

CLIMATE: A Microcomputer Program Allowing Student Preparation of Climatic Maps for Indiana

GARY E. DOLPH
Department of Botany
Indiana University at Kokomo
Kokomo, Indiana 46902

When studying the natural history or ecology of Indiana, one topic that the students should master is climate, because of its influence on the distribution of plants and animals in the State. However, effective class discussion of a series of climatic maps can be very difficult. To increase student understanding of climatic variation in Indiana, I prepared a computer program, called CLIMATE, for use on the Apple IIe. Using CLIMATE, the students can generate their own climatic maps of Indiana, and they can compare variation in climate with variation in plant distribution and plant morphology. CLIMATE's data base contains information on temperature and precipitation from 91 weather stations in Indiana and the adjacent states of Michigan, Ohio, Kentucky, and Illinois. Information on seven different climatic variables is available: temperature, range in temperature, precipitation, biotemperature, potential evapotranspiration ratio, effective temperature, and equability. Copies of CLIMATE as well as the other support programs mentioned in the text may be obtained by sending a blank disk to the author.

Weather Stations

Figure 1 shows the locations of the 91 weather stations used as data sources in Indiana, Michigan, Ohio, Kentucky, and Illinois. The monthly normals of temperature and precipitation for the period from 1941 to 1970 are recorded for each weather station in the data base (11-15). More recent information is available from the National Climatic Center in Asheville, North Carolina, but it was not used for two reasons. First, the measurements of temperature and precipitation for the period from 1941 to 1970 are as accurate as for any subsequent period. Second, the older data were used to minimize the ever increasing effects of industrialization and urbanization following World War II (10). However, if more recent information is desired, a totally new data base may be constructed using the programs (MTEMP and APREC) discussed below.

Temperature data are available from 65 weather stations in Indiana; and precipitation data are available from 84. Because information about both temperature and precipitation is required to calculate the potential evapotranspiration ratio, only information from weather stations recording both temperature and precipitation is included in the data base. This requirement limited the number of usable weather stations in Indiana to 65. The remaining 26 weather stations in the data base are from the surrounding states of Michigan, Ohio, Kentucky, and Illinois. Inclusion of these 26 weather stations minimizes the distortion of the climatic contours at Indiana's borders.

Programs for Modifying and Collecting Climatic Data

Four programs (Mean TEMPerature, (MTEMP), MODify TEMPerature (MODTEMP), Average PRECipitation (APREC), and MODify PRECipitation (MODPREC)) were used to collect and correct the initial climatic data. These four programs do not require the user to specify how much data the programs will be handling. Therefore, these programs can be used to collect and correct variable amounts

