6B.10

ENSO FORCING OF STREAMFLOW CONDITIONS IN THE PEARL RIVER BASIN

R. Jason Caldwell *
Lower Mississippi River Forecast Center, Slidell, LA 70460

Robert J. Ricks, Jr.
National Weather Service Forecast Office, Slidell, LA 70460

1. INTRODUCTION

The potential for improved streamflow predictions provides reservoir operators and river commerce interests with significant economic benefits (Maurer and Lettenmaier 2004). Maurer and Lettenmaier (2004) found that small reservoirs with storage volumes of 36 x 10^9 m^3 along the Missouri River could expect a 7.1% increase in hydropower benefits, or $25.7 million, if a perfect forecast for climate, snow, and soil moisture could be achieved. Given realistic predictability, only $6.8 million are attainable and a majority of that amount is attributed to climate indices. The results of Maurer and Lettenmaier (2004) show that improved climate forecast information can improve runoff predictions and provide a modest economic value that increases as the size of the reservoir system decreases.

Another application of long range streamflow predictions are flood potential outlooks produced at the National Weather Service. Flash flooding is defined as flooding that occurs due to excessive rainfall and incipient runoff within a period of 6 hours duration or shorter. River or mainstem flooding occurs as a response to a longer duration or high intensity rainfall which forces rivers to reach flood stage beyond the flash flood timeframe of 6 hours. At the National Weather Service River Forecast Centers, operational river forecasts are issued daily and include variable amounts of forecast precipitation. During the late winter and early spring seasons, the risk of river flooding increases across the Lower Mississippi River Valley as a number of synoptic systems in the sub-tropical jet stream traverse the region, providing ample forcing for the generation of heavy precipitation.

Long range flood outlooks benefit the local Weather Forecast Offices (WFO) considering water resource management issues at the state and county/parish level and staffing resources locally within the WFO. The current methodology used at the LMRFC for the Spring Flood Potential Outlook utilizes current streamflow conditions relative to hydroclimatology, snowpack over the mountainous regions of the Appalachians, soil moisture conditions, and the 90-day forecasts of temperature and precipitation anomalies from the Climate Prediction Center.

Due to the potential benefits of improved long range streamflow predictions, the Lower Mississippi River Forecast Center is evaluating a new long-range forecast tool that may provide additional hydrologic guidance to WFOs and regional partners (e.g. USACE, USGS). The current project highlights the product evaluation, current year forecasts, results of the hindcast verification, and major findings related to El Nino/Southern Oscillation forcing of river flow conditions in the Pearl River Basin. Section 2 will provide background information on ENSO precipitation patterns across the southeastern United States and describe the methodology used to produce climate-based composites for above and below normal flows across the Pearl River Basin. Results of the composite analysis and significant findings follow in Section 3. A summary of results and future research conclude the paper in Section 4.

* *Corresponding author address:* R. Jason Caldwell, Lower Mississippi River Forecast Center, National Weather Service, 62300 Airport Road, Slidell, LA 70460; e-mail: Jason.Caldwell@noaa.gov.

2. METHODOLOGY

2.1 Hydrologic Data

The Pearl River Basin includes areas of central and southern Mississippi and southeast Louisiana with drainages from the Yockanookany River, Tuscolameta Creek, Strong River, and Bogue Chitto, among other smaller tributaries, contributing to the mainstem flow. The Lower Mississippi River Forecast Center in Slidell, Louisiana, models 19 points in the Pearl River Basin (Table 1).

FORECAST POINTS ON THE PEARL RIVER

Site ID	Location	River/Tributary	Period of Record	Days Missing
MTCM6 &	***Monticello, MS***	***Pearl River***	***1938-2006***	***0***
CLMM6	***Columbia, MS***	***Pearl River***	***1928-2006***	***16289***
ENBM6 &	***Edinburg, MS***	***Pearl River***	***1928-2006***	***0***
CARM6	***Carthage, MS***	***Pearl River***	***1962-2006****	***---***
JACM6 &	***Jackson, MS***	***Pearl River***	***1901-2006***	***17***
BXAL1 &	***Bogalusa, LA***	***Pearl River***	***1938-2006***	***8***
KSCM6 &	***Kosciusko, MS***	***Yockanookany River***	***1938-2006***	***0***
OFAM6 &	***Ofahoma, MS***	***Yockanookany River***	***1943-2006***	***48***
DLAM6	***D'Lo, MS***	***Strong River***	***1928-2006***	***8036***
TYTM6 &	***Tylertown, MS***	***Bogue Chitto River***	***1944-2006***	***0***
BSHL1 &	***Bush, LA***	***Bogue Chitto River***	***1937-2006***	***12***
WTGM6	Walnut Grove, MS	Tuscolameta Creek		
FRNL1	Franklinton, LA	Bogue Chitto River		
PLAM6	Philadelphia, MS	Pearl River		
PERL1	Pearl River, LA	Pearl River		
ROCM6	Rockport, MS	Pearl River		
GDHM6	Good Hope, MS	Pearl River		
RATM6	Ratliffs Ferry, MS	Pearl River		
JSNM6	Ross Barnett Dam, MS	Pearl River		

Table 1 Forecast points of the Pearl River Basin indicating the eleven sites with percentile data available from the USGS (bold), sites with insufficient period of record (*), and missing data used to select gauge locations for the historical composite analyses (&). Other sites listed complete the 19 sites in the Pearl River forecast group.

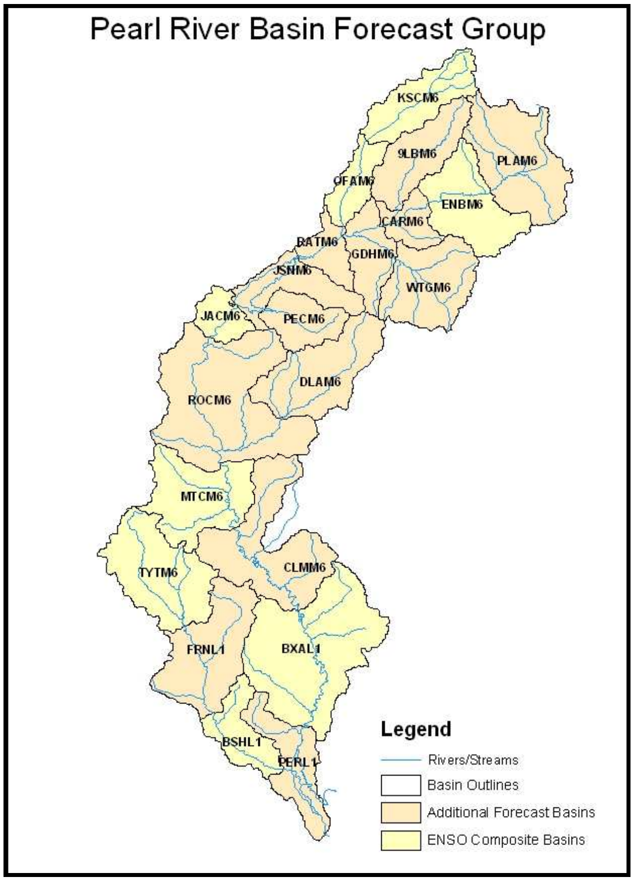

Figure 1 Graphical display of the 19 forecast points of the Pearl River forecast group.

