Working Groups Report

ECMWF-WWRP/THORPEX Polar Prediction Workshop
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Summary

The joint ECMWF-WWRP/THORPEX workshop on polar prediction tasked three working groups to discuss polar specific issues related to (i) physical processes, observations and verification, (ii) multi-scale modelling and coupling, and (iii) data assimilation and ensembles. The working groups were also asked to produce recommendations for the WWRP Polar Prediction Project (PPP) and its Year Of Polar Prediction (YOPP) as well as suggestions for enhancements of the operational ECMWF system that are expected to improve forecast skill in polar areas and beyond.

Regarding physical processes, the correct interplay between boundary layer, cloud and surface processes was highlighted as being 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. To date the main problem areas are: the representation of stable boundary layers and their interaction with stratiform clouds and snow covered surfaces; the role of moisture advection and turbulence in cloud formation given very low CCN concentrations; the speed of hydrometeor phase transitions in mixed phase clouds; and the role of rather heterogeneous sea-ice states through the seasons (thickness, leads, melting ponds, snow on ice) as the lower boundary mediating the fluxes at the interface.

The working groups strongly suggest studying these processes in a concerted way and in communication with existing groups like GASS to enable improvement of parametrisations. They recommend revisiting the wealth of information from existing field campaigns such as SHEBA, and also to define observational requirements for planned activities like MOSAiC that will be aligned with YOPP. 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.

Snow is currently only crudely represented in global NWP models but the working groups state that existing multi-layer snow models can already produce a significant step towards improved atmosphere-surface coupling, particularly through melting and freezing conditions, as well as in the presence of vegetation, trees and snow on top of sea-ice.

Unanimously, all groups recommend investing in the coupled modelling of sea-ice, ocean (waves) and the atmosphere, also for short and medium range applications. For sea-ice, types, concentration and thickness need to be included and the interaction with ocean currents and waves, snow and the lower atmosphere are critical for the accurate description of ice evolution. This will need much enhanced observational capabilities of ice mass balance over large areas. Again, campaigns like MOSAiC are expected to be of fundamental importance here.

More explicit modelling of both snow and sea-ice requires initialization through data assimilation. There is much less experience with this at global scales and with

relevance to medium and extended range than in atmospheric data assimilation. The lack of consistent observational networks and the difficulty to define sea-ice model errors imposes a significant risk on coupled data assimilation, but pragmatic solutions through weak coupling may be an option.

A specific recommendation for ECMWF was to aim for an experimental version of a coupled atmosphere/ocean/sea-ice modelling analysis and forecasting system 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.

It was highlighted that there are a number of mechanisms driving teleconnections between polar and lower latitude areas that depend on sea-ice/ocean state, troposphere-stratosphere interaction, the poleward advection of heat, momentum and moisture by synoptic weather patterns and regime dependent (e.g. AO) large-scale connectivity. The working groups concluded that this topic poses the need for a dedicated research theme under PPP in collaboration with PCPI.

The working groups also concluded that atmospheric data assimilation in polar regions 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.

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.

Observations play a crucial role for both verification and data assimilation. The sparseness of routine observing stations in polar areas is evident and their coverage is not representative of the conditions over large parts of the Arctic sea ice or the Antarctic continent. Observations of opportunity onboard the increasing shipping fleet along ice-free passages and aircrafts supplying permanent stations should be exploited PPP is encouraged to initiate this by approaching, e.g., EUMETNET and EUCOS.

Again, detailed sea-ice observations (mostly concentration, thickness and density; snow on ice) have been requested by all working groups. Some of these can be provided from satellites by active and, within limitations, passive remote sensing. Here, PPP has a clear role in defining observational requirements to be communicated to space agencies for future mission design, but also specific requirements for existing observations during YOPP. This will also benefit space agencies through enhanced Cal/Val support.

PPP also has a role in fostering education and the working groups encouraged workshops dedicated to sub-topics of the above list of themes as well as training courses aimed at early-career scientists.

Working group 1: Physical Processes, Observation, Verification

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1 Current “gaps” in the understanding of polar physical process

Polar regions are often considered drivers for climate and climate change and this tends to motivate advances in understanding of physical processes in cold regions. However, this can often lead to a focus on timescales that are characteristic of seasonal to decadal prediction. The Polar Prediction Project of WWRP and the ECMWF-WWRP/THORPEX workshop offer the opportunity to focus on shorter timescales (the medium-range) and identify areas in which observations and modelling efforts can trigger “game-changing” advances. Problems tend to be in analysis as well in forecasts so accurate representation of physical processes is crucial.

