Environment Canada Environnement Canada

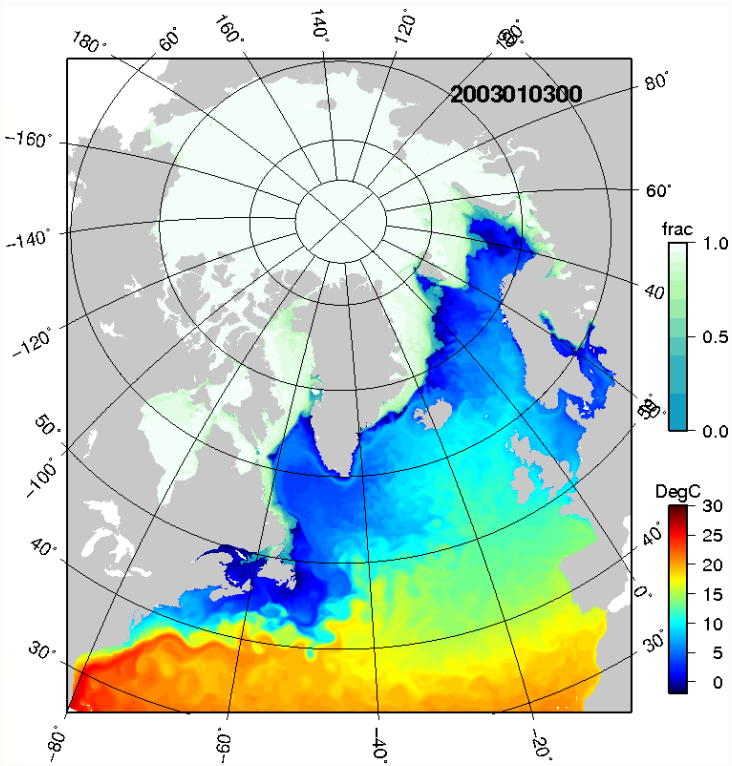
Fisheries and Oceans Canada

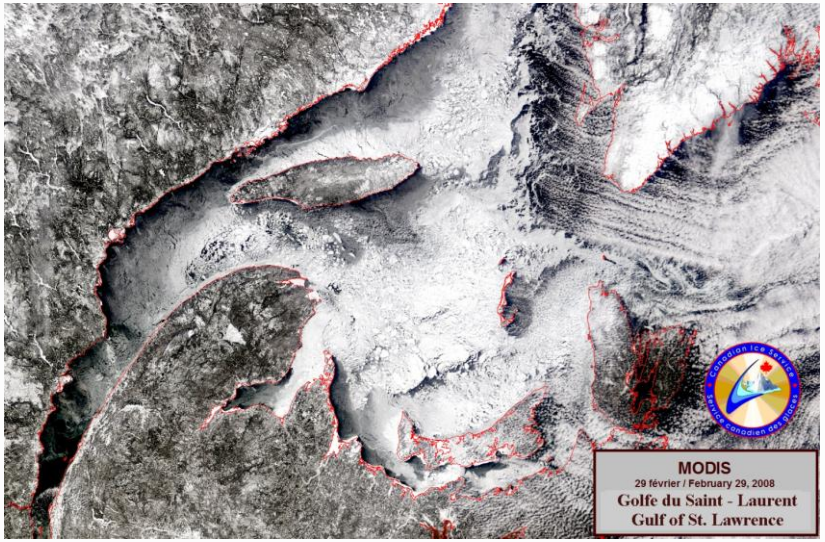
Mercator Ocean
Ocean Forecasters

National Defence

The role of high resolution ocean models in short-range predictions

Hal Ritchie and Greg Smith
Environment and Climate Change Canada
and the CONCEPTS Team

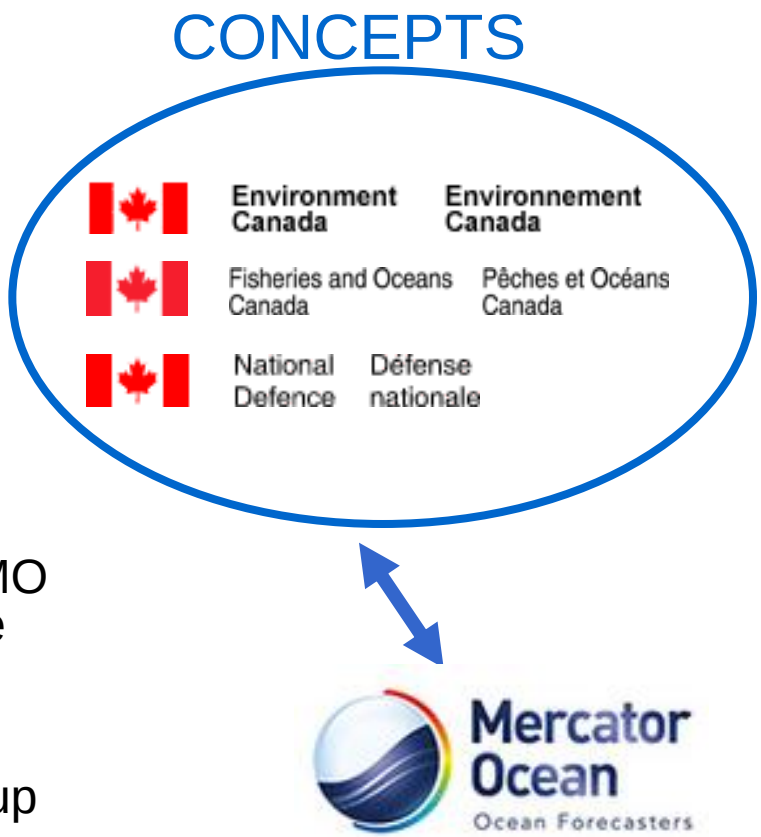




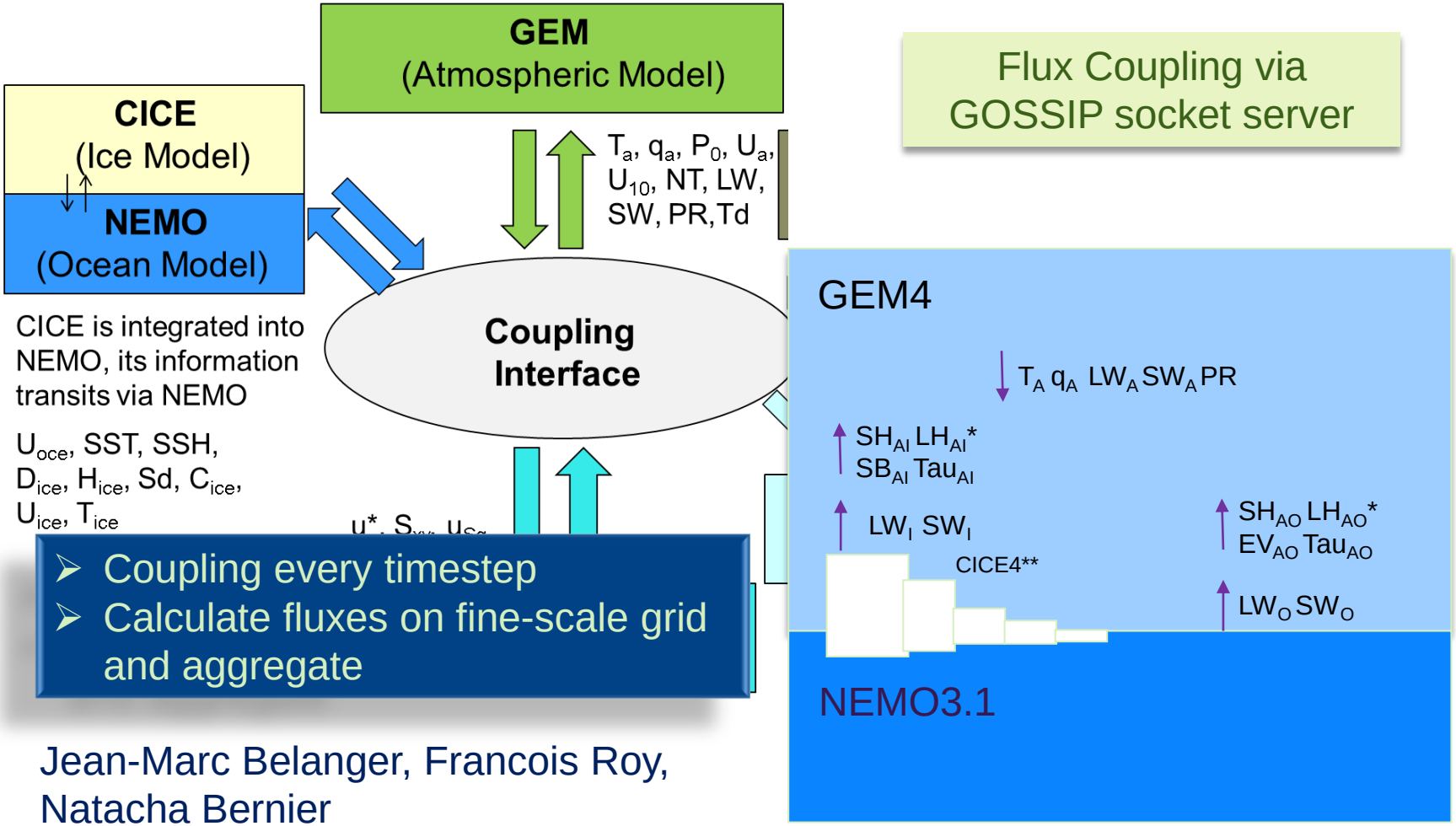
High-Resolution Ocean Modelling for Coupled Seamless Predictions Workshop, Met Office, Exeter UK, 13-15 April 2016

CONCEPTS connection

- Several new coupled systems under development as part of CONCEPTS
  - Canadian Operational Network of Coupled Environmental Prediction Systems
- Tri-departmental collaboration
  - To develop coupled atmosphere-ice-ocean forecasting systems
- Model development
  - Coupling GEM (Global Environmental Multi-scale) atmospheric model to NEMO (Nucleus for European Modelling of the Ocean)
- Collaboration with Mercator
  - French operational oceanographic group



Coupling Method



Flux Coupling via GOSSIP socket server

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

Jean-Marc Belanger, Francois Roy, Natacha Bernier

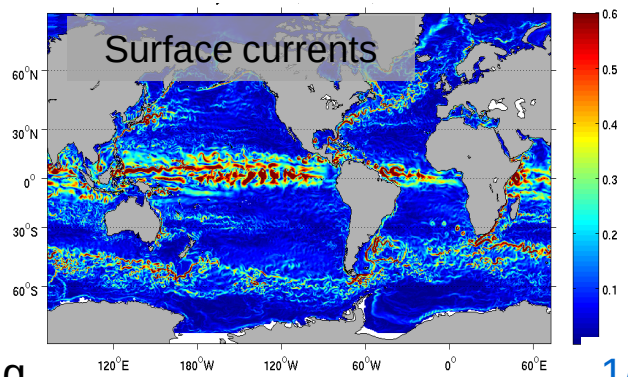
Ice-ocean modelling with NEMO

Operational
Experimental (fall 2015)
In development

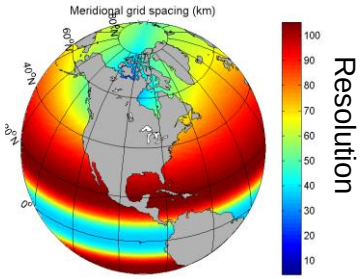
Applications and domains

- Global 1/4° resolution (GIOPS)
  - Medium-monthly forecasting
- Global 1° resolution (CanSIPS)
  - Seasonal forecasting
- N. Atlantic and Arctic 1/12° (RIOPS)
  - Short-to-medium range forecasting
- East and West Coastal 1/36° (CIOPS)
- Great Lakes 2km (RMPS-GL)
- Gulf of St. Lawrence 5km (RMPS-GSL)
  - Short-term forecasting

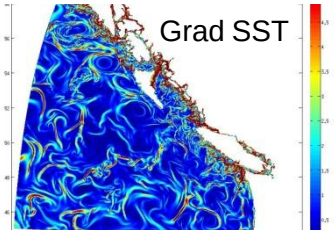
1/4° Global



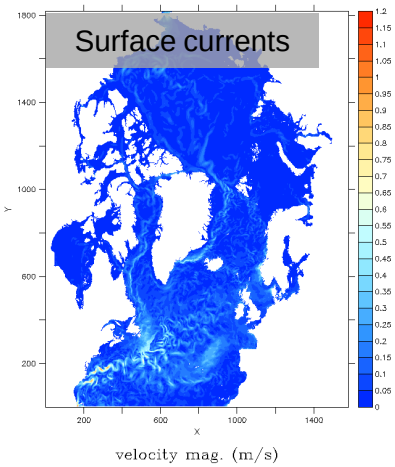
1° Global



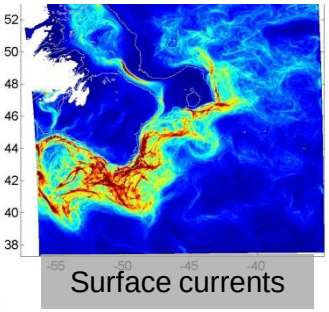
1/36° Northeast Pac.

