United States
Department of
Agriculture

Statistical
Reporting
Service

**Research
Division**

Stochastic Simulation of Daily Climate Data

Greg A. Larsen
Roberta B. Pense

STOCHASTIC SIMULATION OF DAILY CLIMATE DATA. By Greg A. Larsen and Roberta B. Pense; Research Division, Statistical Reporting Service; U.S. Department of Agriculture, September 1981. SRS Staff Report No. AGES810831.

ABSTRACT

Bond (1979) developed a stochastic weather simulation model for generating daily climate data. This model has been expanded and modified to generate possible sequences of daily precipitation, maximum and minimum temperature, and solar radiation for an entire year. A first order, two-state Markov chain simulates precipitation occurrence with the amount of precipitation then calculated from a two-parameter gamma probability distribution. Two bi-variate normal distributions are used to simulate temperature. Solar radiation values are generated using either a gamma or beta probability distribution, depending on the precipitation status. This paper describes the model and presents results of validation tests for the following locations: Columbia, MO, Caribou, ME, Miami, FL, Medford, OR and Albuquerque, NM. These tests indicate that the simulation model can be used in a variety of settings to replace long series of historical data, which may not be available, convenient or appropriate.

ACKNOWLEDGEMENTS

Special recognition should go to Douglas C. Bond, whose previous work in weather simulation provided the basis for the present simulation model. In addition, the authors wish to thank William Iwig, Chapman Gleason, Fred Warren and William Arends for their review of the paper. Special thanks should also go to Sharon Skaluba and Verla Hall for their excellent typing and to George Roney for his work in preparing the graphs. Thanks are also extended to Paul Dyke, USDA, ERS, who provided the climate data for four of the locations used in validating the model.

CONTENTS

September
1981

INTRODUCTION

There have been several recent efforts to stochastically simulate possible sequences of daily precipitation occurrence and amount, maximum and minimum air temperature, and total solar radiation received at the earth's surface (Nicks and Harp, 1980; Bruhn, et al., 1980; Richardson, 1981). While the goal of the presently proposed model is the same, it is believed that methodology differs enough to warrant separate consideration. This study is an expansion of earlier work by Bond, (1979), in which precipitation and maximum and minimum temperature were simulated for the growing season May through August. The methodology has been refined somewhat for these variables, solar radiation has been added and the entire model expanded to be appropriate for the full year.

Simulated daily weather variates can be used in a variety of settings to replace long series of historic data which may not be available, convenient or appropriate. Simulated data can be used in hydrologic models for watershed planning, evaluation and design purposes (Nicks and Harp, 1980). Simulated data can be used in various types of agricultural management models to assess the risk associated with different alternatives (Bruhn, et al., 1980). In a realtime mode, possible future sequences of data can be used in plant simulation models to make yield forecasts (Arkin, et al., 1980). The proposed weather simulation model has been used to estimate the probability associated with segments on plant model sensitivity analysis response curves to better judge which input variables realistically produce the greatest change in model output.

How closely a stochastic weather simulation model needs to represent the real system depends on the application. While the model can become quite complex (several possible added complexities are later suggested), clearly there has to be a balance between complexity and the foreseen uses or effort may be largely wasted or, at best, simply acedemic. In view of this, the proposed model is intended to produce simulated data which are statistically comparable to data from the real system in measures of central tendency, dispersion and distribution while preserving major interrelationships among the variables. The model is also intended to be applicable to a wide range of locations at any time of the year. A rather extensive model validation is presented to assess these claims.

Three other models which stochastically simulate daily data for the same weather variables have been previously mentioned. Table 1 briefly summarizes the basic approach of each of these along with the presently proposed model which is referred to, for lack of a better name, as the SRS model (SRS being the acronym for Statistical Reporting Service, an agency within USDA). While Table 1 does not completely convey the methodological approach of each model, it is hoped that general comparisons can be made.

TABLE 1 - COMPARISON OF SEVERAL STOCHASTIC DAILY WEATHER SIMULATION MODELS

MODEL	PERIOD COVERED	RAIN OCCURRENCE	RAIN AMOUNT	TEMPERATURE	SOLAR RADIATION	OTHER FEATURES
Bruhn, et al. 1980	May-Sept.	First order two state Markov chain. Transition probabilities assumed to be homogeneous within month. Wet ≥ .25mm Dry < .25mm	Two parameter gamma distribution. Not conditioned on previous day precipitation status.	Two bi-variate normal distributions. First distribution simulates current day max temp. from previous day max temp. Second distribution simulates current day min temp. from simulated current day max. Conditioned on previous day precipitation status.	Normal distribution conditioned on current day precipitation status.	All distributional parameters are assumed to be homogeneous within month. Model also simulates daily relative humidity with a normal distribution conditioned on previous and current day precipitation status.
Nicks and Harp 1980	Full Year	First order two state Markov chain. Transition probabilities assumed to be homogeneous within month.	Not simulated in present reference. Simulated separately in Nicks, 1974.	Two bi-variate normal distributions. One distribution simulates current day max temp. from previous day max temp. The other distribution simulates current min temp. from previous day min temp. Conditioned on previous and current day precipitation status.	Bi-variate normal distribution. Current day solar radiation is simulated from previous day solar radiation. Conditioned on previous and current day precipitation status.	All distributional parameters are assumed to be homogeneous within month.
Richardson 1981	Full Year	First order two state Markov chain. Continuous finite Fourier series fit to bi-weekly transition probability estimates so that probabilities change daily. Wet ≥ .20mm Dry < .20mm	One parameter exponential distribution. Not conditioned on previous day precipitation status.	A weakly stationary generating process proposed by Matalas, 1967, is used to simulate residual sequences of max and min temperature and solar radiation. The procedure involves two matrices containing twelve different serial and cross correlation coefficient combinations of the three variables. The correlations are assumed to be homogeneous within year and are not conditioned on precipitation status. Fourier series are fit to bi-weekly mean and standard deviation estimates of the three variables. The fitted Fourier series are conditioned on precipitation status of the current day. Residuals are obtained for each daily observation by subtracting the mean and dividing by the standard deviation which come from the fitted Fourier series. Normality is assumed for each variable.		With the Fourier series fits to the transition probabilities and distributional parameters, a continuous series of estimates are made. However, the bi-weekly parameter estimates are smoothed to varying degrees.
SRS	Full Year	First order two state Markov chain. Transition probabilities assumed to be homogeneous within month. Wet ≥ 0 Dry = 0	Two parameter gamma distribution. Conditioned on previous day precipitation status.	Two bi-variate normal distributions are used to simulate the difference between the observed temperature and a fitted three parameter sine curve describing daily mean max or min temp. First distribution simulates either current max or current min from previous max temp. depending on which correlation is higher. Second distribution simulates the remaining current temp. from the simulated current temp. Conditioned on current day precipitation status.	Difference between observed and max clear day radiation is simulated with a two parameter gamma distribution on dry days and a two parameter beta distribution on wet days. Hence, conditioning is based on current day precipitation status.	All distributional parameters are estimated monthly. Continuous seasonal trends are preserved by the differencing procedure.

MODEL METHODOLOGY

Precipitation Occurrence

A first order Markov chain was used to simulate the occurrence of precipitation. A first order Markov chain has been used satisfactorily in a number of studies (e.g. see Nicks, 1980 or Richardson, 1981 for a list of references). In the earlier work by Bond, (1979), it was shown that the first order was appropriate for the months June, July and August but not for May in Columbia, Missouri. Bruhn, et al., (1980), showed that the first order was appropriate for May, June, July and September but not for August in Geneva, New York.

Two states were used in the Markov chain - wet and dry. A wet day is defined to occur whenever a trace or larger amount of precipitation was recorded. Dry days are days which are not wet. The decision to include trace amounts in the wet category arose primarily from solar radiation simulation considerations. Days with trace amounts were defined as dry by Bond, (1979). The impact of this definitional difference was investigated and is discussed in the section on model validation.

Formally, suppose that X_t is a sequence of daily precipitation occurrence values

where

$$X_t = \begin{cases} 0 \text{ if day } t \text{ is dry} \\ 1 \text{ if day } t \text{ is wet} \end{cases}$$

and $t = 0, 1, 2 \ldots$

Then, by definition of a first order Markov chain,

$$P[X_t = j | X_{t-1} = i_{t-1}, X_{t-2} = i_{t-2}, \ldots, X_0 = i_0]$$

$$= P[X_t = j | X_{t-1} = i_{t-1}]$$

for every j and i_t where $t = 0, 1, 2, \ldots$

In words, this definition says that the probability that day t is in state j depends only on the state i of the previous day t-1. The conditional probabilities $P[X_{t+1} = j | X_t = i]$, are called single-step transition probabilities. It has been further assumed that the transition probabilities are independent of t within any particular month. Hence,

$$P[X_t = j | X_{t-1} = i] = p_{ij}^{(m)}$$

where $m = 1, 2, \ldots, 12$

To estimate the elements in $p_{ij}^{(m)}$, define the following frequency

$$f_{tij} = \begin{cases} 1 \text{ if } X_t = j \text{ and } X_{t-1} = i \\ 0 \text{ otherwise.} \end{cases}$$

Then,

$$p_{ij}^{(m)} = \frac{\sum_{t=1}^{n_m}(f_{tij})}{n_m}$$

where n_m = number of days in month m
$i = 0,1$
$j = 0,1$

Only the first column need be calculated since

$$p_{i1}^{(m)} = 1 - p_{i0}^{(m)}.$$

An additional category was defined to account for the occurrence of trace amounts separately.

Let

$$T_t = \begin{cases} 0 \text{ if trace did not occur on day t} \\ 1 \text{ if trace occurred on day t} \end{cases}$$

The probability that a trace amount occurrs on a wet day in month m, $pt^{(m)}$, was estimated by

$$pt^{(m)} = \frac{\sum_{t=1}^{n_m} T_t}{\sum_{t=1}^{n_m} X_t}$$

where n_m = number of days in month n.

After the transition matrices and probabilities of trace amounts were estimated, precipitation occurrence was simulated for each day by obtaining a random uniform number, U_1, on the interval [0, 1]. If $U_1 > p_{i0}^{(m)}$ then today was wet otherwise, today was dry. If today was wet, another random uniform number, U_2, was obtained. If $U_2 \leq pt^{(m)}$ then a trace amount occurred otherwise, an amount larger than a trace occurred. Trace amounts were set equal to .001 inch.

Precipitation Amount

A two-parameter gamma distribution was used to simulate precipitation amounts greater than a trace on wet days. This distribution has been widely used in the past (e.g. Bruhn, et.al., 1980; Jones, 1972). The general form of the gamma probability density function is

$$P_X(x) = \frac{(x - \gamma)^{\alpha-1} \text{Exp} (- (x - \gamma)/\beta)}{\beta^\alpha \Gamma(\alpha)}$$

where $\alpha > 0$
$\beta > 0$
$\gamma < x$

The third parameter γ establishes the lower bound for the random variable X. For precipitation amount we assume $\gamma = 0$ which, indeed, is reasonable since amounts will approach zero but will not be equal to or less than zero. Setting $\gamma = 0$ leaves two parameters, α and β, to be estimated. The gamma distribution has two quite different shapes depending on whether α is less than one or greater than or equal to one. The first case has a reverse "J" shape in the first quadrant where the curve goes asymptotic to both the x and y axes. The second case results in a curve in the first quadrant starting near the origin and then resembling a normal curve with a positive (right) skew eventually going asymptotic to the x-axis. The two-parameter gamma with $0< \alpha< 1$ is the appropriate distribution for precipitation amount since this gives relatively high probability to small rainfall amounts and increasingly less probability to larger amounts. Parameter estimates were made monthly and conditioned on the precipitation status of the previous day. This conditioning is probably preferrable since "wet" and "dry" parameter estimates may be quite different in certain months. However, care must be taken to assure that sufficient data is available to support this subsetting. For example in a dry climate, a large number of years of data may be necessary to obtain a sufficient number of wet days to make parameter estimates with the desired precision. Conditioning on previous day precipitation status may not be practical if precision has to be sacrificed.

Maximum likelihood estimates are not available when α is less than one and are quite unstable when α is between one and 2.5. Method of moments estimators are even less precise than maximum likelihood and especially so for values of α less than, say, 40. An approximate maximum likelihood parameter estimation procedure suggested by Greenwood and Durand, (1960), was chosen. The error of this procedure for $\alpha< 1$ is stated by Johnson and Kotz, (Vol. I, pg. 189) to not exceed .0054%. (For a general discussion on gamma parameter estimation see Johnson and Kotz, Vol. I. pp. 184-193). Using the Greenwood and Durand method, define

$$Y = \log \left(\frac{\text{arithmetic mean}}{\text{geometric mean}}\right) = \log \left(\frac{\sum_{i=1}^{n} x_i/n}{\left(\prod_{i=1}^{n} x_i\right)^{1/n}} \right)$$

then,

$$\hat{\alpha} \simeq \frac{(8.898919 + 9.059950Y + .9775373Y^2)}{Y(17.79728 + 11.968477Y + Y^2)}$$

$$\hat{\beta} \simeq \frac{\sum_{i=1}^{n} x_i}{n \hat{\alpha}}$$

where x_i = precipitation amount on day i
n = number of days in the month

This formula for $\hat{\alpha}$ is appropriate only for $0 < \alpha < 1$. After parameter estimates were made for each month conditioned on previous day precipitation status, precipitation was simulated by obtaining gamma random variates using the method of Johnk (Berman, 1971). This method uses a rather complicated combination of standard uniform random variates to obtain a random variate appearing to come from a gamma distribution with the desired parameters. Simulated precipitation amounts were rounded to the nearest .01 inch. Amounts which were simulated to be smaller than .005 inch were not rounded to zero but rather were discarded and another random amount simulated. This procedure was used because zero amounts (i.e. dry) and trace amounts (arbitrarily set equal to .001 inch) were previously determined.

Temperature

Two bi-variate normal distributions were used to simulate daily maximum and minimum temperature differences conditioned on the current day precipitation status. The temperature differences were obtained by subtracting the observed daily temperature from two fitted three-parameter sine curves representing the mean daily maximum and minimum temperatures. The sine functions are of the form

$$T = SIN((JDATE - A) * .017214) * B + C$$

where T = daily mean maximum or minimum temperature

JDATE = julian date.

The three parameters, A, B, and C, were estimated by the least squares Marquardt method as contained in the Statistical Analysis System computer package (Barr, et al., 1979 Edition). The parameter A controls the shift in the horizontal time axis, B establishes the amplitude of the sine curve and C controls the shift in the vertical temperature axis. Fits using this three-parameter sine function were very good (R^2 values in excess of .97).

The assumption of normality of the temperature variables was tested using the non-parametric Lilliefors test (for details, see Conover, 1971). Tests were done by month and current day precipitation status for Columbia, Missouri. For dry day maximum temperature, 4 of 12 months were rejected at the $\alpha = .05$ level (1 of 12 at $\alpha = .01$). For wet day maximum temperature, 5 of 12 months were rejected at $\alpha = .05$ (3 of 12 at $\alpha = .01$). For dry minimum temperature, there were 9 of 12 months rejected at $\alpha = .05$ (5 of 12 at $\alpha = .01$). For wet minimum temperature, 4 of 12 months were rejected at $\alpha = .05$ (2 of 12 at $\alpha = .01$). However, the approach that was used assumes the temperature differences to be normally distributed. Tests of normality on the differences indicated the same or a smaller number of hypothesis rejections in all cases. Non-normality of the temperature variables typically occurred during winter months and asymmetry was the probable cause. (Normality could also be rejected, for example, when a distribution is symmetric but multimodal.)

A multivariate normal approach was used because tests of significance on serial and cross correlations between temperature variables showed all correlations by month and precipitation status to be greatly different from zero ($\alpha = .0001$). The magnitude of the correlations for the differences was comparable to that for the raw temperatures.

The need for conditioning the bi-variate normal distributions on current day precipitation status was examined by testing for differences between wet and dry mean temperatures within month. As indicated by t-tests, means were significantly different at the $\alpha = .05$ level for all but one month. Differences between wet and dry variances were not tested but it is noted that wet day variances generally exceeded those on dry days. It is further noted that correlations were generally smaller on wet days. In the earlier analysis, Bond, (1979) indicated that conditioning on the precipitation status for the previous day in addition to the current day did not produce simulated data significantly different from the simpler alternative. It should also be pointed out that the added level of conditioning would roughly cut in half the number of observations available for each parameter estimate and, hence, precision might suffer.

Daily temperatures were generated using one bi-variate normal to simulate either current maximum temperature or current minimum temperature from previous day maximum temperature. The current temperature simulated was determined by the higher of the two correlations. The second bi-variate normal was used to simulate the remaining current temperature from the current temperature generated by the first bi-variate normal. This procedure takes advantage of the highest correlations. It is noted that in Columbia, Missouri the correlation between previous maximum and current minimum was almost always larger on dry days and sometimes larger on wet days than the correlation between previous maximum and current maximum. Three means, three variances and three correlations were estimated for each month and precipitation status. Parameters were estimated from the temperature differences using the usual formulae. After parameter estimates were made, daily temperature differences were simulated using the following general equation.

$$T_2 = \hat{\mu}_2 + \hat{\rho}_{12}\, \hat{\sigma}_2\, (T_1 - \hat{\mu}_1)/\hat{\sigma}_1 + \hat{\sigma}_2\, (1 - \hat{\rho}^2_{12})^{1/2}\, Z$$

where T_1 = difference for either previous day maximum temperature or current temperature

T_2 = current temperature difference

Z = standard normal random variate

The simulated temperatures were obtained by adding the appropriate daily values from the fitted sine functions to the values obtained for T_2.

The temperature simulation methodology just described assumes that temperature difference parameter estimates are homogeneous within month and precipitation status. This assumption is thought to be much more conservative than is the assumption that parameter estimates based on raw temperatures are homogeneous within month and precipitation status. The latter assumption is clearly subject to criticism during the spring and fall months when seasonal weather changes are relatively fast. Raw temperature parameters could, of course, be estimated for shorter intervals of time than monthly. However, this would require more historic data to maintain the same estimation precision and an increased number of parameters would have to be estimated and passed to the simulation algorithm.

There are other ways to simulate temperatures and, hopefully, preserve the daily seasonal trend. Richardson, (1981), fit finite Fourier series to bi-weekly parameter estimates so that daily parameter estimates could be passed to the simulator. This method would tend to preserve seasonal trend in the daily simulated data and has the additional advantage that, in most cases, three Fourier coefficients could be used to describe all the bi-weekly estimates for a particular parameter. Thus, a greatly reduced number of parameter estimates need be passed to the simulator. A possible disadvantage of this procedure, however, is that depending on how harmonic the bi-weekly estimates are over time, there may be either a substantial amount of smoothing with resultant loss of precision or the number of Fourier coefficients required to adequately describe the bi-weekly estimates may approach the number of bi-weekly estimates. The latter possibility, of course, would be of no advantage. Also, fitting Fourier series adds expense, which, depending on the estimation procedure selected, may or may not be insignificant. Jones, et al. (1972), used polynomial fits to pass weekly parameter estimates to the weather simulation program. (This topic is discussed further in the recommendations section.)

Solar Radiation

Daily solar radiation differences were simulated from a gamma distribution on dry days and a beta distribution on wet days. The solar radiation differences were obtained by subtracting the observed solar radiation value from the maximum clear day radiation. The latter values were computed from a series of equations which depend only on the latitude and julian date. The equations were obtained from unpublished material with permission from J. T. Ritchie. In the interest of brevity, the equations are not reproduced here but can be obtained from the computer program discussed at the end of this section.

Solar radiation was not assumed to be normally distributed within month and precipitation status because Lilliefors tests of normality were rejected ($\alpha = .01$) for raw and differenced radiation in all cases. Plots of the observed data and computation of skewness coefficients (see 1979 SAS manual pg. 303 for skewness formula) indicated that the raw solar radiation was skewed in the negative direction on dry days and in the positive direction on wet days in Columbia, Missouri. Differenced solar radiation showed just the opposite skew. The physical explanation for the skewness in the raw data is that on dry days there was a preponderance of observations approaching the clear day maximum amount possible but there were also many dry cloudy days where solar radiation values were relatively low. Hence, with an upper limit on the maximum amount possible and a lower limit (zero) a long way from the mode, a negative skew is expected. The skew tended to be greater in the winter because hazy conditions on many summer days moved the mode farther from the maximum clear day radiation. On wet days, the largest number of observations tended to be nearer zero than the maximum clear day radiation but since some wet days had a relatively short period of cloud cover, observations approached the upper limit. Hence, the skew was in the positive direction but generally the absolute skewness was less than on dry days since even on the cloudiest days radiation amounts tended to be well above zero. If wet and dry days were to be combined within month, the negative skew would more than offset the positive skew in all but one month and, though not specifically tested, normality would likely be rejected for the majority of months.

Several distributions were considered in an effort to account for the skewness in the solar radiation data. The candidates included the truncated normal, log normal, gamma and beta distributions. Two-sample Kolmogorov-Smirnov test statistics were computed to see which distribution best represented the data. (See Conover, pp. 309-314 for details.) The beta distribution emerged as the best overall because of its ability to accomodate either positive or negative skewness without additional data transformations. However, the beta did not perform as well on dry days as on wet because of the severe skew in some months. The gamma distribution was more suitable on dry days than the beta so a gamma and beta combination was selected to represent the data overall.

