PREDICTING SNOWPACK USING THE SOUTHERN OSCILLATION INDEX

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Abstract

The El Niño-Southern Oscillation phenomenon is a known factor influencing the climate and streamflow patterns in the western United States. Previous studies have incorporated the Southern Oscillation Index (SOI) into statistically-based streamflow forecast procedures. This paper highlights some problems those studies have identified and discusses a new forecast procedure. Since the majority of the water supply in the Northwest starts as snow in the mountains during the winter months, snow water equivalent (SWE) is used as the dependent variable in this new non-statistical forecast procedure. This procedure uses the SOI to predict seasonal precipitation as measured by SWE at a designated site. The SOI data through June is used in mid-July to prepare a forecast of the October through December snow accumulation. Similarly, the SOI data through September is used in mid-October to prepare a forecast of the January through March snow accumulation. The procedure compares the changing SOI over time to historical SOI and SWE patterns. The results show that it is possible to predict future SWE for the Vienna Mine Snotel site in southern Idaho using current year SOI data. The forecast would be for "near-average," "above near-average," or "below near-average" snow accumulation during the period.

Introduction

The El Niño-Southern Oscillation (ENSO) phenomenon is a known factor influencing the climate patterns affecting the western United States (Koch et al, 1991; Redmond and Koch, 1991; Redmond and Cayan, 1994). This ocean phenomenon affects the sea surface temperatures (SST) in the Pacific Ocean. The temperatures in the eastern Pacific Ocean, in turn, strongly influence the temperature and movement of the winds and precipitation moving easterly across the United States. If the SST is in a stable pattern, the climate patterns will be stable. As the SST changes, the large-scale atmospheric patterns also change (Redmond and Koch, 1991). With these changes, the storm tracks shift, causing other locations to experience the heavier or lighter precipitation and warmer or cooler temperatures associated with the storm track patterns.

These ocean conditions are stable enough to cause consistency in climate patterns throughout entire seasons. Koch and others (Koch et al, 1991) have investigated procedures to predict the streamflow in the Pacific Northwest resulting from the various ENSO conditions. Using the Southern Oscillation Index (SOI) as a measure of the strength of the ENSO condition, Garen (1992) and others at the Natural Resources Conservation Service (NRCS) have modified several existing statistical forecast procedures to incorporate the ENSO phenomenon.

This paper is limited to discussions of a method of using the SOI information to predict the overall level of precipitation at a given location. No effort is made to describe the actual SST or storm track patterns that will yield that precipitation.

The hypothesis of this research is that the recent change in SOI and the rate of change of SOI can be combined with the actual SOI value to create a more accurate indicator of climate conditions and SWE accumulation. The SOI influence on SST and storm track patterns takes time to occur, which allows a lead time in the forecast of SWE accumulation.

This differs from the work by Garen and others at the NRCS (Garen, 1992) which uses SOI data averaged for various combinations of summer months to predict the following year's streamflow volumes. By using data from shorter periods throughout the year and looking for patterns within that data, this method produces forecasts for SWE accumulation during shorter, discrete periods.

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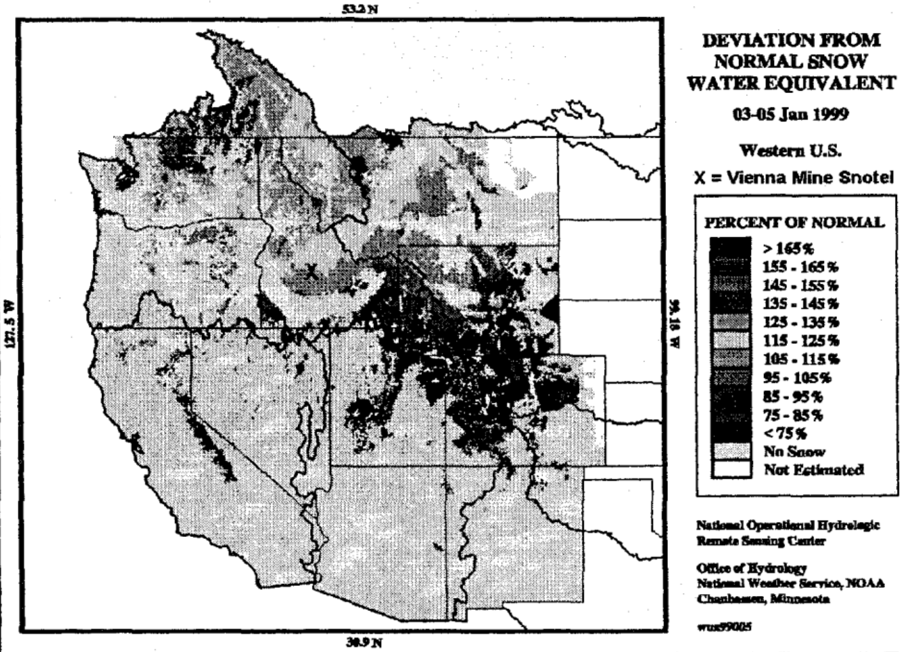
The Vienna Mine Snotel site is located in the mountains at the northwestern edge of southern Idaho's Snake River Plain, as shown in Figure 1. This mountain range marks the southern edge of the region for which Garen and others (Garen, 1992) have found the best statistical correlation between SOI and streamflow in the Pacific Northwest. South of these mountains, the correlations they have found are not as accurate.

