Canadian Coupled Atmosphere - Ocean - Ice Forecast System for the Gulf of St. Lawrence

Manon Faucher

CMC, February 8th, 2008

Collaborators

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- Denis Lefaivre, Maurice-Lamontagne Institute (IML)
- François J. Saucier, Institut des Sciences de la Mer à Rimouski (ISMER)
- Sophie Valcke, CERFACS (Toulouse, France)
- Doug Bender, Mark McCrady, Dominic Racette CMC, CMOI
- Tom Carrieres, Canadian Ice Service (CIS)

Environnement Canada Environment Canada

Pêches et Oceans Canada Fisheries and Oceans Canada

Outline

- Introduction
  - Goal
  - Motivation, study area, problematic
  - Project objectives
- Coupled system
  - Methodology
    - Models, coupler, coupling strategy
  - Evaluation
- Discussion / Conclusion

- To include atmosphere - ocean - ice interactions into the CMC forecast system
  - To improve the regional weather forecasts 00-48hr
  - To extend the forecast system to other environmental components
    - Sea Ice, Ocean current

Foxe Basin

Hudson Bay

Hudson St

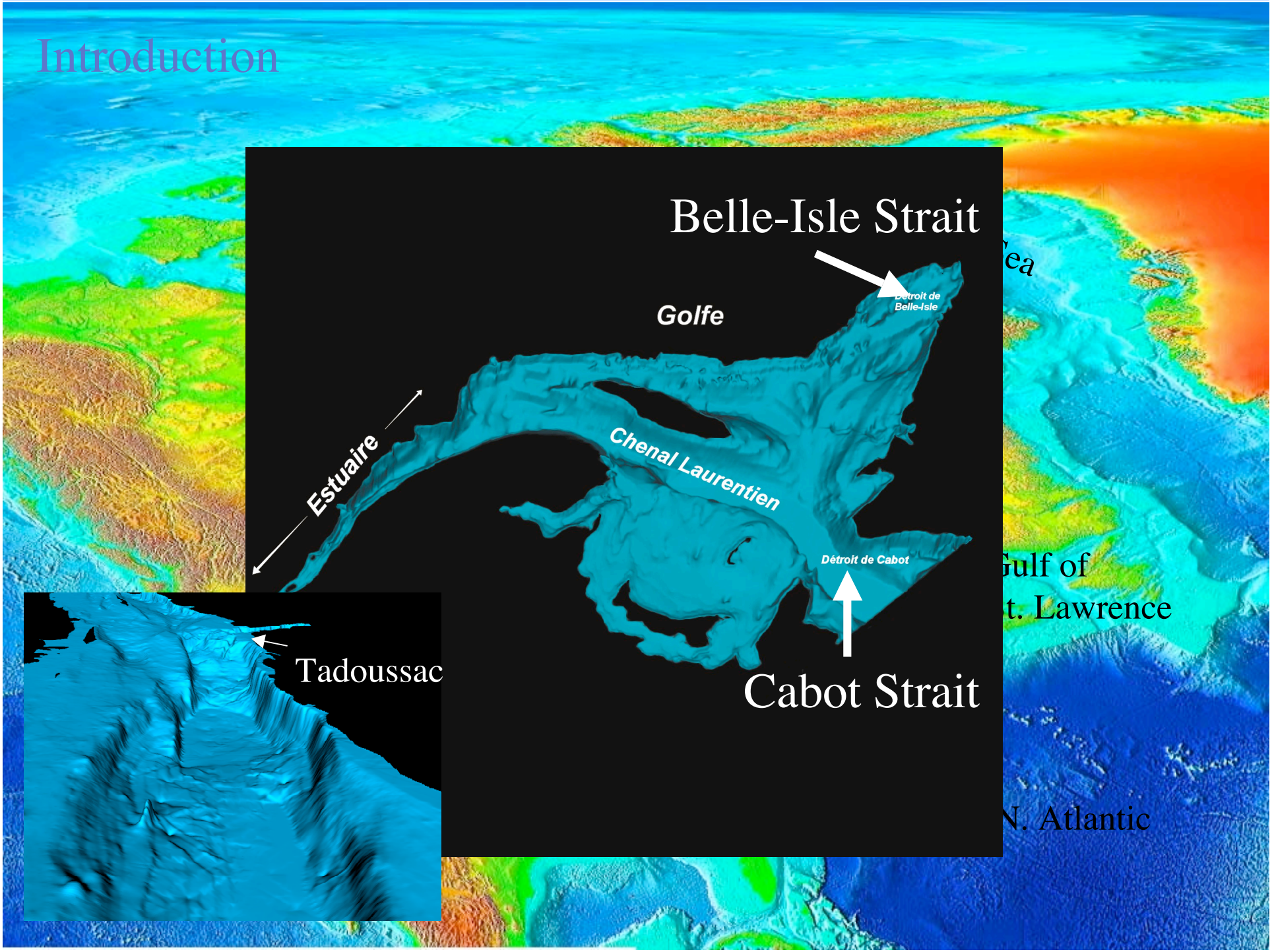
GSL

Great Lakes

N. Atlantic

Pellerin P., Ritchie H., Saucier F.J., Roy F., Desjardins S., Valin M. and Lee V. (2004) Impact of a Two-Way Coupling between an Atmospheric and Ocean-Ice Model over the Gulf of St. Lawrence. Monthly Weather Review, vol **132**, June 2004, 1379-1398.

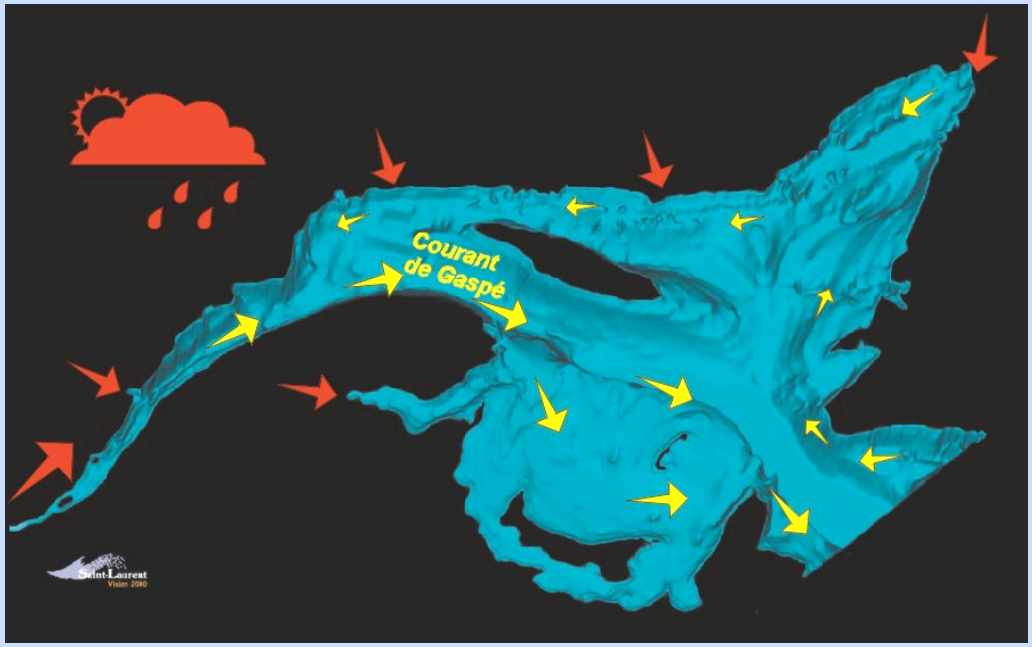
Introduction



Forçing in the Gulf of St.Lawrence

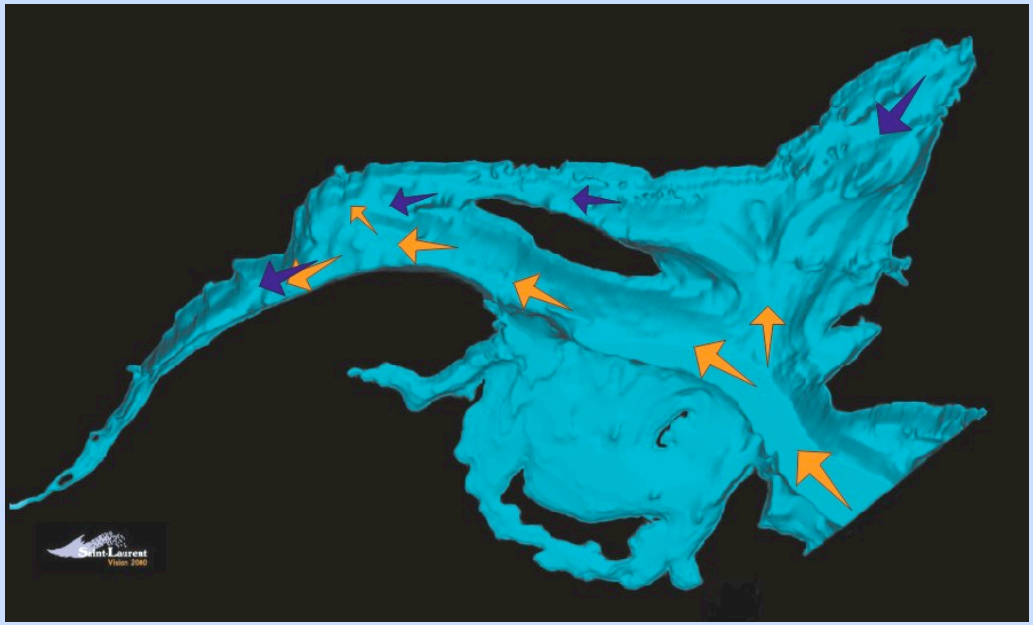
- Tide
  - Semi-diurnal (M2, period 24h50):
  - Diurnal (K1, period 23h56):
    - 0.2m à 0.5m, and up to 2m in the Estuary;
- Meteorology
  - Wind, precipitation, temperature;
- Buoyancy forcing
  - River runoff (28 rivers and St.-Lawrence);
    - 14,000 m^3/s to 32,000 m^3/s;
  - Heat flux;
    - Winter mean value: 250 W m^{-2}
- Oceanic
  - Deep water intrusion from North Atlantic Ocean and Labrador Sea;

Introduction



Surface currents

- Cyclonic circulation
- Gaspé current
- Small-scale gyres
- Estuary-type exchange at Cabot Strait

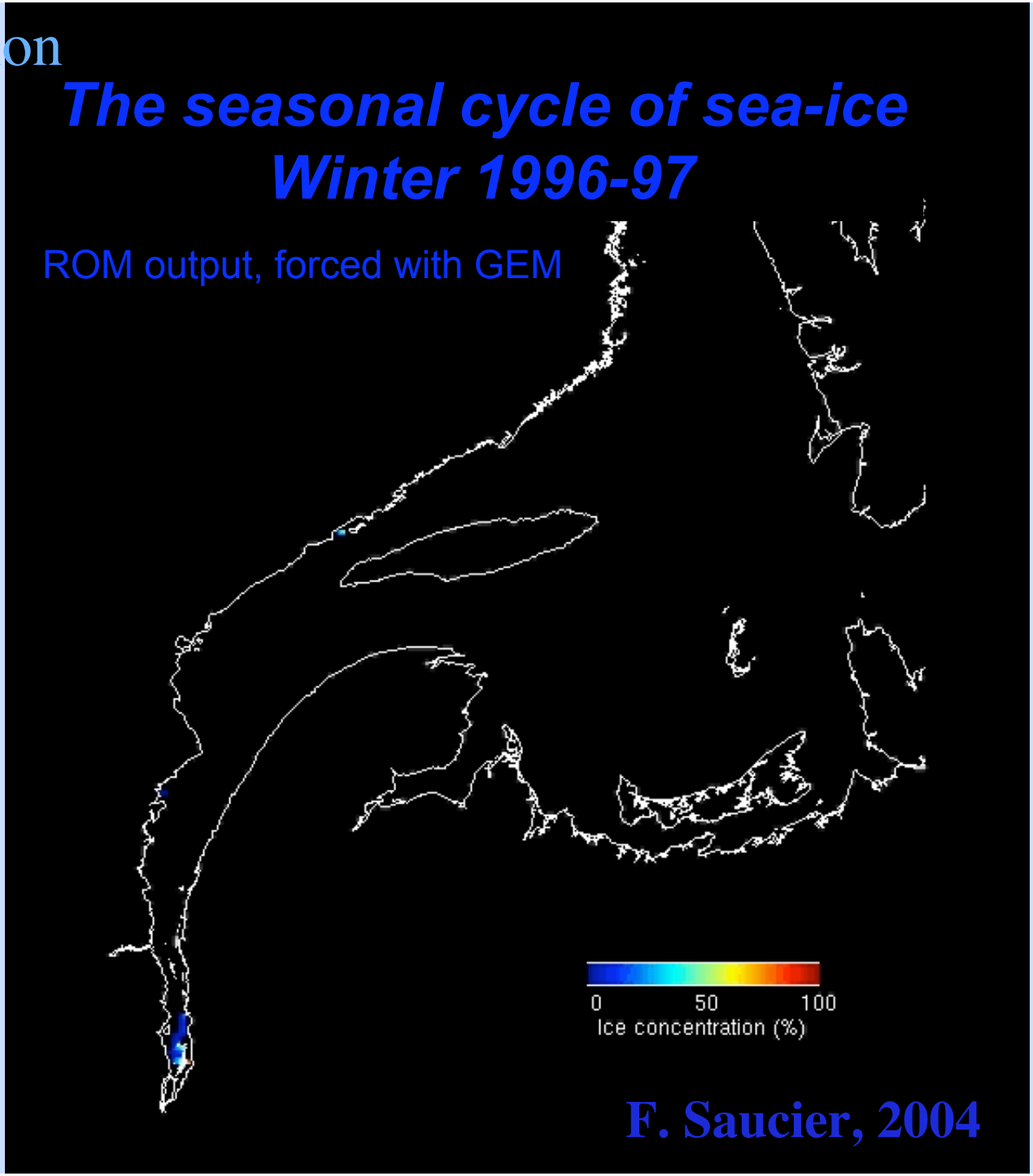


Mid-bottom currents

- Cold water from the Labrador Sea
- Warmer, saltier deep water from the North Atlantic ocean

The seasonal cycle of sea-ice Winter 1996-97

ROM output, forced with GEM



Project Objectives

- Implement the different components of the coupled system in the CMC operational forecast system
  - LAM version for GEM
  - GSL ocean-ice forecast system (GSL model)
  - Coupler to link the models
- Develop a coupling strategy
- Develop a data assimilation strategy for ocean temperature and sea ice
  - Produce balanced initial temperature & salinity conditions for the ocean model (Mark Buehner and Alain Caya)
- Develop a validation strategy for the coupled model outputs
- Issue daily atmosphere-ocean-sea ice coupled forecasts
  - 24/7 schedule

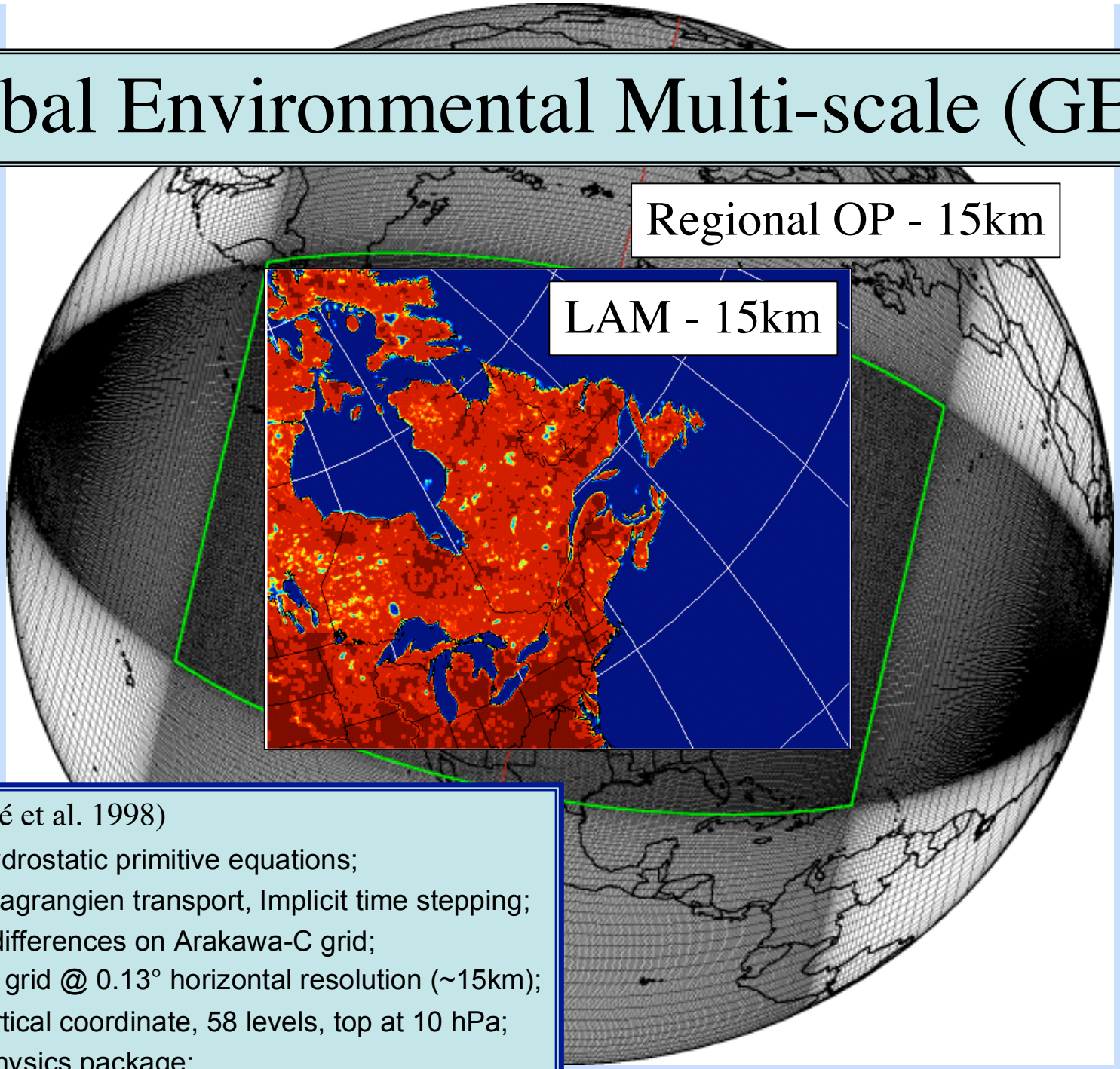
Project Objectives…

- Support DFO development and operational needs at Maurice-Lamontagne Institute and Canadian Coast Guard
  - Sea Surface current for
    - Search & Rescue, CCG College
    - Oil Spills trajectory forecast, CCG Environmental Response
    - Wave forecast model (MSC Quebec Region)
  - Sea ice forecast for
    - Icebreaking, Escort and Flood Control, CCG Quebec Region
  - Full ocean model results, 3-D hourly outputs
    - To forecast changes in water properties
    - To drive Biological Models of Primary Productivity
- Support development & operational needs at the Canadian Ice Services (CIS): Ice modelling & analysis

Models & coupler

- Global Environmental Multi-scale (GEM, Côté et al. 1998):
  - Regional configuration LAM @ 15km and 58 levels;
  - Dynamic 3.2.2+, physics 4.0+;
- Gulf of St. Lawrence Model (MoGSL, Saucier et al. 2003):
  - 3D Ocean @ 5km and 73 levels; version 4.9.5 (5.2.2);
  - Sea-ice (dynamic - thermodynamic);
    - Elastic-viscous-plastic (EVP) model (Hunke & Dukowicz, Los Alamos CICE model, 1997);
    - Thermodynamic: Semtner, 1976;
- OASIS3-GOSSIP2 (Valcke 2005);

