WORLD METEOROLOGICAL ORGANIZATION

EXECUTIVE COUNCIL
PANEL OF EXPERTS ON POLAR OBSERVATIONS, RESEARCH AND SERVICES
Fifth session

Wellington, New Zealand, 25 – 28 February 2014

EC-PORS-5/ INF. 12(1)

Date: 31 January 2014

AGENDA ITEM: 3.2

REVIEW OF EC-PORS ACTIVITY SINCE EC-PORS 4 WWRP Polar Prediction Project (Year of Polar Prediction Implementation Plan)

(Submitted by the ICO for Polar Prediction)

ISSUES TO BE DISCUSSED

The draft Implementation Plan for the Year of Polar Prediction (YOPP).

DECISIONS/ACTIONS REQUIRED:

- To review the draft implementation plan for the Year of Polar Prediction (YOPP) and provide guidance for the further development of YOPP

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

DRAFT 4 FEBRUARY 2014
FOR EXTERNAL INPUT AND COMMENT

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, verification, user-engagement and education activities".

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

The objectives of YOPP are to:

1. Improve the polar observing system to provide good coverage of high-quality observations in a cost effective manner.

2. Gather additional observations through field programmes aimed at improving understanding of polar key processes.

3. Developed improved representation of polar key processes in uncoupled and coupled models used for prediction, including those which are particular hindrances to high-quality prediction for the polar regions, such as stable boundary layer representation, surface exchange, extreme thermal contrasts, and steep orography.

4. Develop improved data assimilation systems that account for challenges in the polar regions such as sparseness of observational data, steep orography, model error and the importance of coupled processes (e.g., atmosphere-sea ice interaction).

5. Explore the predictability of sea ice on time scales from days to a season.

6. Improve understanding of linkages between polar regions and lower latitudes and assess skill of models representing these.

7. Improve verification of polar weather and environmental predictions to obtain quantitative knowledge on model performance, and on the skill of operational forecasting systems for user-relevant parameters; and efficiently monitor progress.

8. Improve understanding of the benefits of using existing prediction information and services in the polar regions, differentiated across the spectrum of user types and benefit areas.

9. Provide training opportunities to generate a sound knowledge base on polar prediction related issues.

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

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1 Introduction

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

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

YOPP is an extended period of coordinated intensive observational and modelling activities, in order to improve prediction capabilities for the Arctic, the Antarctic, and beyond, on a wide range of time scales from hours to seasons, supporting improved weather and climate services, including the Global Framework for Climate Services (GFCS). This concerted effort will be augmented by research into forecast-stakeholder interaction, verification and a strong educational component. Being focussed on polar prediction rather than a very broad range of activities, YOPP is quite different from the IPY (International Polar Year) that took place 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 optimize the polar observing system, generate the knowledge necessary to improve the representation of polar key processes in models, and provide ground-truthing that it is so important to exploit the full potential of the space-borne satellite network.

A unique aspect of YOPP will be a strong virtual component through support from the numerical modelling community, encompassing models of the atmosphere, 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 would 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 unchartered territory in the area of polar forecast verification; YOPP will contribute to our understanding of the value of improved polar prediction capabilities; and YOPP will help to educate the next generation of scientists who will contribute to implementing the Global Integrated Polar Prediction System (GIPPS).

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

1.1 Background

In 2011, the World Meteorological Congress decided to embark on a decadal endeavour - the Global Integrated Polar Prediction System (GIPPS) – as a legacy of the International Polar Year (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, polar clouds and precipitation, ice edge and orographic effects, sea ice/ocean dynamics, hydrology, permafrost and ice sheet dynamics, and enhancements to observations, data assimilation, and modelling systems to improve predictions on all time scales.

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

1. WMO's World Weather Research Programme (WWRP) has established the Polar Prediction Project, whose mission is to "Promote cooperative international research enabling development of improved weather and environmental prediction services for the polar regions, on time scales from hours to seasonal."
2. The World Climate Research Programme (WCRP) has established the Polar Climate Predictability Initiative (PCPI) which has a similar purpose, but on time scales of a season and beyond.

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

Two plans have been developed and published: the *WWRP-PPP Science Plan* (WWRP/PPP No. 1 – 2013) and the *WWRP-PPP Implementation Plan* (WWRP/PPP No. 2 – 2013).

The *Science Plan* provides background information on the science issues, while the *Implementation Plan* should be seen as the definitive document for the project. Both plans are available via the ICO at http://polarprediction.net.

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

YOPP as initially envisaged is covered in Chapter 5 of the *WWRP-PPP Implementation Plan*. This current YOPP Implementation Plan document expands on that, based on discussions and decisions from the first planning meeting for YOPP (YPM-1) held on 27 and 28 June 2013 at the European Centre for Medium-Range Weather Forecasts (ECMWF), in Reading, UK. (Other meeting reports, including that of YPM-1, are also available from the ICO at http://polarprediction.net.)

This YOPP Implementation Plan has been further refined based on discussions at the fourth meeting of the WWRP-PPP Steering Group, held from 1-3 October 2013 in Boulder, Colorado, USA, and will continue to be updated as required by the YOPP Planning Group (YPG).

1.2 YOPP Goal

The Goal for YOPP is to:

"Enable a significant improvement in environmental prediction capabilities for the polar regions and beyond, by coordinating a period of intensive observing, modelling, 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 WMO Global Integrated Polar Prediction System (GIPPS)."

1.3 YOPP Objectives and Strategies

Improvement in the area of reliable predictions associated with polar regions requires international, collaborative research to address challenges to achieve the following Objectives:

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

In order to achieve the above research Objectives the following Strategies will need to be pursued:

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

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 and user engagement activities in order to improve polar prediction capabilities on time scales from hourly to seasonal. This will be augmented by research into forecast-stakeholder interaction, verification and a strong educational component. YOPP is quite different from the IPY that took place in 2007-2008, with YOPP being focussed on polar prediction, as compared to IPY's broad range of activities including studies of the Earth's inner core and social processes that shape resilience of circumpolar human societies.

