MEOPAR

MARINE ENVIRONMENTAL OBSERVATION PREDICTION & RESPONSE NETWORK

A Relocatable Coupled Atmosphere-Ocean Prediction System: Overview with Emphasis on Modelling and Data Assimilation

By: Hal Ritchie and Project Team
Dalhousie University & Environment Canada

MEETING THE CHALLENGES OF OUR CHANGING OCEAN

MEOPAR is a Network of Centres of Excellence

Over 65 researchers from 21 Canadian universities and 4 federal departments

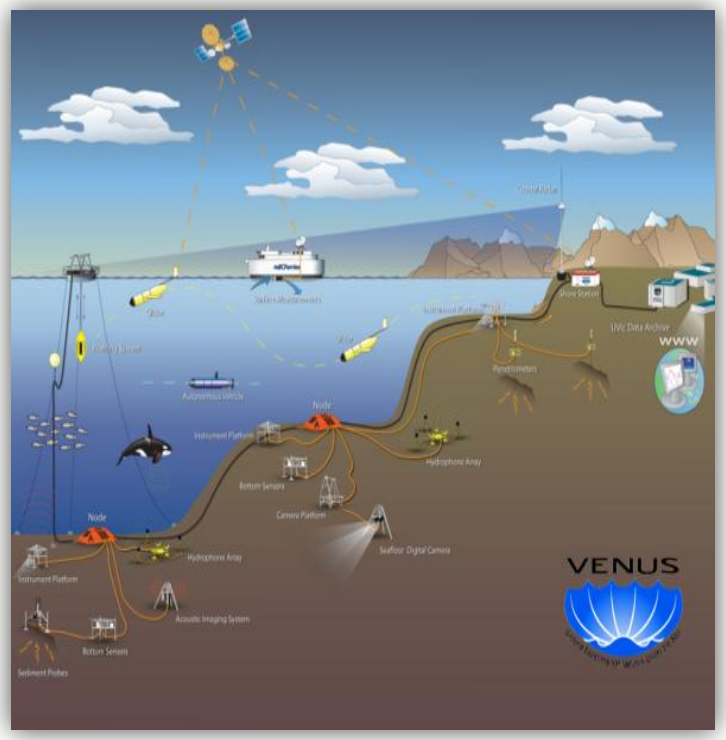
Headquartered in Halifax, Nova Scotia at Dalhousie University

Established in 2012; 1st funding cycle ends March 2017

Our Specific Project Objectives

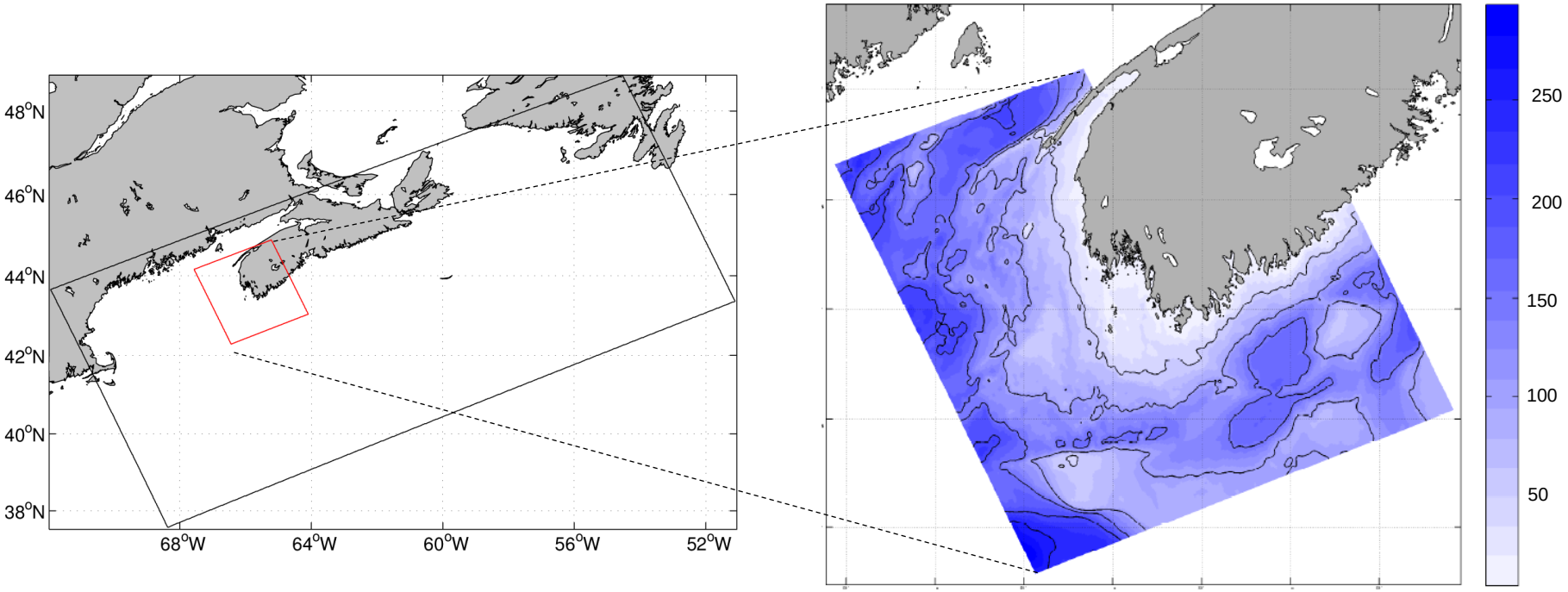
In collaboration with our government partners

- Build and test an atmosphere-ocean forecast system that can be set-up within hours of marine emergency, anywhere in Canadian waters
- Provide short-term forecasts (hours to days) of physical properties to guide response to a marine emergency
- Develop ability to assimilate data (e.g., obs from altimeters, gliders) and downscale predictions from larger scale models
- Develop modules for offline prediction of movement and dispersion of plumes of hazardous materials



High resolution relocatable ocean model

Fatemeh Chegini, Youyu Lu, Hal Ritchie, Keith Thompson



Global (1/12 deg) → Regional (1/36 deg) → High resolution (500 m)

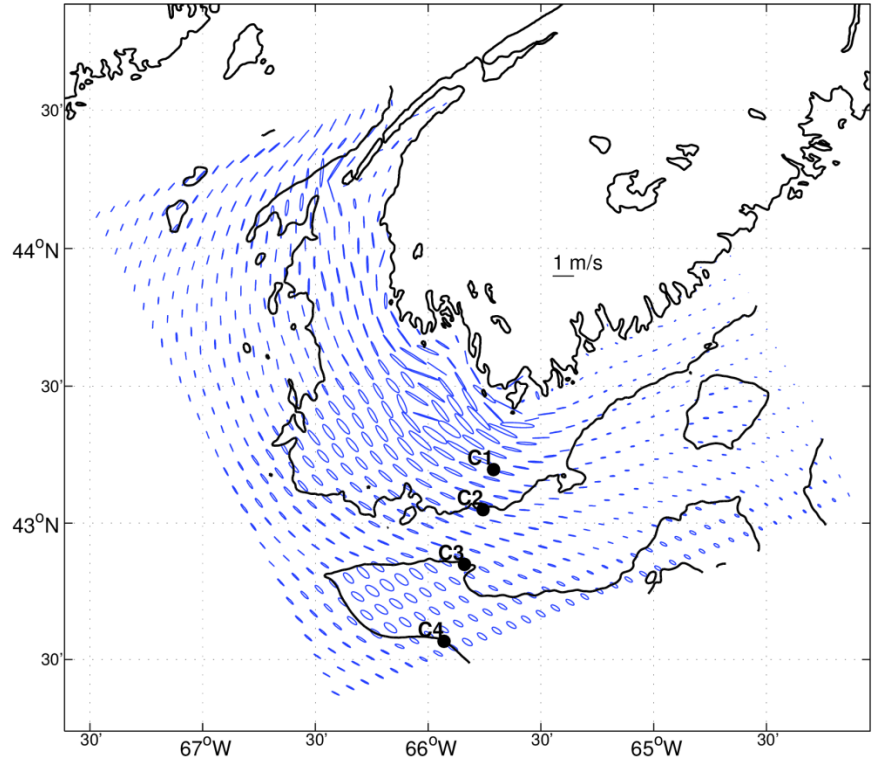
High resolution relocatable model

- Ability to respond in case of marine emergency
- High resolution models are required for certain applications
- Aim: Develop the ability to downscale by developing required tools

