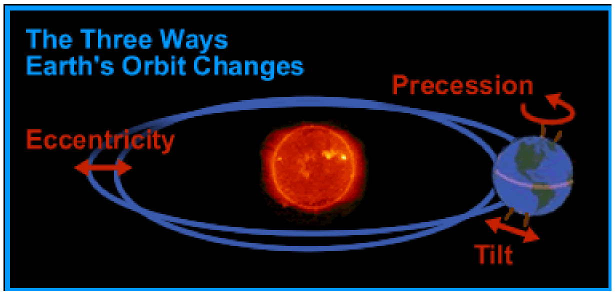
How the Sun Affects Climate
Solar and Milankovitch Cycles



The shape of Earth's orbit becomes more or less oval (eccentricity), Earth wobbles as it spins (precession), and Earth's axis changes too (tilt). All these changes, over thousands of years, causes Earth's climate to change.
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Windows to the Universe

Earth gets all its energy from the Sun and it is the Sun's energy that keeps Earth warm. But the amount of energy Earth receives is not always the same. Changes in the Sun and changes in Earth's orbit affect the amount of energy that reaches the Earth.

The 11-Year Solar Cycle
When the Sun has fewer sunspots, it gives off less energy, less energy makes its way to Earth, and our planet cools down. More than three hundred years ago, when the climate was cooler for a time called the "Little Ice Age", people noticed there were no sunspots for several decades. Over time, scientists have noticed a pattern in the number of sunspots. About every 11 years the number of sunspots reaches a high and then decreases again.

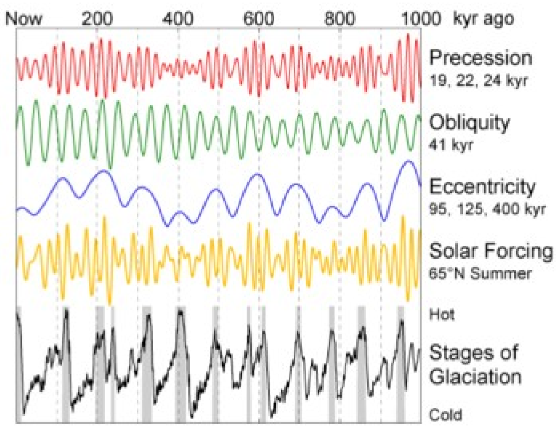
Milankovitch Cycles
Over thousands of years, changes in Earth's orbit cause changes in the amount of the Sun's energy that gets to the planet. Over the past several million years these changes have caused cycles of global warming and cooling.

There are three ways that Earth's orbit changes over time.

- **Eccentricity**: The shape of Earth's orbit around the Sun becomes slightly more and then less oval every 100,000 years.
- **Precession**: Earth wobbles on it axis as it spins, completing a full wobble every 23,000 years.
- **Tilt**: The angle of the Earth's axis relative to the plane of its orbit changes about three degrees every 41,000 years.

Once the Sun's energy reaches the Earth, several things can happen. The energy can be absorbed by the planet, reflected back into space, or become trapped in the atmosphere.

Milankovitch cycles



Milankovitch Theory are the collective effect of changes in the Earth's movements upon its climate, named after Serbian civil engineer and mathematician Milutin Milanković. The eccentricity, axial tilt, and precession of the Earth's orbit vary in several patterns, resulting in 100,000-year ice age cycles of the Quaternary glaciation over the last few million years. The Earth's axis completes one full cycle of precession approximately every 26,000 years. At the same time, the elliptical orbit rotates, more slowly, leading to a 21,000-year cycle between the seasons and the orbit. In addition, the angle between Earth's rotational axis and the normal to the plane of its orbit moves from 22.1 degrees to 24.5 degrees and back again on a 41,000-year cycle. Currently, this angle is 23.44 degrees and is decreasing.

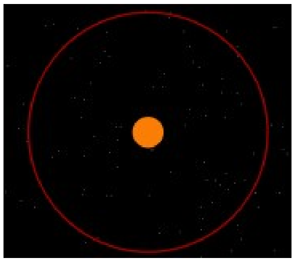
The Milankovitch theory of climate change is not perfectly worked out; in particular, the largest observed response is at the 100,000-year timescale, but the forcing is apparently small at this scale, in regard to the ice ages.[1] Various feedbacks (from carbon dioxide, or from ice sheet dynamics) are invoked to explain this discrepancy.

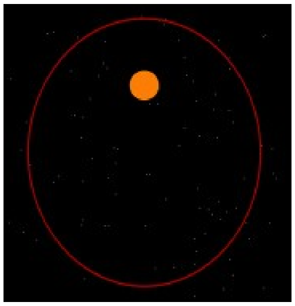
Milankovitch-like theories were advanced by Joseph Adhemar, James Croll and others, but verification was difficult due to the absence of reliably dated evidence and doubts as to exactly which periods were important. Not until the advent of deep-ocean cores and a seminal paper by Hays, Imbrie and Shackleton, "Variations in the Earth's Orbit: Pacemaker of the Ice Ages", in *Science*, 1976,[2] did the theory attain its present state.

Earth’s movements

As the Earth spins around its axis and orbits around the Sun, several quasi-periodic variations occur. Although the curves have a large number of sinusoidal components, a few components are dominant. Milankovitch studied changes in the orbital eccentricity, obliquity, and precession (astronomy) of Earth's movements. Such changes in movement and orientation change the amount and location of solar radiation reaching the Earth. This is known as *solar forcing* (an example of radiative forcing). Changes near the north polar area are considered important due to the large amount of land, which reacts to such changes more quickly than the oceans do.

Orbital shape (eccentricity)


Circular orbit, no eccentricity.


Orbit with 0.5 eccentricity.

The Earth's orbit is an ellipse. The eccentricity is a measure of the departure of this ellipse from circularity. The shape of the Earth's orbit varies from being nearly circular (low eccentricity of 0.005) to being mildly elliptical (high eccentricity of 0.058) and has a mean eccentricity of 0.028 (or 0.017 which is current value, if we take geometric mean, because phenomena in a gravitational field of Lobachevskian pseudosphere as used by Einstein behave logarithmically). The major component of these variations occurs on a period of 413,000 years (eccentricity variation of ±0.012). A number of other terms vary between 95,000 and 136,000 years, and loosely combine into a 100,000-year cycle (variation of −0.03 to +0.02). The present eccentricity is 0.017.

If the Earth were the only planet orbiting our Sun, the eccentricity of its orbit would not vary over time. The Earth's eccentricity varies primarily due to interactions with the gravitational fields of Jupiter and Saturn. As the eccentricity of the orbit evolves, the semi-major axis of the orbital ellipse remains unchanged. From the perspective of the perturbation theory used in celestial mechanics to compute the evolution of the orbit, the semi-major axis is an adiabatic invariant. According to Kepler's third law the period of the orbit is determined by the semi-major axis. It follows that the Earth's orbital period, the length of a sidereal year, also remains unchanged as the orbit evolves.

