Marine Ecosystem Dynamics Modeling Laboratory (MEDM)

A Global-Regional-Estuarine Nested FVCOM System: A Unstructured-grid Ocean Model With Aim at Simulating the Multi-scale Oceanic Response to Climate Change

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Version 3.1

FVCOM

http://fvcom.smast.umassd.edu/

Outline

1. Review of critical needs for a model to resolve multi-scale processes over global-basin-coastal-estuarine-watershed scales;

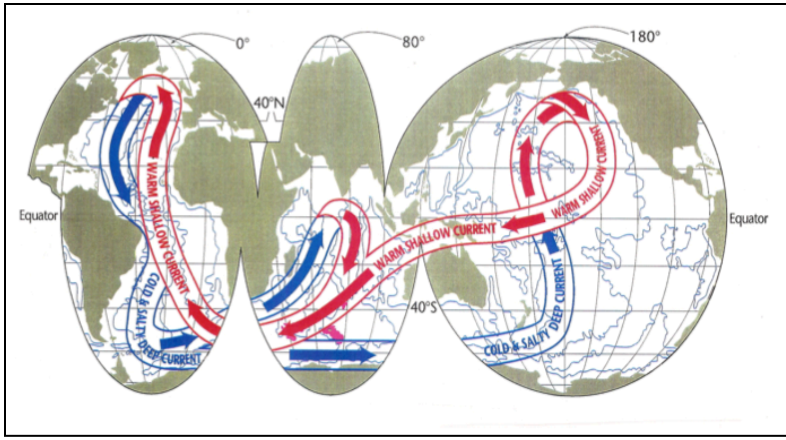
2. Updated development of unstructured grid Finite-Volume Coastal Ocean Model (FVCOM) system;

3. Examples of applications of FVCOM to multi-scale problems; The northeast US coast and China Seas

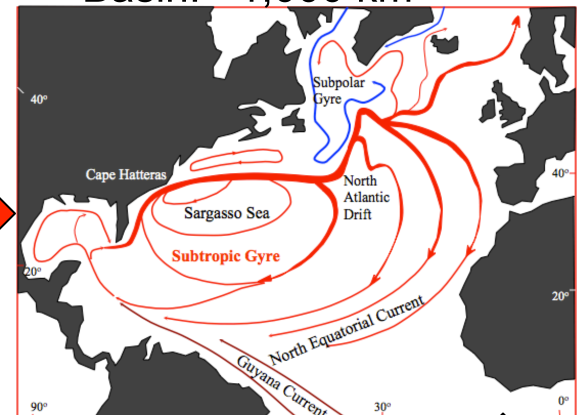
4. Summary

Examples of Multi-Scale Physical Processes

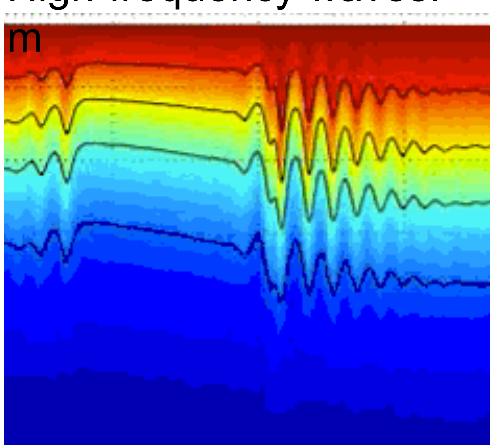
Global: ~10,000 km



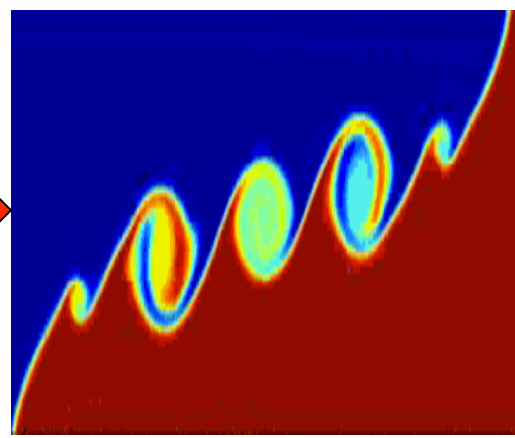
Basin: ~1,000 km



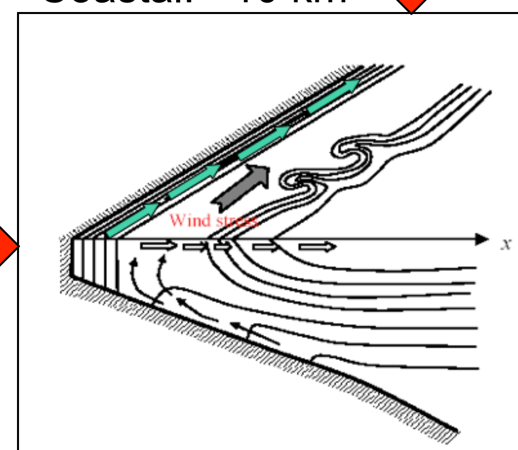
High-frequency waves: ~ 1 m

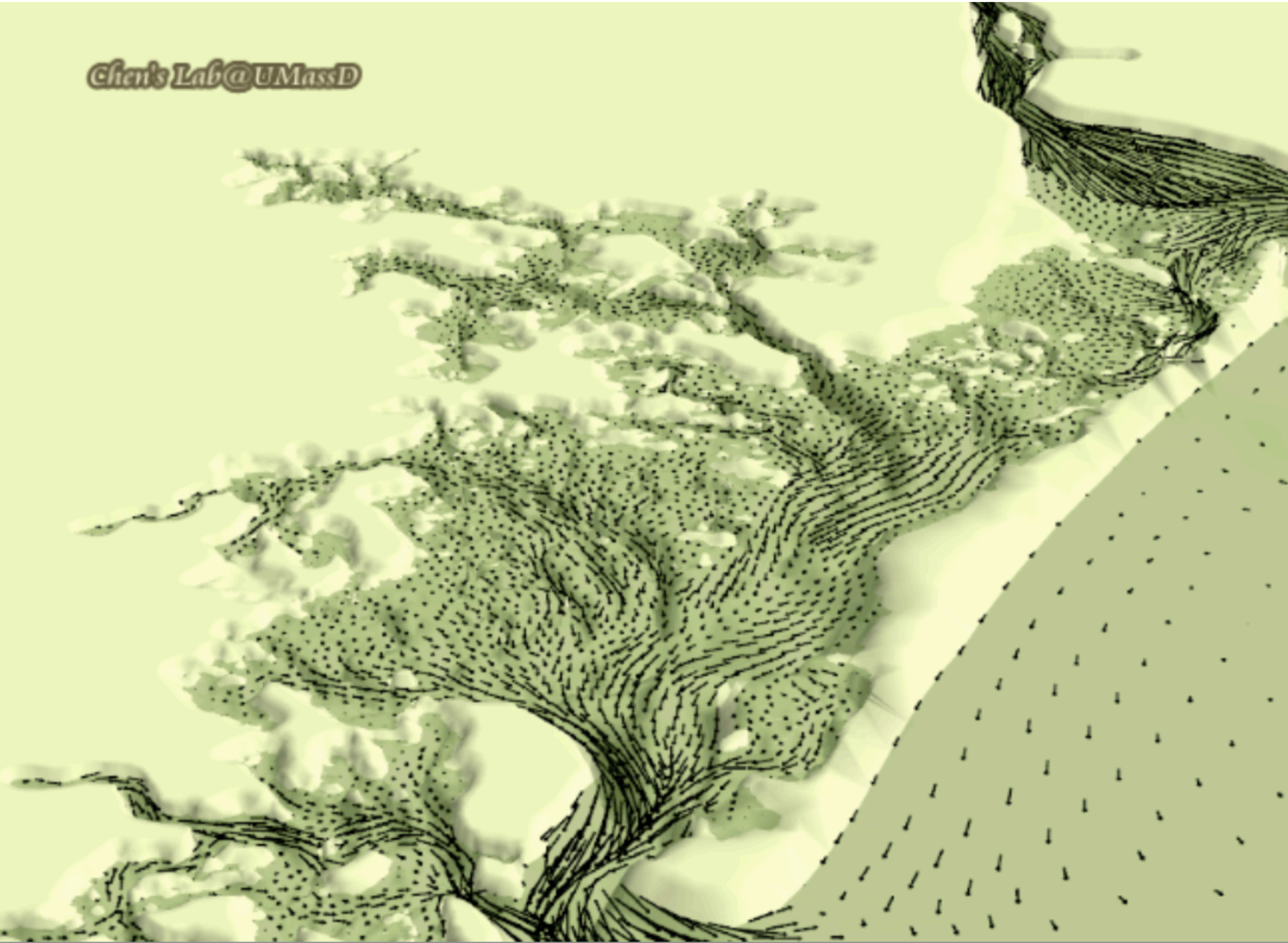


Convection: ~ 1 km



Coastal: ~10 km

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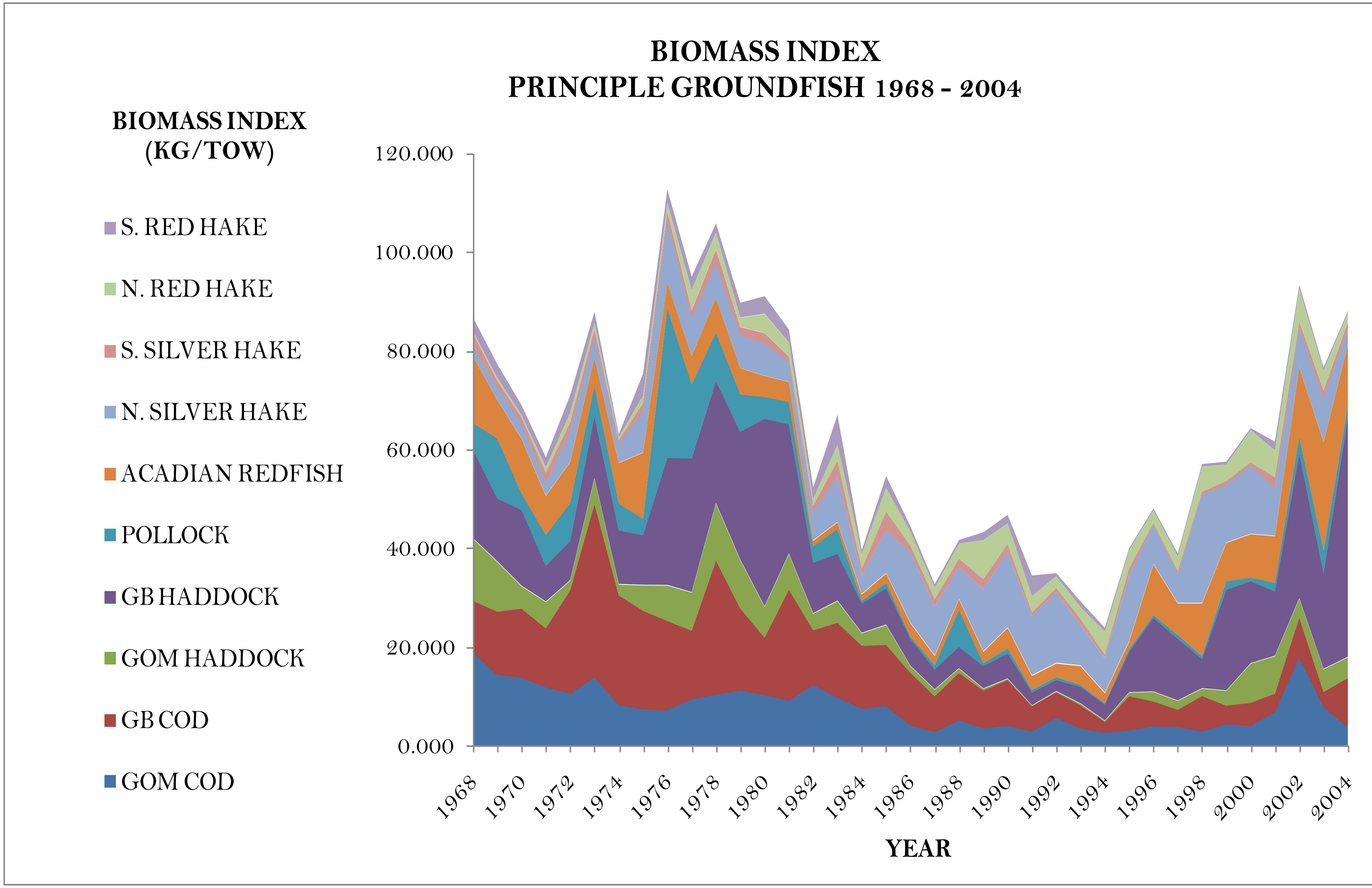
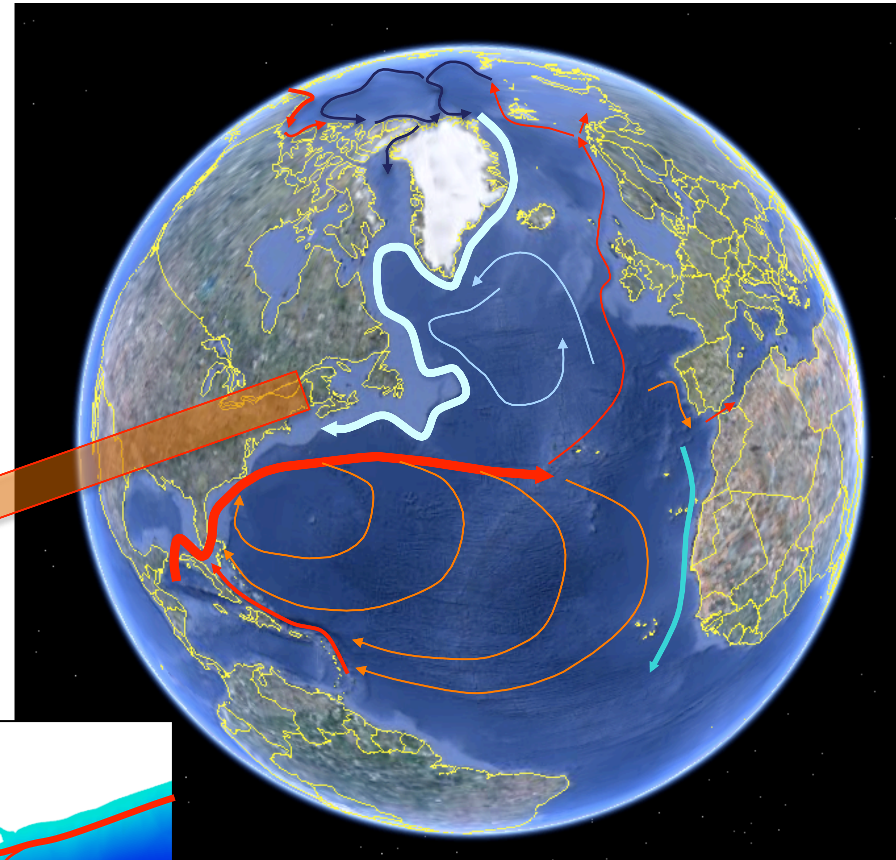
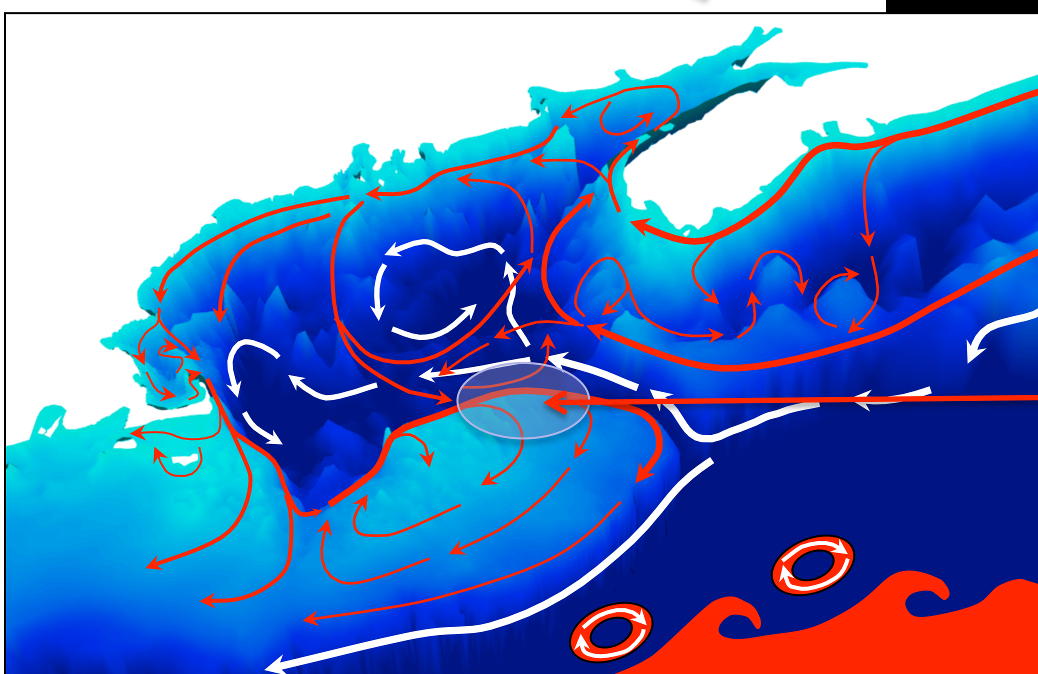
From Emily F Keiley and Brian Rothschild (SMAST)

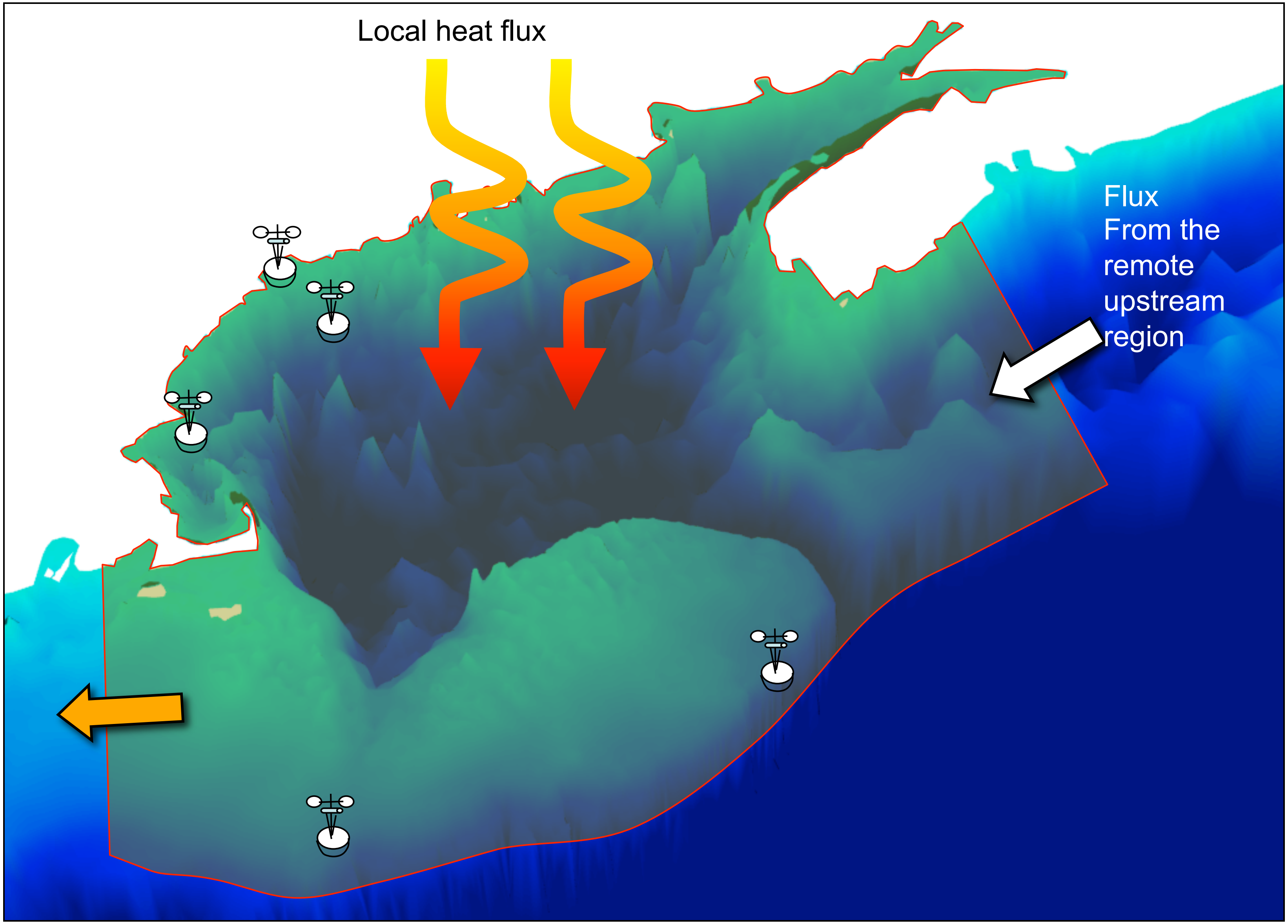


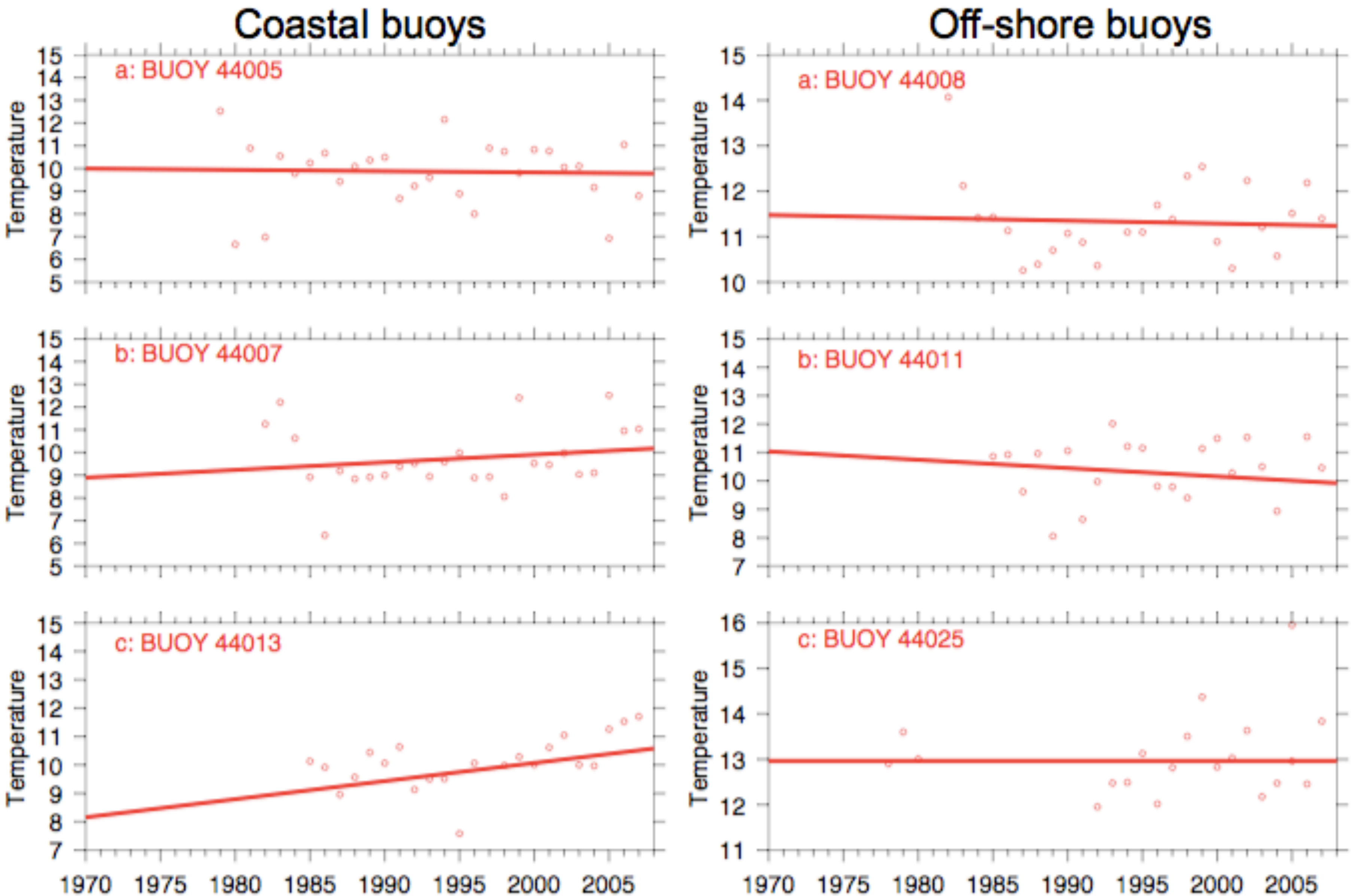
Impact of the Arctic Ocean to the western coastal region of the North Atlantic Ocean

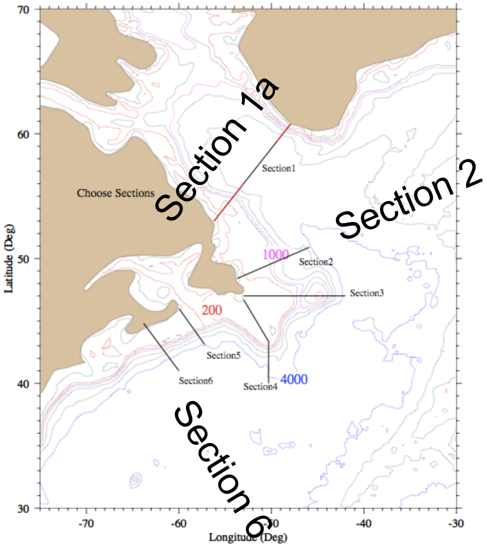




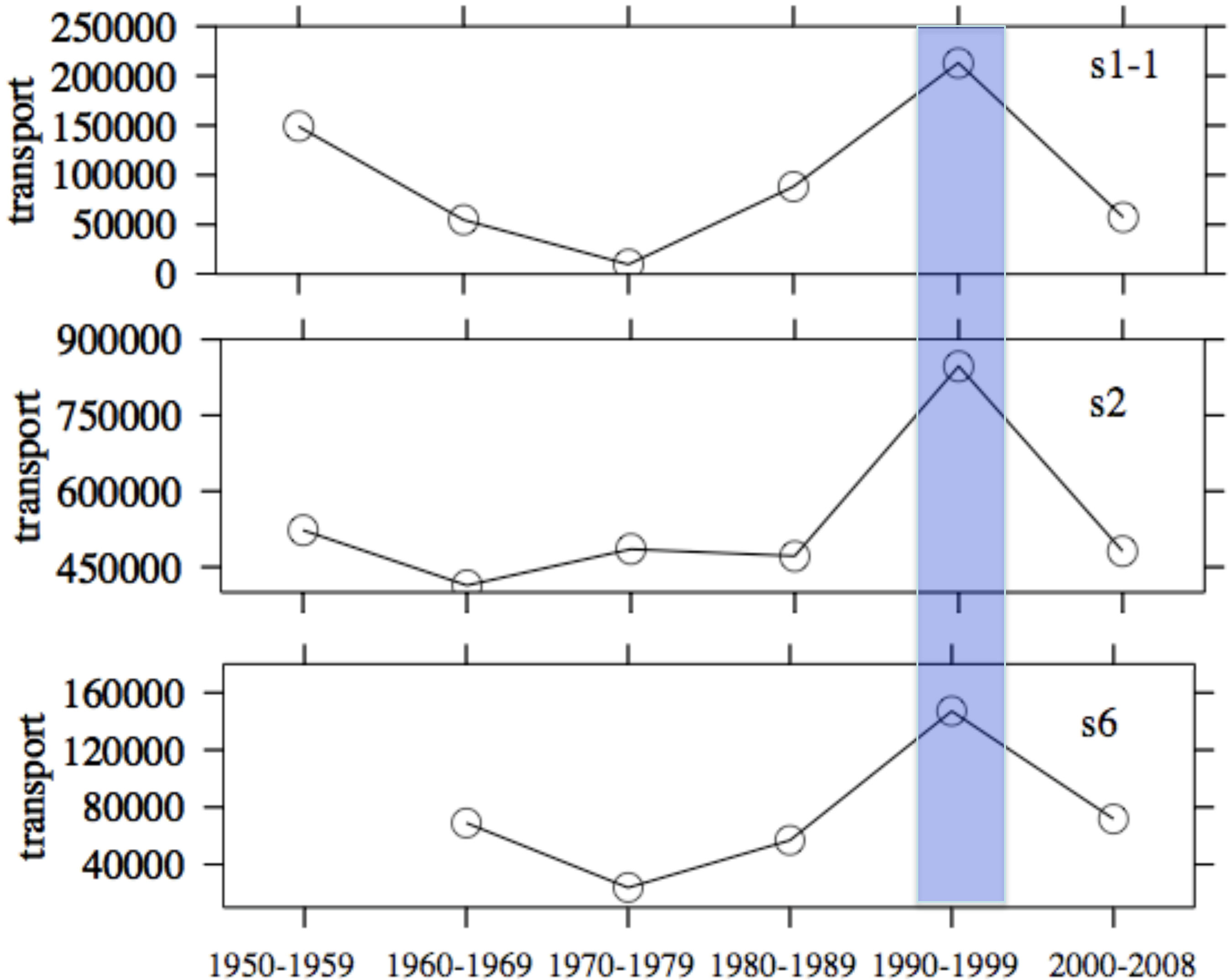
Local via Remote Forcing




Coastal buoys
Off-shore buoys
a: BUOY 44005
b: BUOY 44007
c: BUOY 44013
a: BUOY 44008
b: BUOY 44011
c: BUOY 44025
Temperature
1970
1975
1980
1985
1990
1995
2000
2005

