USING THE MONTHLY CLASSIFICATION OF GLOBAL SSTS AND 500 HPA HEIGHT ANOMALIES TO PREDICT TEMPERATURE AND PRECIPITATION REGIMES ONE TO TWO SEASONS IN ADVANCE FOR THE MID-MISSISSIPPI REGION

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Abstract

Using the results from previous studies of the interannual variability of local mean monthly temperature and precipitation by this group, long range forecasts were generated for summer and winter season temperatures and precipitation four to five months in advance using analogs and/or contingency tables. These forecasts also included information about El Niño phase and east Pacific region blocking events. Summer and winter season forecasts of temperature and precipitation are of interest to the local and regional media as well as the agricultural communities in the mid-Mississippi River Valley. A simple forecast verification scheme was borrowed and used to score the long range forecasts, and skill scores were used to compare and evaluate the forecasts against climatology. The results show that these forecasts have been better than climatology, in general, especially in the summer season and for seasonal temperature forecasts.

The research results used here have demonstrated that Pacific region SSTs and SST anomalies can be separated into seven general synoptic classifications ("clusters", A-G). Some of these clusters are shown to have a distinct impact on the barotropic component of the mean tropospheric height distributions as well. Clusters A, B, E, and G (C, D, and F) have been shown to be representative of La Niña (El Niño) type SST distributions by previous studies. Further, an analysis of the SST patterns from 1955 – 2007 demonstrated that certain clusters were prominent from 1955 – 1977, and from 1999 to the present; others dominated the period in between. This shift in prominent patterns during 1977 and 1999 corresponded roughly with a change in phase of the Pacific Decadal Oscillation (PDO). Some SST anomalies were correlated with warmer or cooler than normal conditions in the mid-Mississippi region, while others did not produce definitive results.

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1. Introduction

Many recent studies have attempted to link variations in global circulation changes (e.g., Wallace and Gutzler 1981; Gershanov and Barnett 1998; Enfield and Mestas-Nuñez 1999; Mestas-Nuñez and Enfield 1999, 2001; Wiedenmann et al. 2002), or local (and regional) climate variations (e.g., Kung and Chern 1995 [*hereafter KC95*]; Kunkel and Angel 1999; Lupo et al. 2007) with interannual and interdecadal variations in sea surface temperatures (SSTs) and pressures in the Pacific Ocean basin and/or the changes in the character of the atmospheric and oceanic circulations in the Atlantic Ocean basin (e.g., Hu et al. 1998). The interactions between the atmosphere and oceans are important processes to consider when attempting to either understand the relevant physics of the earth's climate system or to make long-range forecasts (e.g., Anderson et al. 1999; Barnston et al. 2005).

The dominant interannual variations in global and regional climate characteristics are largely influenced by El Niño and Southern Oscillation (ENSO) modes (e.g., Mokhov et al. 2000, 2004). Diagnosing regional and local climate variability has been a topic of interest lately, since global circulation models are used heavily to study the potential for climate change (Houghton et al. 2001) and in long range forecasting. Thus, it is critically important that these models be able to demonstrate that they can faithfully simulate not only the range of regional and local climates, but the interannual and interdecadal variations as well. It is well known that tropical SST distributions and "anomalous" SST distributions have a large impact on the weather and climate by changing heat and mass distributions of the troposphere. Through this influence, SSTs can ultimately alter the prevailing wind patterns over a large portion of the globe (e.g., Namias 1982, 1983; Enfield and Mestas-Nuñez 1999; Mestas-Nuñez and Enfield 1999, 2001; Wiedenmann et al. 2002). This in turn can impact the frequency, occurrence, and intensity of such phenomena as mid-latitude cyclones (e.g., Key and Chan 1999), tropical cyclones (e.g., Gray 1984) and blocking anticyclones (e.g., Wiedenmann et al. 2002). However, there are studies (e.g., Enfield and Mestas-Nuñez 1999; Mestas-Nuñez and Enfield,1999, 2001; Kushnir et al. 2002) that point out that mid-latitude SSTs may not be very influential on mid-latitude circulations. Nonetheless, the influence of tropical SSTs on the mid-Missouri area regional climate have been demonstrated, albeit indirectly, via the impacts on snowfall regimes (e.g., Lupo et al. 2005), tornado occurrences (e.g., Akyuz et al. 2004), and temperature and precipitation regimes (e.g., Hu et al. 1998; Lupo et al. 2007).

KC95 used principal component analysis (e.g.,Wilks 2006) to extract the large-scale modes of monthly mean global SST anomalies and the Northern Hemisphere tropospheric circulation anomalies during the period 1955 – 1993. A similar analysis was performed by Enfield and Mestas-Nuñez (1999) and Mestas-Nuñez and Enfield (1999, 2001), but using data covering the period from 1870 – 1991. The KC95 study provided an archive which can be used as guidance for long-range forecasting applications (e.g., forecasting by the use of analogs and/or contingency tables). This analysis was then extended to 2005 by Lupo et al. (2007). A by-product of these analyses demonstrates that global SST anomalies could be classified into one of seven distinct pattern types (A – G). Each of these was correlated with corresponding Northern Hemisphere tropospheric mass distributions or flow anomalies, and in subsequent work, correlated with surface climatic characteristics in mid-Missouri (Lee and Kung 2000). It is noted here, however, that correlations between SSTs and atmospheric flow patterns do not imply any cause and effect relationship between these quantities. KC95 and Lupo et al. (2007) also noted that anomaly types (clusters) A, B, E, and G (C, D, and F) are representative of La Niña or neutral (El Niño) type SST distributions within the Pacific Ocean basin. They also demonstrated that clusters A-D dominated the negative phase of the Pacific Decadal Oscillation (PDO) (1955 – 1977, and 1999-present), while E and F type clusters dominated the middle portion (1977-1998). Lupo et al. (2007) then demonstrated that some of these are associated strongly with certain temperature and precipitation regimes in the mid-Mississippi valley region (e.g., D-type patterns are strongly correlated with dry months in the region).

Thus, this work has two primary objectives. First, the work of Lupo et al. (2007) will be discussed (sections 2 and 3) and this includes an analysis of SST anomaly types and their correlation to monthly temperatures and precipitation in the mid-Mississippi valley region as represented by a time series from the Columbia Regional Airport. Their work is then extended here (section 4) to discuss the synoptic-scale flow regimes associated with prolonged SST anomaly distributions of each of the seven types discussed above. This paper then examines the usefulness of these results in making long range forecasts made by the long range prediction group at the University of Missouri – Columbia, and the verification of these forecasts (section 5). This includes a discussion of summer season blocking in the East Pacific and the relationship to temperatures and precipitation in our study region. We will demonstrate that these forecasts are better than a commonly used baseline forecast (climatology).

2. Data and Methodologies

a. Data collection

The analyses used in this study were the global monthly mean and reconstructed SSTs and SST anomalies compiled by the National Centers for Environmental Prediction (NCEP) and available through the National Oceanic and Atmospheric Administration (NOAA) online archive available online at http://www.cdc.noaa.gov/cdc/reanalysis/. Monthly SSTs and anomalies are also available and these can be found in the monthly *Climate Diagnostics Bulletin* online at www.cpc.ncep.noaa.gov. The mean SST anomalies in the ENSO region are available from 1864 to the present through the Center for Ocean and Atmospheric Prediction Studies (COAPS – www.coaps.fsu.edu), and the phase of the ENSO (Table 1), which can also be found at the COAPS site.

The ENSO definition is used in many studies (e.g., Lupo et al. 2005; 2007 *and references therein*). In summary, the index classifies years as El Niño (EN), La Niña LN, and neutral (NEU) based on 6-month running-mean Pacific Ocean basin sea surface temperatures (SST) anomaly thresholds bounded by the region 5° N, 5° S, 150° W, and 90° W. The defined region encompasses both the Nino 3 and 3.4 regions in the tropical Pacific. The anomaly thresholds used to define EN years are those greater than +0.5° C, less than -0.5° C for LN years and NEU otherwise. The ENSO year is defined as beginning on 1 October for the year appearing in Table 2 and ending in September the next year (following the references above and COAPS).

The 500 hPa heights and height anomalies from the NCEP re-analysis project (Kalnay et al. 1996) were also examined and are available via the many of the same sources referenced above. Finally, the mean monthly temperature and precipitation records for the Columbia Regional Airport (1955 – 2007) were provided through the Missouri Climate Center and the Midwestern Regional Climate Center. This represents a continuous record for each variable; however, the Airport did change location around 1970. This station moved approximately 25 km southward, but there are no indications that this move resulted in significant changes in the climatology (Lupo et al. 2007). Degrees Fahrenheit and inches are used for the analysis of monthly mean surface temperatures and precipitation since these are still the standard units used for archival of these monthly records and are still the standard for United States surface observations. Also, the precise units of the data used in this analysis were not germane to the discussion presented here.

b. SST analysis

For each month, visual inspection of the monthly SST and 500 hPa height charts was shown to be a reliable method by KC95 and Lupo et al. (2007) for classifying the SST anomaly distributions into one of seven different synoptic categories (A – G) over the entire map area (see Fig. 1, Table 2). Manual inspection was also used by KC95 after they used the clustering method of Fukunaga (1972) to derive seven distinct anomaly types. In Fig. 1, examples of the seven different SST anomaly clusters are shown as taken from Lupo et al. (2007). These monthly SSTs are not the same plots shown in KC95. Their plots represent the extracted large-scale mode, while here we show the actual SST anomalies, which were classified similarly to those found in their (KC95) Fig. 1 over the map region. Thus, it is conceded that our Fig. 1 may contain smaller-scale noise.

Briefly, SST clusters B and G are representative of La Niña type clusters in the Pacific Ocean basin. The cool anomaly is centered east of the dateline and is stronger than -1° C. These clusters have the opposite signal of each other in the Atlantic Ocean Basin, where one is positive and the other is negative in general. Clusters A and E are characteristic of weak La Niña to ENSO Neutral type conditions (centered in the eastern Pacific near the continent and is generally weaker than -1° C), including a fairly weak signal in the tropics and a stronger mid-latitude signal. These SST anomaly distributions are similar in each major ocean basin, with the exception that E-type

Table 1. A list of years examined in this study separated by ENSO phase. Each ENSO year begins in October and ends in September. The El Niño year (for example 1969) is defined as starting in October (1969) and ending in September (1970). ENSO definition can be found online at www.coaps.fsu.edu/jma.shtml.

