

WWRP/PPP No. 3 - 2014

WWRP Polar Prediction Project Implementation Plan for the Year of Polar Prediction (YOPP)



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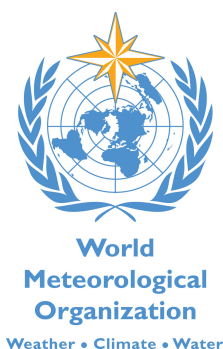
WORLD METEOROLOGICAL ORGANIZATION

WORLD WEATHER RESEARCH PROGRAMME

WWRP/PPP No. 3

WWRP Polar Prediction Project

Implementation Plan for the Year of Polar Prediction (YOPP)



October 2014

WWRP Polar Prediction Project

Year of Polar Prediction (YOPP) Implementation Plan

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For updated versions and recent documents refer to <http://polarprediction.net>

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EXECUTIVE SUMMARY

The Year of Polar Prediction (YOPP) is planned for mid-2017 to mid-2019, centred on 2018. Its goal is to “Enable a significant improvement in environmental prediction capabilities for the polar regions and beyond, by coordinating a period of intensive observing, modelling, prediction, verification, user-engagement and education activities”.

YOPP is a major initiative of WMO's World Weather Research Programme Polar Prediction Project (WWRP-PPP), and is being planned and coordinated by a Planning Group comprising the PPP Steering Group together with representatives from partners and other initiatives, including the World Climate Research Programme's Polar Climate Predictability Initiative (PCPI).

The objectives of YOPP are to:

1. Improve the polar observing system to provide better coverage of high-quality observations in a cost effective manner, primarily by carrying out observing system (simulation) experiments.
2. Gather additional observations through field programmes aimed at improving understanding of key polar processes.
3. Develop improved representation of key polar processes in uncoupled and coupled models used for prediction, including those which are particular hindrances to high-quality prediction for the polar regions, such as those relating to stable boundary layer representation, surface exchange, permafrost, mixed phase clouds, winds, extreme thermal contrasts, and steep orography.
4. Develop improved data assimilation systems that account for challenges in the polar regions such as sparseness of observational data, steep orography, cryosphere uncertainties, model error and the importance of coupled processes (e.g., atmosphere-sea ice interaction and atmosphere-land surface interaction).
5. Explore the predictability of the atmosphere-cryosphere-ocean, with a focus on sea ice, on time scales from days to a season.
6. Improve understanding of linkages between polar regions and lower latitudes and assess skill of models representing these.
7. Improve verification of polar weather and environmental predictions to obtain quantitative knowledge on model performance, and on the skill of operational forecasting systems for user-relevant parameters; and efficiently monitor progress.
8. Improve understanding of the benefits of using existing prediction information and services in the polar regions, differentiated across the spectrum of user types and benefit areas.
9. Provide training opportunities to generate a sound knowledge base on polar prediction related issues.

During the YOPP Preparation Phase (until mid-2017) plans will be further developed through international workshops, there will be engagement with stakeholders and arrangement of funding, coordination of observations and models, and preparatory research. YOPP from mid-2017 to mid-2019 encompasses four major elements: an intensive observing period, a complementary intensive modelling and prediction period, a period of enhanced monitoring of forecast use in decision making including verification, and a special educational effort. The YOPP Consolidation Phase from mid-2019 to 2022 will provide a legacy of data and publications, as well as implementation of YOPP findings to achieve the significant improvement in environmental prediction capabilities for the polar regions – and beyond, because of linkages with lower latitudes.

1. INTRODUCTION

There has been growing interest in the polar regions in recent years due to the opportunities and risks associated with anthropogenic climate change. Increasing economic, touristic, transportation and scientific activities in polar regions are leading to more demands for enhanced environmental prediction capabilities to support decision-making. Furthermore, it is increasingly obvious that weather and climate in the polar regions has an influence on the lower latitudes.

Recognising this, a number of initiatives are underway which focus on improved polar science and predictions. One particularly important international initiative is the Year of Polar Prediction, or YOPP, which will take place between mid-2017 and mid-2019, centred on the year 2018. YOPP is a key element of the WWRP Polar Prediction Project (WWRP-PPP), as explained further in Section 1.1.

YOPP is an extended period of coordinated intensive observational and modelling activities, in order to improve prediction capabilities for the Arctic, the Antarctic, and beyond, on a wide range of time scales from hours to seasons, supporting improved weather and climate services, including the Global Framework for Climate Services (GFCS). This concerted effort will be augmented by research into forecast-stakeholder interaction, verification, and a strong educational component. Being focussed on polar prediction rather than a very broad range of activities, YOPP is quite different from the IPY (the International Polar Year 2007-2008). Prediction of sea ice and other key variables such as visibility, wind, and precipitation will be central to YOPP. The presence of atmospheric linkages between polar and non-polar regions suggests that the benefit of YOPP will extend beyond the polar regions.

Extra observations will be crucial to YOPP in order to improve the polar observing system, generate the knowledge necessary to improve the representation of key polar processes in models, and provide ground-truthing that it is so important to exploit the full potential of the space-borne satellite network. YOPP will provide an opportunity for testing new observational activities, and will encourage research, development and employment of innovative systems.

A unique aspect of YOPP will be a strong virtual component through support from the numerical modelling community, encompassing models of the atmosphere, land, ocean and sea ice. Operational model runs will cover time scales from hours to seasons, with a particular focus on sea ice, since for polar regions sea ice is both a critically important environmental variable to be predicted, and a strong modulator of other weather-related predictands across a wide range of time scales.

Output from operational models and dedicated numerical experiments during YOPP will be archived and made available for researchers to better understand polar processes and prediction capabilities. The resultant archive will be valuable in itself, even without the additional planned observations to assimilate into models and help improve process understanding at a detailed level. YOPP will also explore largely uncharted territory in the area of polar forecast verification; YOPP will contribute to our understanding of the value of improved polar prediction capabilities; and YOPP will help to educate the next generation of scientists who will contribute to implementing the Global Integrated Polar Prediction System (GIPPS).

YOPP will be carried out in three stages – the YOPP Preparation Phase from 2013 to mid-2017, the YOPP Phase from mid-2017 to mid-2019, and the YOPP Consolidation Phase from mid-2019 to 2023. These are covered in Sections 3, 4 and 5 respectively.

1.1 Background

In 2011, the World Meteorological Congress decided to embark on a decadal endeavour - the Global Integrated Polar Prediction System (GIPPS) – as a legacy of the International Polar Year 2007-2008 (IPY), to benefit the global community.

Realising GIPPS will require research to improve scientific understanding of processes and interactions in polar regions, including stable boundary layers over flat and sloping terrain, atmospheric dynamics and polar specific weather, mixed-phase clouds and precipitation, ice edge and orographic effects, sea ice/ocean dynamics, hydrology, permafrost and ice sheet dynamics, and enhancements to observations, data assimilation, and modelling systems to improve predictions on all time scales.

Two closely related initiatives are underway to coordinate the required research and development:

1. WMO's World Weather Research Programme (WWRP) has established the Polar Prediction Project, whose mission 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."
2. The World Climate Research Programme (WCRP) has established the Polar Climate Predictability Initiative (PCPI) which has a similar purpose, but on time scales of a season and beyond.

The WWRP-PPP was formally established by a Resolution of WMO's Executive Council in June 2012. A Steering Group oversees the Project. An International Coordination Office for Polar Prediction (ICO) was formally established at the Alfred Wegener Institute for Polar and Marine Research (AWI) in September 2013.

Two plans have been developed and published: the *WWRP-PPP Science Plan* (WWRP/PPP No. 1 – 2013) and the *WWRP-PPP Implementation Plan* (WWRP/PPP No. 2 – 2013). The *Science Plan* provides background information on the science issues, while the *Implementation Plan* should be seen as the definitive document for the project. Both plans are available via the ICO at <http://polarprediction.net>.

One of the key elements of the WWRP-PPP is the Year of Polar Prediction, or YOPP.

YOPP as initially envisaged is covered in Chapter 5 of the *WWRP-PPP Implementation Plan*. This current YOPP Implementation Plan document (version 1.0) expands on that, based on discussions and decisions from, the following meetings, and input from external consultation during the first half of 2014. Comments and contributions from many individuals and organizations are gratefully acknowledged.

1. The first planning meeting for YOPP (YPM-1) held on 27 and 28 June 2013 at the European Centre for Medium-Range Weather Forecasts (ECMWF), in Reading, UK.
2. The fourth meeting of the WWRP-PPP Steering Group, held from 1-3 October 2013 in Boulder, Colorado, USA.
3. The second planning meeting for YOPP (YPM-2), focussing on observations, held on 8 April 2014 in Helsinki, Finland.
4. The third planning meeting for YOPP (YPM-3), focussing on modelling, held in association with the World Weather Open Science Conference in Montréal, Canada and the 5th meeting of the PPP Steering Group.

The plan will continue to be updated as required by the YOPP Planning Group (YPG).

1.2 YOPP Goal

The Goal for YOPP is to:

“Enable a significant improvement in environmental prediction capabilities for the polar regions and beyond, by coordinating a period of intensive observing, modelling, prediction, verification, user-engagement and education activities.”

This contributes to the overall Mission of the Polar Prediction Project 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.”

noting that:

“This constitutes the hours to seasonal research component of the Global Integrated Polar Prediction System (GIPPS).”

1.3 YOPP Objectives and Strategies

Improvement of predictions for polar regions requires collaborative international research to achieve the following objectives:

1. Improve the polar observing system to provide better coverage of high-quality observations in a cost effective manner, primarily by carrying out observing system (simulation) experiments.
2. Gather additional observations through field programmes aimed at improving understanding of key polar processes.
3. Develop improved representation of key polar processes in uncoupled and coupled models used for prediction, including those which are particular hindrances to high-quality prediction for the polar regions, such as those relating to stable boundary layer representation, surface exchange, permafrost, mixed phase clouds, winds, extreme thermal contrasts, and steep orography.
4. Develop improved data assimilation systems that account for challenges in the polar regions such as sparseness of observational data, steep orography, cryosphere uncertainties, model error and the importance of coupled processes (e.g., atmosphere-sea ice interaction and atmosphere-land surface interaction).
5. Explore the predictability of the atmosphere-cryosphere-ocean, with a focus on sea ice, on time scales from days to a season.
6. Improve understanding of linkages between polar regions and lower latitudes and assess skill of models representing these.
7. Improve verification of polar weather and environmental predictions to obtain quantitative knowledge on model performance, and on the skill of operational forecasting systems for user-relevant parameters; and efficiently monitor progress.
8. Improve understanding of the benefits of using existing prediction information and services in the polar regions, differentiated across the spectrum of user types and benefit areas.
9. Provide training opportunities to generate a sound knowledge base on polar prediction related issues.

In order to achieve the above research objectives the following strategies will need to be pursued:

- A. Strengthen linkages between academia, research institutions and operational forecasting centres.
- B. Establish and exploit special research data sets that can be used by the wider research community and forecast product users.
- C. Establish a common data archive.
- D. Link with space agencies
- E. Promote YOPP with funding agencies.
- F. Develop strong linkages with other initiatives.
- G. Promote interactions and communication between research and stakeholders.
- H. Foster education and outreach.

These strategies have all been borne in mind in the development of, and underpin, the following plans.

2. YOPP STAGES AND MILESTONES

The Year of Polar Prediction is scheduled to take place from mid-2017 to mid-2019, centred on the year 2018. The intention is to have an extended period of coordinated intensive observational, modelling, prediction and user engagement activities in order to improve polar prediction capabilities on time scales from hourly to seasonal. This will be augmented by research into forecast-stakeholder interaction, verification and a strong educational component. YOPP is quite different from the IPY that took place in 2007-2008, with YOPP being focussed on polar prediction, as compared to IPY's broad range of activities including studies of the Earth's inner core and social processes that shape resilience of circumpolar human societies.

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

YOPP will be implemented in three different stages: a Preparation Phase, the YOPP Phase, and a Consolidation Phase, as outlined in Figure 1 below.

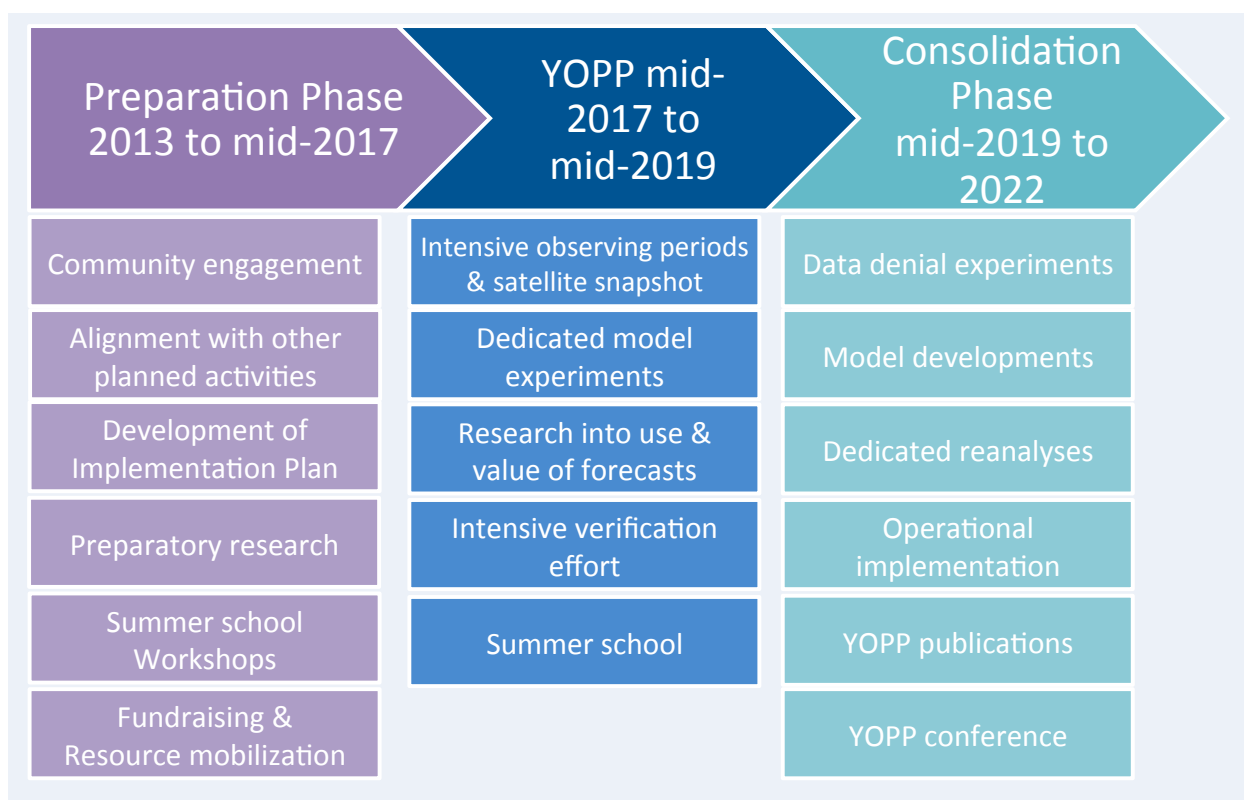


Figure 1. Three stages of YOPP, including the main activities for each stage

The key milestones for the project are shown in Table 1. A more comprehensive list of future milestones is given in Annex 1, and will be regularly updated as the project proceeds.