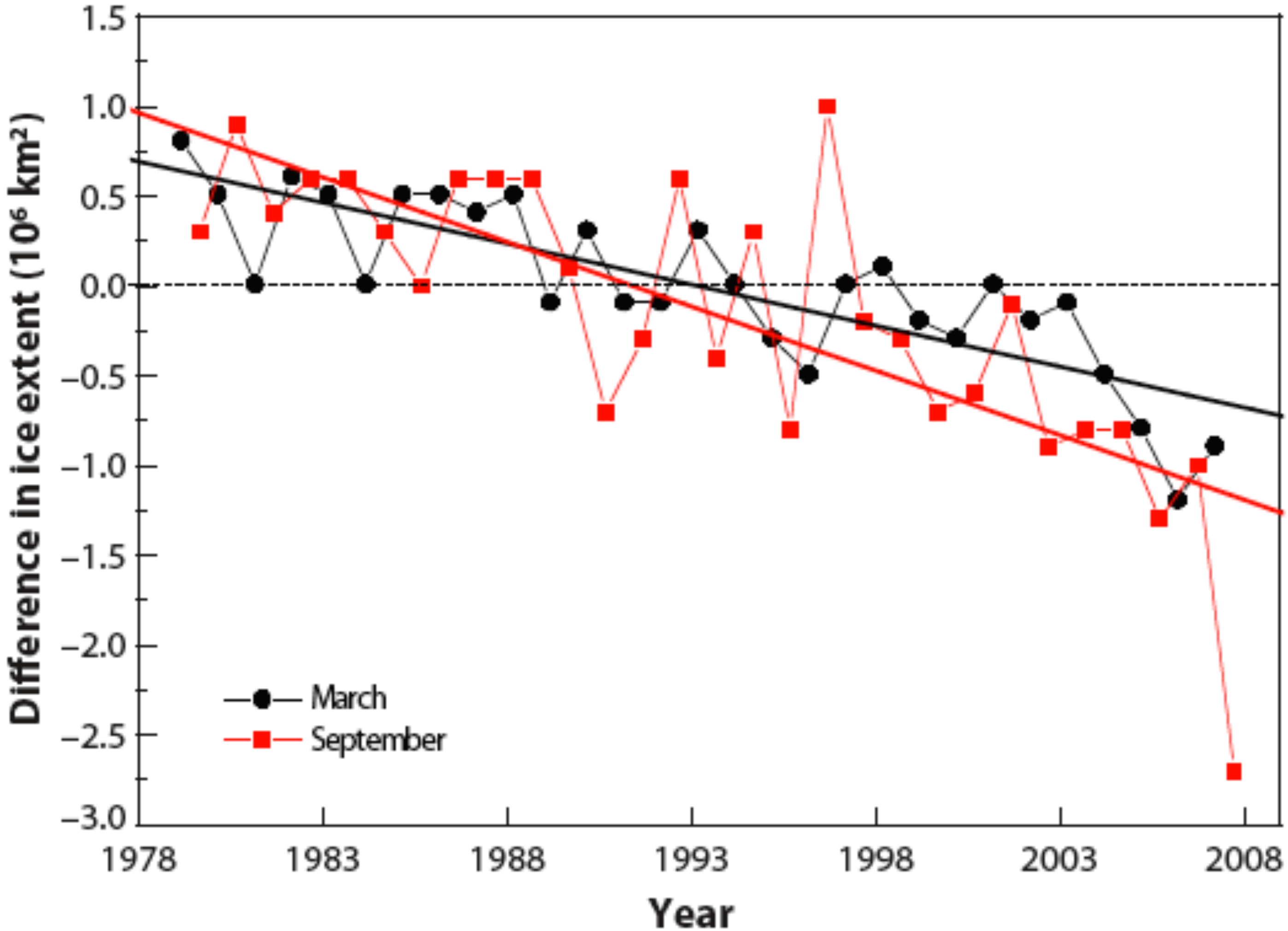


Geostrophic Water Transport on Sections 1, 2 and 6

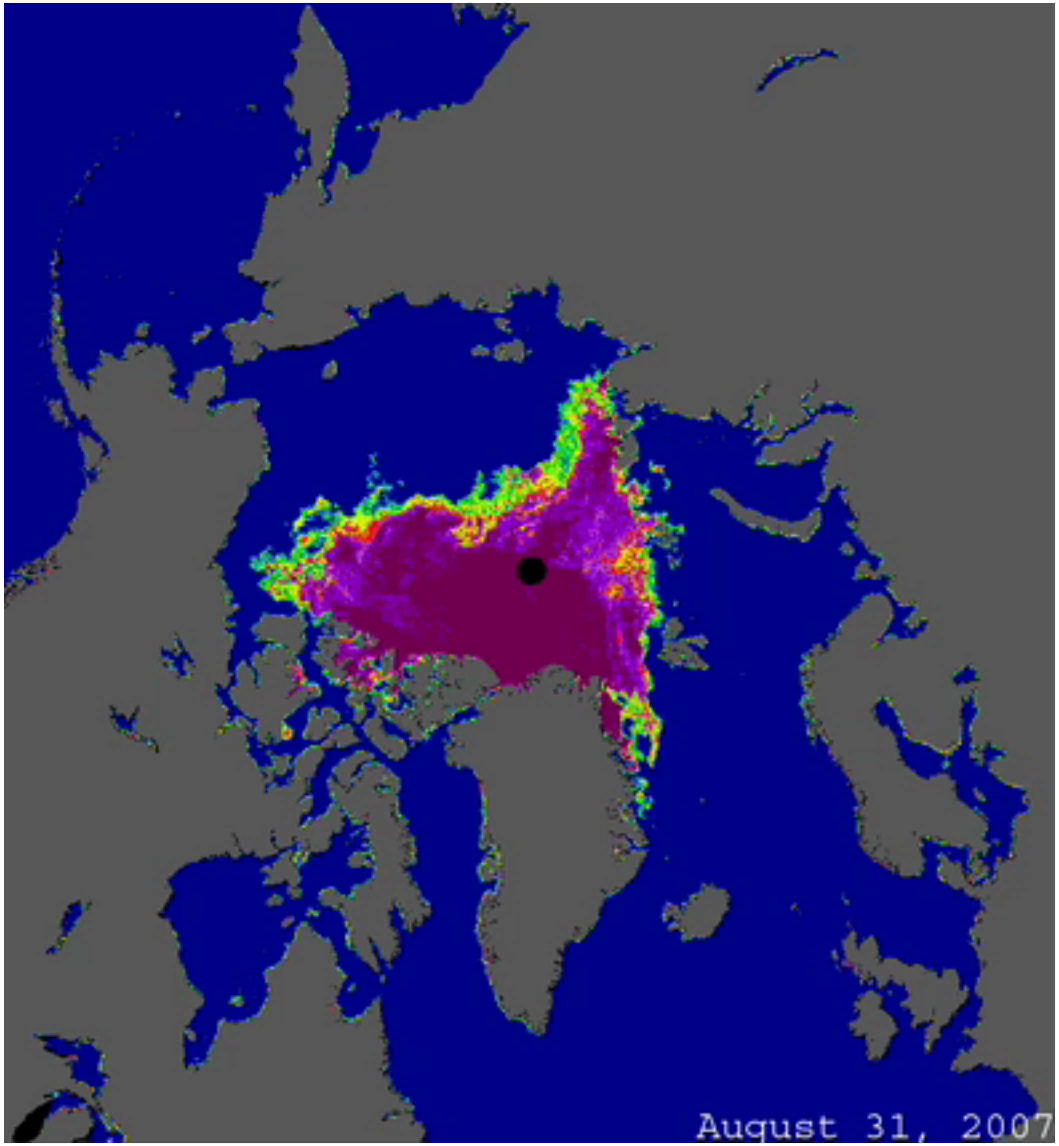


From D. K. Perovich and J. A. Richter-Menge

(Annu. Rev. Marine Sci, 2009, 417-441)

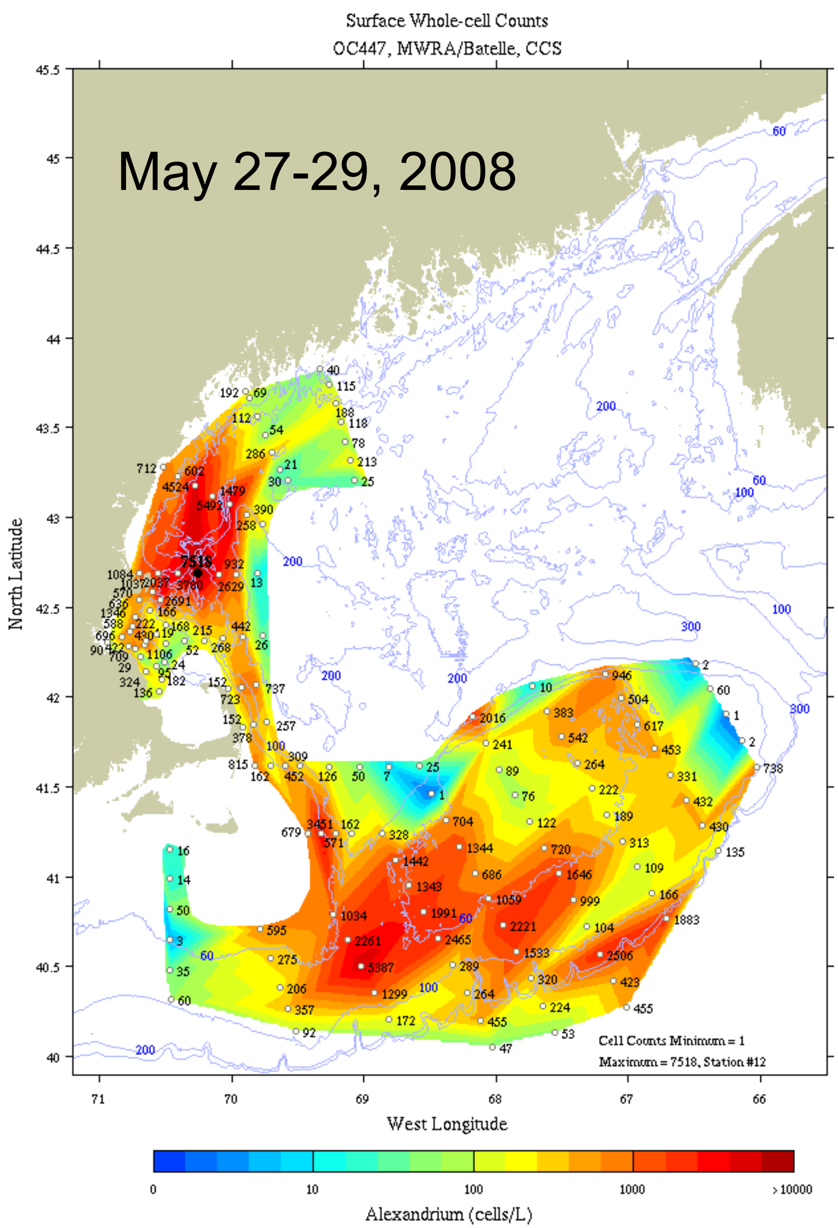


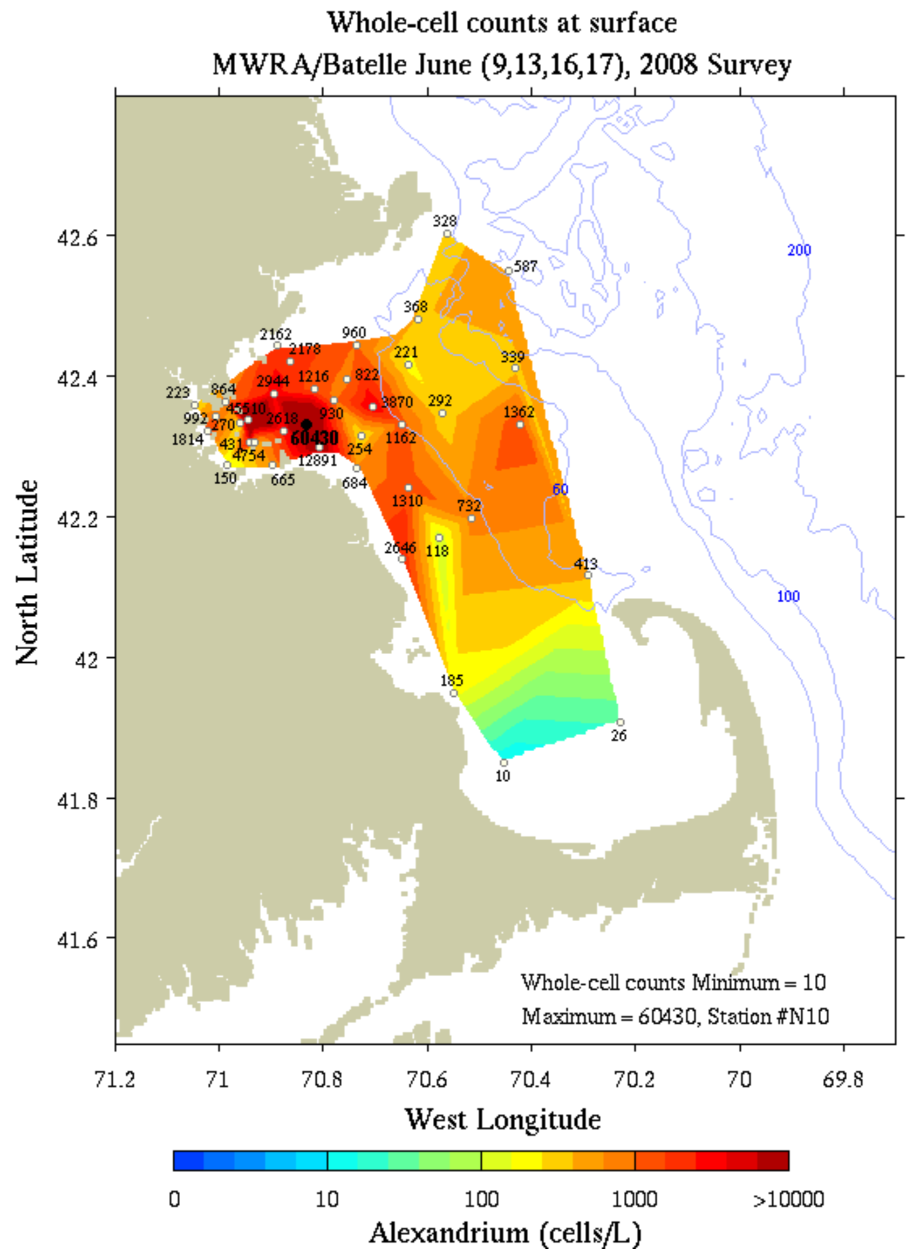
Arctic Sea ice in summer 2007, an animation downloaded from www.nsidc.org/



Images from NASA Earth Observing System Advanced Microave Scanning Radiometer- Institute of Environmental Physics at the University of Bremen,: National Snow and Ice Date Center.

From Don Anderson (WHOI) (Presentation at the MWRA meeting)





From Joe DelliCarpini (National Weather Service at Taunton)

Challenges We Are Facing to

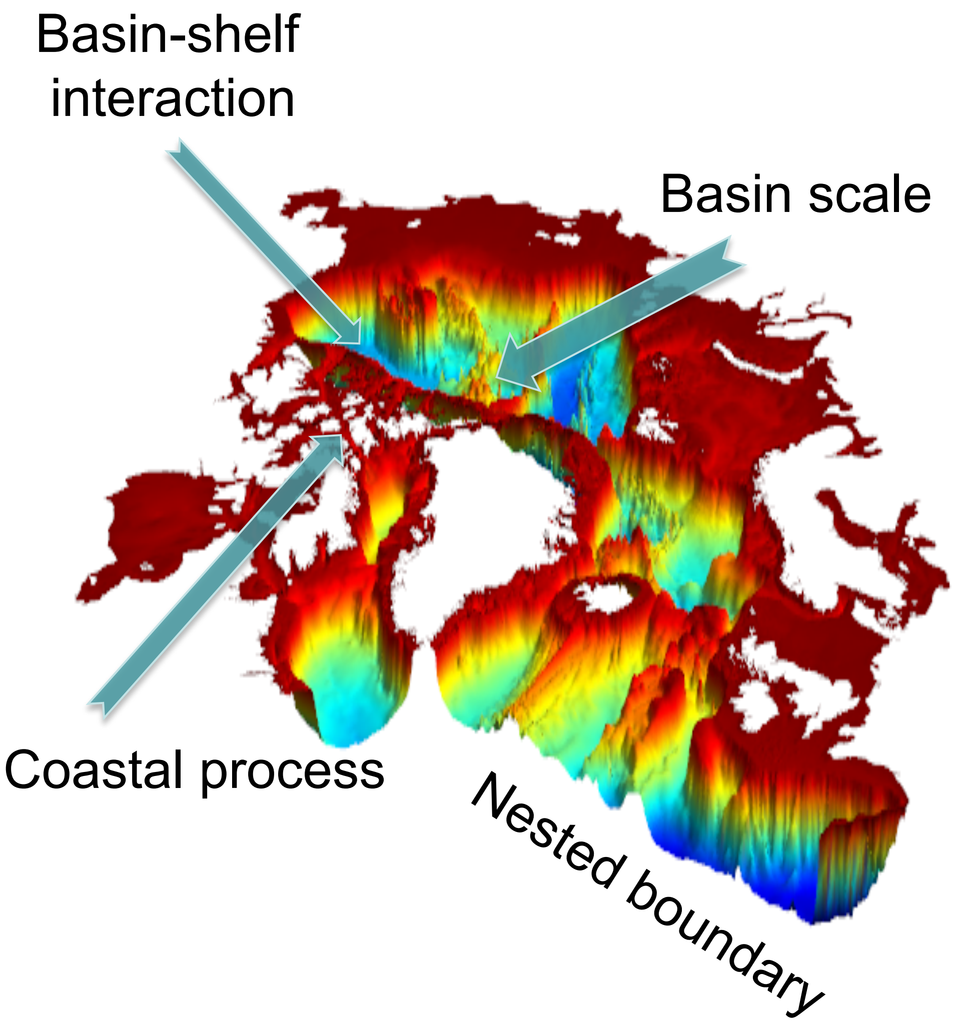
- Lack of the observation 4-dimensional (x,y,z,t) network that is capable of resolving the multi-scale physical and ecosystem processes;

- Lack of the systematic understanding of impacts of global climate change on the coastal physical and ecosystem processes.

Key Issues

Multi-Scale (global-basin-coastal-estuarine-wetland) Interaction !

Two Critical Issues:



1. Multi-scale dynamics: Basin-shelf interaction, convection via advection, etc.

2. Open boundary connected to the North Atlantic Ocean and Pacific Ocean

Ocean Model Dynamics

~1 ~1000 km

Hydrostatic

$$\frac{\text{Surface elevation}}{\text{Local water depth}} = \frac{\zeta}{H} << 1$$

Large-scale motion in which the vertical motion is at least one order of magnitude smaller than the horizontal motion.

Vertical convection, over-turning, and high frequency internal waves are not resolved.

~ a few meters

Non-hydrostatic

$$\frac{\text{Surface elevation}}{\text{Local water depth}} = \frac{\zeta}{H} \sim 1$$

Small-scale motion in which vertical motion is the same order of the horizontal motion.

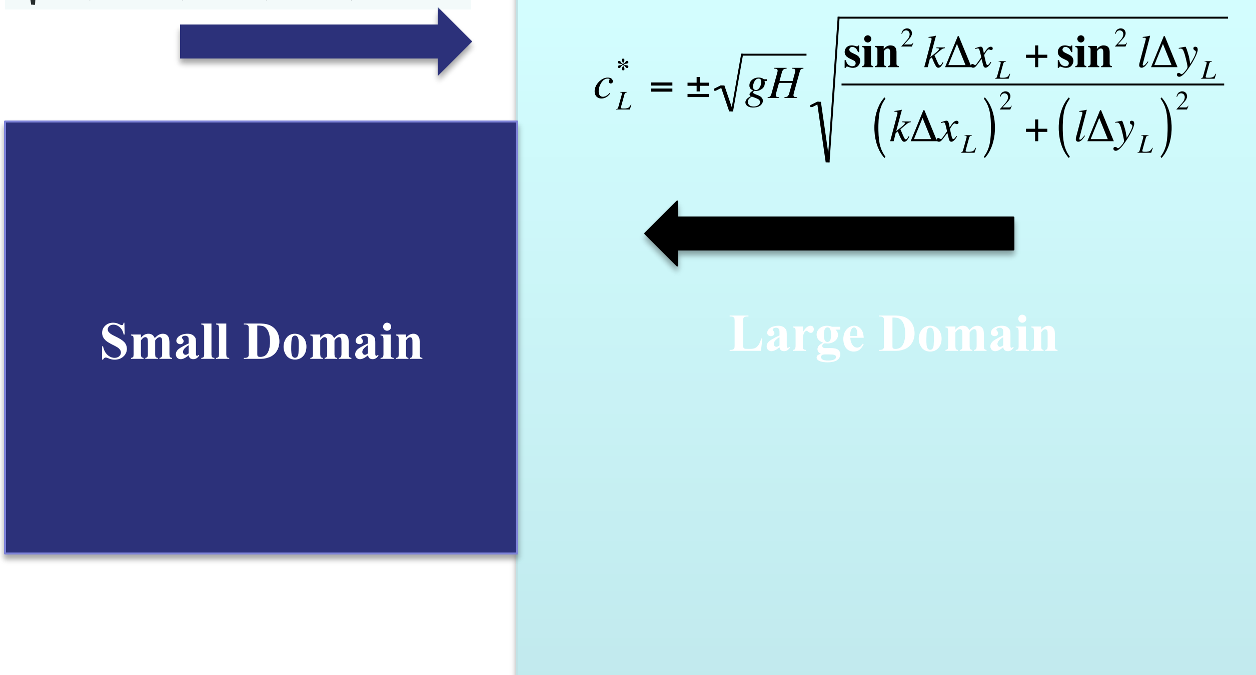
Vertical convection, over-turning, and high frequency internal waves can be resolved.

In the ocean,

Numerical error speed

$$c_s^* = \pm\sqrt{gH}\sqrt{\frac{\sin^2 k\Delta x_s + \sin^2 l\Delta y_s}{(k\Delta x_s)^2 + (l\Delta y_s)^2}}$$

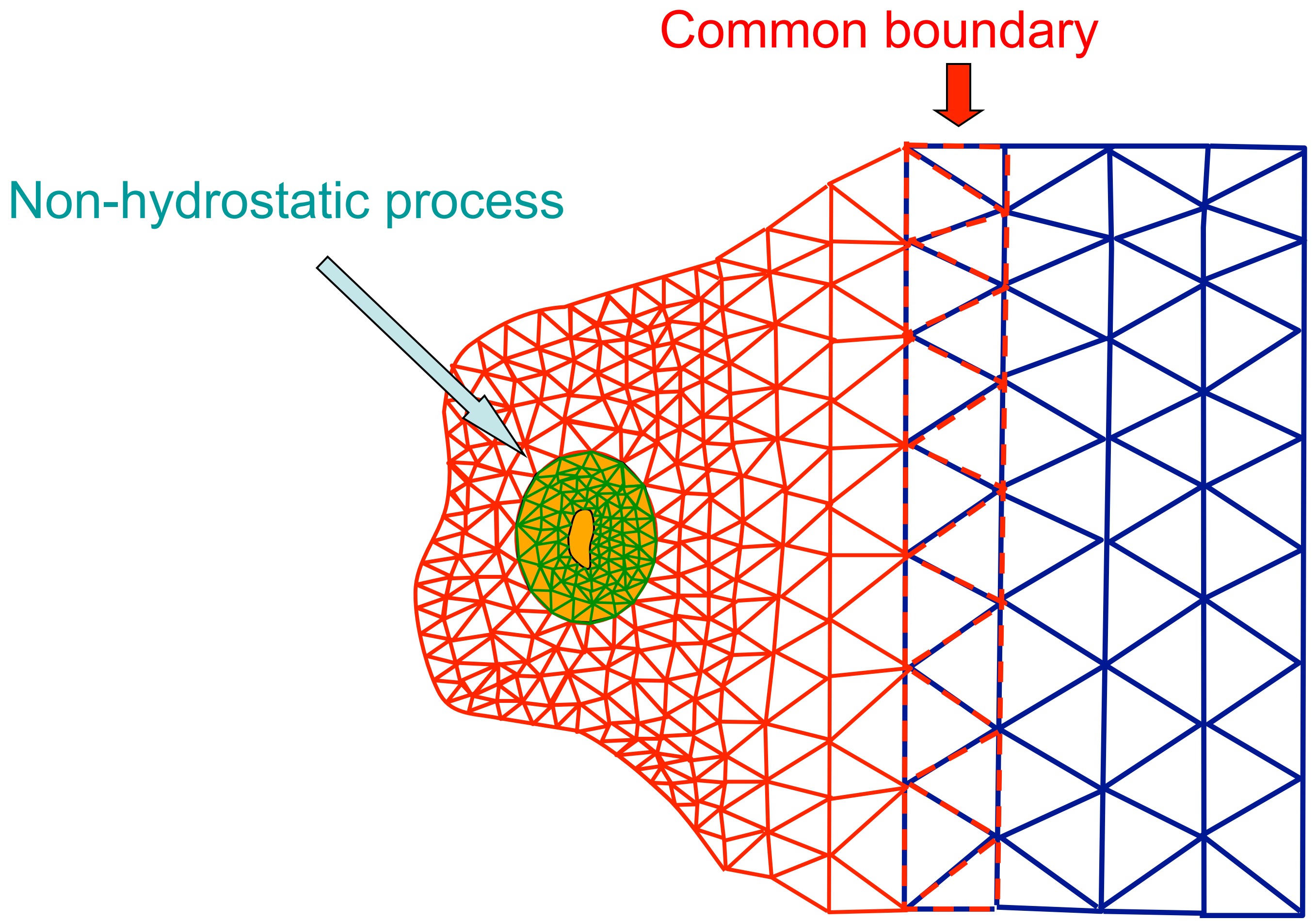
$$c_L^* = \pm\sqrt{gH}\sqrt{\frac{\sin^2 k\Delta x_L + \sin^2 l\Delta y_L}{(k\Delta x_L)^2 + (l\Delta y_L)^2}}$$



Because $\Delta x_s \neq \Delta x_L$; $\Delta y_s \neq \Delta y_L$; The surface gravity wave speed propagating from the small domain is not equal at the nesting boundary.

Energy accumulation at the boundary !

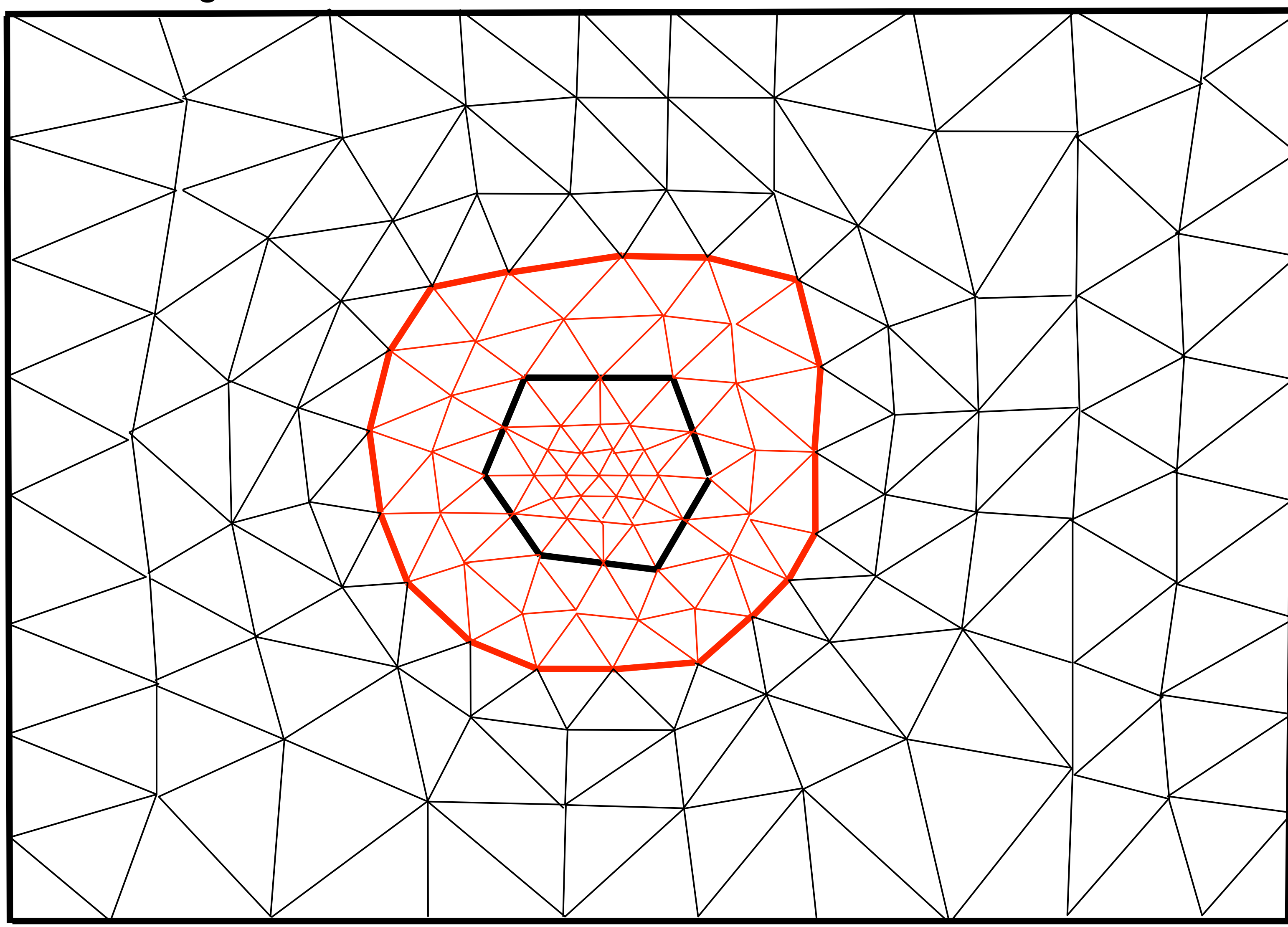
Unstructured grid



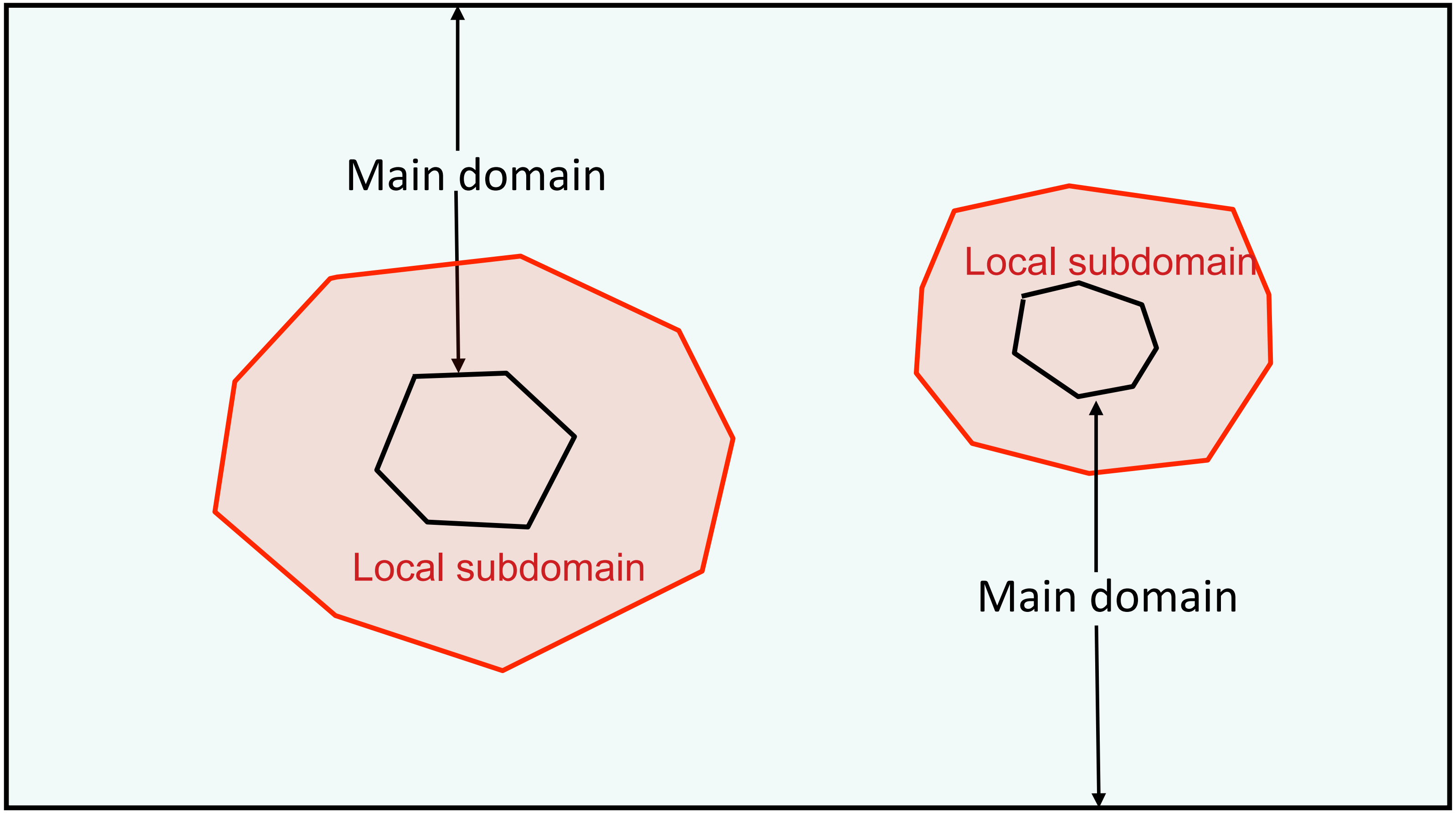
Unstructured nesting approach: Mass conservation

Two-way Nesting (under development)

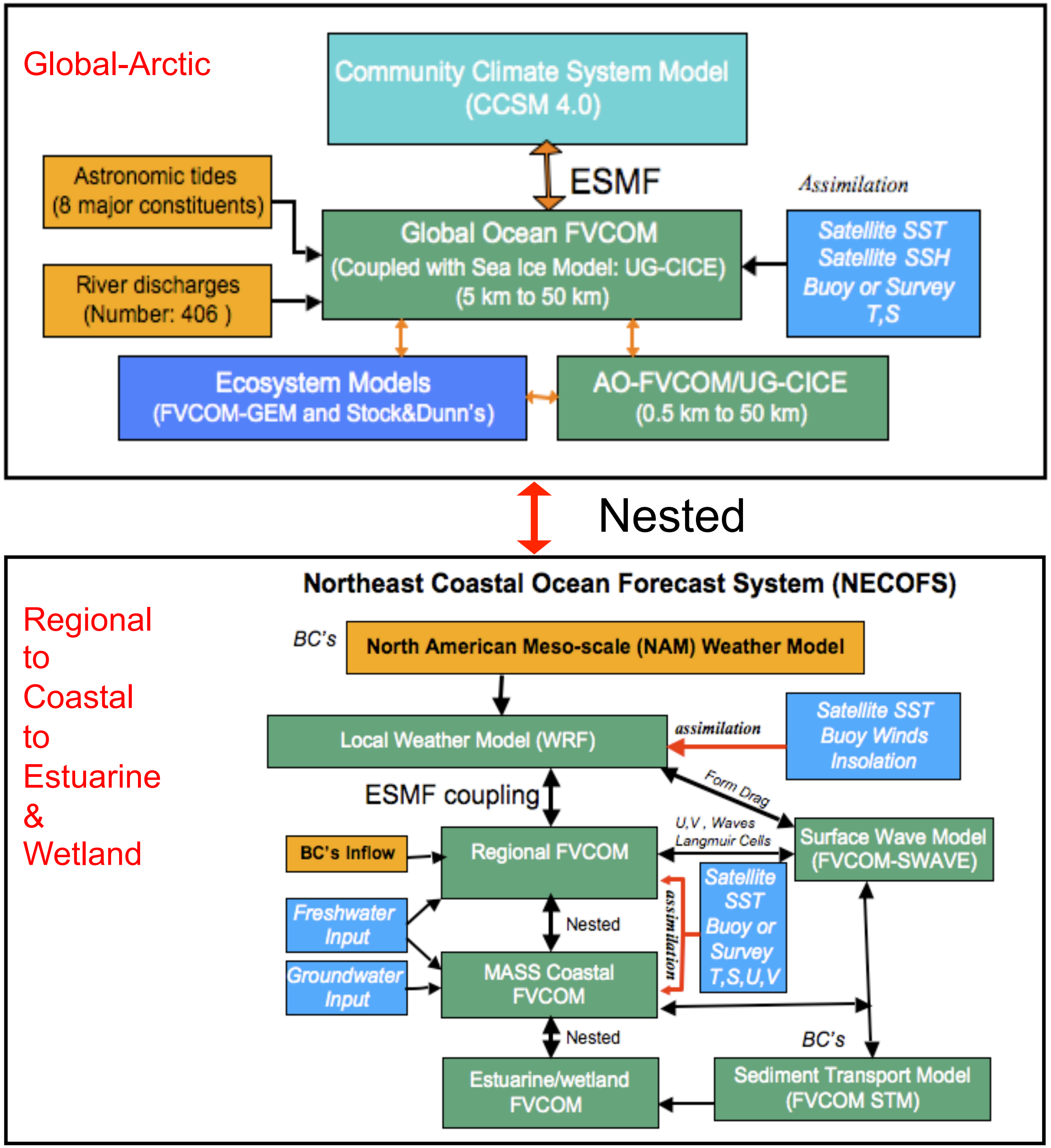
Patched grid:



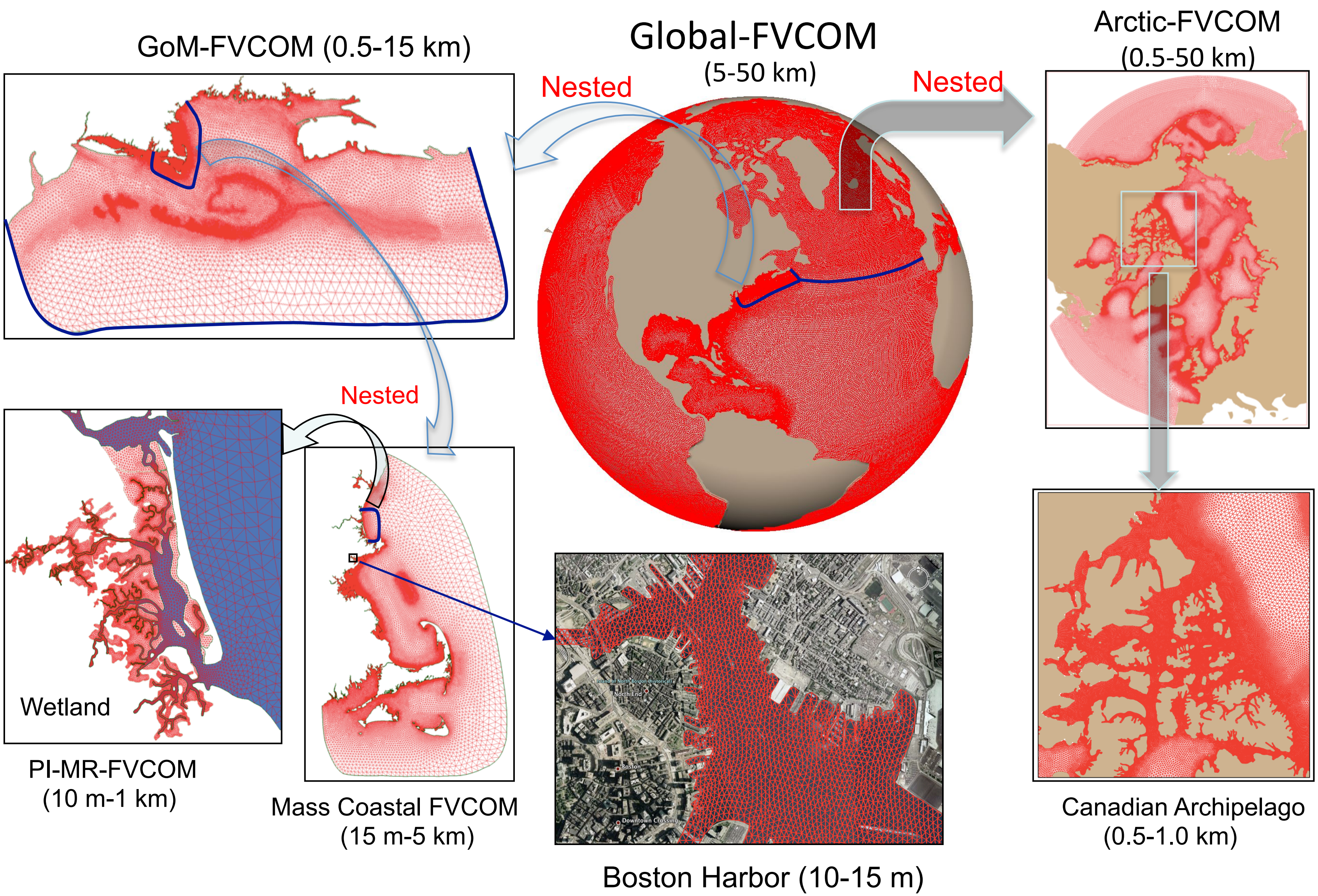
Two-way Nesting



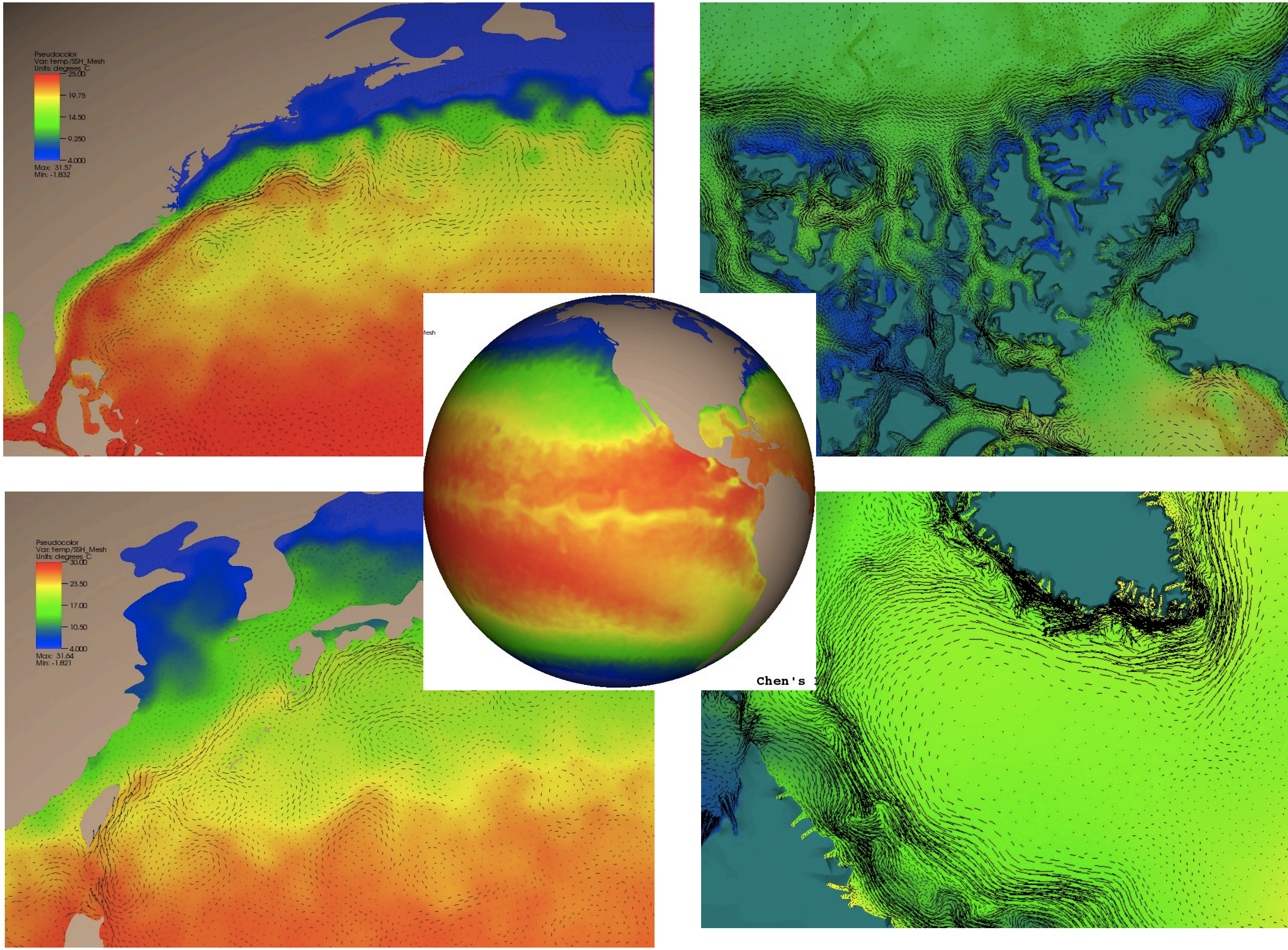
The main domain uses the interior meshes of the local subdomain as the boundary,while the local subdomain uses the interior meshes of the main domain as the boundary.

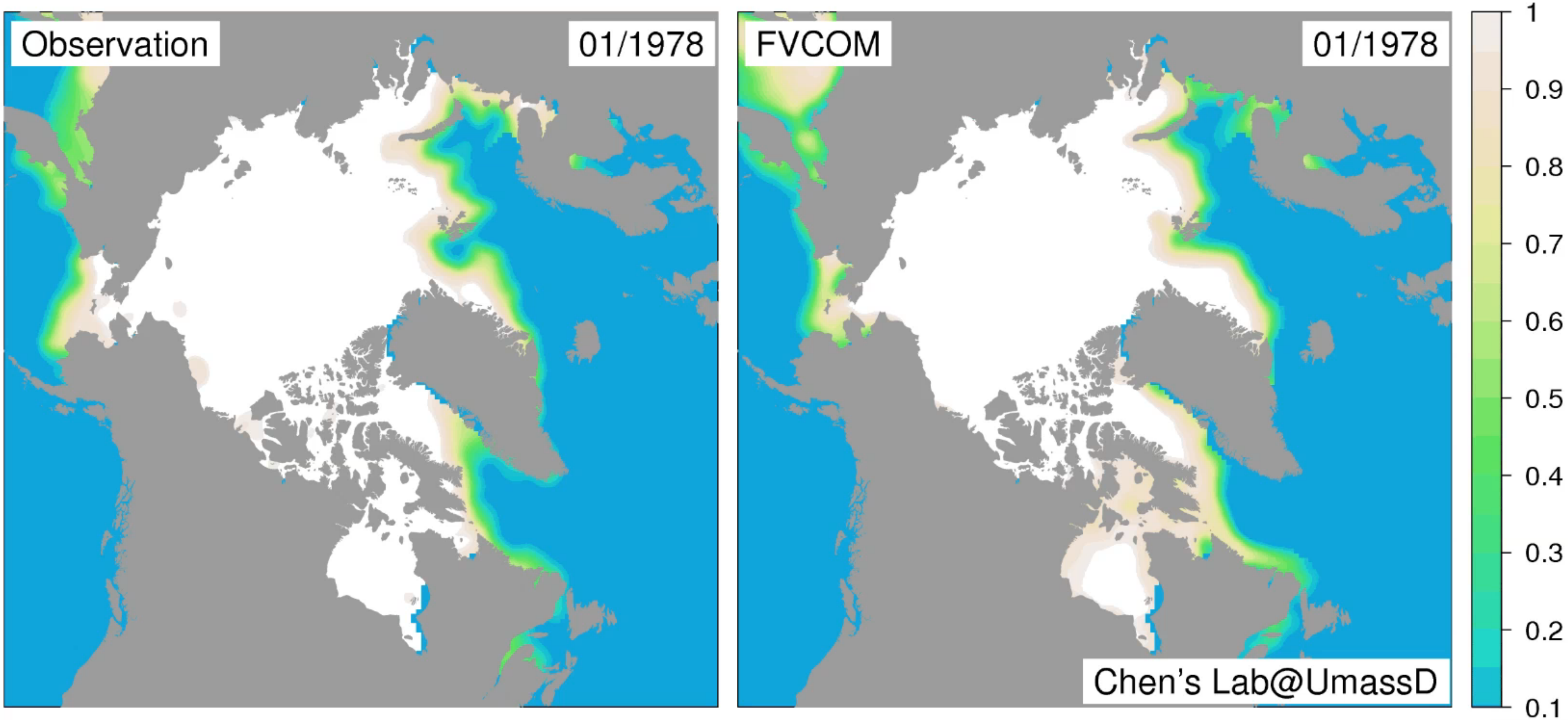


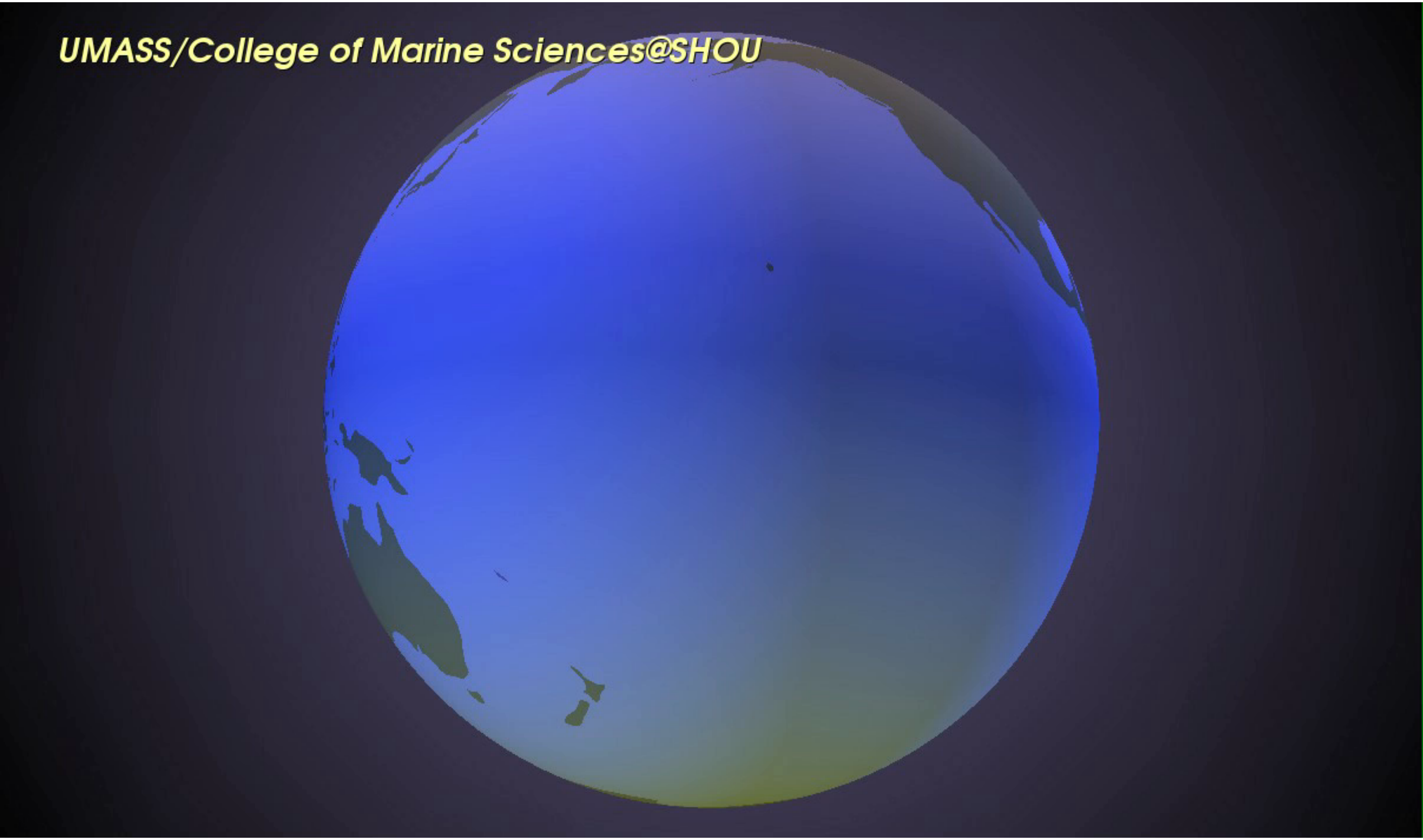
Global-Arctic
Community Climate System Model (CCSM 4.0)
ESMF
Astronomic tides (8 major constituents)
River discharges (Number: 406)
Global Ocean FVCOM (Coupled with Sea Ice Model: UG-CICE) (5 km to 50 km)
Assimilation
Satellite SST Satellite SSH Buoy or Survey T,S
Ecosystem Models (FVCOM-GEM and Stock&Dunn's)
AO-FVCOM/UG-CICE (0.5 km to 50 km)
Nested
Northeast Coastal Ocean Forecast System (NECOFS)
Regional to Coastal to Estuarine & Wetland
BC's
North American Meso-scale (NAM) Weather Model
Local Weather Model (WRF)
assimilation
Satellite SST Buoy Winds Insolation
Form Drag
ESMF coupling
BC's Inflow
Regional FVCOM
U,V , Waves Langmuir Cells
Surface Wave Model (FVCOM-SWAVE)
Freshwater Input
Groundwater Input
Nested
assimilation
Satellite SST Buoy or Survey T,S,U,V
MASS Coastal FVCOM
Nested
BC's
Estuarine/wetland FVCOM
Sediment Transport Model (FVCOM STM)

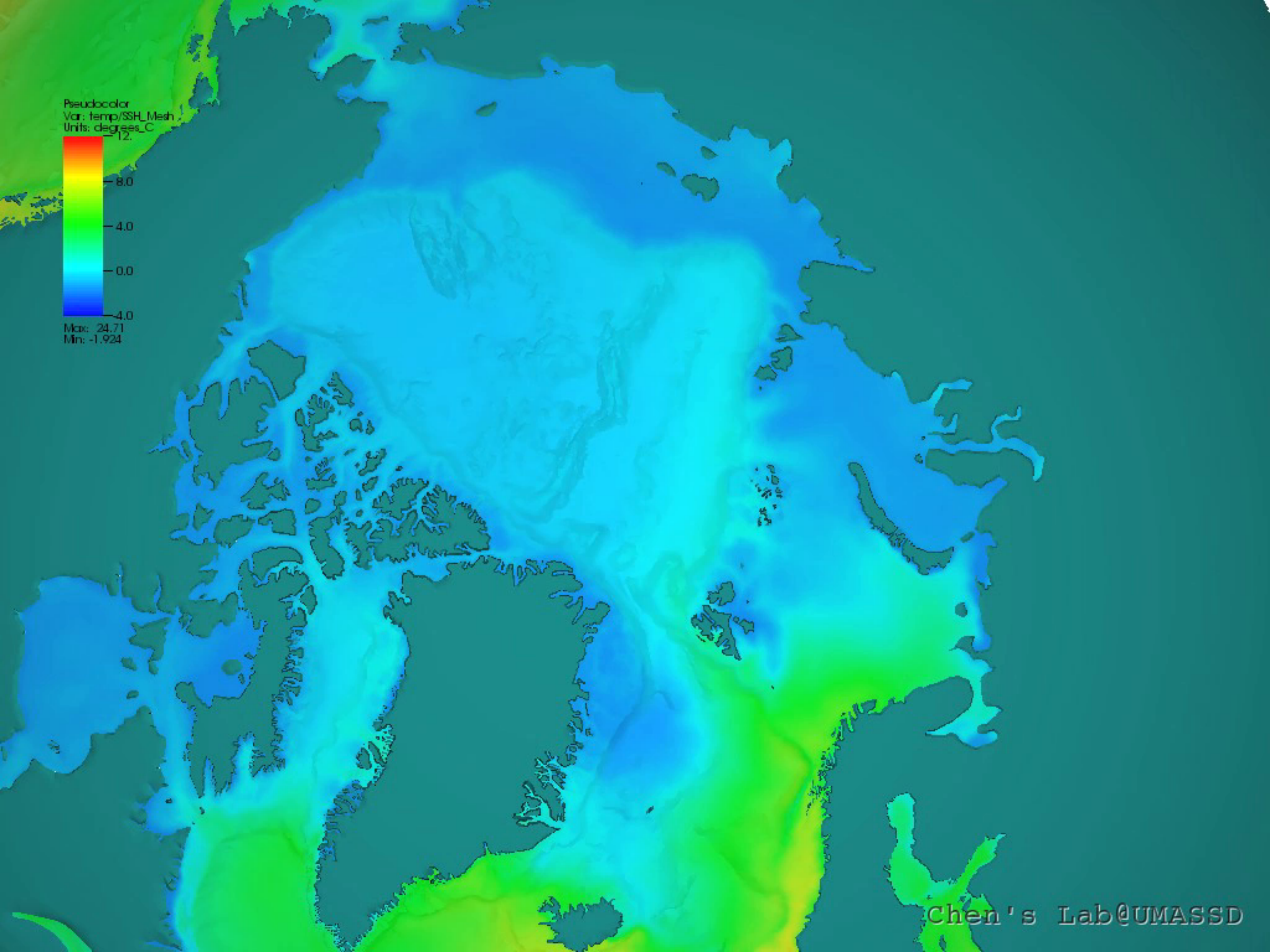


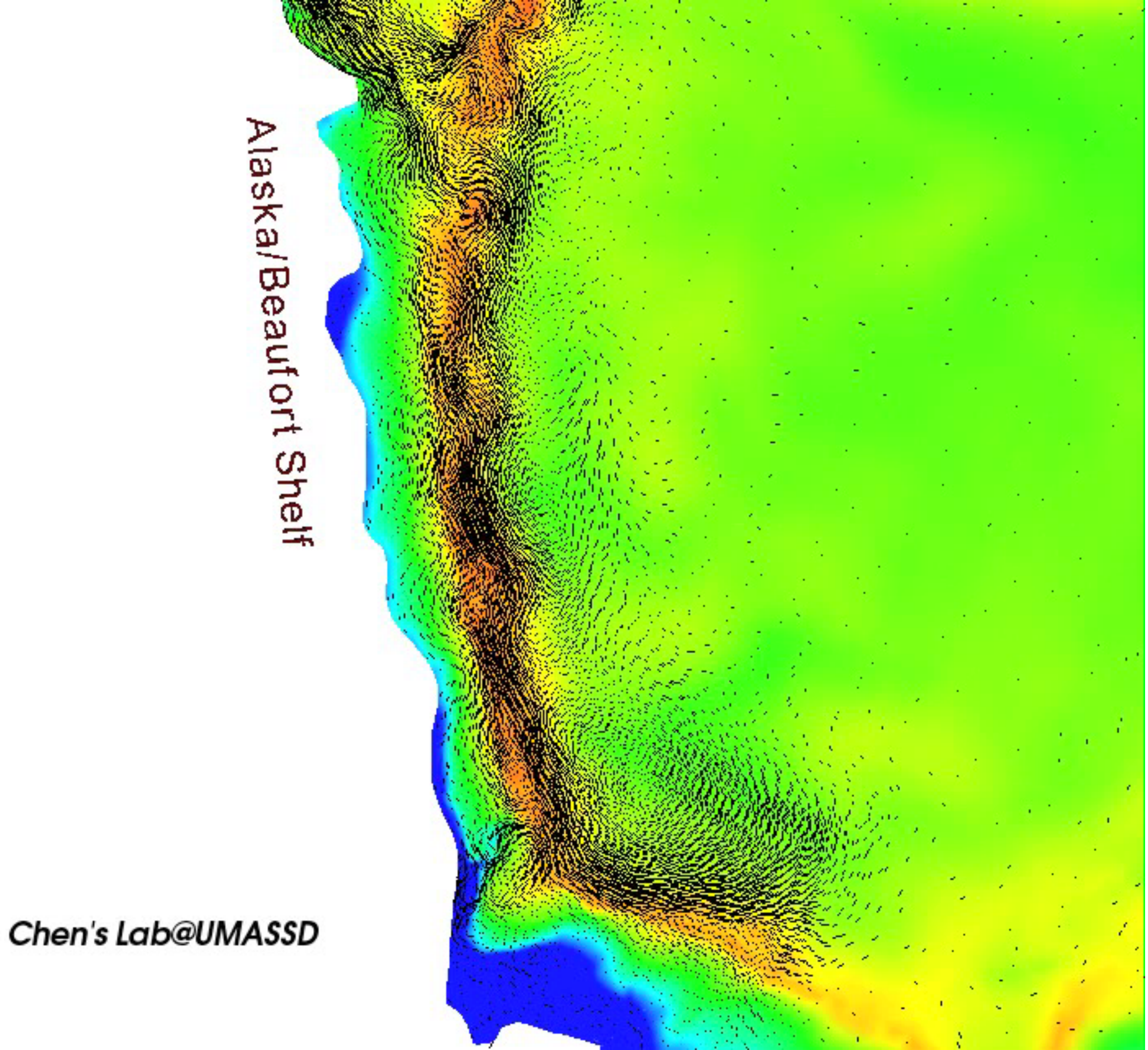
GoM-FVCOM (0.5-15 km)
Nested
Global-FVCOM
(5-50 km)
Nested
Arctic-FVCOM
(0.5-50 km)
Nested
Wetland
PI-MR-FVCOM
(10 m-1 km)
Mass Coastal FVCOM
(15 m-5 km)
Boston Harbor (10-15 m)
Canadian Archipelago
(0.5-1.0 km)

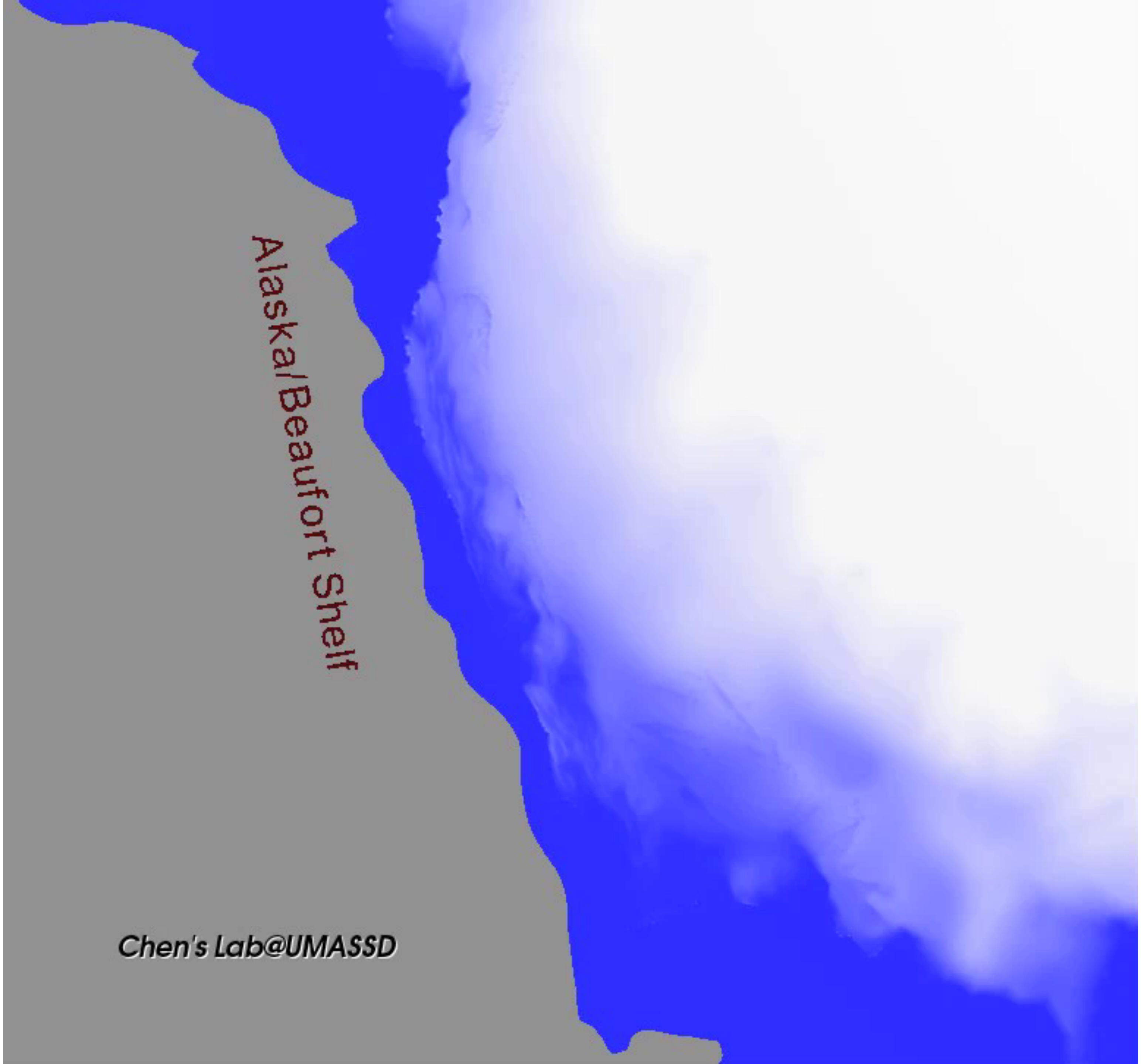

Pseudocolor
Var: temp/SSH_Mesh
Units: degrees_C
25.00
19.75
14.50
9.250
4.000
Max: 31.57
Min: -1.832
Pseudocolor
Var: temp/SSH_Mesh
Units: degrees_C
30.00
23.50
17.00
10.50
4.000
Max: 31.64
Min: -1.821
Chen's


Observation
01/1978
FVCOM
01/1978
Chen's Lab@UmassD
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

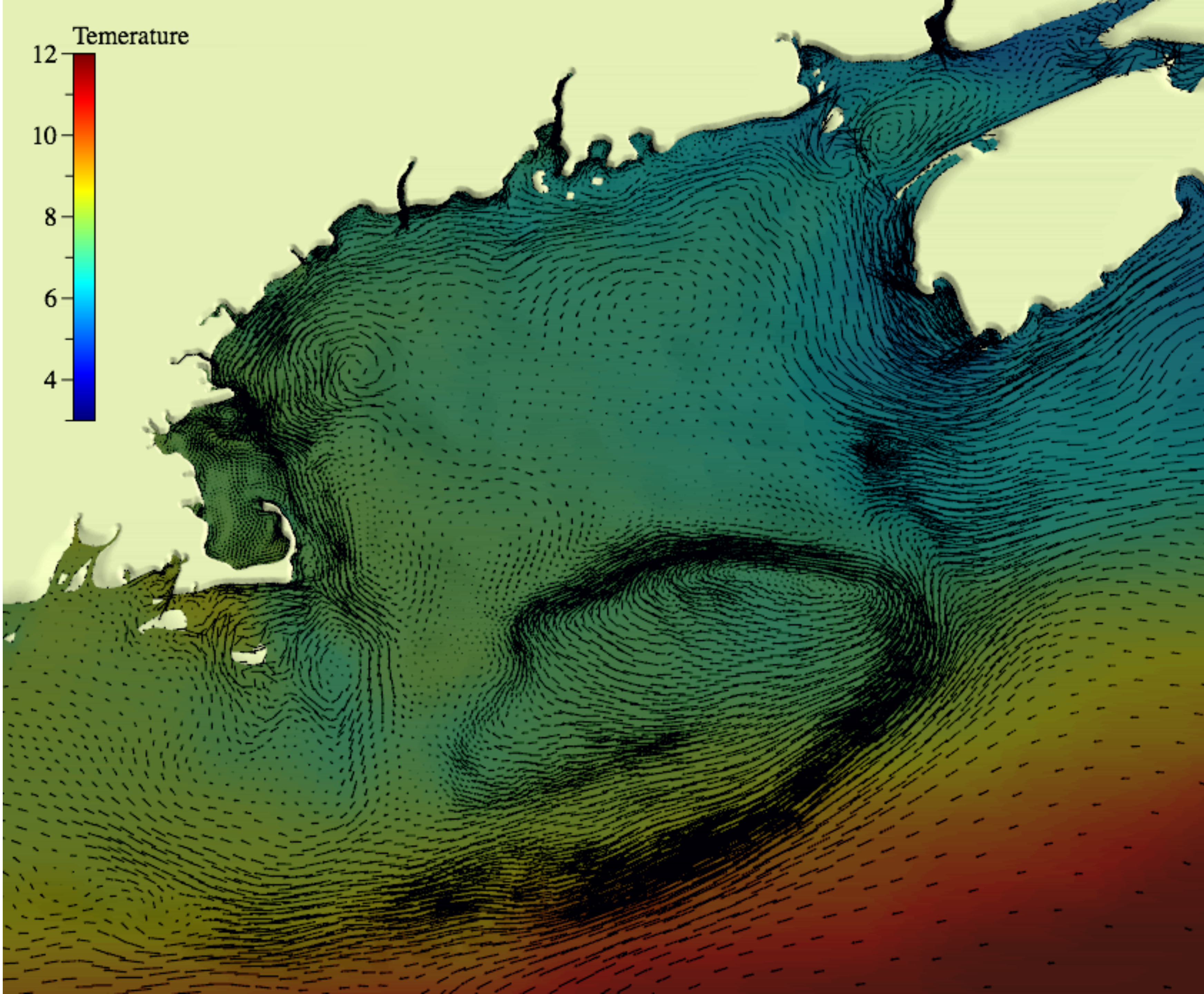

UMASS/College of Marine Sciences@SHOU

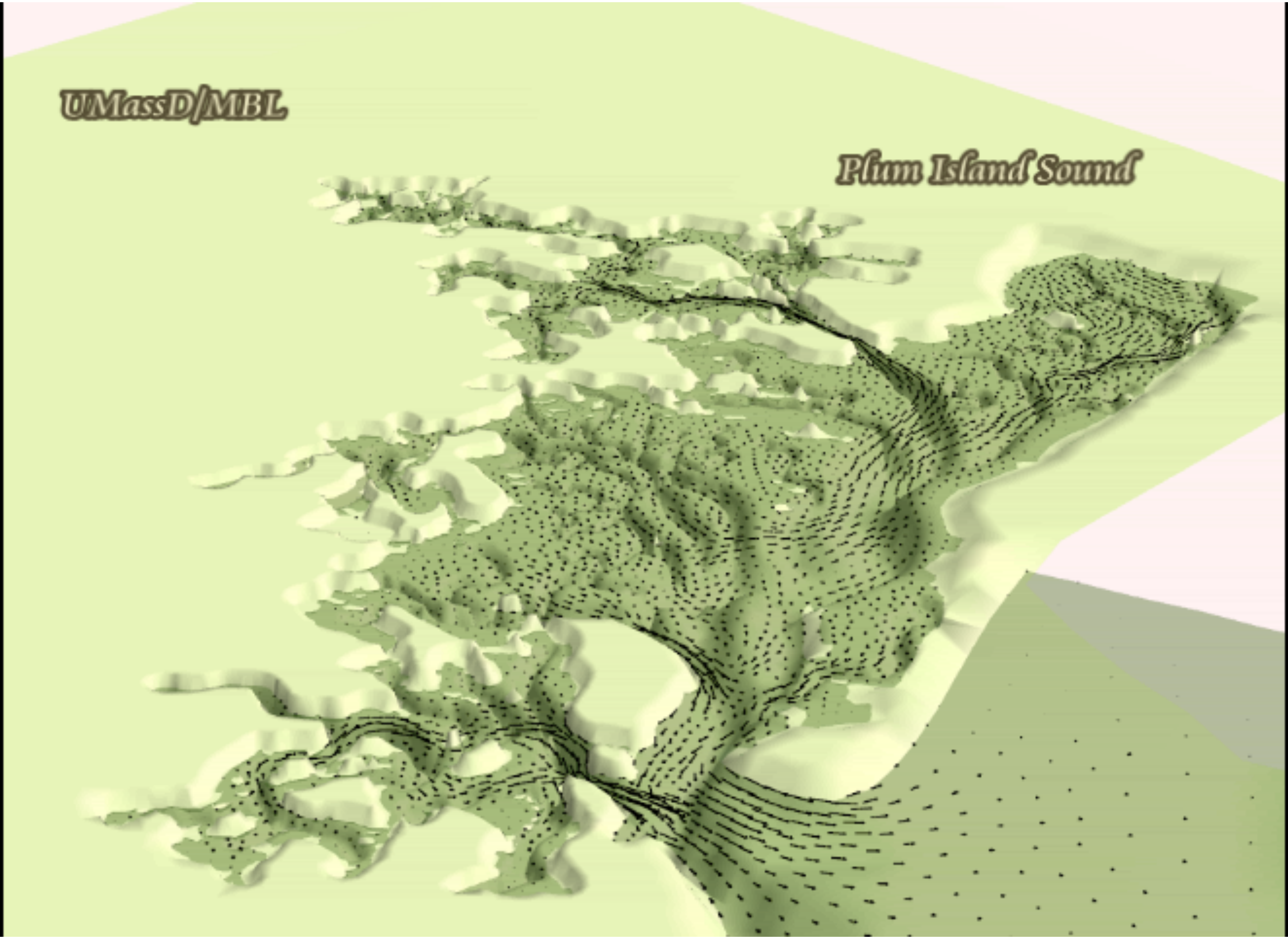

Pseudocolor
Var: temp/SSH_Mesh
Units: degrees_C
12.
8.0
4.0
0.0
-4.0
Max: 24.71
Min: -1.924
Chen's Lab@UMASSD