Figure 1
Vienna Mine Snotel Location



The accuracy of those modified forecast procedures has been limited because of a relatively poor correlation between the SOI and the streamflow in the Pacific Northwest. As shown in Figure 2, when the SOI is negative, streamflow volumes tend to be lower. Strongly positive SOI values tend to indicate higher streamflow volumes. However, negative SOI values can sometimes indicate higher streamflow than certain positive SOI values.

Figure 2
SOI vs. Streamflow
1970-95

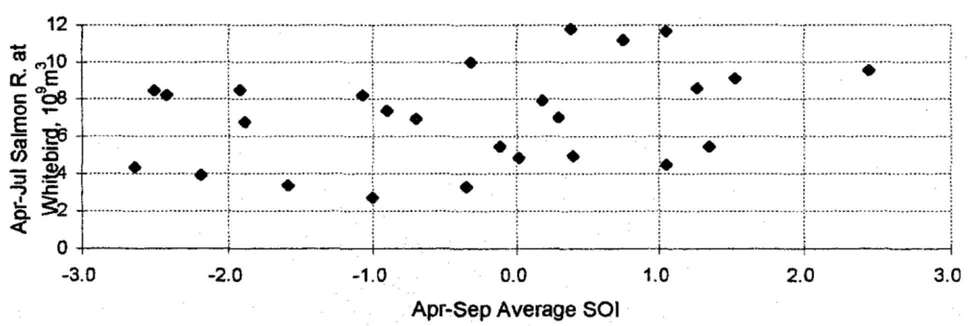


Figure 3 shows that the snow water equivalent (SWE) at the Vienna Mine Snotel site and the streamflow in the Salmon River at Whitebird have much better correlation than the SOI vs. streamflow at Whitebird that was shown in Figure 2.

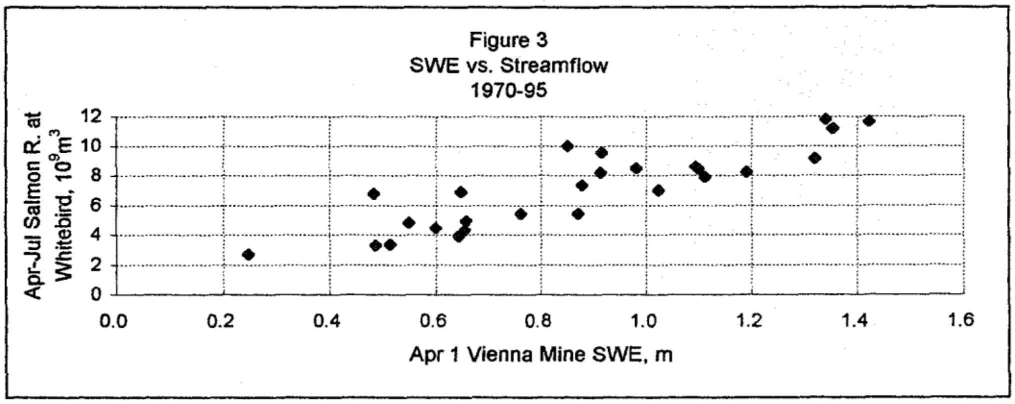
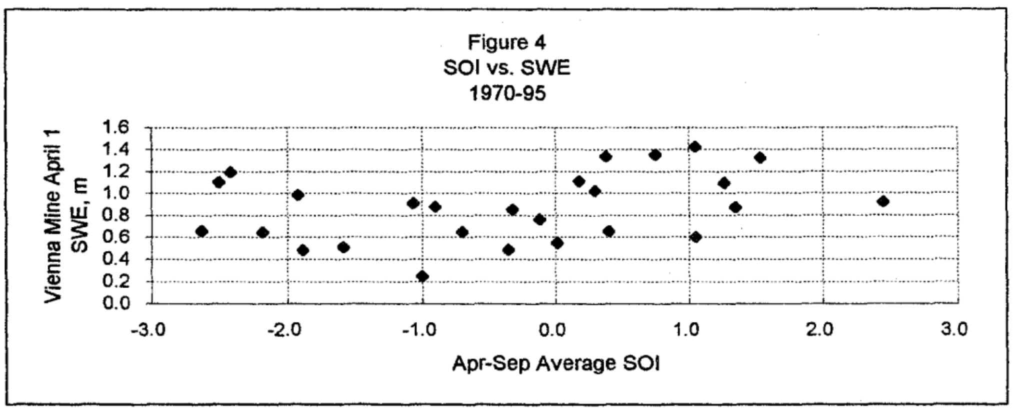