Currently the difference between closest approach to the Sun (perihelion) and furthest distance (aphelion) is only 3.4% (5.1 million km). This difference is equivalent to about a 6.8% change in incoming solar radiation. Perihelion presently occurs around January 3, while aphelion is around July 4. When the orbit is at its most elliptical, the amount of solar radiation at perihelion is about 23% greater than at aphelion. This difference is roughly 4 times the value of the eccentricity.

Season (Northern Hemisphere) Durations

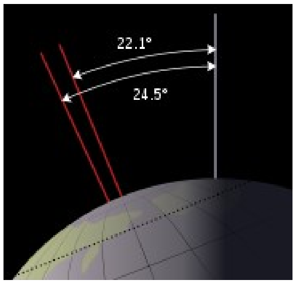
data from United States Naval Observatory

Year	Date: GMT	Season Duration
2005 Winter Solstice	12/21/2005 18:35	88.99 days
2006 Spring Equinox	3/20/2006 18:26	92.75 days
2006 Summer Solstice	6/21/2006 12:26	93.65 days
2006 Autumn Equinox	9/23/2006 4:03	89.85 days
2006 Winter Solstice	12/22/2006 0:22	88.99 days
2007 Spring Equinox	3/21/2007 0:07	92.75 days
2007 Summer Solstice	6/21/2007 18:06	93.66 days
2007 Autumn Equinox	9/23/2007 9:51	89.85 days
2007 Winter Solstice	12/22/2007 06:08	

Orbital mechanics require that the length of the seasons be proportional to the areas of the seasonal quadrants, so when the eccentricity is extreme, the seasons on the far side of the orbit can be substantially longer in duration. When autumn and winter occur at closest approach, as is the case currently in the northern hemisphere, the earth is moving at its maximum velocity and therefore autumn and winter are slightly shorter than spring and summer. Thus, summer in the northern hemisphere is 4.66 days longer than winter and spring is 2.9 days longer than autumn.

Axial tilt (obliquity)

Main article: Axial tilt



22.1-24.5° range of Earth's obliquity.

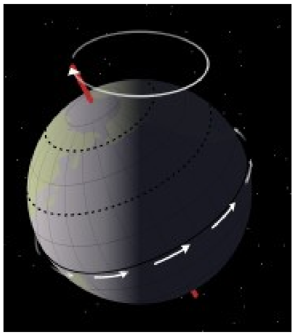
The angle of the Earth's axial tilt (obliquity) varies with respect to the plane of the Earth's orbit. These slow 2.4° obliquity variations are roughly periodic, taking approximately 41,000 years to shift between a tilt of 22.1° and 24.5° and back again. When the obliquity increases, the amplitude of the seasonal cycle in insolation (INcident SOLar radiATION) increases, with summers in both hemispheres receiving more radiative flux from the Sun, and the winters less radiative flux. As a result, it is assumed that the winters become colder and summers warmer.

But these changes of opposite sign in the summer and winter are not of the same magnitude. The annual mean insolation increases in high latitudes with increasing obliquity, while lower latitudes experience a reduction in insolation. Cooler summers are suspected of encouraging the start of an ice age by melting less of the previous winter's ice and snow. So it can be argued that lower obliquity favors ice ages both because of the mean insolation reduction in high latitudes as well as the additional reduction in summer insolation.

Currently the Earth is tilted at 23.44 degrees from its orbital plane, roughly half way between its extreme values. The tilt is in the decreasing phase of its cycle, and will reach its minimum value around the year 10,000 AD.

Precession (axial rotation)

Precessional movement.



Precession is the change in the direction of the Earth's axis of rotation relative to the fixed stars, with a period of roughly 26,000 years. This gyroscopic motion is due to the tidal forces exerted by the sun and the moon on the solid Earth, associated with the fact that the Earth is not a perfect sphere but has an equatorial bulge. The sun and moon contribute roughly equally to this effect. In addition, the orbital ellipse itself precesses in space (anomalistic precession), primarily as a result of interactions with Jupiter and Saturn. This orbital precession is in the opposite sense to the gyroscopic motion of the axis of rotation, shortening the period of the precession of the equinoxes with respect to the perihelion from 25,771.5 to ~21,636 years.

When the axis is aligned so it points toward the Sun during perihelion, one polar hemisphere will have a greater difference between the seasons while the other hemisphere will have milder seasons. The hemisphere which is in summer at perihelion will receive much of the corresponding increase in solar radiation, but that same hemisphere will be in winter at aphelion and have a colder winter. The other hemisphere will have a relatively warmer winter and cooler summer.

When the Earth's axis is aligned such that aphelion and perihelion occur near the equinoxes, the Northern and Southern Hemispheres will have similar contrasts in the seasons.

At present, perihelion occurs during the Southern Hemisphere's summer, and aphelion is reached during the southern winter. Thus the Southern Hemisphere seasons are somewhat more extreme than the Northern Hemisphere seasons, when other factors are equal.

Orbital inclination

The inclination of Earth's orbit drifts up and down relative to its present orbit with a cycle having a period of about 70,000 years. Milankovitch did not study this three-dimensional movement.

More recent researchers noted this drift and that the orbit also moves relative to the orbits of the other planets. The invariable plane, the plane that represents the angular momentum of the solar system, is approximately the orbital plane of Jupiter. The inclination of the Earth's orbit has a 100,000 year cycle relative to the invariable plane. This 100,000-year cycle closely matches the 100,000-year pattern of ice ages.

It has been proposed that a disk of dust and other debris is in the invariable plane, and this affects the Earth's climate through several possible means. The Earth presently moves through this plane around January 9 and July 9, when there is an increase in radar-detected meteors and meteor-related noctilucent clouds.[3][4]

A study of the chronology of Antarctic ice cores using oxygen to nitrogen ratios in air bubbles trapped in the ice, which appear to respond directly to the local insolation, concluded that the climatic response documented in the ice cores was driven by Northern Hemisphere insolation as proposed by the Milankovitch hypothesis (Kawamura et al, Nature, 23 August 2007, vol 448, p912-917). This is an additional validation of the Milankovitch hypothesis by a relatively novel method, and is inconsistent with the "inclination" theory of the 100,000-year cycle.

Problems

The nature of sediments can vary in a cyclic fashion, and these cycles can be displayed in the sedimentary record. Here, cycles can be observed in the colouration and resistance of different strata

Because the observed periodicities of climate fit so well with the orbital periods, the orbital theory has overwhelming support. Nonetheless, there are several difficulties in reconciling theory with observations.