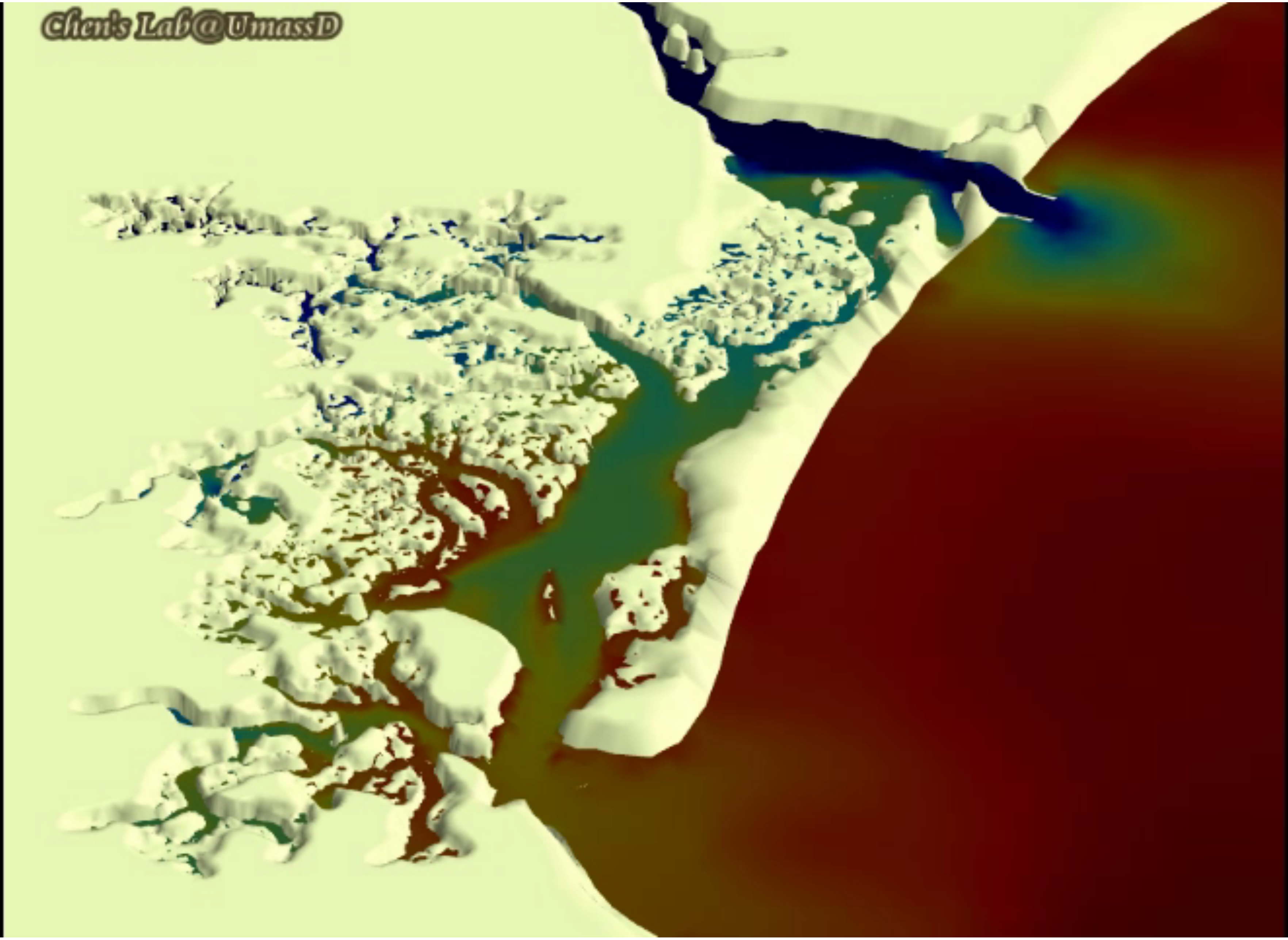

Alaska/Beaufort Shelf
Chen's Lab@UMASSD

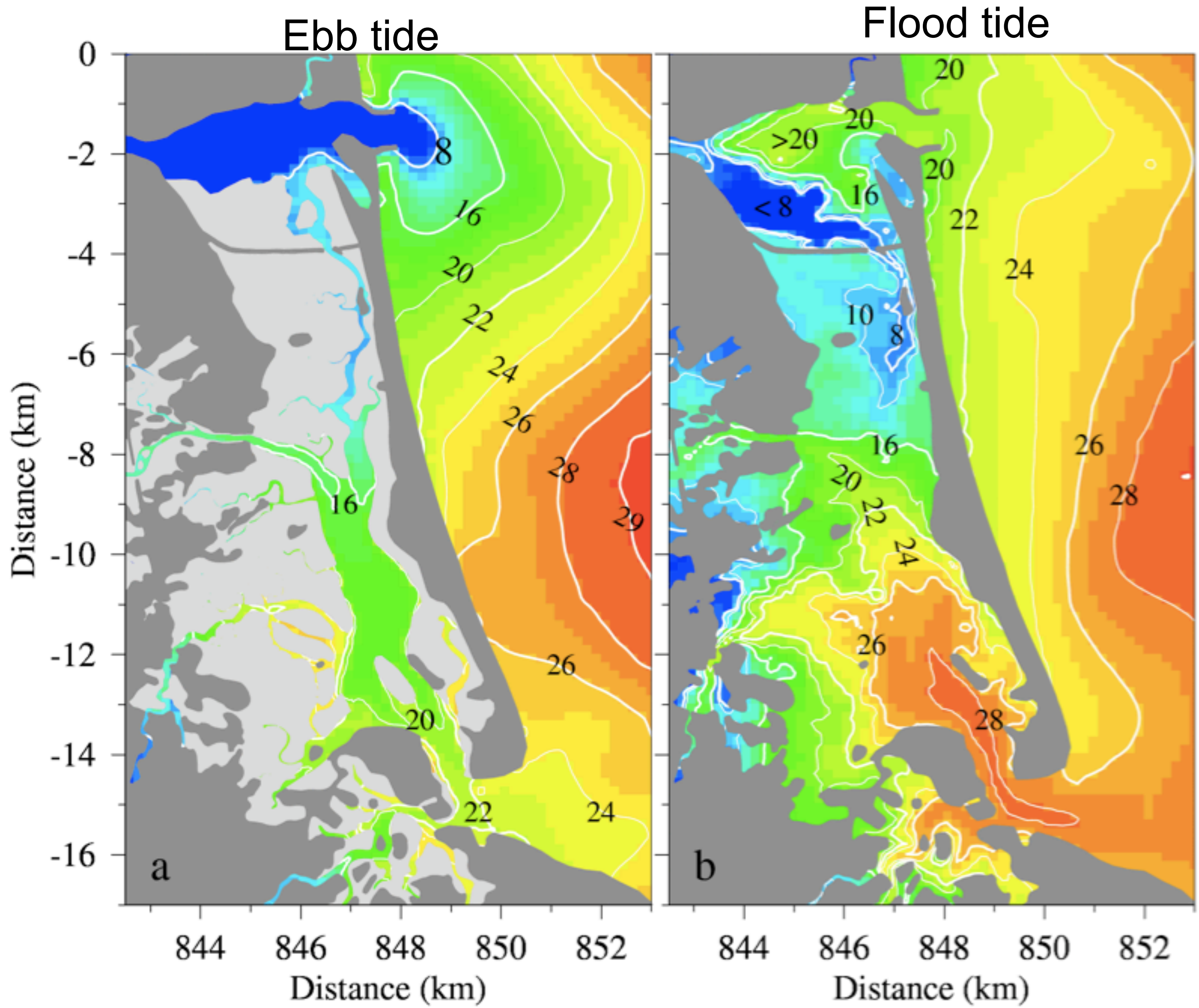


Alaska/Beaufort Shelf
Chen's Lab@UMASSD

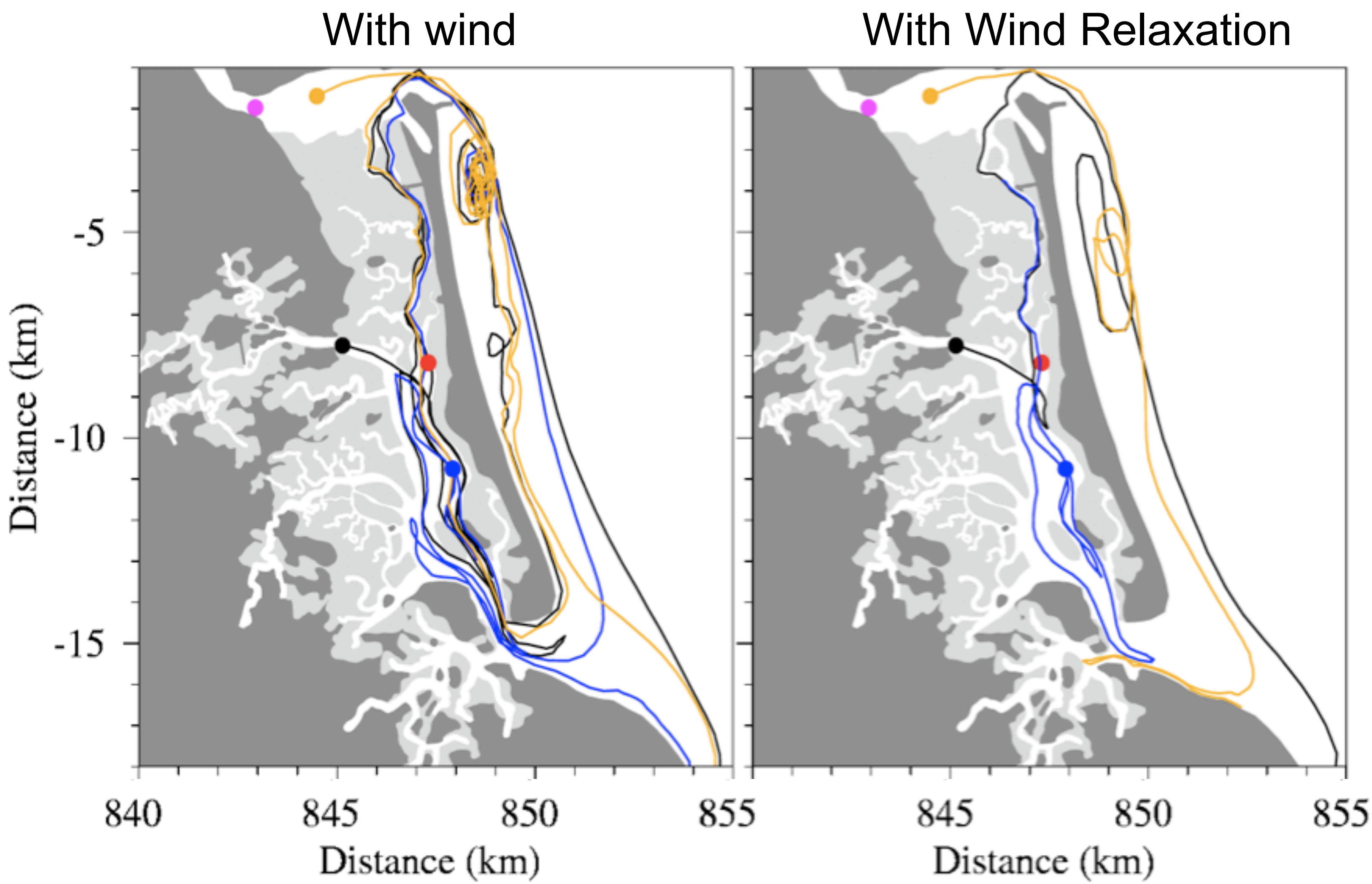

Temerature
12
10
8
6
4


UMassD/MBL
Plum Island Sound


Chen's Lab@UmassD

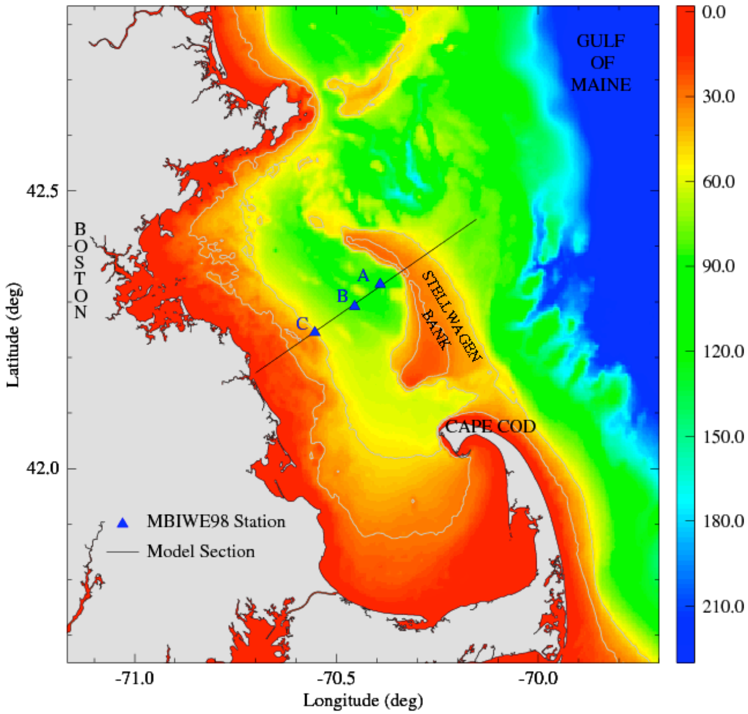


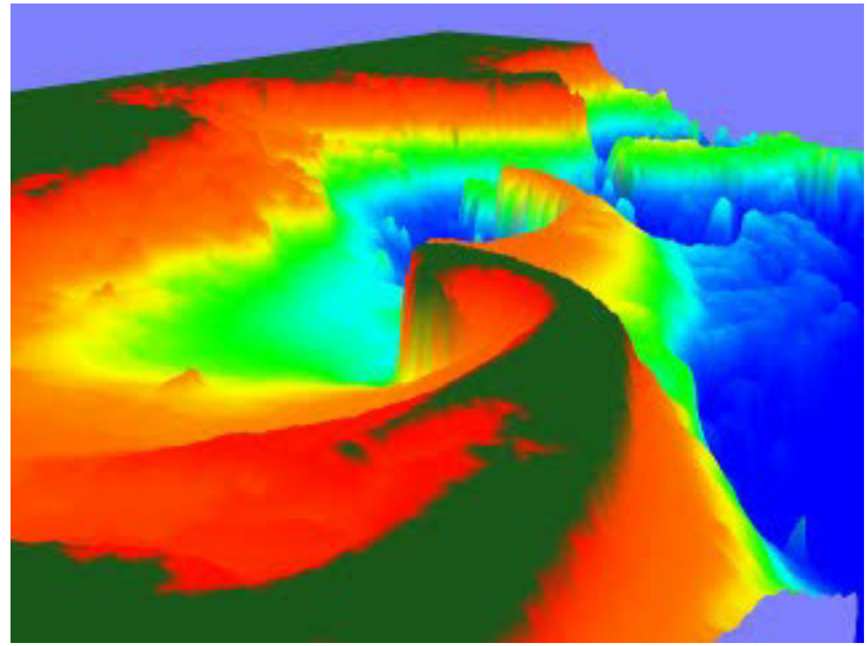
Ebb tide
Flood tide
Distance (km)
Distance (km)
Distance (km)
a
b
8
16
20
22
24
26
28
29
>20
< 8
10
844
846
848
850
852
0
-2
-4
-6
-8
-10
-12
-14
-16

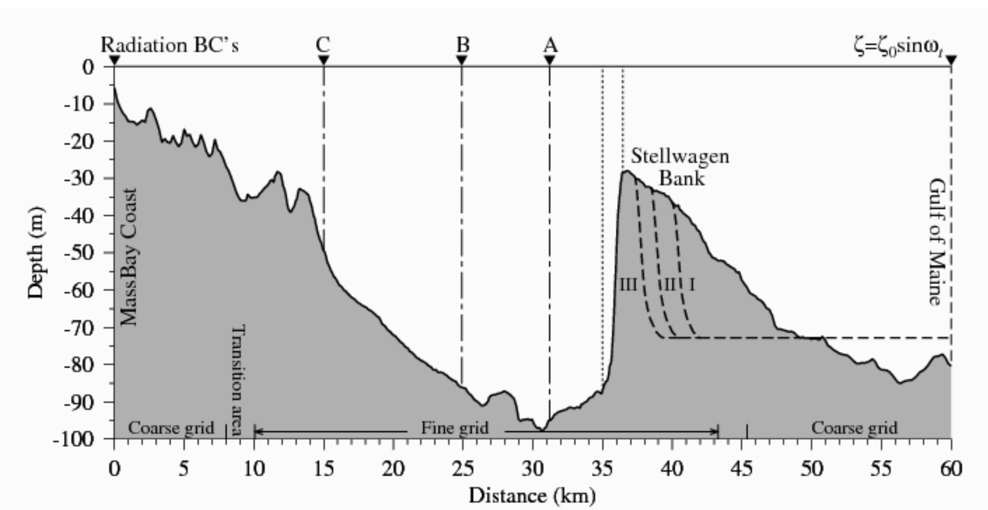


With wind
With Wind Relaxation
Distance (km)
-5
-10
-15
840
845
850
855
845
850
855
Distance (km)
Distance (km)

Stellwagen Bank, Massachusetts



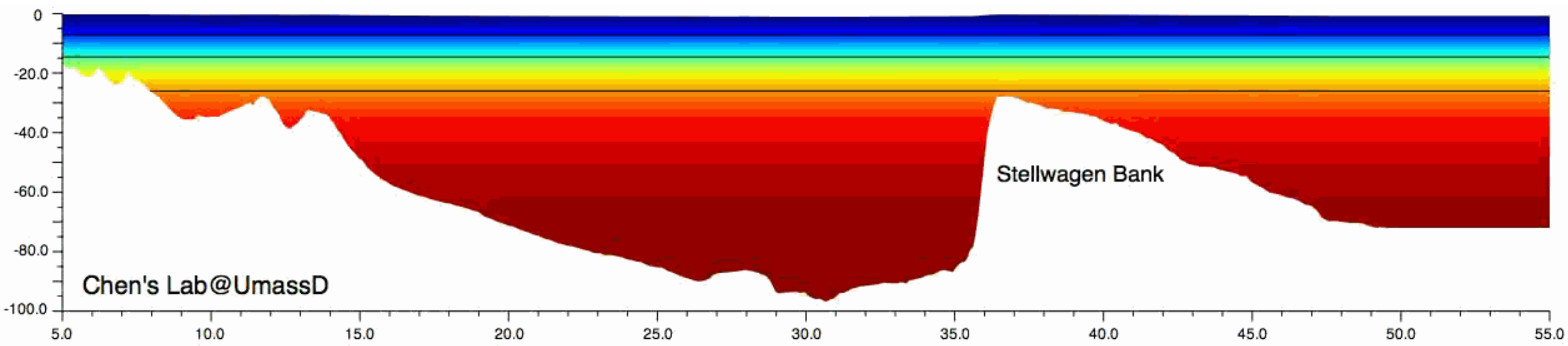




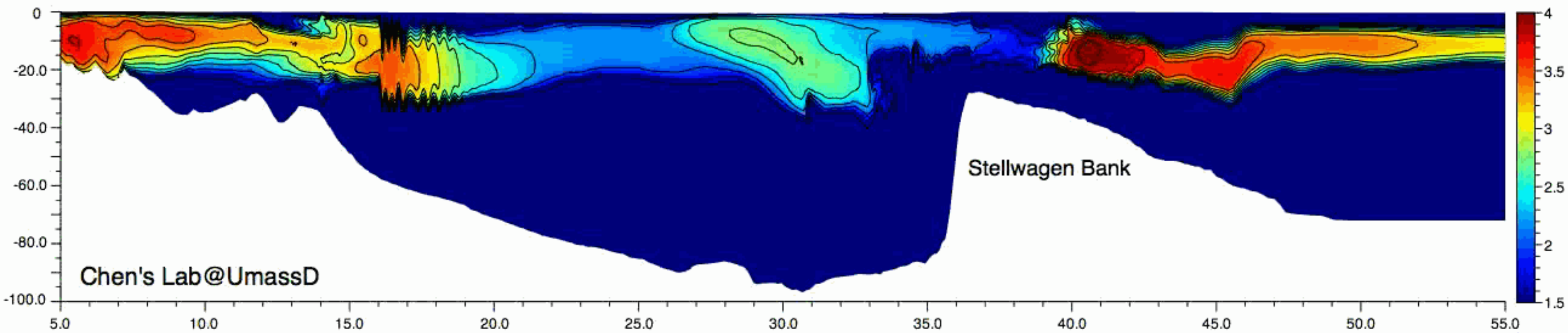
High-frequency internal waves:

Period: ~10 minutes
Wavelength: 200 m
Vertical displacement: 30-40 m
Phase speed: 40-60 cm/s
Solitary wave numbers: 7-12

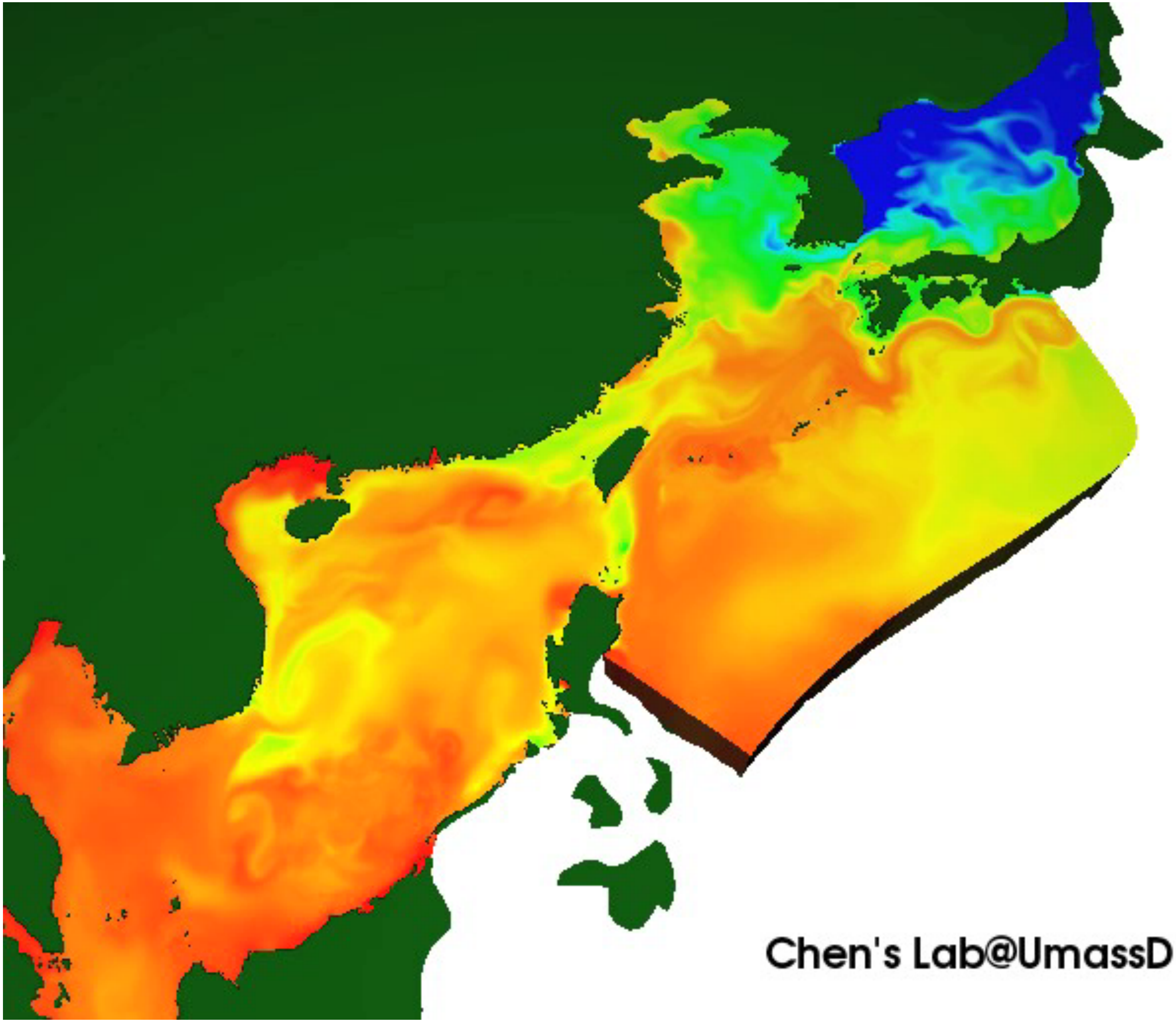
Note: the animation is from Rich Signell at USGS



0
-20.0
-40.0
-60.0
-80.0
-100.0
Stellwagen Bank
Chen's Lab@UmassD
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0



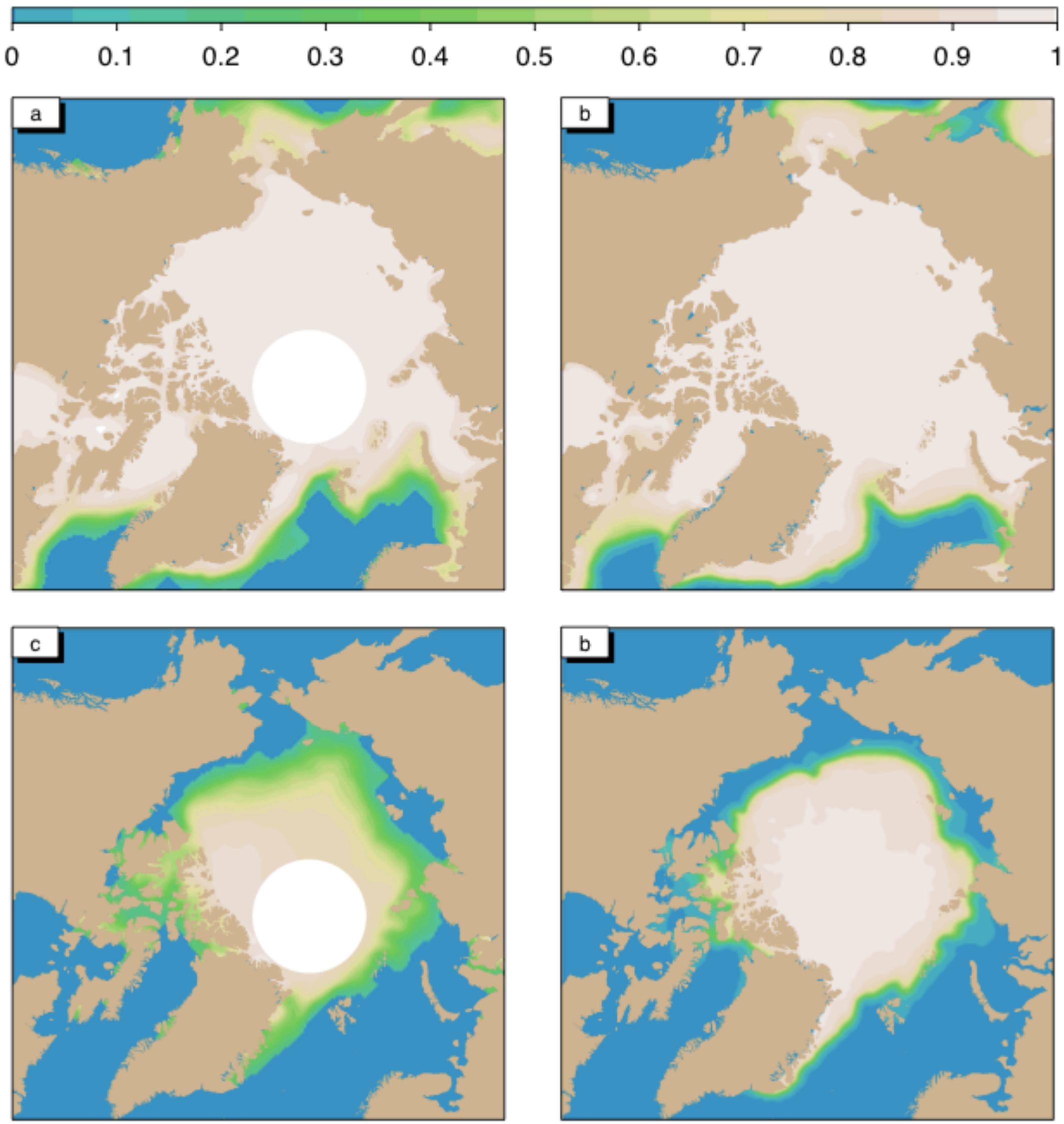
0
-20.0
-40.0
-60.0
-80.0
-100.0
Stellwagen Bank
Chen's Lab@UmassD
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
4
3.5
3
2.5
2
1.5


Chen's Lab@UmassD

Observed
(Averaged over 1979-94)