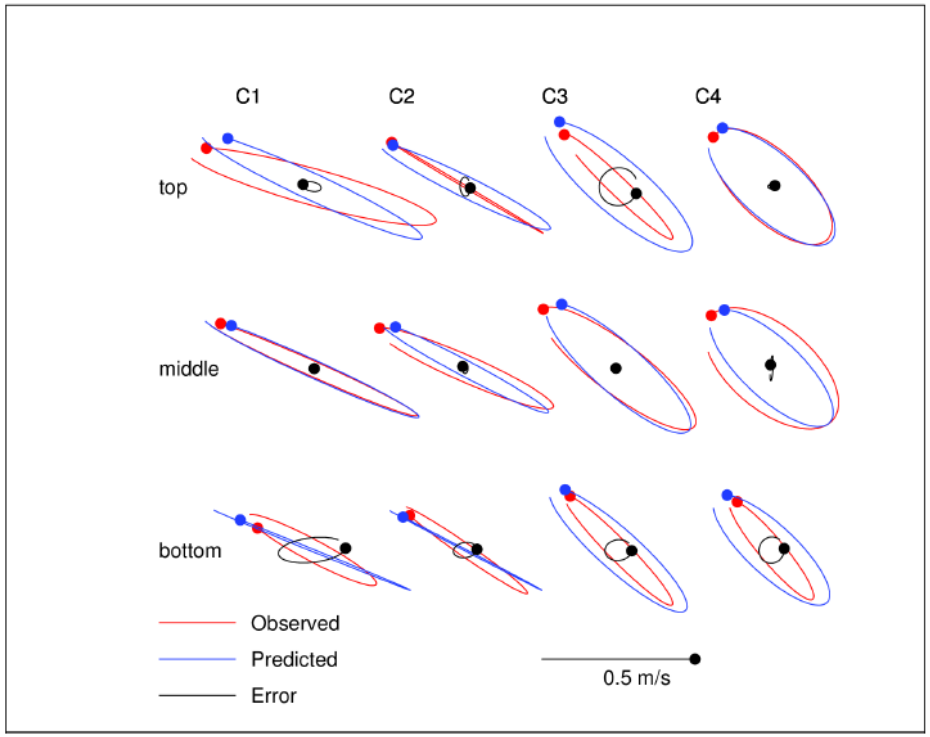
What we have achieved

1. Developed tools to setup model in a few hours
   - High resolution bathymetry and coordinates
   - Initial conditions from regional model
   - Tools to generate boundary conditions from regional model
   - Weights file for atmospheric forcing
2. Evaluated the ability of NEMO model when applied at high resolution
3. Successfully applied the tools to model SW Nova Scotia circulation (complex spatial and temporal oceanography features; impact of tides, density and atmospheric forcing on circulations and their interactions; high productivity area with practical applications for fisheries)