The need for conditioning by precipitation status was alluded to in the discussion on skewness. Additionally, t-tests indicated significant differences between wet and dry means for all months ($\alpha = .01$). Variances were always larger for wet days, and during the summer months, were as much as fourfold larger. Though not specifically tested, wet and dry variances would probably be significantly different for at least half the months.

Before parameters were estimated for the gamma distribution, a transformation was made to the dry day solar radiation differences. As previously mentioned, the raw dry day solar radiation values are negatively skewed and, hence, the differences are positively skewed. This fits the general shape of a gamma distribution with $\alpha \geq 1$. Referring back to the general three-parameter gamma distribution discussed in the precipitation amount section, recall that the third parameter, γ, establishes the lower bound. While γ could realistically be assumed to be zero for precipitation, this is not, in general, a good assumption for solar radiation. Although maximum likelihood estimators exist for all three gamma parameters, the estimates are unstable when α is less than 2.5. Aside from maximum likelihood estimation, a good first approximation for γ is a number slightly less than the observed minimum (Johnson and Kotz, pg. 187). Rather than explicitly estimate γ, the differenced solar radiation data were transformed by the following equation.

$$TSRD_G = SRD - MINSRD + 3$$

where SRD = solar radiation difference

MINSRD = minimum solar radiation difference within month and precipitation status

$TSRD_G$ = transformed solar radiation difference

Since the transformed solar radiation difference values start at a minimum of 3 for all months, γ can be assumed to be zero. The addition of 3 arose from programming considerations to avoid the possibility of roundoff created zero values. The α and β parameters were estimated using the Greenwood and Durand method. This choice was made because of the limitation in the maximum likelihood estimators for α values less than 2.5. For Columbia, Missouri, $\hat{\alpha}$ generally ranged between 2 and 4. The formula for estimating α by the Greenwood and Durand method follows.

$$\hat{\alpha} \simeq \frac{(.5000876 + .1648852Y - .0544274Y^2)}{Y}$$

where $Y = \log\left(\frac{\text{arithmetic mean}}{\text{geometric mean}}\right)$

This formula for $\hat{\alpha}$ is appropriate for $\alpha \geq 1$. Johnson and Kotz (pg. 189) state that the error of this approximation does not exceed .0088%. Beta was estimated as before.

The beta distribution was hypothesized for wet day solar radiation differences. The standard form of the beta distribution is

$$P_X(x) = \frac{(p + q - 1)!}{(p - 1)!\ (q - 1)!}\ x^{p-1}\ (1 - x)^{q-1}$$

where $p > 0$
$q > 0$
$0 \leq x \leq 1$

To get the solar radiation differences on the interval [0, 1], the following transformation was made.

$$TSRD_B = \frac{SRD - MINSRD}{MAXSRD - MINSRD}$$

where SRD = solar radiation difference

MINSRD = minimum SRD within month and precipitation status

MAXSRD = maximum SRD within month and precipitation status

$TSRD_B$ = transformed SRD

Formulas for estimating p and q were obtained using the method of moments and are as follows.

$$\hat{p} = \frac{w - v(1 + w)^2}{v(1 + w)^3}$$

$$\hat{q} = \hat{p}w$$

where v = sample variance

$w = (1 - \bar{x})/\bar{x}$

$\bar{x}$ = sample mean

After all parameter estimates were made, the appropriate transformed solar radiation differences were simulated by month and precipitation status. In the case of dry days, gamma random variates were simulated using the same procedure as for precipitation. Each random variate was then transformed back to the original scale by adding MINSRD, subtracting 3 and adding the maximum clear day radiation. In the case of wet days, beta random variates were simulated by taking advantage of the following relationship.

$$\beta\ (p,q) = \frac{\Gamma(p,1)}{\Gamma(p,1) + \Gamma(q,1)}$$

Thus, a beta random variate was obtained from a combination of two gamma random variates. Daily solar radiation values were then computed in the original scale by reversing the transformations previously indicated.

Parameter Estimation and Simulation Programs

All the parameter estimates which have been discussed were calculated using the Statistical Analysis System (Barr, et al., 1979). This SAS program takes daily climate data for whatever period of record is desired, computes all the required parameter estimates and outputs them in a form which is compatible with the simulation program. The parameter estimation program consists of 342 statements about half of which are comments.

The simulation program is written in Fortran and consists of 460 lines about 270 of which are comments. The simulation program reads the parameters from the SAS program and two additional cards which indicate starting conditions and the period of time to be simulated. The simulation program outputs the calendar date, julian date, precipitation amount, maximum and minimum temperature and solar radiation on a daily basis. The parameter estimation and simulation programs can be obtained either in printed form or on magnetic tape or cards by request to

Librarian
Yield Research Branch
Statistical Reporting Service
Room 4833, South Building
U.S. Dept. of Agriculture
Washington, D.C. 20250.

MODEL VALIDATION

General

The data base for model development came from Columbia, MO. These data consisted of 80 years (1890-1969) of precipitation and temperature values and 22 years (July, 1952-June, 1974) of daily solar radiation values. Parameter estimates came from the 17-year period (1953-1969) in which all climate variables were available. Extensive model testing was done at Columbia because of the availability of a long historic record for precipitation and temperature. Simulated data were compared to the 17-year historic base period and to the entire length of record. The former tests indicate whether model assumptions are valid and the latter tests show whether the base period is of sufficient length to adequately represent the entire data set. In addition, tests were made on the base period to see whether model performance was influenced by defining trace precipitation amounts as dry instead of wet.

Model validation at Columbia consisted of several types of tests. T-tests were used to compare the means, and F-tests were used to compare the variances of mean daily precipitation, maximum temperature, minimum temperature, and solar radiation for each month and precipitation status (wet or dry). The ranges of these weather variables were also examined. Chi-square tests were used to compare the frequency of wet days for each month. Two-sample Kolmogorov-Smirnov (K-S) tests were used to compare cumulative distribution functions (CDF'S) by month and precipitation status. Since some of the K-S tests involved large numbers of observations, historic and simulated data were sometimes sub-sampled so that tests were done on no more than roughly 200 observations in each set. When sub-sampling occurred, it was done using a random method. The means, standard deviations, and ranges of wet spells, dry spells, freezing spells and hot spells (95°F or above) were computed for each month for the 80 years of historic data and 99 years of simulated data. Finally, the frequency distributions of the wet, dry, freezing, and hot spells as well as the CDF's which were declared significantly different by the K-S tests were graphed for the historic and simulated data.

The model was also validated at four other locations representing a wide range in latitude, altitude and precipitation pattern. Twenty years of daily climate data (1951-1970) were obtained for Albuquerque, NM, Caribou, ME, Medford, OR, and Miami, FL. Together, the five sites range in latitude from 26° at Miami to 47° at Caribou. Altitudes go from a low of 15 feet at Miami to a high of 5326 feet at Albuquerque. Average annual precipitation amounts range from less than 8 inches at Albuquerque to nearly 60 inches at Miami.

Parameter estimates for the additional 4 sites were made from the entire 20 years of available data at Medford. However, due to missing daily solar radiation values in excess of 20% for some years, the base period for Albuquerque was 19 years, for Caribou, 16 years, and for Miami, 18 years. Since missing solar observations were not likely to be distributed randomly, entire years were left out of the parameter estimation to avoid the possibility of introducing bias. Comparisons were made using 50 years of simulated data and the entire 20-year historic period for each of the four additional locations. Tests were made for frequency of wet days and means, variances, and CDF's for each climate variable. Ranges were also examined.

The results of the tests at the five locations are discussed for each climate variable separately in the following subsections. The test statistics for each site are summarized in Appendices A through G with each appendix containing comparisons for a single site.

The tables which are numbered with a one (A1, B1, etc.) present the Chi-square test for frequency of wet days. Tables numbered with a two contain t-tests, F-tests and ranges of the weather variables. K-S tests for the CDF's are presented in tables numbered with a three. Graphs of those CDF's which were declared significantly different in Table E3 are also found in Appendix E. Table G4 contains means, standard deviations and ranges for the various weather spells. Appendix G also contains graphs showing the frequency distributions of the spells.

A brief summary of the results for all sites is found in Table 2 on page 19. This table presents only the number of significant (at $\alpha = .05$) and nonsignificant results for each location and variable, while the appendices present more detailed information.

Precipitation

Precipitation amounts are simulated in two steps. First, it is determined whether the current day is wet or dry and then an amount is simulated for each wet day. The method used to simulate precipitation occurrence appears to be working very well. No significant differences in frequency of wet days were found at any of the 5 locations when the simulated data were compared to the historic data used for parameter estimation. There were also no significant differences when trace amounts were included in the dry day category for Columbia. Based on this information, it appears that the model works equally well at Columbia for both categorizations of trace rain. When the frequencies of the simulated data (based on 17 years) are compared to all 80 years of historic data, significant differences were found in January, March, April, August, and December. This indicates that for these months, 17 years is not a long enough base period if the simulated data are to be representative of the entire 80 years. When the lengths of wet and dry spells (number of consecutive wet or dry days) are compared, it appears that the means, standard deviations and ranges of the simulated and historic data are similar for most months. This analysis was run using all 80 years of historic data. Therefore, some variation in precipitation patterns should be expected since the 17 years used to estimate the parameters do not appear to be representative of all 80 years.

The method used to simulate precipitation amounts on wet days works well. A comparison of the simulated data to the historic data from which the parameters were estimated showed no significant differences in the means for any site. This was also true for Columbia when trace amounts of rain were classified as dry. Between four and ten variances (out of 12) were found to be significantly different at each site. No significant differences in the cumulative distribution functions occurred at Albuquerque. Only one significant difference was found at Miami and Columbia (trace defined as wet), two at Medford and Columbia (trace rain defined as dry), and 5 at Caribou.

When the simulated data are compared to the entire 80 years of historic data at Columbia, the model works adequately but the correspondence is not as good. Four means and ten variances (out of 12) were declared significantly different. Both the means and the variances tended to be smaller for the simulated data. However, no CDF's were found to be significantly different.

The average annual rainfall totals for the simulated data are not significantly different from the historic at any of the locations. However, they are always greater than the observed. The largest difference was at Miami where 3.15 more inches of rain were simulated than observed. This constitutes a 5% bias. The standard deviations of the simulated rainfall totals were always less than the observed with one significant difference (at Miami). At Columbia, when the simulated data were compared to the historic data for the entire 80 years the simulated total rainfall was significantly different. This again indicates that the 17 years used for parameter estimation were not representative of the 80-year period.

Temperature

The algorithm used to simulate maximum and minimum daily temperature performs very well. When the simulated data were compared to the historic data used to estimate the parameters, only 1 to 4 means (out of 48) were found to be significantly different at each location. Looking at the data closely, nine of the 15 total significant differences at all locations were less than one degree Fahrenheit, and 4 of the differences were less than .5°F. Thus, most of these statistically significant differences would be of little practical consequence in many applications. There is a tendency for the simulated means to be low on wet days. The number of variances which were declared significantly different ranged from zero (for Columbia) to three out of 48 comparisons at each location. The simulated variances do not appear to be biased. The temperature algorithm as formulated previously by Bond (1979), tended to simulate variances smaller than those observed. An advantage of estimating parameters separately for wet and dry days can be seen by examining the means and ranges of the temperature variables for each precipitation status. In most cases, the maximum temperature for wet days is slightly less than for dry days, and the minimum temperature for wet days is slightly higher than for dry days. This observation is consistent with the historic data. Only one to five CDF's (out of 48) were declared significantly different at each location.

The annual means and variances for the simulated temperature are very close to those observed at all five locations. The largest difference in the means occurred at Caribou and was less than .3°F. The simulated maximum temperature means were always slightly less than the historic.

When trace amounts of rain are defined as dry, the model does not work as well. Nine means and one variance (out of 48) were declared significantly different. Nine pairs of cumulative distribution functions differed significantly. When trace amounts of rain are classified as wet, only one mean, no variances and one CDF were found to be significantly different. Thus, for temperature, defining trace amounts of rain to be wet appears to be superior to the dry classification.

When the simulated data, using parameters based on 17 years, are compared against all 80 years of historic data, the model appears to work satisfactorily but the relationship is not as good. Eighteen means and 22 variances (out of 48) were significantly different. Six of the significant differences were less then 1°F. About three times as many simulated means were high as low but the annual means very close. This may indicate slightly warmer temperatures for the base period than for the entire 80 years. The variances of the simulated temperatures tended to be slightly smaller than the historic temperature variances. The annual variances were significantly different for the maximum temperature. Eight pairs of CDF's (out of 48) were significantly different. The means, variances and ranges of freezing and hot spells for the simulated and historic data also appear to be similar. Thus, for Colubmia, 17 years of data should be sufficient to estimate the temperature parameters for the model.

Solar Radiation

The solar radiation algorithm appears to be working extremely well. When the simulated data were compared to the historic data used to estimate the parameters, only two means were declared significantly different. Both of these occurred at Caribou. Only one variance was declared significantly different for Miami while two were significantly different at Columbia. Five to six variances (out of 24) differed significantly at each of the other locations. There was only one significant difference in the CDF's at Albuquerque, Caribou and Columbia. There were three significant differences at Miami and four at Medford.

The annual mean daily solar radiation for the simulated data is very close to the observed. The largest difference occurred at Miami but was less than 1%. The range of the simulated solar radiation over all months generally compares well to the historic. An exception is at Albuquerque where the simulated range does not come close to the observed maximum of 994. However, this value reportedly occurred in September when the maximum radiation at the top of the atmosphere is at most 830 langleys. Therefore, the observed value of 994 appears to be in error.

The model appears to work better when trace amounts of rain are classified as wet. With traces in the dry category one mean, six variances and two CDF's were declared significantly different. Moreover, the variances of the observed daily solar radiation appear to be smaller when the trace amounts of rain are classified as wet. This is true for all but the winter months, and is particularly true for the dry precipitation status. Smaller variances are desirable because this indicates that the observations within precipitation status are more alike and the separation between wet and dry can be made with greater precision.

When comparing the simulated data to all the historic data at Columbia, the model continues to perform well. However, it should be noted that only 22 years of historic data are available. No significant differences in means were found. Two variances and seven cumulative distribution functions were declared significantly different. The CDF significant differences all occurred for wet days and may indicate that the 17-year base period is not long enough but the historic record is too short to make any conclusions.

Table 2: Summary of Validation Results: Number of Significant (α = .05) and Nonsignificant (NS) Results for Each Variable at each location

LOCATION	Miami, FL		Albuquerque, NM		Medford, OR		Caribou, ME		Columbia, MO1/		Columbia, MO2/		Columbia, MO3/	
Lat./Alt.	26°/15 ft		35°/5326 ft.		42°/1312 ft.		47°/624 ft.		39°/887 ft.		39°/887 ft.		39°/887 ft.	
Ann. Rainfall	59.7		7.7		20.6		35.9		34.0		34.0		37.9	
	Significant	NS	Significant	NS	Significant	NS	Significant	NS	Significant	NS	Significant	NS	Significant	NS
Precip Occur.	0	12	0	12	0	12	0	12	0	12	0	12	5	7
Precip. Amount														
mean.........	0	12	0	12	0	12	0	12	0	12	0	12	4	8
variance.....	8	4	8	4	10	2	7	5	4	8	7	5	10	2
K-S test.....	1	11	0	12	2	10	5	7	1	11	2	10	0	12
Max. Temp.														
mean.........	4	20	1	23	4	20	2	22	0	24	5	19	9	15
variance.....	0	24	2	22	3	21	1	23	0	24	1	23	9	15
K-S test	2	22	1	23	5	19	1	23	0	24	4	20	1	23
Min. Temp.														
mean.........	0	24	2	22	0	24	1	23	1	23	4	20	9	15
variance.....	1	23	1	23	0	24	2	22	0	24	0	24	13	11
K-S test.....	3	21	2	22	0	24	2	22	1	23	5	19	7	17
Solar Radiation:														
mean.........	0	24	0	24	0	24	2	22	0	24	1	23	0	24
variance.....	1	23	6	18	5	19	5	19	2	22	6	18	2	22
K-S test.....	3	21	1	23	4	20	1	23	1	23	2	22	7	17

1/ Historical (17 yrs) vs. simulated (50 years) - trace rain defined as wet.
2/ Historical (17 yrs) vs. simulated (50 years) - trace rain defined as dry.
3/ Historical (80 yrs) vs. simulated (99 years) - trace rain defined as wet.

NOTE: Only 22 years of historical solar radiation data was available.

SUMMARY AND RECOMMENDATIONS

Summary

A stochastic weather simulation model was developed and validated for a wide range of climates. The model produces possible sequences of daily precipitation amount, maximum and minimum air temperature, and total solar radiation at the earth's surface. The simulated weather data are useful in a variety of settings to replace long series of historic data which may not be available, convenient or appropriate.

The model uses a first order two-state Markov chain to simulate the occurrence of wet and dry days. Probabilities are used to simulate the occurrence of trace amounts on wet days. A two-parameter gamma distribution conditioned on the previous day precipitation status is used to generate greater than trace precipitation amounts on the current day.

The model uses three-parameter sine functions to describe the long term mean daily maximum and minimum temperatures over the year. Two bi-variate normal distributions conditioned on the current day precipitation status are used to simulate the difference between the observed temperature and the fitted three-parameter sine curve. The first distribution generates either the current maximum or current minimum temperature difference from the previous day maximum temperature difference depending on which current difference has the higher correlation to the previous day. The second distribution generates the remaining current difference. The simulated temperatures are obtained by adding the appropriate daily values from the fitted sine curves to the simulated differences.

The model uses a series of equations to compute the current maximum clear day solar radiation from the date and latitude. A two-parameter gamma distribution simulates the difference between the observed and the maximum clear day solar radiation on dry days. A two-parameter beta distribution is used to generate the difference on wet days. The simulated solar radiation values are obtained by subtracting the simulated difference from the maximum clear day value.

The model was developed on data from Columbia, Missouri. The validation of the model was done at Columbia and four additional locations varying widely in climate. Of the five sites, Miami, Florida has the lowest elevation and latitude and the highest average annual precipitation and temperature. Albuquerque, New Mexico has the lowest total rainfall and highest elevation and total solar radiation. Caribou, Maine has the highest latitude and lowest mean temperature and total solar radiation. The fifth site used in the validation was Medford, Oregon which was chosen primarily for its Northwest location.

The validation showed that the method used to simulate precipitation occurrence worked very well for the base period at all locations. At Columbia where 80 years of precipitation and temperature data were available, the simulated precipitation frequencies (based on the most recent 17-year period) did not compare well to the long term averages for five of twelve months.

The simulated precipitation amounts compared favorably to the base period for all locations. The annual totals showed a slight positive bias and the associated variances a slight negative bias. Comparison of the simulated data to the entire 80-year period of record at Columbia revealed a negative bias in the average monthly rainfall amounts and variances. The simulated total annual rainfall was significantly lower than the historic.

The algorithm used to generate daily maximum and minimum temperatures worked very well. Comparisons to the base period showed a tendency for the monthly means to be low on wet days. The average annual maximum temperatures showed a slight negative bias. The simulated data compared satisfactorily to the 80-year period at Columbia although there was some indication that the 17-year base was slightly warmer. The variances for the average annual maximum temperature were significantly different

The method used to simulate solar radiation worked extremely well. No biases were evident in any of the comparisons. There was not a long enough period of record available at Columbia to determine whether the 17-year base period was of sufficient length.

Overall, the analysis indicated that for precipitation at Columbia 17 years were not long enough to adequately represent the 80 years of recorded data. If adequate representation is desired, a longer base period for parameter estimation would be required. However, many times it is better for the simulated data to represent recent history rather than a long time period. This is particularly true if the simulated data are used to assess the risk of current decisions or represent future weather. It may also be possible that the simulator may function satisfactorily with only a 10 to 15-year base period for temperature and solar radiation. However, too short of a base would cause the simulated data to have unrealistically low variance. The choice of the length of the base period depends in part on the purpose of the simulation.

Another goal of the validation was to determine whether including days with trace precipitation amounts in the wet category was preferable to the dry. This choice made no appreciable difference in the simulation of precipitation but was clearly advantageous for the temperature and solar radiation.

Recommendations

There are many ways the weather simulation model could be refined to provide more realistic climate data. Most of these would add to the complexity and likely increase the cost of running the model. Thus, the practicality of the changes would have to be weighed against the gains in light of the application. Several possible refinements are suggested.

(1) All parameters in the model are estimated monthly. An obvious way to improve the simulation would be to estimate at more frequent intervals. This would increase the number of parameter estimates needed to describe the climate at a particular location. There are presently 405 parameter estimates so, for example, bi-weekly parameter estimation would require about 867.

(2) To reduce the number of parameter estimates, a finite Fourier series can be used to describe the values of a particular parameter over time. At Columbia it was found that a constant term and two harmonics were generally enough to adequately represent 12 monthly points for the parameters which were examined. The same number of Fourier coefficients would likely represent 26 bi-weekly points as well. Either monthly or bi-weekly points could then be used and the total number of parameter estimates would be roughly 108.

