Environment and Climate Change Canada | Environnement et Changement climatique Canada | ECCC | Canada

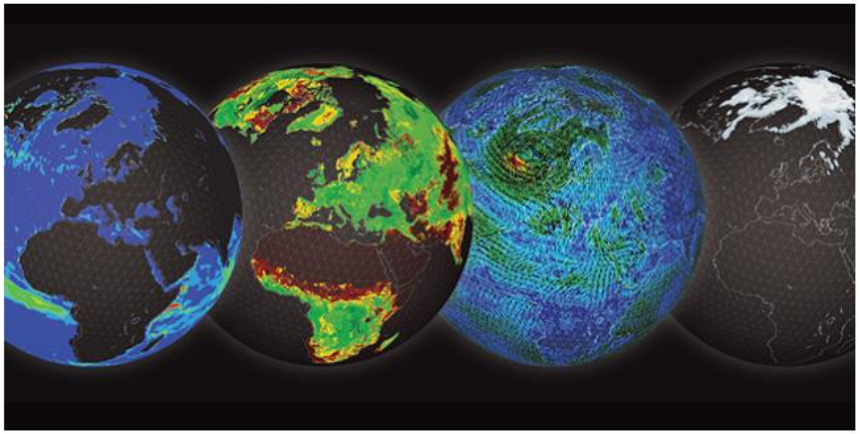
Environmental Prediction at the Canadian Centre for Meteorological and Environmental Prediction (CCMEP)

Gregory C. Smith

Meteorological Research Division, RPN-E, ECCC

Annual Seminar 2016

ECMWF | Reading | 5-8 September 2016

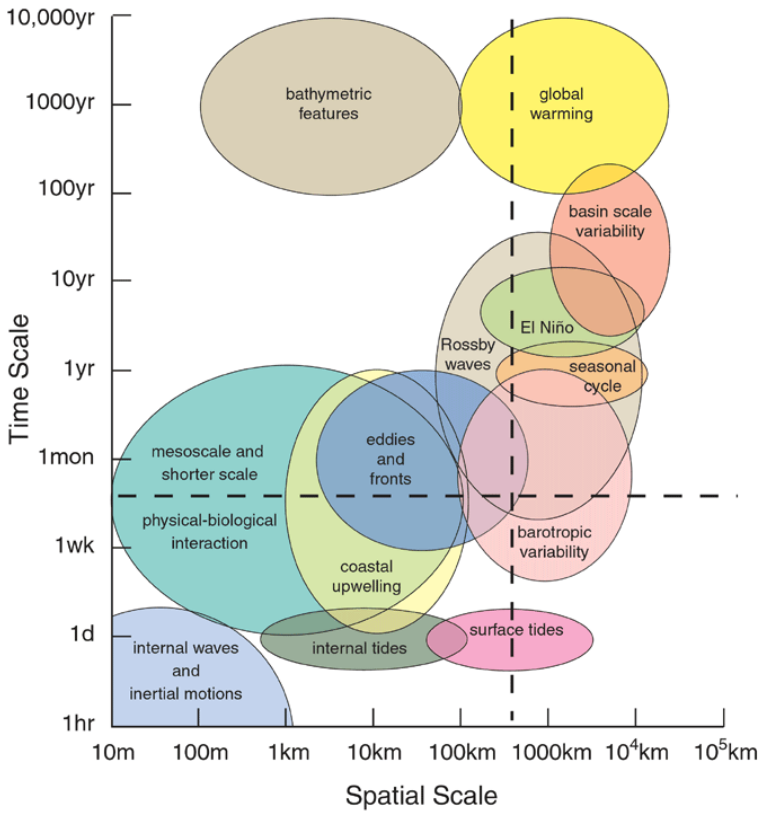


Overview

- Motivation for Environmental Prediction at CCMEP
- Coupling methodology
- Global Coupled Medium-range Forecasting System
  - Ocean initialization
  - Ice initialization
  - Improved ice physics
  - Forecasting trials
- Gulf of St. Lawrence Coupled Forecasting System
- Great lakes and St. Lawrence Water Cycle Prediction System
- Summary

Potential benefits of coupling for numerical weather prediction

- Classic view:
  - Ocean timescales are slow compared to the atmosphere
- However, numerous short-time/space scale processes relevant for coupled NWP
  - Tropical convection,
  - Hurricanes, extra-tropical storms
  - Coastal upwelling,
  - Sea ice (polynyas, leads)
- Made possible by
  - Global Ocean Observing System (e.g. Argo)
  - Improved ice-ocean modelling and data assimilation capacity



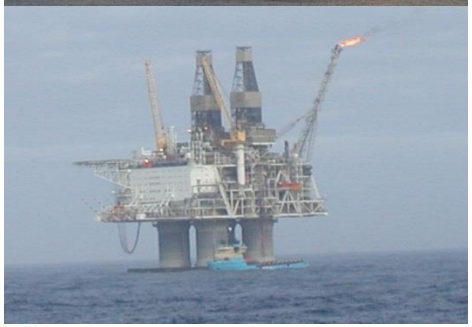
Brassington et al., J. Op. Ocean, 2015

The Need for Coupled Atmosphere-Ice-Ocean Prediction

Davidson et al., SCOR, 2013

Environment Canada requires ice-ocean forecasts and information services for:

- Improved weather and wave prediction
  - Timescales from days to seasons
  - Sea ice, tropical cyclones, surface interactions
  - Initialization of seasonal forecasts
- Sea ice prediction
  - Improved automated analyses and forecasts
  - Dangerous high pressure areas
- Emergency response
  - Comprehensive trajectory modelling capacity
  - E.g. dispersion of pollutants
- Collaboration with other GoC departments
  - Fisheries and Oceans, Coast Guard
  - National Defense



CONCEPTS

Environment Canada | Fisheries and Oceans Canada | National Defence | Défense nationale | Mercator Ocean Ocean Forecasters | Canada

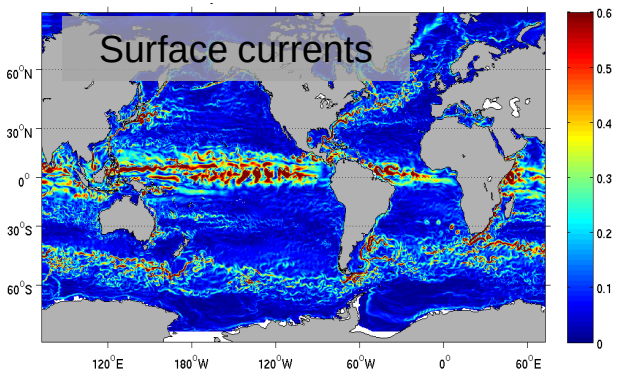
Ice-ocean modelling with NEMO + CICE

Operational
Experimental
In development

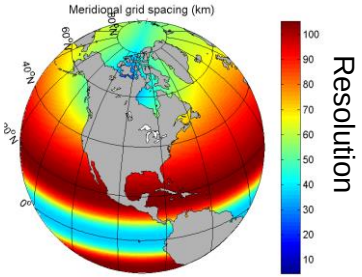
Applications and domains

- Global 1/4° resolution (GIOPS)
  - Medium-monthly forecasting
  - Fully-coupled for NWP
- Global 1° resolution (CanSIPS-GN)
  - Seasonal forecasting
- N. Atlantic and Arctic 1/12° (RIOPS)
  - Short-to-medium range forecasting
  - Coupled HRDPS-Polar for YOPP
- Great Lakes 2km (RMPS-GL)
- Gulf of St. Lawrence 5km (RMPS-GSL)
  - Short-term forecasting

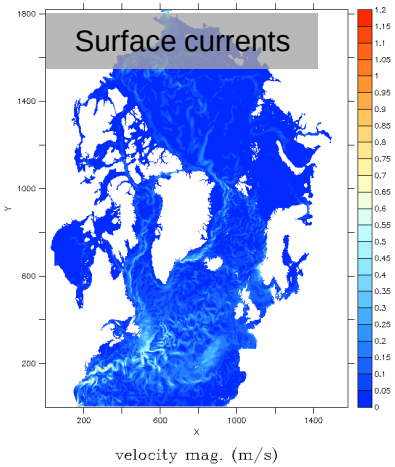
1/4° Global

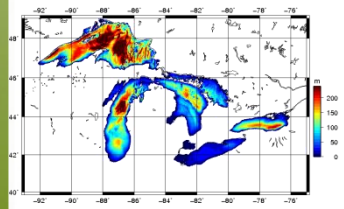


1° Global

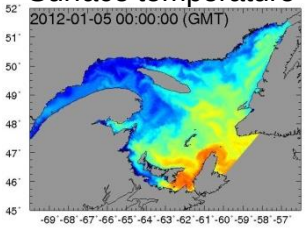


1/12° N. Atlantic and Arctic




Bathymetry

Surface temperature

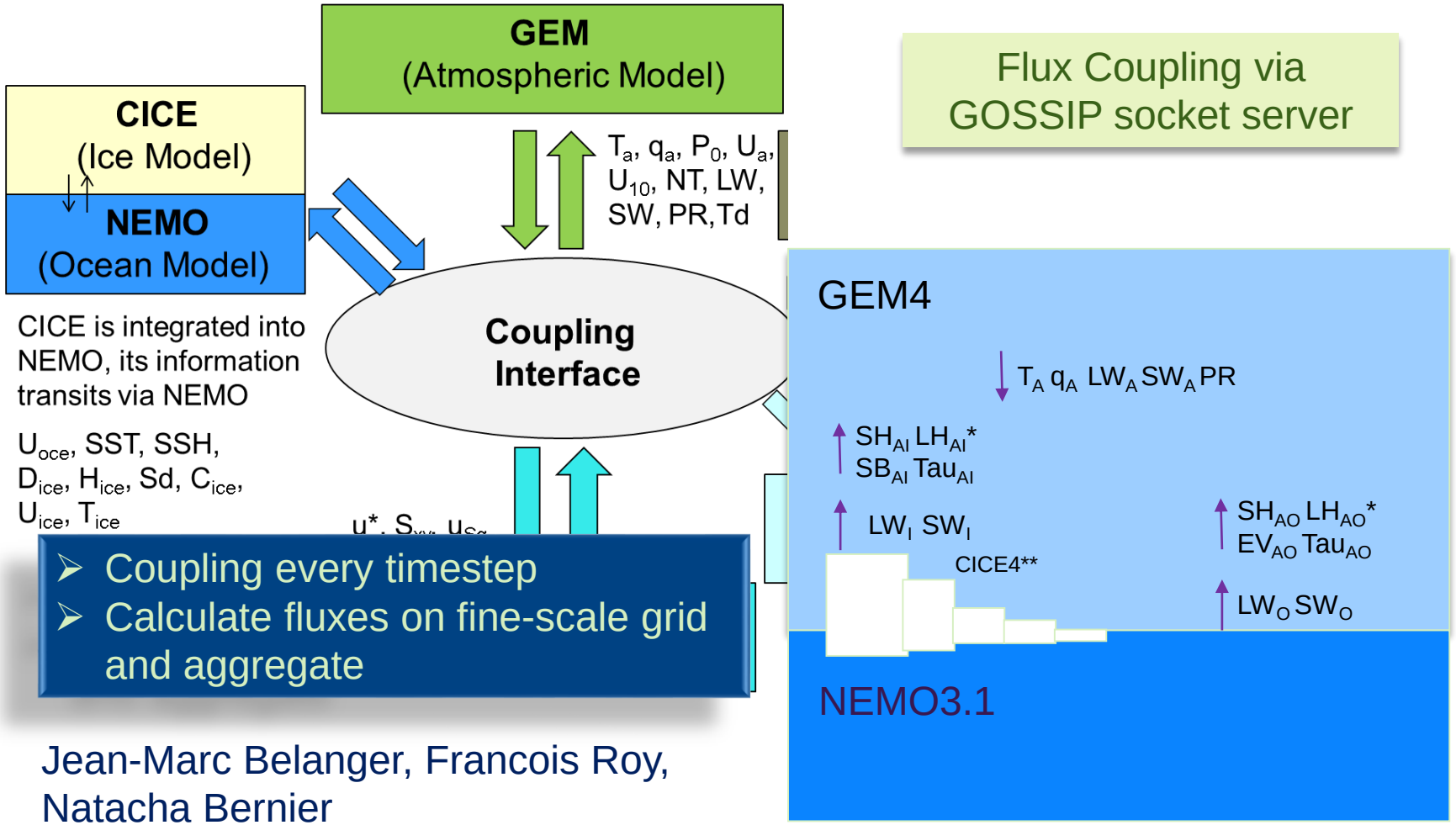


CONCEPTS
CANADIAN OPERATIONAL NETWORK OF COUPLED ENVIRONMENTAL PREDICTION SYSTEMS

Environment Canada | Fisheries and Oceans Canada | National Defence / Défense nationale | Mercator Ocean Ocean Forecasters | Canada

Coupling Method

Same method used by Gulf of St. Lawrence, Great Lakes, GDPS and Seasonal Systems



- Coupling every timestep
- Calculate fluxes on fine-scale grid and aggregate

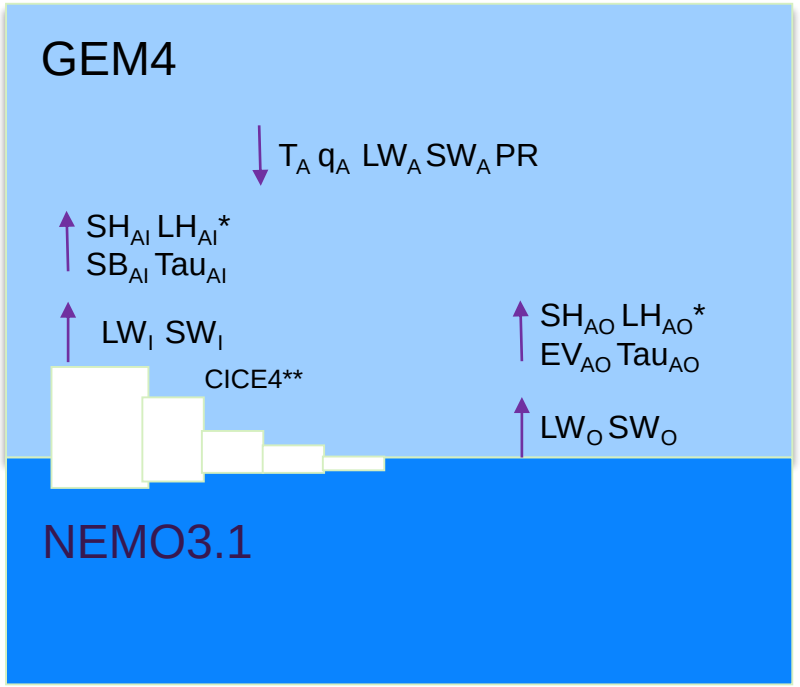
Jean-Marc Belanger, Francois Roy, Natacha Bernier

Coupling Method

Same method used by Gulf of St. Lawrence, Great Lakes, GDPS and Seasonal Systems

- To produce forecasts that exchange fluxes between GEM and NEMO/CICE at every timestep:
  - Calculate fluxes in NEMO/CICE using GEM flux library
  - Regridding done in respective models using pre-calculated weights
  - Surface fluxes in GEM are only modified where coupling mask is activated (i.e. over the ocean)
  - Exchange fluxes at every timestep using GOSSIP socket server over TCP/IP
- Allows for efficient exchanges and independent model evolution

Flux Coupling via GOSSIP socket server



Sources of differences in fluxes between coupled and uncoupled forecasts

- Differences in SST and sea ice initial condition
  - Including concentration, thickness and snow cover
- Evolution of ocean/ice fields over forecast
  - Seasonal cycle, diurnal cycle, small scale features (leads)
- Fluxes across sea ice take into account ice thickness categories
  - i.e. flux aggregation instead of thickness aggregation