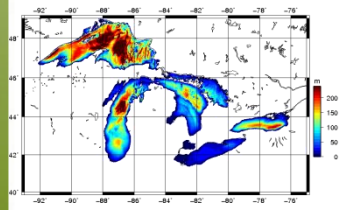


1/12° N. Atlantic and Arctic



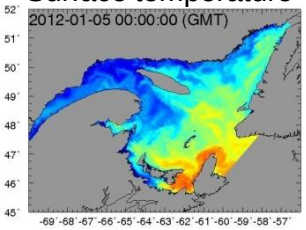
1/36° Grand Banks





Bathymetry

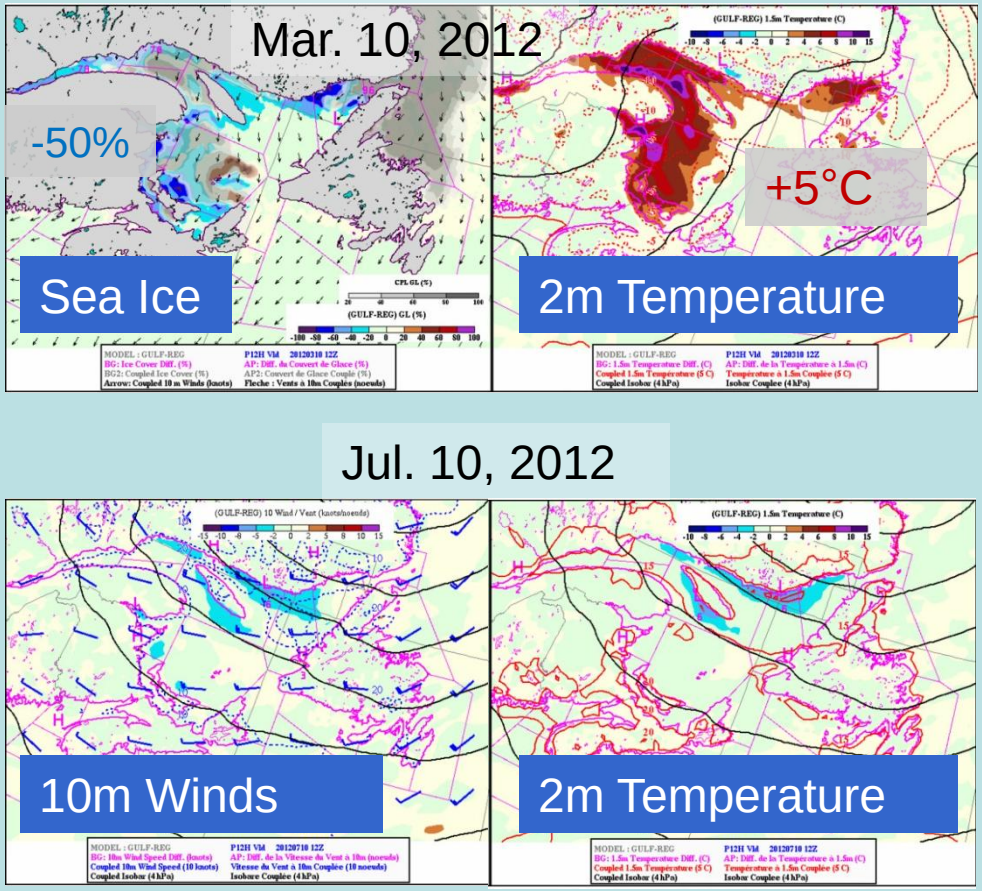
Surface temperature



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
  - PAN AM games

Coupled – Uncoupled differences

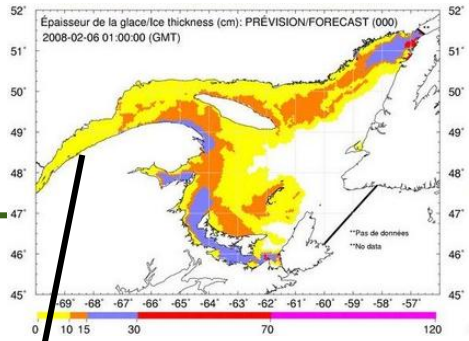


Environment Canada

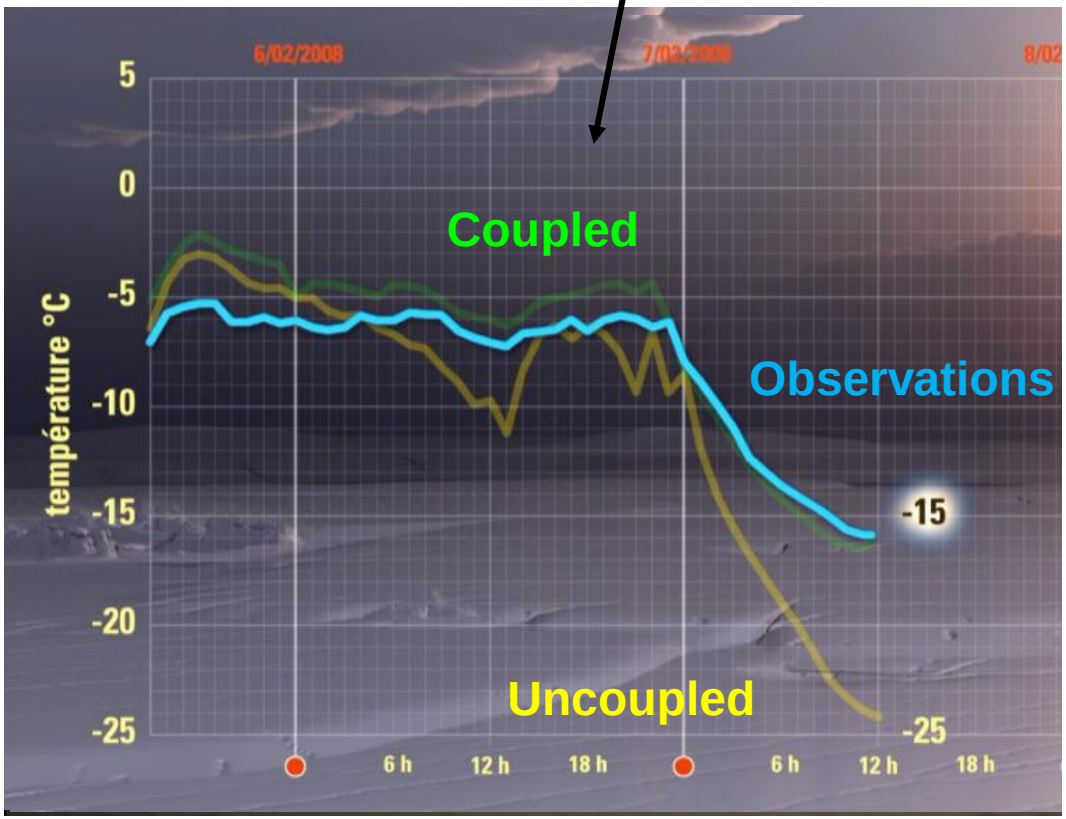
Francois Roy, Sarah Dyck, Mark Pilon, …

Canada

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

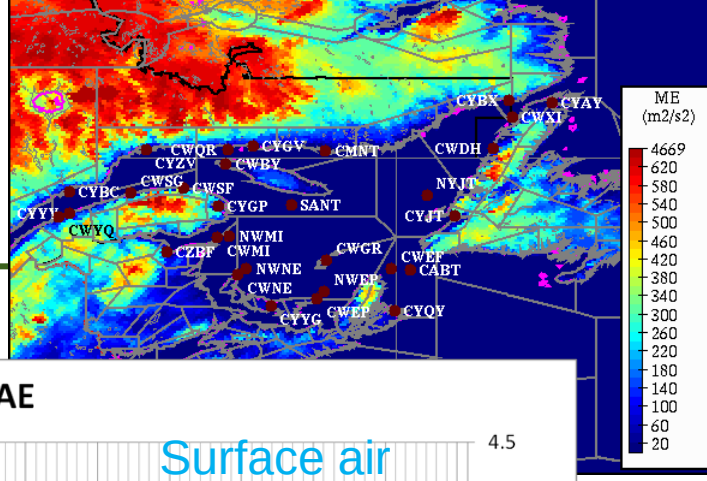


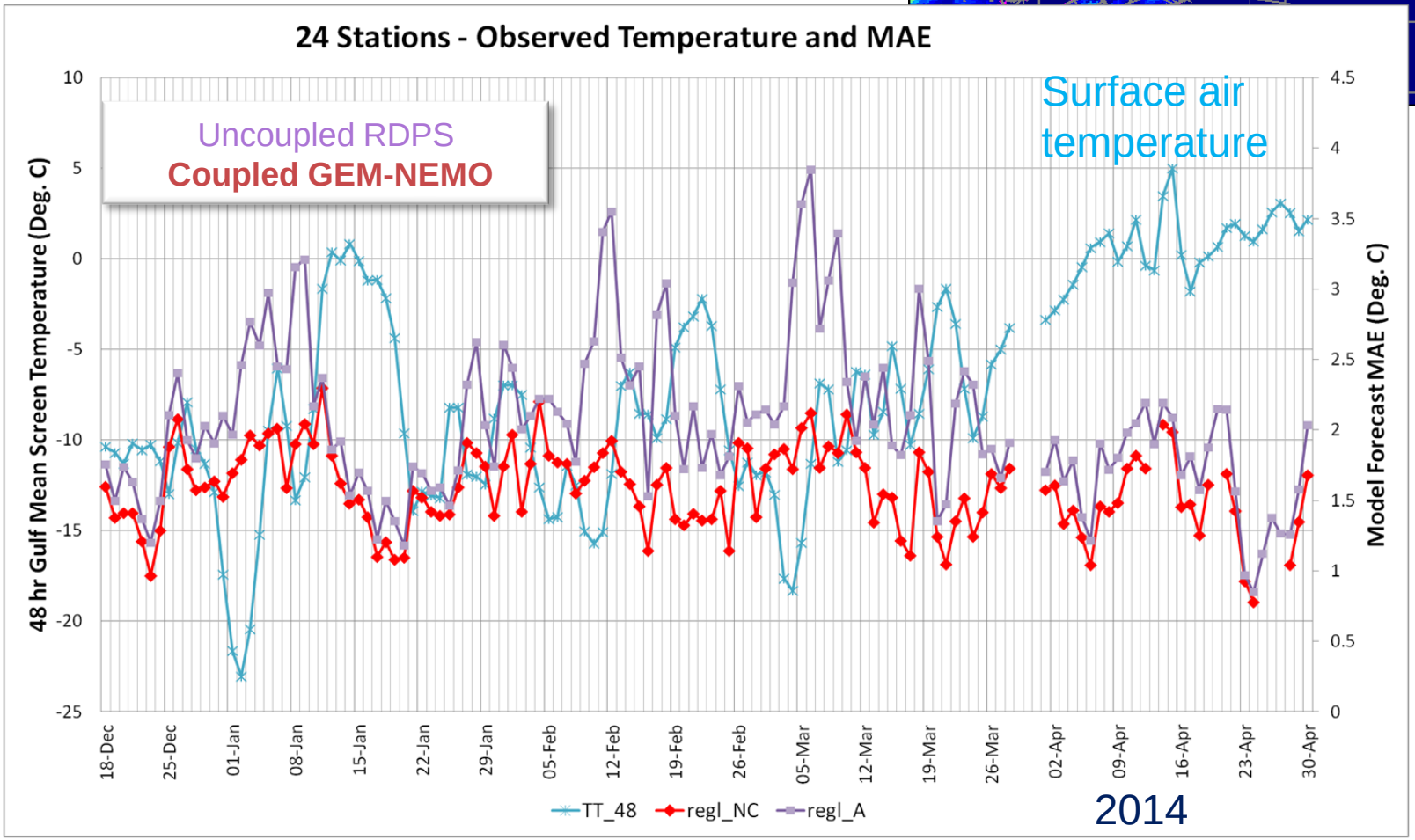
- A dynamic representation of sea surface conditions improves the meteorological forecast locally
- Time-evolving ice cover in coupled model allows vast stretches of ice-free water to open up, buffering atmospheric temperatures
- Use of coupled model results in significantly improved forecasts all around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



Real-time evaluation of Coupled GSL Forecasting System

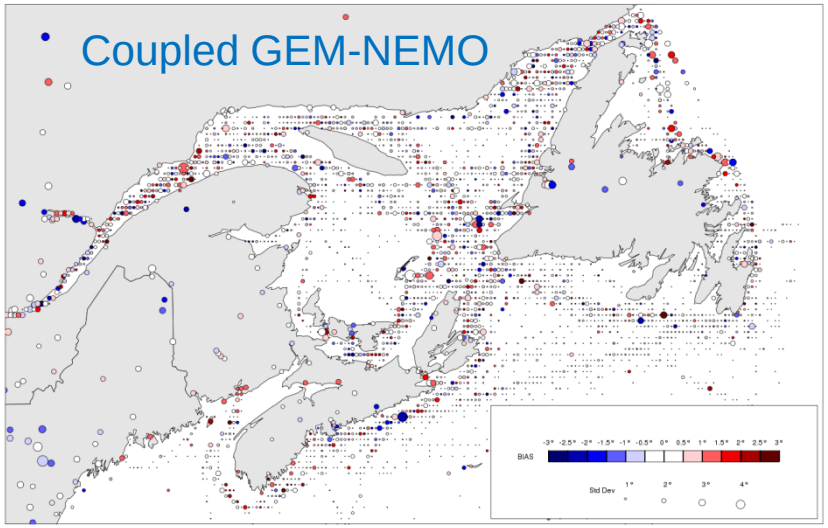
Mark Pilon, Sarah Dyck, Francois Roy

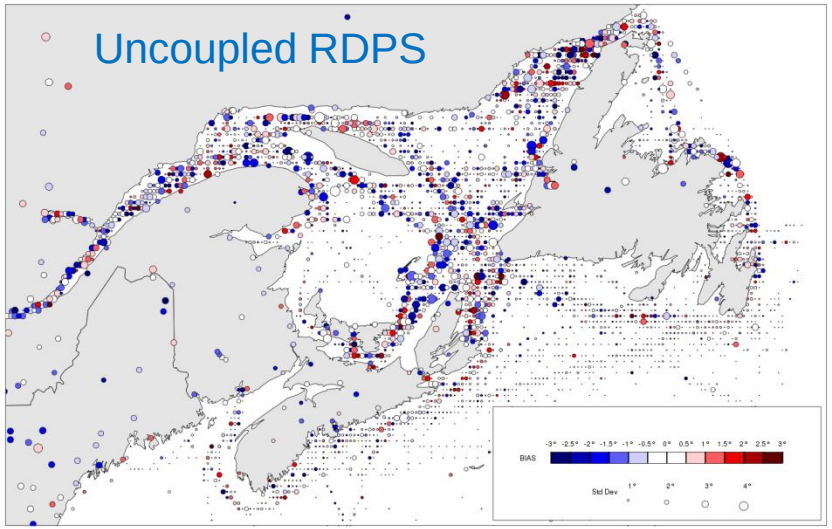




Impact of Coupled Forecasts over the Gulf of St. Lawrence

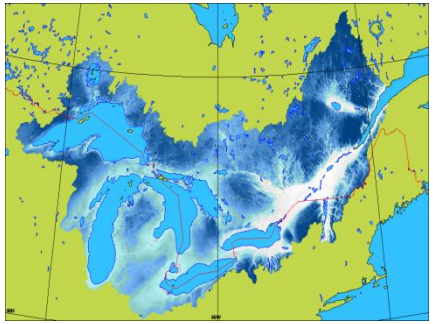
- Evaluation against all surface temperature observations
  - 48hr forecasts over Jan-Mar 2014
  - Colours show bias
  - Standard deviation shown by the size of each circle
- Smaller errors in coupled system over water
- GSL is an ideal laboratory for studying impacts of coupling!



