DEVELOPMENT OF A TSUNAMI FORECAST MODEL FOR CAPE HATTERAS, NORTH CAROLINA

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Abstract

This report describes the development of a tsunami forecast model for Cape Hatteras, North Carolina, as a component of the National Oceanic and Atmospheric Administration (NOAA) Short-term Inundation Forecasting for Tsunamis (SIFT) system. The optimized MOST model can obtain accurate amplitude of first waves and reasonable inundation limit within 10 minutes for the study area upon receiving the information of the earthquake source determined from real-time data assimilation and inversion. The model is validated using numerical results from a high-resolution MOST reference model since there are no historical tsunami instrumental records for the island. The developed SIM is tested against different scenarios of large virtual tsunamis numerically generated the Puerto Rico Trench. Based on the SIM testing for Cape Hatteras it is suggested that the model run for longer that the standard four hour simulation time.

1.0 Background and Objectives

The NOAA Center for Tsunami Research (NCTR) at NOAA's Pacific Marine Environmental Laboratory (PMEL) is developing a tsunami forecasting tool known as Short-term Inundation Forecasting for Tsunamis (SIFT) for NOAA Tsunami Warning Centers (Titov *et al.*, 2005). The primary goal of the system is to provide NOAA Tsunami Warning Centers with operational tools that combine real-time deep-ocean Bottom Pressure Recorder (BPR) recordings from the DART tsunameter network (González *et al.*, 2005) and seismic data with a suite of numerical codes, Method of Splitting Tsunami (MOST) (Titov and Synolakis, 1998; Titov and González, 1997), to produce efficient forecasts of tsunami arrival time, heights and inundation. To achieve accurate and detailed information on the likely impact of incoming tsunami on specific coastal communities within certain time limits and to reduce false alarms, Standby Inundation Models (SIMs) being developed and integrated as crucial components of SIFT for a limited number of 75 US coastal cities and territories that are potentially at most risk.

The primary objective of this study was to develop and test a tsunami forecast model for a real time forecast of tsunami waves and inundation estimates for the community of Cape Hatteras, North Carolina.

2.0 Forecast Methodology

2.1 Tsunami Modeling and Methodology for the NOAA SIFT System

MOST (Titov and Synolakis, 1998; Titov and González, 1997) is a 2D finite-differences numerical model based on the nonlinear long-wave approximation. It uses a splitting scheme to separate the original two-dimensional problem into two sequential one-dimensional problems.

The MOST model accommodates a base level grid (0), for wave transoceanic propagation and three levels of nested grids (A, B, and C) with increasing spatial and temporal resolution for simulation of wave inundation onto dry land. The linear solution is evaluated at the base level while the nonlinear are calculated at the next three. Grid 0 is not dynamically coupled with the other three. This is more efficient since it can

provide multiple sets of boundary conditions for subsequent detailed calculations at different locations.

The numerical solution is obtained by an explicit finite-differences scheme with a second-order approximation in space and first order in time. The MOST model uses a Neumann-type technique to determine the waterline position through the computed flow velocity.

The PMEL real-time tsunami forecasting scheme is a process that comprises of two steps, (1) data assimilation and inversion, and (2) forecasting by Standby Inundation Models (SIMs). Each one of these two steps is explained in the following sections.

2.1.1 Methodology for the NOAA SIFT System
The PMEL real-time tsunami forecasting scheme is a process that comprises of two steps, (1) data assimilation and inversion, and (2) forecasting by Standby Inundation Models (SIMs). Each one of these two steps is explained next.

2.1.2 Data Assimilation and Inversion
Besides seismic and coastal tide gauges, real-time deep ocean bottom pressure data from the NTHMP tsunameter network, Deep-ocean Assessment and Reporting of Tsunamis (DART), is used as a primary data source since it can provide rapid tsunami observation without harbor and instrument responses. The linearity of wave dynamics of tsunami propagation in the deep ocean allows for applications of inversion schemes to construct a tsunami scenario based on the best fit to given tsunameter data. Details of the inversion method can be found in Titov et al. (2003) and Wei et al. (2003).

PMEL has developed a linear propagation model database for unit sources in the Atlantic and Caribbean Sea, with each unit source a typical Mw = 7.5 subduction zone earthquake (Gica et al 2008). Based on a sensitivity study of far-field tsunami characteristics (Titov et al., 1999), the parameters of the unit sources are: length = 100 km, width = 50 km, dip = 15°, rake = 90°, depth = 5 km, slip = 1 m. The strike of each source is aligned with the local orientation of the subduction zone. The model simulation results for each unit solution, including amplitudes and velocities, are stored in a database. The database also provides the offshore forecast of tsunami amplitudes and all other wave parameters around the Caribbean Sea and North Atlantic Ocean immediately once the data assimilation is complete. The inversion algorithm, which combines real-time tsunami-meter data of offshore amplitude with the propagation database, provides an accurate offshore tsunami scenario without additional time-consuming model runs.

2.1.3 Standby Inundation Model (SIM) Forecasting
A SIM applies the non-linear components of the MOST model using three nested grids (A, B, and C), with increasing resolution to telescope into the inundation forecasting area. The inundation area (grid C) includes the high concentration of population in the coastal communities, and the National Weather Service Warning Points (WP).

To provide site-specific forecasting for rapid, critical decision-making in emergency management, SIMs are implemented and optimized for both speed and accuracy. First, a SIM utilizes the pre-computed time series of offshore wave height and depth-averaged velocity from the database as the boundary and initial conditions once the offshore scenario is defined. Second, by reducing the calculation areas and grid resolutions, the optimized setup can provide forecasting results within 10 minutes (for a minimum of 4 hours of simulation time), which allows larger time steps without violations of the CFL conditions. Finally, to insure forecasting accuracy, results from the optimized runs are validated with historical tsunami tide gauge records (if available) as

well as a reference model run made with higher resolutions and larger calculation domains.

2.2 Study Area – context
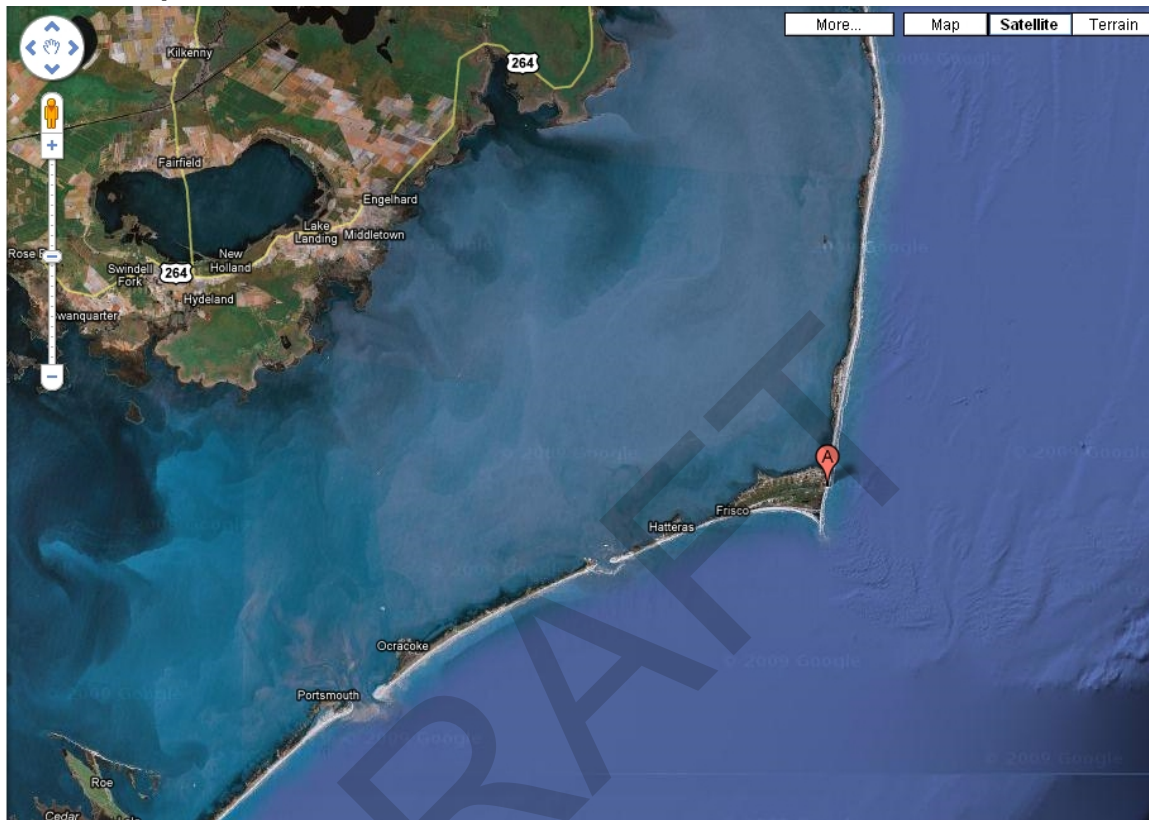
Figure 1 Google Earth image of Cape Hatteras, North Carolina.