La Niña (LN)	Neutral (NEU)	El Niño (EN)
1949	1945-1948	1951
1954-1956	1950	1957
1964	1952-1953	1963
1967	1958-1962	1965
1970-1971	1966	1969
1973-1975	1968	1972
1988	1977-1981	1976
1998-1999	1983-1985	1982
	1989-1990	1986-1987
	1992-1996	1991
	2000-2001	1997
	2003-2005	2002
		2006

anomalies are associated with a more widespread coverage of warm anomalies in general. The remaining clusters are C, D, and F type anomalies, which are representative of El Niño-type SST distributions in the Pacific Ocean basin. The D-type cluster represents fairly weak ENSO conditions, with the strong SST anomaly located closer to the east-central Tropical Pacific and is generally between 1 – 2° C. The C and F type anomalies represent stronger El Niño conditions, with the warm SST anomalies located in the far eastern Tropical Pacific Ocean. The stronger ENSO events are associated with stronger SST anomalies that are also located farther east, and this result agrees with the

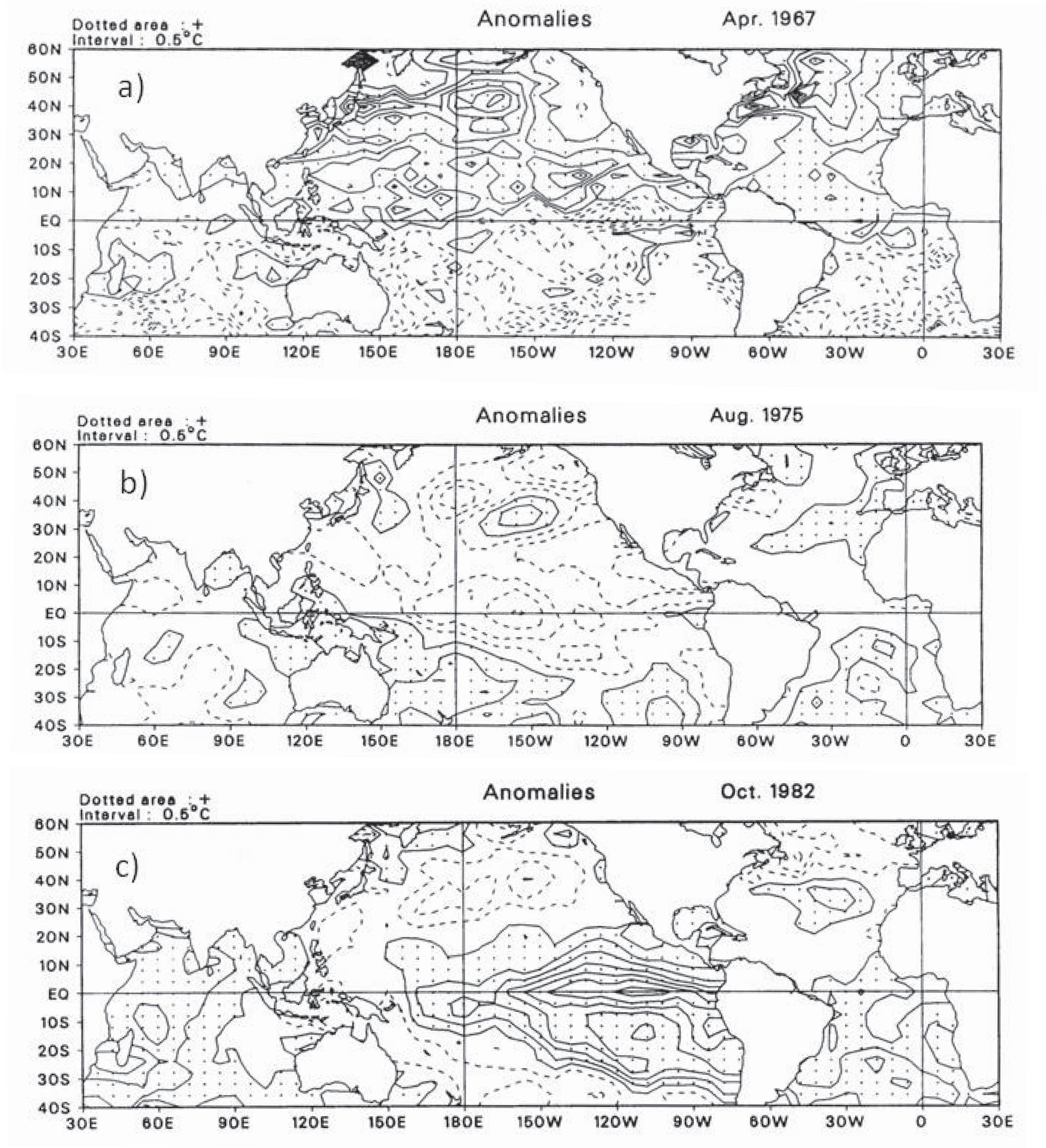
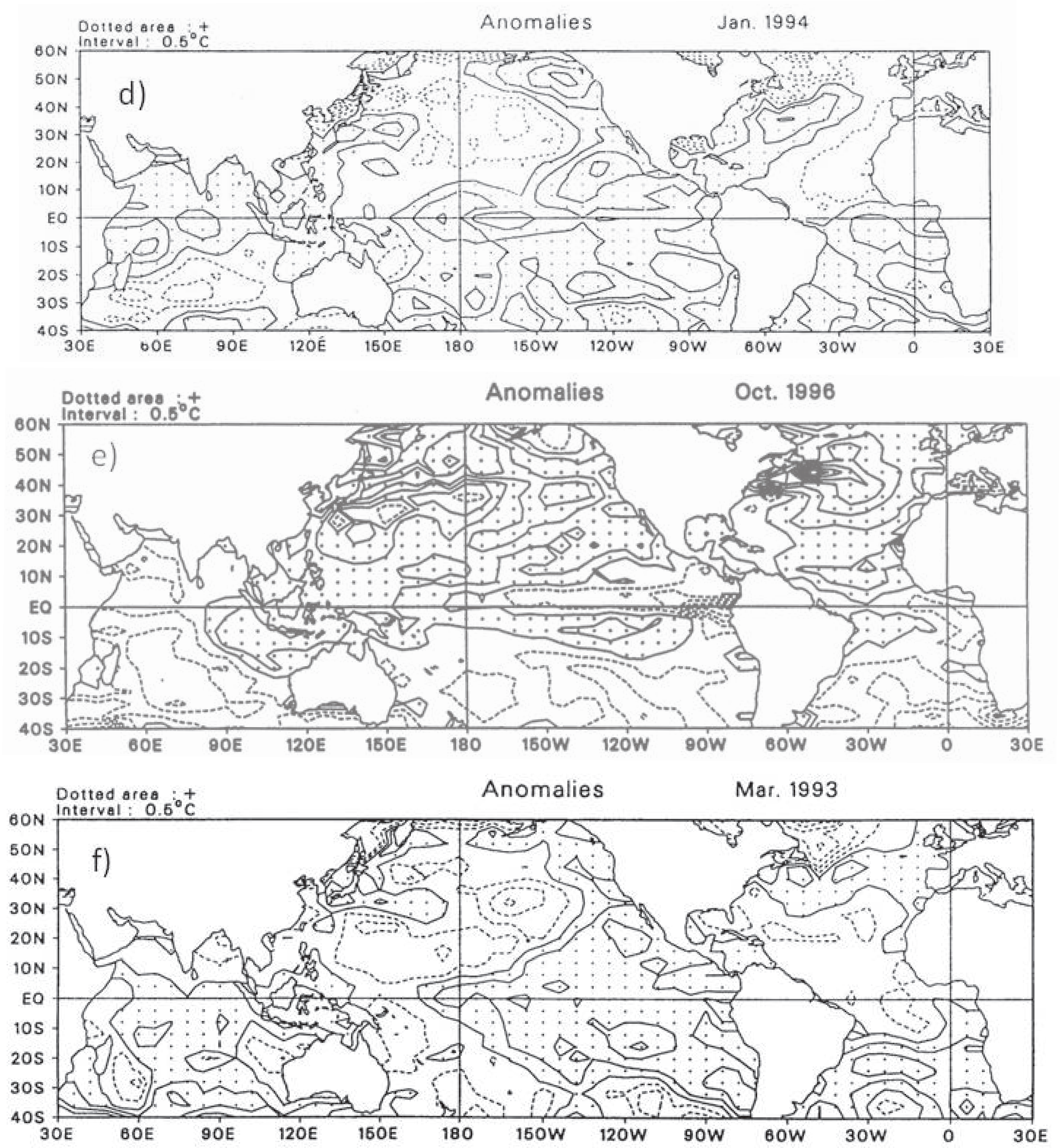


Fig. 1(a-g). The seven identified types of SST (A-G) anomalies similar to Fig. 1 in KC95, except using an observed monthly SST map as an example (adapted from Lupo et al. 2007 their Fig. 6). Solid (dashed) lines represent positive or warm (negative or cool) anomaly contours at 0.5° C intervals (Fig. 1 g is on p. 6).

results of Clarke and Li (1995). C and F type anomalies are also similar to each other with the exception that F type anomalies are associated with more widespread coverage of warm anomalies especially in the North Pacific and Atlantic Ocean basins and is generally between 1 – 3° C. The C-type anomalies are characterized also by a strong warm (positive) SST anomaly oriented along the equator and are frequently greater than 3° C.

Table 2 was reproduced from Lupo et al. (2007) and summarized in Fig. 2. Briefly, the PDO1 (PDO2) is described as the positive or warm (negative or cool) phase for Pacific region sea surface temperatures and is characterized by warmer (cooler) waters in the eastern Pacific Region (e.g., Gershunov and Barnett 1998). Table 2 shows that following 1994, there was an extended period of E-type anomalies (34 months, second longest period in



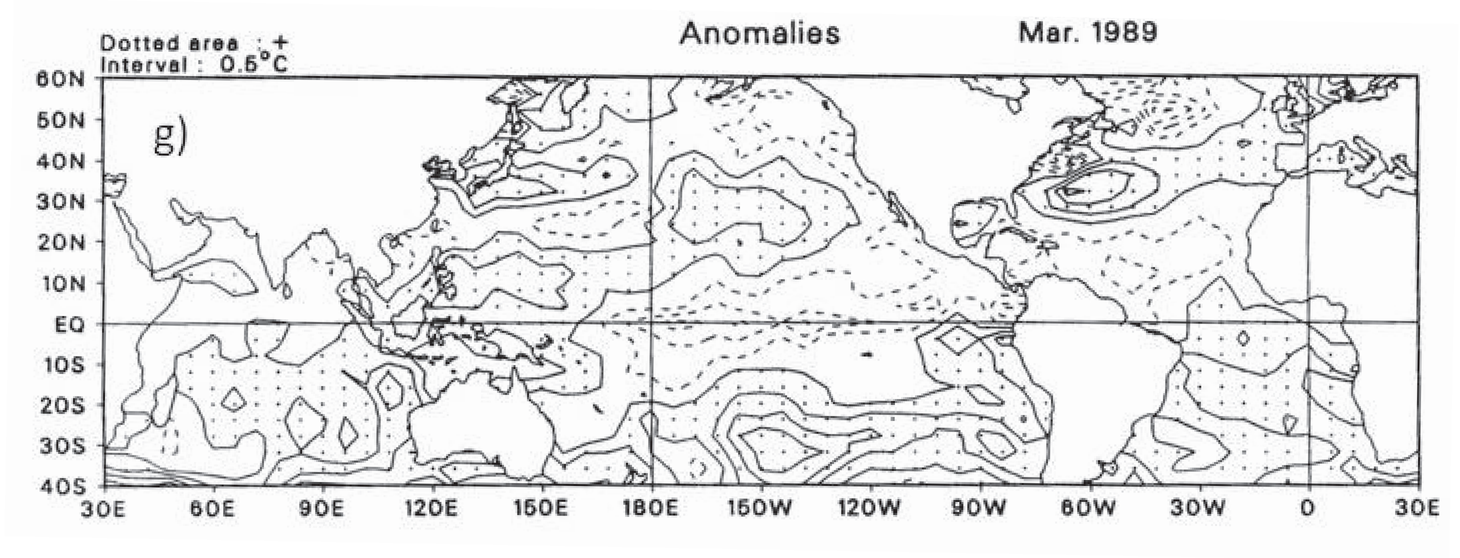


Table 2. The monthly classification of global SSTs (A–G) from 1955 – 2007. The classifications from 1955 – 1993 are adapted from Kung and Chern (1995).

