WWRP Polar Prediction Project
Implementation Plan

FINAL VERSION – 12 JANUARY 2013

EXECUTIVE SUMMARY

There has been a growing interest in the polar regions in recent years, because of concerns about amplification of anthropogenic climate change. Furthermore, increased economic and transportation activities in polar regions are leading to more demands for sustained and improved availability of integrated observational and predictive weather, climate and water 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.

The aim of the WWRP Polar Prediction Project (WWRP-PPP) therefore is to "Promote cooperative international research enabling development of improved weather and environmental prediction services for the polar regions, on time scales from hours to seasonal." This project constitutes the hours to seasonal research component of the emerging WMO Global Integrated Polar Prediction System (GIPPS). A closely related WCRP Polar Climate Predictability Initiative covers GIPPS research on seasonal to decadal time scales.

In order to meet growing demand for skilful and reliable predictions in polar regions and beyond the following eight key research goals were identified:

1) Improve the understanding of the requirements for, and evaluate the benefits of, enhanced prediction information and services in polar regions
2) Establish and apply verification methods appropriate for polar regions
3) Provide guidance on optimizing polar observing systems, and coordinate additional observations to support modelling and verification
4) Improve representation of key processes in models of the polar atmosphere, land, ocean and cryosphere
5) Develop data assimilation systems that account for the unique characteristics of polar regions
6) Develop and exploit ensemble prediction systems with appropriate representation of initial condition and model uncertainty for polar regions
7) Determine predictability and identify key sources of forecast errors in polar regions
8) Improve knowledge of two-way linkages between polar and lower latitudes, and their implications for global prediction

In order to achieve the above research goals it is advocated to 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.

It is emphasized that the expected benefits go beyond the time scales (hours to seasonal) and regions (Arctic and Antarctic) considered in the proposed research project. Anticipated improvements in the representation of key polar processes in (coupled) models such as stable boundary layers and sea ice dynamics are expected to reduce systematic errors in climate model integrations and, hence, help narrow uncertainties of regional climate change projections. Furthermore, improved environmental predictions in the polar regions will lead to more precise predictions for non-polar regions due to the existence of global connectivities. To exploit the full potential of this truly "seamless" area of research, it will be mandatory

to maintain and develop close ties with the climate research community and that part of the weather prediction community which has traditionally focussed on the non-polar regions.

In order to deliver its goals the WWRP Polar Prediction Project will require:

- A Steering Group representing both the research and operational communities. The steering group will be responsible for the implementation of the project;
- The establishment of an international coordination office to coordinate the day-to-day activities of the project and manage the logistics of workshops and meetings. It is desirable to share an office with the WCRP Polar Climate Predictability Initiative to ensure close coordination of both efforts;
- A major research activity in the optimization of the observing system, development of forecast models, enhancement of data assimilation systems and improvements of the ensemble prediction capabilities taking into account particularities of the polar regions;
- A major research effort in evaluating polar predictability, diagnosing forecasting system short-comings, forecast verification and user needs;
- An intensive observing and modelling effort to advance polar prediction. This activity, termed the Year of Polar Prediction (YOPP), is envisaged to take place in 2017-18 and will require close coordination with other planned activities;
- Establishment and exploitation of special research data sets that can be used by the wider research community and forecast product users;
- A series of science workshops and educational events on polar prediction.

This comprehensive project will require 10 years.

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1 Introduction

Interest in the polar regions has been increasing considerably in recent years, largely because of concerns about amplification of anthropogenic climate change and evidence of large changes. There has also been an increasing economic interest in the polar regions, especially in the Arctic. The retreat of Arctic sea ice during the boreal summer, for example, has the potential to open up new shipping lanes which may shorten routes between Europe and East Asia substantially. Furthermore, the offshore industry with its gas and oil exploration activities is playing an increasingly important role in the Arctic, and the mounting interest in polar regions by the general public has become evident from increased levels of tourism in both hemispheres. The ongoing and projected changes in polar regions and increases in economic activities also lead to concerns for indigenous societies and northern communities. Traditional means of predicting environmental conditions, for example, may cease to be valid in a changing climate and all northern communities are at an increasing risk from accidents such as oil spills associated with increased economic and transportation activities. Finally, through the 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 'sensitivity' has always existed, its ramifications are only now being understood.

The context of development pressure coupled with significant socio-cultural, technological and environmental change translates into a great potential demand for weather and environmental prediction and related services—essentially 'more' of the polar regions is 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 greater need for sustained, improved, and available 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 environmental polar predictions actually are at present, and where the limits of predictability lie for features such as blowing snow or 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 adjusted for the polar regions. It will be crucial, for example, to consider coupled atmosphere-sea ice-ocean-hydrology models in relatively short 'weather-timescale' predictions which have traditionally been carried out using atmospheric models only.

The International Polar Year 2007-2008[1] (March 2007 to March 2009) brought a renewed and timely scientific focus to the polar regions. This included an IPY-THORPEX cluster[2] of nine projects contributing to the core THORPEX aim of improving forecasting of high impact weather out to fourteen days. In fact, the WWRP Polar Prediction Project can be seen as a legacy project which will help to maintain and enhance the momentum generated by IPY-THORPEX. Compared to IPY-THORPEX and other related previous activities, however, this new project will, for the benefit of regional and extra-regional stakeholders:

- put a high priority on the needs of forecast users,

[1] http://ipy.org/

[2] http://www.ipy-thorpex.no/en/the-research/about-ipy-thorpex/the-thorpex-cluster-1

- cover environmental predictions on a wider range of time scales (i.e., from hours to seasonal),
- consider the coupled atmosphere-sea ice-ocean-land-hydrology system, and
- consider the global climate system from a polar perspective

This project can also be seen as contributing to another legacy of IPY: the International Polar Initiative (IPI), a new framework for long-term cooperation between the stakeholders with a mandate and interest in the Polar Regions. An International Steering Group is currently developing the concept for this long-term initiative.

1.1 Mission Statement

The overall Mission of the project is to:

> ***"Promote cooperative international research enabling development of improved weather and environmental prediction services for the polar regions, on time scales from hours to seasonal."***

Along with this Mission, it is important to note that:

> ***"This constitutes the hours to seasonal research component of the WMO Global Integrated Polar Prediction System (GIPPS)."***

1.2 Key Project Goals

The ultimate aim of the WWRP Polar Prediction Project is to improve weather and environmental predictions on time scales from a few hours to seasonal in order to meet growing demand for skilful and reliable predictions in polar regions and beyond.

Improvement in the area of polar prediction will require international, collaborative research to address challenges by the following actions:

- Improve understanding of the benefits of using existing prediction information and services in polar regions, differentiated across the spectrum of user types and benefit areas.
- Improve verification of polar weather and environmental predictions to obtain quantitative knowledge of the skill of operational forecasting systems for user-relevant parameters and efficiently monitor future progress.
- Optimize the polar observing system to provide good coverage of high-quality observations of all components of the polar climate system in a cost effective manner.
- Develop uncoupled and coupled model systems with a realistic representation of key physical, dynamical, chemical and hydrological processes in the polar regions.
- Develop improved data assimilation systems that account for challenges in the polar regions such as sparseness of observational data, steep orography, model error and the importance of coupled processes (e.g., atmosphere-sea ice interaction).
- Develop ensemble prediction systems with a realistic representation of model and initial condition uncertainty in the polar regions.

- Improve understanding of the origins and limits of predictability in the polar regions including diagnosis of key forecasting system weaknesses that limit predictive skill in operational systems.
- Establish quantitative knowledge of the teleconnectivity between polar atmospheric, oceanic, and cryospheric processes and those in lower latitude regions.

In order to achieve the above research goals the following more strategic goals will need to be pursued:

- Develop strong linkages with other initiatives.
- Strengthen linkages between academia, research institutions and operational forecasting centres.
- Establish and exploit special research data sets that can be used by the wider research community and forecast product users.
- Link with space agencies.
- Promote interactions and communication between research and stakeholders.
- Foster education and outreach.

1.3 Key Milestones

A complete Implementation Schedule for the project is given later, in Section 8. There are also particular details about the Year of Polar Prediction (YOPP) in Section 5.

Following are some of the key milestones and activities during the 10 year period of the project:

Period	Milestone
2013-2014	Establish International Coordination Office and website
	Form YOPP Planning Committee
	Hold Polar Prediction Workshop at ECMWF
	Define baseline verification metrics
	Hold YOPP Stakeholder Engagement Workshop
	Assess accuracy of polar processes simulated by currently used model
	Evaluate existing analysis and reanalysis data sets from a consolidated Polar Prediction Project point of view

Period	**Milestone**
2015-2016	Design model and data assimilation experiments for YOPP
	Identify case studies to be looked at during YOPP on polar-mid-latitude linkages
	Better understand the use of predictions by users in polar regions, in preparation for YOPP
	Work to make existing less accessible observations (e.g., from the Arctic Observing Network) available during the YOPP period
2017-2018 (YOPP)	Mid-term project review
	Obtain extra observations for YOPP which aid verification, allow observing system design, and support coupled model development
	Run model and data assimilation experiments for YOPP (including Transpose AMIP and Transpose CMIP runs in collaboration with the climate research community)
	Evaluate forecast systems and the user benefits of enhanced products, as compared with “normal” systems, during YOPP
2018-2022	Observing system design (making use of data denial experiments, etc., from YOPP)
	Operational implementation of improved forecasting systems
	Ongoing innovation based on what has been learned from YOPP, with proven benefits through prediction experiments, etc.
	A legacy of YOPP data which can be used for ongoing work
	Publication of societal benefit assessment, experiences and best practices, and development of a capacity-building initiative targeted to NMHSs and groups of users
	Develop fully coupled data assimilation including sea ice
	Determine flow-dependence of interactions between polar regions and lower latitudes using reanalysis and reforecast data sets
	Other publications on findings

1.4 Background to Project Initiation

This project has been initiated as a legacy of the IPY through the combined decisions and actions of a number of bodies, including the World Meteorological Organization (WMO) Congress, the WMO Executive Council, the WMO Executive Council Panel of Experts on Polar Observations, Research, and Services (EC-PORS), the WMO Commission for Atmospheric Sciences (CAS), the THORPEX International Core Steering Committee (ICSC), and the World Climate Research Programme (WCRP).

EC-PORS was established in 2008 to assist the WMO Executive Council in its oversight of WMO Polar activities. It considered the need for enhanced polar prediction systems at its first meeting in Ottawa in October 2009, and its second meeting in Hobart in October 2010 formulated proposals for a Global Integrated Polar Prediction System (GIPPS).

CAS recommended in November 2009, as a legacy of the IPY, the establishment of a THORPEX Polar Research project to improve understanding of the impact of polar processes on polar weather, the assimilation of data in Polar Regions, and the prediction of high impact weather over Polar Regions.

In developing this recommendation CAS acknowledged that important steps forward in the polar analysis and prediction had resulted from:

- the success of the THORPEX IPY Cluster Project,
- the success of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) IPY Ice Logistics Portal,
- the European Global Monitoring for Environment and Security (GMES) Marine Core service and its polar prediction and ice information provision services, and
- scientific and operational advances in satellite data assimilation.

CAS recognized that the research outcomes of these efforts would provide valuable input to the programme of work for such a legacy project.

The following year, in October 2010, a successful joint WMO World Weather Research Programme (WWRP)/THORPEX and WCRP Workshop on “Improvement of Weather and Environmental Prediction in Polar Regions” was held in Oslo, Norway. The outcome of this workshop was the establishment of a basis for this IPY legacy project which is intended to provide a framework for cooperative international research and development efforts to improve high impact weather, climate, and environmental prediction capabilities for the polar regions.

WMO’s supreme body (the World Meteorological Congress) met in its sixteenth session in May/June 2011. Congress noted with interest the decadal initiative to develop a Global Integrated Polar Prediction System (GIPPS), capable of providing information to meet user needs for decision making on timescales from hours to centuries. It noted the global potential benefits of such a system in enabling service delivery and developing observing strategies in Polar Regions, and in addressing key uncertainties in weather, climate, water and related environmental variability and change, thereby improving global prediction, contributing to all WMO high priorities, in particular Disaster Risk Reduction, and the Global Framework for Climate Services (GFCS).

The World Meteorological Congress agreed to embark on a multi-year endeavour towards GIPPS, as an IPY Legacy to benefit the global community, and adopted Resolution 57 (Cg-XVI) on the Global Integrated Polar Prediction system. In effect the present proposal constitutes the hours to seasonal research component of GIPPS. There is a counterpart and closely aligned WCRP Polar Climate

Predictability Initiative for seasonal and longer timescales also underway, as proposed in the result of the science-driven WCRP Workshop held in Bergen, Norway in October 2010[3].

Congress also acknowledged the success of the ten projects of the International Polar Year (IPY) THORPEX cluster, and supported the CAS recommendation that, as a legacy of the IPY, a THORPEX Polar Research project be established to improve the understanding of the impact of polar processes on polar weather, the assimilation of data in Polar Regions, and the prediction of high impact weather over Polar Regions. Congress also emphasized the need to have an adequate observational and telecommunication network for the Polar Regions in order to provide the relevant high impact weather services for the region.

The ninth session of the THORPEX International Core Steering Committee (ICSC), held in September 2011, considered the outcomes of Congress and CAS deliberations, and of the October 2010 Oslo Workshop, and in its Decision/Action ICSC (9) 24 "… endorsed the Polar Prediction Project." It also encouraged the WWRP and WCRP steering groups to co-ordinate their respective Implementation Plans and in particular to identify those activities that should be implemented jointly and those that are best tackled separately."

