Circulation and Hydrographic Structure in the Bras d'Or Lakes: A Numerical Study

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AquaNet

(November 24, 2006)

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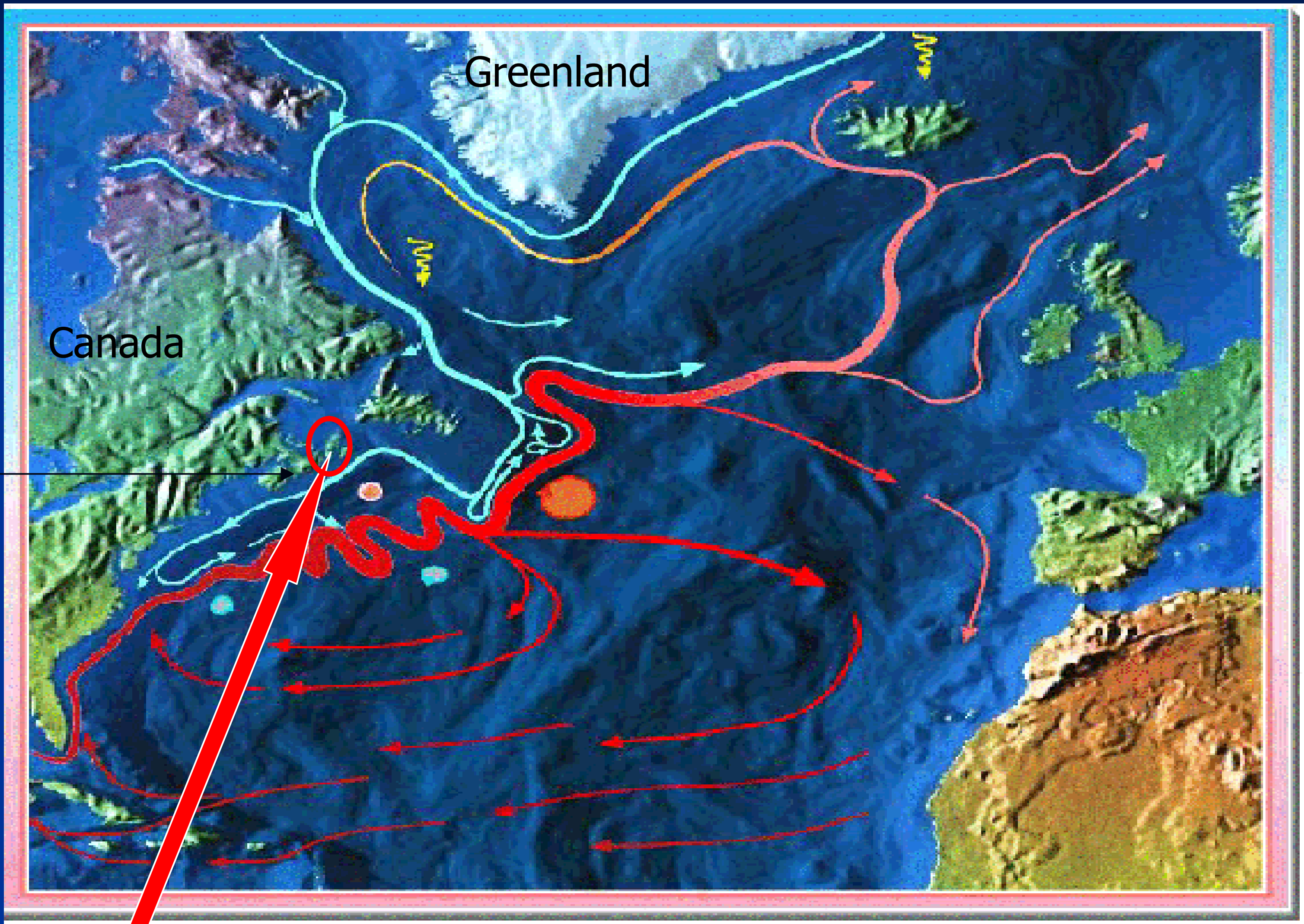
Introduction



Halifax

(courtesy of Dr. Igor Yashayaev)

Bras d'Or Lakes, Nova Scotia, Canada

Introduction

•The Bras d'Or Lakes are situated in Cape Breton Island at the northern end of Nova Scotia.

• Surface extension of about 1,100 km^2, with maximum depths of greater than 250 m and an averaged water depth of about 30 m.

Bras d'Or Lakes

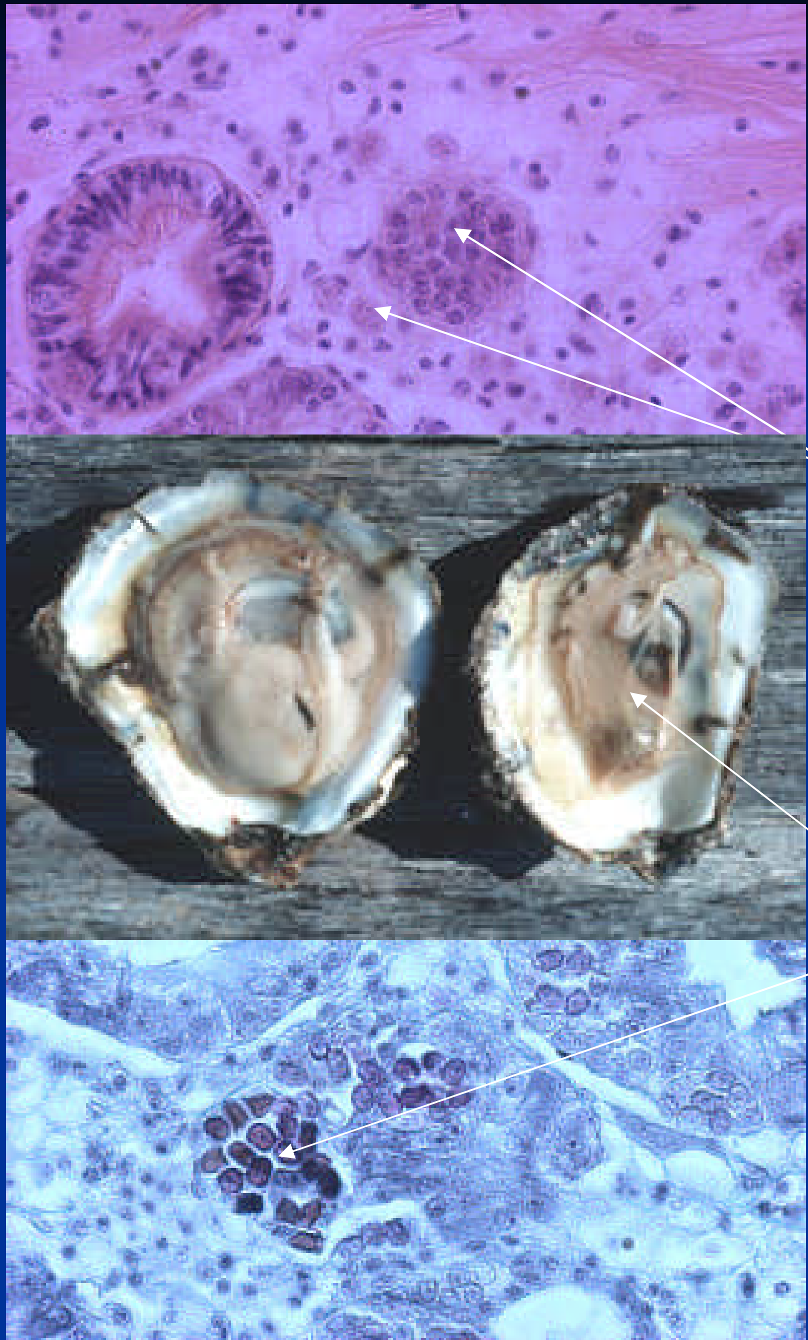
• Connected to the North Atlantic Ocean though three channels (Great and Little Bras d'Or Channels, St. Peter's Canal).

• **The Lakes are one of Canada's charismatic ecosystems, sustaining ecological and cultural communities unique in many aspects.**

MSX Disease in Bras d'Or Lakes

- *Haplosporidium nelsoni* (MSX, an oyster parasite) was discovered in the Bras d'Or Lakes in October 2000. The disease kills most of the oysters that become infected.
- High numbers of oysters died in affected areas in 2002 and local oyster industry was severely disrupted.
- The life stage of MSX is thought to be waterborne, indicating the disease could be dispersed with ocean currents over the region.

MSX Bioparticles



Haplosporidium nelsoni in oyster tissue:

- Plasmodia : 30-40µM dia.
  - Non-motile, Not know to be free-living outside tissue
  - Possibility of alternative host
- *Crassostrea virginica*
- Spores : 8-12µM dia.
  - Non-motile (passive), thought to be free-living
  - Neutral buoyancy "drifters"?

(Photos courtesy R. Beresford)

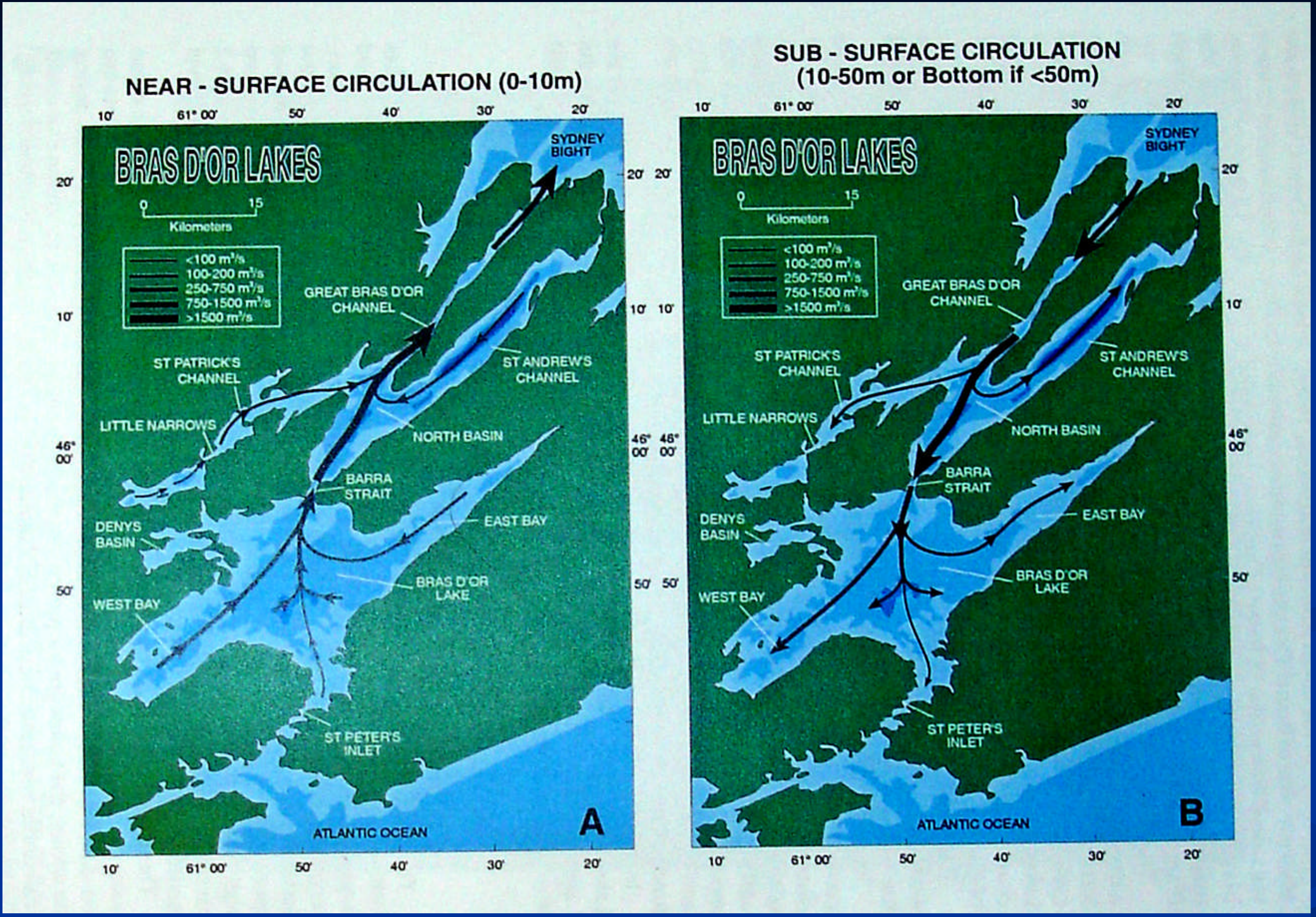
- A multi-disciplinary research project was funded by AquaNet (supported by NSERC) to develop tools to study the biological and environmental limitations of MSX infections in the Lakes.

- As part of the project, our research term is to develop a 3D baroclinic circulation model for the lakes.

- The 3D model results will be used to study the hydrodynamic connectivity among cultivation sites and risks of MSX spreading in the lakes.

Review of Previous Research in PO

- Krauel (1975) conducted a broad scale survey of the Lakes from August 1972 to July 1974.
- Gurbutt and Petrie (1995) described a large-scale feature of horizontal and vertical water transport.
- Petrie (1999) studied sea level variability in the Lakes.
- Petrie and Bugden (2002) reviewed the physical oceanography of the Lakes (circulation, mixing, TS distributions, sea level & sea ice).
- Dupont et al. (2003) simulated the tides of the Lakes.



Schematic presentations of near-surface and sub-surface circulations in the Bras d'Or Lakes. The line thickness is proportional to the strength of the flow (Petrie and Bugden, 2002)

Previous circulation models developed for the Bras d'Or Lakes

- Gurbutt and Petrie (1993) developed **a multiple box model**, which consists of 2 or 3 layers in 9 different regions to estimate horizontal and vertical transport for Lakes.
- Petrie(1999) developed a **1D, cross-sectionally averaged model** to study the sea level variability in the lakes.
- Dupont et al. (2003) developed a **2D finite element tidal model** incorporating realistic topography to simulate 5 major constituents (M_2, S_2, N_2, K_1, O_1).

Great challenges in developing a 3D model for the Bras d'Or Lakes

- Complex topography
- Effects of ocean tides and boundary currents associated with air pressure perturbations
- Buoyancy forcing associated with freshwater runoff from rivers
- Typical 2-layer estuarine circulation

Developing a nested-grid, 3D, circulation model for the Bras d'Or Lakes

- As the first step toward a nested-grid modelling system for the Bras d'Or lakes, we developed a single-domain circulation model, with horizontal resolution of 500 m and vertical resolution of 2 m in the top 40 m.
- The single-domain model is used as the outer model of the nested-grid circulation model under the development.
- The nested model has two subcomponents: an outer model and inner model(s).
- The lake circulation model is based on CANDIE.

CANDIE: a 3D Ocean circulation model

- The free-surface version of CANDIE was used in the development, CANDIE stands for CANadian version of Diecast (Sheng, Wright, Greatbatch and Dietrich, 1998; Lu et al., 2001; Sheng and Wang, JGR, 2004; Wang et al., JPO, in press).

- A three-dimensional, primitive equation, finite-difference, z-level model.

- Uses the fourth-order numerics and flux limiter.

