Assessing Far Field Effects of tidal Power Extraction on the Bay of Fundy and the Gulf of Maine using a Numerical Model

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(JONSMOD 2010, Delft)

DALHOUSIE UNIVERSITY
Inspiring Minds

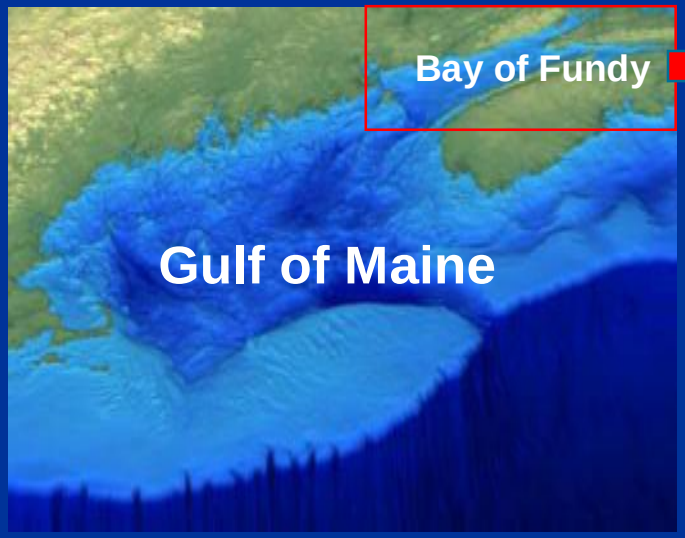
OERA Offshore Energy Environmental Research Association
OETR Offshore Energy Technical Research Association

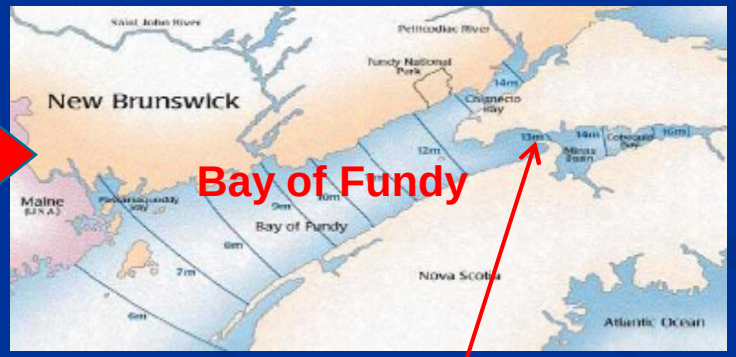
Outline

1. Introduction
2. Development of a nested-grid modelling system for the Bay of Fundy: NCOPS-BOF
3. Preliminary model results
4. Summary

1. Introduction

- The Bay of Fundy and Gulf of Maine system has a natural resonant period very close to the main semi-diurnal lunar tide. This results in the world's highest tides and strong tidal currents in the Bay of Fundy, particularly in Minas Channel and Minas Basin.
- The Bay of Fundy was chosen as a test bed for in-stream tidal power generation.

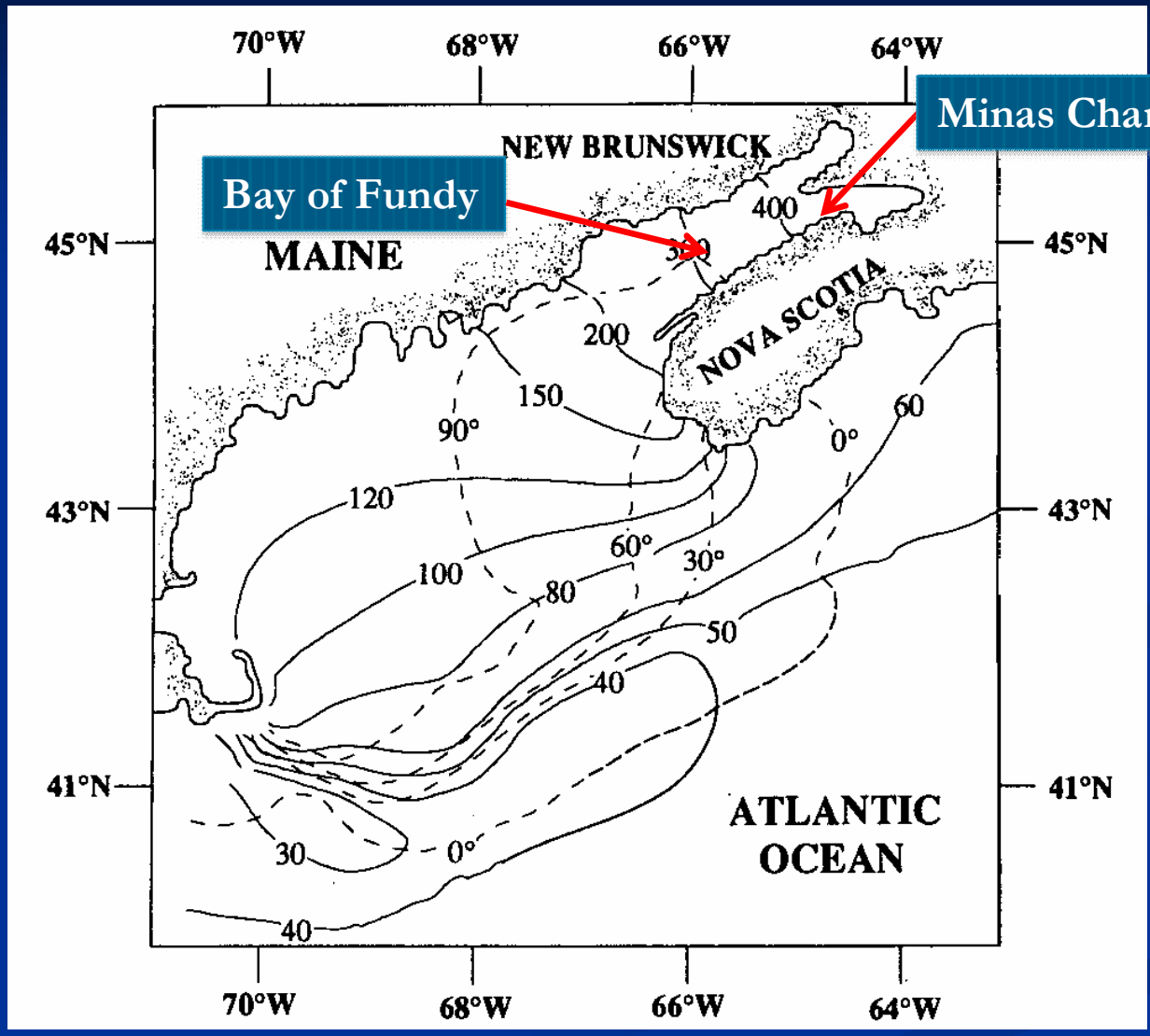




(Bay of Fundy is in the7th place in the New Wonders of Nature Contest)

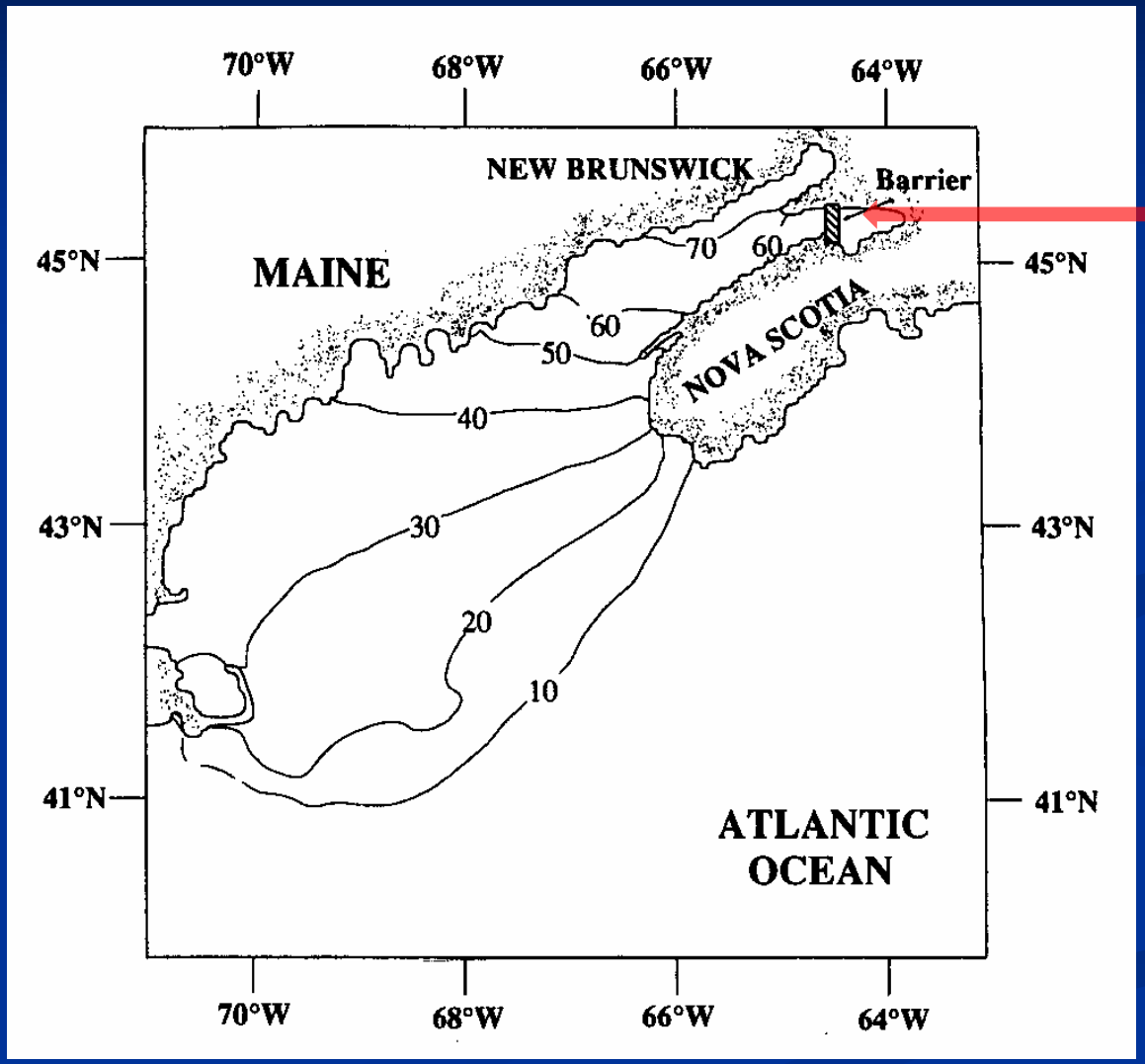
An OpenHydro Turbine was deployed at the Minas Channel for testing

