The US Northeast Coastal Ocean Forecast System (NECOFS):

Applications for simulations of Hurricane- and Extratropic Storm-Induced Surges and Inundations

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Supported from the IOOS Coastal Ocean Modeling Testbed Program

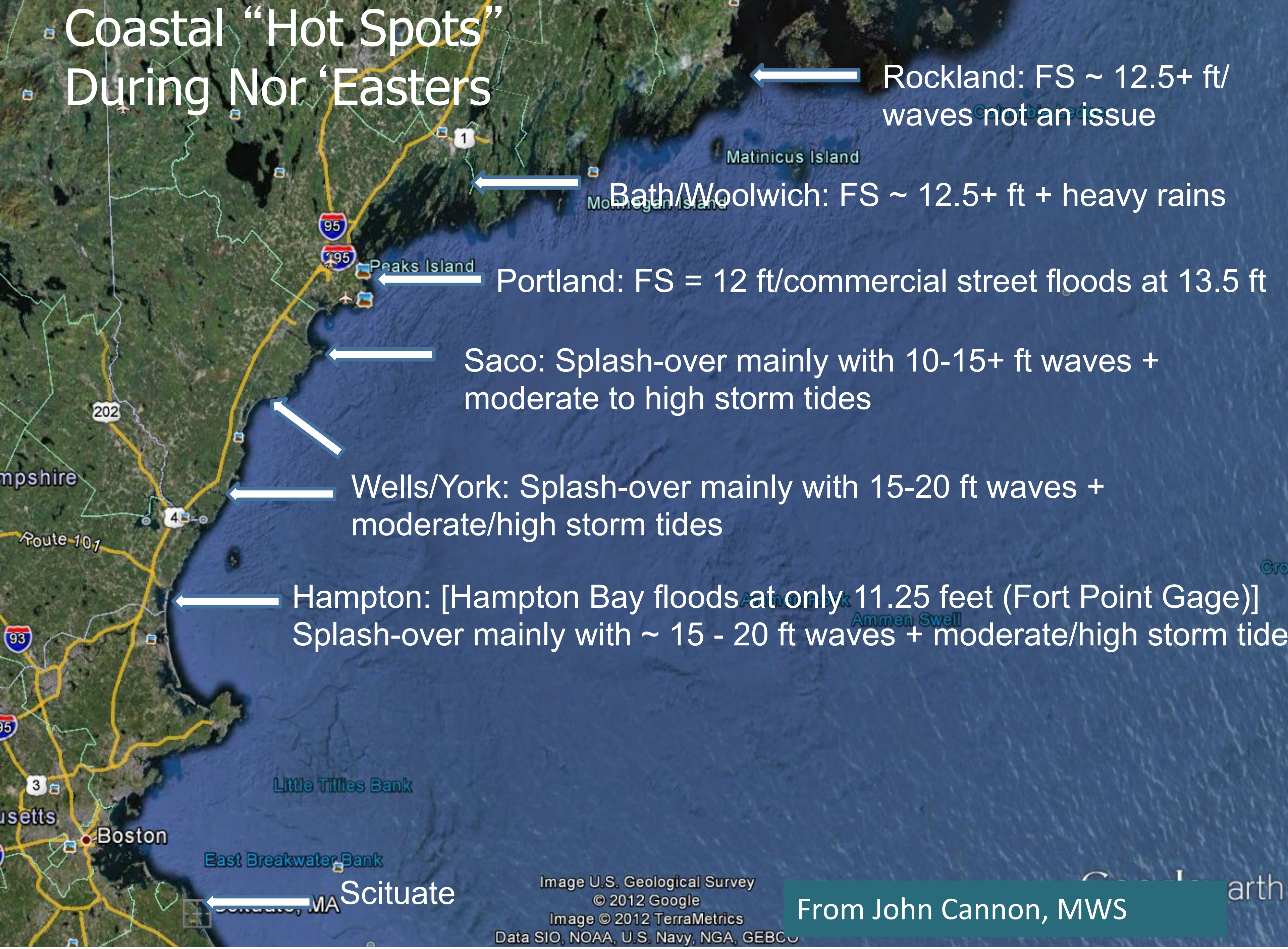
Coastal "Hot Spots" During Nor 'Easters
Rockland: FS ~ 12.5+ ft/ waves not an issue
Matinicus Island
Bath/Woolwich: FS ~ 12.5+ ft + heavy rains
Peaks Island
Portland: FS = 12 ft/commercial street floods at 13.5 ft
Saco: Splash-over mainly with 10-15+ ft waves + moderate to high storm tides
Wells/York: Splash-over mainly with 15-20 ft waves + moderate/high storm tides
Hampton: [Hampton Bay floods at only 11.25 feet (Fort Point Gage)]
Splash-over mainly with ~ 15 - 20 ft waves + moderate/high storm tide
Ammen Swell
202
Route 101
Little Tillies Bank
Boston
East Breakwater Bank
Scituate
Image U.S. Geological Survey
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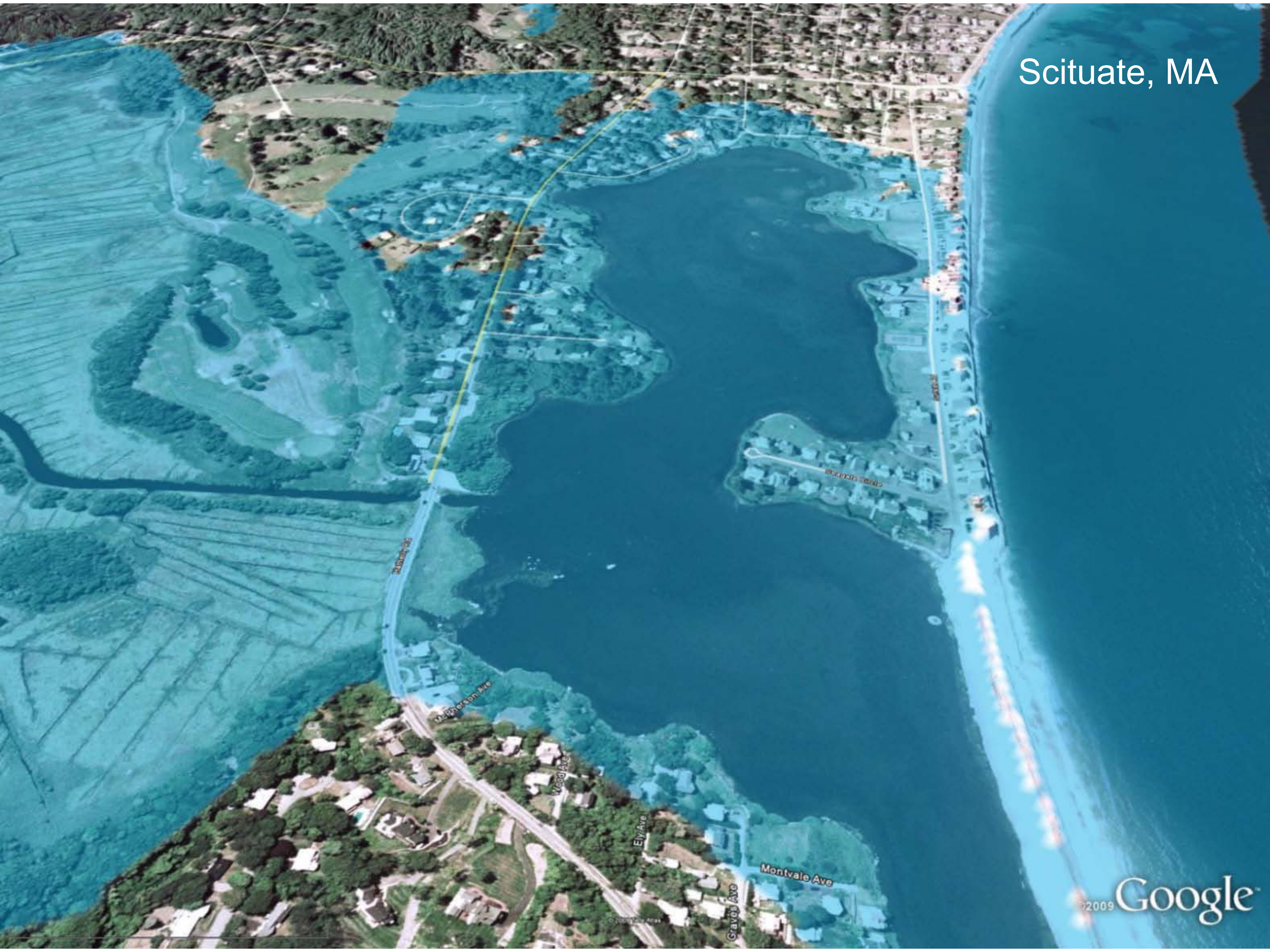
Image © 2012 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
From John Cannon, MWS



Scituate, MA
McPherson Ave
Wood Ave
Ely Ave
Montvale Ave
Graves Ave
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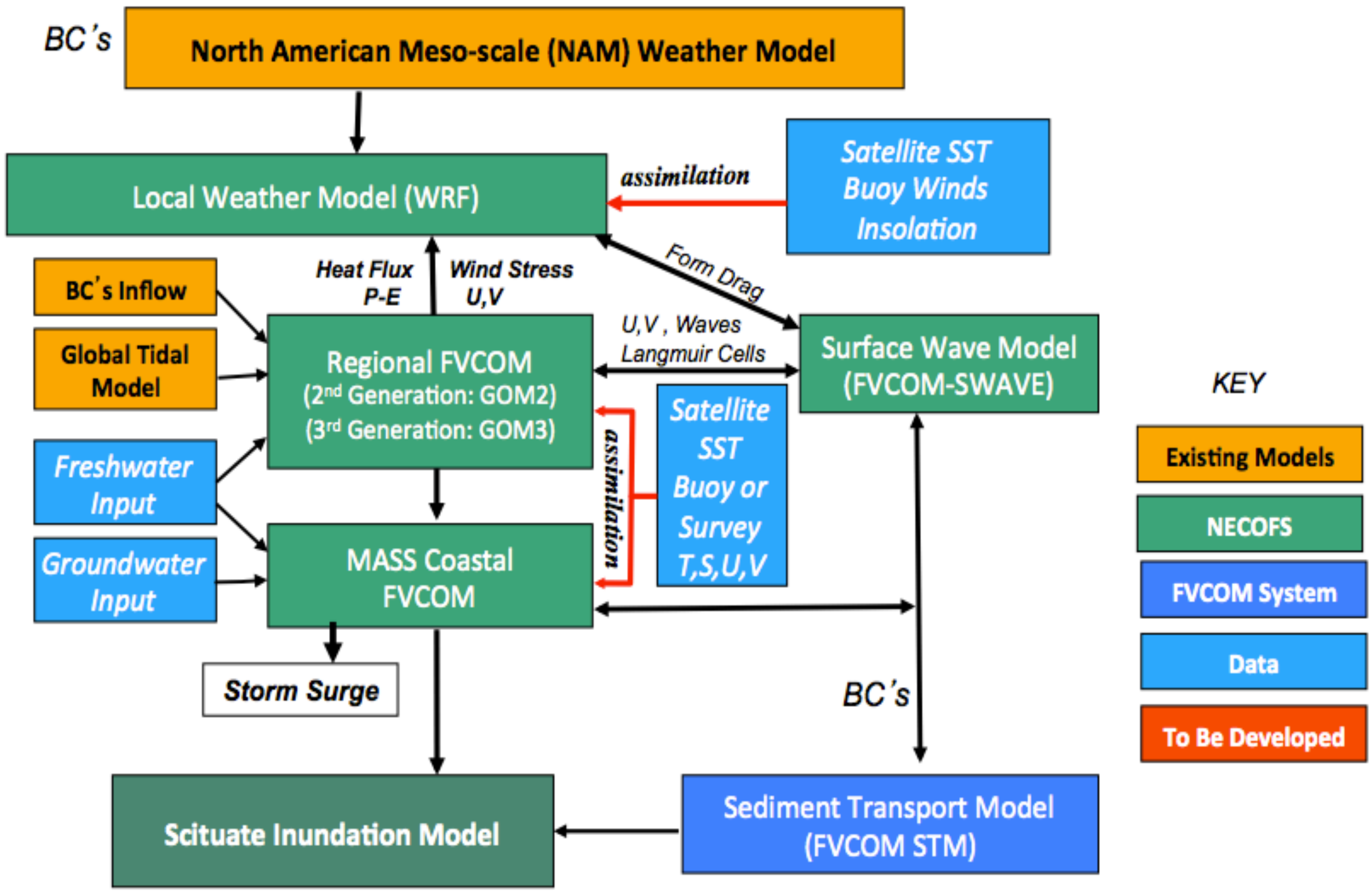
From John Cannon, MWS

Northeast Coastal Ocean Forecast System (NECOFS) -

produces 3-day forecast of surface weather, waves, elevation, 3D currents, temperature, salinity



Operation Components

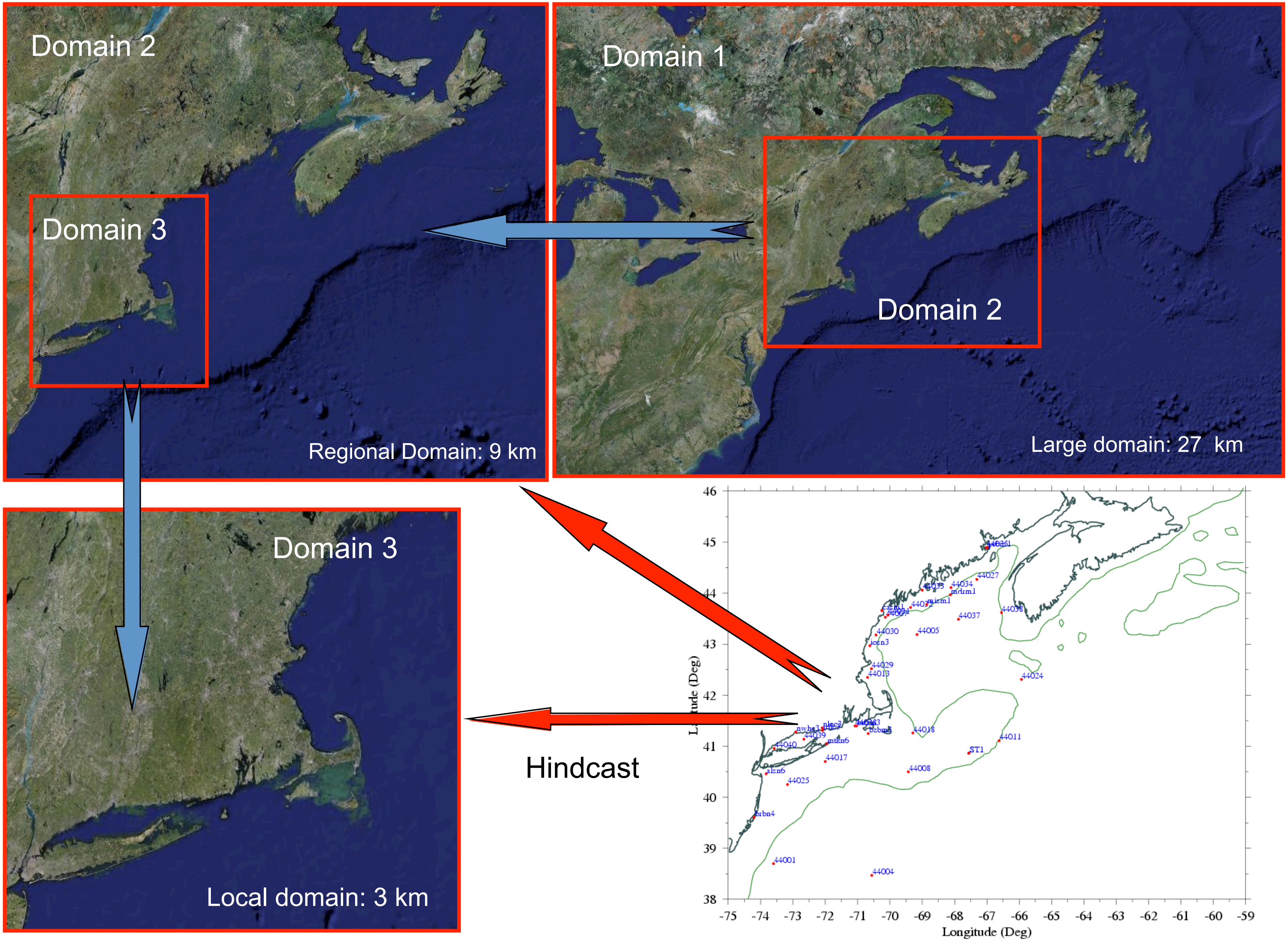
1. Meso-scale meteorological forecast model (WRF), with horizontal resolution of 9 km.

2. Hydrodynamics-temperature, salinity, 3-D currents, sea level. GOM2: Cut off 300-m off the shelf break region; GOM3: Cut off 1500-m off the shelf break. The upstream boundary conditions are specified by the wind-induced flux. Horizontal resolution varies from 25 km to 500 m.

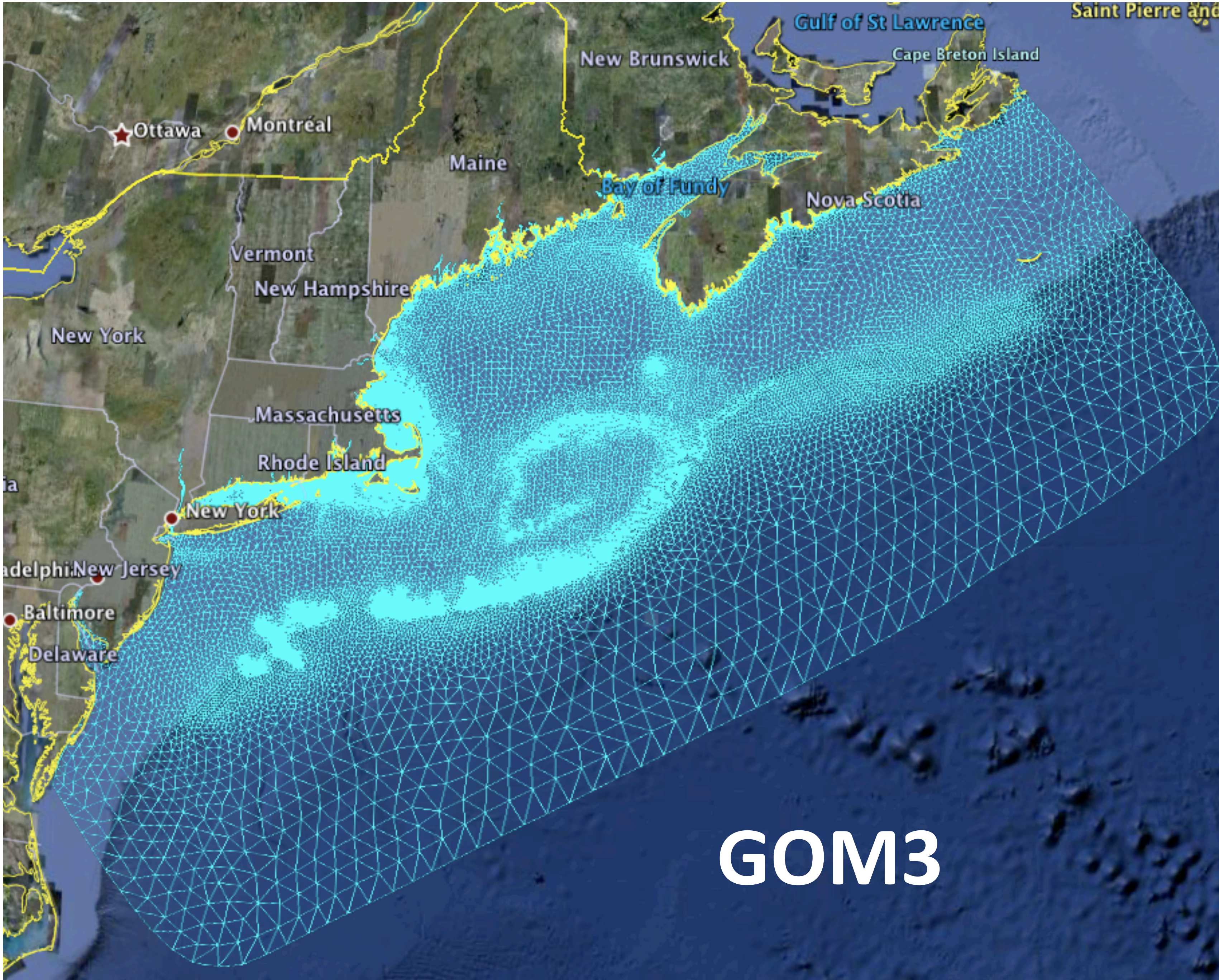
3. Surface waves- A nested WWIII-SWAVE system;

4. Mass Coastal FVCOM: High-resolution coastal model nested with GOM3, with horizontal resolution up to 15 m.

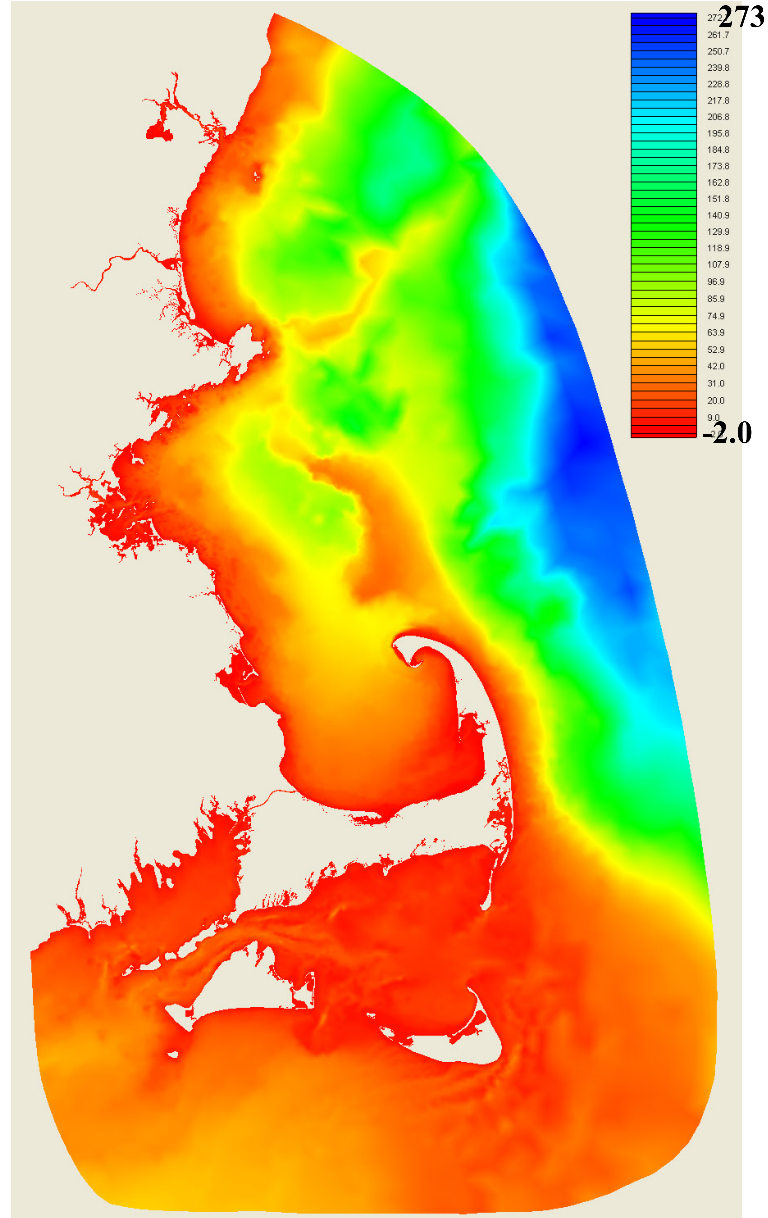
5. Scituate Inundation FVCOM: A fully current-wave coupled model system, with horizontal resolutions up to 10 m.