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

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

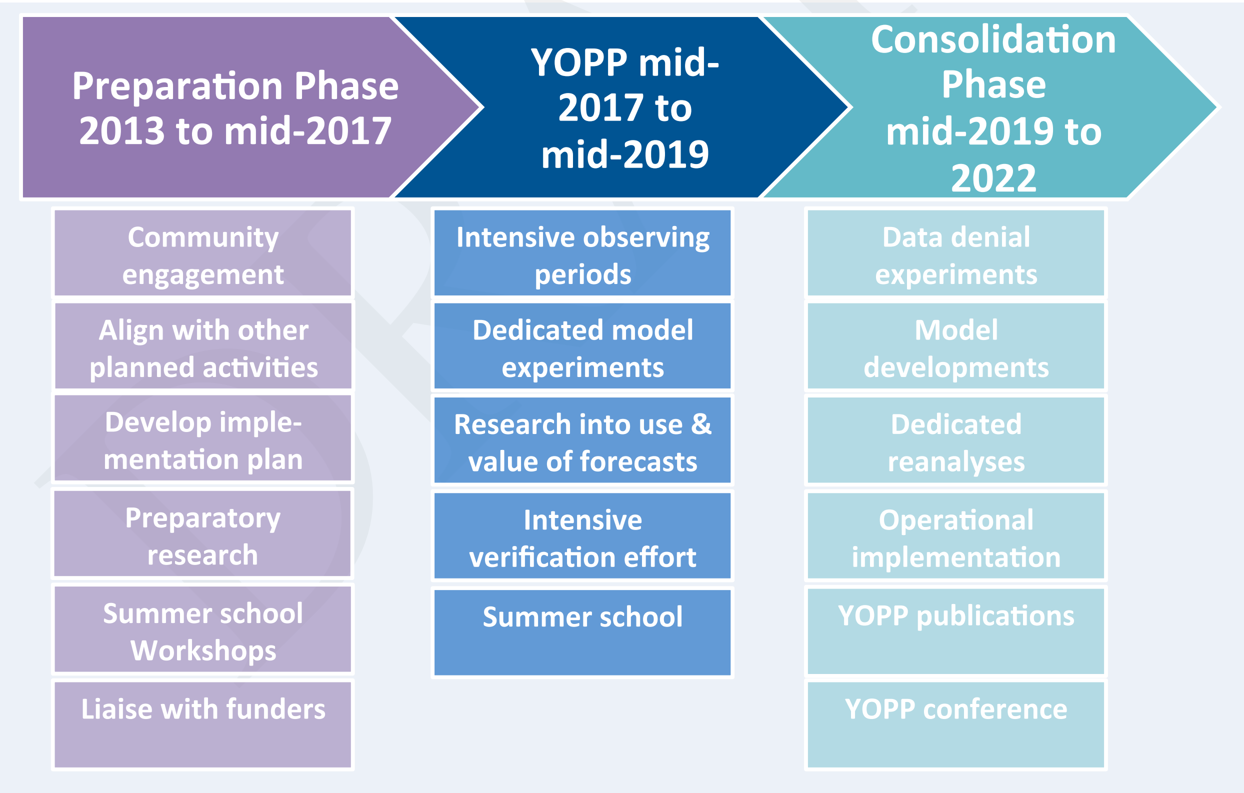

Figure 1: Three stages of YOPP, including the main activities for each stage.

The key milestones for the project are shown in Table 1. A more comprehensive list is given in Section 7 (Appendix 1), and will be regularly updated as the project proceeds.

Table 1: Key Milestones for YOPP

Milestone	Target Date (YYYY.MM format)
PPP Implementation Plan published, including chapter on YOPP	2013.04
First YOPP Planning meeting, in association with Polar Prediction Workshop at ECMWF in Reading, England	2013.06
YPM-Obs meeting in association with Arctic Science Summit Week and Arctic Observing Summit in Helsinki, Finland	2014.04
PPP-SG-5 and YPM-Modelling meeting in association with the World Weather Open Science Conference in Montréal, Canada	2014.08
YOPP Summit in March 2015 (in association with PPP-IAMAS Polar Meteorology Meeting in Bergen, Norway) or May 2015	2015.05
First YOPP Summer School (2015 or 2016)	2015.07
YOPP Data Centre established	2016.12
Experimental operational coupled atmosphere-sea ice-ocean models ready to run by operational modelling centres	2016.12
End of YOPP Preparation Phase and Start of YOPP	2017.06
Second YOPP Summer School	2018.06
MOSAiC Planned to Commence	2018.09
End of YOPP Phase / Start of YOPP Consolidation Phase	2019.06
YOPP Synthesis Workshop	2020.06
YOPP Final Conference	2021.05
End of YOPP Consolidation Phase	2022.12

3 YOPP Preparation Phase (2013 to mid-2017)

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

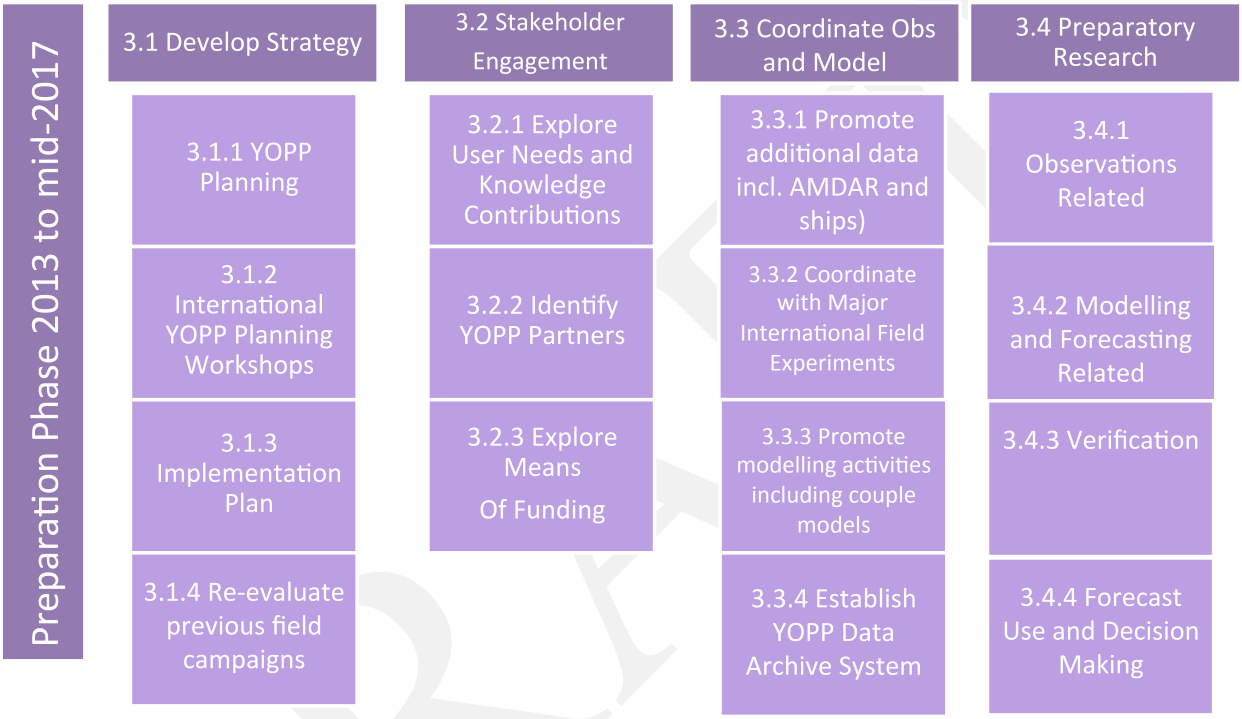

Figure 2: YOPP Preparation Phase

3.1 Develop Strategy

3.1.1 YOPP Planning

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

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

A YOPP Planning Group (YPG) was established in October 2013 during the fourth meeting of the PPP Steering Group in Boulder, CO USA. This consists of the full PPP Steering Group, augmented, as available and agreed, by representatives of other relevant partners and initiatives (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). Beside being responsible for planning, the YPG will also coordinate/oversee preparatory research activities (2013-2016), and assist in presenting YOPP plans to relevant funding agencies (2014), e.g., Horizon 2020.

