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A PHENOLOGICAL MODEL FOR SOUTHEASTERN UNITED STATES

*Richard J. Kopec**

In 1938, A. D. Hopkins introduced his magnum opus, *Bioclimatics, A Science of Life and Climate Relations*, culminating twenty years of research in entomology. (1) In this massive work, he set forth the principles of bioclimatics and provided a phenologic model for predicting the annual occurrence of natural phenomena in space and time. Remaining obscure for many years, this manuscript found periodic revival and has recently been rediscovered and reevaluated by some botanists. In a recent response to a request by Bliss (2) for help in establishing a phenology program as part of the International Biological Program, Leith and Radford (3) suggested the adoption of a modified phenologic model originally presented by Hopkins and subsequently adapted by Schnelle (4) and Kopec (5) to their needs. It is believed that an examination of phenology and Hopkins' Bioclimatic Law may serve to introduce and provide physical geographers and climatologists, by way of illustration, with a practical analytical tool in their studies of the physical environment.

Phenology, defined as that science which deals with the influence of climate on the cyclic activity of natural phenomena, has been by and large ignored by practitioners of our discipline. With today's emphasis on ecological network studies and social concern with natural environment systems, a reexamination of phenology seems well advised. The influence that climate exerts on all biotic activity is pervasive, and perhaps because it is, its significance is diminished. Yet geographers are constantly made aware that climate control remains the primary environmental parameter in determining the cyclic behavior of physical phenomena, be it diurnal, annual or seasonal. A phenologic model which would permit prediction, within reasonable tolerances, of such reoccurrences as the beginning of the frost free season or the spatial character of annual insect migrations would be of considerable technical value. Further, a bioclimatic model would make possible the identification and understanding of the physical controls underlying cyclic aberration of phenomenal occurrence which would enhance the development of more realistic theoretical and empirical resource management models. Hopkins recognized the need for such a model and formulated the Principles of Bioclimatic Law which state as follows:

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- (1) Under the requirements of astronomic law, phenomena of life and climate should be equal under equal astronomic causes along the parallels of latitude around the earth.
- (2) Under the requirements of bioclimatic law, phenomena of life and climate as modified by terrestrial influences should be equal under equal influences at the same level across the continents along lines which depart from the parallels of latitude at the assumed rate of 1° of latitude to 5° of longitude. These lines are called isophanes.
- (3) Since, however, the influences of the local, regional, and continental causation complex are never equal, departures or variations of the observed effects from the requirements of astronomic and bioclimatic law must occur. Such variations, as determined by bioclimatic methods and expressed in units of time, temperature, or distance, serve (a) as measures of the relative intensity of the modifying influences, and (b) as indices to the interpretation of causes and factors and to the prediction of bioclimatic elements at given geographic position within the latitude and altitude range of the influences represented by a record position and its variation indices.
- (4) Under the laws, principles, systems, and methods of bioclimatics, the bioclimatic elements of any record position can be analyzed and directly compared, on a strictly coordinate basis, with those of any other position or continent.
- (5) The bioclimatic zone and zonal types of a place, area or local region are the most reliable indices to the species of plants and animals and to the types of agriculture that are best adapted to the local conditions and requirements. (6)

By providing this theoretical base neutralizing the controls of continentality, latitude and altitude, Hopkins made possible the prediction of phenomenal reoccurrences and the determination of the intensity and areal pattern of secondary climatic influences on the distribution of biophenomena. To illustrate the efficacy and flexibility of Hopkins' Bioclimatic Law, a phenological model of the southeastern United States was constructed and isoplethic maps relating to this model are presented and discussed.

Construction procedure required the selection of a reference point in the southwest corner of the study area. This point may be within or immediately outside the boundaries of the region. (In this instance, because of the peculiar shape of the region, the position at 28°N , 95°W was selected.) From this point of departure, a series of isophanes, unadjusted for altitude, was drawn slanting from northwest to southeast at intervals of 1° latitude to 5° longitude (dashed lines on Figure 1). According to bioclimatic law, a phenomenon such as the start of the frost free season advances northeastward at a rate of four days per

