Determining the Spring to Summer Transition in the Missouri Ozarks Using Synoptic Scale Atmospheric Data

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Submitted to:

Transactions to the Missouri Academy of Sciences

August 2002

Revised:

December 2002

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Abstract

There is abundant anecdotal evidence available to suggest that the transition from a spring to summer season flow regime is often quite abrupt. This same transition renders long-range forecasting problematic as the forecast time period crosses through the spring and summer seasons. Despite these problems, the transition from spring-to-summer flow regimes is a problem that has not been examined in detail in the published literature. In this study, the transition is examined from a regional perspective over a 20-year period (1981 – 2000) and includes the development of a criterion for identifying the transition based on using routinely available synoptic observations. Within the East-central Ozarks region of Missouri, the transition from spring-to-summer season flow regimes is often abrupt, and is identified as occurring in mid-June. The transition could also be identified for the entire Northern Hemisphere using the 500 hPa wave amplitude index for some years during the 1980's. The results found here are consistent with the results of the one other study found in the literature that also addresses the spring-to-summer transition issue for the entire Northern Hemisphere. Additionally, this study found that the average date of summer onset in the region is June, and the 20-year set of summer onset dates was normally distributed with respect to this mean. It was also shown that there is an abrupt change in the average period between heavy precipitation events. Finally, it is demonstrated that late arriving summers are generally associated with a transition in the phase of the El Nino and Southern Oscillation (ENSO), especially the La Nina phase, while early arriving summers are generally associated with steady-state ENSO conditions.

1. INTRODUCTION

There is anecdotal evidence available suggesting that the transition from spring-to-summer flow regimes in the Northern Hemispheric troposphere can occur abruptly. However, this transition is a topic that has not been studied very frequently. A web-based search of all the American Meteorological Society journals from 1944 to 2002[1] revealed that there was only one article (Nogues-Peagle and Mo, 1987) published that devotes the full article to the subject, and only 171 articles that discuss the concept at all (e.g., O'Lenic and Livezey, 1989). Using spherical harmonics to decompose global fields of the geostrophic streamfunction (Ψ), velocity potential (χ), and height (z), Nogues-Peagle and Mo (1987) demonstrate that this spring-to-summer transition occurred rapidly during the May to July 1979 period via the amplification of planetary-scale waves as represented using the four lowest harmonics. Many other articles mention this rapid seasonal transition within the context of the difficulty the transition creates for the analysis of observations (e.g., O'Lenic and Livezy, 1989) or the difficulty such rapid transitions in the large-scale flow regimes present to model simulations or forecasts (e.g. Palmer, 1988).

The large-scale flow over the North American Continent has long been shown to be influenced by an atmospheric teleconnection pattern (e.g., Wallace and Gutzler, 1981) known as the Pacific North American (PNA) teleconnection. This teleconnectivity, which has four centers of action associated with it, is most likely the result of Rossby wave excitation by tropical convection in the central Pacific Ocean Region and the subsequent propagation of these waves downstream (e.g., Ambrizzi and Hoskins, 1996). Also, the PNA pattern has been shown to have several modes (e.g., Keables, 1992) and the predominance of particular modes has been shown to be related to the phase of the El Nino and Southern Oscillation (e.g., Kung and Chern, 1995). However, this teleconnectivity has been shown to be strongest during the winter season.

The transition to a summer regime over North America has been investigated with respect to large-scale circulation shifts which lead to, for example, the onset of the southwest monsoon in Arizona, New Mexico, and Northwest Mexico (e.g., Higgins et al., 1997). The Southwest Monsoon has also been shown to be modulated by an oscillation linked to tropical convection and with a period of 3 to 4 weeks (Mo, 2000). This oscillation is also partly linked to the Madden Julian Oscillation (MJO), which is a 30 – 60 day oscillation in tropical convection linked to an equatorially trapped Kelvin wave. Mo (2000) also demonstrates that this oscillation propagates eastward into the Great Plains and Midwestern States as well. Occasionally, the summer PNA pattern over North America will imply a shorter wavelength in this pattern than described above and be associated with five centers of action. This type of activity has been shown to predominate over North America during dry summers (e.g., Namias, 1982, 1983), and in association with continental region blocking (e.g., Lupo and Bosart, 1999).

It has been observed that in Central Missouri the sultry, oppressive days of the summer season frequently make an abrupt entrance, often in mid-June. The mild and frequently wet pattern of the Midwest spring evolves quickly into a prolonged period of intense heat and humidity. The northward migration of the East Pacific and Bermuda highs and the mid-latitude storm track along with the development of a thermal trough (“heat low”) in the desert southwest and a “plateau high” (see Tang and Reiter, 1984) over the four corners region accompany the transition to a summer like flow regime. In the Midwest, the enhanced northward flow of moist air from the Gulf of Mexico associated with the westward extension of the Bermuda high provide a hot, humid regime with infrequent periods of precipitation, as the mid-latitude jet resides over southern Canada (Bryson and Hare, 1976).

