WWRP/PPP No. 4 - 2016

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

WEATHER CLIMATE WATER

WORLD
METEOROLOGICAL
ORGANIZATION

WWRP WORLD WEATHER RESEARCH PROGRAMME

AWI ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

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Version 2.0

WORLD METEOROLOGICAL ORGANIZATION

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

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

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For related documents refer to http://polarprediction.net

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and many other contributors from the international polar research community whose valuable suggestions and comments we would like to acknowledge.

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**. With a focus on time scales from hours to a season, YOPP is a major initiative of the World Meteorological Organization's World Weather Research Programme (WWRP) and a key component of the Polar Prediction Project (PPP). YOPP is being planned and coordinated by 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 existing **polar observing system** (enhanced coverage, higher-quality observations).
2. Gather **additional observations** through field programmes aimed at improving understanding of key polar processes.
3. Develop improved representation of **key polar processes** in (un)coupled models used for prediction.
4. Develop improved (coupled) **data assimilation systems** accounting for challenges in the polar regions such as sparseness of observational data.
5. Explore the **predictability** of the atmosphere-cryosphere-ocean system, with a focus on sea ice, on time scales from hours to a season.
6. Improve understanding of **linkages** between polar regions and lower latitudes, assess skill of models representing these linkages, and determine the impact of improved polar prediction on forecast skill in lower latitudes.
7. Improve **verification** of polar weather and environmental predictions to obtain better quantitative knowledge on model performance, and on the skill, especially for user-relevant parameters.
8. Identify various stakeholders and establish their **decisionmaking needs** with respect to weather, climate, ice, and related environmental services.
9. Assess the **costs and benefits** of using predictive information for a spectrum of users and services.
10. Provide **training opportunities** to generate a sound knowledge base (and its transfer across generations) on polar prediction related issues.

YOPP is implemented in three distinct phases. During the YOPP Preparation Phase (2013 through to mid-2017) this Implementation Plan was developed, which includes key outcomes of consultations with partners at the YOPP Summit in July 2015. Plans will be further developed and refined through focused international workshops. There will be engagement with stakeholders and arrangement of funding, coordination of observations and modelling activities, and preparatory research. During the YOPP Core Phase (mid-2017 to mid-2019), four elements will be staged: intensive observing periods for both hemispheres, a complementary intensive modelling and prediction period, a period of enhanced monitoring of forecast use in decisionmaking including verification, and a special educational effort. Finally, during the YOPP Consolidation Phase (mid-2019 to 2022) the legacy of data, science and publications will be organized.

The WWRP-PPP Steering Group provides endorsement throughout the YOPP phases for projects that contribute to YOPP. This process facilitates coordination and enhances visibility, communication, and networking.

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 decisionmaking. Furthermore, it is increasingly obvious that weather and climate in the polar regions have an influence on the lower latitudes.

Recognizing this, a number of initiatives are underway which focus on improving 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 World Weather Research Programme's 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 on a very broad range of activities, YOPP is quite different from the International Polar Year (IPY) in 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, to generate the knowledge necessary to improve the representation of key polar processes in models, and to provide ground-truthing that is needed 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 Core Phase from mid-2017 to mid-2019, and the YOPP Consolidation Phase from mid-2019 to 2022. Details on the YOPP phases are covered in Sections 3, 4 and 5.

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. The World Meteorological Organization's (WMO) World Weather Research Programme (WWRP) has established the Polar Prediction Project (WWRP-PPP) 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 (ICO) for Polar Prediction 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 (YOPP). YOPP as initially envisaged is covered in Chapter 5 of the WWRP-PPP Implementation Plan. Given the complexity involved in YOPP, however, it was decided to develop a separate YOPP Implementation Plan (version 1.0), which expands on the initial planning taking into account discussions and decisions from various WWRP-PPP and YOPP planning meetings, and input from external consultation during the first half of 2014. Additional comments and contributions from many individuals and organizations are gratefully acknowledged.

1. The first YOPP Planning Meeting (YPM-1) was 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 was held from 1-3 October 2013 in Boulder, Colorado, USA.
3. The second planning meeting for YOPP (YPM-2), focussing on observations, was held on 8 April 2014 in Helsinki, Finland.
4. The third planning meeting for YOPP (YPM-3), focussing on modelling, was held in association with the World Weather Open Science Conference and the 5th meeting of the PPP Steering Group from 21-23 August 2014 in Montréal, Canada.

Following the YOPP Summit and PPP SG-6 in Geneva in July 2015 it was decided to develop an updated version of the YOPP Implementation Plan (version 2.0 – this document) which takes into account a number of recent developments, including recommendations from a major international workshop on Polar-Lower Latitude Linkages and Their Role in Weather and Climate Prediction.

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 existing **polar observing system** (enhanced coverage, higher-quality observations).
2. Gather **additional observations** through field programmes aimed at improving understanding of key polar processes.
3. Develop improved representation of **key polar processes** in (un)coupled models used for prediction.
4. Develop improved (coupled) **data assimilation systems** accounting for challenges in the polar regions such as sparseness of observational data.
5. Explore the **predictability** of the atmosphere-cryosphere-ocean system, with a focus on sea ice, on time scales from hours to a season.
6. Improve understanding of **linkages** between polar regions and lower latitudes, assess skill of models representing these linkages, and determine the impact of improved polar prediction on forecast skill in lower latitudes.
7. Improve **verification** of polar weather and environmental predictions to obtain better quantitative knowledge on model performance, and on the skill, especially for user-relevant parameters.
8. Identify various stakeholders and establish their **decisionmaking needs** with respect to weather, climate, ice and related environmental services.
9. Assess the **costs and benefits** of using predictive information for a spectrum of users and services.
10. Provide **training opportunities** to generate a sound knowledge base (and its transfer across generations) 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 datasets that can be used by the wider research community and other 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 among users (including researchers) and other 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, a Core Phase (the actual YOPP), and a Consolidation Phase, as outlined in Figure 1 below.

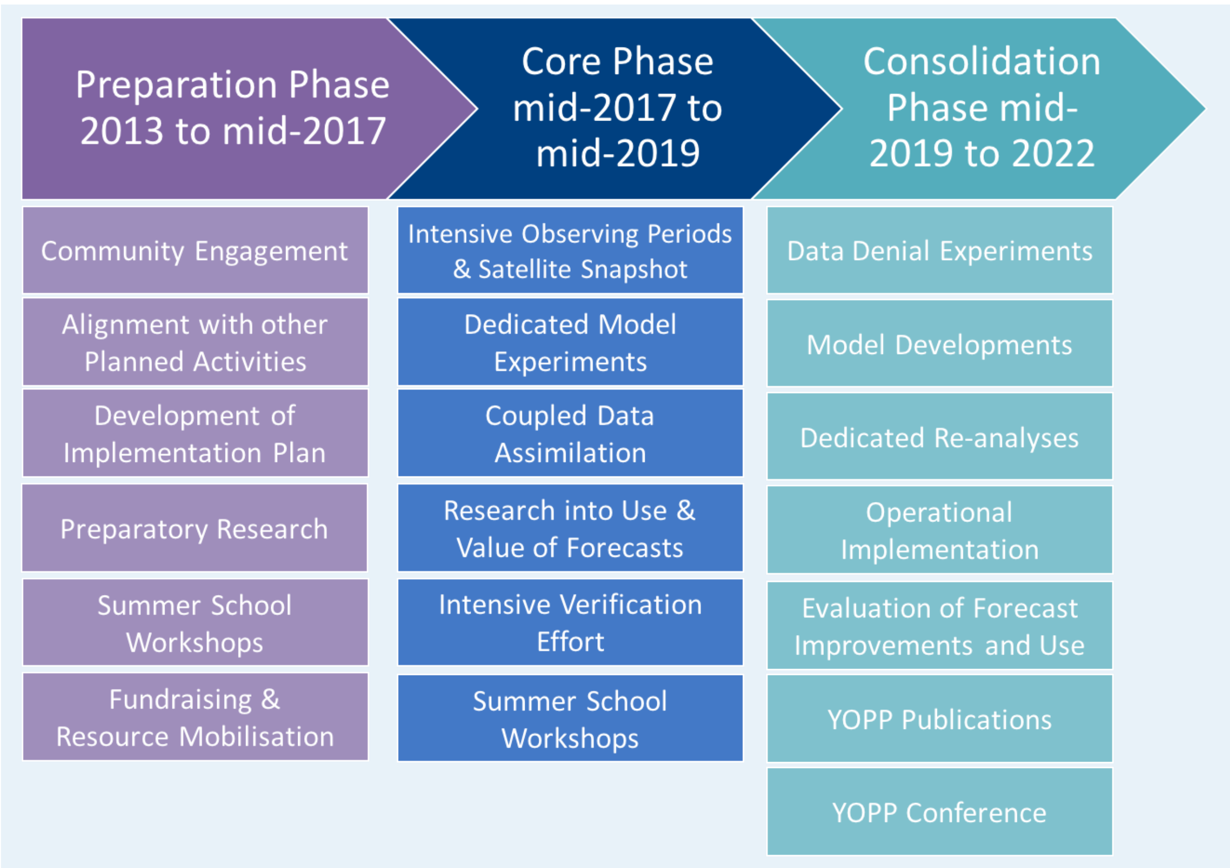

Figure 1. Three stages of YOPP, including the main activities for each stage

A comprehensive list of future milestones is given in Annex 1.

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

The Preparation Phase is important for the success of YOPP. It involves a number of aspects including overall planning, engagement with stakeholders, coordination of observations and related field programmes, promotion of modelling activities, establishment of data archive systems, establishment of the endorsement process for collaborating projects, preparatory research, and involvement of funding agencies.

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, the Atmospheric Working Group (AWG) of the International Arctic Science Committee (IASC), the International Study of Arctic Change (ISAC), and the Sub-seasonal to Seasonal Prediction (S2S) project.

A YOPP Planning Group (YPG) was established in October 2013 during the fourth meeting of the PPP Steering Group in Boulder, Colorado, USA. This consists of the full PPP Steering Group, augmented, as available and agreed, by representatives of other relevant partners and initiatives (see Table 1). 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 (as from 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 the Arctic Observing Summit in Helsinki, Finland. YPM-3 in August 2014 concentrated on modelling aspects, and was organized in association with the World Weather Open Science Conference and the 5th meeting of the PPP Steering Group in Montréal, Canada.

The fourth international YOPP Planning Workshop, called the YOPP Summit (Goessling et al., 2016), was a major event and was held at WMO in Geneva, Switzerland during July 2015. One outcome of the Summit was the establishment of a Coordinating Committee for YOPP activities in the Southern Hemisphere (YOPP-SH; http://polarmet.osu.edu/YOPP-SH/). This committee is needed to promote Antarctic and Southern Ocean research that contributes to YOPP in view of the so far rather strong YOPP emphasis on the Arctic. The YOPP-SH coordination committee is tasked with identifying the Intensive Observing Period(s) and enhanced observing to be undertaken during YOPP in the Southern Hemisphere.

3.1.3 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 organized 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 Exploring user needs and knowledge contributions

It will be essential to engage with various stakeholders interested in YOPP activities to understand how they make decisions and perceive potential risks, and how they access, use, interpret or produce weather-related information. This will help to ensure that stakeholders' needs and their potential contributions to YOPP will be addressed appropriately. To this end, it is planned to consult with stakeholders at planned PPP meetings and other events, including YOPP-related field campaigns. The Societal and Economic Research Applications (SERA) sub-committee of the PPP will develop these activities in consultation with the PPP-ICO, the PPP-SG, and representatives from EC-PHORS, NMHS, and WWRP JWGFVR. Close collaboration will also be conducted with key stakeholders and other relevant social and interdisciplinary scientific bodies such as the International Arctic Social Sciences Association (IASSA) and the Humanities and Social Sciences Expert Group (HASSEG) of the Scientific Committee on Antarctic Research (SCAR).