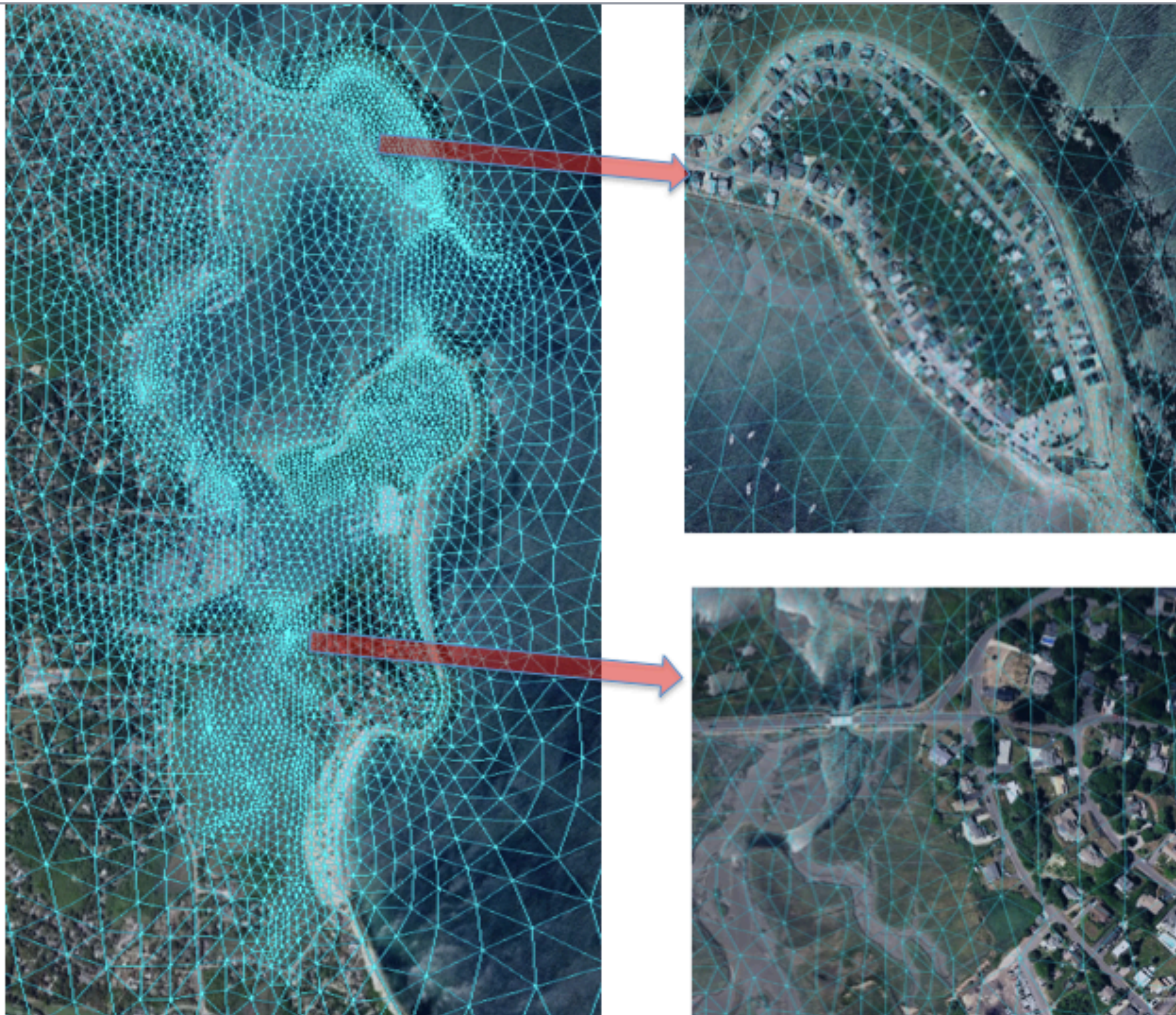
Domain 2
Domain 3
Regional Domain: 9 km
Domain 1
Domain 2
Large domain: 27 km
Domain 3
Local domain: 3 km
Hindcast
44037
44005
44030
44029
44013
44024
44018
44011
ST1
44008
44017
44025
44039
44040
44001
44004
44027
44034
44038
Longitude (Deg)

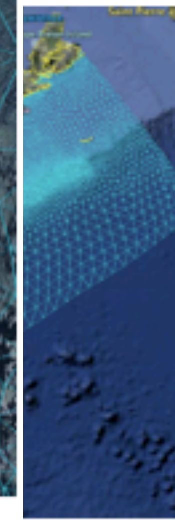

Gulf of St Lawrence
Saint Pierre and
Cape Breton Island
New Brunswick
Ottawa
Montreal
Maine
Bay of Fundy
Nova Scotia
Vermont
New Hampshire
New York
Massachusetts
Rhode Island
New York
New Jersey
Baltimore
Delaware
GOM3

Mass Coastal FVCOM (Finest resolution: 15 m)

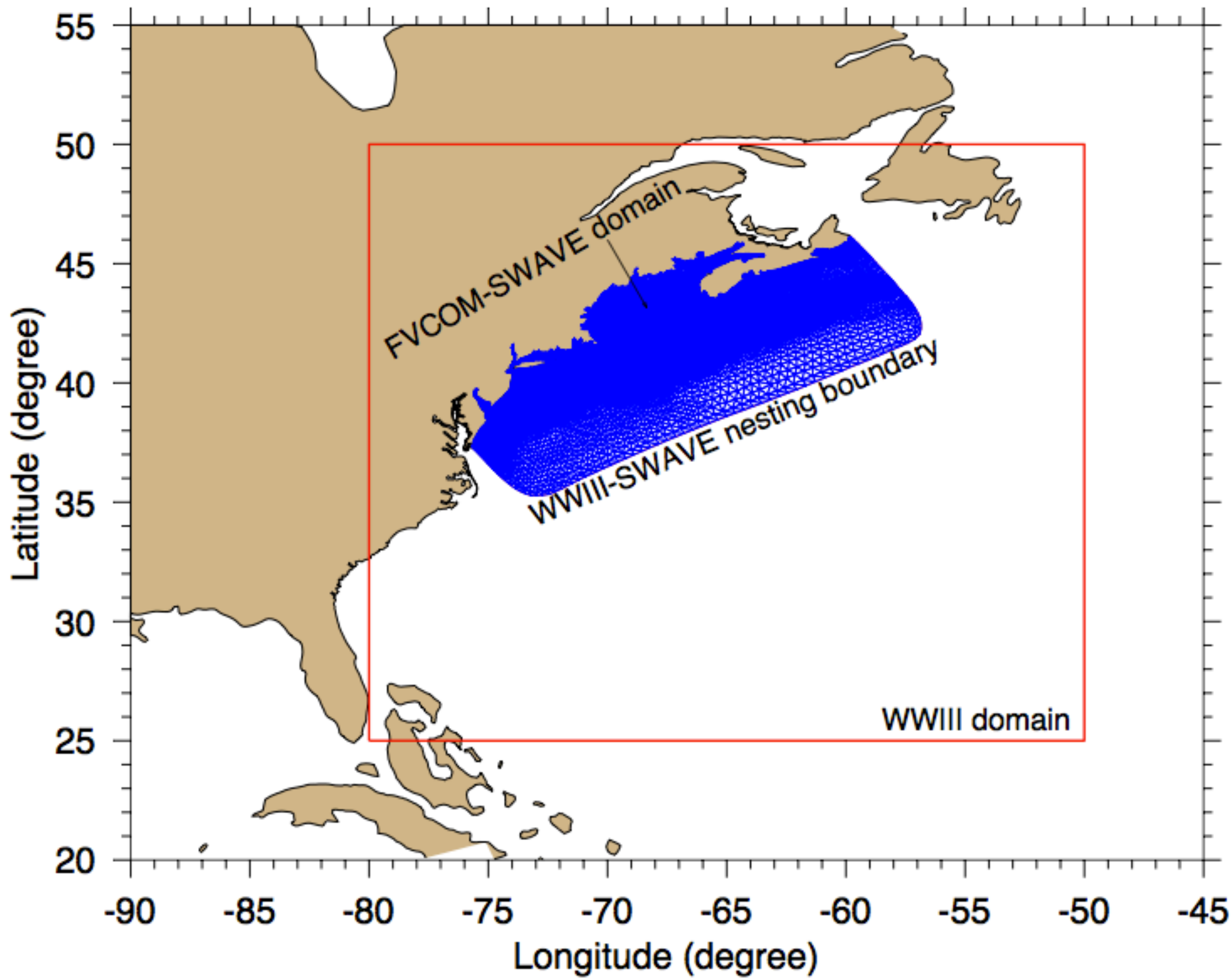


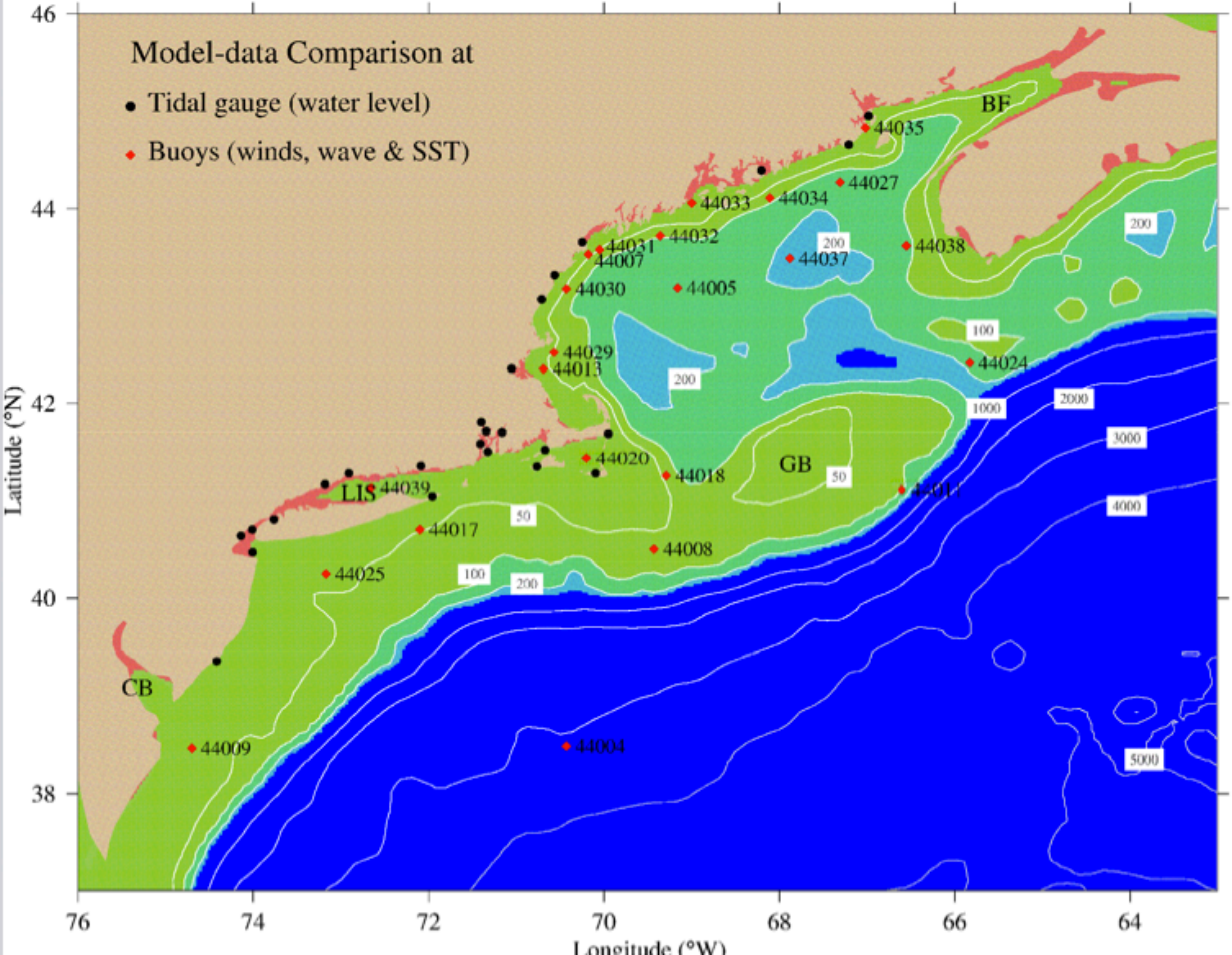
Ocean
FS)





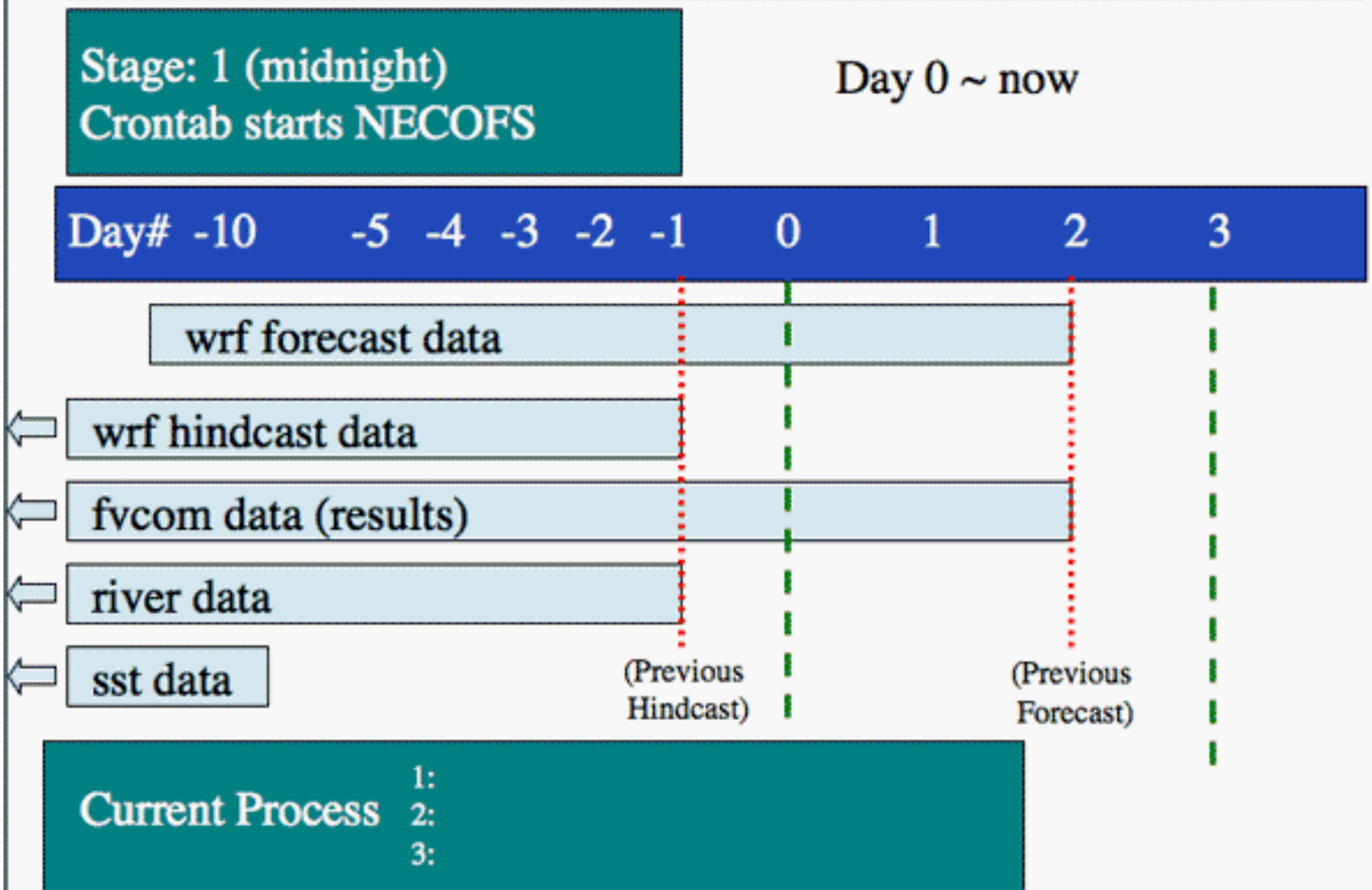
WWIII-FVCOM-SWAVE Nesting



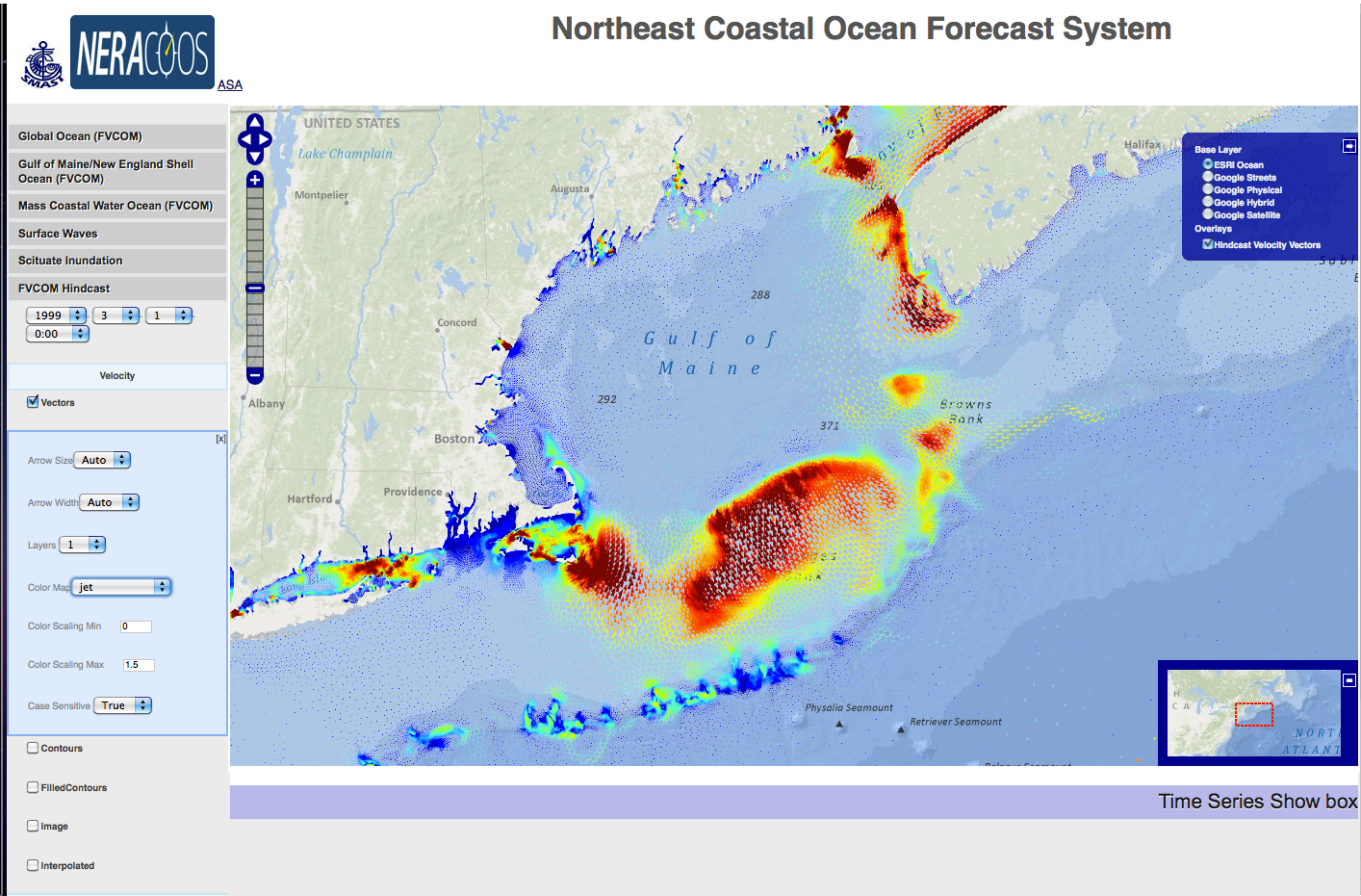


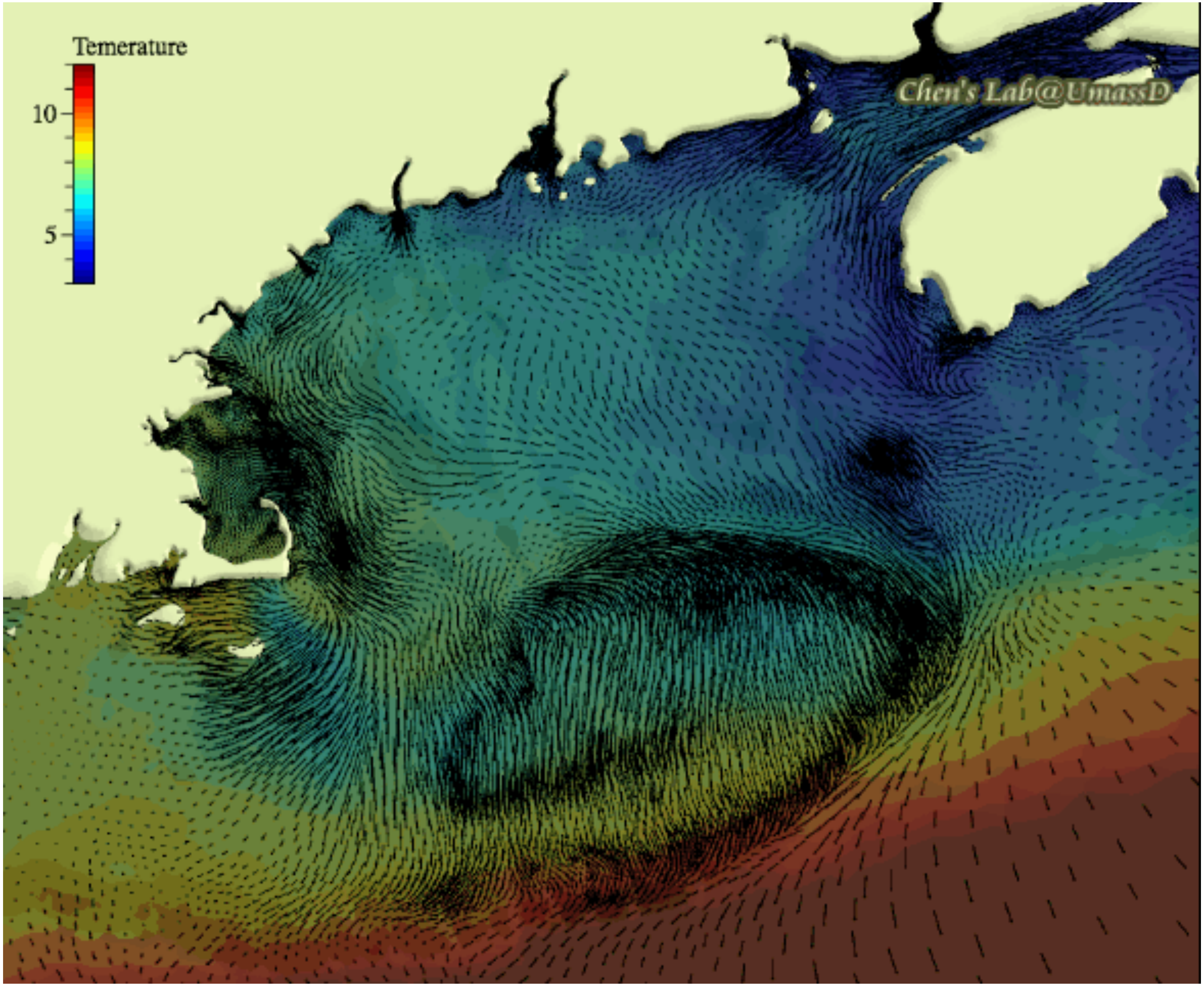
Model-data Comparison at
Tidal gauge (water level)
Buoys (winds, wave & SST)
46
44
42
40
38
Latitude (°N)
76
74
72
70
68
66
64
Longitude (°W)
BF
GB
LIS
CB
44035
44027
44034
44033
44032
44031
44007
44038
44037
44030
44005
44029
44013
44024
44020
44018
44039
44011
44017
44008
44025
44009
44004
50
100
200
1000
2000
3000
4000
5000