Thus, the spring-to-summer season transition in the East Central Ozarks of Missouri, its character, timing, and predictability were the focus of this research. It will be demonstrated that this transition is often abrupt, but identifiable using a set of criterion based on routine synoptic observations. This paper will review the:

(1) criteria chosen for determination of summer onset in Mid-Missouri,

(2) relationship of summer onset to large-scale flow regime changes,

(3) relationship of summer onset dates to precipitation climatology,

(4) a discussion of the results.

2. DATA AND METHODS

The Missouri River to the north, Mississippi River to the east, Arkansas border to the south, and Western Ozarks region to the west outline the region of study (Fig. 1). Much of the karst topography of the East Central Ozarks is covered with oak, hickory forest with few urban areas intermixed, St. Charles being the exception, and low population density. Nine National Weather Service (NWS) Cooperative Stations sites were chosen for daily temperature and precipitation data analysis.

This region was chosen for study since there are several surface stations maintained by the Missouri Climate Center that are also located in this region. This data could be used if needed for quality control. Also, for each NWS cooperative station location there is climatic data available from 1918 to the present. In the paper, the data from Jefferson City is used to represent the East Central Ozark region. An analysis of summer season precipitation using principal components analysis (PCA) by Palecki and Leathers (2000) suggests that this station would be representative of the summer climate of the East Central Ozark region, at least for this initial analysis. Additionally, the study by Park and Kung (1988) and Lee and Kung (2000) using similar techniques suggest that interannual variations of temperature across the region would behave similarly.

The daily temperature records from April 1 to September 1 at Jefferson City are analyzed and the following criteria are applied in order to determine the summer transition date:

(1) the beginning of the first period of fifteen consecutive days with mean temperature exceeding 21.1^{o} C (70^{o} F) and at least ten of those days exceeding 23.9^{o} C (75^{o} F).

(2) the beginning of the first period of fifteen consecutive days with maximum temperature exceeding 25^{o} C (77^{o} F) and at least 10 of those days above 27.8^{o} C (82^{o} F).

These means were chosen on the basis that the base thresholds are whole numbers close to one standard deviation below the monthly June means. Thus, the summer transition is not based on numbers that are unrealistically high and which might result in a summer transition not being identified at all. Also, by examining 15-day averages, the synoptic and diurnal variations are filtered out (e.g., Yarnal, 1993) and this guarantees that the largest-scale components are captured.

Various types of manually derived climatological classification criterion, such as these two above, do have some shortcomings (e.g., Yarnal, 1993). It was found that the transition date identified by the first criterion was sometimes sensitive to orographic influences, and in particular cool air drainage influencing the daytime mean temperatures. Thus, the second criterion was added in order to alleviate this problem. Also, this indicates that care should be taken in choosing surface stations that have similar surroundings (i.e., rural versus urban stations, see discussion above). Additionally, relating the planetary-scale to the synoptic and meso-scale can be problematic due to the fact that there are complex scale interactions which cannot be accounted for using these simple techniques (e.g., Yarnal, 1993) and may be highly non-linear (e.g., Yarnal, 1993; Lupo, 1997). Lastly, studies of this type may only be applicable in the region of study (e.g., Yarnal), even though the analysis of Palecki and Leathers (2000) and others would suggest would be applicable across most of the eastern two-thirds of the state. This study attempts to address the issue by using statistical parameters in the definitions discussed above. However, it is beyond the scope of this particular study to examine the universality of the proposed spring to summer transition criterion.

In order to address scale issues by bridging the planetary and synoptic-scales, a third criterion is also introduced that is based on the pressure (mass) field. The 500 hPa height data for each summer were examined to locate the initial date of a period persisting ten days or longer in which these heights are in excess of 5820 meters. The rationale for this choice of contour is that the 5820m contour is quite often located along the southern flank of the strong mid-latitude height gradients and represents the mean 500 hPa contour across Central Missouri in June (e.g., Bentley and Mote, 1998). Thus it is suggested that the ‘582’ contour represents a convenient cutoff between the more baroclinic mid-latitude flow and the quasi-barotropic regime which characterizes subtropical flows. Again, a longevity criterion is also paired with the height criterion to filter out synoptic-scale variations.

