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A WWRP, THORPEX, WCRP Workshop
“Improvement of Weather and Environmental Prediction in Polar Regions”
(6 to 8 October 2010, Oslo, Norway)

Outcome of the Workshop
FINAL

1. Background to the Workshop

The International Polar Year (IPY) was a great leap forward which contributed to the enhancement of the observational network, a better understanding of physical processes, and improvements in the use of observations, modelling, and prediction in Polar Regions.

The positive impact of Numerical Weather Prediction (NWP) and Environmental Prediction (EP) on health, safety, and economic competitiveness is recognized worldwide. The benefit of NWP/EP applications in Polar Regions has been somewhat delayed due to the higher priority of forecasting in the more densely populated mid-latitude and tropical regions. Concerns about an amplification of anthropogenic climate change at higher latitudes combined with an increasing interest of many governments throughout the Polar Regions requires a better understanding of weather and environmental processes in Polar Regions in order to improve our ability to make reliable, quantitative predictions up to a season ahead.

Consequently, at its 15th session (November 2009), the WMO Commission of Atmospheric Sciences (CAS) recommended, as a legacy of the International Polar Year (IPY), the establishment of a THORPEX Polar Research project to improve understanding of the impact of polar processes on polar weather, the assimilation of data in Polar Regions, and the prediction of high impact weather over Polar Regions.

In developing this recommendation the CAS acknowledged that important steps forward in the polar analysis and prediction had resulted from

- the success of the THORPEX IPY Cluster Project
- the success of the JCOM IPY Ice Logistics Portal
- the European GMES Marine Core service and its polar prediction and sea-ice information provision services
- the scientific and operational advances in satellite data assimilation.

The CAS recognized that the research outcomes of these efforts would provide valuable input to the programme of work for such a legacy project.

During its deliberations, the CAS noted that the Executive Council Panel of Experts on Polar Observations, Research, and Services (EC-PORS) decided that the design and development of polar prediction systems is an important task that will require effective collaboration across the relevant WMO Technical Commissions along with other partners as appropriate and recommended that efforts be made to further polar prediction for weather and climate and to extend efforts to snow, ice, carbon, and ecosystem modelling and analysis. This would also require the involvement of the World Weather Research Programme (WWRP), including THORPEX, the Global Atmospheric Watch (GAW), and the World Climate Research Programme (WCRP) and support from WMO Members.

Finally, the CAS concurred with the EC-PORS on the requirement for effective collaboration and therefore recommended that any efforts to develop a future prediction system include outcomes from the IPY-THORPEX cluster of projects and from the planned THORPEX legacy project.

2. The Outcome of the Workshop

The Workshop Agenda may be found in Annex I. The outcome of this workshop was the establishment of a basis for an IPY legacy project which is intended to provide a framework for cooperative international research and development efforts to improve high impact weather, climate, and environmental prediction capabilities for the Polar Regions. Three forecast prediction ranges are of interest:

- short-term regional forecasts (one hour to 48 hours);
- medium-range forecasts (one day to two weeks);
- sub-seasonal to one season forecasts.

However, it was clear from the workshop discussions on “gaps” that many of the problems are common to all prediction systems whatever the range – notably, problems with the parameterization of atmospheric, oceanic, and land-surface physical processes.

Improving Polar Predictions – General Recommendations

Verification

The potential for verification and assessment activities in Polar Regions were reviewed. Objective verification of coupled forecast systems poses many challenges in the Polar Regions due to the sparse availability of in situ data, where satellite imagery from polar-orbiting satellites becomes particularly important as compared to geostationary satellites. The verification of sea-ice and coastal forecasting will be a challenge. Thus verification using remote sensing is a critical research area for Polar Regions. It was recommended that:

- formal inter-comparison of polar predictions (pole-wards of 60^o N and 60^o S) using the existing WMO procedures and, if necessary, the adoption of new metrics for these comparisons need to be initiated;
- strengthening of verification activity utilizing operational and research data bases such as the TIGGE data bases is needed.