Subsequently, a Steering Group was set up under the chairmanship of Prof. Thomas Jung, with a first task of preparation of this Implementation Plan. The Steering Group met in Geneva in November 2011, in Montréal in April 2012, and in Reading in December 2012. Progress on the project was reviewed with interest and approval by the WWRP-JSC in April 2012, and by WMO's Executive Council (EC) in June 2012. The EC adopted the following resolution:

RESOLUTION 17 (EC-64) - POLAR PREDICTION PROJECT

THE EXECUTIVE COUNCIL,

> **Noting** the development of an implementation plan for polar prediction research by the WWRP/THORPEX steering group,
>
> **Further noting** the recommendation of the Executive Council Panel of Experts on Polar Observations, Research and Services (EC-PORS) for a combined polar prediction project that includes weather and climate time scales,
>
> **Considering** the changing needs for improved weather predictions in polar areas partially related to relatively rapid changes in these regions as a consequence of warming of the oceans and atmosphere,
>
> **Approves** the establishment of a polar prediction project with strong links with the WCRP polar climate predictability initiative and urges Members to consider hosting a project office and make voluntary contributions to a trust fund to implement the project;
>
> **Requests** the Secretary-General to establish a trust fund and to solicit offers from Members to host a project office for the polar prediction project.

[3] See www.wcrp-climate.org/documents/Polar_WCRP_Report.pdf

2 Benefits

The Polar Prediction Project aims to improve environmental predictions in the polar regions and beyond on time scales from hours to seasonal. Hereby, the focus is on high-impact events of which some are listed in Table 1.

Table 1: List of high-impact environmental events in the polar regions.

Event	Environmental Result	Impacted Users
Polar cyclones	Wind storms, ocean waves, sea levels	Shipping, coastal communities
Blizzards and blowing snow	Wind storms, low visibility (wind chill)	Transportation, including flights
Fog and low-level clouds	Low visibility and icing	Transportation
Katabatic winds	Wind storms, wind chill	Shipping and aviation
Barrier winds	Wind storms	Shipping and aviation
Orographic jets	Wind storms, ocean waves	Shipping
Mountain waves	Clear air turbulence	Aviation
Cold air outbreaks	Wind storms, wind chill, snowfall	Shipping, energy sector, general public
Persistent anticyclones	Low temperatures	Energy sector
Ozone hole	Enhanced circumpolar westerlies in the Southern Hemisphere, UV radiation	General public
River flow	Flooding, erosion, ice jams	Coastal communities
Sea ice	Strong drift, high sea ice pressure and ridging, seasonal anomalies	Shipping, offshore industries
Waves	Freezing spray	Shipping
Arctic haze, ozone	Reduced air quality	General public, tourism

Improved Arctic prediction capabilities will be of direct relevance to indigenous communities and other local residents and visitors. Cultural tools and traditional knowledge used by members of certain indigenous societies in the Arctic to deal with weather-related sensitivities and hazards, for example, are failing in some situations. Social scientists have documented the inconsistency between expectations based on traditional knowledge, for instance when sea ice will support travel or where caribou or other country foods should be available, and what is being actually experienced (e.g., Prno et al. 2011; Furberg et al. 2011). This erosion of the efficacy of natural knowledge may offer an opportunity to incorporate (i.e., complement but not replace) enhanced scientific prediction. In addition, the influx of people and industries into northern polar regions from lower latitudes may be accompanied by inadequate experience with polar weather and environmental conditions—itself a possible source of increased sensitivity.

Activities in polar regions such as transportation, tourism and resource development have increased significantly in recent decades, and all the operating industries are extremely sensitive to the potentially harsh environmental conditions found in the Arctic and Antarctic. Areas of fast drifting sea ice, for example, pose a serious threat to offshore industries. Furthermore, strong winds may lead to the build up of strong sea ice pressure and associated ridging which can trap even the strongest of ships such as ice breakers for extended periods of time. It will be necessary to develop ship routing facilities whose value is ultimately linked to the quality of environmental predictions. Information on ice conditions is vital for the safety of tourism operations in potentially perilous conditions (see Figure 1).

Figure 1: Cruise vessel M/S Explorer sinking off Antarctica in 2007, illustrating the potential perils of operating in polar weather and ice conditions. Photograph from Chilean Navy/Reuters.

With expanding activity comes greater demand for services such as emergency search and rescue, ice-breaking, and navigation support (International Ice Charting Working Group, 2007). Recognition of the important role that polar regions occupy within global environmental systems, including climate, has placed increasing demands for scientific investigation, semi- and permanent research stations, and various forms of in situ and remote environmental monitoring, with corresponding needs for weather and environmental information in support of tactical decision-making (e.g., Antarctica, Bromwich et al. 2005; Powers et al. 2012; various International Polar Year projects). An area of concern for aircraft flights into Antarctica, for example, is the forecasting of fog, low cloud and poor visibility. These flights support a wide range of research activities in the Antarctic. One useful metric of impact is the number of flights leaving New Zealand but having to turn around once they reach the point of safe return because of an unpredicted deterioration in the weather at the one Antarctic landing site (McMurdo Station) for which there are no alternates. A typical cost for such turn-arounds is $US100,000 per occurrence and the frequency of these events has been steadily decreasing since the Antarctic Mesoscale Prediction System (AMPS; http://www.mmm.ucar.edu/rt/amps/) effort was started in 2000.

The benefits of improved polar prediction capabilities go beyond the Arctic and Antarctic, and on time scales well beyond a few days. Some high-impact weather in the mid-latitudes is ultimately linked to environmental conditions in the polar regions. For example, westerly or easterly flow across the southern tip of Greenland leads to the generation of so-called Greenland tip jet events, which cover substantial areas of the northern North Atlantic making this region one of the windiest oceanic areas anywhere on the globe. Furthermore, polar lows – besides their impacts in the Arctic – frequently penetrate well into the mid-latitudes severely affecting countries such as the UK, Netherlands and Germany. There is also an increasing amount of evidence suggesting that loss of Arctic sea ice increases the amplitude and persistence of large-amplitude planetary waves over the whole of the Northern Hemisphere (Francis and

Vavrus, 2012; Overland et al. 2012), which may explain, for example, the frequent occurrence of relatively cold recent winters in Central Europe.

A large part of the anticipated improvement in polar prediction skill is expected to come from advances in forecasting methodologies. This will be of indirect benefit to other areas of research such as climate sciences. Improved representation of key polar processes in models, for example, is expected to feed into climate models, thereby leading to reduced uncertainties of regional climate change projections. Moreover, improvements of polar aspects of data assimilation systems will eventually find their way into future reanalyses. This along with improved conventional and satellite observing systems will enhance our monitoring capabilities of the climate system. The Polar Prediction Project will, therefore, contribute to the Global Framework for Climate Services; in particular, the “Observations and Monitoring” and “Research, Modelling and Prediction” components.

3 Research Plan Goals

In this chapter the focus is on the research areas and key goals – the "what" of the plan. Later chapters will consider "how" those goals will be achieved.

In total there are eight key research areas that need to be addressed in order to fulfil the project's mission. Although the mentioned scale from hours to seasonal is a very broad range of timescales, for the most part an attempt is made to consider the research requirements in a seamless way.

As indicated in Figure 2, the eight goals can be broadly classified into three different classes: *Service-oriented Research* tackles issues of direct relevance to users of environmental forecasts; *Forecasting System Research* encapsulates more "traditional" issues such as observations, modelling, data assimilation and ensemble forecasting; and *Underpinning Research* deals with more fundamental aspects such as predictability of the polar climate system, forecast error diagnosis and weather/climate linkages between polar and non-polar regions.

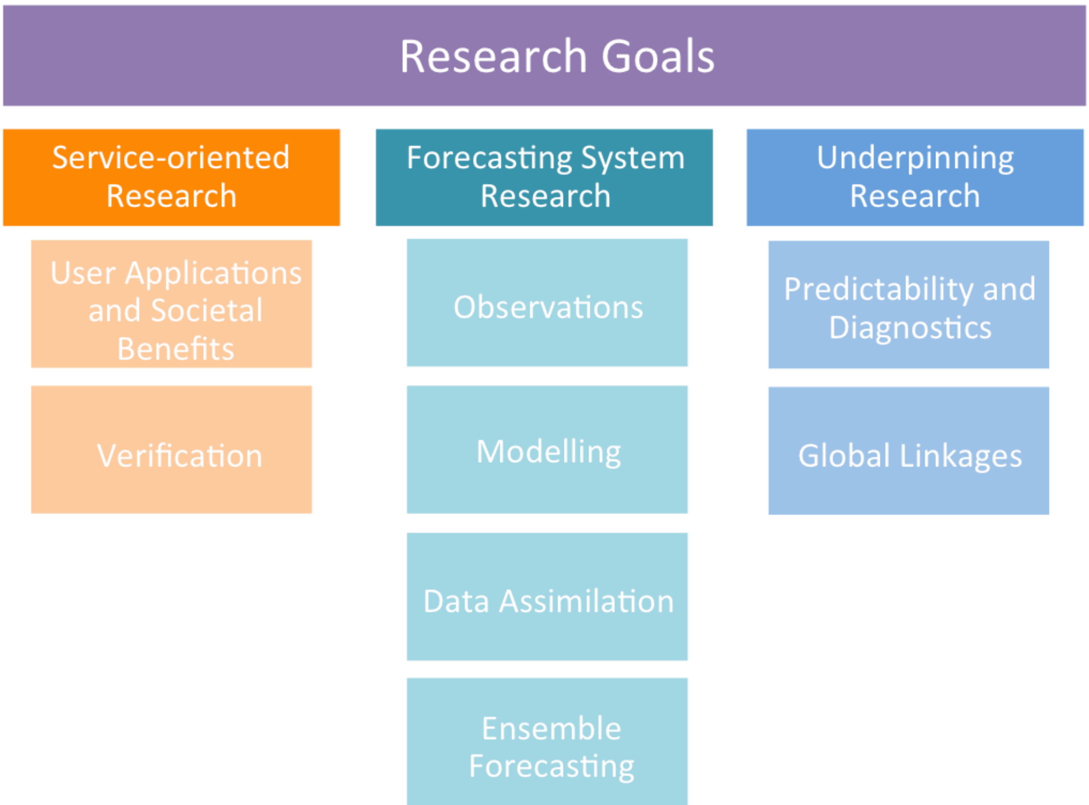

Figure 2: Grouping of Research Goals in the WWRP Polar Prediction Project.

3.1 User Applications and Societal Benefit

3.1.1 Overview

Societal and Economic Research and Applications (SERA) is 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 (e.g., 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 and those identified in Section 3.1.2 below. 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 (though not necessarily social) 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.

3.1.2 Key Challenges

- Estimation and analysis of historic and current use of polar prediction products;
- Communication of risk, opportunity and uncertainty across user types;
- Methods to evaluate and integrate ‘dislocated’ and within-region costs and benefits.

3.1.3 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 workshop (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.

It is anticipated that these activities will be carried out primarily by, and in close coordination with, WWRP-SERA and EC-PORS.

3.2 Verification

3.2.1 Overview

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 processes. 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.

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 – and highly questionable – practice as demonstrated in Figure 3. 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.

3.2.2 Key Challenges

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

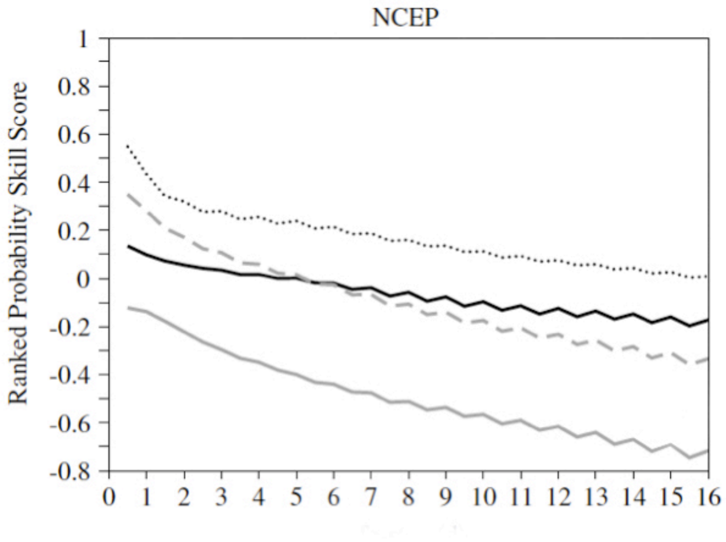

Figure 3: Sensitivity of probabilistic forecast skill to the analysis used for verification, showing the incestuous nature of using the same model for analysis and verification. Average Ranked Probability Skill Score (RPSS) for probabilistic forecasts of tropical temperature at 850 hPa with the NCEP ensemble prediction system using NCEP's own analyses (dotted), and ECMWF (solid-black), Met Office UK (solid-grey) as well as the multi-centre mean analysis (dashed-grey) for verification, for forecast periods out to 16 days. The larger the RPSS the more skilful the ensemble forecasts are. Based on Park et al. (2008).

3.2.3 Selected Activities

- Review existing state of the art 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., blizzards and fog-visibility).

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).

3.3 Observations

3.3.1 Overview

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 4 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 in coupled forecasting.

