Bedford Institute of Oceanography

Located in Halifax/Dartmouth, Nova Scotia

Dalhousie University in same city

The Bedford Institute of Oceanography

Overview

Founded in 1962, BIO is Canada's largest centre for ocean research.

Occupants include:

- Fisheries and Oceans Canada - DFO
- Geological Survey of Canada, Atlantic (Natural Resources Canada) – GSC-Atlantic
- Canadian Coast Guard - CCG
- Defence Research Development Canada - DRDC
- Environment and Climate Change Canada - ECCC

>700 employees engaged in research, technological development, policy, and management.

Research to provide advice and support to government decision-making

DFO Science @ BIO

Maritimes Research and Monitoring Supports:

- Fish population assessment
- Sustainable aquaculture
- Species recovery
- Marine conservation
- Impact assessment
- Safe navigation and emergency response
- Oceanographic forecasting and advice
- Adaptation to changing ecosystems, including impacts of climate change

Modelling and Forecasting of Ocean Currents, Hydrography and Sea Level Changes

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Acknowledgement: Collaborators within
Government & universities in Canada, France & China

Fisheries and Oceans Canada | Pêches et Océans Canada | Environment Canada | Environnement Canada | National Defence | Défense nationale

Outline

- **What is ocean modeling & forecasting?**
- **State-of-the-art (example): Canada's operational ocean forecasting systems**
- **Modelling research: Sea level changes**
- **Practical applications: Examples**

Numerical Ocean Modelling

Physics/Math

Equations

$$\nabla \cdot \mathbf{u} = 0$$

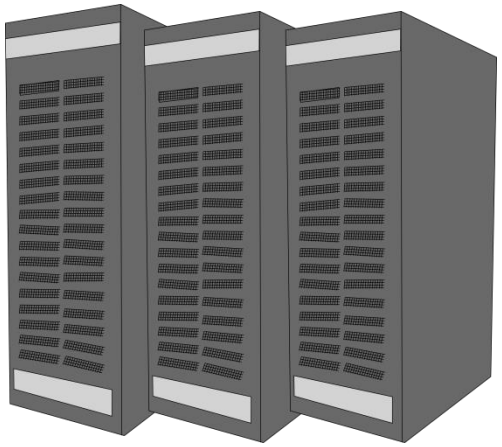
$$\frac{\partial \mathbf{u}_H}{\partial t} + \nabla \cdot (\mathbf{u}\mathbf{u}_H) + 2\boldsymbol{\Omega} \times \mathbf{u}_H = -\nabla_H p / \rho_0 + j_H + F_H$$

$$\frac{\partial p}{\partial z} = -\rho g$$

$$\frac{\partial T}{\partial t} + \nabla \cdot ((\mathbf{u} + u_*)T) = q_T$$

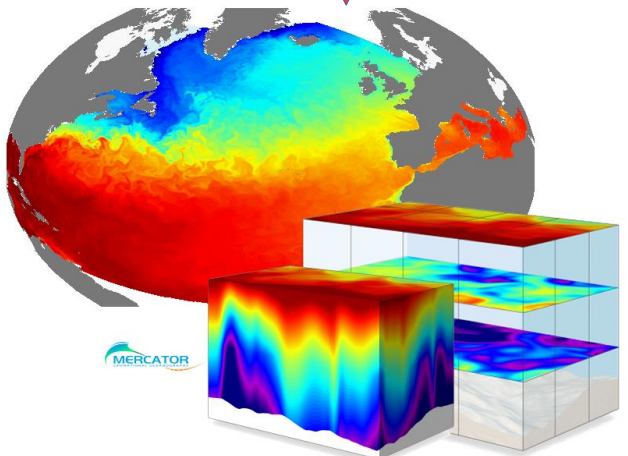
$$\frac{\partial S}{\partial t} + \nabla \cdot ((\mathbf{u} + u_{*)}S) = q_S$$

Computers

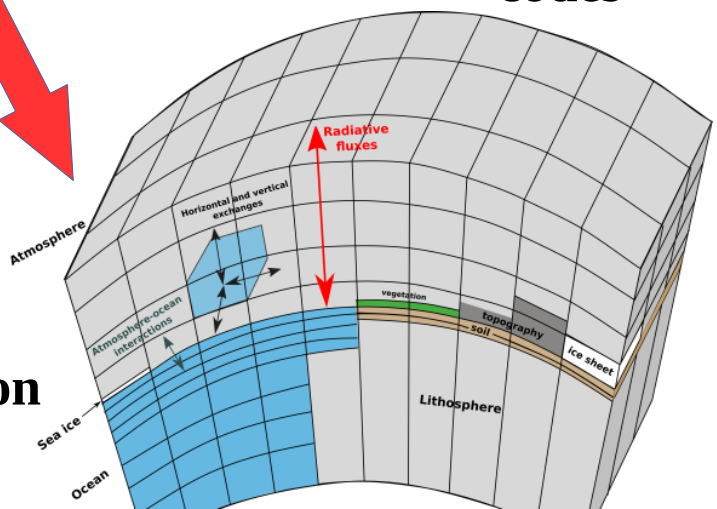


Computer codes

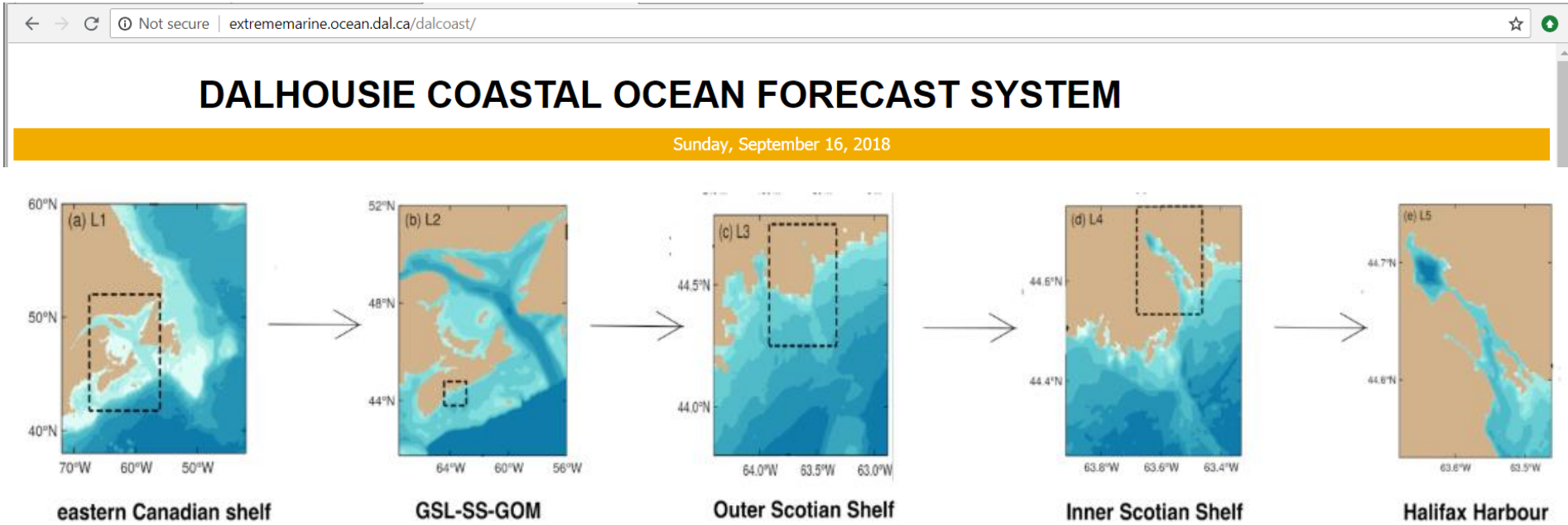
Results



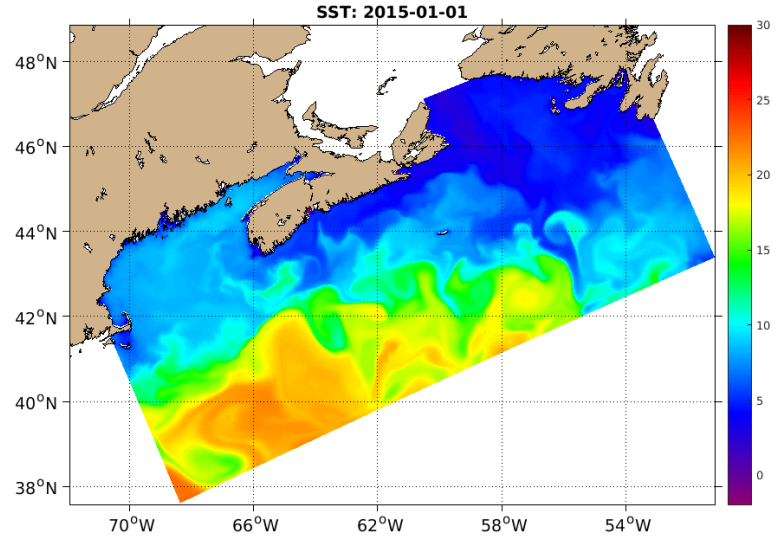
Numerical discretization methods



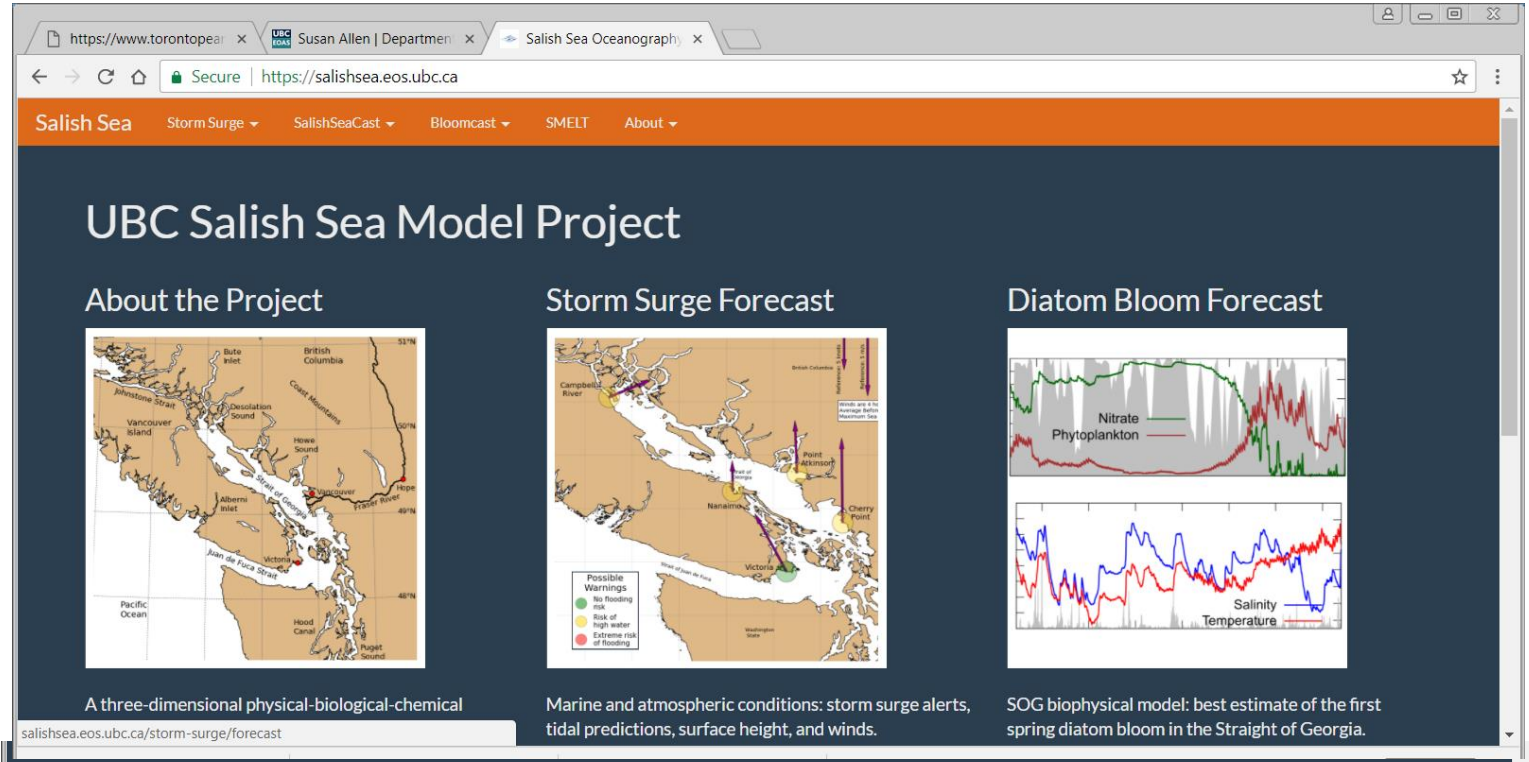
Ocean Foresting in Canada:
Stream 1: Best Effort – mainly by universities

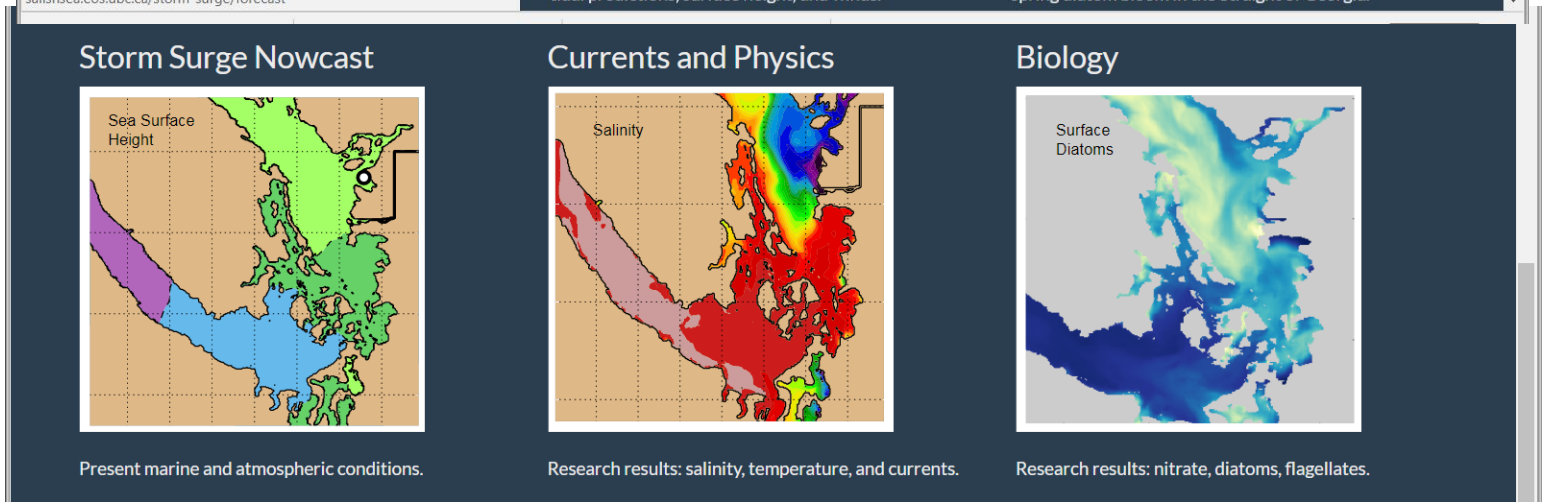


MEOPAR: GoMSS

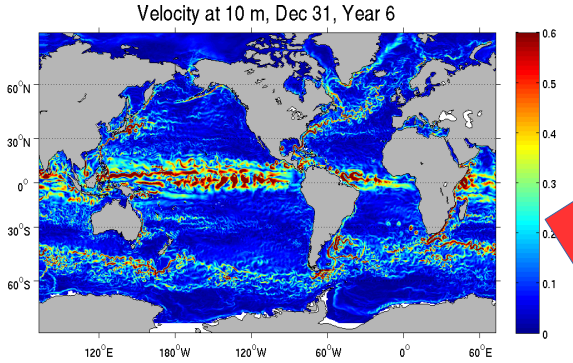


University of British Columbia: Salish Sea Physics & Biogeochemistry

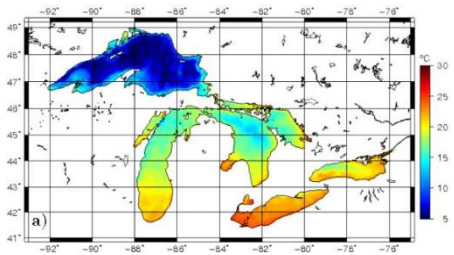




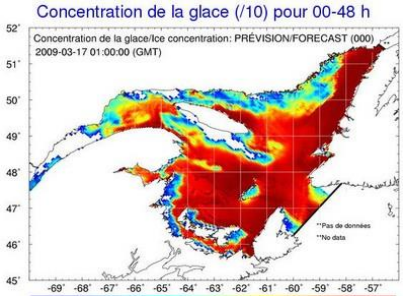
Ocean Forecasting in Canada:
Stream 2: 24/7 support – CONCEPTS efforts



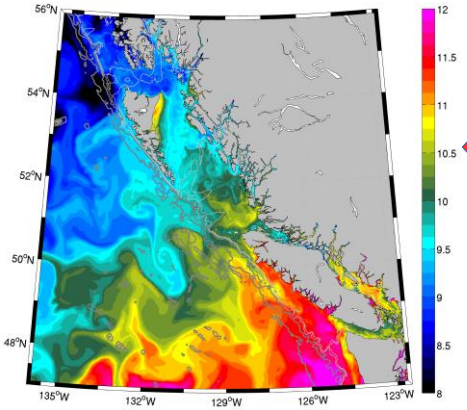
GIOPS: ¼ °, DA, operational since Aug 2015; two versions: 30-day ensemble, 10-day determinist coupled to weather



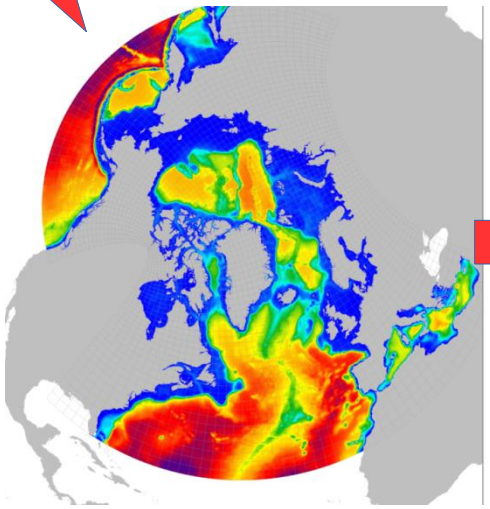
Great Lakes: 2 km, coupled to weather, since 2014



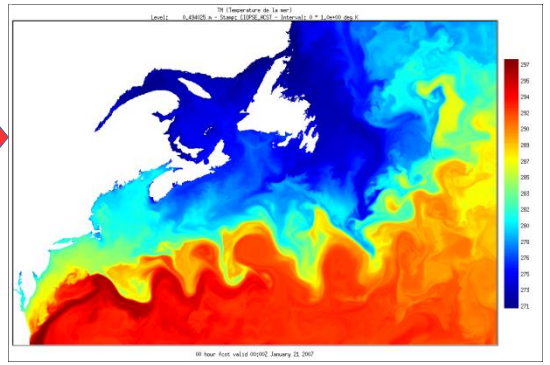
Gulf of St Lawrence: 5 km, coupled to weather, since June 2011; updating to 500m



CIOPS-west: 1/36°, spectral nudging, operation by end 2018



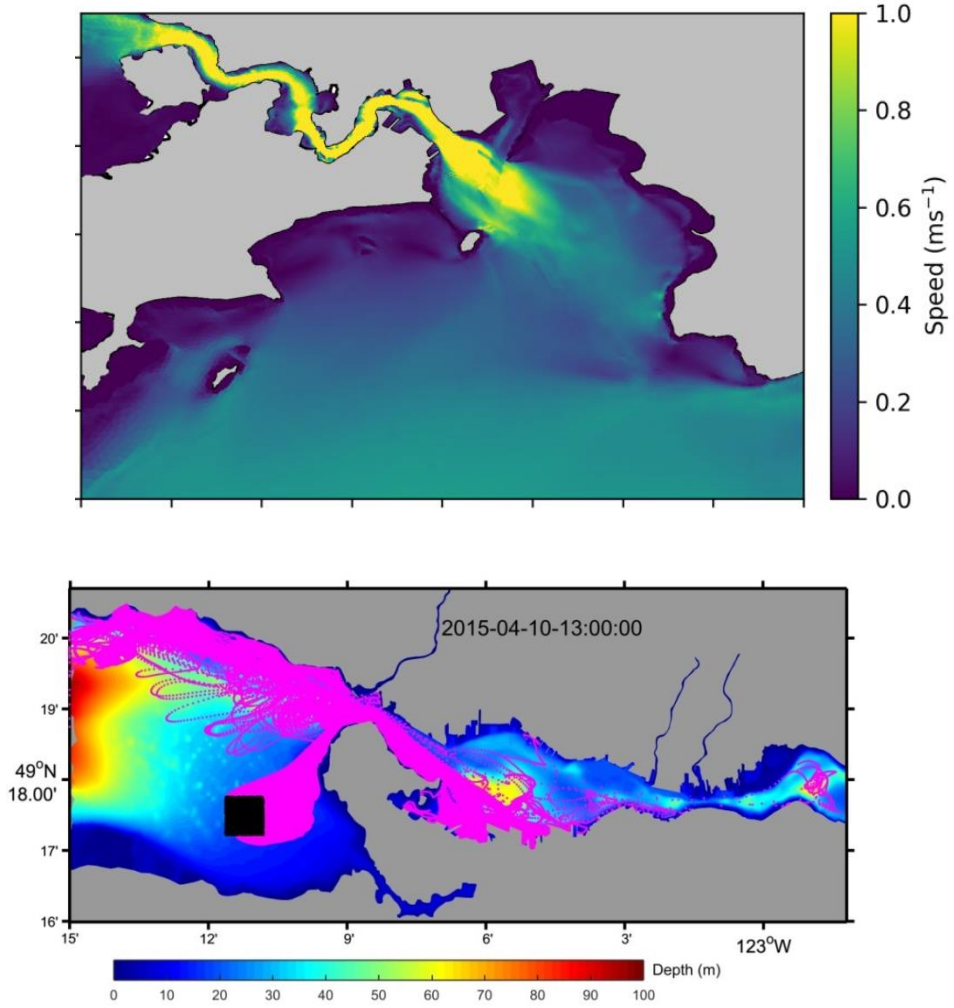
RIOPS: 1/12°, DA, operation



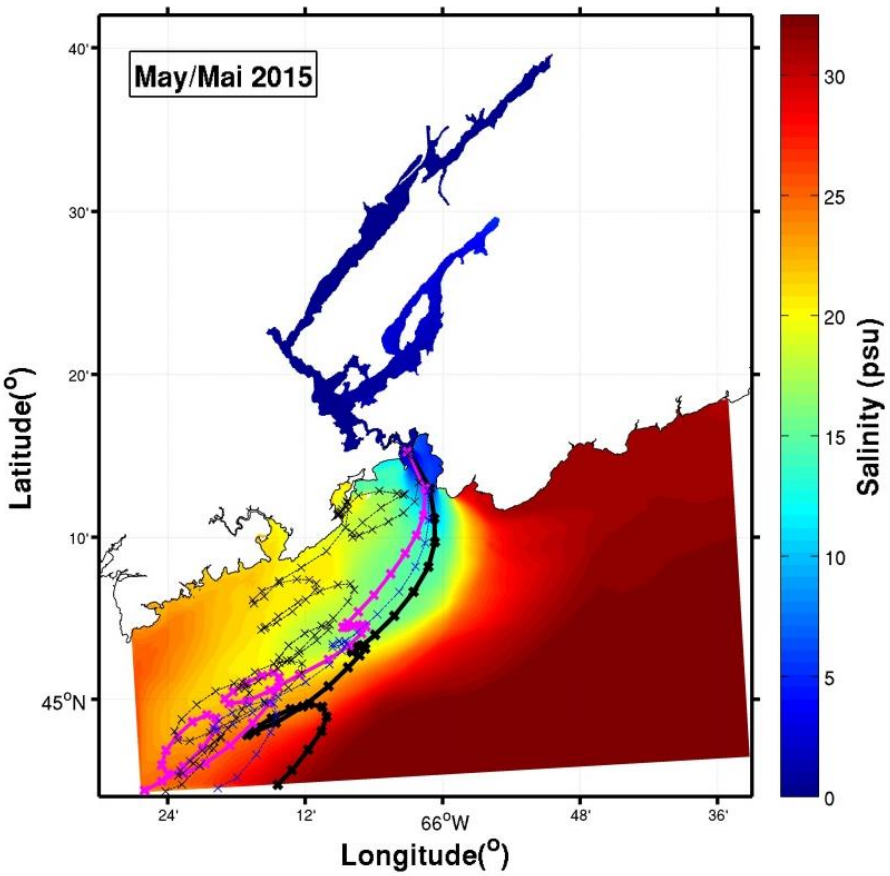
CIOPS-east: 1/36°, under development

Down-scale to coastal harbors: Government of Canada - Ocean Protection Plan

Based on FVCOM



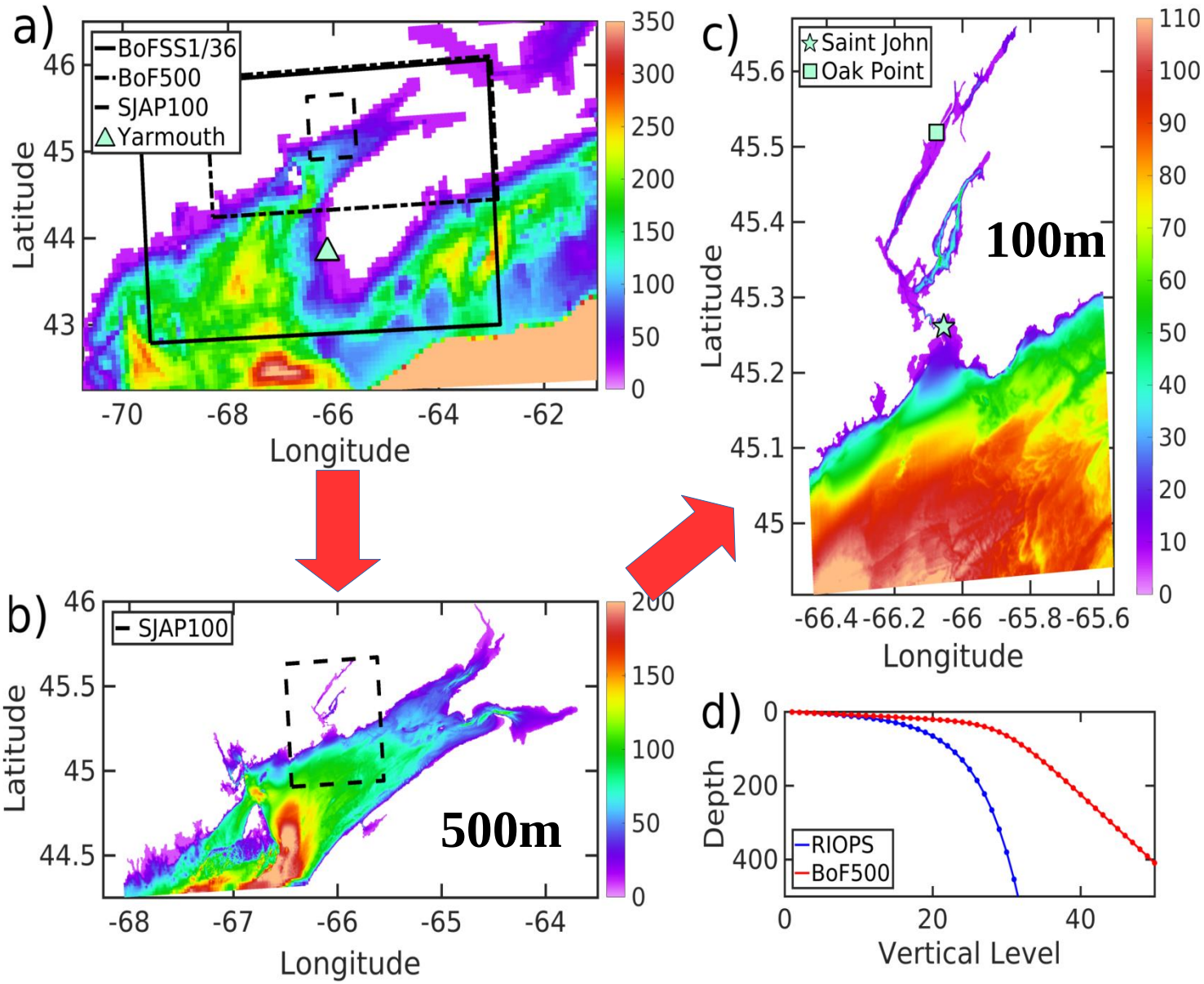
Based on NEMO



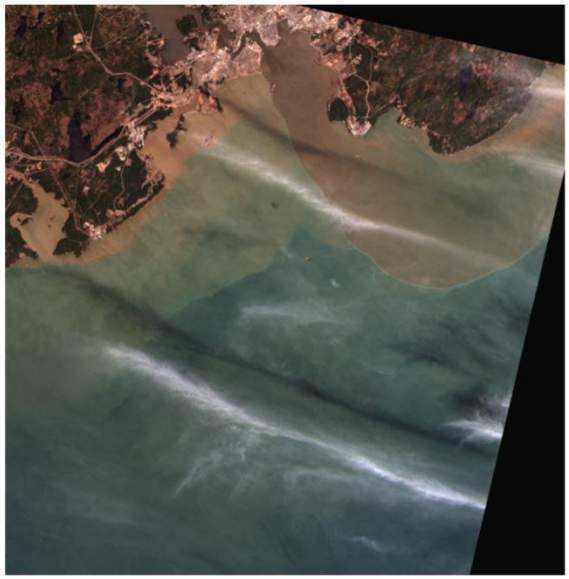
Saint John harbor
NEMO: multi-level 1-way nesting

