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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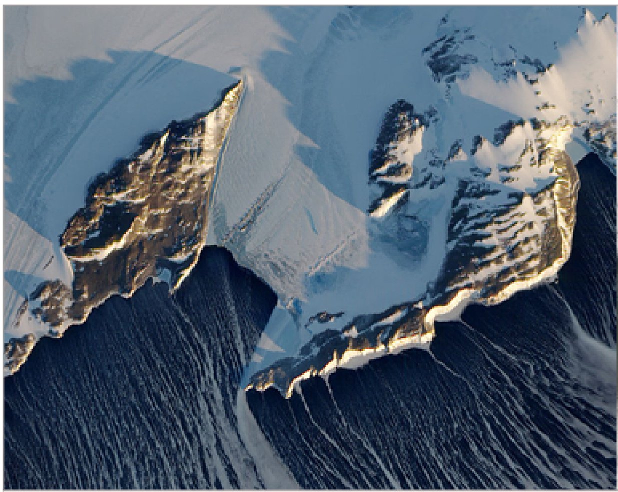
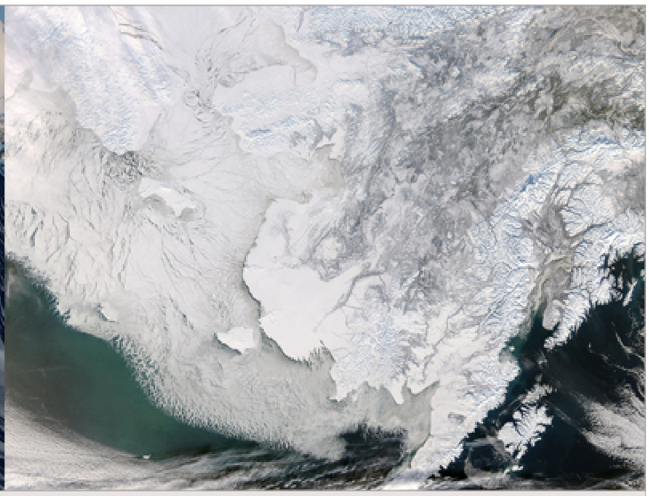




Left. The Nansen Ice Sheet, shortly before the onset of the Southern Hemisphere spring. (Credit: NASA) Right. Sea Ice in the Bering Strait. (Credit: J. Schmaltz/NASA)

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}

kg of carbon) from terrestrial sources in addition to the 200 Pg C from the atmosphere during glacial periods.

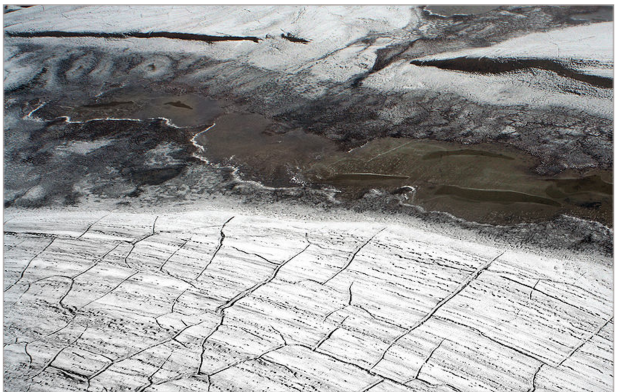
Yet Zech noticed that something had been overlooked: permafrost. Permafrost is soil and sediment that remains, and has remained, frozen for more than two years. In the Northern Hemisphere alone, permafrost occupies around 22.79 million square kilometres of exposed land surface. Zech noted that current organic carbon estimates do not explicitly consider the organic carbon stored below ice sheets in permafrost and new estimates suggest that soil organic carbon (SOC) in the Northern Hemisphere may exceed 1670 Pg C. Zech's research shows that this carbon is repeatedly stored in permafrost during glacial periods and, if not taken into account, it could significantly affect the reliability of climate models.

As permafrost provides an excellent environment for long term carbon storage during glacial periods, there have been increasing concerns about the effects of thawing of permafrost on climate. In a separate study undertaken in 2011, Charles Koven found results in contention with the IPCC 4th Assessment Report. Using a terrestrial ecosystem model of permafrost carbon dynamics, Koven found that Arctic ecosystems warming could shift from being a carbon sink to a carbon source by the end of the 21st century.

Black carbon rich soils on an Icelandic farm. (Credit: Ragnar Sigurdsson/www.arctic-images.com)

Now recognised as an active and crucial component of the carbon system, it is important to map SOC pools accurately. Although researchers have attempted to map SOC behaviour before, they have had little success in producing detailed, high resolution maps until recently. In 2012 Jeroen Meersmans undertook a national soil survey across France, analysing over 2000 soil samples in an effort to measure soil properties and factors controlling SOC and went on to develop a model for predicting spatial and temporal distribution of SOC across France. The resulting model allowed detailed projections of land that will be characterised by a gain or loss in SOC, as well as the possible outcomes of land management decisions – such as whether to farm the land and what should be grown there. This type of tool is extremely important in managing SOC as it allows people to optimise carbon storage in soils and minimise soil-related CO_2 fluxes (that could cause increased global warming).

Understanding SOC storage is also the basis for sustainable agriculture. SOC is an important component of the three main aspects of soil fertility: helping release nutrients such as nitrogen and phosphorous, binding soil mineral particles together for increased water holding and infiltration capacity, and providing a key food source for flora and fauna. Increasing and retaining SOC content is therefore an important mechanism for improving soil 'health' as well as mitigating climate change.



Arctic permafrost. (Credit: Wikimedia Commons user Broken Inaglory)

Earlier this year Kathryn Page investigated the effectiveness of agricultural techniques in retaining SOC and found that 'no-till' management (planting crops without disturbing the soil through digging and overturning) is more effective than conventional methods. Research has also shown that other techniques including improved crop residue management, crop rotations and conversion of marginal cropland to native vegetation or permanent grassland can increase SOC content.

It is important to transfer land management research to decision making tools for land use. Tools such as the Global Biosphere Management Model (GLOBIOM) are a step towards this goal. GLOBIOM tracks effects of land use change and trade, going beyond traditional land management tools by modelling both changes in demand for land use, and changes in land profitability – key determinants of real world land use change.

Despite the breadth of research going on in this area, there remains much to be understood about the nature of SOC, such as how it binds to other minerals inside the soil and how this will affect the stability of SOC as the climate changes.

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