

Palaeoclimatology 2024

A new explanation for the Neoproterozoic Snowball Earth episodes

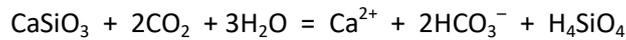
PUBLISHED ON *March 4, 2024*

The Cryogenian Period that lasted from 860 to 635 million years ago is aptly named, for it encompassed two maybe three episodes of glaciation. Each left a mark on every modern continent and extended from the poles to the Equator. In some way, this series of long, frigid catastrophes seems to have been instrumental in a decisive change in Earth's biology that emerged as fossils during the following Ediacaran Period (635 to 541 Ma). That saw [the sudden appearance of multicelled organisms](#) whose macrofossil remains – enigmatic bag-like, quilted and ribbed animals – are found in sedimentary rocks in Australia, eastern Canada and NW Europe. Their type locality is in the Ediacara Hills of South Australia, and there can be little doubt that they were the ultimate ancestors of all succeeding animal phyla. Indeed one of them *Helminthoidichnites*, a stubby worm-like animal, is a candidate for the [first bilaterian animal](#) and thus our own ultimate ancestor. Using the [index for Palaeobiology](#) or the *Search Earth-logs* pane you can discover more about them in 12 posts from 2006 to 2023. The issue here concerns the question: Why did Snowball Earth conditions develop? Again, refresh your knowledge of them, if you wish, using the [index for Palaeoclimatology](#) or *Search Earth-logs*. From 2000 onwards you will find 18 posts: the most for any specific topic covered by Earth-logs. The most recent are [Kicking-off planetary Snowball conditions](#) (August 2020) and [Signs of Milankovich Effect during Snowball Earth episodes](#) (July 2021): see also: [Chapter 17 in Stepping Stones](#).

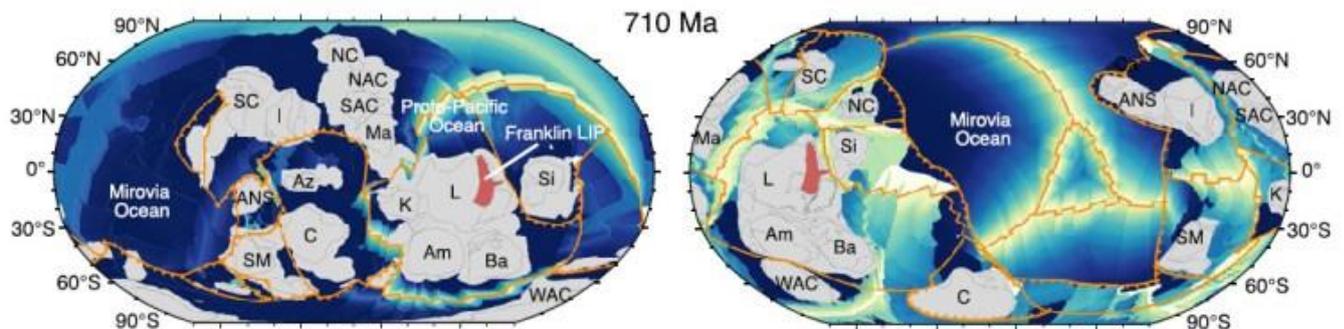
One reason why Snowball Earths are so enigmatic is that CO₂ concentrations in the Neoproterozoic atmospheric were far higher than they are at present. In fact since the Hadean Earth has largely been prevented from being perpetually frozen over by a powerful atmospheric greenhouse effect. Four Ga ago solar heating was about 70 % less intense than today, because of the '[Faint Young Sun](#)' paradox. There was a long episode of glaciation (from 2.5 to 2.2 Ga) at the start of the Palaeoproterozoic Era during which the [Great Oxygenation Event](#) (GOE) occurred once photosynthesis by oxygenic bacteria became far more common than those that produced methane. This resulted in wholesale oxidation to carbon dioxide of atmospheric methane whose loss drove down the early greenhouse effect – perhaps a narrow escape from the fate of Venus. There followed the '[boring billion years](#)' of the Mesoproterozoic during which tectonic processes seem to have been less active. In that geologically tedious episode important proxies ([carbon and sulfur isotopes](#)) that relate to the surface part of the Earth System 'flat-lined'. The plethora of research centred on the Cryogenian glacial events seems to have stemmed from the by-then greater complexity of the Precambrian Earth System.

Since the GOE the main drivers of Earth's climate have been the emission of CO₂ and SO₂ by volcanism, the sedimentary burial of carbonates and organic carbon in the deep oceans, and weathering. Volcanism in the context of climate is a two-edged sword: CO₂ emission results in

greenhouse warming, and SO₂ that enters the stratosphere helps reflect solar radiation away leading to cooling. Silicate minerals in rocks are attacked by hydrogen ions (H⁺) produced by the solution of CO₂ in rain water to form a weak acid (H₂CO₃: carbonic acid). A very simple example of such chemical weathering is the breakdown of calcium silicate:



