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Global warming: the process and its anticipated phytoclimatic effects in temperate and cold zones

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Abstract. Postglacial vegetation dynamics reflects global warming and cooling as these occur in normal progression through precession cycle. It also reflects thermal influences of aberrations such as variations in the Sun's radiation and in the Earth's atmospheric CO_2 concentration. Although the present precession cycle is in the final cooling phase as it approaches a new age of glaciation, global warming caused by man-made increases in atmospheric CO_2 and other greenhouse gases may temporarily, albeit substantially, subvert the cooling climatic tend. The author uses the Manabe ocean-atmosphere model's prediction of a 2.5^o global temperature rise in less than 7-decades to quantify the level of warming, and on this basis, he undertakes an examination of the potential local effects over latitudes in eastern North America and elevations in Hawaii. His results indicate local thermal flux ranging from over 12^o (Arctic Tundra at 58^o N) to under 4^o (Warm Temperate

Evergreen Forest at 32° N)[1]. A comparative evaluation of these lead the author to hypothesize that the present vegetation of the cool temperate and cold region will disintegrate. When this happens, it will beget the rise of new plant communities that will be little more than chance assemblages of population remnants, species poor and ill-defined. But given enough time, migration, competition and environmental sorting will enhance community level differentiation and sharpen a new, climate-determined regional pattern. Neither the communities nor the zonal pattern will be comparable to those of today. The Tundra will lose much of its niche and the Boreal Forest will shrink to quantitatively insignificant isolated stands on azonal northern sites. Elements of the Cool Temperate Deciduous Forest and to some extent the Mixed Conifer-Northern Hardwood Forest will appear in parts of Labrador and adjacent maritime regions to the south. The Oak-Hickory Forest and Savanna, now wedged between grassland and eastern deciduous forests from Minnesota to Oklahoma, and the Warm Temperate Evergreen Forest in the southern Gulf and Atlantic states will be major gainers. Suitable elements of the Oak-Hickory Forest will disperse in north-east direction to form a broad north-south belt extending from subarctic western Quebec to the central Great Lakes where thermal,

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[1] All temperatures in Celsius degrees.

soil moisture, and precipitation regimes will approximate the present conditions in the eastern plane states. Significantly, the Warm Temperate Evergreen Forest will expand north and northeast in step with the expanding influence of the Maritime-Tropical Airmass. On the mountains of Hawaii, the vegetation zones will shift upwards, resulting in the disappearance of the Tropical Alpine Tundra on Mauna Loa and Mauna Kea, and possibly the Tropical Subalpine Scrub vegetation on the lesser high mountains. Regional economies will disintegrate and major dislocations of populations will fan severe regional conflicts.

Purpose and sites

The following sections address global warming, local thermal flux, and anticipated collateral effects in the wake of 2.5° global temperature rise in less than 7-decades. The author's intentions are to examine isolated pieces of evidence and to piece together a general theory of vegetation shifts.

The localities under scrutiny include five sites from the southern limits of the major vegetation zones in eastern North America. These are at Port Harrison (Quebec, Arctic Tundra), Timmins (Ontario, Boreal Forest), Stratford (Ontario, Mixed Conifer-Northern Hardwood Forest), Nashville (Tennessee, Cool Temperate

Deciduous Forest), and Mobil (Alabama, Warm Temperate Evergreen Forest). Two additional sites are in Tropical Alpine and Subalpine vegetation on Mauna Kea in Hawaii.

The extended Port Harrison-Nashville line intercepts four broad bioclimatic belts. In terms of averages, the Arctic Airmass dominates north of the 48th parallel, and the Maritime Tropical Airmass south of the 34th parallel. Between these extremes, the Pacific Airmass shares dominance with the Arctic Airmass above the 44th parallel and with the Maritime Tropical Airmass below the 44th parallel. The semistationary tropical Pacific High located northeast of Hawaii, the southward shift of the northern storm tracks in the winter, relatively low seasonal variation of the energy received from the sun, ocean and orographic effects - such as the lag of seasonal high/low temperatures, average adiabatic laps rate of 0.5^o per 100 m, steep increase up to and then steep decline of precipitation above the temperature inversion line (at about 1000 m elevation windward side), and leeward aridity - characterizes the island environment.