3.1.2 International YOPP Planning Workshops

Two further YOPP planning workshops will be held in 2014. YOPP-Obs in April 2014 will be focussed on observations, and held in association with the Arctic Science Summit Week and Arctic Observing Summit in Helsinki. YPM-Model in August 2014 will be focussed on modelling aspects, and held in association with the World Weather Open Science Conference in Montréal.

A YOPP Summit is tentatively planned for March 2015, in association with IAMAS Polar Meteorology Meeting in Bergen, and the joint PPP-International Commission on Polar Meteorology-International Commission on Dynamic Meteorology workshop on *Dynamics of atmosphere-ocean-sea ice interaction in high-latitudes*.

3.1.3 Implementation Plan

The YOPP Planning Group (YPG) will be responsible for finalising a version of the YOPP Implementation Plan suitable for publishing by September 2014, and then for updating the Plan as required after that.

3.1.4 Re-evaluation of Previous Field Campaigns and Model Datasets

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

3.2 Stakeholder Engagement

3.2.1 Explore User Needs and Knowledge Contributions

It will be essential to engage with forecast users (stakeholders hereafter) to ensure their needs and potential contributions will be addressed, to explore whether a voluntary additional observing system component could be established, and to identify possible external sources of funding. To this end it is planned to convene small-session consultations where groups of similar users already interact. Identifying such opportunities will be a task charged to the WWRP-SERA expert team who will establish a YOPP for Society (YOPP-S) subcommittee in consultation with representatives from EC-PORS, NMHSs, WMO JWGFVR, key user groups, and relevant social science bodies such as the International Arctic Social Sciences Association (IASSA).

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

3.2.2 Identify YOPP Partners

The following key partners have been identified (2):

Table 2: Key partners for YOPP

Group	Role
EC-PORS	Overall
IASC	Planning of YOPP for northern polar regions
SCAR	Planning of YOPP for southern polar regions
WCRP Polar Climate Predictability Initiative (PCPI)	Close coordination of related activities
WGNE	Development and implementation of the intensive modelling campaign (atmosphere)
WGSIP	Development and implementation of the intensive modelling campaign on seasonal time scales (atmosphere)
S2S	Sub-seasonal to seasonal aspects of polar predictions
FAMOS	Development and implementation of the intensive modelling campaign (ice-ocean) (see http://www.whoi.edu/projects/famos/)
GODAE Oceanview	Development and implementation of the intensive modelling campaign (ice-ocean)
WWRP SERA WG	Development of concept for intensive SERA period
JWGFVR	Development of concept for intensive verification period, possibly jointly with S2S and/or HIW
APECS	Implementation of educational component of YOPP
PSTG	Supporting the exploitation of satellite data ("satellite snapshot")
GCW	Cryospheric observations, and potential use of the GCW portal
AMOMFW (including AMPS)	Coordination of Antarctic Modelling Experiments
EUCOS	Additional observations over northern polar regions

3.2.3 Explore Means of Funding

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

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

Many research activities will require international, national or regional funding, and a commitment by modelling and forecasting centres. A full package of promotional material will be prepared, which can be used to assist with national approaches to funding agencies. The general profile of YOPP can also be raised through publications including the WMO Bulletin and the Bulletin of the American Meteorological Society, as well as by participation in events such as the Arctic Science Summit Week in April 2014 in Helsinki, and meetings of SCAR.

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

3.3 Coordinate Observations and Modelling

3.3.1 Promote Additional Observational Data

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

The northern and southern polar regions are very different in terms of their observational networks and characteristics; it is important to ensure that attention is paid to both south and north.

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

- Work with partners such as EUCOS to plan and promote additional routine observations.
- Work with PSTG to promote satellite observations, including:
  - providing a statement of support for the maintenance of the existing satellite network, 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 new satellite mission concepts targeting polar regions (e.g., CoReH2O, ATOMMS).
- Promote observations from supersites.

- Engage the forecast user community in actively taking measurements.
- Promote field campaigns during YOPP.
- Ensure that systems are in place for relevant field campaign observations to be made available in near-real time on the WMO Information System.
- Promote sea ice observations, buoy observations, and snow measurements.
- 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 Expert Team will be asked to provide support for an observing system design for polar regions – using techniques such as adjoint forecast sensitivity to observations.

3.3.2 Coordinate with Major International Field Experiments

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

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

Unlike the previous SHEBA experiment in 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. Additional observations will be taken at points around the central site – to sample mesoscale variability – which should aid in parameterization of subgridscale processes. Scales involved are likely to represent typical "grid boxes" used in weather and climate models. MOSAiC organizers are very interested in input from YOPP on this matter. Small scales are likely to be sampled more frequently near the surface, while the free troposphere will be sampled less frequently and on larger scales.

MOSAiC will also benefit from new technology, and lessons learned since SHEBA's main mission objectives were focused on Arctic clouds and the boundary layer structure while aerosols were not investigated during SHEBA. MOSAiC will target a whole new level of multi-disciplinary processes including biology and broader environmental monitoring.

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

3.3.3 Promote Modelling and Forecasting Activities including Coupled Models

The intention for YOPP is to carry out high-resolution atmospheric and coupled model experiments to explore the benefit of a better representation of polar key processes through significantly enhanced horizontal and vertical resolution. These model experiments will need to be planned and coordinated during the preparation phase. Involvement of global numerical weather prediction centres through WGNE will be a crucial aspect during the planning phase.

Further details on 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 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. Engagement will also be essential with other modelling community partners, including AMOMFW/AMPS and WGNE.

Operational model support for MOSAiC and any other major international field campaigns need to be planned.

The sub-seasonal to seasonal prediction community 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.

3.3.4 Establish YOPP Data Archive System

A YOPP Data Archive should be established in advance of the YOPP Phase, which will allow access to both observational and model data. Such a Data Archive 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 model output archives. Development of the Global Cryosphere Watch (GCW) web portal (see demonstration at http://gcwdemo.met.no/), and consistency with WMO Information System standards, should be taken into consideration. This will be a major effort, and it would also be good to take advantage of expertise and experience from those involved in YOTC and TIGGE.

