

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
Défence

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

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

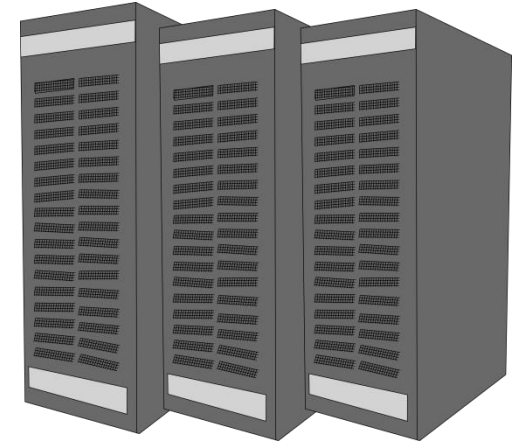
$$\frac{\partial \mathbf{u}_H}{\partial t} + \nabla \cdot (\mathbf{u} \mathbf{u}_H) + 2\boldsymbol{\Omega} \times \mathbf{u}_H = -\nabla_H p / \rho_0 + j_H + F_H$$

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

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

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

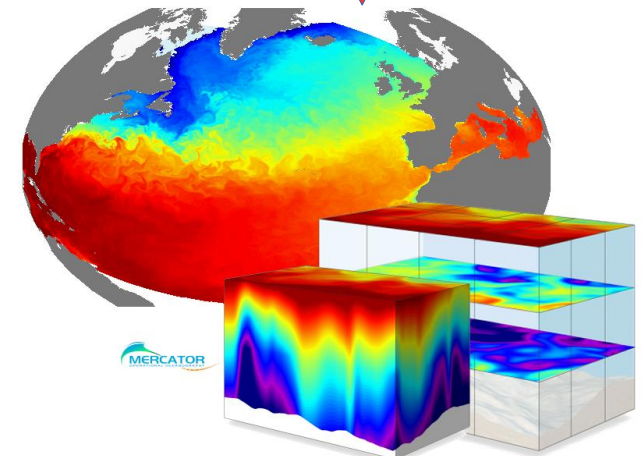
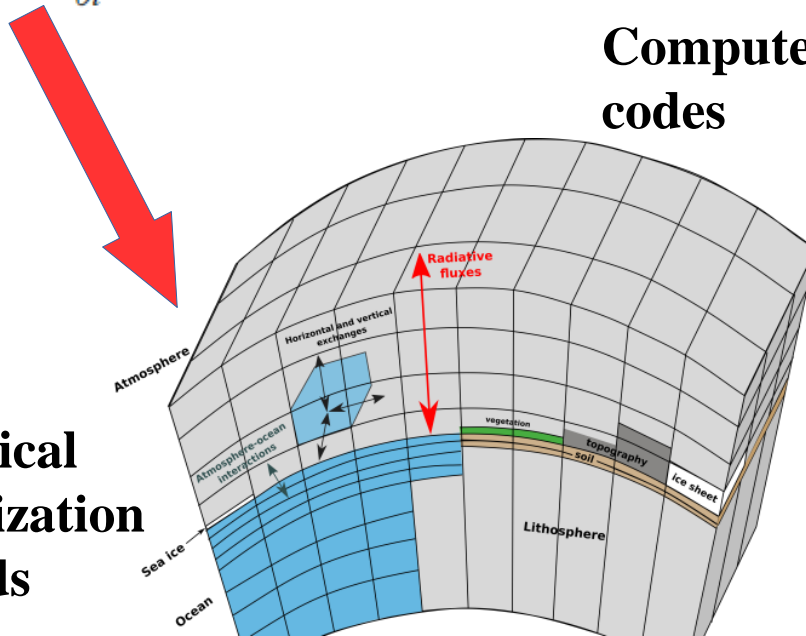
Computers



Computer codes

Results

Numerical discretization methods

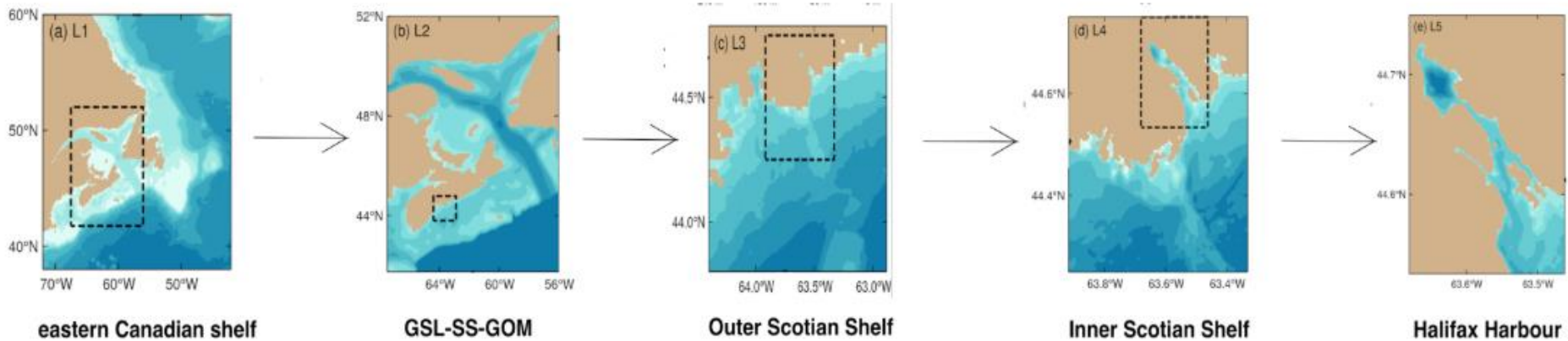


Ocean Forecasting in Canada:

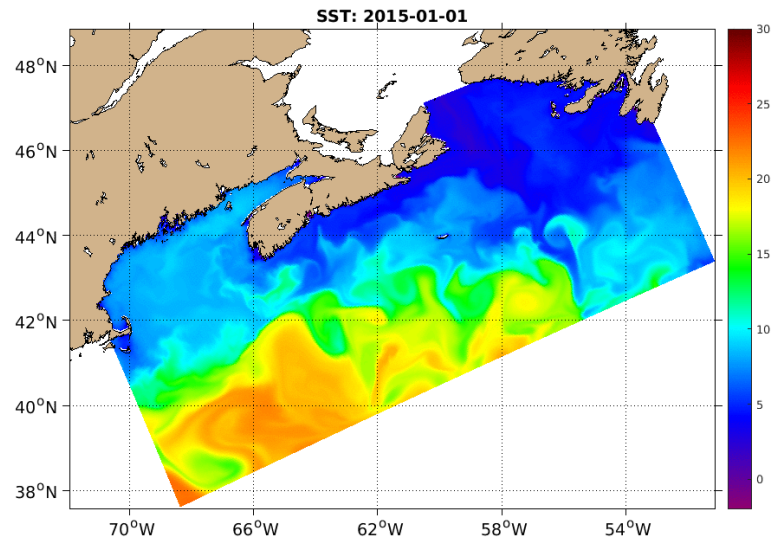
Stream 1: Best Effort – mainly by universities

DALHOUSIE COASTAL OCEAN FORECAST SYSTEM

Sunday, September 16, 2018



**MEOPAR:
GoMSS**



University of British Columbia: Salish Sea Physics & Biogeochemistry


https://www.torontopear... x UBC EOAS Susan Allen | Departmen... x Salish Sea Oceanograph... x

← → ↻ 🏠 🔒 Secure https://salishsea.eos.ubc.ca ☆ ⋮

Salish Sea Storm Surge SalishSeaCast Bloomcast SMELT About

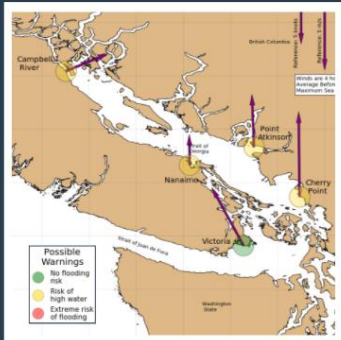
UBC Salish Sea Model Project

About the Project



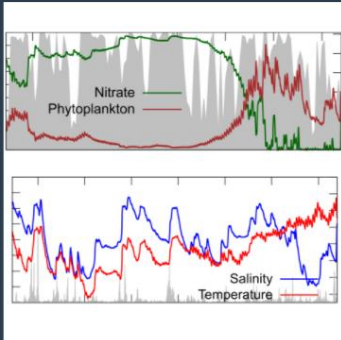
A three-dimensional physical-biological-chemical
salishsea.eos.ubc.ca/storm-surge/forecast

Storm Surge Forecast



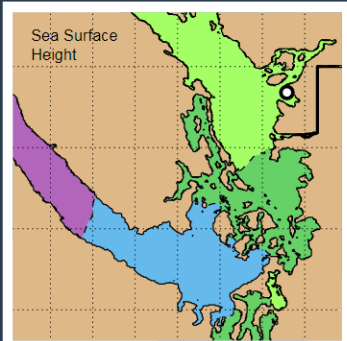
Marine and atmospheric conditions: storm surge alerts, tidal predictions, surface height, and winds.

Diatom Bloom Forecast



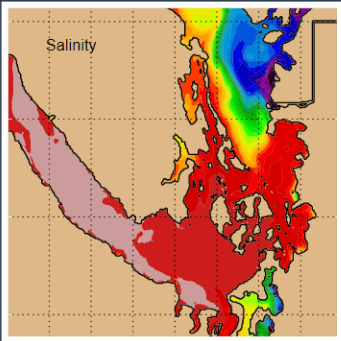
SOG biophysical model: best estimate of the first spring diatom bloom in the Strait of Georgia.

Storm Surge Nowcast



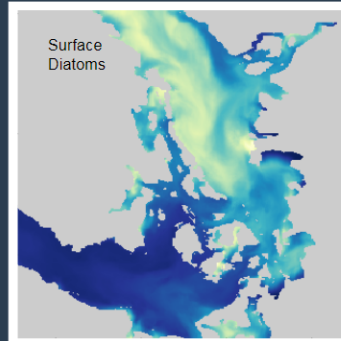
Present marine and atmospheric conditions.

Currents and Physics



Research results: salinity, temperature, and currents.

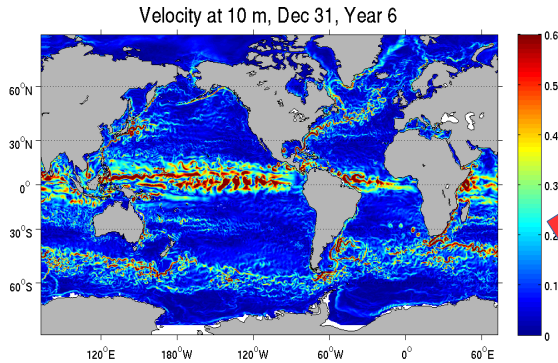
Biology



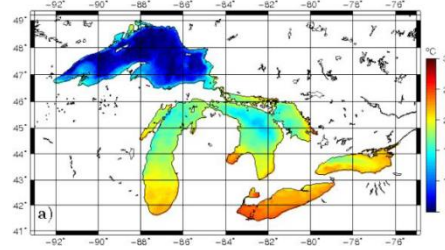
Research results: nitrate, diatoms, flagellates.

Ocean Forecasting in Canada:

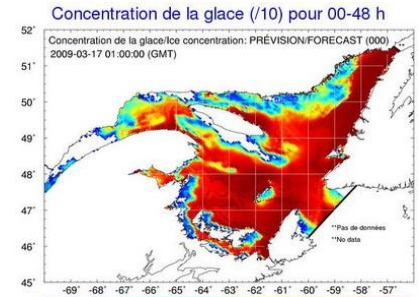
Stream 2: 24/7 support – CONCEPTS efforts



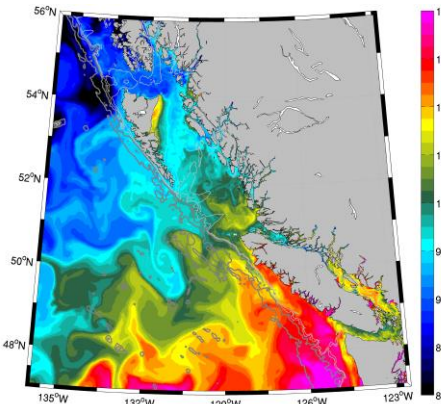
GIOPS: $\frac{1}{4}^\circ$, DA, operational since Aug 2015; two versions: 30-day ensemble, 10-day determinist coupled to weather



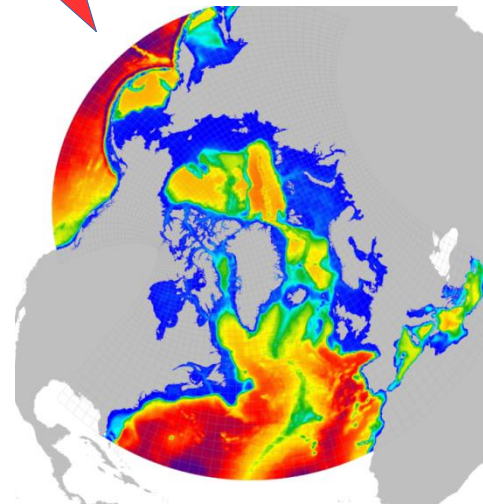
Great Lakes: 2 km, coupled to weather, since 2014



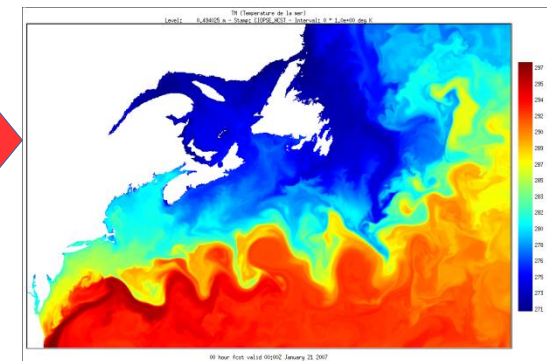
Gulf of St Lawrence: 5 km, coupled to weather, since June 2011; updating to 500m



CIOPS-west: $\frac{1}{36}^\circ$, spectral nudging, operation by end 2018



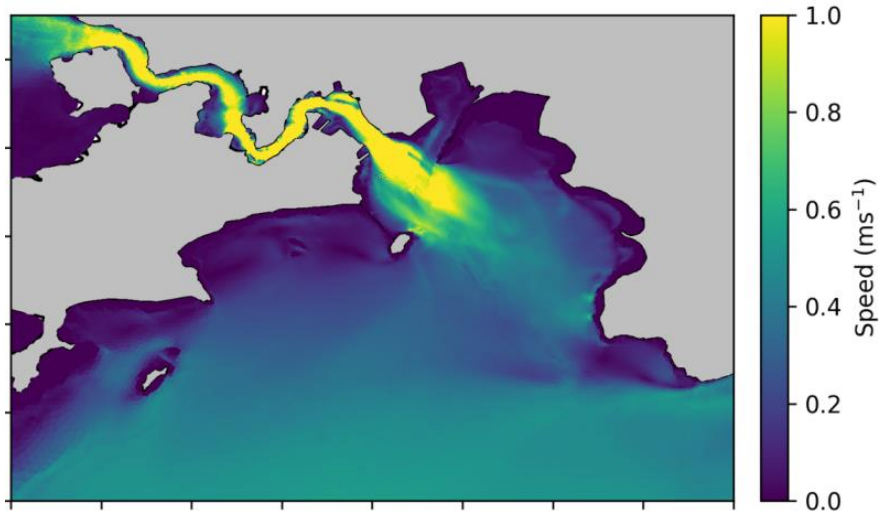
RIOPS: $\frac{1}{12}^\circ$, DA, operation



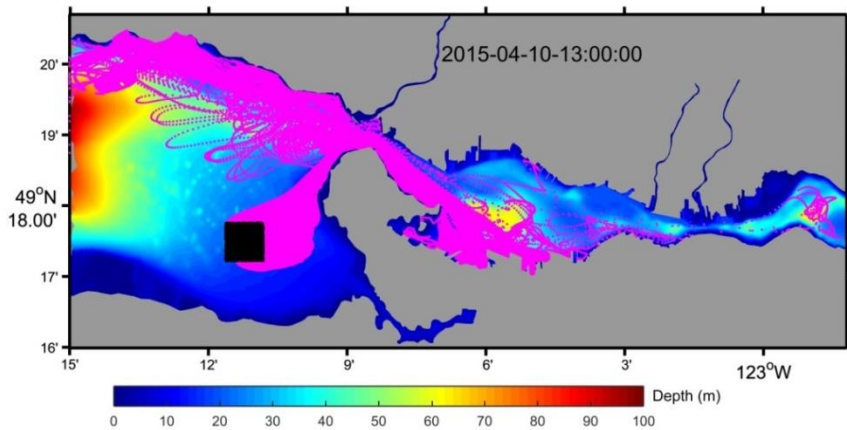
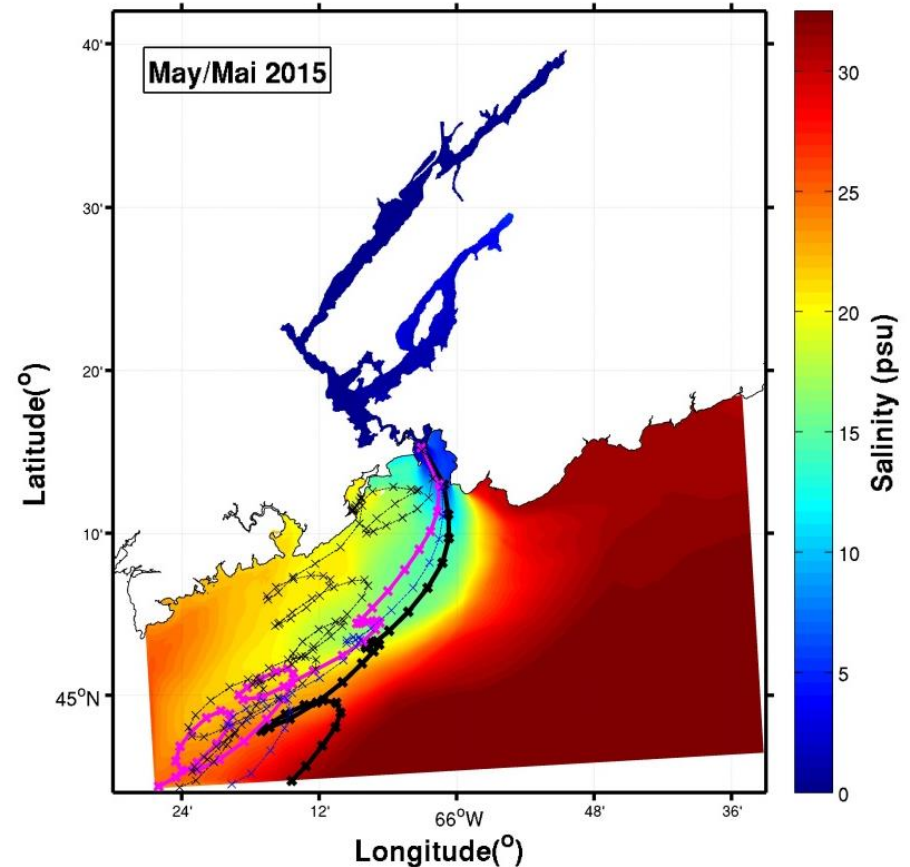
CIOPS-east: $\frac{1}{36}^\circ$, under development

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

Based on FVCOM



Based on NEMO



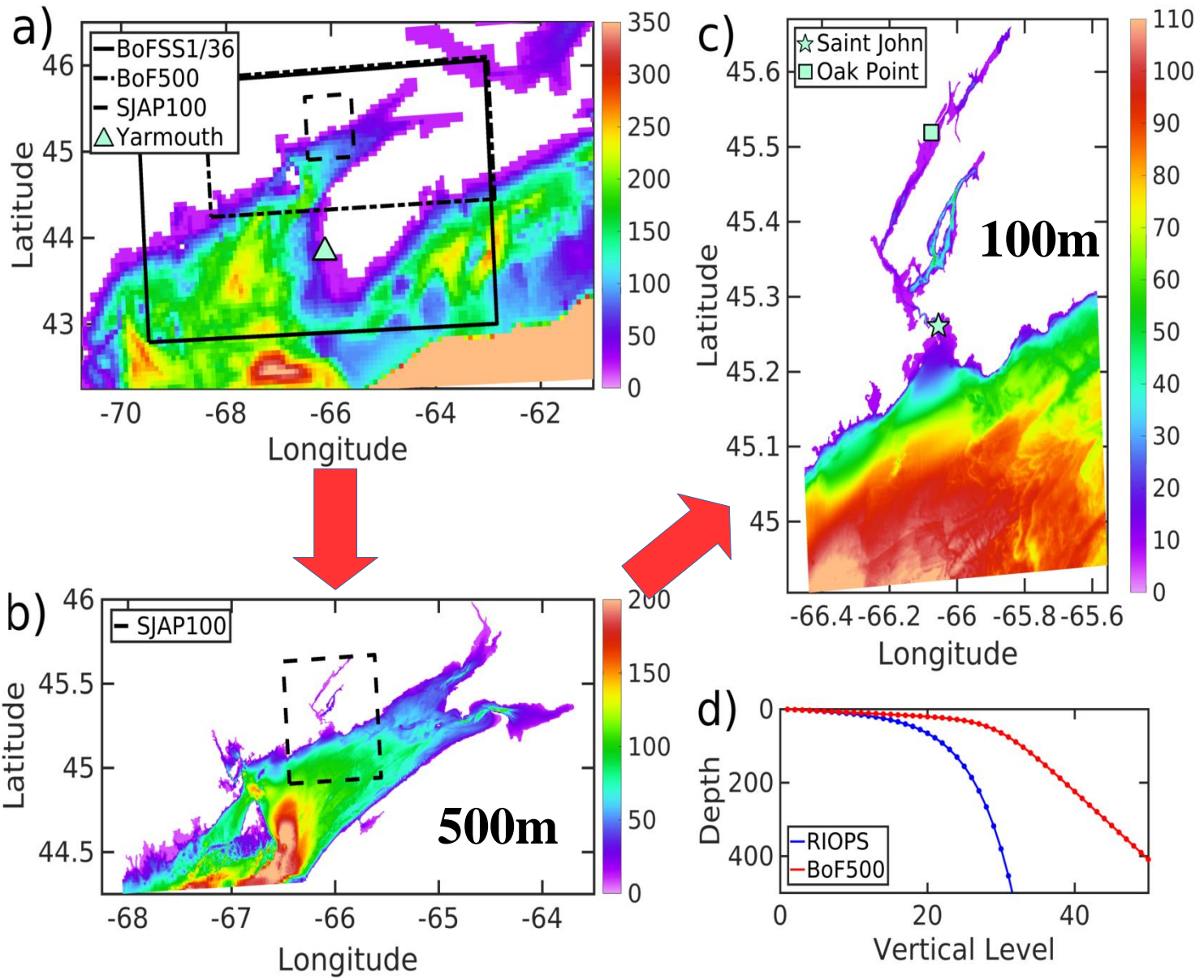
Saint John harbor

NEMO: multi-level 1-way nesting

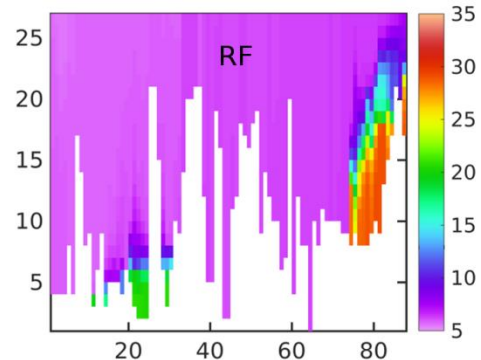
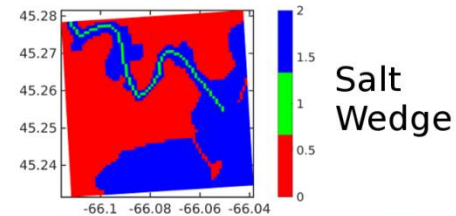
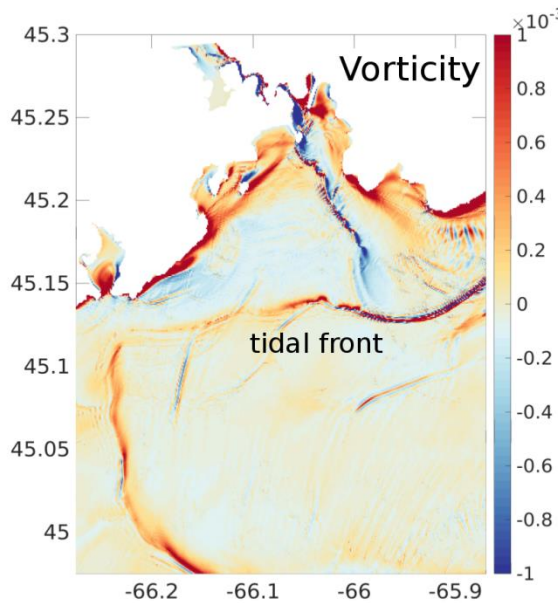
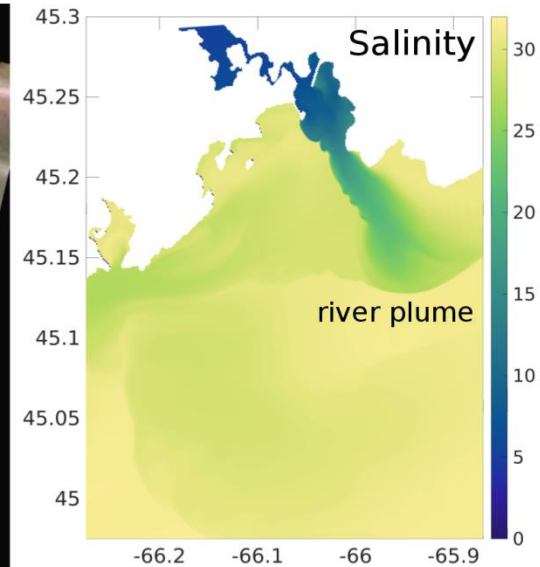
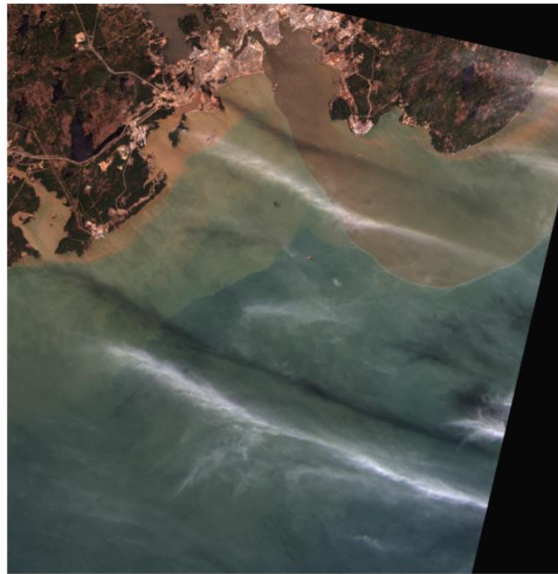
$1/12^\circ$
RIOPS



