Microcomputer Program for Daily Weather Simulation

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Introduction

Daily climatic data, including precipitation, maximum temperature, minimum temperature, and radiation are often essential in system design and short-term decision-making in engineering and agriculture. Examples include: (a) Design of earthen covers for landfills or storage sites for low-level radioactive wastes (1), (b) design of irrigation systems (3), (c) design of urban or agricultural drainage systems, and (d) selection of farm or construction machinery (8). Short-term decisions are often sensitive to adverse weather in the near future, and engineers often find it useful to know probabilities of rainfall in the next few days.

Extensive climatic data have been collected by the National Weather Service and other agencies, and are available in printed form or on magnetic tapes. The published data are expensive to work with, and the magnetic tapes require mainframe computers to be effectively utilized. Recent developments in microcomputers and in stochastic models of daily climatic phenomena combine to make delivery and use of daily climatic data much easier than in the past. In this paper, we describe a system for delivering climatic information to users by means of an interactive microcomputer program. Data from the state of South Dakota are used as an example.

Mathematical Models

Our system for delivering climatic information requires: (a) appropriate stochastic models to describe daily precipitation, maximum and minimum temperature, and radiation, (b) extensive climatic data and appropriate algorithms to estimate the parameter set for the stochastic models, and (c) appropriate interpolation methods to estimate parameters for points between stations at which data are available.

The Markov chain-mixed exponential (MCME) model (9) is used to describe precipitation. The occurrence process is described by a first order Markov chain specified by the transition matrix parameters $p_{00}(n)$ and $p_{10}(n)$; n = 1, 2, · · · 365. Where $p_{00}(n)$ is the probability of a dry day on day n following a dry day and $p_{10}(n)$ is the probability of dry day following a wet day. On wet days, the amount of precipitation greater than 0.254 mm (0.01 inch), X, is distributed as a mixed exponential:

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$$f_X(x) = \alpha/\beta(n) \; \exp\left(-x/\beta(n)\right) + (1-\alpha)/\delta(n) \; \exp\left(-x/\delta(n)\right) \qquad (1)$$

Where the parameter α is a constant, and the parameters β and δ are allowed to vary in time, as described by a finite Fourier series

$$\gamma_i(n) = \gamma_{io} + \sum_{j=i}^{m_i} c_{ij} \; \sin(2\Pi n j/365 + \phi_{ij}) \; ; \; n = 1, \; 2, \; \cdot \; \cdot \; \cdot \; 365 \qquad (2)$$

Where, for example, $\gamma_1(\cdot) = p_{00}(\cdot)$, $\gamma_2(\cdot) = p_{10}(\cdot)$, etc., and $i = 1, \; \cdot \; \cdot \; \cdot \; 4$; m_i = the maximum number of harmonics for the ith parameter, γ_{io} = the annual mean of parameter i, c_{ij} = the amplitude of the jth harmonic, and ϕ_{ij} = the phase angle of the jth harmonic.

The Fourier coefficients for each parameter were estimated from 40 years of data for 20 South Dakota stations using numerical maximum likelihood procedures (9). A likelihood ratio test at the 0.05 level was used to determine significant harmonics. For the stations used in this study, the daily precipitation process could be described by from 15 to 27 coefficients.

The distribution function of N-day precipitation is calculated analytically using an equation presented by Todorovic and Woolhiser (7). The distribution of daily precipitation amounts is approximated by a single exponential with mean equal to the mean of the mixed exponential at the midpoint of the N-day period. The Markov chain parameters are also taken at the midpoint of the period. The length of the period N must be $\leq$ 30 days.

