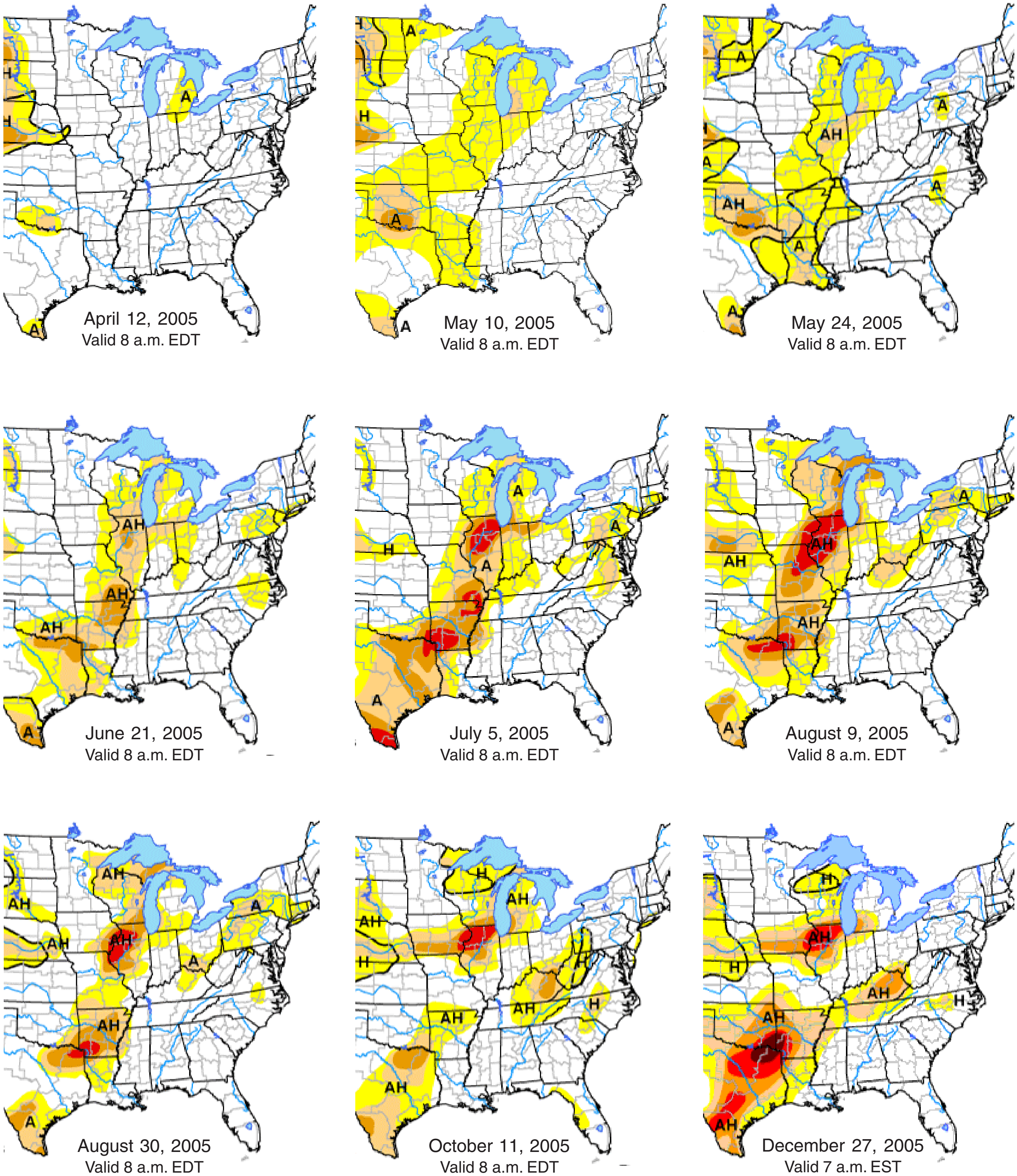


Figure 4-1. Evolution of 2005 *U.S. Drought Monitor* status in the central United States

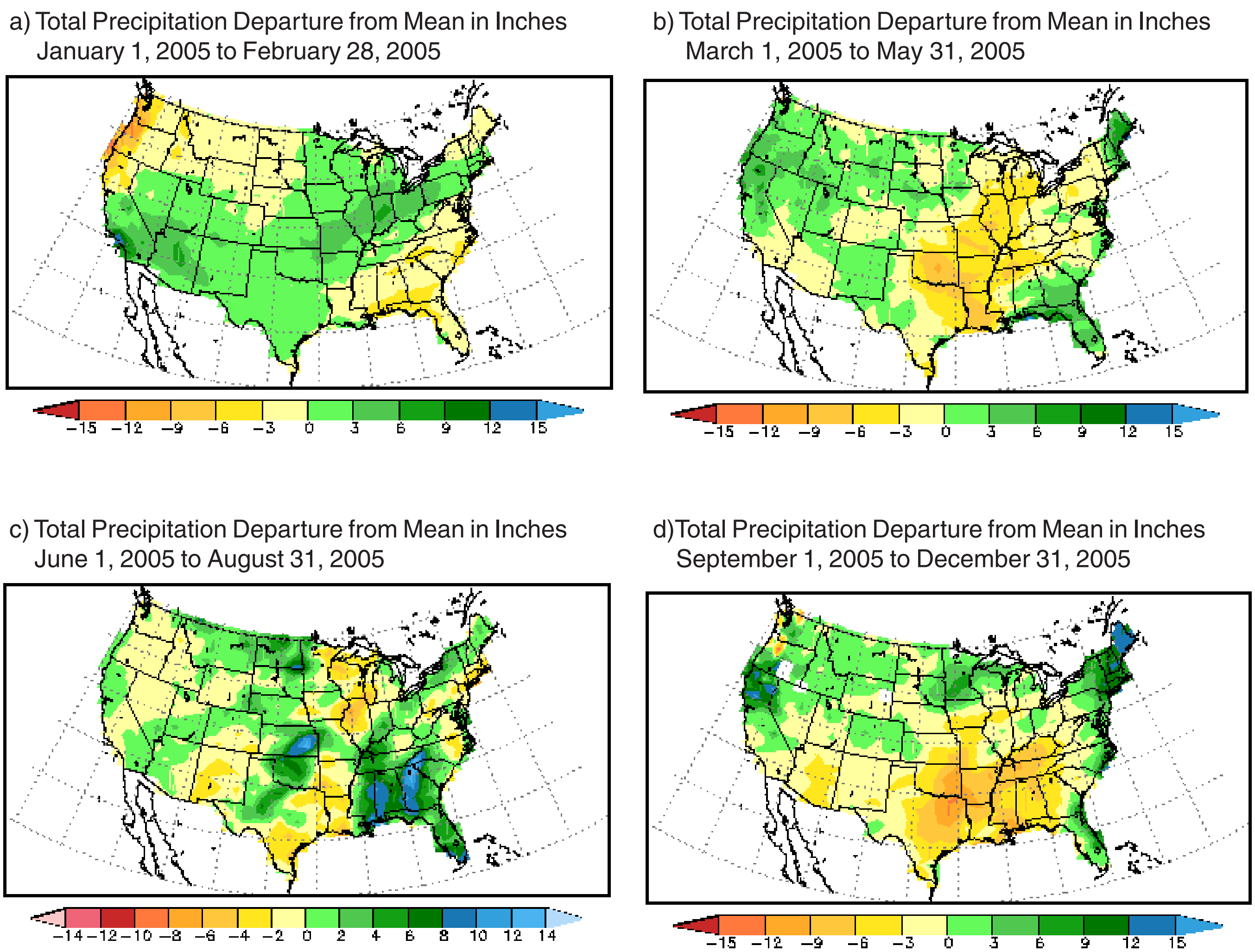


Figure 4-2. Precipitation departures (inches) from the 1971-2000 mean during 2005 in the United States: a) January-February; b) March-May; c) June-August; and d) September-December

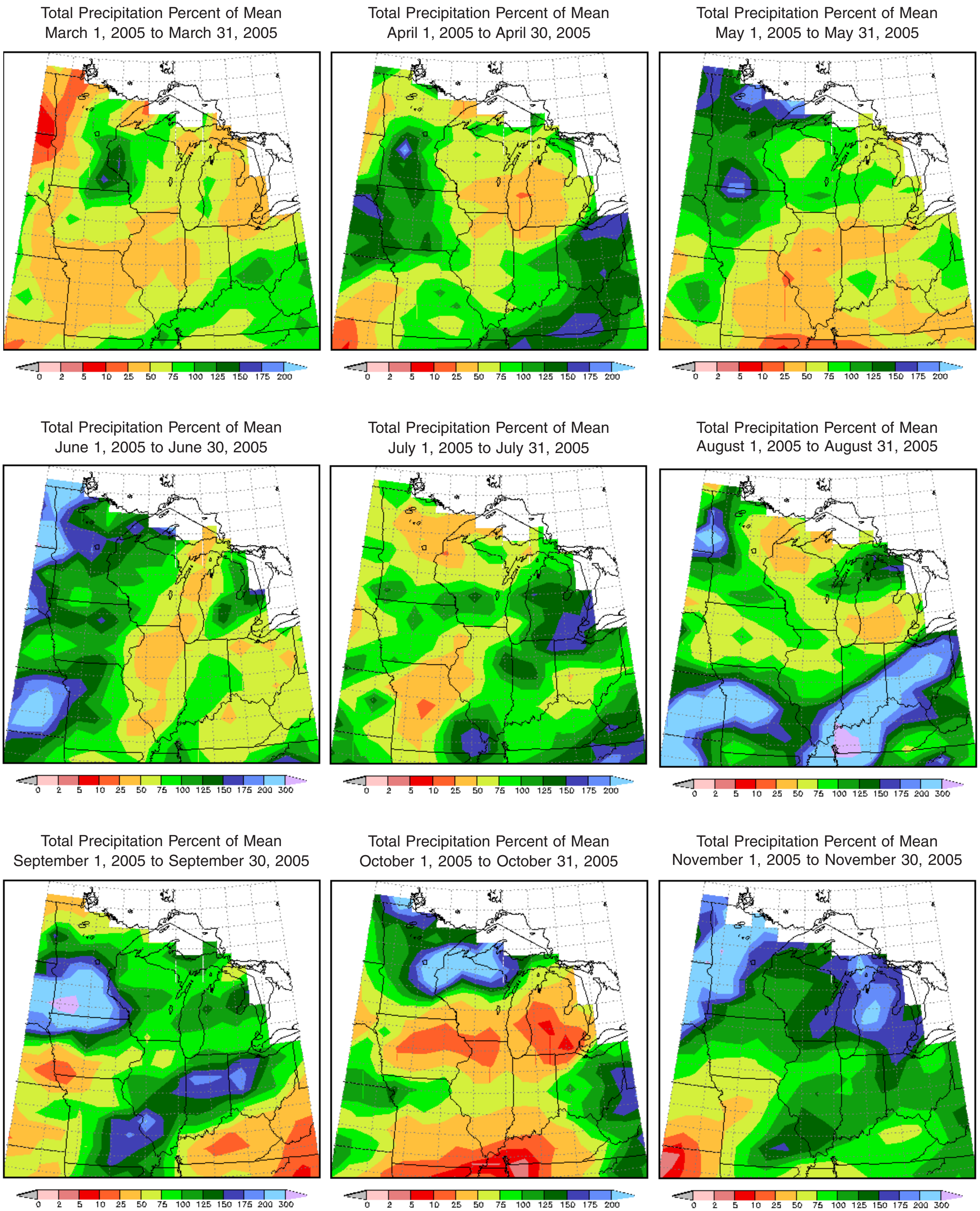


Figure 4-3. Monthly precipitation (percent of the 1971-2000 mean) for the Midwest, March-November 2005

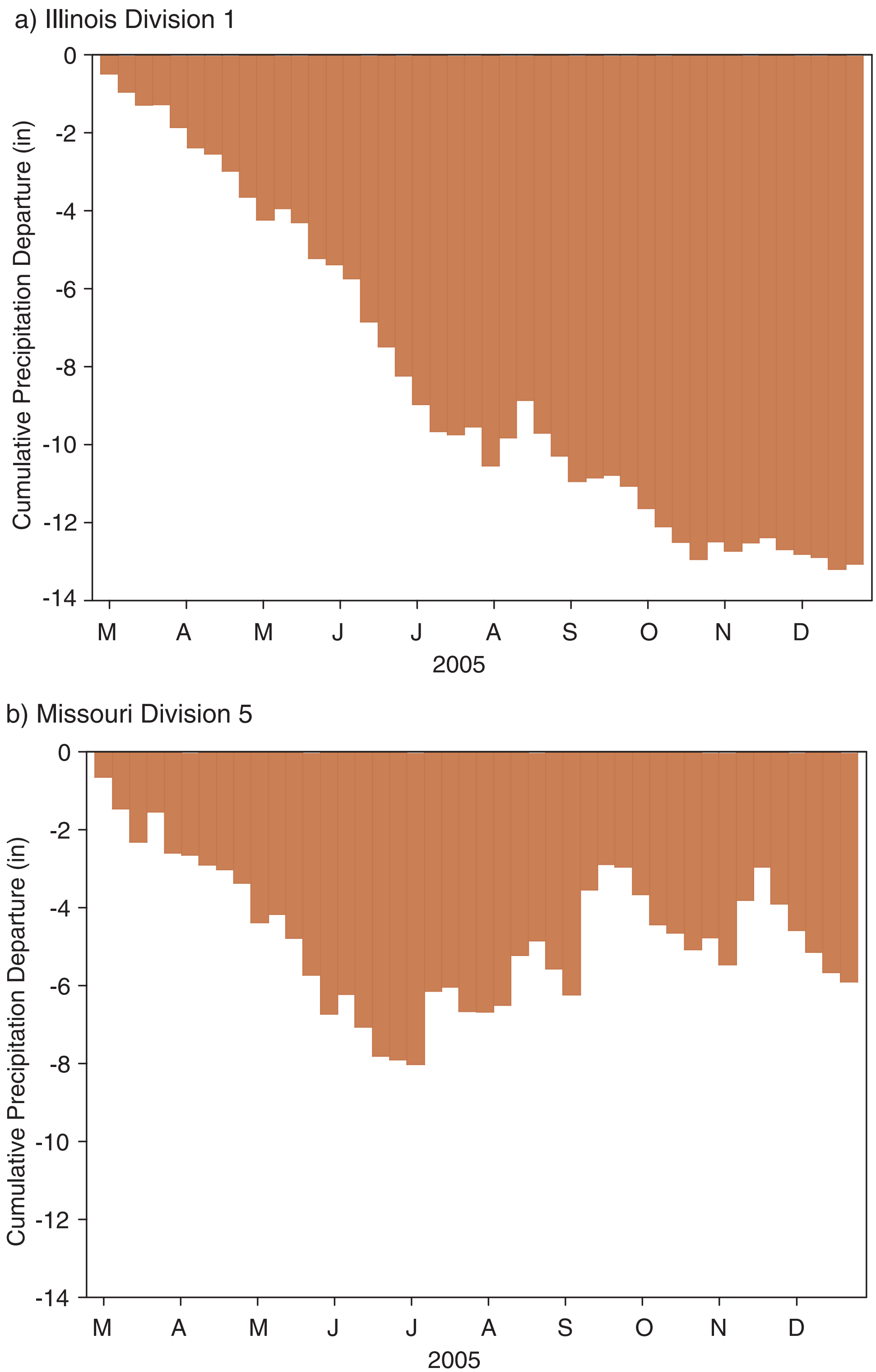
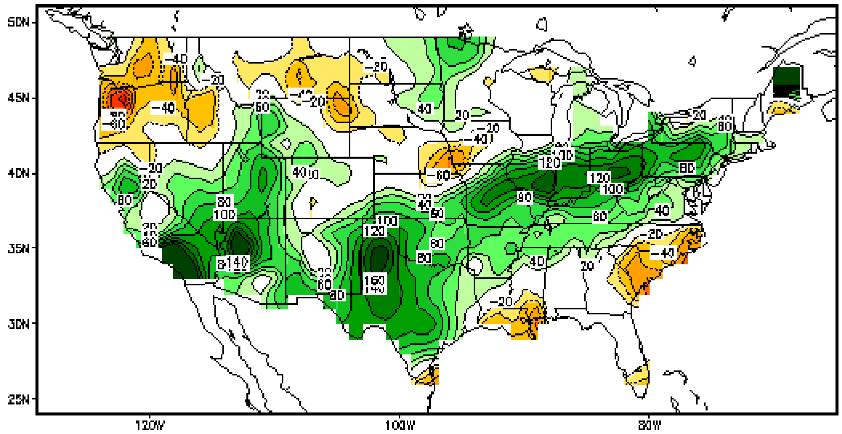
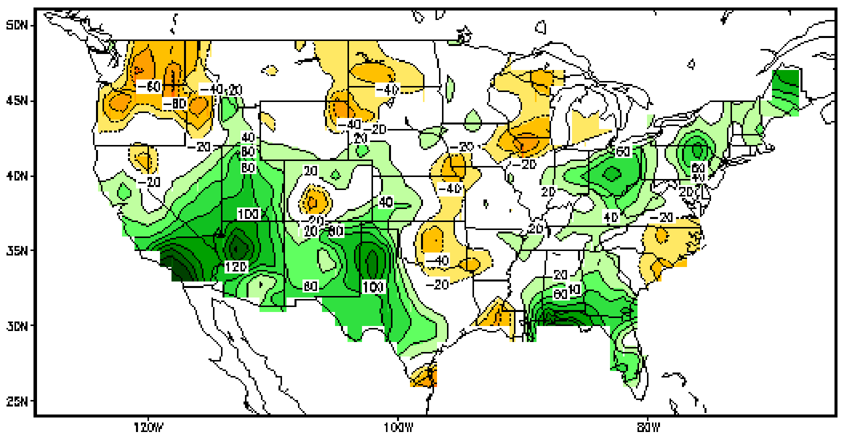


Figure 4-4. Weekly cumulative precipitation departures (inches) from the 1971-2000 mean in Illinois climate division 1 (northwest Illinois) and Missouri climate division 2 (southeast Missouri)

a) Calculated Soil Moisture Anomaly (mm)
January 30, 2005



b) Calculated Soil Moisture Anomaly (mm)
April 30, 2005



c) Calculated Soil Moisture Anomaly (mm)
June 30, 2005

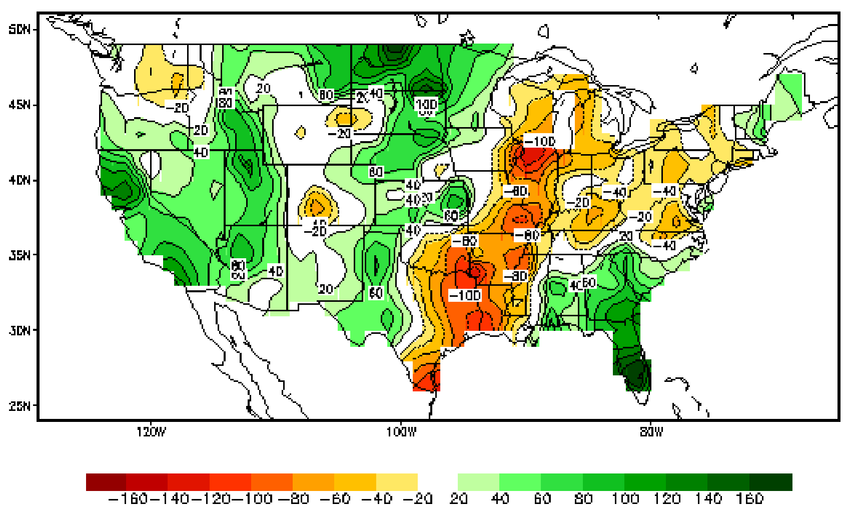
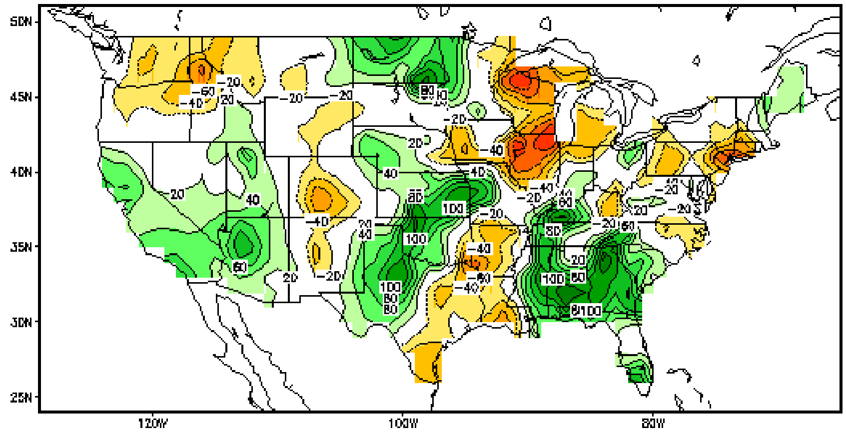
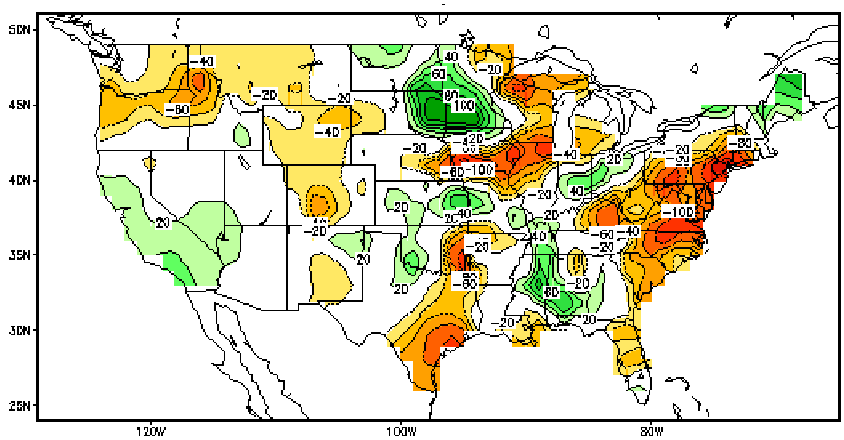


