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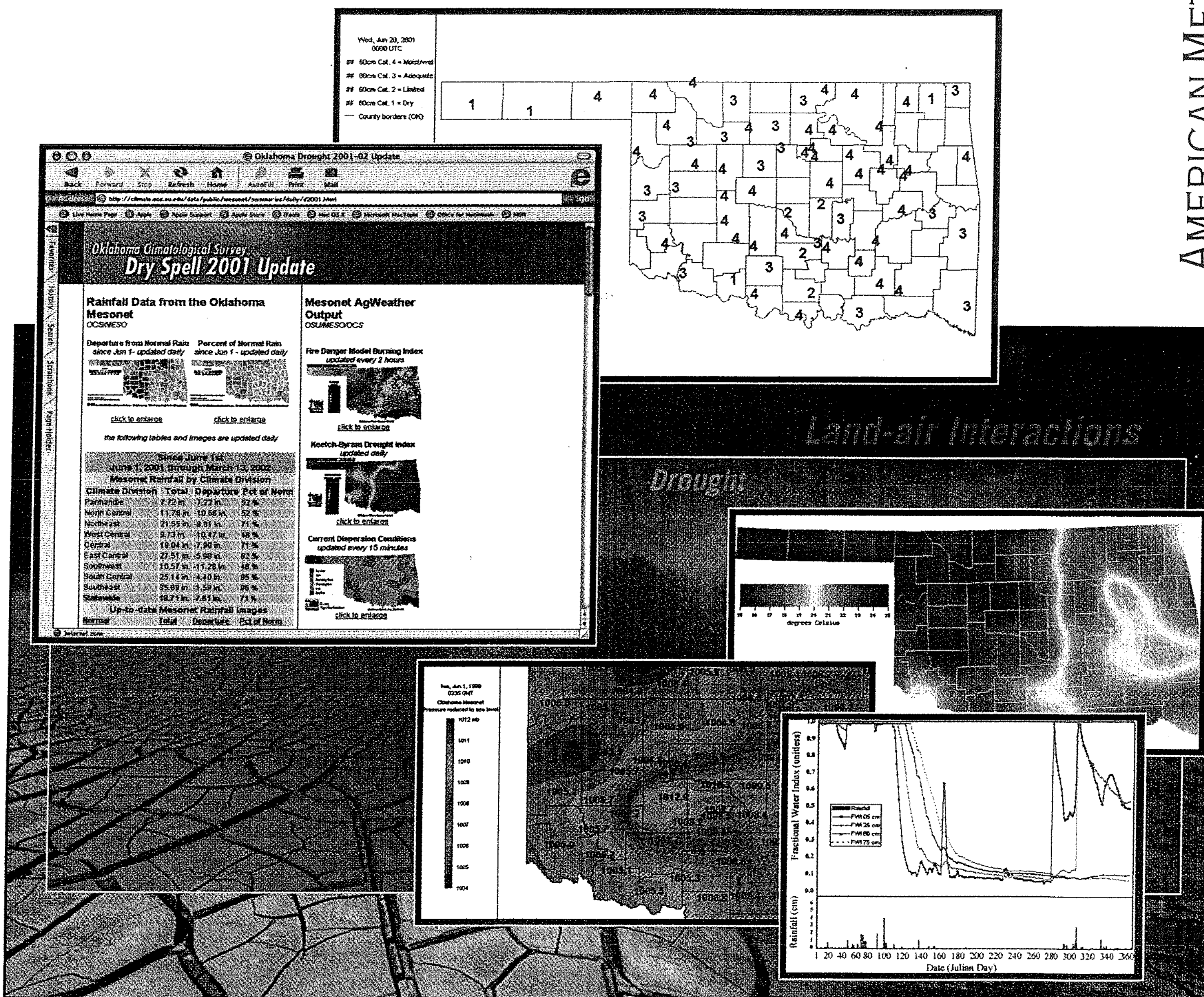

Oklahoma Mesonet

5.3 TELECONNECTION IMPACTS ON REGIONAL DAILY PRECIPITATION MODELING

Tim Keefer* and Dave Goodrich
USDA-ARS-Southwest Watershed Research Center, Tucson, Arizona

