WESTERN REGION TECHNICAL ATTACHMENT
NO. 02-08
June 24, 2002

PACIFIC DECADAL OSCILLATION AND ARIZONA PRECIPITATION

Karen D. Maxwell, Department of Atmospheric Sciences, University of Arizona, Tucson AZ, and Vincent P. Holbrook, Weather Forecast Office, Tucson AZ

Introduction

The Pacific Decadal Oscillation (PDO) is a shift in the North Pacific ocean temperature pattern that occurs on a 20- to 30-year cycle (Mantua et al. 1997). The PDO is in a warm or positive phase (cool or negative) when the northwest Pacific sea surface temperature (SST) anomalies are negative (positive) while SST anomalies in the eastern equatorial Pacific become positive (negative). A PDO phase change, from warm to cool, occurred in late 1998 and should persist through at least 2020. During a cool phase, the jet stream is steered further north so that the northern tier of the U.S. is stormier and wetter during winters and the southern tier becomes dry with drought becoming more probable in the Southwest (NASA/JPL, 2002). Generally, the opposite conditions occur during a warm phase.

Water availability in the desert Southwest is a critical issue due to ever increasing population. Government and industry officials can benefit by planning for water use and availability based upon expected changes in precipitation patterns if a link to PDO phase exists and is quantifiable. Also, predictability of the El Nino Southern Oscillation (ENSO) has improved such that any relationship between ENSO and the PDO would prove a valuable tool to water planners. The goals of this paper are to determine if any correlation exists between the PDO phase and Arizona precipitation, quantify the results, and determine the role of ENSO with PDO phase. This paper was patterned after similar research conducted by Liles (1999) for New Mexico.

Method

Fig 1. Arizona Climate Divisions

The State of Arizona consists of seven climate divisions (Fig. 1). Monthly mean precipitation for each climate division was obtained from the Western Region Climate Data Center and grouped according to calendar year, winter season, and monsoon season. The calendar year precipitation was for the period January through December. Winter season precipitation was from October of the previous year through May of the current year. The winter and monsoon season precipitation groups were established since the circulation systems that cause precipitation in these two seasons are different (monsoon versus jet stream). Winter season precipitation forecasts are also more beneficial to water planners. The monsoon season was defined as the precipitation for the months of July and August. Although the Arizona monsoon generally begins in June and ends in September, these two months were chosen since the precipitation data best represents the monsoon season. Note that the combination of winter season and monsoon season precipitation is not equal to the calendar year since June and September were left out. The data were grouped by warm and cool PDO phase and the mean and standard deviation of the precipitation was calculated for each climate division for the calendar year, winter season, and monsoon season. A separate category for state precipitation was developed using the mean precipitation from the climate divisions.

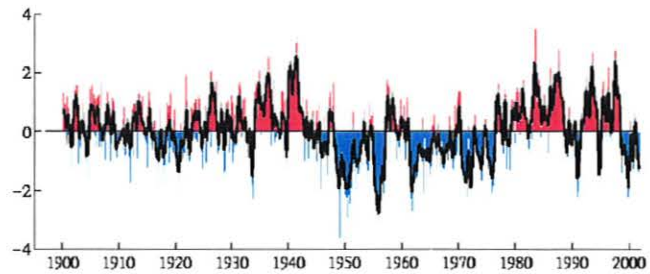

Fig 2. Monthly values of PDO index 1900-2001. The PDO index is defined as the leading principal component of North Pacific monthly sea surface temperature variability (Mantua 2001).

Baseline mean precipitation and standard deviation for the calendar year, winter season, and monsoon season was calculated from 30 randomly selected years in the period from 1948 to 2000 (15 years in each phase) for each climate division and the state. This 53-year period contained precipitation data from two PDO cool phases (see Fig. 2) 1948-1976 and 1999-2000, and the 1977-1998 warm phase. Precipitation data before 1948 were not used due to the low density of stations within the climate divisions. The percent difference between baseline and phase mean precipitation was calculated for both warm and cool phase PDO and is given in Table 1.

