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The WWRP Polar Prediction Project

Thomas Jung

Chair of the WWRP Polar Prediction Project

Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research

24 June 2013

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Background

Month	Milestones
Nov 2009	CAS recommends THORPEX-IPY legacy project
Oct 2010	WWRP and WCRP workshops in Norway
Sep 2011	Endorsement of PPP through THORPEX ICSC
Sep 2011	Formation of PPP steering group
Dec 2011	1st PPP steering group meeting
Mar 2012	2nd PPP steering group meeting
Jun 2012	Approval of PPP through WMO EC
Dec 2012	3rd PPP steering group meeting
Jun 2013	Publication of Implementation and Science Plan

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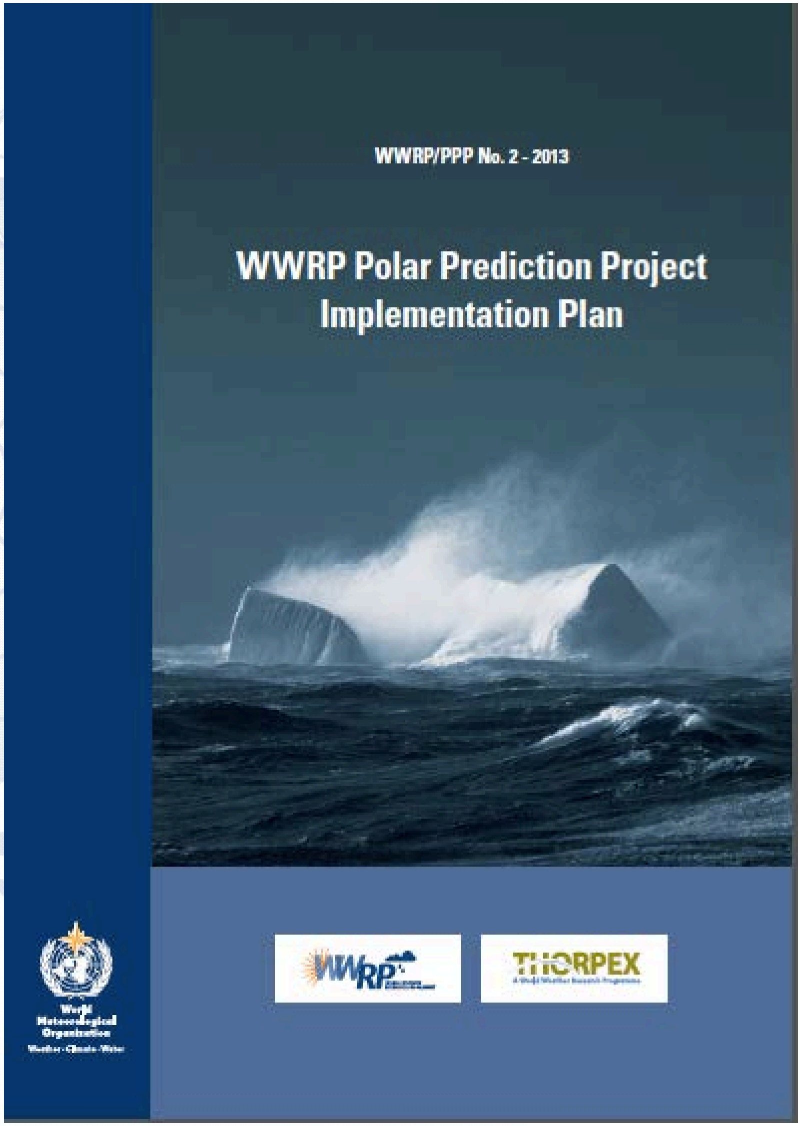
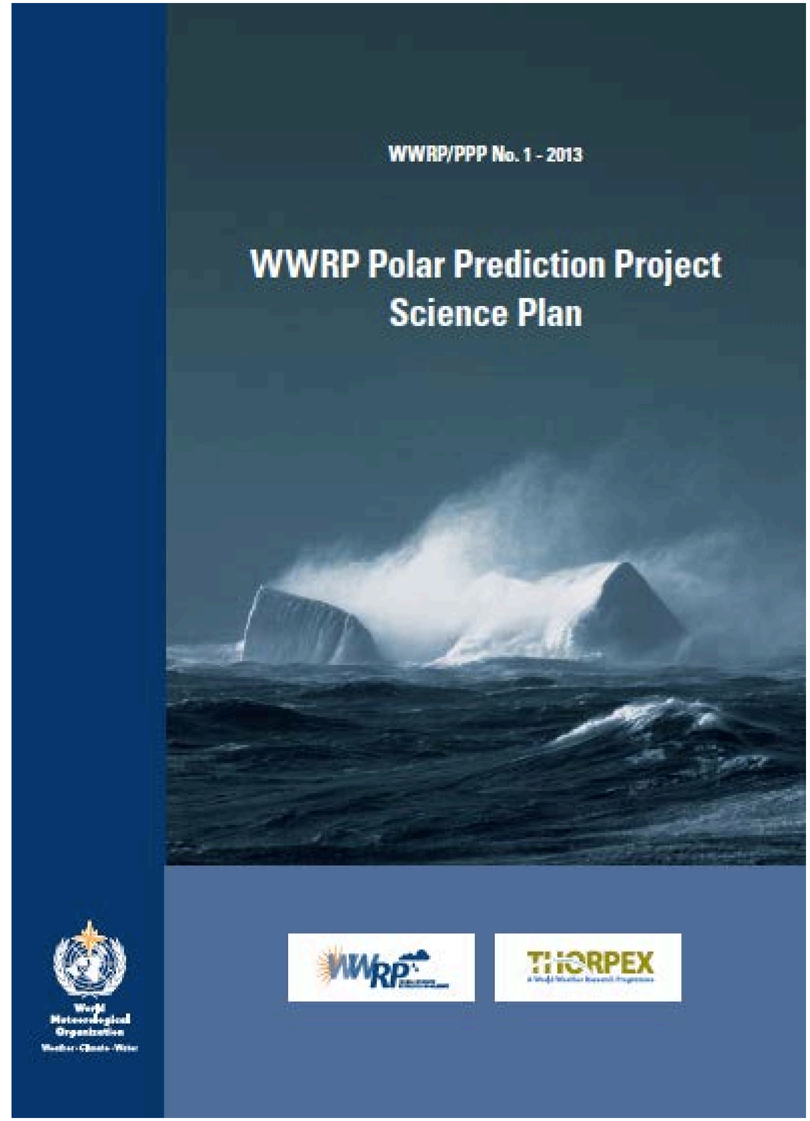
WWRP-PPP Plans





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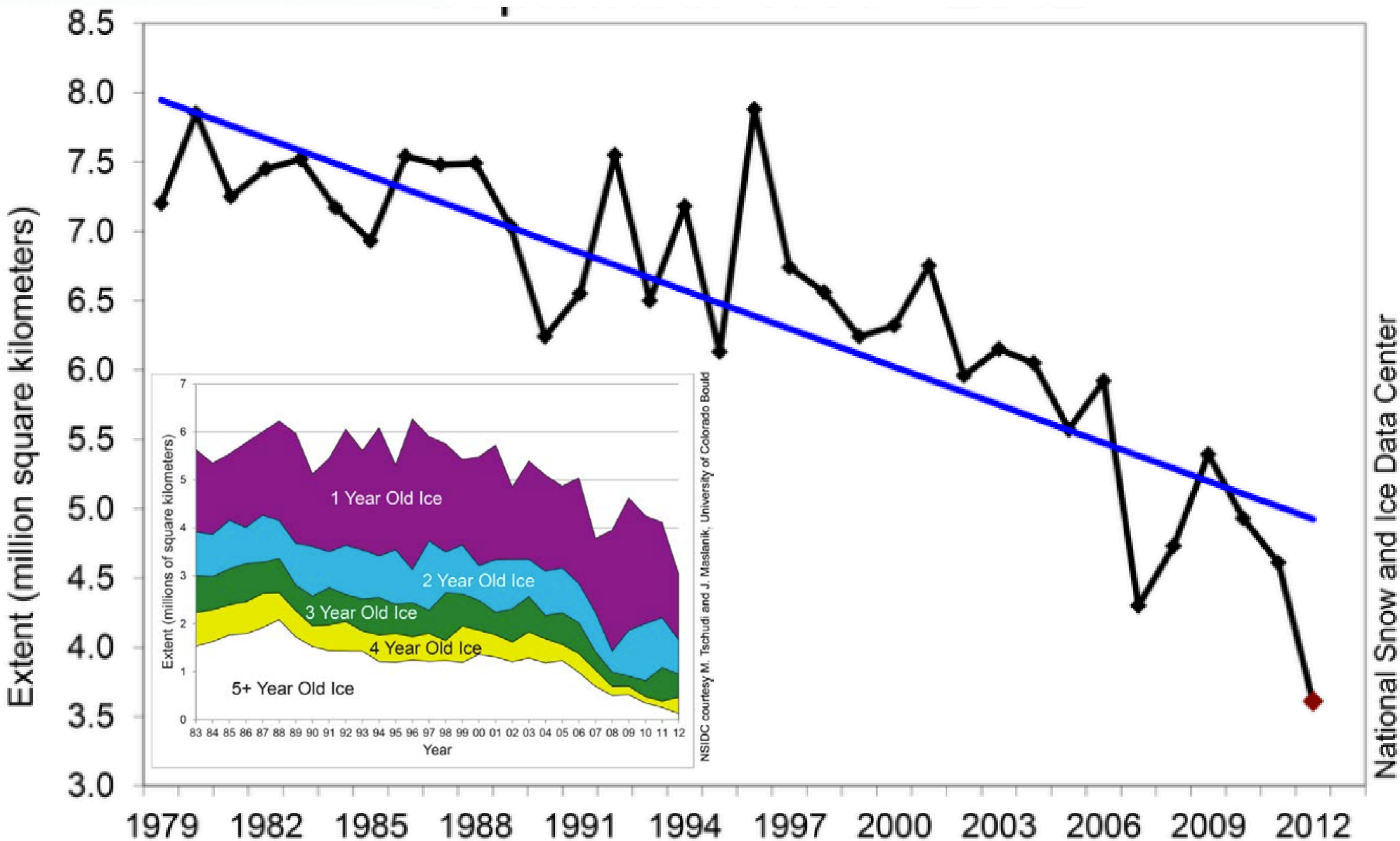
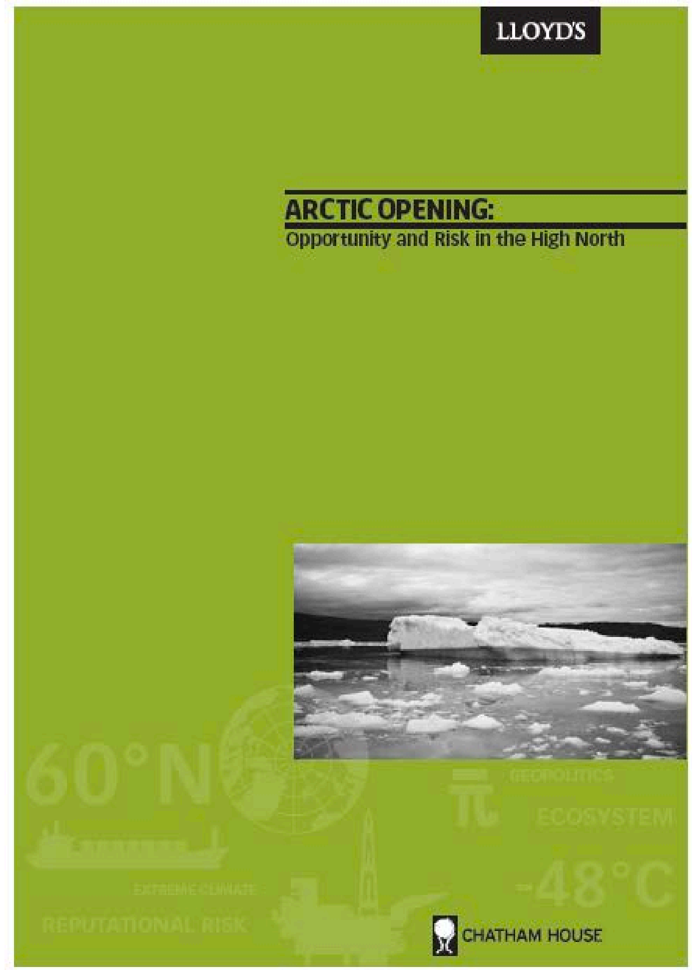
Arctic Climate Change



Opportunities and Risks

Some statements from the report:

- The Arctic is likely to attract substantial investment over the coming decade ($100 bn)
- The environmental consequences of disasters in the Arctic are likely to be worse than in other regions
- Significant knowledge gaps across the Arctic need to be closed urgently



The WWRP-PPP Steering Group

SG3, Reading, 12-13. December 2012

- Thomas Jung (chair)
- Peter Bauer
- Chris Fairall
- David Bromwich
- Trond Iversen
- Marika Holland
- Brian Mills
- Pertti Nurmi
- Ian Renfrew
- Gregory Smith
- Gunilla Svensson
- Mikhail Tolstykh
- Paco Doblas-Reyes
- Peter Lemke
- Neil Gordon (WMO consultant)

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Mission Statement

„Promote cooperative international research enabling development of improved weather and environmental prediction services for the polar regions, on time scales from hourly to seasonal“

An important addition:

„This constitutes the hourly to seasonal research component of the WMO Global Integrated Polar Prediction System (GIPPS)“

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Research Areas

Service-oriented Research

Societal and Economic Research Applications (SERA)	Verification

Underpinning Research

Predictability and Diagnostics	Teleconnections

Forecasting System Research

Observations	Modelling
Data Assimilation	Ensemble Forecasting

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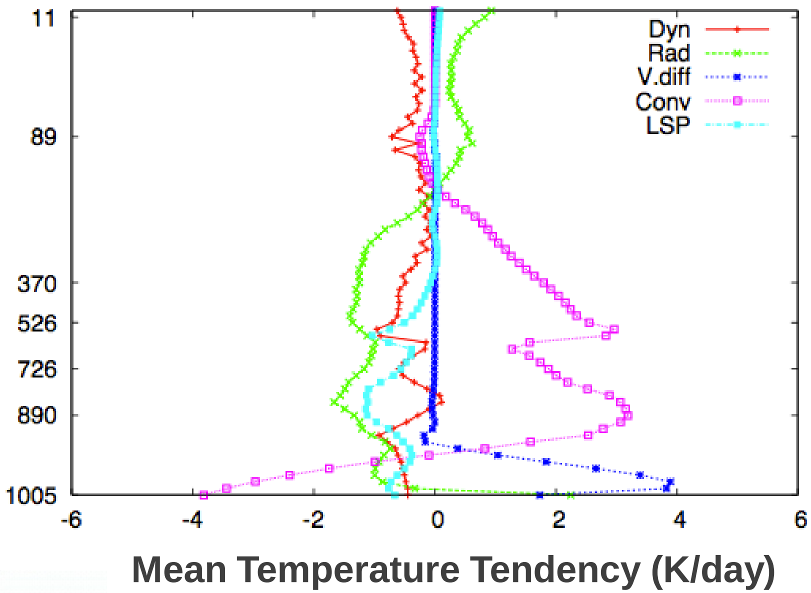
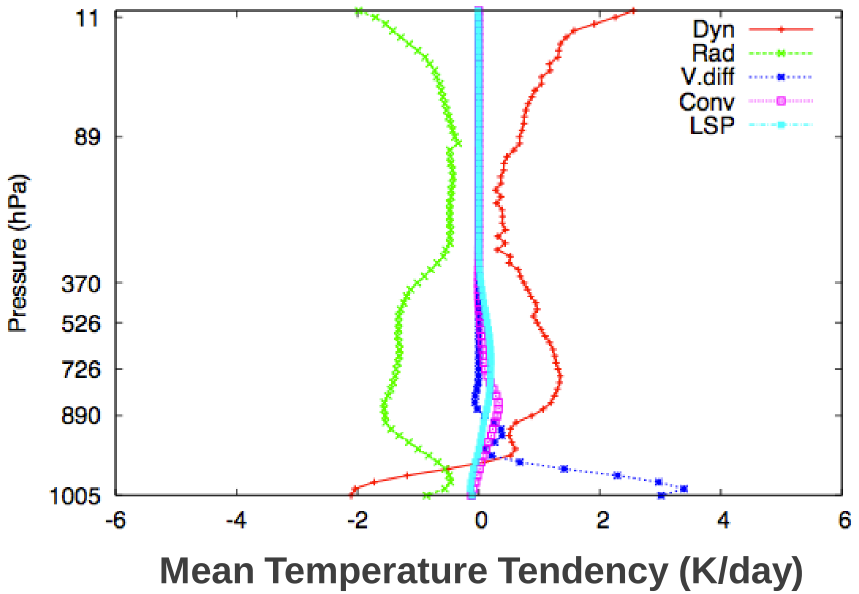
Tropical vs Arctic Atmosphere

Tropical Ocean

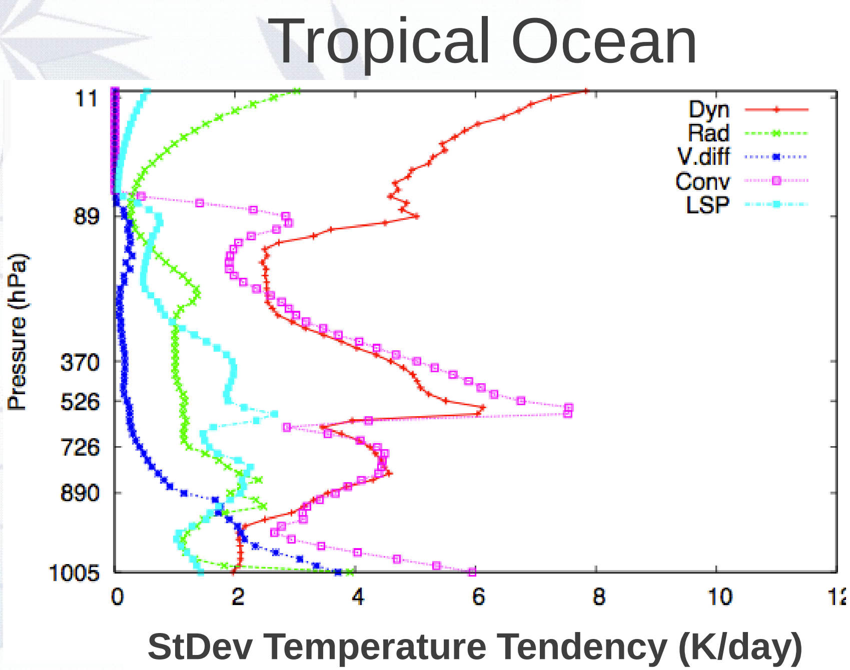


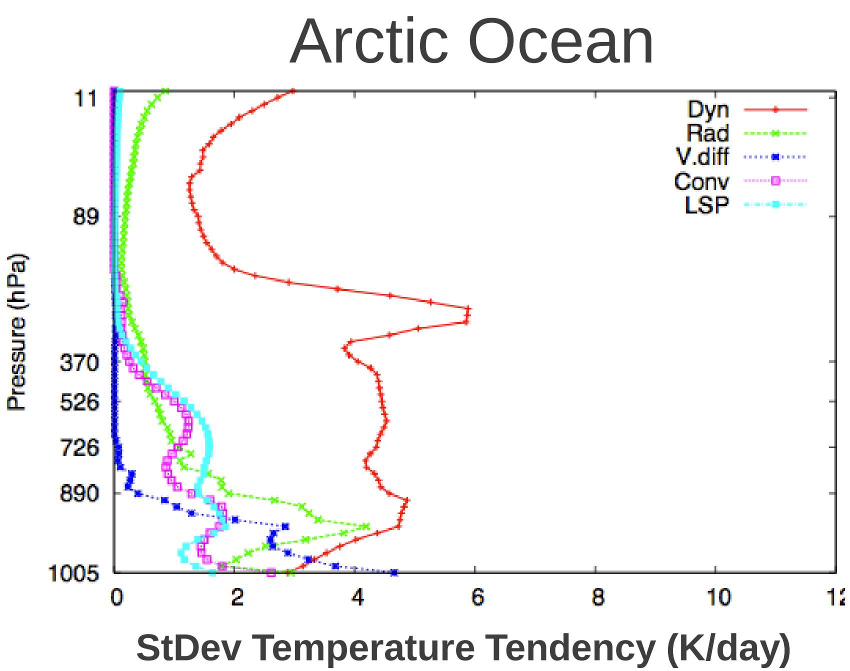
Arctic Ocean



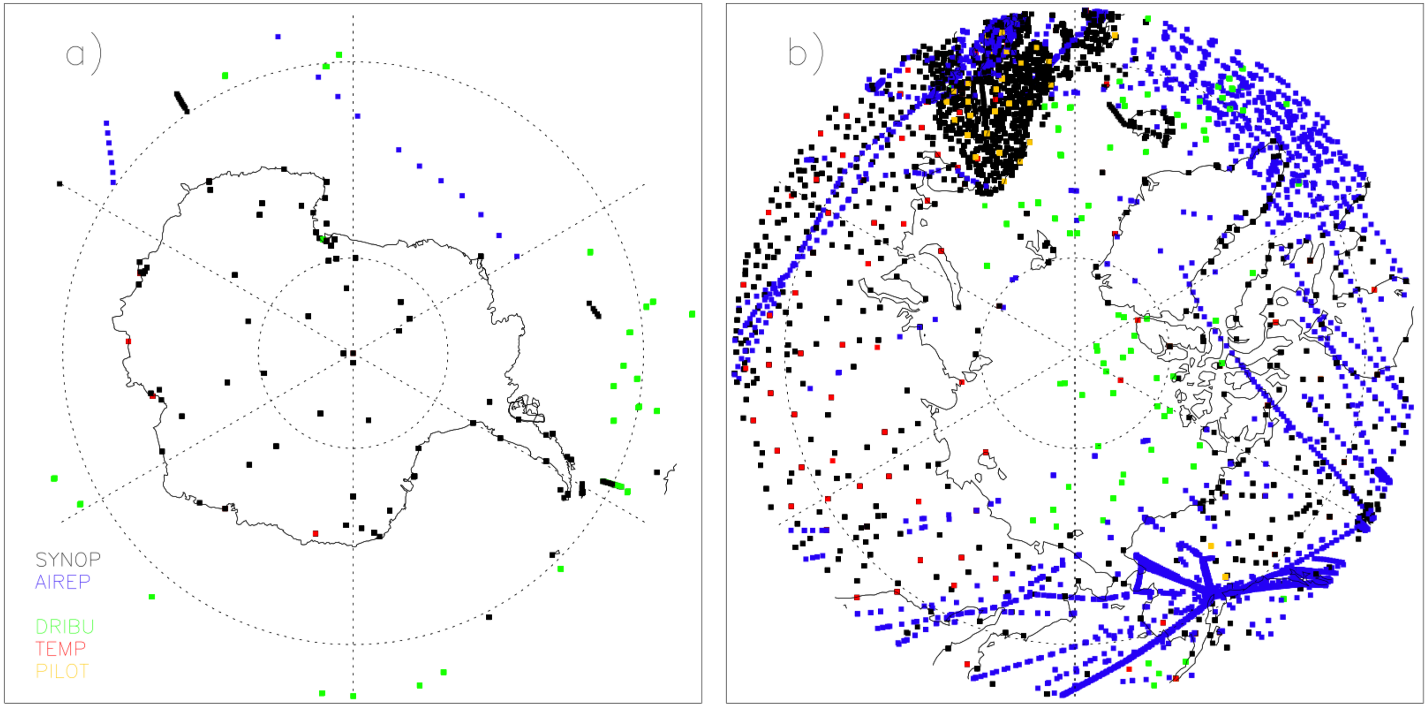
- ECMWF model
- 6-hourly initial tendencies
- 120 forecasts (DJF 1989-2010)

Tropical vs Arctic Atmosphere





Observations: Data Coverage



Synop, AIREP, DRIBU, TEMP and PILOT

Polar data coverage of conventional observations in the ECMWF operational analysis on 1 January 2012

