In general it may be said that wind and air temperature go hand in hand and affect water temperature 12 to 24 hours after they themselves are felt; that is, on the first day of a cold wind the water remains warm, while on the second day it grows cooler.

THE DEEPER WATER ALONG THE SOUTH SHORE AT CRAIGVILLE

The lack of sunned flats, the constant deep water within 3 to 4 feet of the shore, and the absence of marked tidal rise and fall at Craigville all combine to keep the water temperature remarkably even at 74°–75°.

TABLE 6.—*Temperature readings at Craigville*

Date and time	Temperature		Suggested cause of deviation from 74°–75° F.
	Air	Water	
	° *F.*	° *F.*	
July 24, 1925, p. m.	79	78	High on shore wind of July 22.
28, 1926, a. m.	70	76	
Aug. 1, 1925, a. m.	78	75	
2, 1925, a. m.	72	73	
15, 1926, p. m.	79	78	Continued high air temperature.
18, 1926, a. m.		74	Rain for 3 days; lowered temperature.
23, 1925, a. m.	72	73	North wind for 2 days.
Sept. 11, 1926, a. m.		68	Persistent northeast wind and low air temperature.
18, 1925, a. m.	61	69	Rain and northeast wind for 3 days.

NOTE.—The afternoon temperatures seem to run slightly higher than the morning temperatures. This fact is doubtless due to the heating of the water by the sun, the higher afternoon air temperature, and the onshore sea breeze which blows the heated surface water toward the shore.

TABLE 7.—*Comparison of Craigville and Barnstable air and water temperatures*

Date	Craigville				Barnstable			
	Time	Wind	Air	Water	Time	Wind	Air	Water
1925			° *F.*	° *F.*			° *F.*	° *F.*
July 11	5 p. m.	SW. 1	76	74	12 m.	S. 1	81	69
23	4 p. m.	SW. 5		78	4 p. m.	SW. 5	79	63
Aug. 1	11 a. m.	S. 1	78	75	3 p. m.	S. 5	78	67
2	10:30 a. m.	SW. 3	73	73	11 a. m.	SW. 3	72	65
23	3 p. m.	S. 4		73	11 a. m.	S. 1	72	69
Sept. 18	12 m.	SE. 3	61	69	12 m.	SE. 3		63
Average				73.6				66
Average difference				7.6				

To summarize conditions briefly, it may be said that (1) the highest water temperatures at Barnstable occur in the afternoon, on sunny days, when the air temperature is above 70° F. and a gentle wind is blowing from the south or west; and conversely, the lowest water temperatures come in the morning, on either sunny or cloudy days (preferably the latter), when the air temperature is below 65° F, and the wind is blowing from east, north, or from the south with high velocity; (2) where they are found, sunned flats are the all-important factor in affecting the water temperatures; wind of high velocity is the most radical agent; air exerts the steadiest influence, although it is often obscured by the absence of sun or the presence of a high wind.

THE CLIMATIC REGIONS OF NORTH AMERICA

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The accompanying map is the result of an attempt to apply the principles used and explained by Köppen in "Petermanns Mitteilungen," 1918, (**1**) and later in "Die Klimate der Erde" (1923), (**2**) to the data found in the publications of the United States Weather Bureau and the Canadian Meteorological Service.

The map, given in "Petermanns Mitteilungen" and reprinted in black in "Die Klimate der Erde," is of too small a size to show details. Futhermore, the projection used for it distorts the features of North America too seriously to give a clear idea of the distribution of the different climatic zones over this continent.

The study had to be restricted to eastern North America north of the Rio Grande; the data available for Mexico were not sufficient to make a better approximation to a true representation of the conditions than is found on Köppen's map. Also, the number of stations with long records in the area between the Rocky Mountains and the Sierra Nevada and the Cascade Range is inadequate, especially in connection with the great topographical complexity of this region. An attempt to work out Köppen's principles for this partwould necessarily have to be supplemented by observations of the vegetation in the field to fill out the gaps between the stations.

This has been done by R. J. Russell for the State of California in his "Climates of California." (**3**)

The above mentioned studies of Köppen,[1] and some of his publications in the Meteorologische Zeitschrift, (**4, 5**) have served as basis for this study.

