A Growing-Season Hydroclimatology, Focusing on Soil Moisture Deficits, for the Ohio Valley Region

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ABSTRACT

A hydroclimatology, or description of long-term means and interannual variation, that focuses on soil moisture deficits was constructed for the period of 1895–1998 for a six-state region composing the Ohio Valley. The term ''deficit'' is considered from an agricultural point of view whereby moisture-induced crop stress is a combination of insufficient precipitation and soil moisture. Of particular concern are deficits that occur during the growing season (May–September) when vegetation is most susceptible to moisture-induced stress. Evidence suggests that there is considerable temporal variability but no long-term trend toward either wetter or drier conditions in the Ohio Valley. The pattern of growing-season deficit is characterized by multiyear and multidecadal cycles of wet and dry periods. Decreases in precipitation during years with anomalously large growing-season deficits, however, are associated more with the reduced frequency of precipitation events than with any changes in intensity. These variations in precipitation frequency and the conditions conducive to droughts are intimately linked with large-scale atmospheric conditions, including the low-level and upper-level flow patterns.

1. Introduction

U.S. regional water resource problems have become major issues not just in the arid West but also in humid climates such as the Southeast and Midatlantic. Both the Southeast and Midatlantic states have recently suffered through devastating droughts that have affected many facets of their economies, including agriculture. Water rationing in Lexington and Louisville, Kentucky, stemming from severe drought conditions in 1999 produced major impacts on people and businesses. Both cases illustrate that, even in humid regions, there is a need to understand the historical patterns of drought so that informed decisions can be made regarding drought mitigation. Another region that has not been traditionally associated with dryness is the Ohio Valley. This region is an agriculturally important area in which Illinois, Indiana, and Ohio compose the eastern Corn Belt, and farmers in Kentucky and Tennessee are major tobacco and soybean producers. Three of the five states investigated rank in the top 25% of the United States for the value of crops sold (USDA 1997). Because these areas generally receive adequate amounts of precipita-

tion for agricultural production, farmers do not rely on extensive irrigation (USDA 1997). Thus, during dry periods when there is insufficient moisture available for crops, serious economic consequences can occur.

Drought can be defined in a number of different ways, depending on the use intended. Frequently, the persistence and intensity of dryness are used to define drought. A short-term precipitation shortage or a period of high evapotranspiration can lead to an agricultural or soil moisture drought (Leathers et al. 2000). A large decrease in precipitation for a prolonged period of time over a large region is termed a meteorological drought. Last, a hydrologic drought is of longer duration than a meteorological drought and can affect surface hydrologic processes such as streamflow. Although related, hydrologic and meteorological droughts are different phenomena, each having specific onset and recovery characteristics (McNab 1989). Observations verify that the end of a meteorological drought does not necessarily bring about the cessation of a hydrologic drought, primarily because of the time lag associated with the moisture reserves in the surface and subsurface storage zones (Brubaker and Entekhabi 1996). Likewise the onset of a hydrologic drought is often preceded by meteorological drought conditions.

Little research has been conducted on soil moisture deficits in the Ohio Valley. Namias (1959, 1962, 1978,

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1988) has examined the role soil moisture plays in producing drought conditions. He suggests that reduced soil moisture during the late spring or early winter over a midcontinental region could induce a warm, dry summer over the region, further exacerbating the agricultural drought. Leathers et al. (2000) developed a hydroclimatology, or description of long-term means and interannual variation for hydrologic processes, for the northeastern United States. Decadal-scale variations in soil moisture along with spatially distinct regions within the Northeast were identified. Other investigations have evaluated the importance of soil moisture in reinforcing meteorological droughts (Charney 1975; Charney et al. 1977; Walker and Rowntree 1977; Cunnington and Rowntree 1986). These investigations primarily used a general circulation model to evaluate the importance of soil moisture in producing feedbacks between the land surface and large-scale atmospheric processes. Several of these studies illustrate the importance of developing hydroclimatologies that utilize soil moisture to understand climatic and hydrologic variations due to anthropogenic climate change. Many other investigations have focused on atmospheric processes leading to drought conditions in the Great Plains, a region prone to drought and great agricultural losses (Karl and Koscielny 1982; Diaz 1983; Karl 1983; Chang and Wallace 1987).

The study that is presented here is centered on the development of a century-long hydroclimatology for the Ohio Valley with emphasis on periods of moisture deficit. In this paper, the term "deficit" is considered from an agricultural point of view whereby moisture-induced crop stress is a combination of insufficient precipitation and soil moisture. Of particular concern are deficits that occur during the growing season (May–September) when vegetation is most susceptible to moisture-induced stress. The first portion of this study examines the spatial and temporal nature of growing-season deficit. The second part of this study looks at the various mechanisms that can contribute to periods of deficit. Here, a case study of a severe soil moisture deficit year (1953) and surplus year (1950) are used to illustrate the meteorological factors that were in place during these periods.

2. Data and methodology

The climatology of soil moisture drought for the Ohio Valley region was produced using an empirically based water budget technique designed by Thornthwaite and Mather (Mather 1978). This technique relies on commonly measured meteorological variables (temperature and precipitation) and has been widely used for environmental research applications (Brewer 2001; Lavin 1997; Willmott and Feddema 1992; Willmott et al. 1985; Carter and Mather 1966; Thornthwaite and Mather 1955). Temperature and precipitation data were obtained from the climate division dataset available from the National Climatic Data Center (NCDC 1994). This water budget scheme also requires data on the water holding
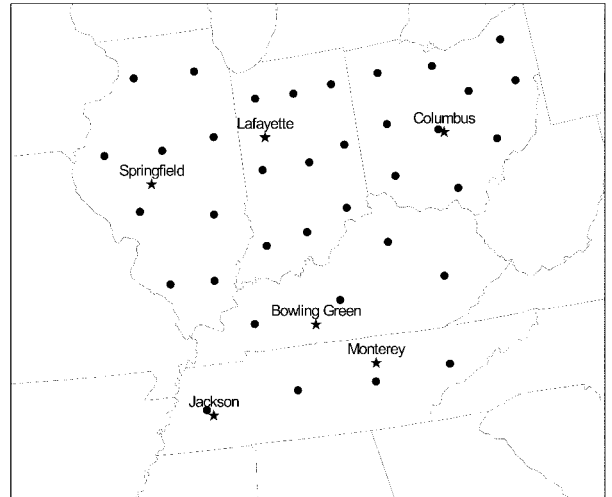

FIG. 1. Study location: filled circles indicate center position of climate divisions with monthly temperature and precipitation data, and stars denote cooperative observing stations used in the daily precipitation frequency and intensity analysis.

capacity of the soil. For each climate, soil water holding capacity was based on estimates by Main (1979).