Besides reducing the number of parameter estimates needed to describe a particular climate, the Fourier representation has the added advantage of providing continuous rather than discrete parameter estimates for the distributions and transition matrix. The differencing procedure used on the temperature and solar radiation could likely be eliminated since the Fourier series serves the same purpose.

The main drawback of using a finite Fourier series to describe parameter estimates is that smoothing occurs whenever the number of Fourier coefficients is less than the number of points. This may make the simulator less responsive to seasonal change. The smoothing could be used to advantage, however, by weighting the discrete monthly or bi-weekly estimates inversely proportional to their relative standard errors. This would cause more smoothing in the Fourier fit for points estimated with lower precision and closer agreement with points which have higher precision.

(3) Most of the distributional problems with the temperature simulation were a result of skewness in the observed data. This could be accommodated by replacing the bi-variate normals with bi-variate betas. The beta distribution can look similar to a normal or possess a skew in either direction. The beta distribution should, therefore, describe the temperature better than the normal.

(4) In the present model, the simulated daily solar radiation is independent of the temperature. Over all days within month, the simulated data would show a weak relationship due to the wet and dry subsetting. In reality, there is generally a fairly good relationship between the temperature change during the day and the solar radiation received at the earth's surface. At Columbia, neither the maximum nor the minimum temperature consistently had a significant correlation to the solar radiation within month and precipitation status. However, the difference between the maximum and minimum (representing the daily change) did have a consistently significant correlation with either the solar radiation or the solar radiation difference (maximum clear day radiation minus the observed). These correlations were typically on the order of .5 to .7 with roughly 250 observations. (The correlations are negative for the solar radiation difference.) The relationship between the daily temperature change and the solar radiation could be used to tie the simulated solar radiation to the temperature.

One way to do this would be to use a bi-variate distribution to simulate the solar radiation difference from the simulated temperature change. At Columbia, frequency plots of the daily temperature change looked fairly normal on dry days but had a negative skew for a couple months. On wet days the temperature change appeared normal about half the time and skewed right the other six months. This suggests that a beta distribution on dry days and a gamma distribution on wet days (or possibly a beta for all) might work fairly well. Since the solar radiation uses a gamma on dry days and a beta on wet, linking the temperature and solar radiation with a bi-variate gamma, beta or both would require some compromise.

Another possible way to use the relationship between the daily temperature change and the solar radiation would be to fit a regression of the solar radiation difference on the temperature change within month and precipitation status. Most likely a non-linear function would be best since the maximum temperature is only going to rise to a point regardless of the amount of solar radiation received after the maximum is reached. If linear regression fits were used, the correlations would be as indicated earlier. The simulation procedure would then be to generate a solar radiation difference about the fitted regression curve with the gamma and beta distributions. The model currently simulates solar radiation differences about the monthly mean difference within precipitation status. The new procedure would simulate a solar radiation difference about a mean dependent on the temperature change already simulated for the current day. The simulated solar radiation values would then tend to be lower on days with relatively small temperature change (and vice versa) while maintaining a distribution simular to the observed data.

REFERENCES

ARKIN, G.F., S.J. Maas, and C.W. Richardson. "Forecasting Grain Sorghum Yields Using Simulated Weather Data and Updating Techniques", Transactions of ASAE 23(3), 676-680, 1980.

BARR, A.J., J.H. Goodnight and J.P. Sall. SAS Users Guide 1979 Edition, SAS Institute Inc., SAS Circle, Box 8000, Cary, NC 27511

BERMAN, M.B.. Generating Gamma Distributed Variates for Computer Simulation Models. Santa Monica, CA: Rand Corporation Publication R-641-PR, 1971.

BOND, D.C.. Generating Daily Weather Values by Computer Simulation Techniques for Crop Yield Forecasting Models., Washington, D.C., Research Division, SRS, USDA, 1979.

BRUHN, J.A., W.E. Fry, and G.W. Fick. "Simulation of Daily Weather Data Using Probability Distributions", J. of Applied Meteorology, 1980.

CONOVER, W.J.. Practical Nonparametric Statistics. John Wiley & Sons: New York, 1971.

GREENWOOD, J.A., D. Durand. "Aids for Fitting the Gamma Distribution by Maximum Likelihood", Technometrics 2, 55-65, 1960.

JOHNSON, N.L., S. Kotz. Distributions in Statistics: Continuous Univariate Distributions. Vol. 1, 2, John Wiley & Sons, New York, 1970.

JONES, J.W., R.F. Colwick, and F.D. Threadgill. "A Simulated Environmental Model of Temperature, Evaporation, Rainfall and Soil Moisture", Transactions of ASAE 15. 366-372, 1972.

MATALAS, N.C., "Mathematical Assessment of Synthetic Hydrology", Water Resources Res. 3(4), 937-945, 1967.

NICKS, A.D. Stochastic Generation of the Occurrence, Pattern and Location of Maximum Amount of Daily Rainfall. Proc. Symp. on Statistical Hydrology, USDA, ARS, Misc. Pub., 1275:154-176.

NICKS, A.D. AND J.F. Harp. "Stochastic Generation of Temperature and Solar Radiation Data", J. of Hydrology 48, 1-17, 1980.

RICHARDSON, C.W. "Stochastic Simulation of Daily Precipitation, Temperature, and Solar Radiation", Water Resources Res. 17(1), 182-190, 1981.

A P P E N D I X   A

Albuquerque, New Mexico

Table A1: Frequency of Wet Days for Historical (20 years) and Simulated (50 runs) -- Albuquerque, N.Mex.*

Month	Frequency of Wet Days
January	
Historical	0.205
Simulated	0.195
February	
Historical	0.274
Simulated	0.283
March	
Historical	0.263
Simulated	0.284
April	
Historical	0.197
Simulated	0.198
May	
Historical	0.268
Simulated	0.279
June	
Historical	0.280
Simulated	0.286
July	
Historical	0.576
Simulated	0.604
August	
Historical	0.561
Simulated	0.523
September	
Historical	0.310
Simulated	0.313
October	
Historical	0.219
Simulated	0.241
November	
Historical	0.200
Simulated	0.201
December	
Historical	0.218
Simulated	0.210

* No significant differences at the $\alpha = .05$ level.

Table A2: Historical (20 years) and Simulated (50 runs) Precipitation and Maximum and Minimum Temperatures and Solar Radiation
Albuquerque, N. Mexico

Month and Precipitation Status	Precipitation (in)			Maximum Temperature (°F)			Minimum Temperature (°F)			Solar Radiation (Ly)		
	Mean	Stan. Dev.	Range	Mean	Stan. Dev.	Range	Mean	Stan. Dev.	Range	Mean	Stan. Dev.	Range
Jan. Dry												
Historical	---	---	---	48.05	8.82	13.0-68.0	22.65	8.01	-7.0-47.0	323.8	57.0*	108.0-426.0
Simulated	---	---	---	48.77	8.38	23.2-73.0	23.70*	7.88	-5.0-49.9	322.5	51.8	27.7-434.8
Jan. Wet												
Historical	0.04	0.11	TR-0.87	44.94	8.61	13.0-64.0	26.95	7.90	-1.0-44.0	203.2	86.0	46.0-405.0
Simulated	0.05	0.09*	TR-0.63	43.52	8.72	17.1-68.9	26.11	8.21	-2.6-50.5	206.3	87.8	36.1-419.2
Feb. Dry												
Historical	---	---	---	54.34	8.90	27.0-72.0	26.72	7.52	-4.0-45.0	422.1	71.1	134.0-559.0
Simulated	---	---	---	54.41	8.91	27.4-84.5	26.85	7.50	3.7-52.4	421.3	69.2	27.4-570.9
Feb. Wet												
Historical	0.05	0.08	TR-0.37	46.24	9.79	18.0-67.0	28.12	8.51	-5.0-46.0	291.3	111.4	81.0-536.0
Simulated	0.05	0.07	TR-0.47	45.72	9.97	15.8-80.7	27.71	8.49	-3.8-51.8	289.9	109.9	35.2-532.6
Mar. Dry												
Historical	---	---	---	61.64	8.78	30.0-80.0	32.13	7.76	9.0-53.0	551.4	91.4	213.0-718.0
Simulated	---	---	---	61.39	8.89	34.6-92.0	32.03	7.71	9.0-58.1	551.4	88.6	174.8-719.9
Mar. Wet												
Historical	0.06	0.11	TR-0.75	52.47	9.66	29.0-73.0	32.45	7.59	13.0-54.0	373.4	121.8	87.0-618.0
Simulated	0.06	0.11	TR-0.64	51.74	9.35	23.6-76.9	32.30	7.52	11.5-59.7	384.9	127.7	72.3-665.1
Apr. Dry												
Historical	---	---	---	71.93	7.30	46.0-89.0	41.22	6.61	23.0-59.0	663.0	87.3	287.0-808.0
Simulated	---	---	---	71.26	7.91*	47.0-96.3	40.61	6.94	18.2-63.6	665.8	79.9*	232.7-800.3
Apr. Wet												
Historical	0.07	0.18	TR-1.66	63.02	8.91	37.0-81.0	40.74	6.02	29.0-60.0	480.2	137.2	126.0-737.0
Simulated	0.06	0.13**	TR-1.26	63.10	9.68	37.0-92.6	41.43	7.01	22.8-60.8	481.6	132.2	191.2-722.6
May Dry												
Historical	---	---	---	81.40	7.35	53.0-98.0	50.06	6.86	28.0-67.0	737.7	76.9	448.0-884.0
Simulated	---	---	---	81.25	7.35	60.9-102.7	50.17	6.69	31.1-72.7	731.8	76.7	338.7-877.5
May Wet												
Historical	0.05	0.11**	TR-0.68	76.75	9.50	48.0-93.0	51.62	6.46	34.0-68.0	585.5	128.1	156.0-818.0
Simulated	0.05	0.09	TR-0.69	76.20	8.84	44.9-101.4	50.90	6.05	32.3-65.3	590.4	131.9	231.1-818.6
Jun Dry												
Historical	---	---	---	90.79	5.49	74.0-101.0	59.52	5.92	43.0-74.0	770.4	72.4*	393.0-908.0
Simulated	---	---	---	90.98	5.22	70.6-109.1	59.38	5.54	40.8-78.8	765.2	66.6	358.3-861.8
Jun Wet												
Historical	0.06	0.18	TR-1.61	87.87	7.67	66.0-102.0	60.73	5.66	44.0-73.0	647.8	112.8	262.0-826.0
Simulated	0.06	0.13**	TR-0.95	88.45	7.56	66.4-110.3	61.06	5.47	44.2-77.0	652.4	112.2	322.1-821.3
Jul Dry												
Historical	---	---	---	93.64	4.58	75.0-104.0	65.54	3.84	54.0-75.0	730.4	74.6	485.0-892.0
Simulated	---	---	---	93.99	4.38	80.2-106.8	65.80	4.04	53.7-78.7	730.4	75.4	400.5-864.6
Jul Wet												
Historical	0.08	0.18	TR-1.64	91.54	5.16	66.0-103.0	65.32	3.46	58.0-76.0	643.3	110.4	159.0-910.0
Simulated	0.08	0.14**	TR-1.24	91.68	5.24	74.0-106.7	65.22	3.53	52.8-76.0	642.3	111.6	283.3-880.8
Aug Dry												
Historical	---	---	---	90.81	4.32	73.0-99.0	63.25	3.60	52.0-72.0	669.4	60.6	410.0-810.0
Simulated	---	---	---	91.58*	4.75	75.6-108.2	63.82*	3.47	54.1-73.5	671.5	60.8	445.1-807.3
Aug Wet												
Historical	0.08	0.16	TR-1.11	88.71	4.88	73.0-99.0	63.90	3.24	54.0-73.0	594.8	100.0	257.0-861.0
Simulated	0.08	0.14**	TR-1.19	88.49	4.55	75.3-100.8	63.75	3.24	55.2-74.1	588.3	100.3	291.7-827.7
Sept. Dry												
Historical	---	---	---	84.78	5.76	63.0-96.0	55.76	5.56	37.0-67.0	589.4	73.3**	193.0-994.0
Simulated	---	---	---	84.48	5.80	64.7-105.7	55.56	5.61	38.4-77.2	588.0	92.6	289.3-829.6
Sept. Wet												
Historical	0.08	0.19	TR-1.92	81.14	7.20	60.0-95.0	58.34	4.55	45.0-68.0	462.3	119.4	107.0-682.0
Simulated	0.08	0.13**	TR-0.85	81.17	7.26	59.2-100.0	58.34	4.76	42.7-69.4	472.7	115.2	134.3-675.2
Oct. Dry												
Historical	---	---	---	73.04	7.37	45.0-87.0	43.88	6.28	25.0-60.0	469.7	65.7	149.0-745.0
Simulated	---	---	---	73.09	7.20	46.4-95.3	44.09	6.47	23.4-63.9	469.8	73.2**	148.7-681.8
Oct. Wet												
Historical	0.12	0.25	TR-1.74	67.11	10.42	43.0-87.0	46.38	6.84	32.0-61.0	338.3	127.9	56.0-565.0
Simulated	0.14	0.23	TR-1.63	67.16	9.31	39.8-91.8	46.35	5.89*	30.9-63.2	330.5	120.6	18.3-578.2
Nov. Dry												
Historical	---	---	---	57.90	8.08	31.0-74.0	31.12	6.48	10.0-46.0	351.6	56.3	105.0-451.0
Simulated	---	---	---	58.10	8.12	25.8-80.7	31.41	6.68	1.6-52.2	353.6	48.3**	143.7-468.0
Nov. Wet												
Historical	0.05	0.10	TR-0.63	52.03	9.32	27.0-70.0	34.88	6.76	18.0-49.0	219.5	89.6	32.0-423.0
Simulated	0.05	0.07**	TR-0.37	51.20	10.58	6.6-80.9	34.45	7.45	6.6-54.1	217.2	88.8	23.3-427.5
Dec. Dry												
Historical	---	---	---	48.30	8.01	25.0-72.0	23.90	6.67	4.0-46.0	297.1	48.1	62.0-376.0
Simulated	---	---	---	48.24	7.89	24.7-73.0	23.80	7.01	0.6-46.0	296.4	44.9	65.0-372.9
Dec. Wet												
Historical	0.08	0.14	TR-0.81	42.91	9.08	21.0-68.0	26.61	8.18	3.0-49.0	192.2	78.4	50.0-336.0
Simulated	0.08	0.13	TR-0.92	43.23	7.68*	25.4-65.2	26.90	7.37	4.3-48.5	190.1	77.4	44.5-335.0
Year 1/												
Historical	7.7	2.1	4.1-10.7	70.11	18.23	13.0-104.0	43.47	16.27	-7.0-76.0	512.3	188.3	32.0-994.0
Simulated	7.9	1.8	4.6-11.7	70.06	18.29	6.6-110.3	43.51	16.22	-5.0-78.8	511.8	187.1	18.0-880.0

* Indicates significantly different at $\alpha = .05$ level.
** Indicates significantly different at $\alpha = .01$ level.
1/ Average total rain, average maximum and minimum temperatures and average solar radiation.

Table A3: Kolmogorov - Smirnov (K-S) Two-Sample Statistics to Test Hypothesis of Equality of Historical (20years) and generated (50runs) Cumulative Distribution Functions (CDF;s) of Daily Variates

Albuquerque, N. Mex.

Month & Precip. Status	Rain n_H	Rain n_s	Rain K-S Value	Maximum Temperature n_H	Maximum Temperature n_s	Maximum Temperature K-S Value	Minimum Temperature n_H	Minimum Temperature n_s	Minimum Temperature K-S Value	Solar Radiation n_H	Solar Radiation n_s	Solar Radiation K-S Value
Jan Dry:	---	---	---	184	202	.1099	184	202	.0755	171	202	.0952
Wet:	127	189	.1180	127	189	.1384	127	189	.1457	117	189	.0700
Feb Dry:	---	---	---	188	187	.0786	188	187	.0546	196	187	.0795
Wet:	155	186	.0742	155	186	.0785	155	186	.1247	141	186	.0629
Mar Dry:	---	---	---	197	212	.1049	197	212	.1321	196	212	.0708
Wet:	163	232	.0810	163	232	.0733	163	232	.0786	144	232	.1257
Apr Dry:	---	---	---	206	205	.0635	206	205	.0707	203	205	.0651
Wet:	118	204	.0605	118	204	.0855	118	204	.1112	102	205	.0686
May Dry:	---	---	---	205	207	.1247	205	207	.0755	203	207	.0816
Wet:	166	197	.1038	166	197	.0857	166	197	.0743	158	197	.0933
Jun Dry:	---	---	---	209	198	.0593	209	198	.0845	214	198	.0641
Wet:	168	189	.0667	168	189	.0608	168	189	.1005	149	189	.1232
Jul Dry:	---	---	---	194	191	.0581	194	191	.0734	193	191	.0885
Wet:	195	190	.0821	195	190	.1014	195	190	.1572*	194	190	.1450*
Aug Dry:	---	---	---	202	196	.1462*	202	196	.1718**	203	196	.1101
Wet:	196	196	.0765	196	196	.0408	196	196	.0867	194	196	.1128
Sep Dry:	---	---	---	205	193	.0972	205	193	.0611	203	193	.1242
Wet:	186	206	.0822	186	206	.1114	186	206	.0454	181	206	.1056
Oct Dry:	---	---	---	186	196	.1139	186	196	.0426	188	196	.0858
Wet:	136	201	.1211	136	201	.0703	136	201	.0862	126	201	.0977
Nov Dry:	---	---	---	206	207	.0912	206	207	.0477	206	207	.1198
Wet:	120	208	.0759	120	208	.0933	120	208	.0875	112	208	.0542
Dec Dry:	---	---	---	208	189	.0960	208	189	.0491	206	189	.1333
Wet:	135	205	.0607	135	205	.0802	135	205	.0623	122	205	.0917

NOTE: n_h = number of observations from the historical data set.

n_s = number of observations from the simulated data set.

* Historical and simulated CDF's are significantly different at α = .05 level.

** Historical and simulated CDF's are significantly different at α = .01 level.

APPENDIX B

Caribou, Maine

Table B1: Frequency of Wet Days for Historical (20 years) and Simulated (50 runs) -- Caribou, ME*

Month	Frequency of Wet Days
January	
Historical	0.747
Simulated	0.709
February	
Historical	0.706
Simulated	0.687
March	
Historical	0.616
Simulated	0.596
April	
Historical	0.588
Simulated	0.589
May	
Historical	0.603
Simulated	0.575
June	
Historical	0.602
Simulated	0.609
July	
Historical	0.622
Simulated	0.630
August	
Historical	0.572
Simulated	0.585
September	
Historical	0.557
Simulated	0.561
October	
Historical	0.556
Simulated	0.562
November	
Historical	0.718
Simulated	0.733
December	
Historical	0.772
Simulated	0.771

* No significant differences at the $\alpha = .05$ level.