Data Assimilation and Observation

Existing and new satellite instruments (high spectral resolution sounders such as the AIRS and IASI, EOS instruments) or space missions such as the Canadian Polar Communication and Weather (PCW) mission can provide a wealth of information on the physical and chemical state of the polar atmosphere. Most currently available measurements are made at the surface at isolated locations (e.g. Eureka), but the new measurements will provide information throughout the Polar Regions and the depth of the atmosphere. The following recommendations of a general nature were identified:

- the establishment of the utility of existing surface based and satellite observations through data assimilation experiments (e.g. CONCORDIASI project);
- “data mining” to catalogue existing databases and reports – this may require the establishment (or nomination) of a few archive centres to manage IPY data and data from past campaigns (e.g. WCRP ACSYS 1994–2003, including observations provided by submarines) and to provide visualization capabilities;

- there is a requirement for new observations for the Polar Regions (with real-time availability including field experiments) like the CEOP/CliV Cold Regions Study, a new study that consists of 40 regional stations providing highly quality energy cycle observations.

Predictability and Physical and Dynamical Processes

The representation of important physical processes in the cold regions has been discussed.

- There is an urgent need for concerted physical process studies which will need new field campaigns.
- The atmosphere–sea-ice–ocean predictability is clearly a coupled problem in coastal regions at short time scales (few hours to weeks). We need to establish well thought out numerical experiments with coupled models in the Polar Regions in collaboration with WCRP (CMIP5, SPARC).
- More efforts need to focus on research and development for coupled atmosphere–hydrological–cryosphere–surface modelling and observation. The energy and water cycle forecasting problem needs to be tackled regionally for very short to seasonal time ranges with proper downscaling and post-processing techniques in collaboration with WCRP/GEWEX.

Improving Polar Predictions – Scientific Challenges

Whilst there is a clear need for more and improved observations, many workshop presentations stressed the crucial need for improvements in modelling, which will, if achieved, result in the improved use of observations and improved predictions at all ranges – particular stress was put on the need for improvements in:

- coupled modelling – involving snow, sea-ice, and the ocean processes;
- physical processes – the Planetary Boundary Layer and clouds (more accurate specification of aerosol and its role in cloud formation being particularly relevant for Polar Regions);
- physical processes – free atmosphere;
- physical processes – orographic effects and their numerical representation;
- physical processes – sea-ice and ocean.

(See detailed report in Annex II.)

Improving Polar Predictions – Establishment of an IPY Legacy Project

The workshop participants agreed that the establishment of an IPY legacy project would provide a valuable framework to foster cooperative international research and development efforts to improve high impact weather and environmental prediction capabilities for the Polar Regions. Such a project would aid the coordination of current and future polar prediction activities and increase awareness of the need for new resources for polar prediction research.

This legacy project should be based on a few NWP internationally coordinated polar initiatives (new or existing). Joint field campaigns and more long term activities for verification (e.g. weather and ice forecasts, monitoring supersites) and optimal utilization of satellite-based and in situ observations that involve nations operating NWP systems for the Polar Regions are examples.

To be successful, a new IPY legacy project should tap into the scientific and human capacity of the National Meteorological and Hydrological Services (NMHSs) who have an interest in scientific, societal, and economic applications for Polar Regions and should include the participation of the WWRP (SERA, MFRWG, JVWG, NWG), THORPEX, and the WCRP (SPARC, CLIC, SOLAS) communities of scientists.

Additionally support for the observational component would be needed from:

- Global Observing System of the World Weather Watch (GOS/WWW) – physical parameters of the atmosphere;
- Global Atmosphere Watch (GAW) – chemical parameters of the atmosphere, including ozone;
- Global Ocean Observing System (GOOS) – physical, chemical, and biological parameters of the ocean;
- World Hydrological Cycle Observing System (WHYCOS)
- Global Terrestrial Observing System (GTOS) – hydrological cycle parameters (GTN-H);
- GCOS Terrestrial Network for Permafrost (GTN-P) and GCOS Terrestrial Network for Glaciers (GTN-G) – parameters of the cryosphere.

The success of the IPY legacy project will also depend on the ability to provide information that impacts user decision making and this will need coordination with WMO WIS and CBS. An IPY legacy project that addresses the development of reanalyses, new observation and monitoring systems, modelling, and data assimilation forecast systems could span a full decade of R&D activities. The concept of an International Polar Decade (IPD) has been discussed.