M_2 Tides in the Gulf of Maine and the Bay of Fundy



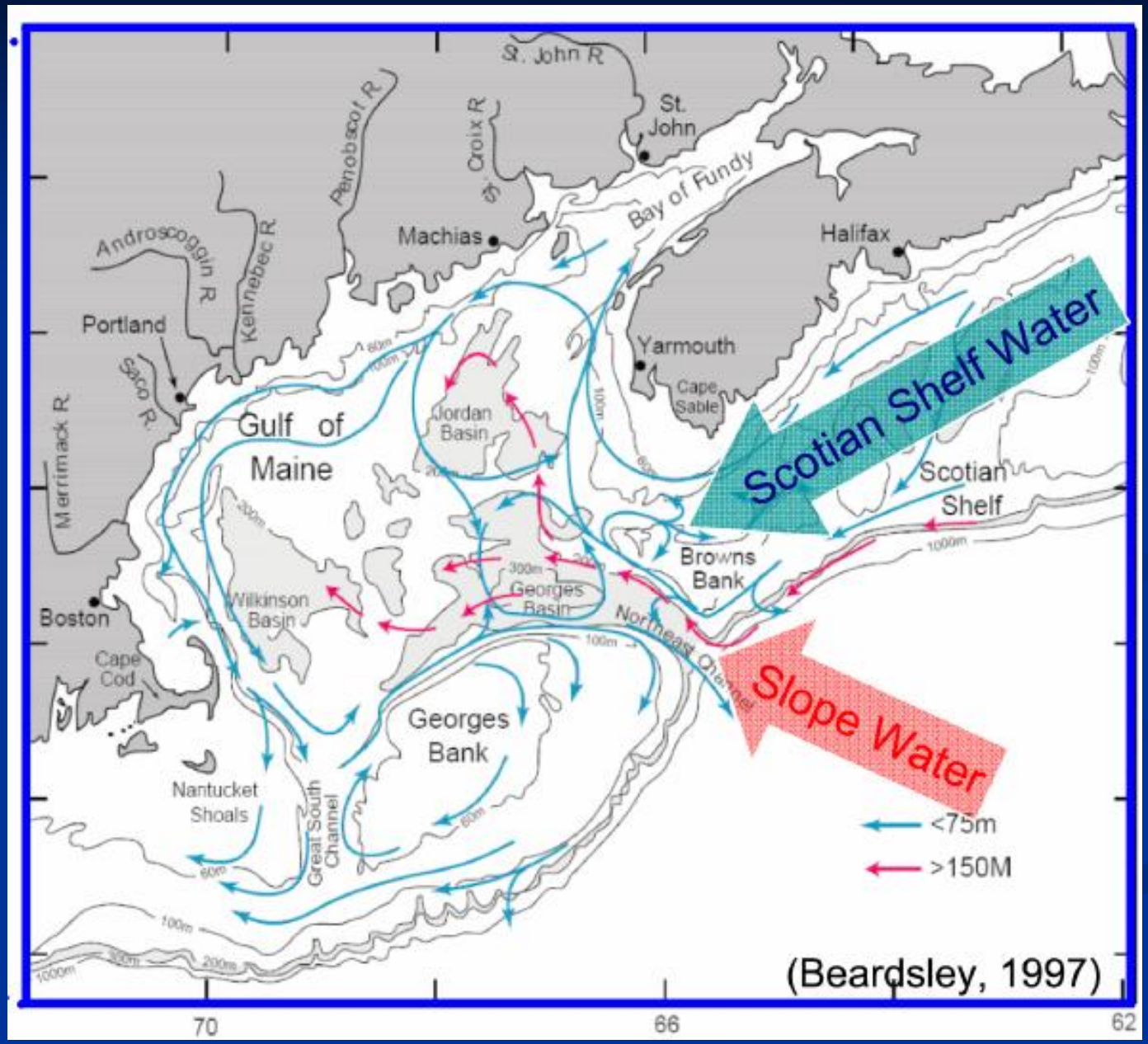
(Sucsy, Pearce and Panchang, JPO, 1993)

Changes in M_2 amplitudes if a barrier is placed in the upper Bay of Fundy

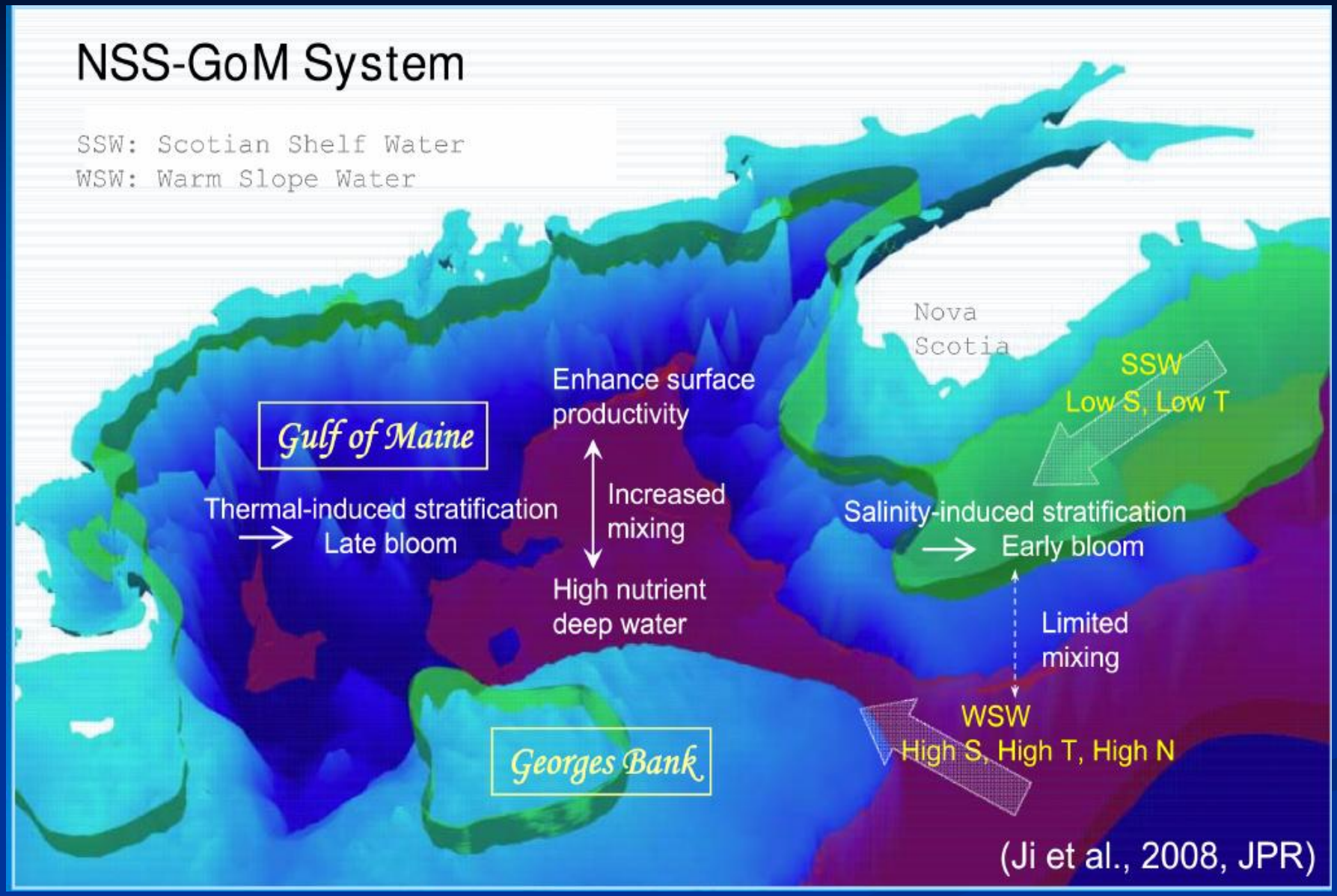


(Sucsy, Pearce and Panchang, JPO, 1993)

Density-Driven Circulation in the Gulf of Maine and Bay of Fundy



NSS-GoM System



Environmental Issue:

Physical and ecological conditions in the “far field” could undergo significant changes given significant extraction of tidal power from this near-resonant system. (The “far field” is defined as regions far from the turbine site).

Main Objective:

To quantify far field effects of tidal energy extraction in the Bay of Fundy on physical environments in the Gulf of Maine-Bay of Fundy (GOM-BOF) including the changes of:

- Tides and tidal circulation
- Temperature and salinity distributions
- Sediment distribution

Research Approach:

A four-level nested-grid ocean circulation model based on POM.

- **Physical variables to be examined: sea level, horizontal current, temperature and salinity, bottom current and bottom stress (for sediment transport calculations).**

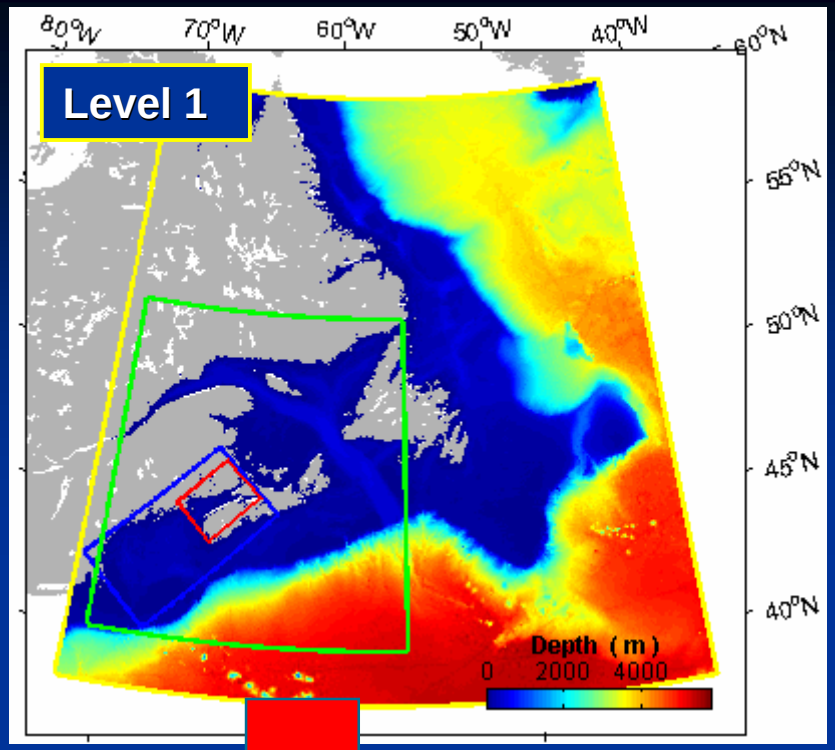
- **For each variable, the combined effect of tide and surge are calculated for two cases: with and without the turbines. Calculations are used to assess the impact of tidal power extraction on the following far field conditions:**

  (a) tides, tidal currents, and horizontal and vertical distributions of water temperature and salinity;

