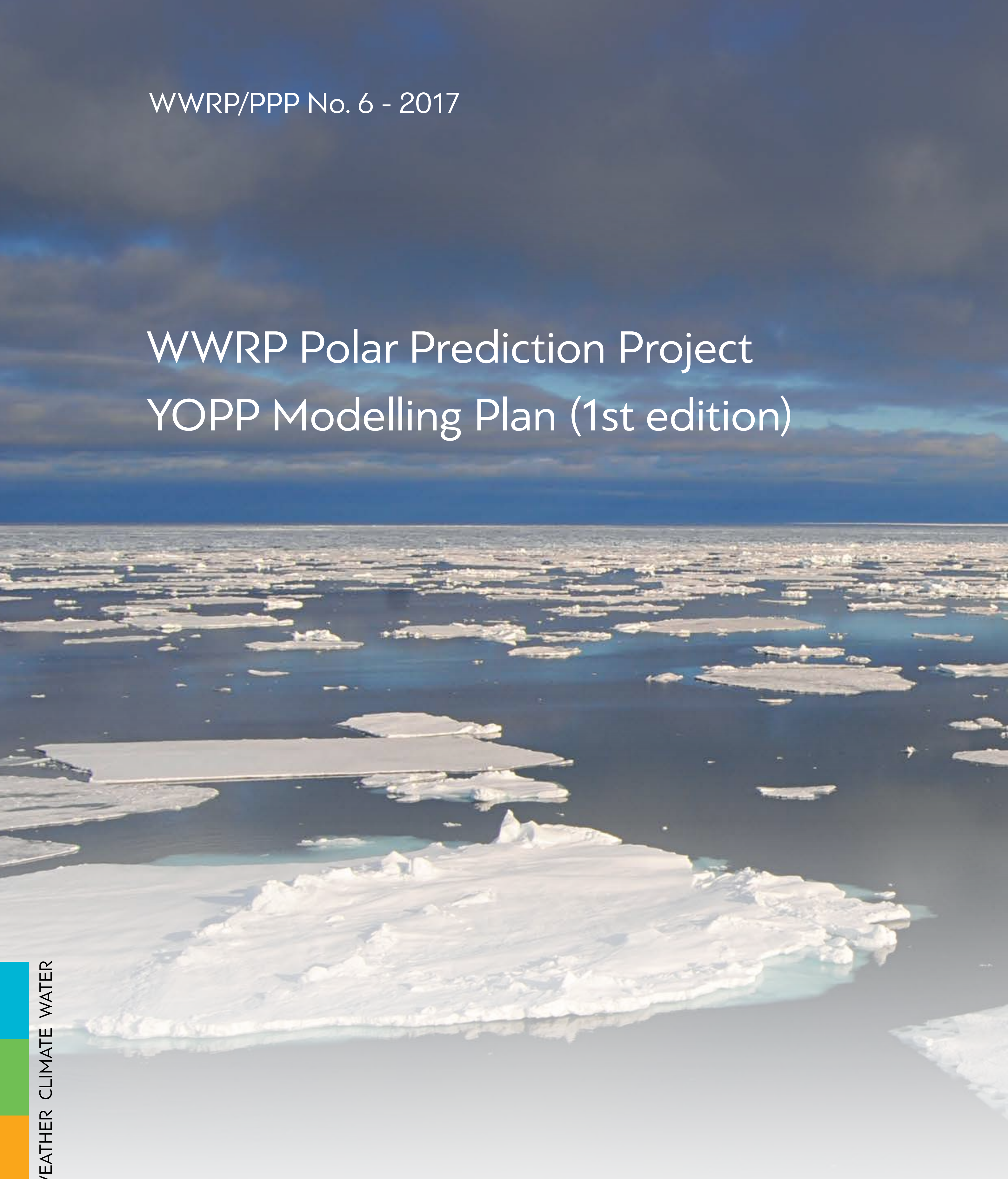
WWRP/PPP No. 6 - 2017

WWRP Polar Prediction Project
YOPP Modelling Plan (1st edition)



WEATHER CLIMATE WATER

WORLD
METEOROLOGICAL
ORGANIZATION

WWRP
WORLD WEATHER
RESEARCH PROGRAMME

WWRP/PPP No. 6 - 2017

WWRP POLAR PREDICTION PROJECT
YOPP MODELLING PLAN (1st edition)

By the YOPP modelling task team

Contributing authors (alphabetical order)

Peter Bauer, UK; Eric Bazile, France; David Bromwich, US; Barbara Casati, Canada; Matthieu Chevallier, France; Jonathan Day, UK; Helge Goessling, Germany; Trond Iversen, Norway; Thomas Jung, Germany; Jørn Kristiansen, Norway; William Merryfield, Canada; Malte Müller, Norway; Gregory Smith, Canada; Gunilla Svensson, Sweden and Richard Swinbank, UK.

WORLD METEOROLOGICAL ORGANIZATION

WORLD WEATHER RESEARCH PROGRAMME

EDITORIAL NOTE

METEOTERM, the WMO terminology database, may be consulted at:
http://www.wmo.int/pages/prog/lsp/meteoterm_wmo_en.html.
Acronyms may also be found at: http://www.wmo.int/pages/themes/acronyms/index_en.html.

Cover photo kindly provided by Kirstin Werner

Chairperson, Publications Board
World Meteorological Organization (WMO)
7 bis, avenue de la Paix
P.O. Box 2300
CH-1211 Geneva 2, Switzerland

Tel.: +41 (0) 22 730 84 03
Fax: +41 (0) 22 730 80 40
E-mail: publications@wmo.int

TABLE OF CONTENTS

1. INTRODUCTION

The Year of Polar Prediction (YOPP) is the main flagship activity of the World Weather Research Programme (WWRP) Polar Prediction Project (PPP; see WWRP, 2013, 2014). The goal of 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. YOPP will be implemented in three phases. The recently completed Preparation Phase ran from 2013 to mid-2017. The main YOPP activities, including observational field campaigns and modelling, will primarily take place in the Core Phase, which has just started and runs from mid-2017 to mid-2019. Results from YOPP activities will continue to be analysed during the Consolidation Phase, from mid-2019 to 2022, leading to operational implementation and scientific publications.

The aim of this document is to summarize plans for modelling work to be carried out as part YOPP. Its scope also includes reference datasets that will support YOPP scientific investigations. This modelling plan supplements the information set out in the PPP and YOPP Implementation Plans (WWRP, 2014; YOPP, 2016a). This plan has been developed following discussions at the YOPP modelling planning workshop held in September 2016 (YOPP, 2016b).