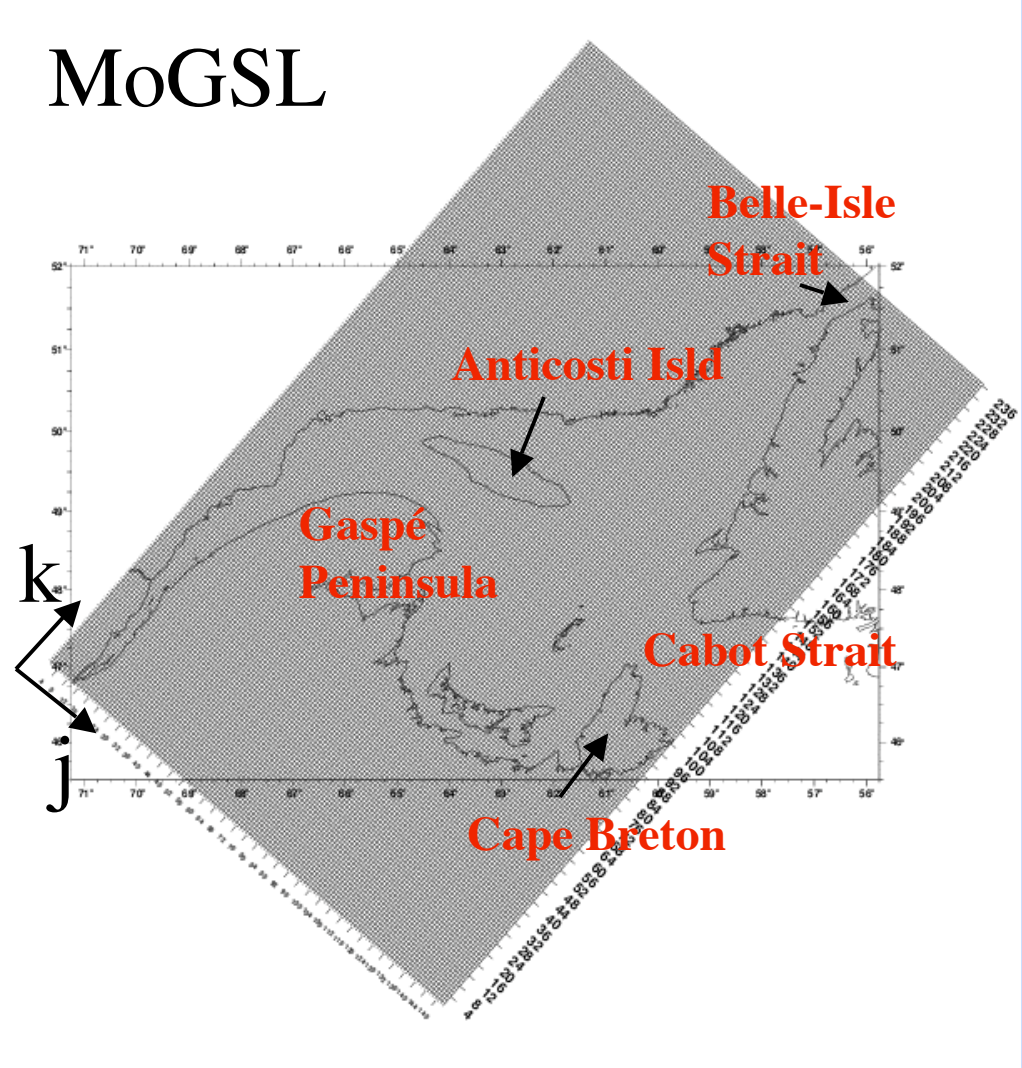
Global Environmental Multi-scale (GEM)



GEM (Coté et al. 1998)

- Non-hydrostatic primitive equations;
- Semi-Lagrangien transport, Implicit time stepping;
- Finite-differences on Arakawa-C grid;
- Lat-lon grid @ 0.13° horizontal resolution (~15km);
- Eta-vertical coordinate, 58 levels, top at 10 hPa;
- RPN physics package;

Gulf of St. Lawrence ocean-ice model



MoGSL (Saucier et al. 2003)

- Hydrostatic, Boussinesq and shallow water Euler fields equations;
- Eulerian advection, flux corrected transport;
- Finite differences on Arakawa-C grid;
- Rectangular grid, Rotated Mercator projection @5km;
- Z-vertical coordinate with 73 levels;
- 2.5 order closure turbulence scheme;
- Multi-categories sea-ice model;

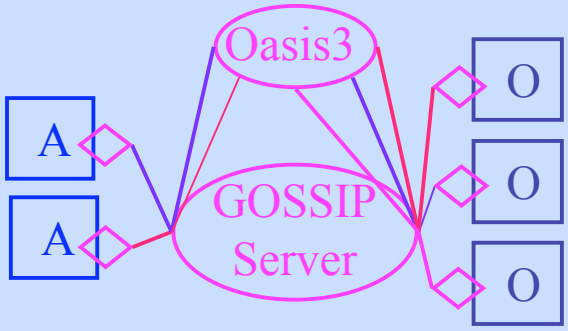
OASIS3-GOSSIP2 coupler

GOSSIP2 (Bouhemhem, D., 2004):

- RPN communication layer based on UNIX sockets;
- Server listens for Clients (model proc or OASIS3) requests; then receives/sends data to Clients;
- Portability, support of distributed computing, no conflict with batch scheduler;

OASIS3 (Valcke et al, 2004):

- CERFACS coupling package;
- Grid transformation;
- 2D horizontal interpolation, aggregation;
- Flux correction, merging;
- Algebric transformation;



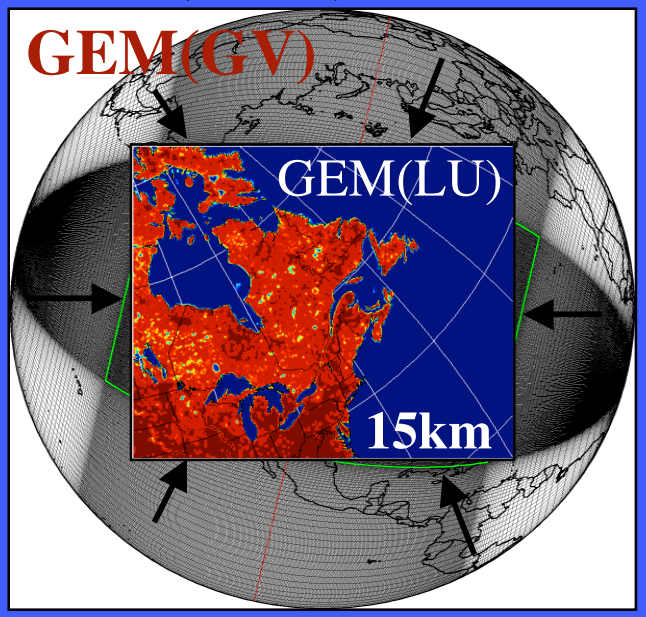
Methodology

Dor-IB(Linux)

OASIS3 - Gossip2

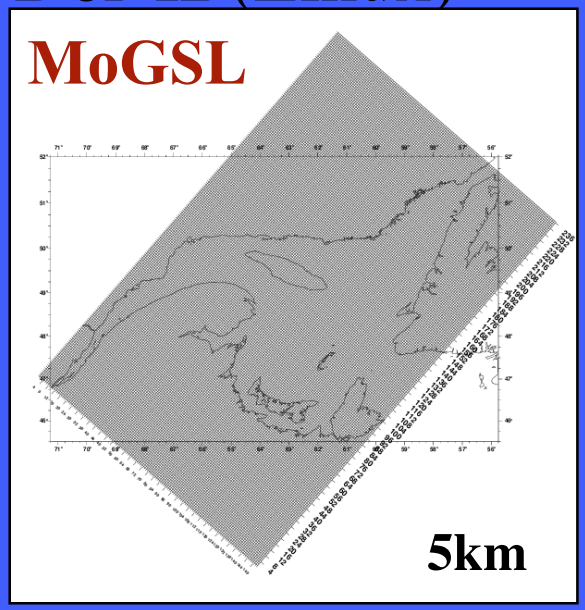
TM, GL, I7, I8, MG

Naos(IBM)



Coupling Δt = 450s

Dor-IB(Linux)



GEM Δt = 450s

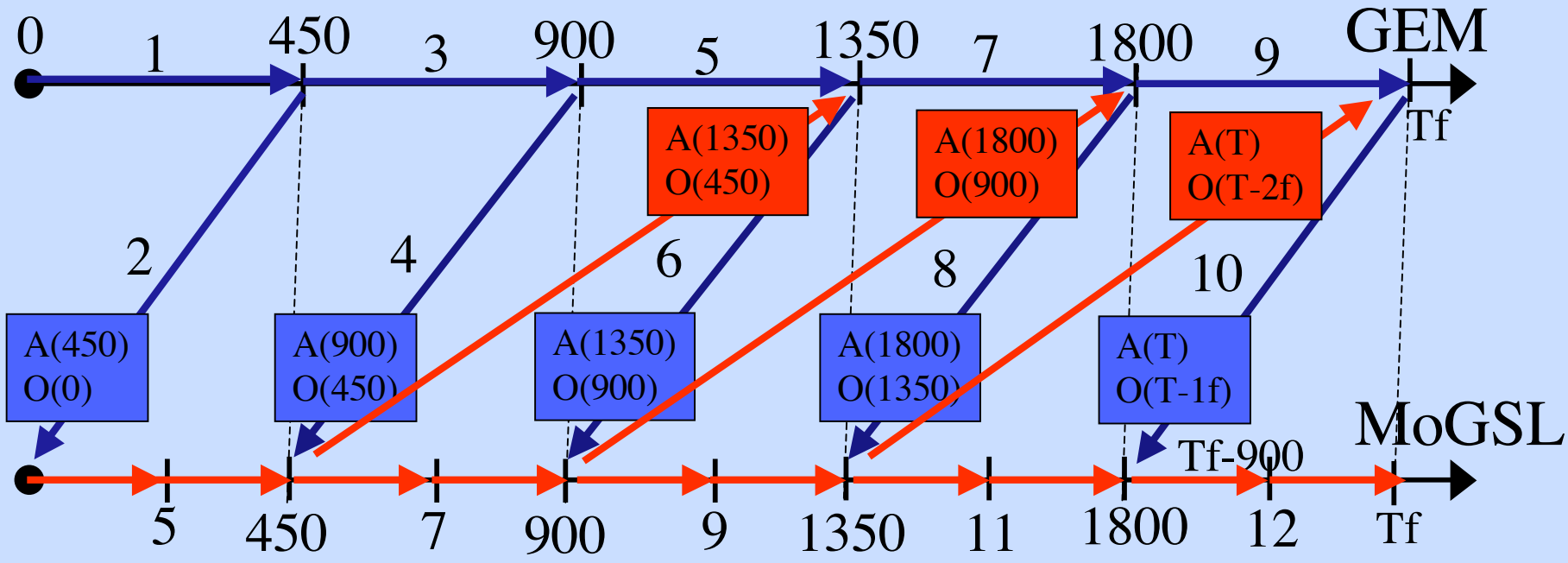
Dor-IB(Linux)

OASIS3 - Gossip2

TJ, TD, UD,VD, FB, FI, RT

MoGSL Δt = 225s

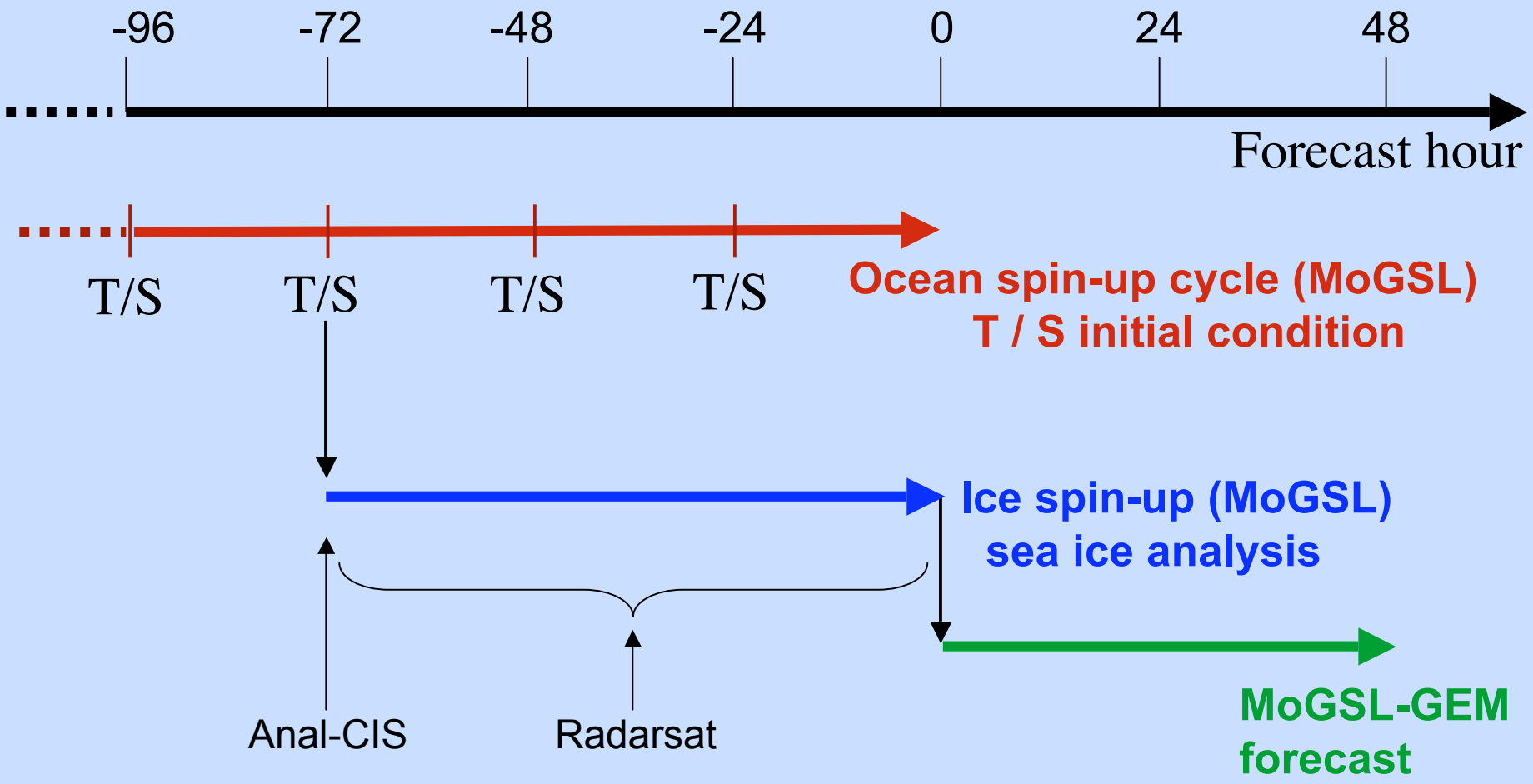
Coupling strategy



GEM sees MoGSL with a lag = -2 coupling frequency:

- A(1350s) is coupled with O(450s);

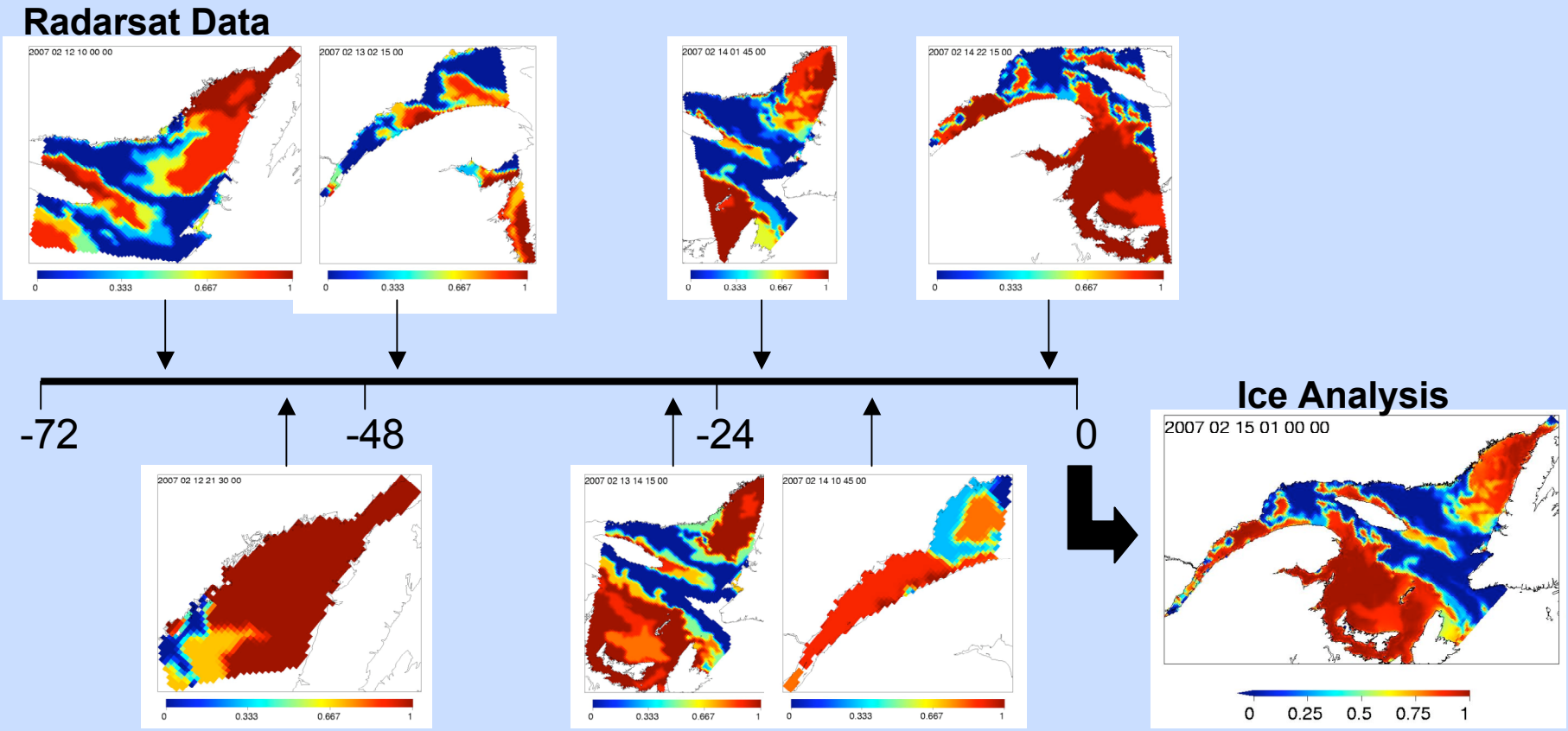
Execution Strategy



1 run / day from 00Z data

Methodology

Daily Sea Ice Analysis for the CMC Coupled Model "Ice Spin-up"



Evaluation Experiment

Hindcast runs for 2 seasons:

- Winter: January, 01 - March 31 2007
- Summer: May 01 - June 30 2007

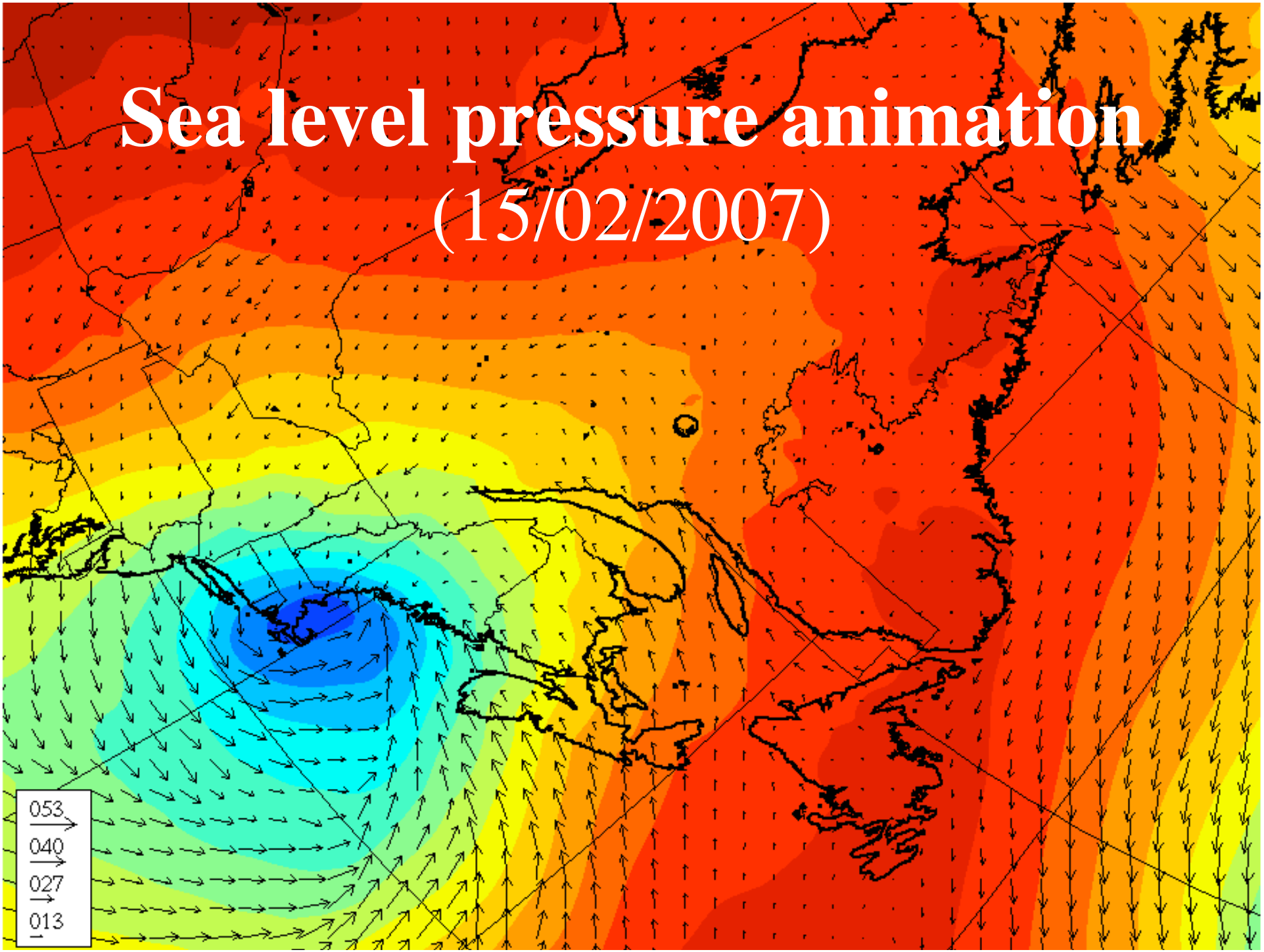
1. Control run (**CTRL**)
   - GEM(LU), no coupling
2. Uncoupled run (**NC**)
   - GEM(LU), no coupling, with sea-ice & TM from the ice spinup
3. Coupled run (**CPL**)
   - GEM(LU) - MoGSL with coupling, with sea-ice & TM from the ice spinup

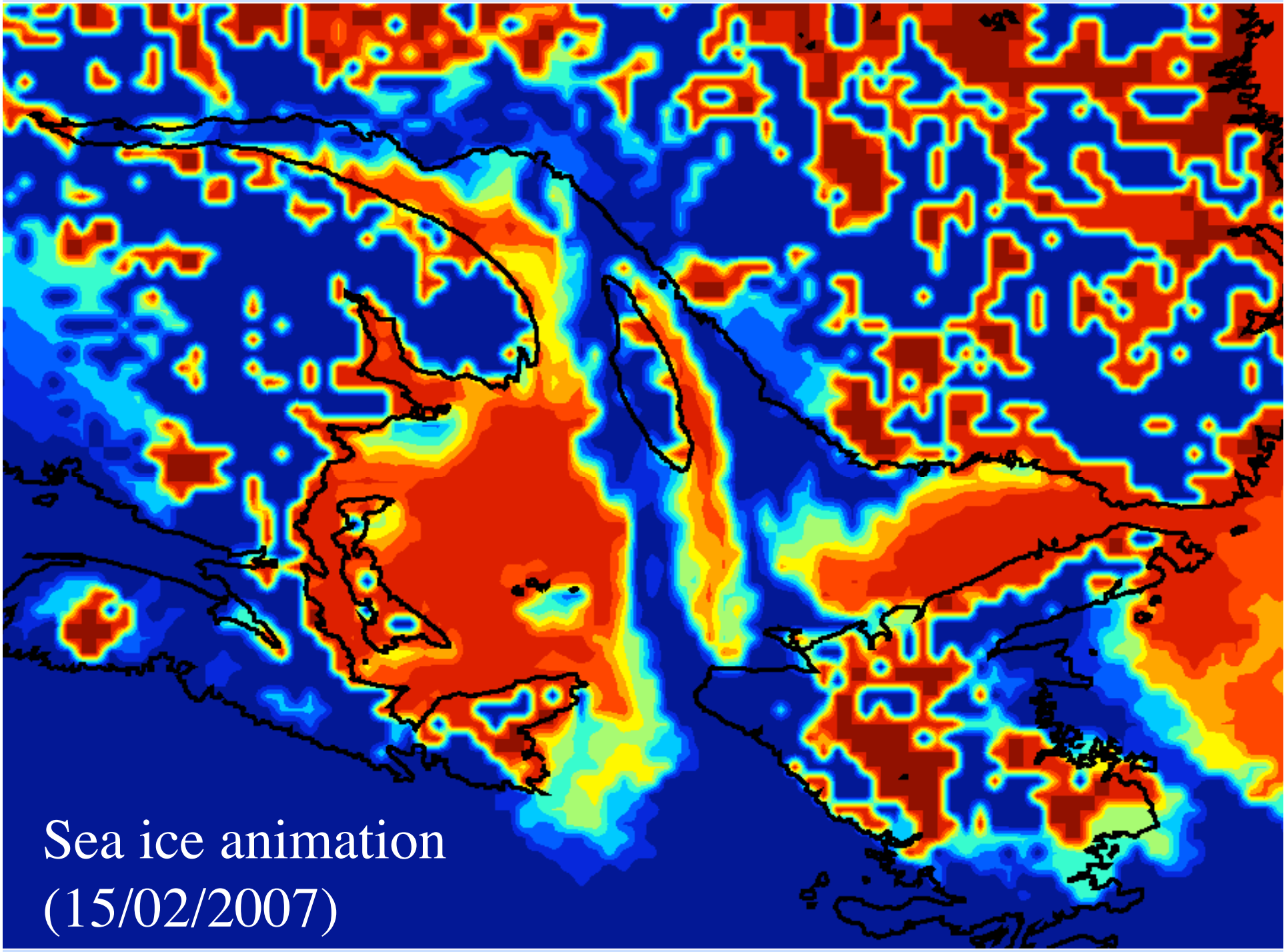
Evaluation Protocole

- Subjective evaluation
  - Atmospheric fields: TT, UU, VV, PR, RT, FC, FC,,,
  - Sea ice coverage in the Gulf of St. Lawrence
    - Comparison with CMC analysis, Radarsat & CIS ice charts;
  - Sea surface temperature in the Gulf of St. Lawrence
    - Comparison with CMC analysis;
- Objective evaluation
  - Arcad scores (3D & surface)
  - CMC precipitation scores
  - Surface scores (MAE, BIAS, RMSE, RV)
    - TT, TD, PN, NT, UU,VV, PR
      - Data base: UMOS (M. Vallée), CAPA (V. Fortin)
    - Sea ice (GL, GE)
      - Data base: GSL model analysis, Radarsat, CIS analysis

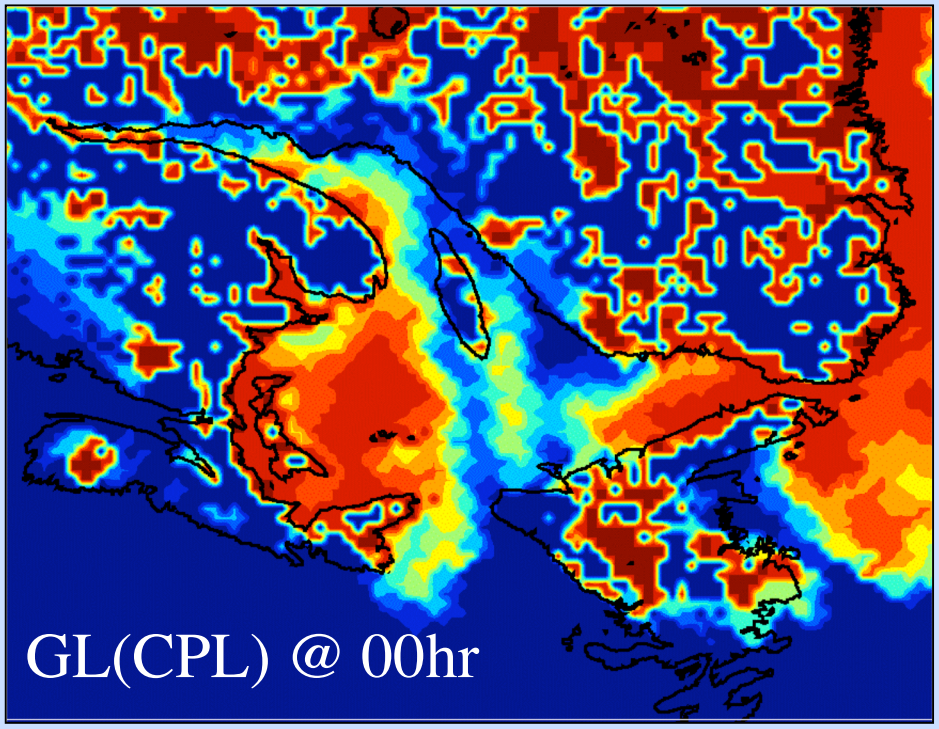
Sea level pressure animation

(15/02/2007)

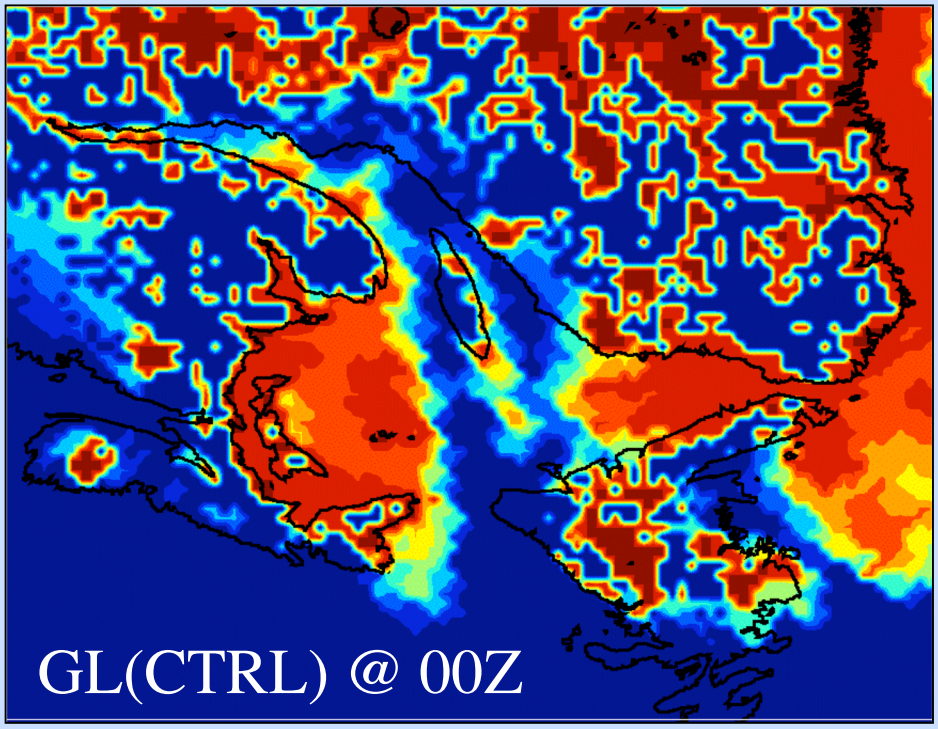



Sea ice animation
(15/02/2007)

