

A CSMP-PROGRAM FOR COMPUTING THORNTHWAITE'S
CLASSIFICATION OF CLIMATE

M. ARBAB

REPORT no. 8, 1972

Dept. of Theoretical Production Ecology
Agricultural University
WAGENINGEN - THE NETHERLANDS

A CSMP-program for computing Thornthwaite's
classification of climate

Introduction

The climate is to a large extent determined by the moisture relationships. We cannot tell whether a climate is moist or dry by knowing only the precipitation. We must know whether precipitation is greater or less than the water needed for evaporation and transpiration: precipitation and evaporation are equally climatic factors. Since precipitation and evapotranspiration are due to different meteorological causes, they are rarely the same in amount or distribution throughout the year.

In some places more rain falls month after month than evaporates or than the vegetation uses. The surplus moves through the ground and over it to form streams and rivers.

In other places, month after month, there is less water in the soil than the vegetation would use if it was available. There is no excess of precipitation and no runoff, except locally where the soil is impermeable and cannot absorb the rain on the rare occasion where it falls. Consequently there are no permanent rivers, and there is little drainage to the sea.

In still other areas the rainfall is deficient in one season and excessive in another, so that a period of drought is followed by one with runoff. The march of precipitation through the year almost never coincides with the changing demands for water.

Where precipitation is in excess of water need, the climate is humid. Where water need is in excess of precipitation, the climate is arid. Where precipitation and water need are equal or nearly equal, the climate is neither humid nor arid.

Determination of the type of climate

The procedure is on the basis of C.W. Thornthwaite's method of climate classification, except the calculation of potential evapotranspiration.

This method consists of:

1. Calculation of monthly, or daily values of potential evapotranspiration, according to the climatic data.

2. Evaluation of the monthly water balance table.
3. Calculation of moisture indices, according to water surplus, and water deficit obtained from water balance table, and total yearly potential evapotranspiration.

Potential evapotranspiration as a climatic factor

In a desert, the vegetations are sparse and they use little water because of shortage of water. They would use more water, and would be less sparse, if more water would be available. There is a distinction, then between the amount of water that actually transpires and evaporates and that which would transpire and evaporate if it was available.

When water supply increases, as in a desert irrigation project, evapotranspiration rises to a maximum that depends only on the climate. This we may call potential evapotranspiration as distinct from actual evapotranspiration.

This most important climatic factor is defined as the amount of water which will be lost from a surface completely covered with vegetation if there is sufficient water in the soil at all times.

Calculation of the potential evapotranspiration

For the selected stations potential evapotranspiration is calculated according to PENMAN's formula:

$$E_o = \frac{\Delta/\gamma \times H_o + E_a}{\Delta/\gamma + 1}$$

E_o = Energy used for evaporation from open water in $\text{cal.cm}^{-2}\text{day}^{-1}$

Δ = Slope of saturation vapor pressure versus temperature curve at the temperature of the air. mm Hg/C°

γ = The psychometric constant, or ratio of specific heat of air to the latent heat of water vaporization ($0.49 \text{ mm Hg/C}^{\circ}$)

H_o = The net radiation in $\text{cal cm}^{-2}\text{day}^{-1}$. It can be calculated from:

$$H_o = R(1-r)-RB$$

R = Total incoming radiation in $\text{cal cm}^{-2}\text{day}^{-1}$

r = Reflection coefficient, 0.05 for open water

RB = Total outgoing radiation in $\text{cal cm}^{-2}\text{day}^{-1}$. It can be calculated from:

$$RB = \sigma T^4 (0.56 - 0.09 \sqrt{ed}) (0.10 + 0.90 n/N)$$

σ = The Stefan Boltzmann constant, 1176×10^{-10} cal cm⁻² day⁻¹

T = The absolute temperature of the air in K^o.

ed = Saturated vapor pressure at the temperature of the air in mm Hg.

n/N = Ratio between actual and possible hours of sunshine

Ea = $0.35 (ed - ea) (1 + U2/100)$, is the drying power of the air in mm of water

ea = Vapor pressure of the air in mm Hg

U2 = Wind speed in miles per day at a height of 2 meter

PENMAN's equation gives estimates of open water evaporation. The potential evapotranspiration from a vegetation surface is somewhat different. The ratio between both varies with the properties of the crops.

In this paper evaporation from an open water surface is used for the potential evapotranspiration.

The potential evapotranspiration for BET-DAGAN, Israel, 32^oN, 34^o49'E, is calculated from daily weather data. For the other selected stations monthly data are used.

Evaluation of the monthly water balance table

When the potential evapotranspiration is compared with the precipitation and allowance is made for the storage of water in the soil and its subsequent use, periods of moisture deficiency and excess are clearly revealed and an understanding of relative humidity or aridity of a climate is obtained. In some places and times precipitation is always more than the evapotranspiration so that the soil remains full of water and a water surplus "S" occurs. In other places and times, precipitation is less than potential evapotranspiration: there is not enough moisture for vegetation to use and a moisture deficit "D" occurs.

Places with both wet and dry seasons normally show:

1. A period of full storage, when precipitation exceeds water need and a moisture surplus "S" accumulates.
2. A drying season when stored soil moisture and precipitation are used in evapotranspiration: storage is steadily reduced, actual evapotranspiration falls below the potential and a moisture deficiency "D" develops.
3. A moistening season when precipitation again exceeds water need and soil moisture is recharged.

The values of "S" and "D" are computed during the budgeting. The moisture holding capacity of a soil depends on the depth of the soil layer considered, and the type and structure of soil. It can be varied from just a few mm on a shallow sand to well over 400 mm on a deep well aerated silt-loam.

In this paper an average of 150 mm is assumed. Table 1 presents the water balance computation for BET DAGEN, Israel, for the year 1968.

When the precipitation is greater than the potential evapotranspiration the actual evapotranspiration equals the potential for at those times there is sufficient moisture in the soil so that evapotranspiration can proceed unhindered. When the precipitation is less than the potential evapotranspiration, the actual evapotranspiration equals the precipitation plus any moisture stored in the ground which is evaporated or transpired (the storage change). Moisture deficit and surplus follow simply from the book-keeping calculations, the former being the difference between potential and actual evapotranspiration while the latter is the excess precipitation which occurs when the moisture holding capacity of the soil layer under consideration is full of water.

The moisture surplus is the water which is available for run-off into streams, rivers and so on.

The moisture detention is the total of the moisture stored in the soil layers at different months. This value can rise considerably higher than the total water holding capacity of the soil for it includes also the gravitational water, the water above the field capacity of the soil and the moisture available for later surface or stream run-off.

The water balance computation and its relative graphs provide a good insight into the moisture relation of an area. For instance, at BET DAGAN, Israel, (Fig. 1), the potential evapotranspiration is small in winter but in early spring it rises rapidly reaching its highest value of the year of more than 200 mm/month in July. It falls rapidly during the autumn months. The precipitation is also not uniformly distributed throughout the year. From midspring till the end of summer there is no precipitation at all; this is the dry season. The rainiest months are December, with more than 200 mm, January, with more than 100 mm and November, with less than 100 mm rainfall. Nearly all the precipitation comes in winter, when evapotranspiration is small. It forms a water surplus and it runs away after recharging the soil moisture storage.

Water balance computation for BET DAGAN, Israel, 1968
 150 mm. depth of water stored in soil at field capacity.
 (All values in mm)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
PE	36.3	50.5	95.7	126.9	171.4	191.7	200.6	181.2	143.2	85.3	48.2	33.1	1364.1
P	112.8	39.4	24.8	44.8	0.4	0.0	0.0	0.0	0.5	40.3	73.2	229.0	565.2
Sto.ch.	0.0	-11.1	-70.9	-68.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	125.0	
Sto.	150.0	138.9	68.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	150.0	
Ac.E	36.3	50.0	95.7	112.8	0.4	0.0	0.0	0.0	0.5	40.3	48.2	33.1	
D	0.0	0.0	0.0	14.1	171.0	191.7	200.6	181.2	142.7	45.0	0.0	0.0	946.3
S	76.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	70.9	147.5
Runoff ⁺	56.0	28.0	14.0	7.0	3.5	1.7	0.9	0.4	0.2	0.1	0.0	35.5	
M.D.	206.0	166.0	82.0	7.0	3.5	1.7	0.9	0.4	0.2	0.1	0.0	185.5	

⁺ Assuming that 50% of the excess water in a month runs off or percolates and the other 50% is carried over to the following month.

- PE = potential Evaporation
- P = precipitation
- Sto.ch. = Storage change
- Sto. = Storage
- Ac.E = Actual Evaporation
- D = Moisture Deficiency
- S = Moisture Surplus
- M.D. = Moisture Detention in soil