Cape Hatteras is a cape on the coast of North Carolina. (Figure 1) It is the point that protrudes the farthest to the southeast along the northeast-to-southwest line of the Atlantic coast of North America. Two major Atlantic currents collide just off Cape Hatteras, the southerly-flowing cold water Labrador Current and the northerly-flowing warm water Florida Current (Gulf Stream), creating turbulent waters and a large expanse of shallow sandbars extending up to 14 miles offshore. As a result, many ships venture close to Cape Hatteras when traveling in the area. In the past, many ships have been lost in the waters around Cape Hatteras.

Physical characteristics give the area its name -- the cape is actually a bend in Hatteras Island, one of the long thin barrier islands that make up the Outer Banks. The first lighthouse at the cape was built in 1803; it was replaced by the current Cape Hatteras Lighthouse in 1870, which is known as the tallest lighthouse in the United States and the tallest brick lighthouse in the world.

In 1999, as the receding shoreline had come dangerously close to Cape Hatteras Lighthouse, the 4830-ton lighthouse was lifted and moved inland a distance of 2900 feet. Its distance from the seashore is now 1500 feet, about the same as when it was originally built (source : http://en.wikipedia.org/wiki/Cape_Hatteras, last accessed April 22, 2009).

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The area is known for its recreation and tourism opportunities. The population of the area increases in the summer months with seasonal day and overnight visitors.

2.3 SIM Setup for Cape Hatteras, North Carolina

2.3.1 Bathymetry and Topography:

For this study the National Geophysical Data Center (NGDC) provided a one-third arc second high-resolution gridded data based on recent shallow water Light Detection and Ranging (LIDAR) topographic and bathymetric surveys and multi-beam surveys for deeper waters.

Xmin (deg)	-76.0500462962963
Xmax (deg)	-75.0500462963243
Ymin (deg)	34.7499537037037
Ymax (deg)	35.7999537036743
Zmin (m)	-2878.30
Zmax (m)	7.92
Cell size (deg)	0.00009259258999999
Cell size (arc-sec)	1/3 (≈ 10 m)
Zonal Cell size (m)	= 8.4
Meridional Cell size (m)	= 10.29
# columns	10801
# rows	11341
# nodes	122,494,141
East-West dimension (km)	90.778
North-South dimension (km)	116.754
Horizontal Datum	WGS 84
Vertical Datum	MHW (meters)

Xmin = longitude of western boundary
Xmax = longitude of eastern boundary
Ymin = latitude of southern boundary
Ymax = latitude of northern boundary

Table 1 1/3 arc second DEM characteristics for Cape Hatteras, North Carolina.

Figure2 shows a Google Earth view of the approximate area covered by the DEM. Figure 3 shows the populated areas (white) along the Cape Hatteras National Seashore. Figure 4 shows a filled contour plot of the DEM at full resolution. Figure 5 shows a contour plot of a 20 m resolution version of the DEM. The preparation of the Reference and Optimized grids went relatively smoothly at this location. The location of the Warning Point is -75.6350° N, 35.2230° W.
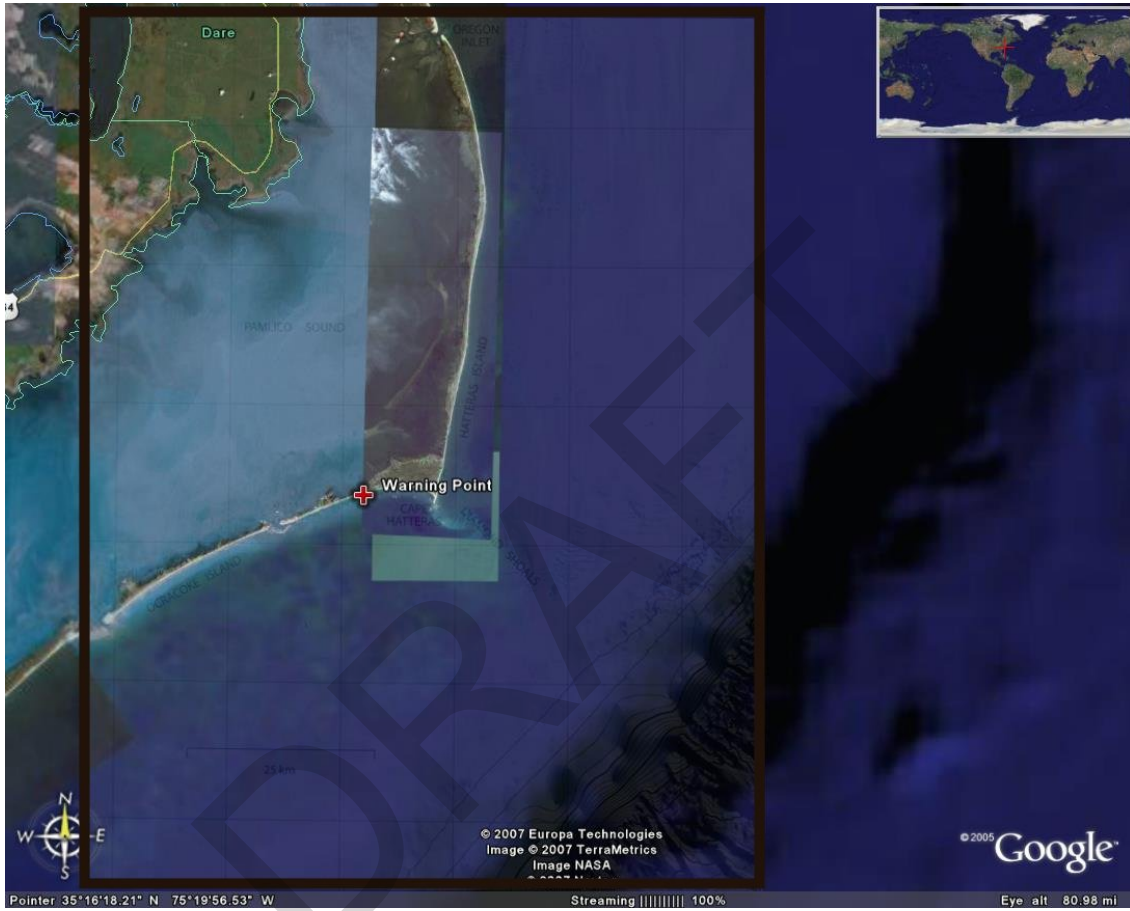
Figure 2 Google Earth view of the approximate area for which the DEM was made available.

