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JP5.6 INTERANNUAL AND INTERDECADAL VARIABILITY IN THE PACIFIC REGION SST ANOMALY PATTERNS AND THEIR IMPACT ON LOCAL CLIMATE

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1. INTRODUCTION

Recent studies have attempted to link variations in global circulation changes (e.g., Wallace and Gutzler, 1981; Gershanov and Barnett, 1998; Weidenmann et al., 2002), or local (and regional) climate variations (e.g., Keables, 1992; Berger et al., 2003) with interannual and interdecadal variations in sea surface temperatures and pressures in the Pacific Ocean basin and/or the changes in the character of the atmospheric and oceanic circulations in 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 make long-range forecasts (e.g., Anderson et al., 1999). The atmosphere and oceans are two important components of the climate system that are considered to be thermodynamically open (they exchange both heat and mass) (e.g., Piexoto and Oort 1992).

Kung and Chern (1995) used principal component analysis to extract the large-scale modes of monthly mean global SST anomalies and the Northern Hemisphere tropospheric circulation anomalies during the period 1955 – 1993. This technique provided an archive which can be used for long-range forecasting applications (e.g., forecasting using analogs). A by-product of this analysis demonstrated that global SST anomalies could be classified into one of seven distinct pattern types of anomaly distributions (A – G). Kung and Chern (1995) also noted that anomaly types (clusters) A, B, E, and G (C, D, and F) are representative of La Nina or neutral (El Nino) type SST distributions within the Pacific Ocean basin. They also demonstrated that clusters A-D dominated the early portion of their study period (1955 – 1977), while E and F type clusters dominated the latter portion (1977-1993). G-type SST anomalies were comparatively rare in either period in the Kung and Chern (1995) study.

Thus, this work has two primary objectives. The first is to apply the methodology of Mokhov et al. (2003) to a local time series of monthly mean temperature and precipitation records, with some beneficial modification to the techniques. These techniques will demonstrate that there is significant ENSO-related interannual and interdecadal variability in the local time series. The interdecadal variability will be shown to be likely related to the influence of the Pacific Decadal Oscillation (PDO) (e.g., Gershunov and Barnett, 1998). The second objective is to extend the Kung and Chern (1995) study from 1993 to the present, and this work will demonstrate that the interdecadal variability in SST clusters noted above may also be related to the PDO. This work will also demonstrate that there are relationships between individual SST types and local variations in a raw sample station temperature and precipitation records but that the statistical relationships may not be straightforward.

2. ANALYSES AND METHODS

2.1 Data

The analyses used in this study were the global monthly mean extended 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[1]. Monthly SSTs and anomalies are available and these can also be found in the monthly Climate Diagnostics Bulletin[2], and the mean 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). Lastly, the mean monthly temperature and precipitation records for the Columbia Regional Airport (1955 – 2003) were provided through the Missouri Climate Center.

2.2Monthly mean temperature and precipitation analysis

The techniques used here to extract interannual and interdecadal variability from a one-dimensional time series are described by Mokhov et al. (2003) and will be briefly presented here with modifications. The techniques used in these references are based on standard dynamic analysis techniques for physical systems (e.g., Lorenz, 1963). Here we use the time series of temperature and precipitation time series for Columbia, MO and use this as an example of the analysis

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technique and the improvement made here. The basis for this analysis is derived by constructing simple phase plots of the first derivative of the time series versus the time series itself. If ideally, the function represented by the cyclic time series is sinusoidal (or approximately sinusoidal),

$$X(t) = A(t)\sin[\omega(t) + \phi(t)] \quad (1)$$

where X(t) represents a time series of some variable, A(t) the amplitude, and ω(t) the frequency, and ϕ(t) the initial phase, then X(t) represents a general solution to an oscillator equation of form;

$$\ddot{X} + \omega^2 X = 0 \quad (2)$$

A simple two-dimensional phase plot of the first derivative versus the time series itself will yield a circular set of trajectories about some mean state.