Table B2: Historical (20 years) and Simulated (50 runs) Precipitation and Maximum and Minimum Temperatures and Solar Radiation
Caribou, ME

Month and Precipitation Status	Precipitation (in) Mean	Stan. Dev.	Range	Maximum Temperature (°F) Mean	Stan. Dev.	Range	Minimum Temperature (°F) Mean	Stan. Dev.	Range	Solar Radiation (Ly) Mean	Stan. Dev.	Range
Jan. Dry												
Historical	---	---	---	15.15	10.68	-14.0-40.0	-3.44	11.12	-28.0-28.0	195.9	42.4	50.0-326.0
Simulated.	---	---	---	15.14	10.83	-17.2-50.7	-3.29	11.00	-35.4-29.1	192.6	41.1	66.9-291.8
Jan. Wet												
Historical	0.09	0.16	TR-1.06	22.12	11.04	-14.0-47.0	4.49	13.54	-32.0-38.0	125.2	55.6	21.0-293.0
Simulated.	0.09	0.15**	TR-1.33	20.78*	11.06	-9.9-67.6	3.74	14.06	-42.3-50.9	128.7	56.3	1.2-285.4
Feb. Dry												
Historical	---	---	---	20.82	11.30	-10.0-46.0	-2.77	11.78	-41.0-31.0	313.5	59.2	131.0-425.0
Simulated.	---	---	---	20.66	11.10	-12.7-55.1	-2.37	11.70	-30.9-37.7	306.6	51.8	123.9-434.3
Feb. Wet												
Historical	0.11	0.19	TR-1.11	24.87	9.68	-4.0-48.0	6.26	13.32	-32.0-41.0	207.7	80.9	36.0-392.0
Simulated	0.12	0.18	TR-1.12	24.15	10.15	-4.7-50.1	5.04	13.37	-37.4-41.0	214.2	84.4	3.9-402.9
Mar. Dry												
Historical	---	---	---	33.52	10.03	4.0-73.0	10.99	11.24	-19.0-35.0	455.4	95.2	106.0-594.0
Simulated.	---	---	---	33.73	10.10	4.2-65.2	10.80	11.36	-18.3-46.6	452.8	83.8*	124.7-614.5
Mar. Wet												
Historical	0.11	0.19	TR-1.12	32.84	7.68	9.0-57.0	17.38	11.31	-20.0-38.0	298.6	116.7	27.0-567.0
Simulated	0.12	0.18	TR-1.43	32.34	8.14	9.8-56.0	16.50	10.79	-20.0-47.6	305.0	128.4*	2.10-604.1
Apr. Dry												
Historical	---	---	---	48.35	9.08	18.0-77.0	26.26	6.80	-2.0-40.0	560.7	129.0	42.0-772.0
Simulated	---	---	---	49.78*	8.48	23.3-75.4	27.53*	6.65	5.9-46.9	568.6	105.4**	115.2-740.3
Apr. Wet												
Historical	0.14	0.23	TR-1.35	44.17	7.72	23.0-68.0	30.20	6.38	4.0-47.0	323.0	162.7	39.0-726.0
Simulated.	0.14	0.25	TR-2.80	43.89	8.12	21.3-73.7	29.69	6.96	10.3-51.3	339.1	172.2	3.1-691.1
May Dry												
Historical	---	---	---	63.92	10.43	40.0-91.0	37.26	6.93	20.0-60.0	636.1	131.8	60.0-818.0
Simulated	---	---	---	64.62	10.65	35.5-92.8	37.35	7.15	18.7-56.6	648.0	113.6**	76.9-818.1
May Wet												
Historical	0.15	0.23	TR-2.08	57.16	9.67	30.0-83.0	40.13	6.85	21.0-60.0	343.5	182.2	44.0-761.0
Simulated	0.16	0.22	TR-2.11	57.62	9.62	21.8-91.4	40.52	7.27	19.6-67.7	346.2	184.1	26.3-756.9
Jun Dry												
Historical	---	---	---	74.16	7.50	52.0-92.0	47.56	6.68	30.0-64.0	664.1	120.2	120.0-843.0
Simulated	---	---	---	73.65	8.14	45.2-93.7	46.73	6.84	23.3-64.2	664.8	115.6	139.9-841.9
Jun Wet												
Historical	0.17	0.28	TR-2.14	68.10	8.98	44.0-92.0	50.10	6.37	33.0-65.0	391.7	192.3	44.0-817.0
Simulated	0.18	0.25*	TR-1.93	67.16	9.06	39.1-97.6	49.93	6.34	26.9-68.8	385.9	187.5	49.8-813.1
Jul Dry												
Historical	---	---	---	78.26	6.42	63.0-95.0	52.56	6.40	36.0-71.0	651.4	114.4	6.0-826.0
Simulated.	---	---	---	77.69	6.46	60.7-96.4	51.92	5.93	33.6-70.4	645.9	117.7	7.5-809.8
Jul Wet												
Historical	0.20	0.34	TR-1.92	73.54	7.36	56.0-95.0	55.12	5.46	37.0-70.0	414.3	177.7	4.0-748.0
Simulated.	0.21	0.29**	TR-1.86	73.52	7.65	50.2-96.4	55.15	5.19	37.9-71.8	414.8	174.1	12.4-743.0
Aug Dry												
Historical	---	---	---	74.74	6.36	60.0-92.0	49.30	6.43	34.0-68.0	548.3*	109.9	61.0-741.0
Simulated.	---	---	---	74.55	6.99	55.0-97.8	49.28	6.78	28.5-76.0	565.5	101.0	66.1-729.7
Aug Wet												
Historical	0.22	0.41	TR-4.08	70.73	7.09	51.0-89.0	52.72	6.45	37.0-70.0	348.8	173.8	25.0-764.0
Simulated.	0.24	0.36**	TR-3.15	69.91	7.31	44.5-91.2	52.08	6.93	30.8-77.6	345.3	162.9	11.1-674.7
Sept. Dry												
Historical	---	---	---	66.23	8.46	44.0-87.0	40.68	7.66	27.0-67.0	420.0	109.6	59.0-618.0
Simulated.	---	---	---	65.91	9.26	40.4-90.3	40.13	7.69	15.0-68.9	426.8	97.5*	71.9-617.4
Sept. Wet												
Historical	0.22	0.49	TR-6.21	62.87	8.60	43.0-86.0	45.77	7.97	25.0-66.0	250.9	146.5	23.0-586.0
Simulated.	0.23	0.36**	TR-2.67	62.64	8.28	37.9-87.1	45.88	8.00	24.0-68.3	245.8	138.2	0.9-611.8
Oct. Dry												
Historical	---	---	---	54.88	9.53	32.0-79.0	33.36	7.59	15.0-57.0	277.5	84.5	26.0-442.0
Simulated.	---	---	---	55.56	9.93	24.4-85.1	33.76	8.26	10.4-60.3	278.7	83.2	6.1-467.0
Oct. Wet												
Historical	0.19	0.39	TR-4.05	50.31	9.49	28.0-77.0	36.18	7.73	18.0-59.0	146.0	93.7	7.0-442.0
Simulated.	0.18	0.30**	TR-2.80	50.58	9.21	26.5-78.7	36.32	7.88	1.8-57.5	157.5	92.8	0.1-442.7
Nov. Dry												
Historical	---	---	---	38.95	9.24	16.0-68.0	22.51	9.15	-3.0-45.0	164.7	63.2	9.0-300.0
Simulated.	---	---	---	38.64	7.57**	19.9-64.7	21.64	7.83*	-0.8-43.5	165.8	57.2	15.2-285.7
Nov. Wet												
Historical	0.16	0.27	TR-1.75	38.27	9.39	15.0-63.0	25.86	9.88	-2.0-53.0	93.3	60.1	7.0-313.0
Simulated.	0.17	0.26	TR-2.63	38.56	8.87	7.8-66.0	26.21	9.48	-1.5-57.4	101.0*	60.2	0.1-298.9
Dec. Dry												
Historical	---	---	---	19.21	10.79	-3.0-46.0	3.03	12.16	-16.0-31.0	147.7	43.2	26.0-220.0
Simulated.	---	---	---	18.92	9.86	-9.6-46.1	3.64	11.33	-28.3-33.3	149.8	41.8	4.4-215.2
Dec. Wet												
Historical	0.12	0.22	TR-1.46	25.77	10.34	-3.0-56.0	10.29	13.15	-24.0-45.0	98.1	47.9	12.0-225.0
Simulated.	0.11	0.20**	TR-1.85	25.48	10.26	-7.5-60.6	9.93	11.99*	-26.6-43.2	99.8	47.8	0.5-214.0
Year 1/												
Historical	35.9	5.2	28.0-51.2	48.50	21.53	-14.0-95.0	29.71	20.32	-41.0-71.0	321.3	210.7	4.0-843.0
Simulated.	37.0	4.1	25.5-45.6	48.28	21.66	-17.2-97.8	29.47	20.42	-42.3-77.6	322.0	207.1	0.1-841.9

* Indicates significantly different at α = .05 level.
** Indicates significantly different at α = .01 level.
1/ Average total rain, average maximum and minimum temperatures, and average solar radiation.

Table B3: Kolmogorov - Smirnov (K-S) Two-Sample Statistics to Test Hypothesis of Equality of Historical (20years) and generated (50runs) Cumulative Distribution Functions (CDF;s) of Daily Variates

Caribou, ME

Month & Precip. Status	Rain			Maximum Temperature			Minimum Temperature			Solar Radiation		
	n_H	n_s	K-S Value	n_H	n_s	K-S Value	n_H	n_s	K-S Value	n_H	n_s	K-S Value
Jan Dry	---	---	---	157	208	.0494	157	208	.0521	135	208	.0697
Jan Wet	196	185	.1380	196	185	.0773	196	185	.0620	193	185	.1096
Feb Dry	---	---	---	166	187	.0622	166	187	.0984	131	187	.1418
Feb Wet	209	210	.1746**	209	210	.0948	209	210	.0460	205	210	.0594
Mar Dry	---	---	---	195	205	.0688	195	205	.0874	188	205	.0876
Mar Wet	215	192	.1822**	215	192	.0860	215	192	.1303	215	192	.0922
Apr Dry	---	---	---	199	197	.0899	199	197	.1127	211	197	.0797
Apr Wet	195	211	.0963	195	211	.0712	195	211	.1547*	195	211	.0930
May Dry	---	---	---	208	202	.0410	208	202	.0569	207	202	.0742
May Wet	200	204	.1394*	200	204	.0564	200	204	.0544	204	205	.0637
Jun Dry	---	---	---	199	188	.0793	199	188	.0382	200	188	.1221
Jun Wet	215	198	.1316	215	198	.1315	215	198	.0796	217	198	.0999
Jul Dry	---	---	---	204	192	.0591	204	192	.0846	204	192	.0558
Jul Wet	204	195	.1612*	204	195	.0704	204	195	.0652	207	195	.0707
Aug Dry	---	---	---	192	209	.0663	192	209	.0501	194	209	.1493*
Aug Wet	194	206	.0933	194	206	.1681**	194	206	.1146	186	206	.0541
Sep Dry	---	---	---	206	229	.0496	206	229	.0711	206	229	.1069
Sep Wet	186	194	.0775	186	194	.0629	186	194	.0795	187	194	.1049
Oct Dry	---	---	---	195	201	.0570	195	201	.1151	198	201	.0626
Oct Wet	187	202	.0869	187	202	.0868	187	202	.0965	189	202	.0953
Nov Dry	---	---	---	169	205	.0672	169	205	.1437*	154	205	.0972
Nov Wet	172	184	.1447*	172	184	.0866	172	184	.0578	174	184	.1248
Dec Dry	---	---	---	141	195	.1207	141	195	.0909	122	195	.0904
Dec Wet	203	211	.0895	203	211	.1168	203	211	.0787	202	211	.0785

NOTE: n_h = number of observations from the historical data set.

n_s = number of observations from the simulated data set.

* Historical and simulated CDF's are significantly different at α = .05 level.

** Historical and simulated CDF's are significantly different at α = .01 level.

A P P E N D I X C

Medford, Oregon

Table C1: Frequency of Wet Days for Historical (20 years) and Simulated (50 runs) -- Medford, OR*

Month	Frequency of Wet Days
January	
Historical	0.732
Simulated	0.744
February	
Historical	0.563
Simulated	0.573
March	
Historical	0.552
Simulated	0.530
April	
Historical	0.440
Simulated	0.435
May	
Historical	0.400
Simulated	0.377
June	
Historical	0.272
Simulated	0.262
July	
Historical	0.098
Simulated	0.098
August	
Historical	0.137
Simulated	0.169
September	
Historical	0.183
Simulated	0.205
October	
Historical	0.374
Simulated	0.374
November	
Historical	0.593
Simulated	0.609
December	
Historical	0.713
Simulated	0.715

* No significant differences at the α = .05 level.

Table C2 Historical (20 years) and Simulated (50 runs) Precipitation and Maximum and Minimum Temperatures and Solar Radiation -- Medford, OR

Month and Precipitation Status	Precipitation (in) Mean	Stan. Dev.	Range	Maximum Temperature (°F) Mean	Stan. Dev.	Range	Minimum Temperature (°F) Mean	Stan. Dev.	Range	Solar Radiation (Ly) Mean	Stan. Dev.	Range
Jan. Dry												
Historical	---	---	---	44.28	8.30	22.0-71.0	25.22	7.74	0.0-48.0	168.0	65.3	39.0-300.0
Simulated	---	---	---	44.46	7.78	17.9-73.3	25.41	7.63	6.5-46.3	175.4	58.6	0.4-293.3
Jan. Wet												
Historical	0.17	0.29**	TR-2.32	45.10	7.30	29.0-70.0	32.54	6.45	10.0-50.0	99.8	49.8	12.0-281.0
Simulated	0.18	0.26	TR-1.90	44.51	7.55	22.2-73.6	32.36	6.42	12.8-52.7	103.8	50.6	0.2-266.7
Feb. Dry												
Historical	---	---	---	55.35*	7.13	34.0-77.0	28.15	5.19	10.0-44.0	276.8	81.9	78.0-435.0
Simulated	---	---	---	54.20	7.34	30.3-77.1	27.90	5.53	15.0-47.5	279.7	76.1	24.2-422.5
Feb. Wet												
Historical	0.14	0.28	TR-1.87	50.75	6.52	34.0-69.0	34.57	6.04	19.0-50.0	171.9	76.5	11.0-356.0
Simulated	0.14	0.25**	TR-2.53	50.82	7.08	29.7-72.2	34.55	6.09	14.4-52.5	175.4	80.3	0.3-385.2
Mar. Dry												
Historical	---	---	---	62.84	7.95	45.0-81.0	31.02	4.95	19.0-45.0	442.1	88.9	104.0-621.0
Simulated	---	---	---	62.63	7.46	36.6-84.8	30.61	5.08	16.3-44.5	437.8	85.3	22.9-603.1
Mar. Wet												
Historical	0.10	0.16	TR-1.22	52.95	6.70	33.0-70.0	35.51	5.31	16.0-49.0	273.6	109.6	42.0-605.0
Simulated	0.10	0.14**	TR-1.03	53.80	6.80	34.3-76.4	35.68	5.33	21.1-52.1	274.2	115.6	7.0-576.6
Apr. Dry												
Historical	---	---	---	69.72	8.08**	49.0-89.0	36.36	5.72	25.0-51.0	559.0	95.8	249.0-739.0
Simulated	---	---	---	68.78	9.20	40.1-97.2	36.40	5.79	20.0-54.3	558.3	93.3	51.2-736.3
Apr. Wet												
Historical	0.07	0.12**	TR-0.90	58.02	6.86	45.0-90.0	38.27	5.11	25.0-53.0	384.5	120.6	75.0-766.0
Simulated	0.07	0.10	TR-0.90	57.34	8.29**	36.4-81.2	37.89	5.53	22.2-57.0	381.8	122.5	65.6-667.7
May Dry												
Historical	---	---	---	77.38	8.50	56.0-96.0	42.82	5.75	28.0-57.0	685.2	93.75*	211.0-843.0
Simulated	---	---	---	78.23	8.49	49.3-111.5	42.80	5.39	28.2-63.5	681.1	85.77	272.6-831.7
May Wet												
Historical	0.10	0.20	TR-1.67	64.83	9.12	46.0-93.0	43.48	5.06	32.0-56.0	453.1	155.5	97.0-789.0
Simulated	0.11	0.15**	TR-0.88	66.61**	9.04	41.1-94.2	44.17	4.79	30.5-58.0	447.6	156.7	100.3-774.4
Jun Dry												
Historical	---	---	---	83.92	9.13	40.0-109.0	49.23	5.80	27.0-64.0	710.2	95.4	182.0-856.0
Simulated	---	---	---	83.54	8.79	51.4-109.4	48.87	5.67	26.3-68.1	711.6	93.4	263.9-854.4
Jun Wet												
Historical	0.08	0.13	TR-0.76	72.46	10.39	55.0-107.0	50.49	6.42	31.0-65.0	476.2	148.5	108.0-772.0
Simulated	0.09	0.12*	TR-0.68	72.74	10.38	42.2-98.3	50.81	6.41	30.0-74.2	484.4	140.9	149.9-745.9
Jul Dry												
Historical	---	---	---	91.30	7.25	67.0-108.0	53.89	5.11	38.0-67.0	718.5	60.3	385.0-836.0
Simulated	---	---	---	91.30	7.71	67.8-117.3	53.79	5.24	32.2-69.2	719.0	57.3	430.0-825.8
Jul Wet												
Historical	0.09	0.21	TR-1.07	83.24	10.30	61.0-107.0	56.75	5.65	46.0-68.0	502.3	162.7	152.0-764.0
Simulated	0.07	0.12**	TR-0.69	82.52	9.58	54.8-105.2	56.11	4.98	42.1-69.1	512.2	157.3	168.1-762.9
Aug Dry												
Historical	---	---	---	90.11	7.30	68.0-107.0	52.86	4.57	39.0-69.0	627.2	65.4	291.0-761.0
Simulated	---	---	---	88.96**	7.57	63.1-112.5	52.45	4.51	36.6-68.8	627.3	57.8**	386.7-749.8
Aug Wet												
Historical	0.09	0.13	TR-0.60	80.01	10.97	60.0-101.0	56.50	5.37	46.0-69.0	429.4	148.0	116.0-728.0
Simulated	0.08	0.16	TR-1.32	82.47	11.04	49.1-112.8	57.29	5.76	43.0-70.1	436.3	149.0	78.5-727.0
Sept. Dry												
Historical	---	---	---	85.13	8.30	65.0-107.0	46.80	6.31	31.0-63.0	495.8	68.9*	176.0-640.0
Simulated	---	---	---	84.45	8.59	56.9-110.4	46.67	6.12	28.7-67.0	495.6	63.1	122.7-642.7
Sept. Wet												
Historical	0.11	0.21	TR-1.32	72.93	9.36	59.0-102.0	50.54	4.86	39.0-67.0	312.9	129.8	44.0-831.0
Simulated	0.12	0.20	TR-1.37	74.09	8.82	52.3-95.7	50.94	4.57	37.3-65.2	321.6	129.0	34.0-700.3
Oct. Dry												
Historical	---	---	---	72.56	9.35	53.0-96.0	38.00	5.96	24.0-55.0	337.0	79.6	84.0-596.0
Simulated	---	---	---	71.93	8.20**	46.5-96.7	37.61	5.79	17.9-55.8	337.8	81.3	85.2-549.2
Oct. Wet												
Historical	0.15	0.29	TR-1.94	62.06	7.66	47.0-87.0	42.54	5.56	30.0-57.0	220.1	101.1	35.0-598.0
Simulated	0.15	0.26*	TR-2.18	62.74	7.99	42.4-86.1	42.72	5.83	23.8-58.5	223.7	113.8*	1.3-590.7
Nov. Dry												
Historical	---	---	---	55.72	8.65	34.0-75.0	30.38	6.90	14.0-56.0	197.0	64.9	41.0-318.0
Simulated	---	---	---	54.72	8.16	33.0-83.0	29.69	6.58	10.5-55.7	195.5	57.8*	7.3-315.8
Nov. Wet												
Historical	0.17	0.31	TR-2.88	51.51	7.89	32.0-70.0	37.31	6.48	19.0-55.0	115.0	59.1	12.0-312.0
Simulated	0.17	0.26**	TR-1.82	52.88**	7.74	28.6-72.9	37.80	6.14	17.0-56.4	114.9	60.1	1.7-282.5
Dec. Dry												
Historical	---	---	---	43.92	6.63	27.0-61.0	26.87	6.38	12.0-42.0	128.4	52.8	25.0-226.0
Simulated	---	---	---	44.49	6.81	26.2-67.3	27.46	6.57	9.3-49.8	134.4	50.7	5.9-230.0
Dec. Wet												
Historical	0.18	0.35	TR-3.30	44.74	7.54	28.0-72.0	33.11	5.80	17.0-52.0	83.37	44.59	9.0-222.0
Simulated	0.17	0.29**	TR-3.07	44.13	7.29	21.6-68.9	32.85	5.80	14.0-50.0	81.19	43.93	1.0-205.1
Year 1/												
Historical	20.6	4.3	10.5-29.1	66.84	18.18	22.0-109.0	40.57	10.42	0.0-69.0	391.1	236.5	9.0-856.0
Simulated	21.2	3.3	14.9-31.5	66.73	18.09	17.9-117.3	40.52	10.41	6.5-74.2	393.2	236.0	0.2-854.4

* Indicates significantly different at α = .05 level.
** Indicates significantly different at α = .01 level.
1/ Average total rain, average maximum and minimum temperatures and average solar radiation.

Table C3: Kolmogorov - Smirnov (K-S) Two-Sample Statistics to Test Hypothesis of Equality of Historical (20 years) and generated (50 runs) Cumulative Distribution Functions (CDF;s) of Daily Variates
Medford, OR

Month & Precip. Status	Rain n_H	Rain n_s	Rain K-S Value	Maximum Temperature n_H	Maximum Temperature n_s	Maximum Temperature K-S Value	Minimum Temperature n_H	Minimum Temperature n_s	Minimum Temperature K-S Value	Solar Radiation n_H	Solar Radiation n_s	Solar Radiation K-S Value
Jan Dry:	---	---	---	166	199	.0861	166	199	.0605	163	199	.1475*
Wet:	190	202	.1718**	190	202	.0817	190	202	.0583	191	202	.1406*
Feb Dry:	---	---	---	202	191	.1370	202	191	.0758	206	191	.0689
Wet:	196	201	.1182	196	201	.1316	196	201	.0979	200	201	.0759
Mar Dry:	---	---	---	203	215	.0530	203	215	.0626	207	215	.0945
Wet:	175	184	.1089	175	184	.0962	175	184	.0765	172	184	.1006
Apr Dry:	---	---	---	204	188	.0674	204	188	.0579	204	188	.0680
Wet:	205	195	.1506*	205	195	.0914	205	195	.0381	210	195	.0769
May Dry:	---	---	---	203	217	.0720	203	217	.0652	201	217	.1385*
Wet:	197	189	.0624	197	189	.1714**	197	189	.1082	205	189	.0832
Jun Dry:	---	---	---	205	202	.0562	205	202	.0639	204	202	.1258
Wet:	163	211	.0434	163	211	.1733**	163	211	.0287	147	211	.0946
Jul Dry:	---	---	---	207	204	.0550	207	204	.0931	205	204	.1187
Wet:	61	152	.1195	61	152	.0782	61	152	.1266	58	152	.0882
Aug Dry:	---	---	---	203	202	.1216	203	202	.0414	202	202	.0396
Wet:	85	204	.0529	85	204	.1774*	85	204	.0951	81	204	.1071
Sep Dry:	---	---	---	203	191	.1159	203	191	.0415	199	191	.0678
Wet:	110	197	.1223	110	197	.1795*	110	197	.0498	105	197	.0716
Oct Dry:	---	---	---	200	198	.1369*	200	198	.1016	197	198	.0738
Wet:	198	207	.0727	198	207	.1034	198	207	.0648	218	207	.0931
Nov Dry:	---	---	---	203	187	.1082	203	187	.1176	200	187	.1143
Wet:	225	185	.0624	225	185	.1154	225	185	.0664	221	185	.0778
Dec Dry:	---	---	---	178	209	.0836	178	209	.0721	177	209	.1456*
Wet:	180	214	.0889	180	214	.0689	180	214	.0594	179	214	.0956

NOTE: n_h = number of observations from the historical data set.
n_s = number of observations from the simulated data set.