The water budget was run for the climate divisions contained within Illinois, Indiana, Ohio, Kentucky, and Tennessee for the period from 1895 through 1998 (Fig. 1). These five states represent a fairly cohesive hydrologic unit, and nearly all the climate divisions reside within the Ohio hydrologic region as defined by the U.S. Geological Survey (Seaber et al. 1987). At each climate division, a monthly value for deficit was computed. Growing-season deficit values were then calculated for the years from 1895 through 1998 by adding monthly deficits from May through September. Although such a method obscures month-to-month variations, it provides a useful assessment of seasonal moisture conditions and is useful for analysis of variations from one year to another.

The long time series of growing-season deficit facilitates a detailed hydroclimatological study of the Ohio Valley. The first portion of this study analyzes the patterns of seasonal soil moisture deficit over both time and space. The second phase of this research evaluates the meteorological and climatological mechanisms that contribute to soil moisture deficits in the Ohio Valley. An analysis of the roles of precipitation frequency and intensity utilize NCDC records of cooperative station observations. A case study approach was then employed to examine atmospheric conditions associated with and leading to periods of soil moisture deficit and surplus. Comparisons of large-scale atmospheric processes during the growing seasons of a very dry year and a wet year were evaluated with the goal of providing guidance as to mechanisms leading to anomalous soil moisture conditions. Data for this portion of the analysis were obtained from the National Center for Atmospheric Research (NCAR)–National Centers for Environmental
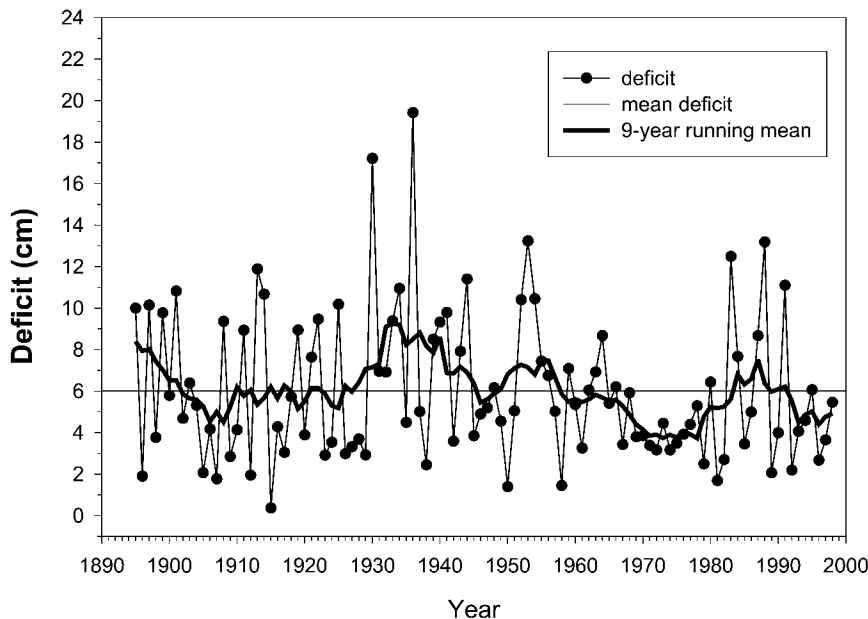
FIG. 2. Areally weighted regional accumulated growing-season moisture deficit for 1895 through 1998.

Prediction (NCEP) reanalysis dataset (Kalnay et al. 1996).

3. Results

a. Temporal and spatial patterns of deficit

The first phase of this study looks at both the temporal and spatial aspects of growing-season deficit over the Ohio Valley. An areally weighted value of average accumulated growing-season deficit for each of the 36 climate divisions is used to identify deficit patterns over time (Fig. 2). There is no consistent trend toward increases or decreases in deficit. Rather, variations in deficit occur in multiyear and decadal cycles of wet (lower-than-average deficit) and dry (greater-than-average deficit) years. These patterns are most clearly revealed by looking at the 9-yr moving average. Wet to near-normal conditions extend from the early part of the century up until the late 1920s. A distinct dry period, present from the mid-1920s to 1960, is only interrupted briefly during the mid-1940s. After 1960, the region is characterized by a wet period with reduced deficits until the early 1980s. A brief dry period occurs in the mid-1980s and is followed by relatively wet conditions through to the present.

The spatial patterns of growing-season deficit are mapped by computing an average, accumulated growing-season deficit value for each climate division over the 104-yr study period (Fig. 3a). A general trend is apparent in which the largest seasonal deficits of 12 cm over eastern Tennessee decrease to values of 6 cm toward the north and east. For most of the region, the widely spaced isolines indicate a gradual decrease in

deficit over space. The more tightly packed isolines over eastern Tennessee, however, indicate a rapid transition from large deficits in the western portion of the state to smaller deficits in the central and eastern portions of the state.

To understand this spatial pattern of seasonal deficit and the relative importance of variations in meteorological variables in affecting deficit, average accumulated growing-season precipitation and average growing-season temperature are presented in Figs. 3b,c. The highest temperatures, exceeding 22°C, are found in the south and decrease by several degrees in the northern portion of the study region (Fig. 3b). Temperatures are also somewhat lower over the eastern portions of Kentucky and Tennessee and are a function of the higher elevations in the Appalachian Mountains. Precipitation is greatest in the south and to the east but decreases steadily by several centimeters northward (Fig. 3c). The temperature and precipitation patterns tend to contradict each other, as seen on the map of seasonal deficit. The largest deficits are found in the southwest portions of the study region, where the greatest precipitation falls but also where temperature and therefore evapotranspiration are greatest. Cooler temperatures and lower evapotranspiration rates but also less precipitation occur over the northern half of the study region, where smaller seasonal deficits are found.