Modelling: The Role of Sea Ice

T2m Difference: Observed Minus Persisted Sea Ice

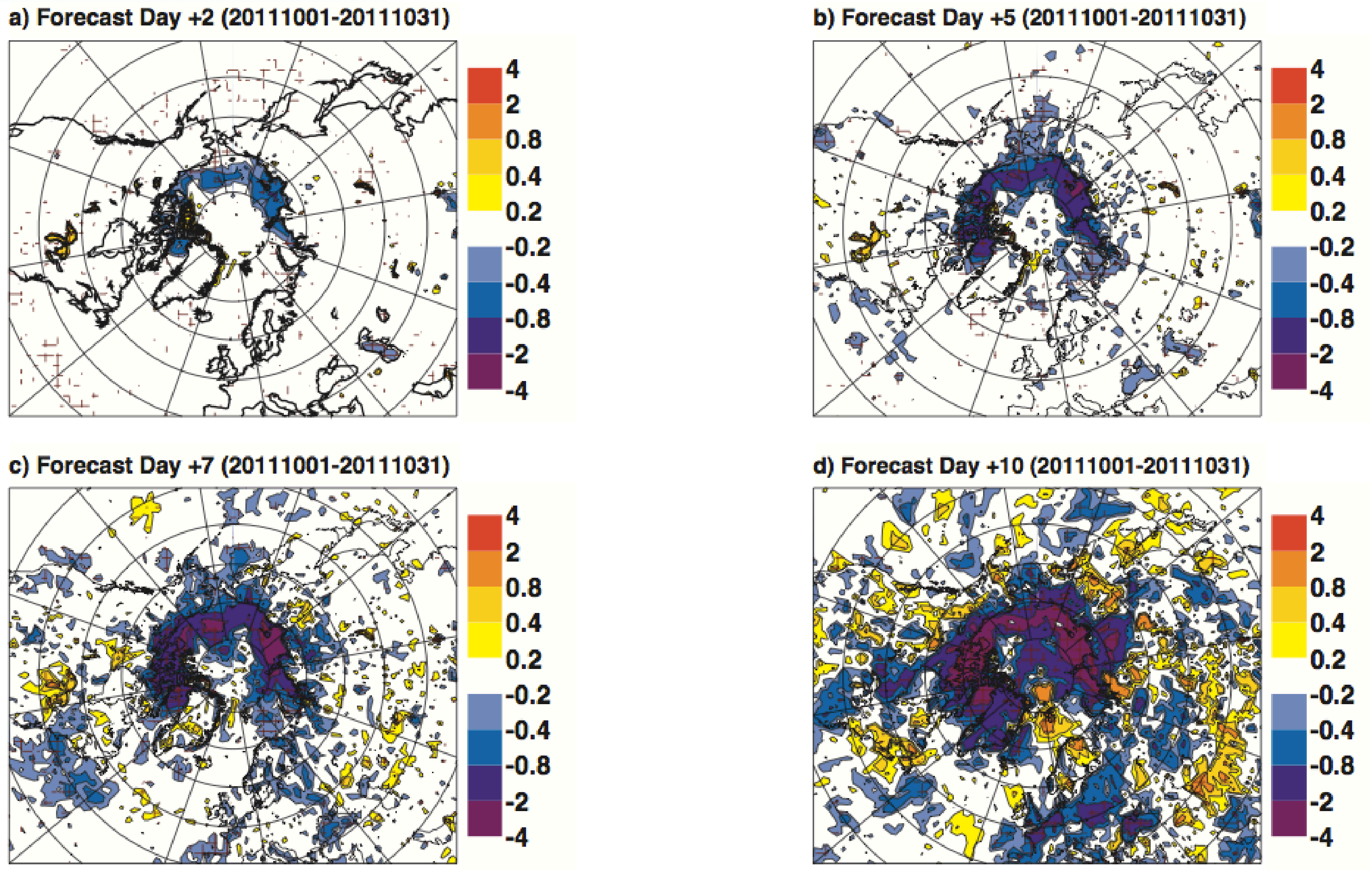


Figure courtesy of P. Bauer (ECMWF)

Modelling: Sea ice models

Mean September sea ice concentrations (1979-2007)

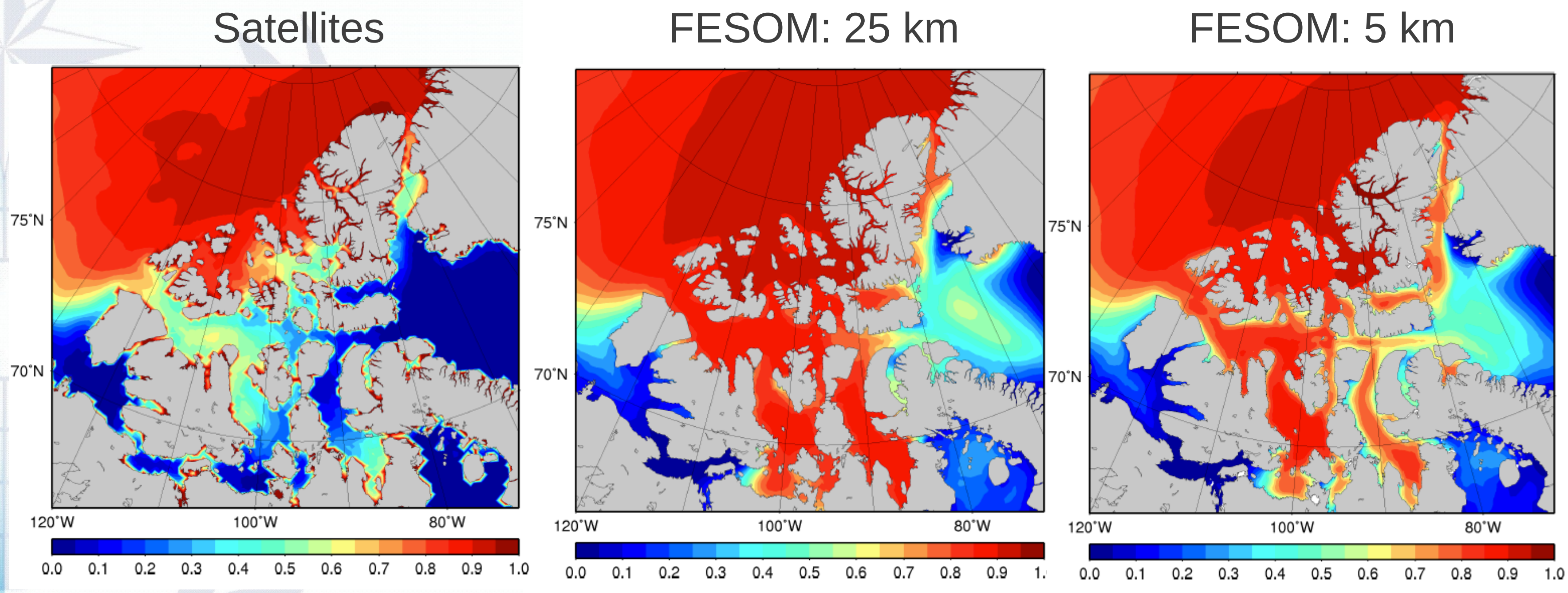


Figure courtesy of C. Wekerle (AWI)

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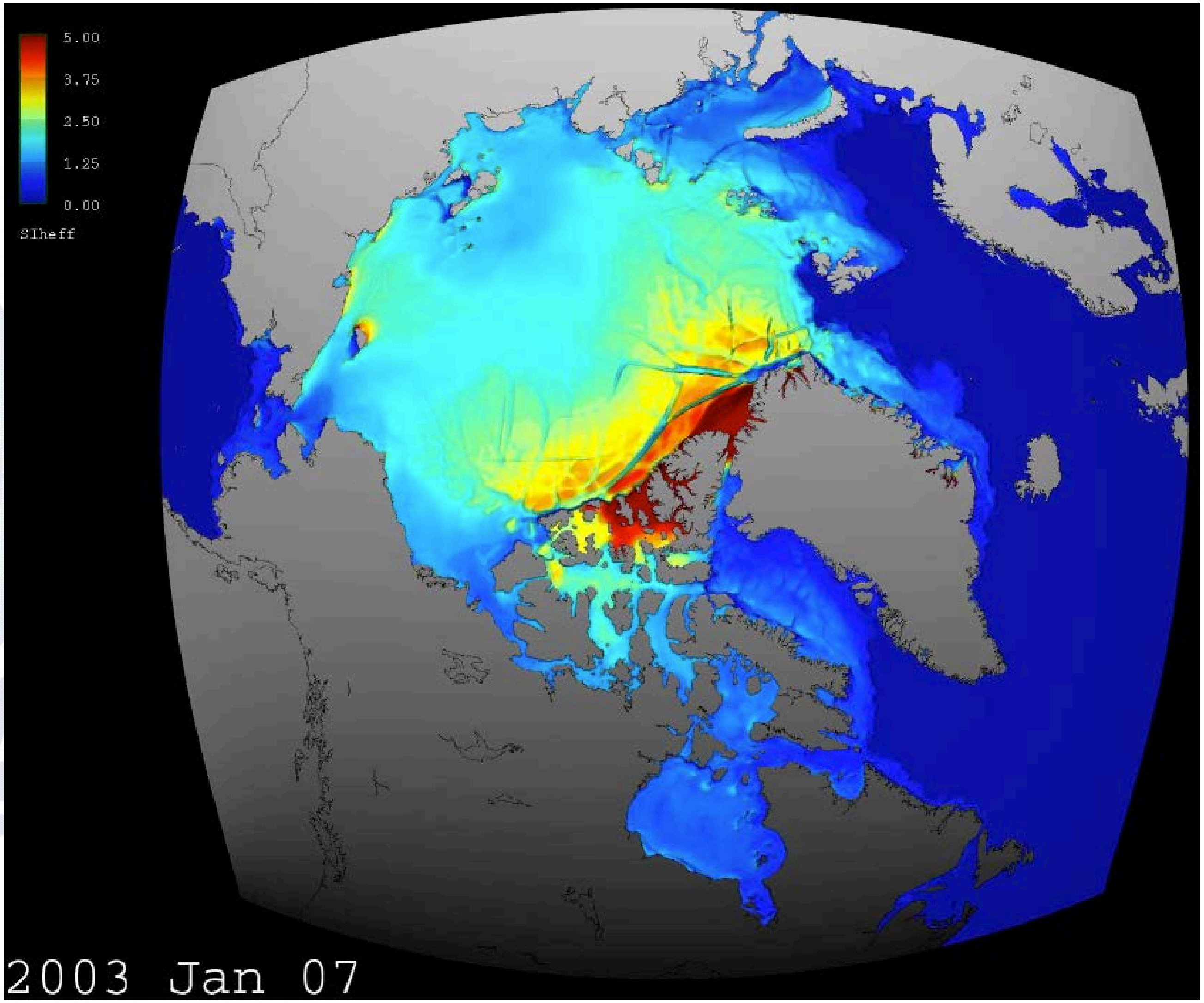
Modelling: Sea ice models



MITgcm @ 4km resolution, Simulation desribed in Nguyen et al (2012) and Rignot et al. (2012)

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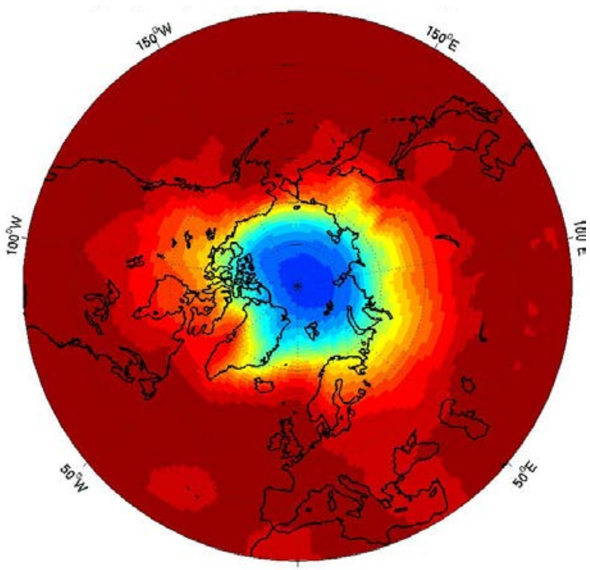
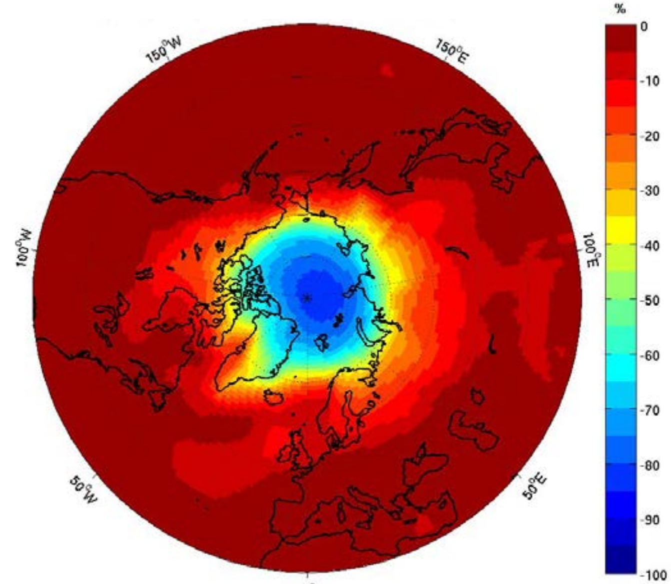
Teleconnections: Role of the Arctic

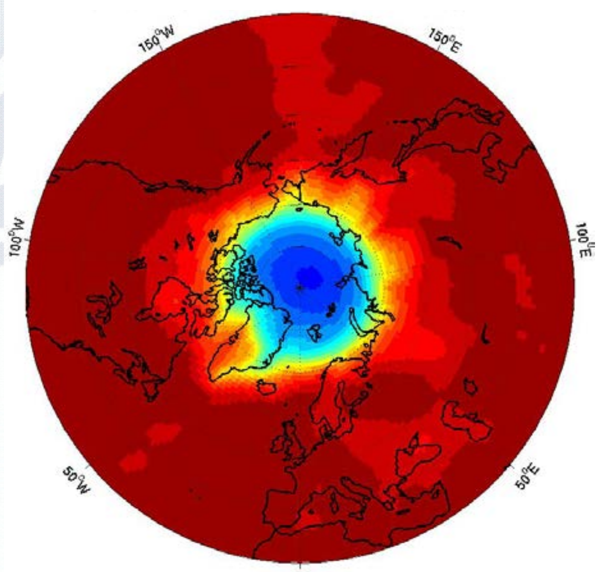
MSLP DJF D+10-D+14



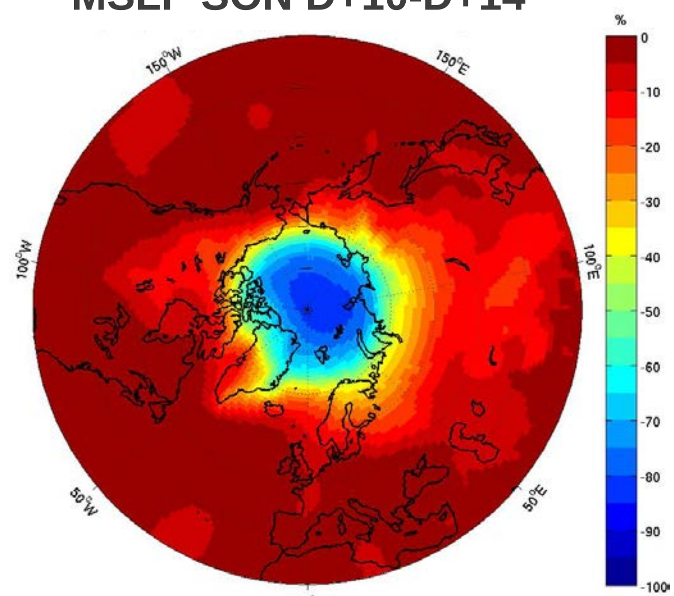
MSLP MAM D+10-D+14



MSLP JJA D+10-D+14



MSLP SON D+10-D+14



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Polar Verification

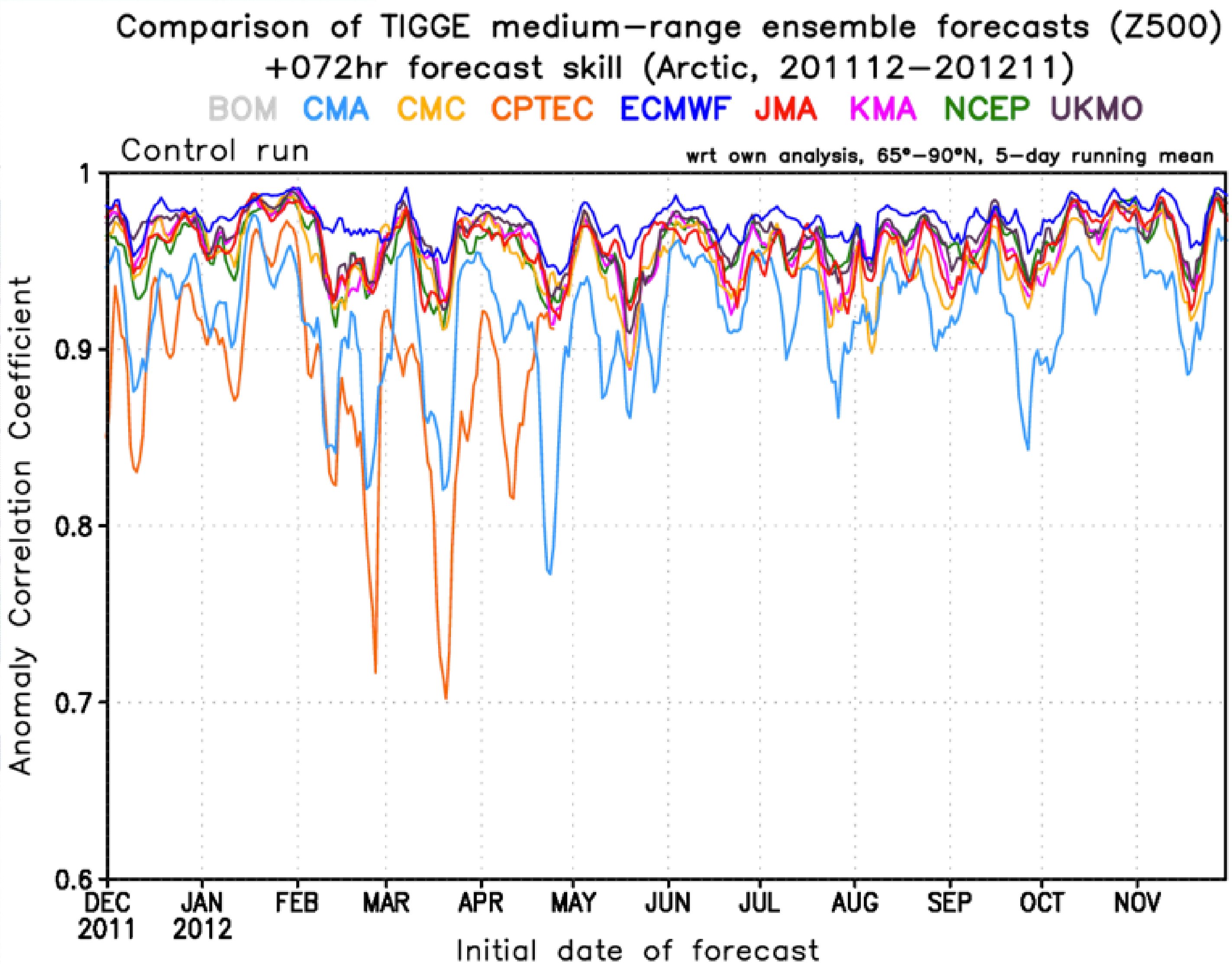

Figure courtesy of Mio Matsueda (Univ. Oxford, JMA)

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Year of Polar Prediction (YOPP)

Aims:

- Intensive observational *and* modelling period to advance polar prediction capabilities
- Research into forecast-stakeholder interaction
- Enhanced verification
- Education of students and early career scientists (APECS)

Important:

- Engagement of the community
- Engagement of other committees
- Alignment with other (planned) activities such as MOSAiC

YOPP: Time line

- Community engagement
- Gap analysis
- Formulation of YOPP plan
- Explore means of funding
- ...

- Data denial experiments
- YOPP special issue
- Establish YOPP data centre
- Operational implementation
- ...

Conclusions

- Polar prediction is an exciting and timely topic
- PPP is one of three follow-on projects to THORPEX
- So, what can PPP do for us?
  - It provides a framework to facilitate international collaboration (YOPP, workshops, coordinated experiments etc.)
  - It can help to influence funding agencies, and
  - It will educate and promote early career scientists
- **We are looking forward to an exciting and productive workshop!**

Thank you!

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Links with WCRP

- PCPI most closely related initiative
- PPP and PCPI will be separate activities
- Possible topics (SG3, Reading)
  - Reanalysis including coupled systems
  - Model error (e.g. Transpose AMIP or CMIP)
  - Subseasonal to seasonal predictability
- Coordination
  - International Coordination Office
  - EC-PORS/GIPPS
  - Joint workshops
  - ...