1. ABSTRACT

El Nino-Southern Oscillation is known to have significant impact on United States hydroclimatology. The warm and cool phases of ENSO, El Nino and La Nina respectively, tend to have opposite effects in certain regions of the western US. These effects are also in opposition between the Pacific Northwest and the Southwest US. This non-periodic forcing by ENSO is responsible for some of the observed interannual variability of precipitation. A stochastic daily precipitation model is used to study the impact of ENSO on model parameters and model output. The Southern Oscillation Index, as a surrogate for ENSO, is used to "perturb" the parameters of a daily precipitation model for both the occurrence process and daily amount. Variances of seasonal precipitation amounts simulated by three parameterizations are compared among each other and to observed precipitation. Examples of seasonal precipitation simulations conditioned on historic SOI are presented as an application of this technique. Extensions to other regions and using other teleconnections are also discussed.

2. BACKGROUND

Ocean-atmospheric teleconnections, such as the El Nino Southern Oscillation (ENSO), are known to impact weather throughout the world. Redmond and Koch (1991) among others have identified the hydroclimatologic response to ENSO in the western US and also observed that the SW US and far NW US respond oppositely to the two phases of ENSO (El Nino and La Nina). Generally, during the winter of a warm El Nino phase there is higher (lower) than normal precipitation in the southwest (northwest), while during the winter of the cool La Nina phase there is lower (higher) than normal precipitation in the southwest (northwest). Woolhiser et al. (1993) linked the parameters of a daily precipitation model to ENSO by 'perturbing' the parameters with the Southern Oscillation Index (SOI), a monthly statistic of differences in tropical Pacific sea level atmospheric pressures. They showed that the parameters of a daily precipitation model are statistically and identifiably sensitive to ENSO for the southwestern US.

This paper is an application and extension of the work of Woolhiser et al. (1993). We apply their methodology to two stations in the semiarid southwest and two in the extreme northwest US. We extend the work by investigating the seasonal differences in ENSO effect on model parameters.

*Corresponding author address: Tim Keefer, USDA-ARS-SWRC, 2000 E. Allen Road, Tucson, AZ 85719
email:keefer@tucson.ars.ag.gov

3. DATA

Precipitation data for a 30 year period (1961 - 1990) from four stations located in Arizona and Oregon were selected for this analysis. These are a subset of a collection of over 200 US locations that the USDA-ARS-Northwest Watershed Research Center has quality checked for simulations with the model Generation of Weather Elements for Multiple Applications (GEM), see **http://www.nwrc.ars.usda.gov/models/gem/**. Site names, locations and annual precipitation statistics are given in **Table 1.**

The Southern Oscillation data are from **http://www.cpc.ncep.noaa.gov/data/indices/**, the NOAA ENSO web-site. Shown in **Figure 1**. are the October, November and December 3-month average SOI and the following February, March and April total precipitation for Tombstone AZ, visually underscoring the suggested link between SOI and subsequent precipitation as noted above.

4. MODEL

4.1 Occurrence

A first order, two state Markov chain is used to describe the daily precipitation occurrence process with transition probabilities P_{ij} on day t:

$$P_{ij}(t) = P[X(t) = j \mid X(t-1) = i] \quad i,j = 0,1 \qquad (1)$$

where :

$X(t) = 0$ if day t is dry,
$X(t) = 1$ if day t is wet,

and a wet day is defined as an amount of precipitation greater than a threshold, λ, 0.25 mm. By the requirements of the transition probability matrix

$$P_{i0} + P_{i1} = 1$$

thus only two transition probabilities must be estimated, P_{00} and P_{10} in this study.

4.2 Amount

Let the amount of precipitation on a wet day be Y(t). Let U(t) be a random variable defined as $Y(t) - \lambda$ and be distributed as a mixed exponential:

$$f_t(u) = [\alpha(t)/\beta(t)]\exp[-u/\beta(t)] + \{[1-\alpha(t)]/\delta(t)\}\exp[-u/\delta(t)] \qquad (2)$$

with the mean of the distribution, $\mu(t)$, given by

$$\mu(t) = \alpha(t)\beta(t) + (1-\alpha(t))\delta(t) \quad (3)$$

The Markov chain-mixed exponential (MCME) model parameters, P_{00}, P_{10}, α, β, and δ are represented by Fourier series and optimized by the technique of maximum likelihood [Woolhiser and Roldan 1982] and [Roldan and Woolhiser 1982] for the period of record of each station given in Table 1.