The frequency of significant precipitation (greater than or equal to 0.25 inches) events prior to and after the estimated summer onset date is inferred from the precipitation period in columns

6 and 7 of Table 2. The number of days between quarter inch rainfall events was averaged from the last event in April to the event prior to the selected date for the seasonal transition. Subsequent intervals to the first quarter inch precipitation event in August are used to calculate post onset period. Precipitation periods reflect the average across the 9 cooperative stations used in the region. Significant precipitation period was examined as opposed to precipitation amounts, since precipitation during the spring and summer within the Eastern Ozarks Region is primarily convective in nature, and thus locally intense precipitation rates can contribute to inflated precipitation amounts even though fewer events may occur. Also, the period with which precipitation occurs can be correlated, at least partially with the period or frequency of the passage of synoptic-scale waves or disturbances through the study area. Finally, for agricultural purposes, the frequency of heavy precipitation is an important variable, since prolonged dry spells may be more detrimental to crop growths and yields than more frequent rain events (A. Akyuz, State Climatologist, Personal Communication, 2002), even if these latter events result in lighter rains.

The interannual variability of the onset of the summer transition with respect to the phase El Nino and Southern Oscillation (ENSO) is also studied here. The Japan Meteorological Agency (JMA) ENSO Index was used in this study. A list of El Nino (EN), La Nina (LN), and Neutral (NEU) years (Table 1), as well as a more detailed description of the JMA ENSO Index, can be found by accessing the Center for Ocean and Atmospheric Prediction Studies (COAPS) website[2]. In summary, the index classifies years as EN, LN, and NEU based on 5-month running-mean Pacific Ocean basin sea surface temperatures (SST) anomaly thresholds bounded by the region 4^o N, 4^o S, 150^o W, and 90^o W. The defined region encompasses both the Nino 3 and 3.4 regions in the central and eastern tropical Pacific (e.g., Pielke and Landsea, 1999). The

SST anomaly thresholds used to define EN years are those greater than or equal to +0.5° C, less than or equal to -0.5° C for LN years, and NEU otherwise. For classification as an EN or LN year, these values must persist for 6 consecutive months including October, November, and December. The JMA ENSO criterion defined the El Nino year as beginning on 1 October of the previous year. Thus, ENSO year 1970 begins in October of 1970 (Table 1) and ends in September 1971. Table 2 classifies the summer-season ENSO phase by labeling the calendar year. The JMA definition, however, has been modified in other studies (e.g., Lupo and Johnston, 2000) in order that that the El Nino year commenced with the initiation of the hurricane season (1 June), or the blocking year (1 July by Wiedenmann et al., 2002). Such modifications can be justified since El Nino conditions typically begin to set in before 1 October, and 1 October is close to the climatological peak of hurricane season (10 September).

In order to determine whether the Northern Hemisphere flow undergoes a transformation in mean energy state, the wave amplitude index (WI) was used (Hansen, 1986; Sutera, 1986). The wave amplitude index is expressed as:

$$WI = \left(\sum_{m=2}^{4} 2Z_m^2 \right)^{1/2} \quad (1)$$

where Zm represents the Fourier coefficients for the zonal wave number m. Zm was calculated by using the twice daily 500-hPa heights from the European Centre for Medium Range Forecasting (ECMWF). For each map-time (0000 UTC and 1200 UTC), the 500 hPa heights from 1 January, 1980 to 31 December 1988 were averaged with respect to latitude from 22.5° N to 77.5° N, and then Fourier decomposed in the zonal direction. The result is WI, which is in reality the square root of the height variance and not the amplitude. The amplitude can be obtained by multiplying by the square root of 2 (Hansen, 1986). The resulting time-series was then filtered to remove high (periods less than 5 days) and very low frequency (e.g., the annual cycle) variability, again using Fourier transformation and re-synthesizing the data after “zeroing out” the unwanted frequencies (Hansen, 1986; Sutera, 1986). Plotting these values on a histogram yields a probability density distribution that is clearly bimodal (see Hansen, 1986 or Sutera, 1986 for more detail) with one peak corresponding to a “low amplitude” (mode 1) flow regime, and the other to a “high amplitude” (mode 2) flow regime. While recent studies attempt to demonstrate using newer statistical methods that these results are not statistically robust (Nitsche et al., 1994) and should be viewed with caution, previous studies of the physical behavior of the solutions to the primitive equations using low-order models (e.g., Lorenz, 1963; Haines and Holland, 1998) suggest the “vacillation” behavior in the planetary-scale flow is quite plausible. Also, such behavior has been noted and observed in planetary-scale flows by forecasters since the late 1950s.