Year	*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
1955	A	A	A	A	A	A	A	A	A	G	G	G
1956	A	A	A	A	A	A	A	A	A	G	G	G
1957	G	A	A	A	A	F	F	F	F	F	F	D
1958	D	D	D	D	D	D	F	F	F	D	D	D
1959	D	D	D	D	D	D	A	A	A	A	A	A
1960	A	A	A	A	A	A	D	A	A	A	G	A
1961	A	A	A	A	A	A	A	A	A	A	G	G
1962	G	G	G	G	G	G	G	D	G	G	G	G
1963	A	A	D	D	D	D	D	D	D	D	D	D
1964	D	D	A	D	A	A	A	G	G	G	A	A
1965	A	A	A	A	A	A	A	F	F	F	F	F
1966	D	D	D	D	D	A	A	A	A	D	D	D
1967	A	A	A	A	A	A	A	A	A	A	A	A
1968	A	A	A	A	A	A	A	F	F	F	D	D
1969	D	D	D	D	D	F	D	E	E	E	D	D
1970	C	C	C	C	C	C	C	B	B	B	B	B
1971	B	B	B	C	B	B	B	B	B	B	B	B
1972	B	B	B	C	C	C	C	F	C	C	C	C
1973	C	C	C	B	B	B	B	B	B	B	B	B
1974	B	B	B	B	B	B	B	B	B	B	B	B
1975	B	B	B	B	B	B	B	B	B	B	B	B
1976	B	B	B	B	B	B	B	C	C	C	F	F
1977	C	C	C	B	B	E	E	E	E	E	C	F
1978	F	F	F	E	E	B	C	E	E	C	F	F
1979	C	C	C	C	C	C	F	F	F	F	F	F
1980	F	F	F	F	F	E	E	E	E	E	E	E
1981	F	F	F	C	C	E	E	E	E	E	E	E

the record), which correspond to the extended period of ENSO neutral conditions during the mid-1990's (Table 1). This compares to the extended period (40 months, longest period in the record) of B-type anomalies which were characterized by La Niña and ENSO neutral conditions during the mid-1970s. This extended period of B-type anomalies was book-ended by mostly C-type anomalies representing the 1972 and 1976 El Niños.

The strong El Niño of 1997 was characterized by the presence of F-type anomalies, and this El Niño was similar in character to the strong El Niño events of 1982 and 1986 - 1987. These El Niño events were also predominated by F-type SST anomalies, although a few C-type anomalies were associated with the 1982 El Niño. Thus, all the El Niño events that occurred during the period 1977–1998 were characterized by the presence of primarily F-type anomalies. This contrasts with the earlier (1955-1976) and later (1999-2003) periods when El Niño events were dominated by C and D-type anomalies (Tables 1, 2). Additionally, the beginning and end of each El Niño (Table 2) described here was matched to the beginning and end of the event as defined using the definition of COAPS based on the Japanese Meteorological Agency (JMA) definition. Each ended within one month of the end of ENSO as identified by this ENSO criterion and each began within 2-4 months of the identified beginning of event as well. However, a perfect match would be difficult to obtain since, as described above, each month was classified by examining the global SST distributions.

Table 2 (continued)

Year	*Jan.*	*Feb*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
1982	E	E	E	E	C	F	F	C	C	C	C	F
1983	C	F	F	F	F	F	F	E	E	C	E	E
1984	E	E	F	B	E	B	E	E	E	E	B	B
1985	B	B	B	B	B	E	E	E	E	E	E	E
1986	E	E	F	E	E	F	F	F	F	F	F	F
1987	F	F	E	E	F	C	F	E	F	E	F	F
1988	E	E	E	E	E	E	E	E	E	A	A	G
1989	G	G	G	G	F	F	E	E	E	E	F	F
1990	A	E	E	F	F	F	F	F	D	D	D	D
1991	D	F	F	C	C	E	E	E	E	F	F	F
1992	F	F	F	F	F	F	F	F	F	F	F	F
1993	F	F	F	F	F	F	F	F	D	F	F	F
1994	D	D	F	E	F	F	D	E	D	D	D	D
1995	E	E	E	E	E	E	E	E	E	E	E	E
1996	E	E	E	E	E	E	E	E	E	E	E	E
1997	E	E	E	E	E	E	E	E	E	E	F	F
1998	F	F	F	F	F	F	F	G	G	G	G	G
1999	G	G	G	G	G	G	G	G	G	G	G	G
2000	G	G	B	B	B	G	G	A	A	A	A	G
2001	G	B	B	B	G	G	G	G	G	A	A	A
2002	B	A	A	A	A	D	D	D	D	D	D	D
2003	D	D	D	B	B	A	A	A	E	E	A	A
2004	A	A	A	B	B	D	D	D	D	D	D	D
2005	D	D	D	B	B	B	B	A	A	A	A	A
2006	A	B	B	B	B	B	B	D	D	D	D	D
2007	D	A	G	G	G	G	G	G	G	A	A	G

Table 3. The phase of the Pacific Decadal Oscillation (PDO) (adapted from Gershunov and Barnett 1998).

PDO Phase	*Period of Record*
Phase 1	1933 - 1946
Phase 2	1947 - 1976
Phase 1	1977 - 1998
Phase 2	1999 - present

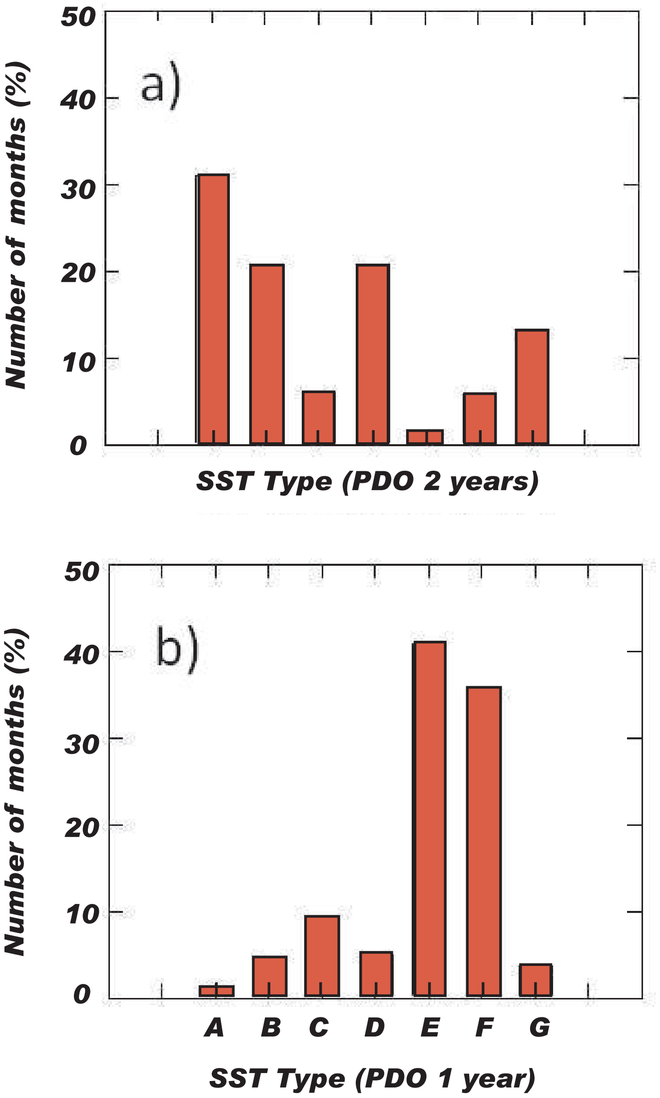


Fig. 2 (a-b) Shows the total number of months (in percent) that each flow regime (A-G) persisted for a) PDO2 years and b) PDO1 years. All months from 1955 – 2007 were used, and a list of the PDO periods are found in Table 3. Types A-G appear on the abscissa from left to right.

Then, during the latter part of 1998 through early 2002, the occurrence of G-type anomalies was prominent early in this period, but these were interspersed with the occasional periods of A, B, or D-type anomalies. The occurrence of G-type anomalies accompanied the La Niña years of 1998 and 1999 and these became A and B-type anomalies thereafter. Until the recent re-emergence of these G-type anomalies, this SST type was not observed to occur often in the KC95 analysis. In their analysis, these G-type anomalies were associated with La Niña years.

Lupo et al. (2007) suggested that the re-emergence of the G-type anomalies was associated with a change in the phase of the PDO (Table 3 and see Gershanov and Barnett, 1998, for a description of the PDO). Just as the occurrence of the predominant SST anomalies changed from E and F type to G, A, and B-type during 1998 and 1999 (Fig. 2), there was the earlier change noted by KC95 as well as Mestas-Nuñez and Enfield (1999) around 1977, which are now widely accepted as changeover periods in the PDO (Table 3). Thus, this archive may capture the change in phase of the PDO. This conclusion is further bolstered by the onset of D-type anomalies beginning in June 2002 and 2004, which also corresponded to the weak El Niño of 2002-2003 and 2004-2005 (Note: the JMA archive at COAPS does not classify 2004-2005 as an El Niño year, see Tables 1 and 2). The Climate Prediction Center (CPC) discussed the weak El Niño (available online at www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/index.html) that occurred during the winter 2002-2003; but during May and June 2003, the dissipation of this event was noted and corresponded here with the onset of B and A anomalies. Additionally, many studies have shown that significant inter-decadal variability in the ENSO pattern can be identified in the Pacific Region SSTs (e.g., Gu and Philander 1995; Mokhov et al. 2004). While this study has identified changes in phase of ENSO and the PDO using SST clusters and associated certain clusters with the phases of each oscillation, there is no speculation here as to the driving mechanism(s) as this subject is beyond the scope of this work at present.

3. Analysis of the Local Long-term Temperature and Precipitation Time Series

Park and Kung (1988) and Lee and Kung (2000) demonstrate that tropical Pacific SSTs have a significant influence on seasonal temperatures and precipitation variations and anomalies in the middle Mississippi region, and this information can then be used to make seasonal forecasts. They also demonstrate there is approximately a 3-6 month lag between the tropical Pacific region SSTs and the seasonal climate of the middle Mississippi Valley region. These findings support the results of other studies which examined the impact of tropical SSTs on North American seasonal climates (e.g., Enfield and Mestas-Nuñez 1999; Mestas-Nuñez and Enfield 1999, 2001; Lupo et al. 2005). We note here, however, that there is considerable disagreement among these and other studies about the degree of the impact of mid-latitude SSTs on mid-latitude weather and climate, and correlations between tropical SSTs and climate do not describe a dynamic link between the two. Additionally, Hu et al. (1998), Ratley et al. (2002), and Palecki and Leathers (2000), who used principal component analysis, suggested the interannual variability in this region may behave similarly for most stations within this geographic region.

Also, Hu et al. (1998) and Changnon (2003) identify interdecadal variability in mid-Mississippi regional precipitation time series and historical records (Fye et al. 2003), and the Hu et al. (1998) study attributed these to inter-decadal modes in the North Atlantic Oscillation (NAO). Lupo et al. (2007) suggested that the interdecadal variability would more naturally be associated with PDO modes (as the mid-Mississippi Valley is downstream of the Pacific Region), and that SST distributions associated with the PDO modes would modulate those associated with the ENSO, and thus manifest itself in interdecadal variations in ENSO variability. As Lupo et al. (2007) attribute interdecadal variability to PDO modes does not necessarily contradict the results of Hu et al. (1998) since other studies have suggested a relationship between the phases of PDO and the North Atlantic Oscillation (NAO) through the deep ocean global circulations (e.g., Gray 1998; Houghton et al. 2001).

Lupo et al. (2007) found some statistical relationships between prolonged periods of certain SST regimes and mid-Missouri monthly mean temperature and precipitation records. These will be summarized here. The results of their analysis are shown in Fig. 3 and Tables 4-6. In Fig. 3, the probability distributions are displayed using a bar-graph. The left and right most bars on the bar graph displays the percentage of the time that the temperature or precipitation anomalies are greater or less than one standard deviation from the mean. The middle bars represent the percentage of the time that the temperature or precipitation anomalies are within one standard deviation from the mean. None of temperature and precipitation regimes for each SST type could be classified as a normal distribution at standard levels of confidence (90% or more), when tested using a simple chi-square goodness of fit test and assuming the null-hypothesis or that there is no *a priori* relationship between SST type and temperature regime.