- **Website: www.phys.ocean.dal.ca/programs/CANDIE**

Model parameters and forcing

- Horizontal resolution: 500 m
- Vertical resolution: 2 m in the top 40 m

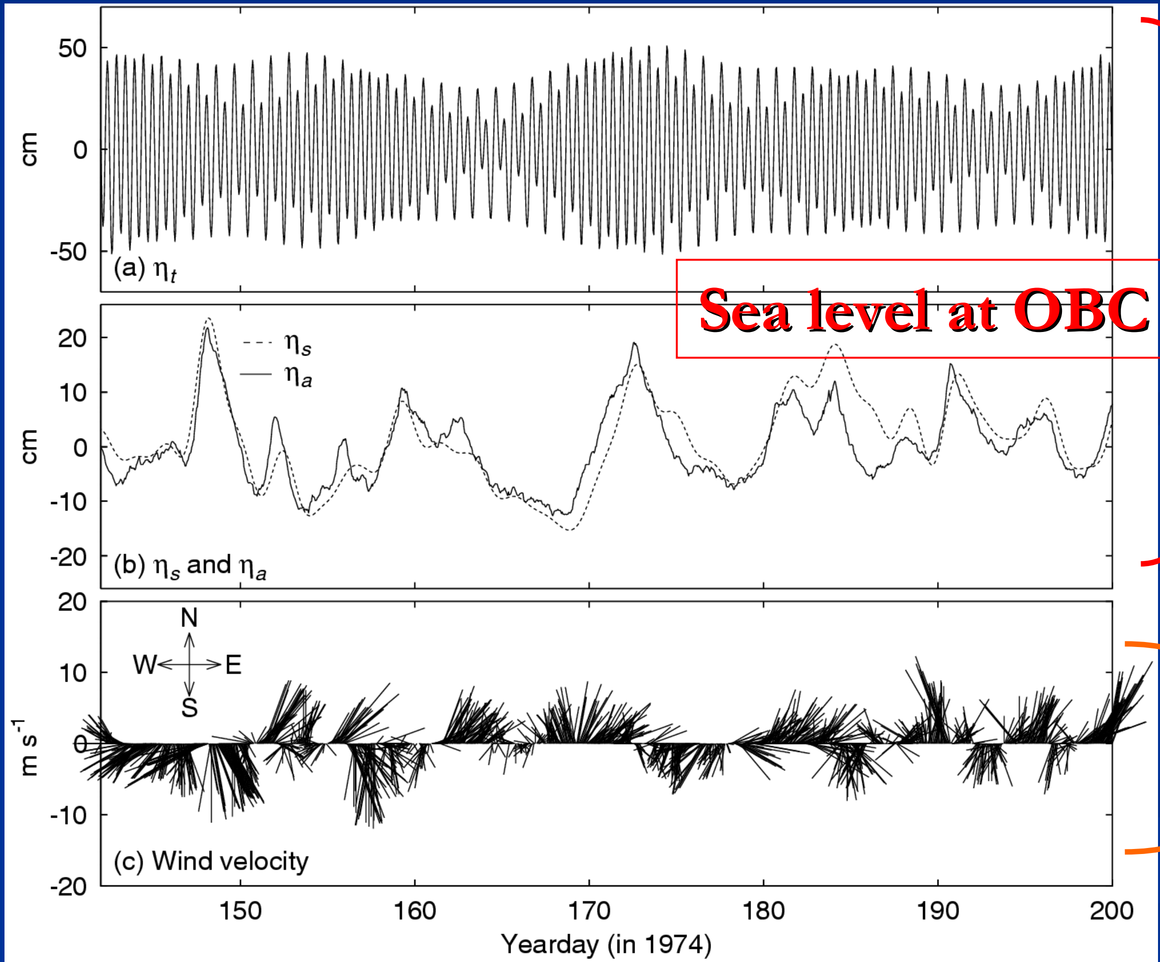
  (except for 4 m in the top z-level)
- Sub-grid mixing parameterizations

  Smagorinsky horizontal mixing scheme (1963)

  Modified KPP scheme for vertical mixing
- Quadratic bottom stress
- Model forcing:

  1. Tidal forcing (M_2, S_2, N_2, K_1, O_1) at the open boundary
  2. Observed wind and air pressure at North Sydney airport
  3. Monthly mean heat flux (climatology)
  4. Monthly mean river runoff (17 rivers)

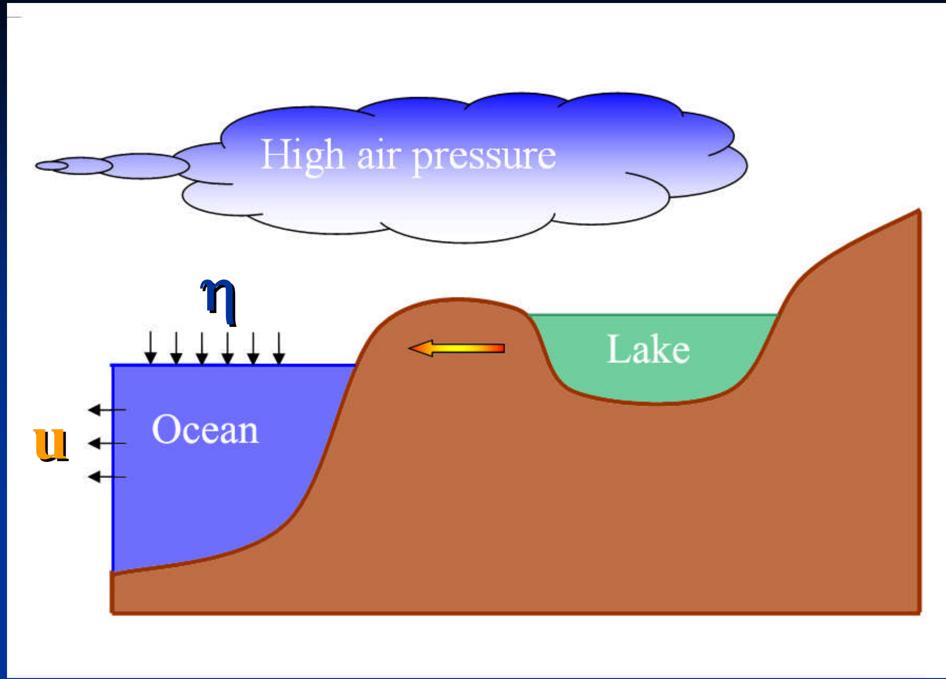
Tidal and sub-tidal seal level variations at OBC and Observed wind speeds



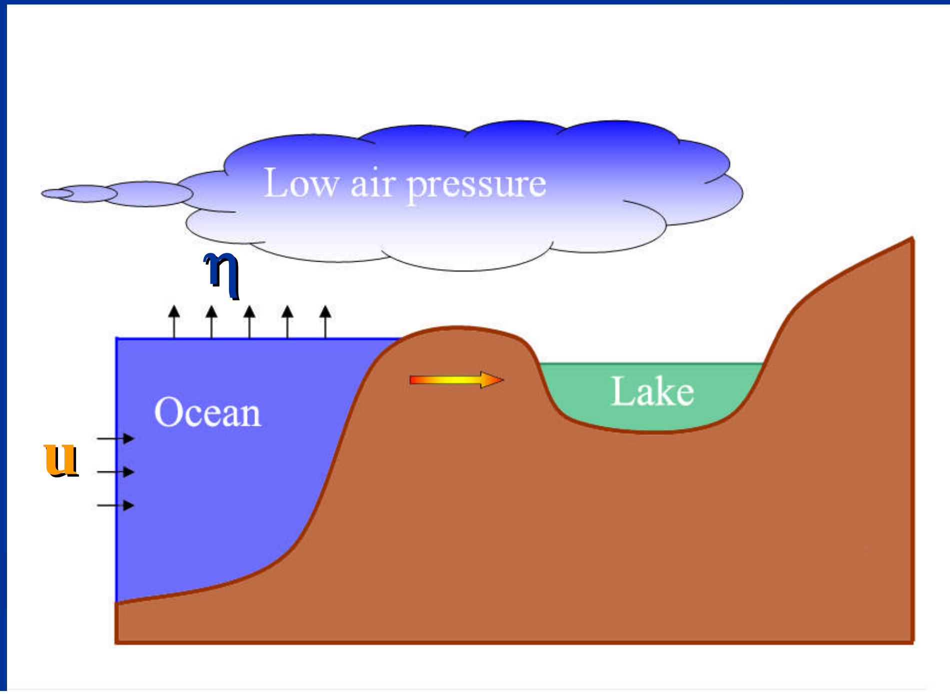
Sea level at OBC

Wind at Sydney Airport

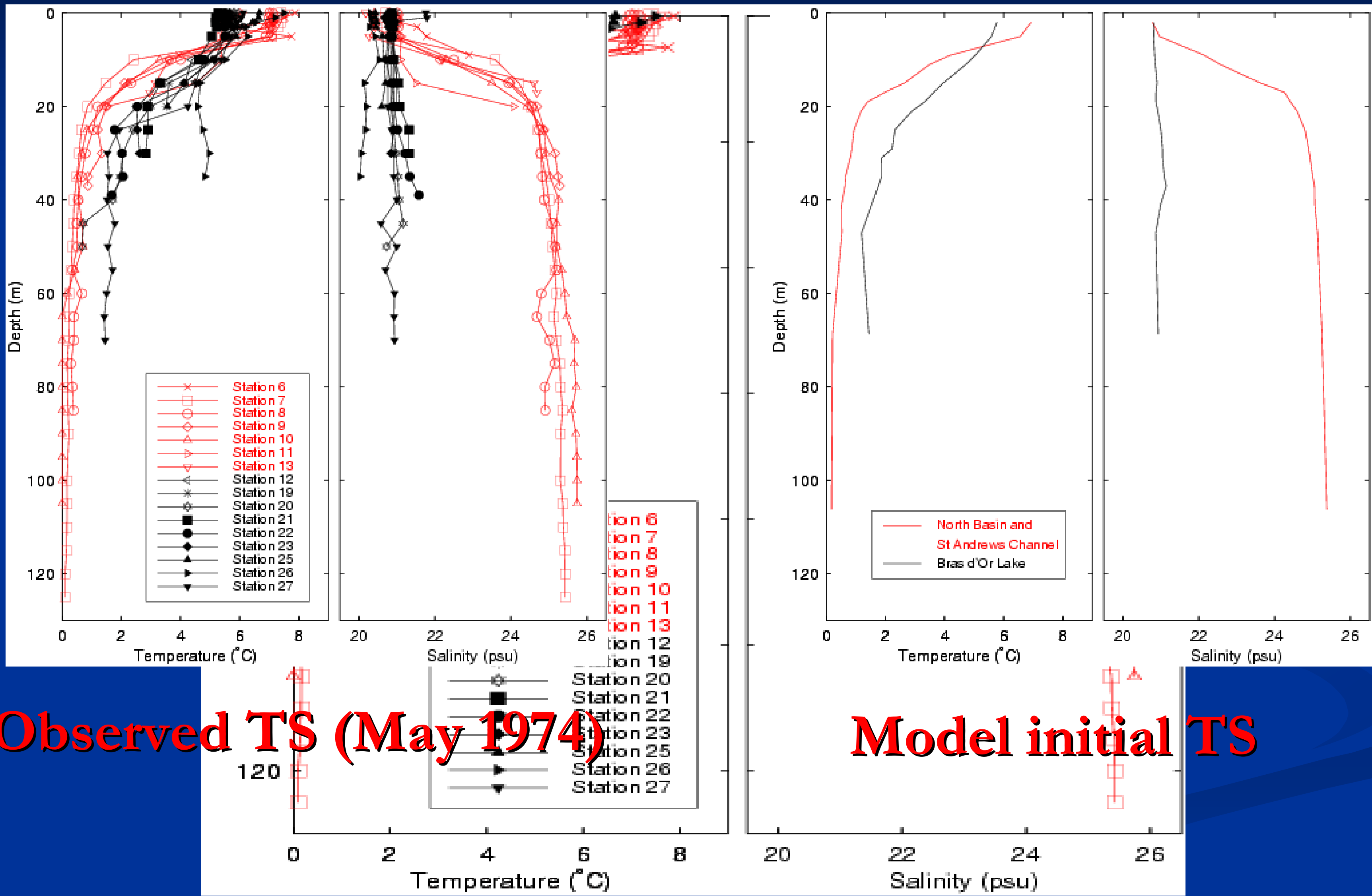
Outflow through the channel under a high air pressure system



Inflow through the channel under a low air pressure system



Observed temperature and salinity profiles



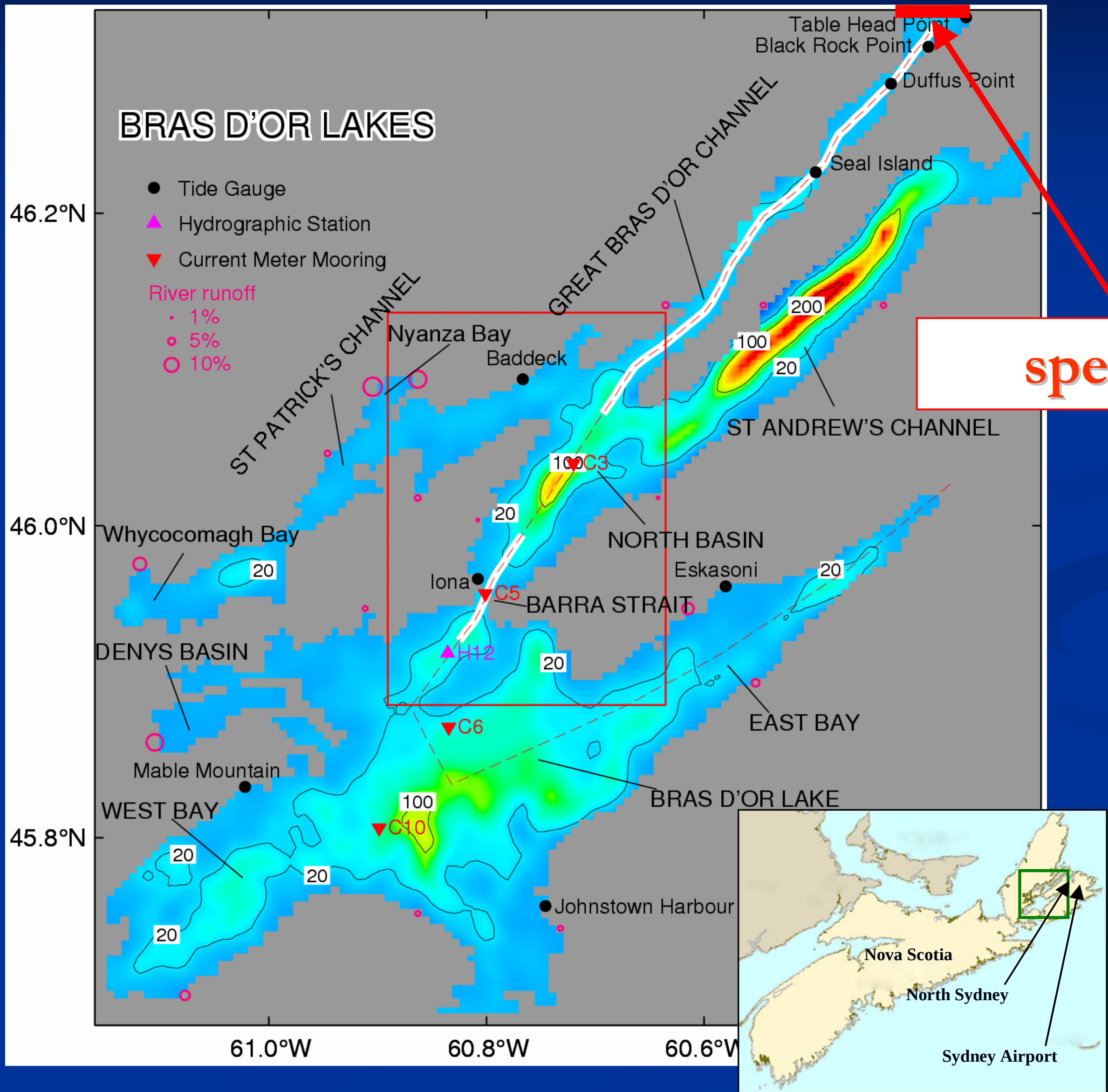
Observed TS (May 1974)

Model initial TS

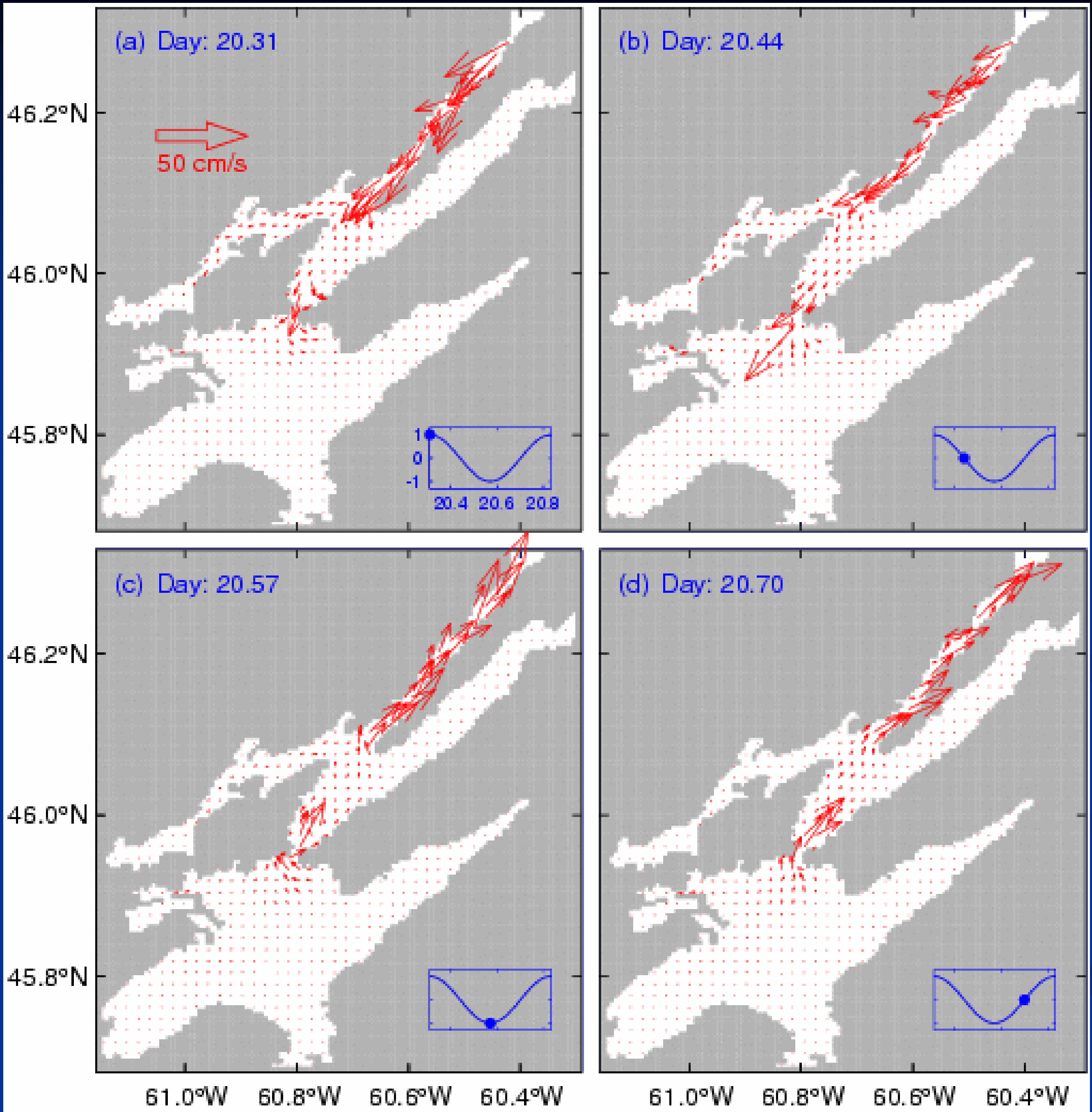
(Single-Domain) Model Results

1. Process study:
   - M_2 tidal circulation
   - Circulation forced by steady wind
   - Buoyancy-driven circulation associated with river runoff
2. Reconstructing circulation and hydrographic distributions in June and July 1974