Sea ice difference: CPL vs CTRL

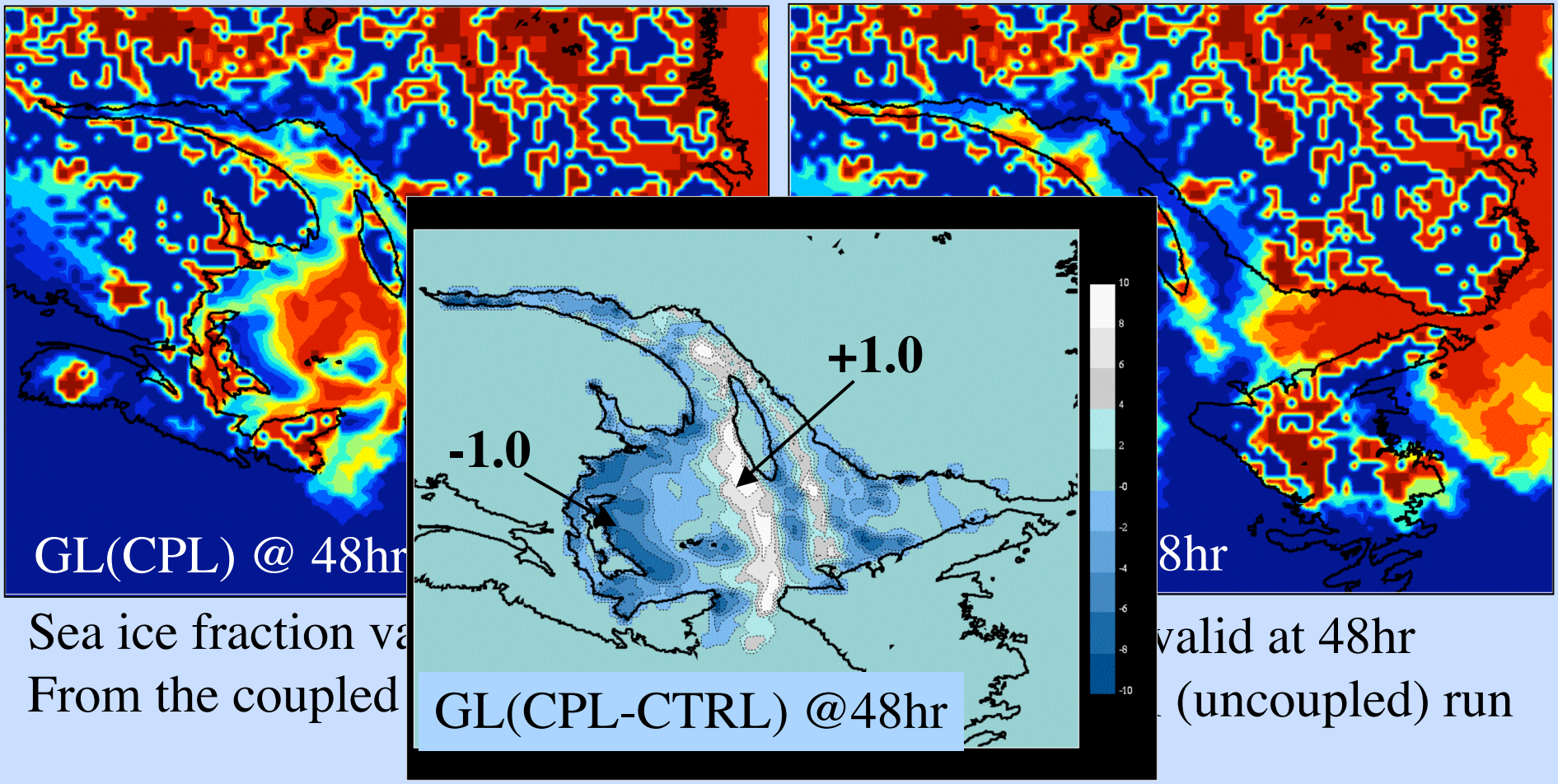


Sea ice fraction valid at 00hr
From the coupled run



Sea ice fraction valid at 00hr
From the uncoupled run

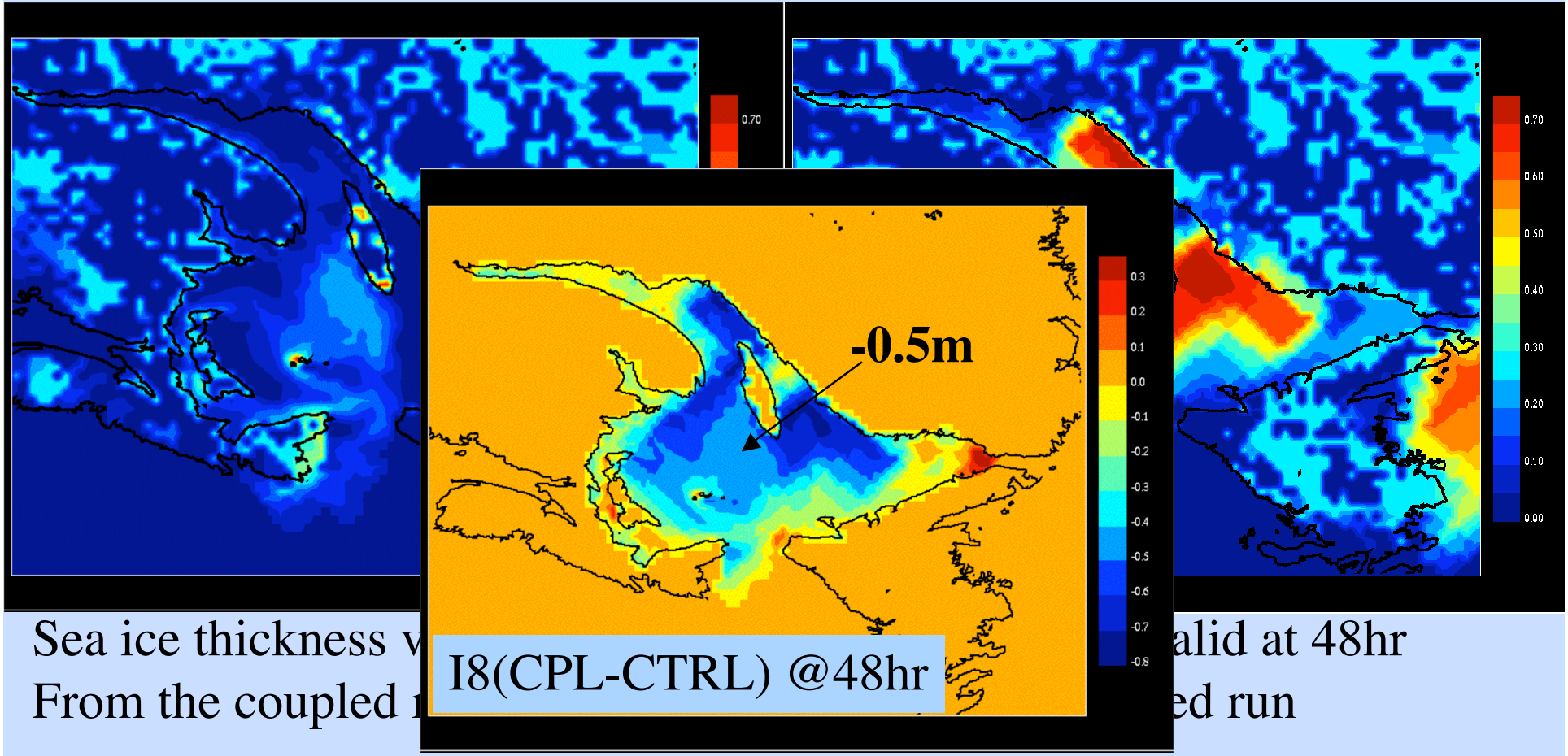
Sea ice difference: CPL vs CTRL…



Sea ice fraction va valid at 48hr
From the coupled (uncoupled) run

Ice fraction difference

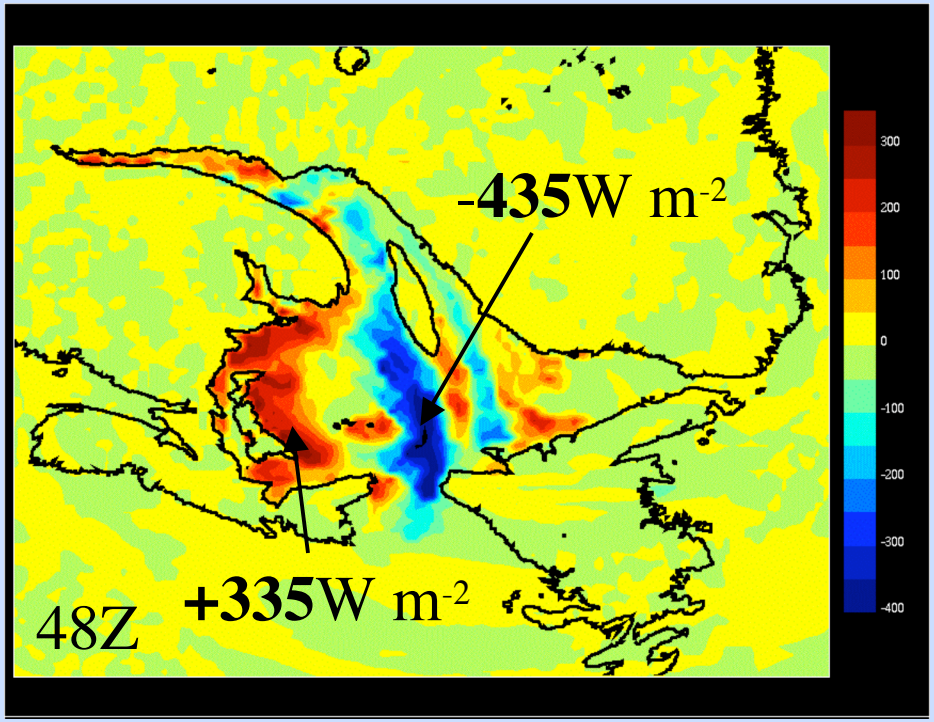
Sea ice difference: CPL vs CTRL…



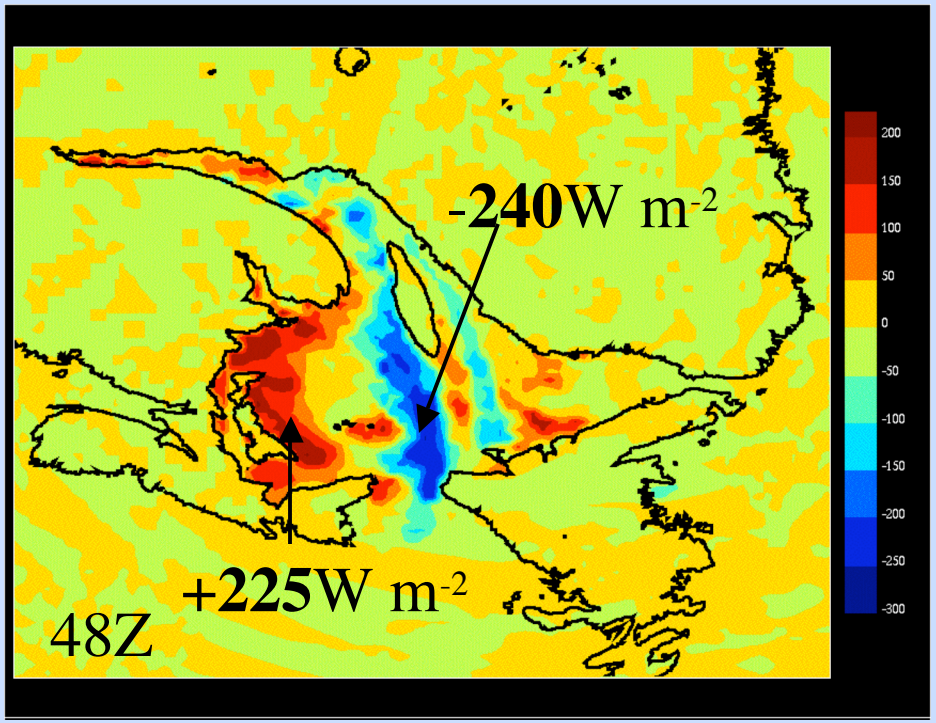
Sea ice thickness v alid at 48hr
From the coupled r ed run

Ice thickness difference

Surface flux difference (CPL - CTRL)

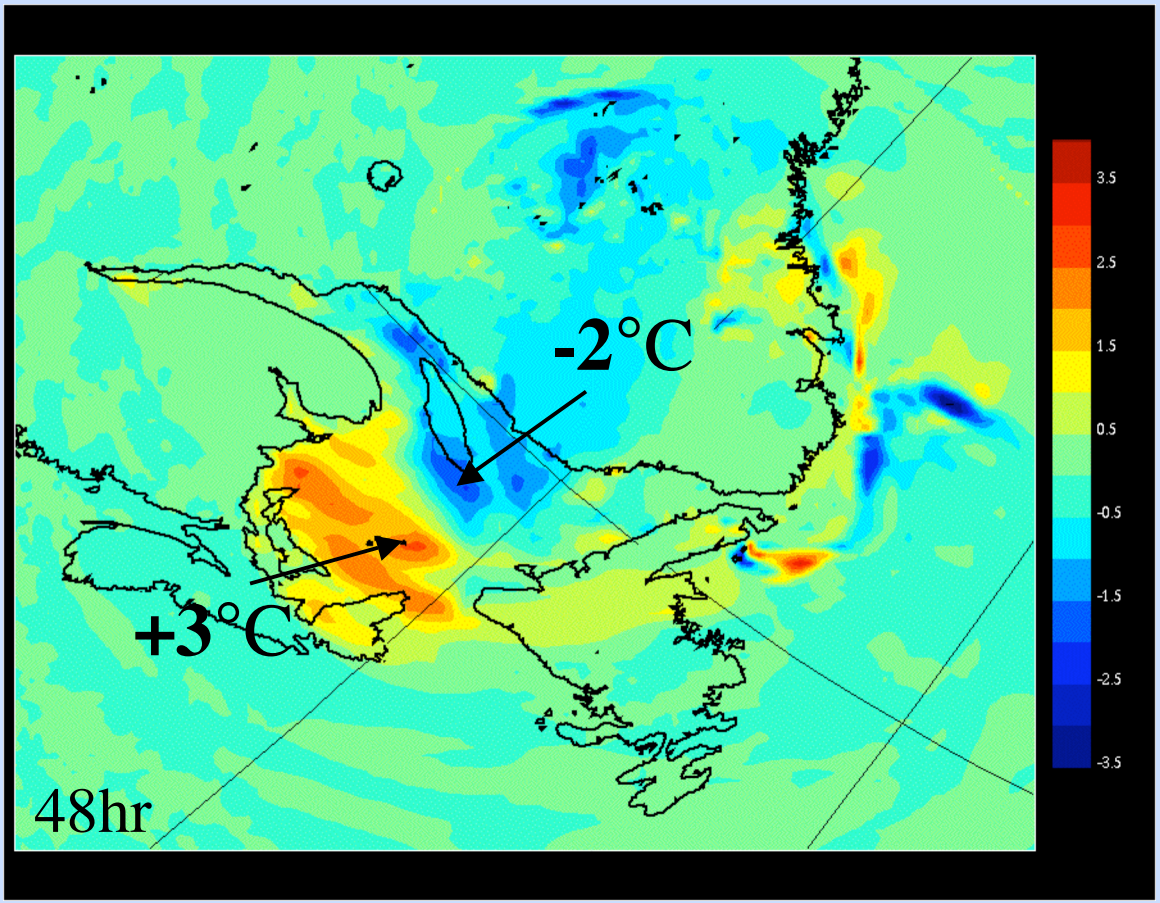


Sensible heat flux (W m^{-2})

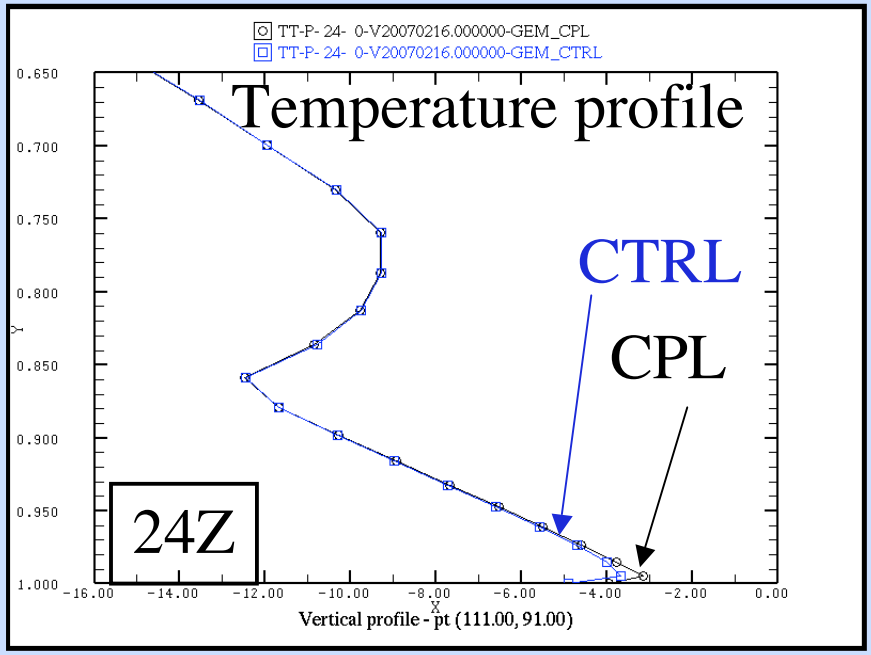


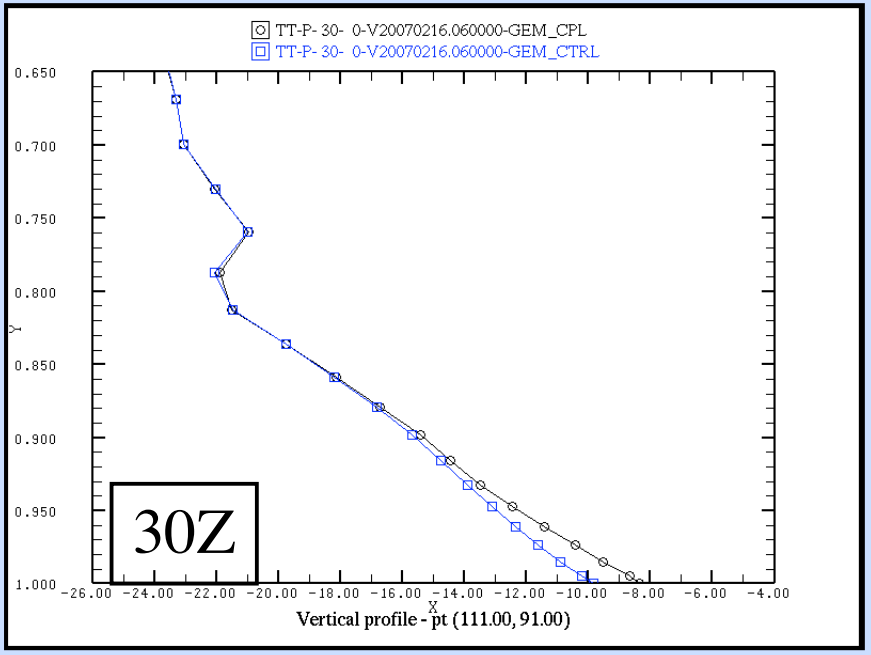
Latent heat flux (W m^{-2})

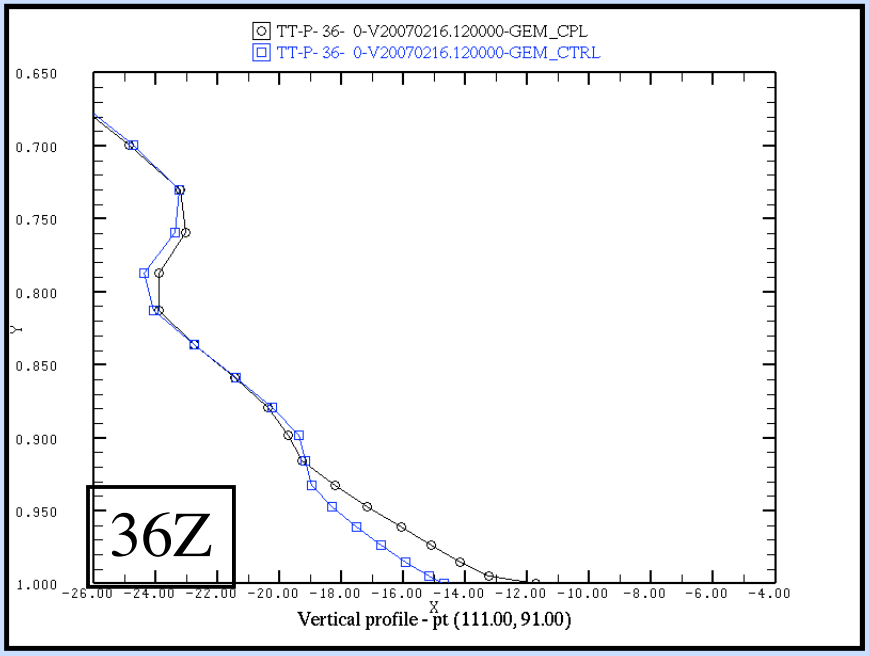
Surface temperature difference

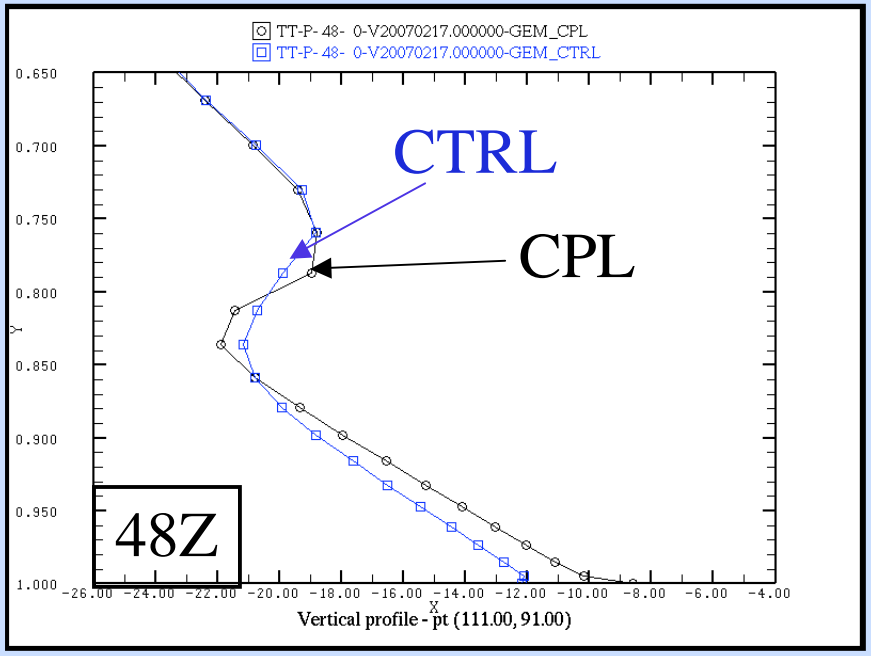


Temperature, eta=0.995 (°C)

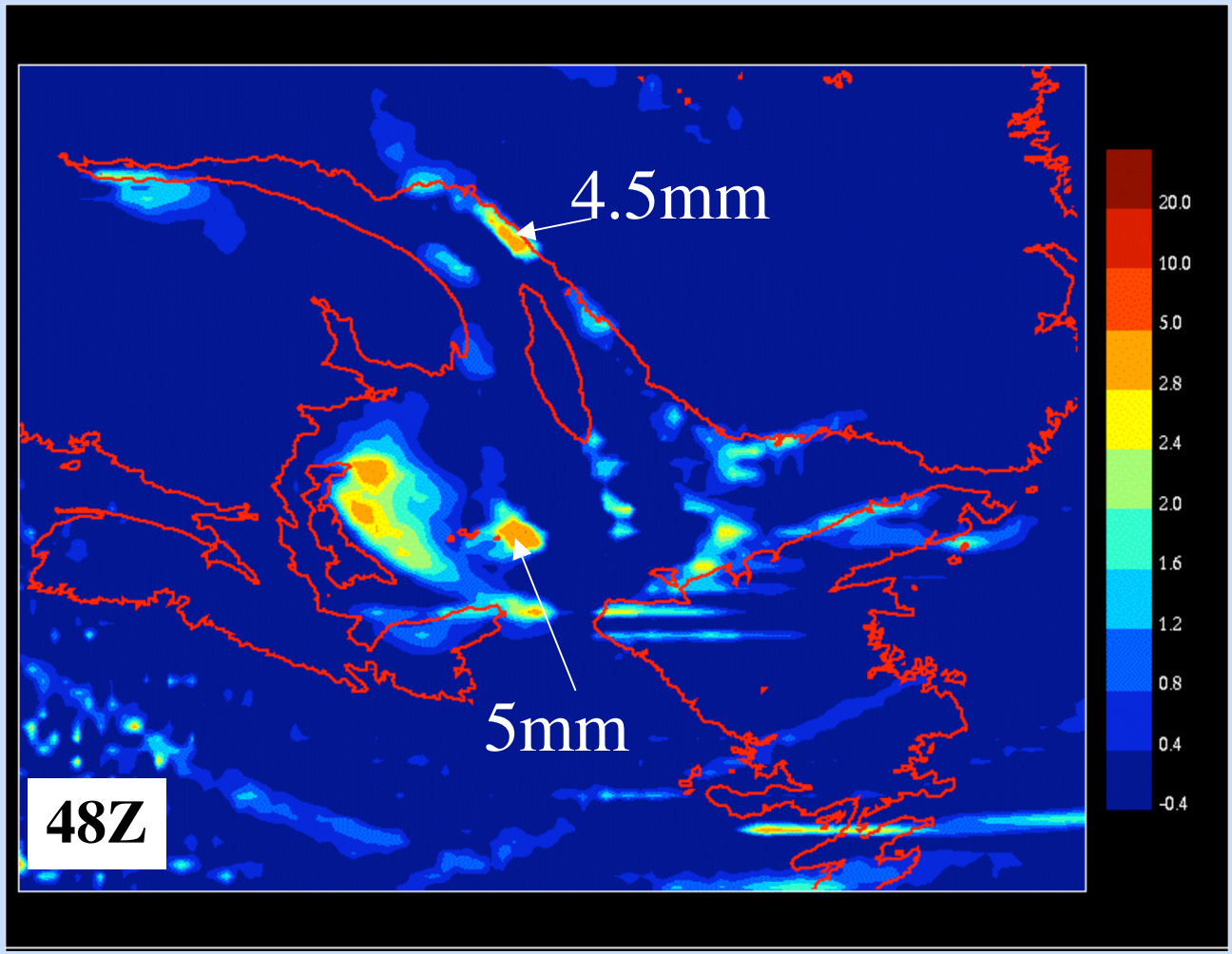

TT-P- 24- 0-V20070216.000000-GEM_CPL
TT-P- 24- 0-V20070216.000000-GEM_CTRL
Temperature profile
CTRL
CPL
24Z
Vertical profile - pt (111.00, 91.00)