The goal here was to find periodicities on the interannual and interdecadal time-scale. Then, a filtering procedure was applied to the time series in order to extract this low order variability, or oscillations on a time-scale longer than two-years. Mokhov et al. (2003) presented results using a two-year running mean. The use of a two-year running mean either requires having two additional years' worth of data than the analysis period, or the loss of two years worth of information. Here we use a simple second-order Shapiro (1970) filter to extract low order variability. The advantage to using this filter is that, with the exception of the two end-points, the length of the time series is retained, and the filter can be applied a successive number of times in order to effectively control the retention of signal versus noise. Due also to the symmetrical nature of this filter, it still preserves some of the annual cycle, does not result in a phase-shift of the low-order variability, and does not introduce significant aliasing error. A simple running mean filter may not necessarily possess these same characteristics (Shapiro, 1970).

A comparison of the filtered temperatures (Fig. 1a,b) using each technique demonstrates that each technique captures the main features of the longer-term variability. The phase plots produced by the 2-year running mean (Fig. 1c,d) also yield similar results, except that the phase plot produced using the Shapiro filter results in smoother trajectories (Fig. 1d). This result is a clearer analysis as the phase plot using the running mean filter (Fig. 1c) is difficult to analyze and may only suggest that the trajectories derived from temperature record over the time period is unstable and/or the mean state is moving over time. However, the smoother phase plot using the Shapiro filter suggests that there are periods of time during the 1955-2003 record where the trajectories suggest the monthly mean temperature record is stable (behaves like a damped oscillator), and there are periods of time when the record is unstable. Then, the system behaves similar to that suggested by Fedorov et al (2003) who examined Pacific Region SSTs, and they suggest that the ENSO phenomenon behaved like a slightly damped oscillator. The same comparisons can be made using the precipitation records

2.3 SST analysis

For each month, visual inspection of the monthly SST and 500 hPa height charts was shown to be a reliable method for classifying the SST anomaly distributions into one of seven different synoptic categories (A – G) as defined in Kung and Chern (1995). In order to be certain that this method was reliable, visual inspections of monthly mean SST anomalies for randomly chosen months within the period of study of Kung and Chern (1995) were carried out in order to verify that observations of this group matched those of Kung and Chern (1995). Manual inspection was also used by Kung and Chern (1995) after they used the clustering method of Fukunaga (1972) to derive seven distinct anomaly types.

3. RESULTS OF THE SST ANALYSIS

In Fig. 2, examples of the seven different SST anomaly clusters are shown. These monthly SSTs are not the same plots shown in Kung and Chern (1995). Their plots represent the extracted large-scale mode, while here we show the actual monthly mean SSTs, which were classified similarly to those found in their Fig. 1.

Briefly, SST clusters B and G are representative of strong La Nina type clusters in the Pacific Ocean basin. These are also characteristic of SST anomaly distributions in the Atlantic Ocean Basin which are the opposite of each other. Clusters A and E are characteristic of weak La Nina to ENSO Neutral type conditions. These SST anomaly distributions are similar in each major ocean basin, with the exception that E-type 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 Nino-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. The C and F type anomalies represent stronger El Nino conditions, with the warm SST anomalies located in the far eastern Tropical Pacific Ocean. That the stronger ENSO events are associated with stronger SST anomalies located farther east agrees with the 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. The C-type anomalies are characterized also by a strong warm SST anomaly oriented along the equator.

Table 1 was reproduced from Kung and Chern (1995) and then extended from January 1994 – June 2003. These results show that following 1993, there was an extended period of E-type anomalies (34 months, second longest period in the record), which correspond to the extended period of ENSO neutral conditions during the mid-1990's (Table 2). This compares to the extended period (40 months, longest period in the record) of B-type anomalies which were characterized by La Nina and ENSO neutral conditions during the mid-1970s. This extended period of B-type anomalies was bookended by mostly C-type anomalies representing the 1972 and 1976 El Ninos.

