Small-scale ice-ocean-wave processes and their impact on coupled environmental polar prediction

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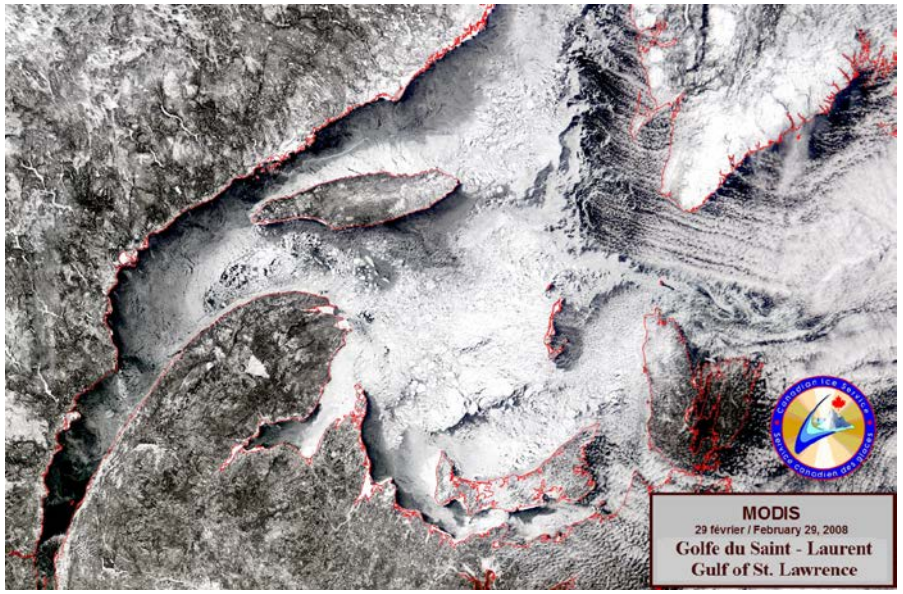
CONCEPTS
CANADIAN OPERATIONAL NETWORK OF COUPLED ENVIRONMENTAL PREDICTION SYSTEMS



ECMWF-WWRP/THORPEX Polar Prediction Workshop
24-27 June 2013, ECMWF Reading, UK

Environment Canada
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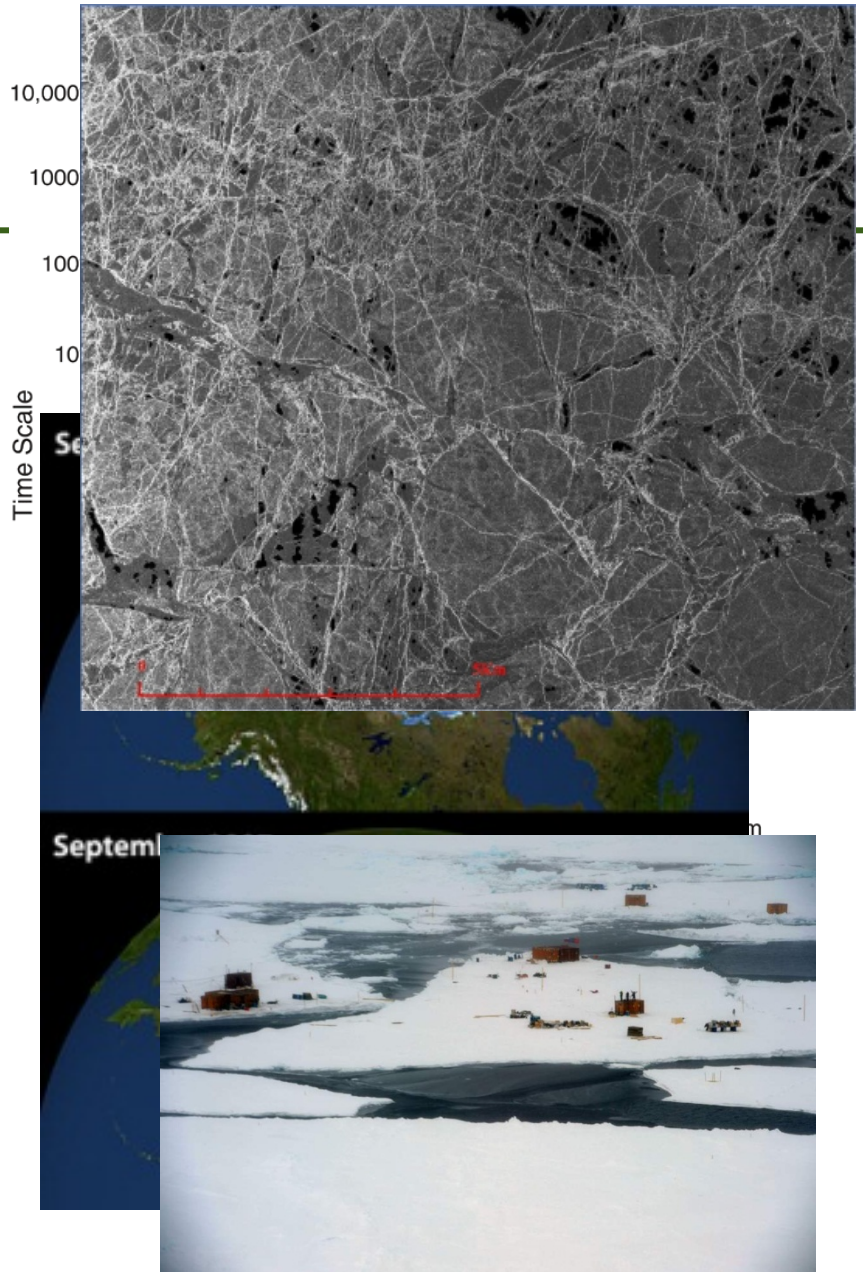
Mercator Ocean Ocean Forecasters
Canada

Background

- Classic view:
  - Ocean timescales are slow compared to the atmosphere
  - Sea ice is an integrator of atmosphere-ocean interactions
- Sea ice cover varies on small time and spatial scales
- Important in of themselves
- Strong impact on atmosphere-ocean interactions on very short (hourly) timescales



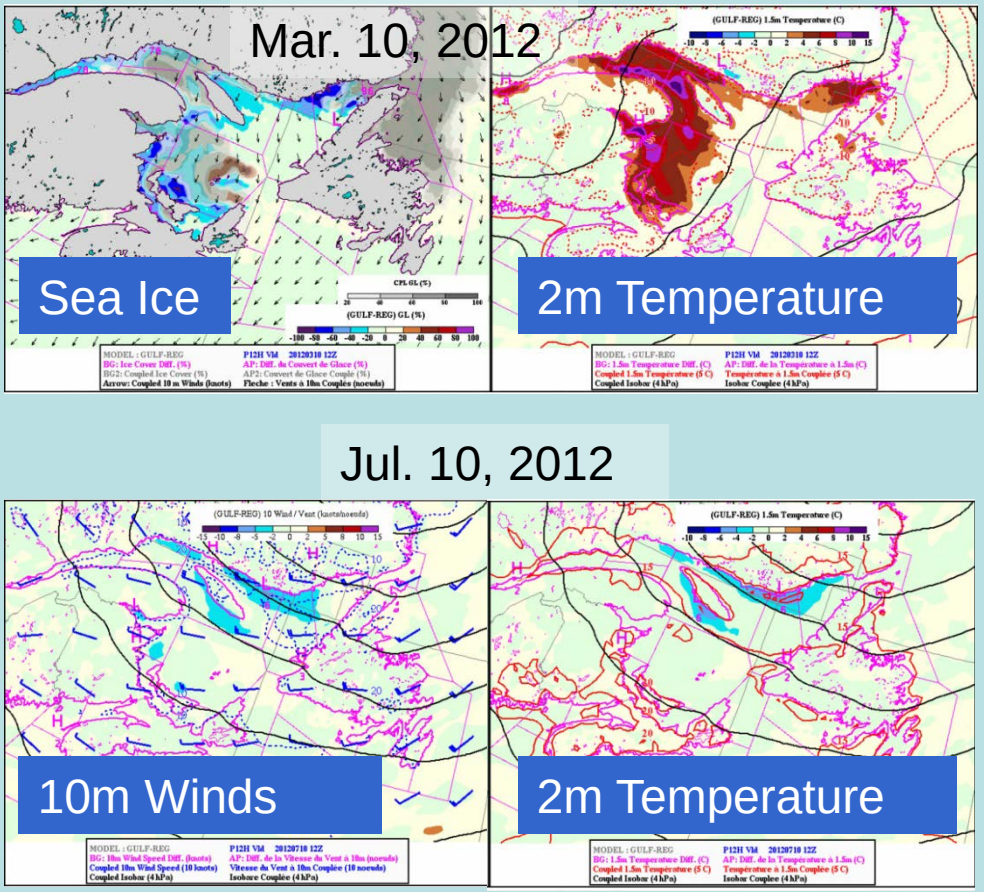
Overview

- Impact of sea ice on short-range coupled predictions
  - Examples from CMC Coupled Gulf of St. Lawrence System
- Role of leads
  - How well do ice models simulate leads?
  - Sensitivity to ice model parameters
- Small-scale ocean variability
- Sea-ice / wave coupling