I have used also Bulletin W of the United States Weather Bureau, the Monthly Records of Meteorological Observations of the Meteorological Service of Canada, "The temperature and precipitation of Alberta, Saskatchewan, and Manitoba," by A. J. Connor, (**6**) and Hann's "Handbuch der Klimatologie." (**7**)

To determine the division lines on the map, more than 300 stations with long records have been used. It was necessary, moreover, to compare the data of many other stations in order to ascertain that some of the values were not due to local conditions and that they increased or decreased regularly to the one or the other side. The use of stations with shorter records than 10 years has been avoided as much as possible.

As Köppen states, climatology has to work with quantitative magnitudes. But those magnitudes in themselves do not have a practical value, and therefore a system of classification built on limits chosen entirely arbitrarly would likewise have no practical value. So we have to look for a parallelism between certain numerical facts or a certain combination of those facts and the phenomena of the organic or inorganic realm of nature. We can not expect more than a parallelism; it is impossible to express life in an exact mathematical formula.

Köppen considers the vegetation as the best object with a practical value for furnishing those limits.

The most important factors to be considered in this connection are:

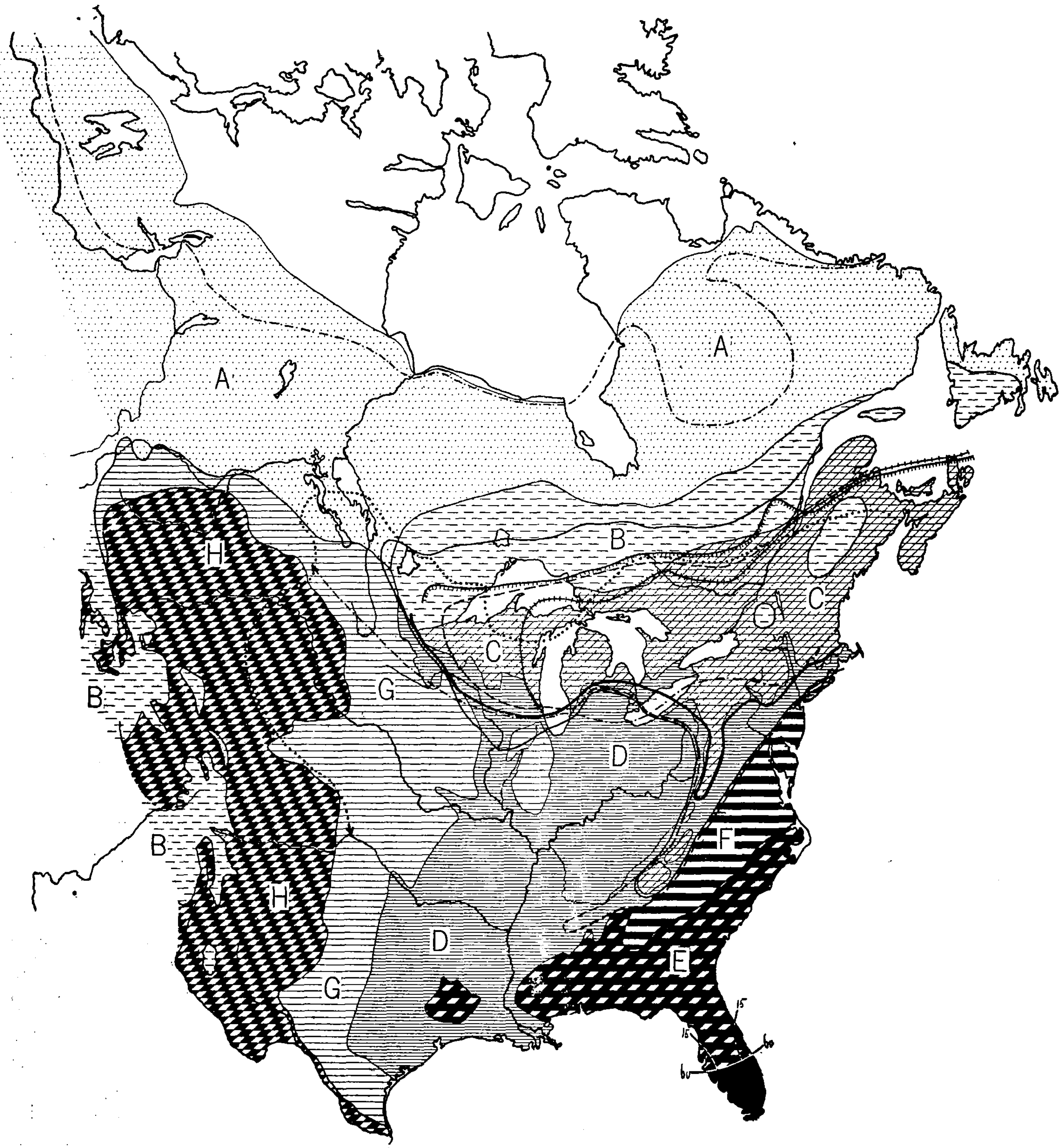
(*a*) Whether rest periods, or at least periods of very restricted organic activity, are present.