3. ANALYSIS

a. Results using the criterion

The evolution to the summer season typically occurs over a period greater than 3 to 5 days, however abrupt changes do occur. For example, increases of 90 meters and 180 meters in the 500 hPa height fields over the region occurred in a 24 hour period during the selected summer onset dates for 1997 and 1998 respectively.

In 9 of the 20 years examined in Table 1, the three summer criteria indicated summer onset within the same +/- 5 calendar-day interval from the chosen onset date. In the remaining years, the summer onset date was chosen where two of the three parameters were in close agreement. If there was significant separation of similar magnitude in all the dates indicated, the onset day was chosen within the time period indicated by averaging the dates. The 20-year mean date for the onset of summer was calculated to be June 15, and mid-June would be in agreement with the results of Nogues-Peagle and Mo (1987) who found the rapid spring-to-summer season transition occurred during the June 1979 period. Sixty percent of the summer onset dates occurred between June 10 - 20, with twenty percent occurring prior to June 10 and twenty percent occurring after June 20. The standard deviation of the sample dates is roughly +/- 10 calendar-days, and 65% of the onset dates occur between June 5 and June 25. There were 3 occurrences earlier and four later than this interval, and, thus, the distribution was consistent with that of normally distributed data, in spite of the small sample acquired here.

In examining each criterion separately (Table 2) and determining the reliability of each to identify the final transition date, it can be shown that the daily mean temperature was the most reliable parameter. If reliability is gauged by stipulating that the criterion and the final transition date selected were within 2 days of each other, the mean temperature criterion was reliable for 18 of the 20 years. The maximum temperature and 500 hPa height contour criteria were reliable for only 10 and 9 years, respectively and can be thought of as criterion which refined the selection of the final date.

b. Analysis of the planetary-scale flow regime

The results above suggest that the spring-to-summer season transition in the East Central Ozarks Region is identifiable using routinely available observational synoptic data. Since the criterion presented here is regional, it is reasonable to assume that the spring-to-summer season transition would not necessarily correspond to that identified in the hemispheric flow regime, if indeed the transition can be identified at all at the largest scales. Fig. 2 presents plots of WI for the May through August period for the years 1981 – 1988 using ECMWF data. The vacillation of

Northern Hemisphere heights between mode 1 and mode 2 episodes occurring at irregular intervals can easily be identified (e.g., Lorenz, 1963, Hansen 1986, Sutera, 1986). A general downward trend is evident in each period except for the 1988 late spring and summer period (Fig. 2h). The years 1981, 1984, 1985, and 1987 (Figs 2a, d, e, and g) reveal that abrupt changes in the index value, which is proportional to the kinetic energy of the geostrophic wind. For the year 1984, this sudden decrease in WI occurs early in the period, while for other three years this change occurred midway through the displayed period. Again, if these represent the identification of an abrupt transition from the spring to summer season as represented by Northern Hemisphere planetary-scale kinetic energies, the timing of these "shifts" (mid-June) would be consistent with the findings of Nogues-Peagle and Mo (1987).

In 1981 (1984) (Figs. 2a and d), the abrupt change in the value of WI occurs shortly after June 20 (around May 25), and our criterion identifies the local spring-to-summer season transition to be June 21 (June 3) (Table 2). For each of these years, the spring-to-summer season transition dates as identified by our criteria are close together and in each case two of the three parameters are within 3 days of each other. For the year 1985 (Fig. 2e), an abrupt change in WI occurred shortly after June 20, however, there was substantial spread among the spring-to-summer season transition date selected by each criterion. Even so, the final date selected for the transition date appeared to occur within approximately one week to ten days of the change in WI. In 1987 (Fig. 2g), an abrupt change in WI occurs close to the end of June while our criterion identifies the spring-to-summer season transition in early June.

For the remaining years, where a gradual decrease or no change in WI is evident (Figs. 2b, c, f, and h), the spring-to-summer transition was easily identified in three of the four years as well. During 1983, there was substantial spread in each of these criteria, while the WI values decreased gradually throughout the period. While the above results constitute a small sample, it is encouraging to note that for three of the eight years, an abrupt change in the kinetic energy of the hemispheric flow reasonably matched the identification of the spring-to-summer season transition for the East Central Ozarks Region of Missouri using daily observations. This occurs despite the fact that an abrupt shift from spring-to-summer season was not consistently identifiable using the hemispheric data. Finally, attempts to find a correspondence between the spring-to-summer season transition and other parameters, such as the occurrence of Northern Hemisphere blocking (Wiedenmann et al., 2002) failed to reveal any further insight.