100,000-year problem

The **100,000-year problem** is that the eccentricity variations have a significantly smaller impact on solar forcing than precession or obliquity and hence might be expected to produce the weakest effects. However, observations show that during the last 1 million years, the strongest climate signal is the 100,000-year cycle. In addition, despite the relatively large 100,000-year cycle, some have argued that the length of the climate record is insufficient to establish a statistically significant relationship between climate and eccentricity variations.[5] Some models can however reproduce the 100,000 year cycles as a result of non-linear interactions between small changes in the Earth's orbit and internal oscillations of the climate system.[6][7]

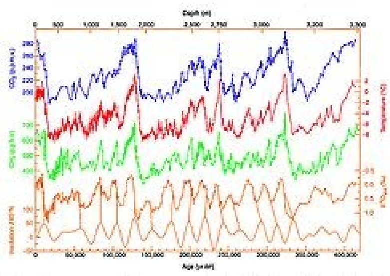
400,000-year problem

The **400,000-year problem** is that the eccentricity variations have a strong 400,000-year cycle. That cycle is only clearly present in climate records older than the last million years. If the 100 ka variations are having such a strong effect, the 400 ka variations might also be expected to be apparent. This is also known as the **stage 11 problem**, after the interglacial in marine isotopic stage 11 which would be unexpected if the 400,000-year cycle has an impact on climate. The relative absence of this periodicity in the marine isotopic record may be due, at least in part, to the response times of the climate system components involved — in particular, the carbon cycle.

Stage 5 problem

The **stage 5 problem** refers to the timing of the penultimate interglacial (in marine isotopic stage 5) which appears to have begun 10 thousand years in advance of the solar forcing hypothesized to have been causing it. This is also referred to as the **causality problem**.

Effect exceeds cause



420,000 years of ice core data from Vostok, Antarctica research station.

The effects of these variations are primarily believed to be due to variations in the intensity of solar radiation upon various parts of the globe. Observations show climate behaviour is much more intense than the calculated variations. Various internal characteristics of climate systems are believed to be sensitive to the insolation changes, causing amplification (positive feedback) and damping responses (negative feedback).

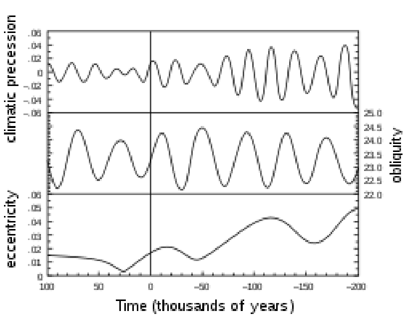
The unsplit peak problem

The **unsplit peak problem** refers to the fact that eccentricity has cleanly resolved variations at both the 95 and 125 ka periods. A sufficiently long, well-dated record of climate change should be able to resolve both frequencies, but some researchers interpret climate records of the last million years as showing only a single spectral peak at 100 ka periodicity. It is debatable whether the quality of existing data ought to be sufficient to resolve both frequencies over the last million years.

The transition problem

The **transition problem** refers to the change in the frequency of climate variations 1 million years ago. From 1-3 million years, climate had a dominant mode matching the 41 ka cycle in obliquity. After 1 million years ago, this changed to a 100 ka variation matching eccentricity. No reason for this change has been established.

Present conditions



The amount of solar radiation (insolation) in the Northern Hemisphere at 65° N seems to be related to occurrence of an ice age. Astronomical calculations show that 65° N summer insolation should increase gradually over the next 25,000 years, and that no declines in 65° N summer insolation sufficient to cause an ice age are expected in the next 50,000 to 100,000 years.

As mentioned above, at present perihelion occurs during the Southern Hemisphere's summer, and aphelion during the southern winter. Thus the Southern Hemisphere seasons should tend to be somewhat more extreme than the Northern Hemisphere seasons. The relatively low eccentricity of the present orbit results in a 6.8% difference in the amount of solar radiation during summer in the two hemispheres.

The future

Since orbital variations are predictable[8], if one has a model that relates orbital variations to climate, it is possible to run such a model forward to "predict" future climate. Two caveats are necessary: that anthropogenic effects and that the mechanism by which orbital forcing influences climate is not well understood.

An often-cited 1980 study by Imbrie and Imbrie determined that, "Ignoring anthropogenic and other possible sources of variation acting at frequencies higher than one cycle per 19,000 years, this model predicts that the long-term cooling trend which began some 6,000 years ago will continue for the next 23,000 years."[9]

More recent work by Berger and Loutre suggests that the current warm climate may last another 50,000 years.[10]

References

1. ^ Milankovitch, Milutin (1998) [1941]. *Canon of Insolation and the Ice Age Problem*. Belgrade: Zavod za Udžbenike i Nastavna Sredstva. ISBN 8617066199.; see also "Astronomical Theory of Climate Change". http://www.ncdc.noaa.gov/paleo/milankovitch.html.
2. ^ Hays, J.D.; Imbrie, J.; Shackleton, N.J. (1976). "Variations in the Earth's Orbit: Pacemaker of the Ice Ages". *Science* **194** (4270): 1121–1132. doi:10.1126/science.194.4270.1121. PMID 17790893.
3. ^ Richard A Muller, Gordon J MacDonald (1997). "Glacial Cycles and Astronomical Forcing". *Science* **277** (1997/07/11): 215–218. doi:10.1126/science.277.5323.215.
4. ^ "Origin of the 100 kyr Glacial Cycle: eccentricity or orbital inclination?". *Richard A Muller*. http://muller.lbl.gov/papers/nature.html. Retrieved on March 2 2005.
5. ^ Wunsch, Carl (2004). "Quantitative estimate of the Milankovitch-forced contribution to observed Quaternary climate change". *Quaternary Science Reviews* **23**: 1001–1012. doi:10.1016/j.quascirev.2004.02.014.
6. ^ Ghil, Michael (1994). "Cryothermodynamics: the chaotic dynamics of paleoclimate". *Physica D* **77** (1-3): 130–159. doi:10.1016/0167-2789(94)90131-7.
7. ^ Gildor H, Tziperman E (2000). "Sea ice as the glacial cycles' climate switch: Role of seasonal and orbital forcing". *Paleoceanography* **15** (6): 605–615. doi:10.1029/1999PA000461.
8. ^ F. Varadi, B. Runnegar, M. Ghil (2003). "Successive Refinements in Long-Term Integrations of Planetary Orbits" (PDF). *The Astrophysical Journal* **592**: 620–630. doi:10.1086/375560. http://astrobiology.ucla.edu/OTHER/SSO/SolarSysInt.pdf.
9. ^ J Imbrie, J Z Imbrie (1980). "Modeling the Climatic Response to Orbital Variations". *Science* **207** (1980/02/29): 943–953. doi:10.1126/science.207.4434.943. PMID 17830447.
10. ^ Berger A, Loutre MF (2002). "Climate: An exceptionally long interglacial ahead?". *Science* **297** (5585): 1287–1288. doi:10.1126/science.1076120. PMID 12193773.