Environment Canada

Fisheries and Oceans Canada

Mercator Ocean
Ocean Forecasters

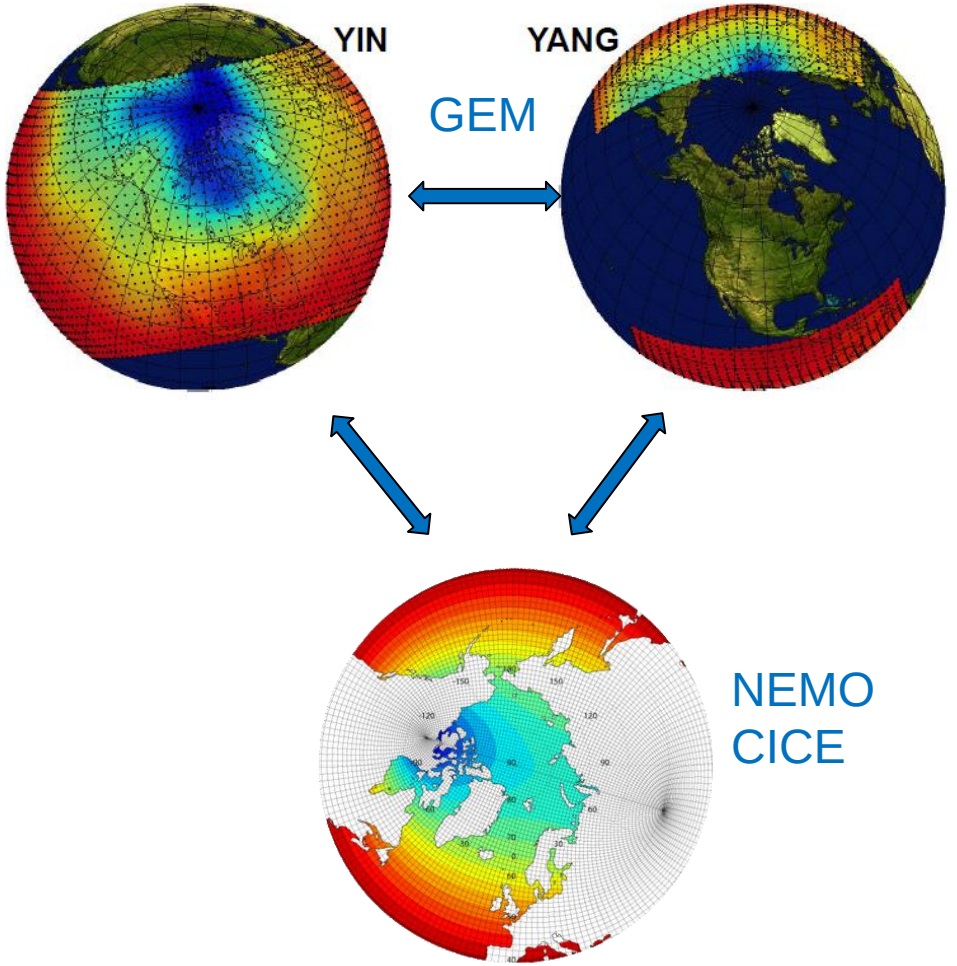
Canada

Coupled Global Deterministic Prediction System

Implementation Details

Global Coupled Medium-range Deterministic Forecasts

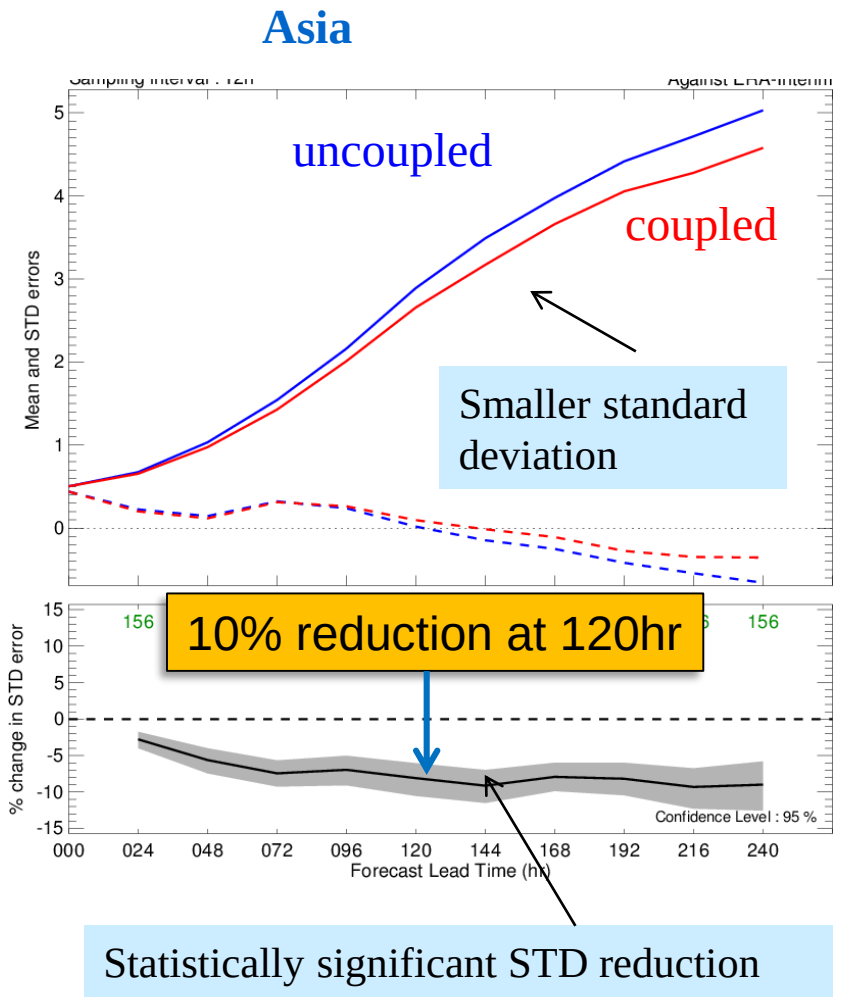
- Coupled NWP system running in operations at CCMEP since 8 July 2016.
  - GDPS coupled to GIOPS
  - Global, fully-coupled A-I-O, 25km(A)-1/4deg(IO),
  - 10 day forecast (2/day)
- Available on RPNWMS:
  - E.g. www.meteocentre.com/plus
- MSC datamart (soon)
  - Atm: GRIB2, Ocean/Ice: Netcdf4



Coupled Global Forecast Trials

J-M Belanger, F Roy, …

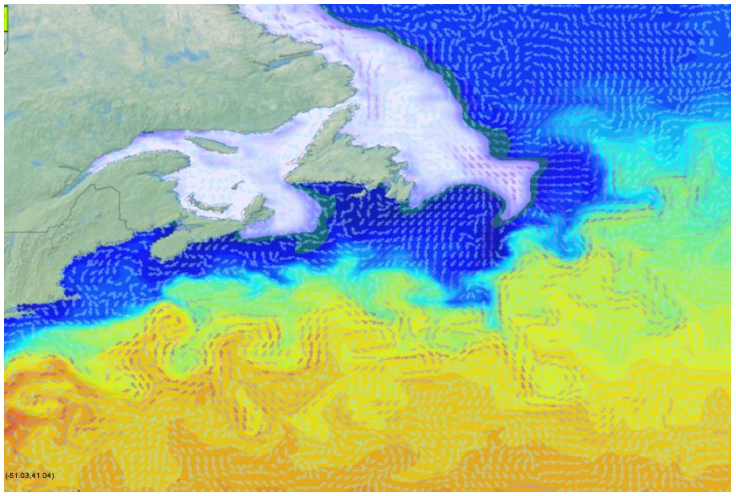
- Coupled model:
  - Atm: GEM 25km
  - Ocean: NEMO-ORCA025 (1/4°)
  - Ice: CICE4
- Evaluation of summer trials
  - Daily 10day forecasts
  - 15 Jun – 31 Aug, 2014
  - Verification against ERA-Interim for geopotential height at 850hPa over Asia

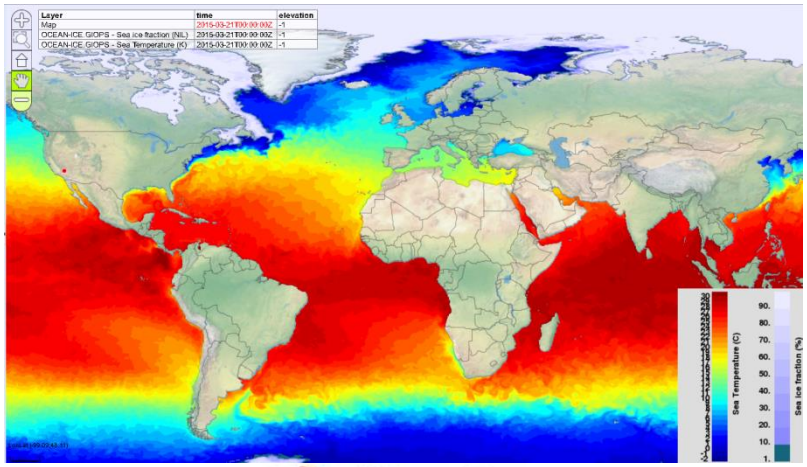


Global Ice-Ocean Prediction System

Dorina Surcel Colan, , Yimin Liu, Matt Reszka, Francois Roy, Barbara Winter …

- Produces daily ice-ocean analyses and 10day forecasts
  - NEMO-CICE (~1/4°), < 15km in Arctic
- Mercator Ocean Assimilation System (SAM2):
  - Sea surface temperature
  - Temperature and salinity profiles
  - Sea level anomaly from satellite altimeters
- 3DVar Ice analysis:
  - SSM/I, SSM/IS, CIS charts, Radarsat image analyses
- Running in real-time since January 2013
- Operational since August 20, 2015
- Dissemination
  - External cluster (pegasus)
  - Available on MSC Datamart (Netcdf4)
    - http://dd.weather.gc.ca/
  - WMS using GeoMet or RPNWMS
    - E.g., www.meteocentre.com/plus





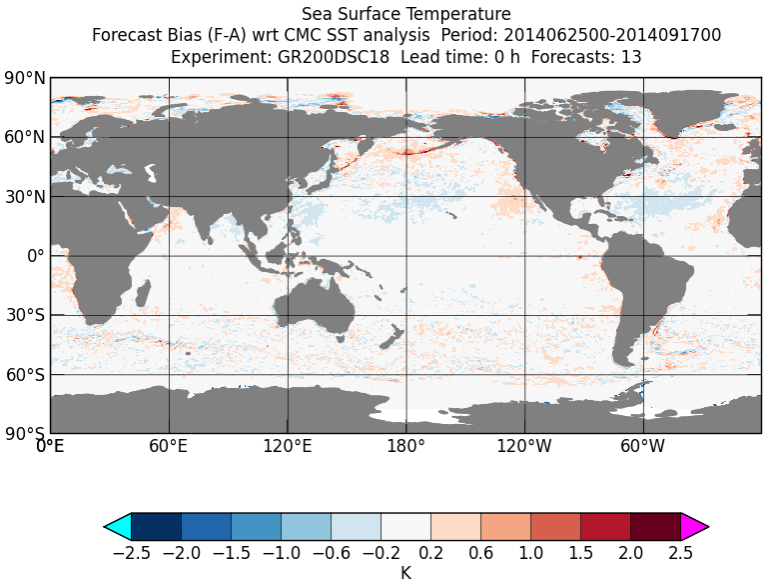
Smith et al., QJRMS, 2015

Comparison with CMC SST Analysis

Mean differences for 2014-06-25 to 2014-09-17

- Special attention paid to SST assimilation
  - Differences mostly < 0.2°C
  - Some areas show differences of up to 0.6°C (N. Pac)
  - Largest errors in summer
- Provide closest SST to that used during atmospheric assimilation (EnVAR)
  - Minimize initialization shock
- Improved under-ice SST assimilation substantially reduces differences with CMCSST

GIOPS – CMC SST analyses



Improvement in GIOPS v1.1 (June 2014)

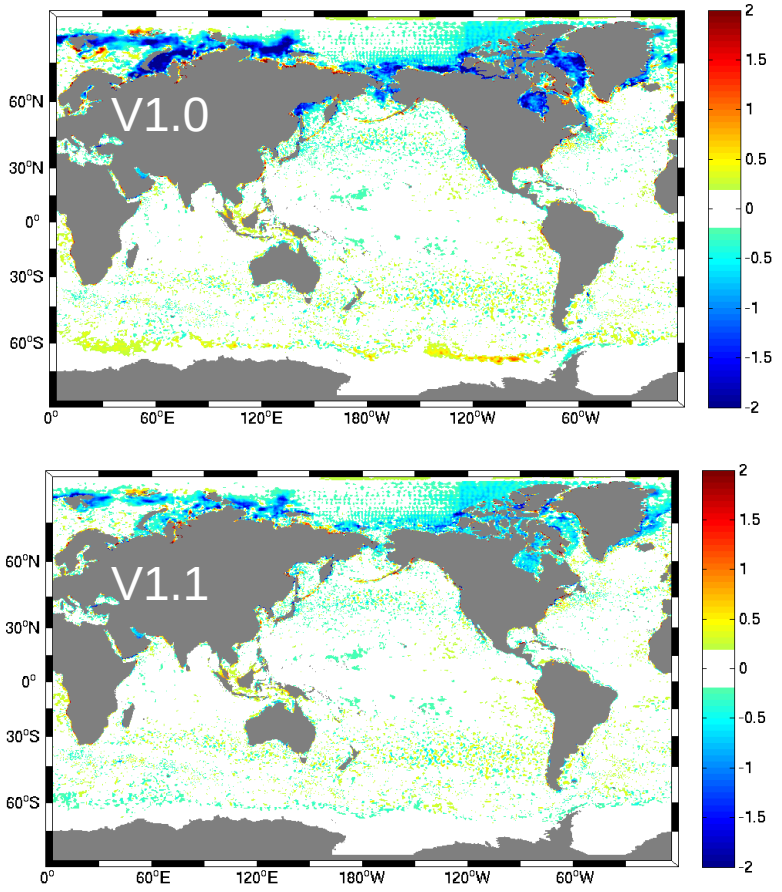
Comparison with CMCSST

Under-ice SST assimilation:

- Set: SST obs=freezing, if IC>20%

- Improved under-ice SST assimilation substantially reduces differences with CMCSST

Mean differences for NH summer 2011

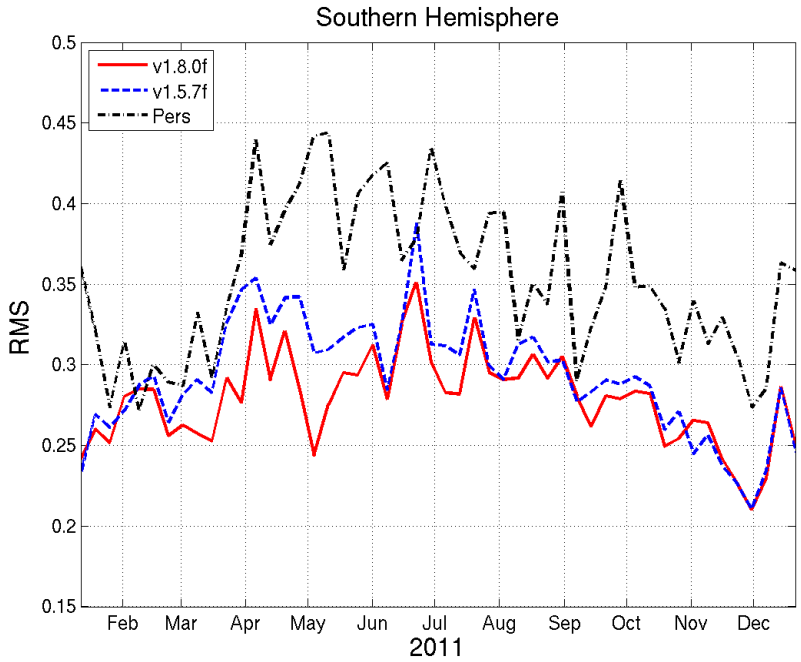


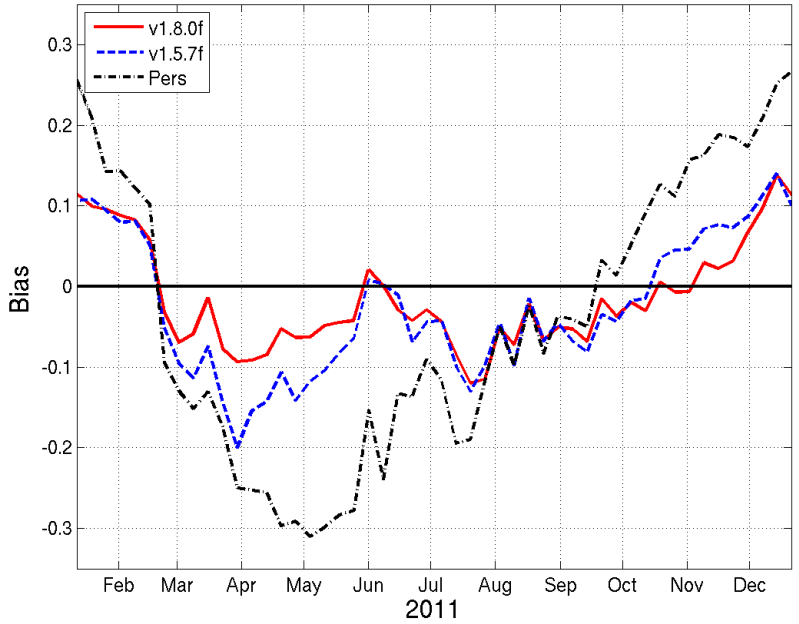
Verification of ice forecast skill

7 day forecasts compared to 3DVar analyses (where ΔGL>0.1)

- Reduction in RMS in both hemispheres
- Improvements most notable in Southern Hemisphere
- Lower RMS error over Antarctic in fall/winter

GIOPSv1.1
GIOPSv1.0
Persistence





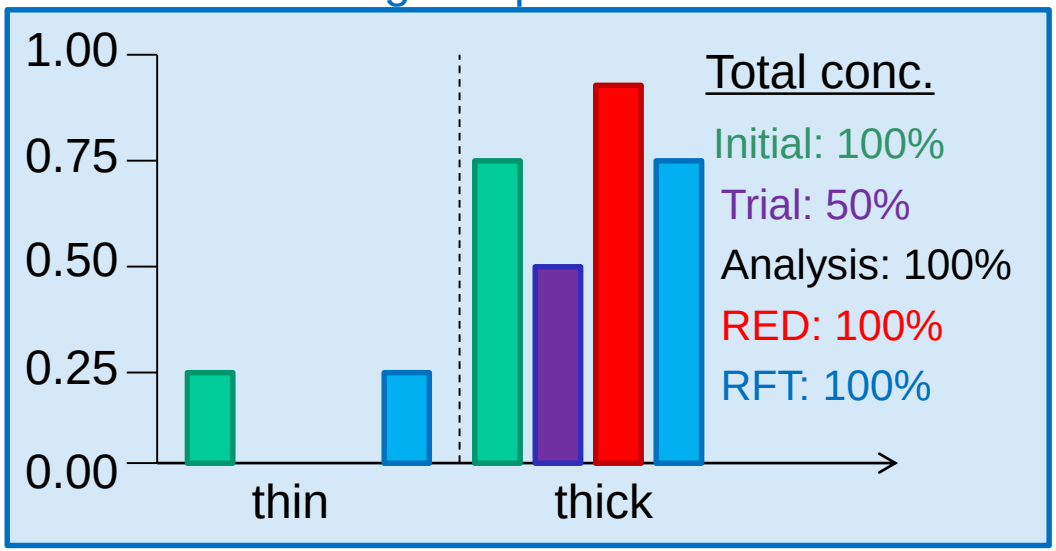
Blending with 3DVAR ice analyses

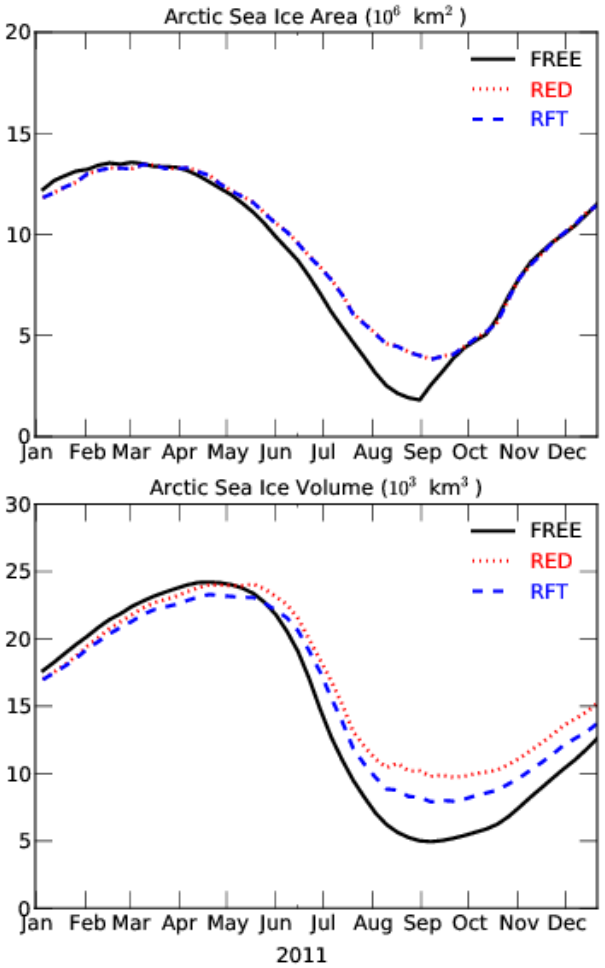
Impact on ice thicknesses

Smith et al., QJRMS, 2015

- Require multicategory blending for CICE
- Method 1: Rescale distribution (RED)
- Method 2: Rescale Fcst Tendency (RFT)
- Use of RFT results in a smaller impact on total ice volume

