Does El Niño Affect Snowpack in Utah

Connely K. Baldwin[1]

ABSTRACT

Nine snow gauging stations in Utah are analyzed to determine the impact of El Niño on snowpack (snow water equivalent) across the state. The stations were chosen based primarily on the length of record. The effect of latitudinal variation as well as temporal variation on El Niño impact is considered. The importance of the stationary atmospheric wave pattern in the N. hemisphere during El Niño events is demonstrated. The Pacific North American (PNA) pattern provides a convenient and effective measure of the state of the atmospheric wave pattern that impacts Utah. A response table showing the impact of various combinations of El Niño and the PNA pattern shows that significant impacts on snowpack occur when both the El Niño and PNA indices are at extreme values. Correlation analysis reveals that N. Utah is negatively correlated with El Niño, while S. Utah is positively correlated with El Niño, with the transition between these two extremes being nearly linear. A forecast based on the results is presented, which indicates that the next two years will be near-normal.

INTRODUCTION

The recent publicity about El Niño has heightened public awareness of the possible teleconnection impacts of changes in the tropical Pacific region. Scientific literature regarding these impacts has increased since the 1982-1983 El Niño event that was nearly as strong as the current 1997-1998 event. El Niño, or the El Niño Southern Oscillation phenomenon is a coupled ocean-atmosphere interaction that varies quasi-periodically in a range of periods from 2 to 8 years. Briefly, during an El Niño event, the warm water that is normally in the Western Equatorial Pacific basin travels eastward and forms an anomalous warm pool of water in the Eastern Equatorial Pacific basin. This warm pool increases the amount of atmospheric moisture through evaporation.

The impact of the 1982-83 event motivated scientists to exert more effort into understanding the phenomenon, its impacts and how to make better predictions (NOAA, 1998). There is a good deal of information available that explain the El Niño Southern Oscillation phenomenon and hence no attempt will be made to describe it here however, a number of documents are available (NOAA, 1998;University Corporation for Atmospheric Research, 1994; Koch et al, 1991).

The attention paid to this phenomenon is well-deserved, the impacts observed in the Tropical region are well-established and are responsible for extreme droughts and floods. The teleconnection impact observed in the N. hemisphere is less certain, but may be equally important. The connection between El Niño and N. hemisphere hydroclimatic variables is dependent on a number of physical factors: strength, timing and location of the tropical sea surface temperature anomalies as well as N. Pacific upper air flow patterns and sea surface temperature anomalies. The impact of extra-tropical forcings such as sea surface temperatures and oceanic circulation has been studied and some insight gained.

The relationship between large scale inter-ocean basin circulation and snowpack in the Pacific Northwest demonstrated an additional climatic mechanism for systematic precipitation changes in addition to El Niño (Allerman, 1996). These changes ocean circulation have been observed in the N. Pacific ocean and atmosphere (Latif and Barnett, 1994) and appear to cause noticeable changes in the climate (Francis, 1998). For example, Baldwin (1997) found that the impact of El Niño on point rainfall was significant in certain seasons in N. and S. Utah, and that the impact varied over time in N. Utah. The changes observed appear to be directly related to regime shifts in the N. Pacific ocean circulation. A number of authors have examined the teleconnection impact of El Niño alone on hydroclimatic variables (Baldwin, 1997; Climate Diagnostics Center, 1998; Guetter and Georgakakos, 1996) with varying degrees of success. Guetter and Georgakakos (1996) in their study of El Niño impacts on streamflow highlight some previous studies that were not successful yet were able to demonstrate significant effects using a different technique.

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[1] Department of Civil and Environmental Engineering & Utah Water Research Laboratory, Utah State University, Logan, Utah. E-mail: cbald@pub.uwrl.usu.edu

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These results motivate the search for climate connections in snowpack data with the goal of predicting snowpack at lead times of up to a year using measures of both tropical (El Niño) and N. Pacific climate state to ameliorate water resource management. The impact of these climate indices on snowpack in different areas of the state of Utah is identified by using a series of snow gauging stations. The interaction between the Tropical and N. Pacific climate states on the change in probability distribution of snow water equivalent (SWE) at these stations is identified. A prediction based on these results is also presented.