c. Precipitation Frequency

For 16 of the 20 years, the heavy precipitation frequency diminished after the summer onset date (Table 2), though in some cases summer precipitation totals exceeded those of spring due to intense though infrequent rainfall events. In Table 2, a lower (higher) number corresponds to an increase (decrease) in heavy precipitation frequency. During the four years in which the precipitation frequency increased, the spring-to-summer season transition was identified as occurring early (1993, 1994) and late (1981, 1989) for two years each. The 20-year mean shows that the heavy precipitation frequency was 6.8 days before the summer transition, but 11.6 days after the transition. This result would be consistent with the poleward migration of the polar front jet stream and storm track through the Midwestern US and into Southern Canada during April to July period.

d. Interannual Variability in Summer Onset Dates

The interannual variability of summer onset dates was examined with respect to the phase ENSO. As mentioned earlier, the ENSO phase was identified for each summer season using the JMA criterion. However, since El Nino and La Nina conditions tend to set in gradually and emerge strongly during the fall months, classification of summer seasons is not straightforward (e.g., Renwick and Revell, 1999; Lupo and Johnston, 2000; Wiedenmann et al., 2002). Thus, summer seasons here are identified using the JMA criterion for the current ENSO year (Table 2) and the following ENSO year. In this way, summer seasons in which ENSO is transitioning phases can be differentiated from extended periods of quasi-steady state conditions (Table 3). Additionally, spring-to-summer season transitions occurring before (after) June 15 are considered to be early (late) transitions, and 10 study periods each were classified as early or late onsets.

For summers classified as early transitions (Table 3) in the East Central Missouri Ozarks region, 7 of these involved periods in which the phase of ENSO was steady state. For 6 of these summer transition periods, the summer season was classified as "neutral" and the upcoming fall "neutral" as well (here we adopt the notation convention "steady state neutral"), while one summer period (1987) was associated with steady state El Nino conditions. Two summers were also associated with the transition from the neutral phase into El Nino conditions, or the onset of El Nino. Thus, 90% early summer transition during this 20 year period were associated with steady state El Nino or neutral conditions, or the onset of El Nino out from neutral conditions.

Conversely, for summers classified as later onset dates (Table 3) within the study region, only three were associated with steady state ENSO conditions. This includes one summer season classified as steady state La Nina conditions (1999), and two which were steady state neutral conditions. All other late arriving summers were associated with a change in ENSO phase. This subset includes 3 out of 4 phase changes in ENSO involving the La Nina phase. Thus, the onset or persistence of La Nina conditions during this 20-year period was associated with late arriving summers. Additionally 80% of the summers in this category involved either the La Nina phase or an ENSO phase transition.

e. Interannual variability in precipitation frequencies

Seasons that involved early transitions from spring-to-summer the average change in frequency of significant precipitation was slightly greater than that for summers associated with a later transition date (7.0 to 12.3 days for early versus 6.6 to 10.9 for late arriving summers). This would suggest, that else being equal, summers with later season transition dates would be wetter in general than summers with early season transition dates. The higher frequency of rain events would mean more chances for rain. The average rainfall in early arriving summers versus late arriving summers at the Columbia Regional Airport (CRA) was 12.23 inches and 13.98 inches, respectively. While this difference is close to two inches, the number is not statistically significant owing to the large standard deviations in precipitation amounts (interannual variability) and the small samples compared. Also, while the CRA is located in a county adjacent to the study region, the interannual variations should behave in a similar manner.

It has been suggested that in the East Central Ozarks region, La Nina summers tend to be drier than El Nino summers. The summers of 1988 and 1999 were two of the driest summers across this region in the latter portion of the 20^{th} century. Given the difficulty in identifying the summer season with one phase or the other, the precipitation period in El Nino and El Nino transition summers are compared to those of La Nina and La Nina transition summers. For El

Nino and El Nino transition summers the precipitation frequency was higher than for La Nina and La Nina transition summers. The precipitation period was 6.5 and 12.9 days for the former, and 7.9 and 14.6 days for the latter, respectively. However, comparing the rainfall totals from the Columbia Regional Airport reveals that the El Nino summers were drier than La Nina summers (10.2 inches of rain versus 12.44 inches, respectively). Thus, it is implied that during El Nino (La Nina) summers, there was more (fewer) rain events with lighter (heavier) rainfall totals. This comparison presents an illustratation of the possible problem in examining rainfall total amounts to uncover interannual variability related to ENSO versus significant rainfall frequency or periods. Again, for agricultural purposes, the La Nina summers represent a less ideal rainfall distribution.