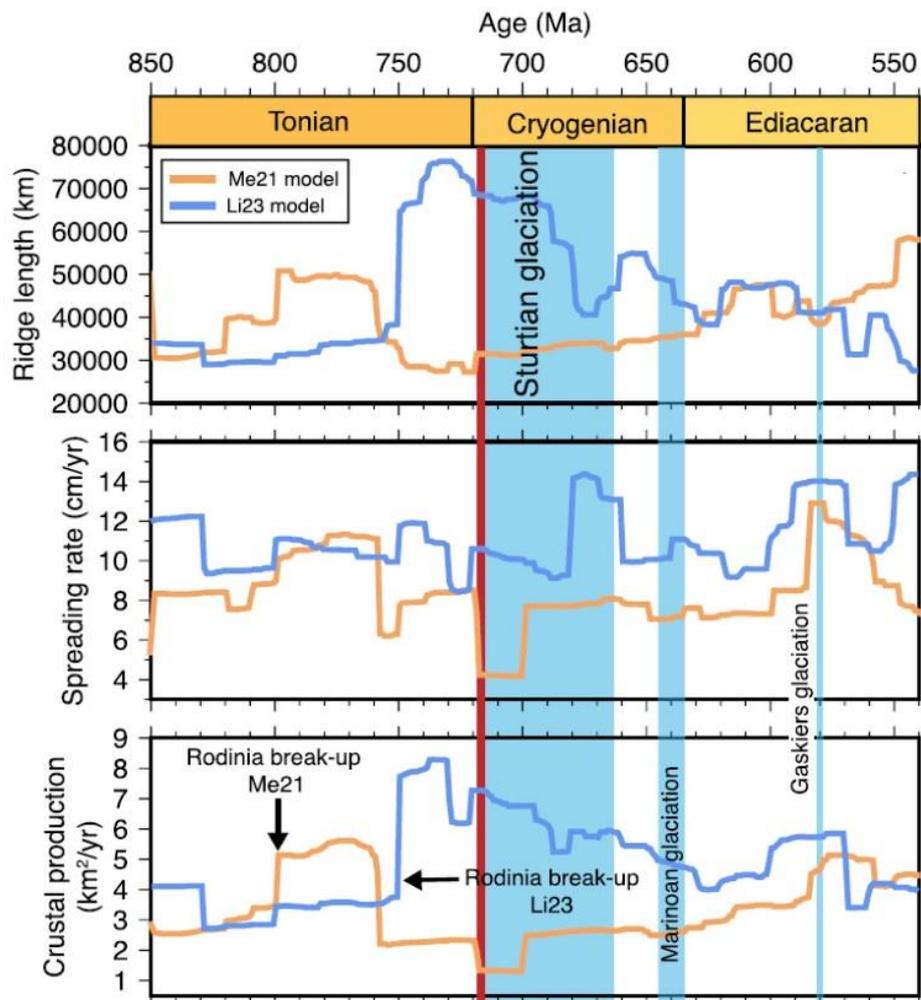
The reaction results in calcium and bicarbonate ions being dissolved in water, eventually to enter the oceans where they are recombined in the shells of planktonic organisms as calcium carbonate. On death, their shells sink and end up in ocean-floor sediments along with unoxidised organic carbon compounds. The net result of this part of the [carbon cycle](#) is reduction in atmospheric CO₂ and a decreased greenhouse effect: increased silicate weathering cools down the climate. Overall, internal processes – particularly volcanism – and surface processes – weathering and carbonate burial – interact. During the ‘boring billion’ they seem to have been in balance. The two processes lie at the core of attempts to model global climate behaviour in the past, along with what is known about developments in plate tectonics – continental break-up, seafloor spreading and orogenies – and large igneous events resulting from mantle plumes. A group of geoscientists from the Universities of Sydney and Adelaide, Australia have evaluated the tectonic factors that may have contributed to the first and longest Snowball Earth of the Neoproterozoic: the Sturtian glaciation (717 to 661 Ma) (Dutkiewicz, A. *et al.* 2024. [Duration of Sturtian “Snowball Earth” glaciation linked to exceptionally low mid-ocean ridge outgassing](#). *Geology*, v. **52**, online early publication; DOI: 10.1130/G51669.1).



Palaeogeographic reconstructions (Robinson projection) during the early part of the Sturtian global glaciation: LEFT based on geological data from Neoproterozoic terrains on modern continents; RIGHT based on palaeomagnetic pole positions from those terrains. Acronyms refer to each terrains, e.g. Am is Amazonia, WAC is the West African Craton. Orange lines are ocean ridges, those with teeth are subduction zone. (Credit: Dutkiewicz et al., parts of Fig. 1)

Shortly before the Sturtian began there was a major flood volcanism event, forming the Franklin large igneous province, remains of which are in Arctic Canada. The Franklin LIP is a subject of interest for triggering the Sturtian, by way of a ‘volcanic winter’ effect from SO₂ emissions or as a sink for CO₂ through its weathering. But both can be ruled out as no subsequent LIP is associated with global cooling and the later, equally intense Marinoan global glaciation (655 to 632 Ma) was bereft of a preceding LIP. Moreover, a world of growing frigidty probably could not sustain the degree of chemical weathering to launch a massive depletion in atmospheric CO₂. In search of an alternative, Adriana Dutkiewicz and colleagues turned to the plate movements of the early Neoproterozoic. Since 2020 there have been two notable developments in modelling global tectonics of that time, which was dominated by the evolution of the Rodinia supercontinent. One is based largely on

geological data from the surviving remnants of Rodinia ([download animation](#)), the other uses palaeomagnetic pole positions to fix their relative positions: the results are very different ([download animation](#)).