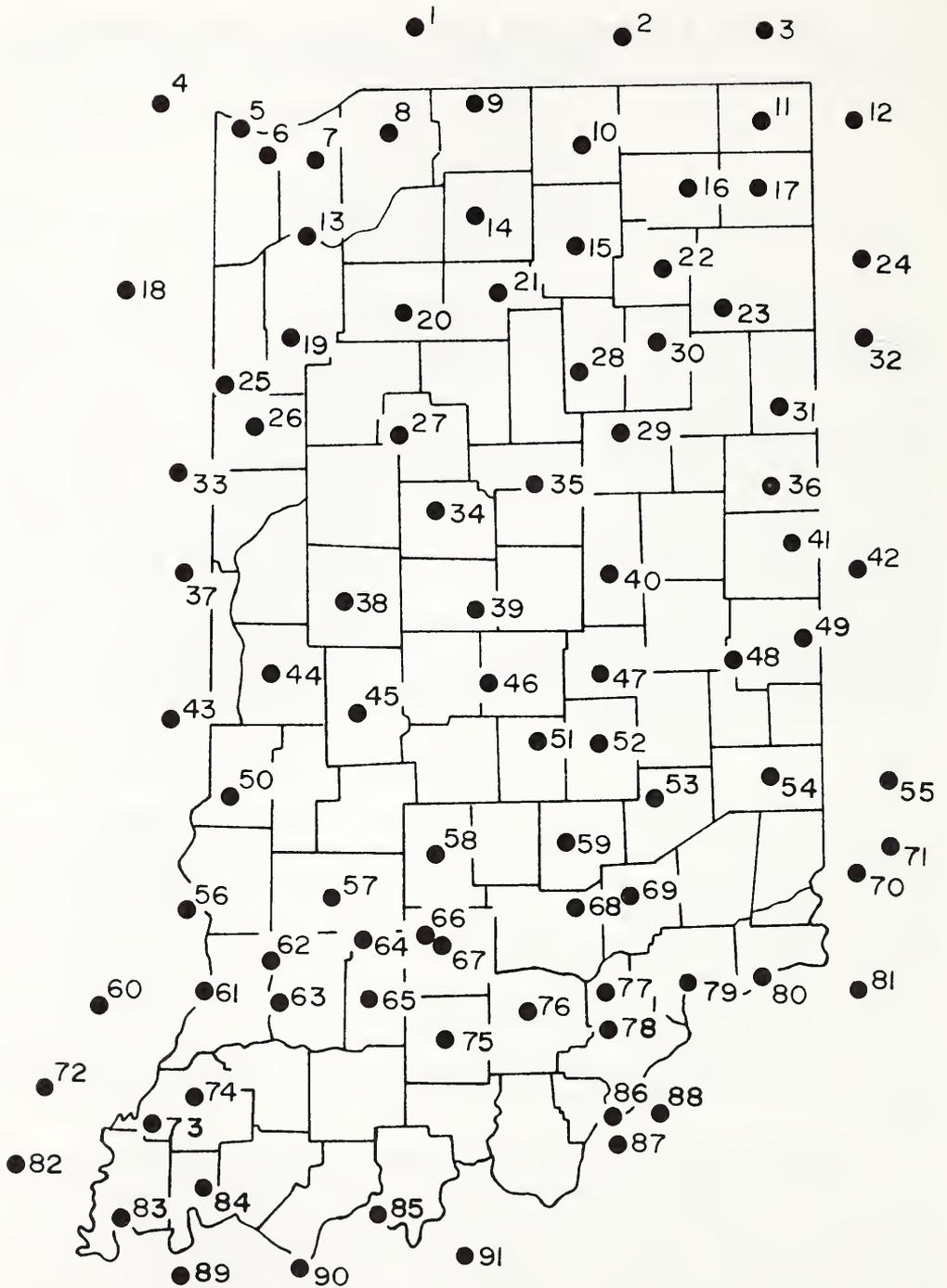


FIGURE 1. Locations of the 91 weather stations for which climatic data are available when using CLIMATE. The names of the weather stations are given in Table 1.

of climatic data for any state or combination of states. Except for prompts specifying the type of data to enter (e.g., precipitation or temperature), MTEMP and APREC function similarly as do MODTEMP and MODPREC. Simplified flow charts for these two sets of programs are given in Figure 2. MTEMP and APREC are diagrammed on the left; and MODTEMP and MODPREC are diagrammed on the right.

MTEMP and APREC are used to collect data. First, each program dimensions an array to hold either temperature or precipitation data. Then, APREC or MTEMP

TABLE 1. Key to the weather stations referenced in Figure 1. Unless otherwise stated, the weather stations are in Indiana.

Number	Weather Station
1	Eau Claire, Michigan
2	Three Rivers, Michigan
3	Coldwater State School, Michigan
4	Chicago University, Illinois
5	Gary
6	Hobart
7	Valparaiso Waterworks
8	LaPorte
9	South Bend WSO
10	Goshen College
11	Angola
12	Montpelier, Ohio
13	Wheatfield
14	Plymouth Power Substation
15	Warsaw
16	Albion
17	Waterloo
18	Kankakee, Illinois
19	St. Joseph's College, Collegeville
20	Winamac
21	Rochester
22	Columbia City
23	Fort Wayne WSO
24	Paulding, Ohio
25	Kentland
26	Fowler
27	Delphi
28	Wabash
29	Marion
30	Huntington
31	Berne
32	Van Wert, Ohio
33	Hoopeston, Illinois
34	Frankfort Disposal Plant
35	Kokomo
36	Salamonia
37	Danville, Illinois
38	Crawfordsville Power Plant
39	Whitestown
40	Anderson Sewage Plant
41	Winchester Airport
42	Greenville Water Plant, Ohio
43	Paris Waterworks, Illinois
44	Rockville
45	Greencastle
46	Indianapolis WSO
47	Greenfield
48	Cambridge City
49	Richmond Waterworks
50	Terre Haute
51	Franklin
52	Shelbyville Sewage Plant
53	Greensburg
54	Brookville
55	Hamilton/Fairfield, Ohio
56	Palestine, Illinois
57	Elliston
58	Indiana University, Bloomington
59	Columbus