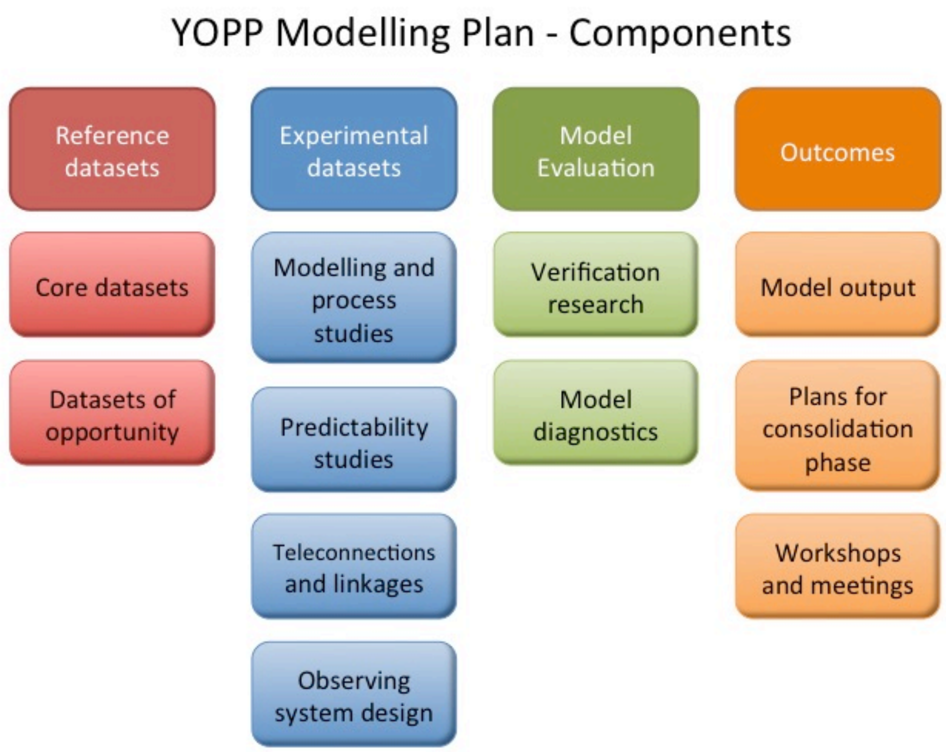


Figure 1. Components of the YOPP modelling plan document

Figure 1 summarizes the structure of the YOPP modelling plan, as set out in this document. For convenience, the modelling datasets are divided into two broad categories (reference and experimental) – further information is shown in Figure 2, and in the next sections of this plan document. Section 2 of the plan covers reference datasets, which support YOPP scientific investigations. Section 3 covers experimental datasets, which include a wide variety of modelling studies that address particular scientific issues. Following descriptions of the modelling datasets, Section 4 covers model evaluation, both using objective verification methods and model diagnostics. The remainder of the plan is concerned with outcomes: Section 5 discusses model output data, Section 6 discusses consolidation of the results following the YOPP Core Phase, while Section 7 sets out plans for future workshop and meetings.

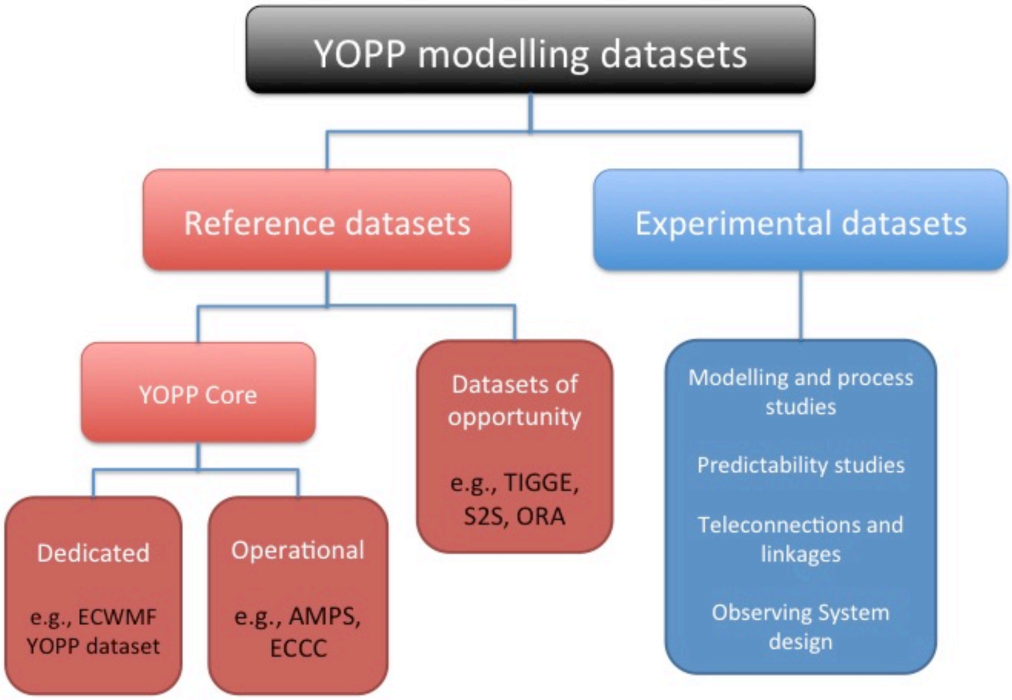


Figure 2. Classification of YOPP modelling datasets

2. REFERENCE DATASETS

There is a range of model datasets that will form an invaluable resource to support both YOPP modelling studies and observational field campaigns. For convenience, we divide the reference datasets into two broad categories: YOPP core datasets and datasets of opportunity. The core datasets includes both dedicated datasets that are specifically tailored for YOPP, for example with output data designed to support YOPP studies, and also operational datasets that will be made available in near real time to support YOPP activities. Datasets of opportunity include a variety of datasets that have typically been developed outside YOPP, which may not be available until well after real time, but nonetheless provide valuable data to support YOPP activities.

Tables 2 and 3 summarize key information about each dataset that will be available in each of the two broad categories of reference data. The primary method to access the reference datasets is via the YOPP data portal, https://yopp.met.no/. Some table entries also show where the datasets may be accessed directly. For each of the reference datasets, the table lists the dataset name, a summary of the dataset contents and model domain, the period for which it will be available and an indication of how close to real time it is available.

2.1 Core datasets

These are the primary modelling datasets that will be used to support YOPP science, including both field campaigns and modelling experiments. These datasets are expected to cover the 2-year YOPP Core Phase (mid-2017 to mid-2019), with possible extension to cover the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) period (until mid-2020). In some cases the core datasets may be limited to the YOPP Special Observing Periods (SOPs), Table 1. Model datasets that cover only shorter periods during YOPP will be classified as experimental datasets. The use of operational model output for YOPP should entail formal collaboration between the operational data providers and YOPP scientists, through the YOPP institutional endorsement process. (Organizations and other groups whose activities contribute to YOPP are invited to request institutional endorsement in order to establish an official link with YOPP.)

Table 1. YOPP Special Observing Periods

Arctic	*Antarctic*
SOP-NH1 February–March 2018	SOP-SH 16 Nov 2018-15 Feb 2019
SOP-NH2 July–September 2018	
SOP-NH3 February 2020 (TBC)	

There will be dedicated datasets produced specifically for YOPP. The YOPP European Centre for Medium-range Weather Forecasts (ECMWF) dataset will follow what was accomplished during Year of Tropical Convection (YOTC, Moncrieff et al., 2012) when an enhanced set of model output (the "YOTC dataset" – a "virtual field campaign") was produced from the operational ECMWF global forecast model, including tendencies from physical processes and fields on many levels. The Canadian Centre for Meteorological and Environmental Prediction (CCMEP) of Environment and Climate Change Canada (ECCC) will produce pan-Arctic high resolution (2.5 km) coupled atmosphere-ice-ocean forecasts using their Regional Ice-Ocean Prediction System (RIOPS).