1.1 Mixed-phase cloud

Microphysics versus moisture advection: The description of liquid water below the freezing temperature (often referred to as super-cooled liquid water), moisture advection and vertical redistribution mechanisms are often poorly represented in NWP models with parameterizations that are both qualitatively and quantitatively unsatisfactory. From a modelling perspective the WG recognizes that this is a coupled and 3-dimensional problem that therefore need to be addressed with appropriate experimental design and involving dedicated observational campaigns. Moisture advected into the polar regions aloft seems vital to cloud formation processes and knowledge on model capacity to bring appropriate amounts of moisture at middle troposphere layer is still missing. Re-analyses such as ERA-Interim (ERA-SAT in near-future) may provide verification material to diagnose moisture flow errors. Large-scale models are ultimately aiming at reproducing broadly the amount of moisture advection with some level of realism of the microphysics, while process-based models can consider higher complexity schemes.

Hydrometeor phase conversion speed: An analysis of the AR4/CMIP5 models indicated that the speed of phase transition is generally too efficient in climate models and it happens on slower and longer time-scale in reality (persistence of cloud decks). The WG discussed whether this can be parameterized in NWP models that have notorious issues with resolving shallow cloud layers. Ad-hoc mass flux schemes are also not adapted to vertical decoupling of liquid and ice contents. The cloud formation cycle (and the speed of transition from hydrometeors) show links with CMIP5 model biases in temperature. A too fast transition does not get the observed persistence in clouds and the timing of phase transition. Stratocumulus cloud representation in models is very much linked to the capacity of sustaining slow transitions. Mixed-phase changes in stratocumulus clouds are shown to have impact on storm-track on both hemispheres.

Super-cooled liquid water: This strongly affects atmospheric radiative transfer particularly in the long-wave spectrum, which remains an active process throughout the year and also during polar nights. The contribution of sub-grid processes such as cloud-top radiative cooling and mixing within clouds, which leads to gradual phase transitions from liquid to ice, require the interplay of atmospheric physical parameterization sustained by moisture inflow.

The coupling of parameterizations of the planetary boundary layer, the formation of clouds (interacting with aerosols and Clouds Condensation Nuclei and Ice Nuclei, CCN/IN), and the occurrence of convection, is still neither qualitatively nor quantitatively satisfactorily represented in present NWP and Climate models.

The WG discussed the possibility to evaluate the representation of mixed-phase clouds in NWP and climate models using observational knowledge readily available, as for instance the SHEBA field campaign over sea-ice or ice-sheet based observatories such as Dome-Concordia or South Pole. Advances could be equally triggered by a further exploitation of A-Train Calipso/Cloudsat satellite datasets to quantify super-cooled liquid water occurrence and to further inform on mixed-phase processes and hydrometeors transition.

Substantial research is still needed to understand polar cloud processes. For instance a Calipso-based classification of optically thin clouds already indicates that about 30% of the time CCN concentrations (30-40 m above surface) are below the values normally expected for clouds. Cloud condensation processes are also important and have been shown to impact surface albedo via frost deposition generating a pristine snow-like layer.

Large Eddy Simulations (LES) linked with sufficiently realistic surface parameterizations are advocated as a way forward for enhanced process understanding. However, a practical and affordable approach to an incremental improvement of NWP and climate models may already be provided by appropriate CCN climatologies (e.g. from the MACC reanalysis, with improved source description) that are validated by field observations. This would avoid the complexity of fully interactive aerosols modelling and data assimilation.

Aerosol-cloud interactions are a target for the broader scientific community and represent a scientific challenge that LES could help to tackle at the process understanding level. A stronger involvement of large-scale modellers in LES research may be beneficial for ensuring research uptake for the benefit of NWP.

1.2 Stable boundary layer

The realistic representation of wintertime inversions in a stably stratified atmosphere in NWP models is often limited by the parameterization of atmospheric vertical diffusion and surface coupling. Vertical diffusion is generally too strong but reduces near-surface temperature errors at the expense of realistic vertical moisture, energy and momentum transport.

The stable planetary boundary layer (PBL) and energy dissipation and partitioning processes are not yet sufficiently covered by research efforts and new initiatives from the Global Atmospheric System Studies (GASS) panel will be focusing on Antarctica sites using Single Column Models (SCMs). The links of PPP with GASS is identified as being important although, at present, the planned experiments are mainly one-dimensional and only consider cloud-free scenarios in which SCMs have fewer issues in simulating vertical profiles. Other PBL modelling comparison efforts are performed at Env. Canada (ref. Ayrton Zadra) but were not covered in the present workshop.