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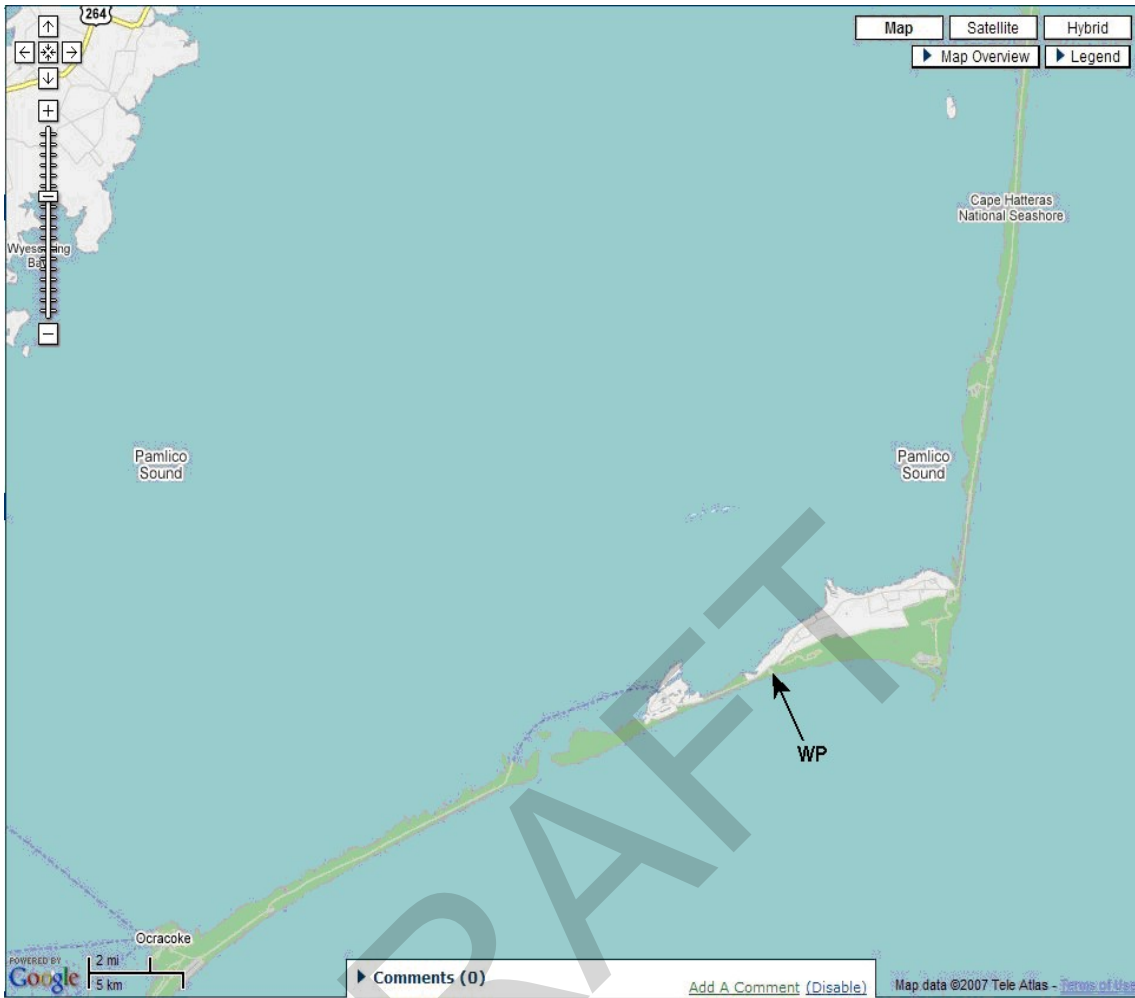
Figure 3 - Populated areas (white) along the Cape Hatteras National Seashore.
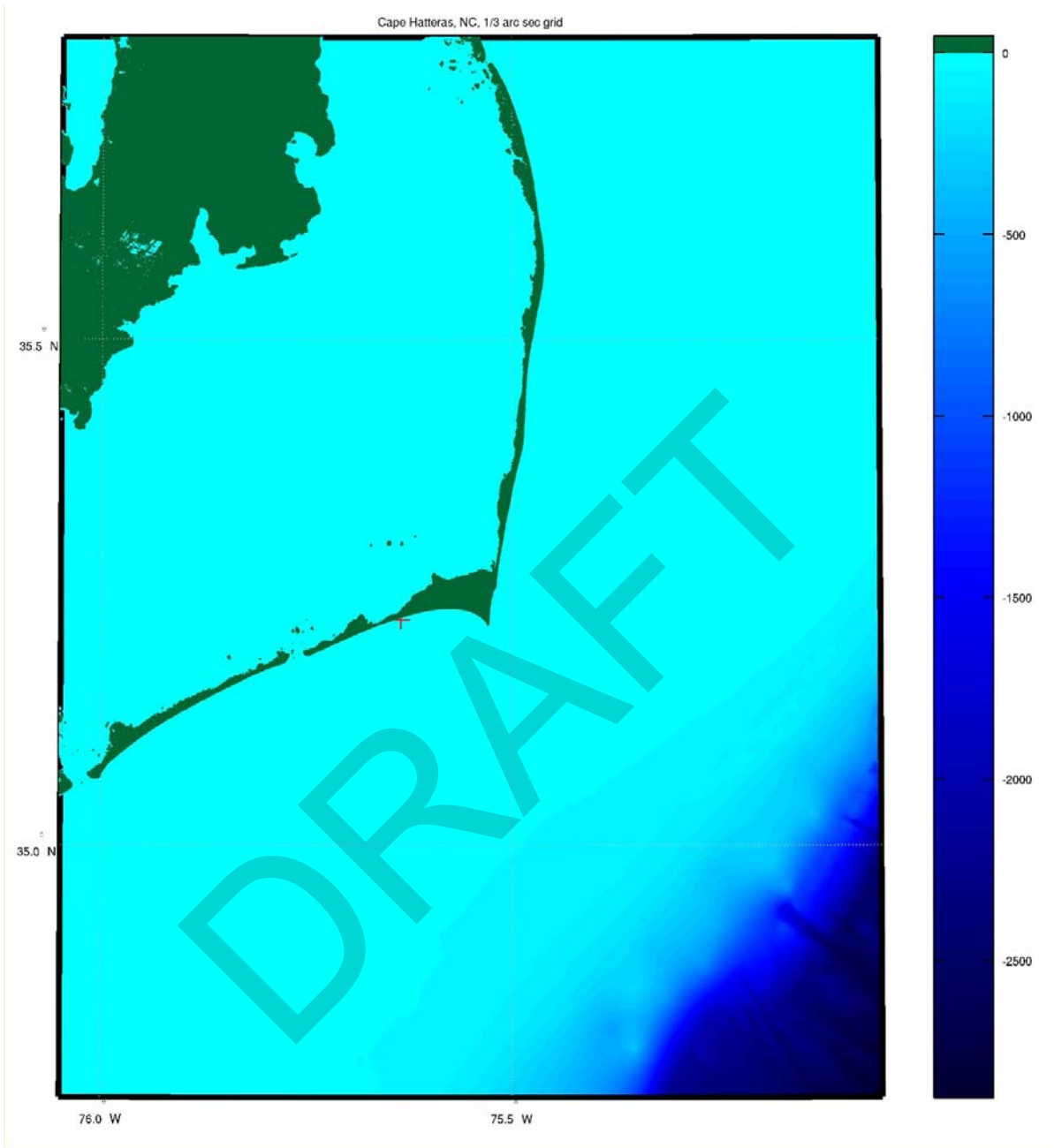
Figure 4– Filled contour plot at full grid resolution of the DEM. Red cross marks the location of the Warning Point (WP).
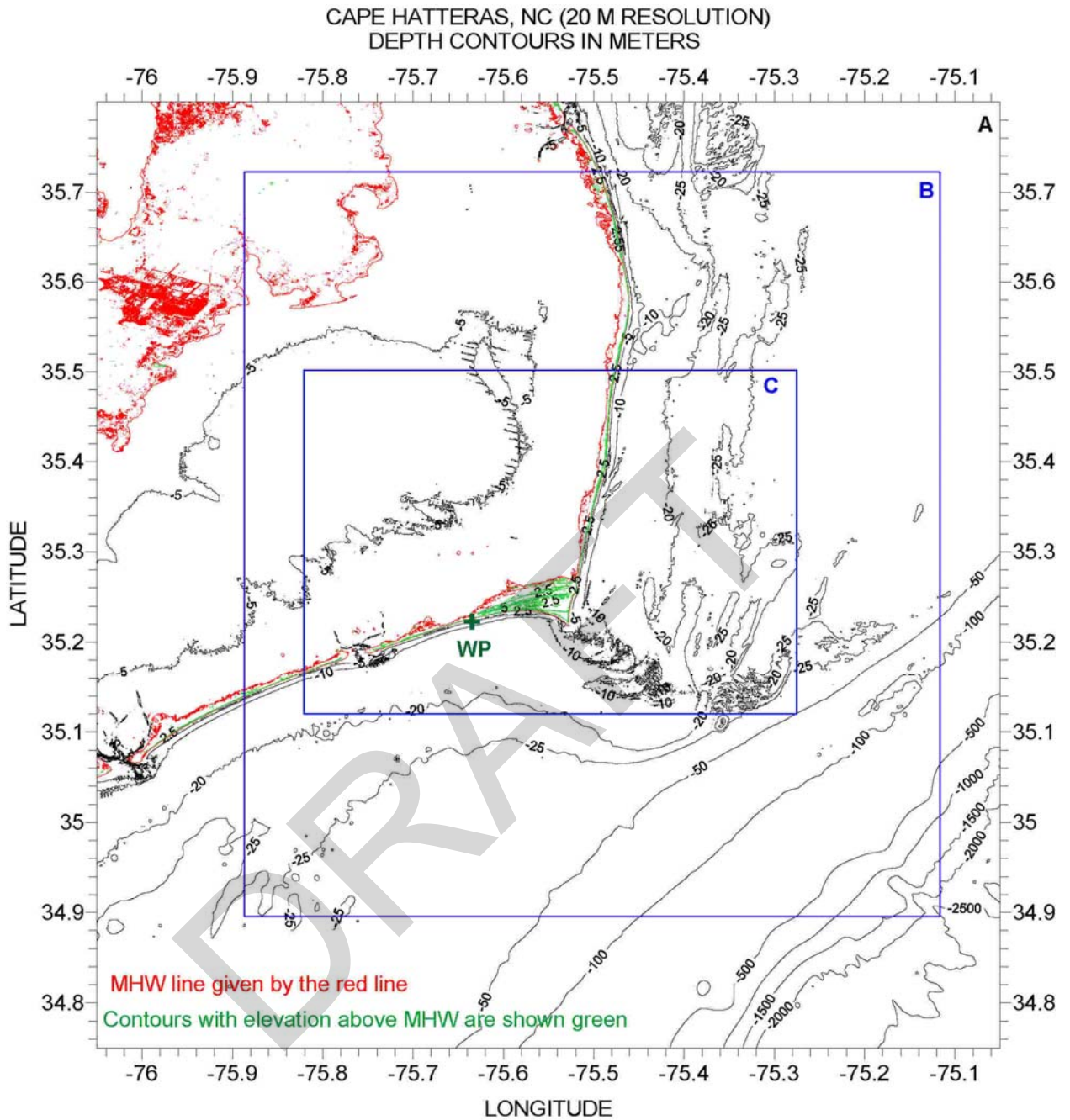
Figure 5– 20m resolution contour plot of the DEM for Cape Haterras. Also shown are the outlines of the Reference Grids B and C. Green cross shows the location of the Warning Point. Land elevation contours are shown in green. MHW line is given by the red contour.