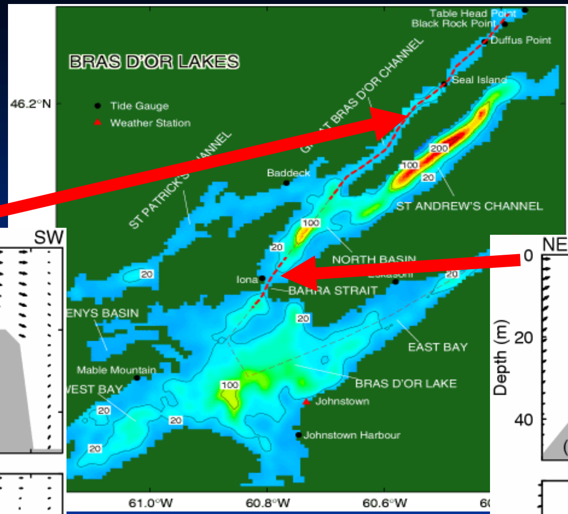
M_2 Tidal Circulation

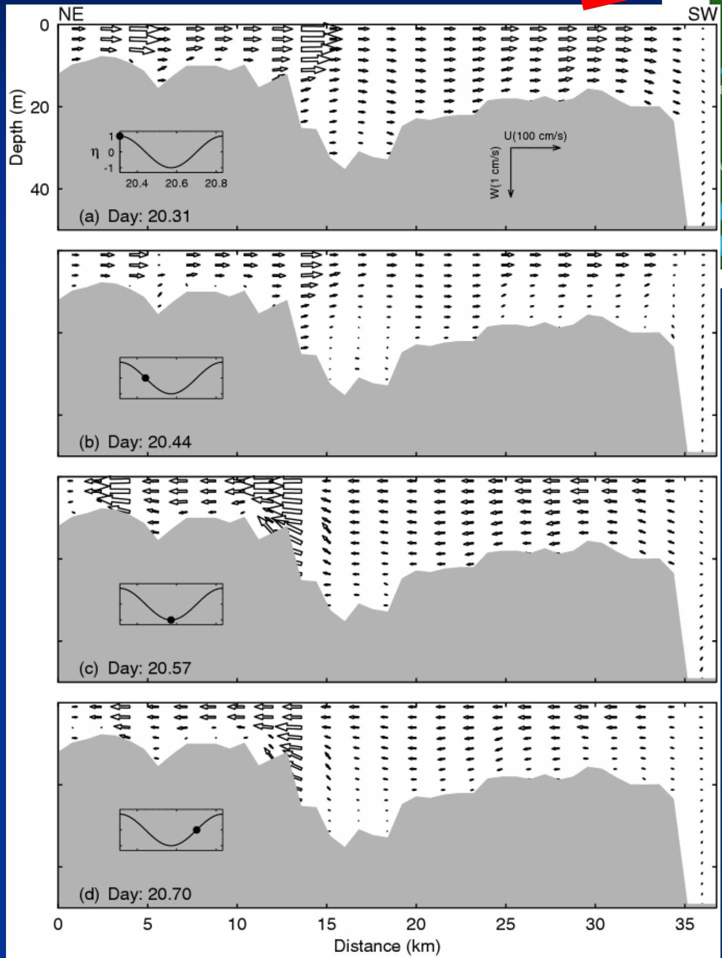


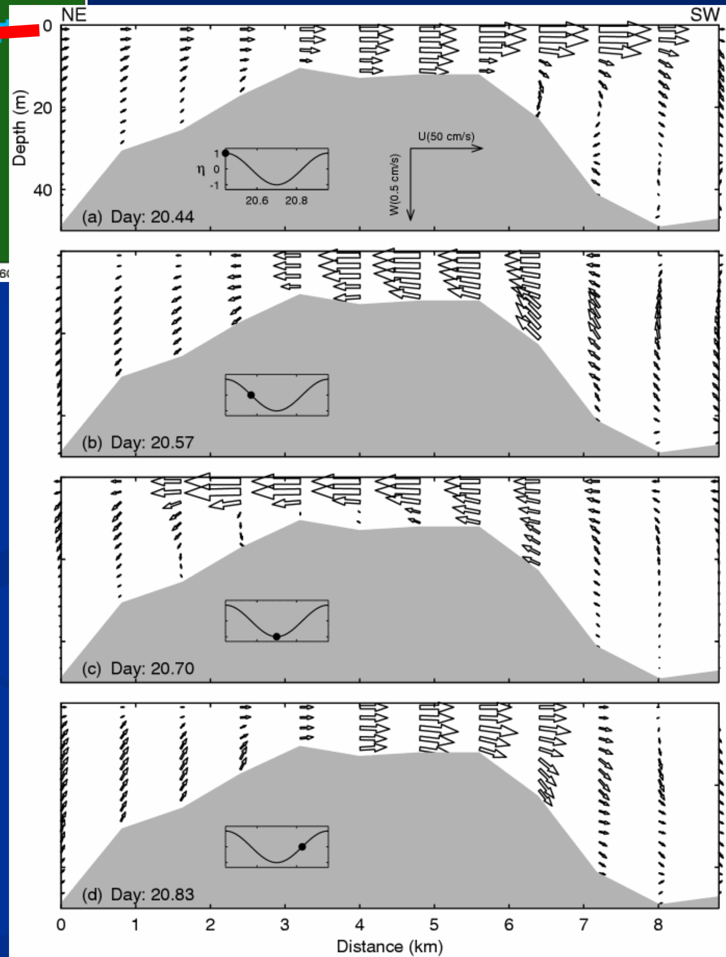
specify M_2



(a) Day: 20.31
(b) Day: 20.44
(c) Day: 20.57
(d) Day: 20.70
50 cm/s
46.2°N
46.0°N
45.8°N
61.0°W
60.8°W
60.6°W
60.4°W
1
0
-1
20.4
20.6
20.8







The Great Bras d'Or Channel

Barra Strait

Table Head Point (THP)

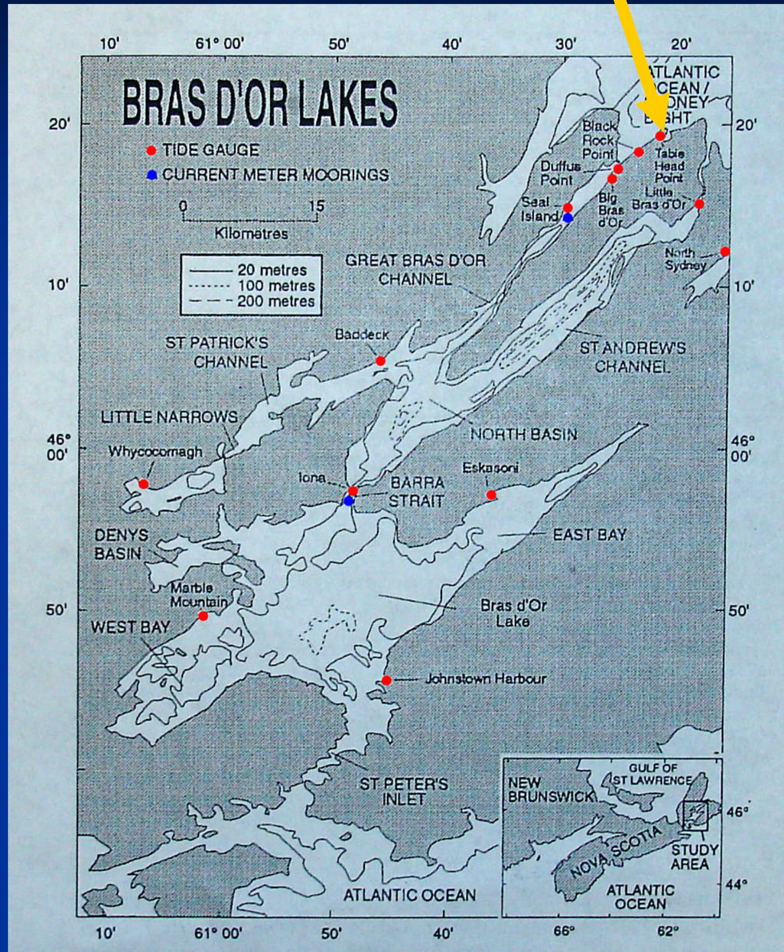
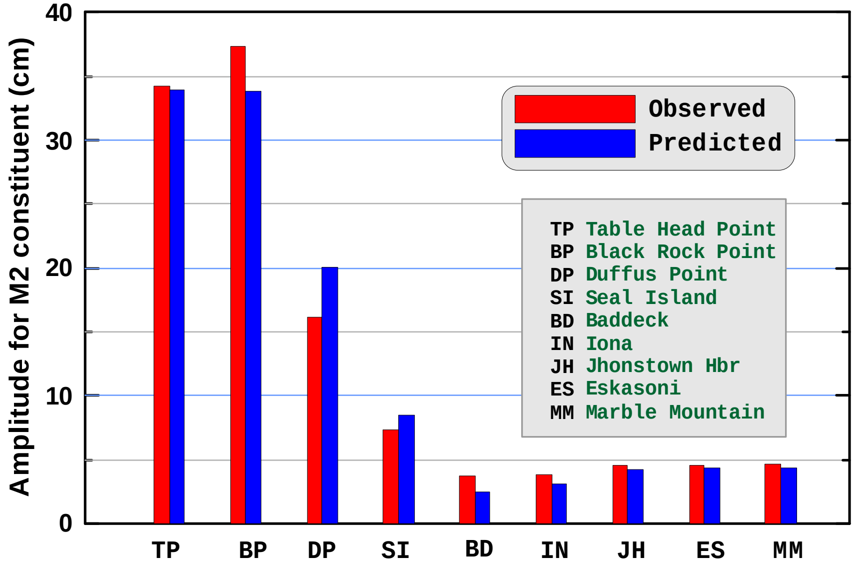


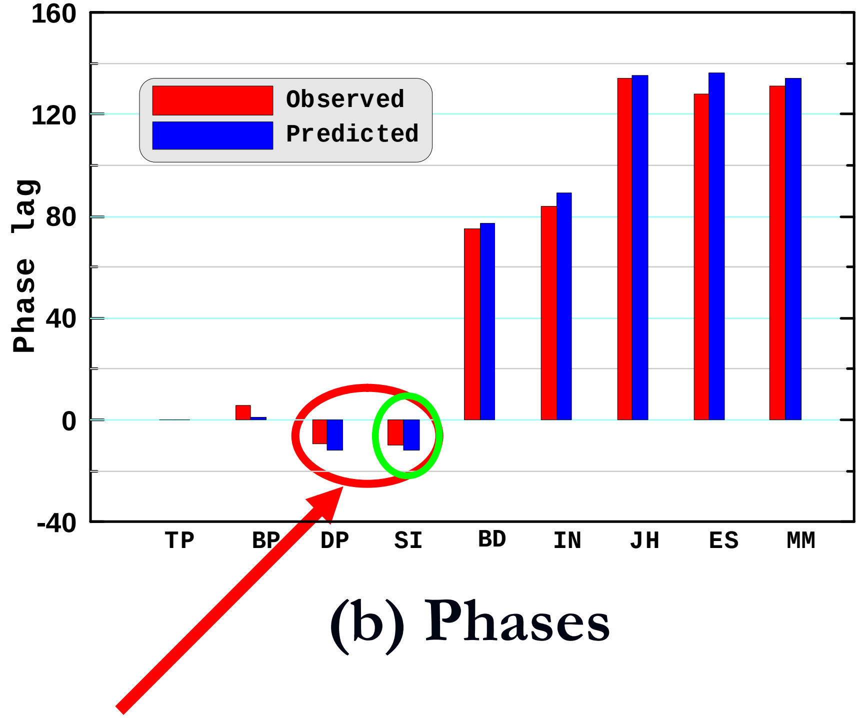
Fig. 1 Geography of the Bras d'Or Lakes with locations of sea level gauges (solid dot) and current meter moorings (open triangle).

Topography of the Bras d'Or Lakes with locations of sea level gauges (red dot) and current meter moorings (blue dot) (From Kraul, 1975).

Observed and calculated M_2 amplitudes and phase lags (relative to BP) at 9 stations

