CHAPTER 19. THE WWRP POLAR PREDICTION PROJECT (PPP)

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Abstract

Mission statement
"Promote cooperative international research enabling development of improved weather and environmental prediction services for the polar regions, on time scales from hours to seasonal".
Increased economic, transportation and research activities in polar regions are leading to more demands for sustained and improved availability of predictive weather and climate information to support decision-making. However, partly as a result of a strong emphasis of previous international efforts on lower and middle latitudes, many gaps in weather, sub-seasonal and seasonal forecasting in polar regions hamper reliable decision making in the Arctic, Antarctic and possibly the middle latitudes as well.

In order to advance polar prediction capabilities, the WWRP Polar Prediction Project (PPP) has been established as one of three THORPEX (THe Observing System Research and Predictability EXperiment) legacy activities. The aim of PPP, a ten year endeavour (2013-2022), is to promote cooperative international research enabling development of improved weather and environmental prediction services for the polar regions, on hourly to seasonal time scales. In order to achieve its goals, PPP will enhance international and interdisciplinary collaboration through the development of strong linkages with related initiatives; strengthen linkages between academia, research institutions and operational forecasting centres; promote interactions and communication between research and stakeholders; and foster education and outreach.

Flagship research activities of PPP include sea ice prediction, polar-lower latitude linkages and the Year of Polar Prediction (YOPP) - an intensive observational, coupled modelling, service-oriented research and educational effort in the period mid-2017 to mid-2019.

19.1 INTRODUCTION

Interest in the polar regions has been increasing considerably in recent years, largely because of concerns about Arctic. There has also been an increasing economic interest (e.g. shipping and tourism) in the polar regions, especially in the Arctic. Record low Arctic summer sea ice in recent years for example, has opened new shipping routes, which have shortened routes between Europe and East Asia substantially (Schøyen and Bråthen, 2011). The ongoing and projected changes in polar regions and increases in economic activities also lead to concerns for indigenous societies and northern communities (e.g. increased exposure to risks associated with industry). Finally, through scientific research and monitoring of polar regions, we are just beginning to appreciate the connectivity between polar atmospheric, oceanic, and cryospheric processes and those in lower latitude regions. While this connectivity has always existed, its ramifications are only now being understood.

The context of development pressure coupled with significant socio-cultural, technological and environmental changes translates into great potentially for demand of weather and environmental prediction and related services - essentially 'more' of the polar regions are becoming exposed to environmental hazards, and that which is exposed may become more sensitive. This is also true for research activities in polar regions whose success crucially depends on availability of efficient logistics which in turn depend on reliable predictions. In summary, there is growing need for sustained and improved availability of environmental predictions across a wide range of time scales to support decision-making.

Partly as a result of a strong emphasis of previous international efforts on lower and middle latitudes, many gaps in weather and environmental forecasting in polar regions hamper reliable decision-making. There are certainly gaps, for example: in data availability, our understanding of how good current environmental polar predictions actually are, and where the limits of predictability lie for features such as high-impact polar weather phenomena, blowing snow, and ice coverage in the Northwest Passage. Furthermore, important parts of every forecasting system, such as the numerical model, the data assimilation system, and the methods to generate ensemble predictions are yet to be thoroughly evaluated and customized for the polar regions. It will be crucial, for example, to consider coupled atmosphere-sea ice-ocean-hydrology models in relatively short 'weather-timescale' prediction systems, which have traditionally been carried out using atmospheric models only.

19.2 RESEARCH GOALS AND KEY ACTIVITIES

In the following an overview of the main research goals of PPP (Figure 1) will be given and plans for a Year of Polar Prediction (YOPP) will be outlined.

