BYTES

THE NEWSLETTER OF THE NATIONAL MODELLING HUB

Issue 8
March 2025

In a nutshell...

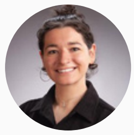
It's been a very busy few months, with many of us working on science proposals for Tranche 2 of the Antarctic Science Platform, reporting on Tranche 1, and submitting logistics plans for next season's fieldwork. Despite all that we've still managed to do some science, and in this issue of BYTES we share with you a Modelling Hub output that has been in the works for a long time.

Focusing on Antarctic coastal polynyas, our new paper presents a state-of-the-science review of what is known about these features, what is still not known, and the challenges that the community faces in trying to learn more about their role in regulating global climate. We also feature an article from Ph.D student Ihanshu Rane, also working on polynyas, as well as a few other updates from the group.

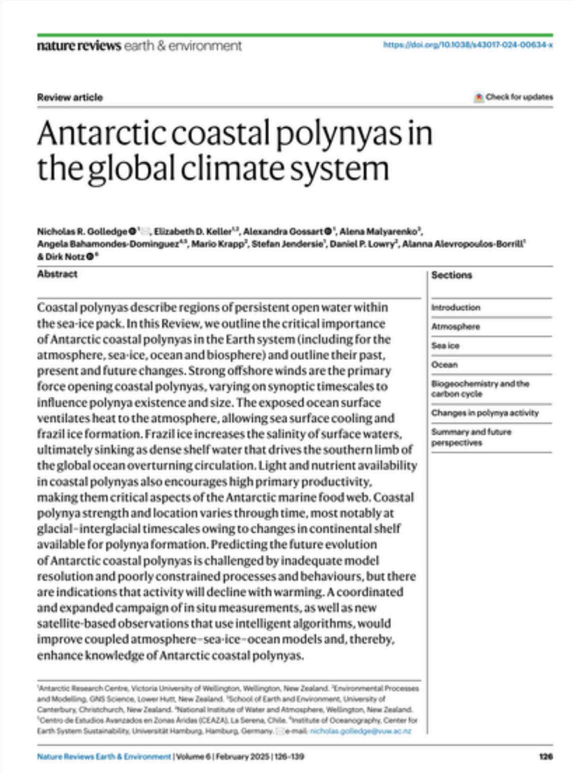
NATIONAL MODELLING HUB

AN UPDATE FROM THE NATIONAL MODELLING HUB IN WELLINGTON, A MULTI-INSTITUTE PARTNERSHIP SUPPORTING THE ANTARCTIC SCIENCE PLATFORM AND NZ SEARISE PROGRAMMES

Publication:
Antarctic coastal polynyas in the global climate system

This paper, published in Nature Reviews Earth & Environment in February this year, brought together expertise from nearly all of the Modelling Hub fellows - from atmospheric and ocean modellers to ice sheet scientists and palaeoenvironmental proxy experts. We also brought in Dr. Dirk Notz (University of Hamburg) for his expertise in sea ice changes at both poles. The Review summarizes the state of knowledge of Antarctic coastal polynyas, from polynya-specific processes to the broader connections between polynyas and the atmosphere, sea-ice, ocean and biogeochemical cycles. We discuss past, present and future polynya changes, and wrap up with both an assessment of current limitations, and with recommendations for future research priorities.
Read the full paper [here](#).



nature reviews earth & environment https://doi.org/10.1038/s43017-024-00634-x

Review article

Check for updates

Antarctic coastal polynyas in the global climate system

Nicholas R. Golledge [1], Elizabeth D. Keller [1,2], Alexandra Gossart [1], Alena Malyarenko [3], Angela Bahamondes-Dominguez [4,5], Mario Krapp [2], Stefan Jendersie [1], Daniel P. Lowry [2], Alanna Alevropoulos-Borrill [1] & Dirk Notz [6]

Abstract

Coastal polynyas describe regions of persistent open water within the sea-ice pack. In this Review, we outline the critical importance of Antarctic coastal polynyas in the Earth system (including for the atmosphere, sea-ice, ocean and biosphere) and outline their past, present and future changes. Strong offshore winds are the primary force opening coastal polynyas, varying on synoptic timescales to influence polynya existence and size. The exposed ocean surface ventilates heat to the atmosphere, allowing sea surface cooling and frazil ice formation. Frazil ice increases the salinity of surface waters, ultimately sinking as dense shelf water that drives the southern limb of the global ocean overturning circulation. Light and nutrient availability in coastal polynyas also encourages high primary productivity, making them critical aspects of the Antarctic marine food web. Coastal polynya strength and location varies through time, most notably at glacial–interglacial timescales owing to changes in continental shelf available for polynya formation. Predicting the future evolution of Antarctic coastal polynyas is challenged by inadequate model resolution and poorly constrained processes and behaviours, but there are indications that activity will decline with warming. A coordinated and expanded campaign of in situ measurements, as well as new satellite-based observations that use intelligent algorithms, would improve coupled atmosphere–sea-ice–ocean models and, thereby, enhance knowledge of Antarctic coastal polynyas.