Existing resources documenting stakeholder requirements will also be evaluated. These include a wide range of existing reports and surveys, such as a white paper produced by the Services Task Team of EC-PHORS and a user requirement review provided by the European Union Seventh Framework (FP7) funded project Sea Ice Downstream Services for Arctic and Antarctic Users and Stakeholders (SIDARUS).

3.2.2 Identifying YOPP partners

Numerous important partners for YOPP have been identified, including various coordinating bodies (Table 1). In addition, many other organizations, projects, and groups are expected to contribute to YOPP. A formal endorsement process has been implemented to continually expand the YOPP network (see next section); an up-to-date overview of endorsed partners, along with their proposed contributions, is given at http://www.polarprediction.net/yopp/yopp-endorsement.html.

Table 1. Key partners (coordinating bodies) for YOPP.
(For abbreviations see Annex 5)

Group	*Role*
APECS	Implementation of the educational component of YOPP
CBS/Integrated Obs. Systems	Facilitating the improvement of polar observing systems
EC-PHORS	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 to ground-truth satellite data
PCPI	Close coordination of YOPP-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
SIPN	Collaboration on sea ice prediction
SOOS	Coordination of Southern Ocean Observations
WCRP/CliC	Close coordination of YOPP-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 sub-seasonal and seasonal predictions

3.2.2.1 Endorsement

Endorsement is provided for projects, programmes, and initiatives that plan to contribute to the aims of the Year of Polar Prediction (YOPP), as described in this document. The purpose of endorsement is to:

- Increase the visibility of the related research activities (e.g. listing on website)
- Provide an international framework for YOPP-related research which can help to leverage support and funding
- Contribute to improving the coordination between different activities
- Enhance networking and communication of related projects.

The endorsement process is described in detail at http://www.polarprediction.net/yopp/yopp-endorsement.html. A request form for YOPP endorsement and an up-to-date overview of endorsed partners, along with their proposed contributions, are also available at this website.

3.2.3 Exploring 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 of WMO Members 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 has been compiled, which can be used to assist with national approaches to funding agencies. The general profile of YOPP will need to be continuously 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.

The European Commission has recently highlighted the relevance of YOPP in their Horizon 2020 funding programme. In two Arctic calls (BG-09-2016, BG-10-2016) with a total volume of 30 Mio EUR direct contributions to YOPP are solicited.

3.3 Coordinating 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 needed and made available to YOPP.

3.3.1 Promoting and exploiting additional observational data

Additional 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 a broad and long-lasting benefit also beyond the phases of YOPP.

The northern and southern polar regions are very different in terms of their observational networks and characteristics; it is therefore important to ensure that attention is paid specifically to each region. However, for both polar regions the observing system is in general sparse so that a few additional observations could make a significant difference to the quality of predictions.

The main activities during the Preparation Phase is to identify and work with partners to promote and exploit additional data and to promote making existing observations available for experimentation during YOPP. The observational data which are considered to be most useful during YOPP are discussed in more detail in Section 4 (YOPP Core Phase). In summary, the approaches needed are to:

- Work with partners such as EUCOS to plan and promote additional routine observations.
- Work with the WMO Polar Space Task Group 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 International Arctic Systems for Observing the Atmosphere (IASOA) sites.
- Coordinate YOPP activities with ongoing polar observing system efforts.
- Provide satellite agencies with a list of priorities for planning future missions.

- Encourage the user community to actively take and contribute 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 Global Telecommunication System of WMO (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 WIS.
- 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 Coordinating 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 will be 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 starting in newly formed Arctic sea ice around and drifting with the ice over the course of at least a year, to study a full annual cycle. The German research icebreaker RV *Polarstern*, operated by AWI, has now committed to MOSAiC but one year later than originally envisaged (now commencing in September 2019). Consequently, the MOSAiC campaign will be running within the early part of the YOPP Consolidation Phase, rather than the YOPP Core Phase. It is anticipated that many of the planned YOPP activities (e.g. additional model runs, etc.) will continue from the YOPP Core Phase into the Consolidation Phase in order to cover the delayed MOSAiC deployment thereby making best use of resources.

The MOSAiC campaign 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 special observing periods – for example, after the polar night when sunlight returns. Such periods are likely to include contributions from aircraft flights, as well as complementary drifting vessels.

Unlike the Surface Heat Budget of the Arctic Ocean (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 locations around the central field 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 by 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, emphasizing the alignment with YOPP objectives. Cross-participation in meetings is planned. YOPP is providing input to the MOSAiC Science Plan by identifying atmosphere, ice, and ocean parameters that are critical to measure as well as by helping to identify the spatial and temporal scales to measure them. In addition, coordinated ice-drift forecast experiments are envisaged within YOPP to give guidance for where to deploy Polarstern and to support operations during the MOSAiC drift.

There are several field campaigns that will be occurring (or have already occurred) during the YOPP Preparation Phase including the six-month long Norwegian Young Sea Ice Cruise 2015 (N-ICE2015) north of Svalbard, the three-month long atmospheric and oceanographic observations during the Swedish-Russian-US Arctic Ocean Investigation of Climate-Cryosphere-Carbon Interactions Program (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 lasting from one to up to three months. 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 Promoting 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 anticipated improvements in predictions from better representation of key polar processes through significantly enhanced horizontal and vertical resolutions, 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, GABLS, S2S and process modellers GASS are crucial aspects during this phase in order to strengthen collaboration and minimize duplication efforts.

Coupled modelling requires realistic descriptions of the individual environmental components (atmosphere, ocean, sea ice, and land surface) as well as the coupling between them through fluxes of momentum and heat. The coupled system poses challenges in finding a proper representation and balance between the levels of complexity of the model components as well as choosing adequate horizontal and vertical model resolutions. Some more important challenges include the representation of snow on sea ice and land, permafrost and land ice, as well as how to best use the sparse observations in the data assimilation algorithm to initialize the coupled system and to design the technical framework employing couplers or integrated code.

Environmental predictions are only meaningful as long as one can rely on the information given about environmental elements on specific sites at future times, and if the predictions are better than simple reference predictions, e.g. based on past climatology. Key forecast qualities are reliability and useful resolution of the information. Exploring the predictability of weather and sea ice in the polar regions is an important part of numerical simulations during YOPP; this includes idealized experiments in the so-called perfect-model framework, but also data assimilation experiments to study the impact of additional observations and enhanced observational programmes.

The predictability inherent to a system is lost when prediction errors saturate at a level where there is no memory of the initial state any more. This predictability limit is a consequence of the instabilities inherent to the system. The growth rates of errors associated with atmospheric flows increases with decreasing scales, that is, smaller-scale features are less predictable than large-scale patterns. 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 (i.e. predictive skill) can be improved, provided model imperfections are also reduced. Experience from the ensemble prediction system at many Numerical Weather Prediction (NWP) centres (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 (two weeks) and for sub-seasonal to seasons ahead. Several of these systems deliver output to the TIGGE archive, which is expected to continue through the YOPP Core Phase. 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 within as well as outside the polar regions. It is obvious that the upper oceans, sea ice, and land-surfaces with vegetation and snow cover are dynamically coupled in such systems, although at present it is unclear how well 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 systems. These systems are developed for lead times up to two to three days 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 produced frequently and quickly 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 operationally or in experimentation today (as of 2014) at forecasting centres, e.g. MET Norway. Extreme or high-impact weather conditions 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 through WGNE and those involved in AMOMFW/AMPS, as well as operational NWP centres of the WMO through its Commission for Basic Systems.

Operational model support for MOSAiC and any other major international field campaigns needs to be planned. Operational centres will need to provide 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 on 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 (ESM), 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-Snow Model Intercomparison Project (ESM-SnowMIP).

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 utilise observations and detailed process models such as Large Eddy Simulations (LES) and Cloud Resolving Models (CRM) to test the parameterizations used in NWP and climate models. Of relevance for the polar regions is the WGNE/GASS Grey Zone Project that focuses on the problems with partly resolved, partly parameterized problems. Their 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 the GEWEX Atmospheric Boundary Layer Study GABLS-4, which focuses on a diurnal cycle in summer at the Antarctic research station Dome C, 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 maritime to Arctic (above-sea ice) air is in focus in a third GASS intercomparison activity.

3.3.4 Establishing YOPP Data Archive System

A YOPP Data Archive System should be established in advance of the YOPP Core 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 Core Phase (see Sections 3.4.3 and 4.3.2).

It should be mandatory for all participating projects to make their respective 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 Core 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 datasets to be published (e.g. one needs a DOI (digital object identifier)). 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 Core 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 willing to host YOPP data should be identified in addition.

Other matters that should be taken into account for the YOPP Data Archive System include the 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 using 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 groups and individuals involved in efforts such YOTC, TIGGE, the D-PHASE, the IASOA Data Access Portal (http://www.esrl.noaa.gov/psd/iasoa/dataataglance), and the Polar Data Catalogue (https://www.polardata.ca/). Existing platforms and protocols such as the Earth System Grid Federation (http://esgf.llnl.gov/), the Observations for Climate Model Simulations (https://www.earthsystemcog.org/projects/obs4mips/) and Analysis for Model Intercomparison Projects (https://www.earthsystemcog.org/projects/ana4mips/) should be considered as well.

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 recognizing that YOPP is different in some aspects. For example, the archive would need to include not just atmospheric model data. The review might include looking at data downloads and reported uses of the YOTC data, although such information needs to be interpreted with care. Some points to consider for the 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), including for ocean models.
- To archive additional fields, such as instantaneous and accumulated fluxes (atmosphere-snow-soil) and the state of continental surfaces (i.e. snow and soil characteristics), more frequently (e.g. hourly).
- To capture important processes in the hours-to-seasonal time scale of 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 short- to medium-range time scales including sea ice and more realistic polar land models should be in place by the YOPP Core Phase. This will allow for the possibility of model intercomparisons in the dataset of fully coupled versus atmospherically driven sea ice predictions.
- 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 will be invaluable for the evaluation of models, parameterization development, and improvement of satellite products.

3.4 Preparatory research

The success of YOPP Core Phase activities will in part be determined by the timely completion of preparatory research in several areas as outlined in subsequent sections. Additionally, fundamental infrastructures must be developed, and critical physical, cultural and socio-economic data need to be compiled during the preparatory phase to support research during the YOPP Core Phase. This includes constructing and obtaining access to coupled prediction systems (atmosphere-ocean-cryosphere) based in NMHS operational forecast centres, as well as development of an inventory and evaluation of weather-related risks and related decisionmaking processes, prediction services, information requirements, and user experiences.

3.4.1 Observations

Preparatory research regarding observations will help guide decisions on which additional observations and field experiments, including their locations and timings, 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 prediction system-oriented applications. The former would mostly aim at a better representation of physical processes, for example associated with polar clouds, stable boundary layers, and atmosphere–land–sea ice–ocean coupling. The latter would aim at enhancing large-scale predictive skill, also beyond polar regions, by modifications of system components such as the data assimilation and the ensemble generation.

Observing System Simulation Experiments (OSSE) 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 OSSE in areas where model biases are large, and about the significant experimental effort involved. More basic evaluation is needed here. 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 helpful for this. Model experiments can also guide the selection of locations for manned and autonomous observatories.

3.4.2 Modelling and forecasting

Preparatory research and development in this category will help guide decisions on modelling systems to be implemented during YOPP, as well as leading to fundamental improvements in those models. During YOPP it is envisaged that numerous studies are sustained over sufficiently long periods, in order to obtain adequate representations of a wide spectrum of forecasting challenges, and to identify those that are not yet well known.

In addition, dedicated campaigns are needed with extensive advanced observations over shorter periods. These are expected to be dedicated to specific features and processes where there is obvious shortage of quantitative knowledge and understanding, where models employ parameterizations of various degrees of sophistication and limitations, and where the role of uncertainties in these parameterizations is poorly known. Operational ensemble predictions, globally and regionally, should be used to increase the success rate of such campaigns, and, even more importantly, modelling groups should be involved in the planning and coordination of these studies. Process models which partly or entirely resolve and represent key physical processes (e.g. convection resolving or permitting models) should be integrated into the experiments from the start of the planning.