DATA

A total of nine stations are used, positioned as shown in Figure 1. The primary consideration in choosing these sites was length of record due to the importance of identifying consistent changes in SWE over time. Thus, stations with long records that fell close to a meridional line as well as two stations in the Uintah mountains were chosen in order to cover a significant portion of the state (Table 1). The majority of the data is from historical manual snow course measurements taken near April 1. When the manual snow course was discontinued in favor of SnoTel stations, the April 1 measurement was used. The time series of the stations used is shown in Figure 2.

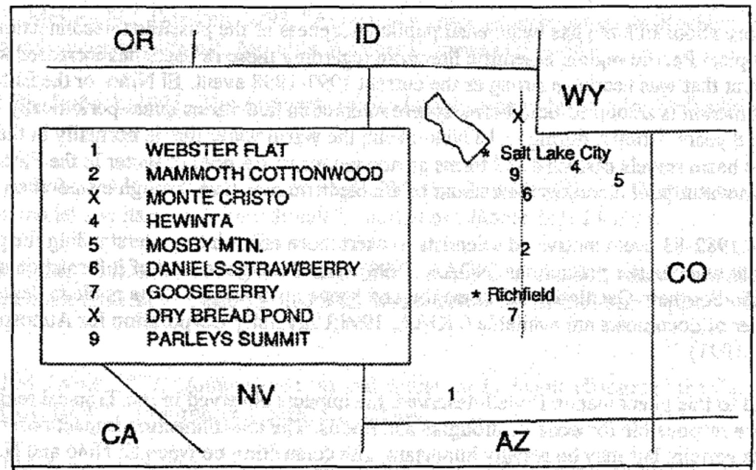

Figure 1. Location of snow gauging sites used in this study.

Table 1. Snow gauging station information

Sitename	Abbreviation	Elev. (m above MSL)	Station Number
MONTE CRISTO R.S.	Mcri	2731	11H12
DRY BREAD POND	Dbrd	2545	11H13
PARLEY'S CANYON SUMMIT	Psmt	2286	11J15
DANIELS-STRAWBERRY	dstr	2438	11J23
MAMMOTH-COTTONWOOD	mctn	2682	11K03
GOOSEBERRY R.S.	gsbr	2560	11L02
WEBSTER FLAT	webf	2804	12M03
HEWINTA G.S.	hew	2896	10J04
MOSBY MOUNTAIN	mmtn	2896	09J05