Table 1. Key Milestones for YOPP

Milestone	Target Date (YYYY.MM format)
PPP Implementation Plan published, including chapter on YOPP	2013.04
First YOPP Planning meeting (YPM-1), in association with Polar Prediction Workshop at ECMWF in Reading, England	2013.06
YPM-2 meeting in association with Arctic Science Summit Week and Arctic Observing Summit in Helsinki, Finland	2014.04
PPP SG-5 (including YPM-3) meeting in association with the World Weather Open Science Conference in Montréal, Canada	2014.08
YOPP Implementation Plan 1.0 Issued	2014.10
PPP-IAMAS High Latitude Dynamics Meeting in Bergen, Norway	2015.03
YOPP Summit in Reading, UK	2015.07
First PPP/YOPP/PCPI Summer School on Polar Prediction in Abisko, Sweden	2016.04
YOPP Data Archive System established	2016.12
Experimental operational coupled atmosphere-sea ice-ocean models ready to run by operational modelling centres	2016.12
YOPP Phase Formally Launched at WMO EC-69	2017.06
Second PPP/YOPP/PCPI Summer School on Polar Prediction	2018.06
MOSAIC Planned to Commence	2018.09
End of YOPP Phase / Start of YOPP Consolidation Phase	2019.06
YOPP Synthesis Workshop	2020.06
YOPP Final Conference	2021.05
End of YOPP Consolidation Phase	2022.12

3. YOPP PREPARATION PHASE (2013 TO MID-2017)

The Preparation Phase will be important for the success of YOPP. It involves a number of aspects – overall planning, engagement with stakeholders, coordination of observations and related field programmes, promotion of modelling activities, establishment of data archive systems, preparatory research, and involvement of funding agencies. The overall structure for the Preparation Phase is shown in Figure 2.

Preparation Phase 2013 to mid-2017	3.1 Development of strategy	3.2 Stakeholder Engagement	3.3 Coordination of Programmes	3.4 Preparatory Research
	3.1.1 YOPP Planning	3.2.1 Exploration of user needs and knowledge contributions	3.3.1 Promotion of additional data (incl. AMDAR and ships)	3.4.1 Observations related
	3.1.2 International YOPP planning workshops	3.2.2 Identification of YOPP partners	3.3.2 Coordination with major interntl. field experiments	3.4.2 Modelling and forecasting related
	3.1.3 Implementation plan	3.2.3 Exploration of means of funding	3.3.3 Promotion of modelling activities incl. coupled models	3.4.3 Verification
	3.1.4 Re-evaluation of previous field campaigns		3.3.4 Establishment of YOPP Data Archive System	3.4.4 Forecast of Use and Decision Making
				3.4.5 Workshops and Education

Figure 2. YOPP Preparation Phase

3.1 Develop Strategy

3.1.1 YOPP Planning

YOPP was devised following the first meeting of the PPP Steering Group in Geneva in December 2011. The initial concept for YOPP is outlined in the PPP Implementation Plan (WWRP/PPP No. 2 – 2013).

The first YOPP Planning Meeting (YPM-1) was held on 28–29 June 2013 at ECMWF, involving members of the WWRP-PPP Steering Group as well as participants representing partners including Arctic ECRA, THORPEX, APECS, WGSIP, MOSAiC, GODAE OceanView, WGNE, IASC/AWG, ISAC, and S2S.

A YOPP Planning Group (YPG) was established in October 2013 during the fourth meeting of the PPP Steering Group in Boulder, CO USA. This consists of the full PPP Steering Group, augmented, as available and agreed, by representatives of other relevant partners and initiatives (see Table 2). Beside being responsible for planning, the YPG will also coordinate/oversee

preparatory research activities (2013-2016), and assist in presenting YOPP plans to relevant funding agencies (2014), e.g., Horizon 2020.

3.1.2 International YOPP Planning Workshops

Two further YOPP planning workshops were held in 2014. YPM-2 in April 2014 was focussed on observations, and held in association with the Arctic Science Summit Week and Arctic Observing Summit in Helsinki. YPM-3 in August 2014 was focussed on modelling aspects, and held in association with the World Weather Open Science Conference in Montréal and the 5th meeting of the PPP Steering Group.

The fourth international YOPP Planning Workshop will be a major event, called the YOPP Summit, and is tentatively planned for July 2015.

3.1.3 Implementation Plan

This is Version 1.0 of the YOPP Implementation Plan. The YOPP Planning Group will update it as required in future.

3.1.4 Re-evaluation of Previous Field Campaigns and Model Datasets

The YPG will re-evaluate data from previous field campaigns and model experiments producing enhanced output for dedicated programmes. Many valuable lessons can be learned about how they were organised and funded, what data were gathered, what was most valuable, how the data were archived, etc. Also, the data themselves continue to be useful and can be further exploited, as noted in Section 3.4 on Preparatory Research.

3.2 Stakeholder Engagement

3.2.1 Explore User Needs and Knowledge Contributions

It will be essential to engage with forecast users (stakeholders hereafter) to ensure their needs and potential contributions 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 WWRP-SERA expert team who will establish a YOPP for Society (YOPP-S) subcommittee in consultation with representatives from EC-PORS, NMHSs, WMO JWGFVR, key user groups, and relevant social science bodies such as the International Arctic Social Sciences Association (IASSA).

Existing resources documenting user requirements will also be used. They include a white paper produced by the Services Task Team of EC-PORS, and a user requirement review by the European Union Seventh Framework (FP7) funded project Sea Ice Downstream services for Arctic and Antarctic Users and Stakeholders (SIDARUS, <http://sidarus.nersc.no/>) available at http://sidarus.nersc.no/sites/sidar.us.nersc.no/files/D1-1_User-requirement-review_v-2_1.pdf.

3.2.2 Identify YOPP Partners

The following key partners have been identified (Table 2). These are the coordinating bodies. Many other organizations and groups are expected to contribute to YOPP. A table of those that have been identified so far, along with their expected activity contributions, is given in Annex 2.

Table 1. Key partners (coordinating bodies) for YOPP

Group	Role
APECS	Implementation of educational component of YOPP
CBS / Integrated Observing Systems	Facilitating the improvement of polar observing systems
EC-PORS	Overall policy perspective
EUCOS	Additional observations over northern polar regions
GASS	Coordination of polar model intercomparison projects
GCW	Cryospheric observations, and potential use of the GCW portal
GODAE Oceanview	Development and implementation of the intensive modelling campaign (ice-ocean)
IASC	Planning of YOPP for northern polar regions
IASOA	Contributing observations and research based on pan-Arctic atmospheric observatories
IICWG	Coordination of operational ice services
MOSAic	Gathering data from and around the drifting observatory to improve coupled models and coupled data assimilation, and for ground truthing of satellite data
PCPI	Close coordination of related activities
PSTG	Supporting the exploitation of satellite data ("satellite snapshot")
S2S	Sub-seasonal to seasonal aspects of polar predictions
SAON	Coordination of Arctic Observations
SCAR	Planning of YOPP for southern polar regions
Sea Ice Prediction Network	Collaboration on Arctic sea ice prediction
SOOS	Coordination of Southern Ocean Observations
WCRP/CliC	Close coordination of related activities of CliC and its working groups
WGNE	Development and implementation of the intensive modelling campaign (atmosphere)
WGSIP	Encouraging institutions with prediction capability to use initial conditions that take advantage of the new available data from YOPP to rerun some sub-seasonal and seasonal predictions

3.2.3 Explore Means of Funding

An ambitious concerted effort such as YOPP will require funding and resources for the various planning and implementation activities.

Funding for planning and coordination will primarily be through contributions to the Polar Prediction Trust Fund, as well as resources provided by Germany for the operation of the International Coordination Office for Polar Prediction, and GFCS-related funding from Environment Canada.

Many research activities will require international, national or regional funding, and a commitment by modelling and forecasting centres. A full package of promotional material is being compiled, which can be used to assist with national approaches to funding agencies. The general profile of YOPP can also be raised through publications including the WMO Bulletin and the Bulletin of the American Meteorological Society, as well as by participation in events such as the Arctic Science Summit Weeks and meetings of SCAR.

Support for YOPP research and planning can also come “in kind” – for example, through provision of observations from commercial shipping, contributions from polar research centres, and other resources.

3.3 Coordinate Observations and Modelling

In the context of YOPP, the coordination of observations and modelling typically has three main objectives: (i) to produce numerical weather predictions to support ad hoc campaigns targeted to diagnose and understand specific processes and phenomena; (ii) to improve initial conditions for operational numerical weather and environmental predictions; (iii) to improve the representation of parameterized processes and surface interactions in models designed for weather prediction and climate simulations. Because YOPP will include both high-resolution atmospheric and fully coupled (atmosphere-land-ocean-ice) model experiments, a wide variety of observations will be of interest.

3.3.1 Promote Additional Observational Data

Observations are needed during YOPP to fill observational gaps and improve model initialization, to provide data for enhanced process understanding and model development, and for verification. The promotion of general additional observational data in polar regions for observing system design and model development is a “Flagship Element” for the overall Polar Prediction Project, and will have wider and longer benefit than just for YOPP.

The northern and southern polar regions are very different in terms of their observational networks and characteristics; it is important to ensure that attention is paid to both south and north. However, for both polar regions the observing system is in general so poor that a few extra observations can make a big difference.

The main activities during the Preparation Phase will be to identify and work with partners to promote additional data and to promote making available existing observations to be used during YOPP. The observational data which are considered to be most useful during YOPP are discussed in more detail in the next section on the YOPP Phase. In summary what is needed is to:

- Work with partners such as EUCOS to plan and promote additional routine observations.
- Work with PSTG to promote satellite observations, including:
 - Providing a statement of support for the suite of polar satellite products, and considering special observational requirements for YOPP.
 - Endorsing preparations for a full exploitation of new EUMETSAT Polar System Second Generation (EPS-SG) instrument capability (e.g., the Ice Cloud Imager - ICI), as well as expressing support for concepts for new satellite missions targeting polar regions (e.g., ATOMMS).

- Promote campaign observations and enhanced and sustainable permanent capacity at supersites and reference sites, including IASOA sites.
- Coordinate YOPP activities with ongoing polar observing system efforts.
- Encourage the forecast user community to actively take measurements (e.g., additional observations from ships).
- Promote field campaigns during YOPP.
- Identify existing data/networks useful for exchange, identify gaps in making such data available on the WMO Information System (WIS), e.g., via the GTS, including aspects such as exchange formats and protocols.
- Ensure that systems are in place for relevant field campaign observations to be made available in near-real time on the WMO Information System.
- Promote YOPP as providing a framework for testing new activities, and explicitly solicit research, development and employment of innovative systems.
- Promote sea ice observations, buoy observations, and snow measurements on land and ice.
- Ensure that polar prediction needs are taken into account as part of WMO's CBS Rolling Review of Requirements (see <http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html>).

During the Preparation Phase, the WWRP DAOS Working Group will be asked to provide support for an observing system design for polar regions – using techniques such as adjoint forecast sensitivity to observations.

3.3.2 Coordinate with Major International Field Experiments

A particularly interesting major international field experiment, currently being planned, is the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC; www.mosaicobservatory.org). This is *potentially* a significant component of the overall YOPP plans; it complements YOPP and contributes to its mission. The main interest for YOPP lies in the use of the data to improve coupled models and coupled data assimilation, and for ground truthing of satellite data.

MOSAiC will be based around a polar research vessel (options are AWI's *Polarstern* or Canada's *Amundsen*) starting in newly formed Arctic sea ice around September 2018, and drifting with the ice over the course of at least a year, to study a full annual cycle. The project is specifically designed to study interdisciplinary process interactions linking the central Arctic sea-ice, atmosphere, ocean, and biosphere. There will also be a number of Intensive Observing Periods (IOPs) – for example, when the light returns. Such IOPs are likely to include contributions from aircraft flights, as well as complementary drifting vessels.

Unlike the previous SHEBA experiment in 1997/1998, MOSAiC will be conducted in first-year sea ice, and modelling links will be built in from the start. Collaboration and involvement of YOPP is therefore particularly important. The central observatory on the research vessel will have intensive, inter-disciplinary observations. Additional observations will be taken at points around the central site – to sample mesoscale variability – which should aid in parameterization of subgrid-scale processes. Scales involved are likely to represent typical “grid boxes” used in weather and climate models. Coordinated planning between the YOPP Planning Group and the MOSAiC organizers will take place, especially regarding aspects on frequency and spatial distribution of observations to best serve the community improving model processes.

MOSAiC will take a number of steps beyond past drifting stations such as SHEBA. It will benefit from new technologies and observing capabilities that have developed in recent decades. Also, while SHEBA was primarily focused on the surface energy budget of multi-year sea ice, MOSAiC is targeting the coupled system and first year sea ice. Specific areas of interest are

clouds, the atmospheric and oceanic boundary layers, the energy budget of sea ice, upper ocean processes, and biogeochemistry.

The YOPP Planning Group has already formally expressed support for MOSAiC, emphasising the alignment with YOPP objectives. Cross-participation in meetings is planned. YOPP is providing input to the MOSAiC Science Plan and is identifying atmosphere, ice, and ocean parameters that are critical to measure and is helping to identify the spatial and temporal scales to measure them.

There are several field campaigns that will be occurring during the YOPP preparation period including a six month long Norwegian young sea cruise 2015 (N-ICE2015) north of Svalbard, the three month long atmospheric and oceanographic observations during SWERUS-3C in 2014 as well as several other experiments in the marginal ice zone in the Chukchi and Beaufort seas. These experiments should provide useful data for YOPP studies.

There is a wealth of data from land-based stations currently being collected as part of the Sustaining Arctic Observing Network (SAON). This network is designed to observe the ongoing changes in the Arctic through manned observatories, field experiments, and autonomous instrument platforms. The YOPP Planning Group will work to coordinate efforts with SAON to both in data assimilation and observing system design.

Based on typical field activity, there will likely be other polar experiments during the YOPP Phase, including a long duration Russian Arctic drift station and also multiple icebreaker cruises from one to three months long. The YOPP Planning Group will reach out to the groups leading these efforts and work to coordinate measurement strategies and data archiving plans.

Other relevant campaigns outside the polar regions include, for example, the T-NAWDEX field experiment in boreal autumn 2016, having clear synergies with YOPP, particularly in relation to linkages between mid-latitude and polar regions and vice versa.

3.3.3 Promote Modelling and Forecasting Activities including Coupled Models

The intention for YOPP is to carry out high-resolution atmospheric and *coupled* model experiments to explore the benefit of a better representation of key polar processes through significantly enhanced horizontal and vertical resolution as well as explore the performance of existing parameterizations in polar regions. These model experiments are planned and coordinated during the Preparation Phase. Involvement of global numerical weather prediction centres through WGNE and process modellers in GASS are crucial aspects during this phase.

Coupled modelling requires realistic descriptions of the individual components (atmosphere, ocean, sea ice, and land) as well as the coupling between them through fluxes of momentum and heat. The coupled system poses difficulties in finding a proper balance between the levels of complexity of the components as well as and choosing adequate model horizontal and vertical resolution. Special challenges in polar areas are snow on sea-ice and land, permafrost and land ice. How to best use the limited observations in the data assimilation algorithm to initialize the coupled system and to design the technical framework employing couplers or integrated code are some of the challenges.