However, the above stratification included some summers (e.g. 1988 and 1998) in both data sets. In order to remove this overlap, only summers prior to onset of El Nino or La Nina, or summer seasons that occurred during prolonged El Nino or La Nina conditions were compared. This stratification effectively uses the summer season ENSO classification scheme of Renwick and Revell (1999), Lupo and Johnston (2000), or Wiedenmann et al. (2002). There was no tendency for these El Nino (or El Nino onset) (1982, 1986, 1987, 1991, 1997) or La Nina (or La Nina onset) summers (1988, 1998, 1999) to arrive early or late (Table 2), however, this 20-year sample is very small. Even so, the spring-to-summer transition results in an even greater lengthening of the precipitation period for the La Nina summers (7.5 days spring to 18.6 days summer), than for El Nino years (5.7 days spring to 9.9 days summer).

f. interannual variations in summer temperatures

An examination of mean summer season surface temperatures in the East Central Ozarks Region were compared with the summer onset dates in order to determine if there were any correlations. The 30-year (1971 – 2000) mean summer season temperatures were 75.5 ^{o}F and the standard deviation was 1.6 ^{o}F. Summers associated with an early onset date were warmer than those with a later onset date (76.1 ^{o}F versus 74.7 ^{o}F, respectively), but these values are not significantly different from the long-term mean or each other at acceptable levels of statistical confidence. Also, the average temperature for La Nina summers was 76.6 ^{o}F, while the mean temperature for El Nino summers was 75.6 ^{o}F. While none of these figures are statistically significant, summers that are drier or associated with longer dry spells (e.g., La Nina years as shown in section 3d), would be expected to be associated with warmer surface temperatures. These summers would be associated with more insolation and less of this insolation would be spent drying the ground. Earlier studies (e.g., Namias, 1982, 1983) associated warm dry summers in middle of North America with strong middle and upper tropospheric ridging over the continent.

4. SUMMARY AND CONCLUSIONS

The transition to the summer season in the East Central Missouri Ozarks commences with a marked and oftentimes abrupt increase in temperature and dew point and a marked decrease in precipitation. Summer onset was identified as early as May 21 and as late as July 1 in the period 1981 to 2000 and using routinely available synoptic observations, though the typical transition period was June 10 to 20, averaging around June 15. Despite the problems outlined in designing climatological classification schemes similar to the one proposed here (e.g., Yarnal, 1993). These results are consistent with the only other published study that could be found in the literature regarding the spring to summer season transition. A comparison to the possible identification of the hemispheric spring-to-summer season transition using the Wave Amplitude Index (Hansen, 1986) was also performed. These results were also somewhat consistent with those of Nogues-Peagle and Mo (1987).

The spring-to-summer season transition was also shown to be associated with a dramatic increase (decrease) in the period (frequency) of significant precipitation amounts. However, there was no statistically significant tendency for differences in precipitation frequency for early versus late arriving summers. An examination of interannual variations as related to ENSO revealed that early (late) arriving summers were commonly associated with steady state (transitioning) ENSO phase conditions, and La Nina summers frequently were also late arriving. Additionally, there was a tendency for La Nina summers to be associated with much lower precipitation frequencies that El Nino summers. These corresponded to years with early summer onsets being warmer on average than those with a later onset date, and La Nina summers were warmer than El Nino summers by one degree Fahrenheit. Thus, when considering precipitation distributions and temperatures, La Nina summers in the East central Ozarks region are more detrimental to agricultural interests here. While none of these results are statistically significant owing to the short period of study (20-years), a longer period of study was not done due to questions about the reliability of earlier data used in this region of study. Thus, obtaining a longer period of record in order to determine if the results found here will withstand rigourous statistical testing will take some years to acquire.

Relationships between the transition to summer in the East Central Missouri Ozarks, and the onset of the Southwest Monsoon, the Southern Oscillation phase, the Pacific North American and North Pacific Oscillation patterns, seasonal snow cover depletion, and the character of the summer itself will continue to be explored.

5. ACKNOWLEDGMENTS

The authors wish to thank Mrs. Sharon Burnham for preparing and editing the text, and Mrs. Tanya Akyüz for preparing some of the figures and tables. We would also like to thank Dr. Adnan Akyüz (Missouri State Climatologist) and Dr. Patrick Guinan (Extension State Climatologist) for their helpful insights and discussions. The authors are also indebted to the anonymous reviewer whose comments were very helpful in improving this manuscript.

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Figure Captions and Footnotes

Figure Captions

Figure 1. A map of Missouri, including the region of study (grey shading).

Figure 2. Plot of the twice daily wave amplitude index values versus time (May 1 – 31 August) for the year a) 1981, b) 1982, c) 1983, d) 1984, e) 1985, f) 1986, g) 1987, and h) 1988.