2.4 Tide gauges

While there are no historic events recorded for the Cape Hatteras area, the tide gauge for Cape Hatteras serves as the warning point for model validation. The Oregon Inlet Marina tide gauge was first established in 1974 and has been in its present installation since March 1994. The GPS recorded location of the tide gauge is 35 47.7' N and 75 32.9' W. The mean range at the tide gauge is recorded as 0.89 feet and the diurnal range is 1.17 feet. Mean sea level is 3.21 feet.

2.5 Reference Grids

The reference Grid A was chosen to have exactly the same geographical dimensions (i.e., Xmin, Xmax, Ymin, Ymax) as the Cape Hatteras DEM sent by NGDC. As to the resolution, it was decided to start with the same cell size as for the San Juan and Mayaguez reference grids previously prepared, which was 12 arc seconds. A Matlab program (regrid_ngdc.m) was made to re-grid the NGDC DEM from 1/3 sec to 12 sec using the Matlab function interp2 with linear interpolation. The result was passed through BATHCORR.F with wave height = 0 and the Steepness Parameter (SP) = 1, and only one pass was required (two pointes were smoothed). In the first attempt to run the Reference grids, MOST became unstable in Grid A right at the shelf break (at the southeast corner of the DEM). So the Reference 12s Grid A was passed again through BATHCORR.F, with wave height = 0, and SP = 0.7, and this solved the problem.

Figure 5 shows a surface plot of Reference 12 s Grid A. The figure also shows the rectangles outlining the finally adopted Reference Grids B and C.

The reference Grid B was chosen to be as large as possible. This was done since we want to make our reference run with as high grid resolution as practically as possible. Figure 5 shows the outline of the Reference Grids B and C. Based on previous work, it was chosen to have a grid cell size of 6 arc seconds.

Reference 6s Grid B was prepared in the same way as Reference 12s Grid A, using regard_ngdc.m and the DEM for Cape Hatteras. It was then passed through BATHCORR.F with only two iterations required, using wave height = 0, and SP = 1. Only two values were smoothed. Figure 6 shows a surface plot of Reference 6s Grid B. The figure also shows the rectangle outlining the finally adopted Reference C.

Reference 1 s Grid C was prepared in the same way as Reference Grids A and B, using regrid_ngdc.m to go from the 1/3 sec DEM up to 1 sec. The output was passed through BATHCORR.F once, with no changes in any cell. Figure 7 shows a surface plot of the finally adopted Reference 1s Grid C. Table 1 summarizes the statistics of all three Reference grids , including the maximum time step, Δt_A, in seconds for the grid as given by BATHCORR.F.

Finally, Figure 8 shows a contour plot of the nested grids showing no depth discontinuities along the grid boundaries.

	A	B	C
Lat	34.7499537-35.7999537	34.896-35.722628	36.7 - 37.2
Long	76.05004629 - 75.05004629	75.887-75.1165	76.3 -75.8
ncols	301	464	1801
nrows	316	497	1801
Cellsize (arc sec)	12	6	1
X Grid spacing (degree)	0.0033333333332399	0.00166412742980	0.00027777
Y Grid spacing (degree)	0.0033333333332381	0.0016665887096	0.00027777
Zmin (m)	-2878.3	-2571.95	-31.2766
Zmax (m)	9.1206	11.6006	29.8783
Final file name	Grid_A_reference_12s.grd	Grid_B_reference_6s.grd	Grid_C_reference_1s_v7.grd
Δt$_A$	1.817 s	0.961 s	1.41s

Table 2 Reference Grid statistics for Cape Hatteras, NC.