Variations in ocean ridge lengths, spreading rates and oceanic crust production during the Neoproterozoic estimated from the geological (orange) and palaeomagnetic (blue) models. Credit: Dutkiewicz et al., parts of Fig. 2)

The geology-based model has Rodinia beginning to break up around 800 Ma ago with a lengthening of global constructive plate margins during disassembly. The resulting continental drift involved an increase in the rate of oceanic crust formation from 3.5 to 5.0 km² yr⁻¹. Around 760 Ma new crust production more than halved and continued at a much slowed rate throughout the Cryogenian and the early part of the Ediacaran Period. The palaeomagnetic model delays breakup of the Rodinia supercontinent until 750 Ma, and instead of the rate of crust production declining through the Cryogenian it more than doubles and remains higher than in the geological model until the late Ediacaran. The production of new oceanic crust is likely to govern the rate at which CO₂ is out-gassed from the mantle to the atmosphere. The geology-based model suggests that from 750 to 580 Ma annual CO₂ additions could have been significantly below what occurred during the Pleistocene ice ages since 2.5 Ma ago. Taking into account the lower solar heat emission, such a drop is a plausible explanation for the recurrent Snowball Earths of the Neoproterozoic. On the other hand, the model

based on palaeomagnetic data suggests significant warming during the Cryogenian contrary to a mass of geological evidence for the opposite.

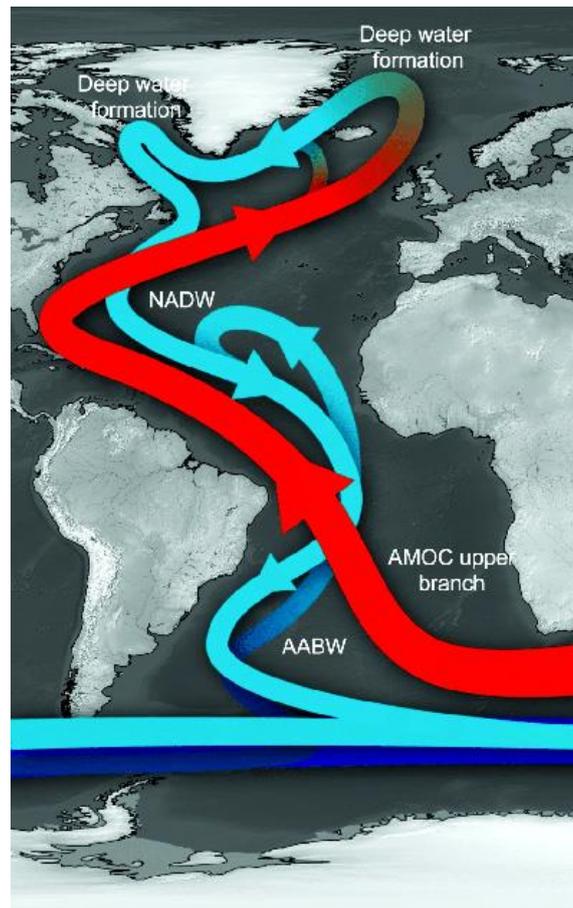
A prolonged decrease in tectonic activity thus seems to be a plausible trigger for global glaciation. Moreover, reconstruction of Precambrian global tectonics using available palaeomagnetic data seems to be flawed, perhaps fatally. One may ask, given the trends in tectonic data: How did the Earth repeatedly emerge from Snowball episodes? The authors suggest that the slowing or shut-down of silicate weathering during glaciations allowed atmospheric CO₂ to gradually build up as a result of on-land volcanism associated with subduction zones that are a quintessential part of any tectonic scenario.

This kind of explanation for recovery of a planet and its biosphere locked in glaciation is in fact not new. From the outset of the Snowball Earth hypothesis much the same escape mechanisms were speculated and endlessly discussed. Adriana Dutkiewicz and colleagues have fleshed out such ideas quite nicely, stressing a central role for tectonics. But the glaring disparities between the two models show that geoscientists remain 'not quite there'. For one thing, [carbon isotope data from the Cryogenian and Ediacaran Periods went haywire](#): living processes almost certainly played a major role in the Neoproterozoic climatic dialectic.

The gross uncertainty of climate tipping points

PUBLISHED ON *August 6, 2024*

That the Earth has undergone sudden large changes is demonstrated by all manner of geoscientific records. It seems that many of these catastrophic events occurred whenever steady changes reach thresholds that trigger new behaviours in the interlinked atmosphere, hydrosphere, atmosphere, biosphere and lithosphere that constitute the Earth system. The driving forces for change, both steady and chaotic, may be extra-terrestrial, such as the Milankovich cycles and asteroid impacts, due to Earth processes themselves or a mixture of the two. Our home world is and always has been supremely complicated; the more obviously so as knowledge advances. Abrupt transitions in components of the Earth system occur when a critical forcing threshold is passed, creating a 'tipping point'. Examples in the geologically short term are ice-sheet instability, the drying of the Sahara, collapse of tropical rain forest in the Amazon Basin, but perhaps the most important is the poleward transfer of heat in the North Atlantic Ocean. That is technically known as the Atlantic Meridional Overturning Circulation with the ominous acronym AMOC.



Simplified Atlantic Meridional Overturning Circulation (AMOC). Red – warm surface currents; cyan – cold deep-water flow. (Credit: Stefano Crivellari)

As things stand today, warm Atlantic surface water, made more saline and dense by evaporation in the tropics is transferred northwards by the Gulf Stream. Its cooling at high latitudes further increases the density of this water, so at low temperatures it sinks to flow southwards at depth. This [thermohaline circulation](#) continually pulls surface water northwards to create the AMOC, thereby making north-western [European winters a lot warmer than they would be otherwise](#). Data from Greenland ice cores show that during the climatic downturn to the last glacial maximum, the cooling trend was repeatedly interrupted by sudden warming-cooling episodes, known as Dansgaard-Oeschger events, one aspect of which was the launching of “armadas” of icebergs to latitudes as far south as Portugal (known as Heinrich events), which left their mark as occasional gravel layers in the otherwise muddy sediments on the deep Atlantic floor (see: [Review of thermohaline circulation](#); February 2002).