Further reading

- Zachos J, Pagani M, Sloan L, Thomas E, Billups K (2001). "Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present". *Science* **292** (5517): 686–693. doi:10.1126/science.1059412. PMID 11326091.
  This review article discusses cycles and large-scale changes in the global climate during the Cenozoic Era.
- Zachos JC, Shackleton NJ, Revenaugh JS, Palike H, Flower BP (2001). "Climate Response to Orbital Forcing Across the Oligocene-Miocene Boundary". *Science* **292** (5515): 274–278. doi:10.1126/science.1058288. PMID 11303100.
  This article shows the influence of Milankovitch cyles on climate variation during the late Oligocene and early Miocene, around 20-25 million years ago.
- Tuenter, Erik (2000) (PDF). *Modeling orbital induced variations in circum-Mediterranean climate*. http://www.knmi.nl/onderzk/phd/tuenter.pdf.
  This thesis has a good introduction on Milankovitch cycles. It nicely describes an indirect influence of Milankovitch orbital variations on rainfall and other climate factors, using results from geological deposits as well as climate simulations. It focuses on the region around the Mediterranean Sea.

- Milankovitch Cycles and Glaciation
- The Milankovitch band
- Some history of the adoption of the Milankovitch hypothesis (and an alternative)
- More detail on orbital obliquity also matching climate patterns
- Graph of variation in insolation Note 20,000 year, 100,000 year, and 400,000 year cycles are clearly visible.
- "Milutin Milankovitch". *On the Shoulders of Giants*. http://earthobservatory.nasa.gov/Library/Giants/Milankovitch/milankovitch.html. Retrieved on November 2 2007.
- Potential Problems with Milankovitch Theory by Sean Pitman
- *The Seasons*
- The NOAA page on Climate Forcing Data includes (calculated) data on orbital variations over the last 50 million years and for the coming 20 million years.
- The orbital simulations by Varadi, Ghil and Runnegar (2003) provide another, slightly different series for orbital eccentricity, and also a series for orbital inclination
- ABC: Earth wobbles linked to extinctions

Milankovitch Cycles in Paleoclimate

Milankovich cycles are cycles in the Earth's orbit that influence the amount of solar radiation striking different parts of the Earth at different times of year. They are named after a Serbian mathematician, Milutin Milankovitch, who explained how these orbital cycles cause the advance and retreat of the polar ice caps. Although they are named after Milankovitch, he was not the first to link orbital cycles to climate. Adhemar (1842) and Croll (1875) were two of the earliest.

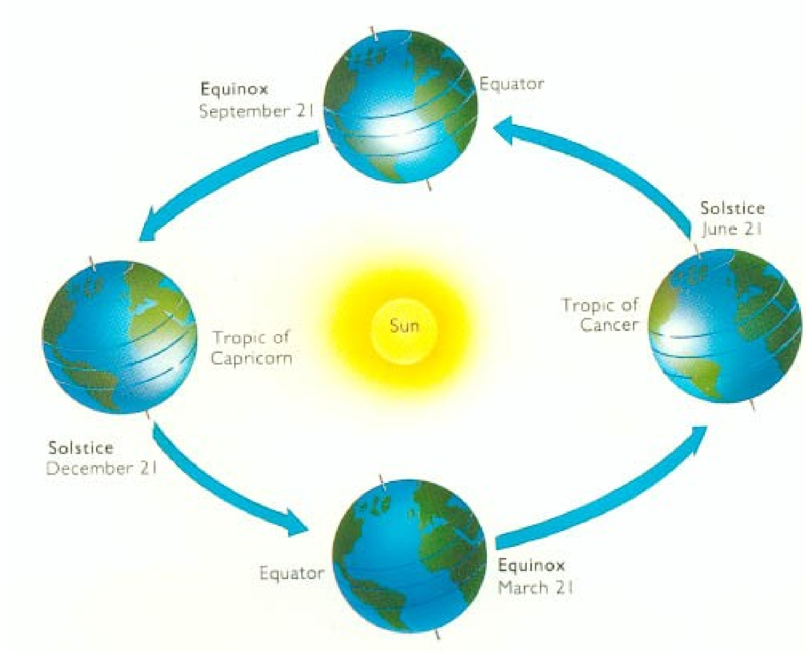
A "wobbling top": The Milankovitch theory

A Serbian mathematician named Milutin Milankovitch was intrigued by this puzzle of climate change, and in the 1930s he presented a theory that might explain it. Milankovitch studied climate records, noting differences over time. He theorized that global climate change was brought about by regular changes in Earth's axis, tilt, and orbit that altered the planet's relationship to the Sun, triggering ice ages.

Earth doesn't rotate perfectly like a wheel about an axis; it spins like a wobbling top. Every 22,000 years, Milankovitch calculated, there is a slight change in its wobble. Every 100,000 years, there is a change in Earth's orbit about the Sun. Its almost circular orbit becomes more elliptical, taking Earth farther from the Sun. And finally, Milankovitch discovered, every 41,000 years there is a change in the tilt of the planet's axis, moving either the Northern or Southern Hemisphere farther from the Sun.

These cycles mean that at certain times there is less sunshine hitting Earth, so there is less melting of snow and ice. Instead of melting, these cold expanses of frozen water grow. The snow and ice last longer and, over many seasons, begin to accumulate. Snow reflects some sunlight back into space, which also contributes to cooling. Temperatures drop, and glaciers begin to advance.

The Orbital Variance Theory



The Earth's Orbit

Milankovic Theories

Milutin Milankovitch was a Serbian scientist who showed that the earth's orbital "cycle" has additional modulations that make it fluctuate considerably. They correspond to three variables (according to Milankovitch) in the earth's orbit.

- Most important of these variations is the eccentricity cycle of 93,408 years (according to Milankovitch) - which is the variation of the Earth's orbit from its almost circular path.

- The second of the orbital cycles is the change in the tilt of the earth's equatorial plane in relation to its orbital plane over a period (according to Milankovitch), averaging 41,000 years.

- The third orbital phenomenon is the 25,920-year precession cycle which causes a gradual shift of the Earth's polar (poles) alignment.