The capacity of models to simulated strong atmospheric inversions is not disjoint from the coupling with the surface and the capacity of land surface and sea-ice schemes to reproduce vertical heat diffusion in the snow/ice/(soil) medium.

At the interface of land-atmosphere or ocean-atmosphere continuum, vertical diffusion processes (in both the PBL and within the surface) are often enhanced to compensate other model errors and this may also prevent predictability gain coming from slowly evolving surface fields.

1.3 Surface heterogeneity and sea-ice coupling

A more accurate treatment of the snow-pack on land, sea-ice and ice-sheets is mentioned as a development necessary for both NWP and climate models. Recent advances in parameterizations offer a range of choices of medium complexity including a 3-6 vertical-layer discretization in the snow-pack to handle different timescales associated with snow deposition, metamorphosis and melting processes and the coupling with underlying soil/ice.

Surface exchange for latent, sensible, and momentum fluxes for both land-atmosphere and sea-ice-ocean-atmosphere requires accurate representation as they are characterized by spatial heterogeneity. Over land, heterogeneity is linked to snow condition and to sub-grid snow drifting and sublimation processes, but very often it is also linked to the land-cover classification maps and their capacity of describing the actual vegetation cover and land-use type and surface roughness conditions. While the broad distinction of snow underneath forest and snow overlaying grasslands is currently present in several models, accurate fractional snow cover parameterizations and snow schemes able to predict the spectral albedo components are still missing, at least in operational NWP models.

Over sea-ice, heterogeneity is associated with the presence of leads, sea-ice melting ponds, rough ice next to smooth ice, that are all relevant surface characteristics for NWP modelling. Next to the coastlines of Greenland and Scandinavia and throughout the polar circle, as well as in Antarctica the impact of orographic complexity on wind and the effect of wind acceleration on ocean circulation and sea-ice concentration is ascribed to orographically induced effects, and generally require high-resolution models running at kilometric scales.

Interaction of sea-ice cover, snow cover, with atmospheric circulation is recognized in several recent publications. The WG commented on this topic being of high relevance to PPP/PCPI and it could be further covered as a joint topic in a polar teleconnection workshop not sufficiently represented in the current workshop (e.g. the work of Cohen et al., Peings et al., Orsolini et al. on snow—atmosphere teleconnections).

The WG acknowledges that diagnosing what is "wrong" in NWP models with respect to teleconnections is generally easier than figuring out ways forward to improve parameterisations, and this gets reflected in the poor predictability of anomalous winters and early spring situations, particularly evident over Europe in recent times.

2 Observations in Arctic and Antarctic

Polar observations are at the heart of modelling and data assimilation advances and therefore great efforts are invested in data mining and data exploitation at WMO-level both in WWRP and in data related projects such as the Global Cryosphere Watch and the Global Atmospheric Watch (GCW and GAW). PPP can actively support new observational campaigns being proposed for YOPP. It is acknowledged that the GCW programme of WMO is already active in setting up a CryoNet observing network for cold regions (the poles, Alps, Rockies, Andes, Tibet, etc.; http://igos-cryosphere.org/docs/cryos_theme_report.pdf)

A wide range of observational platforms offer potential given the difficulties of observing physical processes in-situ in Arctic and Antarctic environments.

2.1 Field campaigns

Three past field campaigns for the Arctic have been identified and discussed in the WG:

- SHEBA (Surface HEat Budget of the Arctic ocean study described at 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).
- ASCOS (Arctic Summer Clouds Ocean Study, described at www.ascos.se/) aiming at studying physical and chemical processes leading to cloud formation.
- 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.

In the future the MOSAiC (Multidisciplinary drifting Observatory for Studies of Arctic Climate, described at www.mosaicobservatory.org/) campaign will be focusing on the process-level understanding of the Arctic atmosphere-sea-ice-ocean system with a field campaign extending through 2017-2018 (with overlap of YOPP period proposed by PPP).

A relevant field campaigns identified for the Antarctic during the WG discussion is the Ice Station Weddell (ISW; Gordon, A. L., and Ice Station Weddell Group of Principal Investigators and Chief Scientists (1993), Weddell Sea exploration from ice station, Eos Trans. AGU, 74(11), 121–126, doi:10.1029/93EO00260.)

2.2 Supersites and observatories

The concept of "super-sites" or observatories is establishing in several region for the purpose of environmental monitoring (sites like Cabauw in the Netherlands or Lindenberg in Germany are collecting a variety of synergistic observations of the energy and water cycle, including atmospheric constituents and surface variables). These sites are gathering high-quality observations supporting process and modelling studies.