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, while recognising that YOPP is a different project. Some differences include that the archive would need to include not just atmospheric model data. The review could look at data downloads and reported uses of the YOTC data, although such information needs to be interpreted with care. Some points to consider for establishment of the model archive are:

- to archive tendencies on model levels (not pressure levels), noting that these will of course be specific to the model;
- to archive model output on native grids (rather than a common interpolated grid), particularly for ocean models;

- to archive additional fields more frequently (e.g., hourly) such as fluxes (atmosphere snow-soil);
- to capture important processes over the hours-to-seasonal time scale of the PPP, it is important to archive at a high temporal resolution.

More than one model should be archived.

Coupled models including sea ice should be in place by the YOPP Phase, which should allow for the possibility of model intercomparisons in the dataset of fully coupled versus atmospherically driven sea ice predictions.

3.4 Preparatory Research

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

3.4.1 Observations Related

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

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

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).

3.4.2 Modelling and Forecasting Related

Preparatory research and development in this category will help guide decisions on modelling systems to be deployed during YOPP, as well as leading to fundamental improvements in those models.

Tests will be carried out to explore the impact of various different vertical and horizontal resolutions, and how they handle orography, convection, dynamics at the sea ice-ocean boundary, atmospheric jet, and mesoscale dynamics.

Processes

With regard to processes, the correct interplay between the boundary layer, cloud and surface processes is crucial for the accurate description of vertical mass and momentum transport, surface radiative and energy budget, and the interaction between the shallow polar lower troposphere and large-scale advection in NWP models. These processes are also critical for accurately reproducing changes in the sea ice cover and ocean.

There is much more detail on YOPP modelling aspects in Appendix 3 (Section 8). 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 CCN concentrations; the speed of hydrometeor phase transitions in mixed phase clouds, and
- the accurate simulation of small-scale sea ice features (e.g. ridges, leads, melt ponds, ice edge).
- The representation of boundary-layer processes and extreme fluxes associated with sharp contrasts in surface properties, in particular the sea-ice border, or open ocean bordering snow-covered land surfaces.

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

Analysis of Model Data

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

- Global and regional reanalyses covering long time periods with a frozen model and data assimilation system reducing the dependence of performance to observation availability and predictability. Examples are ERA-Interim/20C, JRA-55, Arctic System Reanalysis, etc.
- ECMWF Year of Tropical Convection dataset (May 2008 - April 2010, i.e., covering part of IPY period) including output of 3/6 hourly model tendencies for temperature, wind and moisture.
- TIGGE datasets including global ensemble output from major operational centres.
- WGNE Transpose-AMIP project providing NWP type evaluation of AGCM model hindcasts in short and medium range (October 2008 - August 2009, i.e., covering part of IPY period).

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

Data Assimilation

Research and development should be encouraged to improve data assimilation in polar regions; this is sub-optimal because observation operators simulating satellite observations are inaccurate over snow and sea-ice, in the presence of very dry conditions and mixed-phase clouds. This leads to the rejection of large data volumes. Consequently, observation types (such as infrared spectrometers and radio occultation) and analysis techniques that promise better sensing of the shallow lower polar troposphere are important.

Coupled data assimilation is expected to produce significant progress in predictive skill in the near future, particular in the medium range and beyond. Since YOPP is a milestone for running experimental coupled systems at global scale the YOPP preparatory phase is crucial for system development and testing. Suitable algorithms and coupling strategies need to be selected. Data from the THORPEX IPY cluster may be useful for testing. In particular, the development of automated SAR retrievals could provide highly-valuable fine-scale information on the sea ice cover. Space-borne radars and microwave imagers provide information which can be crucial for the initialization of sub-seasonal and seasonal predictions.

Also, background error formulations have been designed and tuned with lower latitudes in mind and require adjusting. Since these formulations drive both the weight given to observations in the analysis and the spread of ensemble analyses and forecasts, better error characterisation promises substantial progress in both NWP analysis accuracy and forecast reliability estimates.

Representation of model uncertainty in polar regions might be an issue here as well. However, this could also be more of a PPP flagship activity that would contribute to YOPP

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

3.4.3 Verification

The preparation phase of YOPP should be used to establish baselines for predictive skill for polar regions, and put in place the verification systems that can be used during the YOPP phase. The following points were noted in YPM-1:

- Definition of polar forecast verification metrics in general, and the investigation of the suitability of analyses for forecast verification in particular
- Define and construct the YOPP archive in such a manner to facilitate comprehensive forecast verification, and to define and establish a common, centralized verification undertaking to include a comprehensive verification package
- There should be special emphasis on sea ice verification for YOPP. Ice centres should be contacted about possible collaboration on this. This would be aided by the trend to automated rather than manual ice analysis, and the planned launch of the RADARSAT Constellation in 2018 (***http://www.asc-csa.gc.ca/eng/satellites/radarsat***) which could be very timely for YOPP
- Find a forecasting centre interested and motivated to initiate development and usage of spatial verification techniques for sea ice verification
- User-relevant parameters should be verified, and include the traditional basic elements such as temperature, wind, precipitation and visibility, using available observations since these tend to be

located where people are anyway Given the special circumstances in both the Arctic and Antarctic, verification of products for shipping are mandatory

- Of the various purposes and users of verification, diagnostic verification (e.g., scale-dependent verification) is of special value and also provides a link between the verification community and modellers
- WGNE carries out many verification activities, and has started to look at polar regions, based on standard verification packages; this should be encouraged.
- Awareness of various verification techniques and benefits of verification should be raised both for early career scientists at summer school and for others (workshops). Attendance by polar scientists at regular, bi-annual forecast verification tutorials run by JWGFVR should be encouraged (e.g., 13-15 April 2014 in New Delhi, India).
- Verification of radiation would be an especially interesting diagnostic measure because of its relevance to many processes
- Surface currents could be verified – these are relevant to users, and also advect sea ice.

3.4.4 Forecast Use and Decision Making

Establishing a baseline understanding of how those in various communities, economic sectors, and government organizations produce, receive, interpret and apply forecast information into decision-making is an important part of the PPP. The preparatory phase of YOPP will be used to develop an inventory and evaluation of current weather-related hazards/impacts, prediction services, information requirements, and user experiences. This initial scoping research will be informed by, and complemented with, a series of regional or sectoral consultation meetings, interviews, focus groups, and workshops, in order to establish up to 5 priority areas for social science proposal development and detailed investigation during the main intense phase of YOPP (2017-19). The consultations will also be used to determine preferences for the archiving of knowledge accumulated through YOPP for Society (YOPP-S) activities.