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Next steps

Month	Milestones
Jun 2013	YOPP planning meeting
Jul 2013	Launch of the ICO (awaiting approval)
Jul 2013	Launch of the PPP website
Sep 2013	YOPP Planning Document
Jun 2013	ECMWF-WWRP/THORPEX Polar Prediction Workshop
Jun 2013	YOPP planning meeting
Oct 2013	4^{th} PPP steering committee meeting

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Polar Verification

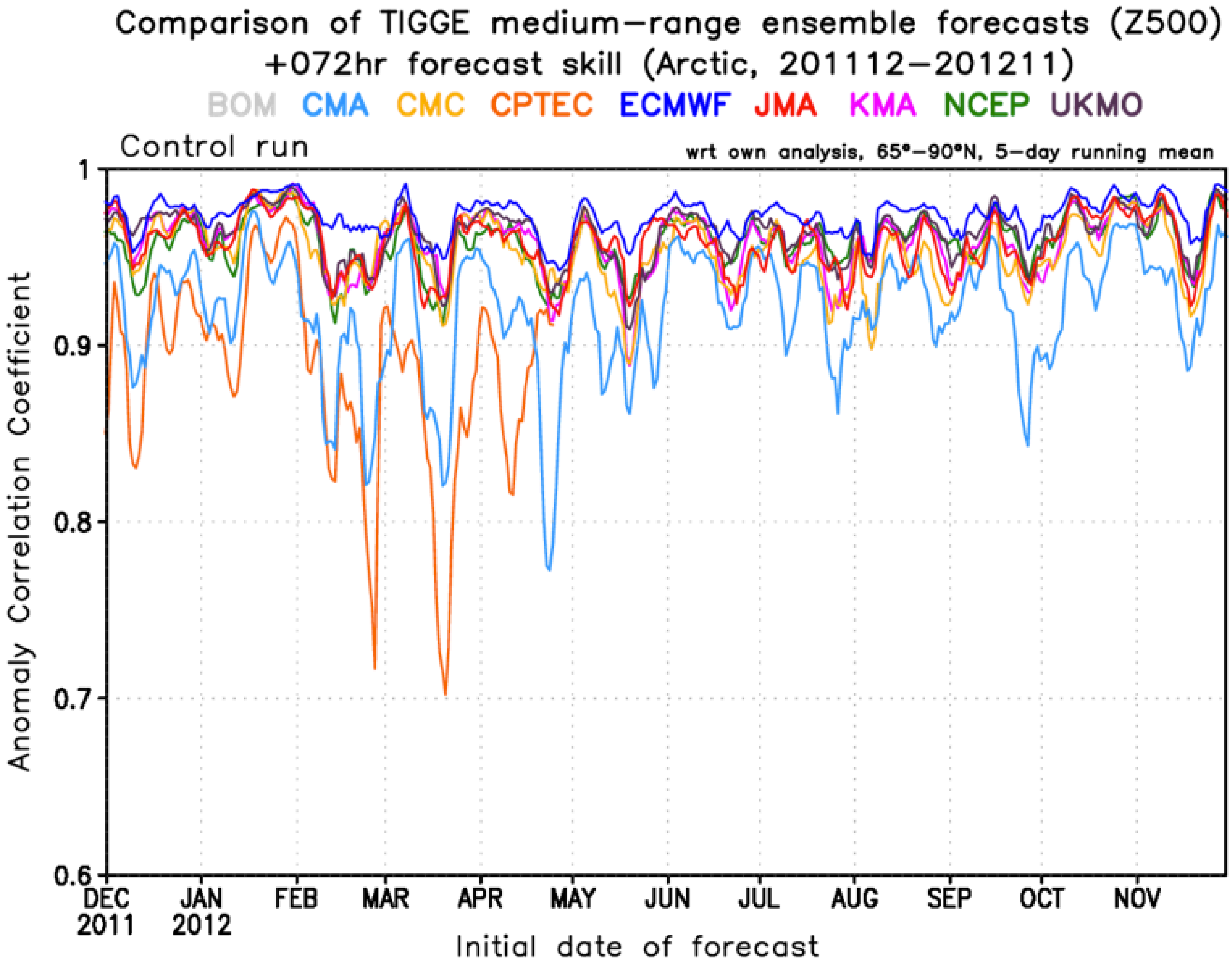

Figure courtesy of Mio Matsueda (Univ. Oxford, JMA)

Preparation phase

Preparation Phase 2012-2016

- Develop Strategy
  - Establish Planning Group in 2012
  - International YOPP Planning Workshops (2013 & 2016)
  - Write Implementation Plan (2013)
- Stakeholder Engagement Workshop (2014)
  - Explore User needs
  - Identify YOPP Partners
  - Explore Means Of Funding
- Present Plans to Funding Agencies
- Preparatory Research (2012-2016)

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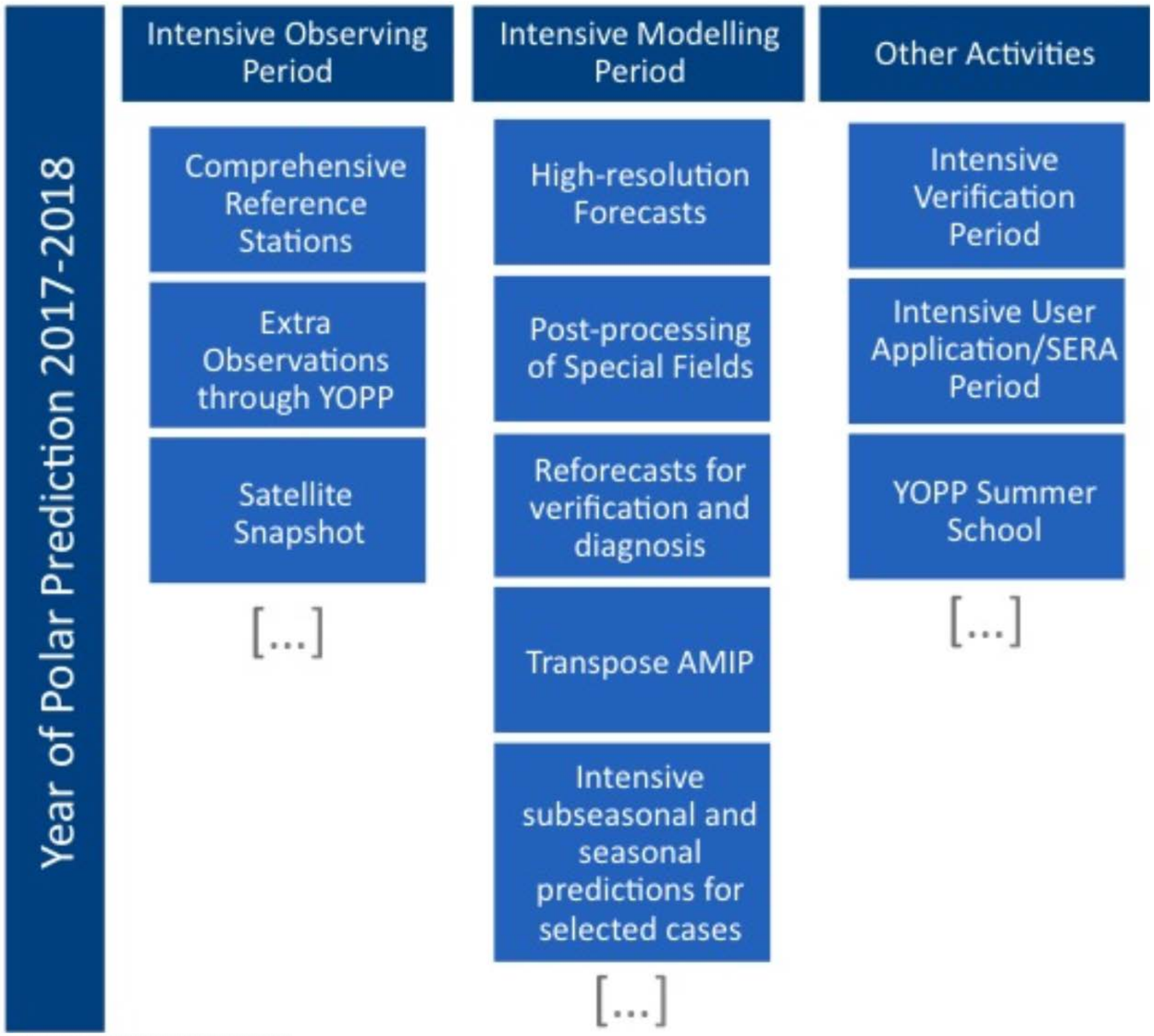
Year of Polar Prediction



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Consolidation phase

Consolidation Phase 2018-2022

- Exploitation of YOPP Data
  - Establish YOPP Data Centre
  - Data Denial Experiments
  - Carry out Reanalyses
  - Analyse Model Data
  - Improve Models
  - Improve Satellite Retrievals
- YOPP Synthesis workshop
- Publications
  - YOPP Overview Paper
  - Specialist Papers
- Implementation of YOPP findings
- Stakeholder Feedback
  - Presentations at Stakeholder Meetings
  - Articles in Trade Magazines
  - General Science Articles

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Agenda

ECMWF-WWRP/THORPEX Polar Prediction Workshop

24-27 June 2013, ECMWF Reading, UK

Monday, 24 June *Overview*			
13:30 - 14:00	Registration		
14:00 - 14:15	Welcome	Erland Källén	ECMWF
14:15 - 14:45	WWRP Polar Prediction Project	Thomas Jung	AWI
14:45 - 15:15	Polar Climate Predictability	Ted Shepherd	U Reading
15:15 - 15:45	*Tea*		
15:45 - 16:15	Polar prediction at ECMWF	Peter Bauer	ECMWF
16:15 - 16:45	Numerical weather prediction for the Arctic and the Antarctic	Dave Bromwich	Ohio State U
16:45 - 17:15	Poster introduction		
17:15 - 19:00	*Reception + Poster Session*		
Tuesday, 25 June *Predictability*			
9:00 - 9:30	Small-scale ice-ocean-wave processes and their impact on coupled environmental polar prediction	Gregory Smith	Env. Canada
9:30 - 10:00	Sea-ice - ocean, extended range	Cecilia Bitz	U Washington
10:00 - 10:30	*Coffee*		
10:30 - 11:00	Using reanalyses for studying past Eurasian snow cover and its relationship with circulation variability	Eric Brun	Météo-France
11:00 - 11:30	Polar lows - Still a considerable challenge for polar weather prediction?	Trond Iversen	Met No
11:30 - 12:00	Remote drivers of the Arctic Oscillation	Adam Scaife	Met Office
12:00 - 13:00	*Lunch*		
Observations/data assimilation			
13:00 - 13:30	Observation networks	Miroslav Ondras	WMO
13:30 - 14:00	Satellites	Mark Drinkwater	ESA
14:00 - 14:30	Field campaigns	Michael Tjernström	U Stockholm

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14:30 - 15:00	Atmospheric data assimilation	Florence Rabier	Météo-France
15:00 - 15:30	*Tea*		
15:30 - 16:00	Sea-ice data assimilation	Mark Buehner	Env. Canada
Modelling			
16:00 - 16:30	Physical processes of the polar atmosphere	Anton Beljaars	ECMWF
16:30 - 17:00	Polar Storms and Polar Jets: Meso-scale weather systems in the Arctic and Antarctic	Ian Renfrew	U East Anglia
17:00 - 17:30	Observations and modeling of polar clouds and their interactions with synoptic/mesoscale "weather" and Arctic surface conditions	Ola Persson	NOAA
19:00	***Workshop dinner***		
Wednesday, 26 June ***Modelling cont'd***			
9:00 - 9:30	Sea-ice/ocean	Elizabeth Hunke	LANL
9:30 - 10:00	Snowpack modelling and data assimilation	Richard Essery	U Edinburgh
10:00 - 10:30	Coffee		
Verification/diagnostics			
10:30 - 11:00	Forecast verification in a polar framework	Pertti Nurmi	FMI
11:00 - 11:30	Diagnostics of the ensemble prediction system in polar regions	Linus Magnusson	ECMWF
11:30 - 11:45	Working group instruction and formation	Thomas Jung / Peter Bauer	AWI / ECMWF
11:45 - 12:30	Working Groups		
12:30 - 13:30	*Lunch*		
13:30 - 18:00	Working Groups		
Thursday, 27 June			
9:00 - 11:00	Working groups		
11:00 - 12:30	Plenary session		
12:30	*Adjourn*		
14:00 - 18:00	YOPP Planning Workshop		
Friday, 28 June			
9:00 - 17:00	YOPP Planning Workshop		

Key Objectives: YOPP Preparation Phase

The key objectives for the YOPP Preparation Phase are to:

1. Know which model and data assimilation experiments we want to run (and what variables we want to archive - and what additional observations would be valuable) – this requires a comprehensive assessment of the skill of forecasting systems in polar regions), e.g.,
   - Identifying what forecast models do well or poorly in polar regions
   - Identifying the importance of model resolution
   - Identifying importance of coupling and sea ice, etc.
2. Know what are the best case studies to be looked at during YOPP on polar-mid-latitude linkages (requires assessment of those linkages)
3. Better understand the use of predictions by users in polar regions
4. Work to make existing less accessible observations (e.g., from the Arctic Observing Network) available during the YOPP period

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YOPP

The key objectives for the YOPP Phase are to:

1. Obtain extra observations which aid verification, allow observing system design, and support coupled model development
2. Run model and data assimilation experiments (including Transpose AMIP and Transpose CMIP runs in collaboration with the climate research community)
3. Evaluate forecast systems and the user benefits of enhanced products as compared with "normal" systems

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YOPP Consolidation Phase

The key objectives for the YOPP Consolidation Phase are:

1. Observing system design (making use of data denial experiments, etc., from YOPP)
2. Operational implementation of improved forecasting systems
3. Ongoing innovation based on what has been learned, with proven benefits through prediction experiments, etc.
4. A legacy of YOPP data which can be used for ongoing work

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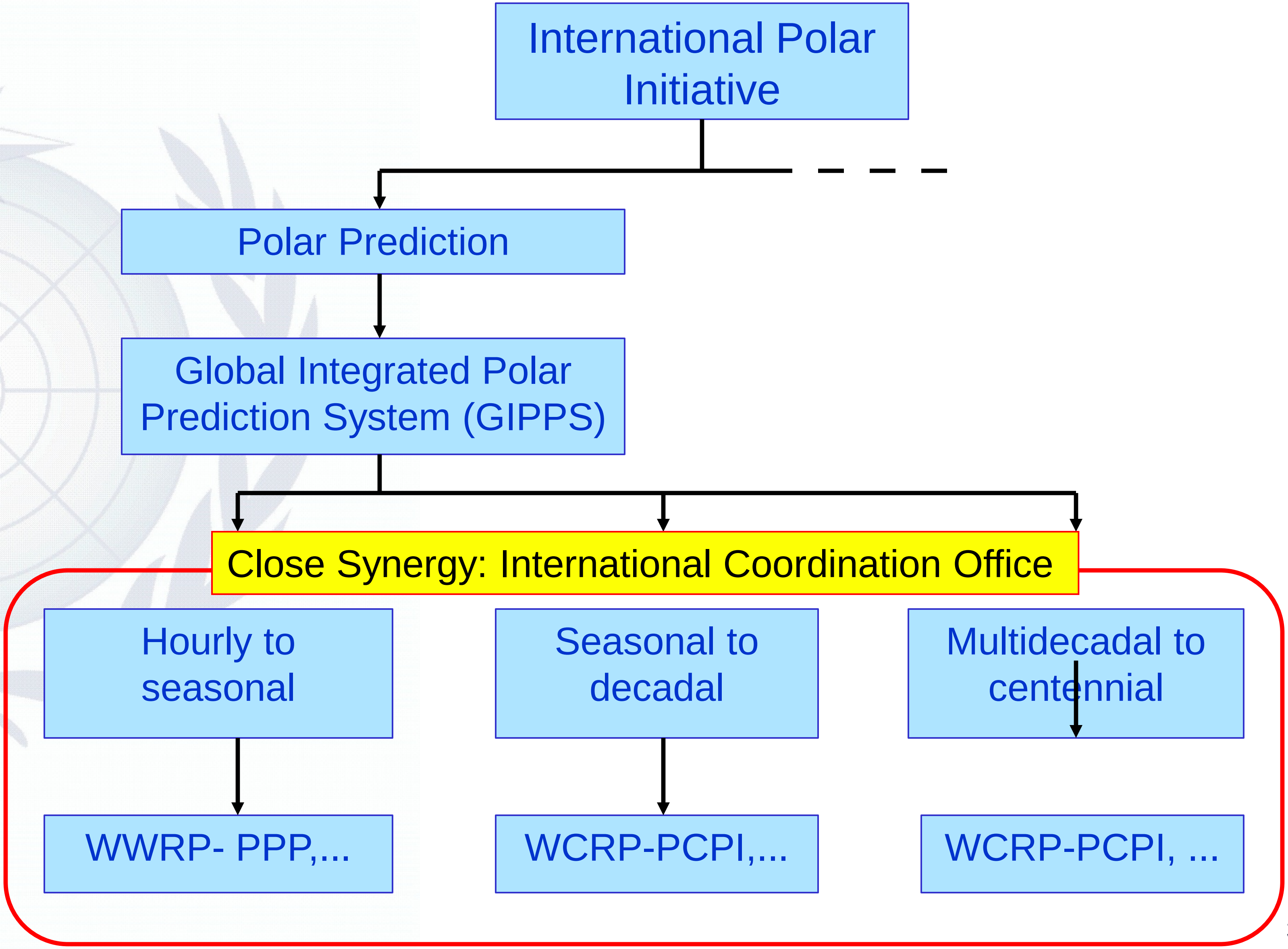
Programmatic Context



Strategies to Achieve Research Goals

- Develop strong linkages with other initiatives
- Strengthen linkages between academia, research institutions and operational prediction centres
- Establish linkages with space agencies and other data providers
- Establish and exploit special research data sets
- Promote interactions and collaboration between research and stakeholders
- Foster education and outreach


MAIN BODIES
RELATED PROJECTS
PPP RESEARCH AREAS
KEY RESEARCH LINKAGES
WCRP
WWRP (CAS)
EC-PORS
CBS
OPERATIONAL FORECAST & RESEARCH CENTRES e.g., ECMWF, AMPS
WCRP Polar Climate Predictability Initiative
WWRP Polar Prediction Project
Sub-Seasonal to Seasonal Project
User Applications
Verification
Observations
Modelling
Data Assimilation
Ensemble Forecasts
Predictability
Global Linkages
WG SERA
EC-PORS Services Task Team
JWGFVR
Polar Space Task Group
GCW
CBS OPAG IOS
EPAC-GAW
SAON
GEWEX
Arctic Hydra
WGNE
DAOS WG
Ice Charting WG
GIFS-TIGGE WG
CBS ET Ensembles
IASC Atmosphere WG
WGSIP
PDP WG

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SERA

Goal: Understand and evaluate the use of enhanced prediction information and services in polar regions

- Link with forecast user community (two-way)
- Communication of risk, opportunity and uncertainty across user types
- Estimation and analysis of historic and current use
  - Develop/test framework to define and assess *expected* polar and lower-latitude benefits in relation to cost
  - Monitor/evaluate *actual* decision-making behaviour, costs and benefits

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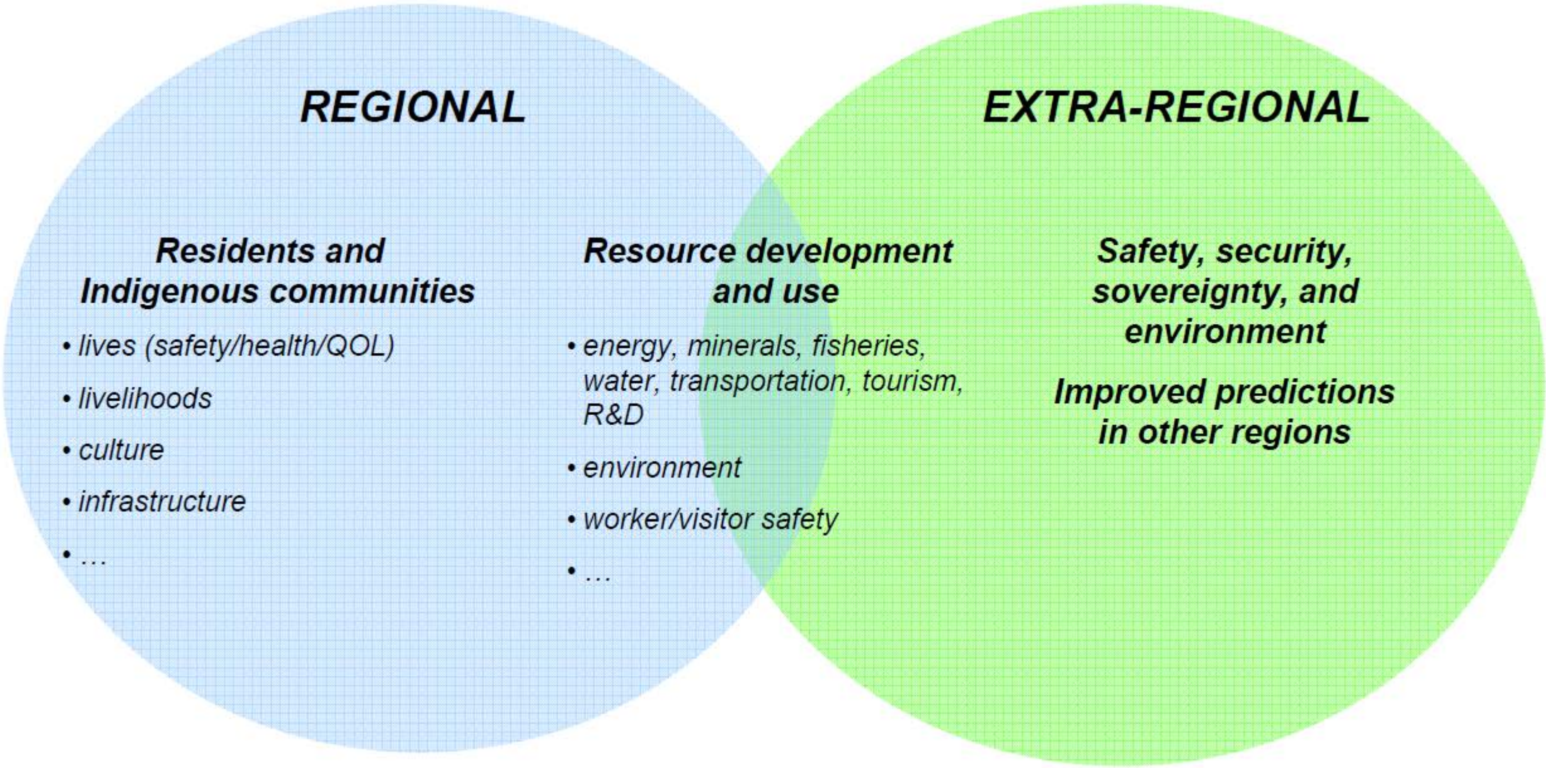
Benefit Areas



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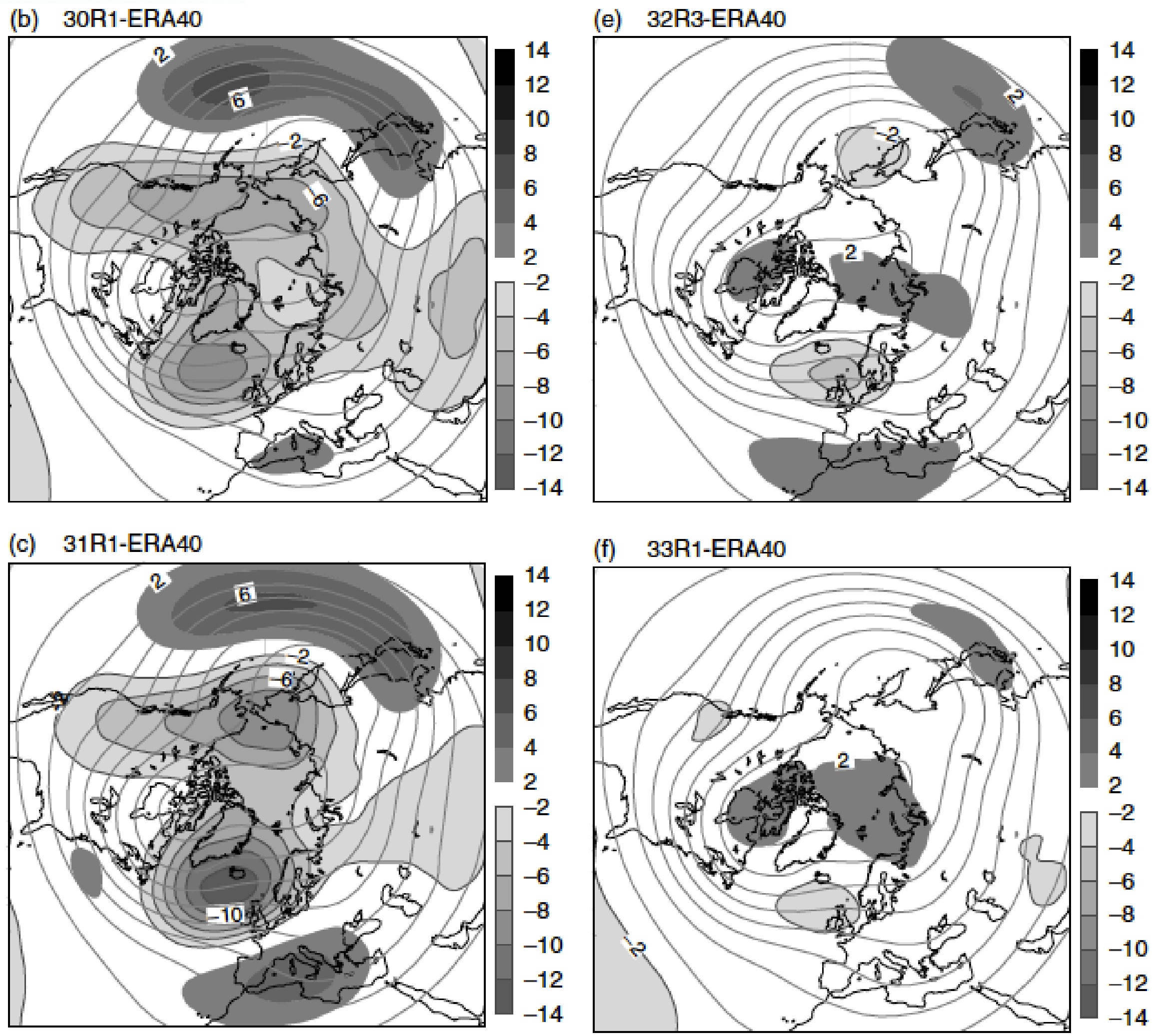
Importance of sea ice forecasts

Benefit Areas (cont'd)