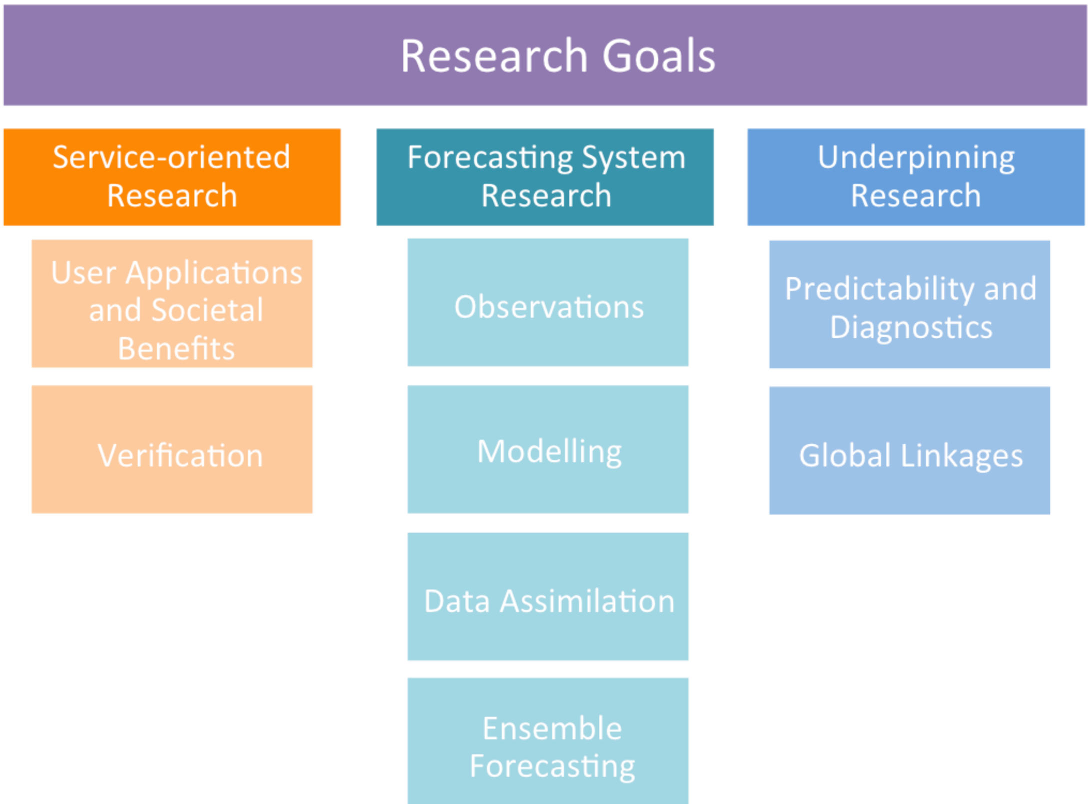

Figure 1. Grouping of research goals in the WWRP Polar Prediction Project

19.2.1 User applications and societal benefit

Background

Societal and Economic Research and Applications (SERA) is synonymous for research conducted into user applications and societal benefit. SERA draws from a variety of social science disciplines, including economics, sociology, psychology, anthropology, political science, human geography, and communication studies, and is chiefly concerned with explaining human behaviour. Applied to the polar prediction theme, this involves exploring how individuals, groups and organizations seek, obtain, perceive, share, comprehend and use weather and related risk information in making decisions. In particular, SERA aims to understand how changes in the attributes of the information and knowledge (for example accuracy, precision, or the manner in which it is communicated) and the characteristics and situational context of the user (who might be a weather forecaster, resident of an Inuit community, or mineral exploration engineer) affect decision-making processes, associated behaviours, and particular outcomes of interest (safety, health, prosperity, etc.).

The methodological domain of SERA encompasses both qualitative and quantitative approaches. Ethnographic field research, whereby the subject participants are observed in their natural settings or through direct interaction with researchers, is an example of the former (e.g. examination of social constructions of a severe weather event in northern Canada; Spinney and Pennesi 2012). A statistical analysis of questionnaire survey data is representative of the latter (e.g. tourist perceptions of weather in Scandinavia, Denstadli et al. 2011).

Blending results from studies adopting qualitative and quantitative approaches will be necessary but difficult for this project (given respective roots in interpretive/critical and positivistic perspectives). The extent to which even quantitative study findings can be aggregated and generalized across polar regions is questionable and a targeted series of independent case studies, demonstrations or applications may be a more achievable objective. Given the sparse population of the Arctic and limited activity in the Antarctic, the availability of large secondary social and economic data sets directly relevant to the use of polar weather forecast information is likely very limited. It will be necessary to invest in original research and data collection, though it may be possible to borrow from recent studies and projects that have examined adjustments to current and potential climate change impacts.

Development of a SERA research framework, including the establishment of linkages with verification and other natural science components of the Polar Prediction Project, will be essential to rising to the challenges noted above. Such a framework must explicitly treat the teleconnections between improvements in the prediction of hydrometeorological processes and phenomena in polar and extra-polar regions, as this may be the greatest source of economic benefit. It must also acknowledge and account for the important role of indigenous and local knowledge concerning weather-related risks and the interactions of such wisdom with scientific sources of information.

Key challenges

- Estimation and analysis of historic and current use and interpretation of polar prediction products
- Communication of risk, opportunity and uncertainty across user types
- Investigation of perceptions and adapted measures of communities in response to polar prediction products
- Methods to evaluate and integrate ‘dislocated’ and within-region costs and benefits

Selected activities

- Carry out literature review, inventory and evaluation of current (historic) weather-related hazards/impacts, prediction services, information requirements, and user experiences in applying information in decision making
- Organize social and interdisciplinary science workshops (Weather and Polar Society) to elaborate on pressing research and application gaps, issues, and needs and begin formulating a formal research framework
- Publish societal benefit assessment, experiences and best practices, and development of a capacity-building initiative targeted to National Meteorological and Hydrological Services (NMHSs) and groups of users

These activities will be further developed by a newly-formed PPP-SERA sub-committee composed of social and interdisciplinary scientists (PPP-SERA 2015), working in close coordination with the PPP Steering Group WWRP-SERA working group and the Executive Council Panel of Experts on Polar Observations, Research and Services (EC-PORS).

19.2.2 Verification

Background

Verification is a process to provide users with information about forecast quality to guide their decision-making procedure, as well as providing useful feedback to the forecasting community to improve their own forecasting tools. Forecasts are typically compared against actual, measured or observed values (or phenomena), and various scores and measures are then used to assess the `goodness` of forecasts. Results are often compared against a `standard`, which represents a minimal level of forecast skill (e.g. climatology or persistence).

