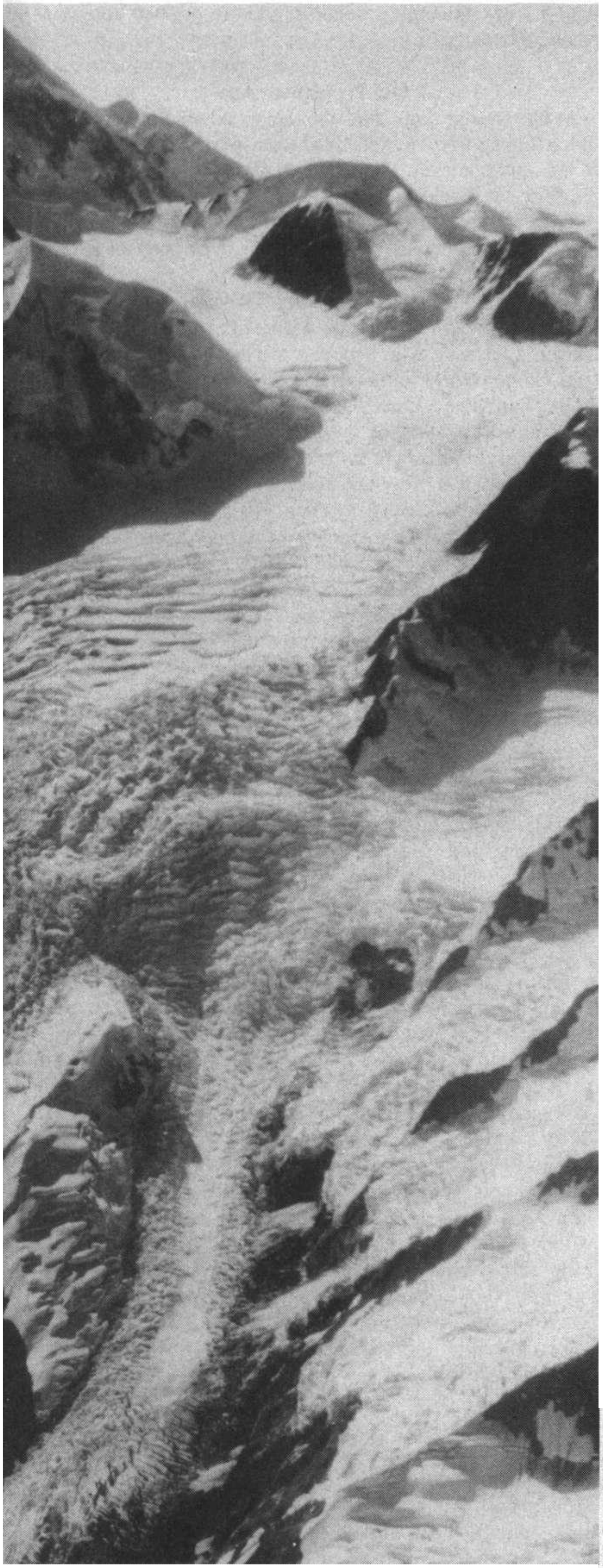


The Coming (or Present) Ice Age

A long-term perspective on the current global warming fad

by Laurence Hecht

We are now in an ice age and have been for about the past 2 million years. Over the past 800,000 or so years, the Earth's climate has gone through eight distinct cycles of roughly 100,000-year duration. These cycles are driven by regular periodicities in the eccentricity, tilt, and precession of the Earth's orbit. In each of the past eight cycles, a period of glacial buildup has ended with a melt, followed by a roughly 10,000-year period—known as an interglacial—in which relatively warm climates prevail over previously ice-covered northern latitudes.

The Margerie Glacier in Glacier Bay National Monument, Alaska, is a typical fast-moving mountain glacier.

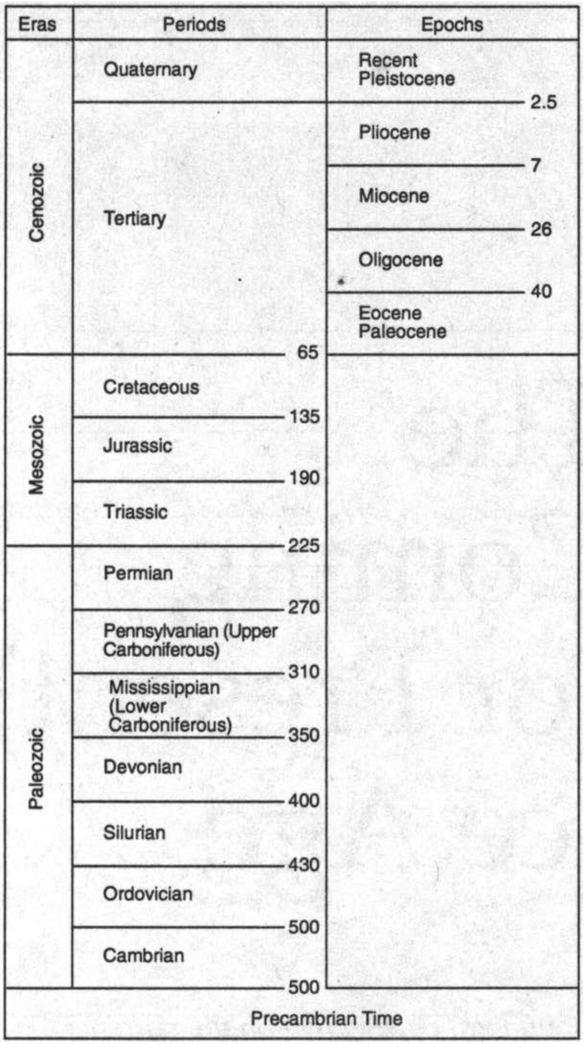


Figure 1
THE GEOLOGIC TIME SCALE
Time units of the geologic time scale. (Numbers are absolute dates in millions of years before present.)

The present interglacial has already lasted beyond the 10,000-year average. One may thus suspect that a new period of glacial advance, a new "ice age/' is in the making. Whether it will take a few thousand years or a few hundred, or whether the process of glacial advance is already under way is difficult to say. Of one thing we are sure: The present hysteria over global warming—with its apocalyptic forecast of melting of the polar ice caps, flooding of the coastal cities, and desertification of the world's breadbaskets—is not helping citizens to understand the real and complex forces that shape the Earth's climate.

We do not wish to counter the global-warming hysterics with a new scare tactic of our own. Nor will we concern ourselves here with refuting every wild conjecture put forward by the proponents of a global warming. Enough holes have already been poked in this "theory" (really only a conjecture) to cause honest scientists to exercise caution.[1] Rather, let us take a sober look at the long-term picture of Earth's climate that has been put together over centuries of careful work in the fascinating and challenging multidisciplinary science known as paleoclimatology.

Our Present Ice Age

At the present time, glaciers—large, slowly flowing masses of ice formed from recrystallized snow—cover about 6 million of the approximately 57 million square miles of land area on the Earth. At the height of an ice age, perhaps another 8 to 12 million square miles of land area, largely in the Northern Hemisphere, becomes covered with a thick layer of ice and crushed snow.