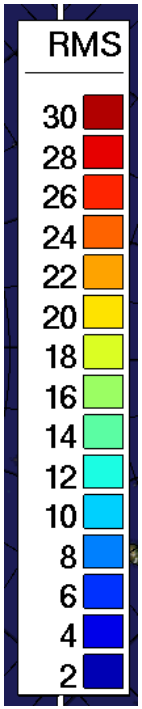
Thought experiment

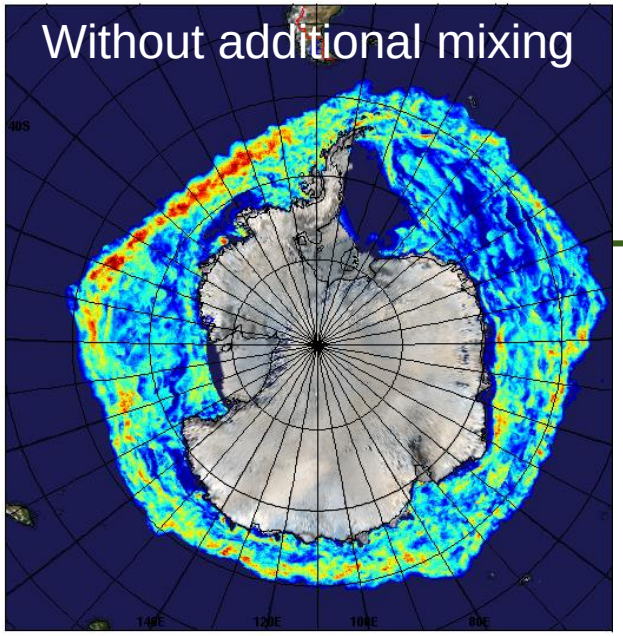


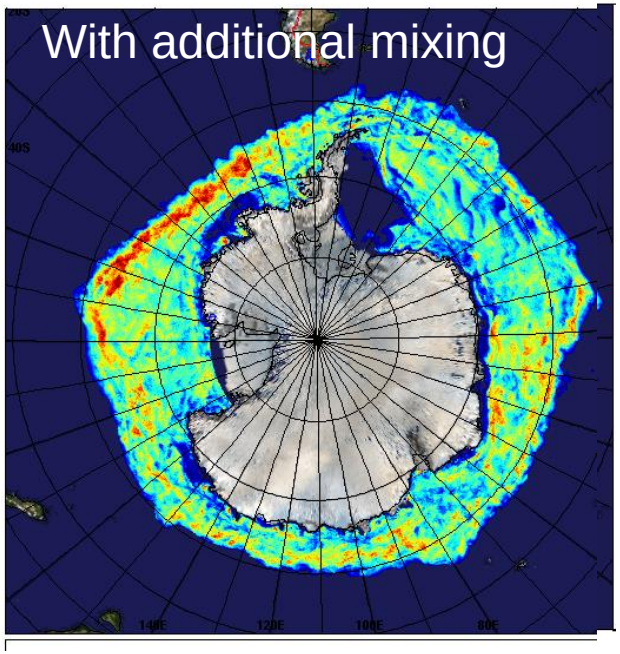


Role of small-scale ocean mixing

- CMC Global Ice-Ocean Prediction System (GIOPS)
  - 7day RMS forecast error evaluated against analyses for 2011 (50 weekly forecasts)
  - Restricted to points where analysis changed by more than 10%
- Ice forecast skill exhibits strong sensitivity to ocean mixing
  - With/without parameterization for surface wave breaking
  - Comparison with Argo shows better results with additional mixing
  - Highlights need for more polar observations!

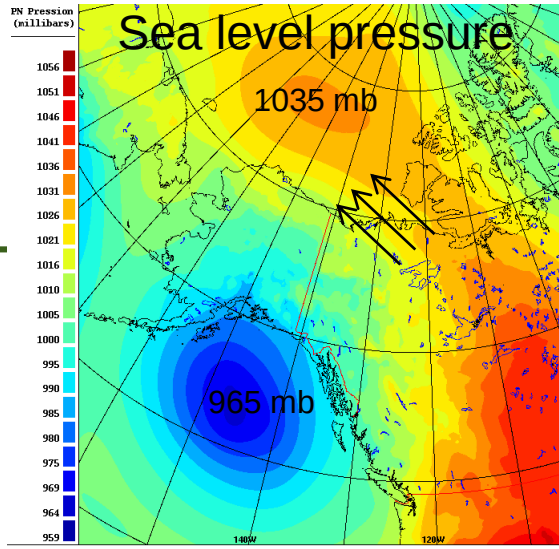




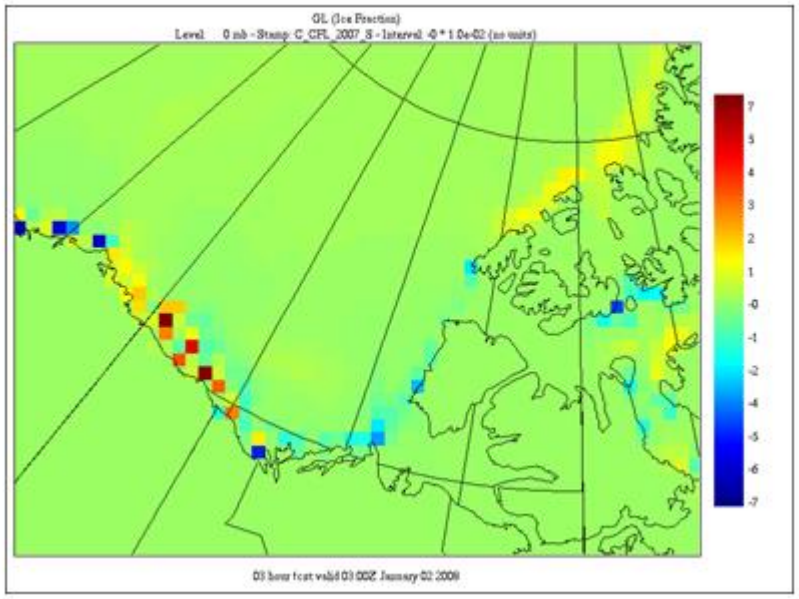


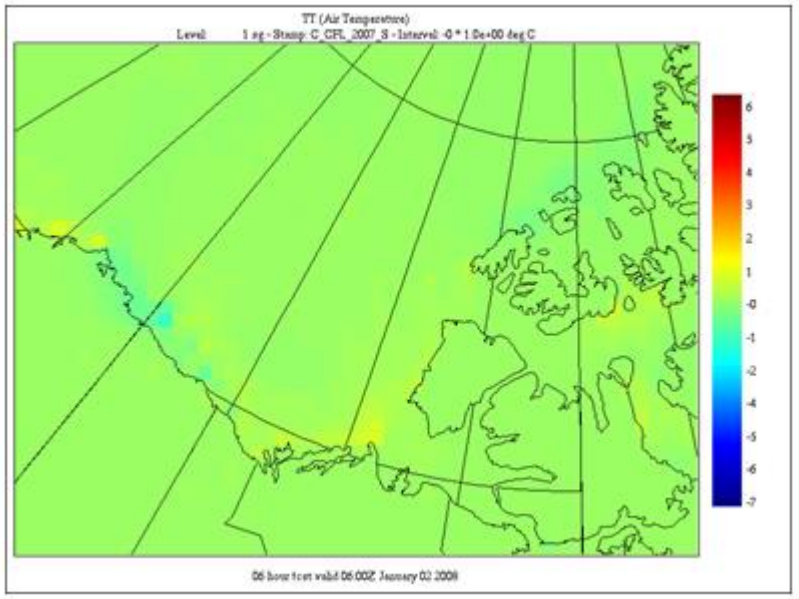
Smith et al., ECMWF Proc., 2013

Impact of a dynamic ice cover on coupled forecasts over the Beaufort Sea



Difference in ice fraction (CPL-UNCPL) Difference in 2m temperature

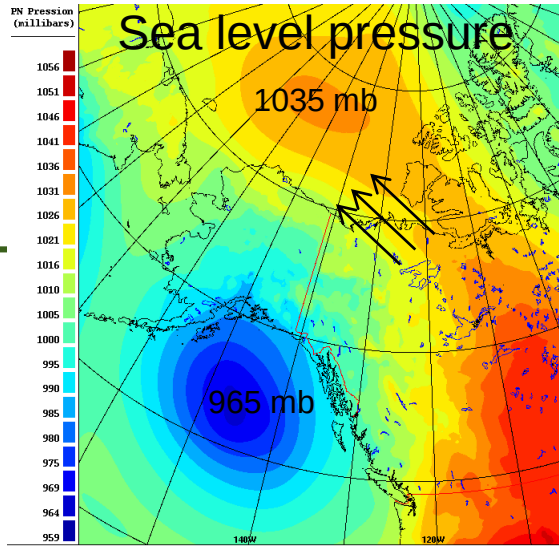




Forecast from global coupled model (GEM-NEMO-CICE; 33km-15km resolution) from the Canadian Meteorological Centre

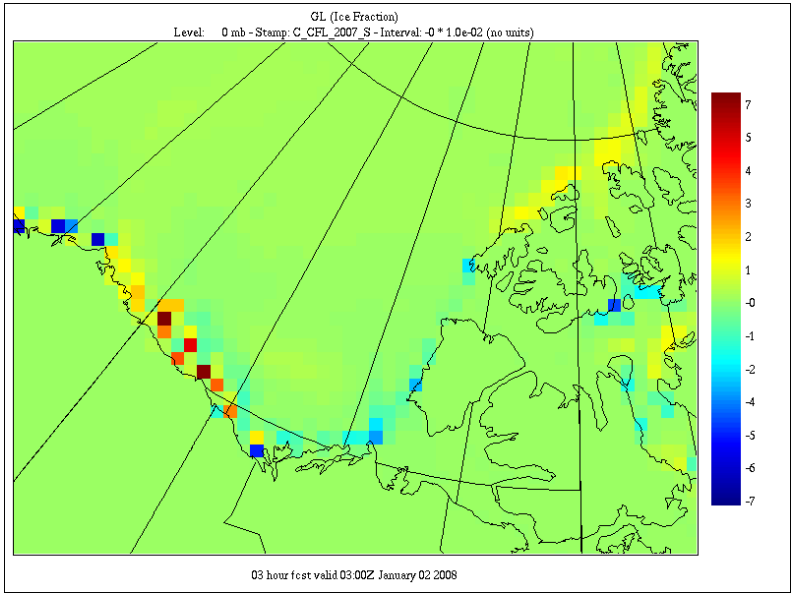
R. Muncaster, F. Roy, J.-M. Belanger

Impact of a dynamic ice cover on coupled forecasts over the Beaufort Sea

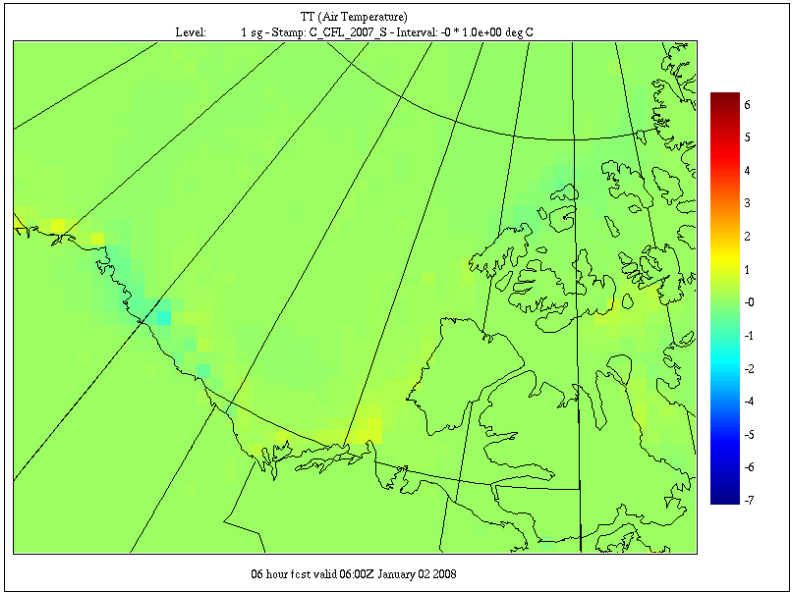


- Coastal polynya formation sensitive to:
  - ➢ Atmosphere-ice and ice-ocean stresses, ice thicknesses, landfast ice parameterization

Difference in ice fraction (CPL-UNCPL)



Difference in 2m temperature

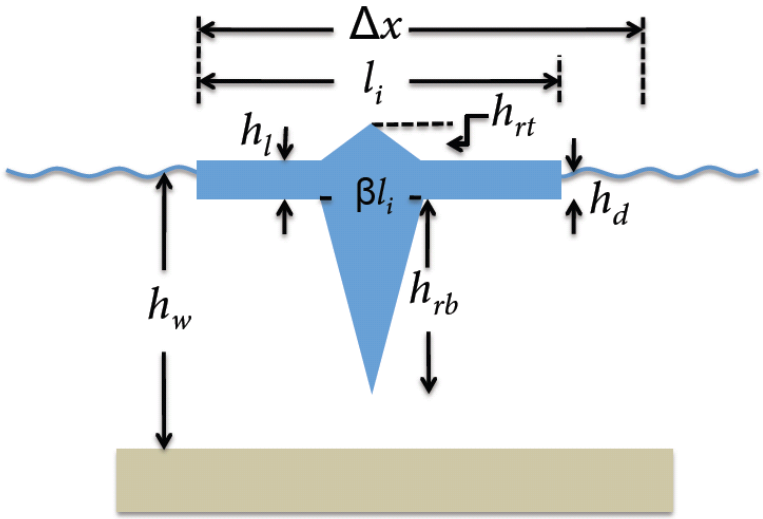


Forecast from global coupled model (GEM-NEMO-CICE; 33km-15km resolution)

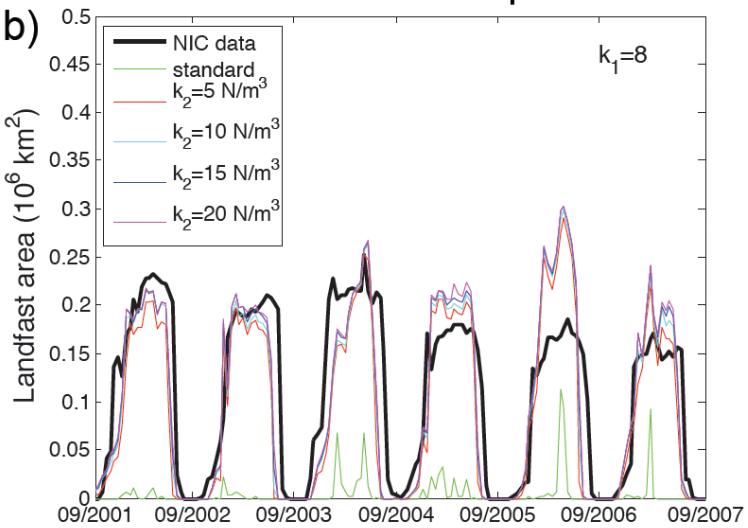
Parameterization of Landfast Ice

Lemieux, J. et al. (2015): A basal stress parameterization for modeling landfast ice. *J. Geophys. Res. Oceans*, doi: 10.1002/2014JC010678

- Landfast ice is parameterized by estimating the drag of ice keels on the ocean bottom
- Currently evaluating impact in operational systems