4 YOPP Phase (mid-2017 to mid-2019)

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

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

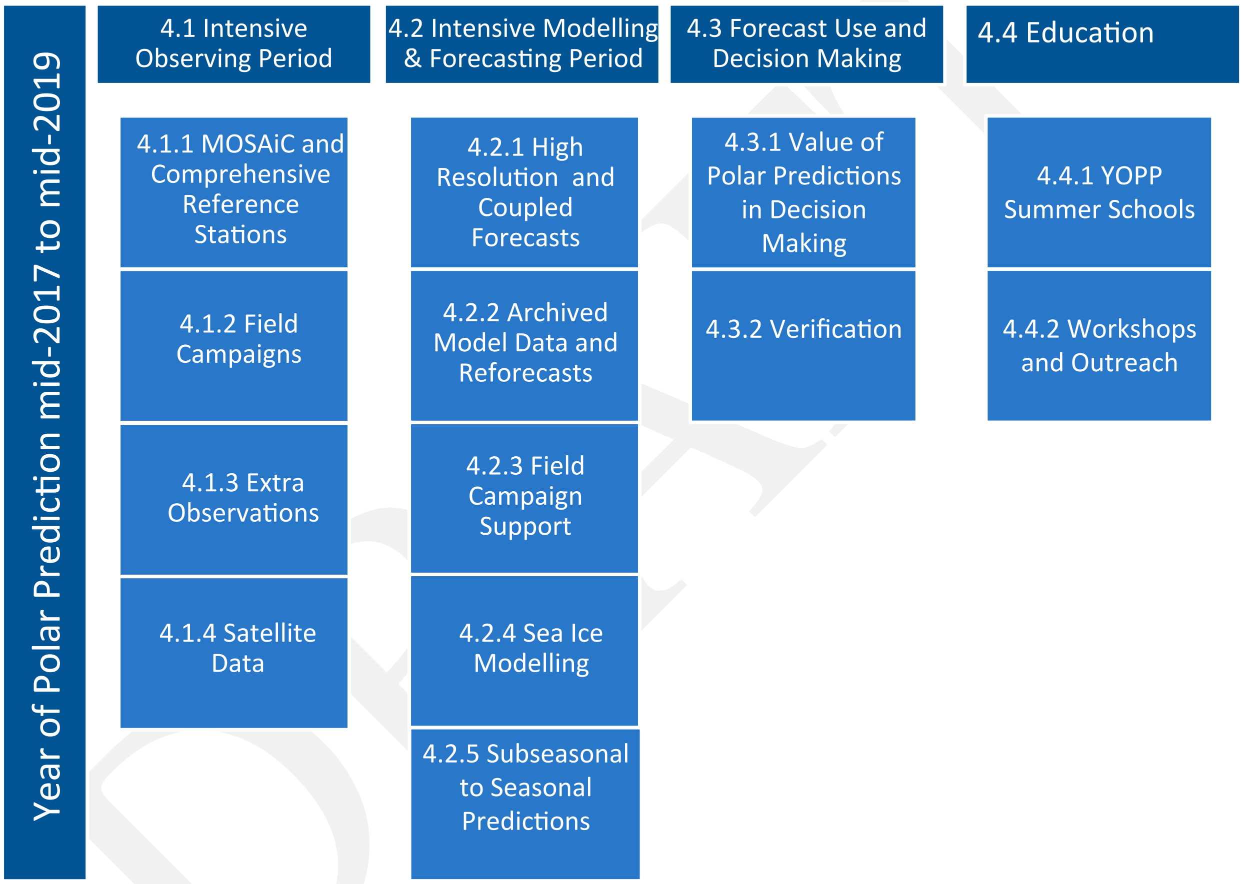

Figure 3: Year of Polar Prediction (mid-2017 to mid-2019)

4.1 Observing

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

4.1.1 Comprehensive Reference Stations

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

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

- Sodankylä (FMI-Arctic research centre, http://fmiarc.fmi.fi) provides an example of an Arctic field site with a complete set of instrumentation that also permits satellite retrieval validation. Its attraction is also its collocation with a satellite receiving station, which facilitates near real-time (NRT) reception of products and rapid product feedback.

- A further interdisciplinary set of sites is being established as part of the Svalbard Integrated Observing System (SIOS http://www.sios-svalbard.org/), which is seen as a contribution to the integrated Arctic observing system

- The International Arctic Systems for Observing the Atmosphere (IASOA) international programme of atmospheric observations, executed by Roshydromet (Russia), NOAA (USA) and FMI (Finland) in Hydrometeorological observatory Tiksi, Russia could be, together with other polar observatories in Summit, Nu-Alesund, Eurica, Alert and Barrow (www.iasoa.org), the important contributor to YOPP as a data source about the polar atmosphere and underlying surface in the area surrounding the Arctic Ocean.

- Dome-Concordia and South Pole are two of the few facilities over Antarctica. A comprehensive list of such sites is still missing and PPP/YOPP could link with other initiatives such as the WMO-GCW & CryoNet survey regarding instrumentation, and to investigate which sites could be supporting process based studies with several collocated observations.

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

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

4.1.2 Field Campaigns

For sea ice, YOPP will benefit from existing plans for a Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) – see details in Section 3.3.2. It is anticipated that MOSAiC will provide the data required for the improvement of models under conditions for which very limited observations are available. MOSAiC will also contribute to the calibration of various satellite instruments. and will afford opportunities for detailed process studies..

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

Improved geographical coverage and temporal frequency of in situ observations and exploitation of advanced satellite and other remotely sensed data are of high priority to obtain sustained enhancement of forecast quality and reliability. Experience from IPY showed that the ability to exploit advanced satellite data in conjunction with additional in situ data can improve complete failures in forecasting extreme weather such as polar lows, but this needs to be confirmed over many cases. Nevertheless, there is also a potential for additional well-designed relatively short-term focussed field campaigns, to explore oceanic areas close to the ice edge where routine in situ observations are difficult to establish and where the atmospheric PBL can become extremely unstable during major cold-air outbreaks. Such conditions are favourable for the generation of polar lows. The success-factor for such intense campaigns increases when they can benefit from an enhanced level of other regular observations that are used for initializing high-resolution NWP models.

Given the central role that sea ice prediction plays, comprehensive sea ice thickness measurements using small and lightweight digitally operated electromagnetic-induction systems ("EM birds") should be made.

Observational data from existing and planned field campaigns (e.g., Marginal Ice Zone Observations and Processes Experiment - MIZOPEX, and the Arctic Ocean Drift Study - AODS) must be made available in near-real-time on the WMO Information System.