4.3 SOI Perturbation

The influence of the SOI is hypothesized to be of the form:

$$G'(N,t) = G(t) + b\,(SOI(N,t-\tau)) \quad (4)$$

where:

$G(N,t)$ is the model parameter P_{00}, P_{10}, or δ on day t of year N(but not α or β);
b is a coefficient and
τ is the lag time between observed SOI and day t, and both b and τ are parameters to be estimated from the data;
$SOI(N,t-\tau)$ is the Southern Oscillation Index preceeding day t by τ

Additionally, to investigate the seasonal influence of the SOI on model parameters, the coefficient and lag parameters are allowed to vary by month, and Eq. 4 is modified slightly:

$$G'(N,t) = G(t) + b(k)\,(SOI(N,t-\tau(k))) \quad (5)$$

where:

$b(k)$ and $\tau(k)$ are parameters that will vary by month k, k = 1,12.

5. PARAMETER IDENTIFICATION PROCEDURE

MCME model parameters are identified from the observed 30 year record. By incorporating the SOI perturbations as given by Eq.(4) or Eq. (5), the likelihood function can be written as a function of the perturbation parameters, b and τ. For the model parameters, P_{00}, P_{10} and δ, unique b and τ (or b(k) and $\tau(k)$ for the monthly parameterization) can be estimated by a series of 3 bivariate optimizations. As with the MCME model parameters, the perturbation model parameters are optimized using maximum log likelihood and the significance of an increase in log likelihood is tested by the Akaike Information Criterion (Akaiake 1974). Only those perturbation parameters which produce a significant increase in log likelihood are retained for each location.

Results of the optimization are three sets of MCME parameters - unperturbed, perturbed, and monthly perturbed. Two derived daily parameters, the probability of a wet day, $P_1(t)$, and mean amount per wet day, $\mu(t)$, can be calculated for each of the three cases. **Figure 2** is a plot of the derived model parameters for Tombstone, AZ for a two year period. The unperturbed daily model parameters repeat on an annual cycle, whereas the daily parameters from the perturbed and monthly perturbed cases are functions of the SOI and vary according to the observed time-series of SOI at lag τ. **Figure 3** is a multiyear plot of $P_1(t)$ and $\mu(t)$ for t = 75 at Tombstone, AZ showing the interannual variability of daily model parameters due solely to the influence of the SOI. These effects on model parameters translate directly into effects on the statistics of sums of simulated daily precipitation.

6. SIMULATION RESULTS

Using each of the three parameter sets, a single realization of 65 years of daily precipitation were simulated for the period1936-2000 for which there was corresponding SOI data. This simulated period includes the 30 year period 1961-1990 used for parameterization.

6.1 Full 65 year period

Figure 4 visually compares the empirical cumulative distribution function (CDF) for 65 year simulated total January, February and March (JFM) amount and number of wet days for Tombstone AZ. Obviously, the interannual variation due to the SOI perturbations is increased for both the amount and number of wet days. Similar results are found for the other three locations, for October, November and December (OND) seasonal totals and annual totals. **Table 2** lists the variance of the simulated seasonal (JFM and OND) and annual total amount and number of wet days for each parameterization and location.

6.2 Common 30 year period

It has been reported by several authors (e.g. Woolhiser 1992, Johnson et al. 1996) that the MCME model preserves the mean of monthly, seasonal and annual amounts and number of wet days, but less so for the variance. **Figure 5** visually compares the empirical cumulative distribution function (CDF) for the common 30 year period historical and simulated JFM, amount and number of wet days for Tombstone AZ. In each instance the mean is preserved but clearly the interannual variation due to the monthly identified SOI perturbations more closely reflects the observed for both the amount and number of wet days. Similar results are found for the other three locations, for OND and annual totals.