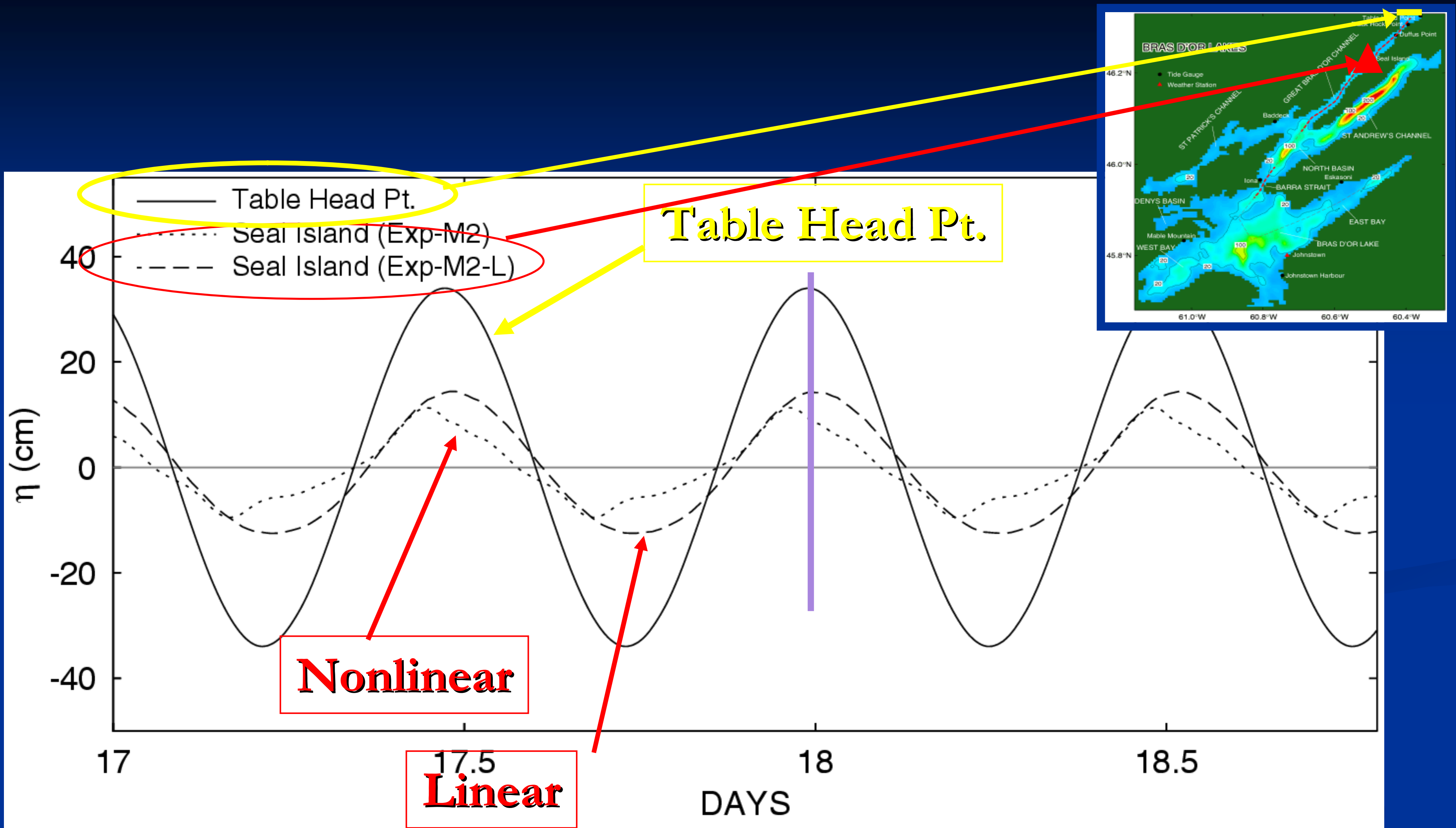


(a) Amplitudes



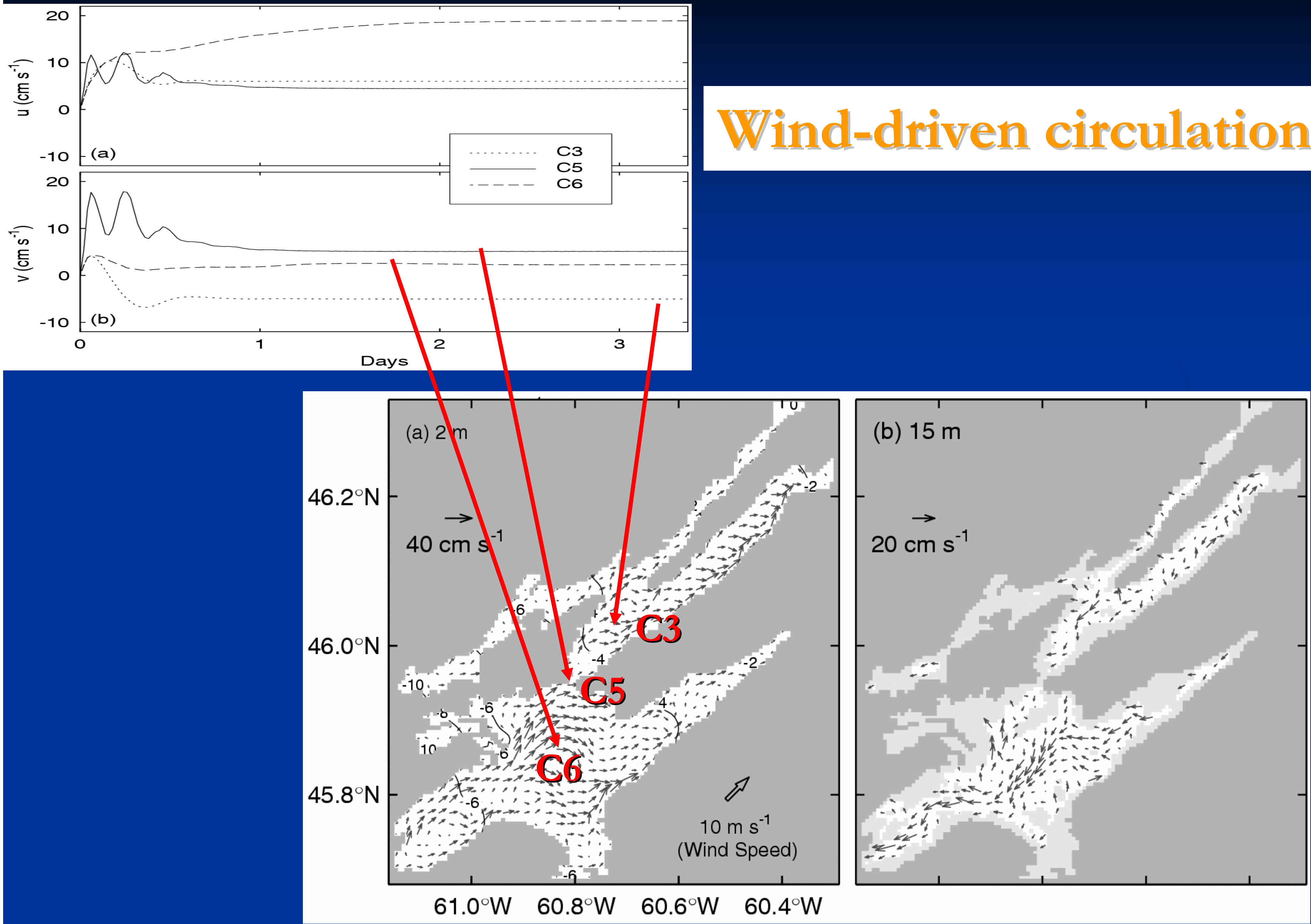
(b) Phases

High water appears earlier than it does at THP, due mainly to strong nonlinear bottom friction (Petrie and Bugden, 2002)

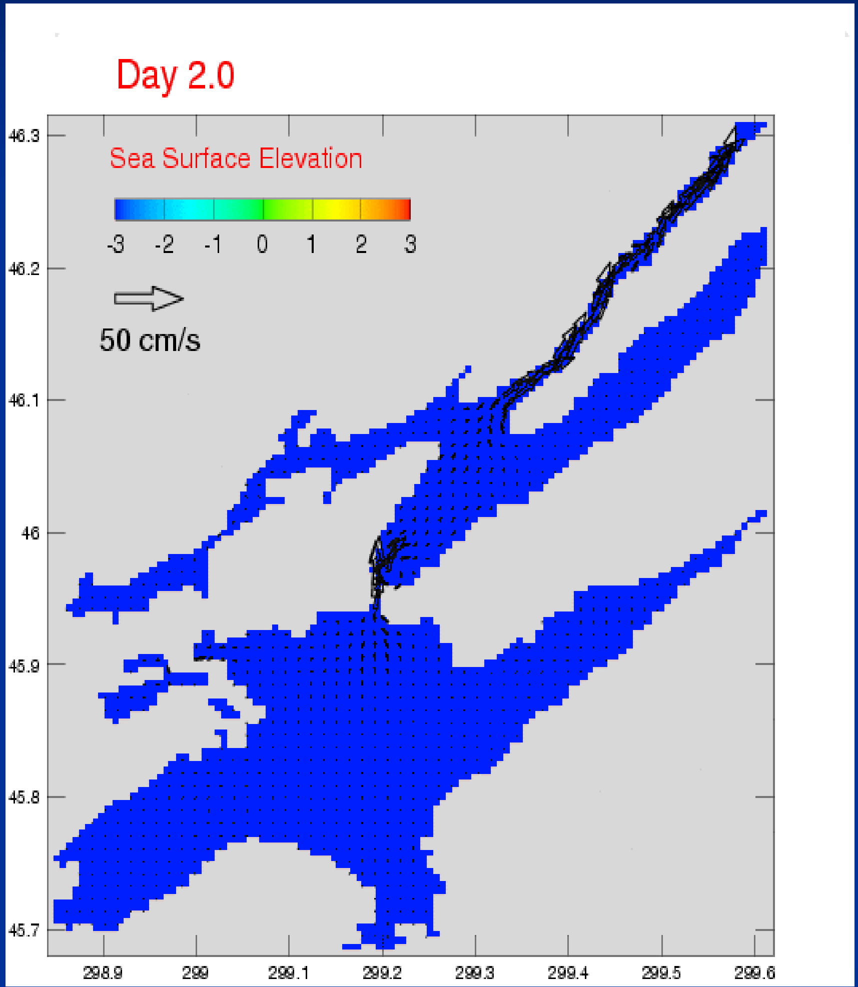


Time series of surface elevations specified at THP and modeled surface elevations at Seal Island.

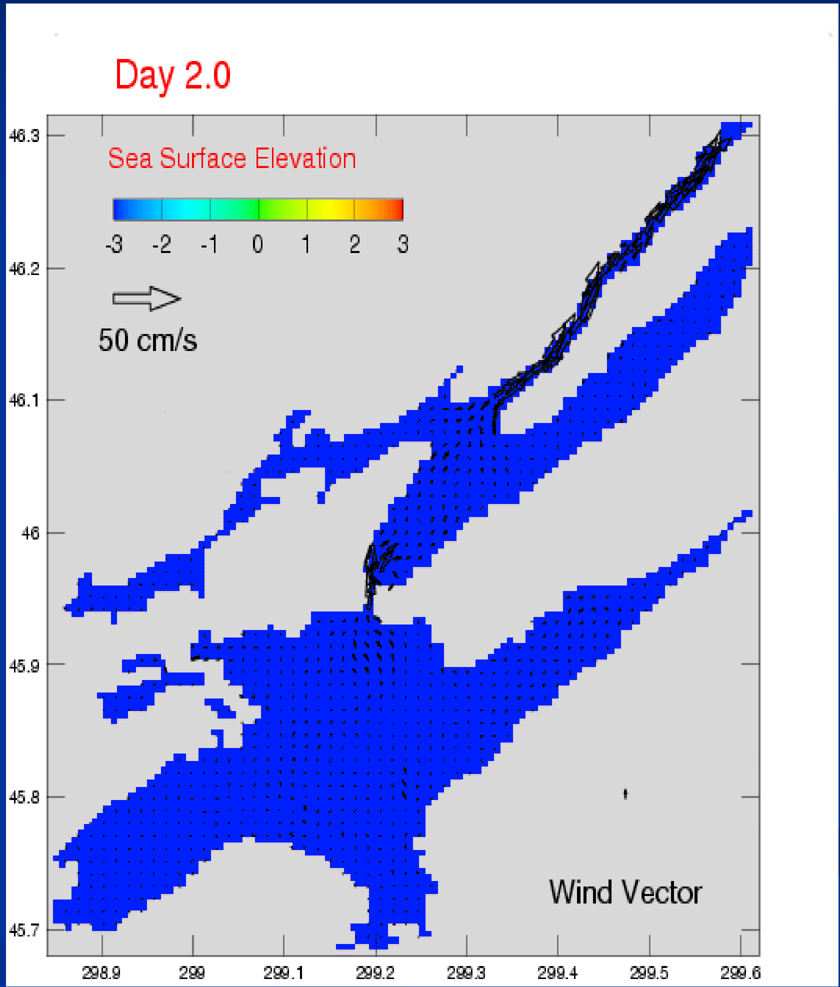
Wind-driven circulation



Calculated surface elevation and depth-mean currents



Tidal forcing only



Tidal and wind forcing

$$S^h = \frac{S^m \cdot V_c + S^r \cdot V_r}{V_c + V_r}$$

Buoyancy-driven circulation (forced by freshwater input only)

Totally 17 rivers are considered, the salinity and surface elevation at each river head are specified based on :

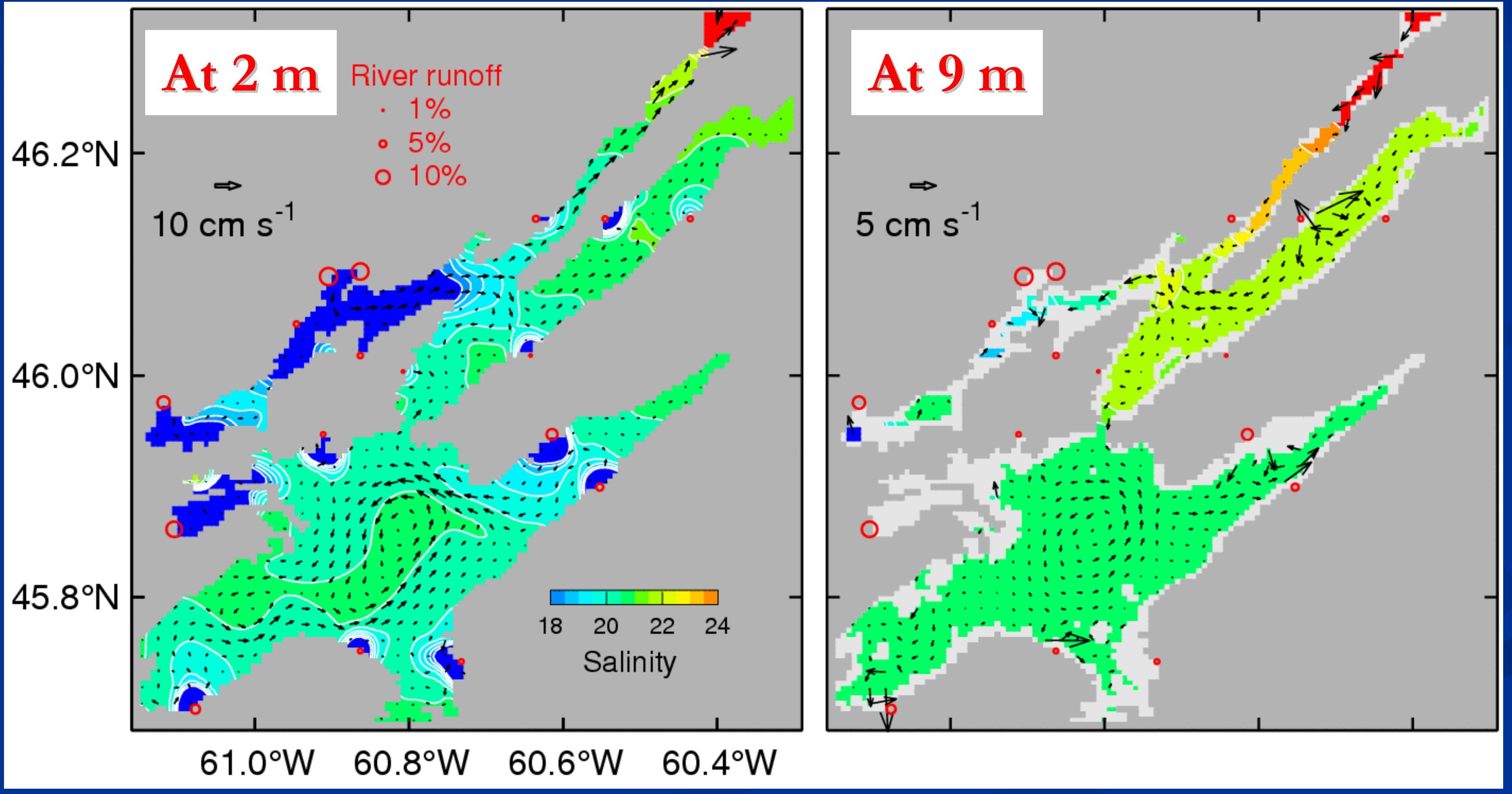
$$S^h = \frac{S^m \cdot V_c + S^r \cdot V_r}{V_c + V_r}$$

(salt balance)

$$\eta^h = \eta^m + V_r / S_c$$

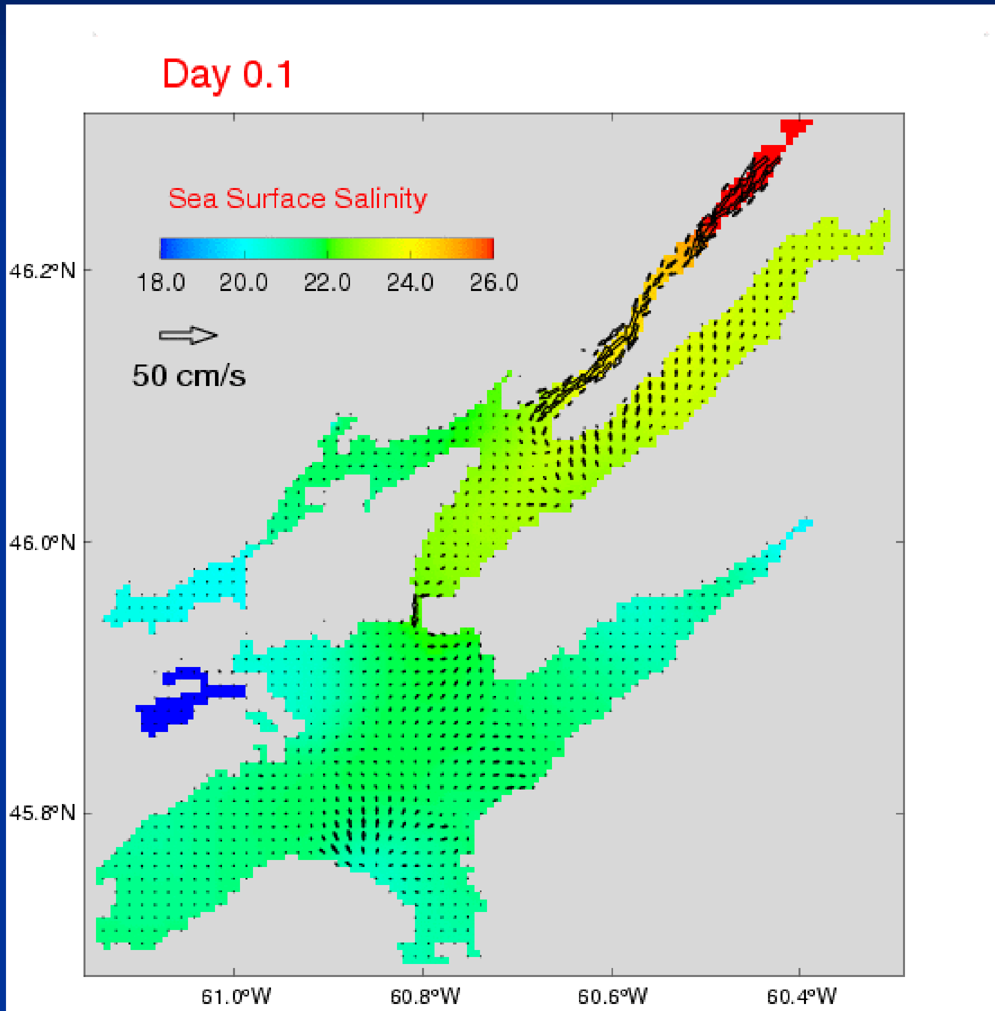
(volume conservation)

Calculated near-surface and sub-surface salinity and currents (forced by freshwater input only)