A case study approach is used to illustrate the range in deficit from one year to the next and the spatial relationships between deficit and meteorological variables such as temperature and precipitation. A year with the largest regionally averaged growing-season deficit (1953) and a year with the smallest deficit (1950) for

the period from 1950 through 1998 is presented. The distinctive nature of each year is emphasized through the use of anomaly maps (anomaly minus climatic average) on which departures from the 104-yr climatic average of growing season deficit, average temperature, and accumulated precipitation are depicted (Figs. 4 and 5).

The spatial pattern for 1953 is very similar to the average pattern, in which the largest accumulated growing-season deficits appear in the southwestern quadrant of the study region. Although the pattern of deficits is similar, the magnitude is considerably different (Fig. 4a). Deficits are larger than the climatic average over the whole region and range from 4 cm greater in the eastern half of the study region to 14 cm greater than normal in the southwestern corner of the study area. Indeed, deficit values through much of the region were 2 times the normal values and nearly 2.5 times the normal over western portions of Tennessee, Kentucky, and Illinois.

The spatial pattern of average seasonal temperature and accumulated growing-season precipitation can help to explain the pattern of deficit. The distribution of temperature across the study area is similar to average conditions but temperatures are 1°C warmer across the western portions of Illinois, Kentucky, and Tennessee (Fig. 4b). Precipitation is substantially less than the climatic average, with departures ranging from 4 to 16 cm across the study area (Fig. 4c). Areas in the western half of the Ohio Valley received roughly one-third less precipitation than normal, but this figure decreases toward the east and southeast where values are only 15%–20% less than the climatic average. Over the whole region, decreased precipitation, as opposed to any increases in evapotranspiration (temperature), was the dominant factor in the severe deficit conditions. Distinctly greater deficits as a percent of normal occur over the western half of the study. This is associated with increased evapotranspiration (warmer temperatures) along with the proportionally larger decreases in precipitation relative to other areas of the region.

Across the entire Ohio Valley region, the accumulated growing-season deficit in 1950 is considerably less than the climatic average (Fig. 5a). Deficit values range from 4 cm below average toward the northern and eastern portions of the area to 8 cm below normal over western Tennessee. In proportion, the sites to the south have deficits that are only 15%–20% of the long-term average, whereas more northern sites have deficits that are 30%–40% of the average. Across the region, growing-season temperatures are only slightly cooler (0.5°–1.0°C) than the climatic average. Precipitation, on the other hand, is substantially larger, particularly in the southern portions of the study region, where seasonal rainfall is over 12 cm greater than the long-term average (Fig. 5c). In addition, the southern half of the region received a proportionally greater increase (20%–30%) in precipitation than the northern half (5%–10%) when
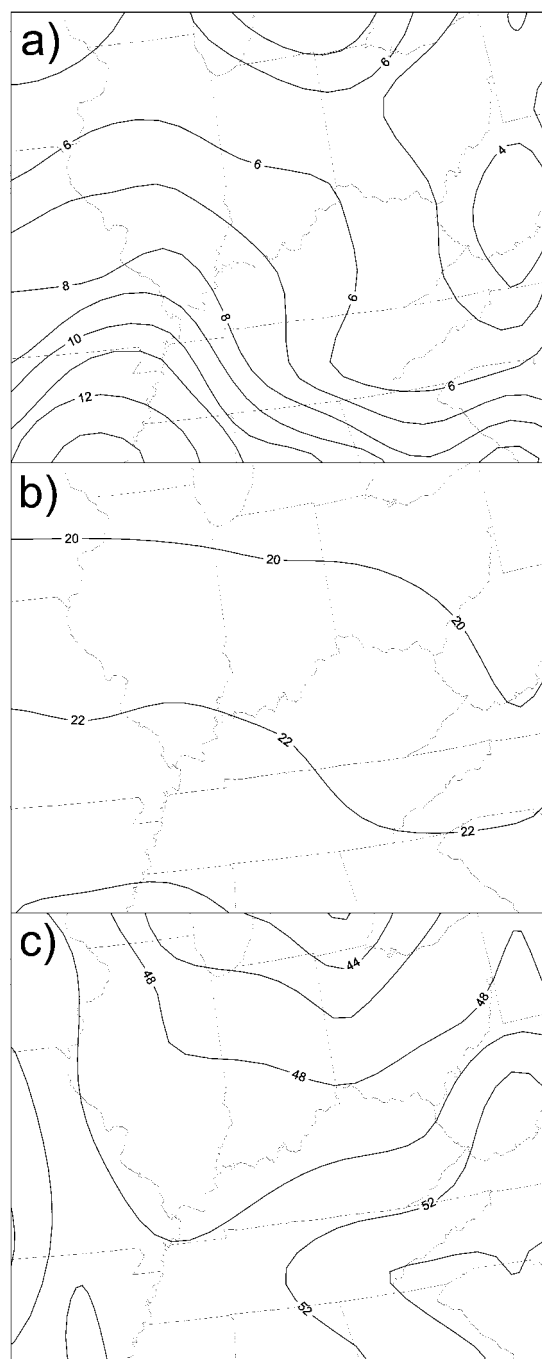

FIG. 3. (a) Average accumulated growing-season deficit (cm), 1895 through 1998. (b) Same as (a), but for average growing-season temperature (°C). (c) Same as (a), but for average accumulated growing-season precipitation (cm).