Figure 4 shows that the relationship between SOI and Vienna Mine SWE is similar to the SOI vs. streamflow relationships — not particularly good.



Combined, Figures 2, 3, and 4 illustrate that a significant portion of the variability in the SOI vs. streamflow relationship can actually be occurring in the SOI vs. SWE portion of the relationship.

Though Vienna Mine is at the edge of the region with better correlation, the poor correlation observed between SOI and SWE indicates a possible starting place to improve streamflow forecasts. Increasing the accuracy of the SWE forecasts using SOI data is the objective of this research.

Procedure

This section describes a new procedure for preparing a forecast. Two forecast periods are used. They are the October through December (O-D) and the January through March (J-M) portions of winter. In mid-July, the O-D forecast is prepared using SOI data through June. In mid-October, the J-M forecast is prepared using SOI data through September. The steps remain the same for each forecast, while the dates for which the data is included vary.

1. Obtain the monthly SOI data from the internet (address http://nic.fb4.noaa.gov/data/cddb/cddb /soi) or equivalent data from other sources as desired. Use the non-standardized data to have the most variation in the values. This variation makes it easier to pick out subtle changes in the data. Since this

is a non-statistical procedure that does not rely on plotting multiple data sets, non-standardized data works the best.

2. Select the appropriate data considering the following interdecadal influences. Recent research into climate patterns by Mantua and others (Mantua et al, 1997) shows evidence of a recurring pattern of interdecadal climate variability affecting ecological systems. This pattern is marked by significant shifts in many environmental variables. The most recent of these shifts occurred in 1976 (Ebbesmeyer et al, 1991).

The forecast procedure described in this paper has significantly improved accuracy if the SOI data used for observed conditions is limited to the period of summer, 1976 to the present. This uses SWE accumulation data for water years 1977 to the present. Problems associated with limiting the data in this way are discussed later in the recommendations.

3. Select the month for forecast preparation. The examples given use October as the forecast date. Accordingly, data from September is used as the last available for the forecast.

4. Arrange the monthly SOI data chronologically as shown in columns 1 through 3 of Table 1. For all years, include the data for at least six months preceding the forecast date in the chronological listing of all the data (i.e., April through September).

