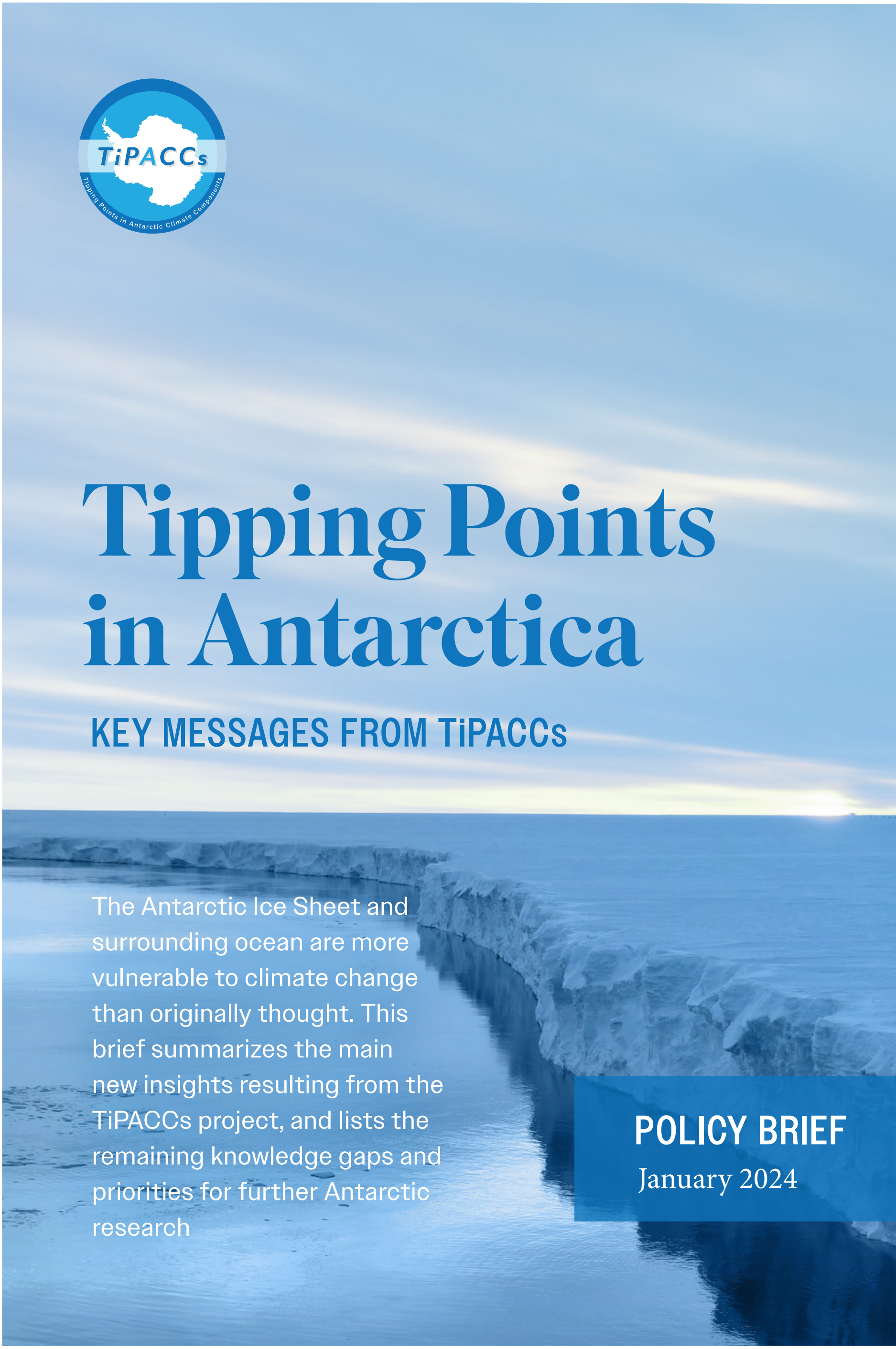

TiPACCs
Tipping Points in Antarctic Climate Components

Tipping Points in Antarctica

KEY MESSAGES FROM TiPACCs

The Antarctic Ice Sheet and surrounding ocean are more vulnerable to climate change than originally thought. This brief summarizes the main new insights resulting from the TiPACCs project, and lists the remaining knowledge gaps and priorities for further Antarctic research