The strong El Nino of 1997 was characterized by the presence of F-type anomalies, and this El Nino was similar in character to the strong El Nino events of 1982 and 1986 -

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[1] wesley.wwb.noaa.gov/ncep_data/index_sgi62_png.html

[2] www.cpc.ncep.noaa.gov/products/analysis_monitoring/bulletin

1987. These El Nino events were also predominated by F-type SST anomalies, although a few C-type anomalies were associated with the 1982 El Nino. Thus, all the El Nino events that occurred during the period 1977–1998 were characterized by the presence of primarily F-type anomalies. This contrasts with the earlier period (1955-1976) when El Nino events were dominated by C and D-type anomalies (Tables 1, 2).

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 period of A or B type anomalies. The occurrence of G-type anomalies accompanied the La Nina years of 1998 and 1999 and the neutral conditions thereafter. Until the recent re-emergence of these G-type anomalies, this SST type was not observed to occur often in the Kung and Chern (1995) analysis. In their analysis, these G-type anomalies were associated with La Nina years.

This work suggests that the re-emergence of the G-type anomalies may have been associated with a change in the phase of the PDO (Table 3). As early as the latter months of 1998, it was suggested that a change in phase of the PDO was underway. More recent publications have also suggested a change in phase of the PDO during this time period (e.g., Houghton et al., 2001). 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, there was the earlier change noted by Kung and Chern (1995) around 1977 (see section 1 here). The change they noted in predominant SST type also matches a change in the phase of 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, which corresponded to the El Nino[3] of 2002-2003. The Climate Prediction Center discussed this weak El Nino during the winter of 2002-2003, but as of May and June 2003, a La Nina episode appeared to be developing and corresponds here with the onset of B and A anomalies[3]. Additionally, many studies have shown that significant interdecadal variability in the ENSO pattern can be identified in the Pacific Region SSTs (e.g., Gu and Philander, 1995; Mokhov et al., 2003). 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.

4. ANALYSIS OF A LOCAL TIME SERIES

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 anomalies, and this information can then be used to make seasonal forecasts. They also demonstrate that there is approximately a 3-6 month lag between the tropical Pacific region SSTs and the seasonal climate of the middle Mississippi Valley region. Additionally, Palecki and Leathers (2000), who used principal component analysis, suggested that the interannual variability in this region may behave similarly for most stations within this geographic region. Thus, the time series analyzed in section 2 will be analyzed further here and will serve as a sample for the mid-Mississippi valley.

Table 1. The monthly classification of global SSTs from 1955 – August 2002. The classifications from 1955 – 1993 are adapted from Kung and Chern (1995).

Year	J	F	M	A	M	J	J	A	S	O	N	D
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
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						

The analysis in section 2b together with that in section 3 suggests that there is interannual and interdecadal variability in the time series for the Columbia, MO monthly mean temperature and precipitation time series that is at least

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[3] www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/index.html

partially associated with ENSO and the PDO. The goal of this section is to determine if specific climate regimes for this area can be associated with the SST types shown in section 3.

Also, Hu et al. (1998) identify interdecadal variability in mid-Mississippi regional precipitation time series and their study attributed these to interdecadal modes in the North Atlantic Oscillation (NAO). Our study suggests 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 SSTs distributions associated with the PDO modes would modulate those associated with the ENSO, and thus manifest itself in interdecadal variations in ENSO variability. That we attribute interdecadal variability here to PDO modes does not necessarily contradict the results of Hu et al. (1998) as other studies have suggested a relationship between the PDO and NAO through the deep ocean global circulations (e.g., Houghton et al., 2001).

Then, in order to evaluate whether, for example, one type of SST anomaly (Table1) can be associated with a particular temperature and precipitation regime, only persistent periods of one type of SST patterns were examined. There may be periods of time when the monthly temperature and precipitation regime may be more predicable even though the current state of ENSO forecasting is poor (Federov et al., 2003). Further, in order to account for a lag period as identified by previous authors referenced in section 1 between SSTs and North American climates, the first 3 months of a persistent SST regime were excluded from the analyses. In spite of these strict criterion, over half the months in the entire 1955 – 2003 series were included with one of the seven SST regimes (319 out of 588). Each month's temperature and precipitation anomalies were calculated and then compared to the 1955 – 2003 mean values and standard deviation for that individual month (Table 4).