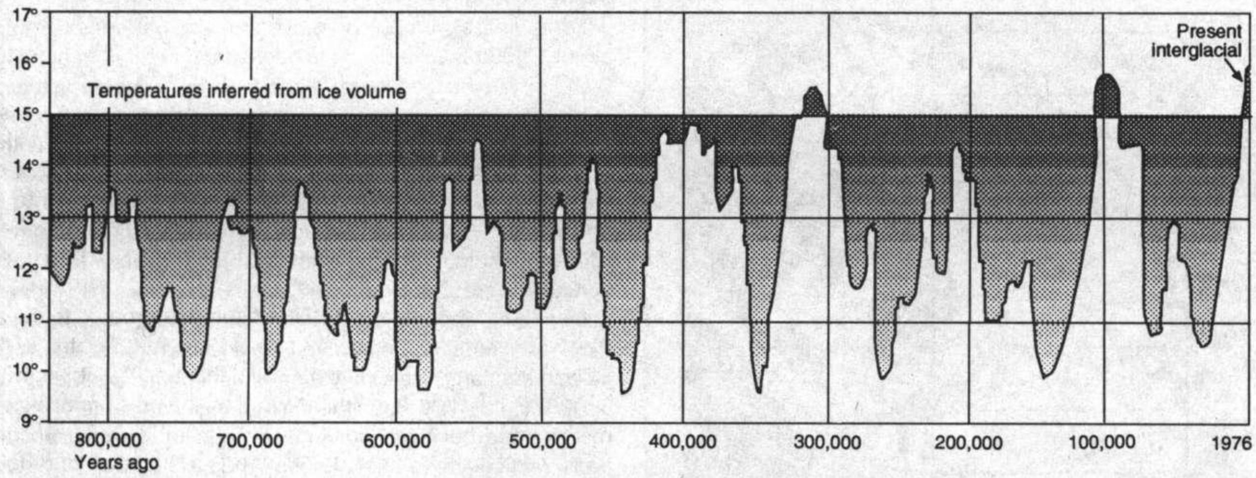
The idea of large-scale glacial motion was brought to the attention of modern science by a Swiss chamois hunter in the early 19th century, who hypothesized that unusual striations in large exposed rocks had been caused by the pressure of a glacier that had since retreated up the mountain. Louis Agassiz, the Swiss paleontologist and associate of the famous Humboldt brothers, waged the fight to convince the scientific community of the truth of this hypothesis, beginning at a conference of the Swiss Society of Natural Sciences at Neuchatel in 1837.

Northern Hemisphere glaciers have been with us only for approximately the past 2 million years, a short stretch on the roughly 4.6 billion-year scale of geologic time, in which our present era, the Cenozoic, occupies the most recent 50 million years (Figure 1). The Cenozoic era is divided into two periods, the Tertiary and Quaternary, the latter of which began about 2 million years ago with the onset of the glacial buildup. Within our present Quaternary period, there are two further subdivisions known as epochs. These are the Pleistocene, which began about 2 million years ago, and the Holocene (or Recent) epoch, which is roughly 10,000 to 12,000 years old. (Some paleontologists argue quite cogently that we are still in the Pleistocene and dispense with the designation of a Recent epoch.)

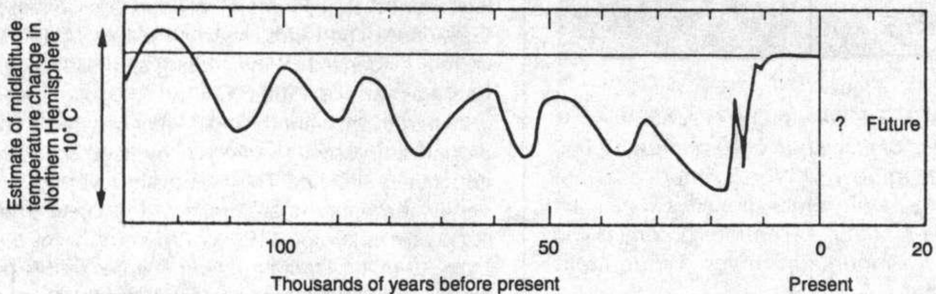
Currently, the greatest area of glaciation is the continental ice sheet of Antarctica (about 5.0 million square miles), which began its expansion about 5 million years ago. The largest Northern Hemisphere glacier is the Greenland ice sheet (about 0.8 million square miles). As the glaciation expands, most of the additional growth takes place in the Northern Hemisphere.

The whole of the last 2 million years, the Quaternary period, is considered an ice age, a relatively rare state of affairs in geologic history. But this long-term ice age has been marked by ebbs and flows in glacial extent. The work of the past two centuries in climatology, paleobiology, meteorology, astronomy, geology, geophysics, and many other fields has confirmed the existence of an *astronomically* determined cyclical pattern within the Quaternary ice age. Driven by well-defined cycles in the Earth's orbital orientation to the Sun, periods of roughly 100,000 years of generally advancing glaciation have been followed by short periods, of roughly 10,000 years' duration, in which the glaciers retreat. These two periods or subdivisions of the ice age are known as *glacials* and *interglacials.*

The 100,000-year periods are not one continuous downward slope of temperature and'glaciation, but are modulated by roughly 20,000-year cycles, consisting of 10,000 years of cooling and glacial advance followed by 10,000 years of warming and retreat. But these shorter-term ups and downs of the glaciation curve tend to get cooler and cooler as the



(a) Past 850,000 years Source: Adapted from Samuel W. Matthews, "What's Happening to Our Climate," *National Geographic* (Nov. 1976), p. 576.



(b) The recent 100,000 years

Source: Estimate of the midlatitude air temperature in the Northern Hemisphere, reprinted with the permission of Macmillan Pubishing Company, a Division of Macmillan, Inc., from *Earth and Cosmos* by Robert S. Kandel, Copyright © 1980

Figure 2
THE EARTH'S CLIMATE OVER THE LAST EIGHT CYCLES

100,000-year cycle advances (Figure 2).

The maximum extent of glaciation, the glacial climax of the last 100,000-year ice age, occurred just 18,000 years ago, at a time when human societies were already well established on the Earth. At that time, a huge continental glacier covered North America down through the northeastern states of the United States, reaching across the midwestern plains and up into Canada (Figure 3). This most recent of the great continental glaciations is known in North America as the Wisconsin (in Europe as the *Weichselian).* Its southernmost limit extended across the middle of Long Island, through northern New Jersey, lower New York State, western Pennsylvania, Ohio, Indiana, Illinois, Iowa, then up diagonally through the northeastern corner of Nebraska, into the Dakotas, and across the southern tier of the Canadian plains.

In more southerly regions, mountain glaciers also spread downward from heights in the Colorado Rockies, the Sierra Nevadas, and the Cascade Range. In western Europe, the glacier reached down from Scandinavia over northern Germany, Poland, and the Baltic nations. It reached deep into Russia and Ukraine south of Kiev, and eastward as far as the central Siberian Plateau. It stretched southwestward over the Netherlands and covered Ireland and most of the British Isles. A separate portion extended outward from the Alps and another one from the Caucasus Mountains in Asia Minor.

An Arctic climate thus prevailed over much of what are now the major population centers of western and central Europe and the United States. The weather over most of the remaining portions of the three northern continents was quite a bit colder than today's. But hunting was apparently good along the fringes of the continental glaciers, and man survived in these regions in a fairly primitive state, wearing animal furs for warmth and seeking shelter in caves.

The changes wrought in geography during the several-thousand-year period of retreat of that glacier were enormous. It is somewhat shocking to realize that major topographical features on the map of the United States are only about 12,000 years old. Before the completion of the glacial retreat, there were no Great Lakes, for example. None of the many lakes, large and small, that dot the northern tier of the United States existed. Other lakes—such as the 20,000-square-mile Lake Bonneville that once covered much of Utah—dried up, leaving behind only a few relatively smaller remnants, like the Great Salt Lake.

The rivers that emerged after the retreat were not the same as those that had been there 100,000 years earlier, before the glaciation. The northern Missouri River, for example, drained northward into Hudson Bay, and what is now the upper Ohio

Figure 3
THE LAST GLACIATION IN NORTH AMERICA
The maximum extent of glaciation occurred just 18,000 years ago and was known in North America as the Wisconsin. The dotted white areas show this huge glacier that covered the northern area of the continent and parts of the western mountain ranges. White areas show today's glaciers.

Source: U.S. Geological Survey

flowed northeast into the Gulf of St. Lawrence. The lower Ohio drained into a now nonexistent river, which geologists have named the Teays.

Where Are We Now?

We are currently beyond the expected end-point of an interglacial period that began more than 10,000 years ago. We are thus at a point on the paleoclimatic timetable where the onset of a new 100,000-year ice age is expected and may even be already in progress. The global climate has been generally cooling over the past 6,000 to 8,000 years, and is now about 1 degree Fahrenheit cooler than at the time of the postglacial climatic optimum. One might cite evidence such as the advance of the Greenland ice sheet and the southward movement of the limit of citrus growing in the southeast United States over the past 40 years to suggest that the expected cooling is even now under way. However, because these astronomically driven cyclical trends are of long duration (10,000 years being the shortest cooling cycle), it is not possible to attribute a climatic trend on a time span so short as a few decades or even a few centuries to a single cause. One must take a broader view.