Daily mean streamflow data for the Pearl River basin was acquired online from the United States Geological Survey (USGS) for the period January 1950 through December 2005. In addition, the USGS provided access to probability of exceedance values for daily mean streamflow for the sites used in the analyses. Of the 19 forecast points, only 11 locations have historical probability of exceedance data available from the USGS. The gauge located at Carthage, MS (CARM6) fails to meet the period of record requirements and is, therefore, not included in the analysis. In addition, the datasets for sites at D'Lo (DLAM6) and Columbia (CLMM6), MS, contain significant data gaps in excess of 10 years and are also omitted. The remaining eight sites were selected along the entire length of the Pearl River and its tributaries and provide excellent coverage representative of basin-wide conditions (Figure 1).

The USGS uses the probability of exceedance values to define above normal and below normal flows as the 75th percentile and 25th percentile, respectively. Using these data, a simple comparison of each observed daily mean to the daily percentile streamflow value was performed to calculate a monthly count of "high flow" and "low flow" events from 1950-2005. To account for missing data at the remaining eight gauges, the daily count is set to zero and is considered a non-event. Thus, the monthly counts are not biased in favor of a greater number of high or low flow events. Instead, the monthly counts are considered a conservative estimate of the actual streamflow conditions which may inadvertently limit the identification of signals due to underestimation.

2.2 Station Composite Analysis

To perform the composite analysis for streamflow, historical values for the NOAA-defined Oceanic Nino Index (ONI) and forecast values for the Nino 3.4 Consolidated Sea Surface Temperature (SST) from the Climate Prediction Center are required (Timofeyeva 2005). The ONI is the departure from normal SST value for the Nino 3.4 region in the equatorial Pacific Ocean and is based on a three month running mean and homogeneous historical SST analyses from 1905-

1998. Values for the ONI are categorized such that,

ONI >= +0.5 C	El Nino
ONI <= -0.5 C	La Nina
-0.5 C < ONI < +0.5	Neutral,

determines the onset of an ENSO episode. An ENSO episode is further defined as a series of five consecutive ONI values within a single category. In determining the ENSO episode for each month and year, the operational definition is used to ensure the SST anomalies are long-term trends and not short-term warming and/or cooling events without significant impacts on global circulation patterns.

Monthly streamflow event data are used to calculate a three month weighted average for each season. Terciles are computed using the 1950-2000 values for individual month and seasonal mean to identify the upper and lower thresholds for above and below normal conditions at the gauge location. Seasons are defined as provided in Table 2. Using the tercile information, each monthly and seasonal value is compared to the tercile information to define the value within an above, below, or near normal category. The ENSO episode is identified and counts for each ENSO episode-category combination are performed to generate the values required for the station composite. Probabilities associated with the counts define the historical composite analysis and permit the generation of forecast probabilities when coupled with the CPC Nino 3.4 Consolidated SST forecasts.

JFM	January February March
FMA	February March April
MAM	March April May
AMJ	April May June
MJJ	May June July
JJA	June July August
JAS	July August September
ASO	August September October
SON	September October November
OND	October November December
NDJ	November December January
DJF	December January February

Table 2 Definition of seasonal abbreviations

A trend adjustment is typically required for the ENSO composite analysis when the climate variable deviates from the expected trend. Initial research by Caldwell et al. (2006) indicate that the analyses of the monthly streamflow exceedance values failed to indicate significant trends by season and, therefore, no adjustments are made to the composites.

Following the historical composite analysis, a risk analysis is performed to assess whether the composite forecast is statistically significant. A hypergeometric distribution is used to describe the probability distribution between all possible outcomes of a category within ENSO episode years. Values are computed for x (number of successes in the sample), n (the size of the sample), M (the number of successes in the population), and N (the population size). These values are gathered from the station composites and probabilities are computed for each possible outcome, P(x). Using the probabilities, observed counts for each ENSO episode-category combination are used to determine if the value falls within the tails of the distribution function to the 10% statistical significance level (confidence interval = 0.90). If any of the combinations result in a statistically significant result, then a composite analysis forecast can be performed. Otherwise, climatology is provided with no forecast issued.

To make a composite analysis forecast, the Nino 3.4 Consolidated SST forecasts from CPC (http://www.cpc.ncep.noaa.gov/products/precip/CWlink/ENSO/sstcon34.txt) are used to compute the forecast probabilities. The probability for equal chances is defined as 33% for each category and, therefore, any probability above or below this value is considered an enhanced or decreased chance of occurrence of the category given the ENSO episode.

2.3 Streamflow and ENSO

The ENSO signal for precipitation across the Southeast United States is strongest in the winter and spring months with generally wetter than normal conditions during El Nino and drier than normal conditions during La Nina (Figure 2). Any impact on the amount and distribution of precipitation during neutral ENSO years tends to be less pronounced. As a result, we expect to find a correlation between increased (decreased) numbers of above normal flow days during the cool season when El Nino (La Nina) conditions exist in the tropical, equatorial Pacific Ocean. The opposite is true for below normal flow days since dry (wet) conditions during La Nina (El Nino) should increase (decrease) the number of days with streamflow below the 25th percentile.

ENSO impacts on the large scale weather patterns across the United States are well-documented (Hidalgo and Dracup 2003, Schimdt et al. 2001) with an identifiable lag time in precipitation and temperature anomalies on the order of months to seasons. Although the SOI index represents a running mean of SST departures, a lag in streamflow response to the SOI has been shown to range from zero to five seasons (Guetter and Georgakakos 1996). The lag time is associated with the time required to establish global and regional circulations conducive to the excess or deficit of precipitation; therefore, the streamflow response may be significantly out of phase with the actual ENSO episode. A study of the Mississippi River Basin by Twine et al. (2005) indicates that while no signal is remarkable for the mainstem, ENSO does impact regional scale hydrologic patterns. El Nino precipitation anomalies tend to increase runoff in the eastern portions of the basin while La Nina decreases runoff in the southern and eastern sections of the basin. The impacts of ENSO are most evident during the cool season (Figure 3) when variations in the position and strength of the Pacific jetstream leads to significant changes in the distribution and amount of precipitation observed across the southern tier of the United States.