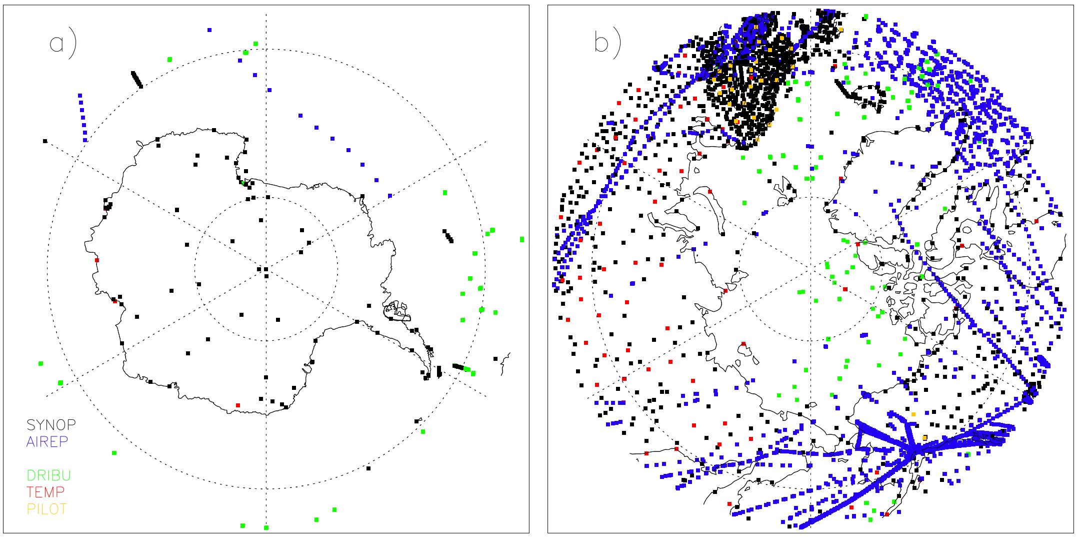

Figure 4: Polar data coverage of conventional observations in the ECMWF operational analysis at 00 UTC on 1 January 2012 (21-09 UTC window) for (a) southern polar region, and (b) northern polar region. SYNOPs are surface reports from land stations; AIREP are in-flight reports from aircraft; DRIBU are 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 for example (e.g., the 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 of a financial one than a logistical one: 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 sort of experiments a sustained observing period is required - a Year of Polar Prediction – see Section 5. In addition, periods of intense process-focussed field campaigns are required to provide comprehensive observations of processes that are known to be currently poorly represented in forecasting systems.

3.3.2 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;
- Constraining small-scale processes characteristic for the polar regions in the initial conditions (e.g., shallow boundary layers, leads and river run-off);
- A need for continual availability of adequate observations in near-real-time.

3.3.3 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.

3.4 Modelling

3.4.1 Overview

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 kind of 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 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 recognized that sub-seasonal and seasonal predictions require the use of models of the full coupled system it is increasingly being 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 (Figure 5).

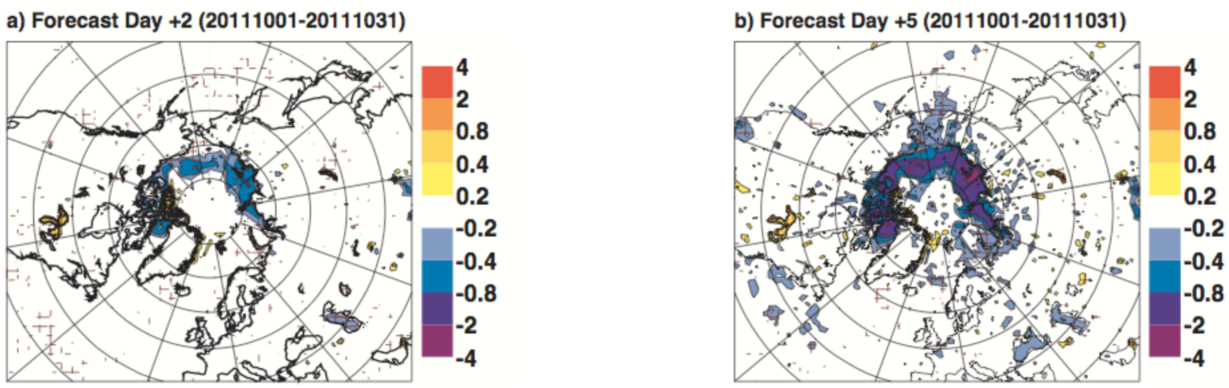

Figure 5: Mean 2-m temperature difference between hindcast experiments using observed and persisted sea-ice/SST for October 2011: (a) Day-2 and (b) day-5 forecasts from ECMWF.

The increasing importance of sea ice-ocean models for polar predictions will require critical review of the strength and weaknesses of existing models. Most sea ice models, for example, still employ rheologies that were developed in the late 1970s. While these rheologies have been successfully applied in the coarse resolution models, for which they have been developed, future increases in resolution raise the question whether the assumptions underlying 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.

3.4.2 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.

3.4.3 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 resolution of the horizontal grid 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.

3.5 Data Assimilation

3.5.1 Overview

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 condition 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 which 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 short to extended range. The atmosphere in which boundary layer processes and atmosphere-surface interaction – particularly with variable sea-ice coverage – are dominant, the small scale of 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 model in the analysis, becomes a key issue.

Figure 6 illustrates the often significant differences of mean analysis states for key parameters between the operational weather forecasting systems. These are due to differences in data assimilation systems, forecast models, actively assimilated observing systems, short-range forecast error formulations etc. For most parameters the differences are particularly large over polar areas and high-altitude terrain.

The Polar Prediction Project aims at addressing models, observations and data assimilation methods together 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.

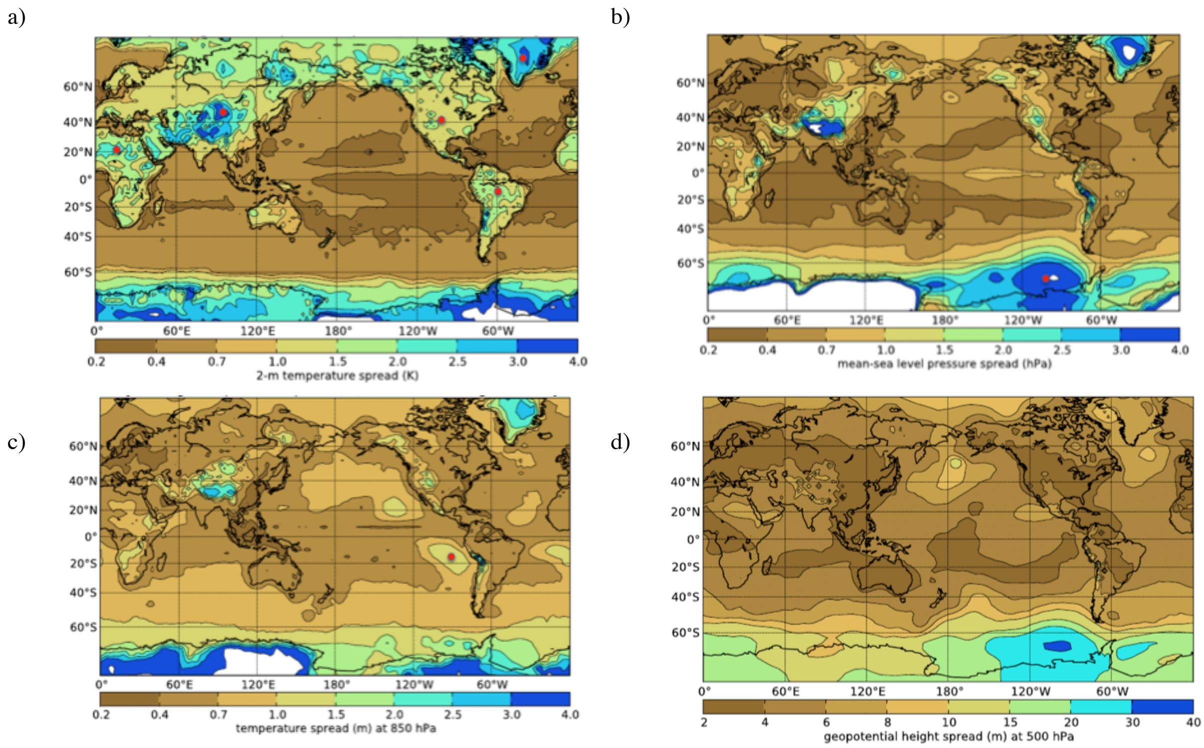

Figure 6: Spread of analysis mean for (a) 2-metre temperature, (b) mean sea-level pressure, (c) 850 hPa temperature, and (d) 500 hPa geopotential height from 5 operational TIGGE models (UKMO ECMWF, NCEP, CMC, CMA; 10/2010-11/2010) (Hamill 2012, pers. comm.).

3.5.2 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).

3.5.3 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., shallow boundary layers and sharp sea ice boundaries);
- Develop coupled data assimilation systems for the polar atmosphere-ocean-sea ice-land system.

3.6 Ensemble Forecasting

3.6.1 Overview

Ensemble forecasting is an approach to reliably quantify uncertainty of a weather or climate forecasts. An ensemble prediction system (usually shortened as 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). An example of ensemble forecasts for the case of a very intense Arctic low pressure system in the beginning of August 2012 is shown in Figure 7. 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. Well-designed EPSs are considered to be reliable, and therefore will produce a range of alternative forecast outcomes, each with an attached probability which will equal the actual frequency of occurrence for each outcome over a (statistically representative) large number of cases. This framework requires a statistical model that converts the set of ensemble members into a probability density function.

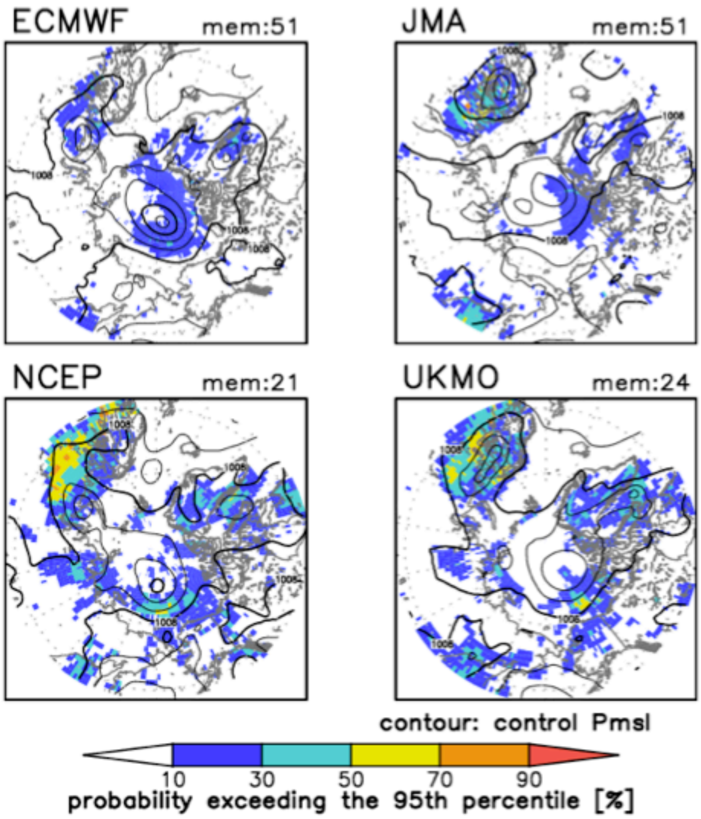

Figure 7 Probability of the occurrence of extremely strong surface winds (% in shading) in 6-day forecasts from 4 different ensemble predictions systems started on 2. August 2012. Also shown are sea level pressure fields (contours). Notice the strong low pressure system over the Arctic which led to a substantial decrease of Arctic sea ice cover. (Plots available from http://tparc.mri-jma.go.jp/TIGGE/tigge_extreme_prob.html)

Existing operational EPSs have been primarily designed with the tropics, sub-tropics and mid-latitudes in mind. 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. Here, 'optimality' refers to perturbations that are designed to ensure their growth, and hence the increase of the ensemble spread, throughout the early stages of the forecasts (i.e., they account for fast-growing patterns associated with the instabilities of the flow, with the intention that the ensemble spread will increase to levels that correspond to a proper representation of the forecast error). 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 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 existing ideas in a polar context. Secondly, improving ensemble forecasting systems by taking polar-specific aspects into account, provides scope for further improvements in probabilistic forecasts in the polar regions and beyond.

3.6.2 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 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;
- Verification of probabilistic forecasts in polar regions using observations.

3.6.3 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 (see http://www.wmolc.org) 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 parametrization versus multi-model methods;
- Explore the growth of uncertainty and its flow-dependence.

3.7 Predictability and Forecast Error Diagnosis

3.7.1 Overview

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 (Figure 8). 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.

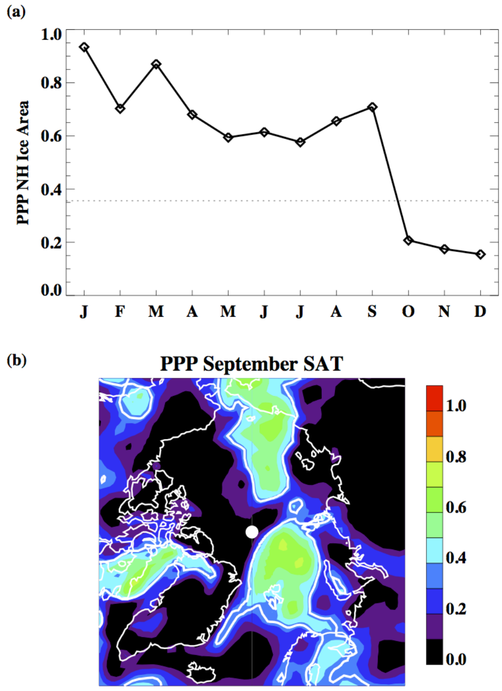

Figure 8: The prognostic potential predictability in (a) northern hemisphere sea ice area as a function of month and (b) September surface air temperature (SAT) for perfect model simulations initialized in January (see Holland et al. 2011). A value of 1 indicates perfect predictability, values above the dotted line in (a) and within the white contour in (b) indicate significant potential predictability. Note that significant potential predictability in SAT generally aligns with the sea ice edge indicating that the predictability resides in the sea ice and its influence on the overlying atmosphere.

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 free tropospheric outflowing air masses, very strong, hurricane-like vortices with diameters typically of a few hundred of kilometres, 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 are inadequate.

The polar atmosphere is 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 free-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 not easily 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.

3.7.2 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.