Table 1
SOI and SWE Data

Year	Month	Non-Std Anomaly SOI	2-Mon Avg SOI	J-M SWE Accum, mm	J-M Accum minus Average, mm
1976	APR	0.2	1.2		
	MAY	0.3	0.3		
	JUN	-0.2	0.1		
	JUL	-1.9	-1.1		
	AUG	-2.2	-2.1		
	SEP	-2.2	-2.2		
	OCT	0.4	-0.9		
	NOV	1.1	0.8		
	DEC	-1.0	0.1		
1977	JAN	-1.1	-1.1		
	FEB	1.7	0.3		
	MAR	-2.1	-0.2		
	APR	-1.3	-1.7	246	-221
	MAY	-1.4	-1.4		
	JUN	-2.5	-2.0		
	JUL	-2.5	-2.5		
	AUG	-2.2	-2.4		
	.	.	.	.	.
	.	.	.	.	.
	.	.	.	.	.
	NOV	-0.1	-0.3		
	DEC	-1.3	-0.7		
1996	JAN	1.7	0.2		
	FEB	-0.2	0.8		
	MAR	1.2	0.5		
	APR	1.1	1.2	579	112
	MAY	0.2	0.7		
	JUN	1.6	0.9		
	JUL	1.0	1.3		
	AUG	0.7	0.9		
	SEP	1.0	0.9		
	OCT	0.7	0.9		
	NOV	-0.3	0.2		
	DEC	1.3	0.5		
1997	JAN	0.8	1.1		
	FEB	2.6	1.7		
	MAR	-1.9	0.4		
	APR	-1.4	-1.7	442	-25
			Average	467	
			25% avg	117	

5. For each month in the record, compute the two-month sliding average of the SOI values. Show the answer on the same line as the second value used in the computation. For example, compute the average of August's and September's SOI and show the results on the line for September. Show the results as shown in column 4 of Table 1.

6. Add the J-M SWE accumulation data for each year to column 5 of Table 1 next to the appropriate April. Compute the average J-M SWE accumulation for the 1977 through present period. As shown in column 6 of Table 1, compute the difference between each SWE accumulation value and the average accumulation. Maintain the sign of the difference (above average years will be positive while below average years will be negative).

7. Copy selected SOI data from Table 1 as shown in columns 1 through 3 of Table 2. Add to this table the data described in steps 8 through 12.

Table 2
Parameters for forecast preparation for Jan-Mar accumulation in chronological sequence

Forecast For WY	Prev Sep Non-Std Anomaly SOI	Prev Sep 2 Mon Avg SOI	Delta Last Mon SOI	Delta Prev Mon SOI	0-2 Month Delta 2 Mon Avg	2-4 Month Delta 2 Mon Avg	J-M SWE Accum (mm) minus Avg if |X-Avg|>25%	J-M SWE Accum (mm) - Average
1977	-2.2	-2.2	0.0	-0.3	-1.2	-1.3	-221	-221
1978	-1.6	-1.9	0.6	0.3	0.6	-1.2		-84
1979	0.1	0.1	0.1	-0.7	-0.6	0.0		-23
1980	0.2	-0.4	1.2	-3.2	-1.8	1.5	305	305
1981	-0.9	-0.5	-0.9	0.4	0.1	0.6	-122	-122
1982	0.6	0.6	0.0	-0.6	-0.9	1.3	259	259
1983	-3.3	-3.7	0.7	-0.8	-0.8	-2.2	226	226
1984	1.7	0.7	2.0	1.0	1.6	-0.2	-132	-132
1985	0.2	0.2	0.1	0.0	0.8	-0.7	-234	-234
1986	-0.1	0.5	-1.2	1.5	1.5	-2.0	328	328
1987	-1.0	-1.3	0.6	-1.8	-2.0	1.1	-135	-135
1988	-1.9	-2.2	0.6	0.3	0.6	0.1		-66
1989	3.4	2.8	1.2	0.5	2.2	0.0		64
1990	0.9	-0.2	2.2	-2.7	-1.3	-1.2		-33
1991	-1.3	-1.2	-0.3	-1.8	-1.5	-0.5	-142	-142
1992	-2.9	-2.2	-1.5	-1.2	-1.6	1.5	-272	-272
1993	0.0	0.0	0.0	1.3	1.6	-0.5		74
1994	-1.3	-1.9	1.1	-0.6	0.2	-0.2	-145	-145
1995	-3.0	-3.0	0.0	-0.1	-0.8	0.1	257	257
1996	0.5	0.2	0.6	-0.7	0.1	1.6		112
1997	1.0	0.9	0.3	-0.3	-0.5	0.7		-25

8. Compute the change in SOI from the previous August to the previous September for each year. Show the results in the column titled Delta Last Month SOI as shown in Table 2.

9. Compute the change in SOI from the previous July to the previous August for each year in the record. Show the results in the column titled Delta Previous Month SOI as shown in Table 2.