Traditionally, forecast verification has focused on weather variables that are of little direct value for most users of weather information, such as the 500 hPa geopotential height. The diversity of verification measures has been relatively limited with a strong emphasis on basic statistical measures like root-mean-square error and correlation metrics. Standard verification has moreover mostly concentrated on mid-latitude and tropical regions. Relatively little is, therefore, known about the skill of current operational forecasting systems in the polar regions (e.g. Jung et al. 2007). Some of the biggest challenges in forecast verification relate to the quality and quantity of observations. In fact, representative observational data are the cornerstone behind all successful verification activities. Given the notorious sparseness or even complete lack of conventional observations in the polar regions, progress in quantifying and monitoring the skill of weather and environmental forecasts will hinge on the availability of additional observations.

Forecast verification against analyses, which are influenced by the model itself during the data assimilation process, is still a common - but questionable - practice. This will be especially harmful in parts of the world, including the polar regions, where the sparseness of high-quality observations leads to a very strong influence of the model’s first guess on the analysis. New methods need to be devised, such as verification in observation space (e.g. satellite data simulators), to reduce issues associated with verification against analysis.

In recent years, there has been a shift in how verification is perceived. It has been widely recognized that verification activities should focus more strongly on user relevant forecast aspects, that more advanced diagnostic verification techniques are required, and that the usefulness of verification depends on the availability of sufficient high quality observational data. These developments need to be strengthened and put forward in the coming years to advance the field of polar forecast verification.

Key challenges

- Raising awareness of the need for comprehensive forecast verification in the polar regions
- Establishment of optimal observational networks and access to reference data sets for verification purposes
- Verification of high-impact weather and climate events in polar regions

Selected activities

- Review existing state-of-the-art verification methods to see how applicable they are to polar regions
- Define an observation strategy to meet forecast verification requirements, particularly for YOPP
- Define verification metrics for use as key polar-relevant performance measures to monitor progress during the 10 year period of the project
- Verify existing forecasting systems in the polar regions for reference information
- Develop forecast verification in observation space using, for example, satellite data simulators
- Devise methods that can be used to verify user-relevant key weather and climate phenomena in polar regions (e.g. visibility, sea ice deformation, polar lows)

It is anticipated that these activities will be carried out primarily by, and in close coordination with, the Joint Working Group on Forecast Verification Research (JWGFVR).

19.2.3 Observations

Background

The polar regions are among the most sparsely observed parts of the globe by conventional observing systems such as surface meteorological stations, radiosonde stations, and aircraft reports. Figure 2 illustrates the situation: contrast the dense network of surface stations (SYNOPs/purple dots) over Scandinavia with the sparse network over the rest of the Arctic; or compare the coarse but arguably adequate network of radiosonde stations (TEMPs/yellow dots) over Eurasia with the handful of stations over Antarctica. The polar oceans are also sparsely observed by the Argo array of automated profiling floats, implying problems for coupled atmosphere-sea ice-ocean forecasting.

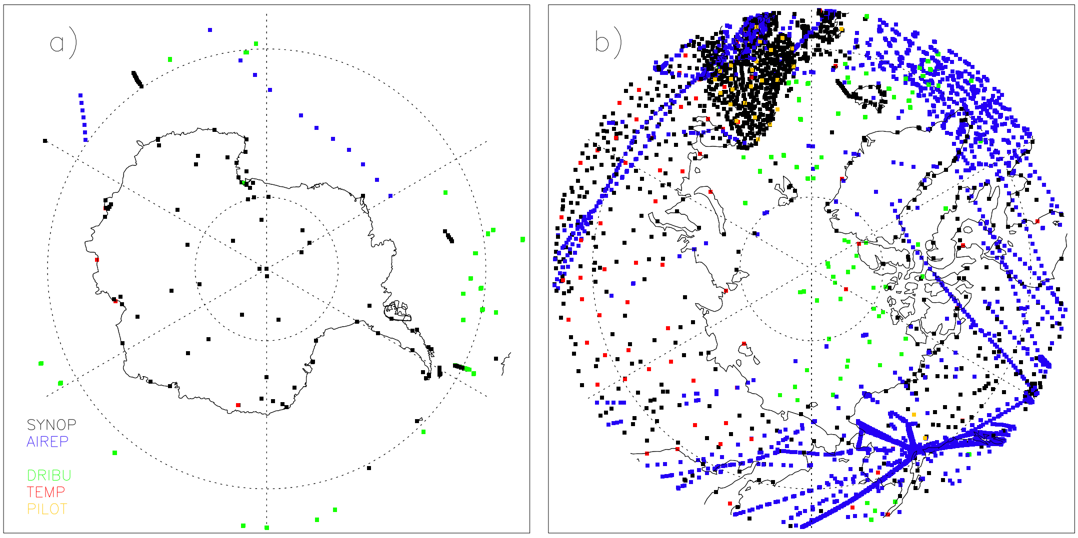

Figure 2. Polar data coverage of conventional observations in the ECMWF operational analysis at 00 UTC on 1 January 2012 (21-09 UTC window) for (a) southern polar region, and (b) northern polar region. SYNOPs are surface reports from land stations; AIREP are in-flight reports from aircraft; DRIBU are surface drifting buoys; TEMP are upper air balloon soundings; PILOT are upper air winds from tracked balloons.