[1]Antarctic Research Centre, Victoria University of Wellington, Wellington, New Zealand. [2]Environmental Processes and Modelling, GNS Science, Lower Hutt, New Zealand. [3]School of Earth and Environment, University of Canterbury, Christchurch, New Zealand. [4]National Institute of Water and Atmosphere, Wellington, New Zealand. [5]Centro de Estudios Avanzados en Zonas Áridas (CEAZA), La Serena, Chile. [6]Institute of Oceanography, Center for Earth System Sustainability, Universität Hamburg, Hamburg, Germany. e-mail: nicholas.golledge@vuw.ac.nz

Nature Reviews Earth & Environment | Volume 6 | February 2025 | 126–139 126

But what are polynyas, and why are they important? Polynyas are areas of persistent open water within the sea-ice pack. They exist in the Arctic and Antarctic (albeit with different characteristics) and are classified into two types depending on the formation and mechanisms that maintain them: (1) open water (or sensible heat) polynyas, formed through the upwelling of comparatively warm water that melts pre-existing ice and prevents new ice formation, as seen in the Weddell Sea Polynya, and (2) coastal (or latent heat) polynyas, formed by offshore winds pushing newly created sea-ice away from its source area, as seen for example in the Ross Ice Shelf Polynya and Terra Nova Bay Polynya.

Over 1998–2014, there were 46 identifiable Antarctic coastal polynyas, covering a total area of over 600,000 km2, representing 1% of the maximum sea-ice area of the Southern Ocean. Collectively, these coastal polynyas serve vital climatic and ecological functions. Because of frequent strong wind events that strip heat from the ocean surface, frazil ice forms in the upper parts of the water (continued...)

column. Acting as sea-ice factories, coastal polynyas produce 6–9 m sea-ice yr^{-1} and contribute 10% of total Antarctic sea-ice growth. Any fluctuations in the spatial extent of coastal polynyas and their rates of ice production — linked to variability in synoptic conditions — can therefore influence intra-annual and inter-annual circumpolar sea-ice variability.

Because sea-ice reflects solar radiation, insulates the surface ocean and, in some locations, regulates the flow speed of floating ice shelves, changes to polynyas have wide-reaching impacts. For example, when frazil ice forms, it leaves behind more salty water - brine - which is critical for the formation of Dense Shelf Water. This water mass can influence ice shelf melt and act as a density barrier in the open ocean. As it flows away from Antarctica, dense shelf water produces Antarctic Bottom Water (AABW), the lower limb of the global meridional overturning circulation. And it's not just the physical environment that depends on polynya activity. Antarctic coastal polynyas are focal locations for biological activity and gas and nutrient exchange, allowing enhanced carbon sequestration. With higher trophic levels depending on primary productivity within polynyas, any interannual variability also has direct impacts on, for example, penguin colony size and location, as well as albatross and seal numbers by influencing food availability.