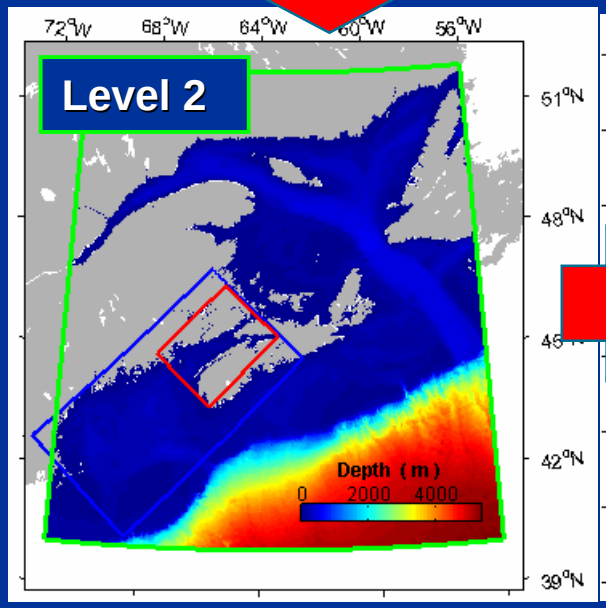
  (b) the change in the frequency (or equivalently return period) of extreme water levels (surge and tide combined) in the Bay of Fundy and Gulf of Maine system;

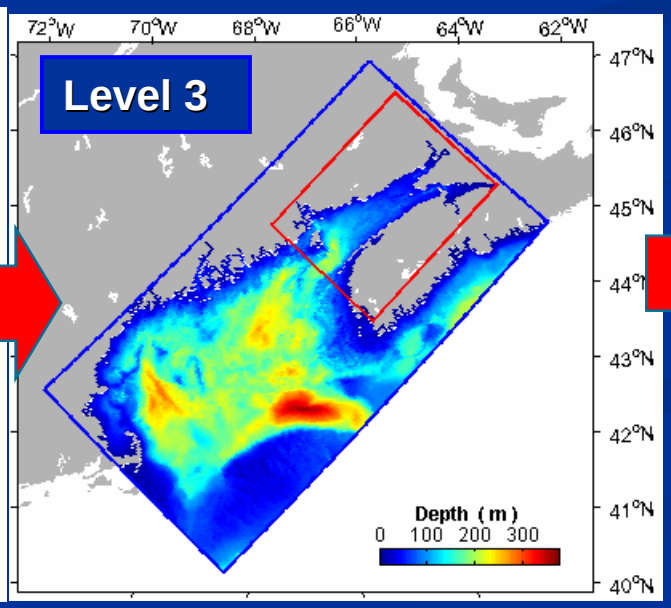
  (c) large-scale sediment patterns in the Bay of Fundy, Gulf of Maine and Scotian Shelf.

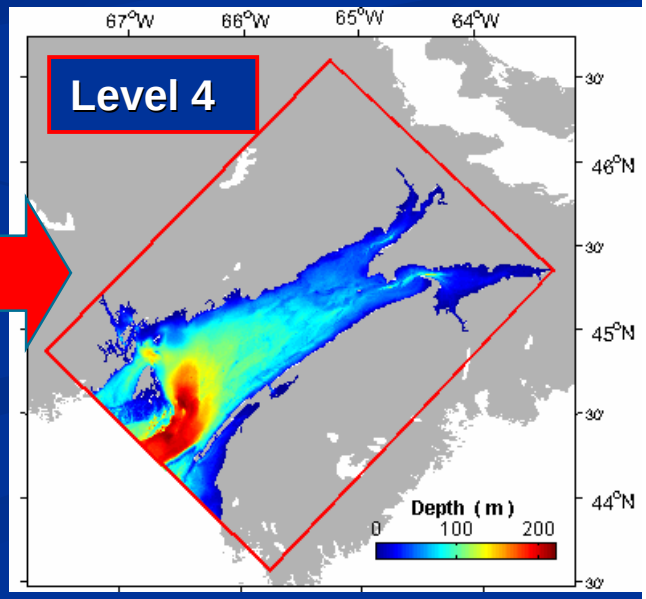
2. NCOPS-BOF



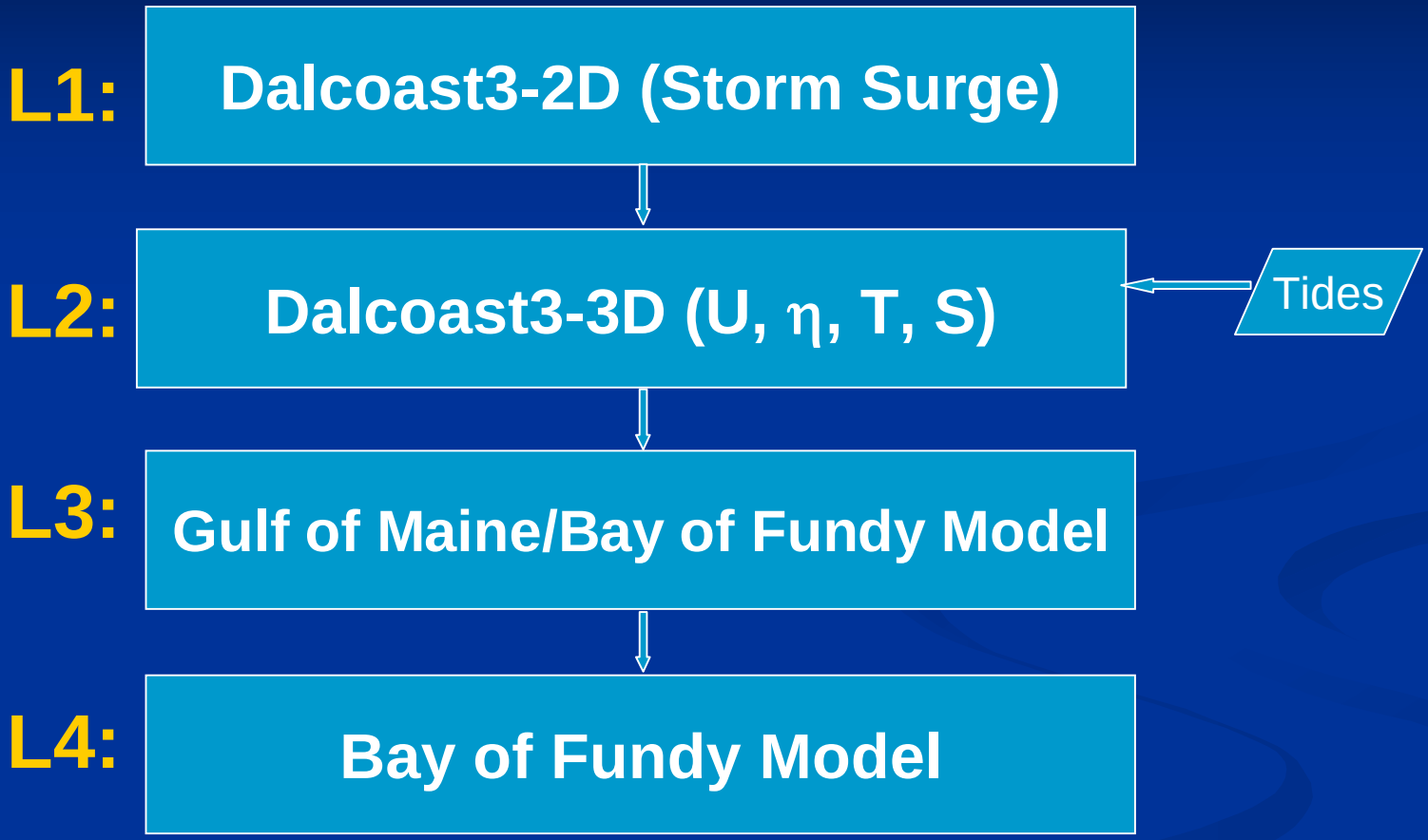
A 4-level nested-grid ocean circulation model for the Bay of Fundy currently under development







NCOPS-BOF (4 level nested-grid model)



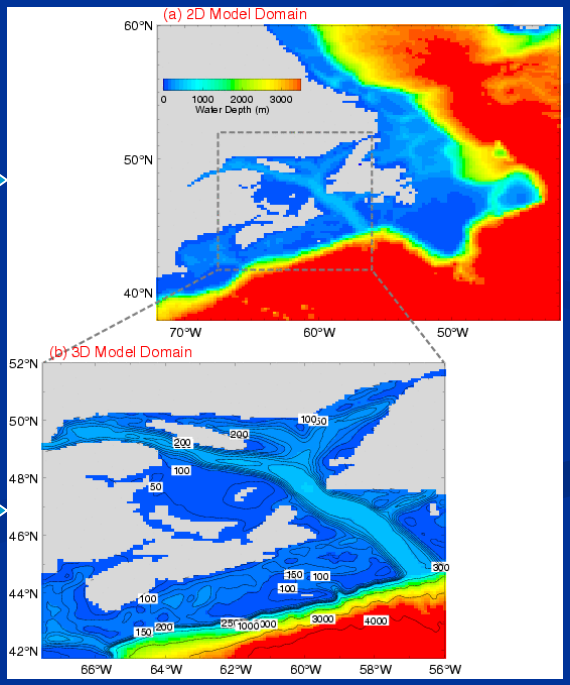
Dalcoast3: Prototype Operational Shelf Circulation forecast system:

DALCOAST3 was developed by originally Josko Bobanovic and Keith Thompson at Dalhousie University based on the Princeton Ocean Model (POM). It comprises two components:

- A 2D barotropic component (storm surge modell) for the eastern Canadian shelf.
- A 3D baroclinic component for the Gulf of St. Lawrence and Scotian Shelf.