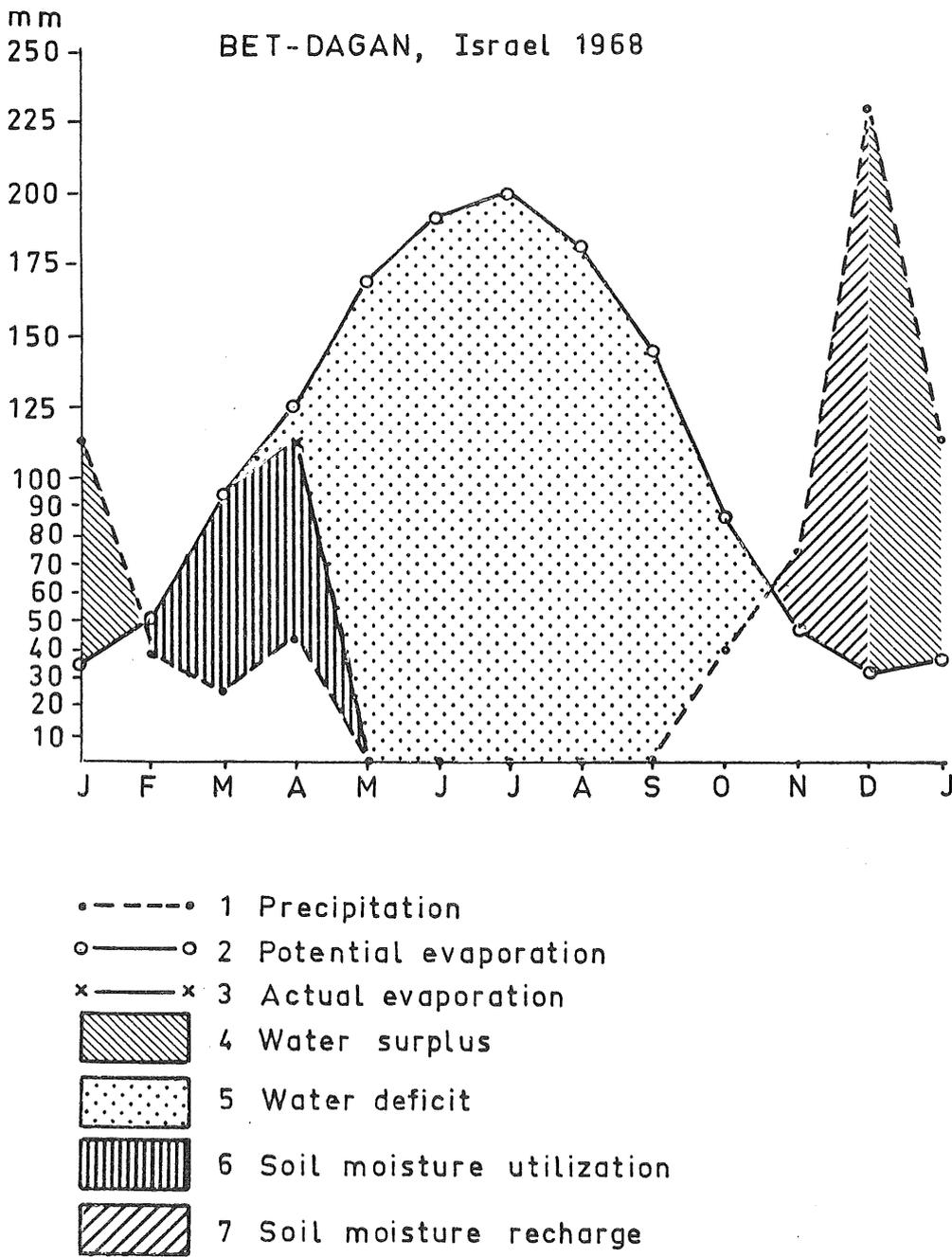


Figure 1

Application of the water balance for classification

A moisture index is obtained by comparing the water-need at a place with the moisture surplus and deficit. It is an essential part of the climate classification.

Where precipitation is exactly the same as potential evapotranspiration all the time and water is available just as needed, there is neither water deficiency nor water excess, and the climate is neither wet nor dry. When water deficiency becomes large with respect to potential evapotranspiration, the climate becomes arid; when the water surplus becomes larger the climate becomes humid. When there is a water surplus, the relation between water surplus and water-need constitutes an index of humidity. Similarly, when there is a water deficiency, the ratio between water deficiency and water need constitutes an index of aridity. Expressed as percentage these two indices are:

$$I_h = \frac{100 S}{PE} \quad \text{and} \quad I_a = \frac{100 D}{PE}$$

where I_h and I_a are indices of humidity and aridity, S is water surplus, D is water deficiency, and PE is water need, or potential evapotranspiration.

Since water surplus and water deficiency occur at different seasons in most places, both must enter into a moisture index: one affecting it positively and the other negatively.

Assuming that a surplus of 6 inches in one season counteracts a deficiency of 10 inches in another, the moisture index is:

$$I_m = \frac{100 S - 60 D}{PE} \quad (\text{Thornthwaite})$$

Moist climates have positive values of I_m , and dry climates have negative values.

The legend below specifies the different climate types with respect to the moisture index.

<u>CLIMATE TYPE</u>	<u>MOISTURE INDEX</u>
A Perhumid	100 and above
B4 Humid	80 to 100
B3 Humid	60 to 80
B2 Humid	40 to 60
B1 Humid	20 to 40
C2 Moist subhumid	0 to 20
C1 Dry subhumid	-20 to 0
D Semiarid	-40 to -20
E Arid	-60 to -40

The moisture index for BET DAGAN is:

$$I_m = \frac{(100 \times 147.5) - (60 \times 946.3)}{1364.1} = -30.7$$

so that climate is Semi arid (D).

Seasonal variation of effective moisture

The moisture index indicates how arid or how humid a climate is, but it can not distinguish climates with seasonal moisture variation from those without it.

It is important to know whether a place is continuously wet or continuously dry, or whether it is wet in one season and dry in another. If there is a dry season in a moist climate, it is necessary to know how dry it is; and the reverse in an arid climate. In moist climates the water deficiency may be large, moderate, little, or non-existent. In a dry climate the same is true for the water surplus.

These climate subdivisions are defined in terms of the humidity and aridity indices as follows:

<u>MOIST CLIMATES (A, B, C2)</u>	<u>ARIDITY INDEX</u>
r little or no water deficiency	0 - 16.7
s moderate summer water deficiency	16.7 - 33.3
w moderate winter water deficiency	16.7 - 33.3
s2 large summer water deficiency	> 33.3
w2 large winter water deficiency	> 33.3

<u>DRY CLIMATES (C1, D, E)</u>	<u>HUMIDITY INDEX</u>
d little or no water surplus	0 - 10
s moderate winter water surplus	10 - 20
w moderate summer water surplus	10 - 20
s2 large winter water surplus	> 20
w2 large summer water surplus	> 20

The symbols s, s2, w, w2, have the same meaning in both moist and dry climates in spite of the fact that they are defined differently. They refer to the season when rainfall is most deficit.

The humidity index for BET DAGAN is:

$$I_h = \frac{100 \times 147.5}{1364.1} = 10.8$$

and indicates, little water surplus (d).

Index of thermal efficiency

Potential evapotranspiration is also an index of thermal efficiency. It possesses the virtue of being an expression of day length as well as of temperature.

In equatorial regions, where mean monthly temperature does not vary appreciable through the year, a mean annual temperature of 23°C is a reasonable boundary between megathermal and mesothermal climates.

When the mean temperature of every month is 23°C for places on the equator, so that there is no variation in day length, the potential evapotranspiration is 114 centimeter according to Thornthwaite's original way of computation. This is taken as the index that separates megathermal and mesothermal climates. Other boundaries are as follows:

PE as THERMAL INDEX cm	CLIMATE TYPE
14.2-----	E ⁻ Frost
28.5-----	D ⁻ Tundra
42.7-----	C ⁻¹ Microthermal
57.0-----	C ⁻²
71.2-----	B ⁻¹
85.5-----	B ⁻²
99.7-----	B ⁻³ Mesothermal
114.0-----	B ⁻⁴
	A ⁻

The various subdivisions of mesothermal, microthermal and humid climatic types do not have individual names but can be referred to only by symbols. Thus it can be said first, second, third, or fourth mesothermal.

The thermal climate of BET DAGAN, with PE = 136.4 cm, is megathermal (A⁻).

Summer concentration of thermal efficiency

At the equator, where day length is the same throughout the year and temperature is also uniform, there is hardly a seasonal variation in potential evapotranspiration. With no variation no season can be called summer, and potential evapotranspiration of any consecutive three months

will constitute 25 % of the total annual. On the other hand, in the polar regions, where the growing season is entirely within the three summer months the potential evapotranspiration of these months will constitute 100 % of the total. Between these extremes, as potential evapotranspiration falls from the characteristic of megathermal (A⁻) climate to that of frost (E⁻) climate, the part that is concentrated in summer gradually rises from 25 % to 100 %.

The total summer potential evapotranspiration is taken to indicate the summer concentration of thermal efficiency. This value is calculated as the percentage of the summer amount of potential evapotranspiration with respect to annual total.

It can be also obtained from

$$S = 157.76 - 66.44 \log E \text{ (Thornthwaite)}$$

where S is summer concentration in %, and E is potential evapotranspiration in inches.

The legend below indicates the summer concentration types.

SUMMER CONCENTRATION in %	SUMMER CONCENTRATION Type
48.0 -----	a ⁻
51.9 -----	b ⁻ 4
56.3 -----	b ⁻ 3
61.6 -----	b ⁻ 2
68.0 -----	b ⁻ 1
76.3 -----	c ⁻ 2
88.0 -----	c ⁻ 1
	d ⁻

The summer concentration index for BET DAGAN is 41, which classified it a⁻.

Elements of the classification

Four symbols used together give a complete description of a climate. BET DAGAN, (Da da⁻), is semiarid, megathermal, with little winter water surplus, and a summer temperature efficiency regime normal to megathermal. Table 2 presents the necessary elements and the climates of some selected places around the Sahara.

Comparative yearly moisture date of selected stations

	ST.	LAT.	LONG.	Water need mm	Summer* need mm	Precipi- tation mm	Water surplus mm	Water deficit mm	Humidity ind.	Aridity ind.	Moisture ind.	Climate type
Nigeria	1	13,00 N	07,30 E	1744.4	27.1	910.9	77.1	910.6	4.4	52.2	-26.9	DdA ^a a ^a
	2	11,00 N	07,30 E	1534.2	23.1	1430.5	468.5	572.2	30.5	37.3	8.2	C2w2A ^a a ^a
	3	07,00 N	07,00 E	1742.6	22.1	1704.4	349.6	387.9	20.1	22.3	6.7	C2w2A ^a a ^a
	4	05,00 N	06,45 E	1490.5	21.0	2421.9	1064.2	132.8	71.4	8.9	66.1	B3w2A ^a a ^a
Ethiopia	1	18,00 N	38,30 E	1739.3	31.8	124.9	0.0	1614.4	0.0	92.8	-55.7	EdA ^a a ^a
	2	14,00 N	38,30 E	1476.1	25.6	1302.1	383.0	557.1	25.9	37.3	3.3	C2w2A ^a a ^a
	3	09,00 N	38,00 E	1380.1	22.8	1109.5	212.9	483.6	15.4	35.0	-5.6	C1wA ^a a ^a
	4	04,00 N	38,00 E	1917.3	23.5	239.5	0.0	1677.8	0.0	87.5	-52.5	EdA ^a a ^a
Tunisia	1	37,00 N	10,00 E	1241.7	47.2	572.0	0.0	669.7	0.0	53.9	-32.4	DdA ^a a ^a
	2	34,00 N	10,30 E	1383.3	44.6	185.1	0.0	1198.2	0.0	86.6	-52.0	EdA ^a a ^a
	3	31,30 N	10,00 E	1412.8	43.6	146.0	0.0	1266.8	0.0	89.7	-53.8	EdA ^a a ^a
Morocco	1	36,00 N	01,00 W	1222.6	44.6	409.0	0.0	813.6	0.0	66.5	-39.9	DdA ^a a ^a
	2	34,00 N	05,00 W	1228.2	43.3	540.6	0.0	687.6	0.0	56.0	-33.6	DdA ^a a ^a
	3	31,30 N	08,00 W	1298.9	40.1	222.2	0.0	1066.8	0.0	82.1	-49.3	EdA ^a a ^a
Senegal	1	16,30 N	15,00 W	1847.3	30.3	364.9	0.0	1482.4	0.0	80.2	-48.1	EdA ^a a ^a
	2	15,00 N	15,00 W	1801.3	28.2	557.7	0.0	1243.6	0.0	69.0	-41.4	EdA ^a a ^a
	3	13,00 N	15,00 W	1741.9	25.0	1395.7	502.7	848.9	28.9	48.7	-0.4	C1w2A ^a a ^a

* June, July, August

Temperature and precipitation data used for these stations are mean monthly values of ten years available observed data.