Tests should 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, clouds, and surface processes in NWP models is crucial for vertical mass and momentum transports, for the surface energy budget, as well as for the interaction between the shallow polar lower troposphere and large-scale advection. These processes are also critical for accurately reproducing changes in the sea ice cover and in the ocean. The focus here is on mesoscale processes near or at the surface, although bearing in mind the importance of synoptic-scale aspects, including upper-level processes (e.g. atmospheric blocking, Rossby wave breaking, formation of tropopause folds).

There is more detail on YOPP modelling 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 concentrations of cloud condensation nuclei, as well as 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.
- The representation of orographic flows in the vicinity of the steep terrain that is prevalent in the polar regions.
- The interactions 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 NASA's IceBridge, revisiting reanalyses to assess the role of moisture transport and cloud formation, and using satellite datasets of observation satellites such as Cloudsat and CALIPSO run by NASA to study mixed phase clouds, promise a well-founded characterization of present model shortcomings.

Analysis of model data

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

- Global and regional reanalyses covering long time periods with fixed modelling and data assimilation systems, reducing the dependence of performance to observation availability and predictability. Examples are the global atmospheric reanalyses ERA-Interim and ERA-20C (ECWMF), the Japanese 55-year Reanalysis JRA-55 (Japan

Meteorological Agency (JMA)), the Modern-Era Retrospective analysis for Research and Applications, Version 2 MERRA-2 (NASA), the Arctic System Reanalyses ASRv1 and ASRv2 (cross-institutional, lead by Byrd Polar and Climate Research Center (BPCRC)), and the Climate Forecast System Reanalysis CFSR (National Centers for Environmental Prediction (NCEP)).

- ECMWF YOTC 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 (global and Limited Area Model variant (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).
- The Stratosphere-troposphere Processes And their Role in Climate (SPARC) IPY Data (http://www.sparc-climate.org/data-center/data-access/sparc-ipy/).

The above listed datasets are expected to provide guidance for dedicated numerical experiments to be run during the YOPP Preparation Phase and the YOPP Core Phase. The combined assessment of reanalyses, YOTC, TIGGE and Transpose-AMIP is expected to help identify dominant sources of model error from analysis and forecast ensemble spread, model tendencies and analysis increments, and allow for 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, as well as 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, and in the presence of very dry conditions and or 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 or effectively exploited.

Coupled data assimilation is expected to result in significant progress in model 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 Synthetic Aperture Radar (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 are 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 focussing on mid-latitudes. These require adjusting for use also over high-latitudes. Since these formulations drive both the weight given to observations in the analysis and the spread of ensemble analyses and forecasts, better error characterization promises substantial progress in both NWP analysis accuracy and forecast reliability estimates. This could be improved by running large ensembles of simulations (without data assimilation) that could help making progress in the characterization of the model error structure. Concerning observation data coverage, the polar regions are more densely observed by polar-orbiting satellites than e.g. 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.

Furthermore, snow on sea ice poses additional observational problems and hence requires special attention.

Representation of model uncertainty in polar regions is an issue here as well. How to generate ensembles that reflect at the same time our incomplete knowledge of initial conditions, the imperfect nature of model physics, and the unpredictable evolution of the atmosphere, is still an open issue. The ultimate objective is thus to have ensembles that are skilful and reliable at the same time.

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 here 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 to 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 implementing the systems to be used during the YOPP Core Phase. In order to be able to establish all required verification activities before the YOPP Core Phase starts, it needs to be assessed and decided whether a (quasi) real-time concerted verification undertaking is feasible during YOPP, and how this is organized. The following issues need to be considered:

- Definition and construction of the YOPP Data Archive System in such a manner to facilitate forecast verification. Definition and implementation of a common, centralised (possibly (quasi) real-time) verification undertaking utilizing comprehensive verification systems/packages; real-time verification against GTS observations during YOPP is encouraged by exploiting existing resources/facilities already available in some major operational centres (e.g. ECMWF). During the YOPP Consolidation Phase, summary verification to monitor and compare pre- and post-YOPP predictions and the impacts on mid-latitude predictability should be coordinated and centralised amongst few key centres (e.g. Environment Canada). 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 polar prediction-relevant variables, observation data sources, 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. Impacts of

observation uncertainties on verification results need to be analysed: development of verification approaches which account for observation uncertainties are desirable.

- Definition of suitable and especially tailored verification metrics. Diagnostic verification (e.g. scale-dependent verification) and process-based diagnostics will be of special value and will also provide a link between modellers and the verification community. Summary verification scores will address the needs of the general user and serve the needs of administrative monitoring. Meaningful verification measures specifically designed to address relevant end-user needs are to be identified. Diagnostics to analyse polar-lower latitude linkages need to be developed.
- 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 (e.g. field-deformation techniques or Hausdorff metrics) should be investigated. Sea ice is a key variable for numerical modelling because it acts as a buffer between ocean and atmosphere. Sea ice is also a major concern to a variety of stakeholders whose needs run the gamut of forecast time and space scales. Hence, ice centres should be contacted for extensive collaboration. This would be aided by moving towards automated rather than manual ice analysis. The planned launch of the Canadian Space Agency's RADARSAT Constellation in 2018 (http://www.asc-csa.gc.ca/eng/satellites/radarsat) could be timely for YOPP.
- It is highly important to have 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 (e.g. ceiling and icing). 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 (e.g. sea ice pressure, icebergs, fog). Verification of the timing of user-relevant events (e.g. onset and clearance of fog) should get more attention.
- The potential of forecasting centres to produce specially tailored probabilistic end user guidance forecasts during YOPP is a tempting option, also to be taken into account for the definition of verification activities and techniques. Input from end users on what they are most concerned about is needed. The development of user-tailored products and services is encouraged. Many operational ice services are in close contact with the shipping industry and could be encouraged to engage their users in verification. Meaningful prediction variables need to be identified, and to evaluate them, in a subsequent step, useful verification metrics and approaches need to be devised.
- Collaboration with the SERA group and social sciences are crucial for enhancing such user-engagement and correctly address the user needs both from the prediction and verification perspectives.
- Until now, observation, prediction, and verification of snow conditions have received less attention than rain and will need more emphasis in the polar context. The WWRP High Impact Weather project (HIWeather) includes disruptive winter weather conditions as one of its hazard focus areas and thus provides good collaboration opportunities with YOPP activities for the verification of snow-storms, blizzards, freezing rain, fog, polar lows, etc. Links should be established with the CIMO-SPICE project working on 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 perform a concerted verification undertaking. More explicitly, these centres would need to adapt standard verification packages for users and to look into the applicability of spatial verification techniques for sea ice verification. Candidates might be ECMWF, NCAR, US Navy, and Environment and Climate Change Canada. However, funding support for 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 (e.g. at summer schools, and workshops) as well as among educated forecast end users.

3.4.4 Forecast use and decisionmaking

Establishing a baseline understanding of how various stakeholders involved in communities, economic sectors, and government organizations produce, receive, interpret and apply forecast information into decisionmaking 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 risks and related decisionmaking processes, prediction services, information requirements, and user experiences. This initial scoping research will be informed by, and complemented with, a series of regional or sectorial consultation meetings, interviews, focus groups, surveys or workshops, in order to establish up to five priority areas for social science proposal development and detailed investigation during the YOPP Core Phase and the subsequent YOPP Consolidation Phase. Coordination with EC-PHORS and its Services Task Team undertaking related activities will be important as will securing the involvement of community representatives and indigenous groups in the Arctic, and collaboration with international Antarctic committees such as the Council of Managers of National Antarctic Programs (COMNAP) and SCAR on Antarctic-related matters. The consultations will also be used to determine preferences for the archiving of knowledge accumulated through SERA-related activities – most likely in a system separate from that used to assemble, process and archive physical scientific observations.

3.4.5 Workshops and education

During the YOPP Preparation Phase, the YOPP Planning Group will organize and promote workshops and education relating to YOPP objectives. Section 4.4 covers overall education aspects for YOPP, including the Polar Prediction School 2016 during the YOPP Preparation Phase.

4. YOPP CORE 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 2018.

YOPP's Core Phase encompasses four major elements: an intensive observing period, a complementary intensive modelling and forecasting period, a period of enhanced verification and monitoring of information use in decisionmaking, and a special educational effort. The overall structure for mid-2017 to mid-2019 is shown in Figure 1.

4.1 Observing

YOPP will take advantage of the existing operational observational data acquired under the WMO Integrated Global Observing System (WIGOS), including data from polar regions. YOPP Preparation Phase activities will promote additional observations described in Section 3.3.1, as well as coordinate with MOSAiC and the ongoing efforts of the Southern Ocean Observing System (SOOS) and the Sustaining Arctic Observing Network (SAON; Section 3.3.2). These efforts should result in additional datasets as described in the following sections.

Note that MOSAiC, which has been delayed to September 2019, now starts at the end of the YOPP Core Phase and continues a year into the YOPP Consolidation Phase (see Section 3.3.2 for details).

4.1.1 Timing: special and intensive observing periods

Given that it is not feasible to maintain certain types of polar observations (e.g. four radiosonde launches daily) over two full years, it was recognized that Special Observing Periods (SOPs) within the YOPP Core Phase are needed, both for the Arctic and the Antarctic. To allow an even stronger focus, there will be even shorter Intensive Observing Periods (IOPs) embedded in the SOPs.

Taking into account operational feasibility, physical processes, benefit for data assimilation systems, and socio-economic relevance, the timing of SOPs was tentatively determined as follows.

Given increased research capacity and the importance of accurate predictions for key stakeholders (e.g. logistics community, tourism industry) during Austral summer, the period from October to March 2018/19 was agreed upon as a starting point for further discussion on the accurate timing of the Antarctic SOP during the YOPP Core Phase. For the Arctic, two SOPs emerged as a consensus, with one covering a full open-water season (June to November) and one focusing on winter (January to March). The start of the Arctic summer SOP has been defined well before the sea ice minimum to ensure that long-term predictions for the economically relevant late summer/early autumn season can be well initialized. To improve predictions on shorter time scales (hours to days) for the same target period, on the other hand, it will be important to enhance observations in late summer and early autumn. Furthermore, it was strongly argued for extending this SOP to late autumn in order to capture the time of year when atmosphere-sea ice-ocean interactions are most vigorous. The shorter Arctic winter SOP will take place in operationally more challenging conditions and will be targeting phenomena such as polar lows, snow, cold-air outbreaks, and stable boundary layer processes.

Building on these tentative SOP timings, final decisions on these and the timing of embedded IOPs will be made and communicated by autumn 2016 at the latest.

An important task of the late YOPP Preparation Phase is to coordinate different campaigns (e.g. aircraft) within the SOPs. Two committees focus on this task, one dedicated to the Arctic and the other to the Antarctic (see Section 6.1). Strong communication and coordination is needed to provide a clear view on the observational component of YOPP (which is populated bottom-up with, e.g. process-study, satellite, and GTS/WIS-type data). One important element is the compilation of a well-structured list of planned observations. The main basis for this will be the YOPP endorsement process (see Section 3.2.2.1), but it is anticipated that numerous non-endorsed activities will also collect YOPP-relevant data; these need to be listed as well.

Each SOP will have a person designated as the central coordinator or "champion" who works with the Steering Group and SOP participants to ensure that field campaigns make effective use of time and resources. This person should coordinate with already-planned coincident campaigns to have them involved in YOPP and to make necessary data available for modelling and prediction efforts.

The temporal focus on the SOPs and IOPs is not equally applicable to the different kinds of observations discussed in the following; due to numerous organizational constraints many YOPP-relevant observations are expected to be taken outside the SOPs. Such observations will still be highly valuable and an important part of the YOPP observational component.

4.1.2 Comprehensive reference stations

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

On land, a network of comprehensive reference stations could be built on existing and planned "supersites" to form the basis for process-understanding studies in both the Arctic and Antarctic. Examples are listed in the following.

