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INVITED MANUSCRIPT

Editorial: Special collection – "Impact of polar observations on predictive skill"

The polar regions, which host some of the world's most rapidly changing environments, have attracted considerable attention in recent years. The long-term decline of Arctic sea ice and the recent record low of Antarctic sea ice extent, the melting of continental snow, the retreat of glaciers, and the rapidly warming low-level troposphere all point to the fact that these regions literally stand as outposts of global climate change. These rapid changes in polar regions have potential global implications. The decrease in high-latitude surface albedo caused by the vanishing Arctic sea ice has a distinct signature on the Earth's radiative balance (Pistone *et al.*, 2014). The acceleration in global sea-level rise over the recent decades has been attributed with high confidence to increasing rates of ice loss from the Greenland and Antarctic ice sheets (IPCC, 2019). Finally, Arctic Amplification, one of the dominant traits of high-latitude climate change for decades, is thought to compete with tropical forcings in shaping the future of midlatitude climate, resulting in an uncertain "tug-of-war"[1] for the decades to come.

The impact of polar regions on weather and climate variability is therefore a topic of great concern and interest. In this context, the study of the impact of polar observations on predictive skill has taken on a new urgency in recent years. Polar regions stand out compared to other regions when it comes to observational coverage. These regions are indeed poorly sampled in terms of *in situ* and conventional observations, as the cost (human and economic) of retrieving data is prohibitive compared to lower-latitude regions. At the same time, polar regions are well-sampled in terms of satellite data due to the shorter return time of low-orbit satellites compared to other regions. It has been unclear to what extent each type of data can be beneficial for environmental predictions from hours to years. In recognition of the importance of this issue, the Year of Polar Prediction (2013–2022) of the World Meteorological Organization (WMO) and the EU H2020 project APPLICATE have launched a co-ordinated international effort to assess the state-of-the-art in this field. We are pleased to see some of the key results of this effort being presented in this special collection.

[1] https://www.nature.com/articles/s41467-019-13714-0

Results from a synthesis paper by Sandu *et al.* (2021) suggest that numerical weather prediction (NWP) systems have reached a level of maturity so that they can be used to formally assess the suitability of current observing systems and their impact on predictions. The study shows that *in situ* observations play a critical role in initializing numerical weather forecasts during the winter season, while satellite microwave sounders are crucial during the summer season. The differences between the seasons in terms of the impact of Arctic observations on predictive skill are most likely due to the difficulty in assimilating microwave sounding observations over snow and sea ice in the winter season, leading to a limited impact. It is argued that observations are also beneficial beyond weather time-scales. Satellite sea-ice thickness observations are shown to be key to improving seasonal predictions of summer Arctic sea-ice concentration. Moreover, the study reviews evidence that numerical models can be utilized to determine the optimal observational coverage for the reconstruction of large-scale quantities such as sea ice volume. With only a few (~10) well-chosen monitoring sites, much of the variability of this quantity can be reconstructed from individual sea-ice thickness measurements.

Lawrence *et al.* (2019) performed a comprehensive assessment of the usage of Arctic atmospheric observations in the European Centre for Medium-Range Weather Forecasts (ECMWF) NWP system. The study, which played an important role in the synthesis of Sandu *et al.* (2021), found that all Arctic observations had a positive impact on forecast skill, with the greatest impact due to microwave, conventional, and infrared sounding observations. Microwave sounding data and conventional data were found to be the key observing systems in the summer and winter seasons, respectively. The study also indicated that observations have positive and statistically significant impacts on forecasts in both the Arctic and midlatitude regions at longer lead times. These results highlight the great importance of polar observations in advancing weather prediction – both in the polar regions and beyond.

The idea of possible remote effects of Arctic observations was further explored in the study by Day *et al.* (2019), highlighting the significant impact of Arctic observations on medium-range weather forecasts in the midlatitudes. The results of the study demonstrate that withdrawing either *in situ* or satellite observations in the Arctic from the data assimilation system used to create the initial conditions for the global forecasts deteriorates the synoptic forecast skill in the midlatitudes, particularly over northern Asia. This degradation is largest during Scandinavian Blocking episodes when error growth is enhanced in the European Arctic and high-amplitude planetary waves allow errors to propagate from the Arctic into midlatitudes. The results of this study, which confirm earlier ones (Jung *et al.*, 2014), highlight the important role played by Scandinavian Blocking in modulating the influence of the Arctic on midlatitudes and provide further evidence for the need to maintain and enhance the current Arctic observing system.

Finally, in the study by Randriamampianina *et al.* (2021), the impact of Arctic conventional and satellite observations on regional short-range weather forecasts was assessed using observing-system experiments. The experiments were conducted with the AROME-Arctic regional mesoscale NWP system, using global observing-system experiments performed at the ECMWF and described by Lawrence *et al.* (2019) as lateral boundary conditions. One of the key findings of the study – which can be considered the "cleanest" of its kind – is that the total impact on the upper-air forecasts was dominated by the impact of observations through their assimilation in the lateral boundary conditions, while the impact on surface fields was dominated by regional data assimilation.

In conclusion, the special collection "Impact of polar observations on predictive skill", which constitutes a major contribution to the Year of Polar Prediction, provides a timely and important contribution to the field. The special collection underlines the need to not only sustain existing infrastructures and observing systems, but also to optimize future networks, as high-latitude observations provide key constraints for environmental predictions from hours to years. The special collection is clearly biased toward the Arctic. The Year of Polar Prediction – Southern Hemisphere (YOPP-SH: Bromwich *et al.*, 2020) has co-ordinated several "Targeted Observing Periods" during which observation uptake was intensified by increasing the number of radiosonde launches in various Antarctic stations. An improvement in the forecast of deep cyclones was demonstrated. The assimilation of more *in situ* data could be key to anticipating other high-impact events such as the remarkable atmospheric river that penetrated the Antarctic interior in March 2022, elevating surface temperatures by about 30 °C above climatology at the Vostok station. We are convinced that this collection will inspire further research and discussions on the role of polar observations in ongoing efforts to improve predictive skill.

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