compared with the long-term average precipitation. Overall, the lower growing-season deficits in 1950 are a function of the increased precipitation coupled with cooler temperatures that depressed evaportanspiration. The proportionally larger decreases in deficit over the southern half of the region correspond to the propor-
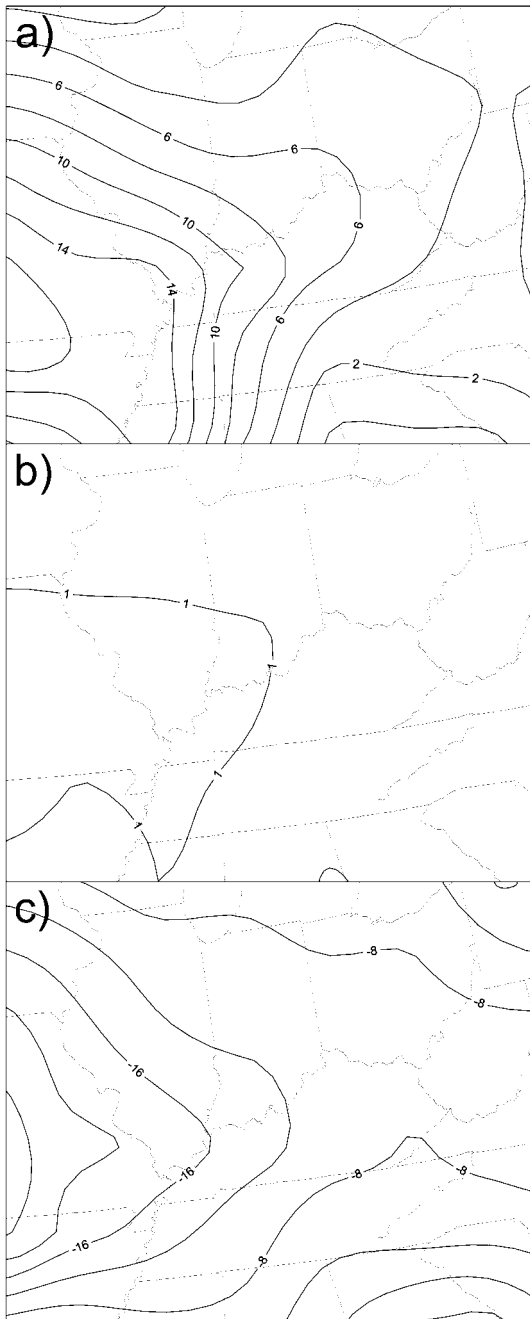
FIG. 4. (a) Accumulated growing-season deficit (cm) departure from average for 1953. (b) Same as (a), but for average growing-season temperature (°C). (c) Same as (a), but for average accumulated growing-season precipitation (cm).

FIG. 5. Same as Fig. 4, but for 1950.

tionally greater increases in accumulated growing-season precipitation.

The case studies indicate how both temperature and precipitation can play a role in the water balance and thus affect the magnitude and spatial pattern of growing-season deficit. The next phase of the analysis seeks to assess the relative importance of various meteorologica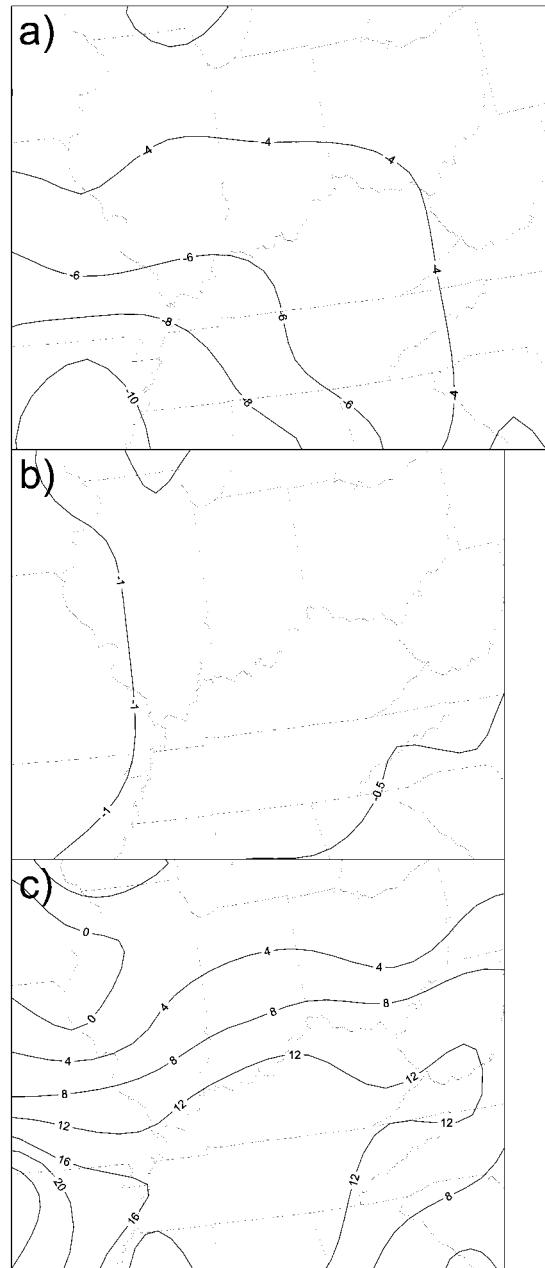l and climatological mechanisms in explaining both the temporal and spatial patterns of accumulated soil moisture deficit.

b. Precipitation frequency and intensity

The character of growing-season deficits is first evaluated by looking at precipitation and temperature variations during periods with unusually small and large soil moisture deficits (Table 1). A ''wet'' period is defined formally as any year in which the areally weighted regional average deficit was −1 standard deviation from normal; a ''dry'' year is defined as any year with an

TABLE 1. Deficit (cm), precipitation (cm), and temperature (°C) departures associated with seasons that are +1 std dev (dry) and −1 std dev (wet) from the 104-yr mean soil moisture deficit.

	Wet	Dry
Deficit	−4.19	+5.71
Precipitation	+9.98	−9.68
Temperature	−0.58	+0.80
No. of seasons	12	19

TABLE 2. Precipitation frequency (days) and intensity (cm day⁻¹) and the explained variance (R^2) between deficit and seasonal precipitation frequency or intensity.