Landfast ice area in Laptev Sea

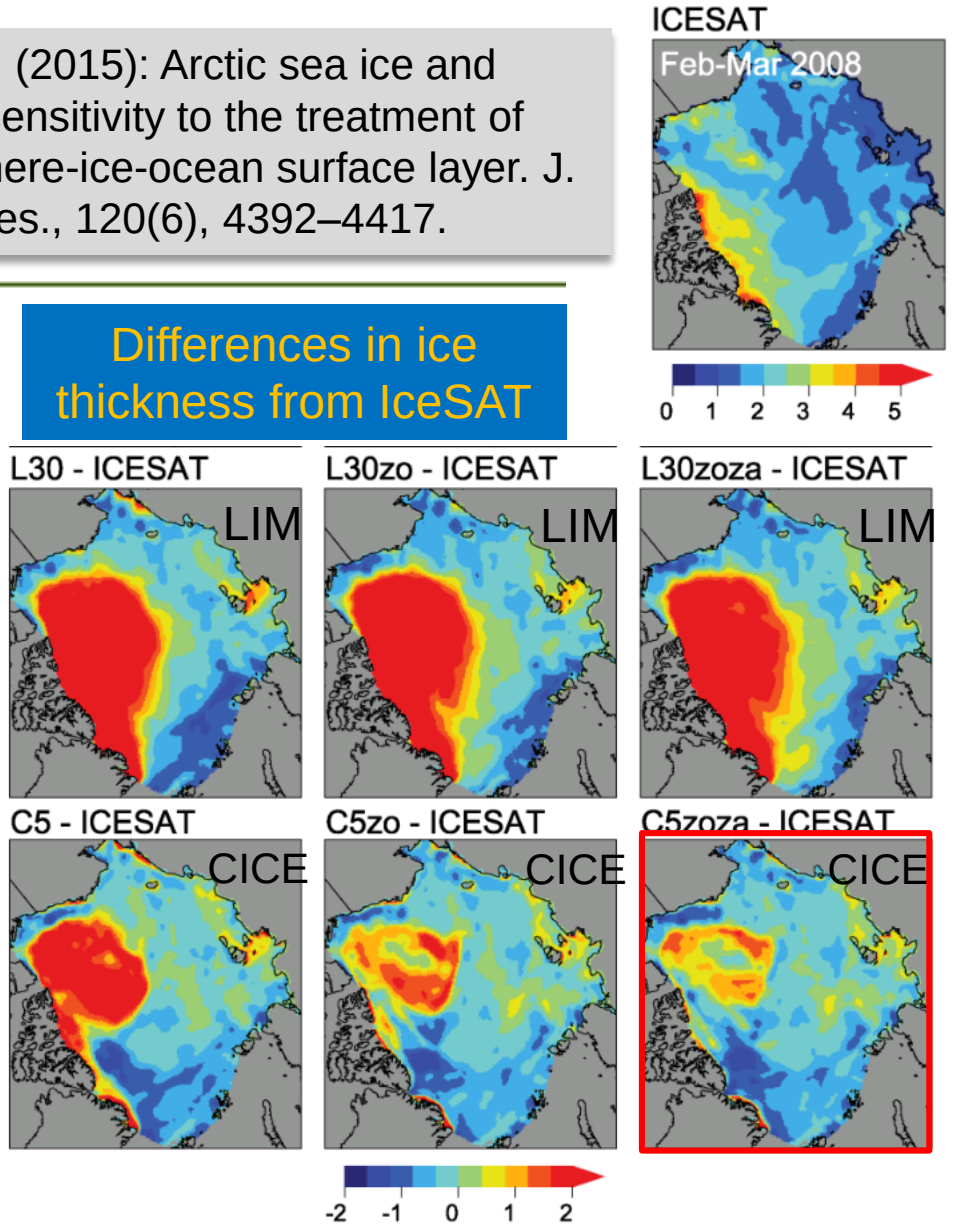


- Parameterization represents well the amplitude of landfast ice area
- Shows some interannual variability
- Addition of tensile strength (Lemieux et al., in review)

Ice-Ocean Coupling

Roy, F. et al. (2015): Arctic sea ice and freshwater sensitivity to the treatment of the atmosphere-ice-ocean surface layer. J. Geophys. Res., 120(6), 4392–4417.

- Entire Arctic freshwater balance shown to be sensitive to surface flux parameterizations
- Improving consistency in atmosphere and ice-ocean models leads to more accurate simulations of ice conditions
- In particular ice roughness has a large effect and impacts net liquid and solid freshwater exports



Environment Canada

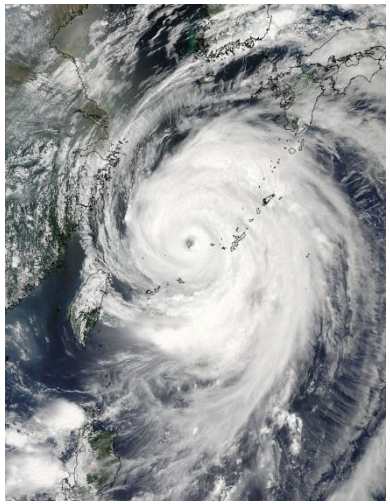
Fisheries and Oceans Canada

Mercator Ocean
Ocean Forecasters

Canada

Coupled Global Deterministic Prediction System

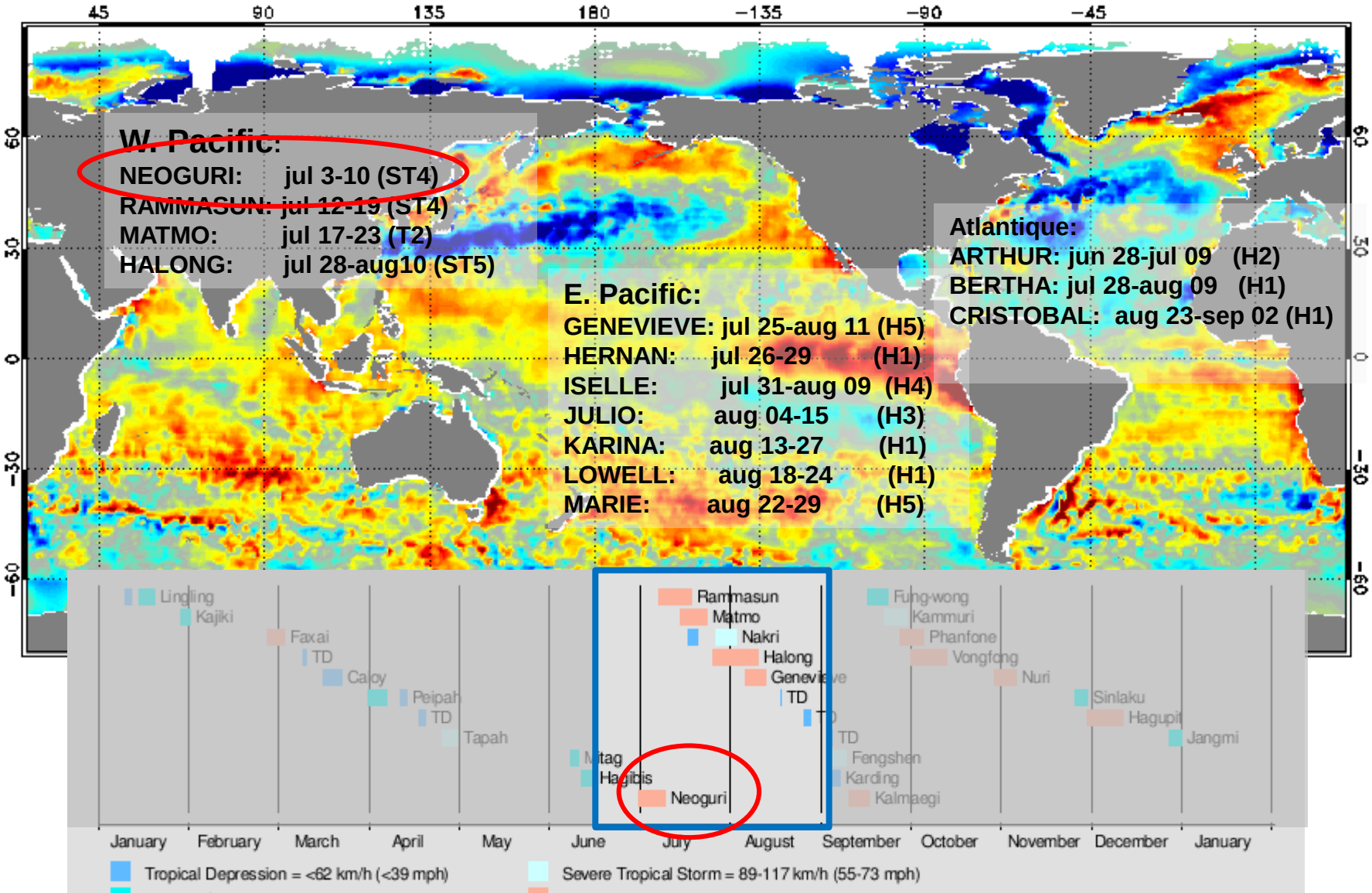
Forecast Trials



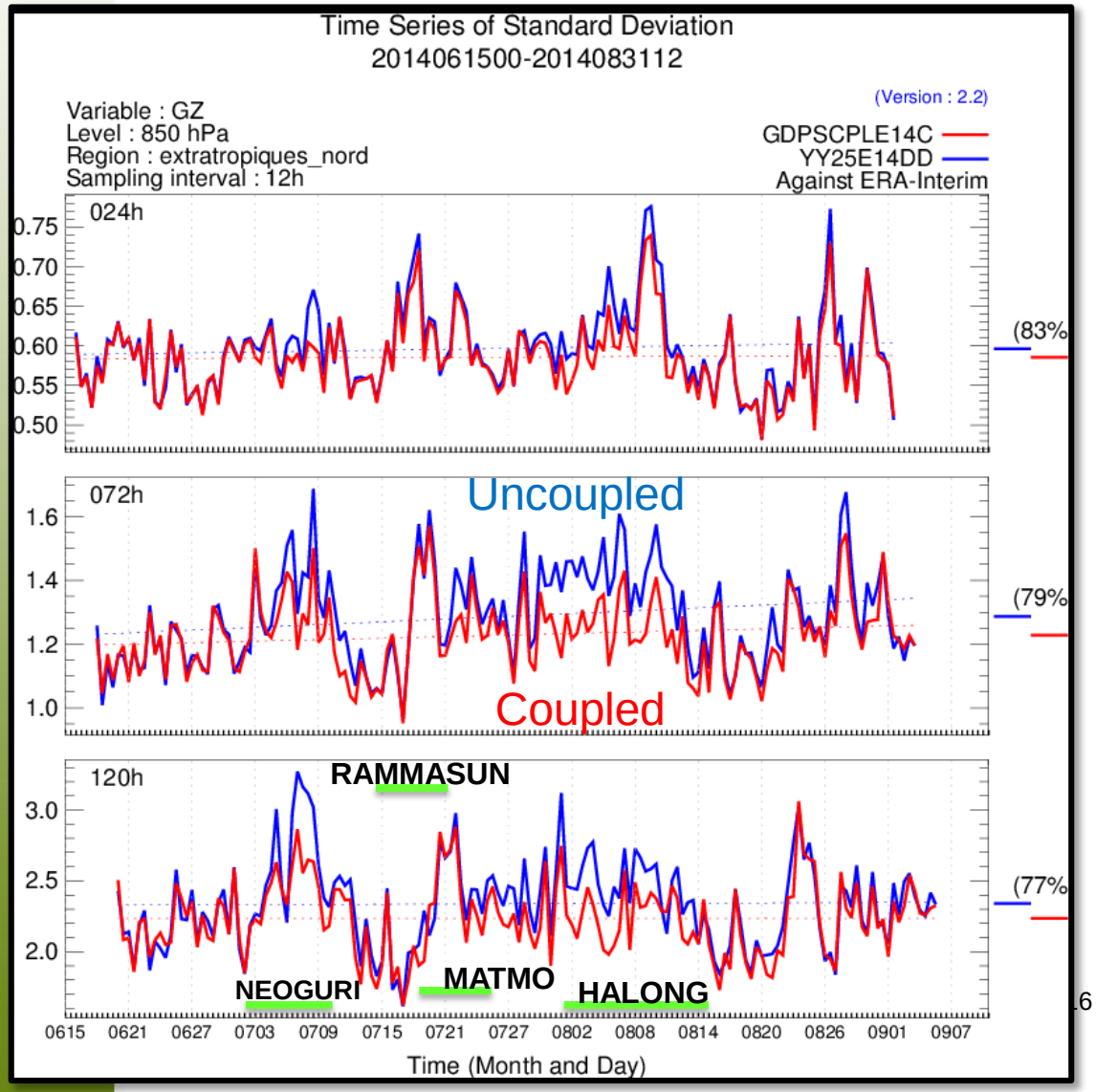
Forecast Evaluation

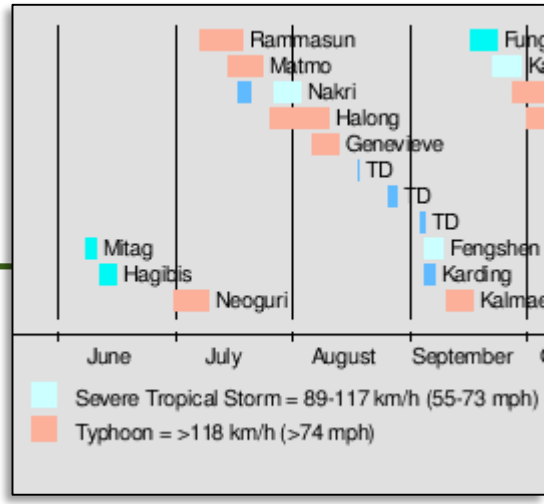
- Produce 10 day coupled forecasts every 12h
  - GEM initialized from GDPSv5 analyses
  - NEMO/CICE initialized from GIOPSv2.1.1 analyses
  - Compare coupled forecasts to uncoupled forecasts from final cycles
- Forecast periods
  - Summer 2014 (June 15-August 31, 2014)
  - Winter 2015 (15 Dec 2014 – 01 Mar 2015)
  - Fall 2015 (Sep 1-Sep 30, 2015)
  - Summer/Winter 2011 (Not shown)

Long-lived storms (> 6days) during summer evaluation period



Geopotential Height at 850hPa over the Northern Extratropics





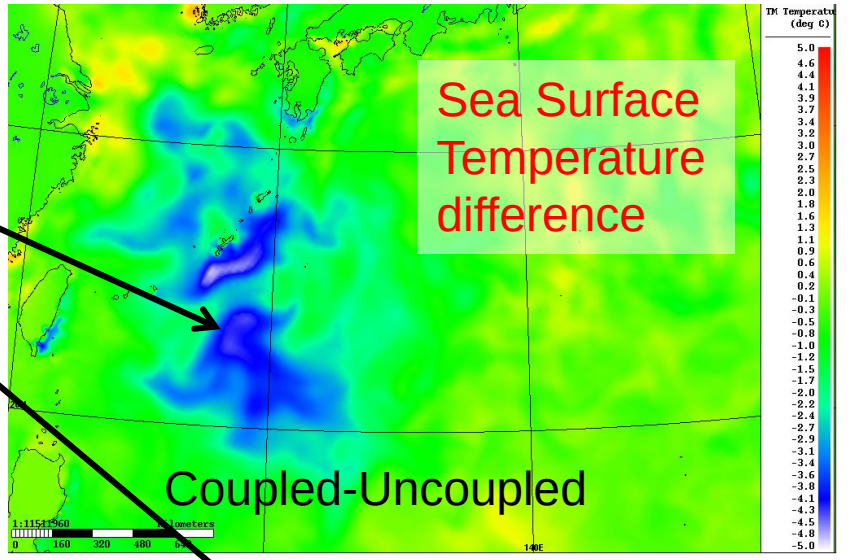
- Strong impact of coupling for four Typhoons.
- Std Dev. of forecast error reduced even at short lead times.

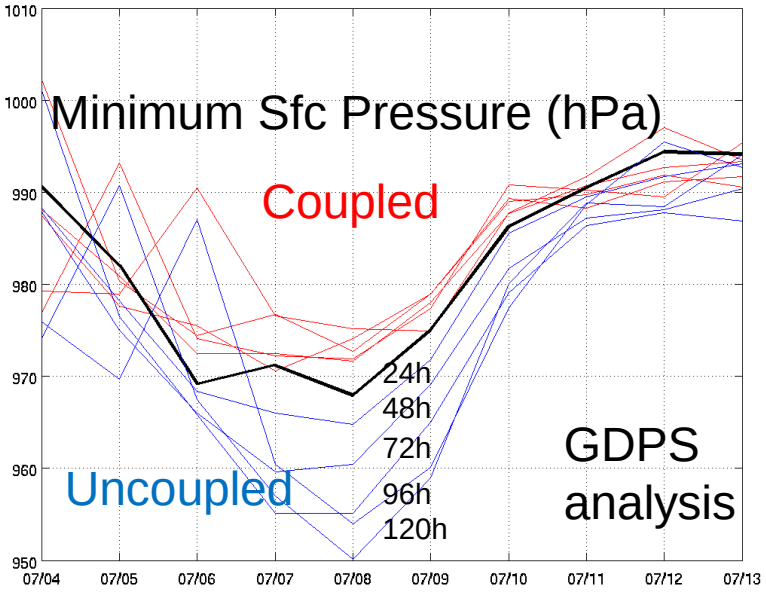
Canada

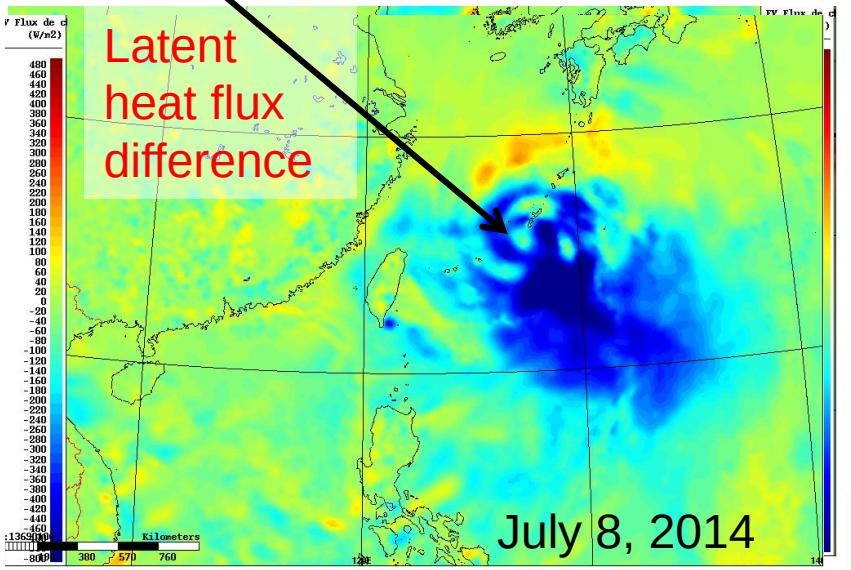
Impact of Coupling on Forecasts for TC Neoguri