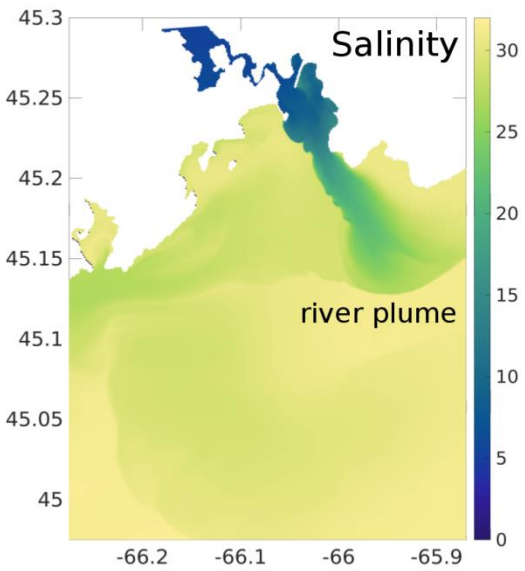
1/12° RIOPS

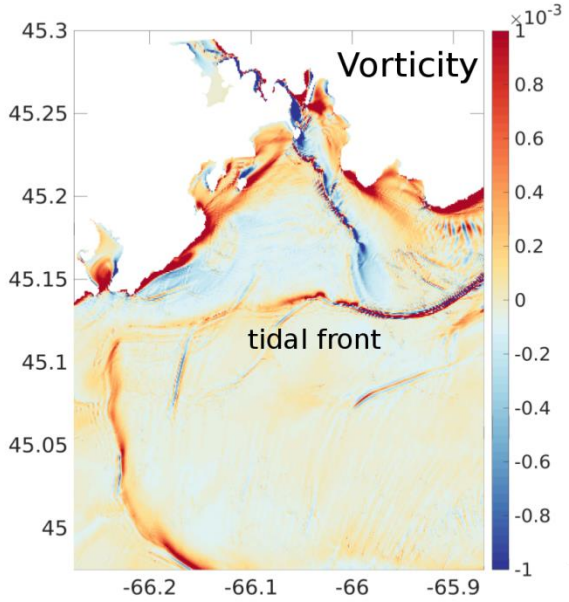
1/36°

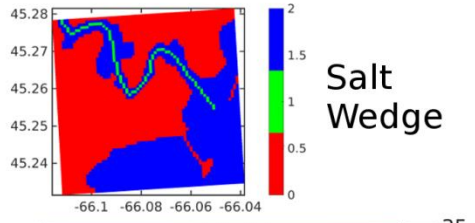


Main features of regional oceanography

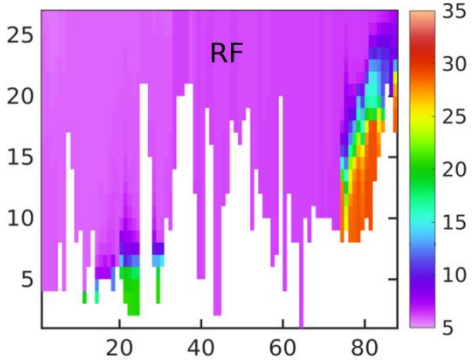




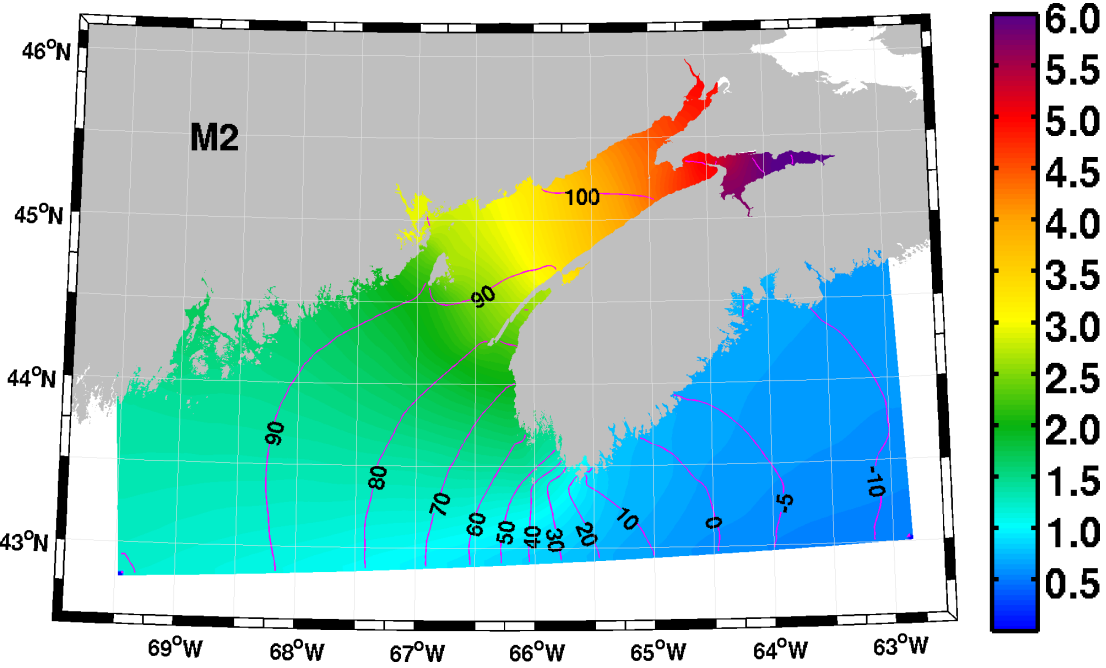


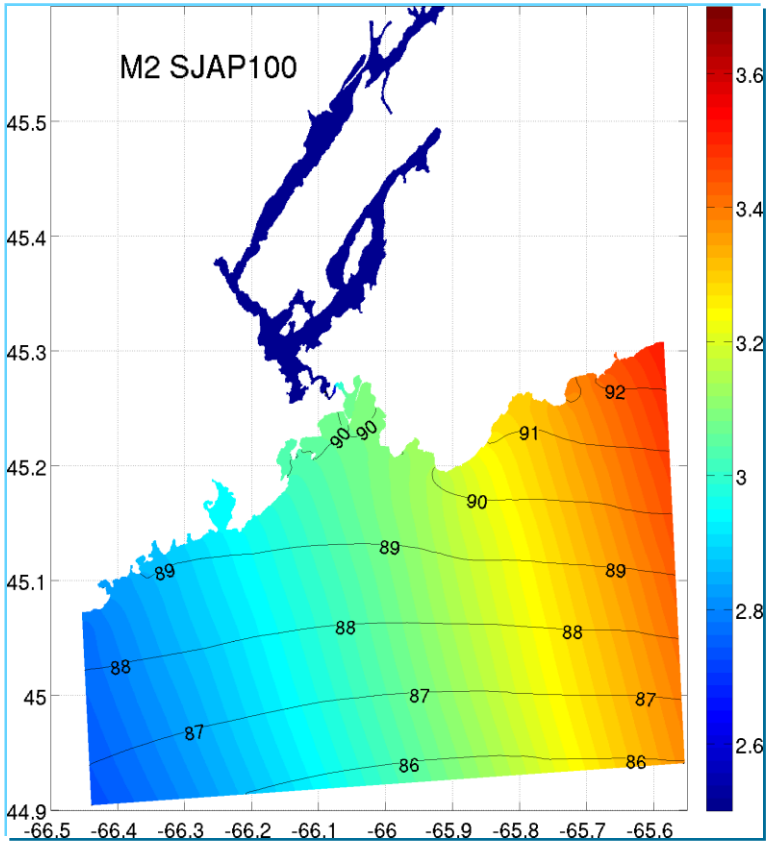


Salt Wedge



Strong tides & Narrow channel

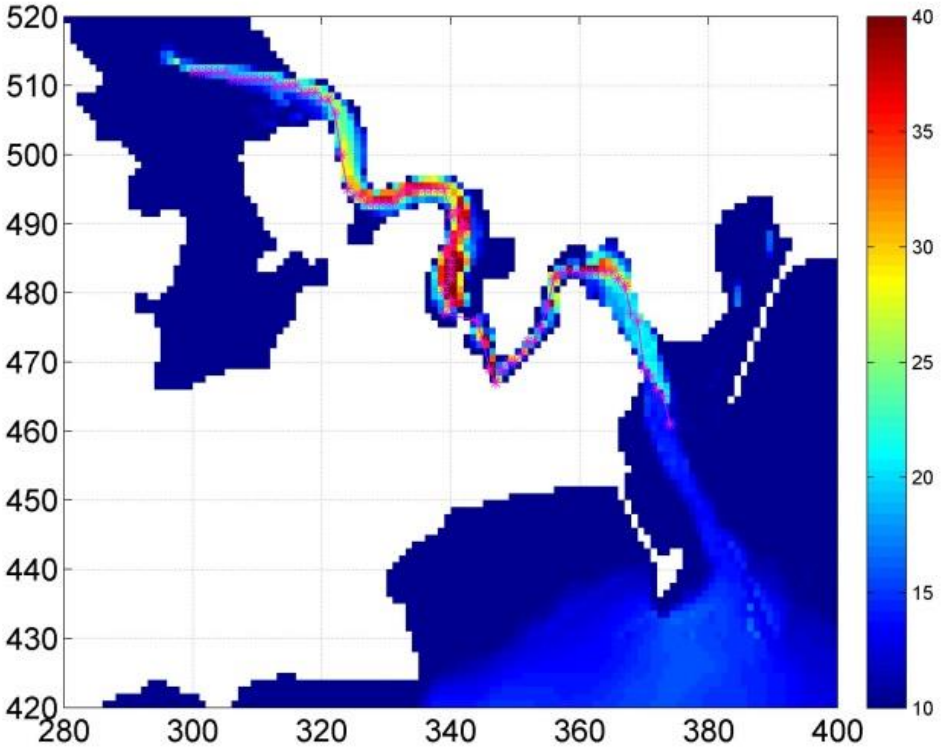




The Reversing Falls

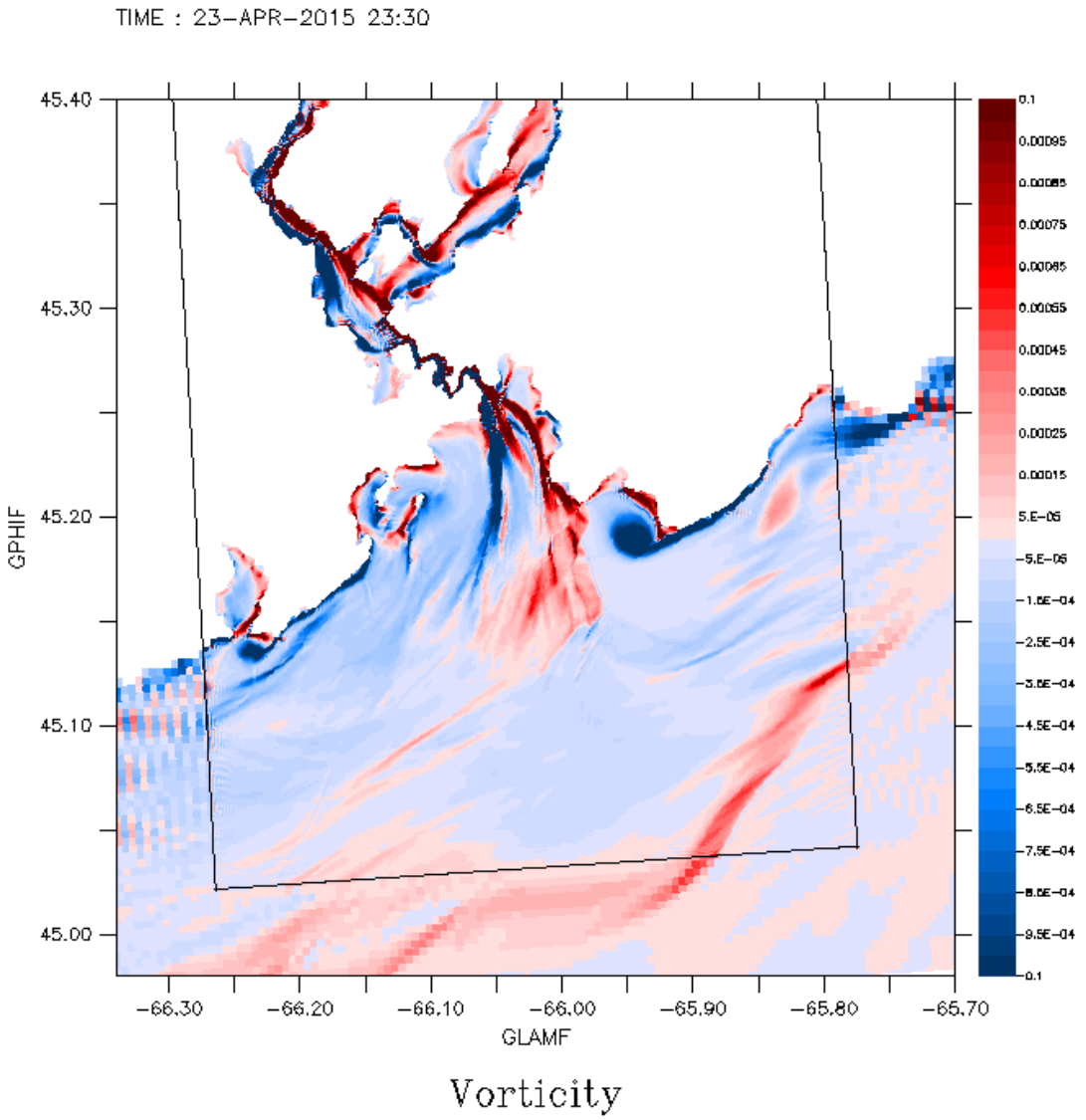
River plume & Salt wedge

sss_20150925.mp4

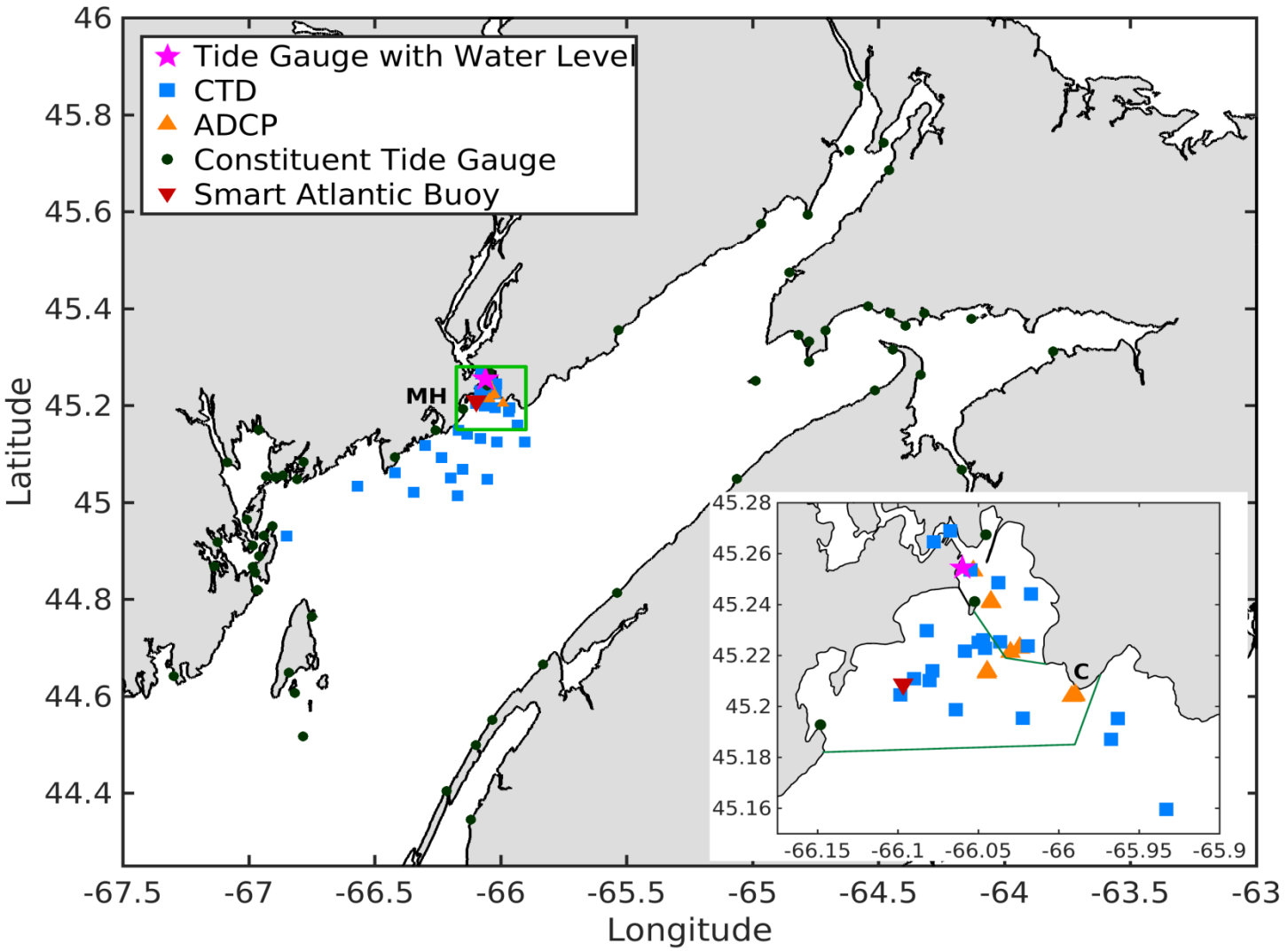


sss_ssh_20150925.mp4

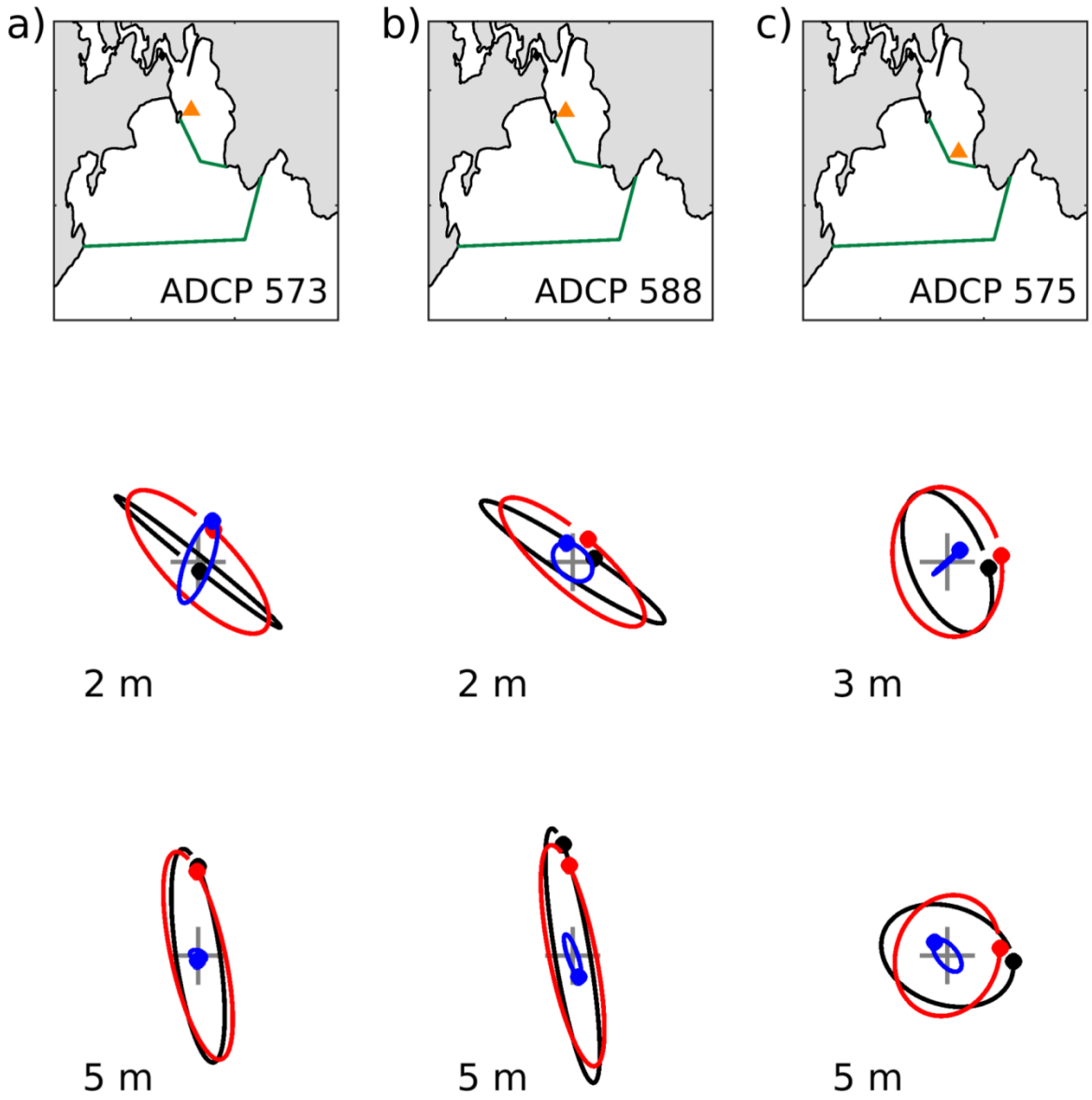
Tidal fronts: Relative vorticity of surface current - 2-way nested σ-coordinate test by J Chanut



