Unpredictable ice ages?

Ice and sediment cores store excellent records of the Earth's history and the isotopes within let geoscientists pin down how global temperature has changed over time. These records show the Earth has alternated between periods of intense cold and warming. But while there are clear patterns in the climate record, the frequency of ice ages is not always constant. Scientists are working to find out why.

The Earth's climate is controlled by astronomical phenomena that operate on timescales tens to hundreds of thousands of years long. One of these phenomena is the variation in the Earth's obliquity – the angle the Earth tilts on its axis. The inclination of the Earth's axis varies from approximately 22 to 24.5 degrees over the course of 41,000 years and the greater the tilt, the stronger the difference between seasons. Thus, when the winter is warmer, there is more moisture available for snowfall, and when the summer is cooler, the winter ice persists longer into the season, stimulating the start of a glacial period.

The other phenomenon is climatic precession, also known as precession index. It combines variations in eccentricity – how elliptical the Earth's orbit is and how that changes over thousands of years – with a parameter known as the longitude of perihelion. The longitude of perihelion controls the time of year at which the Earth is at its closest point to the Sun. At present, the Earth reaches this point in January, but when the closest approach happens in June (as it did 11,000 years ago), the Earth and the Sun are significantly closer. This close proximity causes the Earth to receive more energy, negatively affecting glacier mass balance and preventing glaciation. The changes in the longitude of perihelion occur over timescales of about 23,000 years. Changes in eccentricity, on the other hand, occur over much longer periods and every 100,000 years the Earth's orbit is almost circular.

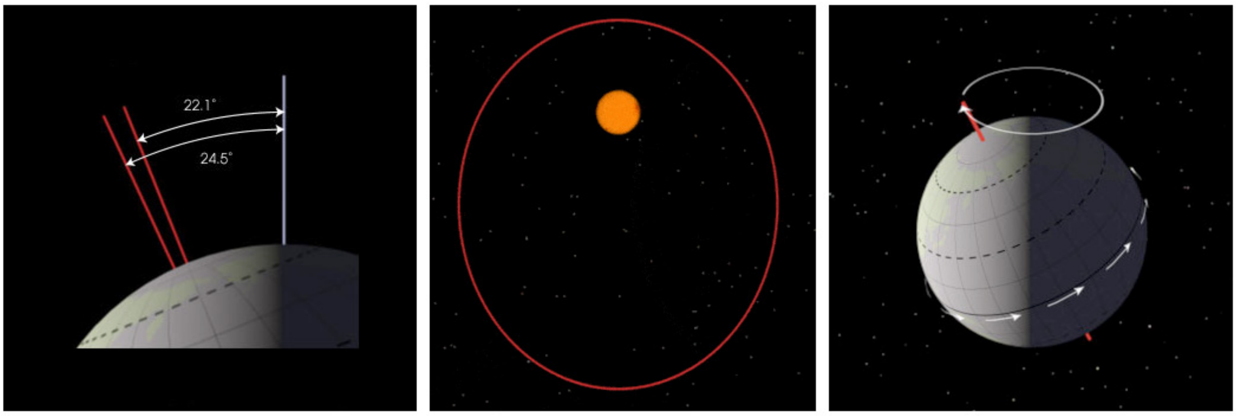
Combined, these changes in orbital parameters and obliquity are known as 'the astronomical pacemaker', a well-known control on the timing of glacial-interglacial cycles. However, the pulse of the Earth's climate is barely regular – in fact, we don't yet know how tightly these astronomical phenomena control the Earth's climate.

Recently, researchers have begun investigating what could cause delays in deglaciation and shifts in the sequences of ice ages in an effort to assess the strength of the astronomical pacemaker. One such scientist is Michel Crucifix, from the Georges Lemaître Centre for Climate Research in Belgium.

Using seven published models, Crucifix set out to see what could disrupt the ice age sequence from the pace set by the Earth's orbit and obliquity, and found that small changes in the amount of solar radiation the Earth receives, or the amount of heat it retains, could cause big shifts in the occurrence of ice ages. "I started playing with simple models of ice ages and it became pretty clear to me that the sequence of ice ages in these models was quite sensitive to parameters…I took this sensitivity issue as a starting point: what are the mathematical mechanisms at work; is this an artefact or does this sensitivity actually tell us about the real world?"

As is often the case, the devil is in the detail and it is random events that affect the climate on short timescales that are responsible for this irregularity. "I really like this idea of a system that is being intermediate between 'chaotic' and 'fully predictable'," Crucifix says. He considered the climate record from the 3.2-km-long ice core at Dome Concordia in Antarctica, which records 800,000 years of climate history: "there is regularity, but there are also a many rapid and not-so-well organised variations that seem to be incompatible with the presence of a nice, solid, pacemaker."