- The Arctic Research Centre of the Finnish Meteorological Institute (FMI) at Sodankylä, Finland (http://fmiarc.fmi.fi) provides an excellent example of an Arctic field site with a complete set of meteorological instrumentation facilities including satellite retrieval validation. The field site also benefits from its collocation with a satellite receiving station, which facilitates near-real-time operation.
- An 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; http://www.iasoa.org) programme will be contributing to YOPP by bringing together and coordinating multiple reference stations for atmosphere and surface measurements. In addition to sites mentioned above, this network includes sites at Tiksi (Siberia, Laptev Sea coast), the Summit Station (Greenland), Eureka research base and the Canadian Forces Station Alert (Nunavut, Canada), Barrow Field Station (Alaska, USA), and others. The IASOA observatories are sites operated by the Global Atmosphere Watch (GAW), and will also be used by CryoNet as part of the Global Cryosphere Watch (GCW) surface observation network.
- Dome-Concordia and South Pole are two of the few research facilities over the Antarctic Plateau. A comprehensive list of Antarctic sites is still missing. PPP/YOPP could connect to other site survey initiatives such as the WMO-GCW and CryoNet in order to investigate which sites could be supporting process-based studies with several collocated observations and what instrumentation would be available.

For the polar oceans, it is possible to exploit existing systems such as the mooring array operated by AWI. During the YOPP planning workshops, extended utilization of the existing system of moorings needs to be discussed. In this context it will be beneficial to liaise with the Ocean Observatories Initiative (OOI). YOPP should also coordinate with SOOS in order to exploit the southern ocean observing systems currently in place.

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 or NOAA. The hubs could also serve as starting points for comprehensive Arctic and Antarctic ice surveys.

4.1.3 Field campaigns

While MOSAiC has been postponed to commence at the end of the YOPP Core Phase, currently there are plans for two Russian drifting "North Pole" stations, one in 2017 and one in 2018. If going ahead, these campaigns would provide important "ground truthing" for the Arctic by comprehensive observations of atmosphere, sea ice, and ocean.

Improved geographical coverage and increased temporal frequency of in situ observations and exploitation of advanced satellite and other remotely sensed data are of high priority to obtain sustained enhancements of forecast quality and reliability. Experience from IPY shows that the ability to exploit advanced satellite data in conjunction with additional in situ data can mitigate complete failures in forecasting extreme or high impact weather features 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 boundary layer 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. the Office of Naval Research's (ONR) Stratified Ocean Dynamics in the Arctic (SODA) Departmental Research Initiative (DRI), and the possible Arctic Ocean Drift Study (AODS)) must therefore be made available in near-real-time on the WMO Information System (e.g. via the GTS).

4.1.4 Aircraft campaigns

Aircraft campaigns are a very valuable source of observational data in polar regions. They provide a unique opportunity to capture spatial and temporal variability of important surface and atmospheric parameters including high quality in situ/contact measurements of cloud properties. However, the drawback is a very high cost of such campaigns.

There are several main institutions/agencies planning aircraft campaigns for the YOPP Core Phase, including for example: NASA, AWI, and the British Antarctic Survey (BAS). Moreover, NASA welcomes requests to use its aircrafts (contact persons: James Overland, Chris Fairall). Furthermore, there is also scope for a Russian involvement in YOPP aircraft campaigns. Therefore, a coordination working group on aircraft campaigns needs to be established in PPP/YOPP. The main goal of such a group would be to ensure that both aircraft observations and data from other field campaigns, including MOSAiC, complement each other.

4.1.5 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 likely other Arctic routes in the future) could provide observation-enhanced capacity at reduced cost. This could include additional ASAP soundings (The EUMETNET Composite Observing System (EUCOS) may be able to assist for the northern polar regions). Reports on local sea ice conditions could also be made from commercial ships. Software for standardized sea ice classification from ships has been developed for both the Arctic (Ice Watch) and Antarctic by the WCRP's Climate and Cryosphere Project (CliC)-affiliated working groups. YOPP should use its available contacts to the shipping industry to provide these sea ice classification systems to commercial ships.

Icebreakers and research vessels routinely operating in polar regions should be instrumented for high-quality observations. The suite of required sensors onboard will need to be defined with a priority list developed by an expert panel. This panel should convene well in advance of the YOPP Core Phase in order to provide recommendations and find the funding to source the instruments for ship-based research in time for the SOPs.

Free troposphere

More observations are needed in the free troposphere, particularly because of the decoupling from the Planetary Boundary Layer (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). Norwegian[1], Japanese[2] and American[3] research corroborates the value of increased observations in the troposphere but funding sources would be needed for additional radiosondes and staffing. Additional AMDAR should also be sought from commercial flights over the Arctic and from logistic flights to Antarctica (EUCOS has been contacted about the Arctic).

The results of the ongoing project Arctic Research Collaboration for Radiosonde Observing System Experiment (ARCROSE) demonstrate an improvement of numerical weather forecasts when additional observations from radiosondes launched from icebreakers and research observatories in the Arctic are assimilated in the NWP model. An increase of the number and frequency of radiosonde launches during YOPP is strongly recommended. A coordination is needed to make sure that radiosonde observations are carried out and made available in real-time during research cruises.

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 Special/Intensive Observing Periods (SOPs/IOPs) with clear objectives, e.g. for coordinated campaigns planned during YOPP.

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 to calibrate and validate satellite data and to study interactions between ocean and sea ice.

Given the central role of sea ice, 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. Ice-thickness products will further improve understanding of deformation processes, especially in first-year ice. The NASA IceBridge campaigns will continue through the YOPP Core Phase, collecting end-of-winter sea ice thickness measurements in both the Arctic and Antarctic. YOPP should coordinate with the IceBridge team in order to plan overflights of YOPP field campaigns wherever possible.

In situ sea ice and upper-ocean measurements include Mass Balance Buoys (with a thermistor string, and acoustic probes looking up and down – see

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

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

[3] *http://dx.doi.org/10.1175/MWR-D-13-00237.1*

http://www.erdc.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/553850/ice-mass-balance-imb-buoy-program/), Ice Tethered profilers (ITP – see http://www.whoi.edu/page.do?pid=20781), ice stress sensors, sea-mammal tags, and sea-gliders. Knowing about sea ice thickness is important as it plays a central role in predictability. Sea ice thickness estimates from submarine and moored Upward Looking Sonar (ULS) may be a valuable additional source. Ocean 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. Recommendations from the data assimilation community on the most useful observations (type, resolution, etc.) to be assimilated into coupled models is needed for the observing community to develop and deploy these instruments.

Furthermore, the WCRP Climate and Cryosphere Project (CliC) has at least three initiatives that are relevant: sea ice modelling forum, SnowMIP for Earth System Models, and Arctic freshwater flux assessment.

Open ocean

From summer through late-fall, large parts of the Arctic Ocean are ice-free and exposed to the atmosphere. This marine environment requires different observing systems, as sea ice is not present to support the installation of instruments. Parameters of particular scientific interest include the surface mixed layer depth as well as ocean temperature and salinity. Satellite measurements of sea surface temperature (SST) supplement buoy data in ice-free areas. SST measurements are complicated by the presence of patchy sea ice, and pixels of satellite images are typically large, resulting in limited coverage of ocean measurements in the polar regions.

Existing buoy programmes, in the Arctic largely coordinated through the International Arctic Buoy Program (IABP), may prove to be highly suitable for data assimilation and forecasting. However, YOPP should coordinate with IABP members in order to make data available in real time for assimilation. Conductivity-Temperature-Depth (CTD) profiles collected by research vessels are logged and will be available during the YOPP Consolidation Phase for ocean model validation, but are unlikely to be available in real time.

Deeper ocean

It is desirable to complement the polar observing system with oceanographic data from the subsurface Arctic Ocean with the highest coverage possible. These observations will 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 strongly engage funding agencies and the 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 the Joint Technical Commission for Oceanography and Marine Meteorology (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 Arctic freshwater flux assessment. The US programme Study of Environmental Arctic Change (SEARCH) would be a key national partner, but more national partners (at least from Norway, Russia, Canada, UK) would be beneficial. Significant cooperation with the oceanographic research community is desirable in order to make deep ocean (CTD) measurements available quickly. Requests for deeper water profile measurements can often be honoured by research vessels. It would, however, be helpful if the modelling community could determine which are the most useful measurements from a polar prediction perspective.

Autonomous sensor systems

Autonomous in situ observations will also be an important element of the future polar observing system. There are autonomous floating systems operated today 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 observed from buoys would also be useful. Contact needs to be established with key groups deploying and operating buoys and ice observations (including Argo floats (http://www.argo.ucsd.edu/), 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.

In order to ensure good spatial and temporal coverage of measurements by autonomous sensor systems it will also be important to explore the possibility of enhancing the Arctic and Antarctic buoy programmes. Enhanced cooperation with the Argo programme is envisaged. Argo buoys can operate around the Antarctic whereas conditions in the Arctic are more challenging for buoys due to the much larger sea ice cover. Thus, Argo buoys could be complemented by Ice-Tethered Profilers, in particular in the Arctic.

By the time of the YOPP Core Phase, the integrated Arctic Ocean Observing System (iAOOS), for example, would provide an excellent and well-tested system to measure various properties in the upper ocean, in sea ice, and in the lower atmosphere. Furthermore, 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 to YOPP. A temporary expansion of the buoy programmes should be achieved both in terms of spatial coverage and inclusion of 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 mammals equipped with tracking devices, subject to appropriate ethical guidelines, are an interesting and potentially valuable source of ocean observations near ice margins where data are otherwise sparse (due to, e.g., absence of Argo floats – see http://www-hrx.ucsd.edu/www-argo/statusbig.gif).

Snow

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

NASA IceBridge flights which carry a snow radar system are scheduled through 2019. YOPP should thus coordinate field campaigns with the IceBridge team to ensure overflights where possible.

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 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, and vegetation characteristics. The abrupt transition from frozen to thawed soil conditions during spring needs to be characterized 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 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.

Boundary layers and clouds

Stable boundary layers are a persistent problem for models, particularly acute in the Arctic, especially over land and closed-cover sea ice. A few case studies based on extensive observations of all relevant physical aspects (following the example of GABLS-4) can be essential to further our understanding. 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 cloud (liquid and ice) condensation nuclei (CCN) concentrations.

MOSAiC will provide significant boundary layer measurements but will occur outside the YOPP Core Phase.

Stakeholders

A series of targeted meetings will be held to understand stakeholder needs and decisionmaking.

Initial conversations suggest, for example, that some stakeholders such as shipping companies operating in the Arctic would be willing to host observing systems on vessels, especially if those data can be integrated into prediction systems that generate local forecasts of weather and sea ice. Observing technologies that can be carried by stakeholders operating vessels in the polar regions are of particular interest, and should thus be encouraged. This involves both adapting existing systems (such as weather stations and buoys) for easier/autonomous operation, and consideration as to how in situ measurements can be best integrated into forecasts.

The SERA subcommittee will promote targeted research focussed on stakeholder initiatives related to observation systems (as detailed in Section 4.3).

YOPP will also build on other programmes engaging polar stakeholders.

4.1.6 Satellite data

Satellites provide unique and wide-ranging observational capabilities for the atmosphere, oceans, and cryosphere. It is 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. This requires coordination of both airborne and ground-based observation efforts (e.g. snow on ice) which needs to be planned during the YOPP Preparation Phase. The locations of existing IASOA and similar observatories, as well as drifting stations such as the Russian drifting “North Pole” stations, and MOSAiC (in the YOPP Consolidation Phase), 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 stably stratified, 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. Therefore many observations are rejected or given inappropriate weights. 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 profiles of wind, temperature, and moisture), clouds (e.g. liquid versus ice phase profiles, particle size distributions, aerosol concentration and type), and snow-cover (e.g. depth, layering, snow water equivalent, melt ponds, albedo, temperature). These and more detailed recommendations could be useful for agencies such as the European Space Agency (ESA) helping to shape their future missions.