The model for maximum and minimum temperature and radiation is based on the work of Richardson (4) and Richardson and Wright (6). In this model, the daily means of maximum temperature, t_{max}, minimum temperature, t_{min}, and radiation, r, conditioned on whether the day is wet or dry, are described by a Fourier series, as are the conditional standard deviations. Deviations from the means are modeled by a weakly stationary generating process described by Matalas (2), which preserves the cross and lag-one serial correlation structure. The generating equation for the residual terms is:

$$Z_n(j) = \underline{A} \; Z_{n-i}(j) + \underline{B} \; \varepsilon_n(j) \qquad (3)$$

Where $Z_n(j)$ is a column vector for day n, whose elements are the residuals of t_{max}, t_{min}, and r for $j = 1$, 2, and 3, respectively, ε_n is a column vector of independent, normally distributed (0,1) random variables, and $\underline{A}$ and $\underline{B}$ are 3 x 3 matrices with elements defined such that the serial and cross-correlation are maintained in simulated sequences. Richardson (5) estimated the serial and cross-correlation by season for 20 years of temperature and solar radiation data for 31 U.S. stations, and found little seasonal or geographic variability. In this model, we use elements of the $\underline{A}$ and $\underline{B}$ matrices determined from the average correlation coefficients as presented by Richardson and Wright (6). Thus:

$$\underline{A} = \begin{bmatrix} 0.567 & 0.086 & -0.002 \\ 0.253 & 0.504 & -0.050 \\ -0.006 & -0.039 & 0.244 \end{bmatrix} \qquad (4)$$

$$\underline{B} = \begin{bmatrix} 0.781 & 0 & 0 \\ 0.328 & 0.637 & 0 \\ 0.238 & -0.341 & 0.873 \end{bmatrix} \qquad (5)$$

The 12 parameter values required for each station were interpolated from maps provided by Richardson and Wright (6).

Interpolation

It has been shown (10) that for 4 test stations in South Dakota, an arithmetic average of parameters for the 6 nearest stations provided better parameter estimates than did spline fitting, linear interpolation, or using the parameter value for the nearest neighboring station. Accordingly, we used the arithmetic average of parameters for all stations within a 100-mile radius as an estimator for each parameter. Non significant harmonic amplitudes were taken as zero, and were averaged with significant amplitudes. Only significant phase angles were averaged. An option is provided so the user can select the parameter values for the nearest station if desired.

The Interactive Program "CLIMATE • BAS"

The program is written in BASIC, and has been operated on a Heath/Zenith Z-100 microcomputer with 192 K RAM and a screen resolution of 640 x 225 pixels, and on a *Compaq computer with 256 K RAM and a screen resolution of 640 x 200 pixels. The capabilities of the program can best be explained by viewing the flow chart shown in Fig. 1. The program is "user friendly" in that the screen displays lead the user through the program by asking questions. If the user should accidentally make an unacceptable response, the question will be repeated.

In its present form, the program can fulfill two major functions. The first is to estimate the probability that the precipitation in a N-day period with a user selected beginning date will be less than, or equal to, x inches. The user is asked if the day before the N-day period was wet or dry, or unknown, and the distribution is conditioned on this information. This calculation can be carried out for an arbitrary number of periods (N < 30 days) at any session. The cumulative distribution function can be displayed graphically on the monitor, output to the line printer, or both.

The second major function is to simulate M years of daily precipitation or daily precipitation, maximum temperature, minimum temperature and radiation, and store it in a sequential file for further use. These "data" would then be readily accessible for use as input for daily simulation models to evaluate, for example, the effects of watershed changes on runoff volumes and peak flows, erosion and sediment transport, and transport of chemicals in surface runoff or by leaching below the root zone. The simulated temperature data could also be useful in evaluating the performance of conventional or solar heating systems.