The precession cycle

The physical bases of global warming and cooling are found, in part, in variation of the Earth's orbital parameters that Milankovitch (1941) described and

Pielou (1991) interpreted to an ecological audience. They are also found in variation of the sun's radiation and in changes of atmospheric composition, particularly in CO_2 concentration (Mason 1990, Mungal and McLaren 1990, Manabe et al. 1990).

The Earth's orbital geometry undergoes long-term and short-term cyclic variation with predictable consequences for the volume of ice on the earth's surface. A short cycle, called precession of the equinoxes, began 18,000-years ago and will end in about 3,000 years. In this cycle, the time point of minimum distance between earth and sun moves through the seasons, causing changes in the apportionment of incoming solar radiation between winter and summer. When the earth is far from the sun in summer, the thermal contrast of the northern summer and winter is reduced (mild summer, mild winter), snow and ice accumulates, and the glacial age is turned on. When the earth is close to the sun in summer, the seasonal thermal contrast sharpens (warm summer, cold winter), the winter snow and ice melts and an interglacial period is turned on, provided that the states of other parameters under the Milankovitch cycle permit this to happen.

At the beginning of the precession cycle, the global annual average temperature was 11°, compared to the present 15°, and the Laurentide ice sheet extended below the 40th parallel (Delcourt and Delcourt 1987, Fig. 1-4)[2]. The southern limit of the narrow Arctic Tundra belt lay just below the 39th parallel, the Boreal Forest had its southern limit just above the 33rd parallel, and the Mixed Conifer-Northern Hardwood Forest occurred in a narrow belt between the boreal forest and the Warm Temperate Southern Evergreen Forest. The Cool Temperate Deciduous Forest did not yet appear as a distinct vegetation formation. The precession cycle has reached its thermal maximum (Hypsithermal, expected highest contrast between summer and winter in energy received from the sun) 10,000 years ago, then the slow descent of the orbital parameters back to their Ice Age states began. Interestingly, the global temperature peaked much later about 5,000 years ago. By that time, the southern limit of the Boreal Forest has been pushed north above the 49th parallel and the Cool Temperate Deciduous Forest attained its present northern limit near the 43th parallel. The present southern limit of the Boreal forest is just above the 48th parallel, where the Arctic Tundra had its southern limit some 9,500 years ago. The southern limit of the Arctic Tundra is put at just above the 55th parallel.

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[2] All latitudinal limits are given on the Port Harrison (Quebec) and Nashville (Tennessee) line.

Precession dynamics was closely followed by substantial altitudinal vegetation shifts on the high mountains of Hawaii. Traces of this are most clearly seen on Mauna Kea (19° 49' N), the highest volcano in Hawaii which attained its impressive height (4000+ m) well before the present precession cycle started. It had an ice cap about 60 m deep 20,000 years ago (Cruikshank 1986) that extended down to the 3200 m level. Coinciding with this, the Tropical Alpine Tundra covered a broad belt from ice edge to the 2500 m level. Today, the Alpine Tundra occupies elevations above 3300 m. By around 10,000 before present, the global climate warmed to 12.5° and Mauna Kea's ice cap melted. The elevations that once supported the Alpine Tundra now support a Tropical Subalpine Scrubland vegetation. Table 1 describes these formations.

Table 1. Elevation related tropical bioclimatic gradient on Mauna Kea, leeward slope. Data from Krajina (1963) with revisions.

Vegetation	Elevation m	Annual mean t. °C	Precipitation mm
Alpine Tundra and Barren	3300 -	0	- 510
Subalpine Scrubland	2000 - 3300	4.4	510 - 1020
Subhumid Savanna	1200 - 2000	10.0	1270 - 1520
Subhumid Open Forest	500 - 1200	20.0	1020 - 1270
Semiarid Thorn Scrub	300 - 500	23.1	640 - 1020
Semiarid Savanna	- 300	24.6	- 640

The effect of greenhouse gases

Postglacial vegetation dynamics reflects not only progression through the Milankovitch precession cycle, but importantly, noncyclic greenhouse warming linked to periodic increases in atmospheric CO_2 concentration. Clearly, CO_2 concentration had a long-period of increase in 17,000 to 10,000 years ago (Neftel et al. 1982) and other times, but the rate of CO_2 increase has taken an alarming turn upwards only in recent decades (Bacastow and Keeling 1981, Bolin 1989, Mason 1990, McKay and Hengeveld 1990, Fig. 7). This happened because of massive man-made emissions. Along with CO_2, other greenhouse gases (CH_4, N_2O, CFCs) also increased.