(*b*) The duration of the period favorable for organic life.

(*c*) The conditions during that period.

These factors were kept in view constantly by Köppen in determining his criteria.

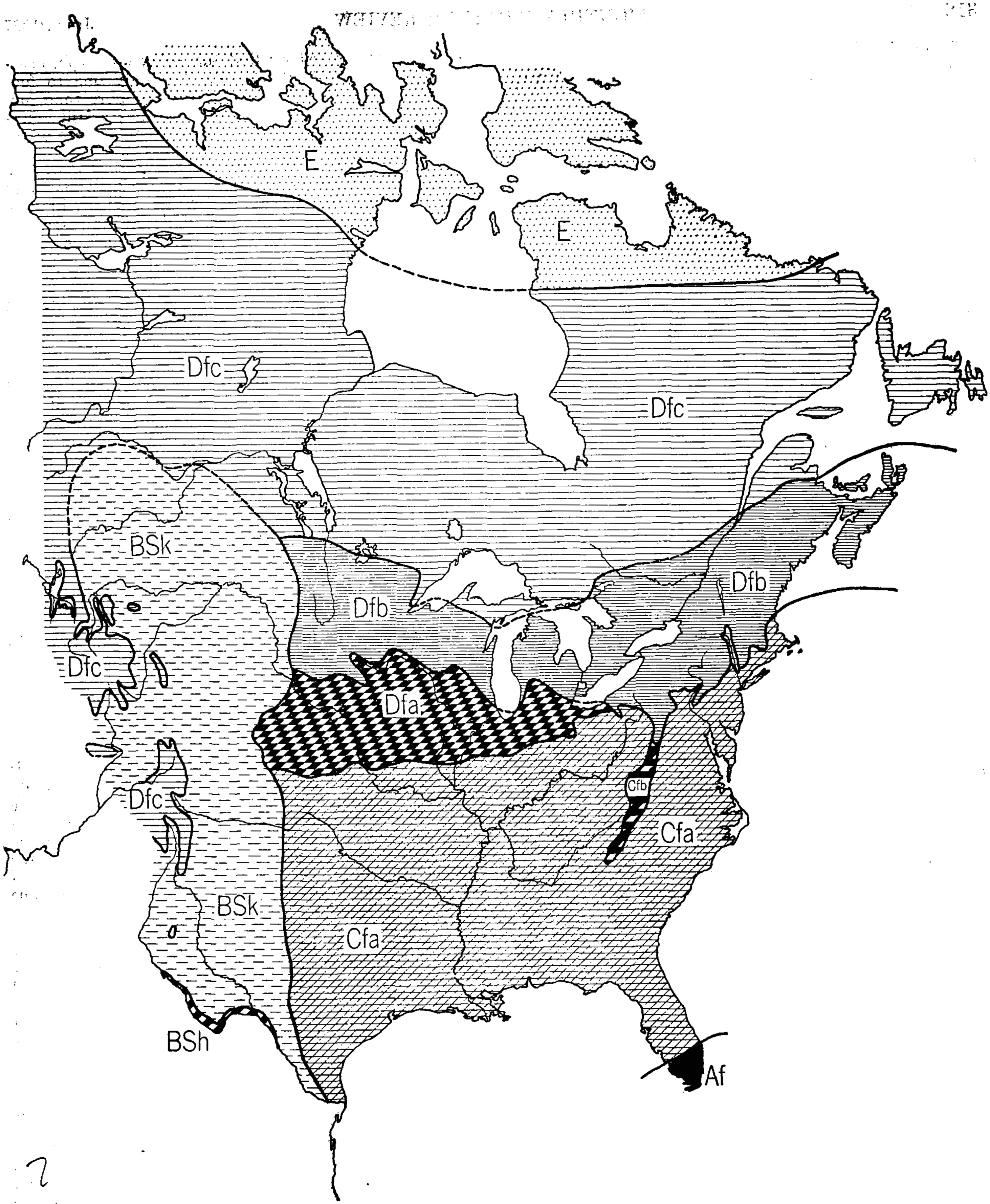
[1] *Vide:* Preston E. James, Köppen's Classification of Climates: A Review, MONTHLY WEATHER REVIEW, February, 1922, 50: 69–72.