Figure 1

isophane. Following this initial cartographic step, all isophanes were adjusted for latitude. This was done by determining the approximate elevation at each one degree intersection of parallels and meridians within the southeastern United States. This adjustment equilibrates altitude to latitude at a ratio of 15 minutes of latitude poleward for every 100 feet of altitude. With reference to the start of the frost free season, this would be interpreted to mean that for each 100 feet of elevation, the occurrence of the frost free season is retarded by one day. Putting it together, if a point in this region lies one unadjusted isophane to the northeast of a reference location and is 200 feet higher in elevation, then the start of the frost free season at that point predictably should occur six days later than the occurrence of this phenomenon at the reference location. The isophanes adjusted for altitude are drawn as solid lines on the map model (Figure 1). On the return cycle, for the end of the frost free season, the isophane values are reversed and the frost period moves southwestward across the area presumably at the same rate as its demise in Spring. (7) By superimposing the actual isochronal pattern for the mean start and end of the frost free season over this theoretical surface, it is possible to calculate time deviations and to relate these deviations causally with climatic controls other than latitude, altitude and continentality.

In order to make this model efficacious it is necessary to attribute an absolute value to the reference point or primary isophane. It is one thing to recognize the relative differences among all points in terms of time and space, but the value of the reference position must be determined "absolutely" to permit prediction. For example, to know that points along adjacent isophanes have a difference of four days or one degree (F.) in the occurrence of cyclic phenomena is useful information, but in order to predict the time or place of an occurrence, a bioclimatic constant must be established for the reference location. To determine a value for the reference line, data representing the occurrence of the phenomena under consideration have to be averaged for points along the primary isophane. That is, in order to calculate the intensity and pattern of deviation of empirical values from the theoretical norm established by the map model, a value has to be derived for the reference isophane by averaging the data for all points along that isophane. Once done, not only relative values but predictions for time, space, and intensity may be gained.

Examination of the model shows the relationships between adjusted (solid lines) and unadjusted (dashed lines) isophanes. The effects of altitude strongly offset the geometric arrangement of isophanes set by latitude and continentality. Using Key West, Florida (or 28°N, 95°W) as the point of departure, each isophane progressing northward represents a four day lapse in time or a one degree Fahrenheit retardation in temperature. (8) The pattern remains zonal and open until the Appalachian Highlands begin to dominate. The mountains cause the

isophanes to crowd and take a meridional alignment. Between the highlands of northwest Virginia and Key West, Florida, there is an 80 day difference in cyclic occurrences, or for instance, between Atlanta, Ga. and Washington, D. C. a time lapse of 17 days exists. Hence, when dogwood blossoms flower in Atlanta, the same phenomena may be expected to occur at Washington, D. C. approximately two and one-half weeks later—unless some local, secondary control exerts an influence which advances or retards its occurrence.

To further illustrate how Hopkins' Bioclimatic Law may be utilized graphically, two additional maps are presented. These maps result from a comparison of empirical data with the map model. The phenomena selected for illustration are the Start of the Frost Free Season (Figure 2) and January Mean Temperatures (Figure 3). No attempt will be made to completely analyze these maps as the subject of this discourse is the graphic illumination of Hopkins' Bioclimatic Law and not the chronological or chorological aspects of any phenomena and its cycles. The distributions of deviations on both maps will be discussed briefly as they relate to demonstrating the utility of the model. The selection of physical events was made arbitrarily as any natural cyclic occurrence could have been considered.

The maps derived from applying Bioclimatic Law to the freeze free season and January mean temperatures in the South may require some explanation before evaluation of their content and the model is possible. Isanomal maps, dealing with any subject, are hypsometric (slope) maps indicating areal patterns and variations of intensity within a continuum. As in the case of the start of the frost free season (Figure 2), the isanomals are really isochrones showing time deviations, while in Figure 3, the deviations from the derived values for January mean temperatures are isanomals representing isotherms of mean temperature. In any case, isanomal maps are slope maps which always consider intensity in terms of time and space. As tools of analysis, it must be realized that where isolines representing any phenomena, real or derived, are aligned in a parallel manner, it may be safely assumed that the controlling parameter is a vector perpendicular to the isoline pattern. Therefore, the effects of an ocean or lake on vicinal land temperatures will cause the isotherms to lie parallel to the coasts and thusly perpendicular to the maritime or lucustrine effect. Furthermore, slope maps signify the variations in intensity exerted by the controlling influence. Where the control is more intense, the isolines are spaced closely together and vice versa. Naturally, for slope maps of deviations from the map model, dense packing of isolines is associated with regions where the phenomena under consideration is strongly influenced by some secondary control not provided for in the construction of the isophanic model. A local control such as a lake's effect or the permanency of a snow cover can significantly influence the pattern of isanomals. Also, where one of the neutralized controls, latitude, altitude, or continentality, is more influential than allowed

Figure 2

Figure 3

for by the model, its intensity may become evident in the pattern and spacing of isolines.