Monographs on global warming point out that water vapor, carbon dioxide (CO_2), methane (CH4), nitrous oxide (N_2O), ozone (O_3), and chlorofluorocarbons (CFCs)▌▌ collectively known as the "greenhouse gases"▌▌ reduce the earth's heat loss to outer space and keep the surface of the earth warm by absorbing infra-red terrestrial radiation. These collectively prevent about 91% of infra-red radiation from escaping from the earth's surface into outer space. Without greenhouse gases, the global average temperature would be -19°, compared to the present +15°. Water vapor and CO_2 are by far the most important infra-red absorbing agents, except at wavelengths from 8 microns to 12 microns where the trace gases are efficient. On a molecular basis, CH_4 is 21 times more effective than CO_2, and the CFCs are over 700 times more effective than NH_4 (Mason 1990). In discussions of the topic, it is usually pointed out that owing to already elevated levels, the atmospheric concentration of greenhouse gases should have caused a 1° temperature rise since the turn of this Century, but it did not, because, as often pointed out, the thermal inertia of deep oceans prevented it. Mason (1990) gives reasons for this and explains that a net 0.5° temperature rise in this Century, calculated by Henderson-Sellers (1990), is not a greenhouse signal.

According to best estimates, terrestrial temperatures will soon begin a greenhouse rise, 0.5° by the year 2010 and 2° - 3° by 2060 (Manabe et al. 1990), assuming that greenhouse gases continue to increase in a manner equivalent to CO_2 concentration rising at a 1% compounded annual rate and doubling by 2060. To put the magnitude of this temperature rise into proper perspective, it will be sufficient to recall three well known facts about the global average temperature:

-- it is only a mere 4° higher today than it used to be at the height of the last glaciation;

-- it probably never exceeded the 15° mark by more than 2.5° during recent interglacial periods;

-- its oscillations remained within a ± 3.5° range over the past 3,000,000 years (McKay and Hengeveld 1990).

These show clearly that a 2° - 3° temperature rise is indeed extreme on the scale of historic events.

Local thermal flux

The general circulation models (Mason 1990) predict it in general terms and it can be seen from the contents of Table 2 in particular cases that the rate at which a given global temperature rise is linked to local temperature increases depends on latitude. The Arctic Tundra is an example. At its southern limit near Port Harrison, the present annual mean temperature is -7.5°. Some 9,500 years ago, its southern edge lay 10 degrees farther south in the Timmins area where the present annual mean temperature is 1.3°. The thermal distance of the historical and present southern limits is 8.8°. Considering that the global average temperature was 12.6° (this number by interpolation) 9,500 years ago and it is 15° at present, the thermal flux rate at Timmins is 8.8/2.4=3.7. In other words the anticipated local temperature rise at Timmins in the wake of a 1° rise in the global average temperature is 3.7°. The anticipated total temperature rise under the Manabe model scenario is 3.7x2.5° or 9.3°, and the anticipated annual mean temperature is 10.6°. Similar calculations yield the values in rows 5, 6, 7 of Table 2.

Anticipated vegetation

The organ and cell-level mechanisms of plant response to cooling and warming are well understood (see references in Mueller-Dombois 1992). Also, vegetation models can be found based on anticipated temperatures (Table 2), precipitation levels (Mason 1990, Figs. 6,7) and soil moisture conditions (Stewart and Tiessen 1990, Fig. 58a) that may serve as sources for migrant populations to compose new plant communities in the wake of greenhouse warming. The following synopsis describes potential states on which warming-induced local vegetation development should converge in the long run:

Port Harrison (58° N). Daily 1 mm rise in precipitation is expected in the immediate vicinity over Hudson Bay in winter, and to the east and north in summer. On this basis, anticipation of 500-600 mm annual precipitation appears realistic. Soil moisture will decline by 20% to 30% on upland sites, and the local temperature will rise by more than 12° to a new annual average of over 4°. These parameters point to the semiarid Oak-Hickory Forest model of western Minnesota. Elements of this model, photoperiod and soil quality permitting, will find suitable niche on upland sites. Tundra and boreal species may continue to exist in cold, sheltered sites on peat.