Table 1. Baseline mean precipitation and percent difference from the baseline for cool and warm phase PDO for each climate division and the state.

	Calendar Year			***Winter season***			***Monsoon Season***		
Climate Division	**Mean (in)**	**Cool %**	**Warm %**	**Mean (in)**	**Cool %**	**Warm %**	**Mean (in)**	**Cool %**	**Warm %**
DIV 1	**8.8**	**-2**	**8**	**5.8**	**-9**	**13**	**2.0**	**5**	**-10**
DIV 2	**14.6**	**-10**	**14**	**8.5**	**-16**	**17**	**4.2**	**-3**	**1**
DIV 3	**15.9**	**-8**	**14**	**9.4**	**-18**	**31**	**4.6**	**3**	**-4**
DIV 4	**18.9**	**-3**	**15**	**11.9**	**-13**	**15**	**5.0**	**5**	**-8**
DIV 5	**4.6**	**-12**	**22**	**2.8**	**-21**	**23**	**1.2**	**-12**	**6**
DIV 6	**10.2**	**-11**	**16**	**6.5**	**-22**	**19**	**2.7**	**-3**	**-2**

Table 1. Baseline mean precipitation and percent difference from the baseline for cool and warm phase PDO for each climate division and the state.									
	Calendar Year			*Winter season*			*Monsoon Season*		
Climate Division	Mean (in)	Cool %	Warm %	Mean (in)	Cool %	Warm %	Mean (in)	Cool %	Warm %
DIV 7	14.6	-7	12	6.6	-22	20	6.0	2	-1
STATE	87.6	-7	13	51.5	-17	17	25.7	1	-3

Extreme precipitation events (+/- one standard deviation from normal precipitation) are important to water planners. Since the Climate Prediction Center (CPC) continues to make advances in predicting ENSO events, we investigated the relationship of extreme precipitation events associated with PDO and ENSO. The ENSO phase for each quarter from 1950-2000 was obtained from the CPC and the individual calendar year, winter season, or monsoon season was determined to be affected by ENSO based upon the following criteria:

Calendar Year - ENSO occurred during first two periods of the year.
Winter season - ENSO occurred during two consecutive periods within the winter season.
Monsoon Year - ENSO occurred only during the April-June period.

The number of years the mean precipitation was a standard deviation above/below the baseline mean precipitation was calculated and separated as a function of ENSO and PDO phase (Table 2).

Table 2. Number of years precipitation was one standard deviation above/below baseline mean precipitation as a function of ENSO and PDO phase for (a) calendar year, (b) winter season, (c) monsoon season. The total number of years meeting the requirements is shown in parenthesis.								
a. Calendar	Cool Phase PDO				Warm Phase PDO			
	El Nino (6)		La Nina (10)		El Nino (8)		La Nina (3)	
	+1	-1	+1	-1	+1	-1	+1	-1
DIV 1	0	1	1	1	4	1	0	1
DIV 2	0	1	0	2	4	0	0	1
DIV 3	0	1	0	3	4	0	0	1
DIV 4	0	1	0	2	4	0	0	1
DIV 5	0	1	1	1	5	0	1	0
DIV 6	0	1	0	2	3	0	1	0
DIV 7	0	1	0	2	2	0	1	1
STATE	0	1	0	2	4	0	1	1

b. Winter	Cool Phase PDO				Warm Phase PDO			
	El Nino (7)		La Nina (14)		El Nino (10)		La Nina (4)	
	+1	-1	+1	-1	+1	-1	+1	-1
DIV 1	3	0	0	2	4	0	0	3
DIV 2	1	1	0	6	4	0	1	1
DIV 3	1	0	0	4	4	0	0	2
DIV 4	1	1	0	3	4	0	0	1
DIV 5	2	0	0	3	4	0	0	1
DIV 6	1	1	0	4	6	0	0	0
DIV 7	2	1	0	6	5	0	1	1
STATE	1	1	0	4	5	0	0	1

