MAR513 Lecture 9: Nesting of Multi-Domains

Oceanic processes are characterized by multi-scales: globe, basin, region, estuary and wetland.

Globe-basin: 1000 km or larger
Region: 10-1000 km
Estuary: a few meters to 1 km
Wetland: a few meters

Classified by dynamics:

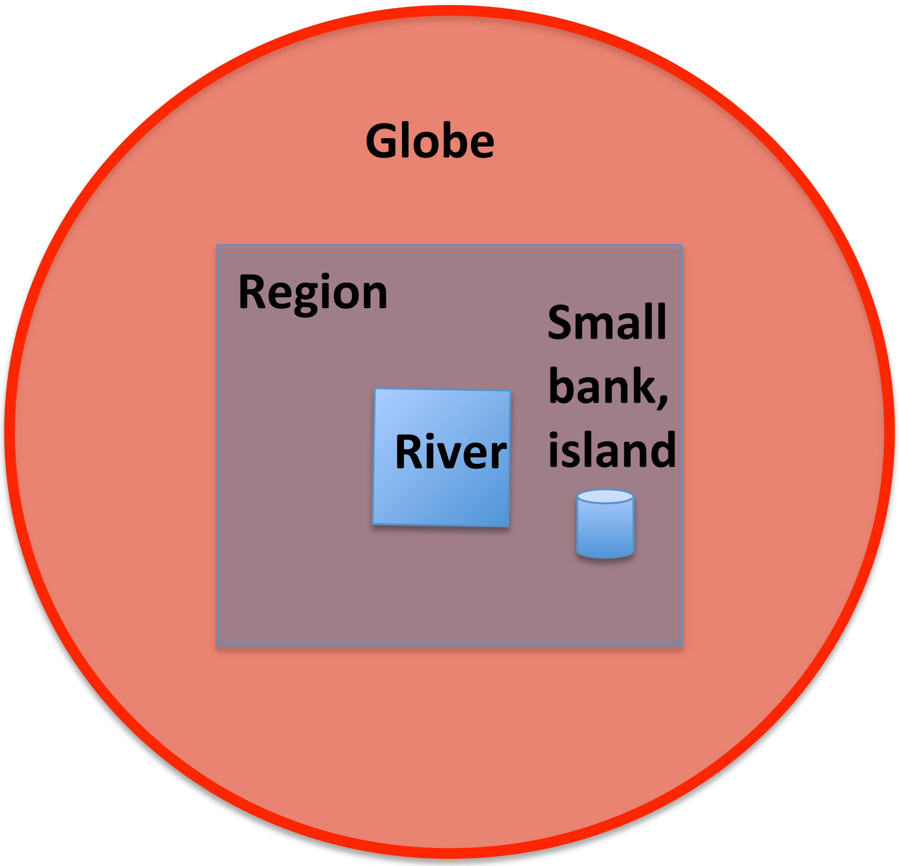
Large-scales: wind-driven circulation, thermocline and thermohaline circulation
Subduction, coastal fronts, low-salinity plumes;

Small scales: high-frequency internal waves, local convection, turbulence mixing

To resolve multi-scale physical processes, we need the variable space resolutions. That is, the resolution must consider a minimum request to resolve physical scale of the motion we study.

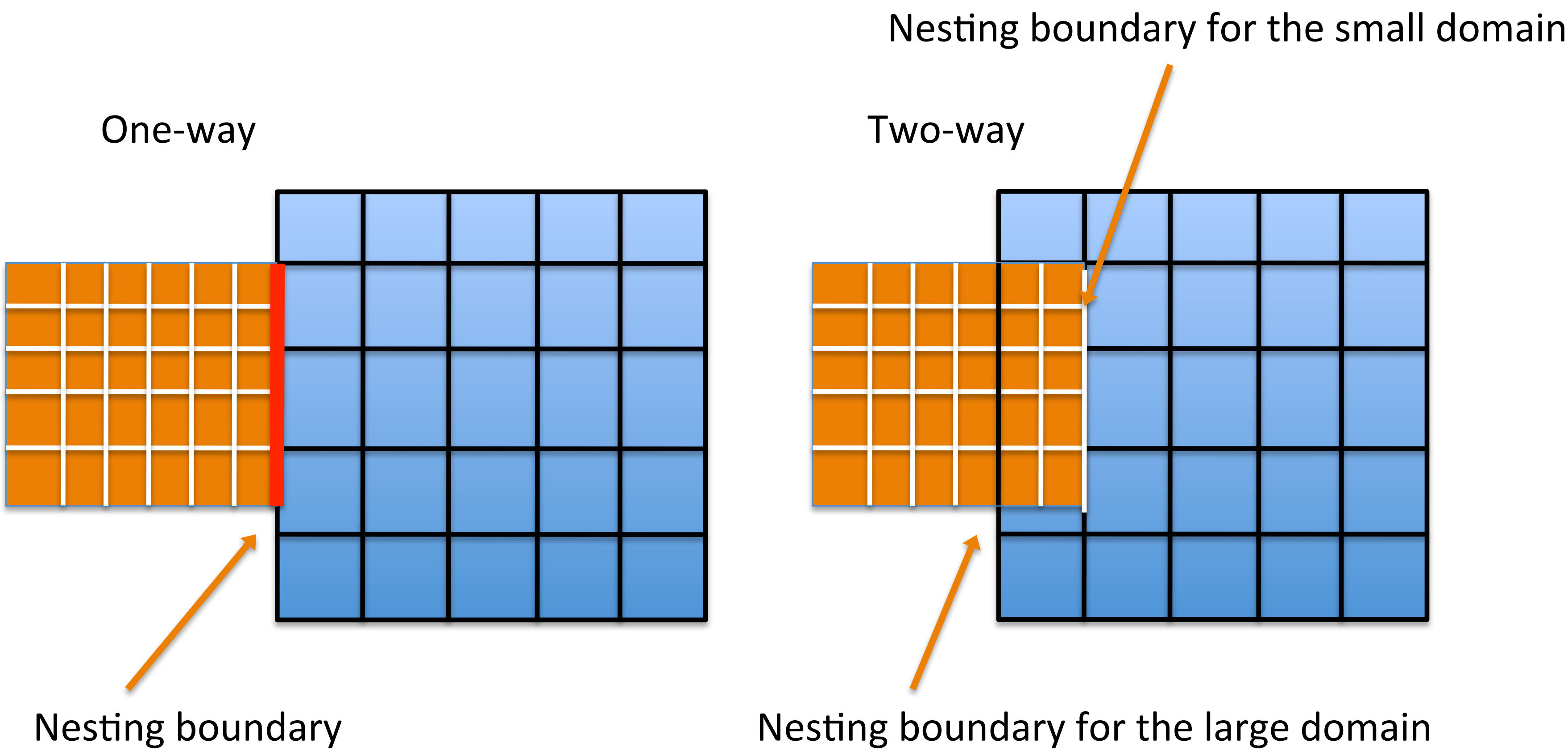
In general, the numerical stability depends on the time step and space resolution.

The computational efficiency always is controlled by the smallest grid size used in the model. For the current computational power we have in a small research laboratory, it is difficult to set up the model to resolve multi-scale motions using one grid size.