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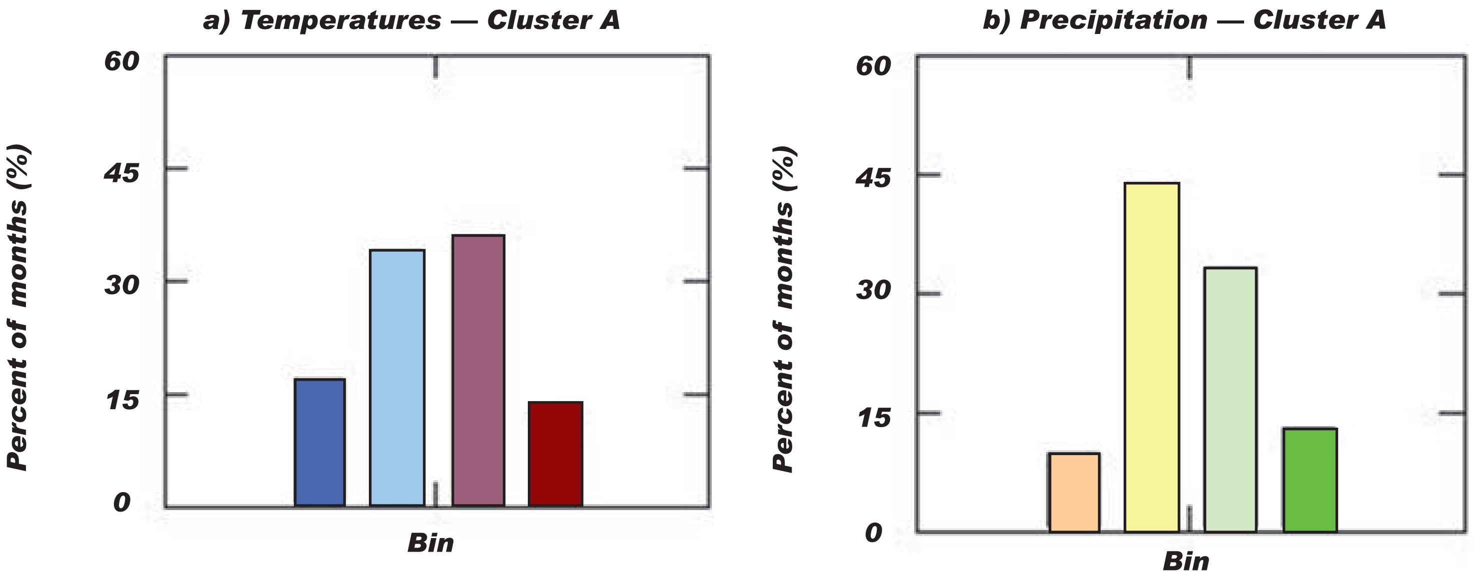
Table 4. Monthly mean temperatures (°F) and precipitation (inches) and their standard deviations for the 1955 – 2005 period for Columbia, Mo. (adapted from Lupo et al., 2007).

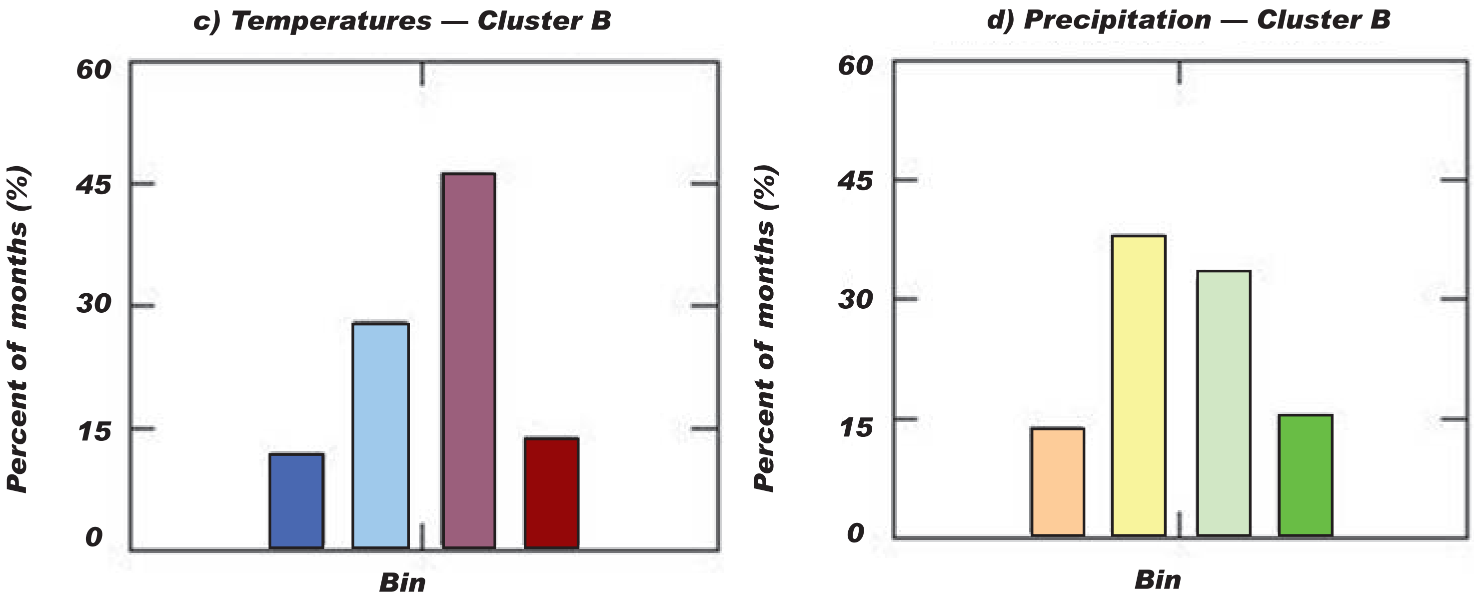
Month	*Temperature*	*σ - Temperature*	*Precipitation*	*σ - Precipitation*
Jan.	28.1	5.1	1.65	1.08
Feb.	33.3	5.0	1.95	1.26
March	43.0	4.4	2.94	1.78
April	55.1	3.0	4.00	2.15
May	64.3	3.3	4.96	2.20
June	72.8	2.3	4.08	2.44
July	77.5	2.4	3.92	2.49
Aug.	76.1	2.5	3.35	2.47
Sept.	68.0	2.8	3.68	2.72
Oct.	56.9	3.1	3.18	1.81
Nov.	43.9	3.7	2.76	2.13
Dec.	32.8	5.1	2.19	1.37

Table 5. Number of months (1955 – 2007) in each SST classification analyzed and the average magnitude of the positive and negative temperature and precipitation anomalies. Also given are the number of months when the anomaly is of the same sign (warm-wet/cool-dry).

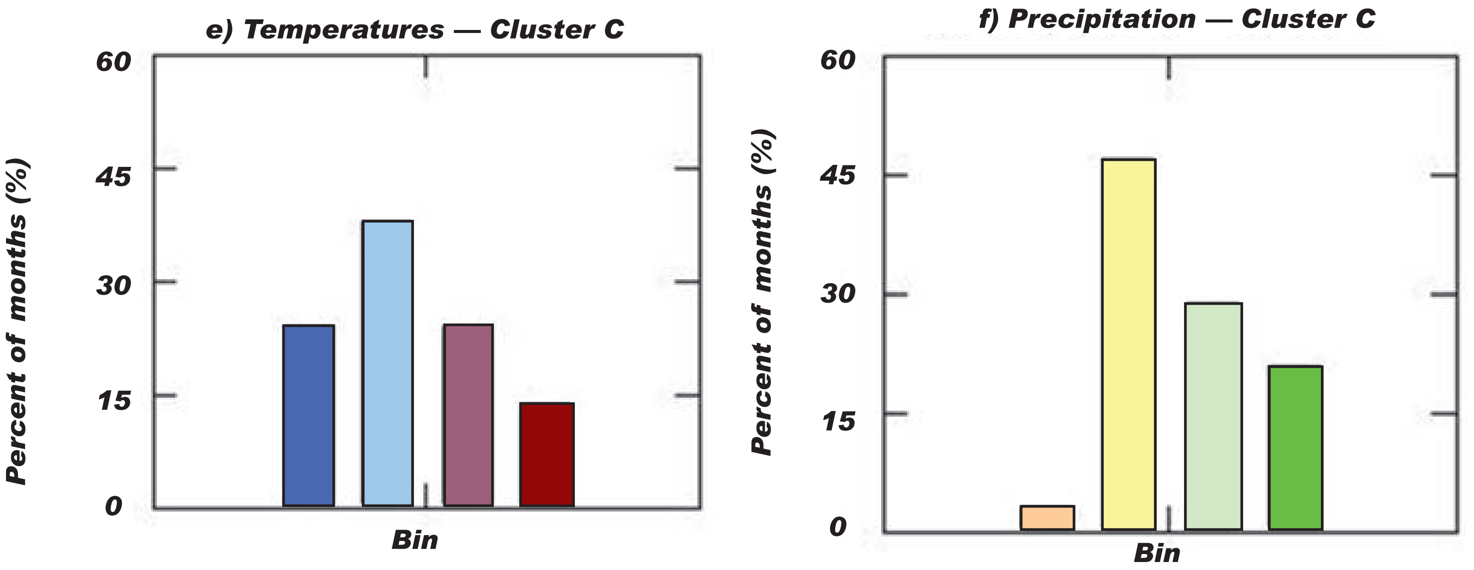
Class	*Months*	*Temperature °F*		*Precipitation (inches)*		*Months – Same Sign*
		Postive	Negative	Positive	Negative	
A	63	2.9	-3.1	1.67	-1.30	36 (16/20)
B	58	2.2	-2.8	1.39	-1.53	25 (15/10)
C	29	2.7	-3.8	2.39	-0.89	19 (8/11)
D	45	2.8	-2.9	1.45	-1.20	17 (7/10)
E	61	1.9	-2.7	1.96	-1.46	29 (10/19)
F	62	3.2	-3.0	2.18	-1.23	35 (13/22)
G	32	3.6	-1.6	0.49	-1.46	21 (8/13)


a) Temperatures — Cluster A

b) Precipitation — Cluster A


c) Temperatures — Cluster B

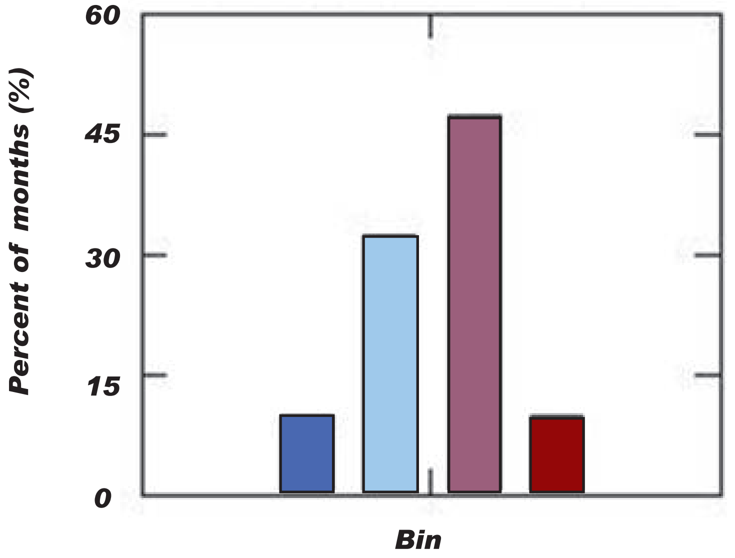
d) Precipitation — Cluster B


e) Temperatures — Cluster C

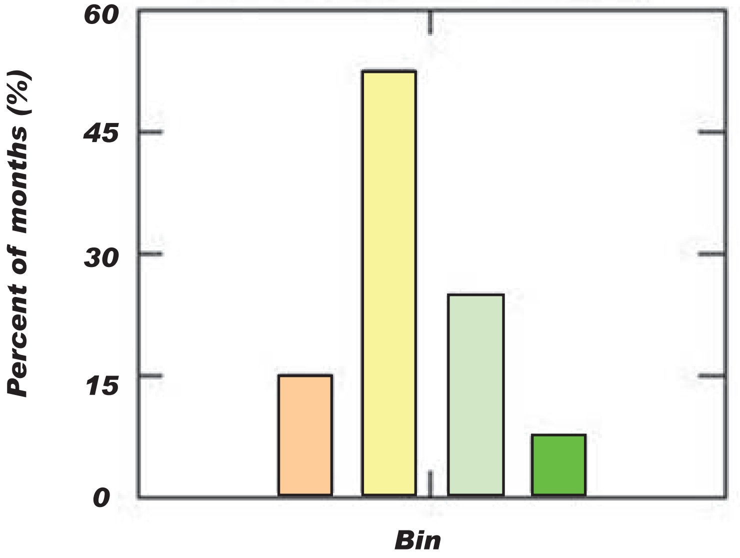
f) Precipitation — Cluster C

Fig. 3 (a-n). The distribution of temperature (a,c,e,g,i,k,m) and precipitation (b,d,f,h,l,n) anomalies by SST category (A – G) for mid-Missouri. The bar on the left (right) of the “tick mark” on the abscissa represents the percentage of the time monthly temperatures/precipitation values were less than 1.0 standard deviations below (above) the monthly mean (adapted from Lupo et al., 2007 – Fig. 7). The left (right) most bar represents the percentage of the time monthly temperatures/precipitation values were greater than 1.0 standard deviations below (above) the monthly mean.