Statistical tests of significance of the equality of the mean and the equality of the variance between the historical data and each of the simulations were performed using the *t* and *F* tests respectively at a significance level of $\alpha = 0.01$. As expected all three model parameterizations did well preserving the mean. Of a total of 72 possible tests of the equivalence of the mean (3 parameterizations, 3 means (JFM, OND, annual) and 4 locations) the only rejections of the

Roldan, J. and Woolhiser, D. 1982. Stochastic daily precipitation models 1. A comparison of occurrence processes. Wat. Res. Res. 18:1451-1459.

Wilks, D. 1989. Conditioning stochastic daily precipitation models on total monthly precipitation. Wat. Res. Res. 23:1429-1439.

Woolhiser, D. 1992. Modeling daily precipitation - progress and problems. *In* A. Walden and P. Guttorp, eds., Statistics in the Enviromental and Earth Sciences, pp.71-89. Edward Arnold, London.

Woolhiser, D. and Roldan, J. 1982. Stochastic daily pecipitation models 2. A comparison of distributions of amounts. Wat. Res. Res. 18:1461-1468.

Woolhiser, D., T. Keefer and K. Redmond. 1993. Southern oscillation effects on daily precipitation in the southwestern United States. Wat. Res. Res. 29:1287-1295.

Site	Latitude	Longitude	Elevation (m)	Mean Amount (mm)	Variance Amount	Mean # Wet Days	Variance # Wet Days
Prescott AZ	34° 65'	112° 43'	1531	536.45	24858.01	72.36	170.37
Tombstone AZ	31° 42'	110° 03'	1405	311.40	6412.89	55.50	141.18
Astoria OR	46° 15'	123° 88'	7	1666.75	65083.74	188.71	315.21
Eugene OR	44° 12'	123° 22'	109	1242.82	52451.51	137.75	246.97

Table 1. Site location and 30 year precipitation statistics, 1961 - 1990.

Site	Model	Variance of Amount			Variance of # of Wet Days		
		JFM	OND	Annual	JFM	OND	Annual
	Unperturbed	3021.4	5070.4	14588.4	28.5	31.3	120.7
Prescott AZ	Perturbed	3750.0	5939.6	16912.6	34.2	36.7	156.1
	Monthly Perturbed	6683.7	10225.6	19360.2	63.5	37.9	165.5
	Unperturbed	407.0	1517.0	4013.2	13.3	19.2	69.2
Tombstone AZ	Perturbed	456.7	2117.9	5387.2	14.6	22.9	87.9
	Monthly Perturbed	1044.7	3399.2	6313.8	25.4	31.3	100.5
	Unperturbed	13893.5	16353.9	31633.7	38.3	35.9	157.3
Astoria OR	Perturbed	14329.9	16597.8	32046.8	38.5	34.8	144.2
	Monthly Perturbed	30264.4	28355.6	59147.5	82.6	83.8	238.2
	Unperturbed	14865.1	13842.9	34925.0	41.5	37.3	139.3
Eugene OR	Perturbed	15578.3	13748.4	35783.4	39.1	38.2	135.1
	Monthly Perturbed	31336.9	25004.5	54278.8	92.9	96.7	238.5

Table 2. Variance of 3-month (January-February-March and October-November-December) and Annual simulated precipitation and number of wet days for 65 years, 1936-2000.

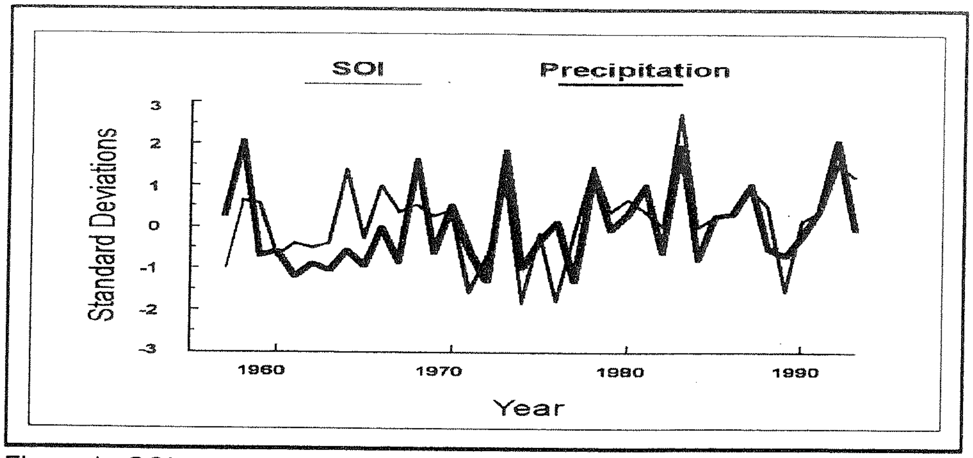

Figure 1. SOI, average of OND multiplied by -1, and Tombstone AZ FMA total precipitation.