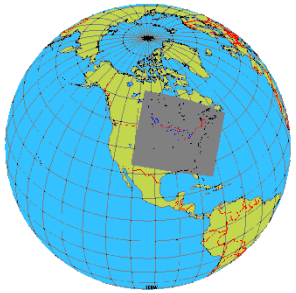


Great Lakes and St. Lawrence Water Cycle Prediction System (Fortin, Dyck et al.)

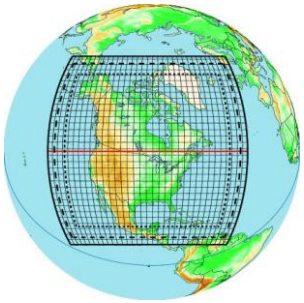
WATROUTE
routing model (1km)



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



GEM RDPS (10 km)
atmospheric model

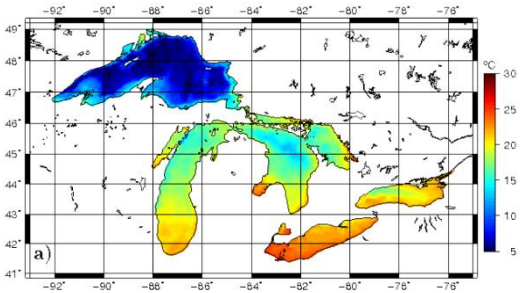


Runoff

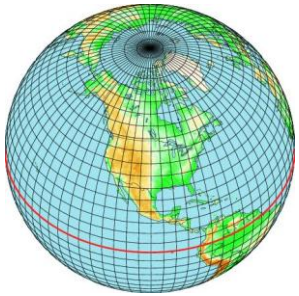
Streamflow

Turbulent fluxes

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



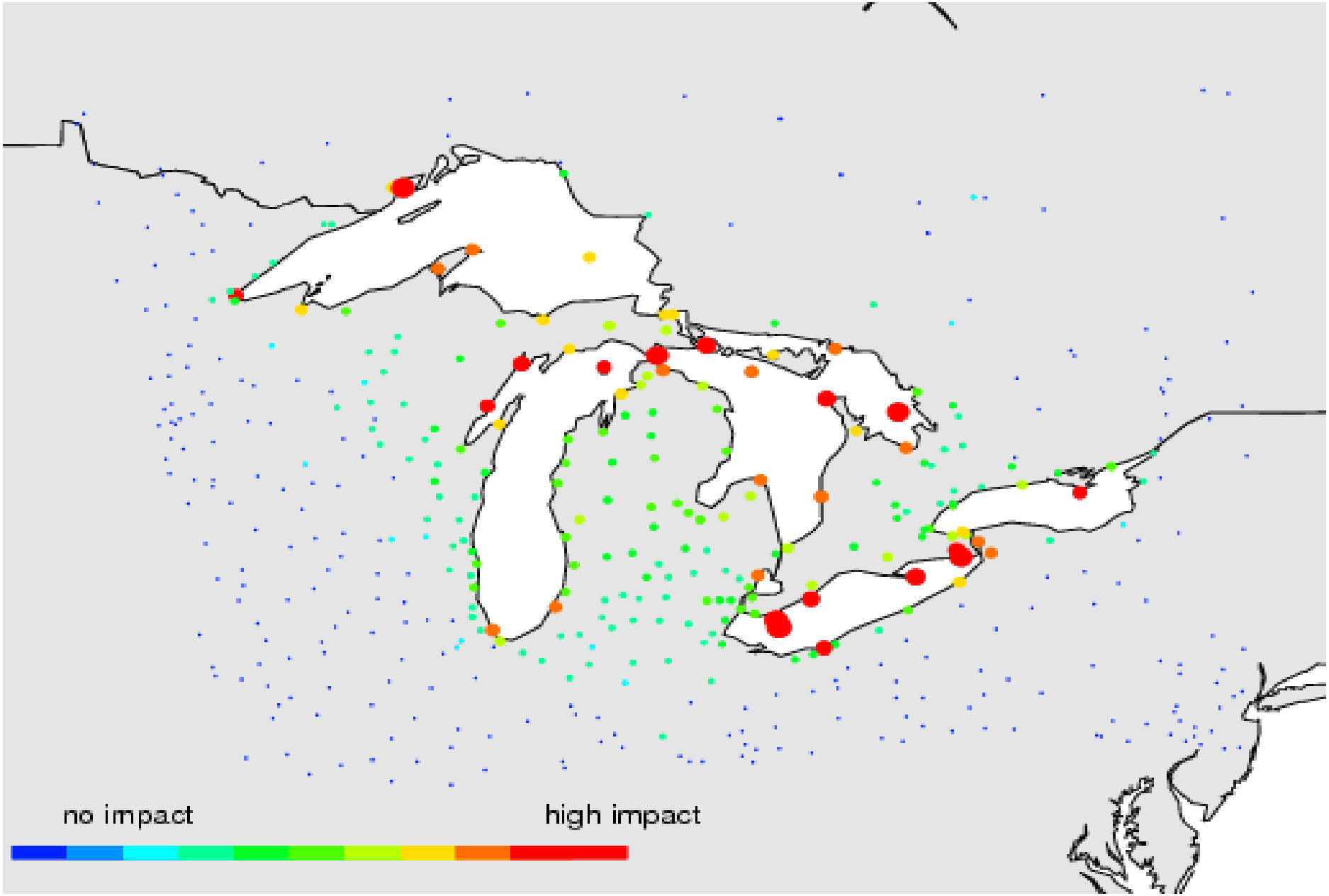
NEMO+CICE (2 km)
ocean-ice model



GEM GDPS (25 km)
atmospheric model

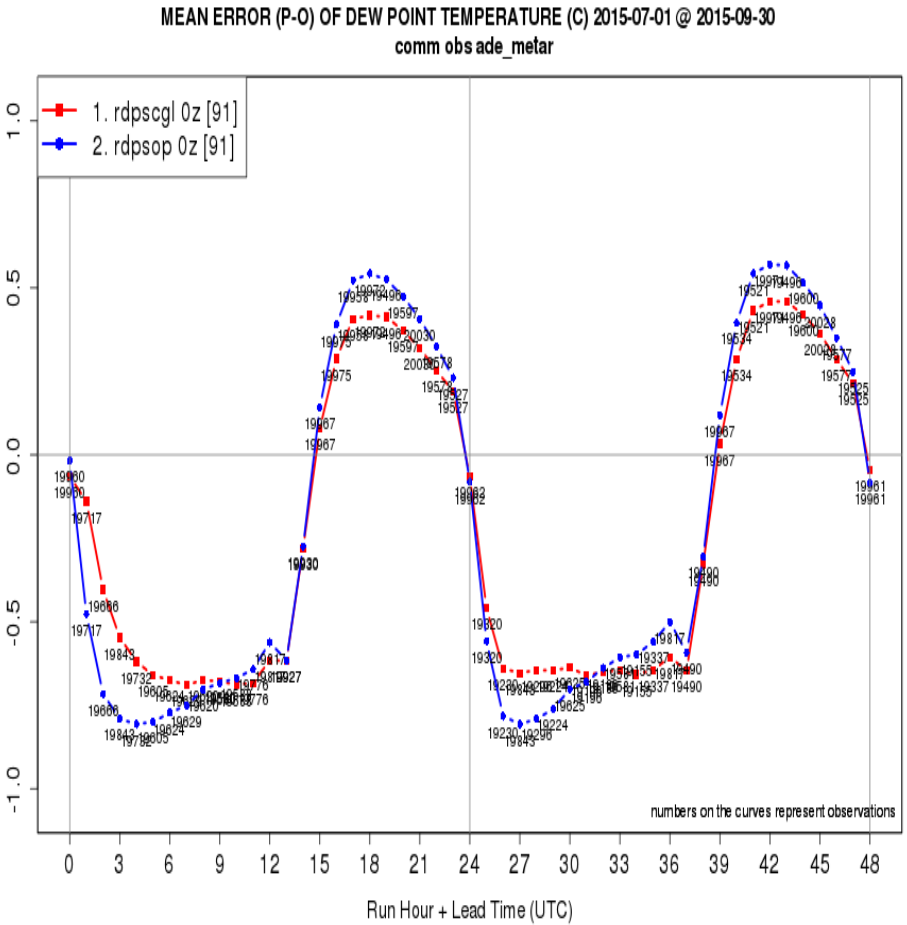
Environment Canada Environnement Canada

Impact of Atmosphere/Lake Coupling
20 cases -- JFM 2011

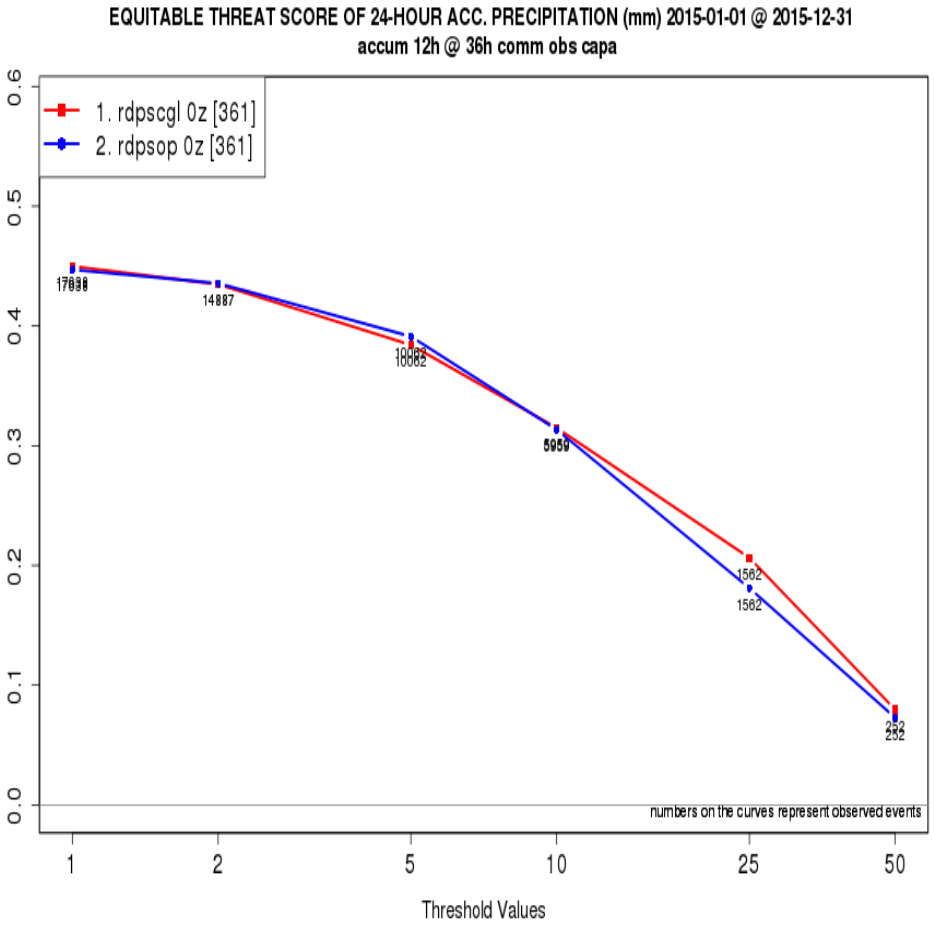


Better weather forecasts

<u>Summer 2015</u>
RDPS
GL-WCPS



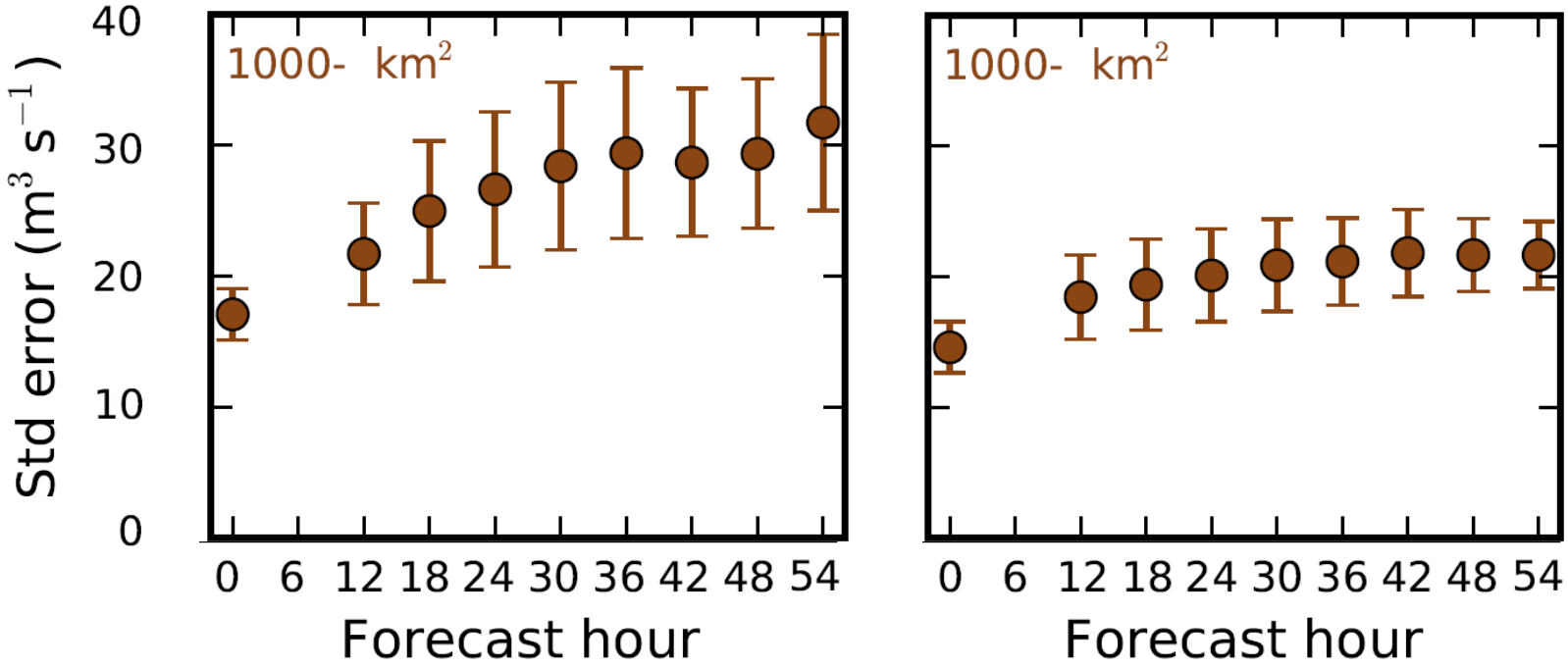
<u>Year 2015</u>
RDPS
GL-WCPS



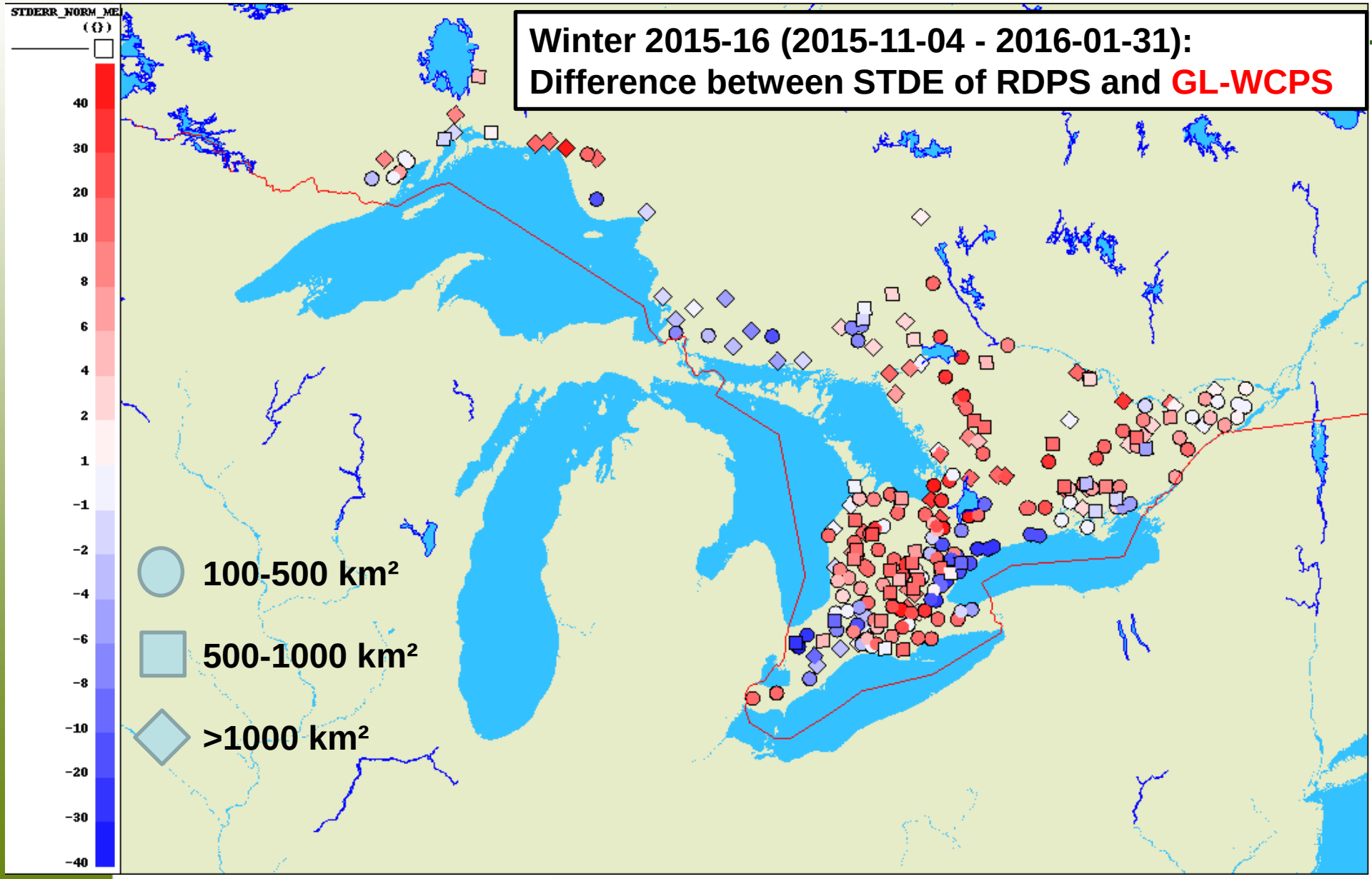
Better streamflow forecasts

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

RDPS **GL-WCPS**



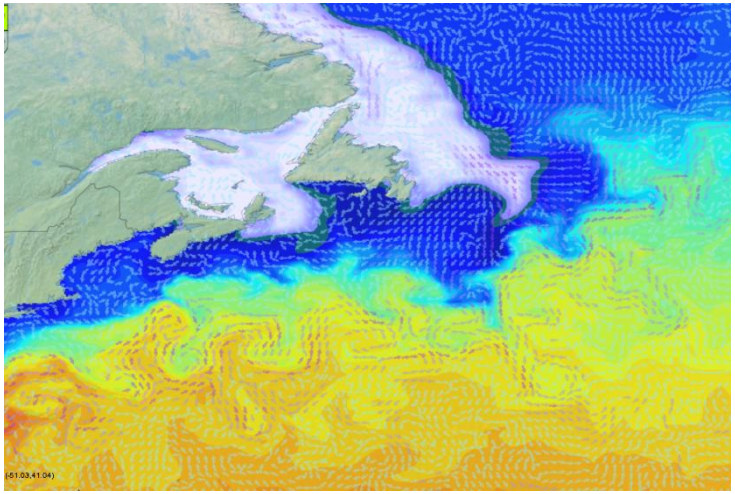
Better streamflow forecasts

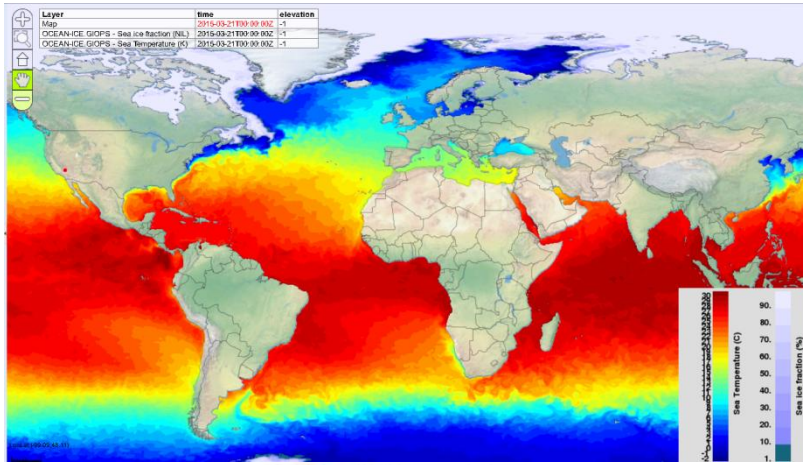


Global Ice-Ocean Prediction System

Dorina Surcel Colan, Matt Reszka, Francois Roy, Daniel Deacu, Yimin Liu, …