10. Compute the change between the SOI two-month sliding averages for 0-2 months and 2-4 months leading up to the forecast date for each year of data. For example, compute the difference between the August-September and June-July averages. Label this the 0-2 month delta of the two-month averages. Repeat this process for the 2-4 month delta (June-July minus April-May) of the two-month averages. Show the results as shown in columns 6 and 7 of Table 2.

11. Determine if the historical J-M SWE accumulation shown in column 5 of Table 1 was near-average, above near-average, or below near-average. "Near-average" is defined as average $\pm$ 25 percent of average. If the absolute value of the J-M SWE accumulation minus average (as shown in column 6 of Table 1) is greater than 25 percent of average accumulation, show the SWE accumulation minus average in column 8 (J-M SWE Accumulation minus Average if |x-avg|>25%) of Table 2. If the absolute value of the SWE minus average is less than or equal to 25 percent of average, show a blank to indicate near-average. The values in this column will be positive if the SWE accumulation is above near-average. They will be negative if the SWE accumulation is below near-average. They will be blank if the SWE accumulation is near-average. Since no data exists for the forecast SWE accumulation, enter "FCST" or some other identifier for the current year.

12. For sorting purposes later, the J-M SWE accumulation minus the average SWE accumulation for all years (from column 6 of Table 1) is shown in column 9 (J-M SWE Accumulation minus Average) of Table 2.

Table 2 should now contain all the data necessary to prepare a forecast. The basic data consists of the year identifying number, the previous September SOI, and the previous September two-month average SOI. Also included are the four parameters to describe the changes in the SOI: The delta of the last month's SOI, the delta of the previous month's SOI, the 0-2 month delta of the two-month average SOI, and the 2-4 month delta of the two-month average SOI. The snow data is shown as the J-M SWE accumulation minus average if the absolute value of that difference is greater than 25 percent of the average SWE. Also, shown is the snow data as the J-M SWE accumulation minus the average SWE accumulation.

13. Sort the data in Table 2 in descending order using the SOI column (column 2) as the first key and the accumulation minus average column (column 9, also in descending order) as the second key. The results will look like Table 3. Note that the year being forecast will be included in the historical data in the sorted table.

Table 3
Parameters for forecast preparation for Jan-Mar accumulation sorted in decreasing SOI and decreasing J-M SWE accumulation minus average sequences

Forecast For WY	Prev Sep Non-Std Anomaly SOI	Prev Sep 2 Mon Avg SOI	Delta Last Mon SOI	Delta Prev Mon SOI	0-2 Month Delta 2 Mon Avg	2-4 Month Delta 2 Mon Avg	J-M SWE Accum (mm) minus Avg if |X-Avg|>25%	J-M SWE Accum (mm) - Average
1989	3.4	2.8	1.2	0.5	2.2	0.1		64
1984	1.7	0.7	2.0	1.0	1.6	-0.2	-132	-132
1997	1.0	0.9	0.3	-0.3	-0.5	0.7		-25
1990	0.9	-0.2	2.2	-2.7	-1.3	-1.2		-33
1982	0.6	0.6	0.0	-0.6	-0.9	1.3	259	259
1996	0.5	0.2	0.6	-0.7	0.1	1.6		112
1980	0.2	-0.4	1.2	-3.2	-1.8	1.5	305	305
1985	0.2	0.2	0.1	0.0	0.8	-0.7	-234	-234
1979	0.1	0.1	0.1	-0.7	-0.6	0.0		-23
1993	0.0	0.0	0.0	1.3	1.6	-0.5		74
1986	-0.1	0.5	-1.2	1.5	1.5	-2.0	328	328
1981	-0.9	-0.5	-0.9	0.4	0.1	0.6	-122	-122
1987	-1.0	-1.3	0.6	-1.8	-2.0	1.1	-135	-135
1991	-1.3	-1.2	-0.3	-1.8	-1.5	-0.5	-142	-142
1994	-1.3	-1.9	1.1	-0.6	0.2	-0.2	-145	-145
1978	-1.6	-1.9	0.6	0.3	0.6	-1.2		-84
1988	-1.9	-2.2	0.6	0.3	0.6	0.1		-66
1977	-2.2	-2.2	0.0	-0.3	-1.2	-1.3	-221	-221
1992	-2.9	-2.2	-1.5	-1.2	-1.6	1.5	-272	-272
1995	-3.0	-3.0	0.0	-0.1	-0.8	0.1	257	257
1983	-3.3	-3.7	0.7	-0.8	-0.8	-2.2	226	226

14. The actual forecast is prepared by comparison of the forecast year to historical conditions. The SOI value is the first indicator used. Select the historical data having an SOI value that is within ±0.5 of the current year's value. This determines a block of similar years that may be used to develop a forecast. If none of the SOI values are within this tolerance, then preparing the forecast becomes an exercise in extrapolation, which is much more difficult. Although it cannot be easily quantified, the uncertainty increases significantly when extrapolation is necessary.