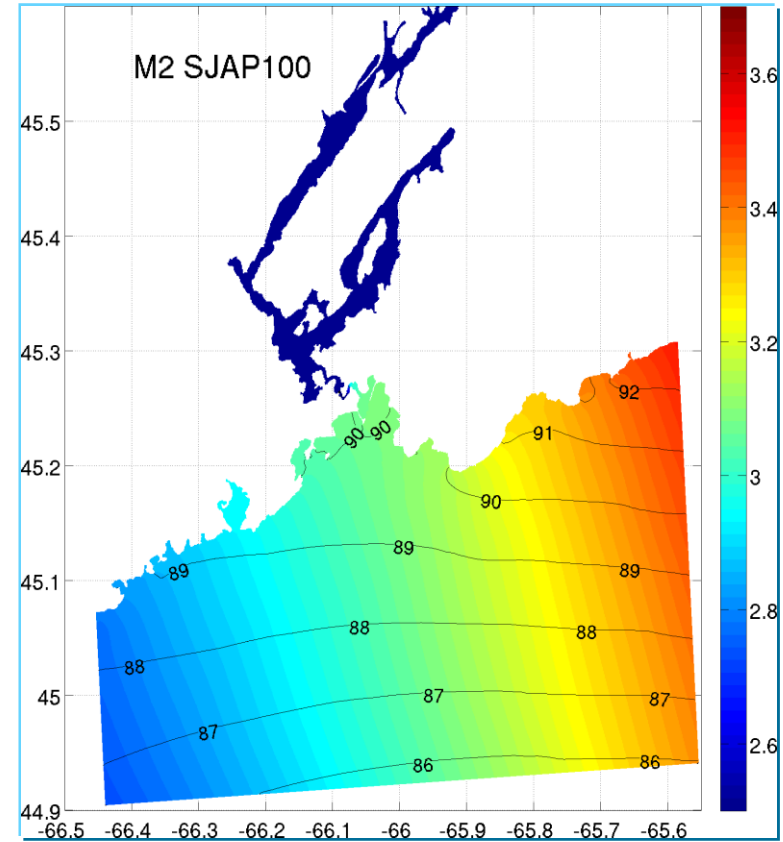
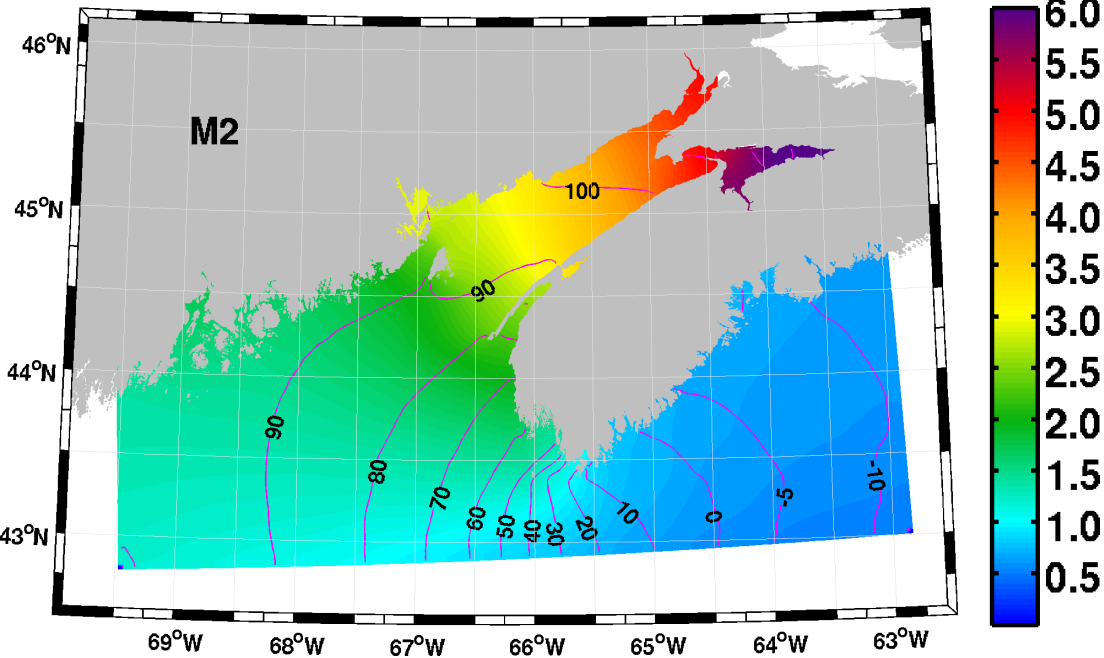
$1/36^\circ$



Main features of regional oceanography



Strong tides & Narrow channel



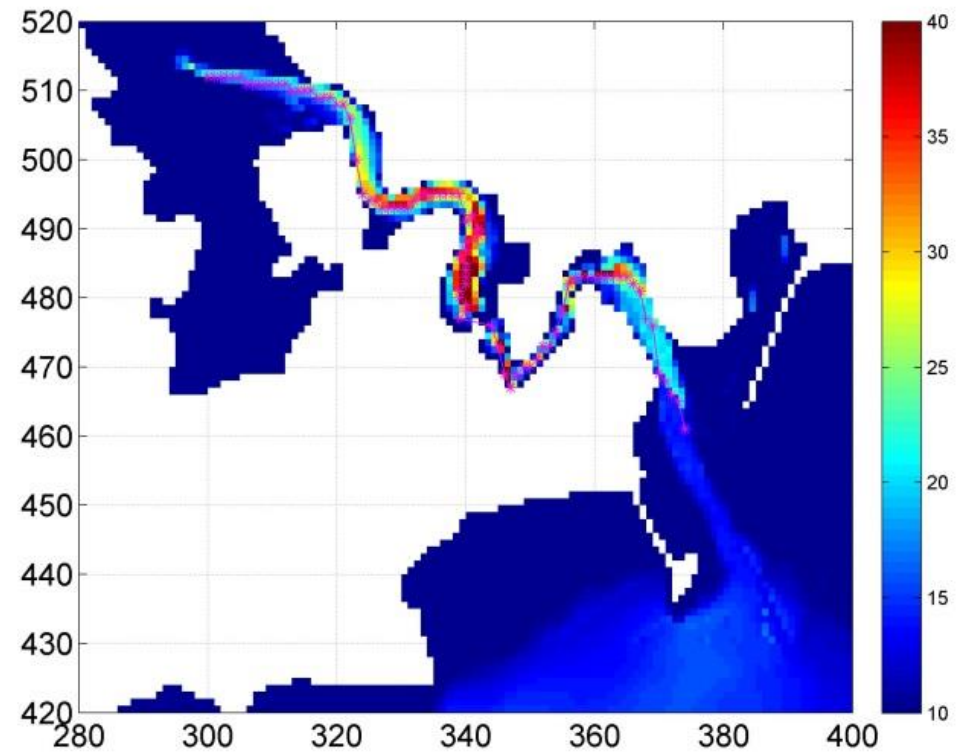
The Reversing Falls



River plume & Salt wedge



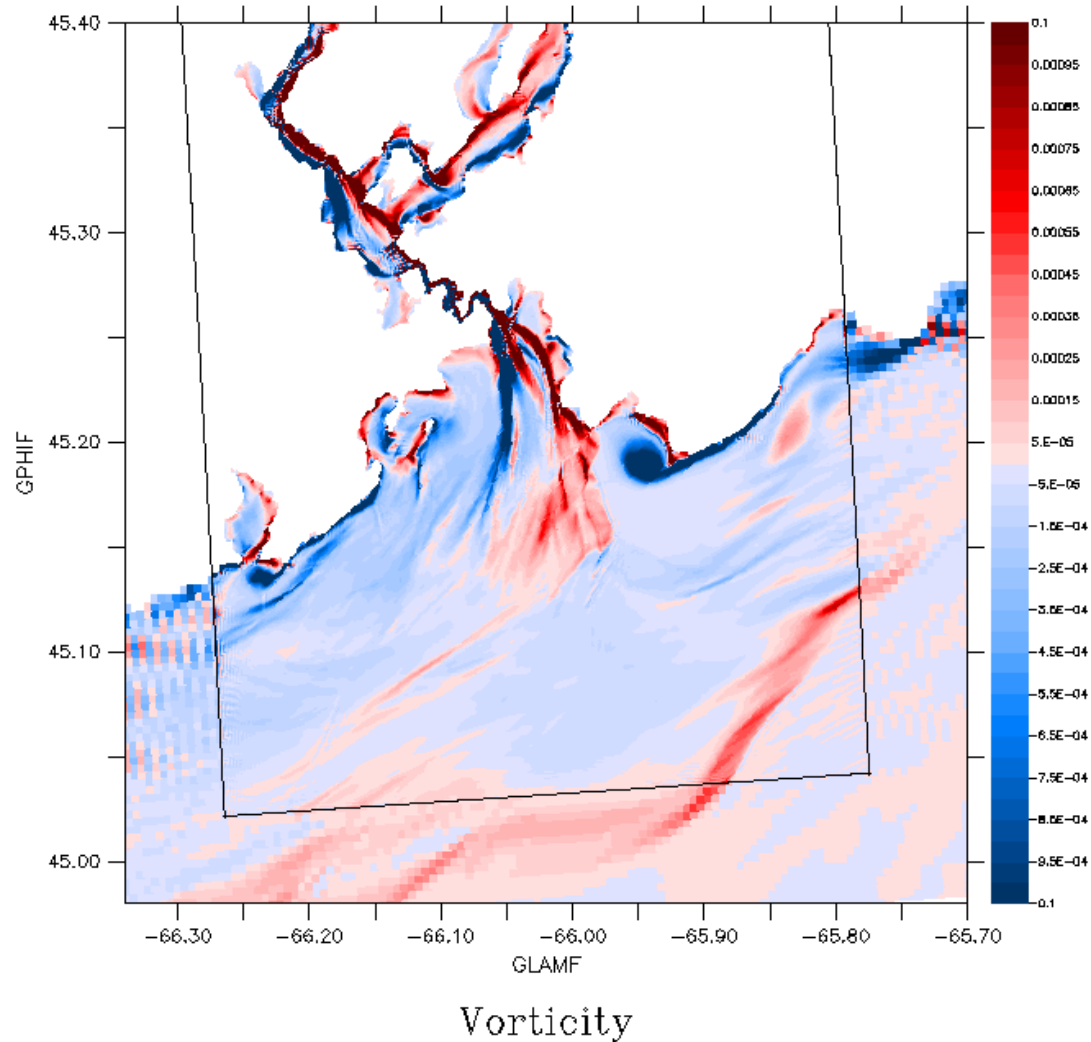
sss_20150925.mp4



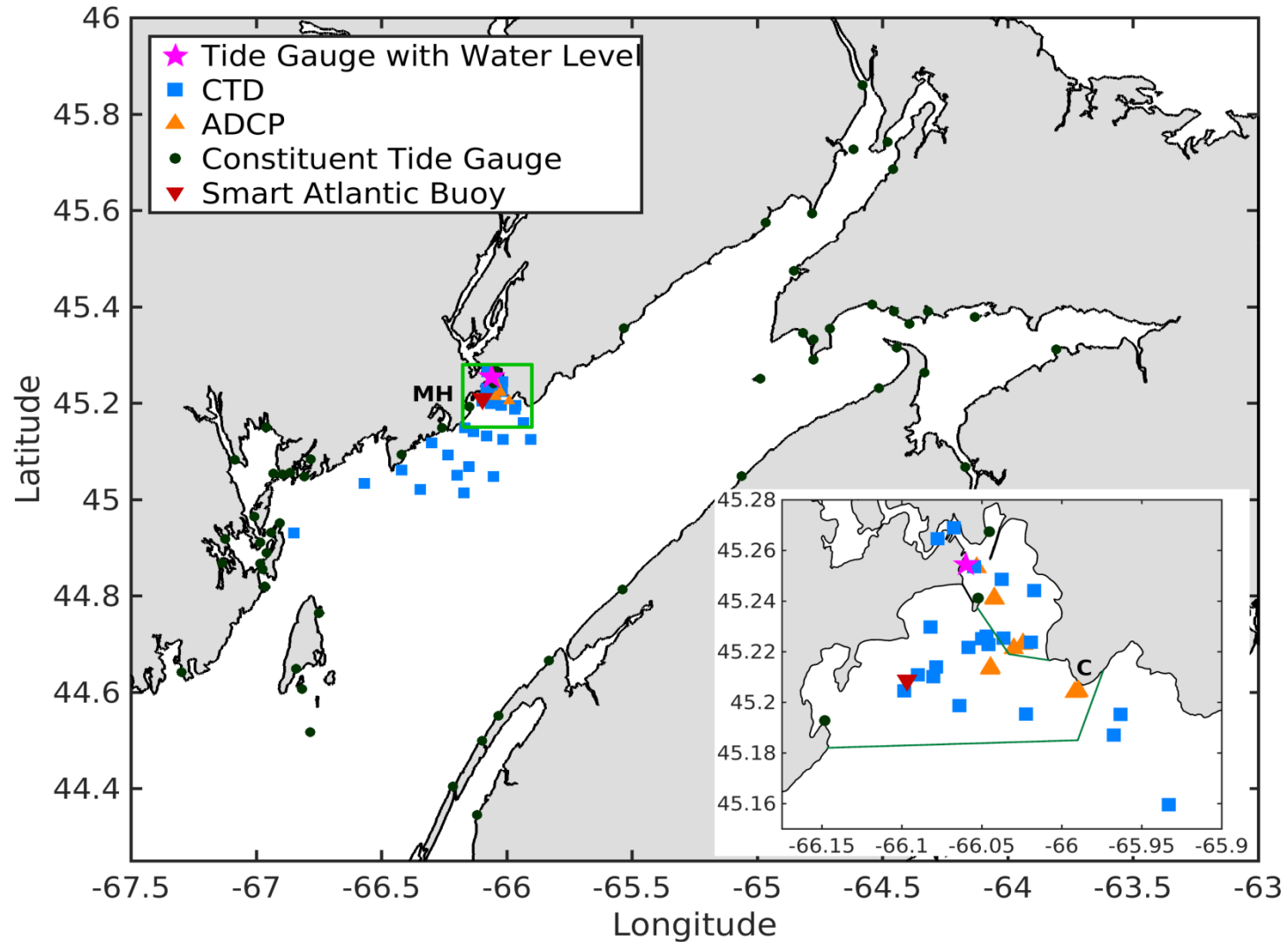
sss_ssh_20150925.mp4

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

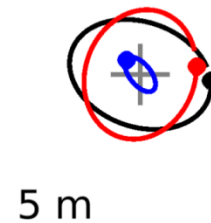
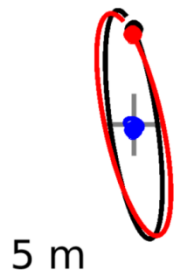
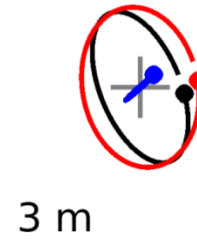
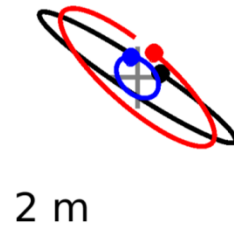
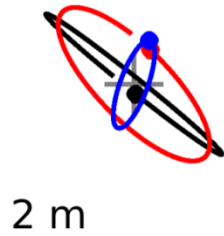
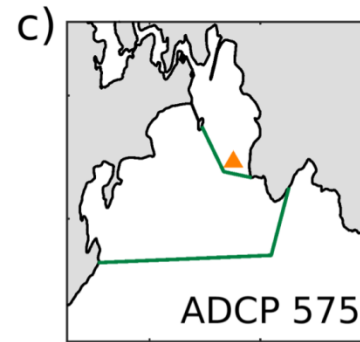
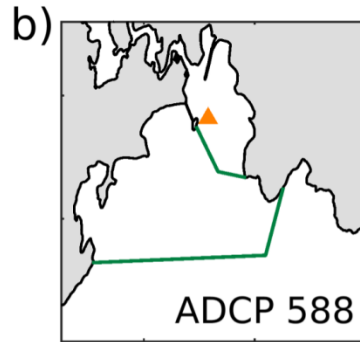
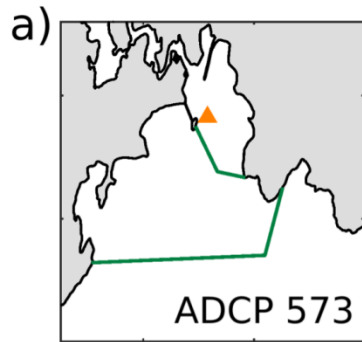
TIME : 23-APR-2015 23:30



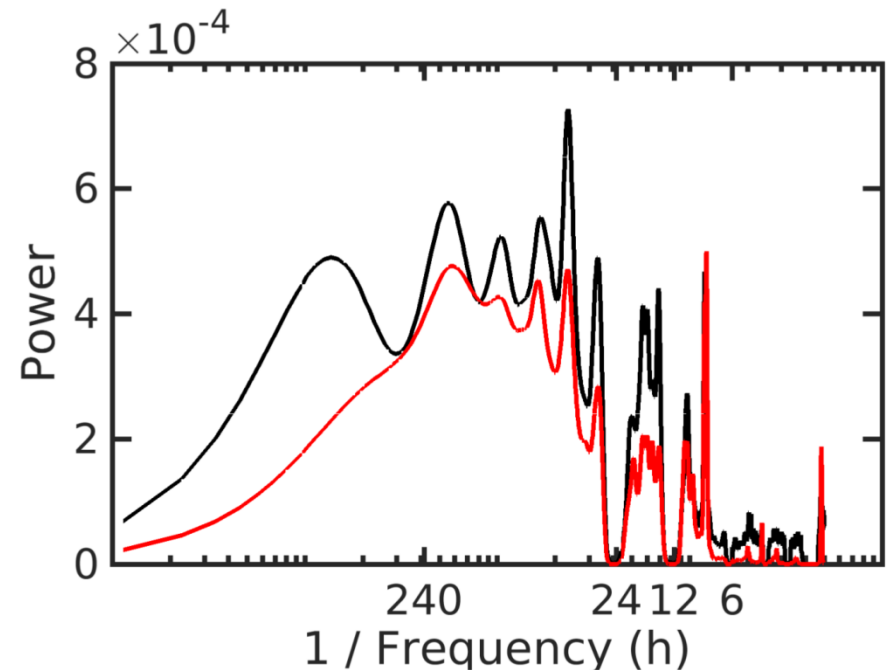
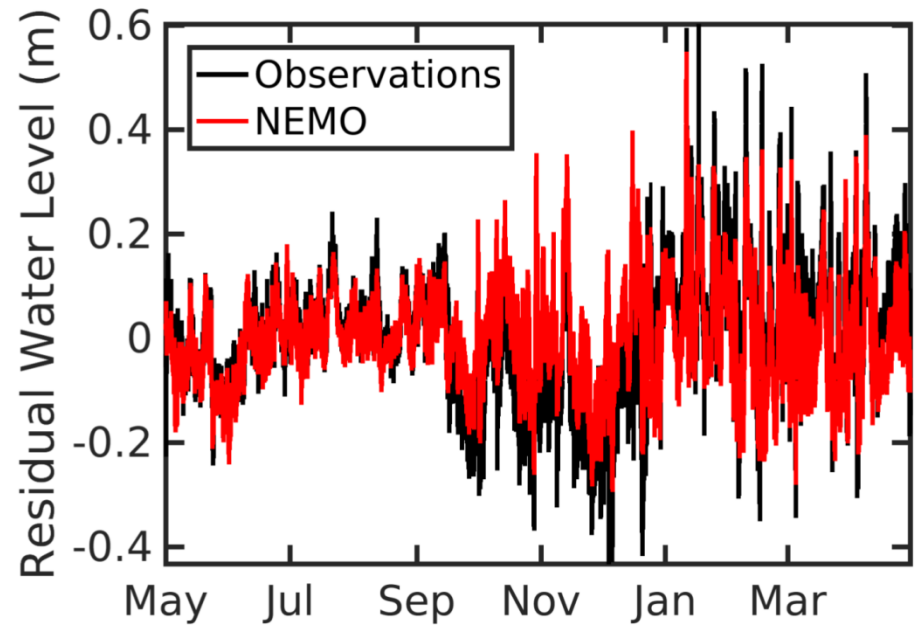
Model evaluation: Observational data