These episodes involved temperature changes over the Greenland icecap of as much as 15°C. They began with warming on this scale within a matter of decades followed by slow cooling to minimal temperatures, before the next turn-over. Various lines of evidence suggest that these events were accompanied by shutdowns of AMOC and hence the Gulf Stream, as shown by variations in the foraminifera species in sea-floor sediments. The culprit was vast amounts of fresh water pouring into the Arctic and northernmost Atlantic Oceans, decreasing the salinity and density of the surface ocean water. In these cases that may have been connected to repeated collapse of circumpolar ice sheets to launch Heinrich’s iceberg armadas. A similar scenario has been proposed for the

millennium-long Younger Dryas cold spell that interrupted the onset of interglacial conditions. In that case the freshening of high-latitude surface water was probably a result of floods released when glacial barriers holding back vast lakes on the Canadian Shield burst.

At present the Greenland icecap is melting rapidly. Rising sea level may undermine the ice sheet's coastal edges causing it to surge seawards and launch an iceberg armada. [This may be critical for AMOC](#) and the continuance of the Gulf Stream, as predicted by modelling: counter-intuitive to the fears of global warming, at least for NW Europe. In August 2024 scientists from Germany and the UK published what amounts to a major caution about attempts to model future catastrophes of this kind (Ben-Yami, M. *et al* 2024, [Uncertainties too large to predict tipping times of major Earth system components from historical data](#), *Science Advances*, v. **10**, article eadl4841; DOI 10.1126/sciadv.adl4841). They focus on records of the AMOC system, for which an earlier modelling study predicted that a [collapse could occur between 2025 and 2095](#): of more concern than global warming beyond the 1.5° C currently predicted by greenhouse-gas climate models .

Maya Ben-Yami and colleagues point out that the assumptions about mechanisms in Earth-system modelling and possible social actions to mitigate sudden change are simplistic. Moreover, models used for forecasting rely on historical data sets that are sparse and incomplete and depend on proxies for actual variables, such as sea-surface and air temperatures. The further back in geological time, the more limited the data are. The authors assess in detail data sets and modelling algorithms that bear on AMOC. Rather than a chance of AMOC collapse in the 21st century, as suggested by others, Ben Yami *et al.* reckon that any such event lies between 2055 and 8065 CE, which begs the question, "Is such forecasting worth the effort?", however appealing it might seem to the academics engaged in climatology. The celebrated British Met Office and other meteorological institutions, use enormous amounts of data, the fastest computers and among the most powerful algorithms on the planet to simulate weather conditions in the very near future. They openly admit a limit on accurate forecasting of no more than 7 day ahead. 'Weather' can be regarded as short-term climate change.

It is impossible to stop scientists being curious and playing sophisticated computer games with whatever data they have to hand. Yet, while it is wise to take climate predictions with a pinch of salt because of their gross limitations, the lessons of the geological past do demand attention. AMOC has shut down in the past – the last being during the Younger Dryas – and it will do so again. Greenhouse global warming probably increases the risk of such planetary hiccups, as may other recent anthropogenic changes in the Earth system. The most productive course of action is to reduce and, where possible, reverse those changes. In my honest opinion, our best bet is swiftly to rid ourselves of an economic system that in the couple of centuries since the 'Industrial Revolution' has wrought these unnatural distortions.

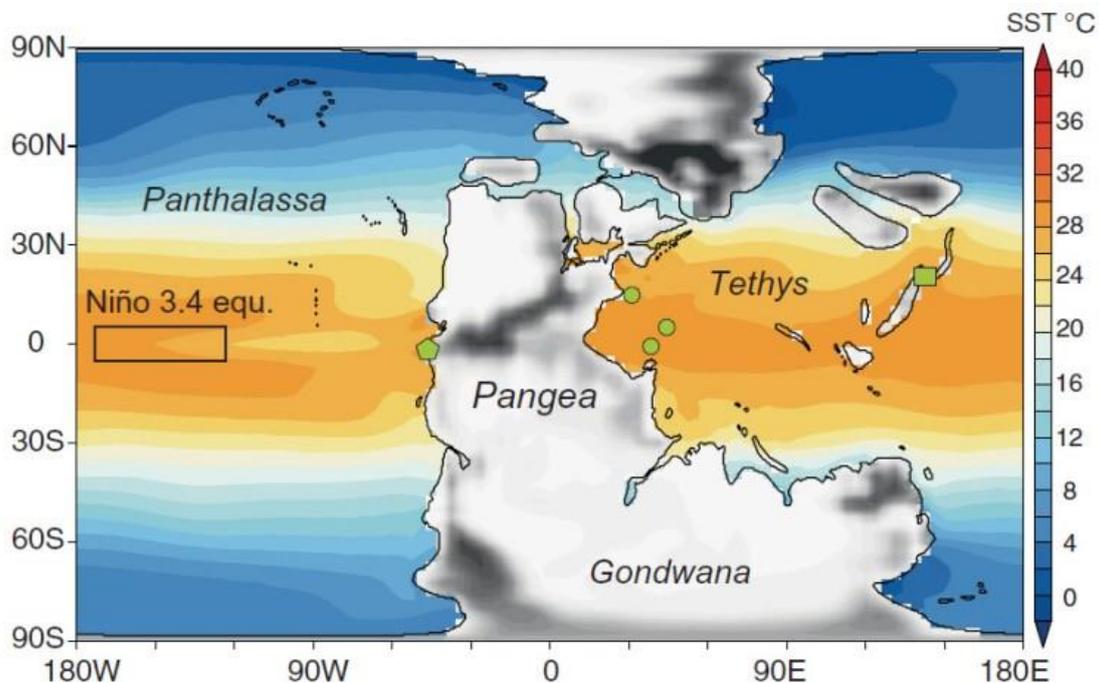
Climate changes and the mass extinction at Permian-Triassic boundary