POLICY BRIEF
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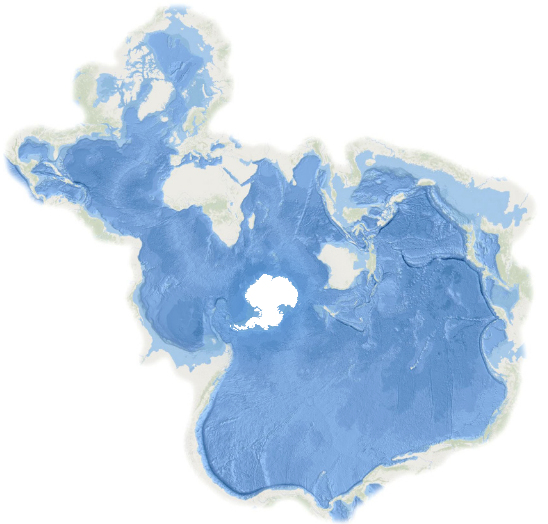


Importance of Antarctic Research

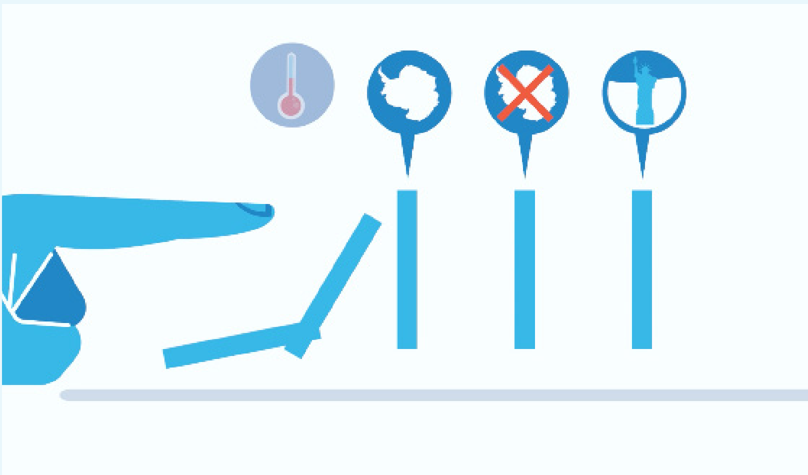
We do not often think of Antarctica, a continent more than half a world away from Europe. While distant from our homes and minds, Antarctica is crucially important and shapes our daily life within Europe and globally. The most direct impact is through sea level rise. Ice melting from the Antarctic continent causes the global mean sea level to rise. Currently Antarctica is still a minor player in ongoing sea level rise. But if ice sheet tipping points are crossed, there is the threat of a sudden increase in sea level due to ice loss from Antarctica. Antarctica, and especially the surrounding Southern Ocean, also have a major play in the Earth's heat budget. The white snow-covered ice sheet reflects solar radiation back out to space. The Southern Ocean is responsible for around 50% of the global uptake of atmospheric carbon dioxide, providing a buffer for ongoing climate change. Antarctic meltwater and iceberg calving, together with changes in sea ice, impact ocean circulation, and therefore the distribution on heat on Earth. Lastly, Antarctica contains a pristine, unique landscape and ecosystems, and as such should be preserved for future generations.

Tipping Points in Antarctica

The Antarctic Ice Sheet is surrounded by the Southern Ocean. In many regions around Antarctica, cold coastal waters protect the ice sheet from warmer waters further away. In West Antarctica, particularly in the Amundsen Sea region, warm waters do reach the ice sheet.

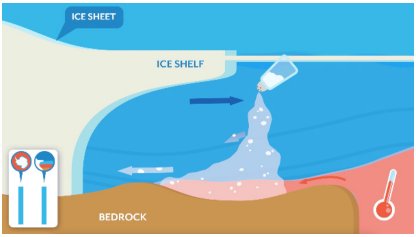
Floating ice shelves hamper the flow of ice from inland, and thereby reduce the impact of Antarctic ice loss on sea level rise. If the colder coastal seas transition to a warmer regime ("Ocean Tipping Point"), more heat will reach the ice shelves causing them to melt more rapidly from below and thin. Thinner ice shelves provide less buttressing (pushback) for the inland ice, causing the grounding lines (where grounded ice becomes afloat) to retreat ("Ice Tipping Point").

In TiPACCs we investigated these two tipping points, both in stand-alone ice sheet and ocean models, as well as in coupled ocean-ice sheet models.