3.7.3 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;

- Carry out initial tendency, data assimilation and Transpose-AMIP (Atmospheric Model Intercomparison Project – running climate models in NWP mode) experiments with weather and climate models to unravel key model short-comings.

3.8 Global Linkages

3.8.1 Overview

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, for example, 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.

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.

In summary, it is 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.

3.8.2 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 quantitative knowledge about remote origins of predictive skill and forecast failures in order to guide future forecasting system development.

3.8.3 Selected Activities

- Revisit teleconnections in the light of polar prediction;
- 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.

4 Strategies to Achieve the Goals

This chapter considers **how** we can achieve the research plan goals.

4.1 Develop Strong Linkages with Other Initiatives

International and interdisciplinary collaboration will be a key to the success of this project; there is a need to develop strong linkages with other initiatives. The polar regions naturally lend themselves to both international and interdisciplinary collaboration. Many countries have interests in these regions, and also operate research programmes. Governance of the Antarctic continent is managed through the Antarctic Treaty, to which there are 50 Treaty Parties who meet annually at the Antarctic Treaty Consultative Meeting to discuss cooperation. In the north, the Arctic Council is a high-level intergovernmental forum to promote cooperation, coordination and interaction among the Arctic States.

Polar prediction from times scales of hours to seasons covers a large number of areas including observations, data assimilation, modelling and ensemble prediction, each of which are addressed by existing activities and initiatives. Figure 9 shows schematically both the various main relevant bodies and programmes, as well as the key research linkages from the eight research goals to other bodies and groups and activities.

The fact that the full coupled system needs to be addressed to ensure progress will help blur boundaries between the weather and climate research communities where these exist. Furthermore, the importance of processes in lower-latitudes for polar predictions, and vice versa, requires close collaboration between communities who traditionally tend to have a strong focus on their respective regions. It is therefore imperative to develop and maintain strong links between the WWRP Polar Prediction Project and existing activities. This is especially true given the vast scientific challenges remaining in the polar regions, the relatively small size of the polar research community, and the financial burdens associated with operating polar research infrastructure.

The most important related research initiative is the WCRP Polar Climate Predictability Initiative, as the seasonal to decadal counterpart of this project. Together, the two initiatives comprise the research component of GIPPS and face similar scientific challenges such as model development, observing system design and development of coupled data assimilation systems. EC-PORS provides a natural framework to ensure synergy between the WWRP and WCRP efforts and to foster collaboration with other existing and planned initiatives.

By pushing the forecast horizon beyond the medium-range the WWRP Polar Prediction Project will have to develop close links with initiatives that have well-established experience with extended-range predictions. The WWRP-WCRP Sub-seasonal to Seasonal Prediction Research Project and the WCRP Working Group on Seasonal to Interannual Prediction constitute the most obvious partners in this context.

The existing working groups within WWRP such as Data Assimilation and Observing Systems (DAOS), Predictability and Dynamical Processes (PDP) and TIGGE will support the WWRP Polar Prediction Project through their expertise and through direct involvement in different PPP related activities (e.g. YOPP).

The WMO-WWRP and WCRP/JSC Working Group on Numerical Experimentation (WGNE) will be another important partner to advance polar prediction due to its responsibility of fostering the development of atmospheric circulation models for use in weather, climate, water and environmental prediction on all time scales and diagnosing and resolving shortcomings. WGNE also monitors progress in data assimilation and provides an efficient link to WCRP.

Operational predictions are provided through centres designated under WMO's Global Data-Processing and Forecasting System (GDPFS). There are twelve officially designated Global Producing Centres (GPCs)) for Long Range Forecasts, as well as a WMO Lead Centre for Long Range Forecast Multi-Model Ensemble (LC-LRFMME)).

With close ties to the Global Atmospheric System Studies (GASS), which sits jointly under GEWEX and WGNE, internationally coordinated process studies and numerical model experiments will be organized with the specific aim of finding model deficiencies and to aid parameterization development to improve representation of atmospheric processes specific for the polar regions.

Various committees coordinate observational activities in the polar regions. Progress in polar prediction hinges on a concerted effort to optimize the observing system including partners such as the Polar Space Task Group (PSTG), Global Cryosphere Watch (GCW), International Arctic Science Committee (IASC) and Scientific Committee on Antarctic Research (SCAR).

An overview of the connections with some of the related initiatives is presented in Figure 9. A more comprehensive list of many related initiatives, organizations, stakeholders and partners is contained in Section 11.1.

Further opportunities will be provided for comment on this Implementation Plan as it is finalised, and for ongoing input and involvement particularly, with the various phases of the Year of Polar Prediction, where it will be essential to coordinate related activities.

The instruments for ensuring strong linkages will include:

- Close coordination between the WWRP Polar Prediction Project and the WCRP Polar Climate Predictability Initiative through a shared project office (if possible);
- Open consultation and involvement with the evolving Implementation Plan and Project activities;
- Workshops to assess the science and plan activities (the first Polar Prediction Workshop is planned for June 2013 at ECMWF);
- Cross-membership between initiatives as appropriate.

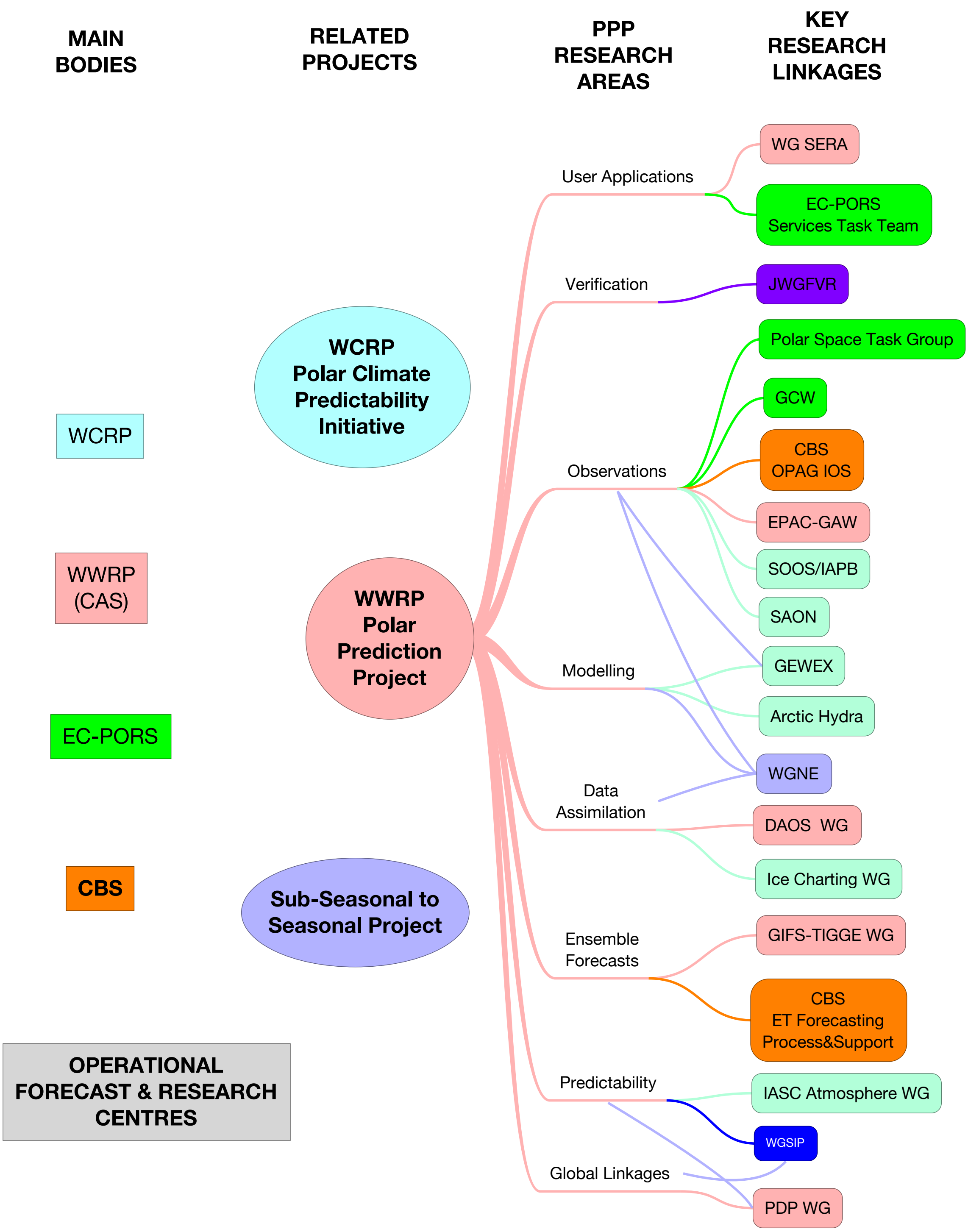

Figure 9: Linkages of the WWRP Polar Prediction Project and its research components with other international initiatives. On the left are the main governing and research bodies and programmes involved, colour coded by type. Also included, in the grey box, are operational forecast & research centres, which will include WMO GDPFS centres as well as AMPS, since connections with these will aid both the research efforts and transition from research to operations. Next over is the Polar Prediction Project as well as the two other closely related projects. Next, the Polar Prediction Project is broken down into the eight research goal areas, and for each of those are shown to the right the key research linkages with other bodies and activities, colour coded in the same fashion as the bodies on the far left. For the most part, a light green colour is used for "other" bodies not directly related just to WCRP, WWRP, EC-PORS or CBS.

4.2 Strengthen Linkages Between Academia, Research Institutions and Operational Centres

As noted in the report from the Oslo WWRP/THORPEX workshop in October 2010: "To be successful, a new IPY legacy project should tap into the scientific and human capacity of the NMHSs who have an interest in scientific, societal, and economic applications for polar regions...".

Such linkages in the first instance are enhanced by having members on the PPP Steering Group drawn from the various communities. Also, since representatives from academia, research institutions and operational centres already come together to interact at major conferences, having special polar prediction sessions at these conferences, as well as targeted workshops, will focus and improve linkages.

For a project which is aimed at improving predictions, the links with operations are particularly important, including:

- How the research results can be exploited to improve operational prediction
- How operational centres can support the research activities carried out by academic and government research institutions
- Further development and modalities of operational polar prediction systems and services

There are examples in the UK, USA and Canada of explicit incentives from funding agencies for such collaboration, as well as similar strong linkages in Sweden. Where possible, funded research contributing to this project's aims should include such explicit incentives as part of the conditions for funding.

Other incentives for collaboration could include operational centres making computer time and other resources available for students and researchers, although operational constraints on resources and the complex nature of some operational systems could be an issue. As one example, ECMWF makes available computing resources for special Member State projects that could be used in Europe.

A very specific opportunity for collaboration will be the Year Of Polar Prediction, with academia and research institutions invited to collaborate on operational system development. This may also provide an opportunity for Polar Prediction Project support to improve severe weather forecasting using the approaches of the Severe Weather Forecast Demonstration Projects (SWFDP).

4.3 Establish and Exploit Special Research Datasets

A list of existing data sources, datasets and portals to data has been compiled, and is given in Annex 2 in Section 11.3. Much of this data can be exploited in pursuit of this project's aims. The experiments will be devised by the PPP steering group in close collaboration with other groups such as WGNE and WGSIP.

In terms of new datasets, one role of this project should be to recommend what data should be archived and made available in reforecast experiments, for example under the auspices of the Working Group on Seasonal to Interannual Prediction (WGSIP). WGSIP will also provide experiment hindcast data from the CHFP dataset, which will help to understand seasonal prediction skill in the Arctic.

Ideally, any new special data sets should be of sufficient length to allow systematic investigation of forecast quality, verification, etc., and be openly accessible and sustainable. Implementation of the Year of Polar Prediction should be supported by relatively long-term reforecasts (etc.) encompassing this period. It would be very useful, for example, to closely follow the example of the special reforecast data set, which has been produced as part of the Year of Tropical Convection (YOTC).

As part of the project, high level guidance should be provided on model experiments for establishing such new datasets. This is particularly relevant given the special nature of polar prediction, and also the importance of coupled models including sea ice.

4.4 Link with Space Agencies

Space agencies are important partners in the Polar Prediction Project (PPP). Given the paucity of surface-based observations in polar regions, satellite information will be a key component of improved polar predictions. On the other hand, high-quality in situ observations are required to validate model simulations and to enhance the interpretation of satellite data. Enhanced models and data assimilation systems will improve our capabilities to support the design of future satellite missions through sensitivity studies, observing system experiments (OSE) and observing system simulation experiments (OSSE).

In order to ensure strong linkages with Space Agencies the PPP Steering Group will engage with WMO's Polar Space Task Group (PSTG). The PSTG is a successor of the International Polar Year Space Task Group (IPY-STG), established for the purpose of space agency planning, processing and archiving of the IPY Earth Observation legacy dataset. The PSTG is established under the auspices of EC-PORS. Since the chair of the PPP Steering Group and both co-chairs of PSTG are members of EC-PORS, this provides an excellent opportunity to ensure close linkages with the space agencies. PSTG exchanges with agencies such as NASA, NOAA, CSA, ESA, EUMETSAT, CMA and JMA are aimed at establishing a polar observation requirement profile that help guide space agency policies for future mission design, data product specification, data reprocessing and funding for scientific studies directed at improved data exploitation in polar areas. The PSTG is also establishing relevant formal reporting lines with the CGMS – the Coordination Group for Meteorological Satellites, and CEOS – the Committee on Earth Observation Satellites.

The exchange of information will be further improved through co-participation in steering group meetings, through representation of space agencies in PPP workshops and through the exchange of documents as they become available.

4.5 Promote Interaction and Communication Between Research and Stakeholders

Ongoing efforts will be required to establish and maintain stakeholder involvement and support of the research. The term Stakeholder is used here to denote other parties who have an interest in the success of this project. This will include indigenous peoples and communities in the northern hemisphere. Activities will include:

- Identifying and communicating effectively with those people or groups who have an influence or interest in the outcome of the project;
- Identifying Stakeholders and their various needs;
- Developing a Stakeholder Engagement Strategy;

- Developing a Stakeholder engagement and communication plan.