The melting of the glaciers that had formed during the last 100,000-year ice age cycle took a long time, and the rate of melting was varied. The North American Laurentide ice sheet was the last to retreat. If we date the beginning of postglacial (interglacial) times to a point roughly 10,000 years ago (c. 8000 B.C.), it is then useful to look at the climate, especially temperature trends, over this recent 10,000 years.

Following a number of short-term oscillations beginning about 12,000 B.C., a rise in temperature that set in about 8300 B.C. led to sustained warm climates in the northern European lands formerly covered by ice. The maximum summer temperatures experienced in Europe over the last 10,000 years occurred in about 6000 B.C. Over North America, where the process of glacial retreat lagged somewhat, the maximum was reached by about 4000 B.C. That period is known as the Postglacial Climatic Optimum (or the altithermal period) when mean temperatures were about 1 degree Fahrenheit warmer than today.

Beginning about 3500 B.C., a sharp reversal known as the Piora oscillation set in, marked by advance of the glaciers in Europe and large-scale migration of agricultural peoples. From 3000 B.C. to 1000 B.C., the climate regained some of its former warmth but was apparently subject to recurrent fluctuations, particularly in rainfall. From 1000 to 500 B.C., the glaciers advanced again. In Europe the most marked change appears from 1200 B.C. to 700 B.C., coinciding with the Dark Age period that Homeric scholarship suggests occurred in Greek-speaking lands. In some places (Alaska, Chile, China) there is evidence that the cooling and readvance of the glaciers began as early as 1500 B.C.[2]

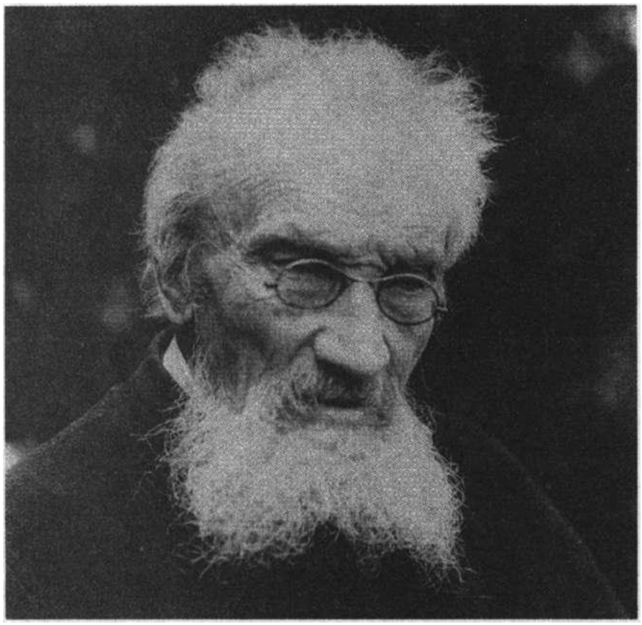
A period of warmth and higher sea level came to Europe around the year 400 followed by another reversion to colder and wetter climates. This was again reversed, and there was a very warm period that culminated in Greenland about 900 to 1200 and in Europe 1100 to 1300. Known as the Medieval (or Little) Climatic Optimum, temperatures in this period became, briefly, nearly as warm as in the postglacial climatic optimum.

As historical climatologist H. H. Lamb describes it: Oats and barley grew in Iceland. The limit of tillage in northern England, Wales, the Scottish highlands, in central Norway, and in high regions of central Europe was extended hundreds of meters up the hills and mountainsides. Mining operations were begun high in the Alps. Norse colonists were catching cod in the sea off western Greenland, and a regular northern sea route developed to North America.

In the Mississippi valley, peoples were moving northward into Wisconsin and eastern Minnesota, and human settlements spread up the valleys of all the major rivers. Renewed moisture in North Africa allowed cattle to thrive in now-arid regions, and journeys across the desert from North Africa to Ghana, Mali, and Kufra are described by the Arab geographers between the 11 th and 14th centuries.

This warming period, which ended as early as 1100 in parts of North America and later in Europe, was followed by a roughly 500-year period of severe cooling known as the Little Ice Age—the *Klima-Verschlechterung,* or climate-worsening in the German literature. The low point of the cooling occurred from about 1550 to 1750, but extreme cold weather began earlier and ended considerably later in many parts. The Greenland colony, for example, died out not long after the year 1400. And in England, tent cities were set up and Frost Fairs celebrated on the frozen river Thames as late as the winter of 1813-14. Some of the symptoms of the cooling as described by Lamb were:

- advance of the inland ice and permafrost in Greenland and of the glaciers in Iceland, Norway, and the Alps;
- spread of Arctic sea ice into the north Atlantic around



E. Kuhlbrodt

Climatologist Vladimir Koppen, Alfred Wegener's father-in-law and collaborator, at the age of 78.

"Die Weissewüste" by K. Aerdemerten

Alfred Wegener in Greenland.

Greenland, forcing abandonment of the sailing routes used from the year 1000 to 1300;

- lowering of the treeline in central European highlands and in the Rockies, spread of lakes and marshes in Europe and northern Russia, swollen rivers and increasing frequency of landslides;
- increasing frequency of freezing of rivers and lakes;
- increasing severity of windstorms and sea floods;
- harvest failures and rising prices of wheat and bread;
- abandonment of tillage, vineyards, and farm villages; and
- increased incidence of disease and death among human and animal populations.

The Conditions for an Ice Age

From the long-range view of the geologist, the last 2 million years of glacial climate conditions are not the global "norm." Only two times in the 600-million year near-term geologic record have the conditions been ripe for an ice age: once in the Permian period of the Paleozoic era, about 250 million years ago, and once more in the present Quaternary period.

There are two basic requirements for an ice age:

First, a configuration of the continents that places a large portion of the land mass in polar and nontropical regions.

Second, a climate in the higher latitudes characterized by wet, snowy winters followed by summers cool enough to not reduce the glacial advances made the previous winter.

Although the causes that give rise to these two conditions are complex and far from perfectly understood, the recognition of their importance and of some of the basic mechanisms governing their genesis dates to no later than the early part of this century. Subsequent advances in nearly all the physical sciences and the work of thousands of researchers in the many fields related to historical climatology have greatly enhanced our understanding and documentation of the climate record. But the big challenge, to understand climate well enough to be able to predict its future course, is still out of reach.

The Köppen-Wegener Connection

If the name of a single person were to be identified with the birth of the modern science of paleoclimatology, it would be one that is little known, even to many specialists in the field: Vladimir Köppen (1846-1940). The St. Petersburg-born meteorologist came from a German family that had settled in Russia during the reign of Catherine II. He began his study of natural sciences in Heidelberg in 1866 and received his doctorate in 1870 with a paper, published in Moscow, on the effects of heat on plant growth. After a brief period of work at the Central Observatory in St. Petersburg, Köppen came to the German Marine Observatory in Hamburg where he stayed for 44 years, becoming first the head of the weather service and then meteorologist of the observatory.

Köppen's list of publications numbers 526 items. Of these, probably the most important for today is the one he coauthored with his son-in-law, Alfred Wegener, in 1924, *Die Klimate der geologischen Vorzeit* (The Climates of the Geological Past).

Alfred Wegener (1880-1930) is known to students of the earth sciences today as the father of the modern theory of continental drift. Wegener's now-famous theory was initially rejected by the science establishment, and became widely accepted only in the 1960s and 1970s, well after his tragic death on the Greenland glacier in 1930.

It is far less well known that Wegener and his father-in-law Koppen were also leading proponents of the modern theory of astronomical determination of the ice age cycles.

The two theories—continental drift and the determination of the ice ages by the cycle of solar insolation—had a common thread. In the minds of Wegener and Köppen they were really one grand conception. The first theory began with Wegener no later than 1910. It is recorded in a charming letter to his wife:

The supercontinent Pangaea I," lay across the Southern Hemisphere in the Cambrian, 510 million years ago.

Life moved from the ocean and began to flourish on land during the Devonian, 380 million years ago.

A single land mass, Gondwanaland, existed in the Southern Hemisphere in the Carboniferous, 340 million years ago.

An ice age occurred in the southern continents, grouped around the pole, in the Permian, 250 million years ago.