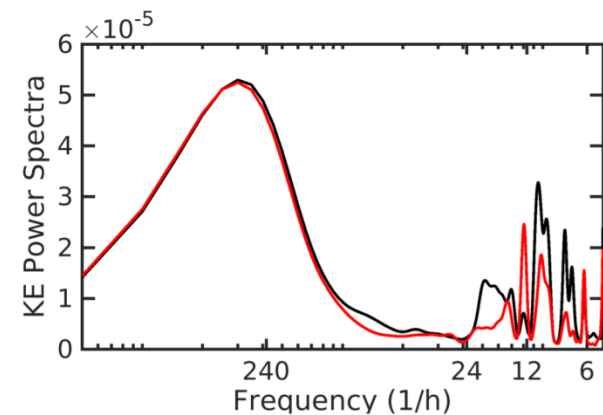
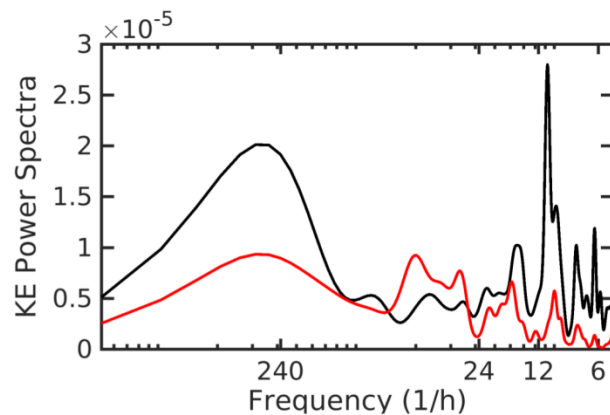
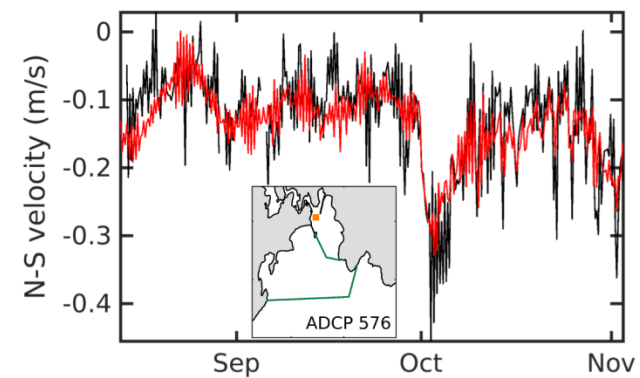
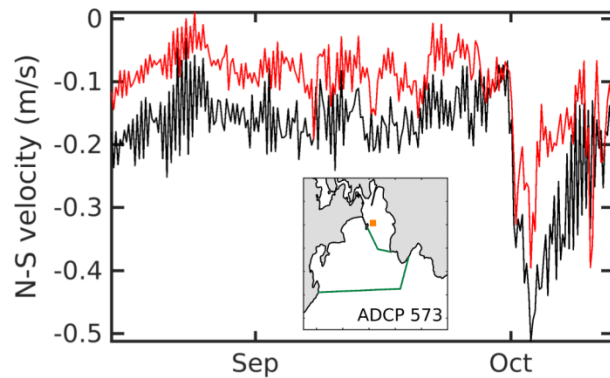
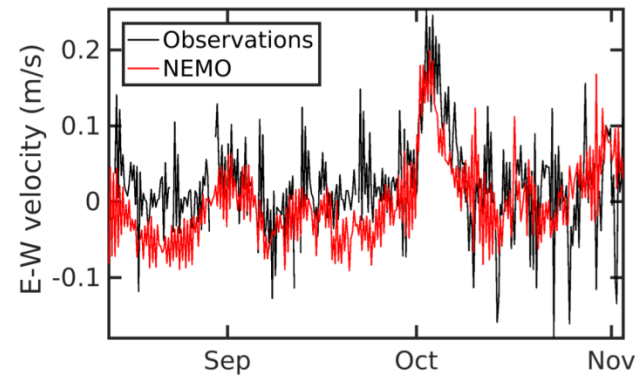
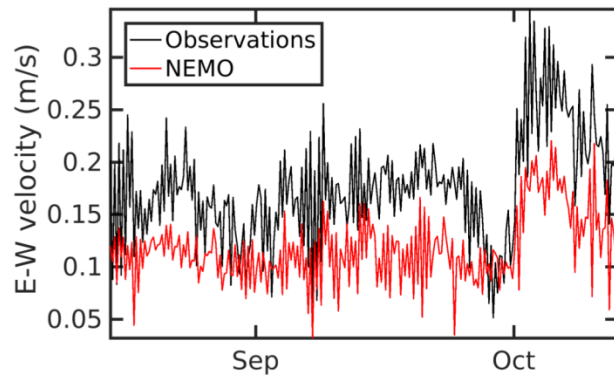
Tidal ellipses: obs (black) model (red) diff (blue)



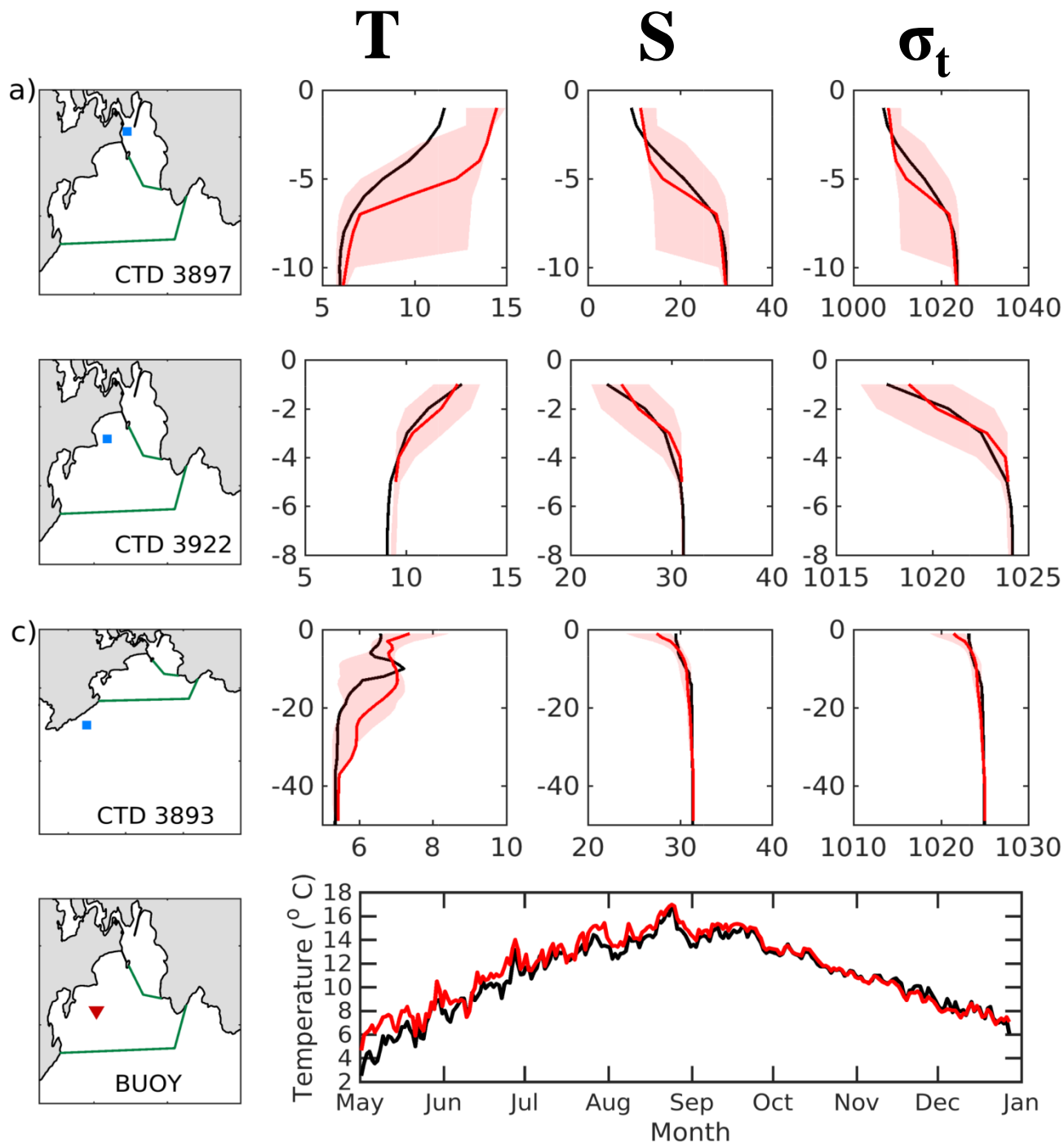
**Non-tidal water level:
obs (black) model (red)**



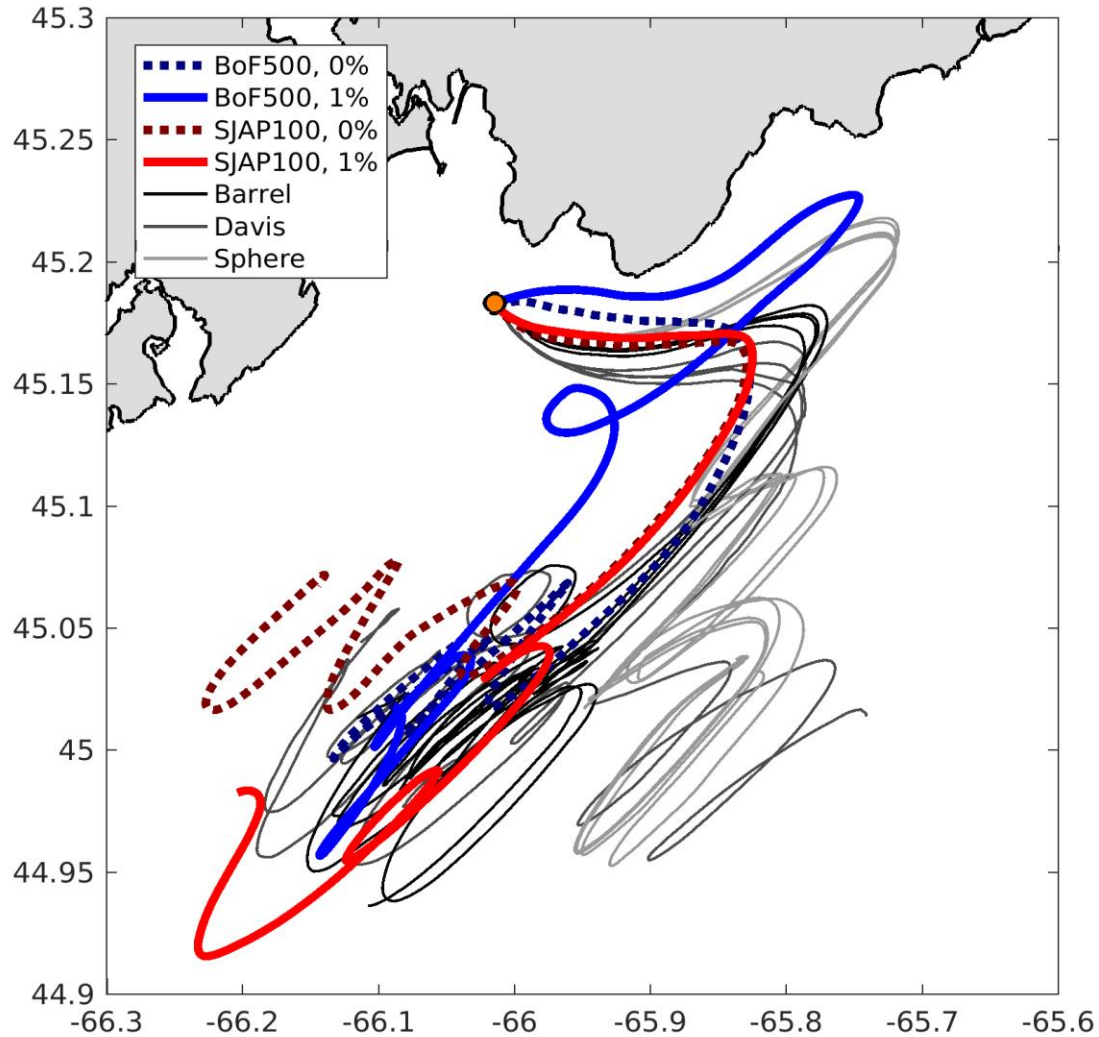
Non-tidal flow: obs (black) model (red)



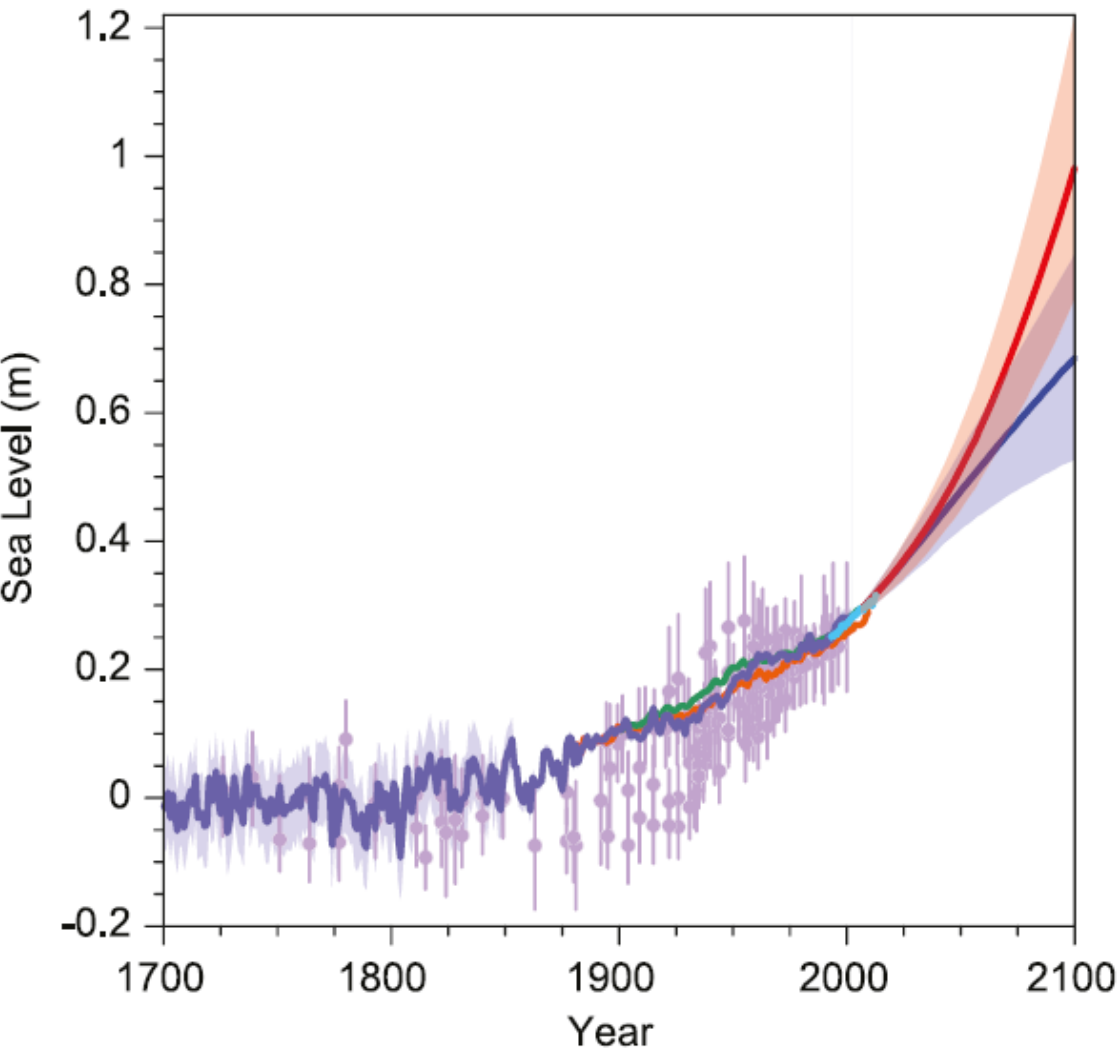
CTD:
obs (black)
model (red)



Surface drifter trajectories



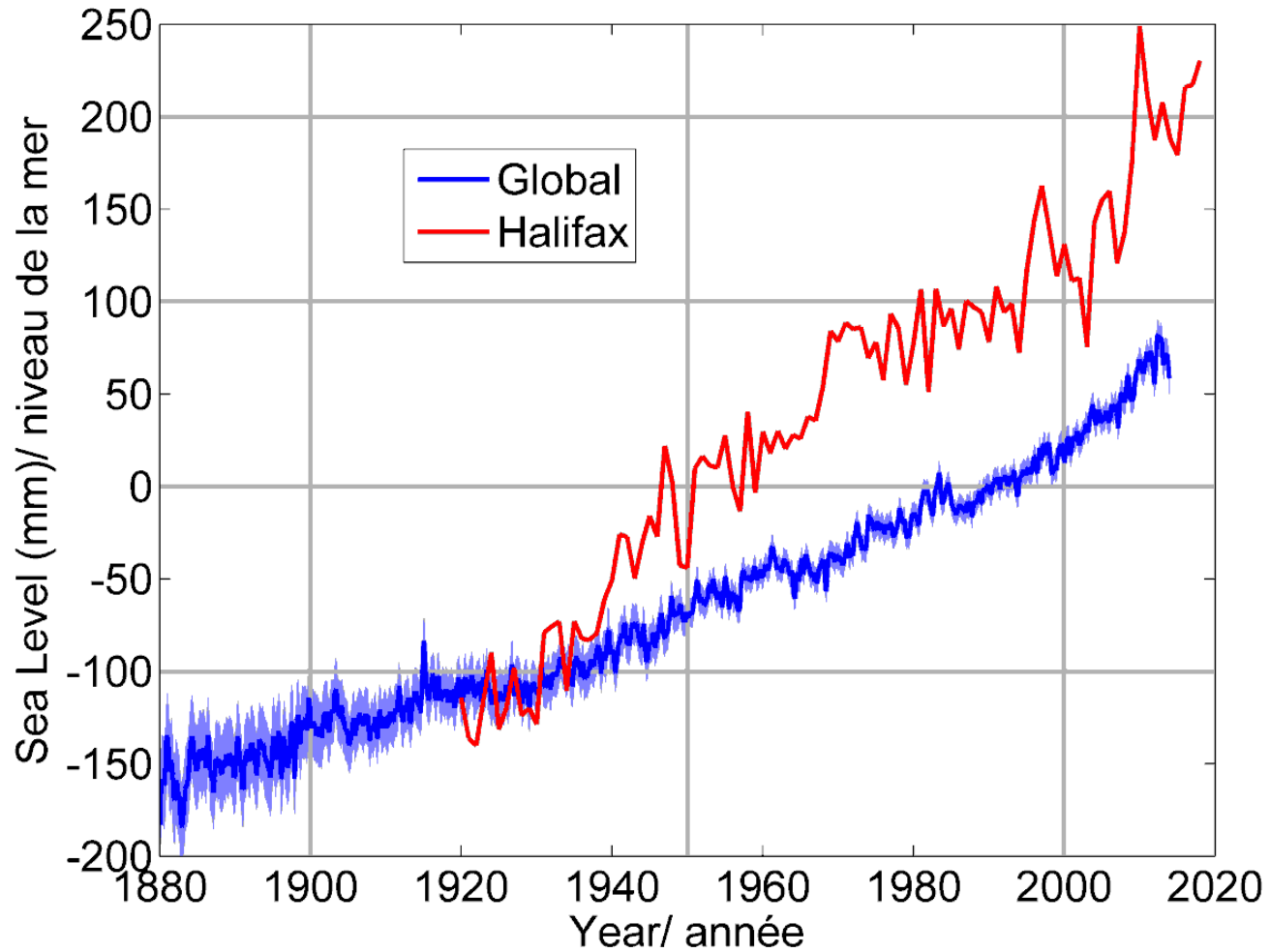
Modelling Research: Sea Level Changes



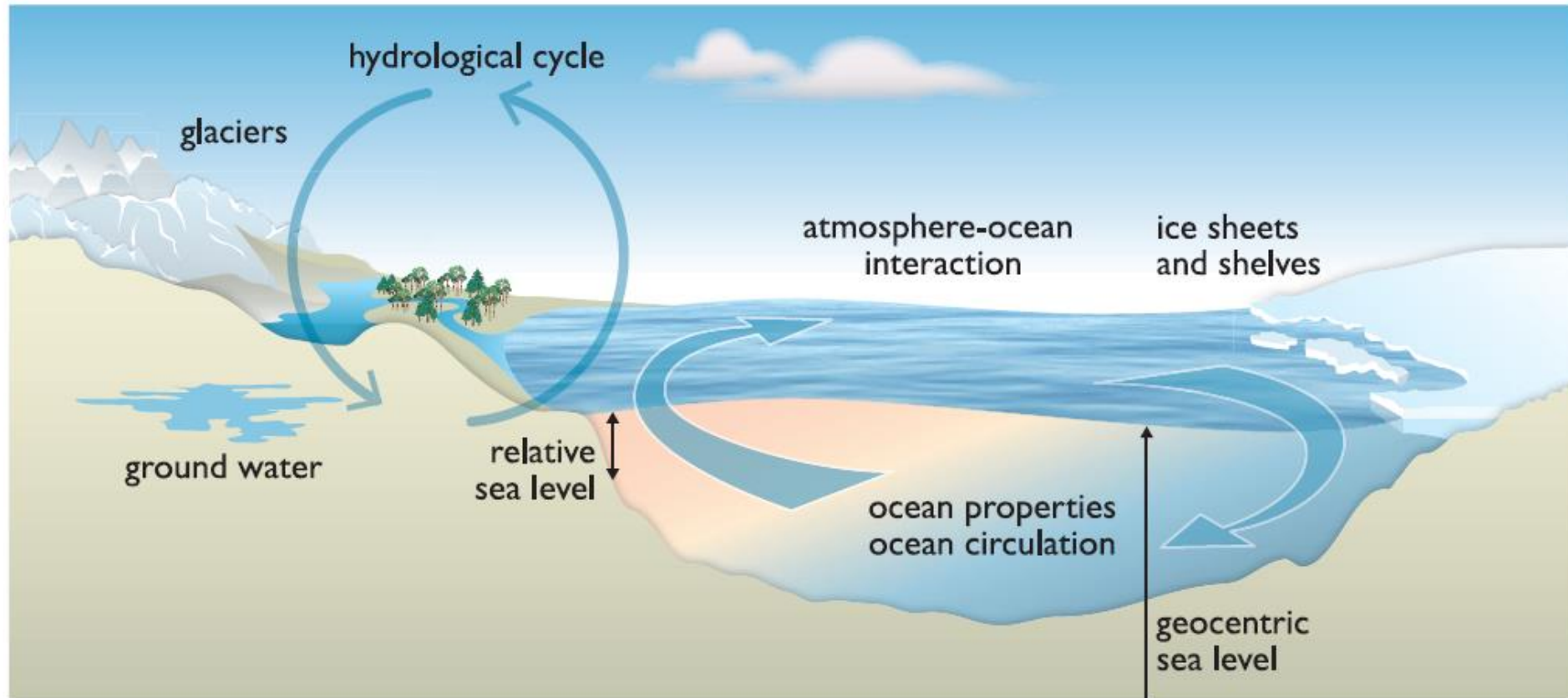
**Global mean sea
level change:
Past & future
projections**