An early draft of the outcomes of the workshop was provided to meetings of the EC-PORS (Hobart, October 2010), the WCRP Polar Workshop (Bergen, October 2010), and the WGNE (Tokyo, October 2010).

3. Establishment of a Joint International Polar Prediction Project Steering Group – A Proposal

Based on the outcome of this workshop and the feedback from EC-PORS and potential partners, a Joint Polar Prediction Project, similar to the Year of Tropical Convection (YOTC) project, supported by WWRP, WCRP, and THORPEX should be established.

This project will require a Steering Group (consisting of members with scientific and operational expertise and representatives of the user community). The first task for the Steering Group will be the preparation of an Implementation Plan which is consistent with the outcome of this workshop and which includes estimates of resources and a strategy for the coordination of polar prediction research.

Eventually, if the YOTC model is followed, a Project Office should be established at an institution with a major interest in polar prediction.

ANNEX I

A WWRP, THORPEX, WCRP POLAR PREDICTION WORKSHOP
"A THORPEX CONTRIBUTION TO THE IMPROVEMENT OF POLAR PREDICTIONS ON WEATHER-TO-SEASONAL TIMESCALES"
(6 TO 8 OCTOBER 2010, OSLO, NORWAY)
PROVISIONAL AGENDA

The main outcome of the workshop is the design of a WMO **THORPEX Polar Prediction Research Project** that provides an efficient framework for cooperative international research and development efforts to improve operational weather and environmental prediction capabilities for the Polar Regions.

The workshop will open with a series of presentations outlining:

- the Scientific Challenges of weather and environmental prediction in the Polar Regions
- programmatic activities
- scientific activities.

The second half of the workshop will be given over to discussions on the requirements and framework for an International Polar Research Project to include the preparation of a "status paper".

Wednesday 6 October			
	09:00-09:30	**Coffee on arrival**	
	09:30–10:00	Welcome and scope of the workshop	Anton Eliassen Thor Erik Nordeng
	Session 1	**Scientific challenges**	**Chair: Gilbert Brunet**
	10.00–10:45	Arctic	David Bromwich
	10:45–11:30	Antarctic	John Turner
	Session 2	**Programmatic activities (research and operations)**	**Chair: Erik Brun** **Rapporteurs: TBD**
	11.30–12.00	Canadian activities	Ayrton Zadra
	12.00–12.30	Australian activities	Neil Adams
	12.30–13.00	USA activities	Jordan Powers
	13.00–14.00	**Lunch**	
	14.00–14.30	Russian activities	Mikhail Tolstykh
	14.30–15.00	Norwegian activities	Jon Egill Kristjansson
	15.00–15.30	NOAA/NCEP activities	David Novak
	15:30–16:00	**Coffee**	
	Session 2	**Programmatic activities continued**	**Chair: Neil Adams** **Rapporteurs: TBD**
	16.00–16.30	Research observations 1	John Cassano
	16.30–17.00	Research observations 2	Ian Renfrew
	17:00–17:30	CONCORDIASI	Eric Brun
	17.30	**Reception**	

Thursday 7 October			
	Session 3	**Scientific activities – weather-to-seasonal prediction**	**Chair: John Cassano Rapporteurs: Ayrton Zadra and Greg Smith**
	09.00–09.30	Coupled modelling – snow	Patrick Samuelsson
	09.30–10.00	Coupled modelling – sea-ice and ocean	Helge Drange
	10.00–10.30	Physical processes – PBL and clouds	Thorsten Mauritsen
	10.30–11.00	**Coffee break**	
	11.00–11.30	Physical processes – free atmosphere processes	Keith Hines
	11.30–12.00	Physical processes – orographic effects	Andrew Orr
	12.00–12.30	Physical processes – sea-ice and ocean	Greg Smith
	12.30–14.00	**Lunch break**	
	14.00–14.30	Data assimilation (global)	Dale Barker
	14.30–15.00	Data assimilation (regional)	Per Kallberg
	15.00–15.30	"Arctic observing system for regional operational NWP – status and future"	Harald Schyberg
	15:30–16:00	**Coffee break**	
	Session 4	**Elements of an international research programme**	**Chair: John Turner Rapporteur: Dale Barker**
	16.00–16.30	Polar research within WCRP	Vladimir Ryabinin
	16.30–17.00	EC-PORS	Barry Goodison
	17.00–17.30	Discussions led by Chair	