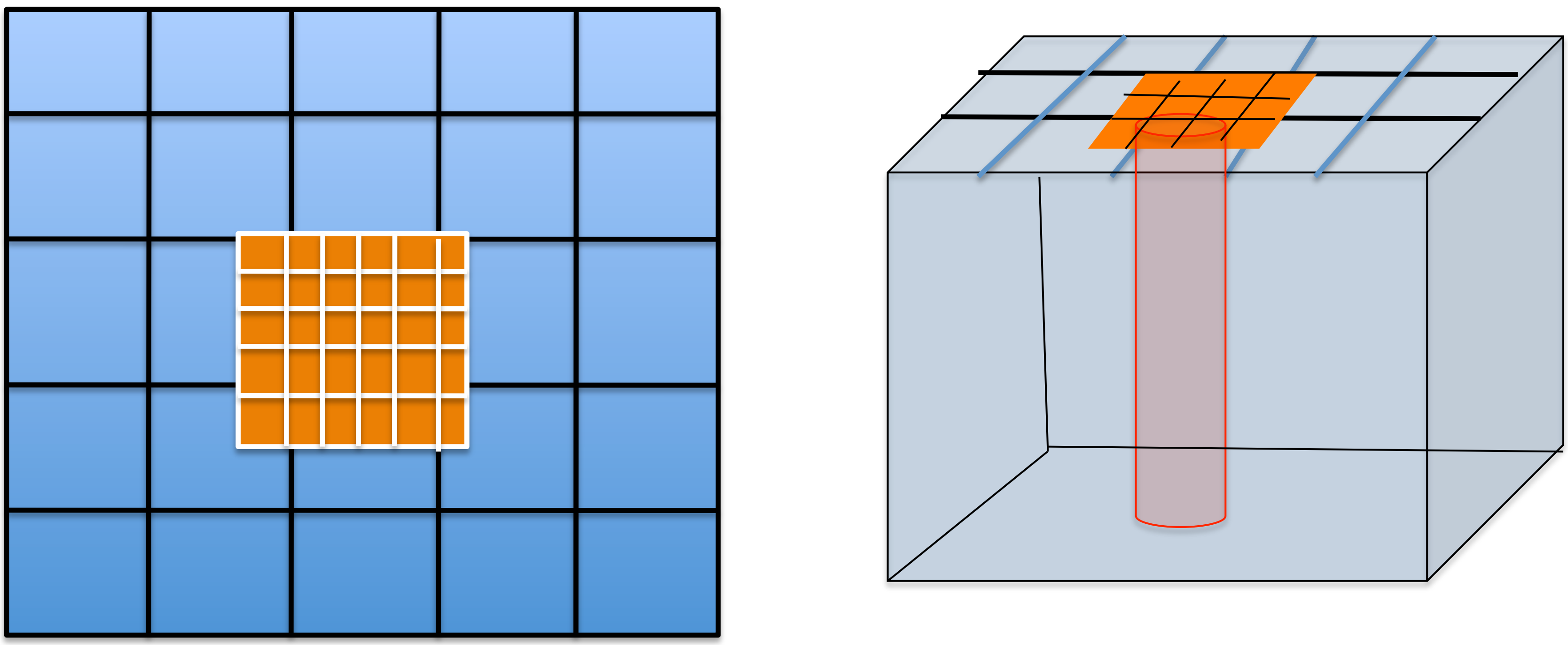


Current Numerical Approach: Nesting

1. Structured grid models



Two-way grid nesting

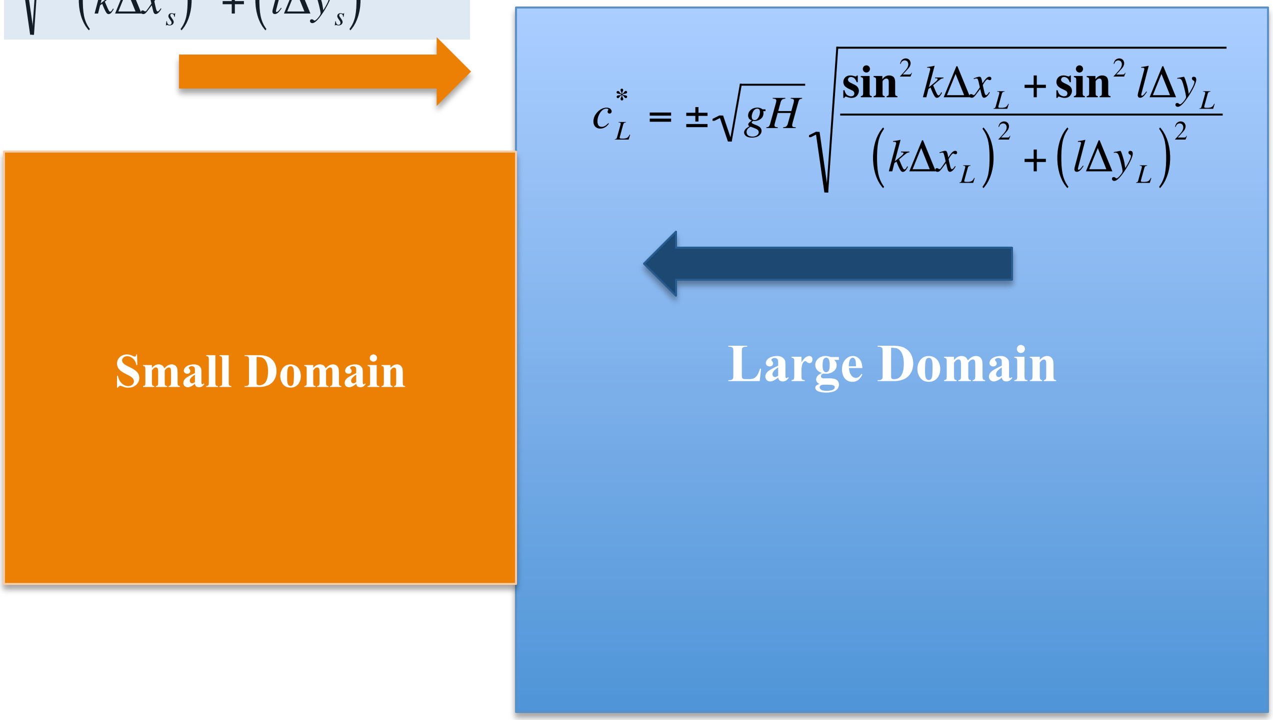


In the coastal ocean, the currents are associated with the local bathymetry or trapped around the slope or islands. The nesting the small scale feature from the small domain to the large domain could amplify the scale of local motion in the large domain and cause the unrealistic simulation.

In the ocean,

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

Numerical error speed



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

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 !**

QS. How could we nest multi-domains in the structured grid model without accumulation of the energy at the nesting boundary?

Approach:

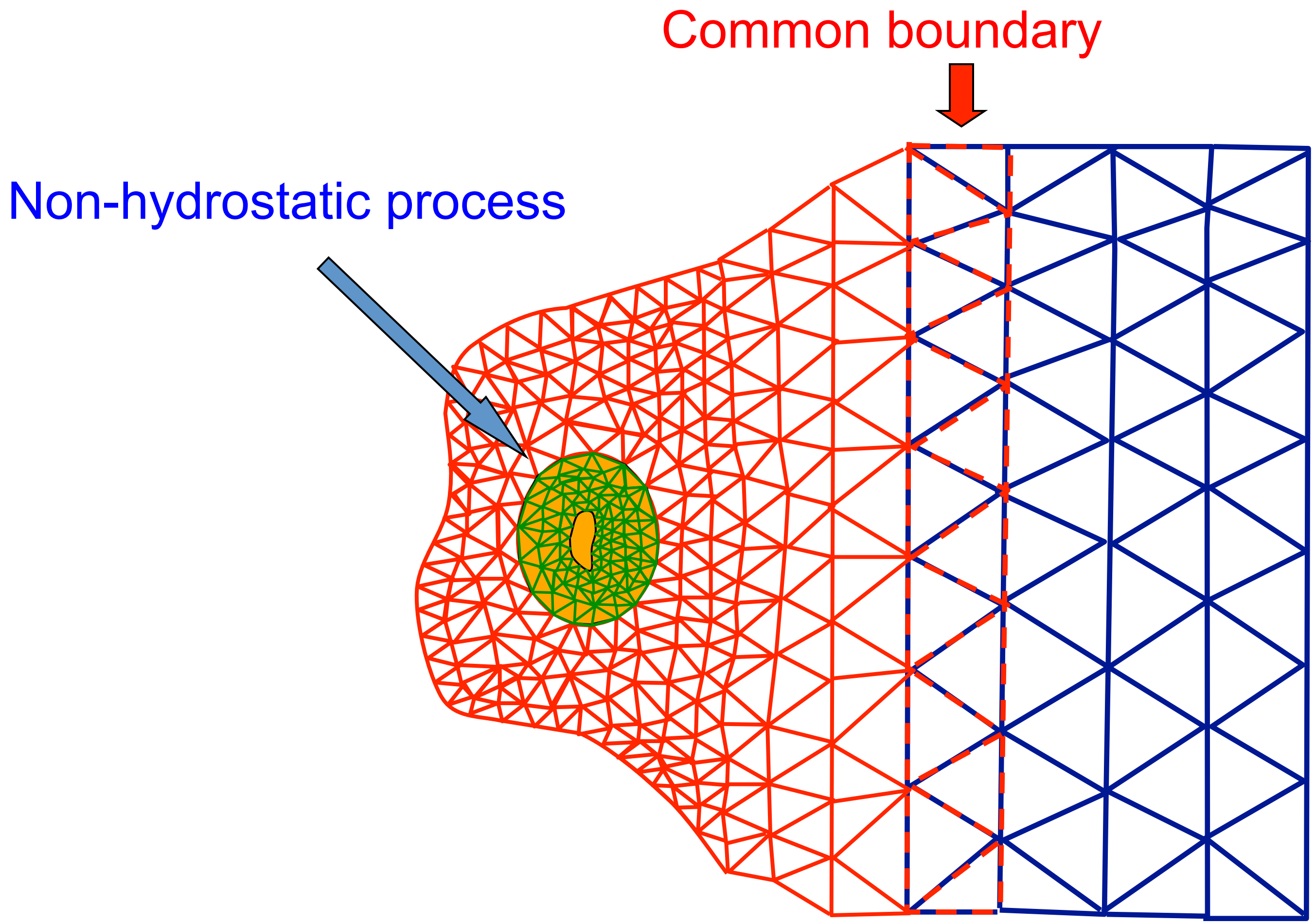
1. Set up the volume and mass conservation constraint in the control volume connected to the nesting boundary;

2. Iterating of integration of the equations at the nesting boundary control volume until the acceptable error level.

Note:

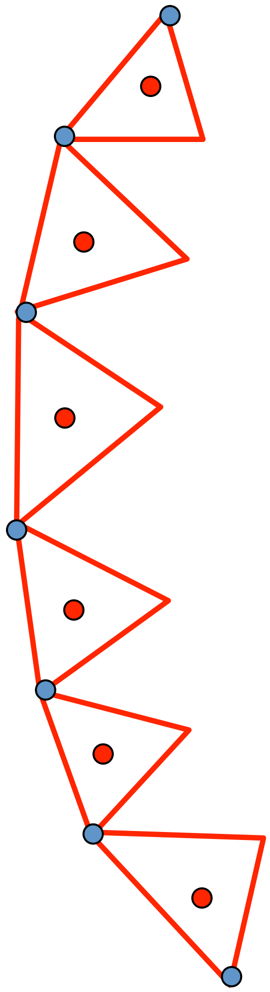
Could it doable? Yes, but it requires significant efforts. In many cases, it requires a large number of iteration. When the system is complex, it might not numerically stable!