	Frequency		Intensity		R^2 Frequency and deficit	R^2 Intensity and deficit
	Dry	Other	Dry	Other		
Bowling Green	47	42	1.07	1.20	0.30	0.00
Columbus	52	47	0.90	0.84	0.20	0.08
Jackson	44	35*	1.20	1.29	0.28	0.00
Monterey	49	44	1.25	1.12	0.24	0.02
Lafayette	44	32*	1.06	1.16	0.26	0.00
Springfield	47	36*	0.96	0.91	0.26	0.02

* Difference in means between extremely dry seasons is significant at the 95% confidence level using a Student's t test.

areally averaged deficit of +1 standard deviation from normal. A composite of wet years, for which the deficit is nearly 4 cm below the climatic normal, indicates that conditions are slightly cooler and wetter. In contrast, the dry-year composite indicates a deficit of nearly 6 cm above the climatic normal, warmer-than-normal temperatures, and less-than-normal precipitation.

Six cooperative observing stations, selected throughout the region, with long, complete periods of record were used to investigate whether decreased precipitation during dry years was the result of decreased days with precipitation, decreased intensity of given precipitation events, or a combination of both (Fig. 1). At each station, the average number of days with measurable precipitation was calculated for the May–September growing season for the five years with the largest growing-season deficit and for the remaining years between 1950 and 1998. Precipitation intensity was computed by summing the daily precipitation values over the growing season and dividing by the number of days with precipitation. It is essentially an indication of event intensity. As with precipitation days, precipitation intensity was computed for the five driest years and for the remaining years from 1950 through 1998.

At each of the six stations, dry years had fewer precipitation days. A Student's t test indicates that this difference was statistically significant at the 95% confidence level for Springfield, Lafayette, and Jackson. In all cases, there was no statistically significant difference in precipitation intensity between the five driest years and the remaining years.

A regression analysis was run among precipitation days, precipitation intensity, and growing-season deficit. Precipitation days explain a substantially larger portion of the variance than does precipitation intensity (Table 2). For the six cooperative stations, it explains from 20% to 30% of the variance; precipitation intensity explains virtually none of the variance in soil moisture deficit. Also, there is virtually no relationship between precipitation frequency and intensity.

c. Large-scale atmospheric processes and soil moisture deficit relationships

A case study examination of the growing seasons during 1950 (smallest deficit) and 1953 (largest deficit) was conducted to reveal atmospheric processes producing and resulting from anomalous soil moisture con-

ditions. To examine these relationships, monthly averages of atmospheric variables were evaluated using the NCEP–NCAR reanalysis dataset. The model and procedures used to construct the NCEP–NCAR reanalysis dataset are contained in Kalnay et al. (1996).

Growing-season precipitation in the Ohio Valley is primarily produced by mesoscale convective processes. However, large-scale forcing and land–atmosphere feedbacks are important in creating an environment conducive for the development and sustenance of convective systems. Mo et al. (1995) examined the 1993 flooding in the Midwest and suggested that increased short-wave activity in late May and early June strengthened and displaced the polar jet southward, which in turn generated more rainfall. A study by Wolfson et al. (1987) supports the important role soil moisture plays in producing heat waves. They concluded that there exists a positive feedback mechanism between soil moisture deficits, heat waves, and drought conditions.

Before examining large-scale atmospheric patterns during the 1950 and 1953 growing seasons, it is necessary to examine the extent and severity of these wet and dry periods over the United States. Figure 6 shows the Palmer Drought Severity Index (PDSI) for 1950 and 1953. The PDSI indicates prolonged anomalous moisture deficiency or excess. As shown, 1950 was a very wet year in the Ohio Valley, with PDSI values ranging from 3 to 4. Values over 3 indicate a "very" to "extreme" moist spell. Much of the east-central United States was experiencing wet conditions, and the desert Southwest was in a drought. During 1953, PDSI values ranged from −1 to −3 over the Ohio Valley, with much lower values through the southern plains. "Mild" to "moderate" drought was occurring over the Ohio Valley according to the PDSI; however, severe soil moisture deficits were experienced at this time.

Several important differences emerge when comparing the upper-level flow pattern between wet and dry years (Fig. 7). During much of the growing season, there is a marked difference between the strength and orientation of the subtropical jet stream. In 1950, there was a noticeable subtropical jet stream during May, June,
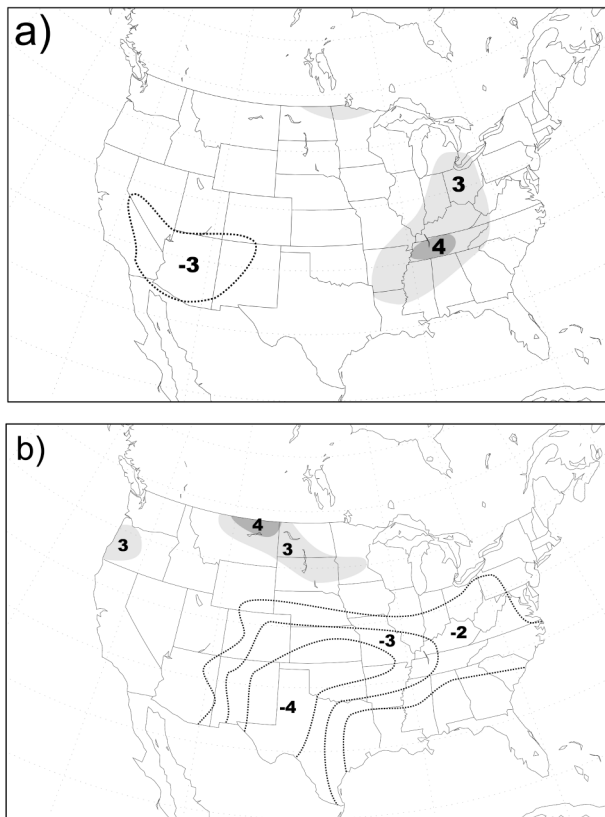
FIG. 6. Palmer Drought Severity Index for the United States for (a) 1950 and (b) 1953.

and August (Figs. 7a,b,d). This jet stream likely transported moisture and combined with the polar jet to energize a southern storm track that produced ample precipitation for the east-central United States. Prior to the 1993 floods, synoptic-scale eddy activity was noted in the Pacific North American area and was associated with the southward displacement of the jet (Mo et al. 1995). Mo et al. (1997) suggest that the Pacific subtropical jet starts to shift southward and extends to the west coast of North America at approximately 18 days before the onset of a wet event leading to flooding. The subtropical jet was noted to be the strongest in May and gradually weakened through the growing season (Fig. 7a). During 1953, the subtropical jet was weaker and the polar jet is displaced northward over southern Canada and New England (Figs. 7e–h). This likely led to an overall northward displacement of the storm track and also a lack of moisture inflow into the Ohio Valley.