In polar regions sites like these are rare: 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: www.sios-svalbard.org/), which is seen as a contribution to the integrated Arctic observing system.

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

2.3 Aircraft campaigns, RPAS (UAVs), balloons, drop-sondes:

Several examples of relevant aircraft campaigns can be found (e.g. GFDEx, the Greenland Flow Distortion Experiment), which are considered complementary to ground-based network or station based field campaigns.

Cheaper observing options might be the re-usable vertical sounding capabilities (UAVs, up to 5 km sounding, with several probing options). Airborne infrared cameras may also be very useful for surface heterogeneity studies.

Possibilities exist to establish plans and to propose a comprehensive coordinated set of aircraft experiment campaigns, possibly in conjunction with MOSAiC field activities and YOPP. NASA recently announced a call for proposals which includes the second solicitation for the Earth Venture Class sub-orbital activities (See:

http://nspires.nasaprs.com/external/solicitations/). This call requests expressions of interest by 8 November 2013 and would require a full proposal by 10 January 2014.

PPP could aim at coordinating with space agencies and national research facilities for aircraft field campaign efforts within the YOPP period. The space agencies have requested that consolidated, scientifically-justified consensus observational requirements be established as a basis for further discussion within the context of the Polar Space Task Group (PSTG, see: www.wmo.int/pages/prog/sat/pstg_en.php).

2.4 Ships

Commercial routes going via the north-east Arctic passage could be enhanced via the EUMETNET Automated Shipboard Aerological Programme (E-ASAP), which is an integrated component of the EUCOS Operational Programme for observations. PPP could investigate possibilities for an enhancement of Arctic/Antarctic E-ASAP ship observations. (see: www.eucos.net/nn_133388/EN/Home/networks/easap/easap__node.html?__nnn=true).

Ocean observations were not well covered by this WG although they are acknowledged to be a highly relevant topic for supporting sea-ice predictive skill studies. A few questions were put forward to other WGs. ARGO-Floats and Gliders, as used in the Ocean Data Assimilation Systems are also relevant for process-understanding.

2.5 Polar orbiting satellites

The satellites CryoSat-2, SMOS, MetOp, Sentinel-3 and GNSS-RO constellations have all been mentioned to provide crucial observations over the polar regions (presentation by Mark Drinkwater, ESA). The endangered future missions (largely funding related) are the COSMIC-2 high inclination (phase 2) component, while the CryoSat observing capability for ice thickness will only be available until the end of satellite's lifetime. Sentinel-3 (82° North limited) will have the SRAL sensor that has CryoSat-like altimetry capability. Icesat-2 is planned for launch in 2018 but the risk of no all-weather altimeter data in the central Arctic is high. SMOS can provide useful complementary sea-ice information thanks to the L-band capability for penetrating thin sea-ice and snow (up to 0.5 m depth).

Space agency (up to 15 agencies) involvement during IPY was able to enhance observing capabilities (e.g. multi-satellite AMV capability and retransmission happened thanks to IPY involvement of Space Agencies).

The NRL forecast sensitivity to observation diagnostics (FSO, see Florence Rabier's presentation) showed a very encouraging contribution from AMVs in the analysis. IASI over Antarctica has shown added value but the data is probably still very much under-utilized. NPP sounding capabilities are too.

Satellite data from Cloudsat and Calipso and, in the future, EarthCARE will support model development (e.g. microphysics development by Forbes et al. in ECMWF model provided an example for Cloudsat/Calipso benefit). The FSO diagnostic tool was mentioned to be a fundamental planning support for space agencies.

YOPP special needs can be put forward for instance to ESA (e.g. generation of special products, aircraft coordinated instrumentation, in conjunction to satellite Cal-Val also with funding). ESA-NASA bilateral can host discussions due to ongoing active collaboration for CryoSat Cal/Val via joint CryoVEx and IceBridge airborne activities (NASA science contact, Ken Jezek).

In the future, the EPS Second Generation (SG) series offers some new complementary measurements from its Multifrequency Microwave Imager (MWI) and Ice Cloud Imager (ICI), as well as new a generation Radio Occultation (RO) instruments and sounders (microwave and infrared). Additionally the ATOMMS (Active Temperature Ozone, Moisture Microwave Spectrometer) planned mission concept will be aiming to extend conventional GPS-RO capabilities by probing water and ozone actively along GPS-RO trajectory. This enables observing temperature (0.4 K accuracy), pressure height (10 m accuracy) WV (1-3% accuracy) with 100-200m vertical resolutions, with a surface insensitive remote sensing technique offering a unique radiosonde-like profiling from orbit (including information on atmospheric stability), and down to surface (better than current AIRS capability).