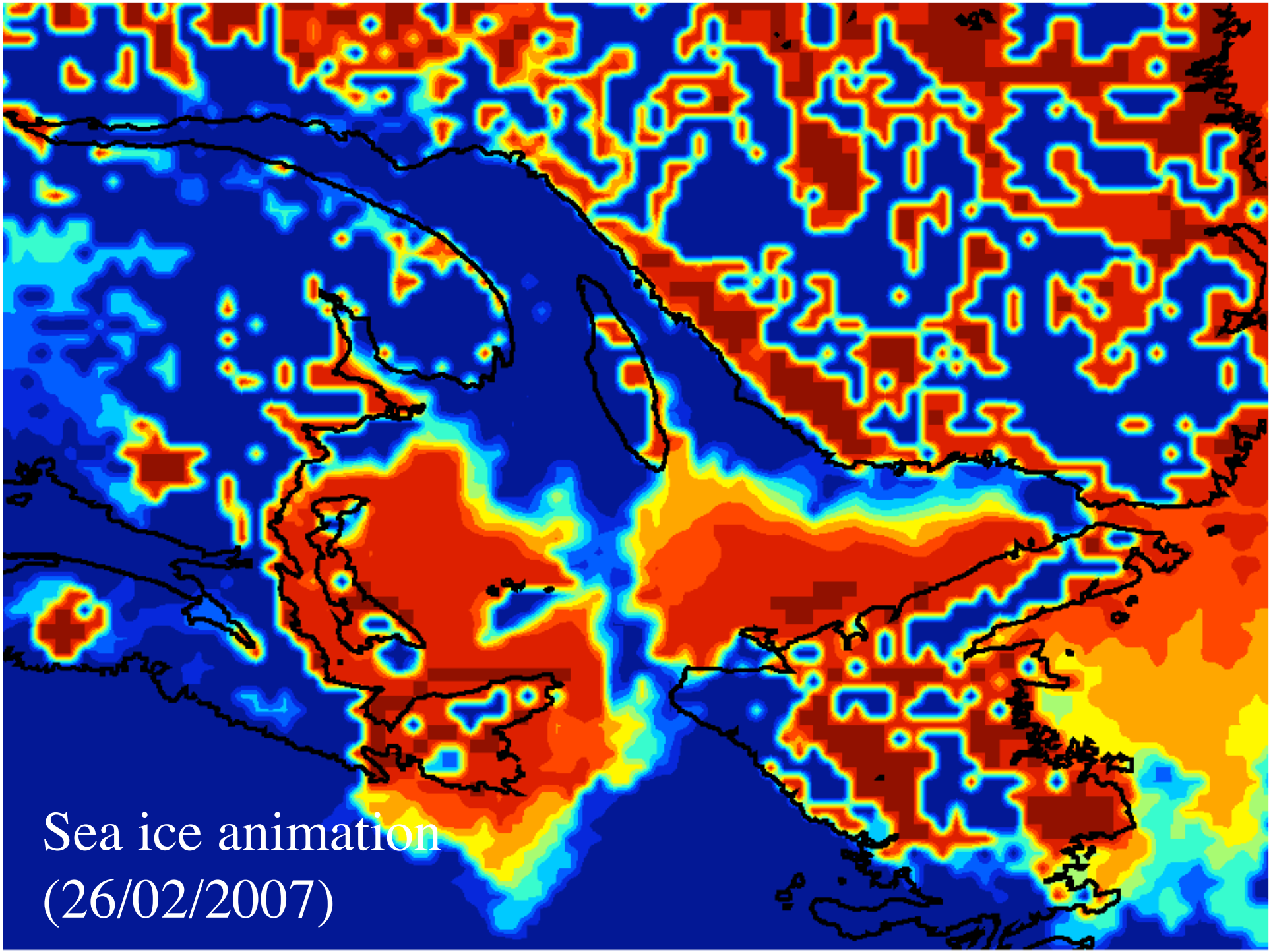

TT-P- 30- 0-V20070216.060000-GEM_CPL
TT-P- 30- 0-V20070216.060000-GEM_CTRL
30Z
Vertical profile - pt (111.00, 91.00)


TT-P- 36- 0-V20070216.120000-GEM_CPL
TT-P- 36- 0-V20070216.120000-GEM_CTRL
36Z
Vertical profile - pt (111.00, 91.00)

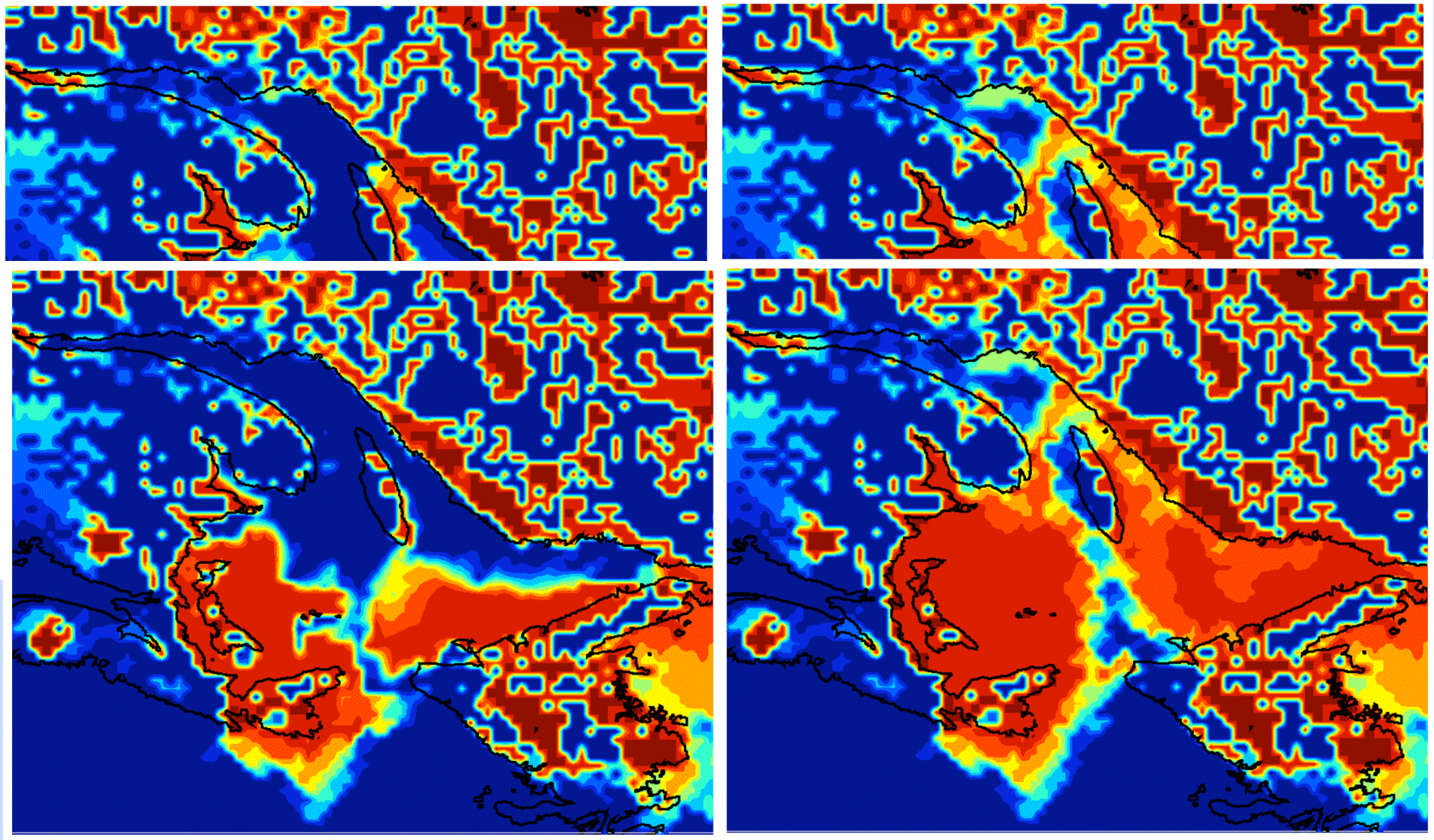

TT-P- 48- 0-V20070217.000000-GEM_CPL
TT-P- 48- 0-V20070217.000000-GEM_CTRL
CTRL
CPL
48Z
Vertical profile - pt (111.00, 91.00)

Precipitation (accumulation): CPL-CTRL



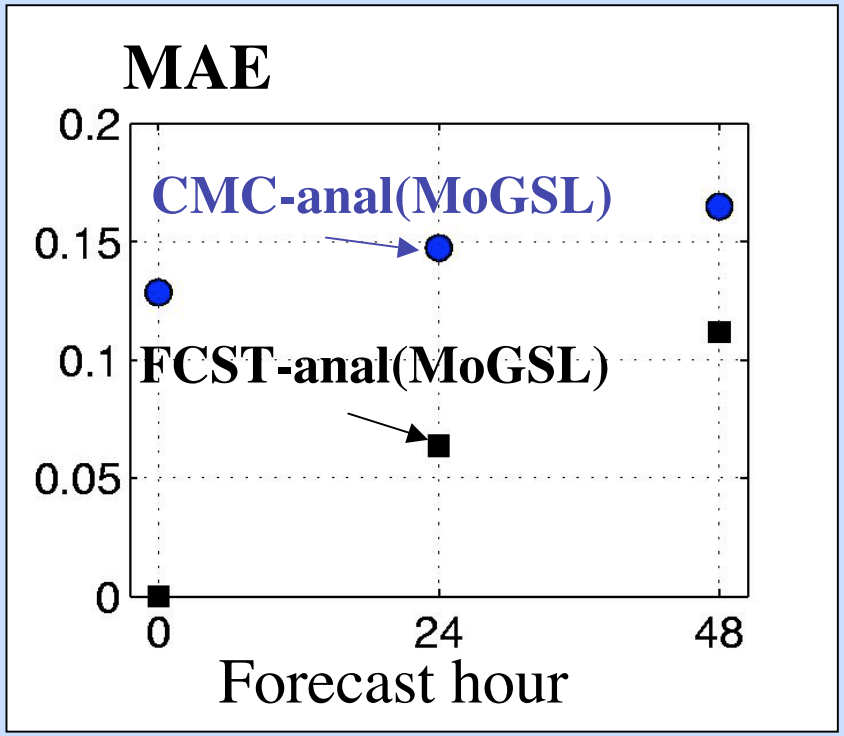

Sea ice animation
(26/02/2007)

Sea ice difference: CPL vs CTRL

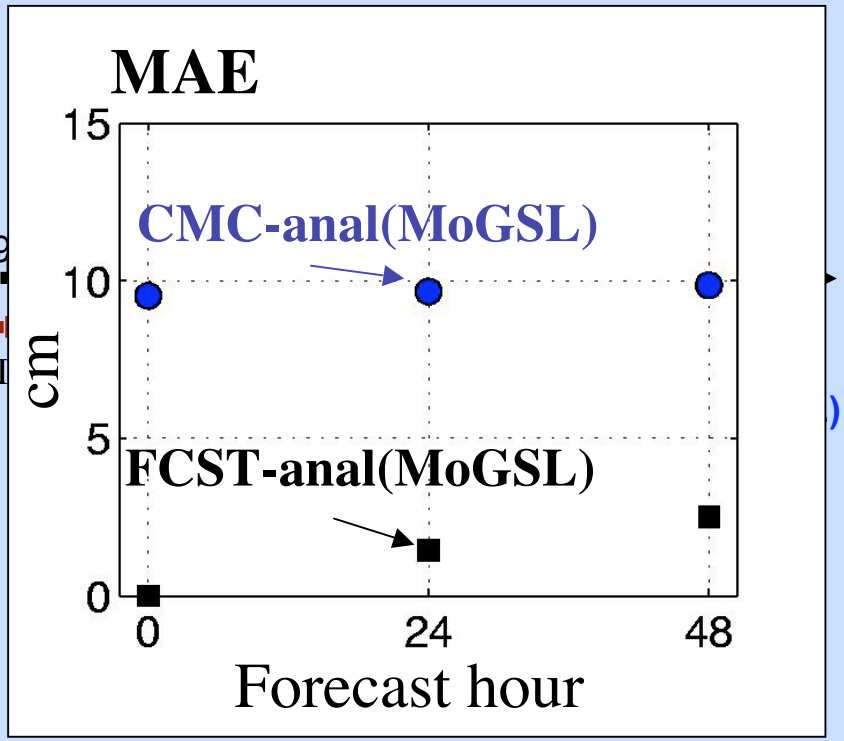


Validation of sea-ice

Sea ice fraction

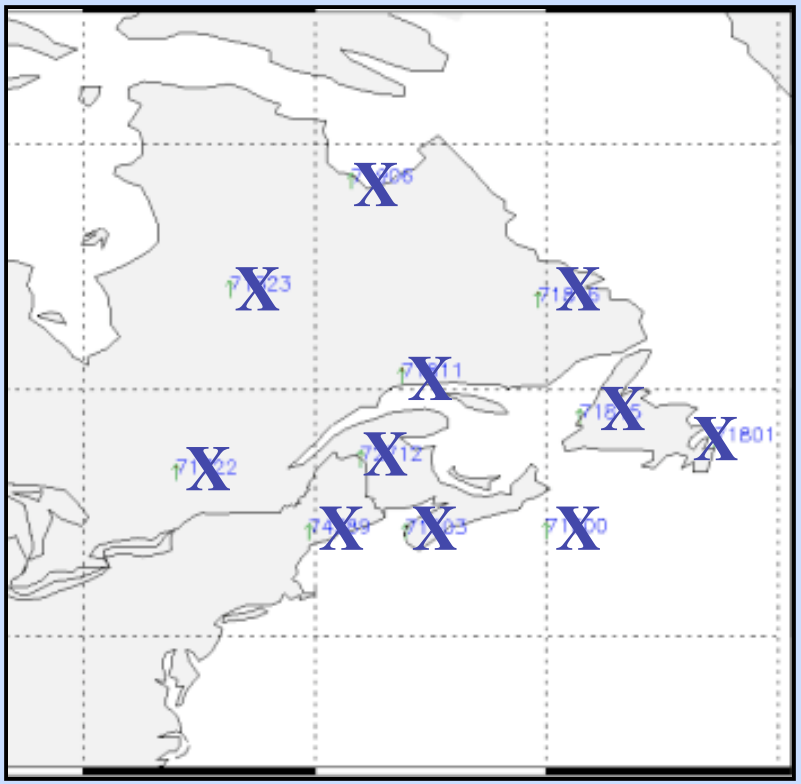


Sea ice thickness

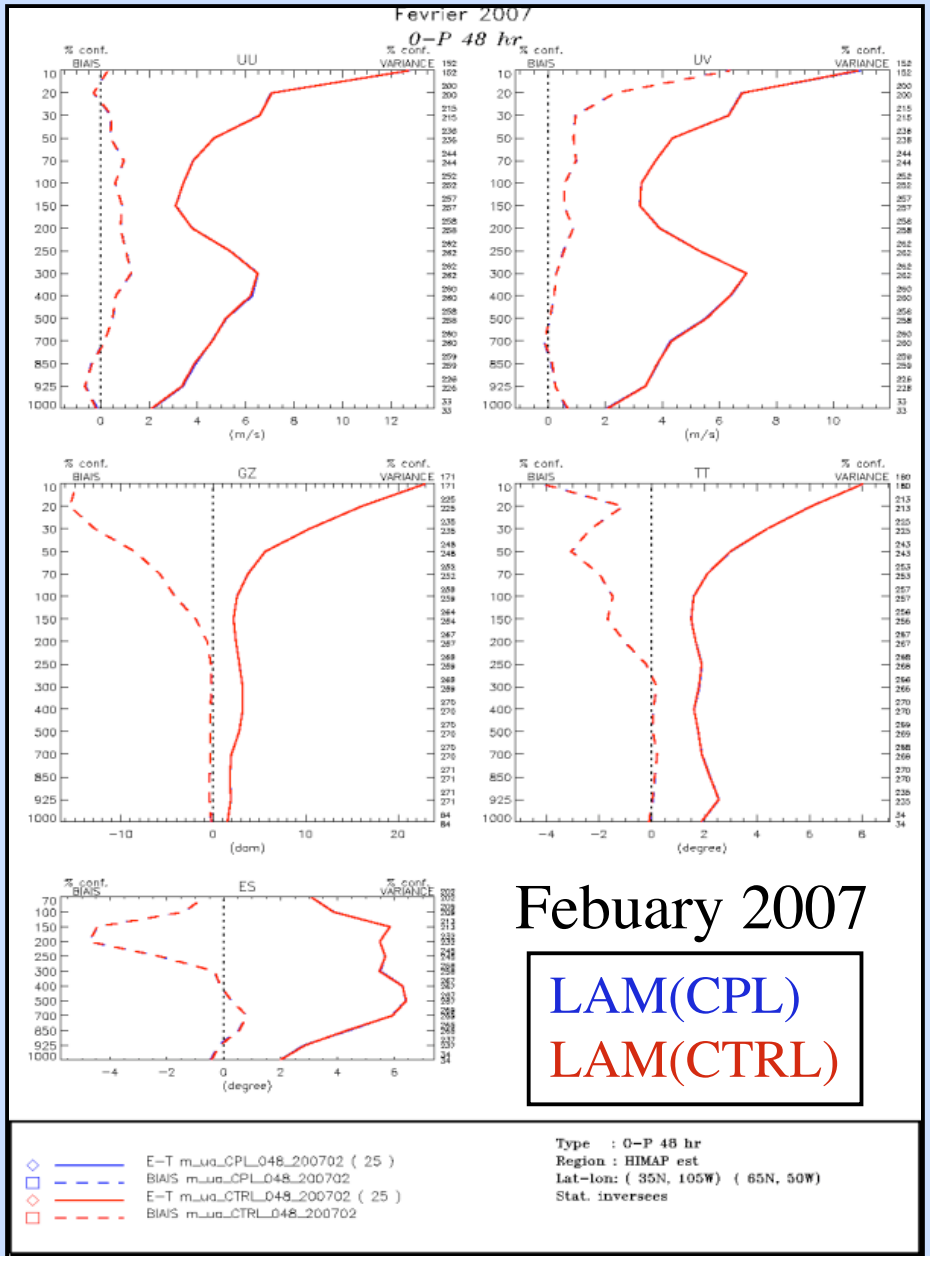


François Roy, 2007

Objective Evaluation



Data upper air data from run g2;

