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Editorial
Editorial for the Quarterly Journal's special issue on Polar Prediction

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This edition of the Quarterly Journal includes a Special Section on Polar Prediction. The collection of articles in this Section provides an assessment of the current state of the art of weather prediction of the polar regions, and provides guidance for future research priorities needed to advance our predictive capabilities.

On 24–27 June 2013, a workshop was held at the European Centre for Medium-Range Weather Forecasts in Reading, UK, that was co-sponsored by the World Meteorological Organization's (WMO) World Weather Research Programme (WWRP). The event was organized to stimulate research dedicated to environmental prediction in polar areas on daily to seasonal time-scales in collaboration with the Polar Prediction Project (PPP). PPP was initiated in 2012 by WWRP as one of three follow-on projects to THe Observing system Research and Predictability Experiment (THORPEX).

The workshop comprised two days of presentations on the specific challenges of modelling, data assimilation, ensemble prediction, observation and verification in polar areas. A selection of articles resulting from these talks is collected in this Special Section of the Quarterly Journal; these articles provide new insights into an area which has attracted relatively little attention in the past: polar prediction. At the workshop, working groups were tasked to identify the most promising avenues for advancing predictive capacity in polar regions and beyond. The articles in this collection are referenced where appropriate in the following workshop summary.

It was highlighted that there are a number of mechanisms driving teleconnections between polar and lower-latitude areas that depend on sea ice/ocean state, troposphere–stratosphere interaction, the poleward advection of heat, momentum and moisture by synoptic weather patterns, and the connectivity between large-scale regimes (e.g. the Arctic Oscillation) and low latitudes (Smith *et al*., 2016a; Guemas *et al*., 2016). The workshop concluded that the teleconnection topic poses the need for a dedicated research theme under PPP in collaboration with the Polar Climate Predictability Initiative (PCPI) activity as part of the World Climate Research Programme (WCRP). Also the representation of sub grid-scale and coupled processes in numerical models presents similar challenges for the community.

Evaluation of predictive skill in polar areas shows comparable performance to lower latitudes, especially in the free atmosphere (Jung and Matsueda, 2016; Bauer *et al*., 2016). However, forecast verification against analyses in the short-to-medium range raises doubts because data usage is poorer over sea ice and snow-covered surfaces; station networks are sparse; and data assimilation methods are not tuned to high-latitude conditions (Bauer *et al*., 2016).

Regarding physical processes, the correct interplay between boundary-layer, cloud and surface processes was highlighted as being crucial for the accurate description of vertical mass and momentum transport, surface radiative and energy budget, and the interaction between the shallow polar lower troposphere and large-scale advection in NWP models. In Greenland and in Antarctica extreme flow regimes near steep orography are also difficult to represent in global models (Elvidge *et al*., 2016), with implications for simulating and predicting the large-scale flow.

To date, the main challenges in modelling are: the representation of stable boundary layers and their interaction with stratiform clouds and snow-covered surfaces; the role of moisture advection and turbulence in cloud formation given very low cloud condensation nuclei concentrations; the speed of hydrometeor phase transitions in mixed-phase clouds; and the role of rather heterogeneous sea-ice states through the seasons as the lower boundary mediating the fluxes at the interface. Snow is currently only crudely represented in global NWP models but the workshop suggested that integrating multi-layer snow models can already produce a significant step towards improved atmosphere–surface coupling, particularly through melting and freezing conditions, as well as in the presence of vegetation, trees and snow on top of sea ice.

The participants strongly suggested studying these processes in collaboration with existing groups like the WCRP's GEWEX Atmospheric System Studies (GASS) project to enable improvement of physical parametrizations that perform at all latitudes. It was recommended to revisit the wealth of information from existing key field campaigns such as Surface HEat Budget over the Arctic ocean (SHEBA), and also to define observational requirements for planned activities like Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) during the Year of Polar Prediction (YOPP). YOPP is a major activity of PPP in 2017–2019. Further, reanalyses play an important role for evaluating the role of moisture transport, cloud formation and surface–atmosphere interaction over long time periods, also including past field campaigns and the International Polar Year (IPY). Existing reanalyses can prove essential for assessing current model and data assimilation performance with a polar focus without demanding significant additional resources (Bromwich *et al*., 2016).

The investment in the coupled modelling of sea ice, ocean (waves) and the atmosphere, from short to extended-range applications, stands out as a high-priority objective. For sea ice, types, concentration and particularly thickness need to be included and the interaction with ocean currents and waves, snow and the lower atmosphere are critical for the accurate description of ice evolution (Hunke, 2016). This will need much enhanced observational sea-ice capabilities over large areas. Again, campaigns like MOSAiC are expected to be of fundamental importance here.

For ensemble prediction, ensemble design and model error formulations have been designed and tuned with lower latitudes in mind and require adjusting to the variability patterns and the dominating physical processes in polar conditions (Hawkins *et al.*, 2016). Since these error formulations drive both the weight given to observations in the analysis and the spread of ensemble analyses and forecasts, better error characterisation promises substantial progress in initial condition uncertainty and forecast reliability estimates.

The more detailed representation of both snow and sea ice in forecast models also requires initialisation through data assimilation. There is much less experience with this at global scales and with relevance to medium and extended range prediction than in atmospheric data assimilation and compared to regional scales for which operational systems already exist (Smith *et al.*, 2016b; Lemieux *et al.*, 2016). The lack of consistent observational networks and the difficulty in characterizing sea-ice model errors presents a significant challenge for coupled data assimilation. It was also shown that atmospheric data assimilation is sub-optimal in polar regions because observation operators simulating satellite observations are inaccurate over snow and sea ice, and in the presence of very dry conditions and mixed-phase clouds. This leads to the rejection of large data volumes. Consequently, observations from passive and active microwave instruments and infrared spectrometers, and analysis techniques that promise better sensing of the shallow lower polar troposphere, are important (Buehner *et al.*, 2016). Also here, much can be gained from assessing reanalyses and observational campaigns targeting the poles such as Concordiasi (Boullot *et al.*, 2016).

Observations provided by advanced satellite instruments such as Cloudsat/Calipso, SMOS, CryoSat promise new process detail, particularly in support of cloud and surface process studies. The sparseness of routine observing stations in polar areas is evident and their coverage is not representative of the conditions over large parts of the ice-covered Arctic Ocean or the Antarctic continent as they are mostly located near coastlines and near steep orography. Observations of opportunity on board the increasing shipping fleet along ice-free passages, and aircraft supplying permanent stations should be exploited operationally. In support of the emerging coupled models, detailed sea-ice observations throughout the seasons are crucial for model initialisation. Given the specific role of observations in polar regions, PPP also has an important role for defining observational requirements to be communicated to space agencies for future mission design but also in support of ground-based network planning.

Since the conclusion of the ECMWF-WWRP workshop, PPP has gained significant momentum and its supporting science community is preparing for dedicated numerical experimentation, prototype coupled reanalyses and observational campaign support for YOPP. The link with WCRP's PCPI has been established through a common coordination office (http://polarprediction.net). This has been manifest in the collaboration between underpinning research and operational forecasting, and between weather and climate prediction.

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