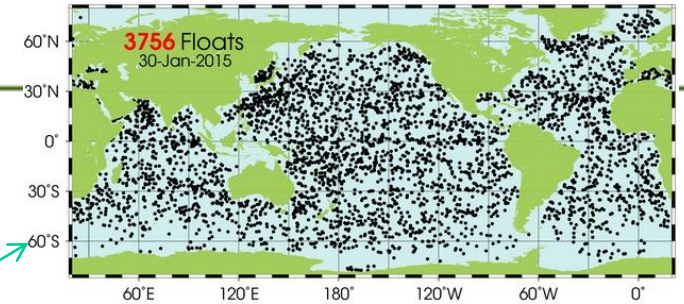
- Produces daily ice-ocean analyses and 10day forecasts
  - NEMO-CICE (~1/4°), < 15km in Arctic
- Mercator Ocean Assimilation System (SAM2):
  - Sea surface temperature
  - Temperature and salinity profiles
  - Sea level anomaly from satellite altimeters
- 3DVar Ice analysis:
  - SSM/I, SSM/IS, CIS charts, Radarsat image analyses
- Experimental implementation (March 2014)
- 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



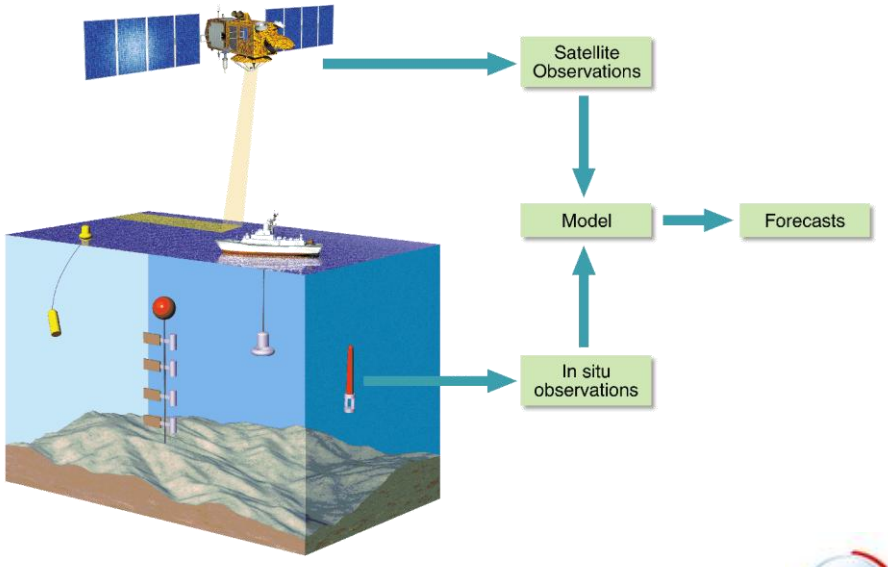


Smith et al., QJRMS, 2015

Ocean data assimilation



- Système d'Assimilation Mercator (SAM) v2
  - Multivariate SEEK filter
- SAM2 assimilates :
  - Subsurface temperature and salinity (from Argo, CTD, XBT, moorings, marine mammals)
  - Sea surface temperature (from both satellite and in situ observations)
  - Sea level anomalies from satellite altimeters (AVISO)



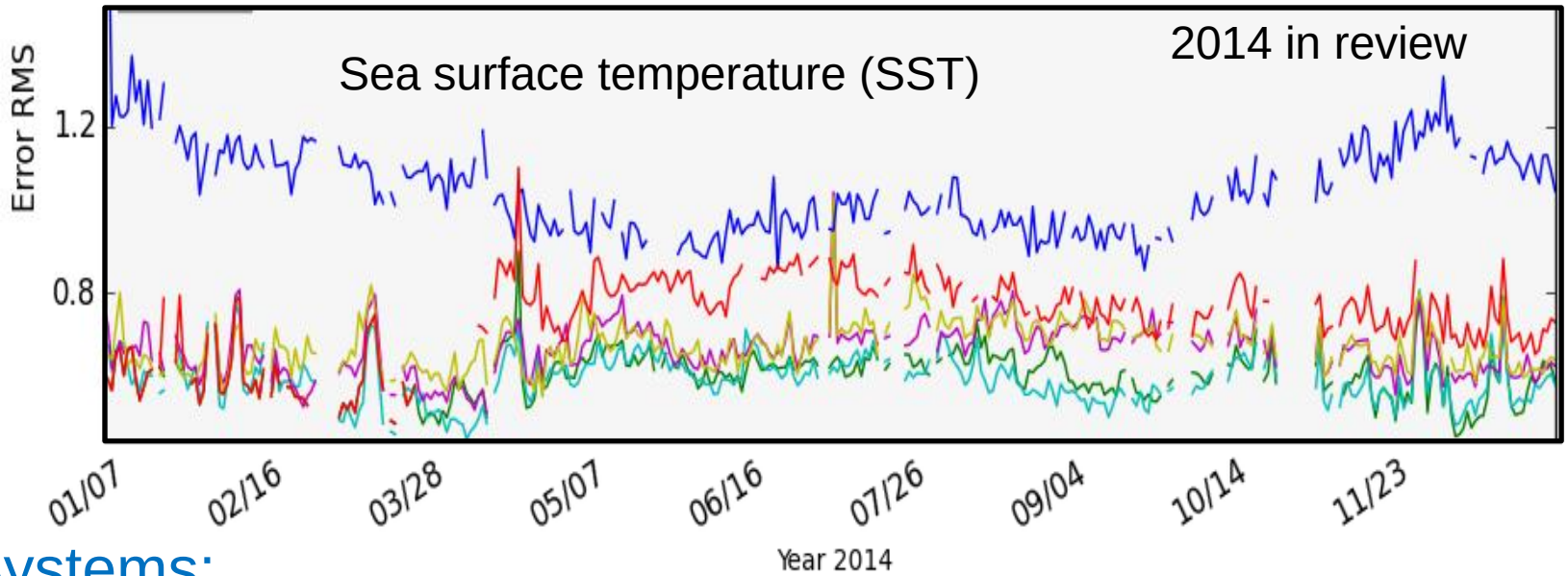
Altimeters:

- Jason 2
- Cryosat2
- Altika

Lellouche et al., 2012
Smith et al., 2015

GODAE Oceanview Intercomparison

International near real-time evaluation of global ocean forecasting systems



- Systems:
  - UK Metoffice (FOAM)
  - Env. Canada (GIOPS)
  - Mercator (PSY3, PSY4)
  - US Navy (RTOFS)
  - Australian BofM (OMAPS)