* Historical and simulated CDF's are significantly different at α = .05 level.
** Historical and simulated CDF's are significantly different at α = .01 level.

A P P E N D I X D

Miami, Florida

Table D1 : Frequency of Wet Days for Historical (20 years) and Simulated (50 runs) -- Miami, FL*

Month	Frequency of Wet Days
January	
Historical	0.395
Simulated	0.404
February	
Historical	0.382
Simulated	0.397
March	
Historical	0.340
Simulated	0.355
April	
Historical	0.358
Simulated	0.339
May	
Historical	0.500
Simulated	0.513
June	
Historical	0.682
Simulated	0.673
July	
Historical	0.694
Simulated	0.688
August	
Historical	0.713
Simulated	0.721
September	
Historical	0.750
Simulated	0.739
October	
Historical	0.634
Simulated	0.660
November	
Historical	0.443
Simulated	0.420
December	
Historical	0.350
Simulated	0.340

* No significant differences at the $\alpha = .05$ level.

Table D2: Historical (20 years) and Simulated (50 runs) Precipitation and Maximum and Minimum Temperatures and Solar Radiation
Miami, Florida

Month and Precipitation Status	Precipitation (in) Mean	Stan. Dev.	Range	Maximum Temperature (°F) Mean	Stan. Dev.	Range	Minimum Temperature (°F) Mean	Stan. Dev.	Range	Solar Radiation (Ly) Mean	Stan. Dev.	Range
Jan. Dry												
Historical	---	---	---	74.25	6.54	50.0-86.0	56.23	9.11	34.0-73.0	374.7	70.5	140.0-523.0
Simulated	---	---	---	74.22	6.60	53.0-94.2	56.53	8.64	32.3-90.4	376.2	71.0	75.3-511.4
Jan. Wet												
Historical	0.18	0.37	TR-2.07	75.80	5.08	59.0-85.0	61.64	6.90	39.0-73.0	268.6	99.0	31.0-505.0
Simulated	0.19	0.38	TR-3.45	75.22	5.40	60.1-92.5	61.04	7.17	39.1-83.0	269.6	101.5	41.4-508.4
Feb. Dry												
Historical	---	---	---	75.46	6.25	55.0-89.0	57.86	8.51	35.0-74.0	442.7	83.1	117.0-607.0
Simulated	---	---	---	75.89	5.96	55.4-94.2	58.01	8.20	34.1-79.7	444.7	82.5	77.8-617.7
Feb. Wet												
Historical	0.20	0.46**	TR-4.54	77.41	5.34	56.0-88.0	62.54	6.95	39.0-74.0	356.0	117.5	73.0-625.0
Simulated	0.21	0.37	TR-3.01	77.17	5.43	55.8-90.5	62.61	6.68	43.0-84.3	356.8	119.2	37.2-600.4
Mar. Dry												
Historical	---	---	---	78.90	5.20	57.0-90.0	62.44	8.28	37.0-78.0	530.8	99.8	119.0-721.0
Simulated	---	---	---	79.25	5.44	62.3-96.3	62.61	8.68	33.4-88.2	536.8	101.0	15.3-731.6
Mar. Wet												
Historical	0.20	0.39	TR-2.69	79.55	5.25	64.0-90.0	64.79	6.16	46.0-75.0	385.9	135.5	45.0-651.0
Simulated	0.18	0.35	TR-2.39	78.89	5.78	60.9-93.8	64.18	6.46	38.5-84.1	390.9	134.8	32.3-676.1
Apr. Dry												
Historical	---	---	---	82.52	3.66	70.0-93.0	67.08	6.19	49.0-78.0	594.4	86.8	284.0-880.0
Simulated	---	---	---	82.51	3.86	68.2-92.7	66.98	6.22	47.3-87.3	599.9	91.6	83.7-805.4
Apr. Wet												
Historical	0.25	0.53	TR-4.85	82.47	4.07	67.0-93.0	69.18	3.76	56.0-76.0	462.5	142.1	87.0-754.0
Simulated	0.27	0.49	TR-3.95	82.48	4.08	67.3-94.7	69.09	4.09	54.9-81.7	461.4	133.8	97.6-722.0
May Dry												
Historical	---	---	---	85.83	2.89	79.0-94.0	70.70	4.76	55.0-79.0	624.1	105.9	223.0-843.0
Simulated	---	---	---	85.51	2.80	75.8-93.5	70.87	4.92	54.5-86.7	622.3	110.4	94.1-809.7
May Wet												
Historical	0.42	0.88	TR-7.02	84.52	2.91	76.0-92.0	71.94	3.38	58.0-79.0	474.0	147.2	66.0-804.0
Simulated	0.45	0.80*	TR-7.01	84.03*	3.01	75.3-92.3	71.79	3.39	63.2-82.8	464.2	146.9	111.5-789.7
Jun Dry												
Historical	---	---	---	89.01	2.37	83.0-95.0	74.85	3.08	65.0-81.0	634.1	82.6	358.0-831.0
Simulated	---	---	---	88.45**	2.60	80.4-96.0	75.16	2.83	67.9-83.3	639.4	82.8	197.9-804.5
Jun Wet												
Historical	0.48	0.77	TR-5.95	86.85	3.05	76.0-94.0	73.81	2.50	67.0-81.0	457.3	157.2	68.0-848.0
Simulated	0.49	0.74	TR-5.97	86.76	2.98	75.8-97.3	74.06	2.47	66.4-81.7	452.5	152.4	84.4-830.2
Jul Dry												
Historical	---	---	---	89.90	1.80	86.0-96.0	76.83	2.41	71.0-83.0	624.8	98.8	231.0-818.0
Simulated	---	---	---	89.89	1.89	85.0-95.2	76.97	2.51	69.6-83.4	625.0	105.0	112.1-799.0
Jul Wet												
Historical	0.29	0.51**	TR-4.51	88.56	2.33	79.0-96.0	75.45	2.20	70.0-82.0	510.2	139.4	121.0-762.0
Simulated	0.31	0.46	TR-3.75	88.53	2.29	81.9-95.6	75.43	2.22	68.4-81.9	514.0	140.3	149.5-756.6
Aug Dry												
Historical	---	---	---	91.13	2.05	86.0-98.0	76.88	2.41	72.0-83.0	592.4	80.0	310.0-736.0
Simulated	---	---	---	90.53**	2.25	84.7-96.4	76.84	2.37	70.0-85.4	587.4	99.2**	21.1-722.9
Aug Wet												
Historical	0.30	0.56	TR-6.41	89.46	2.40	81.0-97.0	75.86	2.27	70.0-83.0	485.1	121.8	93.0-749.0
Simulated	0.31	0.46**	TR-3.51	89.30	2.32	81.7-95.7	75.84	2.32	69.0-85.4	478.6	122.7	148.8-742.4
Sept. Dry												
Historical	---	---	---	89.53	1.74	85.0-95.0	76.11	2.27	71.0-82.0	529.6	83.5	291.0-724.0
Simulated	---	---	---	89.20	1.99	83.1-93.7	76.00	2.54	69.0-82.9	524.2	87.9	129.6-697.8
Sept. Wet												
Historical	0.38	0.69	TR-6.07	87.66	2.59	78.0-94.0	75.12	2.18	69.0-82.0	414.6	130.1	29.0-679.0
Simulated	0.41	0.61	TR-6.66	87.75	2.54	79.4-96.0	75.09	2.52**	67.3-81.8	408.1	137.8	31.2-675.9
Oct. Dry												
Historical	---	---	---	84.06	3.56	71.0-91.0	68.67	5.16	56.0-80.0	457.6	70.0	238.0-596.0
Simulated	---	---	---	84.10	3.46	74.5-97.6	68.97	5.16	53.1-84.6	461.0	78.4	44.3-613.1
Oct. Wet												
Historical	0.43	0.85	TR-7.88	84.57	3.04	70.0-91.0	72.68	3.37	54.0-81.0	355.8	116.0	53.0-598.0
Simulated	0.42	0.67**	TR-5.17	84.58	2.81	76.4-94.9	72.60	3.34	62.8-84.0	350.2	114.6	69.8-594.4
Nov. Dry												
Historical	---	---	---	79.44	4.81	58.0-88.0	62.94	7.58	40.0-77.0	387.3	64.9	147.0-509.0
Simulated	---	---	---	79.64	4.70	65.9-94.5	63.33	7.58	37.3-83.8	385.0	65.6	32.5-513.5
Nov. Wet												
Historical	0.20	0.63	TR-6.78	80.06	4.03	61.0-89.0	66.86	5.64	42.0-75.0	311.2	89.0	23.0-519.0
Simulated	0.24	0.51**	TR-5.15	79.66	4.01	68.1-89.9	66.65	5.74	45.7-81.3	307.6	83.6	80.4-508.0
Dec. Dry												
Historical	---	---	---	75.29	5.51	51.0-85.0	57.49	8.87	34.0-74.0	351.2	62.3	50.0-458.0
Simulated	---	---	---	75.08	5.36	57.8-92.0	57.15	8.29	32.9-82.8	351.3	67.0	37.0-457.6
Dec. Wet												
Historical	0.16	0.43	TR-4.38	77.19*	4.18	62.0-86.0	63.70	6.76	46.0-76.0	272.4	86.2	61.0-636.0
Simulated	0.17	0.34**	TR-2.60	76.32	4.37	61.3-90.0	62.73	7.32	41.9-85.2	265.9	84.7	79.0-502.1
Year 1/												
Historical	59.7	16.2**	37.1-89.4	82.74	6.65	50.0-98.0	68.16	8.79	34.0-83.0	452.8	148.2	23.0-880.0
Simulated	62.9	8.8	41.1-79.2	82.61	6.65	53.0-97.6	68.15	8.80	32.3-90.4	449.5	149.7	15.3-830.2

* Indicates significantly different at α = .05 level.
** Indicates significantly different at α = .01 level.
1/ Average total rain, average maximum and minimum temperatures, and average solar radiation.

Table D3: Kolmogorov - Smirnov (K-S) Two-Sample Statistics to Test Hypothesis of Equality of Historical (20years) and generated (50runs) Cumulative Distribution Functions (CDF;s) of Daily Variates

Miami, FL

Month & Precip. Status	Rain n_H	Rain n_s	Rain K-S Value	Maximum Temperature n_H	Maximum Temperature n_s	Maximum Temperature K-S Value	Minimum Temperature n_H	Minimum Temperature n_s	Minimum Temperature K-S Value	Solar Radiation n_H	Solar Radiation n_s	Solar Radiation K-S Value
Jan Dry	---	---	---	202	190	.1140	202	190	.1376*	195	190	.0902
Jan Wet	206	181	.1184	206	181	.1245	206	181	.1240	215	181	.1490*
Feb Dry	---	---	---	198	195	.0775	198	195	.0849	204	195	.0500
Feb Wet	207	196	.1355	207	196	.0882	207	196	.0811	178	196	.0785
Mar Dry	---	---	---	185	190	.1159	185	190	.0996	179	190	.0888
Mar Wet	201	198	.1126	201	198	.1202	201	198	.0771	200	198	.0720
Apr Dry	---	---	---	201	208	.0589	201	208	.0709	203	208	.1210
Apr Wet	204	214	.1546*	204	214	.1137	204	214	.0538	206	214	.0643
May Dry	---	---	---	202	201	.0320	202	201	.0493	205	201	.0636
May Wet	200	209	.0990	200	209	.1069	200	209	.0852	200	209	.0927
Jun Dry	---	---	---	191	218	.1155	191	218	.0484	185	218	.0718
Jun Wet	191	214	.0641	191	214	.0571	191	214	.1178	193	214	.0605
Jul Dry	---	---	---	190	212	.0525	190	212	.1068	179	212	.0939
Jul Wet	192	182	.1077	192	182	.0432	192	182	.0643	193	182	.0668
Aug Dry	---	---	---	178	206	.1235	178	206	.0674	171	206	.0895
Aug Wet	202	202	.0643	202	202	.0544	202	202	.0445	204	202	.0807
Sep Dry	---	---	---	150	199	.0725	150	199	.0855	137	199	.0889
Sep Wet	212	179	.1148	212	179	.1172	212	179	.1009	211	179	.0571
Oct Dry	---	---	---	206	209	.0936	206	209	.0546	205	209	.0715
Oct Wet	208	203	.1159	208	203	.0959	208	203	.0319	198	203	.0604
Nov Dry	---	---	---	203	192	.0618	203	192	.0483	205	192	.0901
Nov Wet	205	204	.1233	205	204	.1437*	205	204	.1390*	203	204	.1552*
Dec Dry	---	---	---	197	197	.1015	197	197	.0609	206	197	.1144
Dec Wet	204	192	.0848	204	192	.2332**	204	192	.2383**	204	192	.1516*

NOTE: n_h = number of observations from the historical data set.
n_s = number of observations from the simulated data set.

* Historical and simulated CDF's are significantly different at α = .05 level.
** Historical and simulated CDF's are significantly different at α = .01 level.

A P P E N D I X   E

Columbia, Missouri

Trace Rain Defined as Wet

Table E1: Frequency of Wet Days for Historical (17 years) and Simulated (50 runs) -- Columbia, MO (Trace Rain = Wet)*

Month	Frequency of Wet Days
January	
Historical	0.488
Simulated	0.493
February	
Historical	0.442
Simulated	0.425
March	
Historical	0.522
Simulated	0.503
April	
Historical	0.535
Simulated	0.556
May	
Historical	0.488
Simulated	0.504
June	
Historical	0.445
Simulated	0.452
July	
Historical	0.431
Simulated	0.421
August	
Historical	0.349
Simulated	0.343
September	
Historical	0.386
Simulated	0.375
October	
Historical	0.338
Simulated	0.352
November	
Historical	0.363
Simulated	0.357
December	
Historical	0.440
Simulated	0.454

* No significant differences at the $\alpha = .05$ level.

Table E2: Historical (17 years) and Simulated (50 runs) Precipitation and Maximum and Minimum Temperatures and Solar Radiation -- Columbia, MO, Trace Days = wet

Month and Precipitation Status	Precipitation (in) Mean	Stan. Dev.	Range	Maximum Temperature (°F) Mean	Stan. Dev.	Range	Minimum Temperature (°F) Mean	Stan. Dev.	Range	Solar Radiation (Ly) Mean	Stan. Dev.	Range
Jan. Dry												
Historical	---	---	---	39.87	13.40	1.0-75.0	19.17	11.80	-11.0-52.0	237.8	73.5	51.0-399.6
Simulated	---	---	---	40.50	13.36	2.9-76.5	20.19	12.10	-14.6-54.4	247.1	66.9	3.8-390.7
Jan. Wet												
Historical	0.10	0.22	TR-1.49	36.34	13.46	-2.0-73.0	20.32	12.76	-10.0-57.0	128.4	85.3	12.6-352.1
Simulated	0.10	0.19**	TR-1.41	35.47	13.98	-5.2-81.2	19.66	13.18	-16.4-69.2	137.6	82.4	0.8-349.8
Feb. Dry												
Historical	---	---	---	44.65	12.69	11.0-77.0	22.96	10.78	-8.0-46.0	331.9	93.4	60.5-523.6
Simulated	---	---	---	46.26	12.31	-4.7-79.7	24.55*	10.86	-8.4-55.2	335.0	89.6	8.1-530.8
Feb. Wet												
Historical	0.13	0.24	TR-1.31	40.90	11.19	14.0-73.0	25.43	10.62	-5.0-54.0	181.7	125.2	17.2-522.5
Simulated	0.14	0.22	TR-1.33	40.02	10.80	3.2-75.3	24.50	10.42	0.0-58.5	190.4	123.1	0.60-531.5
Mar. Dry												
Historical	---	---	---	55.46	13.17	26.0-85.0	31.50	10.18	-2.0-65.0	450.8	117.8	68.1-656.7
Simulated	---	---	---	56.54	13.41	5.4-96.4	32.44	10.51	-4.6-61.3	452.4	114.8	82.1-676.4
Mar. Wet												
Historical	0.15	0.29	TR-2.35	48.89	14.59	12.0-84.0	31.84	11.51	-9.0-60.0	259.3	163.4	1.7-633.9
Simulated	0.16	0.25**	TR-1.73	48.49	14.52	2.1-86.5	31.55	11.41	-0.1-69.9	260.5	155.7	0.4-672.6
Apr. Dry												
Historical	---	---	---	67.24	11.29	38.0-91.0	42.32	9.15	23.0-67.0	567.5	130.8	131.0-750.9
Simulated	---	---	---	67.46	11.10	27.3-99.1	42.72	8.57	12.3-69.0	570.3	114.7*	43.1-776.6
Apr. Wet												
Historical	0.22	0.34	TR-1.84	65.82	11.87	38.0-90.0	47.13	9.18	26.0-67.0	321.8	170.2	29.6-698.5
Simulated	0.23	0.35	TR-3.76	64.66	11.73	25.8-106.0	46.34	9.07	17.2-75.5	322.6	174.2	15.2-704.9
May Dry												
Historical	---	---	---	77.68	8.78	51.0-93.0	53.73	9.16	33.0-73.0	643.9	109.3	171.3-824.8
Simulated	---	---	---	78.03	9.67	50.4-111.3	53.74	9.82	22.5-88.6	636.8	112.1	101.5-820.3
May Wet												
Historical	0.28	0.43	TR-2.54	73.36	9.61	50.0-91.0	55.00	7.22	33.0-69.0	407.5	181.8	34.6-788.6
Simulated	0.29	0.43	TR-3.22	72.43	10.13	42.4-112.0	54.42	7.62	30.3-77.7	398.3	179.7	37.0-801.8
Jun Dry												
Historical	---	---	---	85.38	6.68	68.0-102.0	62.63	6.95	45.0-76.0	667.7	90.6	264.9-802.5
Simulated	---	---	---	85.80	6.36	65.8-106.4	63.35	6.45	43.5-83.2	665.9	90.5	282.4-801.2
Jun Wet												
Historical	0.30	0.50	TR-3.27	82.32	7.82	59.0-101.0	63.93	5.17	50.0-76.0	450.7	167.1	67.2-775.5
Simulated	0.30	0.48	TR-3.81	81.81	7.73	61.2-106.9	63.72	5.16	47.3-81.4	458.3	167.6	81.1-766.7
Jul Dry												
Historical	---	---	---	89.98	6.37	70.0-113.0	67.13	6.47	49.0-82.0	650.8	78.8	334.0-803.4
Simulated	---	---	---	90.06	6.54	70.2-112.4	67.38	6.71	43.5-91.9	653.7	78.0	297.5-788.9
Jul Wet												
Historical	0.31	0.51	TR-3.86	87.25	6.16	72.0-113.0	68.47	3.76	57.0-78.0	485.9	158.1	74.6-768.4
Simulated	0.28	0.41**	TR-2.89	87.07	6.65	66.1-106.8	68.47	3.76	56.1-79.4	485.2	160.7	109.2-764.9
Aug Dry												
Historical	---	---	---	88.44	6.38	71.0-103.0	64.57	6.20	46.0-78.0	587.8	78.2	247.9-730.3
Simulated	---	---	---	88.92	6.69	69.5-107.9	65.05	6.50	44.5-84.1	592.6	72.4	272.9-718.9
Aug Wet												
Historical	0.21	0.40	TR-2.60	86.80	7.68	65.0-101.0	67.71	4.78	47.0-77.0	419.4	155.0	68.3-730.7
Simulated	0.25	0.40	TR-2.96	86.22	7.75	65.4-107.1	67.38	4.97	54.7-84.3	403.0	154.3	62.6-714.4
Sept. Dry												
Historical	---	---	---	82.06	8.81	56.0-102.0	56.12	8.42	35.0-75.0	501.8	82.4	166.9-671.0
Simulated	---	---	---	82.51	8.72	55.9-111.1	56.69	8.19	32.9-81.4	503.3	82.9	158.8-677.7
Sept. Wet												
Historical	0.32	0.59	TR-3.35	78.78	8.82	55.0-99.0	60.10	6.80	41.0-73.0	307.6	141.1	21.8-681.5
Simulated	o.34	0.58	TR-4.11	77.55	8.48	53.3-101.1	59.95	6.36	41.3-82.2	312.9	145.7	11.5-664.6
Oct. Dry												
Historical	---	---	---	71.21	10.76	40.0-92.0	45.70	9.22	25.0-73.0	379.4	77.8*	67.1-533.9
Simulated	---	---	---	71.65	11.02	30.6-107.7	46.28	9.59	17.3-73.8	377.8	71.4	59.2-527.3
Oct. Wet												
Historical	0.32	0.55	TR-3.74	66.86	10.34	43.0-90.0	50.03	8.77	31.0-69.0	194.5	111.0	10.0-438.2
Simulated	0.32	0.52	TR-3.51	66.11	10.34	38.7-95.8	49.60	8.69	26.6-72.9	202.8	110.6	3.5-472.9
Nov. Dry												
Historical	---	---	---	55.82	12.46	20.0-80.0	33.54	10.65	1.0-63.0	257.9	70.9	53.5-397.0
Simulated	---	---	---	55.22	11.71	20.7-91.8	32.98	10.03	4.0-61.2	261.4	67.0	7.7-393.0
Nov. Wet												
Historical	0.13	0.25	TR-1.62	52.60	11.98	25.0-78.0	36.26	10.71	8.0-61.0	132.2	85.5	10.4-378.7
Simulated	0.14	0.22**	TR-1.44	51.78	11.30	19.8-82.9	35.22	10.33	6.5-67.0	142.2	83.0	1.3-356.1
Dec. Dry												
Historical	---	---	---	42.86	12.85	8.0-72.0	23.13	10.80	-8.0-49.0	208.1	60.0	28.9-313.1
Simulated	---	---	---	43.56	13.06	0.7-82.2	23.93	11.01	-9.5-59.4	209.7	60.0	4.4-318.6
Dec. Wet												
Historical	0.12	0.24	TR-2.05	40.64	12.59	10.0-72.0	26.72	11.10	-3.0-55.0	106.0	76.9	6.8-318.3
Simulated	0.14	0.23	TR-1.52	39.15	12.81	5.4-80.5	25.90	10.96	-12.6-65.2	109.1	76.7	0.5-323.6
Year 1/												
Historical	34.0	7.4	25.2-50.4	65.35	20.95	-2.-113.0	44.71	19.01	-11.0-82.0	380.8	206.2	1.7-824.8
Simulated	35.3	6.0	22.9-46.7	65.26	21.01	-5.2-112.4	44.80	19.01	-16.4-91.9	382.6	203.2	0.4-820.3

* Indicates significantly different at = .05 level.
** Indicates significantly different at = .01 level.
1/ Average total rain, average maximum and minimum temperatures and average solar radiation.