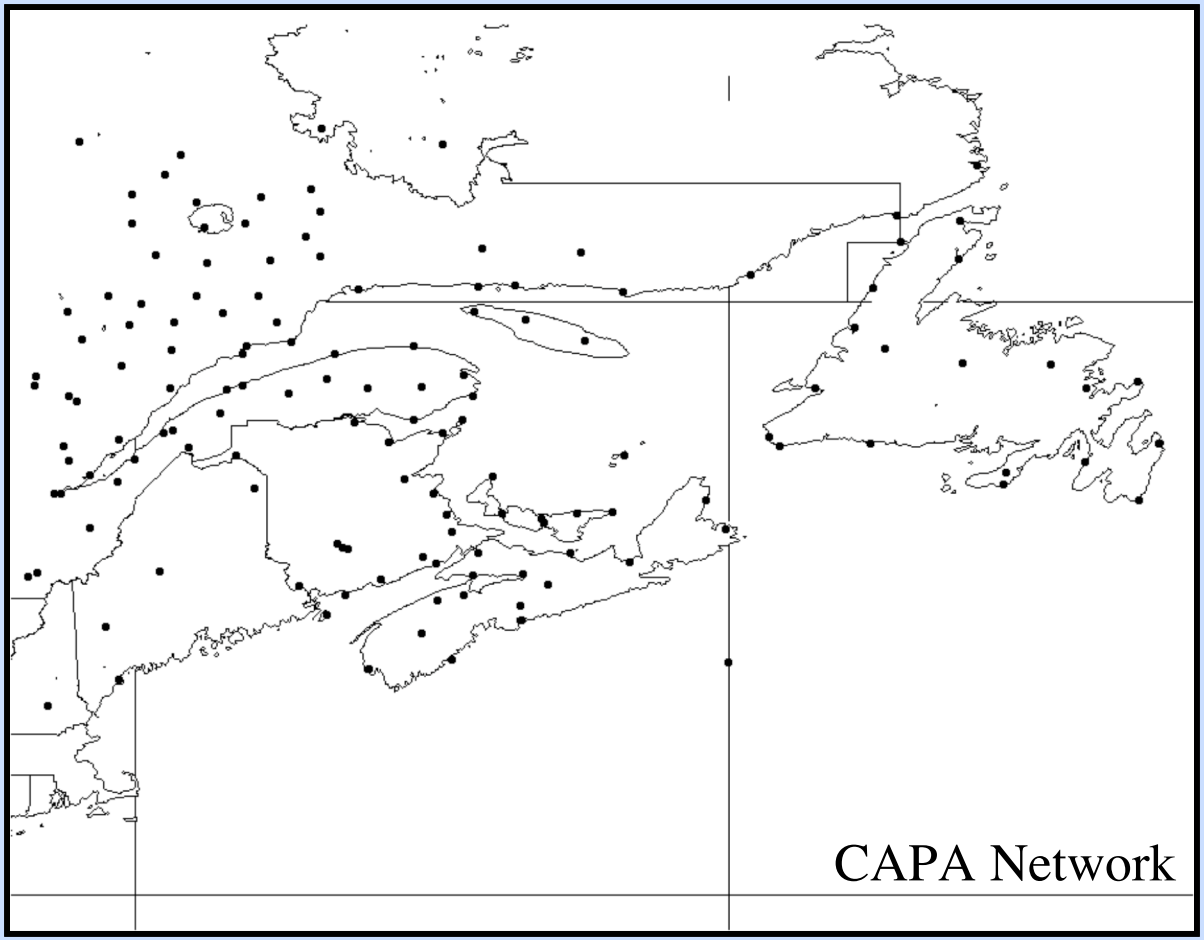


Febuary 2007

LAM(CPL)

LAM(CTRL)

Surface stations



Data: 6-hourly precipitation, dew point temperature, surface pressure, cloud cover, wind;

Database: metar, synop, RCMQ;

Method: krigeage;

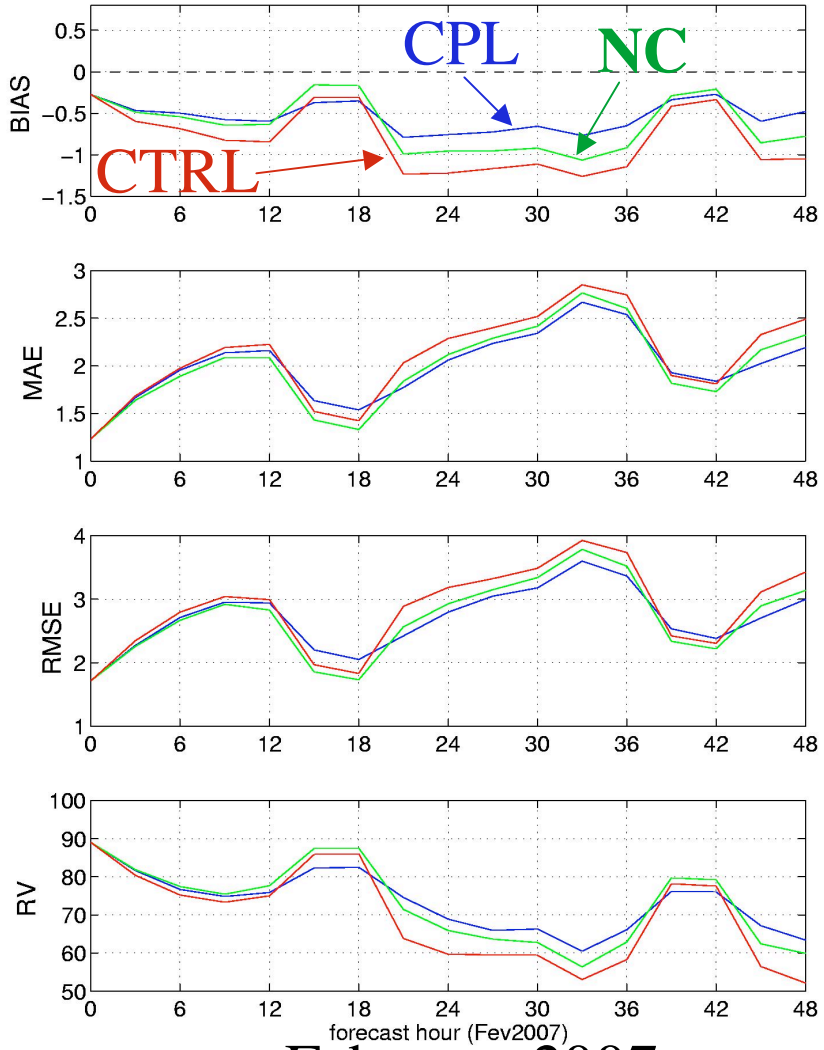
From CAPA system (V. Fortin)

Data: 3-hourly precipitation, surface pressure, cloud cover, wind;

Database: metar and synop;

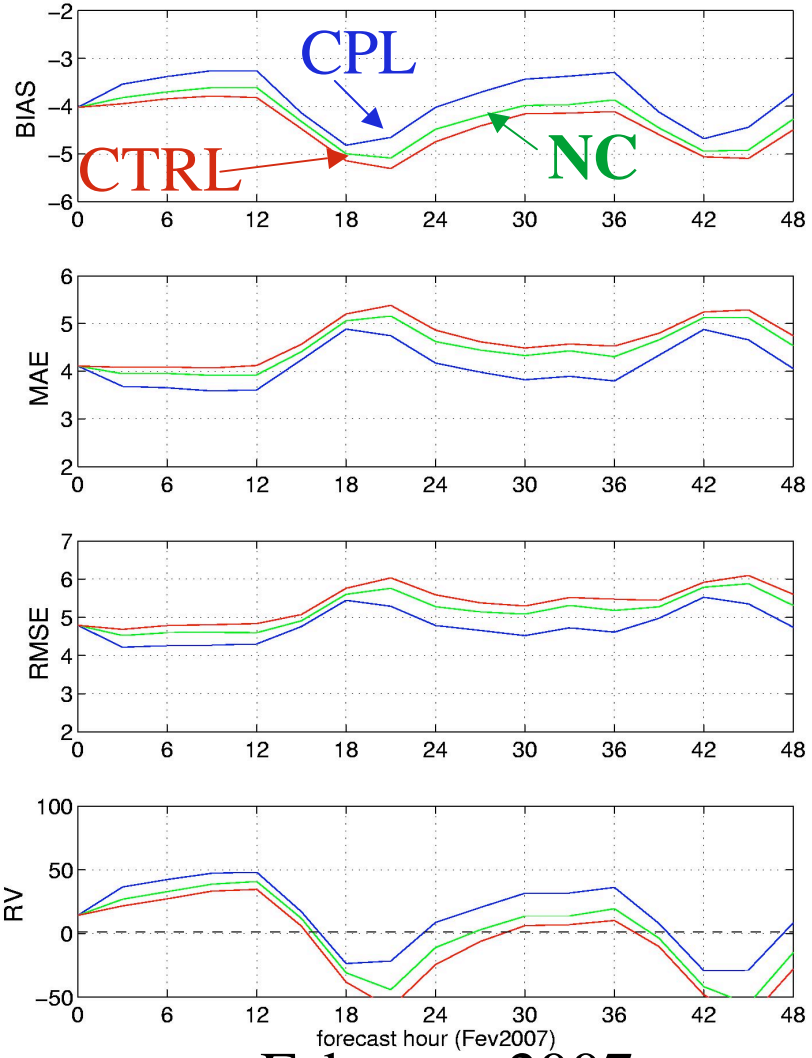
From UMOS system (M. Vallée)

Surface temperature (TT)



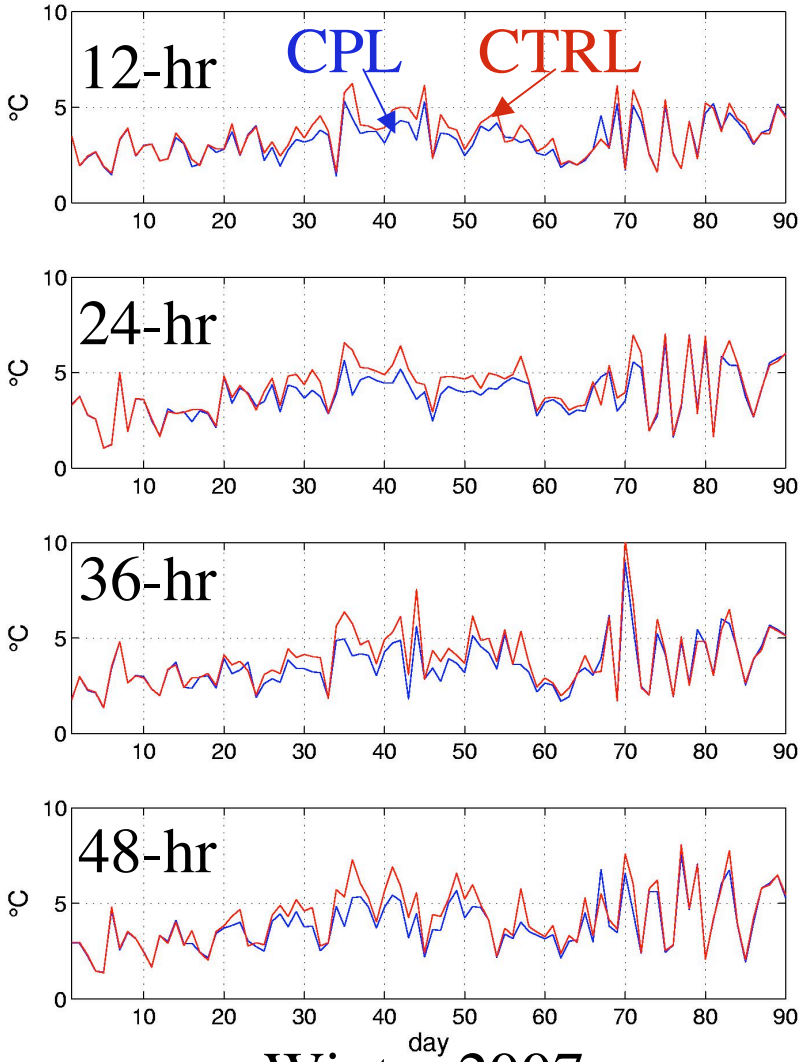
February 2007

Dew point temperature (TD)