South West Nova Scotia
Model evaluation

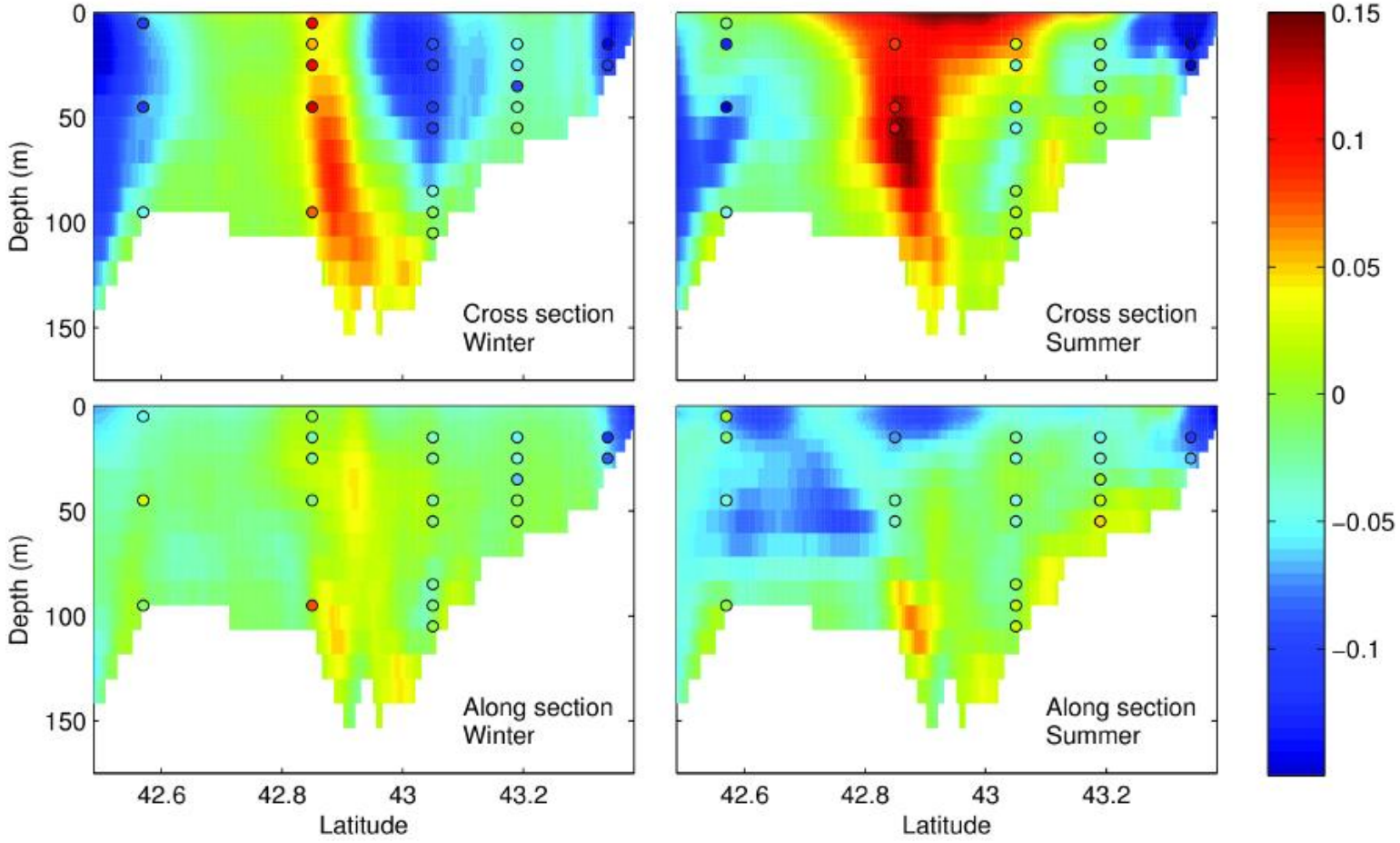


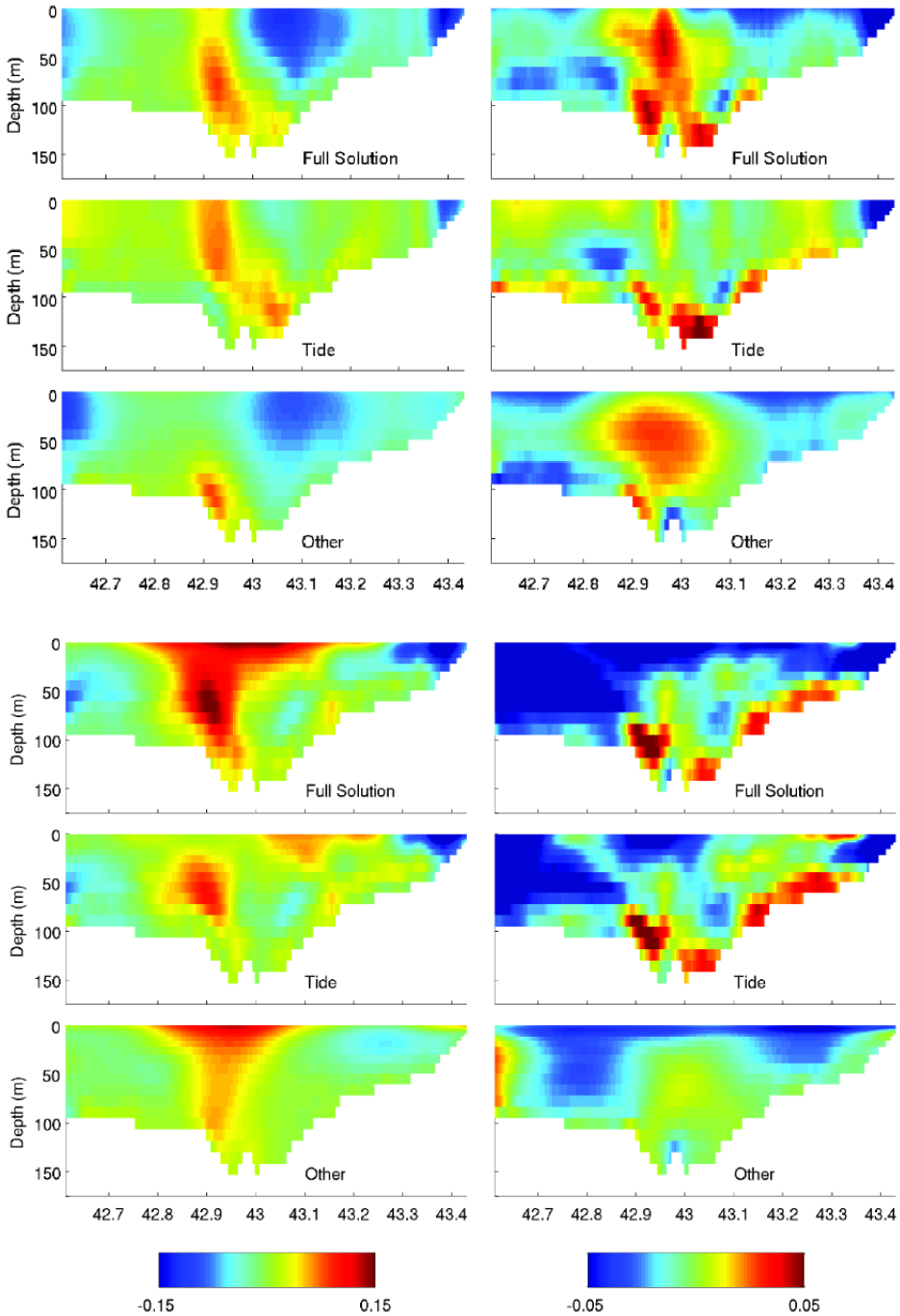
Depth average tidal ellipse



Comparison of Observed and predicted tidal ellipse

South West Nova Scotia
Model evaluation – Velocity field





Full Solution

Tidal contribution

Other forcing

Winter

Full Solution

Tidal contribution

Other forcing

Summer

Left: Along section, + eastward
Right: Cross section, + shoreward, stronger
In summer, near coast

Summary

High resolution relocatable Model

- Developed all the required tools
- Technically no issue for applying to other domains
- Confirmed the ability of model for high resolution
- Model performance is reasonable compared to observations

South West Nova Scotia

- Different dominant forcing in summer and winter
- Near bottom cross isobath currents
  - Jun-Oct: Strong in summer (whole region)
  - Nov-Jun: Only in deeper regions and weaker
- Confirmed that shoreward currents are due to tides

<u>Future Work</u>

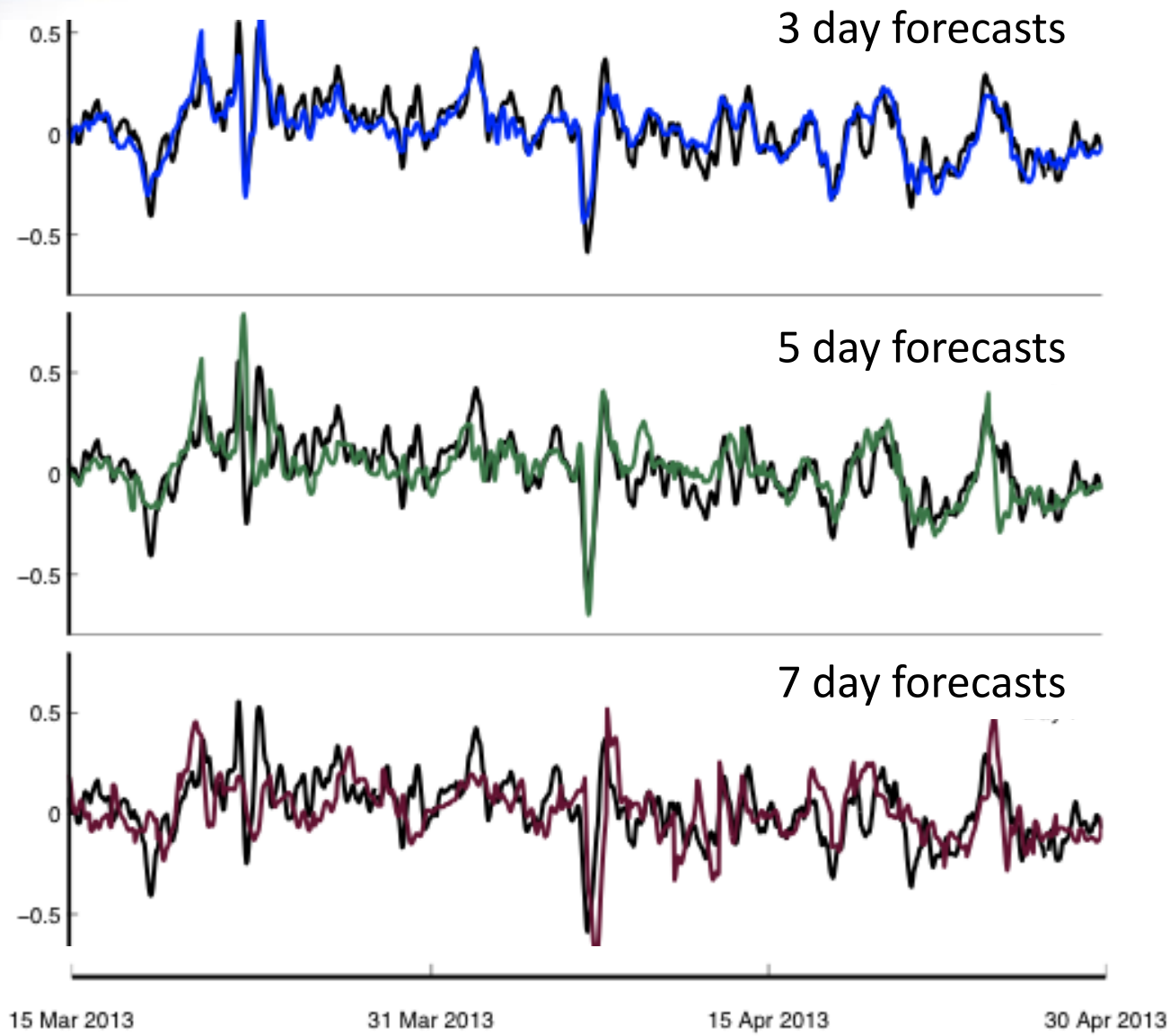
Article in preparation : A high resolution baroclinic model of circulation in a coastal upwelling area

Tidal and Surge Boundary Conditions for the Relocatable Model

Tsubasa Kodaira and Keith R. Thompson
Dalhousie University

Natacha Bernier
Environment Canada

Development and Evaluation of New Regional Deterministic and Ensemble Surge Prediction Systems