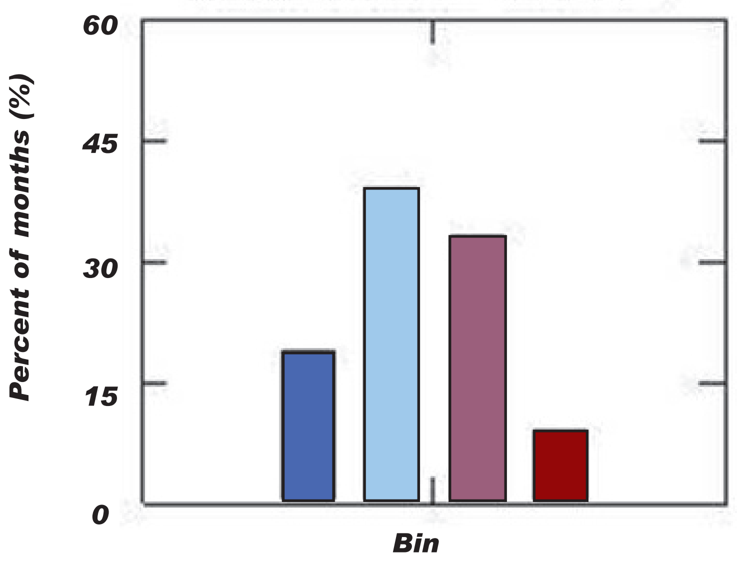
g) Temperatures — Cluster D



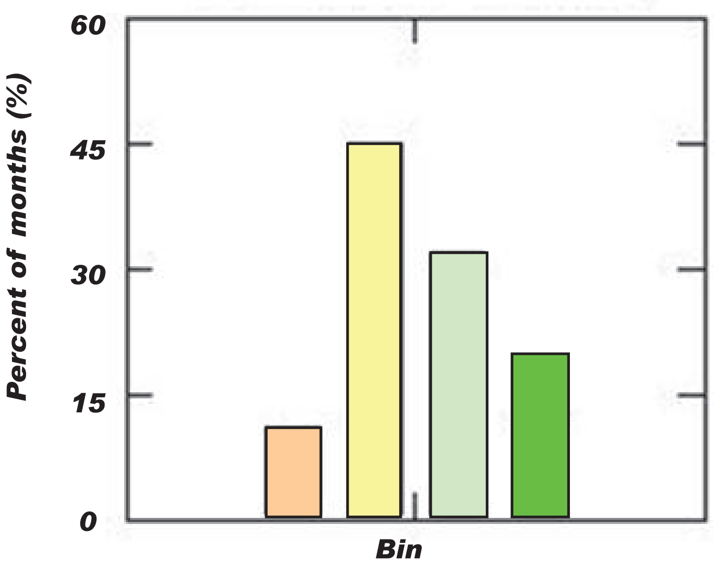
h) Precipitation — Cluster D



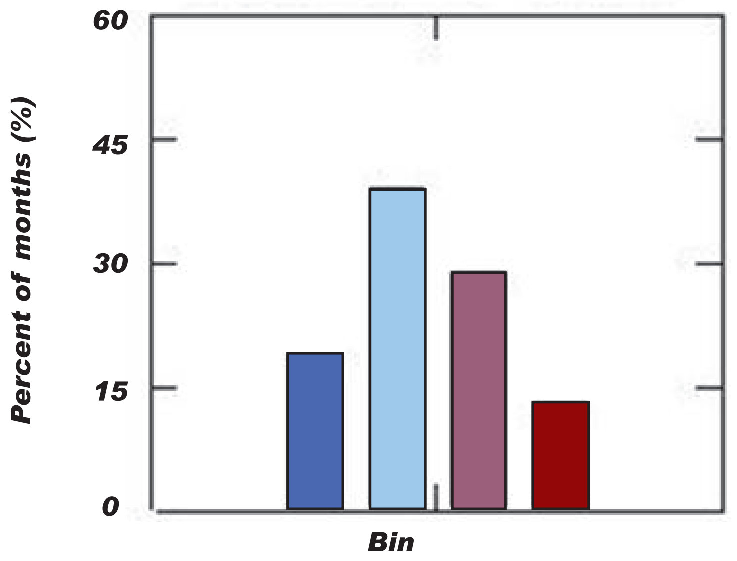
i) Temperatures — Cluster E



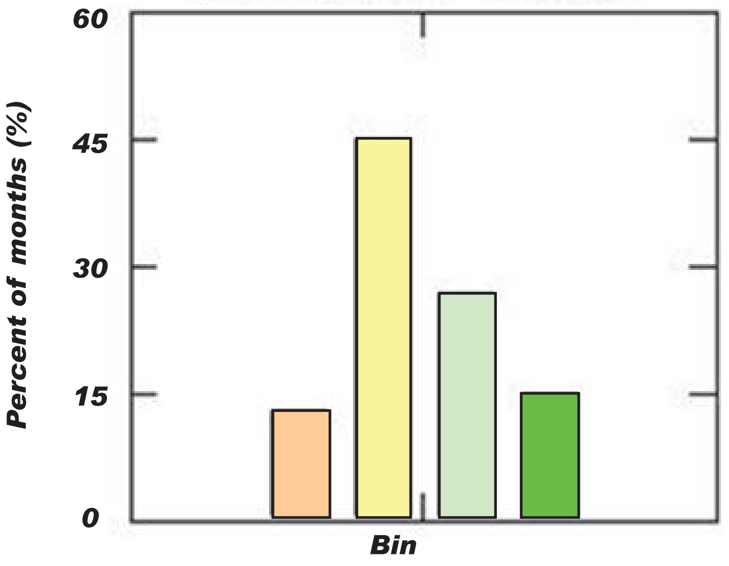
j) Precipitation — Cluster E

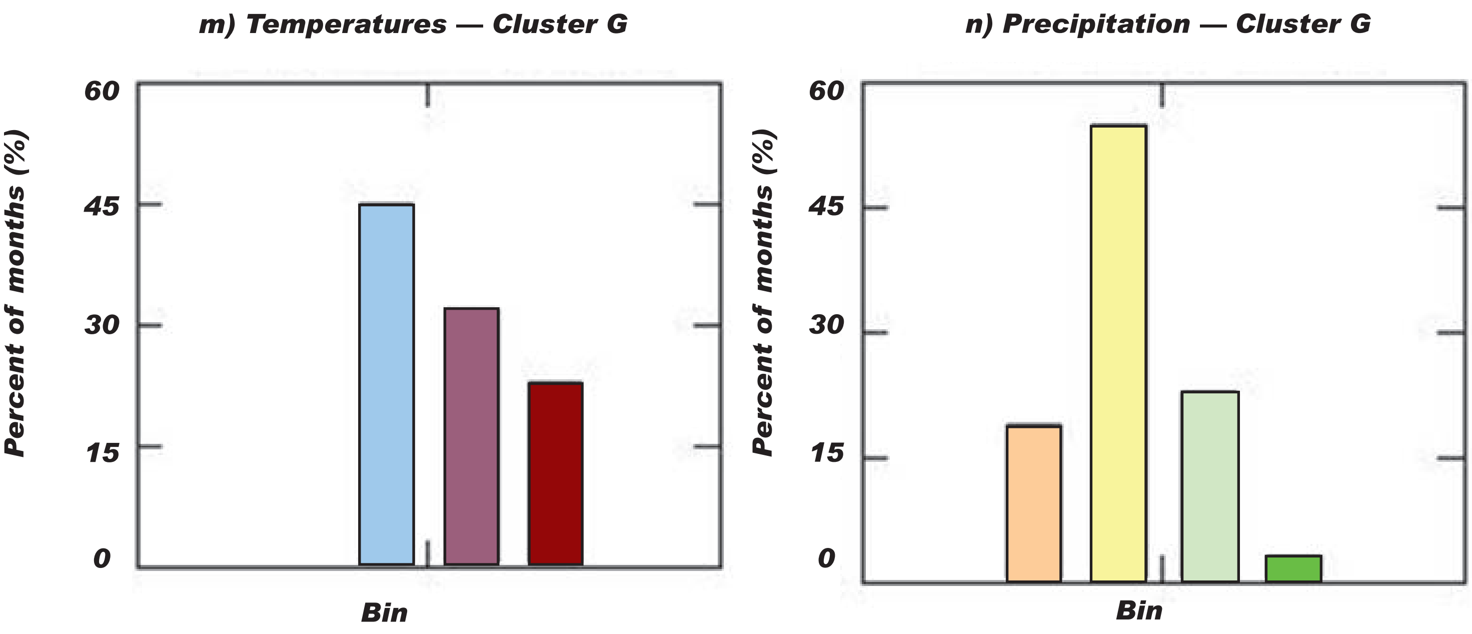


k) Temperatures — Cluster F



l) Precipitation — Cluster F





a. PDO2 SST clusters

During PDO2 years the predominant SST types were A – D, and G. For the A-type regime, the distribution monthly mean temperature regime was skewed toward cooler temperatures, but these departures did not rise to the level of statistical significance (Fig. 3a). It is noted here that the positive phase of the PDO is characterized by an anomalously deep Aleutian Low. Cold western and central north Pacific waters, warm eastern Pacific coastal waters, and warm tropical Pacific waters also characterize this phase of the PDO, which we refer to as PDO1. The reverse conditions characterize the low phase of PDO and we refer to these conditions as PDO2. The precipitation regime was skewed toward drier months being associated with A SST types, and this distribution was different from a normal distribution at the 90% confidence level (Fig. 3b). The analysis of prolonged B-type anomalies showed no tendencies that rose to the level of statistical significance (Figs. 3c, d). While the monthly mean temperatures were skewed toward warmer months during B regimes, these months were evenly split between warm and wet, and warm and dry regimes. A simple test for the statistical independence of bivariate multinomial populations (here monthly mean temperatures and precipitation) demonstrated that for A- and B-type regimes, these variables are independent of each other. Also, the A- and B-type anomalies do display a very strong tropical signal, but they do have stronger extratropical anomalies which have been shown to be not as influential on extratropical weather as natural synoptic variability (Kushnir et al. 2002). Thus, this may explain the weak correspondence between A and B patterns and the climate of the mid-Mississippi Valley region.