Examples of stakeholders include:

- NMHSs;
- IASC;
- SCAR;
- WMO Technical Commissions;
- Private sector service providers.

A more complete list is found in the Annex in Section 11.1.

Interactions will vary with the stakeholder group. For instance, briefings and feedback on the project should be provided to the annual meeting of the Executive Council, and to sessions of the WMO and other bodies. Interactions with the private sector might be through participation in existing conferences which they attended, or through the holding of science and educational workshops.

Other opportunities will continue to be sought to present and discuss with other stakeholders, as for example took place at IPY2012 in Montréal in April 2012.

4.6 Foster Education and Outreach

4.6.1 Education

Delivering on the goals of the WWRP Polar Prediction Project will require innovative international polar research. It will be crucial for the success of the project, therefore, that early career and next generation scientists with interest in polar prediction be stimulated and educated.

In order to develop and deliver a strong educational program, interactions are planned together with the Association of Polar Early Career Scientists (APECS, http://www.apecs.is/):

- One of the key elements of the educational program will be the engagement of senior scientists as APECS mentors and "Cool Speakers";
- Senior scientists will give introductory Webinars and presentations to introduce early career scientists to various aspects of polar prediction (e.g., predictability, data assimilation and probabilistic forecasting);
- "Virtual poster sessions" will be carried out which incorporate relevant presentations from both students and mentors to discuss relevant current research;
- Where possible, APECS representatives will be invited to steering group meetings to provide input on educational and early career matters.

Summer schools provide an excellent opportunity for educating early career scientists. WWRP is planning a summer school on Earth System Modelling in 2013 that could have a polar prediction component.

It is proposed to initiate polar prediction fellowships for PhD students and postdoctoral researchers. Such fellowships could be sponsored by agencies and/or interested research institutions. It should be envisaged to have at least one fellowship in each of the research goal topics (e.g., SERA, data assimilation etc.). For the fellowship strong linkage to operational prediction centres should be mandatory.

As one example of educational opportunities, the European Centre for Medium-Range Weather Forecasts (ECMWF) already holds a high-profile educational annual seminar on selected topics relevant to weather and climate prediction. For the future it is envisaged to hold an annual seminar entitled “Polar Prediction” which will be co-sponsored by WWRP and WCRP. Another example is provided by the annual Antarctic Meteorological Observation, Modeling and Forecasting Workshop (AMOMFW) where the operational, research and educational communities get together to discuss Antarctic meteorological topics of mutual interest.

4.6.2 Outreach

Whereas education is directed at people who are involved in the field of polar meteorology, outreach is "reaching out" beyond that to other constituencies, including scientists not so directly involved. A website will be developed and installed at the host institution of the international coordination office. This website will provide general information, news and links related to the Polar Prediction Project; however, it will be important to make sure that this does not duplicate resources and information available elsewhere. In addition to being a valuable resource for researchers, the information will also be accessible to targeted interested users. To reach a broader constituency, it may also be useful to develop activities that teachers and science centres can use, and to take part in larger activities such as an activity at AGU meetings or during an International Polar Week. Engagement via social media could also add value – e.g., via the Facebook page of Polar Educators International.

5 Year of Polar Prediction – YOPP

One of the proposed key elements of the Polar Prediction Project is The Year of Polar Prediction, or YOPP, which will consider both the Arctic and Antarctic, and is tentatively scheduled to take place in 2017-2018. The intention is to have an extended period of coordinated intensive observational and modelling activities in order to improve polar prediction capabilities on a wide range of time scales. This will be augmented by research into forecast-stakeholder interaction, verification and a strong educational component. It is quite different from the IPY in 2007-2008, being focussed on polar prediction rather than a very broad range of activities.

A YOPP is expected to foster relationships with partners, provide common focussed objectives, and be held over a bit more than a one-year period in association with a field campaign providing additional observations. It should coincide with, support, and draw on other related planned activities for polar regions.

It is envisaged to implement YOPP in three different stages: a preparation phase, the YOPP, and a consolidation phase (see Figure 10).

Figure 10: Main phases of YOPP

5.1 Preparation Phase (2012-2016)

The first task will be to set up a YOPP planning group, which should consist of selected members of the Polar Prediction Project Steering Group and representatives of other relevant initiatives (see Table 2).

Table 2: Key partners for YOPP

Group	Role
EC-PORS	Overall
IASC	Planning of YOPP for northern polar regions
SCAR	Planning of YOPP for southern polar regions
WCRP Polar Climate Predictability Initiative	Close coordination of related activities
WGNE	Development and implementation of the intensive modelling campaign

WGSIP	Development and implementation of the intensive modelling campaign
WWRP SERA WG	Development of concept for intensive SERA period
JWGFVR	Development of concept for intensive verification period
APECS	Implementation of educational component of YOPP
PSTG	Supporting the exploitation of satellite data (“satellite snapshot”)

The YOPP planning group will be responsible for organizing two international YOPP planning workshops (2013 and 2016), for developing a strategy for YOPP, for writing an implementation plan (2013), for coordinating/overseeing preparatory research activities (2012-2016), and for presenting YOPP plans to relevant funding agencies (2014). The overall structure for the Preparation Phase is shown in Figure 11.

It will also be crucial to engage with forecast users (stakeholders hereafter) to ensure their needs will be addressed, to explore whether a voluntary additional observing system component could be established, and to identify possible external sources of funding. To this end it is planned to convene small-session consultations where groups of similar users already interact. Identifying such opportunities will be a task charged to the SERA expert team.

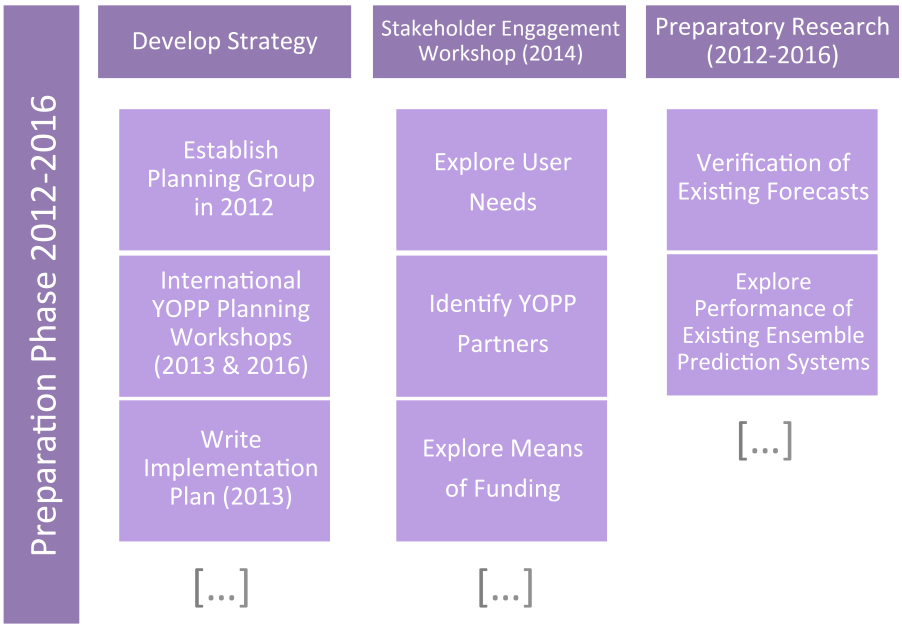

Figure 11: Phase 1 of YOPP: Preparation Phase structure

The key objectives for the YOPP Preparation Phase are to:

1. Know which model and data assimilation experiments we want to run (and what variables we want to archive - and what additional observations would be valuable) – this requires a comprehensive assessment of the skill of forecasting systems in polar regions), e.g.,
    - Identifying what forecast models do well or poorly in polar regions
    - Identifying the importance of model resolution
    - Identifying importance of coupling and sea ice, etc.
2. Know what are the best case studies to be looked at during YOPP on polar-mid-latitude linkages (requires assessment of those linkages)
3. Better understand the use of predictions by users in polar regions
4. Work to make existing less accessible observations (e.g., from the Arctic Observing Network) available during the YOPP period

5.2 YOPP (2017-2018)

The main YOPP activities are planned to take place during the period 2017-2018. The period almost automatically needs to be longer than a calendar year because of seasonal activities in boreal and austral summers. YOPP encompasses four major elements: an intensive observing period, a complementary intensive modelling period, a period of enhanced monitoring of forecast use in decision making, and a special educational effort. The overall structure for 2017-2018 is shown in Figure 12.

YOPP will require comprehensive reference stations on sea ice, land and in the ocean. For sea ice YOPP will benefit from existing plans for a Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC), which is scheduled to take place in 2017-2018. This is an international, multi-year, manned, drifting observatory in the central Arctic sea-ice pack designed to obtain comprehensive observations of interdependent atmosphere, sea-ice, and ocean processes. It will be important, therefore, to ensure close coordination of both efforts. It is anticipated that MOSAiC will provide the data required for the improvement of models under conditions for which very limited observations are available. MOSAiC will also contribute to the calibration of various satellite instruments.

Comprehensive reference stations on land could be built around existing (super) sites. For the Arctic, YOPP efforts could build on The International Arctic Systems for Observing the Atmosphere (IASOA) . In Antarctica, possible stations include, for example, Concordia, Neumayer, and McMurdo.

For the polar oceans it is possible to exploit existing systems such as AWI's mooring array. Whether the existing system needs to be extended for YOPP will require discussion during the YOPP planning workshops. In this context it will be beneficial to liaise with the Ocean Observatories Initiative (OOI) .

The reference sites on sea ice and land could also serve as hubs for wide-ranging observations using, for example, mobile platforms. These will provide the horizontal 'context' to close budgets, interpret grid-scale averaging issues, and feed into satellite and assimilation efforts. This would also be a good opportunity to exploit new technology such as Unmanned Aerial Vehicles (UAV), which could be made available for example through NASA. The hubs could also serve as starting points for comprehensive Arctic and Antarctic ice surveys.

There is certainly need for short-term focussed field campaigns. It will be crucial, for example, to explore oceanic areas close to the ice edge where the atmospheric PBL can become extremely unstable at times; these conditions are favourable for the generation of one of the most extreme atmospheric phenomena on this planet – polar lows.

Icebreakers and research vessels routinely operating in polar regions should be instrumented for high-quality observations. The mix of sensors will need to be studied and a priority list developed by an expert panel.

The increasing amount of commercial traffic in the Arctic suggests that commercial ships could provide an important element of the Arctic observing system during YOPP. A YOPP stakeholder engagement workshop would be a useful approach to probe the willingness of stakeholders to active participation.

In order to ensure good spatial and temporal coverage it will also be important to explore the possibility of enhancing the Arctic and developing an Antarctic buoy programme. The integrated Arctic Ocean Observing System (iAOOS), for example, would provide an excellent, by-then well-tested system to measure the upper ocean, sea ice properties and the lower atmosphere. The International Programme for Antarctic Buoys (IPAB) and the Southern Ocean Observing System (SOOS) will also be encouraged to contribute.

It will also be crucial to exploit the available satellite data during YOPP. The timing of YOPP is chosen such that the projected availability of polar-relevant satellites (e.g., CryoSat2, Sentinel1-3, COSMO-SkyMed and PCW) will allow the compilation of a comprehensive satellite snapshot for further analysis. All conventional observational activities during YOPP should provide data that can be used to validate and calibrate satellite retrievals of important polar geophysical parameters.

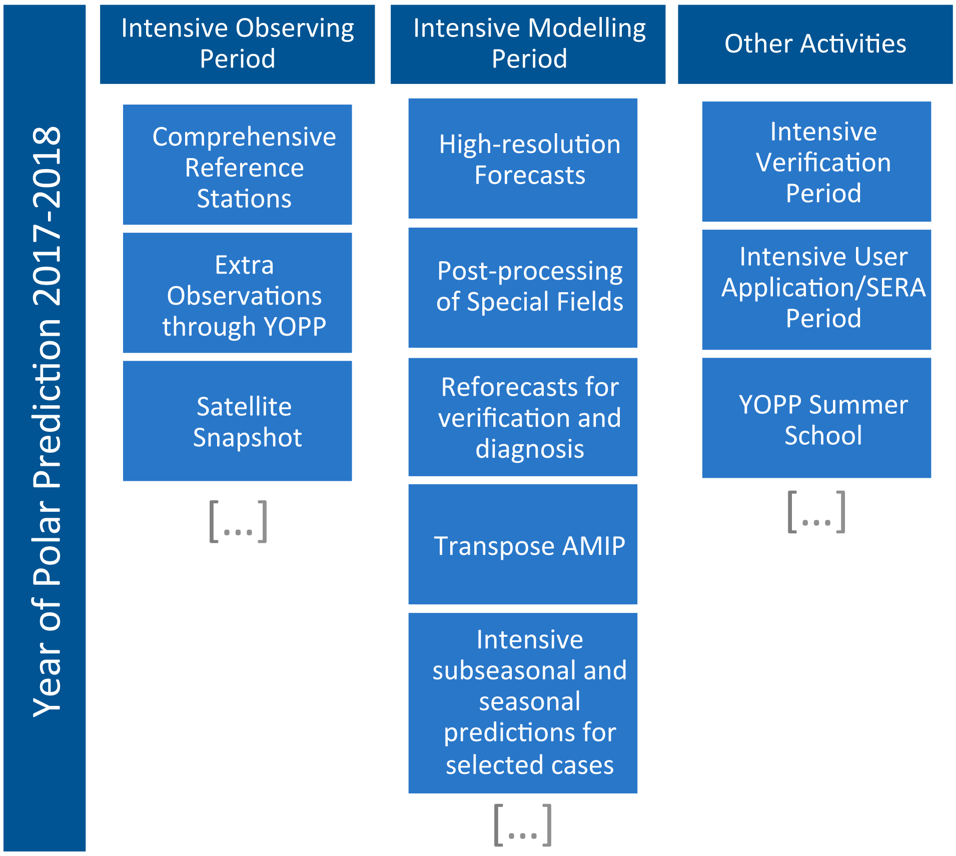

Figure 12: Phase 2: Year of Polar Prediction 2017-2018 Structure.