Table E3 Kolmogorov - Smirnov (K-S) Two-Sample Statistics to Test Hypothesis of Equality of Historical (17years) and generated (50runs) Cumulative Distribution Functions (CDF;s) of Daily Variates
Columbia, MO -- (Trace Rain = wet)

Month & Precip. Status	Rain n_H	Rain n_s	Rain K-S Value	Maximum Temperature n_H	Maximum Temperature n_s	Maximum Temperature K-S Value	Minimum Temperature n_H	Minimum Temperature n_s	Minimum Temperature K-S Value	Solar Radiation n_H	Solar Radiation n_s	Solar Radiation K-S Value
Jan Dry:	---	---	---	270	200	.0896	270	200	.0691	263	200	.0919
Wet:	257	201	.0702	257	201	.0657	257	201	.0538	247	201	.1025
Feb Dry:	---	---	---	268	235	.0905	268	235	.0897	265	235	.0665
Wet:	212	213	.0731	212	213	.0766	212	213	.1014	210	213	.0739
Mar Dry:	---	---	---	252	208	.1136	252	208	.1455*	242	208	.0905
Wet:	275	204	.0795	275	204	.0486	275	204	.1004	267	204	.0812
Apr Dry:	---	---	---	237	193	.0608	237	193	.0853	218	193	.0912
Wet:	273	186	.1103	273	186	.1074	273	186	.0985	256	186	.0612
May Dry:	---	---	---	269	196	.0829	269	196	.0686	266	196	.0806
Wet:	257	195	.0548	257	195	.0940	257	195	.1143	246	195	.0588
Jun Dry:	---	---	---	283	212	.0857	283	212	.0975	277	212	.1149
Wet:	227	181	.0823	227	181	.1265	227	181	.1140	224	181	.0401
Jul Dry:	---	---	---	300	204	.0618	300	204	.0820	294	204	.0641
Wet:	227	206	.0650	227	206	.0616	227	206	.0688	222	206	.0719
Aug Dry:	---	---	---	343	202	.0744	343	202	.0667	340	202	.0419
Wet:	184	184	.1032	184	184	.1413	184	184	.1359	180	184	.1970**
Sep Dry:	---	---	---	313	221	.0893	313	221	.0778	309	221	.0778
Wet:	197	214	.0764	197	214	.1202	197	214	.1232	192	214	.1049
Oct Dry:	---	---	---	349	191	.0637	349	193	.1184	346	191	.0784
Wet:	178	211	.0827	178	211	.0485	178	211	.0675	177	211	.0755
Nov Dry:	---	---	---	325	179	.0781	325	179	.0666	322	179	.0768
Wet:	185	211	.0846	185	211	.0997	185	211	.1198	181	211	.1292
Dec Dry:	---	---	---	295	201	.0602	295	201	.0842	288	201	.0648
Wet:	232	191	.1356*	232	191	.1137	232	191	.0756	229	191	.0748

NOTE: n_h = number of observations from the historical data set.
n_s = number of observations from the simulated data set.

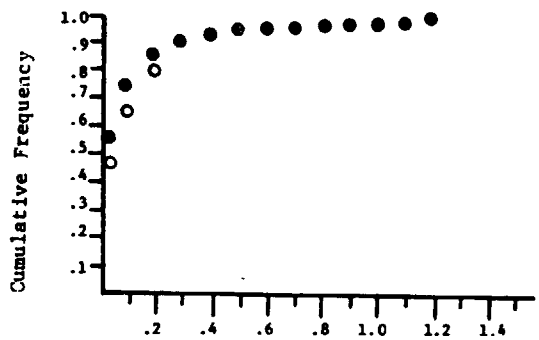
* Historical and simulated CDF's are significantly different at α = .05 level.
** Historical and simulated CDF's are significantly different at α = .01 level.

Figures E1, E2, E3: Cumulative Distribution Functions which were Declared Significantly Different Based on the Kolmogorov-Smirnov Test

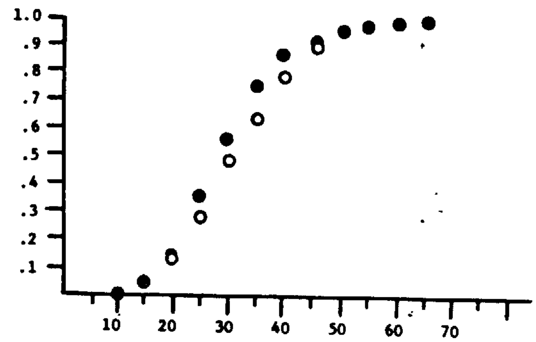
● Historical

○ Simulated

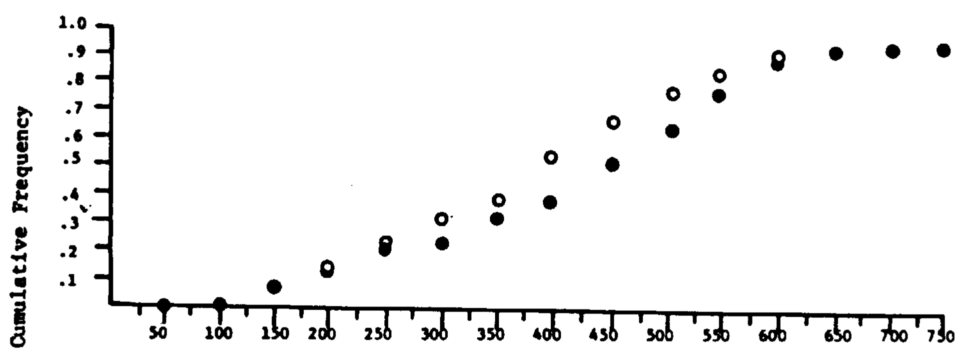
● Historical and simulated too close to separate



Daily Rainfall -- December



Daily Minimum Temperature -- March dry



Daily Solar Radiation -- August, wet

APPENDIX F

Columbia, Missouri
Trace Rain Defined as Dry

Table F1: Frequency of Wet Days for Historical (17 years) and Simulated (50 runs)
Columbia, MO -- (Trace Rain = Dry)*

Month	Frequency of Wet Days
January	
Historical	0.232
Simulated	0.246
February	
Historical	0.269
Simulated	0.266
March	
Historical	0.321
Simulated	0.326
April	
Historical	0.374
Simulated	0.386
May	
Historical	0.330
Simulated	0.334
June	
Historical	0.328
Simulated	0.309
July	
Historical	0.311
Simulated	0.316
August	
Historical	0.220
Simulated	0.243
September	
Historical	0.249
Simulated	0.258
October	
Historical	0.241
Simulated	0.239
November	
Historical	0.204
Simulated	0.219
December	
Historical	0.268
Simulated	0.246

* No significant differences at the $\alpha = .05$ level.

Table F2: Historical (17 years) and Simulated (50 runs) Precipitation and Maximum and Minimum Temperatures and Solar Radiation

Columbia, MO -- (Trace Rain = Dry)

Month and Precipitation Status	Precipitation (in) Mean	Precipitation (in) Stan. Dev.	Precipitation (in) Range	Maximum Temperature (°F) Mean	Maximum Temperature (°F) Stan. Dev.	Maximum Temperature (°F) Range	Minimum Temperature (°F) Mean	Minimum Temperature (°F) Stan. Dev.	Minimum Temperature (°F) Range	Solar Radiation (Ly) Mean	Solar Radiation (Ly) Stan. Dev.	Solar Radiation (Ly) Range
Jan. Dry												
Historical	---	---	---	37.85	13.38	-2.0-75.0	18.74	11.78	-11.0-52.0	211.2	87.0	13.9-399.6
Simulated	---	---	---	38.04	13.44	-12.8-79.7	19.14	11.83	-27.0-54.8	218.4	77.1**	0.3-395.0
Jan. Wet												
Historical	0.20	0.29	.01-1.49	39.15	14.05	9.0-73.0	23.03	13.34	-6.0-57.0	96.1	70.2	12.6-320.5
Simulated	0.20	0.27	.01-2.41	36.71	14.47	-8.2-74.2	21.71	13.50	-12.6-58.8	99.0	65.3	1.0-283.7
Feb. Dry												
Historical	---	---	---	42.96	12.37	11.0-77.0	22.70	10.44	-8.0-46.0	309.8	108.1	41.2-523.6
Simulated	---	---	---	42.25	12.77	-1.3-96.1	22.35	11.12	-15.2-62.7	318.3	99.7	1.0-532.1
Feb. Wet												
Historical	0.21	0.27	.01-1.31	43.08**	11.72	14.0-73.0	27.71	10.84	-5.0-54.0	144.1	112.8	17.2-472.5
Simulated	0.21	0.24*	.01-1.67	39.60	11.46	4.6-82.9	25.36*	10.51	-4.9-54.3	152.4	108.6	0.1-476.8
Mar. Dry												
Historical	---	---	---	53.39	14.31	16.0-85.0	31.18	10.95	-9.0-65.0	412.2	142.9	28.4-656.7
Simulated	---	---	---	53.38	14.28	18.2-100.4	31.49	11.21	-0.4-75.5	415.9	136.2	3.7-688.3
Mar. Wet												
Historical	0.25	0.34	.01-2.35	49.16	13.88	12.0-80.0	32.73	10.71	-5.0-60.0	220.3	156.3	1.7-633.9
Simulated	0.27	0.30*	.01-2.25	47.68	13.50	-3.9-93.7	31.64	10.41	-3.9-62.2	228.6	147.4	1.0-586.3
Apr. Dry												
Historical	---	---	---	66.67	11.30	38.0-91.0	42.82	8.99	23.0-67.0	522.6	159.9	74.3-750.9
Simulated	---	---	---	68.91**	11.94	28.3-106.5	44.82**	9.61	11.1-77.1	527.5	145.6*	11.9-766.2
Apr. Wet												
Historical	0.31	0.37	.01-1.84	66.18	12.14	38.0-90.0	48.37	9.23	26.0-67.0	290.0	161.9	29.6-698.1
Simulated	0.31	0.32*	.01-2.25	66.05	12.16	33.0-106.1	48.23	9.58	24.3-81.8	291.8	163.7	1.6-696.0
May Dry												
Historical	---	---	---	76.76	9.28	50.0-93.0	53.80	8.84	33.0-73.0	605.3	143.2	111.2-824.8
Simulated	---	---	---	76.93	10.43**	43.8-113.7	53.95	9.59	25.7-82.2	607.0	136.3	32.5-823.0
May Wet												
Historical	0.42	0.46	.01-2.54	73.17	9.33	50.0-91.0	55.47	6.90	38.0-68.0	375.4	180.4	34.6-726.7
Simulated	0.41	0.45	.01-4.13	71.55*	9.34	43.6-99.5	53.99*	7.11	29.9-76.2	361.0	171.7	17.4-722.6
Jun Dry												
Historical	---	---	---	84.85	7.10	60.0-102.0	62.81	6.83	45.0-76.0	638.1	124.5	142.4-802.5
Simulated	---	---	---	85.16	6.82	64.1-107.8	63.33	6.54	38.7-88.4	640.1	110.7**	159.7-802.3
Jun Wet												
Historical	0.41	0.55	.01-3.27	82.31	7.61	59.0-101.0	64.02	4.78	50.0-76.0	433.4	165.6	67.2-775.5
Simulated	0.42	0.48*	.01-2.94	81.83	7.81	61.0-106.2	63.76	4.69	51.7-78.4	436.0	164.2	90.1-769.1
Jul Dry												
Historical	---	---	---	89.77	6.53	70.0-113.0	67.36	6.23	49.0-82.0	629.5	102.4	151.6-803.4
Simulated	---	---	---	89.66	6.45	69.6-114.5	67.26	6.18	49.3-90.5	631.6	91.7**	219.4-799.2
Jul Wet												
Historical	0.43	0.56	.01-3.86	86.67	5.61	72.0-100.0	68.48	3.25	57.0-76.0	469.6	163.3	74.6-768.4
Simulated	0.47	0.56	.01-3.27	86.18	6.07	70.5-104.2	68.36	3.34	58.0-77.8	474.6	161.1	79.9-766.7
Aug Dry												
Historical	---	---	---	88.37	6.56	71.0-103.0	65.14	6.22	46.0-78.0	565.7	103.4**	159.2-730.3
Simulated	---	---	---	88.68	6.80	64.2-106.9	65.36	6.37	46.0-86.1	568.1	93.0	31.1-735.1
Aug Wet												
Historical	0.34	0.46**	.01-2.60	86.09	7.76	65.0-101.0	67.53	4.31	54.0-75.0	399.3	161.5	68.3-730.7
Simulated	0.32	0.36	.01-2.41	85.61	8.14	63.6-107.0	66.97	4.79	53.6-83.0	408.1	165.1	83.6-695.2
Sept. Dry												
Historical	---	---	---	81.55	8.89	55.0-102.0	56.72	8.37	35.0-75.0	474.6	105.9	124.0-671.0
Simulated	---	---	---	81.60	8.87	51.9-114.3	56.98	8.08	27.7-80.4	475.3	107.3	44.1-675.7
Sept. Wet												
Historical	0.50	0.68	.01-3.35	78.50	8.76	57.0-99.0	60.47	6.29	41.0-72.0	282.1	148.6	21.8-681.5
Simulated	0.51	0.58*	.01-3.66	76.56*	8.69	54.8-107.4	59.99	6.16	40.0-76.7	281.8	137.3	7.6-612.6
Oct. Dry												
Historical	---	---	---	70.53	10.99	40.0-92.0	45.96	9.26	25.0-73.0	362.5	91.4	63.6-533.9
Simulated	---	---	---	70.92	11.04	31.8-110.6	46.68	9.38	18.0-75.6	359.5	87.6	5.3-543.7
Oct. Wet												
Historical	0.44	0.61	.01-3.74	67.24	9.84	41.0-90.0	50.94	8.37	31.0-69.0	173.0	110.1	10.0-438.2
Simulated	0.45	0.55	.01-3.13	67.04	9.75	37.6-95.0	50.59	8.36	26.4-75.7	184.9	107.2	0.4-482.1
Nov. Dry												
Historical	---	---	---	54.74	12.44	20.0-80.0	33.60	10.50	1.0-63.0	238.3	83.2	25.6-397.0
Simulated	---	---	---	55.46	12.71	15.3-114.0	34.35	10.86	-1.7-82.0	243.0	78.4	2.7-392.3
Nov. Wet												
Historical	0.23	0.30	.01-1.62	54.30	12.16	27.0-78.0	38.16	10.96	8.0-61.0	110.7	91.6	10.4-325.6
Simulated	0.24	0.28	.01-2.27	52.86	12.17	22.1-82.5	36.83	10.76	6.8-64.1	129.8*	84.6	0.5-327.2
Dec. Dry												
Historical	---	---	---	41.36	12.68	8.0-72.0	23.00	10.63	-8.0-49.0	190.1	73.7	6.8-313.1
Simulated	---	---	---	40.98	12.83	-4.9-85.0	22.89	10.88	-14.1-61.5	196.0	66.6*	3.4-320.0
Dec. Wet												
Historical	0.20	0.28**	.01-2.05	43.31	12.96	15.0-72.0	29.38	10.94	-3.0-55.0	89.6	67.8	7.5-318.3
Simulated	0.20	0.22	.01-1.24	39.45**	11.59	6.1-89.2	26.79**	9.74	5.6-55.2	90.0	66.9	0.1-303.9
Year 1/												
Historical	34.0	7.4*	25.2-50.4	65.35	20.95	-2.0-113.0	44.71	19.01	-11.0-82.0	380.8	206.2*	1.7-824.8
Simulated	35.1	5.1	23.9-46.7	65.11	21.32	-12.8-114.5	44.72	19.20	-27.0-90.5	383.7	201.6	0.1-823.0

* Indicates a significant difference at the α = .05 level.
** Indicates a significant difference at the α = .01 level.
1/ Average total rain, average maximum and minimum temperatures and average solar radiation.

Table F3: Kolmogorov - Smirnov (K-S) Two-Sample Statistics to Test Hypothesis of Equality of Historical (17 years) and generated (50 runs) Cumulative Distribution Functions (CDF;s) of Daily Variates
Columbia, MO -- (Trace Rain = Dry)

Month & Precip. Status	Rain n_H	Rain n_s	Rain K-S Value	Maximum Temperature n_H	Maximum Temperature n_s	Maximum Temperature K-S Value	Minimum Temperature n_H	Minimum Temperature n_s	Minimum Temperature K-S Value	Solar Radiation n_H	Solar Radiation n_s	Solar Radiation K-S Value
Jan Dry:	---	---	---	405	200	.0963	405	200	.0901	393	200	.0879
Wet:	122	206	.1264	122	206	.1076	122	206	.0968	117	206	.0941
Feb Dry:	---	---	---	351	188	.0960	351	188	.1179	348	188	.0942
Wet:	129	196	.1980**	129	196	.1936**	129	196	.2390**	127	196	.1732*
Mar Dry:	---	---	---	358	206	.0717	358	206	.0728	345	206	.0786
Wet:	169	209	.1528*	169	209	.0743	169	209	.0597	164	209	.1225
Apr Dry:	---	---	---	319	185	.1248	319	185	.1574**	295	185	.0594
Wet:	191	215	.1007	191	215	.0695	191	215	.0739	179	215	.0627
May Dry:	---	---	---	352	210	.1231*	352	210	.0498	345	210	.1095
Wet:	174	211	.0543	174	211	.1510*	174	211	.1845**	167	211	.1138
Jun Dry:	---	---	---	343	184	.0773	343	184	.0699	336	184	.0608
Wet:	167	189	.1036	167	189	.0658	167	189	.0854	165	189	.0712
Jul Dry:	---	---	---	363	197	.0491	363	197	.0737	356	197	.1070
Wet:	164	211	.0654	164	211	.0958	164	211	.0817	160	211	.0737
Aug Dry:	---	---	---	411	203	.0612	411	203	.0501	407	203	.0746
Wet:	116	205	.0952	116	205	.1135	116	205	.1428	113	205	.0777
Sep Dry:	---	---	---	383	186	.0764	383	186	.1094	378	186	.0615
Wet:	127	200	.1029	127	200	.1493	127	200	.1267	123	200	.0438
Oct Dry:	---	---	---	400	190	.0836	400	190	.1501**	397	190	.1114
Wet:	127	221	.1147	127	221	.0670	127	221	.0589	126	221	.1403
Nov Dry:	---	---	---	406	187	.0675	406	187	.0808	402	187	.0752
Wet:	104	216	.0969	104	216	.1079	104	216	.0915	101	216	.2261**
Dec Dry:	---	---	---	386	190	.0296	386	190	.0678	377	190	.0861
Wet:	141	188	.1134	141	188	.1578*	141	188	.1613*	140	188	.1006

NOTE: n_h = number of observations from the historical data set.
n_s = number of observations from the simulated data set.