Table 6 (a-b). Number of months (1955 – 2007) in which a) temperature and b) precipitation in the study region for each SST classification were above or below (A/B) normal. These results are also stratified by season.

a) Temperature

Class	*Spring*	*Summer*	*Fall*	*Winter*	*Total*
A	13 / 9	7 / 10	5 / 7	6 / 6	31 / 32
B	10 / 5	7 / 7	9 / 4	9 / 7	35 / 23
C	7 / 3	0 / 5	2 / 4	2 / 6	11 / 18
D	7 / 6	3 / 3	7 / 2	10 / 7	27 / 18
E	4 / 8	6 / 6	9 / 14	6 / 8	25 / 36
F	3 / 13	6 / 9	4 / 10	13 / 4	26 / 36
G	3 / 5	5 / 4	3 / 3	7 / 2	18 / 14

b) Precipitation

Class	*Spring*	*Summer*	*Fall*	*Winter*	*Total*
A	11 / 11	9 / 8	4 / 8	5 / 7	29 / 34
B	8 / 7	4 / 10	6 / 7	10 / 6	28 / 30
C	8 / 1	1 / 4	3 / 3	3 / 5	15 / 14
D	3 / 10	4 / 2	3 / 6	5 / 12	15 / 30
E	6 / 6	5 / 7	9 / 14	7 / 7	27 / 34
F	6 / 10	8 / 7	6 / 8	7 / 10	27 / 35
G	3 / 5	0 / 9	0 / 6	5 / 4	8 / 24

An analysis of prolonged D-type regimes demonstrates the monthly mean temperatures are skewed toward cooler months (Fig. 3g), and the distribution is different from the normal distribution at the 95% confidence interval indicating a strong relationship. Prolonged D-type regimes are heavily skewed toward the drier months (70% of these months were drier than normal) (Fig. 3h), and this distribution was different from normal at the 99% confidence level. However, about 45% of all D-type months (18) were warm and dry. This is particularly true of D-type months in the warm season (warm and dry), and this result was significant at the 95% confidence level. The D-type months tended to lead to cooler than normal conditions for the region during the cold season (not shown here). Nonetheless, examining the distribution of monthly mean temperatures and precipitation anomalies separately and forming conclusions based on these (e.g., for D-type SST anomalies cool - dry months probably prevail in the mid-Mississippi region) may lead to an erroneous forecast. Recently, two prolonged periods of D-type anomalies in 2002-2003 (2004-2005) (Table 2), in which four of six (all seven) months were cooler (warmer) than normal. In both cases, however, the period was drier than normal (10 of 13 months).

The analysis for G-type anomalies revealed both the monthly mean temperature and precipitation anomaly distributions (Figs. 3m, n) were different from normal at the 99% confidence level. The temperature (precipitation) regime was skewed toward warmer (wetter) than normal months. However, warmer than normal months were evenly distributed between wetter and drier than normal, while more than one third of all G-type months (13) were cool and dry. Warm season G-type months tended to be dry (but evenly split between warm and cooler than normal), while cool season G-type months tended to be warmer than normal, which was the opposite of the D-regime. When applying the same test for statistical independence of monthly mean temperature and precipitation in the D- and G-type regimes, these variables were found to be dependent variables at the 95% confidence level. That these variables demonstrate a high degree of statistical dependence in the D-and G-type regimes when there is no reason to believe they should be dependent *a priori*, suggests there may be a synoptic explanation for this dependence and this issue will be explored below. This also suggests operational value for these results found here, since D and G anomalies had a strong tropical signal, and had a profound impact on mid-Mississippi Valley climate.

b. PDO1 SST clusters

The PDO1 years were dominated by the occurrence of more El Niño events and these El Niño events were stronger events (e.g., 1982-1983, and the 1997-1998 events). Prolonged periods of E- or F-type anomalies did not result in any statistically significant trends in the temperature or precipitation distributions (Figs. 3i-l) independent of seasons. When considering the combined E and F categories, cool dry months accounted for more than one-third of all months, while the rest of the sample months were distributed evenly among each category. Among F-type months only (strong El Niño type), however, these tended to be cooler than normal during the summer months and much warmer than normal during the winter months. It is well known that there is a strong correlation (e.g., use the statistical tool found at: http://www.cdc.noaa.gov/USclimate/Correlation) supporting the observation that El Niño winters were warmer than normal in the Midwest and upper Midwest during the 1977 – 1998 period (when F anomalies were a dominant El Niño type during these winters). For E-type months only there were no distinct tendencies for warm or cool season months and again the E-type SST pattern was representative of ENSO neutral or weak La Niña type conditions. The test for statistical independence of monthly mean temperatures and precipitation yielded similar results to the A- and B-type regimes, in that temperatures and precipitation were found to be independent variables in these regimes. Also, the explanation for the weak correspondence found for the E-category may also be similar to that for the A- and B-type anomalies.

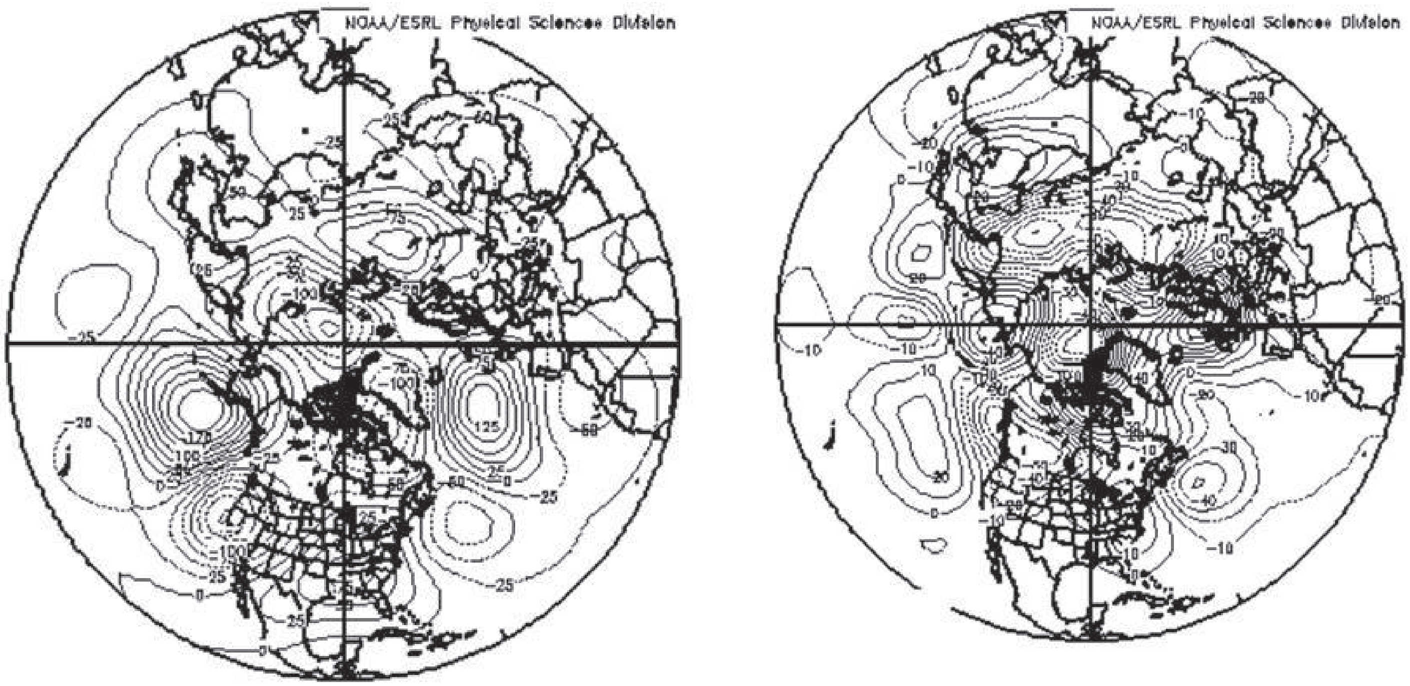
c. *C-type SST clusters*

The sample size for prolonged C-type (ENSO type) clusters was small, but analyzing these is also more complex as it was the only SST type in which there were nearly equal occurrences of these in both PDO1 and PDO2 years. The overall behavior of these distributions (Fig. 3e, f) demonstrates that these distributions were different from normal at the 95% and 99% confidence level for monthly mean temperatures and precipitation, respectively. These C-type months were skewed toward cooler conditions and wetter conditions, but were fairly evenly distributed when considering these as a bivariate population.

d. An initial seasonal analysis

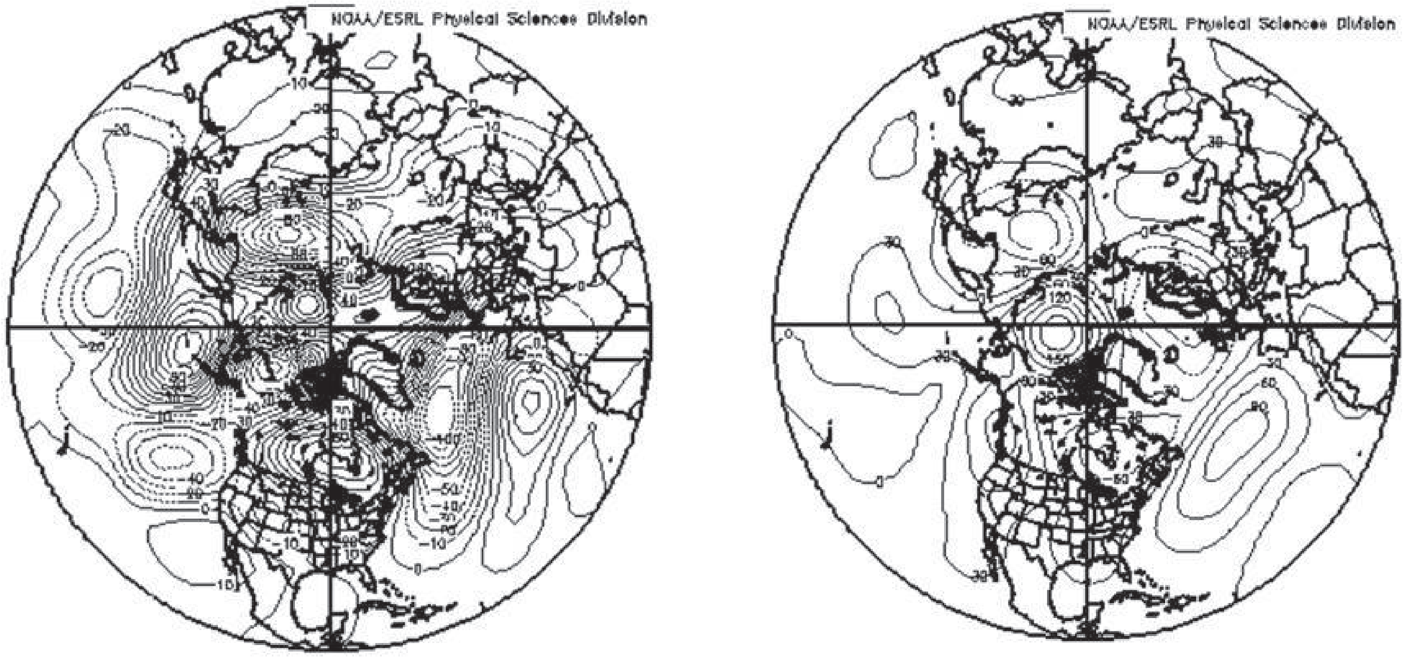
Table 6 displays the number of months in which the temperature and precipitation was above or below normal for the prolonged SST clusters analyzed above in order to determine if particular seasons showed any bias toward particular conditions. No statistical analysis for significance was performed here for each season as the seasonal sample sizes are small. However, this information can provide supplementary guidance to the discussion above in order to determine whether SST clusters discussed above correlate uniformly across all the seasons, or whether the results discussed above were more prevalent in a particular season.