Figure 4-5. Climate Prediction Center Soil Moisture Anomaly (mm) maps: a) January 30, 2005; b) April 30, 2005; and c) June 30, 2005

a) Calculated Soil Moisture Anomaly (mm)
August 31, 2005



b) Calculated Soil Moisture Anomaly (mm)
September 30, 2005



c) Calculated Soil Moisture Anomaly (mm)
December 31, 2005

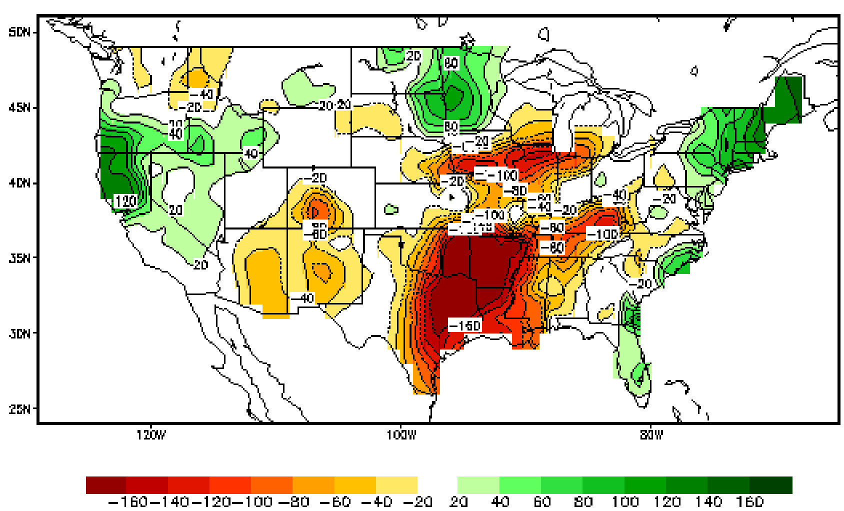


Figure 4-6. Climate Prediction Center Soil Moisture Anomaly (mm) maps: a) August 31, 2005; b) September 30, 2005; and c) December 31, 2005

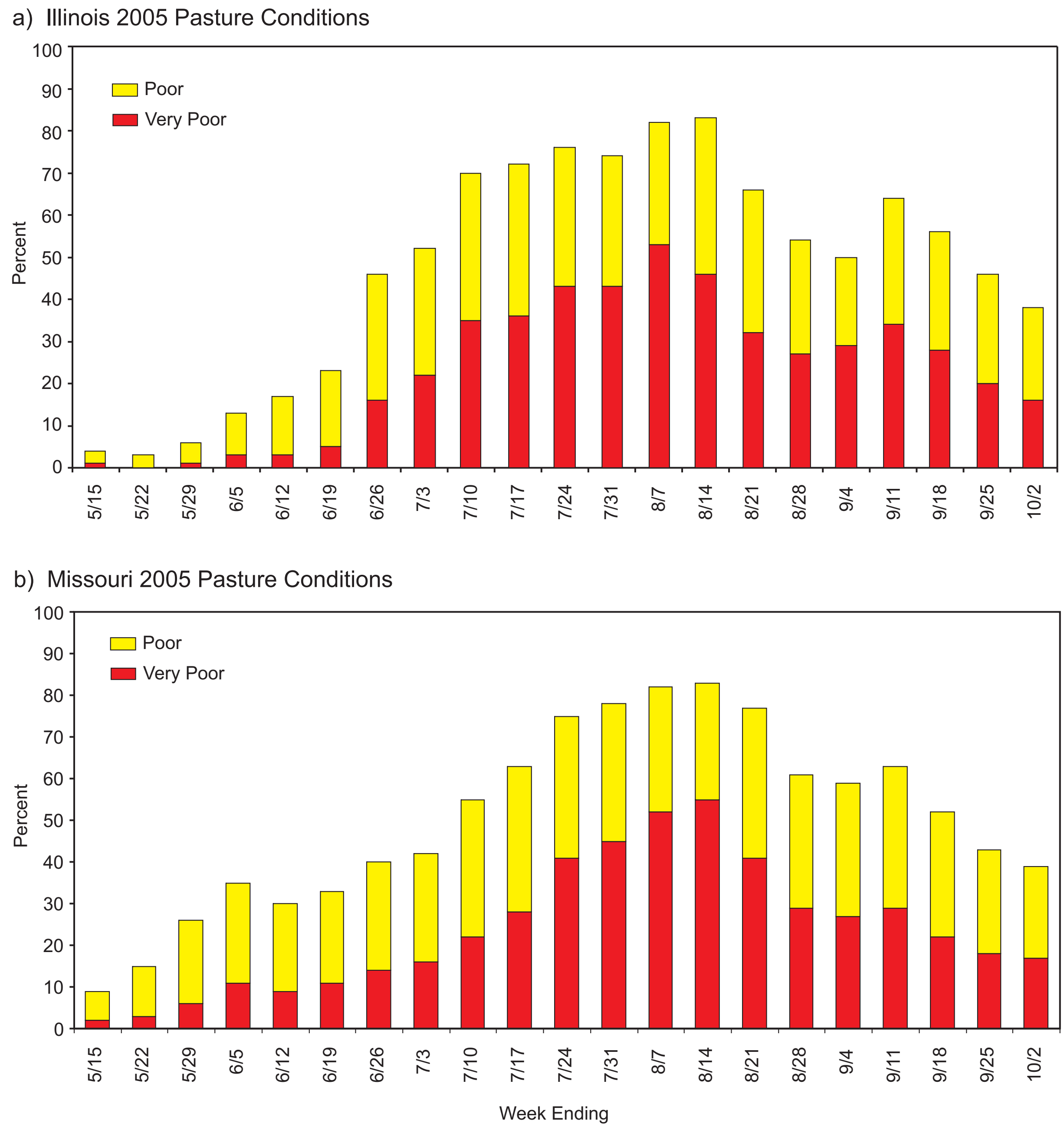


Figure 4-7. Percent of pasture acreage in poor or very poor condition: a) Illinois; and b) Missouri

Chapter 5. Continental and Hemispheric Circulation Patterns

Kenneth E. Kunkel, Michael Palecki, and Steven D. Hilberg

Introduction

The major sources of water vapor for warm-season precipitation processes in the central United States are the Gulf of Mexico and adjacent North Atlantic Ocean. A principal feature of the atmospheric circulation in this region is a semi-permanent high-pressure system over the subtropical North Atlantic, sometimes called the "Bermuda High." Clockwise circulation around the high-pressure center brings moisture northward into the central United States on the western side of this feature. During spring, the western limb of the Bermuda High moves over the southeastern United States and eastern Gulf of Mexico. The Bermuda High is strongest in late spring and summer. The accompanying flow of moisture northward around the western edge of the high is often unstable or conditionally unstable and prone to convective activity, accounting for generally abundant growing season precipitation in the central and eastern United States.

Circulation Patterns in 2005

During both spring and summer 2005, the Bermuda High was weaker than normal, leading to reduced atmospheric flow across the coast of the Gulf of Mexico. During spring, the subtropical high center was on the far eastern side of the Atlantic (Figure 5-1a), shifted to the east compared to average conditions, and was much weaker than normal (Figure 5-1b). Examination of flow patterns at a pressure level of 850 hPa (located at an altitude of approximately 5,000 feet) is quite revealing. During normal spring conditions (Figure 5-2a), the 850-hPa flow above Illinois is on the northern and western edges of a plume of moist air coming north from the western Gulf region and turning eastward over the Midwest. In 2005 (Figure 5-2b), the low-level flow pattern (wind direction) was normal, but wind speeds were weaker than normal, a usual circulation feature associated with dry springs in Illinois. A composite map of the 850-hPa flow departures from the five driest springs between 1950 and 2004 (1956, 1971, 1987, 1988, and 1992) displays anomalous flow in the direction opposite to normal flow (Figure 5-2c), indicating that a reduction in moist air inflow from the south occurs consistently in dry springs and a feature that was very prominent in 2005 (Figure 5-2d).

During a typical summer, the Bermuda High shifts northward and becomes stronger than during spring. The high-pressure center in 2005 (Figure 5-3a), while no longer spatially shifted compared to normal, was still somewhat weaker than the long-term mean pattern (Figure 5-3b). Long-term mean flow at 850 hPa (Figure 5-4a) is highlighted by an even stronger northerly flow over Texas curving into northern Illinois and the Great Lakes region. There was strong flow over Texas in 2005 (Figure 5-4b), but close examination indicates that this flow penetrated further northward than normal before curving east, a common feature to many of the driest summers in Illinois. A composite anomaly pattern from the five driest summers in Illinois between 1950 and 2004 (1966, 1976, 1984, 1988, and 1991) shows enhanced northerly flow through the Great Plains and into Canada (Figure 5-4c), with vectors opposite to the normal flow over Illinois, demonstrating weakening flow of air from the Gulf moisture source. This was even more prominent in 2005 (Figure 5-4d), when anticylconic flow around the Bermuda High was much weaker than normal. By contrast, precipitation was above normal in the northern Great Plains and Minnesota. Further south and east of Illinois, precipitation was generally near to above normal, mostly due to substantial rainfall from several tropical systems (see Chapter 6). Were it not for that rainfall, the area of rainfall deficits would have included much of the eastern Corn Belt.

During spring 2005, anomalies in the height of the 500-hPa pressure level (approximately 18,000 feet; Figure 5-5a) were configured very similarly to the composite pattern of the five driest springs (Figure 5-5c), but were stronger, especially in eastern North America. These height anomalies were part of a persistent negative North Atlantic Oscillation regime and positive Pacific/North American pattern. This combination results in a northwesterly jet stream flow over the Midwest, reducing chances of strong moisture advection into Illinois. By summer, a mid-tropospheric high-pressure anomaly was located over the northeastern United States and southeastern Canada (Figure 5-5b), where the surface air was 4-7ºF above the 1971-2000 mean for the season due to the anomalous circulation. In most of the five driest summers, the lack of precipitation in Illinois was associated with drought over a broader central U.S. region. When soil moisture is depleted after a drought has persisted for several weeks or more, a greater (lesser) fraction of solar radiation is used to heat the air (to evaporate soil moisture), causing greater warming of the air column. Upper air high-pressure ridges are a reflection of warm temperatures in the entire air column below the ridge, and excess heating of the air at the surface can contribute to development of a high-pressure ridge anomaly over the Great Plains and Canada that further suppresses precipitation (Figure 5-5d). In 2005, however, soil moisture in the Great Plains was adequate through the summer growing season. Therefore, this land-surface feedback mechanism was likely not strong.

Possible Causes

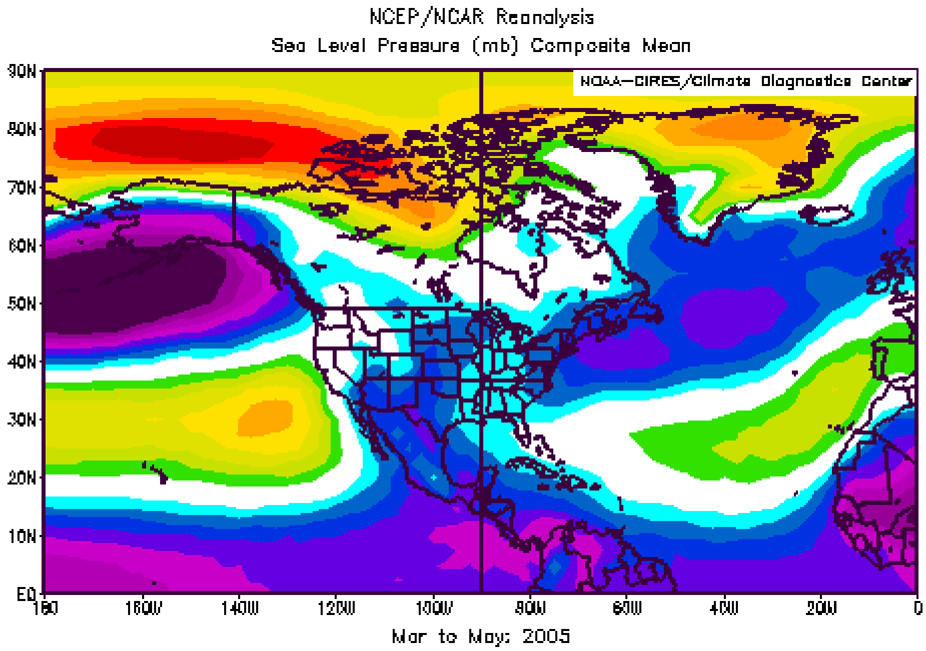
It is usually difficult to definitively identify causal factors for circulation features. However, sea surface temperatures (SSTs) were generally above normal in the North Atlantic during both spring and summer 2005, particularly in subtropical and subpolar regions (Figures 5-6a and 5-6b). This likely had two effects on the warm season circulation. First, the strength of the Bermuda High results, in part, from Atlantic SSTs that are relatively cooler than land masses to the east and west during late spring, summer, and early fall (Griffiths and Driscoll, 1982). During 2005, SSTs above normal directly may have contributed to the weaker-than-normal Bermuda High. Second, a necessary (but not sufficient) condition for tropical storm and hurricane formation is warm SSTs. Anomalously warm SSTs in the subtropical Atlantic almost certainly contributed to the unusually long and active nature of the 2005 hurricane season. These tropical storms and hurricanes ameliorated dry conditions in parts of Illinois (see Chapter 6) and did much more across areas south and east of Illinois by preventing formation of widespread drought that potentially could have provided regional feedbacks strong enough to promote upper-level ridging. The SST anomalies (Figures 5-6c and 5-6d) for the five driest springs (1925, 1930, 1934, 1936, and 1971) and five driest summers in Illinois between 1900 and 2004 (1930, 1933, 1936, 1988, and 1991) display much less subtropical warming in the Atlantic, and actually show cool La Niña conditions in the eastern tropical Pacific. Because the 2005 drought started with weak El Niño conditions that lasted into late spring before becoming neutral, most dry years used in the composite represented a different dynamic forcing component from the Pacific Ocean sector.

Little drought recovery occurred in fall, as October was very dry, and September and November precipitation was near average for the state. The summer 500-hPa level positive anomaly in southeastern Canada expanded westward and southward through the Midwest during September and October (Figure 5-7a). The lower atmospheric flow continued to circumvent Illinois to the west and north (Figure 5-7b), making precipitation more common in Minnesota and Wisconsin but keeping Illinois generally dry. Major deviations from this pattern occurred in early and late September, when remnants of Hurricanes Katrina and Rita passed over southeastern Illinois and accounted for much of the precipitation that fell during September and October. Atmospheric flow patterns that had persisted since spring finally changed in November when 500-hPa-level anomalies became negative north of the Great Lakes (Figure 5-7c). This change, combined with positive anomalies in the southwestern United States, reflected a more west-to-east circulation, bringing Pacific low-pressure centers through Illinois and leading to more normal precipitation in northwestern Illinois, the extreme drought area. The change in circulation may have been associated with the onset of a La Niña event, marked by rapidly cooling SSTs in the eastern tropical Pacific (Figure 5-7d).

Summary

Observed precipitation deficits are consistent with observed weaker-than-normal low-level flow from the Gulf of Mexico and Atlantic Ocean. The drought zone formed at the western edge of the main path through which moisture usually arrives from the south. Upper level flow also was weaker and more northwesterly than normal over Illinois, reducing the number of surface low-pressure centers and upper level disturbances moving through the state. Areal coverage of large precipitation deficits was restricted by fortuitous passage of remnants of four tropical systems south and east of Illinois. Warm SSTs in the North Atlantic may have contributed both to the weaker northward flow and the occurrence of tropical storms and hurricanes. Late in 2005, the onset of a La Niña event in the tropical Pacific led to establishment of a more zonal flow in November that brought more frequent low-pressure centers to Illinois.

a) 2005 Mean March-May Sea Level Pressure



b) 1968 -1996 Mean March-May Sea Level Pressure

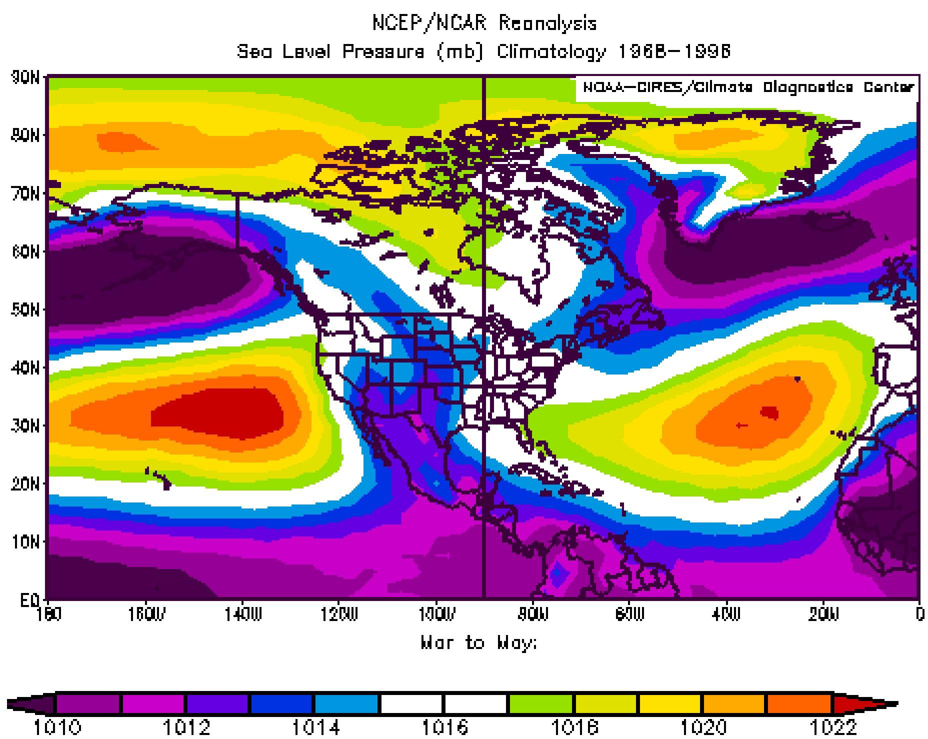


Figure 5-1. Mean March-April-May sea level pressure (hPa) based on the NCEP/NCAR reanalysis: a) 2005; and b) 1968-1996. **Source**: NOAA Climate Diagnostic Center, Boulder, CO.

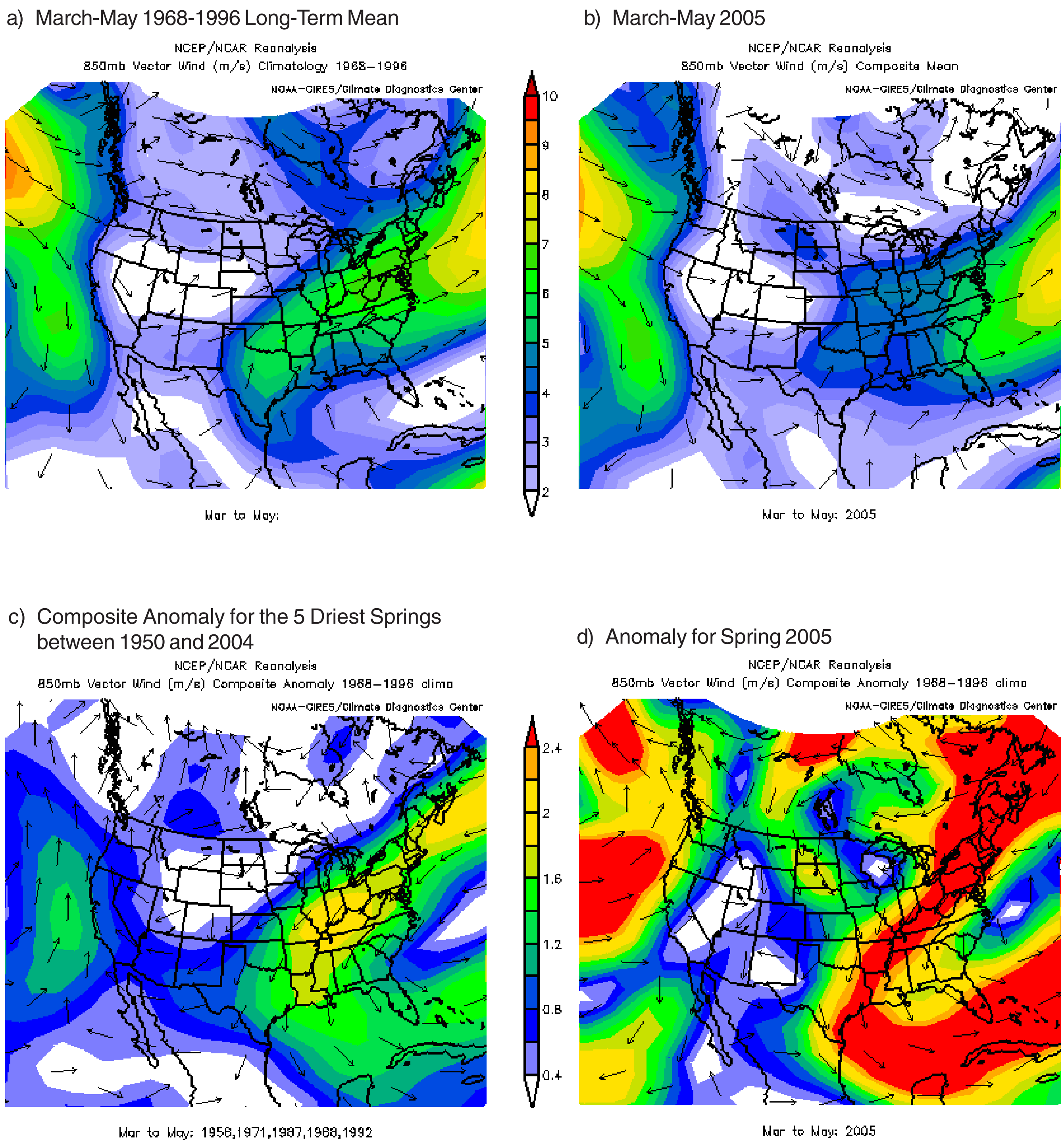


Figure 5-2. March-April-May 850 hPa level vector winds (m/s) based on the NCEP/NCAR reanalysis: a) 1968-1996 long-term mean; b) 2005 mean; and c) composite anomaly for the five driest springs between 1950 and 2004: 1956, 1971, 1987, 1988, and 1992; and d) anomaly for spring 2005. **Source**: NOAA Climate Diagnostic Center, Boulder, CO.
Note that the color code in c) and d) is different than in a) and b).