Given that the project is about “prediction” – not just modelling – it is useful to reflect on what that means. Weather prediction is only meaningful as long as one can trust the information given about weather elements on specific sites at future times, and the information content is higher than can be extracted from climate statistics for the same site and date. Key forecast qualities are reliability and resolution of the information. Predictability is lost when prediction errors

no longer grow with lead time and thus no qualified prediction is systematically better than any arbitrary climatic state. If there are no systematic errors, a sufficiently large sample of forecasts will produce the climate statistics for all lead times.

The predictability limit is a consequence of the inherent instabilities, and the growth rates of errors associated with free flows increases with decreasing scales, and errors saturate first for the smallest scales. For near perfect prediction models, the accuracy of very short-range forecasts will therefore determine an upper bound of the predictability. With improved observations and methods to exploit them in data-assimilation, the realized predictability can be improved, provided model imperfections are also reduced. Experience from the ensemble prediction system (e.g. at ECMWF) shows that the realized predictability is mainly extended when both the modelling of dynamical instabilities and the assimilation of data are improved.

Probabilistic predictions, presumably in the form of carefully selected ensembles of deterministic forecasts, are necessary to fulfil the requirements for reliability with as high information resolution as possible. There are a number of operational global ensemble systems available designed for the medium range (several weeks) and for seasons ahead. Several deliver output to the TIGGE archive, which is expected to continue through the YOPP period. Global ensemble analysis and prediction systems may well study the impacts of improved polar observations and model processes on predictions up to seasons ahead, and on prediction quality inside as well as outside the polar regions. It is obvious that the upper oceans, sea-ice, land-surface with vegetation and snow cover are dynamically coupled in such systems, although at present it is unclear how good they are represented in models. Uncertainties associated with these surface processes need to be included in order to obtain realistic estimates of prediction spread, and thus reliability and resolution, for all forecast ranges and regions.

Short-range ensemble prediction systems on the mesoscale are less widely developed than global. These systems are developed for lead times up to 2-3 days, or even shorter, and with frequent updates. The associated spatial scales involve instability dynamics with fast growth rates and short predictability horizon, except for the subset forced by interactions with large scale features and quasi-fixed lower boundary conditions, for which the errors grow in accordance with the large-scale errors. In order to operate meaningfully, initial states and their uncertainty need to be frequently and quickly produced with high accuracy. Also, uncertainties arising from lateral and lower boundary conditions must be estimated. There are only a few short-range operational systems with partial coverage of polar regions available today (2014) at forecasting centres, e.g., MET Norway. Extreme weather in challenging environments are generally in focus, such as polar lows, low-level jets, and topographically influenced flows such as katabatic winds and hydraulic shocks. Forecast centres with polar responsibilities and ambitions are highly encouraged to participate in YOPP and express their particular challenges and opportunities.

Further details on the proposed YOPP model experiments are given in Section 4.2.1.

A specific recommendation from the Polar Prediction Workshop (held at ECMWF in June 2013) was to aim for an experimental version of prototype *short- to medium-range* coupled atmosphere/ocean/sea-ice modelling analysis and forecasting systems at operational weather centres by the time of YOPP. This would allow the timely evaluation of this system in coordination with other centres and with the best available datasets. Other major centres should also be encouraged to implement experimental or operational fully coupled modelling systems, which can be used for experiments during YOPP. Such coupled models are already running at several leading operational *long-range* forecast centres. Engagement will also be essential with other modelling community partners and contributors, including WGNE and those involved in AMOFW/AMPS.

Operational model support for MOSAiC and any other major international field campaigns needs to be planned. Operational centres will need to offer free and real-time data dissemination useful for campaign planning. The locations and equipment of existing IASOA and similar observatories, as well as drifting stations such as MOSAiC and the Russian drifting “North Pole” stations, should be assessed for defining their relevance for model evaluation and expected impact in data assimilation experiments. The observations should be provided in real time and also become an important component of the YOPP Data Archive, also for later use in numerical experiments.

The sub-seasonal to seasonal prediction community, including through the S2S project, as well as the WMO Global Producing Centres for long-range forecasts, should be engaged to perform intensive real-time predictions during YOPP with frequent updates (once a day for sub-seasonal and once a week for seasonal) during interesting case studies. In coordination with WCRP PCPI coupled short-term forecasts with Earth System Models (ESMs), Transpose CMIP experiments, can be conducted to learn about biases in fast model processes that lead to systematic errors. This could become a contribution to the ESM-SnowMIP (Snow Models Intercomparison) initiative.

Process-oriented model intercomparison projects of interest for YOPP are already ongoing and will be further developed in GASS. The projects typically target a specific model problem and utilize observations and detailed process models such as LES and CRMs to test the parameterizations used in NWP and climate models. Of relevance for the Polar regions are the WGNE/GASS Grey-zone project that focus on the problems with partly resolved, partly parameterized problems and the first study case is an Arctic cold air outbreak event that attract participation from a whole suit of models ranging from LES, via limited area models to global weather and climate models. Another example is GABLS4, which focuses on a diurnal cycle in summer at Dome C in Antarctica, a case that was designed to meet a specific need identified at the ECMWF Polar Prediction Workshop. The interaction between the atmosphere and the snow-covered surface is of particular interest in this case besides the boundary layer that becomes strongly stably stratified and very shallow during the night. Transformation from marine to Arctic air is in focus in a third GASS intercomparison activity.

3.3.4 Establish YOPP Data Archive System

A YOPP Data Archive System should be established in advance of the YOPP Phase, which will allow access to observational, model and forecast data. Such a Data Archive System is likely to be in the form of a portal with consistent metadata and pointers to other online locations where data can be retrieved, including formally published data, and model output archives. The YOPP Data Archive System will serve as the backbone of concerted verification activities during the YOPP Phase (see Sections 3.4.3 and 4.3.2).

It should be mandatory, where possible, for all participating projects to make their data available through the GTS/WIS, using WMO standards including BUFR. This will ensure the data are available for operational use, and that existing global data archives will automatically include additional data gathered during the YOPP Phase.

There should be a special issue on YOPP in the data publishing journal Earth System Science Data (ESSD, <http://www.earth-system-science-data.net/>). There are some requirements for data sets to be published (e.g., one needs a DOI). At the moment ESSD is indexed in the subscriber-only Scopus bibliographic database, but it is anticipated that ESSD will also be indexed by the Web of Science (WoS) databases by the time the YOPP Phase starts in mid-2017.

The data archive PANGAEA (<http://www.pangaea.de/>) fulfils the requirements of ESSD and would be willing to serve as one of the "hubs" for YOPP related data. Data centres in other countries that would also be happy to host YOPP data should be identified.

Other matters that should be taken into account for the YOPP Data Archive System include development of the WMO Global Cryosphere Watch (GCW) web portal (see pre-operational portal at <http://gcwdemo.met.no/>), and consistency with WMO Information System (WIS) standards. This includes the use of WMO standards such as BUFR for data encoding, rather than developing new formats. Using BUFR will help making observations visible for operational forecasting centres.

It would also be good to take advantage of expertise and experience from those involved in efforts such as YOTC, TIGGE, D-PHASE, the IASOA Data Access Portal (<http://www.esrl.noaa.gov/psd/iasoa/dataataglace>), and the Polar Data Catalogue (<https://www.polardata.ca/>) Existing platforms and protocols such as the Earth System Grid Federation (<http://esgf.org>), Observations for Climate Model Simulations (<https://www.earthsystemcog.org/projects/obs4mips/>) and Analysis for Model Intercomparison Projects (<https://earthsystemcog.org/projects/ana4mips/>) should be considered.

A registration system for users of YOPP Data will allow better tracking of downloading and usage of data, and facilitate attribution and acknowledgement of data sources in research papers.

For model datasets, the archive may be similar to that which was implemented for the Year of Tropical Convection (YOTC) – see <http://yotc.ucar.edu>.

Planning for the model dataset archive should be through a small subgroup, which can review the experiences of archiving for YOTC and TIGGE, as well as the implementation of the S2S database, while recognising that YOPP is a different project. Some differences include that the archive would need to include not just atmospheric model data. The review could look at data downloads and reported uses of the YOTC data, although such information needs to be interpreted with care. Some points to consider for establishment of the model archive are:

- To archive tendencies primarily on pressure levels (model levels may also be useful for particular purposes including boundary layer studies).
- To archive model output on native grids (rather than a common interpolated grid), particularly for ocean models.
- To archive additional fields more frequently (e.g., hourly) such as instantaneous and accumulated fluxes (atmosphere snow-soil) and the state of continental surfaces (i.e., snow and soil characteristics).
- To capture important processes over the hours-to-seasonal time scale of the PPP, it is important to archive at a high temporal resolution.
- More than one model should be archived and ensemble forecasts should be included where available.
- Coupled models on the short- to medium-range time scales including sea ice and more realistic polar land models should be in place by the YOPP Phase, which should allow for the possibility of model intercomparisons in the dataset of fully coupled versus atmospherically driven sea ice predictions. (Such coupled models already exist for longer ranges.)
- The locations of existing IASOA and similar observatories, as well as drifting stations such as MOSAiC and the Russian drifting "North Pole" stations, should be targeted for scale-relevant comprehensive model outputs as well as satellite products. These will form an

important component of the YOPP Data Archive System, and be invaluable for evaluation of models, parameterization development and improvement of satellite products.

3.4 Preparatory Research

Preparatory research in the following areas must be accompanied by the development of coupled prediction systems (atmosphere-ocean-cryosphere) that are in place for YOPP, at least for some centres. Many of these research activities will of course extend into and beyond YOPP.

3.4.1 Observation Related

Preparatory research in this category will help guide decisions on what additional observations and field experiments, and where, would be most valuable during YOPP.

Data denial experiments can help assess the analysis and forecast impact of observations in areas and periods where additional observations have been made available - for example, additional buoys deployed during IPY, SHEBA data, and data of the Russian drifting “North Pole” stations. The same approach can be applied to other observation types such as satellite data to obtain a global picture of basic observational requirements and optimized future observing systems. The experiments need to distinguish between process and predictive skill oriented applications. The former would mostly aim at a better representation of physical processes for critical topics such as clouds, boundary layers and atmosphere – land - sea ice - ocean coupling while the latter would aim at enhancing large-scale predictive skill also beyond polar regions. Both require regime dependent evaluation.

OSSEs can provide guidance for development and deployment of new sensors and observation networks, both satellite and surface-based. However, there are concerns about the validity of OSSEs in areas where model biases are large, and the significant experimental effort involved. More basic evaluation is needed.

Data assimilation offers a number of tools to investigate the value of observations such as ensemble statistics providing information on analysis uncertainty, analysis increments and adjoint sensitivity which provide parameter, level and region specific information on where observational impact is large and model errors are significant. Tendency diagnostics enable projection of this information onto individual processes. Model experiments can also assist planning for field experiments such as MOSAiC – in particular, relating to subgrid parameterization and Large Eddy Simulations (LES); collaboration within GASS will be of aid in this. Model experiments can also guide the selection of locations for manned and autonomous observatories.

3.4.2 Modelling and Forecasting Related

Preparatory research and development in this category will help guide decisions on modelling systems to be deployed during YOPP, as well as leading to fundamental improvements in those models. During YOPP it is envisaged that increased engagements are sustained over longer periods, in order to obtain representations of a wide spectre of forecast challenges, including any that possibly not yet are well known.

In addition, further campaigns are needed with extensive advanced observations over shorter periods. These are expected to be dedicated to specific features and processes where obvious shortage of quantitative knowledge and understanding is limited, and models employs parameterizations of various degree of sophistication, and the role of uncertainties in these parameterizations are hardly known. Operational ensemble predictions, global and regional, should be used to increase the success-rate of such campaigns, and, even more important, model groups should be involved in the planning. Process models which partly or entirely resolve key

physical processes (e.g., convection resolving or permitting models) should be integrated in the experiments from the start of the planning.

Tests will be carried out to explore the impact of various different vertical and horizontal resolutions, and how they handle orography, convection, clouds, dynamics at the sea ice-ocean boundary, synoptic systems, polar lows, atmospheric jets, and mesoscale dynamics. Aspects related to the partial resolution of convection, for example near the sea-ice border in cold-air outbreaks, are already coordinated with the GASS/WGNE grey-zone project.

Processes

With regard to processes, the correct interplay between the boundary layer, cloud and surface processes is crucial for the accurate description of vertical mass and momentum transport, surface radiative and energy budget, and the interaction between the shallow polar lower troposphere and large-scale advection in NWP models. These processes are also critical for accurately reproducing changes in the sea ice cover and ocean. The focus here is on mesoscale processes near or at the surface, which is not to minimise the importance also of the relevant synoptic scale aspects, including upper-level processes (e.g., blocking, Rossby wave breaking, formation of tropopause folds).

There is more detail on YOPP modelling aspects in Annex 3. The main problem areas are:

- The representation of stable boundary layers (over flat and sloping terrain) and their interaction with stratiform clouds and snow covered surfaces.
- The role of horizontal and vertical moisture advection, and turbulence in cloud formation given very low Cloud Condensation Nuclei and Ice Nuclei concentrations; the speed of hydrometeor phase transitions in mixed phase clouds.
- The accurate simulation of small-scale sea ice features (e.g., ridges, leads, melt ponds, ice edge), including impacts of waves.
- The representation of boundary-layer processes and extreme fluxes associated with sharp contrasts in surface properties, in particular the sea-ice border and leads or open ocean bordering snow-covered land surfaces.
- Experimentation and observation of land and freshwater systems in the cryospheric system.

These processes should be studied in a concerted way and in communication with existing groups such as GASS and FAMOS to enable improvement of parameterizations. Exploiting the wealth of information from existing field campaigns such as SHEBA and IceBridge, and revisiting reanalyses to assess the role of moisture transport and cloud formation, and Cloudsat/Calipso datasets to study mixed phase clouds, promises a well-founded characterization of model shortcomings.

Analysis of Model Data

The Preparation Phase can benefit from existing datasets that have been produced for similar or other projects but that include more output than usually available from operational centres:

- Global and regional reanalyses covering long time periods with a frozen model and data assimilation system reducing the dependence of performance to observation availability and predictability. Examples are ERA-Interim/20C, JRA-55, MERRA-2, Arctic System Reanalysis, Climate Forecast System Reanalysis, etc.

- ECMWF Year of Tropical Convection dataset (May 2008 - April 2010, i.e., covering part of IPY period) including output of 3/6 hourly model tendencies for temperature, wind and moisture.
- TIGGE and TIGGE-LAM datasets including global and regional ensemble output from operational centres.
- Data denial experiments focusing on impacts of existing observations, and thus envisaging potential impacts of new observations.
- WGNE Transpose-AMIP project providing NWP type evaluation of Atmospheric General Circulation Model hindcasts in short and medium range (October 2008 - August 2009, i.e., covering part of IPY period).
- SPARC IPY Data (<http://www.sparc-climate.org/data-center/data-access/sparc-ipy/>).

The above datasets are expected to provide guidance for dedicated numerical experiments to be run in the YOPP Preparation Phase and the YOPP Phase itself. The combined assessment of reanalyses, YOTC, TIGGE and Transpose-AMIP is expected to help the identification of dominant sources of model error from analysis and forecast ensemble spread, model tendencies and analysis increments, and allow defining commonalities between NWP and climate models in this respect.

