How predictable are Arctic sea ice conditions?

THE ISSUE. Improved predictions of Arctic sea ice conditions are important to numerous stakeholders. Understanding opportunities to advance predictive capabilities, as well as inherent limitations, is necessary to develop optimal prediction products across different user communities, regions, and timeframes.

WHY IT MATTERS. With large-scale loss of sea ice, marine access to the Arctic Ocean has increased. Yet, despite ice loss, the Arctic remains a remote and harsh environment with hazardous extreme events. More accurate prediction of sea ice conditions helps to:

1. **Reduce the risk of human and environmental disasters** by those navigating the marine environment, including Indigenous hunters, the shipping industry, search and rescue personnel, and tourism industry.
2. **Minimize financial risks and improve logistics** for operations that move resources and supplies in and out of the Arctic, such as oil, gas, and mining industries as well as northern village supply operations.
3. **Inform long-term planning by decision-makers** working on Arctic infrastructure, national security strategies, and conservation planning.
4. **Improve prediction of weather,** including atmosphere and ocean conditions.

The U.S. Coast Guard cutter Healy escorts Russian ice-strengthened oil tanker Renda. (Credit: U.S. Coast Guard/ Petty Officer 1st Class Sara Francis)

STATE OF KNOWLEDGE. Accurate predictions of environmental conditions can arise from two factors: (1) a knowledge of today's state of the system (initial conditions) that provides the starting point for the system's evolution into the future, and (2) the effects of climate forcing of the system, such as that associated with rising atmospheric greenhouse gas concentrations (Lorenz, 1975). These two factors of predictability are limited by different mechanisms that act on different timescales. Accurate initial conditions provide predictability of Arctic sea ice area on shorter, seasonal to interannual timescales, while rising greenhouse gases result in a predictable loss of sea ice area on longer, decadal scales (Blanchard-Wrigglesworth et al., 2011).

Most predictions use models that start with an estimate of the current state of the system obtained from observations and then solve equations of the physical laws that describe how ocean, atmosphere, land, and sea ice interact to determine their evolution into the future. The forecast accuracy of these models relies on both accurate initial conditions and an accurate depiction of the forces that influence the movement, melting, and growth of sea ice. Because of the chaotic nature of the climate system and the fact that initial conditions cannot be known perfectly, errors in initial forecast conditions grow with time and lead to a loss of forecast accuracy. This provides inherent limits to predictability, which need to be better characterized and understood.

Practical limits on forecast accuracy stem from our restricted ability to observe important sea ice and related environmental conditions. For example, research has shown that the area of September ice is dependent on ice thickness many months prior (Blanchard-Wrigglesworth et al., 2011). Thicker ice withstands melt out during summer and is less mobile. Therefore, an ability to more accurately observe ice thickness in a particular region during winter and spring will improve predictions of the following summer minimum ice cover. Similarly, ocean surface temperatures influence how rapidly sea ice area can grow in the fall and winter months. Because ocean temperatures can be long-lived, knowing them several months in advance may improve predictions of the location of the ice edge (Blanchard-Wrigglesworth et al., 2011).

On longer timescales, sea ice loss is driven by increasing temperatures caused by greenhouse gas emissions from human activity. The response of Arctic-wide ice conditions from emissions can be predicted decades into the future as rising greenhouse gas concentrations increase global temperature and sea ice loss. However, there are limits to predictability on these timescales as well, due to uncertainties in future emissions and the magnitude of the sea ice response to those emissions. Natural environmental variability also limits predictability and can counteract or reinforce greenhouse gas driven changes on decadal scales (Kay et al., 2011, Ding et al., 2017). As a result, at this point there is an irreducible uncertainty in predicting the timing of an Arctic ice-free summer of about two decades (Jahn et al., 2016). Nevertheless, there is a high degree of forecast certainty that business-as-usual industrial activities will result in an Arctic ice-free summer in the second half of the 21st Century.

Where the Science is Headed. Research indicates that sea ice forecasting can be improved. Because of this, the science community is focused on improving sea ice forecasting by improving how we model the physical processes that drive the evolution of sea ice. Field campaigns to better understand ice-ocean-atmosphere interactions at play in the "New Arctic", such as the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC), combined with targeted model development hold promise for enhancing the realism of the modeling tools used for sea ice forecasting.

Improvements are also underway to better estimate the starting environmental state of the system (the forecast's initial conditions). This includes work not only to gather data on a particular variable but also work to better understand the acceptable level of accuracy needed in those data to gain a desired level of improvement in sea ice forecasting. This has important practical implications for measurements, such as the accuracy required of ice thickness measurements derived from the satellite ICESat-2, which was launched by NASA in September 2018.

Finally, the research community is working to better characterize the predictability of sea ice properties that are relevant to stakeholders. In this work, there is considerable value when scientists engage with potential users of predictions to identify information needs. Some stakeholders do not require detailed predictions of ice location but may instead benefit from regional probabilities of the expected dates for when the ocean continuously freezes in fall or melts in spring. Also, many stakeholders are only concerned with the marginal ice zone (along the outer edge of the ice pack where ice concentration is between 0-20%) and the coastal regions where encroaching ice may leave local vessels at danger. A better understanding of stakeholder needs will allow the science community to balance effort placed on improving predictions of pan-arctic sea ice extent versus other sea ice properties that may be more relevant at regional scales.

Key References

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