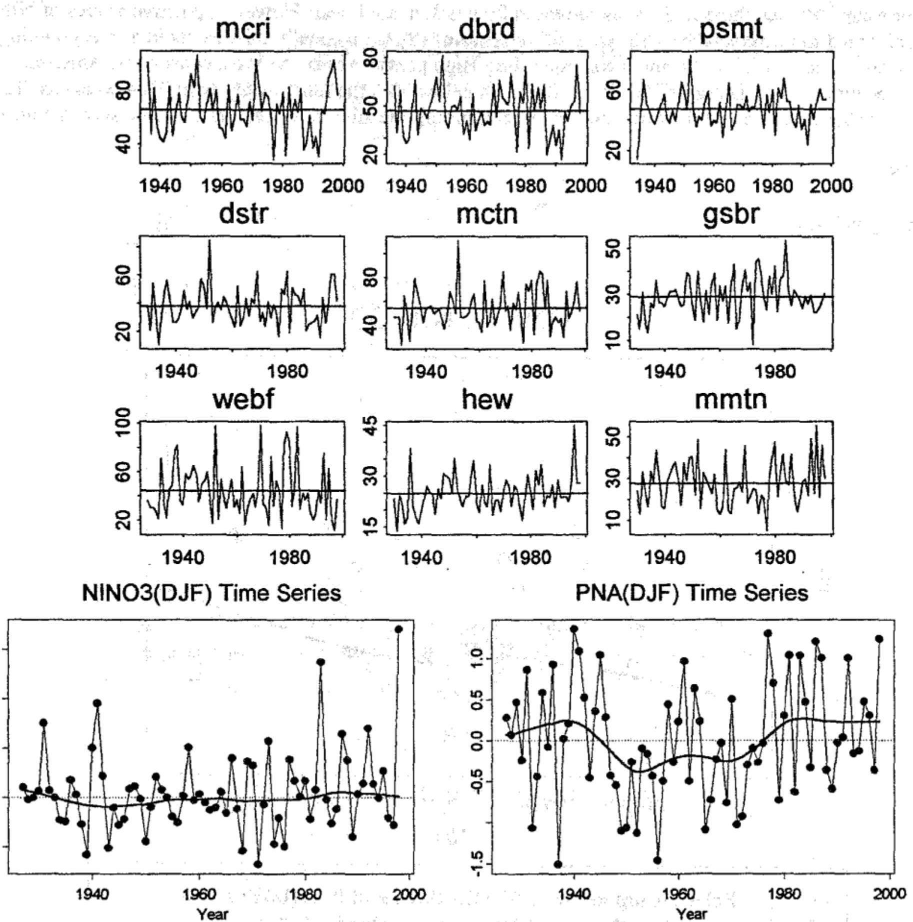

Figure 2. Time series of snow gauging stations snow water equivalent (cm) and NINO3(DJF) and PNA(DJF) and a LOWESS smooth (Cleveland and Devlin, 1988).

As noted earlier, changes in the climate state of the Tropical and N. Pacific regions both appear to affect Utah (Baldwin, 1997). A common El Niño index is the average SSTA in the equatorial Pacific Ocean region known as El Niño box 3 or NINO3, which is located between (5° N, 5° S) and (150°, 90° W) (http://nic.fb4.noaa.gov/data/cddb/cddb/sstoi.indices). The N. Pacific index used is the Pacific North American (PNA) index which essentially measures the location of the jet stream over N. America (Wallace and Gutzler, 1981; picture available at http://nic.fb4.noaa.gov/data/teledoc/pnampa.gif). The PNA index is only calculated back to 1950 and a longer period of record is available for snowpack. Therefore, the PNA index was extended by regression with a similar index in the region that is highly correlated, the Central North Pacific (Cayan and Peterson, 1989) index which had a long period of record but has not been updated since 1995.

The winter time average (December-February) of the monthly indices is used throughout this paper, since this period has the greatest impact on circulation patterns in the N. hemisphere. The time series of these indices and a smooth of the data is shown in Figure 2.

The relationship between these indices, as shown in Figure 3, is nonlinear. However, positive values of NINO3 (El Niño events) tend to be associated with the positive phase of PNA. Physically this results in a strengthening of the Aleutian Low in the North Pacific and a corresponding High pressure over the West coast of N. America resulting in lower precipitation in this region. When NINO3 falls below –0.5 the relationship with PNA weakens. The importance of both indices and their interaction in determining the amount of snowfall will be shown below.

RESULTS

Correlation Analysis

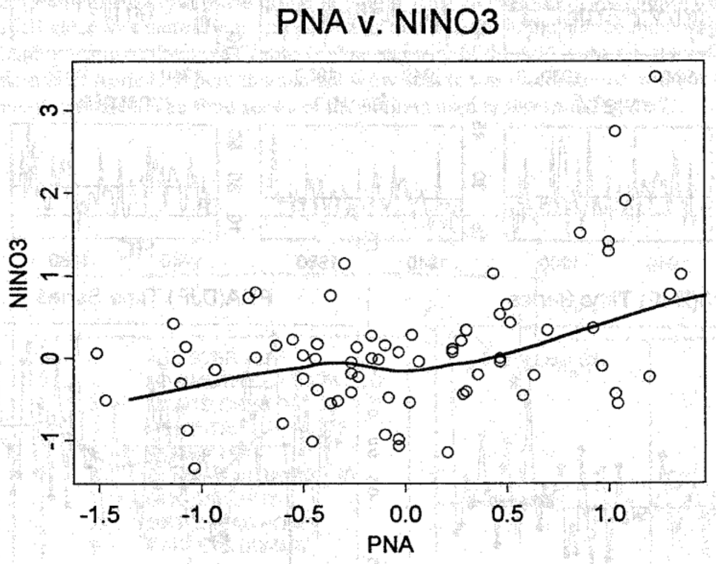

Figure 3. Relationship between NINO3(DJF) and PNA(DJF) and a LOWESS smooth of the data (Cleveland and Devlin, 1988).

The importance of both indices is demonstrated by correlation analysis. Figure 4 shows the correlation with NINO3 and PNA as a function of latitude. Several features are noted. (1) NINO3 is negatively correlated with SWE in N. Utah and positively correlated in S. Utah. This implies that El Niño events will have opposite results in N. and S. Utah. (2) The change in sign of the correlation with NINO3 occurs near 40° N, implying that El Niño events have no effect on snowpack in these areas. (3) PNA is more highly correlated than NINO3 in N. Utah, but does decrease with latitude. Note that even though NINO3 is not correlated with snowpack at 40°N, PNA is, and may be useful for prediction in this region. Both variables are likely to be important in N. and S. Utah. The correlation of the E. Utah stations (not shown) are similar to Mammoth-Cottonwood (mctn): near zero correlation with NINO3 and slightly negative correlation (about –0.22) with PNA.