A rift appeared in "Pangaea II," as it began to crack during the Triassic, 220 million years ago.

The continents began to drift toward the poles again during the Jurassic, 170 million years ago.

A warm and equable climate prevailed during the Cretaceous, 100 million years ago.

By Tertiary times, 50 million years ago, conditions were similar to those of today, and suitable for ice-caps to form.

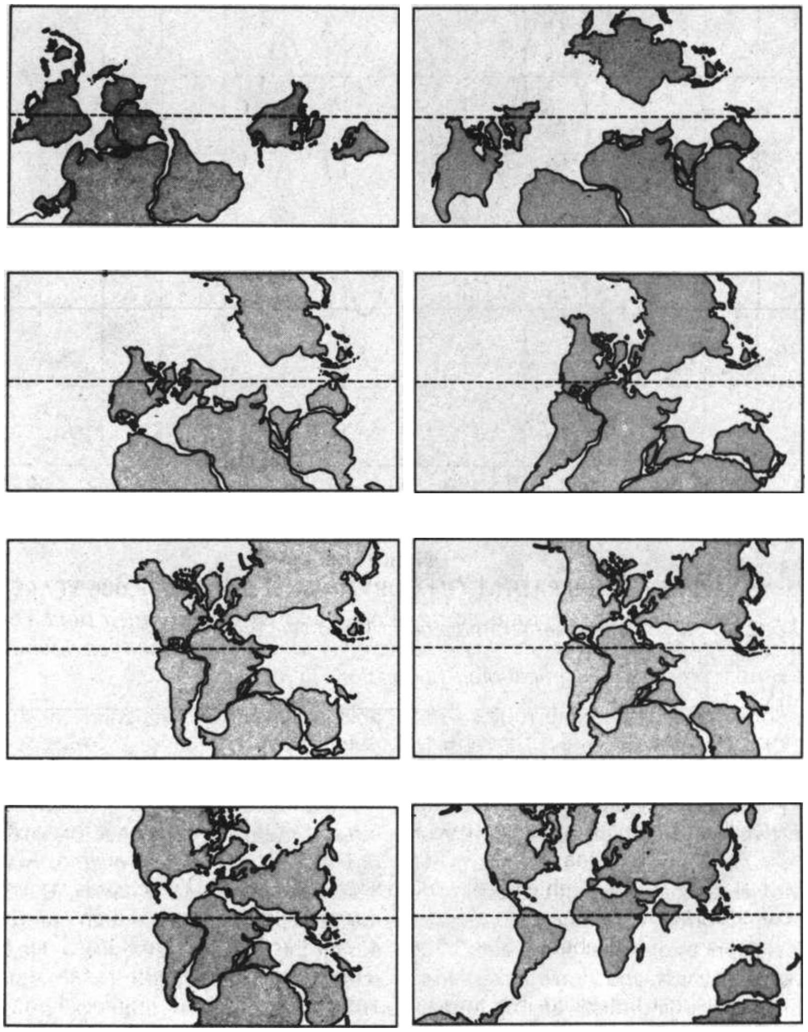


Figure 4

Ice ages occur not because the Earth as a whole is plunged into a deep freeze with ice extending down to the equator, but because in the Earth's evolution, the slow process of continental drift carries continents to high latitudes, where snow can fall and build up into great ice-sheets.

"Doesn't the east coast of South America fit exactly against the west coast of Africa, as if they had once been joined? The fit is even better if you look at a map of the floor of the Atlantic and compare the edges of the dropoff into the ocean basin rather than the current edges of the continents. This is an idea I'll have to pursue."[3] The idea itself was not new; it had been noted in Alexander von Humboldt's famous *Cosmos,* among other locations.

But Wegener had at his command the extensive researches of the previous century, which included data of both a geologic and paleobiology sort, suggesting the possibility that the continents had once been linked. The similarity of South American and African fossils and the close relationship of flora and fauna of many regions separated by oceans had already been noticed by investigators. One prominent attempt at an explanation was the hypothesis that land bridges had once existed, for example, connecting South Africa with southern South America, North Africa with Florida and the Caribbean, and so forth. Twenty years before Wegener, the great Viennese geologist Eduard Suess had proposed that the continents may have been linked together in one supercontinent, which he called Gondwanaland. The similarity in geological development of the continents of the Southern Hemisphere (including the Indian subcontinent), and their marked difference from those of the north, had already suggested some such link. But Suess was not sufficiently versed in these fields to recognize the paleobiological and climatological significance of his hypothesis.

Wegener drew on Suess's differentiation of the two major types of rocks *sial* (for silicon-alumina) and *sima* (for silicon-

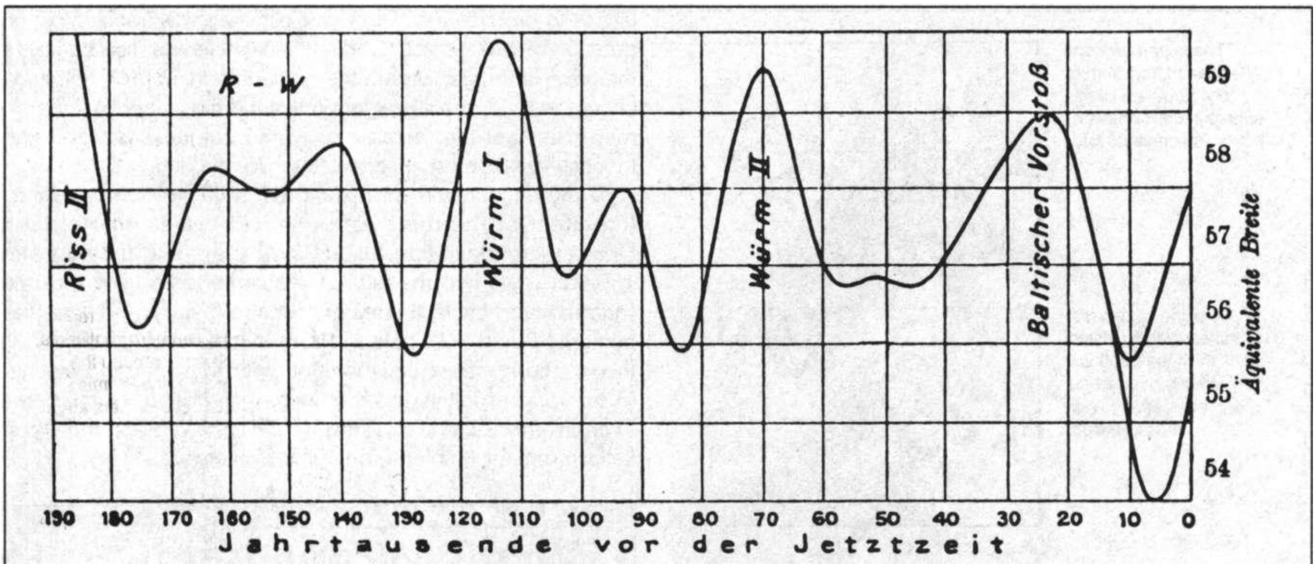


Figure 5
MILANKOVITCH'S RADIATION CURVE FOR THE LAST 190,000 YEARS
This radiation curve by Milankovitch was reproduced by Koppen and Wegener in their book Die Klimate der geologischen Vorzeit *(The Climates of the Geological Past), a pioneering work in paleoclimatology published in 1924. The horizontal axis shows years from present; the vertical plots fluctuations in radiation.*

magnesia) that make up, respectively, the bulk of the crustal material of the continents and the ocean floors. The sial, which corresponds most closely to granite, has a specific gravity (a measure of its weight in comparison to an equivalent volume of water) of 2.7, while the sima, which is like basalt, is somewhat heavier at 3.0. Thus the lighter rock making up the continental crust could be thought of as formed into giant blocks floating, somewhat like icebergs, above the denser sima.