* Historical and simulated CDF's are significantly different at α = .05 level.
** Historical and simulated CDF's are significantly different at α = .01 level.

APPENDIX G

Columbia, Missouri

Trace Rain Defined as Wet
All Historical Data Included

Table G1: Frequency of Wet Days for Historical (80 years) and Simulated (99 runs)
Columbia, MO -- (Trace Rain = Wet)

Month	Frequency of Wet Days
January	
Historical...........	0.431
Simulated............	0.493**
February	
Historical...........	0.438
Simulated............	0.446
March	
Historical...........	0.485
Simulated............	0.533**
April	
Historical...........	0.505
Simulated............	0.551**
May	
Historical...........	0.515
Simulated............	0.499
June	
Historical...........	0.467
Simulated............	0.456
July	
Historical...........	0.382
Simulated............	0.407
August	
Historical...........	0.385
Simulated............	0.355*
September	
Historical...........	0.380
Simulated............	0.406
October	
Historical...........	0.327
Simulated............	0.350
November	
Historical...........	0.363
Simulated............	0.366
December	
Historical...........	0.400
Simulated............	0.457**

* Significantly different at the $\alpha = .05$ level.
** Significantly different at the $\alpha = .01$ level.

Table G7: Historical (80 years) and Simulated (99 runs) Precipitation and Maximum and Minimum Temperatures and Solar Radiation
Columbia, MO (Trace Rain = Wet)

Month and Precipitation Status	Precipitation (in)			Maximum Temperature (°F)			Minimum Temperature (°F)			Solar Radiation (Ly)		
	Mean	Stan. Dev.	Range	Mean	Stan. Dev.	Range	Mean	Stan. Dev.	Range	Mean	Stan. Dev.	Range
Jan. Dry												
Historical	---	---	---	40.41	13.82	-5.0-78.0	20.25	12.69	-20.0-61.0	237.8	73.5	51.0-399.6
Simulated	---	---	---	40.02	13.10	-1.1-76.5	19.75	11.73**	-14.6-54.4	244.3	67.6	3.8-390.7
Jan. Wet												
Historical	0.14**	0.30	TR-3.88	37.72	13.65	-3.0-74.0	21.83**	12.84	-19.0-57.0	128.4	85.3	12.6-352.1
Simulated	0.10	0.21**	TR-2.37	35.48**	13.27	-6.2-81.2	19.68	12.57	-21.3-69.2	136.4	82.3	0.2-349.8
Feb. Dry												
Historical	---	---	---	44.20*	13.95**	-2.0-81.0	22.85	11.95	-26.0-63.0	331.9	93.4	60.5-523.6
Simulated	---	---	---	45.25	12.69	-4.7-88.6	23.75*	10.99**	-8.4-59.4	336.3	90.3	0.8-530.8
Feb. Wet												
Historical	0.14	0.25	TR-1.80	39.94	12.80	1.0-76.0	24.52	12.13	-21.0-58.0	181.7	125.2	17.2-522.5
Simulated	0.14	0.22**	TR-1.87	40.13	11.10**	3.2-75.3	24.69	10.56**	-3.0-58.5	187.1	120.7	0.3-531.5
Mar. Dry												
Historical	---	---	---	55.98	13.65	18.0-92.0	31.95	10.76	-6.0-65.0	450.8	117.8	68.1-656.7
Simulated	---	---	---	57.05*	14.11	5.4-104.1	32.73	11.02	-4.6-67.4	450.7	114.7	0.9-676.4
Mar. Wet												
Historical	0.19	0.34	TR-3.11	50.49	14.46	12.0-86.0	33.71**	11.25	-9.0-66.0	259.3	163.4	1.7-633.9
Simulated	0.16**	0.25**	TR-1.83	48.59**	14.50	2.1-99.7	31.54	11.25	-2.5-71.3	268.2	160.1	0.4-672.6
Apr. Dry												
Historical	---	---	---	67.18	11.48	36.0-93.0	42.79	9.76	14.0-70.0	567.5	130.8	131.0-750.9
Simulated	---	---	---	67.15	11.22	27.3-99.1	52.50	9.08**	11.2-69.0	570.8	114.4**	43.1-778.9
Apr. Wet												
Historical	0.24	0.39	TR-3.15	64.05	12.17	30.0-90.0	45.99	9.15	18.0-71.0	321.8	170.2	29.6-698.5
Simulated	0.22	0.32**	TR-3.76	64.50	12.06	19.5-106.0	46.16	9.29	12.7-77.3	326.6	173.1	2.6-704.9
May Dry												
Historical	---	---	---	77.16	8.88	46.0-101.0	52.82	9.05	28.0-74.0	643.9	109.3	171.3-824.8
Simulated	---	---	---	78.21**	9.65**	44.7-111.3	53.92**	9.63*	22.5-88.6	642.3	107.8	101.5-820.3
May Wet												
Historical	0.29	0.44	TR-3.17	73.16	9.81	43.0-99.0	55.00	7.58	33.0-71.0	407.5	181.8	34.6-788.6
Simulated	0.29	0.44	TR-3.22	72.73	10.00	42.4-112.0	54.55	7.58	30.3-77.7	401.3	180.6	37.0-801.8
Jun Dry												
Historical	---	---	---	85.60	7.48	59.0-105.0	62.92	7.43	42.0-80.0	667.7	90.6	264.9-802.5
Simulated	---	---	---	86.03	6.48**	65.2-110.2	63.43	6.56**	43.5-83.2	667.1	90.9	111.8-801.2
Jun Wet												
Historical	0.34	0.52	TR-4.79	81.92	7.84	54.0-102.0	63.67	5.40	45.0-76.0	450.7	167.1	67.2-775.5
Simulated	0.31	0.49*	TR-5.34	82.24	7.70	57.4-106.9	63.88	5.20	47.1-81.4	461.1	165.1	81.0-768.7
Jul Dry												
Historical	---	---	---	89.99*	6.59	70.0-113.0	66.61	6.44	45.0-84.0	652.8	77.9	334.0-803.4
Simulated	---	---	---	90.50	6.45	67.5-112.4	67.65**	6.70	43.5-91.9	650.6	77.0	297.5-792.8
Jul Wet												
Historical	0.30	0.48**	TR-3.86	86.86	6.53	63.0-113.0	67.82	4.42	50.0-80.0	483.7	157.8	74.6-768.4
Simulated	0.30	0.44	TR-2.93	87.26	6.47	65.6-106.8	68.44**	3.72**	56.1-80.7	482.0	159.1	109.2-764.9
Aug Dry												
Historical	---	---	---	88.82	7.16**	64.0-110.0	64.69	7.05	40.0-85.0	588.0	78.8	247.9-730.3
Simulated	---	---	---	89.00	6.68	68.1-110.1	65.13	6.53**	43.3-84.1	592.8	71.6*	272.9-728.2
Aug Wet												
Historical	0.30**	0.51	TR-3.75	85.64	7.53	64.0-110.0	66.80	4.93	47.0-81.0	418.4	155.9	68.3-730.7
Simulated	0.23	0.39**	TR-2.98	86.42*	7.65	60.4-109.1	67.43**	4.98	52.2-84.3	409.4	152.9	62.6-716.1
Sept. Dry												
Historical	---	---	---	82.00	9.58	53.0-104.0	56.66	9.64**	26.0-79.0	505.2	81.6	166.9-671.0
Simulated	---	---	---	82.54	8.69**	50.1-111.1	56.81	8.05	32.3-85.9	503.7	83.0	102.9-679.6
Sept. Wet												
Historical	0.38	0.65**	TR-6.61	77.53	9.63**	45.0-100.0	59.92	7.59**	34.0-77.0	307.5	141.6	21.8-681.5
Simulated	0.34	0.58	TR-4.11	78.10	8.70	49.6-105.0	60.10	6.77	34.4-82.2	312.2	143.2	3.1-667.7
Oct. Dry												
Historical	---	---	---	71.08*	11.01	32.0-96.0	45.34	10.02	19.0-73.0	383.6	77.7	67.1-537.7
Simulated	---	---	---	71.85	10.84	30.6-107.7	46.46**	9.36**	17.3-79.3	376.0	72.9	41.6-545.3
Oct. Wet												
Historical	0.29	0.48	TR-3.74	65.96	11.38**	27.0-92.0	49.21	9.51*	24.0-70.0	194.7	111.8	10.0-438.2
Simulated	0.32	0.50	TR-3.51	66.58	10.30	36.1-100.0	49.70	8.77	25.0-76.8	206.2	112.5	0.1-497.7
Nov. Dry												
Historical	---	---	---	55.15	12.31	16.0-84.0	32.82	10.37	0.0-66.0	259.8	71.5	53.5-401.2
Simulated	---	---	---	55.58	12.25	12.8-99.9	33.14	10.40	-5.8-64.9	259.1	67.5	3.4-393.0
Nov. Wet												
Historical	0.20	0.34**	TR-2.45	52.57	13.02*	13.0-84.0	36.50*	10.70	-3.0-63.0	131.5	84.8	10.4-378.7
Simulated	0.14**	0.22	TR-2.08	51.57	12.22	12.6-91.6	35.29	10.47	4.3-67.0	140.7	84.6	0.5-357.2
Dec. Dry												
Historical	---	---	---	43.37	12.73	1.0-75.0	23.94	11.08	-23.0-54.0	209.3	59.7	28.9-313.1
Simulated	---	---	---	43.76	13.12	0.7-82.2	24.08	11.10	-9.5-63.5	208.0	60.3	4.4-318.6
Dec. Wet												
Historical	0.15	0.30**	TR-3.86	39.91*	12.52	3.0-74.0	26.11	11.93**	-9.0-57.0	103.7	75.4	6.8-318.3
Simulated	0.14	0.22	TR-1.52	38.86	12.78	-0.2-80.5	25.51	11.01	-12.6-65.2	109.1	76.6	0.1-323.6
Year 1/												
Historical	37.9	7.2	21.4-54.6	65.24	20.96	-5.0-113.0	44.67	19.00	-26.0-85.0	379.9	207.2	1.7-824.0
Simulated	35.7*	6.0	22.8-52.5	65.30	21.21*	-6.2-112.4	44.82	19.12	-21.3-91.9	381.9	203.9	0.1-820.3

* Indicates a significant difference at the α = .05 level.
** Indicates a significant difference at the α = .01 level.
1/ Average total rain, average maximum and minimum temperatures, and average solar radiation.

Table G3: Kolmogorov - Smirnov (K-S) Two-Sample Statistics to Test Hypothesis of Equality of Historical (80 years) and generated (99 runs) Cumulative Distribution Functions (CDF;s) of Daily Variates
Columbia, MO (Trace Rain = Wet)

Month & Precip. Status	Rain			Maximum Temperature			Minimum Temperature			Solar Radiation		
	n_H	n_s	K-S Value	n_H	n_s	K-S Value	n_H	n_s	K-S Value	n_H	n_s	K-S Value
Jan Dry:	---	---	---	203	200	.1181	203	200	.0909	232	200	.1834**
Wet:	196	201	.1061	196	201	.0936	196	201	.1152	156	201	.1007
Feb Dry:	---	---	---	192	235	.0617	192	235	.0678	245	235	.1334*
Wet:	203	213	.0442	203	213	.0628	203	213	.1294	165	213	.0789
Mar Dry:	---	---	---	218	208	.0964	218	208	.1214	232	208	.1928**
Wet:	190	204	.1023	190	204	.1084	190	204	.2059**	171	204	.0878
Apr Dry:	---	---	---	205	193	.0782	205	193	.1007	251	193	.1450*
Wet:	208	186	.0586	208	186	.0664	208	186	.0669	166	186	.0867
May Dry:	---	---	---	215	196	.0857	215	196	.0834	239	196	.1224
Wet:	202	195	.0950	202	195	.1341	202	195	.1838**	154	195	.0847
Jun Dry:	---	---	---	206	212	.1047	206	212	.0962	216	212	.0939
Wet:	192	181	.1089	192	181	.1295	192	181	.1599*	180	181	.0565
Jul Dry:	---	---	---	191	204	.0863	191	204	.0868	213	204	.1075
Wet:	229	206	.1051	229	206	.0828	229	206	.1411*	182	206	.0763
Aug Dry:	---	---	---	197	202	.1185	197	202	.0621	204	202	.1159
Wet:	191	184	.0828	191	184	.0728	191	184	.0946	184	184	.1956**
Sep Dry:	---	---	---	184	221	.0690	184	221	.0726	200	221	.1238
Wet:	212	214	.0984	212	214	.0877	212	214	.1350*	165	214	.0885
Oct Dry:	---	---	---	189	193	.0857	189	193	.1410*	221	193	.1089
Wet:	197	211	.0982	197	211	.0866	197	211	.0858	156	211	.0688
Nov Dry:	---	---	---	203	179	.0436	203	179	.0839	232	179	.1392*
Wet:	185	211	.0882	185	211	.1583*	185	211	.1684**	155	211	.1141
Dec Dry:	---	---	---	180	201	.0644	180	201	.0966	221	201	.1371*
Wet:	202	191	.1265	202	191	.0705	202	191	.0933	159	191	.1013

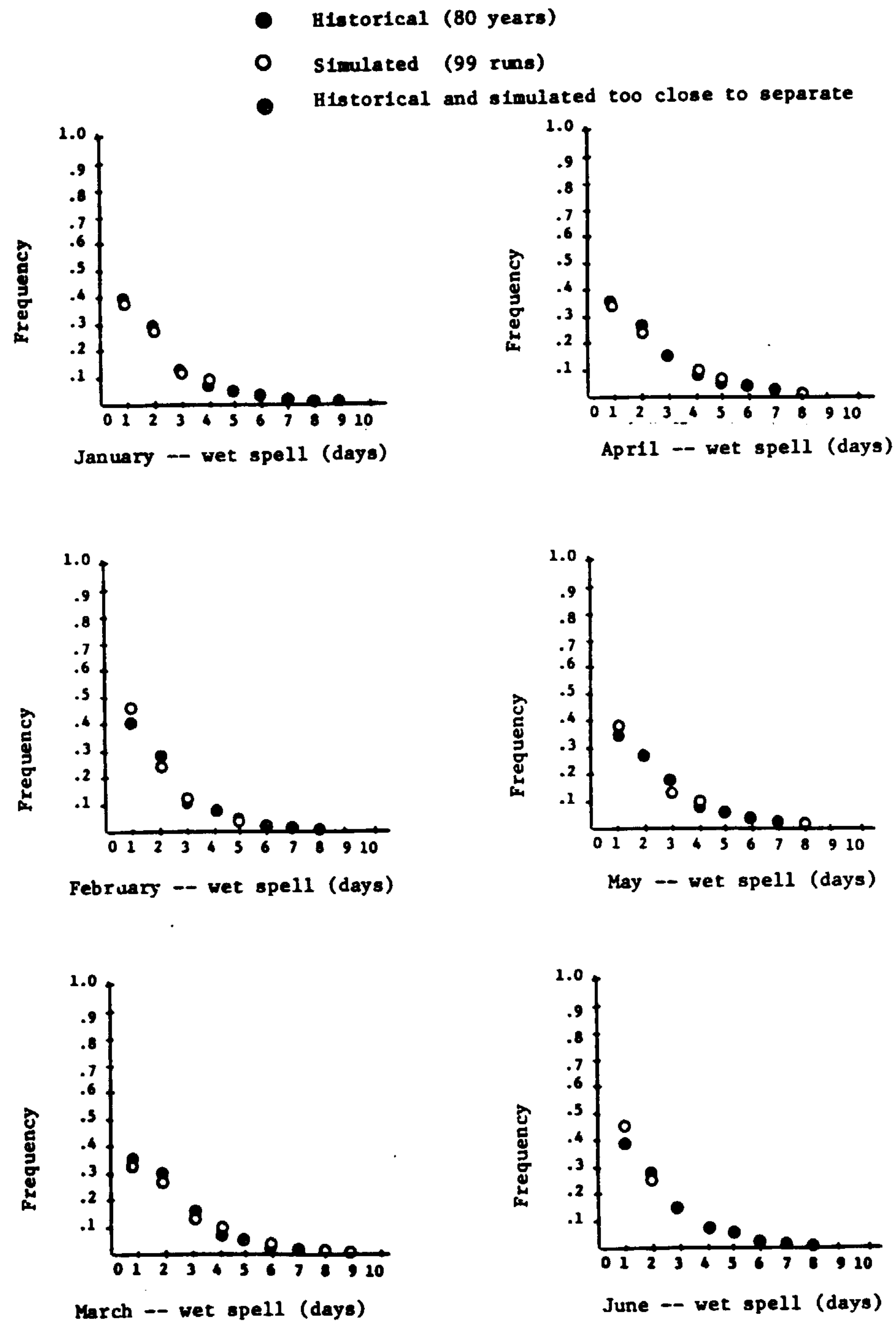
NOTE: n_h = number of observations from the historical data set.
n_s = number of observations from the simulated data set.

* Historical and simulated CDF's are significantly different at α = .05 level.
** Historical and simulated CDF's are significantly different at α = .01 level.

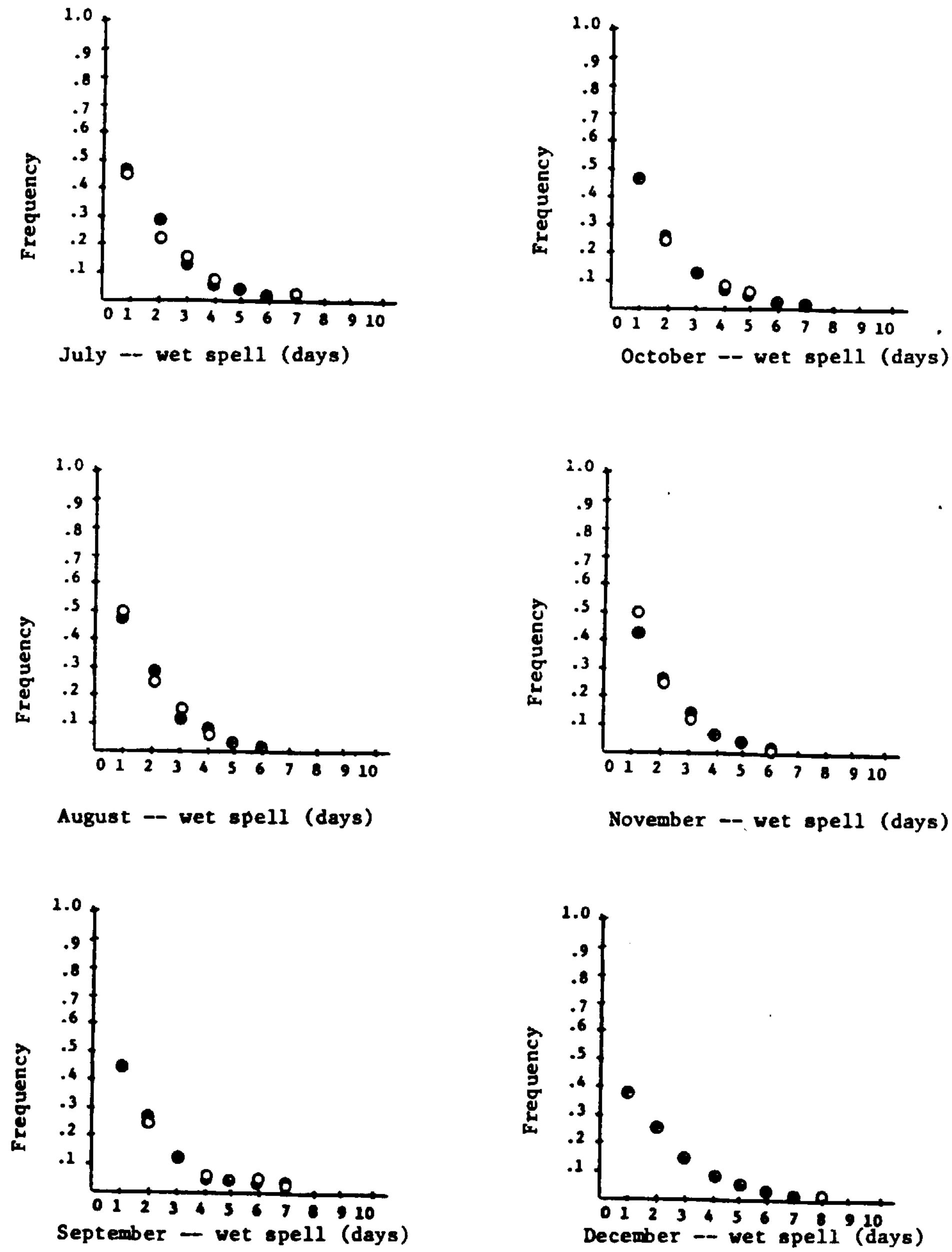
Table G4: Lengths of Wet, Dry, Freeze and Hot Spells for Historical (80 years) and Simulated (99 runs) -- Columbia, MO