PUBLISHED ON [September 18, 2024](#)

The [greatest mass extinction in Earth's history](#) at around 252 Ma ago snuffed out 81% of marine animal species, 70% of vertebrates and many invertebrates that lived on land. It is not known how

many land plants were removed, but the complete absence of coals from the first 10 Ma of the Early Triassic suggests that luxuriant forests that characterised low-lying humid area in the Permian disappeared. A clear sign of the sudden dearth of plant life is that Early Triassic river sediments were no longer deposited by meandering rivers but by braided channels. Meanders of large river channels typify land surfaces with abundant vegetation whose root systems bind alluvium. Where vegetation cover is sparse, there is little to constrain river flow and alluvial erosion, and wide braided river courses develop (see: [End-Permian devastation of land plants](#); September 2000. You can follow 21st century developments regarding the P-Tr extinction using the [Palaeobiology index](#)).

The most likely culprit was the Siberian Trap flood basalts effusion whose lavas emitted huge amounts of CO₂ and even more through underground burning of older coal deposits (see: [Coal and the end-Permian mass extinction](#); March 2011) which triggered severe global warming. That, however, is a broad-brush approach to what was undoubtedly a very complex event. Of about 20 volcanism-driven global warming events during the Phanerozoic only a few coincide with mass extinctions. Of those none comes close the devastation of 'The Great Dying', which begs the question, 'Were there other factors at play 252 Ma ago?' That there must have been is highlighted by the terrestrial extinctions having begun significantly earlier than did those in marine ecosystems, and they preceded direct evidence for climatic warming. Also temperature records – obtained from shifts in oxygen isotopes held in fossils – for that episode are widely spaced in time and tell palaeoclimatologists next to nothing about the details of the variation of air- and sea-surface temperature (SST) variations.



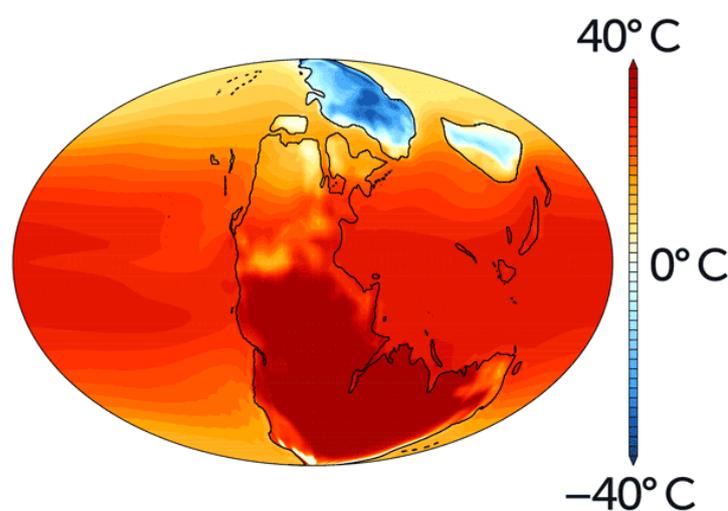
Modelled sea-surface temperatures in the tropics in the early stages of Siberian Trap eruptions with atmospheric CO₂ at 857 ppm – twice today's level. (Credit: Sun et al., Fig. 1A)

Earth at the end of the Permian was very different from its current wide dispersal of continents and multiple oceans and seas. Then it was dominated by Pangea, a single supercontinent that stretched almost from pole to pole, and a surrounding vast ocean known as Panthalassa. Geoscientists from China, Germany, Britain and Austria used this simple palaeogeography and the available Early

Triassic greenhouse-gas and palaeo-temperature data as input to a climate prediction model ([HadCM3BL](#)) (Yadong Sun and 7 others 2024. Mega El Niño instigated the end-Permian mass extinction. *Science* 385, p. 1189–1195; DOI: 10.1126/science.ado2030 – contact yadong.sun@cug.edu.cn for PDF).. The computer model was developed by the Hadley Centre of the UK Met Office to assess possible global outcomes of modern anthropogenic global warming. It assesses heat transport by atmospheric flow and ocean currents and their interactions. The researchers ran it for various levels of atmospheric CO₂ concentrations over the estimate 100 ka duration of the P-Tr mass extinction.

The pole-to-pole continental configuration of Pangaea lends itself to equatorial El Niño and El Niña type climatic events that occur today along the Pacific coast of the Americas, known as the [El Niño-Southern Oscillation](#). In the first, warm surface water builds-up in the eastern tropical Pacific Ocean. It then then drifts westwards to allow cold surface water to flow northwards along the Pacific shore of South America to result in El Niña. Today, this climatic ‘teleconnection’ not only affects the Americas but also winds, temperature and precipitation across the whole planet. The simpler topography at the end of the Permian seems likely to have made such global cycles even more dominant.