Footnotes

1. The internet address for the American Meteorological Society is; www.ametsoc.org/AMS/. This search was conducted on the journals homepage using the words "spring-to-summer transition".

2. The COAPS website is at: http://www.coaps.fsu.edu.

Table 1. A list of years examined in this study separated by ENSO phase.

La Nina (LN)	Neutral (NEU)	El Nino (EN)
1970	1974	1969
1971	1977-1981	1972
1973	1983-1985	1976
1975	1989-1990	1982
1988	1992-1996	1986-1987
1998-1999	2000	1991
		1997

Table 2. Summer transition period estimated according to maximum temperature, mean temperature and 500 millibar height criteria as well as estimated date. The precipitation (> 0.25 inches per day) prior to and post onset of summer data and the El Nino - Southern Oscillation phase according to the JMA criteria for the summer are listed in the last three columns (1=La Niña, 2=Neutral, 3=El Niño). The numbers in the header block are column numbers.

Summer Transition Criteria Dates					Precipitation Period (days)		ENSO
1	2	3	4	5	6	7	9
Yr	MxT	MnT	500H	Date Selected	PRE	POST	
2000	7-2	7-2	7-1	7-1	7.5	8.1	1
1999	6-19	6-21	6-3	6-19	7.0	20.8	1
1998	6-17	6-17	6-17	6-17	5.7	11.3	3
1997	6-15	6-16	6-9	6-19	7.6	10.1	2
1996	6-12	6-12	6-3	6-13	6.9	6.9	2
1995	6-13	6-15	7-7	6-15	6.6	19.5	2
1994	6-11	6-11	6-13	6-11	10.0	7.8	2
1993	6-8	6-10	6-11	6-10	6.9	5.9	2
1992	6-23	6-29	7-1	6-28	6.7	9.0	3
1991	5-21	5-21	6-6	5-21	2.5	10.0	2
1990	6-6	6-7	6-5	6-6	5.2	9.7	2
1989	6-17	6-19	6-19	6-19	9.8	8.9	1
1988	6-6	6-12	6-10	6-10	9.7	23.7	3
1987	5-26	6-6	6-5	6-5	11.0	10.7	3
1986	6-4	6-14	6-16	6-13	4.0	12.8	2
1985	6-19	6-29	7-7	6-29	4.0	9.8	2
1984	5-31	6-3	6-9	6-3	7.5	15.6	2
1983	6-15	6-18	7-1	6-20	7.5	22.7	3
1982	6-20	7-2	6-29	6-27	3.5	5.7	2
1981	6-18	6-23	6-21	6-21	6.0	4.3	2

Table 3. Summer onsets identified as an early or late onset by year and ENSO phase (during the summer of that year and the upcoming year classification).

Early		Late	
Year	ENSO phase	Year	ENSO phase
1996	neu – pre neu	2000	LN – pre neu
1995	neu – pre neu	1999	LN – pre LN
1994	neu – pre neu	1998	EN – pre LN
1993	neu – pre neu	1997	neu – pre EN
1991	neu – pre EN	1992	EN – pre neu
1990	neu – pre neu	1989	LN – pre neu
1988	EN – pre LN	1985	neu – pre neu
1987	EN – pre EN	1983	EN – pre neu
1986	neu – pre EN	1982	neu – pre EN
1984	neu – pre neu	1981	neu – pre neu