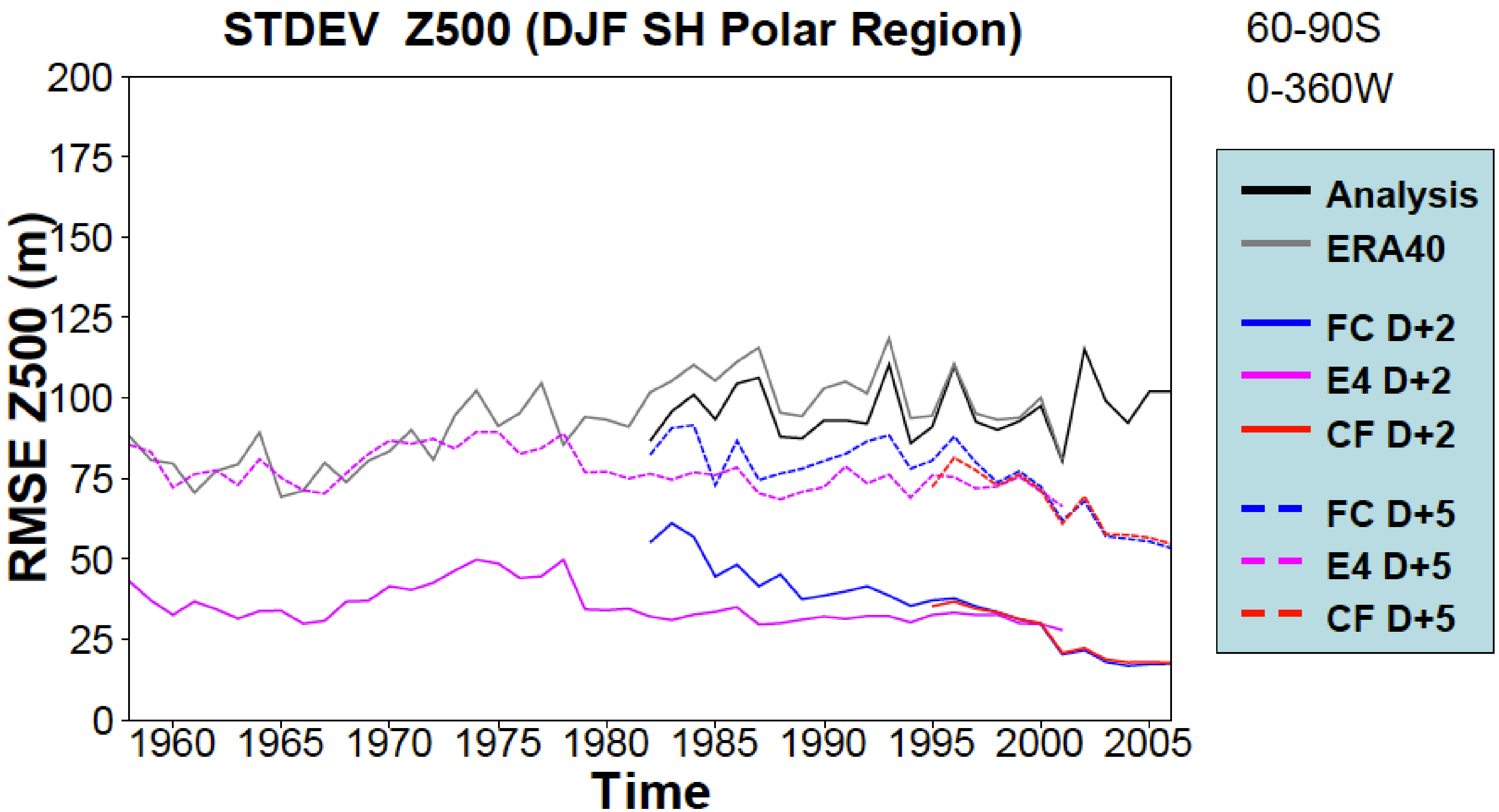
Jung et al. (2010)

Verification

Goal: Establish and apply verification methods appropriate for polar regions

- Verify existing forecasting systems in the polar regions
- Develop key performance headline measures with polar relevance to monitor progress
- Devise methods that can be used to verify user-relevant key weather and climate phenomena in polar regions (e.g. blizzards and fog-visibility)
- Define an observation strategy to meet forecast verification requirements
- Develop forecast verification in observation space using, for example, satellite data simulators

Deterministic Skill: Z500 Antarctic



Jung and Leutbecher (2007)

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Predictability and Diagnostics

Goal: Determine predictability and identify key sources of forecast errors in polar regions

- Determine
  - mechanisms providing predictability
  - Instabilities of the polar climate system
  - Structure of imperfections (analysis and model error)
- Apply/develop diagnostic techiques that help to understand model error at the process level
- Central: Explore the role of sea ice (time scales from days to seasonal)

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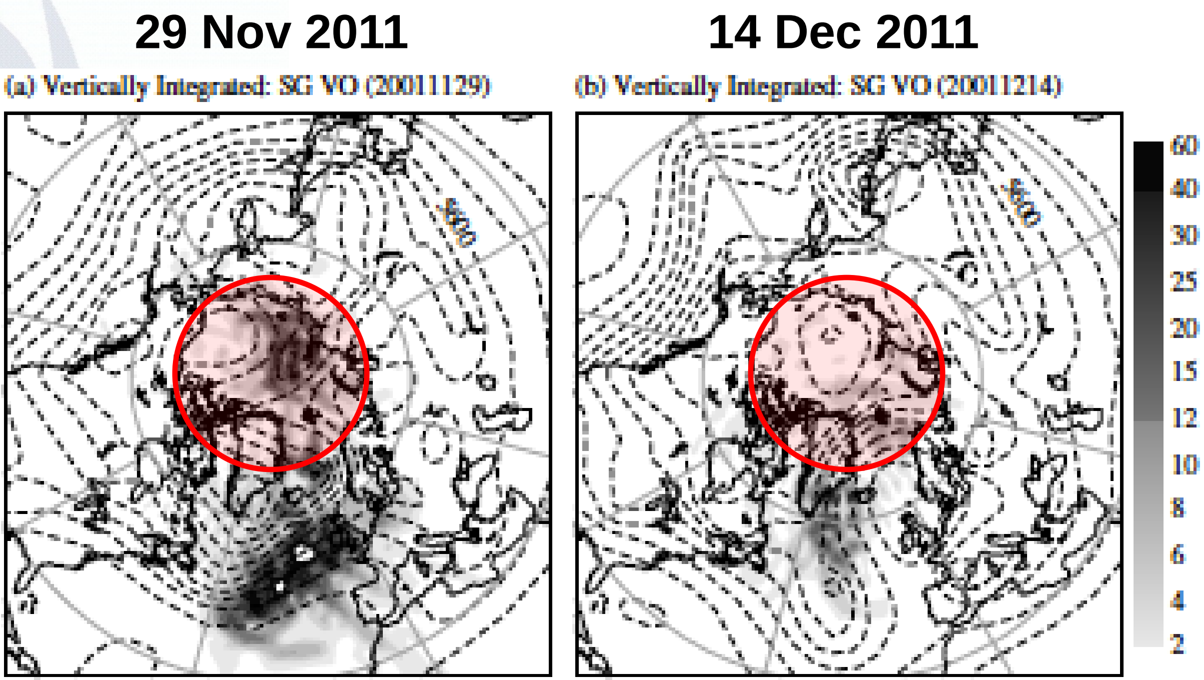
Teleconnections

Goal: Improve knowledge of two-way teleconnections between polar and lower latitudes, and their implications for polar prediction

Lower-latitudes → (?) → Polar regions

Lower-latitudes ← ? ← Polar regions

D+2 Forecast Sensitivity to Initial Perturbations



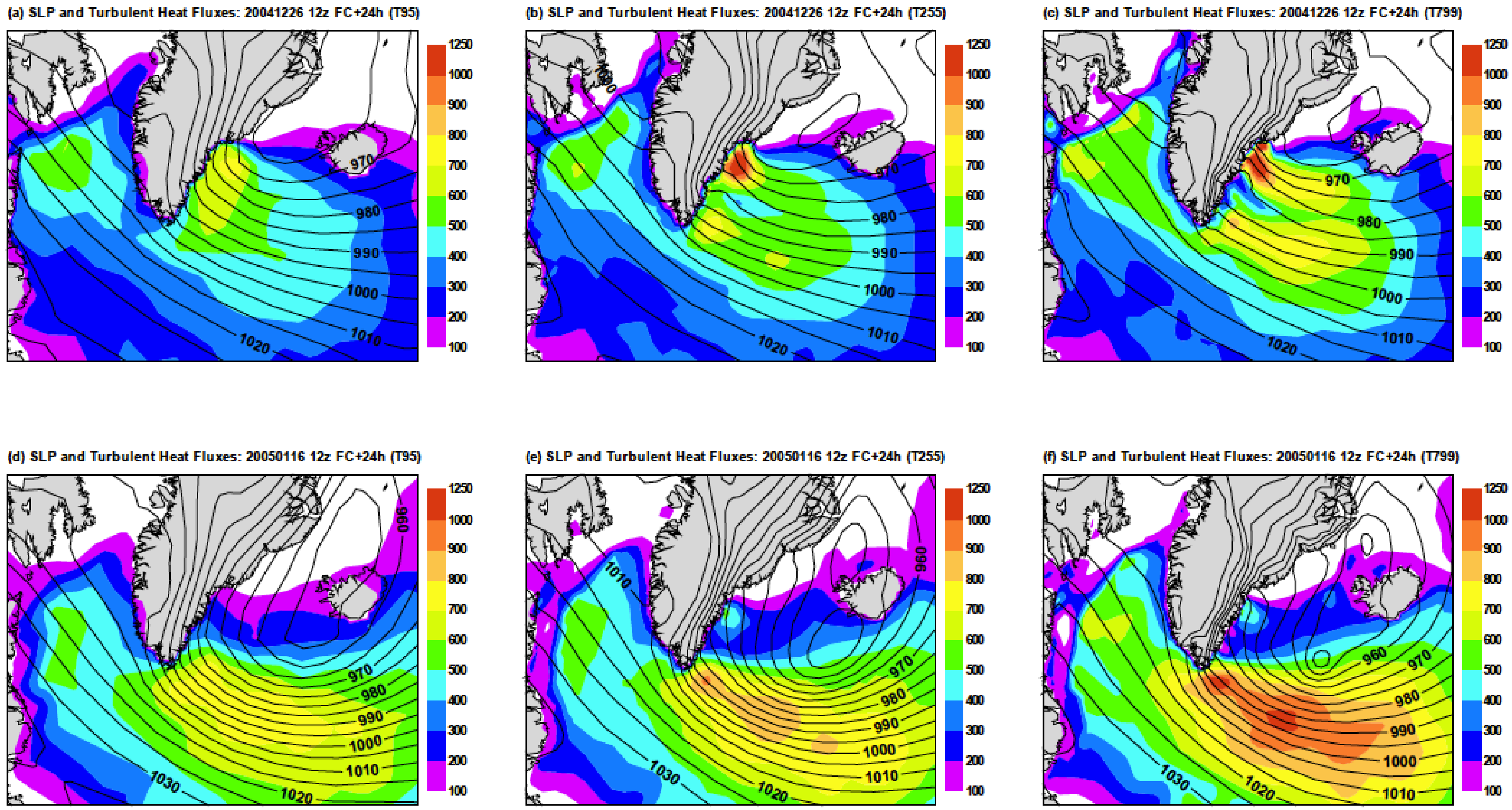
Jung and Leutbecher (2007)

Modelling

Goal: Improve representation of key processes in models of the polar atmosphere, land, ocean and cryosphere

- Improve representation of key dynamical and physical processes (e.g. PBL, sea ice rheologies)
- Develop stochastic parametrizations
- Explore the role of horizontal and vertical resolution
- Develop coupled model systems across all forecast ranges

Topograhic Jets and Resolution



Jung and Rhines (2007)

Scale dependent predictability

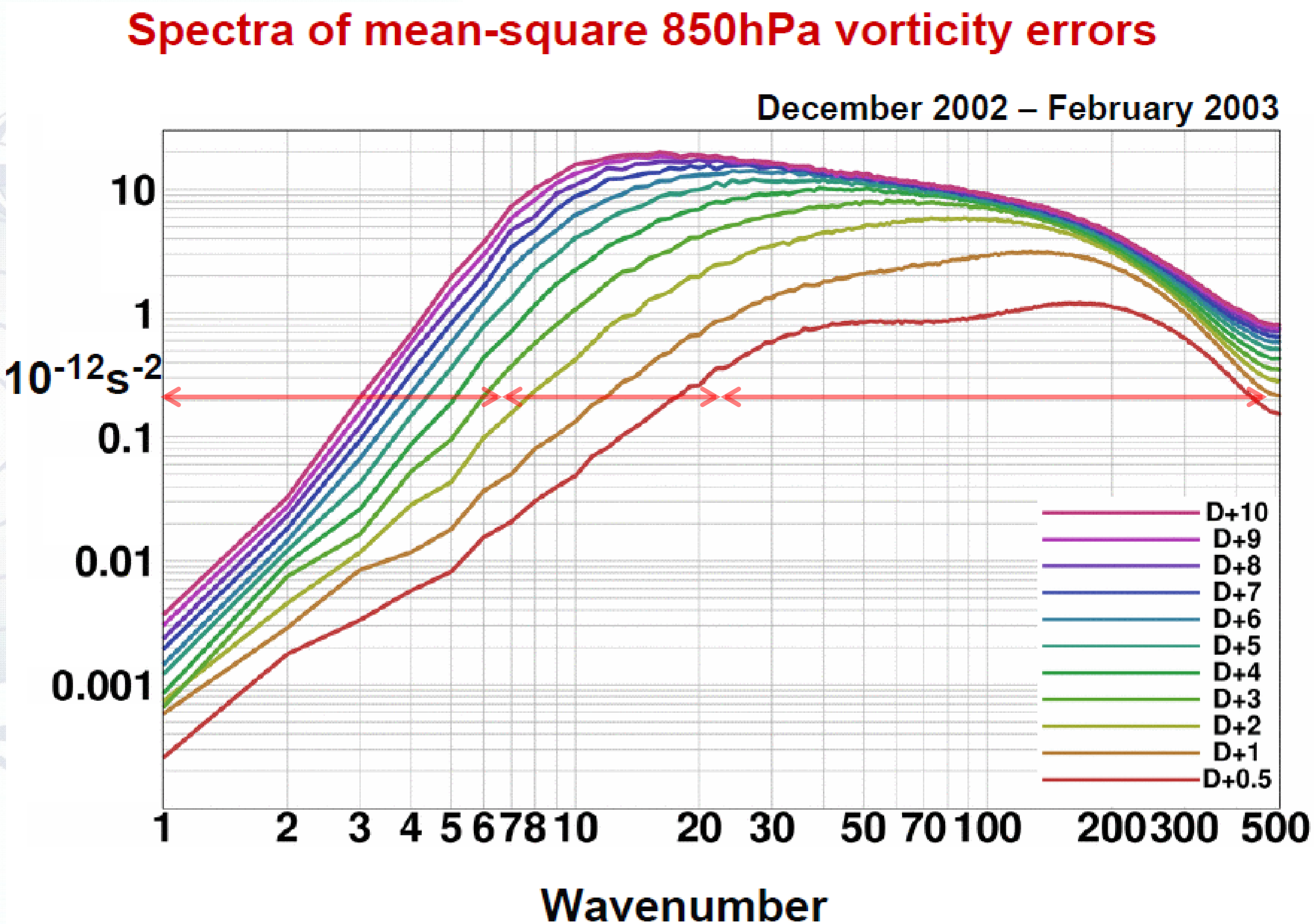
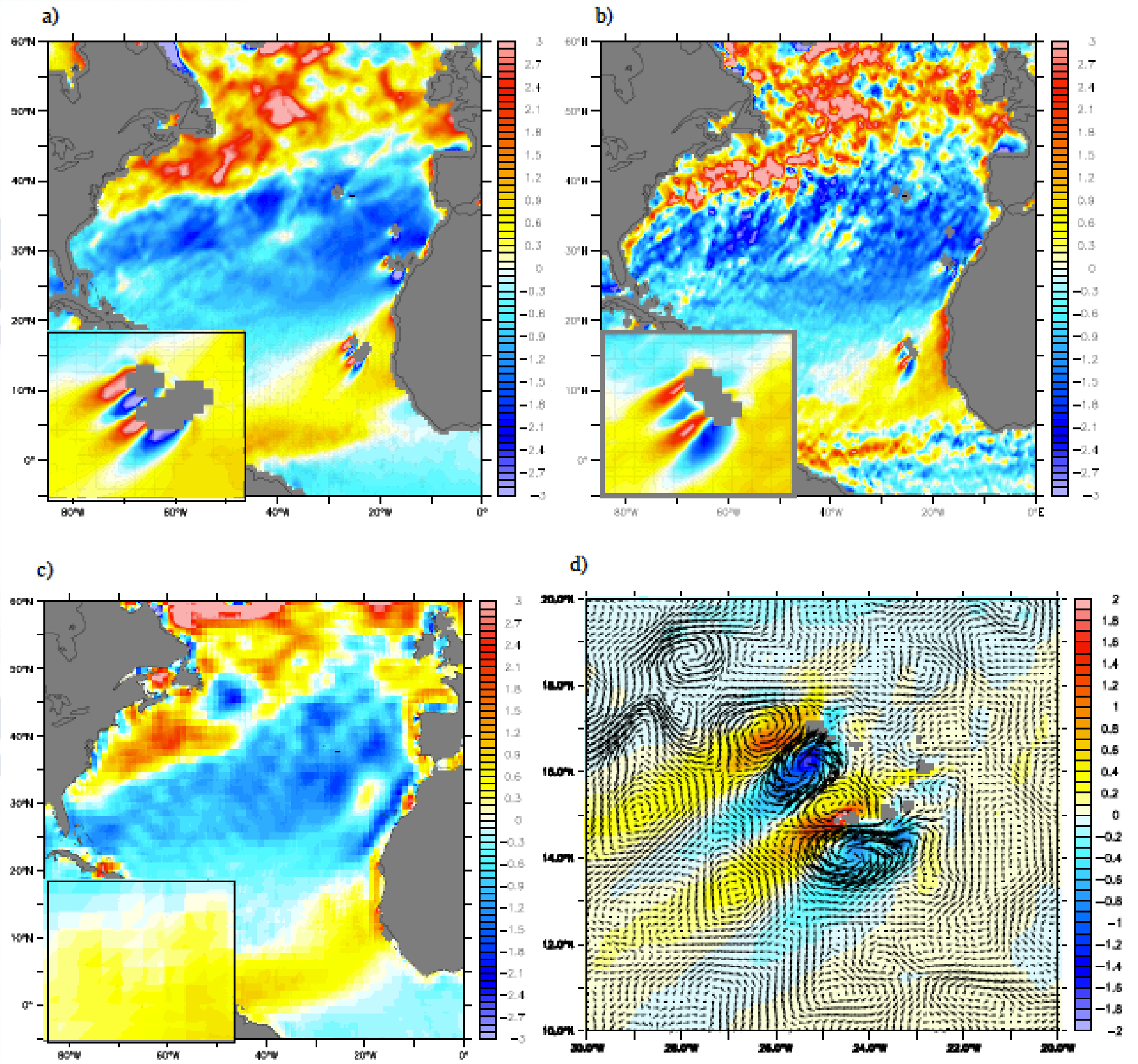


Figure courtesy of A. Simmons (ECMWF)

Oceanic response to high-resolution atmospheric forcing



Eden and Jung (2006)

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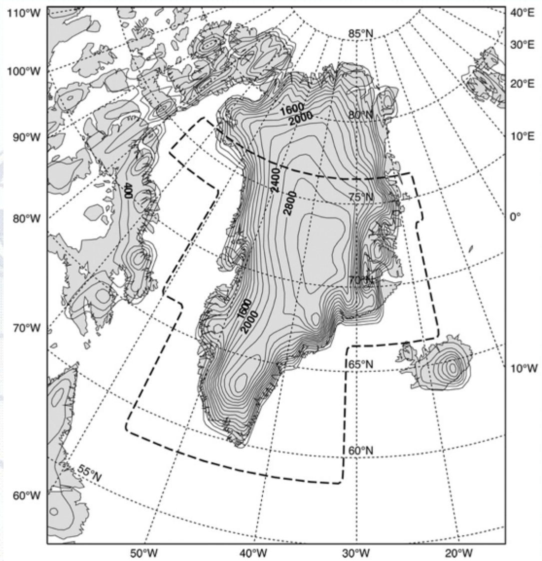
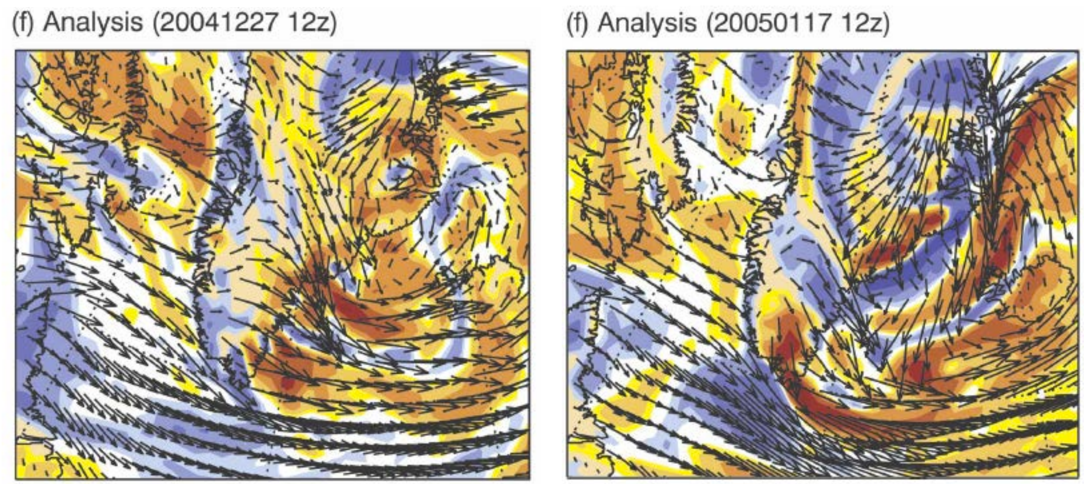
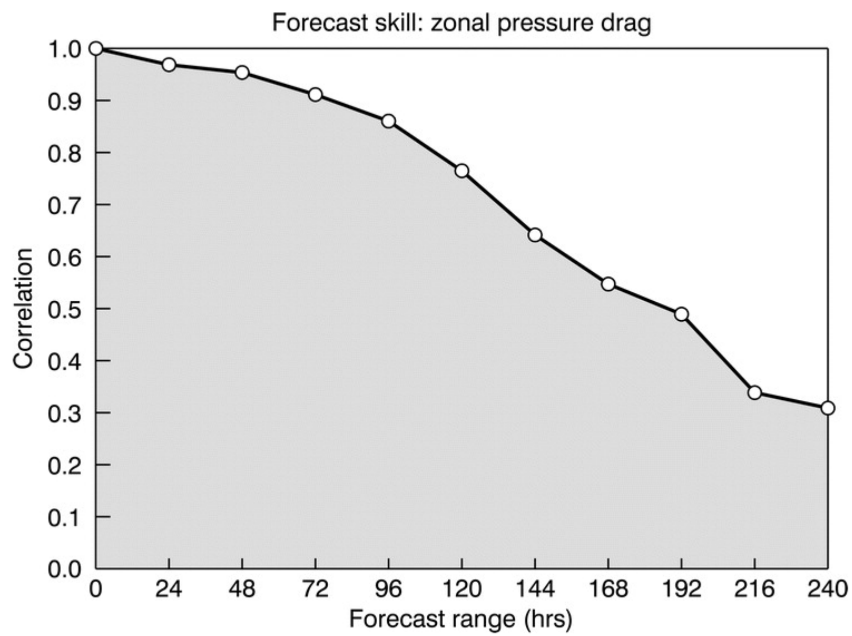
Scale dependent predictability