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. Providing researchers and stakeholders with comprehensive satellite-based sea ice and iceberg products will thus 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 – coordinate 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.

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 (at least daily) observation is needed. While fine resolution (1 to 10 m) is required for specific studies to better understand deformation processes, basin-wide observations compatible with sea ice models are expected to be run at resolutions from 1 to 10 km. In order to balance specific needs it would be beneficial to operate radar instruments in wide swath (WS) mode (e.g. for the satellite Sentinel-1: 250 km in Interferometric WS and 400 km in Extra WS) on a regular basis with occasional campaigns at higher resolution in specific target areas. It would also be desirable that certain agencies such as the German aeronautics and space research centre (DLR) implement dedicated calls for YOPP to ensure space-borne support for intensive observation and modelling periods.

For longer-term sub-seasonal to seasonal predictions, proper initialization of sea ice thickness is crucial. Information about relatively thick sea ice can be provided through ESA’s research satellite 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, data from the Soil Moisture and Ocean Salinity (SMOS) mission (ESA) and the Soil Moisture Active Passive (SMAP) remote sensing observatory (NASA) 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; the WMO Rolling Review of Requirement’s 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

The challenge in this theme is to identify scientific issues that are specific to high-latitude prediction and which require addressing in NWP and sea ice forecasting systems in order to advance predictive skill. To that end, numerical experiments will be devised to provide guidance on how to implement improvements in operational forecasting systems.

The main problem areas can be grouped into those which are specific to model forecasts, and those that are concerned with the analysis of observations for model initialization. The main problems for model forecasts are:

- Physics of polar atmospheres (boundary layer, mixed phase, snow etc.)
- Sea-ice, ocean, waves, land (coupling)
- Linkages (lower-higher latitudes, stratosphere-troposphere etc.)
- Representation of model uncertainty

And for analysis:

- Surface/lower troposphere sensitive satellite observations
- Sparse (non-representative) networks
- Coupling
- Representation of observation/model uncertainty

The main modelling and forecasting tasks are summarized in Figure 2. A major contribution to YOPP will be the provision of more extensive output from operational NWP systems which will allow detailed diagnosis of the systems' treatment of high-latitude processes – see Section 4.2.1. This will be complemented by a wide range of other experiments which are discussed in the remainder of Section 4.2.

YOPP Preparation Phase		YOPP Core Phase	
Task	Contents	Task	Contents
Establish configurations for prototype global/ regional reanalyses	• model configuration • coupled ensembles • global providing initial/boundary conditions for regional	Global/regional reanalyses production	• coupled ensembles • enhanced diagnostics output (model and observations)

Re-evaluate YOTC dataset* for:
• IPY period
• selected events / regions
	• sensitivity experiments:
	  • data assimilation
	  • relaxation
		YOPP dataset* production	• with operational suites
			• observation monitoring
			• sensitivity experiments

New experiments for: • selected events / regions • linkage focused • model/observation focused	• OSE, OSSE, relaxation, coupled-observed • employing all analysis and forecast diagnostics	New experiments for: • selected events/ regions • linkage focused • model/observation focused	• OSE, OSSE, relaxation, coupled-observed • employing all analysis and forecast diagnostics

Figure 2. Summary of selected YOPP modelling and forecast tasks for the YOPP Preparation and Core phases. *The YOTC and YOPP datasets refer to output from operational global models including additional time steps, model levels and model tendencies, see text.

In order to address the modelling and forecasting issues, a range of diagnostic tools will need to be deployed to analyse and diagnose the model and analysis data. Some examples are:

- First, the impact of observations on both the analysis and the predictive skill will need to be explored, using a range of tools, including data assimilation system diagnostics (e.g. Forecast Sensitivity to Observations), or Observing System Experiments (OSE) and Observing System Simulation Experiments (OSSE). This will entail liaison with experts from the Data Assimilation and Observing Systems (DAOS) working group.
- A second area is the use of ensemble diagnostics; many modern NWP systems use an ensemble to represent uncertainties from the definition of forecast initial conditions to the use of probabilistic forecast products. This entails the consistent definition of analysis uncertainty, improving the representation of model uncertainty (e.g. using stochastic physics), and analysis of sensitivity of the forecasts to initial condition uncertainty. Scientific advice in the area will be provided by the working group on Predictability, Dynamics and Ensemble Forecasting (PDEF).
- Third, the predictability of weather systems should be explored using techniques such as relaxation experiments, in which forecasts are relaxed back to "accurate" states in selected areas. This could be used to explore the linkages between high-latitude weather systems and those in the middle and low latitudes. Again, scientific advice on predictability will be provided by the PDEF working group.
- Fourth, model tendency diagnostics should be used to elucidate the contribution of different physical processes to the tendencies, and their contributions to growth the forecast error. Such diagnostics should be complemented by studies of budgets from reanalysis datasets. These studies will help improve the parameterization of physical processes at high latitudes.

The coordination of modelling and forecasting activities will require flexibility from participating modelling centres in the definition of their experimental protocols, including the definition of model domain. This will require a high level of coordination for the elements listed hereafter.

4.2.1 Archived model data and reforecasts

A major contribution by operational centres to YOPP will be the provision of additional data to the research community that are not normally available from operational archives (e.g. process tendencies and extra parameters at an increased frequency). In this context, the concept for a special dataset developed for the YOTC could serve as a very good starting point. The YOTC dataset by ECMWF included tendencies from the physical parameterizations and parameters at increased time frequency. In addition, NASA GMAO have provided high resolution analysis and forecast products, and NCEP have made available operational and reanalysis data for the YOTC period. These datasets served as the basis of a virtual field campaign to study how the numerical model simulated a range of tropical phenomena, such as the Inter-Tropical Convergence Zone (ITCZ), El Nino Southern Oscillation (ENSO), Madden-Julian Oscillation (MJO), monsoons and tropical cyclones.

For YOPP, a similar type of dataset could provide an invaluable complement to the observational data that will be collected during the YOPP Core Phase. In addition to ECMWF, it is expected that other centres will also be participating (e.g. an Arctic version of the Finnish HIRLAM, and AMPS).

While the YOTC dataset is outstanding in terms of its resolution and the availability of model parameters, YOTC is, however, limited in terms of its temporal length when it comes to diagnosis and forecast verification, especially in terms of flow-dependent forecast error and extreme weather events. It is therefore planned to carry out reforecasts initialized from reanalysis data from previous years covering the satellite era, that is, from 1979 onwards.
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) should be set up in collaboration with WGSIP to explore seasonal prediction skills 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).

4.2.2 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 whereas the majority of experiments is envisaged to be conducted during the YOPP Core Phase, with some continuing into the YOPP Consolidation Phase. It is important to emphasize that new experimental production suites should be run during the YOPP Core Phase, rather than just relying on the standard operational models. Limited-area, high-resolution, and convection-permitting ensembles should be run for short-range probabilistic forecasts over relevant regions. In parallel, it is desirable to have at least one high-resolution operational *coupled* prediction system covering the pan-Arctic domain. That system would issue forecasts at timescales that go beyond those used in the operational exercise, and would be the missing piece bridging operational and seasonal forecasting.

The proposed model experiments will need to be carried out at high spatial (horizontal and vertical) resolution, using a hierarchy of global, regional and process models. The regional and process models will enable more detailed studies at the highest resolutions, while global models will enable the results to be put into a broader context.

Extra parameters such as physical process tendencies should be archived, at least during the SOPs, to enable detailed diagnostic studies. Similarly, the model experiments should produce forcing datasets for use in subsequent dedicated experiments with sea ice and ocean models.

Experiment types

Broadly speaking, six kinds of experiments are envisaged:

1. Forecast and reforecast datasets to allow for robust estimates of forecast skill and to diagnose sources of forecast failures.
2. Sensitivity studies – explore the role of model formulation (resolution, parameterizations 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.
3. Case studies – how well does the modelling system in various configurations deal with particular extreme events? In order to enable robust conclusions, it will be required to evaluate YOPP cases alongside cases/data from previous campaigns (the PPP Implementation Plan goes into more detail on polar extreme weather).
4. Multi-year "free" model simulations – investigate the ability of the modelling systems to capture interannual variability and assess system biases and imbalances.
5. Potential predictability studies – explore the limits of predictability for atmosphere-cryosphere-ocean, with a particular focus on sea ice characteristics and other relevant variables.
6. Process resolving simulations (Large Eddy Simulations, Convection-Resolving Models, Single Column Models) to guide development of improved subgrid-scale parameterizations.

Each of those types of experiment could potentially address the six aspects set out in the following subsections.

Coupling

The coupling between different components of the earth system is particularly important for prediction at high latitudes, where atmosphere-ocean-ice interactions are critical and not completely understood. Experiments will need to compare coupled versus uncoupled predictions of the various environmental system components (atmosphere, land, sea ice, ocean, wave, snow) – as well as coupled versus uncoupled data assimilation.
The experiments should focus on the identification of sources of coupled forecasting skill, and dependencies on model parameters (e.g. resolution, sea ice rheology, snow-cover characteristics).

Sea ice prediction

The prediction of sea ice remains a major challenge, and several specific actions are proposed:

- Observing System Simulation Experiments to assist in identifying the observational requirements for skilful predictions. For example, these experiments could aim to recommend a target density for observations (by, e.g. 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. The importance of coupling for modifying sea ice predictability characteristics should be assessed. 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 the spread resultant 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 dataset could be used by the international community to explore the skill of sea ice predictions, to investigate the sensitivity to model formulation, and for comparison 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. The first step would be to carry out (or make use of) predictions with the existing forecast systems. Then experiments would be performed using improved sea ice initial states based on observations made during YOPP, and alternative model physics if wanted. The forecasts should then be validated against YOPP observations.

Orography

A key question is what horizontal and vertical resolutions are required in order to accurately represent orographic effects in numerical models. Experiments should be carried out to explore the role of resolution and orography in the representation of orographic drag, what parameterization of vertical diffusion is required, and how land surface coupling processes are best simulated. Experiments should focus on the simulation of orographic flows, such as barrier winds, tip jets, gap flows, foehn winds and katabatic winds.

Probabilistic prediction of mesoscale and synoptic scale systems

Ensemble prediction methods are becoming increasingly important for forecasting the risks of high-impact weather events. Probabilistic prediction is no less valuable at polar latitudes than it is elsewhere. Experimental high-resolution regional ensemble prediction systems should be run in order to demonstrate the benefit of probabilistic prediction of mesoscale and synoptic scale weather systems. Experiments should focus on the prediction of: polar lows and orographic flows; arctic fronts; low-level jets associated with sea ice borders; and topographically influenced wind systems and lee cyclones

Particular attention will need to be paid to the representation of vertical fluxes of sensible and latent heat in extremely unstable marine boundary layers.

Stable boundary layer

Stable boundary layers are ubiquitous in the polar regions. 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, wind, and moisture. Boundary layer clouds, especially Arctic stratus, continue to undermine Arctic boundary layer simulations.

Clouds

The representation of clouds is crucial to the high-latitude energy budget. Modelling centres are requested to compare model predictions with observations from sites where there are high resolution cloud observations (e.g. the Atmospheric Radiation Measurement Program (ARM) of the US Department of Energy). Verification with surface radiation observations is crucial because it allows differentiation between cloud, surface, and water vapour errors.
A range of model diagnostics needs to be produced and archived in order to study the influence of clouds. Diagnostics should include clear sky radiances and column liquid water. The range of diagnostics should follow what was agreed for the Cloud Feedback Model Intercomparison Project (CFMIP). (Only cloud fractions were archived in CMIP.)