*International Panel
of Climate Change:
5th Assessment
Report*

Regional Sea Level Rise

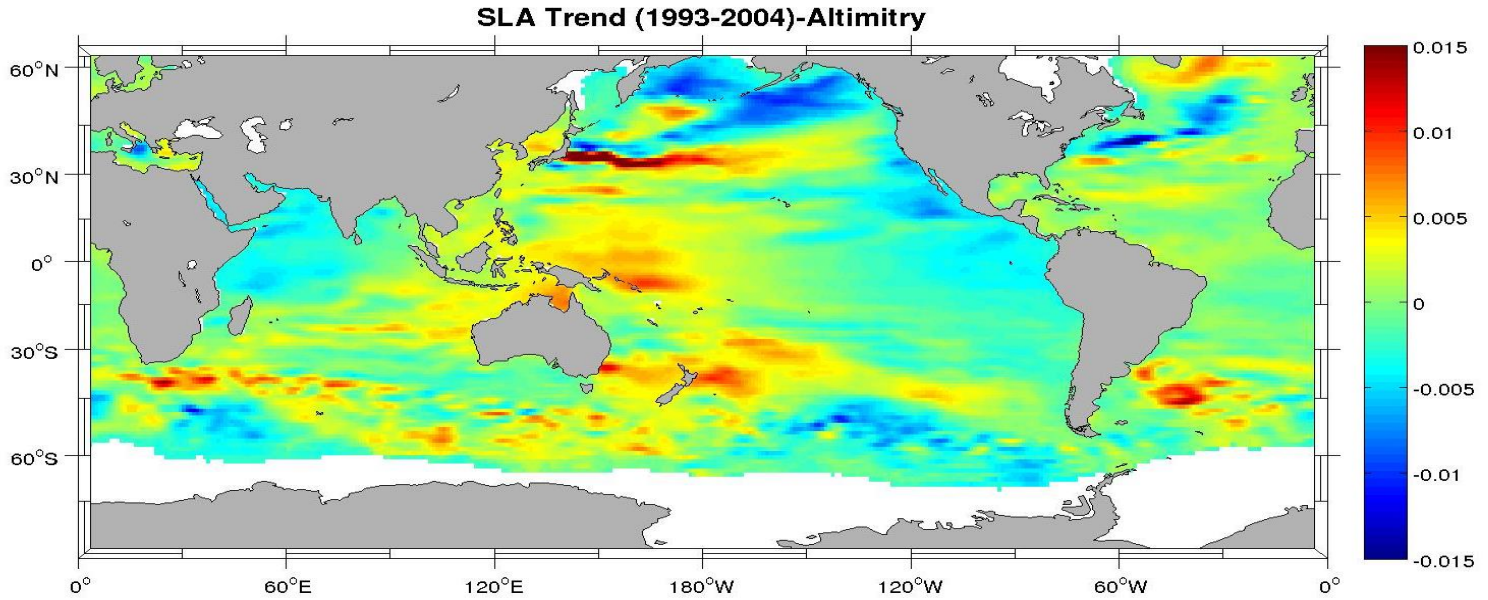


Processes Influencing Sea Level Changes

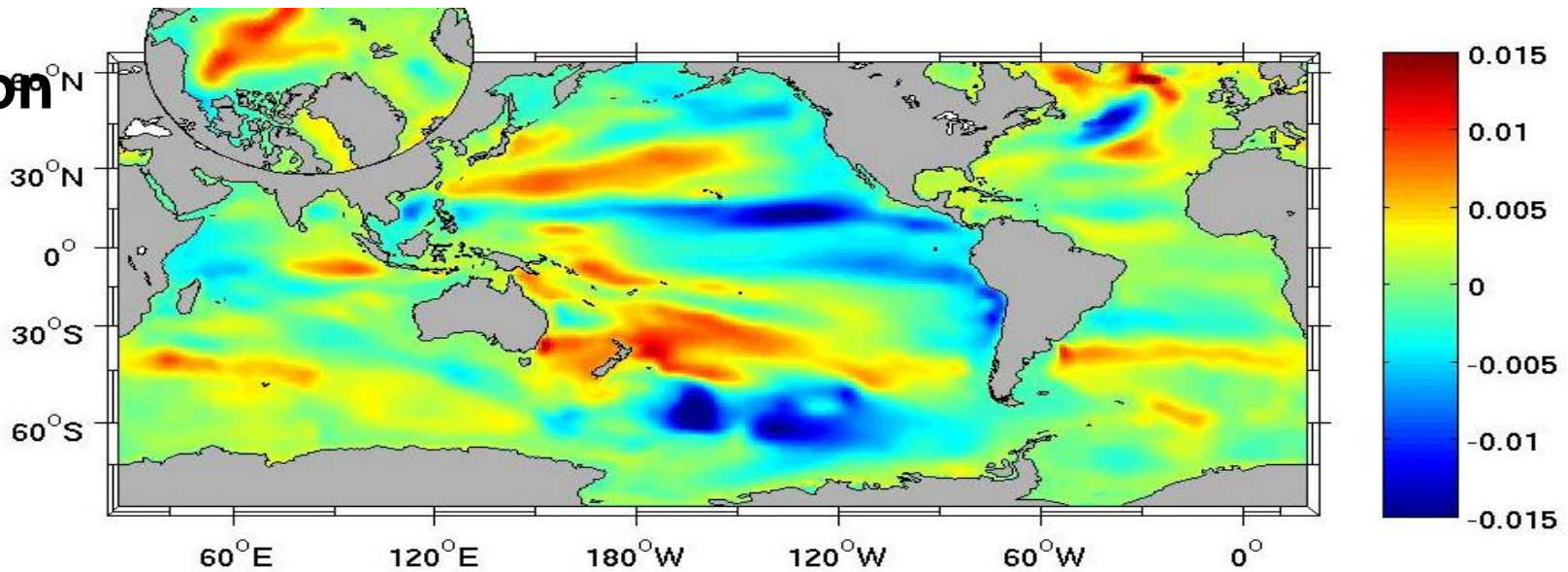


Remove global mean: Non-uniform Sea-Level Trend 1993-2004 (m/yr)

Satellite
Obs

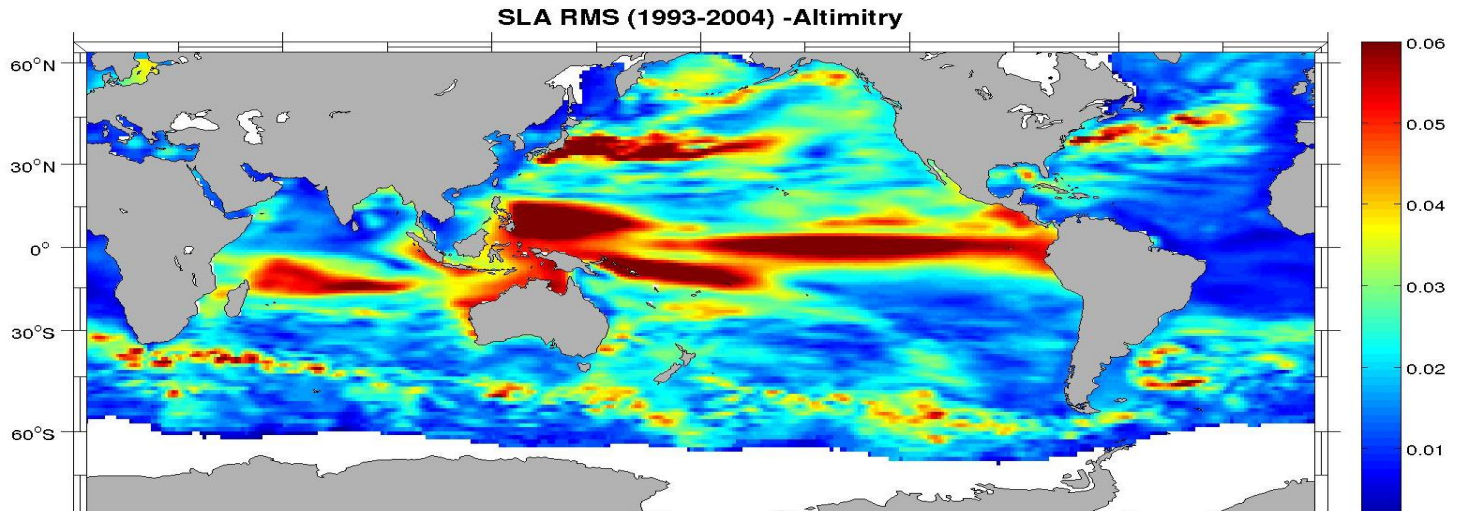


Coarse
resolution
model

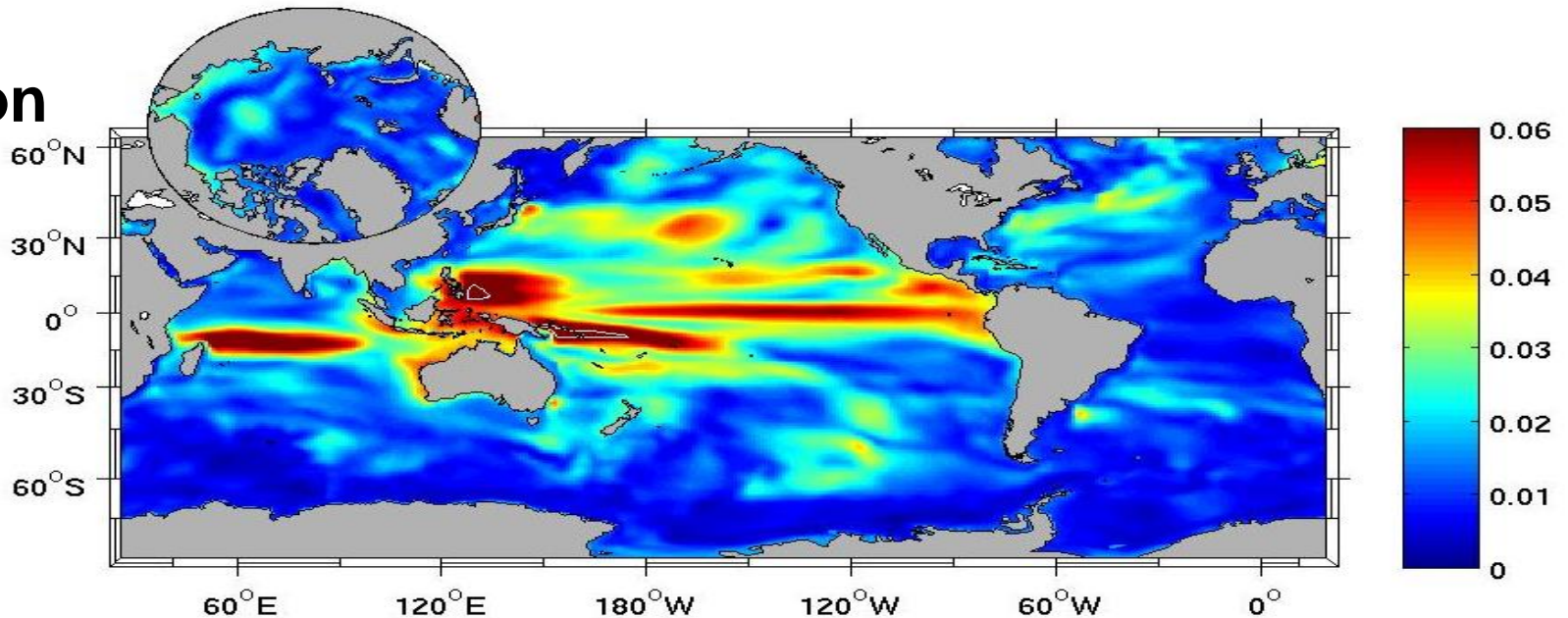


Inter-Annual Variation: RMS 1993-2004 (m)

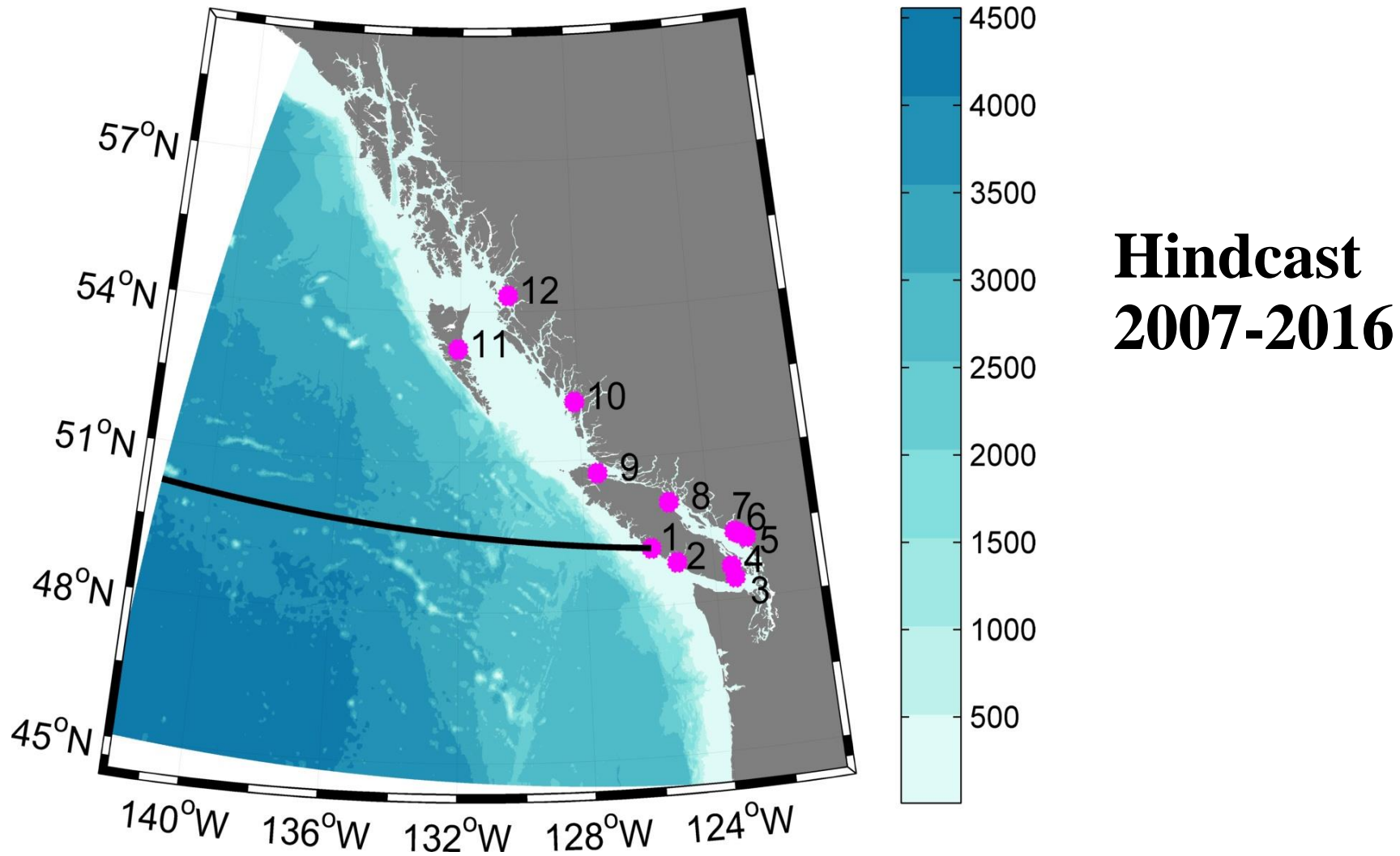
**Satellite
Obs**



**Coarse
resolution
Model**

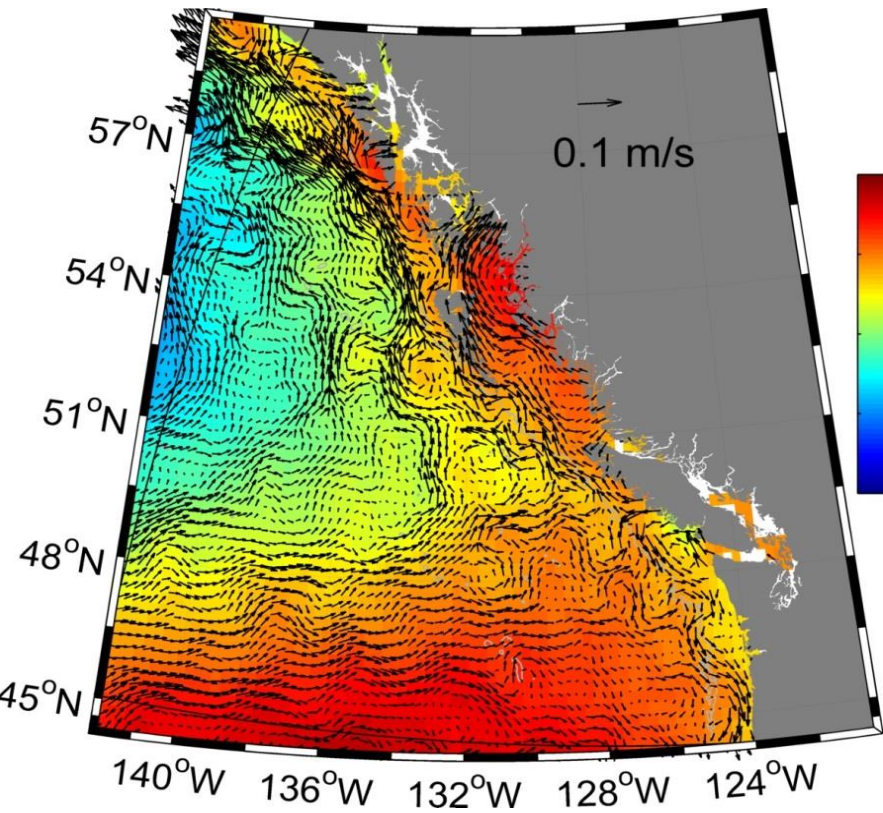


Study based on high-resolution ocean model: *Seasonal, intra-seasonal & inter-annual sea level variations on shelf off Canada's west coast*

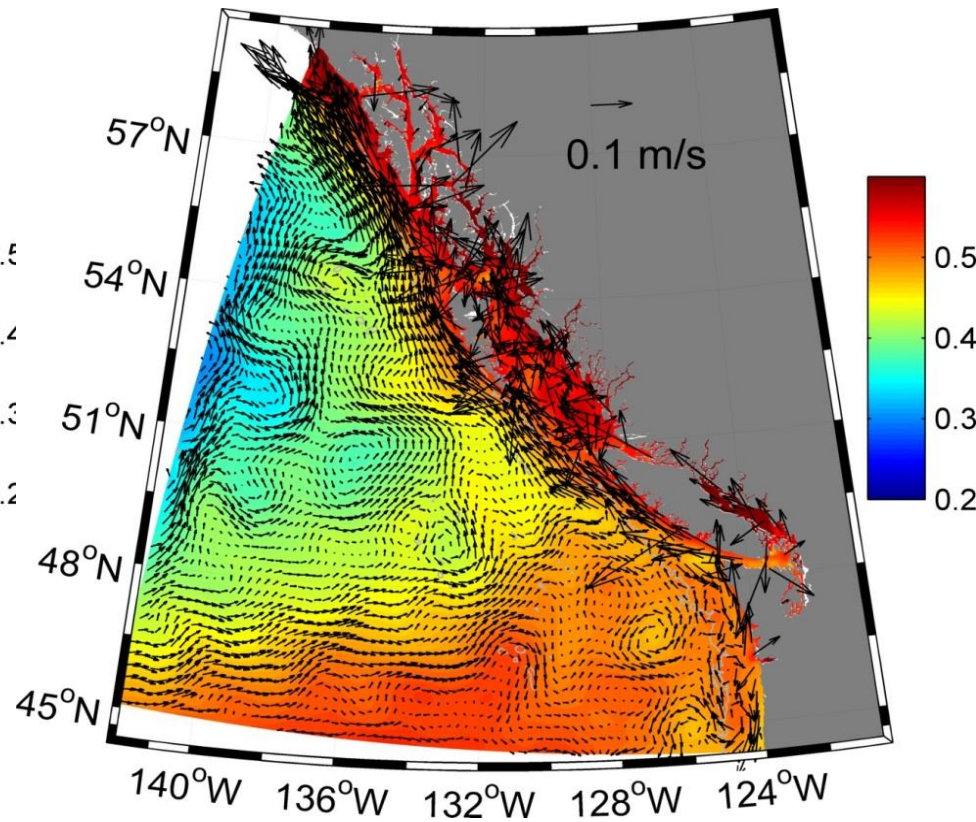


Mean Sea Level (2008-2016)

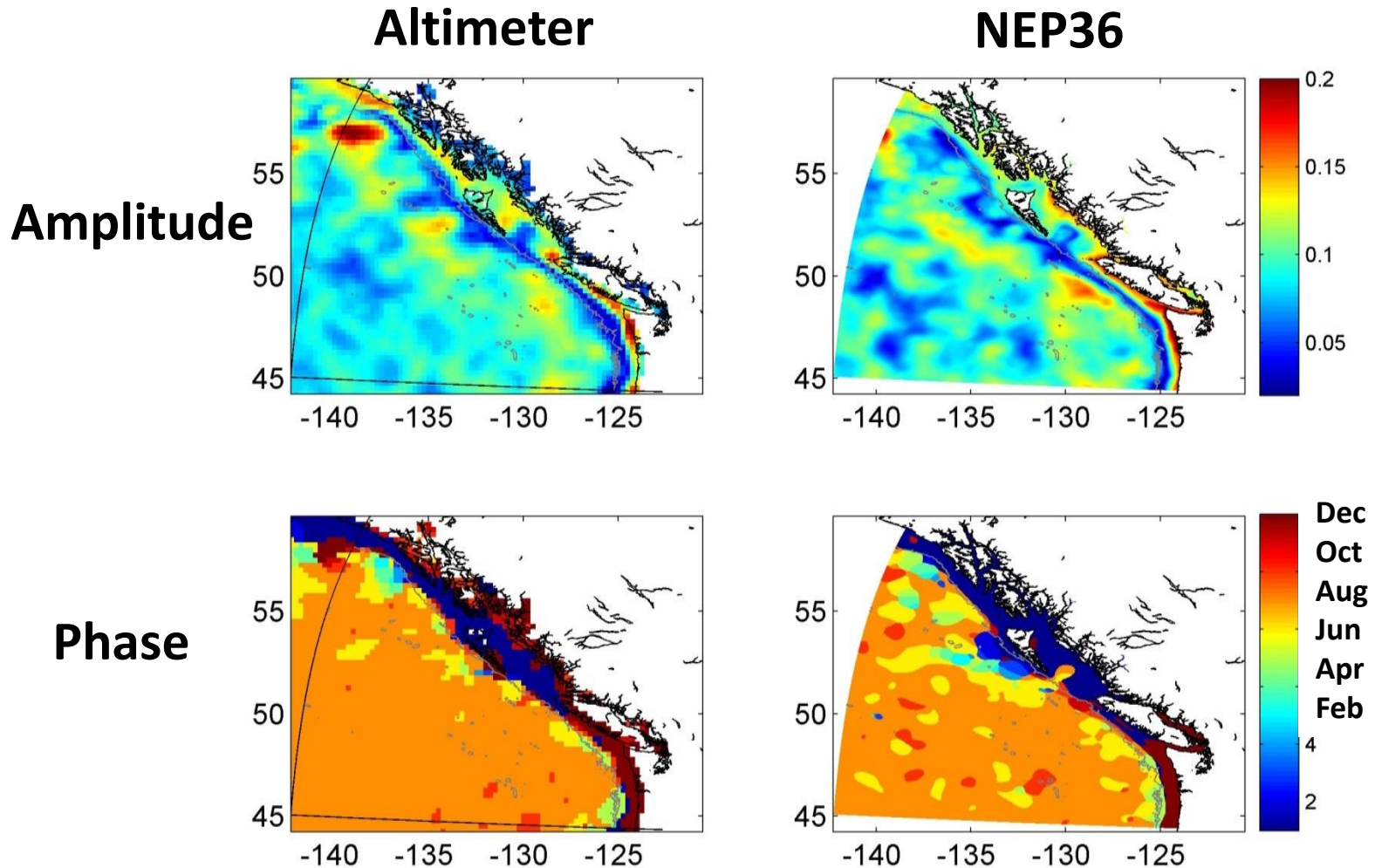
Altimeter obs



NEP36 Model



Seasonal Cycle of Sea Level



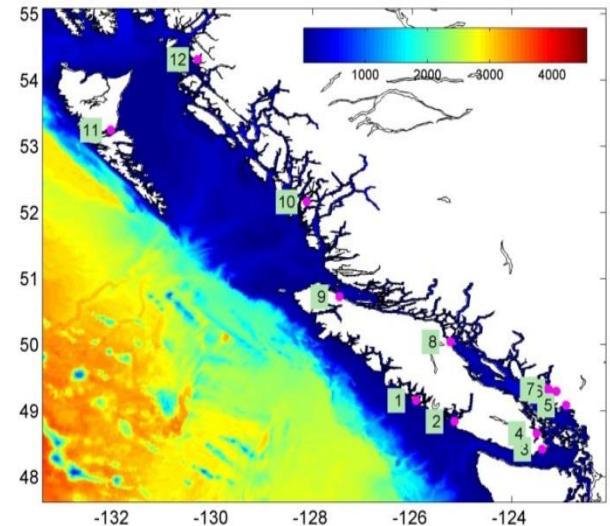
- **Amplitude:** difference between maximum & minimum of monthly climatology; Large spatial variations
- **Phase:** month when maximum occurs; Seasonal cycles on the shelf & off the shelf break are out of phase

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

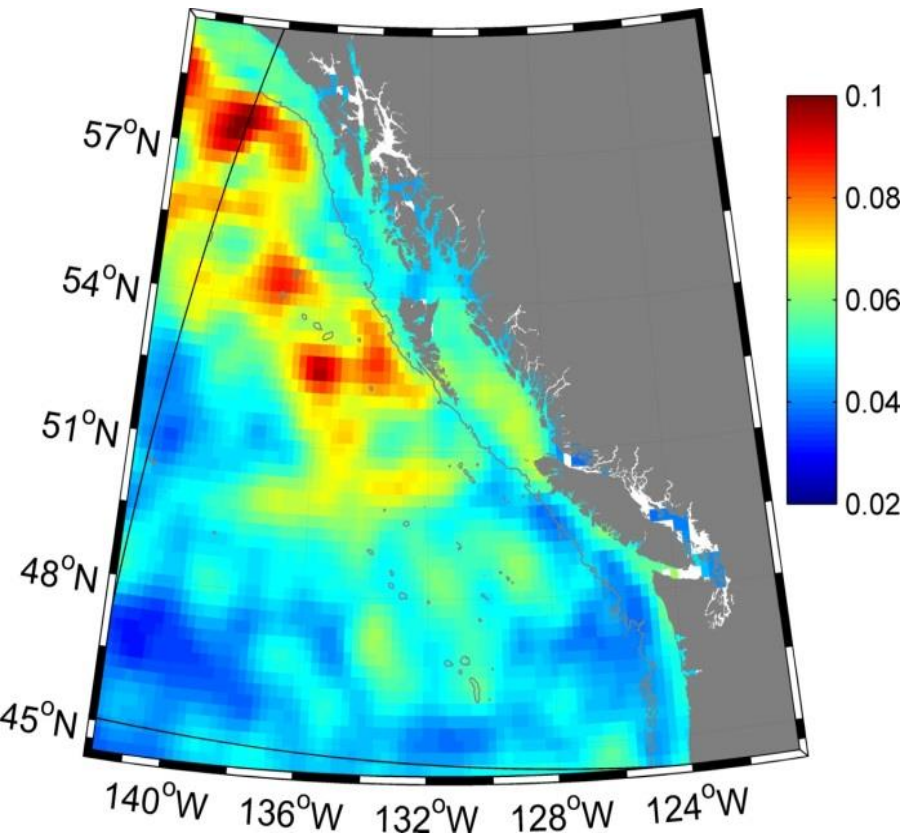
• Good agreement between NEP36 and tide gauge observations