The 250-hPa height field also illustrates variations in the upper-level atmosphere between wet and dry seasons. During 1950, an intense long-wave trough developed over the central United States with negative height anomalies of 150 geopotential meters (Figs. 8a–d). This trough persisted through the majority of the growing season. The location of this trough places the Ohio Valley in an area conducive to upper-level divergence—a

preferred region for precipitation. Likewise, an upper-level ridge developed through the central and eastern United States during 1953 (Figs. 8e–h). Although not as amplified as the trough in 1950, this ridge would provide subsidence over the drought region, further enhancing the already dry conditions. Persistent negative height anomalies were also found off the west coast of the United States, illustrating the presence of a trough over this region. This further supports the development of a high-amplitude ridge over the eastern United States in response to the western trough.

The low-level jet (LLJ) and moisture fields also indicate changes in atmospheric circulation during anomalous soil moisture conditions (Fig. 9). During 1950, the LLJ was found arching from eastern Texas into Kentucky for most of the growing season. This transported moisture from the Gulf of Mexico into the Ohio Valley, likely enhancing convective instability and providing lift through low-level speed convergence in this region. The orientation and strength of the LLJ appear to be partly modulated by surface conditions. Evaporation appears to play a role in LLJ development, especially during drought conditions (Brubaker and Entekhabi 1996). Soil moisture deficit in the southern and central Great Plains can lead to higher surface temperatures that, in turn, lead to a strengthening of the LLJ. This is evident when examining the 850-hPa winds during the 1953 growing season (Figs. 9e–h). Regions strongly influenced by the advection of Gulf of Mexico moisture show an increase in the advection of this moisture as a result of reduced soil moisture (Oglesby and Erickson 1989). Moisture transport is affected by these changes in LLJ orientation and intensity. In 1950, orientation of the LLJ likely advected moisture into the central Great Plains and Ohio Valley enhancing convective instability and low-level speed convergence in both regions (Figs. 9a–d). However, in 1953 the central and southern Great Plains were experiencing extreme drought (Fig. 6). This increased heating likely lead to an increase in LLJ intensity through the central and northern Great Plains as seen in the July and August 850-hPa wind vectors (Figs. 9e–h). The drought and associated high-amplitude ridge over the southeastern United States and Ohio Valley also appeared to force a more north–south-oriented LLJ axis through the central United States. This limited low-level moisture and convergence in the Ohio Valley as Gulf of Mexico moisture was transported northward into the northern Great Plains (Figs. 9e–h). Mass convergence of the wind field and moisture advection likely combined to produce wet conditions in the northern Great Plains during 1953 (Fig. 9). In contrast, the LLJ had a more easterly component in 1950, enhancing low-level convergence and moisture advection in the Ohio Valley region.