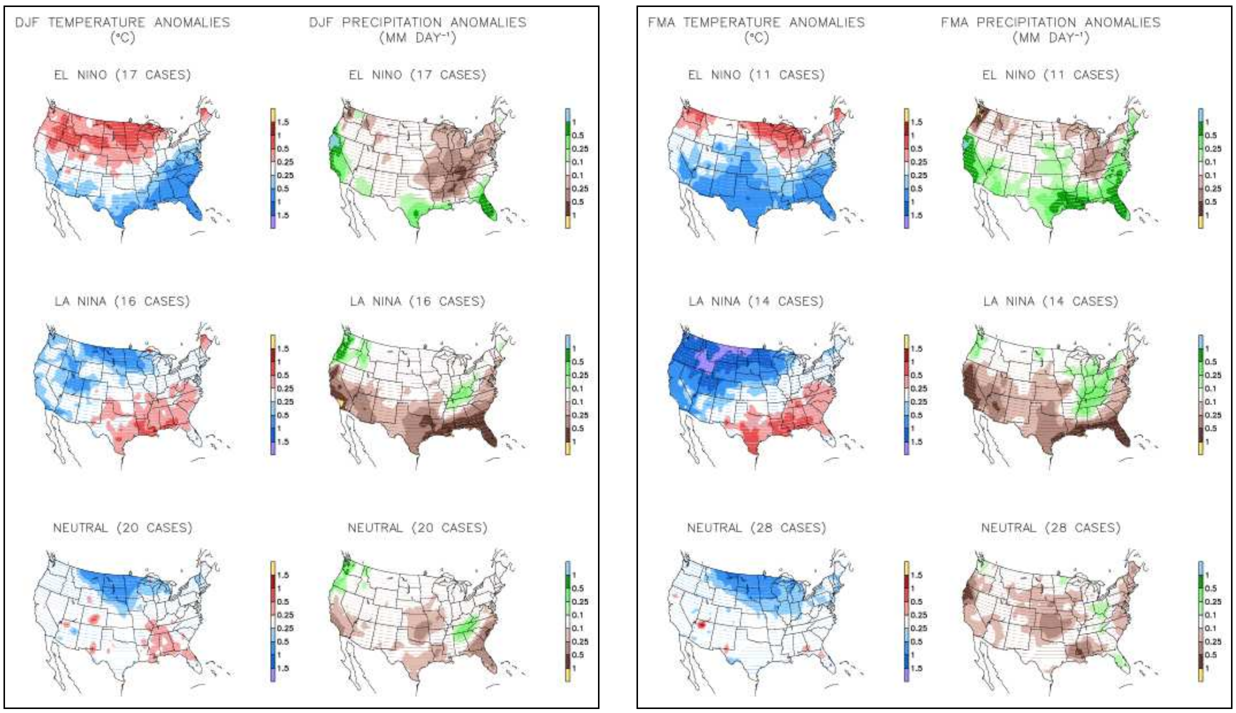

Figure 2 Composites for temperature and precipitation across the United States for DJF (left) and FMA (right). Dry conditions are shaded in brown and wet conditions in green (Courtesy: Climate Prediction Center).

2.4 Forecast Verification

To examine the performance of the ENSO-based forecasts of flow conditions in the Pearl River basin, historical forecasts of sea surface temperatures in the Nino 3.4 Region from CPC were used to produce probabilistic forecasts of above, near, or below normal streamflow for each site along the Pearl River Basin. Since the Spring Flood Potential Outlook constitutes a seasonal outlook for the upcoming 90 days, only the 0.5-month lead time forecasts from the Climate Prediction Center are used to verify forecast performance. The lag time of ENSO impacts is not currently considered in this research as forecast skill is expected to decline with increasing lead time. Comparison of the forecasts to actual observations was performed using the Heidke Skill Score (HSS), Ranked Probability Score (RPS), and Ranked Probability Skill Score (RPSS) (Panofsky and Brier 1958). Additional statistical information was acquired through the 3rd International Verification Methods Workshop resource page (http://www.bom.gov.au/bmrc/ wefor/staff/eee/verif/verif_web_page.html).

The Heidke Skill score is used to identify the improved skill of the ENSO-based forecasts relative to random chance and is computing using the formula,

$$HSS = \frac{C - E}{N - E}$$

where C is the number of correct forecasts, N is the total number of forecasts, and E is the expected number to be correct based on chance. Although the Heidke Skill Score provides some idea as to the relative skill of the ENSO composites on streamflow forecasts, the RPS and RPSS evaluate the performance of the ENSO-based guidance in predicting the proper category.

The equations used to compute RPS and RPSS are as follows:

$$RPS = \frac{1}{M-1}\sum_{m=1}^{M}\left[\left(\sum_{k=1}^{m} p_k\right) - \left(\sum_{k=1}^{m} o_k\right)\right]^2$$

and

$$RPSS = \frac{\overline{RPS} - \overline{RPS}_{reference}}{0 - \overline{RPS}_{reference}} = 1 - \frac{\overline{RPS}}{\overline{RPS}_{reference}}$$

For the HSS, values range from 0 (no skill) to 1 (perfect forecast). For the RPS, values range from 0 to 1, as well, with zero being the perfect score and 1 being an indication that the forecasts failed. Lastly, the RPSS can range from -∞ to 1, where negative values indicate worse forecasts than climatology, 0 indicates no improvement over climatology, and 1 indicates a perfect score.

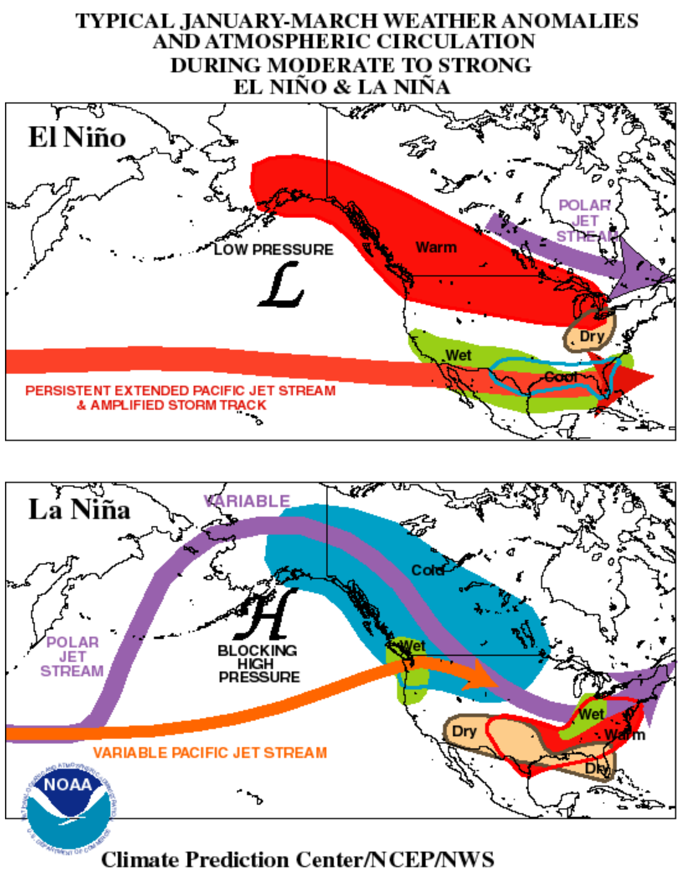

Figure 3 Typical cool season variations in jet stream patterns and precipitation/temperature regimes across North America (Courtesy: Climate Prediction Center)

3. RESULTS

Only statistically significant relationships found in the generation of the ENSO composites are used to make generalized statements regarding the impact of ENSO signal on streamflow conditions in the Pearl River basin. The 75th percentile composite results are shown in tabular form for La Nina (Table 3), Neutral (Table 4), and El Nino (Table 5) events with the 25th percentile data in Tables 6 through 8. The tables are divided into three sections to represent the Yockanookany River, mainstem Pearl River, and Bogue Chitto River. To be considered a signal across the basin, at least half of the sites within the mainstem or sub-basin must indicate similar relationships for a given ENSO episode.