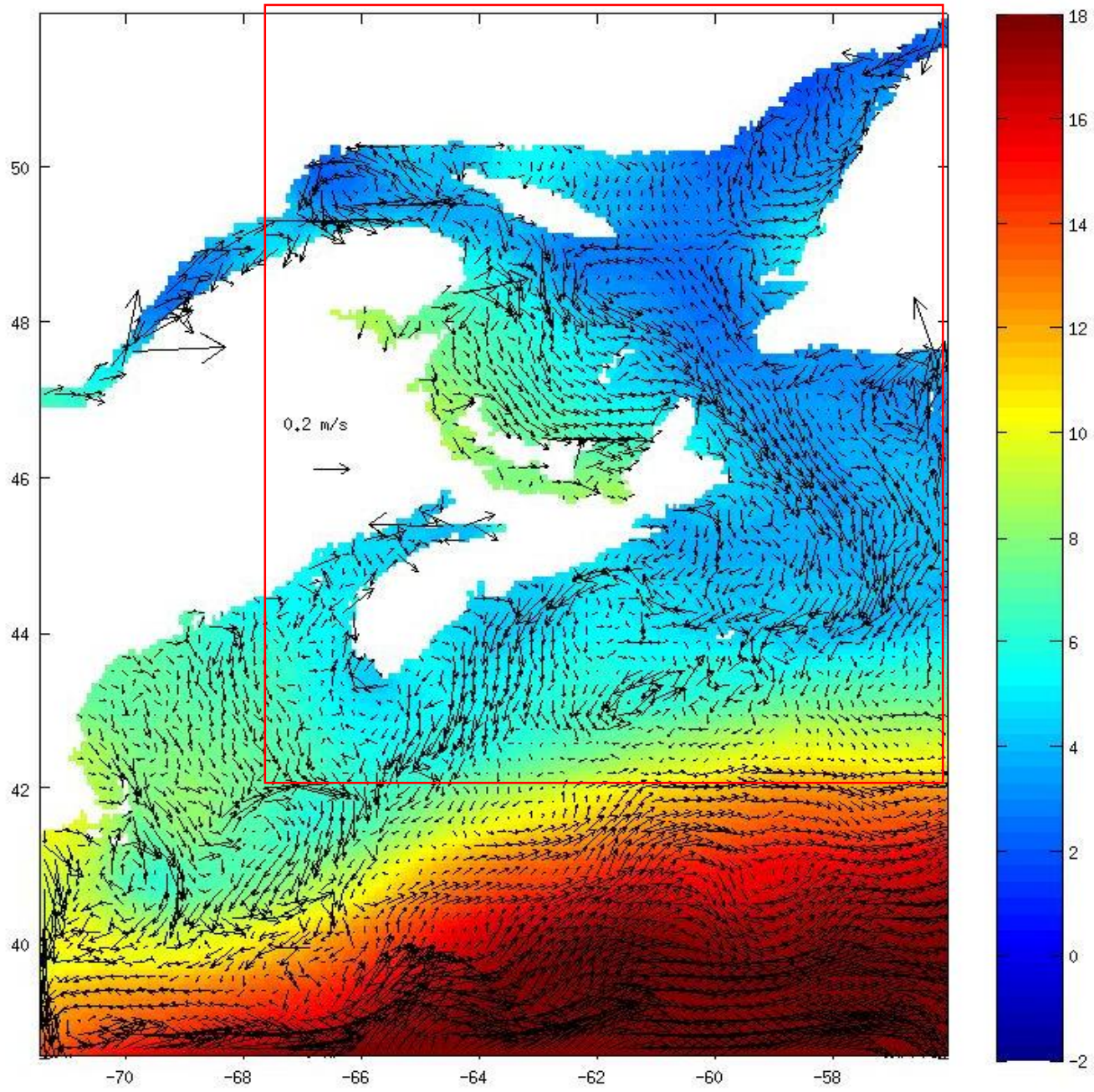
Model domain for barotropic mode

Model domain for baroclinic mode



Main features of DALCOAST:

- Forecast and hindcast capacity of predicting storm surge over the eastern Canada shelf
- Forecast capacity of predicting 3D circulation and temperature/salinity on the Scotian Shelf and Gulf of St. Lawrence
- Hindcast capacity of simulating 3D circulation and T/S fields on the Scotian Shelf.
- Dalcoast has well be calibrated and validated


0.2 m/s
50
48
46
44
42
40
-70
-68
-66
-64
-62
-60
-58
18
16
14
12
10
8
6
4
2
0
-2

3. Sub-Models L3 and L4 and Preliminary Model Results

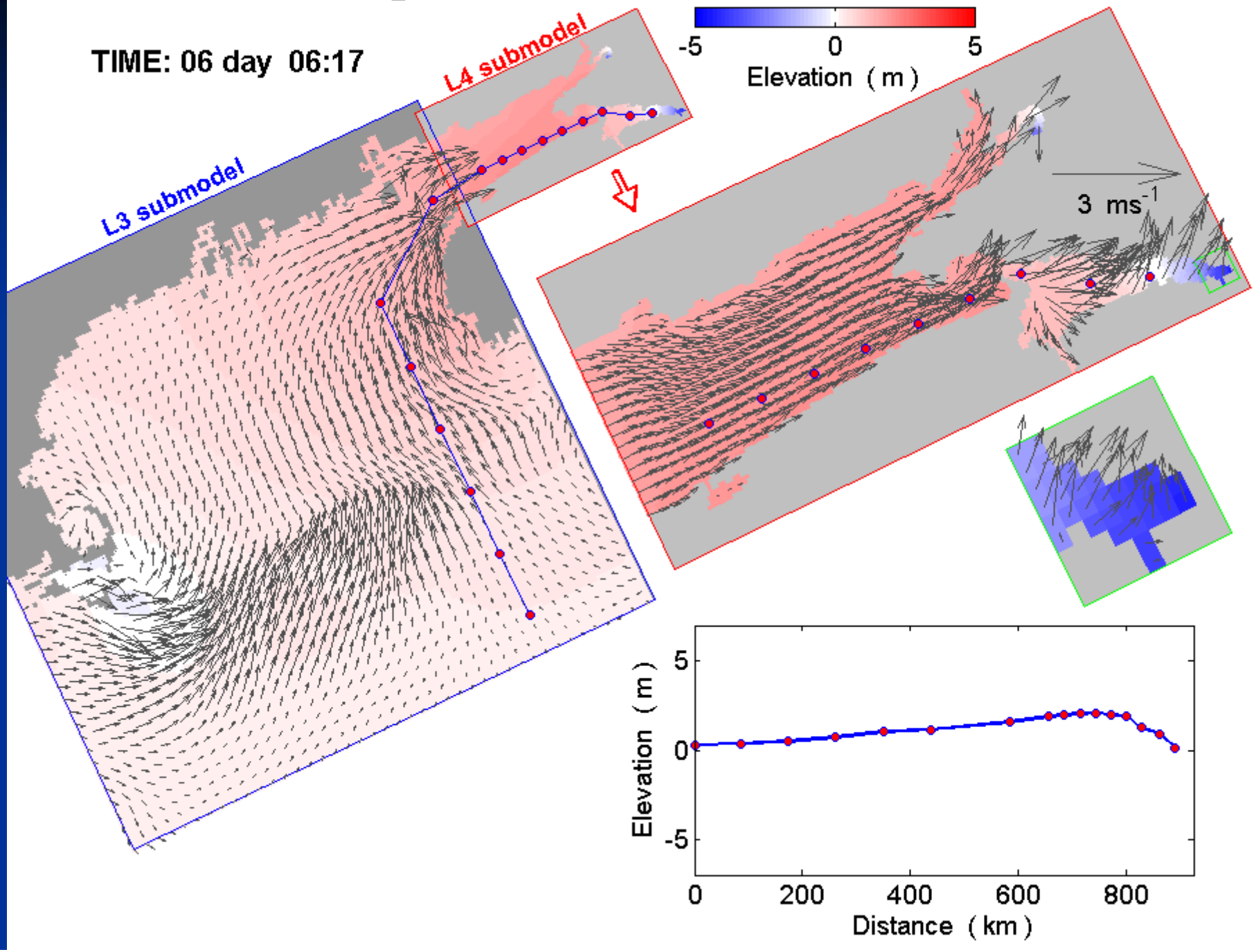
Efforts have been made in developing submodels L3 and L4 using POM.

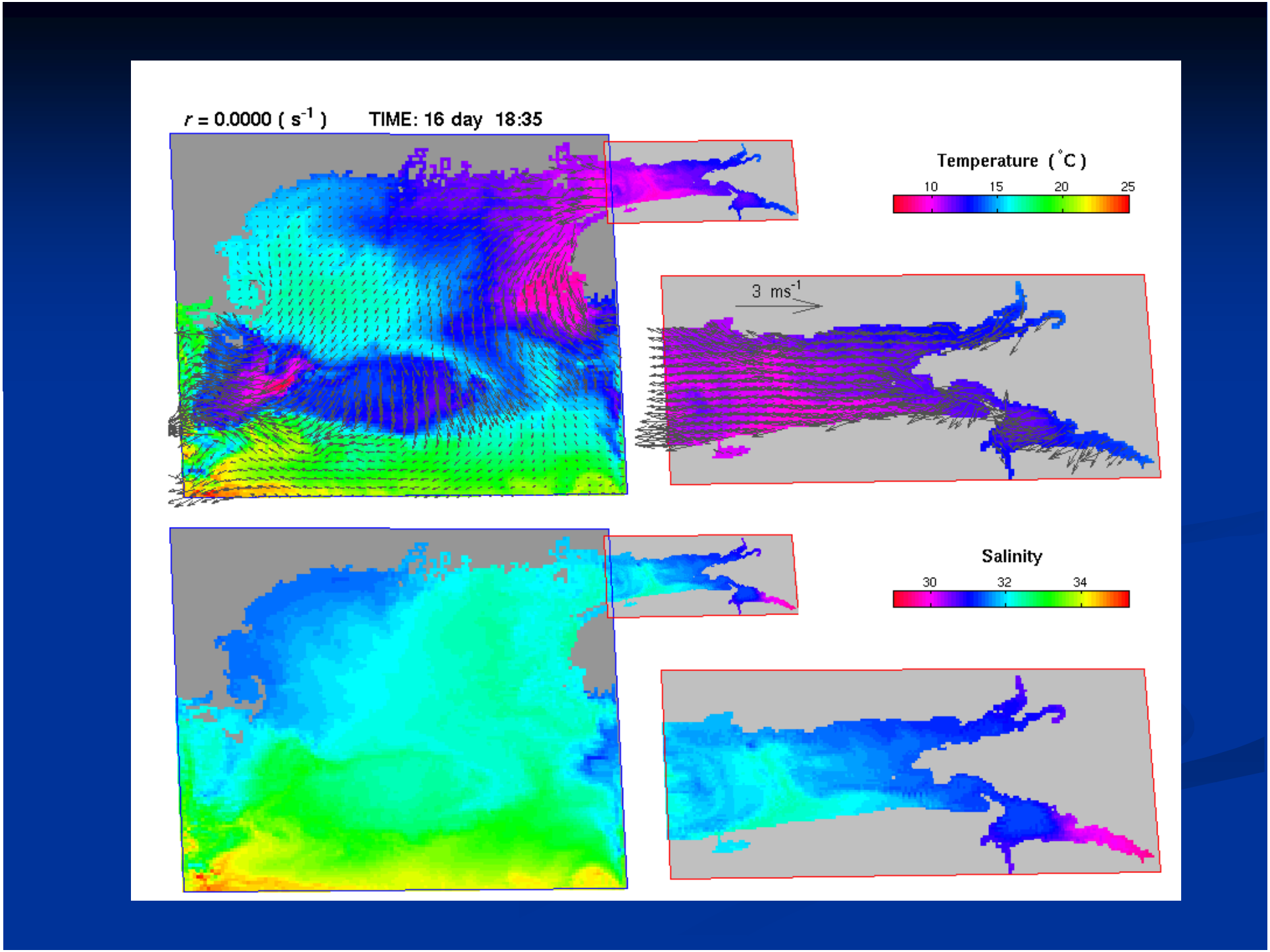
A two-way nesting technique based on the combination of adaptive and restoring boundary conditions for model variables along the dynamic interface of the two submodels

Davies and Flather (1978)'s boundary condition is also used for depth-mean currents over the dynamic interface.