a) Mean June - August 2005

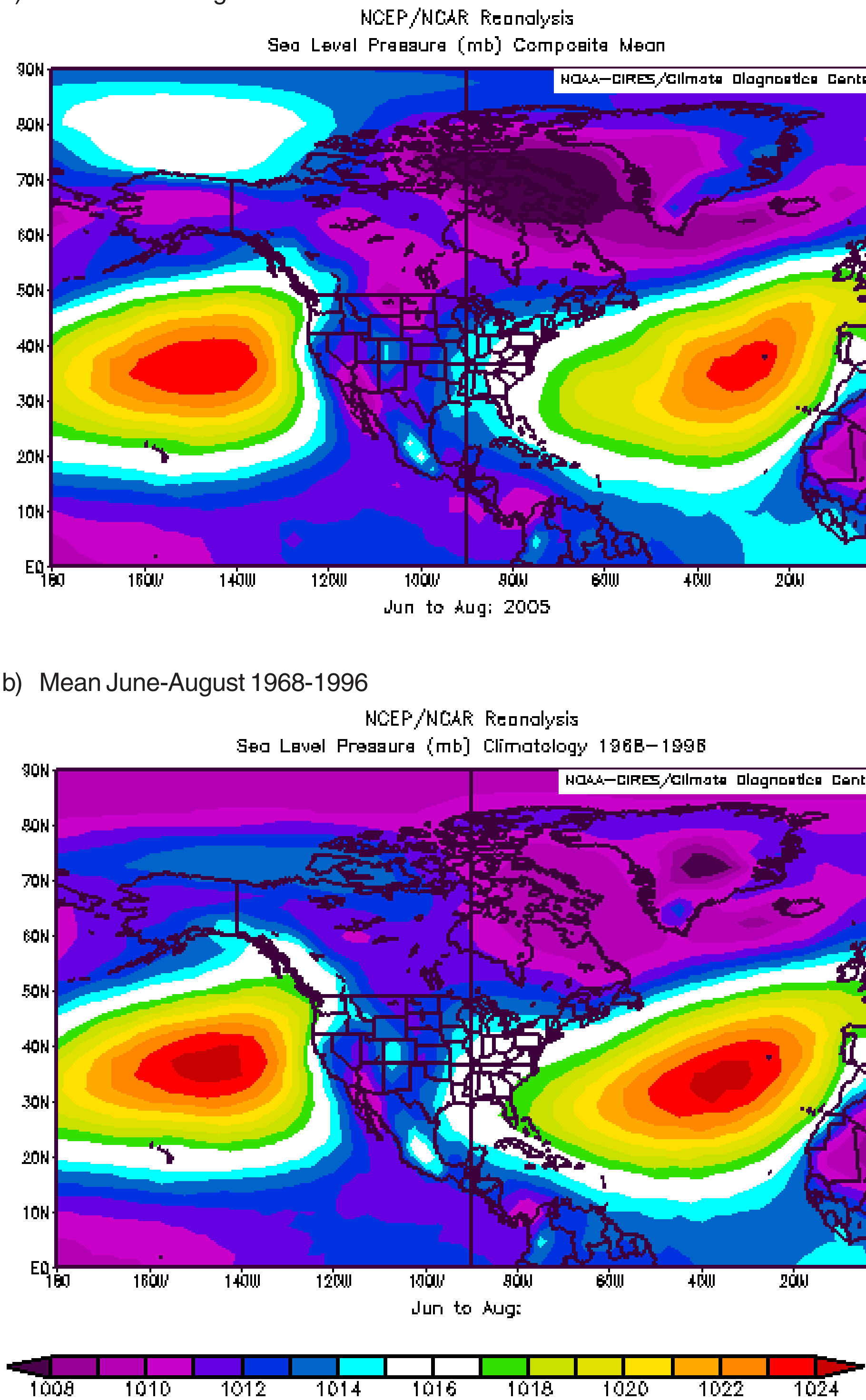


Figure 5-3. Mean June-July-August sea level pressure (hPa) based on the NCAR/NCEP reanalysis: a) 2005; and b) 1968-1996. **Source:** NOAA Climate Diagnostic Center, Boulder, CO.

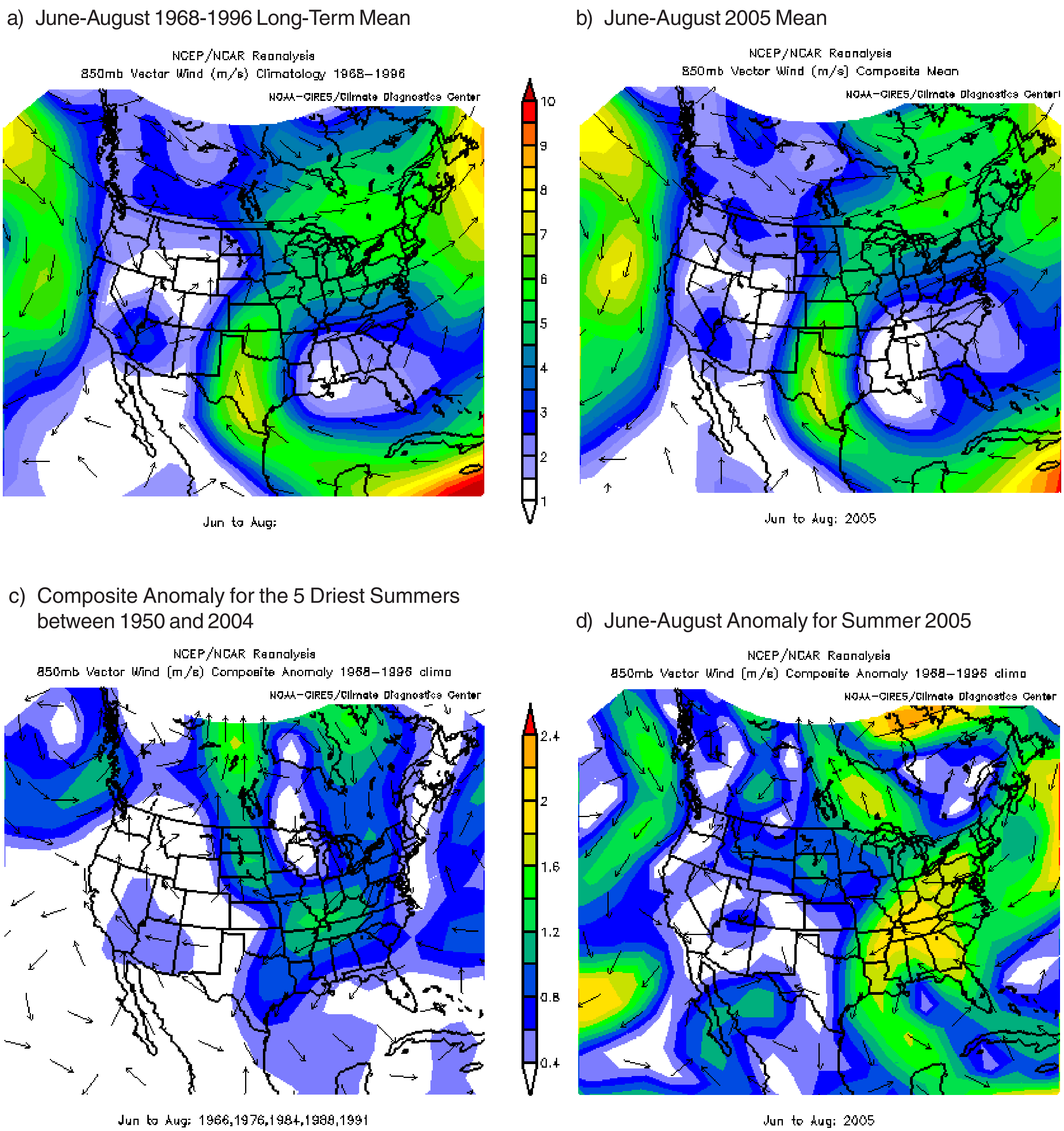


Figure 5-4. June-July-August 850 hPa level vector winds (m/s) from the NCEP/NCAR reanalysis: a)1968-1996 long-term mean; b) 2005 mean; c) composite anomaly for the five driest summers between 1950 and 2004: 1966, 1976, 1984, 1988, and 1991; and d) anomaly for summer 2005.
Source: NOAA Climate Diagnostic Center, Boulder, CO.
Note that the color code in c) and d) is different than in a) and b).

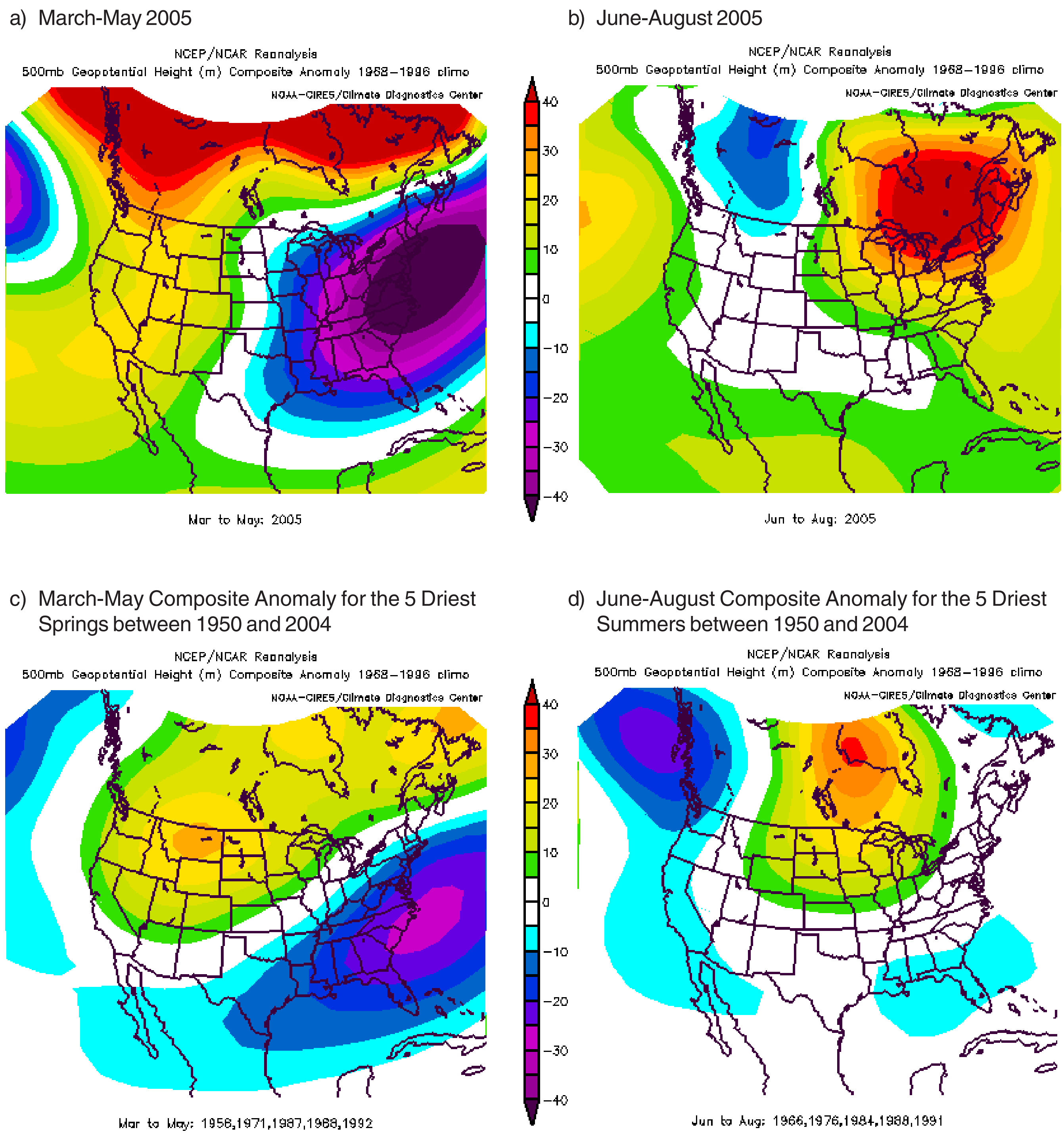
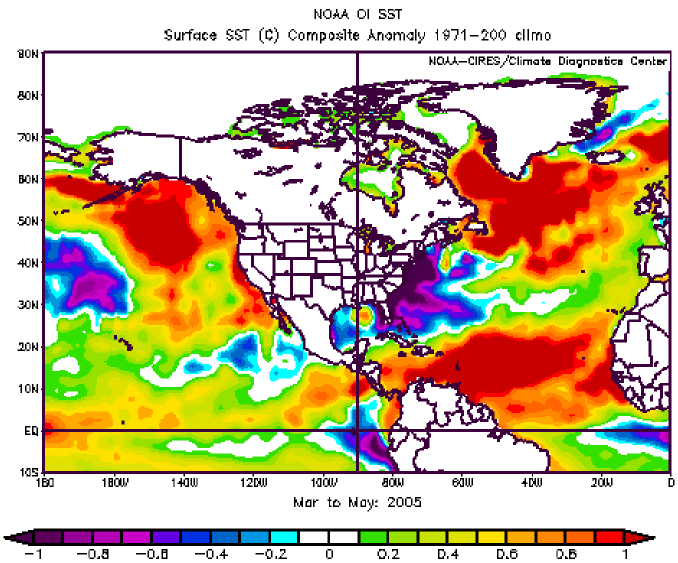
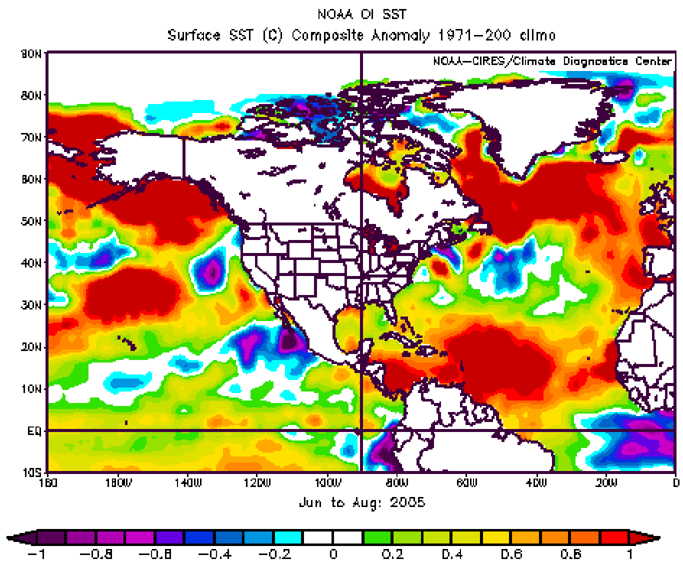


Figure 5-5. 500 hPa level geopotential height anomalies from the 1968-1996 mean (gpm) from the NCEP/NCAR reanalysis: a) March-May 2005; b) June-August 2005; c) composite anomaly for the five driest springs between 1950 and 2004: 1956, 1971, 1987, 1988 and 1992; and d) composite anomaly for the five driest summers between 1950 and 2004:1966, 1976, 1984, 1988, and 1991.
Source: NOAA Climate Diagnostic Center, Boulder, CO.

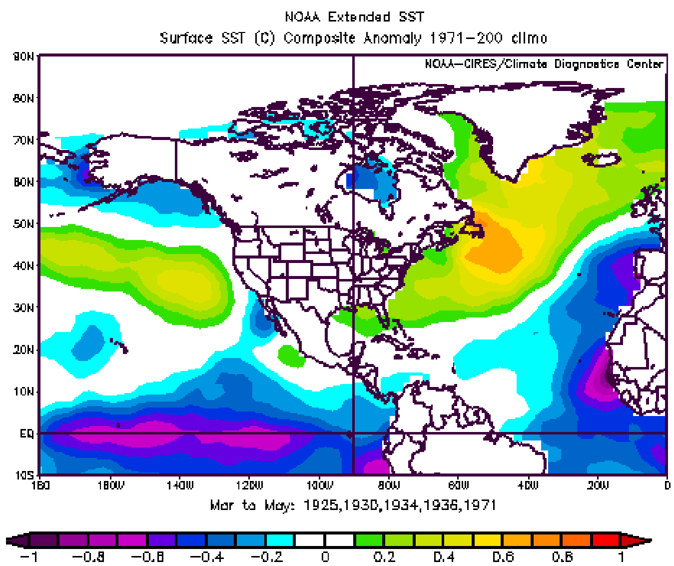
a) March-May 2005



b) June-August 2005



c) March-May Composite Anomalies for the 5 driest Springs between 1990 and 2004



b) June-August Composite Anomalies for the 5 driest Summers between 1990 and 2004

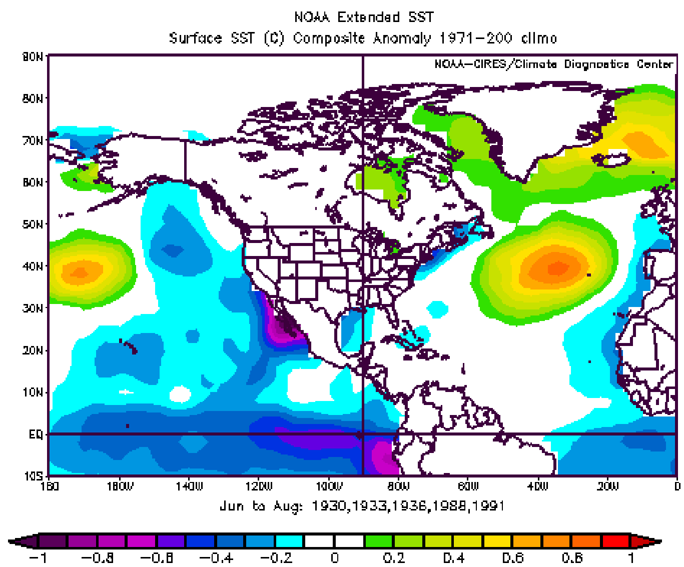


Figure 5-6. Sea surface temperature anomalies from the 1971-2000 mean (°C): a) March-May 2005; b) June-August 2005; c) composite anomaly for the five driest springs between 1990 and 2004: 1925, 1930, 1934, 1936, and 1971; and d) composite anomaly for the five driest summers between 1990 and 2004: 1930, 1933, 1936, 1988, and 1991.
Source: NOAA Climate Diagnostic Center, Boulder, CO.

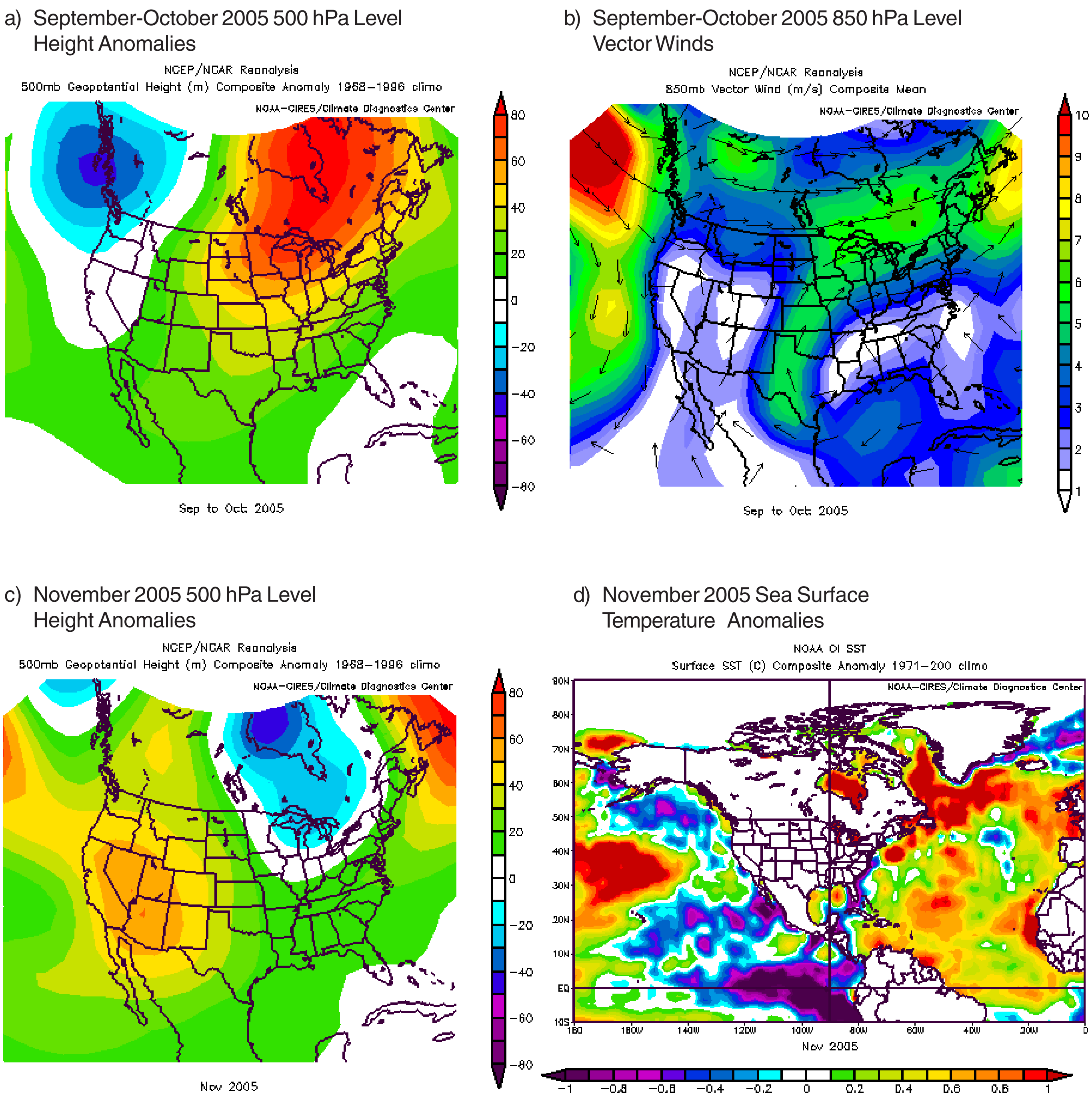


Figure 5-7. Autumn circulation conditions: a) September-October 2005 500 hPa level height anomalies (gpm); b) September-October 2005 mean 850 hPa level vector winds (m/s); c) November 2005 500 hPa level height anomalies from the 1968-1996 mean (gpm); and d) November 2005 sea surface temperature anomalies from the 1971-2000 mean (°C).
Source: NOAA Climate Diagnostic Center, Boulder, CO.