Model data can also be a resource for exploring linkages between mid-latitude and polar regions. Mechanisms for this may include poleward breaking Rossby waves, blocking and heat extremes, cold-air outbreaks, and water vapour and heat transport.

Data Assimilation

Research and development should be encouraged to improve data assimilation in polar regions. Observational data usage is sub-optimal because observation operators simulating satellite observations are inaccurate over snow and sea-ice, in the presence of very dry conditions and mixed-phase clouds. This leads to the rejection of large data volumes. Consequently, observation types (such as infrared spectrometers and radio occultation) and analysis techniques that promise better sensing of the shallow lower polar troposphere are not fully exploited.

Coupled data assimilation is expected to produce significant progress in predictive skill in the near future, particular in the medium range and beyond. Since YOPP is a milestone for running experimental coupled systems at global scale the YOPP Preparation Phase is crucial for system development and testing. Suitable algorithms and coupling strategies need to be selected for application from short to seasonal range. There is a large challenge in formulating ice state estimation systems and coupled error covariance between atmosphere, land, ice, wave and ocean components. Data from the THORPEX IPY cluster may be useful for testing. In particular, the development of automated SAR retrievals could provide highly-valuable fine-scale information on the sea ice cover. Space-borne radars and microwave imagers provide information which can be crucial for the initialization of sub-seasonal and seasonal predictions. As SAR data is used in the operational ice chart production, assimilation of such charts is a possible way to better include SAR based sea ice information into operational models.

Also, background error formulations have been designed and tuned with lower latitudes in mind and require adjusting. Since these formulations drive both the weight given to observations in the analysis and the spread of ensemble analyses and forecasts, better error characterisation promises substantial progress in both NWP analysis accuracy and forecast reliability estimates. Concerning observation data coverage, the polar regions are more densely observed by polar-orbiting satellites than, say, the tropics. This implies that the observation-error statistics, including spatial error correlations, are especially important for polar data assimilation, and this needs to be studied.

A special focus is expected on the assimilation of regular and extra observations of the continental surface conditions (i.e., snow cover characteristics and soil conditions such as soil moisture and permafrost) and on the evaluation of snow cover and polar soil analyses in NWP systems. Snow on sea-ice poses additional observational problems.

Representation of model uncertainty in polar regions is an issue here as well.

Another area where YOPP can play a larger part is in data assimilation and modelling of the stratosphere, including the assimilation of ozone measurements. The two leading aspects are ozone monitoring and the representation of the dynamic interaction between troposphere and stratosphere. For the latter, ozone observations provide wind tracing information and drive radiative heating. Other trace gases, namely water vapour, are relevant in this context as well. PPP/YOPP could suggest to WGNE that they carry out experiments on improved data assimilation in the stratosphere, with the assistance of the WWRP DAOS Working Group. This can also be an area of collaboration between PPP and PCPI.

3.4.3 Verification

The Preparation Phase of YOPP will focus (i) on estimating the baselines for predictive skill in polar regions, and (ii) on establishing the verification framework and on implementing the systems to be used during the YOPP Phase. It needs to be assessed and decided as early as possible (2015 at the latest), whether a (quasi) real-time concerted verification undertaking is feasible - and by whom - during YOPP in order to be able to establish all required verification activities before YOPP starts. The following issues need to be considered:

- Definition and construction of the YOPP Data Archive System (ref. Para 3.3.4) in such a manner to facilitate forecast verification, and the definition and implementation of a common, centralized (possibly (quasi) real-time) verification undertaking utilizing comprehensive verification systems/packages. Lessons learnt from TIGGE and, in a smaller and more regional scale, from the WWRP FROST-2014 verification activities should be taken into account.
- Definition of data sources, polar prediction variables and especially appropriate and relevant verification metrics and suitable processing methods for the observation datasets. Verification issues and potential drawbacks when using model analyses originating from data assimilation systems need to be studied and realized. The recently initiated work by WGNE on the evaluation of systematic differences between analyses should continue jointly with YOPP activities, given the assumption that analysis biases are likely to be more significant in polar regions. Only a few quantities, if any, are observed adequately in polar regions, especially at the surface and in the lower atmosphere. Satellite data are therefore expected to become more important as a reliable verification data source.
- Diagnostic verification (e.g., scale-dependent verification) will be of special value and will also provide a link between modellers and the verification community.
- In addition to various traditional meteorological variables, there should be special emphasis on sea ice verification during YOPP. Especially for sea ice verification, the applicability of spatial verification methods should be investigated. Sea ice is a major concern to a variety of stakeholders whose needs run the gamut of forecast time and space scales and, hence, ice centres should be contacted for extensive collaboration. This would be aided by moving towards automated rather than manual ice analysis, and the planned launch of the RADARSAT Constellation in 2018 (<http://www.asc-csa.gc.ca/eng/satellites/radarsat>) which could be timely for YOPP.
- It is highly important to have all user-relevant parameters being verified, including traditional basic variables like temperature, wind, precipitation and visibility, and by using all available

observations, because these tend to be located where people are, anyway. Since many communities in polar regions are critically dependent on aviation, attention should be given to the verification of aviation weather variables. Icing conditions are also a concern for the wind energy sector. Given the special circumstances in both the Arctic and Antarctic, verification of products for shipping - addressing marine safety - are mandatory. Verification of the timing of user-relevant events (e.g., onset and clearance of fog) should get more attention. The potential of some forecasting centres producing specially tailored probabilistic end user guidance forecasts during YOPP is a tempting option to also take into account in the definition of verification activities and techniques. Input from end users on what they're most concerned about is needed. Many operational ice services are in close contact with the shipping industry and could be encouraged to engage their users in verification. Further steps are needed to define meaningful prediction variables and only after that come up with useful verification metrics and approaches to evaluate them.

- Snow observation, prediction and verification has until now had less attention than rain and will need more emphasis in the polar context. The WWRP HIWeather project includes disruptive winter weather as one of its hazard focus areas and thus provides good collaboration opportunities with YOPP for the verification of blizzards, freezing rain and fog, polar lows, etc. Links should be established with the CIMO-SPICE project working on the better estimation of uncertainties in snow observations.
- Promotion of verification activities to be adopted by forecasting centres will be an essential YOPP Preparation Phase action. In particular, it is a challenge to find a forecasting or research centre interested to undertake a concerted verification undertaking. More explicitly, adapting to use of standard verification packages and looking into the applicability of spatial verification techniques for sea ice verification. Candidates might be NCAR, US Navy or Canadian Ice Branch; however, funding of such widespread verification efforts will be an issue.
- Collaboration with JWGFVR on verification methodology development to be applied during YOPP is encouraged.
- Awareness and knowledge of various verification methods and techniques and of the widespread benefits of verification should be raised both among early career and other polar scientists (at summer schools, workshops) as well as among educated forecast end users.

3.4.4 Forecast Use and Decision Making

Establishing a baseline understanding of how those in various communities, economic sectors, and government organizations produce, receive, interpret and apply forecast information into decision-making is an important part of the PPP. The Preparation Phase of YOPP will be used to develop an inventory and evaluation of current weather-related hazards/impacts, prediction services, information requirements, and user experiences. This initial scoping research will be informed by, and complemented with, a series of regional or sectoral consultation meetings, interviews, focus groups, and workshops, in order to establish up to five priority areas for social science proposal development and detailed investigation during the main intense phase of YOPP (2017-19). It will be important to involve indigenous groups in the Arctic. The consultations will also be used to determine preferences for the archiving of knowledge accumulated through YOPP for Society (YOPP-S) activities.

3.4.5 Workshops and Education

During the preparation phase, the PPP Steering Group and YOPP Planning Group will organise and promote workshops and education relating to the YOPP objectives. Section 4.4 covers education aspects for YOPP overall, including a planned Summer School in 2016 during the YOPP Preparation Phase.

4. YOPP PHASE (MID-2017 TO MID-2019)

The main YOPP activities are planned to take place during the period mid-2017 to mid-2019 – centred on the year of 2018. This will allow for YOPP to run for about a year before MOSAiC is planned to commence in September 2018. Should MOSAiC be delayed beyond that, YOPP will still proceed.

YOPP encompasses four major elements: an intensive observing period, a complementary intensive modelling and forecasting period, a period of enhanced monitoring of forecast use in decision making including verification, and a special educational effort. The overall structure for mid-2017 to mid-2019 is shown in Figure 3.

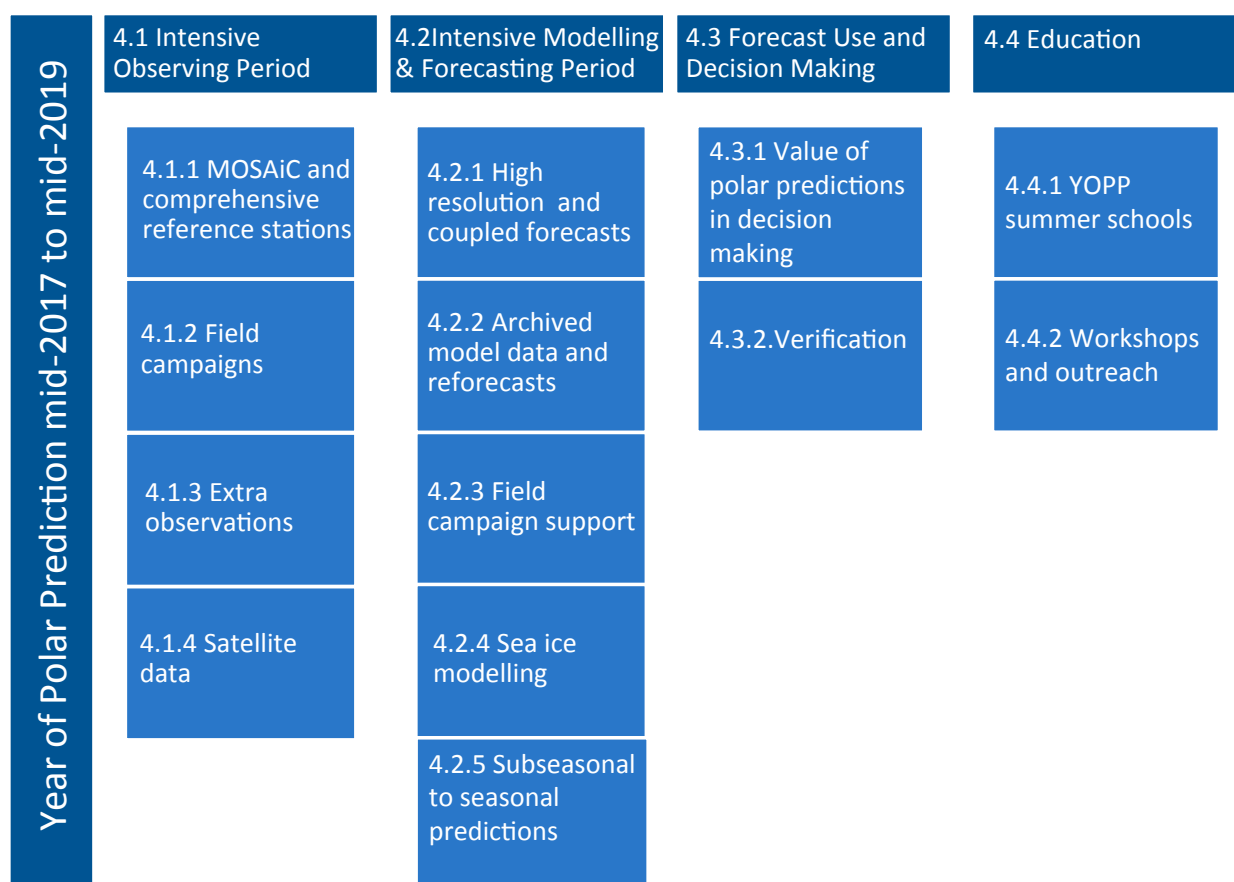


Figure 3. Year of Polar Prediction (mid-2017 to mid-2019)

4.1 Observing

YOPP will take advantage of the existing operational data gathered under WMO auspices for the globe, including polar regions. The YOPP Preparation Phase activities to promote additional observations described in Section 3.3.1, as well as coordination with MOSAiC and the ongoing efforts of the Southern Ocean Observing System (SOOS) and the Sustaining Arctic Observing Network (Section 3.3.2) should result in additional data under the following categories:

4.1.1 Comprehensive Reference Stations

YOPP will require comprehensive reference stations on land, sea ice, and in the ocean.

Comprehensive reference stations on land could be built around existing and planned “supersites” to form the basis for process understanding studies in both the Arctic and Antarctic.

- Sodankylä (FMI -Arctic research centre, <http://fmiarc.fmi.fi>) provides an example of an Arctic field site with a complete set of instrumentation that also permits satellite retrieval validation. Its attraction is also its collocation with a satellite receiving station, which facilitates near real-time (reception of products and rapid product feedback).
- A further interdisciplinary set of sites is being established as part of the Svalbard Integrated Observing System (SIOS <http://www.sios-svalbard.org/>), which is seen as a contribution to an integrated Arctic observing system.
- The International Arctic Systems for Observing the Atmosphere (IASOA, www.iasoa.org) programme will be important contributors to YOPP by bringing together and coordinating multiple reference stations for atmosphere and surface measurements. In addition to the other sites mentioned above, this network includes sites at Tiksi, Summit, Eureka, Alert, Barrow, and others. The IASOA observatories are Global Atmosphere Watch (GAW) sites, and will also be Global Cryosphere Watch (GCW) CryoNet sites.
- Dome-Concordia and South Pole are two of the few facilities over the Antarctic Plateau. A comprehensive list of such sites is still missing and PPP/YOPP could link with other initiatives such as the WMO-GCW & CryoNet survey regarding instrumentation, and to investigate which sites could be supporting process based studies with several collocated observations.

For the polar oceans it is possible to exploit existing systems such as AWI’s mooring array. How the existing system can 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.

4.1.2 Field Campaigns

For coupled system processes over sea ice, YOPP will benefit from existing plans for a Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) – see details in Section 3.3.2. 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 validation of satellite measurements and geophysical products, and will afford opportunities for detailed process studies.

Additionally to MOSAiC there may be Russian drifting “North Pole” stations (if organized during the project). This would increase the area of the Arctic Ocean covered by comprehensive observations in atmosphere, sea ice and ocean.

Improved geographical coverage and temporal frequency of in situ observations and exploitation of advanced satellite and other remotely sensed data are of high priority to obtain sustained enhancement of forecast quality and reliability. Experience from IPY showed that the ability to exploit advanced satellite data in conjunction with additional in situ data can mitigate complete failures in forecasting extreme weather such as polar lows, but this needs to be confirmed over many cases. Nevertheless, there is also a potential for additional well-designed relatively short-term focussed field campaigns, to explore oceanic areas close to the ice edge where routine in situ observations are difficult to establish and where the atmospheric PBL can become extremely unstable during major cold-air outbreaks. Such conditions are favourable for the generation of polar lows. The success-factor for such intense campaigns increases when they can benefit from an enhanced level of other regular observations that are used for initializing high-resolution NWP models. Observational data from existing and planned field campaigns (e.g., Marginal Ice Zone Observations and Processes Experiment - MIZOPEX, and the possible Arctic Ocean Drift Study - AODS) must be made available in near-real-time on the WMO Information System (e.g., via the GTS).