Wegener's drift hypothesis was first presented in Frankfurt-am-Main on Jan. 6, 1912, at the annual meeting of the Geological Association. The first book-length account, *Die Enstehung der Kontinente und Ozeane* (The Origin of the Continents and Oceans), appeared in 1915. Here and in his other early papers, Wegener was somewhat at a loss to explain by what mechanism the drifting apart of these blocks would occur. In 1929, he tentatively proposed the answer accepted today, referring to the possibility of convection currents in the *magma*—the layer of molten rock on which the Earth's crust is thought to float. The high mountain ranges found near the edge of continents—the Alps, Himalayas, and the Cordilleras, which range from Alaska to southern Chile—were seen as produced by the crumpling up of layers of rock on the leading edge of the drifting continents, produced by forces similar to that of a bow wave.[4]

Together, these ideas condensed in the notion that the continental blocks had once been united in a single great continent, called *Pangaea,* and had subsequently drifted apart, taking up various configurations before arriving at the one we know today. In its details, the Wegener hypothesis also went a long way toward explaining some of the climatic anomalies in the fossil record and other paleobiology evidence from widely varying places on the Earth. A snapshot summary of the modern reconstruction of the theory of drifting continents can be seen in the map series showing reconstructions of the global map at major points on the geologic time scale (Figure 4).

The Solar Astronomical Cycles

In 1910, the same year that Wegener was formulating the theory of continental drift, his father-in-law, Koppen, was musing over the earlier research of glaciologists Albrecht Penck (1858-1945) and Eduard Brückner (1862-1927), *Die Alpen in Eiszeitalter* (The Alps in the Ice Age). Through their extensive fieldwork in Alpine regions, Penck and Brückner had been able to distinguish four separate cycles of glacial advance and retreat over the ages, and they produced a climatic curve for the ice age. Köppen conceived the idea of superimposing on this curve the time-scale produced by examining the changes in insolation caused by regular cycles in the Earth's orbital relationship to the Sun. Köppen's hope was that the cycles of glacial advance and retreat could be dated by correlating them to the astronomical cycles.

The idea of a correlation between long-term changes in climate and the solar-astronomical cycles goes back to a hypothesis put forth in 1830 by Sir John Herschel, the son of the great astronomer Friedrich Wilhelm Herschel and a leading figure in 19th-century British science. Herschel thought that the 21,000-year cycle of seasonal predession of the equinox might have a determining effect on climatic history. His hypothesis was taken up and elaborated first by the French mathematician J.F. Adhémar in 1842, and then by the self-taught Scottish climatologist James Croll beginning in 1860, who added into his calculations the cycle of change of the eccentricity of the orbit. However, at the end of the 19th century, the exact periodicity and extent of this cyclical variable had not been precisely calculated. Croll was also hampered by his incorrect supposition that periods of ice buildup would coincide with the harshest winters.

K. Brunnacker

Milutin Milankovitch, the Yugoslav climatologist who calculated the astronomical cycles.

It has since been deduced that mild summers, in which the glacial advance of the previous winter's snow is not erased, are more important than the harshness of winter. Nevertheless, against great opposition, Croll defended the hypothesis first advanced by Herschel into the end of the 19th century. In 1910, when Koppen and then Wegener took it up again, it was neither a popular nor a widely accepted hypothesis.

Milutin Milankovitch

But one man, Milutin Milankovitch (1879-1958), a skilled mathematician from the University of Belgrade, had independently begun his own investigation of the astronomical theory of climate. From 1911 until his first contact with Koppen in 1920, Milankovitch carried out painstaking calculations of the long curve of the variability of solar insolation (the amount of sunlight) at northern latitudes, in hopes of demonstrating its forcing effect on the ice age cycles (Figure 5). He published a few small papers on his work and then, in 1920, a book in the French language, *The Mathematical Theory of Heat Phenomena Produced by Solar Radiation,* which came to the attention of Koppen.

In that work, Milankovitch spelled out his theory of astronomical rhythms, carefully determining the effect of three major cyclical variables:

• the 26,000-year period of the precession of the equinox, which, when combined with the advance of the perihelion, the point at which the Earth is closest to the Sun, produces a 21,000-year cycle;

• the 40,000-year cycle of variation of the obliquity of the ecliptic (the tilt of the Earth's axis), which varies from 22 to 24.5 degrees;

• the 90,000 to 100,000-year cycle of variation of the eccentricity of the Earth's elliptical orbit.

A postcard from Koppen initiated an extended correspondence between the two men. Milankovitch, who hoped to use his calculations to produce a curve of past climates, was troubled by the question of which season and which latitude was most critical to the advance of glaciation. One of the important fruits of the exchange was Köppen's conclusion that it is the diminution of summer heat—not the increase of winter coldness, as Croll had thought—that is most important to the ice buildup.

At the encouragement of Koppen, Milankovitch calculated the effect of the three astronomical cycles on Northern Hemisphere glaciation for 650,000 years into the past and 160,000 years into the future. This came to be known as the Milankovitch-cycle theory of climatic history. In a popular book published in Leipzig in 1936, Milankovitch described his theory and his close collaboration with Koppen and Wegener in the form of letters to an imaginary girlfriend, *Durch Feme Welten und Zeiten. . .* (Through Distant Worlds and Ages: Letters from an Ambler through the Universe).[5]

What's Wrong with Global Warming Theory?

Everyone would like to know what the temperature will be tomorrow and some far-sighted people wonder what it will be like fifty, one hundred, or even thousands of years into the future. The only honest answer is that we really do not know.

As indicated by the fluctuations and sometimes rather rapid reversals of global and regional climate briefly documented here, it is not possible to draw competent conclusions from trends of a few decades, or even centuries concerning the direction of climatic trends. It is certainly not possible to forecast future climates on the basis of one parameter (CO_2 density). What the historical record does tell us is that we are in a secular tendency toward a new glaciation. To propose—as does the currently popular Malthusian fad known as global warming—that we are moving into a period of substantial glacial melt and sea-level rise runs counter to the evidence and the conclusions of more than two centuries of scientific work.

It is sufficient to point out a few anomalies to call the whole global warming conjecture into serious doubt:

• The Greenland ice sheet and snow buildup in Antarctica have recently advanced.

• Since 1980, there has been an advance of more than 55 percent of the 625 mountain glaciers (Austria, Switzerland, Italy, Iceland, United States, and Soviet Union) under observation by the World Glacier Monitoring group in Zurich. (From 1926 to 1960, 70 to 95 percent of the monitored glaciers were in retreat.)

• The limit of the citrus-growing region in the U.S. Southeast has moved southward, and the U.S. Department of Agriculture has revised its hardiness zones southward.

On Temperature Increases

The often cited figures for the current warming trend show a rise in mean global temperature of about 1 degree F since 1880. However, these data are somewhat suspect. A great deal of statistical manipulation is required to try to

Wegener's theory of continental drift, the Milankovitch theory of astronomical cycles was not widely accepted by the scientific establishment. Nevertheless, a number of paleoclimatologists in America and Europe took it up and carried out pioneering work from the 1930s onward, which tended to corroborate the Milankovitch cycles. Much of this was in the field of paleobiology, examining core samples from various marine basins under the microscope, using innovative means of dating the biota and determining sea levels and temperature levels coinciding with the time of their formation.

Although Milankovitch was still fighting an uphill battle at the time of his death in 1958, today his general theory is widely accepted. Deep-sea core samples taken in the 1970s showed the Milankovitch 20,000, 40,000, and 100,000-year periodicities going back for 1.7 million years. The new work was reported in *Science* magazine in 1976 in a paper written by a team of young researchers at Columbia University's Lamont-Doherty Geological Laboratory.[6] Somewhat ironically, the geology department at that university had been one of the staunchest holdouts against Wegener's theory of continental drift.

Dr. John Imbrie, who ran the computer programs analyzing the data, was the first to hypothesize that the evident periodicities were caused by the Milankovitch cycles. He found that the 100,000-year cycle was predominant. (Milankovitch had expected that the 40,000-year cycle of the angle of obliquity would be the dominant one; it was for the periods before about 800,000 years ago. But since that time, for reasons not yet fully understood, the 100,000-year periodicity has become dominant.)

To understand the solar astronomical cycles, which are one of the foundations of the scientific theory of climate history, we need only examine some of the key geometric features of the

discount the warming caused by urbanization around the monitoring stations. What one should bear in mind is that the global climate in 1880, including the Northern Hemisphere was exceptionally cool. Thus the curve starts from a point in time when temperatures were unusually low, which exaggerates the warming effect.

