HAMILTON RODDIS
MEMORIAL LECTURE SERIES

Simulating Past And Forecasting Future Climates

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MEMORIAL LECTURE SERIES

This Memorial Lecture Series honors the late Hamilton Roddis who served as Secretary, President and Chairman of the Board of Directors of the Roddis Plywood Corporation for more than sixty years.

Hamilton Roddis was born in 1875 in Milwaukee, Wisconsin, and moved to Marshfield with his family in 1894 when his father invested in and assumed the direction of the Hatteberg Veneer Company. Mr. Roddis enrolled in the University of Wisconsin–Madison Law School in 1896 intending to proceed through a normal course of study. A fire destroyed the Hatteberg Veneer plant in 1897 and Hamilton Roddis remained in Marshfield to help get the new plant running smoothly—simultaneously, by independent study, he pursued his second-year law program by studying at night. He later rejoined his class in Madison and graduated on schedule. His capacity to operate on many functional levels served him well during the ensuing years in meeting the many challenges of the business world and at the same time maintaining an active involvement in civic, church and cultural affairs. Originally intending to enter the law profession, he was instead persuaded to join his father's firm (then known as the Roddis Veneer Company); he became president in 1920 and headed the company until his death in 1960. His character and intellect combined with his imaginative and progressive leadership spurred a business success through what we would today tout as Quality Management.

The Roddis enterprise spearheaded many innovations in forest products. It was the first to recognize the potential of the flush door and manufacture it on a large scale. During WW II it produced materials for the war effort by fabricating interior plywood for the Liberty ships and aircraft plywood for the British Mosquito bomber and reconnaissance plane. In August of 1960 the Roddis Plywood Corporation, with holdings throughout the U.S. and Canada, was merged with the Weyerhaeuser Corporation.

Mr. Roddis' family, friends and university beneficiaries are pleased to honor the man and his extraordinary accomplishments in the Hamilton Roddis Memorial Lecture Series.

Simulating Past And Forecasting Future Climates

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There is widespread current interest in "global change" and the human consequences of global geophysical events. Why this should be the case is a matter of considerable interest, but regardless of the reasons, the interest is intense and ubiquitous. It appears in both the scientific and popular press. Very large sums of public and private money are being spent on various aspects of the subject; probably more on media presentations than on research, however. Many non-governmental organizations have taken the topic of "global change", and in particular "global greenhouse warming", as their "battle cries." As citizens and scholars, it is incumbent on us to consider whether "global change" is indeed something that everyone should consider the foremost problem, or at least a commanding challenge, facing the world today.

A large part of this interest in "global change" can be traced to the recent renewal of interest in the question of whether the measured increase of carbon dioxide in the atmosphere and projected future increases really are the primary cause of climatic change, and whether such climatic changes as might occur are a dire threat to mankind. It is a renewal of interest, for the question was raised more than a century ago. Indeed, in 1898–1899 the famous geologist T.C. Chamberlin published extensively on the carbon dioxide "greenhouse" effect, concluding that a doubling of atmospheric carbon dioxide would raise the temperature of the earth about 4 or 5 degrees Centigrade (Chamberlin, 1898, 1899). This value, obtained by hand computation, is comparable to the values obtained today with modern, very complicated computer models of the atmosphere.

As scientists and citizens, we must question whether there is evidence that either of these calculations is correct. The fact that large computer models indicate such a temperature rise as a consequence of increased carbon dioxide cannot be taken as evidence of truth, for any model is simply a formal statement of the modeler's opinion of how the atmospheric system works. It is often stated that there is a consensus among atmospheric scientists that the models are correct. This is, of course, no evidence at all. Within my lifetime it was once the consensus that the continents did not move, but it appears now that the consensus was wrong. Scientific consensus has often been wrong. A consensus is the equivalent of a vote, and taking a vote is not the proper way to establish scientific validity. Indeed, there is no credible evidence that there even is a consensus —just statements that there is.

It is my firm conviction that the past is the key to the future. If one cannot understand changes in past climates and their consequences, then one has no hope for predicting future climates and environments.

UNDERSTANDING CLIMATE HISTORY—DATA, PROXY DATA, AND MODELS

The primary lesson that scholars of past climates have learned is that the climate has changed throughout all earth history. The second lesson is that though past climatic variations have had profound influences on life and the environment of mankind, the changes have been numerically small. For example, the difference in mean global temperature between the maxima and the minima of the Pleistocene Ice Ages was only on the order of 6°C.

Worldwide instrumental weather records have been available only for the past century or so. Properly processed, these records give us data on the climate. To extend the record farther into the past, we must use records of other than weather or climate variables that can be interpreted in terms of climate. These I have called proxy records.