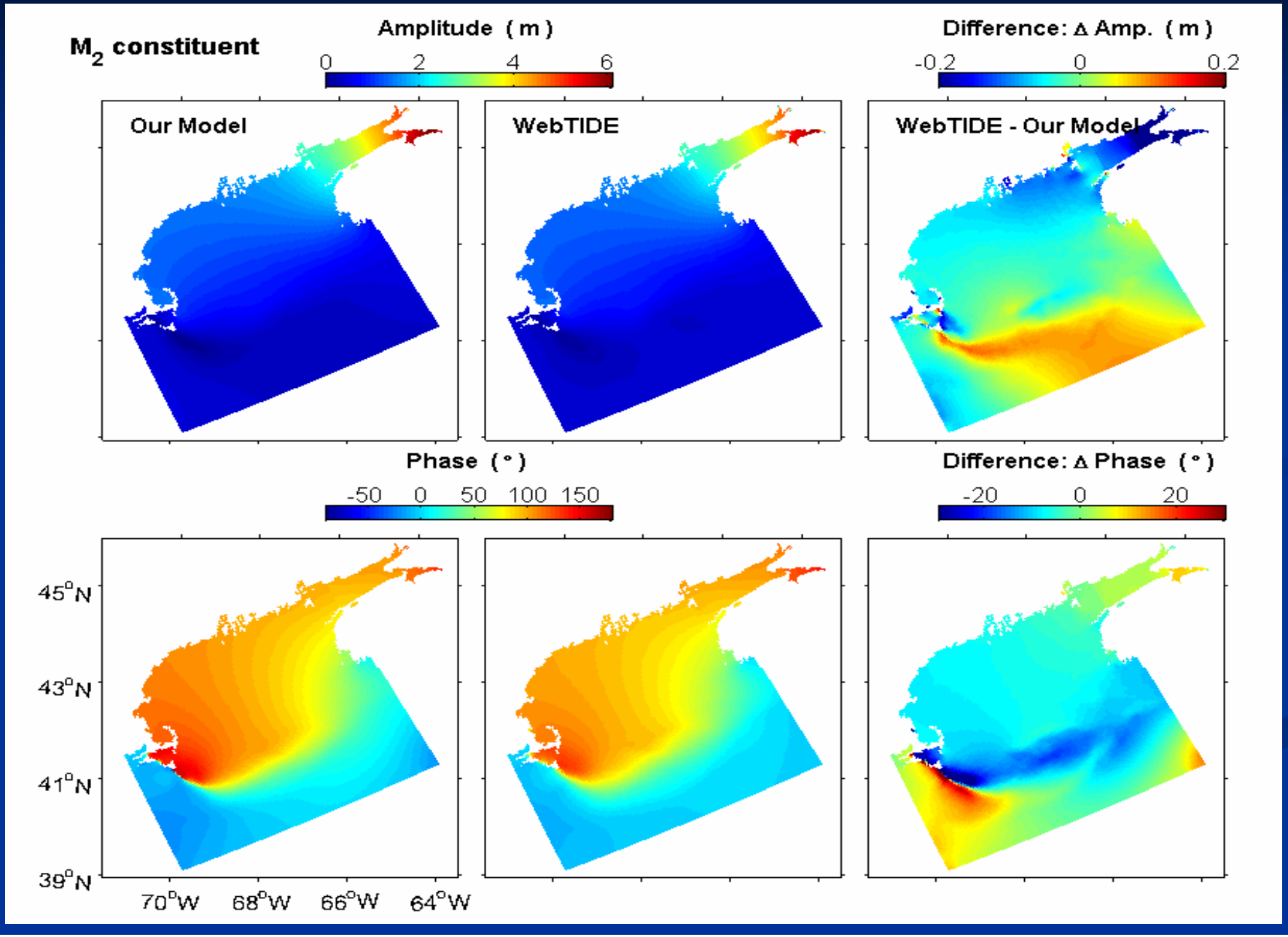
This talk focuses mainly on preliminary model results produced by submodels L3 and L4.

L3 & L4 sub-models (M_2 run)

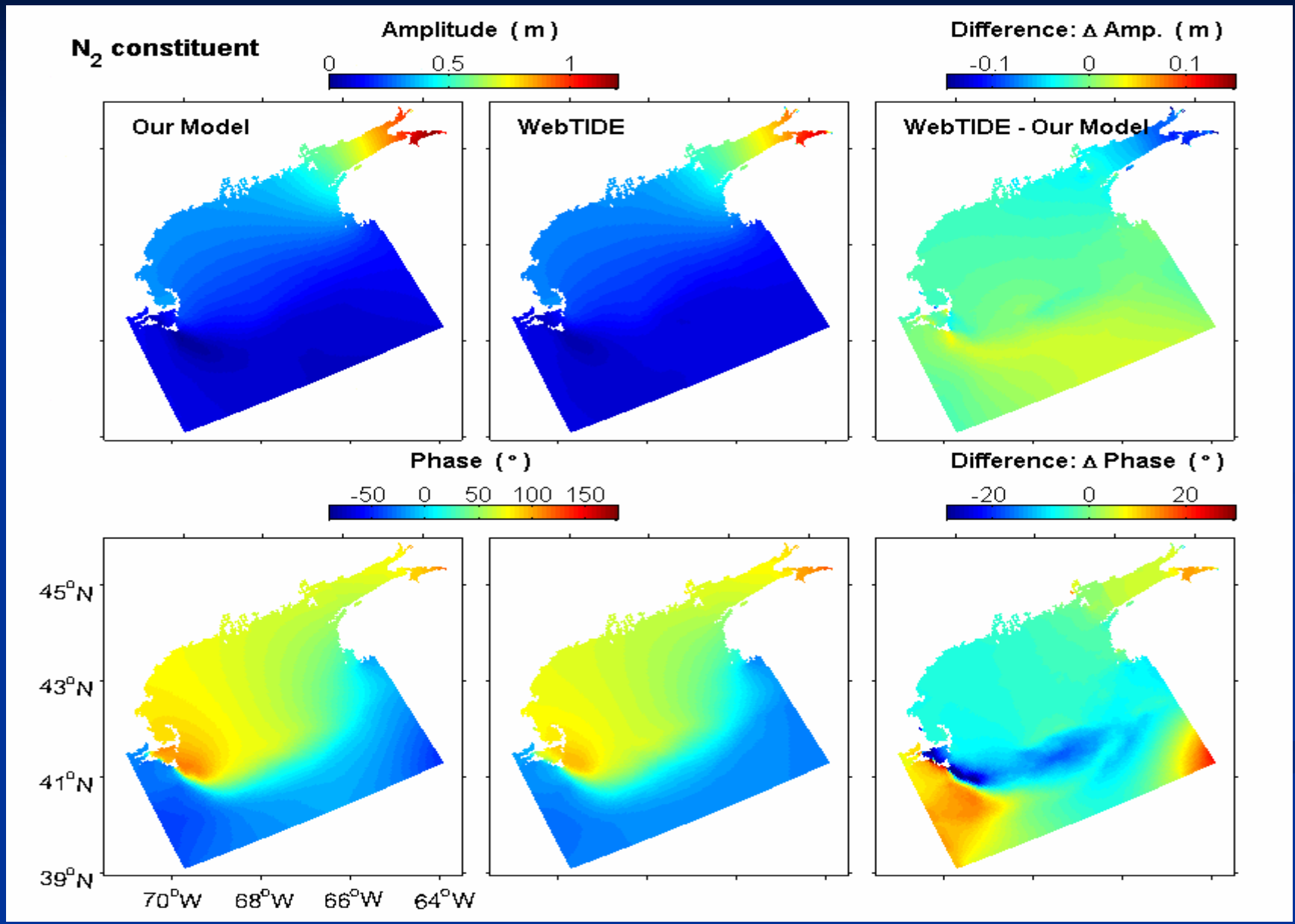



r = 0.0000 (s-1)
TIME: 16 day 18:35
Temperature (˚C)
10
15
20
25
3 ms-1
Salinity
30
32
34