High quality SST critical for coupled forecasting

Jinshan Xu and Fraser Davidson

Environment Canada

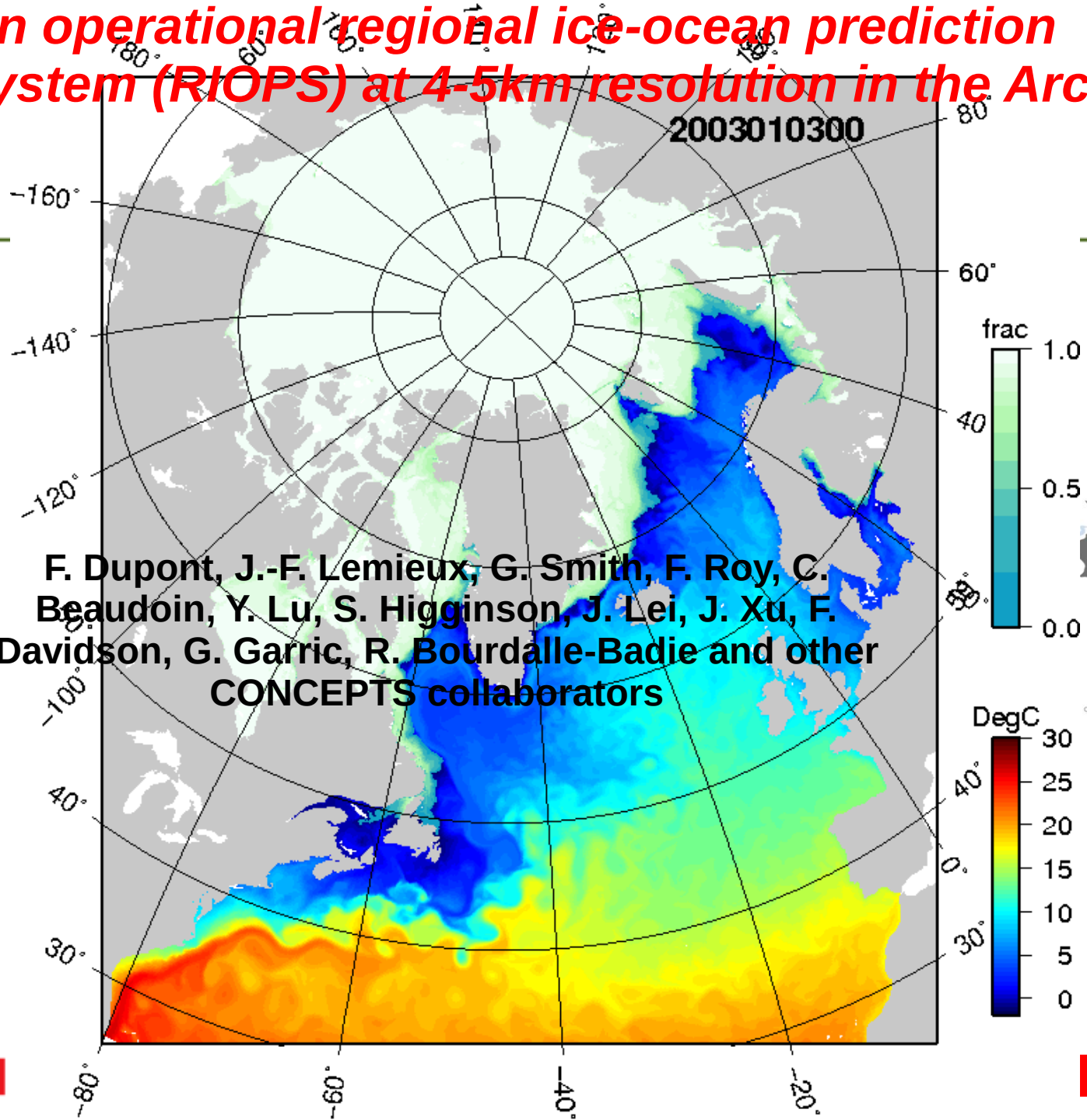
Fisheries and Oceans Canada

Mercator Ocean
Ocean Forecasters

CONCEPTS

National Defence

An operational regional ice-ocean prediction system (RIOPS) at 4-5km resolution in the Arctic



F. Dupont, J.-F. Lemieux, G. Smith, F. Roy, C. Beaudoin, Y. Lu, S. Higginson, J. Lei, J. Xu, F. Davidson, G. Garric, R. Bourdalle-Badie and other CONCEPTS collaborators

CONCEPTS
CANADIAN OPERATIONAL NETWORK OF COUPLED ENVIRONMENTAL PREDICTION SYSTEMS

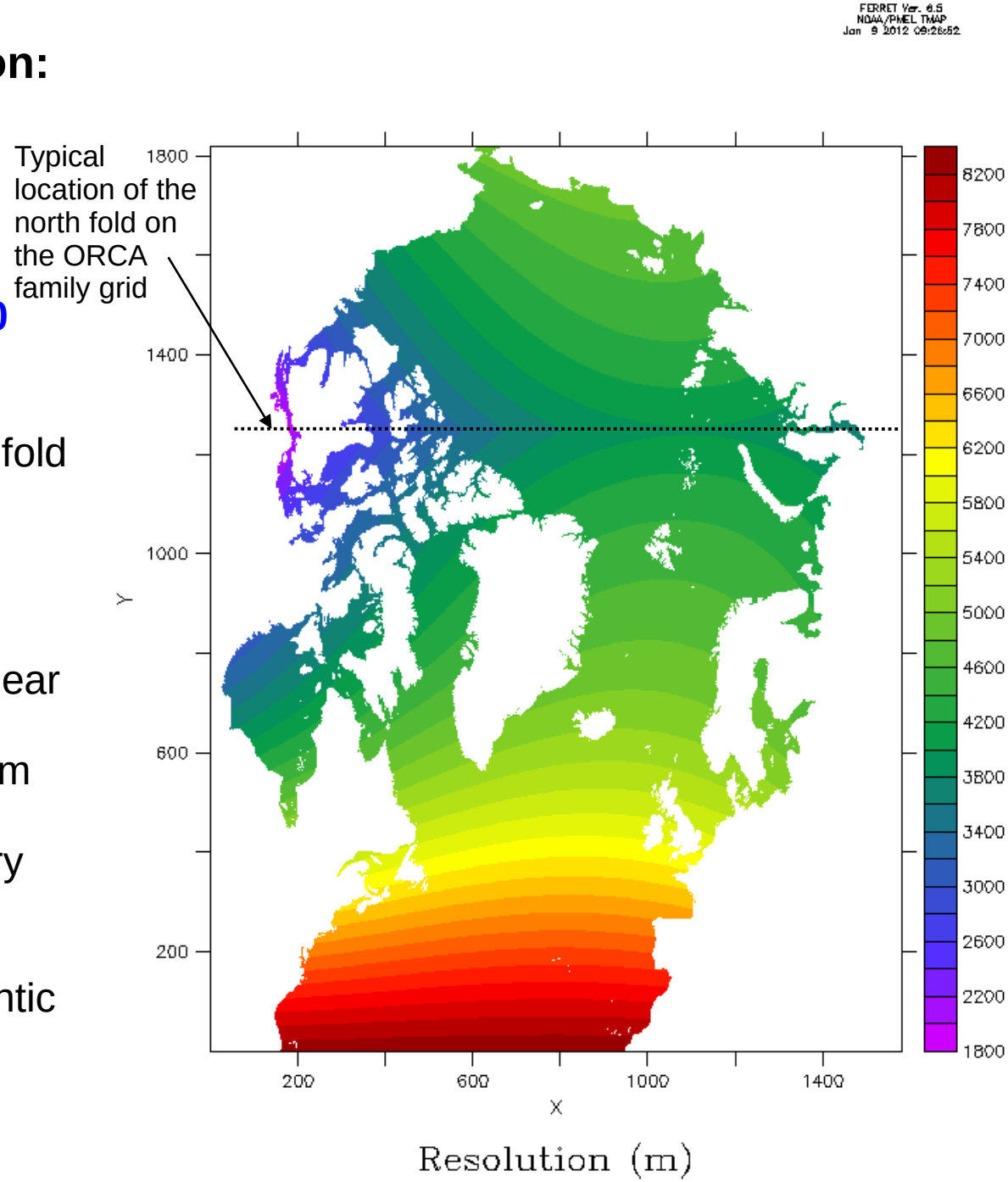
National Defence

Domain presentation: 1580x1817x50 512 procs

Domain is as in RIPS2.0 (32 procs).
Extracted from ORCA12 (Mercator) with the north fold stitched back. Regional CONCEPTS domain (CREG).

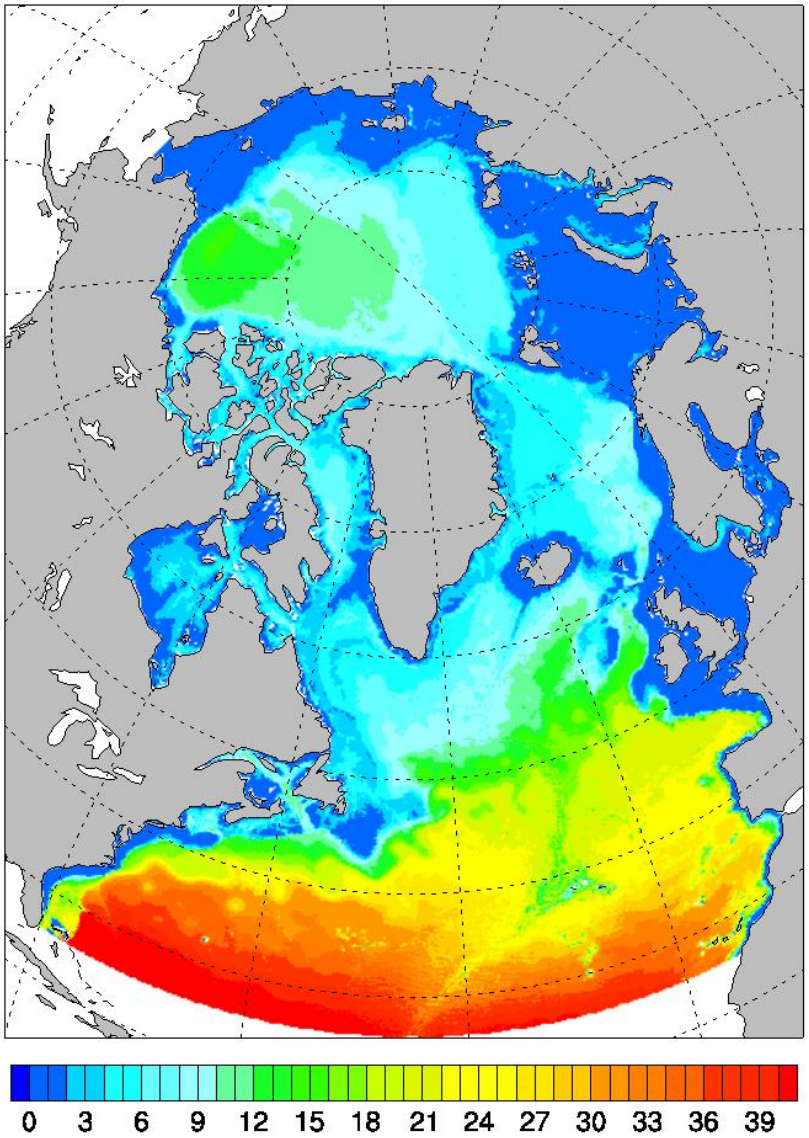
Resolution is maximum near the artificial pole over northern Canada at 1.8 km and minimum along the Atlantic northern boundary (8.2km)

Covers part of North Atlantic (27N), the whole Arctic Ocean.

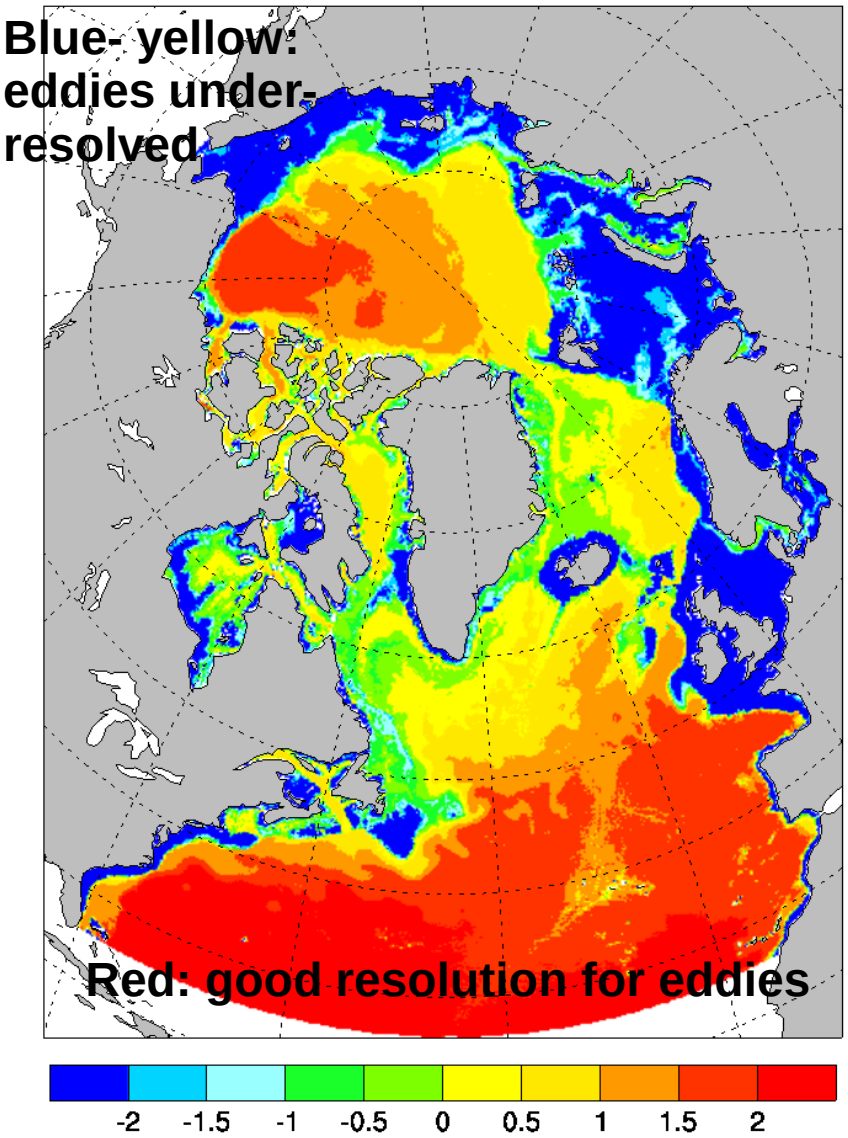


First Rossby radius of deformation

Radius (km)