4. Discussion and conclusions

The Ohio Valley region is an important agricultural region in which periods of deficit can contribute to sub-
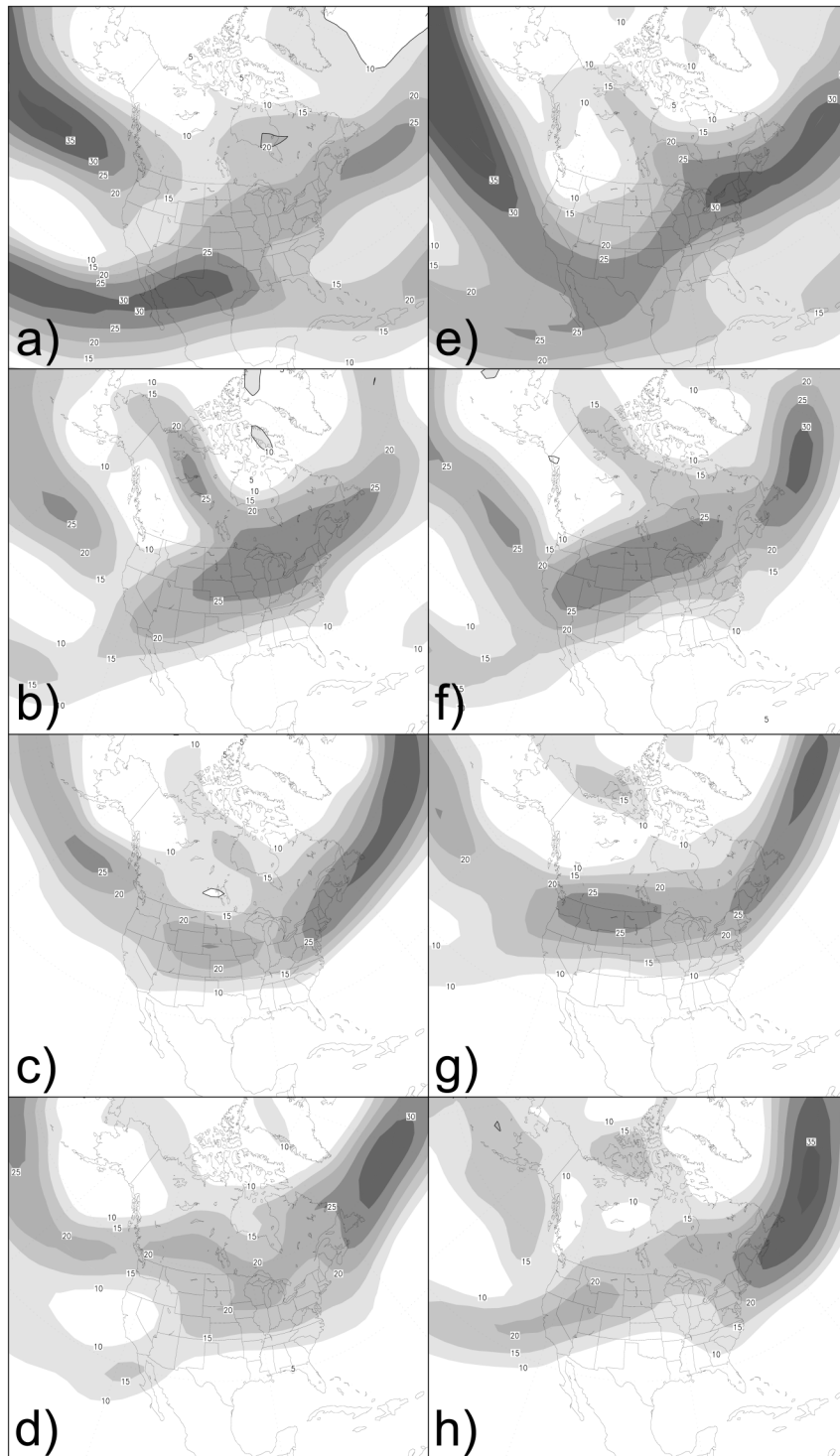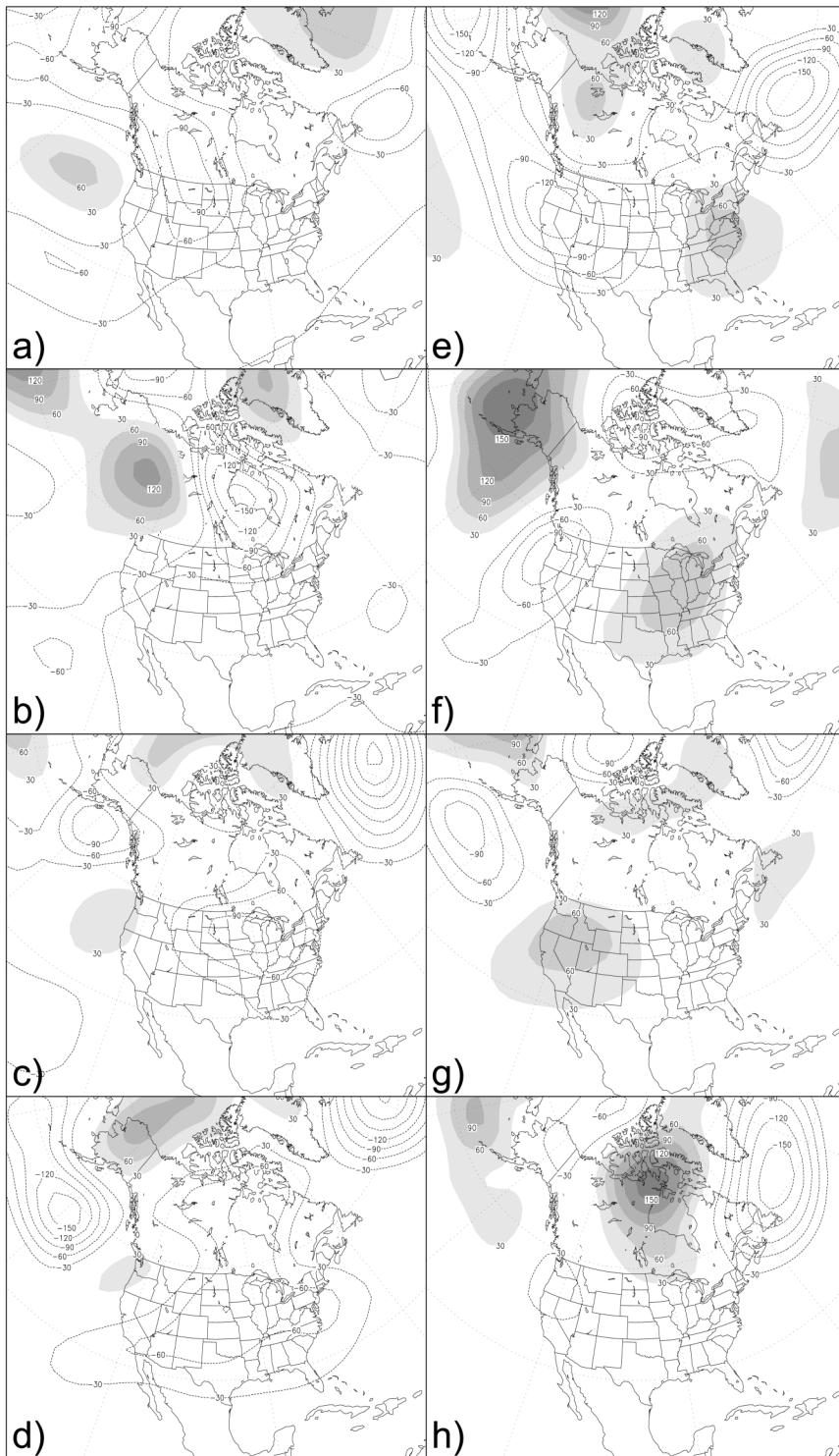
FIG. 7. 250-hPa isotachs (m s^{-1}): (a) May 1950, (b) Jun 1950, (c) Jul 1950, (d) Aug 1950, (e) May 1953, (f) Jun 1953, (g) Jul 1953, and (h) Aug 1953.

stantial economic losses. This study has analyzed the hydroclimatology of the region and documented the spatial and temporal patterns of growing-season deficit. The results indicate that there is considerable temporal var-

iability but no long-term trend toward either wetter or drier conditions. The pattern of growing-season deficit is characterized by multiyear and multidecadal cycles of wet and dry periods. A most pronounced dry period,