4.1.3 Extra Observations

Shipping

The increasing amount of commercial traffic in the Arctic suggests that commercial ships could provide an important element of the Arctic observing system during YOPP. Ships going via the North-East Passage (and others in future) could provide observation-enhanced capacity at reduced cost. This could include additional Automated Ship Aerological Programme (ASAP) soundings (EUCOS may be able to assist for the northern polar regions). Reports on local sea ice conditions could also be made.

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

Free Troposphere

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

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

Sea Ice

Sea ice observations will be very important for PPP and YOPP; there is a particular need for more high quality sea ice observations for calibration / validation activities to understand satellite data.

Spot sea ice and ocean measurements include Mass Balance Buoys (with a thermistor string, and acoustic probes looking up and down) (see http://imb.crrel.usace.army.mil/), and Ice Tethered Platforms (ITP – see http://www.whoi.edu/page.do?pid=20781) and ice stress sensors. Integrated atmosphere – ice – ocean observations including ocean mixed layer properties (salinity, temperature, depth) are important for coupled data assimilation

Buoys

Buoy observations will also be very important. Contact will have been be established with the key groups deploying and operating buoys and ice observations (including Argo floats, polar profiling floats, gliders, ice mass balance buoys, etc.) If not already available, surface pressure and any wind observations from buoys should be promoted.

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

The integrated Arctic Ocean Observing System (iAOOS), for example, would provide an excellent, by-then well-tested system to measure the upper ocean, sea ice properties and the lower atmosphere. The Arctic Observing Network includes autonomous sea ice based sites as well as manned and unmanned terrestrial stations.

The International Programme for Antarctic Buoys (IPAB) and the Southern Ocean Observing System (SOOS) will also be encouraged to contribute. However, a temporary expansion of buoy programmes should be made both in terms of spatial coverage as well as to include less frequently observed properties such as internal ice temperature and stress.

Marine mammal observations are an interesting and potentially valuable source of ocean observations near ice margins, which are otherwise data sparse (no Argo floats – see *http://www-hrx.ucsd.edu/www-argo/statusbig.gif*)

Snow

It is of high priority to obtain proper manual measurements of snow including information on depth, density, grain size (for Microwave retrievals). These are really the only reliable measurements. This includes snow over sea ice.

A YOPP stakeholder engagement workshop, in association with political discussions if required, would be a useful approach to probe the willingness of stakeholders to active participation. YOPP will build on other programs engaging polar stakeholders.

4.1.4 Satellite Data

Satellites provide unique observational capabilities for the atmosphere, oceans and cryosphere. It will be crucial to exploit the available satellite data during YOPP. The timing of YOPP is chosen such that the projected availability of polar-relevant satellites (e.g., CryoSat2, IceSat2, Sentinel1-3, COSMO-SkyMed, PCW), SMOS and GNSS-RO will allow the compilation of a comprehensive satellite snapshot for further analysis. All conventional observational activities during YOPP should provide data that can be used to validate and calibrate satellite retrievals of important polar geophysical parameters.

4.2 Modelling and Forecasting

4.2.1 High Resolution and Coupled Forecasts

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

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

Some of the key aspects of proposed model experiments are:

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

There could be six kinds of experiments:

(A) Forecast and reforecast data sets to allow for robust estimates of forecast skill and to diagnose sources of forecast failures.

(B) Sensitivity studies – explore the role of model formulation (resolution and parameterisations).

(C) Case studies – how well does the modelling system in various configurations deal with particular extreme events? In order to provide any indication of conclusive results with confidence, it will be crucial to evaluate YOPP cases alongside cases/data from previous campaigns.

(D) Multi-year 'free' model simulations – investigate the ability of the modelling systems to capture interannual variability and assess system biases and imbalances.

(E) Potential predictability studies – explore the limits of predictability for sea ice characteristics and other relevant variables.

(F) Process resolving simulations (Large eddy simulations) to guide development of subgrid-scale parameterisations.

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

(1) Coupling

- Coupled versus uncoupled predictions of the various environmental system components (atmosphere, sea ice, ocean, wave, snow).

- Identification of sources of coupled forecasting skill and dependencies on model parameters (e.g., resolution, sea ice rheology).

(2) Sea ice prediction

- Observing System Simulation Experiments could be performed to assist in identifying the observational requirements for YOPP. For example, these experiments could aim to recommend a target density for ice buoys, ice stress sensors and IMB buoys.

- Experiments to assess the sensitivity to atmospheric forcing and related errors. This could include errors due to atmospheric radiation, boundary layer physics and model resolution. Assess the importance of coupling for modifying sea ice predictability characteristics. There could also be an ensemble of sea ice predictions based on different atmospheric ensemble members; the spread of the resulting ice predictions based on "pure" atmospheric spread, could be compared with what the spread is from using different ice modelling parameterizations and/or models..

- Sensitivity studies to quantify the relative ice forecast error due to different ice model characteristics and parameterizations as a function of time of year and location (e.g., sea ice rheology, landfast ice, resolution, melt ponds, snow on ice, tides, waves).

(3) Orography

- What horizontal and what vertical resolution is required

- Explore the role of resolution and orography

    - Orographic drag

    - Vertical diffusion

    - Land surface coupling

    - Orographic flows, such as barrier winds, tip jets, gap flows, foehn flows, katabatic flows

(4) Mesoscale and synoptic scale systems

- polar lows and orographic flows

- Arctic front systems,

- low-level jets associated with sea-ice borders

- topographically influenced wind systems and lee cyclones

(5) Clouds

- Request model centres to compare model predictions with sites (ARM, etc.) where there are high resolution cloud observations. Verification with surface radiation observations is crucial because it allows differentiation between cloud, surface, water vapour errors.

- Clear sky radiances; column liquid water.

- For archived model variables – see what was asked for CFMIP (CMIP only saved cloud fraction).

4.2.2 Archived Model Data and Reforecasts

It will be important to get support from operational centres in providing the research community with extra data normally not available from operational archives (e.g., process tendencies and extra parameters at an increased frequency). In this context, the concept for a special data set developed for the YOTC could serve as a very good starting point. Although YOTC used only ECMWF data, it is expected that additional centres will be participating (e.g., a Finnish HIRLAM Arctic version, and AMPS).

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

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

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

4.2.3 Field Campaign Related

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

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

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

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

4.2.4 Sea Ice Modelling

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

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

4.2.5 Subseasonal to Seasonal Predictions

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

4.3 Forecast Use and Decision Making

4.3.1 Value of Polar Predictions in Decision Making

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

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

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

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

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

4.3.2 Verification

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

4.4 Education

4.4.1 YOPP Summer Schools

YOPP will provide many early career scientists (postgraduate students and postdocs) with the opportunity to actively participate in an event that is expected to significantly advance polar research in general, and polar prediction in particular. In order to provide interested students with the necessary background, it is planned to hold at least two YOPP summer schools, coordinated with APECS. One will be during the YOPP Preparation Phase – in 2015 or 2016 – and the other in 2018.