Radius/DX (log2)



RIOPS Prediction System

3 Components: RIPS 3DVar ice analysis, Pseudo-Analysis and 48hr Forecasts

A 24h run from previous restart is nudged to the GIOPS analysis using spectral nudging (Thompson et al., 2006)

2015060800 → 2015060900 → 2015061000

RIOPS Pseudo-Analysis (RIOPS-PA)

RIOPS Forecast 4 x day (RIOPS-F)

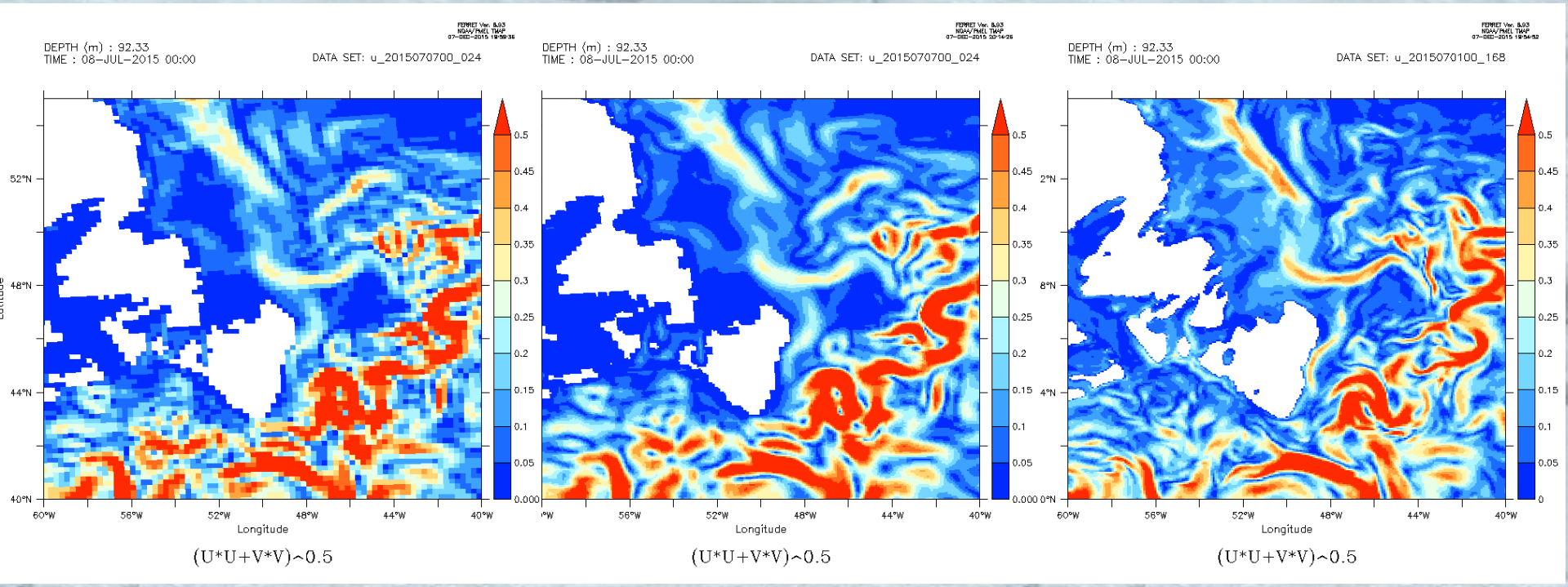
2015060900 forecast — 6Z — 48h forecast

2015060906 forecast — 12Z — 48h forecast

2015060912 forecast — 18Z — 48h forecast

2015060918 forecast — 48h forecast

Comparison of velocity on 2015-07-08



GIOPS

GIOPS interpolated on CREG12

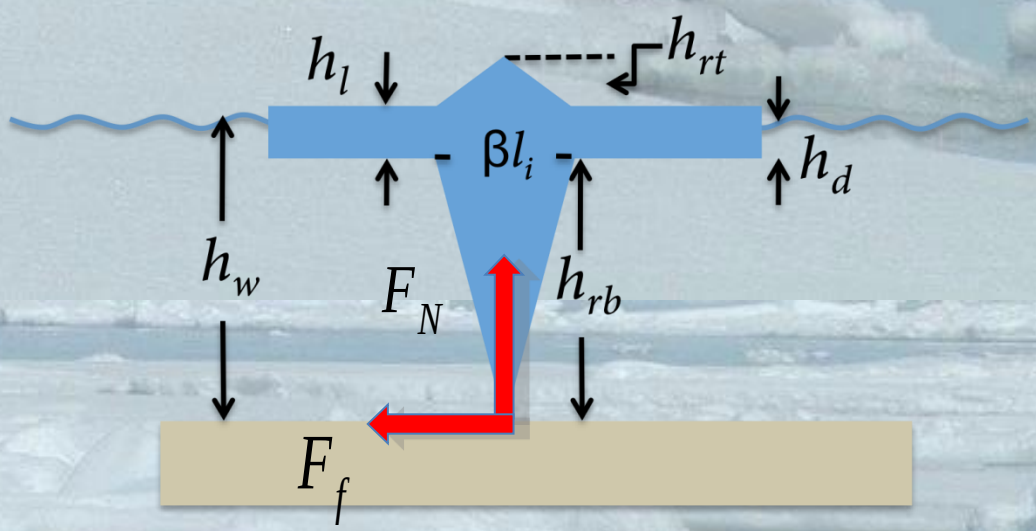
RIOPS

Use of spectral nudging (Thompson et al. 2006, in space) towards GIOPS with timescale of 1 day

Other approaches that are implemented in RIOPS:

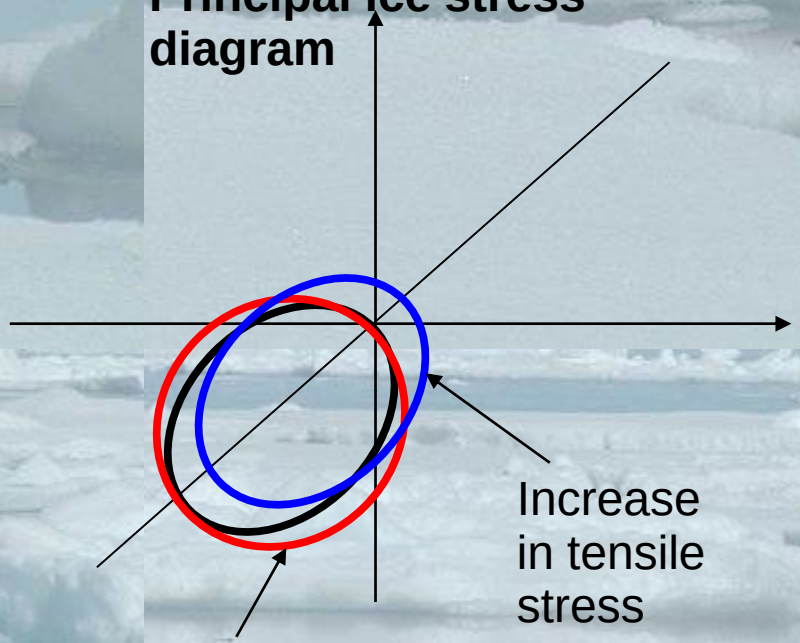
-Grounded landfast ice represented by a basal stress parametrization (Lemieux et al. 2015)

-Increase in shear and tension resistance (Lemieux et al., in preparation) improves the representation of land-locked ice (another form of landfast ice).

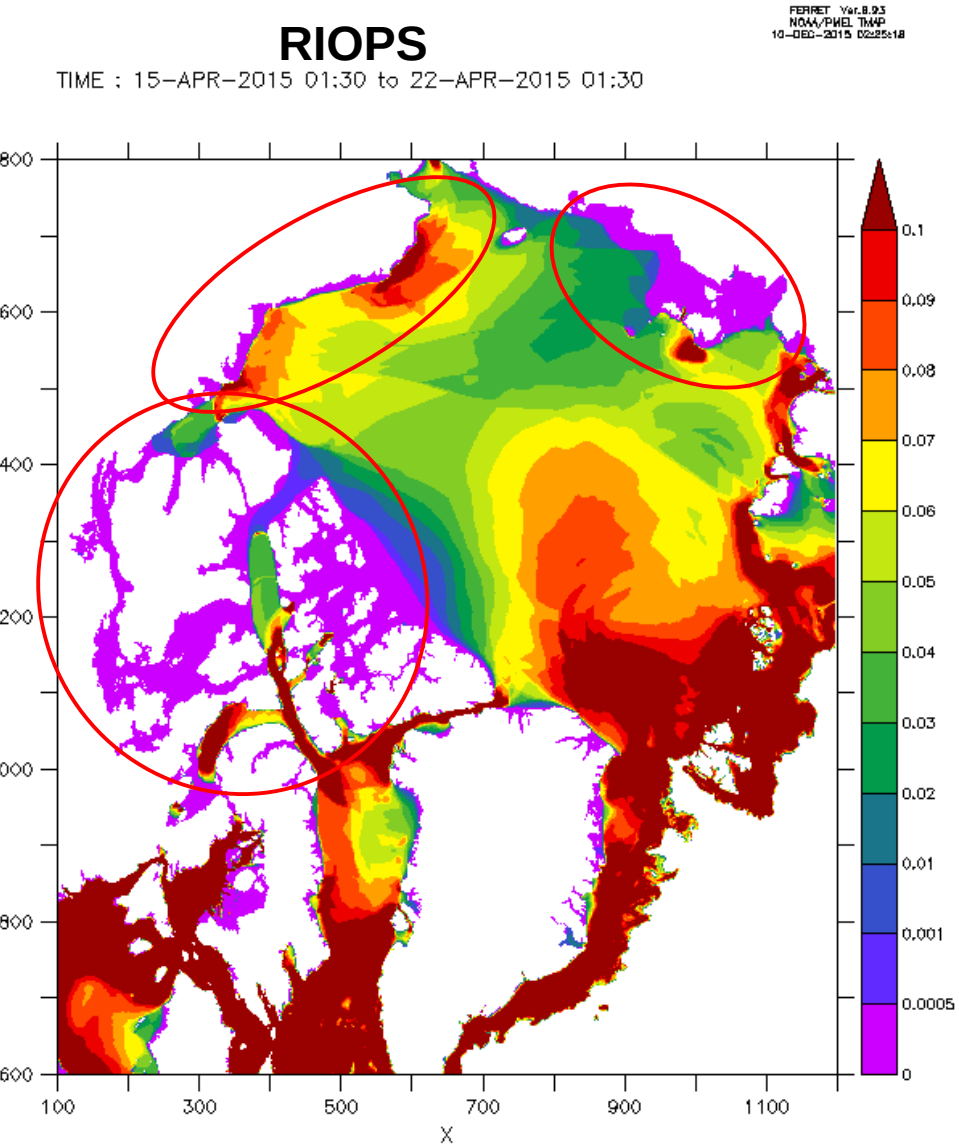


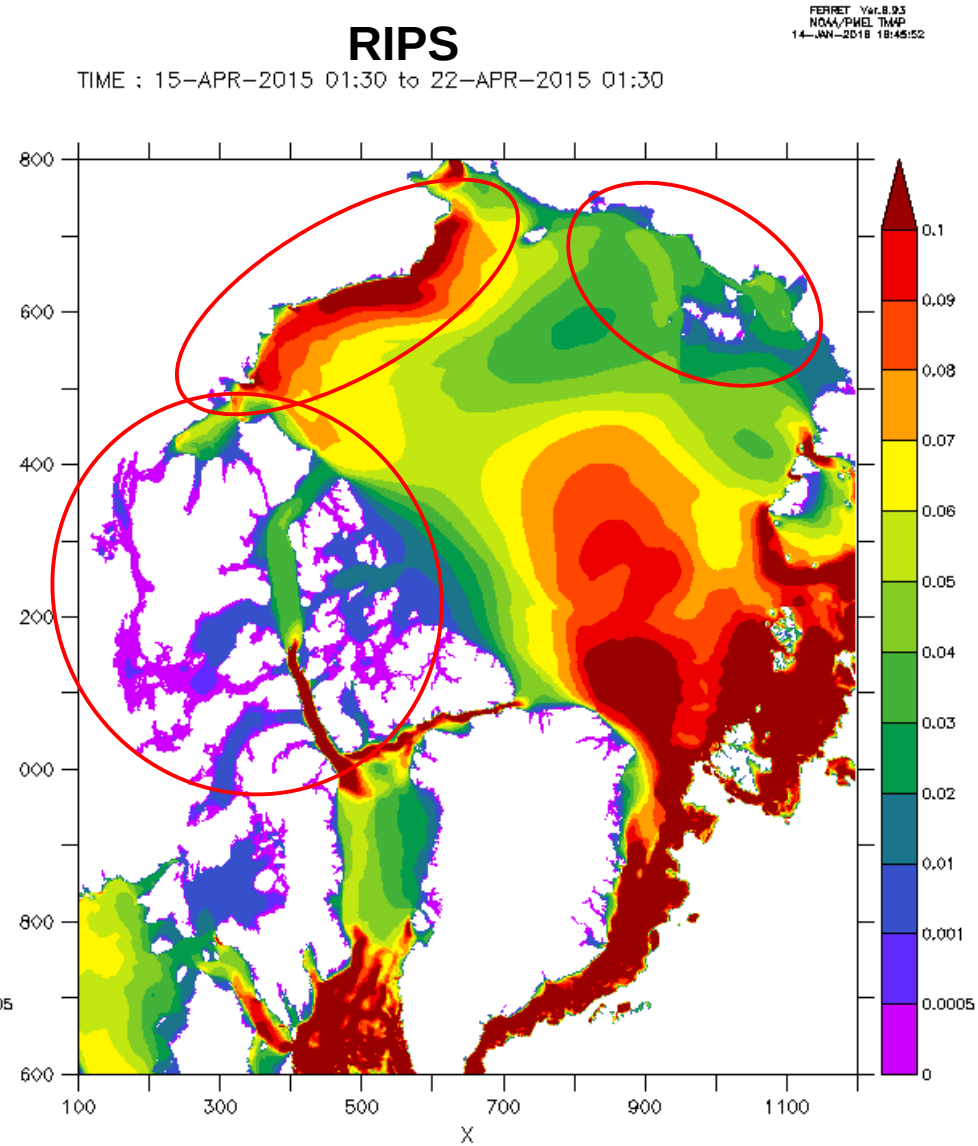
Ice ridge touching the ground

Principal ice stress diagram



Landfast ice detection from mean ice speed over 7 days from 3-hourly averaged output. RIOPS is the more realistic of the two.