15. From this block of similar years, select the historical data for which the two-month average of the SOI is also within ±0.5 of the current year's value. These are the historical years that may be considered similar to the forecast year. If none of the historical values are within this tolerance, a forecast is still possible. However, the uncertainty of the forecast increases.

16. Within the selected block of data, compare the rest of the data parameters available. Determine patterns in the data. For example, is the SOI decreasing, steady, or increasing? How fast is the SOI changing? When does the change in SOI go from positive to negative or from negative to positive? How fast does the change in SOI change from positive to negative or from negative to positive?

As an example, look at 1988 data shown in Table 3. The September SOI is -1.9. This compares favorably with 1978 (SOI = -1.6) and 1977 (SOI = -2.2). The two-month averages are also comparable as described above. The other parameters show that the deltas for the last month, the previous month, and 0-2 month averages (columns 4 through 6) for both 1978 and 1988 match identically. The same deltas for 1988 and 1977 do not match well at all. In 1977, the SOI was decreasing but the change was slowing while in 1978 and 1988 the SOI was increasing steadily. A forecast for 1988 would be similar to 1978, that is, a forecast of near-average SWE accumulation (column 8 of Table 3). Note that the 2-4 month delta of the two-month average (column 9) was not used. This data is not used all the time. It seems to be of most value for years when extrapolation from historical data is necessary.

If the SOI matches and the two-month average of the SOI does not match, the forecast preparation can become more difficult. For example, a year like 1980 could be the forecast year using the data shown in Table 3. The SOI is 0.2, which compares well with 1982 (SOI = 0.6), 1996 (SOI = 0.5), 1985 (SOI = 0.2), 1979 (SOI = 0.1), 1993 (SOI = 0.0), and 1986 (SOI = -0.1). The two-month average SOI values, however, only match for 1979 (Avg = 0.1) and 1993 (Avg = 0.0). Neither 1979 nor 1993 match well for the other parameters so the confidence is high that the forecast is not near-average. The four parameters do not match well for 1986 so the forecast might be "not wet," but the confidence would be lower. Looking at 1985, the four parameters do not match well, so with lower confidence, the forecast might be "not dry." The four parameters do not match well for 1996 so, again, the forecast is probably not near-average. Recognizing that the confidence will be less than ideal, the four parameters for 1982 are the closest for the general trends. In the 2-4 month averages, 1980 is moving strongly positive like 1982. The 0-2 month averages are both moving negative. The previous month SOI values are both moving negative but at significantly different rates. In the last month, the 1980 SOI has started moving positive while the 1982 SOI stalled, leading to the uncertainty. Overall, the data indicates that the likelihood is highest that 1980 would be wet, like 1982 so the forecast would be for above near-average accumulation.

A third example in the sample data is when the SOI does not match other years. Assume a year like 1984 is the year being forecast, again using the data shown in Table 3. The September SOI (1.7) does not match either 1989 (SOI = 3.4) or 1997 (SOI = 1.0). The two-month average of the SOI matches 1997 (0.7 vs. 0.9), but this does not help since the SOI does not match. Extrapolation beyond the current data set is necessary. In 1989, the SOI was moving positive at an unstable rate (columns 4 through 6). In 1997, the SOI was unsteady, moving negative and positive. Both years had near-average SWE accumulation for the J-M period. However, neither year matches the parameters for 1984. In 1984, the SOI was moving positive more strongly than in 1989. Since the SOI in 1984 was much less than in 1989, the storm tracks would not be expected to produce the same SWE accumulation as in 1989, even with the stronger positive movement of the SOI. Therefore, the SWE accumulation in 1984 would likely be either above or below near-average. When the SOI was between 0.2 and 0.9 and was unstable in 1990, 1982, 1996, and 1980, the SWE accumulation tended to be near-average to above near-average. As the SOI and change in SOI move more positive and the deltas become stronger, the storm tracks will likely shift causing the SWE accumulation to move away from above near-average conditions. The forecast, then, would be for below near-average. However, confidence in the forecast would be relatively low due to the extrapolation from the limited period of record used for comparison. Given 1984 numbers, future forecasts for similar SOI values and patterns will have improved confidence.