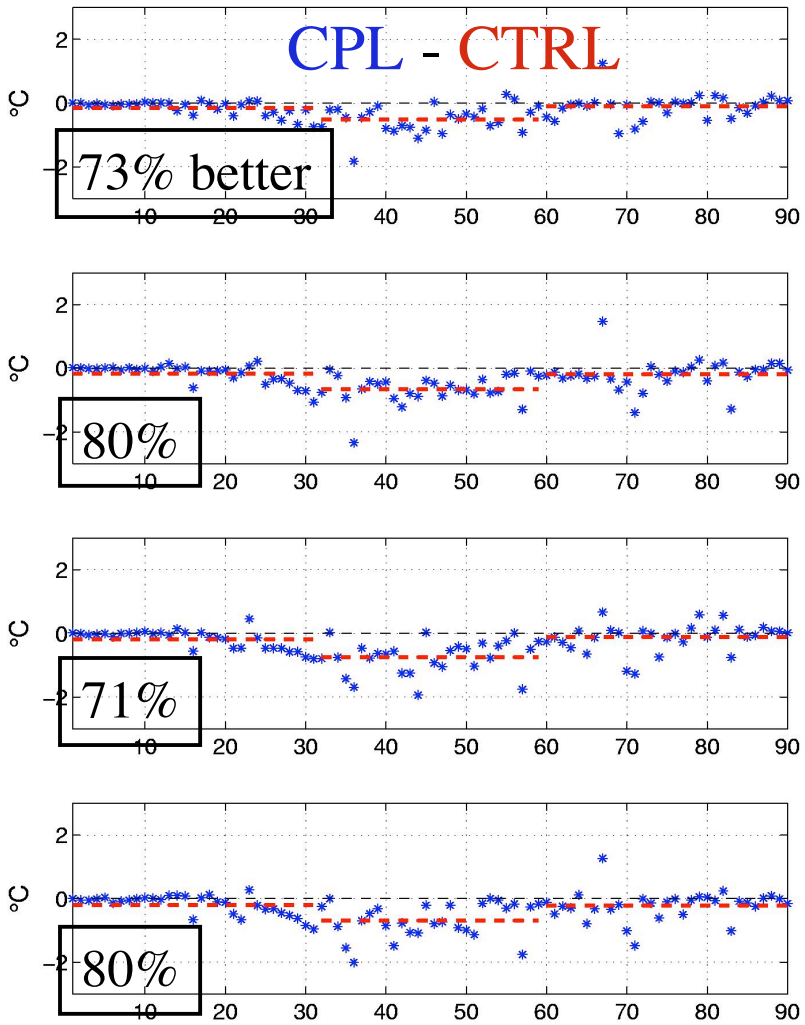
February 2007

MAE for TD



Winter 2007

MAE difference for TD

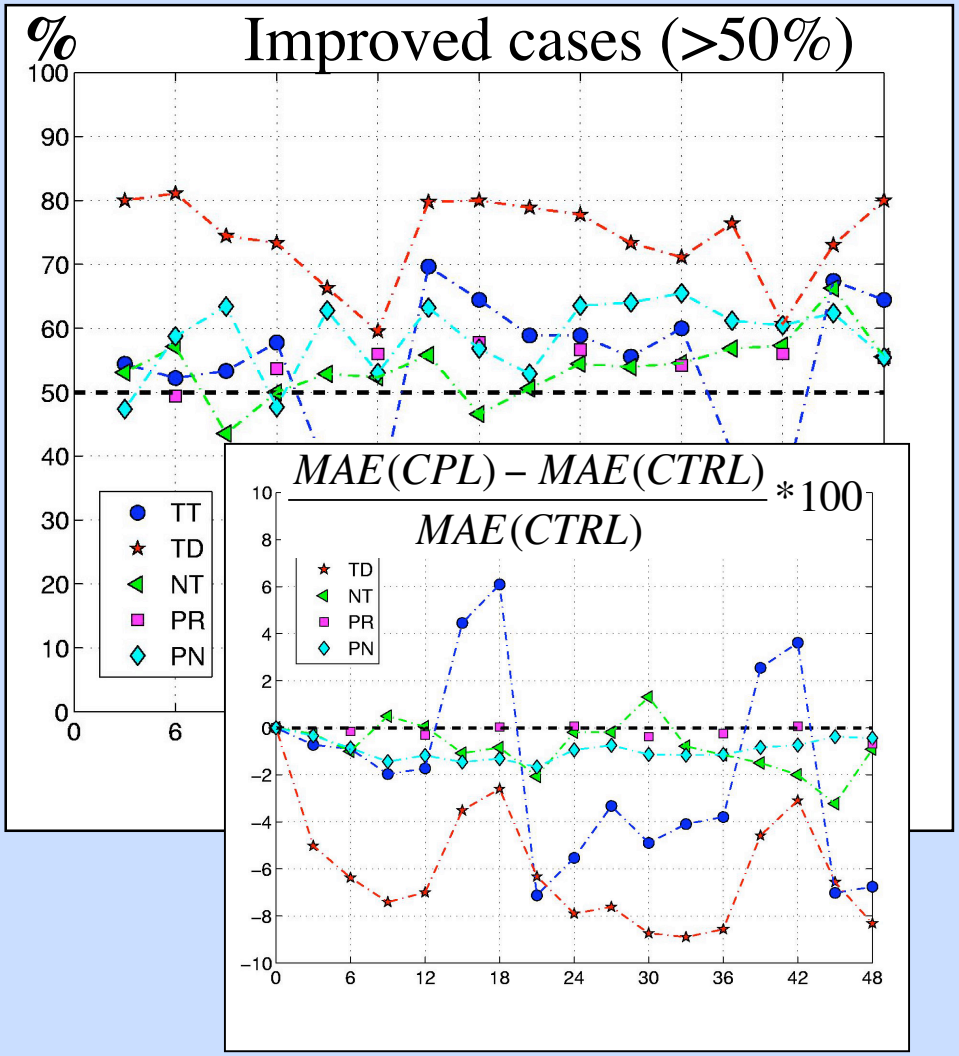


Winter 2007

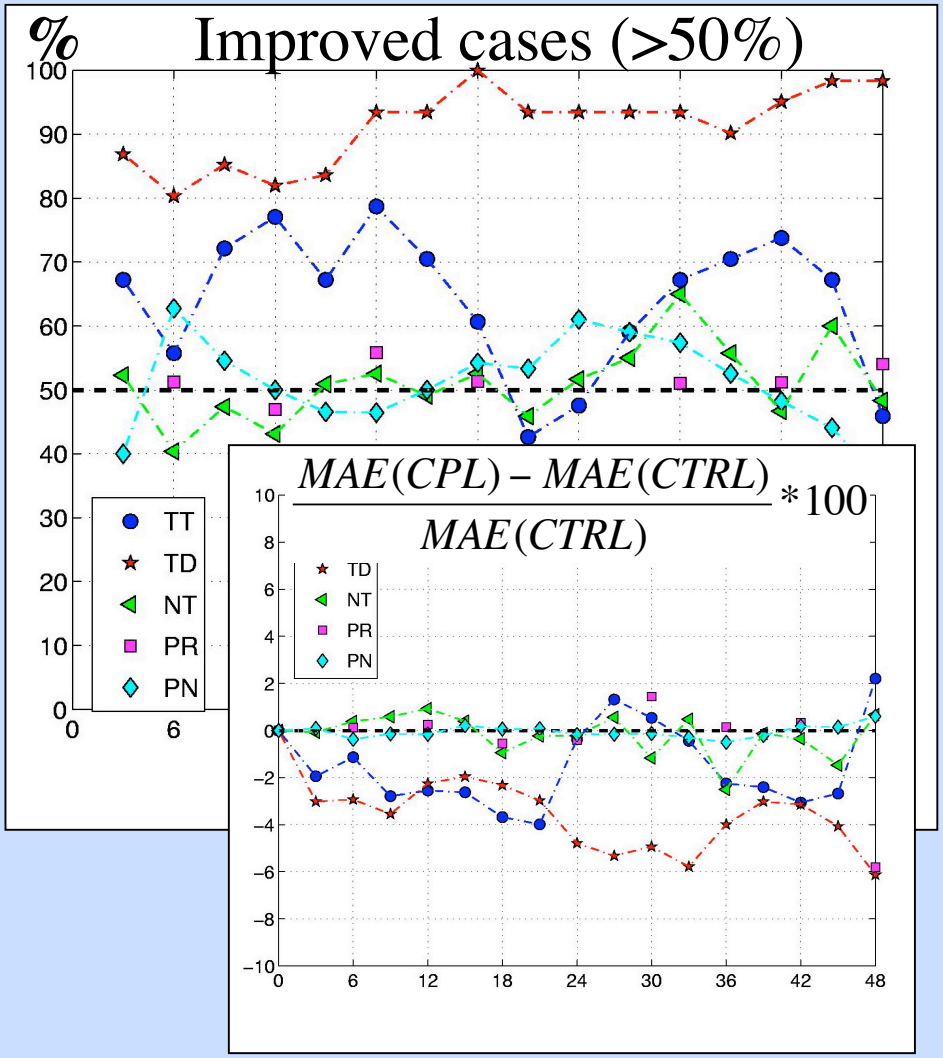
Evaluation

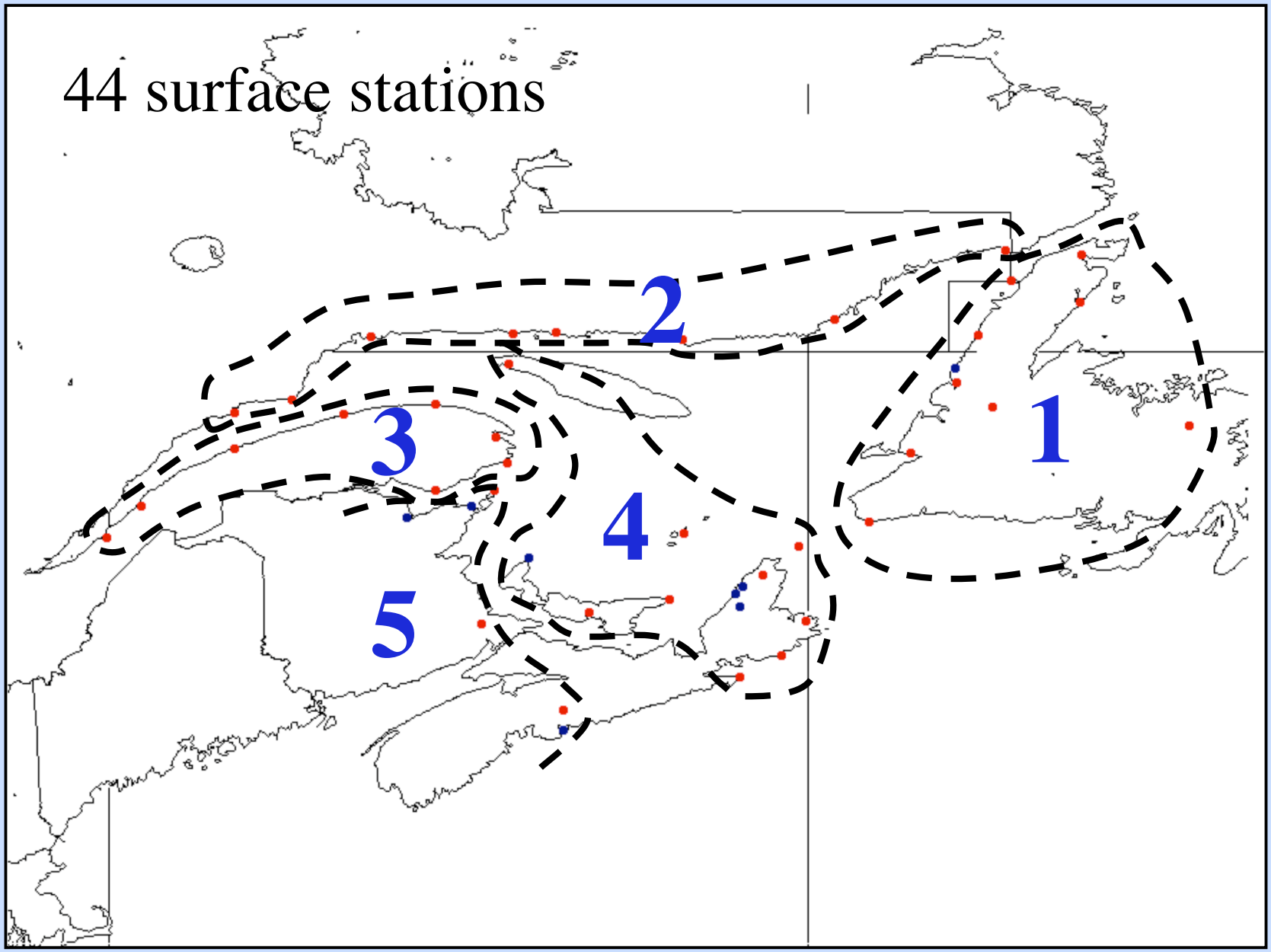
Are we doing better ?

Winter



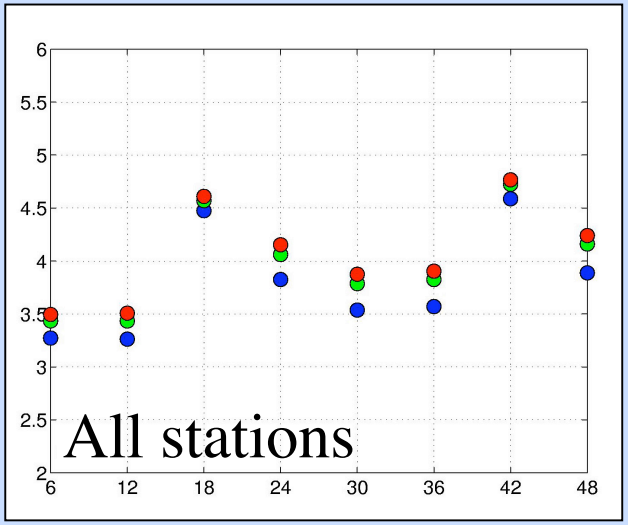
Summer

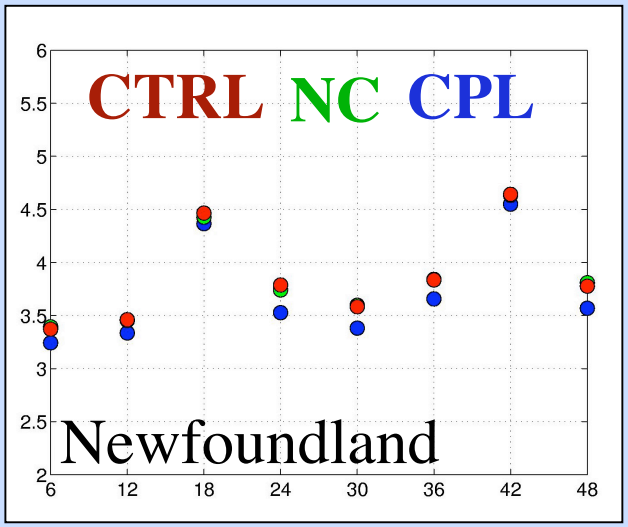


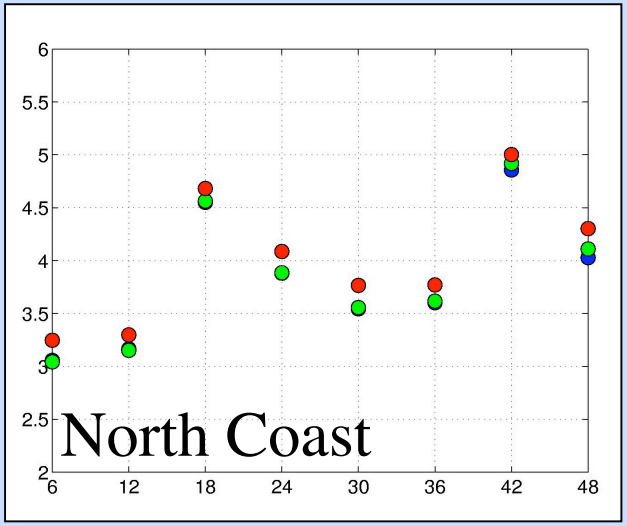

44 surface stations
1
2
3
4
5

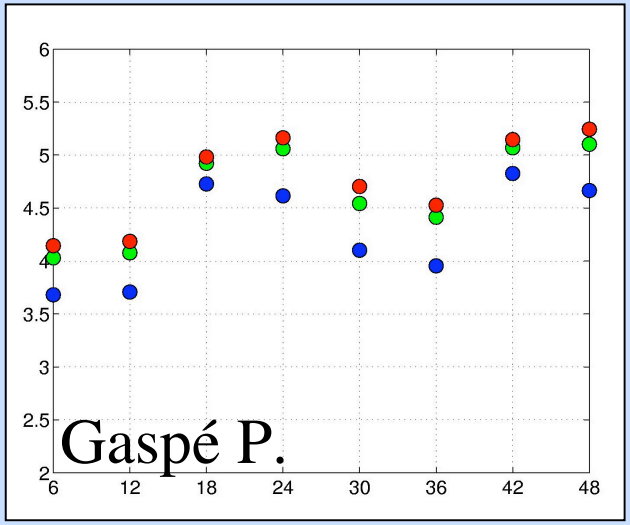
Evaluation

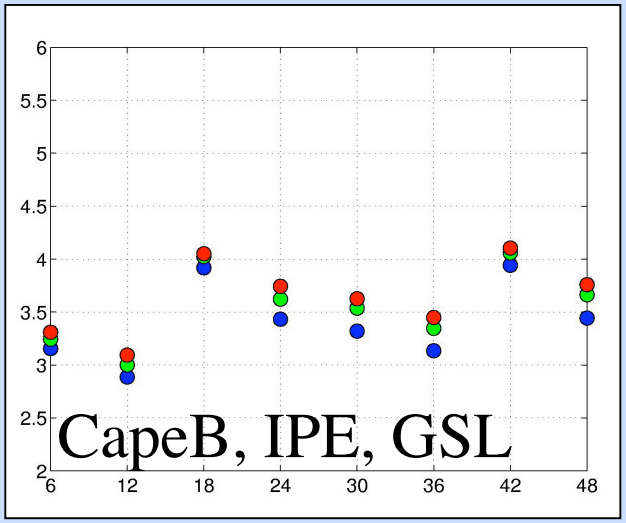
MAE for TD, Winter 2007

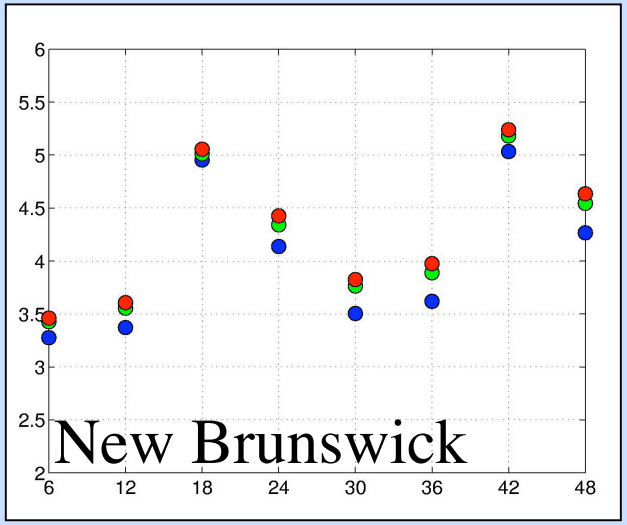




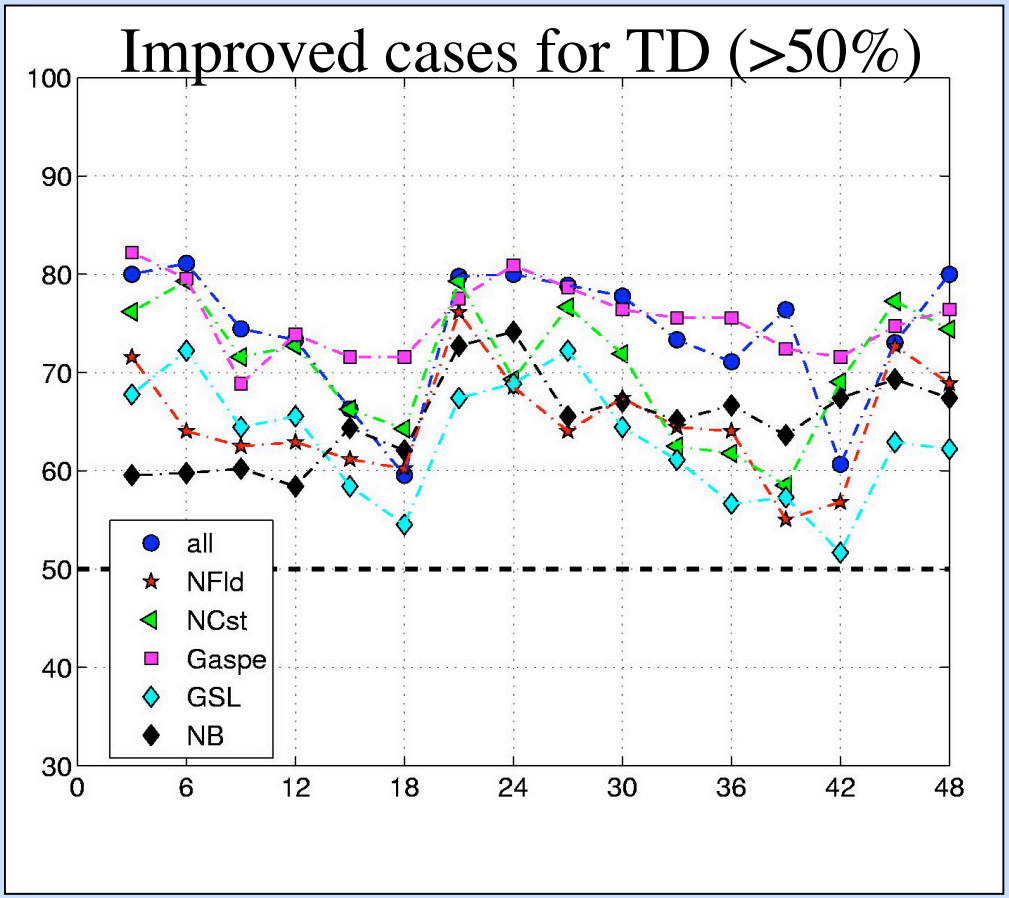








Regionally …



All	74%
New Foundland	65%
North Coast	70%
Gaspe Peninsula	75%
CB, IPE, GSL	63%
New Brunswick	65%

Discussion of results

- Better representation of sea surface conditions in the GSL in winter and summer
  - Initial conditions for SST and sea ice
  - Evolution of sea ice through the coupling
- Improved short term (00-48 hours) forecasts for surface variables
  - Air temperature, dew point temperature, clouds, surface pressure, precipitation, sea ice distribution & thickness
    - Regionally over the GSL and adjacent coastal areas
  - The scores improved through the forecast hour
  - The dew point temperature is more sensitive to the coupling

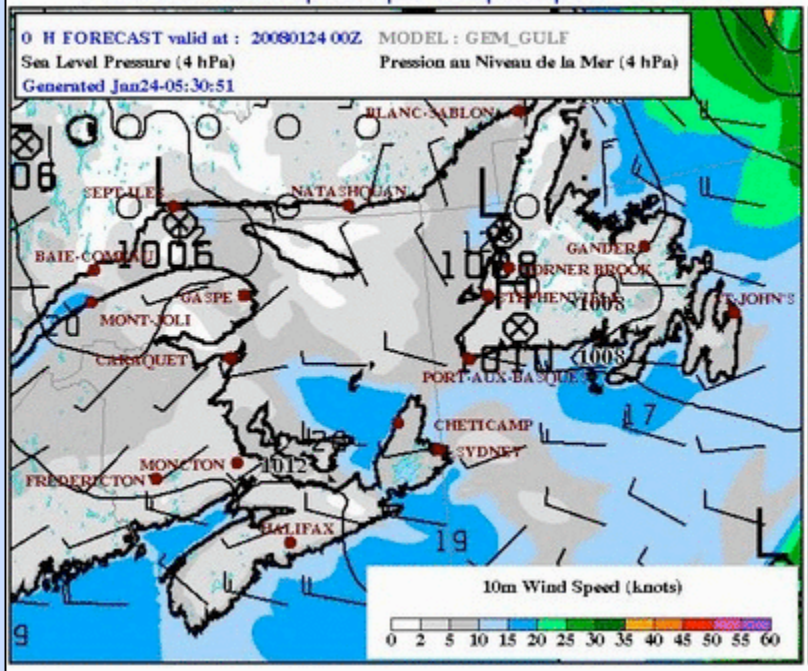
Discussion of results…

- Further work is required to
  - Re-visit the coupling strategy for
    - Efficiency, performance, maintainability
  - Evaluate the effect of coupling for CMC post-processing products (SCRIB…)
  - Improve the sea-ice analysis with 3D-var data assimilation
  - Develop validation tools for the current operational GSL ocean - ice model products
    - Ice fields
      - Total ice cover and thickness
      - Ice fraction for 8 categories
      - Ice Growth, Severity index, ice pressure
    - Ocean fields
      - Ocean currents, temperature, salinity, water levels…
  - Develop the CPOP standard

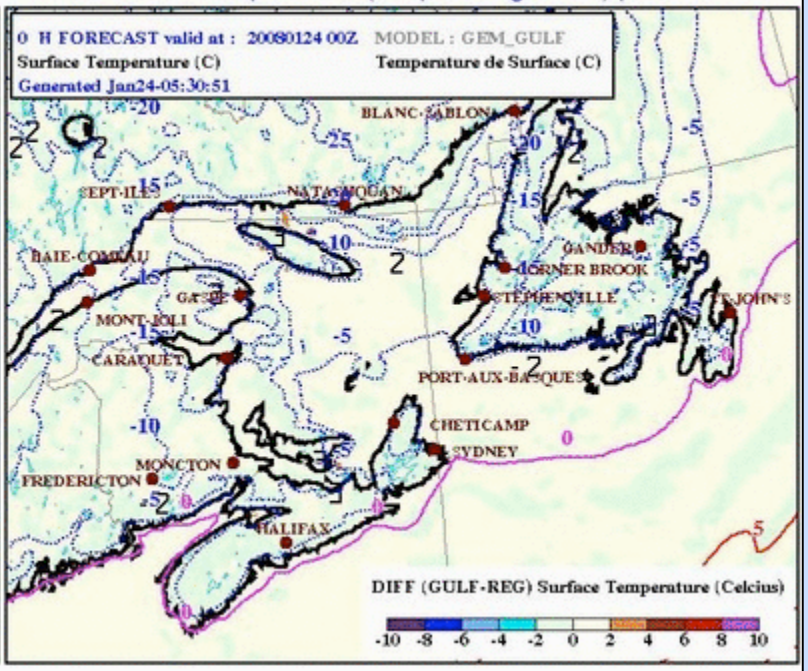
Experimental Run at CMOI

- Coupled forecast run
  - Started December 17, 2007 until April 30, 2008
  - 1 run / day from 00Z data
- Operational evaluation
  - Regional weather offices
    - Halifax, Quebec, Newfoundland regions
      - Web page, evaluation table
        - » http://collaboration.cmc.ec.gc.ca/science/rpn/PROJ/CPL/dokuwiki/doku.php
        - » http://web-mrb/mrb/rpn/PROJ/CPL/dokuwiki/doku.php
  - CMC
    - CMDN (M. Faucher and F. Roy)
    - A & P (Richard Moffet)
  - IML and CIS