3 Verification techniques for Polar Regions

Polar verification and validation of models is undoubtedly a complex task due to (i) observation quality and quantity issues, (ii) gaps in space and time and sensor capabilities, (iii) large discrepancies between analyses and observations.

PPP could promote polar verification via a dedicated workshop or theme, and link with existing initiatives on data collection efforts for polar regions aiming at a connections database, consistency-policy, etc.

The acquisition of routine verification observations in polar region is still a shortcoming. One may distinguish the verification into routine verification and model (or retrieval) validation:

3.1 Routine verification

Routine verification for polar regions could make use of observations such as pre-processed radiances that were not used in the data assimilation system. This may be especially valuable for stratospheric verification that is not very well supported by conventional observations. There is potential to further explore verification in observation space for the medium-range (day-3 to day-5). Polar orbiting atmospheric sensors (IASI, AIRS) are important sources for this.

The use of AMVs (especially the enhanced product from multi-satellite composites) could also be considered routinely.

Snow verification (FC-SYNOP depths) was also discussed as an area of routine verification in which the SYNOP daily observations can be complemented by national networks.

Precipitation radar data such as from the station in Barrow (Alaska) could be employed for routine verification.

3.2 Model/retrieval validation

Surface energy balance sensing and ground based remote sensing of clouds (eg. vertically pointing radars/lidars/sodars) can provide local validation for model or satellite retrievals.

Sub grid-scale heat flux variability is important for both the atmosphere PBL evolution and the ocean (mixed layer). Thus high-resolution datasets (satellite-based, and at km-scale from e.g. MODIS) are needed to support heterogeneity characterisation in models.

4 Recommendations

4.1 High priority

- 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.
- Pursue an integrated approach so that cloud, PBL and surface exchange schemes "work well together" preserving process relationships as diagnosed from observations. We recommend testing with LES. Also implementing parameterizations addressing known issues is proposed (e.g. a prognostic mixed-phase cloud scheme).
- 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.
- Test improved sea-ice - surface exchange parameterisations (a number of new schemes are now available). Elements of interest in these new schemes are adding a snow layer on top of sea ice, include ice roughness classes and sub-grid processes such as leads, ponds.
- Ships going via North-East Passage (and others in future) could provide observation-enhanced capacity at reduced cost. Action for PPP to connect to EUCOS (E-ASAP programme for radiosondes) for exploring possibility of an enhanced ship observation facility and transmission of the data onto the GTS.
- Engage with marine science community regarding observing systems: ARGO, Sea-mammal-tags, gliders, etc.

4.2 Medium priority

- Work towards a more realistic representation of vertical diffusion, e.g. for stable boundary layers. It is acknowledged that this has a connection to large-scale circulation and also that this is a long standing issue (see 2011 ECMWF-GABLS Workshop).
- Engage in coordinated intercomparison activities to analyse model shortcomings regarding energy partitioning and phase transitioning (persistence of clouds, mixed-phase, wave dissipation).

- Identify existing "supersites" for process understanding studies both in Arctic and Antarctic (also initiate discussion on instrumentation available at those sites, with GCW-WMO initiatives such as CryoNet).
- Arctic teleconnections and sensitivity to sea-ice/snow-cover and these topics are probably not sufficiently well represented here (Cohen et al. 2012 and Orsolini et al. 2013 work) but there is substantial work surfacing in the literature and a workshop dedicated to high-latitude teleconnection would be recommended on a 1-2 year timescale, cosponsored by WWRP/WCRP. PPP to contact IASC working group and investigate if the ICARP-3 Conference in Japan in 2015 may offer the right venue to host such a topic.
- YOPP satellite Cal/Val and IOP coordination activities are recommended for an avenue of collaboration and a new platform at PPP-level as there will be more opportunities for (a) funding, (b) involvement of the broader science community (these 2 components not necessarily being correlated), (c) use of several observation facilities available also at universities and national research centres.
- PPP should provide a statement of support for the maintenance of the existing satellite network and consider special requirements for YOPP. PPP to endorse preparations for a full exploitation of new EPS-SG instrument capability (e.g. ICI), as well as expressing support for new satellite mission concepts targeting polar regions (e.g. CoReH2O, ATOMMS).
- Encourage existing field campaigns (e.g. Marginal Ice Zone experiment, AODS) to place observations onto GTS and help facilitate the procedure for data submission).
- Better engagement with the Antarctic science community (BAS, LGGE, etc.).