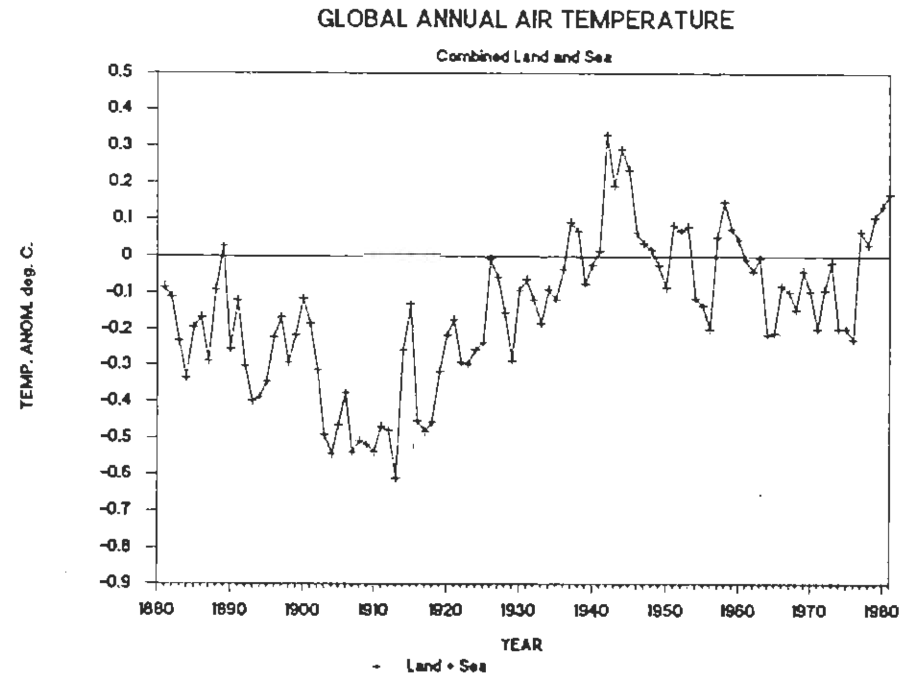

Figure 1 A carefully compiled record of world-wide marine air temperatures, (Folland et al., 1985), combined with a predominantly continental record (Hanson and Lebedeff, 1988) to give a record of global surface temperatures during the past century.

Instrumental Data. Even the instrumental record of the past century shows that the climate is variable, regardless of whose version of the record is considered. One might expect that there should be only one answer to the question of what the data tell us about mean annual global or hemispheric temperatures for the past century. However, there are almost as many versions as there are published papers on the subject.

Essentially all authors have shown that the temperature of the hemispheres and the globe has risen in the past century. Though presumably they used a common data set, the details from year to year and decade to decade differ from version to version, and the overall amount of increase differs.

In my opinion, the most carefully worked out and least biassed record is that compiled by Folland et al. (1984) and by Parker and Folland (1990). They alone used a careful analysis of the very large array of shipboard observations for the 70% of the earth that is sea, rather than just the more readily available island stations. Their results (Figure 1), do not show the most recent years as the warmest as do the records based primarily on land stations, nor did they find as large a change over the century as did some other authors. It is most interesting that the larger increases putatively shown by the data were found by those who espouse global "greenhouse warming" as the major cause of climatic variation.

Before one can attach much significance to the warming of the past century, one must consider whether such warming is unique in direction or magnitude. For that a longer record is needed, one which requires the use of proxy records.

Proxy Data. Proxy data series provide a story of what has happened climatically for some variables, but not why.

The work of the paleoclimatologist is eased greatly by the fact that nature has recorded its own history in many places. All that is necessary is for the scholar of past environments to learn how to read the record, or translate the language of nature into humanly understandable terms, quantitatively if possible. This has proven possible in some cases, especially for the interpretation of pollen profiles (see Webb and Bryson, 1972, for the first reasonably accurate quantitative method for translating pollen spectra into climatic spectra).

Examples of proxies range from tree rings to pollen rain to oxygen isotope ratios in sea floor sediments. Trees are not thermometers or raingauges, however; nor is the array of pollen taxa that falls at a place. Trees tend to trade off the effects of temperature and rainfall in terms of radial growth increment. Colder approximates wetter and warm approximates dry and vice versa. Extraction of the variables that we like to use from the tree-ring records is conceptually quite simple. We must develop as many ring thickness versus climate equations as there are unknowns. Most tree-ring records that are published, however, have the inter-specific and inter-site variance removed, so that development of the requisite number of equations is precluded. Oxygen isotope ratios in fossils on the deep sea floor don't record climate at all, but rather the integral of the snowfall minus wastage rates on the land; i.e., the continental glacier volume. Still, it is possible to extract data useful for paleoclimatic interpretation from such records.

Pollen arrays extracted from stratified sediments have the right number of pollen variables to allow the calculation of a number of climatic variables. There are pitfalls in the translation of the pollen record to a climatic record, but rather unequivocal answers seem to be possible, as shown for data from southeastern Minnesota (Figure 2).

The most satisfactory source of past environmental data for a specific locale is a good proxy data record for that local area. For example, Baerreis and Bryson (1967) were able to reconstruct, from pollen and bones, the environment of the Mill Creek people in northwestern Iowa (ca. 900–1400 AD). In this case, the data were obtained from the village areas themselves. That is not always possible, especially in areas of

alkaline soil where pollen is not well-preserved. But the proxy data does not answer why the environment was what it was or why it changed.