TABLE 1.—Continued

Number	Weather Station
60	Olney, Illinois
61	Vincennes
62	Edwardsport Power Plant
63	Washington
64	Crane Naval Depot
65	Highway 50 Bridge, Shoals
66	Purdue Experimental Farm, Oolitic
67	Bedford
68	Seymour
69	North Vernon
70	Covington WSA, Kentucky
71	Abbe Observatory, Cincinnati, Ohio
72	Fairfield Radio, WFIW, Illinois
73	Johnson Experimental Farm
74	Princeton
75	Paoli Radio, WVAK
76	Salem
77	Scottsburg
78	Henryville State Forest
79	Madison Sewage Plant
80	Vevay
81	Williamstown, Kentucky
82	McLeansboro, Illinois
83	Mt. Vernon
84	Evansville WSO
85	Tell City Power Plant
86	Jeffersonville
87	Louisville NSO, Kentucky
88	Anchorage, Kentucky
89	Henderson, Kentucky
90	Owensboro, Kentucky
91	Irvington, Kentucky

sequentially requests the following information: 1) the number of the weather station, 2) the mean temperature or average precipitation for each month beginning with January, and 3) the mean annual temperature or average annual precipitation over the thirty year period from 1941 to 1970. When these operations are completed, the information for that weather station (one record) is transferred to the disk. The data base which is ultimately constructed represents a random access data file. Each record contains only one complete data set (i.e., temperature or precipitation data for a single weather station). This structure allows for fast access to the data, whether the required information is located in the first or last record in the file, through the use of a record number, the weather station number.

MODTEMP and MODPREC are used to make additions or corrections to the data base constructed using MTEMP and APREC. First, MODTEMP or MODPREC requests the number of the weather station (record number) for which incorrect information has been recorded. This entire record will be printed on the monitor. A correction is made by specifying the number of the month having incorrect data (1 for January up to 13 for the thirty-year mean). After any corrections have been made, the new record replaces the old on the disk.

Using these programs, two data bases were constructed for use with CLIMATE: TEMPDAT (TEMPERature DATa), containing temperature data; and PRECDAT (PRECipitation DATa), containing precipitation data. The data were recorded in the