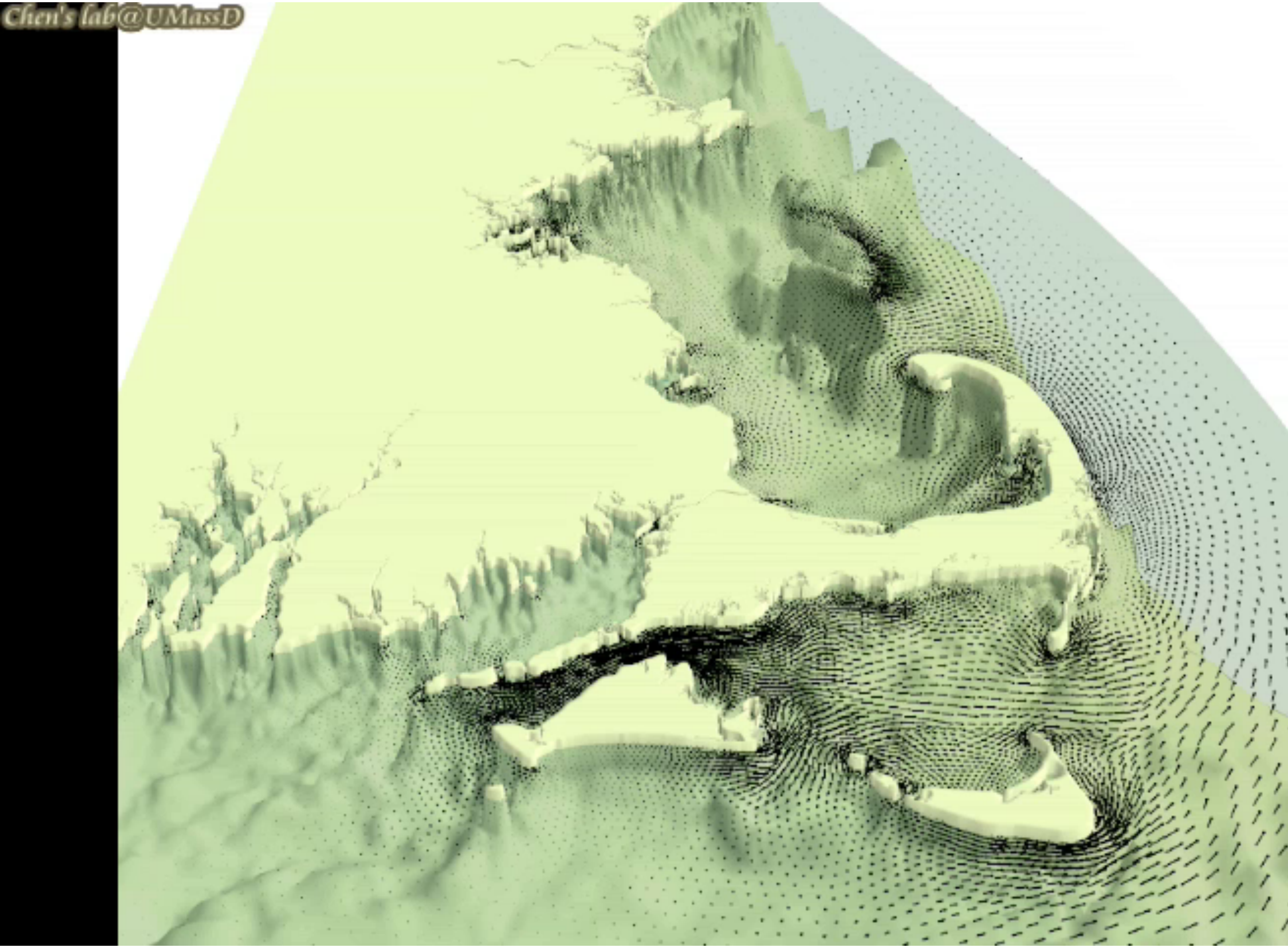
NECOFS Model Flow Diagram: 1.0

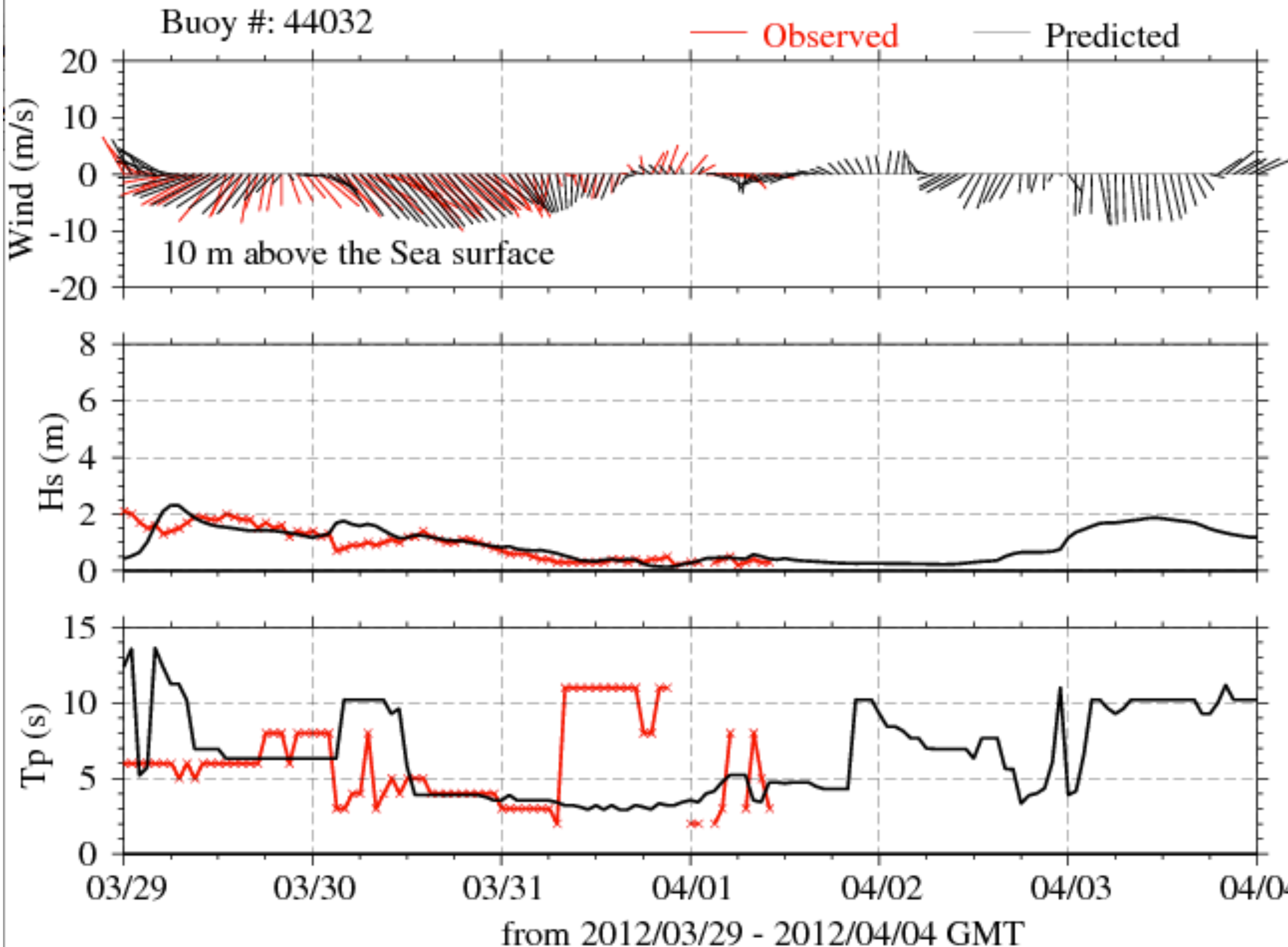


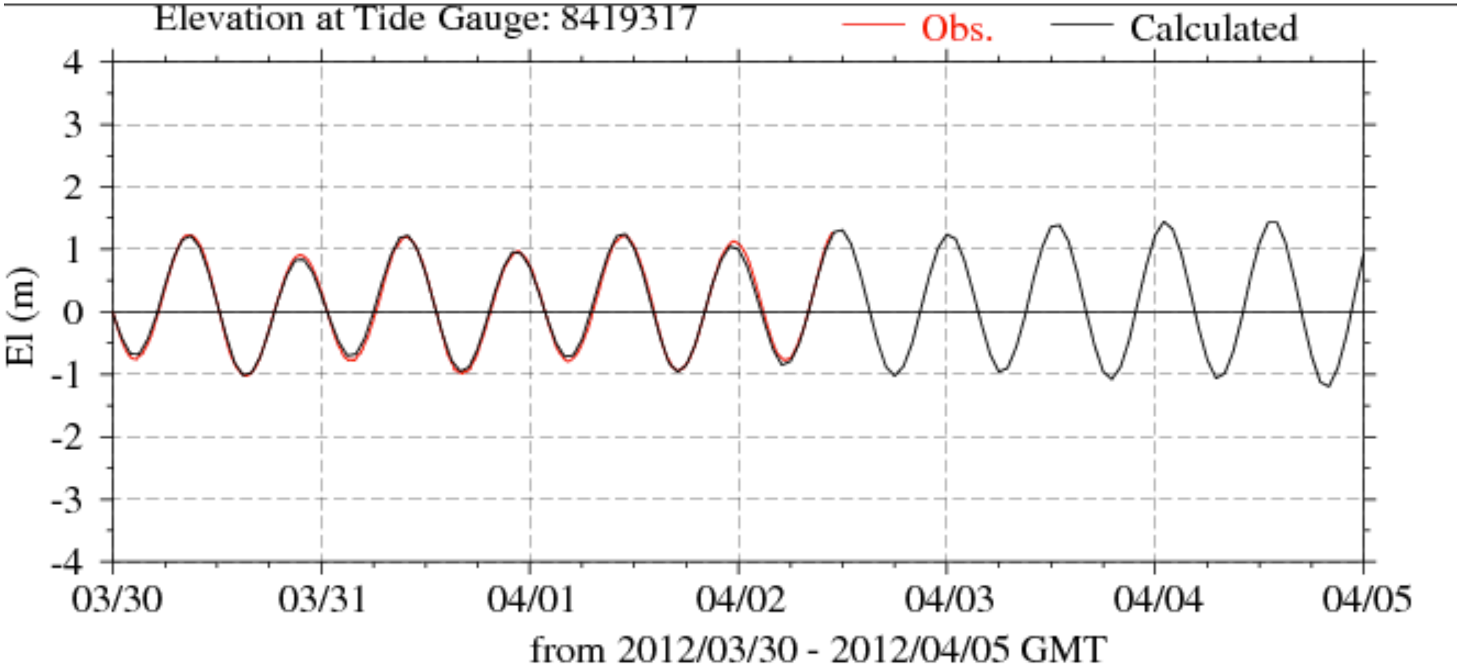
Web Map Server to display the hindcast data

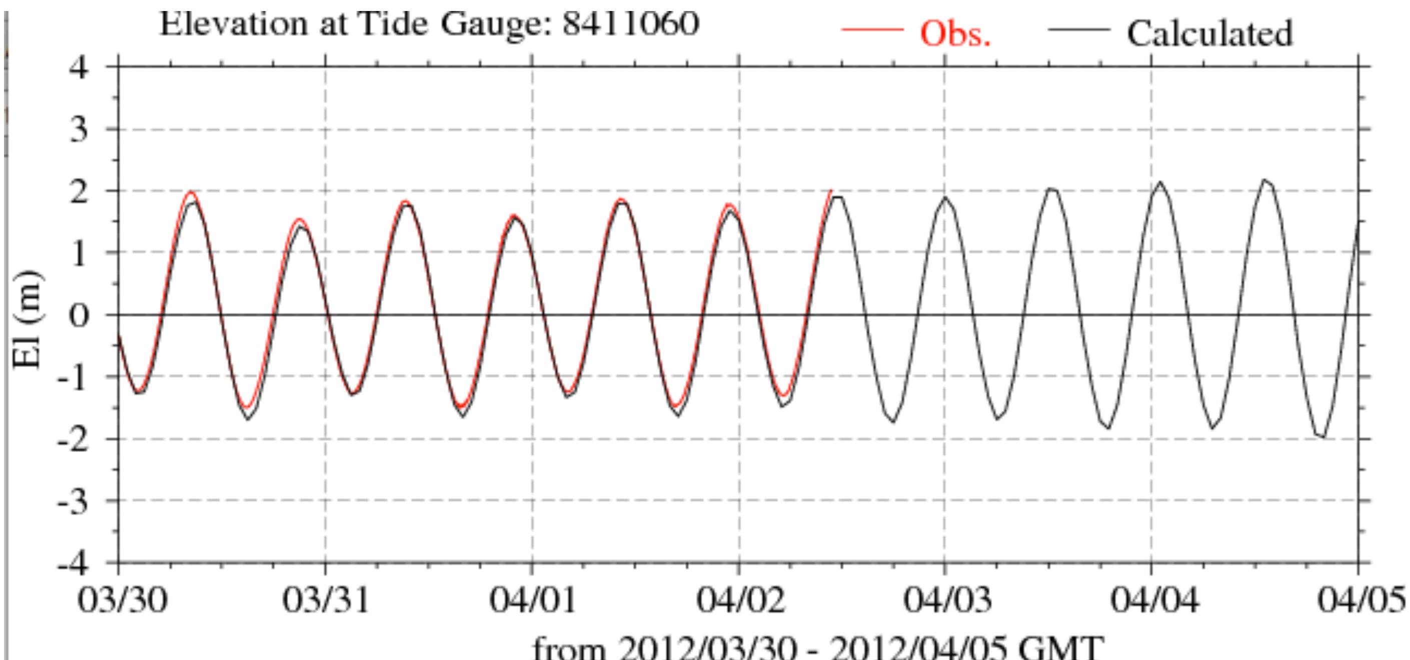


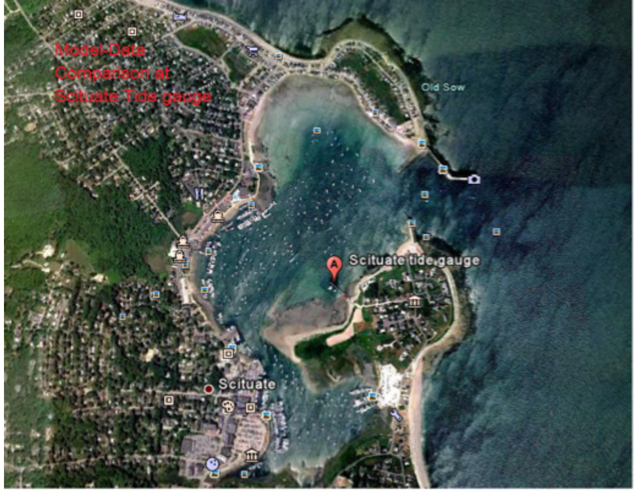

Temerature
10
5
Chen's Lab@UmassD

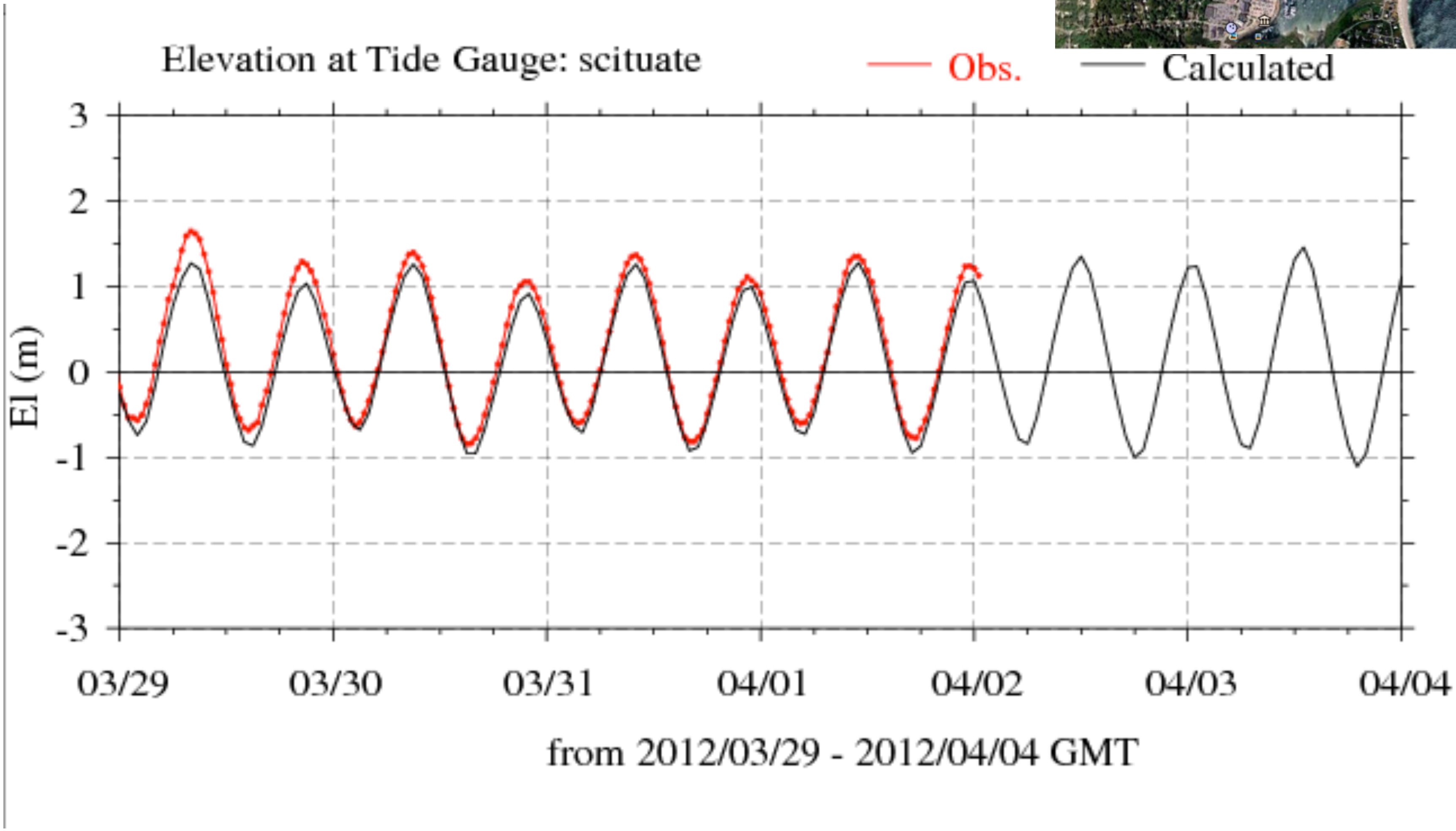

Chen's lab@UMassD


Buoy #: 44032
Observed
Predicted
Wind (m/s)
20
10
0
-10
-20
10 m above the Sea surface
Hs (m)
8
6
4
2
0
Tp (s)
15
10
5
0
03/29
03/30
03/31
04/01
04/02
04/03
04/04
from 2012/03/29 - 2012/04/04 GMT


Elevation at Tide Gauge: 8419317
Obs.
Calculated
El (m)
4
3
2
1
0
-1
-2
-3
-4
03/30
03/31
04/01
04/02
04/03
04/04
04/05
from 2012/03/30 - 2012/04/05 GMT


Elevation at Tide Gauge: 8411060
Obs.
Calculated
El (m)
4
3
2
1
0
-1
-2
-3
-4
03/30
03/31
04/01
04/02
04/03
04/04
04/05
from 2012/03/30 - 2012/04/05 GMT


Model-Data
Comparison at
Scituate Tide gauge
Old Sow
Scituate tide gauge
Scituate


Elevation at Tide Gauge: scituate
Obs.
Calculated
El (m)
3
2
1
0
-1
-2
-3
03/29
03/30
03/31
04/01
04/02
04/03
04/04
from 2012/03/29 - 2012/04/04 GMT

Impacts of Current-Wave Interactions on Hurricane- and Extratropic Storm-induced Surges and Coastal Inundations

Example 1:

IOOS/SURA Extratropical Storm Inundation Testbed: Preliminary Results for Scituate, Massachusetts.

Example 2:

1991 Hurricane Bob-induced storm surges over the New England Shelf.

Overall Goal

Investigate roles of model structure and physics, waves, wave-surge interaction, grid resolution, computational effort on hindcasting inundation on a local scale driven by an extratropical storm in the Gulf of Maine.

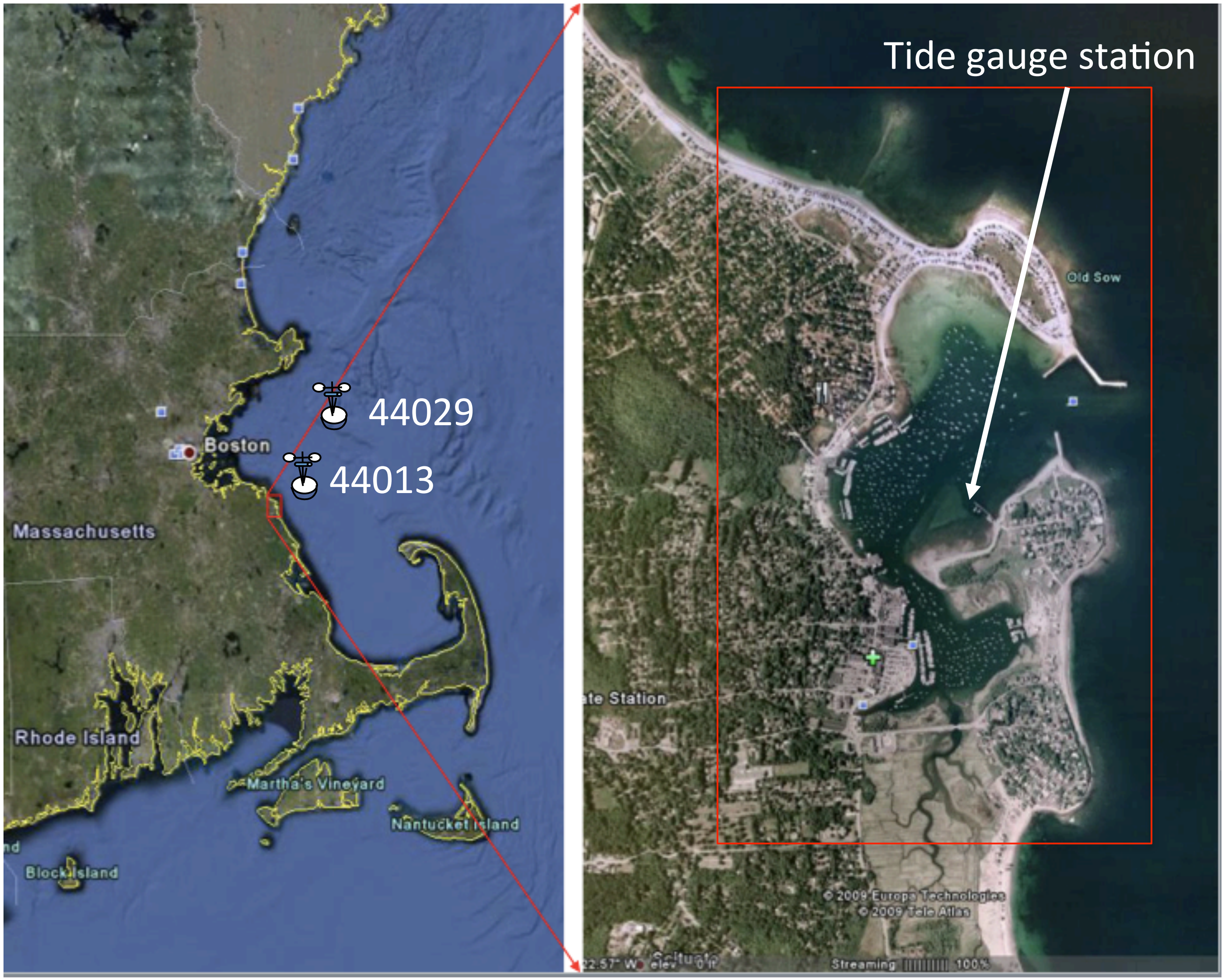
Objectives

- Hindcast inundation at Scituate (MA) during two recent (2005 and 2007) Nor'easters using suite of models with the same grid and forcing;
- Compare model output with available field data;
- Inter-compare model output;
- Formulate initial comparison results and plans for additional model tests.