Potential topics for the summer schools include:

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

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

4.4.2 Workshops and Outreach

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

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

5 YOPP Consolidation Phase (mid-2019 to 2022)

The Consolidation Phase will be a crucial element of YOPP given that it will help to provide a legacy of both the Polar Prediction Project in general and YOPP in particular.

The overall structure of the Consolidation Phase is outlined in Figure 4.

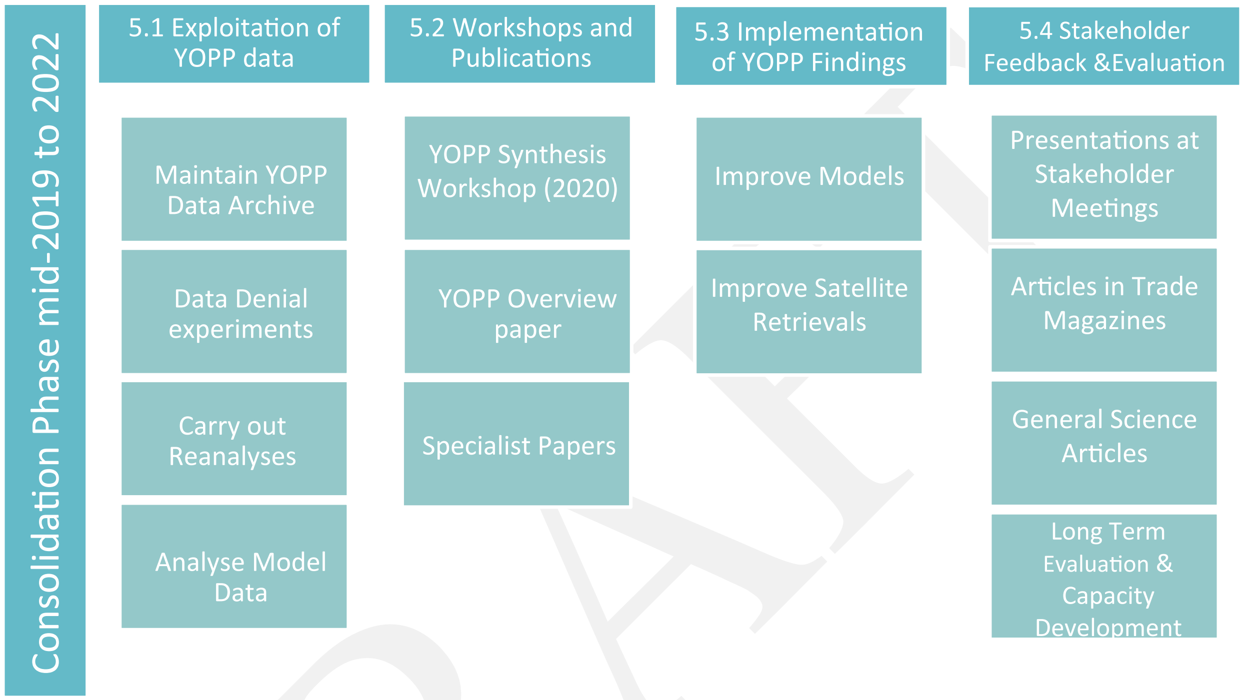

Figure 4: YOPP Consolidation Phase

5.1 Exploitation of YOPP Data

An important task right at the beginning of the Consolidation Phase will be to ensure proper archiving, availability and traceability (Digital Object Identifiers) of all the additional observational data generated during YOPP. The YOPP data task team will oversee this process.

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

The breadth of numerical experiments available through the YOPP Data Centre 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).

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

5.2 Workshops and Publications

In order to ensure a lasting legacy it will be essential to hold a YOPP synthesis workshop in 2020. Such a workshop would help to exchange the knowledge gained during YOPP, provide a good opportunity to discuss a YOPP overview paper and to develop plans for a special issue or issues on YOPP in the peer-reviewed literature. The YOPP synthesis workshop is also expected to contribute to the operational implementation of YOPP findings. To ensure "buy in" from the operational centres this synthesis workshop will be promoted through WWRP/WMO directly to the centres; hosting the workshop at a centre such as ECMWF or one of the GPCs may also assist.

5.3 Implementation of YOPP Findings

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

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

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

5.4 Stakeholder Feedback and Evaluation

It would be important to feed back some of the improvements made, new products, etc., directly to the stakeholders. This could be done through a series of meetings and 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 (WWRP SSC). (Note - this was formerly called the WWRP-JSC, prior to CAS-16 in November 2013).

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

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

An International Coordination Office (ICO) for Polar Prediction was formally established at the Alfred Wegener Institute for Polar and Marine Research in September 2013.

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

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

7 APPENDIX 1 – TIMELINE

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

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

Milestone	Target Date (YYYY.MM format)
Promotional YOPP brochure produced	2014.02
Key partners identified and engaged	2014.02
YOPP Plan draft has been updated based on SG comments, and is circulated for external comment	2014.02
Formal advice provided to S2S and TIGGE on data archiving requirements to support YOPP (and PPP)	2014.02
List of potential funding sources has been compiled	2014.02
EC-PORS-5 meeting in Wellington covers PPP and YOPP	2014.02
WGNE Meeting in Melbourne includes discussion of YOPP modelling needs	2014.03
YOPP data archiving group established (taking advantage of expertise from those involved in YOTC and TIGGE)	2014.03
Full package of YOPP promotional material is available to assist with approaches to funding agencies	2014.03
YOPP Plan draft updated to take into account external comment, and available for discussion at YPM-Obs in Helsinki (YOPP Planning Meeting focussing on Observations)	2014.03
YPM-Obs meeting in association with Arctic Science Summit Week and Arctic Observing Summit in Helsinki	2014.04
WWRP Working Groups have been tasked with specific YOPP-related support needs	2014.04
YOPP modelling strategy finalised, including an agreed list of participating operational modelling centres	2014.06
PPP SG-5 Meeting in association with World Weather Open Science	2014.08