Calculated surface Salinity and near-surface currents

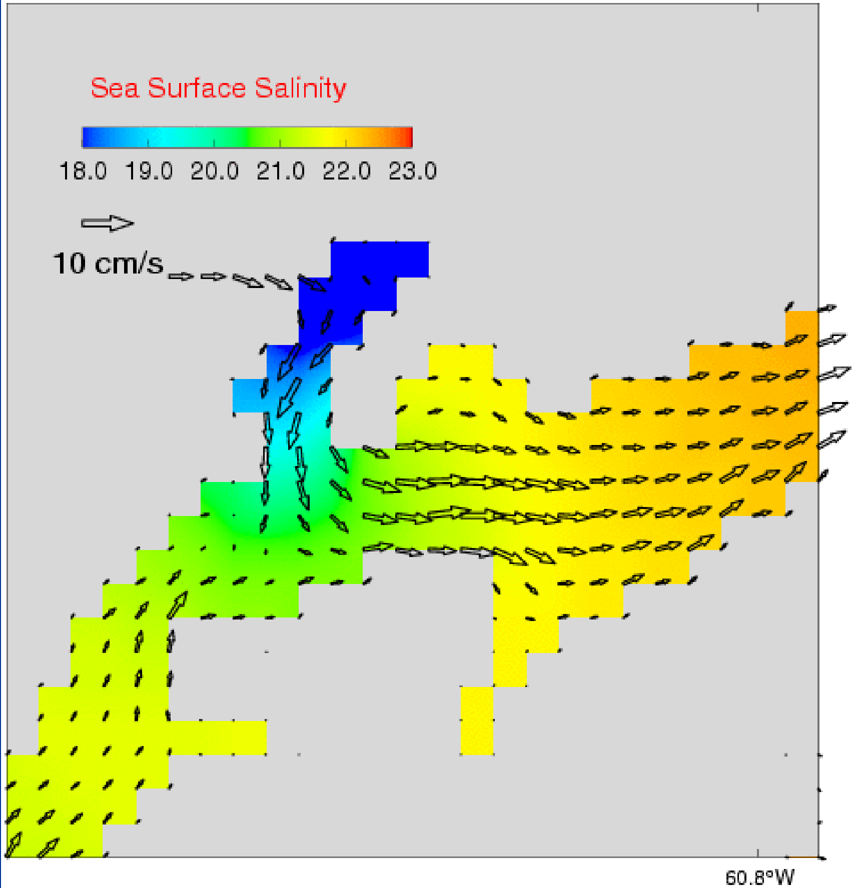
(using tidal data at THP and freshwater runoff from rivers)



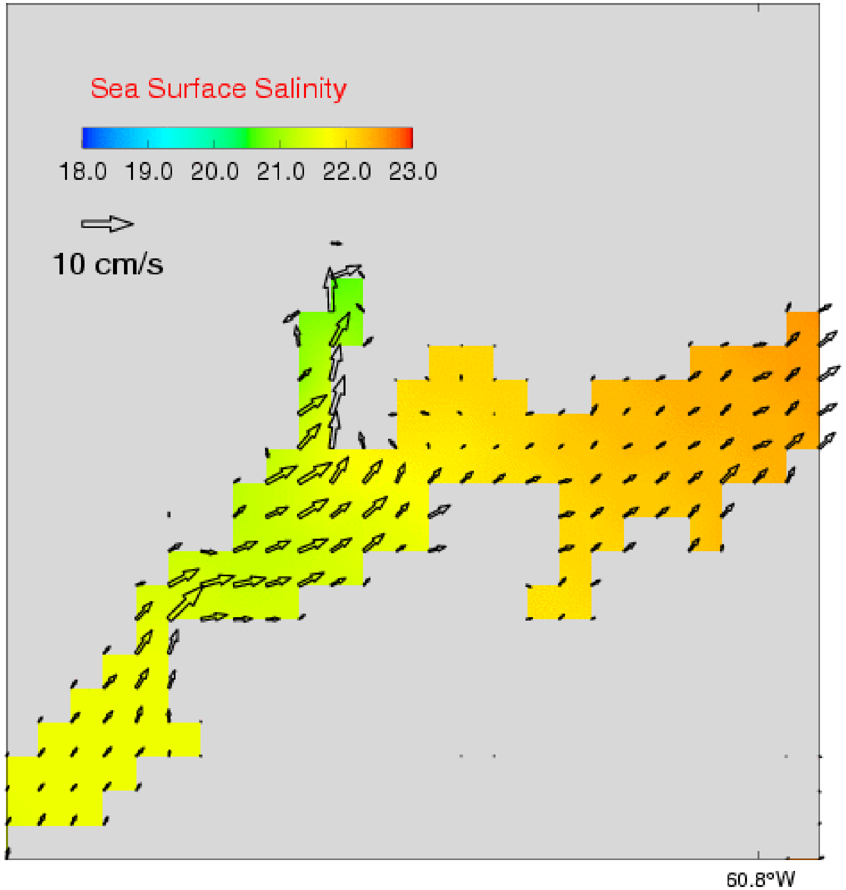
Tides and Freshwater input

Calculated near-surface and sub-surface salinity and currents in St. Patrick's Channel (forced by freshwater input only)

At 2 m



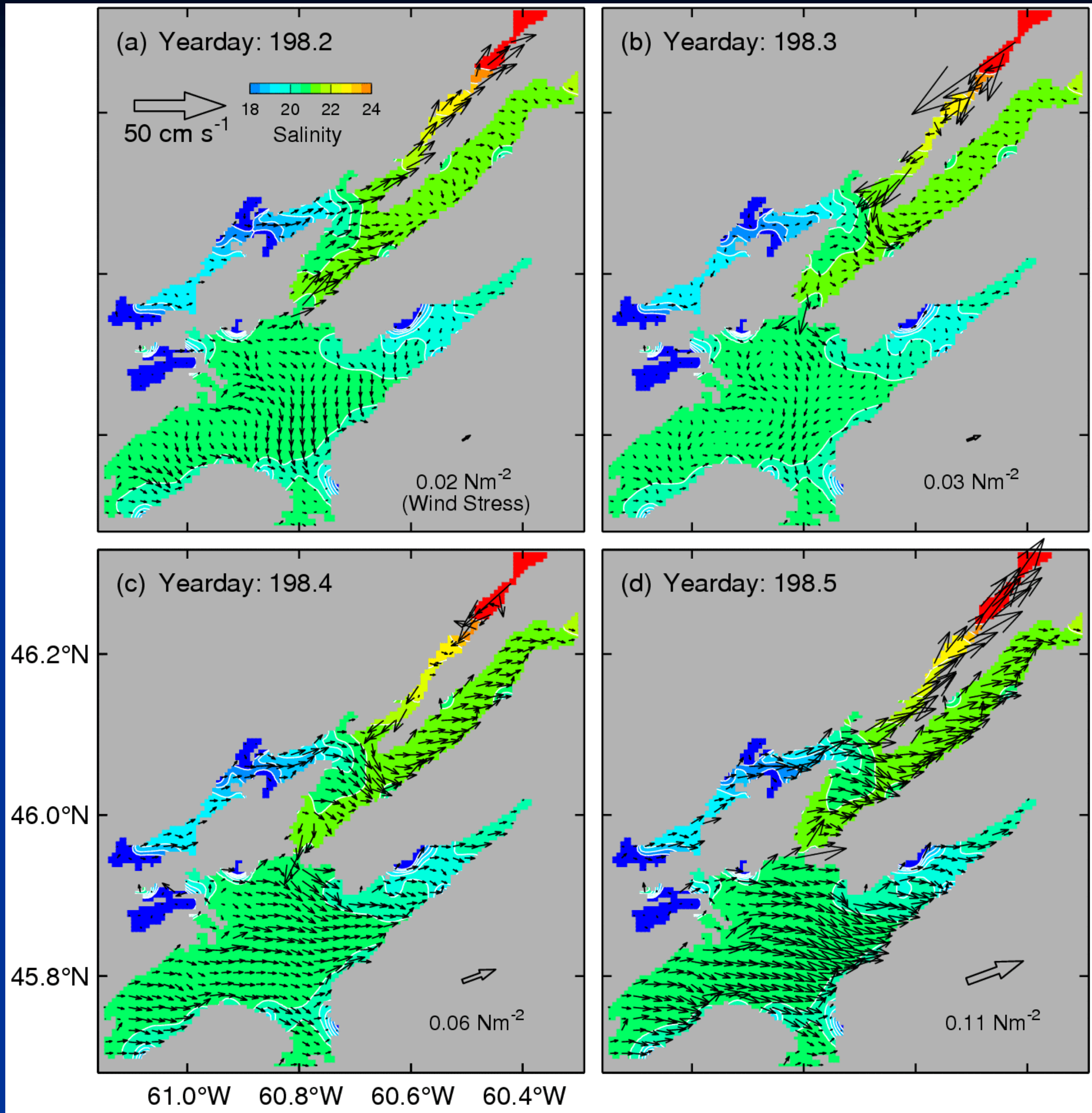
At 5 m



Reproducing circulation and hydrographic structure in June and July 1974

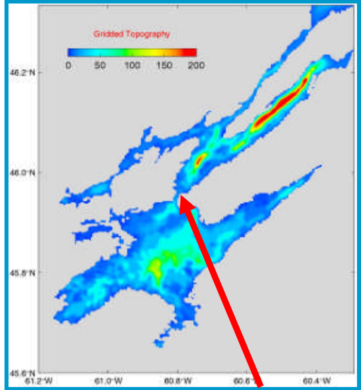
The model is forced by

- **Hourly observed wind at the Airport**
- **Tides at the north open boundary based on harmonic constant of five constituents (M_2, S_2, N_2, K_1, and O_1) estimated by Petrie (1999)**
- **Monthly mean river runoff from 17 rivers**
- **Boundary flow associated with air-pressure perturbations**
- **Monthly mean surface heat flux (climatology)**

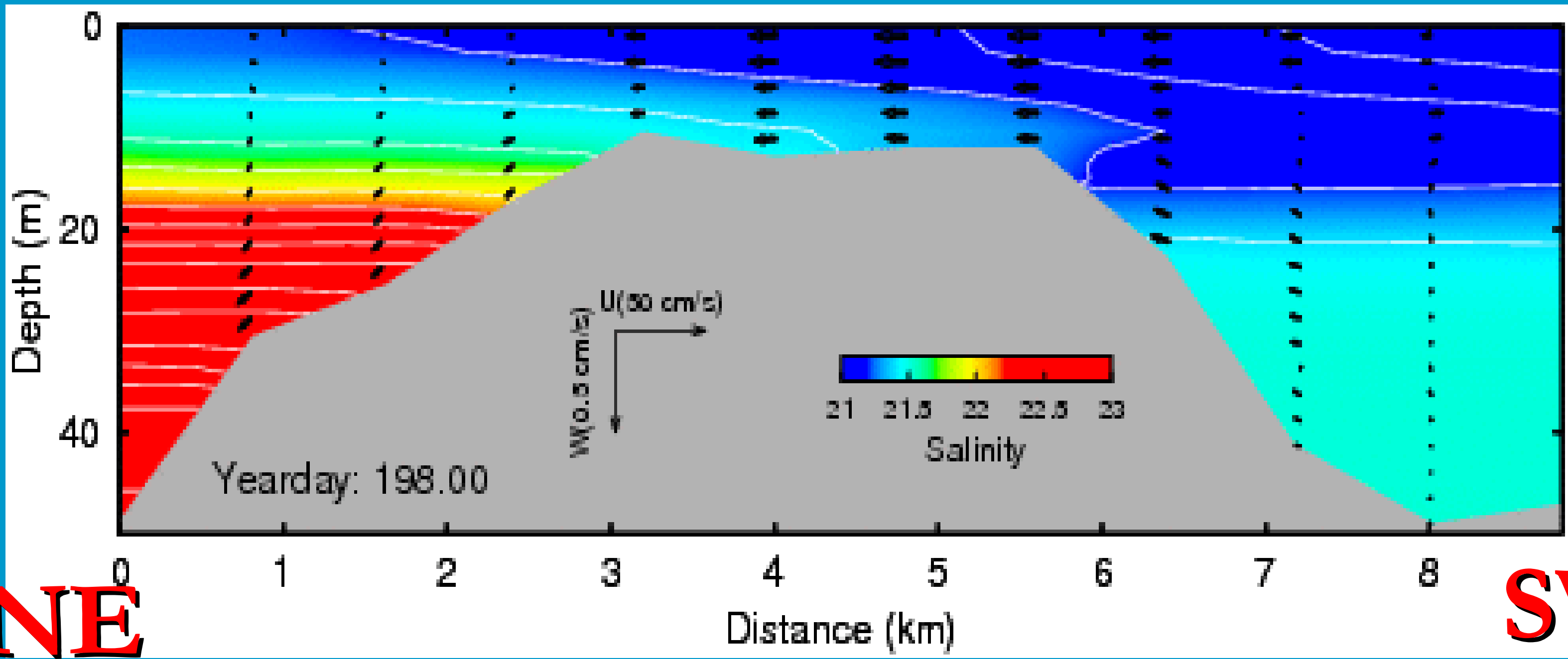


Model-calculated near-surface (2 m) currents and salinities in 1974.

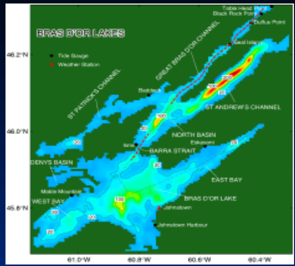
Vertical distributions of salinity and currents along central Barra Strait