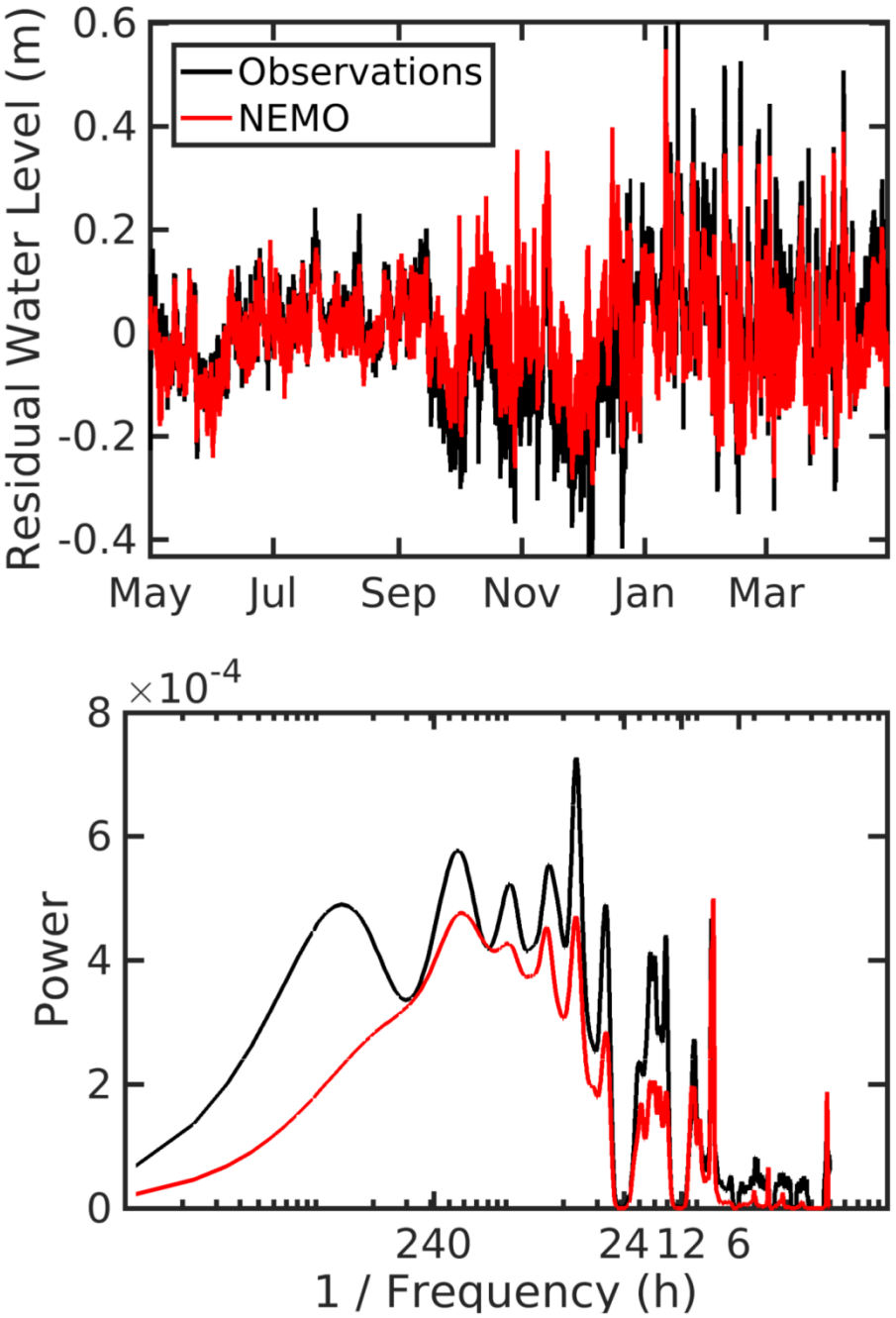
Model evaluation: Observational data



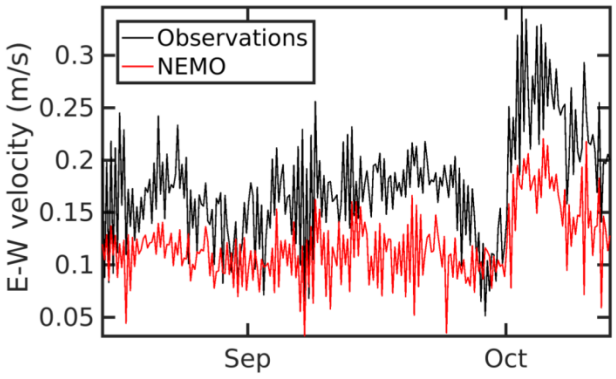
Tidal ellipses: obs (black) model (red) diff (blue)

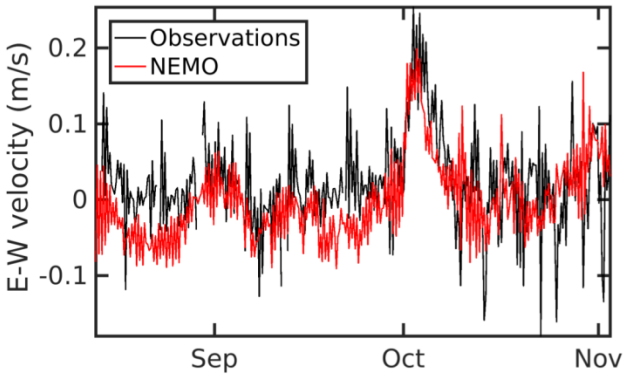


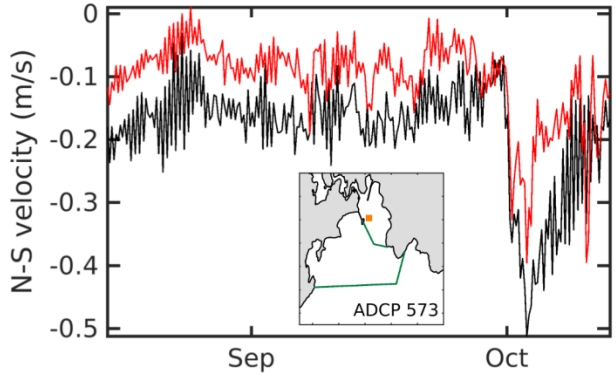
Non-tidal water level: obs (black) model (red)

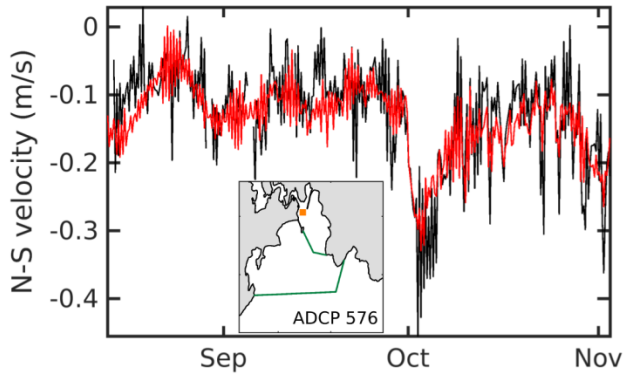


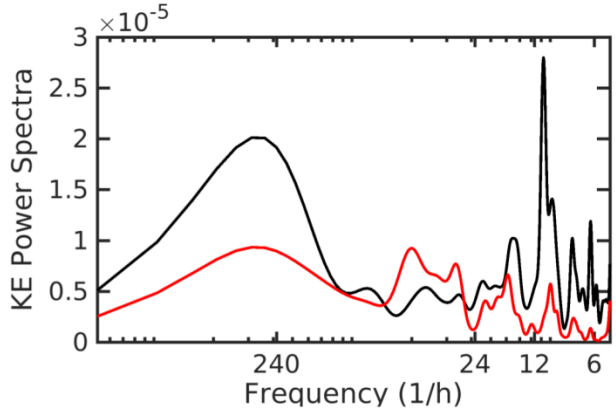
Non-tidal flow: obs (black) model (red)

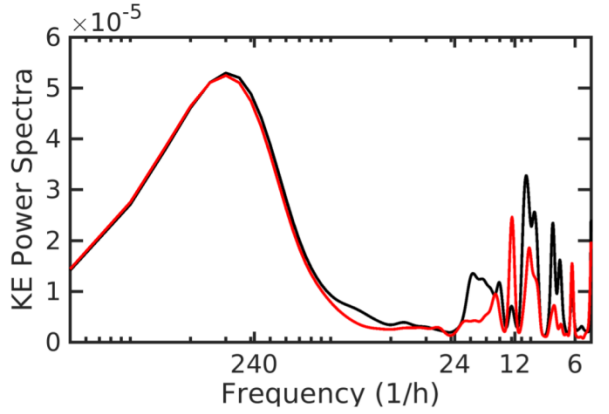




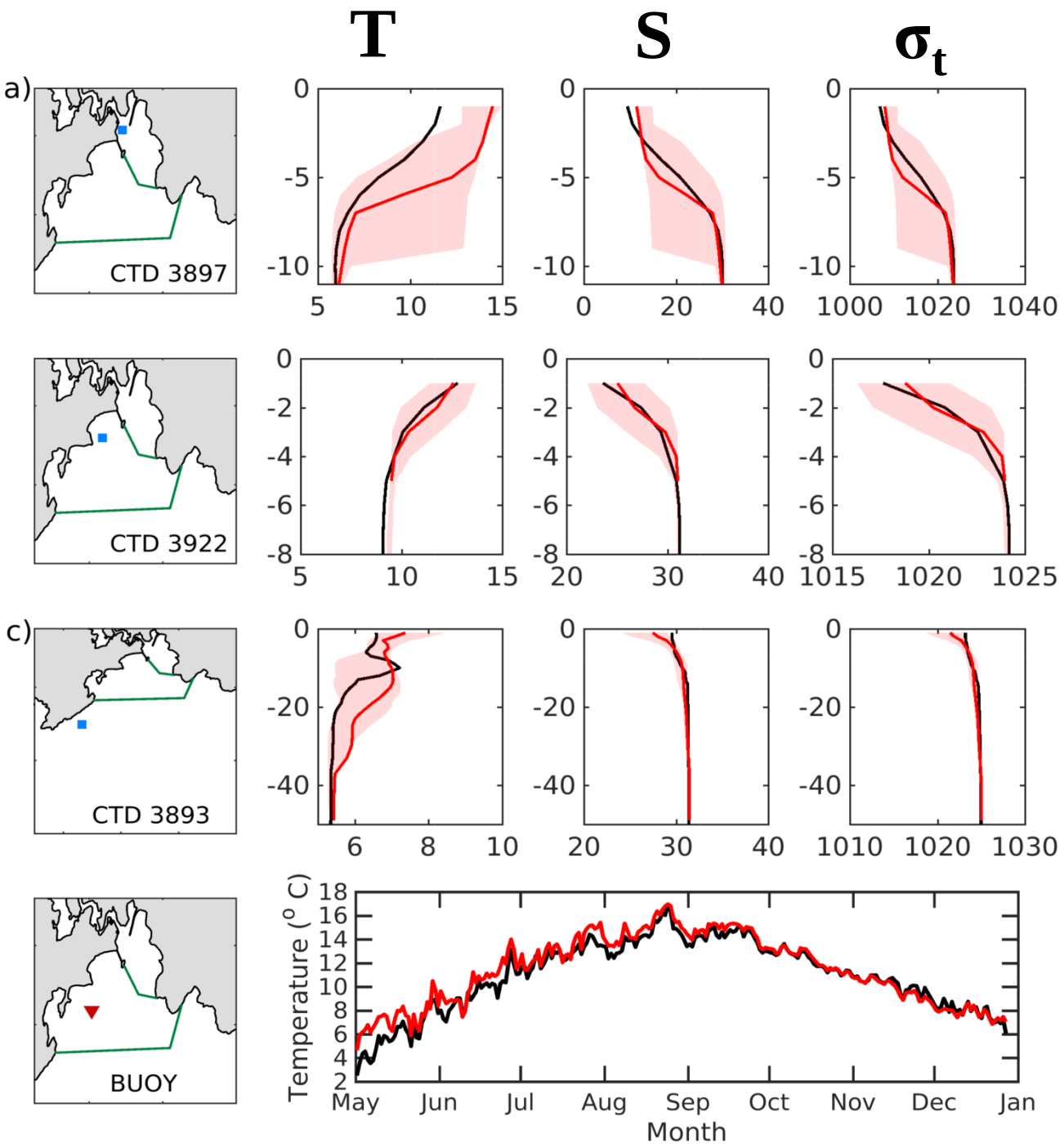




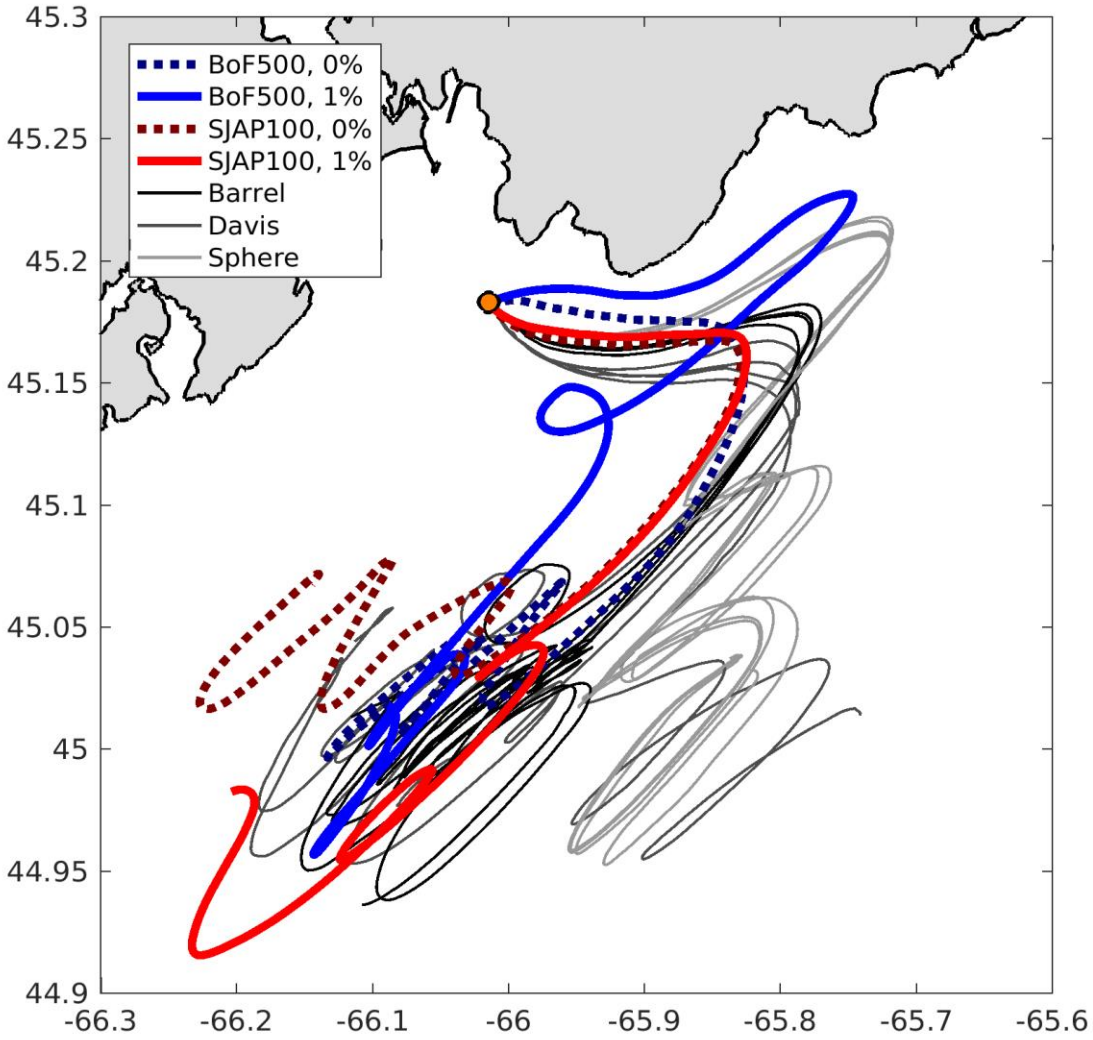




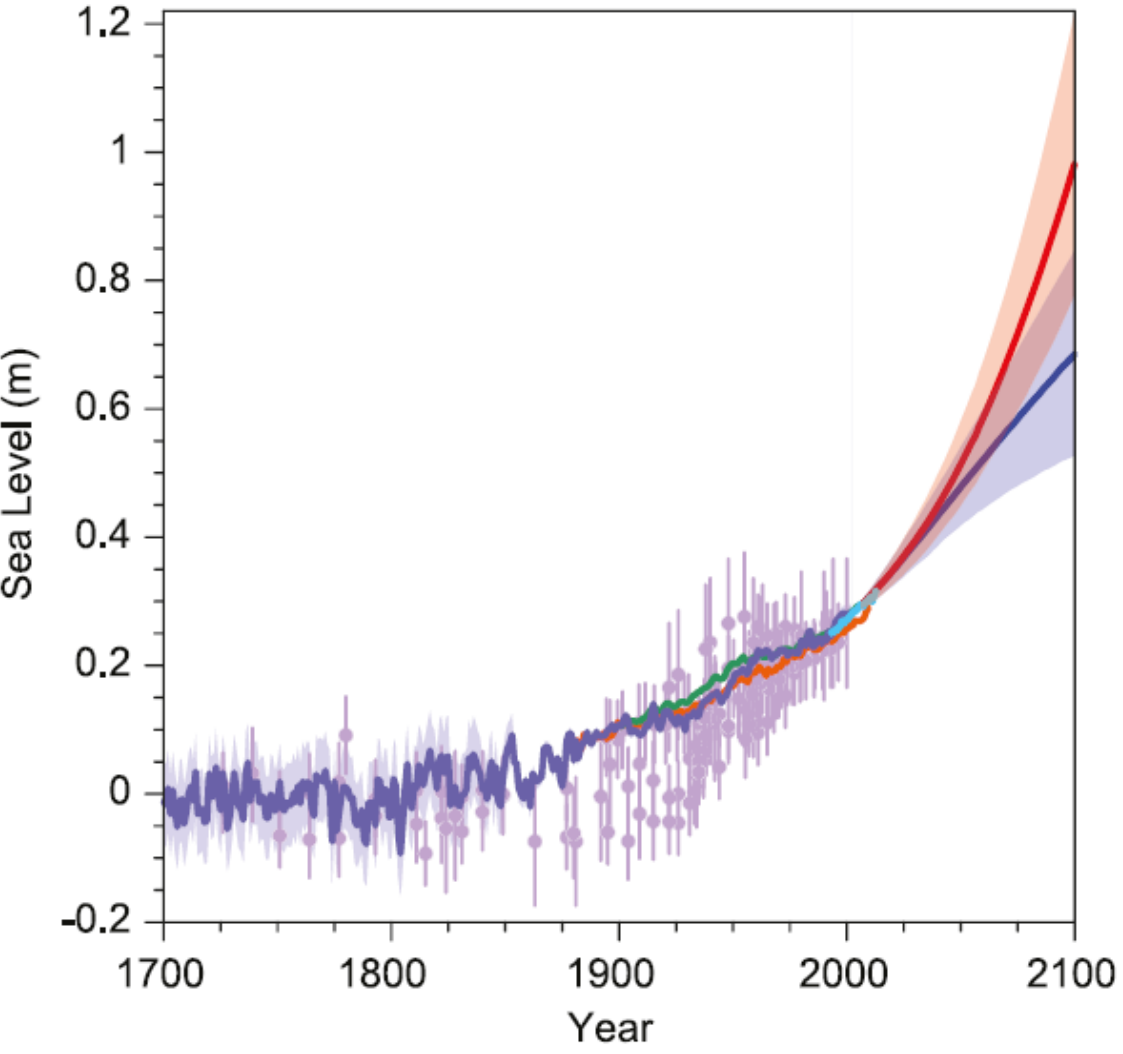
CTD:
obs (black)
model (red)



Surface drifter trajectories



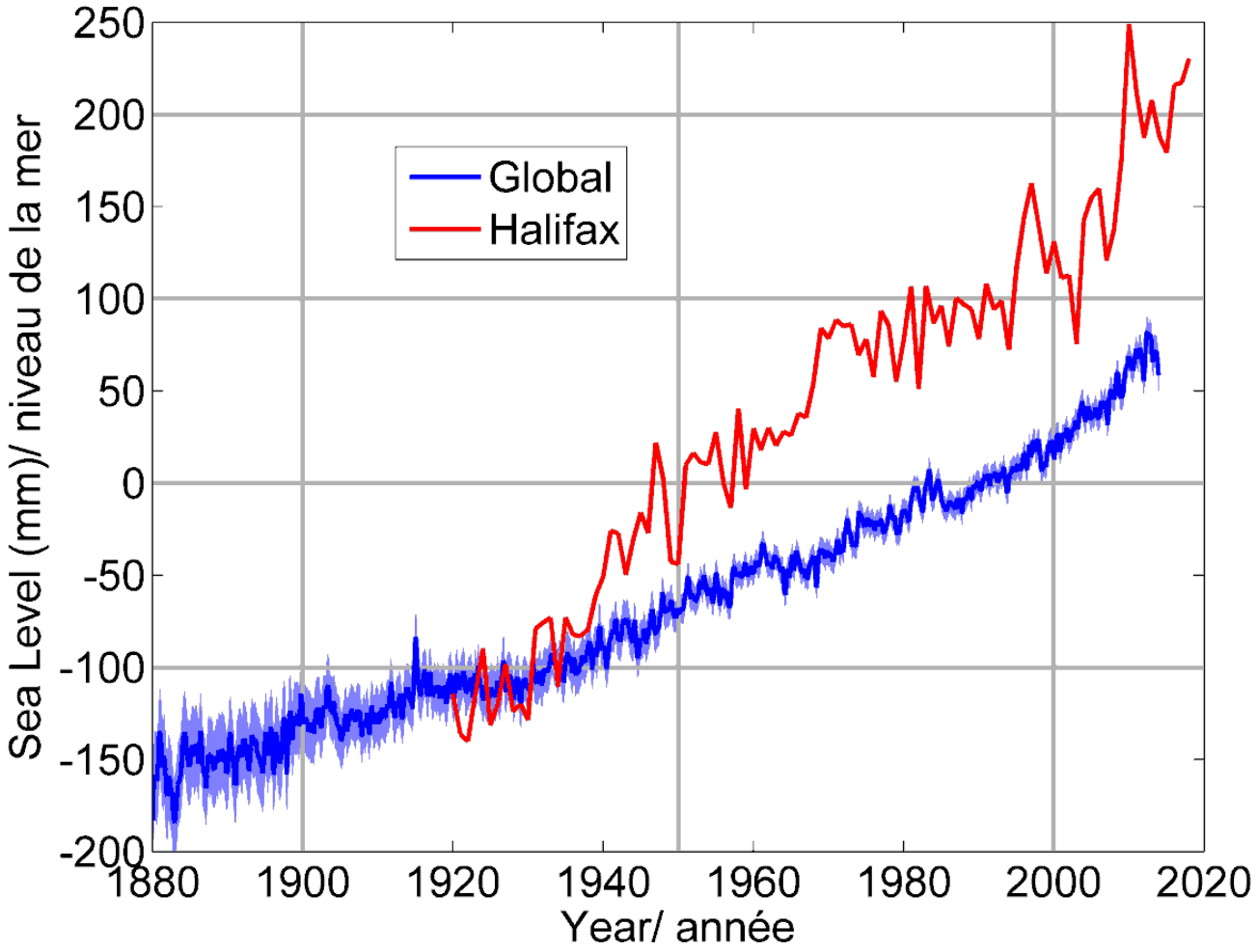
Modelling Research: Sea Level Changes



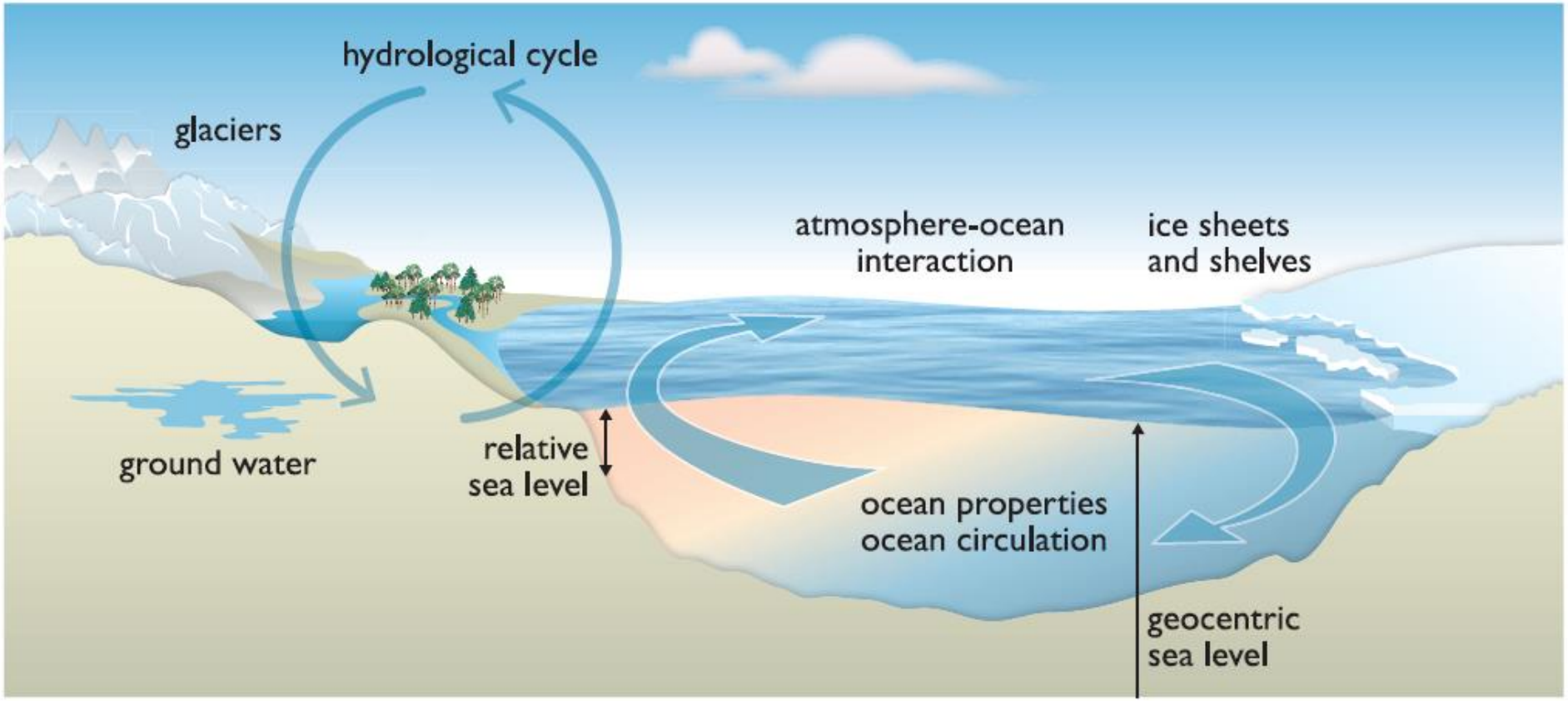
Global mean sea level change: Past & future projections

