ORBITAL FORCING

Orbital forcing (The Milankovitch Theory) is the hypothesis that small cyclic variations in three of the Earth's orbital motions can bring about global climate change. This hypothesis enjoys very strong support from the body of scientific evidence and is accepted by virtually all professional atmospheric scientists.

The basic concept is simple. The Earth has a number of variations in its various orbital motions that are cyclic: that is, values vary over various periods of time, but keep returning to the same sequence of values over and over again. The time interval for each complete cycle is different for each of the three major cycles, but they all come together and reinforce one another at roughly 100,000 year intervals.

"The paleoclimate record shows peaks at exactly those intervals. Ocean cores showed that the Earth passed through regular ice ages—not just the 3 or 4 recorded on land by misplaced boulders and glacial loess deposits—but 10 in the last million years, and around 100 in the last 2.5 million years." [1]

The last cooling trend reached its maximum some 20,000 years ago and we are currently 20,000 years into a 50,000 year warming trend. Orbital forcing has been accepted as a mechanism of climate change by the National Research Council (NRC), by the U.S. National Academy of Sciences (NAS), and by the U.S. National Atmospheric and Space Administration (NASA).

"...orbital variations remain the most thoroughly examined mechanism of climatic change on time scales of tens of thousands of years and are by far the clearest case of a direct effect of changing insolation on the lower atmosphere of Earth (National Research Council)." [2]

When all of these cycles coincide, Northern Hemisphere winters have very short days, get very little sunshine during those days, and the winters themselves are very long. This leads to the possibility that the winter snowfall will not completely melt during the following summer. Snow on the ground during the summer reflects heat back into space rather than absorbing it and brings about a drop in global temperatures. This drop makes the succeeding winter even colder and snowier, and a new Ice Age is born.

Fifty-thousand years later, just the opposite happens. The winter season is shorter, winter days are longer, and the winter sunshine is warmer. The continental glaciers begin to melt, and a new warm inter-glacial period comes into being.

THE THREE ORBITAL-FORCING CONTROLS

The three orbital-forcing variations that bring on the Ice Ages (and make them disappear) at 100,000 year intervals are:

1) Eccentricity of the Earth's orbit around the Sun.
2) Obliquity of the Earth's axis to the plane of its orbit.
3) Precession of the Equinoxes that brings Midwinter's Day closer to and then farther away from the Earth's greatest distance from the Sun.

Eccentricity of the Earth's Orbit

The Earth's orbit is a function of the gravitational force between the Earth and the Sun and the speed of the Earth in its plane of revolution about the Sun. Eccentricities have a numerical value between 0 and 1. At 0, the orbit is a perfect circle with the Sun at its center. At 1, the orbit becomes what is called as escape parabola and the Earth would leave the gravitational pull of the Sun and hurl itself into outer space. This is not going to happen.

The eccentricity of the Earth's orbit varies from 0.0034 (almost circular) to 0.058 (slightly ellipsoid). At the present time (2013), the eccentricity of the Earth's orbit is roughly 0.0167, which is not much by planetary standards. The greater the eccentricity, the more elongated the orbital ellipse becomes. At the present time, this eccentricity is diminishing. That is, the Earth's orbit is becoming more circular and less elliptical. This means that the Earth is getting farther away from the Sun at its closest approach and closer to the Sun at its farthest point.

Perihelion – The earth is closest to the sun on or about the fourth of January each year. This date will vary over the next several decades from the 2nd to the 5th depending upon a number of astronomic factors that need not concern us at this moment. At the instant of perihelion, the amount of energy that will be received by one square meter at the outside of the earth's atmosphere will be approximately 353 Watts—an increase over the average (342 Watts) of some 11 Watts.

Aphelion – The earth is farthest from the sun on or about the 4th of July each year. This date will vary from the 3rd to the 7th over the next several decades, depending upon the same astronomic factors mentioned above. At the time of aphelion, the amount of energy that will be received by one square meter at the outside of the earth's atmosphere will be approximately 330 Watts—a decrease over the average of some 12 Watts.

Total Current Orbital Variation – The total variation in incoming insolation from aphelion to perihelion is some 23 Watts per square meter at the present time. This value will increase and the Earth's orbit becomes more elliptical and decrease as the Earth's orbit becomes more circular.

Periodic Variations in Eccentricity – The eccentricity of the Earth's orbit varies over a cycle of roughly 100,000 years. On the one hand, it approaches zero eccentricity (a circular orbit). At that value, the variation in insolation from aphelion to perihelion becomes virtually insignificant. At the other extreme, the eccentricity approaches 0.06. At that value, the annual variation in insolation from aphelion to perihelion increases to some 82 Watts. This is a substantial difference from the present time. It is, for instance, greater that the total energy absorbed by all of the carbon dioxide in the Earth's atmosphere (about 53 Watts).

Eccentricity and Climate Change – When combined with the precession of the equinox and the variation in obliquity (see below for both), the result is a strong increase in the seasonal range of temperature. This 100,000 year cycle of variations in the Earth's eccentricity is one of the three cycles upon which the **Milankovitch Hypothesis** is based, and appears—at the present time—to be the dominant cycle.

Obliquity of the Earth's Axis

The elliptical orbit of the earth around the sun defines a geometric plane—the plane of the ecliptic. The Earth's axis of rotation is not perpendicular to that plane. Instead, it is tilted some 23.4°away from the perpendicular in the current year 2013.

Variations in the obliquity – This tilt varies over time with various wobbles in the earth's axis. This tilt is diminishing at the present time as part of a 41,000-year cycle in which it varies between 22.1° and 24.5° from the perpendicular.

Obliquity and insolation – If the Earth's axis were perpendicular to its plane of revolution, every place on Earth would get twelve hours of daylight and twelve hours of dark every day of the year. Moreover, the height of the Sun above the horizon at solar noon would be the same every day of the year.