5 Other items discussed

- IASI provides opportunity for better soundings (channels underutilised) but lack of resources preventing this (see WG-3).
- A North Pole initiative that could mirror the interdisciplinary aspects of other initiative (e.g. ConcordIASI, using drop-sondes, ice-based instrumentation, and satellite radiances) so that retrieval techniques for ice-snow-atmosphere observation operator improvements in data assimilation. The YOPP period is the target for planning a campaign (2017) that may include this multi-platform observing facility for the Arctic.
- "Secondary" processes (sea-ice rheology related) are target for science community to reach better understanding?
- Horizon 2020 directions (ECRA, WWRP-link): Are there going to be polar dedicated research efforts? Can PPP encourage suitable calls?
- Discussions on resolution left some open questions:
    - Is 10 km adequate for representing meso-scale features relevant for polar predictability?

- Is a resolution of 1-5 km necessary for representation of complex orography-coast interaction?
- The question of how much resolution is required for certain processes will also change if physical parameterizations are changed. So the 'balance' between resolution and computational expense needs careful monitoring as other issues are addressed.
- NWP research is most likely going to focus on the 5-10 km "grey" zone. Is this compatible with PPP expectations?
- Are coupled ocean-atmosphere models going to explore "Eddy-resolving" vs "eddy-permitting" oceans (1/10 degree or ¼ degree) contributions?

Working Group 2: Multi-scale modelling and coupling

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1 Overview

Our group thought that the main modelling areas that were currently holding us back in terms of capturing processes in the polar regions were mixed phase stratiform clouds and sea ice modelling (e.g. representation of melt ponds, ridging and rafting etc.). There was consensus that we need coupled models for prediction on the medium-range time scale in this region.

2 Identification of "Game-changing" developments

There were two elements to what could be considered game changing in terms of model development. One is incorporating well developed models of sea ice into the medium-range prediction system to allow us to: predict sea ice evolution (leads, edge, surface conditions, snow cover) for our forecast users; and improve predictions of the coupled system in the polar regions and potentially the mid-latitudes as well. The second element is the improvement of the model to represent processes that are important for the polar region; the most important of these being identified as mixed-phase stratiform clouds.

One of the essential elements for improving our prediction system is to have a coupled atmosphere-ocean-ice-land model that has a consistent treatment of the interface between these components. That is to say that the fluxes should be conservative between the components.

Other necessary elements of the Earth's system to capture well are: the polar oceans and in particular the shelf seas and the polar water mass circulation; snow on land (including vegetation interaction); lakes; sea ice including snow cover on sea ice; and mesoscale atmospheric features (such as polar lows).

The group noted that we do not have a complete picture of the requirements of forecast-users in polar regions in both terms of time and space scales. Users do require information on a range of timescales; on a lead time of days for shipping to weeks for ports and disaster management. There are increasing numbers of requests by hydrocarbon industries to have probabilistic estimates of ice-free and freeze up dates on seasonal lead times.

3 General Modelling and ensemble issues

One of the main modelling issues is the minimum model requirements needed to represent the critical processes for the polar region. Our group considered for polar prediction the minimum model requirements for each element of the Earth's system are:

- Atmospheric vertical resolution for clouds (50 m at the top of the boundary layer) with a model top above the stratosphere.
- ¼° ocean model with multi-category sea-ice model (with snow on the ice).
- Land snow model having at least 4-5 layers with a good soil model beneath; 10 soil levels (20 m deep) with no constraint on bottom boundary temperature.

Going to higher resolution may help resolve processes that are important for prediction in polar regions, but how much improvement could be gained is uncertain and we recommend that this is something that should be investigated by operational centres. Another question that needs to be addressed is how well our current models work at higher resolution, for example we may need to move to non-hydrostatic/cloud resolving/new sea ice rheology.

More could be done to validate models using data that already exists from previous observational campaigns and we suggest that model intercomparison studies should be carried out using past observational campaigns (SHEBA, ConcordIASI). Areas in particular that should be focused on are surface fluxes, cloud characteristics and mesoscale features. We recognise the importance of making sure that the correct model output is archived/generated when carrying out experiments to diagnose sources of model error e.g. model tendencies (on model levels). Using SHEBA data may help to identify parameters.

There are several experiments which could be run to assess: limits of predictability, especially for sea ice; model performance and diagnose which areas should be prioritised for development.