FIG. 8. 250-hPa height anomaly (gpm): (a) May 1950, (b) Jun 1950, (c) Jul 1950, (d) Aug 1950, (e) May 1953, (f) Jun 1953, (g) Jul 1953, and (h) Aug 1953.
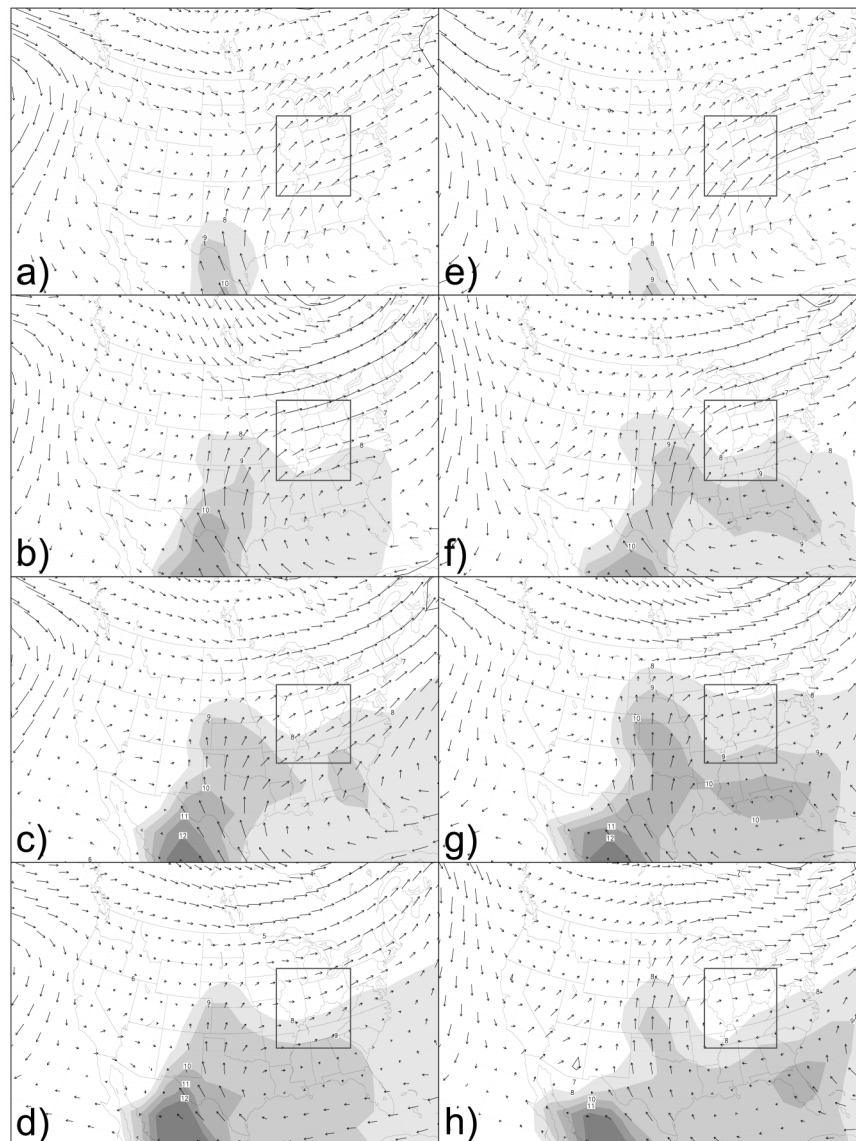
FIG. 9. 850-hPa specific humidity (contours and shaded area; g kg^{-1}) and wind vectors (boxed area highlights the study region): (a) May 1950, (b) Jun 1950, (c) Jul 1950, (d) Aug 1950, (e) May 1953, (f) Jun 1953, (g) Jul 1953, and (h) Aug 1953.

for instance, extended from the 1920s through to the early 1960s. For much of the period since then, the region has been in a cycle with lower-than-average accumulated growing-season deficits. In space the growing-season deficit was found to be largest across the southwestern corner of the study region and then decreased northward and eastward.

The nature of precipitation variability during periods of extreme soil moisture deficits was examined by studying both the frequency and intensity of precipitation events. Decreases in precipitation during years with anomalously large growing-season deficits are associated more with the reduced frequency of precipitation events than to any changes in intensity. These variations

in precipitation frequency and the conditions conducive to droughts are intimately linked with large-scale atmospheric conditions. Enhanced ridging, especially in the upper levels, was found over the Ohio Valley region during 1953. This westward extension of the Bermuda high provided subsidence and weak flow that likely inhibited convective development during the growing season. As surface heating increased from the lack of evaporation, the LLJ intensified and directed moisture northward into the northern Great Plains. This further cut off the moisture ''pipeline'' into the Ohio Valley and weakened the low-level wind field. During 1950, an upper-level trough was found to have developed over the central United States. This enhanced large-scale upward

motion over the Ohio Valley and also cooled mid- to upper-level temperatures. The LLJ continued to provide adequate moisture from the Gulf of Mexico into the central Great Plains. However, instead of advecting moisture into the northern Great Plains, the LLJ arched into the Ohio Valley, enhancing low-level moisture in the region and also producing low-level mass convergence. These conditions likely produced precipitation leading to soil moisture surpluses.

Water resource issues have become increasingly important topics, even in the humid eastern one-third of the United States. Population growth in many areas in the United States has placed incredible stress on local water supplies. Layered on top of such immediate concerns loom possible hydrologic impacts from anthropogenic warming. Indeed, recent research has suggested that drought in midcontinental areas may be enhanced under various global warming scenarios (Gregory et al. 1997; Wetherald and Manabe 1999). By providing a historical baseline of growing-season deficit in the Ohio Valley, this study will aid those involved in water resource planning. In addition, meteorological conditions leading to anomalous soil moisture conditions were determined.

Future research will investigate individual severe drought periods in greater detail. In particular, this work will examine the spatial evolution of severe droughts and wet periods. Atmospheric elements such as stability and the radiation budget will be examined as well as feedbacks between anomolous soil moisture conditions and the atmosphere to further our understanding of drought in the Ohio Valley.

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