Sun *et al*'s simulations used stepwise increases in the atmospheric concentration of CO₂ from an estimated 412 parts per million (ppm) before the eruption of the Siberian Traps (similar to those today) to a maximum of 4000 ppm during the late-stage magmatism that set buried coals ablaze. As levels reached 857 ppm SSTs peaked at 2 °C above the mean level during El Niño events and the cycles doubled in length. Further increase in emissions led to greater anomalies that lasted longer, rising to 4°C above the mean at 4000 ppm. The El Niña cooler parts of the cycle steadily became equally anomalous and long lasting. This amplification of the 252 Ma equivalent of the El Niño-Southern Oscillation would have added to the environmental stress of an ever increasing global mean surface temperature. The severity is clear from an animation of mean surface temperature change during a Triassic ENSO event.



Animation of monthly average surface temperatures across the Earth during an ENSO event at the height of the P-Tr mass extinction. (Credit: Alex Farnsworth, University of Bristol, UK)

The results from the modelling suggest increasing weather chaos across the Triassic Earth, with the interior of Pangaea locked in permanent drought. Its high latitude parts would undergo extreme heating and then cooling from 40°C to -40°C during the El Niño- El Niña cycles. The authors suggest that conditions on the continents became inimical for terrestrial life, which would be unable to survive even if they migrated long distances. That can explain why terrestrial extinctions at the P-Tr boundary preceded those in the global ocean. The marine biota probably succumbed to anoxia (See: [Chemical conditions for the end-Permian mass extinction](#); November 2008)

There is a timely warning here. The El Niño-Southern Oscillation is becoming stronger, although each El Niño is a mere 2 years long at most, compared with up to 8 years at the height of the P-Tr extinction event. But it lay behind the record 2023-2024 summer temperatures in both northern and southern hemispheres, the North American heatwave of June 2024 being 15°C higher than normal. Many areas are now experiencing unprecedentedly severe annual wildfires. There also finds a parallel with conditions on the fringes of Early Triassic Pangaea. During the early part of the warming charcoal is common in the relics of the coastal swamps of tropical Pangaea, suggesting extensive and repeated wildfires. Then charcoal suddenly vanishes from the sedimentary record: all that could burn had burnt to leave the supercontinent deforested.

See also: Voosen, P. 2024. [Strong El Niños primed Earth for mass extinction](#). *Science* 385, p. 1151; DOI: 10.1126/science.z04mx5b; Buehler, J. 2024. [Mega El Niños kicked off the world's worst mass extinction](#). *ScienceNews*, 12 September 2024.

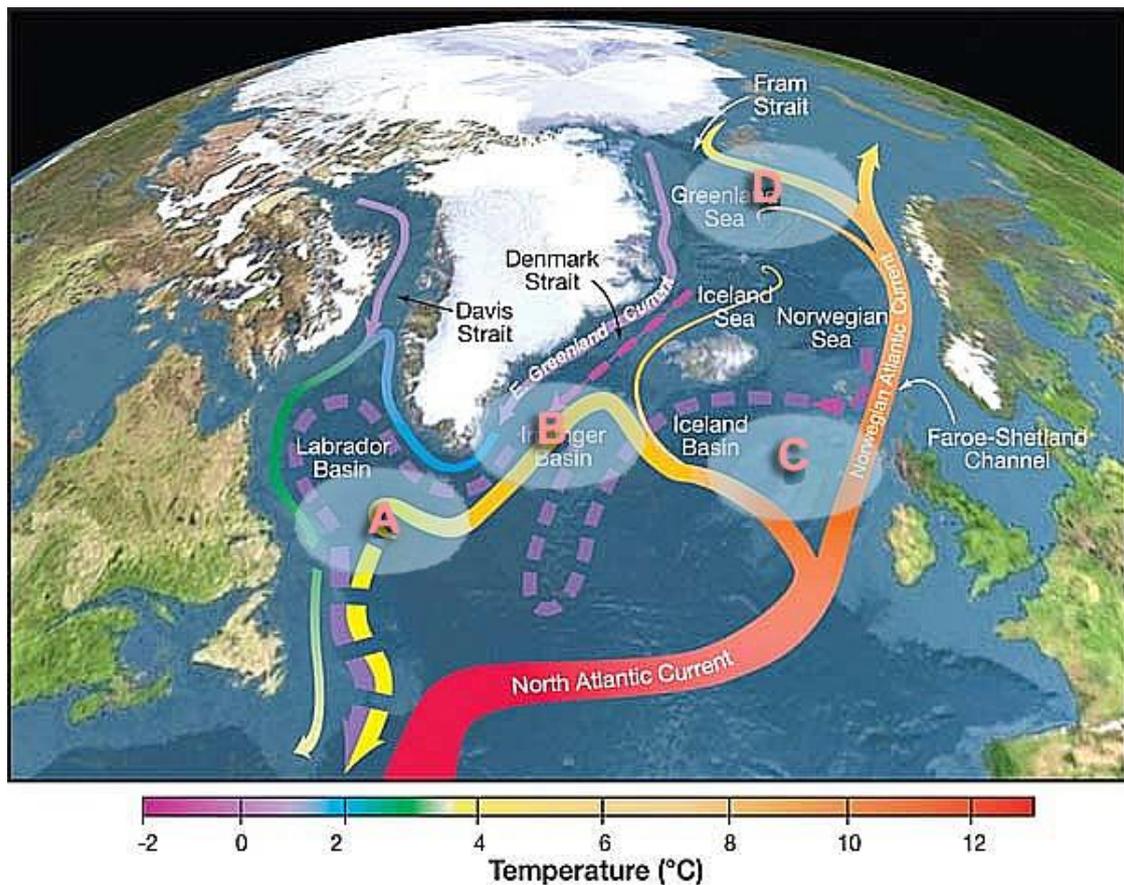
Divining the possible climatic impacts of slowing North Atlantic current patterns