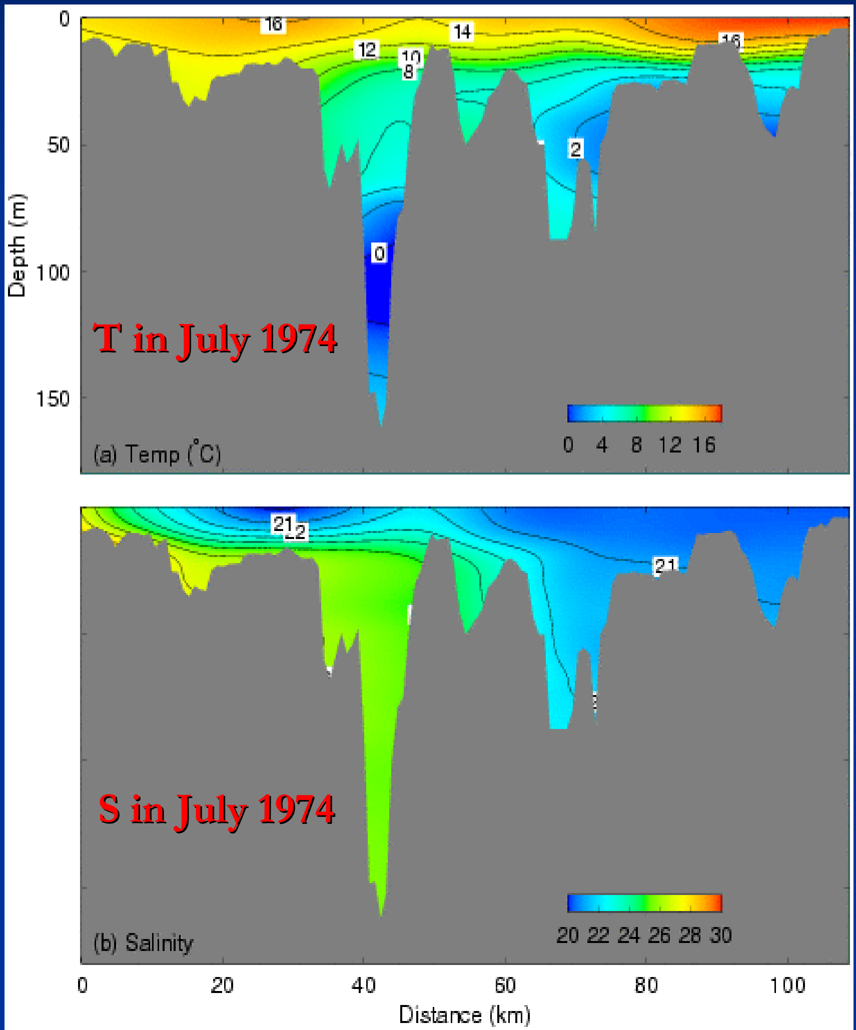


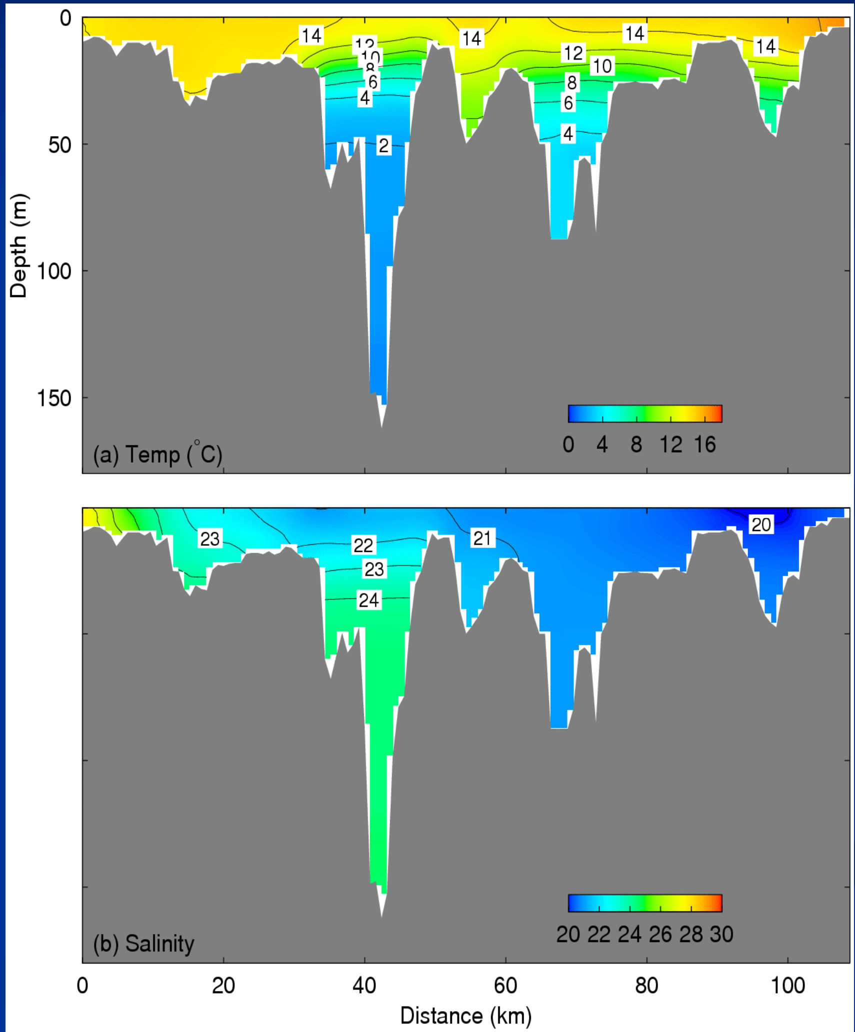
Barra Strait



Vertical distribution of TS



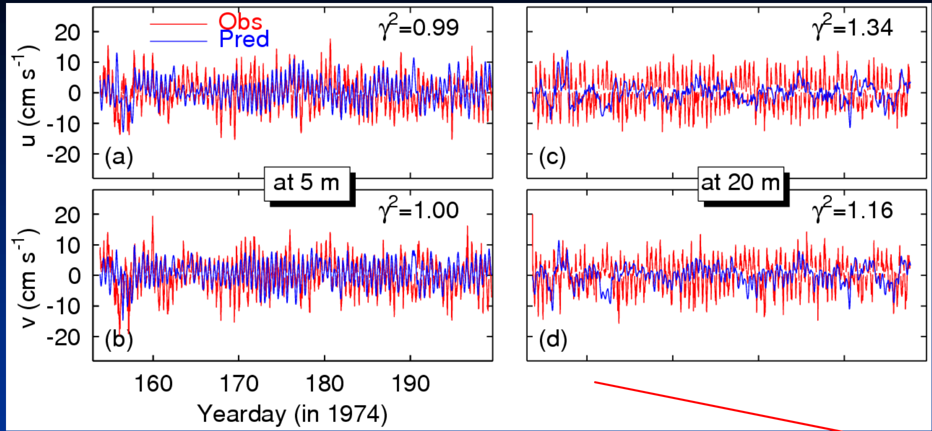


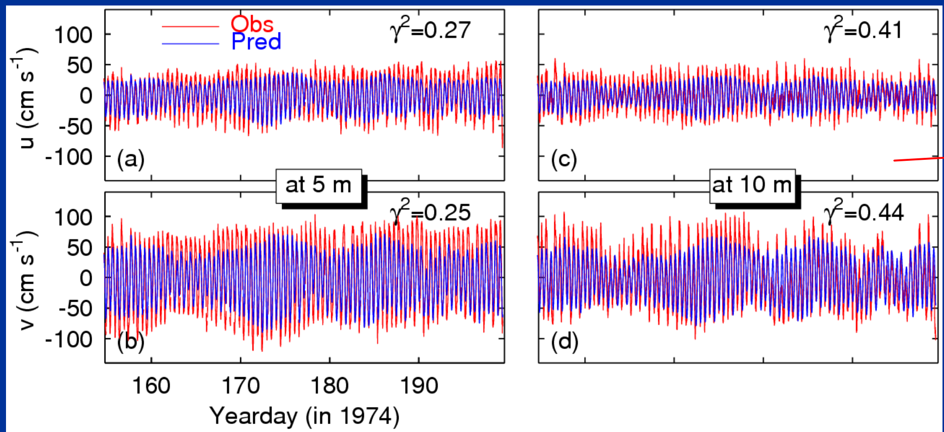


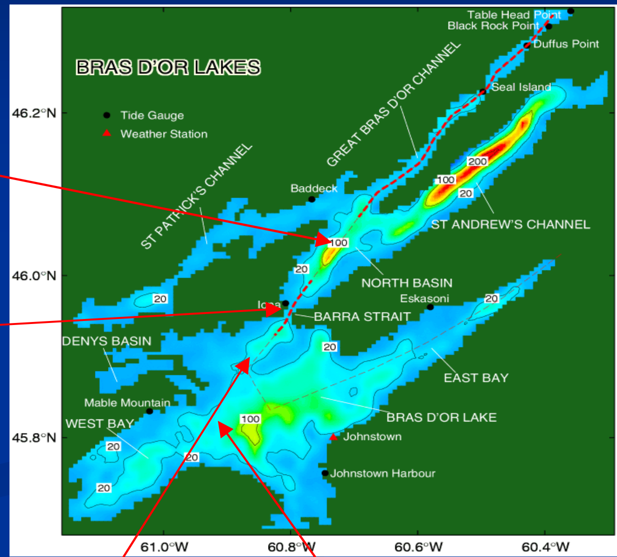
Observed T and S

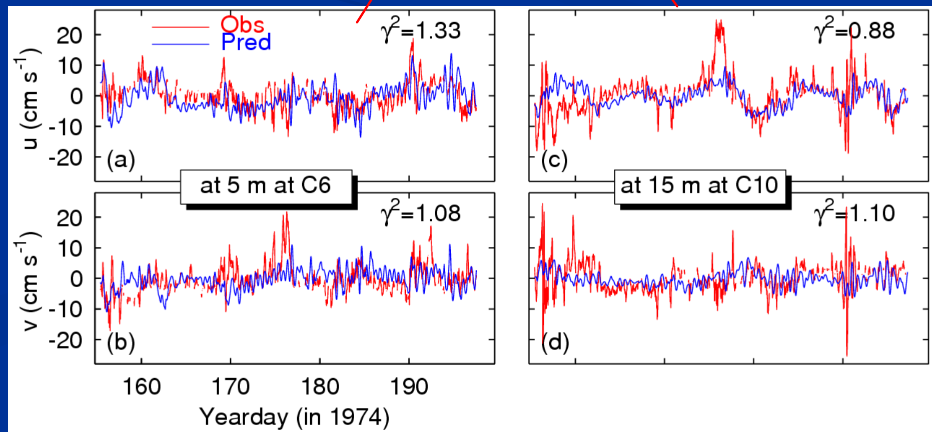
Simulated T and S

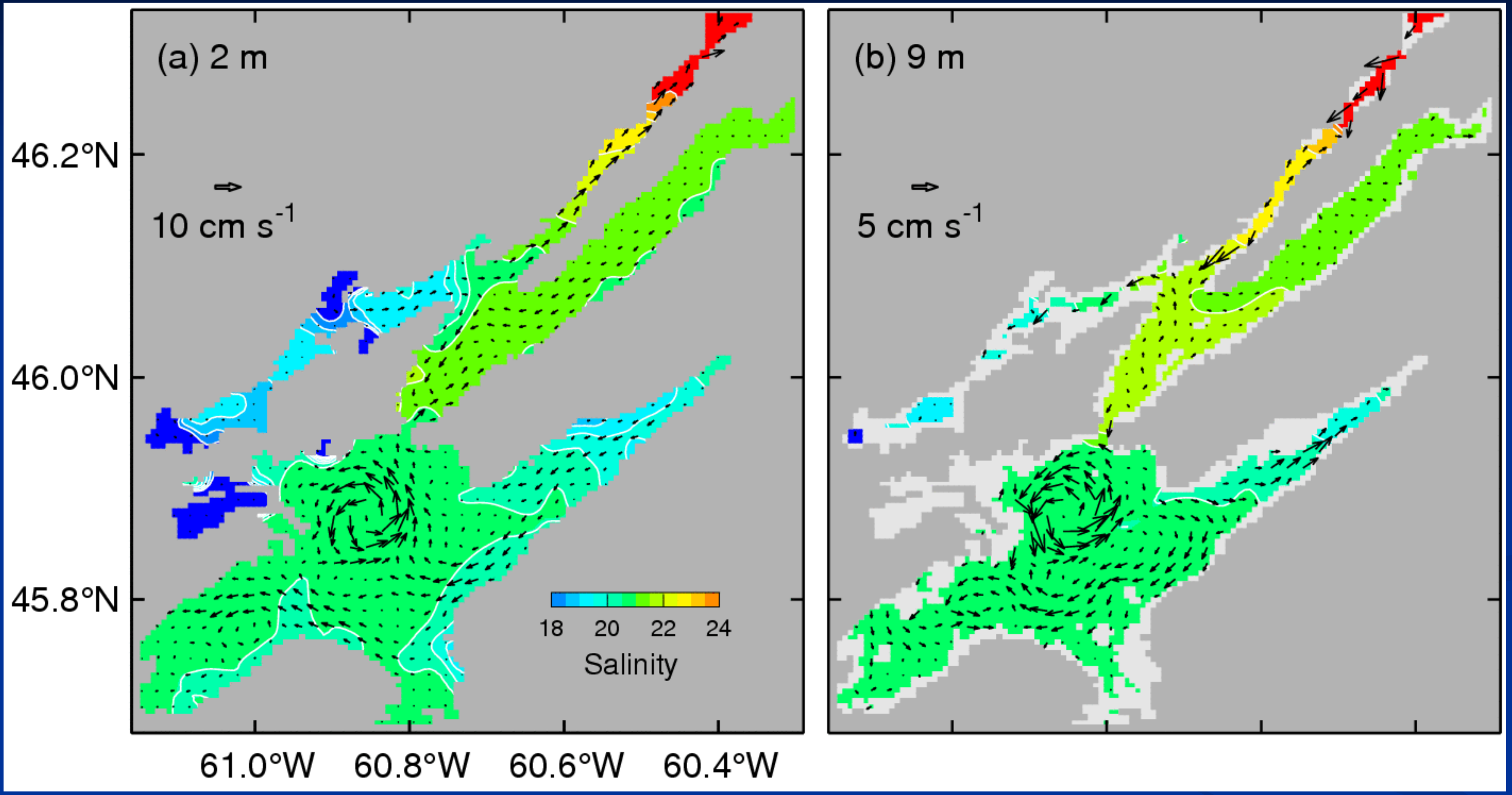
Comparison of observed and simulated currents (preliminary model results)



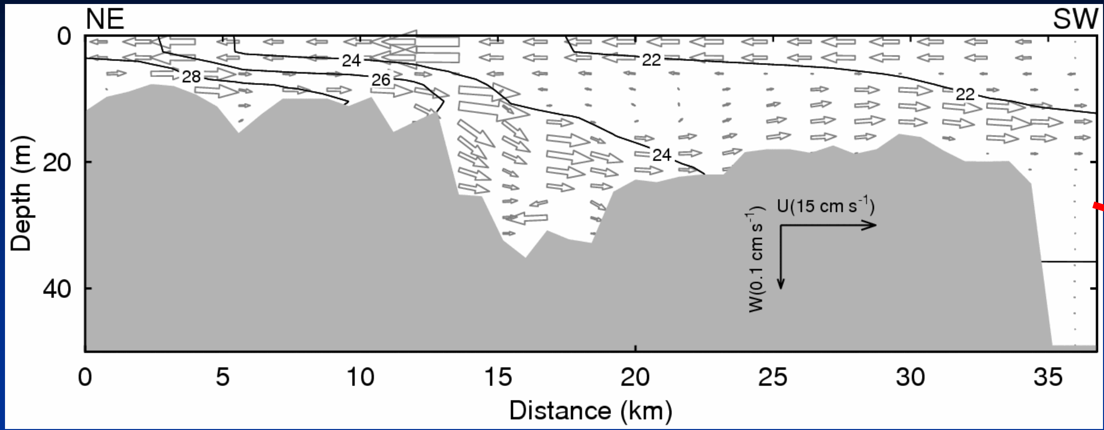


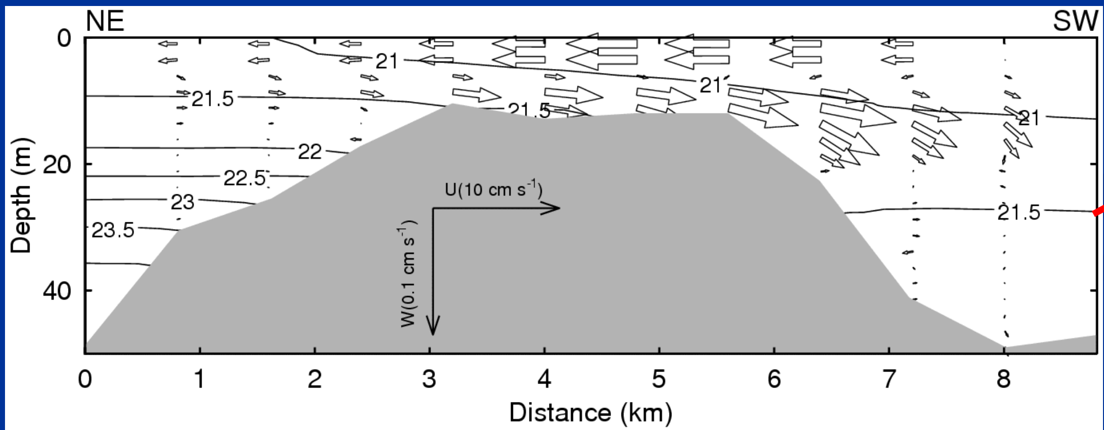


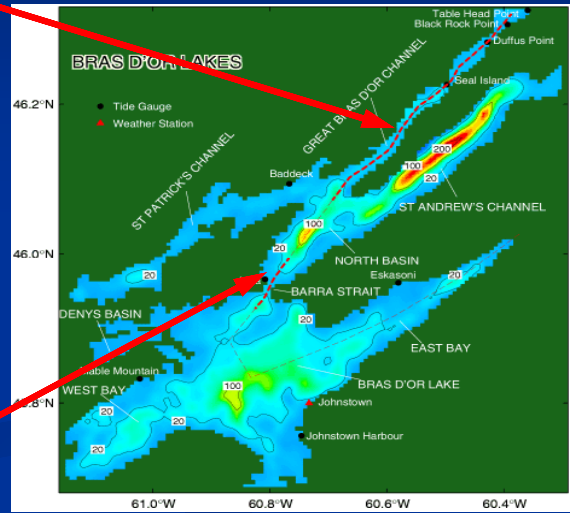




Density-driven currents (without any external forcing)