International Panel of Climate Change: 5th Assessment Report

Regional Sea Level Rise

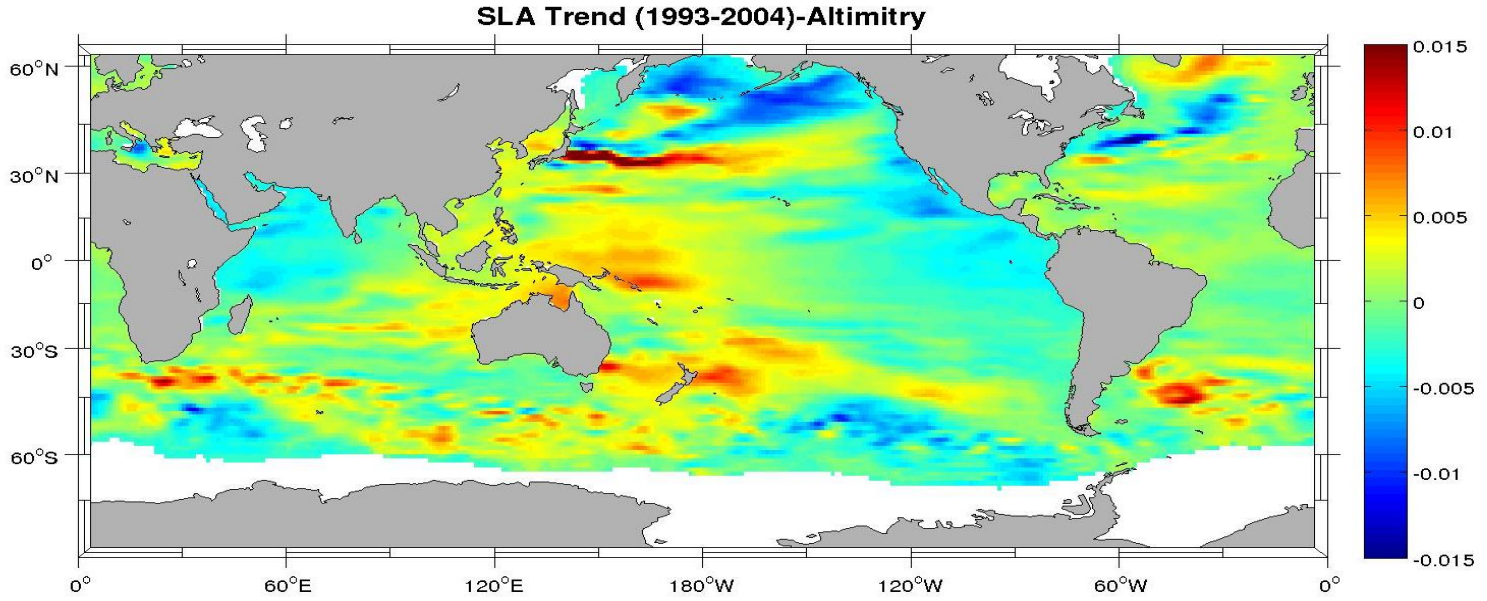


Processes Influencing Sea Level Changes

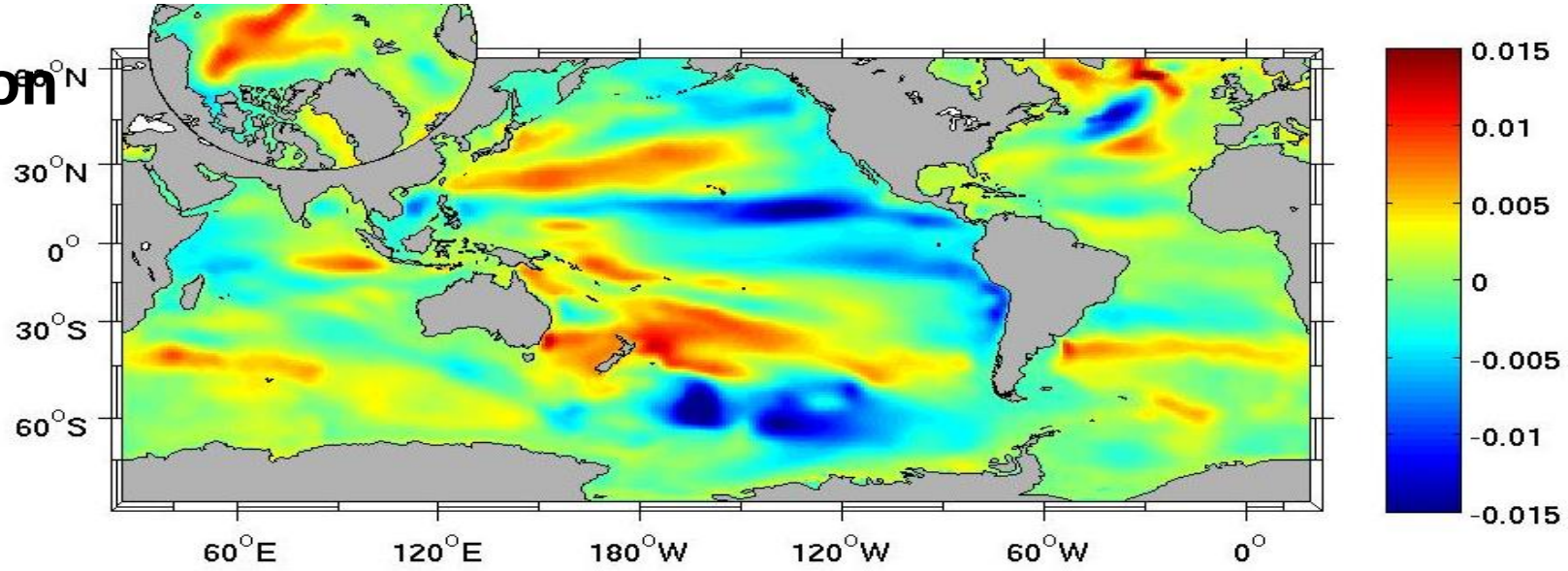


Remove global mean: Non-uniform Sea-Level Trend 1993-2004 (m/yr)

Satellite Obs

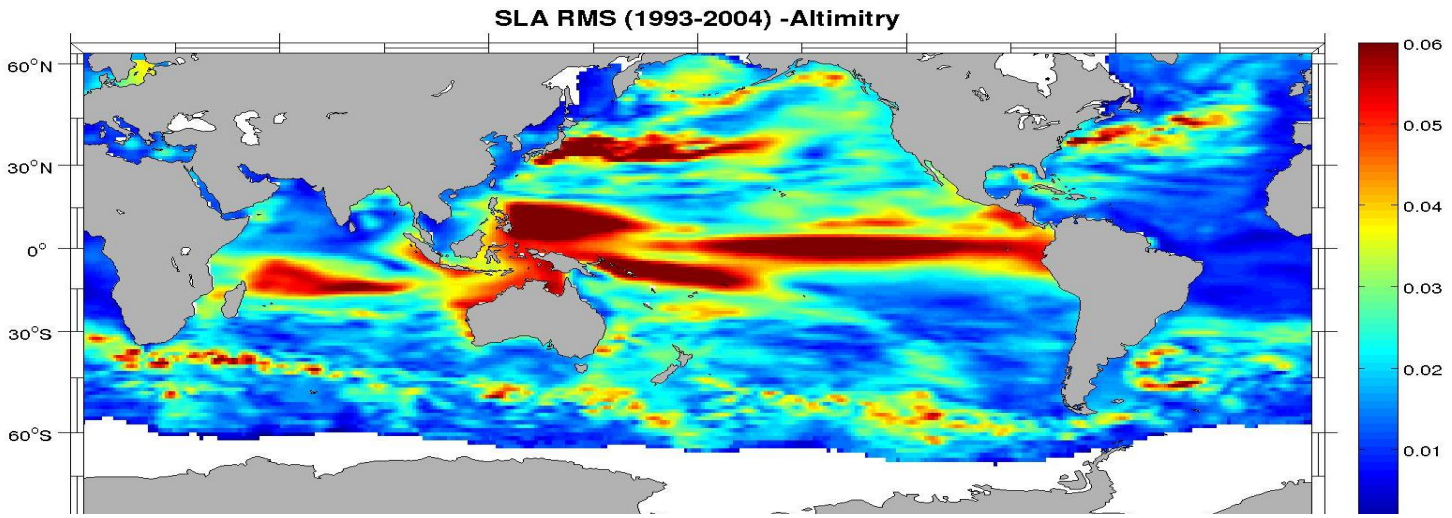


Coarse resolution model

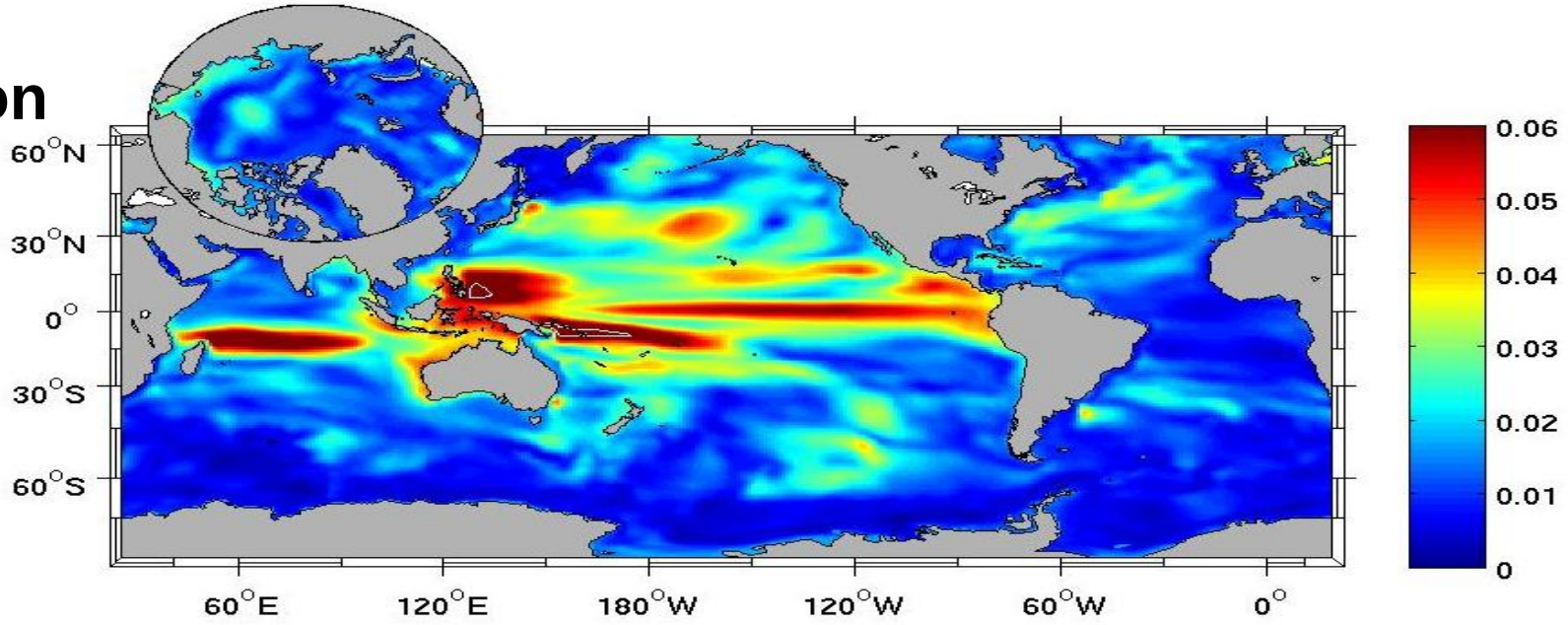


Inter-Annual Variation: RMS 1993-2004 (m)

Satellite Obs

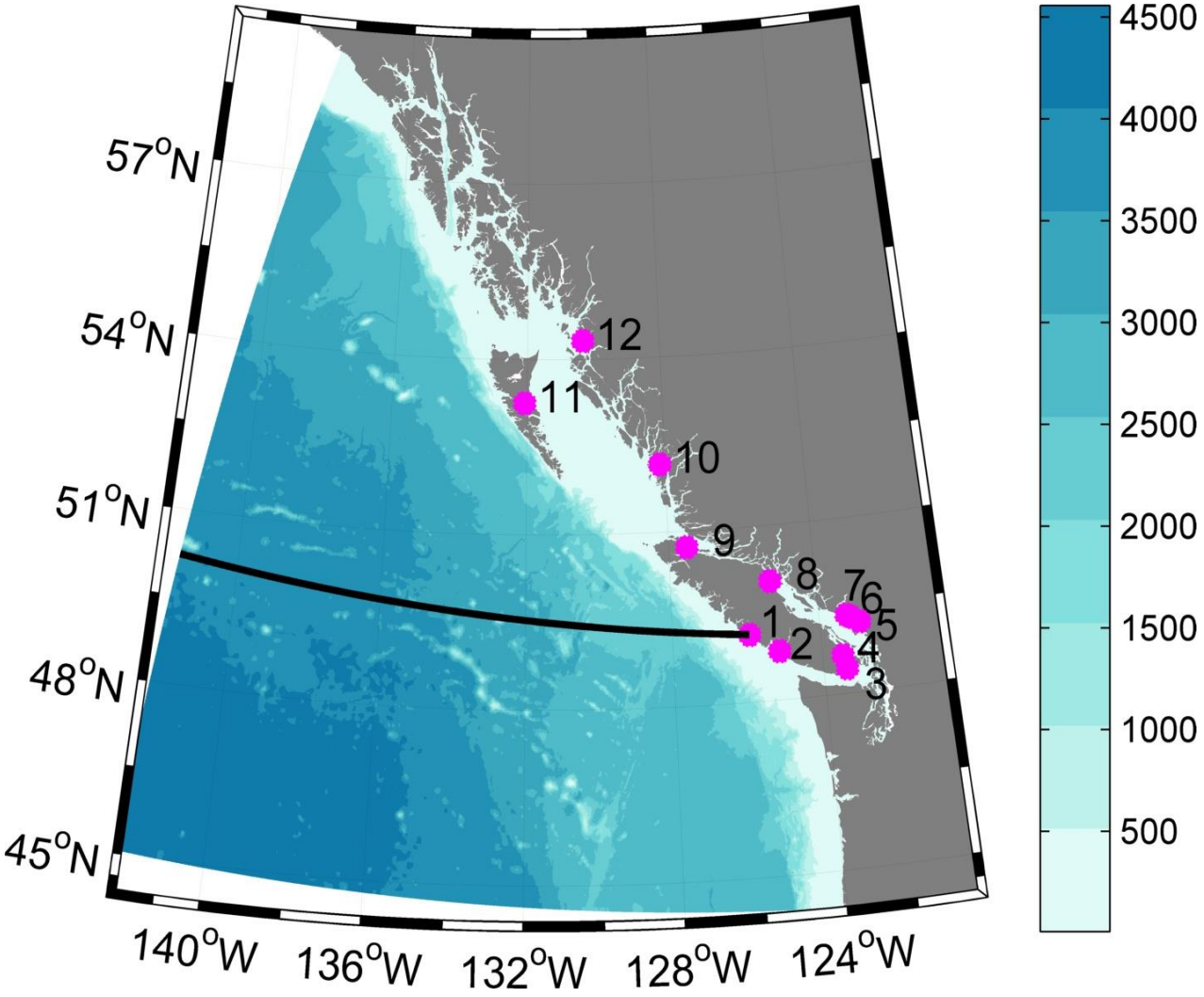


Coarse resolution Model



Study based on high-resolution ocean model:

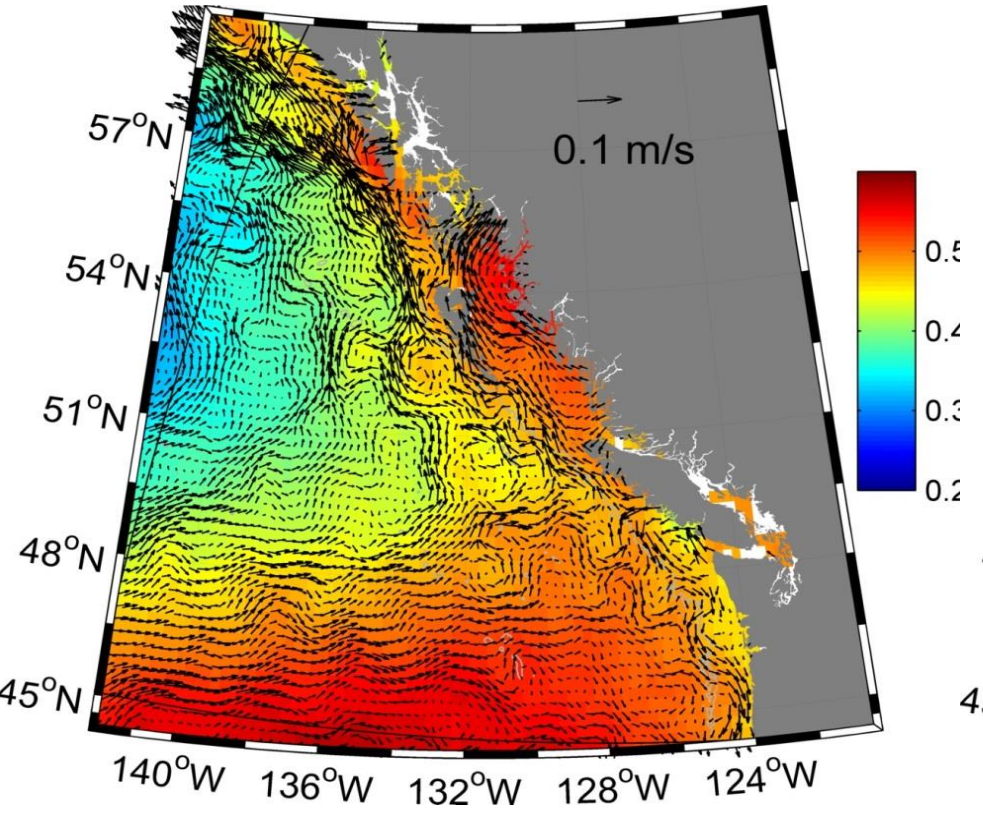
Seasonal, intra-seasonal & inter-annual sea level variations on shelf off Canada's west coast



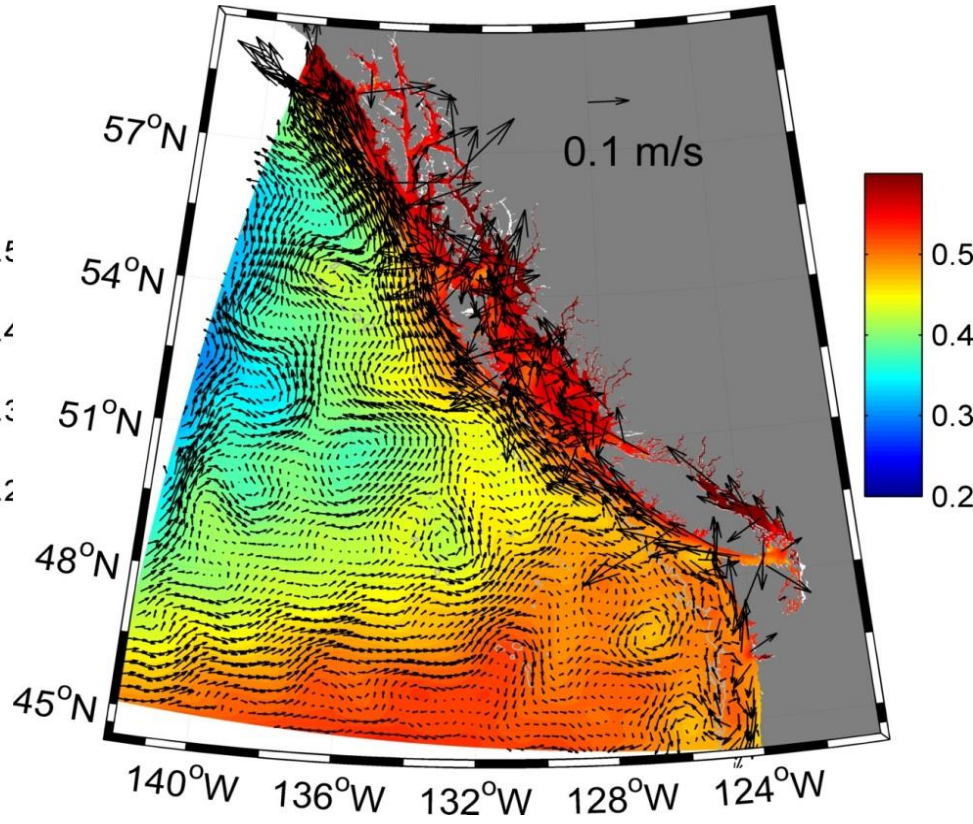
Hindcast 2007-2016

Mean Sea Level (2008-2016)

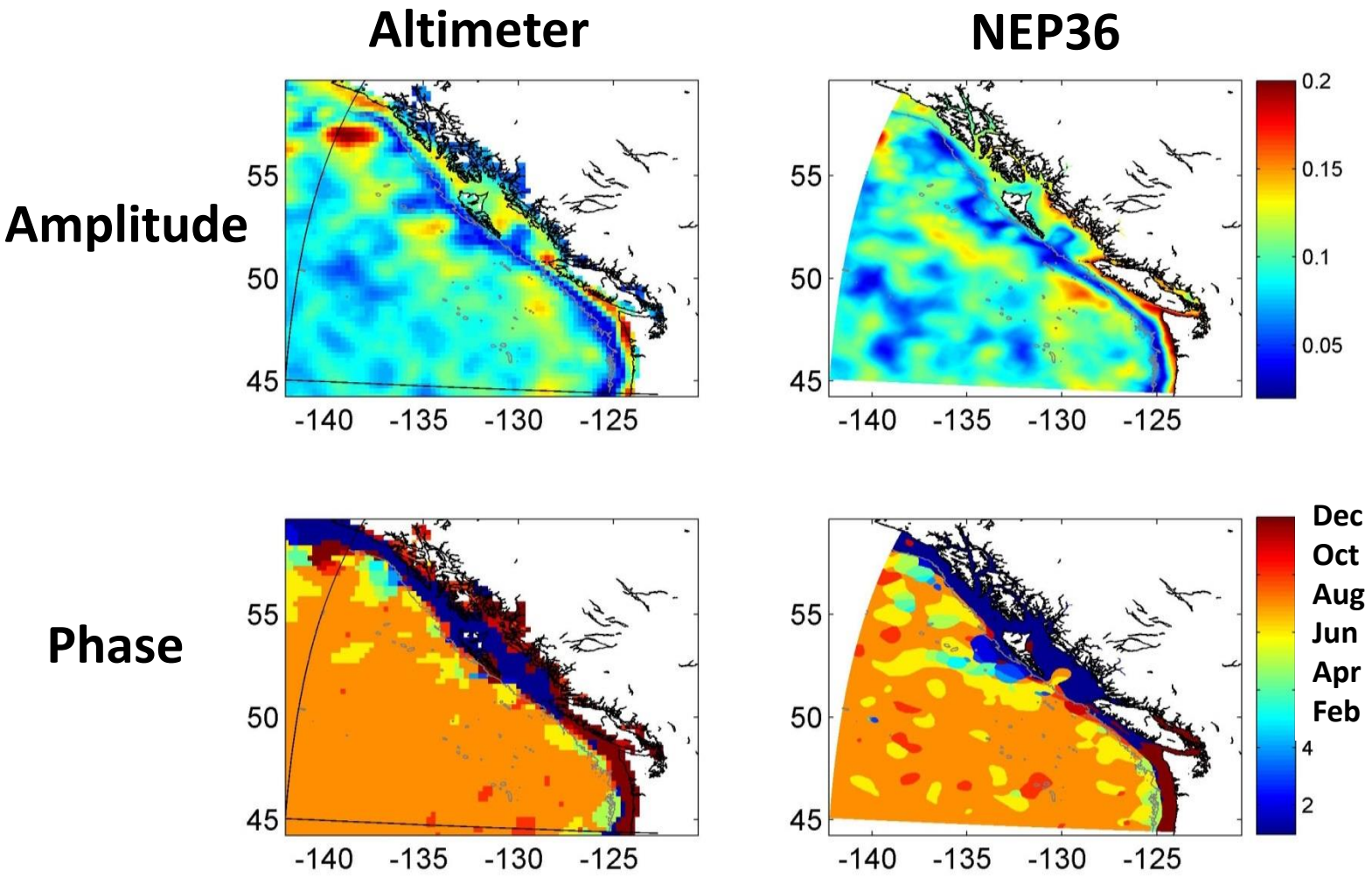
Altimeter obs



NEP36 Model



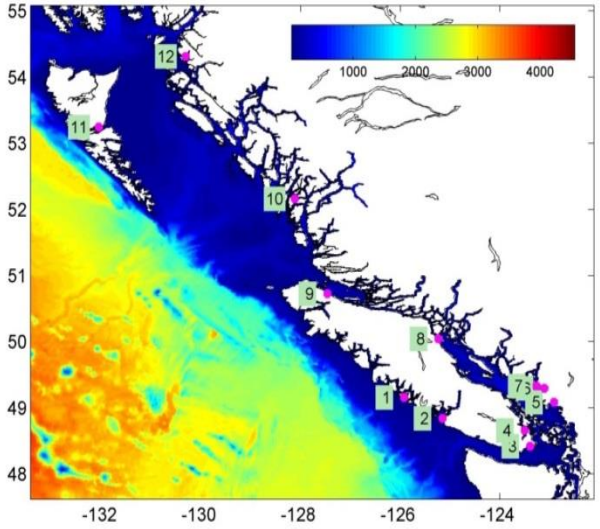
Seasonal Cycle of Sea Level



- **Amplitude: difference between maximum & minimum of monthly climatology; Large spatial variations**
- **Phase: month when maximum occurs; Seasonal cycles on the shelf & off the shelf break are out of phase**

Amplitudes of Seasonal Cycle

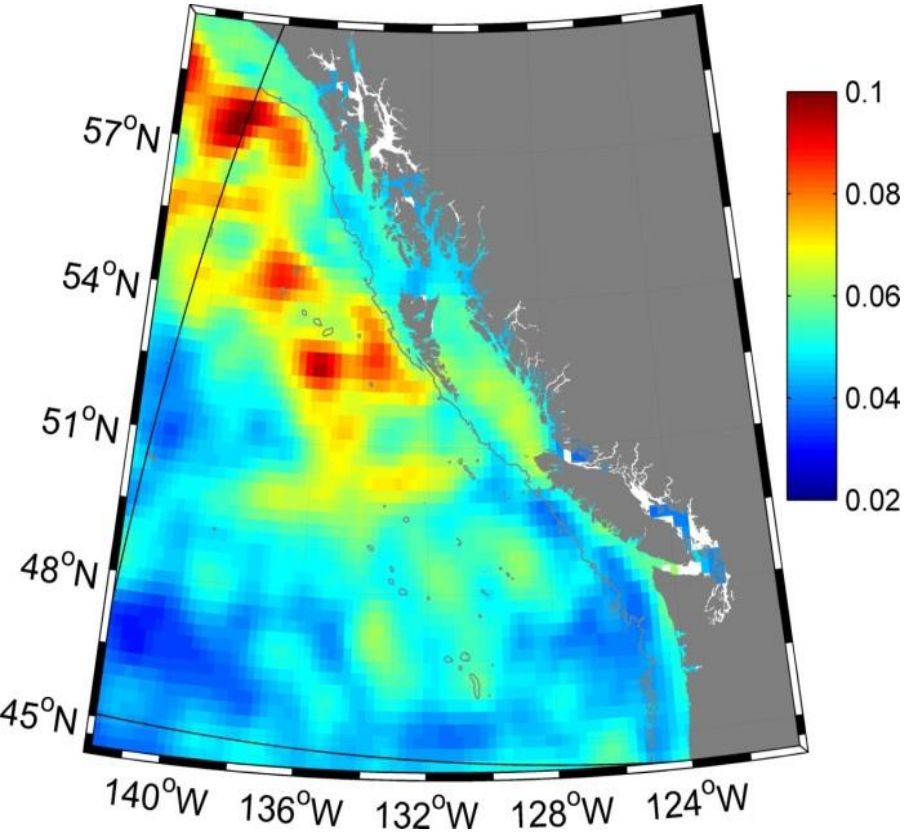
Number	Station Name	Tide Gauge	NEP36
1	Tofino	0.21	0.16
2	Bamfield	0.19	0.15
3	Victoria Harbour	0.16	0.14
4	Patricia Bay	0.14	0.14
5	New Westminster	0.61	0.13
6	Vancouver	0.14	0.11
7	Point Atkinson	0.13	0.11
8	Campbell River	0.15	0.14
9	Port Hardy	0.16	0.15
10	Bella Bella	0.17	0.14
11	Queen Charlotte City	0.08	0.06
12	Prince Rupert	0.16	0.13