Sea ice modelling studies also require further development of assimilation methods for sea ice, so that they use available thickness observations, and treat the known concentration observation errors consistently. Experiments are needed to test the impacts of initial sea ice thickness on the prediction of sea ice itself and the associated atmospheric and oceanic fields. In addition, coordinated experiments among centres/institutions with the same initial conditions of sea ice thickness will help understand the uncertainties due to the differences in model physics. Initial investigations looking at potential predictability are underway with the APPOSITE project on seasonal to interannual timescales, but there is still much more to be on the weather prediction timescale.

Atmospheric modelling studies that could be done to identify polar boundary layer weaknesses are relaxation experiments and investigations of the behaviour of the polar boundary layer behaviour across the full range of polar stabilities/instabilities, including abrupt stability transitions. The coupling between low-level stratiform clouds and the boundary layer is another important topic to address.

The group also noted the need to develop verification methods for variables with non-Gaussian error characteristics such as sea ice and perform multivariate analysis of model error and also develop metrics to assess the strength of feedbacks in coupled system.

4 Observations and YOPP

The group noted the importance of continuous measurements for initialisation of prediction systems as well as campaigns for parameterization/calibration and verification of modelled processes. Some data sets may be improved by other observations, for example, sea ice thickness estimates from satellite measurements of sea ice freeboard have to make assumptions about the snow cover on the sea ice. The group noted that closer coordination between data providers and modellers is desirable to increase the understanding of data user requirements and provision of data sets that are in a format to allow ease of comparison between models and observations. The following observations were considered important/essential for model development and prediction of the polar region:

- Sea ice thickness,
- Snow on sea ice (depth, grain size, density, moisture) and snowfall,
- Blowing snow,
- Boundary layer winds, temperatures, and moisture amounts,
- Cloud depth and phase along with aerosol characteristics,
- Turbulent fluxes,
- Ice mass balance buoys,
- In situ ocean data profiles (e.g. ice tethered profilers, gliders…).

In preparation for YOPP and future modelling studies the following suggestions were made for ERA-SAT archived fields:

- Snow soil heat flux,
- Diabatic heating rates,
- Output frequency for surface fields (hourly) – turbulent fluxes,
- Tools for easy monitoring of assimilated data,
- Tile information from surface scheme,
- Vertically integrated horizontal fluxes (latent, sensible),
- Instantaneous and accumulated surface fluxes (hourly).

Specific Recommendations for YOPP would be to facilitate a post-reanalysis project, which would be high resolution for the observational period and identify model developments that are needed.

The group also noted the importance of operational centres' engagement with the research community, through sharing data sets and computing time, and running dedicated model experiments for observational campaigns.

5 Suggestions for summer school/workshop topics

- Coupled environmental prediction for polar regions.
- Specialised workshops on particular aspects e.g. mixed-phase clouds, meso-scale features, polar boundary layers.
- Summer school and/or workshop on sea ice prediction and user needs (involve operational centres).
- Workshop: Exploring the limits of resolution of sea ice models and the coupling interface.

6 Recommendations to ECMWF

- Multicategory sea ice with ¼° ocean model.
- Sea ice thickness initialisation.
- Multilayer snow models.
- Coupled assimilation/reanalysis system.

Working group 3: Data assimilation and ensembles

Chair: Florence Rabier (CNRM-GAME)

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1 Identification of "Game-changing" developments

The working group identified the importance of including sea-ice and ocean data assimilation for NWP and the inclusion of a sea-ice model in the forecasting system as crucial for simulating the processes and variability in polar areas. Ideally, the assimilation of all components (atmosphere, ocean, sea-ice, snow) should take place in a coupled data assimilation framework. One alternative here (already on-going research at ECMWF) is to use a weakly coupled system where all components use individual data assimilation (DA) but share the non-linear trajectories. The system should be run in ensemble mode to simulate the uncertainties in all components. Another alternative (following the ideas developed in particular at Env. Canada) is to use an Ensemble Kalman Filter to generate the covariances between the components. A viable target for the system development is to have a prototype to test during YOPP.

To quantify the quality of the variances obtained by ensemble data assimilation (both EDA and EnKF) more ensemble based diagnostics is needed, especially in the boundary layer. Here the group recognised that the forecasts have to be verified against observations but several difficulties are present. The number of permanent observations in the polar area is limited and quantifying the representativeness error is critical to draw any conclusions from the ensemble variance.

The simulation of model uncertainties (e.g. SPPT used at ECMWF), should be extended to the boundary layer. Today the SPPT perturbations are set to zero for the lowest 300 metres in the atmosphere and have full amplitude above 1300 metres. To include the boundary layer is especially important for the Arctic.