Testing of Procedure

To test an early version of the procedure, 11 of 46 years of observed SWE data were arbitrarily removed from the data tables. "Forecasts" of the missing data were prepared. Using the entire period of record as the basis, disregarding the interdecadal oscillation influences, the procedure produced accurate forecasts of near-average, above near-average or below near-average accumulation 64 percent of the time.

When the interdecadal oscillation influences were included in the procedure, the size of the observed data tables decreased substantially to 21 years. Due to the subjective nature of the procedure, familiarity with the data prevented an accurate, objective test of the procedure using the reduced data tables. When viewed subjectively, however, the patterns of changes in the SOI data appeared to be much more consistent.

In a real-time test of the procedure, SWE accumulation forecasts were prepared for the 1997-98 and 1998-99 winters. The forecasts and results are shown in Table 4. In this test of four forecasts, the procedure was correct 25 percent of the time.

Table 4
Test results from real-time application of the procedure

Forecast period	Forecast SWE Accumulation, mm	Actual SWE Accumulation, mm	Assessment
O-D, 1997	269<A<452	244	Fcst was High
J-M, 1998	A<351	538	Fcst was Low
O-D, 1998	251<A<455	404	Correct
J-M, 1999	592<A	475	Fcst was High
		Percent Correct	25 percent

The results of the recently completed real-time test were disappointing. Preliminary review of the data indicates the forecasts were quite close to being accurate. Further study of the discrepancies is being conducted.

Recommendations

This work is based on the SWE data for one site and is, therefore, very preliminary. Further tests of this procedure are needed to determine whether it will provide accurate forecasts for areas farther south in Idaho, Nevada, and Utah. Similarly, the procedure may be useful to estimate the precipitation throughout the western U.S., since the climate patterns all tend to be related to the ENSO conditions.

Some problems became apparent during this work. One is the question of lead time. Are the SOI data through June and through September the best choices for the respective snow accumulation seasons? They are the best found so far, but since we would like the longest lead time possible in climate forecasting, it may be worthwhile to investigate other, particularly earlier, forecast dates.

Second, to prepare a forecast for a year that does not have similar historical data, extrapolations from the data are necessary. These tend to be very difficult and confidence in these forecasts is much lower. Further analysis may produce guidelines to help understand the ocean conditions and corresponding storm tracks in these situations. Alternatively, development of a mathematical method to describe the patterns in the SOI data might improve the accuracy by illustrating consistencies in the data for differing SOI values. This would serve to reduce the subjectivity in the forecast preparation. It may also reduce the time necessary to prepare a forecast.

Third, problems occur when the interdecadal oscillation influences are included in the procedure. The duration of the period of record used to compare conditions is significantly limited. This restricts the number of historical patterns available for comparison. Similarly, the observed SOI and SWE data for forecast preparation is skewed to drier conditions for the current interdecadal oscillation conditions. This will give greater uncertainty in the forecast when wetter conditions occur. Over time, a longer record may alleviate this problem.

The user of this procedure must be cognizant of the status of the interdecadal oscillation. The next time the climate shifts in this interdecadal manner, this forecast procedure will not recognize the shift. Under the new conditions, the procedure will likely give erroneous SWE forecasts until the appropriate observed data is used.

Conclusions

The procedure described here uses the SOI to predict seasonal precipitation as measured by SWE accumulation at a designated site. By comparing the changing SOI over time to historical SOI and SWE accumulation patterns, the procedure predicts future SWE accumulation for the Vienna Mine Snotel site in southern Idaho using current year SOI data. The mid-July forecast of the October through December snow accumulation and the mid-October forecast of the January through March snow accumulation give the user an estimate of snow availability for use in streamflow forecasting procedures or for other uses. The forecast would be for "near-average," "above near-average," or "below near-average" snow accumulation during the period. Use of this procedure at other Snotel sites may allow forecasting of water availability in other basins.

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