One of the key elements of YOPP is to develop a well-coordinated programme that combines a strong observational component with a comprehensive modelling campaign such that the representation of key processes in the polar regions in models can be improved. During YOPP it is planned to carry out very high-resolution atmospheric and coupled model experiments to explore the benefit of a better representation of polar key processes through significantly enhanced horizontal and vertical resolution.

Furthermore, it will be important to get support from operational centres in providing the research community with extra data normally not available from operational archives (e.g., process tendencies and extra parameters at an increased frequency). In this context, the concept for a special data set developed for the YOTC could serve as a very good starting point.

The sub-seasonal to seasonal prediction community should be engaged to perform intensive real-time predictions with extra start dates (once a day for sub-seasonal and once a week for seasonal) during interesting case studies. The idea is to assess the consistency of the forecasts and their spread in polar regions. Besides, the availability of extra observations will allow verification of sub-seasonal and seasonal forecasts against observations (instead of reanalyses) for polar regions. This may be done in coordination with the WMO Lead Centre for the Long Range Forecast Verification System.

While the YOTC data set is outstanding in terms of its resolution and the availability of model parameters it is somewhat limited in terms of its length when it comes to diagnosis and forecast verification, especially in terms of flow-dependent forecast error and extreme weather events. To overcome this shortcoming it is planned to carry out reforecasts for longer time periods (i.e., the satellite period).

It will be crucial to involve the WCRP community in the planning and execution of YOPP. Common activities could involve, for example, Transpose-AMIP experiments (weather forecasting with climate models) to evaluate climate models with YOPP observations. Moreover, specifically designed numerical experiments (e.g. case studies, role of snow cover and sea ice initialization etc.) should be set up in collaboration with WGSIP to explore seasonal prediction skill in the polar regions.

The numerical experiments planned for YOPP will require significant computing resources. It will therefore be necessary to explore the preparedness of operational forecasting centres to provide some of the required computational resources. Additionally, it will be necessary to apply for "external" supercomputing resources like in the framework of the Partnership for Advanced Computing in Europe (PRACE).

During YOPP it is also planned to carry out comprehensive research in the use and value of polar predictions in decision-making, ideally before, during and after a new decision-support tool has been implemented (e.g., an improved weather forecast, or a sophisticated decision support system). That said, it would potentially be useful to coordinate a period of intense monitoring/reporting of weather-related impacts to complement atmospheric-oceanic observations for particular regions.

YOPP will provide an excellent opportunity to thoroughly validate weather, sub-seasonal and seasonal forecasts in polar regions through the availability of special reforecast data sets. Archiving of user-relevant parameters such as sea ice pressure for ship routing will provide a unique opportunity to develop and test new verification metrics and techniques. During YOPP it is also planned to bring the spatial verification method comparison project to the polar regions. Finally, the availability of extra observations will allow investigation into how data sparseness, which is especially problematic in the polar regions, will affect verification results.

YOPP will provide many early career scientists (students and postdocs) with the opportunity to actively participate in an event, which is expected to significantly advance polar research in general and polar prediction in particular. In order to provide interested students with the necessary background it is planned to hold a YOPP summer school in early 2017, coordinated with APECS.

The key objectives for the YOPP Phase are to:

1. Obtain extra observations which aid verification, allow observing system design, and support coupled model development
2. Run model and data assimilation experiments (including Transpose AMIP and Transpose CMIP runs in collaboration with the climate research community)
3. Evaluate forecast systems and the user benefits of enhanced products as compared with "normal" systems

5.3 Consolidation Phase (2018-2022)

The consolidation phase will be a crucial element of YOPP given that it will help to provide a legacy of both the Polar Prediction Project in general and YOPP in particular. In this context, it will also be important to develop a YOPP data legacy strategy, which could comprise, for example, a YOPP data centre or a YOPP portal for distributed data sets where only the metadata are uploaded.

The additional data collected during the YOPP intensive observing period will be used during the Consolidation Phase to evaluate the benefit of extra observations for polar predictions by, for example, carrying out data denial experiments. Furthermore, the extra observations along with the high-resolution numerical experiments will serve as a basis to improve atmosphere, sea ice and ocean models, especially in terms of their representation of subgrid-scale processes. The overall structure of the Consolidation Phase is outlined in Figure 13.

In order to synthesize the available YOPP data and to confront models with them, it would be useful to carry out a special high-resolution Arctic and Antarctic reanalysis. Such a reanalysis along with the availability of reforecast data sets will provide the basis for diagnostic and verification studies that are expected to advance polar prediction across a wide range of time scales.

In order to ensure a lasting legacy it will be crucial to hold a YOPP synthesis workshop in 2018. Such a workshop would help to exchange the knowledge gained during YOPP, provide a good opportunity to discuss a YOPP overview paper and to develop plans for a special issue or issues on YOPP in the peer-reviewed literature. The YOPP synthesis workshop is also expected to contribute to the operational implementation of YOPP findings. To ensure "buy in" from the operational centres this synthesis workshop will be promoted through WWRP/WMO directly to the centres; hosting the workshop at a centre such as ECMWF or one of the GPCs may also assist.

It would be important to feed back some of the improvements made, new products, etc., directly to the stakeholders. This could be done through a series of meetings and trainings sessions perhaps vetted through national service agencies and other associations, articles in trade magazines, and general science articles.

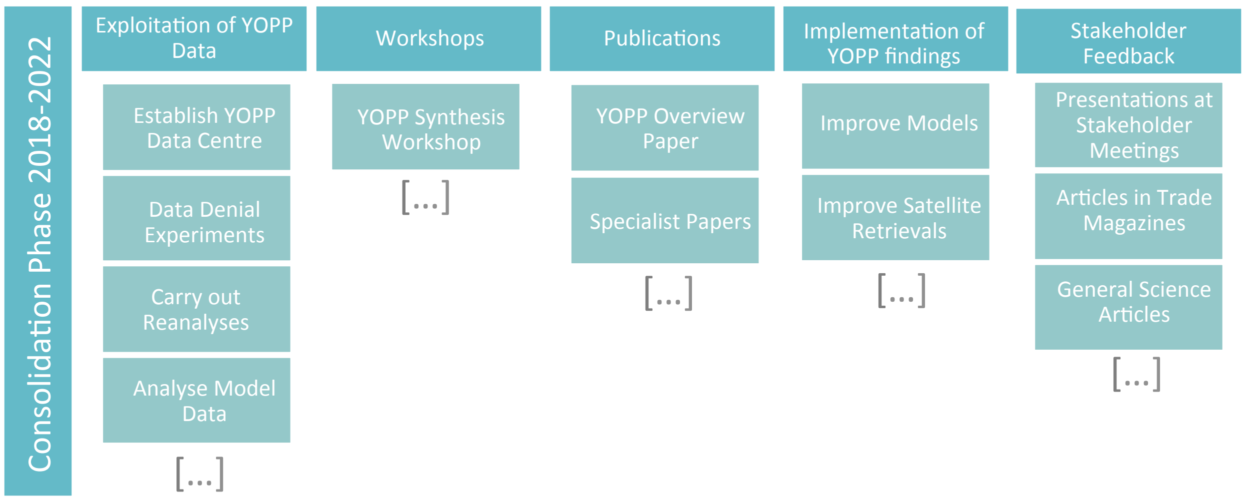

Figure 13: Phase 3: Consolidation Phase, Structure

The key objectives for the YOPP Consolidation Phase are:

1. Observing system design (making use of data denial experiments, etc., from YOPP)

2. Operational implementation of improved forecasting systems

3. Ongoing innovation based on what has been learned, with proven benefits through prediction experiments, etc.

4. A legacy of YOPP data which can be used for ongoing work

6 Governance and Management

This project comes within the World Weather Research Programme (WWRP) of WMO. It is therefore formally under the overall direction of the WWRP Joint Scientific Committee (WWRP-JSC). The Chair of the Polar Prediction Project Steering Group (PPP-SG) reports to the Chair of the WWRP-JSC.

Given that the project is a major research component of the Global Interactive Polar Prediction System (GIPPS) which is led by the Executive Council Panel of Experts on Polar Observations, Research and Services, the Chair of the PPP-SG is also an ex-office Expert member of EC-PORS in order to maintain close collaboration.

6.1 Project Steering Group

A Steering Group (SG) was established for this project in 2011, with an initial task of preparing the Implementation Plan. From the start of the project this Steering Group will take on the implementation, with Terms of Reference as annexed in Section 11.4.

The SG will meet at most annually to review progress and ensure momentum. All other discussions will be via email and other electronic communication.

6.2 International Coordination Office

An International Coordination Office (ICO) is needed to coordinate the day to day activities of the project and manage the logistics of workshops and meetings. Terms of Reference for the ICO are given in Section 11.5. It is desirable to share an office with the WCRP Polar Climate Predictability Project to ensure close coordination of both efforts

In its Resolution 17 (EC-64) the WMO Executive Council urged Members to consider hosting the international coordination [project] office for the Polar Prediction Project, and requested the Secretary-General to solicit offers to host it. In August 2012 a formal process was initiated by the WMO Secretariat to seek offers. Informally, it is understood that the Alfred Wegener Institute in Bremerhaven, Germany has conditionally offered to host it.

6.3 Monitoring and Review

Regular review will take place as part of annual Project Steering Group meetings, to track progress on the Implementation Plan. As performance measures are developed (see Section 3.2 Verification) they will be used to track the resulting improvements in polar predictions.

The project is envisaged to have a lifetime of 10 years, starting in 2013, and with a thorough mid-term review highlighting progress, achievements, remaining gaps and the activities to address these gaps in the final 5 years.

7 Financial Plan

There are four types of activities for which funding will be needed for the project, and potential funding sources:

(1) Steering Group Meetings. Following the endorsement of the Implementation Plan, it is expected that these will take place annually. The approximate cost for associated travel and expenses is CHF40,000 per annum.

(2) International Coordination Office Staffing and Operation. It is assumed that the host institution will cover all operational and office expenses, and possibly also the salary of any local support staff. However, there may be expenses for consultant support involved as well.

(3) Workshops/seminars. Some funding may come from WMO regular budget, or through collaborative activities which support the project goals. Funding could also be provided to leverage APECS involvement.

(4) Science campaigns and research funding. It is assumed these will be met from funding agencies and institutions involved.

In accordance with Resolution 17 (EC-64) of the WMO Executive Council, a Polar Prediction Fund has been established, which will help meet the expenses required for the first three items.

8 Implementation Schedule

The following Table summarises the schedule of activities by year, with the YOPP period of 2017-2018 highlighted.

ACTIVITY	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PROJECT MANAGEMENT										
Fully establish International Coordination Office (ICO)	■									
Establish project website	■									
YOPP Planning	■	■	■	■						
YOPP Implementation					■	■				
Project Review						■				
Project Final Report										■
Annual: PPP-SG meeting; Report to WWRP-JSC; Presentations to other partners	■	■	■	■	■	■	■	■	■	■
WORKSHOPS/CONFERENCES										
ECMWF Polar Prediction Workshop	■									
YOPP Planning Workshops	■			■						
YOPP Stakeholder Engagement Workshop		■								
YOPP Summer School					■		■		■	
YOPP Synthesis Workshops							■		■	
USER APPLICATIONS AND SOCIETAL BENEFIT										
Establish joint expert team involving WWRP-SERA and EC-PORS Services Task Group	■									
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	■	■								
Organise social and interdisciplinary science workshop (Weather and Polar Society) to elaborate on pressing research and application gaps, issues, and needs and begin formulating a formal research framework.		■	■							

ACTIVITY	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Plan User Applications YOPP Activities		■	■	■						
Intensive User Application activities for YOPP				■	■	■	■			
Publication of societal benefit assessment, experiences and best practices, and development of a Capacity-building initiative targeted to NMHSs and groups of users							■	■	■	■
VERIFICATION										
Review existing state of the art methods to see how applicable they are to polar regions	■	■								
Define an observation strategy to meet forecast verification requirements	■	■								
Define verification metrics that can be used as key polar-relevant performance headline measures to monitor progress during the 10-year period of the project	■	■								
Verify existing forecast systems in 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., blizzards and fog-visibility)			■	■	■	■	■	■	■	
Verify impacts of YOPP and post-YOPP consolidation				■	■	■	■	■	■	■
OBSERVATIONS										
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		■	■	■	■	■	■			
Design observational requirements for YOPP	■	■	■	■						
YOPP Observing Programme					■	■				
Evaluate the benefit of extra observations for polar predictions by carrying out data denial experiments making use of richer data sources from YOPP							■	■		
Provide advice on optimal improvements to polar observing systems based on results of YOPP							■	■	■	■