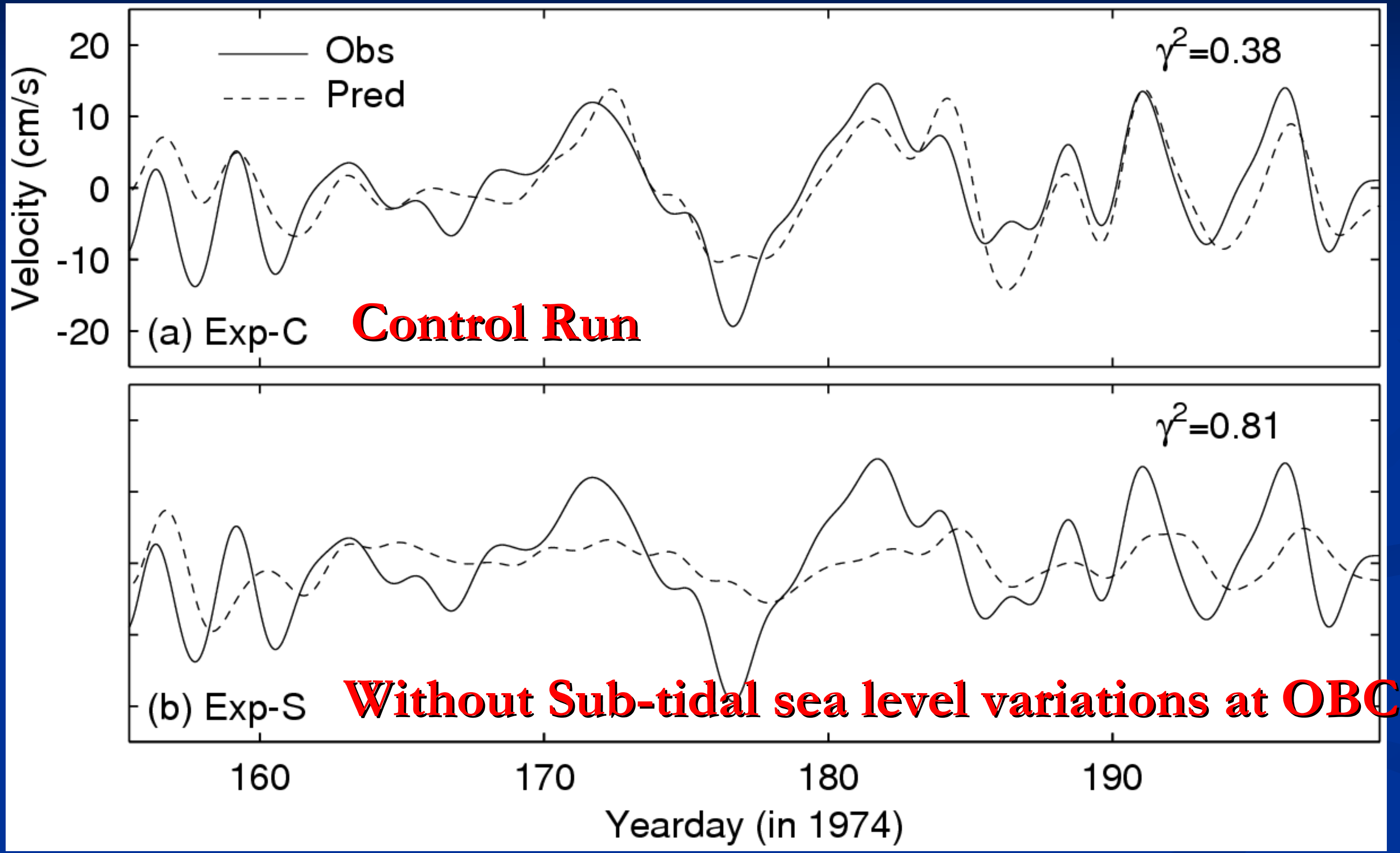






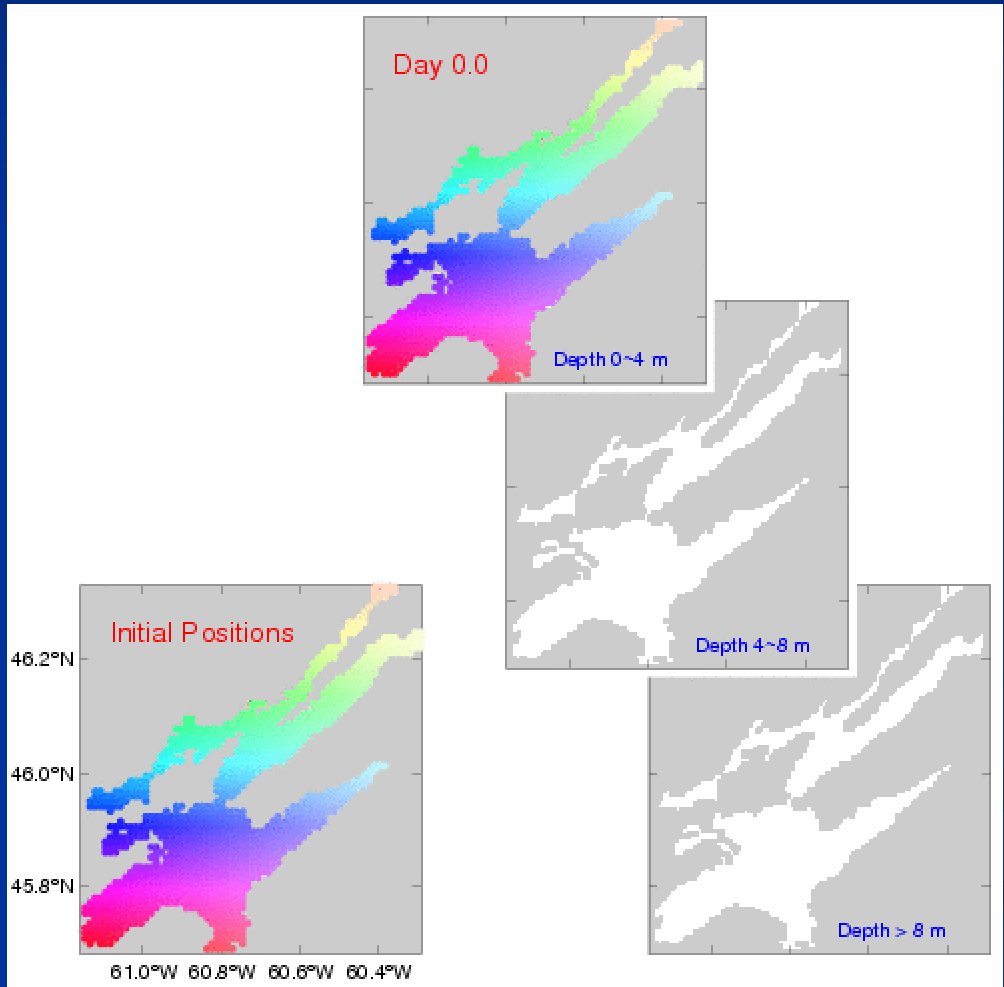
Salinity and density-driven currents (without external forcing)

Sensitivity Study

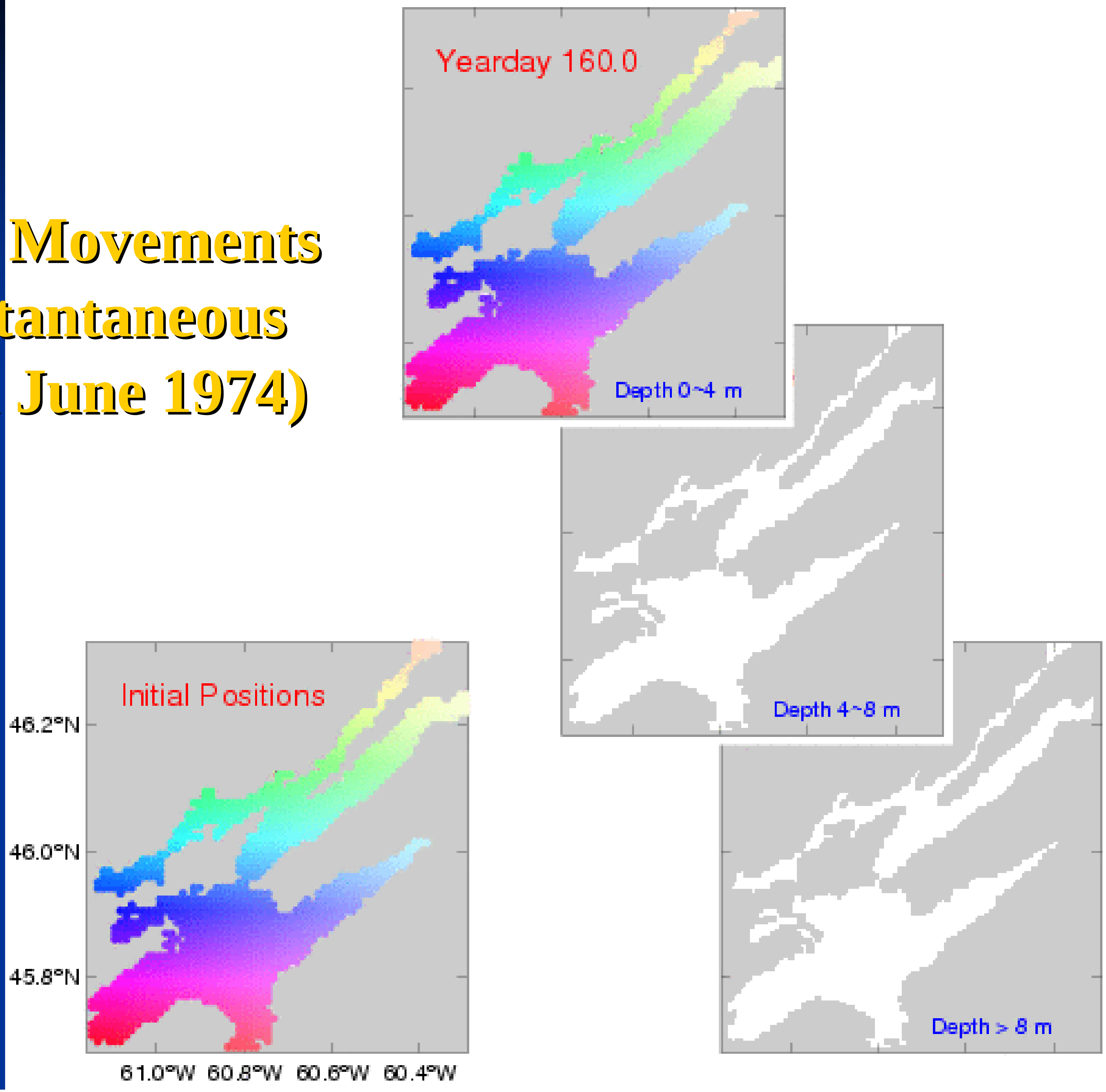


Model-calculated and observed filtered depth-mean currents along the channel axis of Barra Strait.

Particle Movements
(based on monthly mean currents, June 1974)

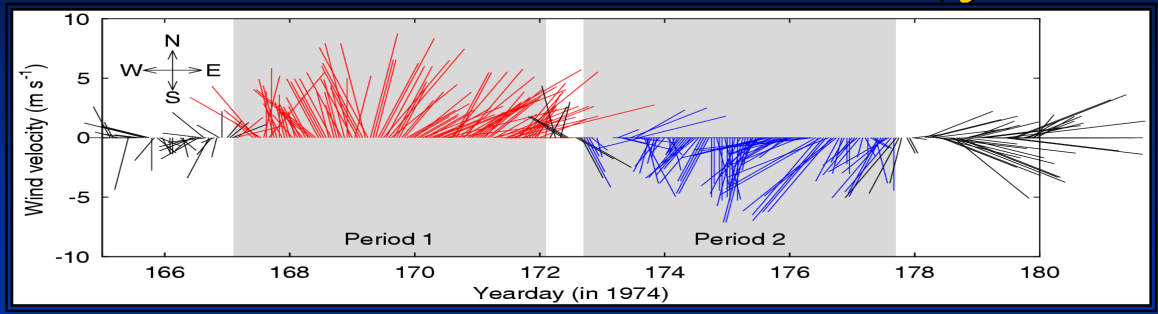


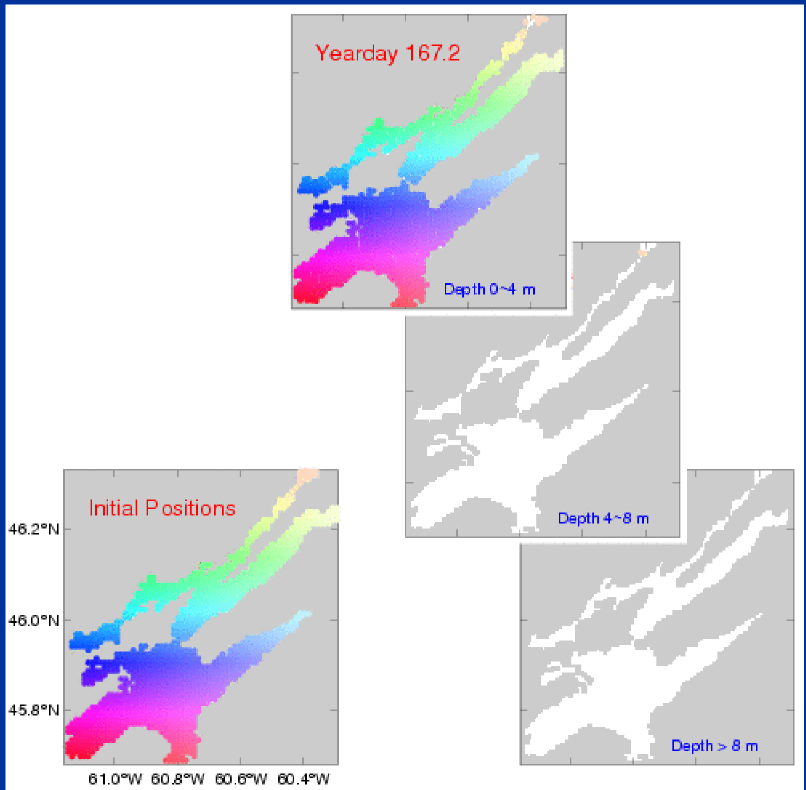
3D Particle Movements (Using instantaneous currents in June 1974)

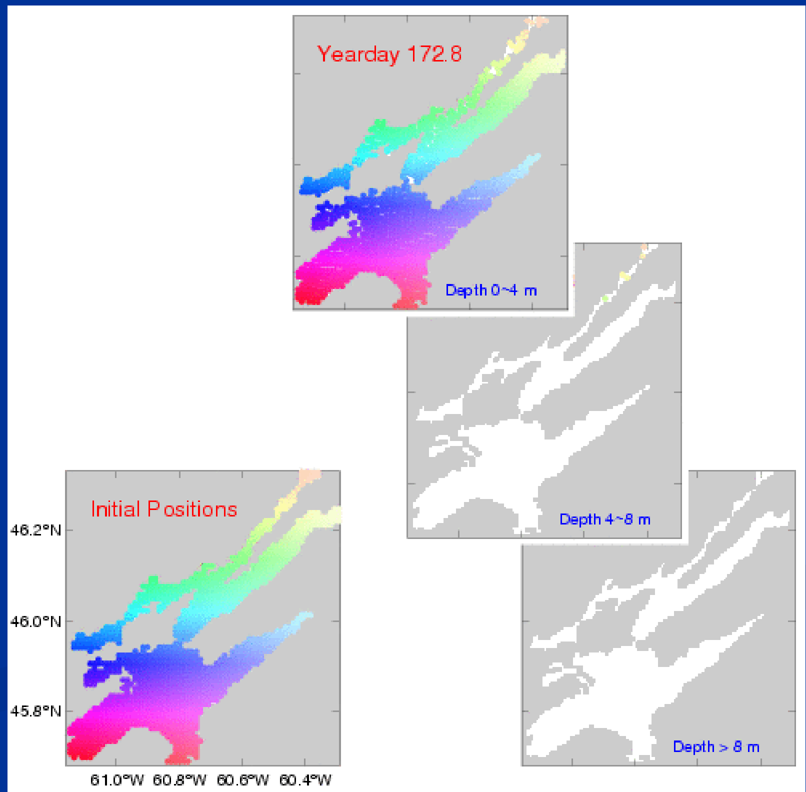


Particle Movements During 2 Wind Events

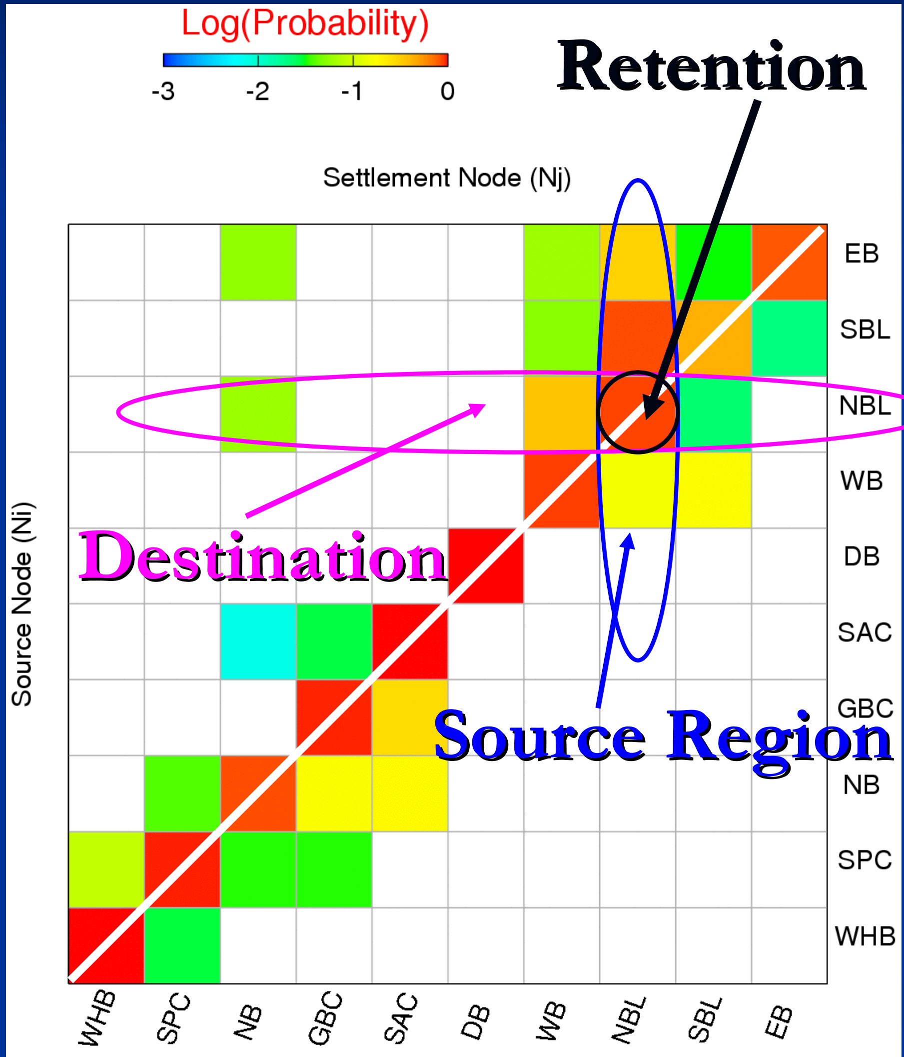
(based on instantaneous baroclinic currents, June 1974)