Wind speed, due to the absence of observed data for the stations, is considered as 80 km day^{-1} , which is a mean of ten years monthly available observed values in BET DAGAN, Israel.

Figure 2 gives the water balance diagrams for each station. Locations of the selected stations are given in plate 1.

References

Thornthwaite, C.W., 1948: An approach toward a rational classification of climate.

Thornthwaite, C.W., 1955: The water balance.

Thompson, B.W., 1965: Climate of Africa.

U.S. Department of Commerce, 1967: World weather records, 1951-60.

Volume 5.

Smithsonian Physical tables, 1956: Prepared by William Elmer Forsythe.

IBM System/360 Continuous System Modeling Program (360A-CX-16X).

User's Manual.

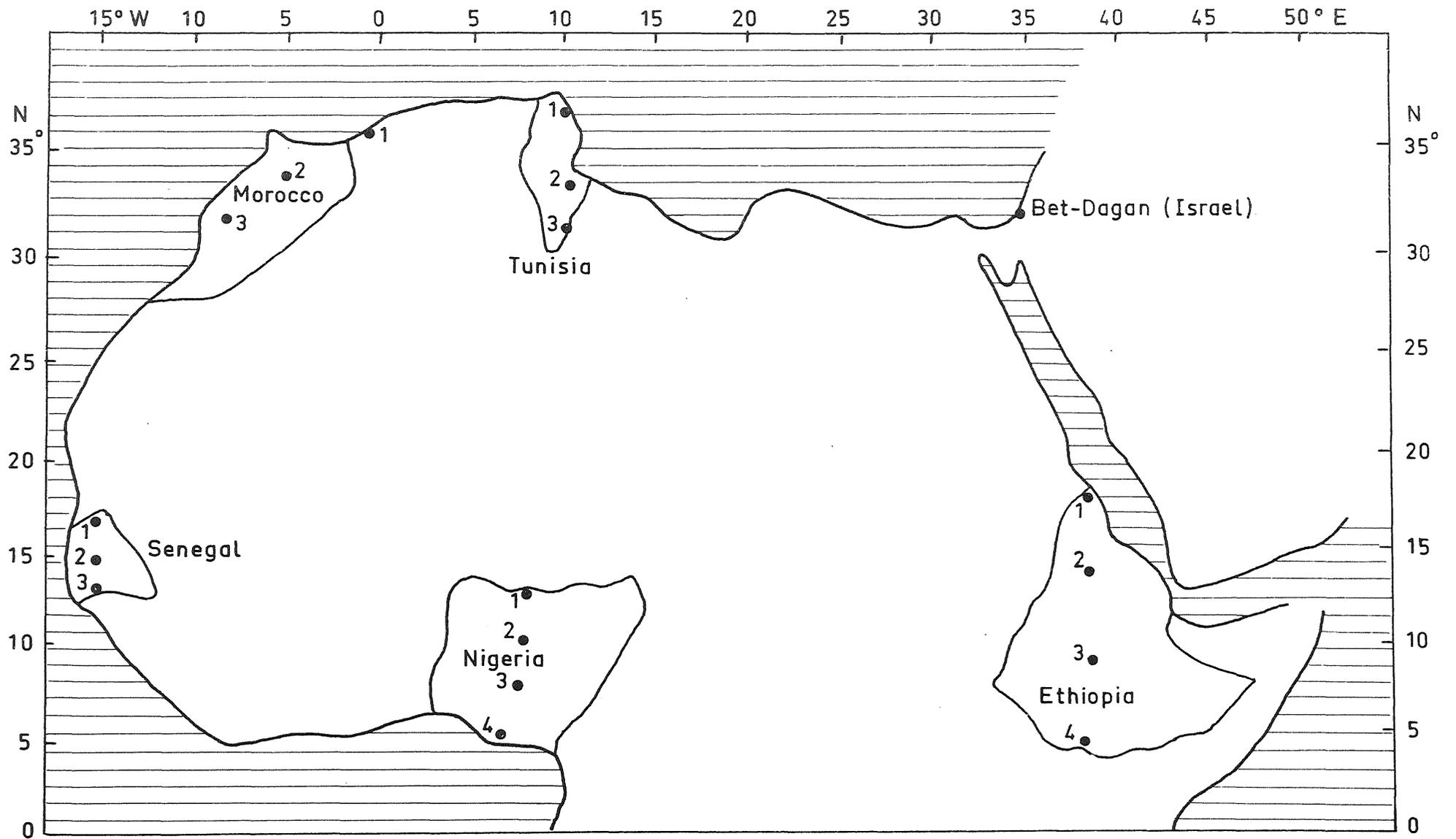


Plate 1. Location of the selected stations.

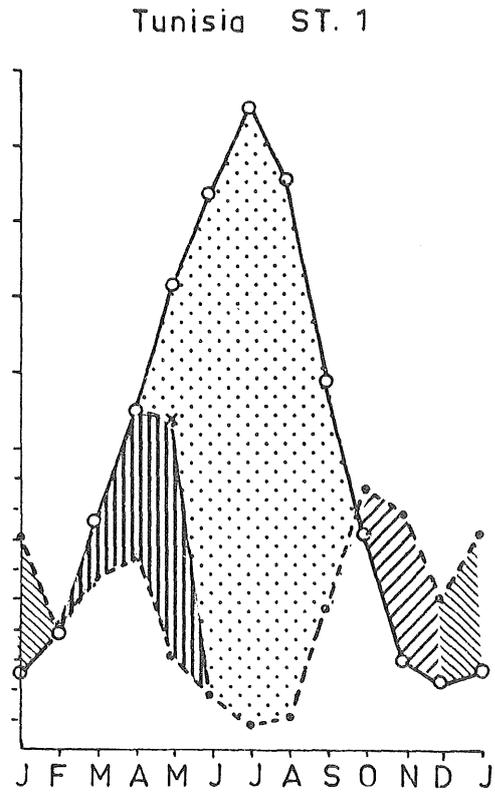
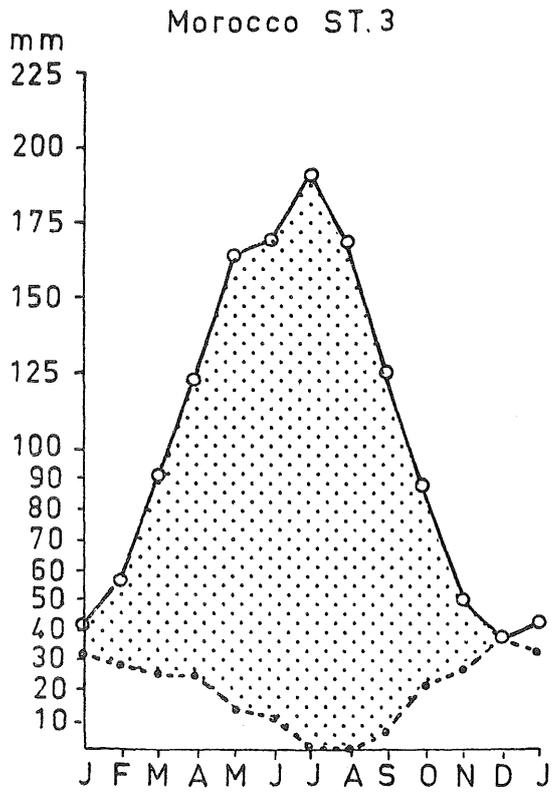
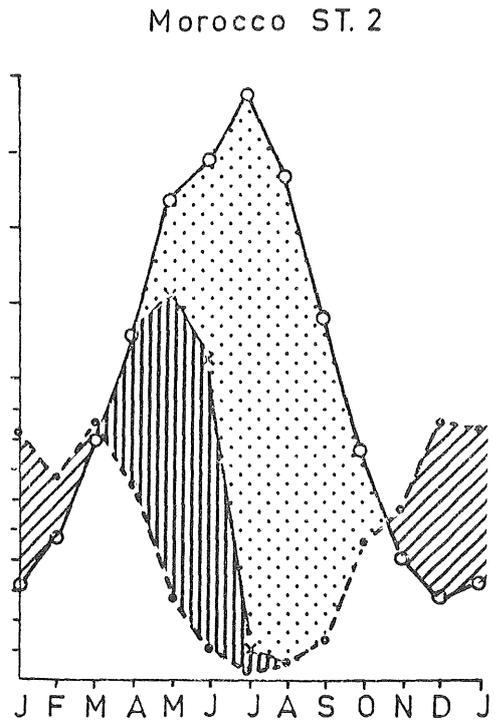
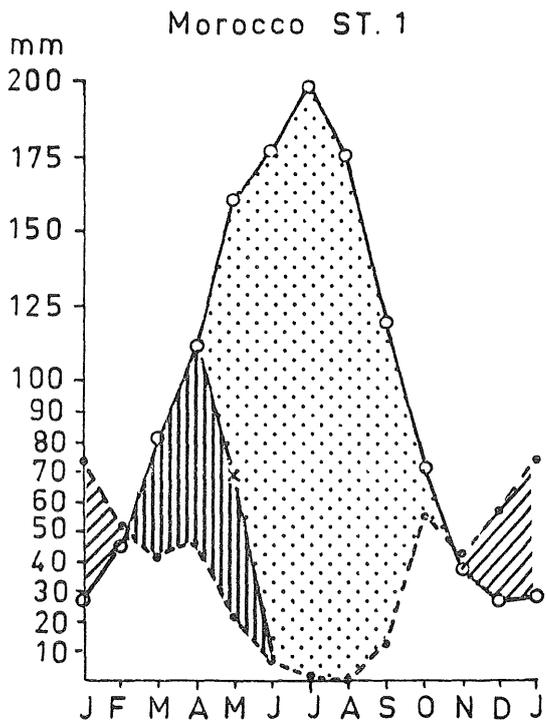