Historical Composites for La Nina 75th Percentile Events in the Pearl River Basin

	Yockanookany		*Mainstem Pearl*				*Bogue Chitto*	
	KSCM6	**OFAM6**	**JACM6**	**ENBM6**	**MTCM6**	**BXAL1**	**TYTM6**	**BSHL1**
JFM	Above 47.1% Below 23.5%	Above 41.2%	NS	NS	Below 23.5%	Below 23.5%	NS	NS
FMA	NS	NS	NS	Below 13.3%	Below 13.3%	Below 20.0%	Above 0.0%	Above 0.0%
MAM	NS	NS	NS	NS	NS	NS	NS	Above 6.7%
AMJ	NS	Below 53.3%	NS	NS	NS	Below 66.7%	NS	Below 66.7%
MJJ	NS	NS	NS	NS	Below 53.8%	Below 76.9%	NS	NS
JJA	NS	NS	Above 53.8%	Above 53.8%	NS	NS	NS	NS
JAS	NS	NS	NS	NS	NS	NS	NS	NS
ASO	NS	NS	NS	NS	NS	Below 18.8%	NS	NS
SON	NS	NS	NS	NS	NS	NS	NS	NS
OND	Below 26.3%	NS	Above 42.0%	NS	NS	NS	NS	NS
NDJ	NS	NS	NS	NS	NS	Below 42.1%	NS	NS
DJF	Below 15.0%	Below 20.0%	Below 30.0%	NS	NS	NS	NS	NS

*** Only statistically significant relationships (90% confidence interval) are shown. NS indicates no signal identified.

Table 3 Historical composites for 75th Percentile Flow during La Nina events in the Pearl River Basin. Shading indicates wetter/above normal 75th percentile flow days (green) and drier/below normal 75th percentile flow days (orange).

Historical Composites for Neutral 75th Percentile Events in the Pearl River Basin

	Yockanookany		*Mainstem Pearl*				*Bogue Chitto*	
	KSCM6	**OFAM6**	**JACM6**	**ENBM6**	**MTCM6**	**BXAL1**	**TYTM6**	**BSHL1**
JFM	NS	NS	Above 11.5%	NS	Below 57.7%	Below 57.7%	NS	NS
FMA	NS	NS	Below 43.3%	Below 50.0%	Below 53.3%	Below 56.7%	NS	NS
MAM	Below 12.9%	NS	NS	NS	NS	NS	NS	NS
AMJ	NS	NS	NS	NS	NS	NS	Above 14.3%	Above 10.7%
MJJ	NS	Below 46.7%	NS	NS	NS	NS	NS	NS
JJA	NS	NS	NS	NS	NS	NS	NS	NS
JAS	NS	NS	NS	NS	NS	NS	NS	Above 40.0%
ASO	Above 20.8%	Above 41.3%	Above 33.3%	Above 37.5% Below 18.8%	NS	Below 50.0%	NS	NS
SON	NS	NS	NS	NS	NS	NS	Below 57.1%	NS
OND	Above 10.0% Below 65.0%	Above 10.0% Below 55.0%	Above 10.0%	Above 15.0%	Above 15.0% Below 55.0%	NS	Below 57.1%	Above 15.0%
NDJ	Below 60.0%	Below 65.0%	NS	NS	Above 15.0%	Above 15.0% Below 80.0%	NS	Below 60.0%
DJF	NS	NS	NS	NS	NS	NS	NS	Above 40.0%

*** Only statistically significant relationships (90% confidence interval) are shown. NS indicates no signal identified.

Table 4 Historical composites for 75th Percentile Flow during Neutral events in the Pearl River Basin. Shading indicates wetter/above normal 75th percentile flow days (green) and drier/below normal 75th percentile flow days (orange).

Historical Composites for El Nino 75th Percentile Events in the Pearl River Basin

	Yockanookany		*Mainstem Pearl*				*Bogue Chitto*	
	KSCM6	**OFAM6**	**JACM6**	**ENBM6**	**MTCM6**	**BXAL1**	**TYTM6**	**BSHL1**
JFM	NS	NS	NS	NS	NS	NS	Above 46.2% Below 23.1%	Above 46.2% Below 23.1%
FMA	NS	NS	NS	NS	NS	NS	Below 18.2%	Below 0.0%
MAM	NS	NS	NS	NS	NS	NS	Below 20.0%	Below 10.0%
AMJ	NS	NS	NS	Below 15.4%	NS	NS	Above 46.2%	Above 38.5% Below 23.1%
MJJ	NS	Below 23.1%	Below 0.0%	Below 7.7%	Above 53.8% Below 15.4%	Above 53.8% Below 30.3%	NS	NS
JJA	NS	NS	NS	NS	NS	NS	NS	Above 7.7%
JAS	NS	NS	NS	NS	NS	NS	NS	NS
ASO	NS	NS	NS	NS	NS	NS	NS	NS
SON	Above 50.0%	NS	NS	NS	NS	NS	NS	NS
OND	Above 47.1%	NS	NS	NS	NS	NS	NS	Above 47.1%
NDJ	NS	NS	Above 5.9%	NS	NS	NS	NS	Above 41.2%
DJF	Below 62.5%	Above 12.5% Below 68.8%	NS	NS	NS	Above 56.3%	NS	NS

*** Only statistically significant relationships (90% confidence interval) are shown. NS indicates no signal identified.

Table 5 Historical composites for 75th Percentile Flow during El Nino events in the Pearl River Basin. Shading indicates wetter/above normal 75th percentile flow days (green) and drier/below normal 75th percentile flow days (orange).

3.1 75th Percentile Historical Composites

3.1.1 La Nina

The strongest signal during La Nina conditions shows above normal 75th percentile flow days from DJF through FMA (Table 3). The Bogue Chitto does not exhibit the same wet signal with 0.0% chance of above normal flow events in FMA (Figure 4). Drier conditions along the coast in precipitation anomaly composites (Figure 2) and wider, flatter topography of the basin may explain the drier conditions near the coast. A secondary signal in AMJ through MJJ of drier conditions becomes evident across the remainder of the Pearl River basin before enhanced tropical activity during La Nina increases probabilities for high flow events sporadically through the late summer.