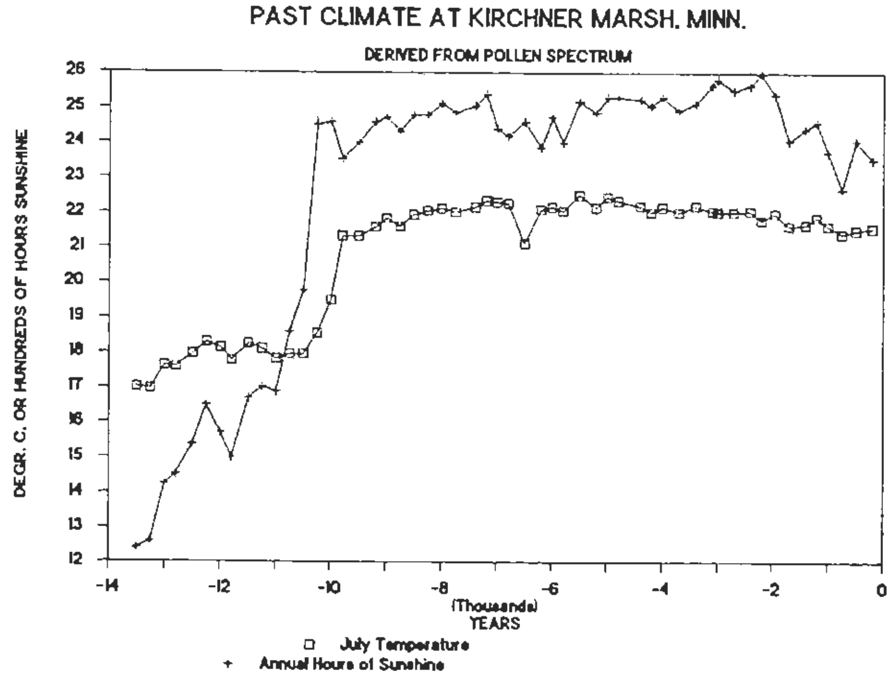

Figure 2a. Past July temperature and hours of sunshine annually at Kirchner Marsh, in southeastern Minnesota, reconstructed using plant pollen as a proxy climate indicator.

Proxy data of various kinds are in accord that global warming during the past century is not unique in any way. There are past times of warming and cooling of quite comparable magnitude. If a theory of climatic change is to be acceptable, it must explain these past warmings and coolings as well as that of the last century.

The study of a very large array of proxy series and cultural data has shown that globally there are strongly preferred times of environmental change and culture change (Wendland and Bryson, 1974). Further study has shown these times to appear in regional data as well (Bryson, in press). For a listing of the apparent global dates of climatic change see Appendix 1.

The relationship between climatic and cultural change should not be unexpected, for environmental change has been long recognized as a possible mechanism involved in culture change through its impact on the agricultural base of most cultures. A characteristic of both palaeo-climatology and history is that they appear to be multicausal. This then, requires that some way be developed to integrate the effects of each variable into a coherent picture, as well as sorting out the various cause-effect relationships.

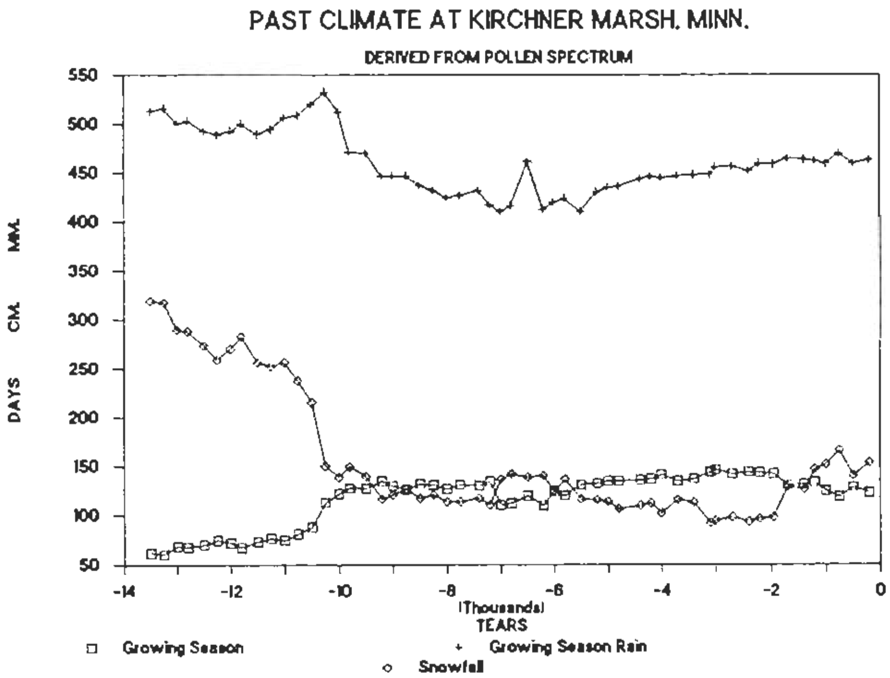

Figure 2b. Length of growing season, precipitation during the growing season, and annual snowfall at Kirchner Marsh, Minnesota, derived from pollen fall as in figure 2a.

SIMULATION OF PAST CLIMATES

In order to answer the questions of causality with respect to climatic change, or to interpolate between places with objective environmental data, it is essential to have a realistic understanding of how the climate system works and why it changes. A formal statement of how the scientist thinks the real world works is called a model. Such a model, or any model for that matter, is nothing more than the modeler's opinion of how the system works. I repeat, nothing more—and model output is just that, and not data, except data on how the model works.

Before a model can be used for explanatory purposes it must be tested against reality. For the present purpose, this means that the model must be capable of simulating the past history of the climate, or at least the present climate, as shown by the field data. If it cannot, then clearly the assumptions embodied in the model are inadequate for understanding the causes of climate and climatic change.

In the following paragraphs some experiments or simulations with two kinds of climate models will be described.

General Circulation Models. As mentioned previously, the literature, both popular and scientific, is currently charged with discussions of the putative effects of a carbon dioxide induced warming of the earth. Every few years, following a major volcanic eruption, there is also discussion of the consequent climatic change and its impact.