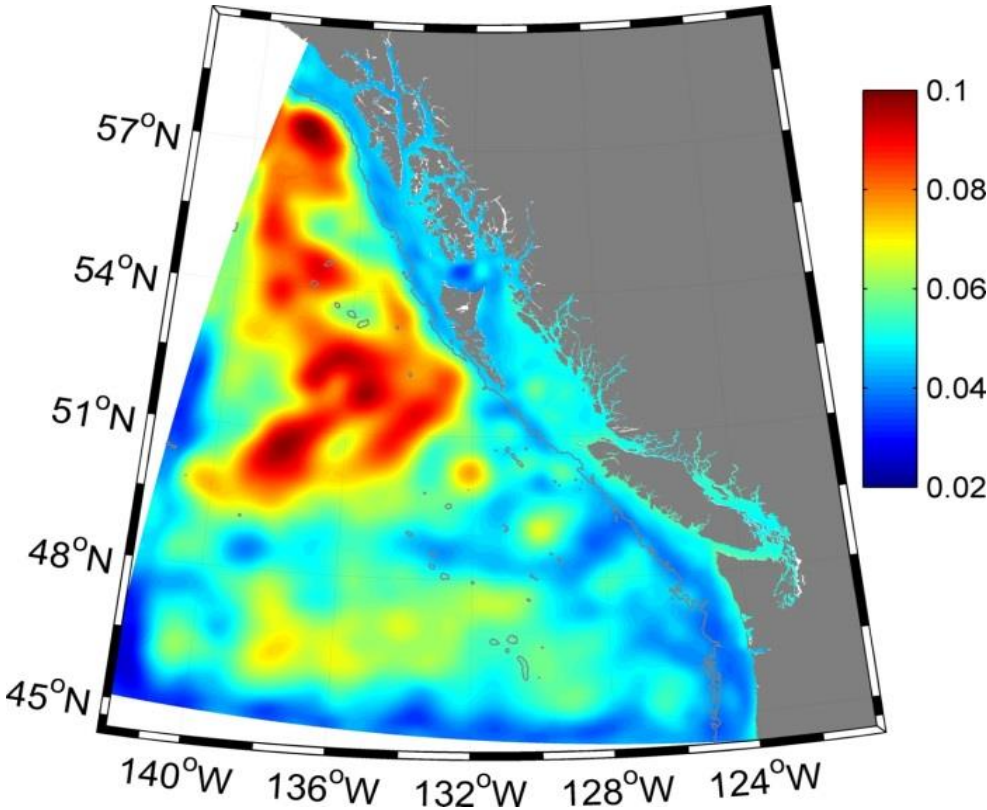
- **Good agreement between NEP36 and tide gauge observations**
- **Difference is less than 5 cm**

Standard Deviations of Sea Level Anomaly

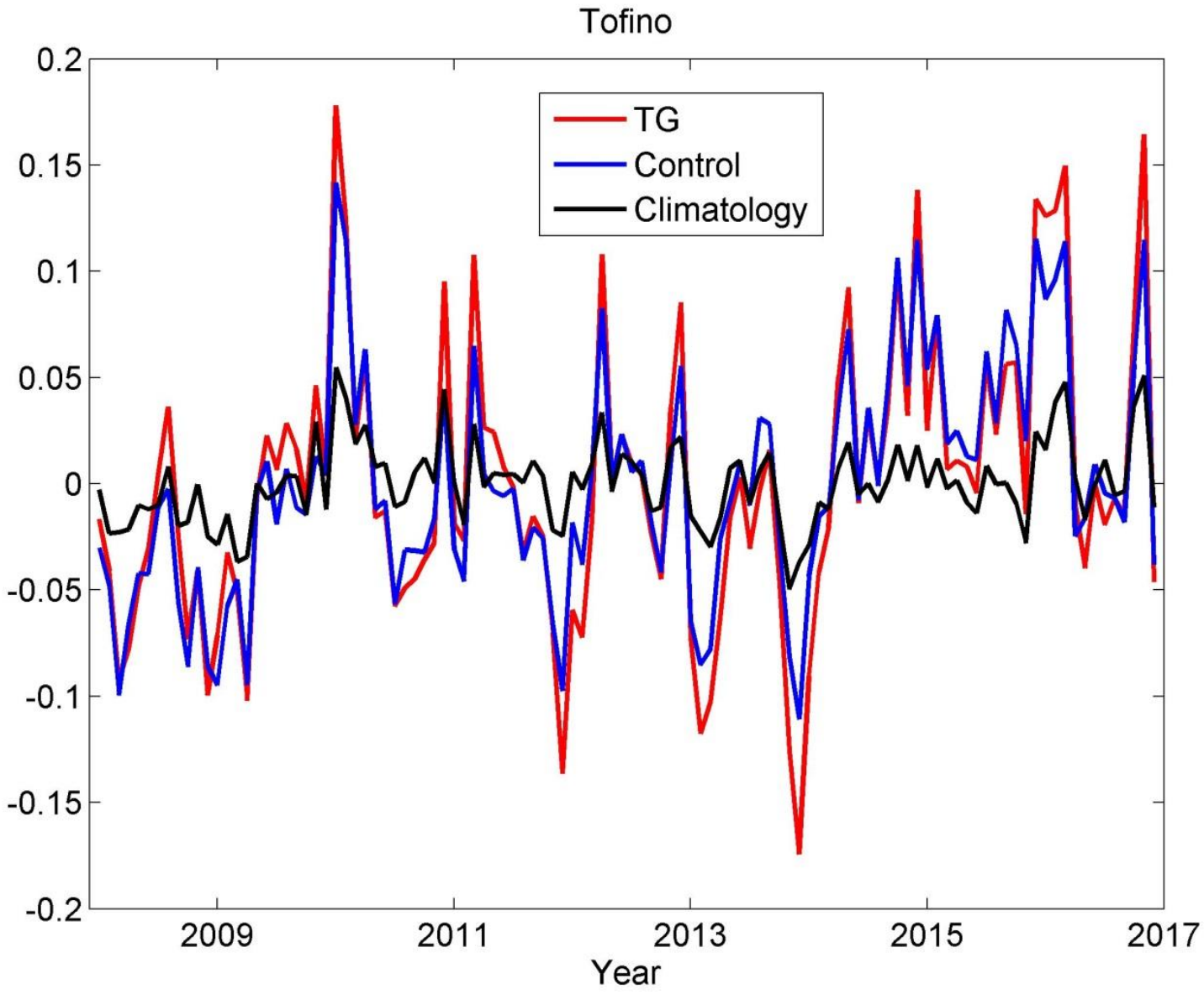
Altimeter obs



NEP36 model

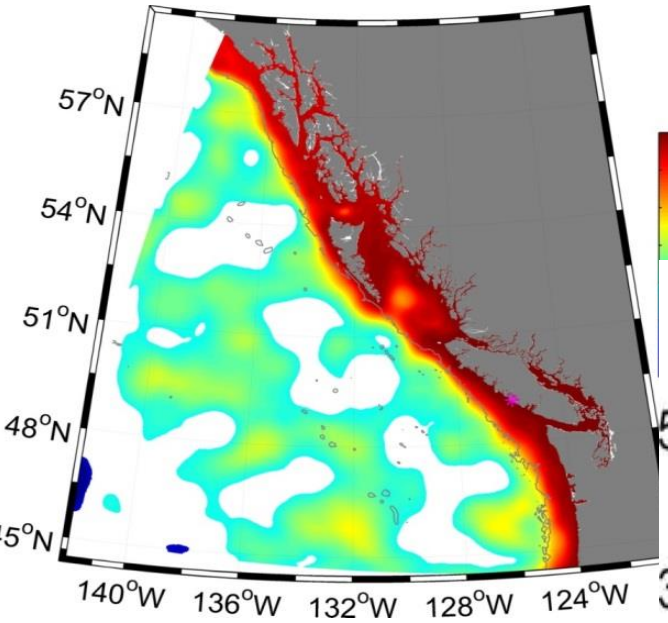


Sea Level Anomaly at Tide Gauge Tofino

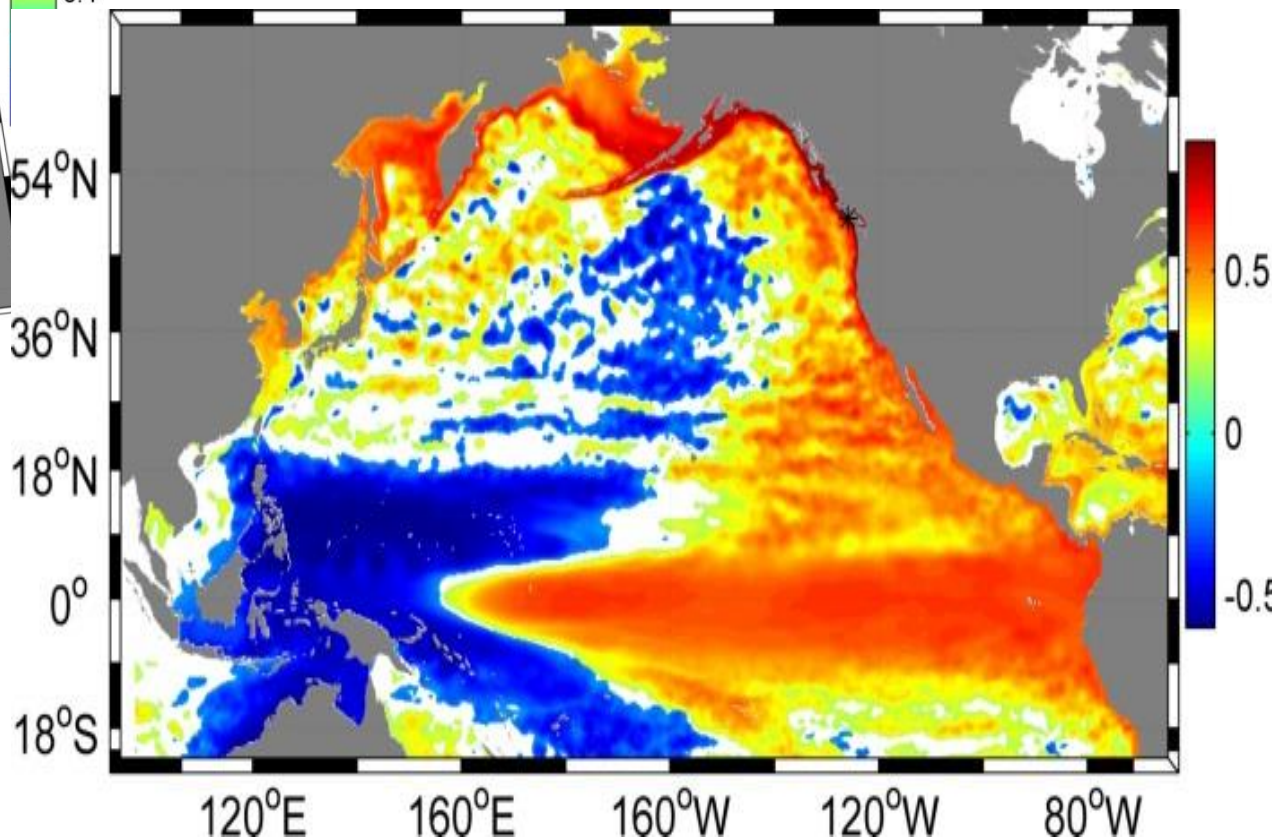


Correlation of Sea Level Anomaly @ Tofino with large scale

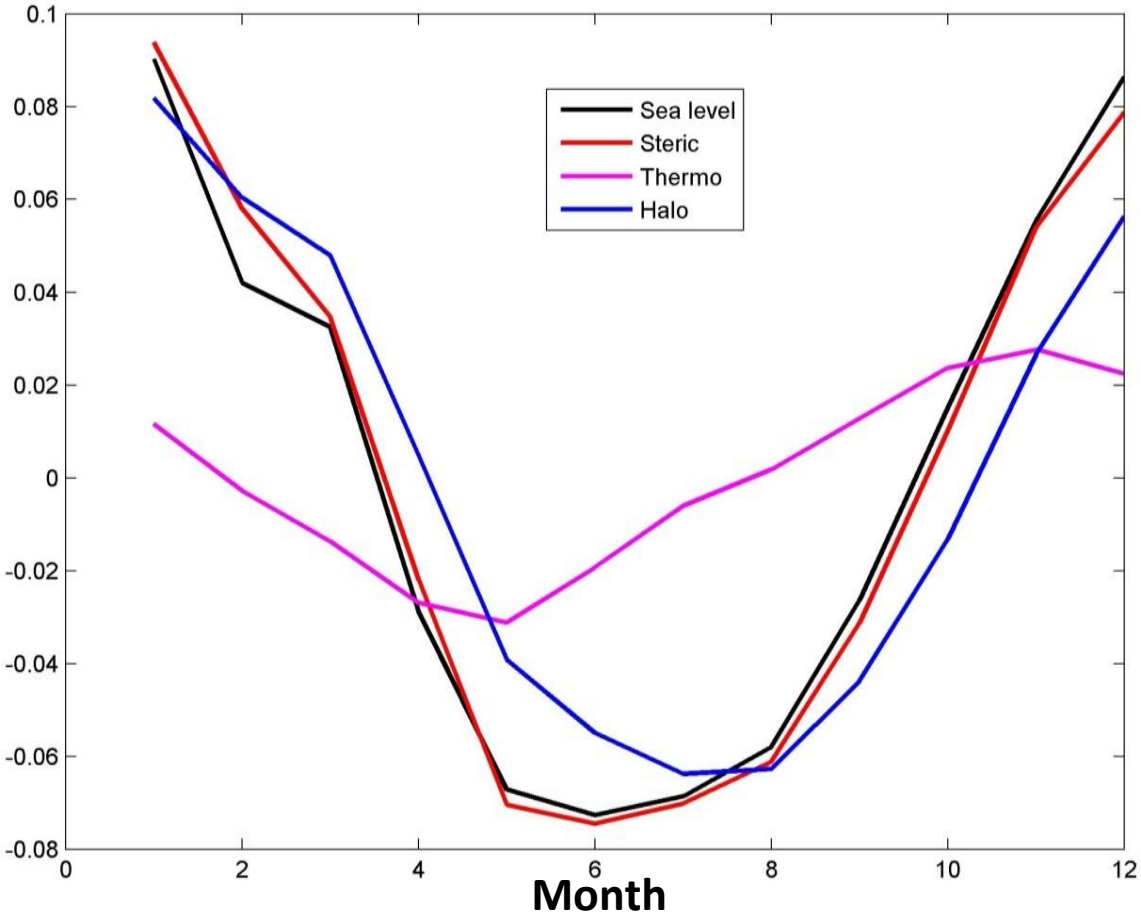
NEP36 model



GLORYS model

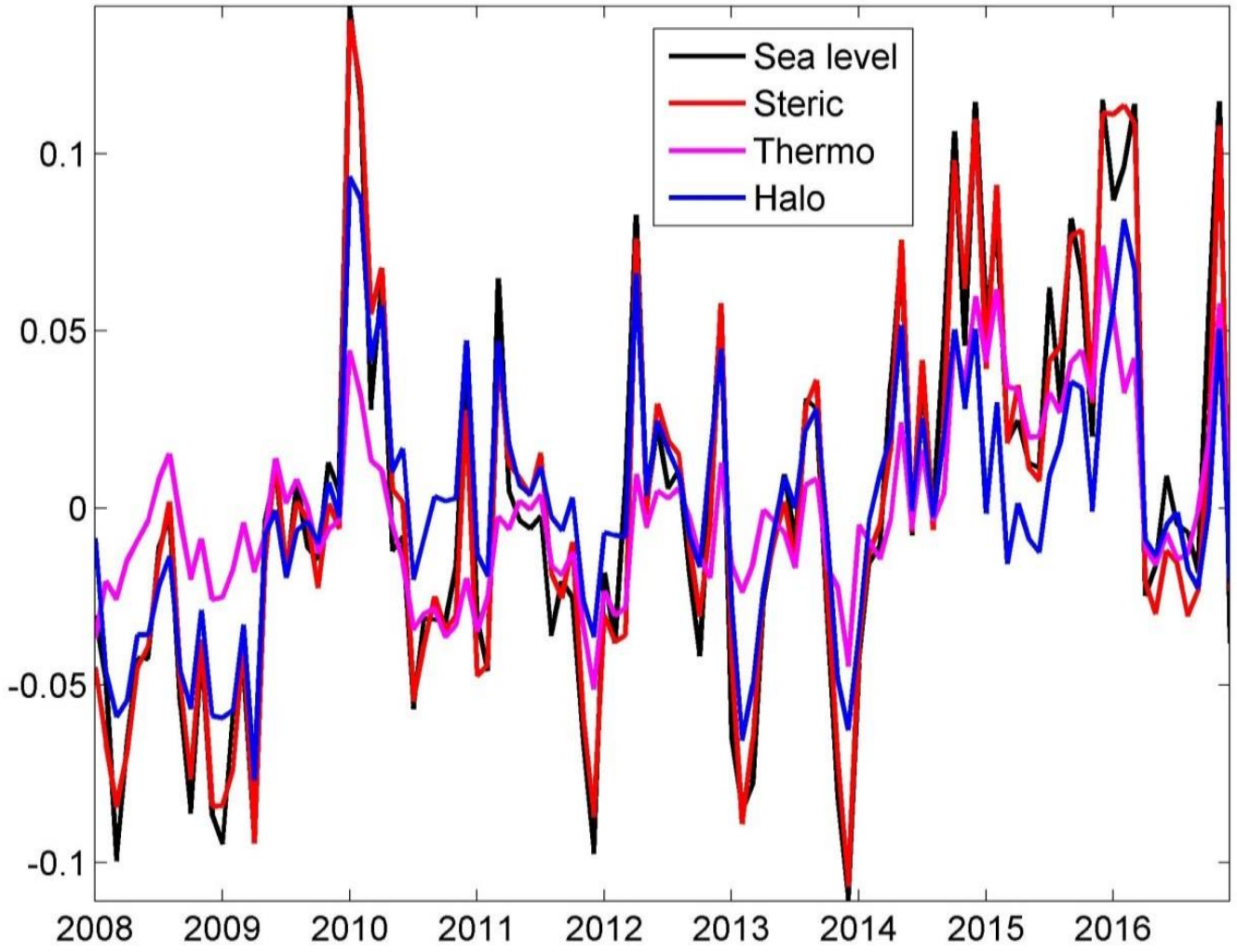


Tofino – Seasonal Cycle

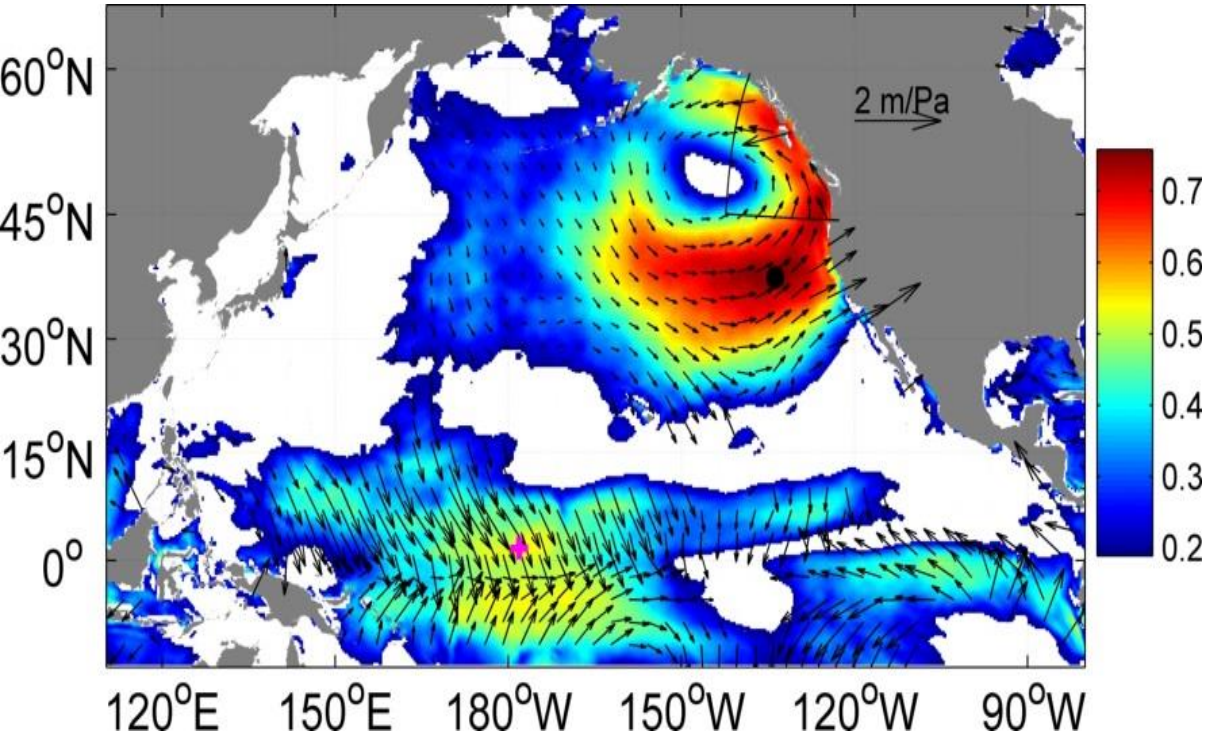


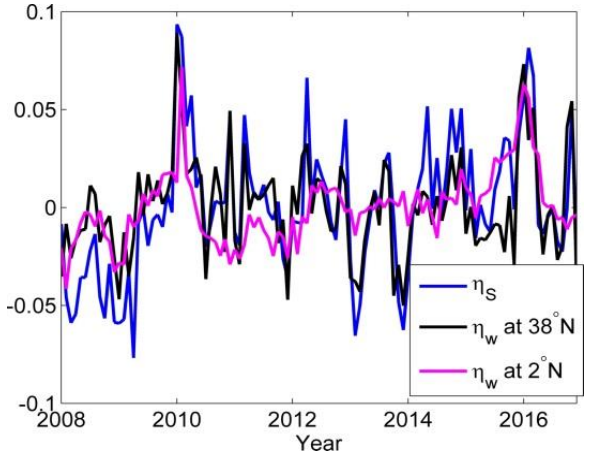
- **Steric height can account for seasonal variations of sea level**
- **Halosteric height dominates seasonal cycle of total steric height**