Milestone	Target Date (YYYY.MM format)
Conference in Montréal	
YPM-Model (YOPP Planning Meeting focussing on Modelling) in association with PPP SG-5	2014.08
National YOPP Planning Networks established, where appropriate	2014.09
Submission of Bulletin of American Meteorological Society Paper on PPP, including YOPP Outline	2014.10
Polar-midlatitude Linkages Workshop in Barcelona	2014.12
YOPP Data Centre plans finalised	2014.12
YOPP has been promoted to key national/EU funding agencies by YPG members (making use of additional national support)	2014.12
Baseline polar prediction performance has been documented, based on TIGGE, etc.	2014.12
Commitments have been secured from major modelling centres for preparation phase model experiments	2014.12
YOPP Summit in March 2015 (in association with PPP-IAMAS Polar Meteorology Meeting in Bergen) or May 2015	2015.05
First YOPP Summer School (2015 or 2016)	2015.07
International YOPP Planning Workshop	2016.05
YOPP Data Centre established	2016.12
Experimental operational coupled atmosphere-sea ice-ocean models ready to run by operational modelling centres	2016.12
YOPP sea ice intercomparison metrics defined and agreed upon by participating centres	2016.12
Observational requirements document finalized	2016.12
Start of YOPP Phase	2017.07
Second YOPP Summer School	2018.06
MOSAiC Planned to Commence	2018.09
End of YOPP Phase / Start of YOPP Consolidation Phase	2019.06
YOPP Synthesis Workshop	2020.06

Milestone	Target Date (YYYY.MM format)
YOPP Final Conference	2021.05
YOPP Paper Published in Bulletin of American Meteorological Society	2022.05
End of YOPP Consolidation Phase	2022.12

8 APPENDIX 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 Phase.

High Priority

1) Boundary Layer Including Mixed Phase Clouds

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

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

2) Sea Ice Modelling

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

   1. 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.
   2. The simulations of melt ponds and their impact on the modeled 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.
   3. 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.
   4. Improve sea ice mechanics, including ridging/rafting and how it influences the subgridscale ice and snow thickness distributions

3) Physics of Coupling, Including Snow On Sea Ice

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

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

4) High Resolution Modelling Including Ensembles

High resolution local modelling will be important to capture the physics involved in polar regions. Priority should be placed on this area.

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

5) Model validation and intercomparison

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

1. SHEBA (Surface HEat Budget of the Arctic ocean study described at http://www.eol.ucar.edu/projects/sheba/) aiming to quantify the heat transfer processes that occur between Arctic ocean/ice and atmosphere over a full annual cycle).
2. ASCOS (Arctic Summer Clouds Ocean Study, described at http://www.ascos.se/) aiming at studying physical and chemical processes leading to cloud formation.
3. AOE (Arctic Ocean Experiment, described at http://gcss-dime.giss.nasa.gov/aoe2001/aoe2001.html) to enhance understanding of how natural sources of atmospheric aerosols affect climate through impact on the radiation balance.
4. Old and modern data of drifting stations "North Pole" (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.

Medium Priority

6) Upper Ocean Processes

There are large heat fluxes on a small scale – e.g., across leads. 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).

Low Priority

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. WGNE activities in this area are mostly case study approaches on atmospheric radiative impacts and not the impact on snow and ice.

9 APPENDIX 3 – ABBREVIATIONS

A	
AMDAR	Aircraft Meteorological DAta Relay
AMOFW	Antarctic Meteorological Observations, Modeling, & Forecasting Workshop
AMPS	Antarctic Mesoscale Prediction System
AODS	Arctic Ocean Drift Study
APECS	Association of Polar Early Career Scientists
ARM	Atmospheric Radiation Measurement Program of the US Department of Energy
ASAP	Automated Ship Aerological Programme
ATOMMS	Active Temperature Ozone, Moisture Microwave Spectrometer
AWG	Atmospheric Working Group
AWI	Alfred Wegener Institute for Polar and Marine Research
C	
CBS	WMO's Commission for Basic Systems
CoReH2O	Cold Regions Hydrology High-resolution Observatory
COSMO-SkyMed	**CO**nstellation of small **S**atellites for the **M**editerranean basin **O**bservation
D	
DAOS	Data Assimilation and Observing Systems
E	
ECMWF	European Centre for Medium-Range Weather Forecasts
ECRA	European Climate Research Alliance
EPS-SG	EUMETSAT Polar System - Second Generation
EUCOS	EUMETNET Composite Observing System
EUMETNET	European Meteorological Services Network
F	
FAMOS	Forum for Arctic Ocean Modeling and Observational Synthesis
G	
GASS	Global Atmospheric System Studies (part of WCRP's GEWEX)
GEWEX	Global Energy and Water EXchanges project (WCRP)
GFCS	Global Framework for Climate Services
GNSS-RO	Global Navigation Satellite System - Radio Occultation
GODAE	Global Ocean Data Assimilation Experiment
GPC	A WMO Global Producing Centre
I	
iAOOS	integrated Arctic Ocean Observing System
IASC	International Arctic Science Committee
ICI	Ice Cloud Imager
ICO	International Coordination Office for Polar Prediction
IICWG	International Ice Charting Working Group
IOP	Intensive Observing Period
IPAB	International Programme for Antarctic Buoys
IPY	International Polar Year
ISAC	International Study of Arctic Change
ITP	Ice Tethered Platforms
J	
JWGFVR	Joint Working Group on Forecast Verification Research
L	
LES	Large Eddy Simulations
M	
MIZOPEX	Marginal Ice Zone Observations and Processes EXperiment
MOSAiC	Multidisciplinary drifting Observatory for the Study of Arctic Climate

N

NASA .... National Aeronautical and Space Administration

O

OOI .... Ocean Observatories Initiative

P

PBL .... Planetary Boundary Layer
PCPI .... Polar Climate Predictability Initiative
PCW .... Polar Communication and Weather Mission
PRACE .... Partnership for Advanced Computing in Europe
PSTG .... Polar Satellite Task Group

R

RMSE .... Root Mean Square Error

S

S2S .... Sub-Seasonal To Seasonal Project (WWRP/WCRP)
SCAR .... Scientific Committee for Antarctic Research
SERA .... Societal and Economic Research Applications
SHEBA .... Surface HEat Budget of the Arctic ocean
SIOS .... Svalbard Integrated Observing System
SNAP .... Stratospheric Network for the Assessment of Predictability
SOOS .... Southern Ocean Observing System
SPARC .... Stratosphere-troposphere Processes And their Role in Climate

T

Transpose-AMIP .... Weather forecasting with climate models

U

UAV .... Unmanned Aerial Vehicles

W

WCRP .... World Climate Research Programme
WGNE .... Working Group on Numerical Experimentation
WGSIP .... Working Group on Seasonal to Interannual Prediction
WMO .... World Meteorological Organization
WWRP .... World Weather Research Programme of WMO
WWRP SSC .... Scientific Steering Committee of WMO's WWRP (successor to WWRP-JSC)
WWRP-JSC .... Joint Scientific Committee of WMO's WWRP

Y

YOPP .... Year Of Polar Prediction
YOPP-S .... YOPP for Society – SERA aspects subgroup
YOTC .... Year of Tropical Convection
YPG .... YOPP Planning Group
YPM .... YOPP Planning Meeting
YPM-Model .... YOPP Planning Meeting focussing on Modelling
YPM-Obs .... YOPP Planning Meeting focussing on Observations