4.1.3 Extra Observations

Shipping

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. Ships going via the North-East Passage (and others in future) could provide observation-enhanced capacity at reduced cost. This could include additional Automated Ship Aerological Programme (ASAP) soundings (EUCOS may be able to assist for the northern polar regions). Reports on local sea ice conditions could also be made.

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.

Free Troposphere

More observations are needed in the free troposphere (particularly because of the decoupling from the PBL). The most cost effective way may be additional soundings from existing sites ringing the Arctic and over Antarctica (e.g., four times a day rather than once or twice). Norwegian¹, Japanese² and American³ Research supports the value of this, but funding sources would be needed for additional radiosondes and staffing. Additional AMDAR should also be sought from commercial flights over Arctic and logistic flights to Antarctica. (EUCOS has been contacted about the Arctic.)

Soundings which are made during scientific field campaigns must be exploited. Dropsondes would be expensive as part of routine observing system, but could be useful for Intensive Observing Periods (IOPs) with clear objectives, for coordinated existing planned campaigns.

¹ http://www.polarprediction.net/fileadmin/user_upload/redakteur/Home/Meetings/YPM2_Presentations/4.09_MET_Norway.pdf

² http://www.polarprediction.net/fileadmin/user_upload/redakteur/Home/Meetings/YPM2_Presentations/4.11_NiPR_Japan.pdf

³ <http://dx.doi.org/10.1175/MWR-D-13-00237.1>

Sea Ice and Upper Ocean

Sea ice observations will be very important for PPP and YOPP; there is a particular need for more high quality sea ice observations for calibration / validation activities to understand satellite data, as well as enabling the understanding of the interaction between ocean and sea ice.

Given the central role that sea ice prediction plays, comprehensive sea ice thickness measurements using small and lightweight digitally operated electromagnetic-induction systems (“EM birds”) should be made. These will also be valuable for validation of satellite measurements and geophysical products.

Spot sea ice and upper ocean measurements include Mass Balance Buoys (with a thermistor string, and acoustic probes looking up and down – see <http://www.crrel.usace.army.mil/>), and Ice Tethered profilers (ITP – see <http://www.whoi.edu/page.do?pid=20781>) and ice stress sensors. Sea ice thickness is important, and may play a central role in predictability. Sea ice thickness estimates from submarine and moored Upward Looking Sonar (ULS) may be a valuable additional source. Currents below sea ice can be observed from mooring lines. Integrated atmosphere – ice – ocean observations including ocean mixed layer properties (salinity, temperature, depth) are important for coupled data assimilation.

Deeper Ocean

It would be desirable if the polar observing system could be complemented by a good deal of oceanographic data from as large a part of the subsurface Arctic Ocean as possible. These observations would be crucial for the initialization of sub-seasonal, seasonal and longer-term forecasts and for improving sea ice-ocean models in a region that poses an enormous modelling challenge.

Therefore it is necessary to truly engage funding agencies and oceanographic research community to participate in YOPP. Examples for groups to be involved include the CLIVAR Working Group on Ocean Model Development (WGOMD), the International Arctic Science Committee (IASC) and ships of opportunity of JCOMM. Furthermore, the WCRP Climate and Cryosphere Project (CliC.) has at least three initiatives that are very relevant: sea-ice modelling forum, SnowMIP for Earth System Models, and Freshwater flux assessment. US SEARCH would be a key national partner but more national partners (at least from Norway, Russia, Canada, UK) would be desirable.

Autonomous sensor systems

Autonomous in situ observations will also be very important. Contact will have been established with the key groups deploying and operating buoys and ice observations (including Argo floats, polar profiling floats, gliders, ice tethered profilers, ice mass balance buoys, etc.) This includes the International Arctic Buoy Programme (IABP, <http://iabp.apl.washington.edu>), the Arctic Observing Network and the Southern Ocean Observing System. There are autonomous systems that incorporate a suite of sensors observing the atmosphere, ice, and ocean. If not already available, surface pressure and any wind observations from buoys should be vigorously promoted. Additional elements such as radiation from buoys would also be useful.

In order to ensure good spatial and temporal coverage it will also be important to explore the possibility of enhancing the Arctic and Antarctic buoy programmes.

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 Arctic Observing Network includes autonomous sea ice based sites as well as manned and unmanned terrestrial stations.

The International Programme for Antarctic Buoys (IPAB) and the Southern Ocean Observing System will also be encouraged to contribute. However, a temporary expansion of buoy programmes should be made both in terms of spatial coverage as well as to include less frequently observed properties such as internal ice temperature and stress. Modelling work during the YOPP preparation phase can help determine optimal deployment locations for buoys.

Observations from marine mammal equipped with tracking devices, subject to appropriate ethical guidelines, are an interesting and potentially valuable source of ocean observations near ice margins, which are otherwise data sparse (no Argo floats – see <http://www-hrx.ucsd.edu/www-argo/statusbig.gif>).

Snow

It is of high priority to obtain proper manual measurements of snow including information on depth, density, and grain size (for microwave retrievals). This includes snow over sea ice.

Land

In addition to snow cover and its patchiness due to blowing snow events, there is a great need for much more information about the state of the land surface in the greater Arctic, including soil temperature; soil moisture; soil ice; the presence of liquid water layers in tundra regions; the active layer depth; comprehensive surface energy balance measurements; the extent, depth, and ice cover of smaller Arctic lakes; more discharge measurements of Arctic rivers and streams; vegetation characteristics; etc. The abrupt spring transition from frozen to thawed is very important to characterize in detail. Greenhouse gas fluxes over northern land areas are important considerations from the global climate change perspective. Data are available for many of these variables from the IASOA sites. The Circumpolar Active Layer Monitoring Network (CALM; <http://www.gwu.edu/~calm/>) observes the response of the active layer and near-surface permafrost to climate change over long (multi-decadal) time scales. A comprehensive review of the many existing data sets is needed to perform an effective gap analysis to prioritize the most important missing observations.

Boundary Layers and clouds

Stable boundary layers are still a perplexing problem for models that is particularly acute in the Arctic, especially over land. A few well-observed cases studies from an intensive observing period (like GABLS-4) can be essential to further our understanding. Rather fewer periods and more extensive observations of all physical aspects during them, if there is a need to choose. Surface properties, surface energy and momentum fluxes and boundary layer conditions as well as the free troposphere should be measured with high resolution and frequency. Boundary layers over sea-ice are often cloudy, such sites needs to be complemented with detailed observations of cloud properties as well as CCN and IN concentrations.

Stakeholders

A YOPP stakeholder engagement workshop would be a useful approach to probe the willingness of stakeholders to active participation. YOPP will build on other programmes engaging polar stakeholders.

4.1.4 Satellite Data

Satellites provide unique observational capabilities for the atmosphere, oceans and cryosphere. It will 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 will allow the compilation of a comprehensive satellite snapshot for further analysis.

The prospect of a comprehensive satellite snapshot during YOPP calls for the development of a satellite validation component, which requires coordination of airborne and ground based observation efforts (e.g. snow on ice) and that needs to be planned during the YOPP Preparation Phase. The locations of existing IASOA and similar observatories, as well as drifting stations such as MOSAiC and the Russian drifting “North Pole” stations, should be targeted for specific satellite products.

For the atmosphere the use of satellite observations in polar areas is currently limited, mostly because the lower troposphere is nearly isothermal, often cloud covered and the optical properties of snow/sea-ice covered surfaces are difficult to characterize thus limiting the use and effectiveness of temperature and moisture sounder data. Furthermore model biases are large and data assimilation systems are sub-optimally adapted to polar conditions thus many observations are rejected or given inappropriate weight. This also implies that model and data assimilation developments are of fundamental importance to making optimal use of observational datasets, and that investments have to be directed accordingly.

The most important requirements for space-borne atmospheric observations are a good representation of the lower atmospheric structure (e.g., high-resolution wind, temperature, moisture profiles), clouds (e.g., liquid versus ice phase profiles, particle size distributions, aerosol concentration and type) and snow-cover (depth, layering, snow water equivalent, melting ponds, albedo, temperature).

Providing researchers and stakeholders with comprehensive satellite-based sea ice and iceberg products will be crucial to advance ice prediction capabilities in the coming years. One promising way forward would be to establish close collaboration with existing Programmes such as PolarView and MyOcean2. These platforms could be updated to cater to specific community needs during YOPP. In this context, it would be desirable to gather and – where possible – harmonize information from various private and national ice services in order to facilitate a thorough assessment of existing ice service products by the international research community. Icebergs provide a threat to commercial activities in high latitudes. Satellite data are crucial to determine the location and drift paths of icebergs. This information is needed for improving models for simulating and forecasting iceberg drift and decay.

On time scales from hours to days, providing skilful predictive information about deformation characteristics of sea ice (leads and pressure ridges) will be key. In order to evaluate, advance and initialize forecasting systems, radar information from satellites such as Sentinel-1 and RadarSat need to be widely available. The recent move towards freely available satellite data from agencies such as ESA and NASA is therefore extremely useful for delivering PPP’s mission. Given that sea ice deformation is non-linear, highly dynamic and can have wide-ranging effects, frequent observation (at least daily) is needed. While fine resolution (1-10 m) is required for specific studies to better understand deformation processes, this must be balanced against the need for basin-wide observations compatible with sea ice models that are expected to be run at resolutions from 1-10 km. It is suggested that it would be beneficial to operate radar instruments in wide swath (WS) mode (e.g., for Sentinel-1: 250 km in Interferometric WS and 400 km in Extra WS) on a routine, regular basis with occasional campaigns at higher resolution in specific target areas. It

would also be desirable that certain agencies such as DLR in Germany implement dedicated calls for YOPP to ensure space-borne support for intensive observation and modelling periods.

For longer term sub-seasonal to seasonal prediction, proper initialisation of sea ice thickness is crucial. Information about relatively thick sea ice can be provided through CryoSat-2. It would be very important, therefore, to ensure extension of the CryoSat mission to cover YOPP. Algorithms to determine sea ice thickness from Cryo-Sat2 data are currently being developed by various groups. In order to retrieve thickness for thinner sea ice, SMOS (ESA) and SMAP (NASA) data will be very useful. Given that little information about the accuracy of satellite retrieved sea ice thickness exists, an intercomparison of various sea ice thickness products is desirable. YOPP will provide important new information to space agencies. Examples include the estimation of satellite observational impact on analysis and forecast accuracy for atmosphere, ocean and sea-ice in polar areas and mid-latitudes; rolling requirement definition for observational data in polar areas including guidance on new observation types addressing the main science questions; and guidance on optimizing observational data usage in polar areas for process studies and long-term environmental monitoring.

4.2 Modelling and Forecasting

4.2.1 High Resolution and Coupled Forecasts

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 high-resolution atmospheric and coupled model experiments to explore the benefit of a better representation of key polar processes through significantly enhanced horizontal and vertical resolution.

Some initial model development and experiments will be carried out during the YOPP Preparation Phase, and then the major experiments during the YOPP Phase. It is important to emphasise that new experimental production suites should be run during YOPP, rather than just relying on the standard operational models. Limited-area, high-resolution, convection-permitting ensembles should be run for short-range probabilistic forecasts over relevant regions.

Some of the key aspects of proposed model experiments are:

- High spatial resolution in global, regional and process models
- Archiving of extra parameters such as physical process tendencies
- Provision of forcing data sets for dedicated experiments with sea ice and ocean

Broadly speaking, there could be six kinds of experiments:

- a) Forecast and reforecast data sets to allow for robust estimates of forecast skill and to diagnose sources of forecast failures.
- b) Sensitivity studies – explore the role of model formulation (resolution, parameterisations and coupling). Of particular interest will be to determine the influence of uncertain parameters in sea ice models through perturbed parameters ensembles and the use of adjoint methods.
- c) Case studies – how well does the modelling system in various configurations deal with particular extreme events? In order to provide any indication of conclusive results with confidence, it will be crucial to evaluate YOPP cases alongside cases/data from previous

campaigns. (The PPP Implementation Plan goes into more detail on polar extreme weather.)

- d) Multi-year ‘free’ model simulations – investigate the ability of the modelling systems to capture interannual variability and assess system biases and imbalances.
- e) Potential predictability studies – explore the limits of predictability for atmosphere-cryosphere-ocean, with a particular focus on sea ice characteristics and other relevant variables.
- f) Process resolving simulations (Large Eddy Simulations, Convection-Resolving Models, Single Column Models) to guide development of improved subgrid-scale parameterisations.

The focus of the model experiments could be on the following six aspects:

- (1) Coupling
 - Coupled versus uncoupled predictions of the various environmental system components (atmosphere, land, sea ice, ocean, wave, snow) – as well as coupled versus uncoupled assimilation.
 - Identification of sources of coupled forecasting skill and dependencies on model parameters (e.g., resolution, sea ice rheology, snow cover characteristics).
- (2) Stable boundary layer
 - Stable boundary layers are ubiquitous in the Arctic. Yet they remain a major modelling challenge. Vertical resolution will be as important to consider as horizontal resolution, if not more important. The transition from weakly turbulent to fully turbulent is especially challenging for models to capture. There are often major deficiencies in the modelled profiles of temperature, vector wind, and moisture. Boundary layer clouds, especially Arctic stratus, continue to undermine Arctic boundary layer simulations.
- (3) Sea ice prediction
 - Observing System Simulation Experiments could be performed to assist in identifying the observational requirements for YOPP. For example, these experiments could aim to recommend a target density for observations (ice buoys, ice stress sensors and IMB buoys) for a given target spatial and temporal scale.
 - Experiments to assess the sensitivity to atmospheric forcing and related errors. This could include errors due to atmospheric radiation, boundary layer physics and model resolution. Assess the importance of coupling for modifying sea ice predictability characteristics. There could also be an ensemble of sea ice predictions based on different atmospheric ensemble members; the spread of the resulting ice predictions based on “pure” atmospheric spread, could be compared with what the spread is from using different ice modelling parameterizations and/or models.
 - Sensitivity studies to quantify the relative ice forecast error due to different ice model characteristics and parameterizations as a function of time of year and location (e.g., sea ice rheology, landfast ice, resolution, melt ponds, snow on ice, tides, waves).
 - Using the atmospheric TIGGE fields to drive different sea ice-ocean models. This data set could be used by the international community to explore the skill of sea ice predictions, investigate the sensitivity to model formulation and by comparing the results with forecasts using full coupled systems.
 - Carry out a coordinated inter-comparison in seasonal sea ice prediction among operational centres as well as interested research institutions. This would test the capability of the coupled models and their dependence on the initial sea ice thickness and model physics:

- Carry out (or make use of) predictions with the existing forecast systems
 - Perform experiments with improved alternative sea ice thickness based on observations during YOPP, and alternative model physics if wanted
 - Validate the forecasts against YOPP observations
- (4) Orography
- What horizontal and what vertical resolution is required
 - Explore the role of resolution and orography
 - Orographic drag
 - Vertical diffusion
 - Land surface coupling
 - Orographic flows, such as barrier winds, tip jets, gap flows, foehn flows, katabatic flows
- (5) The probabilistic prediction of mesoscale and synoptic scale systems:
- The representation of vertical fluxes of sensible and latent heat in extremely unstable marine boundary layers
 - Polar lows and orographic flows
 - Arctic fronts
 - Low-level jets associated with sea-ice borders
 - Topographically influenced wind systems and lee cyclones
- (6) Clouds
- Request model centres to compare model predictions with sites (ARM, etc.) where there are high resolution cloud observations. Verification with surface radiation observations is crucial because it allows differentiation between cloud, surface, and water vapour errors.
 - Clear sky radiances; column liquid water.
 - For archived model variables – see what was asked for the Cloud Feedback Model Intercomparison project (CFMIP) – CMIP only saved cloud fraction.