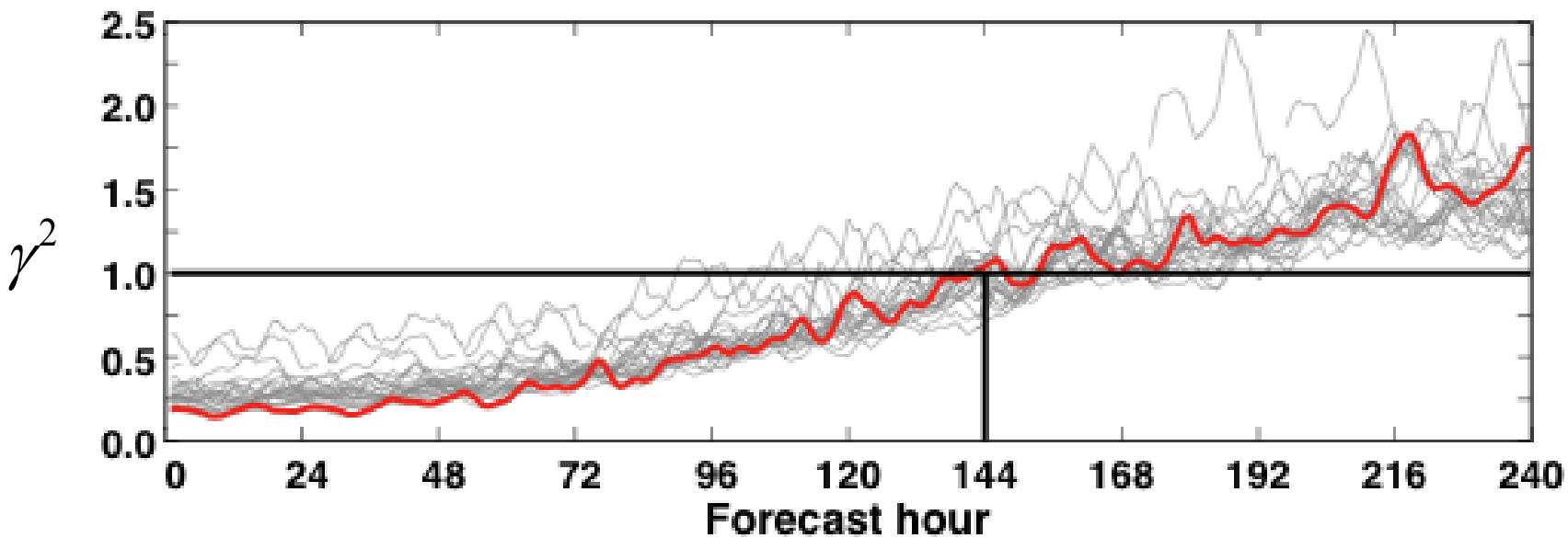
Typical Deterministic Forecasts

Rimouski
Obs in black

How Good are the Deterministic Forecasts?

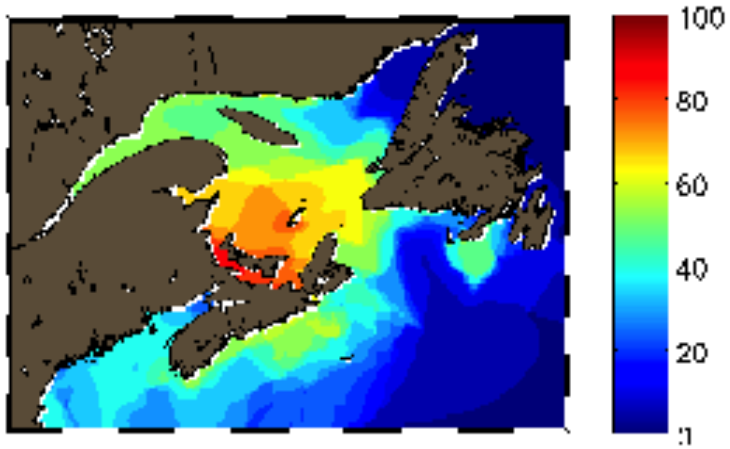
For each of the 22 tide gauges calculate

$$\gamma^2 = \frac{\mathrm{var}(\eta_{obs} - \eta_{\mathrm{mod}})}{\mathrm{var}(\eta_{obs})} \approx \frac{error}{obs}$$

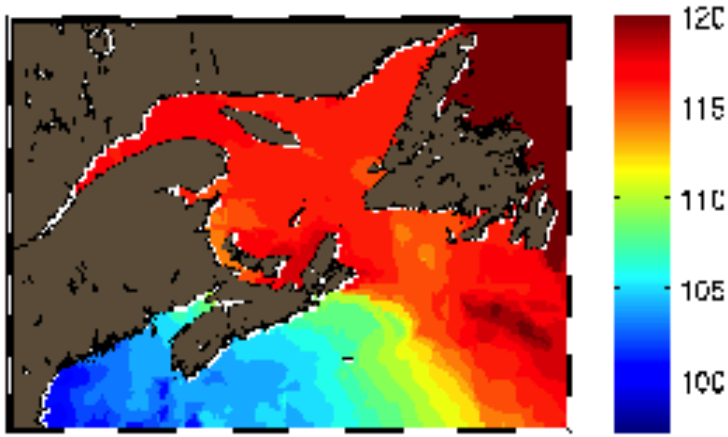


Visualizing Ensemble Surge Forecasts

Pr(surge>0.4m)

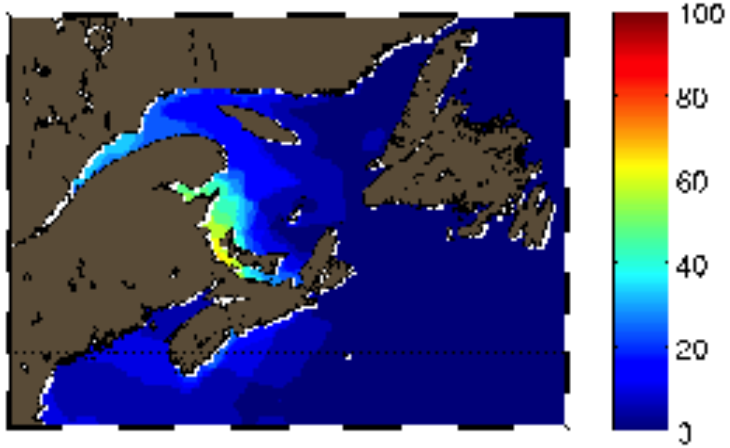


Median of peak times (h)

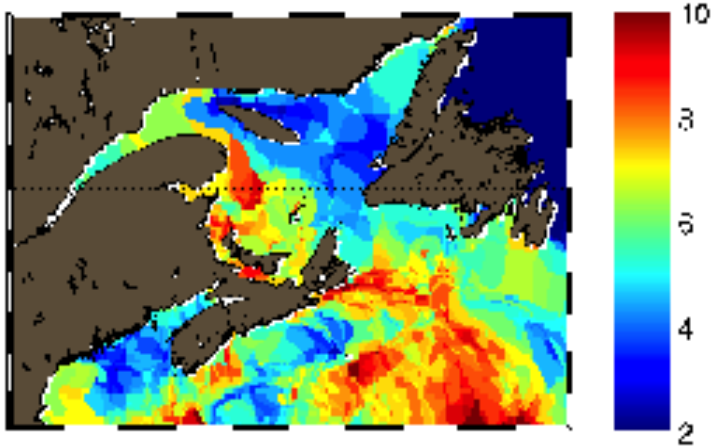


5d forecast for
22 March 2013

Pr(surge>0.6m)



Spread of peak times (h)



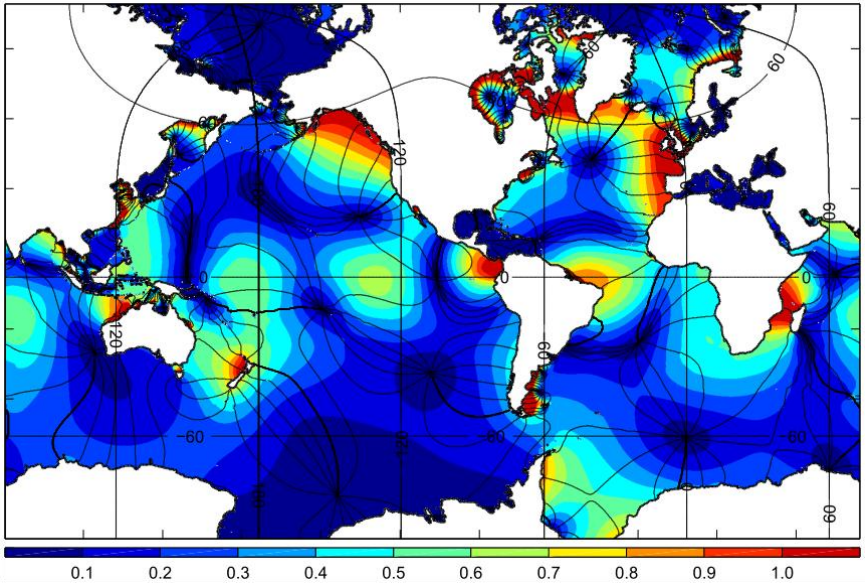
Deterministic and ensemble storm surge prediction for Atlantic Canada with lead times of hours to ten days (Bernier and Thompson, Ocean Modelling, 2015)

