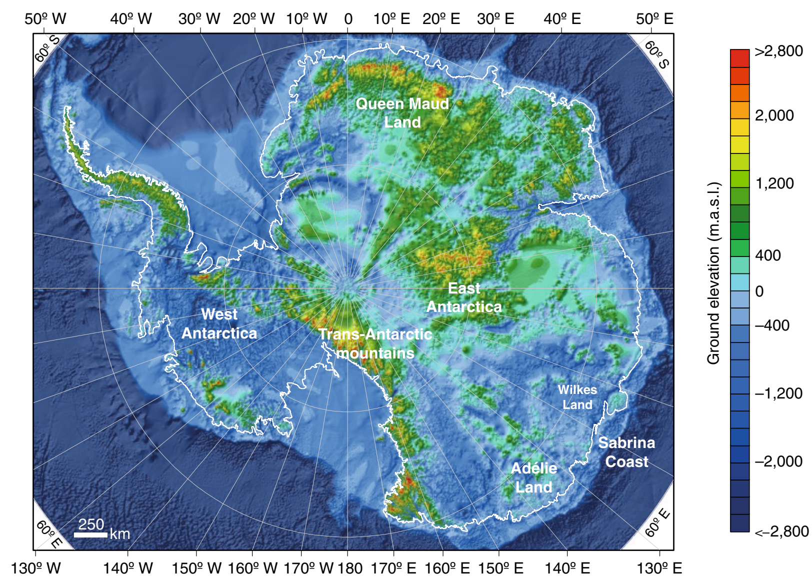
A history of instability

The East Antarctic ice sheet may be gaining mass in the current, warming climate. The palaeoclimate record shows, however, that it has retreated during previous episodes of prolonged warmth.

The phrase "at a glacial pace" once invoked a sense of slow and unchangeable movement, an almost imperceptible motion. But decades of remote sensing and seafloor observations have shown that glaciers and ice sheets can respond to disturbances much more dynamically than once thought. But as satellites captured the surges and retreat of Greenland's maritime glaciers in the past decades the Antarctic ice sheets — east and west of the Trans-Antarctic mountains — were at least assumed to be stable. But this, too, turned out to be wrong. First came sediment[1] and model[2] evidence that the West Antarctic ice sheet collapsed during previous interglacial periods and under Pliocene warmth. Then came erosional data showing that several regions of the East Antarctic ice sheet also retreated and advanced throughout the Pliocene[3]. An extended record[4] of ice-sheet extent from elsewhere on the East Antarctic coast now paints a more complicated picture of the sensitivity of this ice sheet to warming.



Credit: Figure adapted from ref. [11], Elsevier

The East Antarctic ice sheet is currently the largest ice mass on Earth. If it melted in its entirety, global sea levels would rise by more than 50 metres. Because much of this ice is based on land, it is thought to be less vulnerable to retreat than, for instance, West Antarctica, where much of the ice is grounded below sea level. Nevertheless, several sectors of the East Antarctic ice sheet have responded to past periods of warmth. Ice streams in Wilkes Land and Adélie Land broke up during the late Miocene and Pliocene[5], between about 7 and 3.5 million years ago, and the entire East Antarctic ice sheet waxed and waned with orbital forcing throughout the Oligocene and Miocene[6].

Oligocene and Miocene instability is also seen in a record from the Sabrina Coast[4], near Totten Glacier. This region underwent a fairly early onset of glaciation, following the Eocene climatic optimum. But this early East Antarctic ice sheet was far from stable — it advanced and retreated at least eleven times in the tens of millions of years between the Eocene and the late Miocene. This dynamic glaciation — in contrast to the more stable ice seen under cooler climates — was associated with the development of regional subglacial hydrologic systems fed by high volumes of surface meltwater. The development of such systems under warmer conditions may have an analogue in the most recent deglaciation. Prior to the Holocene retreat of the East Antarctic ice sheet in the western Ross Sea, extensive subglacial channels carried meltwater to the ice shelf grounding line[7].

Intriguingly the Sabrina coast record shows some evidence of Pliocene instability, but nothing as drastic as the response seen in Adélie Land, where the ice margin repeatedly retreated several hundred kilometres inland. Moreover, periods of retreat in Adélie Land and Wilkes Land during the Pliocene were not synchronous. It is thus clear that the East Antarctic ice sheet does not respond uniformly to warming.

Modern climate and cryosphere variations provide some insights into the complex response of the ice sheet to oceanic and atmospheric warming, albeit on much shorter timescales. Warming has led to increased snowfall and accumulation in Queen Maud Land, which appears to be unprecedented in the past two millennia[8]. Mass gain has been accelerating in this region[9], but the volume of the floating ice shelves that buttress the East Antarctic ice sheet has been decreasing[10] since 2003. Ice-shelf thickness is controlled by a complex interplay between snowfall accumulation and melting from beneath; the balance between these processes seems to respond to even subtle shifts in climate, see for instance page 121. Variations in the response of ice shelves to oceanic and atmospheric warming, and hence in their effects on ice-sheet stability, could be one reason why the response of the East Antarctic ice sheet to warming was so complex.

In terms of immediate sea-level rise, it is reassuring that it seems to require prolonged periods of lasting hundreds of thousands to millions of years to induce even partial retreat. Nevertheless, we must not take its stability completely for granted — we cannot be sure how the East Antarctic ice sheet will respond to rates of warming that might exceed one to two degrees in a few thousand years. ❐

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