Gulf of St. Lawrence Coupled Atm-Ice-Ocean Forecasting System

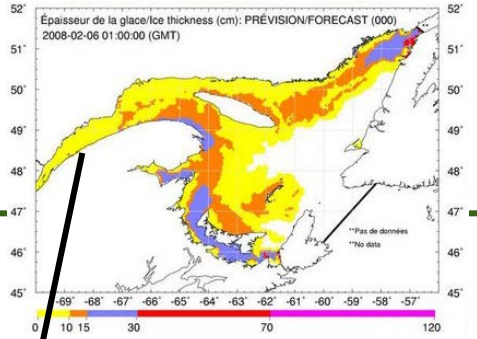
- Operational since June 2011
  - 48 forecast daily at 00Z
- Coupled system:
  - Atm: GEM (10km)
  - Ice: CICE (5km)
  - Ocean: MoGSL (5km)

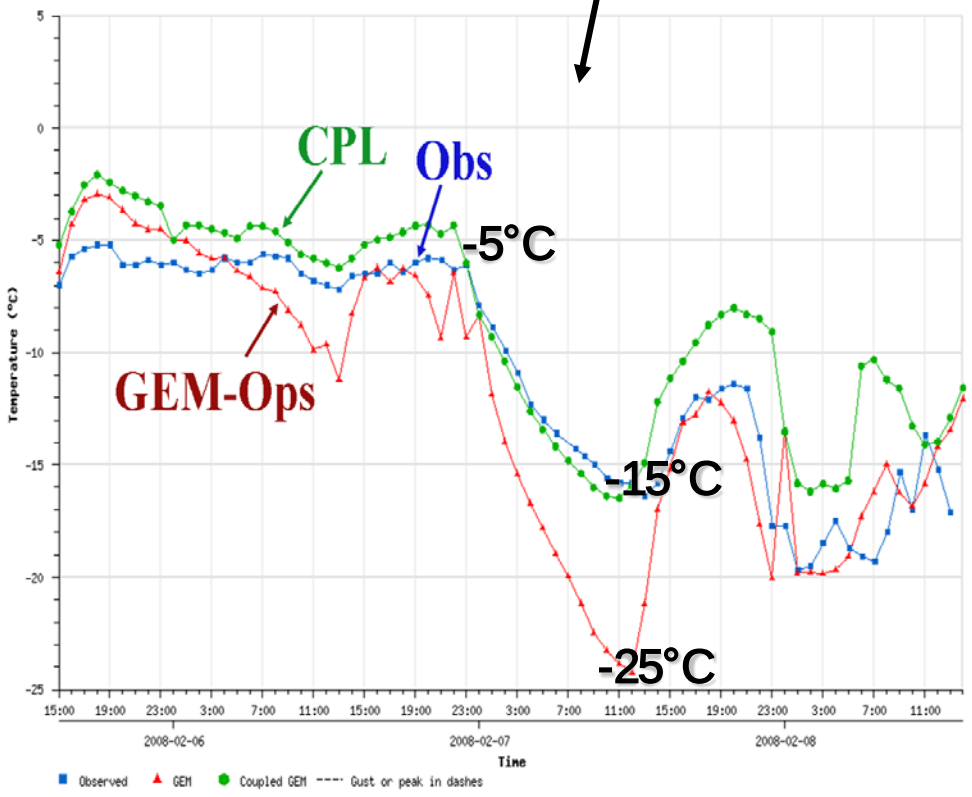
Coupled – Uncoupled differences



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

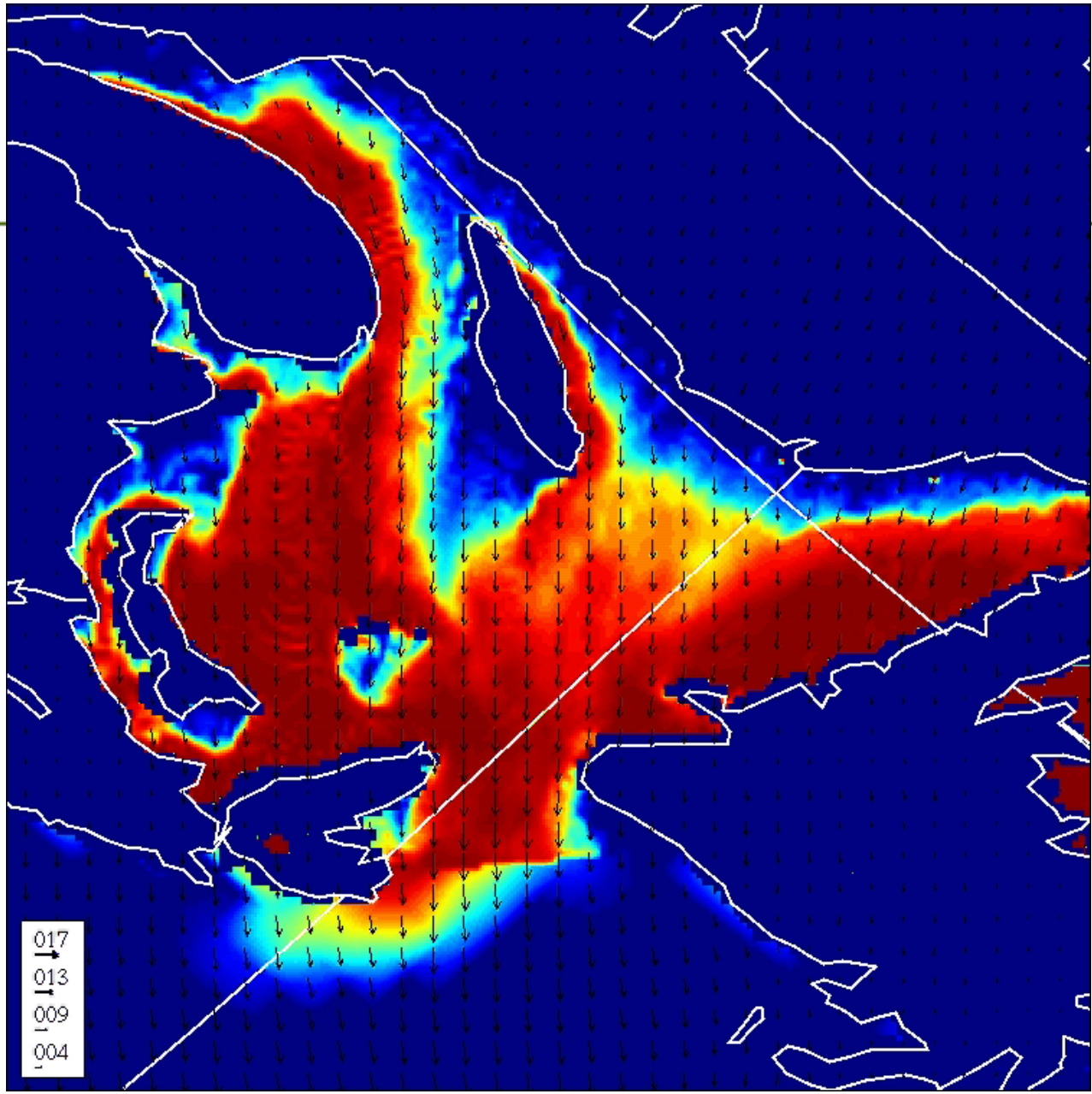




Atmosphere-Ice-Ocean Interactions: An interesting Case