Polar-lower latitude linkages

Another important aspect will be to determine the impact of polar-lower latitude linkages and their role in weather and climate prediction. To discuss the way forward, eighty scientists from twenty nations gathered in Barcelona from 12-14 December 2014. This workshop, which was co-organized by PPP, developed the following set of recommendations:

- Improve understanding of the key processes in atmosphere, snow, sea ice, and ocean responsible for linking the polar regions with the lower latitudes. Progress hinges on an improved observational base and on bringing expertise in high-latitude and mid-latitude dynamics together.
- Ensure that these key processes are well represented in models used to carry out weather and climate predictions. This task includes data assimilation, improved Arctic-centred model development and parameterizations, and thorough forecast assessments.
- Link the research performed for weather and climate forecasting with that carried out to project future climate to obtain the largest benefit from their synergies. This task should be planned well ahead of phase 6 of the Coupled Model Intercomparison Project (CMIP6) exercise.
- The community must distinguish between a potential Arctic influence on the net seasonal response and the possibility of regional episodic amplification of existing planetary wave patterns and related short-term weather events.

- Carry out coordinated model experiments to thoroughly assess possible remote impacts of polar climate change. Emphasis should be put on both local and possible global consequences of Arctic amplification.
- Explore the limits of predictability of polar weather and climate and their role for mid-latitude forecasting.
- Determine the impacts of enhanced predictive capacity in the polar regions for mid-latitude forecasting by carrying out coordinated forecasting experiments (e.g. data denial and relaxation experiments). Studying linkages from a sub-seasonal prediction perspective will allow better understanding of the prediction process and verification of polar lower-latitude pathways.
- Ensure that environmental prediction and model assessment requirements will have a high priority in the future development of the polar observing systems. YOPP provides a unique opportunity for the international community to jointly advance our observational capacity.

4.2.3 Field campaign related

Modelling support will be provided for any intensive field campaigns contributing to YOPP (see Section 4.1.3). This includes MOSAiC.

Also, to take advantage of 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 the YOPP Core Phase. Sea ice models are currently validated for the most part using satellite imagery/SAR. Field campaigns should provide additional detailed sea ice measurements, including imagery from UAV. During SOPs, there should be expanded field observations and aircraft flights (including microwave brightness measurements). Satellite calibration based on such measurements will increase the value of future satellite observations.

Post-processing and archiving of physical model tendencies planned for the YOPP Core Phase 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 not only to provide ice products (e.g. frequently updated ice charts) for polar marine users, but also to provide more accurate surface conditions for atmospheric predictions. It is expected that by the time of the YOPP Core Phase a number of coupled and uncoupled ice forecasting systems will be in place producing both deterministic and probabilistic (ensemble-based) sea 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.

High-resolution sea ice modelling will be central to YOPP. The multiple simulations that will be carried out during the three phases should be an opportunity to test the hypothesis that some parts of model physics have to be revised as resolution increases. In particular, an inter-model study of how realistic the elastic-viscous-plastic (EVP) model for sea ice rheology is at resolutions of ~5 km or less should be undertaken to guide future sea ice model development.

4.2.5 Sub-seasonal 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

Sensitivity integrations should be performed to determine the relative importance of these various factors to prediction. 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 sub-seasonal to seasonal forecasting community would enable an assessment of the consistency of polar forecasts and what causes inconsistencies, and what factors reliably contribute to predictive skill. These analyses and the design of the experiments should take into account the short period of the YOPP Core Phase (two years), which prevents the creation of homogenous long hindcast datasets. Where appropriate, the sensitivity studies discussed earlier (Section 4.2.2, e.g. experiments addressing the sensitivity to specific parameterizations to identify the parameters responsible for differences between models) should be analysed regarding their predictive skill on sub-seasonal to seasonal timescales to provide 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. Such activities will also allow for improved initialization of future operational forecasts. This should be done in coordination with the WMO as the lead centre for the Long Range Forecast Verification System, as well as with WMO Global Producing Centres for Long Range Forecasts, and the S2S project, with which the model output dissemination should be coordinated.

4.3 Verification and forecast use in decisionmaking

The potential impact of better information will be evaluated through a number of methods discussed in Section 4.3.1. Plans for verification research must be undertaken in concert with the design and implementation of the observation, modelling, and archiving systems, but definitive statements regarding the impact of YOPP observations to decisionmaking processes will likely be deferred until the YOPP Consolidation Phase and the availability of the complete database for analysis.

4.3.1 Understanding the potential use and value of improved forecast information in decisionmaking

During the YOPP Preparation Phase, a complex suite of activities (including community movement, shipping, fishing, tourism, governmental activities and research) will be examined as part of a comprehensive research agenda focused on the use and value of improved polar predictions in decisionmaking. Through the YOPP Core and Consolidation Phases, deeper inquiry and application of a variety of social science research methods will be employed to characterize and evaluate the use and wider societal implications of improved predictions. Contingent on funding and organizational support, the following research priorities, identified in a number of past PPP-SERA workshops, will be addressed:

- Exploration of how users and providers perceive risks and how this influences decisionmaking processes.

- Characterization of aspects that define and affect the mobilities and activities of various stakeholders in the polar regions.
- Assessment of the diverse channels and interfaces used by stakeholders for accessing weather and sea ice information.
- Understanding the goals and limitations of information providers in tailoring products to specific user needs.
- Understanding the dynamic and complex roles of stakeholders as being both users and providers of information.
- Evaluation of the context within which decisions are made, including socio-economic, legal, and institutional factors that may constrain access to and provision of information.
- Assessment of stakeholder preferences and the role of trust and other factors in utilizing specific information services.
- Examination of mechanisms for stakeholder feedback concerning information services.
- Assessment of the wider societal implications of developments in observing and predicting efforts.

To address the above research priorities a suite of qualitative and quantitative methods will be applied, including interviews, focus groups, content analysis, survey-based approaches, ethnographic field research, social simulation, cost-benefit analysis, and decision analysis.
To the extent possible, 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 assessment of weather and sea ice forecasts in polar regions by using the special forecast datasets to be archived in the YOPP Data Archive System. Archiving of end user-relevant parameters (e.g. 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 novel spatial verification techniques for sea ice in the polar regions during YOPP. The availability of additional observations will allow for investigating how data sparseness in the polar regions affects verification results. Moreover, enhanced observations during YOPP will enable to better quantify observation uncertainties and possibly develop verification strategies to cope with such uncertainties.

If there was a (quasi) real-time verification environment running during YOPP, it would serve both scientists and forecasters at operational centres. Potentially, a “built-in” end user product verification interface could be included as well. It would be desirable to have also some spatial verification components as part of a real-time system. Building on presently existing operational verification system(s) (e.g. the system currently running at ECMWF) rather than to design a new dedicated polar verification package would be preferable. It should also be noted that diagnostic 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 in situ observational data. Therefore, there is the strong argument to use model analyses generated by data assimilation systems as "truth" information. The drawbacks of using model analyses need to be carefully studied and considered. 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 variables 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 satellites 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 (i.e. visible, near infrared, infrared, microwave) will help reduce observation uncertainties (e.g. inherent errors in the assumptions relating radiances with temperatures and/or clouds). 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 from a modelling perspective and should be observed and verified, especially as part of process studies. This can be a major challenge because of differences in the representative scales between a model parameter, e.g. surface albedo, and a corresponding radiometer measurement, but the scale issues can be handled through aggregation.

Sea ice is of fundamental relevance both for modelling and 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 end users. Presently, most of the focus is still on sea ice extent at a certain given date. However, such a variable is not very helpful for decision-makers. By contrast, the spatial distribution of ice thickness and concentration, the ice edge position, motion of ice bergs and floes, as well as dates of freeze-up and break-up are relevant to end users. Due to high spatial variability and a lack of observations for sea ice thickness, verification of this quantity is particularly difficult.

Surface currents could also be verified. These are relevant to many users, including the coupled modelling community. Similar to the atmosphere, the ocean surface circulation consists of eddies and gyres of different scales, some of which evolve quite rapidly. This makes adequate observation, prediction and verification of surface currents challenging.

Studying diagnostic and spatial verification techniques such as scale-dependent verification is expected to strengthen collaboration between the verification community and modellers. Most spatial verification methods require high-resolution observations, implying that this approach is likely to be seriously constrained by the general lack of high-resolution observations. If such data are available, most spatial methods can in principle be tested for sea ice and cloud forecasts. Scale-separation techniques can be especially useful in polar prediction verification because they can help diagnose the sources of model error. Scale-tracking techniques (e.g. given by combining a Hovmöller diagram with a scale-separation approach) can be developed to verify the propagation of flow-dependent signals from polar regions to mid-latitudes. Some of the neighbourhood approaches that match a window of forecasts to a point observation might be useful to compare the performance of models with coarse versus finer resolution. Some promising methods are field-deformation techniques for ice fields (e.g. ice motion and ice pressure), object-based techniques for ice floe predictions, and Hausdorff distance metrics for the ice edge. SAR data is assumed to be fundamental for spatial verification of ice forecasts.

The importance of the evaluation of user-relevant parameters and products has already been emphasized. This should include all traditional basic surface variables (e.g. temperature, wind, precipitation, visibility), and the use of all available observations at their highest resolution. Attention needs also to 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 (e.g. visibility, ceiling and icing, sea ice, fog) which have a high societal relevance in the polar regions.

Verification-related collaboration with various research initiatives, programmes and groups will be important to make progress 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, with SERA for identifying stakeholders’ needs, and with WWRP JWGFVR on verification methodology.

Interplay should be advanced between scientists possessing expertise in verification methodology and polar scientists who may have questions relating to verification, e.g. regarding the use of data to test the utility of various diagnostic and spatial verification methods. Accordingly, participation of verification specialists in polar science workshops and conferences, and vice versa, should be supported.

4.4 Education and outreach

YOPP will provide many students and 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 Polar Prediction Schools, coordinated with APECS and PCPI. The first one will be held during the YOPP Preparation Phase in 2016, a second school is planned for 2018. A possible continuation in the YOPP Consolidation Phase might be considered at a later stage.

The first Polar Prediction School took place in April 2016 at the Abisko Research Station in Sweden. Further information about this joint venture between WWRP-PPP, WCRP-PCPI/CliC, APECS, and the Bolin Centre, University of Stockholm can be found on the CliC website: http://www.climate-cryosphere.org/wcrp/pcpi/meetings/abisko-pp-2016.

A joint PPP-APECS webinar series on polar prediction is ongoing and has attracted 30-40 participants each time, with established scientists in polar region research as invited speakers. The webinars provide an online forum for early career researchers to learn about and discuss polar prediction topics. This approach was also used to disseminate preparation instructions for the participants of the 2016 Polar Prediction School.

Activities aimed at YOPP-related outreach beyond the polar prediction science community will be developed ahead of the YOPP Core Phase by the PPP International Coordination Office in close collaboration with the communication departments of WMO and AWI.

SERA will organize a workshop on the theme “Weather and Society” to be held during the YOPP Core Phase. To the extent possible, SERA will also contribute to other workshops and events.

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. In the following a general overview of this phase and its elements is given. Much more detailed plans will be developed during the YOPP Core Phase.

The overall structure of YOPP is outlined in Figure 1.

5.1 Coordination with MOSAiC

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 currently. MOSAiC will also contribute to the validation of satellite measurements and geophysical products, and will afford opportunities for detailed process studies.

Given the unique comprehensive data expected from MOSAiC and their high relevance for YOPP, this field campaign has the potential to contribute substantially to YOPP even though it commences in September 2019, that is, right after the YOPP Core Phase ends. MOSAiC is thus envisaged to play a special role during the YOPP Consolidation Phase.

5.2 Ensuring the wider use of YOPP data

An important task before and at the beginning of the Consolidation Phase will be the proper archiving of all the additional observational data generated during YOPP to ensure availability and traceability (e.g. using Digital Object Identifiers). 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 YOPP 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 additional observations along with high-resolution numerical experiments will benefit model development and the enhancement of value of satellite data in a prediction context (see Section 5.4 below).

In order to synthesize the available YOPP data and to exploit them in models, it will be desirable to carry out special high-resolution reanalyses for both the Arctic and the Antarctic. These reanalyses will be an ongoing activity during the YOPP Consolidation Phase. They will, along with the availability of reforecast datasets, provide the basis for probabilistic forecast calibration, as well as for 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.