There has also developed a convincing set of studies that the variation in irradiance, first intensively studied as a climatic forcing mechanism by Milankovitch, is indeed the clock that times the advances of the great continental glaciers (Imbrie et al., 1984; Kutzbach and Guetter, 1986; Bryson and Goodman, 1986).

The most frequently used type of model for studying the effects of various causes of climatic change is the General Circulation Model, or GCM. This is a very complicated interlinking of equations thought to describe the behavior of the atmosphere. It requires a very large computer indeed to simulate the global state of the atmosphere with a GCM, and may require a million iterations of the calculations. This is because the physics of the model is what I call "microphysics," meaning that it is applicable strictly speaking to very small space and time dimensions. Since the world is very large, this means integrating (adding up) the local physics over very large multiples of the basic scale. In addition, though the physics is non-linear, the millions of mathematical solutions require linearization over short time spans and recalculation. These factors make the computational problem immense and costly.

There are several versions of the GCM in use at present, but they are essentially clones of each other with relatively small technical differences. Unfortunately, they generally contain no provision for several causes of climatic variation. Most have been used to simulate climatic variation due to variations in carbon dioxide concentration in the atmosphere, but the work of Kutzbach and his colleagues mentioned above considers the long-term variation of incoming solar radiation as well.

The test of any model is how well it simulates reality (field evidence). A recent study of the major GCMs shows that they do not do well at all in simulating even our present climate (Kalkstein, 1991). Though there are differences in pattern of error from one model to another, they all have similar magnitudes of error, i. e., over 100% error in simulated precipitation, and generally 2°C in temperature but up to 20°C in Antarctica and 10°C in the Arctic. This is not reassuring when the models are used for forecasts. In fact, when the modeler says that with carbon dioxide doubled, the temperature will be higher by two degrees, what he really means is that would be the case if the errors of the models are fixed at their present values at the future date as well. That, however, is faith on the part of the modeler—not science, for there is no objective evidence that the assumption of fixed error pattern is correct.

Use of a GCM to simulate past climates at intervals of several millennia using calculated variations in solar input and observed changes in the nature of the land and sea surface apparently has been somewhat successful at simulating the general nature of the climatic pattern over a millennium or so (Kutzbach et al., op. cit.).

The problem in part is that, though complex, the models are used to answer rather naive univariate questions without including all of the pertinent data, such as the atmospheric content of volcanic aerosol. In fact, no variables are included that operate on the decade scale, and only one that might cause variation on the century scale.

Still it is possible to make some general calculations on the time scale of centuries that should be pertinent to questions of change in the economic base of past cultures, and that might provide some insight into at least one factor in forest history. This alternate type of climatic model has a time resolution of decades to centuries, and may be used to drive specialized models for regions about the size of most biotic regions.

I call these models, of the type that I have been developing, "macrophysical models."

AN EXAMPLE OF MACROPHYSICAL MODELING.

In the following paragraphs a generalized climate model for the Northern Hemisphere will be described as a preliminary guide to the climatic mechanisms which appear to produce realistic results as judged by the match of the output of the model with the field data. It will also provide a crude guide to when climatically induced cultural and biotic changes might be expected.

There are two fundamentally different ways to model the climate of the earth. The first, the basis of the widely used "General Circulation Models" (GCMs), is microphysical in nature and was described briefly above.

The second type is simpler and may not require iteration. This is based on a macrophysical approach. Relationships of a large scale nature are used, such as the Rossby long wave equations, the thermal wind relationship, or the Z-criterion derived from the work of Smagorinsky (1963). These are examples of relationships which properly apply on the scale of a few thousand miles and hours to days, rather than centimeters and seconds. Models of this sort may be constructed for a microcomputer and require only seconds to run.

The model of West African rainfall which is discussed below required first a model of global glacial volume at intervals of a few centuries, from which the glaciated area could be calculated and the ice albedo effect estimated (Bryson and Goodman, 1986). A hemispheric temperature model was then possible using the so-called Milankovitch type variations in solar irradiance as modulated by volcanic aerosols (Bryson, 1989). The detailed ice volume history has not yet been modeled using a GCM, nor have they included the history of volcanic aerosol variation.

Going from hemispheric or global models to regional models requires that some broad-scale relationships be used. For example, one knows that the westerlies must become stronger with height, up to about 10 km, because the earth is colder at the poles than at the equator, and the upward rate of increase is proportional to the magnitude of the temperature difference. Since equatorial temperatures change little even from glacial to non-glacial times, the average hemispheric temperature and the temperature gradient must both depend primarily on high-latitude temperatures.

With lower polar temperatures, the equatorward edge of the circumpolar westerlies extends closer to the equator. In addition, the intensity of inflow from equatorial oceans into higher-latitude continents is observed to be related to the annual temperature range over the continents. It is thus possible, if one has a simulation of past seasonal hemispheric temperatures, to simulate the west-east and north-south components of the general wind field in monsoon regions (Bryson, 1989).

The simulation may be carried a step farther to simulate the past monthly latitudes of the subtropical anticyclones, the monthly latitudes of the intertropical convergence (ITC) in the Saharan region, the monthly latitudes of the jetstream, and the monthly rainfall in portions of the Saharan region. (The ITC is the line or zone along

which the airstreams from the two hemispheres meet).