Unstructured grid



Unstructured nesting approach: Mass conservation

One-way Nesting (implemented)



1. The nesting boundary consists of the boundary nodes and triangles connected to the boundary nodes;

2. The model output includes all variables at boundary nodes and velocities in the triangle cells

3. A nesting file with inclusion of boundary node and cell index is pre-defined when the nesting approach is used

4. The nested domain model runs with the nesting file as the boundary forcing

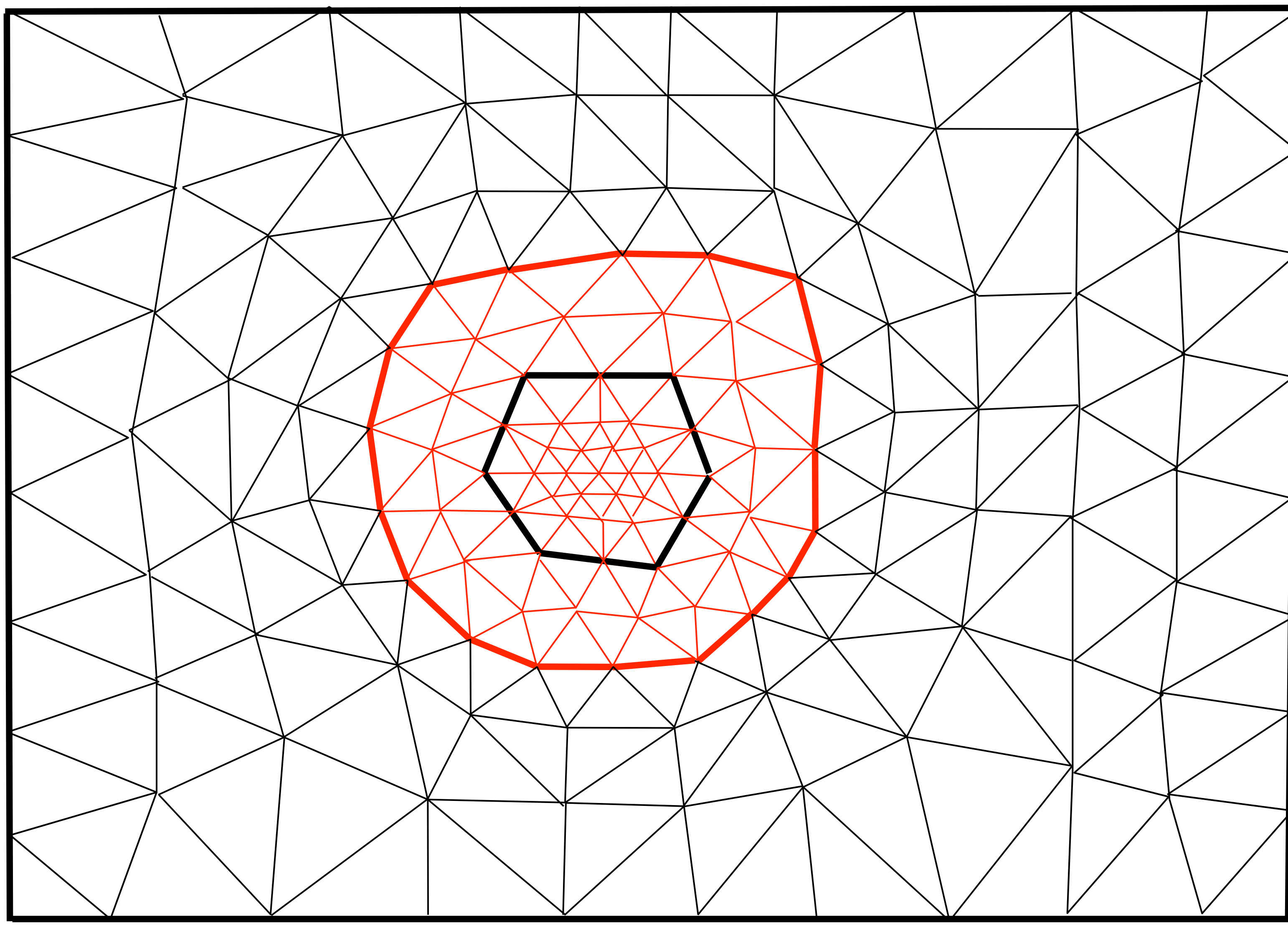
Disadvantage:

1. Two meshes are required for master and nested domains;

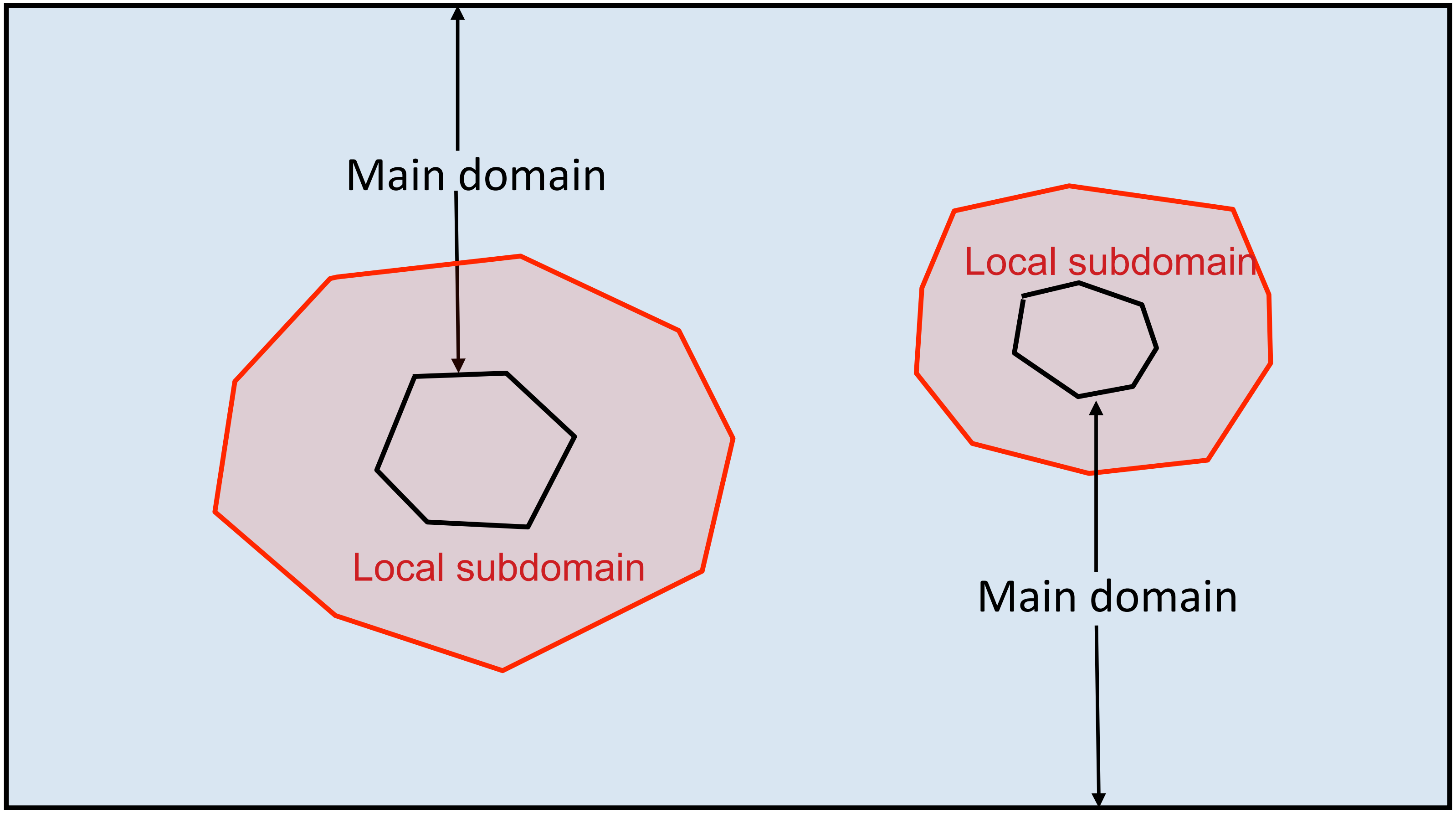
2. The operation is just like running two models.

Two-way Nesting (under development)

Patched grid:



Two-way Nesting

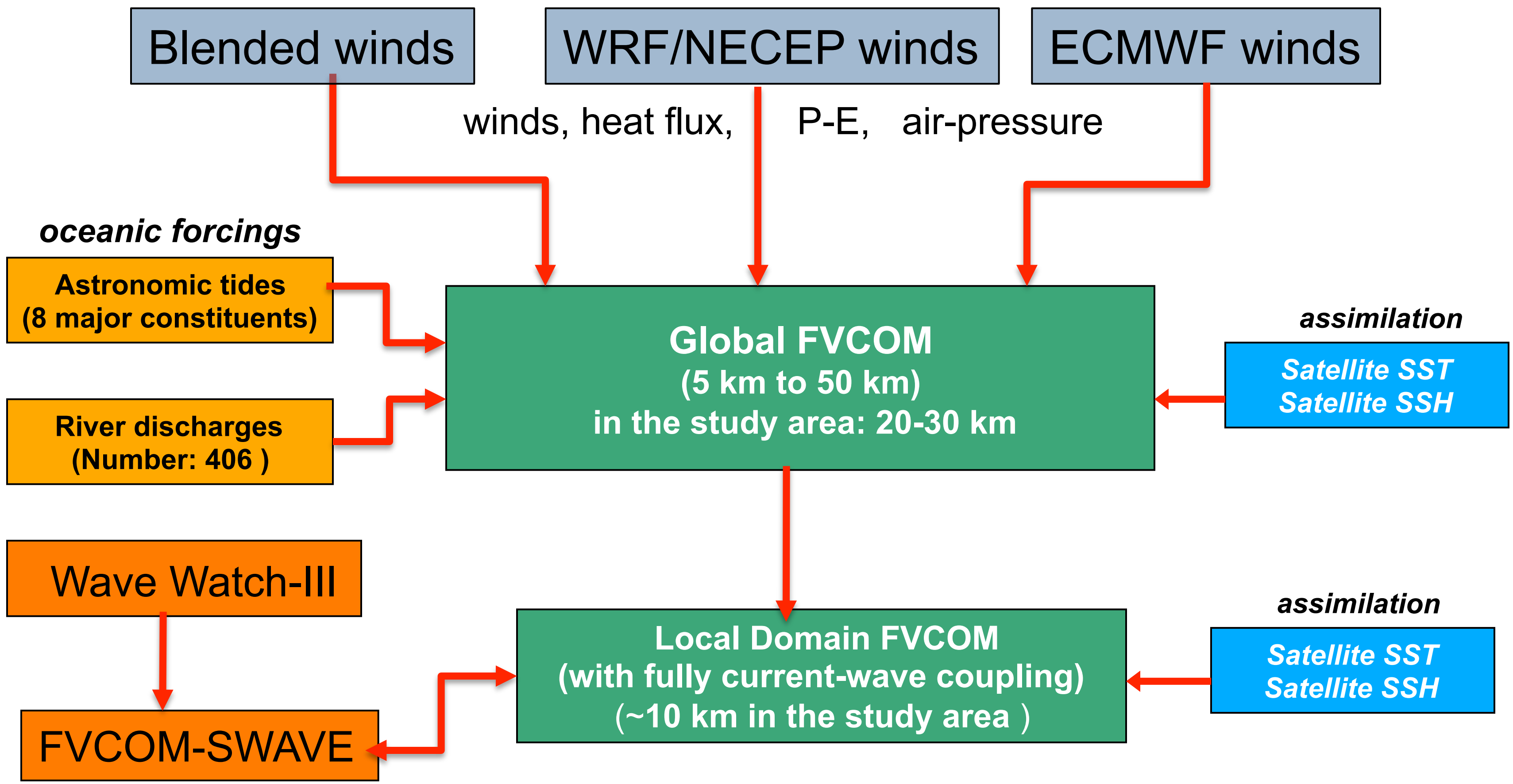


The main domain uses the interior meshes of the local subdomain as the boundary,while the local subdomain uses the interior meshes of the main domain as the boundary.