c. Monsoon	Cool Phase PDO				Warm Phase PDO			
	El Nino (6)		La Nina (9)		El Nino (8)		La Nina (3)	
	+1	-1	+1	-1	+1	-1	+1	-1
DIV 1	1	0	2	0	1	0	1	1
DIV 2	0	0	1	0	1	0	1	0
DIV 3	1	0	1	2	1	0	1	0
DIV 4	0	1	2	0	1	1	1	0
DIV 5	0	0	1	1	0	0	1	1
DIV 6	0	0	2	0	1	0	1	0
DIV 7	0	0	3	0	0	0	1	0
STATE	0	0	2	0	1	1	1	0

Warm (cold) phase PDO SST anomalies in the equatorial Pacific appear similar to El Nino (La Nina). We classified warm (cold) phase PDO occurring with El Nino (La Nina) as being "in-phase" and a warm phase (cold) PDO occurring with a La Nina (El Nino) being "out-of-phase." Although the effects would be opposite as far as mean precipitation was concerned by combining the two groups, the significance of PDO/ENSO being in phase is highlighted (Table 3).

Table 3. Number of years standard deviation of precipitation for the calendar and winter season was in or out of agreement when ENSO and PDO were in-phase. The total number of in-phase years is given in parenthesis.				
Climate Division	Calendar Year (18)		Winter season (24)	
	in	out	in	out
Div 1	5	2	6	0
Div 2	6	0	10	0
Div 3	7	0	8	0
Div 4	6	0	7	0
Div 5	6	1	7	0
Div 6	5	0	10	0
Div 7	4	0	11	0
State	6	0	9	0

Results

Table 1 shows that cold (warm) phase PDO resulted in a decrease (increase) in Arizona precipitation for both the calendar and winter season. For the calendar year, the cool phase PDO is not as dry as the warm PDO phase is wet. Monsoon season precipitation appears to be unaffected by PDO phase.

The results shown in Tables 2 and 3 offer useful guidance for forecasting precipitation in Arizona because the relationship between PDO and ENSO phases was established. In the calendar and winter seasons, the PDO and ENSO tend to enhance each other when they are "in-phase" with one another. Cold (warm) phase PDO and La Nina (El Nino) produce more years with the mean precipitation a standard deviation below (above) normal. Winter season has the higher number of events than calendar year due to the influence of monsoon season on the calendar year precipitation. Another result from Table 3 is that the possibility of a precipitation a standard deviation opposite of the in-phase signal is negligible. For example, if the in-phase situation of a La Nina occurring during a cold phase PDO the likelihood of the mean precipitation a standard deviation above normal is minimal. When PDO and ENSO are out-of-phase, the PDO tends to moderate the effect of ENSO and the ability to forecast the outcome is more difficult although the number of extreme precipitation events drops. The total number of out-of-phase events was about half the in-phase events, which suggests that El Nino and La Nina frequency is a function of PDO phase. The monsoon season results indicate little relationship between PDO and monsoon season precipitation.

The Arizona calendar year results are consistent to what Liles (1999) found in the research of PDO impact on New Mexico precipitation, especially for the New Mexico climate divisions 4 and 7 which are adjacent to Arizona climate division 7. In addition, Liles (1999) identified years where the PDO index values were either strongly negative or positive and then separated calendar year precipitation of wet, normal, and dry precipitation (normal was within10 percent of the long-term average) versus the PDO index. These results were similar to the Arizona in-phase results found in Table 3.

Conclusions

It is evident from the results that a relationship between PDO cycle and Arizona precipitation exists. Generally, below normal amounts of precipitation can be expected within a cool phase and above normal within a warm phase. With a PDO cycle of 20 to 30 years, water planners can use this information, especially within the first 10-15 years after entering a new PDO phase. With the ever increasing ability to forecast ENSO past one season, water planners can use the relationship between Arizona precipitation and PDO/ENSO.