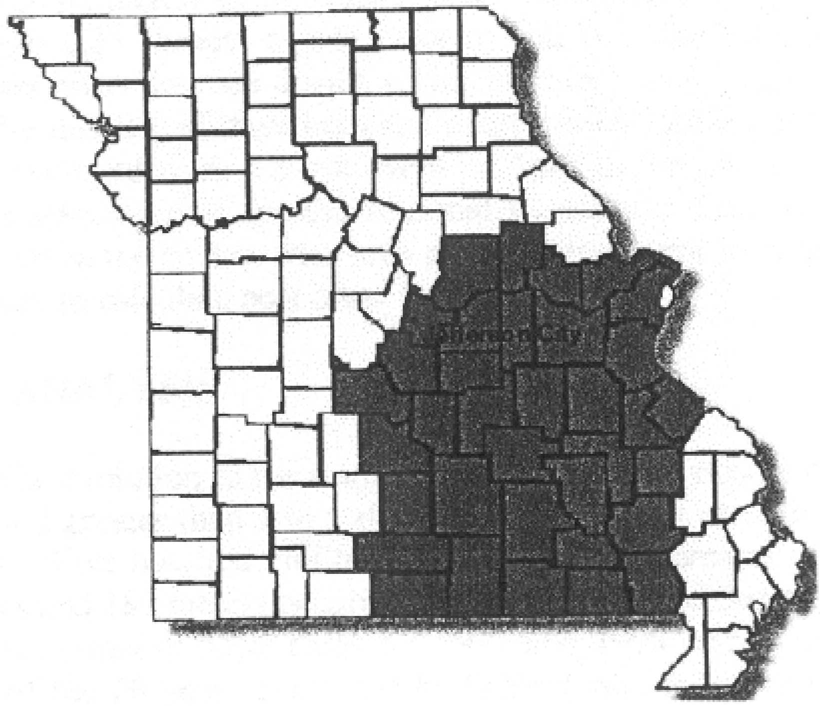
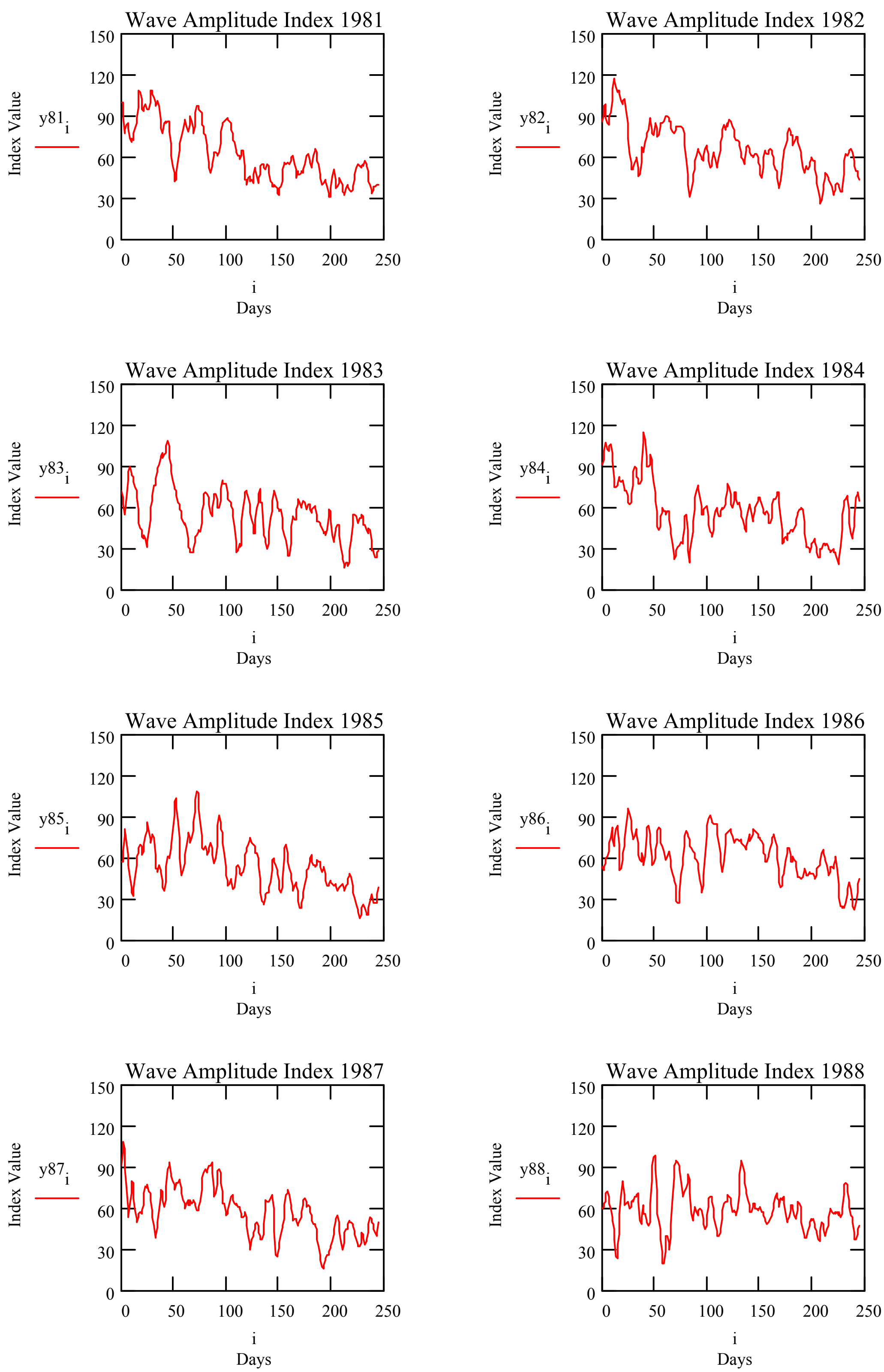


Figure 1. A map of Missouri, including the region of study (grey shading).



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