Ice fraction
48h forecast
2 way coupled

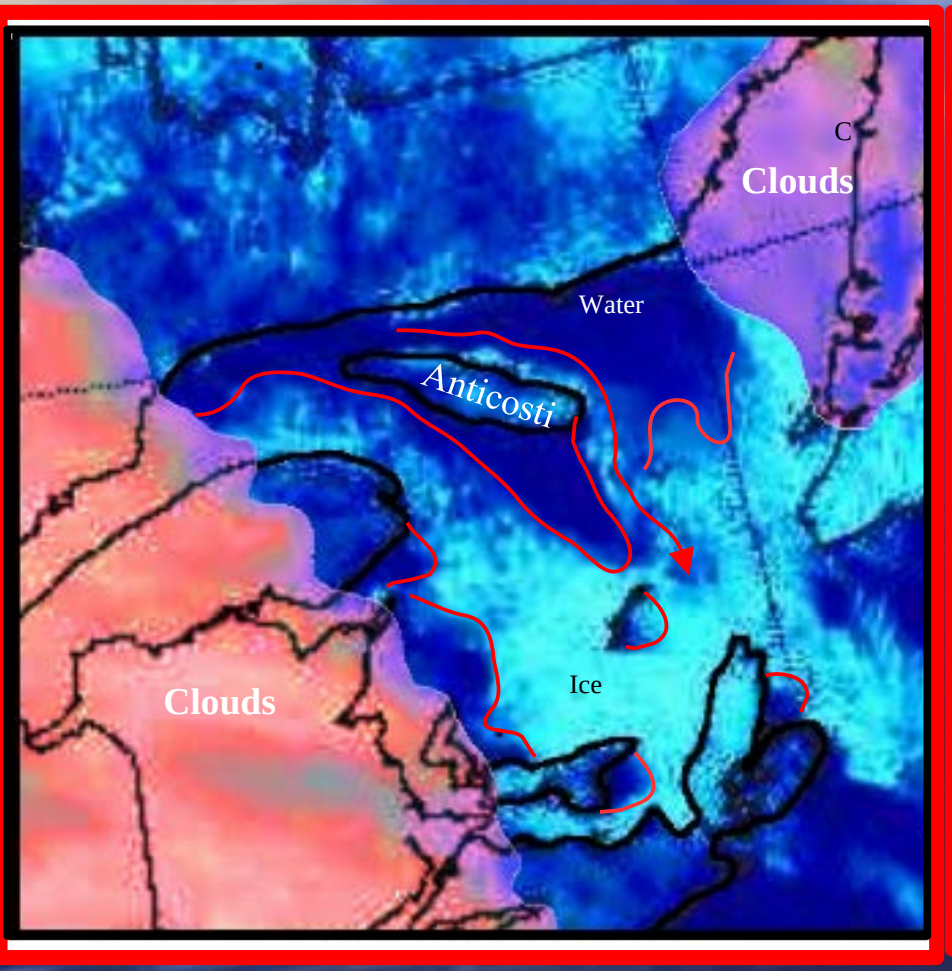
Case: Particularly interesting given that the intense atmospheric circulation that dramatically changed the ice conditions in only 48 hours was preceded by a cold and relatively quiet period.



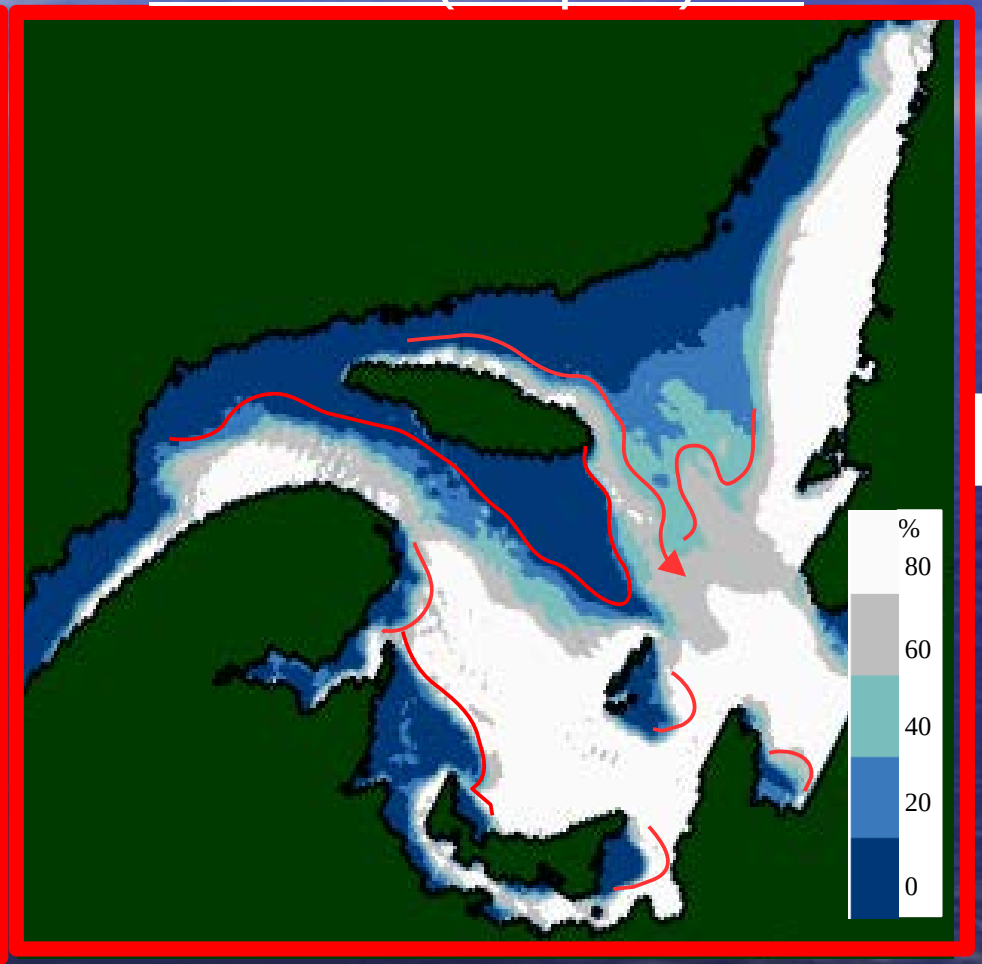
Atmosphere-Ice-Ocean Interactions:
An interesting Case

Ice Forecast

Ice Observation



Forecast (coupled) Ice

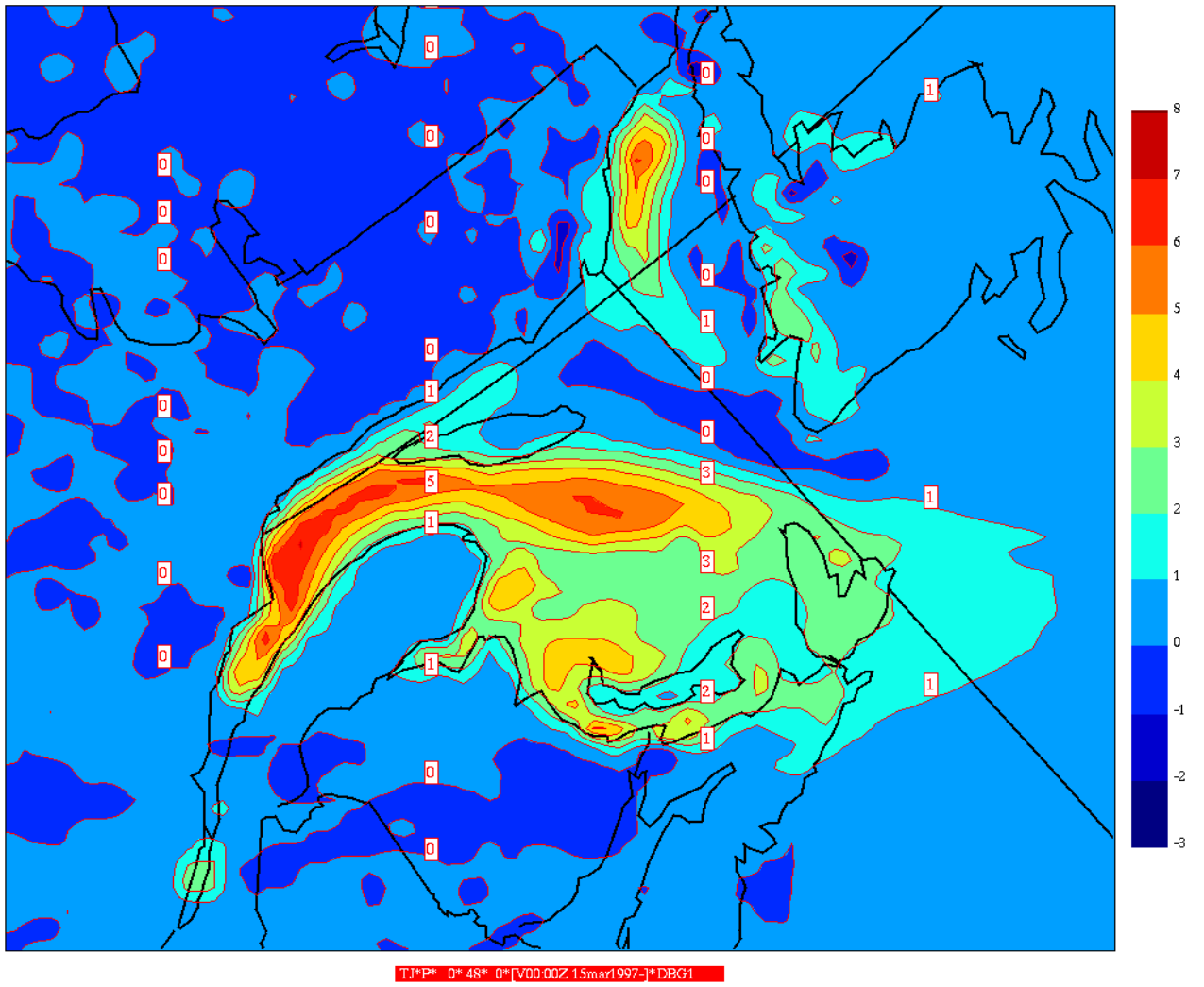


d)