Table 2. A list of years examined in this study separated by ENSO phase (ENSO definition found at www.coaps.fsu.edu).

La Nina (LN)	Neutral (NEU)	El Nino (EN)
1949	1945-1948	1951
1954	1950	1957
1955	1952-1953	1963
1956	1958-1962	1965
1964	1966	1969
1967	1968	1972
1970	1974	1976
1971	1977-1981	1982
1973	1983-1985	1986
1975	1989-1990	1987
1988	1992-1996	1991
1998-1999	2000	1997

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. Table 5 demonstrates that most of the SST regimes produced sufficiently large samples, with only the C and G-type SST regime resulting in fewer than 30 members. It is also conceded that, due to shorter-term oscillations (e.g., the 30 – 60 day oscillation) in the observations, statistical relationships may be difficult to establish. We attempt, however, to find useful relationships based on the raw data as such information is routinely archived and analyzed most frequently in an operational sense.

4.1. PDO2 SST clusters

As shown in section 3, the predominant SST modes during the PDO2 years were of types A – D. Of these type, prolonged periods of A,B, and D-type anomalies were nearly exclusive to these years. Prolonged periods of G-type anomalies were also nearly exclusive to this PDO regime as well. 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. The precipitation regime was skewed toward drier months being associated with A-SST types, and this distribution was different from that of a normal distribution at the 90% confidence level. When monthly anomalies are binned by combined categories (warm – wet, warm - dry, cool – wet, and cool – dry, respectively), there were nearly equal numbers of months in each bin, with the exception that there were slightly more cool-dry months (Table 5). The analysis of prolonged B-type anomalies showed no tendencies that rose to the level of statistical significance. 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) demonstrates that for A and B-type regimes, these variables are independent of each other.

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

An analysis of prolonged D-type regimes demonstrates that the monthly mean temperatures are skewed toward cooler months, and the distribution is different from the normal distribution at the 70% confidence interval indicating a likely relationship. Prolonged D-type regimes are heavily skewed toward the drier months (67% of these months were drier than normal), and this distribution was different from normal at the 99% confidence level. However, the cooler than normal months were split nearly evenly between wet and dry months. Even though the temperature distributions are skewed toward cooler months, more than one-third of all D-type months (13) were warm and dry. This is particularly true of D-type months in the warm season (warm and dry), while these 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 errors. It is also conceded, however, that this category was comprised of one of the smallest samples here.

Table 4. Monthly mean temperatures (^{o}F) and precipitation (inches) and their standard deviations for the 1955 – 2003 period for Columbia, Missouri.

Month	Temp	σ - Temp	Precip	σ - Pcp
January	28.1	5.1	1.64	1.08
February	33.3	5.0	1.98	1.26
March	43.0	4.4	2.86	1.69
April	55.1	3.0	4.00	2.17
May	64.2	3.3	4.95	2.22
June	72.8	2.3	4.11	2.46
July	77.6	2.2	3.90	2.51
August	76.2	2.4	3.30	2.46
September	68.1	2.7	3.66	2.60
October	56.9	3.2	3.24	1.80
November	43.8	3.7	2.73	2.12
December	32.7	5.1	2.20	1.36

A similar analysis for G-type anomalies reveals, that both the monthly mean temperature and precipitation anomaly distributions 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 (12) were cool and dry. Warm season G-type months tended to be cool and dry, while cool season G-type months tended to be warmer than normal. 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 that they should be dependent *a priori*, suggests that there may be a synoptic explanation for this dependence and this issue will be explored below. Also, further testing found that there was no statistically significant correlation between the magnitude and sign of these anomalies in spite of the statistical dependence.