Furthermore, the global temperature curve shows warming from 1880 to 1940, cooling from 1940 to 1976, and renewed warming from 1976 to the present—the net rise being 0.5 Celsius or about 1 degree Fahrenheit. The point should be made that most of this warming took place in the first half of the century before widespread use of fossil fuels (and increased carbon dioxide emissions).


U.S. Geological Survey

The evidence points more to coming glaciation than to warming. Here, the four-mile wide front of the massive (425 square mile) Columbia glacier, near Valdez, Alaska.

Moreover, the recent global temperature increase has occurred over tropical regions. As atmospheric scientist Hugh Ellsaesser points out (*21st Century,* Winter 1991, p. 53): "While the warming up to 1940 was greatest in the North Atlantic and in winter, the more recent warming since 1976 has been greatest in the tropics, and some of the earlier warming in the North Atlantic has gone away." These are conditions that can and apparently do favor advance of glaciation.

Regarding measurement of carbon dioxide and our understanding of its role in the atmosphere, one should consider the following:

- Estimates of the preindustrial levels of CO_2 are subjective. Nineteenth century measurements of CO_2 were carried out with error factors of up to 100 percent.
- The Mauna Loa observatory in Hawaii is considered an ideal site for CO_2 monitoring. However it is also near the site of an active volcano whose CO_2 emissions must be "edited" from the data.
- The concentrations of CO_2 in air bubbles trapped in ice are often taken as previous atmospheric concentrations, which assumes that the air's composition remains unchanged. However, studies show that CO_2 content in ice can be greatly enriched or depleted in comparison to original atmospheric levels.
- The outgassing of CO_2 from the Earth's mantle annually is 10 times that of man-made sources, and the CO_2 exchanged annually between the ocean and the atmosphere is much greater than that. If all the Earth's fossil fuels were burned it is likely that the CO_2 produced would be dissolved in the ocean, before reaching an atmospheric concentration double current CO_2 levels.

It is not out of the question that a short-term, counter-cyclical trend, such as the conjectured warming caused by human production of CO_2 and other greenhouse gases (of which water vapor of natural origin is by far the most prevalent), might disrupt a longer-term cooling trend. But this must be proven, as it has not been.

Any competent scientific discussion of the global warming conjecture would have to be located in the context of the secular tendency toward an ice age. The global warming case has not been put forth as science, however. Instead, what has been set before the public are scare scenarios of massive polar ice melt, sea level rise, and catastrophic flooding for the coastal regions, combined with heat and drought conditions over large parts of the rest of the globe. This is not science but intellectual dishonesty bordering on fraud.

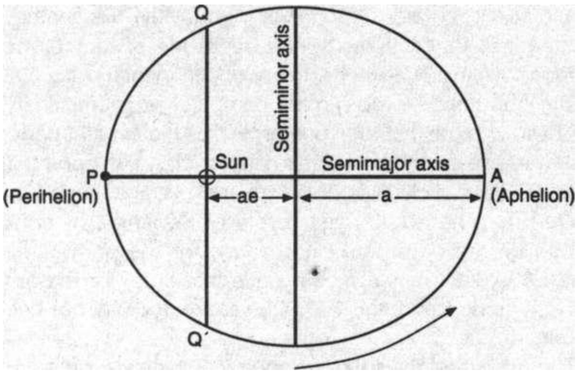


Figure 6
ORBITAL MOTION OF THE EARTH AROUND THE SUN

Earth's elliptical orbit. Johannes Kepler's discovery in the early 17th century that the planets move in ellipses about the Sun, with the Sun at one focus, and his elaboration of the laws of this motion are the basis of all astronomical hypothesis concerning climate. (Wegener, in fact, had studied classical astronomy and wrote his dissertation at the University of Berlin on the subject "The Alphonsine Tables for the Use of a Modern Calculator," a recalculation of the old tables used to ascertain the positions of the Sun, Moon, and the five then-known planets.)

Geometry of the Solar Cycles

Let *PQ'AQ* represent the elliptical orbit of the Earth around the Sun at S (Figure 6). Looking down upon the North Pole of the Earth, the orbital motion is counter-clockwise from P to Q* to *A* to *Q* and back to P again. We have exaggerated the ellipse in order to simplify visualization of the processes described. As the Sun sits at one focus of the ellipse, the distance from Earth to Sun is least when the Earth is at P, the position known as *perihelion,* and greatest at A, the *aphelion.*

Let us examine the change in the amount of solar radiation that will be received as the Earth moves from aphelion to perihelion. (The radiation received at the edge of the Earth's atmosphere is known as *insolation.)*

An ellipse is completely described by two parameters, the length of its semi major axis, a, and the value of the eccentricity, e, which is the factor by which *a* is multiplied to find the foci. Measuring from the center of the ellipse (where the semimajor and semiminor axes cross), a focus is located at a distance *ae* along the semimajor axis. The eccentricity e is thus always a number between 0 and 1.

With this in mind, we see that the perihelion point, P, sits at a distance (a - ae) from the Sun while the aphelion, A, is at the distance (a + ae). If, to simplify, we let a = 1, then the distances from the Sun are:

$$P = 1 - e, \text{ and}$$
$$A = 1 + e.$$

Now, since the intensity of light varies as the inverse square of the distance from the source, the insolation at *A* and P will be:

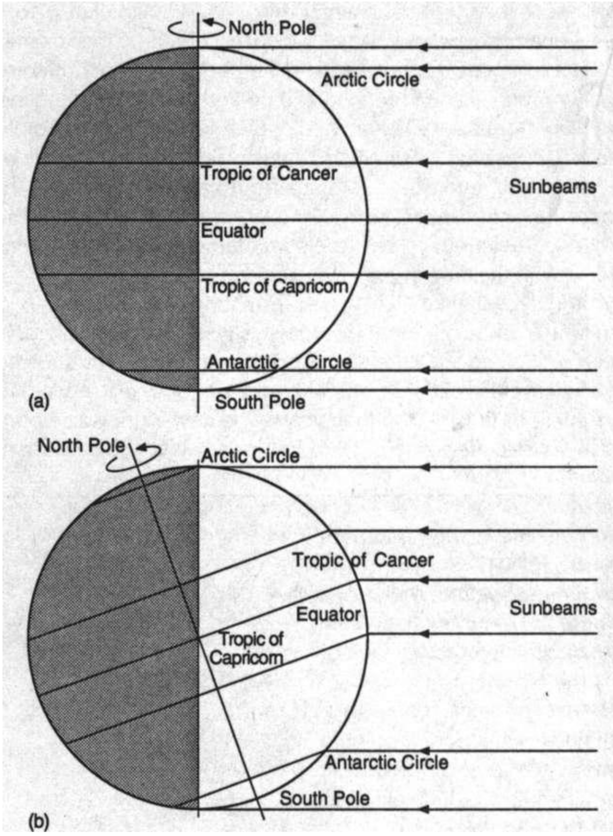


Figure 7
OBLIQUITY AND INTENSITY OF THE SUN'S RAYS
Even without a tilt of the axis, the variation in angle of incidence of the Sun's rays (a) would cause the poles to be cooler. Increasing the angle of obliquity spreads the effect (b).

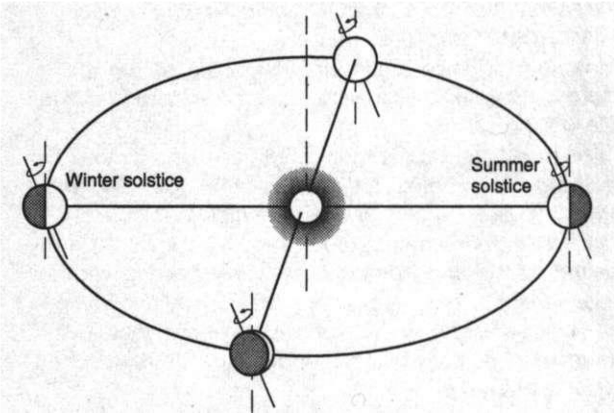


Figure 8
SEASONS AND OBLIQUITY
Seasonal change results from the combined effect of the orbital inclination and the yearly revolution of the Earth around the ellipse. When the Earth's spin axis is pointed away from the pole of the ecliptic, the Northern Hemisphere has its shortest day (winter solstice), while the Southern Hemisphere has its longest day (summer solstice).