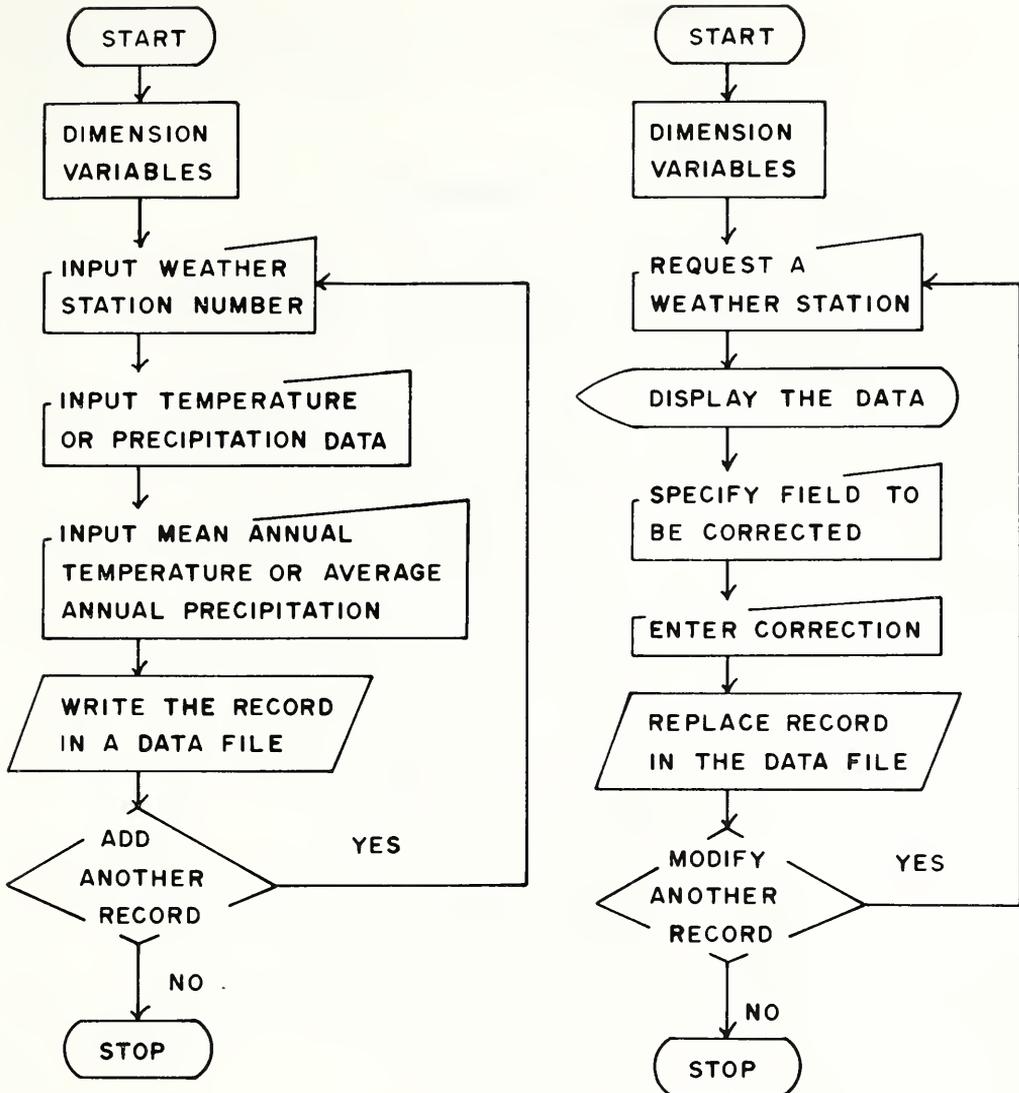


FIGURE 2. Simplified flow charts illustrating the functioning of MTEMP and APREC (left) as well as MODTEMP and MODPREC (right).

English system. This mode of data storage was adopted for two reasons. First, the data may still be compared directly to the information in the original data sources (11-15). Second, although CLIMATE provides information to the students in the metric system, the program can be modified to work with information in the English system.

Climate

The flow chart in Figure 3 illustrates how CLIMATE functions. At the start of execution, CLIMATE constructs two arrays, one for temperature data and one for precipitation data, based on the two data bases, TEMPDAT and PRECDAT. Then, CLIMATE sequentially requests the following information: 1) the type of climatic parameter to analyze; 2) the time period over which to calculate the climatic parameter; and 3) the number of the weather station at which to calculate the climatic parameter. Seven different climatic parameters may be studied (see below). Values for these climatic parameters may be calculated for the whole year or for selected portions of the year,