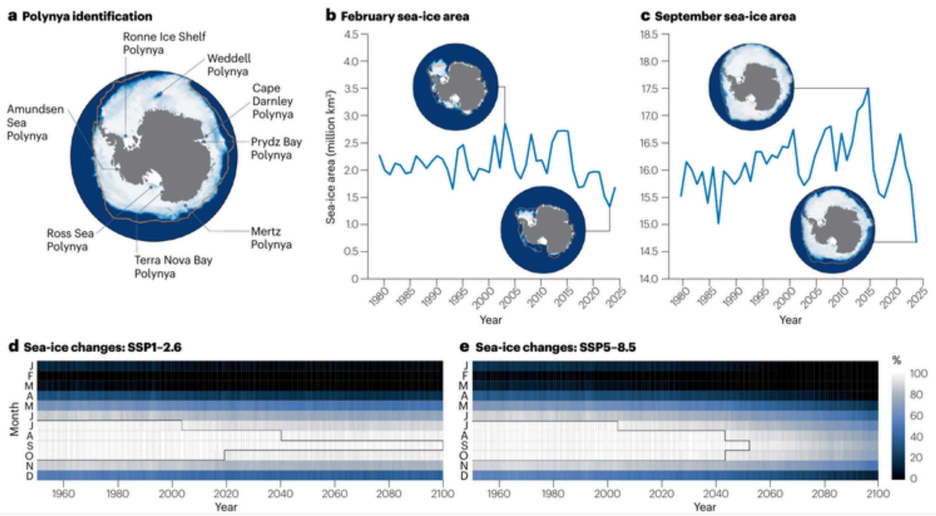


Figure 1 | Observed and projected changes in Antarctic sea-ice. a, Location of the major Antarctic coastal polynyas (pale blue areas). b, February and c, September Antarctic sea-ice (1979 to 2023). Historical and projected monthly sea-ice concentration under d, SSP1-2.6 and e, SSP5-8.5 emissions scenarios.

The outlook, however, is not good. Currently observed sea-ice changes, as well as those projected for the future (Fig. 1), threaten the critical ecological and climatic functioning of polynyas. One study reported a 30% reduction in Ross Ice Shelf Polynya ice production from 1992 to 2001 and suggested that dense water export from Antarctica might decline by 40% under a surface warming of 2 °C, owing to reduced polynya activity. As a result of the declining number, extent and efficiency of active coastal polynyas, Antarctic sea-ice hit an all-time low in February 2023 (Fig. 1b) and persisted through the winter months (Fig. 1c); such sea-ice losses are projected to continue under stringent (Fig. 1d) and absent (Fig. 1e) mitigation scenarios. As our climate continues to change, it seems there is an increasing need to understand Antarctic coastal polynyas - and the global consequences of losing them.

Publication:
Increasing sea ice growth with global warming?

It is well known that Arctic sea ice has been diminishing over the past decades due to global warming. However, if we focus on the ice-growing season (September to March), Arctic sea ice growth has been increasing. This is a robust phenomenon found in observations (blue line in the figure) and many climate models.

Peter Siew and scientists from Columbia University have recently published a paper addressing why sea ice growth has increased. This is driven by a negative feedback, where a significant decline of September sea ice (yellow line) provides more open water that accelerates sea ice formation when the ocean is still cold enough. This negative feedback has been strong and will continue for some years, as suggested by the climate models.

However, in the near future, this negative feedback will weaken because of the rapidly rising Arctic ocean temperature that hinders sea ice freezing. We expect that large-scale atmospheric circulation will exert more control on winter sea ice growth in the coming decades.

[Please read Siew et al. for details]

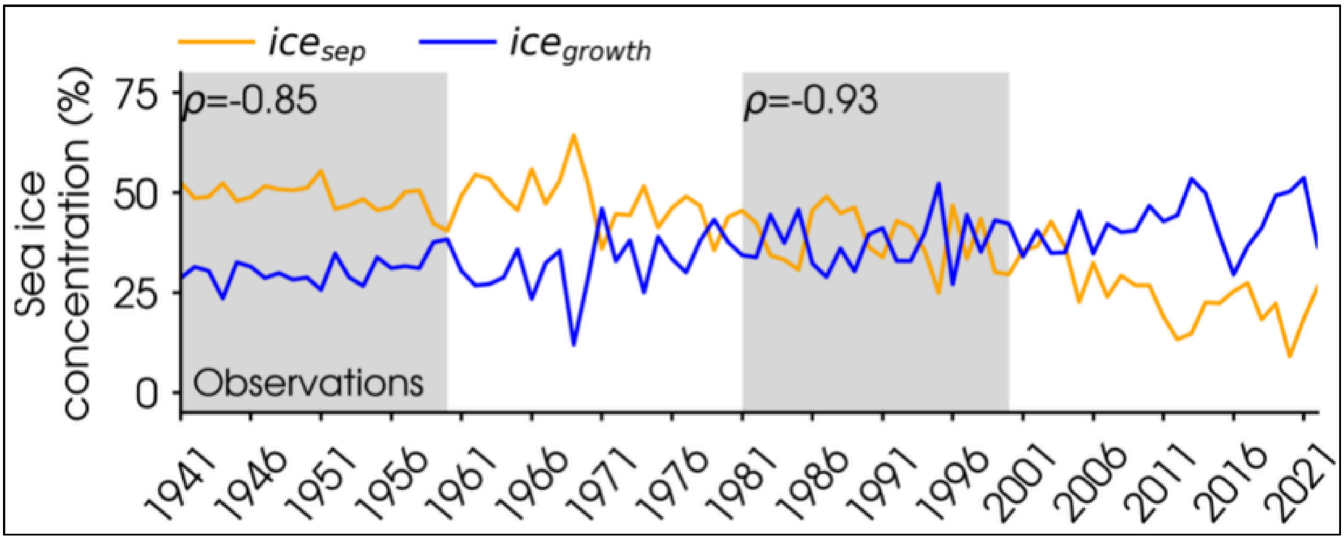


Figure 2 | Wintertime Arctic sea ice growth (blue line, icegrowth) and September sea ice (yellow line, icesep) in observations from 1941 to 2022. ρ indicates the correlation between the two timeseries over the shaded period.