☐
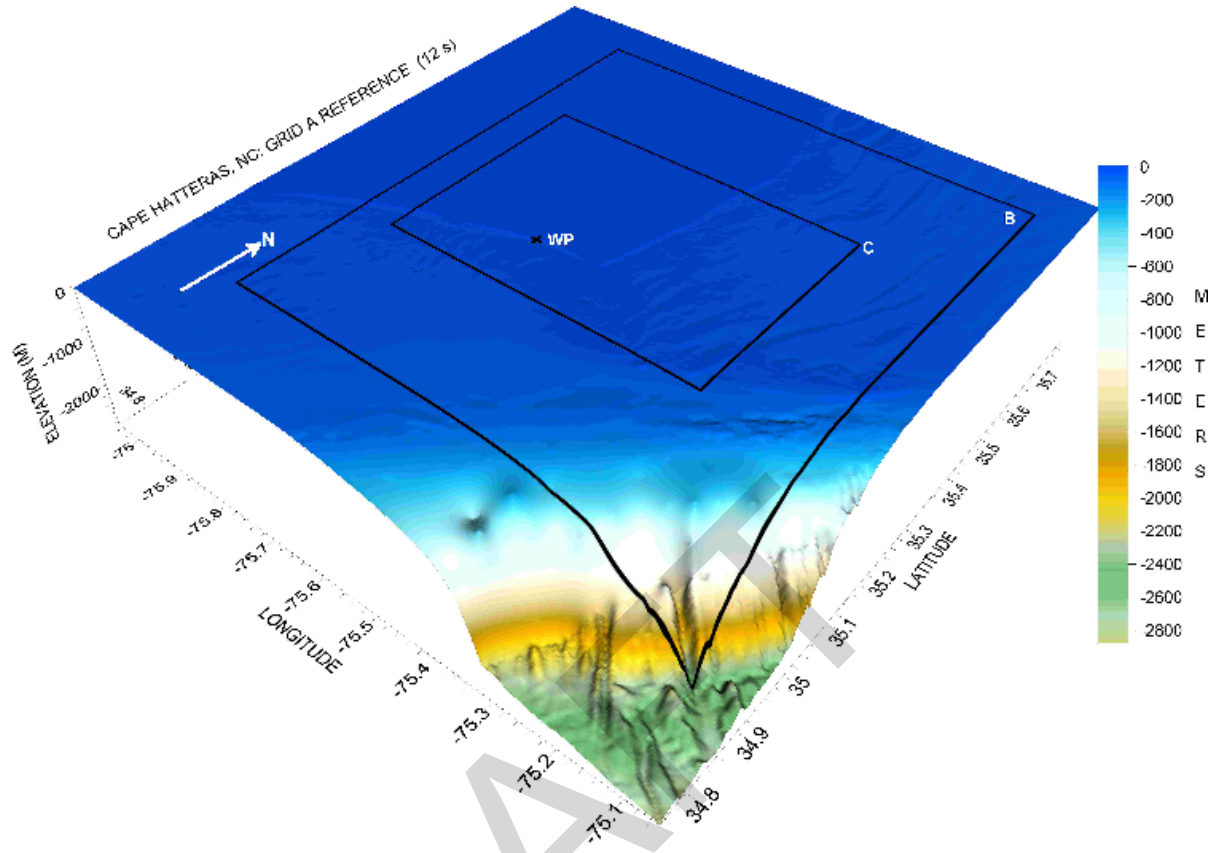
Figure 6 – Surface plot of Reference 12 s Grid A, looking from the southeast. The outline of the finally adopted Reference Grids B and C are also shown. Black cross shows the location of the Warning Point (WP).
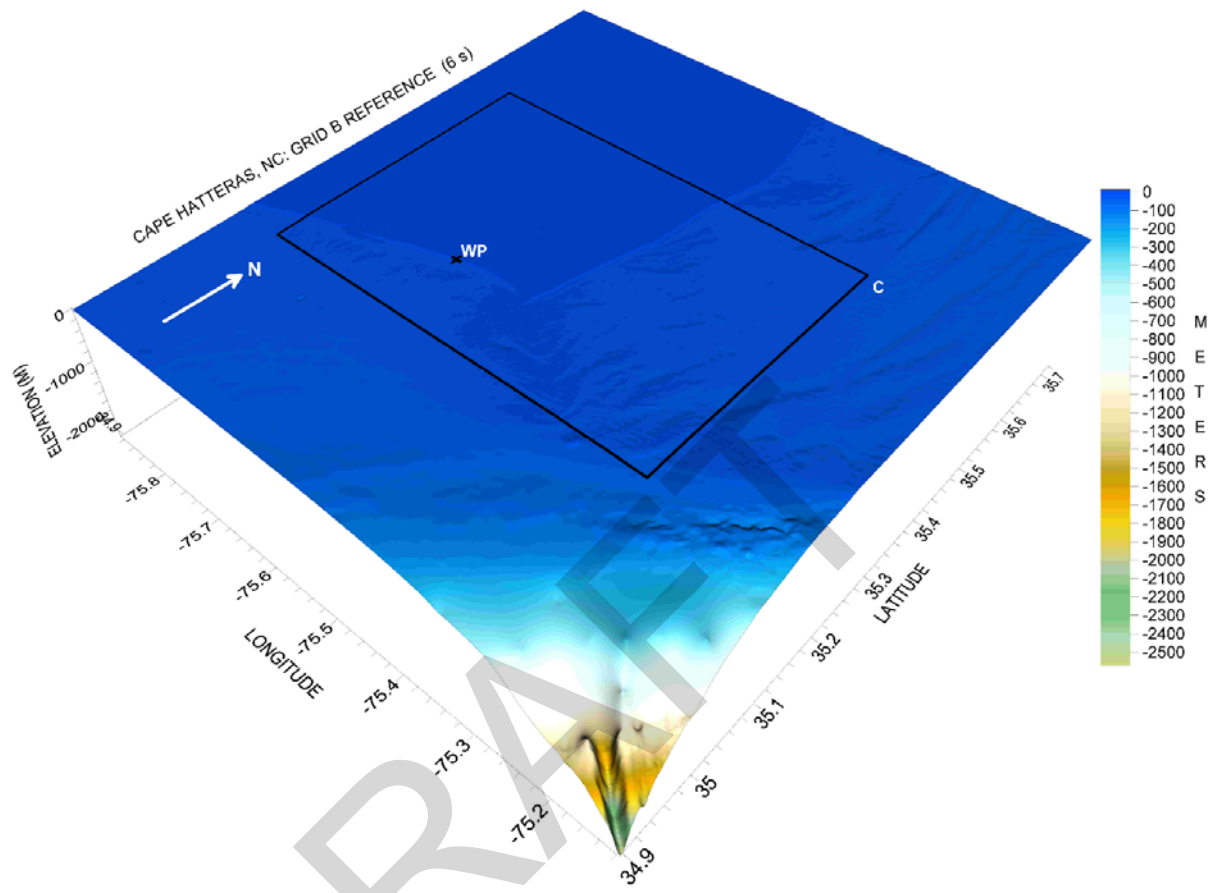
Figure 7 Surface plot of the finally adopted Reference 6 s Grid B, looking from the SE. The outline of the finally adopted Reference Grid C is also shown. Black cross shows the location of the Warning Point (WP).
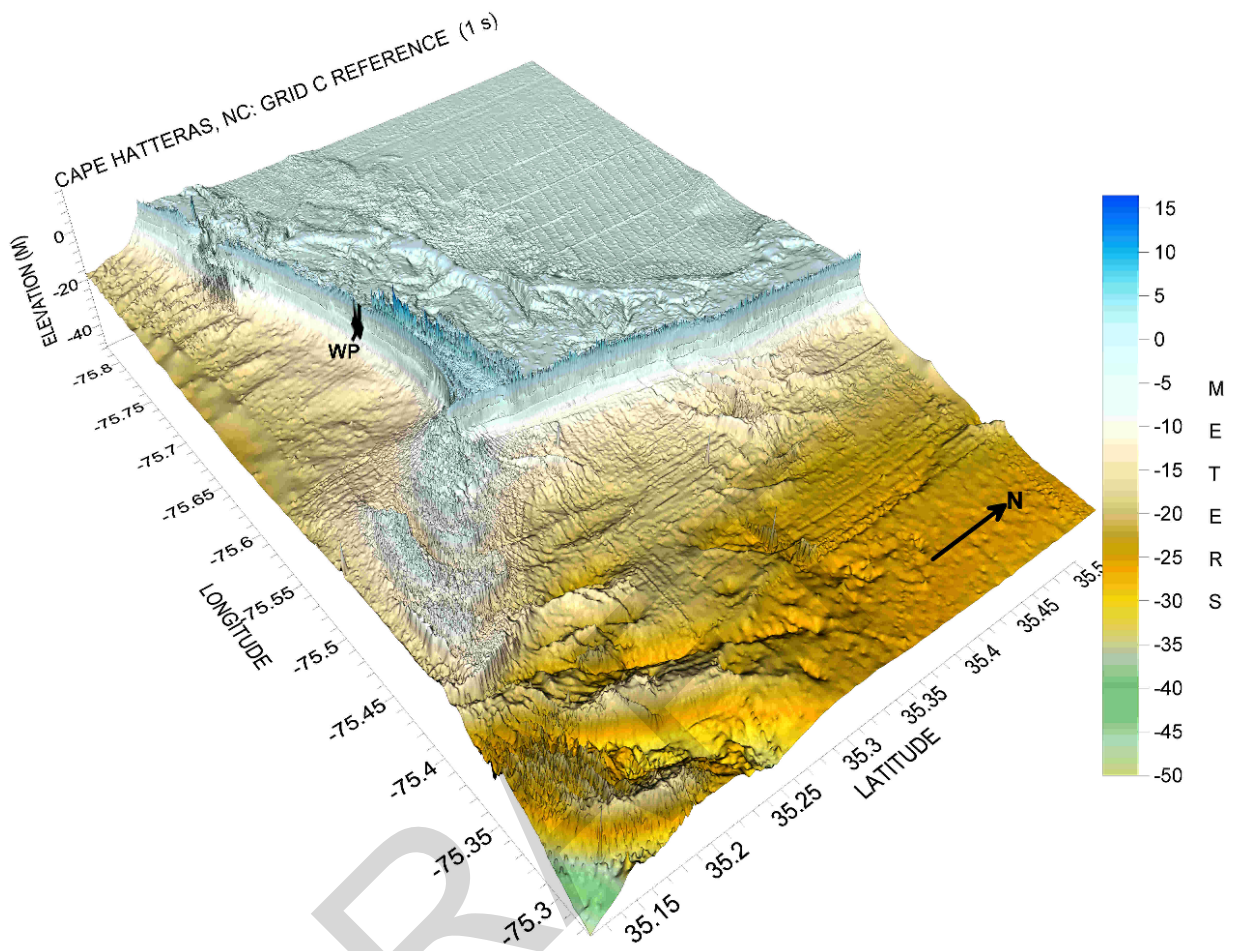
Figure 8 Surface plot of the finally adopted Reference 1 s Grid C, looking from the SE. Black cross shows the location of the WP.

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	A	B	C
Lat	17.6541-18.7309	17.9000-18.6000	18.1662-18.3000
Long	67.9470-65.0662	67.44029-67.13357	67.2462 -67.1373
ncols	433	185	393
nrows	162	421	482
Cellsize (arc sec)	24	6	1
X Grid spacing (degree)	0.006668	0.001666	0.000277
Y Grid spacing (degree)	0.006688	0.0016666	0.000278
Zmin (m)	-5015.02	-3692.19	-339.02
Zmax (m)	1281.0941	349.602	159.90

Table 3 Final reference grid parameters for Cape Hatteras, NC.

2.6 Optimized Grids

Several attempts were made in order to come up with Optimized Grids A, B, and C. They are all shown in Figure 9. All were guided by the grid resolution obtained before for the optimized grids used in the Puerto Rico study. That is, Optimized Grid A was tried at 24 s resolution, Optimized Grid B at 8 s, and Optimized Grid C at 3 s.