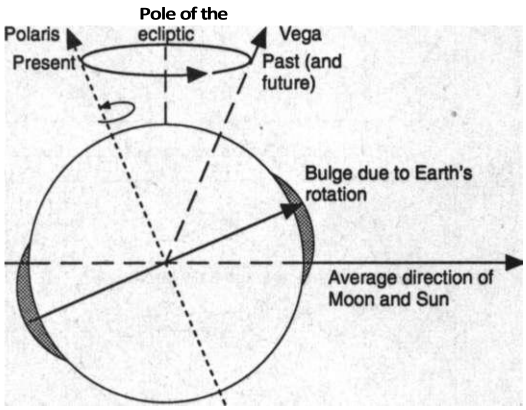


Figure 9
PRECESSION AND CHANGE OF POLE STAR
The Earth's spin axis makes a complete rotation around the pole of the ecliptic in a cycle of approximately 26,000 years. The pole star is now Polaris, but about 13,000 years ago it was Vega.

$$P_{\text{insol}} = 1/(1-e)^2$$
$$A_{\text{insol}} = 1/(1+e)^2.$$

And the difference of the two is:

$$\frac{1}{(1-e)^2} - \frac{1}{(1+e)^2} = \frac{4e}{(1-e^2)^2}.$$

This is the maximum variation of insolation between perihelion and aphelion. Since for small values of e the denominator differs insignificantly from 1, the value 4e provides a very good approximation for this flux difference.

The present value of eccentricity for the Earth's orbit is 0.017, and the variation in insolation thus comes to 0.068, or approximately 7 percent. But the orbital eccentricity is known to pass through a complete cycle in approximately 94,000 years, varying from near 0 (a circular orbit) to 0.07. At the latter value, the difference in insolation between aphelion and perihelion becomes 28 percent.

Now, the Earth is not simply a moving point, but a solid body of more or less spherical shape. It rotates about an axis that is inclined to the plane of the ellipse by a certain angle known as the *angle of obliquity.* It is this inclination of the Earth's axis, which is now about 23.5 degrees, that causes the main difference in temperature between polar and equatorial regions. The flux of the Sun's rays striking the Earth obliquely is spread over a greater surface area than that of the rays that strike in a more perpendicular direction. Even without that obliquity there would be some variation in temperature between pole and equator, because of the changing angle at which the parallel rays of the Sun will strike the circular arc that represents the Earth's surface (Figure 7). An increase in the angle of obliquity tends to exacerbate this effect.

Seasonal change, that is the yearly passage through spring-summer-fall-winter, is caused by the combined effect of the orbital inclination and the yearly revolution of the Earth around the ellipse. In the course of a year, the Earth's axis of rotation will point to the same approximate direction in the distant sky, no matter where on the ellipse we find ourselves (Figure 8). However, in one annual revolution around the Sun, the axis will take up all orientations with respect to the line perpendicular to the plane of the ellipse and passing through the center of the Sun, which is known as the pole of the ecliptic. When the Earth's spin axis is pointed away from the pole of the ecliptic, the Northern Hemisphere experiences its shortest day, known as the winter solstice. On the same day, the Southern Hemisphere experiences its longest day, the summer solstice; The opposite situation occurs at the position 180 degrees around the ellipse.

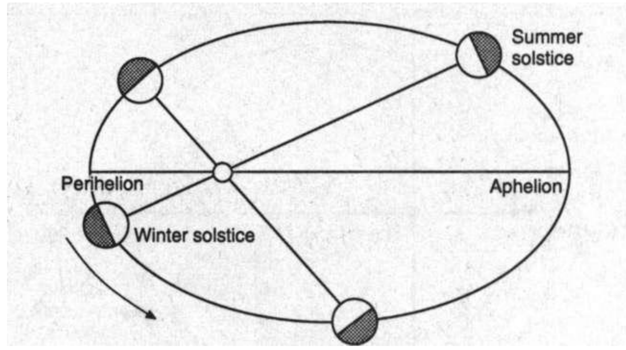


Figure 10
PRECESSION AND LOCATION OF THE SOLSTICE
The precession cycle changes the location on the ellipse where the winter and summer solstices occur. The approximate positions on the ellipse are shown for the solstices today.

If the axis of the Earth had no motion of its own, the seasons would always occur at the same points in the orbit. But the direction in the sky to which the Earth's axis of rotation points varies on a cycle of approximately 26,000 years. In the course of that cycle, the spin axis makes a complete rotation around the pole of the ecliptic, one obvious consequence of which is a change in the pole star (Figure 9). Another consequence, which was noted by the ancient astronomers, was the long-period change of that constellation in which they observed the Sun rising on the day of the vernal (spring) equinox. Later comparison of the physical dynamics of this phenomenon to the precession of a spinning top (the wobbling as it winds down) led to the name *precession of the equinox* for the 26,000-year cycle.

As a result of this phenomenon, we must take into account where on the ellipse the winter and summer solstices occur. When the Earth is at P in Figure 6 and the axis is turned 180 degrees away from the Sun, we will have winter in the Northern Hemisphere. That was the situation in approximately the year 1250. Today we have moved a bit on the precession cycle and find the Northern Hemisphere winter occurring at roughly the position shown in Figure 10.

In addition to the phenomenon known as precession of the equinox, the perturbations in the Earth's orbit caused by the motion of the other planets, most notably Jupiter, cause a

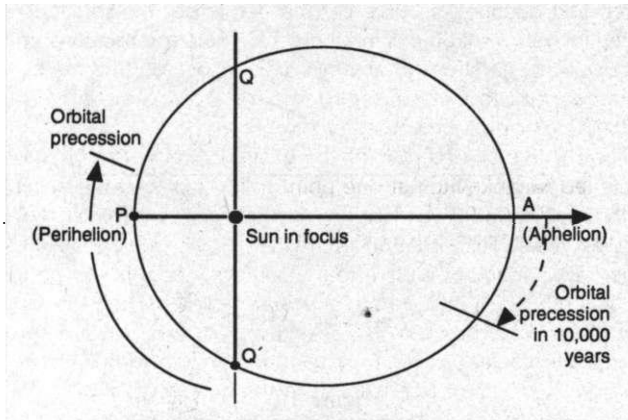


Figure 11
ADVANCE OF THE PERIHELION OR ORBITAL PRECESSION

Perturbations in the Earth's orbit, the result of the motion of the other planets (in particular, Jupiter) cause a phenomenon known as advance of the perihelion or precession of the orbit, in which the complete cycle of precession takes approximately 21,000 years, not 26,000.

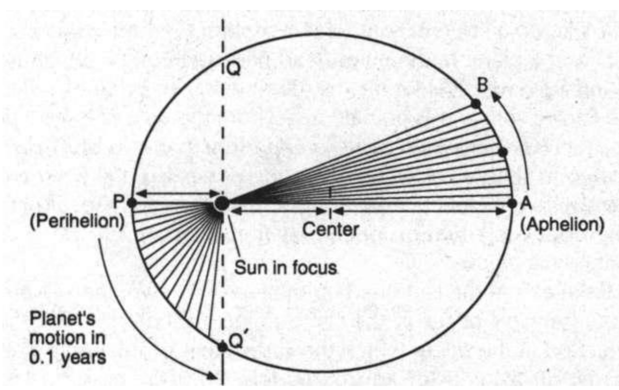


Figure 12
INSOLATION AND THE EQUAL AREA LAW

As Kepler demonstrated, the rate of motion of the Earth in its elliptical orbit is not uniform: Planets move more swiftly when near to the Sun at perihelion than when at aphelion. In this ellipse of high eccentricity, e = 0.5, *the planet takes the same time to move from aphelion to* B *as it takes from perihelion to* Q'. *The rate of change of the angle that the radius vector makes with a fixed direction is inversely proportional to the square of the distance between the Sun and planet. This is the same law that describes the diminution of insolation with distance.*

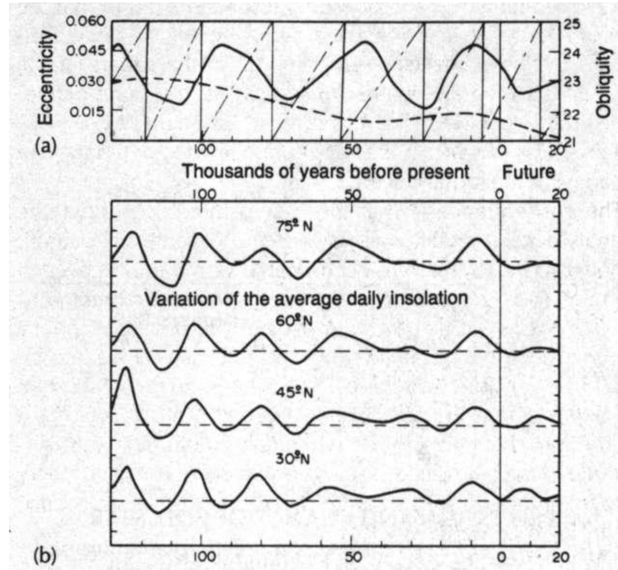


Figure 13
MILANKOVITCH CURVES AND THE LAST GLACIATION

Milankovitch calculated variations of the orbital and rotational parameters of the Earth, and climate, over the past 130,000 years and the next 20,000.