Northern and southern limit of:
——— *Pinus strobus*
– – – – *Tsuga canadensis*
–·–·– *Populus balsamifera*
Southern limit of:
▬▬▬ *Abies balsamea*

Northern limit of:
Quercus rubra
• • • • • • *Quercus macrocarpa*
Fagus americana
60—60 Number of evergreen broad leaved trees south of line

A, Tropical rainy climates.
B, Dry climates.
C, Warm temperate rainy climates.
D, Subarctic climates.
E, Snow climates.
a, Temperature of warmest month>72° F.
b, Temperature of warmest month<72° F., more than four months>50° F.
c, One to four months>50° F., coldest month>−36° F.
f, Enough rain or snow in all months.
S, Steppe climate.
k, Cold; some months<50° F.
h, Hot; coldest month>50° F.



Northern coniferous forests.
Eastern coniferous forests.
Mixed coniferous and hardwood forests.
Deciduous forests.
Southeastern pine forests.
Transition zone between deciduous forests and southeastern pine forests.
Long grass region.
Short grass region.

Northern and southern limit of:
———— Pinus strobus.
— — — — Tsuga canadensis.
— . — . — Populus balsamifera.
Southern limit of:
— — — — Abies balsamea.
Northern limit of:
— . — . — Quercus rubra.
. . . . Quercus macrocarpa.
———— Fagus americana.
15, 60, indicate number of broad-leaved evergreen trees south of lines.

The main climatic areas are, according to him:

A. The tropical rainy climates	coldest month averaging above 18° C. (64.4° F.).
B. The dry climates	precipitation below the limit of dryness.
C. The warm temperate rainy climates.	coldest month between 18° C. and −3° C.
D. The sub-arctic climates	coldest month below −3° C. (26° F.) and warmest month above 10° C. (50° F.).
E. The snow climates	warmest month below 10° C. (50° F.).

This classification runs parallel to the classification of plants given by A. de Candolle, in:

A. Megatherms.
B. Xerophytes.
C. Mesotherms.
D. Microtherms.
E. Hekistotherms.

For the subdivisions the following criteria are used for the region under consideration:

a. Temperature of the warmest month >22° C. (71.6° F.).
b. Temperature of the warmest month <22° C. (71.6° F.) and more than 4 months above 10° C. (50° F.).
c. One to 4 months above 10° C. (50° F.).
d. Temperature of the coldest month below −38° C. (−36.4° F.).
f. Humid.
h. Hot; average annual temperature >18° C. (64.4° F.).
k. Cold; average annual temperature <10° C. (50° F.); warmest month above 18° C. (64.4° F.).

In criticizing Köppen's principles and maps we have to keep in view that the classification derives its greatest value from its applicability to the whole world and that we can not without losing part of this advantage change it by taking into consideration factors that can probably be applied only for North America. Furthermore, a general classification should have as few subdivisions as possible, so that we have not attempted to introduce new secondary zones.