- The "YOPP ECMWF Dataset" will comprise extended output from the operational global coupled prediction system, including physical tendencies on each post-processing level and grid point. While its primary application will be to support polar studies, it will also be valuable for studies across the globe.
- The ECCC CAPS-RIOPS dataset will comprise high-resolution (2.5 km) coupled atmosphere-ice-ocean forecasts for the Arctic region, to support both field campaigns and scientific studies. Real-time forecasts will be available from the MSC Datamart as well as from data archive (http://dd.beta.weather.gc.ca) during the YOPP Core Phase. Production of uncoupled forecasts started being produced in May 2017 and will be coupled starting in fall 2017.

The other core datasets will comprise operational model output that will be made available to support YOPP. In some cases they will be available by special arrangement with the data providers, and in other cases they may already be publicly available for research purposes. Generally speaking, these operational forecast data will be available reasonably quickly (within

days). Note that operational models will most likely be updated during the YOPP core period, as part of the normal ongoing improvement of operational forecast systems.
A key question is what analysis and forecast data is required to support field campaigns in real time. Forecast data will need to be available speedily, to support flight planning, etc., so this will require strong coordination between campaign organizers and forecast providers. Requests for access should be made to the relevant operational centres well in advance; requests may be made via relevant representatives on the PPP steering group, or via the PPP International Coordination Office (ICO) (see contact details on http://www.polarprediction.net). In addition to the datasets listed in Table 2, it is anticipated that other model runs will be undertaken specifically to support particular observation campaigns.

The core reference datasets also include data that will be used to support scientific investigations. Examples include:

- MET Norway and the Nansen Environmental and Remote Sensing Center (NERSC) plan to provide ocean prediction data using the pan-Arctic CMEMS (Copernicus Marine Environment Monitoring Service) ARCMFC (Arctic Marine Forecast Centre) ocean, sea ice and wave models. It is planned to provide an extended set of output variables during the YOPP Core Phase. Furthermore, a coupled sea-ice ocean reanalysis will be provided for the period 1991 onward (currently till 2015). Real-time and archived forecasts will be available from the CMEMS data dissemination system.
- Antarctic Mesoscale Prediction System (AMPS). AMPS has been running since 2000 to support the US Antarctic Programme. AMPS is based on the Polar WRF model. AMPS analyses and forecasts are archived at the US National Center for Atmospheric Research (NCAR) and available for scientific investigations via a web interface.

Reanalysis projects are generally major undertakings, taking much longer to produce output. They use fixed assimilation systems to ingest the fullest set of observational data, and will generally only be available much later (often years after real time). At this stage, no dedicated YOPP reanalysis is being planned, but could be considered for the YOPP Consolidation Phase. So current reanalyses fit in the category of datasets of opportunity, and are covered in Section 2.2.

2.2 Datasets of opportunity

This category covers reference datasets that stem from initiatives that are independent of YOPP, but will nonetheless be very useful to support YOPP. These datasets of opportunity include datasets produced by a range of reanalysis projects and also other initiatives from WWRP and the Global Ocean Data Assimilation Experiment (GODAE). The datasets are summarized in Table 3.

WWRP supports two major datasets of ensemble forecasts that will be a valuable resource for YOPP. Both datasets include ensemble forecasts from several operational centres. The International Grand Global Ensemble (TIGGE) dataset was established in 2006 to support The Observing System Research and Predictability Experiment (THORPEX) research programme, while the S2S dataset supports the Sub-seasonal to Seasonal (S2S) prediction project. All TIGGE and S2S data are publicly available from ECMWF (and also from the China Meteorological Administration (CMA)):

Table 2[a] Summary of core dedicated and operational reference datasets

Name	*Available from*	*Type*	*Domain*	*Period*	*Timeliness*
ECMWF YOPP dataset	ECMWF	Coupled analysis and forecast, including model tendencies	Globe	YOPP core period	Near real time
CAPS-RIOPS	CCMEP; available on ECCC YOPP Archive: dd.beta.weather.gc.ca	Regional high-resolution coupled atmosphere-ice-ocean forecasts	Arctic and North-Atlantic	YOPP core period	Real time
CMEMS ARCMFC	MET Norway	Regional coupled ocean, sea-ice, wave forecasts	Pan-Arctic	YOPP core period	Real time
AMPS	NCAR	Analysis and forecast	Antarctic	From 2000 onwards	Near real time
ECMWF forecasts	Available from ECMWF under licence	Operational atmospheric analysis & forecasts	Globe	YOPP field campaigns	Real time
AROME-Arctic	MET Norway; available from thredds.met.no/thredds/metno.html	Regional atmospheric forecasts at 2.5 km	Arctic, north of Norway, Nordic and Barents Sea	From November 2015 onwards	Real time
ARPEGE	Meteo-France	Atmospheric forecasts	Globe (standard configuration stretched over France)	Current	
ARPEGE YOPP-SH	Meteo-France	Atmospheric forecasts	Globe (YOPP-SH configuration stretched over Dome C/Antarctica),	YOPP	
AROME-MF-Arctic	Meteo-France	Regional atmospheric forecasts at 1.3 km	Same as AROME-Arctic from MET Norway	YOPP	
AROME-MF-SH	Meteo-France	Regional atmospheric forecasts at 1.3 km or 2.5 km	TBD: several possible options	YOPP-SH field campaigns	

Meteo-France seasonal forecasting system 6	Meteo-France	Global seasonal forecasts with CNRM-CM	Globe	From the end of 2017. System 5 will be available before	Real time
GDPS-GIOPS	CCMEP; available on MSC Datamart (dd.weather.gc.ca)	Coupled atmosphere-ice-ocean model (10 day)	Globe	From Sept 2017 onwards	Real time
GIOPS	CCMEP; available on ECCC YOPP Archive: dd.beta.weather.gc.ca	Monthly ensemble predictions	Globe	From Sept 2017 onwards	Real time
CanSIPS	ECCC-Canada; available on ECCC YOPP Archive: dd.beta.weather.gc.ca	Seasonal ensemble predictions, experimental ice products	Globe	From Sept 2017 onwards	Real time
RASM	NOAA ESRL	Short-range Arctic forecasts	Arctic		
GOFS	US Navy	Ocean Forecasts	Globe		
NCEP sea-ice drift model	NCEP	Ice drift + coupled forecasts	?		
COSMO-RU-ARCT	(Russia)	Atmospheric forecasts	Russian Arctic	Expected to be available during 2018	
Global SL_AV	Russia- available to registered users	Global atmospheric forecasts	Globe	Current	A few hours behind real time
MACSSIMIZE high resolution MetUM forecast	Met Office	Trial 2.2 km forecasts	Centred on Alaska	During MACCSIMIZE aircraft campaigns	
Met Office GloSea	CMEMS (Copernicus Marine Service)	7-day sea-ice and ocean analyses and forecasts from GloSea coupled model	Global		

[a] *This table will be updated as soon as further commitments are made.*

- TIGGE dataset – medium range ensemble predictions (~ 2 weeks range), see Bougeault et al. (2010), Swinbank et al. (2016).
- S2S dataset – sub-seasonal to seasonal predictions (~ 2 months range), see Vitart et al. (2017).

Six centres currently produce near-term sea-ice forecasts under the auspices of the GODAE Ocean View (GOV) project. The Canadian datasets (Global Ice Ocean Prediction System (GIOPS), RIOPS) will be available, for YOPP and other participating centres are working to obtain approval to make their datasets available. Initiatives coordinating sea-ice forecasts at longer lead times are addressed in Section 3.2 (predictability studies).