4.2. PDO1 SST Clusters

These years were dominated by the occurrence of more El Nino events and these El Nino events were stronger events (e.g., 1982-3, and the 1997-8 events). Prolonged periods of E or F type anomalies did not result in any statistically significant trends in the temperature or precipitation distributions independent of seasons. When considering the combined 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, these tended to be cooler than normal during the summer months and much warmer than normal during the winter months. For E-type months there was no distinct tendencies for warm or cool season months and again the E-type SST pattern was representative of ENSO neutral or weak La Nina type conditions. The test for statistical independence of monthly mean temperatures and precipitation yielded similar results to the A and B-type regimes.

4.3 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 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.

5. SUMMARY AND CONCLUSIONS

Using monthly mean SST data routinely available via the internet or other regular monthly publications, as well as monthly mean temperature and precipitation time series from a station that is representative of the mid-Mississippi valley, interannual and interdecadal variations in the climate of this region were examined. In performing an analysis on the time series to identify the predominant low-order modes, the techniques of Mokhov et al. (2003) (and references therein) were used with the modification of the filtering technique.

The SST anomaly classification archive initiated by Kung and Chern (1995) for the period 1955 – 1993 was updated to include all months up to June 2003. Manual inspection on the SST anomalies was performed in order to verify that this analysis agreed with those of Kung and Chern (1995). Then the months from January 1994 to June 2003 were examined and classified. Then analyses were performed to determine whether there is a correlation between monthly SST anomalies for each cluster and mid-Mississippi Region monthly temperature and precipitation anomalies.

The results validate the conclusions of Kung and Chern (1995), in that SST clusters A, B, E, and G (C, D, F) are representative of La Nina or neutral (El Nino) conditions within the Pacific Ocean basin. These results also provide strong circumstantial evidence that certain classes of SST anomalies could be associated with distinct phases of the PDO, and, thus, changes in the phase of the PDO were associated with changes in the predominant SST modes. In particular, the period 1955-1976 was dominated by SST types A – D, while the period 1977 – 1998 was associated with the occurrence of E, F, and occasionally C modes. The most recent period has been predominated by G, A, and B modes. Finally, the most months have marked the occurrence of an El Nino event, which was associated with D-type anomalies.

Thus, this most recent El Nino event is closer in character to El Nino events of the 1955-1976 period rather than the El Nino events of the 1977 – 1998.

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 49 year period were binned for the mid-Mississippi region. However, most of the long-lived SST clusters were not associated with statistically significant deviations from normal. Only 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-Nino (La-Nina) 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 that may be explained by examining the 500 hPa height anomaly distributions. However, a correlation between the strength of monthly temperature and precipitation anomalies for each of these regimes did not rise to the level of statistical significance.

Table 5. Number of months 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	Temp	^{o}F	Precip	(inches)	Months
		+	-	+	-	Same Sign
A	56	2.5	-3.2	1.62	-1.31	31 (14/17)
B	54	2.3	-2.8	1.39	-1.44	25 (15/10)
C	29	2.7	-3.8	2.39	-0.89	19 (8/11)
D	33	2.7	-3.1	1.25	-1.27	12 (3/9)
E	57	1.9	-2.6	2.03	-1.48	26 (9/17)
F	62	3.2	-3.0	2.18	-1.23	35 (13/22)
G	28	3.6	-1.6	0.49	-1.45	20 (8/12)

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., Mokhov et al., 2003), 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). Then, regarding the interdecadal variability as superimposed on interannual variations should be considered as well.