Advantages of unstructured-grid two-way nesting:

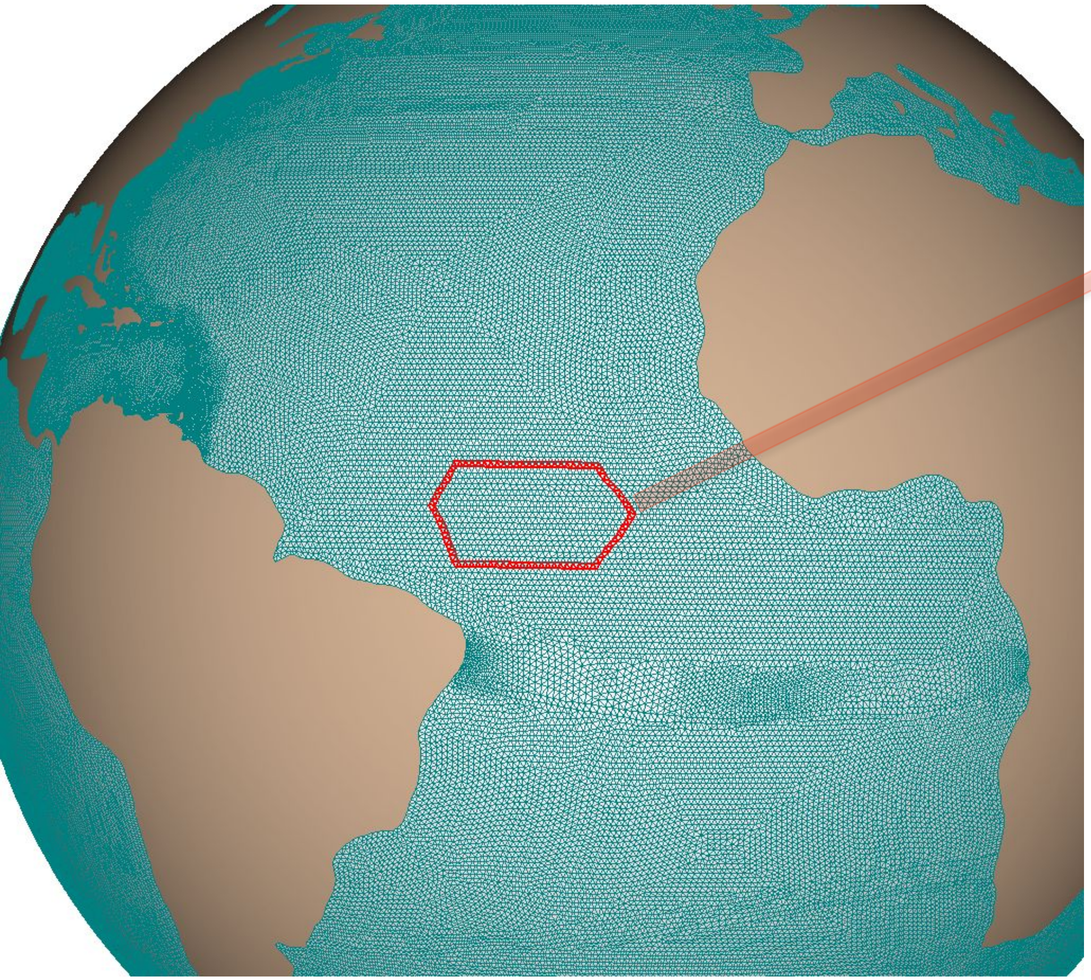
- Only one grid file is required;
- The model can run with different time steps and with different dynamics setup in individual domains with their own MPI parallelization;
- Volume and mass conservations are guaranteed with no need of adding additional adjustment;
- Make it easy to develop a forecast operation system covering global-basin-regional-estuarine-watershed scales.

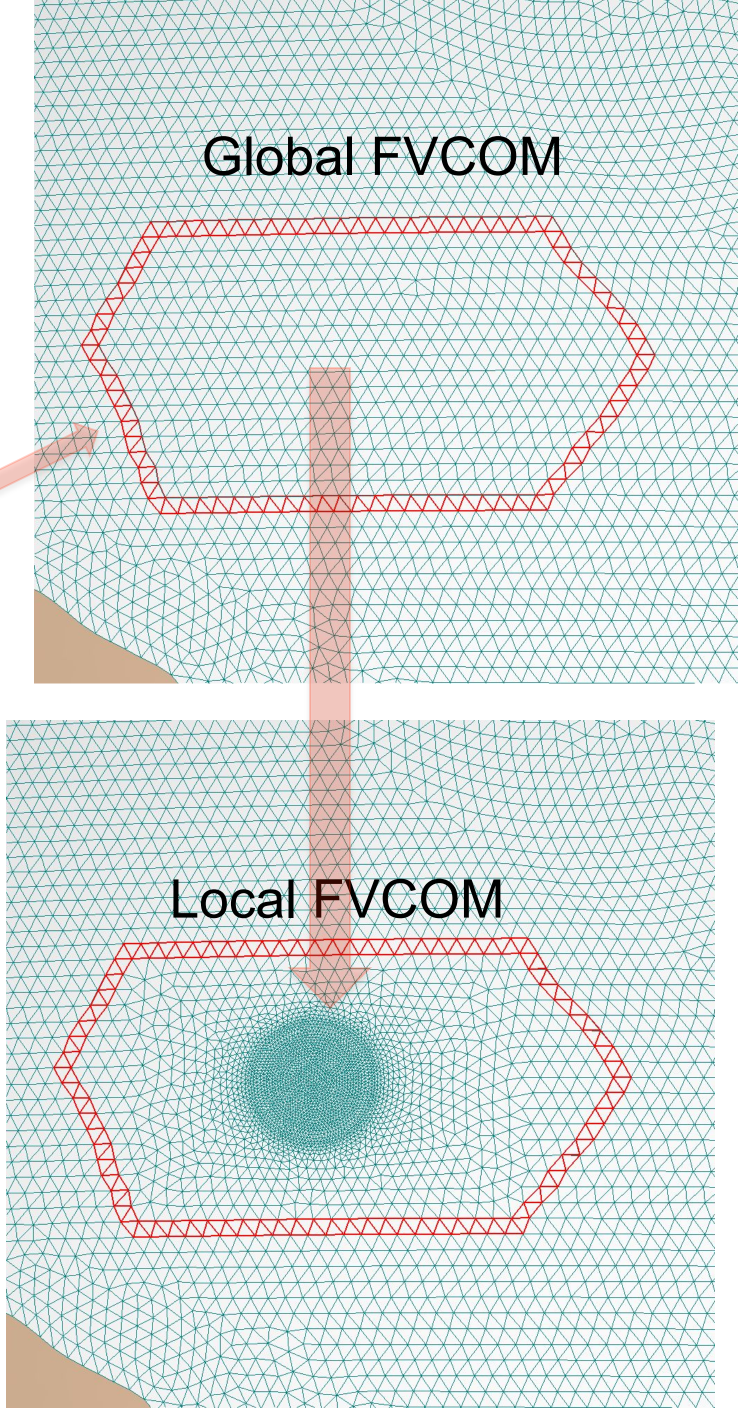
Ensemble Model Experiments using Global-FVCOM



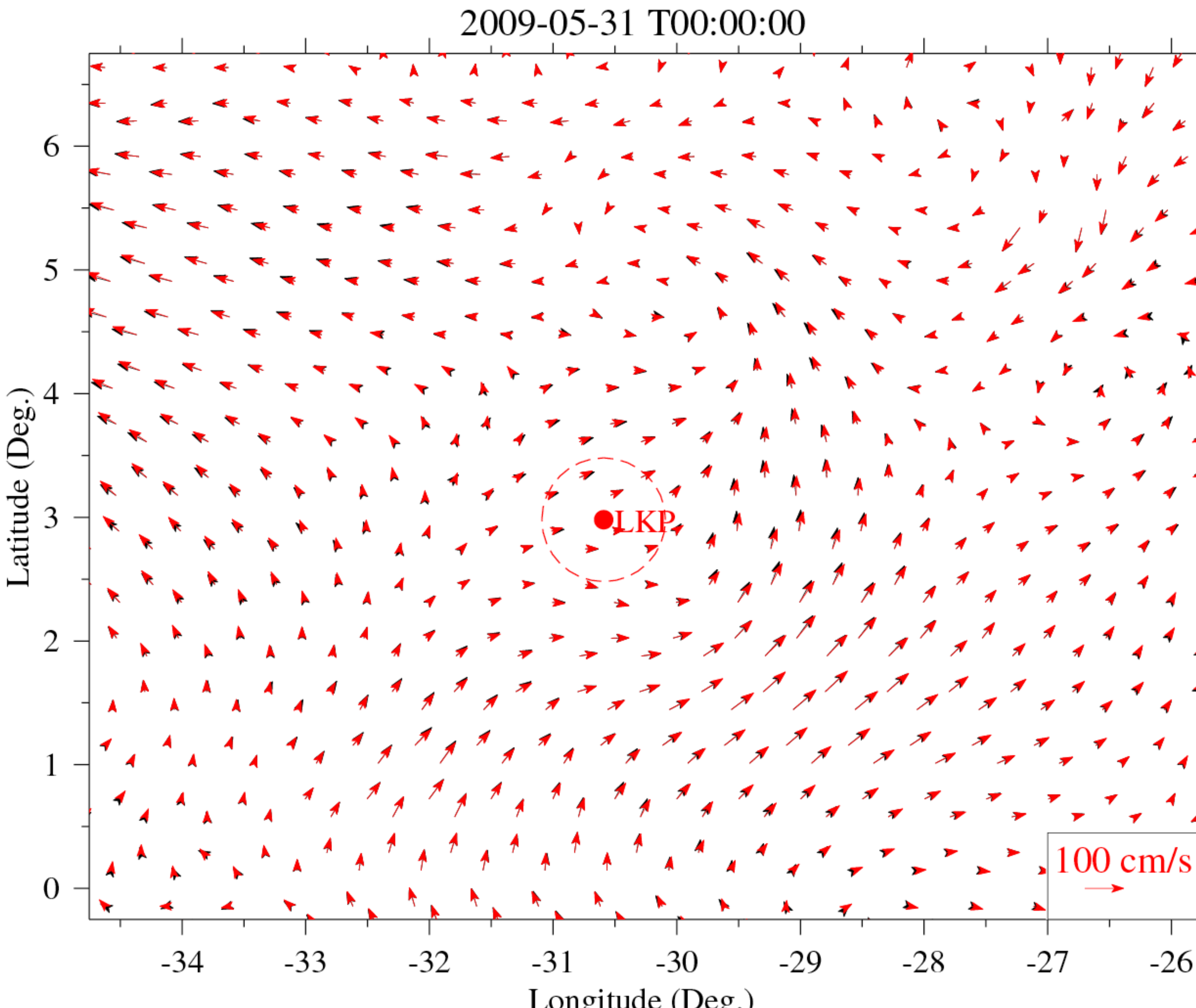
FVCOM-the unstructured grid, Finite-Volume Coastal Ocean Model
FVCOM-SWAVE-the unstructured grid SWAN (developed by the FVCOM team)

