Earth Gauge
A National Environmental Education Foundation Program

Paleoclimate:
The Quaternary Period

This is the third installment in a series of fact sheets on Paleoclimate. The series seeks to provide a frame of reference for recent climate trends by highlighting what drove climate changes in Earth's distant past.

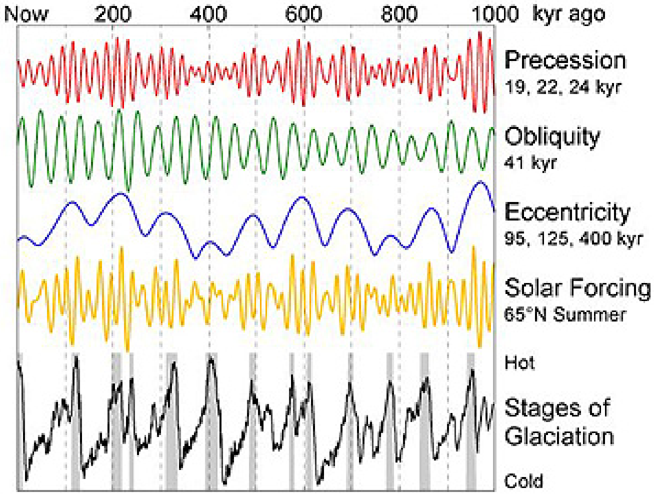

Image courtesy of NASA.

THE BIRTH OF THE MODERN CLIMATE

The transition from the warm, greenhouse climate of the Tertiary period (65 to 1.8 million years ago) to the much colder world of the Quaternary (1.8 million years ago to present) was, for the most part, gradual. Between 55 and five million years ago, increased transport of moisture to higher latitudes as a result of changes in continental positions and mountain building, combined with the evolution of more sophisticated ecosystems, resulted in a decline in atmospheric carbon dioxide (CO_2) levels. During this period, variations in the properties of the Earth's orbit (see graph, right), which determines how sunlight hits the Earth, had negligible effects compared to what would follow.

What changed? During the Tertiary period, orbital forcings were not powerful enough to override the high atmospheric carbon concentrations (up to 1000 parts per million, or ppm) and set in motion the positive feedbacks that allow glaciers at the poles to grow into the mid-latitudes. An overview of these feedback cycles follows the description of orbital forcings below.

ORBITAL FORCINGS

Three primary features of Earth's orbital patterns provide the best theory available for what controls the strength and seasonality of the sunlight that hits the Earth and controls the amount of ice present on the planet's surface:

1. ***Eccentricity:*** When a smaller object orbits a larger one, it generally does not move in a perfect circle; there will be points when the objects will be closer or farther from each other. Eccentricity is the measure of how much an orbital pattern departs from a perfect circle. Currently, the Earth's eccentricity is 0.017, meaning that Earth is 3.2 million miles closer to the sun at the perihelion (orbital point closest to the sun) than it is at the aphelion (orbital point farthest away). Periodic fluctuations in eccentricity are caused by variability in the gravitational influences of Jupiter and Saturn. Two generalizations about eccentricity's effect on Earth's climate, given the current continental orientation, are (a) things are warmer when the perihelion occurs during the time of the boreal summer solstice and cooler when this solstice falls during the aphelion; (b) more eccentricity generally (but not always) corresponds to more glaciation.

2. ***Obliquity:*** Earth's orbit has an axial tilt, which means that the Equator is not in line with the plane of orbit around the Sun. Currently, Earth's axial tilt is about 23.44 degrees and oscillates between 22.1 and 24.5 degrees over a period of 41,000 years. This axial tilt creates seasons; less obliquity means less variation in solar intensity at the high latitudes. Less variation makes conditions more favorable for glacier development at the poles.

3. ***Precession:*** As the Earth rotates, oceans exert drag on the solid surface. The ebb and flow of tides cause this drag to be periodically stronger or weaker at different points on the Earth, and variations in the ebb and flow result from changes in the relative positions of the Sun and Moon. This, along with the fact that Earth has a "bulge" at the equator (Earth is not a perfect sphere), causes the direction of the rotational axis to oscillate on a period of about 26,000 years, a phenomenon known as precession. If the axis is pointed at the Sun during the perihelion, then one hemisphere will have more extreme seasons than the other. Extreme summers in the Northern Hemisphere (again given modern continental orientation) result in the expansion of tree cover there, and trees absorb more incoming radiation than grassland. This results in warming, glacial retreat, further expansion of the forest and more warming.