In (a), the obliquity of the ecliptic (solid line) and the eccentricity of the orbit (dashed line) are shown. The dash-dot line gives the variation of the angle between perihelion and the position at vernal equinox, now about 90°, and going from 0 to 360° in about 20,000 years.

The variation of the average daily insolation from the values of the year 1950 is shown in (b), with 1 unit of the vertical scale corresponding to 25 watts per square meter.

Source: Adapted from A. Berger, 1977, *Celestial Mechanics,* Vol. 15, p. 53, and 1978, *Quaternary Research,* Vol. 9, p. 139. Reprinted with the permission of Macmillan Publishing Company, a Division of Macmillan, Inc., from *Earth and Cosmos* by Robert S. Kandel, Copyright © 1980

phenomenon known as *precession of the orbit,* or *advance of the perihelion.* The result is that the complete cycle of return to the position where Northern Hemisphere winter occurs at P takes approximately 21,000, not 26,000, years (Figure 11).

Recalling that the most important astronomical requirement for glacial advance is a string of mild summers in which the winter snow buildup is not completely erased by melt, we are now in a position to examine how the orientations of the orbit might contribute to meeting this need.

Astronomy and Climate

It might at first appear that the occurrence of Northern Hemisphere summer at *A,* combined with a relatively high eccentricity, would produce the most favorable conditions.

However, we have yet to take one other consideration into account. The rate of motion of the Earth in its elliptical orbit is not uniform. As Kepler was able to demonstrate, the planets move more swiftly when near to the Sun at position P than when at position *A.* He was able to define the rate of change of velocity as such that the radius vector of the moving planet sweeps out equal areas on the surface of the ellipse in equal times (the Equal Area Law). The case is illustrated for an ellipse of high eccentricity (e = 0.5) in which the planet's motion in one-tenth of a year is marked out in portions of the orbit near perihelion and aphelion (Figure 12). When this variation in time is analyzed more closely, it is found that the rate of change of angle that the radius vector makes with a fixed direction is inversely proportional to the square of the distance between the Sun and planet. Thus, the same mathematical law that describes the diminution of insolation with distance also describes the diminution in rate of change of the angle of the radius vector.

The consequence is that the planet intercepts the same quantity of solar radiation for each degree of angular rotation, although it passes through each degree of rotation at a varying rate. Thus, if the orbit is divided up into four quadrants, such as by the points *P, Q', A, Q* and the lines connecting them to the Sun, the planet will receive exactly the same insolation in all four quadrants. The trick is to recognize that the time spent in the two larger quadrants that surround *A* is longer than that spent in the two smaller quadrants that surround P. Thus, the same insolation is received over a longer number of days in the two larger quadrants and its flux density per day is consequently less.

If winter solstice occurs at *P,* climatologists call the two smaller quadrants *caloric winter* and the two larger ones *caloric summer.* One sees then that another way of describing the condition described above is to say that the summer is longer and milder (at least with respect to solar insolation) than winter. The difference in length between caloric summer and winter can be as great as 33 days. At the present time, the difference is 7 days. This will vary with the eccentricity, which, as we have mentioned, has a cycle of about 94,000 years.

As the position of the winter solstice moves around the ellipse, a pair of perpendicular lines drawn through the Sun will always describe the four seasonal positions. Thus it can be seen that a cycle of 21,000 years' duration will be superimposed on the longer cycle of 94,000 years' duration. Let us suppose, for example, that we begin at a point in time when the winter solstice is at P and the orbital eccentricity is at a maximum. The greatest excess in the number of days of caloric summer over winter will then be experienced, and consequently the lowest flux density of the summer insolation. Assuming the proper meteorological dynamics, this should be an ideal position for the rapid advance of glaciation.

Let the rotational axis then move through one-half of its 21,000-year cycle of seasonal precession—10,500 years—bringing us to the position where the winter solstice is occurring at *A.* As the eccentricity will have lessened by only about one-fifth of its greatest value in this position (its cycle of change is not perfectly linear), the Earth will now experience a most intense daily flux of solar radiation during the relatively brief caloric summer, creating ideal conditions for glacial melt. The winter, however, will be longer and colder than normal insofar as the solar flux affects it. The outcome is perhaps a toss-up. Half a precessional cycle later, winter solstice occurs again at P and the eccentricity is still relatively great. Conditions for glacial advance are again good.

It will only rarely be the case, however, that the ideal situation should occur, in which the maximum of eccentricity and a winter solstice at P take place simultaneously. Further, a third cycle, the one that Milankovitch thought primary, must be considered—the variation in the angle of obliquity over a 40,000-year period. When these added considerations are taken into account, a curve can be derived of the sort illustrated for various latitudes in Figure 13. The close relationship between the variations of average daily insolation and the estimated variation in average temperature during the last 100,000-year-plus ice age cycle is seen.

The relative smoothness of the future 20,000 years of the cycle led Milankovitch at one point to forecast that the onset of the next 100,000-year ice age would not occur for another 20,000 years. The situation is not so simple, however. One sees a similar smoothness in the insolation curve in the period 20,000 to 50,000 years before the present, when the ice age cycle was known to be advancing, in fact, toward the maximum glaciation. Many other things must be taken into account, and one cannot use the mathematically derived curves exactly as a fortune-telling wheel. One of the interesting features of the climate cycle is the fact that an advance of glaciation seems to be self-feeding, because of the increase in the Earth's surface albedo (the reflectance of incident light) caused by a covering of bright white ice or snow. The effect, however, is never direct, but is modulated by weather patterns—the production of winds, clouds, ocean currents, and all the many other interrelated factors that make weather forecasting so difficult and imprecise a science.

Milankovitch's own reflections on the validity of his theory of the astronomical cycles are worth noting: "The fluctuations in the radiation received by the Earth over long periods of time are only *one* component of the climate of the past, but they are the most important one, and, moreover, one which is amenable to precise investigation."[7]

Laurence Hecht is an associate editor of 21 st Century *magazine. He began serving a 33-year sentence as a political prisoner in the state of Virginia on Nov. 4, 1993, along with five other associates of Lyndon LaRouche.*

Notes

1. See, for example, Hugh W. Ellsaesser, 1991. "Setting the 10,000-year Climate Record Straight," *21st Century,* Winter, p. 52; and Dixy Lee Ray, 1990. "Scientific Evidence Vs. Climate Hoaxes: Greenhouse Earth," *21st Century,* Winter, p. 28.
2. H.H. Lamb, 1985. *Climatic History and the Future* (Princeton, N.J.: Princeton Univ. Press), pp. 437-39.
3. Martin Schwarzbach, 1986. *Alfred Wegener: The Father of Continental Drift* (Madison, Wis.: Science Tech, Inc.), p. 76.
4. Schwarzbach, p. 82.
5. Schwarzbach, p. 97.
6. J.D. Hays, J. Imbrie, and N.J. Shackelton, 1976. "Variations in the Earth's Orbit: Pacemaker of the Ice Ages," *Science,* Vol. 194, pp. 1121-32.
7. Schwarzbach, pp. 97-98.

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