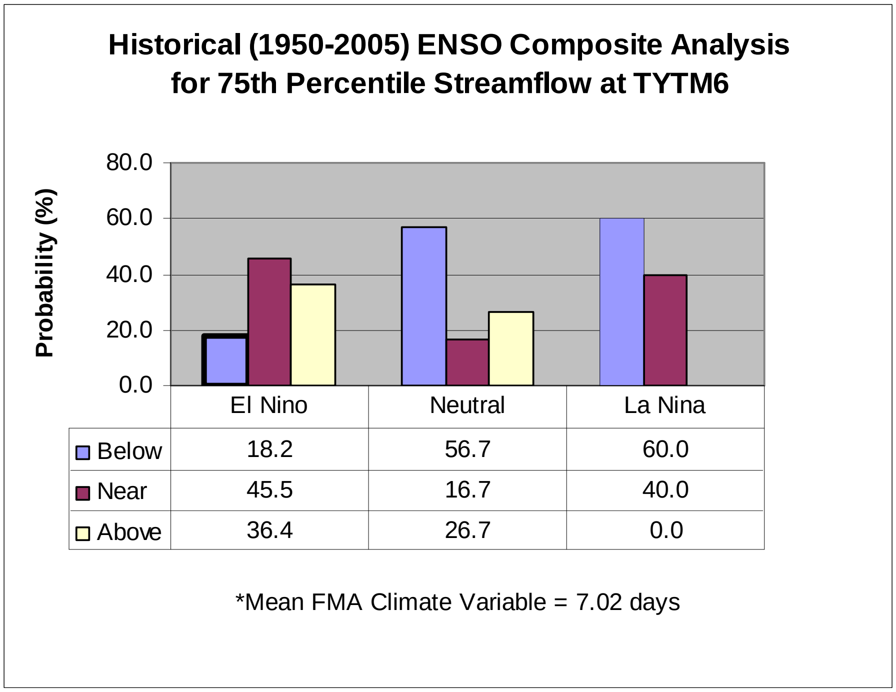

Figure 4 Historical, composite analysis for TYTM6 indicating the statistically significant relationship during La Nina conditions during FMA with no above normal streamflow days observed.

3.1.2 Neutral

Neutral ENSO episodes exhibit two distinct signals: (1) a predominantly dry period from OND through FMA and (2) highly variable streamflow in the summer months (Table 4). In JFM and FMA, the mainstem Pearl provides a dry signal while the Bogue Chitto and Yockanookany Rivers fail to indicate a streamflow tendency. Again in OND and NDJ, the dry signal continues across the mainstem with the tributaries now also evidenced in the historical composites as a dry signal (Figure 5). The variability during the warm season is clear with conflicting signals at KSCM6, OFAM, JACM6, ENBM6, and BXAL1.

3.1.3 El Nino

During El Nino conditions, the cool season (JFM-AMJ) indicates a wet tendency, particularly across the Bogue Chitto River basin with increased probability of above normal high flow days and decreased chances of below normal 75th percentile flows (Table 5). Early in the cool season, DJF composites show neutral to dry conditions across the Yockanookany River and mainstem Pearl. In AMJ-MJJ, the wet signal migrates northward into the Yockanookany and upper Pearl River basins (Figure 6). By summer, however, a lack of ENSO signal is indicated in 75th percentile flows, potentially related to a lack of tropical activity in the Atlantic Ocean during El Nino events. Base flow during the summer months also limits the probability of daily mean streamflow exceeding the 75th percentile.

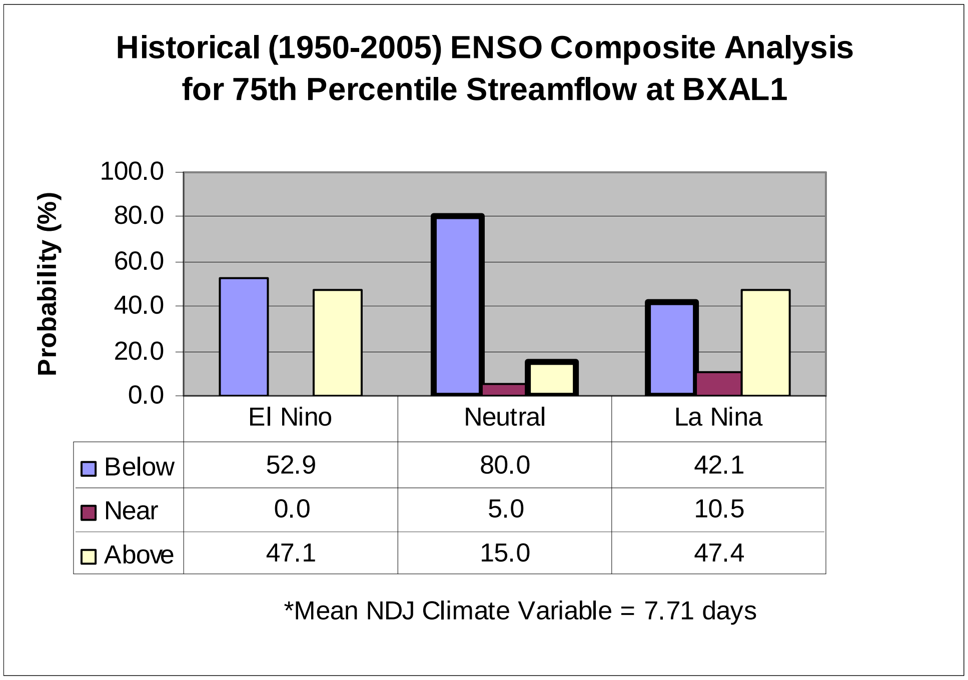

Figure 5 Historical, composite analysis for BXAL1 indicating the statistically significant relationship during Neutral conditions during NDJ with an 80% probability of below normal streamflow days observed.

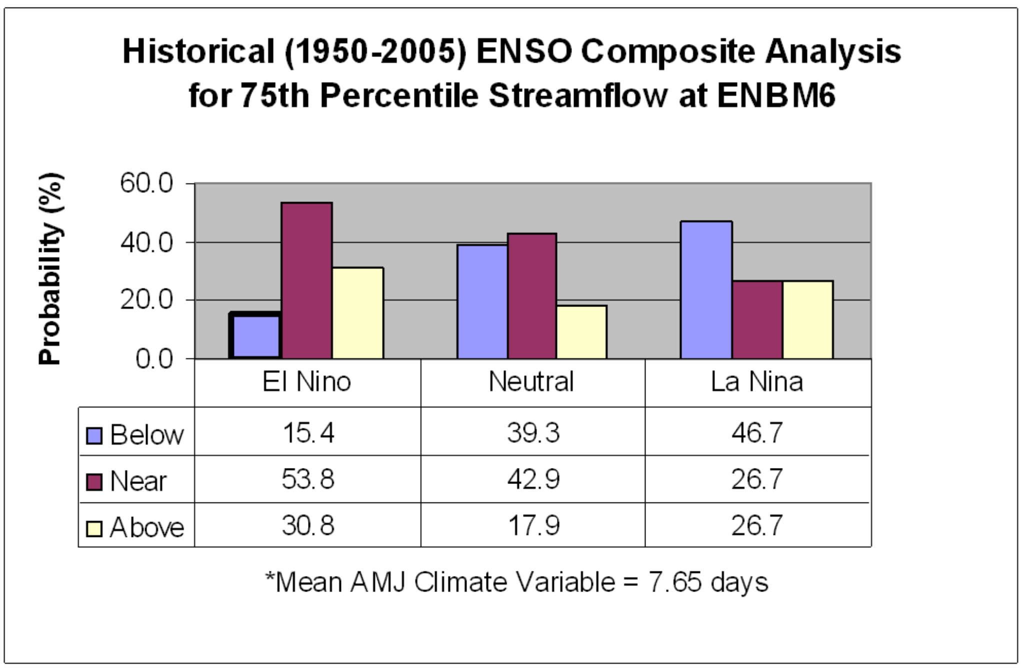

Figure 6 Historical, composite analysis for BXAL1 indicating the statistically significant relationship during El Nino conditions during AMJ with a 15.4% probability of below normal streamflow days observed.