Reanalysis datasets are produced in delayed mode use a fixed numerical model and data assimilation system. Compared to operational systems, reanalyses have the advantage of not being affected by periodic system upgrades, but have the disadvantage of (usually) running well behind real time. Several reanalysis projects are particularly relevant to YOPP, as listed in Table 3. Examples include:

- Arctic System Reanalysis v3. Two previous reanalyses have been carried out for the greater Arctic Regions, covering the years 2000–2012 (Bromwich et al., 2016). Both use the Polar WRF model, with 3DVar WRF DA, at 30 (v1) and 15 km (v2) resolutions. A proposal has been submitted to carry out a more comprehensive atmospheric reanalysis (v3) for the greater Arctic spanning 1979-2020, including the YOPP and MOSAiC periods. This will include better atmospheric and land surface modelling and a contemporary data assimilation system. Resolution will be 10-15 km with more vertical levels. Depending on funding, ASRv3 data are likely to start to become available later in the YOPP Core Phase.
- ECMWF global coupled reanalyses for the ERA-Clim2 project. This includes a high-resolution CERA-SAT dataset based on conventional and satellite observations. Although the ERA-Clim2 project will have been completed before the YOPP Core Phase, it is planned to extend the CERA-SAT reanalysis to span this period. Availability of the data will depend on when a stable coupled system is available and on computing resources.
- ALERA2 – an experimental ensemble reanalysis approach, developed by the Japan Agency for Marine-Earth Science and Technology JAMSTEC.
- PORA-IP – Polar Ocean Reanalysis Intercomparison Project – established following the GSOP/GOV ORA-IP project (Balmaseda et al., 2015), within the EU COST ES-1402 "Evaluation of Ocean Synthesis" action. A database with global and regional ocean sea-ice reanalyses and observational datasets has been set up and is updated following updates of reanalysis systems. Note that, at the time of writing there is no intention to update the database in near real time.

Table 3[b]. Summary of supplementary reference datasets

Name	*Available from*	*Type*	*Domain*	*Period*	*Timeliness*
TIGGE	ECMWF and CMA	Medium-range Ensemble forecasts from multiple providers	Globe	2006 onwards	2 days behind real time
S2S	ECMWF and CMA	Sub-seasonal ensemble forecasts from multiple providers	Globe	2015 onwards	3 weeks behind real time
GOV	(via YOPP data portal)	Sea-ice analyses and forecasts from multiple providers collocated with AMSR2 retrievals	Global	2015 onwards	14 days behind real time
PORA-IP	University of Hamburg (ORA-IP database)	Ocean/sea-ice reanalyses from multiple providers; observational datasets for evaluation	Globe & regional	Most products: 1993-2012	To be confirmed
CERA-SAT	ECMWF	Coupled reanalysis -	Globe	2009 onwards, through YOPP core period	To be confirmed
ARCMFC-reanalysis	MET Norway	Regional coupled ocean, sea-ice reanalysis	Arctic	From 1991 onwards	Delayed by 1-2 years
ASR v3	NCAR	Coupled reanalysis	Arctic	From 2000 (?) through YOPP core period	To be confirmed – expected to start to be available later in YOPP Core Phase
ALERA2	JAMSTEC	JAMSTEC Ensemble reanalysis	Globe	From 2008 onwards	3 months behind real time
CBHAR	?	Regional reanalyses	Chuckhi & Beaufort Seas	1979-2009 – hope to extend to cover YOPP core	To be confirmed
CARRA (MET Norway and DMI)	Climate Data Store (C3S)	Arctic 2.5 km reanalyses	European Arctic	Tbd-present	Production starts end 2019

[b] *This table will be updated as soon as further commitments are made*.

3. EXPERIMENTAL DATASETS

This category covers most of the modelling and data assimilation experiments that will be run during YOPP, which will be aimed at studying and improving model performance for polar prediction. The experiments will include contributions from a wide range of YOPP scientists. A more detailed discussion of the scope and priorities is set out below for each of the broad scientific topics covered by YOPP. Each subsection includes a list of specific activities, followed by a table setting out examples of planned experiments (Tables 4-7).

While the reference datasets cover the YOPP core period, and in many cases longer, experimental datasets will focus on more restricted periods.

- The YOPP special observing periods (SOPs, see Table 1) are periods when enhancements will be made to the operational routine observing network, in particular additional radiosondes. Model experiments to optimize the polar observing system will focus on those periods.
- YOPP field campaigns are periods of more intensive specialist observations, including both airborne and ground-based campaigns. Modelling studies will be carried out to support the observation campaigns, and for process understanding to aid parameterization development.

Periods, based on existing observational data as well as YOPP field campaigns, will be chosen for model-intercomparison studies. Multi-scale modelling studies are set up such that the large scale can be provided by one of the reference datasets, which provides boundary conditions for nested regional models, which in turn provides the environment for large eddy simulations or single-column models.

The development of improved models relies heavily on observation data. For example, we need more co-located profile information from the ocean and the atmosphere. Ice buoys will be deployed in support of special observing periods and field campaigns. It is recognised that data from marine mammals is valuable too. A lot of data are available from past campaigns (e.g. IPY, International Polar Year) that have not yet been well exploited. It is noted that model development is held up by not having a reliable (ocean and sea ice) observing system available 24/7 all year.

3.1 Modelling and process studies

Improving the representation of physical processes (‘model physics’) in polar regions is a fundamental aim of YOPP. This will entail a range of process modelling studies in combination with observations. The main focus will be on physical processes in the lower atmosphere and coupling with ocean and sea ice.

A process model simulates a physical process using a highly resolved numerical laboratory, e.g. large eddy simulation (LES) models or single column models (SCM). Observation and process studies are closely tied together: process modelling studies during YOPP will be linked with particular YOPP field campaigns, including airborne, ground-based and marine observation campaigns. Modelling experiments will be used to interpret and understand the observations to further add to the knowledge base needed for model improvements.

YOPP will bring together different modelling communities with different models, insights and expertise. Process models are important for understanding physical processes, but forecast models are used at different horizontal resolution, thus model formulations that are developed should work across a range of scales. That will entail comparing model simulations at high and low resolutions. Traditional model output from large-scale models does not easily lend themselves to study physical processes. The planned ‘ECMWF YOPP dataset’ will include model tendencies at high temporal frequency from the different physical parameterizations at model levels, which will provide invaluable information for model analysis and development.

The coupling between different components of the earth system (ocean, sea ice, snow, land and atmosphere) is particularly important for high-latitude prediction. Many models are clearly not properly representing processes important for sea-ice modelling, including fast ice, snow, deformation, leads, melt ponds, flow distribution and drags acting both above and below sea ice. Special attention should be paid to the representation of subgrid-scale variability due to surface heterogeneities in models, and their impact on the simulated atmosphere-ice-ocean surface layer. Improving the representation of snow on sea ice and land, and of coupled land-atmosphere processes in the high latitude is also critical. A better understanding of coupling processes would also improve the use of observations in data assimilation systems, by enabling better observation operators to be developed.

An important contribution to understanding coupling process will come from the use of coupled SCMs to study physical processes around the interface between the atmosphere, ice and ocean.