*Mention of a brand name product is for the reader's information only, and does not imply endorsement of the product by the U.S. Department of Agriculture.
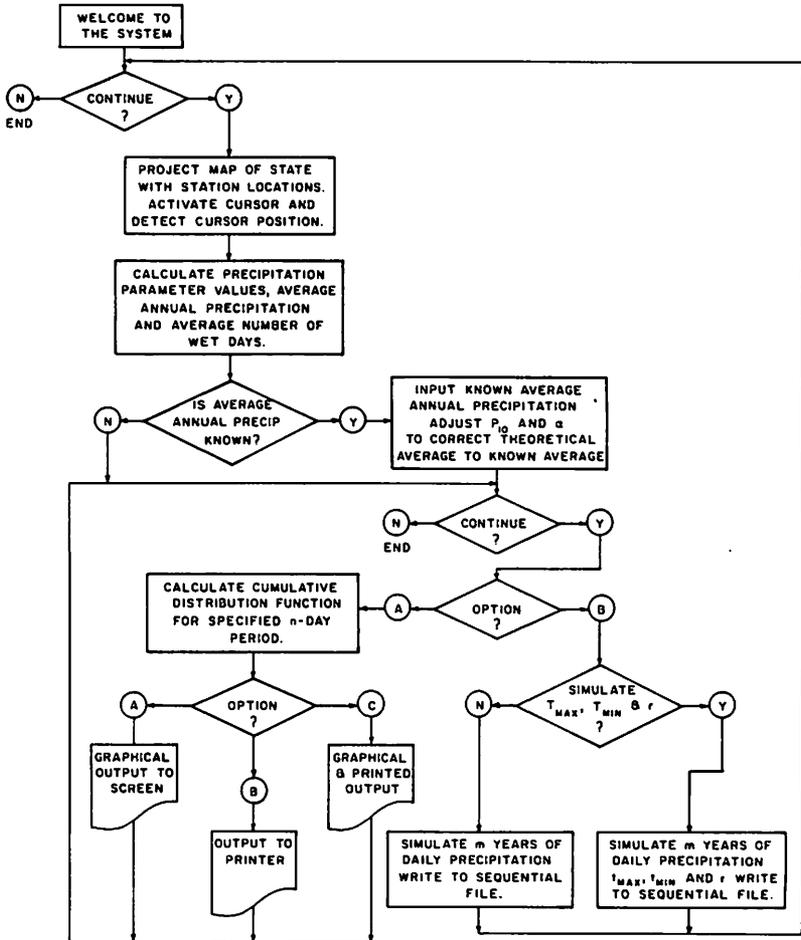
Figure 1. Flow Chart for CLIMATE • BAS.

Because the parameter averaging scheme used does not ensure that the average annual precipitation will be preserved (except at the stations for which the data and parameters were obtained), the user has the option of entering the average annual precipitation, and the annual means of the parameters p_{10} and α are adjusted until the theoretical mean is within 0.254 mm (0.01 inch) of the observed mean.

Example

Let us suppose that 25 years of simulated daily precipitation, maximum temperature, minimum temperature, and radiation data are needed

for input to a model to calculate the average annual surface runoff and
its distribution at a site near Huron, SD, 44°23' N. Lat. 98°13' W.
Long. The average annual precipitation at this location, as interpola-
ted from a map presented by Woolhiser and Roldan (10) is about 488 mm
(19.21 inches). The elapsed time required to calculate the parameters
for the daily precipitation model and the temperature and radiation
model on the Heath/Zenith Z-100 was 7 minutes - a considerable time
savings compared to the alternative of manual entry. The daily simula-
tion required approximately 10 seconds per year for precipitation only,
and 5 minutes per year for daily precipitation, maximum temperature,
minimum temperature, and radiation. Accuracy of simulated data has
been discussed by Woolhiser and Roldán (10) and Richardson and Wright
(6).

Summary

    An interactive microcomputer program has been written in BASIC to
provide an effective system for delivering climatic data to the user.
The voluminous data on daily precipitation, maximum temperature, mini-
mum temperature, and radiation are "compressed" by estimating parame-
ters for stochastic models that describe the temporal variability of
these processes and their cross and lag-one serial correlation. Inter-
polation in space is handled by averaging parameters within a 100-mile
radius and adjusting parameter values to maintain the average annual
precipitation. Presently available options include: (a) calculate the
cumulative distribution function of N-day rainfall, (b) simulate M
years of precipitation data, and (c) simulate M years of daily precipi-
tation, maximum temperature, minimum temperature, and radiation data.
These simulated data can be used as input for several daily hydrologic
or plant growth models. The program provides a much faster method of
obtaining simulation model parameters than manual input from tables or
maps.

    The program could be easily adapted to other states by modifying
the graphics portion and parameter data files.

Appendix-References

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