FIG. 2

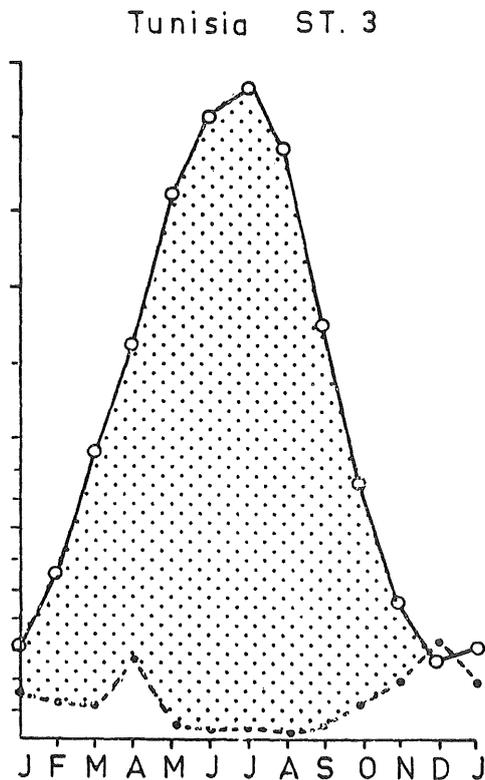
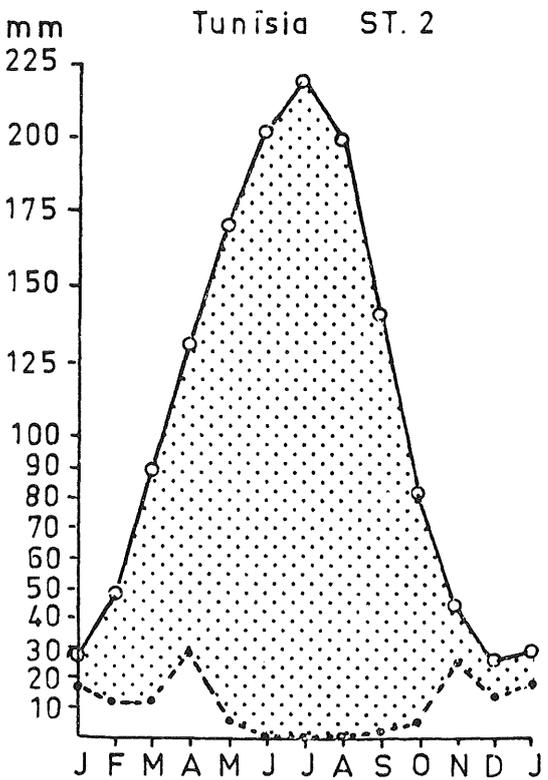
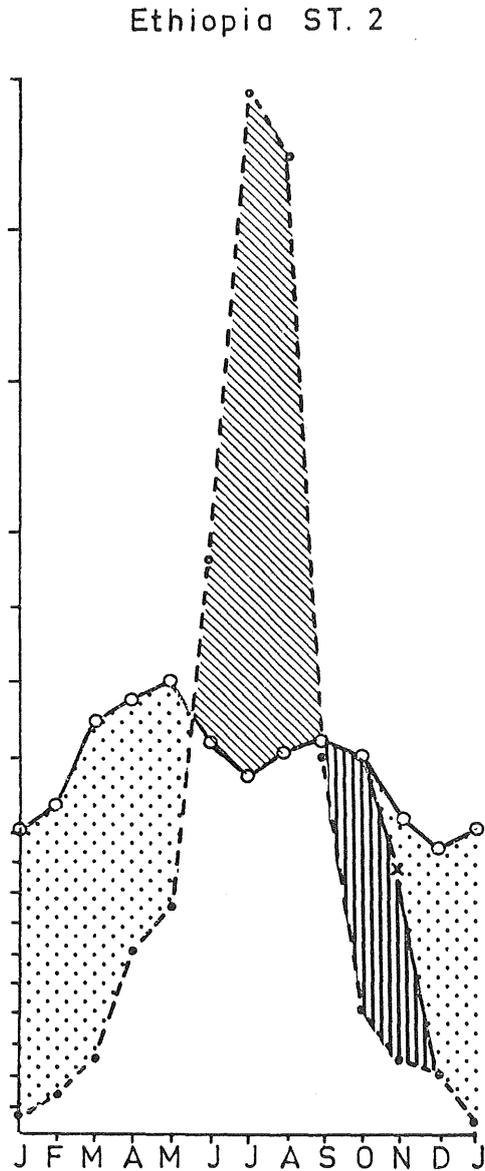
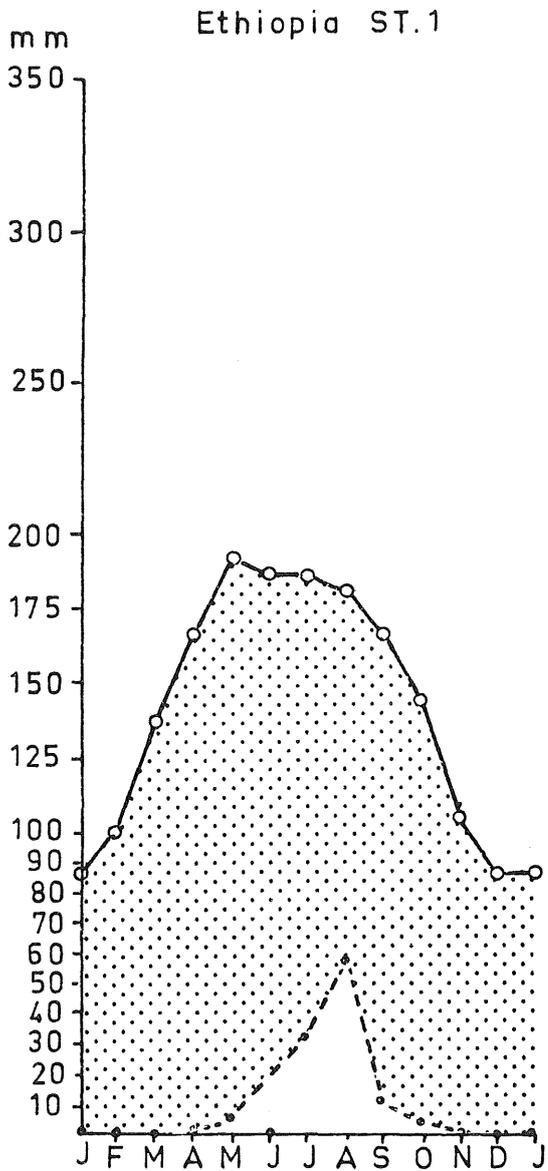


FIG.2 cont.