Specific activities:

- Hold workshops to bring together observation and modelling specialists to discuss the use of observations for model validation and modelling studies using observation data. Two meetings are currently planned, a workshop in Stockholm from 6 to 9 November 2017 and the 2nd Pan-GASS conference from 26 February to 2 March 2018 in Lorne, near Melbourne, Australia.
- Undertake model intercomparison studies using LES and observations to compare with SCMs from Numerical Weather Prediction (NWP) and climate models, in conjunction with the Global Energy and Water Cycle Exchanges Project (GEWEX), e.g. GABLS and Larcform.
- Coordinate process model studies with YOPP observation campaigns and MOSAiC. Agree on case study periods.
- Coordinate the production of sea and coupled forecasts (and common output formats) to facilitate model intercomparison.
- Coordinate an inter-centre virtual operational desk between NWP groups and ice services to intercompare experimental real-time YOPP forecasts and identify events of interest for detailed case study.

Table 4. Proposed experiments on model and process studies

Lead centre(s)/ group	*Description*	*Model type(s)*
APPLICATE project	Use process model studies to develop and improve physical parameterizations for numerical models across a range of resolutions.	Atmosphere, ocean, ice, and coupled; both single-column and 3D models
APPLICATE project	Carry out sensitivity studies to explore the impact of model formulation, and the influence of parameters.	Atmosphere, ocean, ice and coupled
ECMWF	Use physical tendency information from ECMWF YOPP dataset to improve understanding of model physics.	Atmosphere
Legacy project	Development of a high-resolution coupled prediction system to study and improve coupled model processes and improve short-range forecasting in the Arctic	Atmosphere, wave, sea ice and ocean model

3.2 Predictability studies

One focus of predictability studies for YOPP is improving our understanding of mesoscale and synoptic scale weather systems at high latitudes including the formation and evolution of polar lows. For example, while the dynamics of mid-latitude cyclones is reasonably well understood, the behaviour of high-latitude storms are less studied. Case studies should be used to assess how well various model configurations deal with particular extreme events. In order to enable robust conclusions, YOPP cases will need to be compared with a wider set of case studies.

Additional experiments should explore the limits of predictability for atmosphere-cryosphere-ocean, with a particular focus on sea-ice characteristics and other relevant variables. For sub-seasonal and longer predictions, the mechanisms of sea-ice predictability are not clear. Apparently small, or unobserved, differences can have a big effect. A better understanding of uncertainties is needed – when systems are more or less predictable. The quality of sea-ice analyses and reanalyses used to initialize sub-seasonal to seasonal predictions and their impacts on sea-ice predictive skill should also be assessed with a prediction perspective, in order to better understand the role of initial conditions in current predictive skill.

In the short range, it is clear that wind and ocean currents are keys to the prediction of sea-ice dynamics. Further, short-range NWP systems are typically employing relatively simple sea-ice models. This warrants studies on sea-ice dynamics and parameterizations and their uncertainties, e.g. by utilizing Ensemble Prediction System (EPS) systems.

In addition to the GOV sea-ice forecasts (Section 2.2), two community efforts coordinating sea-ice forecasts at longer lead times bear a high potential to shed light on sea-ice predictability and to advance prediction skills: the Sea Ice Prediction Network (SIPN) Sea Ice Outlooks (SIO; Arctic and Antarctic) and the Sea Ice Drift Forecast

Experiment (SIDFEx). While the Arctic SIO, focussing on the September sea-ice extent (and edge), is ongoing for more than 10 years, the Antarctic SIO ("SIPN South", a YOPP-endorsed project: http://apps3.awi.de/YPP/pdf/stream/106) and SIDFEx (http://www.polarprediction.net/en/yopp-activities/sidfex/) have been initiated as dedicated YOPP activities.

Specific activities:

- Use case studies to assess the predictability of severe weather events at high latitudes. Case studies could be identified by discussion between forecast centres.
- Engage with the WWRP working group on Predictability, Dynamics and Ensemble Forecasting (PDEF), to improve our understanding of high latitude systems and their predictability.
- Evaluate the S2S reforecast dataset in the polar regions.
- Engage with the SIPN and SIPN-South, and contribute to Arctic and Antarctic SIO to improve our understanding on sub-seasonal to seasonal sea-ice predictability and to advance predictive skills.
- Coordinate, contribute and engage in evaluation of SIDFEx sea-ice drift forecasts.
- Engage with ORA-IP in the evaluation of ocean/sea-ice analyses and reanalyses in the polar oceans, with a prediction perspective. Assess sea-ice analyses/reanalyses as (i) lateral boundary conditions of atmosphere-only models and (ii) initial conditions of coupled models.

Table 5. Proposed experiments on predictability

Lead centre(s)/ group	*Description*	*Model type(s)*
SIPN & SIPN South project	Use case studies to assess sub-seasonal to seasonal predictability of Arctic sea-ice characteristics, e.g. in collaboration with SIPN. Also develop such coordinated experiments for the Southern Ocean.	Statistical models; stand-alone ocean-ice models; coupled atmosphere-ocean-ice models
WGSIP	Evaluation of the impact of snow initialization on forecast skill, by comparing how state of the art dynamical forecast models vary in their ability to extract forecast skill from snow initialization.	Atmosphere-land models; coupled atmosphere-ocean-ice

MET Norway	Assess the impact of different sea-ice parameterizations and their configurations, e.g. properties of snow pack covering the ice, on short-range NWP forecast skill.	Atmosphere
MET Norway	Study the sensitivity of atmosphere response to ice concentration and ice thickness perturbations by using a convection-allowing ensemble NWP system.	Atmosphere
Legacy project	Study mesoscale predictability and the relevance of coupled model process with a high-resolution coupled prediction system	Atmosphere, wave, sea ice, and ocean model
ORA-IP	Run coupled models initialized with initial conditions obtained (or built) from different ocean/sea-ice reanalyses. Evaluate the sensitivity of prediction skill at sub-seasonal to seasonal time scales. Run atmosphere-only models with different sea-ice analyses as boundary conditions.	Atmosphere-sea ice; coupled atmosphere-ocean-sea ice models

3.3 Teleconnections and linkages

A major motivation for YOPP is to improve our understanding of the connections between weather in the polar regions and at lower latitudes, especially from a prediction perspective. Statistical teleconnection patterns have long been used to highlight large-scale circulation patterns. The "Year of Tropics-Midlatitude Interactions and Teleconnections" (YTMIT) is an initiative linked to the S2S project that will take place in parallel with the YOPP core period. YOPP and YTMIT share a common interest in elucidating such large-scale linkages and their physical basis.

Relaxation experiments can also be used to study linkages between polar and lower latitudes and vice versa. This approach is particularly interesting since provides insight into teleconnections from a prediction perspective; and simulated teleconnections can be verified. It is noted that Northern Europe reaches into the Arctic; we need diagnostics that focus on the circulation mechanisms that connect the two regions in order to better understand how they are linked. Other experiments will explore the role of the stratosphere in the connections between mid- and high latitudes.

Some of the experiments providing guidance for the design of the observing system, such as data denial experiments (see next section), will also shed light on polar-lower latitude linkages from a prediction system ("How do better polar forecasts impact predictions in mid-latitudes?").