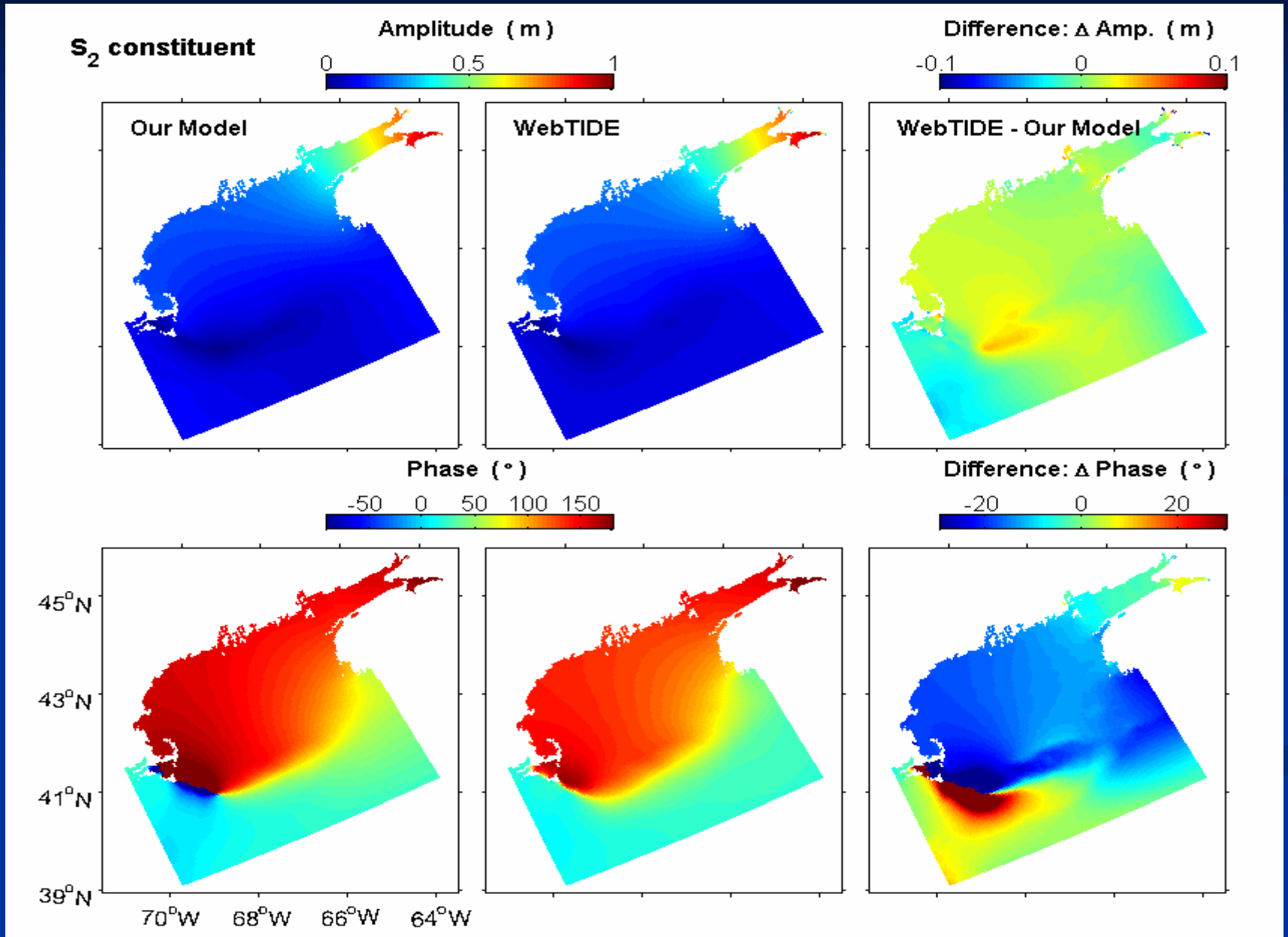
Assessment of model performance



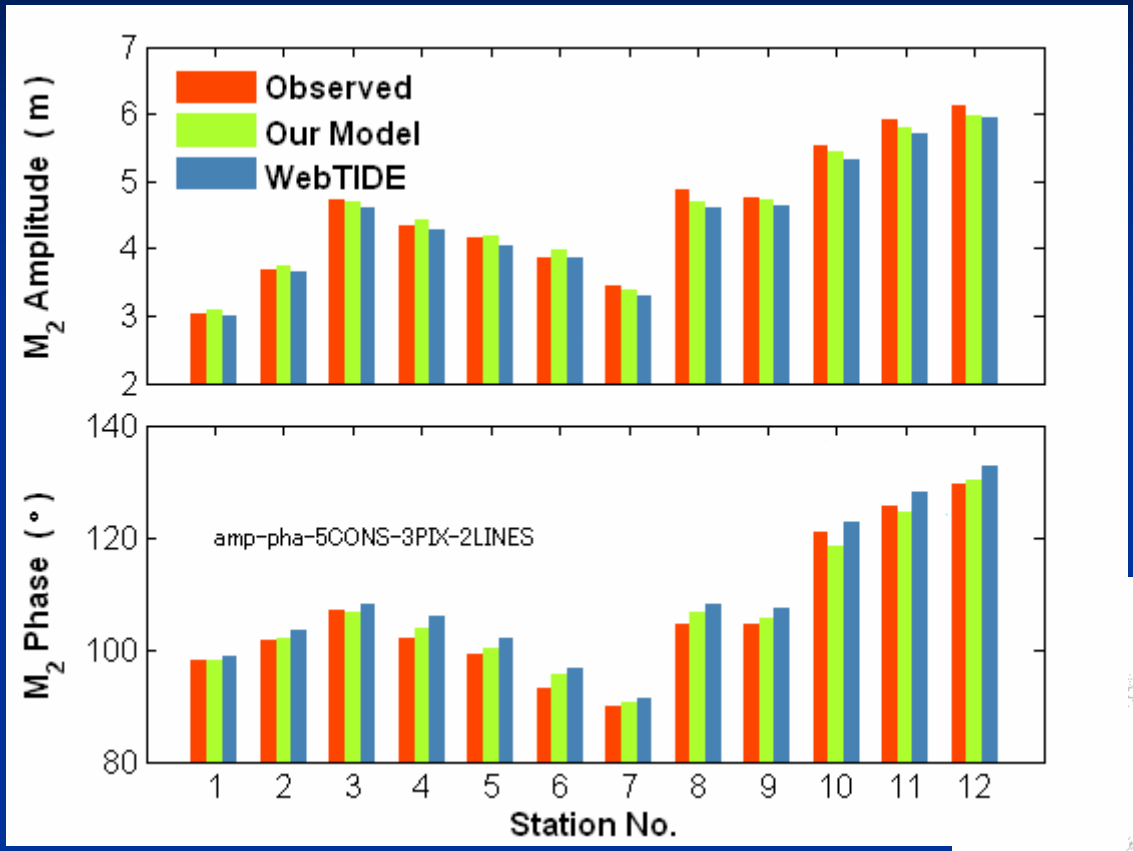
Assessment of model performance

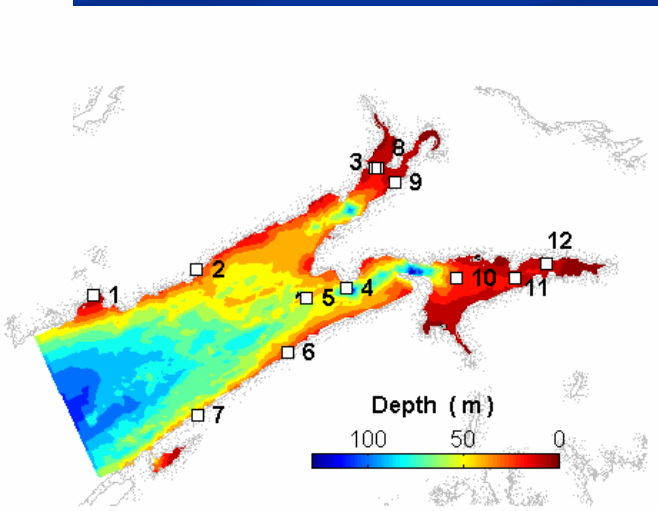


Assessment of model performance

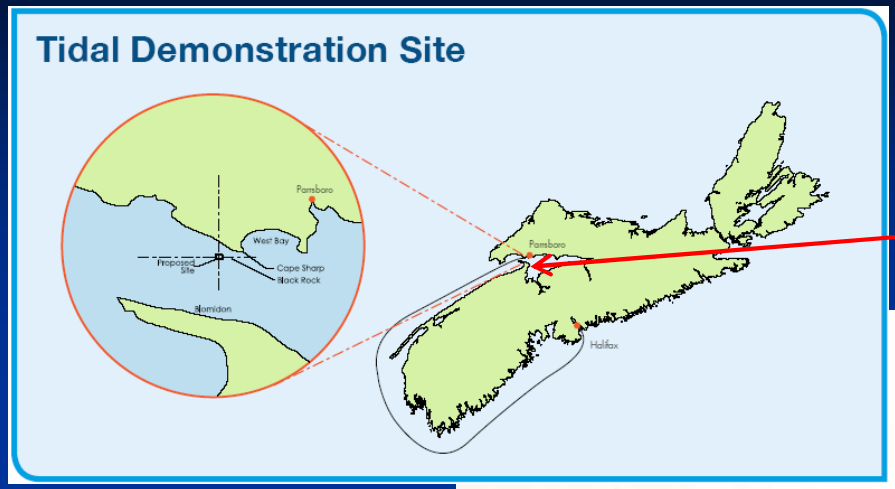


Comparison of observed and predicted amplitudes and phases of M_2 tide in the Bay of Fundy



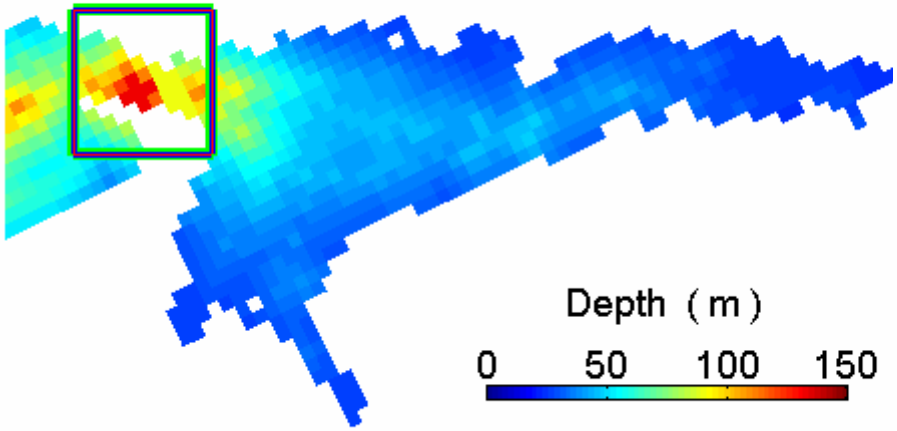


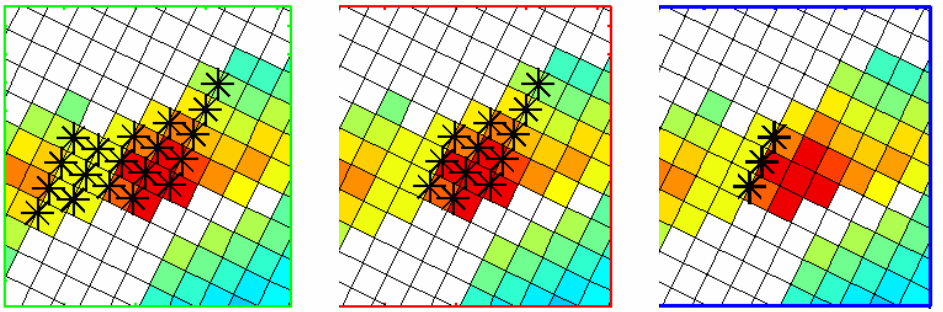
Turbine Test deployment at the Minas Channel



1MW Open-Centre Turbine (6m diameter) with 400-tonne base

Energy Extraction at the Minas Channel

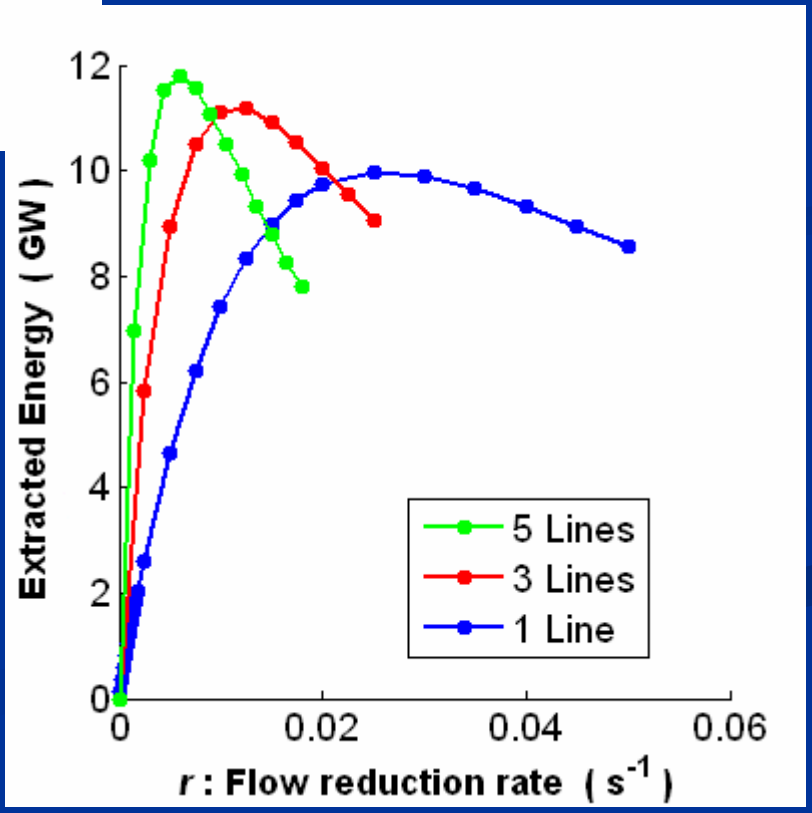




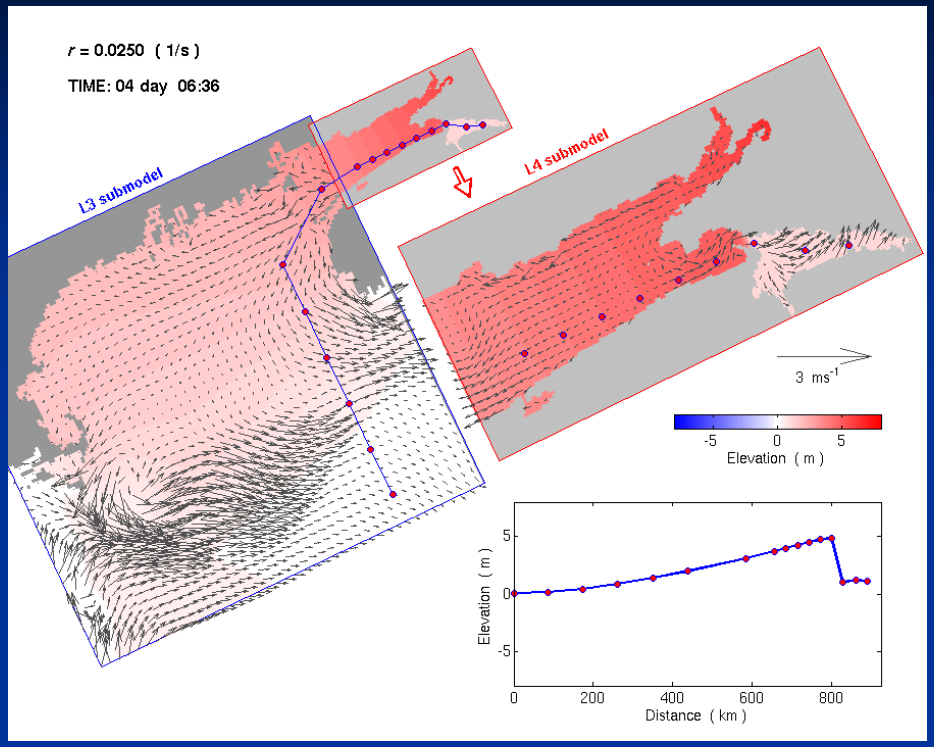
$$\frac{\partial u}{\partial t} = -ru \quad + \ldots$$

r : Flow reduction rate [s^{-1}]