In the past (at least) 100 years, the Earth's orbit (according to the Orbital Variance Theory) has moved us a bit closer to the Sun. When you consider that the Earth's tilt on her axis (approximately 23 degrees) is what causes seasonal changes (Summer to Winter) it is quite

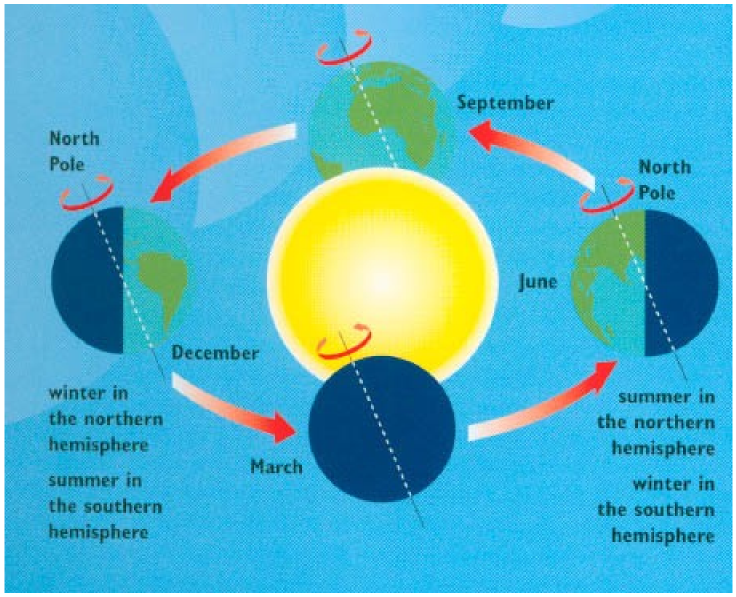
reasonable to believe that a gradual orbital variance will produce dramatic climate fluctuations (ice ages) over the eons.

Milankovitch Cycles: Changes in Earth-Sun Interaction

Seen from *Apollo 17*, Earth glows with the rich vitality of a water planet, nearly three quarters of its surface covered with a global ocean, its poles buried in permanent ice caps, and its atmosphere marbled with water vapor in the form of clouds.

Above:

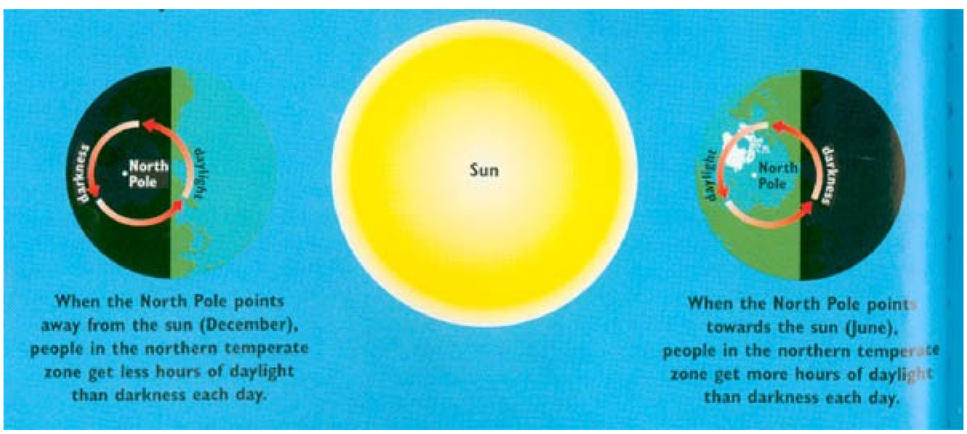
Earth Circling the Sun



The earth like all the other planets travels in an orbit, or path, around the Sun. It takes the Earth a little over 365 days to orbit the Sun once. This is a period of a year.

Earth spins around in space like a top, taking one day to rotate once. It spins around from west to east. This is what makes the Sun seem to travel across the sky in the opposite direction, from east to west.

Earth's Tilt



Earth spins around in space. It spins around on an imaginary line called its axis. The line goes through the North and South Poles. Its axis is tilted at an angle to the direction in which it is traveling. This means that the northern half of Earth is tilted toward the Sun for half of the year and away from the Sun for the other half. When the northern half of Earth is tilted toward that Sun, it received more of the Sun's heat and the weather is warmer. When it is tilted away from the Sun, it receives less heat and the weather is colder.

The changes is temperature caused by the Earth's tilt take place regularly every year. The seasons are changing because of the Earth's tilt.

Milankovic Theory

Milankovitch dedicated his career to developing a mathematical theory of climate based on the seasonal and latitudinal variations of solar radiation received by the Earth. Now known as the Milankovitch Theory, it states that as the Earth travels through space around the sun, cyclical variations in three elements of Earth-sun geometry combine to produce variations in the amount of solar energy that reaches Earth:

1. **Variations in the Earth's orbital eccentricity—the shape of the orbit around the sun.**

2. **Changes in obliquity—changes in the angle that Earth's axis makes with the plane of Earth's orbit.**

3. **Precession—the change in the direction of the Earth's axis of rotation, i.e., the axis of rotation behaves like the spin axis of a top that is winding down; hence it traces a circle on the celestial sphere over a period of time.**

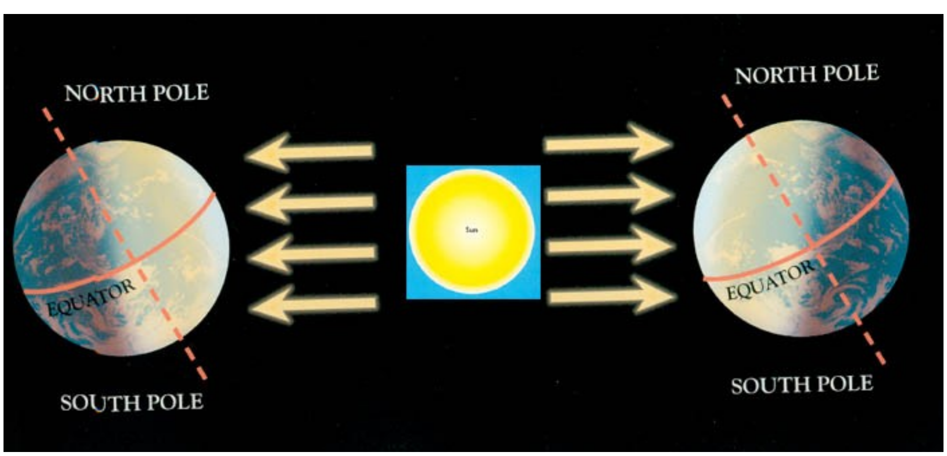
Together, the periods of these orbital motions have become known as Milankovitch cycles.

Glaciers on the Move: Ice Ages in History

Above: A Glacier

Twenty thousand years ago, a sheet of ice covered what is now the northern United States. Nowadays, you won't find glaciers in Massachusetts or Michigan, though the evidence of their passing is carved into the landscape. What brought about this dramatic change in climate? Why aren't these areas still covered in ice?