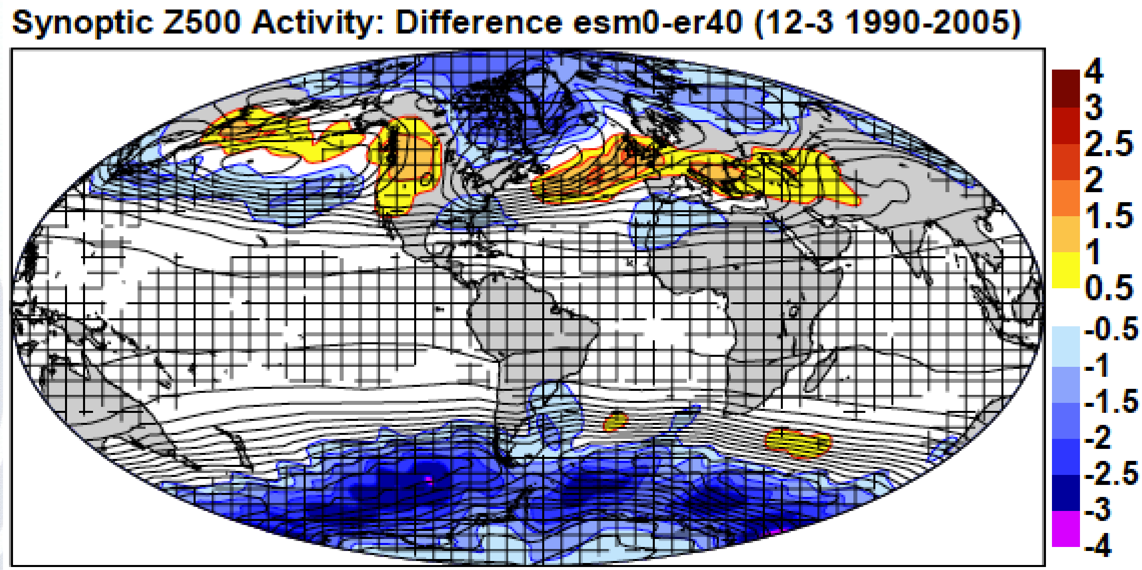




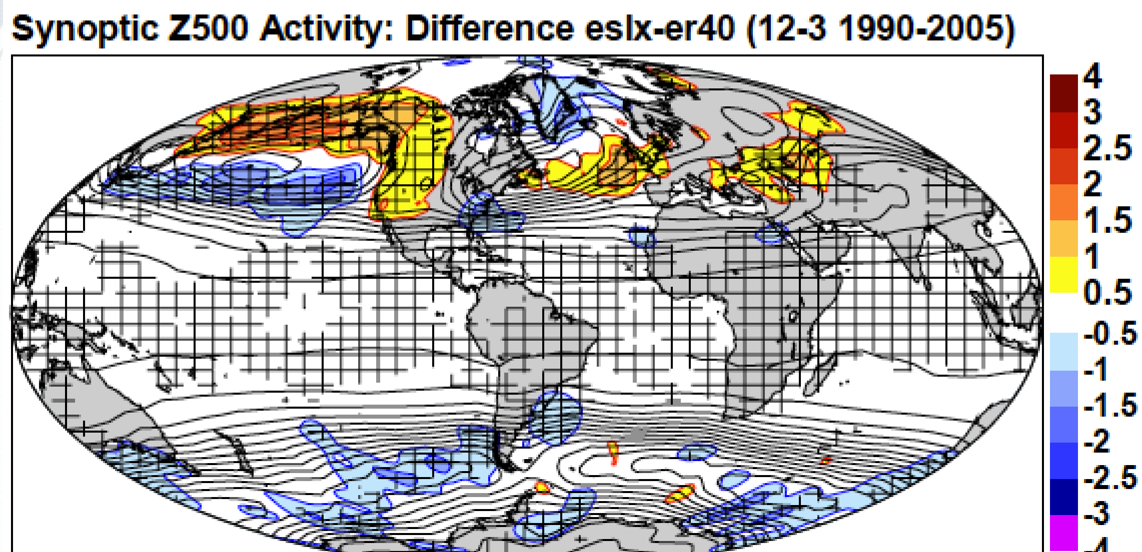
Jung and Rhines (2007)

Synoptic eddy activity and resolution

T95-ERA40

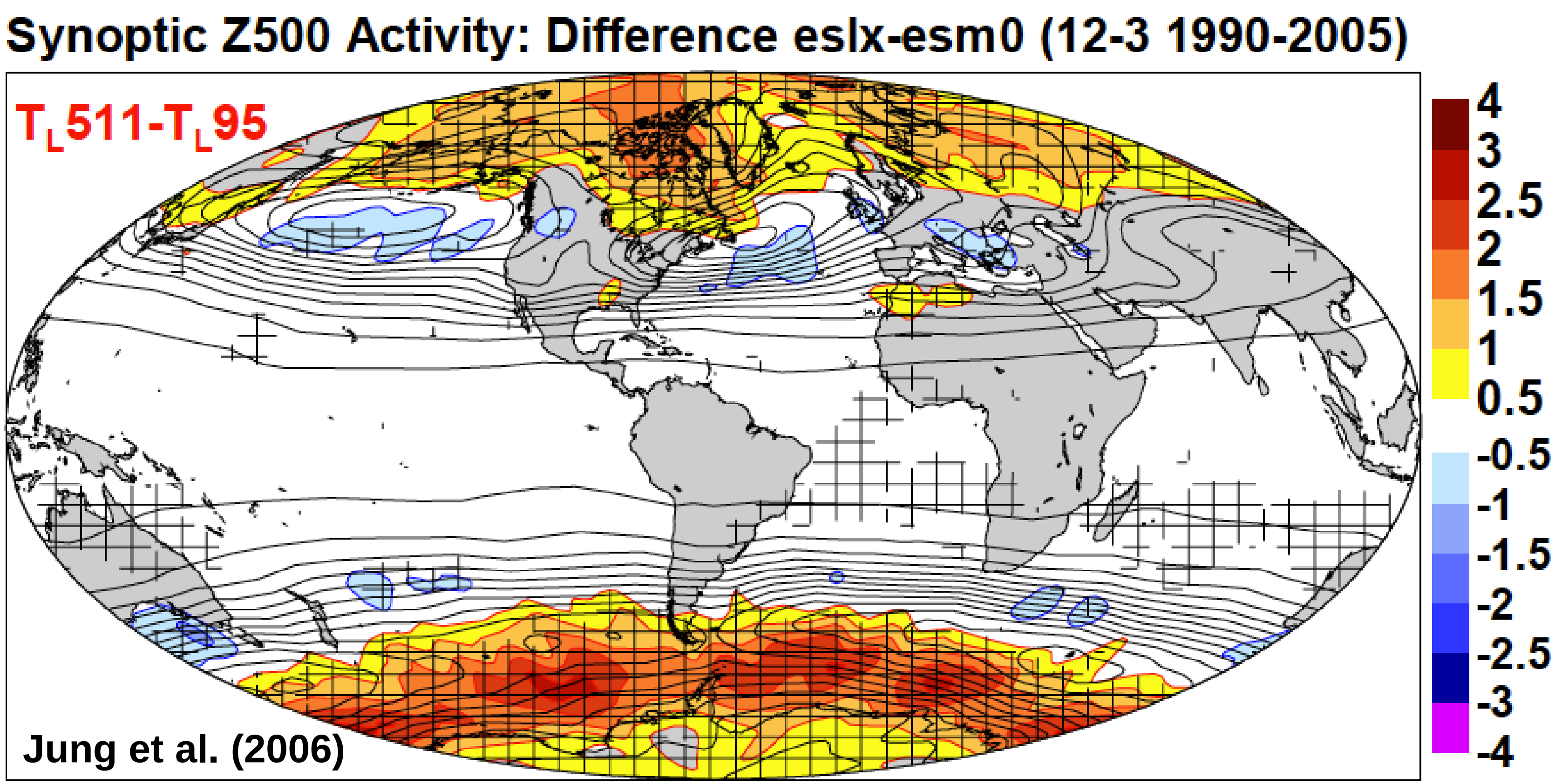


T511-ERA40

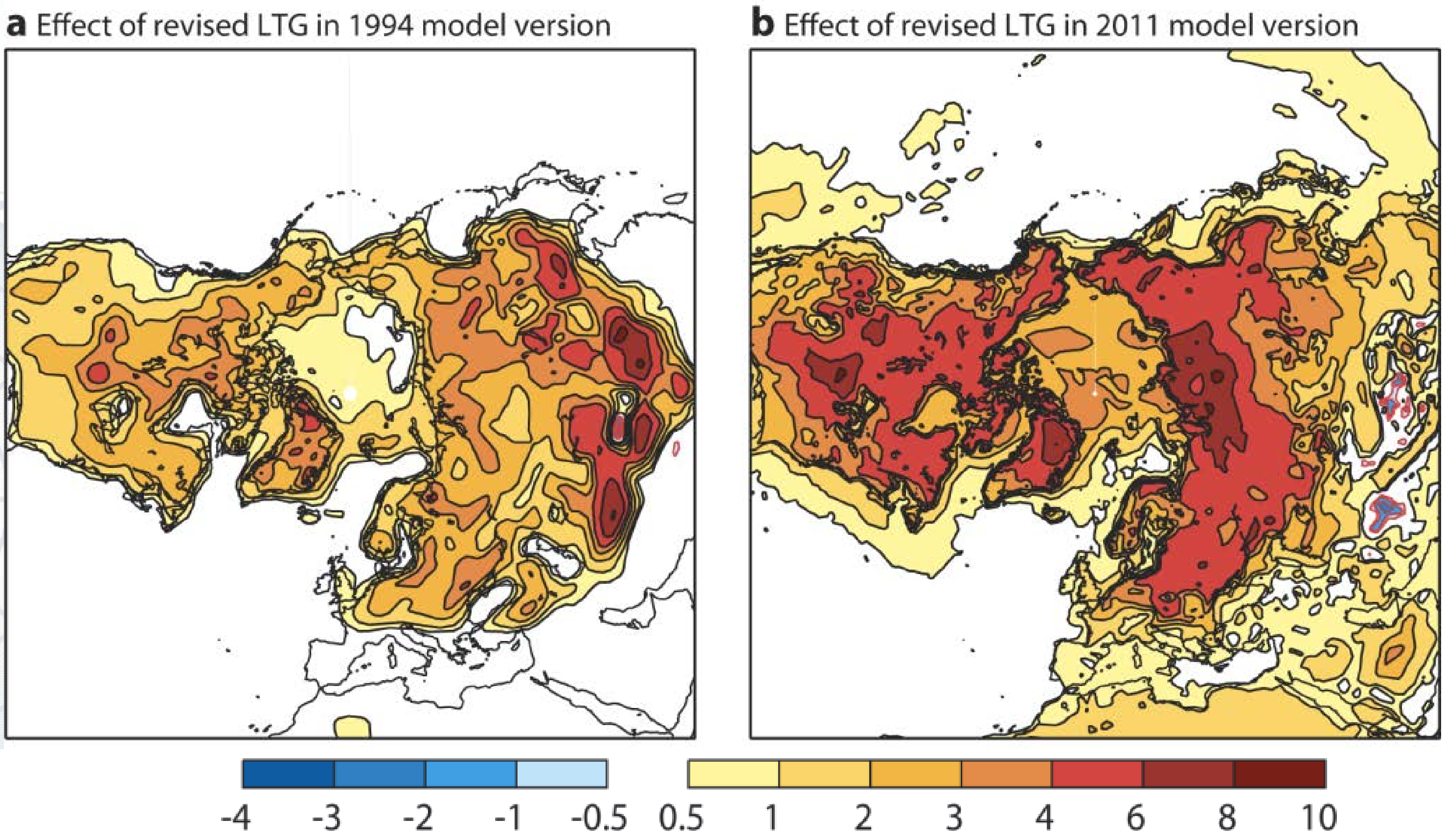


Jung et al. (2006)

Synoptic eddy activity and resolution



Sensitivity to Model Formulation



Effect of revised diffusion in PBL scheme on averaged January 1996 temperature. These sensitivity experiments were performed by starting a long integration from 1 October 1995 and applying relaxation to the 6-hourly operational analyses above 500 m from the surface. This is an efficient way of doing "deterministic" seasonal integrations without constraining the stable boundary layer.

Beljaars (2012)

Ensemble forecasting

Goal: Develop and exploit ensemble prediction systems with appropriate representation of initial and model uncertainty for polar regions

- Assess performance of existing EPSs and LAM-EPSs in polar regions
- Improve initial perturbation methods for the atmosphere
- Develop initial perturbation methods for sea ice, ocean and land surface models
- Develop methods to account for model uncertainty
- Monitor probabilistic prediction skill of high-impact weather and climate events in polar regions

New TIGGE Products

Raise awareness: there are low hanging fruits...

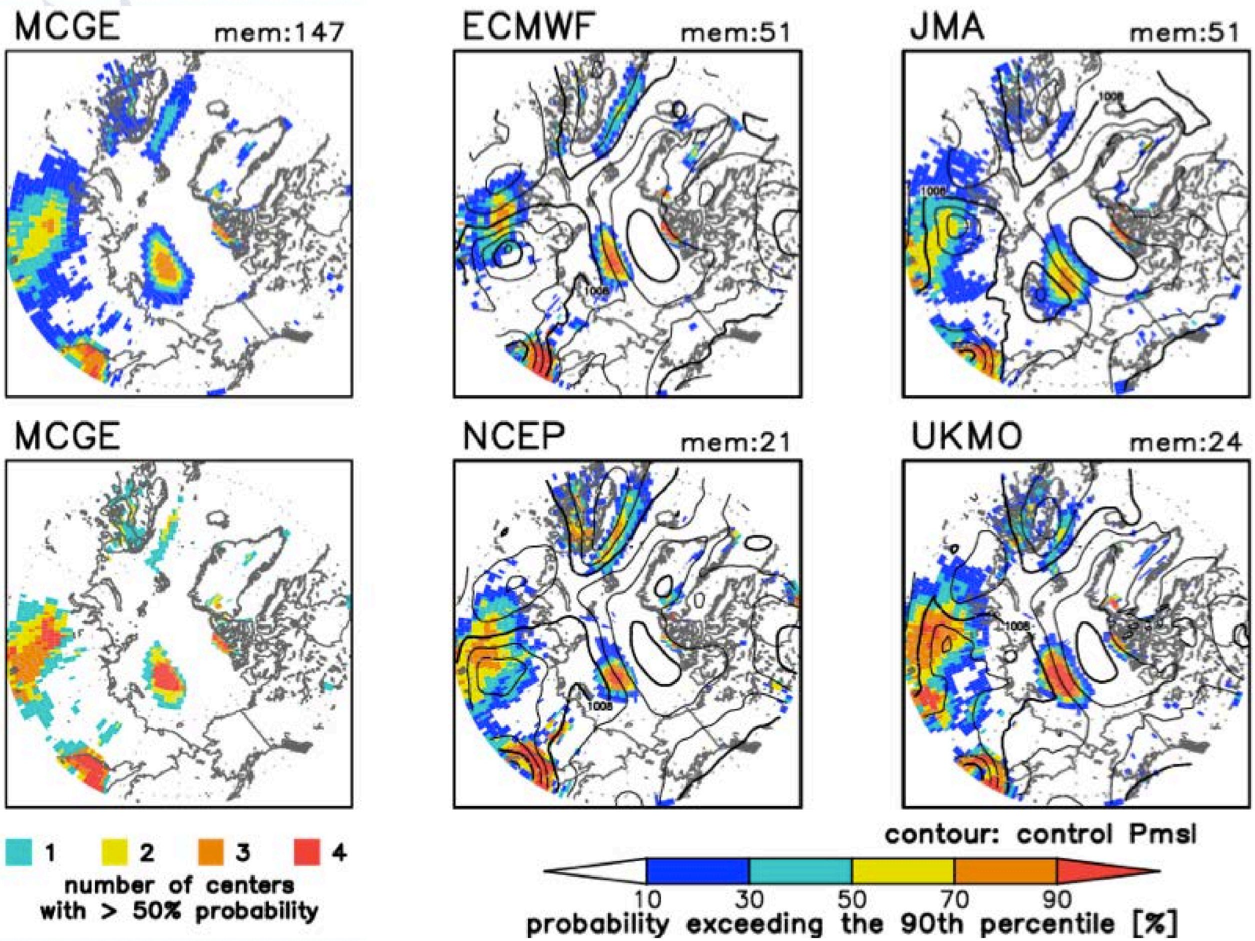


Figure courtesy of Mio Matsueda (Oxford)

New TIGGE Products (cont‘d)

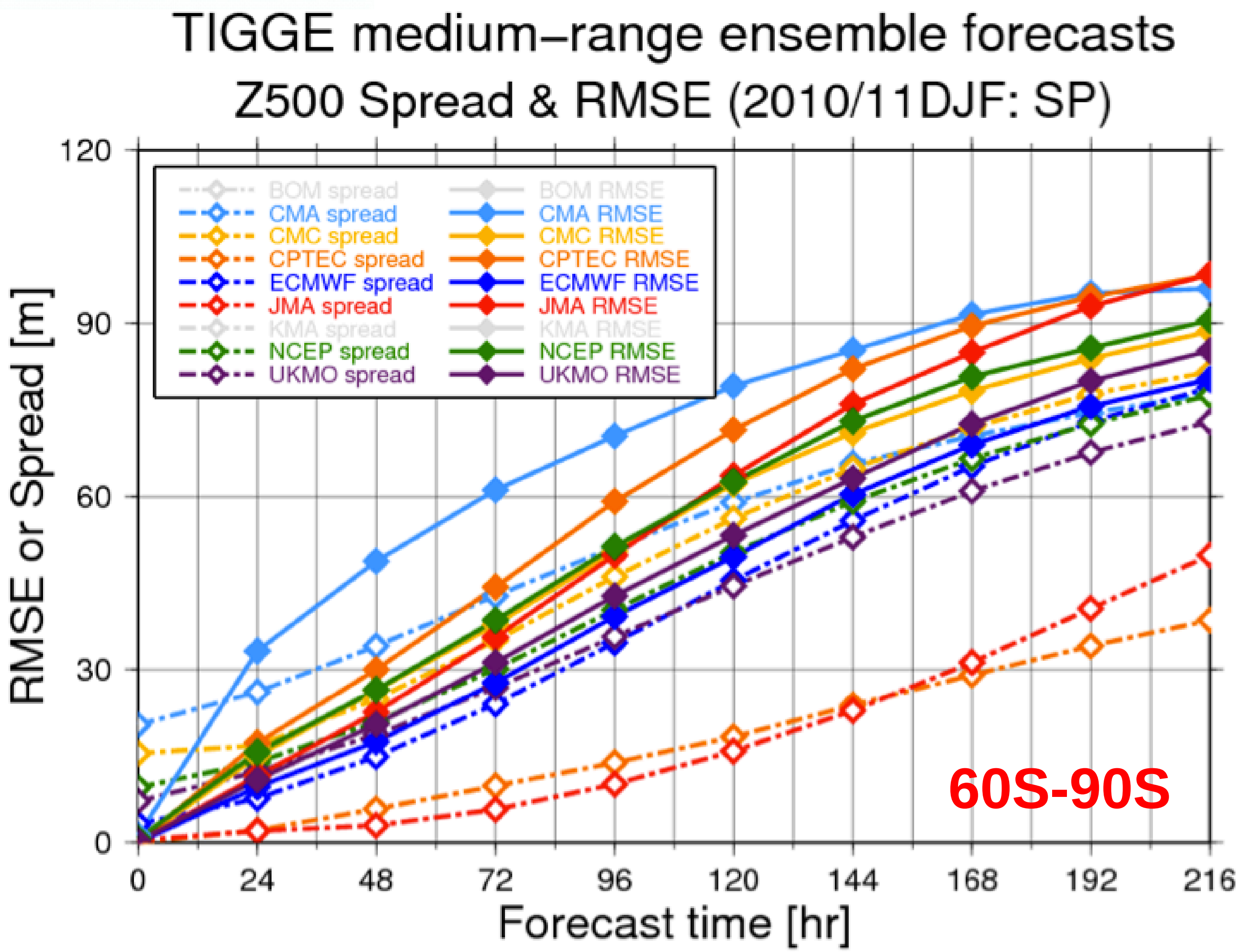
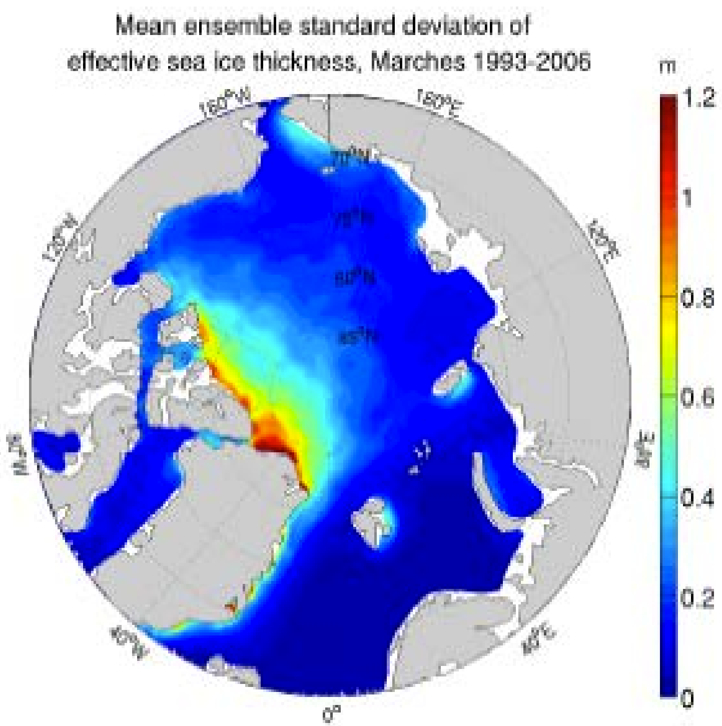


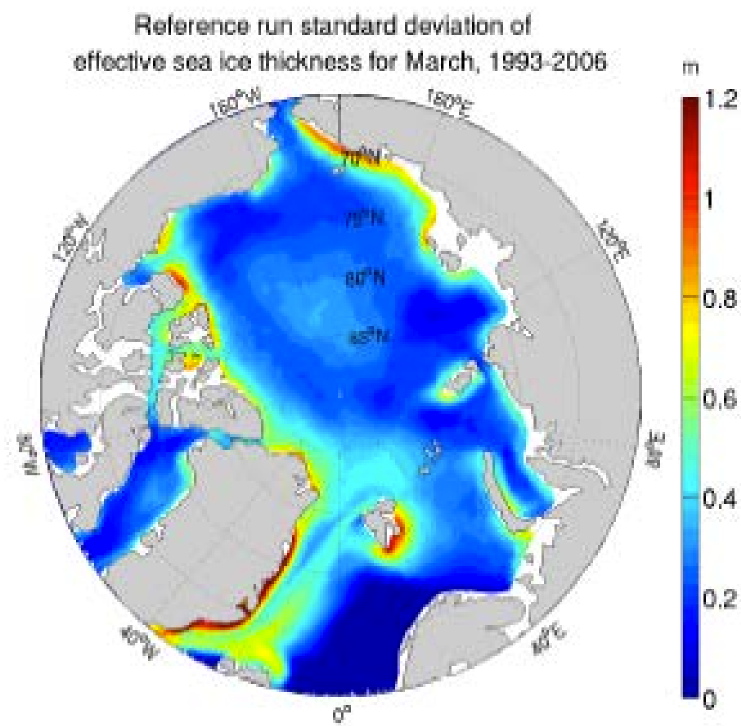
Figure courtesy of Mio Matsueda (Oxford)

Stochastic Sea Ice Parametrizations

Ensemble Spread



Interannual variability



Juricke et al. (2013), J. Climate, accepted

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Data Assimilation

Goal: Develop data assimilation systems that account for the unique character of the polar regions

- Evaluate existing analysis and reanalysis data sets
- Develop improved background error covariance matrices for the polar regions (PBLs, sea ice, ...)
- Develop coupled data assimilation schemes
- Develop data assimilation schemes with representation of model uncertainty
- Improved models for simulating surface emissivity in infrared and microwave spectral range for snow, sea-ice, frozen ground, vegetation etc.