96h forecasts, valid 00Z, July 10, 2014

- Coupling results in ~4°C cooling of sea surface temperature
- with associated >500 W/m2 reduction in latent heat flux
- Leads to reduced intensification at all lead times (24-120h)

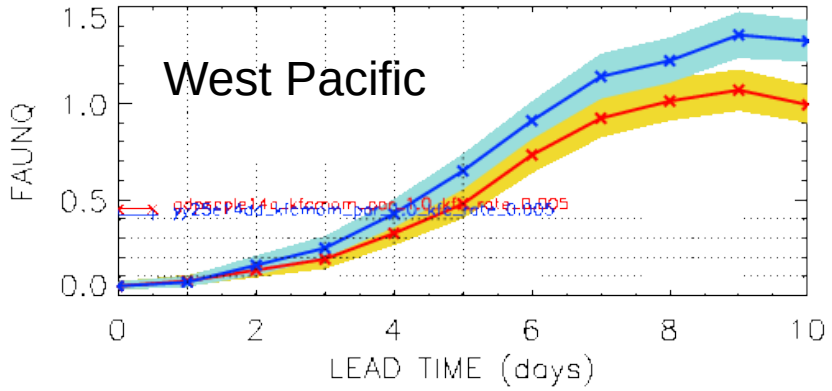


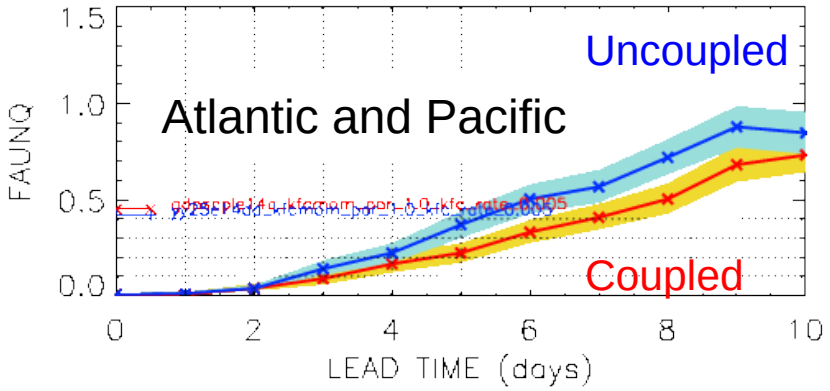


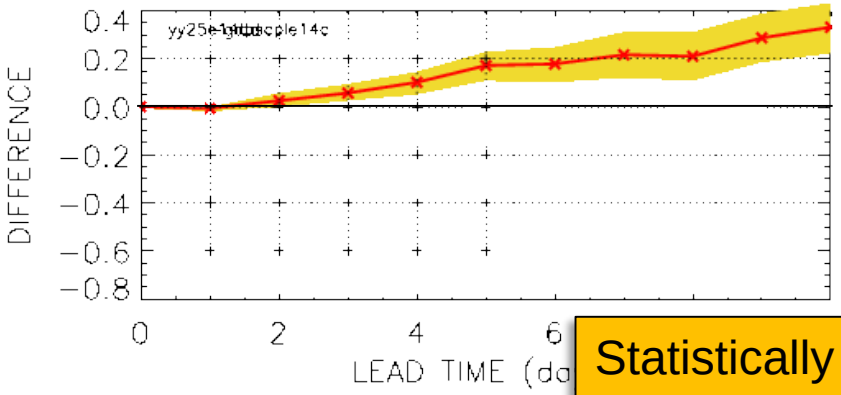


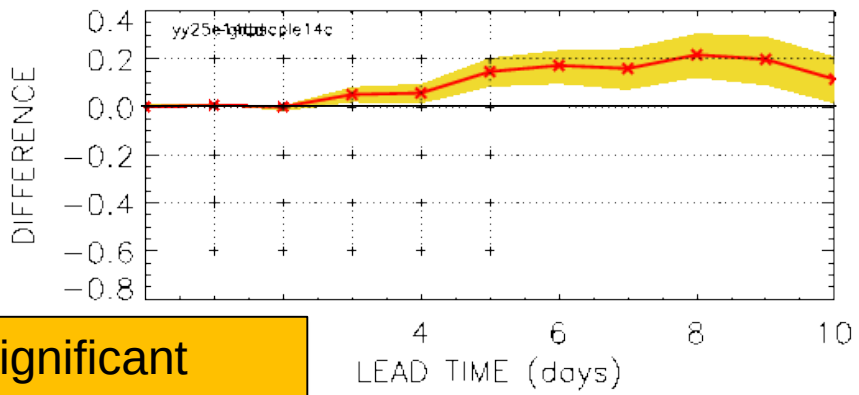
Unequivocal False Alarm Rate

Storm tracking thresholds set as in Zadra et al. (2014)





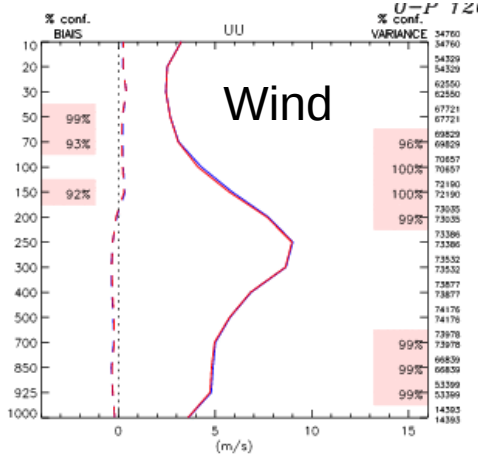




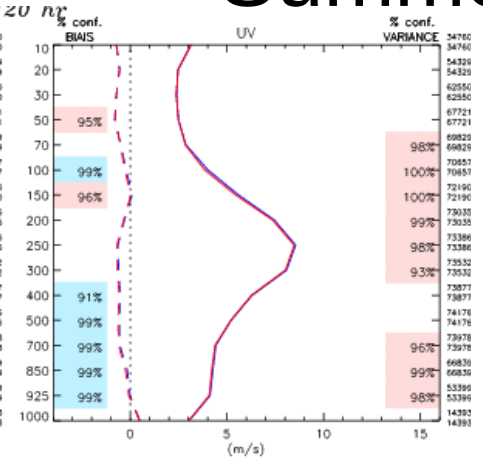
Statistically significant reduction for days 3-10