The polar regions are barely sampled by geostationary satellites, but generally have a denser sampling by polar-orbiting satellites, providing the potential for improvements in satellite sounding (e.g. the Infrared Atmospheric Sounding Interferometer (IASI) sounder), or sea ice thickness (e.g. from Cryosat). Using satellite-based observations of the polar surface is challenging partly due to the ever-changing and highly heterogeneous sea-ice, which prohibits observations of ocean surface temperature and salinity, colour, altimetry/wave height, surface winds, precipitation, etc. Differentiating between snow and ice-covered surfaces and clouds in the atmosphere has also been a long-running challenge. Making better use of existing and new satellite-based observations is a must for improving forecast initialisation and verification.

The relative remoteness and harsh environmental conditions of the polar regions is always going to provide a barrier to enhanced observations. With improved technology and power systems the barrier is becoming more limited financially than logistically: improved observations of the polar regions are possible but are they worth the cost? To answer this, Observing System Experiments (OSEs) are required with a particular focus on user-requirements for these regions. To carry out these kind of experiments a sustained observing period is required - a Year of Polar Prediction (YOPP, see below). In addition, periods of intense process-focussed field campaigns are required to provide comprehensive observations of processes that are poorly represented in current forecasting systems.

Key challenges

- Lack of observations due to remoteness, harshness and cost of operating in the polar regions
- A need for optimization of the observing system and international collaboration
- Constraining small-scale processes characteristic for the polar regions (e.g. shallow boundary layers, leads and river run-off)
- Supplying pertinent observations for data assimilation for regional model forecasts to constrain initial conditions
- A need for continual availability of adequate observations in near-real-time

Selected activities

- Devise new and cost effective means for taking observations in the polar regions (e.g. voluntary observing ships)
- Use techniques such as adjoint sensitivity to quantify the importance of different components of the polar observing system to analysis and forecast quality
- Perform data denial and Observing System Simulation Experiments (OSSEs) to understand the potential benefit of enhanced observation capabilities, and to optimise the overall observing system

19.2.4 Modelling

Background

Numerical models of the atmosphere, ocean, sea ice, land and rivers play an increasingly important role in prediction. For example, models are used to carry out short to seasonal range weather and environmental forecasts; they form an important element in every data assimilation scheme (state estimation); they are used as a numerical laboratory to carry out experiments devised to understand the functioning of the climate system; and they can aid design of future observing systems (e.g. satellite missions) through so-called Observing System Simulation Experiments (OSSEs).
Although numerical models have come a long way, even state-of-the-art systems show substantial shortcomings in the representation of certain key processes. For example, skilful model simulations of stable planetary boundary layers and tenuous polar clouds remain elusive (e.g. Bromwich et al. 2013). The shallowness of stable planetary boundary layers in the polar regions, the smaller spatial scale of rotational systems (e.g. polar cyclones) due to the relatively small Rossby radius of deformation along with the presence of steep topographic features in Greenland and Antarctica. All these points raised above suggest that polar predictions will benefit from increased horizontal and vertical resolution. However, while some of the existing problems may be overcome by increased resolution accessible via the projected availability of supercomputing resources during the coming 10 year period, it is certain that the parameterizations of polar subgrid-scale processes will remain an important area of research for the foreseeable future.

Most existing short-range and medium-range global prediction systems are coupled atmosphere-land surface models. The ocean, sea ice and snow as well as parts of the hydrological cycle (e.g. rivers) are still treated rather simplistically. Although it is well established that sub-seasonal and seasonal predictions require the use of models of the fully coupled system, it is increasingly recognized that the same is true for shorter ‘weather’ forecasts. The expected increase in shipping traffic in the Arctic will require new kinds of forecast products, such as those for sea ice pressure, which require the use of dynamic-thermodynamic sea ice models. Furthermore, the common practice of persisting sea ice during the course of short-term forecasts can lead to substantial errors in near-surface temperature predictions, especially at times when sea ice is changing rapidly.

The increasing importance of sea ice-ocean models for polar predictions will require critical review of the strength and weaknesses of existing models (e.g. Guemas et al. 2014). Most sea ice models, for example, still employ rheologies that were developed in the late 1970s. While these rheologies have been successfully applied in coarse resolution models, for which they have been developed, future increases in resolution raise the question whether the underlying assumptions for the existing formalisms remain valid. Furthermore, until now, interactions between the sea-ice model and the atmosphere and ocean models have been relatively simple in many forecasting systems, with even more simplified interaction when models are used within data assimilation systems in terms of albedo and turbulent heat and momentum exchange at the surface. These interactions also require critical review.

The strong emphasis of the Polar Prediction Project on the improvement of models in polar regions should help to alleviate some of the existing longstanding model biases. The anticipated model improvements will help improve the skill of predictions across a range of time scales in the polar regions and beyond.