Specific activities:

- Teleconnections and linkages were discussed in more detail at the US Climate and Ocean: Variability, Predictability and Change (CLIVAR) meeting, which was held from 31 January to 3 February 2017 in Washington DC, USA. YOPP-related experiments were discussed at that meeting. This discussion, which will lead into a Polar Amplification Model Intercomparison Project (PA-MIP), was continued during a workshop in Aspen, USA, which was held from 12 to 16 June 2017.
- Employ relaxation experiments to study linkages between polar and lower latitudes from a prediction perspective. In the context of the Horizon2020 project APPLICATE such experiments with two different forecasting systems will be carried out.
- Engage with YTMIT to help develop our understanding of the teleconnections between polar and lower latitudes.
- Engage with the Working Group on Seasonal to Interannual Prediction (WGSIP) project to examine influence of tropical precipitation anomalies on the extratropics, in particular the North Atlantic Oscillation that affects the north polar regions in winter.

Table 6. Proposed experiments on teleconnections and linkages

Lead centre(s)/ group	*Description*	*Model type(s)*
ECMWF & CNRM	Relaxation experiments with the ECMWF and CNRM-CM6 models covering the period 1993 to the present	Coupled atmosphere-ocean-ice
APPLICATE project	Polar Amplification Model Intercomparison Project (PA-MIP) – comparison of simulations of polar teleconnections	Atmosphere-only and coupled
WGSIP	Examination of interactions/teleconnections between tropics and extra-tropics, focusing on predictable influences of tropical precipitation anomalies on extratropical climate, including the North Atlantic Oscillation (NAO) which strongly influences circulation and temperature in north polar regions particularly in winter.	Coupled atmosphere-ocean-ice

3.4 Observing system design

YOPP aims to make recommendations to WMO and national meteorological services on the future configuration of the observing system in polar regions. Our aim is to consider the design of the observing system, rather than individual observations.

The additional radiosonde launches planned for the SOPs (see Table 1) will be utilized in a number of model and data assimilation experiments to assess their importance. The additional observations will include more frequent radiosonde launches from operational stations, and additional ones from non-operational stations. The two-month period is chosen in order to obtain statistically reliable assessment of the impact of the additional observations across a range of different weather types. Model experiments will also be used to assess the benefit of observations from buoys deployed during YOPP through the International Arctic and Antarctic Buoy Programmes (International Arctic Buoy Programme (IABP) and the International Programme for Antarctic Buoys (IPAB) respectively).

The impact of the additional observations will be assessed though a range of techniques. "Forecast Sensitivity to Observations" (FSO) is a technique using diagnostics from a data assimilation scheme to compare the impact of different observation types. Observing System Experiments (OSEs), also referred to as 'data denial experiments' is a more comprehensive approach to assess the impact of observations by running sets of analyses and forecasts with and without particular subsets of operational data.

Other possible techniques include the use of Observing System Simulation Experiments (OSSEs), but that requires a substantial model infrastructure, and the careful simulation of observations from a "nature run". Another technique that may be useful is "Quantitative Network Design", a simpler but less comprehensive way to evaluate the impact of simulated observations.

Confidence in the results of these studies is increased if similar conclusions are reached across a range of models and systems. Hence, coordination across modelling centres for these studies are envisioned.

Specific activities:

- Collaborate with the WWRP working group on Data Assimilation and Observing Systems to develop recommendations for future developments to the observing network at high latitudes.
- Carry out OSEs at several operational centres, in order to evaluate the benefit of enhancements to the operational observing network.
- Employ other techniques, including FSO, to give additional perspectives on observing system design.

Table 7. Proposed experiments on observing system design

Lead centre(s)/ group	*Description*	*Model type(s)*
ArCS project	Several OSEs focusing on extreme events in polar regions and/or midlatitudes. Comparison of FSO between YOPP/SOPs data and YMC/IOPs data.	Atmosphere

4. MODEL EVALUATION

Evaluation of forecasts is an important component of YOPP. There are several complementary approaches to evaluation, which mainly depend on the purpose and recipients of the evaluation itself, that will need to be employed within YOPP, including:

- Summary verification scores – (which address the general user)
- User-oriented verification – (e.g. for marine transport and aviation)
- Process-based evaluation and model diagnostics – (for model developers)

Members of the WMO Joint Working Group on Forecasting Verification Research have compiled a document setting out a range of objective verification techniques for environmental prediction in polar regions (Casati et al., 2017).

The WMO Commission on Basic Systems (CBS) has agreed on a set of standardized verification scores which are currently exchanged on a monthly basis between the major NWP international centres (WMO No. 485, 893, 1091). These CBS standards should constitute the baseline verification for YOPP.

YOPP bring the challenge of a wider range of model datasets, including reanalyses, ensembles, coupled & uncoupled models, over a wider range of domains and resolutions. The range of observations also goes much wider than traditional atmospheric data, including ocean, ice & snow, land surface measurements from a range of platforms including from mobile platforms and satellites. There is thus a wide range of verification research opportunities during YOPP.

Given the diversity of verification developments, in order to minimize the duplication of technical effort, it is important to coordinate the management of YOPP data and employ standards and unified format for both model and observations – see Section 5.

4.1 Verification research

Observations are the cornerstone of verification. However, one of the greatest challenges of verification in polar regions is the limited amount of reliable observations. Observations networks in polar regions are sparse, inhomogeneous and not representative of the whole polar environment (e.g. most stations are located along the coast). Moreover, due to the harsh environment (and our limited understanding of polar processes, e.g. for observations processed by data assimilation algorithms), observations in polar regions are often affected by larger uncertainties, compared to mid-latitudes. YOPP provides an opportunity for new research into verification approaches which account for observation sparseness and uncertainty.

YOPP could also serve as a platform for enhancing synergies between the verification and data assimilation communities: both communities would gain from shared knowledge on model biases, observation uncertainties, and spatial and temporal representativeness in polar regions, as well as shared tools for (model-independent) quality controls.

Recent years have seen the development of several new verification methods: YOPP provides a unique opportunity to apply these methods. In particular, the recently developed spatial verification methods (Gilleland et al., 2010) are revealing particularly informative, and can be tested, exploited and further developed within YOPP. Spatial methods account for coherent spatial structure characterizing weather variables and the presence of features. They provide information about the physical nature of errors. They can assess the spatial structure and scale-dependence of the forecast skill. They also assess location and timing errors (separately from intensity error), and account for small time-space uncertainties (avoiding the "double-penalty" issue).

It is important to develop user-oriented verification measures, which accounts for the specific end-user parameters and respond to the specific end-user needs, so that the assessment of model forecasts is relevant in a societal and economical context. One example is the verification of specific parameters of sea-ice forecasts (e.g. sea-ice edge and pressure), which are crucial for navigation safety. The PPP-SERA team joint with the YOPP verification task team ensures the development of verification metrics that address the requirements of a range of forecast users.

4.2 Model diagnostics

Strong investment in developing diagnostics of model performance will make an invaluable contribution to model development. Focus on processes (e.g. land-cryosphere-atmosphere coupling; surface fluxes and radiation budget) and a broader selection of variables important for the polar regions will strengthen the utility of the data. With this vision, a common set of YOPP model output has been established (YOPP, 2017), see Section 5. Verification of observed variables that are not generally used for data assimilation (e.g. clouds & precipitation) will provide a strong test of the model physics, especially microphysics.

Examination of the tendencies from different physics schemes is a powerful way to understand the causes of model biases. The inclusion of tendencies in the ECMWF "YOPP dataset" will be very helpful, but tendency diagnostics should also be produced from other models to learn how different schemes and their interaction with the model compare with one another.