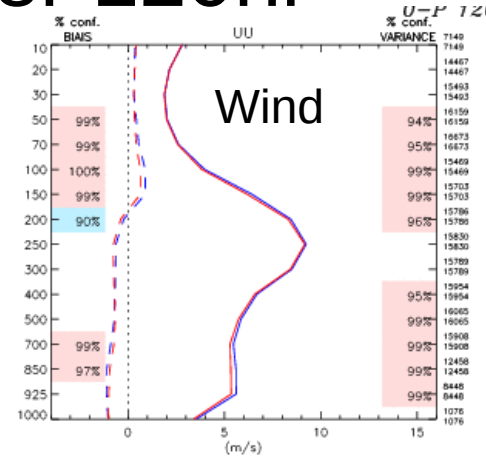
Summer 120hr

Versus radiosondes

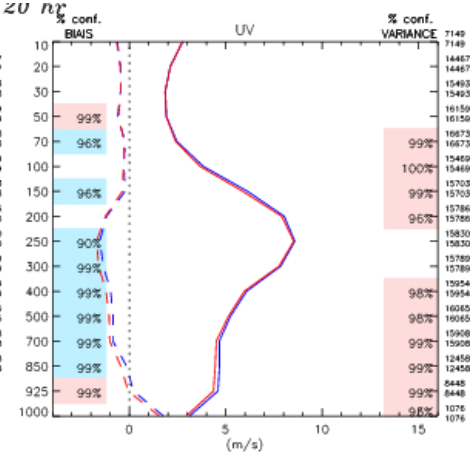


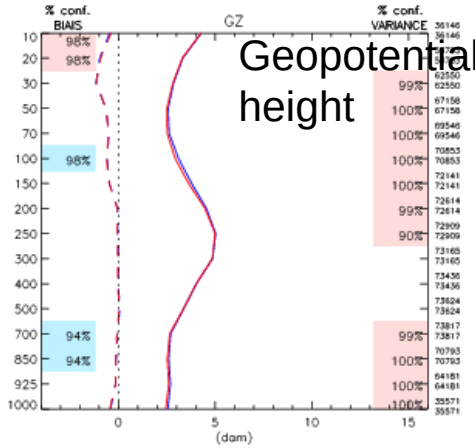
Wind



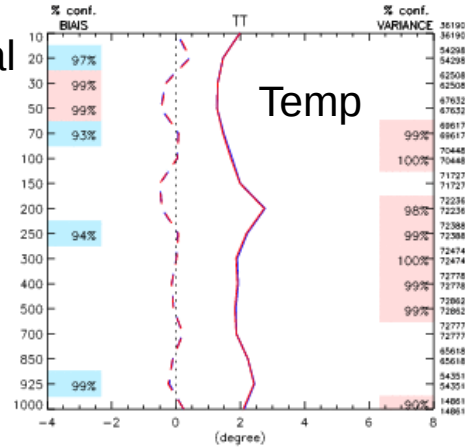


Wind

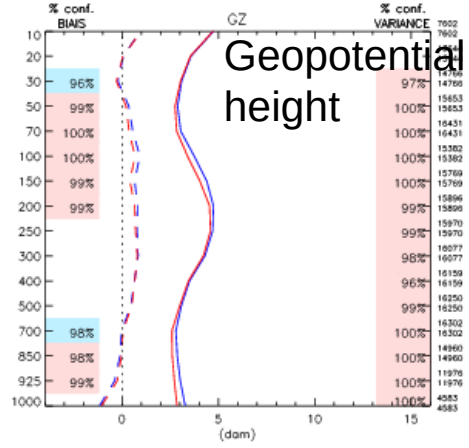




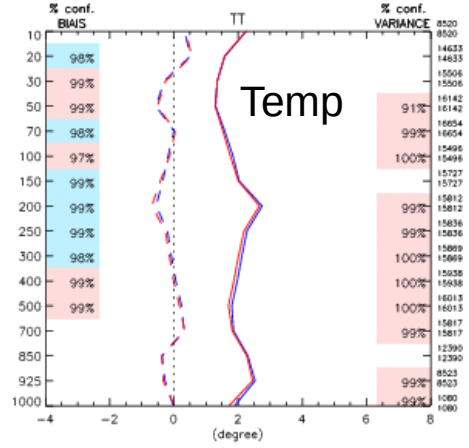
Geopotential height



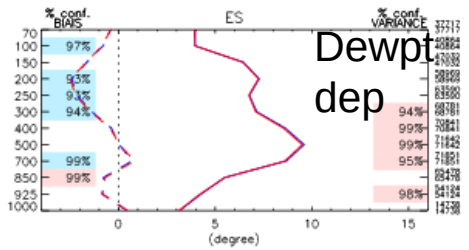
Temp



Geopotential height

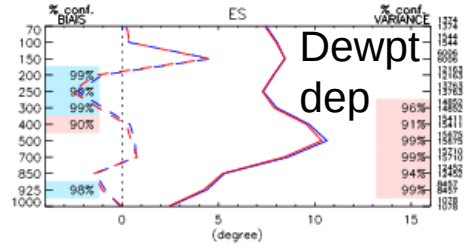


Temp



Dewpt dep

Global

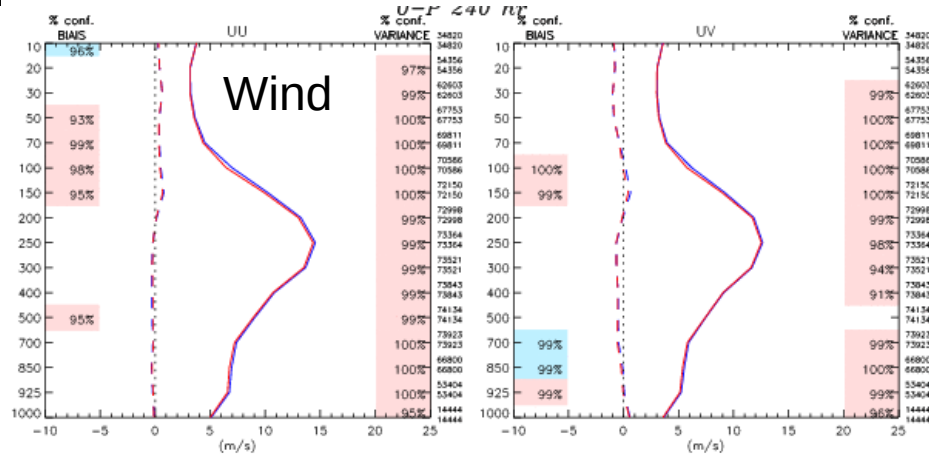


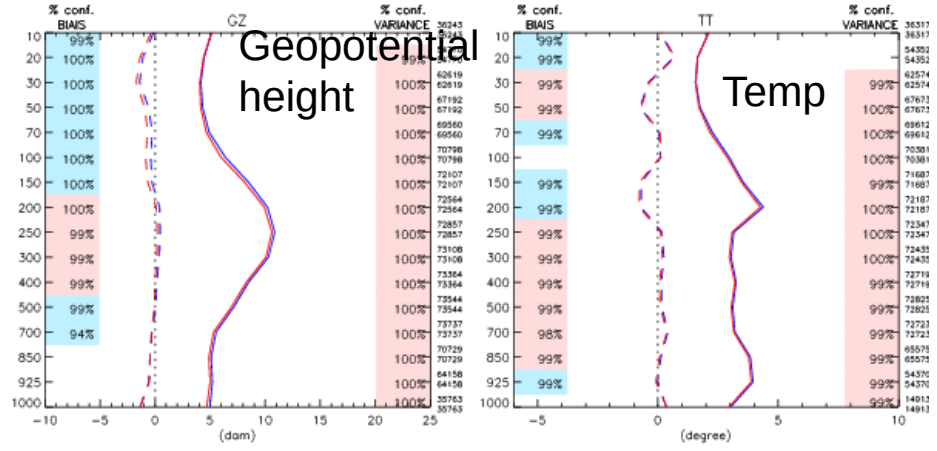
Dewpt dep

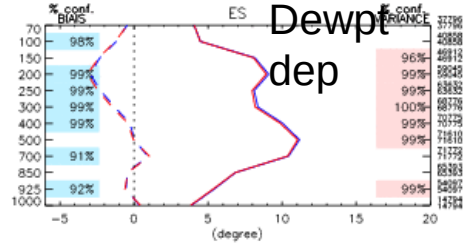
Asia

Summer 240hr

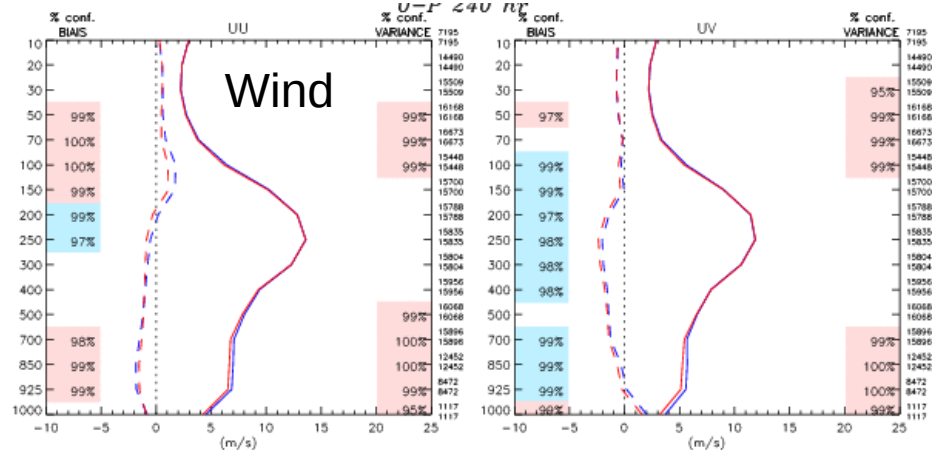
Versus radiosondes

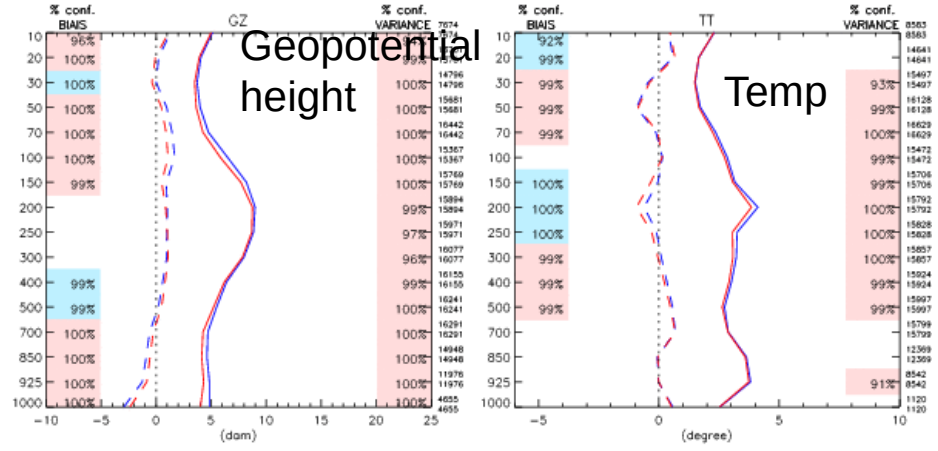


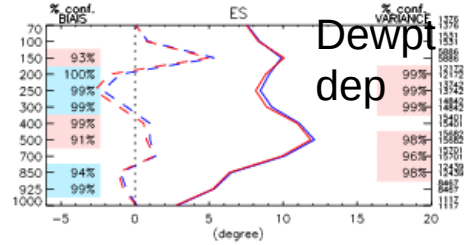




Global





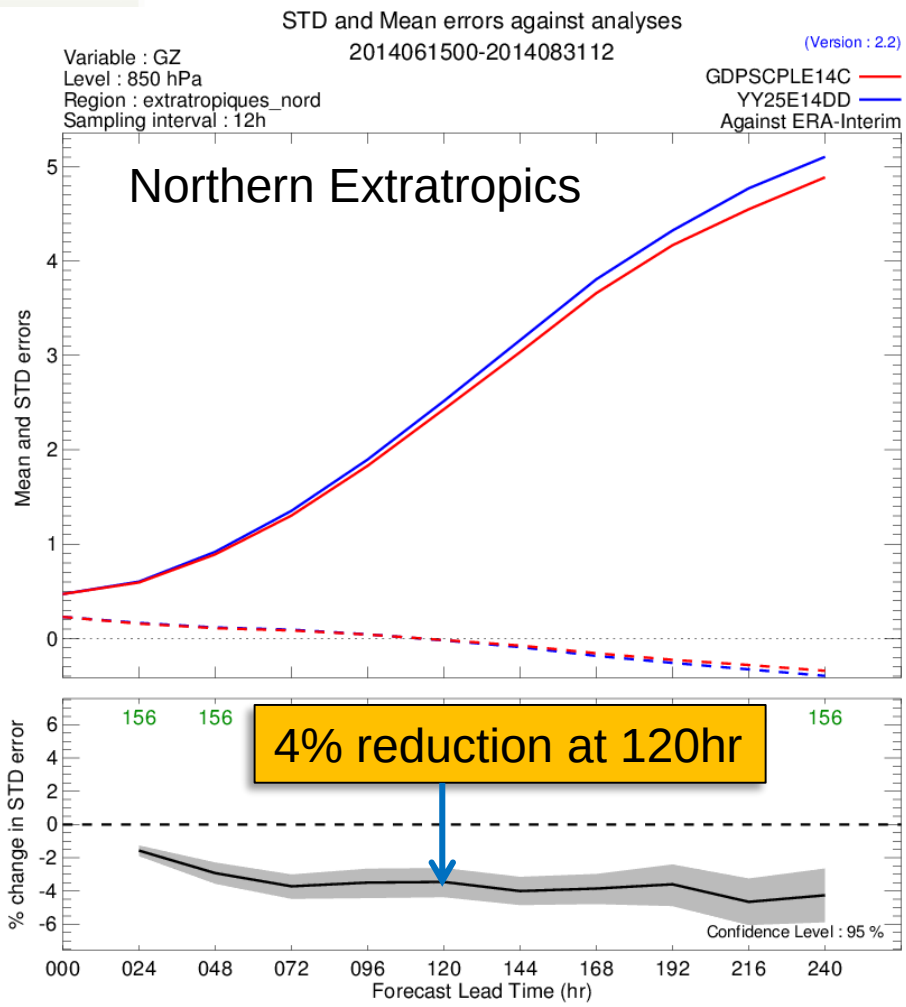


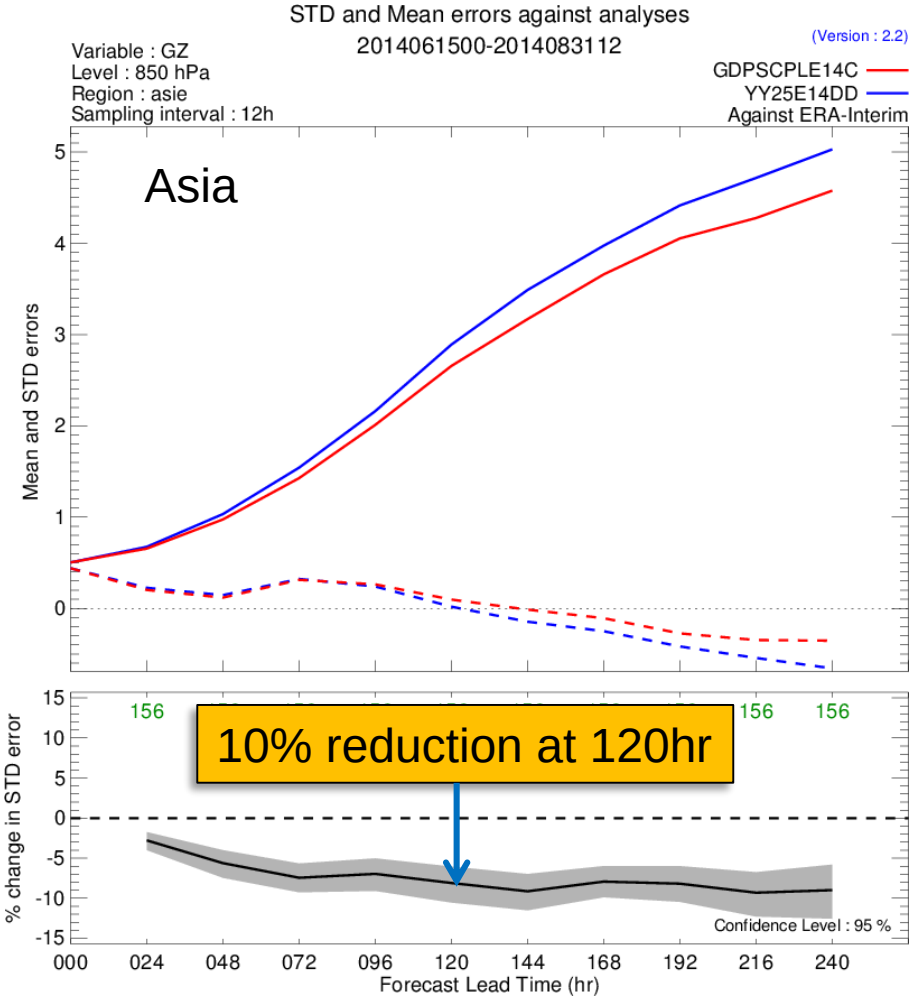
Asia

Type : 0-P 240 hr
Region : Monde
Lat-lon: (90S, 180W) (90N, 180E)
Stat. inversees
E-T m_ua140615_140831_240_coloc_ua_yy25e14dd.ua_GDPScpIE14C (15
BIAIS m_ua140615_140831_240_coloc_ua_yy25e14dd.ua_GDPScpIE14C
E-T m_ua140615_140831_240_coloc_ua_GDPScpIE14C.ua_yy25e14dd (15
BIAIS m_ua140615_140831_240_coloc_ua_GDPScpIE14C.ua_yy25e14dd

Type : 0-P 240 hr
Region : Asie
Lat-lon: (25N, 65E) (60N, 145E)
Stat. inversees
E-T m_ua140615_140831_240_coloc_ua_yy25e14dd.ua_GDPScpIE14C (15
BIAIS m_ua140615_140831_240_coloc_ua_yy25e14dd.ua_GDPScpIE14C
E-T m_ua140615_140831_240_coloc_ua_GDPScpIE14C.ua_yy25e14dd (15
BIAIS m_ua140615_140831_240_coloc_ua_GDPScpIE14C.ua_yy25e14dd

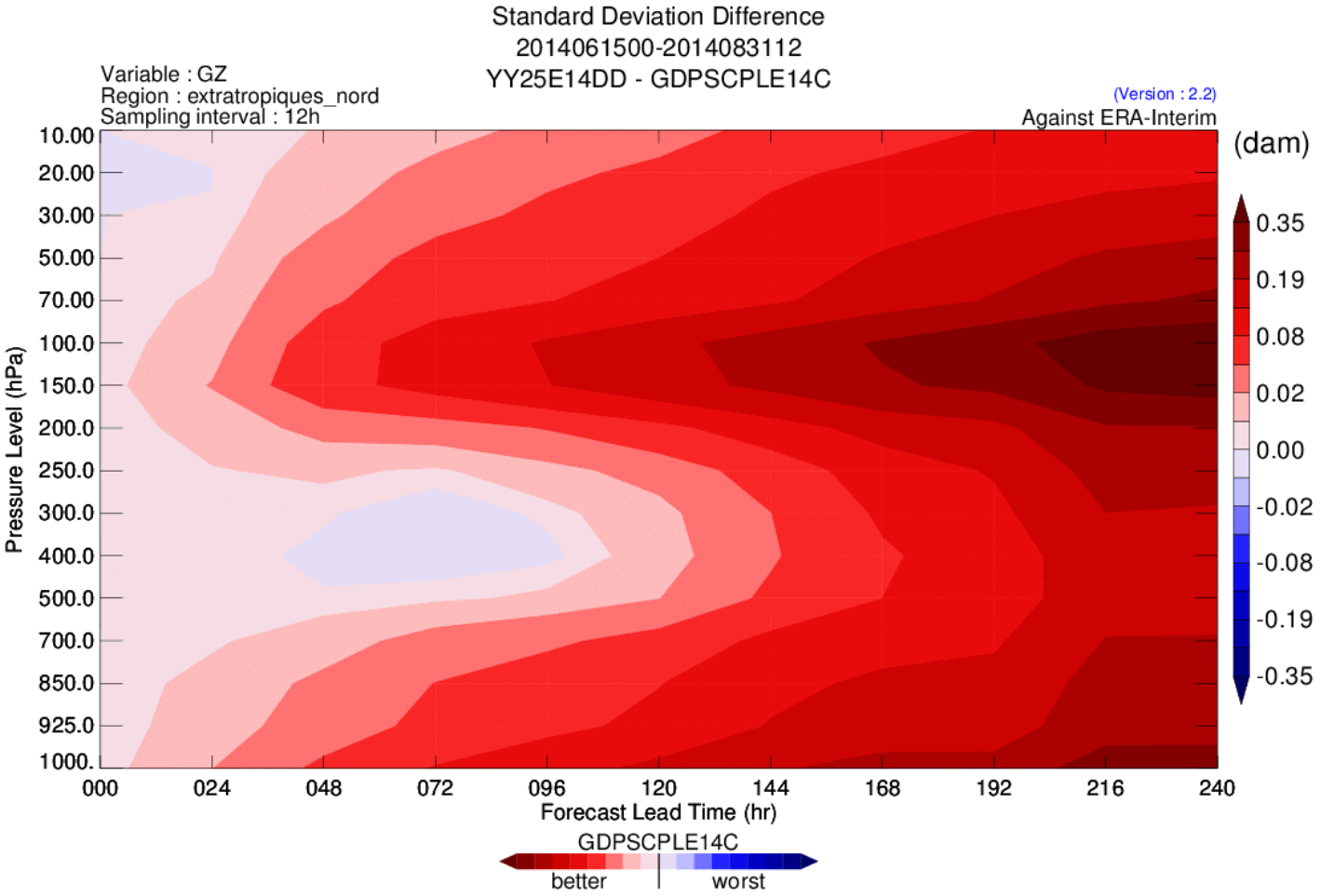
Geopotential Height at 850hPa





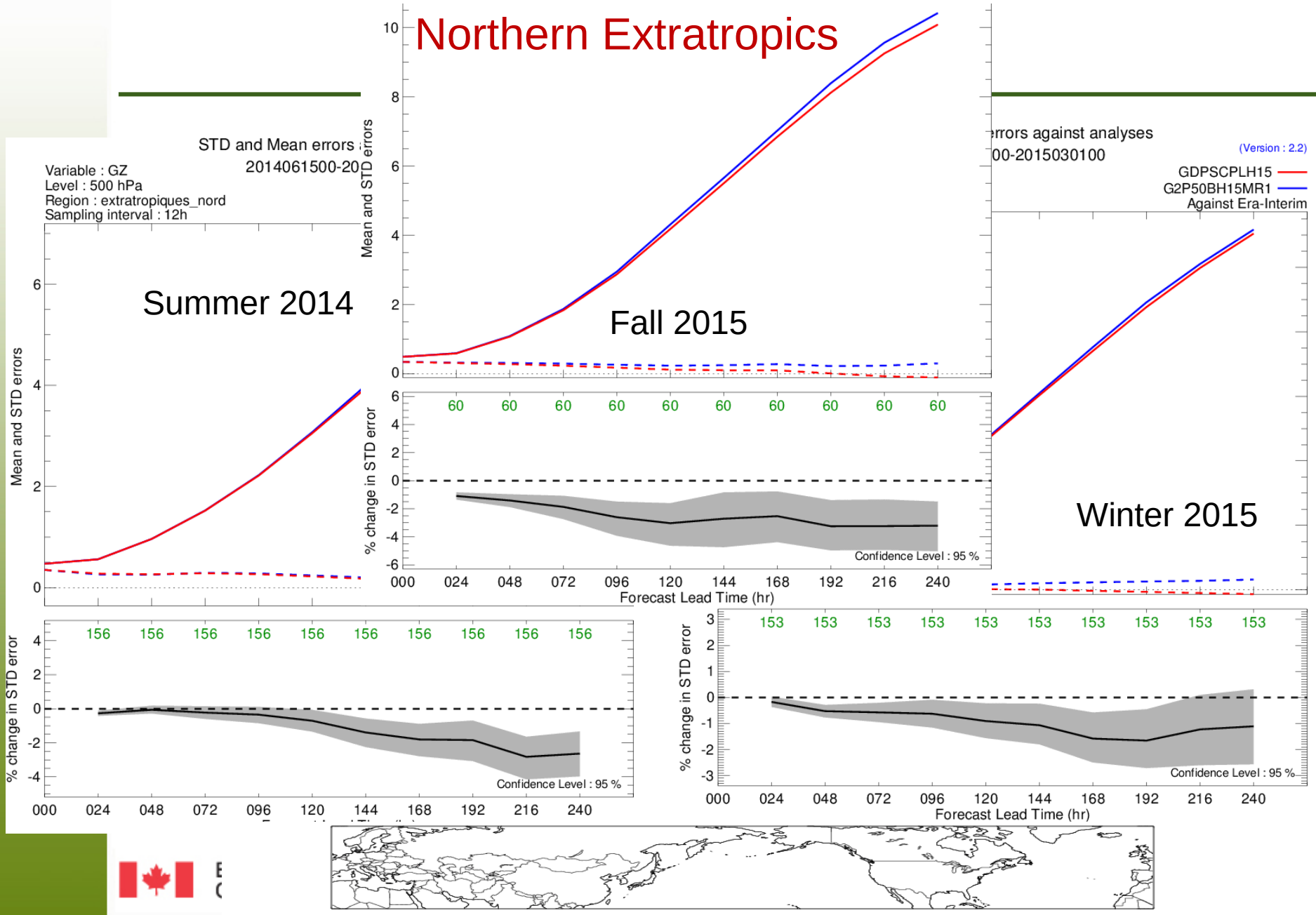
Geopotential heights over the Northern Extratropics

Impact on standard deviation



Impact on 500 hPa Geopotential Height Fields

Northern Extratropics



Environment Canada Environnement Canada

Fisheries and Oceans Canada

Mercator Ocean Ocean Forecasters

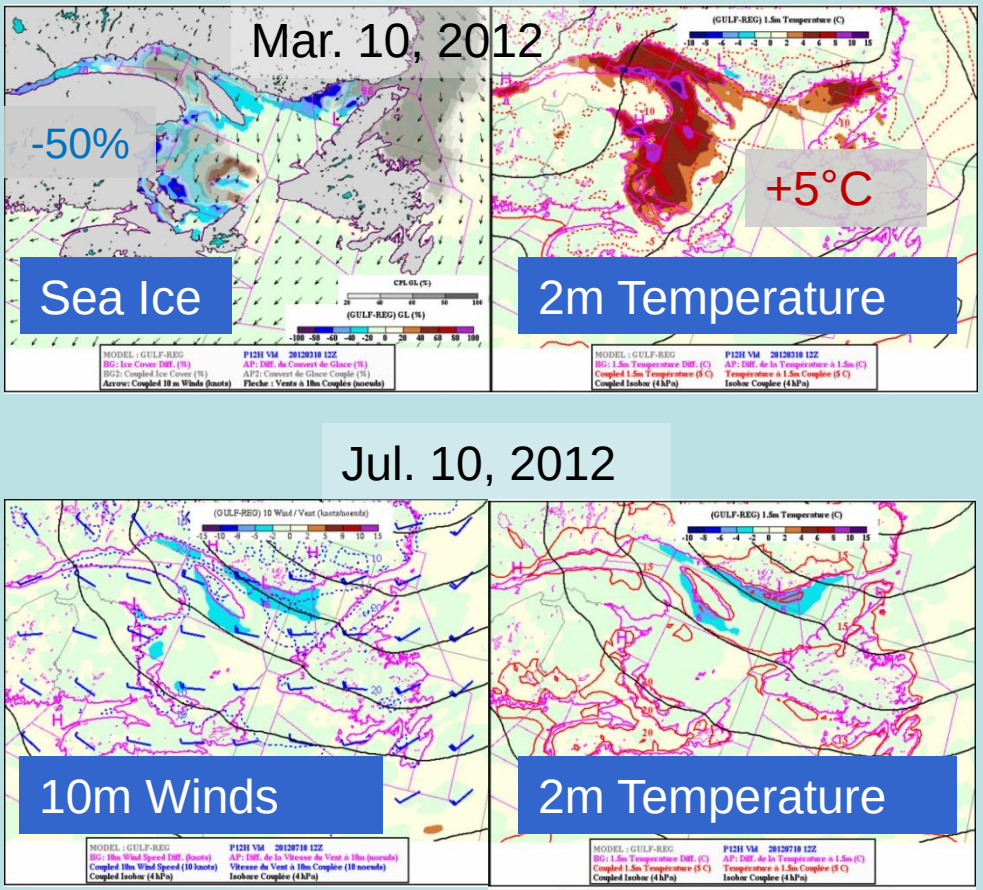
Canada

Regional Coupled Systems

Gulf of St. Lawrence (GSL) Coupled Atmosphere-Ice-Ocean Forecasting System

- Operational since June 2011
  - 48h forecast 4 times/day
- Coupled system:
  - Atmosphere
    - GEM (10 km)
  - Ice-ocean
    - NEMO-CICE (5km)
- Under development:
  - Atmosphere
    - GEM (2.5km),
  - Ice-ocean
    - NEMO-CICE(1km)
  - Include Great Lakes