The change in correlation with NINO3 and PNA over time at one station, Daniels-Strawberry (dstr), is shown in Figure 5. Note that February is correlated most strongly and the correlation with May is essentially zero. This is likely due to the frequent lack of snow in May, all other months with significant snowpack are correlated.

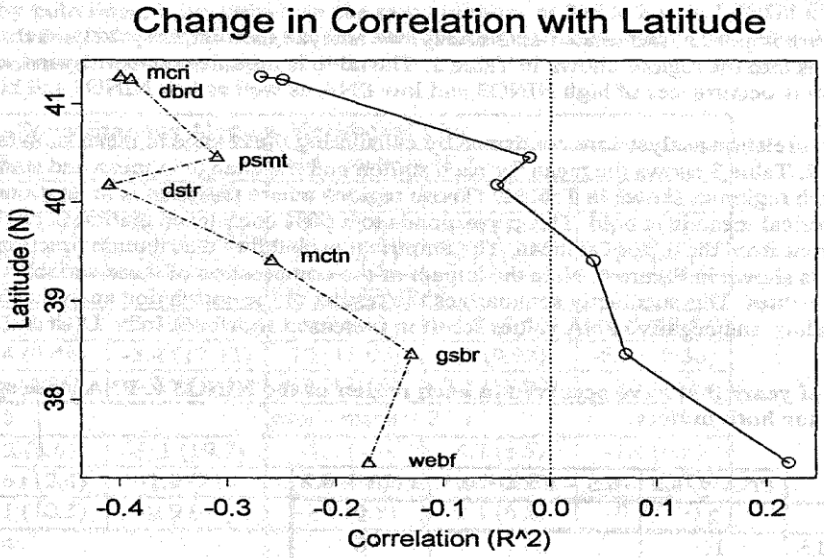

Figure 4. Correlation with NINO3 (solid) and PNA (dashed). Note the change in sign of correlation with NINO3 around 40 deg N Latitude.

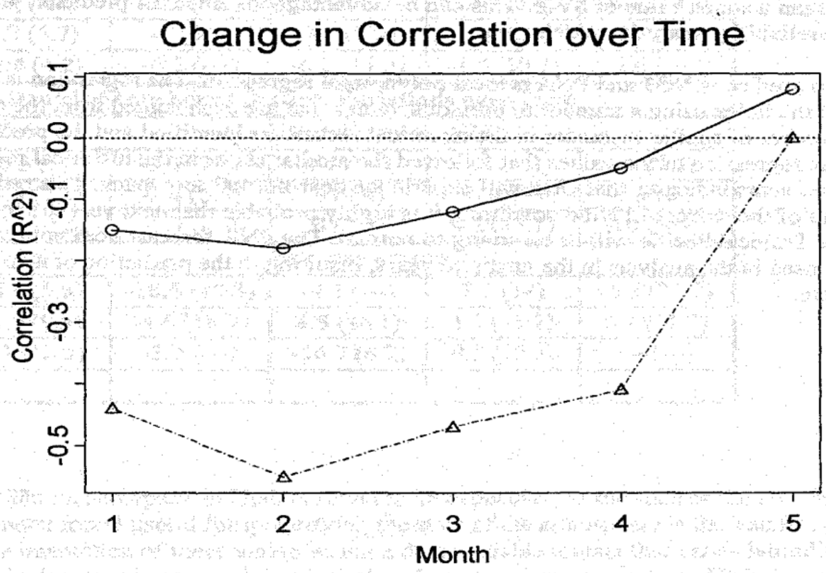

Figure 5. Correlation with NINO3 (solid) and PNA (dashed) over time, where month 1 corresponds to January, etc.

Stratification of Indices

Since both indices are important and related nonlinearly, we analyze their impact jointly. A threshold value is used to stratify the indices into the regions shown in Table 2. The table is organized to correspond with Figure 3. Note that there are very few occurrences of high NINO3 and low PNA as well as low NINO3 and high PNA.