Tofino – Intra-seasonal & Inter-annual Variations

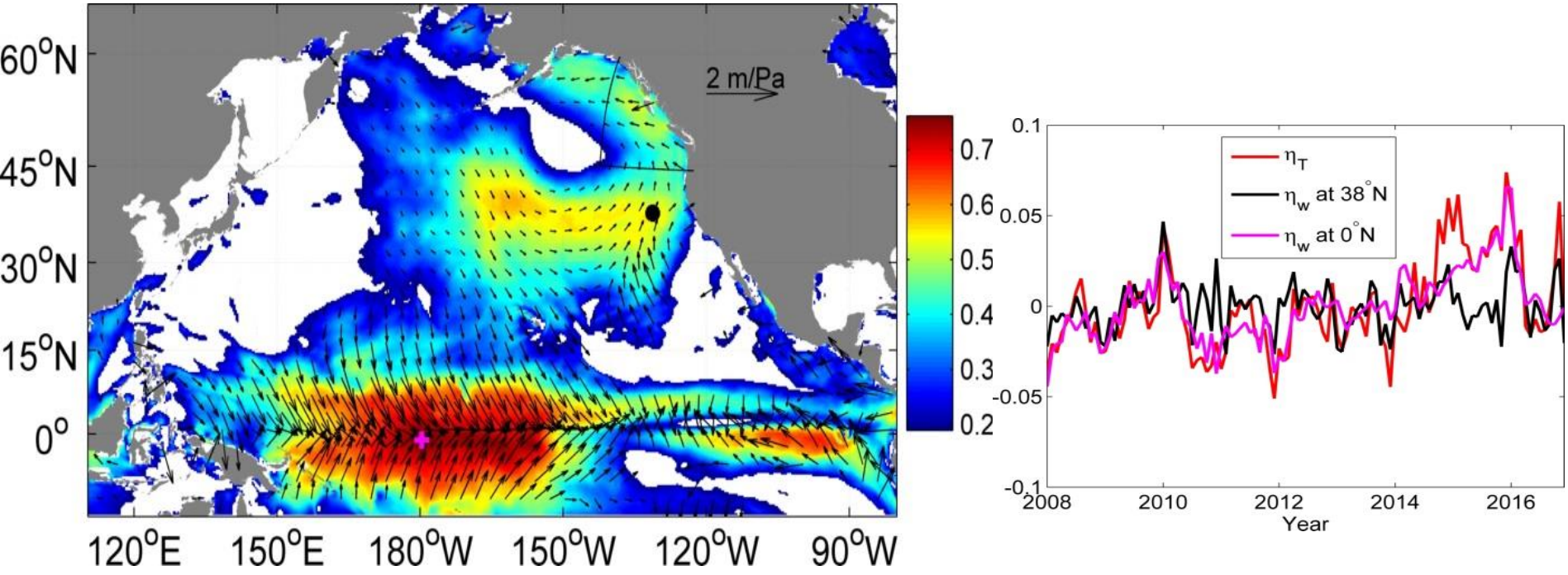


Regression analysis:
Tofino halosteric height vs wind stress





Regression Analysis:
Tofino thermosteric vs wind stress

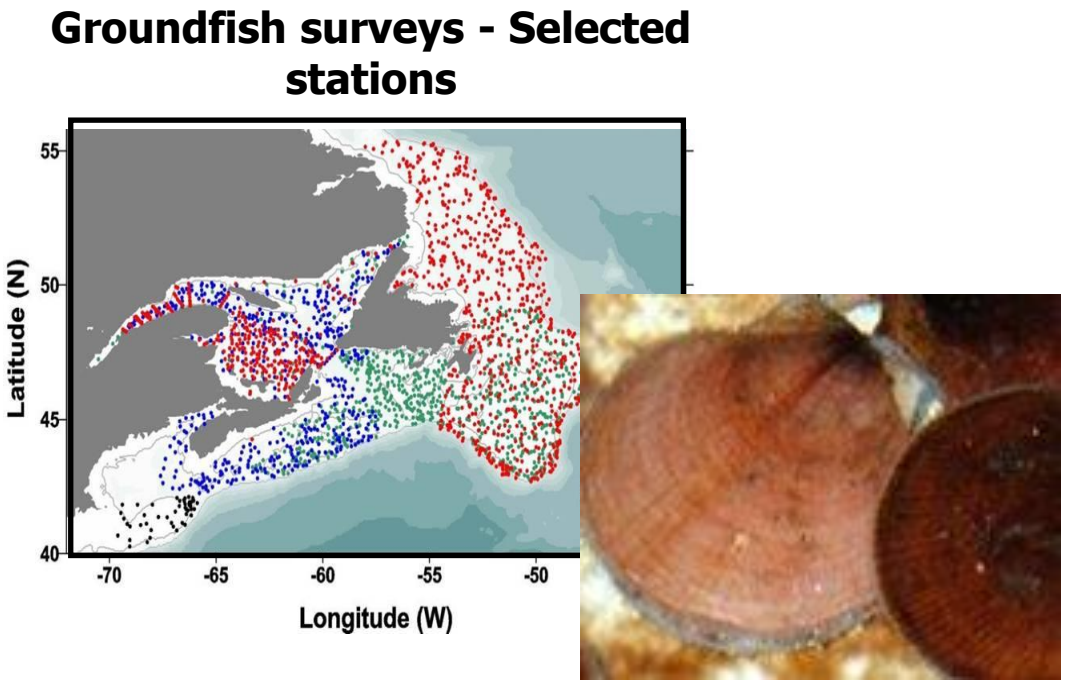


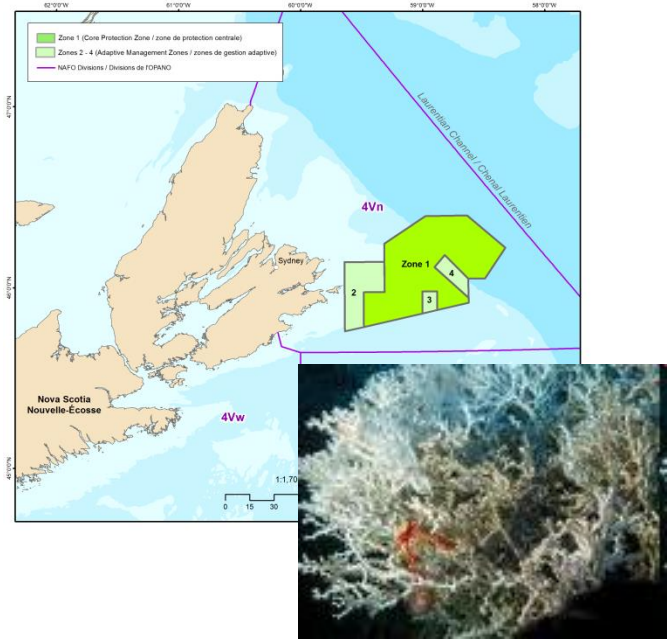
Conclusions: on Sea Level Variations on Shelf off Canada's West Coast

- **High-resolution model results agree well with tide gauge observations**
- **Intra-seasonal, seasonal & inter-annual variations: mainly steric & halo component**
- **Regression analysis:**
- **Wind outside NEP domain drives both halo & thermo steric, in particular at time scales < 1 year**
- **Heat flux & P-E outside NEP domain make smaller contribution but may become important at time scales > 1 year**
- **Implication to prediction – remote winds are important!**

Practical Applications: Search & Rescue, Military, Transportation, Industry

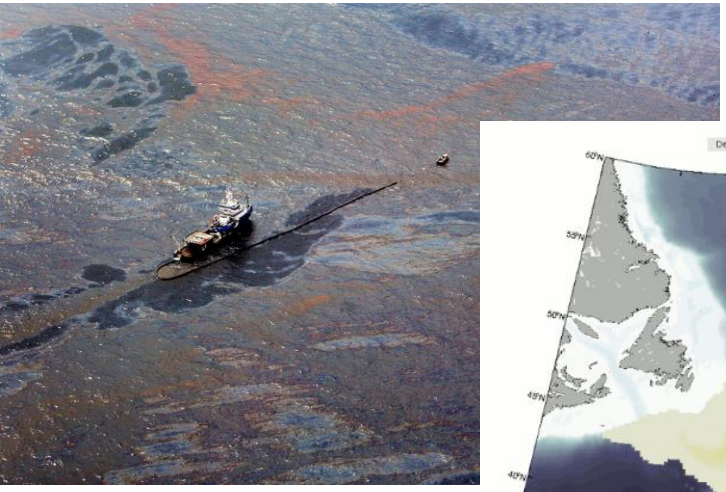
Practical Applications: Fishery Management, Marine Conservation,

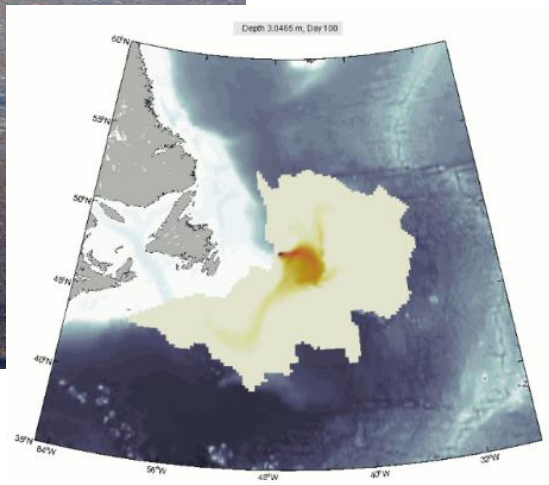


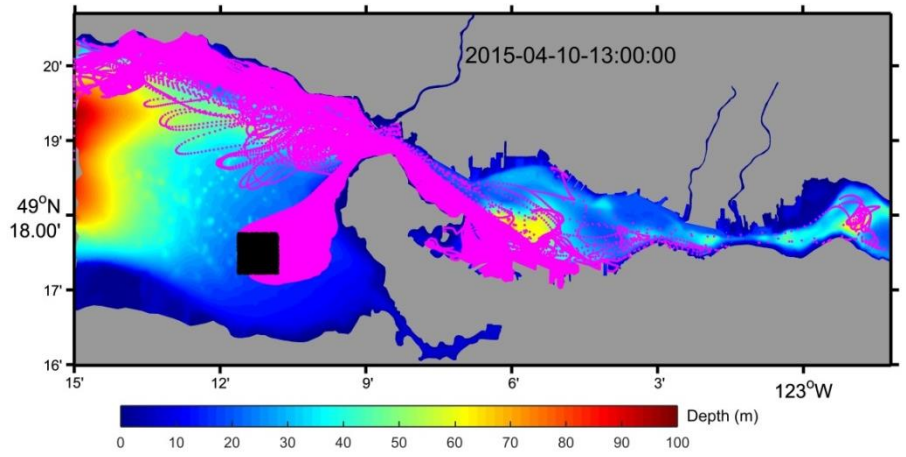


Practical Applications: Environment Protection

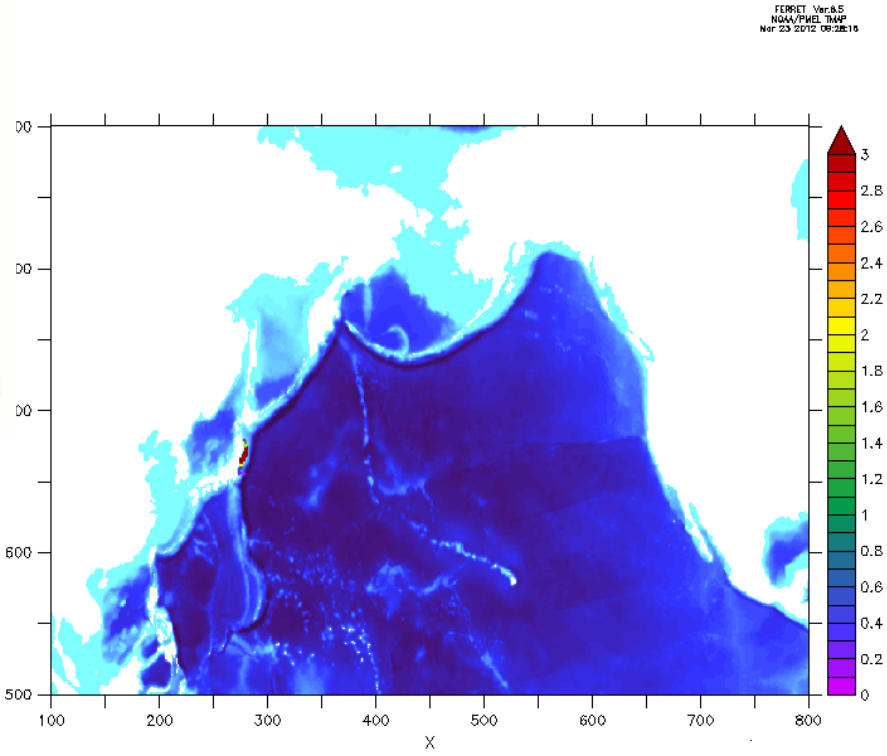
Oil Spill





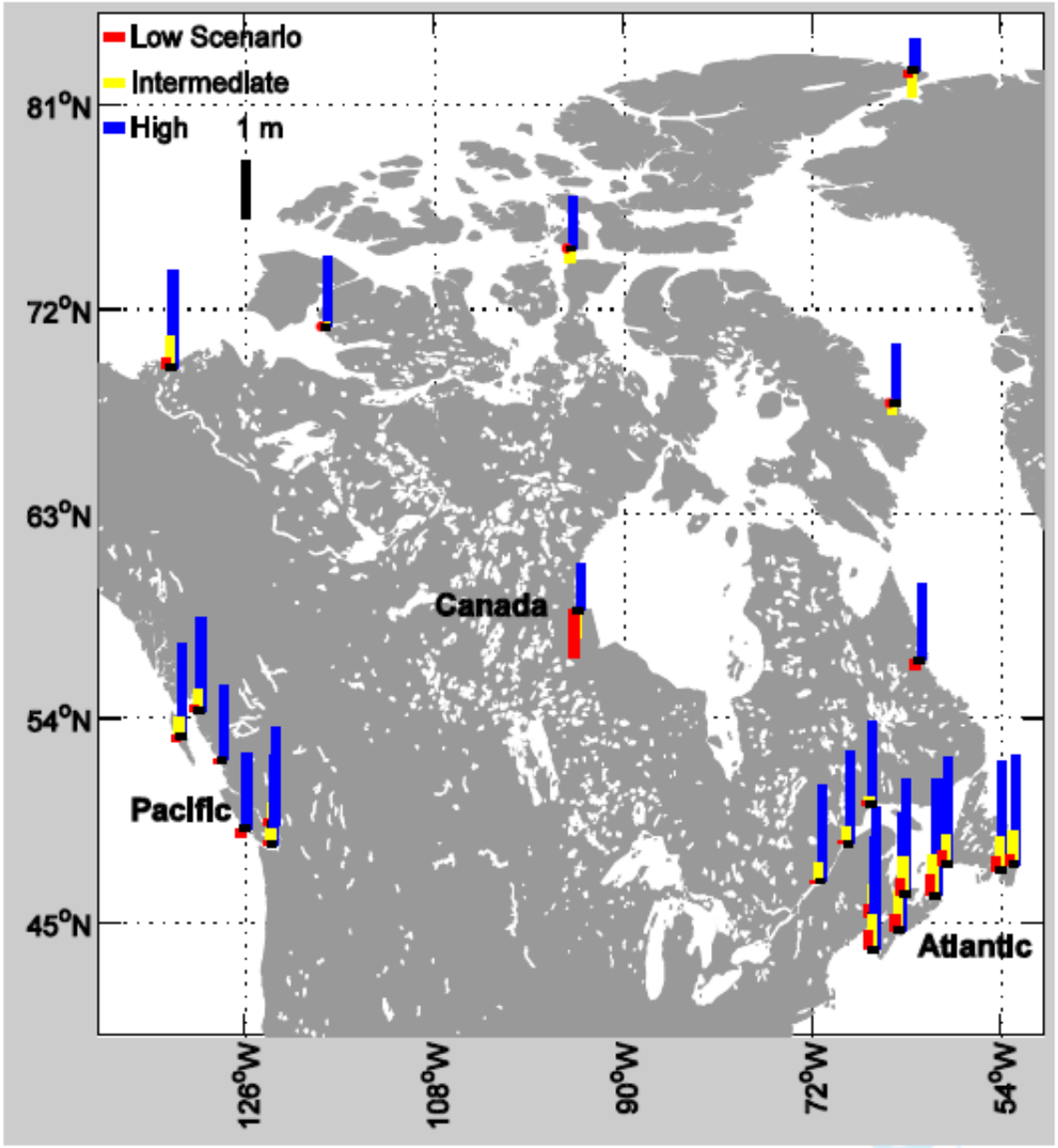


Tsunami debris drifting



Debris log10 tons – 20110309

Regional Projections: Sea Level Rise



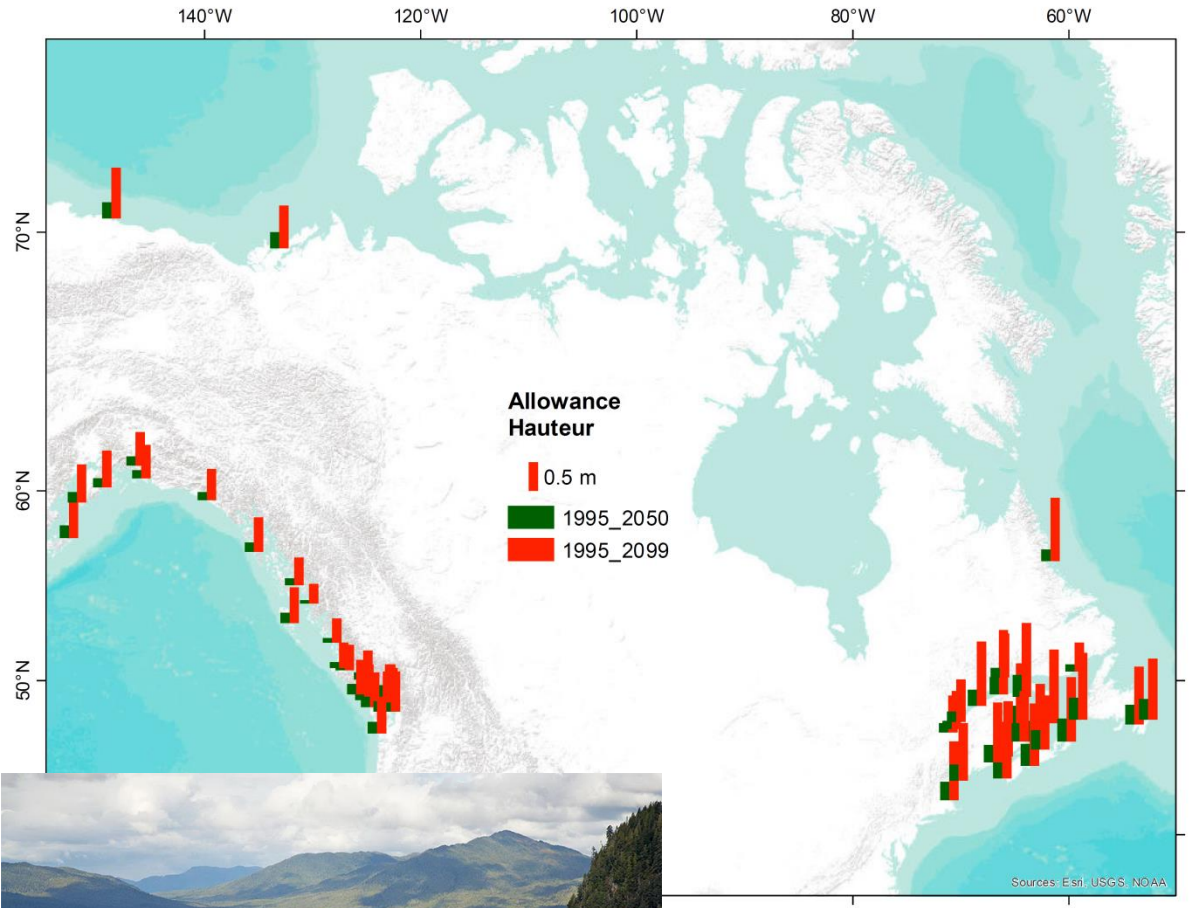
2010-2100 SLR
Under 3 scenarios:

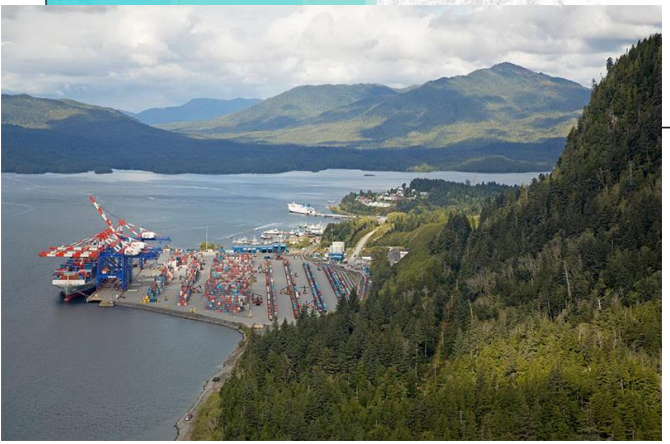
- **Low – extrapolating tidal gauge obs**
- **Intermediate – IPCC RCP8.5**
- **High – RCP8.5 + Antarctic ice sheet contribution**

Vertical land motion considered

Han et al. 2018

Canadian Extreme Water Level Adaptation Tool





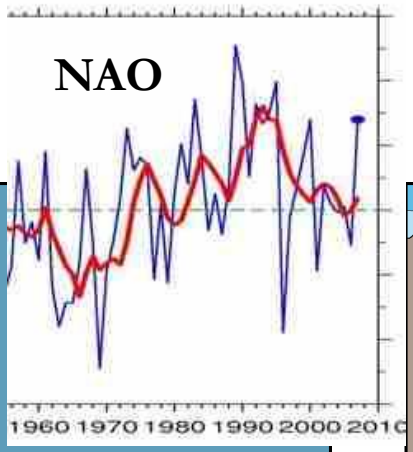
2010-2050 & 2010-2100

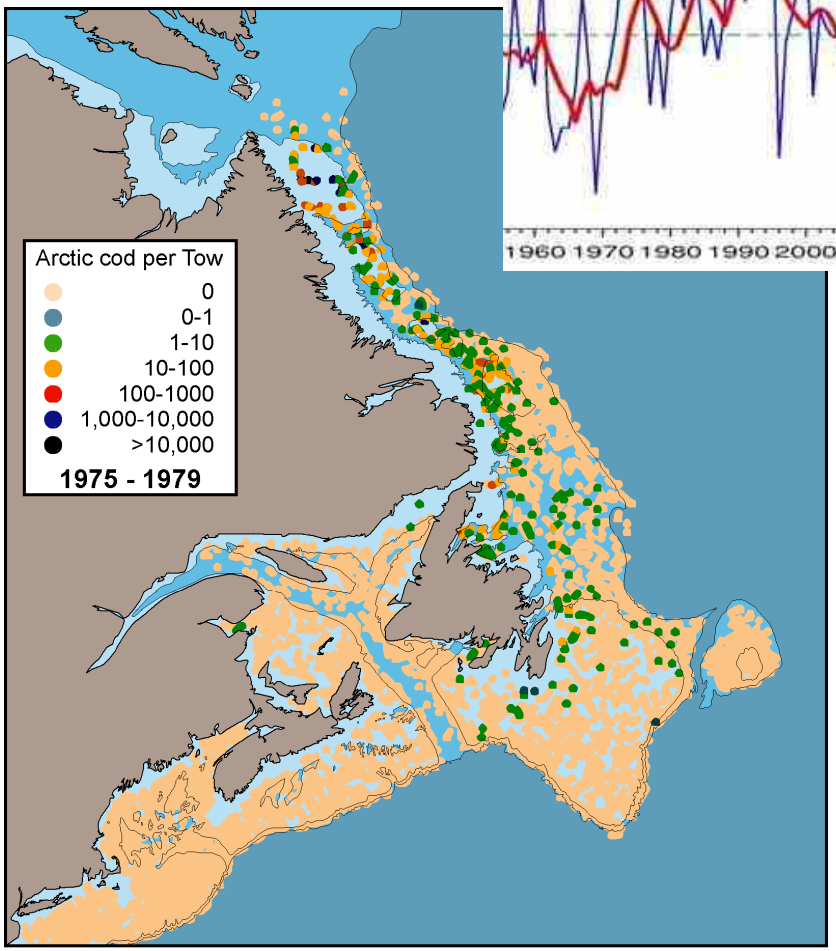
Vertical allowances for RCP8.5 scenario

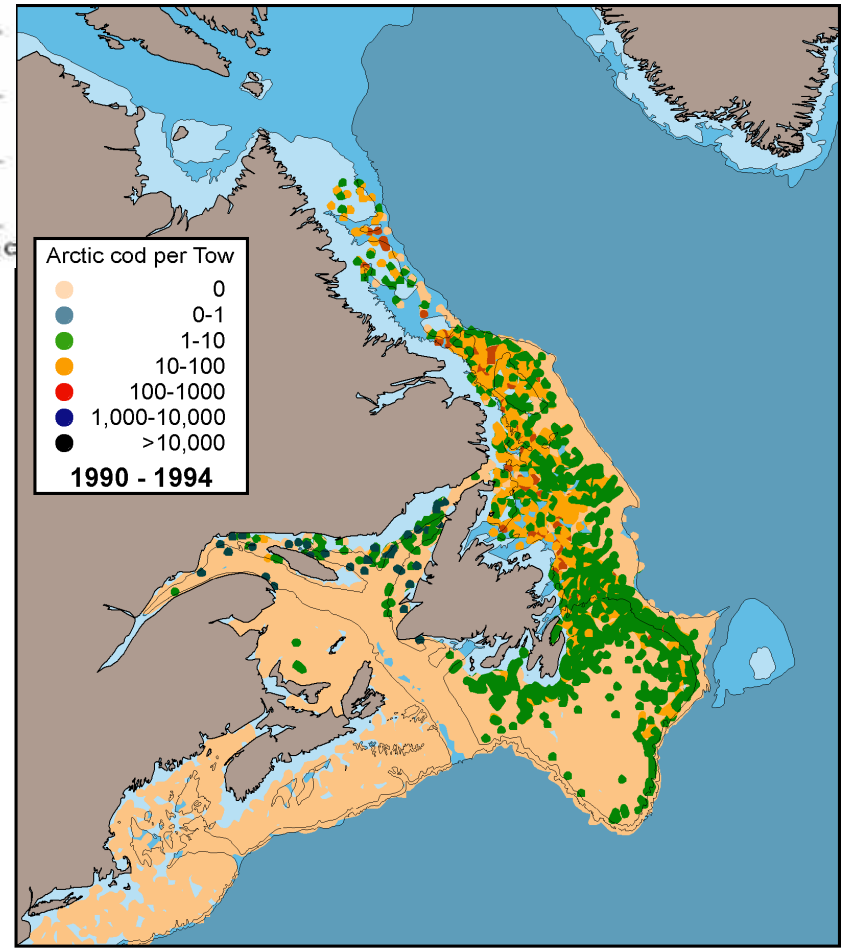
Vertical allowances: recommended changes in elevation of coastal infrastructure required to maintain current level of flooding risk in a future scenario of sea level rise.

