political support in Brazil for the large-scale deployment of electric cars, nor for constructing green diesel plants.

Country-specific IAMs, such as those presented by Rochedo and colleagues[4], are instrumental for identifying, managing and preventing climate and policy-related impacts. The results are sensitive to the technology descriptions embedded in the IAMs: descriptions of energy sector technologies must be specifically tailored for each country and need to be constantly updated, as do the market-mediated considerations for the models. This is particularly important for the case of BECCS, which has a central role in many studies that quantify the emissions reductions necessary to achieve the goals of the Paris Agreement. However, deployment rates required for carbon capture and storage projects are enormous in comparison to those of fossil fuel, renewable or nuclear technologies in the past, and are strongly reliant on policy actions to incentivize its implementation[6]. Model-generated land-use maps must also be cross-checked with observed changes in the real world, to improve the reliability of these complex models for policymakers and scientists.

Large-scale changes in the land-use and energy sectors, as projected in the IAM studies by Rochedo et al.[4] and others, are also likely to lead to impacts in other environmental areas of concern, such as biodiversity[7], water[8] and ecosystems services[9]. We need a better understanding of the co-benefits and trade-offs between the environmental sustainability impacts and predicted economic system changes if we are to realize the optimum mitigation potential of future development alternatives. Policies must be specifically designed to create synergies across the multiple regions and environmental challenges our society is facing, as recognized by the Sustainable Development Goals of the United Nations. ❐

Otavio Cavalett
Industrial Ecology Programme, Norwegian University of Science and Technology (NTNU), Trondheim, Norway.
e-mail: otavio.cavalett@ntnu.no

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CLIMATE DYNAMICS

The atmospheric response to sea-ice loss

The coincident reduction of Arctic sea ice with increasing mid-latitude wintertime extremes has motivated much research on Arctic–mid-latitude linkages. A new study reveals that projected Antarctic sea-ice loss could also impact the Southern Hemisphere mid-latitudes through perturbations to the strength and position of the westerly winds.

Yannick Peings

The polar regions are particularly sensitive to climate change, as evidenced by the dramatic changes observed in recent decades. For example, surface temperatures have increased at twice the global rate — so-called Arctic amplification[1] — while sea-ice extent has decreased by 40% and volume by as much as 70% since the 1970s[2,3]. A concurrent increase in the frequency of mid-latitude cold events has also been observed, calling into question the relationships to Arctic sea-ice loss, and motivating research into how future sea-ice loss may impact mid-latitude climate[4]. In contrast, few studies have explored how Antarctic sea-ice loss influences the overlying atmosphere, motivating England and colleagues[5] to compare atmospheric responses to Arctic and Antarctic sea-ice loss in their study published in the *Journal of Climate*.

In addition to amplifying local atmospheric temperatures via feedback processes, a strong reduction in Arctic sea ice also has the potential to modify remote temperatures. With the Arctic warming faster than the tropics, a decrease in the Equator-to-pole temperature gradient is known to weaken the westerly winds that predominate in the mid-latitudes (through the 'thermal wind' relation between horizontal winds and temperature). As a result, the mid-latitude jet stream becomes disrupted and wavier, increasing the possibility of polar air outbreaks — and consequently frigid temperatures and snowstorms — in the mid-latitude regions[6]. The 2017/2018 winters in the United States/Canada and Europe provide strong case studies for such phenomena.

From a theoretical standpoint, these atmospheric responses should also apply to Antarctic sea-ice loss. In comparison to the Arctic, however, Antarctic sea-ice extent has exhibited a modest hemispheric increase since satellite records began[7], although anthropogenic forcing is projected to result in sea-ice reductions in the future. England et al.[5] therefore use projections of end-of-century sea-ice extent and the Whole Atmosphere Community Climate Model (WACCM) to examine how the atmosphere responds to both Arctic and Antarctic sea-ice loss under the Representative Concentration Pathway (RCP)8.5 scenario of anthropogenic emissions.

In terms of large-scale atmospheric circulation, and as expected based on thermal wind theory, an equatorward shift of the mid-latitude tropospheric jets is found in both hemispheres due to sea-ice loss. However, the corresponding impacts on temperature and precipitation are more pronounced in the Northern Hemisphere than in the Southern Hemisphere, where they do not reach the populated landmasses of Australia or South America. The atmospheric response to Antarctic sea-ice loss is further shown to be more zonally symmetric and less seasonally variable compared with Arctic sea-ice loss, as expected given the geography of the Southern Hemisphere. Importantly, the temperature in the interior of the Antarctic continent — of particular importance for ice sheet stability — is not responsive to Antarctic sea-ice loss.

Credit: Frans Lanting Studio/Alamy Stock Photo

A major conclusion from the study by England et al. is that Antarctic sea-ice loss (similar to the Northern Hemisphere response to Arctic amplification[8,9]) exerts a negative feedback on the general response to climate change: it forces an equatorward shift of the jet, as opposed to the poleward shift found in climate change scenarios with high GHG concentrations. The way the jet responds to these competing effects in the future will have global implications. Indeed, the westerly winds encircling the Antarctic modulate the strength of the oceanic overturning circulation and the amount of anthropogenic carbon uptake in the ocean — two major drivers of the Earth's climate. As the oceanic response is absent in atmosphere-only model experiments used by England and colleagues[5] (sea surface temperature and sea ice are imposed, and do not respond to changing atmospheric motion) this aspect will need to be explored in future studies using fully coupled ocean–atmosphere models.

Nevertheless, studies such as those by England et al. are extremely valuable in isolating the influence of polar changes on the atmosphere. However, given the large uncertainties inherent in such sensitivity studies (for example, due to large internal variability in the atmosphere and model errors), their findings will have to be confirmed using other climate models. Although a consensus is emerging in most recent global climate model studies[10], unravelling the Arctic–mid-latitude linkages is a difficult task. Discrepancies amongst model results have exposed the need for more coordinated modelling efforts on polar-mid-latitude linkages. To this end, the new multi-model Polar Amplification Model Intercomparison Project (PAMIP) aims to coordinate sea-ice sensitivity experiments with climate modelling centres from all over the world[11]. Each PAMIP participant will provide Arctic and Antarctic sea-ice loss experiment similar to England and colleagues, with different climate models but exact same protocols, including coupled ocean–atmosphere simulations. Sharing similar protocols among the modelling studies will allow for a clean comparison of the results and increased confidence in the remote atmospheric/oceanic responses identified. This is a very promising step towards a better understanding of how the changing poles impact our climate, and anticipating future changes in extreme weather events at our latitudes.

Although the impacts of Arctic sea-ice loss will undoubtedly remain in the spotlights in coming years, England and colleagues[5] point out that its Antarctic counterpart must not be ignored as it will impact future climate changes in the Southern Hemisphere, with potential global consequences. ❐

Yannick Peings
Department of Earth System Science, University of California, Irvine, CA, USA.
e-mail: ypeings@uci.edu

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BIOLOGICAL OCEANOGRAPHY

Waves of invasion

Will the Southern Ocean's relentless waves undo Antarctica's ecological isolation? The discovery of a wayward piece of kelp and a simple numerical experiment set new expectations for the potential invasion of Earth's most isolated continent.

Nathan F. Putman

The movement of individual organisms is a crucial component of all ecological and evolutionary processes, including those of growing concern to humans: invasive species, population responses to habitat modification and a rising extinction rate[1]. Our ability to make predictions about how these processes will respond