Calculating the Latitude of the Subtropical Anticyclones and Jet Stream. The northern part of North Africa has winter rains and summer drought, the rains diminishing from west to east. The winter rains are associated with the southward winter expansion of the circumpolar westerlies and the passage of the southern edges of cyclonic storms in the westerlies. In summer, the subtropical anticyclone (high pressure area) in the North Atlantic expands and extends eastward, bringing the Mediterranean coast under divergent flow from the northeast quadrant of the anticyclone (LaFontaine et al., 1990). The winter rains diminish inland towards the heart of the Sahara. Divergent flow means sinking air and aridity.

South of the central Sahara, summer rains penetrate inland from the Gulf of Guinea, associated with the invasion of moist maritime air behind the Intertropical Convergence (ITC). The rains increase southward for some distance from the ITC position and then decrease until close to the coast where the monsoonal rains cannot be distinguished from those associated with coastal effects (Ilesanmi, 1971). How far the monsoon rains penetrate into the interior clearly parallels the latitude attained by the subtropical anticyclone in its annual march. Thus, both the winter rains of the north and the monsoon of the south may be related to the position of the subtropical anticyclone. One might then begin a simulation of the history of North African rainfall by simulating the past movements of the subtropical anticyclone and the tracks of winter cyclonic storms in the Mediterranean region.

It has been shown by Smagorinsky (1963) that the outer edge of the circumpolar westerlies should, according to his formulation, be determined by the vertical rate of variation of the temperature, and by the north-south or meridional temperature gradient.

Since the outer edge of the circumpolar westerly vortex is also the latitude of the subtropical anticyclones at the same height, Smagorinsky's formulation also gives an estimate of the latitude of the anticyclones at the surface. The outer edge of the westerlies aloft is closely related to the latitude of the "jet stream," so by nearly the same formulation we can estimate the jet stream position. Both of these latitudes are crucial to estimates of mid-latitude climates.

Calculating the Latitude of the Intertropical Convergence and Monsoon. Assuming that the present is the key to the past, the relationships discussed above may be applied to the model the history of the Subtropical Anticyclone and, from empirical relationships, to obtain estimates of the latitude of the intertropical convergence in North Africa and elsewhere.

In calculating the latitude of the ITC, it was assumed that the penetration of the monsoon into the interior is proportional to the subtropical anticyclone latitude, proportional to the excess of the Northern Hemisphere temperature over the Southern Hemisphere temperature, and inversely proportional to the regional stability of the air column.

The physical relationships associated with this assumption cannot be specified analytically at present, so the present annual marches of appropriate proxies were used as a calibration.

As a proxy for the regional stability, since no analytic estimate is available for the past, it was taken as constant for each season, but varying between seasons. The simulated history of the August latitude of the ITC is given in figure 3. The range of latitudes calculated agrees well with commonly accepted observed past shifts in the northern limit of significant vegetation.

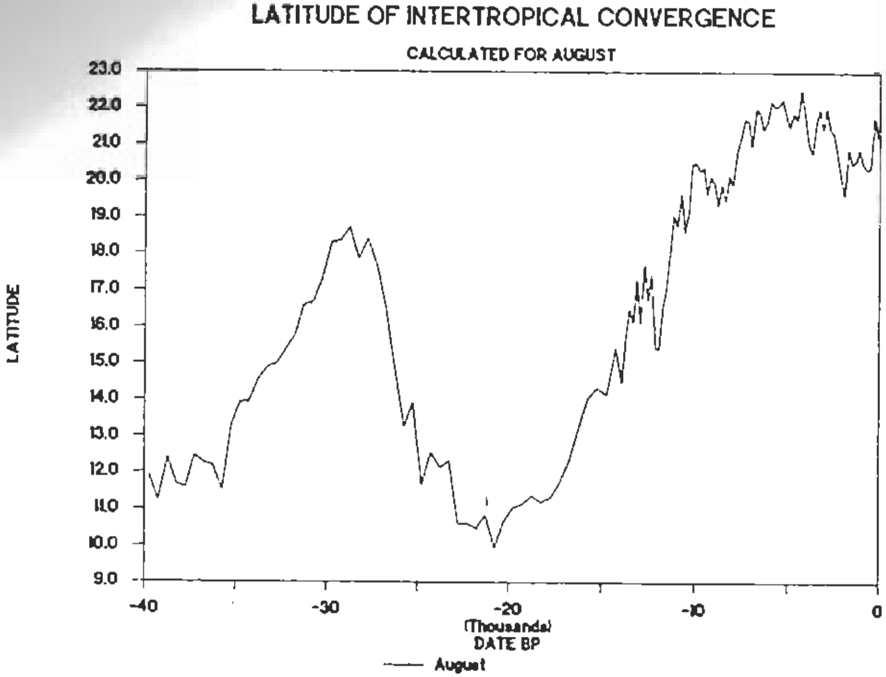

Figure 3. Calculated history of the mean latitude of the Intertropical Convergence in West Africa for August, the month of maximum northward penetration.

Up to this point, the latitude of the ITC has been taken as the mean between 10°W and 30°E. However, the ITC is not a straight line across North Africa. Its latitude varies with longitude, and the variation varies from month to month. Assuming that the variation with longitude is due to the shape of the continent, which has not changed dramatically within the post-glacial period, we can use the present intra-annual east-west variation of the latitude as a function of the mean to estimate past latitudes of the ITC at various longitudes. These are shown for selected past times in figure 4. The figure suggests that while the climatic history of the Ahaggar and Tibesti might be expected to differ, the Air Massif (Adrar Bous), Chad, and Darfur regions might have had similar rainfall histories.