Three Unstructured Grid Models

- ADCIRC/un-SWAN- The Advanced CIRCulation Model
- FVCOM/SWAVE-The Finite Volume Community Ocean Model
- SELFE/WWM-The Semi-implicit Eulerian-Lagrangian Finite Element Model

The Test Site: Scituate, MA

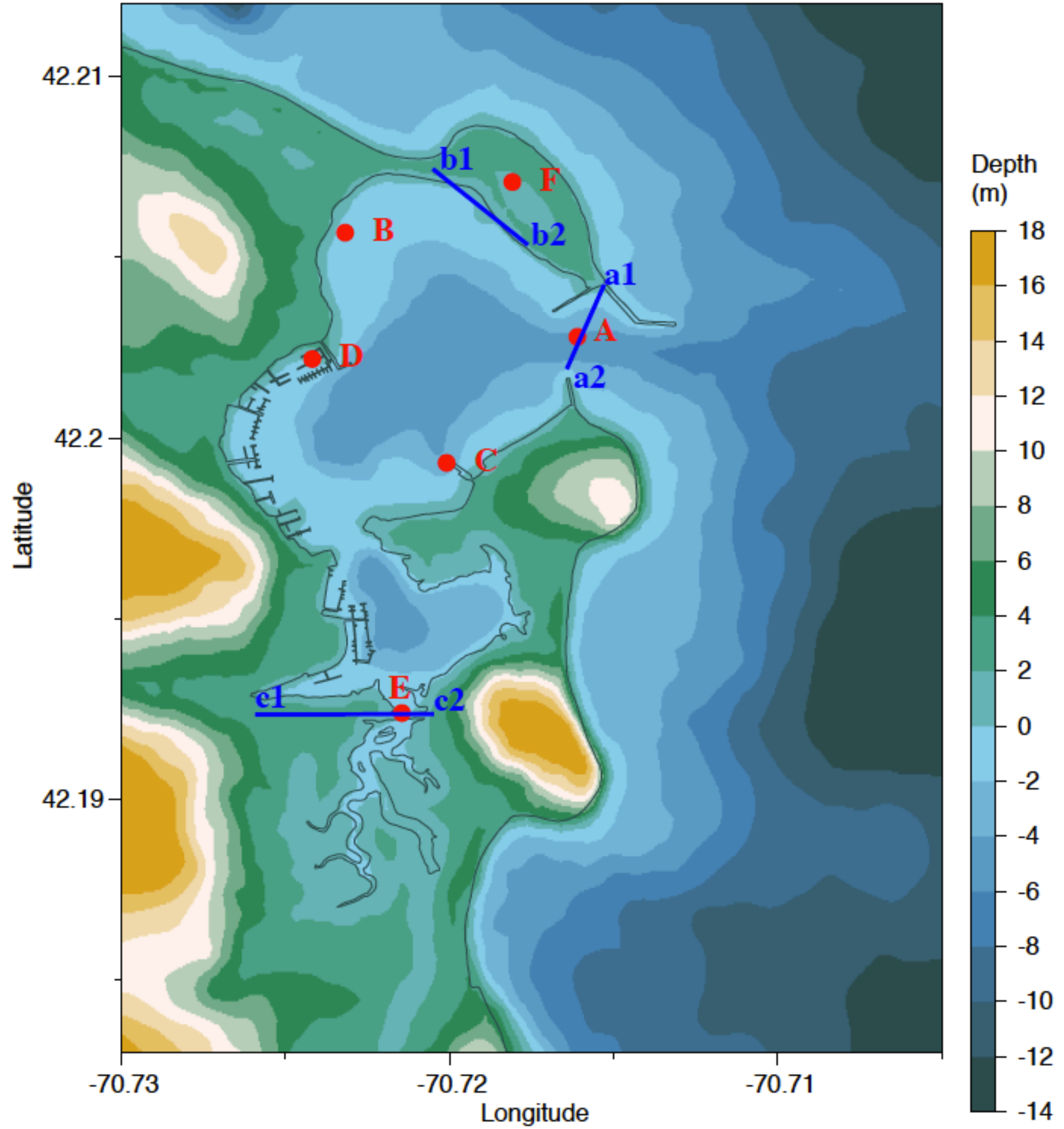


Model-Model Comparisons

- Tides and surface Waves
- The model runs without inclusion of current-wave interaction
- The model runs with inclusion of current-wave interaction

Transects

Stations

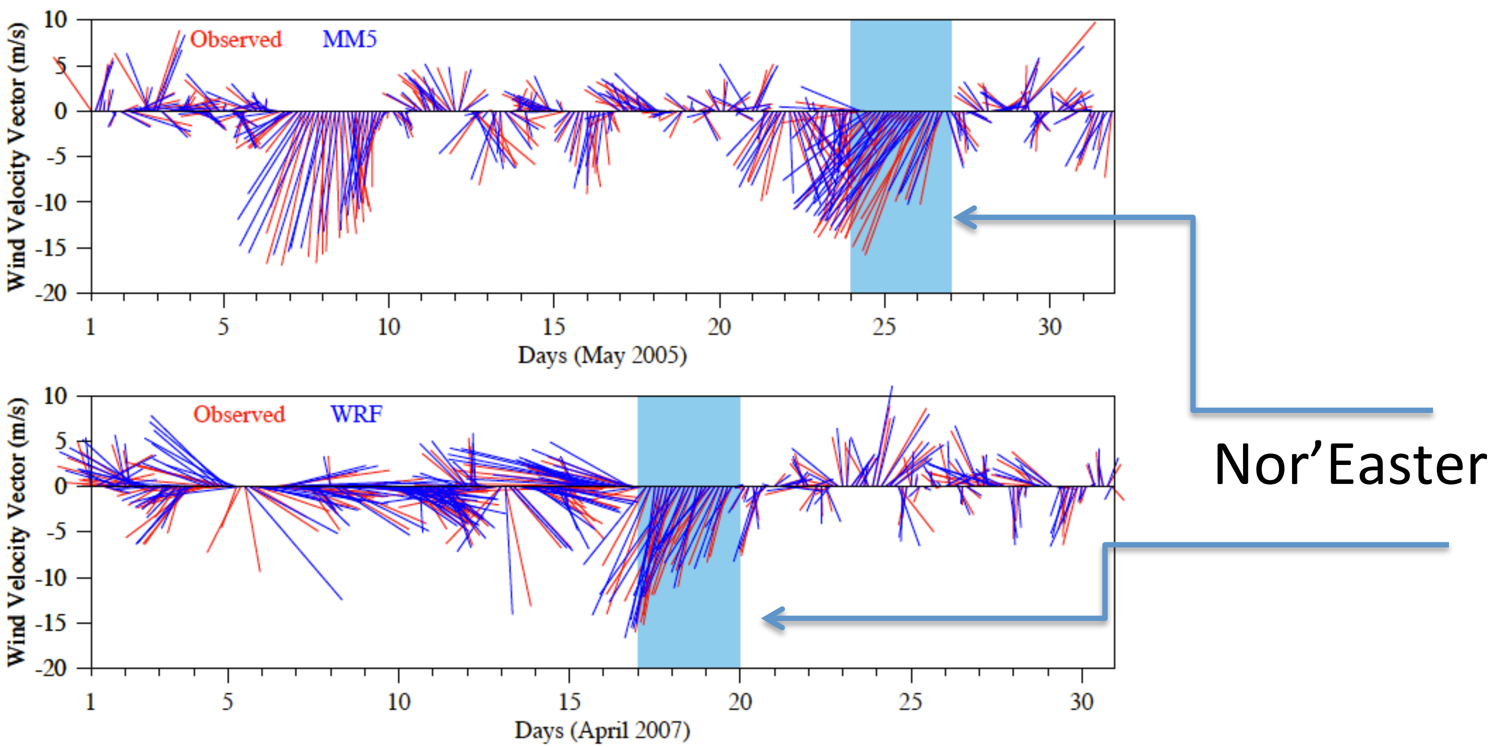


Initial Test Storm Cases

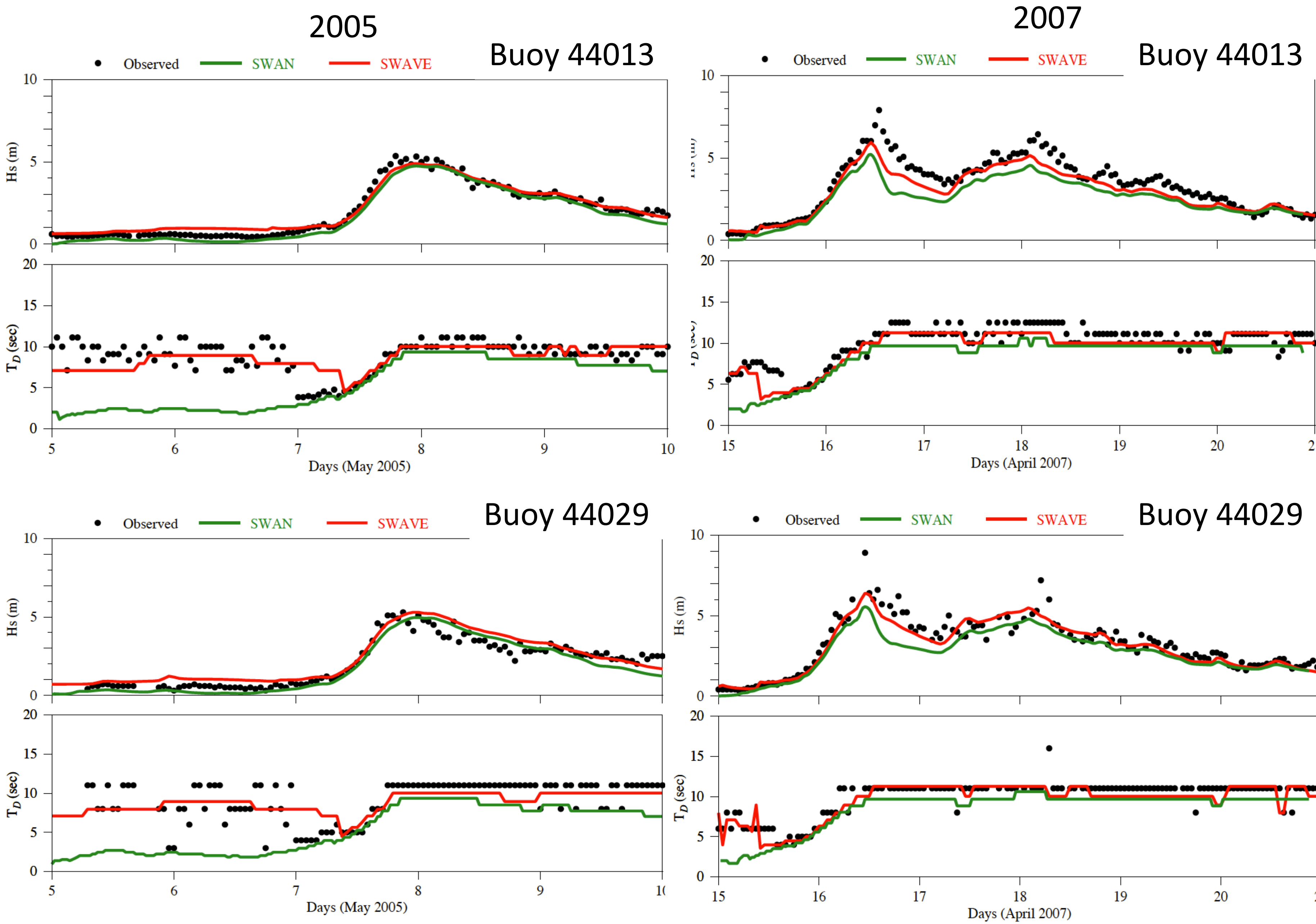
1) May 24 2005 storm;
2) April 17, 2007 ("Patriot's Day") storm.

Boston tide gauge and NOAA 440013

Date	Max TWL (ft)	Wave Height (ft)	Wave Period (sec)	Wind Speed (kts)	Wind Dir (degN)	Wind Gust (kts)	Scituate rating
4/18/07	13.8	18-21	8.5	28	30	35	moderate
5/25/05	13.8	11-15	6.5	30	30	38	"high end" moderate



Surface Wave Simulation in the region domain



Tidal Comparisons at Tidal Gauge Station C

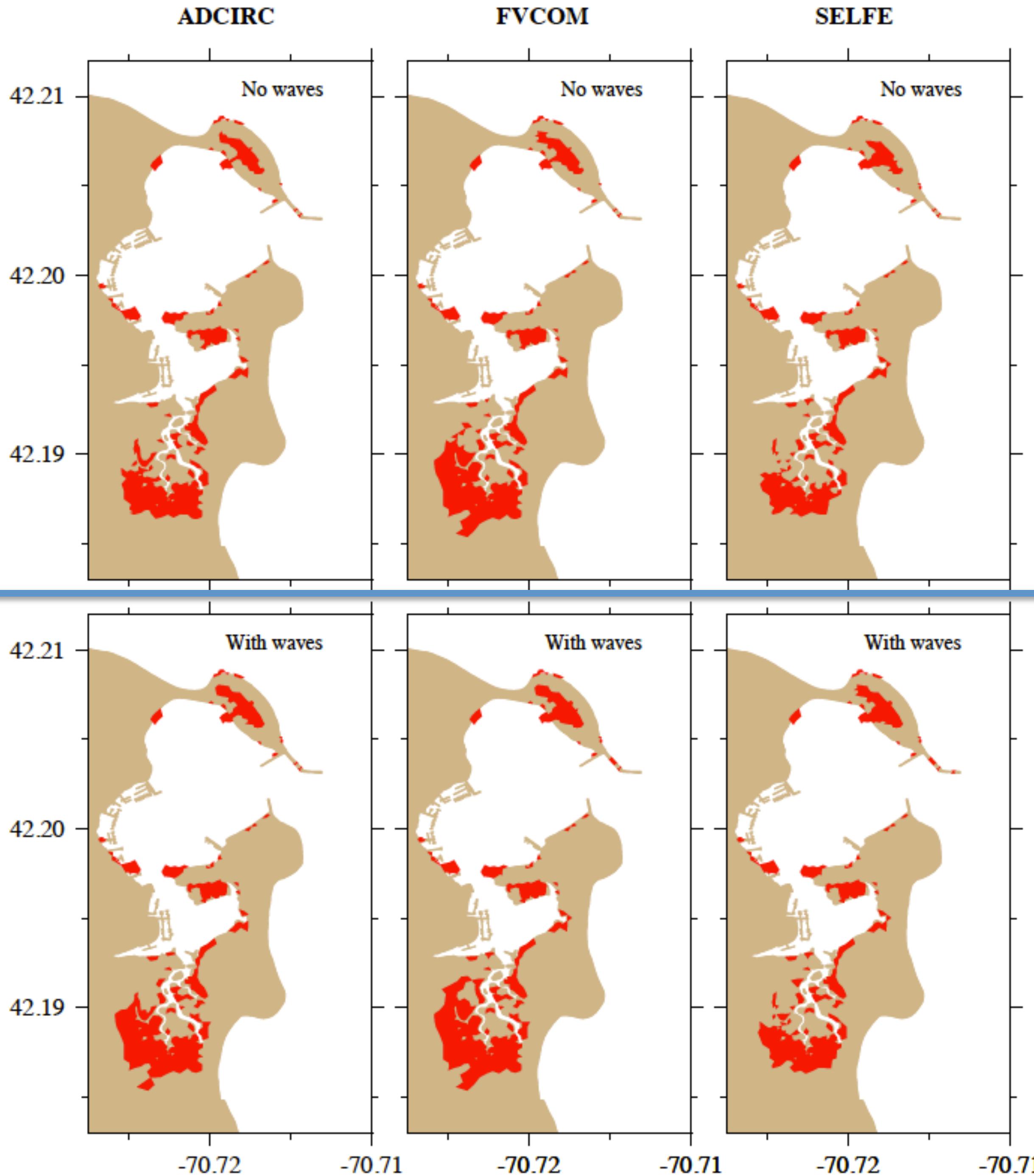
Table 1.1 Scituate tide amplitude comparison (5/1/2010 to 5/31/2010)

	OBS (m)	ADCIRC (m)	Diff (m)	FVCOM (m)	Diff (m)	SELFE (m)	Diff (m)
M2	1.324	1.237	-0.087	1.238	-0.086	1.239	-0.085
N2	0.249	0.281	0.032	0.280	0.031	0.280	0.031
S2	0.166	0.190	0.024	0.190	0.024	0.190	0.024
O1	0.119	0.109	-0.010	0.110	-0.009	0.109	-0.010
K1	0.136	0.128	-0.008	0.128	-0.008	0.128	-0.008

Table 1.2 Scituate tide phase comparison (5/1/2010 to 5/31/2010)

	OBS (deg)	ADCIRC (deg)	Diff (deg)	FVCOM (deg)	Diff (deg)	SELFE (deg)	Diff (deg)
M2	103.46	101.62	-1.84	101.66	-1.80	101.97	-1.49
N2	68.62	69.58	0.96	69.51	0.89	69.87	1.25
S2	141.30	152.58	11.28	152.81	11.51	153.17	11.87
O1	187.13	183.49	-3.64	183.56	-3.57	183.59	-3.54
K1	198.77	193.53	-5.24	193.48	-5.29	193.93	-4.84

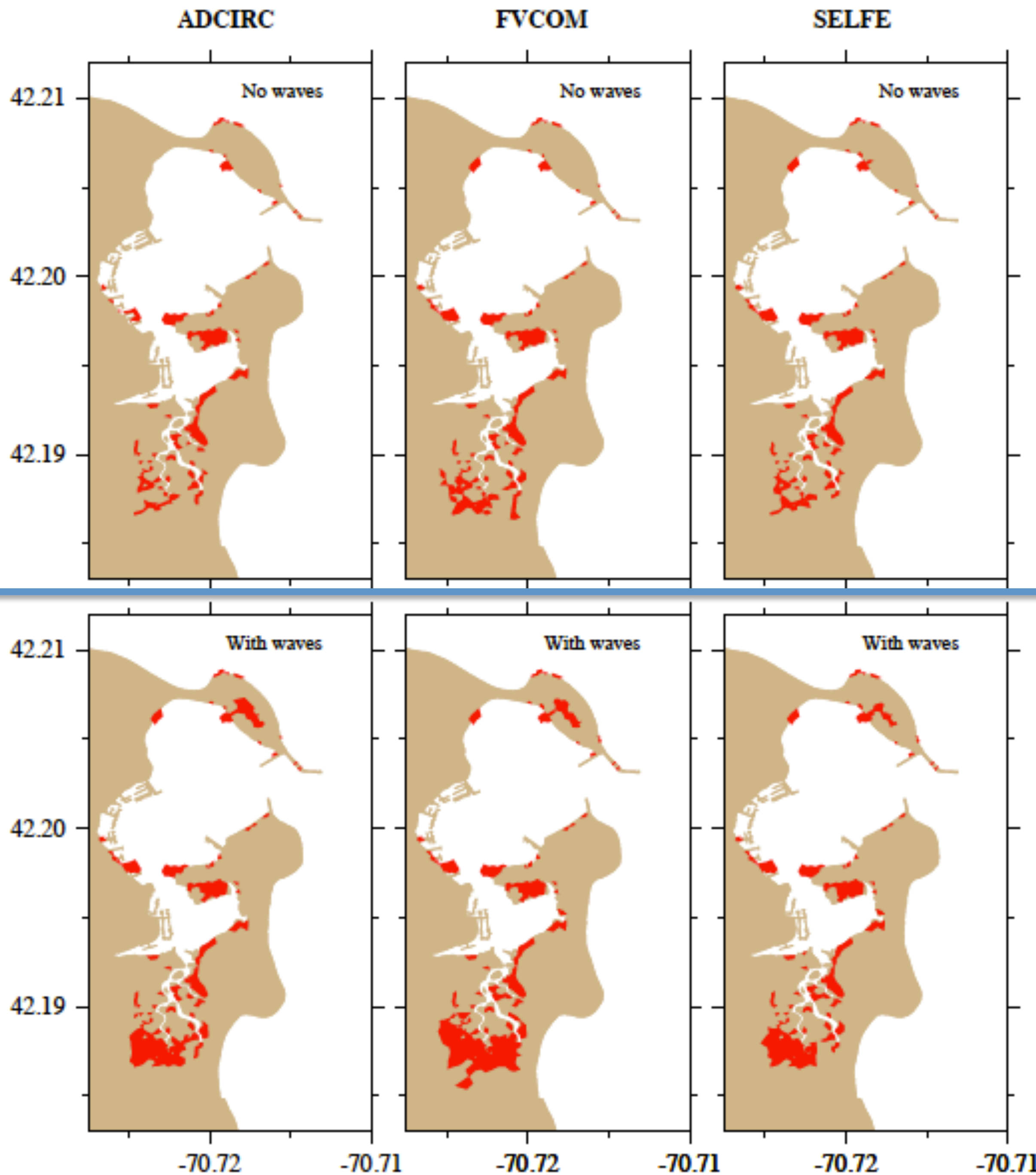
2005 Storm Inundation:



No waves

With waves

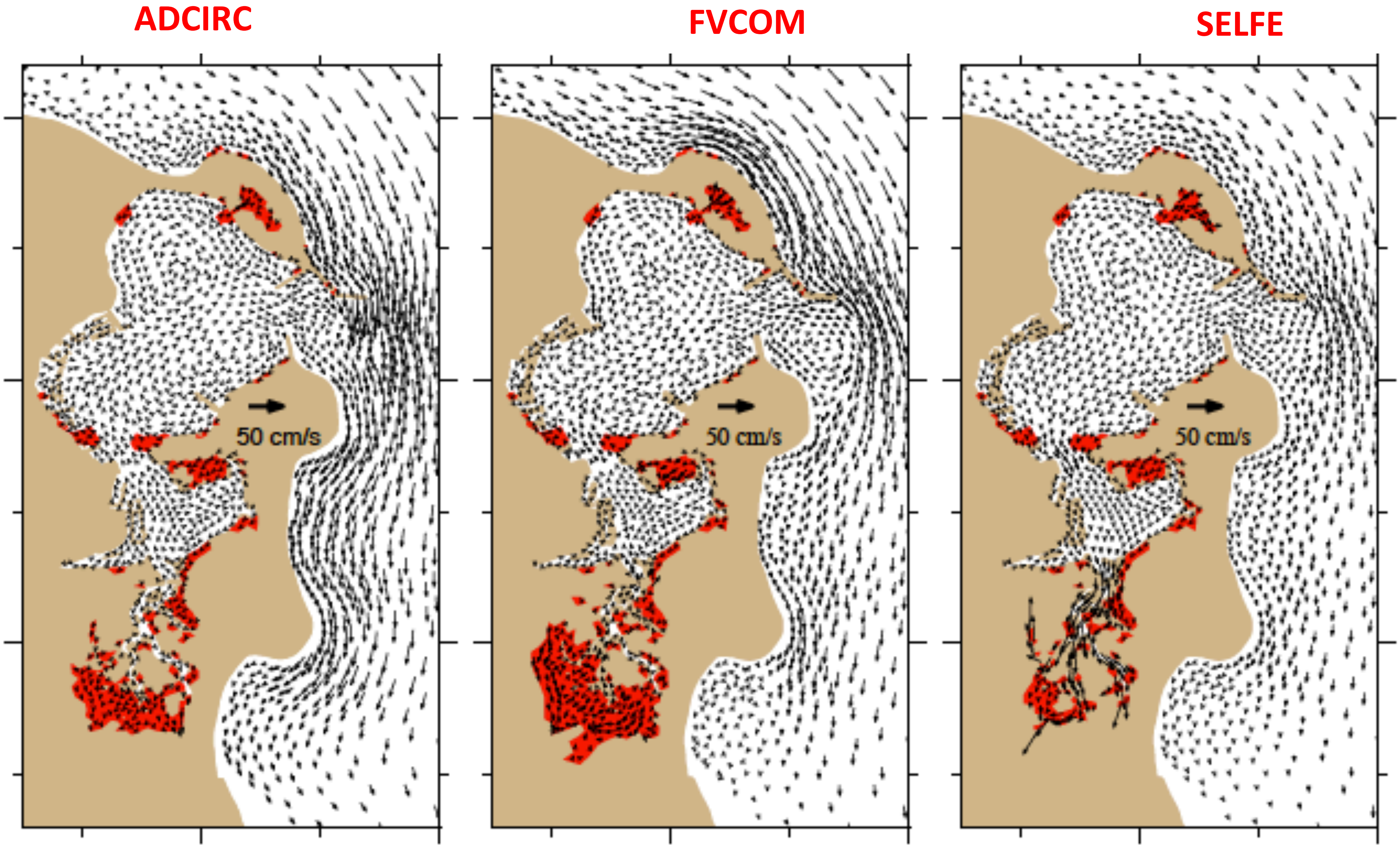
2007 Storm Inundation:



No waves

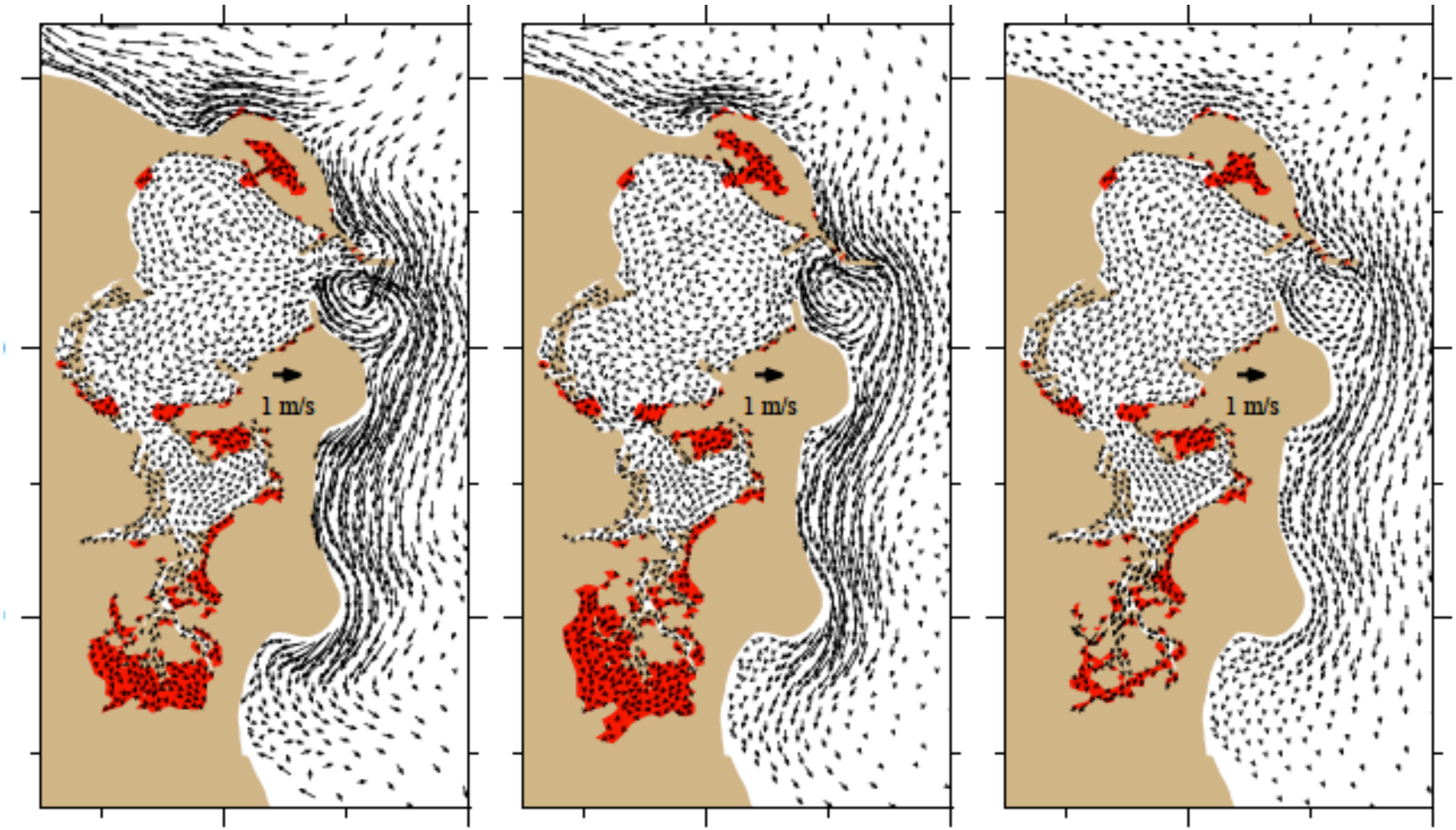
With waves

2005 extra-tropic storm simulation without inclusion of waves (05:00 GMT, May 25, 2005)

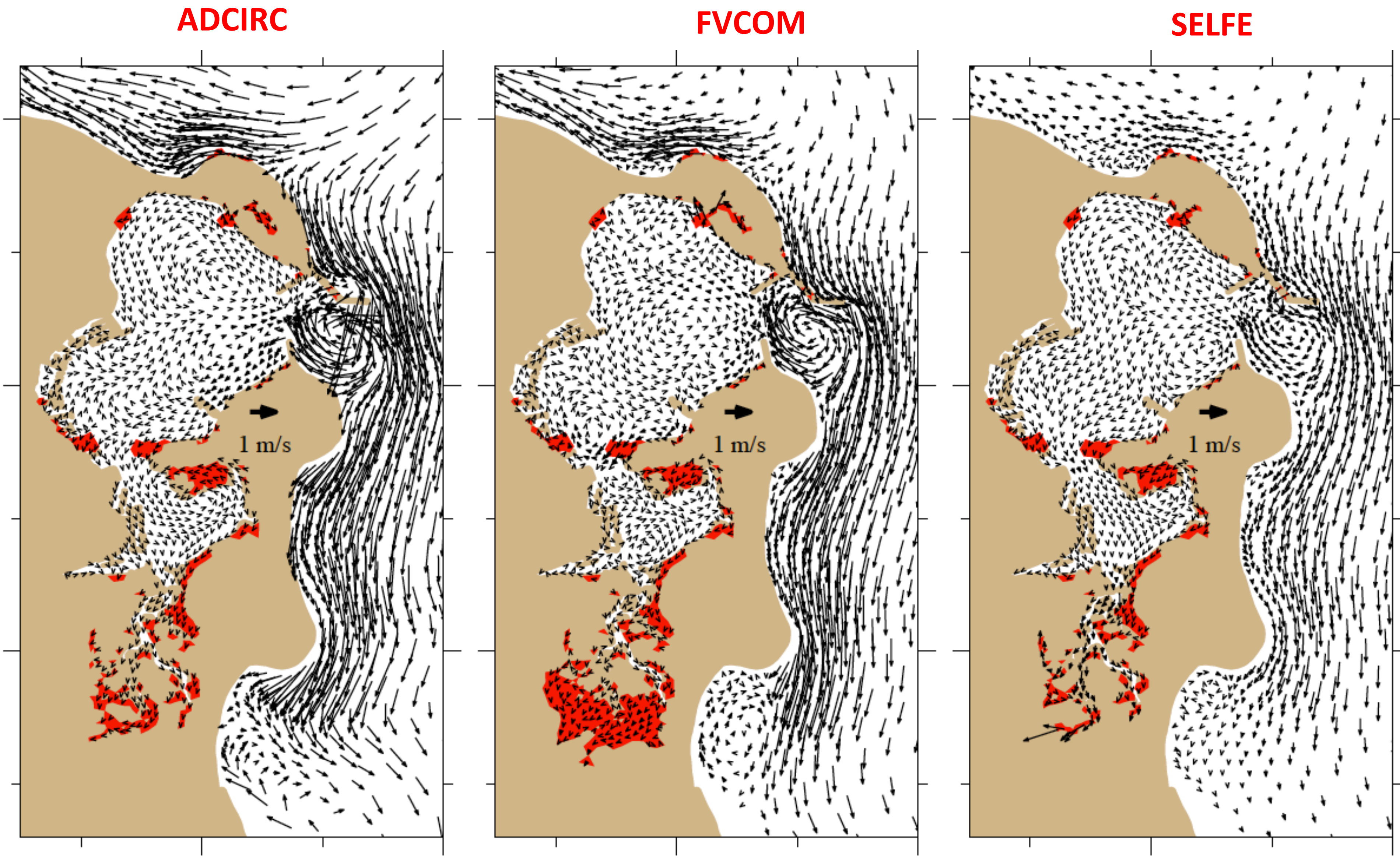


2005 extra-tropic storm simulation with wave-current interactions (05:00 GMT, May 25, 2005)

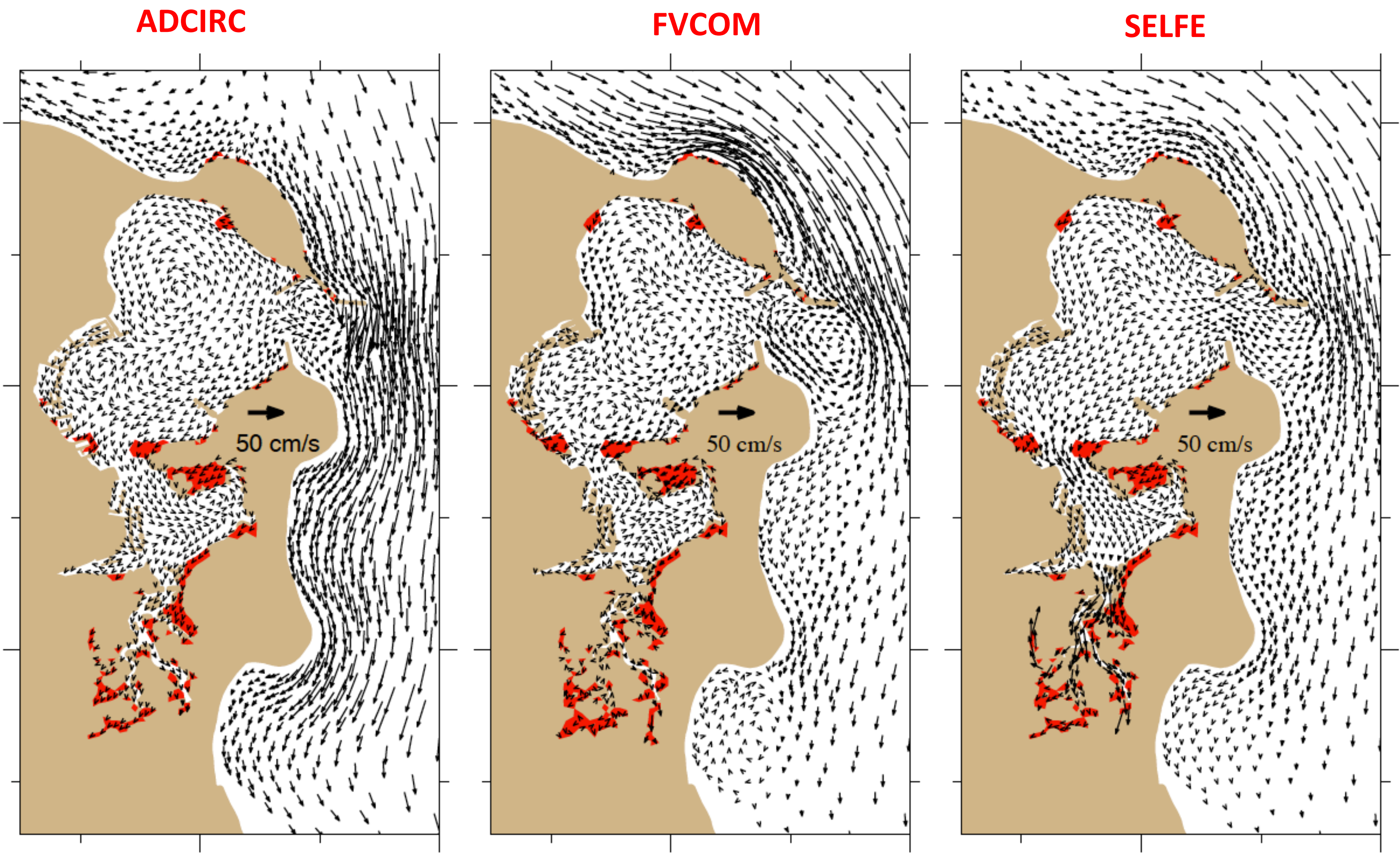
ADCIRC FVCOM SELFE

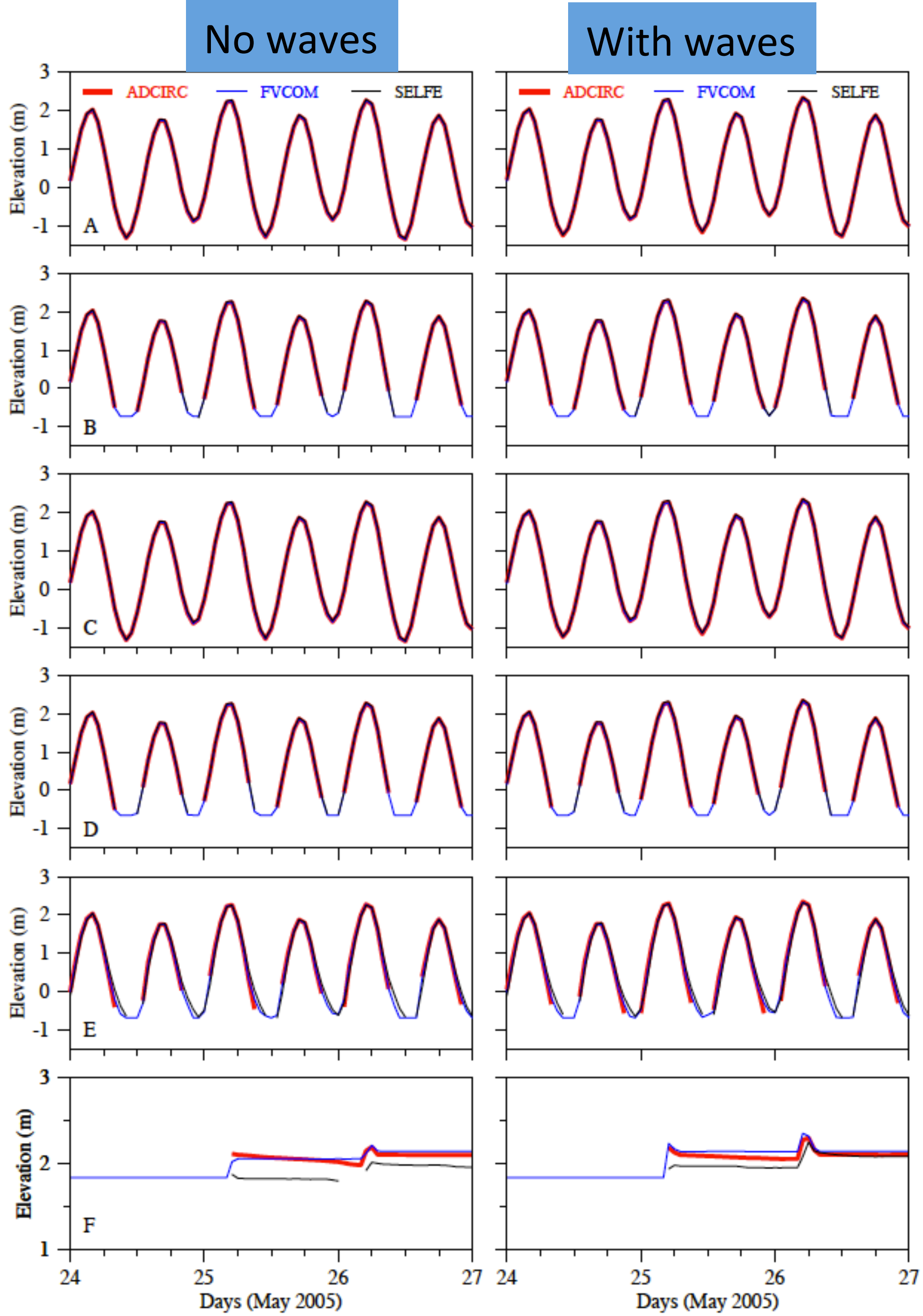


2007 extra-tropic storm simulation without inclusion of waves
(04:00 GMT, April 18, 2007)



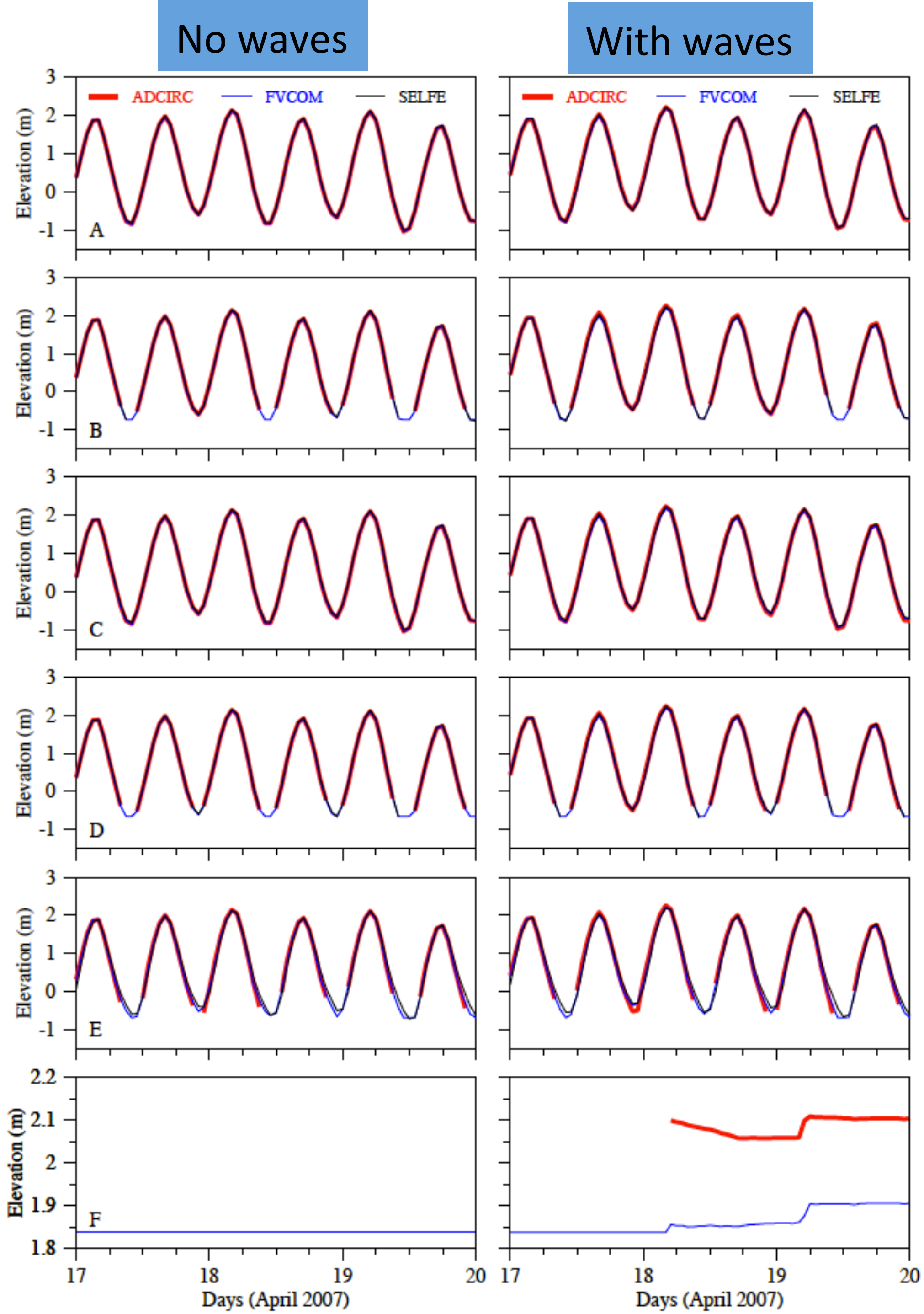
2007 extra-tropic storm simulation with current-wave interactions (04:00 GMT, April 18, 2007)