Global baroclinic tide model using NEMO (ORCA12, 19levels)

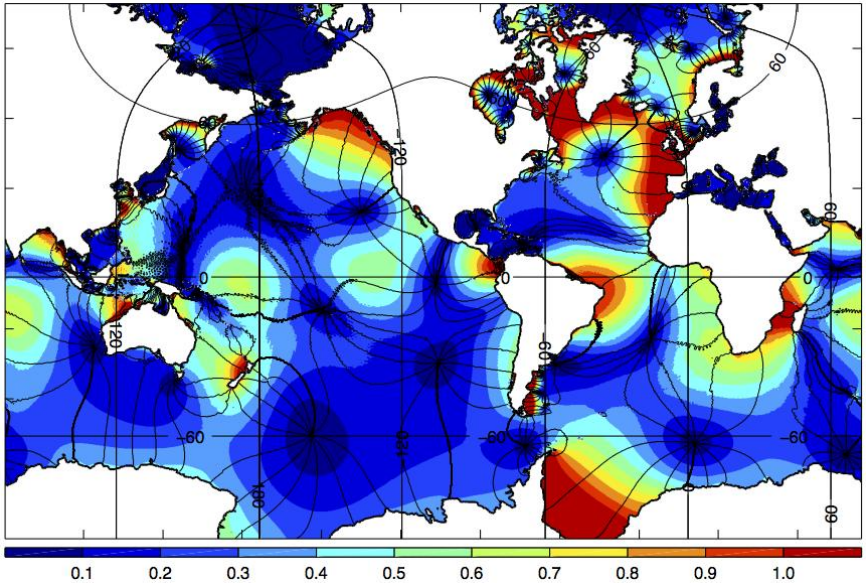
Total water level = **Storm surges** + **Tides**

- **Particular attention is paid to the parameterization of**
  - **Self Attraction and Loading effect (SAL)**
  - **Topographic Internal Wave Drag (IWD)**
  - **Realistic surface M2 tides are obtained.**

FES2004



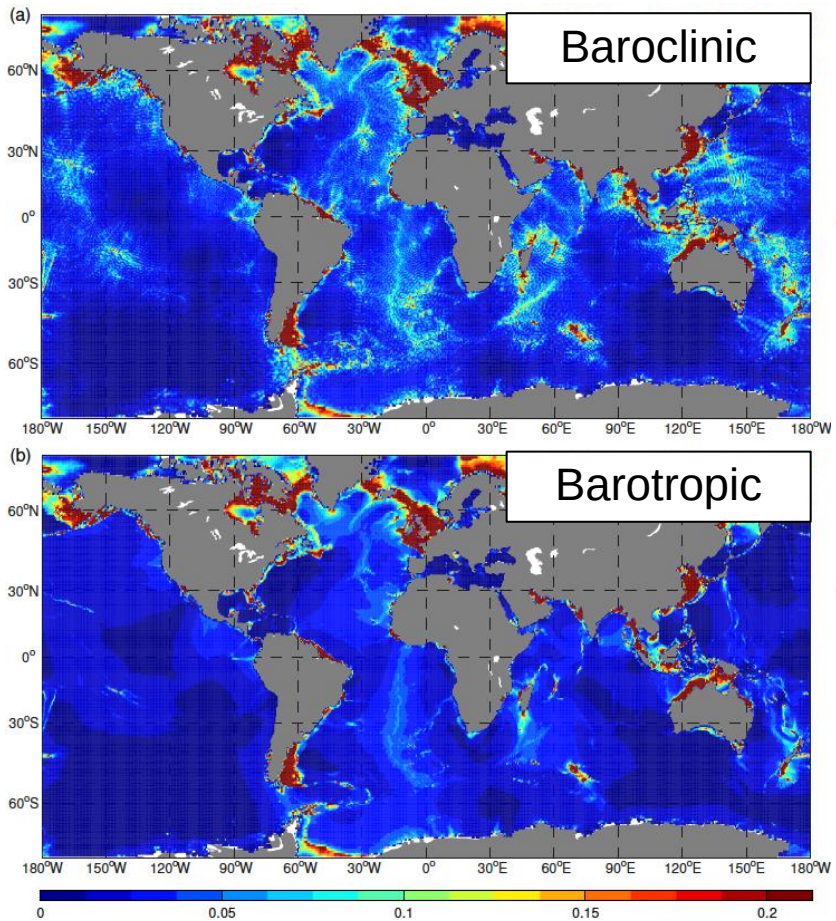
NEMO (No Data Assimilation)

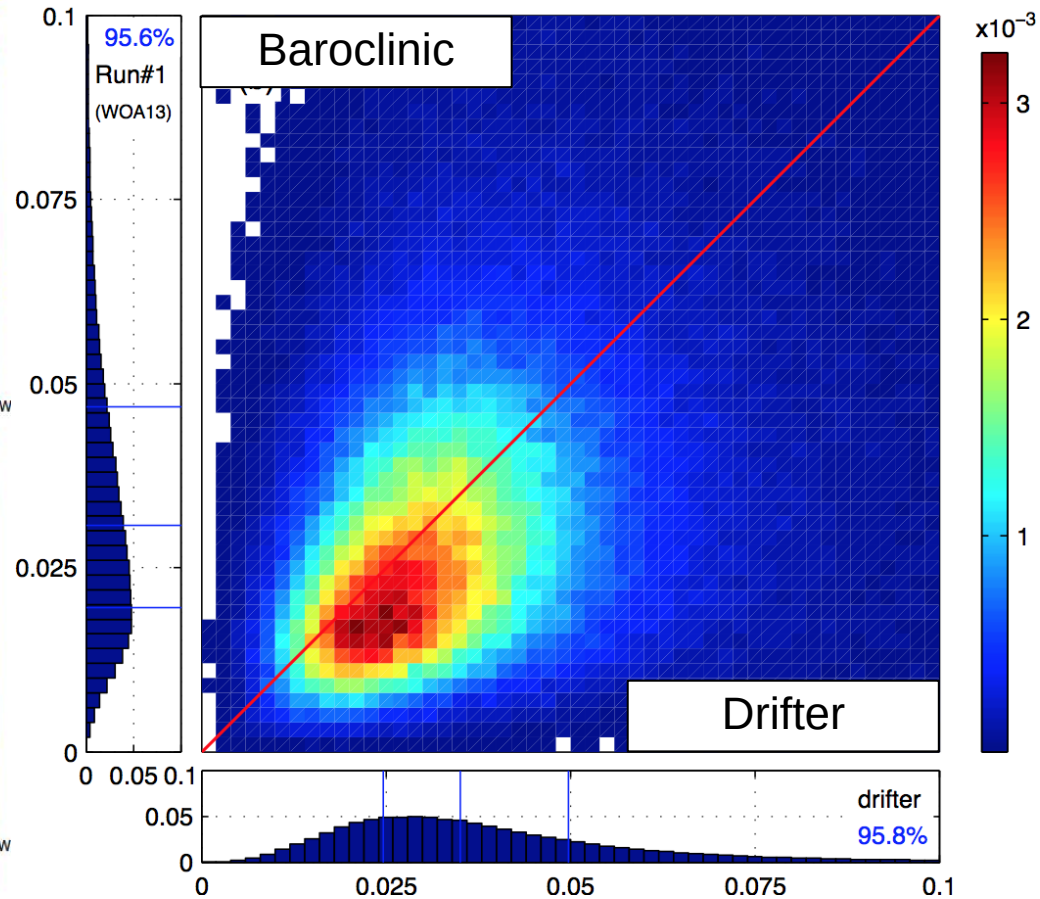


Prediction of surface M2 tidal currents by a global ocean model and evaluation using observed drifter Trajectories (Kodaira et al., JGR-Ocean, under review)