PUBLISHED ON *November 27, 2024*



Meltwater channels and lake on the surface of the Greenland ice sheet

In August 2024 Earth-Logs reported on [the fragile nature of thermohaline circulation of ocean water](#). The post focussed on the Atlantic Meridional Overturning Circulation (AMOC), whose fickle nature seems to have resulted in a succession of climatic blips during the last glacial-interglacial cycle since 100 ka ago. They took the form of warming-cooling cycles known as [Dansgaard-Oeschger events](#), when the poleward movement of warm surface water in the North Atlantic Ocean was disrupted. An operating AMOC normally drags northwards warm water from lower latitudes, which is more saline as a result of evaporation from the ocean surface there. Though it gradually cools in its journey it remains warmer and less dense than the surrounding surface water through which it passes: it effectively 'floats'. But as the north-bound, more saline stream steadily loses energy its density increases. Eventually the density equals and then exceeds that of high-latitude surface water, at around 60° to 70°N, and sinks. Under these conditions the AMOC is self-sustaining and serves to warm the surrounding land masses by influencing climate. This is especially the case for the branch of the AMOC known as the Gulf Stream that today swings eastwards to ameliorate the climate of NW Europe and Scandinavia as far as Norway's North Cape and into the eastern Arctic Ocean. !



Location of the 4 regions in the northern North Atlantic used by Ma et al. in their modelling of AMOC: A Labrador Sea; B Irminger Basin; C NE Atlantic; D Nordic Seas. Colour chart refers to current temperature. Solid line – surface currents, dashed line – deep currents

The suspected driving forces for the Dansgaard-Oeschger events are sudden massive increases in the supply of freshwater into the Atlantic at high northern latitudes, which dilute surface waters and lower their density. So it becomes more difficult for surface water to become denser on being cooled so that it can sink to the ocean floor. The AMOC may weaken and shut down as a result and

so too its warming effect at high latitudes. It also has a major effect on atmospheric circulation and moisture content: a truly complicated climatic phenomenon. Indeed, like the Pacific El Niño-Southern Oscillation (ENSO), major changes in AMOC may have global climatic implications. Qiyun Ma of the Alfred Wegener Institute in Bremerhaven, Germany and colleagues from Germany, China and Romania have modelled how the various possible locations of fresh water input may affect AMOC (Ma, Q. *et al.* 2024. [Revisiting climate impacts of an AMOC slowdown: dependence on freshwater locations in the North Atlantic](#). *Science Advances*, v. **10**, article eadr3243; DOI: 10.1126/sciadv.adr3243). They refer to such sudden inputs as ‘hosing’

First, the likely consequences under current climatic conditions of such ‘hosings’ and AMOC collapses are: a rapid expansion of the Arctic Ocean sea ice; delayed onset of summer ice-free conditions; southward shift of the [Intertropical Convergence Zone](#) (ITCZ) – a roughly equatorial band of low pressure where the NE and SE trade winds converge, and the rough location of the sometimes windless Doldrums. There have been several attempts to model the *general* climatic effects of an AMOC slowdown. Ma *et al.* take matters a step further by using the Alfred Wegener Institute Climate Model (AWI-CM3) to address what may happen following ‘hosing’ in four regions of the North Atlantic: the Labrador Sea (between Labrador and West Greenland); the Irminger Basin (SE of East Greenland, SW of Iceland); the Nordic Seas (north of Iceland; and the Greenland-Iceland-Norwegian seas) and the NE Atlantic (between Iceland, Britain and western Norway).

Prolonged freshwater flow into the Irminger Basin has the most pronounced effect on AMOC weakening, largely due to a U-bend in the AMOC where the surface current changes from northward to south-westward flow parallel to the East Greenland Current. The latter carries meltwater from the Greenland ice sheet whose low density keeps it near the surface. In turn, this strengthens NE and SW winds over the Labrador Sea and Nordic Seas respectively, which slow this part of the AMOC. In turn that complex system slows the entire AMOC further south. Since 2010 an average 270 billion tonnes of ice has melted in Greenland each year. This results in an annual 0.74 mm rise in global sea level, so the melted glacial ice is not being replenished. When sea ice forms it does not take up salt and is just as fresh as glacial ice. Annual melting of sea ice therefore temporarily adds fresh water to surface waters of the Arctic Ocean, but the extent of winter sea ice is rapidly shrinking. So, it too adds to freshening and lowering the density of the ocean-surface layer. The whole polar ocean ‘drains’ southwards by surface currents, mainly along the east coast of Greenland potentially to mix with branches of the AMOC. At present they sink with cooled more saline water to move at depth. To melting can be added calving of Greenlandic glaciers to form icebergs that surface currents transport southwards. A single glacier (Zachariae Isstrom) in NE Greenland lost 160 billion tonnes of ice between 1999 and 2022. Satellite monitoring of the Greenland glaciers suggests that a trillion tonnes have been lost through iceberg formation during the first quarter of the 21st century. Accompanying the Dansgaard-Oeschger events of the last 100 ka were iceberg ‘armadas’ ([Heinrich events](#)) that deposited gravel in ocean-floor sediments as far south as Portugal.