5.3 Workshops and publications

In order to ensure a long lasting legacy it will be essential to hold a YOPP synthesis workshop in 2020. Such a workshop will help to exchange the knowledge gained during YOPP, to provide a good opportunity to discuss a YOPP overview paper, and to develop plans for a special issue or multiple 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 a "buy in" from the operational centres, these need to be involved as much as possible throughout YOPP. The synthesis workshop will be promoted to the centres directly through WWRP/WMO; hosting the workshop at a centre such as ECMWF or one of the GPCs may be beneficial.

5.4 Implementation of YOPP findings

The additional observations and numerical simulations produced during the YOPP phases 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 evolving from YOPP will also serve the climate modelling community. In this context, running Transpose-CMIP experiments for the YOPP Core Phase appears promising.

The additional weather and sea ice 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 NMHS 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 NMHS and user organizations.

5.5 Stakeholder feedback and evaluation

It will be important to communicate improvements made over the course of YOPP, such as new and more skilfully predicted products, to 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 Committee[4] (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 the WMO Executive Council Panel of Experts on Polar Observations, Research and Services (EC-PHORS) 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 is, and will be, conducted by the PPP-SG and International Coordination Office, and by a number of thematic PPP/YOPP subcommittees that involve numerous representatives of other relevant initiatives and bodies, and additional experts.

6.1 PPP Flagship themes/YOPP subcommittees

A number of PPP flagship themes and YOPP subcommittees (or groups) have been established to take the lead in the planning and conduction of important aspects of YOPP (and PPP overall). Each of these aspects is lead by one or two chairs recruited either from the PPP-SG or externally. YOPP subcommittees with the following foci exist:

Subcommittee on:	Point of contact:
Societal and Economic Research Applications (PPP-SERA)	J. Dawson, University of Ottawa, Canada
Education	J. Day, University of Reading, UK
Southern Hemisphere (YOPP-SH)	D. Bromwich, Byrd Polar and Climate Research Centre, US
Arctic Observations	C. Fairall, NOAA, US
Coordinated Modelling	T. Jung, AWI, Germany
Data Strategy	T. Jung, AWI, Germany/Ø. Godoy, Norway
Outreach	ICO for Polar Prediction, AWI, Germany
Sea Ice	G. Smith, ECCC, Canada

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

ANNEX 1

TIMELINE

Below a timeline of past and future planned activities and milestones for PPP and YOPP, including planned meetings and events, is provided. Planned activities will naturally become more detailed over the duration of the YOPP phases; dates given here are thus approximate.

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	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
Submission of Paper on PPP, including YOPP Outline, to the Bulletin of American Meteorological Society	2014.11
International Workshop on Polar-Lower Latitude Linkages and their Role in Weather and Climate Prediction 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 members of the YOPP Planning Group (making use of additional national support)	2015.03
PPP-SERA Committee formed during the Societal and Economic Research and Applications (SERA) Workshop in Ottawa, Canada	2015.03
Announcement for YOPP Summer School	2015.03
PPP-IAMAS High Latitude Dynamics Workshop in Bergen, Norway	2015.03
YOPP Summit (including PPP SG-6) at WMO in Geneva, Switzerland	2015.07
YOPP-Southern Hemisphere Coordination Committee and website established	2015.09
YOPP Data Archive System group established	2015.08
YOPP modelling strategy finalized, 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

PPP-SERA Scoping Document workshop in Christchurch, New Zealand	2016.04
First PPP/YOPP/PCPI Summer School on Polar Prediction in Abisko, Sweden	2016.04
Sea Ice Prediction and Verification Workshop, Frascati, Italy	2016.04
Polar Predictability Workshop 2016, Lamont-Doherty Earth Observatory, Columbia University, New York, USA	2016.05
PPP SG-7 meeting in Beijing, China	2016.05
YOPP Planning meetings (Observation, Data and Modelling) in Reading, UK	2016.09
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 finalised	2016.12
PPP-SERA planning and writing meeting (location tbc)	2017.04
YOPP Core Phase Formally Launched at WMO EC-69	2017.05
Polar Prediction Webinars	2017.10
Second PPP/YOPP/PCPI Summer School on Polar Prediction	2018.06
Polar Prediction Webinars	2018.10
End of YOPP Core Phase/Start of YOPP Consolidation Phase	2019.06
MOSAiC planned to commence	2019.09
YOPP Final Conference	2021.05
YOPP Paper published in Bulletin of American Meteorological Society	2022.05
End of YOPP Consolidation Phase	2022.12

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ANNEX 2

ACTIVITY CONTRIBUTION TABLE/ENDORSED PROJECTS

The activity contribution table as of version 1.0 of this document is replaced by regularly updated information on the PPP website, in particular a list of endorsed projects at http://www.polarprediction.net/yopp/yopp-endorsement.html.

ANNEX 3

DETAILED MODELLING ASPECTS FOR YOPP

The following modelling areas are considered to merit particular attention during both the YOPP Preparation Phase and the YOPP Core 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 Ocean.
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 Large Eddy Simulations (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 subgridscale 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 parameterizations (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 and 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, MET 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 the following studies 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 (see AARI website http:/www.aari.ru) 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.

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ANNEX 4

DATA: THE USE OF WIS AND GTS WITHIN YOPP

Introduction

Much of the success of YOPP will revolve around having observational data made available in real time for the use of Numerical Weather Prediction (NWP) forecasts and experiments. This involves getting data into the WMO's Information System (WIS). This section of the YOPP Implementation Plan introduces WIS for the purpose of YOPP operations and research. It also touches on several points that may be useful in making sure that your data are used to their maximum potential rather than discarded.

Introduction to WIS and the GTS

Many people or groups about to conduct observations for use within YOPP may have heard of the GTS – the WMO's Global Telecommunication System. This system was designed to support global collaboration in operational weather forecasting and weather research. It collects, exchanges, and distributes observational data and forecasting products. The GTS has been operating robustly for many decades, however:

- It is difficult to know what is in there or to retrieve data on demand
- GTS needs special connections
- It is difficult to set up routine delivery of data
- It is almost impossible to set up one-time delivery of data
- It does not readily support WMO Programmes other than the World Weather Watch (WWW)
- It is difficult within the GTS to support more modern observations (e.g. satellite data)

With these points in mind, WMO has designed and implemented the next generation of data exchange – the WMO Information System (WIS). WIS was designed to support all WMO Programmes, not just the WWW. It makes it easier to submit, find and fetch data and allows for the migration of new technologies (e.g. climate services, different observing systems, improved data discoveries, and the use of the World Wide Web). WIS does not replace the GTS but builds on it by improving the delivery of time- and mission-critical data, products and services. It also extends WMO services through discovery, access and retrieval (DAR) facilities, as well as through flexible timely delivery.

Benefits of WIS

For those that collect observational data as a contribution to YOPP, it is important to consider making those data available in real time in order for them to be available for operational use and verification. However, WIS provides an overarching approach to weather and climate data and information management and is not only used for the provision of observations for input in NWP. So, WIS can be helpful for researchers who want:

- Their observations to be used in real time (for example, by NWS)
- To share their specialized data in real time
- To access observations in real time

Getting data into WIS

The following sections discuss some issues that may be faced when getting data into WIS. At some stages brief examples from a cruise report are used (see attached, and with thanks to Benjamin Harden for making it available). It is well worth reading this report in order to understand the type of problems that may be encountered when undertaking observations for the inclusion in WIS. Below is a list of other resources, including useful WIS contacts.

Who is going to use the data?

Data providers need to consider who is going to use their data. If their observations are standard (for example, those from Radiosonde flights) then these may readily be absorbed into the NWP assimilation process. However, if they are a more unusual dataset (for example, in situ sea ice thickness observations) then the data need to be made useable for the YOPP community (e.g. providing sufficient metadata as discussed below).

Knowing the instruments

Understanding the instruments' settings and limitations is crucial since otherwise one may not be operating the instruments under ideal conditions in which case one may not receive the expected observation range (see Figure 3). The usual height for ground based observations is between 15 to 20 km, however, in this example the wind data are available only up to around 5 km. The reason for the reduction in height could be attributed in part to the particularly severe atmospheric conditions.

Therefore, one will need to become familiar with the instruments setting for input into NWP (see Figure 4). In this example, the edited data (EDT) as interpolated by the Vaisala software, filters out the natural fluctuations of the radiosonde to provide a smooth and continuous reading. This is what is needed for input into WIS.

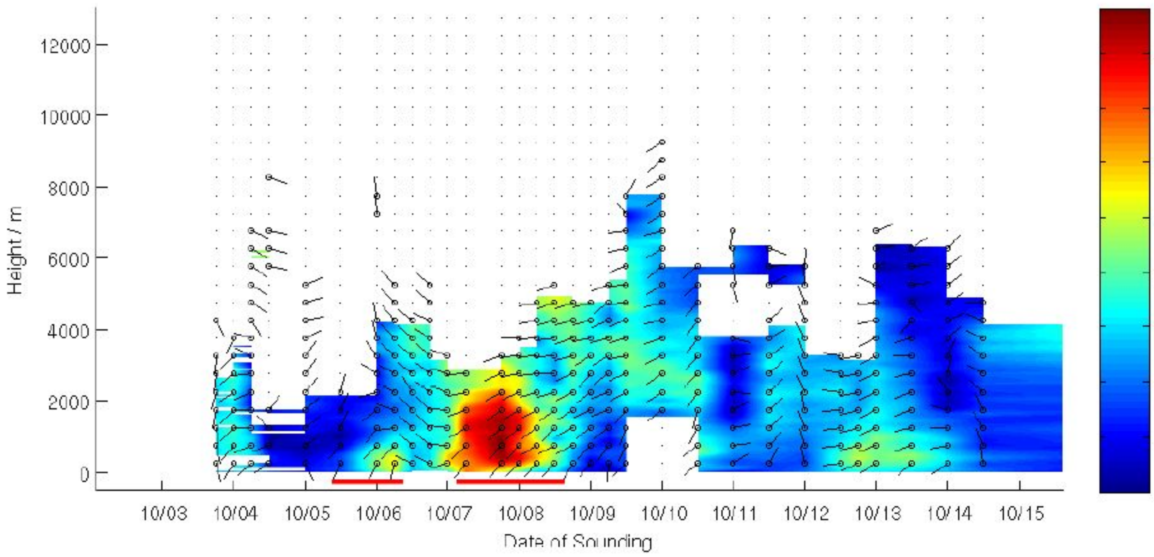

Figure 3. Representation of the wind speed in m/s (colours) and direction (ticks) as a function of height for a subset of the soundings with edited data

Source: (EDT, from Figure 4; Harden, 2009)

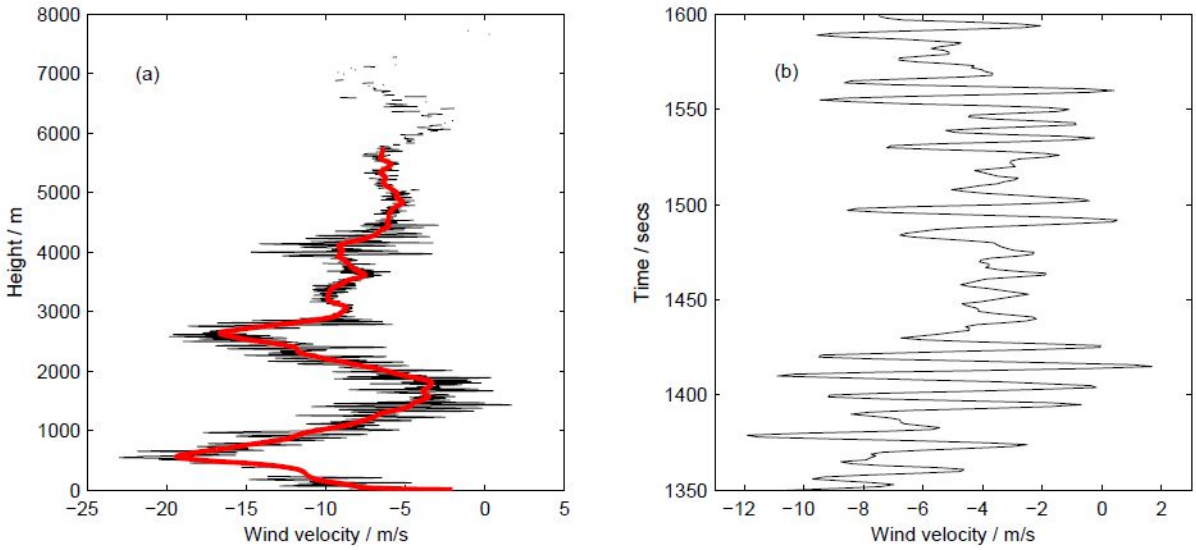

Figure 4. (a) Example sounding (10/10/2008 12:00) showing RAW data (black) and EDT data (red) for the easterly component of the wind velocity against height. (b) Close up of RAW data for the same sounding plotted as a function of time instead of height to show constant wavelength oscillations.