Friday 8 October			
	Session 5	**Research priorities**	**Chair: Thor Erik Nordeng Rapporteur: Gilbert Brunet**
	08:30–10:15	Discussions led by Chair	
	10.15–10.45	**Coffee break**	
	Session 6	**International cooperation/project**	**Chair: G. Brunet Rapporteur: Barry Goodison**
	10:45–12:30	Discussion led by Chair	
	12.30–13.30	**Lunch break**	
	Session 7	**Workshop summary and final discussion**	**Chair: D. Burridge**
	13.30–15.00	Research priorities International cooperation/project Elements of an international research programme	
	15.00	**Close**	**Thor Erik Nordeng**

ANNEX II

A WWRP, THORPEX, WCRP POLAR PREDICTION WORKSHOP
"A THORPEX CONTRIBUTION TO THE IMPROVEMENT OF POLAR PREDICTIONS ON WEATHER-TO-SEASONAL TIMESCALES"
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Scientific Challenges

Synthesis by Thor Erik Nordeng

Based on presentation by Greg Smith and Ayrton Zadra (rapporteurs), discussions in plenary, and individual presentations by P. Samuelsson. H. Drange, T. Mauritsen, K.Hines, A. Orr, G. Smith, D. Barker, P. Kållberg, and H. Schyberg

The presentations focused on various scientific challenges that have to be addressed for improvements in polar prediction. These involve data assimilation, physical parameterization, and coupled modelling. Some of these scientific challenges may be best met through the organization of focused Research Development Programmes (RDPs).

The importance of reanalyses for a wide range of research projects is now well understood but despite the availability of excellent global reanalyses it is recommended to strengthen efforts to carry out high-resolution coupled regional model reanalyses for Polar Regions.

NWP in Polar Regions depends on the quality of the model, boundary forcing, and initial conditions.

a) Data assimilation

A major problem is the insufficient number of radiosondes and surface observations in higher latitudes; one must therefore rely more on the use of satellites. An important challenge is that most radiative channels used for satellite retrieval are for the free atmosphere, while near-surface and lower troposphere coverage is lacking. In addition, the satellite data is more difficult to use over land and sea-ice than over the ocean due to snow covered (cold) surfaces which make it difficult to distinguish between low clouds and the underlying surface. When using data from microwave channels accurate values for sea-ice emissivity, penetration depth (into snow and ice) of microwave radiation, and a realistic first guess of surface temperature have all to be taken into account. Additionally, there is a close link between the microphysical properties of the NWP model and successful satellite data retrieval. This makes satellite retrieval in Polar Regions particularly challenging due to the complex microphysical properties of high latitude clouds (see the microphysics section below).

The following requirements were highlighted:

- Improved quality control and usage of data
- New observational sources/types (for example, there is a potential for an enhanced polar Voluntary Observing Ship, VOS)
- UAVs (Unmanned Aerial Vehicles) were also suggested as a method for obtaining more (and inexpensive) data, for instance combined with targeting.
- Novel diagnostics to assist the design of data assimilation systems and the observing system design (Observation System Simulation Experiments (OSSE) for example)
- Improvements in coupled initialization/data assimilation
- Use of ensemble prediction systems

Ocean and sea-ice models and oceanic and cryospheric observations are necessary components for accurate polar NWP because of the strong interaction between the atmosphere and the surface (see the section on coupled models below). The development and implementation of atmosphere–ocean–cryosphere data assimilation and NWP systems using a multi-sensor observational platform will be an essential element of a Polar Regions prediction framework such as EC-PORS.

b) The underlying surface and the need for surface–sea-ice coupled models

Several presentations stressed the need for an accurate and detailed description of the underlying surface in terms of ice, snow, leads, sea surface temperature, and so on. Of particular importance are accurate descriptions and parameterization of polynyas and tides and sea-ice characteristics (roughness, melt ponds, extent, and thickness) that determine radiative properties and the coupling to the PBL of the atmosphere through fluxes of sensible heat, latent heat, and momentum. In summer, in particular, the mixture of open water (leads), snow covered ice and open ice presents a major challenge. Additionally, ageing (and wet) snow has a different albedo from fresh snow, and short wave (solar) radiation penetrates into snow and ice. This is further complicated by the effects of pollution (black carbon and other aerosols). There is also a hysteresis effect - snow on the ground changes the albedo and the absorption of incoming solar radiation thus lowering the temperature and making the area prone to more snow. It is therefore important for the fractional coverage of snow to be accurate.