• Difference is less than 5 cm

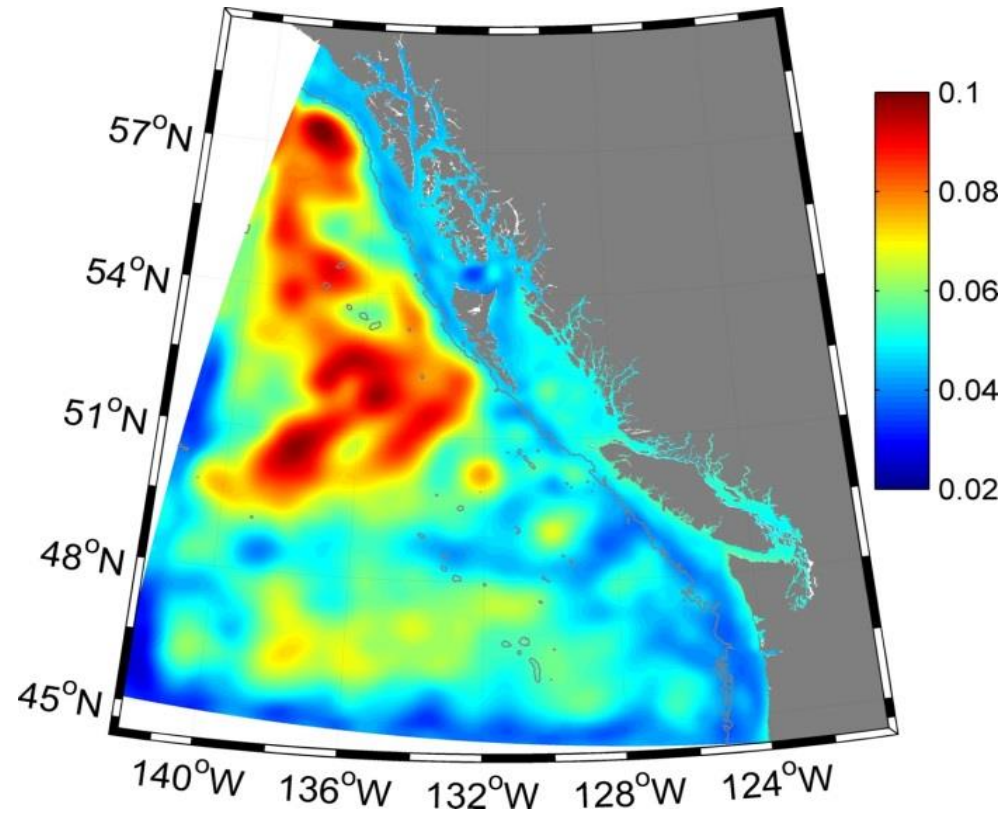


Standard Deviations of Sea Level Anomaly

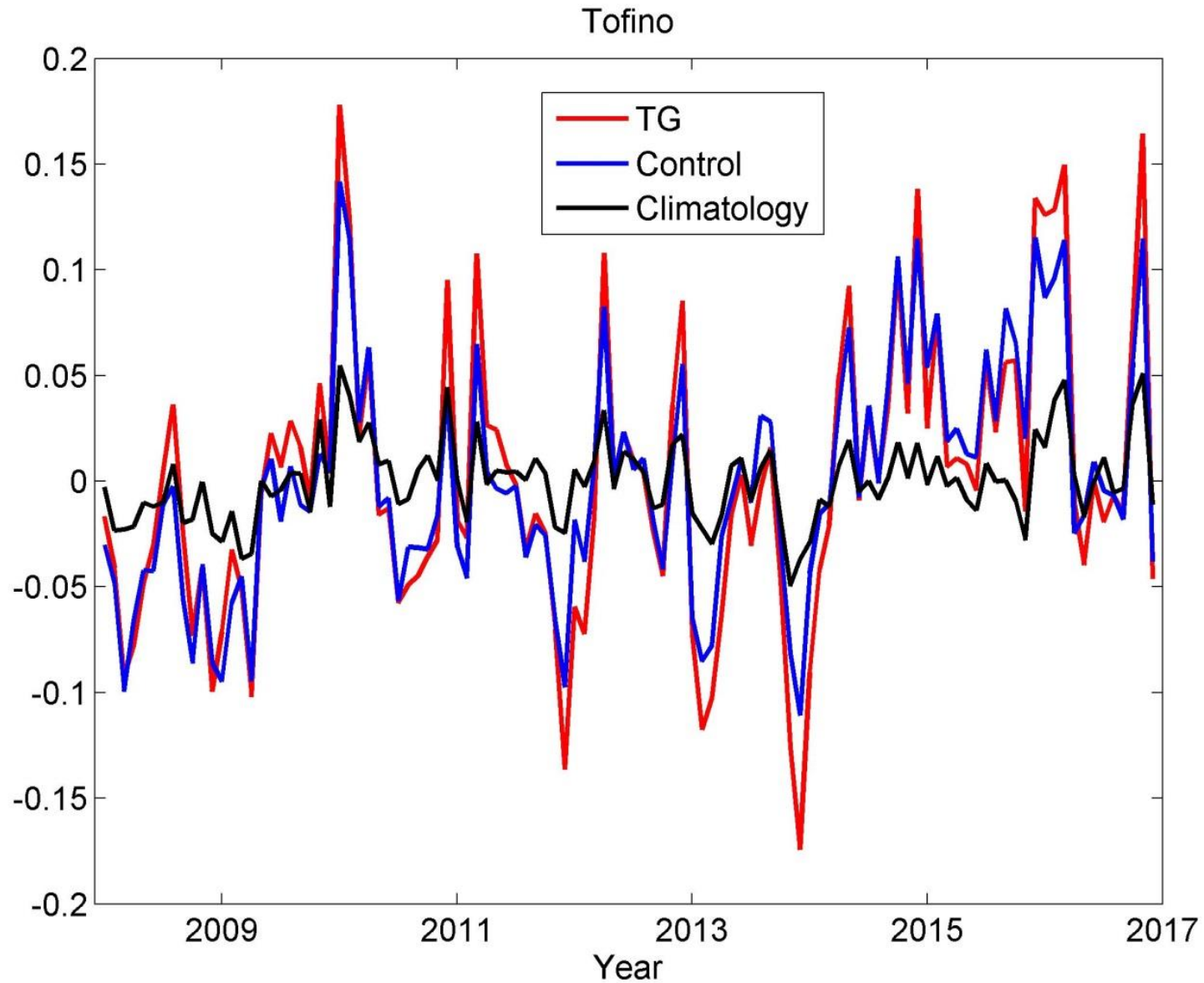
Altimeter obs



NEP36 model

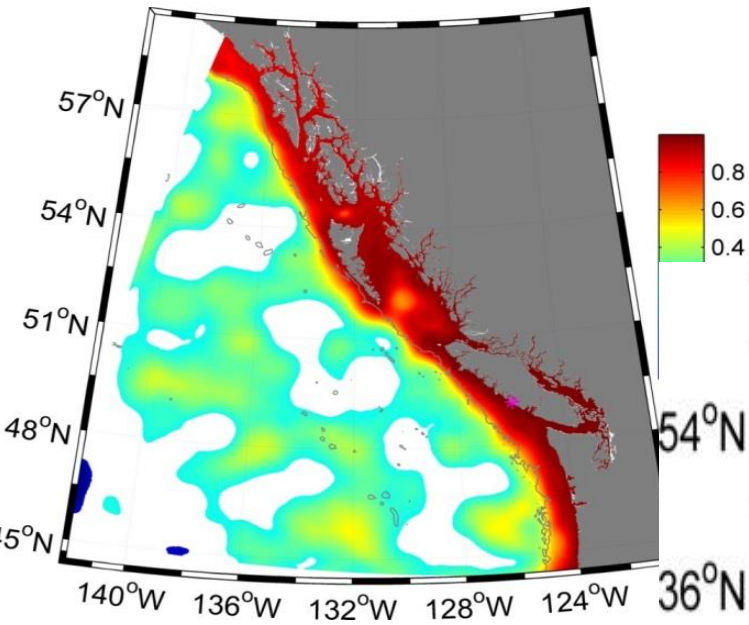


Sea Level Anomaly at Tide Gauge Tofino

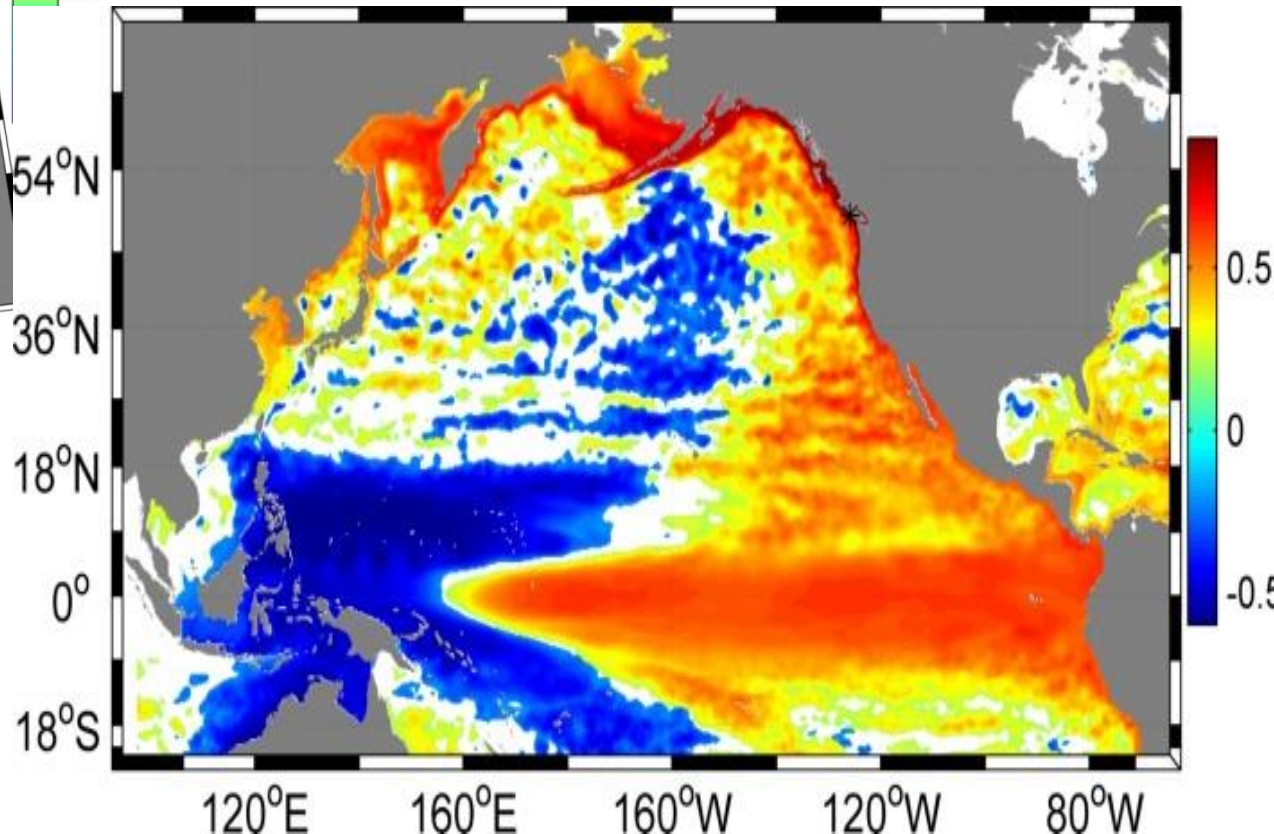


Correlation of Sea Level Anomaly @ Tofino with large scale

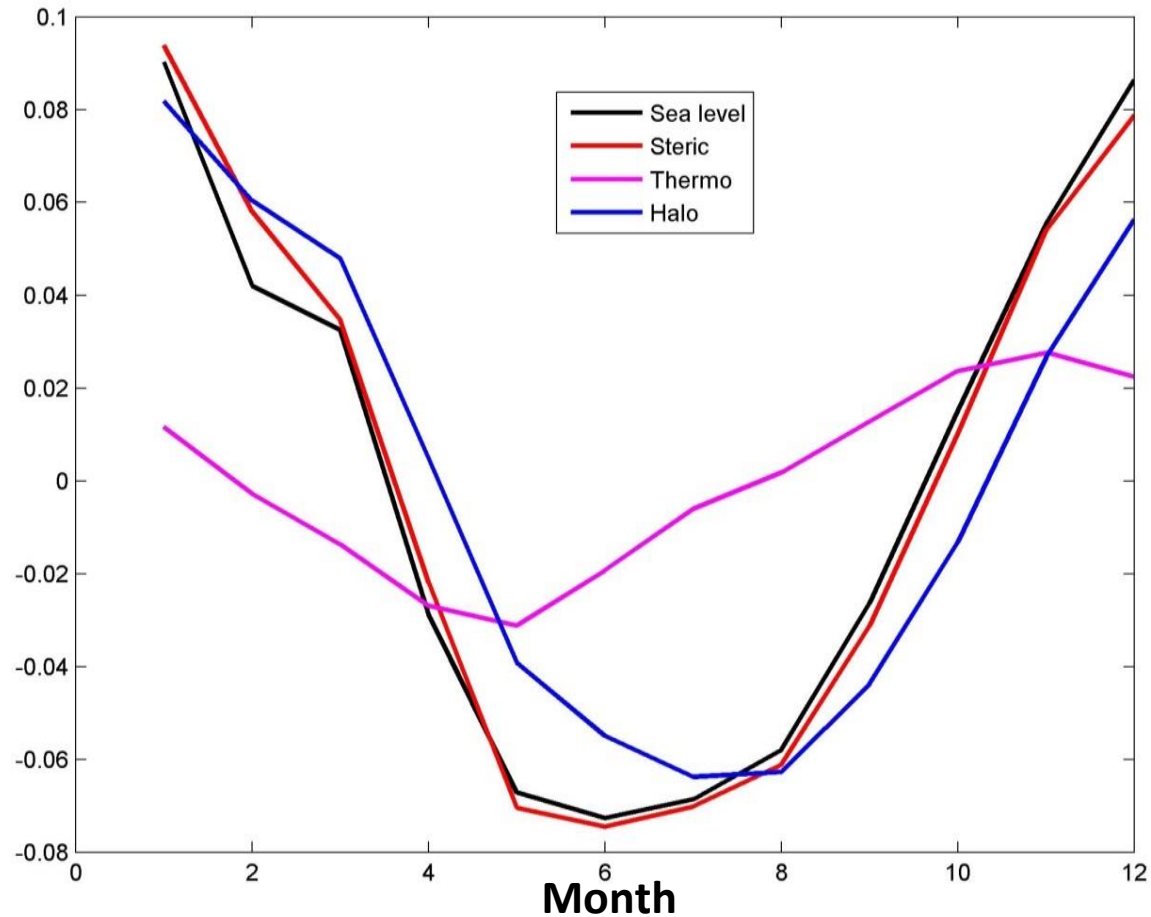
NEP36 model



GLORYS model

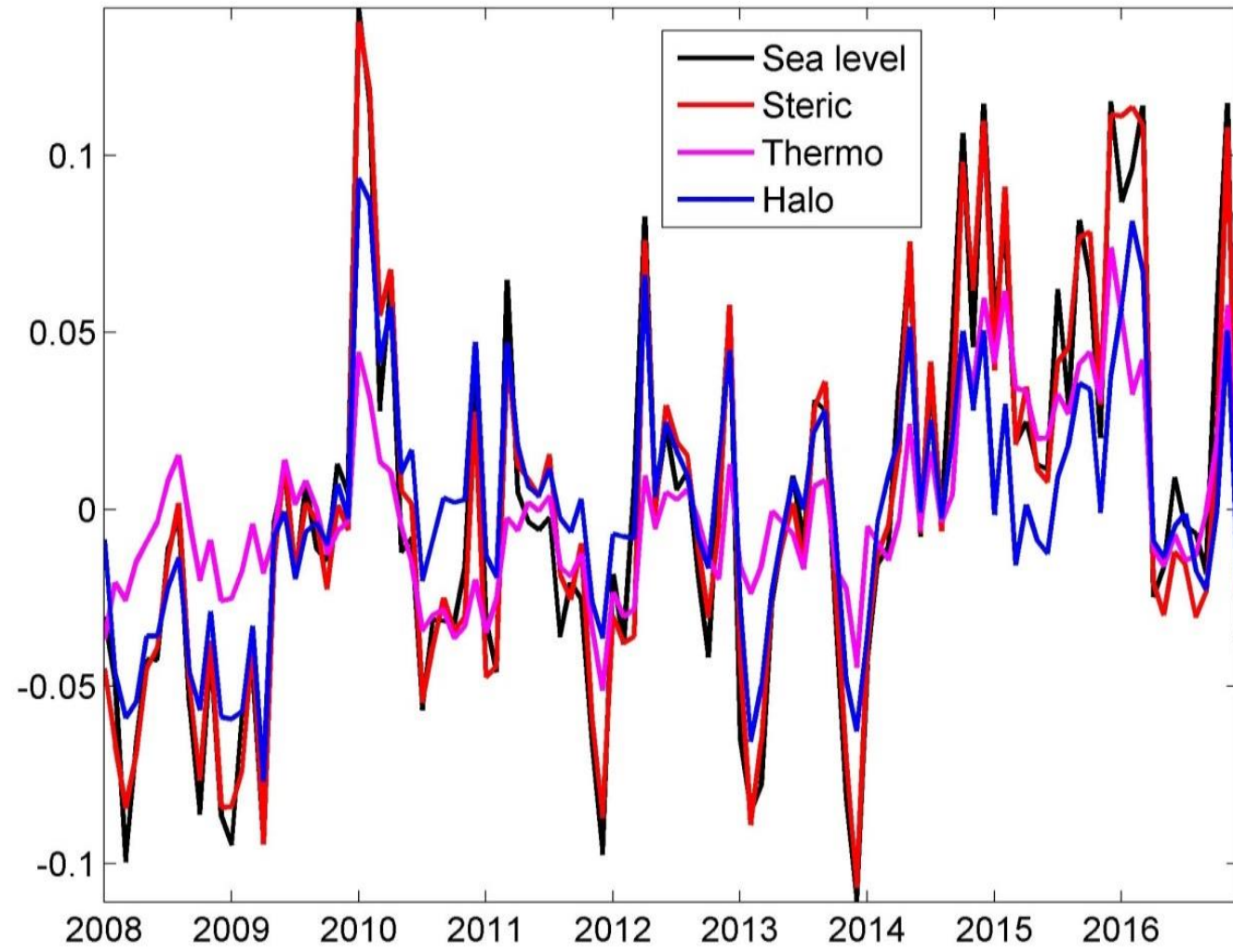


Tofino – Seasonal Cycle

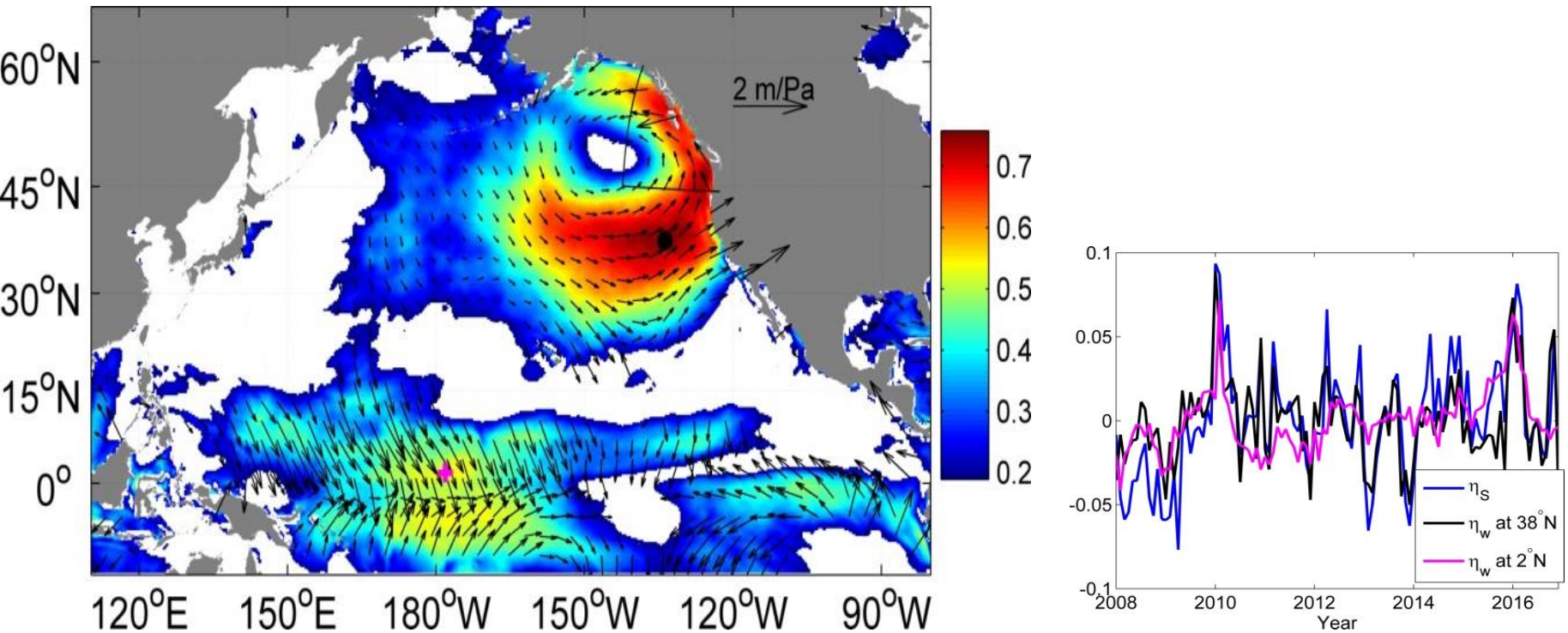


- **Steric height can account for seasonal variations of sea level**
- **Halosteric height dominates seasonal cycle of total steric height**

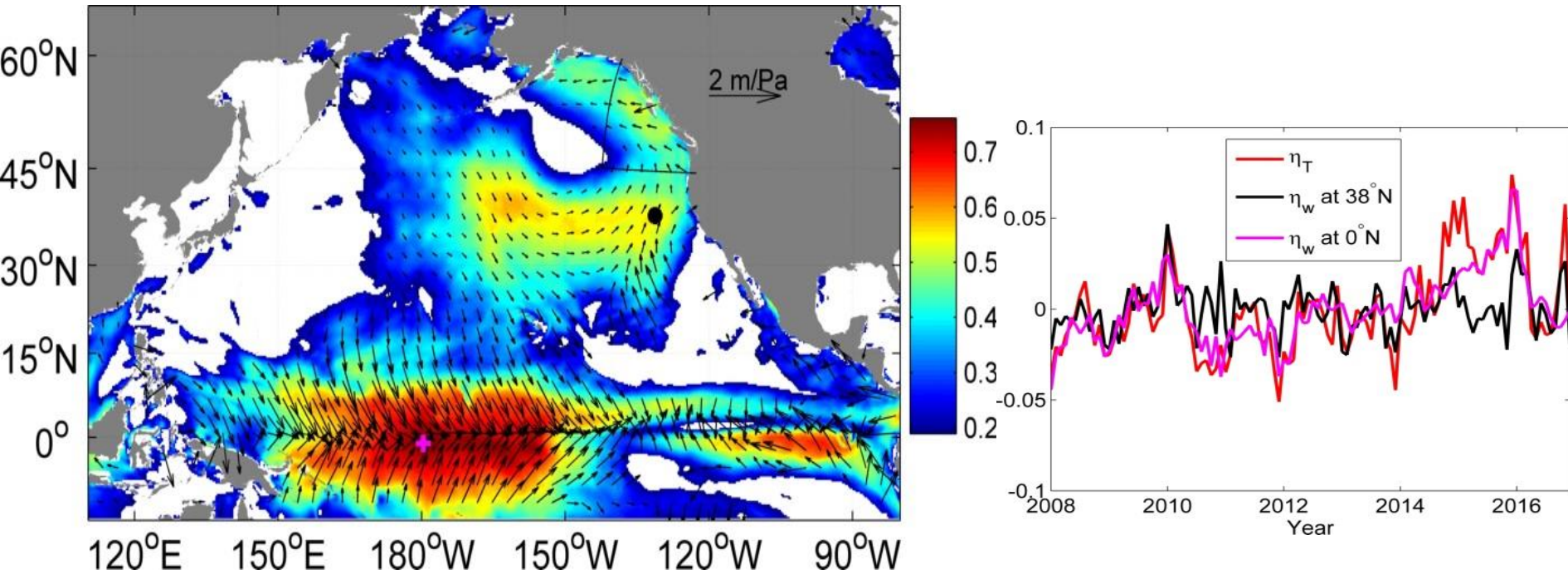
Tofino – Intra-seasonal & Inter-annual Variations