ACTIVITY	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
MODELLING										
Assess accuracy of polar processes simulated by currently used models (“gap analysis”)	■	■								
Improve representation of polar-relevant atmospheric processes such as stable boundary layers, aerosol and cloud microphysical properties		■	■	■	■	■	■	■	■	
Improve parameterizations for river flow, lakes, permafrost, and other high latitude terrestrial processes		■	■	■	■	■	■	■	■	
Assess alternate sea-ice rheologies in light of future increases in horizontal resolution and improved sea ice parameterizations and interactions		■	■	■	■	■				
Use process models (“large eddy simulations”) to guide developments for global models		■	■	■	■	■				
Explore grey zone issues for the Arctic and Antarctic - i.e., the validity of parameterizations when the resolution of the horizontal grid of models is increasing, the use of scale-aware parameterizations in models with regionally refined grids.		■	■	■	■	■				
Develop stochastic parameterization schemes to account for model uncertainty and up-scale effects from subgrid-scale processes.		■	■	■	■	■	■	■		
DATA ASSIMILATION										
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 satellite observations, e.g. ice concentration from Synthetic Aperture Radar data	■	■	■							
Develop error covariance matrices for the polar regions (e.g., shallow boundary layers and sharp sea ice boundaries)		■	■	■	■	■	■	■	■	
Develop coupled data assimilation including sea ice			■	■	■	■	■	■	■	■
ENSEMBLE FORECASTING										
Assess performance of existing global and limited area ensemble prediction system in the polar regions	■	■								
Exploit existing and future special ensemble forecast data sets (e.g., TIGGE and Sub-seasonal to Seasonal data base)	■	■	■	■						
Improve techniques to represent initial and model uncertainty in coupled ensemble prediction system			■	■	■	■	■	■	■	■
Assess benefits of using stochastic parametrization versus multi-model methods			■	■	■	■	■	■	■	■
Explore the growth of uncertainty and its flow-dependence	■	■	■	■						

ACTIVITY	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PREDICTABILITY										
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 resolution on forecast skill Characterize the role of initial condition uncertainty on forecast skill	■	■	■	■						
Establish priorities for model development and observing system design			■	■	■	■	■	■		
Develop efficient diagnostics techniques	■	■	■	■						
Carry out initial tendency, data assimilation and Transpose-AMIP experiments with weather and climate models to unravel key model short-comings				■	■	■	■	■	■	
GLOBAL LINKAGES										
Revisit teleconnections in the light of polar prediction			■	■	■	■	■	■		
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			■	■	■	■	■	■	■	■
Investigate mid-latitude response to sea ice anomalies	■	■	■	■	■	■				

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10 Abbreviations

A

AARI .... Arctic and Antarctic Research Institute, Russia
AMOMFW .... Antarctic Meteorological Observation, Modeling and Forecasting Workshop
AMPS .... Antarctic Mesoscale Prediction System
AO .... Arctic Oscillation
APECS .... Association of Polar Early Career Scientists

C

CAS .... WMO Commission for Atmospheric Sciences
CBS .... Commission for Basic Systems (WMO)
CEOS .... Committee on Earth Observation Satellites
CGMS .... Coordination Group for Meteorological Satellites
CHFP .... Climate System Historical Forecast Project
CLIVAR .... Climate Variability and Predictability
CMA .... China Meteorological Administration
COMNAP .... Council of Managers of National Antarctic Programmes
COSMO-SkyMed .... **CO**nstellation of small **S**atellites for the **M**editerranean basin **O**bservation
CSA .... Canadian Space Agency

D

DPFS .... Data Processing and Forecasting System

E

EC .... WMO Executive Council
EC-PORS .... WMO Executive Council Panel of Experts on Polar Observations, Research and Services
ECRA .... European Climate Research Alliance
EPAC-GAW .... Environmental Pollution and Atmospheric Chemistry-Global Atmosphere Watch
EPS .... Ensemble Prediction System
ESA .... European Space Agency
EUMETSAT .... European Organisation for the Exploitation of Meteorological Satellites

F

FARO .... Forum of Arctic Research Operators

G

GASS .... GEWEX/GASS Global Atmospheric System Studies
GCW .... Global Cryosphere Watch
GDPFS .... Global Data-Processing and Forecasting System
GEWEX .... Global Energy and Water Cycle Experiment
GFCS .... Global Framework for Climate Services
GHP .... GEWEX Hydroclimatology Panel
GIPPS .... Global Integrated Polar Prediction System
GLASS .... GEWEX Global land/Atmosphere System Study
GMES .... European Global Monitoring for Environment and Security
GODAE .... Global Ocean Data Assimilation Experiment
GPC .... Global Producing Centre for Long Range Forecasts
GSOP .... CLIVAR Global Synthesis and Observations Panel
GTN-P .... Global Terrestrial Network for Permafrost

I

IAOOS .... Ice - Atmosphere - Arctic Ocean Observing System
IAOSOA .... International Arctic Systems for Observing the Atmosphere
IAPSO .... International Association for the Physical Sciences of the Oceans
IASC .... International Arctic Science Committee
IASI .... Infrared Atmospheric Sounding Interferometer (satellite)
IceHFP .... Sea-ice Historical Forecast Project
ICO .... International Coordination Office

ICPM ....International Commission on Polar Meteorology
ICSC ....THORPEX International Core Steering Committee
IICWG ....International Ice Charting Working Group
IOS ....Integrated Observing System
IPI ....International Polar Initiative
IPY ....International Polar Year
IPY-STG ....IPY Space Task Group
ISAC ....International Study of Arctic Change

J

JCOMM ....Joint Technical Commission for Oceanography and Marine Meteorology
JMA ....Japan Meteorological Agency
JSC ....Joint Scientific Committee
JWGFVR ....Joint Working Group on Forecast Verification Research

L

LC-LRFMME ....Lead Centre for Long Range Forecast Multi-Model Ensemble

M

MOSAiC ....Multidisciplinary drifting Observatory for the Study of Arctic Climate

N

NASA ....US National Aeronautical and Space Administration
NCAR ....US National Center for Atmospheric Research
NCEP ....National Centres for Environmental Prediction
NERC ....UK Natural Environment Research Council
NMHSs ....National Meteorological and Hydrological Services
NOAA ....US National Oceanic and Atmospheric Administration
NWP ....Numerical Weather Prediction

O

OOI ....Ocean Observatories Initiative
OPAG ....Open Programme Area Group
OSE ....Observing System Experiment
OSSE ....Observing System Simulation Experiment

P

PBL ....Planetary Boundary Layer
PCW ....Polar Communication and Weather Mission
PEI ....Polar Educators International
PPP ....Polar Prediction Project
PPP-SG ....Polar Prediction Project Steering Group
PRACE ....Partnership for Advanced Computing in Europe
PSTG ....Polar Space Task Group

R

RPSS ....Ranked Probability Skill Score

S

SAM ....Southern Annular Mode
SAON ....Sustaining Arctic Observing Networks
SAR ....Synthetic Aperture Radar
SCAR ....Scientific Committee on Antarctic Research
SEARCH ....Study of Environmental Arctic Change
SERA ....Societal and Economic Research Applications
SOOS ....Southern Ocean Observing System
SPARC ....Stratospheric Processes and their Role in Climate
SST ....Sea Surface Temperature
SWFDP ....Severe Weather Forecast Demonstration Project
SYNOP ....Synoptic Observation from a surface station

T

TEMP ....Upper air sounding of temperature and humidity

THORPEX .... The Observing System Research and Predictability Experiment
TIGGE ....THORPEX Interactive Grand Global Ensemble
Transpose AMIP................. Atmospheric Model Intercomparison Project – climate models in NWP mode

U

UAV ....Unmanned Aerial Vehicles

W

WCRP..World Climate Research Programme
WGNE ....Working Group on Numerical Experimentation
WWRP..World Weather Research Programme

Y

YOPP ....Year of Polar Prediction

11 Annexes

11.1 Annex 1 – Contributing Authors

This draft Implementation Plan has been prepared by Thomas Jung, Neil Gordon and Stefanie Klebe, with contributions from PPP Steering Group members: Peter Bauer, David Bromwich, Francisco Doblas-Reyes, Chris Fairall, Keith Hines, Marika Holland, Trond Iversen, Peter Lemke, Brian Mills, Pertti Nurmi, Ian Renfrew, Gregory Smith, Gunilla Svensson and Mikhail Tolstykh. The text has also benefitted from constructive feedback provided during the consultation stage by various individuals and groups, including APECS.

11.2 Annex 2 – Related Initiatives, Organizations, Stakeholders, Partners

The following is a comprehensive list of other related Initiatives, Organizations, Stakeholders and Partners. The term Stakeholder is used here to denote other parties who have an interest in the success of this Polar Prediction Project.

Group	*Web Address*
WCRP (World Climate Research Programme)	
CHFP (Climate System Historical Forecast Project)	http://www.wcrp-climate.org/wgsip/chfp/index.shtml
CliC (Climate and Cryosphere Project)	http://www.climate-cryosphere.org/en/
GEWEX (Global Energy and Water Cycle Experiment)	http://www.gewex.org/gewex_overview.html
GEWEX GASS(Global Atmospheric System Studies	http://www.gewex.org/gass_panel.html
GEWEX GLASS (Global Land/Atmosphere System Study)	http://www.gewex.org/glass.html
GEWEX Hydroclimatology Panel (GHP)	http://www.gewex.org/projects-ghp.html
Global Synthesis and Observations Panel (GSOP) of CLIVAR	http://www.clivar.org/organization/gsop
Ice-HFP (Sea Ice Historical Forecast Project)	http://www.wcrp-climate.org/wgsip/chfp/iceHFP.shtml
SCAR/CliC Antarctic Sea-Ice Processes and Climate (ASPeCT)	http://aspect.antarctica.gov.au
SPARC (Stratospheric Processes and their Role in Climate)	http://www.sparc-climate.org/
Subseasonal to Seasonal Prediction Project	http://www.wmo.int/pages/prog/arep/wwrp/new/documentation_plan_subseasonal_meeting_2011.html
WCRP Polar Climate Predictability Initiative	http://www.atmosp.physics.utoronto.ca/C-SPARC/Polar-WS-website/Polar-Workshop.html
WGSIP (Working Group on Seasonal to Interannual prediction)	http://www.wcrp-climate.org/wgsip/index.shtml
CAS (Commission for Atmospheric Sciences) & WWRP (World Weather Research Programme)	
JSC EPAC/GAW	http://www.wmo.int/pages/prog/arep/gaw/JSC_OPAG_EPAC.html
WWRP Mesoscale WG	http://www.wmo.int/pages/prog/arep/wwrp/new/mesoscale_new.html
WWRP Nowcasting WG	http://www.wmo.int/pages/prog/arep/wwrp/new/nowcasting_research.html

Group	*Web Address*
WWRP SERA WG	http://www.wmo.int/pages/prog/arep/wwrp/new/weather_society.html
THORPEX (The Observing System Research and Predictability Experiment)	
Africa THORPEX	http://www.wmo.int/pages/prog/arep/wwrp/new/african_regional.html
Asia THORPEX	http://www.wmo.int/pages/prog/arep/wwrp/new/asia_regional.html
European THORPEX	http://www.wmo.int/pages/prog/arep/wwrp/new/europe_regional.html
North America THORPEX	http://www.wmo.int/pages/prog/arep/wwrp/new/north_america_regional.html
Southern Hemisphere THORPEX	http://thorpex.cptec.inpe.br/
THORPEX DAOS WG	THORPEX website http://www.wmo.int/pages/prog/arep/wwrp/new/thorpex_new.html
THORPEX GIFS-TIGGE	THORPEX website http://www.wmo.int/pages/prog/arep/wwrp/new/thorpex_new.html
THORPEX PDP WG	THORPEX website http://www.wmo.int/pages/prog/arep/wwrp/new/thorpex_new.html
JOINT	
Join Working Group on Forecast Verification Research (JWGFVR(	http://www.wmo.int/pages/prog/arep/wwrp/new/Forecast_Verification.html
WGNE (Working Group on Numerical Experimentation)	http://www.wmo.int/pages/about/sec/rescrosscut/resdept_wgne.html

CBS (WMO Commission for Basic Systems)	
ET-FPS (Expert Team on Operational Forecasting Process and Support) under OPAG-DPFS (Data Processing and Forecasting System)	http://www.wmo.int/pages/prog/www/CBS/CBS-WorkProgramme/OPAG_DPFS_ETs.html
ET-OPSLS (Joint CBS-CCl Expert Team on Operational Predictions from Sub-seasonal to Longer Time-Scales)	
OPAG-IOS (Open Programme Area Group on the Integrated Observing Systems)	http://www.wmo.int/pages/prog/www/OSY/WorkingStructure/OPAG-IOS_ExpertTeams.html
WMO Lead Centre for Long-Range Forecast Multi-Model Ensemble	http://www.wmolc.org
WMO Lead Centre for the Long Range Forecast Verification System	http://www.bom.gov.au/wmo/lrfvs/
GOVERNANCE	
CAS	http://www.wmo.int/pages/prog/arep/cas/president_welcome.html
EC-PORS	http://www.wmo.int/pages/prog/www/polar/index_en.html
THORPEX ICSC	http://www.wmo.int/pages/prog/arep/wwrp/new/thorpex_new.html
WCRP JSC	http://wcrp.wmo.int/About_Governance.html#JSC
WWRP JSC	http://www.wmo.int/pages/prog/arep/wwrp/new/wwrp_jsc.html
POLAR GROUPS	
ACCESS (Arctic Climate Change, Economy and Science)	http://www.access-eu.org/
Arctic ECRA (European Climate	http://ecra-climate.eu/index.php/collaborative-programmes/arctic-ecra