The Reference 12 s Grid A was passed through Surfer command Extract in order to regrid it from 12 s resolution to 24 s resolution. As a first option, the area coverage was left the same as for the Reference 12 s Grid A (which was the same as for the DEM sent from NGDC). A second option was tried in which the area coverage of Reference 24s Grid A was reduced, as shown under "A_opt_v2" in Figure 9. By the way, the string "opt" appearing in the labels in the figure stands as shorthand of "optimized", not for "option". As can be seen, with this second option the maximum water depth was decreased, allowing for a larger time step. But all attempts using this option of the Optimized 24 s Grid A resulted in a decreased wave height (from approximately 2 m down to less than 1 m) for the first wave crest in Grid C. So, finally it was decided to use as Optimized 24 s Grid A the first option, which has the same area coverage as the original DEM.

The pre-processing of the finally adopted grid was made using BATHCORR.F. Four passes of BATHCORR.F had to be made, varying SP from 1 down to 0.3. Though only a few data points were modified during each pass. Figure 10 shows a surface plot of the finally adopted Optimized 24s Grid A.

As can be seen from Figure 10, four different options were attempted in trying to obtain the Optimized 8s Grid B. They consisted of changing the area coverage both in size and location. The location changes were made trying to increase the maximum time step by decreasing the maximum depth located on the southeast corner of the

grid. The Reference 6s Grid B was passed through Surfer → Spline Smooth in order to regrid it from 6 s resolution to 8 s resolution. The output was passed then through Surfer → Extract in order to change the size and location amongst the four different options. The output was passed through BATHCORR.F with wave height = 0.5, and SP = 1, and only one pass was required, with no changes in depth values. The finally adopted Optimized 8s Grid B was version 4 (see rectangle labeled "B_opt_v4" in Figure 9). Figure 12 shows a surface plot of Optimized 8s Grid B, and the outline of the finally adopted Optimized 3s Grid C.

Figure 10 shows that two different versions of Optimized Grid C were tried, both of 3 s resolution. The final one chosen was the one identified as "C_opt_v2" in the figure due to the large CPU time required for "C_opt_v1". The grid was passed through BATHCORR.F with wave height = 0, and SP = 1, and no changes occurred. Figure 13 shows a surface plot of Optimized 3 s Grid C. As in other locations, the presence of triangular nearshore spikes can be seen. These can be better seen in Figure 14. The concern is that, if artificial, these could have an impact on the amount of inland flooding.