Valid: 14/03/97 20 Z after 44 hours

Impact on surface air temperature

Difference Air temp.
Coupled - Uncoupled

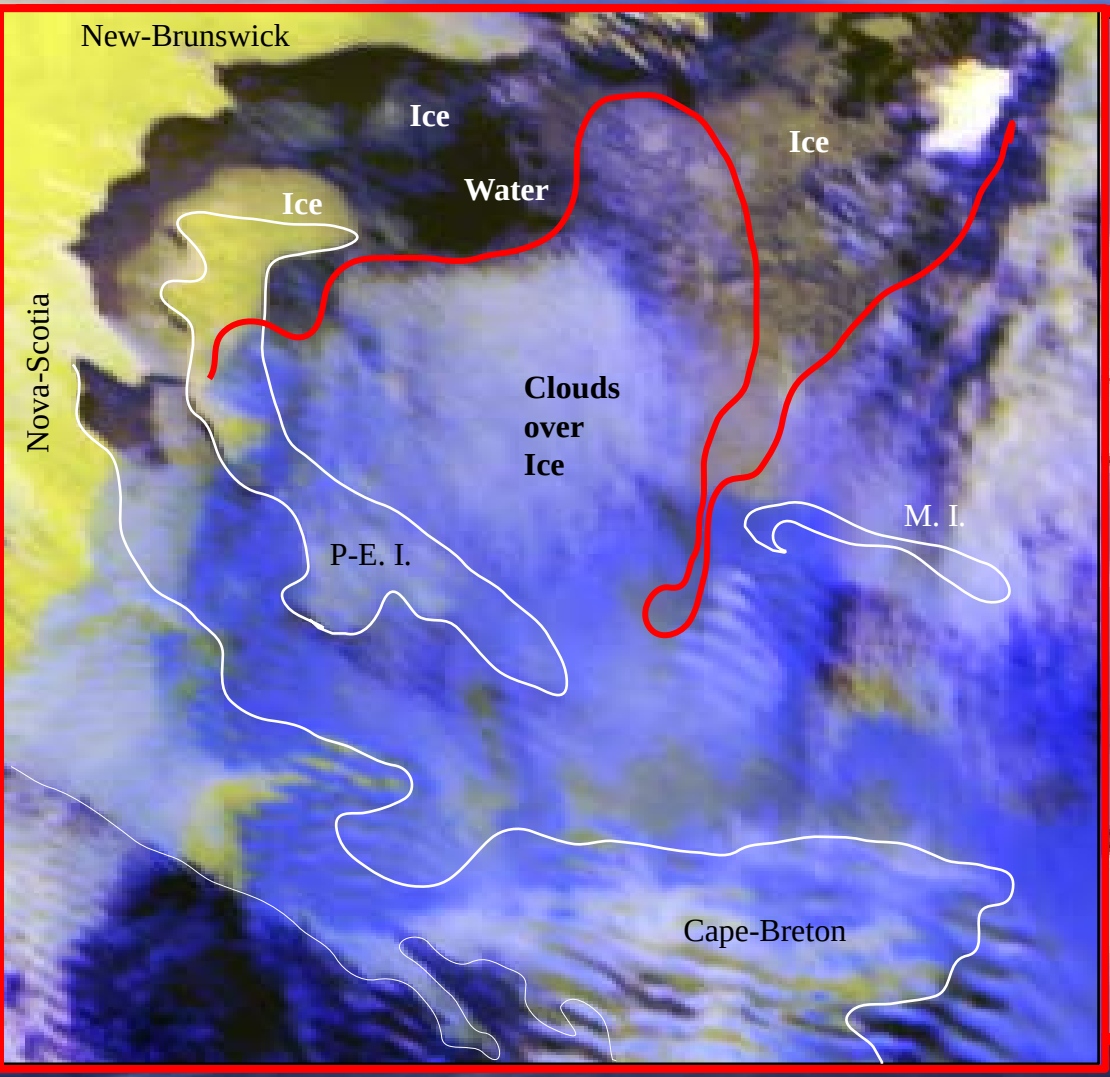


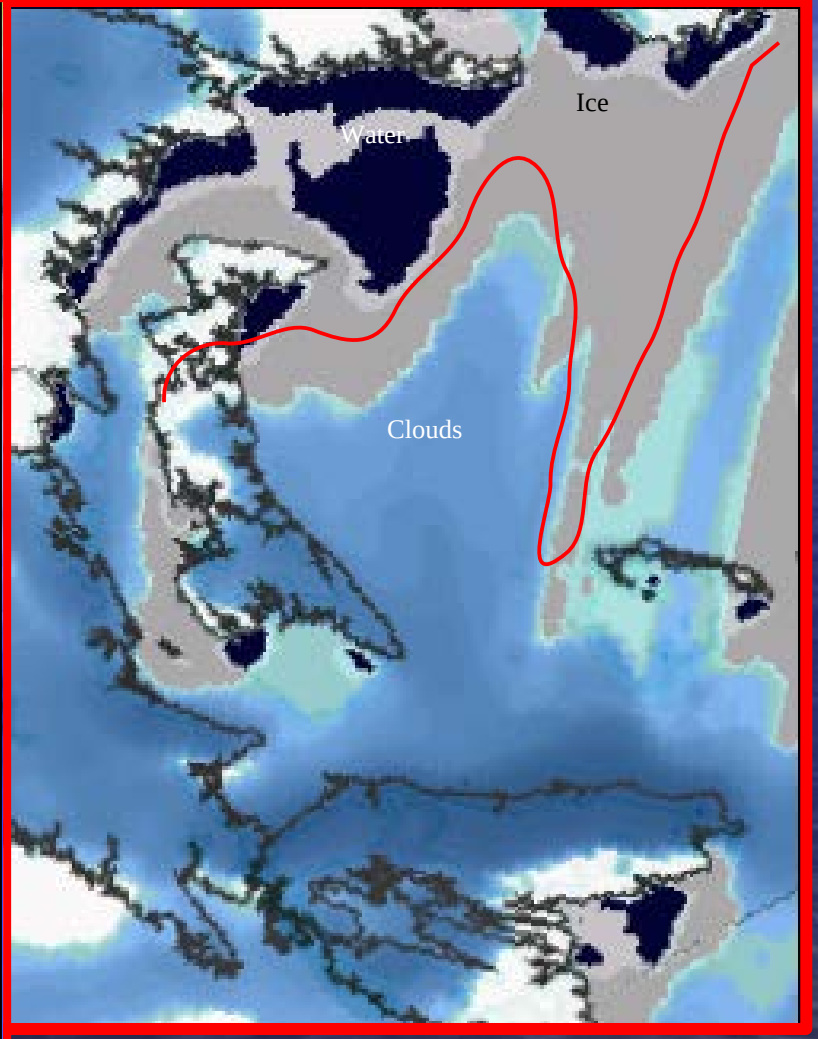
Atmosphere-Ocean-Ice interactions:
An interesting Case

Impacts on low level clouds (air-ocean exchanges)

a) Satellite image (AVHRR)

b) Fully coupled





Gulf of St. Lawrence Coupled Atm-Ice-Ocean Forecasting System

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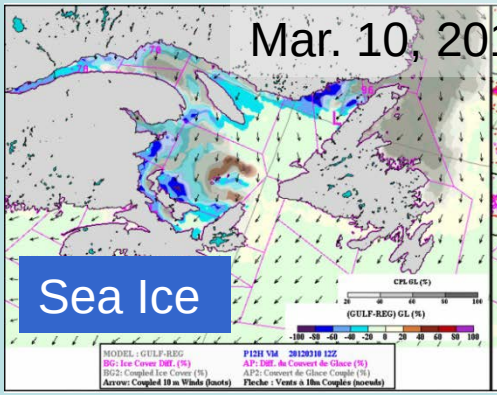
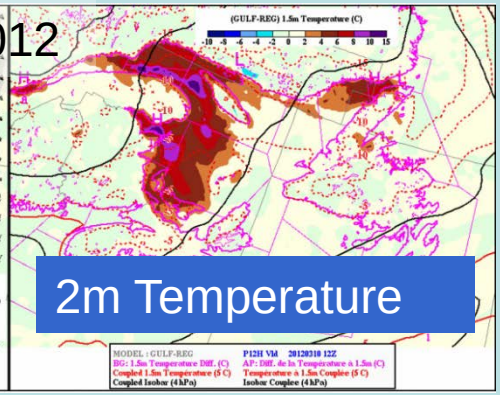
- Coupled system:
  - Atm: GEM (10km)
  - Ice: CICE (5km)
  - Ocean: MoGSL (5km)
- New system (in development):
  - GEM (2.5km)
  - NEMO-CICE-WW3 (1km)
  - Including Great Lakes
- Expansion into the Arctic
  - GEM (10km)
  - NEMO-CICE-WW3 (2-8km)