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Mean T Ensemble Forecast Spread

Ensemble Spread | **RMS An Increment**

200 hPa

1000 hPa

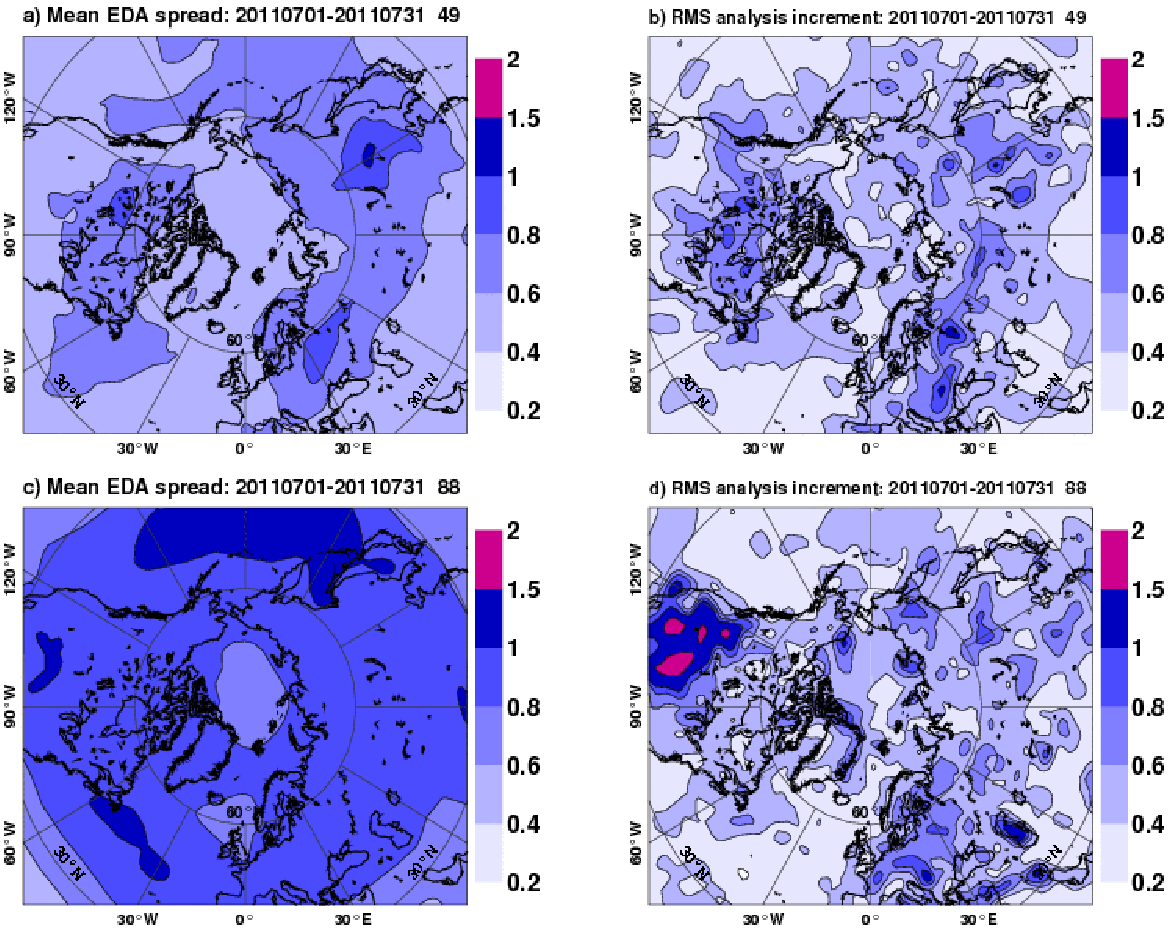

Figure courtesy of P. Bauer (ECMWF)

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Observations

Goal: Provide guidance on optimizing polar observing systems, and coordinate additional observations to support modelling and verification

- Provide observations for
  - forecast initialization
  - model development activities
  - forecast verification
- Assess the sensitivity of analysis and forecast accuracy to observation data usage and error formulations (OSE, adjoint sensitivities)
- Understand potential of future observational capabilities (OSSEs)

International Collaboration

- Forecasting brings together different communities!
- Consultation on the Implementation Plan will increase collaboration
- Cross-membership (e.g. WWRP-PPP and EC-PORS)
- Incentives
  - YOPP
  - Special data sets (establishment and use)
- Workshops, conference meetings and summer schools
- International project office (AWI happy to host!)

Strengthening Linkages Between Academia, Research Institutions and Operational Centres

- Modify funding schemes following UK, USA and Canadian examples (e.g. researchers are required to spend time at operational centres)
- Provision of computing time, experimental support and special data sets by operational centres
- Ensure continual near-real-time availability (e.g. GTS) of future operational and experimental campaign observations
- Committee work

Establish and Exploit Special Research Data Sets

- Inventory of existing data sets: TIGGE, YOTC, reforecasts, DEMETER, Athena etc.
- Formulate special requirements and devise special experiments together with other working groups (e.g. WGNE and SG Subseasonal and Seasonal Prediction)
- Limited value from case studies!
- Need for long sustainable, openly accessible data sets
- High-resolution reanalysis

Other Strategic Issues

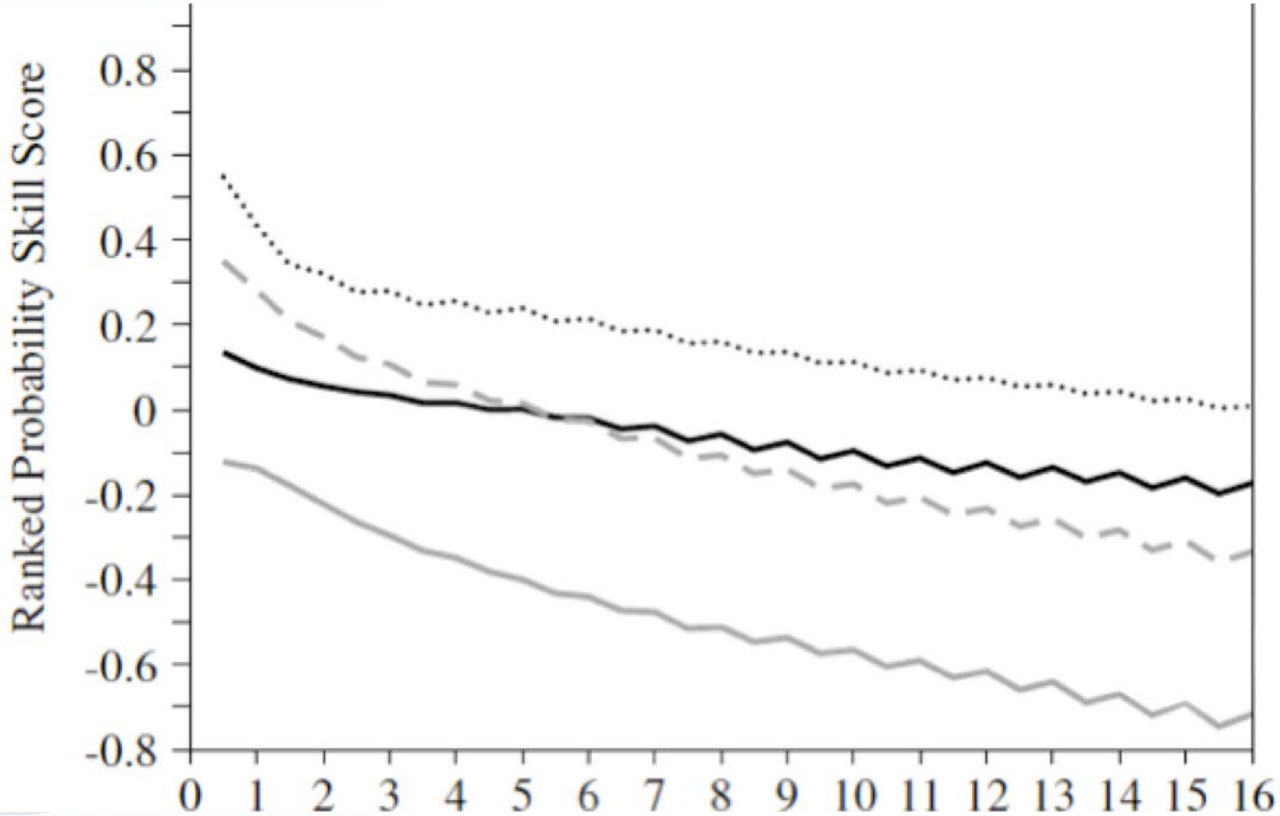
- Write BAMS paper about WWRP Polar Prediction Project
- Prepare WWRP-PPP brochure for funding agencies and stakeholders
- Linkages with space agencies and data providers
  - Liaise with WMO Polar Space Task Group
- Promote interaction and communication between researchers and stakeholders
  - Identification of stakeholders: NMHS, Arctic Council, private sector companies etc.
  - Organize meetings to bring communities together
- Education and outreach (collaboration with APECS)

Additional Figures from Implementation Plan After Here

Potential Polar Perils

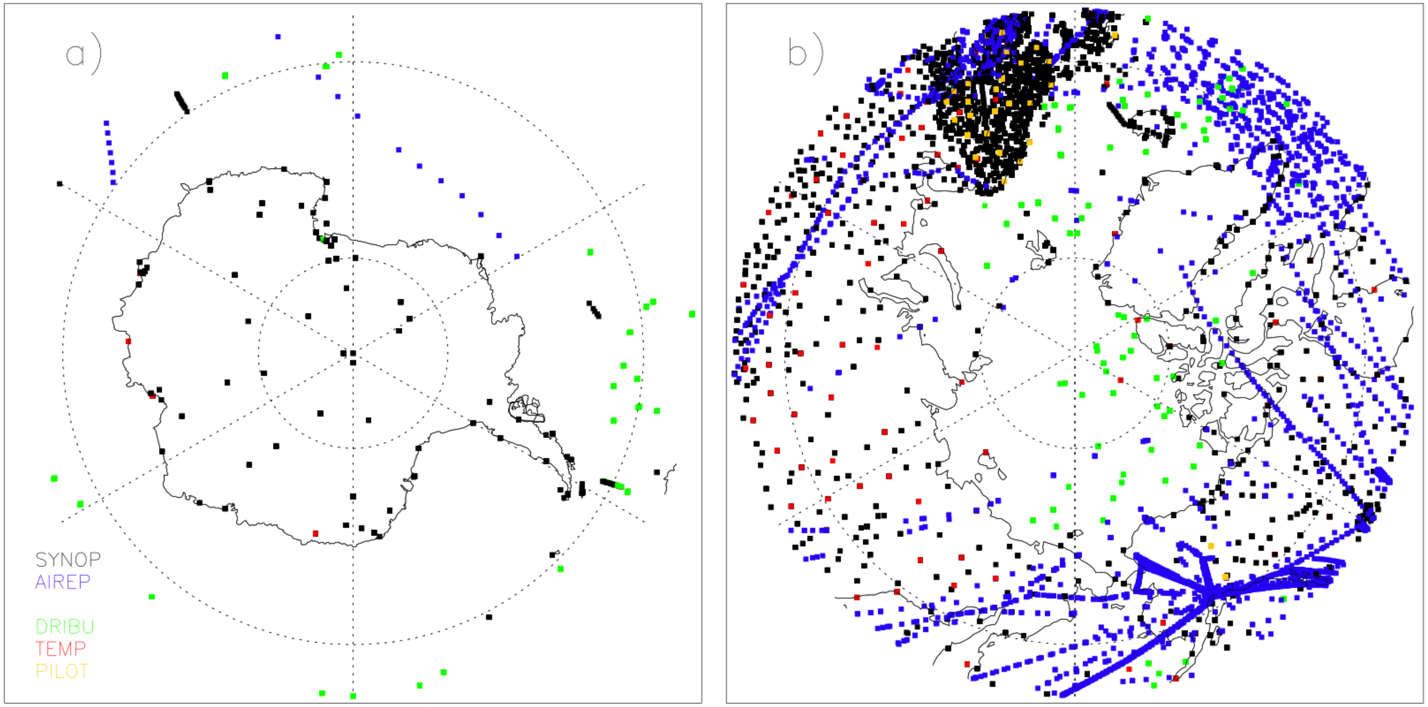
Cruise vessel M/S Explorer sinking off Antarctica in 2007, illustrating the potential perils of operating in polar weather and ice conditions. Photograph from Chilean Navy/Reuters

Verification Sensitivity



Sensitivity of probabilistic forecast skill to the analysis used for verification, showing the incestuous nature of using the same model for analysis and verification. Average Ranked Probability Skill Score (RPSS) for probabilistic forecasts of tropical temperature at 850 hPa with the NCEP ensemble prediction system using NCEP's own analyses (dotted), and ECMWF (solid-black), Met Office UK (solid-grey) as well as the multi-centre mean analysis (dashed-grey) for verification, for forecast periods out to 16 days. The larger the RPSS the more skilful the ensemble forecasts are. Based on Park et al. (2008).

Polar Data Coverage



Polar data coverage of conventional observations in the ECMWF operational analysis at 00 UTC on 1 January 2012 (21-09 UTC window) for (a) southern polar region, and (b) northern polar region. SYNOPs are surface reports from land stations; AIREP are in-flight reports from aircraft; DRIBU are surface drifting buoys; TEMP are upper air balloon soundings; PILOT are upper air winds from tracked balloons.

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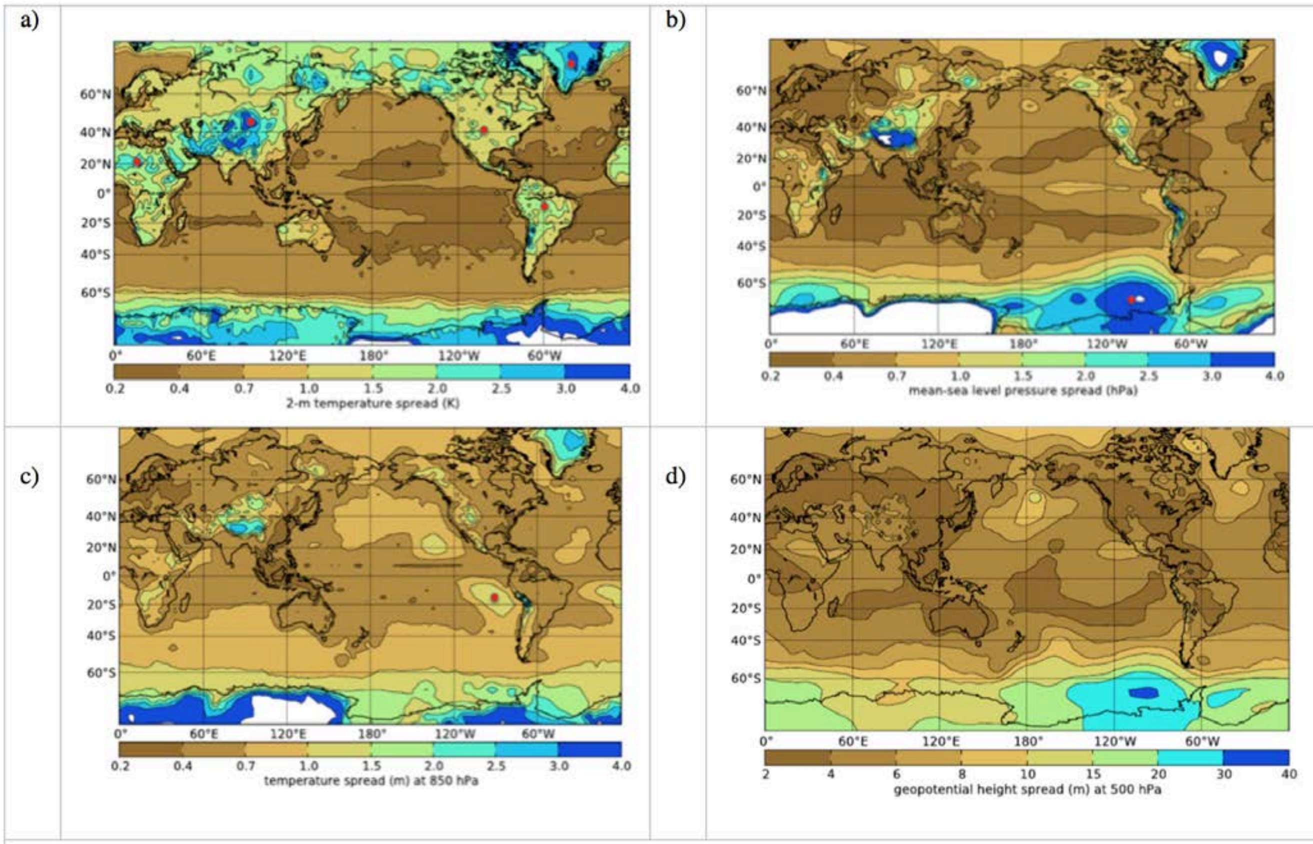
Analysis Differences in Polar Regions and High Terrain



Spread of analysis mean for (a) 2-metre temperature, (b) mean sea-level pressure, (c) 850 hPa temperature, and (d) 500 hPa geopotential height from 5 operational TIGGE models (UKMO ECMWF, NCEP, CMC, CMA; 10/2010-11/2010) (Hamill 2012, pers. comm.).

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Additional Figures from Science Plan After Here

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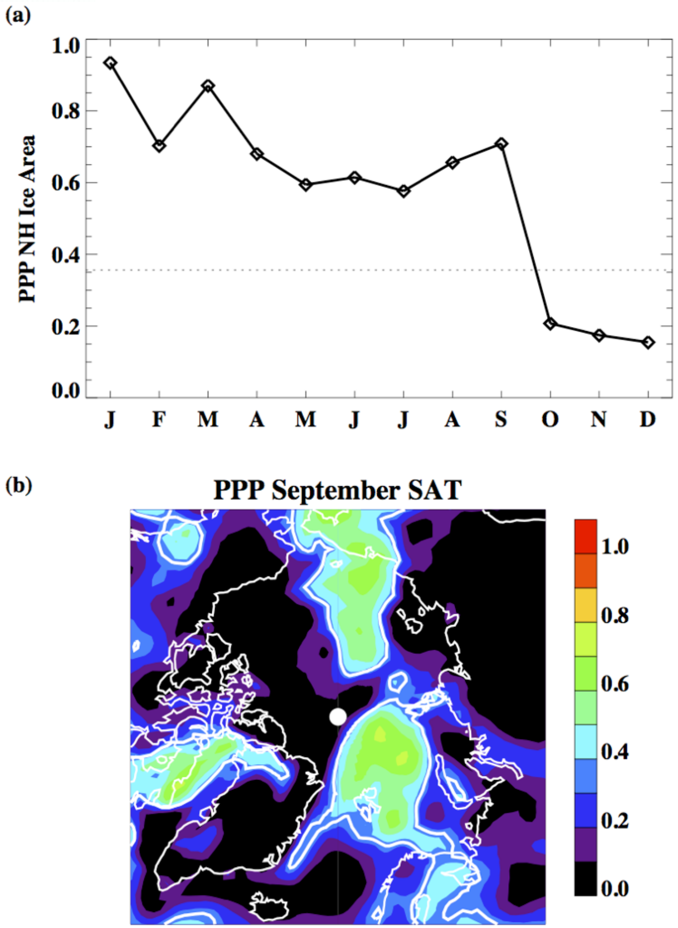
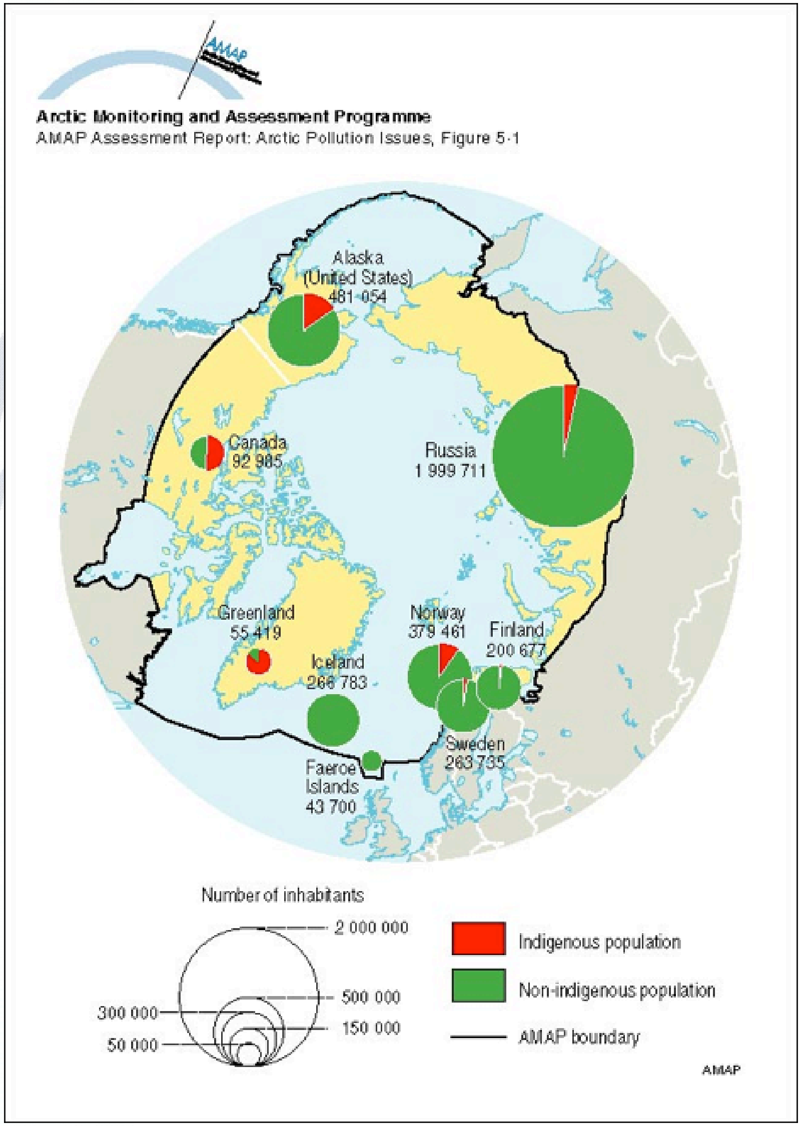
Potential Predictability

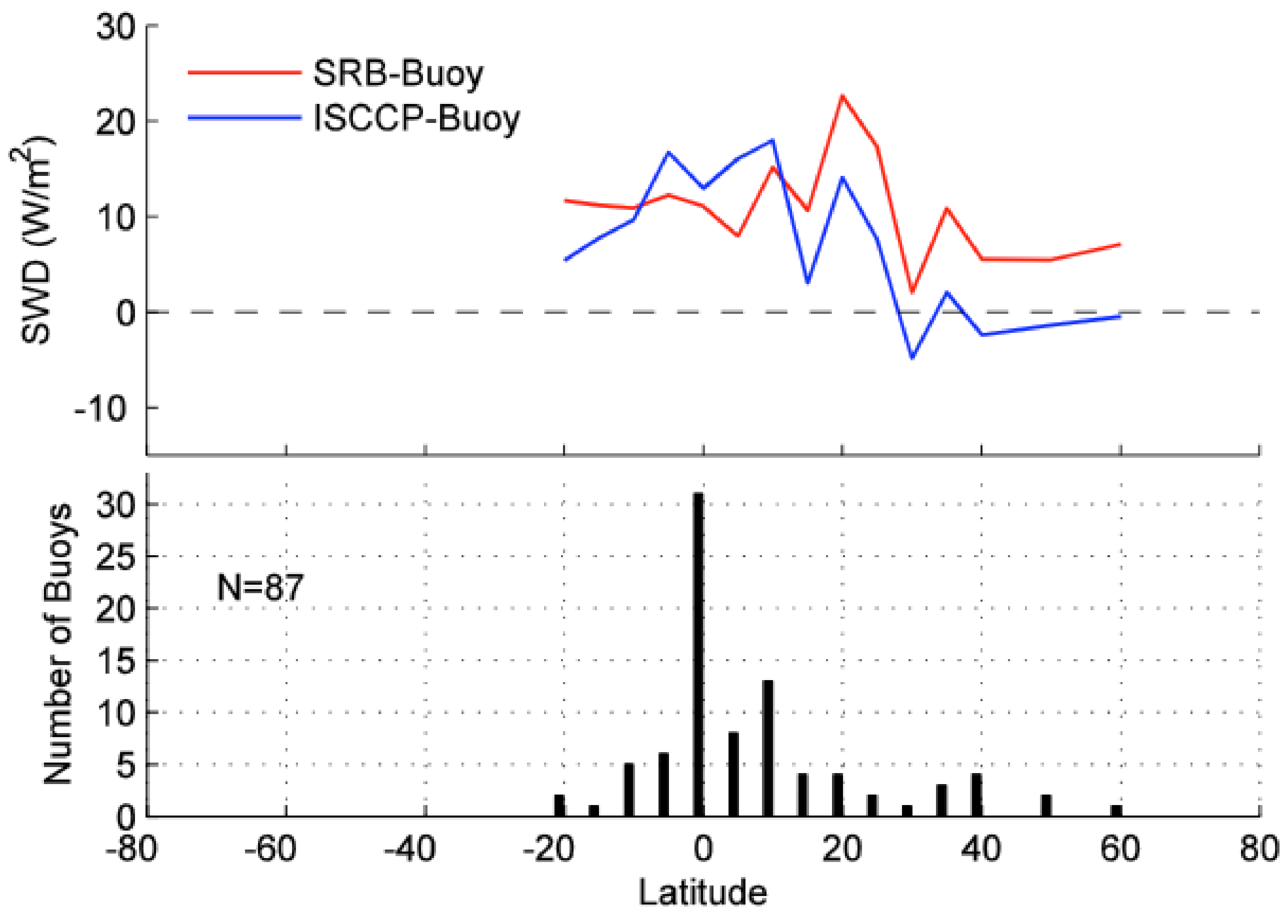


The prognostic potential predictability in (a) northern hemisphere sea ice area as a function of month and (b) September surface air temperature (SAT) for perfect model simulations initialized in January (see Holland et al. 2011). A value of 1 indicates perfect predictability, values above the dotted line in (a) and within the white contour in (b) indicate significant potential predictability. Note that significant potential predictability in SAT generally aligns with the sea ice edge indicating that the predictability resides in the sea ice and its influence on the overlying atmosphere.