Key challenges

- Improvement of the representation of polar key processes in atmosphere, ocean, sea ice, land surface and river-systems through enhanced model formulation and increased horizontal and vertical resolution
- Development of coupled model systems for short-, medium- and extended-range predictions

Selected activities

- Assess accuracy of polar processes and feedbacks simulated by currently used models (“gap analysis”)
- Improve representation of atmospheric processes of particular relevance for polar regions - e.g. stable boundary layers, aerosol and cloud microphysical properties
- Improve parameterizations for river flow, lakes, permafrost and other relevant high-latitude terrestrial processes
- Assess alternate sea-ice rheologies to account for future increases in horizontal resolution and improved sea ice parameterizations and interactions
- Use process models (e.g. “large eddy simulations”) to guide developments for global and regional models
- Explore grey zone issues for the Arctic and Antarctic - i.e. the validity of parameterizations when the horizontal resolution of models is increasing and the possible use of scale-aware parameterizations
- Develop stochastic parameterization schemes for polar regions and processes to account for model uncertainty and up-scale effects from subgrid-scale processes

19.2.5 Data assimilation

Background

Data assimilation systems are used to derive the best possible estimate of the state of a geophysical system valid at a certain time and over a defined area. This is called the analysis. In numerical weather prediction, these systems are based on the numerical model that is also used for forecasting and observations, with an optimization algorithm that combines the model and the observations such that a physically realistic estimate is derived that matches the model prediction and observations within their respective error margins. The analysis also serves for initializing the forecast model. The quality of the analysis is of fundamental importance for forecast skill since weather forecasting is, to a large extent, an initial value problem. Generally, the sensitivity of forecasts to the analysis changes between short, medium and extended range from smaller-scale and fast processes (e.g. turbulence, clouds, convection) to larger-scale and slow processes (e.g. planetary waves, ocean and sea-ice dynamics).

Modern global weather forecasting employs data assimilation systems that use time integrations of the three-dimensional model at 15-25 km resolution and 50-100 vertical levels ($O(10^9)$ grid cells) together with $O(10^7)$ observations resulting in very large numerical optimization problems. Ensemble analysis systems aim at additionally specifying the uncertainty of the analysis that is required for deriving the above mentioned model error margins but also serve as initializations for ensemble forecasts.

Over polar areas, shortcomings in all three main data assimilation components, namely model, observations and assimilation algorithm, contribute to sub-optimal state estimates with detrimental impact on forecast skill from the short to extended range. During atmospheric conditions in which boundary layer processes and atmosphere-surface interaction - particularly with variable sea-ice coverage - are dominant, small scale cyclonic systems (polar lows) and the interaction of the flow with extreme orography are currently not well resolved in global models, and even less well resolved in data assimilation systems. Observations are sparse and mostly lacking over sea-ice and the Antarctic continent. Satellite data are more difficult to interpret due to, for example, little optical contrast between the surface and atmosphere. The specification of model and observation uncertainty, required to balance the contributions from observations and the model in the analysis, becomes a key issue.

The Polar Prediction Project aims at addressing models, observations and data assimilation methods, emphasizing polar-specific aspects, such as the crucial model processes, atmosphere-surface interaction and spatial resolution, enhanced surface-based observational networks and satellite data exploitation, assimilation methods more optimally tuned to high-latitude conditions and coupled atmosphere-ocean-sea ice data assimilation at regional and global scale.

Key challenges

- Representation of model uncertainty
- Data assimilation with coupled atmosphere-ocean-sea ice-land models
- Data assimilation in the vicinity of steep orography (e.g. Greenland and Antarctica)

Selected activities

- Evaluate existing analysis and reanalysis data sets from a consolidated Polar Prediction Project point of view
- Develop automated retrieval/data assimilation algorithms for sea ice observations from satellite - e.g. ice concentration and thickness from Synthetic Aperture Radar and Cryosat data, respectively
- Develop flow-dependent error covariance matrices for the polar regions (e.g. error covariance matrices appropriate to typically shallow boundary layers and sharp sea ice boundaries)
- Develop coupled data assimilation systems for the polar atmosphere-ocean-sea ice-land system

19.2.6 Ensemble forecasting

Background

Ensemble forecasting is an approach to reliably quantify uncertainty of weather or climate forecasts. An ensemble prediction system (EPS) is designed to account for the fact that inevitable errors in the initial conditions and inaccurate model formulations affect forecast skill differently from day to day (flow-dependent error growth). The EPS is implemented by running multiple forecasts in parallel - so-called ensemble members - using slightly different initial conditions that are all plausible given the past and current set of observations. Some EPSs also represent model uncertainty by running different ensemble members with slightly different model formulations. For a well-designed EPS, a relatively low ensemble spread (i.e. different members give similar results irrespective of the existing uncertainties) implies a high level of confidence in the forecast; in contrast, a high ensemble spread implies that the forecasts are uncertain.

Existing operational EPSs have been primarily designed with processes in the tropics, sub-tropics and mid-latitudes in mind. For example, atmospheric singular vectors, which are use to generate initial perturbations, tend to target baroclinic instability in mid-latitudes, whereas stochastic convection schemes are most effective in the tropics in representing model uncertainty. In contrast, ensemble forecasting in the polar regions has attracted relatively little direct attention, a situation the Polar Prediction Project aims to address.

Because of a previous focus on non-polar regions, relatively little is known about the quality of ensemble forecasts, including the associated probability forecasts in polar regions. In fact, a lot of progress in the provision of environmental information can be made by raising awareness of the importance of polar ensemble forecasting and by applying existing ensemble verification techniques to the polar regions.