4.2.2 Archived Model Data and Reforecasts

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. Although YOTC used only ECMWF data, it is expected that additional centres will be participating (e.g., a Finnish HIRLAM Arctic version, and AMPS).

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).

4.2.3 Field Campaign Related

Modelling support will be provided, where possible, for any intensive field campaigns contributing to YOPP (see Section 4.1.2). This includes MOSAiC.

Also, to take advantage of MOSAiC and other field campaign data for model calibration and validation, a range of model experiments should be carried out. In particular, this should include sea ice modelling.

It is expected that sea ice modelling for prediction purposes will become “mainstream” by the time of YOPP. Sea ice models are currently validated for the most part using satellite imagery/SAR; MOSAiC could provide additional detailed sea ice measurements, including imagery from UAVs. During IOPs, there could be expanded surface observations and IOP aircraft flights (e.g., by the Met Office UK and/or AWI aircraft) measuring microwave brightness, with a goal of making better use of satellite observations in future, having calibrated it from both MOSAiC observations and associated aircraft passes.

Post-processing and archiving of physical model tendencies planned for YOPP should be extended to make sure that the full period of MOSAiC will be covered by the dataset.

4.2.4 Sea Ice Modelling

Sea ice models play a key role in environmental prediction by both providing ice products for polar marine users as well as a boundary forcing factor for atmospheric prediction. It is expected that by the time of YOPP a number of coupled and uncoupled ice forecasting systems will be in place producing both deterministic and ensemble ice forecasts.

Given the strong nonlinearities in sea ice physics and the relative few observations available for model development, a coordinated intercomparison in sea ice prediction among operational centres as well as interested research institutions could be of great benefit. This intercomparison could make use of the real-time availability of additional YOPP observations to provide uncertainty estimates for important, yet less well evaluated, fields such as ice pressure, drift and internal temperature. This could provide a means both to highlight best practices (or common errors) as well as to explore the benefits of probabilistic ice forecasting and the potential usefulness of a multi-model sea ice ensemble.

4.2.5 Subseasonal to Seasonal Predictions

The sub-seasonal to seasonal prediction community should be engaged to perform intensive real-time predictions with frequent start dates (once a day for sub-seasonal and once a week for seasonal) during interesting case studies. To further understand the sources of predictability for these cases, local factors that can contribute to predictive skill on these timescales should be investigated, including the role of:

- Stratosphere-troposphere coupling
- Sea ice conditions, including the ocean underneath
- High-latitude land surface properties, including snow cover

If resources allow, sensitivity integrations to address the role of these various factors should be performed. For example, studies that assess the importance of ice thickness initialization (using some type of coupled data assimilation whenever possible) and other similar issues should be explored.

The development of a coordinated set of YOPP-related experiments within the subseasonal to seasonal forecasting community would enable an assessment of the consistency of forecasts, their sources of spread in polar regions, and what factors reliably contribute to predictive skill. These analyses and the design of the experiments should take into account the short length of the YOPP (less than two years), which prevents the creation of homogenous long hindcast datasets. Where appropriate, the sensitivity studies discussed earlier (Section 4.2.1, e.g., sensitivity experiments to specific parameterisations performed to identify the parameters responsible for the multi-model spread) should be analysed for their predictive skill (including using a perfect-model approach) on the subseasonal to seasonal timescales, providing insight on model development needs and uncertainties. Undertaking integrations of this type in the context of YOPP will allow verification of sub-seasonal and seasonal forecasts against observations (instead of reanalyses) for polar regions. Appropriate links to the verification and satellite data (as independent source of validation data) should be built. It will also allow for improved initialization of future operational forecasts. This should be done in coordination with the WMO Lead Centre for the Long Range Forecast Verification System, WMO Global Producing Centres for Long Range Forecasts, and the S2S project, with which the model output dissemination should be coordinated.

4.3 Forecast Use and Decision Making

The availability of reliable predictions, with information content that reflects the actual predictability, is the most valuable tool to help users to take decisions, which are influenced by weather. In polar regions, weather can be harmful for humans, infrastructure, and the natural environment. As the earth's climate warms, transport, exploitation of natural resources, tourism, etc., is expected to expand into these regions. The need for reliable probabilistic predictions on time-scales from a fraction of a day to a few weeks ahead will thus increase. The nature of the need will vary between users and applications, and user-specific products are necessary to exploit the potential value of the predictions.

4.3.1 Value of Polar Predictions in Decision Making

During the preparatory research phase, up to five areas will have been identified for comprehensive research into the use and value of polar predictions in decision-making.

Whereas the preparatory research will provide an overview for beneficial use areas, this intense phase will be scoped much more narrowly, for example within a smaller region, on a particular subset of decision-makers, or on a specific scale of decision problem or issue. This will facilitate deeper inquiry and application of a variety of social science research methods to characterize and evaluate the use and benefit of improved predictions. While specifics will depend on available resources and expertise, some potential types of research include:

- Interviews, focus groups and content analysis of written materials to identify producer and user perceptions and beliefs concerning weather information and important variables and attributes relevant to decision problems.
- Ethnographic field research to observe, record and interpret actual decision-making behaviour and outcomes in real situations, including of northern indigenous peoples.
- Qualitative research to uncover the relative synergistic or conflicting roles of traditional (or experiential) knowledge and scientific information in influencing decisions and behaviours.

- Development of simplified decision models and controlled experiments or simulations to assess the relative impacts/benefits of prediction information with systematically adjusted attributes (e.g., content, precision, timing, uncertainty, presentation format/style).
- Analysis of secondary impact or outcome data to develop robust weather-related risk analyses and models for particular hazards or conditions before and following introduction of improved prediction services.
- Contingent valuation or other survey-based approaches to assess satisfaction and the willingness to pay for improved services or information.

Based on the preferences identified in the Preparation Phase of YOPP-S, primary and secondary data, including survey instruments, interview protocols, and experimental designs, will be archived in a repository database that is accessible to other researchers to facilitate further analysis.

4.3.2 Verification

YOPP will provide an excellent opportunity to perform in-depth verification of weather, sub-seasonal and seasonal forecasts in polar regions by using the special forecast data sets originating in the YOPP Data Archive System. The archiving of end user-relevant parameters, such as sea ice pressure for ship routing, will provide a unique opportunity to develop and test new prediction variables, verification metrics and techniques. It is planned to apply novelty spatial verification techniques for sea ice in the polar regions during YOPP. The availability of extra observations will allow investigation into how the highly problematic data sparseness in the polar regions will affect verification results.

If there will be a (quasi) real-time verification environment running during YOPP, it would serve both scientists and forecasters at operational centres, as well as potentially include a “built-in” end user product verification interface. It would be desirable to have also spatial verification components as part of a real-time system. Building on presently existing operational verification system(s), rather than to design a new dedicated polar verification package, would be the preference. It should also be noted that process-oriented verification tends to be post real-time, especially since new observation types take time to incorporate.

One of the key issues in polar forecast verification is the notorious sparseness of direct observation data. Therefore, there is the strong push to use model analyses generated by data assimilation systems as “truth” information. The potential drawbacks of using model analyses need to be carefully studied. They are likely to differ largely from model to model and are expected to contain significant biases towards the model which is used for the background field. Model analyses in polar regions are likely to be even more problematic than elsewhere. Even multi-model “ensemble analyses” are more likely in polar regions to reflect variations among the associated models than they are to represent the uncertainty in the analysis with respect to the truth, due to the lack of data. The use of multi-model analyses is, however, an improvement over single model analyses for verification purposes, especially when models are being compared. Thus, their use is encouraged.

Only a few surface and lower atmosphere quantities are observed adequately in polar regions. Satellite data will become increasingly important as a verification data source. However, retrievals of cloud and surface properties from satellite are problematic, although evolving YOPP science may improve the situation. Especially when the purpose of the verification is model diagnosis, it is recommended to use the “model to observation” approach and verify model simulated radiances against satellite radiances. Doing this in many parts of the spectrum (visible, near infrared, infrared, microwave) will help diagnose the sources of model errors. Verification of radiation would be an especially interesting diagnostic measure because of its relevance to many

processes. In addition to outgoing radiation, the surface radiation budget is particularly important in polar regions and should be observed and verified, especially as part of process studies (supporting some of the modelling activities highlighted elsewhere in the Implementation Plan). This can be a huge challenge because of scale differences between a model and a radiometer, but the scale issues can be handled through aggregation. Also the albedo will be a big challenge.

Sea ice is of fundamental relevance to a variety of forecast end users and stakeholders. Consequently, sea ice verification and the usefulness and applicability of spatial verification methods will be in special focus during YOPP. It will also be important to consider additional ice related variables which are relevant to the end users. Presently, most of the focus is still on ice extent at a certain given date; such a variable per se is not very helpful for decision-makers. Ice thickness and coverage, concentration, motion of ice bergs and floes and dates of freeze-up and breakup can also be relevant. Of these, ice thickness will be particularly difficult to verify because of lack of observations and high variability. Additional variables like surface currents could be verified. These are relevant to many users, and also particularly relevant to the coupled modelling community. The circulation in the ocean is full of eddies and gyres some of which evolve quite rapidly making adequate observation, prediction and verification a challenge.

Studying diagnostic and spatial verification techniques such as, e.g., scale-dependent verification is expected to strengthen collaboration between the verification community and modellers. There is the prerequisite for high resolution observations for most of the spatial verification methods. This means that their use is likely to be seriously constrained by the general lack of high resolution data. Provided data is available, most spatial methods can in principle be tested for sea ice and cloud forecasts. Scale-tracking techniques such as wavelet methods can be especially useful in polar prediction verification because they ensure that only those spatial scales that are supported by the observations are verified. Some of the neighbourhood approaches that match a window of forecasts to a point observation might be useful, too. Some promising methods are the deformation techniques for ice fields and object techniques for ice floe predictions and forecasts of the ice edge. SAR data is assumed to be particularly useful for spatial verification of ice forecasts.

The importance of the verification of user-relevant parameters and products has already been emphasized. This should cover all traditional basic variables (temperature, wind, precipitation, visibility, etc.) and the use of all available observations. Attention needs also be given to verify the timing of user-relevant events (e.g., onset and clearance of poor visibility) and to include variables relevant for aviation and shipping safety, which has a high societal relevance in the polar regions.

Verification related collaboration with various research initiatives, programmes and groups will be active during YOPP: for example, with CIMO-SPICE on uncertainties in snow observations, with WWRP HIWeather on the verification of high-impact, disruptive winter weather hazards, with WWRP S2S on sub-seasonal to seasonal time scales, and with WWRP JWGFVR on verification methodology. Interplay should be advanced between verification scientists possessing expertise in verification methodology and polar scientists who may have verification questions relating, e.g., to the use of data to test the utility of various diagnostic and spatial verification methods. Accordingly, participation of verification scientists in polar science workshops and conferences and, vice versa, participation of polar scientists in verification workshops should be supported.

4.4 Education

4.4.1 YOPP Summer Schools

YOPP will provide many early career scientists, including postgraduate students and postdocs, with the opportunity to actively participate in an event that 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 at least two YOPP summer schools, coordinated with APECS and PCPI. One will be during the YOPP Preparation Phase – in 2016 – and the other in 2018.

Potential topics for the summer schools include:

- Coupled data assimilation with emphasis on the cryosphere
- Coupled environmental prediction for polar regions
- Specialised sessions on particular aspects – e.g. mixed-phase clouds, mesoscale features, polar boundary layers, Arctic land models
- The geophysics of sea ice
- Sea ice prediction and user needs (involving operational centres)
- Exploring the limits of resolution of sea ice models and the coupling interface
- Two-way linkages between the polar regions and lower latitudes
- Social and economic benefit assessment and other social science methods to evaluate forecast improvements

APECS has been involved in the planning and organisation of a number of field schools over previous years, such as the IPY field schools, three of which have been conducted since 2007 (hosted at UNIS, Svalbard).

4.4.2 Workshops and Outreach

YOPP and APECS are planning a short series of webinars in series with the summer schools to provide prerequisite knowledge and a follow-up forum. In addition, general career development of early career polar prediction researchers will be achieved through workshops attached to a particular conference (such as those run by the American Meteorological Society and/or the European Meteorological Society).

YOPP and APECS are planning to produce short videos about research (i.e., Frostbytes – see <http://www.youtube.com/user/apecsis>) - for an outreach component. This will act as both a tool for dissemination of scientific findings and provide science communication training.

5. YOPP CONSOLIDATION PHASE (MID-2019 TO 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. The overall structure of the Consolidation Phase is outlined in Figure 4.

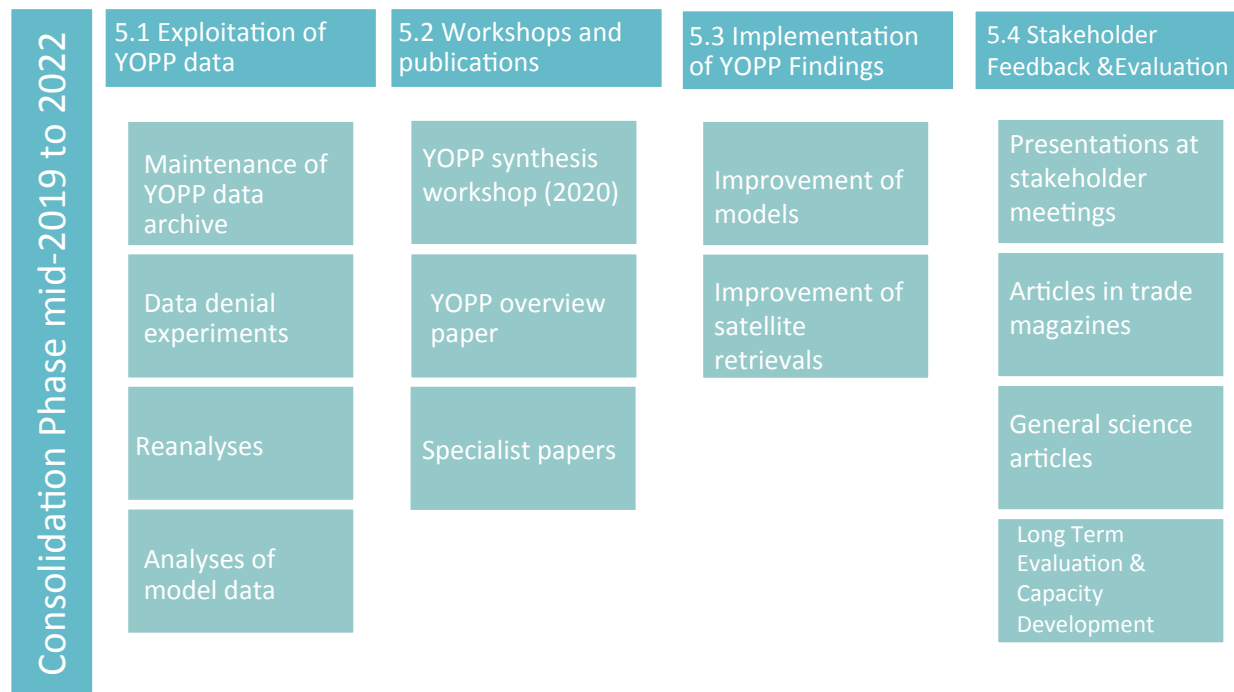


Figure 4. YOPP Consolidation Phase

5.1 Exploitation of YOPP Data

An important task right at the beginning of the Consolidation Phase will be to ensure proper archiving, availability and traceability (Digital Object Identifiers) of all the additional observational data generated during YOPP. The YOPP data task team will oversee this process. Originators of significant YOPP datasets should be considered as authors of the dataset, which should qualify as a high-level peer-reviewed publication.