Chapter 6. The Role of Tropical Systems

James R. Angel

Introduction

One of the outstanding climatic aspects of the 2005 drought was the role of tropical storms in alleviating the drought across southern and central Illinois. Tropical storms have been known to bring beneficial rains to drought-stricken areas, typically along the Gulf and East Coasts. Sugg (1968) documented nine such cases from 1928 to 1963, using the Palmer Drought Severity Index to identify areas in drought. The most significant example was the pair of Hurricanes Diane and Connie, only a week apart in 1955, which produced rains over 80,000 square miles considered to be in drought status along the East Coast. More recently, Hurricane Floyd produced heavy rainfall along the East Coast in September 1999, causing widespread flooding and abruptly ending a drought emergency in New Jersey (Robinson, 2000). Larson et al. (2005) examined the climatology of land-falling tropical cyclones in the United States and Mexico and demonstrated that a significant portion of the mean annual precipitation along the Gulf and East Coasts comes from tropical cyclones. On average, a small contribution (less than 5 percent) extended as far north as extreme southern Illinois.

This chapter examines four tropical storms (Arlene, Dennis, Katrina, and Rita) that passed through Illinois during the 2005 growing season. The precipitation pattern and synoptic features of each storm are reviewed. The aggregated precipitation pattern from the four storms and its impact on the 2005 drought are discussed.

Data and Methodology

Three data sources were used in this study. Gridded precipitation data came from the Midwestern Climate Information System or MICIS (Kunkel et al., 1990) of the Midwestern Regional Climate Center, based on data from the U.S. cooperative observer network. Daily weather maps were obtained from the National Weather Service (2005). Tropical cyclone tracks from the Atlantic and Northeast Pacific Tropical Cyclone HURDAT dataset from the National Hurricane Center (Neumann et al., 1999) cover the period 1851-2004. This last dataset contains both tropical storms and tropical depressions, but not remnant lows.

For the 2005 season, dates when the tropical systems passed through Illinois were determined from the National Hurricane Center tracks. Rainfall amounts from those days then were accumulated separately from the rest of the growing season. Finally, maps of total rainfall from all sources, the total rainfall from tropical storms, and the total rainfall without tropical storms were determined for the growing season. Historical counts of tropical cyclones passing near Illinois were determined by identifying systems that passed north of 35ºN latitude and between 85º and 93ºW longitude. These latitude and longitude criteria were determined based on the tracks of the four storm systems in 2005.

Reconstructing the actual rainfall contribution of a storm system is challenging when using daily data. Because the data are a combination of morning, afternoon, and midnight observations from different stations, it was decided to include data not only from the dates when the tropical system passed through Illinois but also from the day after to include any morning observations after the event. In many cases, tropical systems moving through the Midwest can cover areas hundreds of miles wide and interact with existing synoptic features, such as a passing cold front. As a result, it is not always possible to identify rainfall exclusively from tropical systems.

Results and Discussion

There were four tropical systems of interest in 2005. Rainfall from those storms fell in Illinois on June 11-13 (Tropical Storm Arlene), on July 11-13 (Hurricane Dennis), on August 30-31 (Hurricane Katrina), and on September 25-26 (Hurricane Rita). Figure 6-1 shows their tracks. All four struck the Gulf Coast and then moved up the Mississippi and Ohio River valleys. Examination of previous records reveals that one or more tropical storms do occasionally pass through Illinois: two storms each in 8 years (1901, 1906, 1916, 1948, 1949, 1950, 1960, and 1985) and one storm each in 18 years since 1851 (1879, 1891, 1893, 1898, 1909, 1912, 1923, 1933, 1940, 1942, 1947, 1953, 1955, 1970, 1986, 1988, 2001, and 2002). The 1940s, the most active decade, had seven storms passing through Illinois. Two decades, the 1950s and 1980s, had four storms in each decade. Only in 2005 were four storms reported in one year, the maximum seen in the historical record, a rarity made even more impressive by a total of just three tropical systems passing through Illinois between 1956 and 1984.

There are several important features regarding the timing of the four 2005 events. The four events occurred at intervals of 4 to 6 weeks during the growing season, thus benefiting crop growth and minimizing the threat from flooding. Tropical Storm Arlene and Hurricane Dennis occurred relatively early in the tropical storm season and arrived at critical times in the growing season for Illinois. For example, Hurricane Dennis arrived in mid-July just as many cornfields were beginning the silking and tasseling stage when precipitation is particularly critical.

The first tropical system to pass through Illinois in the 2005 growing season was Tropical Storm Arlene in June 2005. Like the other three systems affecting Illinois that season, the storm moved up through the Gulf of Mexico, following first the Mississippi River valley and then the Ohio River valley. As Figure 6-2 shows, rain in Illinois was confined largely to the southern part of the state along the Wabash River valley. Amounts of 1 to 2 inches were common in this area, with a peak at Mount Carmel of 4.28 inches. The surface weather map for June 12, 2005 (Figure 6-3) showed that a cold front located to the west in Missouri and Iowa did not appear to interact with the passing tropical system. Therefore, it can be concluded that the rainfall on June 11-13 was almost exclusively from Tropical Storm Arlene.

The second tropical system, a category 4 hurricane, was Hurricane Dennis in July 2005. After causing damage along the Gulf Coast, it moved inland and weakened to a tropical depression before reaching Illinois. The surface weather map for July 12, 2005 (Figure 6-4) shows no pre-existing synoptic features in the Midwest to steer this storm. As a result, Hurricane Dennis meandered over Illinois for several days (July 11-13) before dissipating. Once again, timely rains greater than 1.5 inches were produced over southern Illinois (Figure 6-5), including a peak of 5.03 inches at Cairo. Even central Illinois received up to 2 inches of much needed rain. As with Tropical Storm Arlene, little or no rain fell in northern Illinois.

The third tropical system over Illinois was Hurricane Katrina in August 2005. While causing massive damage and more than 1800 deaths along the Gulf Coast, the system brought rain and no severe weather to Illinois. Of the four tropical systems, this one brought the least rain to Illinois and that rainfall was confined largely to southeastern Illinois. Amounts of about an inch were common in that area, southwestern and central Illinois received about 0.25 inches, and northern Illinois received no rainfall (Figure 6-6). The surface weather map for August 30, 2005 (Figure 6-7) indicated no other rain-producing features in the area so all rainfall on August 30-31 in Illinois was attributed to Hurricane Katrina.

The final tropical storm to affect Illinois was Hurricane Rita in September 2005. This storm produced widespread rains across the state (Figure 6-8) with common amounts of 0.5 to 1.5 inches, and up to 2.66 inches at Lebanon on September 25-26. Unlike prior storms, this one had benefits for northern Illinois. The surface weather map for September 25, 2005 (Figure 6-9) indicated the presence of a rain-producing cold front that later moved through northern Illinois. Hurricane Rita may have interacted with this synoptic feature to enhance rainfall across Illinois and is the only one of the four tropical systems from which some rainfall on the chosen dates may have been from other synoptic-scale features.

Rainfall departures of 8 to 11 inches from the 1971-2000 mean for March-September occurred across much of northern and west-central Illinois (Figure 6-10). Rainfall departures in southern Illinois were less severe. What was the total rainfall contribution of those four tropical systems? Figure 6-11 shows that the June-September aggregate rainfall ranged from 3 to 8 inches in southern Illinois, 1 to 3 inches in central Illinois, and less than an inch to 2 inches in northern Illinois. Clearly, timely rains from these four storms reduced drought severity in the southern half of the state and in some areas even eliminated drought completely.

Figure 6-12 shows March-September rainfall departures minus the rainfall of the four tropical systems. Rainfall departures may have been slightly more severe in northern Illinois, which already had the most impact. The biggest impact could have been in central and southern Illinois, which could have experienced drought conditions almost as severe as those in northern Illinois with rainfall deficits since March 2005 of 7 to 10 inches. Such deficits would have had a significant impact on crop production, pastures, streamflow, water levels in small lakes, and groundwater.

Summary

Unprecedented passage of four tropical systems (Tropical Storm Arlene, and Hurricanes Dennis, Katrina, and Rita) alleviated drought impacts during the 2005 growing season, particularly in southern and central Illinois. This study used daily rainfall data, daily weather maps, and tropical cyclone track information to determine the extent of rainfall from these four systems.

Several circumstances make this situation significant from a climatological perspective. The historical tropical cyclone records indicate that while an occasional tropical system passes through Illinois (during 26 years since 1851), 2005 was the first time for four such systems in one season. Timing of 4 to 6 weeks between events benefited agriculture while minimizing flooding. Tropical Storm Arlene and Hurricane Dennis also occurred relatively early in the growing season when critical moisture was needed.

By aggregating rainfall from these four events, it was shown that they provided significant drought relief in southern and central Illinois during the growing season. Aggregated rainfall amounts ranged from nearly 8 inches in far southern Illinois to less than an inch in northern Illinois. Without those four systems, central and southern Illinois could have been in a drought almost as severe as that in northern Illinois with 7-to 10-inch rainfall deficits instead of the observed 1- to 6-inch rainfall deficits.

2005 Tropical Storm Tracks

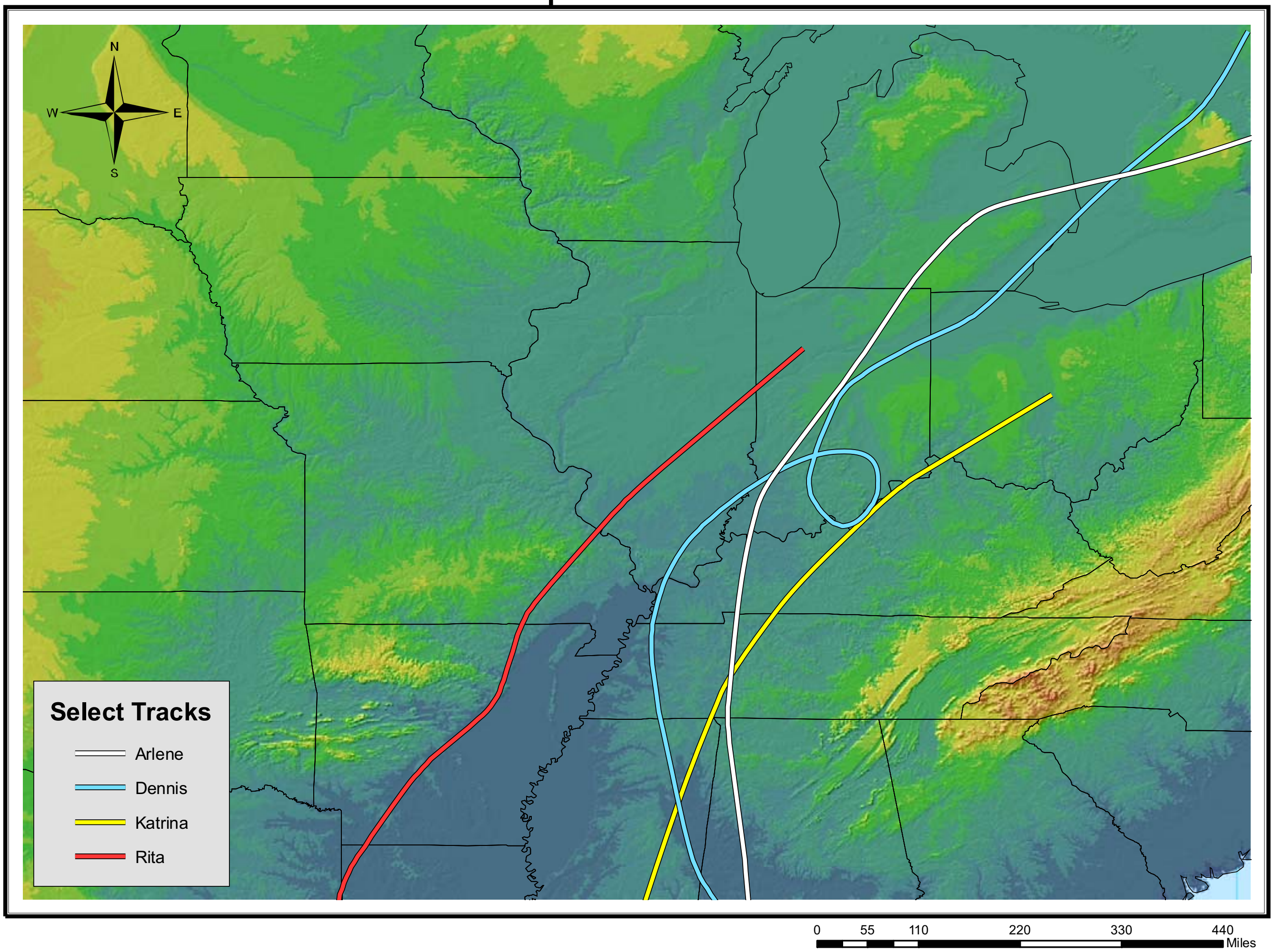


Figure 6-1. The storm tracks of all four tropical storms that passed through Illinois in 2005. They are in chronological order: Tropical Storm Arlene (white), Hurricane Dennis (blue), Hurricane Katrina (yellow), and Hurricane Rita (red).
Source: National Weather Service National Hurricane Center.

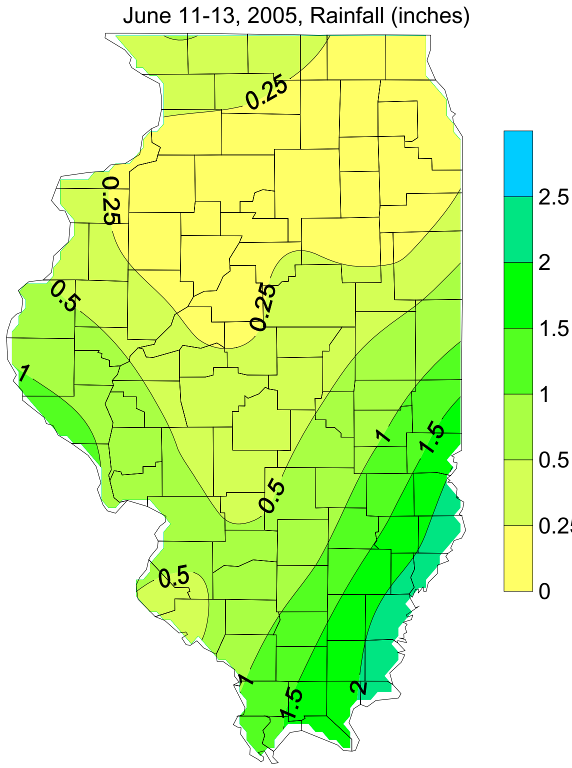


Figure 6-2. Rainfall (inches) from Tropical Storm Arlene.

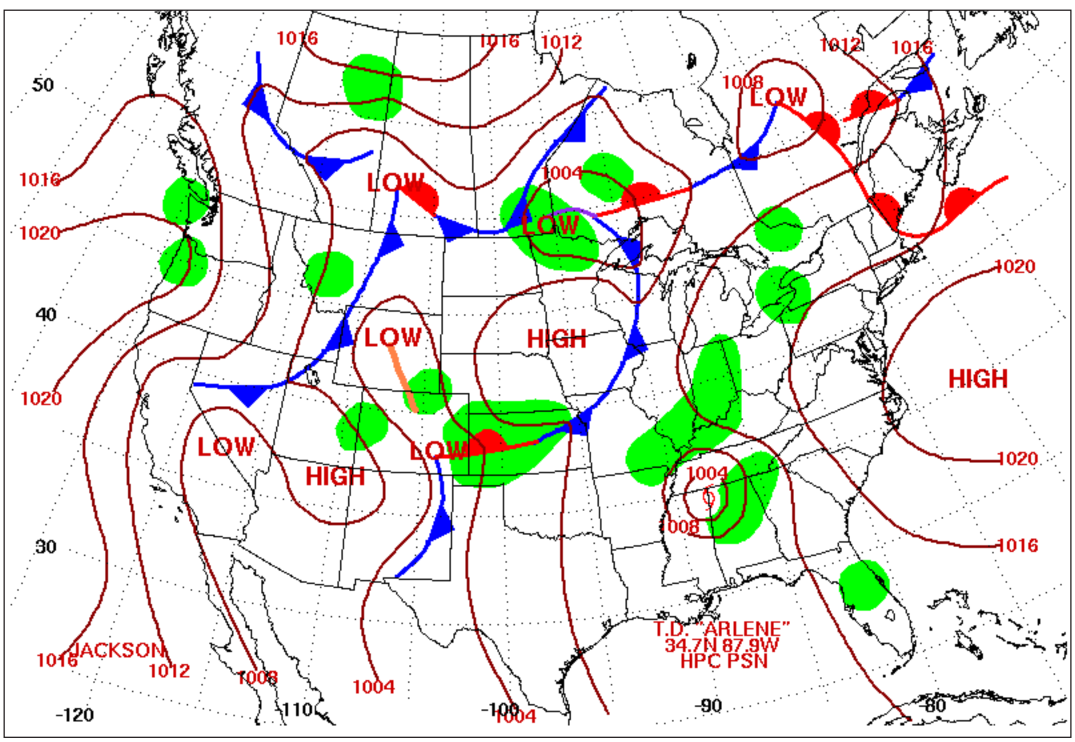


Figure 6-3. Surface weather map, 7:00 A.M. C.D.T. June 12, 2005. **Source:** National Weather Service National Centers for Environmental Prediction.

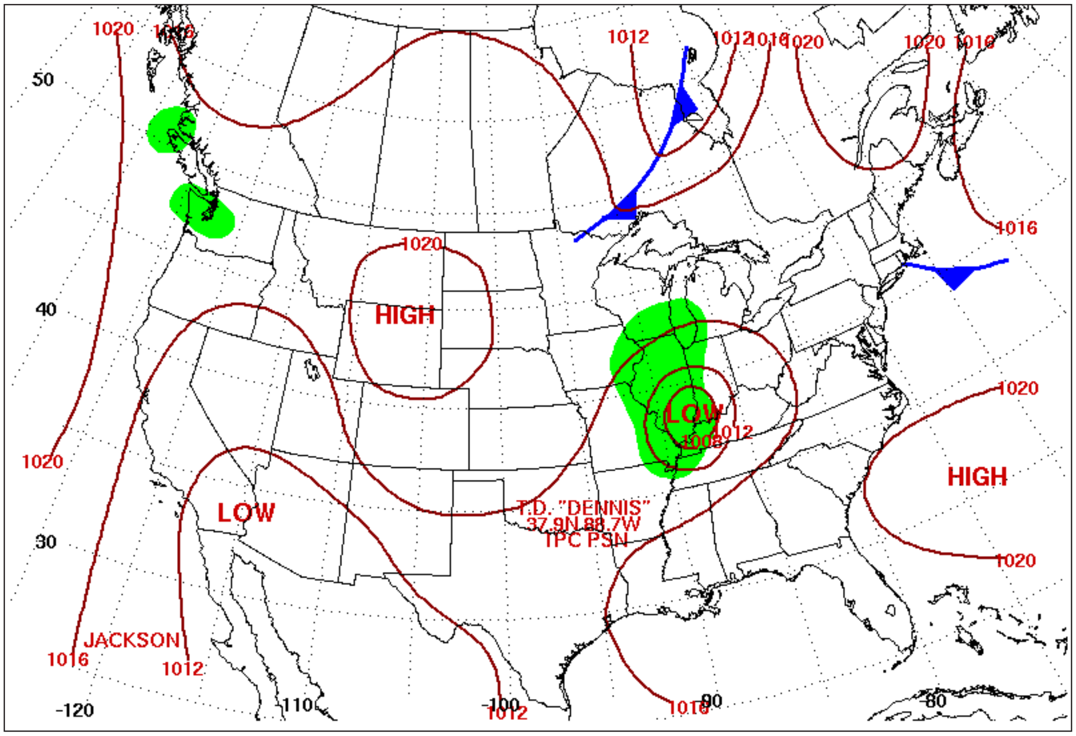


Figure 6-4. Surface weather map, 7:00 A.M. C.D.T. July 12, 2005. **Source:** National Weather Service National Centers for Environmental Prediction.

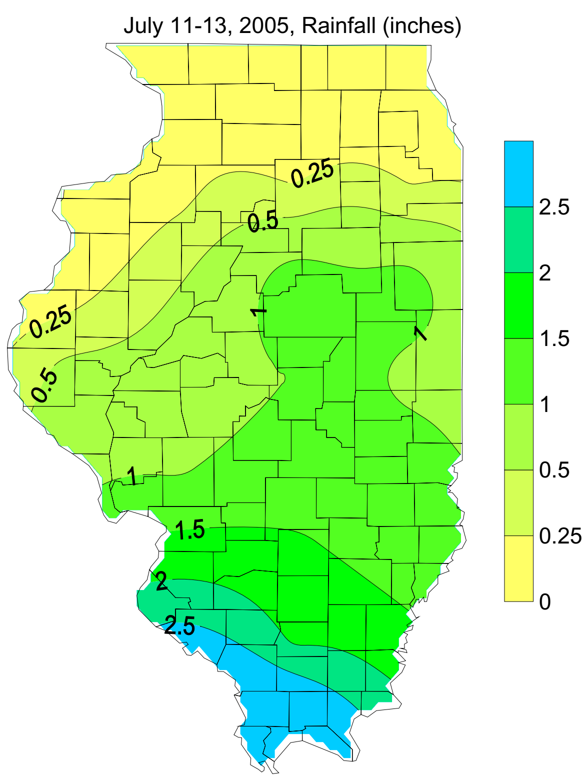


Figure 6-5. Rainfall (inches) from Hurricane Dennis.