Modeling the Monsoon Rainfall. Ilesanmi (1971) has shown that for some distance south of the Intertropical convergence the rainfall increases linearly in the Nigeria–Togo sector. Thus, if we have modeled the latitude of the ITC, we can use that relationship to model the summer monsoon rainfall at those latitudes that are within the linear regime distance south of the ITC.

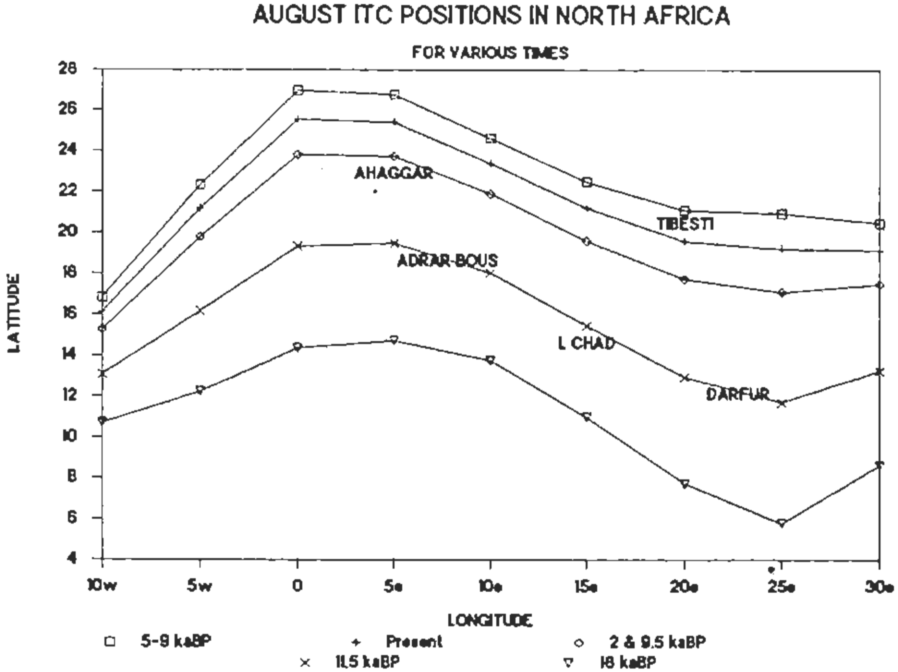

Figure 4. Calculated latitude of the ITC at various longitudes in northern Africa for selected past times, along with the names of important locations.

Using the concept of the Ilesanmi work, the history of summer monsoon rainfall at a fixed latitude may be calculated. The results are given in Figure 5.

Comparison of the Modeled Sub-Saharan Rainfall History With Field Data. There are several sorts of field data with which to compare the model results, but no very good sets of proxy data. We shall first compare the results with data on occupation of the area, on the realistic assumption that without rainfall the region is essentially uninhabitable.

First, all radiocarbon dates for occupation sites within the western North Africa region were extracted from a global data base of dates referring to named cultures within the area. These were then sorted into latitude band groups, and the number of dated occupations per century were counted. As might be expected, the number of occupation dates increased towards the present, certainly in part because older sites are more likely to have been lost by burial or erosion. However the dates diminish within the historical period, from a maximum a few centuries ago to the present, for an investigator is far less likely to incur the expense of running a radiocarbon date if the date is already known because of its historical context. An analysis of this type was done by Geyh and Jakel (1974), but with too little latitudinal specificity for the present purposes.

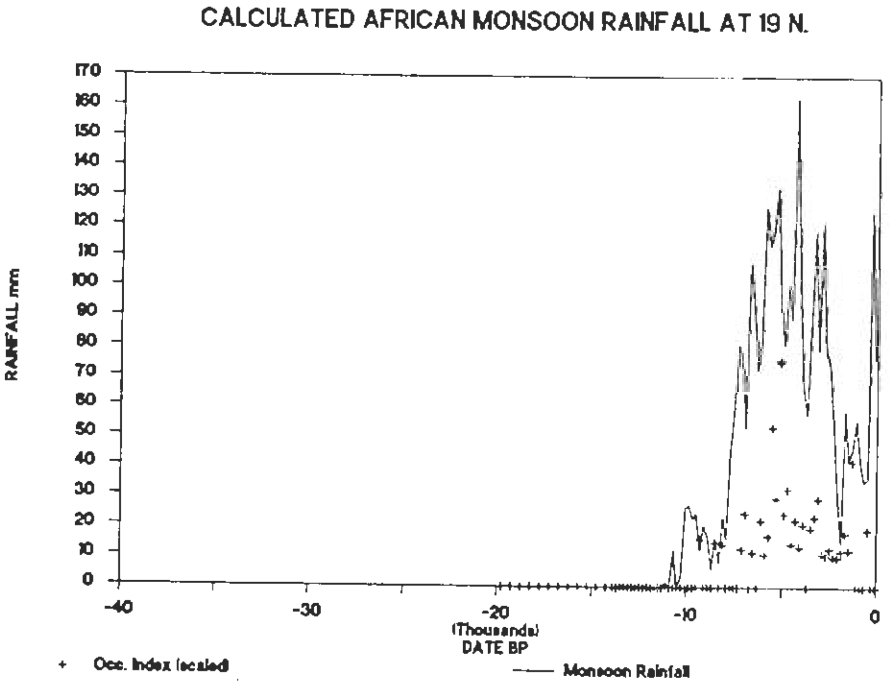

Figure 5. Calculated summer rainfall at 19°N for the 10°W–30°E sector, compared with the Occupation Index as described in the text, scaled to fit on the diagram.