On the start of the freeze free season map, negative isochrones represent an advance in the freeze free season, i.e., the beginning of the season occurs before that time predicted by the model. Positive deviations indicate a retarded start of the frost free season, and zero values indicate no deviation from the theoretic norm, viz., the mean occurrence of the first daily minimum temperature of 32°F or above coincides with the date predicted by the Law of Bioclimatics. Keep in mind that unlike the isophanic model, the isanomals map does not show the relative differences in actual time for the start of the frost free season but simply the deviation in time for its beginning at a specific point. Hence, whereas the start of the frost free season may be expected 17 days earlier at Atlanta than Washington, D. C., at Washington the season for some reason(s) is 16 days earlier than predicted whereas in Atlanta it is only four days ahead of time. Undoubtedly, proximity to the ocean plays a significant part in explaining the difference.

For the southeastern United States, the range of deviations amounts to 56 days; from an advance in the season of 44 days in the Miami area to a retarded start of 12 days in a variety of places. The maritime influence on the start of the frost free season is evident all along the Atlantic and Gulf coast. The isanomals for the most part lie parallel to the coasts almost everywhere except for the west coast of Florida. It must be remembered that Florida is so completely influenced by the adjacent oceans that the isanomals can lie in any pattern and still reflect this influence. The shaded areas where the start of the frost free season is retarded are found generally toward the interior of the region as well as in the piedmont where hills and valleys and the local relief have exceeded the altitudinal factor built into the model. Even though there is a turnover in temperature values in the Spring as land and ocean reverse the style of their influence, areas adjacent to the large water bodies still can be expected to record an end of the frost season before areas farther inland. This factor is evident on Figure 2. Florida, Southern Louisiana, and Cape Hatteras and vicinity all show the influence of the ocean, but on the Virginia-West Virginia border, the advance in the season may reflect the low range of temperatures associated with highlands. Although high altitudes correspond with lower absolute and mean temperatures, average daily and annual temperatures ranges are similar to those conditioned by the oceans. Therefore, when highland minimum temperatures begin to rise above 32°F, there is less chance that freezing temperatures will return. Whereas, at lower elevations, daily minimum temperatures above 32°F may be experienced sooner but the chance of frost remains for a longer time. In other words, the range of dates associated with the mean start of the frost free season is less for highlands than lowlands. This fact is evident in the Virginia-West Virginia mountains as well as all highland regions in the South. In the highlands

farther north, the control of elevation causes a longer-lasting snow cover which effects a retardation in the start of the frost free season.

Through the use of Hopkins' Bioclimatic Law, it is possible to determine the degree to which the frost free season is lengthened or shortened due to one or a combination of controls other than latitude, altitude and continentality. Kopec has done this for the Great Lakes Region. (9) By constructing an isanomal map for both the start and end of the frost free season and comparing values for these periods at specific stations, it was possible to determine, in percent, the effect of the Great Lakes (or some other local control) on the frost free season. This method can be applied to any number of phenomena which exhibit cyclic change and reoccurrence.

The isanomal map of January mean temperatures shows that nearly the entire Southeast is represented by positive values. In this instance, positive values depict temperature deviations higher than predicted by the model. This map conveys the impression that the Southeast is warmer than normal for its latitude and continental position. However, the reader is reminded once again that the major controls of latitude, altitude and continentality have been neutralized and the isanomals reflect climatic controls exclusive of these. If the major controls were evident in the isanomal values, undoubtedly the study region would show everywhere, with the possible exception of peninsula Florida, temperature deviations below normal for the latitude. It was found by Kopec that the area just south of the Great Lakes Region was 8-13°F colder than the norm for that latitude. (10) These values correspond nicely with the northern boundaries of Figure 3 when it is remembered that the major controls are not evident therein.