Finally, Figure 15 shows a contour plot of the nested grids. Table 4 summarizes the parameters of the Optimized Grids used to build the SIM.
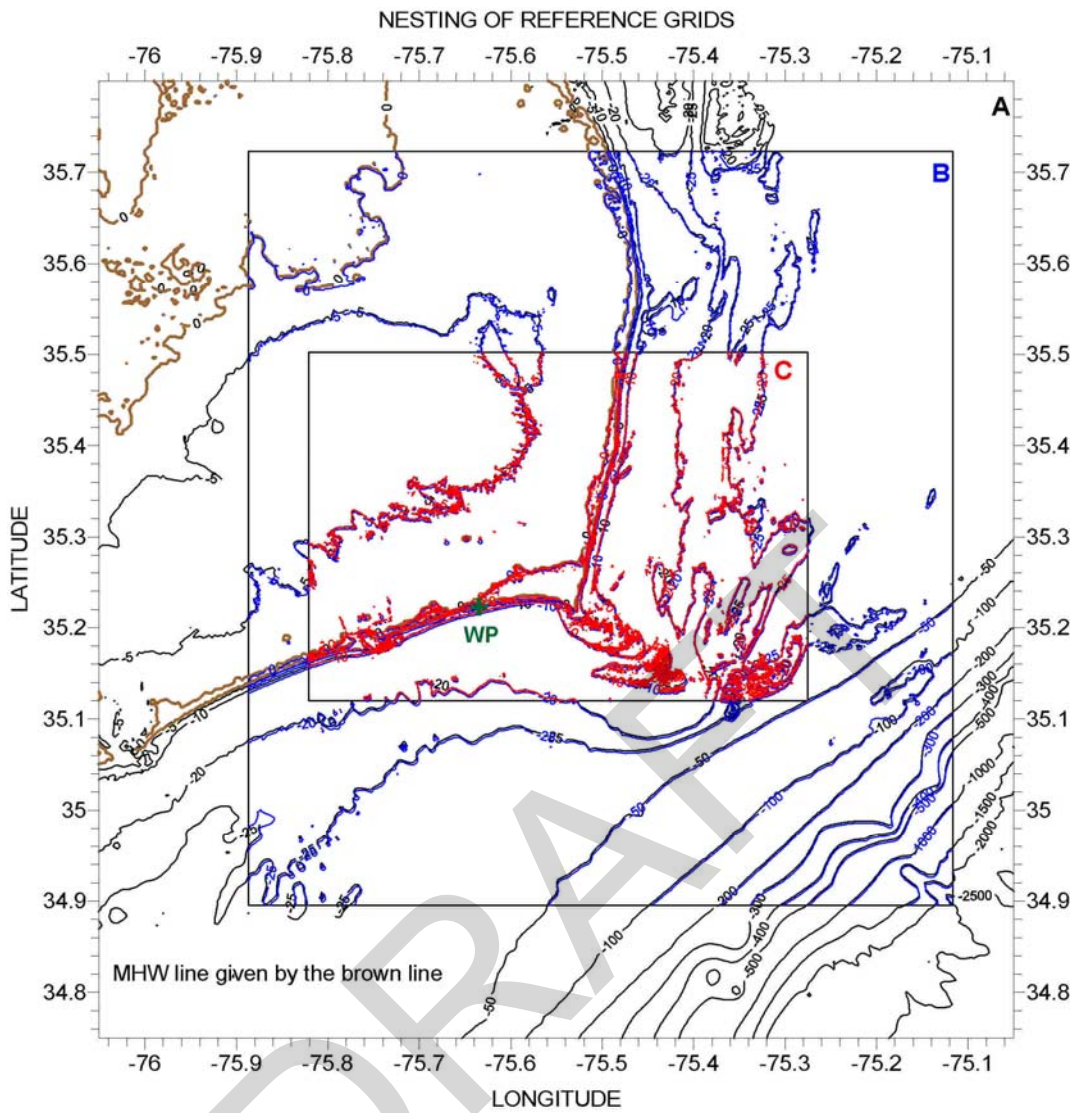
Figure 9 Nesting of reference grids showing no depth discontinuities along the grid boundaries.
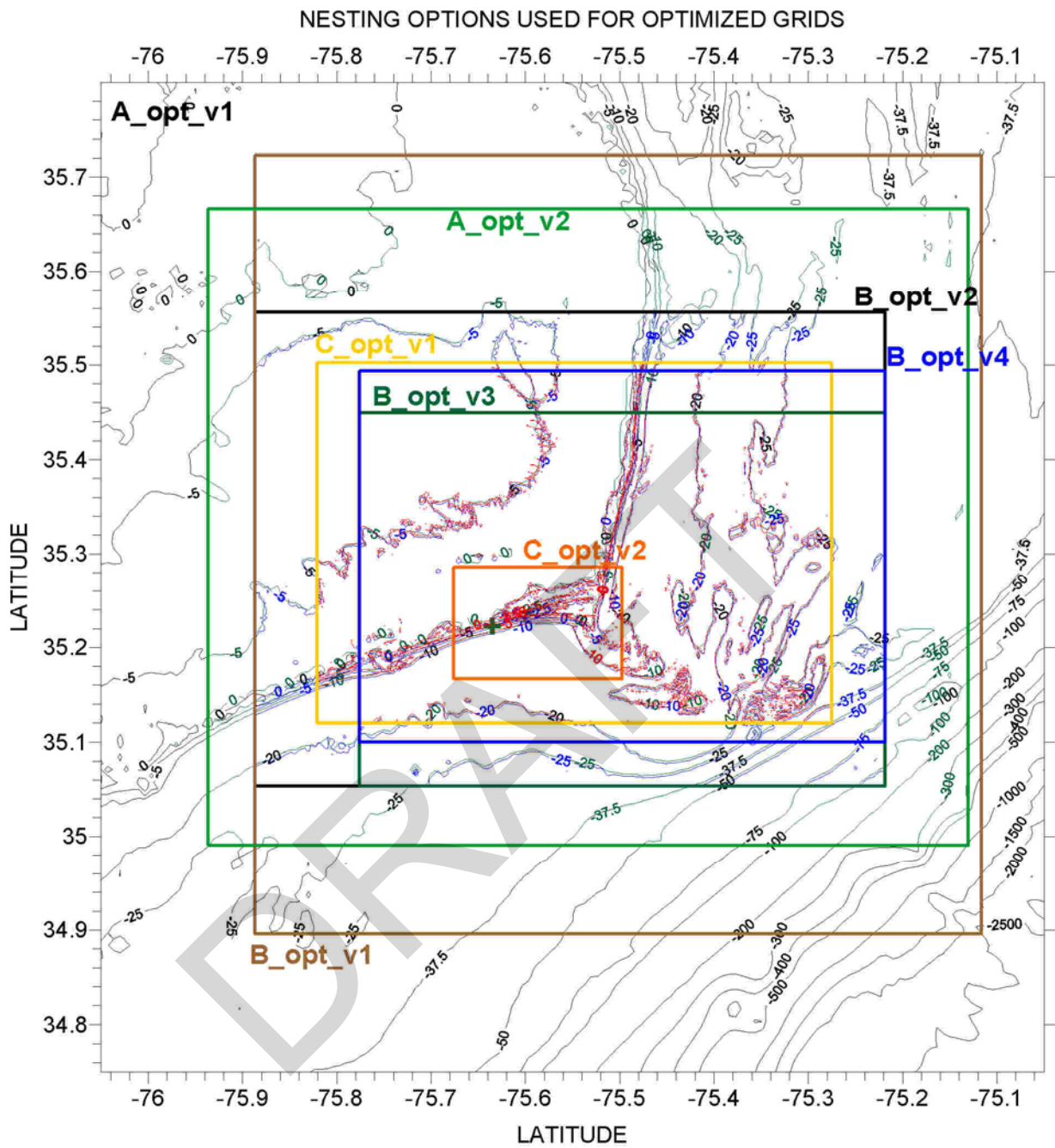
Figure 10 – Plot showing the different options tried in the attempts to get the Optimized Grids A, B, and C.
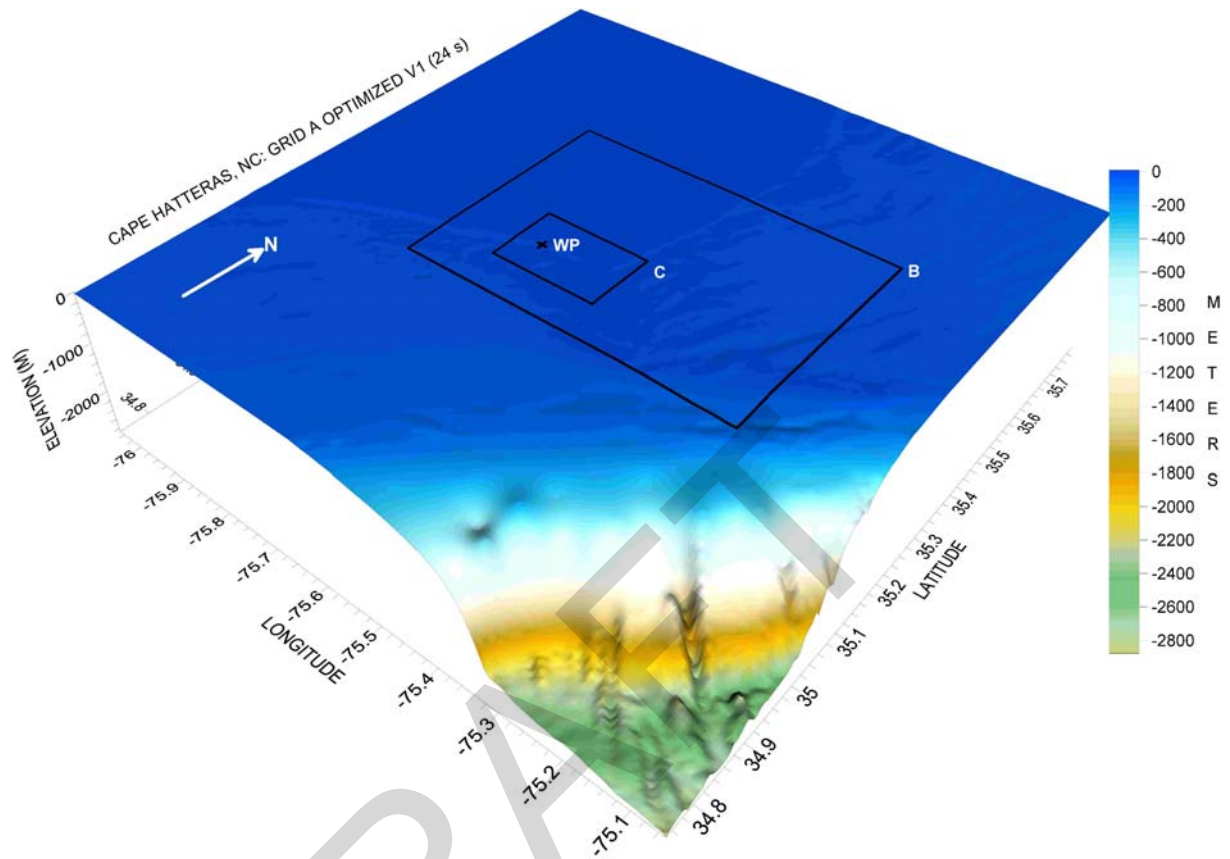
Figure 11 Surface plot of the finally adopted Optimized 24 s Grid A, looking from the SE. Also shown are the outlines of the finally adopted Optimized Grids B and C, and the location of the WP.
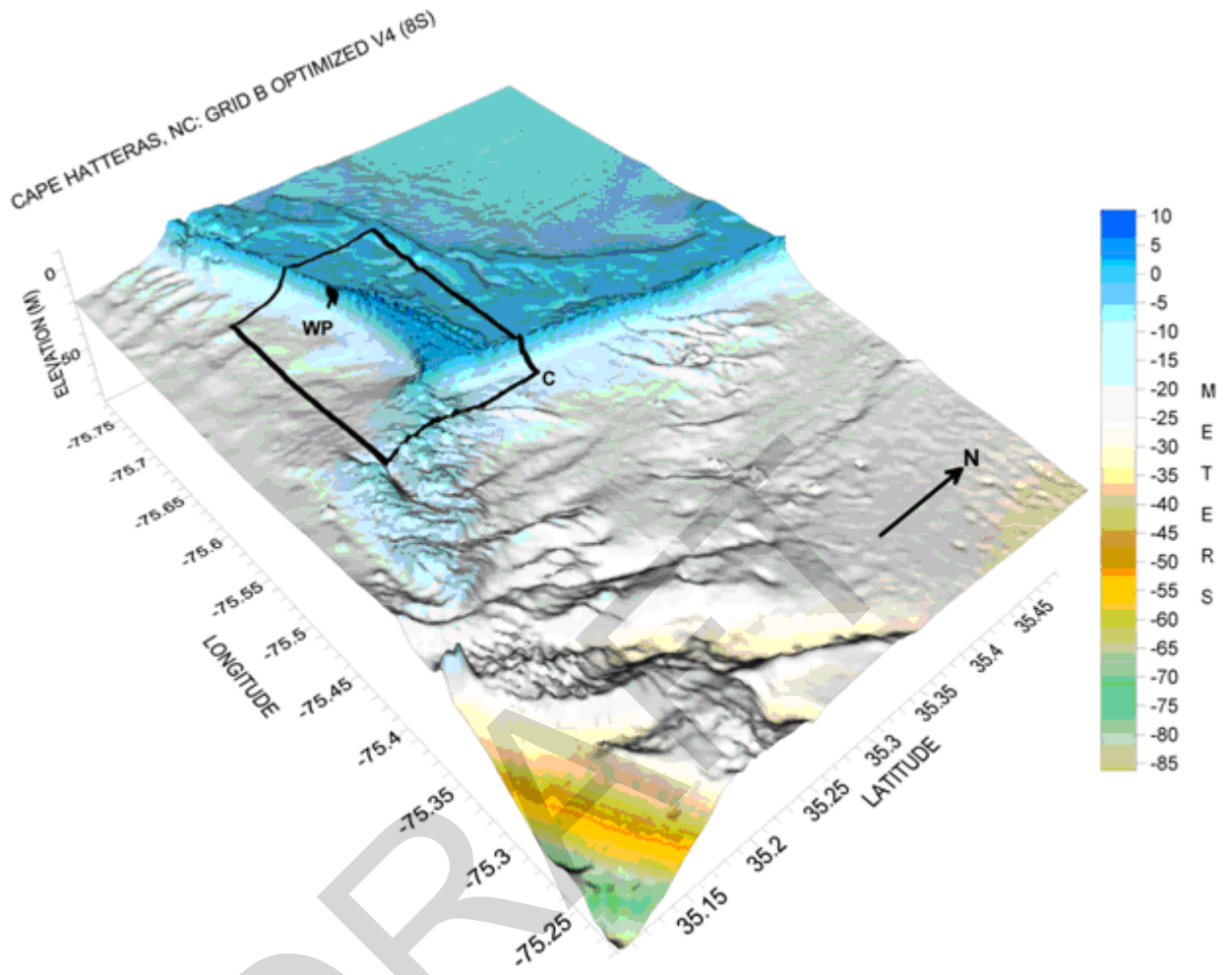
Figure 12 Surface plot of the finally adopted Optimized 8 s Grid B, looking from the SE. The outline of the finally adopted Optimized Grid C is also shown.