The main challenge when designing EPSs lies in the proper representation of initial conditions and their errors and model inaccuracy to obtain reliable estimates of prediction uncertainty and probability forecasts. Most operational EPSs employ optimal perturbations to represent initial condition uncertainty. In the atmospheric mid-latitudes, baroclinic instability dominates the early stage of forecast error growth; in the tropical atmosphere, on the other hand, convective instability plays the dominant role. Although it can be anticipated that baroclinic instability has some role to play in the polar regions, research needs to be carried out to identify other more polar-specific sources of perturbation growth - for the atmosphere, as well as for other components of the polar climate system such as the ocean and the sea ice.

Given the limitations of state-of-the-art models to represent some of the key processes in the polar regions, it will be imperative to properly represent model inaccuracy in operational ensemble forecasts from hours to seasonal time scales. Different approaches have been suggested including multi-models and stochastic parameterizations. Given that most of the existing schemes were built for the tropical, subtropical and mid-latitude atmosphere, it will certainly be important to carry out a separate assessment of the various stochastic techniques for the polar regions and different time scales. Furthermore, given that routine weather forecasts are likely to be carried out with coupled models by the end of this decade, as they are already used for sub-seasonal and seasonal forecasting, the representation of model uncertainty in sea ice, ocean, land surface, and land-based hydrology will also need to be addressed in the Polar Prediction Project.

In summary, there are two ways in which the Polar Prediction Project can contribute to the improvement of operational ensemble forecasting. Firstly, substantial progress can be made by applying well-established NWP methodology (e.g. standard verification scores) in a polar context. Secondly, improving ensemble forecasting systems by taking polar-specific aspects such as sea ice into account provides scope for further improvements in probabilistic forecasts in the polar regions and beyond.

Key challenges

- Identification of forecast relevant instabilities in the polar regions, especially those leading to high-impact events
- Improvement of initial perturbation techniques to realistically represent initial condition uncertainty in polar regions
- Development of techniques to represent model uncertainty in polar regions
- Development of ensemble techniques for sea ice, ocean, land and hydrology models and fully coupled systems
- Verification of probabilistic forecasts in polar regions using observations

Selected activities

- Assess performance of existing global and limited area EPSs in the polar regions
- Exploit existing and future special ensemble forecast data sets - e.g. TIGGE, CHFP (Climate System Historical Forecast Project), WMO Lead Centre for Long-Range Forecast Multimodel Ensemble and the Sub-seasonal to Seasonal data base - and provide feedback to operational institutions
- Improve techniques to represent initial condition and model uncertainty in coupled ensemble prediction system
- Assess the benefits of using stochastic parameterizations versus multi-model methods
- Explore the growth of uncertainty and its flow-dependence

19.2.7 Predictability and forecast error diagnosis

Background

Predictability research is primarily concerned with the mechanisms that potentially influence forecast skill at different time scales. The predictability of a system is determined by its instabilities and nonlinearities, and by the structure of the imperfections (analysis and model error). In forecast error diagnosis, possible weaknesses of different components of forecasting systems can be unravelled through detailed and systematic diagnosis of actual forecast failures and through carefully designed numerical experimentation.

The unique feature of the polar regions is the presence of vast areas of snow and ice. Due to its relative persistence or stability, sea ice anomalies are usually considered a potential source of predictability, especially on sub-seasonal and seasonal time scales. Relatively little is known at present, however, about its role in operational forecasting and how the atmospheric circulation and hence “remote” regions such as Europe and Australia respond to sea ice anomalies. It is also not straightforward to realize the potential predictability associated with sea-ice and snow cover, because of their strong interactions with the atmosphere and the ocean. These interactions constitute very important feedback mechanisms. Additionally, given the remoteness of the region, in situ ocean and ice data needed for model initialization are sparse, which may limit the predictability that can be realized.

The presence of sea ice, snow and ice in the polar regions in conjunction with mid-tropospheric inflow of relatively warm air from the mid-latitudes leads, at times, to the development of relatively shallow and stably stratified planetary boundary layers (PBLs) in the interior of the Arctic and Antarctic during wintertime.

On the other hand, extreme temperature contrasts across the ice edge can lead to very unstable PBLs and turbulent surface heat fluxes in excess of 1000 W/m^2 over the adjacent open ocean regions. Depending on the dynamical conditions associated with the outflowing air masses, very strong, hurricane-like vortices with diameters typically of a few hundred kilometres (polar lows) may develop within a period of a few hours under the influence of sensible and latent heating from the open ocean. These polar lows are responsible for some of the most dangerous weather in the Arctic, due to strong winds, heavy snow fall, and icing on ships and installations. Furthermore, their predictability is highly variable, because of the fast development over areas with sparse observations, and their small scales. It is also likely that some aspects of model formulations pertinent to these systems are inadequate.

The polar atmosphere is often characterised by relatively small-scale features. This can be explained by relatively weak planetary wave activity, the existence of relatively sharp horizontal gradients (e.g. sea ice edge), high and steep topography, a relatively small Rossby radius of deformation, the low height of the tropopause and relatively high tropospheric stability during the winter darkness.

In summary, the particular characteristics of the polar regions change the relative importance of different dynamical and physical processes compared to that in the lower latitudes, which implies that our process understanding gained in the lower latitudes is often not directly transferrable to the polar regions.