The results of the correlation analyses are confirmed by calculating the change in mean snowfall for each region identified in Table 2. Table 3 shows the mean for each station and the change in mean and standard deviation (in parentheses) for each region as shown in Table 2. Those regions where the mean is at least one standard deviation away from the historical mean is in bold. This corresponds to a 68% confidence that mean of SWE that occurs in this region is different from the historical mean. The empirical probability distribution function for a few of the significant regions is shown in Figure 6. Note the impact of the combination of these variables on the probability of extreme snowpack values. This succinctly summarizes the results of the correlation analysis and the stratification, negative NINO3 values and negative PNA values result in increased snowpack in N. Utah and decreased snowpack in S. Utah.

Table 2. Number of years that have occurred in each region of the NINO3 v. PNA state space using -0.5 and 0.5 as a threshold for both indices.

	PNA < -0.5	**-0.5 < PNA < 0.5**	**PNA > 0.5**
NINO3 > 0.5	2	4	9
-0.5 < NINO3 < 0.5	11	25	8
NINO3 < -0.5	4	8	1

Prediction

The joint impact of NINO3 and PNA on SWE has now been identified. Thus, once these indices are forecast, the resulting probability distribution of snowpack can be identified through Table 3. The forecast is then a probability distribution rather than a stated value of SWE. This can be advantageous since the predicted probability distribution can be used in risk/reliability analysis models.

The method used to predict NINO3 and PNA is local polynomial regression. The regression is based on the historical record of the index using a number of previous values that are each lagged from the current value by an amount. A fixed number of similar instances in the historical record are identified and the prediction for the current state is based on the regression of the values that followed the similar states in the historical record. The resulting forecast for next two years indicates that Utah will experience near-normal snowpack. This rather unimpressive forecast is the result of the current El Niño condition; it is highly probable that next year the sea surface temperatures in the Tropical Pacific will be returning to normal. The PNA forecast does not cross the positive or negative threshold used in the analysis in the next two years, resulting in the prediction of near-normal conditions in the N. hemisphere.

Table 3. Change in mean and standard deviation (in parentheses) for each station studied. Each station's table, delineated by bold lines, is organized in the same manner as Table 2 with NINO3 divisions from top to bottom and PNA divisions from left to right. The standard deviation was not calculated for those regions with less than 3 snowpack measurements.

Snow Stations Along a Meridional Line					
mcri – mean = 65.8			dbrd - mean = 47.1		
-0.6 (---)	3.1 (18.8)	**-19 (16.7)**	4.2 (---)	-0.1 (10.7)	**-15.6 (12.5)**
8.6 (16.9)	-2 (14.3)	-4.7 (24.1)	8.2 (13)	-1.4 (12.3)	-1.7 (18.1)
18.8 (17.9)	6.6 (17.3)	-5.1 (---)	8.7 (14.1)	5.7 (14.3)	1.7 (---)
psmt – mean = 47.3			dstr - mean = 38		
-5.6 (---)	1.2 (8.54)	-5.4 (10.17)	8.7 (---)	-1.9 (7.63)	**-10.8 (10.54)**
9.8 (11.18)	-1.4 (9.44)	-5.4 (17.31)	12 (15.07)	-1 (9.92)	-5.3 (15.35)
3.2 (7.92)	2.6 (4.86)	-9.5 (---)	-1 (11.15)	2.1 (10.92)	3.7 (---)
mctn – mean = 54.5			gsbr - mean = 29.1		
8 (---)	0.2 (8.6)	-9.1 (19.7)	-1.2 (---)	4.7 (8.5)	-1.4 (6.5)
12.8 (18.6)	-2.6 (12.4)	-1.9 (22)	4.6 (9.4)	-1.3 (8.7)	-4.2 (7.7)
-0.8 (6.3)	-0.1 (10.3)	-0.9 (---)	-1.8 (5.8)	2.1 (6.3)	-0.7 (---)
webf – mean = 44.4					
25.7 (---)	9.4 (19.4)	-3.4 (24.5)			
15.6 (24.4)	-5.7 (17.1)	-4.9 (21.7)			
-14.6 (7.2)	-0.1 (20.4)	13.8 (---)			
Snow Stations in Eastern Utah					
hew – mean = 25			mmtn - mean = 27.9		
-6 (---)	1.9 (3.5)	-2.2 (5.3)	7.9 (---)	3.4 (16.4)	-6.2 (10.7)
3.6 (4.5)	0.7 (5.7)	-1 (6.7)	7.1 (8.9)	-1 (10.3)	-2.7 (9.4)
0.8 (4.1)	-2.4 (4.2)	-6.2 (---)	-0.5 (11.5)	-1.4 (10.7)	1.6 (---)
Daniels-Strawberry Station Variations over Time					
dstr.jan - mean = 13.9			dstr.feb - mean = 24.4		
4.1 (---)	0.6 (5)	-5.3 (7.6)	9.8 (---)	-1.1 (5.1)	**-9 (7.5)**
6.6 (6.2)	-3.3 (7.1)	-2.4 (8.5)	8 (8.4)	-1.4 (9)	-5.9 (8.3)
5.3 (5.6)	4.1 (10.2)	-2.7 (---)	**8 (7.8)**	4.2 (15.1)	-10.2 (---)
dstr.mar - mean = 33.8			dstr.may - mean = 21.5		
13.4 (---)	-3.6 (5.9)	**-10.5 (10.3)**	-4.1 (---)	3.3 (14)	-6.9 (21.7)
9.4 (10.7)	-1.9 (9.4)	-4.6 (16.7)	8.8 (18.1)	1.1 (15.2)	0.4 (21.3)
3.3 (8)	5.3 (12.5)	-3.3 (---)	**-16.7 (6.7)**	0.5 (15.6)	--- (---)