The additional data collected during the YOPP intensive observing periods will be used during the Consolidation Phase to evaluate the benefit of extra observations for polar predictions. This includes data denial experiments which will provide guidance for optimizing the polar observing system. Furthermore, the extra observations along with the high-resolution numerical experiments will benefit model development and the enhancement of value of satellite data in a prediction context (see Section 5.3 below).

In order to synthesize the available YOPP data and to exploit them in models, it will be desirable to carry out a special high-resolution reanalysis for the Arctic and Antarctic. This will be an ongoing activity during the Consolidation Phase. Such a reanalysis along with the availability of reforecast data sets will provide the basis for probabilistic forecast calibration, diagnostic and verification studies that are expected to advance polar prediction across a wide range of time scales.

The breadth of numerical experiments available through the YOPP Data Archive System will also provide insight into the role of horizontal and vertical resolution for prediction in the polar regions and beyond. Furthermore, the availability of simulated process tendencies from atmospheric models will allow for a comprehensive assessment of the relative importance of different dynamical and physical processes in different polar “regimes” (e.g., unstable versus stable boundary layers).

The availability of unique additional datasets from YOPP will allow detailed case/process studies which would not have been possible without these valuable data.

5.2 Workshops and Publications

In order to ensure a lasting legacy it will be essential to hold a YOPP synthesis workshop in 2020. 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 increase “buy in” from the operational centres they need to have been involved as much as possible throughout the project, and the 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.

5.3 Implementation of YOPP Findings

The additional observations and numerical simulations produced during the YOPP phase will be used to improve the representation of key polar processes in atmospheric, oceanic and sea ice models and at their interfaces. A comparison of ensemble forecasting system experiments with and without improved model formulation or new observation systems will ultimately demonstrate the benefit of YOPP from a modelling perspective. Given the importance of features such as stable boundary layers and mixed phase clouds across a wide range of time scales it is anticipated that model improvements coming out of YOPP will also serve the climate modelling community. In this context, running Transpose-CMIP experiments for the YOPP phase would be very desirable.

The extra observations available through YOPP will also help to improve the use of satellite data for polar prediction purposes. Improvements can be achieved by revising satellite retrievals using new ground truth data. Furthermore, better forward models of the surface and the atmosphere will be helpful when satellite data are used in a data assimilation framework.

It is expected that the intense phase of YOPP will yield important demonstration applications in polar regions. Potential benefits will only be fully realized, however, upon successful transfer and implementation of improved predictions through operations and attendant decision support tools to NMHSs and other stakeholders. A YOPP commitment to long term societal evaluation (and relevant verification studies) for each of the priority application areas is essential to ensuring proper and complete documentation of benefits. Such an effort, which will run the course of the PPP through 2022, should be accompanied with stakeholder involvement through joint training and workshops to build the capacity to conduct and interpret evaluations within NMHSs and user organizations.

5.4 Stakeholder Feedback and Evaluation

It will 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 training sessions, through national service agencies and other associations, articles in trade magazines, and general science articles. As much as possible, providing feedback to stakeholders should also be an interactive process – rather than just a single event, and a one-way flow of information.

There should be a marker event in 2022 that provides a clear end to YOPP, and is also aligned to the completion of the overall Polar Prediction Project. This could be a YOPP Symposium, or a special session at the Annual Meeting of the American Meteorological Society (in early 2023).

6. GOVERNANCE AND MANAGEMENT

The Polar Prediction Project comes within the World Weather Research Programme (WWRP) of WMO. It is therefore formally under the overall direction of the WWRP Scientific Steering Committee⁴ (WWRP SSC).

A Steering Group (PPP-SG) was established for the Polar Prediction Project in December 2011. The Chair of the Polar Prediction Project Steering Group (PPP-SG) reports to the Chair of the WWRP SSC.

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 Expert member of EC-PORS in order to maintain close collaboration.

As a significant component of the Polar Prediction Project, YOPP will be overseen by the PPP-SG, which will consider progress and provide guidance in its regular meetings.

Detailed planning and coordination of YOPP will be conducted by the YOPP Planning Group (YPG) which consists of the PPP-SG augmented by representatives of other relevant initiatives and bodies.

⁴ Prior to CAS-16 in November 2013 this was the WWRP Joint Steering Committee (WWRP-JSC)

Timeline

The following is a timeline of *future* planned activities and milestones for the project, including planned meetings and events. For planning purposes, this will naturally be more detailed for the next year or two; dates are approximate further out.

This list will be regularly maintained and updated, as planned activities evolve, and as completed items can be removed.

Milestone	Target Date (YYYY.MM format)
Submission of Bulletin of American Meteorological Society Paper on PPP, including YOPP Outline	2014.11
Polar-midlatitude Linkages Workshop in Barcelona, Spain (PPP/PCPI)	2014.12
Review progress of WWRP Working Groups in supporting specific YOPP-related needs	2015.03
YOPP has been promoted to key national/EU funding agencies by YPG members (making use of additional national support)	2015.03
YOPP-S (SERA) meeting	2015.03
Announcement for YOPP Summer School	2015.03
PPP-IAMAS High Latitude Dynamics Meeting in Bergen, Norway	2015.03
YOPP Summit in Reading, UK	2015.07
YOPP Data Archive System group established	2015.08
YOPP modelling strategy finalised, including an agreed list of participating operational modelling centres	2015.08
Commitments have been secured from major modelling centres for Preparation Phase model experiments	2015.10
Polar Prediction Webinars (in collaboration with APECS)	2015.10
YOPP-S (SERA) meeting	2016.03
First PPP/YOPP/PCPI Summer School on Polar Prediction in Abisko, Sweden	2016.04

Milestone	Target Date (YYYY.MM format)
Sea Ice Prediction and Verification Workshop	2016.05
Polar Prediction Webinars	2016.10
YOPP Data Archive System established	2016.12
Experimental operational short- to medium-range coupled atmosphere-sea ice-ocean models ready to run by operational modelling centres	2016.12
YOPP sea ice intercomparison metrics defined and agreed upon by participating centres	2016.12
Observational requirements document finalized	2016.12
YOPP-S (SERA) meeting	2017.03
YOPP Phase Formally Launched at WMO EC-69	2017.06
Polar Prediction Webinars	2017.10
Second PPP/YOPP/PCPI Summer School on Polar Prediction	2018.06
MOSAIC Planned to Commence	2018.09
Polar Prediction Webinars	2018.10
End of YOPP Phase / Start of YOPP Consolidation Phase	2019.06
YOPP Synthesis Workshop	2020.06
YOPP Final Conference	2021.05
YOPP Paper Published in Bulletin of American Meteorological Society	2022.05
End of YOPP Consolidation Phase	2022.12

Activity Contribution Table

The following is a list of planned contributions to YOPP. These are in *addition* to the existing and very valuable routine operational observational (including research sites in both northern and southern polar regions) and modelling infrastructure.

Importantly, unless otherwise stated, these activity contributions are *indicative* only, and do not represent in any way a binding obligation on the Contributors listed.

This list will be regularly maintained and updated, as planned activities evolve, as the status of commitments can be confirmed, and as additional contributions (which would be most welcome) are offered.

Contributor	Activity	Status
Met Office UK ⁵	The Met Office is interested in the scientific investigations planned for YOPP and PPP due to the expected improvements to Met Office models through participation in these projects. There are several operational analysis and prediction systems used at the Met Office for predicting global atmospheric and oceanic weather and seasonal to centennial scale climate. As these models extend into the high latitudes, and atmospheric and ocean processes at high latitudes may impact weather and ocean at mid-latitudes, the performance of these models at high latitudes is important to assess through efforts such as the Polar Prediction Project. In addition the global climate forecasting models are used to investigate possible future climate regimes that could be influenced by and will influence polar processes. Further understanding of the validity of these operational and climate models at high latitude is hoped to be achieved by participation in the modelling and observational components of PPP.	Approved statement, May 2014
British Antarctic Survey	Gather additional observations through field programmes and develop improved representation. Upcoming campaigns and proposals are: <ul style="list-style-type: none"> • MAC (Microphysics of Antarctic Clouds). <ul style="list-style-type: none"> ◦ 2014-2015: BAS. • ACRE (Antarctic Clouds and Radiation Experiment). <ul style="list-style-type: none"> ◦ 2017-2018: Australian Antarctic Division – in collaboration with BAS. • SOCRATES (Southern Ocean Clouds, Radiation and Aerosol Transport Experimental Studies). 	Suggestions by BAS representative at YPM-2 meeting on 8 April 2014.

⁵It may be of interest to other organizations that the Met Office UK planned activities to support YOPP are also highly relevant to their own polar interests: (1) They have models that cover the polar regions (global NWP, GloSEA seasonal forecast model, and climate model); (2) For satellite data assimilation a large amount of polar data is available due to the polar orbits of many satellites, but the majority are rejected due to uncertainties in surface temperature, emissivity and cloud cover; (3) For climate studies they are interested in polar and cold region processes, such as permafrost and associated greenhouse gases, and sea ice modelling and extent analysis.

Contributor	Activity	Status
	<ul style="list-style-type: none"> ○ Tentative time frame of the summer of 2016/17 or 2017/18: Monash University (Christian Jakob). <p>It is still possible to develop a proposal for a YOPP related observational effort (seasonal predictability focus?).</p>	
Met Norway	<ul style="list-style-type: none"> • Data from Norwegian Arctic stations • Operational model results • Experimental model integrations (data assimilation, physical parameterization,) for atmosphere, ocean and ice with high resolutions 	Suggestions by Met Norway representative at YPM-2 meeting on 8 April 2014.
Russian Federation	<ul style="list-style-type: none"> • Observations from the Tiksi Hydro-meteorological observatory and possible extended programmes at "Ice Base Cape Baranov". • If funding can be made provided, increasing the usual 1-2 radiosondes per day to 4 radiosondes per day at Russian polar stations. 	Suggestions by Russian (AARI) representative at YPM-2 meeting on 8 April 2014.
Japan	<ul style="list-style-type: none"> • Frequent radiosonde observations from ships & land stations <ul style="list-style-type: none"> ○ Using <i>R/V Mirai</i> & <i>R/V Polarstern</i>, Ny-Alesund, etc. ○ Aimed at improvements of NWP and reanalyses • Data assimilation (DA) using the Earth Simulator <ul style="list-style-type: none"> ○ Observing System Experiment (OSE) ○ Aimed at evaluating the effect of intensive observations, and proposing a future observing network 	Suggestions by Japanese (National Institute of Polar Research) representative at YPM-2 meeting on 8 April 2014.
USA (NOAA)	NOAA aircraft assets that could be relevant are two Orion P3 aircraft (dropsonde and Doppler radar) and a dropsonde launching platform. There is a process within NOAA that needs to be followed to request these platforms for field programmes. This may or may not try to target the MOSAiC drifting station. Another possibility is a UAV programme – the Global Hawk which could fly from California to the North Pole and back, dropping sondes along the way. Other aircraft that could contribute come under NASA, the US Navy, and the National Science Foundation.	Suggestions by USA (NOAA) representative at YPM-2 meeting on 8 April 2014.
Zackenberg Research Station, Greenland	Ongoing monitoring at Zackenberg Basic (www.zackenberg.dk) and at its sister station in Nuuk, Greenland (Nuuk Basic; www.nuuk-basic.dk).	Email from Niels Martin Schmidt, Scientific leader, Zackenberg Research Station, Aarhus University, in April 2014.
SNAP	<ul style="list-style-type: none"> • Polar-relevant results from the shared predictability experiment for the stratosphere and joint activities with S2S to look at longer range impacts on the troposphere, due to be completed by the early 2016 can be shared as part of the Preparation Phase. • Analysis of the YOPP forecast database to examine stratospheric predictability in models and its impact on the troposphere. Potentially there might be also important links to the dynamics of sea-ice. • Investigating the impact of enhanced observational capacity and data assimilation in the stratosphere. 	From SNAP comments on the YOPP Plan draft.

Contributor	Activity	Status
ECMWF	<p>As just one possible contribution – a reanalysis for YOPP which could be called ERA-YOPP.</p> <p>A likely configuration could be the IFS atmospheric model run at T511 (40 km resolution), the ocean model run 1/4 degree including a sea-ice model (possibly LIM3), and in an 11-member ensemble (1 control + 10 perturbed members). The analysis would be run as an incremental 4D-Var in the atmosphere and a 3D-Var FGAT (first-guess at appropriate time) in the ocean. The former is as operations today, the latter still needs to be finalized but ocean 4D-Var could be an option. The outer loops in the analysis would be run fully coupled while the minimizations in atmosphere and ocean would be performed separately. The forecast could be 10 or 15 days in fully coupled mode. The reanalyses would probably start a bit earlier to spin it up technically and to make sure that everything is in place once we enter the YOPP Phase.</p>	Personal communication from Peter Bauer, ECMWF, September 2014.
WGNE	Provide advice on observation strategies for model development / verification during YOPP including the relative value of single point versus grid box approaches.	Action item from report of WGNE-29 in Melbourne Australia, 10-13 Mar 2014.
JWGFVR	Development of concept for intensive verification period, possibly jointly with S2S and/or HIWeather	
WWRP SERA WG	Development of concept for intensive SERA period	
WWRP Mesoscale Working Group	TBA	
WWRP Predictability Dynamics and Ensemble Forecasting (PDEF) Working Group	TBA	
WWRP Data Assimilation and Observing Systems (DAOS) Working Group	TBA, but should include providing support for an observing system design for polar regions – using techniques such as adjoint forecast sensitivity to observations.	
FAMOS	Development and implementation of the intensive modelling campaign (ice-ocean). (See http://www.whoi.edu/projects/famos/)	
AMOMFW (including AMPS)	Coordination of Antarctic Modelling Experiments	

Contributor	Activity	Status
WMO Lead Centre for Long Range Forecasts	Provision of real-time forecasts, including sea ice and other relevant variables. (See www.wmolc.org).	Indicative
Finnish Met. Institute (FMI)	<ul style="list-style-type: none"> Operational model runs for the Arctic region with a dedicated HIRLAM/HARMONIE model version, including tests with new observations (esp. remote sensing) and better coupling with snow-ice and/or marine modelling. Analysis of the role of large-scale atmosphere-ocean interactions, synoptic-scale processes and stratosphere-troposphere coupling to improve NWP, climate and composition modelling Developing advanced sea ice modules for their integration into NWP and climate model systems Experimental, theoretical and modelling studies on Arctic/Antarctic physical processes: surface exchange, aerosol/radiation interactions, snow processes Developing the production of long-term essential variables on terrestrial snow cover Multi-disciplinary analyses of various GHGs and aerosols for investigating potential climate changes (via e.g. effect on radiative forcing) and forecasting dispersion/transport events Enhancing the use of the Sodankylä/Pallas supersite for experimental work, satellite data reception and analyses as well as ground truth activities (CAL-VAL). 	List provided by SG member, Pertti Nurmi
Byrd Polar Research Center at Ohio State University	<ul style="list-style-type: none"> ARISE Project in Boreal Fall 2014: NASA funded aircraft and modelling study of Arctic clouds, especially Arctic mixed phase stratus clouds, over the Beaufort Sea (primarily). AWARE (ARM West Antarctic Radiation Experiment). Deployment of an ARM mobile site for comprehensive cloud and radiation measurements to McMurdo Station and (part of time) West Antarctica from Austral Fall 2015- Austral Summer 2016 (roughly 15 months). Supported by DOE ARM programme. A pending proposal to NSF will determine whether this project goes ahead. 	List provided by SG member David Bromwich.
IICWG	<ul style="list-style-type: none"> Provision of up-to-date and archived operational ice chart data, both in the chart's native format (from the Ice Logistics Portal) and in other formats (e.g., SIGRID-3, EASE-Grid, and, most importantly, NetCDF 	Suggested by IICWG Member, Pablo Clemente-Colón in comments on earlier version of YOPP Plan

Detailed Modelling Aspects for YOPP

The following modelling areas are considered to merit particular attention during both the YOPP Preparation Phase and the YOPP Phase:

1) *Boundary Layer Including Mixed Phase Clouds*

This is a very important area for polar regions (as well as other parts of the globe, so what can be learned and improved is also relevant elsewhere). Clouds have a strong impact on momentum mixing and moisture fluxes, etc.