Predictability research in the Polar Prediction Project will advance our understanding of those key dynamical and physical processes in the polar regions that determine its predictability. This knowledge will be used to explore the limits of polar predictability across all time and space scales considered in the Polar Prediction Project. This improved process understanding will be exploited in diagnostic research activities to identify key problems of operational forecasting systems in order to guide future developments.

Key challenges

- Improving predictions of polar high-impact weather and climate events (e.g. polar lows, blizzards, etc.)
- Understanding the role of the polar ocean, sea ice and stratosphere in medium-range and extended range prediction
- Identification of key sources of forecast error in the polar regions to guide future model development

Selected activities

- Carry out coordinated studies on inherent polar predictability
- Evaluate the role of sea ice, ocean and stratosphere for all forecast ranges
- Characterize the role of model parameterization uncertainty, and of model resolution
- Characterize the influence of initial condition uncertainty
- Establish priorities for model development and observing system design
- Develop efficient diagnostics techniques
- Employ initial tendency diagnostics to unravel key model short-comings

19.2.8 Global Linkages

Background

In order to get a comprehensive understanding of polar predictability it is necessary to go beyond a purely polar perspective and also consider possible linkages with the lower latitudes. There is evidence, that the evolution of polar weather is partly determined by what is happening in the mid-latitudes. On the other hand, recent research indicates that the reduction of summer-time sea ice in the Arctic leads to an increased frequency of occurrence of high-impact weather events in the mid-latitudes suggesting that the polar regions play an important role when it comes to prediction across the globe (e.g. Jung et al. 2014).

Compared to tropical-extratropical interactions, for which a vast body of literature is available, relatively little is known about the dynamics of polar-lower latitude linkages, especially for the atmosphere. For shorter time scales (short-range and medium-range forecasts) it seems likely that atmospheric baroclinic waves will play a crucial role in linking the polar regions with the mid-latitudes and that this link is strongly mediated through the presence of planetary-scale Rossby waves. On longer sub-seasonal and seasonal time scales, lower latitude-polar linkages are probably established through teleconnections to patterns such as the Arctic Oscillation (AO) and Southern Annular Mode (SAM). While these teleconnection patterns are well studied phenomena, there is little quantitative knowledge about their role in transferring forecast skill (or uncertainty) from the polar regions into the mid-latitudes and vice versa. Furthermore, our understanding of the role of polar processes in influencing large-scale atmospheric teleconnection patterns remains limited.

It is therefore expected that research on global linkages will enhance our understanding of the role of the polar regions in the global climate system, both is terms of the underlying dynamics and in terms of predictability on time scales from days to seasons.

Key challenges

- Improved understanding of two-way linkages between the polar regions and the lower latitudes and their flow-dependence on time-scales from days to seasons
- Obtain better understanding of possible polar origins of predictive skill and forecast failures in lower latitudes in order to guide future forecasting system development

Selected activities

- Revisit teleconnections from a prediction perspective
- Carry out relaxation and data denial experiments to understand the influence of improved polar predictions on lower-latitude forecast skill
- Determine flow-dependence of interactions between polar regions and lower latitudes using reanalysis and reforecast data sets
- Determine mid-latitude response to sea ice anomalies

19.2.9 The Year Of Polar Prediction (YOPP)

YOPP is one of PPP's flagship activities. Its mission is to "Enable a significant improvement in environmental prediction capabilities for the polar regions and beyond, by coordinating a period of intensive observing, modelling, verification, user-engagement and education activities".

YOPP will be carried out in close collaboration with the Polar Climate Prediction Initiative (PCPI) of World Climate Research Programme (WCRP) and other related initiatives. YOPP encompasses four major elements: an intensive observing period, a complementary intensive modelling and forecasting period, a period of enhanced monitoring of forecast use in decision making including verification, and a polar prediction focussed educational effort. YOPP is structured in three phases: the preparation phase, central YOPP and the consolidation phase (Figure 3).