AO-FVCOM/UG-CICE

The sea ice concentration



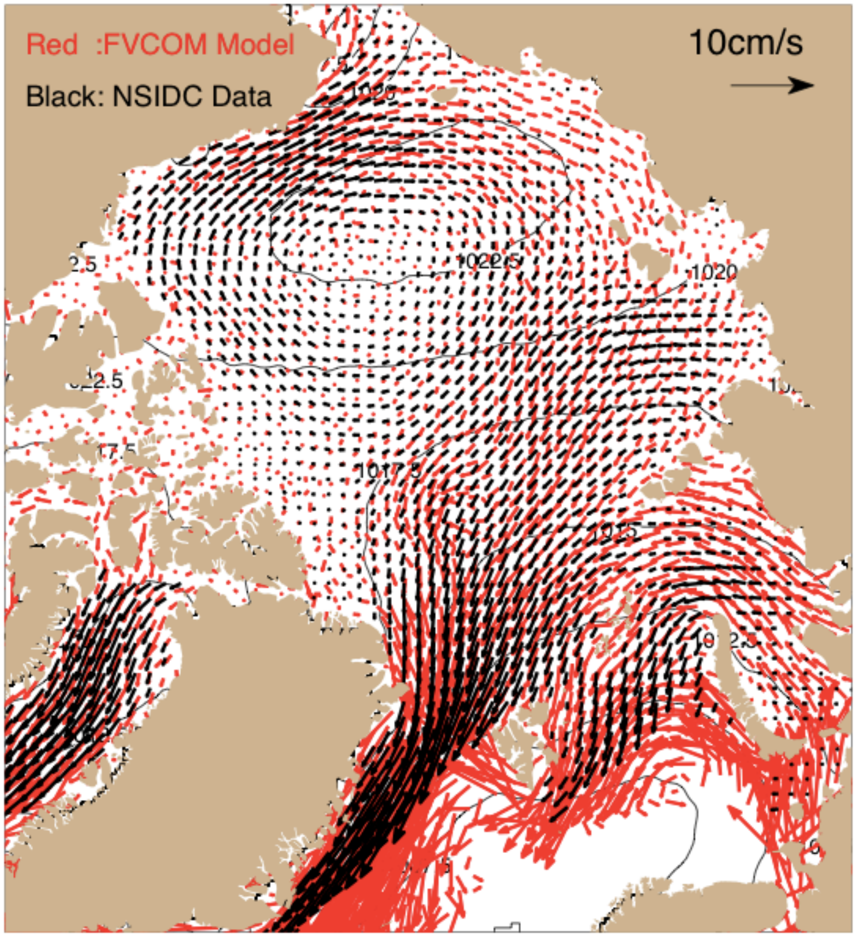
March

September

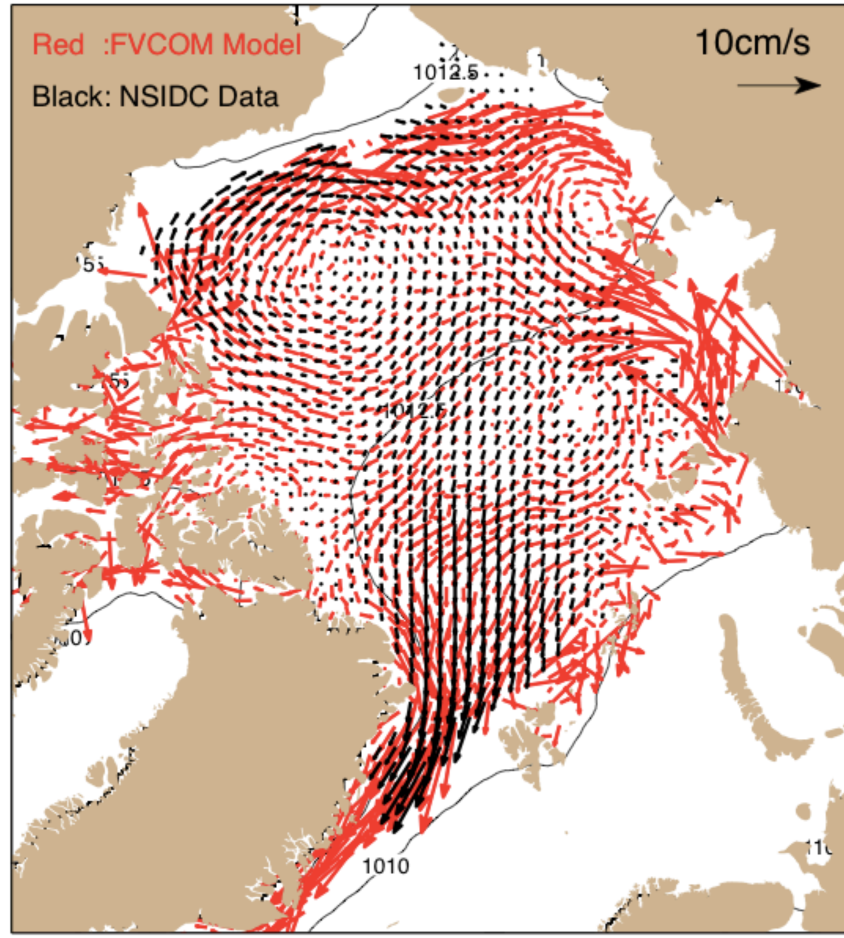
(WHOI)

The NSIDC data show the averaged drifting velocity over 1979-94
FVCOM model results were obtained with the climatologic forcing condition averaged over 1979-94

March



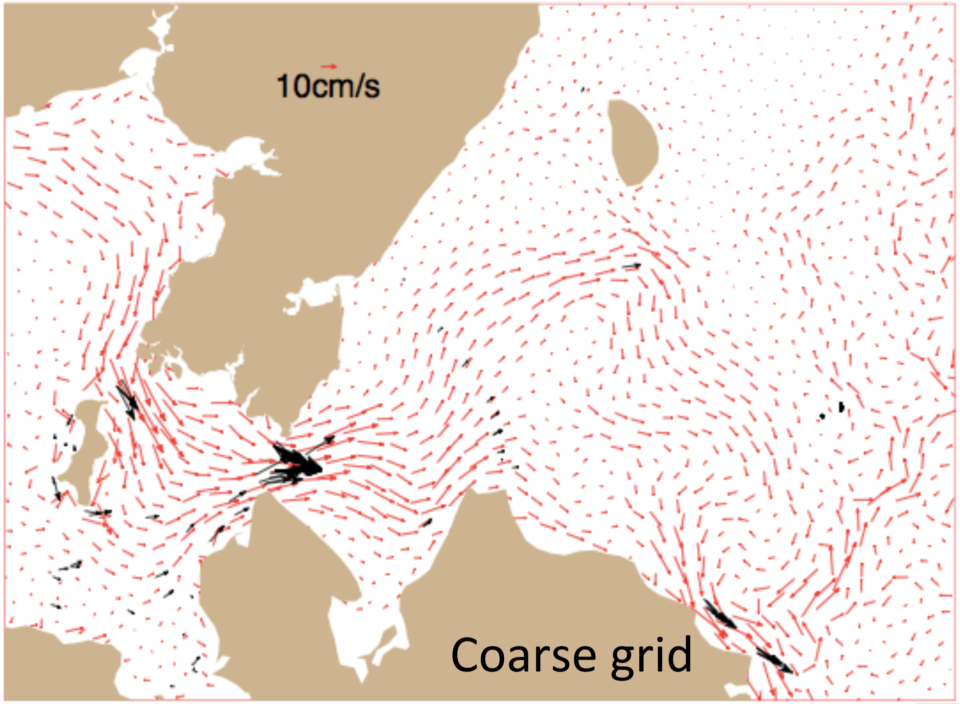
September



Chen, Gao (UMASSD), Beardsley (WHOI)

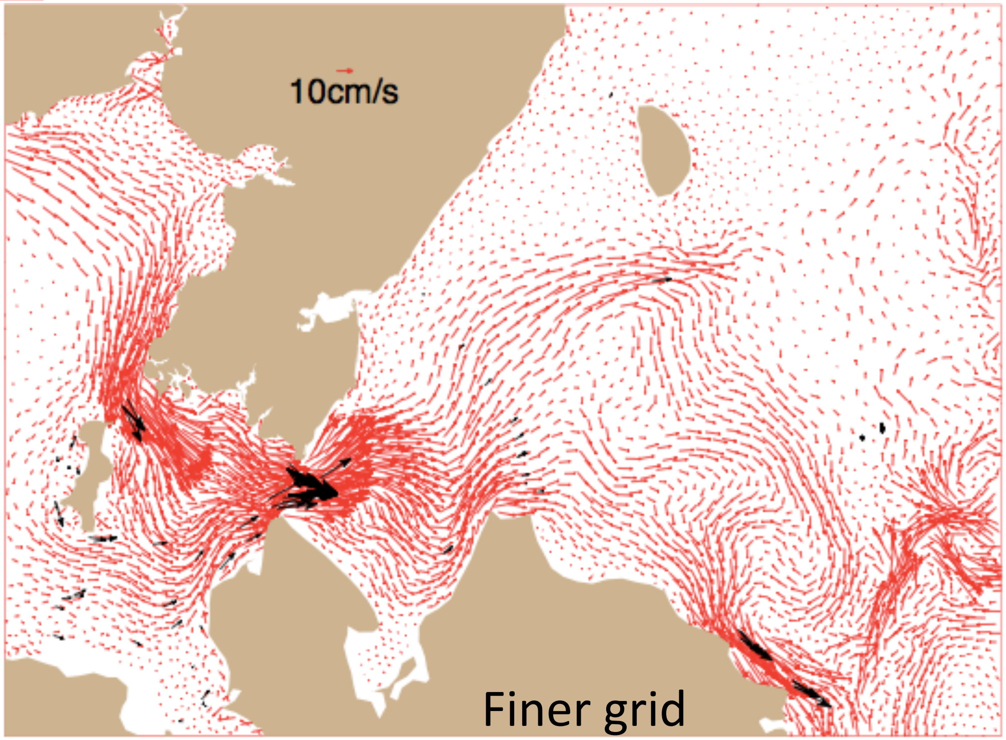
Bering Strait, Chukchi Sea and Alaska coast

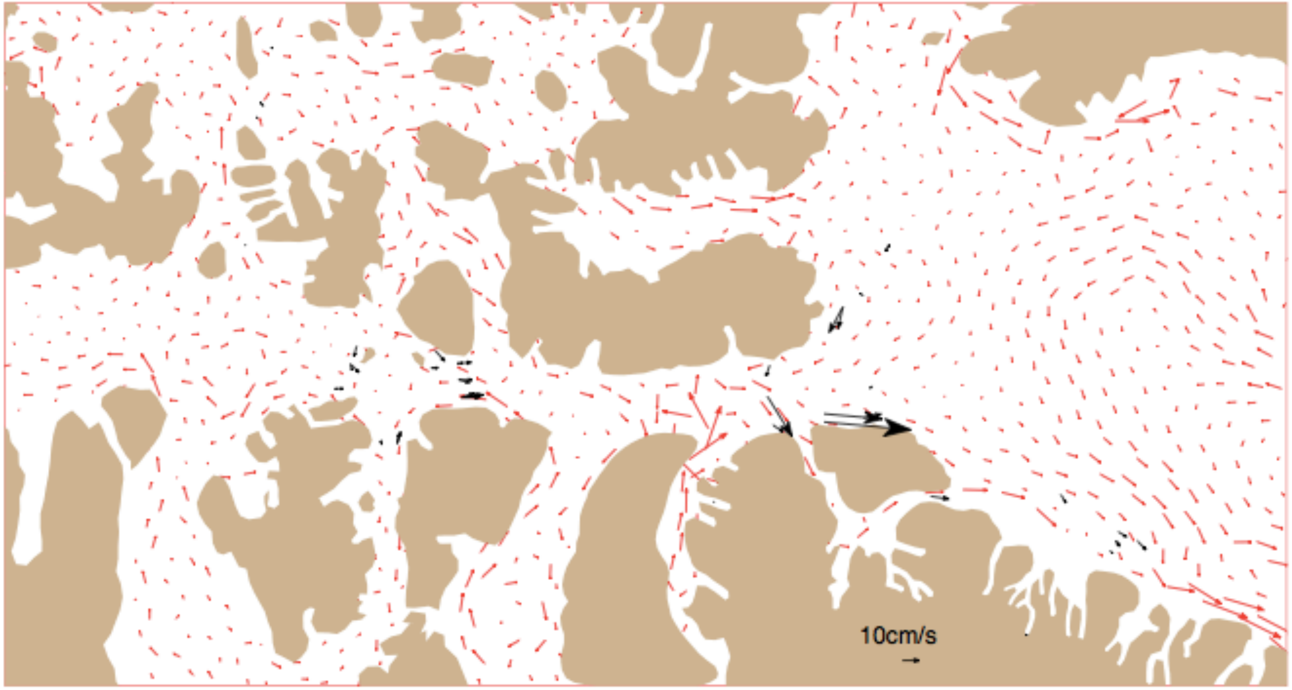
Annual mean vertically averaged currents in the depths of 0-50 m



Transports across Bering Strait:

0.8 Sv for the coarse grid case
1.1 Sv for the finer grid case



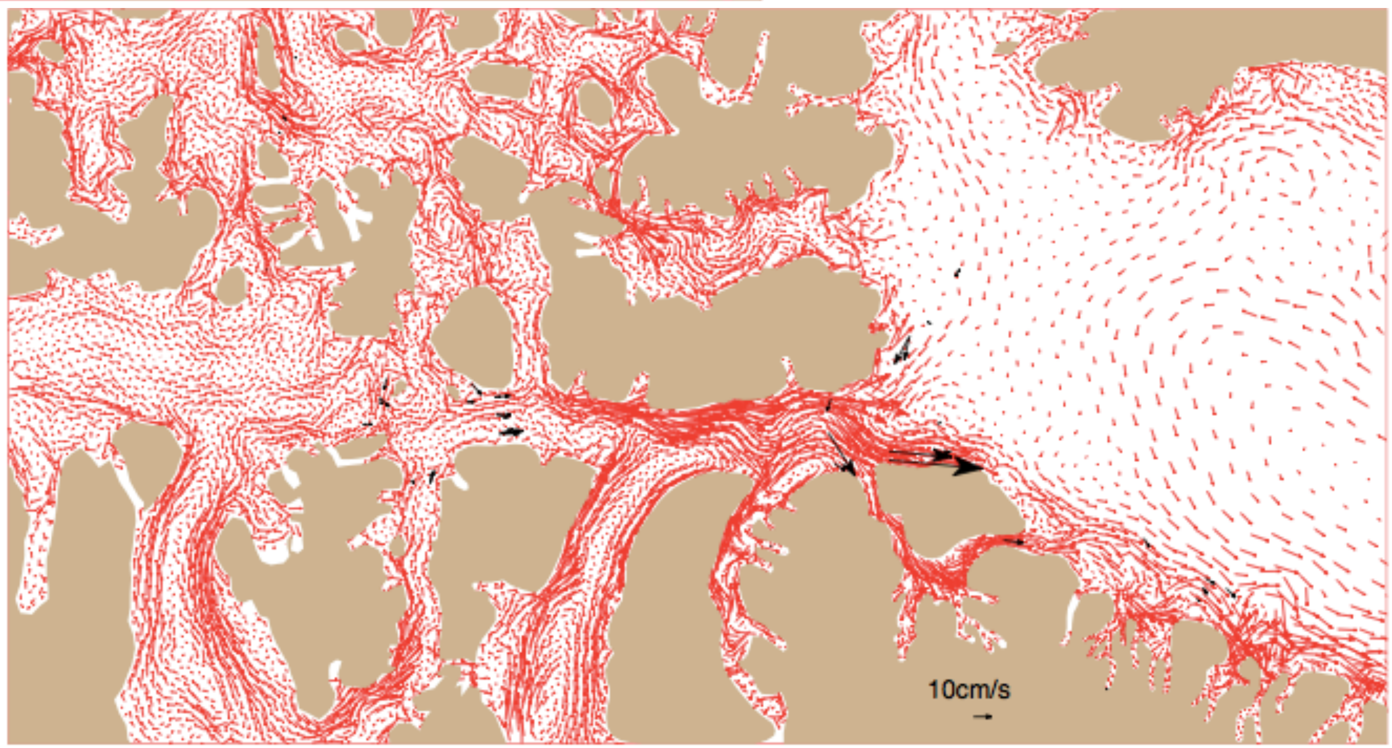


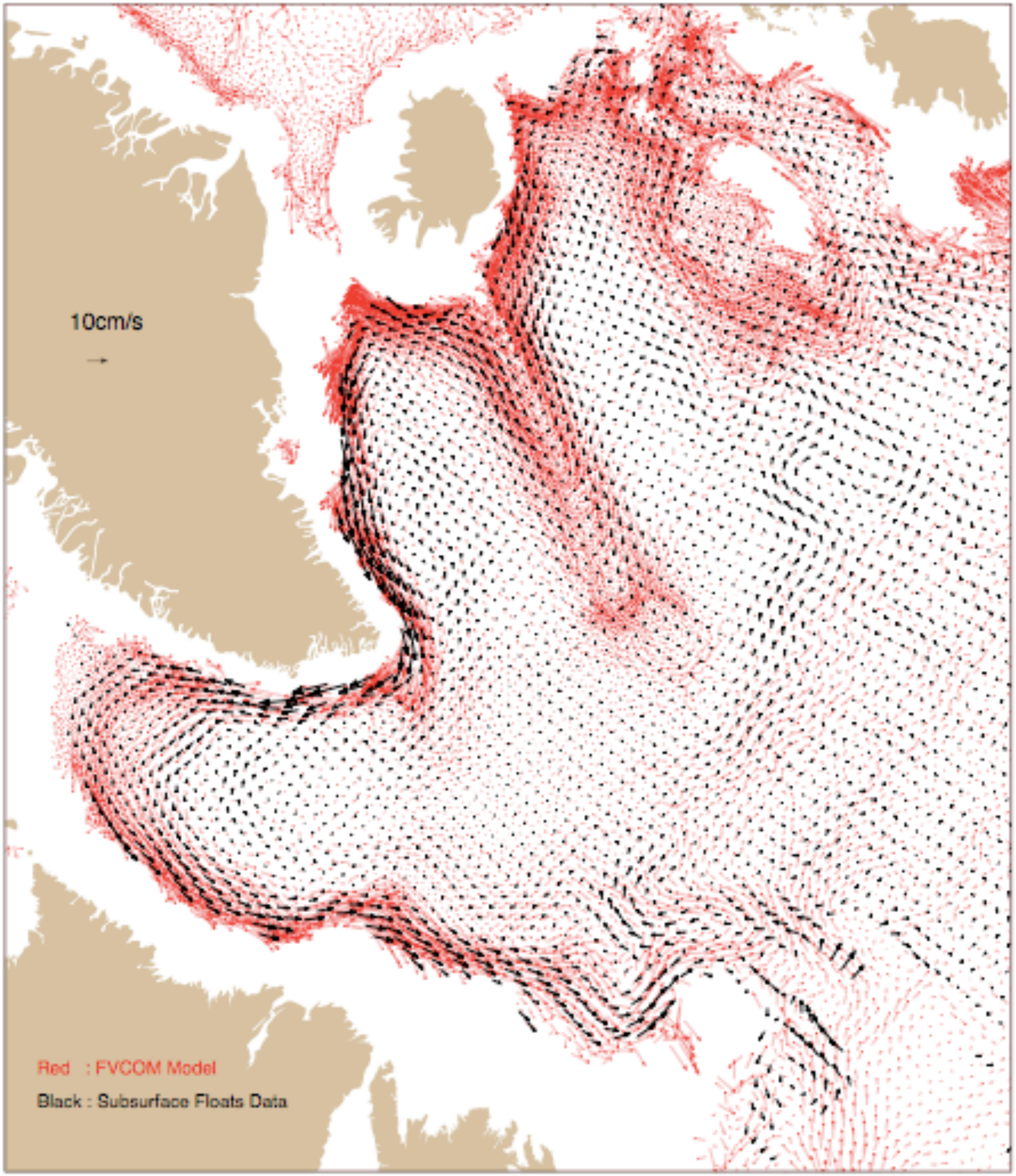
Canadian Archipelago

Annual mean vertically averaged currents in the depths of 0-50 m

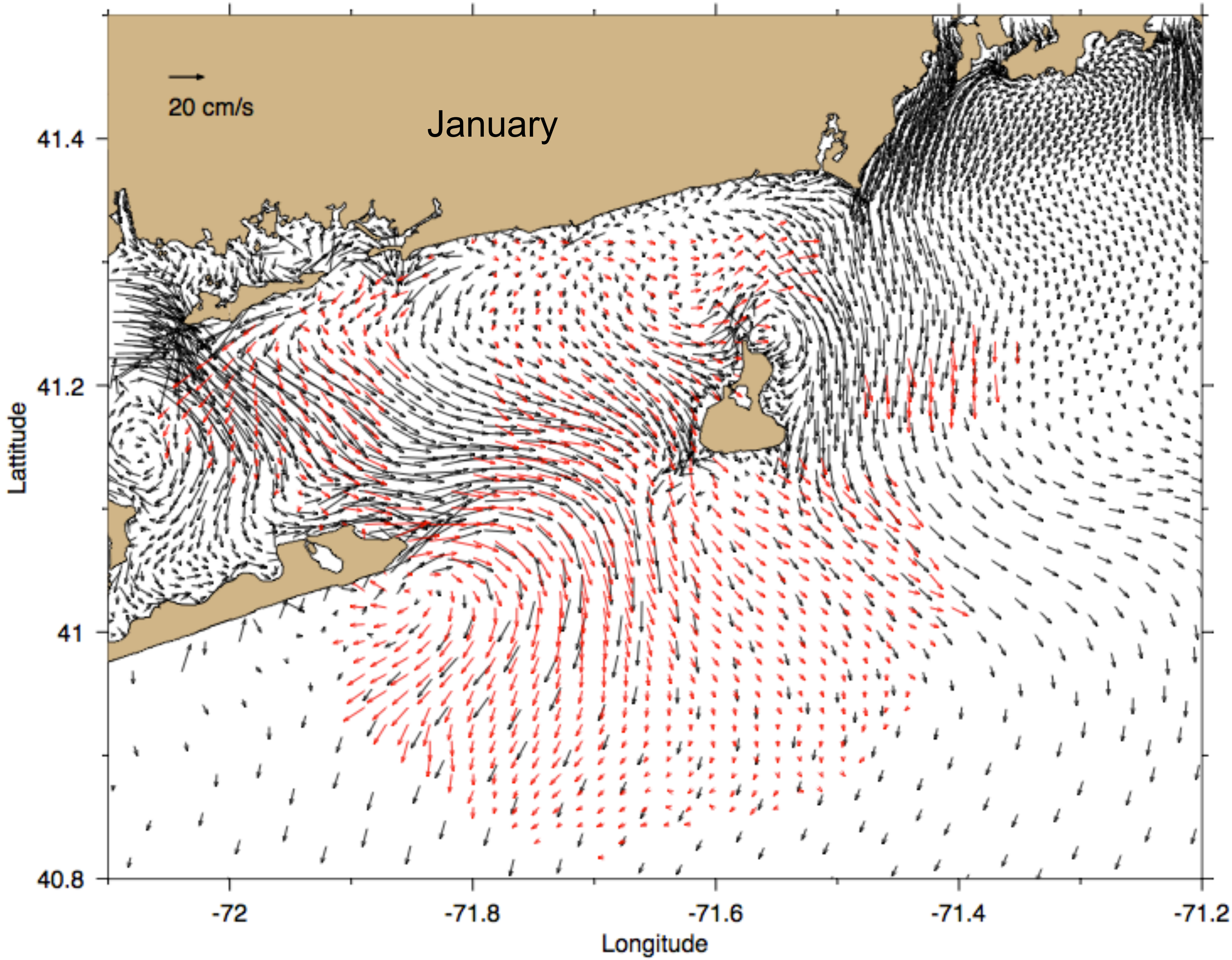
Coarse grid

Finer grid

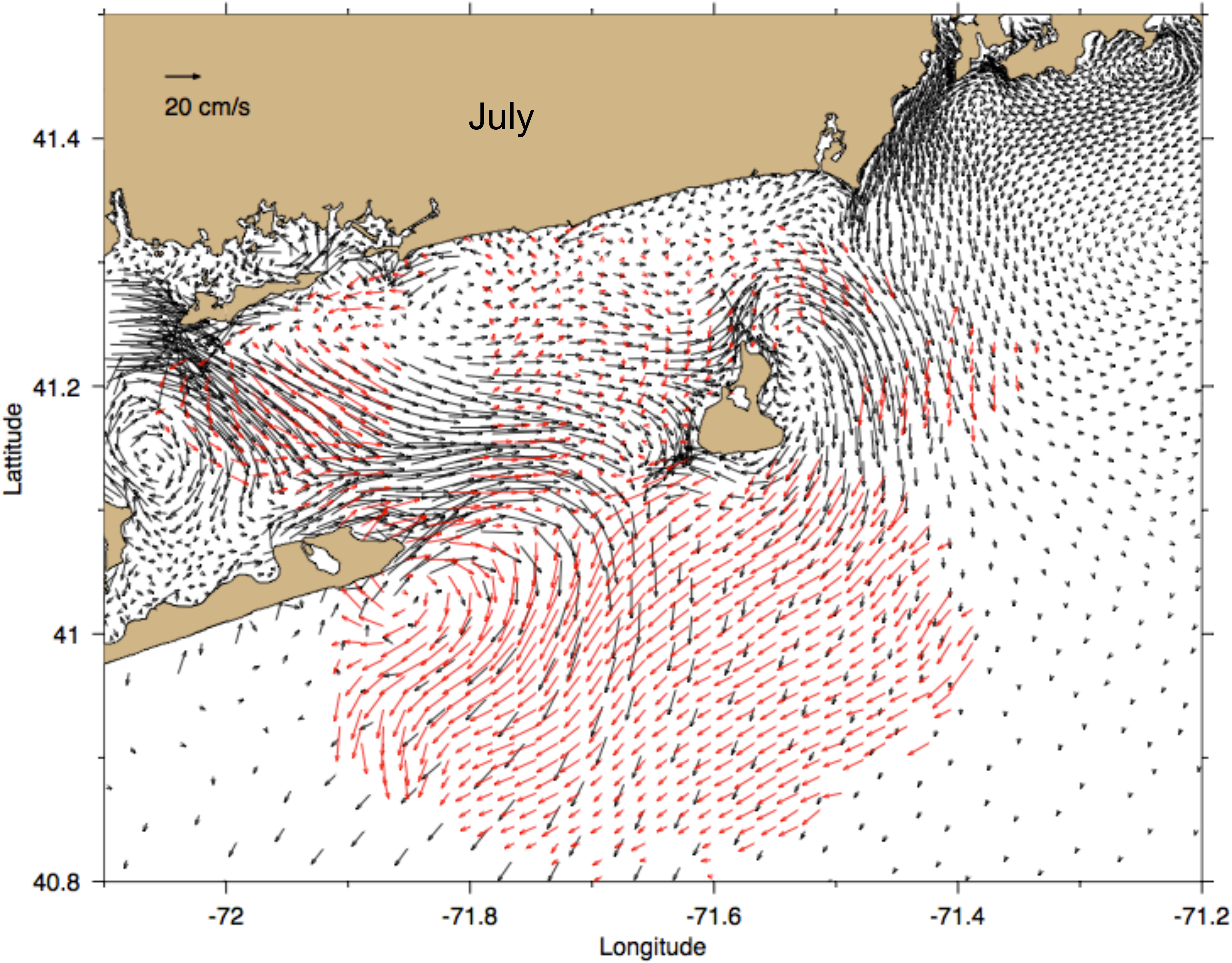




10cm/s
Red : FVCOM Model
Black : Subsurface Floats Data

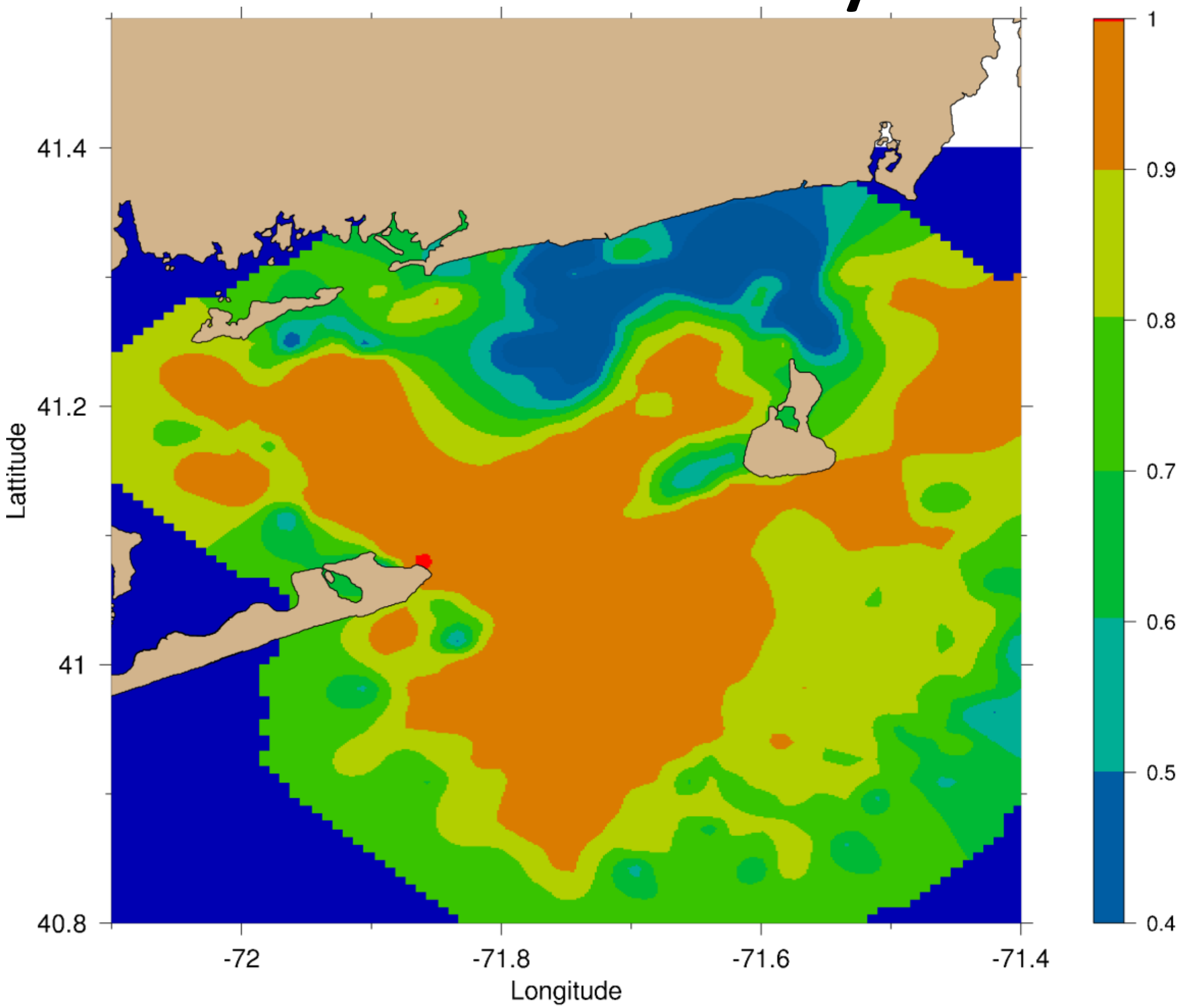


20 cm/s
January
41.4
41.2
41
40.8
Lattitude
-72
-71.8
-71.6
-71.4
-71.2
Longitude

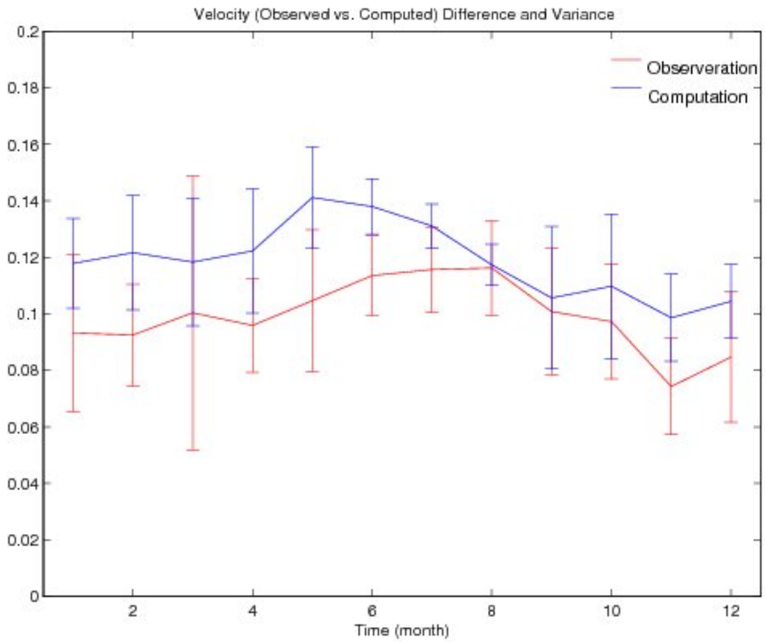


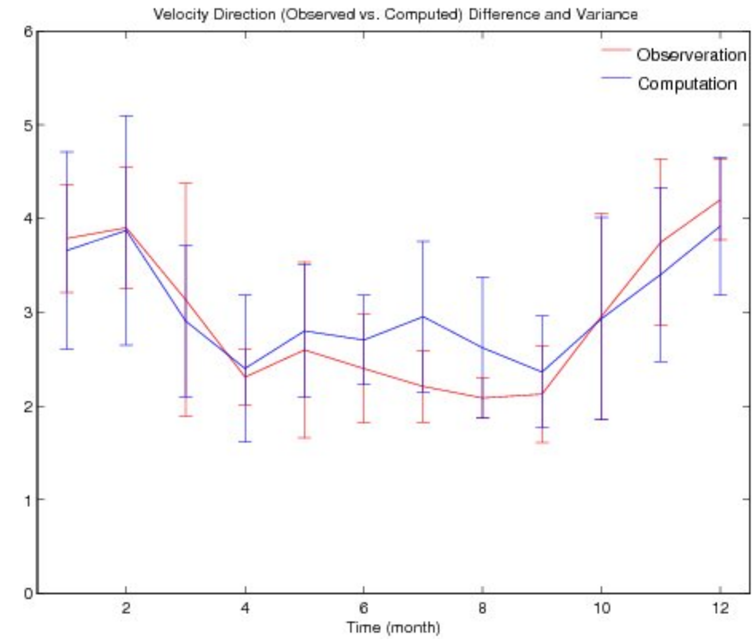
20 cm/s
July
41.4
41.2
41
40.8
Lattitude
-72
-71.8
-71.6
-71.4
-71.2
Longitude