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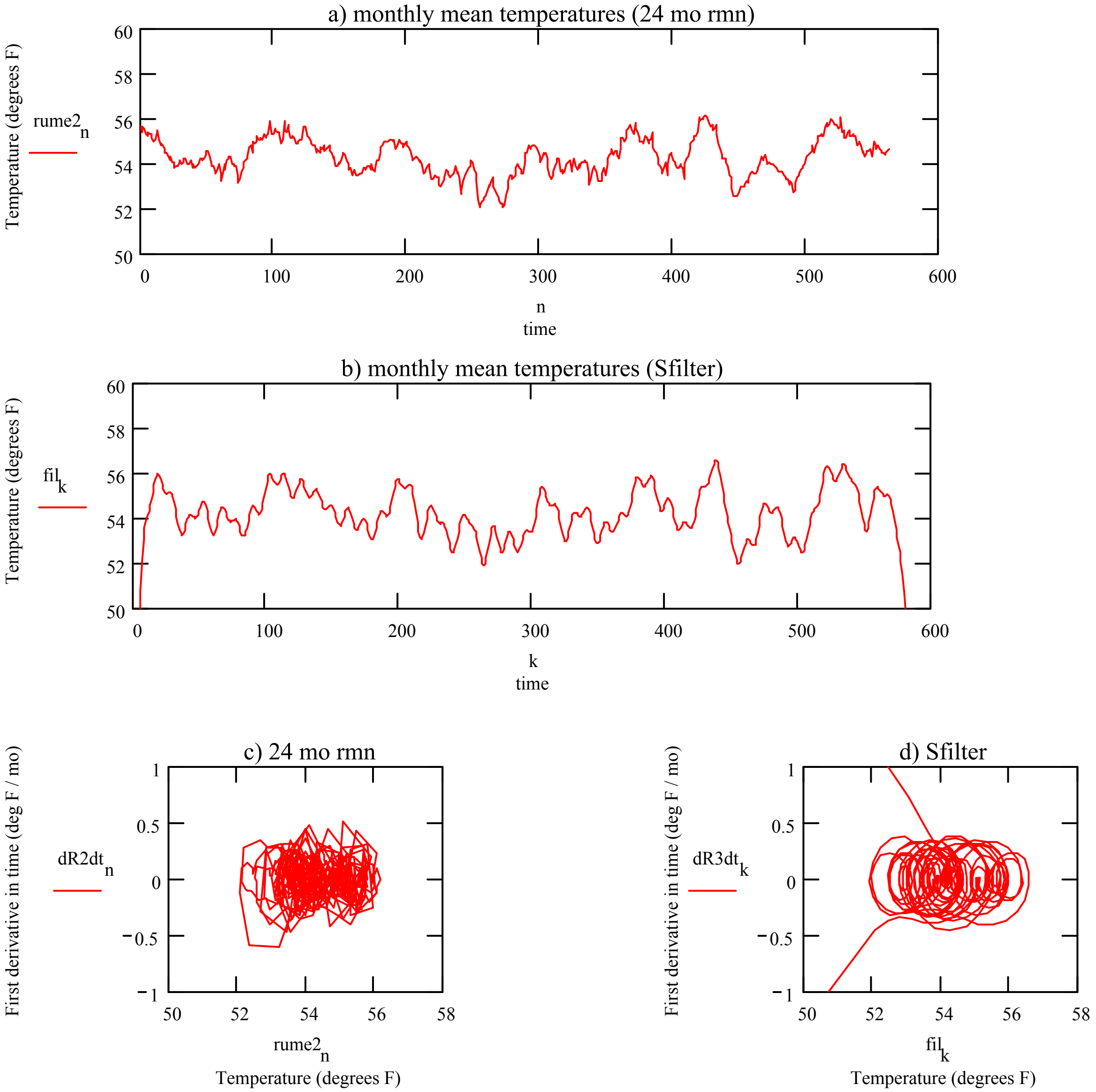

Figure 1. Monthly time series of filtered monthly average temperatures (^{o}F) versus time using the a) 24-month running mean, and b) second order Shapiro (1970) filter. The phase plots, first derivative of temperature (^{o}F mo^{-1}) versus temperature (^{o}F),

correspond to data obtained using c) 24-month running mean, and d) second order Shapiro (1970) filter for Columbia, MO (COU), 1955 - 2003.