CONCLUSIONS

The impact of El Niño on snowpack in Utah is found to be dependant on the state of the atmospheric wave patterns (jet-stream). One index found useful for quantifying the state of the atmosphere is the Pacific North American (PNA) pattern. The interaction of these variables has a demonstrable impact that varies latitudinally. Generally El Niño events result in decreased snowpack in N. Utah and increased snowpack in S. Utah, however when the PNA index is near zero during the event, the impact of El Niño across the state is reduced (see Table 3). When extreme phases of both the NINO3 and PNA indices are observed the impact is significant (see Figure 6), for example when both indices are strongly negative, corresponding to La Niña conditions and an anomalous high pressure in the N. Pacific, SWE is nearly 20 cm above normal at the Monte-Cristo gauging station, and 15 cm below normal at Webster Flat.

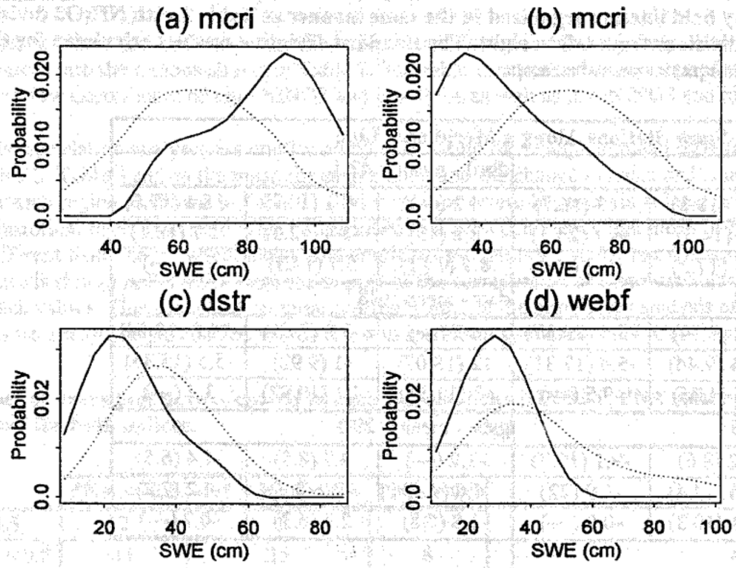

Figure 6. Empirical probability distribution functions (pdf) calculated using averaged shifted histograms (Scott, 1992) for 4 cases highlighted in Table 3. Dashed line is the pdf for all data, the solid line is for the subset of the data indicated. (a) Monte-Cristo when NINO3 < -0.5 and PNA < -0.5 (lower left corner in Table 3), (b) Monte-Cristo when NINO3 > 0.5 and PNA > 0.5 (upper right corner in Table 3), (c) Daniels-Strawberry when NINO3 > 0.5 and PNA > 0.5 (upper right corner in Table 3) and (d) Webster Flat when NINO3 < -0.5 and PNA < -0.5 (lower left corner in

The forecasts for SWE in Utah for the next two years indicate that near-normal conditions will prevail, based on the predicted values for NINO3 and PNA, which are not predicted to be at either extreme in the next two years. This forecast is similar to what occurred after the large 1983 and 1973 El Niño events, where near-normal conditions generally prevailed in N. Utah, which provides a measure of confidence in this forecast. Further research will be done to improve these forecasts in order to improve water resource management.

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