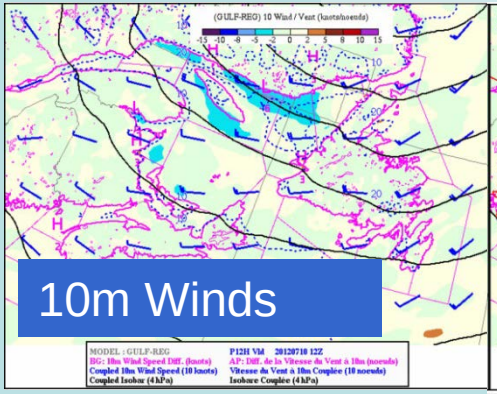
Coupled – Uncoupled differences

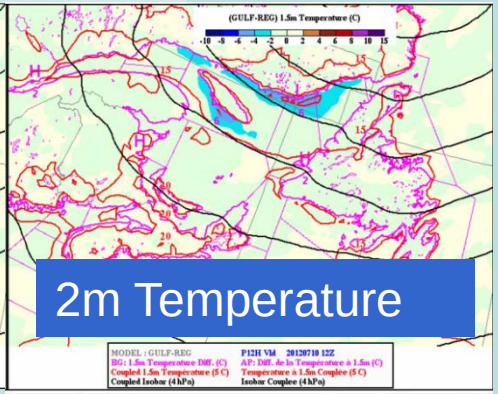
Mar. 10, 2012





Jul. 10, 2012

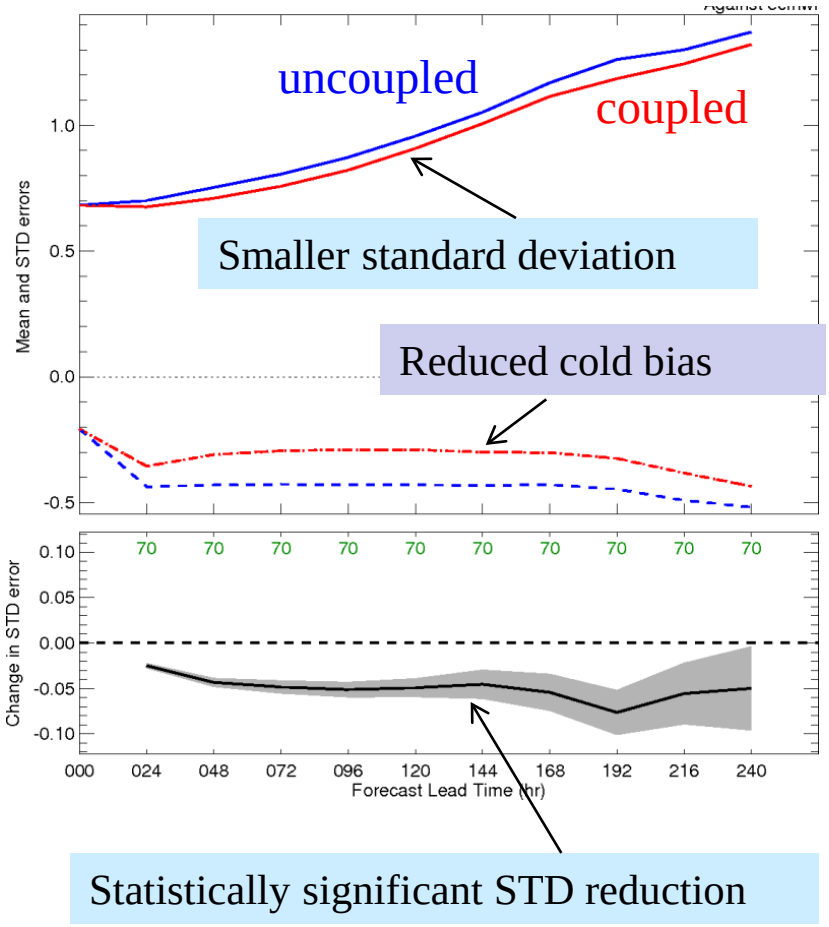




Coupled Global Deterministic Prediction System

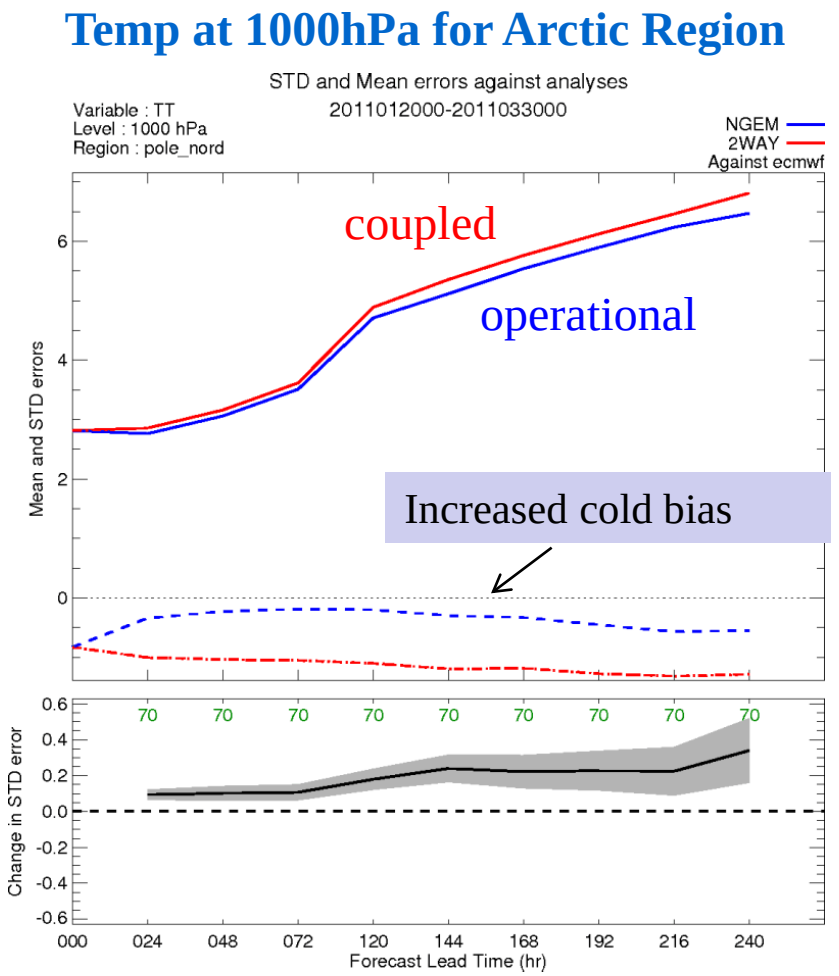
- Coupled model:
  - Atm: GEM 33km
  - Ocean: NEMO-ORCA025 (1/4°)
  - Ice: LIM2-EVP
- Evaluation of winter trials underway
  - Daily 16day forecasts
  - 2011-01-20 to 2011-03-30
  - Example of verification against ECMWF for temp at 925hPa over tropical Indian Ocean.

Temp at 925hPa for Trop. Indian



The role of Arctic leads

- The ice analysis underrepresents leads
  - Only assim CIS charts and SSMI
- GDPS uses static 3% lead fraction
  - I.e. ice conc*0.97
- Coupled model has on average ~1% leads



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The role of Arctic leads

- The ice analysis underrepresents leads
  - Only assim CIS charts and SSMI
- GDPS uses static 3% lead fraction
  - I.e. ice conc*0.97
- Coupled model has on average ~1% leads
- Experiment:
  - Remove 3% lead fraction

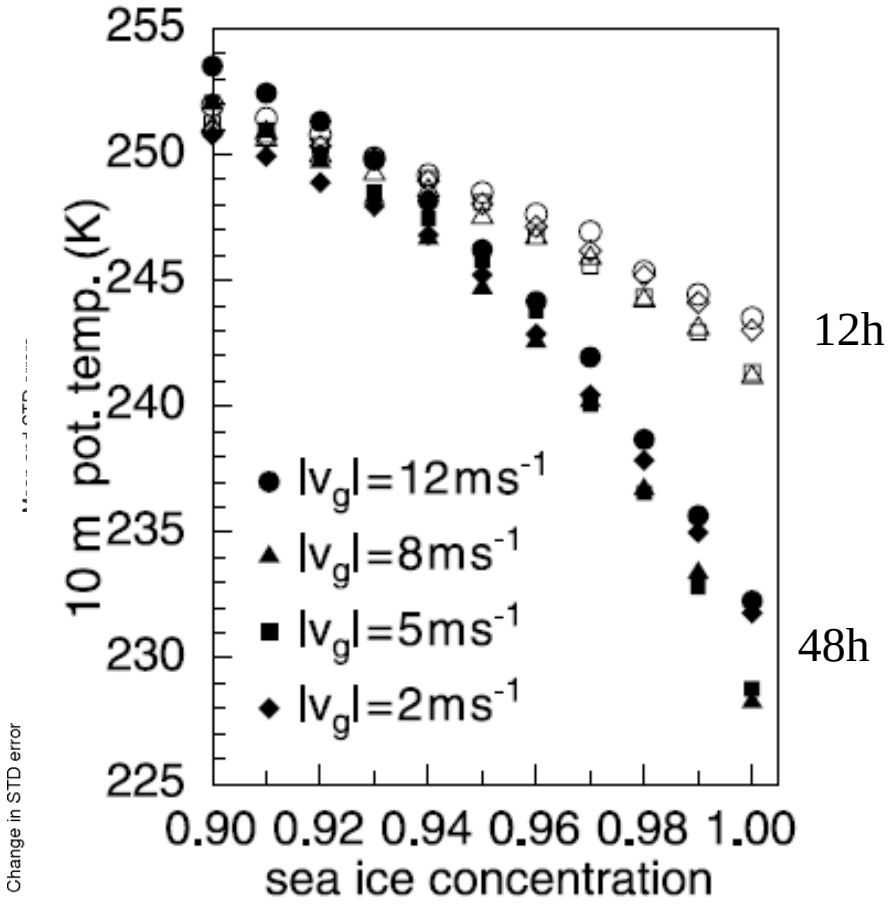


Figure 4. Model results after 12 hours (open symbols) and after two days (solid symbols) simulation time.