Global-FVCOM and Nested Local FVCOM Domains and Grids





Red line area: Nested boundary between global and local FVCOM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Latitude (Deg.)
Longitude (Deg.)
LKP
100 cm/s
6
5
4
3
2
1
0
-34
-33
-32
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-29
-28
-27
-26

Version 2.7.1. vs Version 3.1

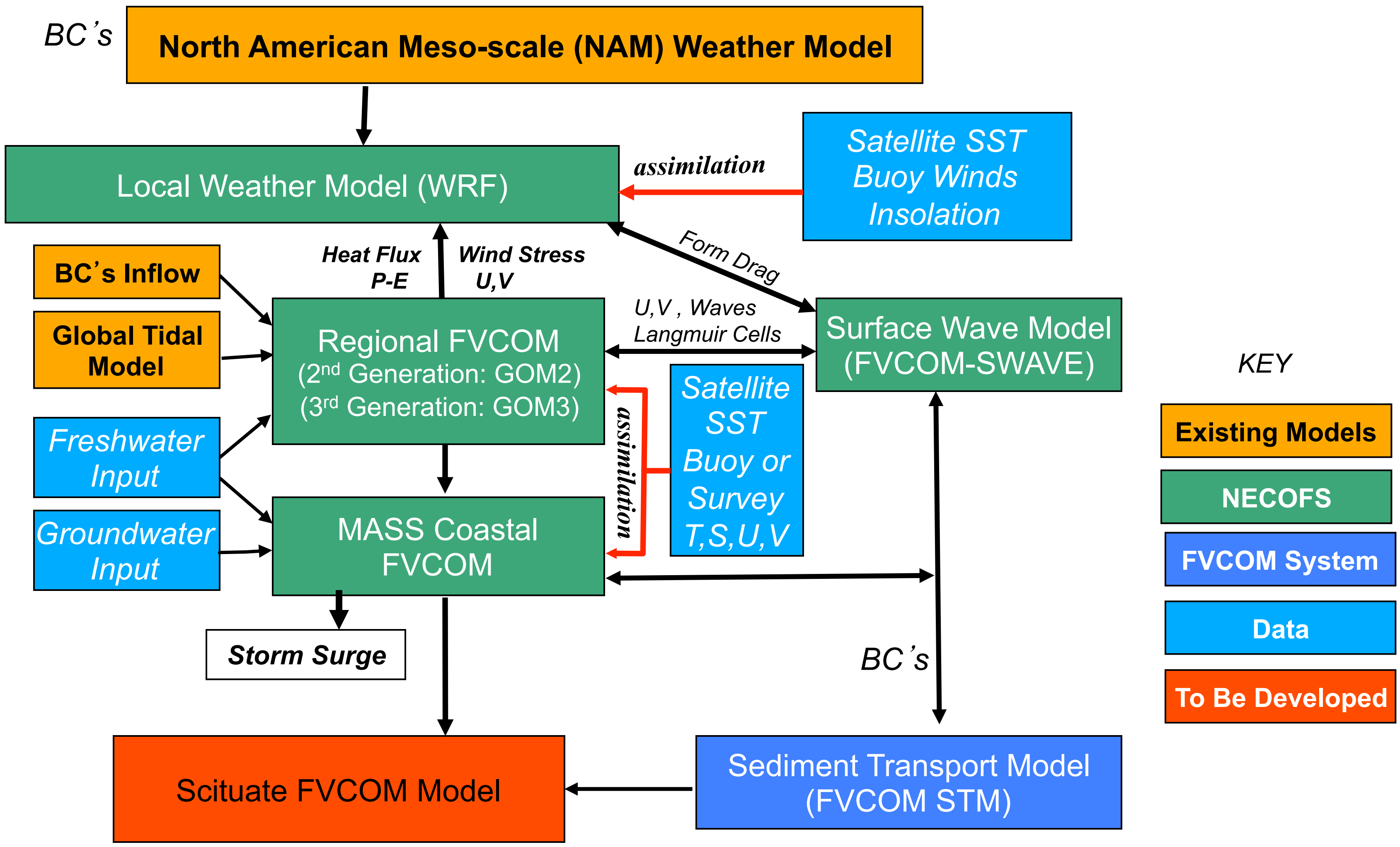
Version 2.7 remains all original setup of FVCOM with inclusion of an option of mode-splitting and semi-implicit solvers

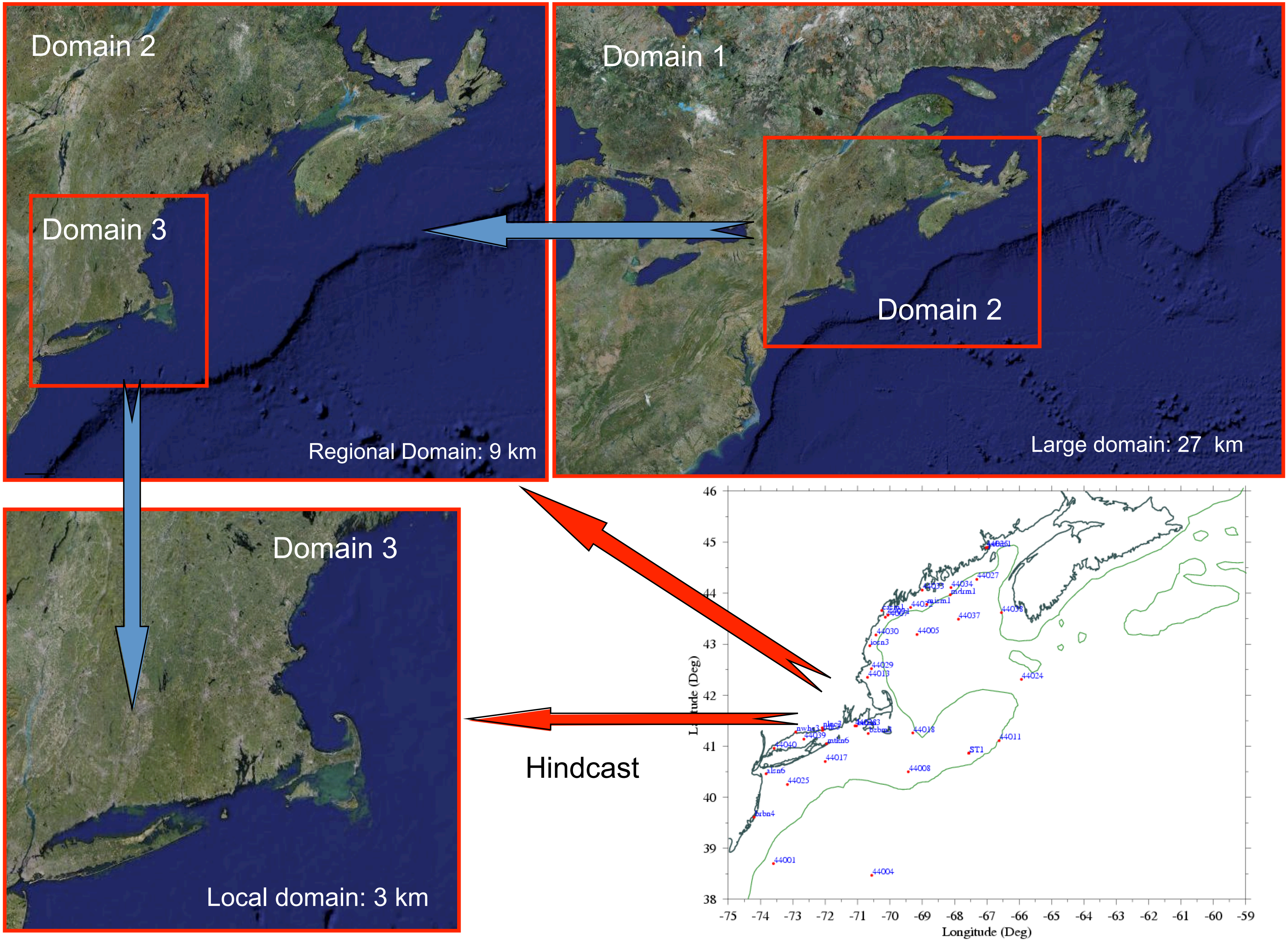
In version 3.1,

1. The input files all use the NetCDF format, which allow ViSiT to view the initial field;
2. The data exchange between computer nodes uses the "POINT" to improve the computational efficiency;
3. Current-wave-sediments are fully coupled;
4. All other modules (assimilation, sea ices, etc) are rewritten;
5. Nesting capability;
6. A complete set of offline ecosystem and water quality models that can be driven directly by the FVCOM outputs;
7. Nonhydrostatic options;
8. Dike and groyne modules