The southern part of Florida, with an average temperature of the coldest month above 18° C. (64.4° F.), belongs to the tropical rainy climates: *Af*. A comparison with the vegetation map, adapted partly from the map in the Section E of the Atlas of American Agriculture by H. L. Shantz and R. Zon, (**11**) and partly from the maps given in The Vegetation of the United States, by B. E. Livingston and Forest Shreve (8) and from the Atlas of Canada (**12, 13**) is interesting and enlightening. We see that the southern part of the Florida Peninsula is characterized by a large number (more than 64 different species) of evergreen broad-leaved plants, the number of which decreases rapidly toward the northwest.

Most of the eastern United States is occupied by the *Cfa* climate; i. e., the average temperature of the coldest month ranges between −3° C. and 18° C. (26.6° and 64.4° F.), and the warmest month is above 22° C. (71.6° F.).

The letter *f* means, as in the previous region, "feucht," humid, and is applied by Köppen to those regions where there is sufficient rainfall the whole year round. The use of this term seems to me somewhat too elastic; the Gulf region and the Hudson Bay region are both marked with the same symbol *f*, although the latter is distinctly dry. So *f* indicates more a distribution of precipitation through the year sufficiently uniform for organic life, rather than any value exceeding a certain annual total. For North America the letter *y* could be used instead.

The higher part of the Appalachians is occupied by the *Cfb* type; the temperature of the warmest month is below 22° C. (71.6° F.), but more than four months have temperatures above 10° C. (50° F.).

Farther northward we find the *Df* types. *Dfc*, occupying a large part of Canada, has only one to four months above 10°C. (50° F.). *Dfb* has more than four months above this temperature. *Dfa* has a still longer and warmer growing season, and the temperature of the warmest month is above 22° C. (71.6° F.).

Again, a comparison with the vegetation map is of value. On the map are shown the southern limits of Pinus strobus, Tsuga canadensis, the southern limit of Abies balsamea, and the northern limits of Pinus strobus, Tsuga canadensis, Fagus americana, and Quercus macrocarpa.

The boundary between *D* and *E* is formed by the isotherm of 10° C. (50° F.) of the warmest month. It has been adapted from the Atlas of Canada and it is based there probably on the northern limit of Picea mariana, P. canadensis, and Larix americana.

There seem to be indications of an eastern Siberian type of climate in the Mackenzie Basin, but the general topography has not permitted the development of such an extreme degree of continentality as in eastern Asia. The temperatures during the winter are only in a few places low enough to come under *d* (Fort Good Hope; average, January, −36.3° F.). Also the winters are generally not dry enough for this type, although, for example, Fond du Lac and Athabasca Landing have a precipitation in the driest month of less than one-tenth of that in the raniest month, the criterium adopted by Köppen for the *Dw* type.

> Fond du Lac: March, 0.19 inch; August, 2.23 inches.
> Athabasca Landing: February, 0.30 inch; June, 3.31 inches.

Köppen uses the following empirical formula to establish the boundaries between the dry *B* climates and the more humid *C* and *D* types:

$N = t + y$, in which
N is the average annual precipitation in cm.
t is the average annual temperature in °C.
y can have three different values: 22, 33, 44.

When the annual amplitude of the temperature is relatively small and when the rainfall is rather evenly distributed throughout the year the constant 33 can be used. When the variation in the value of the two determining factors is rather great (when, for example, the precipitation occurs mainly in the warm season), the value 44 has to be used in connection with the effect of the higher evaporation. In the opposite case the value 22 should be applied.

We have not succeeded in finding a corresponding formula that could be used for inches and °F. On the other hand, the value of Köppen's formula for the territory under consideration is rather doubtful. Of course it is not Köppen's intention that this formula should be handled as an exact mathematical value. But when we apply the formula to the data we find that the statement that $y = 44$, when the precipitation occurs mainly in the warm season, is too general. When we use the value 44, as soon as the rainfall in the warm season is greater than in the cold, then a small difference in the distribution makes the value of y, and consequently also the required value of N, jump from 33 to 44, and that in a region where every inch of rainfall is highly important.

If we use $y = 44$ only in cases where the dry-season precipitation is practically nil, and $y = 33$ when the precipitation is evenly distributed throughout the year, we have to interpolate for every group of stations at least, the special value of y, and the formula loses its meaning entirely.