Table 2. Description of conditions at the lower latitude/elevation limits of vegetation zones. The southern limit of the Warm Temperate Evergreen Forest is not climatic. Values underlined are extrapolations based on TFR = -2.57538+0.12749X in which X represents the decimal equivalent of the locality's northern latitude. The corresponding value of the coefficient of determination is 0.97. Regression does not include the Mauna Kea sites. Abbreviations: TFR - thermal flux rate; LT. - local temperature rise; VP - expected annual mean temperature. Data in rows 3, 4 are from Walter et al. (1975), except last column which are from Krajina (1963).

	Arctic Tundra	Boreal Forest	Mixed Conifer - Northern Hardwood Forest	Cool Temperate Deciduous Forest	Warm Temperate Evergreen Forest	Tropical Alpine Tundra (3,300m)	Tropical Subalpine Scrubland (2,000m)
1. Climatic station	Port Harrison, Quebec	Timmins, Ontario	Stratford, Ontario	Nashville, Tennessee	Mobil, Alabama	Mauna Kea, Hawaii	
2. Northern lat.	58° 26'	48° 31'	43° 22'	36° 10'	31° 42'	19° 49'	
3. Precip. mm	372	711	773	1,144	1,439	510	1020
4. Mean ann. t. °C	-7.5	1.3	8.3	15.6	19.8	0	4.4
5. TFR value	4.9	3.7	2.8	2.1	1.5	1.8	1.8
6. LT. value °C	12.3	9.2	7.0	5.3	3.8	4.5	4.5
7. VP value °C	4.8	10.5	15.3	20.9	23.6	4.5	8.9

Timmins (48° N). Precipitation remains unchanged (711 mm), although soil moisture losses will be substantial (40% to 50%). The annual mean temperature will rise just over 10°. These values point to the Oak-Hickory Forest and Savanna model of eastern central Nebraska as possible source of migrants for upland sites. Boreal and Mixed Conifer-Northern Hardwood Forest species will continue to exist in cool sheltered sites on peat and clay.

Stratford (43° N). Some reduction is expected in summer precipitation and a 30% to 40% reduction in soil moisture. An anticipated 700 mm annual precipitation and over 15° annual mean temperature identify the Oak Hickory Savanna and Grassland models of central Oklahoma as possible species sources.

Nashville (36° N). The average precipitation will be maintained, but the winters will be drier and the summers wetter under the increased influence of the Maritime Tropical Airmass. These and the high (over 20°) annual mean temperature point to elements of the Warm Temperate Evergreen Forest model as possible components of future vegetation. Remnants of the present Temperate Deciduous Forest will survive in the high elevation belt of the Appalachian Mountains.

Mobil (31° N). The high precipitation level and its manner of distribution between seasons remain the same, but the annual mean temperature will rise above 23°.

These will draw some new species into the region without essentially changing the character of the present vegetation.

Mauna Kea (19° N). The local temperature will rise to 9° in the Subalpine zone, and if the same thermal flux rate (1.8) holds, to about 4° in the Alpine Tundra. These will trigger zonal migrations. The Subhumid Savanna invades the present sites of the Subalpine vegetation which in turn, land mass and aridity permitting, invades the present altitudinal belt of the Alpine Tundra.

Approach and accuracy

The choice of localities is incidental, beyond the intention to span many degrees of northern latitudes and to have reliable information about them. The question of accuracy is legitimate in connection with data sources. Admittedly, they are not as optimal as one would prefer, it cannot be said that the baseline data are critically faulty or even inadequate. The derivation of some historic temperature values by linear interpolation matters, but it was performed within a rather tightly linear segment of the time/temperature graph presented in McKay and Hengeveld (1990, Fig. 3). One major methodological deviation from previous practice, that may also bear on accuracy, is the use of historic increases in the global annual mean temperature to determine local thermal flux rates. The values in the last 3 columns of Table 2 are based on 15° as the global annual mean temperature (Mason 1990), therefore, they are somewhat higher than would be if the calculations were based on the 16° figure that McKay and Hengeveld (1990) use.