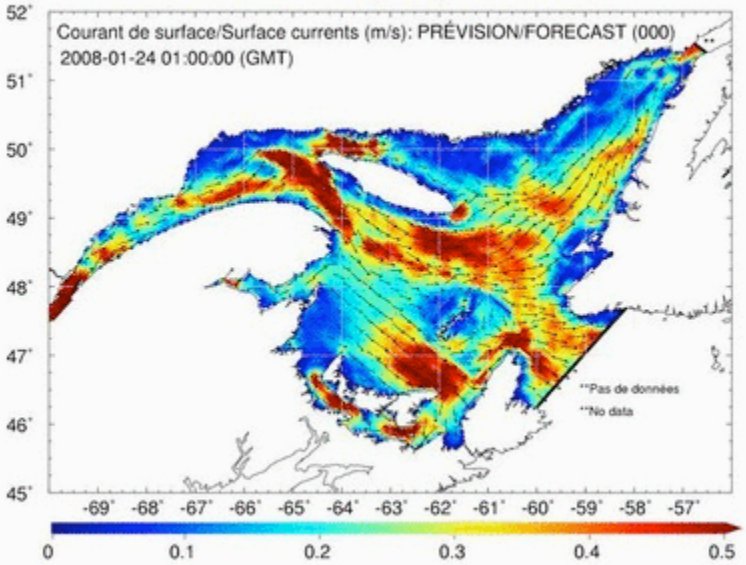
Prévision atmosphérique couplée pour 00-48 h



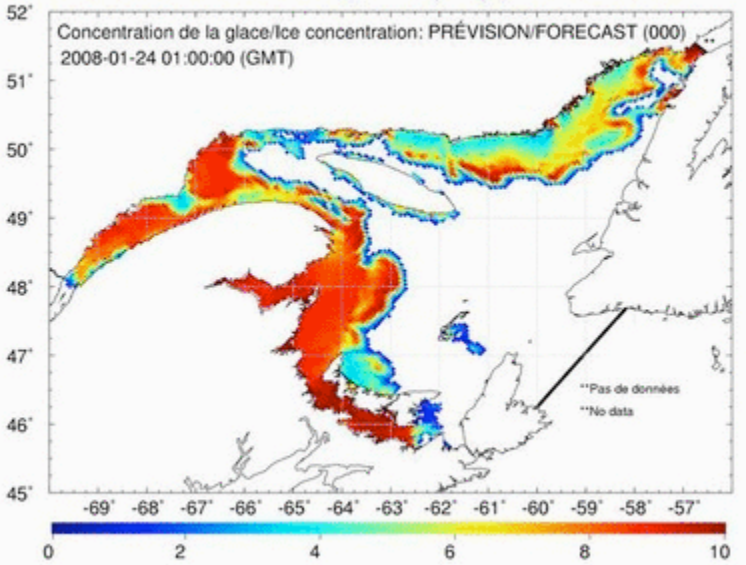
Différence de température (couplée-régionale) pour 00-48 h

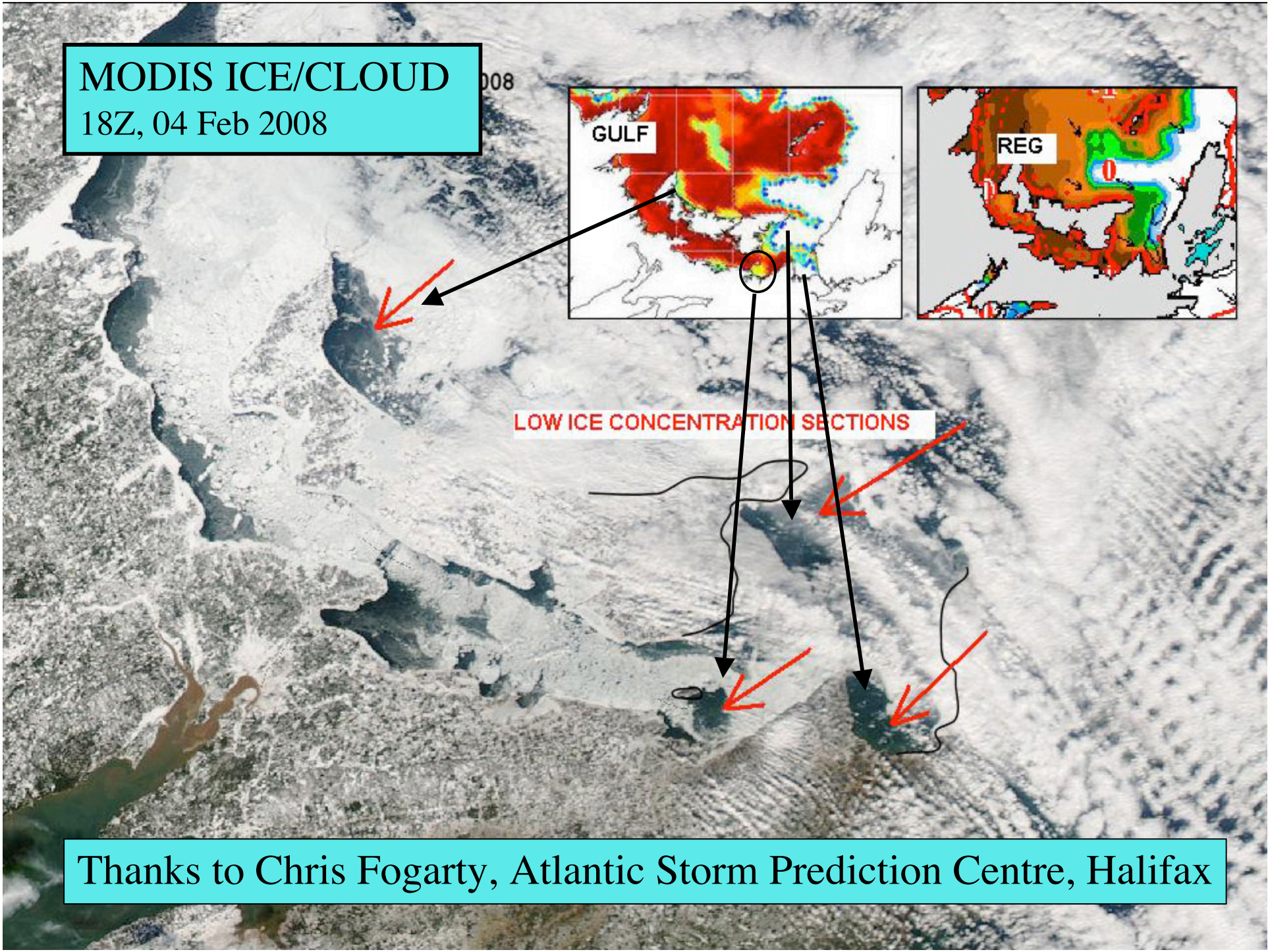


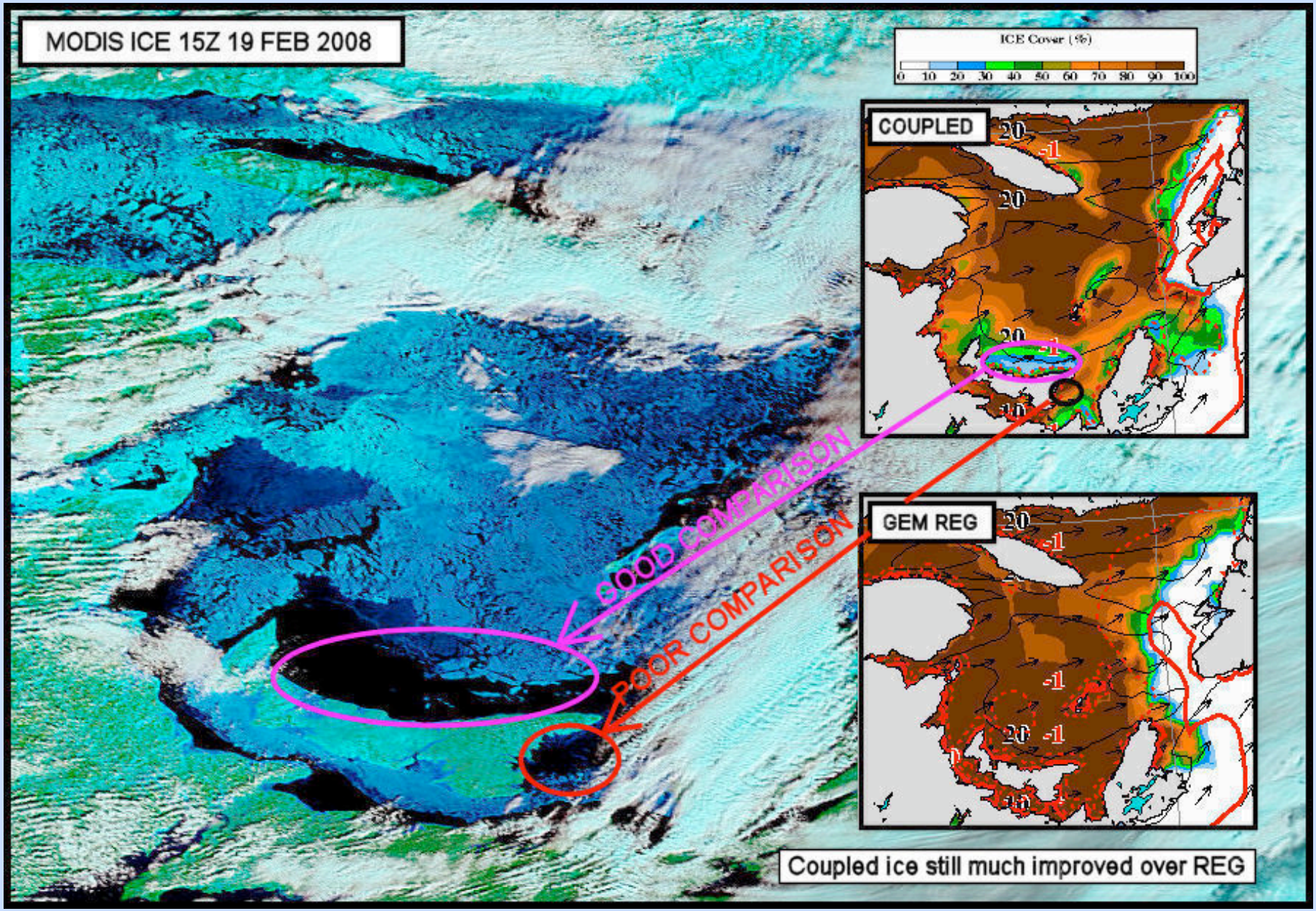
Courants océaniques pour 00-48 h



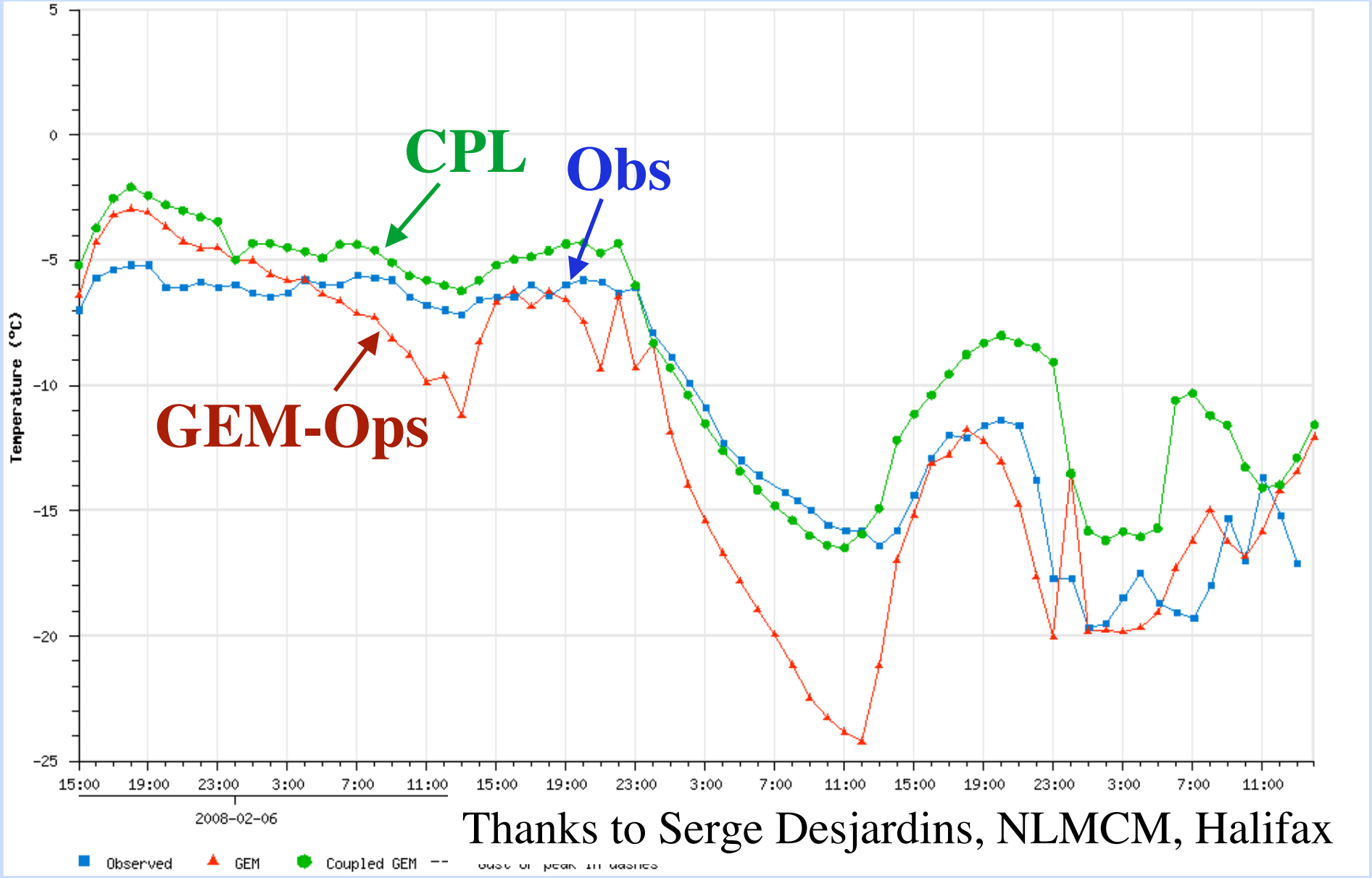
Concentration de la glace (/10) pour 00-48 h




MODIS ICE/CLOUD
18Z, 04 Feb 2008
GULF
REG
LOW ICE CONCENTRATION SECTIONS
Thanks to Chris Fogarty, Atlantic Storm Prediction Centre, Halifax

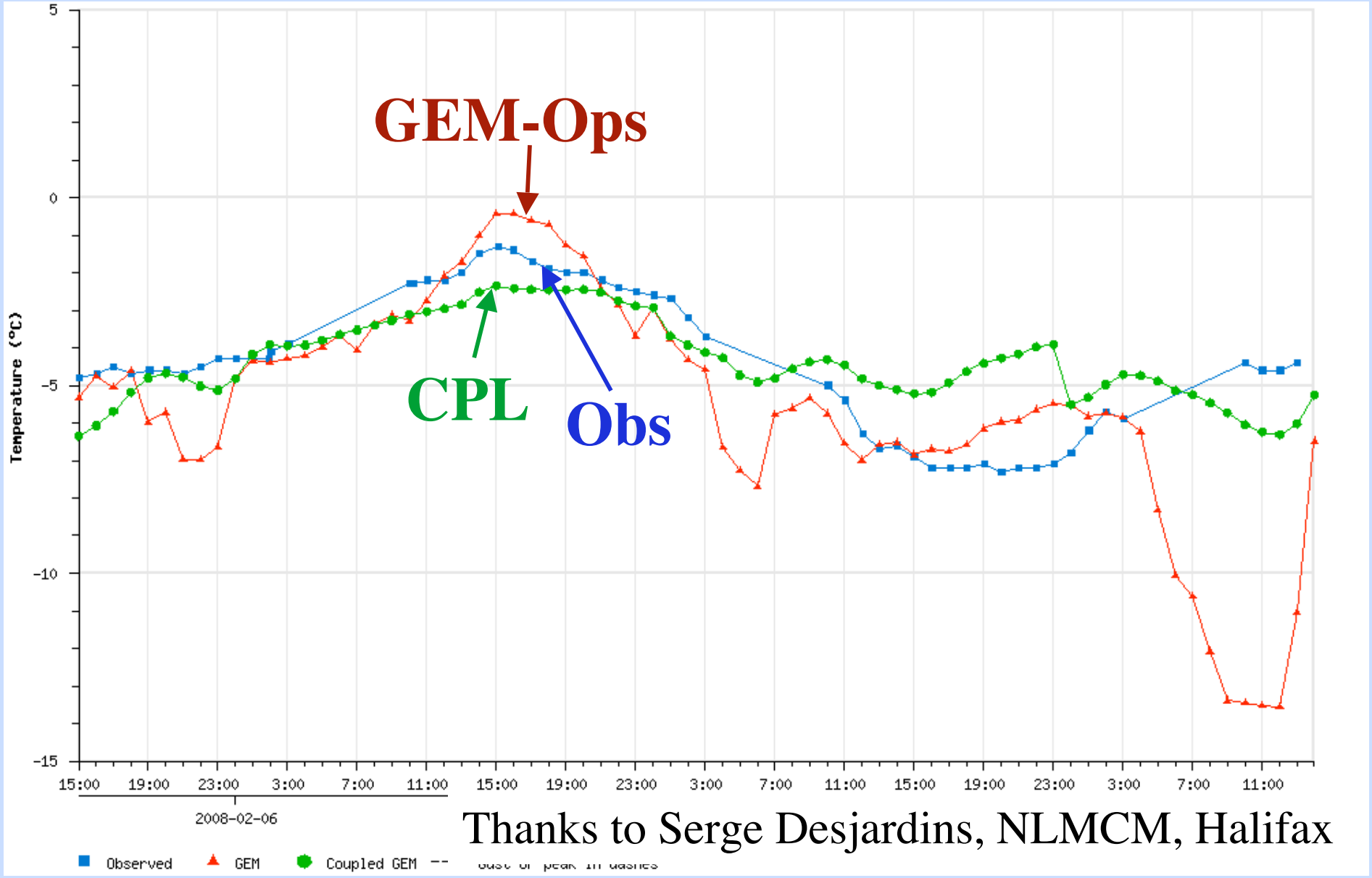

MODIS ICE 15Z 19 FEB 2008
ICE Cover (%)
0 10 20 30 40 50 60 70 80 90 100
COUPLED
GEM REG
GOOD COMPARISON
POOR COMPARISON
Coupled ice still much improved over REG

Mont-Joli, 06 Feb. 2008



Thanks to Serge Desjardins, NLMCM, Halifax

Iles de la Madeleine, 06 Feb. 2008



Thanks to Serge Desjardins, NLMCM, Halifax

Future perspectives of coupling

- Coupling with other models :
  - Hudson Bay ocean model, hydrology, sea ice, global ocean (OPA), surface;
- Assimilation 3D-var ocean-ice;
  - Mark Buehner, Alain Caya
- Improvement of seasonal forecasts, climate predictions
- Collaboration with other research groups;
  - Oceanographers, hydrologists, data assimilation…


Merci!