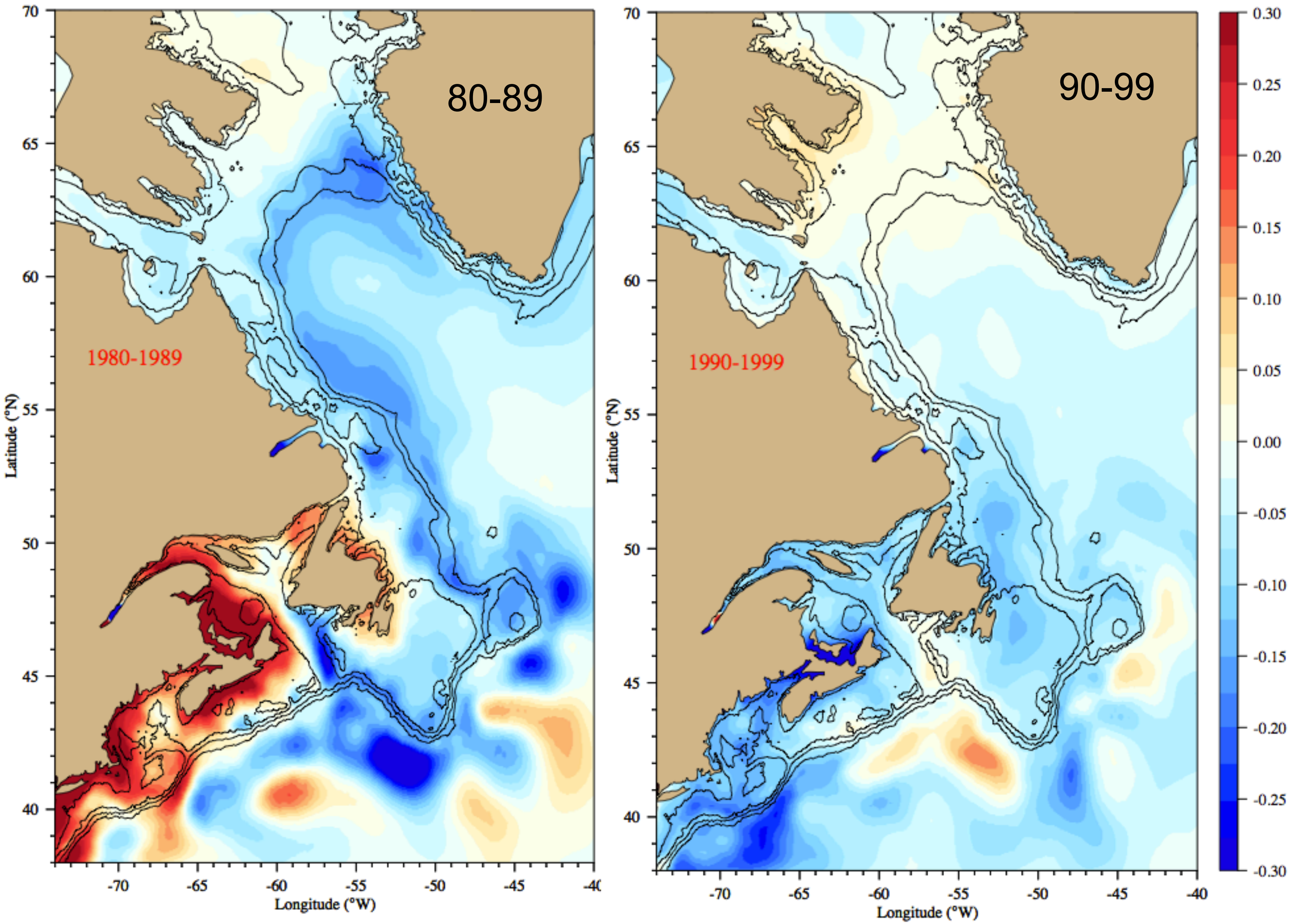
Coherence Analysis

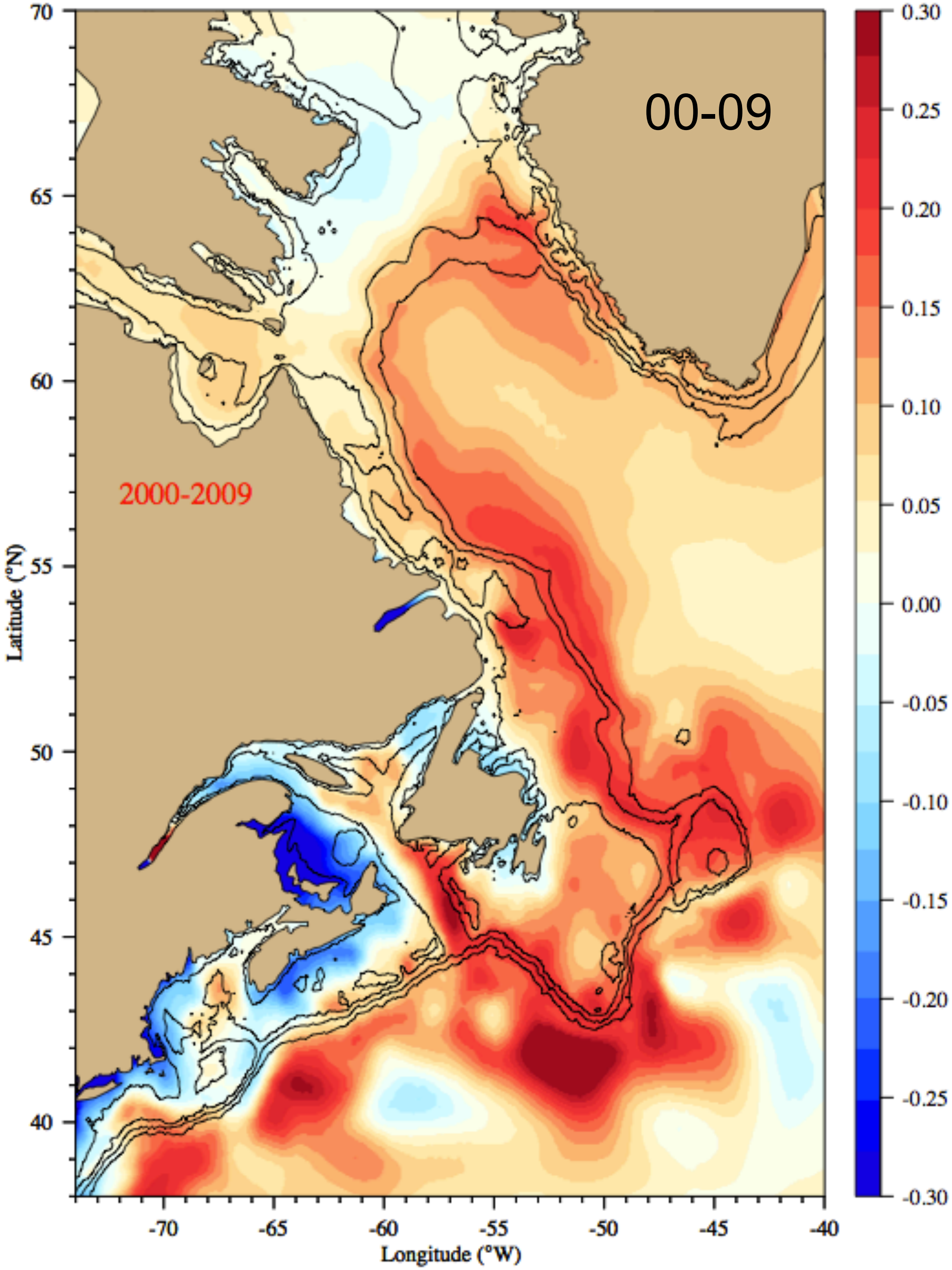


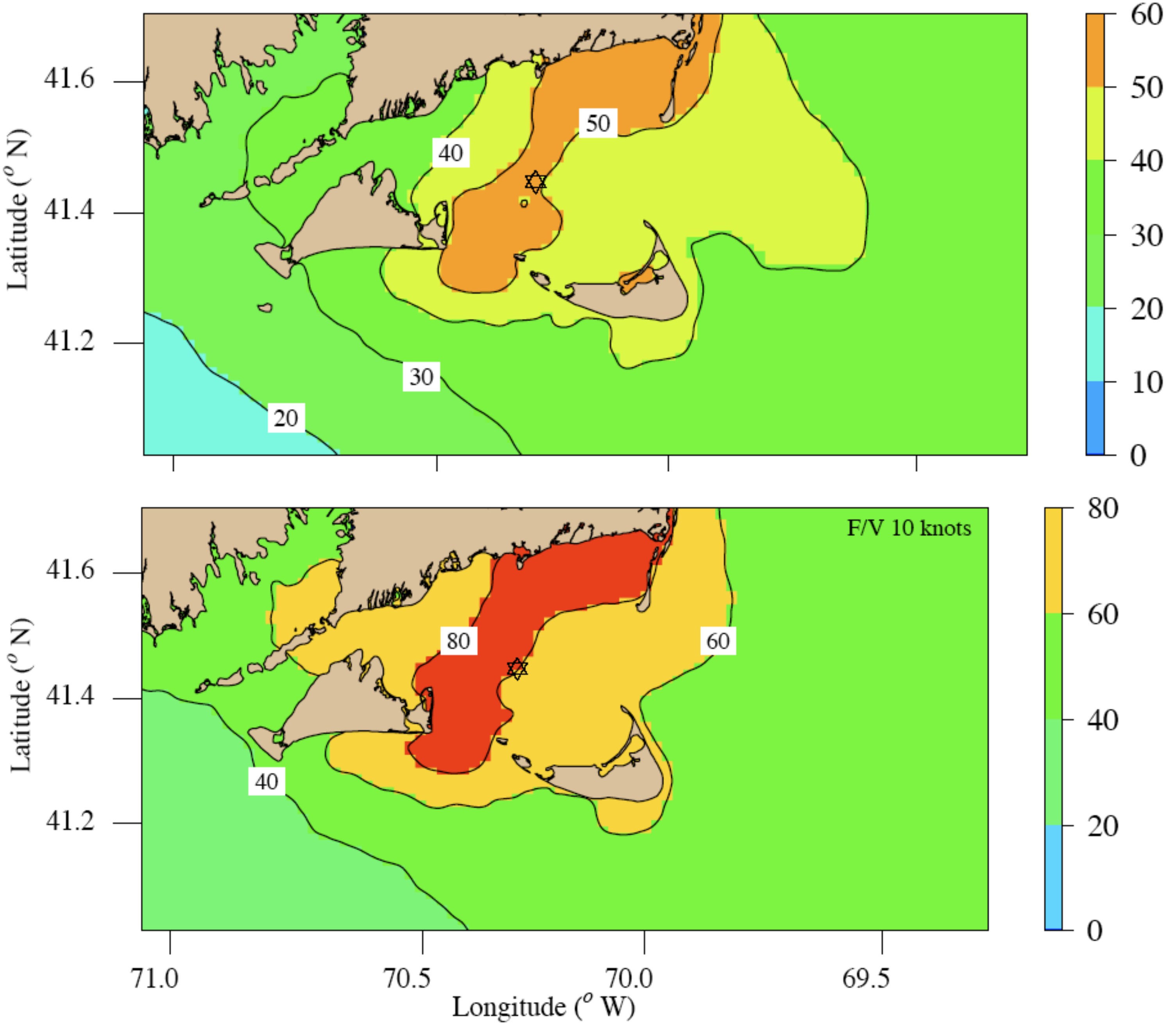
Velocity difference and variance





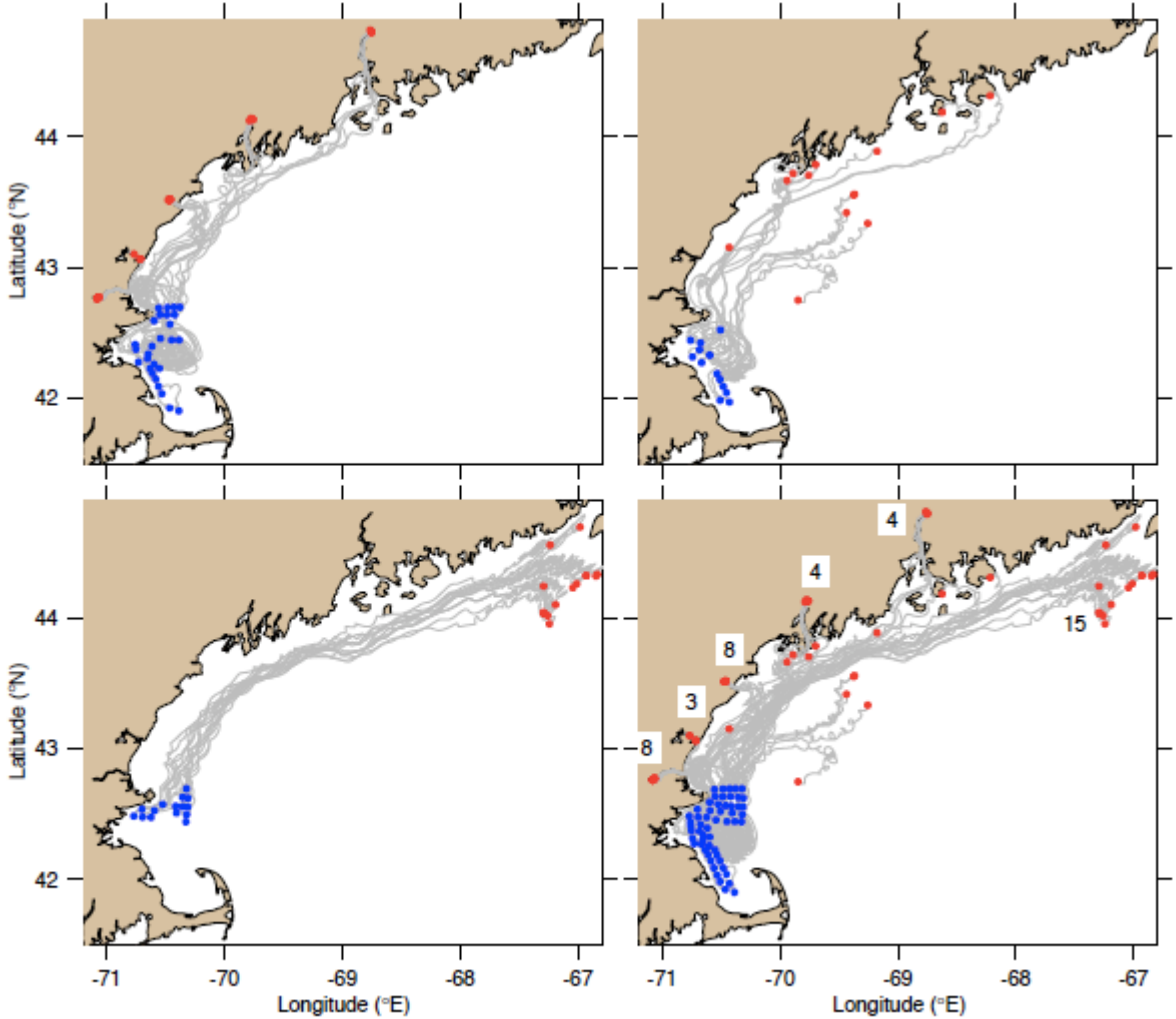

80-89
1980-1989
90-99
1990-1999
Latitude (°N)
Longitude (°W)
70
65
60
55
50
45
40
-70
-65
-60
-55
-50
-45
-40
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30


00-09
2000-2009
Latitude (°N)
Longitude (°W)
70
65
60
55
50
45
40
-70
-65
-60
-55
-50
-45
-40
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30

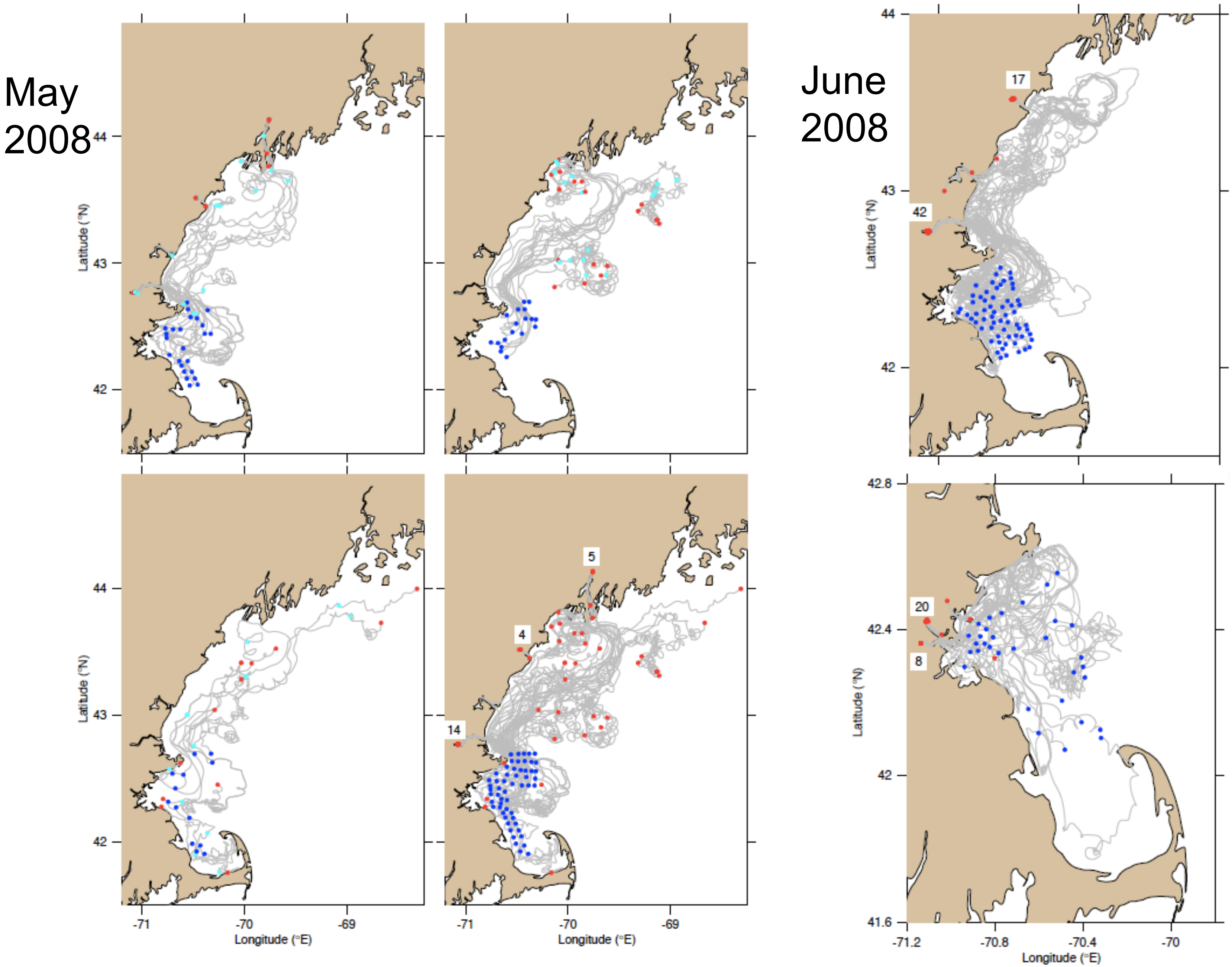


41.6
41.4
41.2
Latitude (° N)
50
40
30
20
60
50
40
30
20
10
0
F/V 10 knots
80
60
40
80
60
40
20
0
71.0
70.5
70.0
69.5
Longitude (° W)

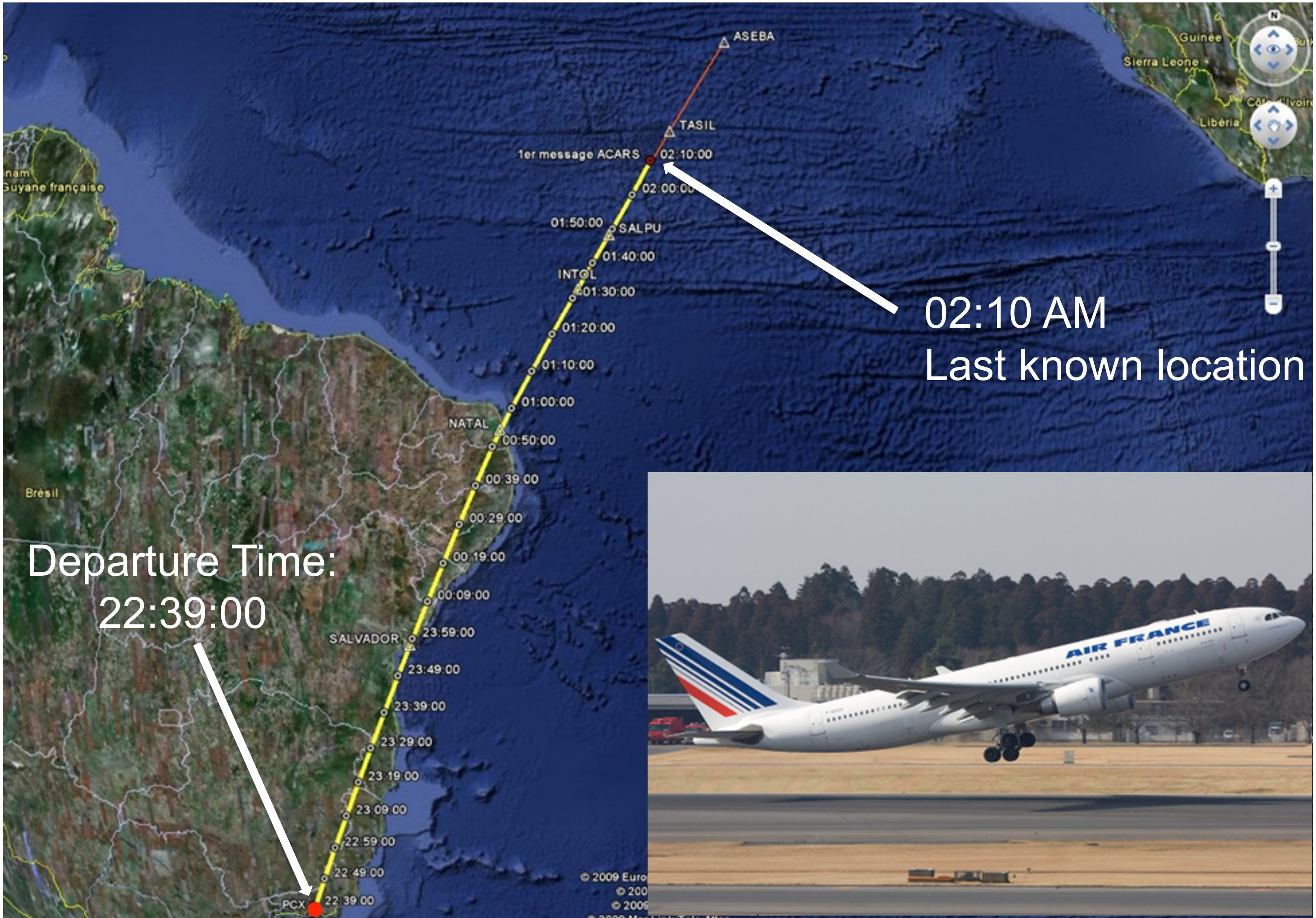
2005 May HABs in the Gulf of Maine/Mass Bay



2008 May and June HABs in the GOM/Mass Bay

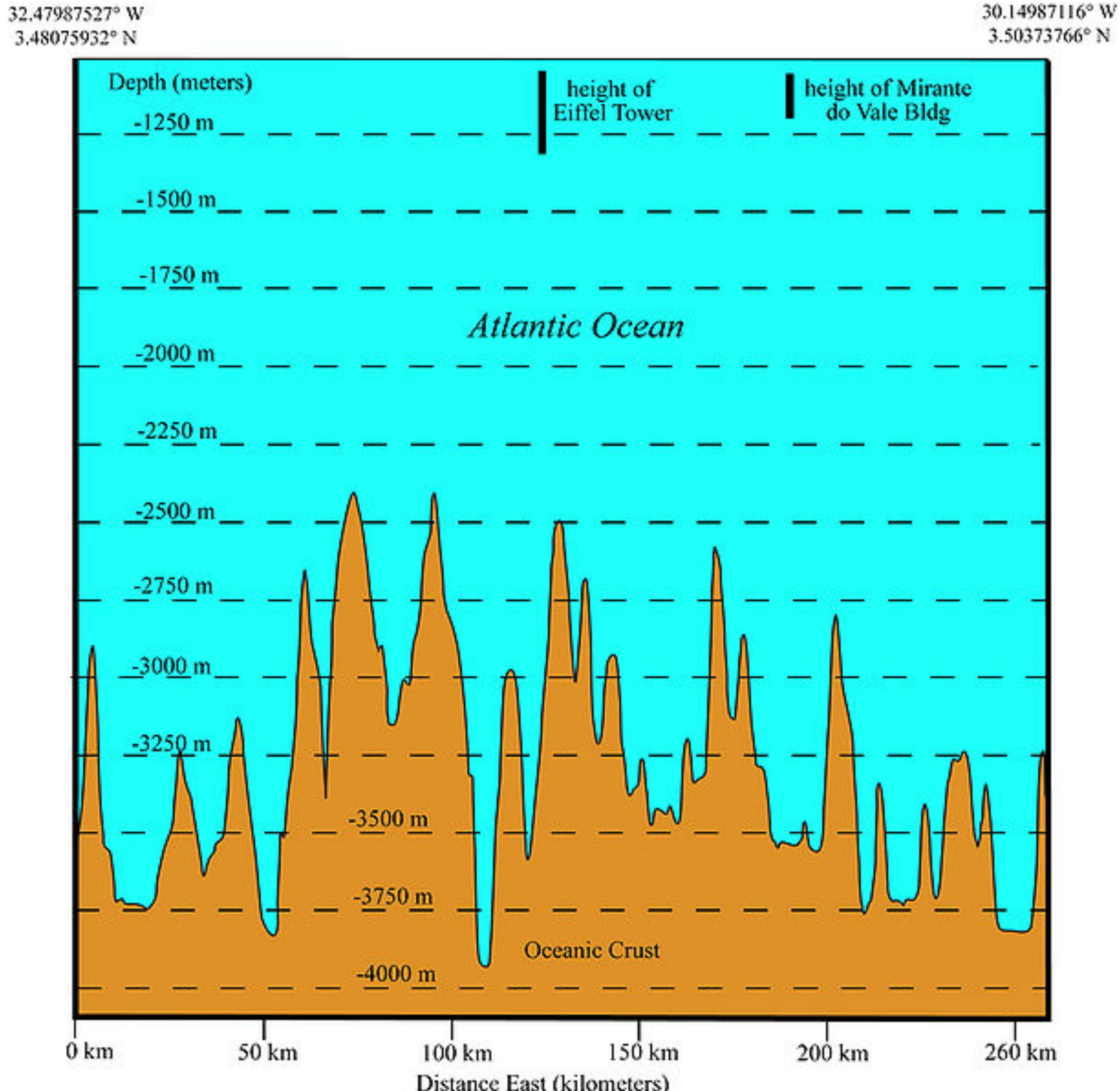


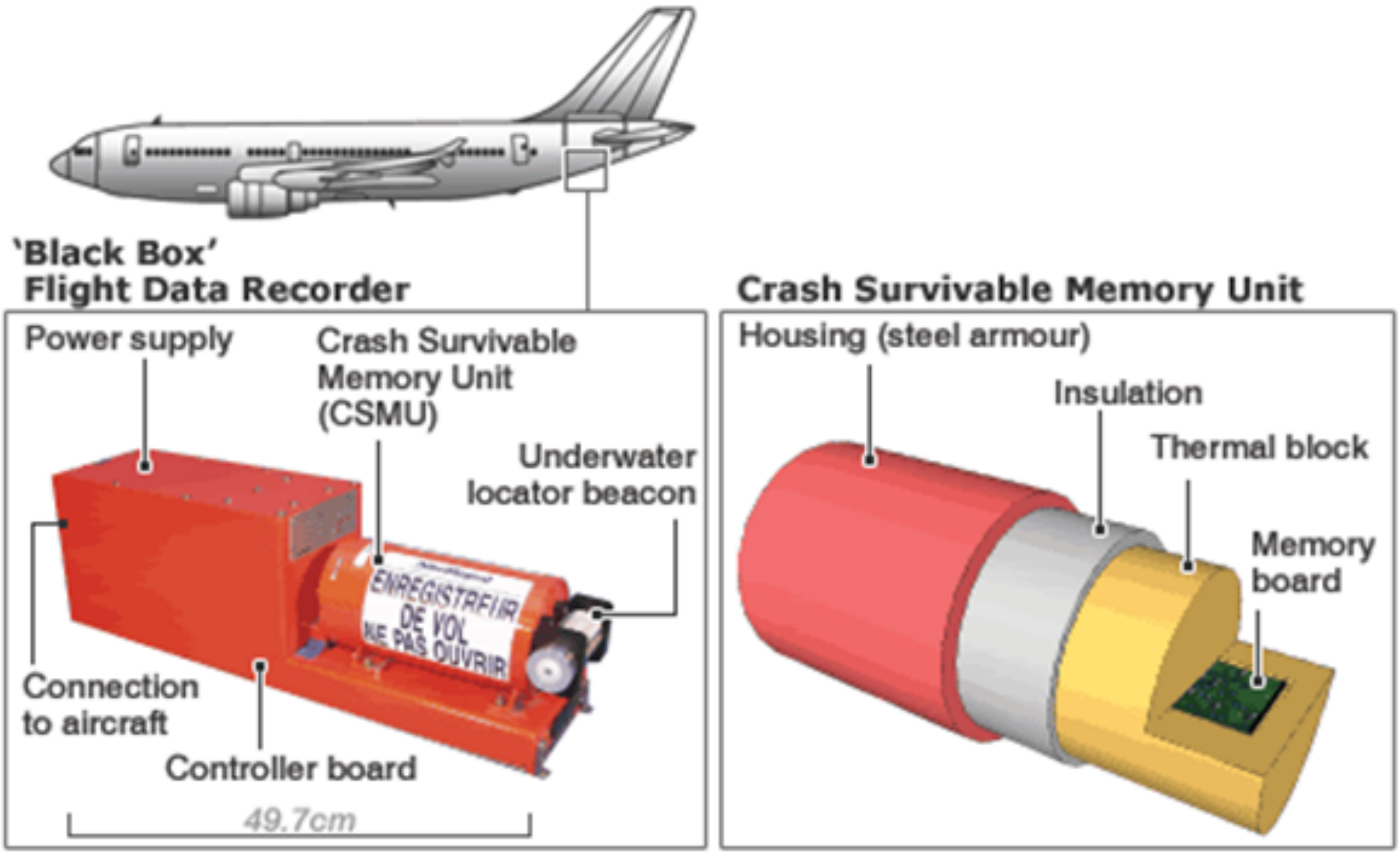
Flight AF 447   A330-203, F-GZCP
Rio de Janeiro – Paris   June 1, 2009



Marinha do Brasil


F CONSTITUICAO


32.47987527° W
3.48075932° N
30.14987116° W
3.50373766° N
Depth (meters)
height of Eiffel Tower
height of Mirante do Vale Bldg
-1250 m
-1500 m
-1750 m
Atlantic Ocean
-2000 m
-2250 m
-2500 m
-2750 m
-3000 m
-3250 m
-3500 m
-3750 m
-4000 m
Oceanic Crust
0 km
50 km
100 km
150 km
200 km
260 km
Distance East (kilometers)