The modelling done by Ma *et al.* also addresses possible wider implications of their ‘hosing’ experiments to the global climate. The authors caution that this aspect is an ‘exploration’ rather than prediction. Globally increased duration of ‘cold extremes’ and dry spells, and the intensity of precipitation may ensue from downturns and potential collapse of AMOC. Europe seems to be most at risk. Ma *et al.* plea for expanded observational and modelling studies focused on the Irminger

Basin because it may play a critical role in understanding the mechanisms and future strength of the AMOC.

See also: Yirka, R. 2024. [Greenland's meltwater will slow Atlantic circulation, climate model suggests](#). *Phys Org*, 21 November 2024

The prospect of climate chaos following major volcano eruptions

PUBLISHED ON *November 18, 2024*



The ash plume towering above Pinatubo volcano in the Philippines on 12 June 1991, which rose to 40 km (Credit: Karin Jackson U.S. Air Force)

It hardly needs mentioning that volcanoes present a major hazard to people living in close proximity. The inhabitants of the Roman cities of Herculaneum and Pompeii in the shadow of Vesuvius were snuffed out by an incandescent pyroclastic during the 79 CE eruption of the volcano.

Since December 2023 long-lasting eruptions from the Sundhnúksíggar crater row on the Reykjanes Peninsula of Iceland have driven the inhabitants of nearby Grindavík from their homes, but no injuries or fatalities have been reported. Far worse was the [1815 eruption of Tambora](#) on Sumbawa, Indonesia, when at least 71,000 people perished. But that event had much wider consequences, which lasted into 1817 at least. As well as an ash cloud the huge plume from Tambora injected 28 million tons of sulfur dioxide into the stratosphere. In the form of sulfuric acid aerosols, this reflected so much solar energy back into space that the Northern Hemisphere cooled by 1° C, making 1816 ‘the year without a summer’. Crop failures in Europe and North America doubled grain prices, leading to widespread social unrest and economic depression. That year also saw unusual weather in India culminate in a cholera outbreak, which spread to unleash the 1817 global pandemic. Tambora is implicated in a global death toll in the tens of millions. Thanks to the record of sulfur in Greenland ice cores it has proved possible to link past volcanic action to historic famines and epidemics, such as the [Plague of Justinian](#) in 541 CE. If they emit large amounts of sulfur gases volcanic eruptions can result in sudden global climatic downturns.

With this in mind Markus Stoffel, Christophe Corona and Scott St. George of the University of Geneva, Switzerland, CNRS, Grenoble France and global insurance brokers WTW, London, respectively, have published a Comment in *Nature* warning of this kind of global hazard (Stoffel, M., Corona, C. & St. George, S. 2024. [The next massive volcano eruption will cause climate chaos — we are unprepared](#). *Nature* v. **635**, p. 286-289; DOI: 10.1038/d41586-024-03680-z). The crux of their argument is that there has been nothing approaching the scale of Tambora for the last two centuries. The 1991 eruption of Pinatubo fed the stratosphere with just over a quarter of Tambora’s complement of SO₂, and decreased global temperatures by around 0.6°C during 1991-2. Should one so-called [Decade Volcanoes](#) – those located in densely populated areas, such as Vesuvius – erupt within the next five years actuaries at [Lloyd’s of London estimate economic impacts](#) of US\$ 3 trillion in the first year and US\$1.5 trillion over the following years. But that is based on just the local risk of ash falls, lava and pyroclastic flows, mud slides and lateral collapse, not global climatic effects. So, a Tambora-sized or larger event is not countenanced by the world’s most famous insurance underwriter: probably because its economic impact is incalculable. Yet the chances of such a repeat certainly are conceivable. A 60 ka record of sulfate in the Greenland ice cores allows the probability of eruptions on the scale of Tambora to be estimated. The data suggest that there is a one-in-six chance that one will occur somewhere during the 21st century, but not necessarily at a site judged by volcanologists to be precarious. Nobody expected the eruption from the Pacific Ocean floor of the [Hunga Tonga-Hunga Ha’apai volcano](#) on January 15, 2022: the largest in the last 30 years.

The authors insist that climate-changing eruptions now need to be viewed in the context of anthropogenic global warming. Superficially, it might seem that a few volcanic winters and years without a summer could be a welcome, albeit short-term, solution. However, Stoffel, Corona and St. George suggest that the interaction of a volcano-induced global cooling with climatic processes would probably be very complex. Global warming heats the lower atmosphere and cools the stratosphere. Such steady changes will affect the height to which explosive volcanic plumes may reach. Atmospheric circulation patterns are changing dramatically as the weather of 2024 seems to show. The same may be said for ocean currents that are changing as sea-surface temperatures increase. Superimposing volcano-induced cooling of the sea surface adds an element of chaos to what is already worrying. What if a volcanic winter coincided with an el Niño event? The Intergovernmental Panel on Climate Change that projects climate changes is ‘flying blind’ as regards

volcanic cooling. Another issue is that our knowledge of the effects in 1815 of Tambora concerned a very different world from ours: a global population then that was eight times smaller than now; very different patterns of agriculture and habitation; a world with industrial production on a tiny proportion of the continental surface. Stoffel, Corona and St. George urge the IPCC to shed light on this major blind spot. Climate modellers need to explore the truly worst-case scenarios since a massive volcanic eruption is bound to happen one day. Unlike global warming from greenhouse-gas emission, there is absolutely nothing that can be done to avert another Tambora.