ENSO: CLIMATE LINCHPIN

About six million years ago the Panama Seaway closed, altering ocean circulation patterns. Around five million years ago, the sub-surface of the ocean had cooled to the point where it became possible for an upwelling of cool water in the eastern tropical Pacific (see image, right) to "break through" the planet-wide layer of warm surface water and establish a "cold tongue." What would develop into the El Niño-Southern Oscillation (ENSO) was born. The rise of this "cold tongue" had two major consequences:

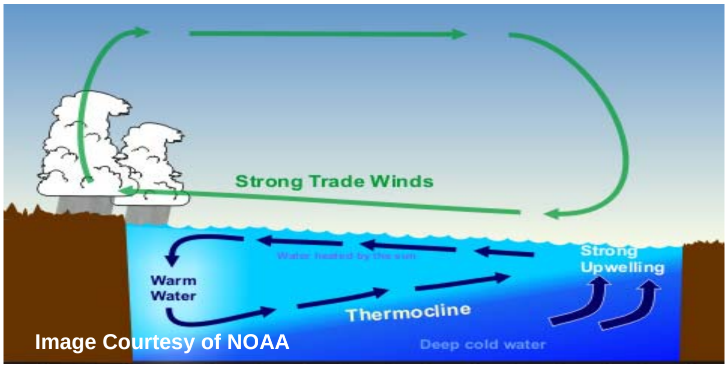

Image Courtesy of NOAA

1. It created a temperature gradient between the eastern and western tropical Pacific (which is at its strongest when the cold tongue protrudes to the surface – the La Niña phase of the ENSO cycle), resulting in an east-west pressure gradient that strengthened the trade winds that blow westward across the Pacific. Intensified trade winds worked to maintain the pressure gradient responsible for their existence in the first place (see image above). The pressure gradient also created divergence in the upper atmosphere that resulted in a movement of the mid-latitude storm tracks closer to the poles, allowing for an increase in wintertime moisture transport to higher latitudes and a sequestration of moisture in the polar glaciers. This resulted in:

    - An increase in planetary albedo, or the ability of a surface to reflect light, which caused further cooling, and;
    - An increase in the height of the ice masses, which reduced their susceptibility to surface melting. The East Antarctic ice sheet for example, is farther above sea level than the West Antarctic ice sheet and has shown to be much more resistant to global climate fluctuations. More robust ice means the high latitudes have a high albedo for more of the year, which means more cooling.

2. The breakthrough of cool and more nutrient rich water from the ocean depths increased the amount of phytoplankton blooms in that part of the ocean. As phytoplankton completed their life cycles, they fell to the bottom of the ocean and sequestered carbon in their bodies, further reducing atmospheric CO_2 concentrations and accentuating the cooling trend.

By 1.8 million years ago (the start of the Pleistocene epoch), things had cooled to the point where the planet was waxing and waning between glacial and interglacial cycles on a period of 41,000 years, in accordance with the oscillations of Earth's obliquity cycle. These glacial cycles continued until about 1.17 million years ago, when further intensification of the "cold tongue" in the eastern Pacific caused the birth of the modern "Walker circulation." This caused even more poleward moisture transport and reinforced the positive feedbacks described above. This intensified glacial growth and resulted in the establishment of the modern 100,000 year glacial cycle.

CHARACTERISTICS OF MODERN GLACIAL-INTERGLACIAL CYCLES

While debate continues regarding the relative importance of the feedbacks that cause glaciation and deglaciation, three key components that have been hypothesized include:

1. ***Glacial CO_2 Storage/Release:*** As glaciers expand, they cover forests and grassland, sequestering biomass (primarily plant tissue) and reducing potential atmospheric carbon concentrations. Once the glaciers reach a certain point, however, their bases begin to melt and streams containing carbon are discharged, allowing contained carbon to "escape." This helps to raise atmospheric carbon levels, and Earth's temperature, particularly if these discharges happen at the inception of orbital conditions more favorable to warming.

2. ***Northern Hemisphere Discharge Events and Southern Ocean CO_2:*** As the Earth cools over time, oceans absorb and store carbon dioxide in their depths. When orbital conditions favorable to warming begin, especially if they occur along with the "carbon escape" described above, the Northern Hemisphere ice sheets start melting and discharge fresh water into the Atlantic, sometimes at a catastrophic pace. Rapid discharges upset the balance between salt and fresh water that keeps the Atlantic Meridional Overturning Circulation (AMOC) functioning. A halt in the AMOC causes an interruption of the ocean currents that bring warm air masses to the high latitudes of the Northern Hemisphere, but also causes warming in the South Atlantic and more upwelling around Antarctica. More Southern Ocean upwelling means more "out-gassing" of stored oceanic CO_2, which contributes to further warming, more ice discharge events, more CO_2 release and more warming.

3. ***Re-growth and Carbon Sequestration:*** As glaciers retreat, vegetation returns, taking carbon out of the atmosphere. Eventually, carbon levels are reduced to the point where, given the right orbital circumstances, glaciation returns and the cycle begins again. For the past million years, this modern glacial-interglacial cycle has featured an approximate nine degree Fahrenheit global temperature fluctuation and a corresponding 80-120 ppm CO_2 fluctuation (putting the glacial-interglacial CO_2 range between 180 and 300 parts per million). We have been in an interglacial period for approximately the past 10,000 years, a period called the Holocene epoch.

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