Initial perturbations should be included for all components in the prediction system. At ECMWF the ocean is already perturbed and the land surface is going to be perturbed in the end of 2013. The group recommend that the sea-ice cover should also be perturbed. Ultimately, these perturbations will be generated by a coupled ensemble data assimilation system (see above). However, before such a system is operational, an interim solution may be needed.

2 General data assimilation (DA) and ensemble issues

The "ring of uncertainties" (50°-70° South), was discussed in the group. There are suspicions that current DA schemes do not work optimally in this region (both regarding the observation usage and the background error formulation) and this will affect the predictability over the Antarctic. The same issues should then be present in the Arctic basin to some degree. Work that could be undertaken to diagnose the performance of DA schemes in these regions is to diagnose the impact of the B-matrix with regard to recent changes at ECMWF.

The benefit of an enhanced description of the microwave emissivity at cold temperatures (cold open water and sea-ice) could be documented (already on-going at ECMWF and Météo-France) and hopefully it could lead to an enhanced use of the data. The question whether the radiance data is sub-optimally used for southern hemisphere needs to be addressed. To better understand the impact of specific data, data denial experiments can be run in ensemble data assimilation mode.

If the DA system is optimally tuned (observation and model errors), the increase in the ensemble variance should match the degradation of the analysis. In particular, one should take special care of the use of hyperspectral sounder data in these areas, as they potentially have the possibility to describe fine structures in the vertical. It is likely that with the future use of more channels or of a large number of principal components, the lower atmospheric levels could be adequately described (although clouds are an issue).

The performance of DA and ensemble systems can be further evaluated with data from the TIGGE archive, both for the analyses and forecasts. However, this relies on a continuation of the TIGGE project, which the working group supports. The analyses in the TIGGE archive can also be used to run the model from an external analysis, as has been used as a diagnostic tool at ECMWF in the past to disentangle analysis and model errors.

The under-utilisation of observations when large departures are present (e.g. during sudden stratospheric warmings) needs to be investigated. The working group discussed whether alternative approaches to scaling the spread in EDA to capture such a sudden events, or at least prevent rejection of a correct observations could be beneficial.

The discussion in the group also touched issues around steep orography. Here a fully flow-dependent B-matrix is needed (instead of a hybrid B-matrix) at a high resolution in the model.

The lack of observations in polar areas is also an issue for verification, which is especially true for extreme weather such as polar lows and low-level jets that need a high resolution network to be captured. For ensemble forecasts the lack of observations in the lower troposphere makes the evaluation of the reliability (e.g. spread-error relationship) difficult.

The representativeness of the observations is an issue in polar regions with the presence of steep orography, land-sea contrasts and snow cover. Both for DA and verification, site-dependent errors could be considered and also the flow-dependent characterisation of the errors is needed. The representativeness issue (including sub-grid variability) is especially a problem when verifying the spread-error relationship for ensemble forecasts. The ensemble system is only expected to simulate uncertainties on scales larger than the grid scale; therefore the ensemble system will look under-dispersive in presence of large sub-grid variability.

3 Observations and YOPP

Variances from the EDA could be used to highlight areas of high uncertainties in the analysis and for suggesting sites suited for deployment of long-term observations (YOPP). For YOPP detailed observations for estimating model process uncertainty are of interest (such as in-situ measurements of the spatial variability of ice thickness). There is also a need of observations of the ocean state under the ice sheet.

Further evaluation of retrieval/assimilation of satellite ice-thickness observations from Cryosat and SMOS can be undertaken and also a combination of the information from both satellites.

One should try to use more GPS-RO observations close to the surface and the WG also found the concept of the ATOMMS project interesting. In terms of winds, there are some interesting developments such as the LEO-GEO and tandem wind products developed, respectively, at CIMSS (Madison) and EUMETSAT. Also the potential use of active observations (Calipso, Cloudsat, EarthCARE) for mixed-phase clouds should be exploited.

The possibility to increase the number of aircraft measurements over the polar areas should be investigated. It was pointed out during the assembly session that one source could be the aircrafts supplying research bases in the Antarctic or specific airlines crossing the Arctic.

The exchange of snow depth data on the GTS should be encouraged. An initiative is ongoing within the Snow-Watch component of the WMO Global Cryospheric Watch programme. In particular ECMWF developed a BUFR template for national snow depth measurements. The objective of this initiative is to encourage WMO member states to use this template to improve their snow depth data availability to the NWP community.

4 Suggestion of topic for summer school

- Coupled data assimilation with emphasis on the cryosphere.