This bias of date numbers towards the early historic period can be compensated for by fitting a suitable curve to the entire assembly of dates and then expressing the date numbers per century as an index defined as the departure of the observed date numbers from the "expected" number (based on the fitted curve), divided by the expected number, plus one to make all indices positive. A curve suitable for expressing the "expected" number is the familiar "serpentine curve."

The Occupation Index for the Sahelian region, scaled for convenience, is included in figure 5. There are essentially no sites more than about 9,000 years old. For this zone, the agreement is surprisingly good. When the model simulation indicates essentially no rainfall, there are no people, all of the occupation of the region being restricted to the period of indicated rainfall adequate to support some vegetation.

Rognon (1976) has summarized a large amount of field evidence for the Saharan region, as well as attempting a dynamic interpretation of the atmospheric circulation that might have influenced the climates of the last 40,000 years in the area. His summary, as well as the summaries of others (e.g. McIntosh and McIntosh, 1981), indicates maximum rainfall in sub-Saharan Africa in the period from about 10,500 BP to about 6,000 BP. (BP means years before 1950). Most authors cited suggest a decline from

6,000 to about 2,000 BP or so rather than a decrease as rapid as the increase at the onset of the Holocene. These summaries are in accord with the modeled results shown in Figure 5. Several of the authors cited in these summaries also found the absolute minimum of Holocene rainfall to be about 2,000 BP with a small maximum a couple of centuries ago. This also accords with figure 5.

Simulation of the Climatic History of the Pacific Northwest. Simulation of the past climate of the Pacific Northwest is much more complex than simulating the African monsoon, because of its west coast position athwart the westerlies and its mountainous terrain. There are two anticyclones to deal with, and two branches of the jet stream. The climate is also sensitive to the longitude of the major ridges and troughs in the westerlies. There are also more varieties of air to deal with. In principle, however, it is a similar problem. Enough progress has been made to indicate that at least a tentative climatic history can be constructed for testing by Quaternary scholars.

The macrophysical model described above is being used to drive a regional model designed for the specific conditions of the Pacific Northwest. Empirical relations between the positions of the jet streams, troughs and anticyclones and the rainfall at Portland were then developed for each month of the year. As a first test, linear relations between the circulation features and the rainfall were used.

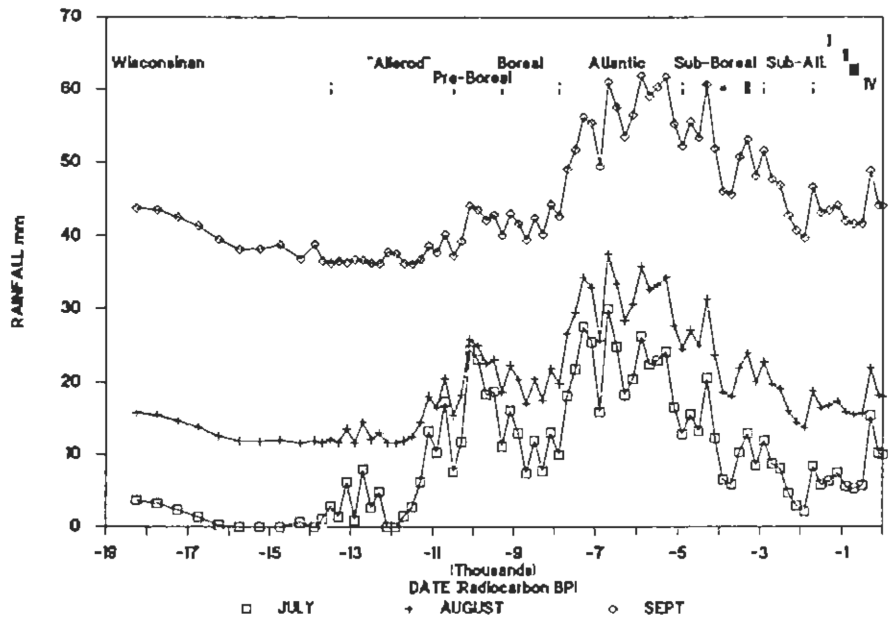

Figure 6. Tentative simulation of past rainfall at Portland, Oregon for the summer months. Global climatic episodes are identified at the top of the graph to identify the corresponding episodes in Oregon.

Figure 6 displays the results of this first crude output of the regional model driven by the macrophysical hemispheric climate model. The most dramatic event suggested by the results is the onset of some July rainfall at the beginning of the Holocene, rising to well over double the present value during the Atlantic climatic episode. The second most recent point on the graph suggests somewhat wetter summers during the sub-episode marked IV in the figure, a sub-episode that has been named the Neo-Atlantic and is popularly known as the "Little Ice Age." This of course extends into the historic period and can be easily verified by reference to the local weather records.

There remains the challenging job of elaborating and improving the present crude model and, above all, testing it against field data, especially the available proxy data. This must include a much more sophisticated understanding of climate in montane regions. This is under way, however, and the preliminary results are very promising.

PREDICTING FUTURE CLIMATES

What the future climate will be is more important to our society than what past climates have been, but to repeat for emphasis: If we cannot simulate the past climate, we do not understand climate well enough to simulate or predict the future climate. A climate model, to be successful at simulation, must at least contain the factors that cause variation.