Distribution of Arctic Indigenous and Non-Indigenous Population

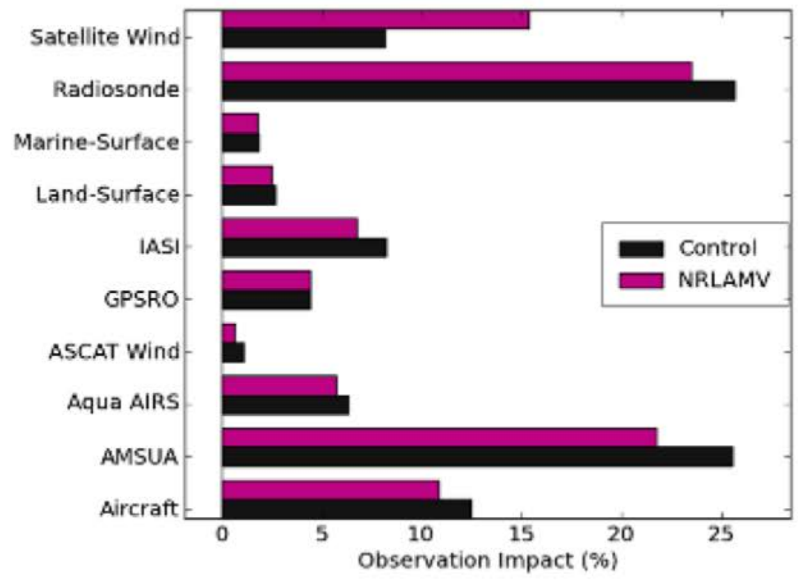


Satellite and Buoy Comparison



Differences of mean downward solar radiation satellite products with buoy observations for the last 20 years as a function of latitude: upper panel, mean difference; lower panel, number of buoy sites (Fairall et al. 2012).

Observational Impacts



Fractional observation impacts for forecasts run from December 10, 2010 to January 31, 2011. The control runs (black) made use of the standard GEOS-5 data set, while the NRLAMV runs (magenta) substitute FNMOC AMVs for those normally used in GEOS-5.

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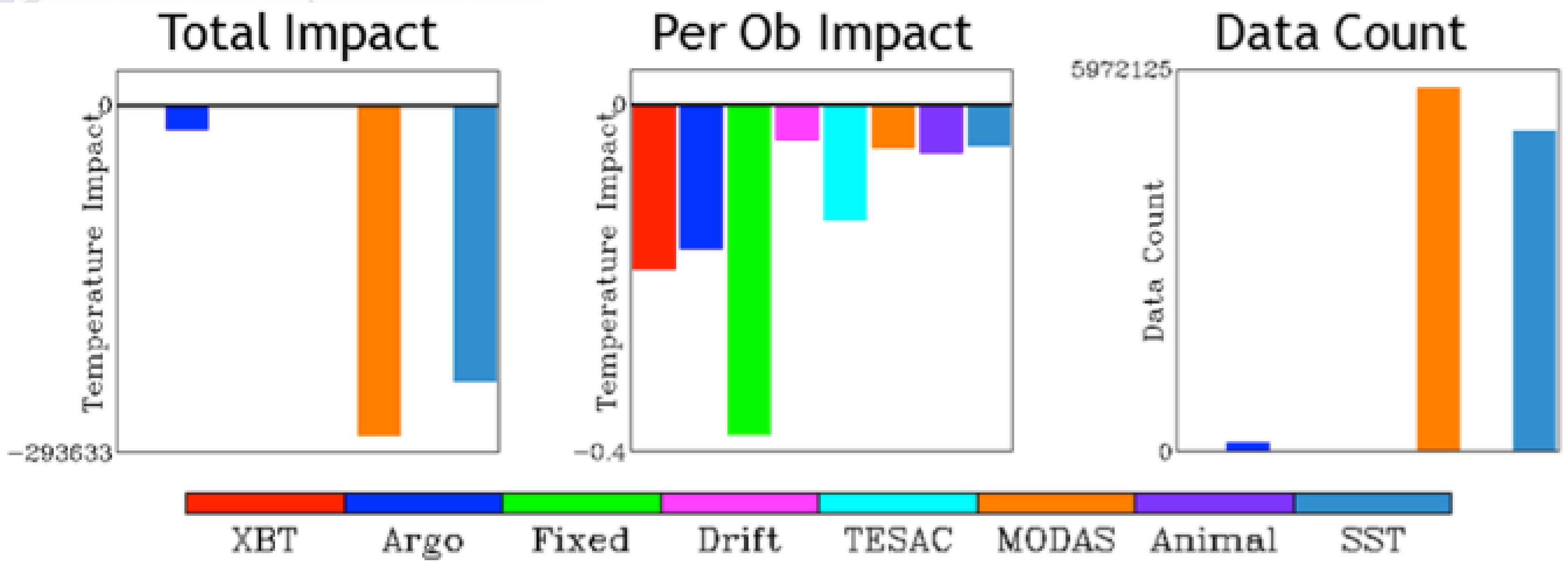
Temperature Data Impatcs US Navy HYCOM



Histogram plots of impact of temperature data in global HYCOM Atlantic basin domain for October through November 2012. A negative value indicates a beneficial data impact (assimilation of that data type reduced forecast error). Similar results are found for other ocean basins (Indian, Pacific, Arctic). XBT: expendable bathythermographs; Argo: Argo profiling floats; Fixed: fixed buoys; Drift: drifting buoys with thermistor chains; TESAC: CTD, ocean gliders; MODAS: synthetic temperature profiles from altimeter SSH; Animal: animal borne sensors; SST: satellite and in-situ sea surface temperature.

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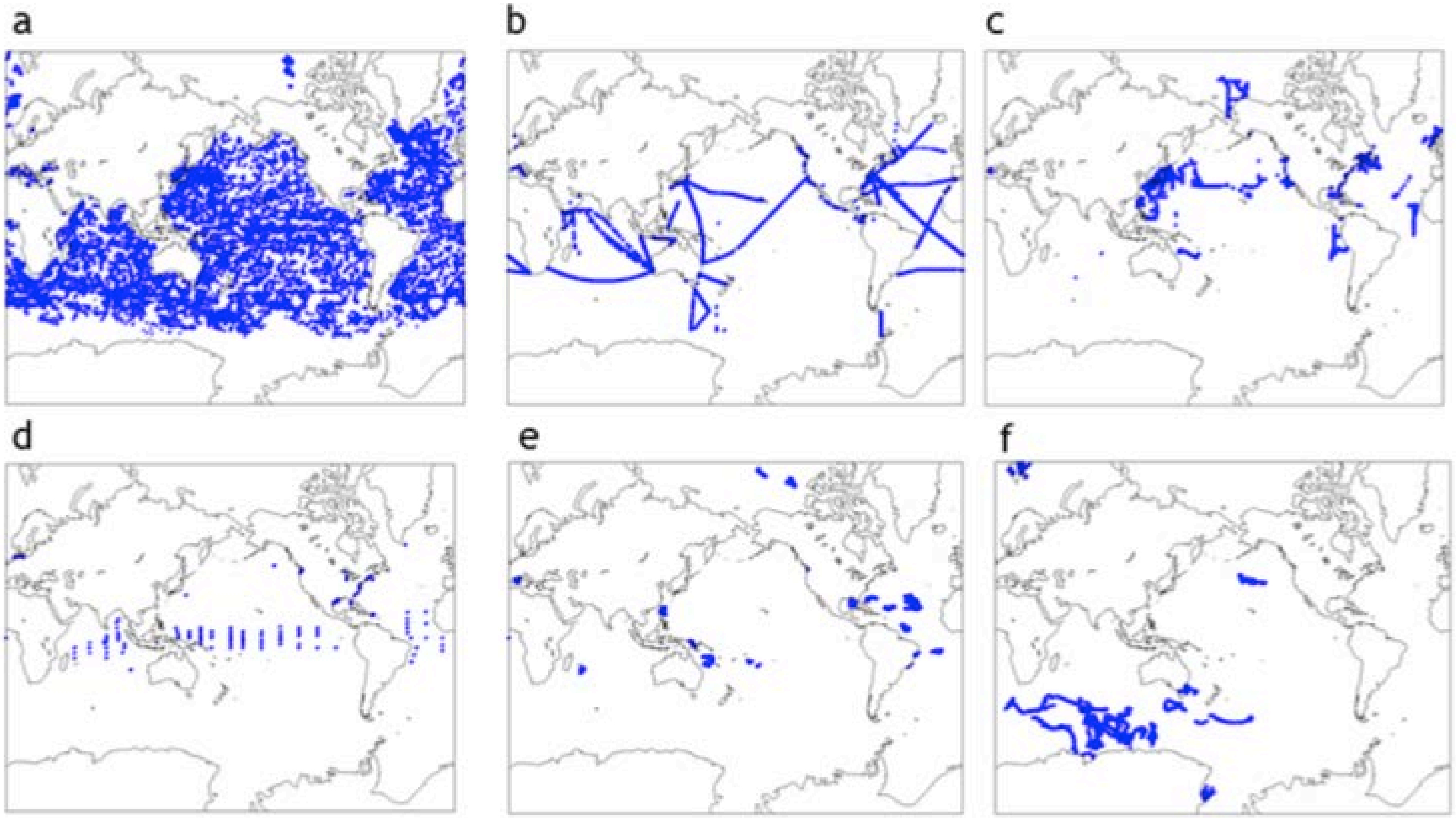
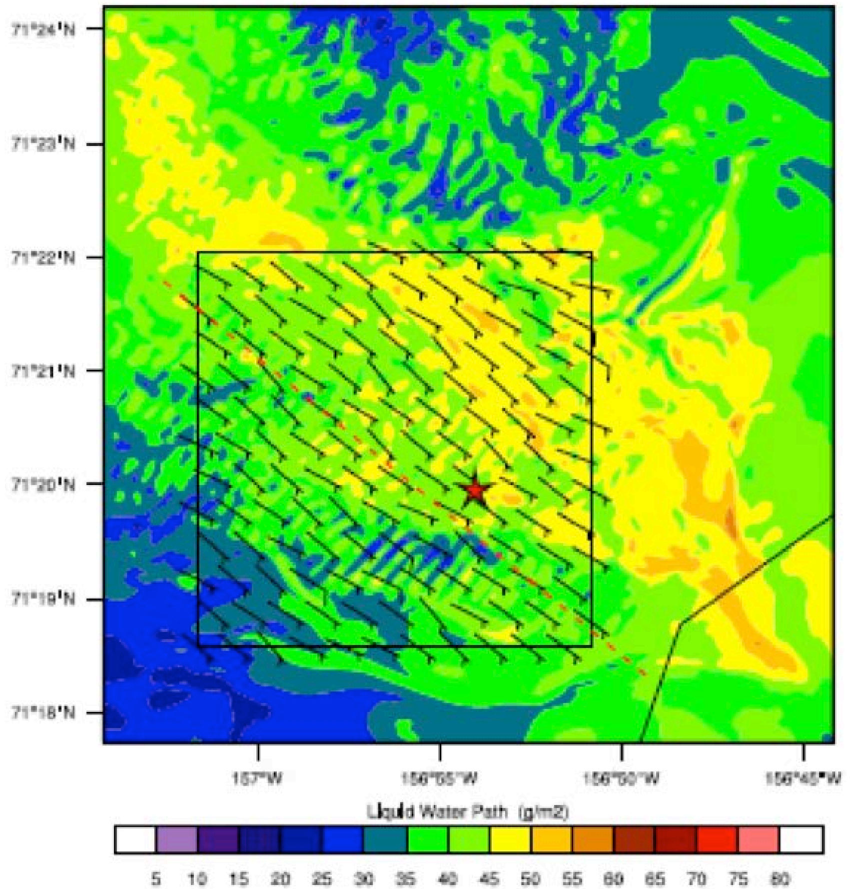
Data Coverage of Profiling Data Types



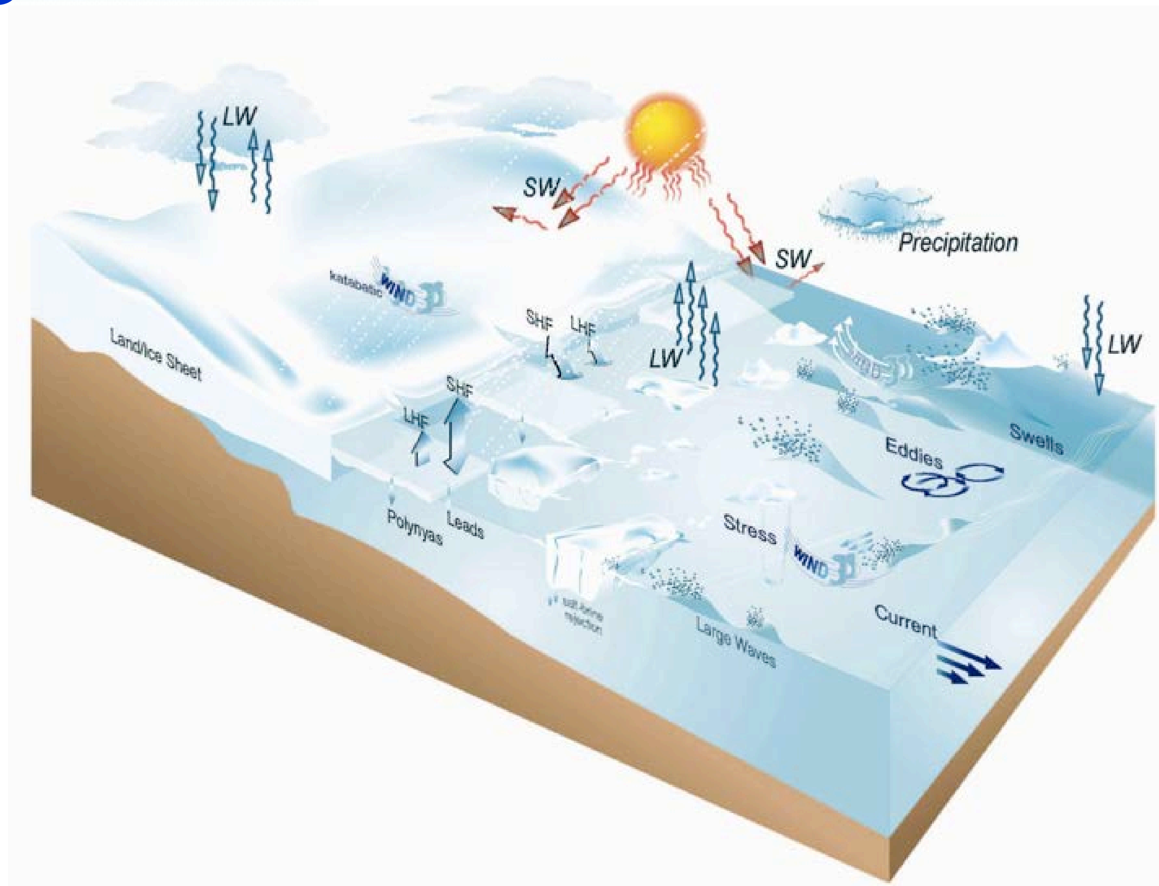
Data coverage of profiling data types for September through November, 2012. (a) Argo, (b) XBT, (c) TESAC, (d) fixed buoys, (e) drifting buoys with thermistor chains, (f) animal borne sensors. TESAC is a WMO code form and includes CTD and ocean glider observations.

Large Eddy Simulation Alaska



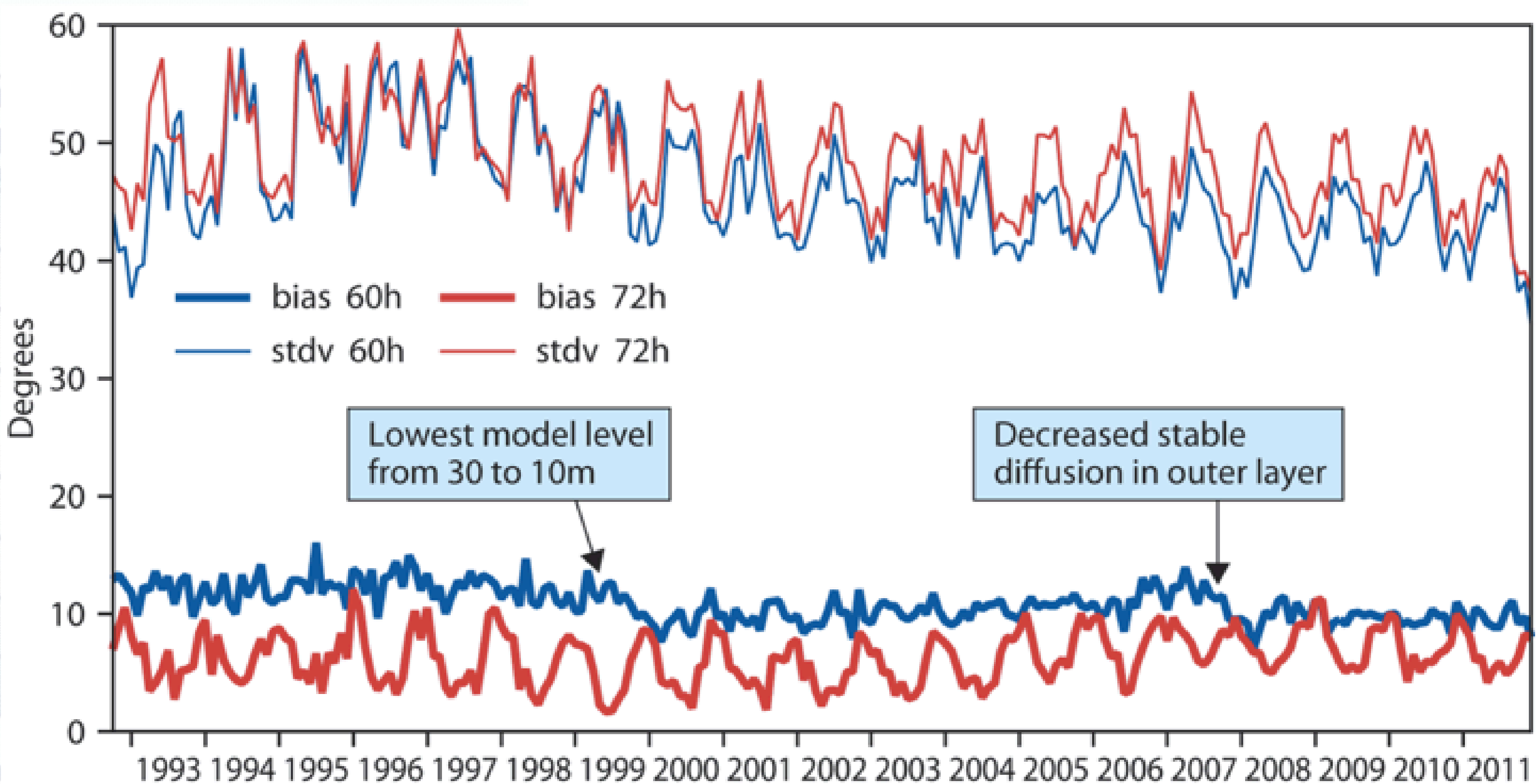
Liquid water path (colour) and winds (flags) at maximum liquid water level at 20 Z on 8 April 2008 for the 50 m nest LES simulation. A half barb on the wind flags indicates 5ms^{-1} and a full barb 10ms^{-1}. The square marks the region used to make total, downdraft, and updraft averages (130×130 grid points). The red star marks the location of vertical profiles used for model-observation comparisons. Barrow, Alaska is located directly to the east of the red star, to the right of thin black lines in the lower right marking the Alaska coastline. From Solomon et al. (2009).

High Latitude Surface Processes



Schematic of surface fluxes and related processes for high latitudes. Radiative fluxes are both shortwave (SW) and longwave (LW). Surface turbulent fluxes are stress, sensible heat (SHF), and latent heat (LHF). Ocean surface moisture fluxes are precipitation and evaporation (proportional to LHF.) Processes specific to high-latitude regimes can modify fluxes. These include strong katabatic winds, effects due to ice cover and small-scale open patches of water associated with leads and polynyas, air-sea temperature differences that vary on the scale of eddies and fronts (i.e., on the scale of the oceanic Rossby radius, which can be short at high latitudes), and enhanced fresh water input associated with blowing snow. From Bourassa et al. (2013).

Surface Wind Direction Bias



Historic evolution of 10m wind direction errors of the operational ECMWF system. These are monthly values of mean and standard deviation of errors for step 60 and 72 h forecasts initialized daily at 1200 UTC, verifying at 0000 UTC (blue) and 1200 UTC (red) respectively. The verification is against about 800 SYNOP stations over Europe (30°N-72°N/ 22°W-72°E).