We're accustomed to thinking of our planet as stable, steady, and solid. In reality, Earth is dynamic. Our climate is changeable. The history of Earth's climate has been marked by many ice ages and warm spells, some measured in millenium and others in centuries. You may be surprised to find that there are some patterns in this changeability, though. Climate change seems to be cyclical.



Obliquity

On a 42,000 year cycle, the earth wobbles and the angle of the axis, with respect to the plane of revolution around the sun, varies between 22.1° and 24.5° . Less of an angle than our current 23.45° means less seasonal differences between the Northern and Southern Hemispheres while a greater angle means greater seasonal differences (i.e. a warmer summer and cooler winter).

While we're all familiar with the axis of the earth pointing toward the North Star (Polaris) at an angle of 23.45° and that the earth is approximately 91-94 million miles from the sun, these facts are not absolute or constant. The interaction between the earth and sun, known as orbital variation, changes and has changed throughout the 4.6 billion year history of our planet.

Above: The Solar System

Exploration of Mars, an Ancient Dream

Humanity has been fascinated by Mars for thousands of years. Mars is the planet closest to us and the fourth planet from the sun. Mars is the most Earthlike planet in the Solar System. It has seasons and days similar in length to the Earth's, and an atmosphere and polar caps that change with the seasons.

As ancient astronomers watched the stars sweep across the sky, they noticed a strange reddish object that didn't seem to follow the laws of the universe. Nearly all the stars seemed to move along the same arc, but Mars was one of only a handful of objects in the sky that did not follow the proper trajectory.

In 140 A.D. Claudius Ptolemy, a scholar from Alexandria, Egypt, put the Earth at the center of the Solar System. Although incorrect, Ptolemy's theory survived 1500 years. Observations of Mars' movement helped to establish the evidence of Copernican theory that the sun, not the Earth, is the center of the Solar System. The key observations were made by Galileo, who noted that the diameter of Mars as seen through the telescope seems to vary, according to differences in the distance between Mars and Earth. This observation argues in favor of the Copernican theory. Galileo succeeded in demolishing the Ptolemaic theory.

In 1609, Johannes Kepler announced that the orbit of Mars was not a circle but an ellipse. He also explained his laws of motion that all planets move in elliptical orbits with the sun. In 1877, the Italian astronomer Giovanni Schiaparelli reported that he had discovered a strange network of lines on the surface of Mars. He called these lines *canali* (canals). Shiaparelli did not suggest that intelligent being built the canals, but others believed so. Many people including scientists gained a strong belief that Mars was a planet of intelligent life.

H.G. Wells wrote a science fiction novel The War of the Worlds, a story of a Martian invasion on Earth. A dramatic radio play of this novel took place on the CBS radio network on the night before Halloween, 1938. The radio narrator was Orson Welles. The radio show was so real and frightening to listeners that many people abandoned their homes in panic, fleeing what they thought was the imminent arrival of the Martian monsters.

Nikola Tesla financially supported by J.P. Morgan, built the Warenclyffe laboratory and its famous transmitting tower in Shoreham, Long Island between 1901 and 1905. This huge landmark was 187 feet high, capped by a 68-foot copper dome, which housed the magnifying transmitter. It was planned to be the first broadcast system, transmitting both signals and power without wires to any point on the globe.

Tesla's wireless "World System" in Long Island was planned for use in radio communication with Mars. Tesla was preoccupied with the idea of radio contact with Mars for almost half a century. In numerous newspaper articles and interviews, Tesla expressed his belief that radio communication with Mars is possible a concept he shared with his contemporaries, Guglielmo Marconi, Professor Percival Lowell and Thomas Edison.

On July 4,1997, NASA explorer-robot Sojourner landed on Mars and become the first radio-guided vehicle to roam the surface of the Red Planet. Remotely controlled exploration of the cosmos began 100 years ago when Nikola Tesla, demonstrated the invention of the robot in New York City. In 1898 he was granted a patent which described radio remote control for use in guided vehicles. Space exploration developed from this first building block. Tesla publicly demonstrated his first working model of a robot guided by radio waves. This device was unveiled to many astonished viewers at the Electrical Exposition held at Madison Square Garden in May 1898. This was the front-page news in America at the time.

The Polish astronomer
Nicolaus Copernicus

Johannes Kepler (1571–1630), a German astronomer, studied the motion of the planets.

MAGAZINE The Sun SECTION

SECTION SEVEN | NEW YORK, SUNDAY, JANUARY [illegible] | TWELVE PAGES

Marconi Credits Mystery Flash to Far Planet

Strange Wireless Signals Stimulate Inventor's Belief We Soon May Communicate With Mars or Other Celestial Bodies—Edison and Tesla Regard Success Possible

Poster by: Dr. Ljubo Vujovic

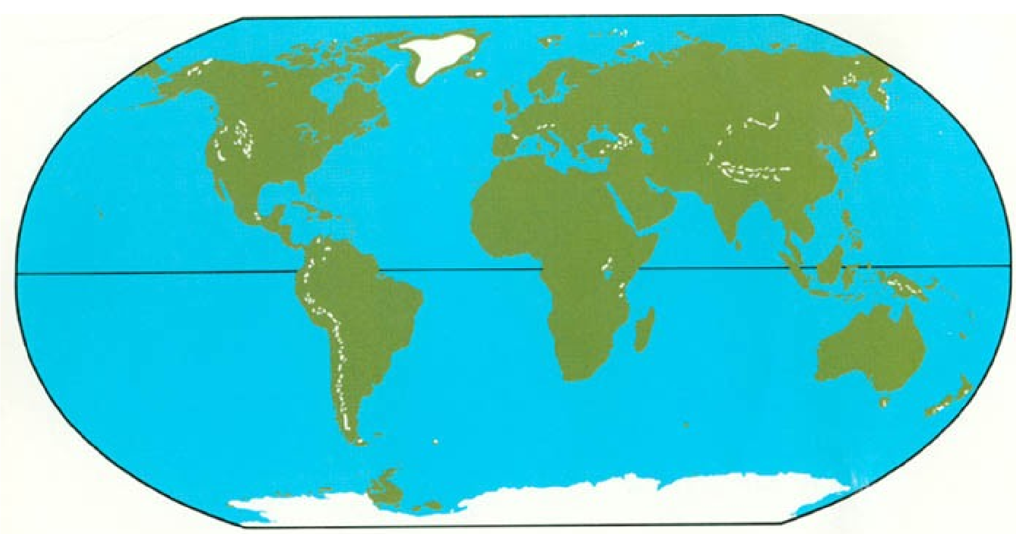
The Milankovic or astronomical theory of climate change is an explanation for changes in the seasons whish result from changes in the earth's orbit around the sun. Milutin Milankovic, the Serbian astronomer, calculated the slow changes in the earth's orbit by

careful measurement of the position of the stars and using the gravitational pull of other planets and stars. He determined that the earth "wobbles" in its orbit. The earth "tilt" is what causes seasons, and changes in the tilt of the earth change the season. The season can also be accentuated or modified by the eccentricity (degree of roundness) of the orbital path around the sun.

