The study of Li and colleagues is based on a single state-of-the-art climate model, which can cast a shadow over the results, as all models have biases. Here, however, additional simulations with a simplified atmospheric model are presented in an effort to show that the mechanisms underlying the inter-basin connections are in fact very simple — and, as such, should be the same, regardless of the details of the model used.

Ultimately, the work of Li and co-authors[6] highlights that the tropical Atlantic, Indian and Pacific ocean basins are linked more closely than previously thought, which leads to the authors proposing that on decadal timescales the tropical oceans should really be considered as a single entity. ❐

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ARCTIC WARMING

Short-term solutions

Arctic temperatures are increasing because of long- and short-lived climate forcers, with reduction of the short-lived species potentially offering some quick mitigation. Now a regional assessment reveals the emission locations of these short-lived species and indicates international co-operation is needed to develop an effective mitigation plan.

Julia Schmale

Short-lived climate-forcing pollutants (SLCPs), such as black carbon (BC) and ozone, are substances that affect both air quality and climate. As the name suggests, they remain in the atmosphere for only short periods, that is, weeks or even days, and so their impact on climate can be mitigated almost instantaneously. Quantifying the warming impact of SLCPs is needed to aid quick and effective mitigation strategies and to slow warming as soon as possible. This is highly relevant to the Arctic, a region particularly susceptible to climate change, where warming is occurring twice as fast as the global average[1]. Writing in *Nature Climate Change*, Maria Sand and colleagues[2] show that global emissions of BC and ozone precursors — chemical compounds that react with sunlight to form ozone — cause Arctic warming of currently about 0.5 °C. They project that this warming could be reduced by 0.2 °C by 2050 under an ambitious but possible global mitigation scenario[3], thereby slowing sea-ice retreat and Greenland ice-sheet melt.

SLCPs can be emitted from natural sources such as wild fires, or from anthropogenic activities such as driving or generating electrical power from coal. Each of these sources emits a cocktail of SLCPs that interacts differently with sunlight. Sulphur-rich emissions form sunlight-scattering aerosols that have a cooling effect, or negative radiative forcing. Conversely, BC-rich emissions absorb light, leading to atmospheric warming, or positive radiative forcing. Therefore, understanding the effect of SLCPs on atmospheric temperatures requires identification of the various sources and quantification of their relative

Air pollutants emitted globally can reach the Arctic and significantly change the radiative balance there. View of Spitzbergen, an island on the remote Arctic archipelago of Svalbard, on a hazy day (top), and on a clear day (bottom). Adapted from ref. 11, © 2007 Copernicus.

impact. Producing such a comprehensive assessment for the Arctic was not straightforward. Sand and colleagues[2] considered six different SLCP species across seven emission regions and six emission sectors (domestic activities, energy/industry/waste, transport, agricultural fires, forest fires and gas flaring). This was achieved through the use of five different chemistry transport models and the introduction of the concept of regional climate sensitivities (RCSs) to determine the Arctic surface temperature response per unit of radiative forcing for each substance. These RCSs allow the quantification of contributions that happen within and outside of the Arctic region. For instance, high BC emissions at lower latitudes can warm the local atmosphere, thus creating a larger temperature gradient towards higher latitudes, resulting in increased northward heatflux. Inside the Arctic, warming contributions are more direct — BC pollution just above the ground will trap heat and warm the surrounding air immediately.

The estimated Arctic surface temperature response to all global natural and anthropogenic SLCP emissions in 2010 is –0.44 °C (–1.02 to –0.04 °C), meaning that the Arctic would be 0.44 °C warmer without any SLCP emissions. This reduction in temperature is caused by cooling through sulphate aerosol (–0.85 °C, –0.57 to –1.29 °C) and organic carbon (–0.18 °C, –0.30 to 0.03 °C), which together outweigh the warming from BC of +0.48 °C (0.33 to 0.66 °C) and ozone +0.05 °C (0.04 to 0.05 °C). (Note that the total temperature change of –0.44 °C represents an Arctic equilibrium temperature. Central estimates of individual SLCP contributions do not add up exactly, but reflect the magnitude of their influence.) In terms of regional contributions, roughly two-thirds of the forcing occurs outside the Arctic, and only one-third within. Although local emissions are the smaller contributor, normalization of the response (as °C per emitted teragram per year) shows that the Arctic is most sensitive to them, with flaring emissions from Russia the largest contributor, followed by forest fire and flaring emissions from the Nordic countries. These emissions have a stronger impact than those further away (up to 14 times higher) because they can have a double effect: for example, BC warms the atmosphere while also reducing snow and ice reflectivity. Based on earlier indications of this[4,5], the Arctic states have already committed to ambitious action to reduce their SLCP emissions[6] and these quantitative findings now provide information for concrete priority setting.

Previous work determined the impact on Arctic radiative forcing through only a subset of SLCPs focusing on BC[4]. Sand *et al.* extend this by including more species and explicitly accounting for the cooling impact of SLCPs. With this approach, they identify Asia as the largest emitter of warming and cooling agents affecting the Arctic. From a climate perspective, reducing BC emissions in general, and particularly from domestic heating and cooking, would be sufficient for mitigation. However, from a local-air-quality perspective, reducing all SLCPs emissions, specifically from the energy sector, is crucial, as this would decrease pollution and have added benefits for health and the environment, including in the Arctic[7,8]. However, this would also cut cooling-agent emissions, and decrease climate mitigation results locally and for the Arctic. These associated benefits seemingly in conflict with Arctic climate change mitigation make it apparent that a holistic approach, which includes not only short-lived but also long-lived forcers, needs to be considered. In this way, aggressive CO_2 reductions, such as projected under the low emissions scenario (RCP2.6) in the IPCC AR5[9], combined with BC-related cuts from the mitigation scenario[3] applied by Sand *et al.*, could reduce Arctic warming by 0.7 °C in 2050 compared with 0.2 °C from reduction of SLCPs only.

Health/air quality and climate are not the only considerations for policymaking; economics also need to be examined. A recent publication[10] on the social cost of atmospheric release provides a framework for estimating environmental damage costs simultaneously from CO_2 and other pollutants. For example, in the US, electricity production from coal causes two to four times higher damage costs for health, climate and agriculture than production from gas. This type of information can help to set policy priorities that simultaneously account for local (for example, health) and global benefits (for example, climate). Such an integrated approach makes policy development more complex but also more effective.

The findings of Sand *et al.* show that the Arctic states alone can play a significant role in slowing Arctic warming, but that international co-operation will be necessary to tackle the full magnitude of the problem. It is the large amounts of non-Arctic emissions that are important drivers of Arctic warming, and the involvement of these emitting nations in policy discussions is critical. This was acknowledged by the 2015 Arctic Council Framework for Action[6] as essential for designing an effective action agenda. Platforms such as the International Maritime Organization, the Convention on Long-Range Transboundary Air Pollution, the United Nations Environment Programme or the UN Framework Convention on Climate Change could help facilitate this. ❐

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