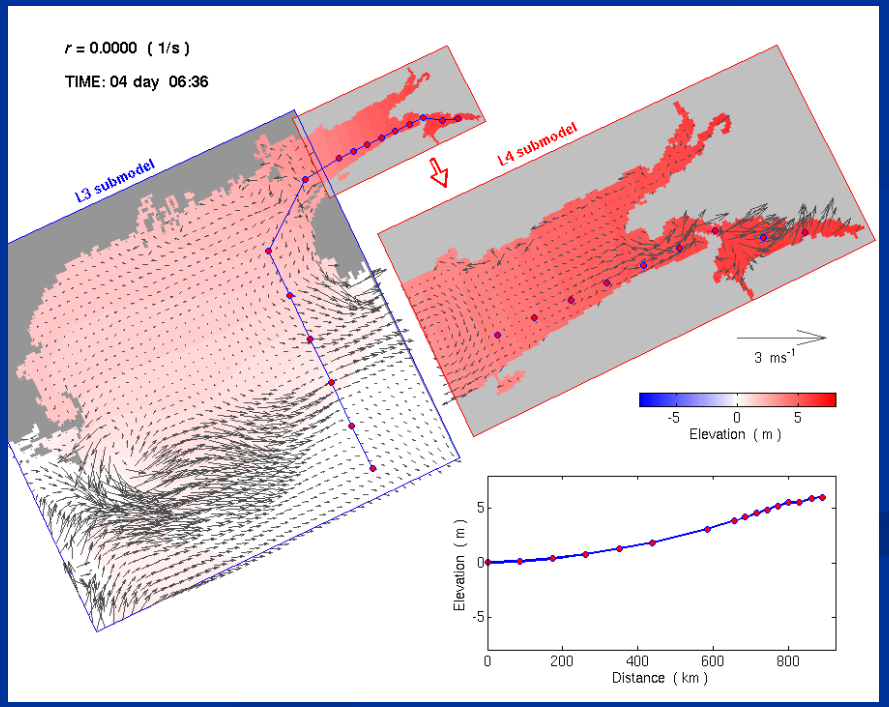
$$\frac{\partial u}{\partial t}\frac{1}{2}mu^2 = -rmu^2 \quad + \ldots$$