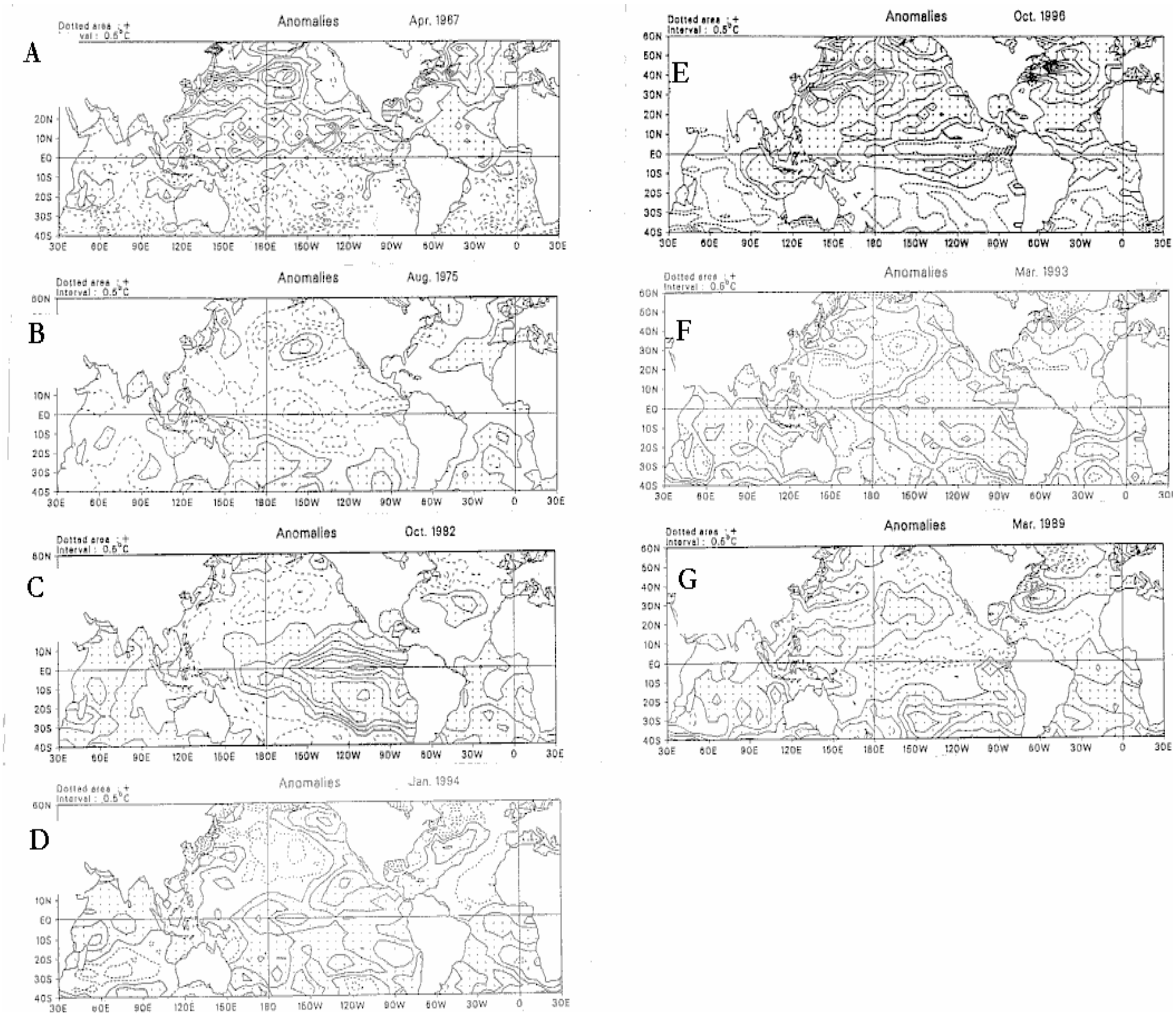

Figure 2. The seven identified types of SST (A-G) anomalies from Kung and Chern (1995).