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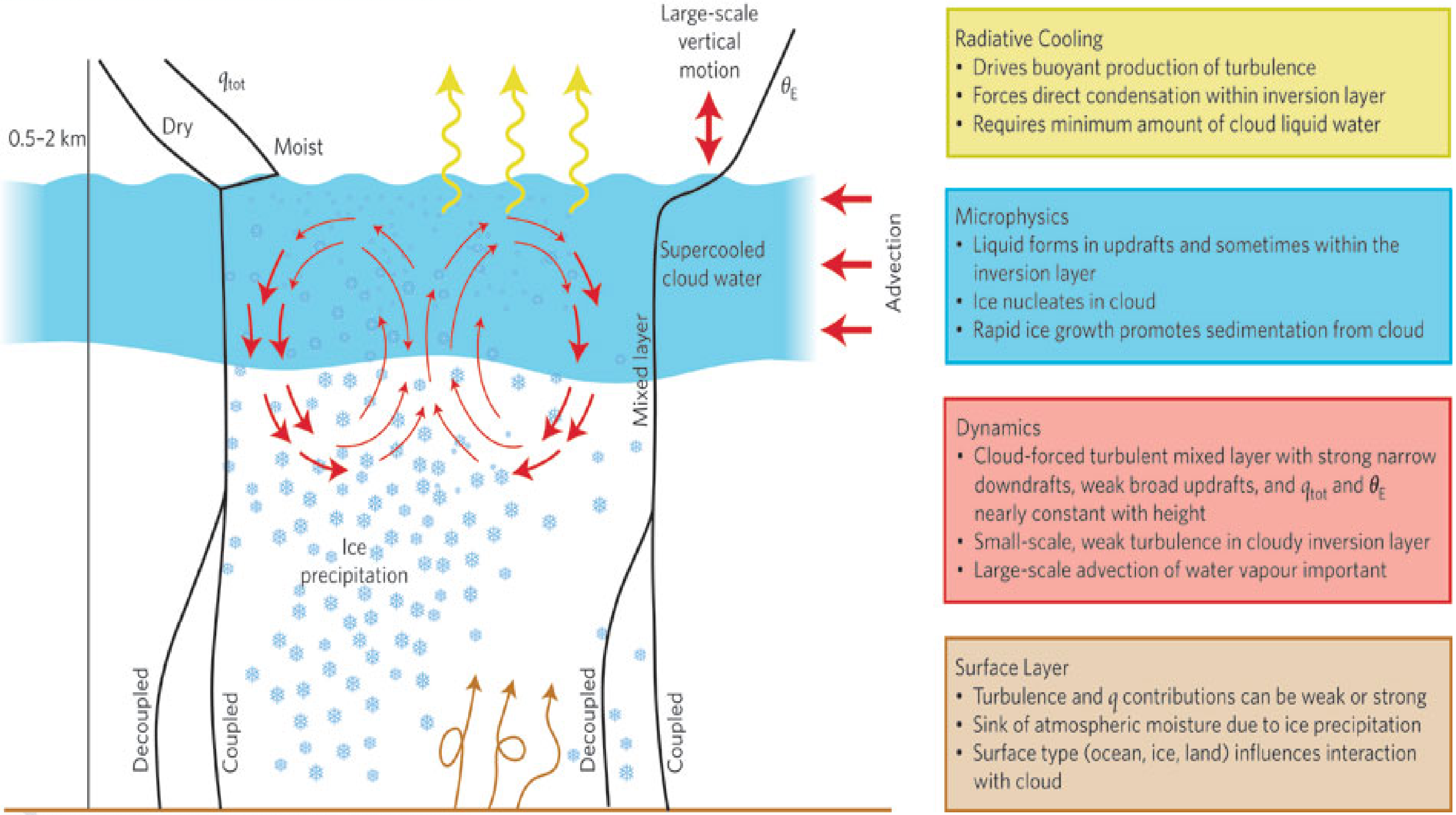
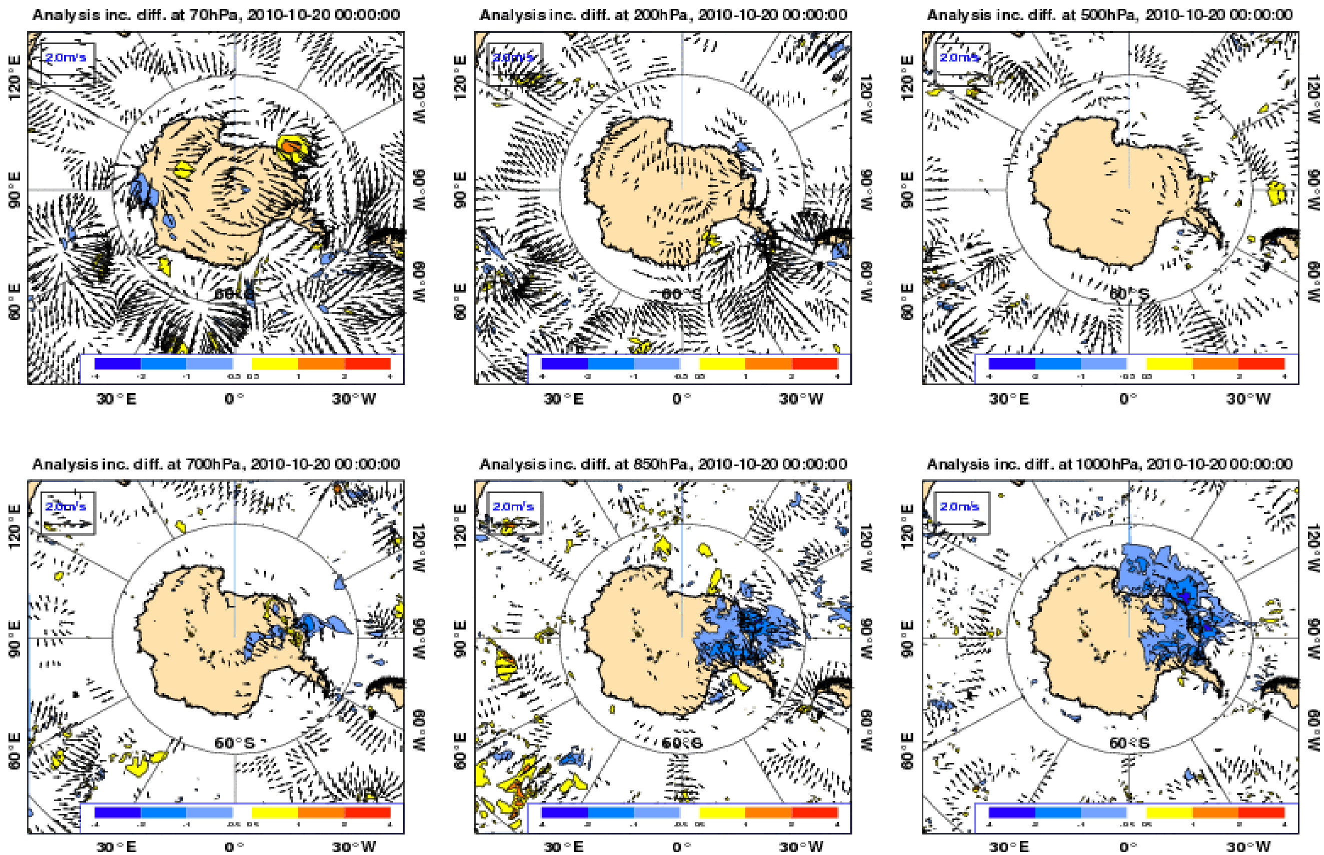
Arctic Mixed Phase Cloud Processes



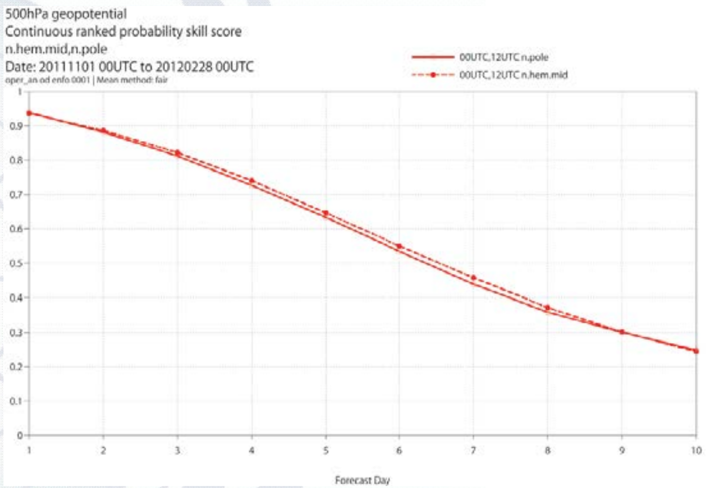
Characteristic profiles are provided of total water (vapour, liquid and ice) mixing ratio (q_{tot}) and equivalent potential temperature (θ_E). Cloud-top height is 0.5–2 km. Although this diagram illustrates many features, it does not fully represent all manifestations of these clouds. From Morrison et al. (2012).

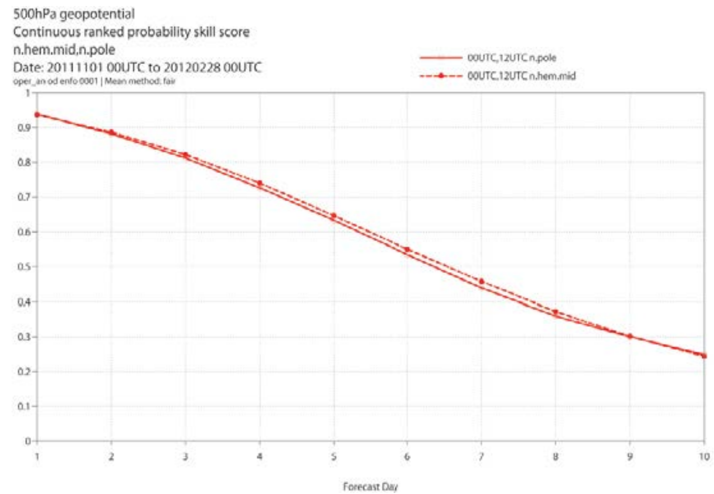
Concordiasi Impact



Difference of temperature (colour) and wind (arrows) increments between analysis runs with and without assimilating Concordiasi gondola/dropsonde observations. Panels show results at 70, 200, 500, 700, 850, 1000 hPa on 20 October 2010 (top left to bottom right).

Polar Verifications





The continuous rank probability skill score (CRPSS) for the ECMWF probabilistic forecasts of 500 hPa geopotential height over extended 4-months winter periods. Left: November 2011 through February 2012 for the NH extratropics (dashed), and the area north of 65°N (continuous). Right: May through August 2011 for the SH extratropics (dashed), and south of 65°S (continuous). (Source: L. Magnusson, ECMWF).

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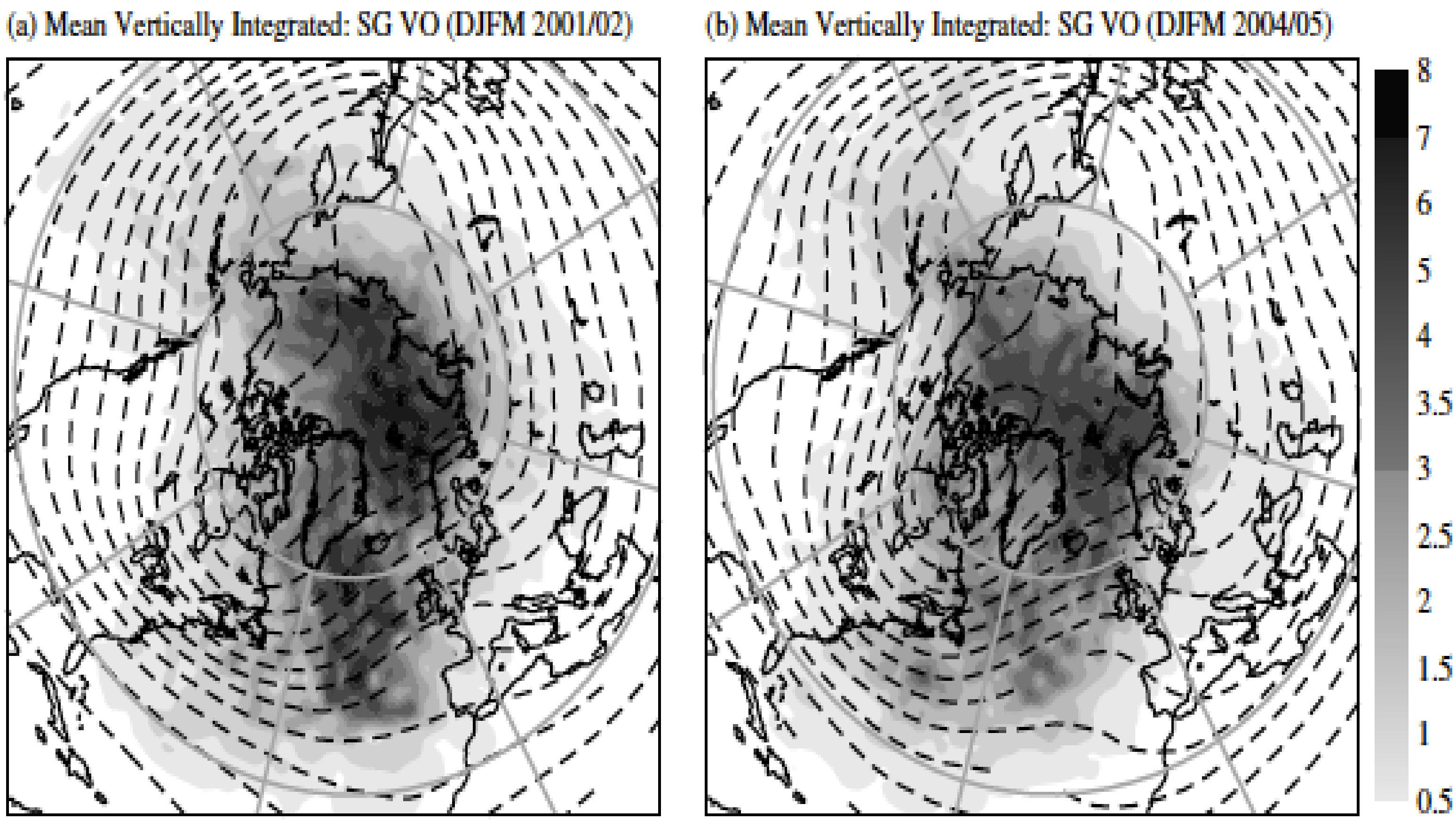
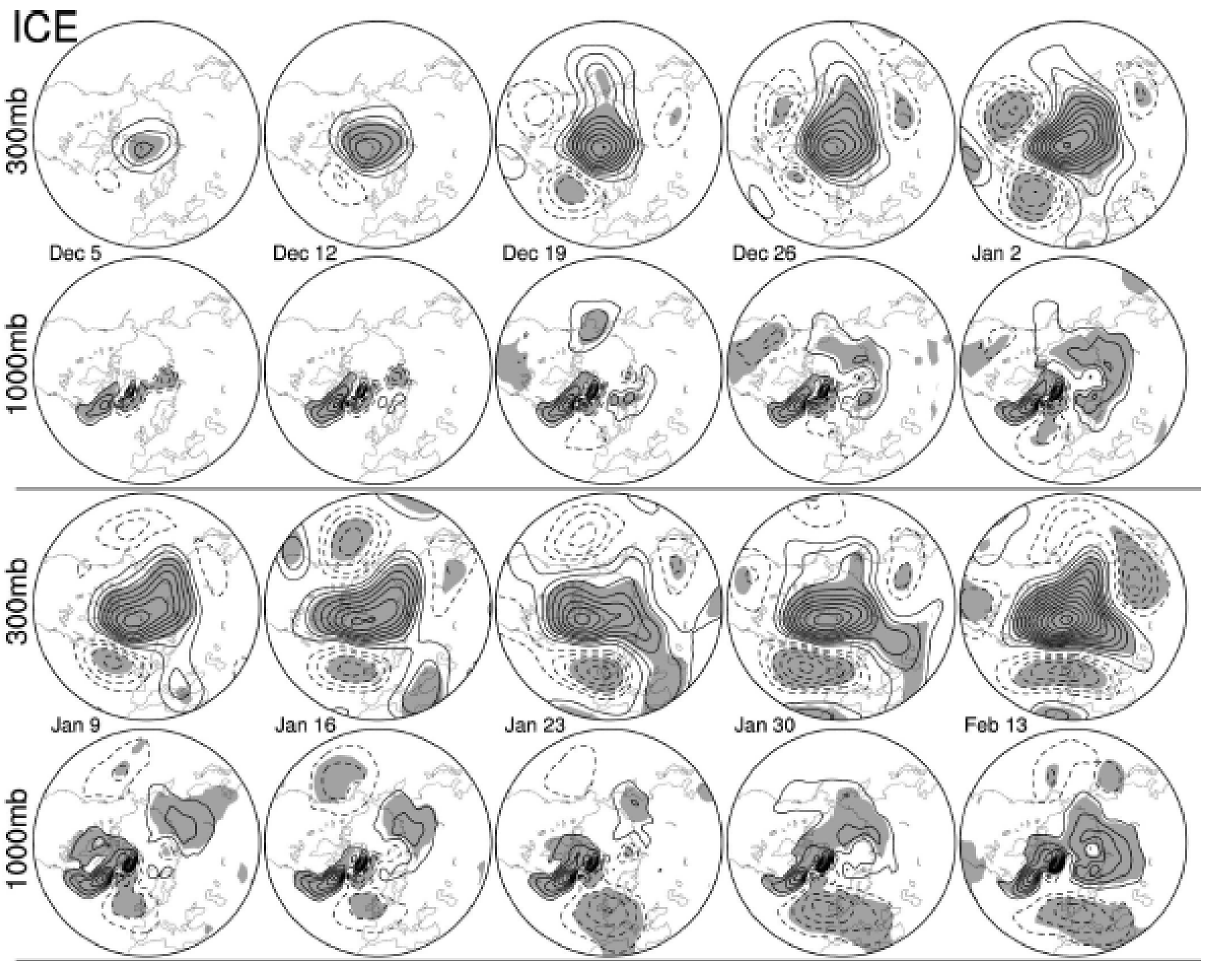
Mid-latitude Influence on Arctic



Mean of vertically-integrated absolute value of daily sensitivity gradients of D+2 forecast error north of 70oN to tropospheric initial perturbation of vorticity (shading) for two winters (December-March): (a) 2001/02 and (b) 2004/05. Large (small) values indicate a large (small) influence on subsequent forecast error over the Arctic. Also shown are winter mean values of 300 hPa geopotential height (contour interval, 100 m) (from Jung and Leutbecher, 2007).

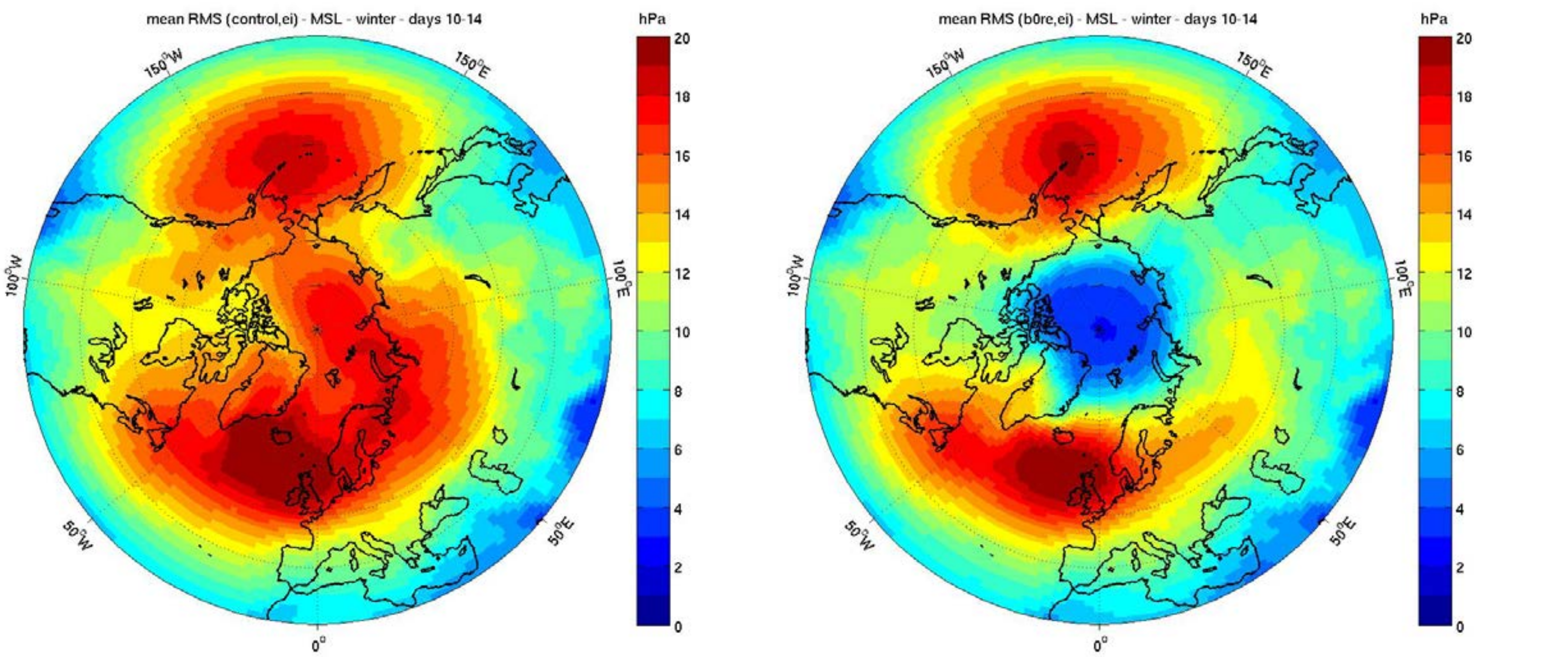
Impact of Sea Ice Anomalies



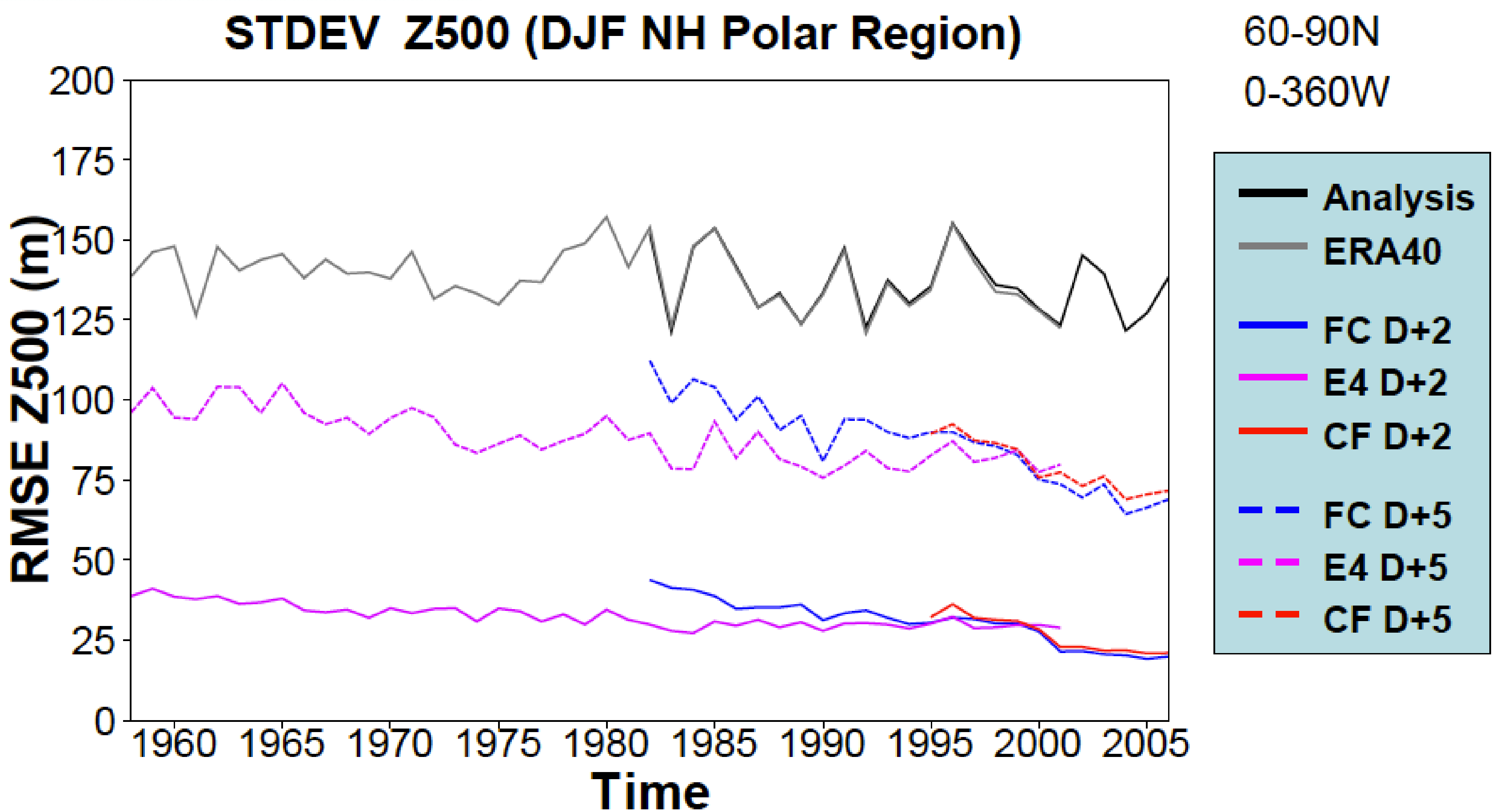
Ensemble-mean 1000-hPa and 300-hPa geopotential height anomalies (contour interval is 10 m) for the first weeks (Dec 5=1 week, Dec 12=2 weeks and so forth) of an atmospheric model experiment in which the ice extent has been reduced (increased) in the Labrador Sea (GIN seas). (From Deser et al. 2007).

Arctic Influence on Mid-latitude Weather

$$\frac{\partial \mathbf{x}}{dt} = F(\mathbf{x}) - \lambda(\mathbf{x} - \mathbf{x}_{ref})$$



Verification: Deterministic skill in the Arctic



Jung and Leutbecher (2007)