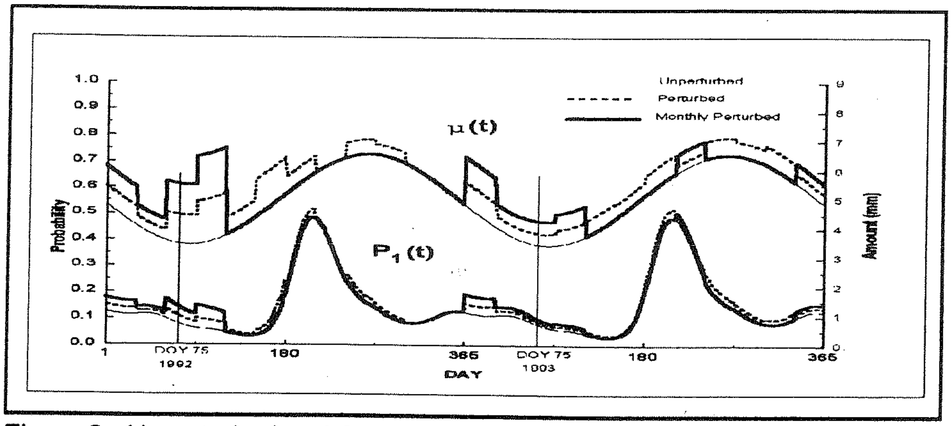

Figure 2. Unperturbed and SOI perturbed mean amount per wet day, μ, and probability of a wet day, P_1, Tombstone AZ 1992 and 1993.

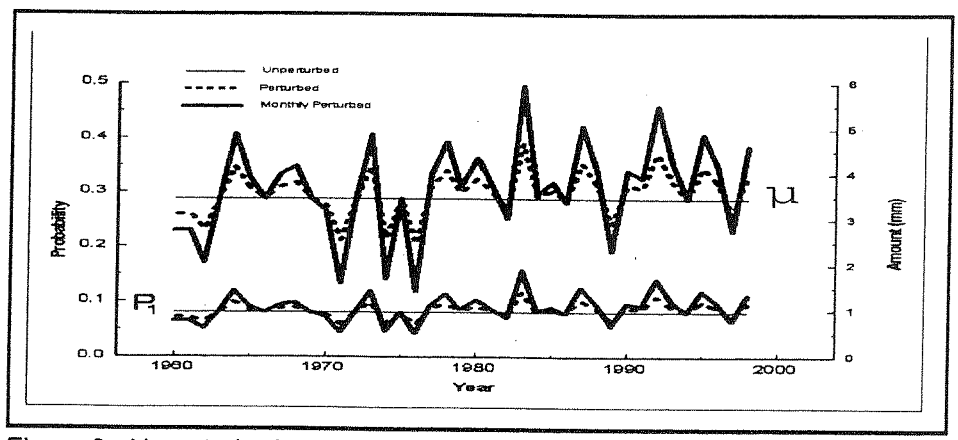

Figure 3. Unperturbed and SOI perturbed mean amount per wet day, μ, and probability of a wet day, P_1, Tombstone AZ day-of-year 75.