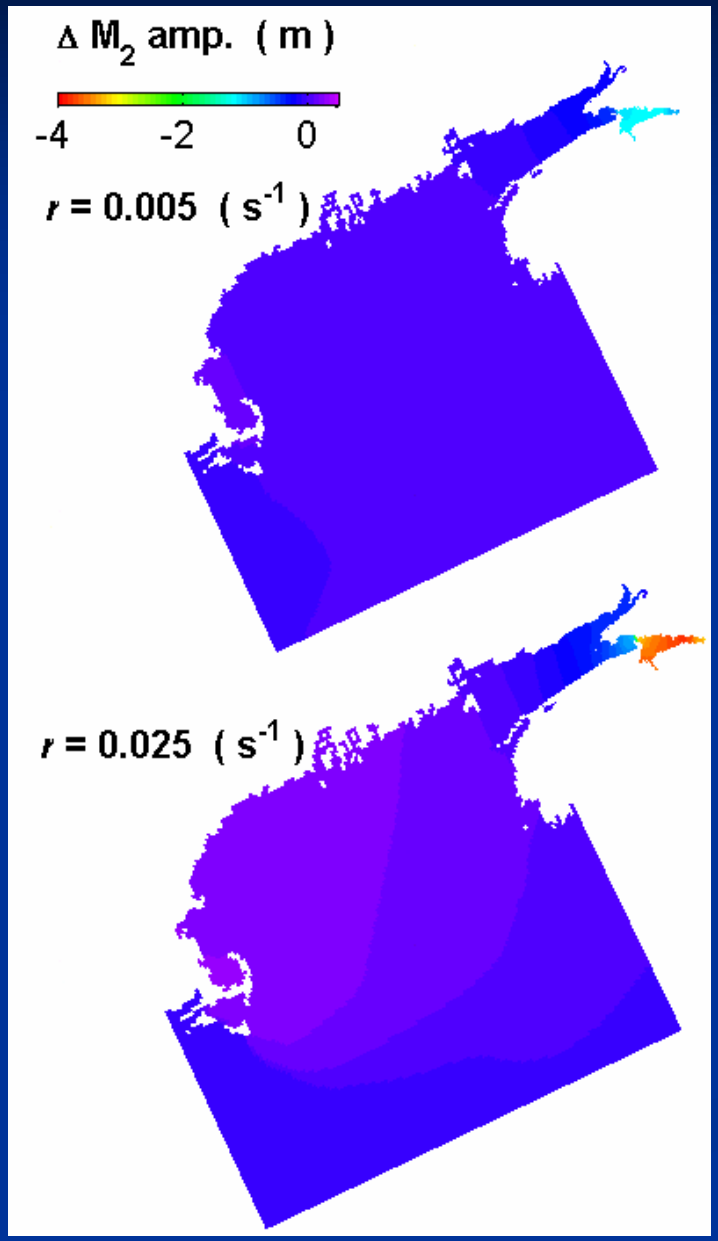
With Energy Extraction

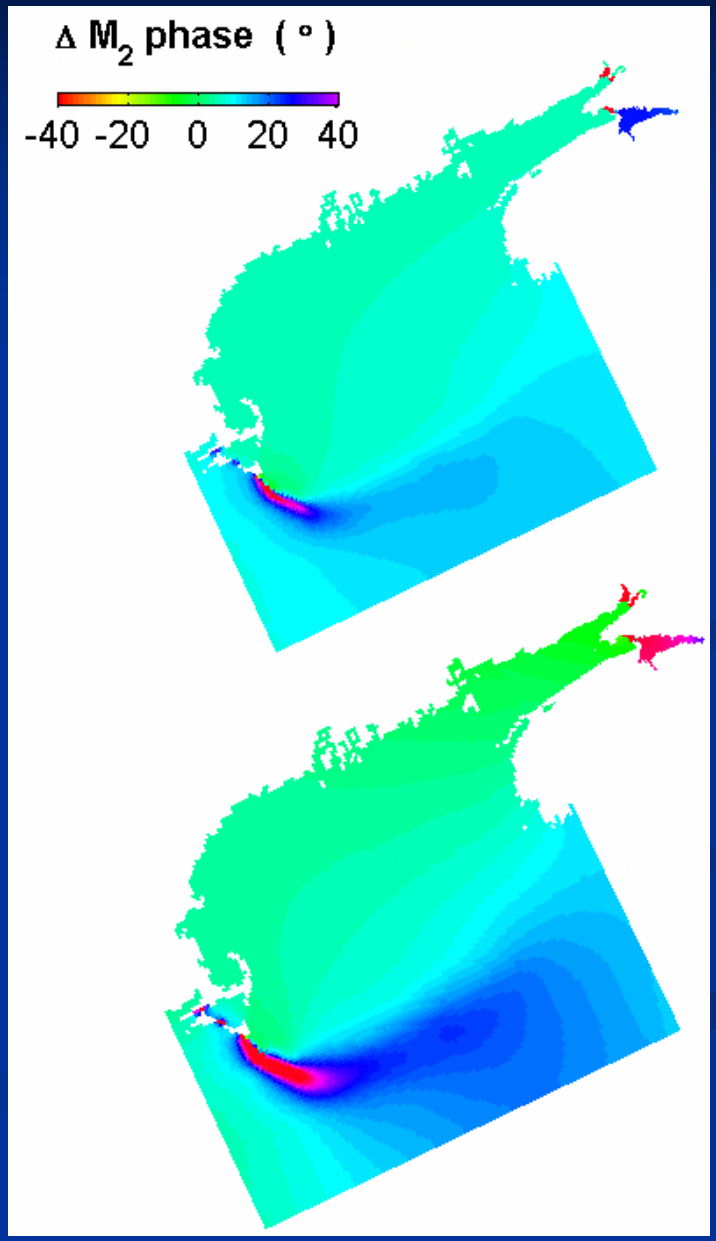


Without Energy Extraction

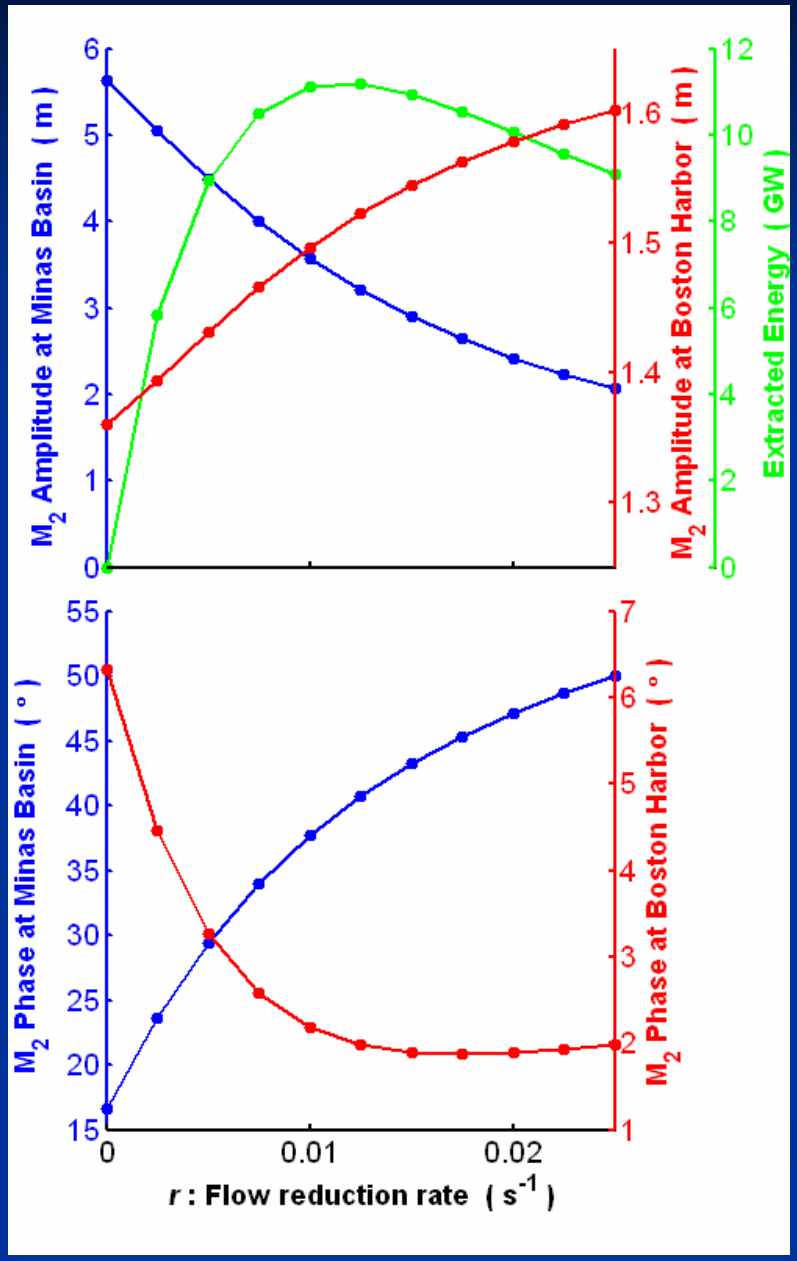


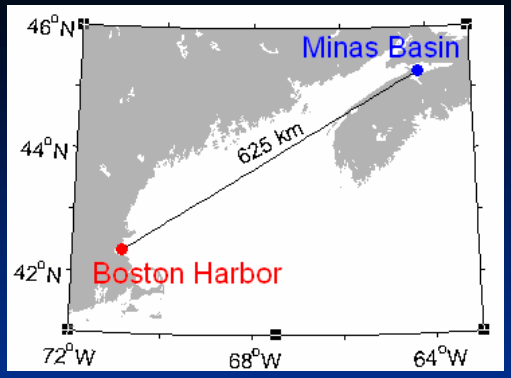
Effects of 9GW Energy Extraction





Effect of Energy Extraction





Two scenarios of
9GW Energy Extraction

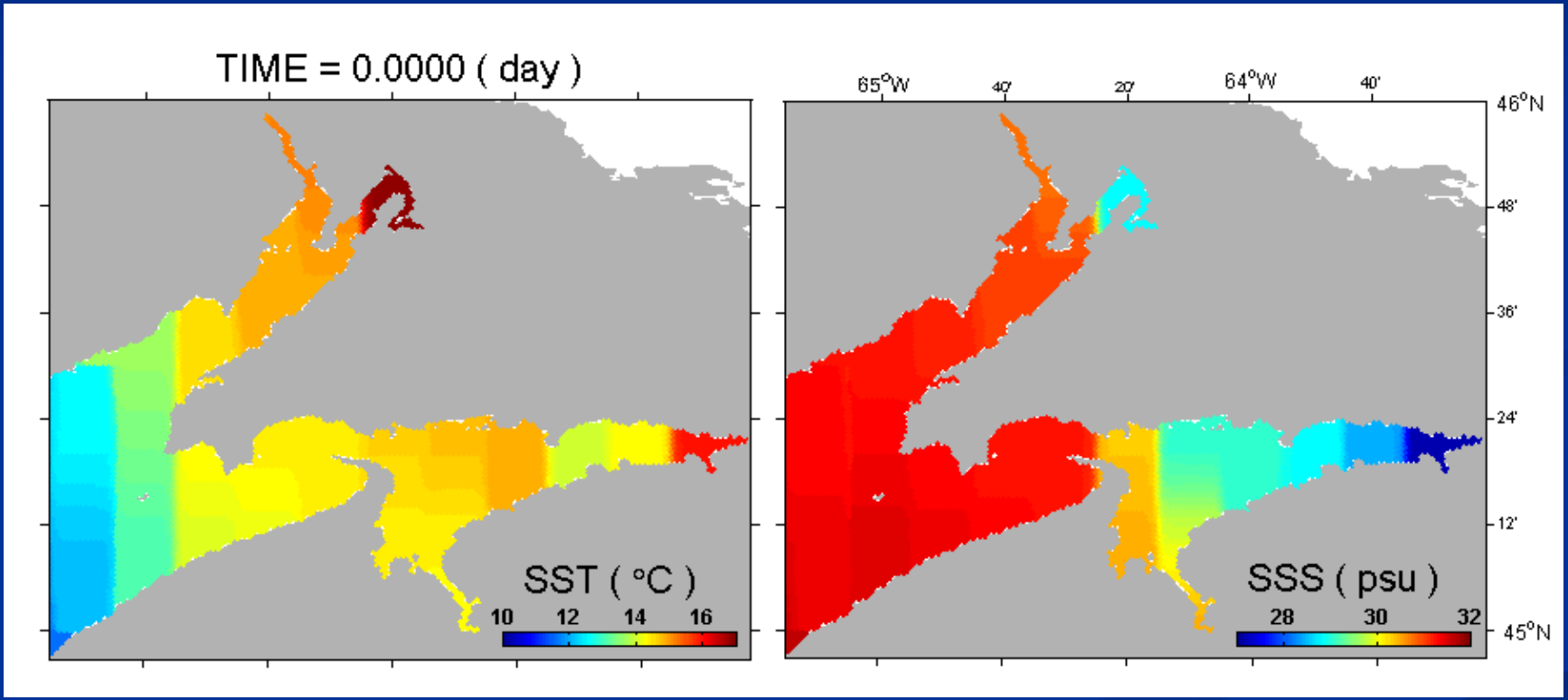
Changes at Minas Basin:

r (1/s)	0.005	0.025
ΔM_2Amp. (m)	-1.14	-3.57
ΔM_2Phase (°)	+13	+33

Changes at Boston Harbor:

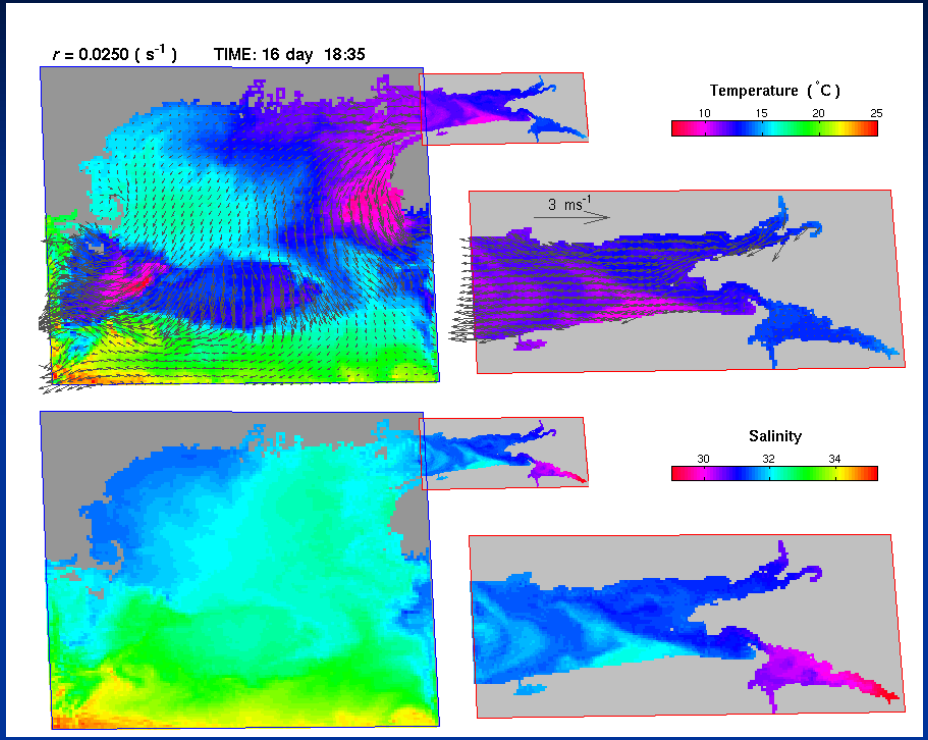
r (1/s)	0.005	0.025
ΔM_2Amp. (m)	+0.07	+0.24
ΔM_2Phase (°)	-3.0	-4.3

Simulated sea surface temperature (SST) and salinity (SSS)

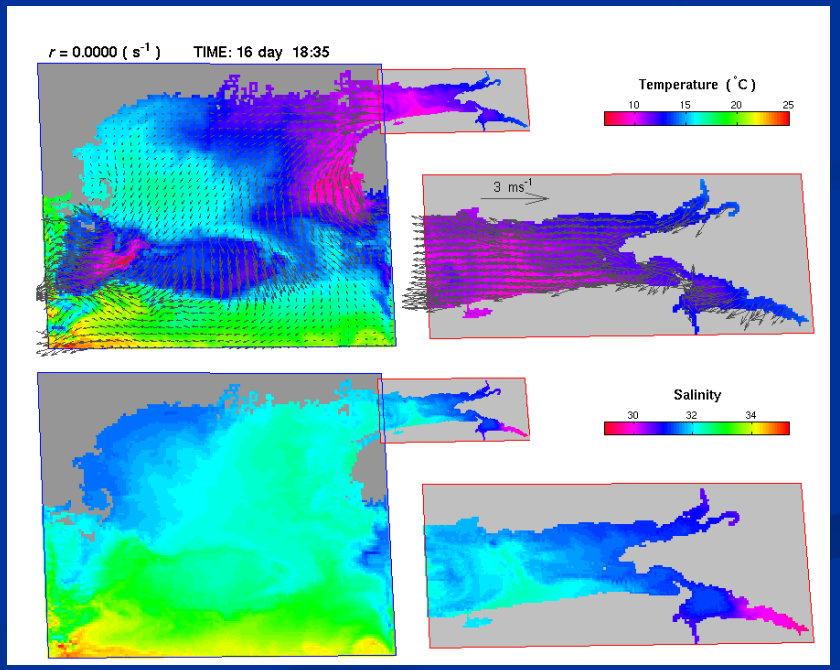


(Produced by sub-model L4 of NCOPS-BOF)

With Energy Extraction



Without Energy Extraction



4. Summary

- A two-level nested-grid model was developed for the Bay of Fundy (BoF). This model will be coupled to Dalcoast3 to form a 4-level nested-grid modelling system (NCOPS-BoF).
- Model performance of L3 and L4 in simulating tidal circulation was assessed.
- The farfield effect of energy extraction in the Minas Basin on the tidal circulation in the Gulf of Maine and Bay of Fundy was examined using the two-level nested-grid model.
- Research is under way to examine the effect of energy extraction on other physical variables, such as temperature and salinity fields, bottom stress and sediment distribution.