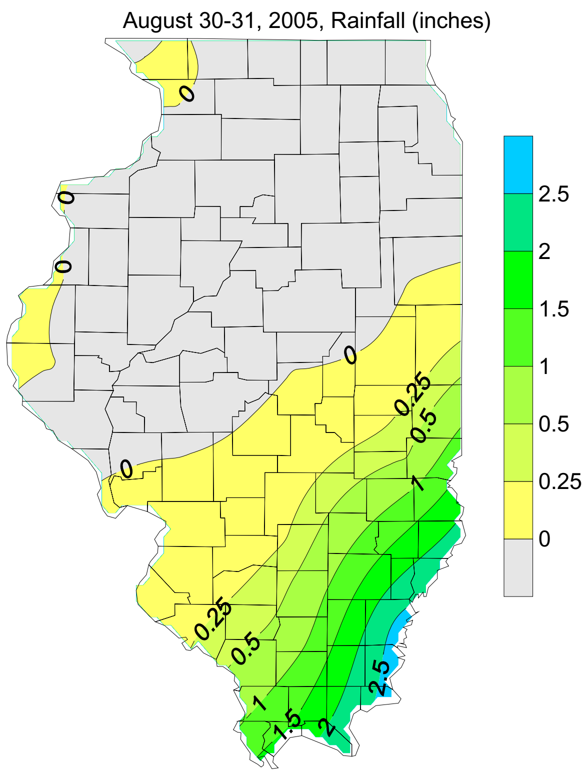


Figure 6-6. Rainfall (inches) from Hurricane Katrina.

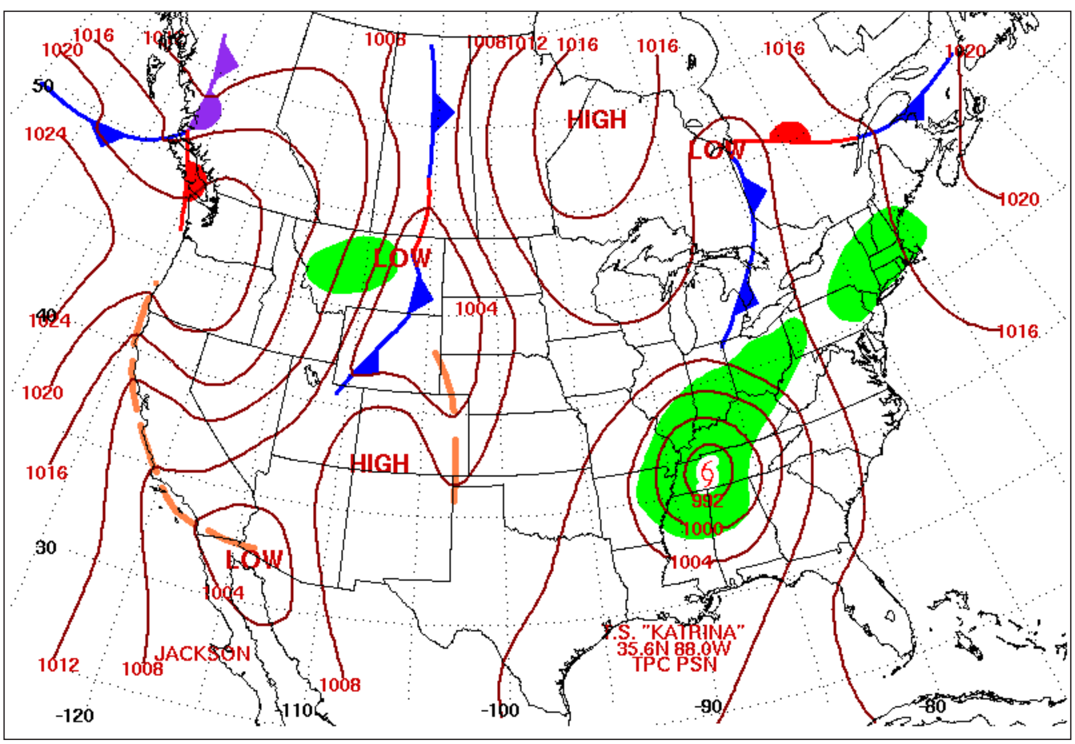


Figure 6-7. Surface weather map, 7:00 A.M. C.D.T. August 30, 2005. **Source:** National Weather Service National Centers for Environmental Prediction.

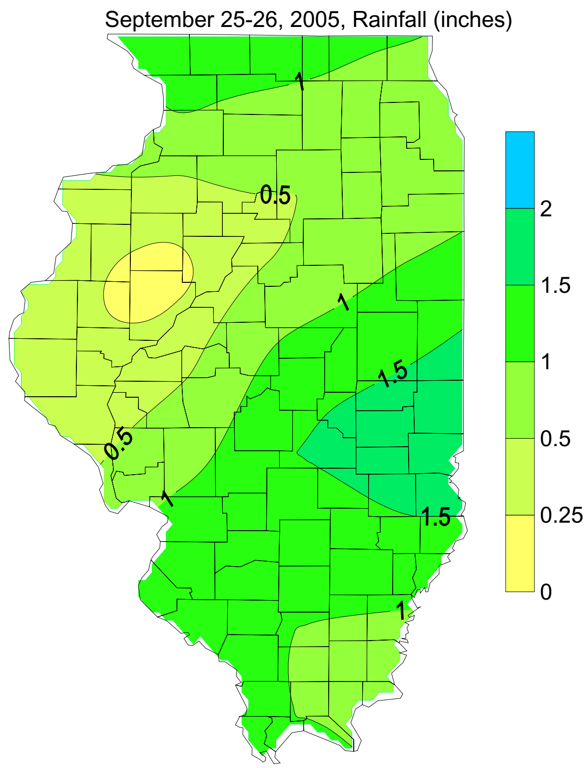


Figure 6-8. Rainfall (inches) from Hurricane Rita.

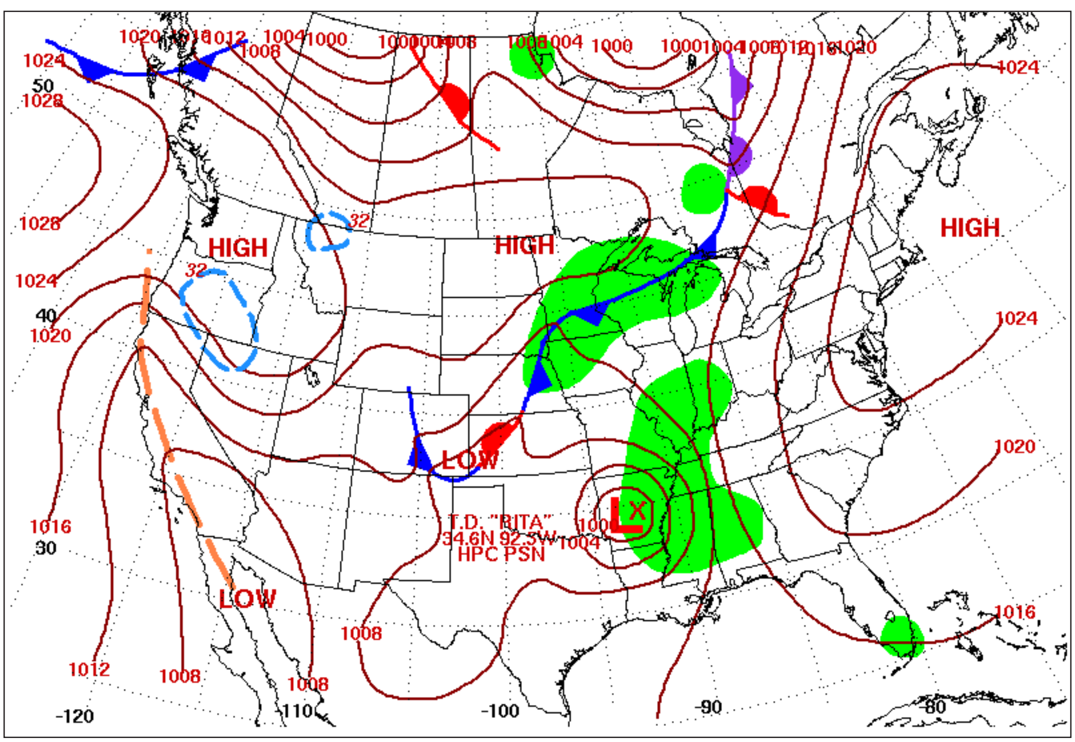


Figure 6-9. Surface weather map, 7:00 A.M. C.D.T. September 25, 2005. **Source:** National Weather Service National Centers for Environmental Prediction.

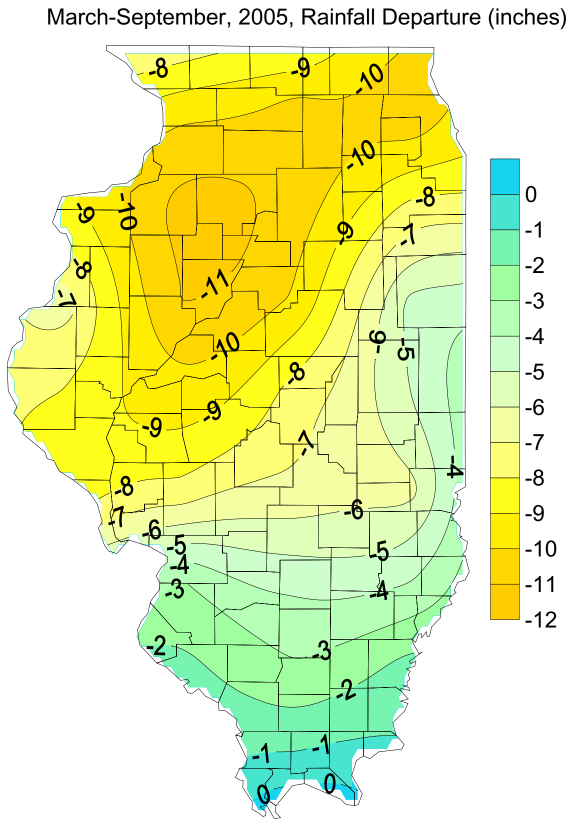


Figure 6-10. March-September rainfall departure from the 1971-2000 mean (inches).

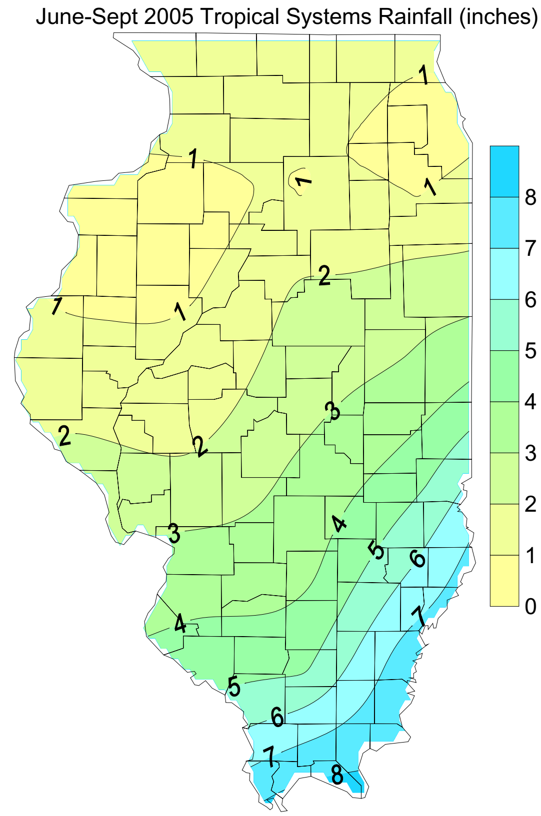


Figure 6-11. Accumulated contribution of total rainfall (inches) from four tropical systems through Illinois during 2005 growing season.

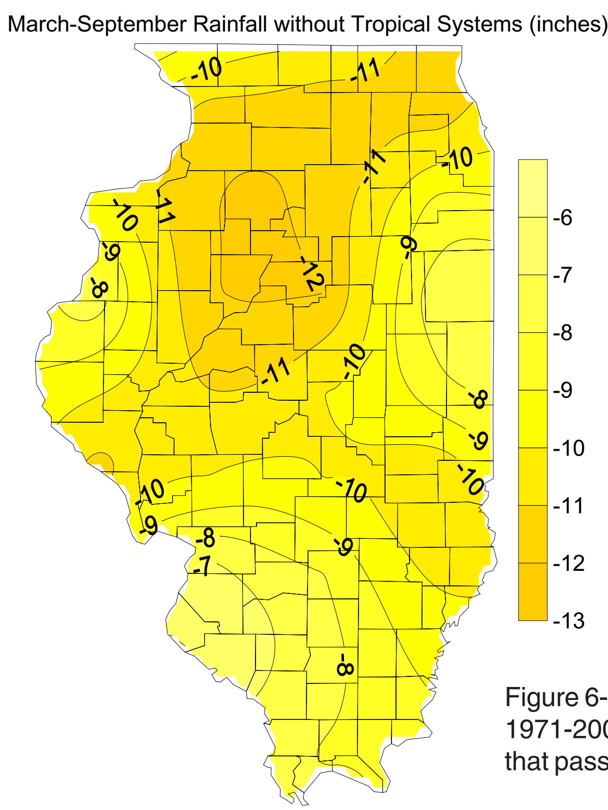


Figure 6-12. March-September rainfall departure from the 1971-2000 mean (inches), without four tropical systems that passed through Illinois during 2005 growing season.

Chapter 7. Societal and Economic Impacts

Stanley A. Changnon and H. Vernon Knapp

Introduction

This chapter focuses on the societal and economic impacts resulting from the drought. Many of these impacts occurred within the agricultural sector, an important part of the state's economy. These impacts produced several policy-related impacts as state leaders sought federal financial assistance for Illinois farmers. Impacts to other sectors of the state's economy were minor.

Agricultural Sector

Crop Conditions and Yields

The decreases in moisture extending throughout the surface and subsurface of the state's hydrologic cycle translated into impacts envisioned to be severe for agriculture, the sector most affected by the 2005 drought. A major drought can affect all aspects of an economy, but a growing-season drought, as that in 2005, normally influences primarily agriculture, with few serious impacts elsewhere in the economy. The dry March-May allowed rapid planting of 94 percent of the corn by May 8, 2005, compared to the average of 78 percent on this date (Illinois Agricultural Statistics Service, May 13, 2005). Soybeans also were 98 percent planted by June 5, 2005, compared to the average of 84 percent.

Agricultural Extension assessments of statewide crop conditions during the summer are shown (Table 7-1). The quality of the state's corn crop changed from 49 percent good and 11 percent poor/very poor in early June to only 12 percent and 61 percent poor/very poor by early August. Very poor corn was reported for only 2 percent of the state's crop in early June, but grew to 29 percent by early August. Status of the soybean crop also shifted dramatically, from 55 percent rated as good to excellent in early June to only 19 percent in early August.

The rainfall from Hurricane Dennis that fell on July 11-13 across the southeastern half of the state (Figure 6-5) was extremely timely for the corn crop. Research has shown that rainfall amounts during the June 30-July 12 period have more positive influence on corn yields than rains at any other time in the growing season (Changnon and Neill, 1968). By early August crop experts reported that any future rain would not help the corn crop but might be of small aid to the soybean yields (Grant, 2005b).

Table 7-1. The Status of Illinois Corn and Soybean Crops on Certain Dates during 2005. The amount of each crop in each category is expressed in percentages of the total crop in Illinois.

Crop	*Date*	*Excellent*	*Good*	*Fair*	*Poor*	*Very poor*
Corn	June 5	6	49	34	9	2
Corn	July 2	3	29	40	20	8
Corn	August 7	0	12	27	32	29
Soybeans	June 5	5	50	33	10	2
Soybeans	July 2	2	31	43	17	7
Soybeans	August 7	1	18	40	25	16

Estimates by the U. S. Department of Agriculture (USDA) of Illinois' crop yields, as first issued in early July, were 128 bushels/acre for corn and 41 bushels/acre for soybeans. These values declined in the USDA's yield predictions issued in early August to 125 bushels/acre for corn and 39 bushels/acre for soybeans. Interestingly, the USDA's yield estimates issued in early September called for higher yields of both crops, 136 bushels/acre for corn and 41 bushels/acre for soybeans. Many crop experts were surprised by these increases and questioned the USDA estimates. Crop surveys of many Illinois fields in late August found wide differences within many counties: the lowest corn yield was 6.7 bushels/acre, and the highest was 203 bushels/acre (Grant, 2005a).

The drought produced mixed outcomes for yield-reducing crop diseases and insect pests. Dry conditions were favorable for limiting populations of Japanese beetles and aphids. The corn crop was made vulnerable to corn rootworms, and dry soils limited plant uptake of pre-applied herbicides. The drought and lack of rain held off feared infestations of Asian soybean rust and many wheat diseases (Ross, 2005c).

Harvest began in September with warm and dry conditions that persisted for three weeks, helping crops to dry. By September 15, 6 percent of the state's corn crop and 8 percent of the soybean crop were harvested. By September 18, 74 percent of the state's corn was mature (National Weather Service, September 20, 2005). By mid-October, 89 percent of the corn crop and 93 percent of the soybean crop were harvested. Many farmers expressed surprise at their higher-than-expected yields (Illinois Agriculture Statistical Service, October 12, 2005). Although rainfall in July, a critical time for corn, was well below average, the timely rainfall from passage of Hurricane Dennis on July 11-13 helped corn crops in the southern two-thirds of Illinois.

The harvested statewide average corn yield was 143 bushels/acre, one bushel above the 1994-2003 average but 37 bushels less than record high yields of 2004. The harvested statewide average soybean yield was 47 bushels/acre, 5 bushels above the average and the second highest soybean yield on record. The record high set in 2004 for soybeans was 50 bushels/acre.

The spatial distribution of 2005 crop yields revealed wide differences across the state. Table 7-2 presents yield statistics for the state's nine crop districts. Corn yields were above average in 5 crop districts with yield averages greater than 10 bushels above average in East, Southwest, and Southeast districts. Corn yields in the Northwest, Northeast, West, and Central districts were below average, but the only major decrease occurred in the Northeast (-14 bushels).

Soybean yields (Table 7-3) were above average in all nine districts, and 5 bushels or more above average in the East, East-Southeast, Southwest, and Southeast. Harvested yields of both crops were much higher than expected in most of Illinois. The large difference between the low crop yields predicted during summer, and as identified by the crop surveys, and final yields above average for both crops, raises major questions about the cause. Some experts during the fall credited the timely rains as the critical weather factor behind the high yields, but if they were important, their effect went undetected by the experts during the growing season.

The drought did not hurt the state's winter wheat crop and yields averaged 64 bushels/acre, just one bushel below the 2004 record. Summer heat and dryness had detrimental effects on garden crops and pumpkins, and these yields were greatly reduced (Grant, 2005d). Orchard crops also were hurt by the heat, especially in areas where dry conditions prevailed. Peach yields were down 39 percent from those in 2004 (Illinois Agricultural Statistics Service, September 13, 2005). The drought also hurt hay and alfalfa crops, leading to increased prices for livestock feed (Grant, 2005k).

Table 7-2. Regional Corn Yields in Illinois for 2004, 2005, Averages for 1994-2003, and the Difference between the Average and the 2005 Value. (Illinois Department of Agriculture)

Corn	*NW*	*NE*	*W*	*C*	*E*	*WSW*	*ESE*	*SW*	*SE*
2005	140	129	141	146	158	151	139	133	130
2004	184	174	192	186	180	186	175	158	158
Average	149	143	149	154	144	147	130	110	110
Difference	-9	-14	-8	-8	+14	+4	+9	+23	+20

Source: Illinois Agricultural Statistics Service

Table 7-3. Regional Soybean Yields in Illinois for 2004, 2005, Averages for 1994-2003, and the Difference between the Average and the 2005 Value. (Illinois Department of Agriculture)

Soybeans	*NW*	*NE*	*W*	*C*	*E*	*WSW*	*ESE*	*SW*	*SE*
2005	48	44	47	51	51	46	46	42	44
2004	52	51	53	54	52	51	50	44	44
Average	46	43	46	47	45	43	39	34	34
Difference	+2	+1	+1	+4	+6	+3	+7	+8	+10

Source: Illinois Agricultural Statistics Service

Economic Impacts

Poor yields in parts of Illinois and good yields elsewhere meant various economic outcomes for Illinois farmers. Many faced low yields and low crop prices. Flow of the Mississippi River was reduced sufficiently by August to affect barges carrying grain. Barge loadings had to be reduced, resulting in higher shipping costs (*The News-Gazette*, August 11, 2005). Farm costs for energy and shipping went up. Hurricane Katrina did great damage on August 29 not only to grain elevators in the New Orleans area that handles 50 percent of all Illinois' grain crops for export, but also to oil production facilities along the Gulf Coast. These two outcomes brought higher grain shipping costs and higher fuel costs for grain drying and harvest. Experts reported that the 2005 crops in Illinois were the most expensive ever (Grant, 2005i) with average costs of $206 per acre for corn and $113 per acre for soybeans. Thus, agricultural experts predicted low yields, low prices, and higher costs would lead many Illinois farmers to store, not sell their crops.

What did the drought cost Illinois' farmers? In mid-August, the head of the Illinois Farm Bureau estimated that the loss to farmers would be $2 billion, as measured from 2004 incomes when yields set all-time record highs (Shipman, 2005a). Loss estimates issued later were less, with crop experts claiming losses slightly would exceed $1 billion (Biemer, 2005). The USDA stated on September 20 that the drought loss in Illinois would be $1.3 billion (*The News-Gazette*, September 21, 2005).