3.2 25th Percentile Historical Composites

Using the same test of statistical significance and site minimum for signal designation, the low flow regime has very few ENSO signal relationships (Tables 6-8). In fact, limited signals are seen for any ENSO episode in the 25th percentile flows. La Nina composites support the 75th percentile data with drier conditions much of the year in the Bogue Chitto River basin (Table 6). Historical composites of the neutral ENSO phase again shows increased variability during ASO, but may suggest wetter conditions along the Gulf Coast where tropical activity is somewhat enhanced (Table 7). Again during El Nino, the exception is on the Bogue Chitto where the wet signal during the cool season remains evident (Table 8).

Historical Composites for La Nina 25th Percentile Events in the Pearl River Basin

	Yockanookany		*Mainstem Pearl*				*Bogue Chitto*	
	KSCM6	**OFAM6**	**JACM6**	**ENBM6**	**MTCM6**	**BXAL1**	**TYTM6**	**BSHL1**
JFM	NS	NS	NS	NS	NS	NS	NS	Above 70.6%
FMA	NS	NS	NS	NS	NS	NS	NS	Above 66.7% Below 6.7%
MAM	NS	NS	NS	NS	NS	NS	Above 53.3%	Below 6.7%
AMJ	NS	NS	NS	NS	NS	NS	Above 53.3%	NS
MJJ	NS	NS	NS	NS	NS	NS	Above 61.5%	NS
JJA	NS	NS	NS	NS	NS	NS	NS	NS
JAS	NS	NS	NS	NS	NS	NS	Above 53.8%	NS
ASO	NS	NS	NS	NS	NS	NS	NS	NS
SON	NS	NS	Above 47.4%	NS	NS	NS	NS	NS
OND	NS	NS	NS	NS	NS	NS	NS	NS
NDJ	NS	NS	NS	NS	NS	NS	NS	NS
DJF	Below 40.0%	Below 40.0%	NS	NS	NS	NS	NS	NS

*** Only statistically significant relationships (90% confidence interval) are shown. NS indicates no signal identified.

Table 6 Historical composites for 25th Percentile Flow during La Nina events in the Pearl River Basin. Shading indicates wetter/below normal 25th percentile flow days (green) and drier/above normal 25th percentile flow days (orange).

Historical Composites for Neutral 25th Percentile Events in the Pearl River Basin

	Yockanookany		*Mainstem Pearl*				*Bogue Chitto*	
	KSCM6	**OFAM6**	**JACM6**	**ENBM6**	**MTCM6**	**BXAL1**	**TYTM6**	**BSHL1**
JFM	NS	NS	NS	NS	NS	NS	NS	NS
FMA	NS	NS	NS	NS	NS	NS	NS	NS
MAM	NS	NS	NS	NS	NS	NS	NS	NS
AMJ	NS	NS	NS	NS	NS	NS	NS	NS
MJJ	NS	NS	NS	NS	NS	NS	NS	NS
JJA	NS	NS	NS	NS	NS	NS	NS	NS
JAS	NS	NS	NS	NS	NS	NS	Above 23.3%	NS
ASO	NS	NS	NS	NS	Above 50.0%	NS	NS	Above 29.2%
SON	NS	NS	NS	NS	NS	NS	NS	NS
OND	NS	NS	NS	NS	NS	NS	NS	NS
NDJ	NS	NS	NS	NS	NS	NS	NS	NS
DJF	NS	NS	NS	NS	NS	NS	NS	NS

*** Only statistically significant relationships (90% confidence interval) are shown. NS indicates no signal identified.

Table 7 Historical composites for 25th Percentile Flow during Neutral events in the Pearl River Basin. Shading indicates wetter/below normal 25th percentile flow days (green) and drier/above normal 25th percentile flow days (orange).

Historical Composites for El Nino 25th Percentile Events in the Pearl River Basin

	Yockanookany		*Mainstem Pearl*				*Bogue Chitto*	
	KSCM6	**OFAM6**	**JACM6**	**ENBM6**	**MTCM6**	**BXAL1**	**TYTM6**	**BSHL1**
JFM	NS	NS	NS	NS	NS	NS	Above 15.4%	Above 23.1%
FMA	NS	NS	NS	NS	NS	NS	Above 18.2% Below 72.7%	Above 18.2% Below 54.5%
MAM	NS	NS	NS	NS	NS	NS		NS
AMJ	Above 15.9%	NS	NS	NS	NS	NS	Below 69.2%	NS
MJJ	NS	NS	NS	NS	NS	NS	NS	NS
JJA	NS	NS	NS	NS	NS	NS	NS	NS
JAS	NS	NS	NS	NS	NS	NS	NS	NS
ASO	NS	NS	NS	NS	NS	NS	NS	Above 62.5%
SON	NS	NS	NS	NS	NS	NS	NS	NS
OND	NS	NS	NS	NS	NS	NS	NS	NS
NDJ	NS	NS	NS	NS	NS	NS	Below 70.6%	NS
DJF	Below 6.3%	NS	NS	NS	NS	NS	NS	Below 18.8%

*** Only statistically significant relationships (90% confidence interval) are shown. NS indicates no signal identified.

Table 6 Historical composites for 25th Percentile Flow during El Nino events in the Pearl River Basin. Shading indicates wetter/below normal 25th percentile flow days (green) and drier/above normal 25th percentile flow days (orange).

3.3 Forecast Skill

Heidke skill scores were computed for each season and for all seasons combined. The results from individual season and cumulative scores were similar in magnitude. The lowest skill scores were indicated for BXAL1, TYTM6, and BSHL1 with a range of 0.04 to 0.09, indicating little improvement of the ENSO composite method over chance (Figure 7). The greatest improvement over random selection was indicated across the mainstem Pearl River and in the Yockanookany with scores ranging from 0.13 to 0.25.

Ranked probability score is a measure of the ability of a forecast to hit the correct category and provides some skill for forecasts closer to the correct category. For the ENSO composite forecasts, the skill is marginal with RPS ranging from 0.40 to 0.46 (Figure 8).

The RPSS (Figure 9) provides the improvement of a forecast over climatology. The all-seasons calculations show limited improvement with 4 to 8 percent improvement across the upper Pearl upstream of, and including, JACM6 and little or no skill downstream. In fact, forecasts at BXAL1 are actually worse than using climatology. TYTM6 and BSHL1 on the Bogue Chitto River, however, do exhibit some skill over climatology with RPSS of 0.01 to 0.02.