Surface tidal current along the major axis

- **Internal tides create significant surface currents (top left).**
- **Reasonable agreements with the independent estimates based on a statistical analysis of observed drifter trajectories (right).**





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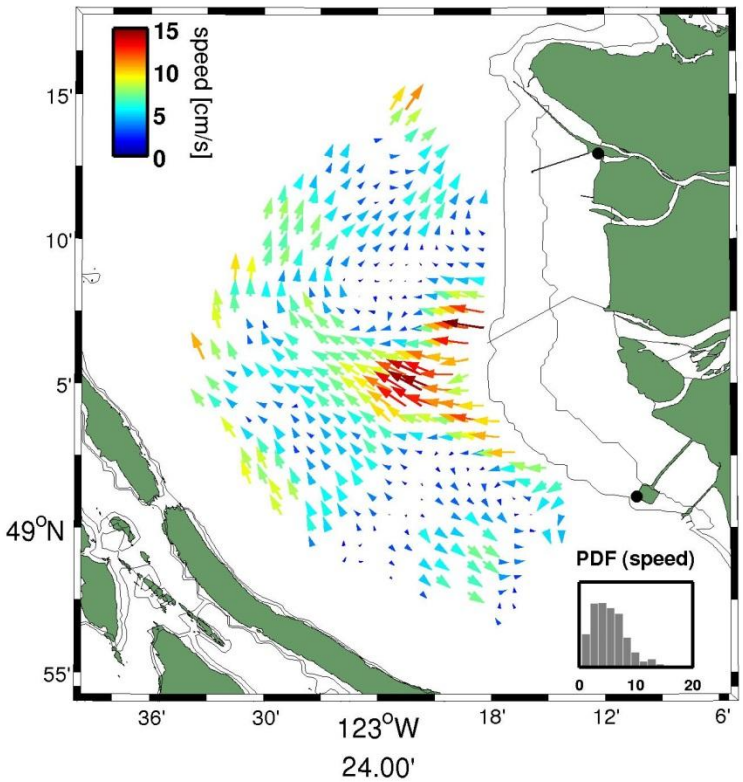
MARINE ENVIRONMENTAL OBSERVATION PREDICTION & RESPONSE NETWORK

Preparation and Diagnostics of Ocean Observations and Data Sets

By: Rich Pawlowicz, Mark Halverson
Department of Earth, Ocean, and Atmospheric Sciences
University of British Columbia

MEETING THE CHALLENGES OF OUR CHANGING OCEAN

CODAR currents



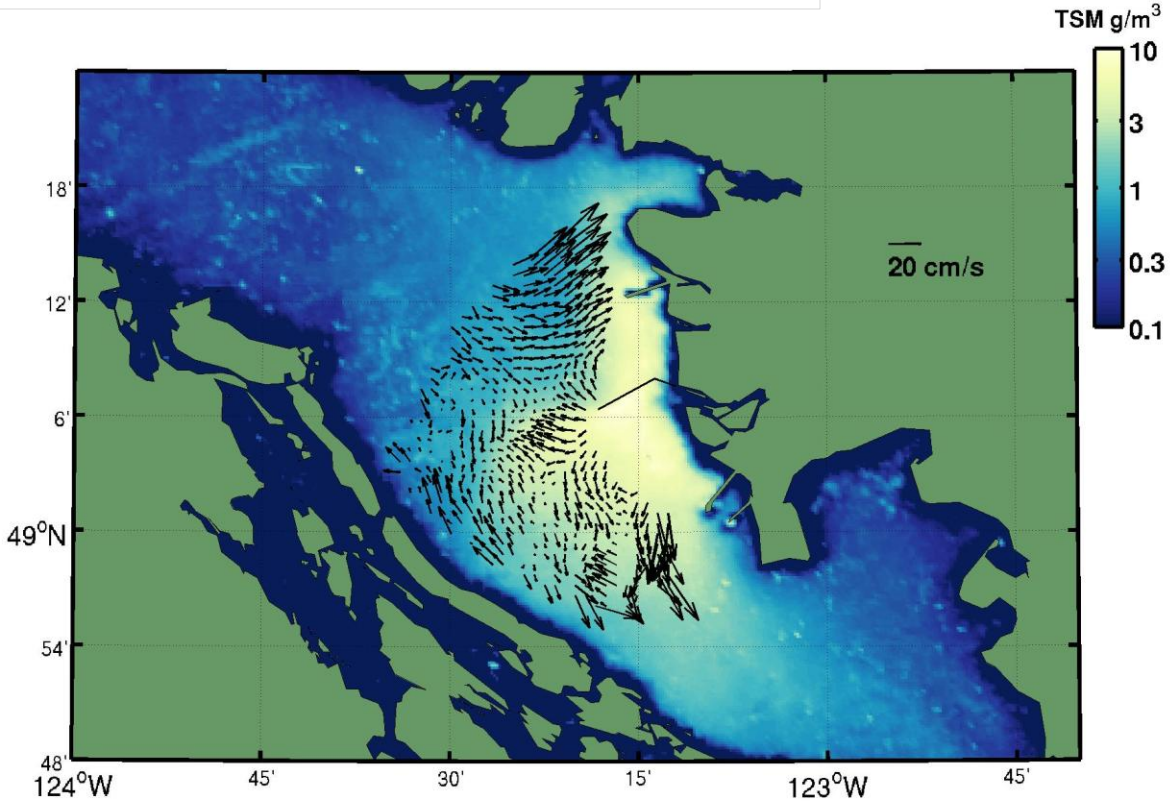
Mean flow over 10 month period

Flow away from river mouth at ≈ 14 cm/s

Outflow turns north (anticyclonic)

Variance exceeds the mean nearly everywhere

Suspended sediment from MODIS

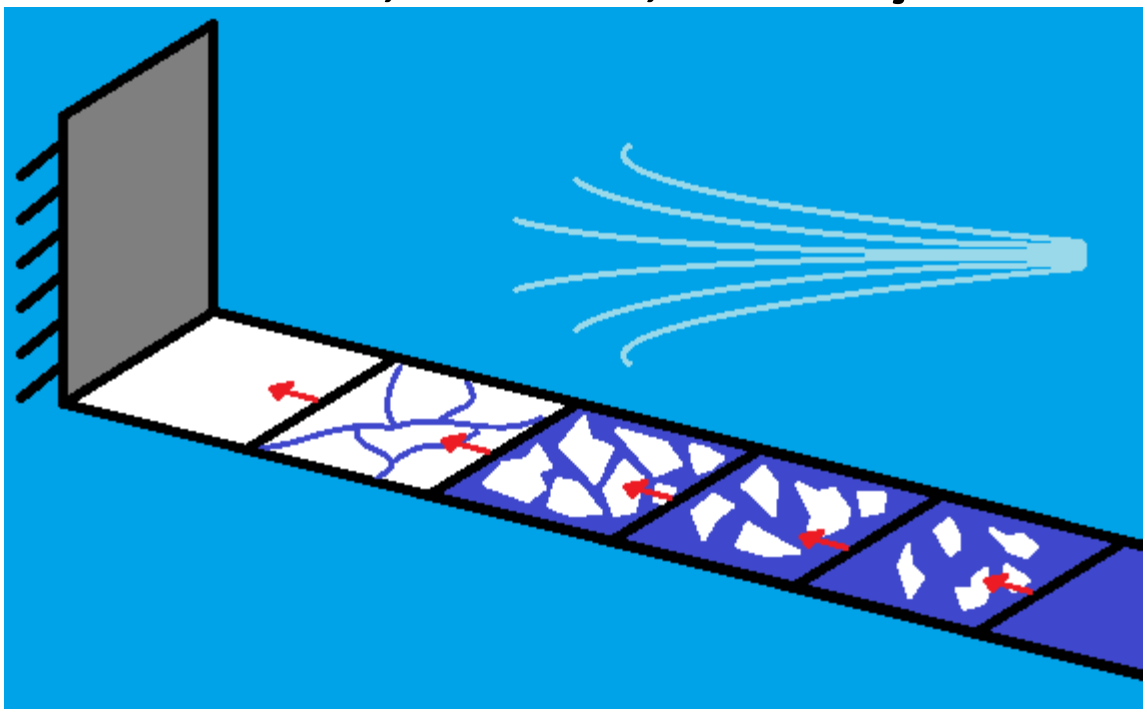


Average of 60 MODIS images tuned to measure suspended sediment
Suspended sediment concentration a proxy for salinity

Similar analyses and diagnostics (CODAR, drifters, remote sensing,…) will be applied to the Scotian Shelf Experiment.