The improvement in models for Polar applications is hampered by the lack of observations and an understanding of the physical processes in Polar regions. In addition to improvements in the regular observing system, new field campaign data are required to help design parametrization schemes and to improve daily operational NWP. Since many surface elements are typically much smaller than a grid-cell, the tiling approach was recognized as a useful tool in obtaining a good grid-cell average from a number of heterogeneous sub-areas. Issues that were recognized as important for NWP are how to initialize (snow analyse) and how to treat blowing snow. In this respect it was noted that some help and knowledge may be gained through CryoSat. The ESA's Earth Explorer CryoSat mission, launched on 8 April 2010, is dedicated to precise monitoring of the changes in the thickness of marine ice floating in the polar oceans and variations in the thickness of the vast ice sheets that overlie Greenland and Antarctica. There is a need for detailed process studies and careful parameterizations supported by observations. It was also noted that there exist a large number of (archived) data which may be valuable for such studies as the Marginal Ice Zone Experiment (MYZEX) and IPY International Ice Chart Working Group (IICWG) data bases.

c) Planetary Boundary Layer (PBL) parameterization including PBL clouds

The Earth's surface and the atmosphere exchange energy, moisture and matter through the planetary boundary layer (PBL). In addition, boundary layers frequently contain clouds which regulate the exchange of short- and long-wave radiation. A proper representation of these turbulent processes is known to be essential for the quality of both short- to medium range weather prediction and climate modelling. The Arctic offer significant challenges relative to the lower latitudes, in particular the lower troposphere is characterized by the semi-permanent Arctic inversion caused by inflow of warm air from lower latitudes at mid-levels, and the very frequent occurrence of clouds peaking at more than 90% in summer. It was stressed that PBL schemes need to consider the presence of clouds, while in order to solve the polar cloud issue, one has to work on cross-cutting issues linked to the PBL, surface, microphysics, and radiation, as these processes are closely linked. Further, it was emphasized that the vertical resolution is often insufficient to represent PBL processes.

Successful parameterizations of stably stratified turbulence, such as the scheme implemented at the ECMWF, typically offer far more turbulent diffusion than what can be justified by micro-meteorological observations. Considerable amounts of research has been devoted to understanding this enigma, yet so far, no really clear explanation has been given. This overly diffusive turbulence parameterization results in too deep boundary layers and too much heat transfer from the atmosphere towards the surface, relative to detailed computer simulations. The too strong diffusion causes erosion of the inversions, which is believed to be essential for strati-form cloud formation.

Fundamental to modelling turbulent processes in the atmosphere is the assumption of a spectral energy gap between small scale motion and the synoptic scales. Observational studies show that the assumed mesoscale spectral gap seems absent in the Arctic, although it does occur under certain conditions. It has been hypothesized that this is due to the Arctic inversion, which allows internal gravity waves and/or Kelvin-Helmholtz waves to interact with the below PBL turbulence at nearly the same time-scales. The same issue of an absent spectral gap has previously been observed in marine stratocumulus-topped boundary layers at lower latitudes, which are also typically capped by an inversion, and it remains an open question whether the original observations of the spectral gap from the 1950's was an artefact of the signal processing available at the time. The lack of a spectral gap significantly complicates the parameterization problem as stability functions may have to depend on model resolution.

Modelling of clouds in atmospheric models is notoriously difficult. Clouds are essential for establishing the Earths radiation balance, determines the distribution of precipitation and impacts weather and climate on all timescales. Yet, our fundamental knowledge of cloud processes is highly limited, and we lack key observations to constrain even highly simplified cloud parameterizations. It is well known that atmospheric models have particular problems in representing stratocumulus clouds capped by inversions, most prominently apparent in the semi-permanent sub-tropical high regions off the continents. The Arctic offers similar conditions with inversions capping the cloud-topped boundary layer. It is fully possible that some of the scatter among models in the Arctic is related to poor parameterizations of vertical mixing in these inversion layers, combined with the coarse vertical resolution frequently applied, ultimately resulting in erroneous clouds.