Research Alliance)	
IASC (International Arctic Science Committee) Atmosphere Group	http://www.iasc.info/index.php/home/groups/working-groups/atmosphere
IICWG (International Ice Charting Working Group)	http://nsidc.org/noaa/iicwg/
PSTG (Polar Space Task Group)	http://www.wmo.int/pages/prog/sat/pstg_en.php
SAON (Sustaining Arctic Observing Networks)	http://www.arcticobserving.org/
SCAR (Scientific Committee on Antarctic Research)	http://www.scar.org/
SEARCH (Study of Environmental Arctic Change)	http://www.arcus.org/search/index.php
ADDITIONAL PARTNERS & STAKEHOLDERS	
AARI (Arctic and Antarctic Research Institute, Russia)	http://www.aari.nw.ru/main.php?lg=1
Alfred-Wegener Institute for Polar and Marine Research	http://www.awi.de/en/
Antarctica New Zealand	http://www.antarcticanz.govt.nz
Arctic Model Intercomparison Project (AOMIP)	http://www.whoi.edu/page.do?pid=29836
Arctic Council	http://www.arctic-council.org/index.php/en/
Arctic Council Indigenous People's Secretariat	http://www.arcticpeoples.org/
Arctic Hydra	http://arctichydra.arcticportal.org/
Arctic Research Consortium of the US	http://www.arcus.org/arcus/index.html
Arctic RIMS	http://rims.unh.edu/
ArcticNet (Canada)	http://www.arcticnet.ulaval.ca/
Association of Polar Early Career Scientists	http://www.apecs.is/
Australian Antarctic Division	http://www.antarctica.gov.au/
British Antarctic Survey	http://www.antarctica.ac.uk/

CGMS (Coordination Group for Meteorological Satellites)	http://www.cgms-info.org
Community Earth System Model (CESM) Polar Climate Working Group	http://www.cesm.ucar.edu/working_groups/Polar/
Council of Managers of National Antarctic Programmes (COMNAP)	https://www.comnap.aq/
Forum of Arctic Research Operators (FARO)	http://faro-arctic.org/
Global Terrestrial Network for Permafrost (GTN-P)	http://gtnp.org/index_e.html
GODAE (Global Ocean Data Assimilation Experiment) OceanView	https://www.godae-oceanview.org/
iAOOS - Ice - Atmosphere - Arctic Ocean Observing System)	http://www.iaoos-equipex.upmc.fr
International Arctic Buoy Programme	http://iabp.apl.washington.edu/index.html
International Arctic Science Committee	http://www.iasc.info
International Arctic Social Sciences Association	http://www.iassa.org/
International Association for the Physical Sciences of the Oceans (IAPSO) of IUGG	http://iapso.iugg.org/
International Commission on Polar Meteorology (ICPM) of IUGG-IAMAS	http://www.icpm-iamas.aq/
International Permafrost Association	http://ipa.arcticportal.org/
International Programme for Antarctic Buoys (IPAB)	http://www.ipab.aq/
International Study of Arctic Change (ISAC)	http://www.arcticchange.org/
MORSE – Arctic Coastal Initiative	http://www.morsearctic.net
Norwegian Polar Institute	http://www.npolar.no/en/
Polar Educators International	http://www.educapoles.org/news/news_detail/join_polar_educators_international/
SCAR Expert Group on Operational Meteorology in the Antarctic	http://www.antarctica.ac.uk/met/jds/met/SCAR_oma.htm
SCAR Southern Ocean Observing System (SOOS)	http://www.scar.org/soos/
Secretariat of the Antarctic Treaty	http://www.ats.aq/index_e.htm
UK Natural Environment Research Council (NERC) UK	http://www.arctic.ac.uk/

Arctic Office	
US Board on Atmospheric Sciences and Climate US.BASC	http://dels.nas.edu/global/basc/Climate-Research-Committee
Voeikov Main Geophysical Observatory	http://www.voeikovmgo.ru/en/
CIRCUMPOLAR & SOME OTHER NMSs/MODELLING CENTRES	
AMPS	http://www.mmm.ucar.edu/rt/amps/
Argentina	http://www.smn.gov.ar/
Australia	http://www.bom.gov.au/ and http://cawcr.gov.au/aboutus/orgchart.php
Brazil	http://www.inmet.gov.br/
Canada	http://www.ec.gc.ca/
Chile	http://www.meteochile.gob.cl/
ECMWF	http://www.ecmwf.int
Finland	http://en.ilmatieteenlaitos.fi/home
Iceland	http://en.vedur.is/
New Zealand	Operational services: http://www.metservice.com Research in modelling, seasonal aspects, oceanography and ice: http://niwa.co.nz
Norway	http://met.no/English/
Russian Federation	http://wmc.meteoinfo.ru
South Africa	http://www.weathersa.co.za/web/
Sweden	http://www.smhi.se/en
UK	http://www.metoffice.gov.uk/
USA (NCEP)	http://www.ncep.noaa.gov/

11.3 Annex 3 – Existing Data Sources, Datasets and Portals

Data Source	Web Address
Antarctic and Southern Ocean Data Portal	http://www.marine-geo.org/portals/antarctic/
Antarctic Hindcast Project	http://polarmet.osu.edu/PolarMet/ant_hindcast.html
Antarctic Mesoscale Prediction System (includes archive)	http://www.mmm.ucar.edu/rt/amps/
Antarctic Meteorological Research Center	http://amrc.ssec.wisc.edu/
Antarctic Observing Network - AntON - definition of station sites; not data	http://www.wmo.int/pages/prog/www/ois/rbsn-rbcn/rbsn-rbcn-home.htm
Arctic Data Centre (will replace ipycoord.met.no)	http://arcticdata.met.no/
Arctic Polar WRF	http://polarmet.osu.edu/nwp/?model=arctic_wrf
Arctic Portal	http://arcticportal.org/
Arctic System Reanalysis	http://polarmet.osu.edu/ASR/index.html
Australian Antarctic Data Centre	http://data.aad.gov.au/aadc/portal/
AWI Meteorological Observatories	http://www.awi.de/en/go/meteorological_observatories
Baseline Surface Radiation Network (includes polar)	http://www.bsrn.awi.de/
British Antarctic Survey Data	http://www.antarctica.ac.uk/bas_research/data/index.php
British Atmospheric Data Centre (more than polar)	http://badc.nerc.ac.uk/home/index.html
Climate-system Historical Forecast Project (CHFP) Data Archive	http://www.clivar.org/organization/wgsip/chfp/chfp_data
Cooperative Arctic Data and Information Service (ACADIS)	http://aoncadis.org
Data Publisher for Earth & Environmental Science (AWI) - Search Portal	http://www.pangaea.de/
ECMWF Data Server (including ERA-40, etc.)	http://data-portal.ecmwf.int/
ESA's GlobICE	http://globice.mssl.ucl.ac.uk/
EU MyOcean Project Data Catalogue	http://www.myocean.eu/web/24-catalogue.php

Data Source	Web Address
GAW World Data Centre for Aerosols (global, including polar)	http://www.gaw-wdca.org/
GAWSIS - metadata for GAW data, including polar	http://gaw.empa.ch/gawsis/
GCMD IPY Data Portal	http://gcmd.nasa.gov/portals/ipy/
GEOmon Distributed Database - portal	http://geomon.nilu.no/
Global Cryosphere Watch (work in progress)	http://www.climate-cryosphere.org/en/achievements/cryospherewatch.html
Global NWP & in-situ obs of surface fluxes	http://www.ncdc.noaa.gov/oa/rsad/air-sea/surfa.html
IASOA Data Archive Links	http://iasoa.org/iasoa/index.php?option=com_content&task=view&id=170&Itemid=171
IASOA Observatories	http://iasoa.org/iasoa/index.php?option=com_content&task=view&id=85&Itemid=123
Ice Logistics Portal	http://www.bsis-ice.de/IcePortal/index.html
International Arctic Systems for Observing the Atmosphere (IASOA)	http://www.iasoa.org
IPY Data and Information Services	http://ipydis.org/
Meta: List of Potential Links from Byrd Polar Research Center	http://bprc.osu.edu/polar_pointers/index.php?category=Data
NASA Satellite Data (including Giovanni)	http://disc.sci.gsfc.nasa.gov/data-holdings
NCEP/NCAR Reanalysis Data	http://dss.ucar.edu/pub/reanalysis/
Network for Detection of Atmospheric Composition Change (NDACC) includes polar	http://www.ndsc.ncep.noaa.gov/
Norwegian Arctic Climate Data - (amongst others)	http://eklima.met.no
Norwegian Institute for Air Research (NILU) database	http://ebas.nilu.no/
Ocean and Sea Ice (OSI) Satellite Application Facility (SAF)	http://saf.met.no/p/download.html
Physical Oceanography Distributed Active Archive Centre (PO.DAAC)7	http://podaac.jpl.nasa.gov/
Polar Data Catalog (Canada)	http://www.polardata.ca/
Polar Information Commons	http://polarcommons.org/

Data Source	Web Address
Polarview	http://www.polarview.org/
Project Athena	http://wxmaps.org/athena/home/
Research Vessel Surface Meteorology Data Center (some polar data)	http://coaps.fsu.edu/RVSMDC/html/data.shtml
SAMOS (shipboard) data archive	http://samos.coaps.fsu.edu/html/nav.php?s=2
SCAR Met Database	http://www.antarctica.ac.uk/met/READER/
SCAR Ocean database	http://www.antarctica.ac.uk/met/SCAR_ssg_ps/OceanREADER/
SEARCH-Relevant Datasets	http://www.arcus.org/search/searchscience/data.php
SHEBA Data Archives	http://www.eol.ucar.edu/projects/sheba/
Specific AWI/PANGAEA data - Cruise Reports	http://www.pangaea.de/PHP/CruiseReports.php?b=Polarstern
Sub-seasonal to Seasonal Prediction Research Project Data	http://www.clivar.org/organization/wgsip/resources/chfp/chfp-projects (to be added to this)
TIGGE Databases	http://tigge.ecmwf.int/#portals
U.S. National Ice Center	http://www.natice.noaa.gov/ims/
US National Snow and Ice Data Centre	http://nsidc.org/data/
US NOAA Arctic Data Links	http://www.arctic.noaa.gov/data.html
WIS Global Information System Centre (GISC) at DWD	http://gisc.dwd.de/GISC_DWD/start_js_JSP.do
WMO Information System - WIS Centres	http://www.wmo.int/pages/prog/www/WIS/centres/index.html
WMO Lead Centre for the Long Range Forecast Verification System	http://www.wmolc.org
World Ozone and Ultraviolet Radiation Data Centre (WOUDC) includes polar	http://www.woudc.org/index_e.html

11.4 Annex 4 – Steering Group Terms of Reference

The WWRP Polar Prediction Project (PPP) will promote cooperative international research enabling development of improved weather and environmental prediction services for the Polar Regions, on time scales from hourly to seasonal. This constitutes the hourly to seasonal research component of the WMO Global Integrated Polar Prediction System, as adopted by the Sixteenth WMO Congress in Resolution 57 (Cg-XVI) and confirmed in Resolution 17 of EC-64.

The project is envisaged to have a lifetime of 10 years, starting in 2013, and with thorough mid-term review highlighting progress, achievements, remaining gaps and the activities to address these gaps in the final five years.

A Steering Group has been established for this project, with an initial task of preparing the Implementation Plan. This core PPP Steering Group (PPP-SG) could be enhanced by engaging additional members for specific expertise and will focus on the implementation and refinement of the Implementation Plan.

Role

The PPP Steering Group (PPP-SG) shall be responsible (with the support of the WMO Secretariat) for:

1) Leading, coordinating and promoting the PPP, as the hourly to seasonal component of GIPPS and as an important contribution towards developing improved GFCS services in Polar Regions.
2) Facilitating implementation of the PPP through existing activities or coordinating new ones, as required.
3) Coordinating the activities with other relevant international programmes and activities, and in particular with the WCRP Polar Climate Predictability Initiative of which the focus will be on longer time scales.
4) Promoting the PPP Implementation Plan and communicating progress with the communities engaged in the activities and those who can benefit from the outcomes.
5) Monitoring and reporting progress on the Implementation Plan, and assisting with removing any barriers to progress.
6) Revising the Implementation Plan, based on best practices and lessons learned, as needed.

Reporting

7) The Chair of the PPP-SG reports annually on progress to the WWRP Joint Scientific Committee.
8) The Chair of the PPP-SG shall prepare a thorough mid-term review highlighting progress, achievements, remaining gaps and the activities to address those gaps in the final five years.
9) The Chair of the PPP-SG shall be responsible for coordination of related initiatives with bodies as set out in 3) above, including EC-PORS.

Composition

10) Members of the PPP-SG shall be from institutions involved in polar weather and climate-related research and services, chosen for a broad spread of expertise, as well as geographic and gender balance.

11) Membership of the PPP-SG shall be for terms of four years, with a possible subsequent renewal term of two years. The additional two year term may be requested based on exceptional circumstances to ensure effective implementation of the PPP.

12) The Chair of the PPP-SG is selected based on his/her complementary qualification and expertise by the Chair of the WWRP Joint Scientific Committee.

11.5 Annex 5 – International Coordination Office Terms of Reference

1) The Polar Prediction Project (PPP) International Coordination Office (ICO) is established in response to Resolution 17 of the sixty-fourth session of the WMO Executive Council.
2) The primary function of the ICO is to provide support to planning and implementation of PPP priorities, to ensure appropriate international coordination between the PPP participating Members and collaboration with related WMO programmes and other international programmes.
3) The ICO consists of qualified professional(s) and support staff. Subject to the overall policy directives of the Secretary-General of WMO and in consultation with the Director of the ARE Branch, the ICO works in close cooperation with the WMO Secretariat. The ICO is located at [TO BE DECIDED] (city, country).
4) The ICO may be supported by the WMO Member countries through secondment of experts and/or cash contributions to the PPP Trust Fund.
5) The ICO has the following responsibilities:
    a) To support and coordinate planning and implementation of PPP activities;
    b) To provide scientific, technical and secretarial support to the PPP Steering Group (PPP-SG);
    c) To assist in cooperation between the PPP and appropriate Working Groups and Expert Teams within WWRP, WCRP, CAS, CBS and other partners' relevant activities, and in particular with the WCRP Polar Climate Predictability Initiative to ensure progress in delivering the Global Integrated Polar Prediction System (GIPPS);
    d) To assist in the organization of appropriate meetings, conferences and other activities relevant to PPP;
    e) To prepare reports, correspondence and publications;
    f) To manage the PPP website and data base;
    g) To assist in fund raising and recruiting secondments to join the ICO.