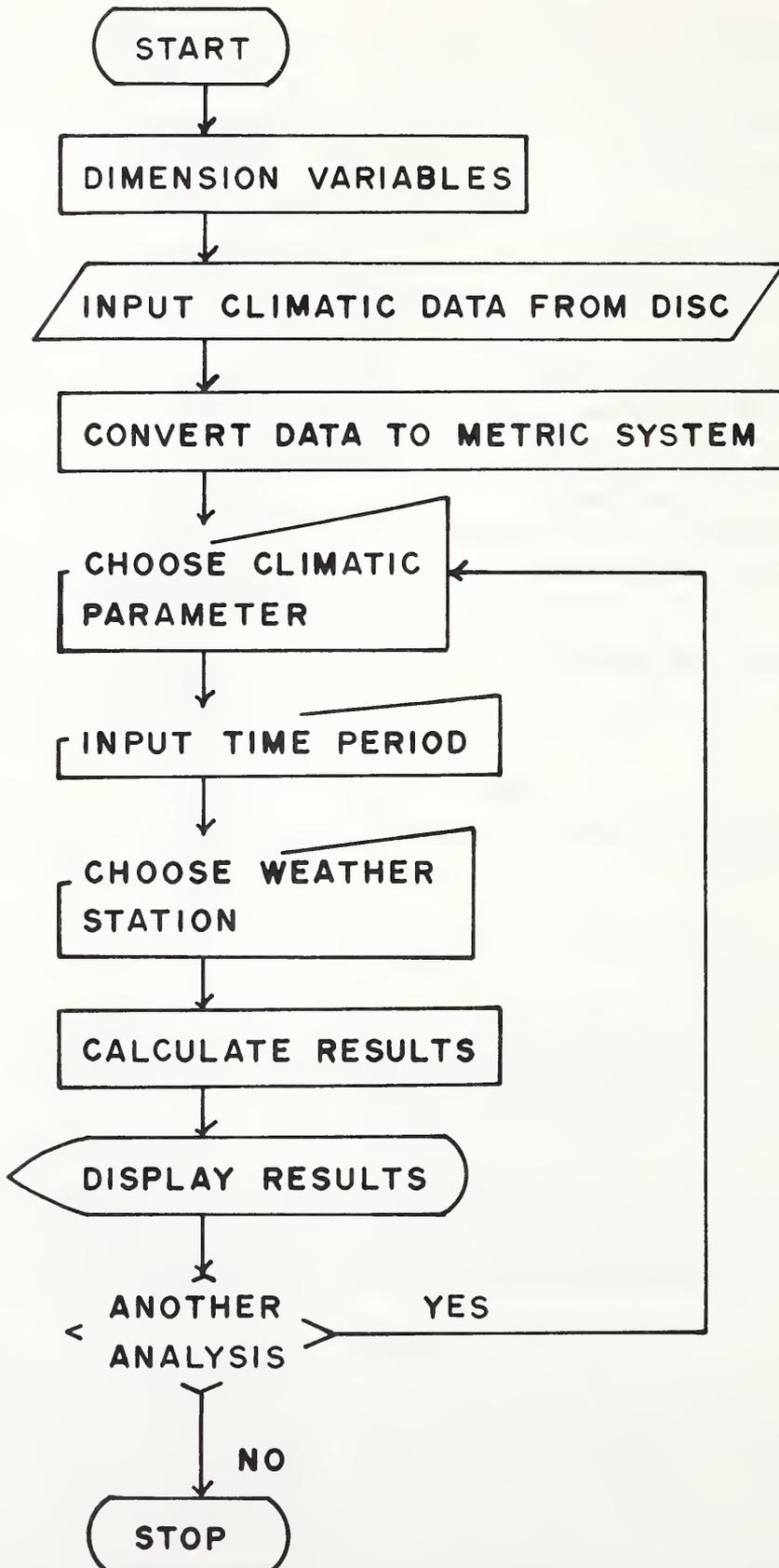


FIGURE 3. Simplified flow chart showing the overall operation of CLIMATE.

such as the growing season. Any of the 91 weather stations may be chosen as a data source. After the calculations are completed, the results are displayed on the monitor. After each calculation, the student can decide whether or not to continue with the analysis.

Climatic Parameters

Seven climatic parameters can be studied using CLIMATE: temperature, range in temperature, precipitation, biotemperature, potential evapotranspiration ratio, effective temperature, and equability. In addition to being unique expressions of various aspects of the environment, these seven climatic parameters represent three different methods of correlating climate with plant form. First, several attempts have been made to relate mean annual temperature, mean annual range in temperature, and/or total annual precipitation to variation in vegetational cover or to variation in plant form (e.g., 9, 16-20). Second, Holdridge (7, 8) uses mean annual biotemperature, average annual precipitation, and the potential evapotranspiration ratio to define the life zone, the basis of his vegetational classification. Finally, Bailey (1-4) believes that effective temperature (how frost free a given locality is) and equability (the freedom of a locality from extreme heat and cold) can be used along with mean annual temperature and mean annual rainfall to delineate the distribution of modern plant communities.

Average temperature is calculated by summing the mean temperature for a specific number of months and then dividing by the total number of months in that time period. The whole year or only a portion of the year may be selected. When values for the whole year are requested, the mean annual temperature is calculated. If only a portion of the year, such as the growing season, is desired, two numbers ranging from 1 (January) to 12 (December) are used to indicate the starting and stopping months for the calculation.

The range in temperature is calculated by subtracting the lowest mean monthly temperature in the selected time period from the highest. When values for the whole year are used, the mean annual range in temperature is calculated. The range in temperature for less than a full year is requested by selecting the appropriate starting and stopping months.

Summing the average monthly precipitation over a specified time period yields the total precipitation. If values for all twelve months are requested, the average annual precipitation is calculated. The total precipitation for periods of less than a year is calculated by selecting the appropriate starting and stopping months.