So what could cause the Earth to 'skip a beat' in a glacial cycle? Possible causes are volcanic eruptions and interactions between the ocean and atmosphere that are capable of perturbing the Earth's climate. Volcanic eruptions, for example, emit large quantities of sulphate aerosol into the upper atmosphere – particles that are a starting point for clouds. Clouds reflect solar radiation back



Components of the astronomical pacemaker: the Earth's obliquity (tilt on its axis), eccentricity (elliptical character of the Earth's orbit) and precession (the wobble of the Earth's axis that controls the time of year the Earth is closest to the Sun). (Credit: modified from NASA) into space and cause the Earth to cool – such a change could be enough to stimulate the start of an ice age.

Records of what caused these climate perturbations, as well as what their effect on climate was, are recorded in ice cores. In the case of a volcanic eruption, you might find a layer of ash or sulphate that indicates a large volcanic event in an ice core, and can correlate this with changes in temperature on short – and possibly longer – timescales when looking at isotope data.

But the factors that cause these shifts are not yet known. "My intuition is that very small perturbations could do the job (as small as atmospheric perturbations), but which magnitude is needed and when they actually matter is not yet quantified," says Crucifix.

Indeed, Crucifix's findings show just that: small perturbations can alter the rhythm of glacial cycles. This lends support to a theory put forward by Eric Wolff known as 'the proximal cause of terminations': that the timing of the end of a glacial period can be influenced by the occurrence of abrupt climate events in the thousands of years that precede its termination. The research also builds on the findings of pioneers in climate theory such as Barry Saltzman and Ed Lorenz, who first considered the role of chaos in climate modelling. Crucifix shares his enthusiasm for his work: "I really feel like I am standing on the shoulders of giants…being able to borrow concepts introduced by these great scientists and extract an idea that was latent in their work but not explicitly formulated is thrilling."

Even small variations of climate model parameters can mean the difference between an ice age and an interglacial period, what we need to know now is when in the astronomical cycle can small changes in solar radiation lead to big changes in climate.

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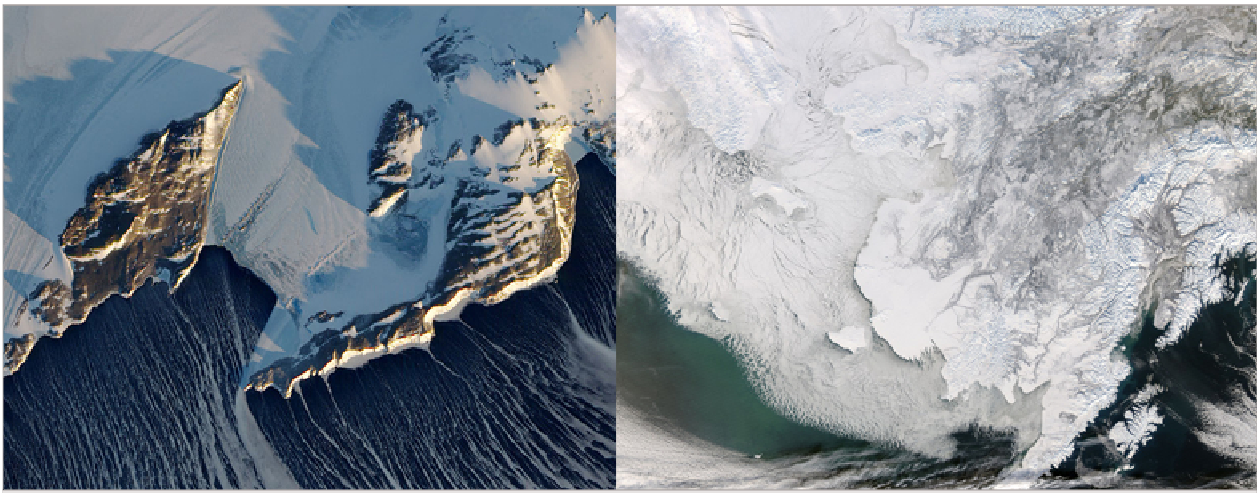

Left. The Nansen Ice Sheet, shortly before the onset of the Southern Hemisphere spring. (Credit: NASA) Right. Sea Ice in the Bering Strait. (Credit: J. Schmaltz/NASA)

Misunderstood? Soil organic carbon and climate change

Soils are essential to global development. They are the sustaining force that keeps communities alive globally and locally; without soil we would not have the ability to grow crops that feed the majority of the world's population. But soil also has another crucial role related to the Earth and its present and future populations: the storage of organic carbon. The importance of this, in relation to climate and development, has only recently been recognised.

Up until 2010, most climate models attributed the majority of carbon storage during glacial periods to the oceans. However, there has been no success in finding sinks of 'old radiocarbon' in the oceans to support this widely accepted hypothesis. In 2011, Roland Zech and his team investigated a key question that this idea raised: can the change in carbon pools over glacial-interglacial periods be quantified more accurately across the marine and terrestrial realms? Zech noticed that terrestrial estimates for carbon assumed that there was a decrease in stored organic carbon on the continents during glacial periods, meaning that the oceans take up somewhere in the region of 300–800 Pg C (petagrams of carbon, where 1 Pg is equal to 10^{12}