The large, complex General Circulation Models have not successfully simulated past climatic fluctuations on the scale of decades to centuries. They have not been given inputs that have variation at that time scale, and variations on that time scale have not been demonstrated to arise from internally produced variations or variation in the carbon dioxide content of the atmosphere. Simulation of long-term climatic variation with GCMs has done quite well on the multi-millennial time scale but only with the input of known ice cover. This we do not know for the future.

One test of whether variations in weather (and by extension, climate) might arise internally in the atmosphere lies in daily weather forecasting and seasonal forecasting. This is done by assuming that tomorrow's weather, or next month's, develops almost entirely as a consequence of what is already there in the atmospheric dynamics. It is clear that this works for one day, less well for two days, still worse for three days, etc., until there is little skill after five days. Long range forecasts of a month or more have not achieved results much better than obtained by flipping a coin. One then must wonder whether adding a single factor to the forecast scheme can produce meaningful forecasts at 50 years in advance. That is exactly what the prediction of global warming due to increased carbon dioxide is, a very long-range forecast based on a model totally untested for long-range forecasting.

Some other types of models, such as the macrophysical model described above, have demonstrated the ability to simulate the shorter scale past fluctuations in the climate because they have included volcanic modulation of the incoming solar radiation. Both types of model, when run out into the future, predict another major advance of the continental glaciers as a consequence of predicted changes in the earth-sun geometric relations. This advance should peak 8–10 thousand years in the future, but the

more interesting question is when the next ice age will start. Here a comparison cannot be made because no comparable forecasts with the same inputs have been made, and in order to include the effect of volcanic aerosols a forecast of future volcanic activity would have to be made.

Using the only model that has demonstrated ability to simulate the five-year mean variations of climate in the past century, and assuming the scenario that the volcanoes will remain constant at the 1970 level, the conclusion is reached that, when carbon dioxide doubles, the Northern Hemisphere temperature will be about what it was in 1951 (Bryson and Dittberner, 1976). That hardly seems catastrophic since we got through 1951 without much difficulty.

Since global volcanic activity is somewhat periodic, a rough forecast can be made. Combined with the macrophysical model, the combination of calculated radiation and predicted volcanicity gives the forecast that the onset of ice age climates sufficient to cause the growth of continental glaciation should be within the next four centuries. Unfortunately, I probably will not be here long enough to find out whether the forecast is correct and improve the model!

SUMMARY

Climatic change is not a new phenomenon, nor is it random, since most of the variation can be explained in terms of variations in the sunlight reaching the surface of the earth. The solar energy reaching the surface is modified by the aerosols in the atmosphere, of course, and that means primarily aerosols of volcanic origin.

The climatic history of the earth is divided into episodes with abrupt beginnings and ends. Rapid changes from one climatic state to another are normal. The fluctuations within this century do not appear to be unusual in any respect.

To the author's knowledge, there is no evidence that past climatic changes, including those of the past decades, are related to changes in carbon dioxide in the atmosphere, except perhaps warmer nights in the midwest. It is not possible to simulate past climates using carbon dioxide content as the main variable, but it is possible using calculated solar radiation as modified by volcanic aerosols. This strongly suggests that forecasts of the climatic future based on carbon dioxide increases are suspect.

Computerized models of the climate that can simulate decadal and century variations of climate as well as variations on the millennium scale suggest that the climate will not warm dramatically in the next fifty years, but will, rather soon after that, begin a rather rapid change towards the next glacial climate.

Changes in our global array of cultures sufficient to affect the global climate in a way we perceive as beneficial, probably are not possible within centuries without massive conflict. There are both winners and losers when the climate changes in a non-uniform pattern, as it always does. It is a well-known fact that a global change of 0.5°C in mean temperature might produce some regions of 10°C change in either direction and some regions with no change, and an array of rainfall changes of various magnitudes. Russians would welcome warming of their climate.

The problems with attempting to modify the global climate in a particular direction are enormous and incredibly expensive. This is compounded by not knowing what the climate would do without intervention. Only one thing is truly clear, and that is that the present knowledge of the climatic effect of changing carbon dioxide content of the atmosphere is totally inadequate as a basis for initiating any global attempt to change the climate.

The indicated action would appear to be to engage in some high quality climatic research based on sound science before taking global risks greater than those that might arise from the putative "global warming."

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APPENDIX

Tentative Division of the Holocene into Climatic Episodes, Based on Globally Preferred Dates of Climatic Change

CLIMATIC EPISODE	SUB-EPISODE	PROVISIONAL TERMINI	POSSIBLE SUB-DIVISION TERMINI
		Present	
	Modern		
		1915-1920 AD	
	Neo-Boreal ("Little Ice Age")		1885
			1820
			1765
Post Sub-Atlantic			1720
			1600
		1550 AD	
	Pacific		1400
		1150-1200 AD	
	Neo-Atlantic ("Med. warm period")		1000
		700-750 AD	
	Scandic		
		300-400 AD	
Sub-Atlantic	S-A III		
		50-100 BC	
	S-A II		
		ca 500 BC	
	S-A I		
		ca 950 BC	
Sub-Boreal	S-B II		
		2100 BC	
	S-B I		
		2900-3000 BC	
Atlantic "Climatic Optimum"	A IV		
		ca 4920 BC (5970 BP)	
A III			
		6740 BP	
	A II		
		7060 BP	
	A I		
		7900 BP	
Boreal	B II		
		8490 BP	
	B I		
		9160 BP	
Pre-Boreal			
		10800 BP	

Note: BC= calendar date, BP= radiocarbon date