Northeast Coastal Ocean Forecast System (NECOFS)

simplified for storm surge and inundation prediction





Domain 2
Domain 3
Regional Domain: 9 km
Domain 1
Domain 2
Large domain: 27 km
Domain 3
Local domain: 3 km
Hindcast
44027
44034
44037
44038
44005
44030
44029
44013
44024
44018
44011
ST1
44008
44017
44039
44040
44025
44001
44004
46
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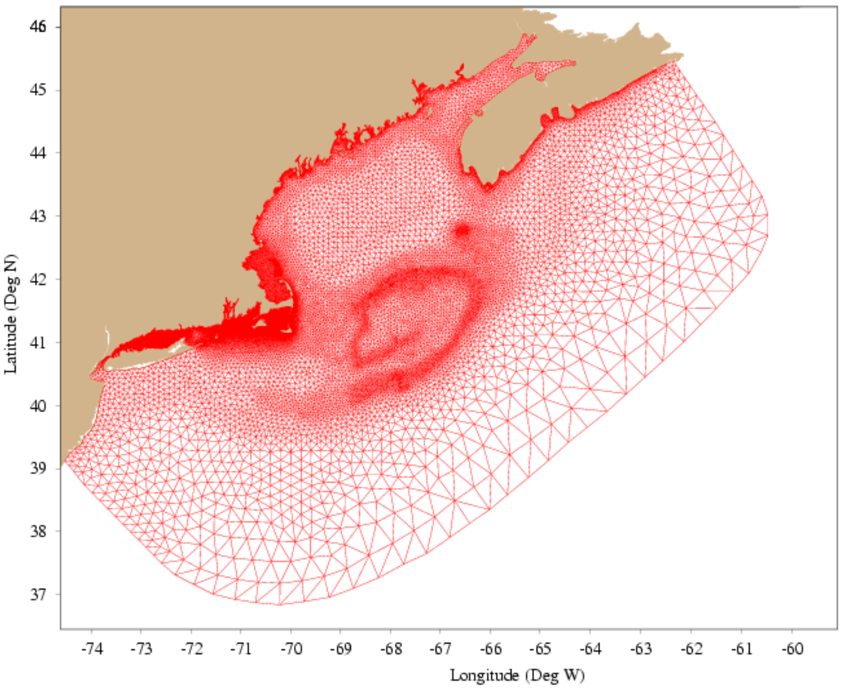
42
41
40
39
38
-75 -74 -73 -72 -71 -70 -69 -68 -67 -66 -65 -64 -63 -62 -61 -60 -59
Longitude (Deg)

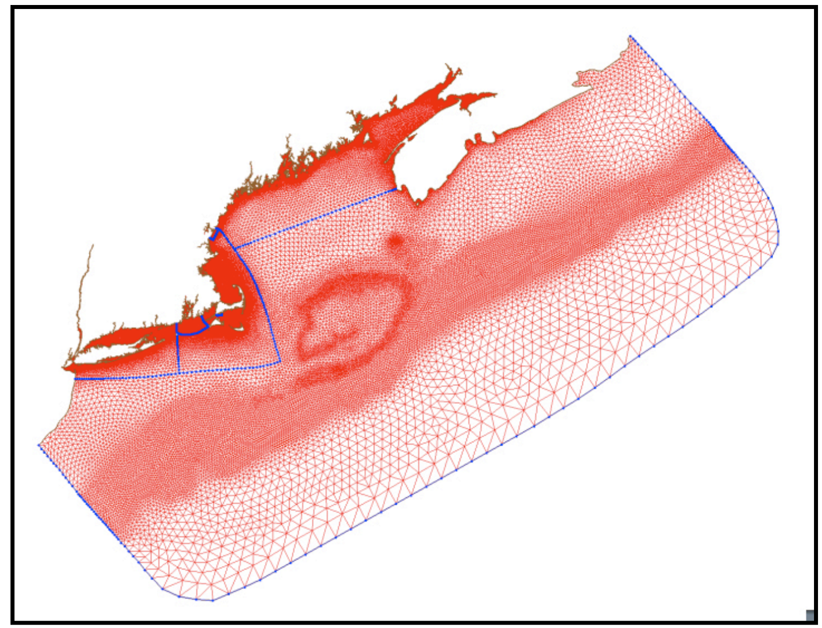
NERACOOS regional FVCOM grids

Second Generation



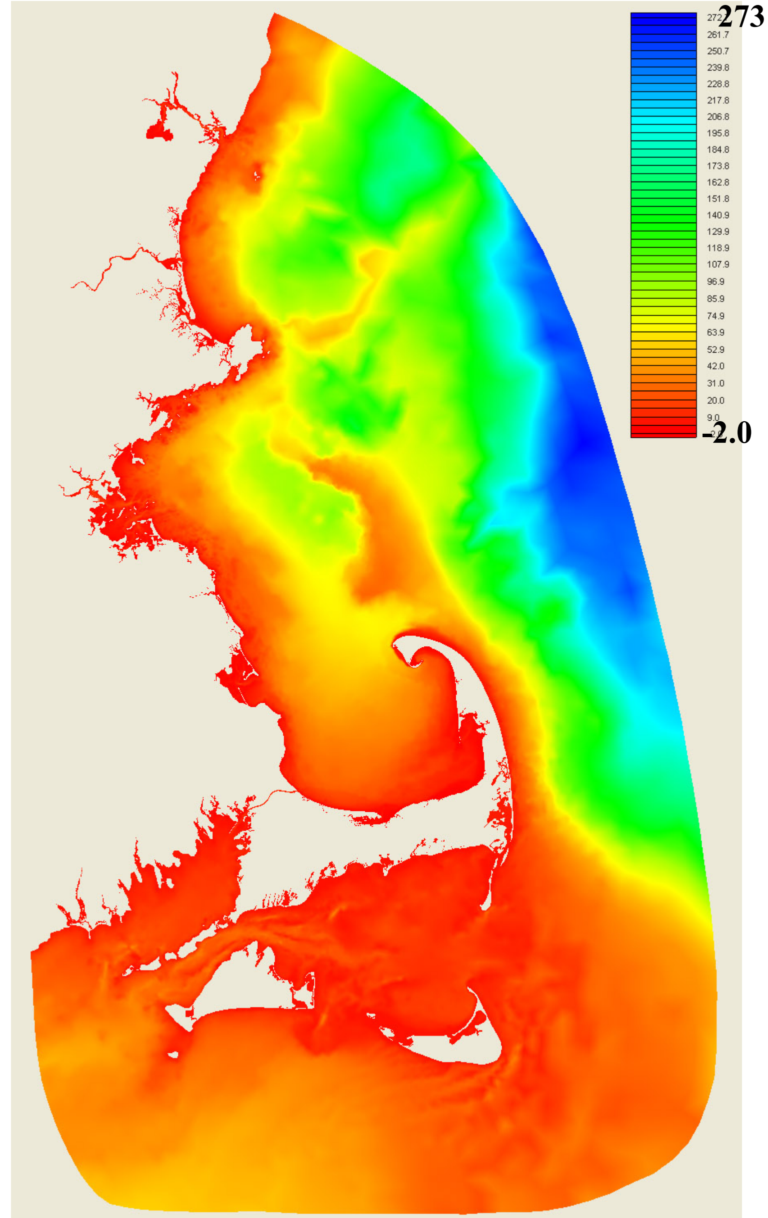
- Horizontal resolution: 0.5-1.0 km in the coastal region;
- Sigma-coordinates: 31 vertical layers
- 300-m cutoff off Georges Bank

Third Generation



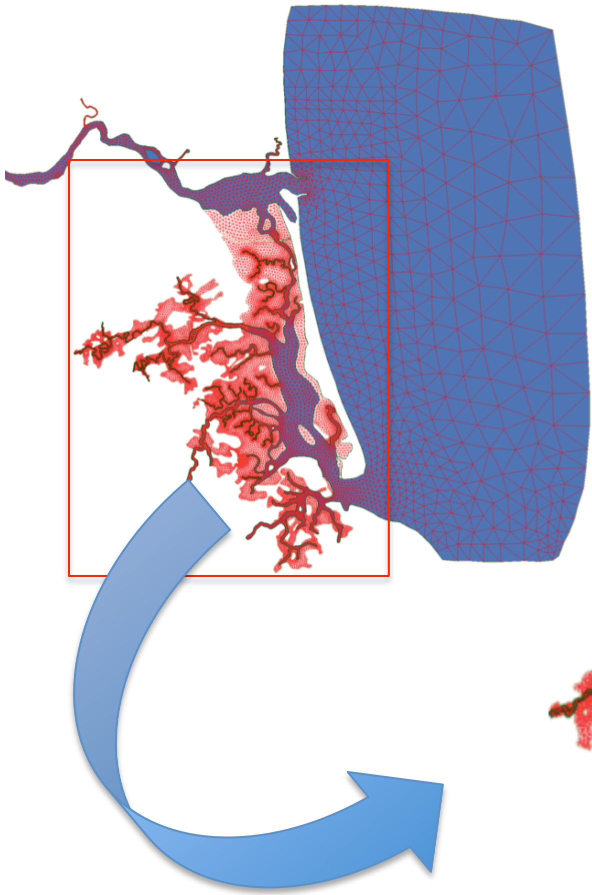
- Horizontal resolution: 0.3-1.0 km in the coastal region;
- Generalized terrain-following coordinates: 46 layers: 10 uniform layers in the surface and bottom boundary layers, respectively.
- 1500-m cutoff off Georges Bank
- Capable to nest to the coastal-estuarine model with a horizontal resolution of ~10-500 m;