It is also highly informative to examine how model biases develop starting from observation-based initial conditions, at a range of timescales from the first few time-steps, though days and months. The WGSIP Long-Range Forecast Transient Intercomparison Project (LRFTIP) compares behaviour across models using an array of diagnostics, some of which will focus on the polar regions.

Another important issue is to evaluate how well uncertainty is represented in ensemble forecasts and data assimilation; a range of ensemble diagnostics should be used to inform future development of ensemble assimilation and prediction systems. Another approach is to study the reliability budget of an ensemble data assimilation scheme – this can highlight biases and other types of error, as well as diagnosing the impact of particular observing systems.

Although these techniques have primarily been developed for atmospheric models, similar diagnostic techniques should also be explored for the other components of the coupled system.

5. MODEL OUTPUT DATA ARCHIVING

In order to facilitate research with YOPP data, it is vital that both model and observation data are shared as widely as possible, using consistent standardized formats.

A data portal (http://yopp.met.no/) has been established for YOPP, hosted by MET Norway. This will provide researchers with access to both YOPP observational data and model output. All investigators working on YOPP endorsed projects are asked to make relevant model datasets available to the research community as early as possible. The datasets will be discoverable through the data portal, although the data will normally be held elsewhere.

In order to facilitate comparison between different models, and between model and observations, all coordinated model experiments need to follow a data protocol. The YOPP core reference datasets (Table 2) and experimental model datasets (Tables 4-7), to the extent feasible, will contain a core set of diagnostics. The output covers atmospheric model variables that reflect the model performance both near the surface and in the free atmosphere, including radiation and surface energy and momentum fluxes, along with the standard upper-air and surface and a range of single-level variables. In addition, a small core set of cryosphere, sea ice and ocean variables will be output from simulations that include a dynamic ocean and sea ice. This standard set of output fields is set out in the document "A Common set of Model Output for YOPP" (YOPP, 2017).

In order to exploit the high frequency and physical complexity of multi-variate observations at the Arctic and Antarctic super-sites, vertical profiles of some of the YOPP core-models will be archived, for a large portfolio of selected process-specific variables, at high frequency (of the order of minutes) for a set of representative grid-points surrounding those sites. The standard sites will include IASOA sites (https://www.esrl.noaa.gov/psd/iasoa) and the MOSAIC drifting observatory (http://www.mosaicobservatory.org/). There is an increasing interest in the so-called "third pole" (Himalayas and Tibetan Plateau), so a few key locations will also be defined in that region. The site-specific data will enable process-based studies (including verification and analysis of the representativeness error), where the target processes include: the representation of the radiation budget; surface energy and momentum fluxes (in presence of land, ocean, snow and ice); clouds optical properties, vertical profiles of water vapour, and cloud liquid and ice water content, hydrometeors microphysics. High frequency data will also be extracted at a few locations over the Arctic and Southern Oceans where limited, or no, observation data are available, in order to facilitate model intercomparison and process studies focused on the interface between the ocean, sea-ice and atmosphere.

6. CONSOLIDATION

To ensure that the knowledge gained from the YOPP modelling studies is used to benefit operational prediction systems a number of actions are needed which will take place during the YOPP Consolidation Phase.

While the main observational campaigns will be carried out during the YOPP Core Phase, the related experimental modelling work will carry on into the YOPP Consolidation Phase. In addition, the MOSAiC programme will continue to produce observational measurements through 2019/20, into the consolidation phase. More specific plans for modelling experiments will be developed, depending on how the YOPP field campaigns proceed.

It is anticipated that the results of YOPP scientific research will start to be published during the core phase, and even more so during the consolidation phase. Appropriate research results will be included in educational and outreach activities during that period, including a YOPP Summer School.

7. WORKSHOPS AND MEETINGS

As noted above, this document was initially developed following the YOPP planning meeting on modelling activities that was held at ECMWF in September 2016 (YOPP, 2016b). This modelling meeting was held immediately after an observation planning workshop. As plans for YOPP field campaigns continue to be developed, a further planning workshop is proposed, subject to funding. A major motivation is to bring together the observation and modelling communities to ensure that appropriate modelling work is directed to improve our understanding of the observation data, in order to improve polar prediction. As detailed in Section 3.1, two meetings are currently planned that will bring together observation and modelling specialists. It will also be important to confirm that model prediction and reanalysis data will be available to support observational studies.

A data planning meeting for the YOPP data archiving was held in November 2016, covering both model and observation data. As discussed in Section 5, model output archiving is an important aspect of this model plan. Discussion of both model and observation data, and how the data should be exchanged and disseminated is an important aspect of YOPP planning.

In addition, more focused discussions will take place in amongst YOPP task teams (see http://www.polarprediction.net/yopp-activities/yopp-task-teams/). While these will mostly be carried out remotely via video and teleconferences, there will also be benefit from specialist meetings on, for example YOPP planning for the southern hemisphere and PPP-SERA.

It is envisaged that YOPP scientists will also make major contributions to a range of scientific meetings relevant to Polar Prediction. A Polar Prediction workshop, for example, was held on 27-29 March 2017 at the Alfred Wegener Institute (AWI), jointly organized by the Polar Climate Predictability Initiative (PCPI), PPP and SIPN. It is proposed to hold further workshops on Polar Prediction in future.

Research results from YOPP will be presented at specialist meetings, including workshops held in conjunction with projects such as the Forum for Arctic Modelling and Observational Synthesis (FAMOS), International Ice Chart Working Group (IICWG) and the Horizon 2020 projects APPLICATE and Blue Action. In order to gain the widest publicity, YOPP results will also be presented at more general scientific conferences such as the International Union of Geodesy and Geophysics (IUGG), American Geophysical Union (AGU) and the European Geophysical Union (EGU). As noted above, research results will also be included in educational and outreach activities during the consolidation phase, including a YOPP Summer School.

REFERENCES

Balmaseda, M., et al., 2015: The Ocean Reanalysis Intercomparison Project (ORA-IP), *Journal of Operational Oceanography,* 8(1), s80-s97, doi: 10.1080/1755876X.2015.1022329.

Bromwich, D.H., A.B. Wilson, L. Bai, G.W.K. Moore and P. Bauer, 2016: A comparison of the regional Arctic System Reanalysis and the global ERA-Interim Reanalysis for the Arctic. *Quarterly Journal of the Royal Meteorological Society*, 142, 644-658, doi: 10.1002/qj.2527.

Bougeault, P. et al., 2010: The THORPEX Interactive Grand Global Ensemble (TIGGE). *Bulletin of the American Meteorological Society*, 91, 1059–1072, doi: 10.1175/2010BAMS2853.1.

Casati, B., T. Haiden, B. Brown, P. Nurmi and J.-F. Lemieux, 2017: Verification of Environmental Prediction in Polar Regions: Recommendations for the Year of Polar Prediction, WWRP-2017-1 report available at: http://www.polarprediction.net/fileadmin/user_upload/www.polarprediction.net/Home/Organization/Task_Teams/Verification/Casati.YOPPverif.final2017.pdf

Chevallier, M., G.C. Smith, F. Dupont, J.F. Lemieux, G. Forget, Y. Fujii et al., 2016: Intercomparison of the Arctic sea ice cover in global ocean–sea ice reanalyses from the ORA-IP project, *Climate Dynamics*, 1-30, Special Issue "Ocean Reanalyses".