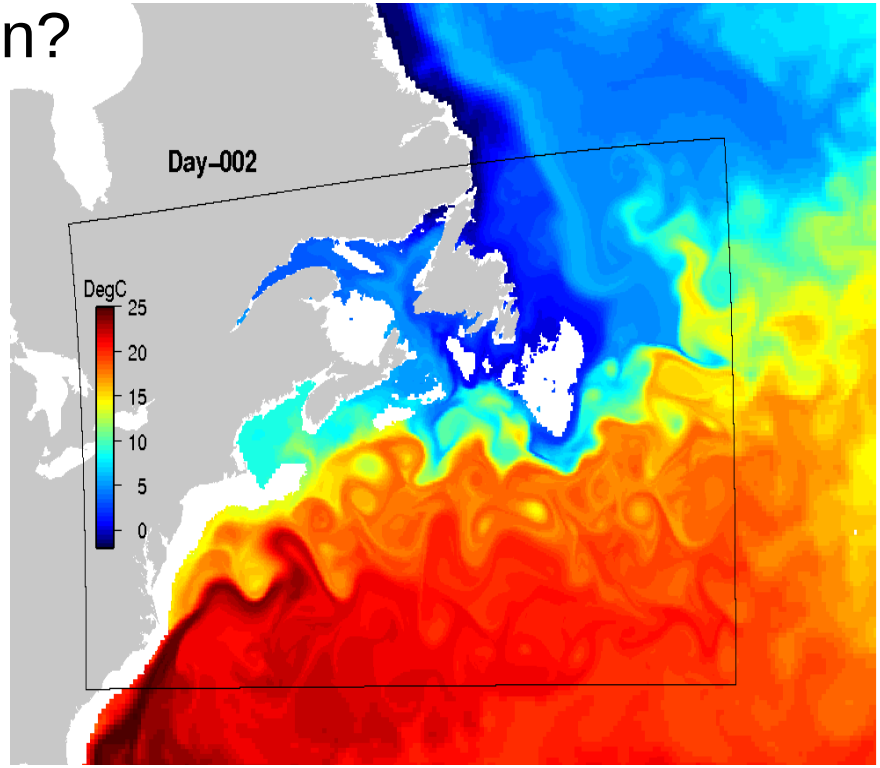




Coastal Ice-Ocean Prediction System (CIOPS-E)

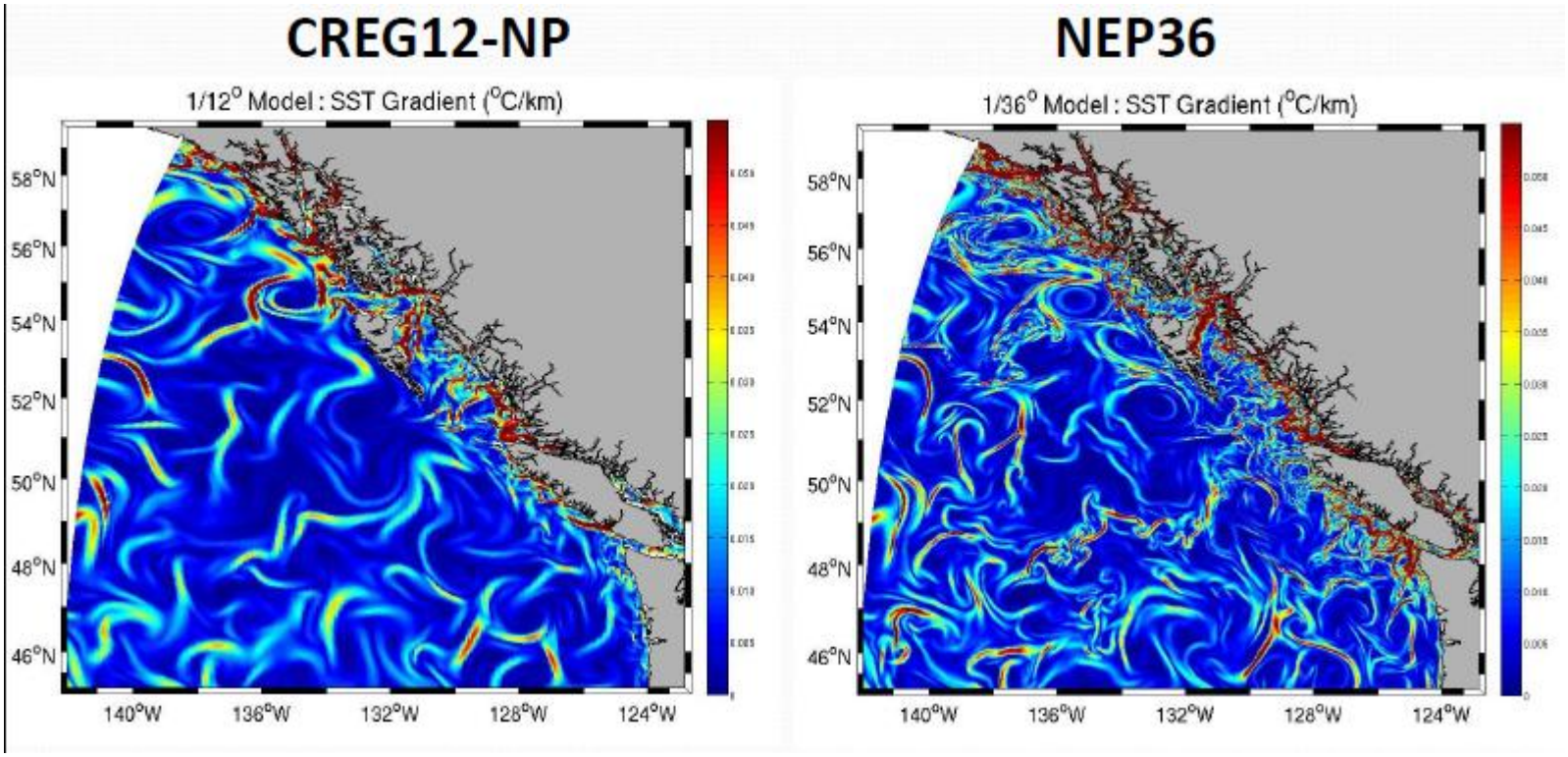
✓ Has a more energetic eddy field than RIOPS, but…

- Can data assimilation adequately constrain small scales?
- Does SLA filtering affect verification scores?
- What is the effective resolution?



Coastal Ice-Ocean Prediction System (CIOPS-W)

Gradient of Sea Surface Temperature



CIOPS Configurations can serve as testbeds for development of high-resolution prediction techniques

Year of Polar Prediction (YOPP)

- Intensive observational *and* modelling period to advance polar prediction capabilities.
- This will be augmented by research into forecast-stakeholder interaction, verification and a strong educational component
- YOPP Summit held in Geneva (July 13-15, 2015)

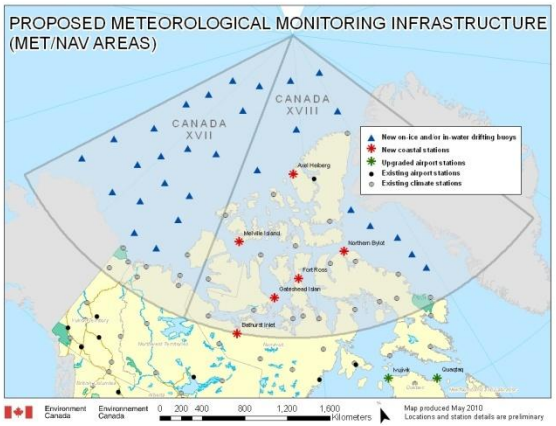
Preparation Phase 2013 to mid-2017	YOPP mid-2017 to mid-2019	Consolidation-Phase mid-2019 to 2022
Community engagement	Intensive observing periods	Data denial experiments
Align with other planned activities	Dedicated model experiments	Model development
Develop imple-mentation plan	Coupled data assimilation	Dedicated reanalyses
Preparatory research	Use & value of forecasts research	Operational implementation
Polar Prediction school/workshops	Intensive verification effort	YOPP publications
Liaise with funders	Polar Prediction school	YOPP conference

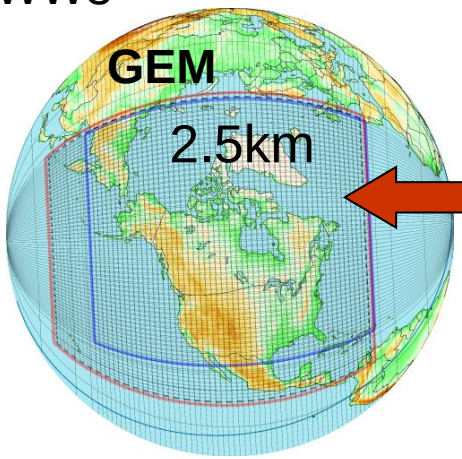
ECCC YOPP Contribution

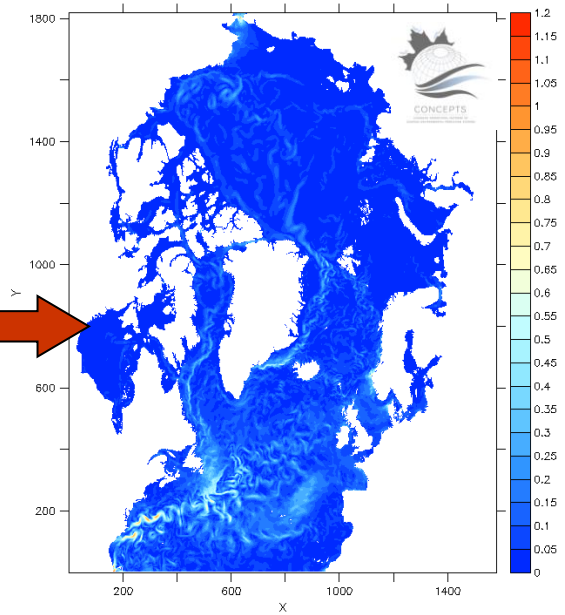
Modelling

High-resolution coupled atmosphere-ice-ocean prediction system

- In support of :
  - EC METAREAs Services
  - Marine emergency response
- Coupled atmosphere-ice-ocean model
  - GEM (2.5km)
  - NEMO-CICE (3-8km) and WW3
    - Tides, landfast ice,
    - wave-ice coupling
  - 48-72hr forecasts



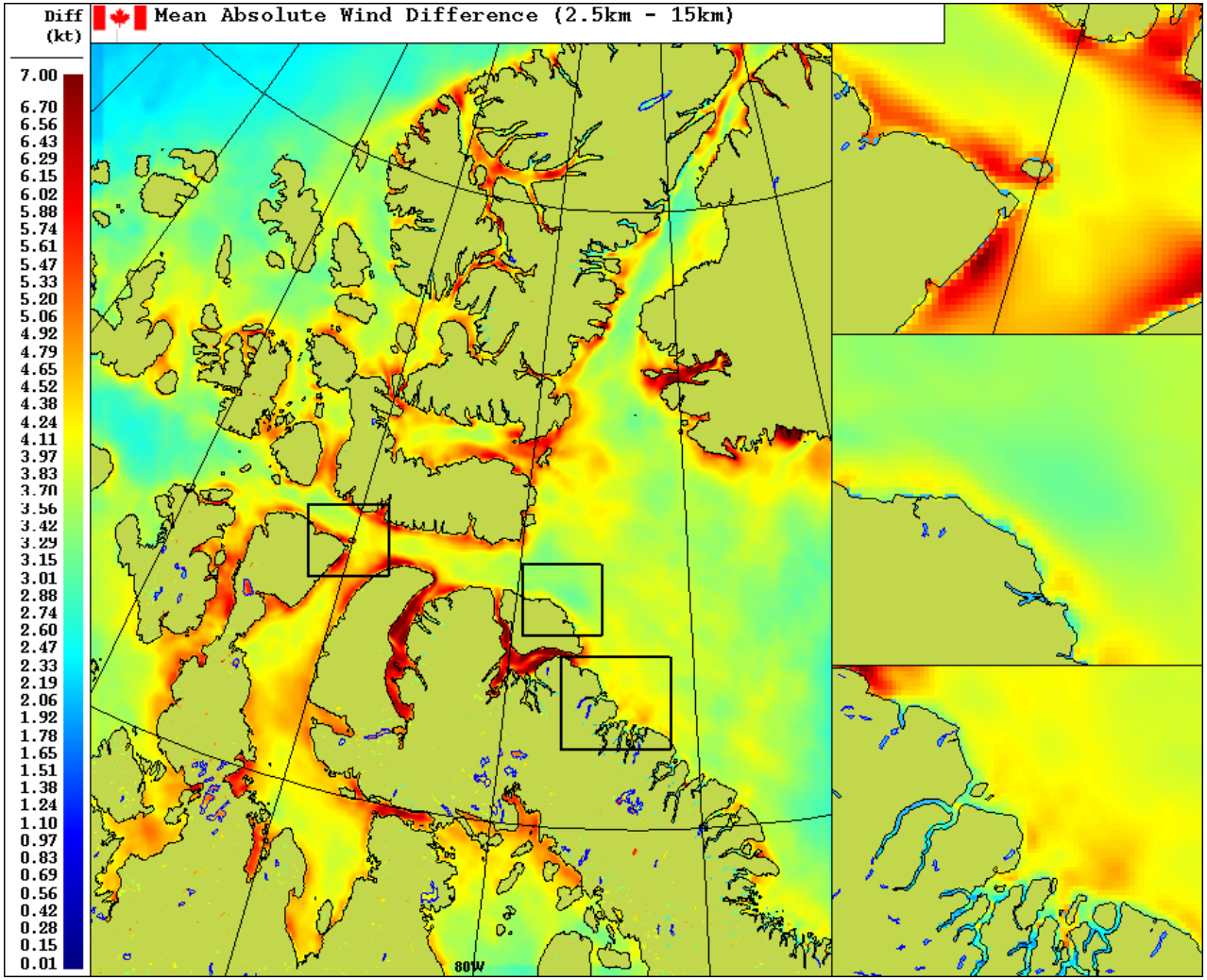




RIOPS velocity mag. (m/s)