Given low prices, 2005 production of corn (1.73 billion bushels) and of soybeans (425 million bushels) in Illinois translated into income that totaled $5.626 billion. Assessment of farm incomes for 2005, which incorporated crop expenses, fuel costs, and low crop prices, translated into a statewide average value of $38,787 (Grant, 2006). This is less than half the 2004 value of $77,906 and $1,625 less than the 2000-2004 average, largely a result of the drought and high costs (Grant, 2005h). Sharp regional differences occurred as a result of the drought's spatial variations. The average 2005 farm income in northeastern Illinois, where the drought was most severe, was only $16,407. Farm incomes in wetter districts with good soils averaged $68,454 (East district) and $65,806 (West-Southwest district).

Without the rains from the four tropical storms that each affected large parts of the state, losses would have been much higher. Farmers in the southern half of Illinois greatly benefited from these unusual rains, and their yields were well above average (Table 7-3).

Future Impacts

Drought impacts had various effects on future agricultural activities. One such potential impact was a lowering of farm land prices (Grant, 2005l). However, farmland prices during 2005 actually increased by 9 to 18 percent, continuing a multi-year trend (Aupperle, D.E., 2006). The drought limited the uptake of nitrogen fertilizer in many fields, and this meant that less fertilizer would need to be applied in 2006. Some crop experts felt that successful winter wheat yields in 2005 likely would increase planting of wheat in 2006. Greater problems with corn yields than with soybean yields in 2005, plus winter forecasts of relatively higher soybean prices in 2006, may increase planting of soybeans in 2006 and reduce corn acreage. The lower income and tight economic conditions on many farms also would reduce purchases of farm equipment. Sales decreased dramatically during the drought months. By late fall 2005, however, many farmers expressed interest in purchasing new farm equipment in 2006 (Grant, 2005f), attributed to optimism resulting from the higher-than-expected yields in 2005.

Major seed firms reported no loss of seed corn supplies for 2006. Drought impacts and fear of continuation into 2006 led to major winter 2005-2006 sales of biotech corn varieties that tend to be drought resistant. Two seed firms reported that their triple trait (stack) corn varieties were completely sold out by December 1 (Grant, 2005j).

Government Actions

A major activity that developed as the potentially serious impacts of the drought on Illinois crop yields became evident involved government assistance for Illinois farmers. In early July, the Illinois Department of Agriculture began monitoring crop conditions in 51 counties for use in development of a possible disaster declaration. To qualify for federal disaster assistance, a county must have at least 30 percent production losses in one major crop. Farmers were advised to certify their crop acreage by July 15 to qualify for inclusion in a disaster declaration or to obtain federal crop insurance. After its activation by the Governor of Illinois on June 26, the Drought Response Task Force continued to meet during July and August to assess and report on drought status.

The Governor also decided in mid-July to request federal disaster assistance, and the federal Farm Service Agency (FSA) began assessing eligible counties. The FSA found that 101 counties qualified for disaster declarations, and the Governor formally requested federal aid in late July. The Illinois Treasurer also initiated a $100 million drought relief program to provide low interest farm loans (Shipman, 2005d). By the end of August, the 700 loans made totaled $47 million. Approximately 65 percent of Illinois' corn and bean crops had been insured (Ross, 2005b). Assessment in late August revealed that 74,000 Illinois farms had projected drought-related crop losses greater than 30 percent (Ross, 2005a).

Illinois members of Congress agreed to push for federal aid for the drought, admitting that aid would be difficult to obtain because the drought problem area was confined largely to only one state, Illinois. Obtaining the desired aid likely would require Congressional extension of the 2003-2004 disaster assistance program legislation, slated to terminate on September 1, 2005. The advent of Hurricane Katrina on August 29 with huge losses along the Gulf Coast immediately became a national issue that affected the potential for drought assistance for Illinois. As September wore on, Illinois' two senators pushed for a "drought relief plan" to extend the 2003-2004 assistance legislation. Illinois members of the House of Representatives offered three bills with different relief plans, revealing a need for a compromise.

As the harvest progressed, yields were found to be much higher than expected, particularly in central and southern Illinois, and relief assistance was seen as being needed only for farmers in northern Illinois (Grant, 2005c). Political endeavors to get federal disaster funds for Illinois' farmers were on hold during October and November. Some policy experts concluded that Congressional efforts to get federal aid funds ended when the statewide corn and soybean yields above average appeared in early October. In mid-December, Congress was debating dimensions of the $453 billion defense spending bill that contained several other nondefense items, including funds for agricultural relief and for Hurricane Katrina victims. The Senate had inserted $1.6 billion in the defense bill for farm relief resulting from losses due to drought, floods, or hurricanes. The House refused to include the added farm relief funding, insisting that all relief funding ($29 billion) go to victims of Hurricane Katrina (Zuckman, 2005). Illinois' two senators argued against the House position, but were told that Illinois' key House members went along with President Bush's wishes, not farm relief. House members further claimed that the farm relief efforts of Illinois' two senators were only a political ploy being used to thwart other aspects of the defense funding bill. Essentially, federal disaster relief for Illinois' farmers had become a political issue. The debate continued into May-June 2006 as Illinois' senators sought to get President Bush to approve a disaster aid bill that included $200 million for Illinois farmers struck by the 2005 drought (Grant, 2006).

Effects on Agribusinesses

The drought and its impacts on crops had further impacts on certain agribusinesses. For example, John Deere, a major producer of farm equipment, reported in August that sales declined by 3.5 percent because of the drought, and the company's stock values fell 11 percent, leading the company to cut production (Miller, 2005). Major seed companies and fertilizer firms, however, reported no impacts from the Illinois-centered drought. The lower flow on the Mississippi River reduced barge loads, which was costly to Illinois' farmers and barge companies. One barge firm reported having lost $300,000 due to smaller loads (*The News Gazette*, August 11, 2005). The outcome for grain elevators was mixed with much grain assigned to storage. Elevator managers who followed the early and mid-summer predictions of greatly reduced grain yields in Illinois held off selling their stored 2004 corn. Then, by September, many corn and soybean yields were average or higher, resulting in surplus corn supplies but only limited storage available. By late October, 97 million tons of corn were stored on the ground outside elevators (Figure 7-1), an outcome of the higher-than-expected yields, rapid harvest, and shipping problems (Grant, 2005g).

Energy Sector

The drought and its high summer temperatures had impacts on the energy industry. Temperatures above normal created extensive use of air conditioning, increasing incomes of utilities and costs for consumers. Added use of electricity caused utilities to use large amounts of natural gas at their electric generating units. The price of natural gas was high when summer 2005 began, but enhanced use of gas to generate electricity helped drive natural gas prices up even further (*The News- Gazette*, August 25, 2005). Coal sales and production also increased to meet the enhanced demand for electricity for air conditioning, thus benefiting several Illinois coal companies.

Water Resources

Surface water and shallow groundwater supply systems are typically most vulnerable to the impacts of drought. Compared to central and southern Illinois, the region of northern Illinois that was hardest hit by the 2005 drought has relatively abundant and deep groundwater resources that are relatively insensitive to the impacts of drought. The Chicago metropolitan region gets its water from Lake Michigan, and thus its supply was unaffected by the drought, as were the supplies for communities that rely upon deep groundwater. Of the other surface water supplies in the region, most withdraw water from major rivers that historically have proven to have sustainable low flows during drought periods. Some Chicago suburban dwellers dependent on shallow wells for their home supplies experienced supply problems as water levels fell. This led to the digging of new wells at many homes.

Many communities in northern Illinois experienced sizable increases in water use during the hot, dry weather in the summer of 2005, with most of the increases related to lawn watering and other outdoor uses of water. Newer neighborhoods that lacked mature landscaping had particularly high levels of water use, with some neighborhoods reporting an increase in average water use of about 300 percent. The overall water use for Rockford swelled to 40 mgd for much of June, up from a normal rate of 25 mgd (Seibert, 2005). Many communities in northeastern Illinois imposed bans against the use of sprinklers and other forms of outdoor watering. In most cases, the restrictions were not imposed because aquifers lacked sufficient water, but that the wells and distribution systems were not designed to provide the substantial increase in water use – often leading to low pressure in the outer portions of the distribution system. Increased pumping rates during the 2005 summer led to high water pressure in pipes near the East St. Louis Illinois-American water plant, and which, combined with dryness and hardening of the soil, caused numerous cracks in water mains (Jadhav, 2005). Boil orders were in effect because of concerns with potential contamination of the treated water.

Although the precipitation deficit in central Illinois was not as great as in northern Illinois, the region still experienced concerns about the drought's potential impacts on water supply. The cities of Springfield and Decatur took proactive measures to mitigate the potential impacts of the drought by using alternative sources of water to augment their supply reservoirs. Before Lake Springfield had dropped a foot below its normal level, the city had activated the pumping system that withdraws water from the South Fork Sangamon River to replenish the storage in the lake. It is estimated that between June 2005 and February 2006, this auxiliary supply had collectively added more than 3 feet to the water level in the lake (Reynolds, 2006). Even then, as of the end of February 2006, the lake level was 3.3 feet below full pool. In a similar manner, Decatur began pumping water from their well field in DeWitt County to augment the streamflow in the Sangamon River that flows into Lake Decatur. The watershed of Lake Decatur received timely rainfall in fall 2005 such that the lake level returned to full pool in November 2005.

Low water levels were observed at several smaller public supply reservoirs in central Illinois. Canton Lake was more than 6 feet below full pool by January 2006, with a loss of storage of roughly 40 percent. The two supply reservoirs at Ashland reached 4 and 6 feet below full pool. One of the primary reasons of concern for some small communities (for example, Altamont, Ashland, and Greenfield) is because their reservoirs have an uncertain capacity, as no bathymetric survey has been conducted.

Despite preliminary concerns, the drought did not develop sufficiently by the spring of 2006 to bring about serious threats of water shortages for any communities. Most of these reservoirs typically can provide water through the course of multi-year droughts. Of the supply reservoirs that were noticeably below normal in 2005, most returned to full capacity (or nearly full) by the end of April 2006. There were two known exceptions, these being the community reservoirs at Altamont and Greenfield, which remained 3.5 and 4.5 feet below normal, respectively, heading into the summer of 2006.

Retail Business

Some businesses were winners and others losers as a result of the 2005 drought and associated summer heat wave (*Chicago Tribune*, August 5, 2005). Winners included companies that install home swimming pools. The heat increased demand for pool installations. Companies that install home irrigation systems also reported increased sales. Firms that dig and develop home wells reported a 50 percent increase in residential well installations in the Chicago suburbs. Hot, dry conditions also led people to water parks for recreation, and attendance at several such parks was up 28 percent over that in past years.

Several retail firms reported that the drought and summer heat had hurt sales. Commercial firms that mow grass had reductions due to poor grass growth. Landscaping firms reported a major decline in sales and losses from having to replant recent plant installations that had died from the heat and dryness. Firms that install sod also had low sales, as did companies that seal basements and roofs (*The News-Gazette,* July 27, 2005).

Summary

Development of a drought in spring 2005 led to greatly lowered soil moisture levels by early June across large parts of the state. Soil moisture shortages persisted through the summer as below average rainfall continued in northern and western Illinois. This translated into reduced crop yields in those areas. Yields were hurt further by high summer temperatures and plant stress from numerous extremely hot days. Late summer rainfall was near normal in the southeastern half of Illinois because of passage of four tropical storms, resulting in above average yields of corn and soybeans in southern Illinois and parts of central Illinois.

Corn yields for Illinois averaged 143 bushels/acre, a bushel more than the average (1994-2003), and 37 bushels less than the record-high 2004 yields. Soybean yields for Illinois were 47 bushels/acre, 5 bushels above average, 3 bushels less than in 2004, and the second highest soybean yield on record. Corn yields in five of the state's nine crop districts (southernmost) were above average, and soybean yields were above average in all crop districts.

The difference between in-season yield predictions of crop experts calling for major crop losses from the drought versus the actual high corn and soybean yields in most of the state raised an important question. What factors produced the unexpected positive crop outcomes? Did pre-March wetness that saturated Illinois' soils before the drought, May and June dryness that produced deep rooting corn plants, and/or timeliness of the few rains in June and July do more for crops than was recognized by agricultural specialists? Did the drought greatly reduce crop diseases? Has advanced genetic breeding led to seed varieties that are much more productive under moisture and heat stress? Biotech corn varieties developed very deep and complex root systems in 2005 and produced corn yields 10 to 30 bushels/acre greater than standard corn varieties (Grant, 2005j). Have improvements in farming practices also made a big difference in the weather-crop yield relationships? Regardless of the reasons, circumstances in 2005 suggest a need for new definitions of weather-crop yield relationships.

The 2005 yield outcomes and other external factors translated into incomes below average for Illinois farmers. Income was reduced by low crop prices as most Corn Belt crop yields were average or above, and by added costs for higher fuel prices and shipping costs for harvested crops. Total farm income from Illinois' corn and soybeans in 2005 was $5.2 billion. The net income for Illinois farms in 2005 averaged $38,787, 4 percent less than the 1994-2003 average and 51 percent less than in 2004 when record-high yields occurred. These near average yields and political issues in Congress kept federal relief funds from being awarded to Illinois' farmers.

Some economic impacts occurred in other sectors: energy, water resources, and certain retail businesses. These impacts were all minor in comparison with agricultural impacts, however.

An important and interesting aspect of the 2005 growing-season drought was the considerable rainfall, mainly in the southern third of the state, from the unusual passages of four tropical storms that produced sufficient rainfall to bring major benefits to that part of Illinois. Consequently, that area enjoyed above average crop yields and no serious public water-supply shortages.

Figure 7-1. The higher-than-expected yields in 2005 resulted in surpluses and major grain storage problems in Illinois. Millions of bushels of corn are stored outside a Champaign elevator in early November because the numerous storage bins are already filled.

Chapter 8. Chemical Climatology of the 2005 Drought

Derek Winstanley, Roger Claybrooke, and Robert S. Larson

Introduction

A key finding of this report is that the 2005 drought in Illinois was a core area of a much larger regional drought (see Chapter 4). At various times drought effects occurred within a fairly narrow band from Texas to the Great Lakes, and abnormally dry conditions extended eastward to the Atlantic coast (see Figure 4-1). Precipitation deficits reported were consistent with observed weaker-than-normal flow from the east and south around the western edge of the Bermuda High (see Chapter 5). Drought developed along the western edge of the main path through which moisture normally is transported into the Midwest United States.

This report, like most drought reports, focuses on anomalies in precipitation quantities and atmospheric flow patterns. Given the description of anomalous atmospheric flow and precipitation patterns described in previous chapters, the authors of this chapter asked whether there also were associated anomalies in precipitation quality, which is determined by the concentration of chemicals in precipitation and the amounts of these chemicals deposited on the earth's surface in precipitation. In general, the higher the concentration of chemicals in precipitation and the higher the amount of precipitation, the higher will be the amount of chemicals deposited on the earth's surface. Dry deposition of chemicals to the earth's surface as gases and particles also occurs, but this chapter deals only with wet deposition.

Many natural and human-made chemicals occur in the atmosphere. Typically, their sources are on land and in oceans. From their source regions, emissions of these chemicals can be mixed in the atmosphere and transported long distances by winds. Atmospheric concentrations can be increased or decreased by atmospheric processes such as convergence and divergence. Some chemicals reside in the atmosphere for only seconds or days, and others for days or years.

Longer-lived species, such as carbon dioxide and chlorofluorocarbons, are mixed thoroughly throughout the global atmosphere, and atmospheric concentrations of these chemicals are quite uniform throughout the lower atmosphere. Ultimately, these species either are removed from the lower atmosphere through transformations and disassociation, transported into the upper atmosphere, or deposited on the earth's surface. The presence of these long-lived species in the atmosphere over Illinois reflects global emissions (Houghton et al., 2001).

Other chemical species reside in the atmosphere for only seconds to days before natural processes transform, disassociate, or remove them from the atmosphere. Sulfate, nitrate, chloride, and sodium ions are examples of shorter-lived species. Sulfate ion is formed largely from sulfur dioxide emitted during combustion of fossil fuels, mainly coal. Nitrate ion also is released during combustion of fossil fuels. Chloride and sodium ions are the constituents of sea salt, and the atmosphere picks up these as air moves over oceans. Some emissions are deposited close to the emissions sources and some are transported over thousands of miles, but the typical residence time in the atmosphere for sulfate, nitrate, chloride, and sodium ions is a few minutes to a few days. This results in the maximum concentration and deposition of these species at a distance of a few miles to a few hundred miles from the sources.

The Acid Deposition Control Program started in 1990 and required a substantial reduction in the emissions of sulfur dioxide from power plants to reduce the amount of sulfate and acid deposited on the earth's surface. Success of the sulfur reduction program can be seen in the gradual reduction in the amount of sulfate ion deposited over the Midwest and the Northeast. This reduction in sulfur dioxide emissions is from power plants located mainly in the Midwest and the Northeast (http://nadp.sws.uiuc.edu/amaps2/so4/amaps.html).

Another important chemical that can affect human health is mercury. Like sulfur, mercury occurs naturally in coal and is emitted to the atmosphere during coal combustion. There are also natural emissions of mercury from soil and ocean reservoirs containing naturally occurring mercury. This long-lived species typically resides in the atmosphere for a year or more (http://nadp.sws.uiuc.edu/lib/brochures/mdn.pdf).

The mission of the ISWS is to evaluate water and atmospheric resources. This includes air quality and composition of chemical substances removed from the atmosphere. An important national program housed at the ISWS is the National Atmospheric Deposition Program (NADP), a long-term monitoring program organized in 1977 in support of research on the effects of atmospheric chemical deposition. Today the NADP operates three networks that monitor precipitation chemistry, including chloride, sodium, nitrate, sulfate, and mercury at more than 300 sites across the country.

The NADP's National Trends Network (NTN) is the only network providing a long-term record of precipitation chemistry across the United States. The NTN began in 1978 with 22 sites and now has more than 250 sites. The NTN provides data on the amounts, trends, and geographic distributions of the atmospheric deposition of acids, nutrients, and base cations. Precipitation samples collected are analyzed according to standard operating procedures.

The NADP's Mercury Deposition Network (MDN) has more than 90 sites and joined the NADP in 1996. The NADP Mercury Analytical Laboratory analyzes all samples for total mercury but also offers optional methyl mercury measurements.

This chapter presents maps to show the average deposition of some natural and human-made chemicals from the atmosphere over the United States. Short-term reference conditions are provided by deposition values for the four years immediately prior to the 2005 drought, 2001-2004, based on precipitation-weighted weekly samples and precipitation amounts. Chemicals depicted are sulfate, nitrate, chloride, and sodium ions, and total mercury. Subsequent maps show March-May 2005 anomalies from the long-term-average (1990-2004) March-May deposition amounts of the same chemicals. A 15-year period provides a longer reference period. As sulfate ion deposition has decreased steadily since 1990, the March-May 2005 sulfate ion deposition anomaly also was calculated for a shorter 2001-2004 reference period to avoid bias of the 2005 anomalies by high values of sulfate ion deposition in the 1990s, or the decreasing trend since then. March-May 2005 anomalies for total mercury deposition were compared only with 2000-2004 reference period due to data limitations.

Chemical Climate in 2001-2004

As would be expected over a period of years, chloride and sodium ion concentrations were greatest along the coasts. For the period 2001-2004, chloride ion deposition was highest along the northern Pacific coast and along coasts of the Gulf of Mexico and the Atlantic Ocean. Chloride ion deposition decreased as air moved eastward from the Pacific Ocean and northward from the Gulf of Mexico and the Atlantic Ocean. Chloride ion deposition in southern Illinois was >2.0 kilograms per hectare (kg/ha) and decreased to <1.0 kg/ha in northern Illinois (Figure 8-1).

Sodium ion deposition showed the same pattern. Sodium ion deposition in southern Illinois was >1.0 kg/ha, which decreased to <0.5 kg/ha in northern Illinois (Figure 8-2).

Deposition of sulfate and nitrate ions, on the other hand, was greatest near their source in the Ohio River valley. Sulfate ion deposition was highest (>18.0 kg/ha) there and in the northeastern United States. Sulfate ion deposition was >18 kg/ha in southeastern Illinois, which decreased to <12.0 kg/ha in northwestern Illinois (Figure 8-3).

Nitrate ion deposition showed a similar pattern: >14 kg/ha over the upper Ohio River valley and the northeastern United States. Deposition of nitrate ion in southeastern and northeastern Illinois was >12.0 kg/ha but <12.0 kg/ha in the rest of the state (Figure 8-4).

Total mercury wet deposition data are available primarily for the eastern half of the continental United States and showed a somewhat different pattern. Total mercury wet deposition was highest (>14 micrograms per square meter or $\mu g/m^2$) along the coast of the Gulf of Mexico and Florida and in a tongue extending northward along the Mississippi River valley and into the Ohio River valley. Mercury deposition generally decreased northward and was <8 $\mu g/m^2$ along the Canadian border. Mercury deposition in Illinois was about 9-12 $\mu g/m^2$ (Figure 8-5).

Climate and Chemical Climate Anomalies in Spring 2005

Evolution of drought across the contiguous 48 states during March-May 2005 is shown in Figure 4-1, and precipitation anomalies are shown in Figure 4-2. The main features are positive precipitation anomalies in much of the western and southeastern United States and parts of Atlantic costal areas, and negative precipitation anomalies from the Texas-Mexico border northeastward to the Great Lakes and the northeastern United States.

Figures 8-6 to 8-9 show the mean March-May 2005 deposition of chloride, sodium, sulfate, and nitrate ions, respectively. These values are shown as anomalies from the long-term 1990-2004 March-May average values.

Chloride and sodium ion deposition anomalies were similar (Figures 8-6 and 8-7). Positive anomalies occurred along the Pacific coast, extending across the Rockies, and in New England, indicating increased deposition during the 2005 period where precipitation amounts were high. Negative anomalies occurred over much of the southern and southeastern United States, extending northward into Illinois, indicating lower deposition where precipitation amounts were low.