Parameterizations of strati-form clouds, by far most common in both the Arctic and Antarctic, rely heavily on cloud micro-physical processes. In these cold climates clouds can be either all liquid, mixed phase or all ice phase in the range from a few degrees below the freezing point down to minus 30 Celsius. It is currently not known what determines the phase and mixture of clouds, however, evidence points to influences from internal cloud dynamics and from the properties of aerosol particles. It has been suggested that the Arctic clouds are particularly susceptible to changes in the aerosol particle composition and concentrations, both because these clouds tend to be optically thin and because of the relatively low levels of background aerosol concentrations. Recent observational studies show that over the ice-covered Arctic Ocean the aerosol concentrations are frequently so low that clouds can barely form.

The workshop highlighted the need for comprehensive observational studies to improve cloud detection in Polar Regions and aerosol content. Here, other studies, for example OASIS, PolarCAT, AICI, and AERONET and ASCOS-2008, may be able to contribute. The international multidisciplinary Ocean Atmosphere Sea Ice Snowpack (OASIS) programme studies chemical and physical exchange processes between the title reservoirs. It focuses on their impact on tropospheric chemistry and climate, as well as on the surface/biosphere and their feedbacks in the Arctic. The Polar Study using Aircraft, Remote Sensing, Surface Measurements, and Models of Climate, Chemistry, Aerosols, and Transport (POLARCAT) has carried out a series of aircraft experiments at different times of the year in order to follow pollution plumes of different origin as they are transported into the Arctic and to observe the chemistry, aerosol processes, and radiation effects of these plumes. Air Ice Chemical

Interactions (AICI) has investigated how the presence of snow and ice affects the chemistry of air above the polar ice caps.

d) Physical parameterization for the free atmosphere

Clouds play an important role in many feedbacks, especially through cloud–radiation interaction. We have already stressed the importance of PBL clouds. It is just as important to correctly parameterize the mixed-phase clouds and super-cooled water. Water and mixed-phase clouds are observed to be common in spite of very low temperatures. For this, it may be necessary to include aerosols in the models and to take cloud–aerosol interaction into account. Arctic haze occurs frequently and is closely linked to pollution (and hence aerosols).

Convection may be a minor issue over the ice and over Antarctica, but it is even more important over the adjacent seas when cold polar air encounters areas with relatively warm water (e.g. in cold air outbreaks). Stratocumulus clouds manifested as cloud streaks are common some distance downstream from the ice-edge and these clouds often group into convective clusters further downstream, producing huge amounts of snow with high intensity and very poor visibility. They are therefore a major forecasting issue. There is a need to refine convective schemes for high latitudes. Present schemes are basically developed for the tropics and middle latitudes and even though they are based on physical principles, they may have to be retuned in order to work optimally for Polar Regions.

e) Coupled modelling – sea-ice and ocean

From the longer range perspective (decadal) there seems to be a connection between predictability and the thermohaline circulation. On seasonal time scales there are suggestions that thicker sea ice is more predictable (than thin), but comprehensive research is needed to confirm this and to understand why. On the shorter NWP time scales predictability seems to be sensitive to ocean initial state and near-ice-edge conditions. There is a need for enhanced operational analysis where observations of ice parameters (ice thickness, snow data, albedo, etc.) are essential.

Ocean initialization (analysis) may be a particular problem although some information may be gained through the CLIVAR Working Group on Ocean Model Development – CORE programme.

f) Orographic effects

Greenland and Antarctica are massive large scale mountainous plateaus and both have significant impact on the atmospheric conditions in their respective areas. The rugged orography and coastal steep slope make high resolution simulations necessary to properly capture their effect on the large scale flow in general, but also on the local dynamics. Blocking effects, gravity-wave drag, katabatic winds, rotors, barrier jets, tip jets, and coastal jets are all phenomena that are important to capture accurately for successful NWP operations. There is a clear link between the PBL and steep terrain, and new parameterization methods for the PBL in steep orography may have to be developed. A new high-resolution topographic dataset would be necessary including an up-to-date and accurate land sea mask (with shelves), as would observational studies. Knowledge may be gained from detailed model studies (Large Eddy Simulation, LES, approach) supported by observations.