Coupled – Uncoupled differences



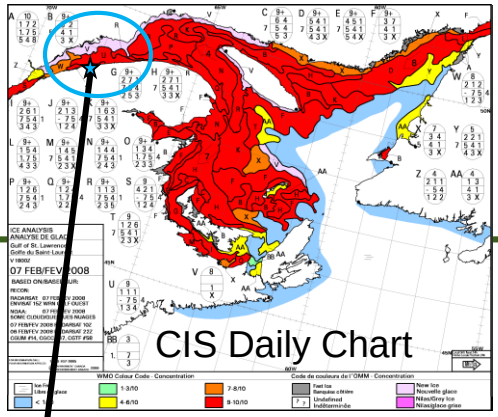
Environment Canada

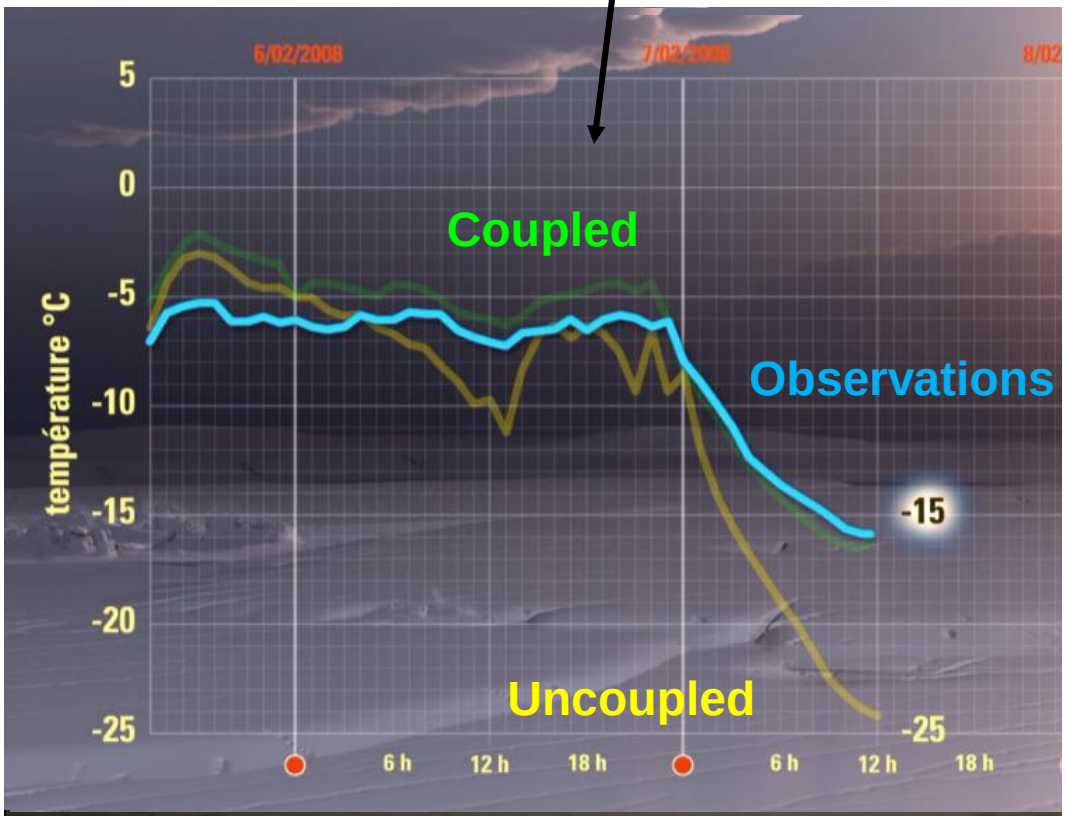
Francois Roy, Sarah Dyck, Mark Pilon, …

Canada

The Gulf of St. Lawrence (GSL) Coupled Atmosphere-Ice-Ocean Forecasting System

- Running Operationally at the Canadian Meteorological Centre since 2011
- A dynamic representation of sea surface conditions improves the meteorological forecast locally
- Time-evolving ice cover in coupled model allows vast stretches of ice-free water to open up, buffering atmospheric temperatures
- Use of coupled model results in significantly improved forecasts all around the GSL
- Demonstrates importance of air-sea-ice coupling even for short-range weather forecasts

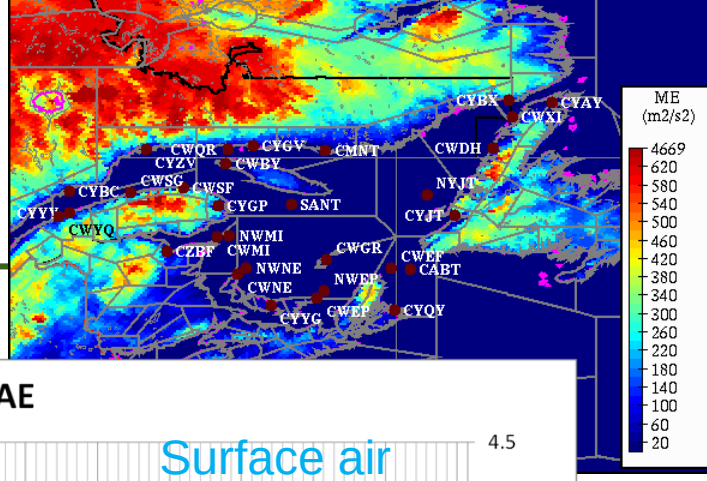


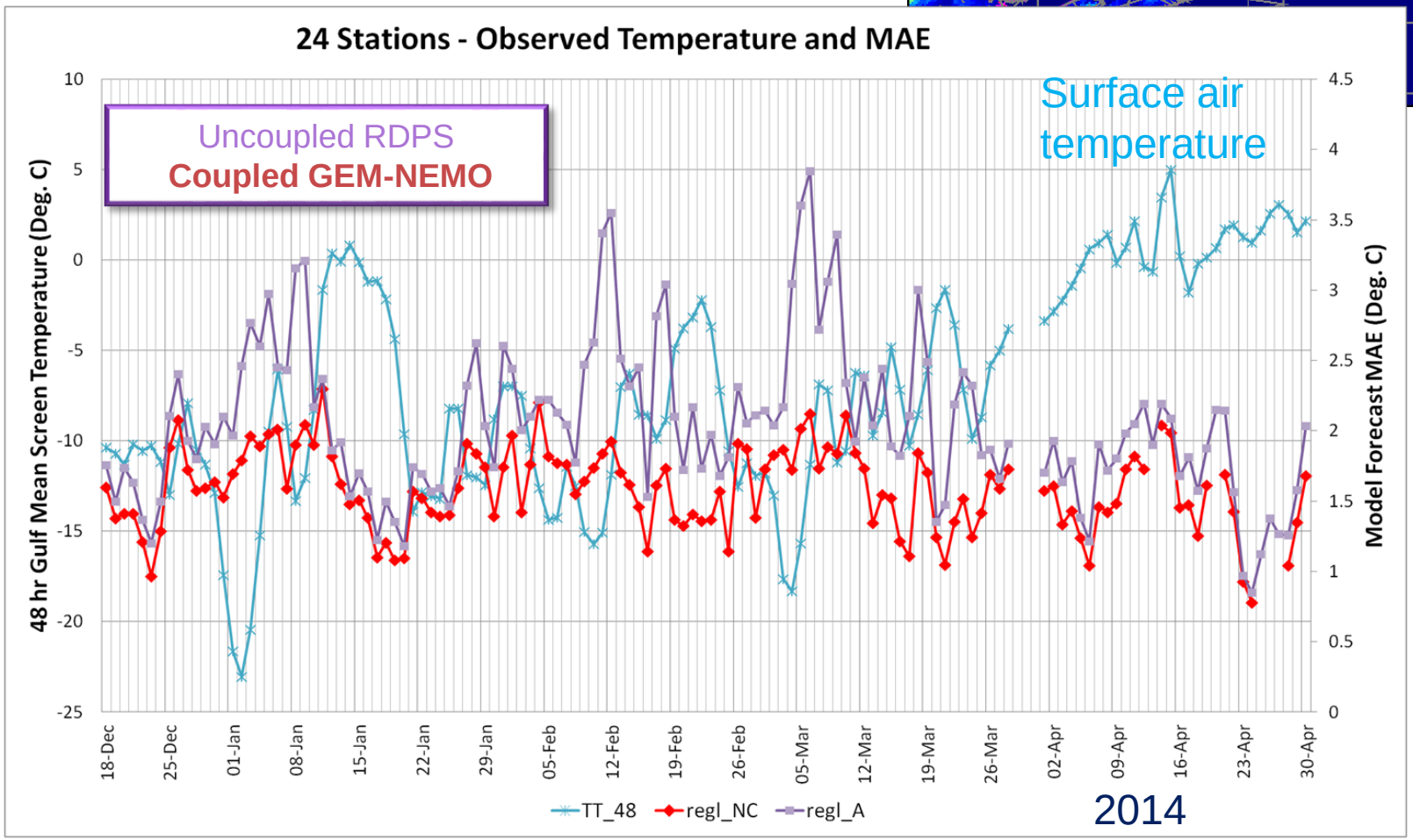


Courtesy Radio-Canada

Real-time evaluation of Coupled GSL Forecasting System

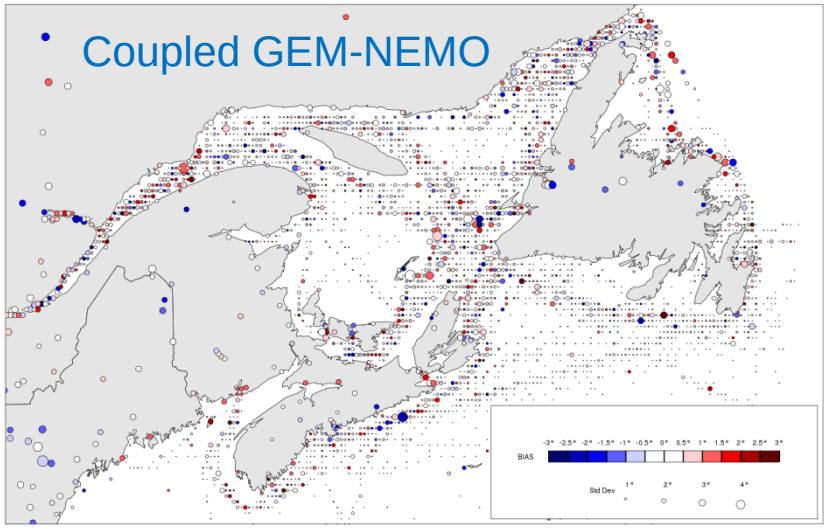
Mark Pilon, Sarah Dyck, Francois Roy

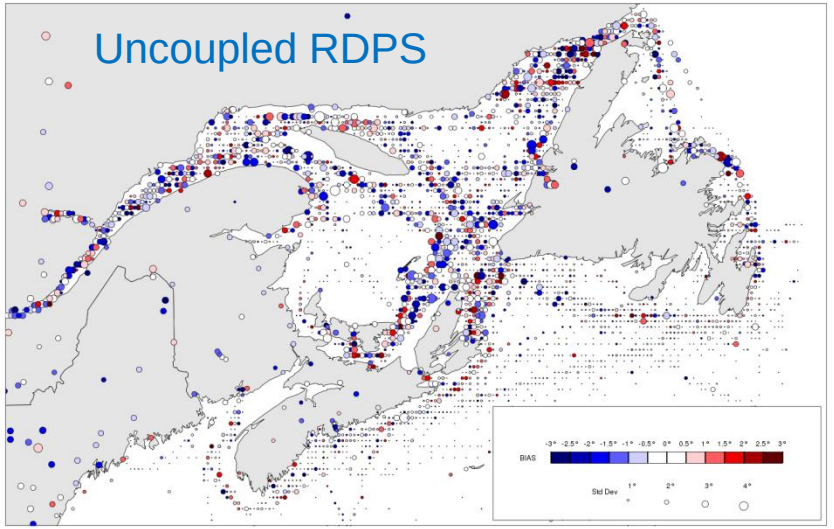




Real-time evaluation of Coupled GSL Forecasting System

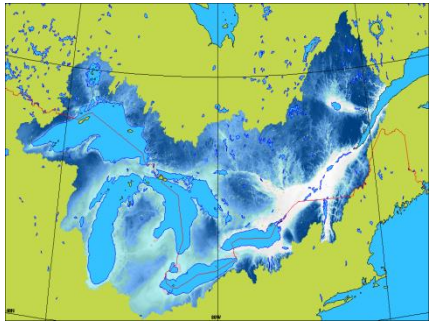
- Evaluation against all surface temperature observations
  - 48hr forecasts over Jan-Mar 2014
  - Colours show bias
  - Standard deviation shown by the size of each circle
- Smaller errors in coupled system over water
- GSL is an ideal laboratory for studying impacts of coupling!





Great Lakes and St. Lawrence Water Cycle Prediction System

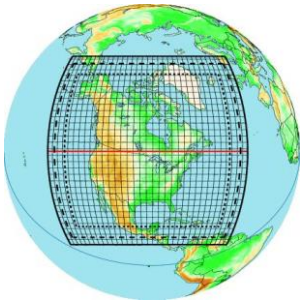
WATROUTE
routing model (1km)



GEM LAM (10 km)
atmospheric model
(ISBA land-surface scheme)

Runoff

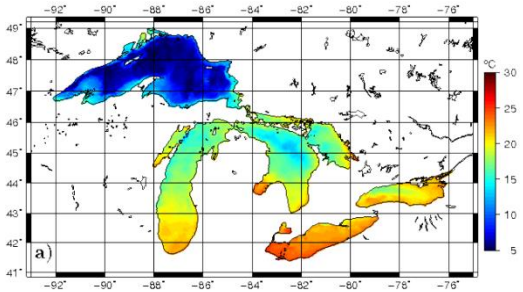
GEM RDPS (10 km)
atmospheric model



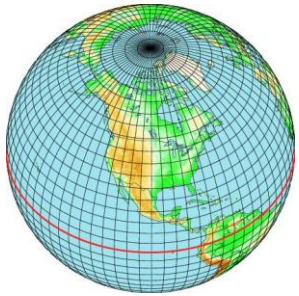
Streamflow

Turbulent fluxes

- **2 forecasts/day (00Z and 12Z)**
- **48-h forecasts**
- **Assimilation cycle: direct insertion of RADARSAT ice cover and WSC streamflow**