1. Improve the representation of mixed-phase super-cooled (stratocumulus) clouds. This has great potential for improving analyses and forecasts in Arctic and also in other regions of known concern such as the southern oceans.
2. Pursue an integrated approach so that cloud, PBL and surface exchange schemes “work well together” preserving process relationships as diagnosed from observations. Test with LES. Also implementing parameterizations addressing known issues is proposed (e.g., a prognostic mixed-phase cloud scheme).

2) *Sea Ice Modelling*

An accurate simulation of the sea ice cover and its interactions with the ocean and the atmosphere requires the correct representation of various features such as pressure ridges, leads, landfast ice, ice arches, melt ponds, etc. Important aspects to be considered are:

1. Representing the properties and processes of a predominantly first year ice cover in the Arctic atmosphere-ice-ocean system.
2. Determining the sea ice thickness distribution.
3. Characterizing the properties of the snow cover on sea ice.
4. The representation of landfast ice. Current sea ice models are not capable of simulating landfast ice. A study of the mechanisms (tensile strength, basal stress due to grounded keels, etc.) responsible for the formation of landfast ice should be performed. Parameterizations should be developed for sea ice models to be able to simulate landfast ice.
5. The simulations of melt ponds and their impact on the modelled ice mass balance. Melt ponds are usually poorly represented in sea ice models. Recently developed melt pond models should be included in sea ice models and tested. An investigation of the impact of melt ponds on the sea ice thickness distribution should be performed.
6. The inclusion of form drag. Models usually only consider skin drag in the calculation of the air-ice and ocean-ice stresses. Form drag, which strongly depends on the sea ice thickness distribution, should also be considered in models.
7. Improving treatment of melt processes including ocean heat flux and impact of floe size distribution on lateral melting.
8. Improving sea ice mechanics, including ridging/rafting and how it influences the subgrid-scale ice and snow thickness distributions.
9. Simulation of sea ice deformation statistics at all scales.

10. Simulations of wave-ice interactions in the Marginal Ice Zone

3) **Physics of Coupling, Including Snow On Sea Ice**

This also implies the need for joint observations relating to coupled processes (e.g., sea salinity and sea ice). Often such measurements may be held within research institutions and not made real-time available in operational formats.

1. Test and possibly implement a multi-layer snow scheme for NWP applications. It is acknowledged that more physics leads to more variability, which may increase RMSE locally but reduce biases.
2. Test improved sea-ice - surface exchange parameterisations (a number of new schemes are now available). Elements of interest in these new schemes are including ice roughness classes and sub-grid processes such as leads, ponds.
3. Test and develop improved schemes for moist convection associated with extremely unstable boundary layers when very cold air flows over open ocean sea-surfaces. Elements to consider are the time-constant for growing moist convection under such conditions, and thus the horizontal distance downstream of sharp surface borders (e.g. between sea-ice and open ocean) where deep convective clouds with vigorous showers develop. This also influences the vertical profile of released latent heat.

4) **High Resolution Modelling Including Ensembles**

High resolution local modelling will be important to capture the physics involved in polar regions. Priority should be placed on this area. A special model archive (akin to the TIGGE-LAM archive) may be useful.

Ensembles are also very much a part of modern prediction systems, including those run at high resolution. For example, Norway already provides operational ensemble-based strike probabilities for polar lows. But do we know enough about model uncertainties to have reliable probabilities? Can the models generate the mesoscale features (in the central Arctic)?

5) **Model Validation and Intercomparison**

This can be carried out using data that already exists from previous observational campaigns – for example, ConcordIASI in the Antarctic, data from the IPY-THORPEX (e.g., the Greenland Flow Distortion Experiment, Norwegian IPY-THORPEX) cluster, and these three in the Arctic:

1. SHEBA (Surface HEat Budget of the Arctic ocean study described at <http://www.eol.ucar.edu/projects/sheba/>) aiming to quantify the heat transfer processes that occur between Arctic ocean/ice and atmosphere over a full annual cycle).
2. ASCOS (Arctic Summer Clouds Ocean Study, described at <http://www.ascos.se/>) aiming at studying physical and chemical processes leading to cloud formation.
3. AOE (Arctic Ocean Experiment, described at <http://gcss-dime.giss.nasa.gov/aoe2001/>) to enhance understanding of how natural sources of atmospheric aerosols affect climate through impact on the radiation balance.
4. Archived and new data from Russian drifting “North Pole” stations (<http://www.aari.ru/main.php?lg=1>) could be used for model validation and intercomparison.

Areas in particular that should be focused on are surface fluxes, cloud characteristics and mesoscale features. This should also assist in planning how model data is archived for the YOPP phase, for further validation and intercomparison studies.

6) *Upper Ocean Processes*

There are large heat fluxes on a small scale – e.g., across leads. In winter leads are a significant source of heat and moisture transfer from the ocean to the atmosphere. In summer, leads absorb over 90% of the incident solar radiation enhancing ice melt and heat storage in the ocean. This could influence the way some observations are taken, and will be useful to guide how experiments are conducted during YOPP.

7) *The Stratosphere*

As one of the main sources of predictive skill for S2S scales, this is an area with many initiatives already taking place – e.g., through SPARC, and S2S. The S2S project will be archiving high-resolution climate forecasts.

While this is an issue for YOPP, it is expected that it will primarily be carried out by and in collaboration with other groups such as the Stratospheric Network for the Assessment of Predictability (SNAP).

8) *Chemistry (Aerosols; Ozone)*

Transport of soot (black carbon) from mid-latitudes to higher latitudes, followed by deposition on snow and ice could have significant impacts in northern polar regions. WGNE activities in this area are mostly case study approaches on atmospheric radiative impacts and not the impact on snow and ice.

Abbreviations

A

AARI	Russian Arctic and Antarctic Research Institute, Russian Arctic and Antarctic Research Institute
ACRE	Antarctic Clouds and Radiation Experiment
AMDAR	Aircraft Meteorological DATA Relay
AMOFW	Antarctic Meteorological Observations, Modeling, & Forecasting Workshop
AMPS	Antarctic Mesoscale Prediction System
AODS	Arctic Ocean Drift Study, Arctic Ocean Drift Study, Arctic Ocean Drift Study
AOE	Arctic Ocean Experiment
APECS	Association of Polar Early Career Scientists
ARM	Atmospheric Radiation Measurement Program of the US Department of Energy
ASAP	Automated Ship Aerological Programme
ASCOS	Arctic Summer Clouds Ocean Study
ATOMMS	Active Temperature Ozone, Moisture Microwave Spectrometer
AWARE	ARM West Antarctic Radiation Experiment
AWG	Atmospheric Working Group
AWI	Alfred Wegener Institute for Polar and Marine Research

B

BAS	British Antarctic Survey
BUFR	Binary Universal Form for the Representation of meteorological data – WMO standard

C

CALM	Circumpolar Active Layer Monitoring Network
CAL-VAL	Calibration and Validation
CBS	Commission for Basic Systems of WMO
CCN	Cloud Condensation Nuclei
CFMIP	Cloud Feedback Model Intercomparison project
CIMO	Commission for Instruments and Methods of Observation of WMO
CIIC	Climate and Cryosphere Project of WCRP
CLIVAR	Climate Variability and Predictability
CMIP	Coupled Model Intercomparison Project

D

DAOS	Data Assimilation and Observing Systems
DLR	German Aerospace Centre
DOE	Department Of Energy (US)
D-PHASE	Demo of Probabilistic. Hydro and Atmos Simulation of flood Events in the Alpine region

E

EASE-Grid	Equal-Area Scalable Earth Grid
EC	Executive Council of WMO
ECMWF	European Centre for Medium-Range Weather Forecasts
EC-PORS	Executive Council Panel of Experts on Polar Observations, Research and Services, of WMO
ECRA	European Climate Research Alliance
EPS-SG	EUMETSAT Polar System - Second Generation
ERA	ECMWF Re-Analysis
ESA	European Space Agency
ESSD	Earth System Science Data Journal

EUCOS	EUMETNET Composite Observing System
EUMETNET	European Meteorological Services Network
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites

F

FAMOS	Forum for Arctic Modeling and Observational Synthesis
FMI	Finnish Meteorological Institute
FROST-2014	Forecast and Research: the Olympic Sochi Testbed

G

GABLS	GEWEX Atmospheric Boundary Layer Study
GASS	Global Atmospheric System Studies (part of WCRP's GEWEX)
GAW	Global Atmosphere Watch
GCW	Global Cryosphere Watch
GEWEX	Global Energy and Water EXchanges project (WCRP)
GFCS	Global Framework for Climate Services
GIPPS	Global Integrated Polar Prediction System
GNSS-RO	Global Navigation Satellite System - Radio Occultation
GODAE	Global Ocean Data Assimilation Experiment
GPC	Global Producing Centre of WMO
GTS	Global Telecommunication System of WMO

H

HIRLAM	High Resolution Limited Area Model
HIWeather	WWRP THORPEX Legacy Project on High Impact Weather

I

IABP	International Arctic Buoy Programme
IAMAS	International Association of Meteorology and Atmospheric Sciences
iAOOS	integrated Arctic Ocean Observing System
IASC	International Arctic Science Committee
IASOA	International Arctic Systems for Observing the Atmosphere
IASSA	International Arctic Social Sciences Association
IceBridge	An Airborne Mission for Earth's Polar Ice (NASA)
ICI	Ice Cloud Imager
ICO	International Coordination Office for Polar Prediction
IICWG	International Ice Charting Working Group
IMB	Ice Mass Balance buoy
IOC	Intergovernmental Oceanographic Commission
IOP	Intensive Observing Period
IPAB	International Programme for Antarctic Buoys
IPY	the International Polar Year 2000-2008
ISAC	International Study of Arctic Change
ITP	Ice Tethered Profilers

J

JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology, WMO-IOC
JRA-55	Japanese 55-year Reanalysis
JWGFVR	Joint Working Group on Forecast Verification Research

L

LES	Large Eddy Simulations
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M

MAC	Microphysics of Antarctic Clouds
MERRA	Modern-Era Retrospective Analysis for Research and Applications
MIZOPEX	Marginal Ice Zone Observations and Processes EXperiment
MOSAIC	Multidisciplinary drifting Observatory for the Study of Arctic Climate

N

NASA	National Aeronautical and Space Administration
NetCDF	Network Common Data Format
NMHS	National Hydrological and Hydrometeorological Services of WMO Members
NOAA	USA National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction

O

OOI	Ocean Observatories Initiative
OSE	Observing System Experiment
OSSE	Observing System Simulation Experiment

P

PBL	Planetary Boundary Layer
PCPI	Polar Climate Predictability Initiative
PRACE	Partnership for Advanced Computing in Europe
PSTG	Polar Space Task Group

R

RMSE	Root Mean Square Error
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S

S2S	Sub-Seasonal To Seasonal Project (WWRP/WCRP)
SAON	Sustaining Arctic Observing Network
SAR	Synthetic Aperture Radar (usually satellite-based)
SCAR	Scientific Committee for Antarctic Research
SEARCH	Study of Environmental Arctic Change
SERA	Societal and Economic Research Applications
SG	Steering Group
SHEBA	Surface HEat Budget of the Arctic ocean
SIDARUS	Sea Ice Downstream services for Arctic and Antarctic Users
SIGRID	Sea Ice Gridded Format
SIOS	Svalbard Integrated Observing System
SMAP	Soil Moisture Active Passive satellite
SMOS	Soil Moisture and Ocean Salinity satellite
SNAP	Stratospheric Network for the Assessment of Predictability
SnowMIP	Snow Models Intercomparison Project
SOCRATES	Southern Ocean Clouds, Radiation and Aerosol Transport Experimental Studies
SPARC	Stratosphere-troposphere Processes And their Role in Climate
SPICE	Solid Precipitation Intercomparison Experiment

T

THORPEX	THe Observing system Research and Prediction EXperiment
TIGGE	WMO's THORPEX Interactive Grand Global Ensemble
TIGGE-LAM	TIGGE Limited Area Model project
T-NAWDEX	THORPEX-North Atlantic Waveguide and Downstream Impact Experiment
Transpose-AMIP	Weather forecasting with climate models

U

UAV	Unmanned Aerial Vehicles
ULS	Upward Looking Sonar
UNIS	University Centre in Svalbard

W

WCRP	World Climate Research Programme
WGNE	Working Group on Numerical Experimentation
WGOMD	CLIVAR Working Group on Ocean Model Development Climate Variability
WGSIP	Working Group on Seasonal to Interannual Prediction
WIS	WMO Information System
WMO	World Meteorological Organization
WoS	Web of Science bibliographic databases
WS	Wide Swath (satellite)
WWRP	World Weather Research Programme of WMO
WWRP SSC	Scientific Steering Committee of WMO's WWRP (successor to WWRP-JSC)
WWRP-JSC	Joint Scientific Committee of WMO's WWRP

Y

YOPP	Year Of Polar Prediction
YOPP-S	YOPP for Society – SERA aspects subgroup
YOTC	Year of Tropical Convection
YPG	YOPP Planning Group
YPM	YOPP Planning Meeting

LIST OF WWRP POLAR PREDICTION PROJECT PUBLICATIONS

1. WWRP Polar Prediction Project Science Plan, WWRP/PPP No. 1 – 2013
2. WWRP Polar Prediction Project Implementation Plan, WWRP/PPP No. 2 – 2013