Small positive anomalies of sulfate and nitrate ion deposition extended from the Pacific coast eastward across the Rockies (Figures 8-8 and 8-9). Greater positive anomalies occurred in the southeast. A large area of negative anomalies extended from northern Texas to the Great Lakes and to the Atlantic coast. Figure 8-10 shows that when sulfate ion anomalies are evaluated against this shorter, more recent period, a band of negative deposition anomalies remains from Texas through the Great Lakes and across the northeastern United States. Positive deposition anomalies extended across the southern United States, particularly along the Gulf coast.

The total mercury wet deposition record is shorter and less geographically extensive than records for chloride, sodium, sulfate, and nitrate ions. Because the most complete set of total mercury deposition values occur since 2001, total mercury deposition anomalies for March-May 2005 also were calculated against a 2001-2004 reference period. Figure 8-11 shows positive anomalies of total mercury deposition >1 $\mu g/m^2$ in the southeast and negative deposition anomalies >1 $\mu g/m^2$ over the Midwest and across to the Atlantic coast. In Illinois, a negative mercury deposition anomaly of about 0.4 $\mu g/m^2$ in the south increased to about 2.0 $\mu g/m^2$ in the north, where drought was most intense.

Summary

Chemical climate anomalies were established by using long-term, wet-deposition monitoring data collected, analyzed, and quality controlled by the NADP.

In March-May 2005, precipitation below normal occurred in a band from Texas through the Midwest and across to the Atlantic coast, and was associated with weaker-than-normal southerly flow of moist air from the Gulf of Mexico. Reduced atmospheric wet deposition of chloride, sodium, sulfate, and nitrate ions, and total mercury was associated with these precipitation and flow anomalies.

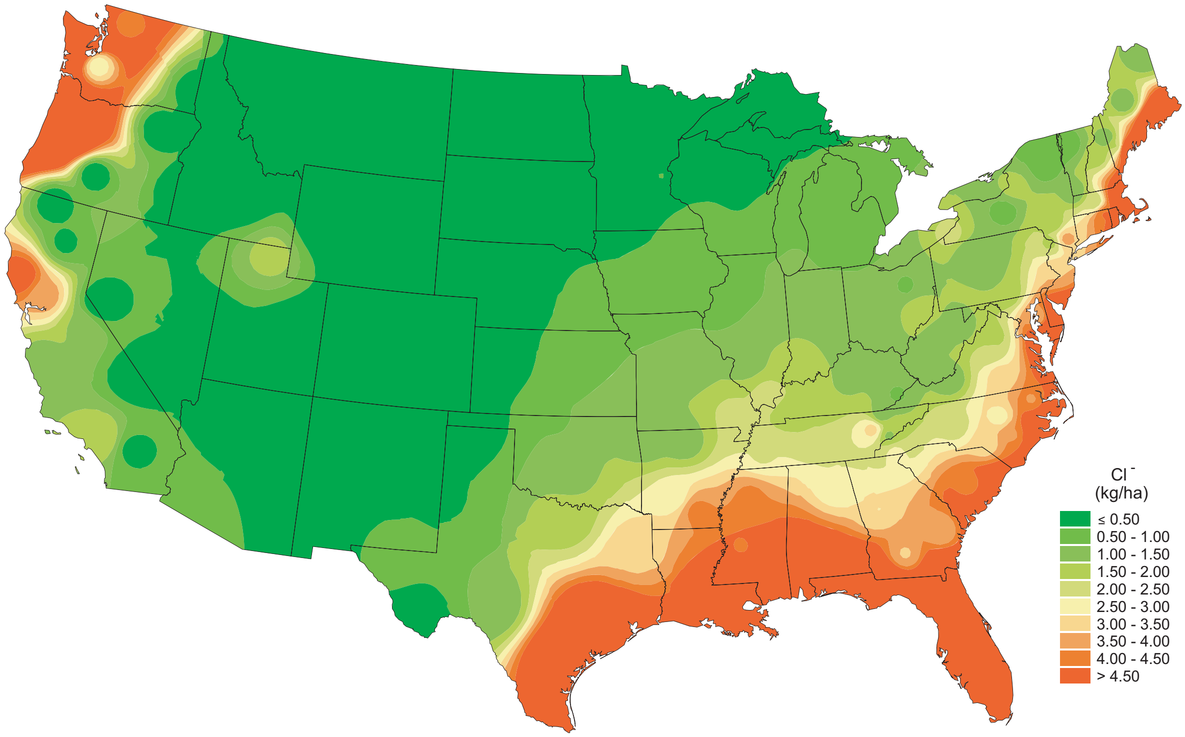


Figure 8-1. Chloride ion deposition for spring (March-May) averaged for 2001-2004

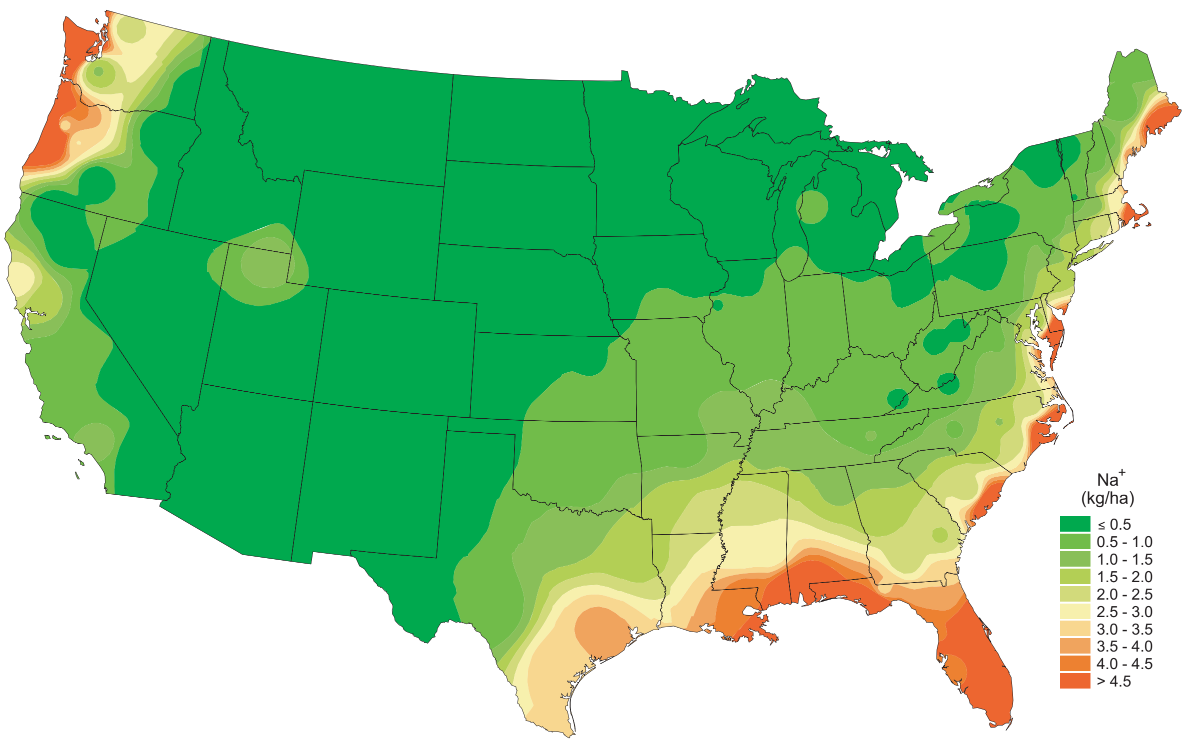


Figure 8-2. Sodium ion deposition for spring (March-May) averaged for 2001- 2004

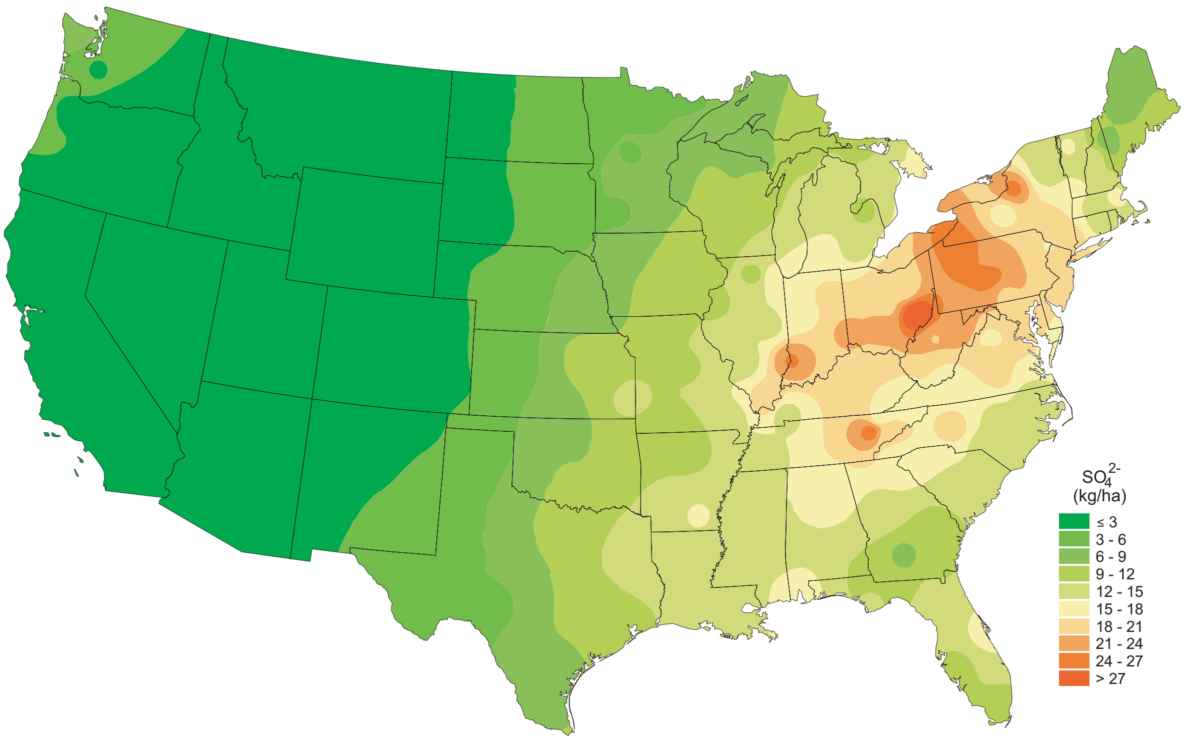


Figure 8-3. Sulfate ion deposition for spring (March-May) averaged for 2001-2004

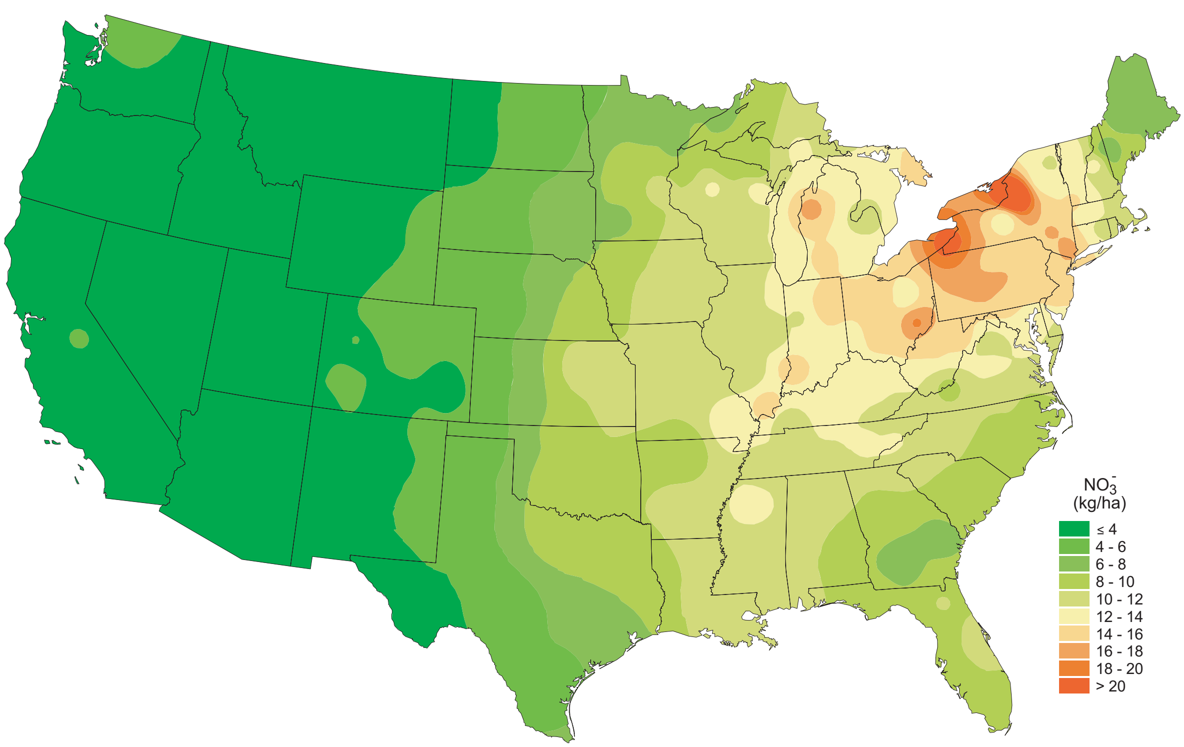


Figure 8-4. Nitrate ion deposition for spring (March-May) averaged for 2001-2004

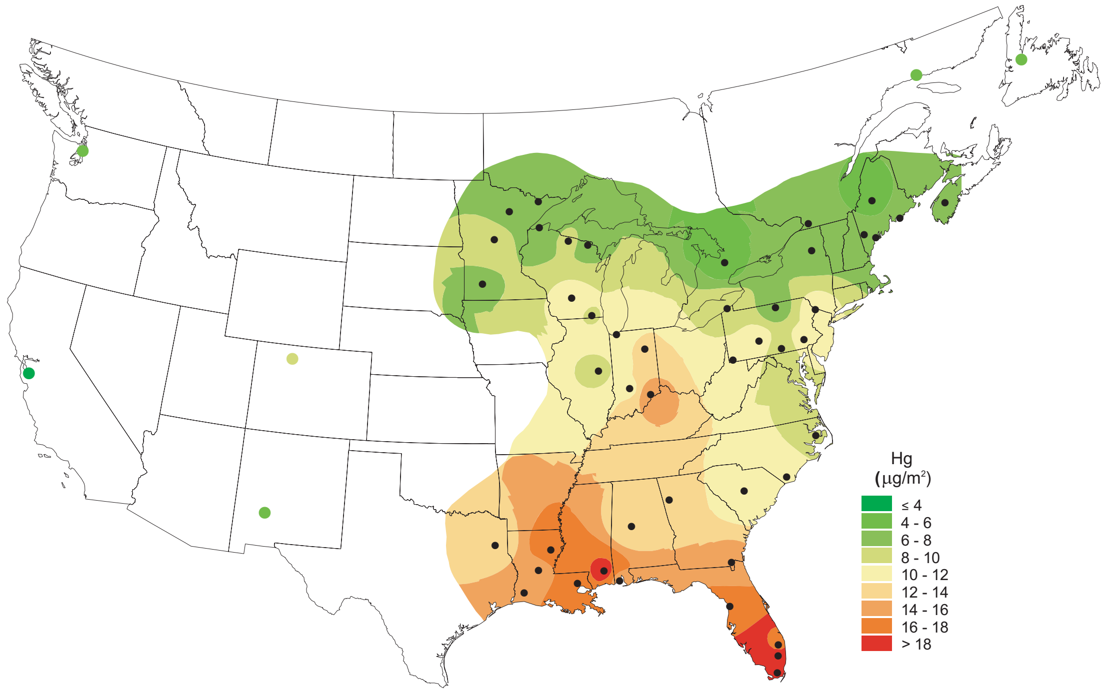


Figure 8-5. Mercury deposition for spring (March-May) averaged for 2001-2004

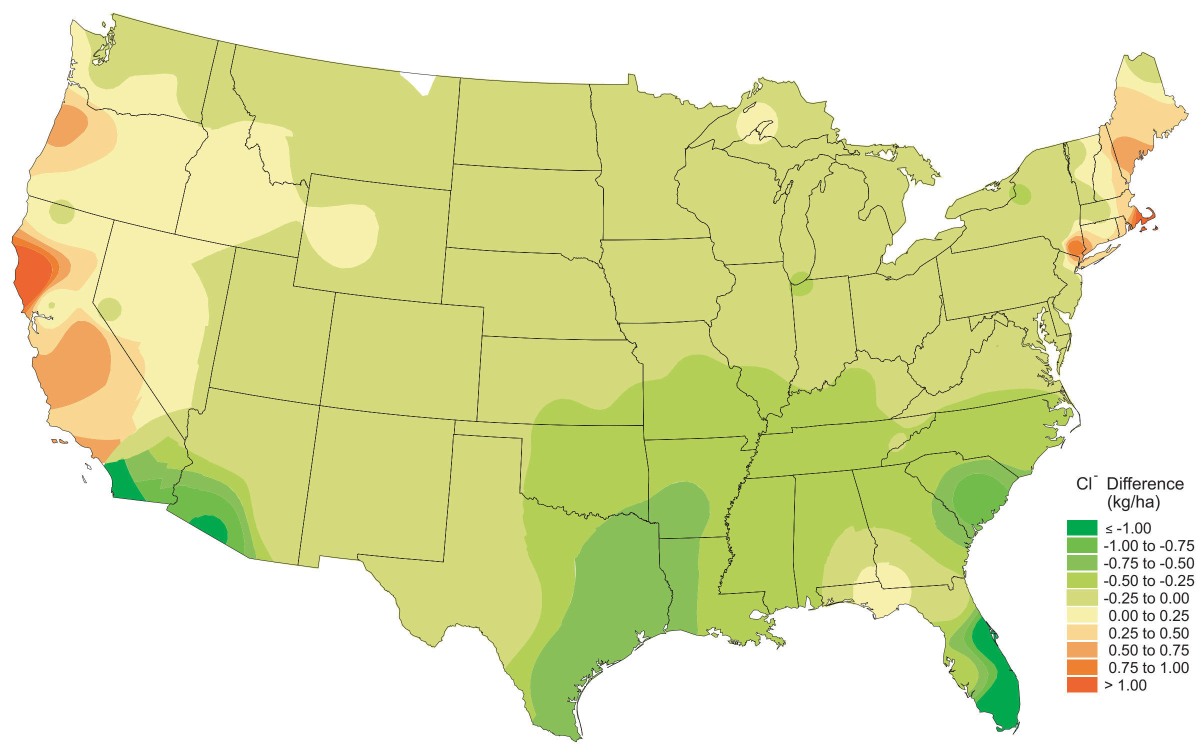


Figure 8-6. Chloride ion deposition for spring (March-May) 2005 expressed as anomalies from the 1990-2004 average

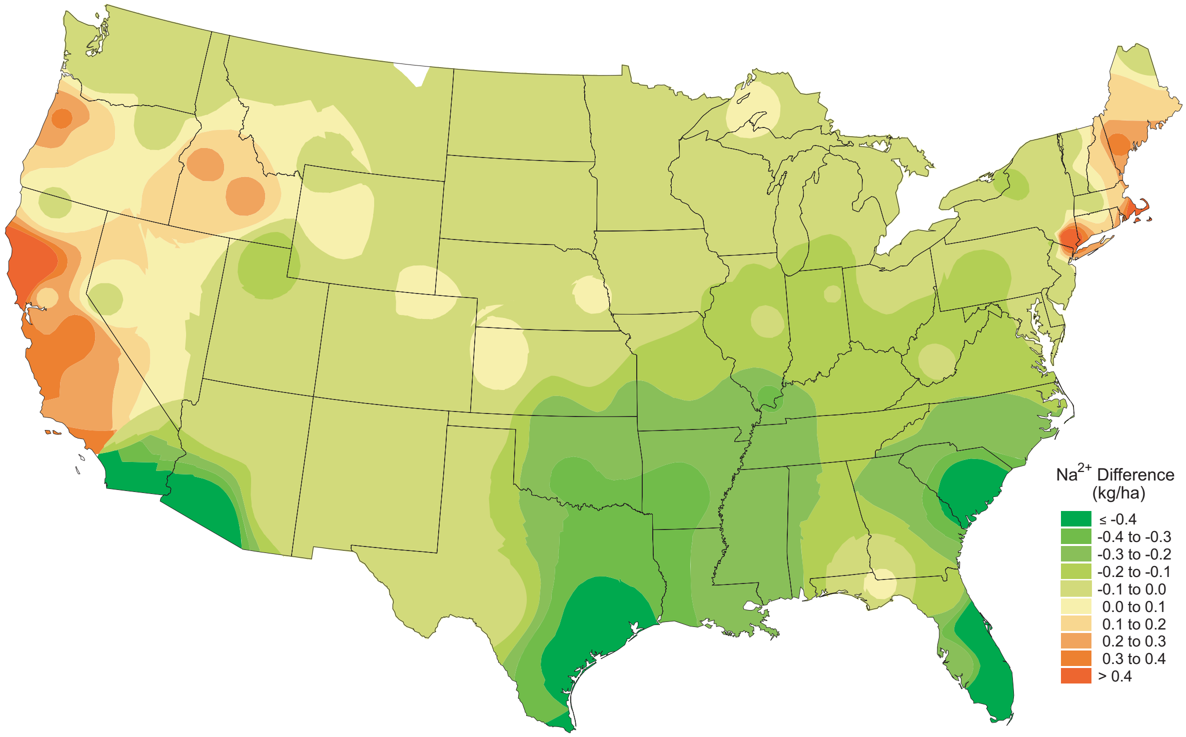


Figure 8-7. Sodium ion deposition for spring (March-May) 2005 expressed as anomalies from the 1990-2004 average