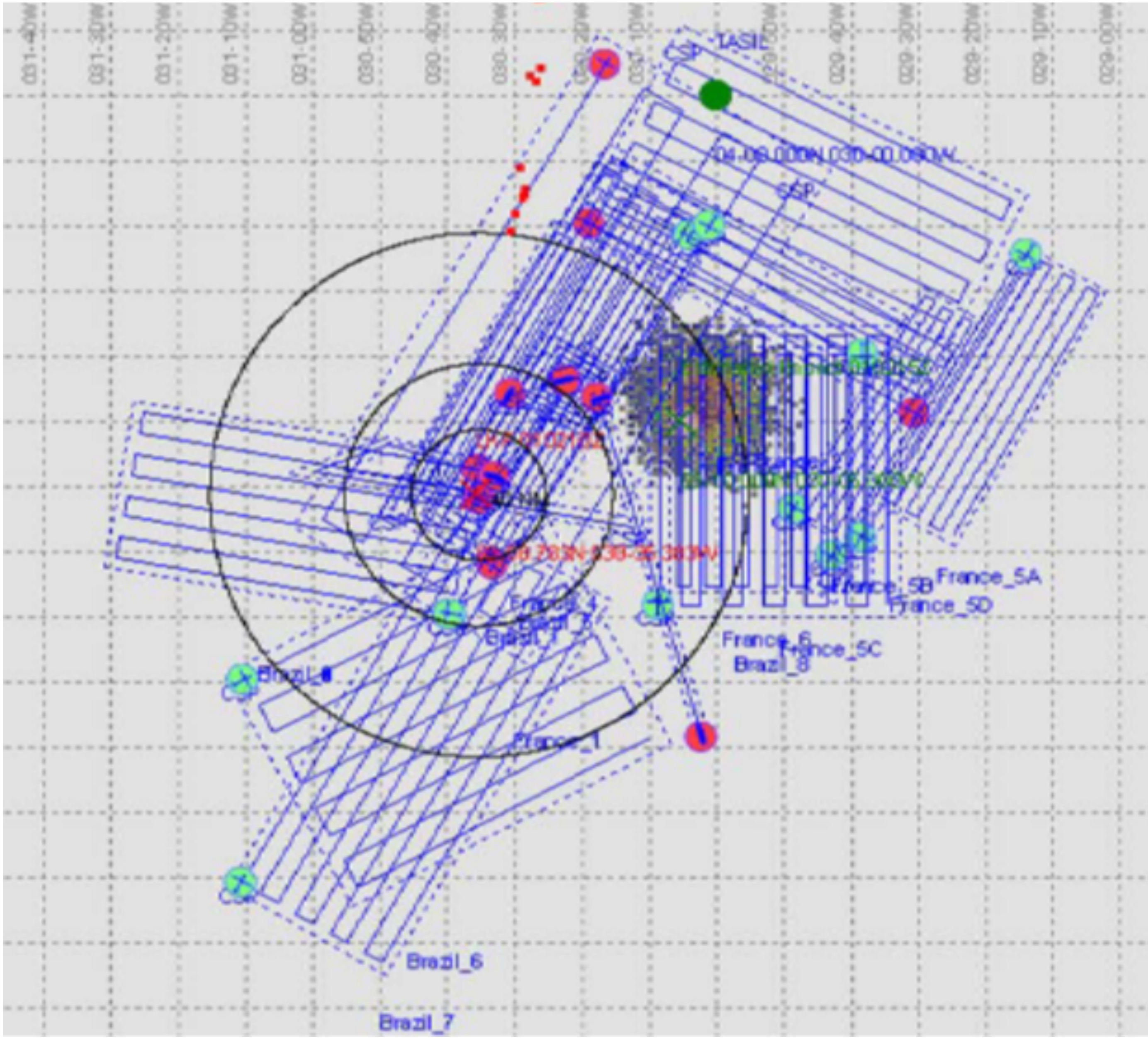

'Black Box'
Flight Data Recorder
Power supply
Crash Survivable
Memory Unit
(CSMU)
Underwater
locator beacon
ENREGISTREUR
DE VOL
NE PAS OUVRIR
Connection
to aircraft
Controller board
49.7cm
Crash Survivable Memory Unit
Housing (steel armour)
Insulation
Thermal block
Memory
board

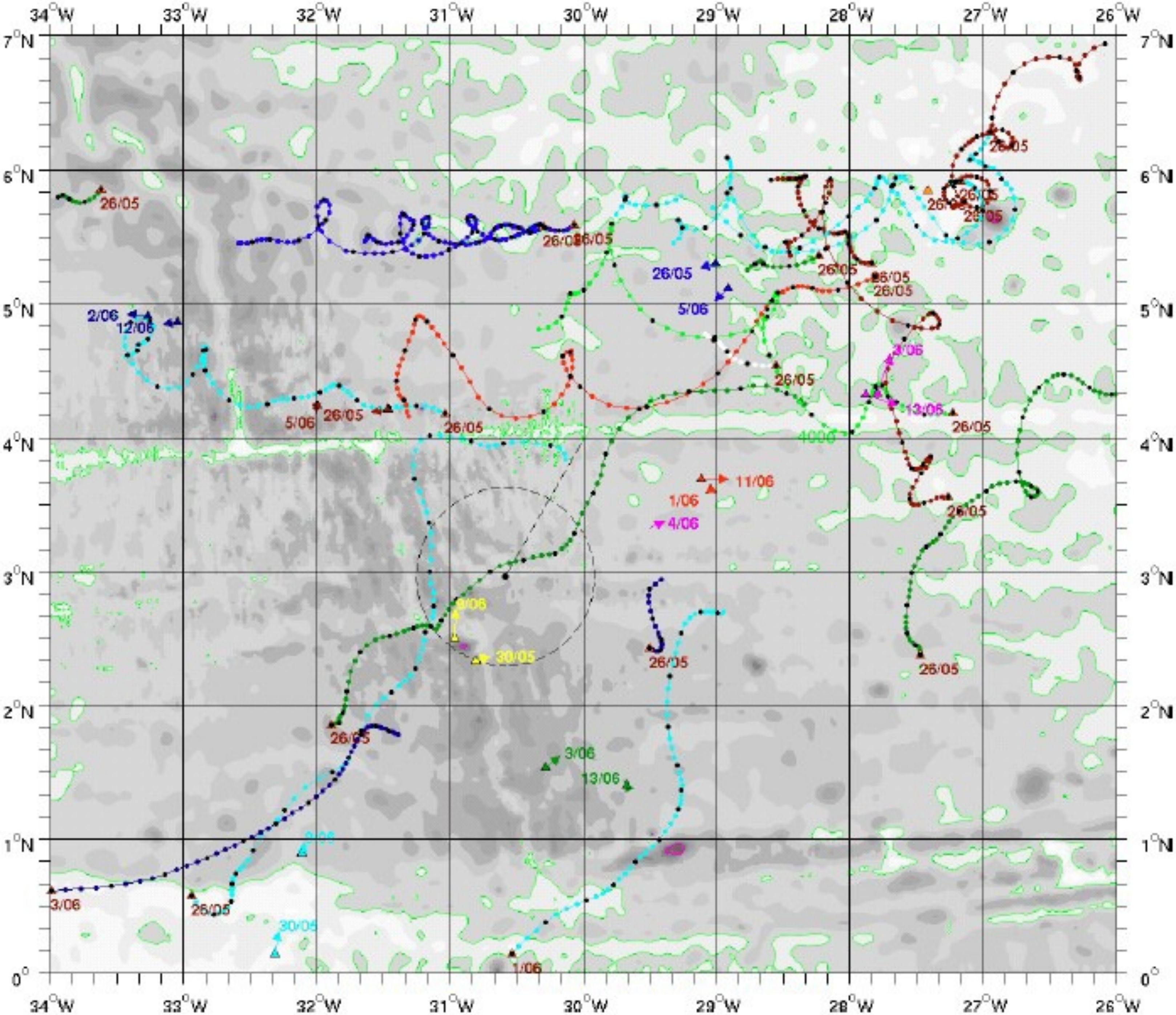
First Search

- Use the global ocean forecast model to track the debris reversely to determine where the plane probably was.

1. **G-NCOM-Global Navy Coastal Ocean Model**
2. **US Navy Global Ocean Model (HYCOM)**
3. **French Atlantic Ocean Model (MERCATOR)**

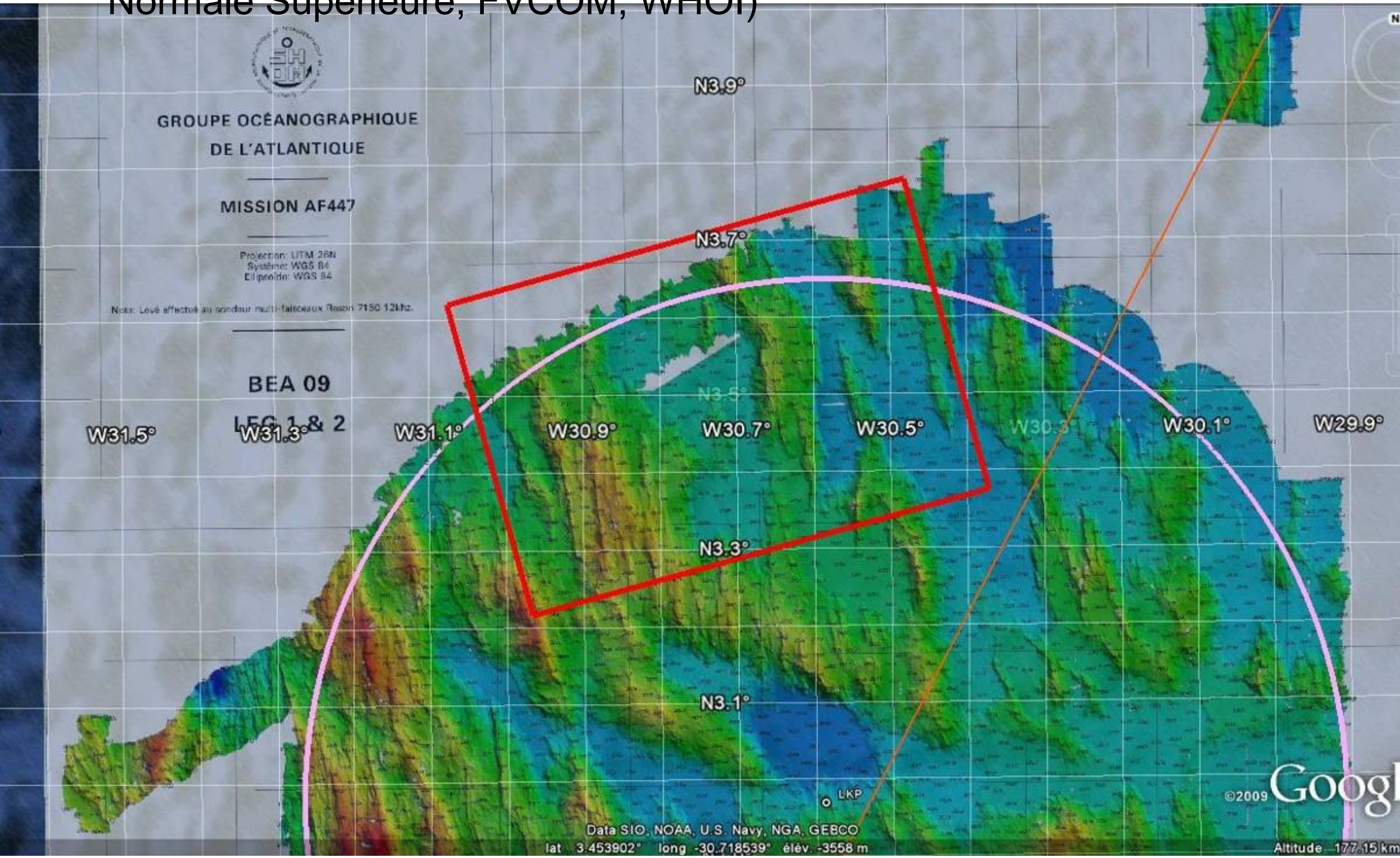
Why did it take 6 days to find the surface debris?



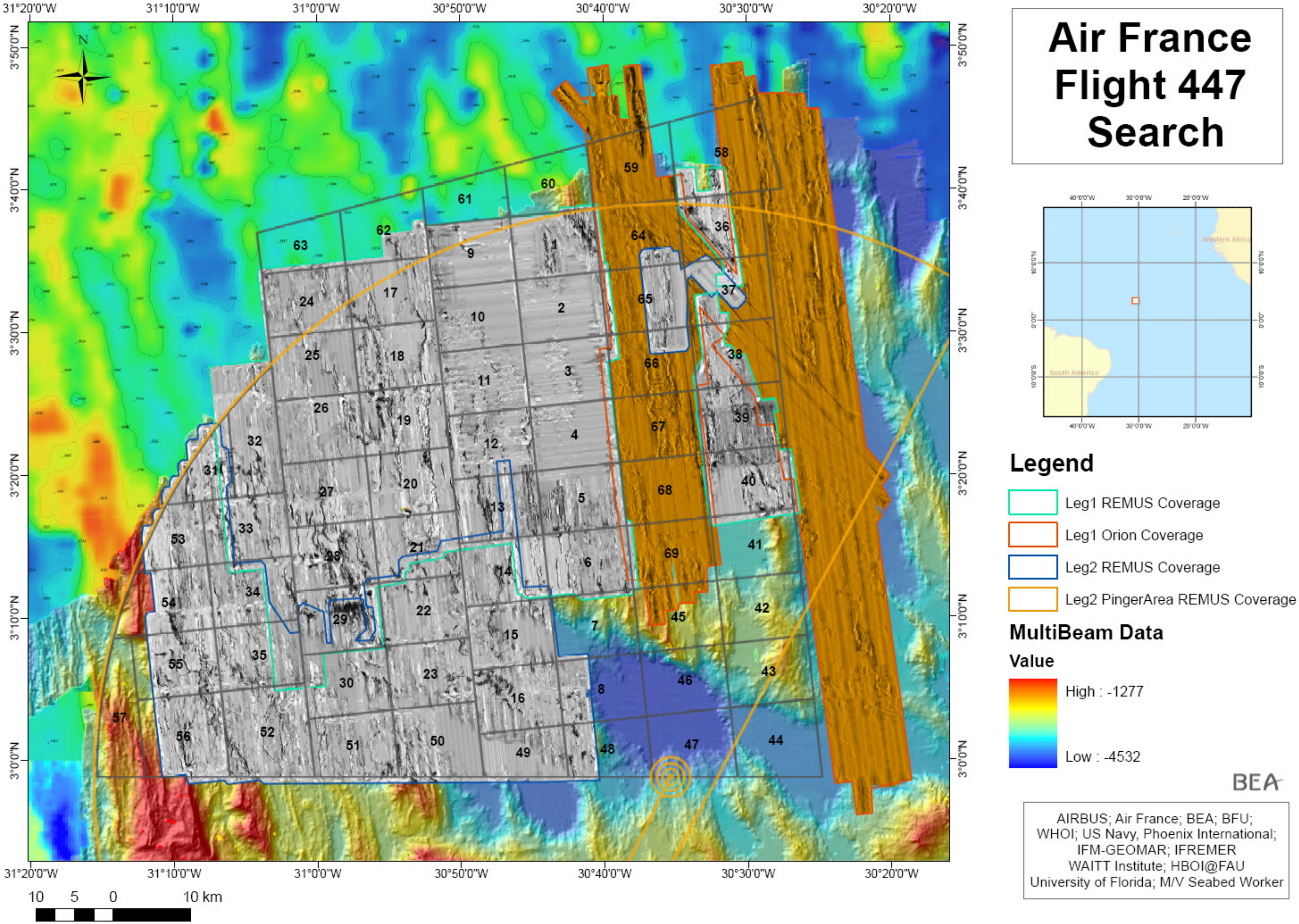


34°W
33°W
32°W
31°W
30°W
29°W
28°W
27°W
26°W
7°N
6°N
5°N
4°N
3°N
2°N
1°N
0°
26/05
2/06
12/06
5/06
1/06
11/06
4/06
3/06
13/06
9/06
30/05
4000

Phase 3 International Modeling Group (Mercator, IOS Southampton, CLS, Meteo France, Ifremer, UBrest, SHOM, INM Russia, Ecole Normale Supérieure, FVCOM, WHOI)



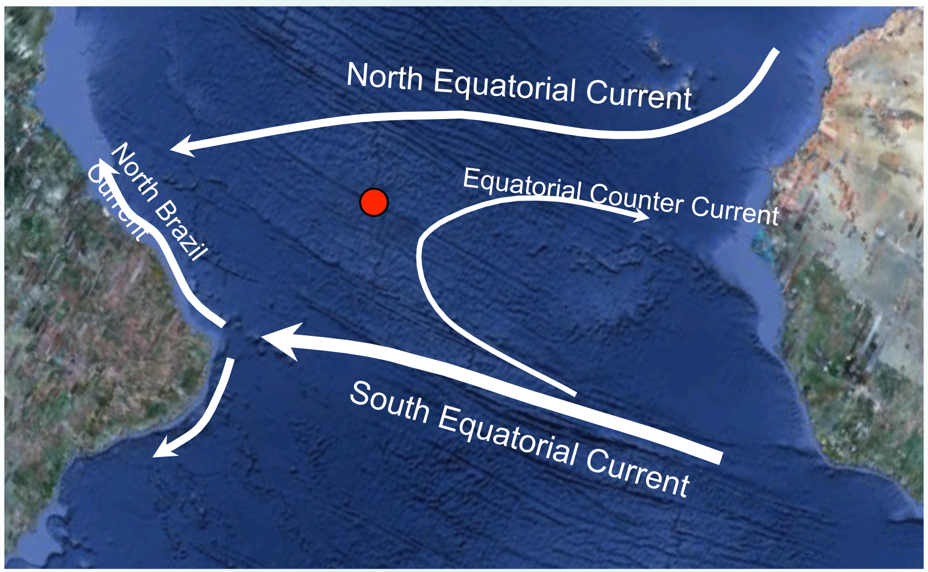

WAITT INSTITUTE



Air France Flight 447 Search
Legend
Leg1 REMUS Coverage
Leg1 Orion Coverage
Leg2 REMUS Coverage
Leg2 PingerArea REMUS Coverage
MultiBeam Data
Value
High : -1277
Low : -4532
BEA
AIRBUS; Air France; BEA; BFU;
WHOI; US Navy, Phoenix International;
IFM-GEOMAR; IFREMER
WAITT Institute; HBOI@FAU
University of Florida; M/V Seabed Worker
31°20'0"W
31°10'0"W
31°0'0"W
30°50'0"W
30°40'0"W
30°30'0"W
30°20'0"W
3°50'0"N
3°40'0"N
3°30'0"N
3°20'0"N
3°10'0"N
3°0'0"N
10 5 0 10 km
N
Western Africa
South America

Background and Requirement for Model Simulation

Background oceanic environment



- In a range of the inter-tropic wind convergence zone
- Near-surface currents varies significantly with time and in space;

Requirement for model simulation

- Accurate meteorological forcing (winds, air-pressure ; heat flux, etc)
- Resolve the meso-scale variability of the sea surface elevation (or Sea Surface Height-SSH)
- Reproduce the surface mixed layer
- ….

Difficulties for Modeling

1. We have no well-validated meteorological forcing conditions

   1) Blended winds-from multi-satellite measurements
   http://www.ncdc.noaa.gov/oa/rsad/air-sea.html

   2) NCEP reanalysis global winds (~ one degree)
   https://dss.ucar.edu/datazone/dsszone/ds083.2/index.html

   3) ECMWF global winds

2. No high-resolution satellite-derived SST and SSH available in the local region to resolve short-term and meso-scale variations

   1) SST: ~8 km (but it is constructed from multi-day data)

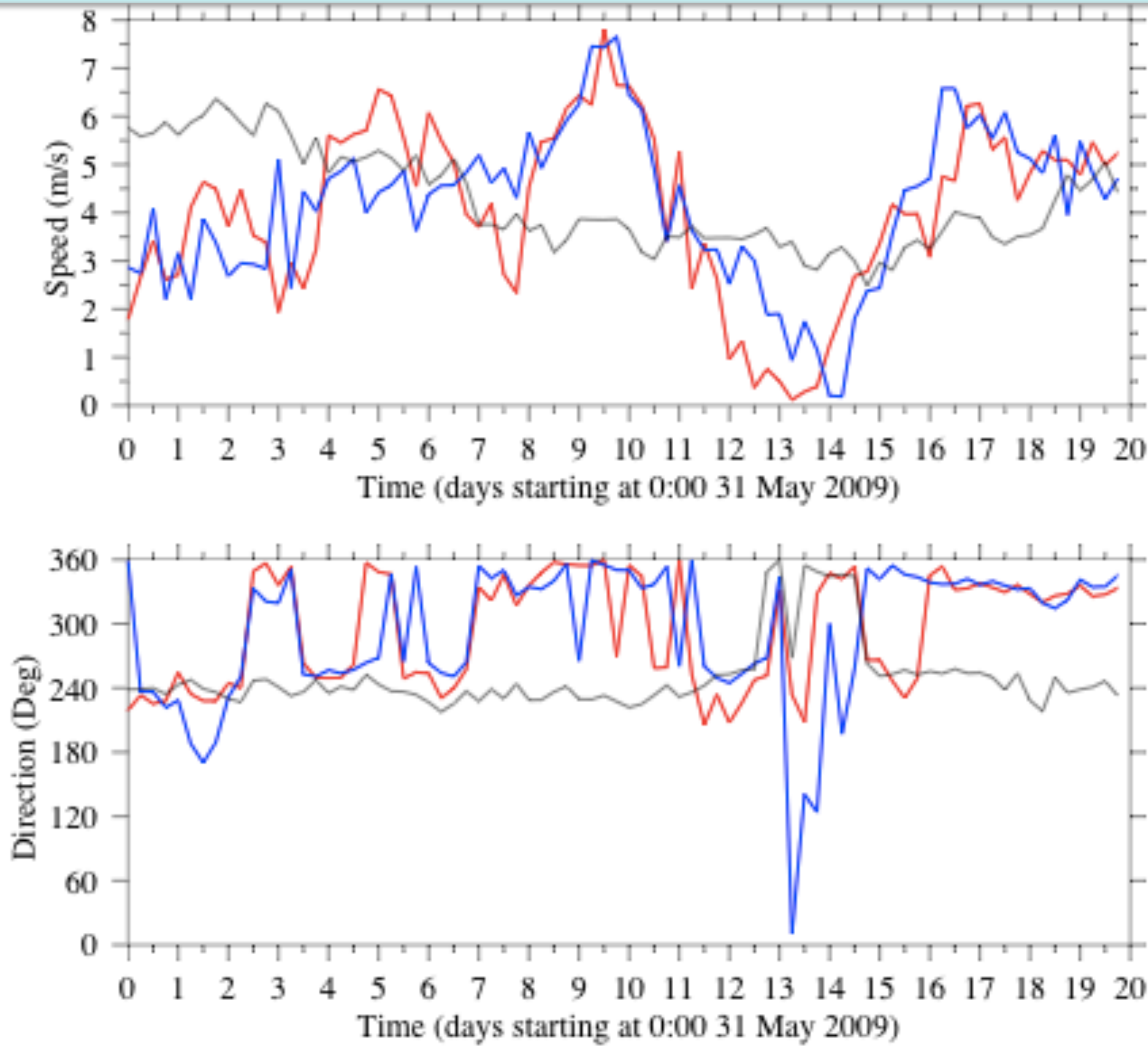
   2) SSH: ~every 7 days (do have daily date from March-June, 2009) and ~30 km
   (http://www.aviso.oceanobs.com/en/data/products/sea-surface-height-products/)

3. No sufficient local data to validate the model

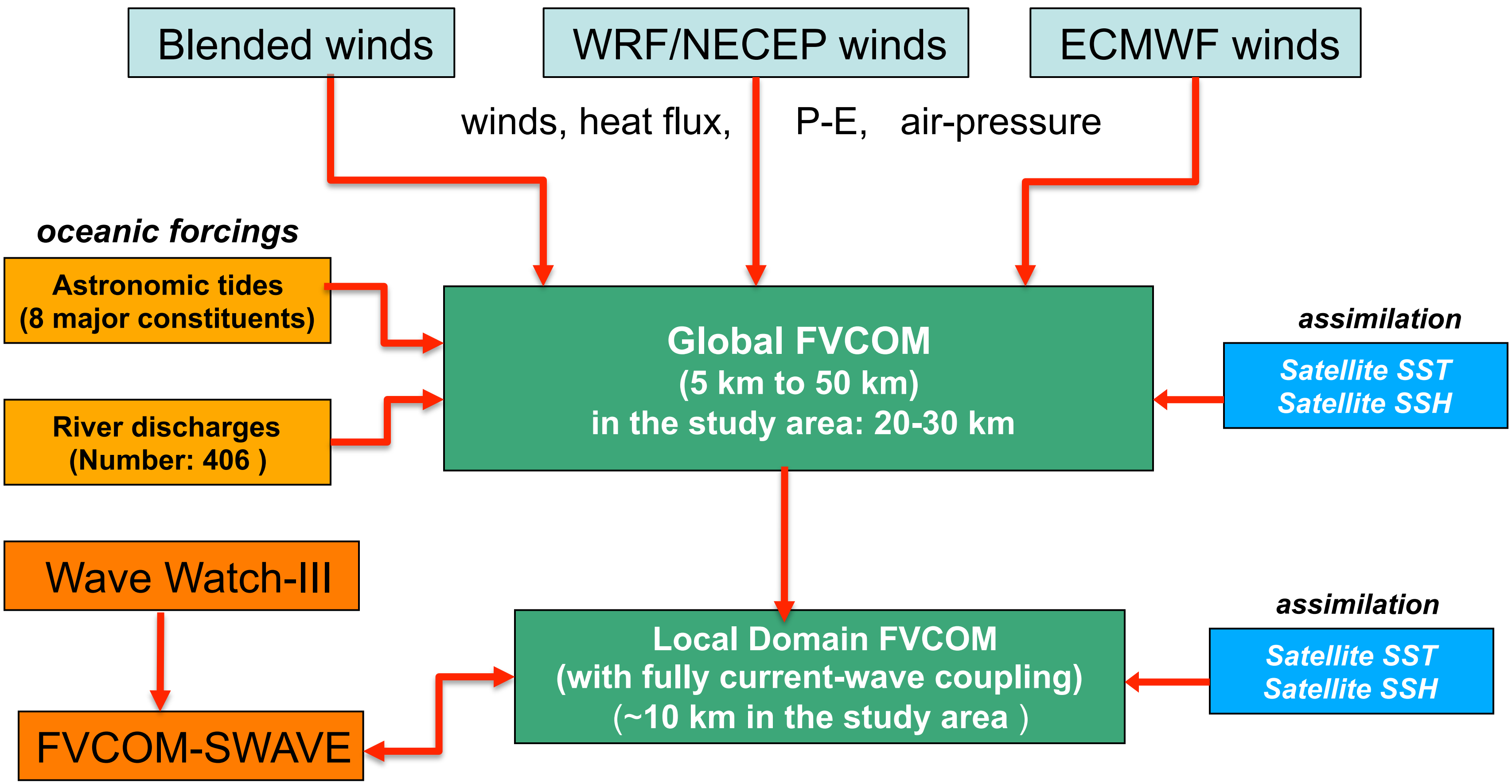
WRF ECMWF Blended

Location:

-30.96289W
4.01686N

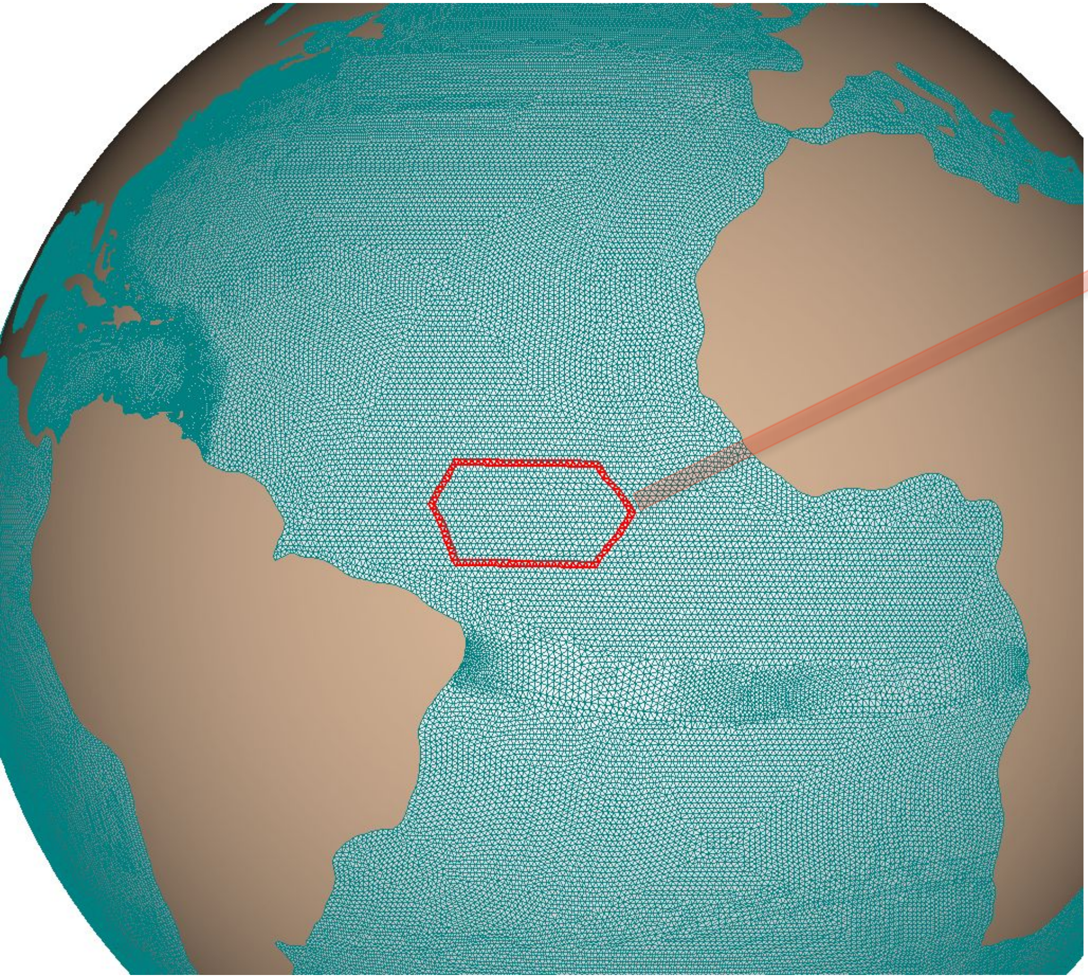


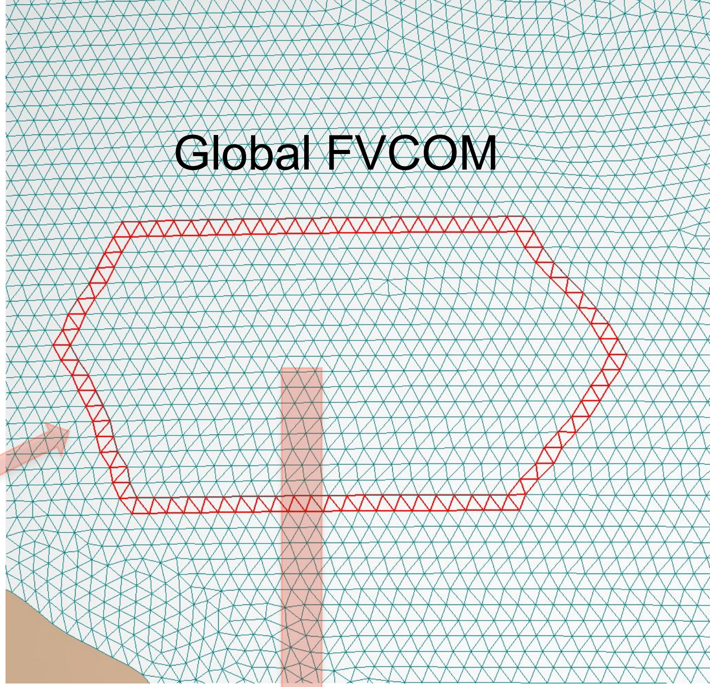
Ensemble Model Experiments using Global-FVCOM

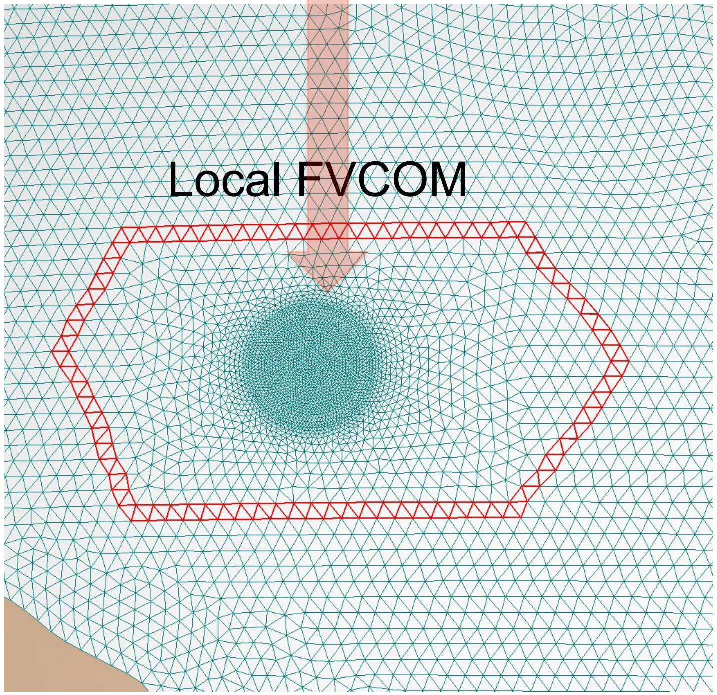


FVCOM-the unstructured grid, Finite-Volume Coastal Ocean Model
FVCOM-SWAVE-the unstructured grid SWAN (developed by the FVCOM team)