Regression analysis: Tofino halosteric height vs wind stress



Regression Analysis: Tofino thermoclinic vs wind stress



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

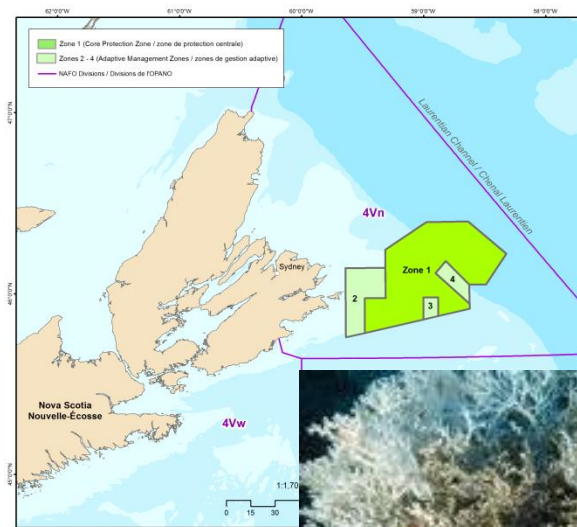
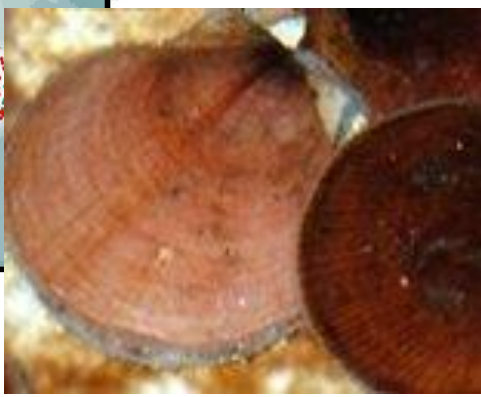
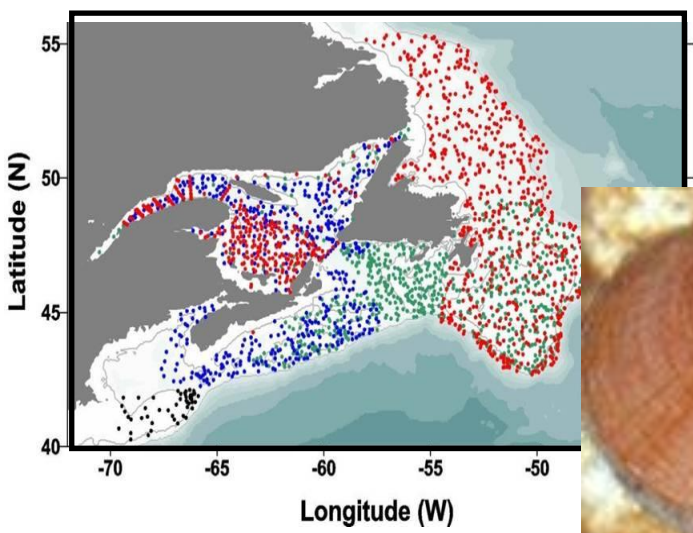
- **High-resolution model results agree well with tide gauge observations**
- **Intra-seasonal, seasonal & inter-annual variations: mainly steric & halo component**
- **Regression analysis:**
 - **Wind outside NEP domain drives both halo & thermo steric, in particular at time scales < 1 year**
 - **Heat 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



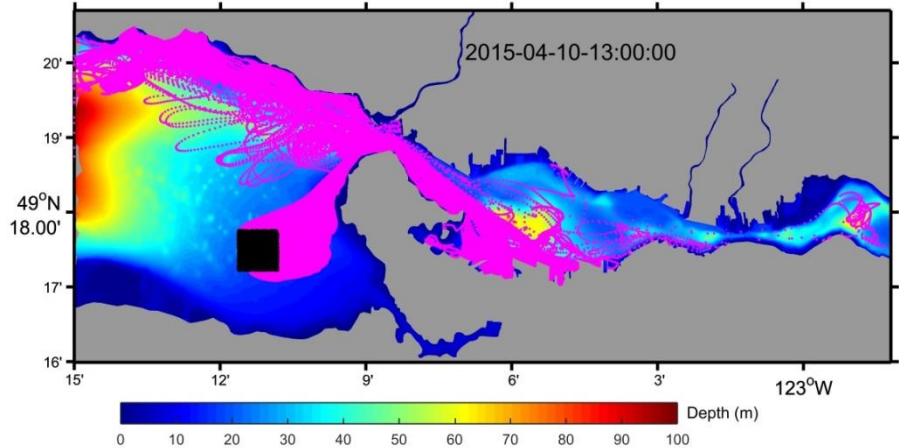
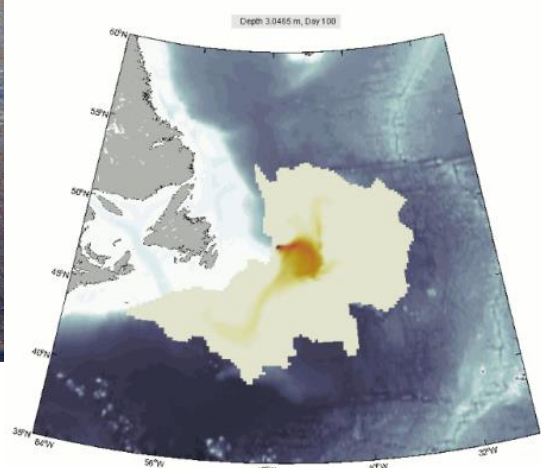
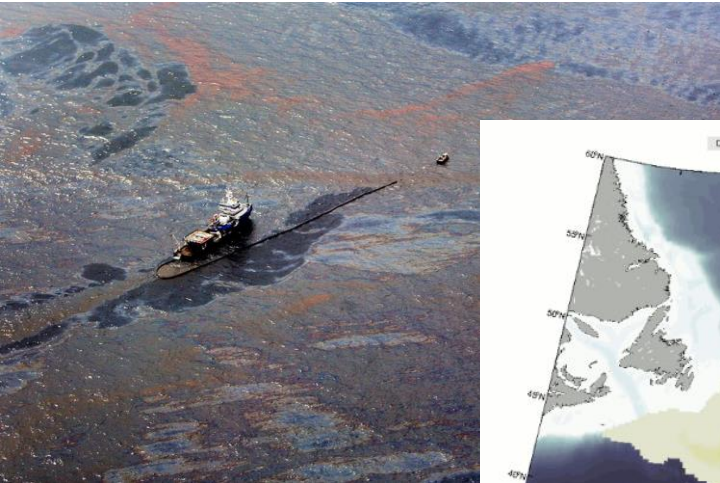
Practical Applications: Fishery Management, Marine Conservation,

Groundfish surveys - Selected stations

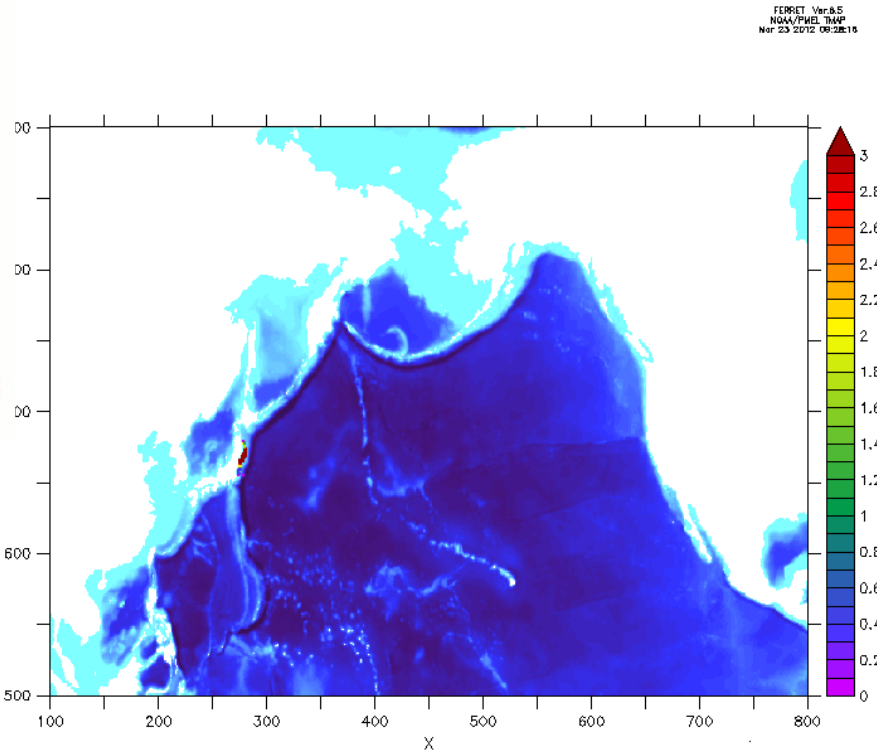


Practical Applications: Environment Protection

Oil Spill



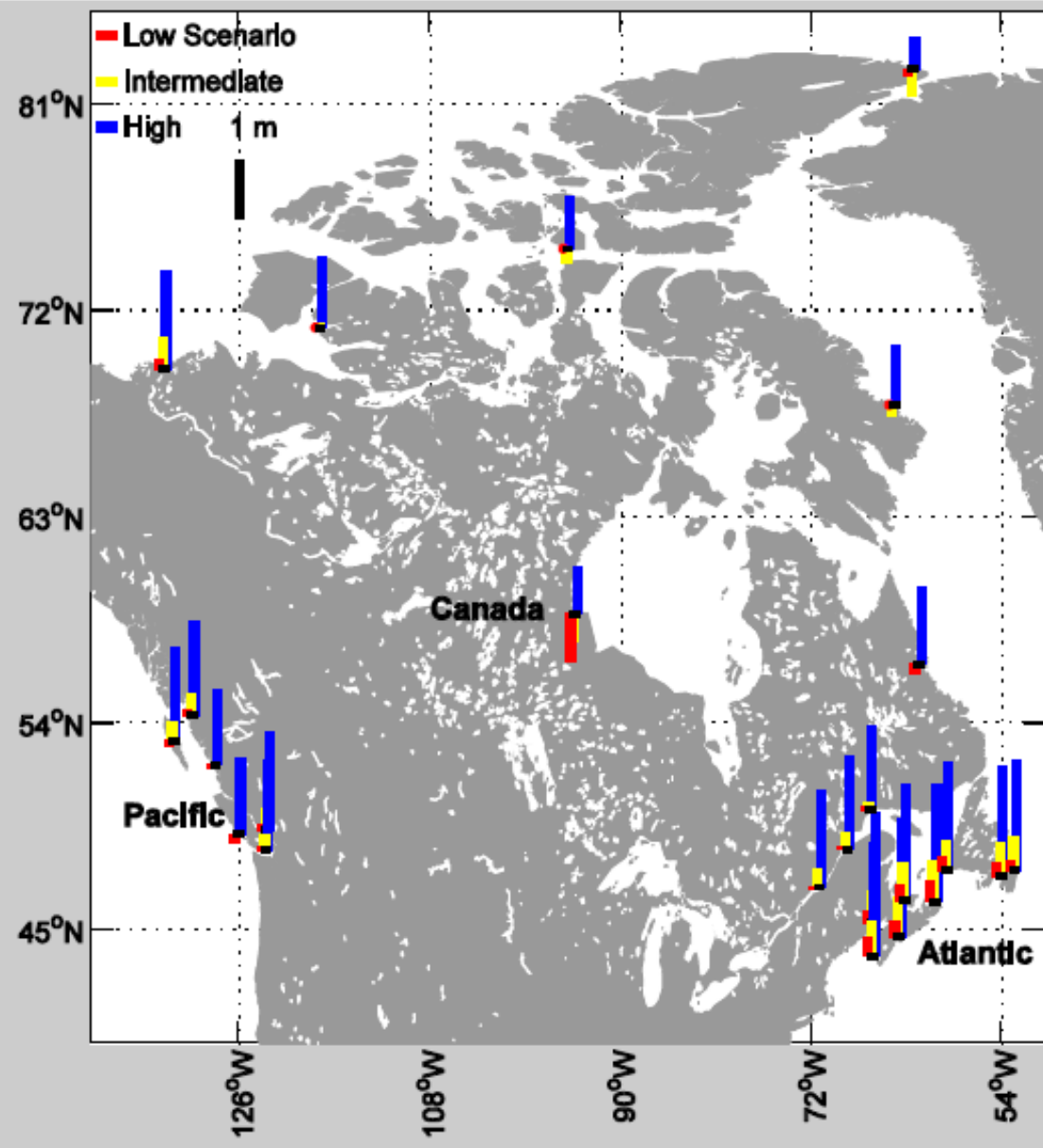
Tsunami debris drifting



FERRET Ver.6.5
NOAA/PMEL TRIP
Nov 23 2012 09:28:15

Debris log10 tons - 20110309

Regional Projections: Sea Level Rise



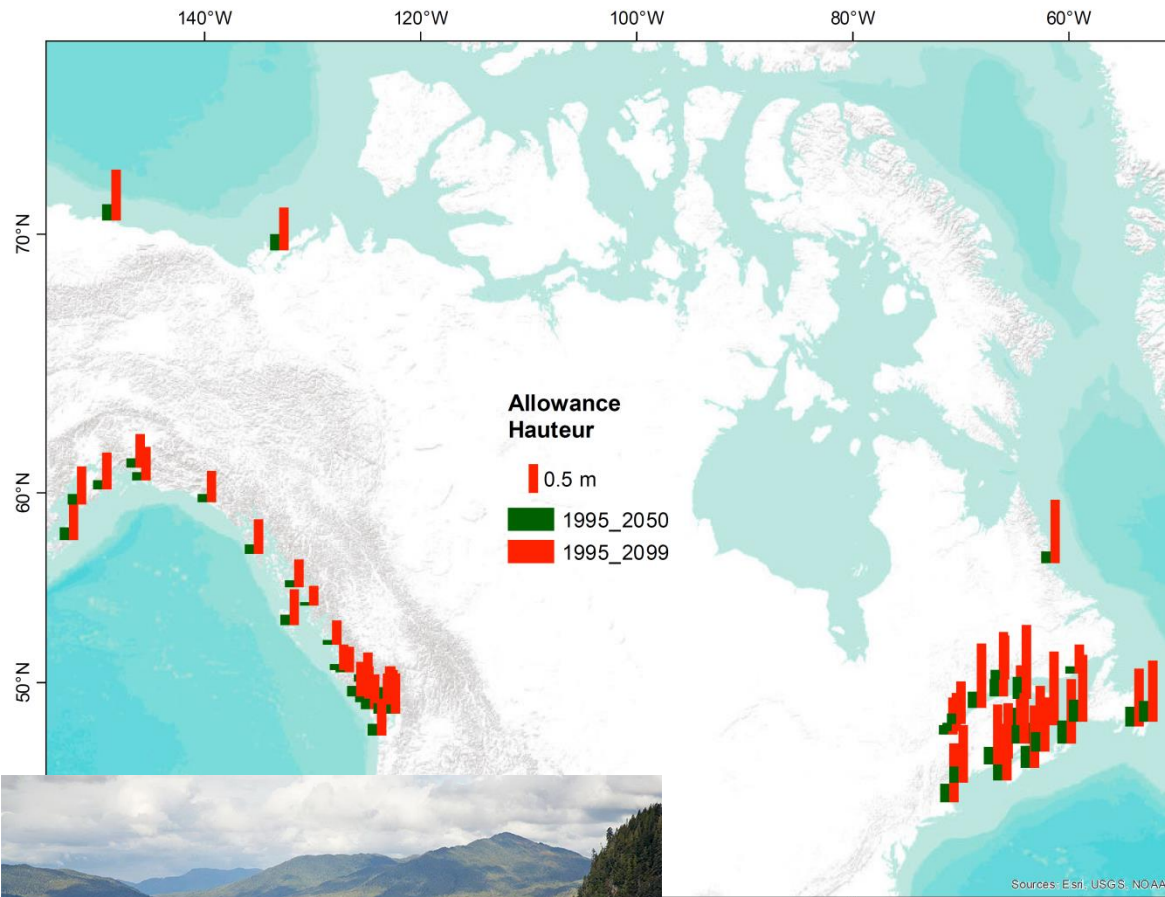
2010-2100 SLR
Under 3 scenarios:

- **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

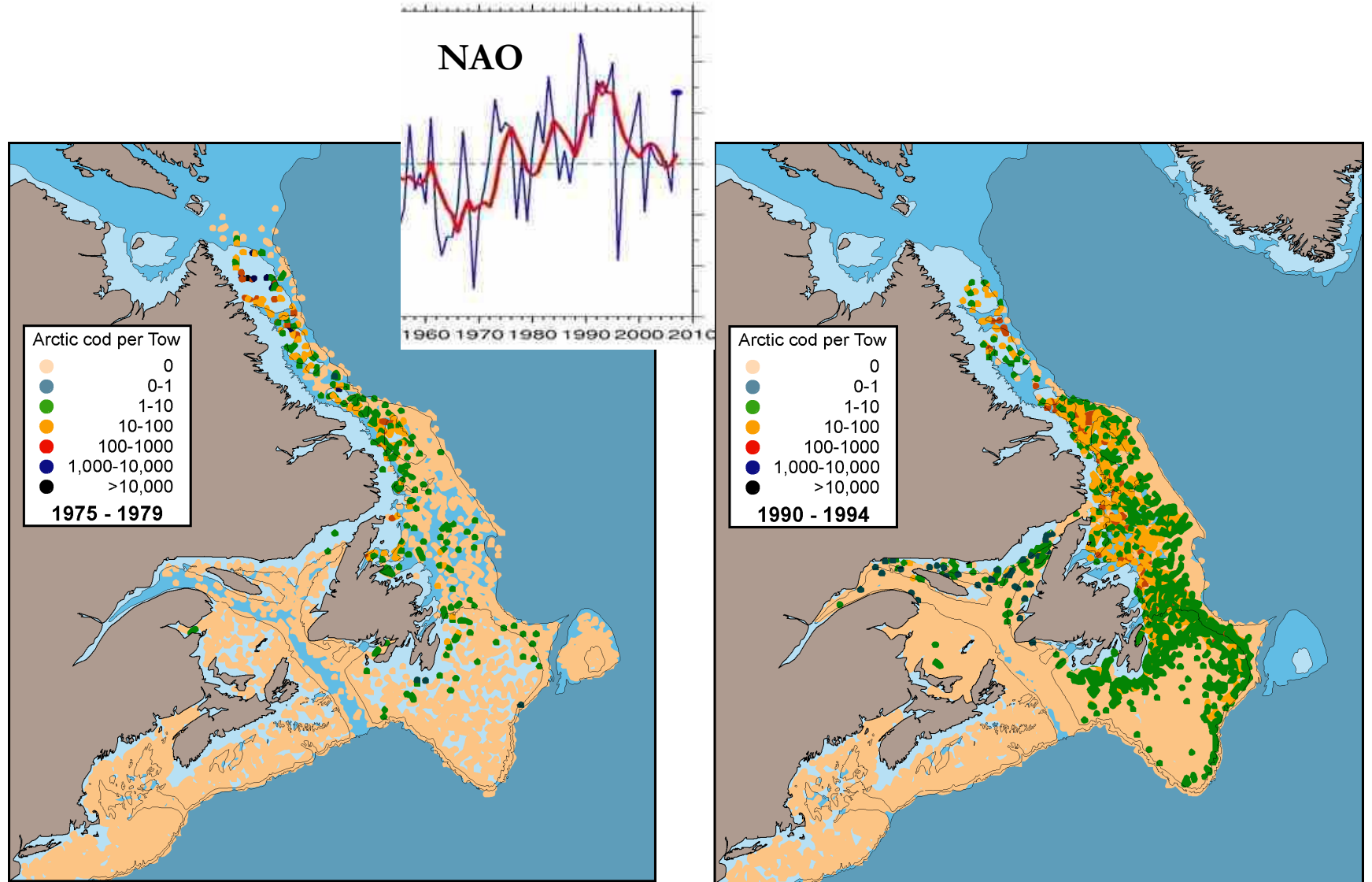
Vertical allowances for RCP8.5 scenario

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



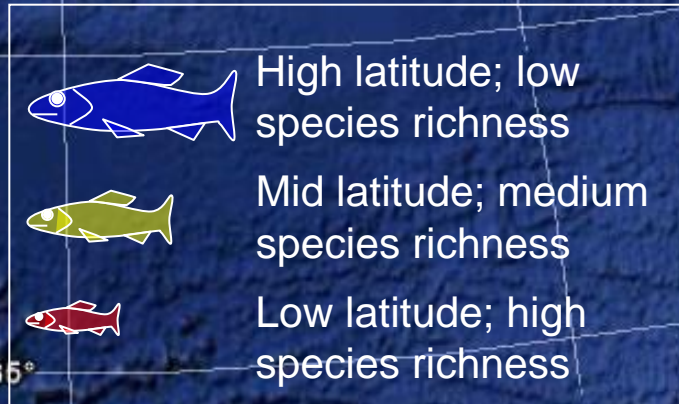
Low NAO

High NAO

+ NAO years

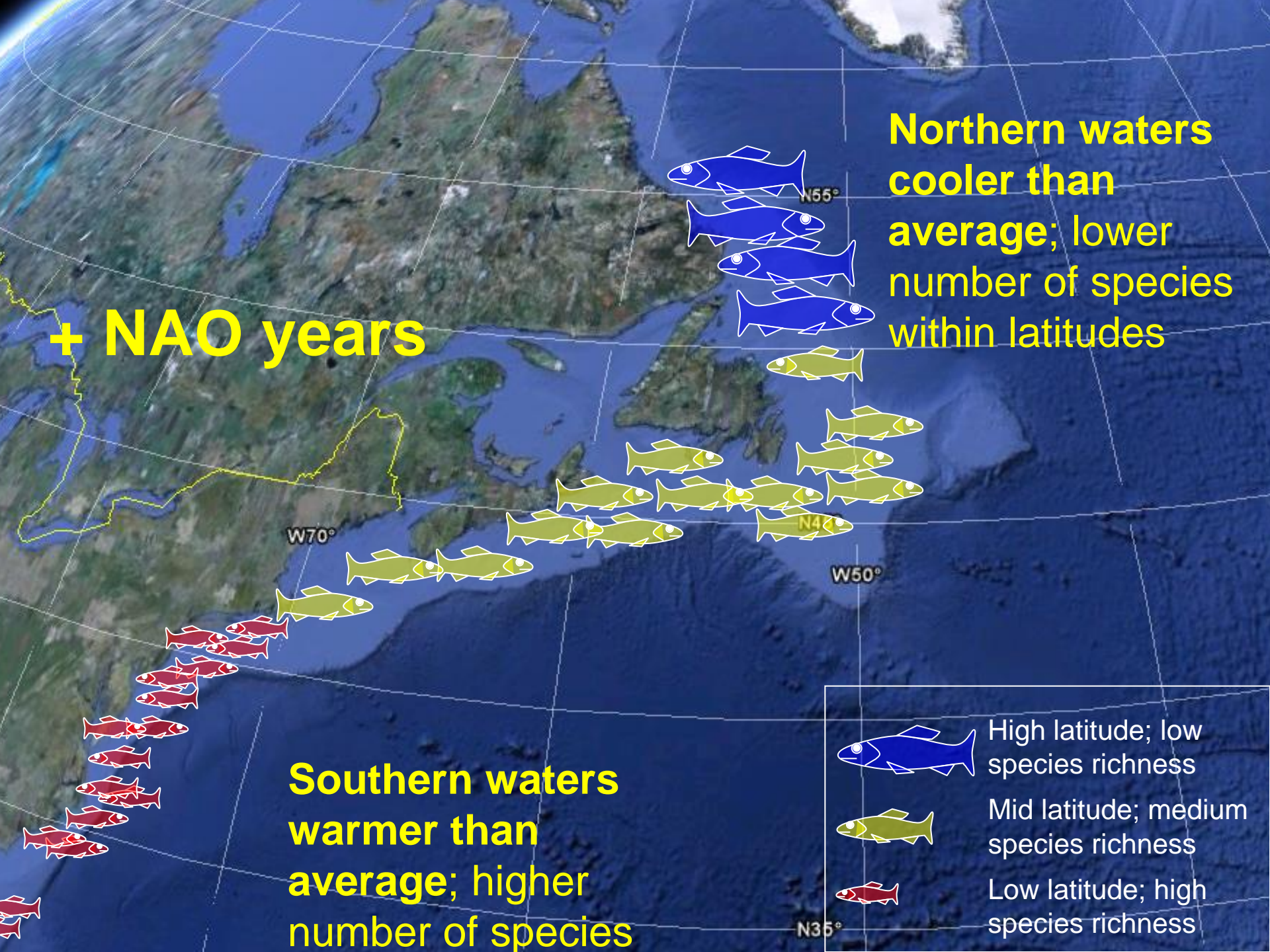
Northern waters cooler than average; lower number of species within latitudes

Southern waters warmer than average; higher number of species



A legend box in the bottom right corner contains three fish icons and their corresponding descriptions. The top icon is a blue fish, the middle is a green fish, and the bottom is a red fish. The text is white on a dark background.