Source: (from Figure 5; Harden, 2009)

Data formats

WIS can take data in any format (e.g. NetCDF), however, if you want your data going into operations it should be in BUFR, or secondary in CREX.

When data is submitted to WIS, the chosen data format will almost certainly be dictated by the observational dataset and mechanism. Many standard observations will already have set data formats: for example, Vaisala instruments transmit in BUFR, and with correct settings such data will readily be utilized within NWP.

It is possible that observations, even though suitable for real-time provision, are not readily suitable for transmission in BUFR or CREX. In these cases it is important to work closely with a WIS Centre (as discussed below) in order for making the data usable for its intended audience.

Metadata

A prerequisite for entering data into WIS is the descriptive metadata. If the observations are "standard" then this will be a relatively easy step. Otherwise, as for the data format, this will require more care and guidance from a WIS Centre (as discussed below).

Contact a relevant WIS Centre

The WIS network consists of a number of centres such as the Global Information System Centres (GISC), Data Collection or Production Centres (DCPC), and National Centres (NC) (see Figure 3). However, there are also National Focal Points on WIS matters (see link below) which are usually associated with meteorological organizations within each country. For anyone being new to adding observational data to WIS, these should be the first contact points.

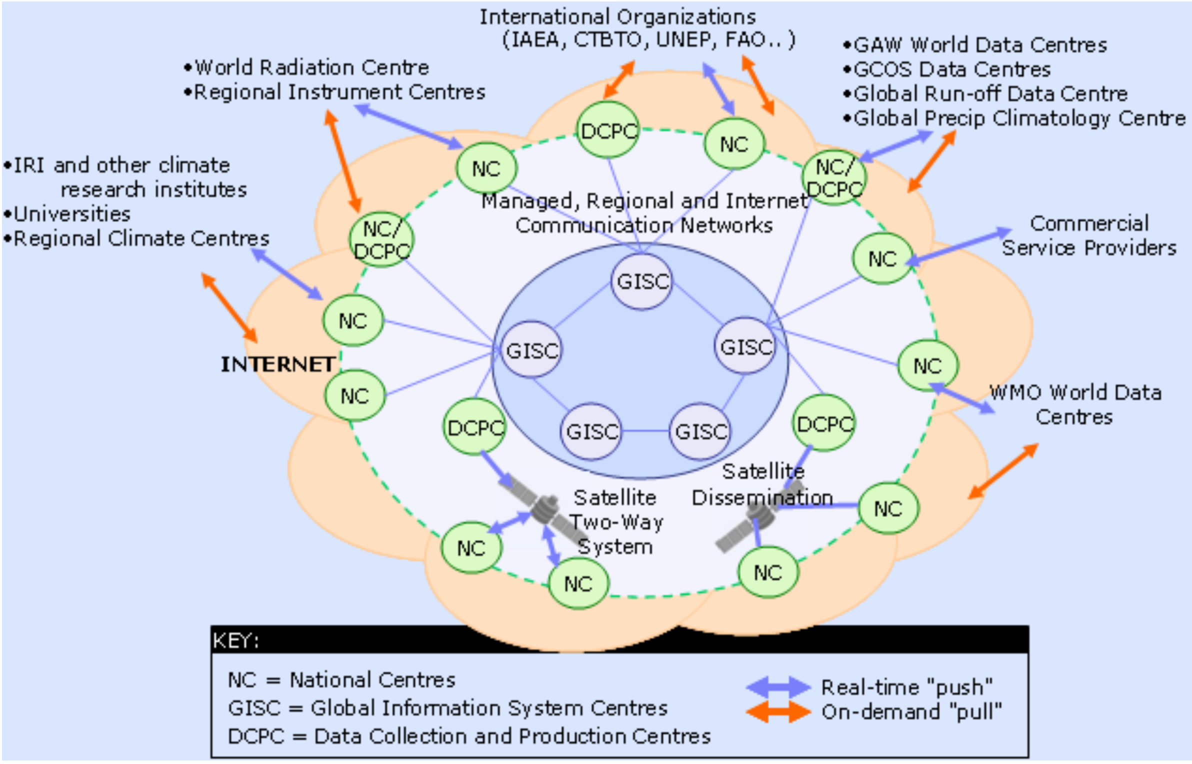

Figure 5. Types of WIS Centres and their typical interactions

The other side of WIS – OpenWIS

OpenWIS is the public front-end to WIS. It allows to find and fetch data on demand within WIS. One can perform one-off data request or subscribe to have automated delivery of data. Delivery may be to an email or ftp site.

Links of WIS relevant information

WMO WIS website where manuals and technical information can be obtained:

- https://www.wmo.int/pages/prog/www/WIS/

List of National Focal Points on WIS matters:

- http://www.wmo.int/pages/prog/www/CBS/Lists_WorkGroups/CBS/cross-cutting/fp%20wis/members

OpenWIS sites: There are a number of OpenWIS sites. Some include:

- http://wis.bom.gov.au/openwis-user-portal/srv/en/main.home
- https://wis.metoffice.gov.uk/openwis-user-portal/srv/en/main.home
- http://wispi.meteo.fr/openwis-user-portal/srv/en/main.home

ANNEX 5

FURTHER READING

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Gordon, Neil et al., 2014: The Polar Prediction Project, in: WMO Bulletin Vol. 63(1), p.42-43.

Jung, Thomas et al., 2015:Polar-lower latitude linkages and their role in weather and climate prediction, *Bulletin of the American Meteorological Society,* doi:10.1175/BAMS-D-15-00121.1.

Jung, Thomas et al., 2016: Advancing polar prediction capabilities on daily to seasonal time scales, *Bulletin of the American Meteorological Society*, doi:10.1175/BAMS-D-14-00246.1.

PPP Steering Group & Co-authors, 2014: "WWRP Polar Prediction Project Implementation Plan" WWRP/PPP No. 2.

PPP Steering Group & Co-authors, 2013: "WWRP Polar Prediction Project Science Plan" WWRP/PPP No. 1.

Quarterly Journal of the Royal Meteorological Society's special issue on Polar Prediction, 2016: Volume 142, Issue 695, doi: 10.1002/qj.2639.

ANNEX 6

ABBREVIATIONS

A

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

B

BAS... British Antarctic Survey
BPCRC .... Byrd Polar and Climate Research Center
BUFR...... Binary Universal Form for the Representation of meteorological data – WMO standard

C

CALM.. Circumpolar Active Layer Monitoring Network
CBS.. Commission for Basic Systems of WMO
CCN .... Cloud Condensation Nuclei
CFMIP.. Cloud Feedback Model Intercomparison project
CFSR .... Climate Forecast System Reanalysis
CIMO................................ Commission for Instruments and Methods of Observation of WMO
CliC .... Climate and Cryosphere Project of WCRP
CLIVAR .... Climate Variability and Predictability
CRM .... Cloud Resolving Model
CMIP .... Coupled Model Intercomparison Project
COMNAP .... Council of Managers of National Antarctic Programs
CTD .... Conductivity-Temperature-Depth
CryoNet .... Core Component of GCW surface observation network

D

DAOS .... Data Assimilation and Observing Systems
DAR .... Discovery Access and Retrieval, WMO
DCPC.. Data Collection or Production Centre
DLR... German Aerospace Centre
DOI... Digital Object Identifier
D-PHASE........ Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood Events in the Alpine region
DRI .... Departmental Research Initiative

E

EC.. Executive Council of WMO
ECCC.. Environmental and Climate Change Canada
ECMWF .... European Centre for Medium-Range Weather Forecasts

EC-PHORS.......... Executive Council Panel of Experts on Polar and High Mountain Observations, Research and Services of WMO
ECRA........European Climate Research Alliance
ENSO ....El Nino Southern Oscillation
EPS-SG........EUMETSAT Polar System - Second Generation
ERA........ECMWF meteorological reanalysis products
ESA........European Space Agency
ESM ....Earth System Model
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
FP7 .... Seventh Framework Programme for Research and Technological Development
FSOI ....Forecast Sensitivity Observation Impact
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 Atmospheric Watch
GCW .... Global Cryosphere Watch
GEWEX........Global Energy and Water Cycle EXchanges Project, WCRP
GFCS........ Global Framework for Climate Services
GISC ....Global Information System Centre
GIPPS........ Global Integrated Polar Prediction System
GMAO........ Global Modeling and Assimilation Office, NASA
GODAE .... Global Ocean Data Assimilation Experiment
GPC........ Global Producing Centre of WMO
GTS........Global Telecommunication System of WMO

H
HASSEG........Humanities and Social Sciences Expert Group, SCAR
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
Ice Watch ....Sea ice classification from ships for Arctic
ICI .... Ice Cloud Imager
ICO ....International Coordination Office for Polar Prediction
IICWG .... International Ice Charting Working Group
IMB buoys........ Ice Mass Balance buoys
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

ITCZ........Inter-Tropical Convergence Zone

J

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

L

LES ....Large Eddy Simulations

M

MERRA .... Modern-Era Retrospective Analysis for Research and Applications
MJO .... Madden-Julian Oscillation
MOSAiC .... Multidisciplinary drifting Observatory for the Study of Arctic Climate

N

NASA........ National Aeronautical and Space Administration
NC .... National Centres
NCAR .... National Center for Atmospheric Research
NCEP........ National Centers for Environmental Prediction, NOAA
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

ONR .... Office of Naval Research
OOI........ Ocean Observatories Initiative
OSE .... Observing System Experiment
OSSE........Observing System Simulation Experiment

P

PANGAEA .... Information system archiving, publishing and distributing data from global change research
PBL ....Planetary Boundary Layer
PCPI........Polar Climate Predictability Initiative
PDEF ....Predictability, Dynamics and Ensemble Forecasting
PPP .... Polar Prediction Project
PRACE .... Partnership for Advanced Computing in Europe
PSTG........ Polar Space Task Group

R

RMSE ....Root Mean Square Error

S

S2S........ Sub-Seasonal To Seasonal Project (WWRP/WCRP)
SAON .... Sustaining Arctic Observing Networks
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
SIOS .... Svalbard Integrated Observing System
SIPN ....Sea Ice Prediction Network
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
SODA .... Stratified Ocean Dynamics in the Arctic
SOOS .... Southern Ocean Observing System
SOP .... Special Observing Period
SPARC .... Stratosphere-troposphere Processes And their Role in Climate
SPICE .... Solid Precipitation Intercomparison Experiment
SSC .... Scientific Steering Committee
SST .... Sea surface temperature

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

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
WIGOS .... WMO Integrated Global Observing System
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
WWW .... World Weather Watch

Y
YOPP .... Year Of Polar Prediction
YOPP-SH .... Activities in the Southern Hemisphere, YOPP sub-committee
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.

3. WWRP Polar Prediction Project Implementation Plan for the Year of Polar Prediction (YOPP), WWRP/PPP No. 3 – 2014.

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