http://www.bio.gc.ca/science/data-donnees/can-ewlat/index-en.php

Example: Atlantic Cod

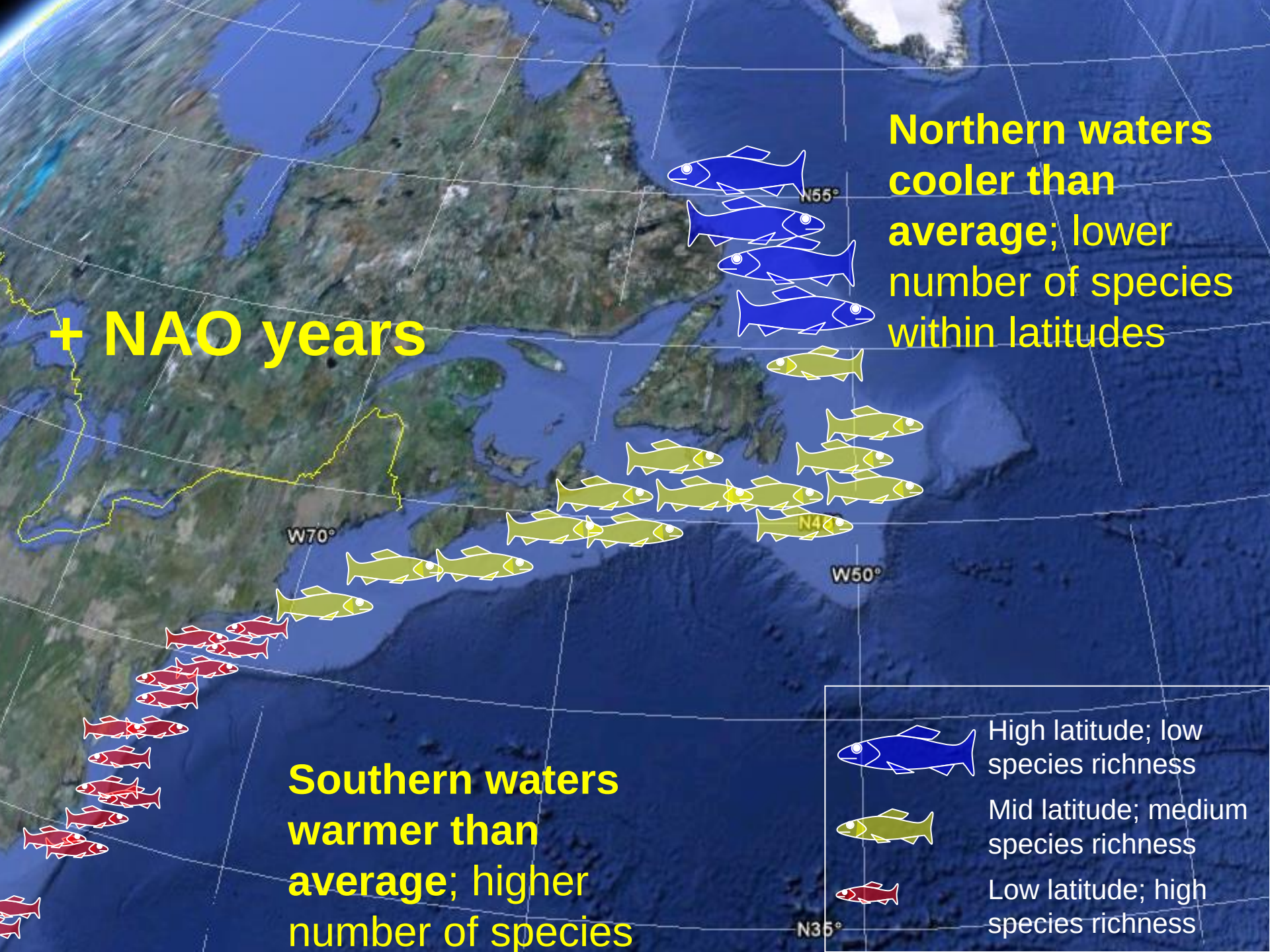


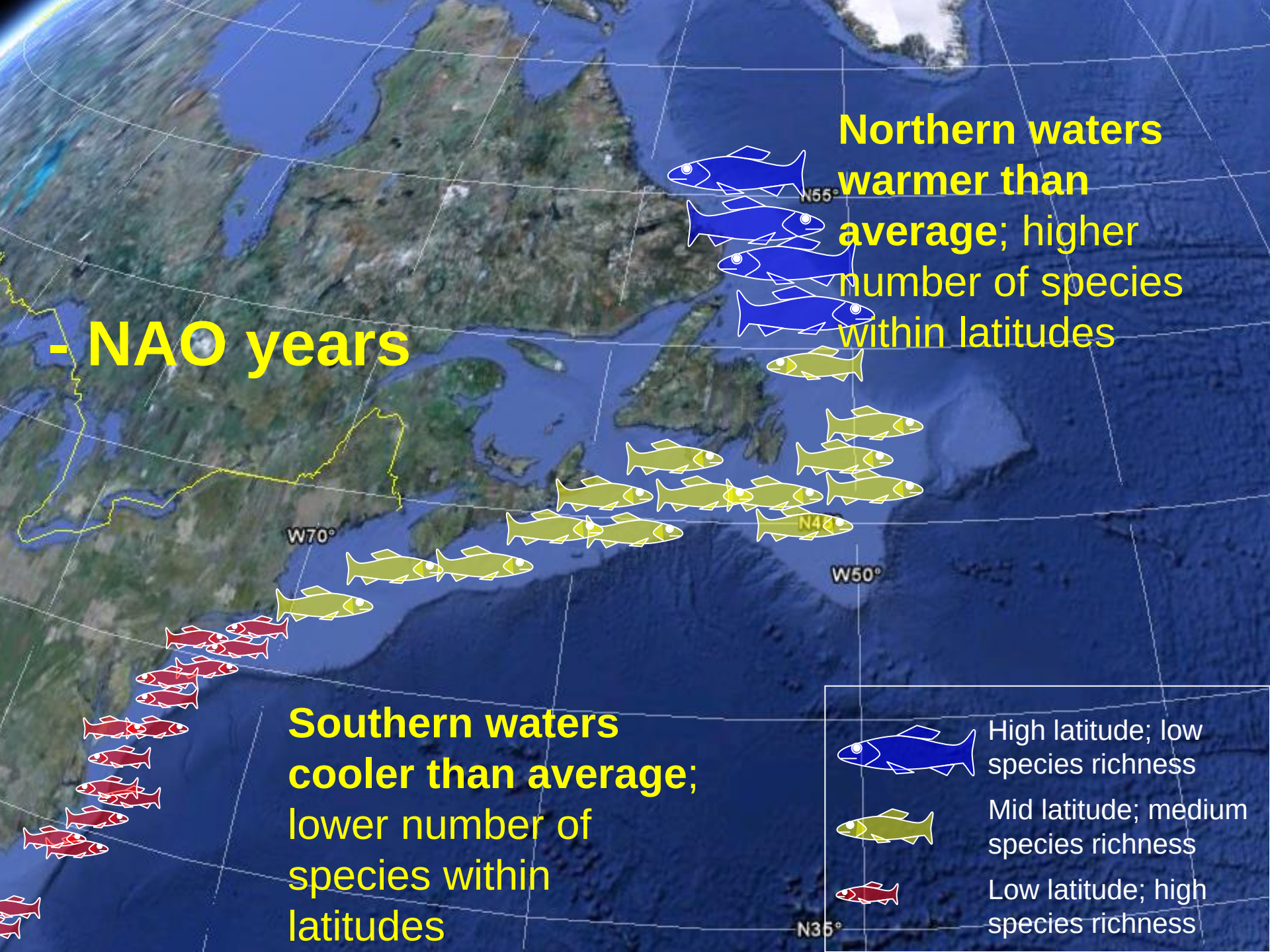




Low NAO

High NAO

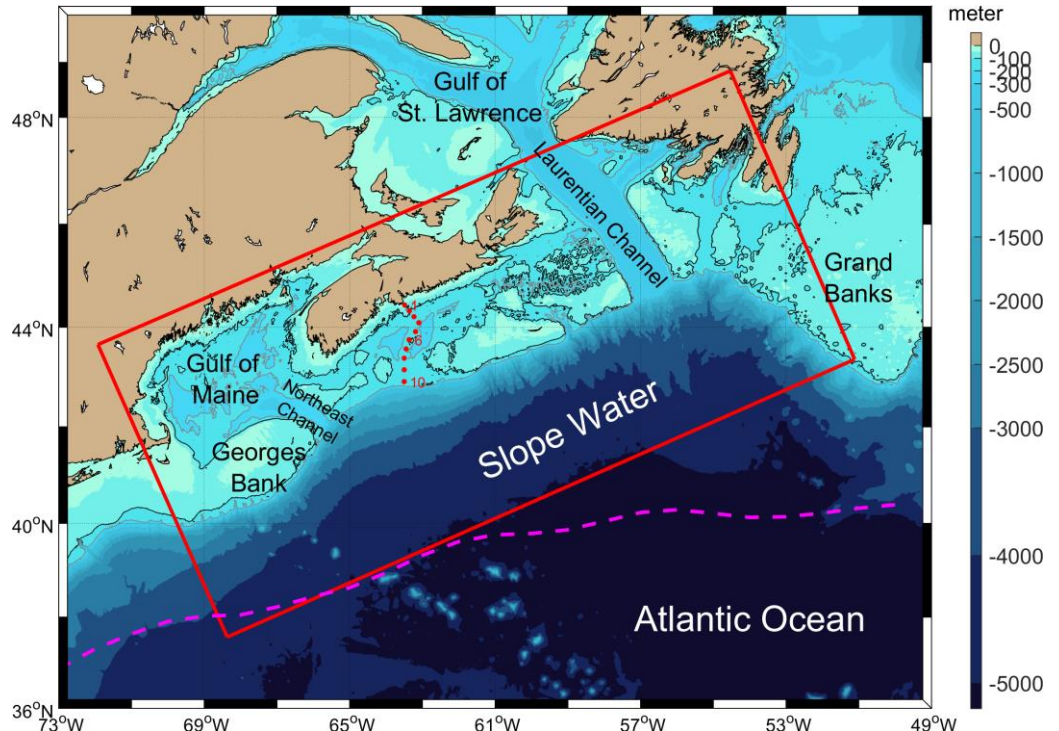

+ NAO years
Northern waters cooler than average; lower number of species within latitudes
Southern waters warmer than average; higher number of species
N55°
W70°
W50°
N35°
High latitude; low species richness
Mid latitude; medium species richness
Low latitude; high species richness


- NAO years
Northern waters warmer than average; higher number of species within latitudes
Southern waters cooler than average; lower number of species within latitudes
N55°
W70°
W50°
N35°
High latitude; low species richness
Mid latitude; medium species richness
Low latitude; high species richness

Gulf of Maine & Scotian Shelf Operational Nowcasting/Forecasting

Developed & Maintained at Dalhousie University:

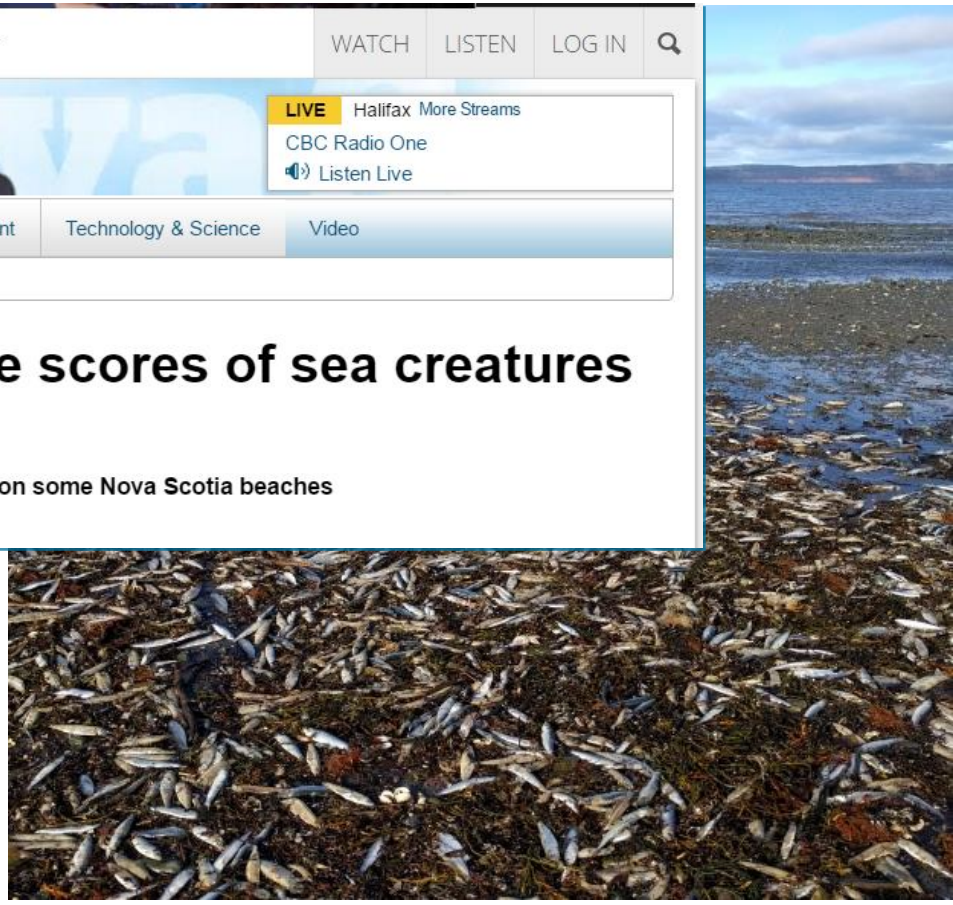
- **Initial development & validation (Katavouta et al. 2016, JPO)**
- **2.5 km horizontal resolution with 50 vertical levels**
- **Forced with ECCC weather forecasts also with 2.5 km resolution**
- **Operational "nowcast" since Dec 7, 2016**



Application: Southwest NS "Dead-Fish" Incident

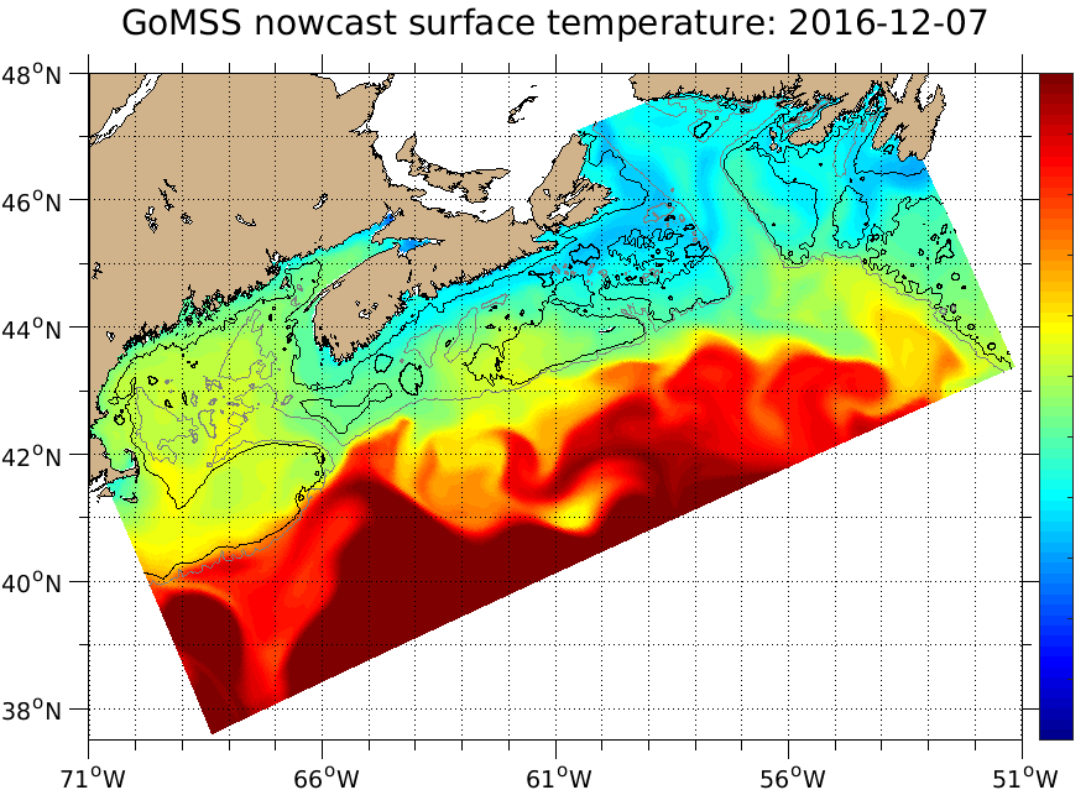
December 2016, dead fish washed ashore attracting intense public attention and need to determine causes, e.g.

http://www.cbc.ca/news/canada/nova-scotia/dfo-update-dead-sea-creatures-nova-scotia-digby-1.3916481

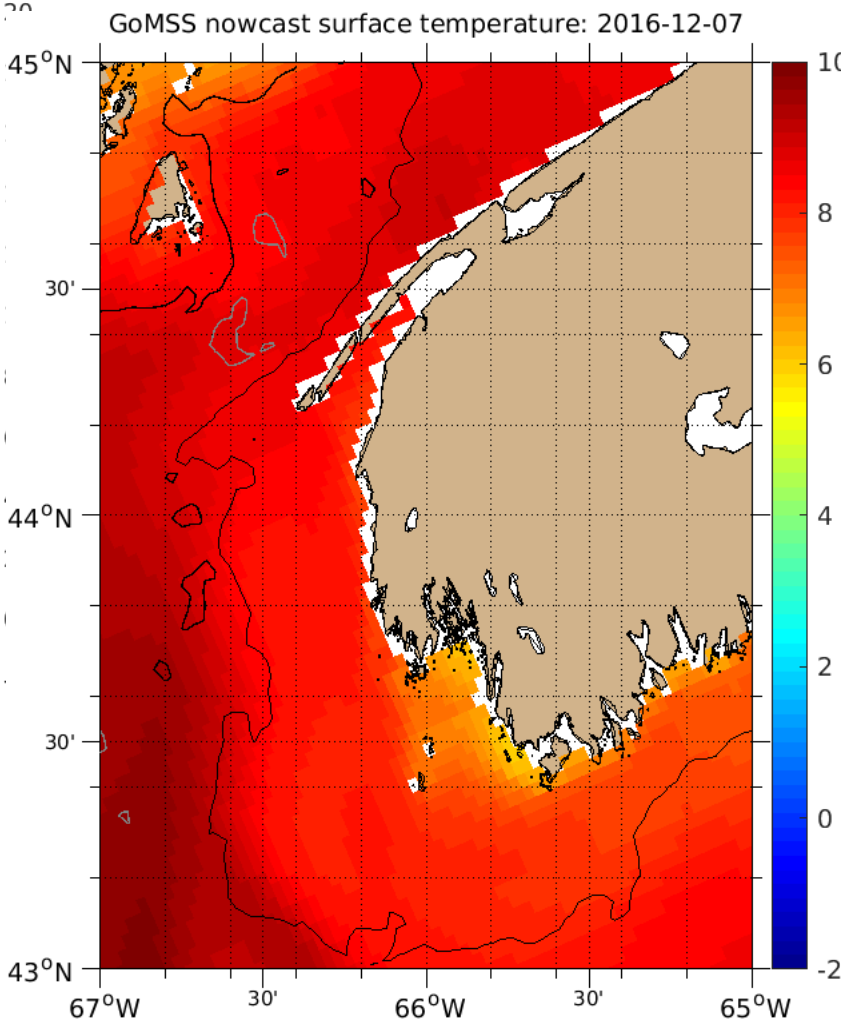


Output from GoMSS nowcast: daily SST Dec 7-30

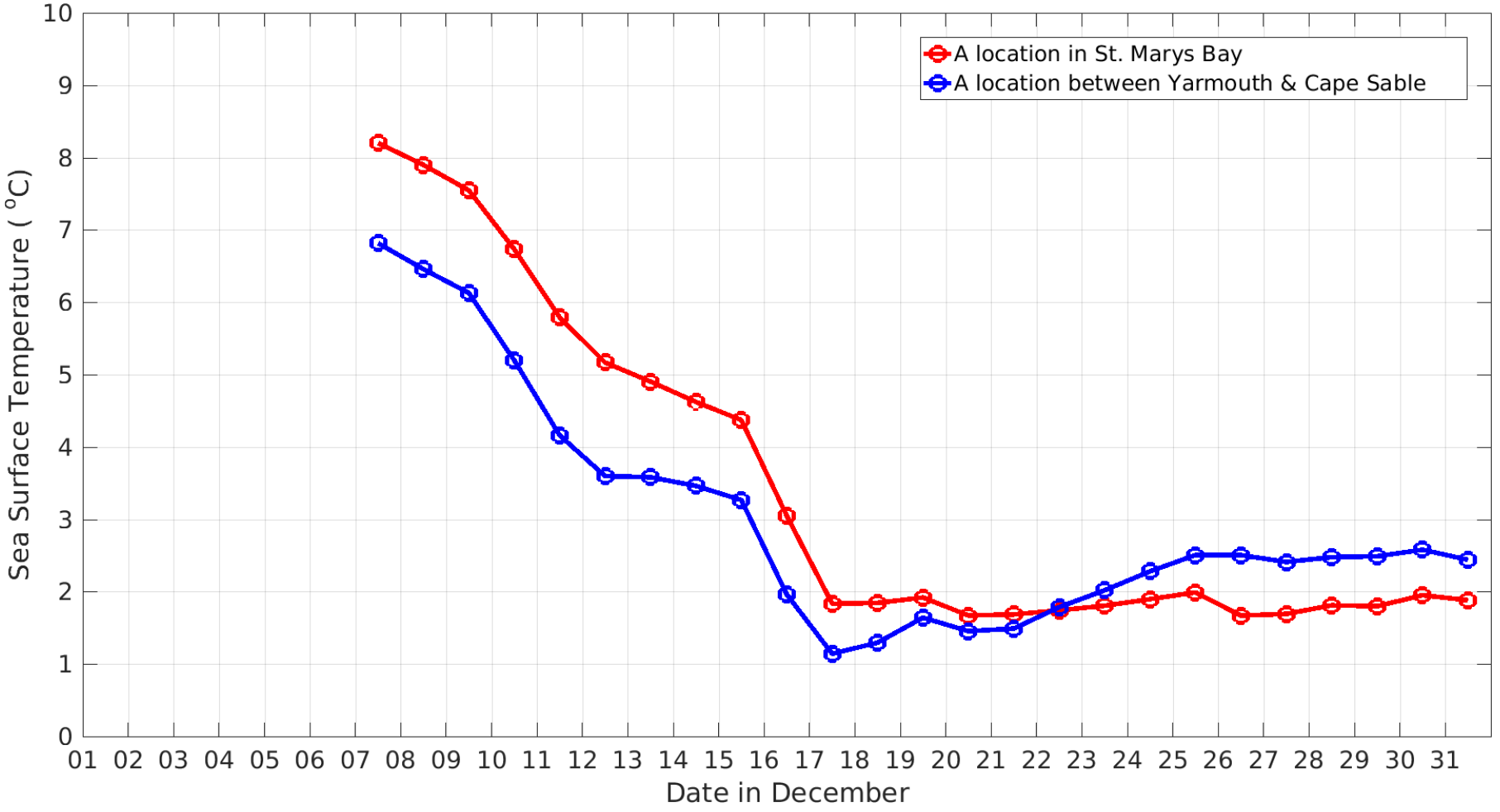
Whole model domain



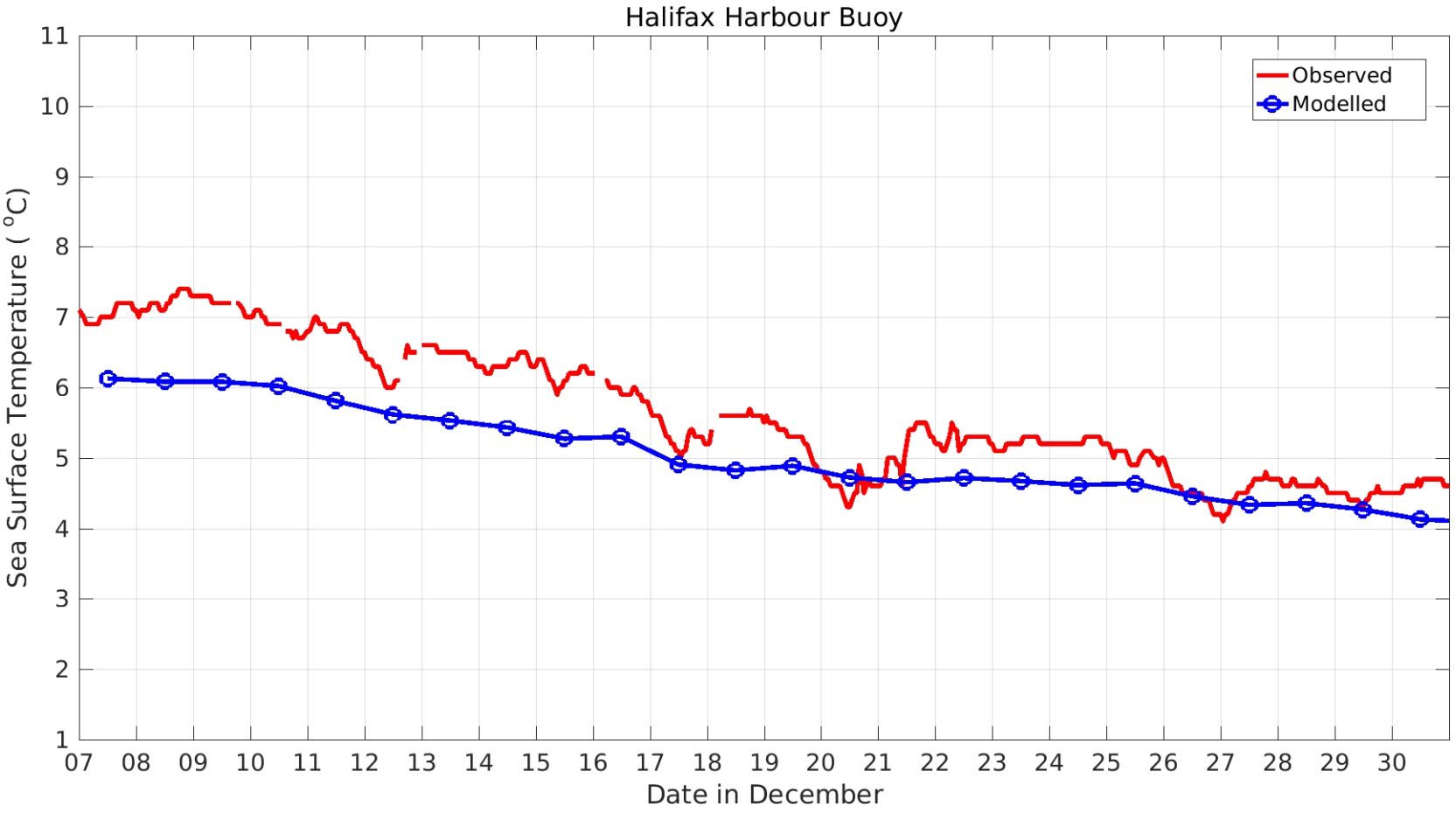
Zoom in southwestern NS



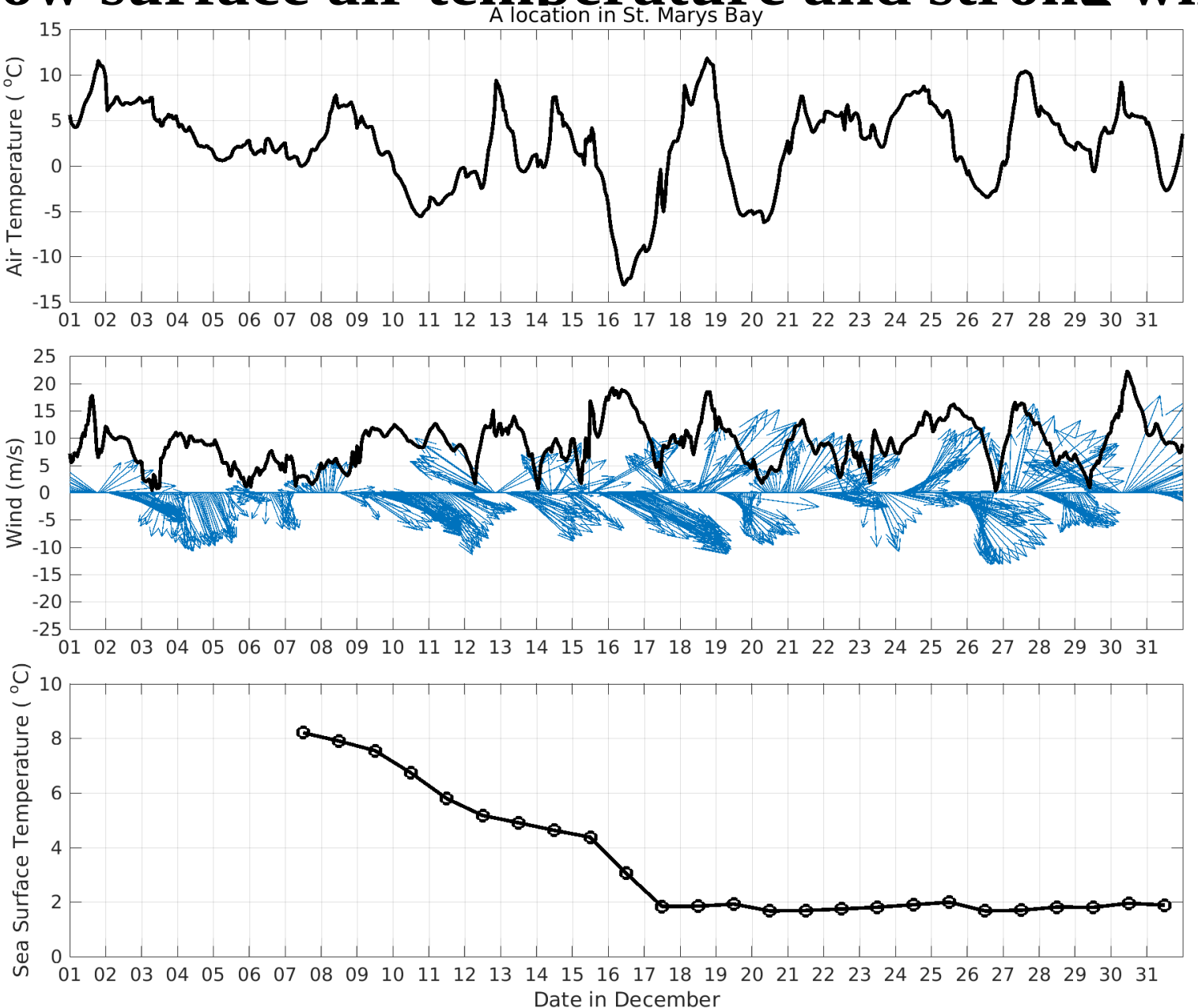
Time series of predicted SST off SW Nova Scotia where strong cooling occurred