Predicting polynyas with Machine Learning PhD candidate Ihanshu Rane

As we saw in the lead article of this issue, Antarctic coastal polynyas are areas of open water enclosed by winter sea-ice, where very cold, local high-speed winds drive the sea-ice away from the coast and so intensify the generation of new sea-ice. The intense sea-ice production and associated brine rejection leads to formation of very dense shelf-water, that sinks and contributes to the formation of Antarctic Bottom Water. But most coastal polynyas with intense sea-ice production are not represented in current Earth System Models (ESMs), leading to significant underestimation of heat and salt fluxes, and causing key Antarctic processes to be overlooked in global climate projections.

Running ESMs at the required high spatial resolutions would be computationally too expensive. This project aims to offer a computationally efficient solution using Machine Learning (ML), trained on observational and reanalysis data. A ML-model using Convolutional Neural Network will be trained with features such as surface wind speed, surface wind direction, surface air temperature, sea-surface temperature, coastal orientation, and gradient wind.

Polynya size is traditionally defined from sea-ice concentration. However, this definition of polynya size does not give the actual area of salt production due to brine rejection, but rather quantifies the ocean-exposed area in the region. To assess the salt flux production in polynyas, we are defining a new method, which is using sea-ice production rates instead of sea-ice concentration. The ML-model will predict both sea-ice concentration values and sea-ice production values. The overall objective is to develop a ML-model that predicts occurrence and size of coastal polynyas and provide a correction term for polynya-associated surface fluxes, thus avoiding the need to resolve fine to small scale polynya processes in ESMs.

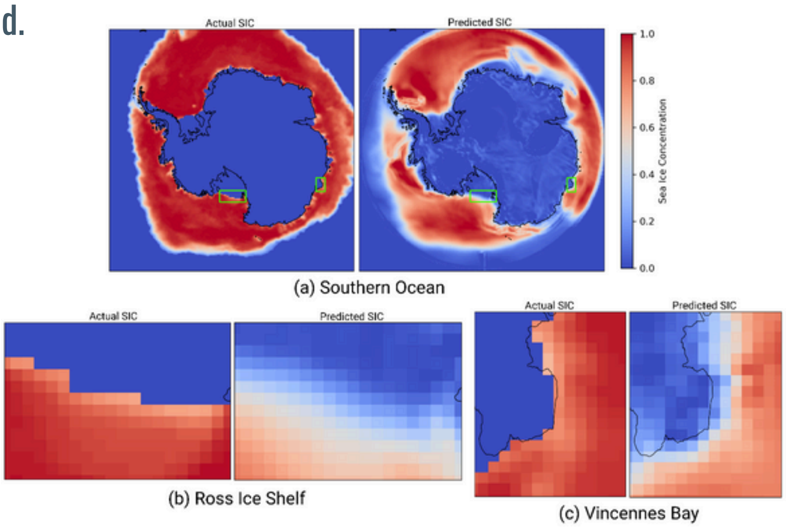


Figure 3 | Performance testing of ML-model Comparison of actual [left] vs ML-model predicted [right] sea-ice concentration (SIC) for August-2012 in, (a) Southern Ocean, (b) Ross Ice Shelf region, and (c) Vincennes Bay region. At current stage the ML-model effectively captures the overall SIC extent. However, when zooming into individual regions, the ML-model underestimates the SIC values and only predicts the gradual variations in SIC. Further refinements to the ML-model architecture will focus on improving regional accuracy.