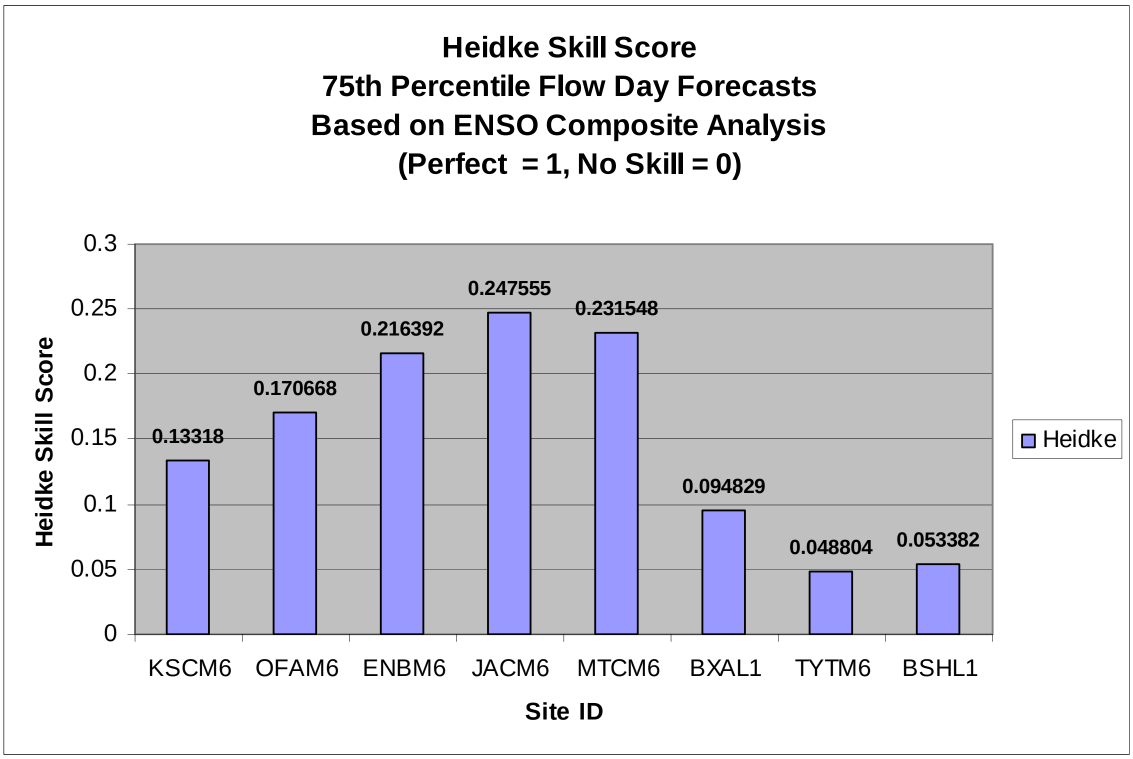

Figure 7 Heidke skill scores for all-seasons forecasts of 75^{th} percentile flow days.

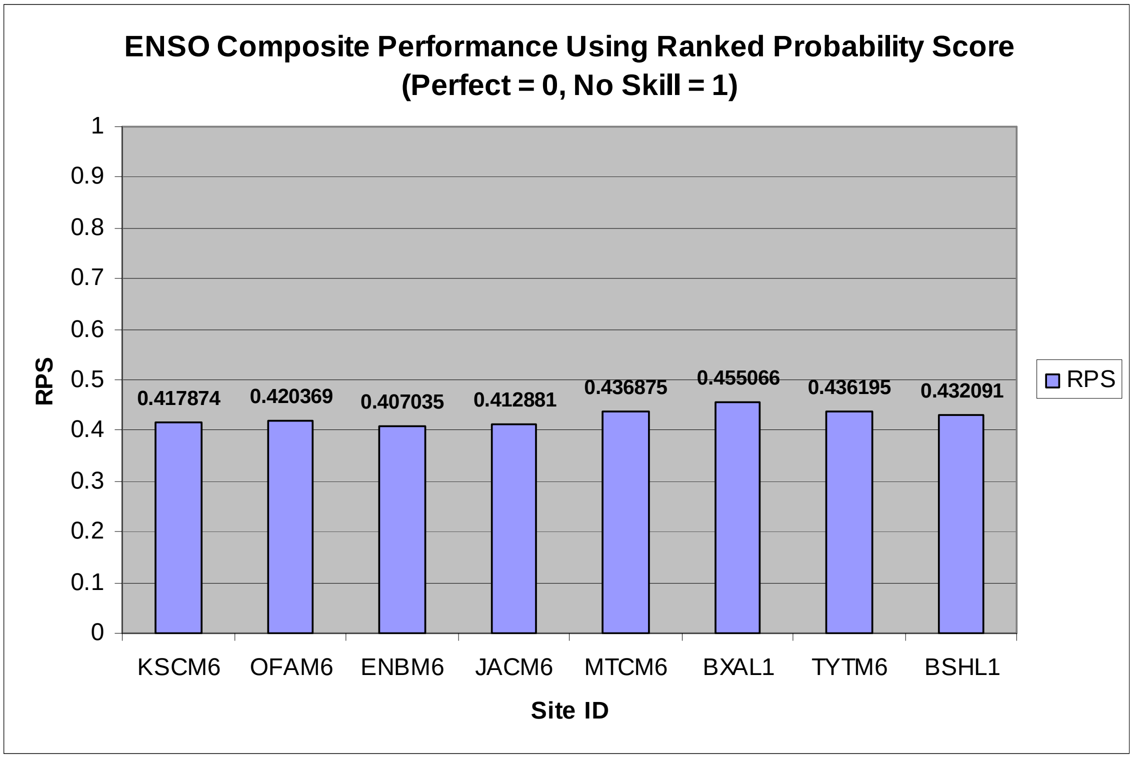

Figure 8 Ranked probability scores for all-seasons forecasts of 75th percentile flow days