Milankovitch Cycles

Astronomer Milutin Milankovitch developed the mathematical formulas upon which these orbital variations are based. He hypothesized that when some parts of the cyclic variations are combined and occur at the same time, they are responsible for major changes to the earth's climate (even ice ages). Milankovitch estimated climatic fluctuations over the last 450,000 years and described cold and warm periods. Though he did his work in the first half of the 20th century, Milankovich's results weren't proven until the 1970s.

A 1976 study, published in the journal *Science* examined deep-sea sediment cores and found that Milankovich's theory corresponded to periods of climate change. Indeed, ice ages had occurred when the earth was going through different stages of orbital variation.



Glaciers are represented by the white areas in this map of the world.

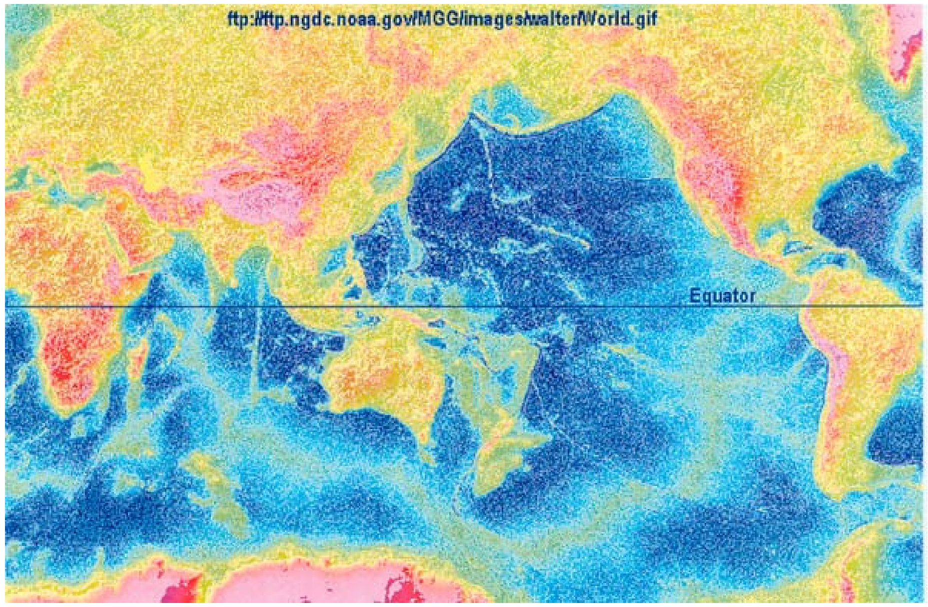
Approximately one-tenth of the earth's surface is covered by glaciers. They exist as giant sheets of ice in polar regions such as Antarctica and parts of Greenland, Iceland, Canada, the Soviet Union and Alaska. Smaller glaciers are found on tall mountains all over the world. If all existing glaciers were to melt, world sea levels would rise more

than 180 feet (55 m). Coastal cities like Los Angeles, New York, London, Paris and Bombay would be under water.

Above: Here is a photograph of the highest mountains on Earth - the Himalayas in Asia. The Himalayas are still rising. The snow covered mountains are more than twelve thousand feet high.

Glaciers form in places where the air temperature never gets warm enough to completely melt the snow. Over the years, the snow becomes deeper as new snow falls.

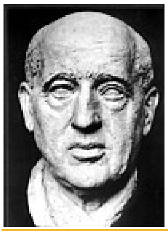
Above: Mountains of Alaska Range covered with ice with the aurora borealis or Northern Lights



From NOAA's National Geophysical Data Center

The episodic nature of the Earth's glacial and interglacial periods within the present Ice Age (the last couple of million years) have been caused primarily by cyclical changes in the Earth's circumnavigation of the Sun. Variations in the Earth's eccentricity, axial tilt, and precession comprise the three dominant cycles, collectively known as the Milankovitch Cycles for Milutin Milankovitch, the Serbian astronomer who is generally credited with calculating their magnitude. Taken in unison, variations in these three cycles creates alterations in the seasonality of solar radiation reaching the Earth's surface. These times of increased or decreased solar radiation directly influence the Earth's climate system, thus impacting the advance and retreat of Earth's glaciers.

The Ice Ages which have dominated the Earth's environment for around the past two million years are thought to be caused primarily by orbital fluctuations that, while changing the sunlight received by only a few percent, have major impact on climate systems. These orbital forces include the 22,000 year cycle of precession, 100,000 and 400,000 cycles of eccentricity, and 41,000-year cycles of Earth's obliquity or axial tilt. Scientists are still researching exactly what mechanisms trigger the flux and flow of Ice Ages.



Milutin Milankovic

Milutin Milankovic was born on May 28, 1879, at Dali near Osijek, in what was then Austria-Hungary.

He received a degree from the School of Civil Engineering in June, 1902, having submitted a project for a reinforced concrete bridge. His thesis, *Theorie der Druckkurven (Theory of Pressure Lines)*, was noted for its original approach; it was published in 1907, in the eminent German scientific, non-technical, review *Zeitschrift für Mathematik und Physik, Bd. 55*.

At the beginning of 1905, Milankovic took up practical work and joined the then famous firm of Adolf Baron Pittel Betonbau-Unternehmung in Vienna. He built dams, bridges, viaducts, aqueducts and other structures in reinforced concrete throughout the Austria-Hungary of the time. Milankovic continued to practice civil engineering in Vienna until the autumn of 1909 when he was offered the chair of applied mathematics (rational mechanics, celestial mechanics, theoretical physics) in Belgrade. The year 1909 marked a turning point in his life. Though he continued to pursue his investigations of various problems pertaining to the application of reinforced concrete, he decided to concentrate on fundamental research.

Turbulent events took place as soon as he had settled down in Belgrade when the Balkan Wars were followed by World War I. When World War I broke out (he was just married), he was interned in Nezsider and later in Budapest, where he was allowed to work in the library of the Hungarian Academy of Sciences. As early as 1912, his interests turned to solar climates and temperatures prevailing on the planets. Throughout his internment in Budapest he devoted his time to the work in this field and, by the end of the war, he had finished a monograph on the problem which was published in 1920, in the editions of the Yugoslav Academy of Sciences and Arts by Gauthiers-Villards in Paris, under the title *Théorie mathématique des phénomènes thermiques produits par la radiation solaire (Mathematical theory of thermic phenomena caused by solar radiations)*.