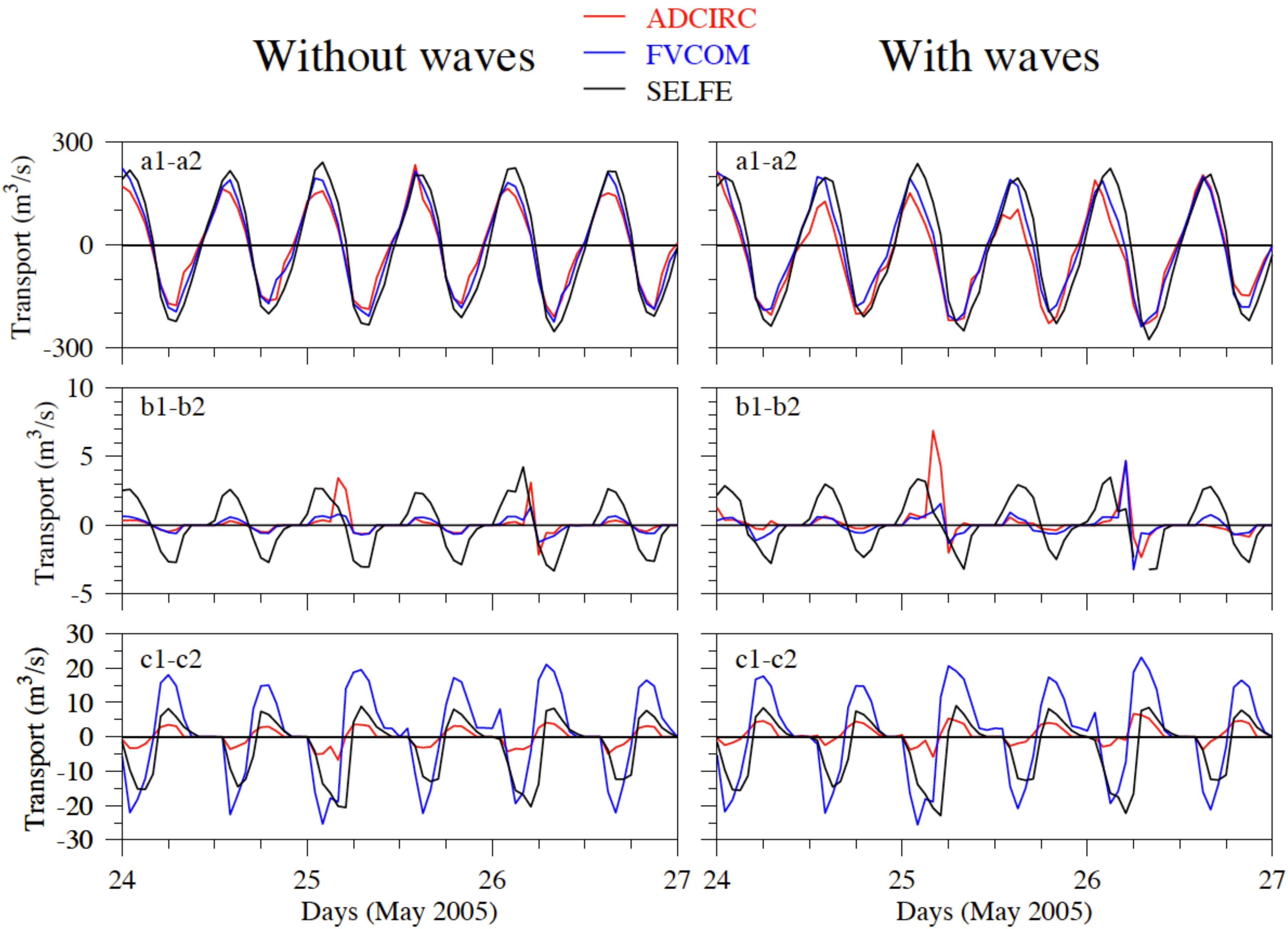




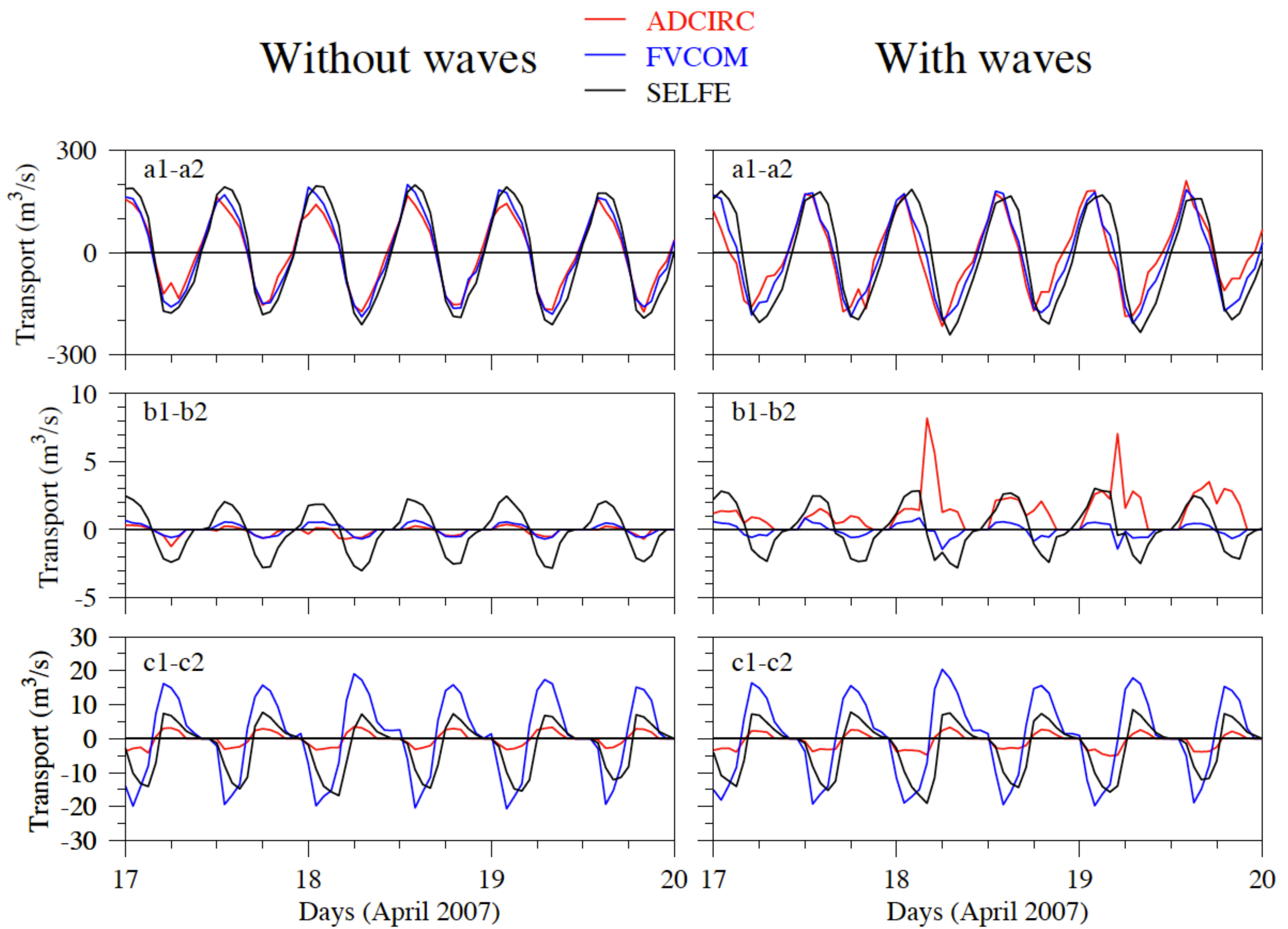
2005
Nor’Easter Storm

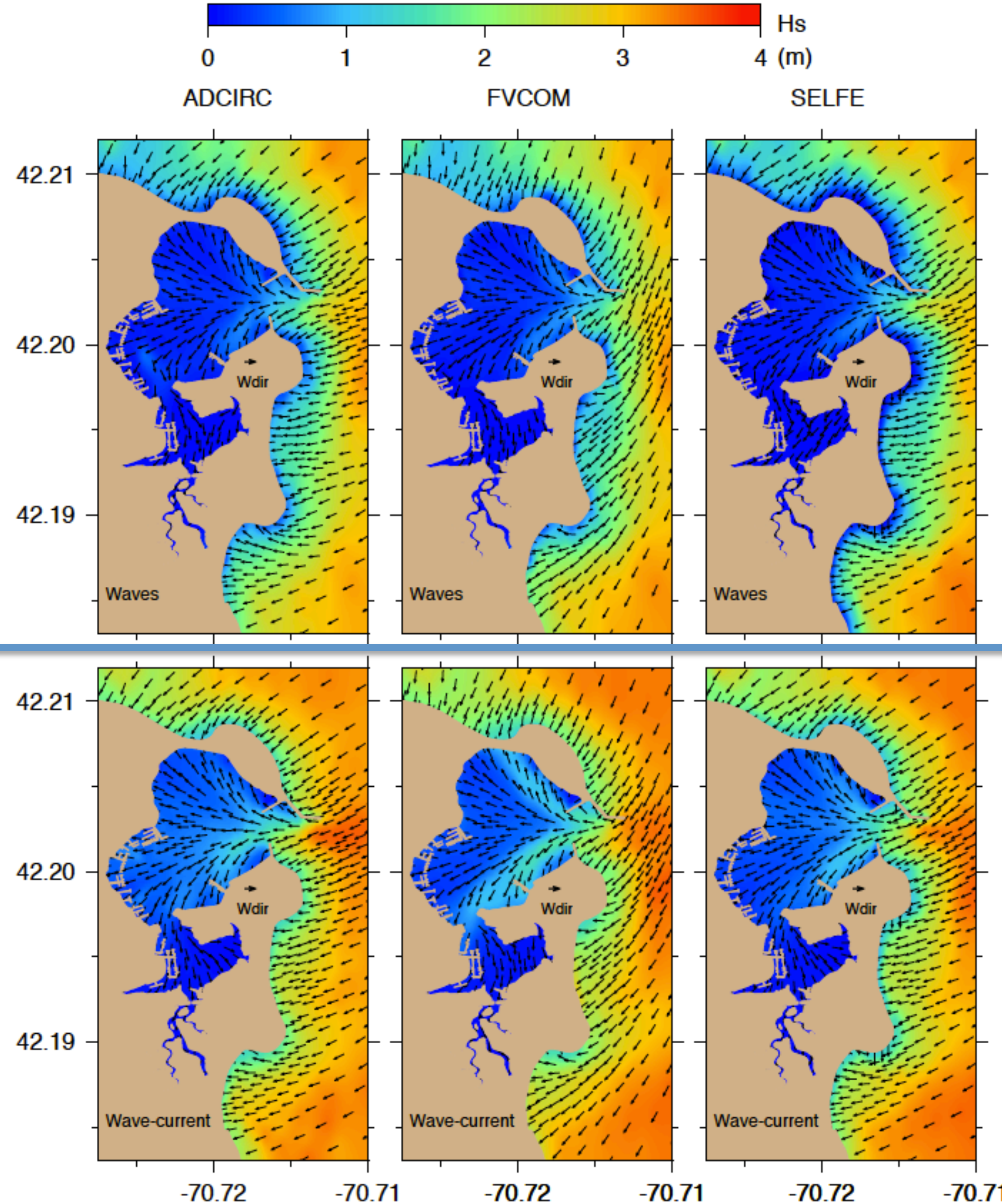
2007
Nor'Easter Storm





ADCIRC
FVCOM
SELFE
Without waves
With waves
a1-a2
b1-b2
c1-c2
Transport (m³/s)
Days (May 2005)
300
0
-300
10
5
0
-5
30
20
10
0
-10
-20
-30
24
25
26
27

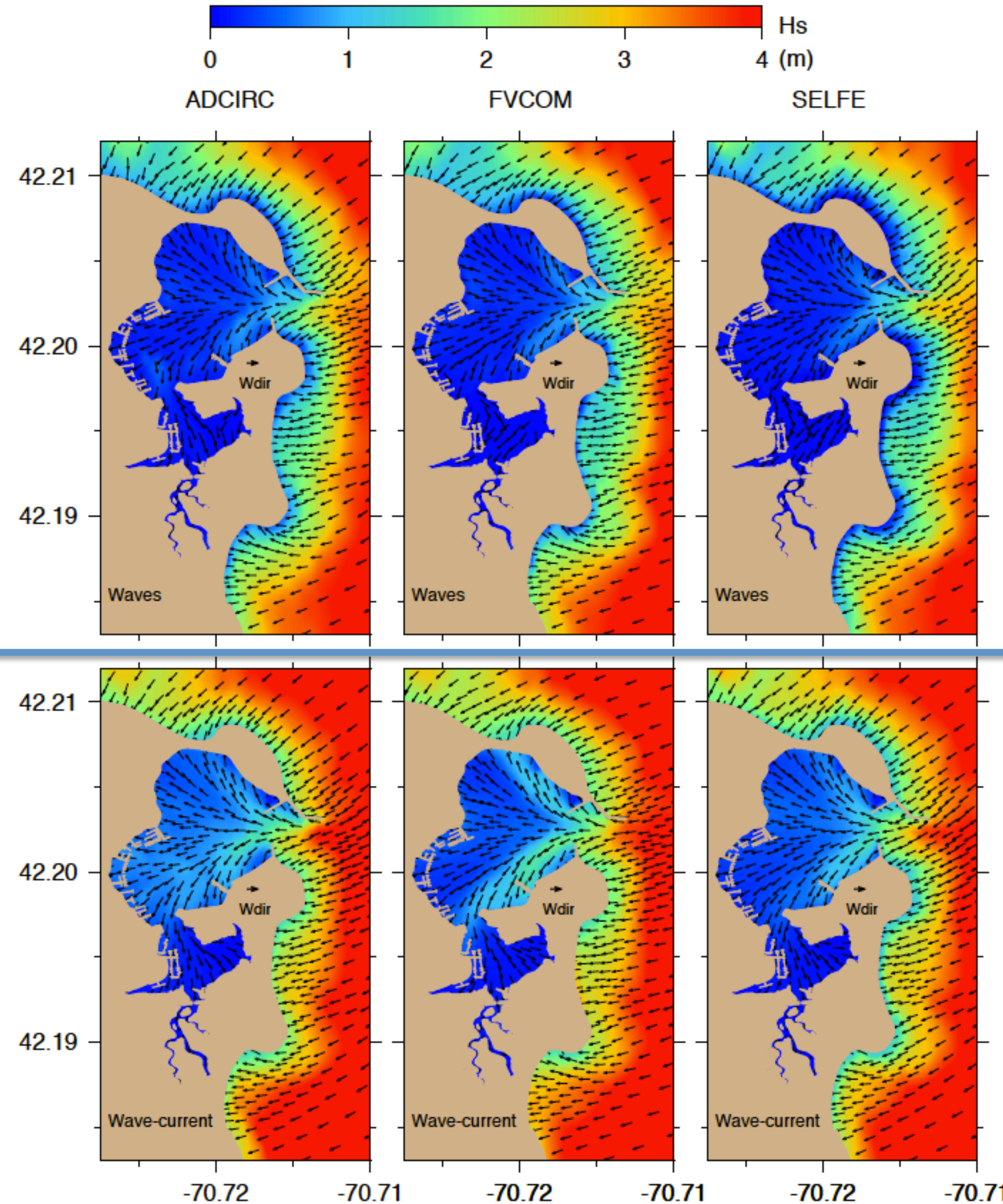

ADCIRC
FVCOM
SELFE
Without waves
With waves
a1-a2
b1-b2
c1-c2
Transport (m³/s)
300
0
-300
10
5
0
-5
30
20
10
0
-10
-20
-30
17
18
19
20
Days (April 2007)



2005
Nor'Easter Storm

Waves only

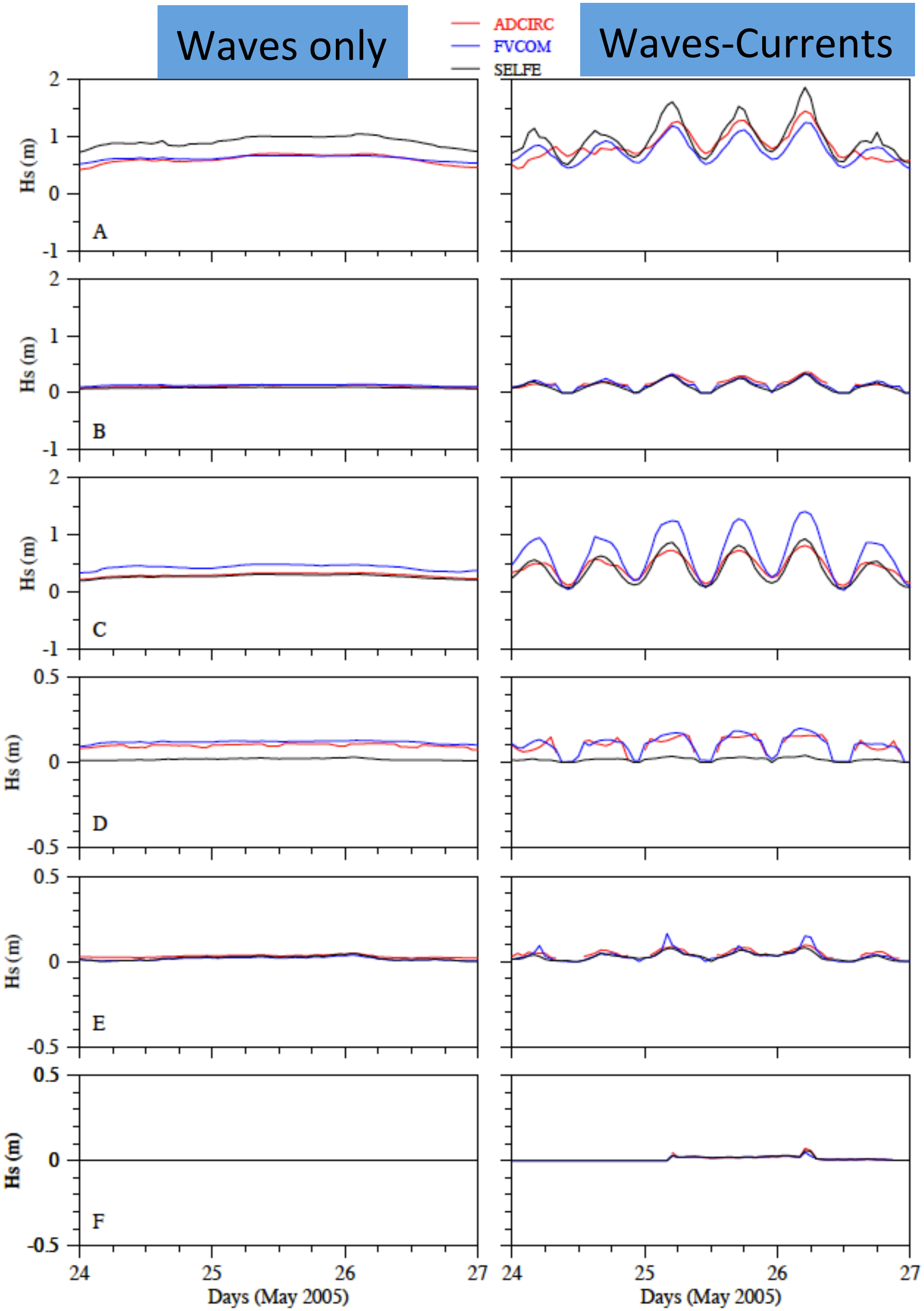
Waves-currents



2007
’Easter Storm

Vaves only

aves-currents



Significant Wave Heights

2005
Nor'Easter Storm

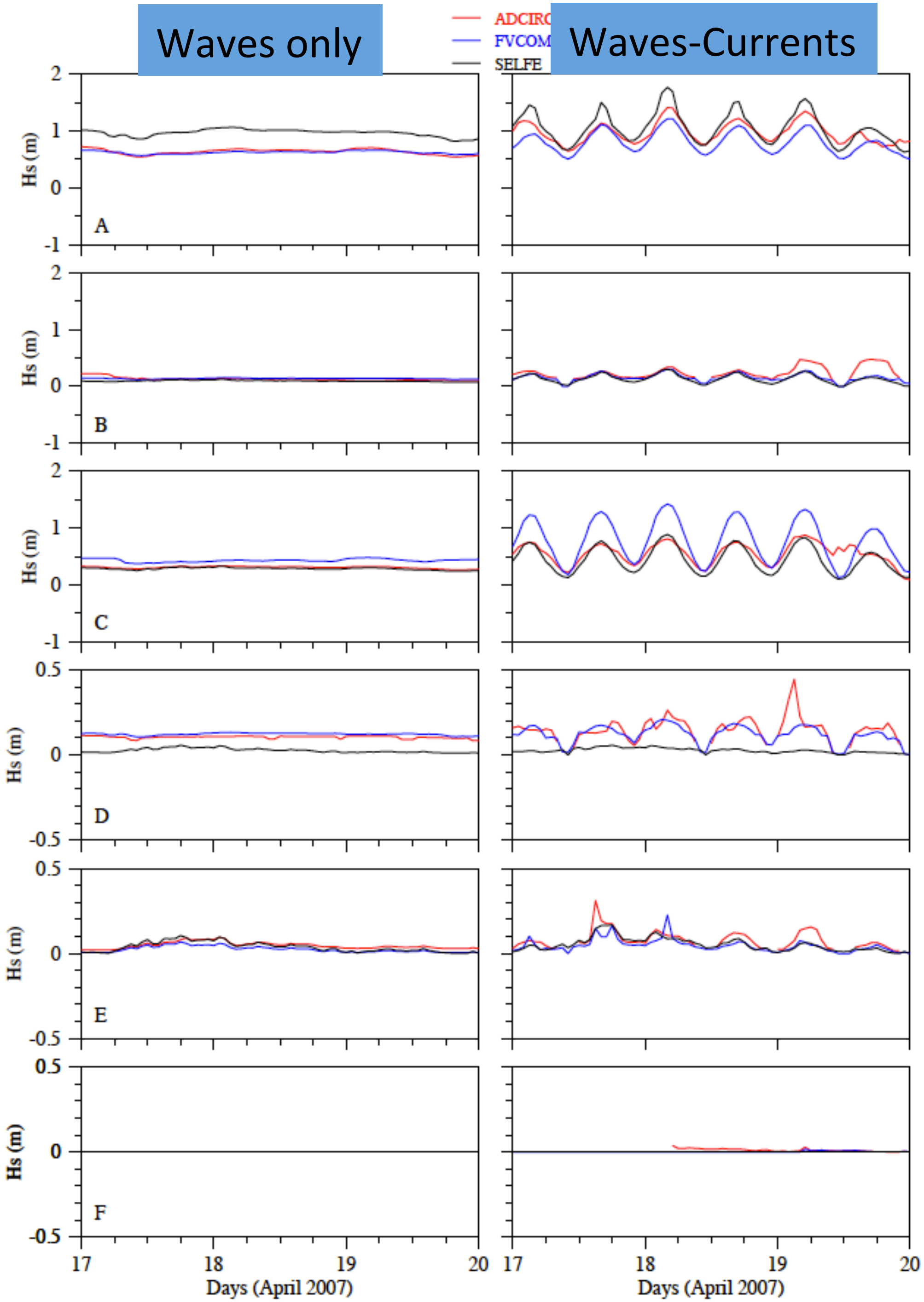
ADCIRC

FVCOM

SELFE

Significant Wave Heights

2007
Nor'Easter Storm



ADCIRC

FVCOM

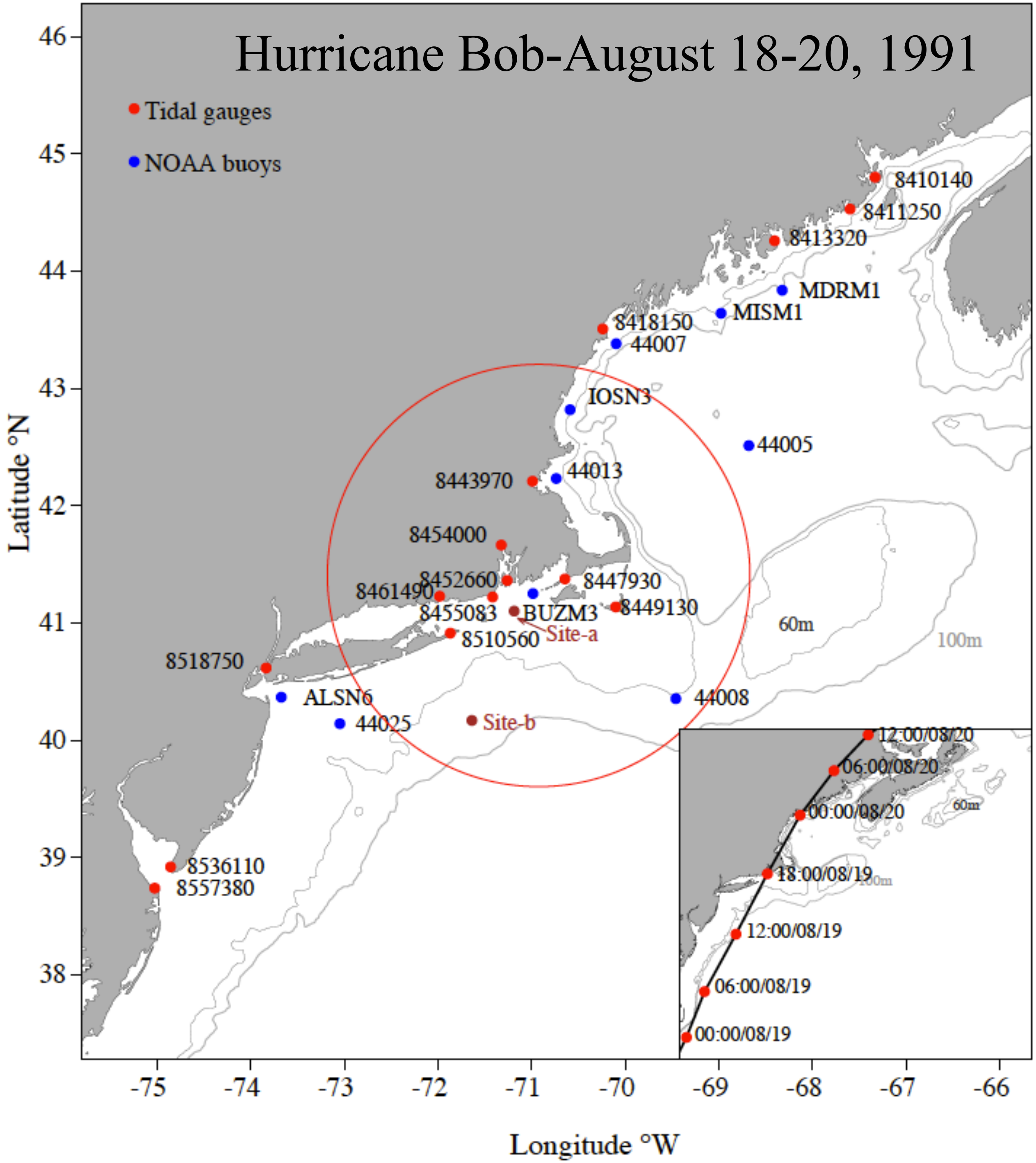
SELFE

Summary

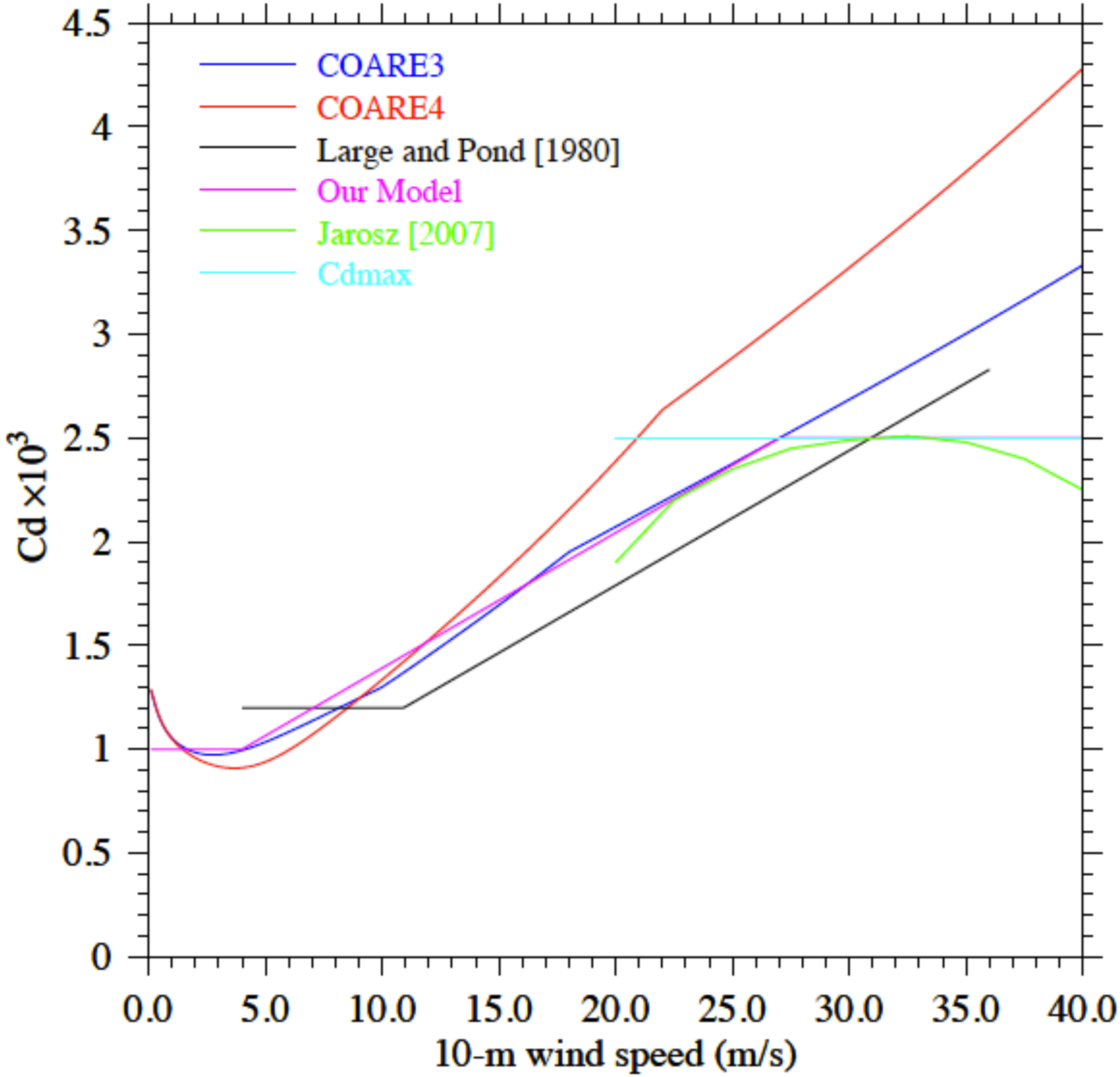
- For given same forcing conditions, all three unstructured grid models are capable of reproducing the tides in Scituate, MA;

- All three models produced the same accuracy of the sea surface elevation and the same patterns of currents over the shelf outside Scituate.