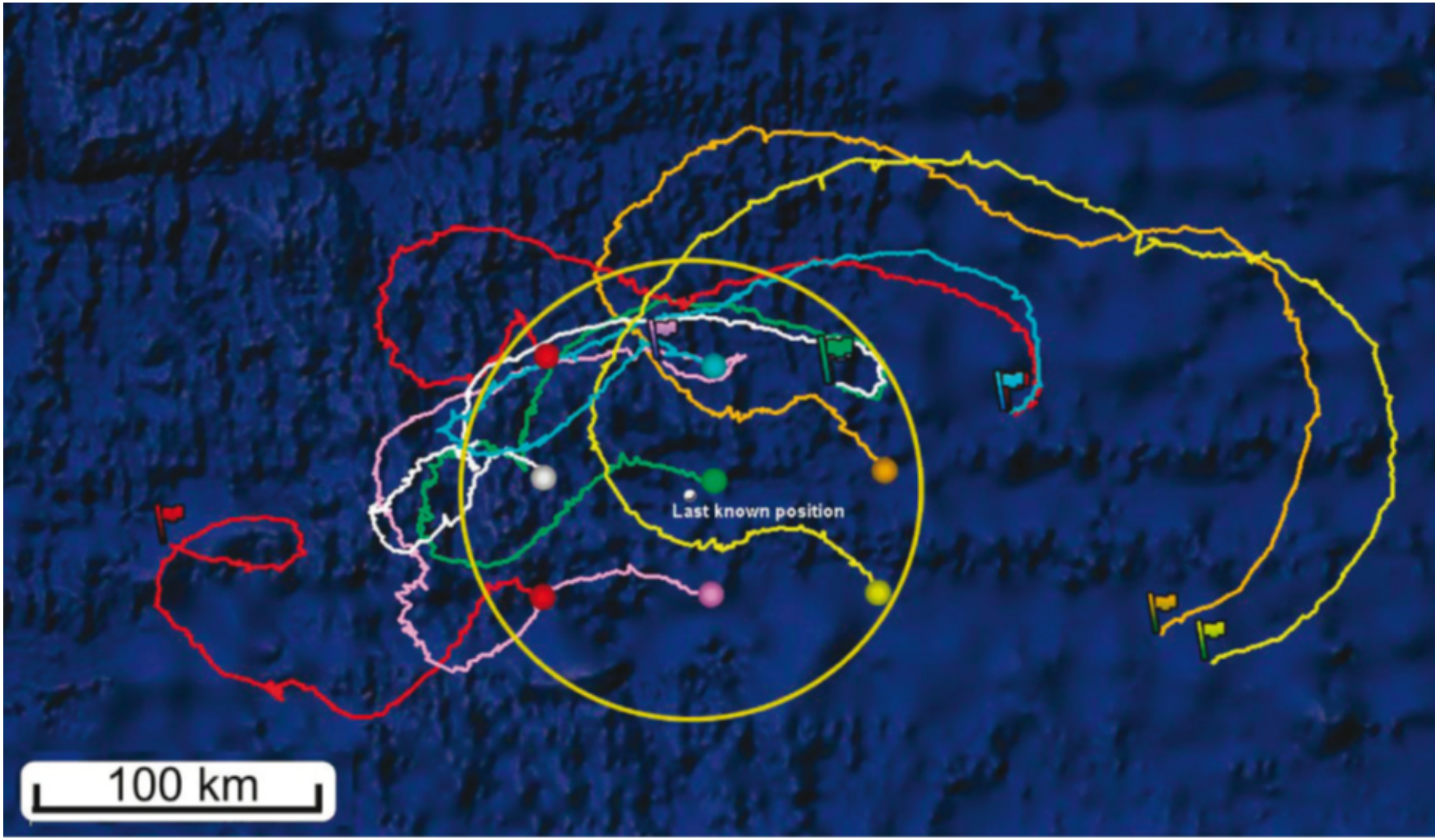
Global-FVCOM and Nested Local FVCOM Domains and Grids



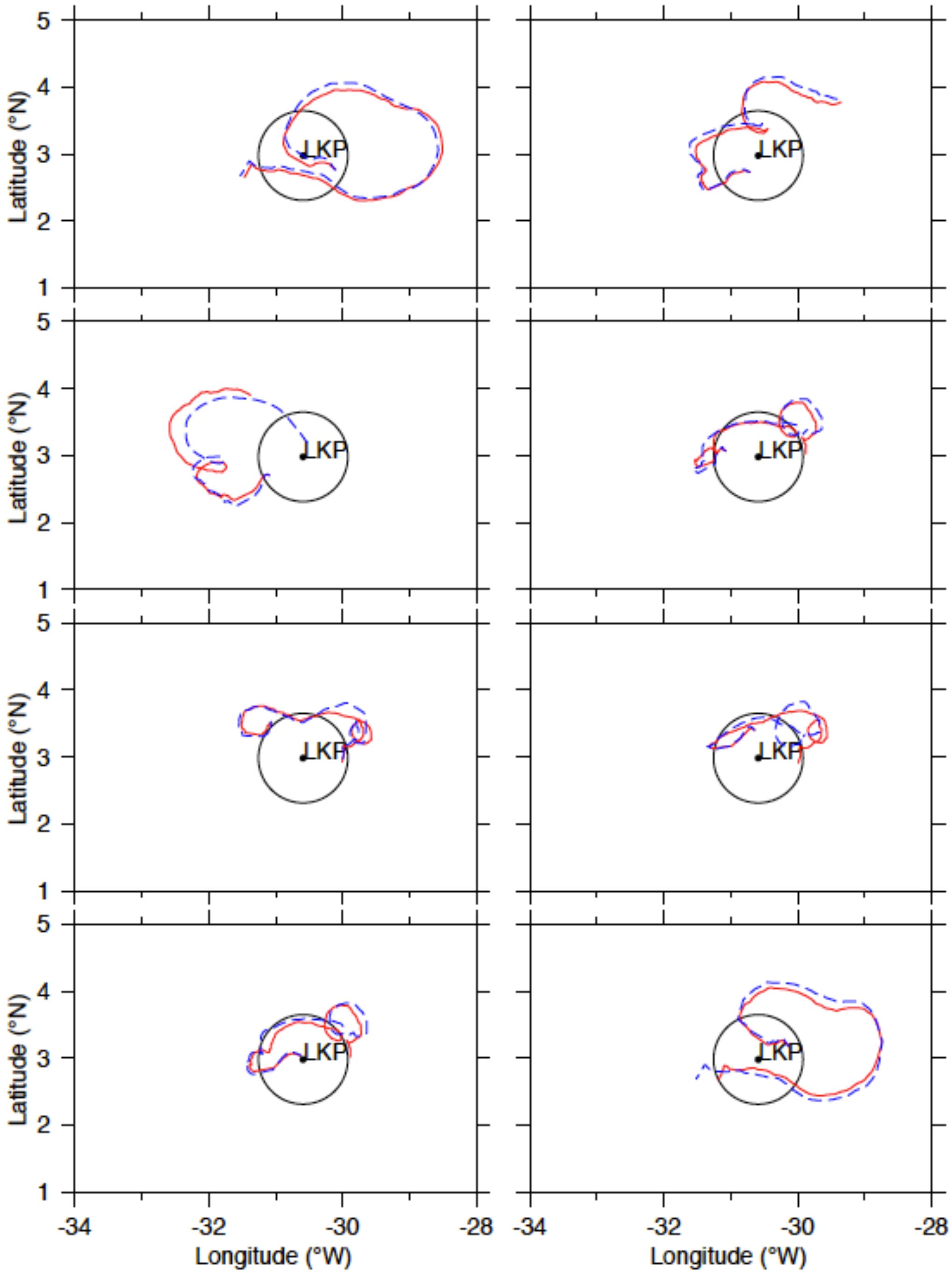




Red line area: Nested boundary between global and local FVCOM



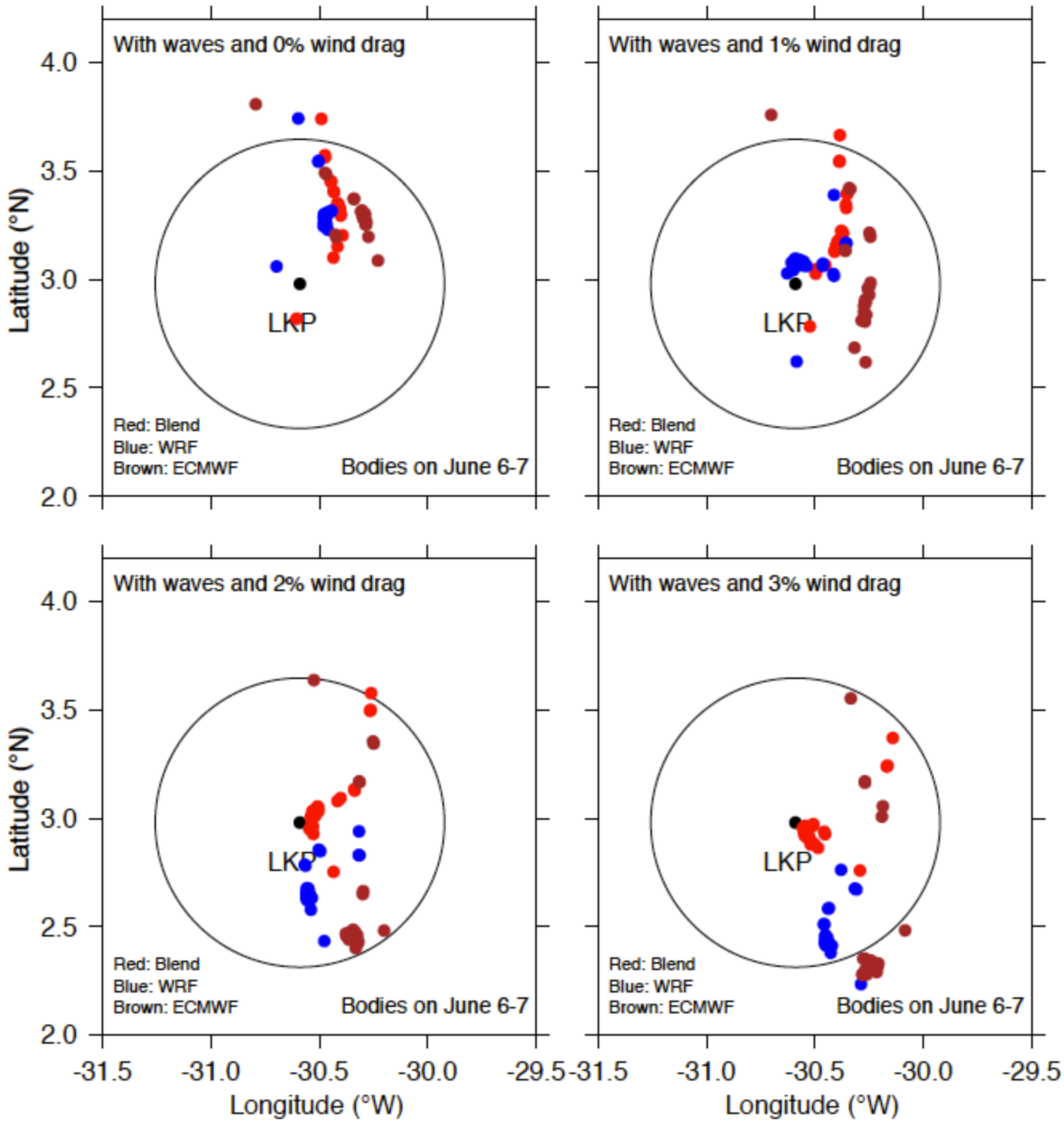
Locations of the 2010 BEA surface drifter deployments (large circles), the airplane last known position (LKP), a circle with a 40 nm radius drawn around the LKP (yellow), and the GPS drifter tracks from June 3 -21, 2010.



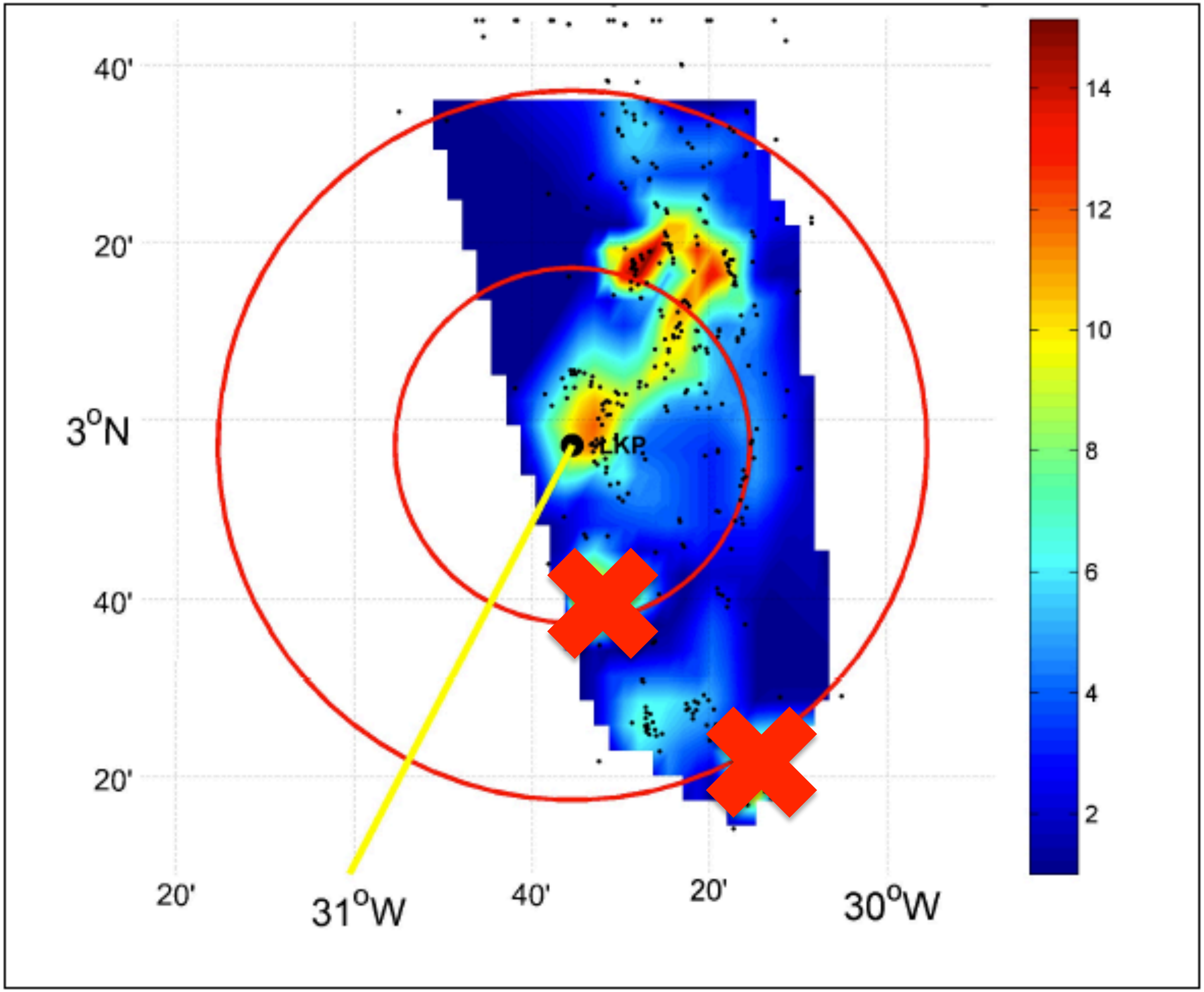
Coherence scale:

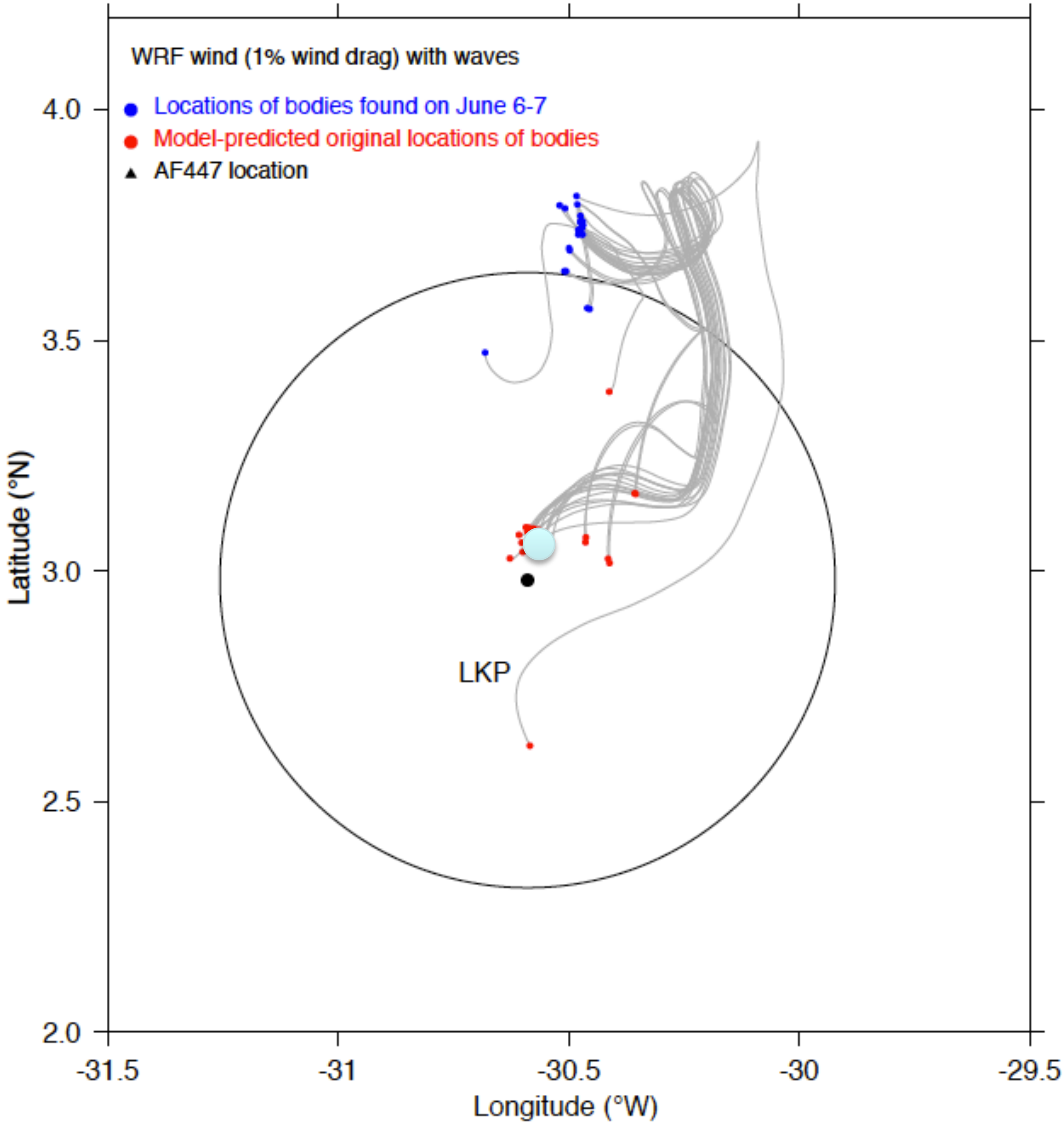
50 km

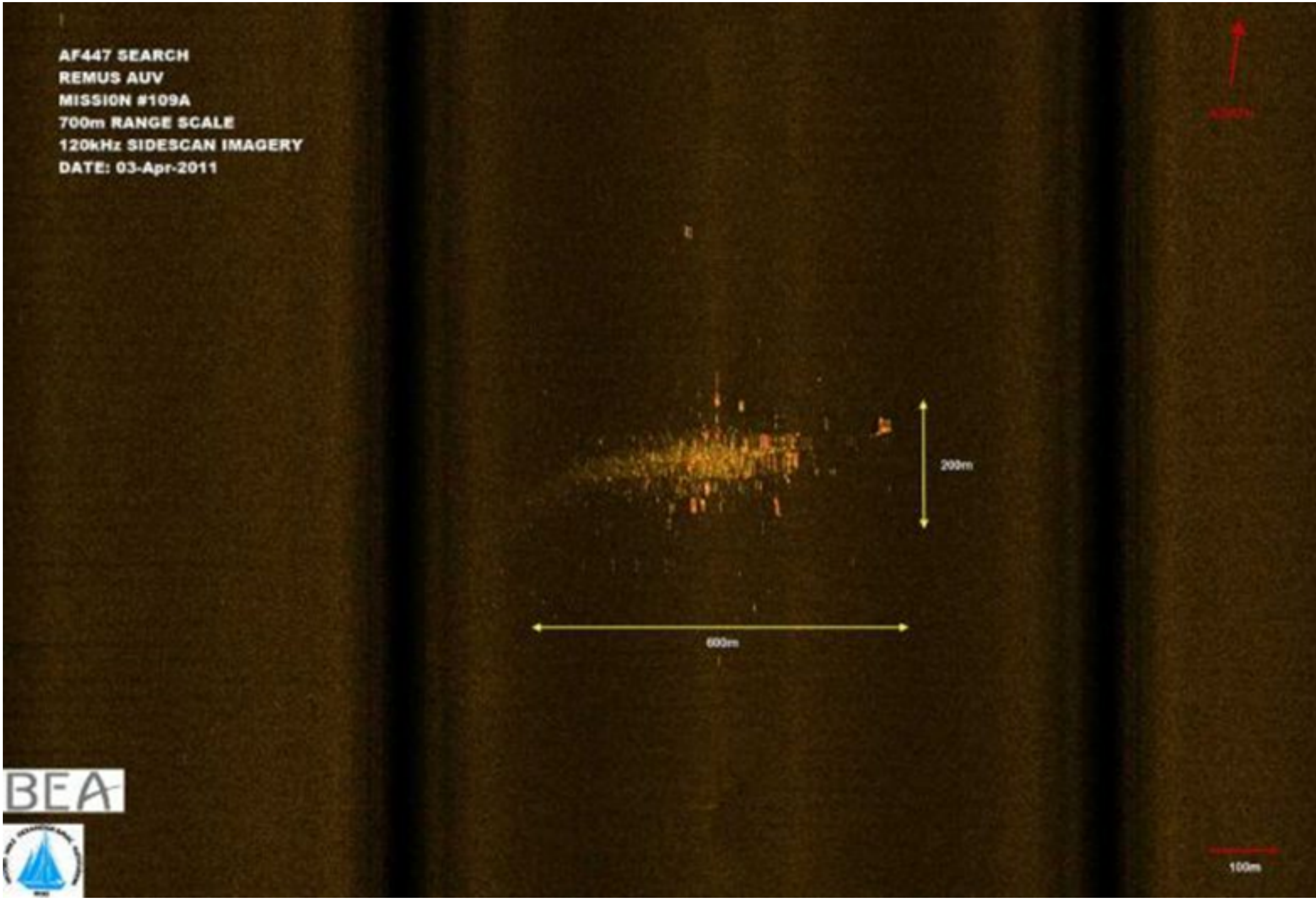
FVCOM was capable of separating tracks of all eight drifters.

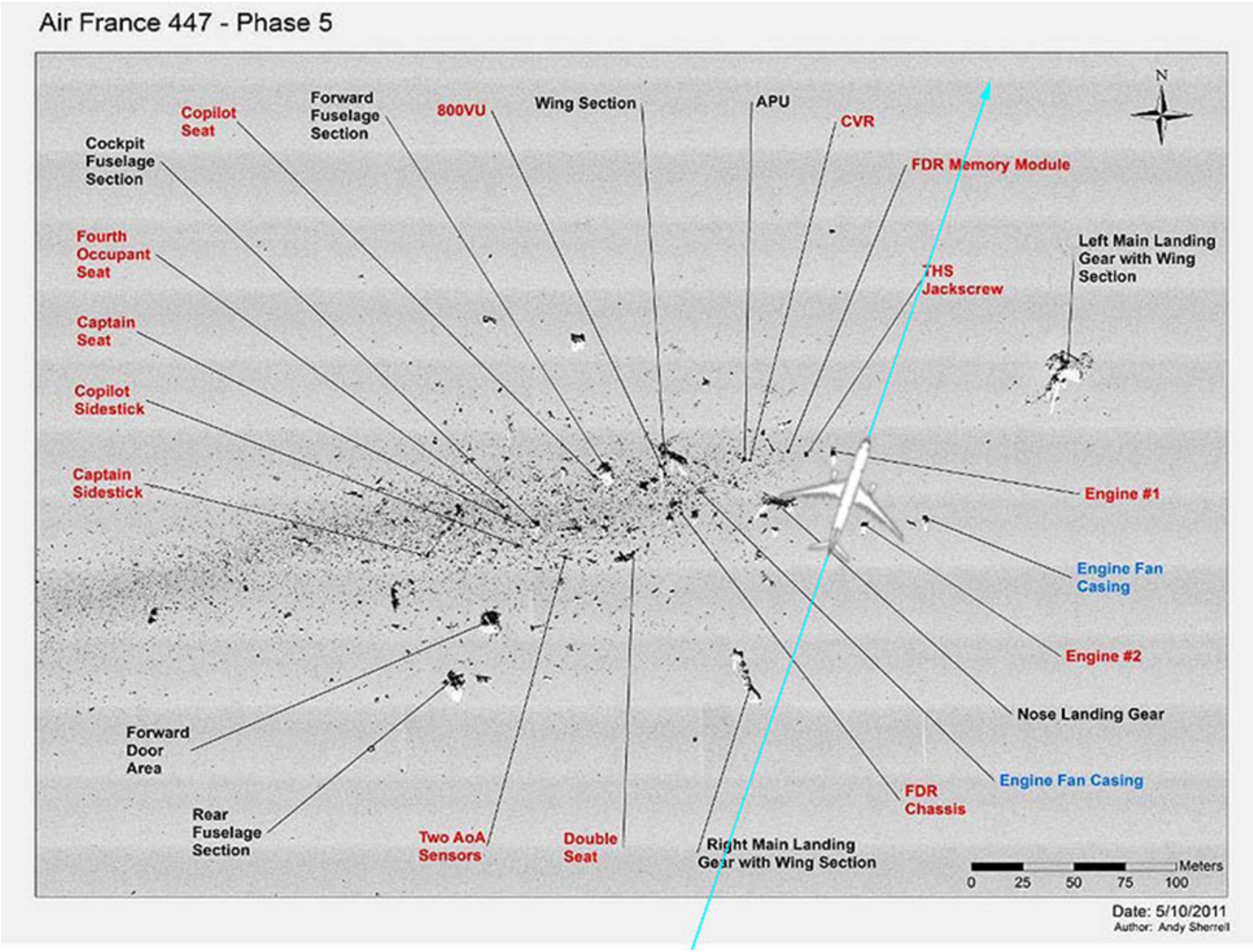

With waves and 0% wind drag
With waves and 1% wind drag
With waves and 2% wind drag
With waves and 3% wind drag
Latitude (°N)
Longitude (°W)
4.0
3.5
3.0
2.5
2.0
-31.5
-31.0
-30.5
-30.0
-29.5
LKP
Red: Blend
Blue: WRF
Brown: ECMWF
Bodies on June 6-7

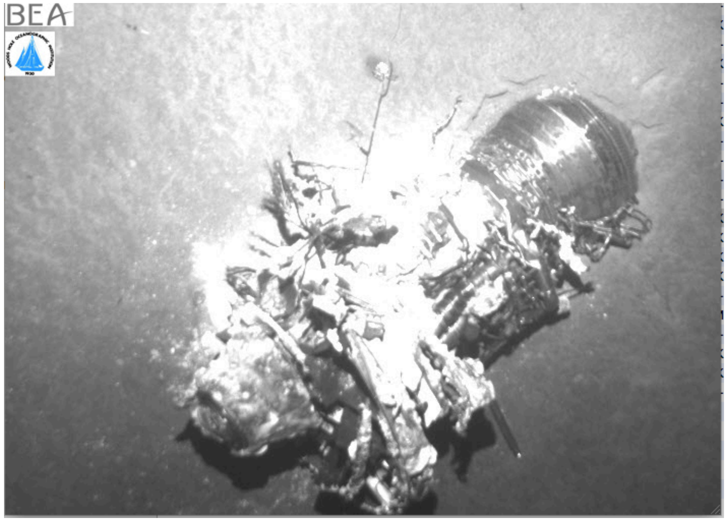
Probability Map

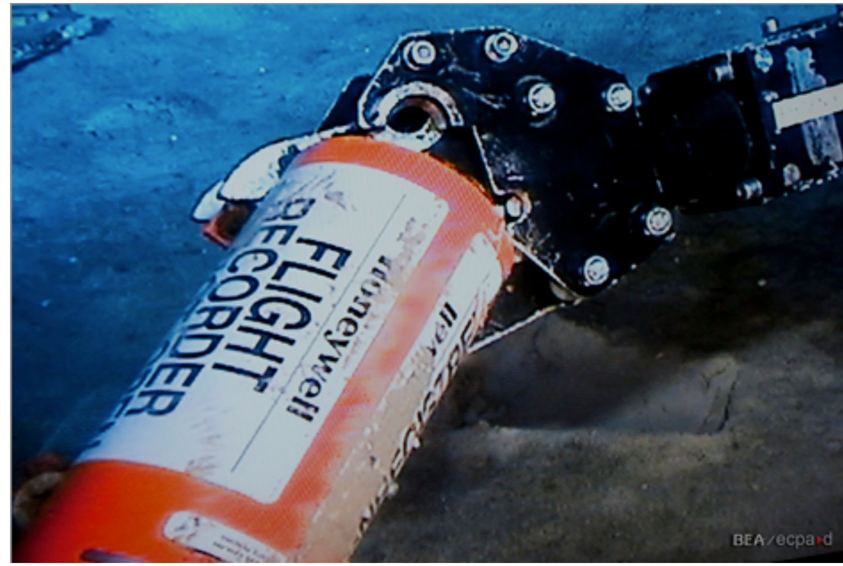



WRF wind (1% wind drag) with waves
Locations of bodies found on June 6-7
Model-predicted original locations of bodies
AF447 location
LKP
Latitude (°N)
4.0
3.5
3.0
2.5
2.0
Longitude (°W)
-31.5
-31
-30.5
-30
-29.5


AF447 SEARCH
REMUS AUV
MISSION #109A
700m RANGE SCALE
120kHz SIDESCAN IMAGERY
DATE: 03-Apr-2011
200m
600m
100m
BEA


Air France 447 - Phase 5
N
Copilot Seat
Forward Fuselage Section
800VU
Wing Section
APU
CVR
FDR Memory Module
Cockpit Fuselage Section
Fourth Occupant Seat
THS Jackscrew
Left Main Landing Gear with Wing Section
Captain Seat
Copilot Sidestick
Captain Sidestick
Engine #1
Engine Fan Casing
Engine #2
Nose Landing Gear
Forward Door Area
Engine Fan Casing
Rear Fuselage Section
FDR Chassis
Two AoA Sensors
Double Seat
Right Main Landing Gear with Wing Section
Meters
0 25 50 75 100
Date: 5/10/2011
Author: Andy Sherrell

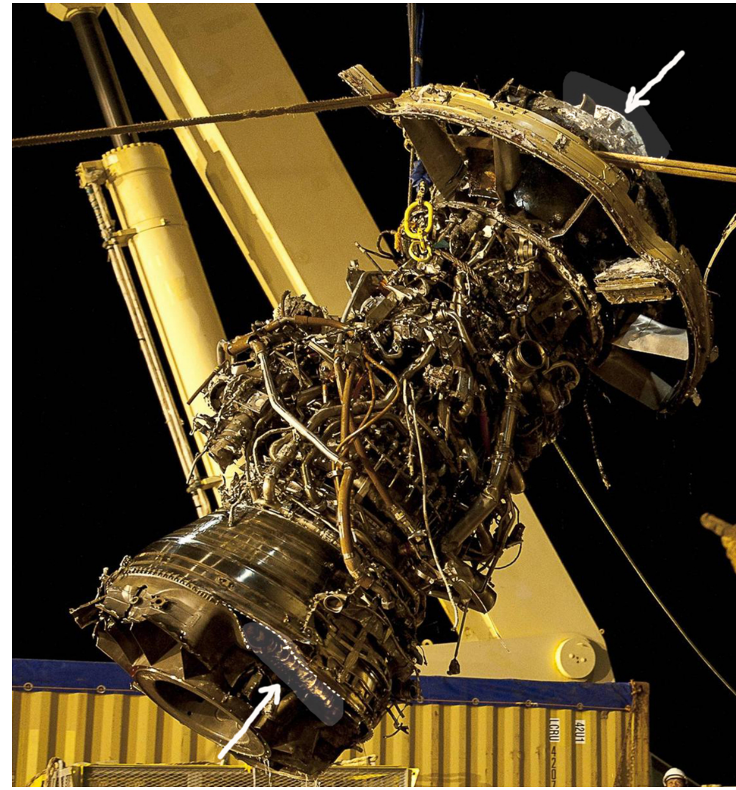

BEA


Honeywell
FLIGHT
BEA/ecpad


BEA


ENREGISTREUR
BEA/ecpad


Remora
BEA



Summary

1. It is challenge to integrate the global and coastal oceans for fully understanding the impact of climate changes on the coastal environment. The FVCOM model system provides such a tool to resolve multi-scale physical and biological processes, with better representation of volume and mass conservations;

2. The rapid development of oceanic modeling technology allows us to convert research products to meet the application need for the national interests, environmental protection, ocean rescues, and disaster forecast.