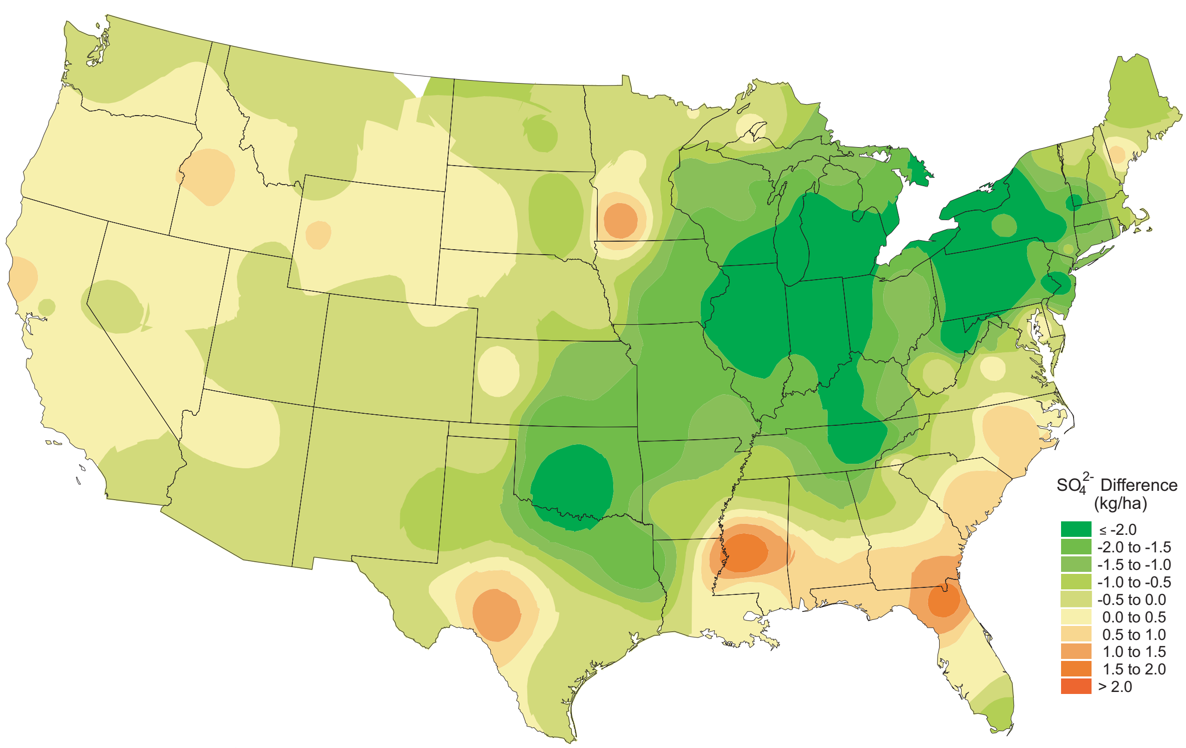


Figure 8-8. Sulfate ion deposition for spring (March-May) 2005 expressed as anomalies from the 1990-2004 average

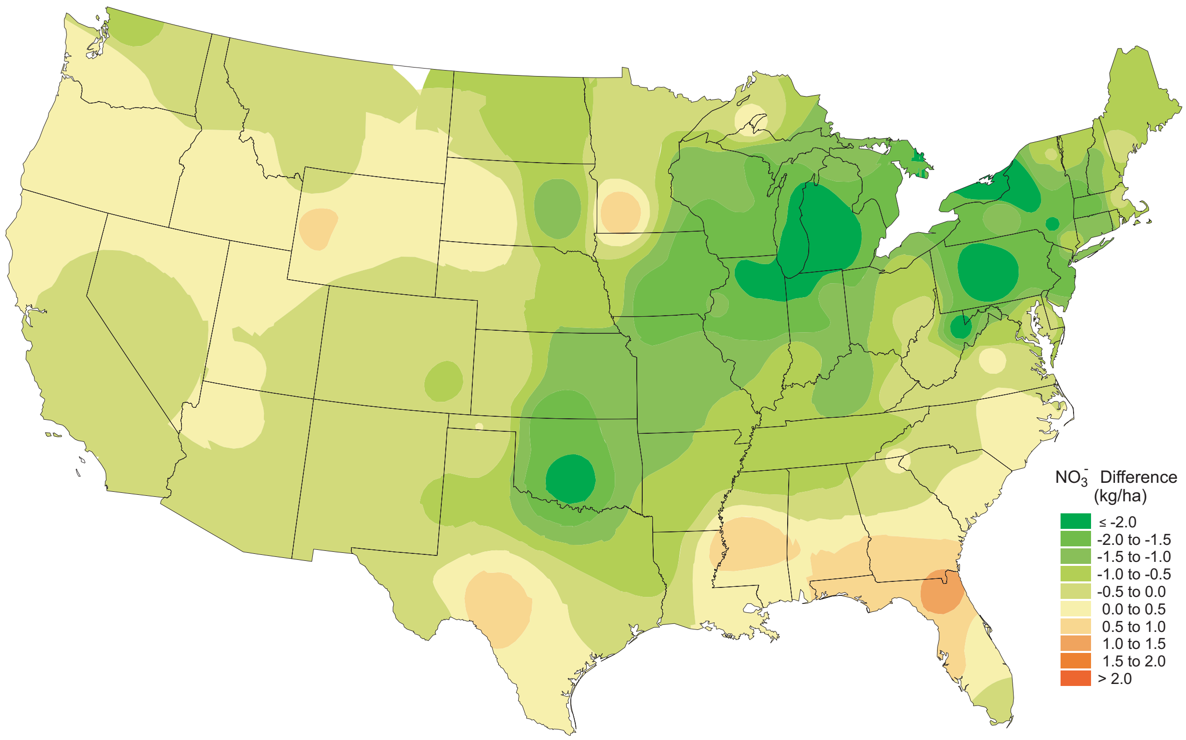


Figure 8-9. Nitrate ion deposition for spring (March-May) 2005 expressed as anomalies from the 1990-2004 average

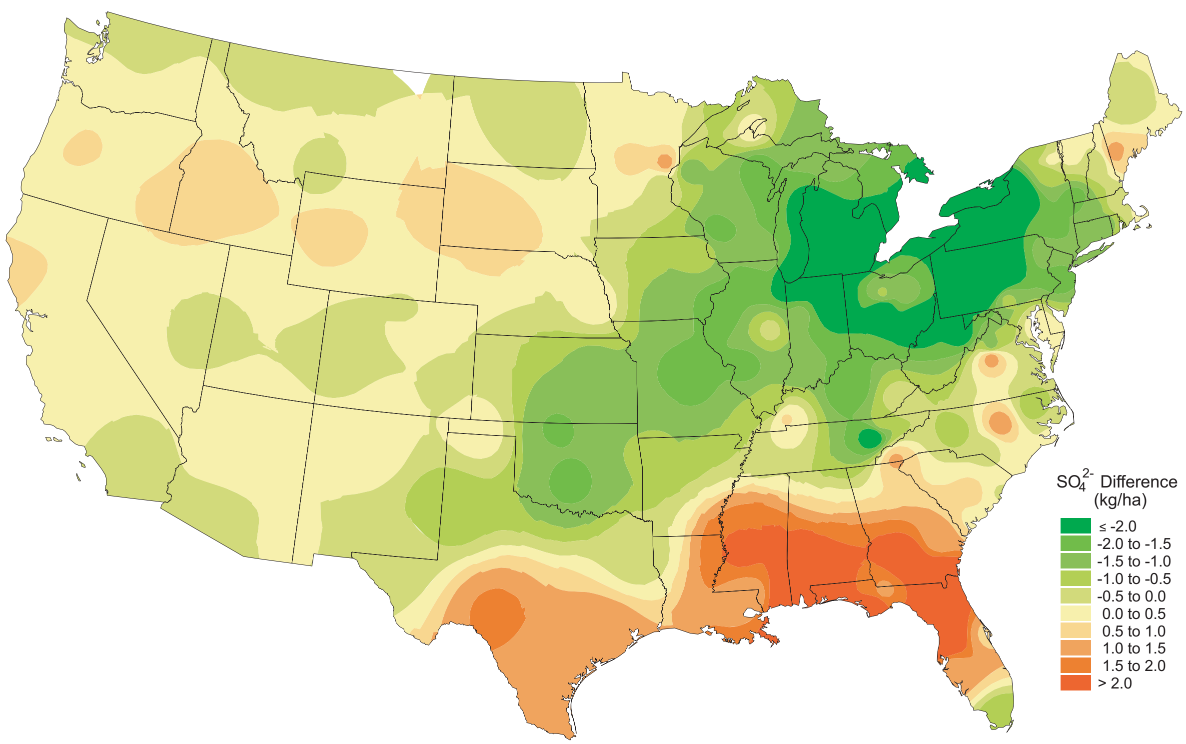


Figure 8-10. Sulfate ion deposition for spring (March-May) 2005 expressed as anomalies from the 2000-2004 average

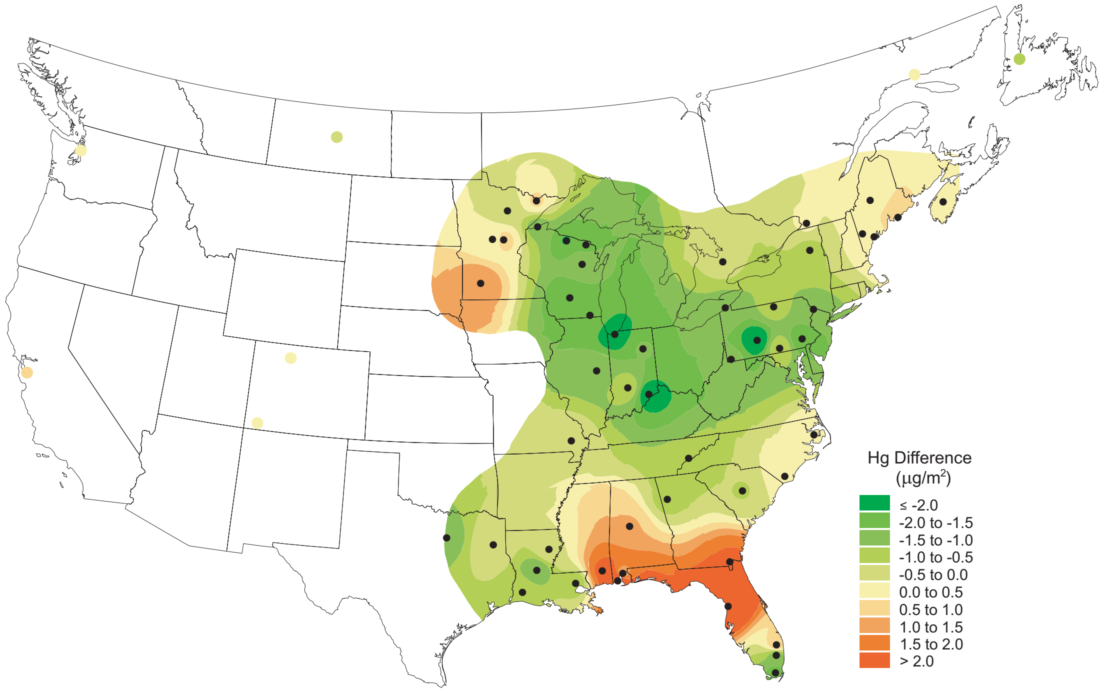


Figure 8-11. Mercury deposition for spring (March-May) 2005 expressed as anomalies from the 2000-2004 average

Chapter 9. Summary

Examination of temperature and precipitation conditions revealed several key features of the 2005 drought. Abnormally wet conditions that prevailed in January led to ample levels of soil moisture, streamflows, and reservoir levels. This was followed by the second driest March-June since 1895, which resulted in drought conditions across the state. Much of northern and central Illinois was classified as being in a category 2 "severe" drought, while the remainder of the state was in a category 1 "moderate" drought. By July, conditions in southern Illinois and parts of central Illinois improved dramatically after timely rains from tropical systems (Chapter 6) while much of northern and western Illinois remained in a category 3 "extreme" drought according to the *U.S. Drought Monitor*. Temperatures during the growing season were generally above normal with a higher frequency of days above 90°F. Data for Illinois indicate 2005 was the 11th driest and 12th warmest year since 1895, with precipitation of 31.48 inches (7.75 inches below normal) and temperatures of 53.8°F (2.1°F above normal).

Soil moisture rapidly responded to the precipitation deficits, exhibiting increasingly negative anomalies beginning in March and reaching the most negative values in June. Although rain in parts of central and southern Illinois resulted in some moderation of negative anomalies, soil moisture generally remained below average through the remainder of 2005. By the end of the summer, the most severe soil moisture deficits were found in an area from central to northeastern Illinois.

The 2005 drought in Illinois was a core area of a much larger regional drought. While northern Illinois was one of the driest areas, considerable drought conditions intermittently occurred from Canada to the Gulf of Mexico, but the drought was never widespread in an east-west dimension. At the end of 2005, severe and extreme drought occupied a substantial amount of the Corn Belt through northern Illinois and southern Iowa, and also a much larger area of Texas, Oklahoma, Arkansas, and southwestern Missouri.

Precipitation deficits observed were consistent with observed weaker-than-normal low-level flow from Gulf of Mexico/Atlantic Ocean moisture sources. The drought zone formed at the western edge of the main path through which moisture usually arrives from the south. Upper level flow also was weaker than normal over Illinois, reducing the number of surface low-pressure centers and upper level disturbances moving through the state. Areal coverage of large deficits was restricted by the fortuitous passage of remnants of four tropical systems south and east of Illinois. Warm SSTs in the North Atlantic may have contributed both to the weaker northward flow and the occurrence of the hurricanes.

Passage of four tropical systems (Tropical Storm Arlene, and Hurricanes Dennis, Katrina, and Rita) alleviated drought impacts, particularly in southern and central Illinois. Several circumstances make this situation climatologically unique. Examination of the historical records indicates that while an occasional tropical system passes through Illinois, this is the first time that four systems did in one season. The timing (4 to 6 weeks between events) maximized their benefit to agriculture while minimizing flooding. Tropical Storm Arlene and Hurricane Dennis occurred relatively early in the growing season when critical moisture was needed. Aggregating the rainfall from these four events reveals that they provided significant moisture to southern and central Illinois during the 2005 growing season. In fact, without those four systems, drought in southern and central Illinois would have been almost as severe as that in northern Illinois.

The 2005 drought led to environmental impacts, including shallow groundwater levels below normal, decreased streamflows, many reservoirs with levels below average, and minor damage to trees and landscapes. The drought's greatest impacts occurred in the agricultural sector. Crop experts all agreed from June through late August that crop impacts would be serious, with expectations for sizable reductions in corn and soybean yields. In July, the state offered low-income loans to drought-stricken farmers, and federal disaster declarations were made for 101 Illinois counties. Unexpectedly, the state's average corn yield was 143 bushels per acre, a bushel above average, and the soybean yield was 47 bushesl per acre, 5 bushels above average and the second highest yield on record. Yields were average or above in the southern two-thirds of Illinois and below average only in northern Illinois. Because yields were relatively high, no federal relief aid was given. Reasons offered for the differences between predicted and actual yields included timely rains and a shift in crop-weather relationships due to improved plant genetics and farming practices that collectively reduce weather stress. Economic consequences included reduced farm income to amounts $1,625 below average per farm, a result of the drought and record crop costs due to high energy prices and shipping problems. Drought and high temperatures led to increased electricity sales, a boon for power companies, decreased income for some agribusinesses, and variable impacts (benefits and losses) for retail businesses.

Chemical climate anomalies were established using long-term, wet-deposition monitoring data collected, analyzed, and quality controlled by NADP. In March-May 2005, precipitation below normal in a band from Texas through the Midwest and across to the Atlantic coast was associated with weaker-than-normal southerly flow of moist air from the Gulf of Mexico. Reduced atmospheric wet deposition of chloride, sodium, sulfate, and nitrate ions, and total mercury was associated with these precipitation and flow anomalies.

References

Aupperle, D.E. 2006. *What's Driving Farmland Prices?* Association of Farm Managers, Champaign, IL.

Biemer, J. 2005. Drought's blessings rain on some. *Chicago Tribune*, September 4, 1.

Burns, G. 2005a. Farmers bet on weather roulette. *Chicago Tribune*, May 29, 1.

Burns, G. 2005b. Grain forecast: Mostly chaos. *Chicago Tribune*, July 5, 1.

Burns, G., J. Biemer, and H. Dardick. 2005. Farmers left high and dry. *Chicago Tribune*, August 13, 1.

Changnon, S.A., and J.C. Neill, 1968, Mesoscale study of corn-weather responses on cash-grain farms. *Journal of Applied Meteorology*. **7**:94-104.

Chicago Tribune. 2005. Summer heat hits retailers in wallet, August 5.

Drought Response Task Force. 2005. *Illinois Drought Update*.

Grant, D. 2006. U of I: No Surprise—Farm earnings decline. *Farm Week*, May 29, 5.

Grant, D. 2005a. County crop tours project wide range of yields. *Farm Week*, August 29, 3.

Grant, D. 2005b. Drought persists: Another month of this stuff? *Farm Week*, August 8, 1.

Grant, D. 2005c. Drought retreat starting in Illinois? Not everywhere. *Farm Week*, October 10, 2.

Grant, D. 2005d. Dryness carves into pumpkin yields: Quality still good. *Farm Week*, September 5, 9.

Grant, D. 2005e. Illinois drought draws comparison to '88. *Farm Week*, June 27, 1.

Grant, D. 2005f. Late-summer rains may have saved more than crops. *Farm Week*, December 5, 4.

Grant, D. 2005g. 100 million bushels of corn on the ground. *Farm Week*, October 31, 1.

Grant, D. 2005h. Projected drop in farm income linked to drought. Farm Week, December 5, 1.

Grant, D. 2005i. Rising costs put drought-stricken farmers in a pinch. *Farm Week*, September 19, 1.

Grant, D. 2005j. Seed purchases for 2006 reflect drought concerns. *Farm Week*, December 19, 12.

Grant, D. 2005k. Serious hay shortage developing in state. *Farm Week*, August 1, 3.

Grant, D. 2005l. Will land prices level off? Broker says maybe. *Farm Week*, August 8, 12.

Griffiths, J.F. and D.M. Driscoll. 1982. Survey of Climatology. *Charles E. Merrill Publishing Co.,* Columbus, OH.

Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.). 2001. *Climate Change 2001: The Scientific Basis. Contributions of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881 pp.

Huang, J., H.M. van den Dool, and K. P. Georgakakos. 1996. Analysis of model-calculated soil moisture over the United States (1931-93) and application to long- range temperature forecasts. *Journal of Climate*, **9**: 1350-1362.

Illinois Agricultural Statistics Service. 2005. *Farm Report*, October 12.

Illinois Agricultural Statistics Service. 2005. *Farm Report*, May 13.

Illinois Agricultural Statistics Service. 2005. *Farm Report*, September 13.

Illinois State Water Survey. 2005. *Illinois Water and Climate Summary*, June, July, and August.

Jadhav, A. 2005. Illinois officials assess water problems. *St. Louis Post Dispatch*, November 16.

Kunkel, K.E., S.A. Changnon, C.G. Lonnquist, and J.R. Angel. 1990. A Real-Time Climate Information System for the Midwestern United States. *Bulletin of the American Meteorological Society*: **71**(11):1601–1609.

Larson, J., Y. Zhou, and R. W. Higgins. 2005. Characteristics of Landfalling Tropical Cyclones in the United States and Mexico: Climatology and Interannual variability. *Journal of Climate*, **18**:1247-1262.

Miller, J.P. 2005. Drought wilts Deere net stock. *Chicago Tribune*, August 17, 3.

National Weather Service. 2005. *Weekly Weather and Crop Bulletin*, September 20.

National Weather Service. 2005. *Daily Weather Maps* (http://www.hpc.ncep.noaa.gov/dailywxmap/index.html).

Neumann, C.J., B.R. Jarvinen, C.J. McAdie, and G.R. Hammer, 1999. Tropical Cyclones of the North Atlantic Ocean, 1871-1998. National Climatic Data Center. [Data resides at the NOAA National Hurricane Center at http://www.nhc.noaa.gov/pastall.shtml].

Reynolds, J. 2006. CWLP eyeing low lake levels. *State Journal-Register*, February 24.

Riebsame, W.E., Changnon, S.A., and T.R. Karl, 1991. *Drought and Natural Resources Management in the United States*. Westview Press, Boulder, CO.

Robinson, D. 2000. Hurricane Floyd rainfall in New Jersey. Proceedings of the 12th Conference on Applied Climatology. American Meteorological Society, Asheville, NC, pp.265-268.

Ross, M. 2005a. Drought aid to follow hurricane relief effort? *Farm Week*, September 5, 1.

Ross, M. 2005b. Durbin: Aid will depend on multiple states' needs. *Farm Week*, August 15,1.

Ross, M. 2005c. Storms could transport, drought could scorch rust. *Farm Week*, July 11, 2.

Seibert, D.J. 2005. Owners try to stand heat. *Rockford Register-Star*, June 23.

Shipman, K. 2005a. Ag Day at Illinois State Fair. *Farm Week*, August 22, 3.

Shipman, K. 2005b. Treasurer pledges $100 million for drought emergency program. *Farm Week*, August 1, 3.

Sugg, A.L. 1968. Beneficial Aspects of the Tropical Cyclone. *Journal of Applied Meteorology*, **7**:39-45.

Svoboda, M., D. LeComte, M. Hayes, R. Heim, K. Gleason, J. Angel, B. Rippey, R. Tinker, M. Palecki, D. Stooksbury, D. Miskus, and S. Stephens. 2002. The Drought Monitor. *Bulletin of the American Meteorological Society*, **83**:1181-1190.

The News-Gazette. 2005. Barges lighten loads, hope for rainfall to buoy cargoes. August 11, C-9.

The News-Gazette. 2005. Hot weather a boon for some businesses. July 27.

The News-Gazette. 2005. USDA says farm losses will approach $900 million. September 21, B-8.

The News-Gazette. 2005. Winter fuel prices expected to soar. August 25, 6.

Zuckman, J. 2005. Farm relief backers ask 'fair shake': Durbin, Obama join call to put disaster aid back in spending bill. *Chicago Tribune*, December 21, 5.

Illinois State WATER Survey (1895)

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