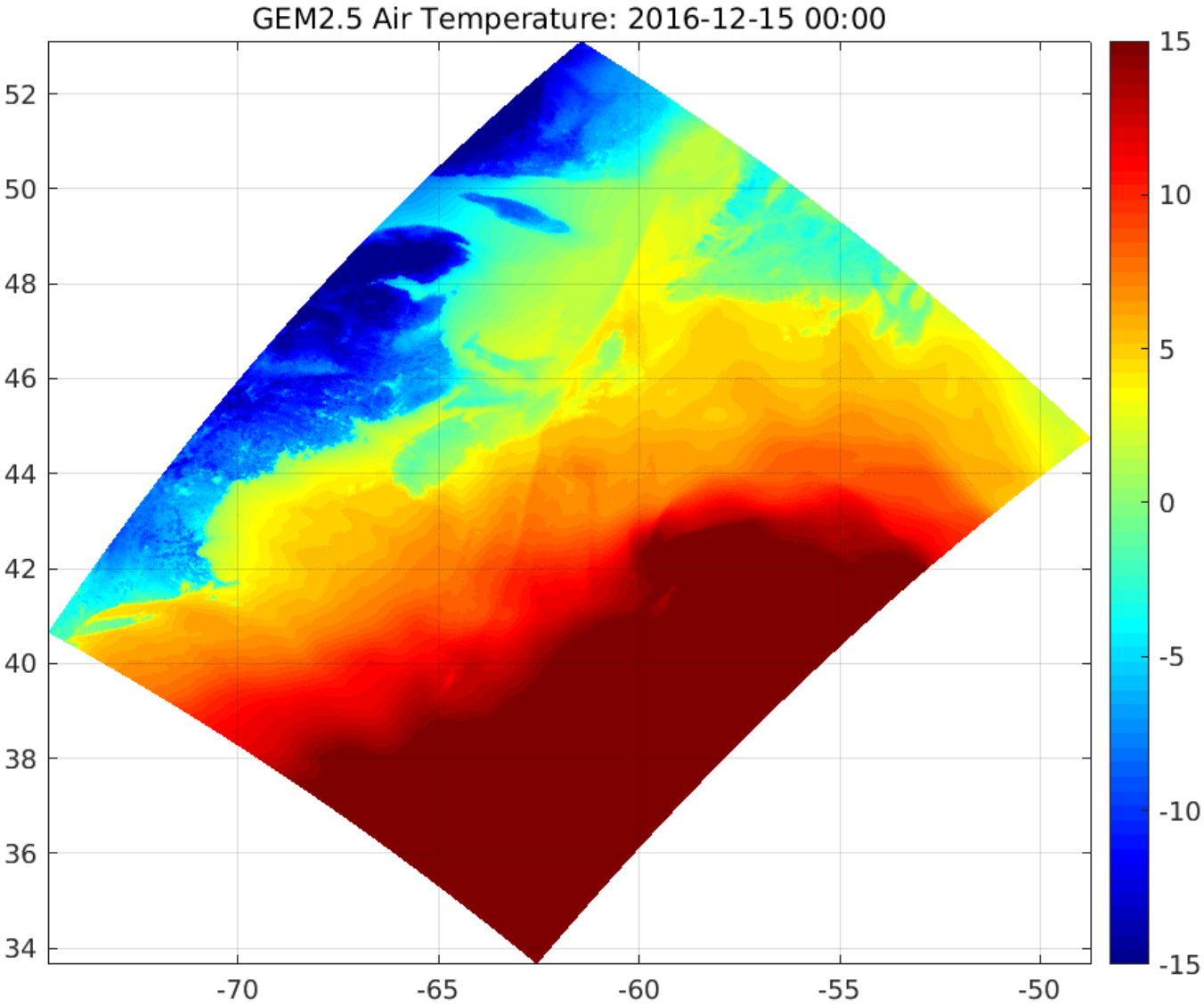
A comparison of GoMSS daily SST with buoy observations in Halifax Harbour (where intense cooling did not occur)



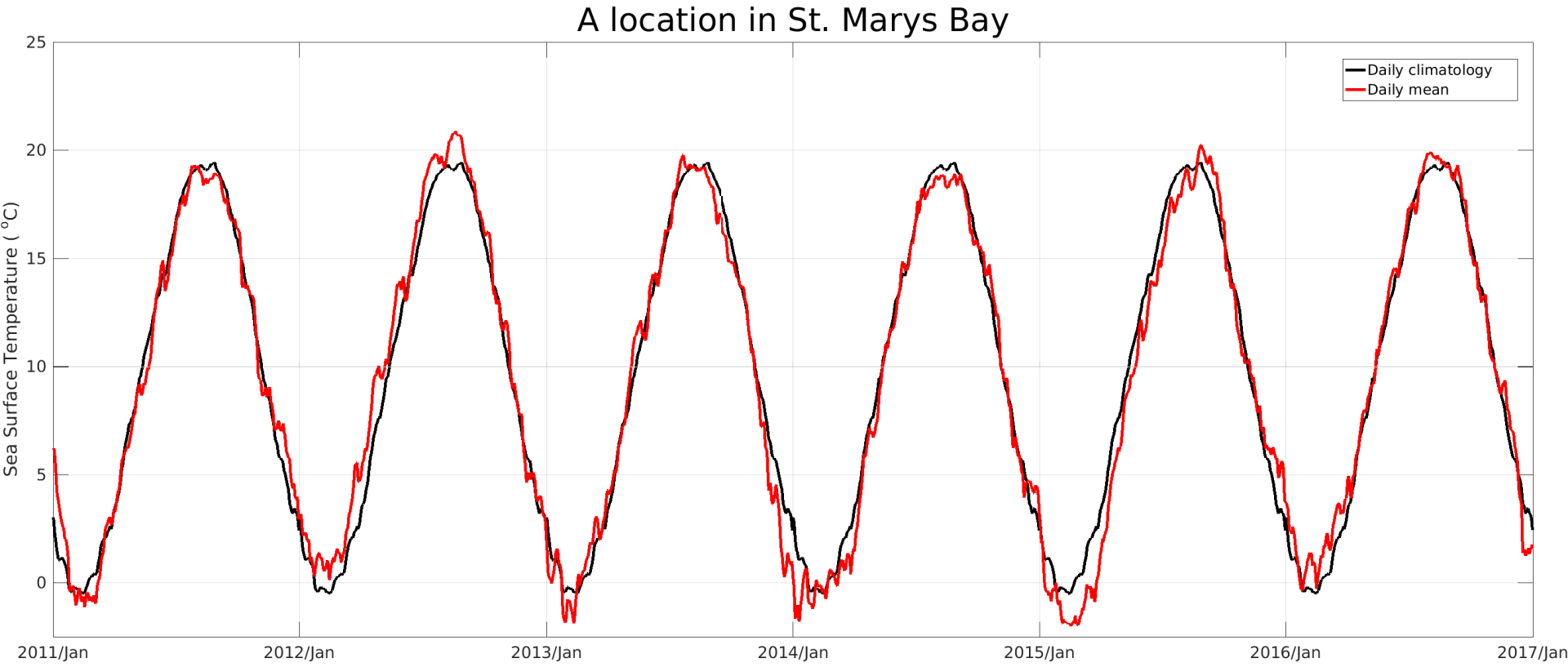
Speculate cooling in St Marys Bay related to low surface air temperature and strong wind



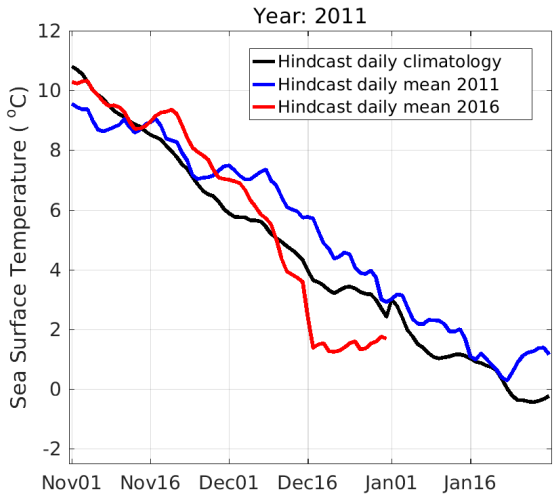
6-hourly surface air temperature Dec 15-18

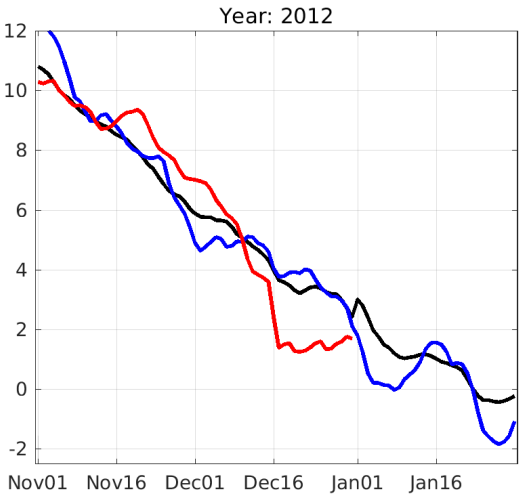


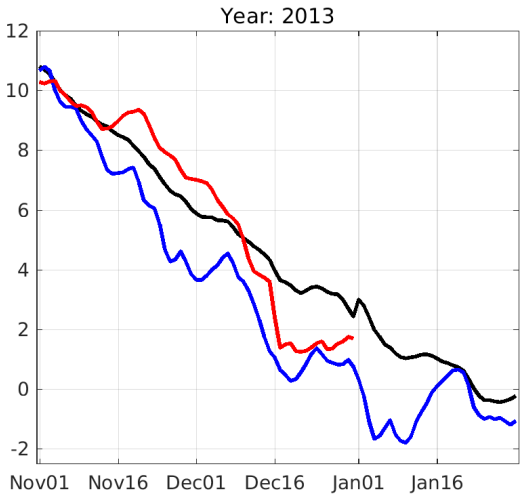
But: Is Dec 2016 unusual? Here is SST from a 6-year GoMSS hindcast using US CFSR forcing

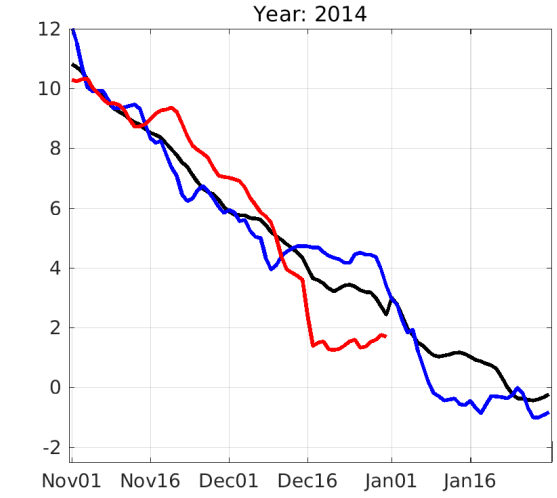


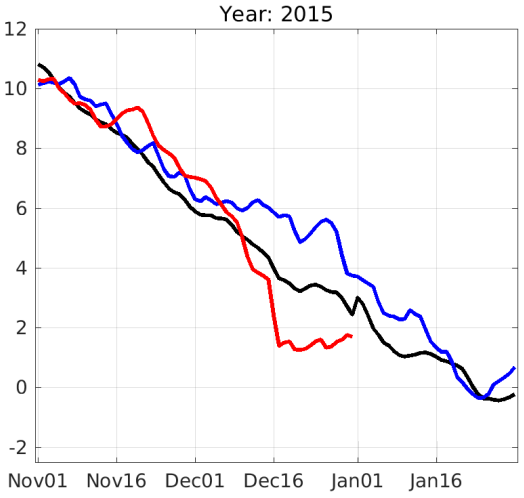
Is Dec 2016 unusual? Focus on Nov-Jan of 6 years

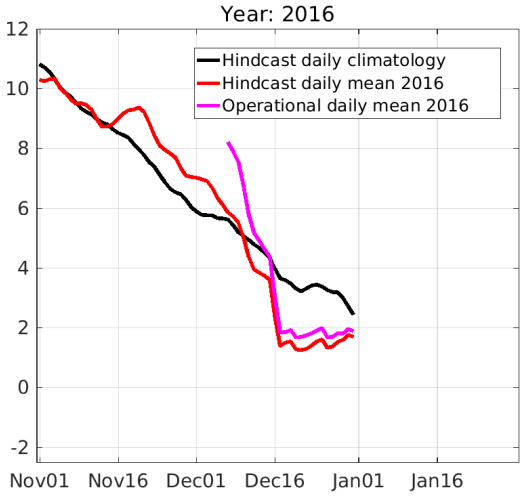












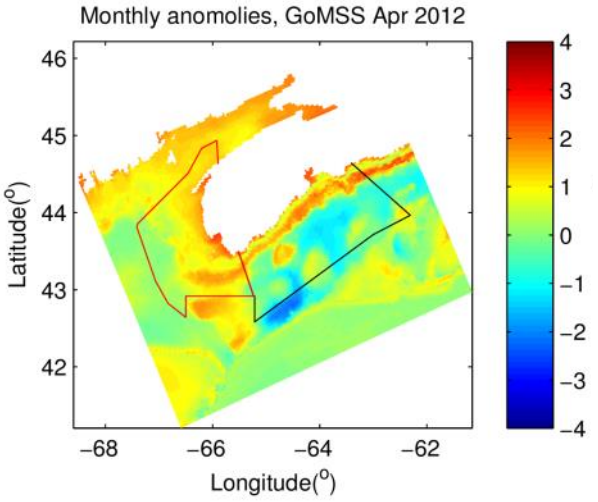
Application: Lobster mobility and catches related to sea bottom temperature?

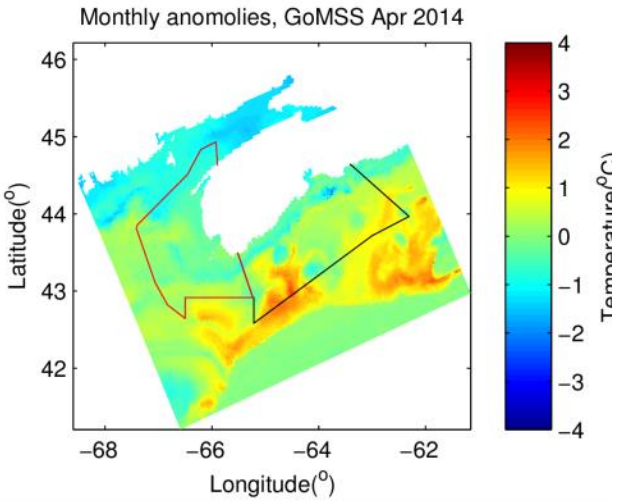
The Chronicle Herald, May 8, 2017:

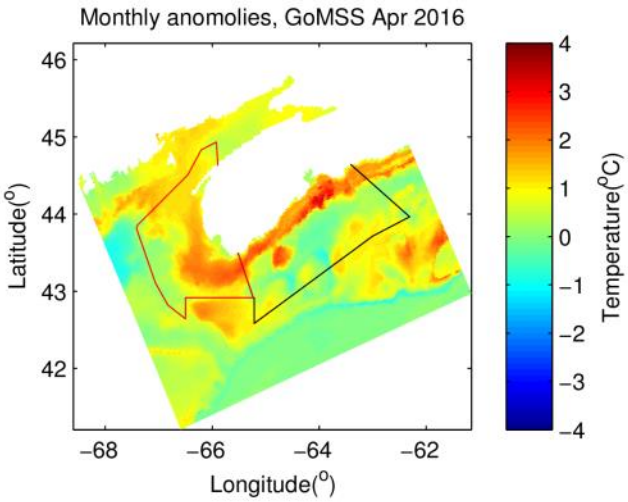
Lobster catches taking nose dive

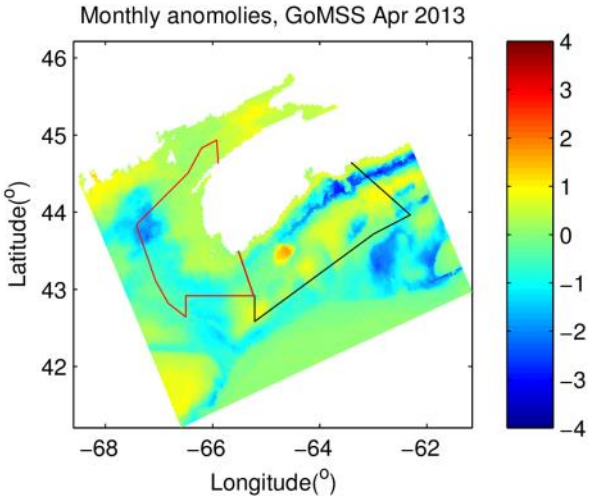
Some Nova Scotia fishers are wondering if they'll be able to break even this season

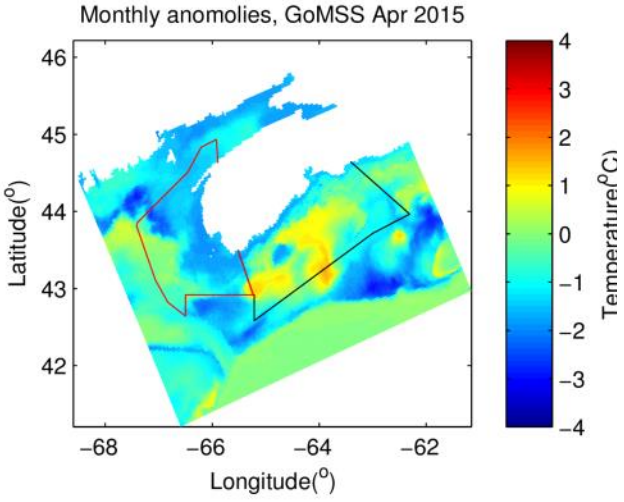
Modelled Bottom Temperature Anomaly in April

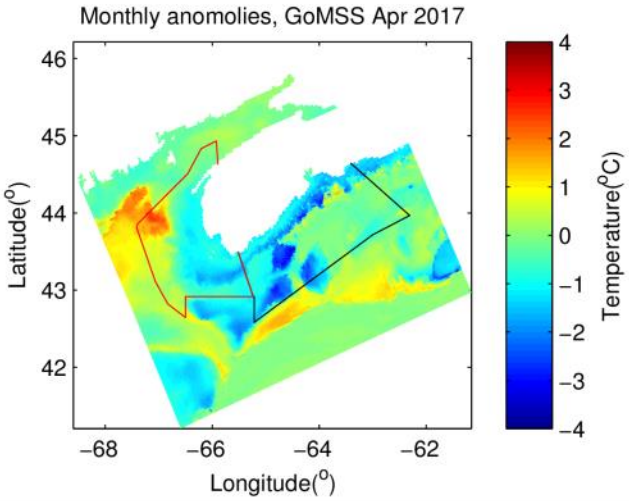




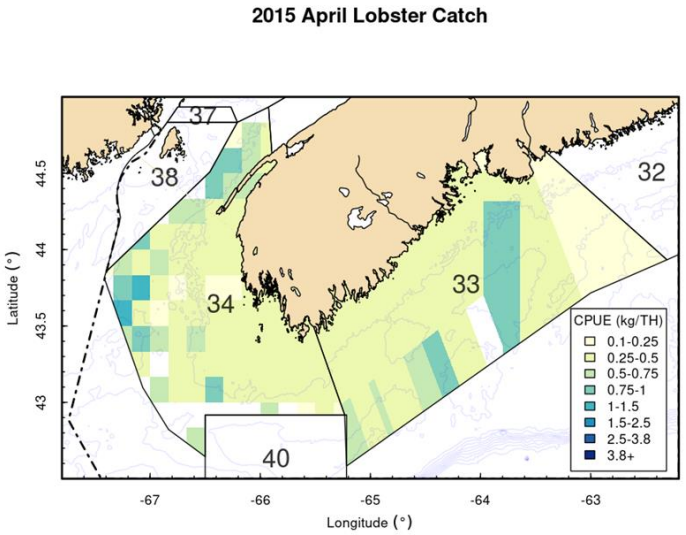


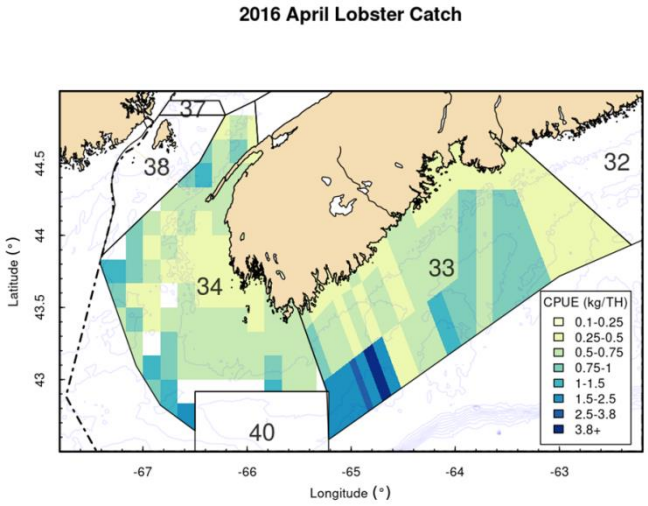


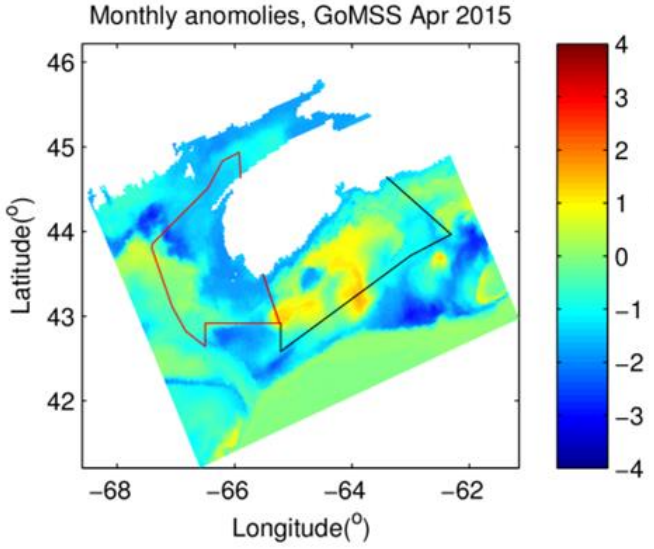


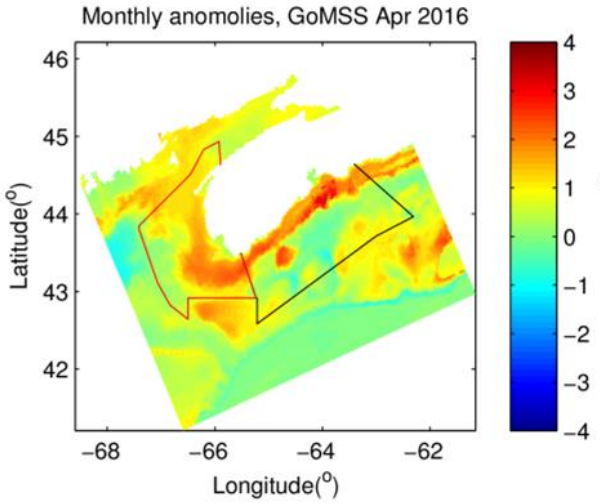


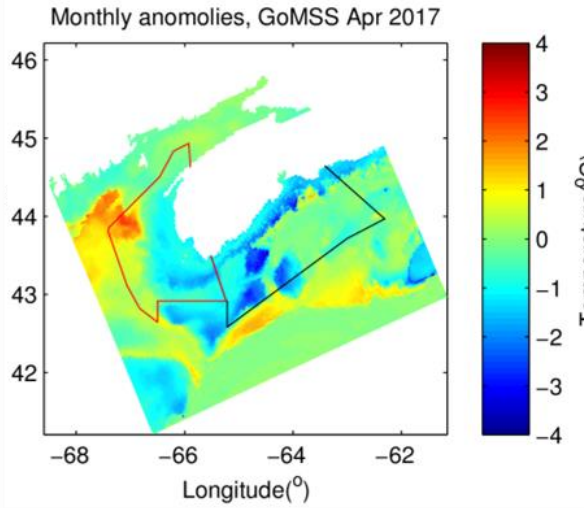
April Lobster Catch & Bottom Temperature











Summary

- **Ocean modelling & forecasting have significantly advanced during past two decades: predicting realistic details of variations**
- **State-of-the-art modelling & forecasts requite planning, collaboration (national & international), investment on human resources & high performance computers**
- **Collaboration with meteorology is critical, and coupled prediction systems are emerging**
- **Numerous applications can be developed, for safe navigation, environment protection , ecosystem & fishery management, etc.**

Questions and Discussions?