The results set forth in this work won him considerable reputation in the scientific world, notably his *curve of insolation* at the Earth's surface. This solar curve was not really accepted until 1924 when the great meteorologist and climatologist Vladimir Köppen with his son-in-law Alfred Wegener, introduced the curve in their work *Klimate der geologischen Vorzeit (Climates of Geological Past)*. After these first tributes, Milankovic was invited, in 1927, to cooperate in two important publications: the first was a handbook on climatology *(Handbuch der Klimatologie)* and the second a handbook on geophysics *(Guttenberg's Handbuch der Geophysik)*. For the former, he wrote the introduction *Mathematische Klimalehre und astronomische Theorie der Klimaschwankungen (Mathematical science of* *climate and astronomical theory of the variations of the climate)*, published in 1930 in German and in 1939 translated into Russian. Here the theory of planetary climate is further developed with special reference to the Earth.

For the second textbook, Milankovic wrote four sections developing and formulating his theory of the secular motion of the Earth's poles and his theory of glacial periods. Fully aware that his theory of solar radiation had been successfully completed and that the papers dealing with this theory were dispersed in separate publications, he decided to collect and publish them under a single cover. Thus, in 1941, on the eve of war in his country, the printing of his great work *Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem (Canon of Insolation of the Earth and Its Application to the Problem of the Ice Ages)* was completed, 626 pages in quarto, in Cemian, published in the editions of the Royal Serbian Academy. This work was translated into English under the title *Canon of Insolation of the Ice-Age Problem*, in 1969 by the Israel Program for Scientific Translations and published for the U.S. Department of commerce and the National Science Foundation, Washington, D.C.

Objections were raised in the 50's against the Milankovic theory of ice ages; these objections came mainly from meteorologists who claimed that the insolation changes due to the changes in the Earth's orbital elements were too small to perturb significantly the climate system. However, in the late 60's and 70's, investigation of the deep-sea sediments and theoretical works in celestial mechanics and climate modelling showed that Milankovic's view was correct and that the astronomically induced changes in insolation, received by the Earth from the Sun, was indeed the primary cause for the waxing and waning of the Quaternary ice sheets.

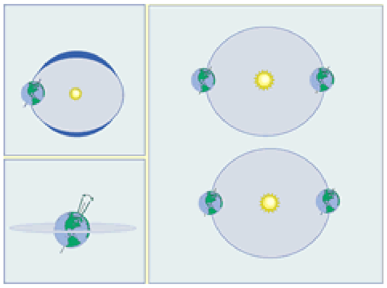
In addition to his scientific work, Milankovic always showed great interest in the historical development of science. In addition to a textbook on the history of astronomy, the wrote two books on a popular level: *Through Space and Centuries* fictionalized the development of astronomy while the other, entitled *Through the Realm of Science*, dealt with the development of exact sciences.

Milankovic also published a three volume autobiography in Serbo-Croatian, *Recollection, Experiences and Vision*, which was never translated. For this reason his son, Vasko Milankovic, has completed a beautiful biography: *My father, Milutin Milankovic*.

Milankovic was elected a corresponding member of the Serbian Academy of Arts and Sciences in 1920, a full member in 1924, a corresponding member of the Yugoslav Academy of Arts and Sciences in 1925 and as member of the German Academy of Naturalists "Leopoldine" in Halle; he was also a member of many scientific societies and related to organizations, both in Yugoslavia and abroad.

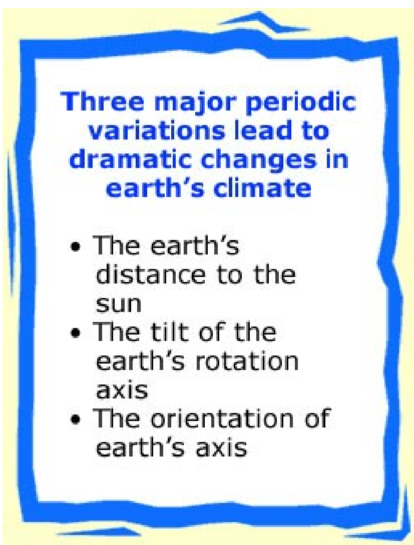
He died on December 12, 1958, in Belgrade.

Greenhouse gases are only one factor in global climate change. Natural, long-term causes of global climate change can be explained by changes in the relative positions of the earth and the sun called Milankovic cycles.



Orbital flexing. The earth's orbit is not always the same shape. The orbit stretches from its most round to its most elliptical and back again every 90,000-100,000 years. Orbital flexing varies the distance from the earth to the sun by more than 11 million miles.

This variation helps determine how much extra solar energy the earth receives at perihelion, the point in earth's orbit closest to the sun, compared to the amount received at aphelion, the point farthest from the sun. When its orbit is most elliptical, earth receives about 20 to 30 percent more solar radiation at perihelion than at aphelion. The difference observed today is 6 percent.



Tilting of earth's axis. The earth rotates about its axis, an imaginary line that passes through the north and south poles. The axis is tilted at an angle to the plane of earth's orbit. The tilt now is about 23.5º. But over a 41,000-year cycle the amount of tilt changes from a minimum of 22.1º to a maximum of 24.5º and back again.

Axial tilting is the key to seasonal differences in climate. If the earth's axis of rotation were perpendicular to the plane of its orbit, there would be no seasons. Each point on earth's surface would receive the same amount of solar energy every day, regardless of where the planet was in its orbit. But because the axis tilts, the amount of solar energy received differs from season to season. Each side of the earth takes its turn facing more towards the sun (summer) and then half a year later when the earth is at the opposite side of its orbit, away from the sun (winter).

Since axial tilt causes seasons, it follows that the greater the tilt, the greater the seasonal variation in climate. Winters are coldest and summers are warmest when earth's axis tilts the most.

Because the three cycles have different periods, they can produce a wide variety of climate changes, depending on how they interact. For example, northern winter is currently moderated because it occurs near perihelion. We can expect more severe winters in about 13,000 years when winter occurs near aphelion.

Precession. The earth's orbit around the sun is not a perfect circle, so the earth is not always the same distance from the sun. When the earth is closest to the sun (perihelion), it receives more solar energy than when it is farthest from the sun (aphelion).

Perihelion does not occur at exactly the same time every year. As the sun and moon's gravity pulls on the earth, its rotational axis wobbles like that of a spinning toy top. Since the tilt of the axis determines when the seasons of the year occur, this wobble slowly changes the date of perihelion, moving it back about one full day every 58 years, or one complete cycle every 21,000 years.

Currently perihelion occurs in early January, during winter in the Northern Hemisphere. 11,000 years ago perihelion occurred--and earth received its maximum amount of solar radiation--in July, during the Northern Hemisphere's summer.