Month	Wet Spell (days)			Dry Spell (days)			Freeze Spell			Hot Spell		
	Mean	Stan. Dev.	Range	Mean	Stan. Dev.	Range	Mean	Stan. Dev.	Range	Mean	Stan. Dev.	Range
January												
Historical....	2.28	1.61	1-10	3.11	2.80	1-22	7.84	7.79	1-39	---	---	---
Simulated.....	2.53	1.97	1-12	3.07	2.69	1-21	8.51	8.11	1-40	---	---	---
February												
Historical....	2.25	1.53	1-9	2.89	2.46	1-17	9.59	12.31	1-79	---	---	---
Simulated.....	2.20	1.68	1-12	2.78	2.16	1-15	7.07	8.45	1-52	---	---	---
March												
Historical....	2.39	1.65	1-11	2.64	2.00	1-14	4.75	5.49	1-46	---	---	---
Simulated.....	2.76	2.05	1-13	2.73	2.08	1-18	4.04	5.74	1-81	---	---	---
April												
Historical....	2.47	1.80	1-15	2.51	1.88	1-14	2.01	1.63	1-11	---	---	---
Simulated.....	2.77	2.08	1-13	2.39	1.81	1-18	1.85	1.68	1-10	1.12	0.48	1-3
May												
Historical....	2.50	1.75	1-13	2.51	1.89	1-10	1.00	0.00	0-1	---	---	---
Simulated.....	2.48	1.83	1-14	2.66	1.97	1-12	1.05	0.22	1-2	1.25	0.70	1-5
June												
Historical....	2.39	1.74	1-10	2.80	2.33	1-14	---	---	---	---	---	---
Simulated.....	2.30	1.78	1-14	2.76	2.01	1-11	---	---	---	1.42	0.77	1-5
July												
Historical....	2.06	1.58	1-15	3.36	2.90	1-29	---	---	---	2.80	2.87	1-18
Simulated.....	2.32	1.76	1-12	2.94	2.51	1-20	---	---	---	2.00	1.63	1-12
August												
Historical....	1.97	1.23	1-8	3.06	2.36	1-14	---	---	---	2.64	2.53	1-16
Simulated.....	2.03	1.45	1-10	3.43	2.73	1-17	---	---	---	1.96	1.61	1-10
September												
Historical....	2.15	1.45	1-9	3.77	3.61	1-31	1.0	0	1-1	2.89	2.74	1-16
Simulated.....	2.28	1.70	1-11	3.52	2.84	1-19	1.0	0	1-1	1.35	0.77	1-5
October												
Historical....	2.09	1.57	1-14	4.11	3.72	1-23	1.59	0.90	1-6	1.33	0.58	1-2
Simulated.....	2.08	1.41	1-10	4.21	3.71	1-22	1.36	0.63	1-4	1.44	0.87	1-4
November												
Historical....	2.13	1.42	1-9	3.84	3.90	1-30	3.00	2.26	1-14	---	---	---
Simulated.....	1.96	1.29	1-9	3.82	3.87	1-48	2.41	1.93	1-13	1.00	0.00	1-1
December												
Historical....	2.35	1.59	1-9	3.53	3.14	1-22	5.96	5.28	1-30	---	---	---
Simulated.....	2.45	1.77	1-11	3.01	2.57	1-17	4.99	4.71	1-30	---	---	---

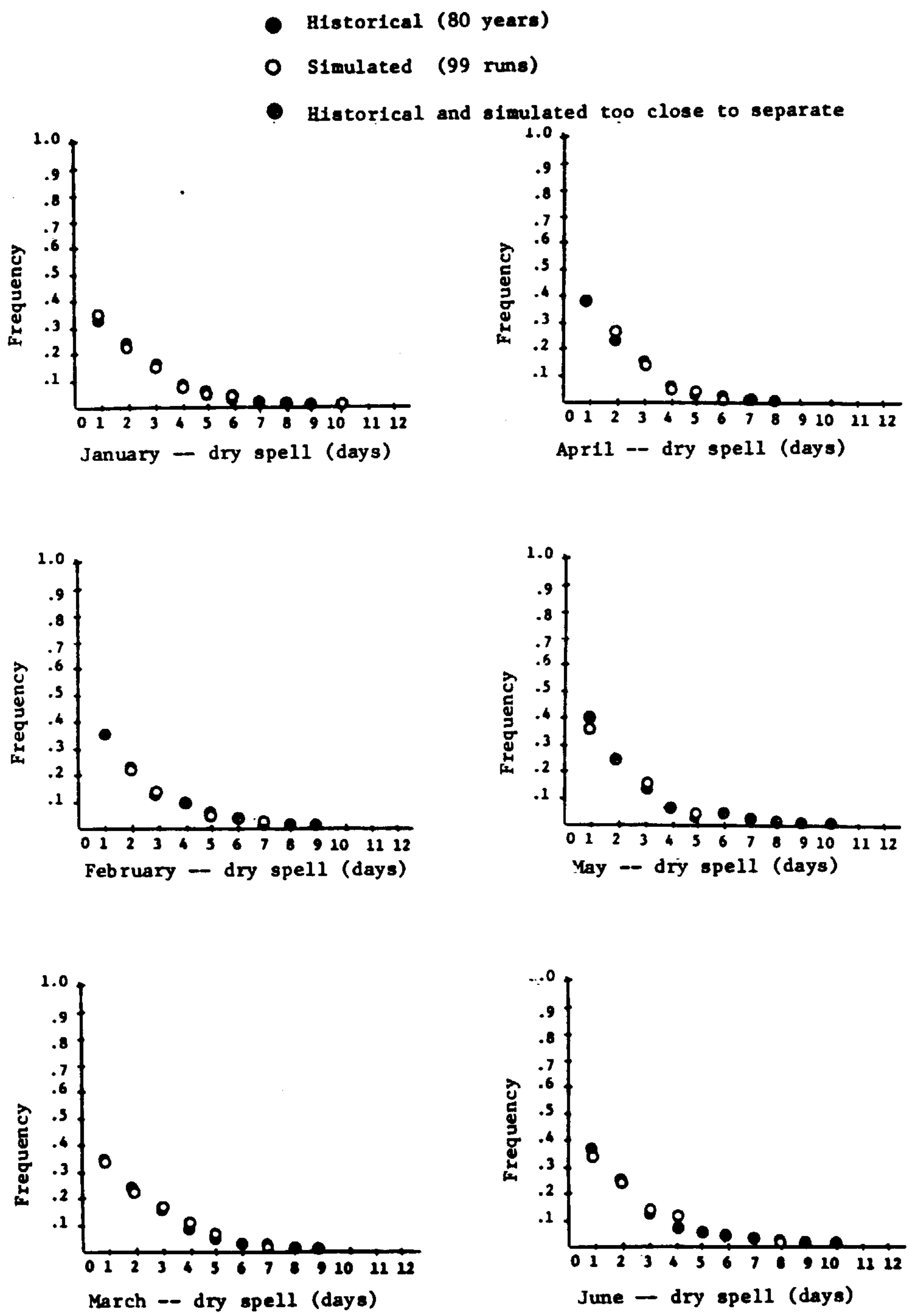
Figures G1-G6 : Frequency Distrubitions of Lengths of Wet Spells (days)



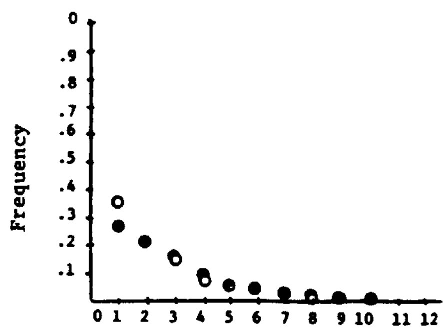
Figures G7-G12: Frequency Distributions of Lengths of Wet Spells (days)



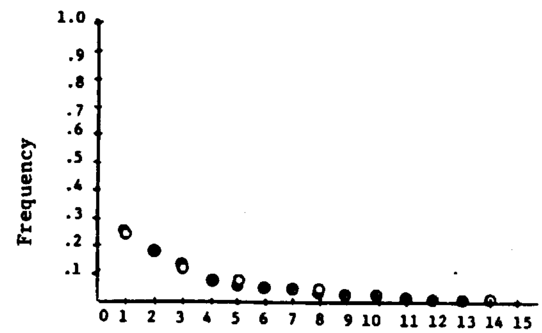
Figures G13-G18: Frequency Distributions of Lengths of Dry Spells (days)



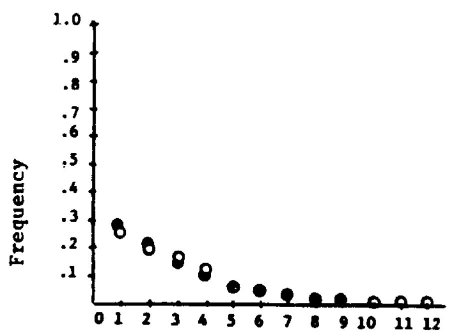
Figures G19-G24:Frequency Distributions of Lengths of Dry Spells (days)



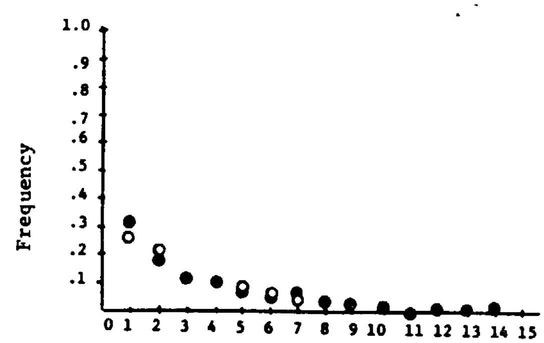
July -- dry spell (days)



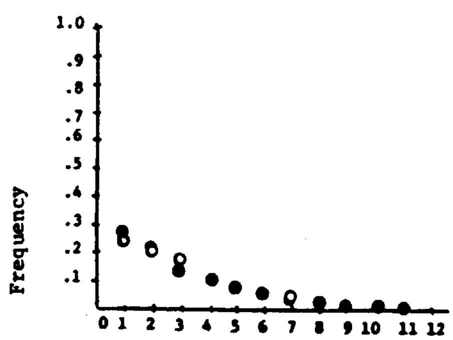
October -- dry spell (days)



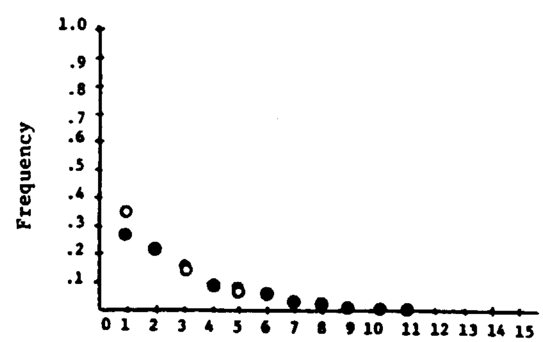
August -- dry spell (days)



November -- dry spell (days)

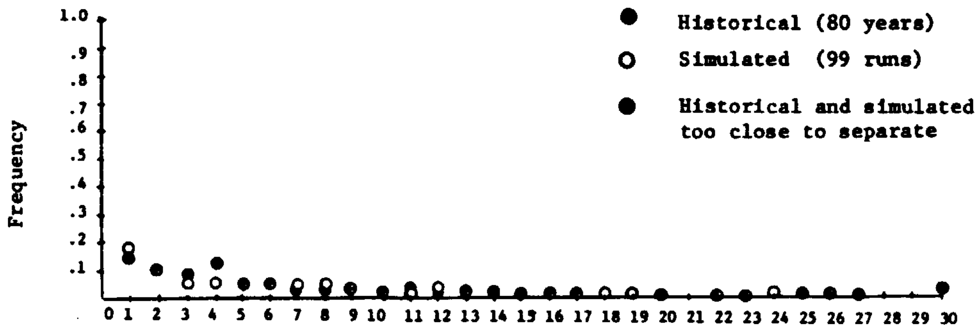


September -- dry spell (days)

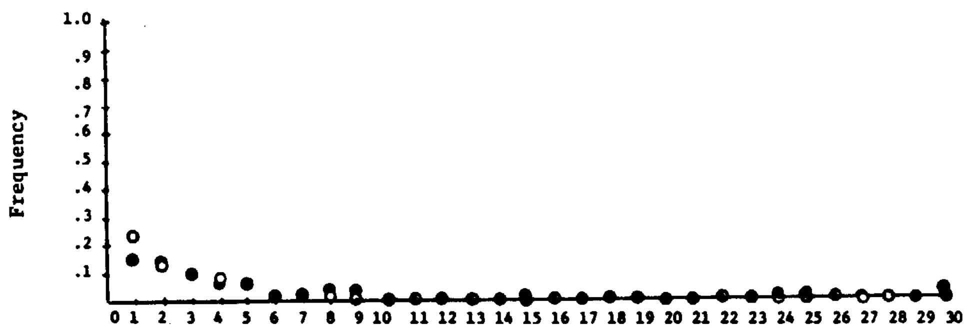


December -- dry spell (days)

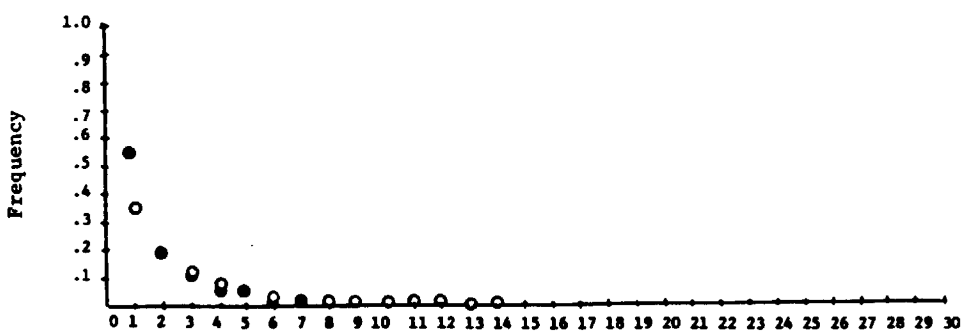
Figures G25-G27: Frequency Distributions of Lengths of Freezing Spells (days)



January -- freezing spell (days)

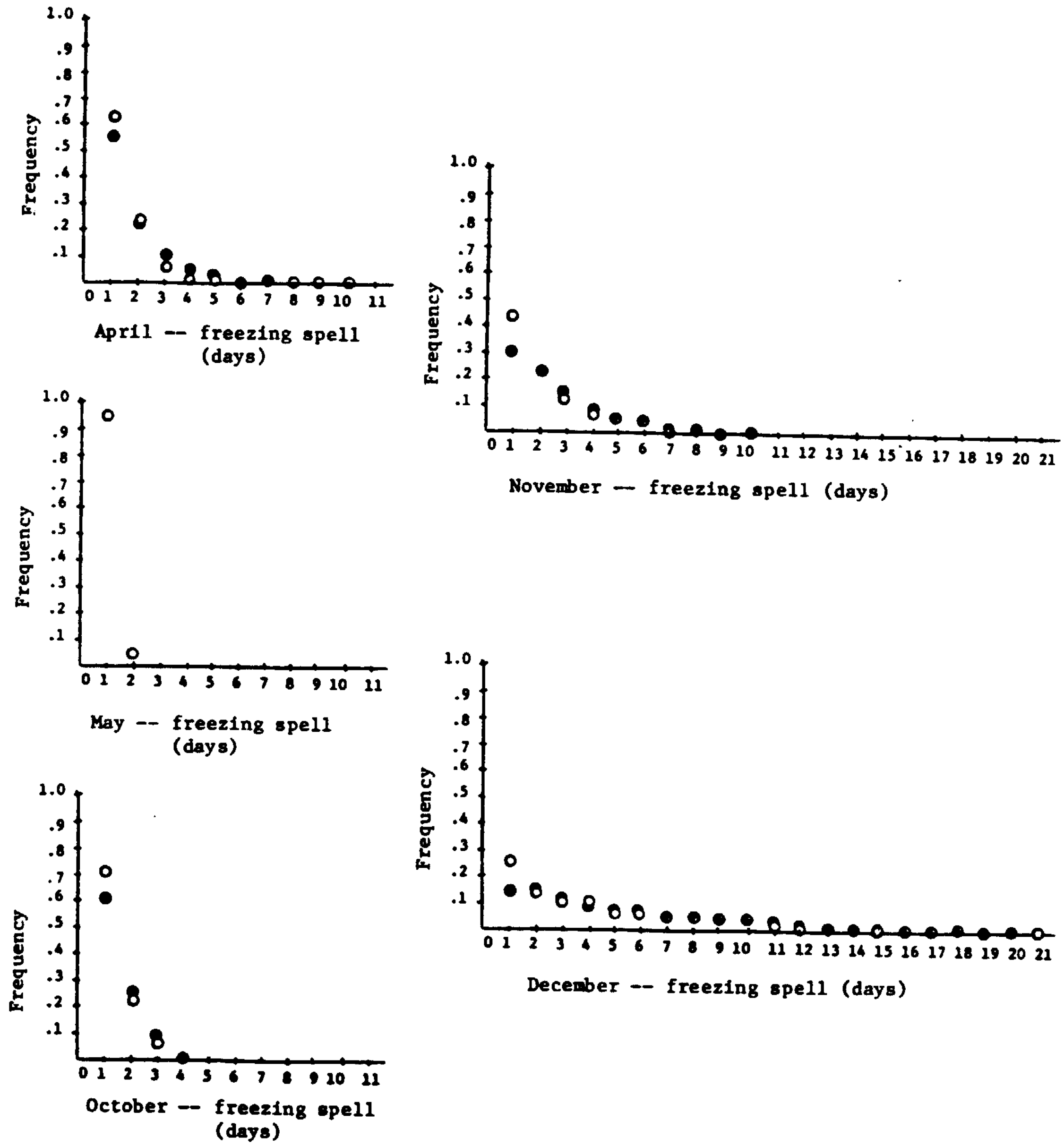


February — freezing spell (days)



March -- freezing spell (days)

Figures G28-G32 : Frequency Distributions of Lengths of Freezing Spells (days)

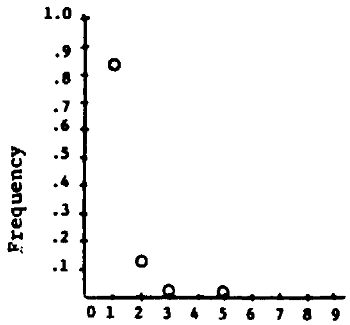


Figures G33-G38 : Frequency Distributions of Lengths of Hot (95°F or greater) Spells (days)

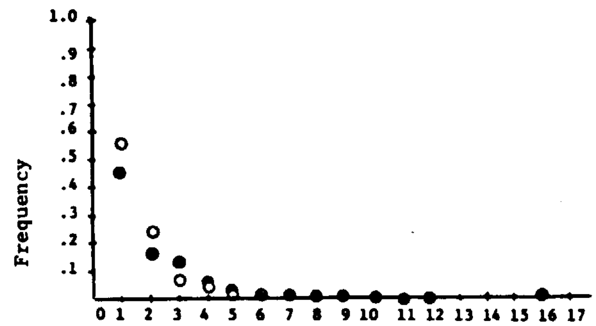
● Historical (80 years)

○ Simulated (99 runs)

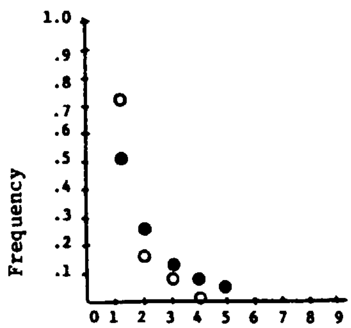
● Historical and simulated too close to separate



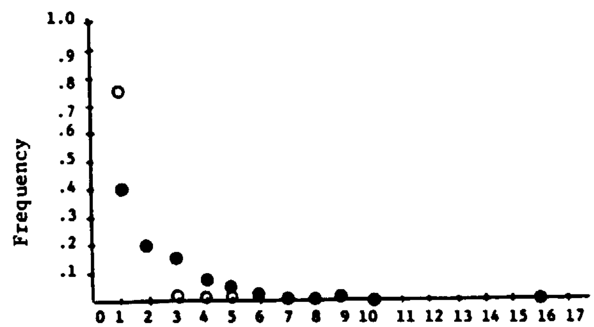
May -- hot spell (days)



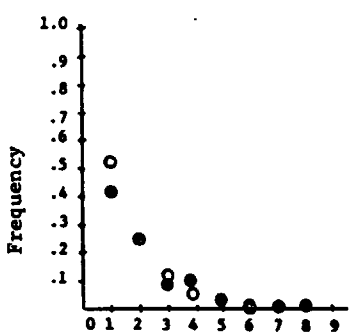
August -- hot spell (days)



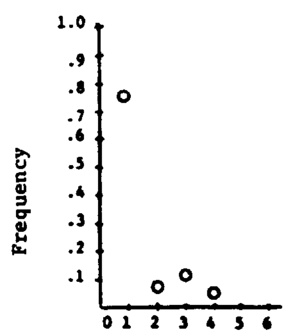
June -- hot spell (days)



September -- hot spell (days)



July -- hot spell (days)



October -- hot spell (days)

*U.S. GOVERNMENT PRINTING OFFICE: 1981-0-340-932/ESS-183