NEMO+CICE (2 km)
ocean-ice model



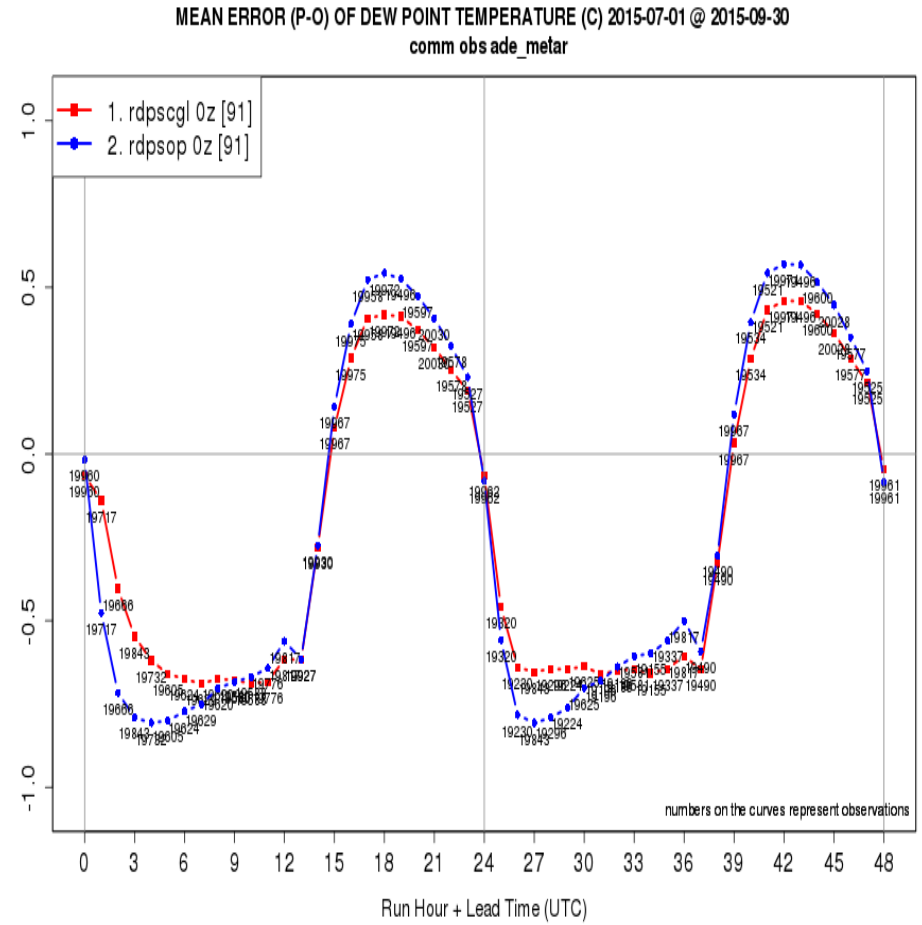
GEM GDPS (25 km)
atmospheric model

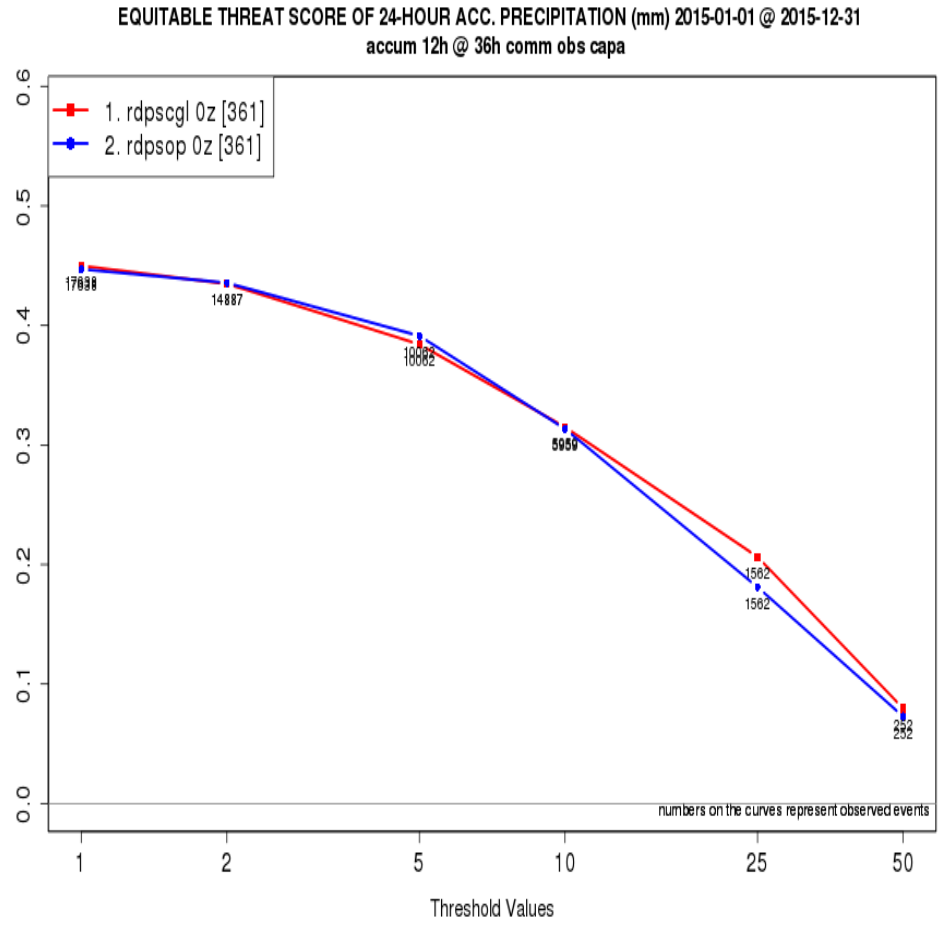
Environment Canada Environnement Canada

Better weather forecasts

Summer 2015
RDPS
GL-WCPS

Year 2015
RDPS
GL-WCPS

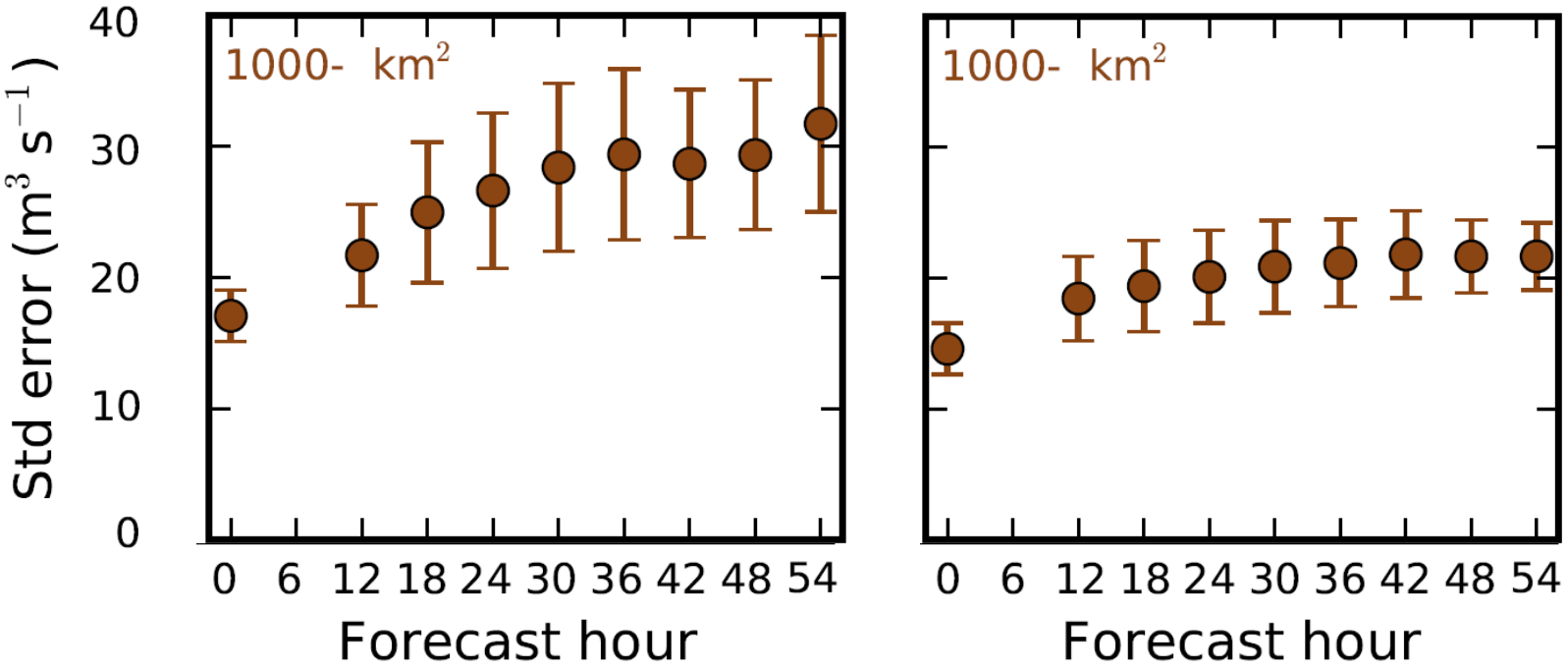




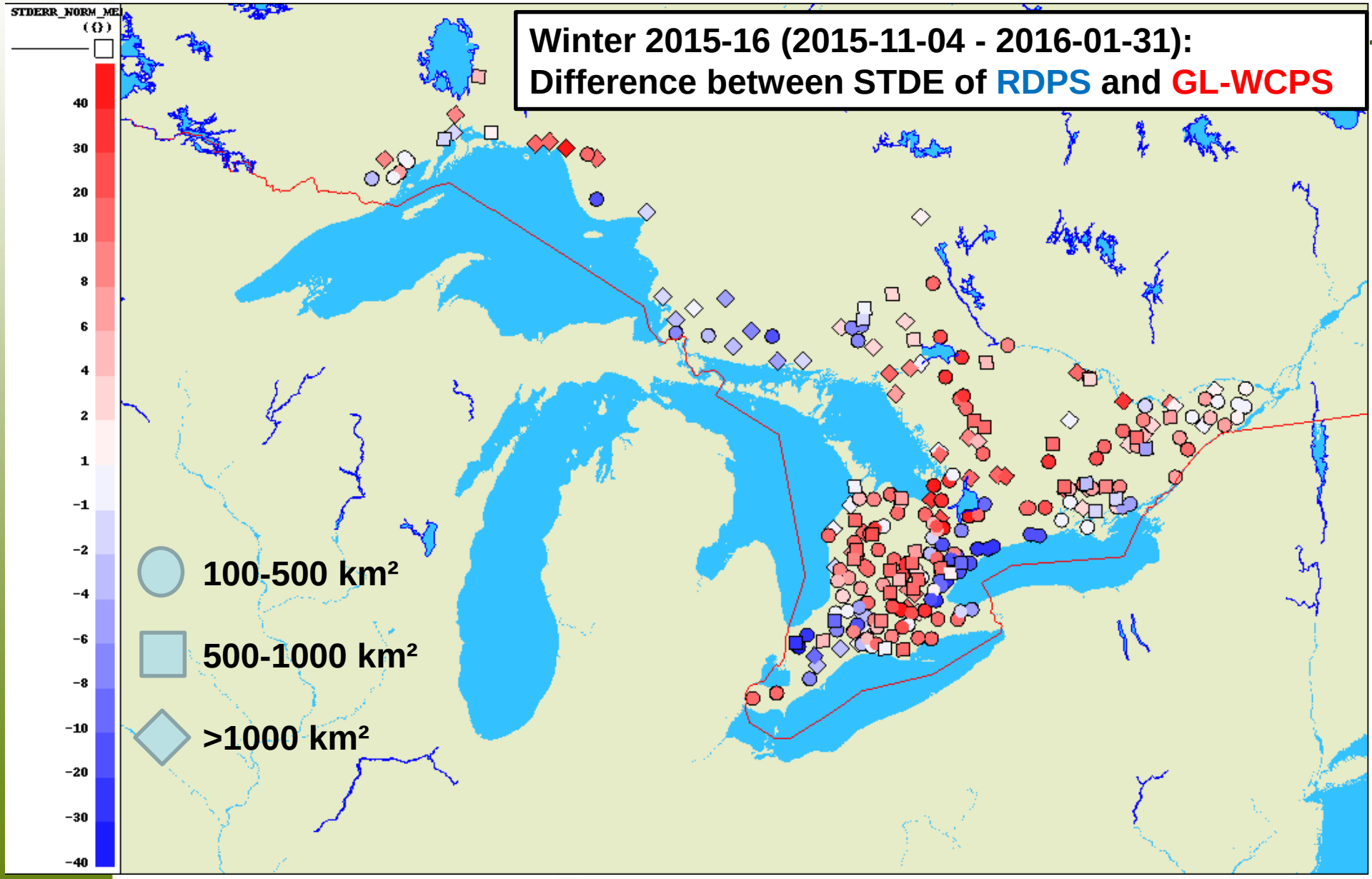
Better streamflow forecasts

Winter 2015-16 (2015-11-04 - 2016-01-31)

RDPS **GL-WCPS**



Better streamflow forecasts



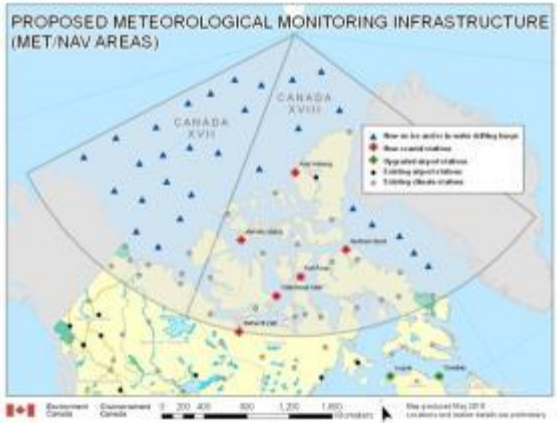
CCMEP Coupled Systems: Status and Plans

- Three systems running in operations
  - Coupled GDPS (25km, 10d fcst, 2/day)
  - Great Lakes Coupled Prediction System (2km; 48h fcst, daily)
  - Coupled A-I-O Gulf of St. Lawrence (5km; 48h fcst, every 6hrs)

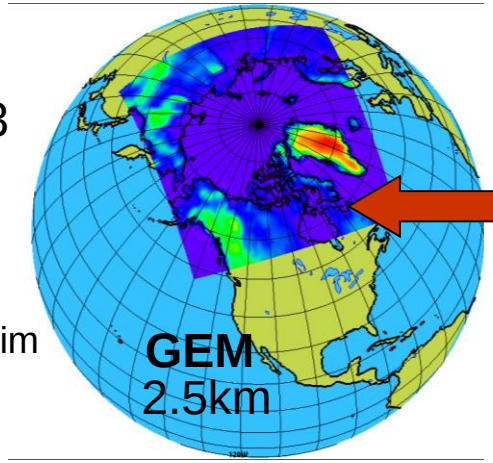
- Several systems in various stages of development
  - Coupled Regional Polar System for YOPP
  - Coupling with regional and ensemble NWP systems
  - Monthly and seasonal forecasting system

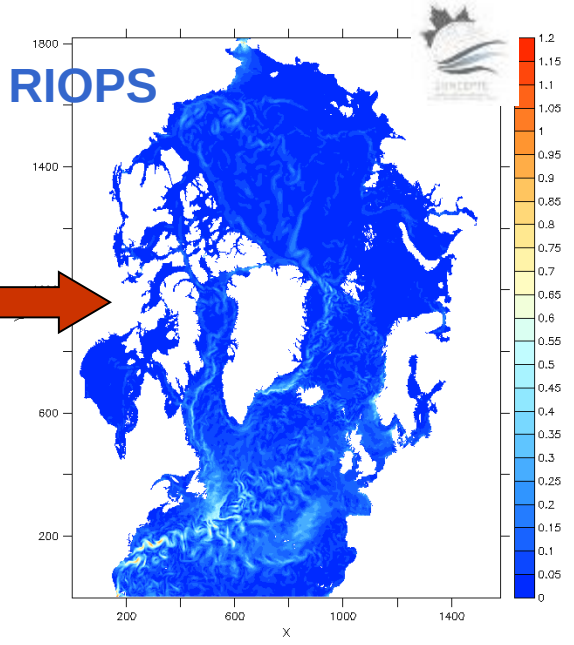
ECCC YOPP Prediction System

High-resolution coupled atmosphere-ice-ocean prediction system



- In support of :
  - Weather prediction for northern Canada
  - EC METAREAs Services
  - Marine emergency response
- Coupled atmosphere-ice-ocean model
  - GEM (2.5km)
    - Improved microphysics
  - NEMO-CICE (3-8km)/WW3
    - Tides, landfast ice
    - Form drag, melt ponds
    - wave-ice coupling
    - Improved ice-ocean assim
    - Arctic Rivers
  - 72hr forecasts (4/day)

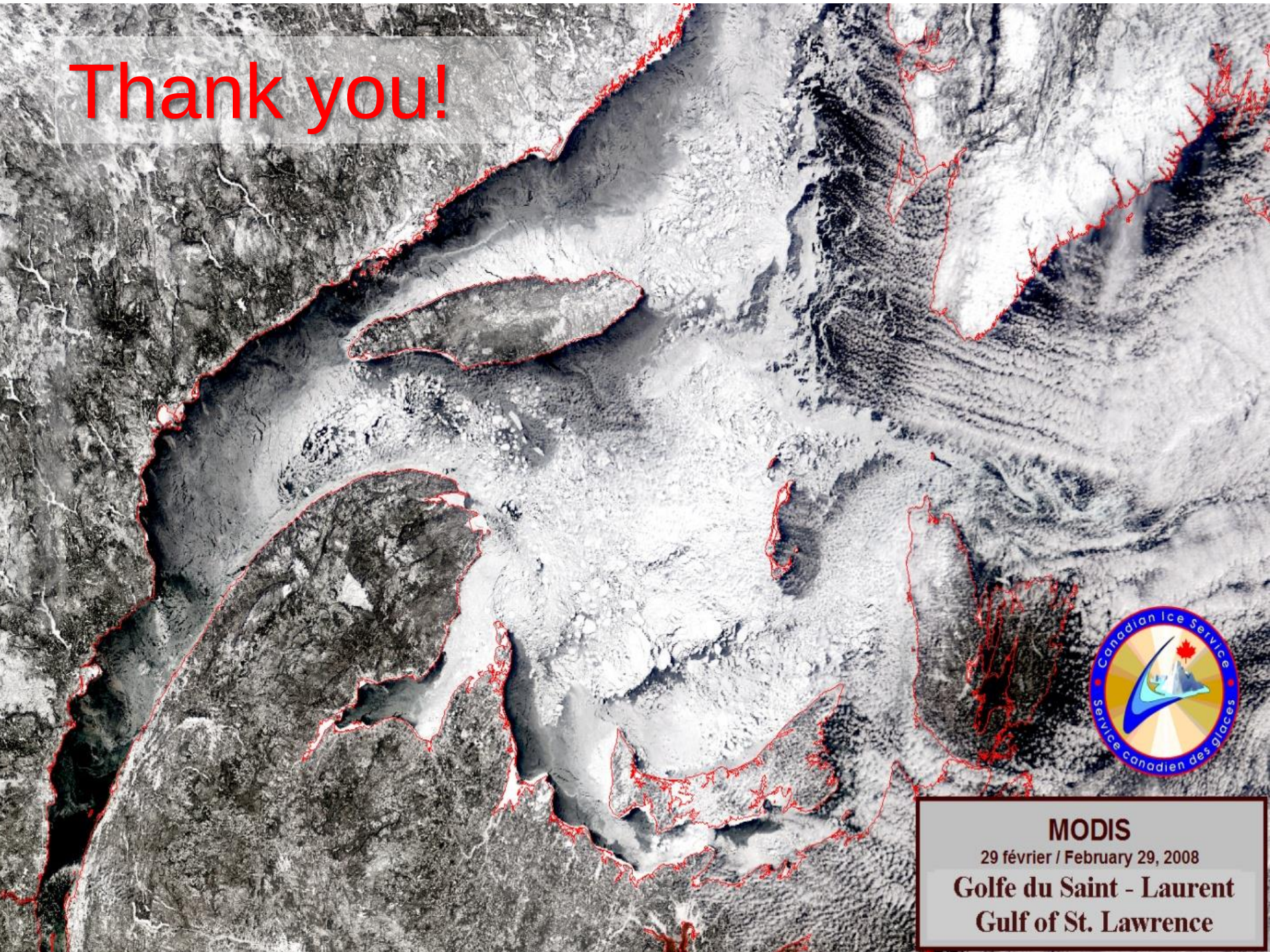




Summary

- CCMEP is currently running a suite of global and regional coupled environmental prediction systems
  - Benefit for weather prediction as well as providing a marine core service
- Global Coupled Medium-range NWP running since July 2016
  - Main impacts due to improved representation of surface fluxes for tropical cyclones
  - Significant impacts for Northern Extratropics growing with increasing lead time
- Evolving sea ice cover affects regional weather forecasts on very short timescales
  - Details matter!
- Successful implementation depends on careful treatment of surface initial conditions and sea ice physics

Thank you!


Canadian Ice Service
Service canadien des glaces
MODIS
29 février / February 29, 2008
Golfe du Saint - Laurent
Gulf of St. Lawrence