The warm bias noted above for the B-type clusters occurred primarily in the transition seasons, and these tended to be distributed such that the cold season as a whole was associated with warmer prolonged B-regimes.



a) April 1987

b) Aug. 1975



c) October 1982

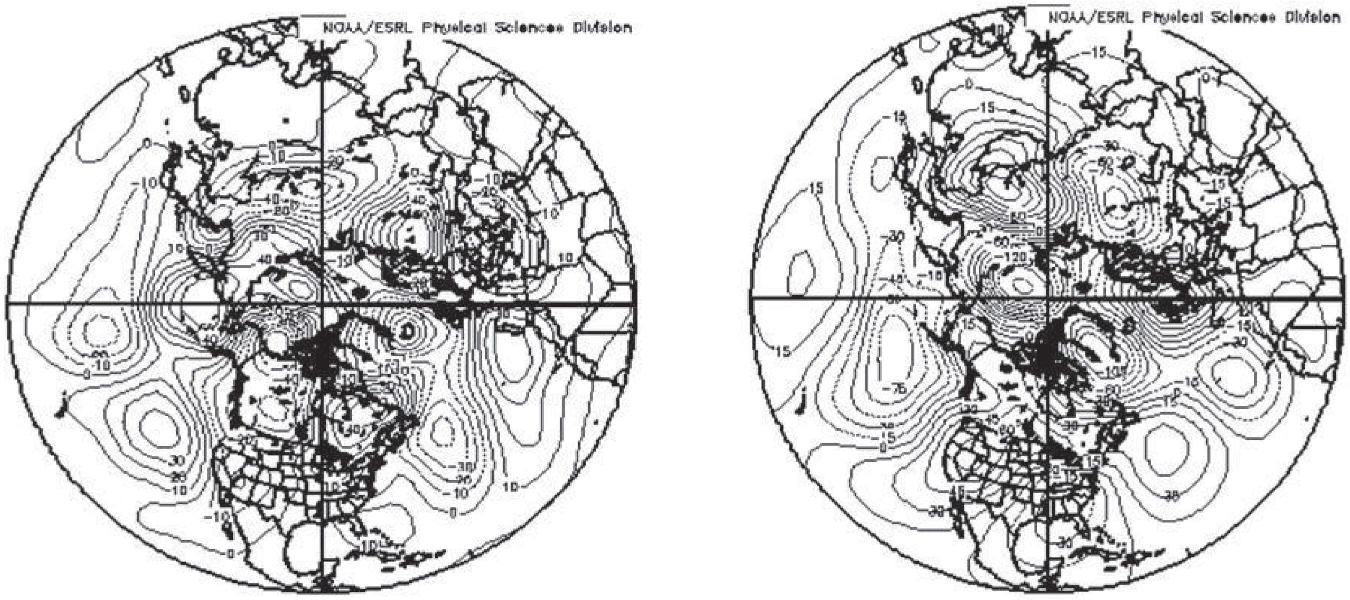
d) January 1994

Fig. 4 (a-h). As in Fig. 1, except using the 500 hPa monthly height anomalies, and including the h) 1971-2000 mean for reference.

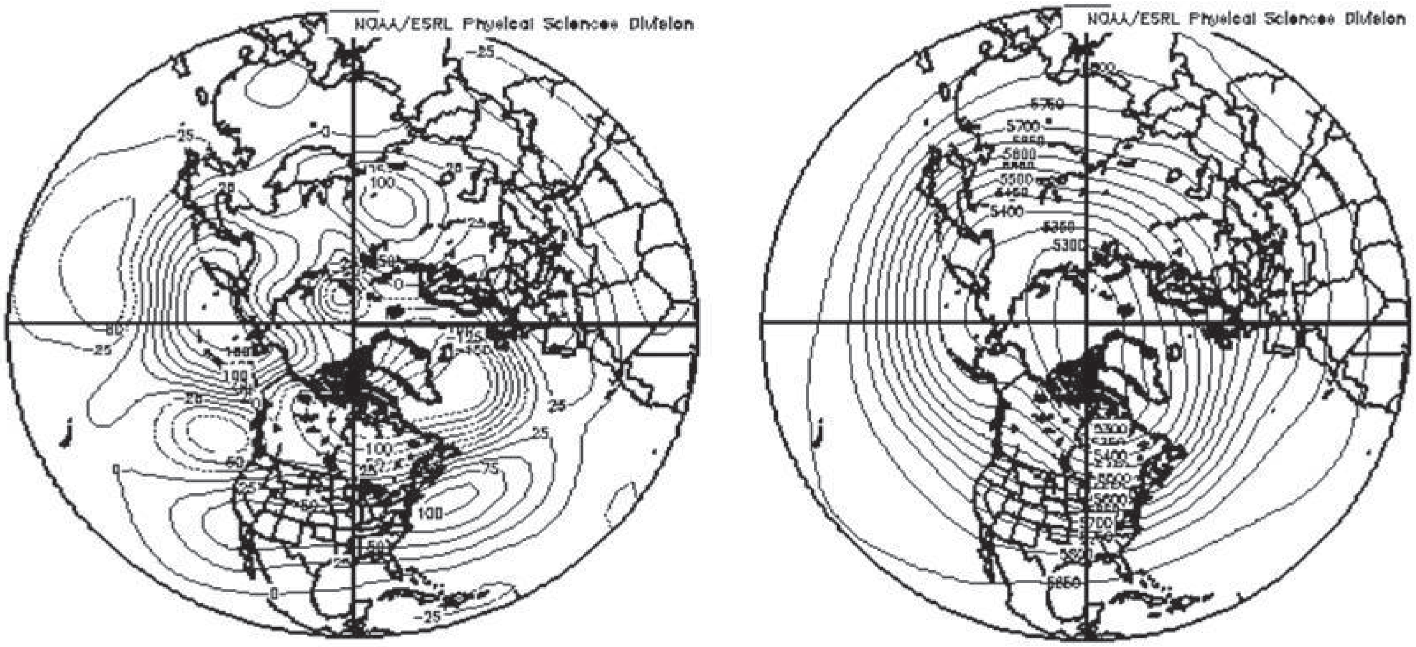
The dry bias found for the D-type clusters was nearly spread evenly throughout the year, except for the summer season. The cool bias found in association with E- and F-type anomalies was evenly distributed throughout the year, with the exception of winter season F-type anomalies. These months were associated with warmer than normal conditions and half of these warm anomalies were one to two standard deviations above the normal for the winter months. Remarkably, the summer and fall months were drier-than-normal for all 14 G-type anomalies during these seasons. Finally, the cool biases associated with the C – type clusters were especially strong during the June – February period, which resulted in cooler condition during the first part of the cool seasons.

4. The 500 hPa Height Anomalies; a Synoptic Analysis

An analysis of the monthly mean 500 hPa height anomalies yielded similar results to those of KC95 when these were categorized by type, and an example using individual monthly 500 hPa height anomalies for the Northern Hemisphere are shown in Fig. 4 (compare to their Fig. 4). Only the 500 hPa heights are examined here as many studies referenced above have shown monthly height anomalies tend to have a strongly equivalent barotropic structure (e.g. KC95). Over North America, the long-term mean 500 hPa height field shows ridging



e) October 1996 **f) March 1993**



g) March 1989 **h) 1971 — 2000 annual means**

(troughing) over western (eastern) North America (e.g., Fig. 4h and see Bentley and Mote 1998).

The A- and B-type anomalies (Fig. 4a, b) are suggestive of more zonal and meridional type flows over North America, respectively, however neither type could be statistically associated with anomalously warm or cool months over the region of study (Fig. 3 and see Lupo et al. 2007 - although A-type months tended to be drier than normal), nor was there a qualitative trend for these type of months to appear in particular seasons. A- and B-type flows, which were associated with La Niña or neutral years, would suggest more blocking events over the eastern Pacific (e.g., KC95; Wiedenmann et al. 2002), however, the tendency for increased ridging over the eastern half of the US may account for the tendency toward warmer B-type months in the mid-Mississippi region. The E-type months seem to be similar to A-type months in that they would result in a more zonal type flow over North America, and these are also correlated to weaker positive and negative monthly temperature anomalies for the mid-Mississippi Region in Table 4. All three of these types of flow regimes demonstrate the difficulty in relating local or regional climates to global climates in that particular months may only be generally classified as one of these types, when reality may suggest mixed modes. Also, all of these SST – 500 hPa height anomaly clusters are La Niña or ENSO neutral, and a weak tropical signal.

G-type 500 hPa anomalies (which were also associated with La Niña years) were dominated by drier than normal conditions in general. The G-type flow regimes (Fig. 4g) suggest more zonal conditions over North America. This is consistent with the observation that these months are warmer than normal in the cold season, and there were slightly more cooler-than-normal months in the warm season (which would be expected with air masses of Pacific origin) over the region of study. In fact, the strongest warm anomalies found in this study were associated with G-type flow regimes (Table 5), and these tended to be winter months. These warm winter months in La Niña years are associated with storm tracks that lay across the northern tier of the US during the cold season, which may also account for the tendency toward dry months in the mid-Mississippi river basin and mid-Missouri. However, the strong positive height anomaly in the Gulf of Alaska in G-type months also suggest more and/or stronger east Pacific blocking events and this is consistent with the observation of more and stronger blocking events in this region during La Niña years, especially in the cooler months (e.g., see Wiedenmann et al. 2002). The presence of blocking in the east Pacific can generally be associated with cooler conditions over the mid-continent and southeast US (e.g., Quiroz 1984). Thus, there seem to be two distinct types of behavior for G-type winter months in the mid-Mississippi region, depending on the occurrence of east Pacific region blocking. Additionally, a seasonal analysis suggests that A-, E-, and G-type clusters are associated with dry summers in the region.

Examining the results found for the D-type anomalies (Fig. 4d) suggests anomalous troughing (ridging) over western (eastern) North America, while the F-type (and C-type as well) anomalies exhibited strong ridging over Canada. Anomalous ridging over much of North America (F-type) suggests weaker zonal winds over the US and split flow over the continent as a whole, as suggested here. Such flows tend to advect more Pacific region air masses over the continent. This observation would be consistent with warmer (cooler) conditions over the mid-Mississippi Valley in the winter (summer) as was observed during ENSO episodes from 1977 – 1998, which were strongly associated with F-and C-type anomalies. The association of warmer winters over the study region and much of the northern US with ENSO conditions during the 1977 – 1998 period is fairly well documented (Section 3a) and websites can be used by the reader (e.g., http://www.cdc.noaa.gov/USclimate/Correlation) to create the “typical” temperature signatures of El Niño winters and correlate these to SSTs.

The D-type SST anomalies were associated with weaker ENSO events and the warm SST anomaly was located over the central Pacific, while C- and F-type ENSO events were associated with stronger events and the warm anomaly was located over the eastern tropical Pacific (e.g., Clarke and Li 1995). This difference in the location (and even the shape and strength) of the warm SST anomalies may be responsible for the apparent “shift” in the phase downstream of the 500 hPa Pacific-North America (PNA) height pattern over North America (compare Fig. 4d and f). The location, shape and strength of the SST anomalies and the accompanying diabatic heating (latent and sensible) would all play a role in the mass field adjustment (height tendencies) as suggested in the model studies of Nakamura et al. (1997) or using simple diagnostic equations (e.g., see Lupo et al. 1992). The D-type height anomalies would suggest a weak trough over North America, but if the troughing is particularly strong, there would be cooler conditions over the United States in general. Within the study region, the winter season months of 1968-1969 and 2002-2003 were both associated with D-type SST and 500 hPa height anomaly clusters (ENSO conditions) which were cool and dry.

While this is a very small sample, the analysis of the individual SST cluster types may demonstrate part of the difficulties in using statistical studies to find strong statistical relationships between SST anomalies and local interannual and interdecadal climate variations. Local variations in climate are strongly suggested by Lupo et al. (2007), but these results also suggest that interannual temperature and precipitation variations due to ENSO-related SST variations may be modulated by interdecadal variations in the mid-Mississippi region (e.g., Gershanov and Barnett 1998). Thus, when examining a long time series, i.e., the interannual variations in local climate, it is not enough to examine only the impact of ENSO. Rather, the interannual variability within an interdecadal time frame may be more reasonably thought of as the response of local climatic parameters to ENSO which may behave differently on an interdecadal timescale (Lupo et al. 2005). Additionally, as suggested by casual analysis of the F-type SST clusters, these studies may produce stronger results if the data were stratified by season, but as of yet, such a stratification provides samples too small to obtain any meaningful statistical analysis.