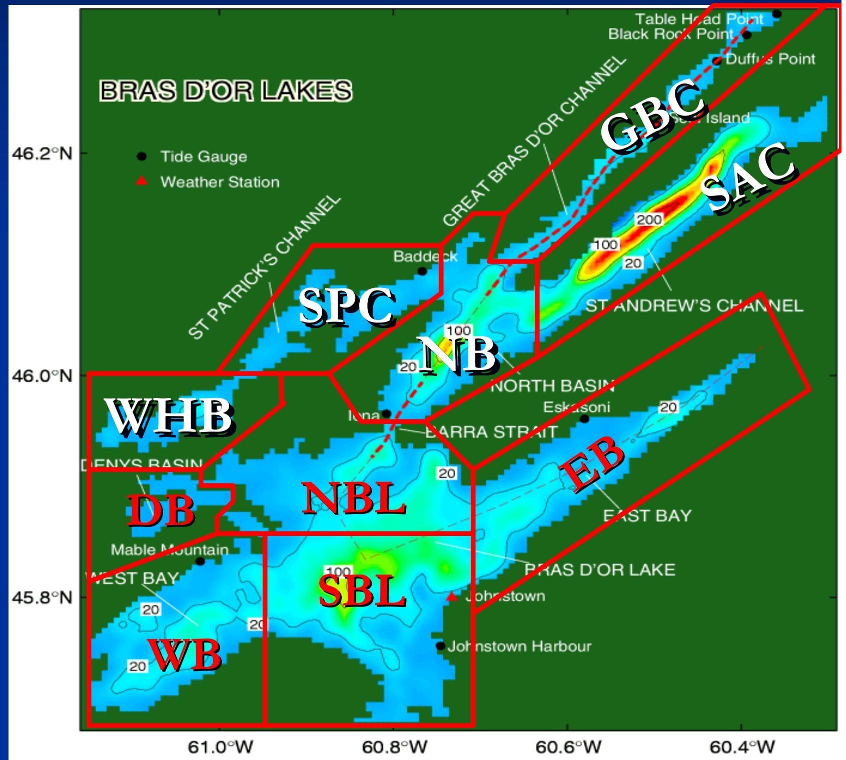






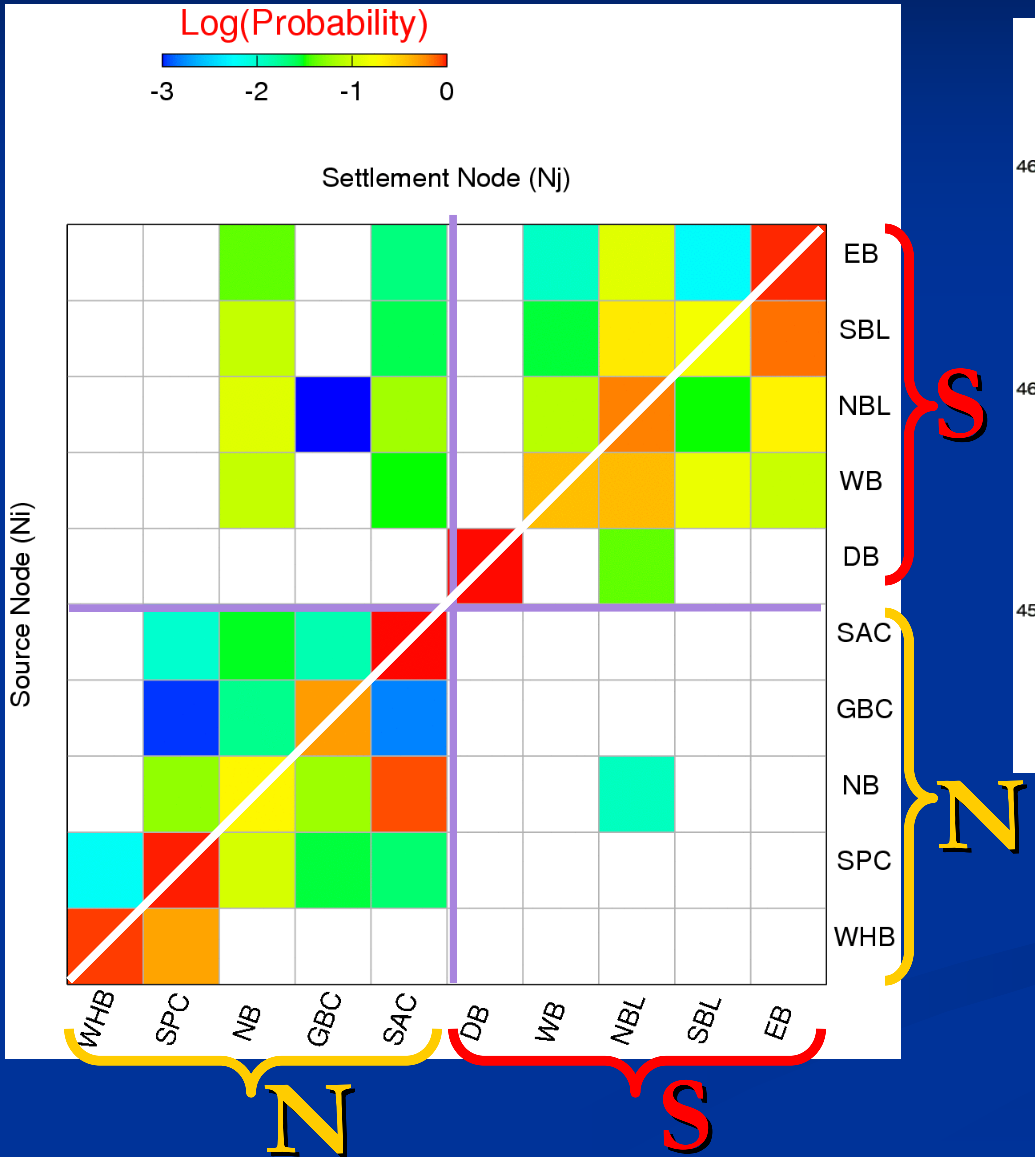
Retention and Dispersion of Near-Surface Particles (based on monthly mean currents in June 1974)

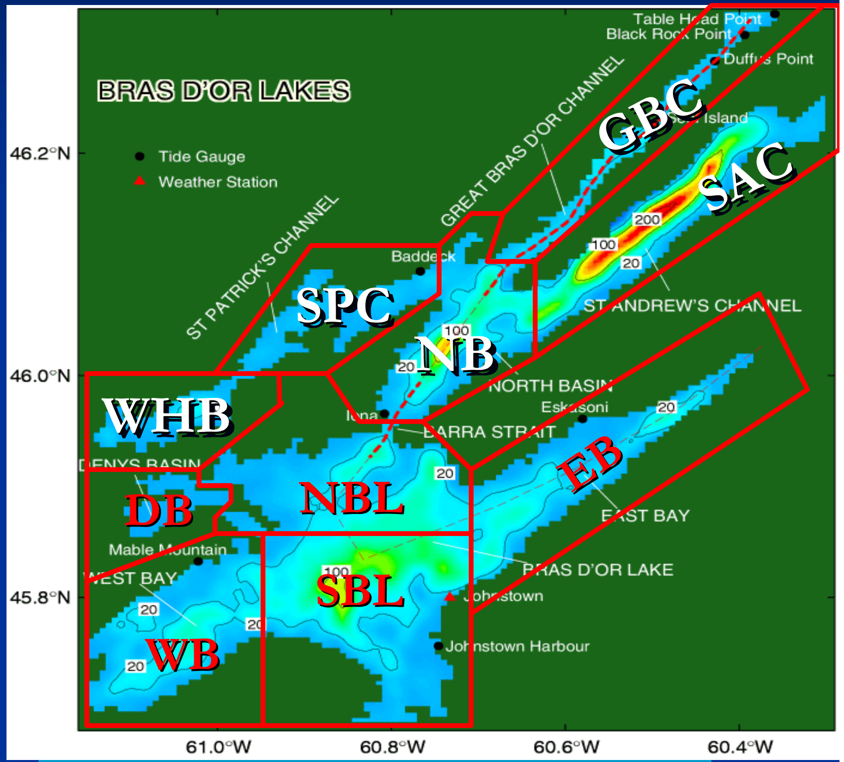




WHB	Whycocomagh Bay
SPC	St. Patrick's Channel
NB	North Basin
GBC	Great Bras d'Or Channel
SAC	St. Andrew's Channel
DB	Denys Basin
WB	West Bay
NBL	Northern Bras d'Or Lake
SBL	Southern Bras d'Or Lake
EB	East Bay

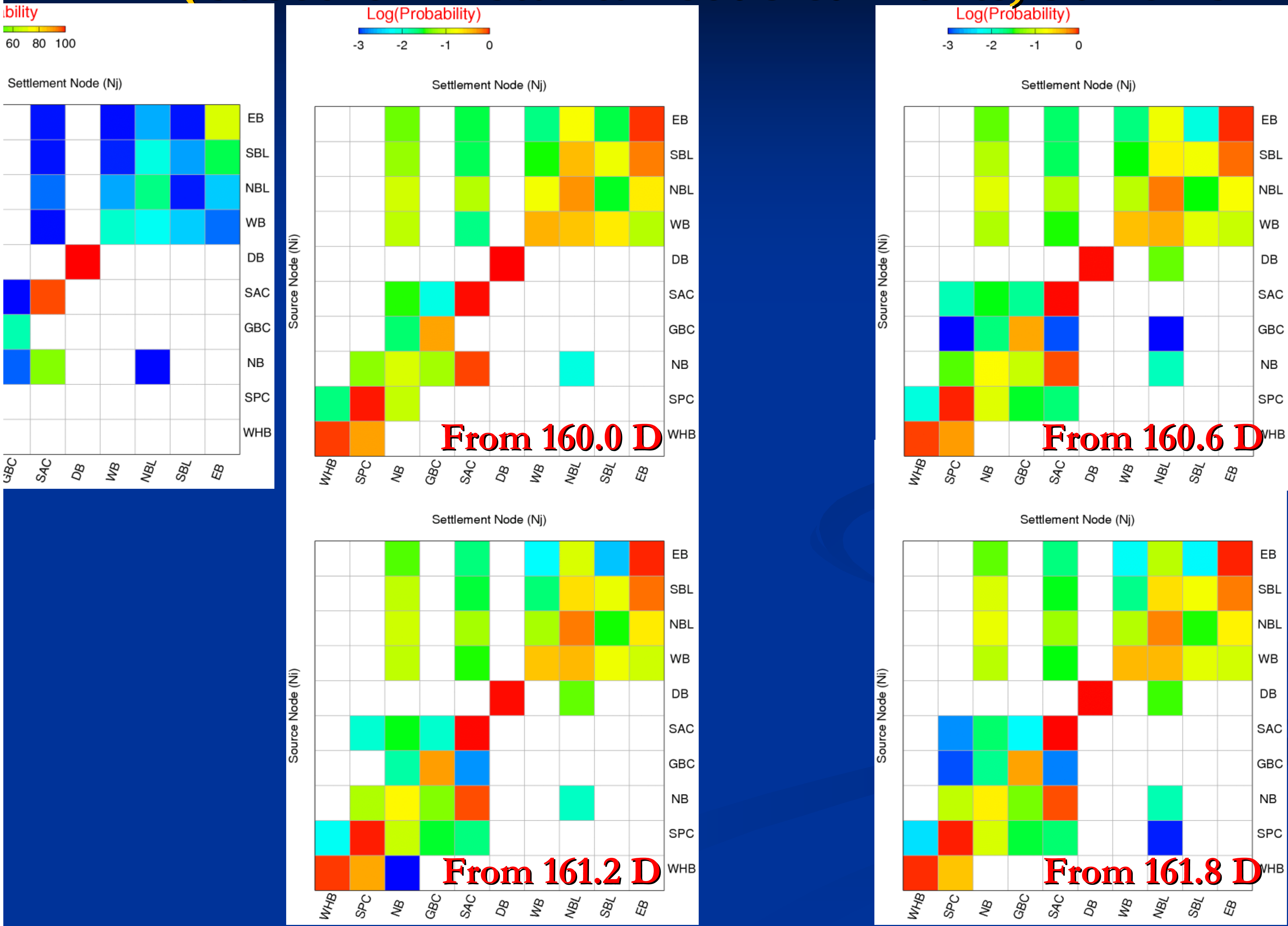
Retention and Dispersion of Near-Surface Particles (based on instantaneous currents in June 1974)





- WHB Whycocomagh Bay
- SPC St. Patrick's Channel
- NB North Basin
- GBC Great Bras d'Or Channel
- SAC St. Andrew's Channel
- DB Denys Basin
- WB West Bay
- NBL Northern Bras d'Or Lake
- SBL Southern Bras d'Or Lake
- EB East Bay

Retention and Dispersion of Near-Surface Particles (based on instantaneous currents, June 1974)



The Nested-Grid Model Domain

The two-way nesting technique based on the semi-prognostic method

For the inner model:

$$\frac{\partial p}{\partial z} = -g\left[\beta_i \rho_{inner} + (1-\beta_i)\rho_{outer}\right]$$

For the outer model:

$$\frac{\partial p}{\partial z} = -g\left[\beta_0 \rho_{outer} + (1-\beta_0)\rho_{inner}\right]$$

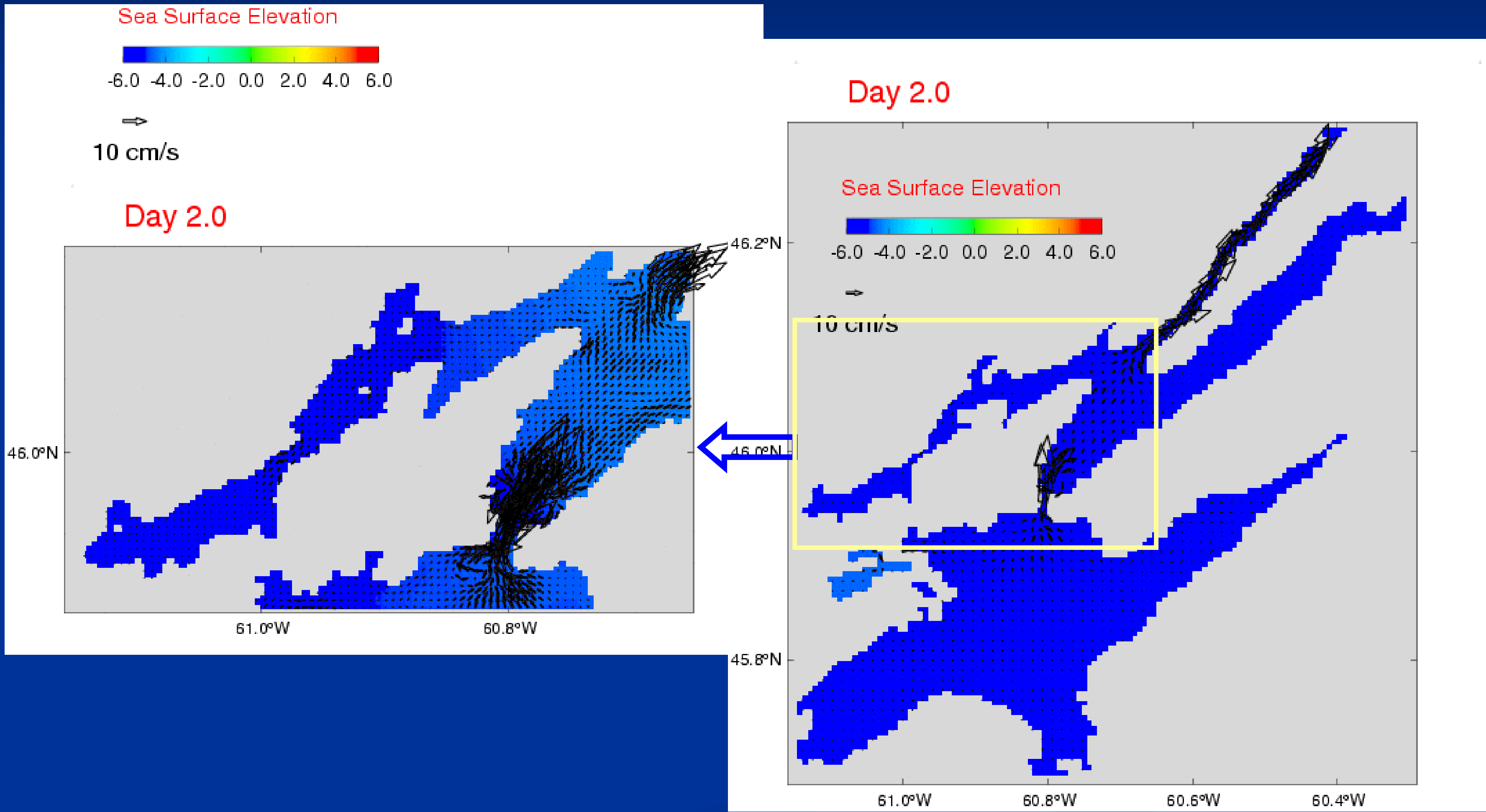
β_o and β_i are set to 0.5

Lateral boundary conditions for the inner model:

- Sommerfield radiation condition (U,V,T,S)
- Restoring to outer model values

References: Sheng et al., OD, 2005; Sheng et al., JGR, 2001; Greatbatch et al., CSR, 2004; Zhao et al., 2006.

Preliminary results of the nested-grid modelling system (M_2 tidal forcing only)



Summary and Conclusion

- A single-domain, 3D, finite-difference model based on CANDIE with horizontal resolution of 500 m was developed for the Bras d'Or Lakes.

- In comparison with observations, the 3D model has reasonable skill in simulating circulation forced by tides, wind forcing, and freshwater discharge from 17 rivers in the Lakes.

- The boundary flow associated with the inverse barometer effect also plays an important role in generating the low-frequency variability circulation in the lakes.

- A nested-grid model is needed to study the 3D circulation in bays and straits (or channels).

Thank you