What is very evident on Figure 3 is the permeating influence of the Atlantic Ocean and the Gulf of Mexico. The isanomals over most of the map lie parallel to the shores of these water bodies relating their influence on continental temperatures. Southern Florida, as expected, indicates the most intense maritime control where deviations reach as high as 20°F. However, north of Cape Hatteras, the cold waters of the Labrador Current exhibit their influence by lowering temperatures in this area to those typical of the land surface attenuating the maritime effect so obvious farther south. This fact is seen in the isoline pattern which no longer lies parallel to the coast but perpendicular to it. Without doubt, a partial explanation of the moderately high positive deviations found to the lee of the Appalachians is found in the sheltering effect provided by these low mountains as they moderate the cA and cP air masses invading this region during the winter season. Where the mountains do not provide a buffering effect, the isanomals display negative values as seen along northern Arkansas and Tennessee.

The two isanomal maps of the Southeast serve to illustrate the utility of Hopkins' Bioclimatic Law. His isophanic model enables the physical

scientist to more precisely predict reoccurrences of phenomena and determine the degree to which secondary climatic influences control physical elements. By reducing latitude, longitude, and altitude to equality in the isophanic model, Hopkins made it possible to calculate and evaluate the involvement ratios of such environmental variables as snow cover, cold and heat waves, lake and ocean effects, peat bogs, etc. Although it is still impossible to isolate the effects of an individual control completely and establish accurately its measure of influence in determining the occurrence and distribution of phenomenal events, nevertheless, the physical scientist can more fully evaluate the significance of minor climatic parameters.

Application of this model to microstudies of the environment is still precarious. This is a relatively coarse model designed for studies at the macro level. This fact has become evident to others who have considered its use. It has been found that the allowance given to altitudinal control, thought by many to be the most important variable in microspatial analyses of the environment, needs further refinement. Also, the model's applicability was intended for use in the middle latitudes as reflected in Hopkins consideration of longitude as a continentality factor. Whether his model will be relevant in low or high latitudes remains to be proven. Finally, ecological studies require the inclusion of appropriate factors such as sunshine, daylength, solar radiation, exposure and slope among others. If these more germane variables can be introduced to Hopkins' model and applied at local study levels, the Principles of Bioclimatic Law may find relevancy in future environmental investigations.

* * *

- (1) Hopkins, A. D., *Bioclimatics, A Science of Life and Climate Relations*, U. S. Dept. of Agriculture, Misc. Publication 280, 1938.
- (2) Bliss, L. C., "Phenology Program of the IBP," *Bioscience*, Vol. 17, 1967, pp. 712-714.
- (3) Leith, H. and Radford, J. S., "Phenology, Resource Management, and Synagraphic Computer Mapping," *Bioscience*, Vol. 21, 1971, pp. 62-70.
- (4) Schnelle, F., *Pflanzen-Phanologie Akadem*, Verlagsges, Leipzig, 1955.
- (5) Kopec, R. J., "Areal Extent of the Great Lakes' Significant Influence on Vicinal Temperature Regimes," unpublished Ph.D. dissertation, Department of Geography, Clark University, Worcester, Mass., 1965.
- (6) Leith and Radford have translated this verbal model into a mathematical notation which reads:

$$\Delta_T = \sum_{i=1}^3 D_i$$

$$D_1 = 4 \Delta^\circ \text{Lat.}$$

$$D_2 = \frac{4}{5} \Delta^\circ \text{Long.}$$

$$D_3 = \frac{1}{100} \Delta^\circ \text{Alt. (ft.)}$$

where

Δ
 Δ_T = Total difference, in days between reference and data points (positive value denotes a lag)

$\Delta^\circ \text{Lat.}$ = Degrees difference in latitude (Data point vs. Reference point)

$\Delta^\circ \text{Long.}$ = Degrees difference in longitude (Data point vs. Reference point)

$\Delta \text{Alt. (ft.)}$ = Altitudinal difference in feet (Data point vs. Reference point)

- (7) This model, adapted to a seven-day interval, was borrowed and used by Leith and Radford, *op. cit.*
- (8) The map model represents the Spring condition when any phenomena such as increasing temperatures would begin in the South or West. For the Autumn situation, the advance of decreasing temperatures would emanate from the North and East. Therefore, the isophane values would reverse themselves although the pattern of isophanes would remain constant.
- (9) Kopec, *op. cit.*; and Kopec, R. J., "Effects of the Great Lakes Thermal Influence on Freeze-Free Dates in Spring and Fall as determined by Hopkins' Bioclimatic Law," *Agricultural Meteorology*, Vol. 4, 1967, pp. 241-253.
- (10) Kopec, 1967, *op. cit.*