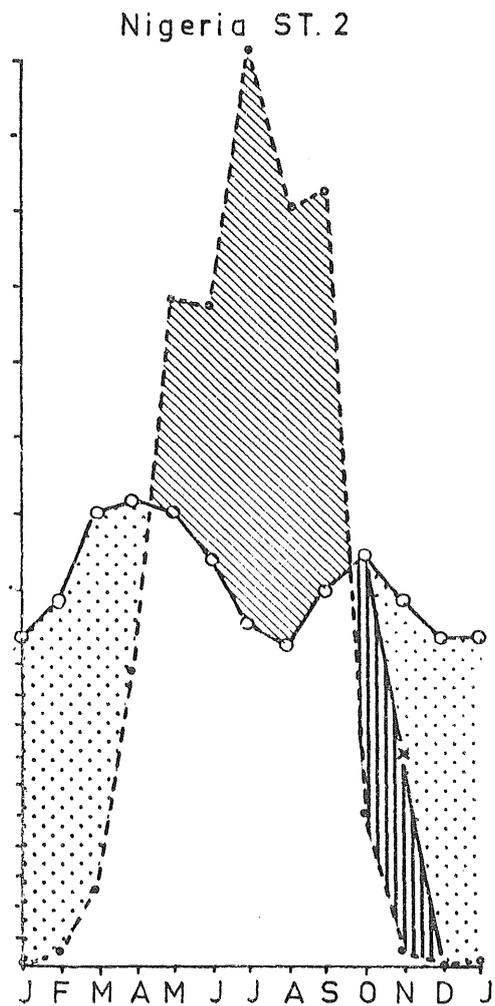
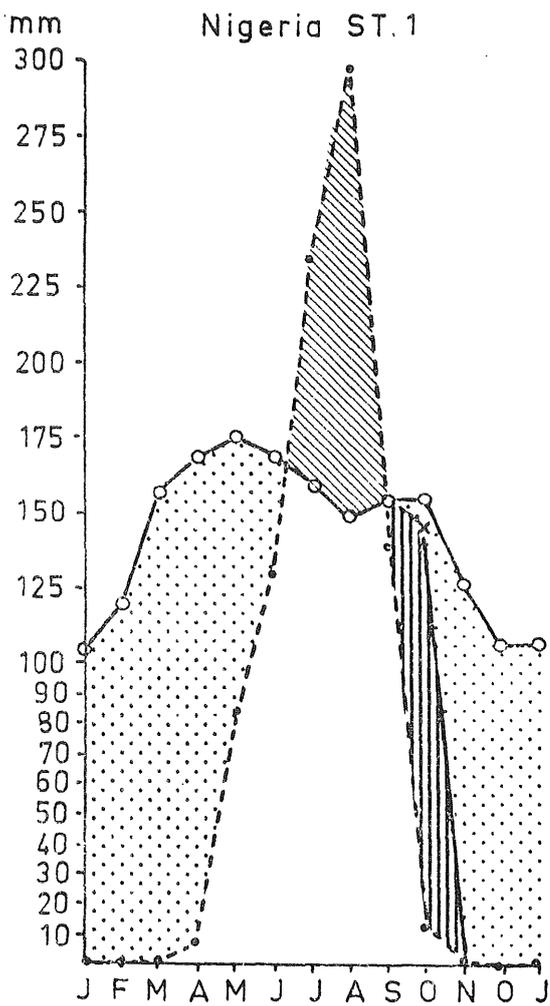
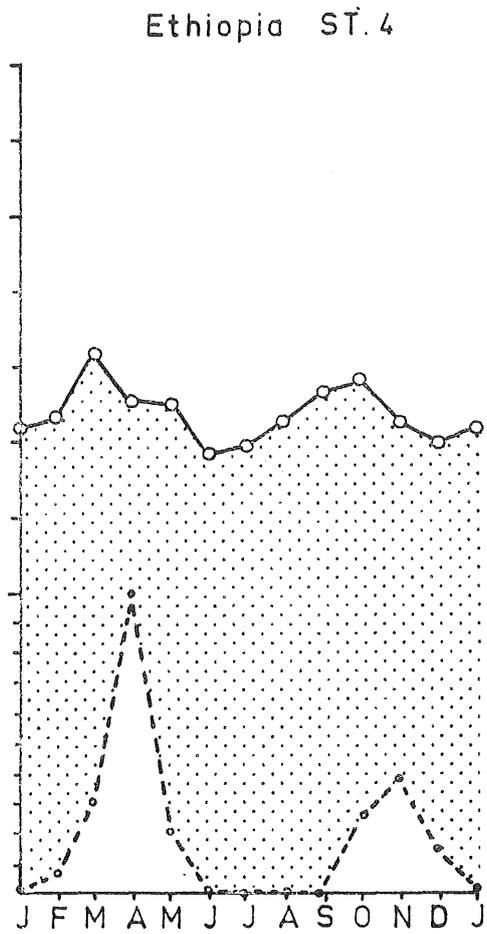
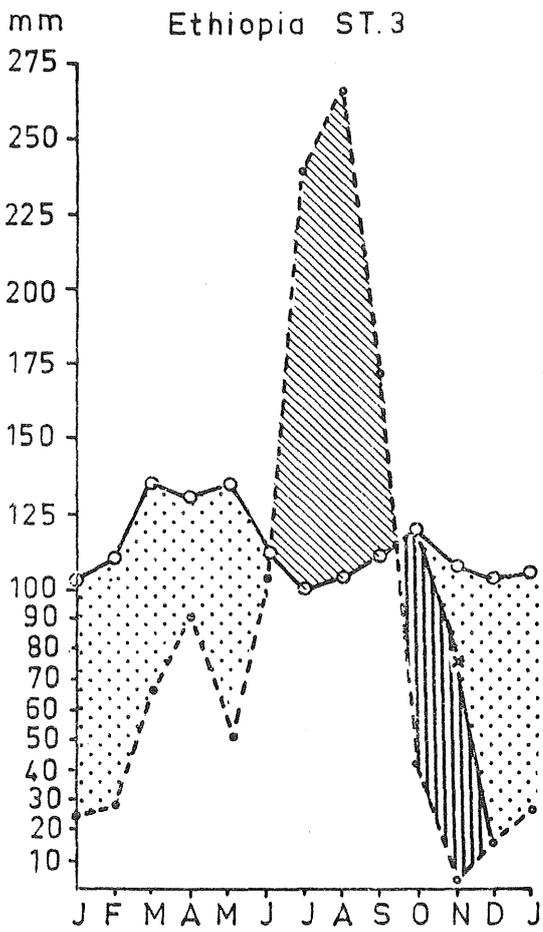


FIG. 2 cont.

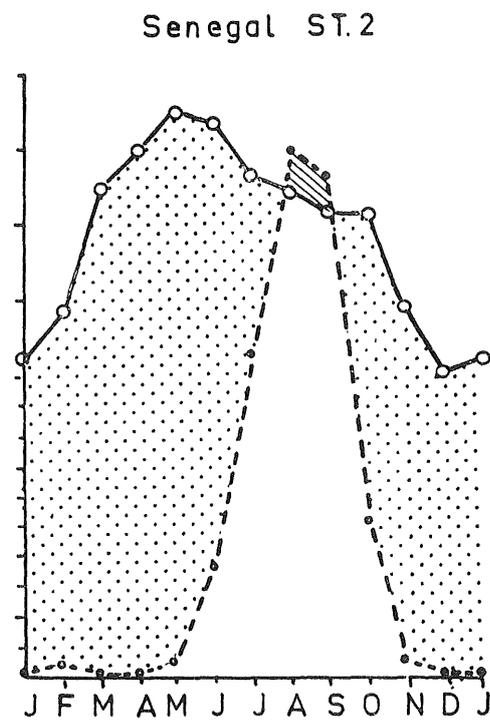
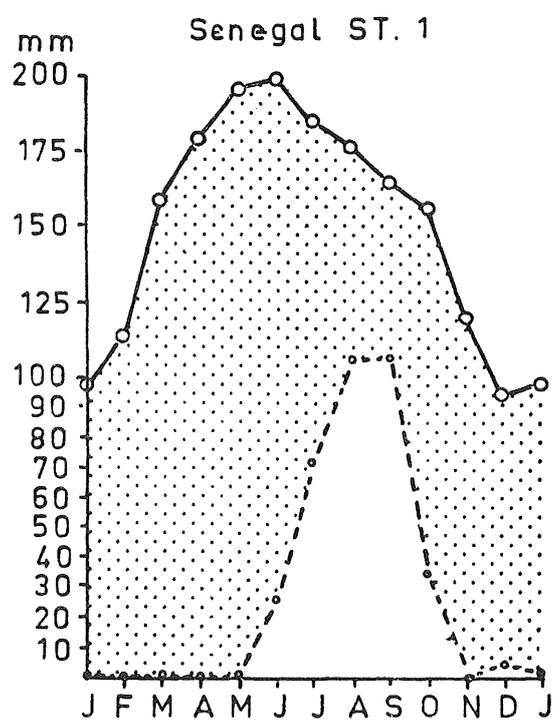
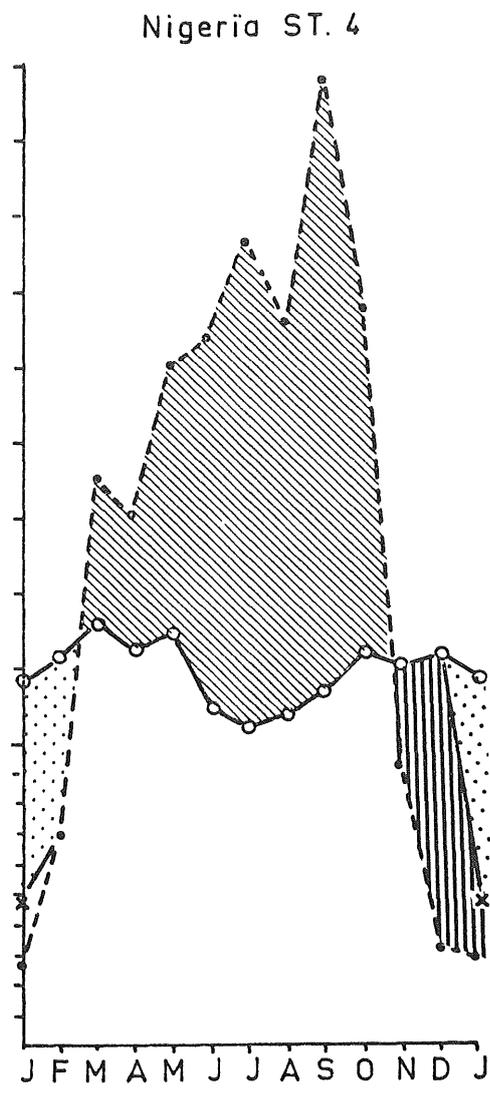
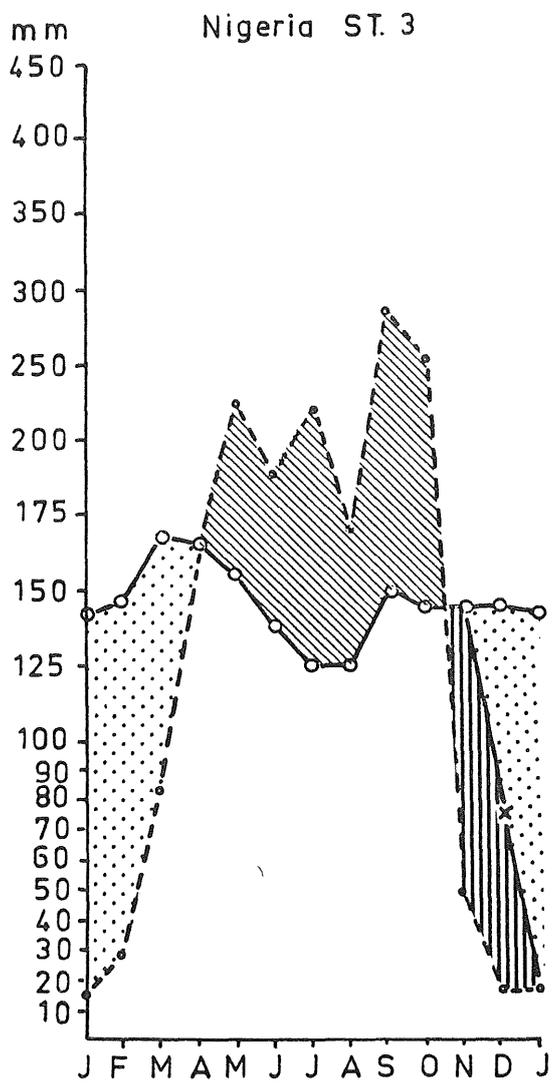


FIG. 2 cont.