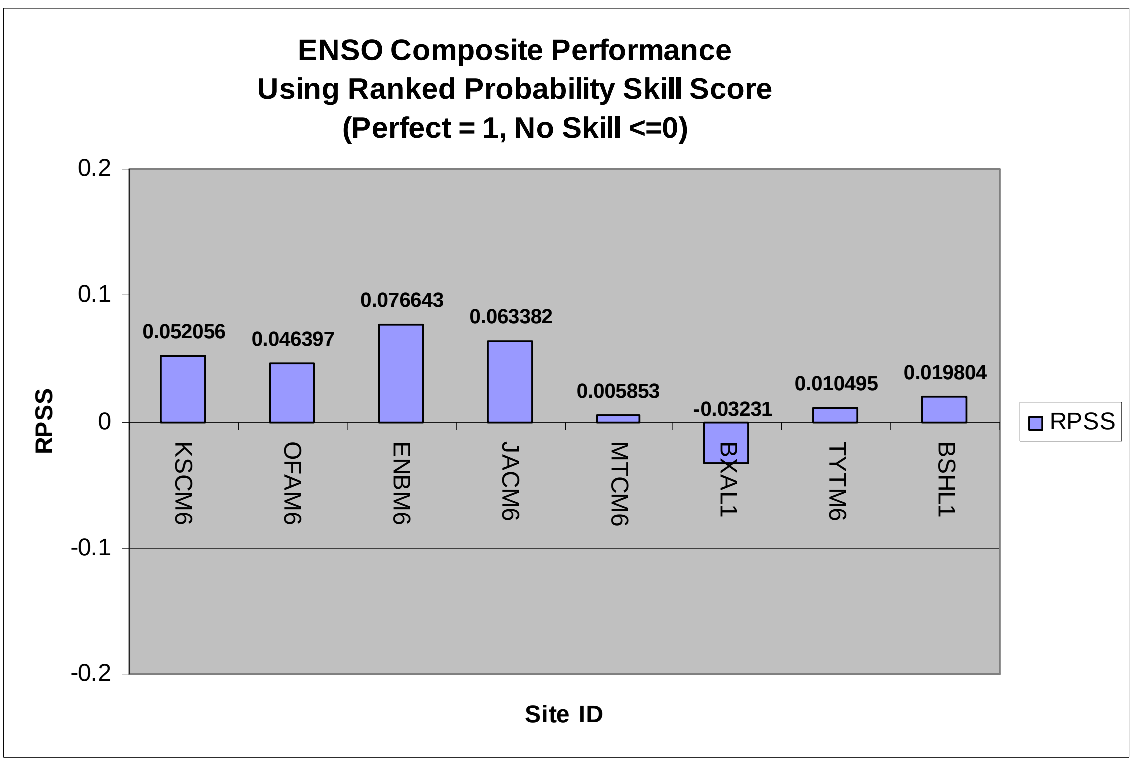

Figure 9 Ranked probability skill scores for all-seasons forecasts of 75th percentile flow days

4. CONCLUSIONS

4.1 Summary

The generation of historical composites of 75th and 25th percentile streamflow events provides an opportunity to identify relationships with ENSO episode that may prove helpful in long-range hydrologic forecasting. As expected, El Nino and La Nina are related to fluctuations in high and low flow events across the Pearl River Basin forced by a meandering jet stream and, therefore, anomalous precipitation and runoff amounts across the region (Figure 3). Due to the enhanced influence of ENSO during the cool season, most of the historical composites indicated statistically significant relationships during the period from October through April with the summer months exhibiting less pronounced or contrasting signals for streamflow events.

The 75th percentile flow data was more robust in producing composite analyses with El Nino, producing an enhanced chance of high flow events and diminished chance of low flow events during the winter months. La Nina was a better indicator of near to above normal totals of high flow days during the winter with lower probabilities for below normal event days. In the spring months, however, La Nina indicated less than 10% chances for above normal high flow days across the Bogue Chitto River basin. El Nino continued to indicate wet conditions from AMJ to MJJ with improved chances for high flows and decreased chances for low flows. ENSO neutral conditions were shown to identify drier conditions across the Pearl River basin during the MJJ season and again in OND and NDJ. La Nina also indicated wetter than normal conditions across the region during the JJA period, perhaps an indication of increased tropical activity in the Atlantic Basin during La Nina years.

For the low flow events data, the statistically significant relationships were confined primarily to the smaller river basins feeding into the mainstem Pearl River. Significant relationships on the Yockanookany River during DJF indicated that La Nina is related to an increased likelihood of less than normal low flow events, or wetter conditions on average. Gauges on the Bogue Chitto River showed El Nino does not typically produce an increased number of low flow days, also indicating wetter conditions during the winter and spring months of JFM through FMA. Neutral ENSO showed only mid-summer contradictory trends across the area. Surprisingly, approximately two-thirds of the significant relationships from the ENSO composites for low flow regimes were found at sites on the Bogue Chitto River.

The forecast skill for the ENSO composite analysis forecasts was found to be limited, but notable, with Heidke skill scores ranging from 0.04 to 0.25. The best performance by the forecasts was exhibited in the upper Pearl River basin north of Kosciusko on the mainstem. Smaller tributaries (Yockanookany and Bogue Chitto) showed less skill than the mainstem when considered forecast performance relative to random chance. Ranked probability score indicated some skill (0.40-0.46) in forecasting the proper category of above, near, or normal number of streamflow events averaged over all seasons. The RPSS for each of the gauges showed the best skill in the upper portion of the Pearl River basin and lesser skill below JACM6 when compared to climatology. Improvements over climatology of approximately 5% can be expected across the Upper Pearl River Basin where forecasts perform best.

4.2 Future Research

The enhanced skill of the forecasts in the upper basin could be partially due to the latitudinal displacement northward from the Gulf Coast. Areas near the Gulf of Mexico may be more heavily influenced by diurnal and tropical effects than ENSO episode and the associated shifts of mid-latitude jet stream patterns. For significant relationships that do exist, the inclusion of ENSO forecasts from the Climate Prediction Center can assist in the improved performance of long range hydrologic forecast guidance such as the Spring Flood Potential Outlook and the Ensemble Streamflow Prediction system.

In accordance with prior research by Guetter and Georgakakos (1996), the importance of lag time must be considered in the production of forecast verification statistics for the hindcasts performed on the Pearl River Basin. Future research will address this topic by substituting the Nino 3.4 SST forecasts from CPC at various lead times into the ENSO composite forecast module.

Due to the limited signals provided in the 25th percentile flow data, the verification statistics were not performed for forecasts of low flow in the Pearl River Basin . However, if future tests using variable lead-time indicate improved skill, the verification may be performed for low flow events, as well.

While the skill associated with the ENSO-based composites is limited at best, it is improved over the former forecast methodology and is better than using climatology alone. In addition, knowledge of the intra-annual variations in the historical composites is important to denote times when El Nino and La Nina act in an opposite and similar manner. Identification of different, and even contrasting, signals at regional and local scales on the mainstem Pearl River and tributaries is also an important consideration to the hydrologic forecaster when making predictions for long range streamflow categories.

Based on the findings of the research, the composite analysis methodology could potentially be applied across the southeast United States to enhance long range forecasts and improve the skill of ensemble models used in dam operations and hydrologic planning. Given an increased forecast skill of 5% annually, benefits to long-term water resource planners would include generous savings of time and monetary resources.

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REFERENCES

Caldwell, R. J., G. M. Forthun, and J. R. Glenn, 2006: An analysis of streamflow trends in the Pearl River Basin. *Under review for submission*, Lower Mississippi River Forecast Center, Slidell, LA, 19 pp.

Guetter, A. K., and K. P. Georgakakos, 1996: Are the El Nino and La Nina predictors of the Iowa River seasonal flows? *J. Appl. Meteor.*, **35**, 690-705.

Hidalgo, H. G., and J. A. Dracup, 2003: ENSO and PDO effects on hydroclimatic variations of the Upper Colorado River Basin. *J. Hydrometeorology*, **4**, 5-23.

Maurer, E. P., and D. P. Lettenmaier, 2004: Potential effects of long-lead hydrologic predictability on Missouri River main-stem reservoirs. *J. Climate*, **17**, 174-186.

Panofsky, H. A., and G. W. Brier, 1958: *Some Applications of Statistics to Meteorology*. The Pennsylvania State University, University Park, PA. 208 pp.

Schmidt, N., E. K. Lipp, J. B. Rose, and M. E. Luther, 2001: ENSO influences on seasonal rainfall and river discharge in Florida. *J. Climate*, **14**, 615-628.

Timofeyeva, M., 2005: *Composite Analysis Instructions*. Climate Services Operations Course, National Weather Service Training Center, Kansas City, MO, 38 pp.

Twine, T. E., C. J. Kucharik, and J. A. Foley, 2005: Effects of El Nino-Southern Oscillation on the climate, water balance, and streamflow of the Mississippi River Basin. *J. Climate*, **18**, 4840-4861.