The boundaries of the main dry areas of the world have a latitudinal direction, and only in the Baraba Steppe in Siberia does the dry region push as far northward as in North America. For such a latitudinal extent the value of t will not differ very much. But in the region under consideration there is a considerable difference between the temperatures in the southern and the northern parts. This leads to complications, because an application of a necessary correction for the whole region is much more difficult.

Let us assume two stations A and B; y has for both the value 44. A has an average annual precipitation of 45 c. m. and an average annual temperature of 2° C. B has an average annual precipitation of 58 c. m. and an average annual temperature of 15° C. Then the formulae for both stations will be:

$$A: 45 < 2 + 44.$$
$$B: 58 < 15 + 44.$$

An increase of 1 c. m. in rainfall would have the same influence for both stations; it would bring them both on the boundary line between the dry and the humid regions.

Trabert (9) considers the following formula as the best expression of the rate of evaporation:

$\surd = c\ (l + \alpha t)\ \sqrt{W}\ (E = e)$, in which

c is a constant depending on the barometric pressure.

w is the wind velocity.

E is the maximum vapor pressure for the temperature of the evaporating surface.

e is the actual vapor pressure in the air above.

When we substitute the corresponding values for the temperatures 5°, 10°, and 15° C., considering c and w as constant, and e also for the region under consideration, we find:

$$V_5 = c \times \frac{278}{273} \times \sqrt{w}\ (6.5 - e).$$

$$V_{10} = c \times \frac{283}{273} \times \sqrt{w}\ (9.2 - e).$$

$$V_{15} = c \times \frac{288}{273} \times \sqrt{w}\ (12.8 - e).$$

The greater increase of the value of V, when t increases, is not expressed in Köppen's formula. The result is, when we apply the formula to the data, that the dry region becomes relatively too broad in the northern part. Stations in the forest region of Canada with a low precipitation but with a still lower average annual temperature, as, for example, Fort McMurray and Fort Vermillion, would have to be included in the B area.

The best values to use in combination with precipitation values would be evaporation data. But these data are as yet very scant, and maps, as used by Livingston and Shreve (8), are too hypothetical to be of any help. The Atlas of American Agriculture (10) gives some available evaporation data from which a decrease in evaporation toward the north is evident, and mentions also that a precipitation of 20 inches in the Dakotas is practically equivalent to one of 40 inches in the southern part of Texas.

We have tried to offset the deviation of the eastern boundary toward the east by interpolating the value for y according to the relative amount of precipitation occurring during the summer season and by using in the northern part 44 as the extreme value (i. e., when the winter precipitation is practically nil), and letting this value increase until 44 becomes the interpolated value in the south. The line in Canada is dotted to indicate its probable position if evaporation and precipitation data could have been used. So it is not necessary to reject the formula entirely, inasmuch as it gives the best basis yet available for a comparison of the largest regions. Let us hope that in the future a greater number of comparable evaporation data will give a sounder basis.

Köppen uses the mean annual isotherm of 18° C. (64.4° F.) for the division of the dry climates into Hot, *h*, and Cold, *k*. As Russell states in "The Climates of California," (3) the value of using such a mean annual isotherm is open to question. On the other hand, the value of using the 0° C. (32° F.) January isotherm applied by Russell, is also rather doubtful. I do not think, as Russell states, that the climate of Pleistocene times can be a justification for the choice of this isotherm, and I suppose that the average American thinks of protecting himself against the cold usually before the thermometer reaches the 32° average. The use of this isotherm would also, entirely unnecessarily, introduce, for example, islands of *BWh* climate in the *BWk* region of Transcaspia. In addition to that, it does not seem warranted to include the southern part of the California valley with the Colorado desert. A more satisfactory boundary would seem to be the isotherm of 50° F. for the coldest month. This line includes practically the creosote bush area on the vegetation map of the United States. (10)

The mountain areas, classified by Köppen as *Dfb*, show mostly the *Dfc* type, and, of course, in the southern part this is somewhat more important than in the northern part. The highest crests of the mountains reach into the *E* zone, but these regions are too small to be shown on the map.

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