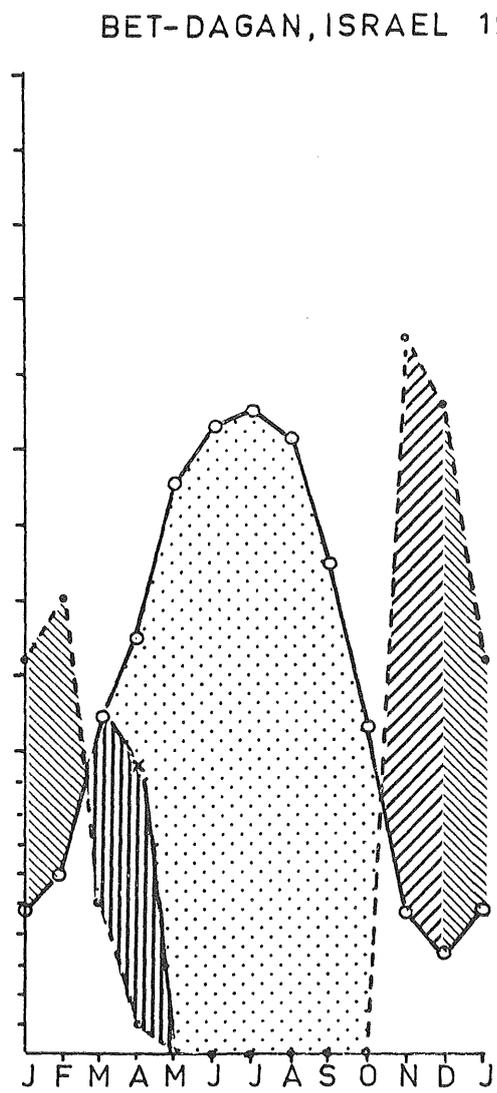
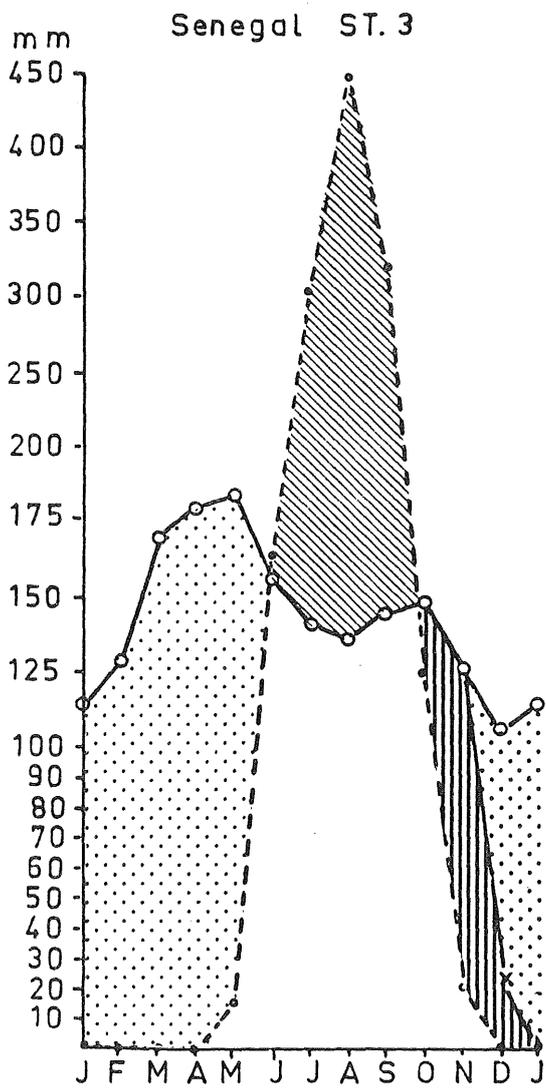


FIG. 2 cont.

Appendix

Programming

A program for computation of the factors of climate classification is given at the end of this paper. The computer program is written in CSMP (Continuous System Modeling Program), which improves readability to a large extent by providing a large number of subroutines. This program has nearly the same order and the same organisation as an ordinary written explanation.

Description of the program

The program consists of the following parts:

1. An initial part which consists here out of the storage and input data.
2. A dynamic part that computes monthly and yearly actual, and potential evaporation storage in the soil, changes in storage, water surplus, and water deficiency.
3. A terminal part that computes the moisture indices.

The lines in the listing beginning with an asterisk are not executed by the computer, but indicate comments. Three points following each other at the end of any line in the listing indicate that the expression is continued on the next line.

The CSMP symbolic names of functions used in this program are described below:

<u>Symbol</u>	<u>Function</u>	<u>Symbol</u>	<u>Function</u>
+	addition	**	exponentiation
-	subtraction	=	replacement
*	multiplication	/	division
ALOG	natural logarithm		
ALOG10	common logarithm		
ATAN	arctangent		
SIN	trigonometric sine		
COS	trigonometric cosine		
SQRT	square root		
EXP	exponential		

PARAMETER indicates the value of constants.

INTGRL is the integral function of CSMP. It performs the correct integration of the rate presented by the second variable between parenthesis, the value of the first name or number represents the level of the integral at the beginning of the program. For instance:

STOR = INTGRL (150., STCHGE)

Evidently the initial value of this integral is 150.

AMAXI indicates that the maximum value of given arguments between parenthesis, is to be taken as output. For instance:

WTSURP = AMAXI (0.,PREC-ACTEV -(MSTOR-STOR)/DELT)

If STORAGE is less than Maximum STORAGE, the difference between PRECipitation and ACTual EVapotranspiration first starts to recharge the STORAGE up to its maximum value. Therefore, the WaTer SURPlus is the difference between PRECi-pitation and ACTual EVapotranspiration minus the difference between Maximum STORAGE and STORAGE.

If this value is negative, there is no water surplus, the maximum value in parenthesis is then 0 and will be considered as output.

When the PRECipitation is smaller than ACTual EVapotranspiration, clearly there is no water surplus and again the maximum value in parenthesis is 0.

AMINI is a functional statement, which takes as output the smallest of the arguments given in parenthesis. For instance:

ACTEV = AMINI (PREC+STOR,EVAP)

means when PRECipitation plus STORAGE is larger than EVAPotranspiration, ACTual EVapotranspiration equals potential EVAPotranspiration. When PRECi-pitation plus STORAGE is smaller than potential EVAPotranspiration, this sum will be the ACTual EVapotranspiration.

STEP is a function of time only.

Y = STEP(P)

This means Y is 0 before time is P, and is 1 from time P on.

LIMIT is a limiting function.

STOR = LIMIT (0., MSTOR, COMPST)

This sets STORAGE equal to 0 or Maximum STORAGE when the COMPuted Storage is smaller than 0 or larger than the Maximum STORAGE, respectively.

ZHOLD is a memory function to store the second variable in parenthesis at a certain time.

Y = ZHOLD(S,X)

As long as S is equal or smaller than 0, Y keeps the same value. When S becomes a positive, Y equals X.

Output and run control

As soil STORAGE in the first month of a year depends on the storage of the last month of the previous year the Maximum STORAGE is not necessarily the initial value of the STORAGE.

To obtain this value the program is run for two years, whereby only the values of the second year are considered. During this time the values of variables must be printed.

Therefore, besides statements defining the structure of the program, run control statements must be given also.

The PRINT instruction states the variables to be printed in a standard format as can be seen in the output.

The PRTPLOT instruction generates plots of the variable against time.

The instruction on the line labeled with TIMER indicates the duration of calculation (FINTIM, months) and the time intervals between printing (PRDEL) and plotting (OUTDEL) and calculating (DELT).

METHOD RECT calls the subroutine for rectangular integration.

The END indicates completion of the calculation for that run of the program.

One or more new parameters or function definitions between two END lines generate a rerun using the same program except for the newly defined variables.

The last run of the program is characterized by STOP after END.