Gilleland, E., D. Ahijevych, B.G. Brown and E.E. Ebert, 2010: Verifying forecasts spatially, *Bulletin of the American Meteorological Society*, 91:1365-1373, doi: 10.1175/2010BAMS2819.1

Swinbank , R., et al., 2016: The TIGGE Project and its Achievements. *Bulletin of the American Meteorological Society,* 97, 49-67, doi: 10.1175/BAMS-D-13-00191.1

Moncrieff, M.W., D.E. Waliser, M.J. Miller, M.A. Shapiro, G.R. Asrar, J. Caughey: 2012: Multiscale Convective Organization and the YOTC Virtual Field Campaign, *Bulletin of the American Meteorological Society*, 93, No 8, 1171-1187, doi: 10.1175/BAMS-D-11-00233.1.

Vitart, F., et al., 2017: The Sub-seasonal to Seasonal Prediction (S2S) Project Database. *Bulletin of the American Meteorological Society,* 98, No 1, 163-173, doi: 10.1175/BAMS-D-16-0017.1

WMO-No. 485: *Manual on the Global Data-Processing and Forecasting System*, World Meteorological Organization, Geneva, available at: http://www.wmo.int/pages/prog/www/DPFS/Manual/GDPFS-Manual.html

WMO-No. 893: *Recommendation 3 (CBS-Ext(98)), Amendments to the Manual on the Global Data-Processing System,* (WMO-No. 485), World Meteorological Organization, Geneva.

WMO-No. 1091: *Guidelines on Ensemble Prediction Systems and Forecasting*, World Meteorological Organization, Geneva, available at: http://www.wmo.int/pages/prog/www/manuals.html.

WWRP, 2013: WWRP Polar Prediction Project Science Plan, Final Version, 19 March 2013, WWRP/PPP No. 1, World Meteorological Organization, Geneva.

WWRP, 2014: WWRP Polar Prediction Project Implementation Plan, Version 1.2, 27 June 2014, WWRP/PPP No. 2, World Meteorological Organization, Geneva.

YOPP, 2016a: WWRP Polar Prediction Project Implementation Plan for the Year of Polar Prediction (YOPP), version 2.0, 31 May 2016, WWRP/PPP No. 4, Geneva.

YOPP, 2016b: YOPP Planning Meetings for Arctic Observations and the YOPP Modelling Component, 5-9 September, Reading, UK, available at: http://www.polarprediction.net/documents/reports/

YOPP, 2017: A common set of model output for YOPP, available at: http://www.polarprediction.net/documents/reports/

ANNEX I

List of Abbreviations

AFES	AGCM for the Earth Simulator
AGCM	Atmospheric General Circulation Model
AGU	American Geophysical Union
ALERA	AFES-LETKF Ensemble Reanalysis
AMPS	Antarctic Mesoscale Prediction System
APPLICATE	Advanced Prediction in Polar regions and beyond: Modelling, observing system design and LInkages associated with a Changing Arctic climate
ArCS	Arctic Challenge for Sustainability
ARCMFC	Arctic Marine Forecast Centre
AROME	Applications de la Recherche à l'Opérationnel à MésoéchellE
ARPEGE	Action de Recherche Petite Echelle Grande Echelle (model)
ASR	Arctic System Reanalysis
C3S	Copernicus Climate Change Services
CanSIPS	Canadian Seasonal to Interannual Prediction System
CAPS	Canadian Arctic Prediction System
CARRA	Copernicus Arctic Regional Reanalysis
CBHAR	Chuckchi-Beaufort High-resolution Atmospheric Reanalysis
CBS	Commission for Basic Systems (WMO)
CERA-SAT	Coupled ECMWF reanalysis (at higher resolution)
CCMEP	Canadian Centre for Meteorological and Environmental Prediction
CLIVAR	Climate and Ocean: Variability, Predictability and Change
CMEMS	Copernicus Marine Environment Monitoring Service
CNRM	Centre National de Recherches Météorologiques (France)
DMI	Danish Meteorological Institute
ECCC	Environment and Climate Change Canada
ECMWF	European Centre for Medium-range Weather Forecasts
EGU	European Geophysical Union
EPS	Ensemble Prediction System
ESRL	Earth System Research Laboratory (NOAA)
FAMOS	Forum for Arctic Modelling and Observational Synthesis
FSO	Forecast Sensitivity to Observations
GABLS	GEWEX Atmospheric Boundary Layer Study
GEWEX	Global Energy and Water Cycle Exchanges Project
GIOPS	Global Ice Ocean Prediction System
GODAE	Global Ocean Data Assimilation Experiment
GOFS	Global Ocean Forecast System
GOV	GODAE Ocean View
IABP	International Arctic Buoy Programme
ICO	International Coordination Office
IICWG	International Ice Chart Working Group

IPAB	International Programme for Antarctic Buoys
IUGG	International Union of Geodesy and Geophysics
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
LETKF	Local Ensemble Transform Kalman Filter
LRFTIP	Long-Range Forecast Transient Intercomparison Project (WGSIP)
MACSSMIZE	Measurements of Arctic Clouds, Snow and Sea Ice near the Marginal Ice ZonE
MetUM	Met Office Unified Model
MF	Météo-France
MOSAiC	The Multidisciplinary drifting Observatory for the Study of Arctic Climate
MSC	Meteorological Service of Canada
NCAR	National Center for Atmospheric Research (USA)
NERSC	Nansen Environmental and Remote Sensing Center
NOAA	National Oceanic and Atmospheric Administration (USA)
NWP	Numerical Weather Prediction
ORA-IP	Ocean Reanalyses Intercomparison Project
OSE	Observing System Experiment
OSSE	Observing System Simulation Experiment
PA-MIP	Polar Amplification Model Intercomparison Project
PDEF	Predictability, Dynamics and Ensemble Forecasting
PORA-IP	Polar Ocean Reanalysis Intercomparison Project
RASM	Regional Arctic System Model
RIOPS	Regional Ice-Ocean Prediction System
S2S	Sub-seasonal to Seasonal Prediction Project
SCM	Single Column Model
SIPN	Sea Ice Prediction Network
SIDFEx	Sea Ice Drift Forecast Experiment
SOP	Special Observing Period
THORPEX	The Observing System Research and Predictability Experiment
TIGGE	The International Grand Global Ensemble (formerly THORPEX Interactive Grand Global Ensemble)
WGSIP	Working Group on Seasonal to Interannual Prediction
WRF	Weather Research and Forecasting (model)
WMO	World Meteorological Organization
WWRP	World Weather Research Programme
YOPP	Year of Polar Prediction
YOPP-SH	YOPP Southern Hemisphere
YOTC	Year of Tropical Convection
YTMIT	Year of Tropics-Midlatitude Interactions and Teleconnections

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)

4. WWRP Polar Prediction Project Implementation Plan for the Year of Polar Prediction (YOPP) Version 2.0, (WWRP/PPP No. 4 - 2016).

5. Navigating Weather, Water, Ice and Climate Information for Safe Polar Mobilities (WWRP/PPP No. 5 - 2017).

For more information, please contact:

World Meteorological Organization

Research Department

World Weather Research Programme

7 bis, avenue de la Paix – P.O. Box 2300 – CH 1211 Geneva 2 – Switzerland

Tel.: +41 (0) 22 730 81 11 – Fax: +41 (0) 22 730 81 81

Email: cpa@wmo.int

Website: http://www.wmo.int/pages/prog/arep/wwrp/new/wwrp_new_en.html

JN 171385 | Cover photo by Kirstin Werner