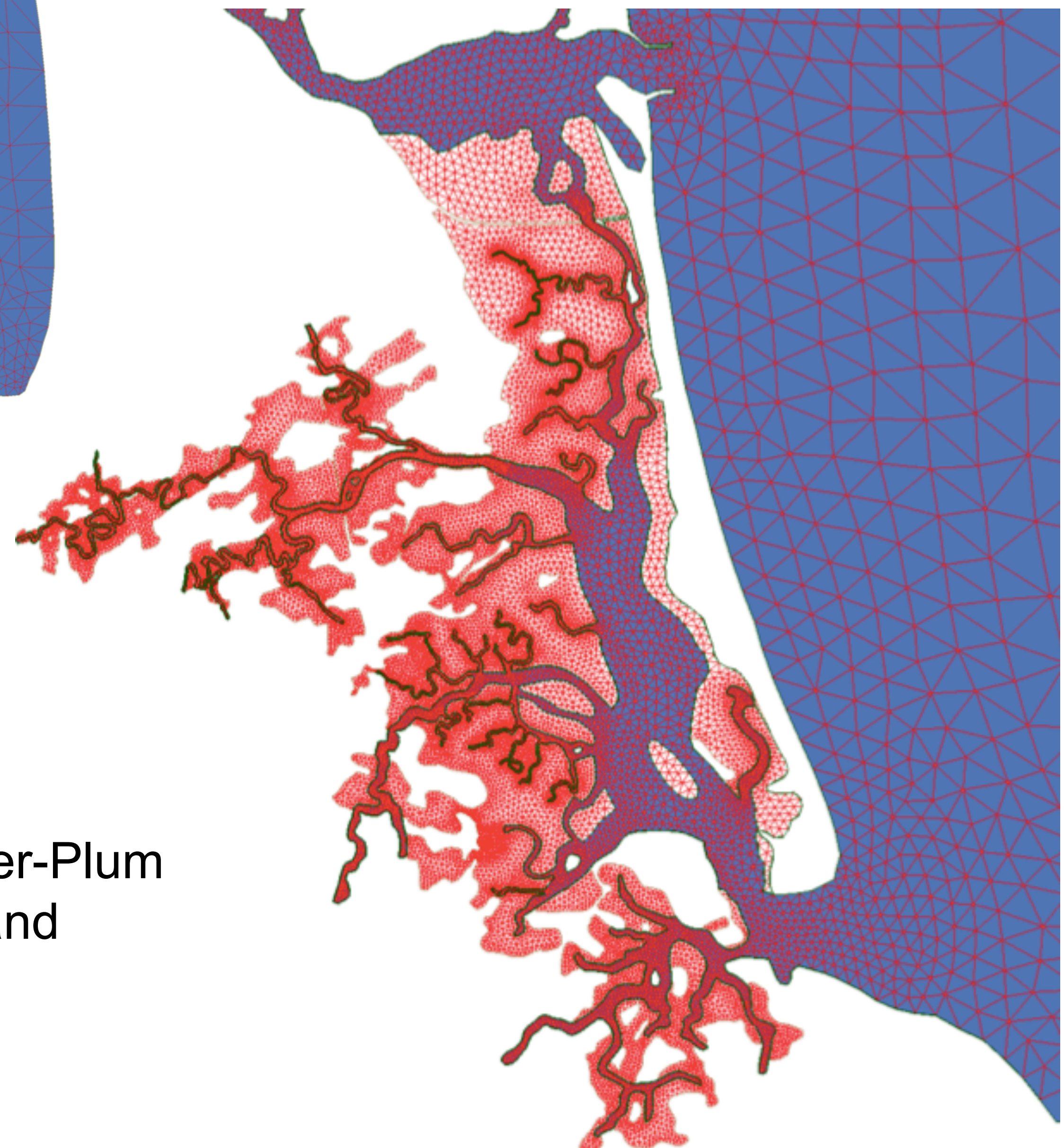
Mass Coastal FVCOM (Finest resolution: 15 m)




Minot
Gannett Rd
Mann Hill Beach
Tar Pouch
Egypt
Hatherly Rd
Old Sow
Manson Corner
Mungo Corner
Jericho Rd
Scituate Station
Maple St
Chief Justice Cushing Hwy
Country Way
Scituate
Kent St
Sherman Corner
Greenbush
Driftway
Wood Island
© 2009 Europa Technologies
Resolution: Max: 435 m
Min: 3 m
Total mesh: 29689