****CONTINUOUS SYSTEM MODELING PROGRAM****

PROBLEM INPUT STATEMENTS

TITLE PROGRAMME TO CALCULATE CHARACTERISTICS FOR CLIMATE CLASSIFICATION.
 TITLE CALCULATION FOR MORACCO STATION 1
 INITIAL
 STORAGE T(12),VP(12),H(12),PR(12),D(12)
 TABLE T(1-12)=10.7,11.6,14.3,15.4,19.,22.1,24.9,25.6,23.3,18.9,15.,12.1
 TABLE PR(1-12)=73.,51.3,41.9,46.8,20.2,9.7,1.5,0.7,12.4,55.1,41.5,54.9
 TABLE H(1-12)=5.,5.5,7.,7.,9.,9.,10.,9.2,7.,6.,5.4,4.
 TABLE VP(1-12)=5.8,6.,7.6,7.8,9.3,9.6,11.1,10.8,9.6,9.4,8.6,6.5
 TABLE D(1-12)=31.,29.,31.,30.,31.,30.,31.,31.,30.,31.,30.,31.
 * TEMPERATURE, PRECIPITATION, HOURS OF SUN SHINE, VAPOR PRESSURE, AND-
 * NUMBER OF DAYS FOR EACH MONTH OF THE YEAR.
 GAMMA=0.49
 * PSYCHROMETRIC CONSTANT
 PARAMETER WS = 80.
 * WIND SPEED IN KM./DAY
 WSP = WS/1.6
 * WIND SPEED IN MILES/DAY
 PARAMETER LAT = 36
 * LATITUDE OF THE STATION
 SINL=SIN(6.2832*LAT/360.)
 COSL=COS(6.2832*LAT/360.)
 * SINE AND COSINE OF THE LATITUDE
 DYNAMIC
 NOSORT
 FIXED I
 I=AMOD(TIME,12.)+1.01
 * INDEX OF TIME
 DMONTH = I
 * THE MONTH AS TIME
 PREC = PR(I)
 TMPA = T(I)
 HRB = H(I)
 VPA = VP(I)
 ND= D(I)
 * PRECIPITATION, TEMPERATURE, HOURS OF SUN SHINE, VAPOR PRESSURE, AND-
 * THE NUMBER OF DAYS, ACCORDING TO THE INPUT TABLES AT TIME INDEX
 SORT
 RB = 1.178E-7*(TMPA+273.)**4*(0.58-0.09*SQRT(VPA))*(0.10+0.9*HRB/MHRB)
 * OUTGOING RADIATION
 MHRB=12.+24./3.1416*ATAN(SINB*SINL/SQRT(COSB*COSB-SINL*SINL))
 * MAXIMUM BRIGHT HOURS OF SUN SHINE
 HZERO = RAD*(1.-REFCF)-RB
 * NET RADIATION
 RAD=QA*(0.28+0.04*HRB)
 * INCOMING RADIATION
 QA=880./920.*120.*(1.-0.05 *DEC /23.4)*(MHRB*SINL*SINB+24./6.2832*2.* ...
 SQRT(COSL*COSL*COSB*COSB-SINL*SINL*SINB*SINB))
 * INCOMING RADIATION OUT OF THE ATMOSPHERE
 PARAMETER REFCF=0.05
 * REFLECTION FACTOR FOR OPEN WATER
 CA = 0.35*(SVPA-VPA)*(0.5+WSP/100.)*LHVAP
 * DRYING POWER OF THE AIR IN CAL./CM**2
 PARAMETER LHVAP = 59.
 * LATENT HEAT OF WATER VAPORIZATION
 SVPA=4.58*EXP(17.4*TMPA/(TMPA+239))
 * SATURATION VAPOR PRESSURE OF THE AIR

```

DELTA=17.4*SVPA*(1.-TMPA/(TMPA+239))/(TMPA+239)
* SLOPE OF THE SATURATION VAPOR PRESSURE VERSUS TEMPERATURE OF THE AIR
EVAP = (H7EP0*DELTA/GAMMA+EA)/(1.+DELTA/GAMMA)*ND/LHVAP
* MONTHLY POTENTIAL EVAPORATION IN MM.
DEF=-23.4*COS(6.2832/12.*(TIME+0.82))
* DECLINATION OF THE SUN IS CALCULATED IN THE MIDDLE OF EACH MONTH
COSB=COS(6.2832*DEC/360.)
SINB=SIN(6.2832*DEC/360.)
* SINE AND COSINE OF THE DECLINATION
STOR=INTGRL(150.,STCHGE)
* STORAGE IN THE SOIL
STCHGE=PREC-ACTEV-WTSURP
* CHANGES IN SOIL STORAGE
PARAMETER MSTOR = 150.
* MAXIMUM STORAGE
YPEVAP=INTGRL(0.,EVAP-YPEVAP*ENDY/DELTA)
YACTEV=INTGRL(0.,ACTEV-YACTEV*ENDY/DELTA)
YWSURP=INTGRL(0.,WTSURP-YWSURP*ENDY/DELTA)
YWTDEF=INTGRL(0.,MWTDEF-YWTDEF*ENDY/DELTA)
* YEARLY POTENTIAL, AND ACTUAL EVAPORATION, WATER SURPLUS, AND WATER-
* DEFICIT.
ENDY=IMPULS(12.,FINTIM)
* END OF THE YEAR
WTSURP=AMAX1(0.,PREC-ACTEV-(MSTOR-STOR)/DELTA)
MWTDEF=EVAP-ACTEV
* MONTHLY WATER SURPLUS AND DEFICIT
ACTEV=AMIN1(PREC+STOR/DELTA,EVAP)
* MONTHLY ACTUAL EVAPORATION
PEVAP3=ZHOLD(0.5-ENDW,YPEVAP)
PEVAP9=ZHOLD(0.5-ENDS,YPEVAP)
WTDEF3=ZHOLD(0.5-ENDW,YWTDEF)
WTDEF9=ZHOLD(0.5-ENDS,YWTDEF)
WSURP3=ZHOLD(0.5-ENDW,YWSURP)
WSURP9=ZHOLD(0.5-ENDS,YWSURP)
* POTENTIAL EVAPORATION, WATER SURPLUS, AND WATER DEFICIT FOR-
* 3 AND 9 MONTHS
ENDW=STEP(D3M)
ENDS=STEP(D9M)
* END OF SUMMER AND WINTER
PARAMETER D3M=15.5 ,D9M=21.5
* D3M IS END OF WINTER IN MONTH,D9M IS END OF SUMMER
TIMER FINTIM= 24.,DELTA=1.,PRDEL= 1.,OUTDEL =1.
METHOD RECT
PRTPLT PREC,EVAP,ACTEV,TMPA
PRINT DMONTH,QA, YPEVAP,YWTDEF,YWSURP,YACTEV,MWTDEF,WTSURP,STOR
TERMINAL
ARIND=100.*YWTDEF/YPEVAP
HUMIND=100.*YWSURP/YPEVAP
MSTIND=HUMIND-C.6*ARIND
* ARIDITY, HUMIDITY, AND MOISTURE INDICES
WRITE (6,850) ARIND,HUMIND,MSTIND
850 FORMAT(1H ,6HARIND F6.1,10H HUMIND F6.1,10H MSTIND F5.1/)
S=157.76-66.44*ALOG10(YPEVAP/25.4)
* SUMMER CONCENTRATION OF THERMAL EFFICIENCY
WRITE(6,925)S
925 FORMAT(1H ,26HSUMMER CONCENTRATION IS F10.2//)
SPEVAP=PEVAP9-PEVAP3
WPEVAP=YPEVAP-SPEVAP
SWTDEF=WTDEF9-WTDEF3
WWTDEF=YWTDEF-SWTDEF
SWSURP=WSURP9-WSURP3
WWSURP=YWSURP-SWSURP

```

```
* POTENTIAL EVAPORATION, WATER DEFICIT, AND WATER SURPLUS IN SUMMER -  
* AND WINTER  
  WRITE(6,800)  
 800 FORMAT(1H ,51HSPEVAP   WPEVAP   SWTDEF   WWTDEF   SWSURP   WWSURP/  
  )  
WRITE(6,801) SPEVAP,WPEVAP,SWTDEF,WWTDEF,SWSURP,WWSURP  
 801 FORMAT(1H ,6F9.2//)  
WRITE (6,802) YPEVAP,YWTDEF,YWSURP,YACTEV,STOR  
802 FORMAT(1H ,40HYPEVAP   YWTDEF   YWSURP   YACTEV   STOR/,5F9.2//)  
END  
* INPUT DATA FOR SECOND STATION  
END  
* INPUT DATA FOR ..... STATION  
END  
STOP
```


PROGRAMME TO CALCULATE CHARACTERISTICS FOR CLIMATE CLASSIFICATION.
CALCULATION FOR MORACCO STATION J

RECT INTEGRATION

TIME = 1.4000E 01	DMONTH= 3.0000E 00 YWSJRP= 0.0 STOR = 8.5493E 01	QA = 6.8124E 02 YACTEV= 7.2405E 01	YPEVAP= 7.2405E 01 MWTDEF= 0.0	YWTDEF= 0.0 WTSURP= 0.0
TIME = 1.5000E 01	DMONTH= 4.0000E 00 YWSJRP= 0.0 STOR = 4.5393E 01	QA = 8.2409E 02 YACTEV= 1.5440E 02	YPEVAP= 1.5440E 02 MWTDEF= 1.8888E 01	YWTDEF= 0.0 WTSURP= 0.0
TIME = 1.6000E 01	DMONTH= 5.0000E 00 YWSJRP= 0.0 STOR = 0.0	QA = 9.1732E 02 YACTEV= 2.4660E 02	YPEVAP= 2.6540E 02 MWTDEF= 1.4011E 02	YWTDEF= 1.8888E 01 WTSURP= 0.0
TIME = 1.7000E 01	DMONTH= 6.0000E 00 YWSJRP= 0.0 STOR = 0.0	QA = 9.5394E 02 YACTEV= 2.6680E 02	YPEVAP= 4.2580E 02 MWTDEF= 1.6736E 02	YWTDEF= 1.5900E 02 WTSURP= 0.0
TIME = 1.8000E 01	DMONTH= 7.0000E 00 YWSJRP= 0.0 STOR = 0.0	QA = 9.3685E 02 YACTEV= 2.7650E 02	YPEVAP= 5.0285E 02 MWTDEF= 1.9522E 02	YWTDEF= 3.2635E 02 WTSURP= 0.0
TIME = 1.9000E 01	DMONTH= 8.0000E 00 YWSJRP= 0.0 STOR = 0.0	QA = 8.6423E 02 YACTEV= 2.7800E 02	YPEVAP= 7.9957E 02 MWTDEF= 1.7095E 02	YWTDEF= 5.2158E 02 WTSURP= 0.0
TIME = 2.0000E 01	DMONTH= 9.0000E 00 YWSJRP= 0.0 STOR = 0.0	QA = 7.3678E 02 YACTEV= 2.7870E 02	YPEVAP= 9.7123E 02 MWTDEF= 1.0433E 02	YWTDEF= 6.9253E 02 WTSURP= 0.0
TIME = 2.1000E 01	DMONTH= 1.0000E 01 YWSJRP= 0.0 STOR = 0.0	QA = 5.7945E 02 YACTEV= 2.9110E 02	YPEVAP= 1.0880E 02 MWTDEF= 1.6755E 01	YWTDEF= 7.9585E 02 WTSURP= 0.0
TIME = 2.2000E 01	DMONTH= 1.1000E 01 YWSJRP= 0.0 STOR = 0.0	QA = 4.4455E 02 YACTEV= 3.4620E 02	YPEVAP= 1.1598E 02 MWTDEF= 0.0	YWTDEF= 8.1361E 02 WTSURP= 0.0
TIME = 2.3000E 01	DMONTH= 1.2000E 01 YWSJRP= 0.0 STOR = 5.8998E 00	QA = 3.8163E 02 YACTEV= 3.8180E 02	YPEVAP= 1.1954E 02 MWTDEF= 0.0	YWTDEF= 8.1361E 02 WTSURP= 0.0
TIME = 2.4000E 01	DMONTH= 1.0000E 00 YWSJRP= 0.0 STOR = 3.3598E 01	QA = 4.1182E 02 YACTEV= 4.0900E 02	YPEVAP= 1.2226E 02 MWTDEF= 0.0	YWTDEF= 8.1361E 02 WTSURP= 0.0

An example of the standard CSMP PRINT output.