- The distinct differences of model results are in the current spatial distribution and coastal inundation inside Scituate, particularly in the case with current-wave interactions.



Hurricane Bob-August 18-20, 1991
Tidal gauges
NOAA buoys
8410140
8411250
8413320
MDRM1
MISM1
8418150
44007
IOSN3
44005
8443970
44013
8454000
8452660
8447930
8461490
8455083
BUZM3
8449130
8510560
Site-a
60m
100m
8518750
ALSN6
44008
44025
Site-b
12:00/08/20
06:00/08/20
00:00/08/20
60m
18:00/08/19
100m
12:00/08/19
06:00/08/19
00:00/08/19
8536110
8557380
Latitude °N
Longitude °W
46
45
44
43
42
41
40
39
38
-75
-74
-73
-72
-71
-70
-69
-68
-67
-66



COARE3
COARE4
Large and Pond [1980]
Our Model
Jarosz [2007]
Cdmax
Cd ×10³
10-m wind speed (m/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0

The correction formula derived by Jelesnianski (1966) with an adjustment of the hurricane moving velocity

$$\vec{V} = \vec{V}_{10sym} + \left(\frac{r / R_{\max}}{1 + \left(r / R_{\max} \right)^2} \right) \cdot \vec{V}_{path} \qquad \vec{V}_{10sym} = 0.8 \cdot \vec{V}_{sym} \qquad \left| \vec{V}_{sym} \right| = \begin{cases} V_{\max} \left(\dfrac{r}{R_{\max}} \right)^X & \left(r < R_{\max} \right) \\ V_{\max} \left(\dfrac{R_{\max}}{r} \right)^X & \left(R_{\max} \le r \le 3R_{\max} \right) \end{cases}$$

$\vec{V}_{10sym}$ the symmetric wind vector at the 10-m height,

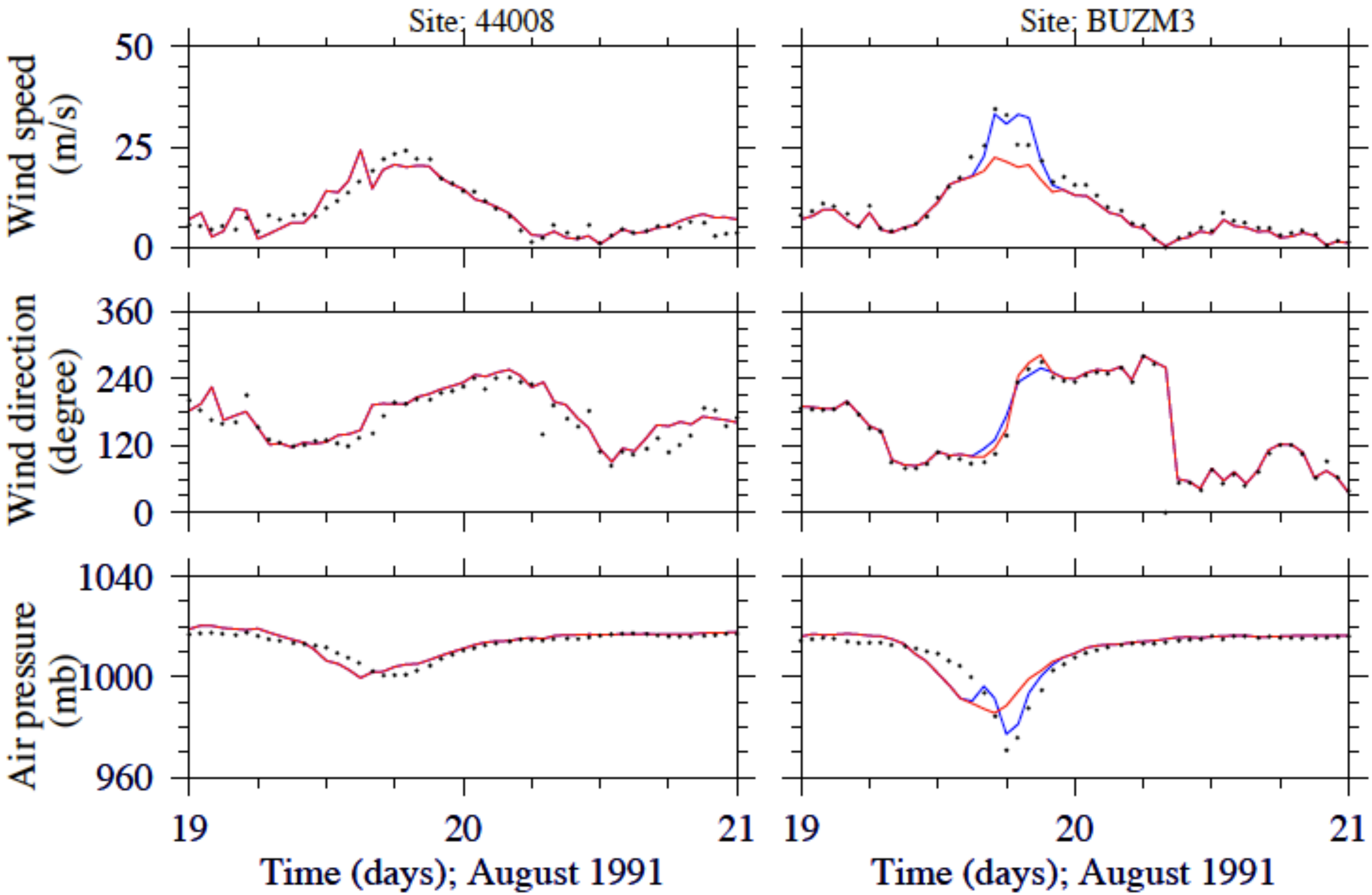
$\vec{V}_{path}$ the hurricane moving velocity vector;

r the radial distance from the hurricane center;

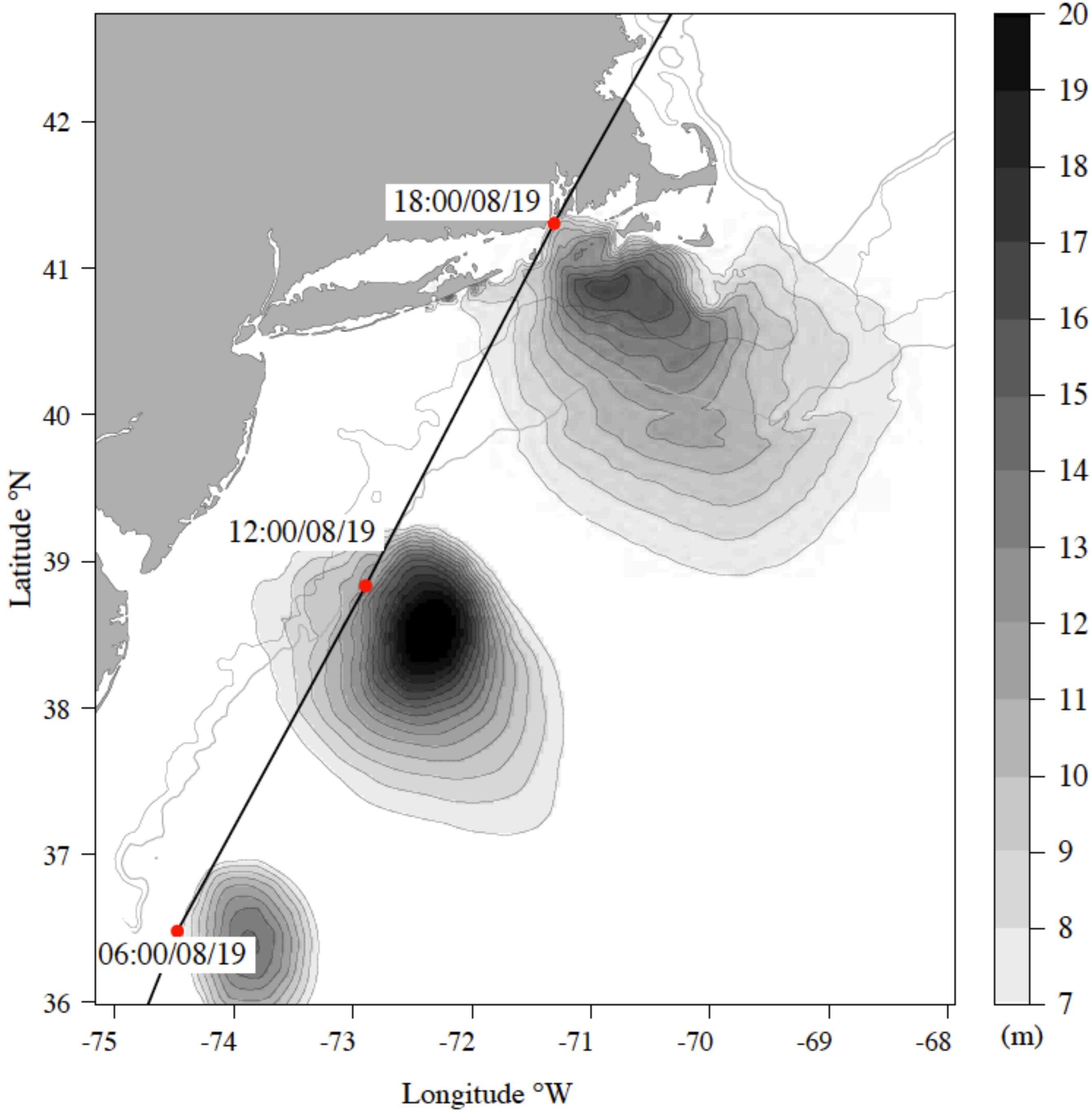
R_{max} the radius of maximum winds

The atmospheric pressure (P) was defined as the sum of the surrounding dynamics pressure (P_d) and the hurricane central atmospheric pressure (P_c), i.e.,

$$P = P_c + P_d \qquad \frac{\partial P_d}{\partial r} = \rho_{air} \left(\frac{\left| \vec{V}_{sym}^2 \right|}{r} + f \left| \vec{V}_{sym} \right| \right)$$

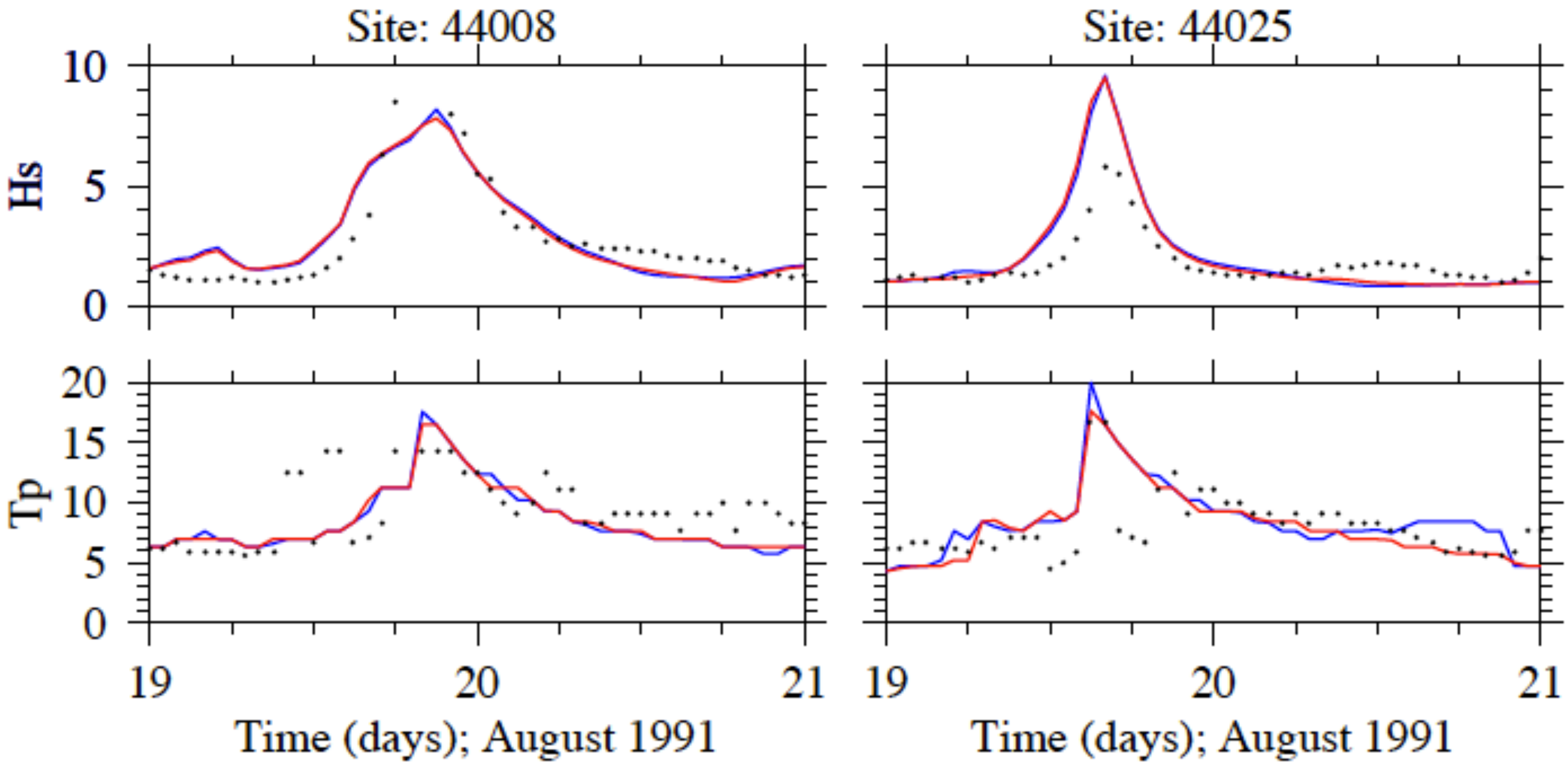


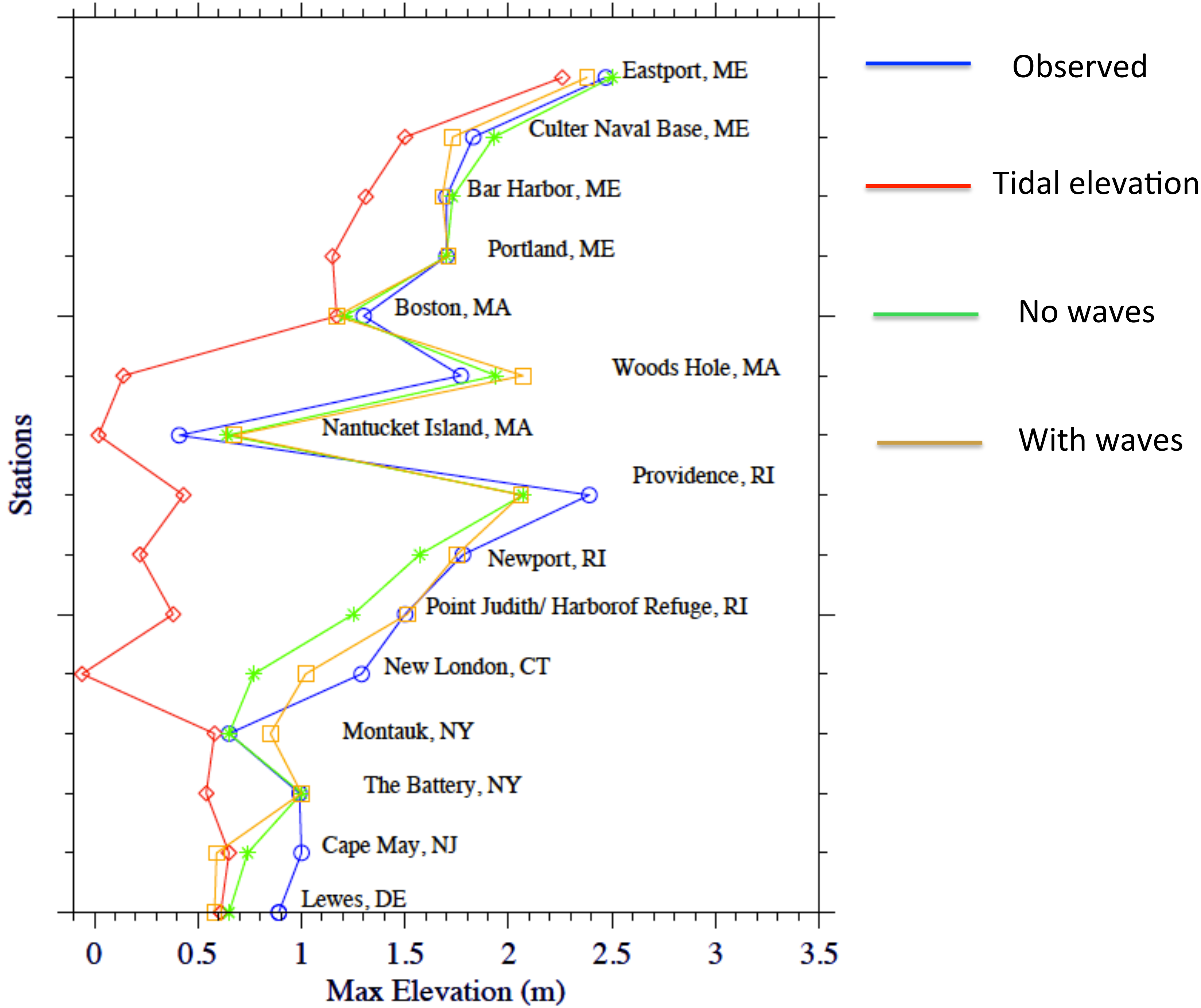
Site: 44008
Site: BUZM3
Wind speed (m/s)
Wind direction (degree)
Air pressure (mb)
50
25
0
360
240
120
0
1040
1000
960
19
20
21
Time (days); August 1991
Time (days); August 1991



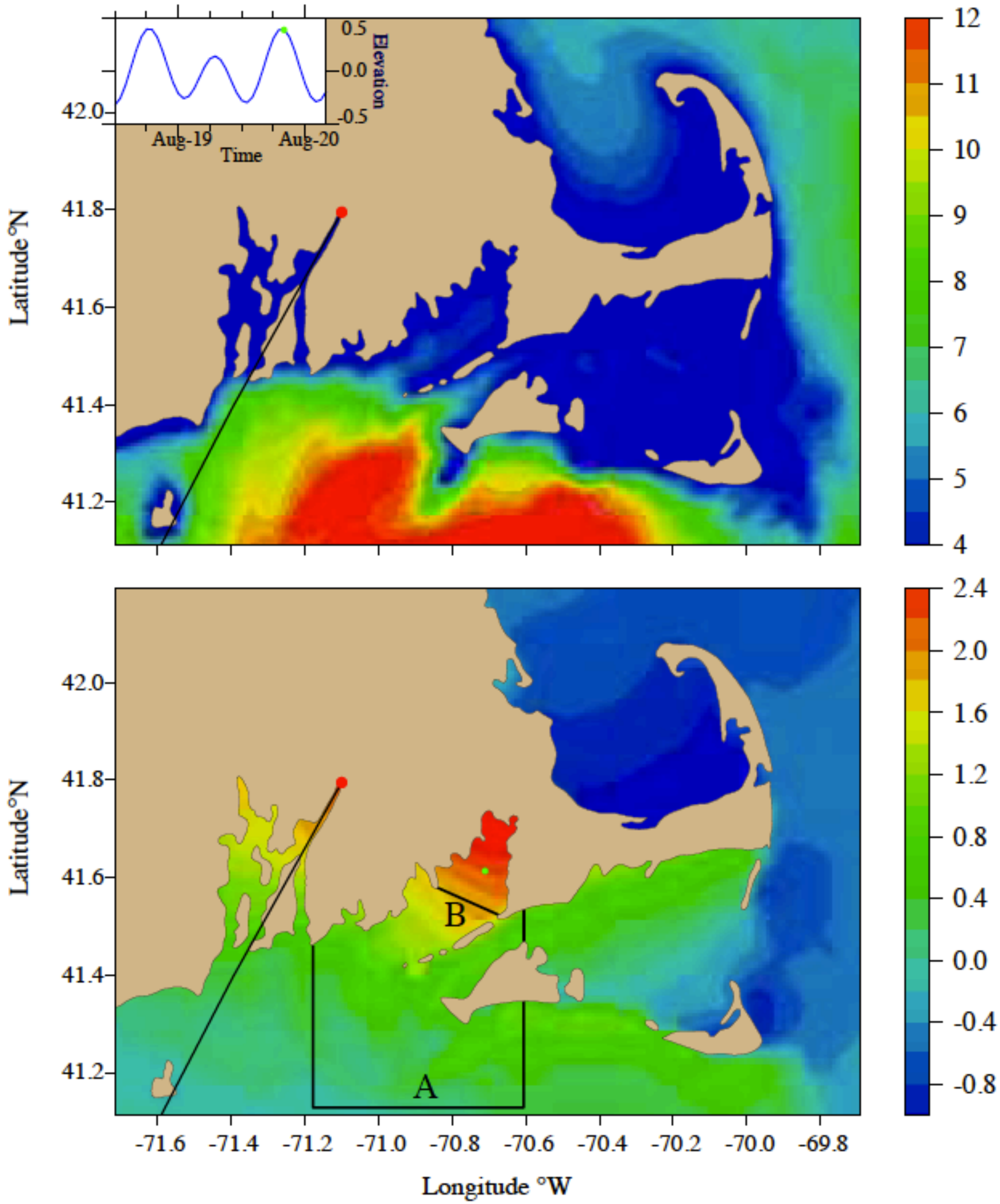
18:00/08/19
12:00/08/19
06:00/08/19
Latitude °N
Longitude °W
42
41
40
39
38
37
36
-75
-74
-73
-72
-71
-70
-69
-68
20
19
18
17
16
15
14
13
12
11
10
9
8
7
(m)