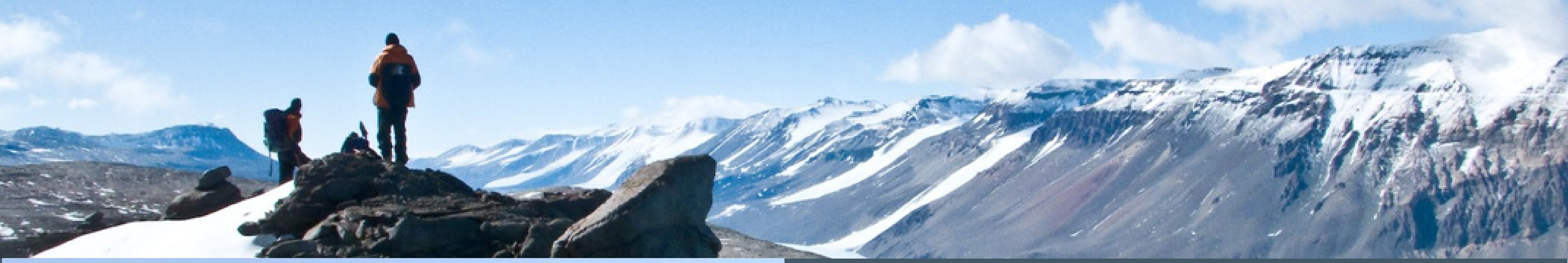


Photo by Alex Gossart

Stefan Jendersie
Moving on...

Stefan joined the Antarctic Research Centre in 2018, bringing high-resolution ocean modelling capability to the NZ Searise programme and to the group as a whole. With expertise in running the Regional Ocean Modeling System model (ROMS), and having spent many years building and testing a model domain specifically for the Ross Sea, Stefan was a perfect fit for our team. Over the last seven years, Stefan's detailed knowledge of Southern Ocean physical oceanography, as well as his fastidious approach to building robust numerical simulations, has been a huge asset to the ARC and to the Modelling Hub that he became part of.

Amongst his immense contributions, one of the most important has been the creation of a coupling framework that facilitates interactive ice sheet-ocean simulations for the current and future centuries. A key aim of the Our Changing Coast programme, this coupled model allows us to examine in detail the processes taking place in ice shelf cavities, and to quantify the sea-level rise impact of feedbacks between Antarctic ice shelves and the Southern Ocean under a range of future emissions scenarios.

Moving back to Germany in April, Stefan will begin a new role at Baltic Sea Research Institute, where he hopes to contribute to more hands-on oceanography than his role at VUW permitted. The Modelling Hub will be sorry to lose a good friend and valuable team member, but we wish Stefan tremendous success in the future and look forward to maintaining many of our current collaborative efforts with him.
Haere rā Stefan!

https://www.leibniz-gemeinschaft.de/en/institutes/leibniz-institutes-all-lists/leibniz-institute-for-baltic-sea-research

NATIONAL MODELLING HUB

RESEARCH TEAM

ALENA MALYARENKO

Ice Shelf cavities, Ross ice sheet, The Terra Nova Bay Polynya

ALANNA ALEVROPOULOS-BORRILL

Ice sheet modelling,
Ice-ocean interaction

ALEX GOSSART

Surface mass balance processes, Ross Sea, Terra Novay Bay

DAN LOWRY

Ice sheet dynamics, Ice shelf-ocean interactions, surface mass balance

LIZ KELLER

Carbon cycle dynamics, changes in Antarctica on global climate

MARIO KRAPP

Statistical modelling, dynamical systems, complexity

NICK GOLLEDGE

Glaciology, climate change, numerical modelling of Earth systems

PETER SIEW

Artificial Intelligence and machine learning

STEFAN JENDERSIE

Ocean circulation around Antarctica, ice shelves, polar oceanography

ABOUT THE HUB

The National Modelling Hub was set up as a partnership between NIWA, VUW and GNS, funded by the Antarctic Science Platform (ASP). Now, the Hub incorporates researchers from VUW, GNS Science and University of Canterbury, all of whom are funded through a range of research programmes. The work of the Hub is coordinated by Nick Golledge and Liz Keller, Co-Chairs of the ASP Modelling and Future Projections Working Group.

The Hub has nine active PhD students: Béatrice Désy, Frank MacKenzie, Huiling Zou, Ihanshu Rane, Prasad Shelke, Vincent Charnay, Timothée Lebrat, Xingyu Wang and Faezeh Bahmani.

VICTORIA UNIVERSITY OF WELLINGTON TE HERENGA WAKA | Te Puna Pātiotio Antarctic Research Centre | GNS SCIENCE TE PŪ AO | NZ SEA RISE TE TAI PARI O AOTEAROA | Antarctic Science Platform | MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT HĪKINA WHAKATUTUKI | UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND | NIWA Taihoro Nukurangi

TO SUBSCRIBE TO THIS NEWSLETTER, PLEASE GO TO OUR SITE: HTTPS://WWW.MODELLINGHUB.ORG

READ PREVIOUS ISSUES OF BYTES HERE