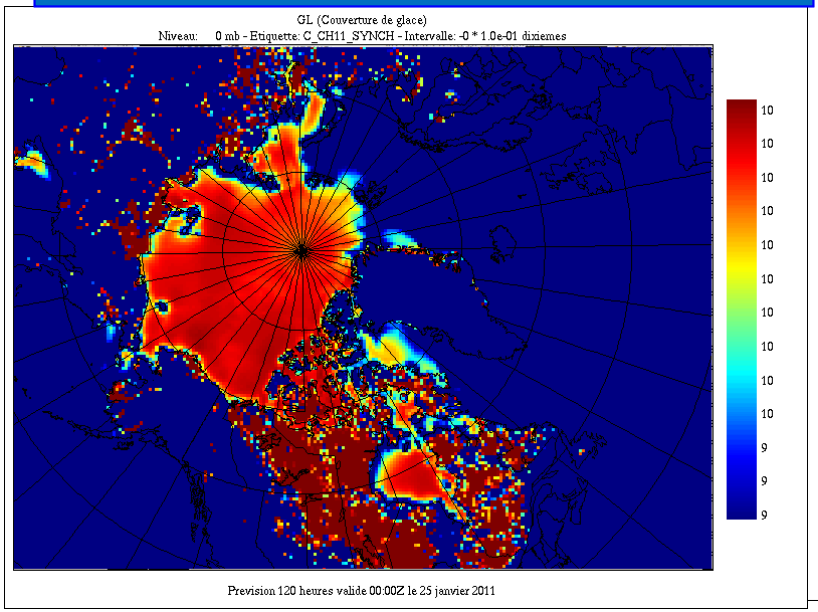
Lupkes et al. (GRL, 2008)

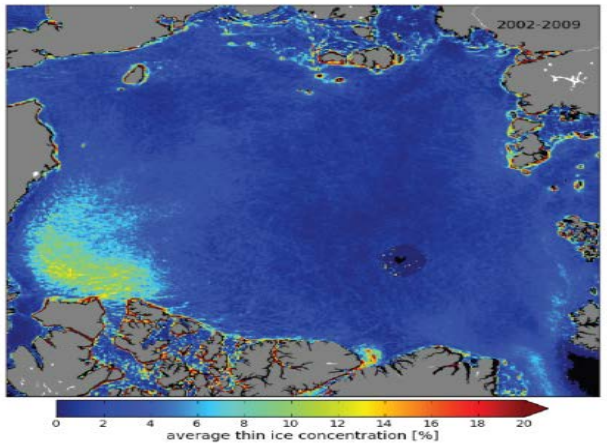
How well do ice models simulate leads?

- Lead fraction can exceed 6% for strong storm events in winter
- Model mean <1% over Jan-Mar
- Estimate from AMSR-E
  - Rohrs and Kaleschke (2010)
- Is model lead fraction too low?
- How does this depend on ice rheology, convergence, thickness, etc..?

- Various issues have already been identified:
  - Underestimate deformations
    - Kwok et al. (2008)
  - Shear lines are too broad
    - Wang and Wang (2009)
  - Deformations statistics incorrect
    - Girard et al. (2009)
  - Landfast ice and ice arching poorly represented
    - Dumont et al. (2009)
- New rheologies being developed…

Mean lead fraction over Jan-Mar





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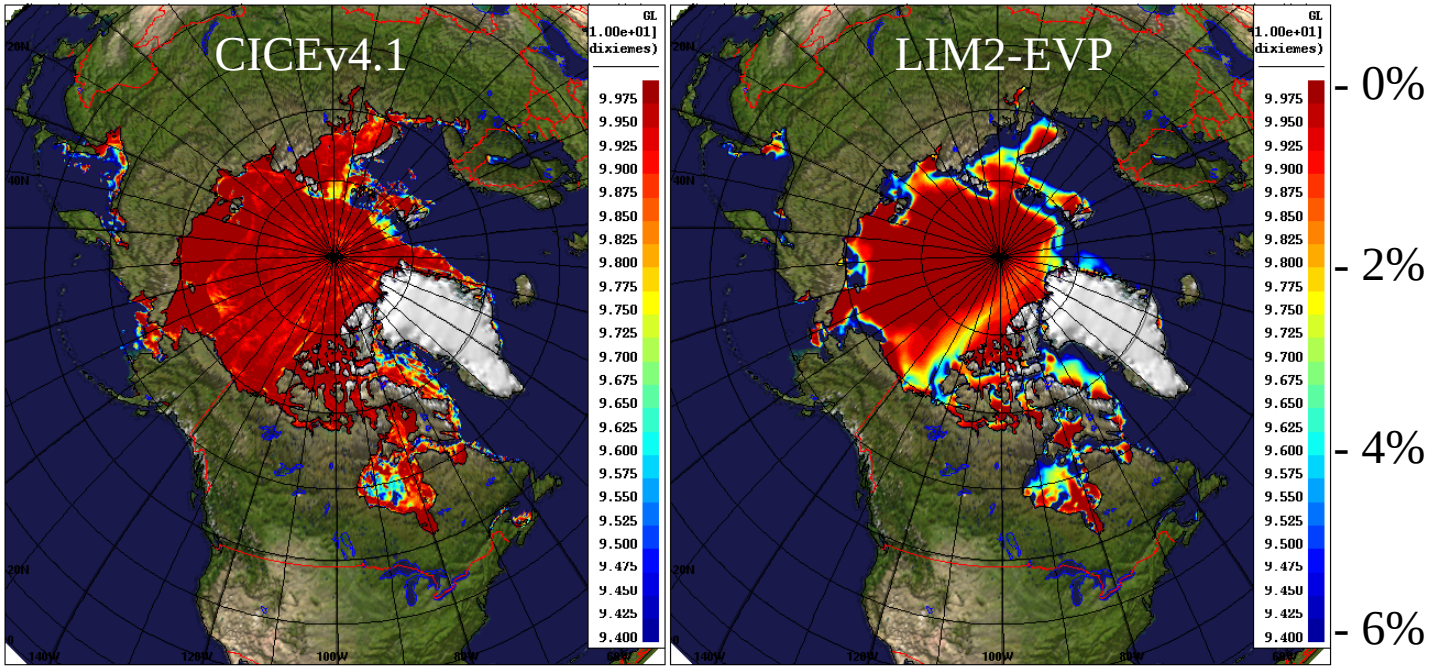
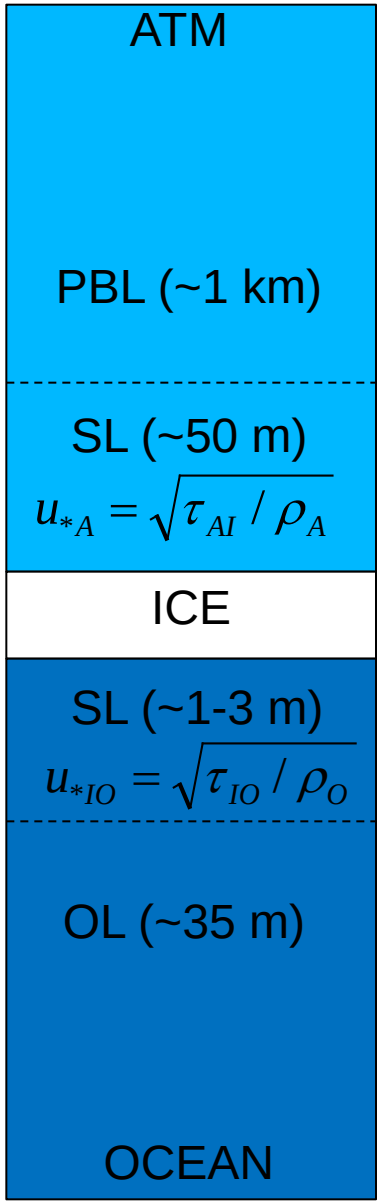
Sensitivity of lead fraction to ice model