Significant Wave Height and Peak Periods

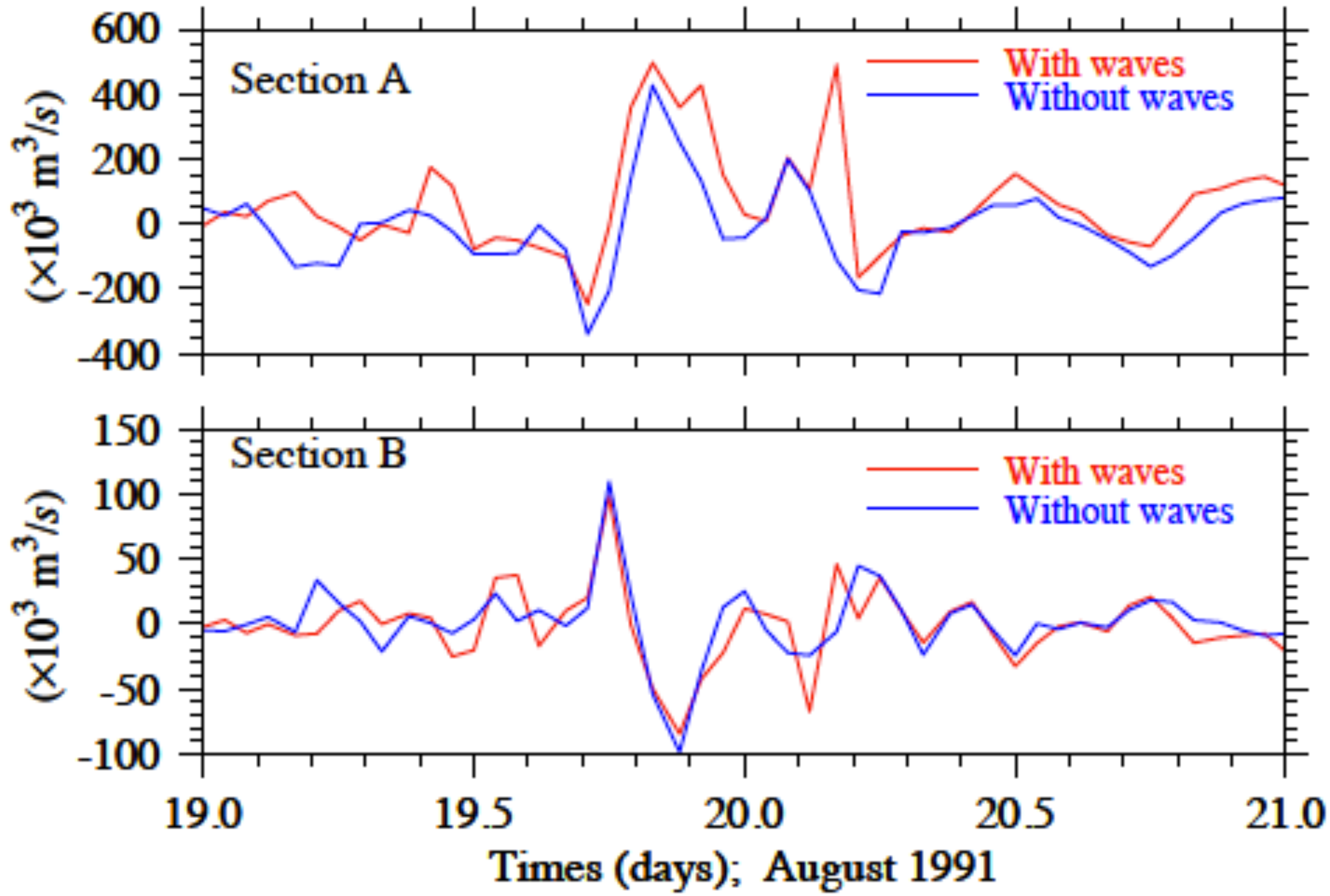




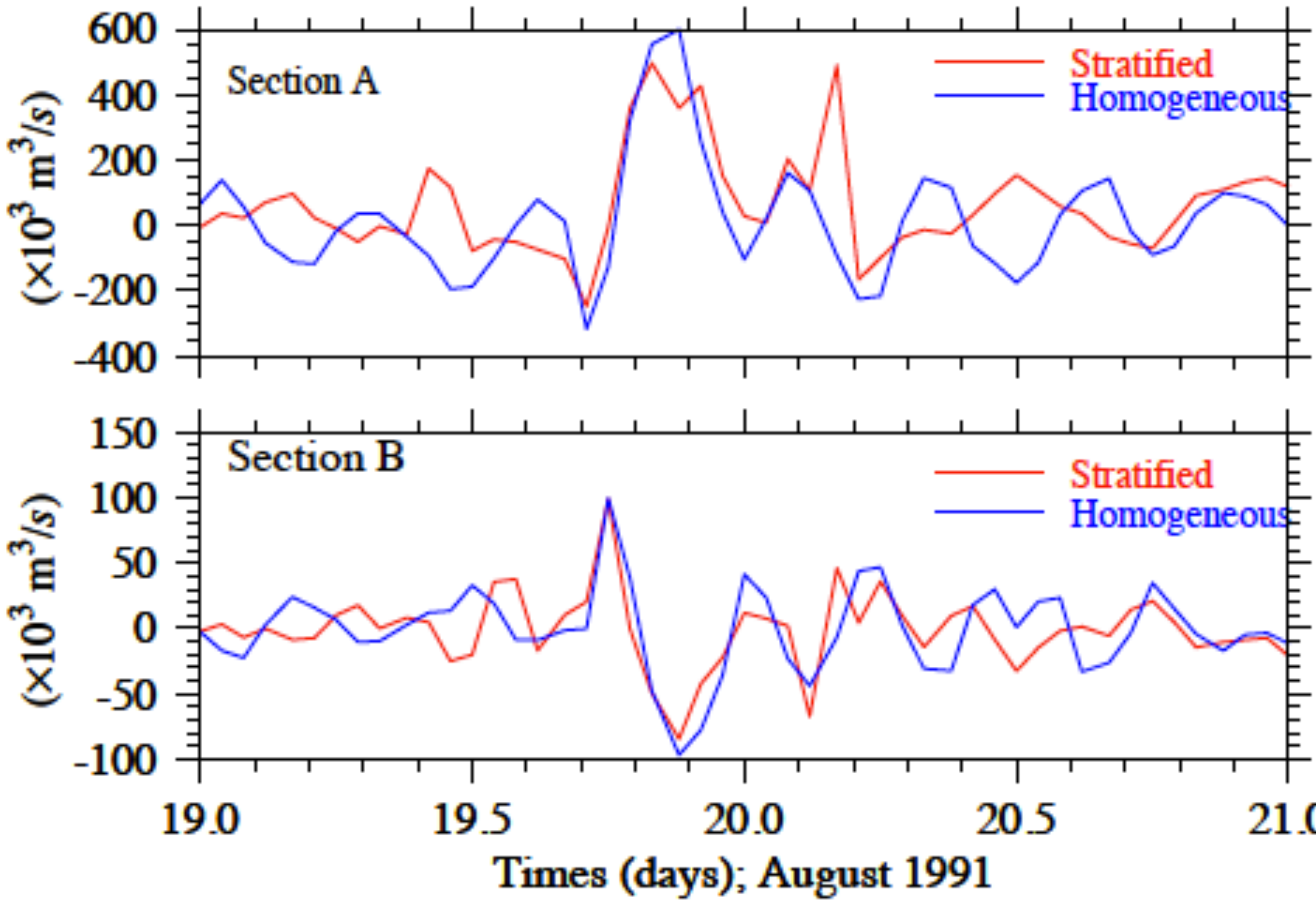
Eastport, ME
Culter Naval Base, ME
Bar Harbor, ME
Portland, ME
Boston, MA
Woods Hole, MA
Nantucket Island, MA
Providence, RI
Newport, RI
Point Judith/ Harborof Refuge, RI
New London, CT
Montauk, NY
The Battery, NY
Cape May, NJ
Lewes, DE
Stations
0
0.5
1
1.5
2
2.5
3
3.5
Max Elevation (m)
Observed
Tidal elevation
No waves
With waves



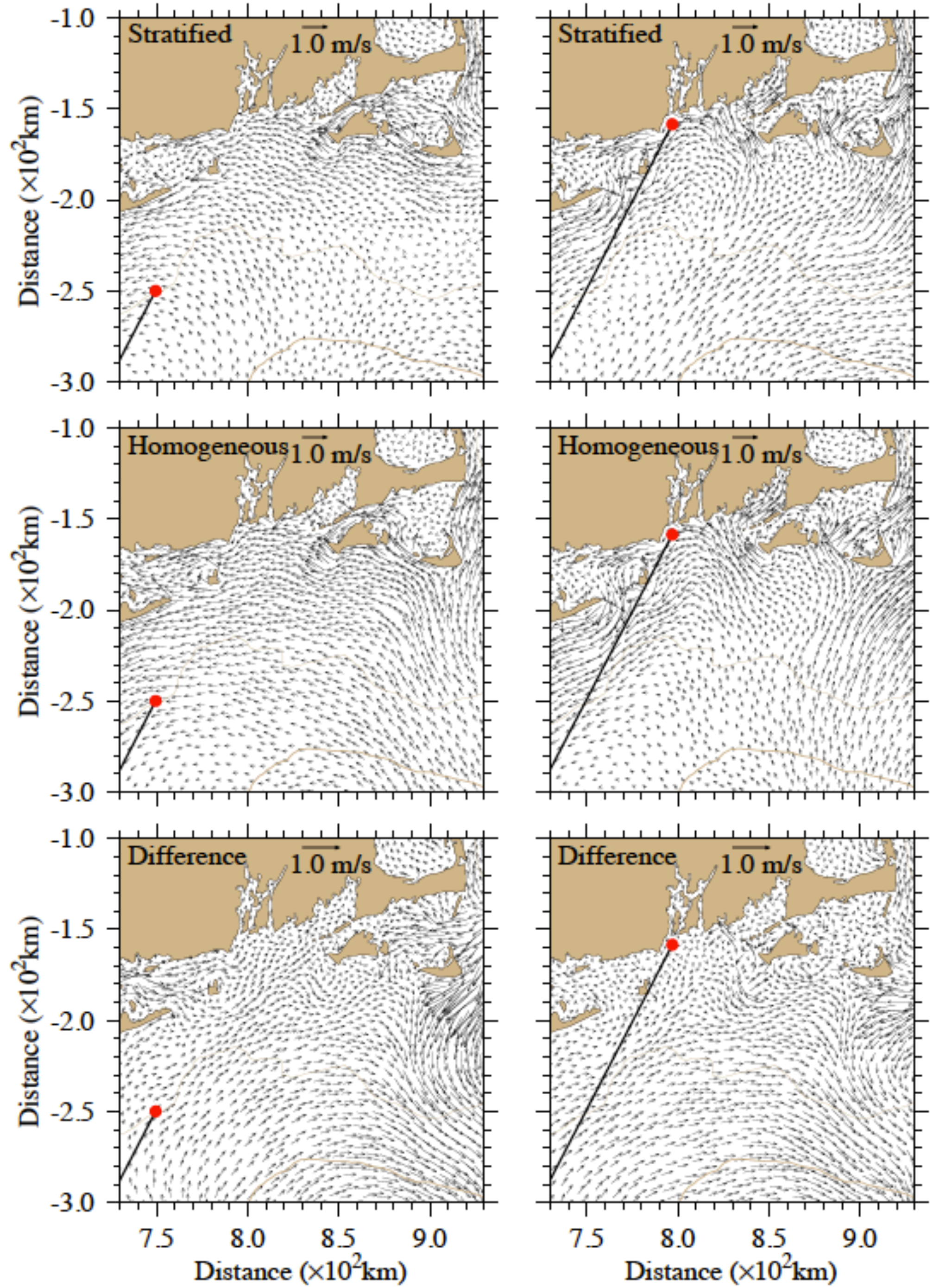
Distributions of Significant wave height



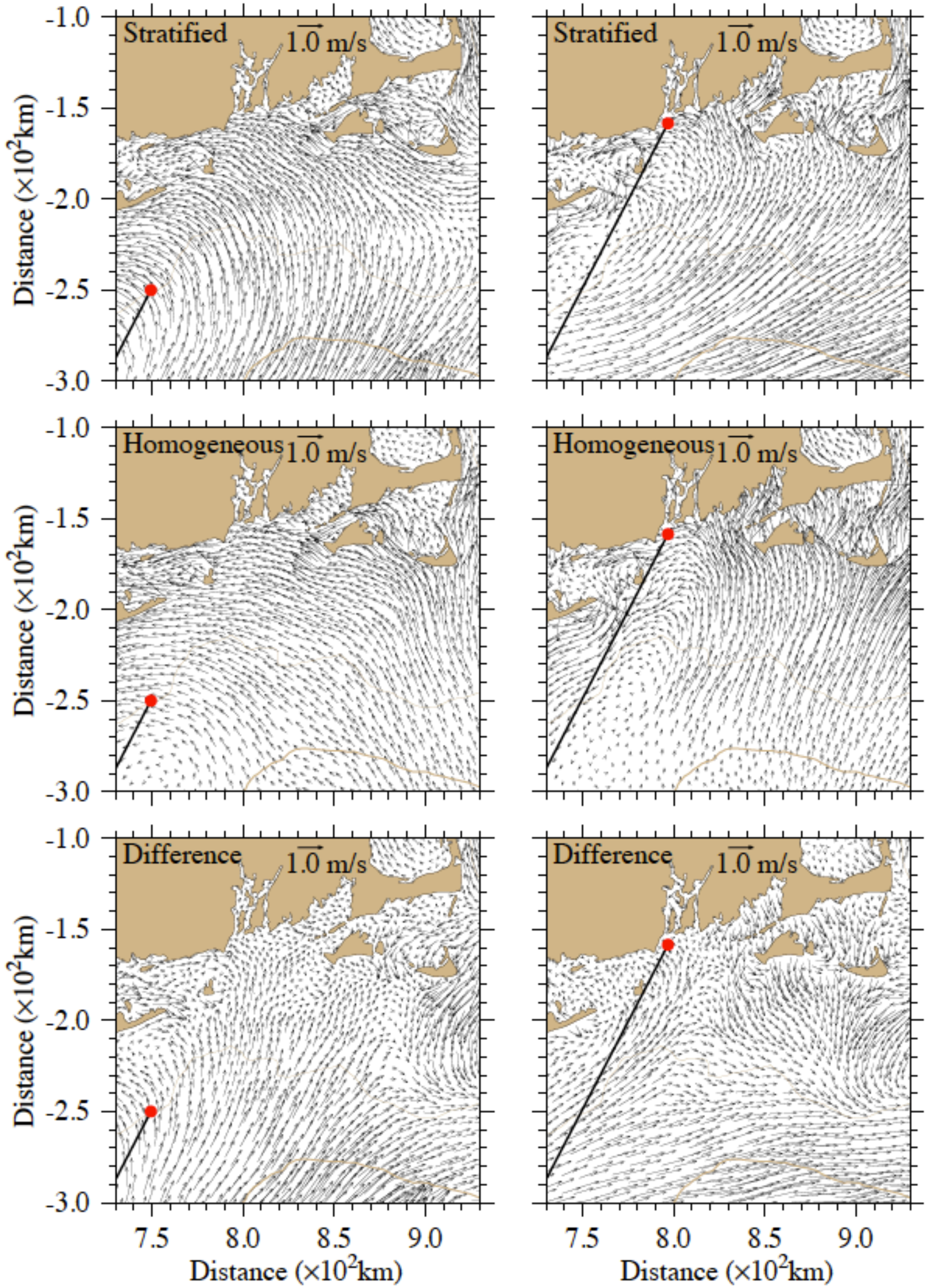
Section A
With waves
Without waves
600
400
200
0
-200
-400
(×10³ m³/s)
Section B
With waves
Without waves
150
100
50
0
-50
-100
(×10³ m³/s)
19.0
19.5
20.0
20.5
21.0
Times (days); August 1991



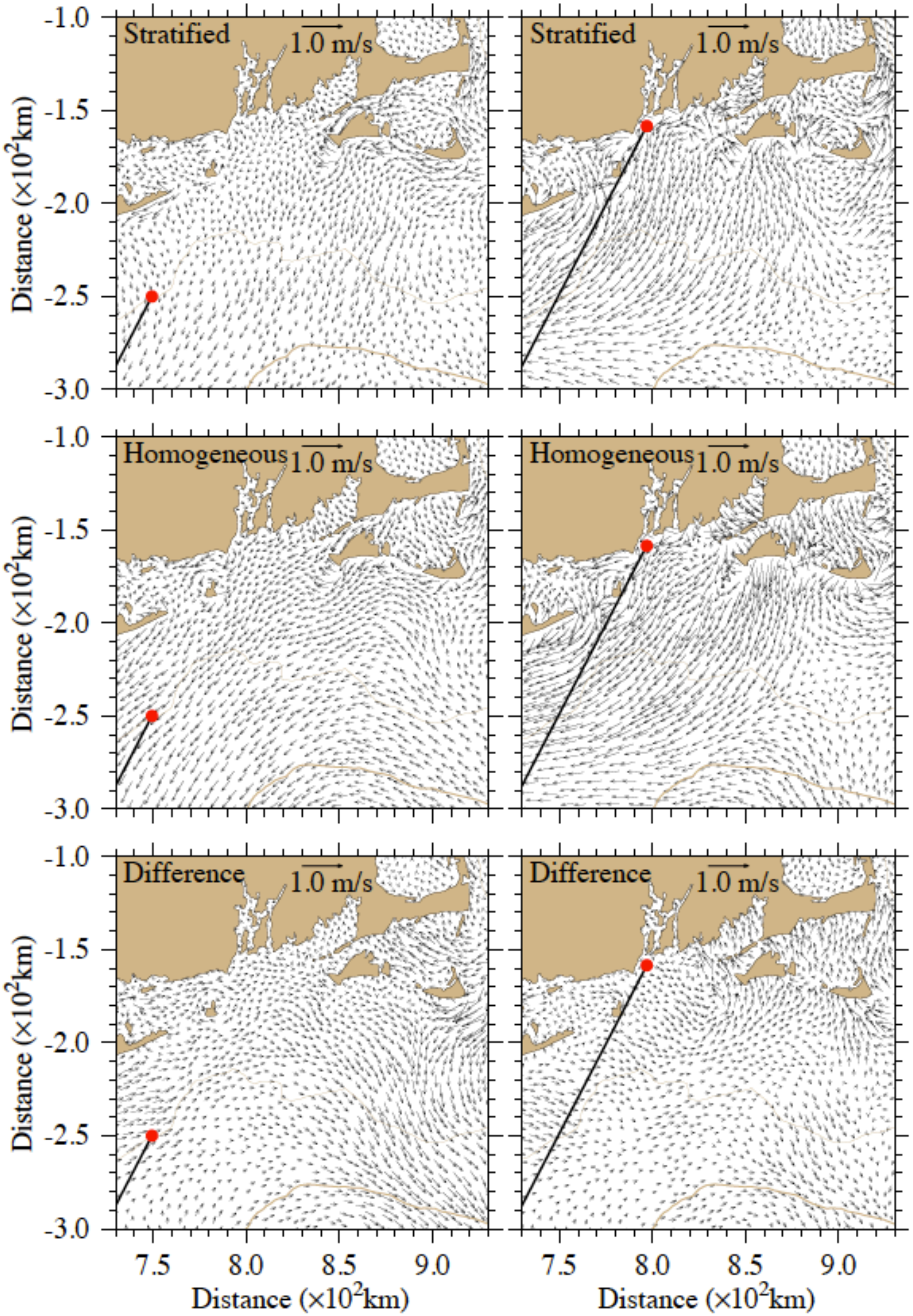
600
400
200
0
-200
-400
Section A
Stratified
Homogeneous
($\times 10^3$ m^3/s)
150
100
50
0
-50
-100
Section B
Stratified
Homogeneous
($\times 10^3$ m^3/s)
19.0
19.5
20.0
20.5
21.0
Times (days); August 1991



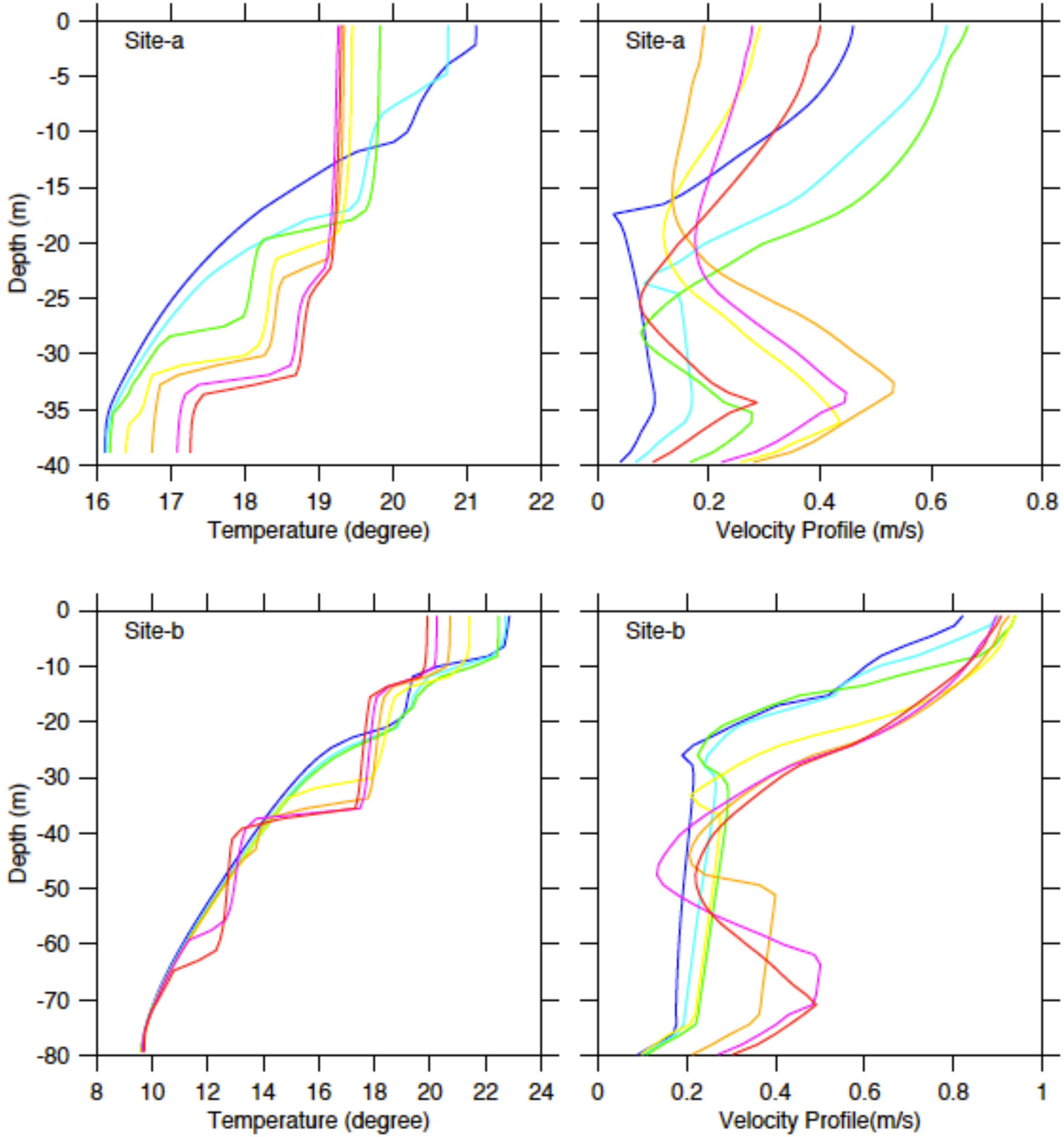
Vertically averaged



Near-surface velocity



Near-bottom velocity



Site-a
Depth (m)
0
-5
-10
-15
-20
-25
-30
-35
-40
16
17
18
19
20
21
22
Temperature (degree)
Site-a
0
0.2
0.4
0.6
0.8
Velocity Profile (m/s)
Site-b
Depth (m)
0
-10
-20
-30
-40
-50
-60
-70
-80
8
10
12
14
16
18
20
22
24
Temperature (degree)
Site-b
0
0.2
0.4
0.6
0.8
1
Velocity Profile(m/s)

Summary

- The wave-current interaction caused a significant change of the current direction and mixing, but had relatively little contribution to the maximum sea level along the coast.

- Diagnostic analyses suggest that the contribution of hurricane-derived wave-current interaction to the net water flux varies in space and time.

- The hurricane-induced wave-current interaction could generate strong vertical current shear in the stratified areas, leading to strong offshore transport near the bottom and enhanced water mixing over the continental shelf. Stratification also could result in a significant difference of water currents around islands where the water is not vertically well mixed.