PROGRAMME TO CALCULATE CHARACTERISTICS FOR CLIMATE CLASSIFICATION.
 CALCULATION FOR MORACCO STATION 1

RECT INTEGRATION

TIME = 0.0	DMONTH= 1.0000E 00 YWSJRP= 0.0 STOR = 1.5000E 02	QA = 4.1182E 02 YACTEV= 0.0	YPEVAP= 0.0 MWTDEF= 0.0	YWTDEF= 0.0 WTSURP= 4.5115E 01
TIME = 1.0000E 00	DMONTH= 2.0000E 00 YWSJRP= 4.5116E 01 STOR = 1.5000E 02	QA = 5.2528E 02 YACTEV= 2.7884E 01	YPEVAP= 2.7884E 01 MWTDEF= 0.0	YWTDEF= 0.0 WTSURP= 6.7799E 00
TIME = 2.0000E 00	DMONTH= 3.0000E 00 YWSJRP= 5.1896E 01 STOR = 1.5000E 02	QA = 6.8124E 02 YACTEV= 7.2404E 01	YPEVAP= 7.2404E 01 MWTDEF= 0.0	YWTDEF= 0.0 WTSURP= 0.0
TIME = 3.0000E 00	DMONTH= 4.0000E 00 YWSJRP= 5.1896E 01 STOR = 1.0990E 02	QA = 8.2409E 02 YACTEV= 1.5440E 02	YPEVAP= 1.5440E 02 MWTDEF= 0.0	YWTDEF= 0.0 WTSURP= 0.0
TIME = 4.0000E 00	DMONTH= 5.0000E 00 YWSJRP= 5.1896E 01 STOR = 4.5620E 01	QA = 9.1732E 02 YACTEV= 2.6548E 02	YPEVAP= 2.6548E 02 MWTDEF= 2.6489E 01	YWTDEF= 0.0 WTSURP= 0.0
TIME = 5.0000E 00	DMONTH= 6.0000E 00 YWSJRP= 5.1896E 01 STOR = 0.0	QA = 9.5394E 02 YACTEV= 3.3130E 02	YPEVAP= 4.2579E 02 MWTDEF= 1.4736E 02	YWTDEF= 2.4489E 01 WTSURP= 0.0
TIME = 6.0000E 00	DMONTH= 7.0000E 00 YWSJRP= 5.1896E 01 STOR = 0.0	QA = 9.3685E 02 YACTEV= 3.4100E 02	YPEVAP= 5.0285E 02 MWTDEF= 1.9522E 02	YWTDEF= 2.6184E 02 WTSURP= 0.0
TIME = 7.0000E 00	DMONTH= 8.0000E 00 YWSJRP= 5.1896E 01 STOR = 0.0	QA = 8.6423E 02 YACTEV= 3.4250E 02	YPEVAP= 7.9957E 02 MWTDEF= 1.7095E 02	YWTDEF= 4.5707E 02 WTSURP= 0.0
TIME = 8.0000E 00	DMONTH= 9.0000E 00 YWSJRP= 5.1896E 01 STOR = 0.0	QA = 7.3678E 02 YACTEV= 3.4320E 02	YPEVAP= 9.7123E 02 MWTDEF= 1.0433E 02	YWTDEF= 6.2802E 02 WTSURP= 0.0
TIME = 9.0000E 00	DMONTH= 1.0000E 01 YWSJRP= 5.1896E 01 STOR = 0.0	QA = 5.7945E 02 YACTEV= 3.5560E 02	YPEVAP= 1.0880E 02 MWTDEF= 1.6755E 01	YWTDEF= 7.3235E 02 WTSURP= 0.0
TIME = 1.0000E 01	DMONTH= 1.1000E 01 YWSJRP= 5.1896E 01 STOR = 0.0	QA = 4.4456E 02 YACTEV= 4.1070E 02	YPEVAP= 1.1598E 02 MWTDEF= 0.0	YWTDEF= 7.4910E 02 WTSURP= 0.0
TIME = 1.1000E 01	DMONTH= 1.2000E 01 YWSJRP= 5.1896E 01 STOR = 5.8994E 00	QA = 3.8163E 02 YACTEV= 4.4630E 02	YPEVAP= 1.1954E 02 MWTDEF= 0.0	YWTDEF= 7.4910E 02 WTSURP= 0.0
TIME = 1.2000E 01	DMONTH= 1.0000E 00 YWSJRP= 5.1896E 01 STOR = 3.3598E 01	QA = 4.1182E 02 YACTEV= 4.7351E 02	YPEVAP= 1.2226E 02 MWTDEF= 0.0	YWTDEF= 7.4910E 02 WTSURP= 0.0
TIME = 1.3000E 01	DMONTH= 2.0000E 00 YWSJRP= 0.0 STOR = 7.8714E 01	QA = 5.2528E 02 YACTEV= 2.7884E 01	YPEVAP= 2.7884E 01 MWTDEF= 0.0	YWTDEF= 0.0 WTSURP= 0.0

An example of the standard CSMP PRINT OUTPUT.

PROBLEM DURATION 0.0

T0 2.4000E 01

VARIABLE	MINIMUM	TIME	MAXIMUM	TIME	
PREC	7.0000E-01	7.0000E 00	7.3000E 01	0.0	
EVAP	2.7202E 01	2.3000E 01	1.9672E 02	6.0000E 00	
ACTEV	7.0000E-01	7.0000E 00	1.1108E 02	3.0000E 00	
TMPA	1.0700E 01	0.0	2.5600E 01	7.0000E 00	
ARIND	66.5	HUMIND	0.0	MSTIND	-39.9

SUMMER CONCENTRATION IS 45.98

SPEVAP	WPEVAP	SWTDEF	WWTDEF	SWSURP	WWSURP
933.55	289.06	796.86	16.75	0.0	0.0

YPEVAP	YWTDEF	YWSURP	YACTEV	STOR
1222.61	813.61	0.0	409.00	33.60

An example of the standard CSMP FORMAT writing output.

TIME	PREC	MINIMUM 7.0000E-01	PREC	VERSUS TIME	MAXIMUM 7.3000E
		I			I
0	7.3000E 01	-----		-----	+
0000E 00	5.1300E 01	-----		-----	+
0000E 00	4.1900E 01	-----		-----	+
0000E 00	4.6800E 01	-----		-----	+
0000E 00	2.0200E 01	-----		-----	+
0000E 00	9.7000E 00	-----		-----	+
0000E 00	1.5000E 00	-----		-----	+
0000E 00	7.0000E-01	-----		-----	+
0000E 00	1.2400E 01	-----		-----	+
0000E 00	5.5100E 01	-----		-----	+
0000E 01	4.1500E 01	-----		-----	+
1000E 01	5.4900E 01	-----		-----	+
2000E 01	7.3000E 01	-----		-----	+
3000E 01	5.1300E 01	-----		-----	+
4000E 01	4.1900E 01	-----		-----	+
5000E 01	4.6800E 01	-----		-----	+
6000E 01	2.0200E 01	-----		-----	+
7000E 01	9.7000E 00	-----		-----	+
8000E 01	1.5000E 00	-----		-----	+
9000E 01	7.0000E-01	-----		-----	+
0000E 01	1.2400E 01	-----		-----	+
1000E 01	5.5100E 01	-----		-----	+
2000E 01	4.1500E 01	-----		-----	+
3000E 01	5.4900E 01	-----		-----	+
4000E 01	7.3000E 01	-----		-----	+

An example of the standard CSMP PRTPLT output. Precipitation versus time.

ME	EVAP	MINIMUM	EVAP	VERSUS TIME	MAXIMUM
		2.7202E 01	I		1.9672E 01
	2.7884E 01		+		
000E 00	4.4520E 01		-----+		
000E 00	8.1999E 01		-----+-----+		
000E 00	1.1108E 02		-----+-----+-----+		
000E 00	1.6031E 02		-----+-----+-----+-----+		
000E 00	1.7706E 02		-----+-----+-----+-----+-----+		
000E 00	1.9672E 02		-----+-----+-----+-----+-----+-----+		
000E 00	1.7165E 02		-----+-----+-----+-----+-----+-----+		
000E 00	1.1673E 02		-----+-----+-----+-----+-----+-----+		
000E 00	7.1855E 01		-----+-----+-----+		
000E 01	3.5601E 01		---+		
000E 01	2.7202E 01		+		
000E 01	2.7884E 01		+		
000E 01	4.4521E 01		-----+		
000E 01	8.2000E 01		-----+-----+		
000E 01	1.1108E 02		-----+-----+-----+		
000E 01	1.6031E 02		-----+-----+-----+-----+		
000E 01	1.7706E 02		-----+-----+-----+-----+-----+		
000E 01	1.9672E 02		-----+-----+-----+-----+-----+-----+		
000E 01	1.7165E 02		-----+-----+-----+-----+-----+-----+		
000E 01	1.1673E 02		-----+-----+-----+-----+-----+-----+		
000E 01	7.1855E 01		-----+-----+-----+		
000E 01	3.5600E 01		---+		
000E 01	2.7202E 01		+		
000E 01	2.7884E 01		+		

Evaporation versus time

	MINIMUM	TMPA	VERSUS TIME	MAXIMUM
	1.0700E 01			2.5600E 01
TIME	TMPA	I		I
000E 00	1.0700E 01	+		
000E 00	1.1600E 01	----+		
000E 00	1.4300E 01	-----+		
000E 00	1.5400E 01	-----+		
000E 00	1.9000E 01	-----+		
000E 00	2.2100E 01	-----+		
000E 00	2.4900E 01	-----+		
000E 00	2.5600E 01	-----+		
000E 00	2.3300E 01	-----+		
000E 00	1.8900E 01	-----+		
000E 01	1.5000E 01	-----+		
000E 01	1.2100E 01	----+		
000E 01	1.0700E 01	+		
000E 01	1.1600E 01	----+		
000E 01	1.4300E 01	-----+		
000E 01	1.5400E 01	-----+		
000E 01	1.9000E 01	-----+		
000E 01	2.2100E 01	-----+		
000E 01	2.4900E 01	-----+		
000E 01	2.5600E 01	-----+		
000E 01	2.3300E 01	-----+		
000E 01	1.8900E 01	-----+		
000E 01	1.5000E 01	-----+		
000E 01	1.2100E 01	----+		
000E 01	1.0700E 01	+		

Temperature of the air versus time