Biotemperature is the average temperature between 0°C and 30°C at which vegetational growth takes place (7, 8). The average biotemperature is the sum of the mean monthly temperatures between 0°C and 30°C over a specific time period divided by the total number of months in that time period. Because months having a mean value above 30°C or below 0°C are not used to calculate biotemperature, values for average biotemperature of less than 0°C or greater than 30°C are not possible. When data for all twelve months are used, the mean annual biotemperature is calculated. If values above 30°C or below 0°C are not encountered within the specified time interval, the calculated values of average biotemperature and mean temperature are equal. The calculated values of average biotemperature and mean temperature are equal in warm temperate states such as North and South Carolina (6), but they are not equal in cold temperate states such as Michigan.

The potential evapotranspiration ratio is a climatic index calculated using both biotemperature data and precipitation data (7, 8). First, potential evapotranspiration, a hypothetical number, is calculated by multiplying the biotemperature for a specific time interval by 58.93. Then, the potential evapotranspiration ratio is calculated by

dividing the potential evapotranspiration by the average precipitation for the same time interval:

$$\text{PER} = (58.93 \times T^{(\text{bio})})/P,$$

where the potential evapotranspiration ration (PER) is a dimensionless number, $T^{(\text{bio})}$ is the biotemperature given in °C, and P is the total precipitation given in mm. A value of 1.00 indicates that precipitation balances potential evapotranspiration over the time period selected. The most favorable habitats for plant growth and human activity cluster about a potential evapotranspiration ratio of 1.00. As the potential evapotranspiration ratio increases, the precipitation is less than needed to balance potential evapotranspiration and the habitat becomes more arid. As the potential evapotranspiration ratio decreases, the precipitation is more than is needed to balance potential evapotranspiration and the habitat becomes more moist. The potential evapotranspiration ratio ranges from a high of 32.0 in the super-arid humidity province to a low of 0.125 in the super-humid humidity province. The potential evapotranspiration ratio may be calculated for the whole year or for a portion of the year by selecting the appropriate starting and stopping months.

Effective temperature is the temperature, expressed in °C, at the beginning and end of a warm period in which vegetational growth occurs (1-4). This warm period will be largely free from frost. Effective temperature (ET) is calculated as:

$$\text{ET} = (8T + 14A) / (8 + A),$$

where T is the average temperature in °C and A is the range in temperature in °C for a specific time period. The change from cold climates to warm climates is indicated by an increase in the value of effective temperature. Polar climates have an effective temperature of less than 10°C; cool midlatitude climates of between 10°C and 14°C; warm midlatitude climates of between 14°C and 18°C and tropical climates of more than 18°C. Each of these categories can be further subdivided into smaller climatic units.

Equability measures the freedom of a specific locality from extremes of heat or cold regardless of whether or not the extremes are perennial or seasonal (1-4). Equability (M) is calculated using the following formula:

$$M = 109.0 - 30 \log ((T-14)^2 + (1.46 + 0.366A)^2),$$

where T is the average temperature in °C and A is the range in temperature in °C for a specific time period. Equability is a dimensionless index, ranging from 0 to 100. The lower the equability, the more extreme the climate. A climate which is totally free from extremes of heat or cold has an equability of 100. The outer limit for temperate climates is an equability of 55.

Classroom Uses

Rather than discussing what must appear to be an endless series of climatic maps in the classroom, CLIMATE allows two different types of analyses to be carried out. First, after analyzing the data and drawing the appropriate climatic maps, the students' maps can be compared with published climatic maps for Indiana (5, 10). Normally, the students' maps will lack the smooth contours characteristic of the published maps. Factors that can influence a climatic measurement, such as elevation, exposure, or the time of day when the measurement was taken, require that a climatologist treat

these measurements as relative and not absolute values. Therefore, there is a tendency for the more divergent measurements to be rejected when publishing a climatic map. The rejection of some data results in a climatic map which is more aesthetically pleasing even if it is not absolutely accurate. By comparing the students' maps with the published maps, the role judgment plays when producing climatic maps can be discussed. Second, when used in conjunction with vegetation maps, the relationship between vegetation and climate as well as the relative merits of the three methods of climatically classifying vegetation may be assessed.

Evaluation

The teaching effectiveness of CLIMATE and two other simulations (work in progress) was evaluated using a pretest-posttest design with experimental and control groups. Both groups were given the same 50 question pretest and posttest. Based on the results of these tests, the mean gain scores registered for each group were calculated. Two different tests (a separate variance estimate of the difference in mean gain scores and an analysis of covariance for the posttest scores of the experimental and control groups) were run to see if the gain in the experimental group was significantly greater than the gain in the control group. In each case, the difference was found to be significant at a 5% significance level.