Seasonal hours of daylight and dark – No matter what the obliquity of the Earth's axis is, every place on Earth gets approximately the same number of hours of daylight and the same number of hours of dark over the course of a year—4,383 hours of each. The more oblique the axis is, the more unevenly these hours are distributed over the seasons. With low obliquity, the number of hours of summer daylight is less and the number of hours of winter daylight is more. With high obliquity, just the opposite happens. The summer daylight periods are longer and the winter daylight periods are shorter.

Seasonal angles of incidence – Moreover, the apparent height of the Sun above the horizon (angle of incidence) also varies. With low obliquity, the Sun does not get as high in the sky at solar noon during the summer months, and gets higher in the sky at solar noon during the winter months. With high obliquity, we get just the opposite once again. The Sun will be higher in the sky during summer noons and lower in the sky during winter noons. It is these variations in the ***angle of incidence*** that directly affect how much solar energy a square meter of the Earth's surface gets at any given time of day and time of year.

Definition of angle of incidence – Imagine a line from the center of the solar disc to any point on the Earth's surface. Imagine a second line from that point to the true horizon along the solar azimuth. Those two lines enclose the angle of incidence. When the sun is directly overhead, the angle of incidence is 90°. When the solar disc is halved by the true horizon, the technical angle of incidence is 0°, but the actual angle of incidence is greater than that because of the diameter of the solar disc. The simpler center-of-the-solar-disc relationship breaks down when any part of the solar disc is below the horizon, but a mean angle of incidence may be calculated using simple trigonometry. When the entire solar disc is below the visible horizon, there is no angle of incidence for the point on the surface under consideration.

Insolation intensity and the angle of incidence – The relationship between insolation intensity and angle of incidence approximates very closely a sine function. That is,

$$I = I_{max} \sin \alpha$$

Here, I is the intensity in joules per second per square meter of receiving surface, Imax is the intensity normal to the solar beam before striking the surface, and α is the angle of incidence.

Angle of Incidence	I as % of Imax
90°	100.0%
85°	99.6%
80°	98.5%

75°	96.6%
60°	86.6%
45°	70.7%
30°	50.0%
15°	25.9%
0°	See text

The intensity is not a true sine function because the angle of incidence must be averaged over the entire solar disc, not just its center. Moreover, diffraction of the Sun's rays as they pass through the atmosphere also plays a part. When the center of the solar disc is on the horizon ($\alpha = 0°$), some insolation will still strike the surface of the Earth from the upper limb of the Sun.

The greater the tilt, the greater the temperature difference between summer and winter in the extra-tropical portions of the globe. At maximum obliquity, summer sunshine will be about 11 Watts per square meter more intense than at minimum obliquity. This may not sound like much, but in climate-forcing terms it is a substantial increase. For comparison, the contribution to the Earth's heat budget of the increase in carbon-dioxide since pre-industrial times is estimated at some 15 Watts per square meter of surface.

This 41,000 year cycle of obliquity is the second of the three cycles upon which the **Milankovitch Theory** is based.

The Precession of the Equinox

In terms of climate change, the easiest way to look at the effects of the precession of the equinoxes is in terms of how close or how far the dates of the solstices are from the dates of perihelion and aphelion. The dates of perihelion and aphelion are discussed above in the section on the Earth's eccentricity.

Dates of the solstices – At the present time (2013), the northern hemisphere summer solstice (Midsummer's Day) occurs around the 21st of June and the winter solstice (Midwinter's Day) around the 21st of December. The exact dates of each will depend upon which time zone you live in and how close the calendar year is to a leap year. These solstices will be reversed in the southern hemisphere, but the dates remain the same.

During Midsummer's Day, the noonday Sun will be at its highest angle of incidence of the entire year, and the length of the daylight period will be at its greatest length of the year. As a consequence of both of these maxima, the amount of insolation reaching the ground during the day will be at its theoretical maximum (assuming cloudless skies and no shading by landforms).

During Midwinter's Day, the noonday Sun will be at its lowest midday angle of incidence of the entire year, and the length of the daylight period will be at its shortest of the year. As a consequence of both of these minima, the amount of insolation reaching the ground during the day will be at its theoretical minimum.

Coincidence of the solstices with aphelion and perihelion – It takes some 26,000 years for aphelion (or perihelion) to work its way around the calendar to coincide with the winter (or summer) solstice. What happens then depends upon which solstice is coinciding with which axial point.

When the summer solstice coincides with aphelion, then the winter solstice will coincide with perihelion. This leads to milder but longer summers in that hemisphere, and milder and shorter winters.

When the summer solstice coincides with perihelion, then the winter solstice will coincide with aphelion. This leads to hotter and shorter summers in that hemisphere and colder and longer winters.

This is the combination that is most likely to trigger the persistence of winter snows into the summer months with the resultant initiation of a new Ice Age. All it takes is the addition of the effects of the obliquity of the Earth's axis. And every 100,000 years or so, all three come together quite nicely.

This 26,000 year cycle of the precession of the equinoxes is the third and final cycle of the three cycles upon which the **Milankovitch Theory** is based.

Summary

Each of the three orbital variations results in a hotter portion of the orbital cycle and a colder portion. When all three come together at their maximum, they trigger a new cold period of continental glaciation. When all three come together at their minimum, they bring about the melting of the continental glaciers and the initiation of a new inter-glacial warm period.

The concept seems fairly complex in theory, but seems to be very simple in its effects on the Earth's global climate.

REFERENCES

[1] http://earthobservatory.nasa.gov/Features/Paleoclimatology_Evidence/

[2] http://earthobservatory.nasa.gov/Features/Milankovitch/