- 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

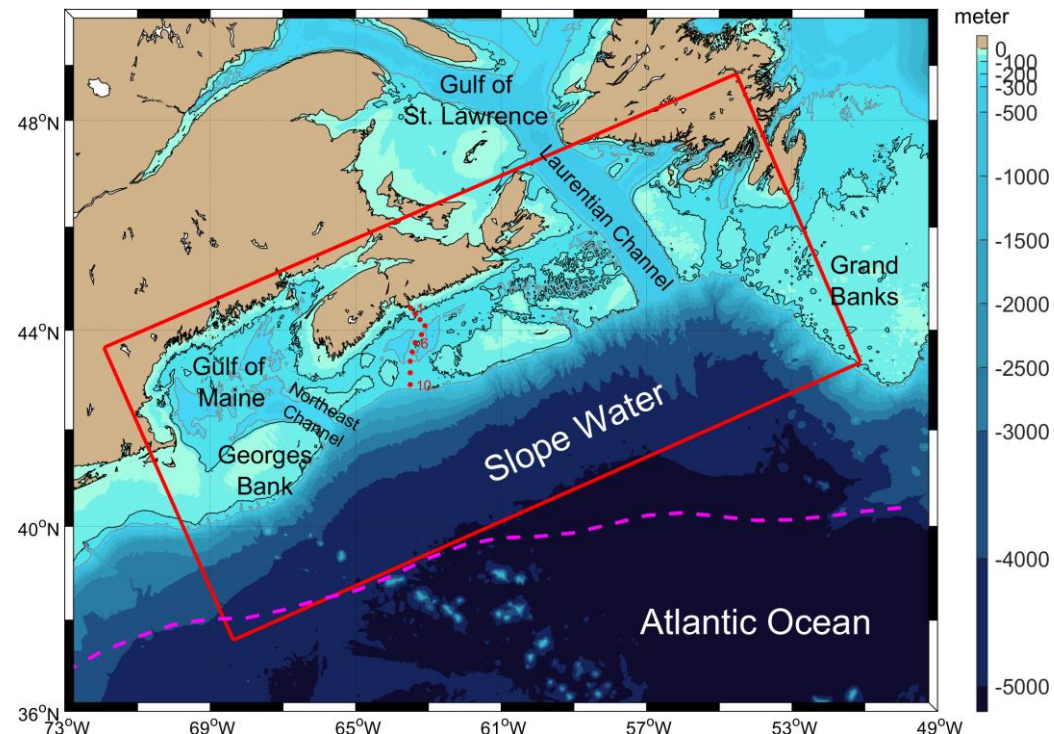
-
-  High latitude; low species richness
 -  Mid latitude; medium species richness
 -  Low latitude; high species richness

Gulf of Maine & Scotian Shelf

Operational Nowcasting/Forecasting

Developed & Maintained at Dalhousie University:

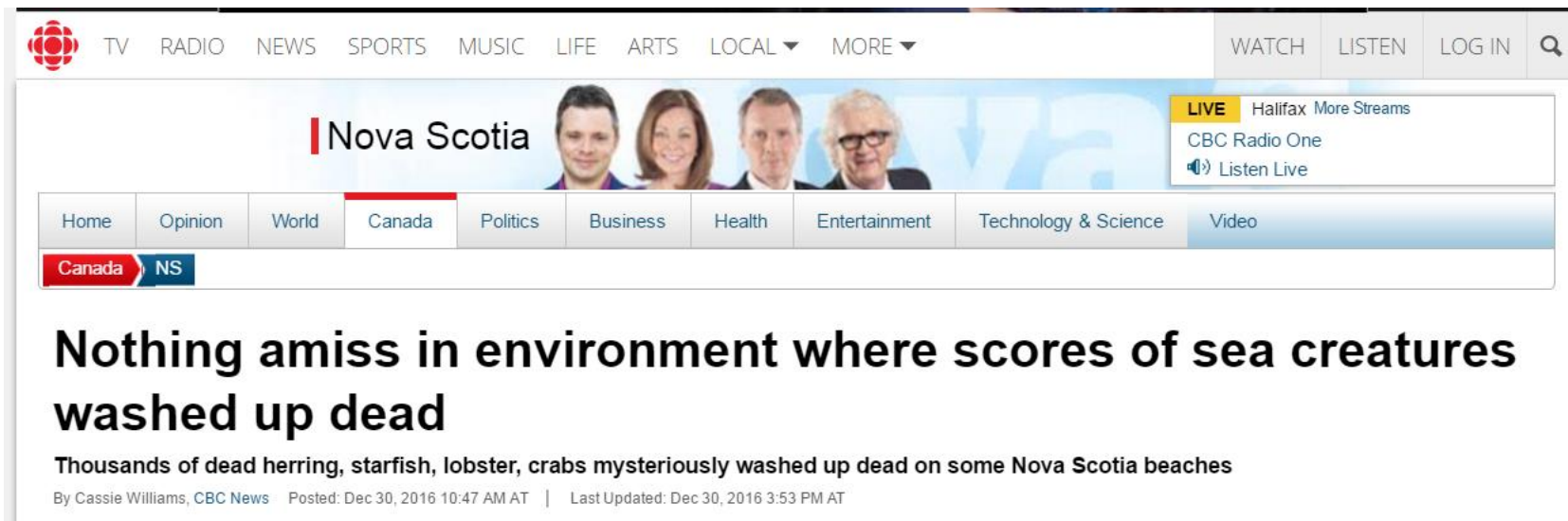
- Initial development & validation (Katavouta et al. 2016, JPO)
- 2.5 km horizontal resolution with 50 vertical levels
- Forced with ECCO weather forecasts also with 2.5 km resolution
- Operational “nowcast” since Dec 7, 2016



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>



The screenshot shows the top portion of a CBC News website. At the top left is the CBC logo, followed by navigation links for TV, RADIO, NEWS, SPORTS, MUSIC, LIFE, ARTS, LOCAL, and MORE. On the right are links for WATCH, LISTEN, LOG IN, and a search icon. Below this is a banner for Nova Scotia featuring four people's faces. A live stream widget for CBC Radio One is visible, showing 'LIVE Halifax More Streams' and a 'Listen Live' button. A horizontal menu contains categories like Home, Opinion, World, Canada (highlighted), Politics, Business, Health, Entertainment, Technology & Science, and Video. Below the menu are 'Canada' and 'NS' buttons. The main headline reads: 'Nothing amiss in environment where scores of sea creatures washed up dead'. The sub-headline states: 'Thousands of dead herring, starfish, lobster, crabs mysteriously washed up dead on some Nova Scotia beaches'. At the bottom, it says 'By Cassie Williams, CBC News' and provides posting and update dates.

TV RADIO NEWS SPORTS MUSIC LIFE ARTS LOCAL MORE WATCH LISTEN LOG IN

Nova Scotia

LIVE Halifax More Streams
CBC Radio One
Listen Live

Home Opinion World **Canada** Politics Business Health Entertainment Technology & Science Video

Canada NS

Nothing amiss in environment where scores of sea creatures washed up dead

Thousands of dead herring, starfish, lobster, crabs mysteriously washed up dead on some Nova Scotia beaches

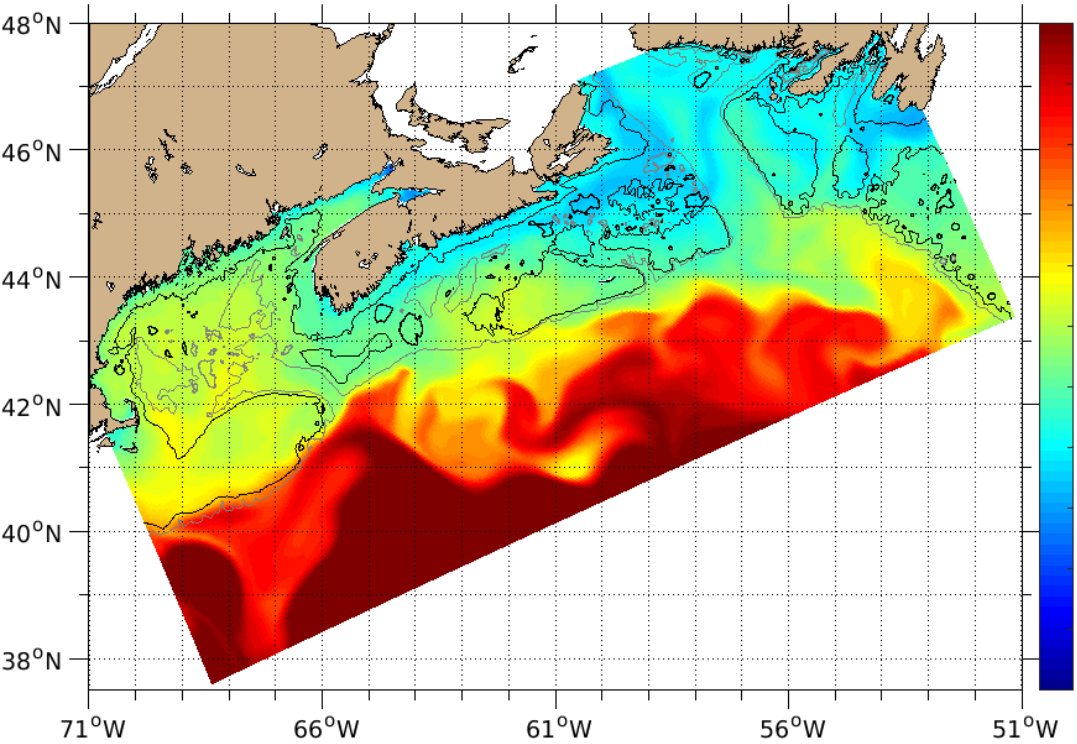
By Cassie Williams, CBC News | Posted: Dec 30, 2016 10:47 AM AT | Last Updated: Dec 30, 2016 3:53 PM AT



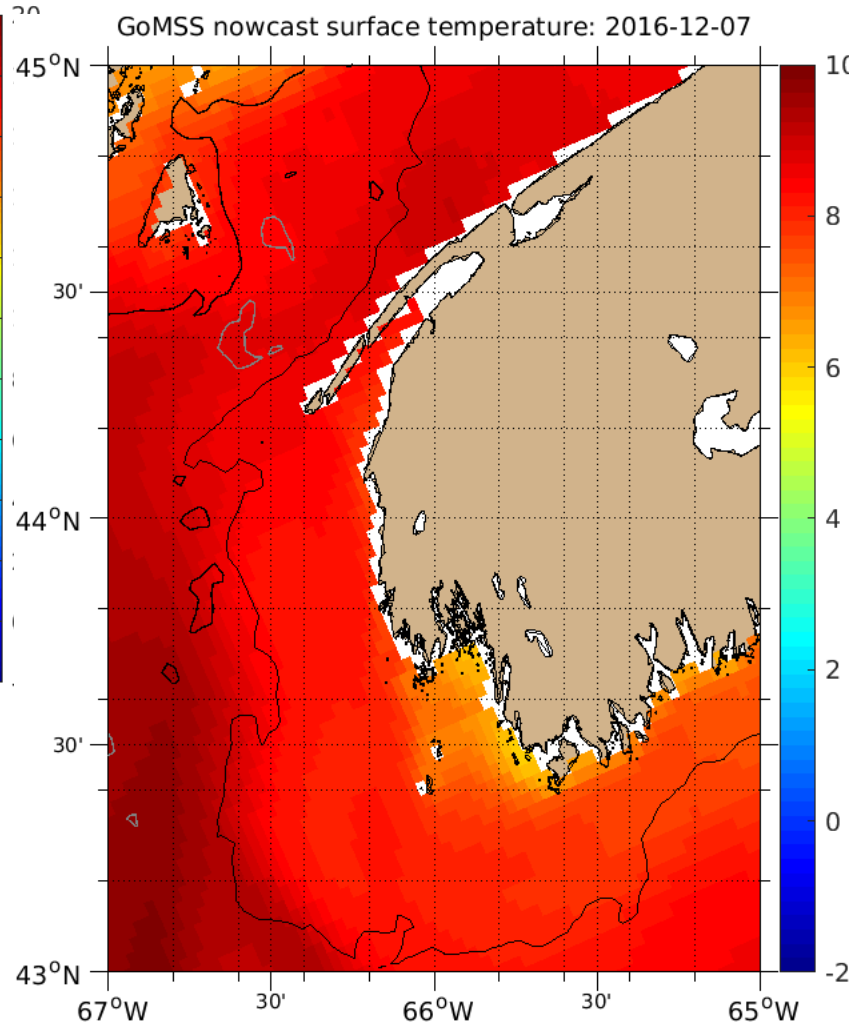
Output from GoMSS nowcast: daily SST Dec 7-30

Whole model domain

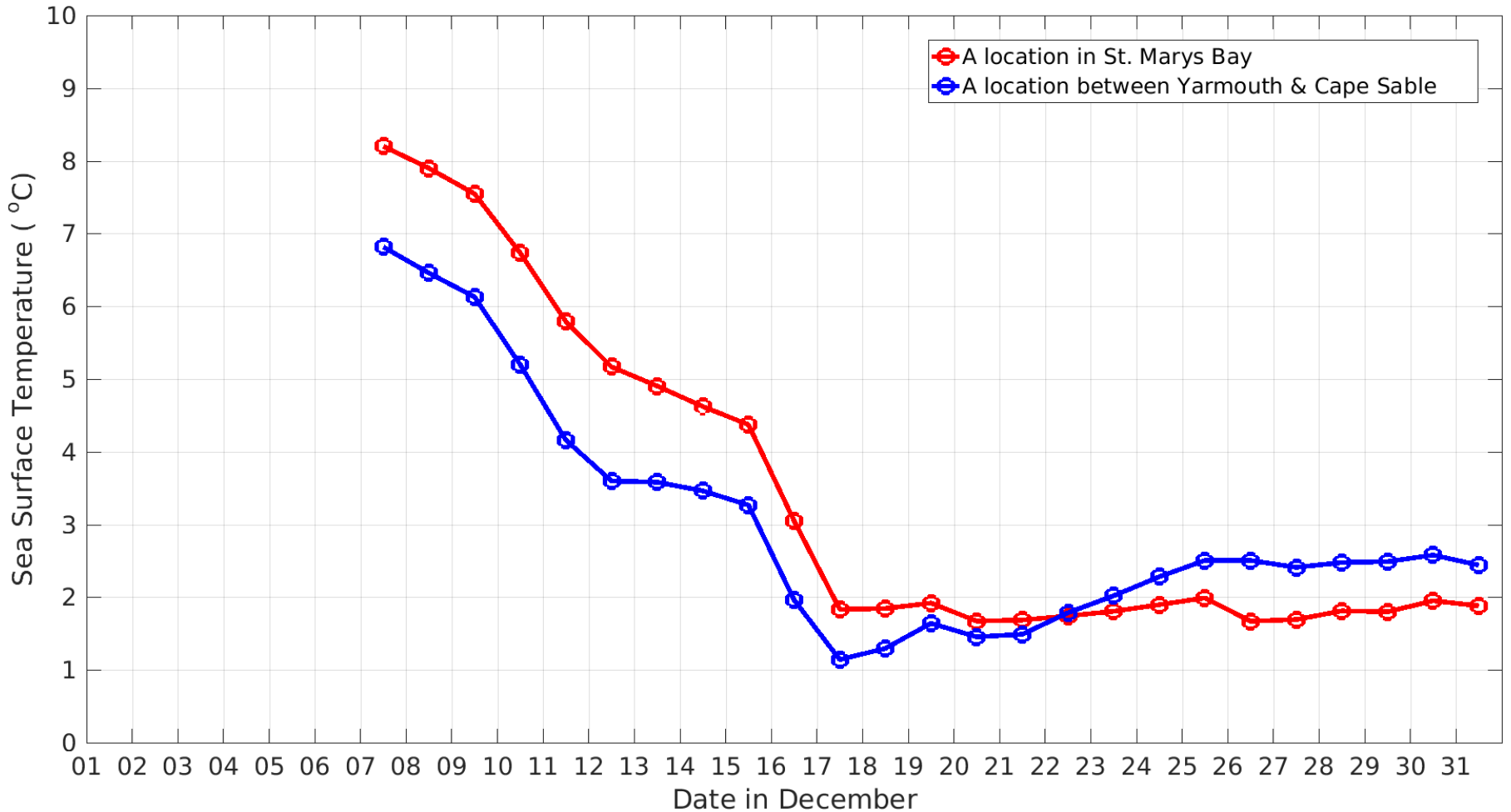
GoMSS nowcast surface temperature: 2016-12-07



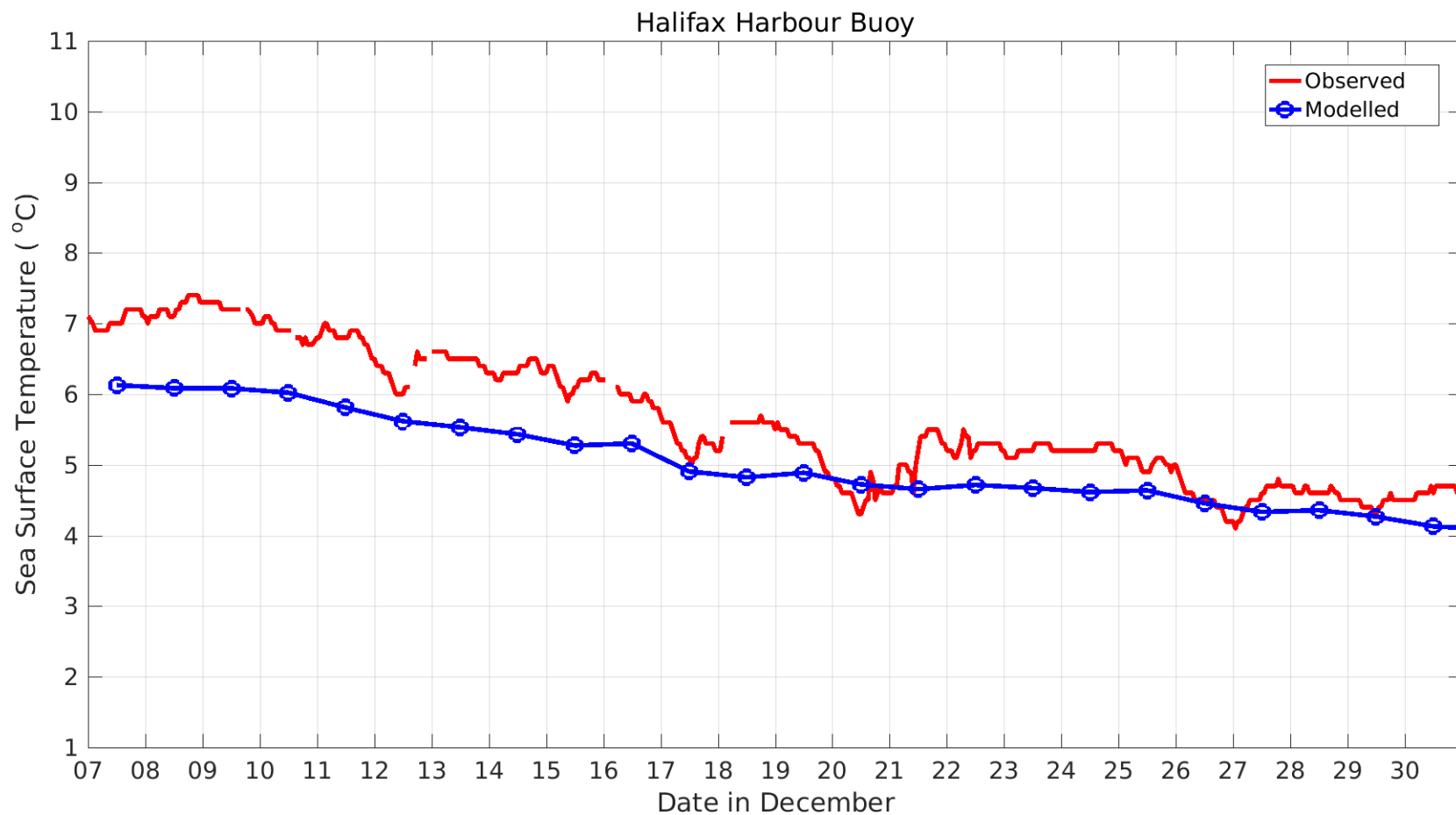
Zoom in southwestern NS



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

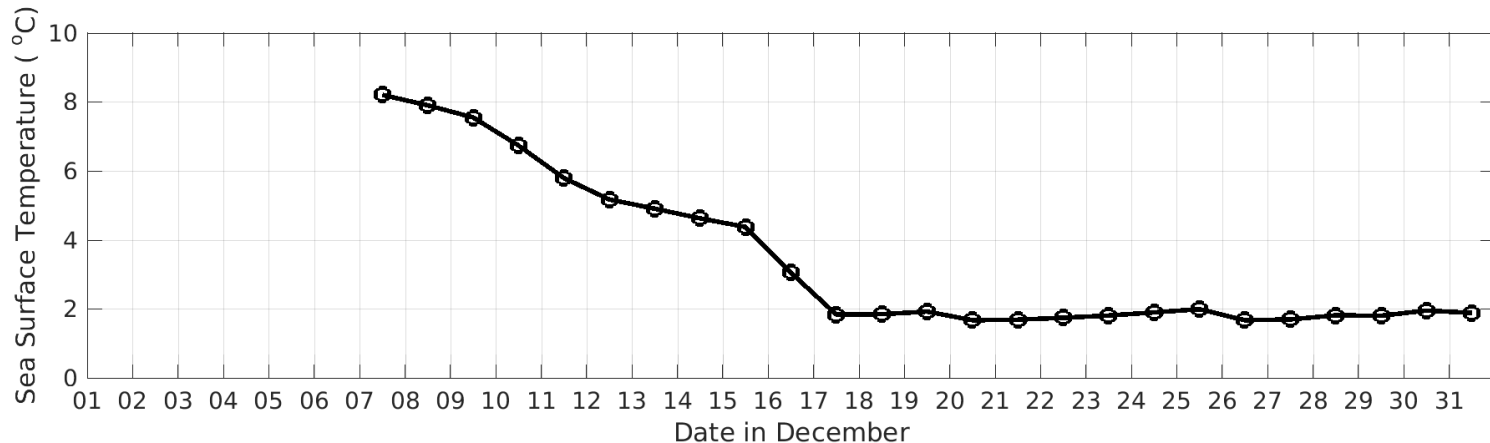
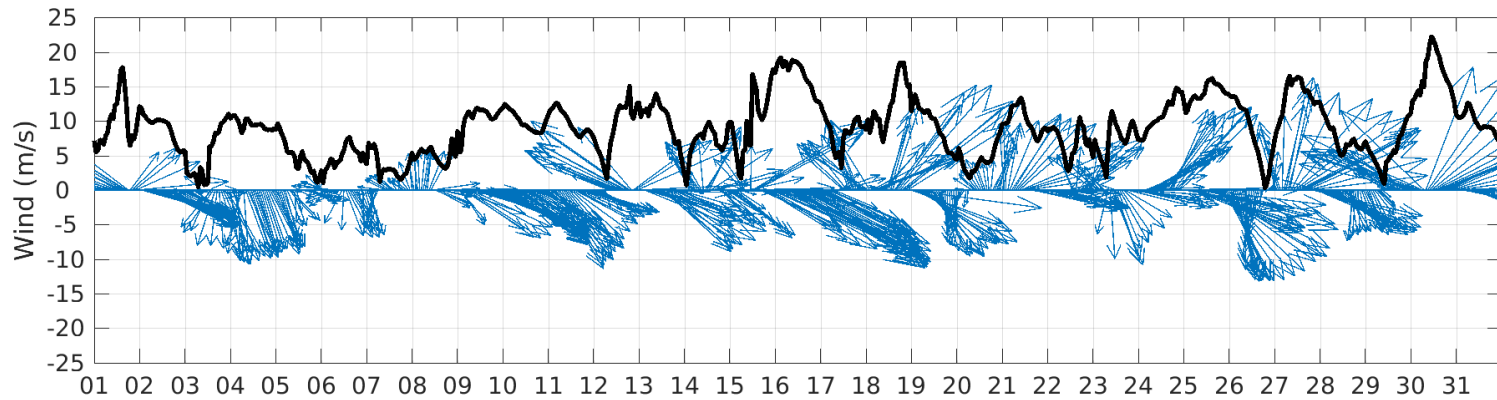
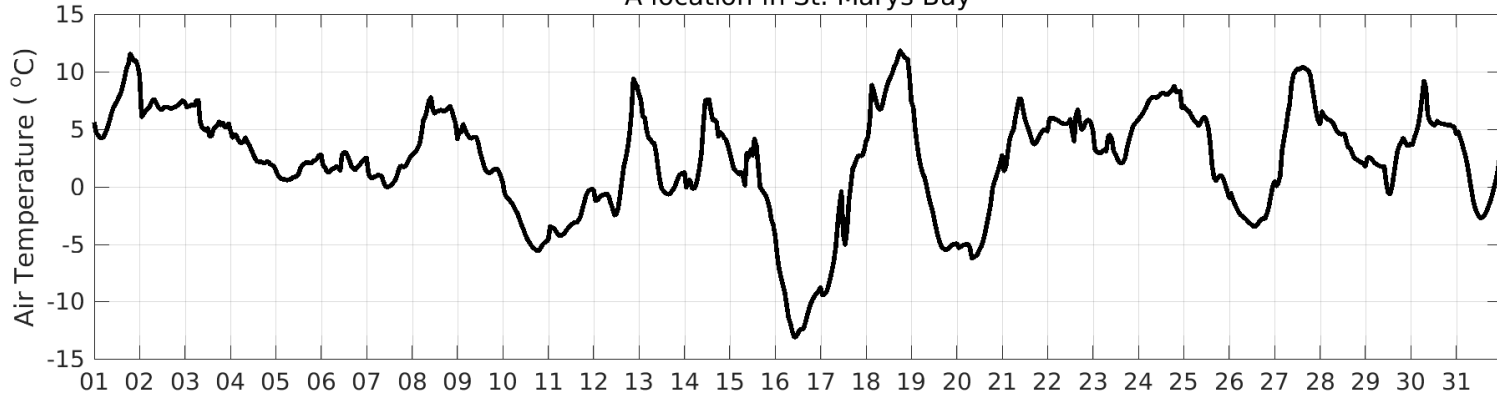