Lead fraction from hindcasts of CICE and LIM differ considerably

- Snapshot after 3yrs using same forcing and elastic timescale
- Difference due to multi-category scheme, numerics, specific parameterizations





$$\tau_{AI} = \rho C_{DAI} U_A^2$$

$$U_A(z) = \frac{u_{*A}}{\kappa}[\ln(z / z_{0is}) - \psi_M(\zeta)]$$

$$C_{DAI}(z) = [\frac{\kappa}{\ln(z / z_{0is}) - \psi_M(\zeta)}]^2$$

Monin-Obukhov similarity

$$-\tau_{AI} = \nabla \cdot \sigma + \tau_{IO} + \textit{smaller terms}$$

$$F_{KE_A} \approx F_{KE_I} + F_{KE_W}$$

$$\tau_{IO} = \rho_O C_{DIO} U_O^2$$

$$U_O(z) = \frac{u_{*IO}}{\kappa}[\ln(z / z_{0ib})]$$

$$C_{DIO}(z) = [\frac{\kappa}{\ln(z / z_{0ib})}]^2$$

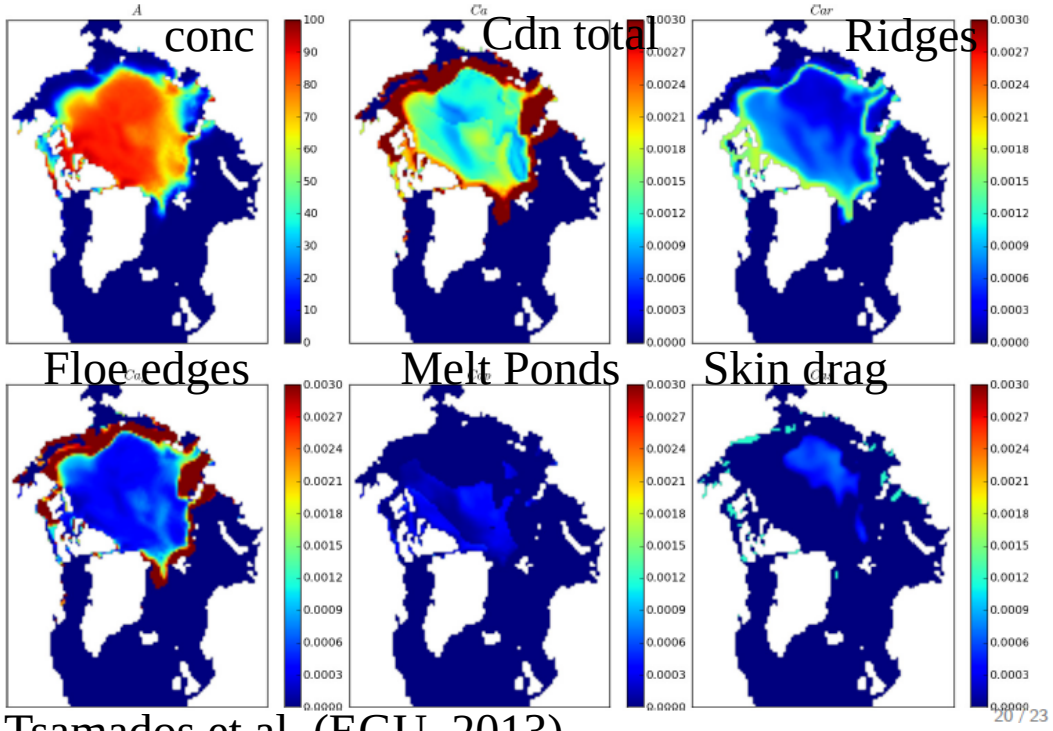
Monin-Obukhov similarity

McPhee *et al. (many papers)* Rossby similarity

$$U(\zeta) - U(\zeta_{sl}) = \frac{\eta_*}{k}\left[\ln\left(\frac{\zeta_{sl}}{\zeta_0}\right) + \delta(\zeta_{sl} - \zeta)\right] \quad \text{for } \zeta \geq \zeta_0$$

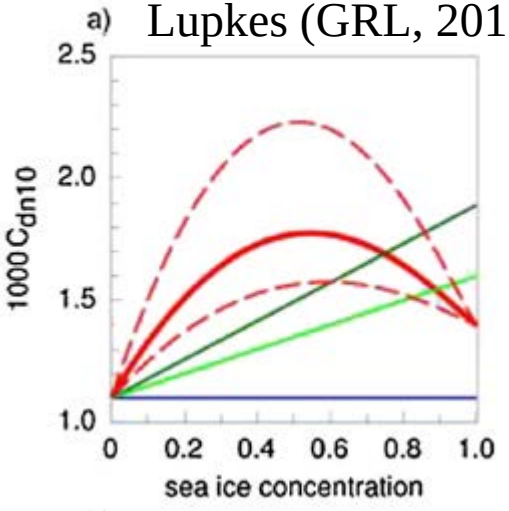
Atmosphere-ice-

- Stress at atm-ice and surfaces will vary depe local features:
  - Ridges and keels
  - Melt ponds
  - Floe edges
- Form drag parameterizations under development:
  - Lupkes et al. (GRL, 2013)
  - Tsamados et al. (EGU, 2013)



Tsamados et al. (EGU, 2013)

Lupkes (GRL, 2013)



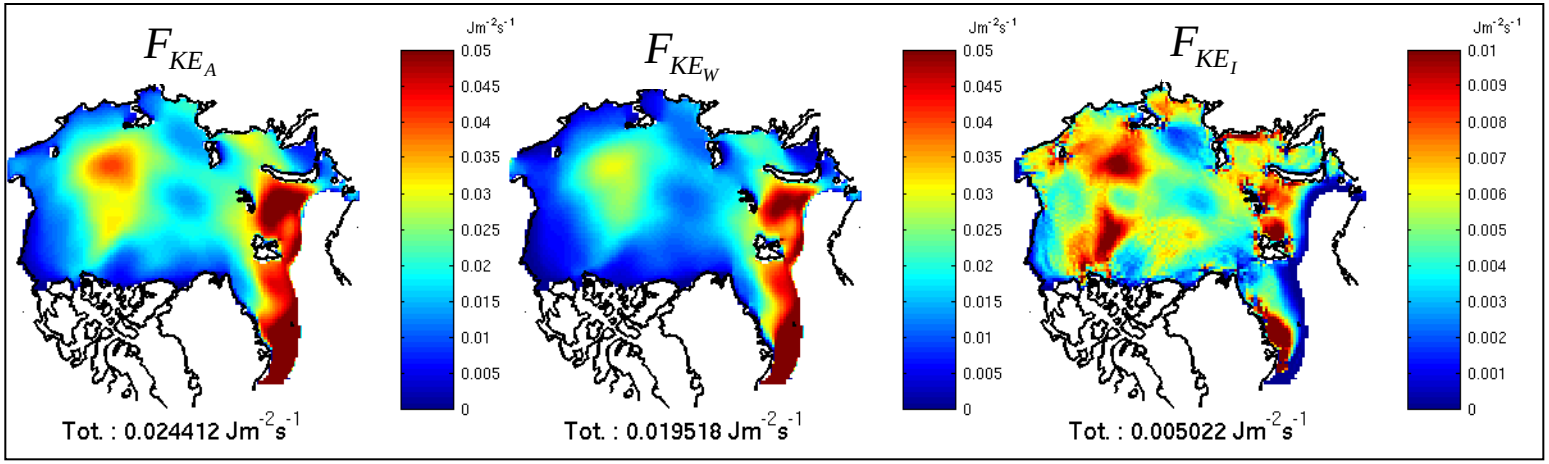
$$F_{KE_A} \approx F_{KE_I} + F_{KE_W}$$

20% + 80% (Arctic – March 1991)

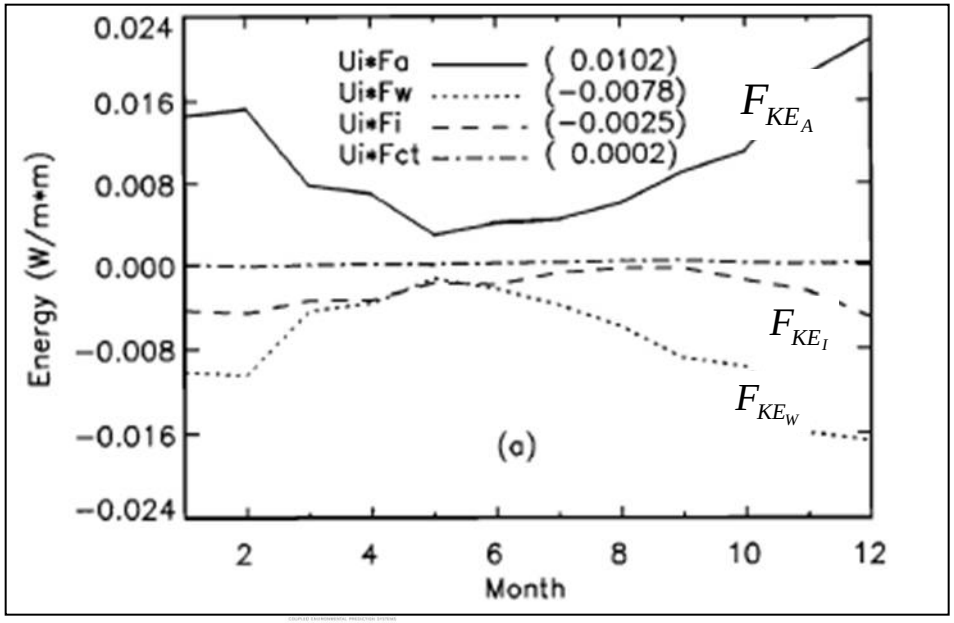
2% + 98% (Arctic – September 1991)

Bouchat and Tremblay (McGill Univ., pers comm.)