Improving sea ice model numerics using the exact Newton's method

Jean-Pierre Auclair, Hal Ritchie, Jean-François Lemieux



Fluxes through leads in sea ice are crucial for atmosphere-ocean coupling, and present solvers have problems, especially at high resolution.

Sea Ice Numerics: Motivations

- **MEOPAR relocatable high resolution coupled model**
- **Increasing model resolution:**
  - Models need to run faster (CPU or Solver)
  - Larger gradients and more significant non-linearity in the governing equations (Solver)
- **Air-sea coupling:**
  - A change from 2% to 4% open waters doubles the fluxes! We need to be accurate.
- **Many opportunities for improvement!**

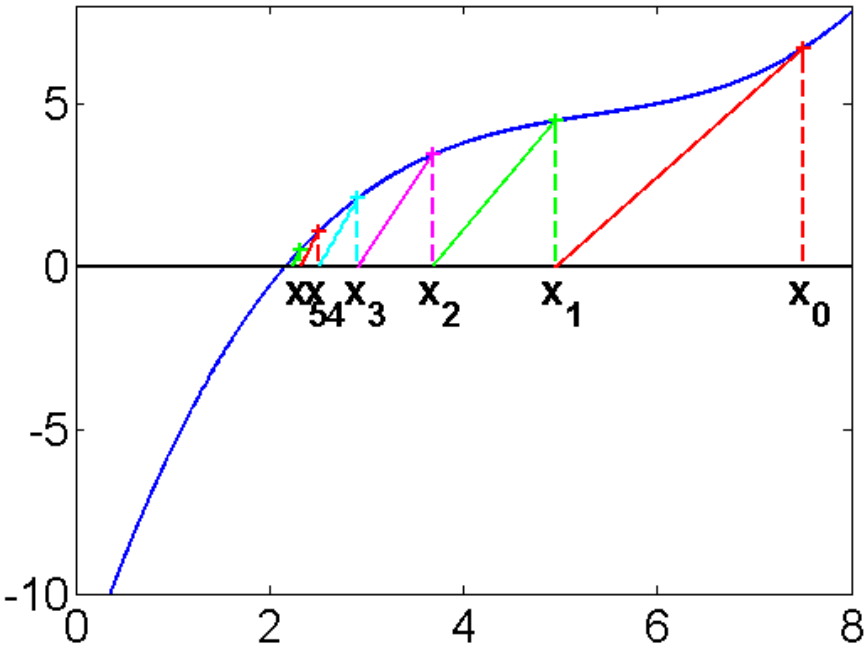
Sea Ice Numerics: Dynamics

- **Things to consider:**
  - Coriolis
  - Wind and current drags
  - Gravity
  - Internal Stresses
- **Momentum equation:**

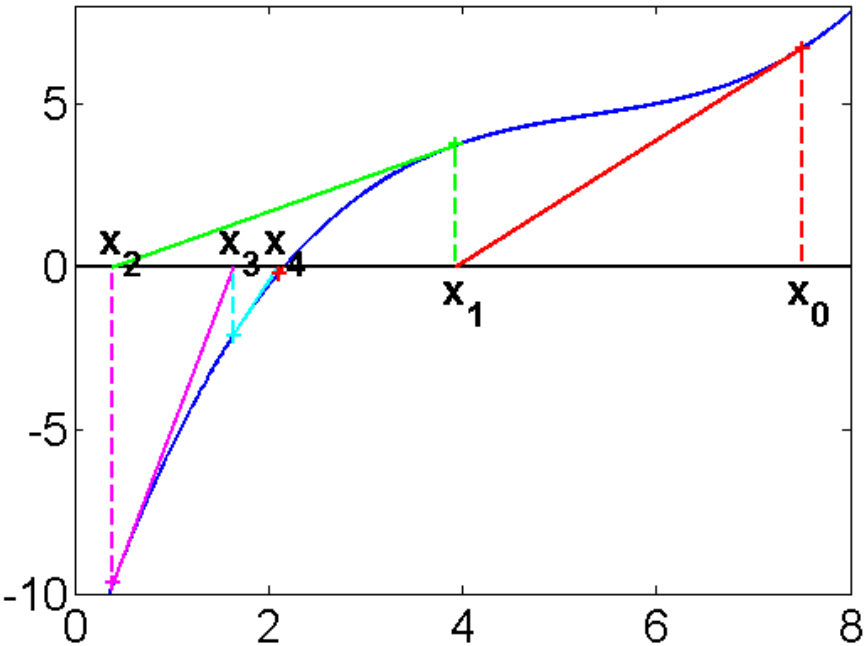
$$0 = -\rho h \frac{D\mathbf{u}}{Dt} - \rho h f \mathbf{k} \times \mathbf{u} + \tau_a - \tau_w - \rho h g \nabla H_d + \nabla \cdot \sigma$$

Sea Ice Numerics: Solving Equations

Linear method:



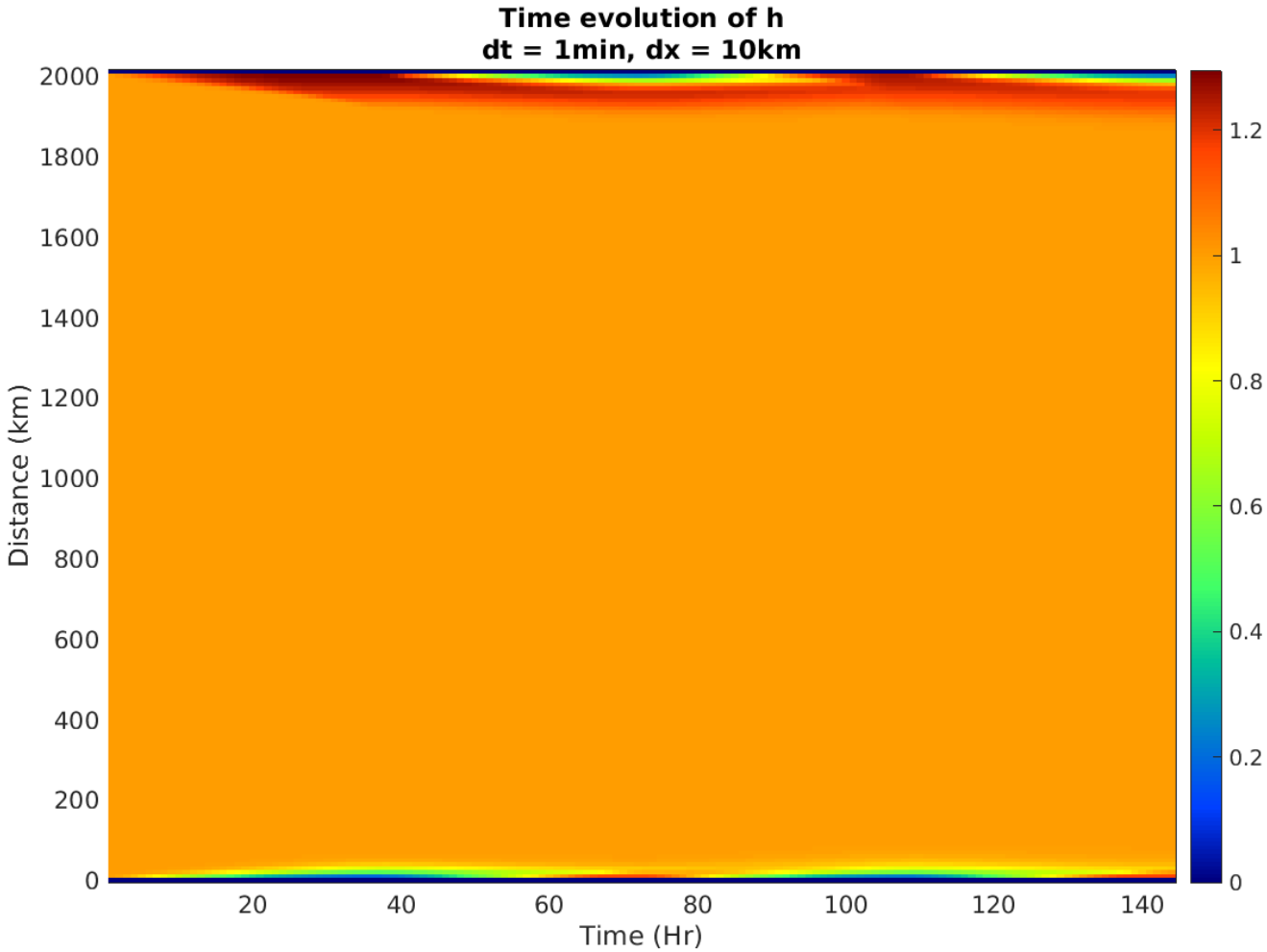
Newton's method:



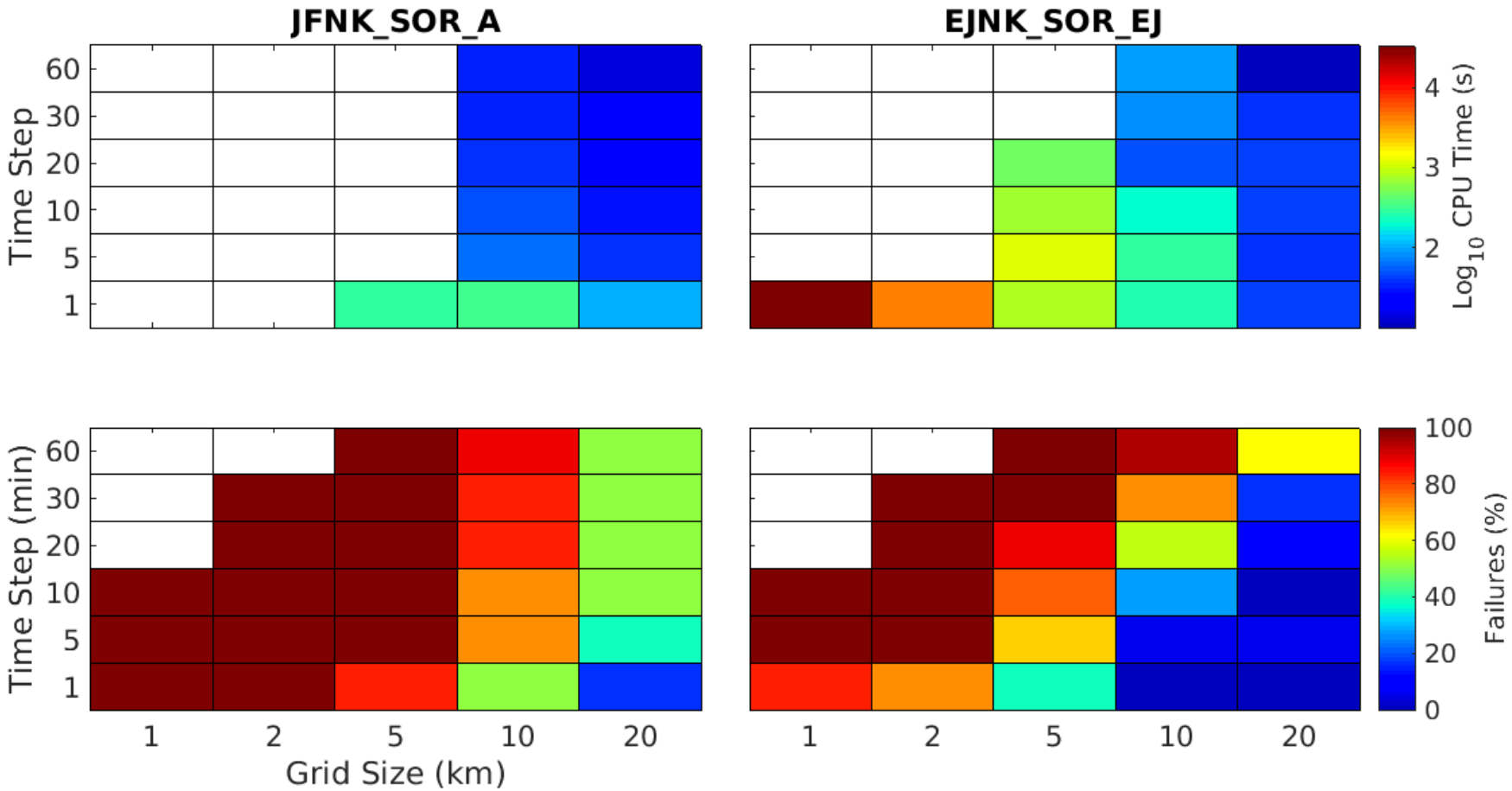
$$x_{i+1} = \frac{-f(0)x_i}{f(x_i) - f(0)}$$

$$x_{i+1} = x_i - \frac{f(x)}{f'(x_i)}$$

Sea Ice Numerics: 1D Experiment - 1



Sea Ice Numerics: 1D Results



Note: Failure means not reaching a high accuracy, mostly smooth solution

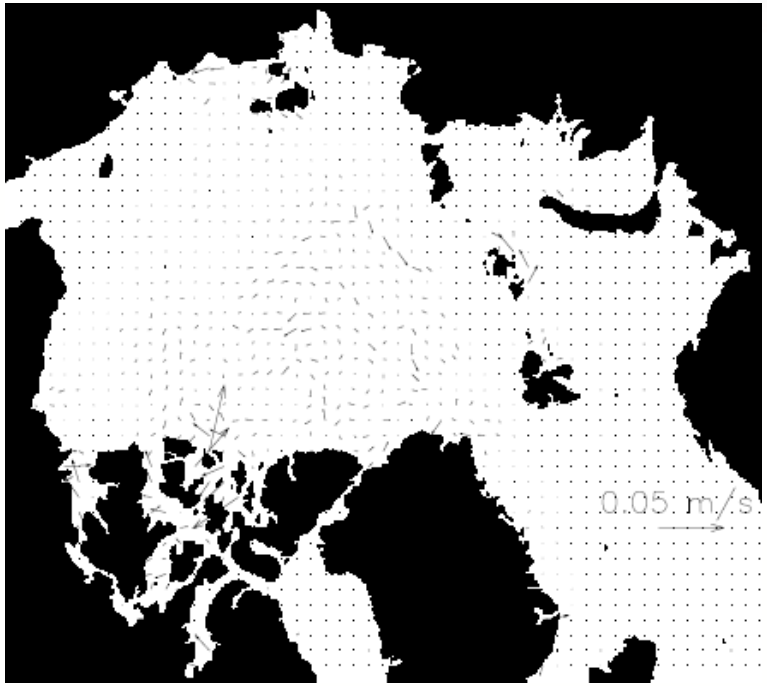
Sea Ice Modeling: Conclusions

The Exact Jacobian solver:

-Faster at a given accuracy
-Able attain higher accuracies
-Resilient to numerical noise
-Easier linear problem to solve
-Susceptible to rapid changes

Next steps:

-Experiment with an hybrid solver
-Derivation of the 2D Jacobian
-Implementation in a full ice model



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Environment Canada

Concluding summary

- MEOPAR is in the 4th year of its first 5-year phase.
- Our project activities are generally on schedule
- Considerable progress has been made on research and development for the components and methodologies.
- Testing and validation are well advanced, particularly for the Strait of Georgia, but also for the Scotian Shelf which will be a focus for years 4 and 5.

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