A comparison of GoMSS daily SST with buoy observations in Halifax Harbour (where intense cooling did not occur)

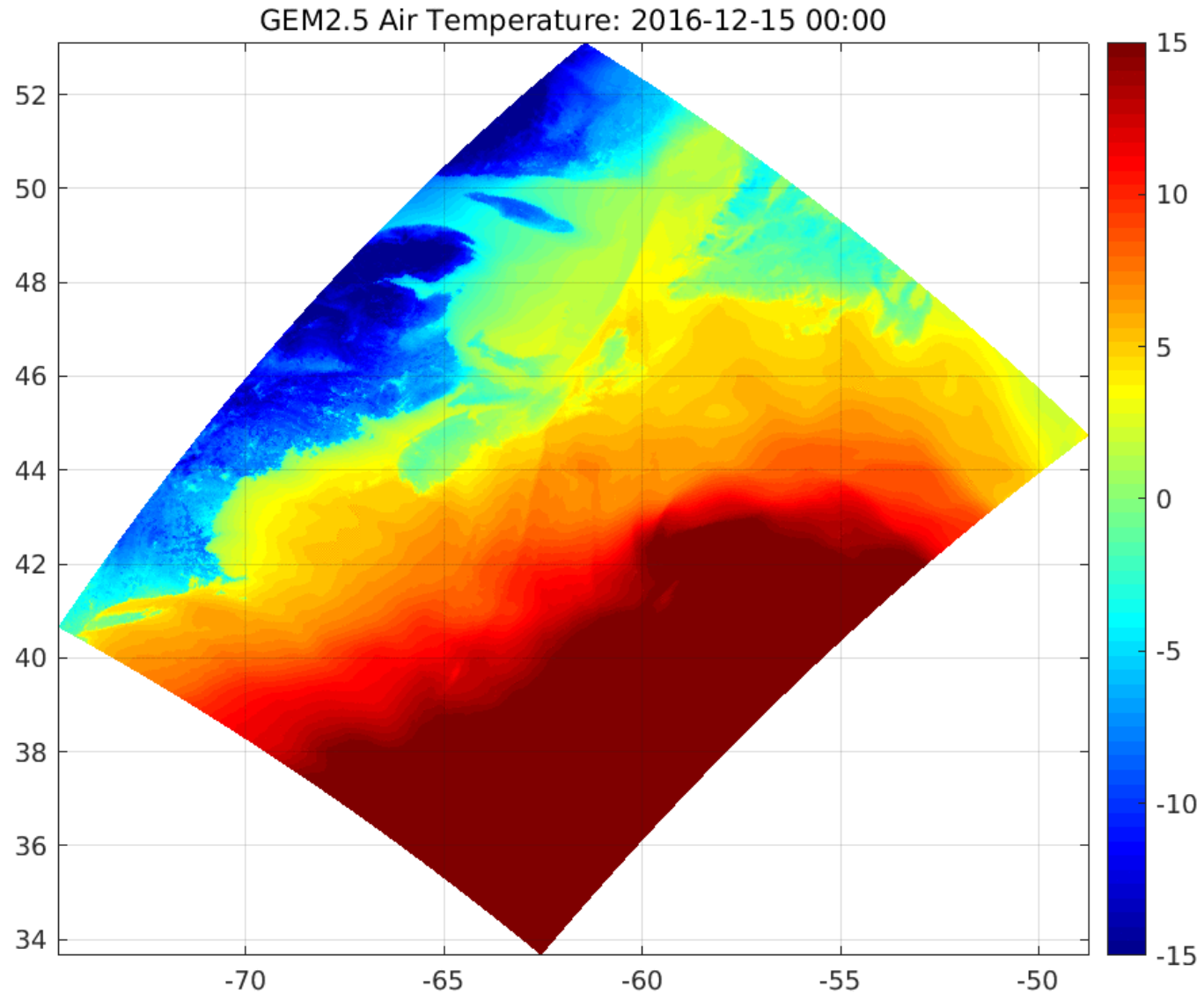


Speculate cooling in St Marys Bay related to low surface air temperature and strong wind

A location in St. Marys Bay

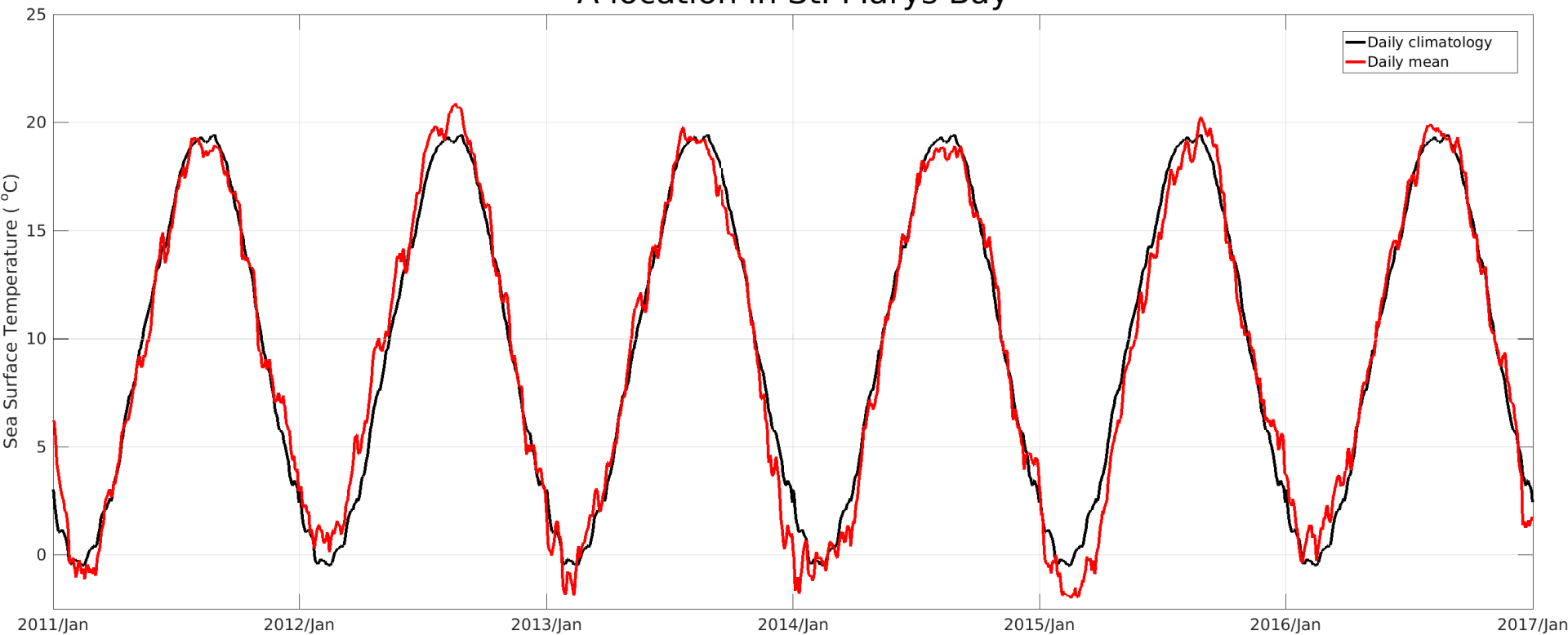


6-hourly surface air temperature Dec 15-18

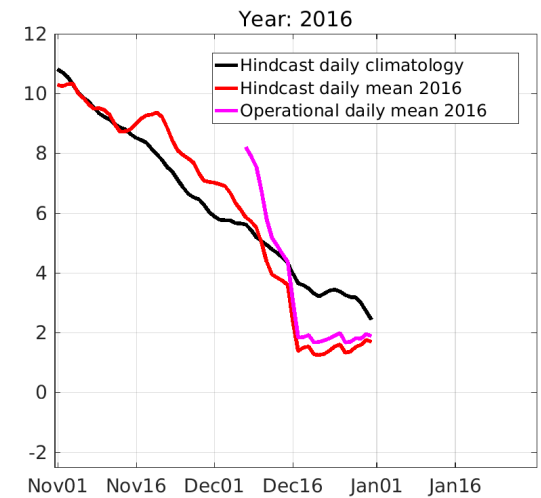
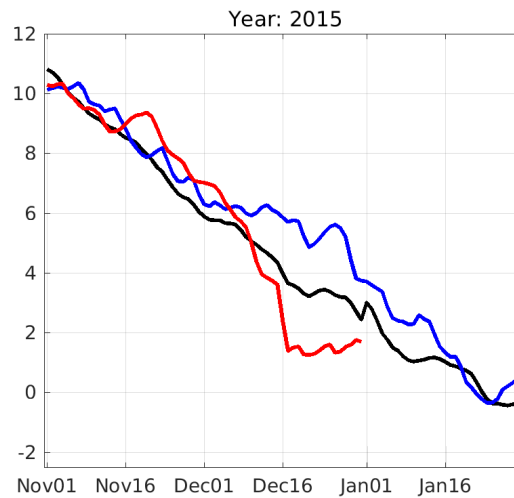
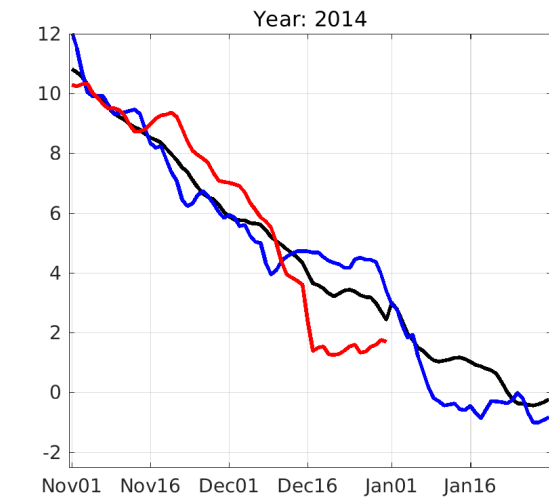
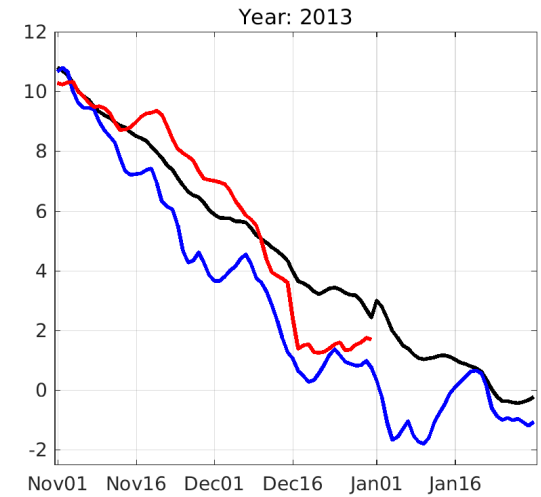
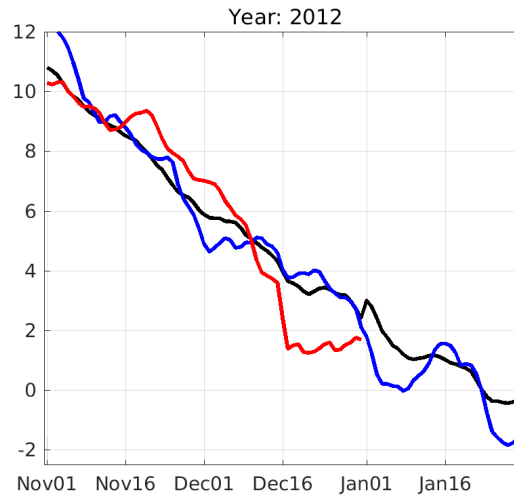
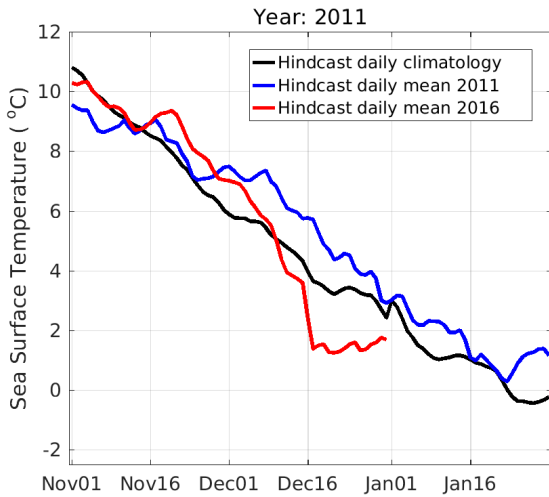


But: Is Dec 2016 unusual? Here is SST from a 6-year GoMSS hindcast using US CFSR forcing

A location in St. Marys Bay



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



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

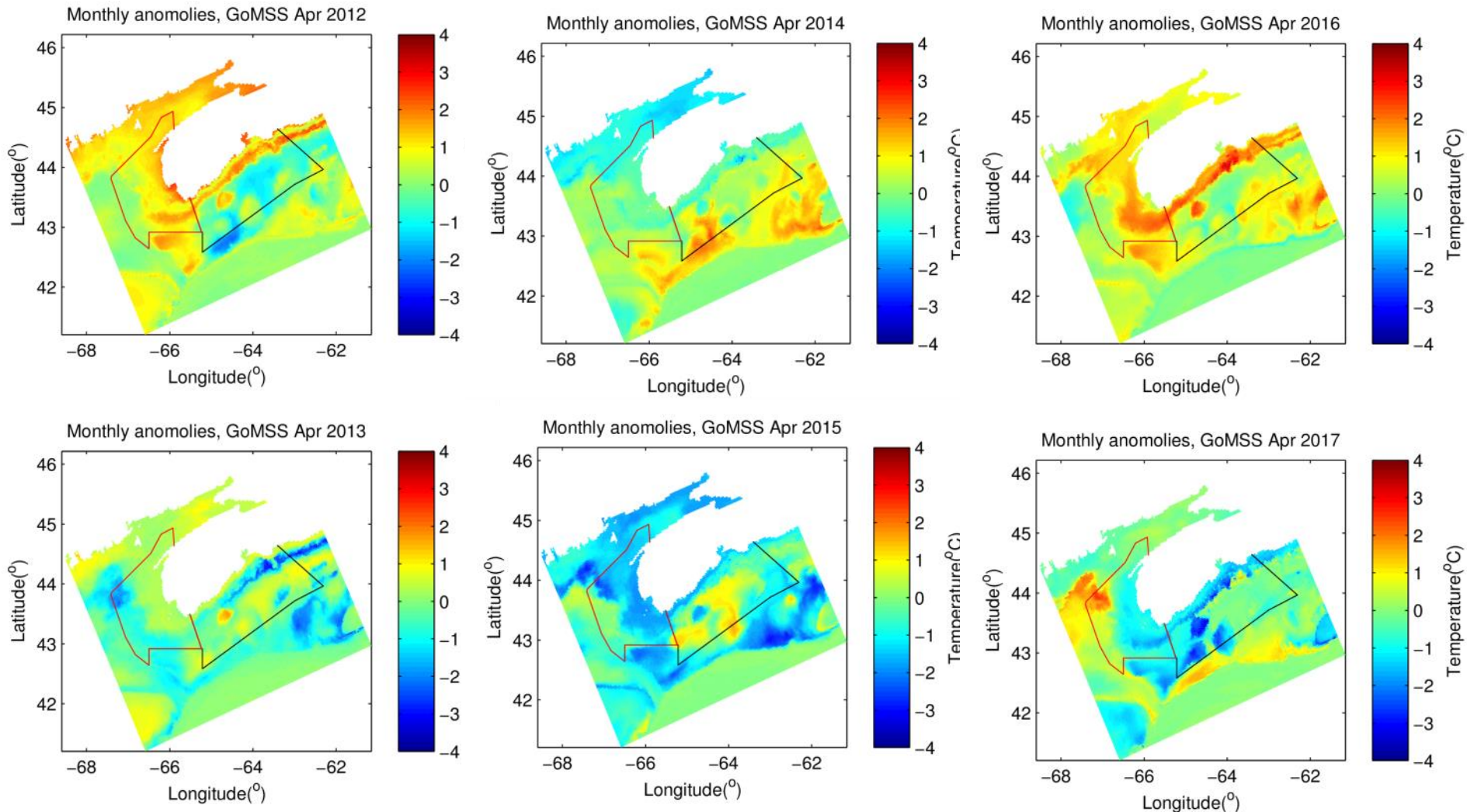
The Chronicle Herald, May 8, 2017:

Lobster catches taking nose dive

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

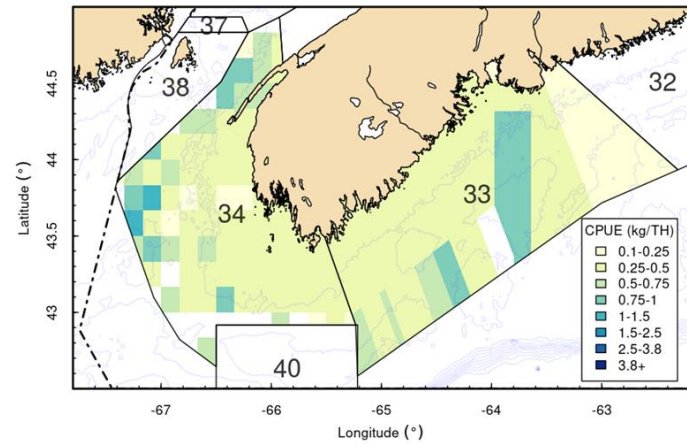


Modelled Bottom Temperature Anomaly in April

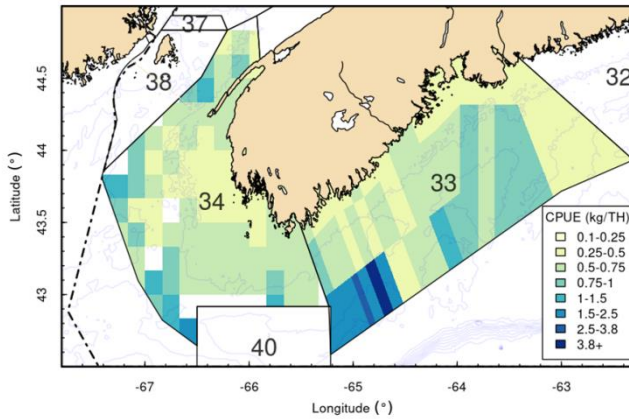


April Lobster Catch & Bottom Temperature

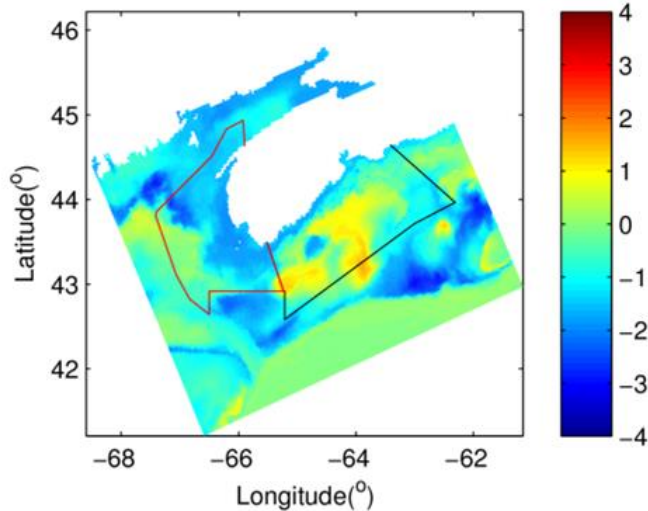
2015 April Lobster Catch



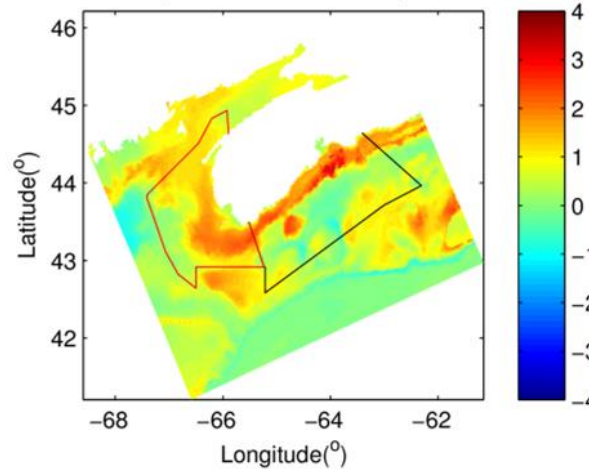
2016 April Lobster Catch



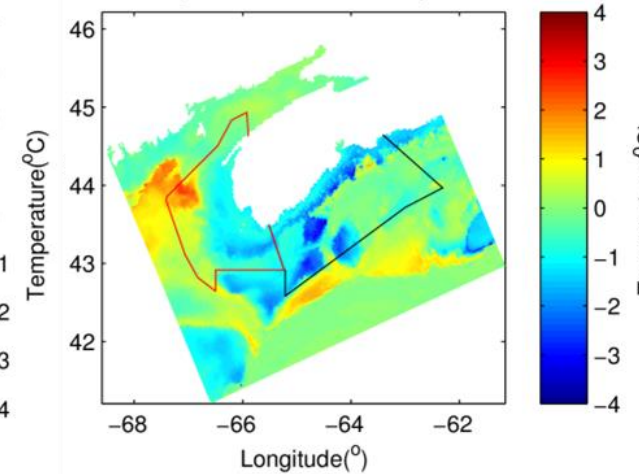
Monthly anomalies, GoMSS Apr 2015



Monthly anomalies, GoMSS Apr 2016



Monthly anomalies, GoMSS Apr 2017



Summary

- **Ocean modelling & forecasting have significantly advanced during past two decades: predicting realistic details of variations**
- **State-of-the-art modelling & forecasts require 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?