March 1991



Similar to Steele et al 1997



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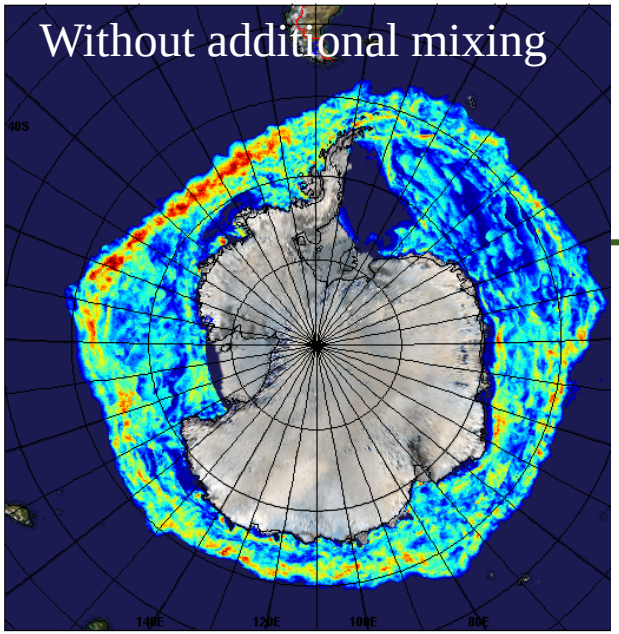
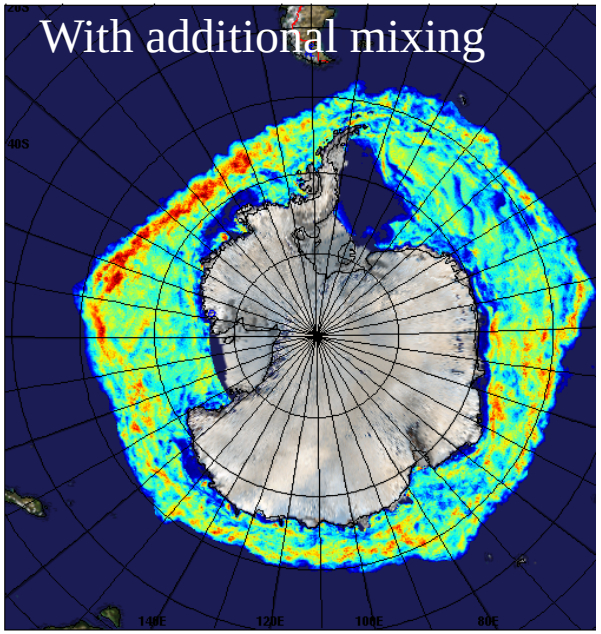
Small-scale ocean variability

- 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

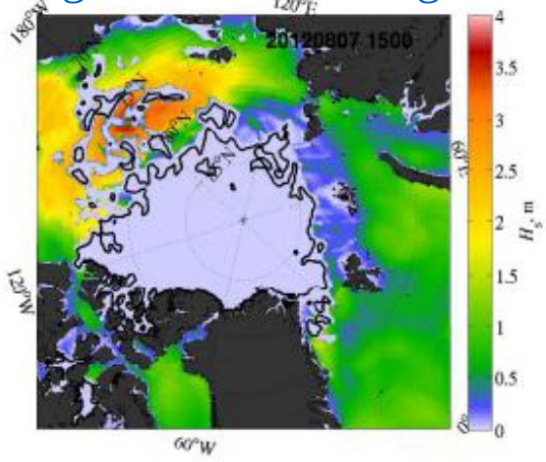




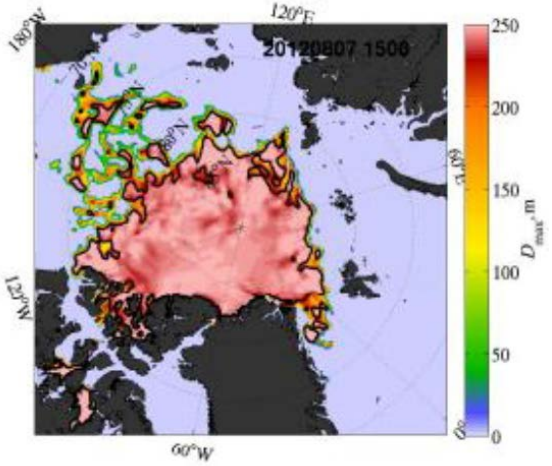
Sea ice – wave interactions

- Strong sea ice – wave coupling in MIZ
- Waves can penetrate ~100km
- Especially important for thin ice regime
- Results from 2D WIM for August 2012 storm (Dumont et al.)

Significant wave height



Maximum floe size



Summary and Challenges

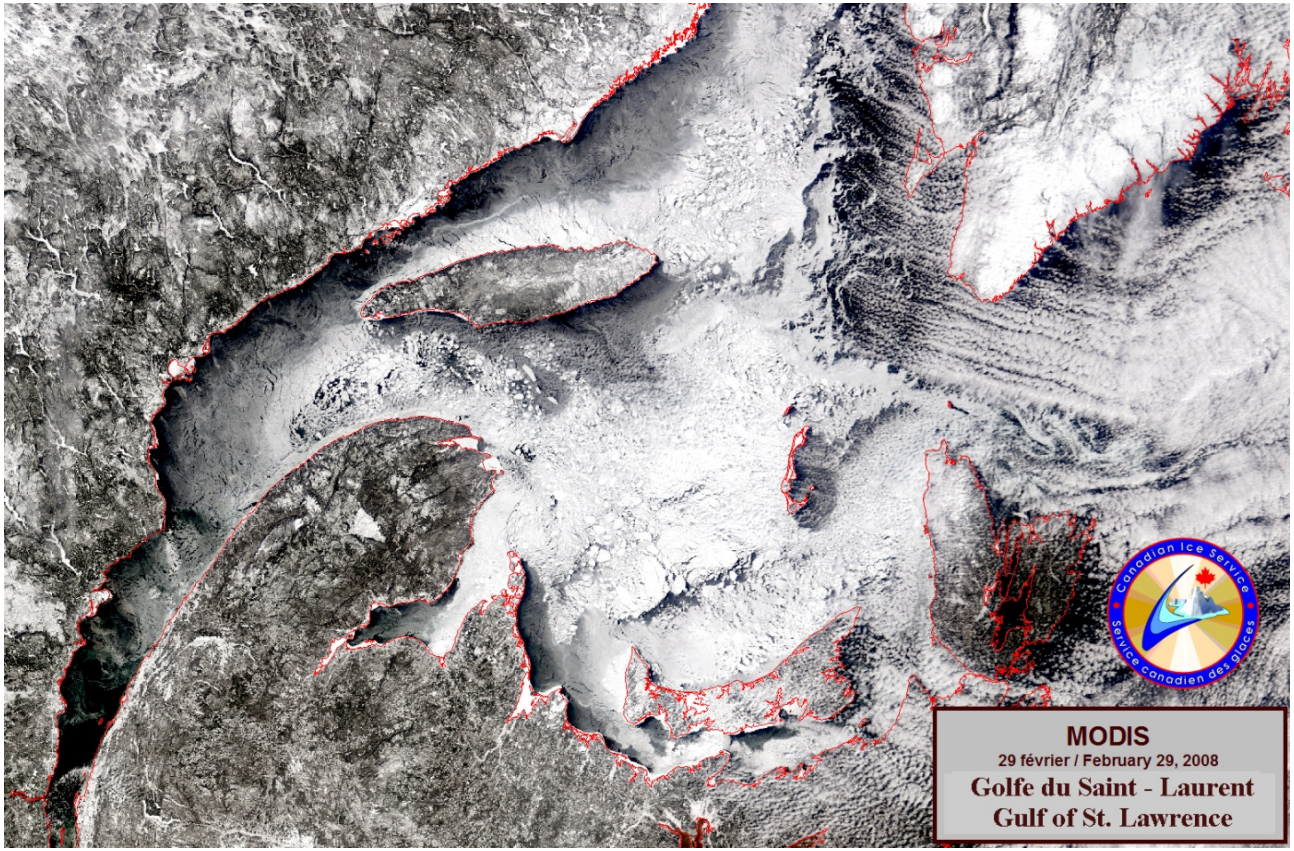
Status

- Evolving sea ice cover affects regional weather forecasts on very short timescales
  - Details matter!
- Arctic leads have a large impact on global coupled forecast skill

Challenges

- Evaluating and improving the representation of leads
- Including wave-ice interactions
- Atmosphere-ice-ocean momentum transfer
- Constraining sea ice thickness
- Sea ice forecast verification

Thank you!


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