However, there are a few obvious problems to consider. First, the PDO cycle is based on long inherent time scales due to the large thermal capacity of the ocean (Schneider, 2000), but this study spanned only one warm and cold phase. We believe inclusion of more PDO cycles would yield similar results. Tree-ring data may be useful since it can be traced back hundreds of years, but one would also have to have similar PDO phase data. Unfortunately, vertical stratification of precipitation between Arizona's valleys and mountains would make it difficult to construct a set of data equivalent to data from the present observation network.

Another problem is that the PDO index within a phase can switch, on a monthly, seasonal, or even yearly time frame. If during a warm PDO phase, a negative PDO index occurs along with a El Nino event, technically this study would have the PDO phase and El Nino in-phase although the PDO index for that time frame and the El Nino would be out-of-phase. From this study, one would forecast above (possibly even one standard deviation above) mean precipitation; but since the PDO phase index temporarily changes, should the precipitation forecast then be treated as out-of-phase? For water planners, we would also have to have an accurate method to forecast the PDO index on a monthly, seasonal, and yearly time frame.

One question this study did not attempt to address is if the PDO cycle can be used to forecast yearly precipitation for years when there is no actual or forecasted ENSO event? Are there other forcing mechanisms that can be tied to PDO phase to aid in forecasting precipitation? In the absence of ENSO, the atmosphere appears to have a wide range of possibilities and, in a sense, is free to act however it wants (Barry, 2000). We can say when entering a cool (warm) phase PDO that over the next two decades, expect normal to dry (normal to wet) conditions, but just as knowing an El Nino is likely to occur tells us little about which month the most rainfall will occur, knowing the PDO phase gives us little ability to predict yearly precipitation.

It is also important how one categorizes an ENSO event year for two reasons. First, the influence the ENSO event has over the precipitation amounts is dependent on which period the ENSO event occurs, especially when you are interested in calendar versus winter season. The CPC classifies the cool and warm episode ENSO by 3-month periods but other sources classify ENSO in a variety of ways. Second, it may be of interest to catagorize these events according to intensity before correlating them to the PDO cycle, but this process is also subjective and until some uniform standard for an objective classification is developed, it really is left up to the interpretation of the individual. Perhaps all these variables can be broken down and organized in such a way that it aids in the modification of the already existing climate prediction models.

References

Barry, P., 2000: La Nina's Ghost. NASA [Available on-line from http://spacescience.com/headlines/y2000/ast15sep_1.html].

Liles, C.A., 1999: Pacific Decadal Oscillation and New Mexico Precipitation. National Weather Service Albuquerque. [Available on-line from http://www.srh.noaa.gov/abq/feature/PDO-NM.html].

Mantua, N.J. and S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis 1997: A Pacific Interdecadal Climate Oscillation with Impacts on Salmon Production. *Bull. Amer. Meteor. Soc.,* 78, pp. 1069-1079.

Mantua, N.J. 2000: The Pacific Decadal Oscillation. Joint Institute for the Study of Atmosphere and Oceans. University of Washington, Seattle, Washington. [Available on-line from http://tao.atmos.washington.edu/pdo/].

NASA Jet Propulsion Laboratory: El Nino/La Nina & PDO. [Available on-line from http://topex-www.jpl.nasa.gov/science/pdo.html].

NOAA Climate Prediction Center: Cold and Warm Episodes by Season. [Available on-line at http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.html].

NOAA Climate Prediction Center: Current Monthly/Seasonal Outlook. [Available on-line http://www.cpc.ncep.gov/products/predictions/multi_season/13_seasonal_outlooks /color/seasonal_forecast.html].

Schneider, N. 2000: Decadal Climate Variations in the Pacific. Experimental Climate Prediction Center, Climate Research Division, La Jolla, CA. [Available on-line from http://ecpc.ucsd.edu/general/SIO219/decadal.html].