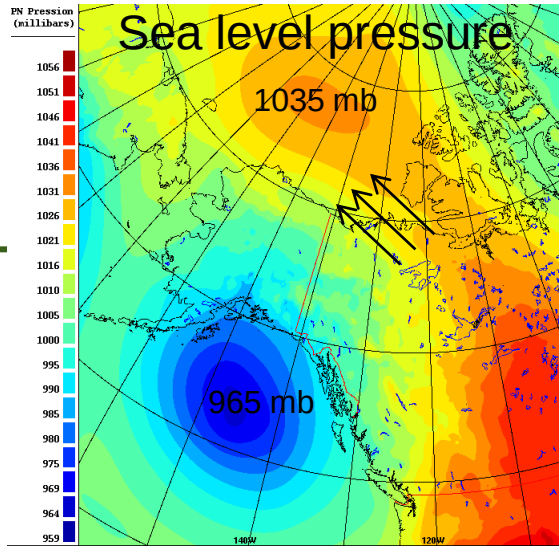
Impact of atmospheric resolution on winds

Difference between daily 2.5km and 15km 48hr forecasts for August 2012

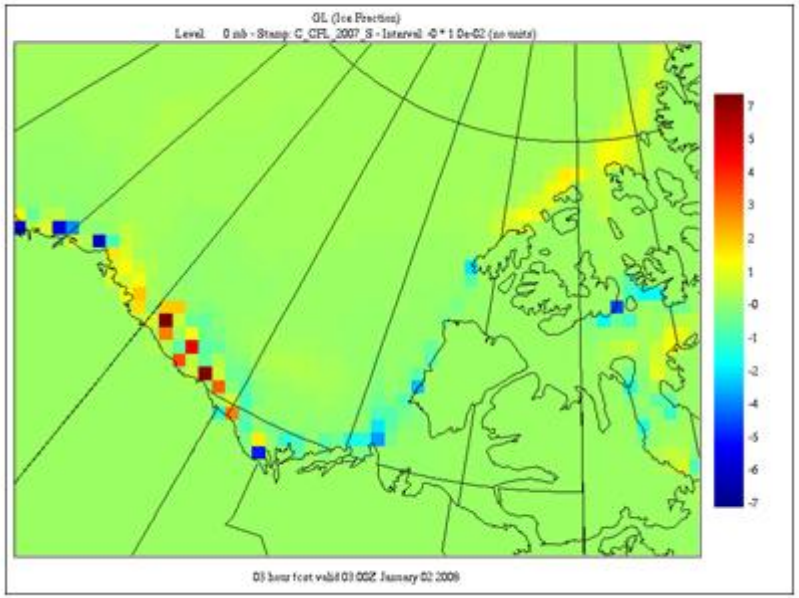


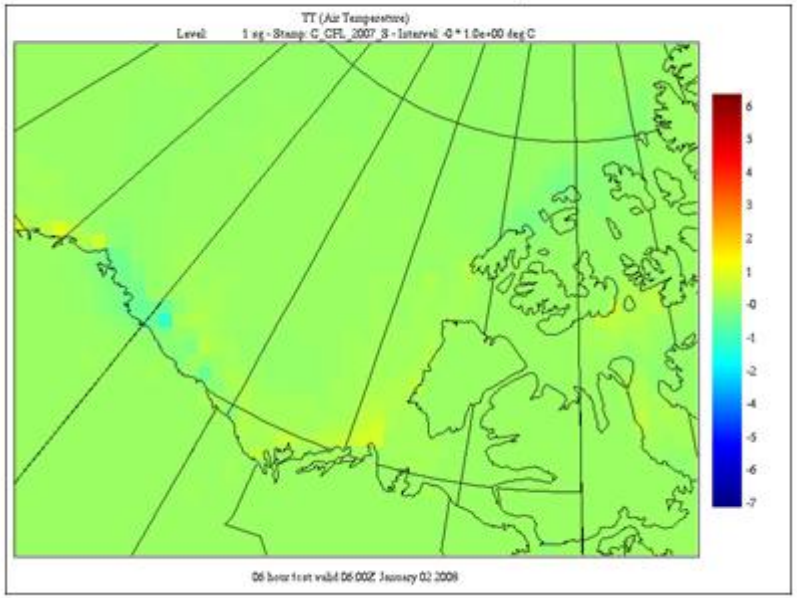
Chris Subich

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



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

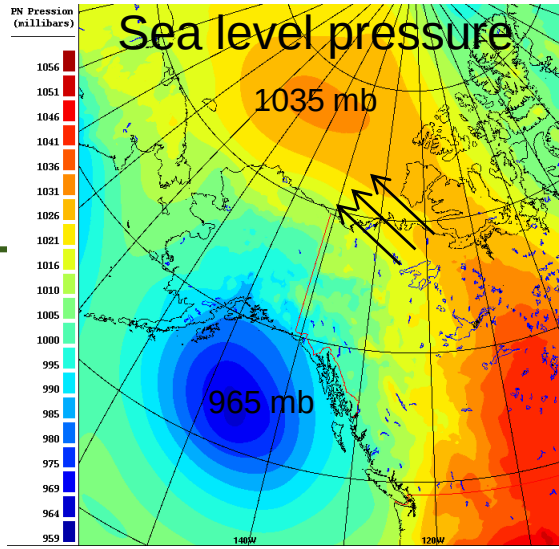




Forecast from global coupled model (GEM-NEMO-CICE; 33km-15km resolution) from the Canadian Meteorological Centre

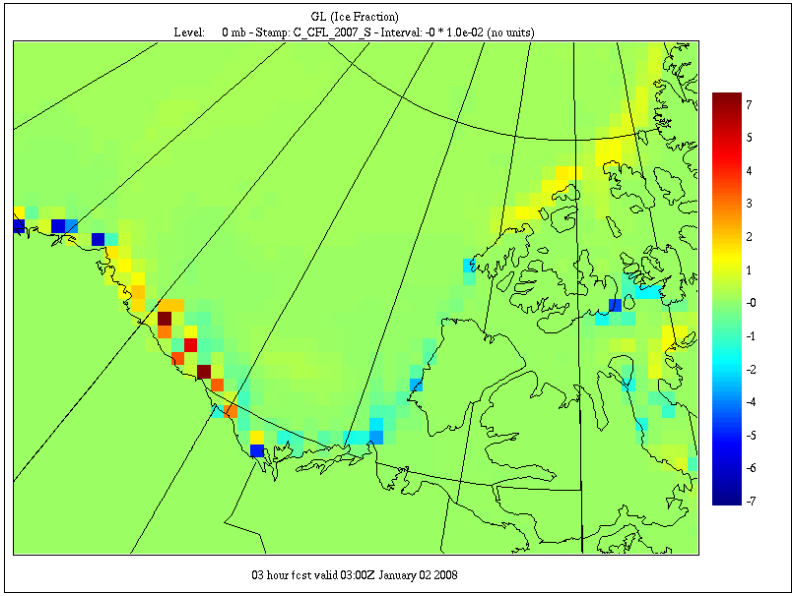
R. Muncaster, F. Roy, J.-M. Belanger

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

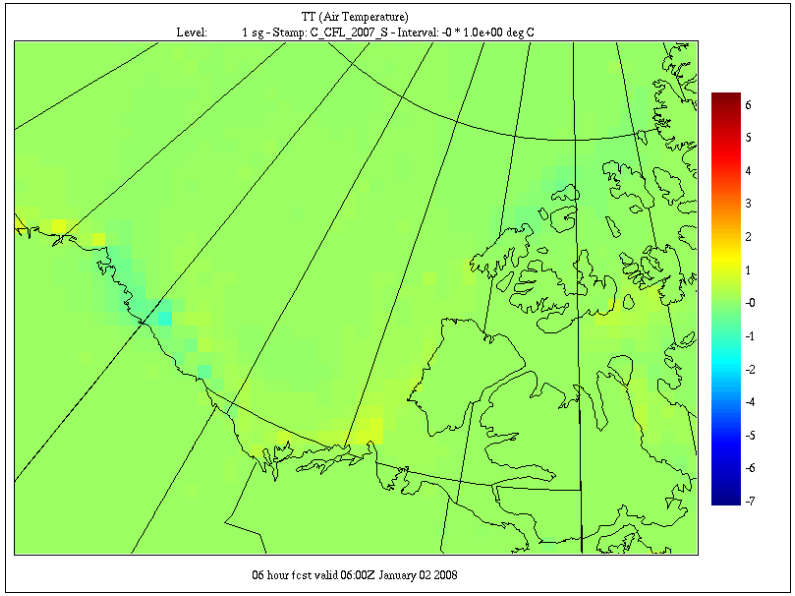


- Coastal polynya formation sensitive to:
  - Atmosphere-ice and ice-ocean stresses, ice thicknesses, parameterization of ice strength (all things we know poorly!)

Difference in ice fraction (CPL-UNCPL)



Difference in 2m temperature



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

Environment Canada Environnement Canada

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

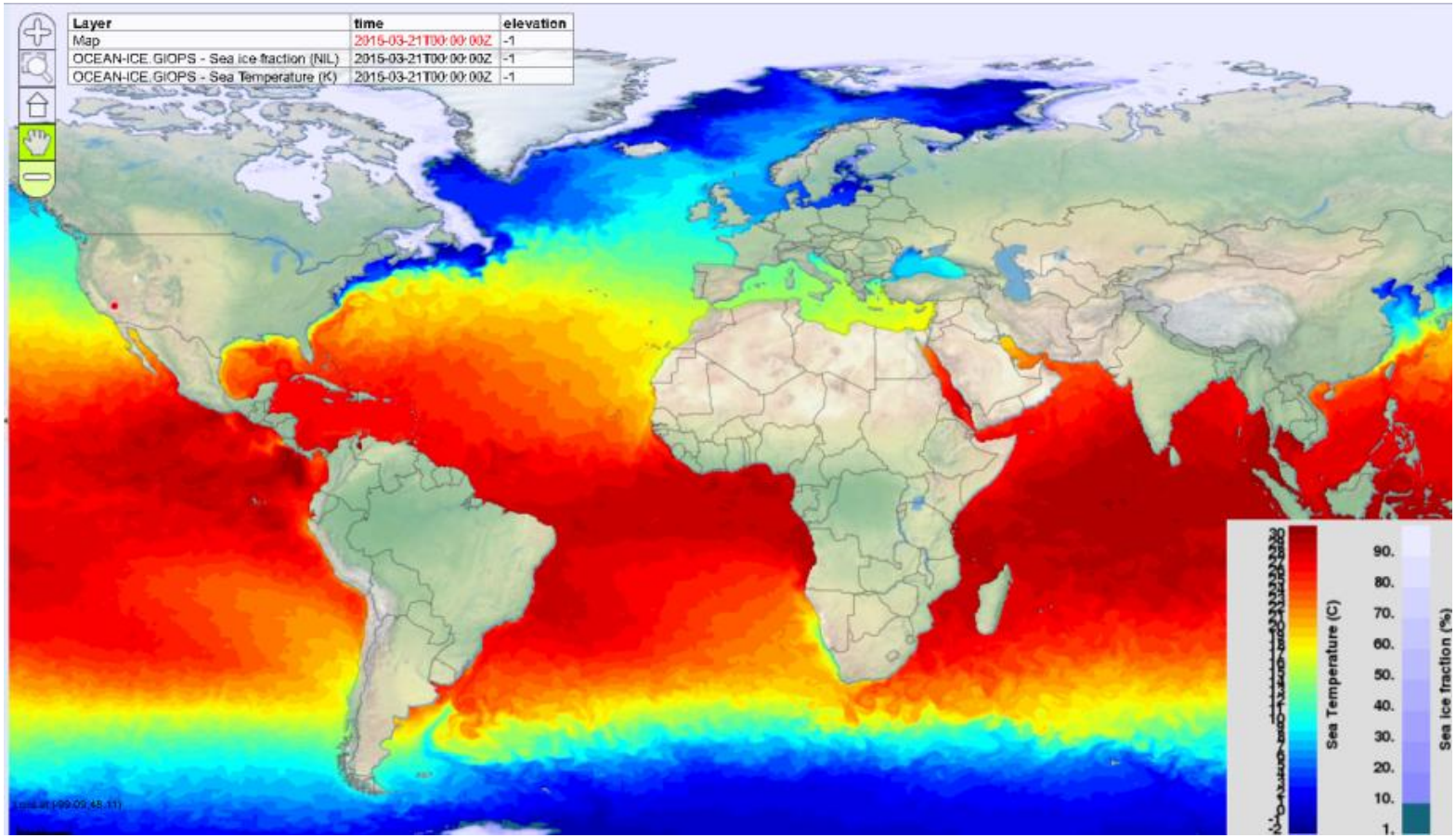
Canada

Summary

- CONCEPTS is currently developing a suite of global and regional coupled environmental prediction systems
  - Benefit for weather prediction as well as providing a marine core service
- Builds on the original Gulf of St. Lawrence system
- High resolution coupled ocean-ice modelling systems are demonstrating benefits compared to both uncoupled systems and lower resolution coupled systems as demonstrated by:
  - The Gulf of St. Lawrence system
  - The regional ice-ocean prediction system
  - The Great Lakes Prediction System

Benefits include more accurate predictions of conventional fields and variables, as well as new fields and variables for a variety of users.

Thank you!



Environment Canada

Fisheries and Oceans Canada

Mercator Ocean
Ocean Forecasters

CONCEPTS

National Defence