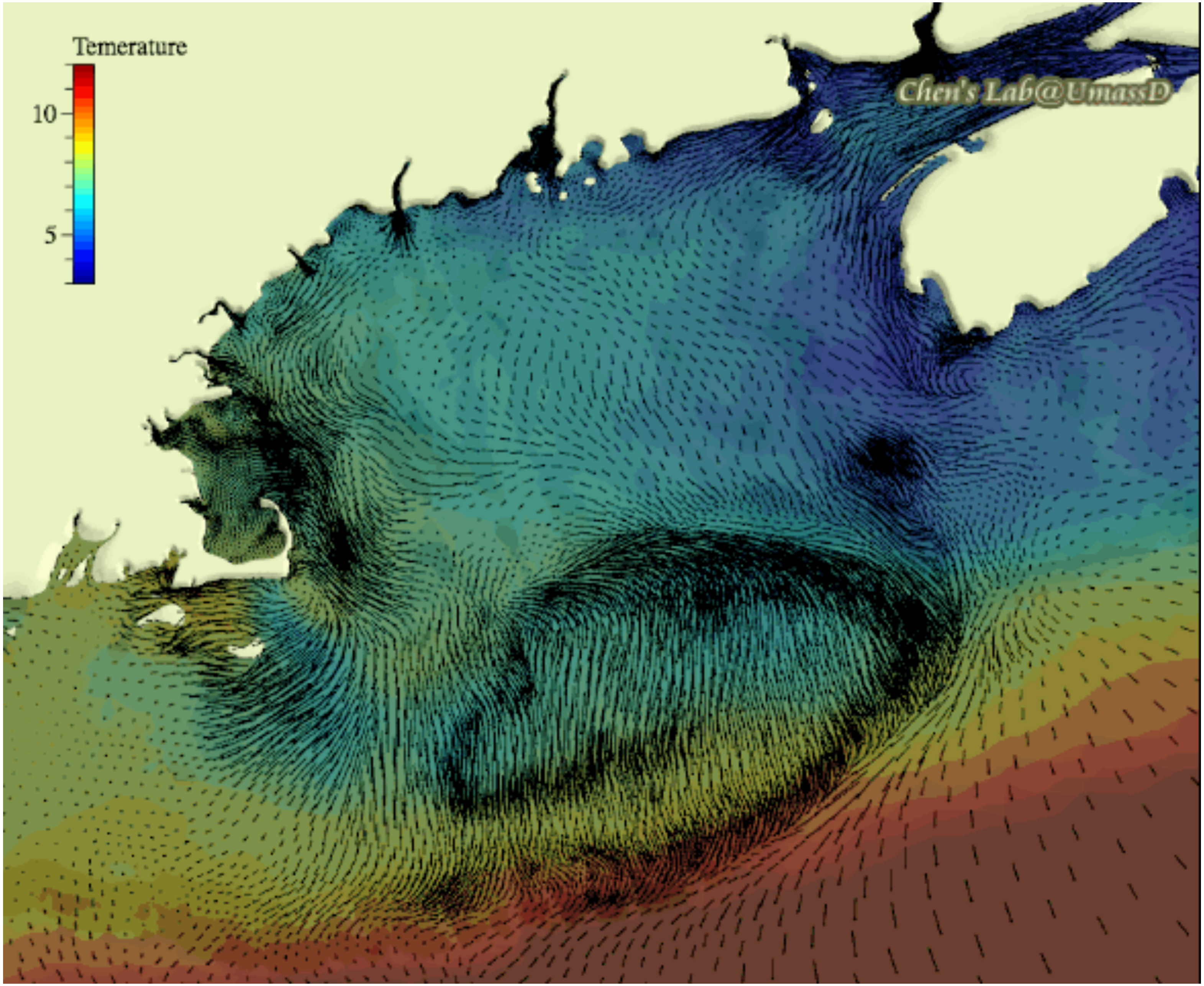

McPherson Ave
Wood Ave
Ely Ave
Montvale Ave
Graves Ave
©2009 Google

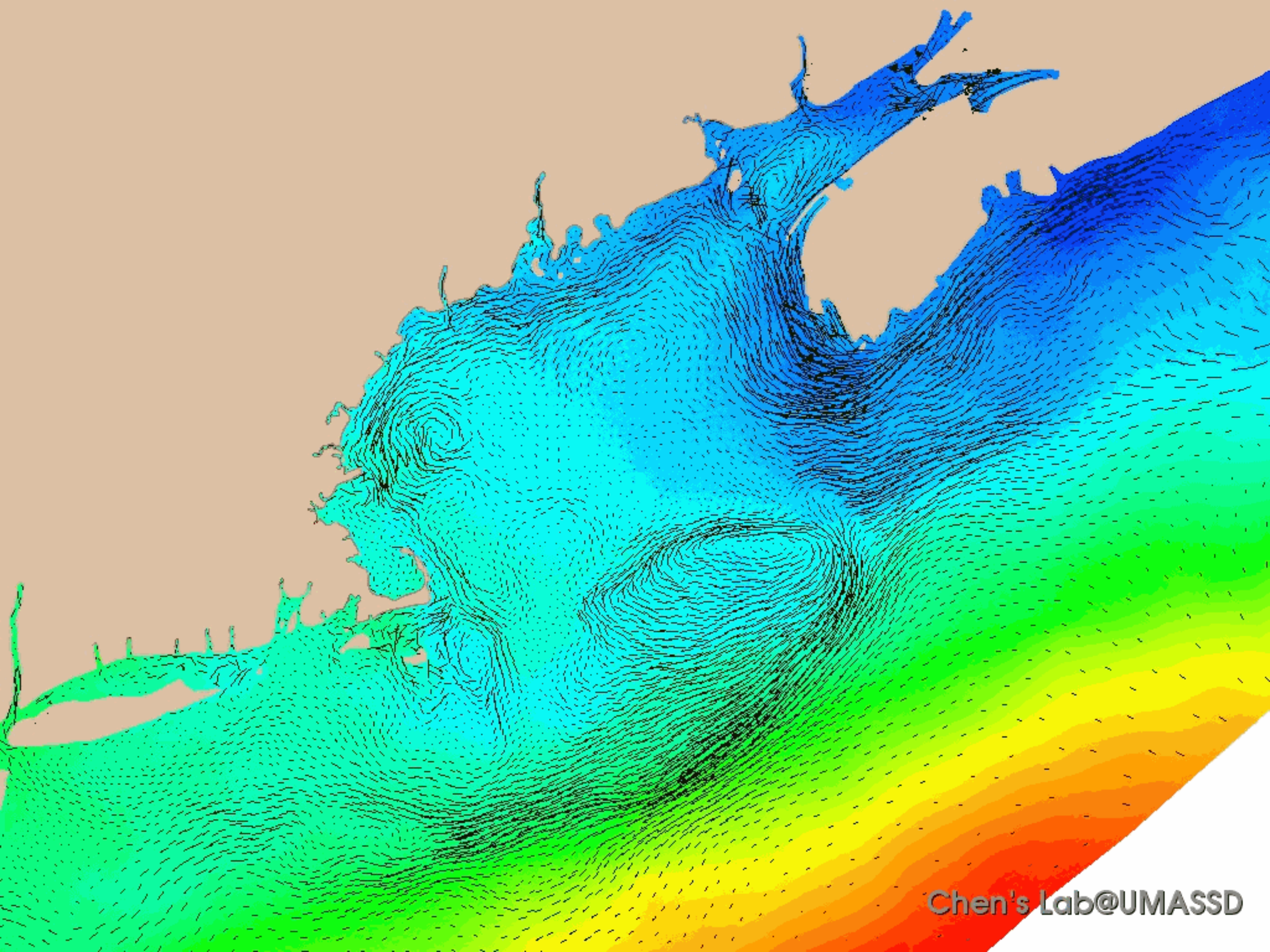


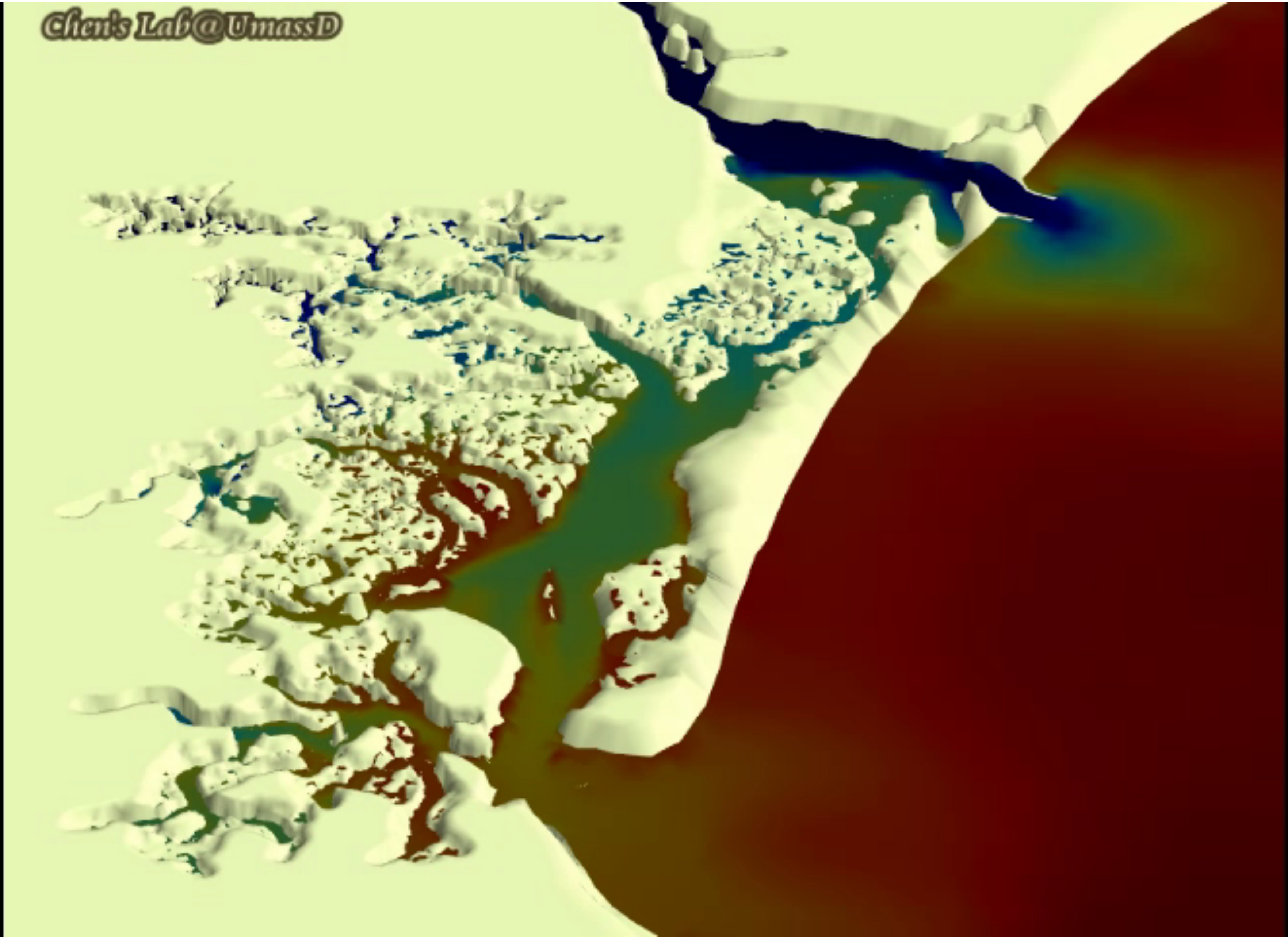


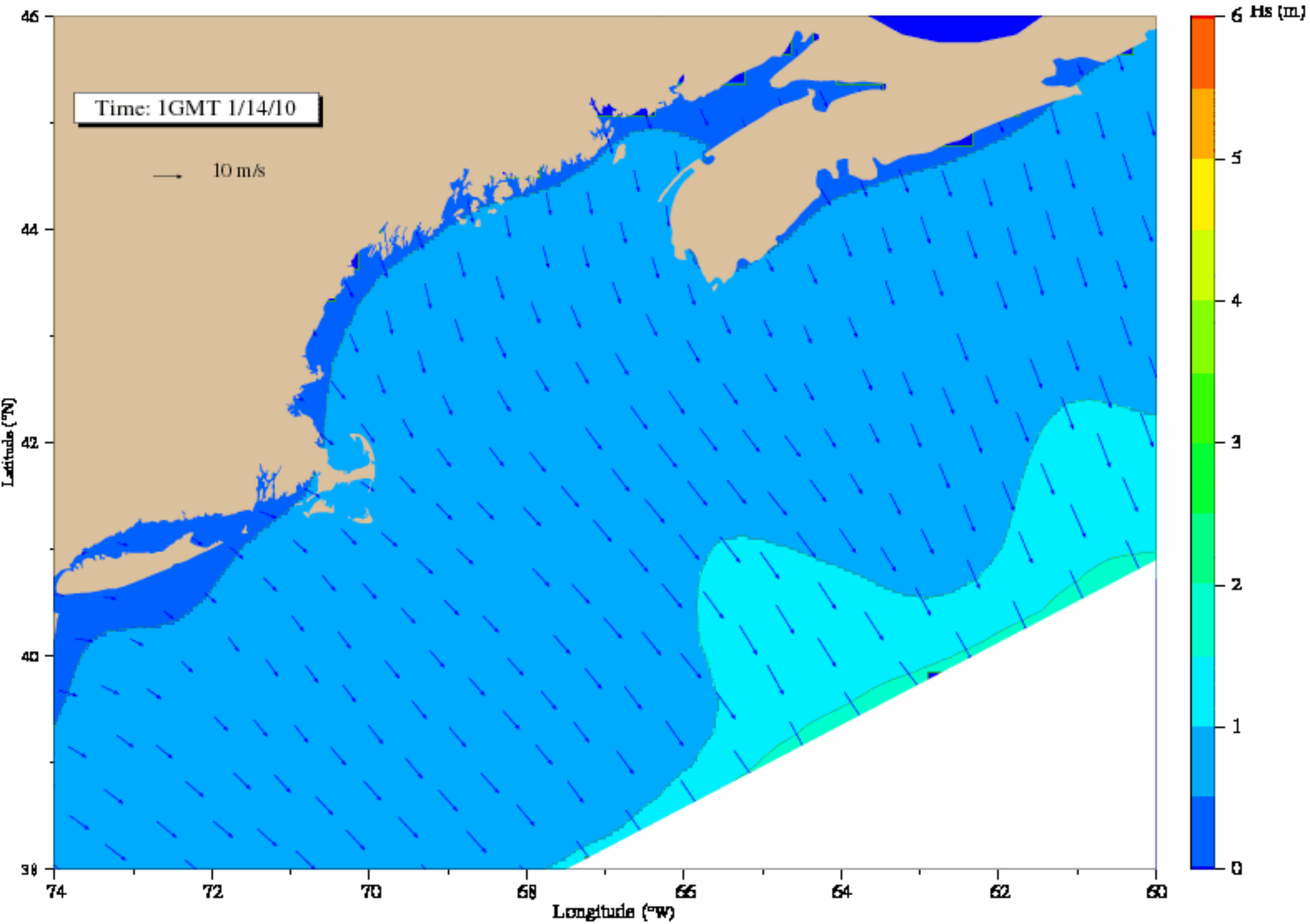
The Merrimack River-Plum Island Sound-Wetland Complex:

Island of North Boston (historical)
North End
Boston
Downtown Crossing
N


Temerature
10
5
Chen's Lab@UmassD


Chen's Lab@UMASSD


Chen's Lab@UmassD



Time: 1GMT 1/14/10
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72
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68
66
64
62
60
Latitude (°N)
Longitude (°W)

Comparison between model-predicted and observed sea surface elevations in January, 2010