5. An Evaluation for Long Range Forecasts

Using these results as one part of constructing long-range forecasts, seasonal forecasts were made and evaluated against climatology. The long range forecasts of temperature and precipitation were made for the winter (December – February) and summer seasons (June – August), which are the time periods of interest for the local and regional media and agricultural communities. The forecasts were made 4 – 5 months in advance of each season. The forecasts were made based on the prevalent SST patterns of the previous few months in Table 2, and a first guess as to how these may evolve over the next few months (using past history and/or forecast discussions/guidance of ENSO). The potential for atmospheric blocking and the evolution of large-scale flow regime (see below and section 4) will also be factors that contribute to the long-range forecast. Thus, the forecasters used the information in Tables 3 – 8 as well as previous or past experience to make the predictions.

The forecasts were qualitative, and used the point-scoring scheme shown in Table 7. The scheme, which is modeled after Lupo and Market (2002), is based on defining normal as within +/- 0.5 standard deviations of the mean, and above and below normal as outside that range. Two points are awarded for a good forecast of seasonal temperature and precipitation (observed category matched the forecast category), while none are awarded for a poor forecast. For example, if a forecaster predicted the summer temperatures would be close to normal (-0.5 – 0.5 standard deviations from the seasonal mean) and the observed was within this range, this constitutes a good forecast. Using the example above, a poor forecast would constitute a situation where the observed seasonal temperatures were greater than one standard deviation above normal. Also, since the understanding and influence of ENSO and the occurrence of blocking are both of crucial importance to long range forecasting, the seasonal potential for blocking was also considered here (see below). Additionally, Ratley et al. (2002) demonstrate there was a correlation between

Table 7. The long range forecast verification scheme used here (adapted from Lupo and Market, 2002).

Forecast Verification Scheme

		Observed: Above	*Observed: Normal*	*Observed: Below*
		Points Scored		
Forecast	*Category*			
Warmer or Wetter	Variable more than +0.5σ above normal	2 – if variable is +0.5 – 1.0σ 1 – if variable is more than +1.0σ	0 – if variable is -0.5 – 0.0σ 1 – if variable is 0.0 - +0.5σ	0 – if variable is more than -1.0σ 0 – if variable is -0.5 - -1.0σ
Normal	Variable within 0.5σ of normal	1 – if variable is +0.5 – 1.0σ 0 – if variable is more than +1.0σ	2 – if variable is -0.5 – 0.0σ 2 – if variable is 0.0 - +0.5σ	0 – if variable is more than -1.0σ 1 – if variable is -0.5 - -1.0σ
Cooler or drier	Variable more than -0.5σ below normal	0 – if variable is +0.5 – 1.0σ 0 – if variable is more than +1.0σ	1 – if variable is -0.5 – 0.0σ 0 – if variable is 0.0 - +0.5σ	1 – if variable is more than -1.0σ 2 – if variable is -0.5 - -1.0σ

Pacific SST's and the warm season precipitation regimes in the forecast region (the Mid-Mississippi River Valley and central Missouri) considered here.

The summer of 2004 in the central part of North America was unusually cool. During August, temperatures were 5° – 7° F cooler than normal across most of Missouri including the study region, and in Columbia this was the third coolest summer since 1889. The cool summer could be linked directly to unusually strong and persistent blocking in the East Pacific and Alaskan Sector (5 blocking events and 56 days). Conversely, blocking was also responsible for the devastating summer heat waves in Eurasia during the summers of 2002, and, especially, 2003 (e.g., Galarneau et al. 2005). In North America, historically (1971 – 2002) cooler and/or wetter summers can be linked to more and/or unusual summer blocking activity over the East Pacific region (Table 8). Thus, the role of blocking plays a significant role in influencing summer season temperature and precipitation regimes. Additionally, there is a strong tendency for cold conditions within the forecast region during individual winter season blocking events (e.g., Quiroz 1984), but also during La Nina years there are more blocking events in Pacific region (e.g., Wiedenmann et al. 2002) which are typically cooler than normal in our study area.

Table 9 shows the results of ten long range forecasts over five years (five winter and five summer seasons). The table includes a primary rationale for each forecast, and a score versus climatology. In examining the outcomes, one forecast by our group and climatology scored perfectly (winter 2003 – 2004), while one forecast was assessed as poor (winter 2004 - 2005). Additionally, two forecasts of the ten (summer 2003, winter 2006-2007) scored lower than climatology, and three scored higher. The winter forecast of 2006 – 2007 scored well, but climatology was perfect after the first part was unusually warm and the second part unusually cool. We also examined the skill scores (Table 10), and these were calculated using the formula from Lupo and Market (2002):

(our forecast – climatology) / (perfect forecast – climatology) * 100% (1)

The long range forecasts issued by our group were better overall, but showed no improvement over climatology in the winter season. In Table 10 the numbers are large, since the number of forecasts issued (and therefore the sample size) is, as of yet, small. During the summer season, our forecasts were better than climatology by 38%, which compares to 0% during the winter season. When examining precipitation, our forecasts were significantly worse than climatology in the winter season (20%), but did not show any difference overall. None of the skill scores shown here are comparable to short range forecast improvement over persistence or climatology (Lupo and Market 2002), however, the overall scores for temperature reported here are good compared to the improvement of human forecasters over numerical models (e.g., Lupo and Market 2002). This is especially true for the summer season Thus, the information derived here has the potential for use as a tool or guidance for long range forecasts in our region (especially during the summer season), and this information could be constructed for other areas of the United States and applied to long range forecasts as well.

Table 8. An assessment of blocking occurring over the East Pacific during the May – August period for the years 1971 – 2002 .

Summers	*Mean number of blocking events*	*Months primarily occurring*	*Mean number of blocking days*	*Intensity*
10 warmest	2.0	July – August	15	2.21
10 coolest	3.0	May – June	19	2.11
10 wettest	3.0	May – June	20	2.17
10 driest	2.0	July – August	14	2.06

6. Summary and Conclusions

Using monthly mean SST and 500 hPa height data routinely available via the internet or other regular monthly publications, as well as monthly mean temperature and precipitation time series from a long-record climate station that is representative of the mid-Mississippi Valley, interannual and interdecadal variations in the climate of this region were examined and compared to synoptic flow regimes. In performing an analysis on the time series to identify the predominant SST clusters the techniques of Lupo et al. (2007) (and references therein) were used. The SST anomaly classification archive initiated by KC95 and continued by Lupo et al. (2007) for the period 1955 – 2005 was used to define the SST regimes.

A further examination of the monthly mean temperature and precipitation record shows that the long-lived SST clusters were not associated with normally distributed monthly temperature and precipitation anomalies, which would be the case when all anomalies in the 52 year period were binned for the mid-

Table 9. A summary of the long-range forecasts generated, rationale, and outcomes.

Forecasts Issued and Outcome

Forecast period	*Forecast Temperatures*	*Forecast Precipitation*	*Primary Reasoning(s)*	*Forecast Verification*
Dec 02 – Feb 03	cooler	Wetter	The onset of a weak F/D El Nino similar to the '68-69 season.	Cooler – 2 (-1.8°) Drier – 0 (-1.48") Climo 1/1
Jun – Aug 03	normal	drier	El Nino wanes (see Ratley et al. 2002)	Below – 0 (-1.9°) Normal - 1 (-1.85") Climo 0 / 2
Dec 03 – Feb 04	normal	normal	No strong tropical SST type; A's prominent when forecast made.	Normal – 2 (+0.2°) Normal – 2 (+0.70") Climo 2 / 2
Jun – Aug 04	cooler	wetter	Same as above, A's slightly biased to cool summers.	Cooler – 1 (-4.0°) Wetter – 2 (+2.46") Climo 0 / 1
Dec 04 – Feb 05	normal	normal	The onset of D-types were similar to 02-03, but not as strong.	Warmer – 0 (+3.6°) Wetter – 0 (+3.02") Climo 0 / 0
Jun – Aug 05	warmer	drier	El Nino wanes similar to 03, but the emergence of B-types push for warm, La Nina develops.	Warmer – 1 (+2.2°) Wetter – 2 (+3.94") Climo 0 / 1
Dec 05 – Feb 06	normal	drier	No strong SST signal, but fall blocking pushes us toward cooler forecast ($< 0.5\sigma$).	Warmer -0 (+3.5°) Drier – 1 (-2.87") Climo 0 / 0
Jun – Aug 06	warmer	drier	The onset of B-type anomalies and prolonged, but weak La Nina conditions.	Warmer – 1 (+2.3°) Normal – 1 (-0.26") Climo 0 / 2
Dec 06 – Feb 07	normal	drier	The onset of El Nino is forecast. Probably a weak D-type. Forecast for cooler by $< 0.5\sigma$	Normal – 2 (+/- 0.0°) Normal – 1 (+ 0.37") Climo 2 / 2
Jun – Aug 07	warmer	drier	Predict both warmer and drier (by 0.5 – 1.0σ). Collapse of El Nino and move toward La Nina. A, B, or G type.	Warmer – 1 (+2.0°) Drier – 2 (-4.71") Climo. 0 / 1
Overall performance	Temperature forecasts can accumulate as many as 2 points.	Same for precipitation, thus 4 points are possible for a perfect forecast.	σ_T sum = 1.72° σ_P sum = 4.91" σ_T win = 2.76° σ_P win = 2.17"	avg fcst: 2.20 pts winter: 2.00 pts smmr: 2.40 pts Temps: 1.00 pts Pcpn: 1.20 pts Climo 0.50 / 1.20

Table 10. Skill Scores for the long range forecast generated here versus climatology.

Forecast period	*Skill Score (%)*
Total (Temperature + Precipitation)	22%
Temperature	33%
Precipitation	0%
Total Summer Season	38%
Temperature	40%
Precipitation	33%
Total Winter Season	0%
Temperature	20%
Precipitation	-20%

Mississippi region (e.g., Lupo et al. 2003). However, most of the long-lived SST clusters were not associated with statistically significant deviations from normal. The long-lived B regimes tended to be warmer than normal (Table 6), while long lived C regimes produced cooler temperatures and greater than normal precipitation amounts. The long-lived D- (G-) type clusters were associated with distributions skewed toward cooler (warmer) and drier (wetter) conditions, and these were associated with El-Niño (La-Niña) years. However, during D- (G-) type months the statistical analysis of these two flow regimes was not straightforward, since during these months, the most common occurrence when treating the data as a bivariate population were warm and dry (cool and dry) months. A statistical test for independence demonstrated a statistical dependence between temperature and precipitation anomalies may be explained by examining the 500 hPa height anomaly distributions.

This examination of the 500 hPa height anomalies reveals that G-type anomalies may be associated with either zonal flow over North America, resulting in warm (cool) conditions during the cold (warm) season for the mid-Mississippi region, or enhanced blocking over the eastern Pacific which would result in cooler conditions over the study region. D-type anomalies were associated with weak El-Niño events and cooler conditions over the study region during the cold season. Even SST clusters that did not result in strong statistical relationships overall revealed characteristics consistent with seasonal observations in this region (e.g., F-type clusters, associated with ENSO conditions in the 1977 – 1998 period were associated with very warm winters). However, a study of prolonged SST anomalies stratified by type may be the subject of future work when a greater volume of reliable data becomes available. Finally, it may not be enough to examine interannual variability over a consecutive 50, 70, or even 100 year period since the occurrence and amplitude of the ENSO phenomenon may change over an extended period (e.g., Gu and Philander 1995; Mokhov et al. 2004), and thus result in a changed or modulated ENSO response in local climatic parameters on an interdecadal time-scale (e.g., Gershanov and Barnett 1998; Lupo et al. 2005). Then, considering the interdecadal variability as superimposed on interannual variations should be considered as well.

Finally, the results of this study and previous studies by this group were used to generate long range forecasts for the summer and winter season temperatures and precipitation four to five months in advance. A forecast verification scheme based on Lupo and Market (2002) was designed and used to score the long range forecasts. The results show that our forecasts have been better than climatology, especially for summer season and temperature forecasts.

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