Overview and conjectures

The 2.5° global warming within seven decades would probably have a less severe effect on the vegetation, if it implied a uniform temperature rise over the earth's surface. The calculations show a practically functional latitude-dependent trend of the expected local temperature rise. It is clear on historical grounds that even at the lesser thermal flux rates, the vegetation response expected to be substantial. All indications point in fact to a severe response in the high flux rate areas, probably complete disintegration of the vegetation in the cool temperate and cold region, including substantial species losses. Disintegration will beget chance associations[3] of populations that can withstand the thermal stress or have propagules equipped to disperse quickly over great distances, develop under soil conditions that are initially out of phase with the changing climate, and flourish under the given photoperiod.

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[3] The low altitude vegetation on the Hawaiian Islands is an example where haphazard assemblages of species compose communities. Significantly, these came into existence by deliberate or accidental transplantation of species. Just one monomaniac, H. Lyon, introduced some 10,000 exotic trees and other plants to Hawaii in the span of 27 years. These surely included hundreds of species which my source (Welcome to Foster Garden: Self-Guided Tour) does not specify.

The initial population configurations will converge, probably in the time span of centuries, on a mosaic of distinct plant communities and a climate-determined unique zonal pattern.

Two major directions of migration will result in the new zonal pattern. One from the south-west will propel suitable elements of the Oak-Hickory Forest and Savanna, that today stretches in a well-defined belt from Minnesota to Oklahoma, between the Tall-Grass Prairie and the eastern deciduous forests, north-east into a similar wide belt, extending from eastern subarctic Quebec to the central Great Lakes and possibly some distance beyond to the south. The exact southern limit of this belt will depend on how far the Maritime-Tropical Airmass of the Gulf of Mexico will extend its climatic influence north and northeast. Port Harrison, Timmins, Stratford will be in different floristic provinces of this belt. Another major direction of migration points from the south-east Gulf region to the north and northeast. This will draw the Warm Temperate Southeastern Evergreen Forest farther inside the continent and up along the Atlantic Coast in step with the expanded dominance of the Maritime-Tropical Airmass. Warming will dislodge the Cool Temperate Deciduous Forest and the Mixed Conifer-Northern Hardwood Forest from their present sites. Elements of the Cool Temperate Deciduous Forest, and to a lesser extent, elements of the Mixed Conifer-Northern Hardwood Forest, will find refugia in Labrador and adjacent maritime regions to the south and on high elevations in the Appalachian Mountains. The Boreal Forest will end up having no significant niches left in the region, except locally on northern azonal sites. There are no altitudes high enough to preserve the Boreal bioclimatic environment anywhere in eastern North-America, and low precipitation will prevent its extension into the high Arctic.

The vegetation of Hawaii will begin a zonal march up through elevation belts. The Tropical Alpine Tundra will disappear. The lesser high mountains will loose the Tropical Subalpine Scrubland.

Closing remarks

The 20th Century is ending with the global climate warmer than at its beginning. A new greenhouse warming may be just around the corner in the 21st Century. The major circulation models are rather clear on this when they forecast a sharp temperature rise beginning in less than 2-decades. Ironically, society is defenseless, since no ameliorative measures can stop greenhouse warming immediately. They can only reduce the rate of atmospheric deterioration that could lead to more greenhouse warming.

Bioclimatic projections usually assume gradual change at a slow rate on the time scale of organism longevity. The post-glacial bioclimatic process is on average this kind. This is quite apparent from the orderly march of vegetation zones through time and latitudes in the reflections of fossil pollen and microtissue spectra. Significantly, this regularity is the product of a convolution of natural processes. The anticipated greenhouse warming is very different. It issues from man-made emissions of carbon dioxide and other greenhouse gases into the atmosphere and it can change the global temperature very quickly in a matter of decades. Matters are made even worse by ill-conceived forestry practices. All know the dangers in these, yet the deleterious practices not only continue but *horribile dictu* may even accelerate through basically negative planning. The most typical case of this is the narrowing of the rotation cycle (Botkin et al. 1992) seen as an answer to minimizing future business losses of the forest industry in the wake of greenhouse warming.

Will a 2.5° greenhouse warming really happen within the suggested time frame? Its consistency with basic physical principles and causal factors on trend with processes that did lead to greenhouse warming at other times in the precession cycle, are good reasons for society to start planning. The plans should consider as potential outcomes, the disintegration of regional economies, major population shifts, and inter- and intranational conflicts.

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