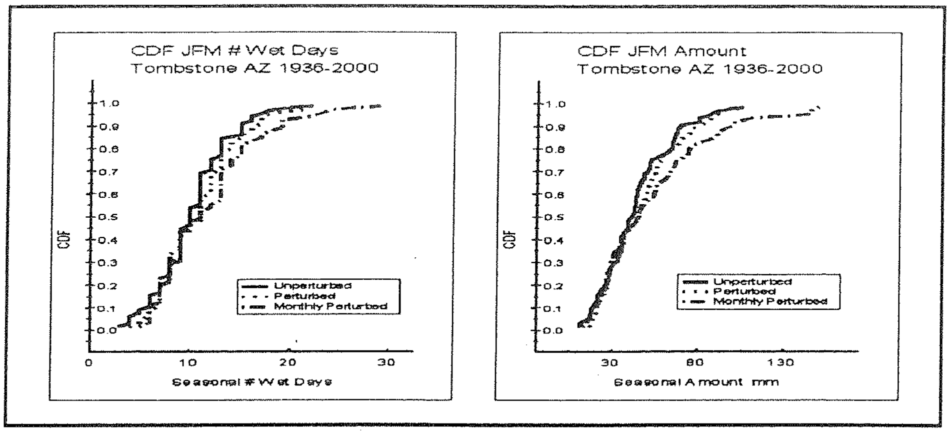

Figure 4. Empirical CDF of simulated JFM precipitation.

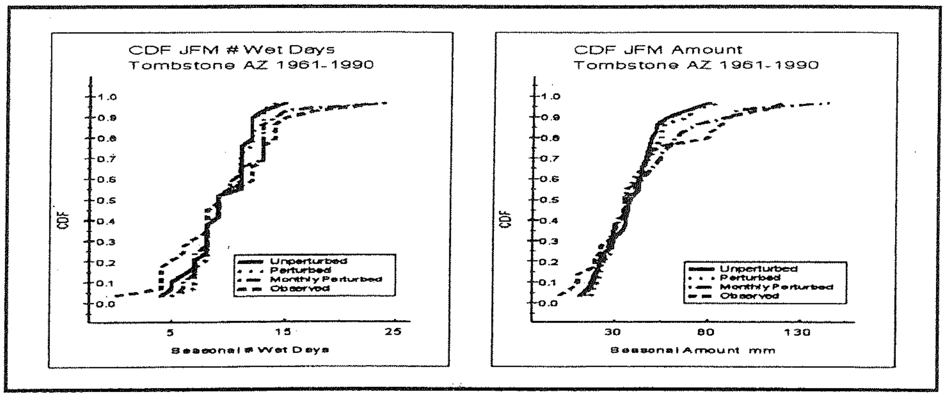

Figure 5. Empirical CDF of observed and simulated JFM precipitation.

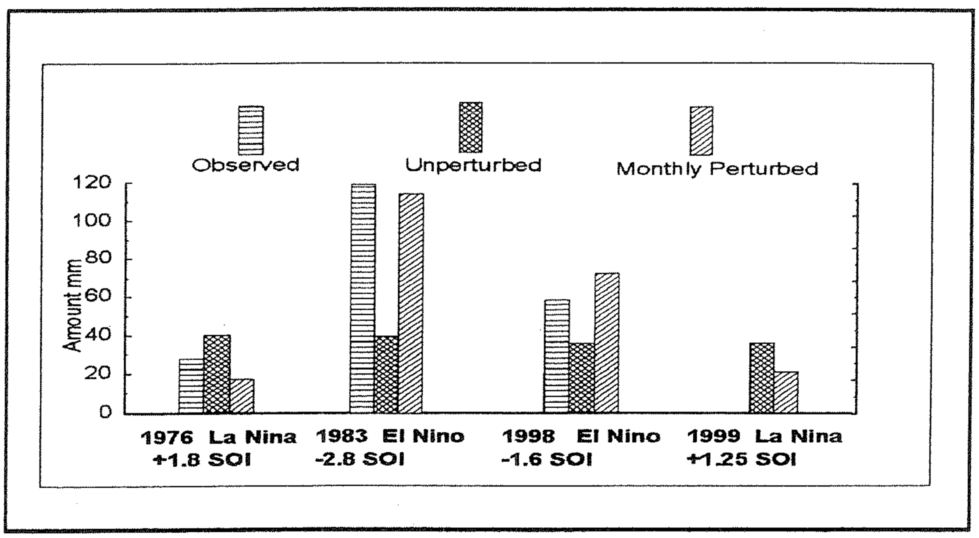

Figure 6. Observed and simulated Tombstone AZ JFM precipitation during strong El Nino and La Nina episodes. Simulated values are averages of 100 simulations. Observed 1999 JFM precipitation is zero.