Outcomes

A number of important student outcomes result from using CLIMATE:

- 1) By calculating the positions of their own contour lines, the students gain valuable insights into how maps, such as weather maps, geologic maps, or vegetation maps, are constructed.
- 2) After discussing trends in climatic variables, the students should find it easier to identify trends in other mappable variables, such as vegetation characteristics.
- 3) By being actively involved in constructing and analyzing climatic maps, the students gain greater appreciation for the variation in Indiana's climate than could be obtained by passively attending lecture.
- 4) By comparing their maps with published climatic maps for Indiana, the students can see how the acceptance or rejection of data from various weather stations can influence the final form of their maps.
- 5) By comparing the ability of different climatic parameters to explain the variation in vegetation patterns in Indiana, the students can begin to explore the relationship between vegetation and climate.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. SER 8004789. The author would like to express his thanks to Dr. Lian-Hwang Chiu for assisting with the statistical analysis and to Dr. Charles R. Barman for critically reviewing the manuscript.

Literature Cited

1. Axelrod, D.I. and H.P. Bailey. 1969. Paleotemperature analysis of Tertiary floras. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 6:163-195.

2. Bailey, H.P. 1960. A method of determining the warmth and temperateness of climate. *Geograf. Ann.* 42:1-16.
3. _____. 1945. Toward a unified concept of temperate climate. *Geograph. Rev.* 54:516-545.
4. _____. 1966. The mean annual range and standard deviation as measures of dispersion of temperature around the annual mean. *Geograf. Ann.* 48:183-194.
5. Dolph, G.E. 1984. Leaf form of the woody plants of Indiana as related to environment. In: N.S. Margaris, M. Arianoustou-Farragitaki, and W.C. Oechel (Eds.), *Being Alive on Land*, pp. 51-61, Tasks for Vegetational Science, Vol. 13, Dr. W. Junk Publishers, The Hague, 322 pp.
6. ____ and D.L. Dilcher. 1979. Foliar physiognomy as an aid in determining paleoclimate. *Palaeontographica, Abt. B*, 170:151-172.
7. Holdridge, L.R. 1967. Life zone ecology. Tropical Science Center, San Jose, Costa Rica, 206 pp.
8. ____, W.C. Grenke, W.H. Hatheway, T. Laing, and J.A. Tosi, Jr. 1971. Forest environments in tropical life zones: A pilot study. Pergamon, New York. 747 pp.
9. Raunkiaer, C. 1934. The life-forms of plants and statistical plant geography. Oxford University Press, Oxford, 632 pp.
10. Schaal, L.A. 1966. Climate. In: A.A. Lindsey (Ed.), *Natural Features of Indiana*, pp. 156-170, Indiana Academy of Science, Indianapolis, 597 pp.
11. U.S. Department of Commerce Environmental Data Service. 1973a. Climatology of the United States, No. 81 (Illinois). Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-1970. Asheville, North Carolina.
12. _____. 1973b. Climatology of the United States, No. 81 (Indiana). Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-1970. Asheville, North Carolina.
13. _____. 1973c. Climatology of the United States, No. 81 (Kentucky). Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-1970. Asheville, North Carolina.
14. _____. 1973d. Climatology of the United States, No. 81 (Michigan). Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-1970. Asheville, North Carolina.
15. _____. 1973e. Climatology of the United States, No. 81 (Ohio). Monthly normals of temperature, precipitation, and heating and cooling degree days 1941-1970. Asheville, North Carolina.
16. Wolfe, J.A. 1969. Paleogene floras from the Gulf of Alaska region. U.S. Geol. Surv. Open-file Rep. 114 pp.
17. _____. 1971. Tertiary climatic fluctuations and methods of analysis of Tertiary floras. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 9:27-57.
18. _____. 1978. A paleobotanical interpretation of Tertiary climates in the Northern Hemisphere. *Amer. Sci.* 66:694-703.
19. _____. 1981. Paleoclimatic significance of the Oligocene and Neogene floras of the northwestern United States. In: K.J. Niklas (Ed.), *Paleobotany, Paleoecology, and Evolution, Volume 2*, pp. 79-101, Praeger, New York, 269 pp.
20. ____ and D.M. Hopkins. 1967. Climate changes recorded by land floras in northwestern North American. In: K. Hatai (Ed.), *Tertiary correlations and climatic changes in the Pacific*, pp. 67-76, Symp. Pacific Sci. Congr., Tokyo.