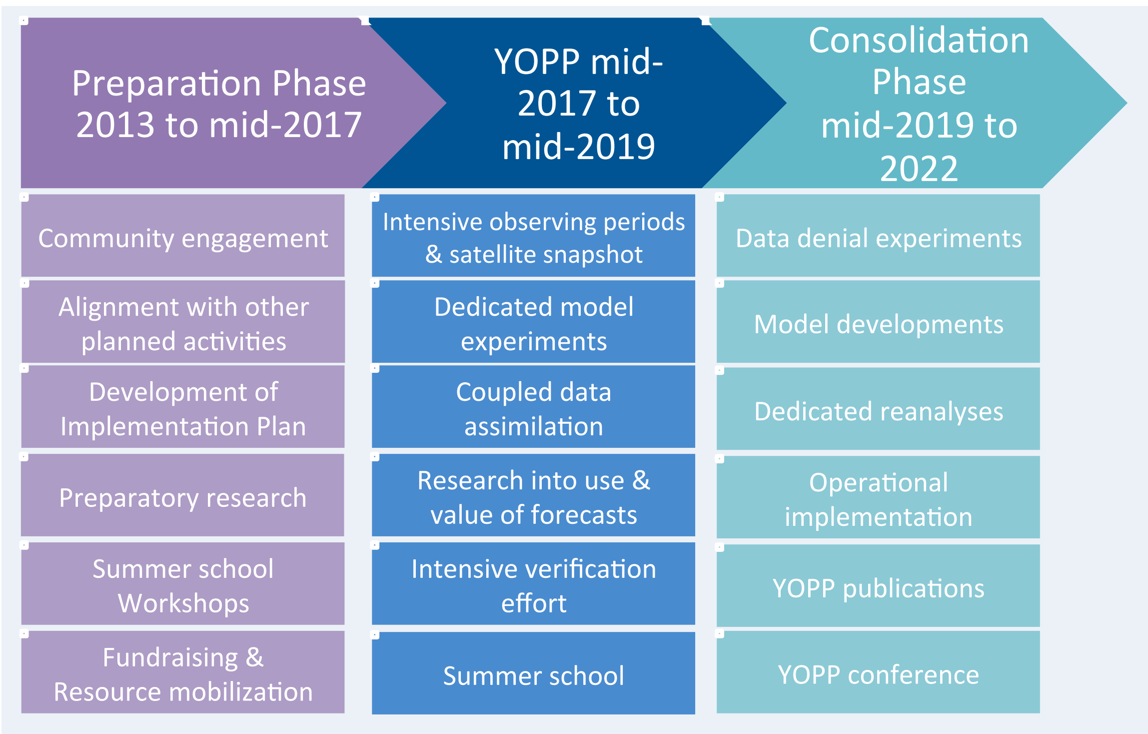

Figure 3. Three stages of YOPP, including the main activities for each stage

The preparation phase of YOPP covers the period from 2013 to mid-2017 and is characterized by the following key activities: community engagement, coordination with other planned activities, preparatory experimentation, preparation of observational and modelling strategies, development of implementation plan, organisation of summer school and workshops, liaison with funders. YOPP itself extends over the period from mid-2017 to mid-2019 and comprises periods of intensive observations, dedicated model experiments, research into the use and value of forecasts and intensive verification efforts. A consolidation phase marks the end of the YOPP decade. Data denial experiments, model development, dedicated reanalyses, operational implementation and YOPP-specific publications are its main features.

Specific objectives of YOPP are to:

- Improve the polar observing system to provide good coverage of high-quality observations in a cost effective manner. Gather additional observations through field programmes aimed at improving understanding of polar key processes.
- Develop improved representation of polar key processes in uncoupled and coupled models used for prediction, including those which are a particular hindrance to high-quality prediction for the polar regions, such as stable boundary layer representation, surface exchange, and steep orography.
- Develop improved data assimilation systems that account for challenges in the polar regions such as sparseness of observational data, steep orography, mesoscale polar systems (e.g. polar lows), model error and the importance of coupled processes (e.g. atmosphere-sea ice interaction).
- Explore the predictability of sea ice on time scales from days to a season.
- Improve understanding of linkages between polar regions and lower latitudes and assess skill of models representing these.
- Improve verification of polar weather and environmental predictions to obtain quantitative knowledge on model performance, and on the skill of operational forecasting systems for user-relevant parameters; and efficiently monitor progress.
- Improve understanding of the benefits of using existing prediction information and services in the polar regions, differentiated across the spectrum of user types and benefit areas.
- Provide training and educational opportunities for early career scientists to develop expertise in polar prediction related issues.

19.3 CONCLUSION

The ten year (2013-2022) World Weather Research Programme (WWRP) Polar Prediction Project (PPP) is one of three THORPEX legacy projects that will help to enhance prediction capabilities in the polar regions and lower latitudes. PPP will address the increasing needs for reliable forecasts in parts of the globe that have attracted relatively little attention in previous international research programmes.

There are many gaps in our knowledge and understanding of key processes in polar regions of how best to improve computer models and prediction systems, how to optimize the observing system, and what services should be provided. Polar research is an extremely resource-demanding endeavour requiring large-scale infrastructure. Coordination of research activities at an international level is therefore especially important for generating the knowledge required to improve prediction capabilities for the polar regions and beyond.

As a result of the Project, many who live in, or visit, the polar regions, where activities related to transportation, tourism and resource development are on the rise, will benefit from improved predictions. However, the expected benefits will go beyond the provision of more accurate predictions on various time scales (hourly to seasonal) in the two regions (Arctic and Antarctic). Improvements anticipated in the representation of polar processes in coupled numerical weather models will help to narrow uncertainties in regional climate change projections. Furthermore, improved environmental predictions in the polar regions will result in more accurate predictions for non-polar regions, especially in the middle latitudes, through atmospheric linkages.

PPP is an international effort that aims to provide advanced prediction capabilities in two regions that are becoming increasingly important, but which, thus far, have attracted relatively little attention from the forecasting community. The Steering Group has developed science and implementations plans and strategies in collaboration with partners from the research community and operational centres (see *http://polarprediction.net*). PPP may become a crucial WMO contribution into an emerging International Polar Partnership Initiative, which will unite efforts of many agencies and organizations in achieving socially important objectives in the polar regions.

Ultimately, the success of the Polar Projection Project will depend on support from WMO Members through contributions to the Polar Prediction Trust Fund to ensure proper international coordination, on in-kind support from operational centres, research institutions and universities, and on an enhanced level of interest in polar prediction by national and international funding agencies.

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