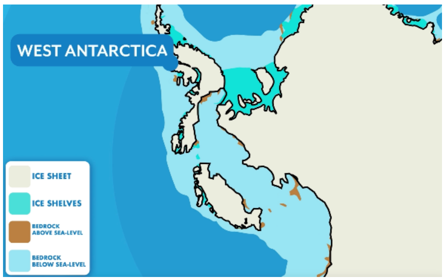
Key Messages from TiPACCs

Ocean Tipping Point:



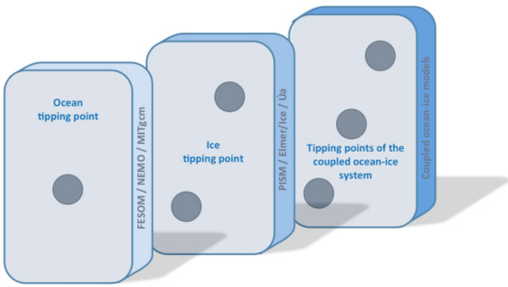
Warm seawater is reaching the grounding lines of several ice shelves in the Amundsen Sea, resulting in increased basal melting. Our models show that this already warm state could transition to a cold state under a cooler climate regime. The regime is reversible, with the critical factor being how dense the cold waters near the coast can be made when sea ice forms in winter and enhances the salinity of the underlying ocean. Recent observations reveal episodes of warm water infiltrating the southern Weddell Sea and approaching the ice shelves. Our models replicate these occurrences, indicating a likelihood of increased frequency of warm water incursions in a warming climate. Tipping to a warm regime is associated with decreased sea ice formation, which lowers the density of the cold coastal waters, allowing the infiltration of warmer water. Both observations and models point consistently to the potential for a regime shift from cold to warm waters. The timescales over which these shifts occur vary per model and ocean basin.

Ice Tipping Point:



Even though several grounding lines in West Antarctica are retreating, our research shows that we have not yet crossed large scale ice sheet tipping points. However, in our current climate, we are well on the way to cross them. Most vulnerable are regions in West Antarctica. Even under constant present-day climate conditions, assuming no future extra warming, we are committed to losing large parts of the West Antarctic ice sheet, causing a rise in global mean sea level of about 3 meters. Depending on the intensity of climate forcing, this committed ice loss will unfold over 100s–1000s of years. Our research also suggests that we have crossed deglaciation and glaciation thresholds during the last 400,000 years, causing changes in ice sheet size impacting sea level up to around 5 meters.

Coupled Ocean-Ice System:
We have made enormous technical progress in coupling ocean and ice sheet models, and have been able to describe, for the first time, the interactions between the Southern Ocean and the Antarctic Ice Sheet in a coupled ice+ocean modelling framework. Our modelling studies clearly indicate the possibility of a future regime shift in the Southern Ocean whereby intrusions of the relatively warm modified Circumpolar Deep Water around Antarctica replace the colder Ice Shelf Waters currently occupying most of the ice shelf cavities. The exact timing and the conditions under which such a regime change takes place is uncertain and requires more research, but we find the regime shift can take place within decades under high-end future emission scenarios such as SSP585. The implications of such a regime shift within the ice shelf cavities for the Antarctic Ice Sheet are profound, as this increases ocean-induced melt by an order of magnitude and leads to a loss in ice shelf buttressing and a concomitant increase in ice flow across grounding lines. The predicted regime shift is a robust feature as we find it in simulations done with each of our three numerical uncoupled ocean models as well in the independent coupled ice+ocean configurations.



Knowledge Gaps and Priorities

TiPACCs made huge advances both in technical innovations and in our understanding of the tipping point processes in Antarctica. Here we list topics and challenges that we suggest should be prioritized for future Antarctic research:

- ❑ Verifying and constraining ice sheet and ocean (climate) models:
  - Encourage better use of satellite records and other observations.
  - Targeted and long-term monitoring of seawater beneath ice shelves.
- ❑ Advancing procedures for (coupled) model initialization
- ❑ Evolution of surface mass balance (important for longer time scales)
- ❑ Important to keep on studying and including missing or not-well understood processes in our models, such as:
  - Icebergs: Calving of icebergs, and grounding of large icebergs
  - Localized ice shelf processes, such as damage
  - Stratification of continental shelf seas (and within the ice shelf cavities) and feedbacks to sea ice, freshwater fluxes and mixing.
  - Hydrology: (Subglacial) melt water, where does it go and where does it drain?
  - Subglacial volcanism can impact ice flow and/or ice properties: how important is this?
- ❑ Holistic view of the Antarctic Ice Sheet and surrounding ocean, atmosphere and land. Further development of coupled ice-sheet – ocean models and/or full Earth System Models are needed to fully address all feedbacks.

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