

## Modulation of Ice Ages (part 1)

Ralph Ellis and Michael Palmer have an extremely interesting paper in the Elsevier publication "[Geoscience Frontiers](#)" titled: **Modulation of ice ages via precession and dust-albedo feedbacks** ([link to open access version](#), May 2016). This long paper (19 pages!) is very readable, but nevertheless needs more than one reading to fully understand the important details. So I will try in this blog the resume the most important findings of that outstanding paper.

### 1. The Milankovic cycles

The climate of the Earth is a system-response to the insolation of the sun. As this insolation (or irradiance) is not constant, it is no surprise that Earth's climate is not constant, and never was. There are short variations, like seasons, El Nino's, 11/22 years and 60 years changes from solar and oceanic oscillations etc. The much longer periodic changes like the ice ages are known since Milutin Milankovic's [seminal papers](#) to be caused by variations of (at least) 3 astronomical parameters related to the Earth revolving in our solar system, variations that cause important changes in the insolation of planet Earth,

The most important parameter is the **precession** of the Earth's axis: this gyroscopic effect (first studied by the great mathematician Euler) means that the axis (which is inclined w.r. to the ecliptic plane, i.e. the plane of the orbit of the earth circling around the sun) makes a slow rotation around the perpendicular to the ecliptic plane. The axis oscillates between two extreme positions, where it points to Polaris (the Northern Star) or to Vega. When the axis is tilted towards Polaris (which is close to the actual situation), the North Hemispheric (NH) winters correspond to a position where the globe is closest to the sun, and the NH summers where is it farthest. This precessional cycle (including a complication caused by the rotation of the elliptical orbit (=apsidal precession) has a cycle length of about 22200 years, a period often called a Seasonal Great Year (SGY). A Great Season takes 1/4 of this period, about **5700** years; one speaks of a Great Summer, a Great Winter and so on. This precession of the axis has by far the biggest influence on solar insolation (details will follow).

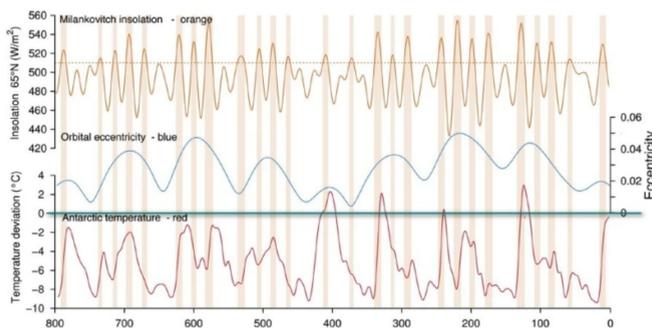
A second important astronomical parameter is the **obliquity** or **axial tilt**. The angle between the axis and the perpendicular to the ecliptic plane varies between 21.5° and 24.5°; the actual value is 23.5°. This angle essentially impacts the severity of the seasons. Actually the NH winters are moderate, as the solar rays are more close to the perpendicular of the globe's surface, and the summers are moderate too, as the solar rays are more inclined, which diminishes their heating potential. The length of one obliquity cycle is 41000 years. Precession and obliquity cause a complicated wobbling movement of the Earth's axis.

Finally the last important factor is the **eccentricity** of the Earth's orbit. The orbit is an ellipse, close but not quite equal to a circle. The eccentricity describes the deviation from a perfect circle, and in the case of our planet this parameter is not constant but varies slowly under the influence of the other planets with time. The cycle length is approx. 100000 years. The changes in eccentricity are small, between 0.034 and 0.058 (actual value is 0.0167, which means that the orbit actual is near circular). The main influence of the changing eccentricity is a (small) time shift of the seasons during the year.

For climate related questions, the most important parameter is the change in solar irradiance (or insolation) at high latitudes of the NH. Usually one looks at the changes observed (or calculated) at northern latitude 65° (NH 65). Here are the extreme changes caused by the variations of the three astronomical parameters shown above:

Precession: 110 W/m<sup>2</sup>  
Obliquity: 25 W/m<sup>2</sup>  
Eccentricity: 0.4 W/m<sup>2</sup>

These changes can be lumped together in the so called Milankovic Cycle (figure from the Ellis/Palmer paper, the time axis is KY (kilo-years) before present):



The upper plot shows the changes in solar irradiance, the lower the temperature deviations from a mean value of the Antarctic. I added a zero line to make clearer where the intra-glacial periods happen (the peaks above the zero line) and where the ice ages are (the periods in-between: note that the ice ages are the "normal" state of the Earth climate, and that the intra-glacials are, geologically speaking, exceptions to that state). The orange/red bands represent the (Seasonal) Great Summers. Clearly, not all Great Summers cause an intra-glacial warming, as there are about 4 to 5 Great Summers from one intra-glacial to the next. The Ellis/Palmer paper tries to explain this with a novel theory; I will discuss this in the [part 2](#) of this blog.

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