	A	B	C
Lat	34.749953703 -35.79995370	35.10043 - 35.49374	35.1660822- 35.2861611
Long	76.050046296296 - 75.050046296324	75.77597824- 75.2186490	75.6760470964 - 75.49777168624
ncols	151	178	215
nrows	158	252	145
Cellsize (arc sec)	24	8	3
X Grid spacing (degree)	0.006666	0.0022204351	0.0008330626643
Y Grid spacing (degree)	0.0066878	0.002222118	0.000833881597
Zmin (m)	-2878.3	-86.2251	-18.8177
Zmax (m)	7.98	11.0621	13.3826
Δt_B	3.64 s	6.99	5.58
Final file name	Grid_A_opt_v1_24s.grd	Grid_B_opt_v4_8s.grd	M1s_pass9.dat

Table 4 Summary of Optimized grid parameters for Cape Hatteras, NC.
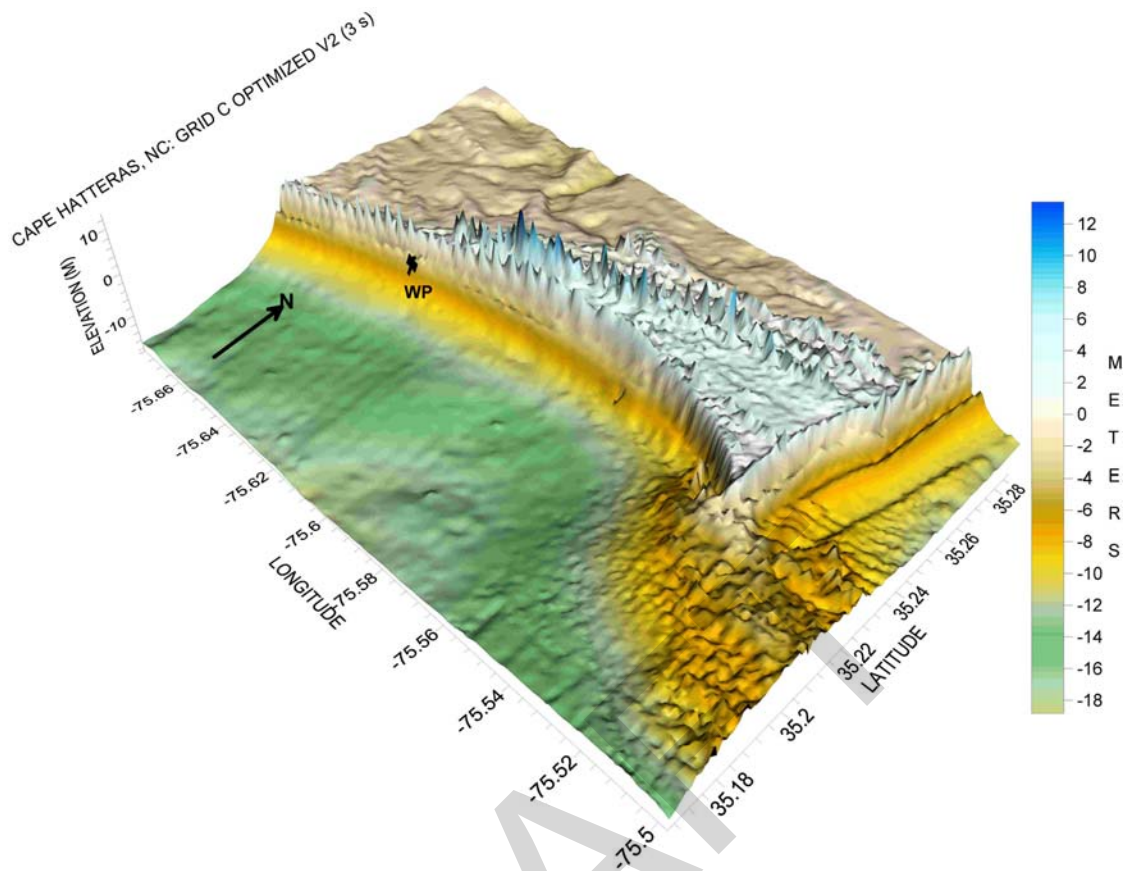
Figure 13 – Surface plot of the finally adopted Optimized 3 s Grid C, looking from the SE.
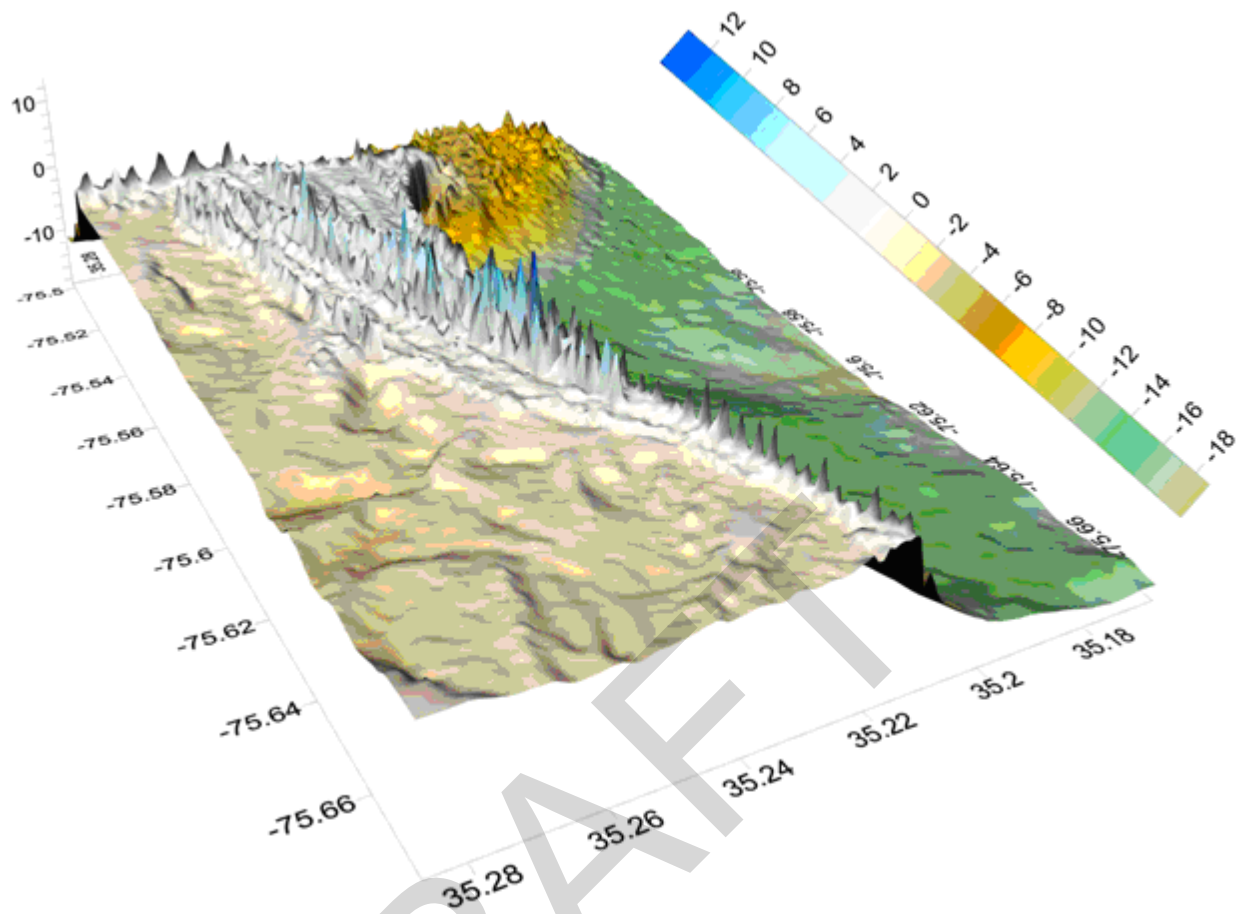
Figure 14 – Another view of Optimized 3 s Grid C, showing the alongshore row of spikes
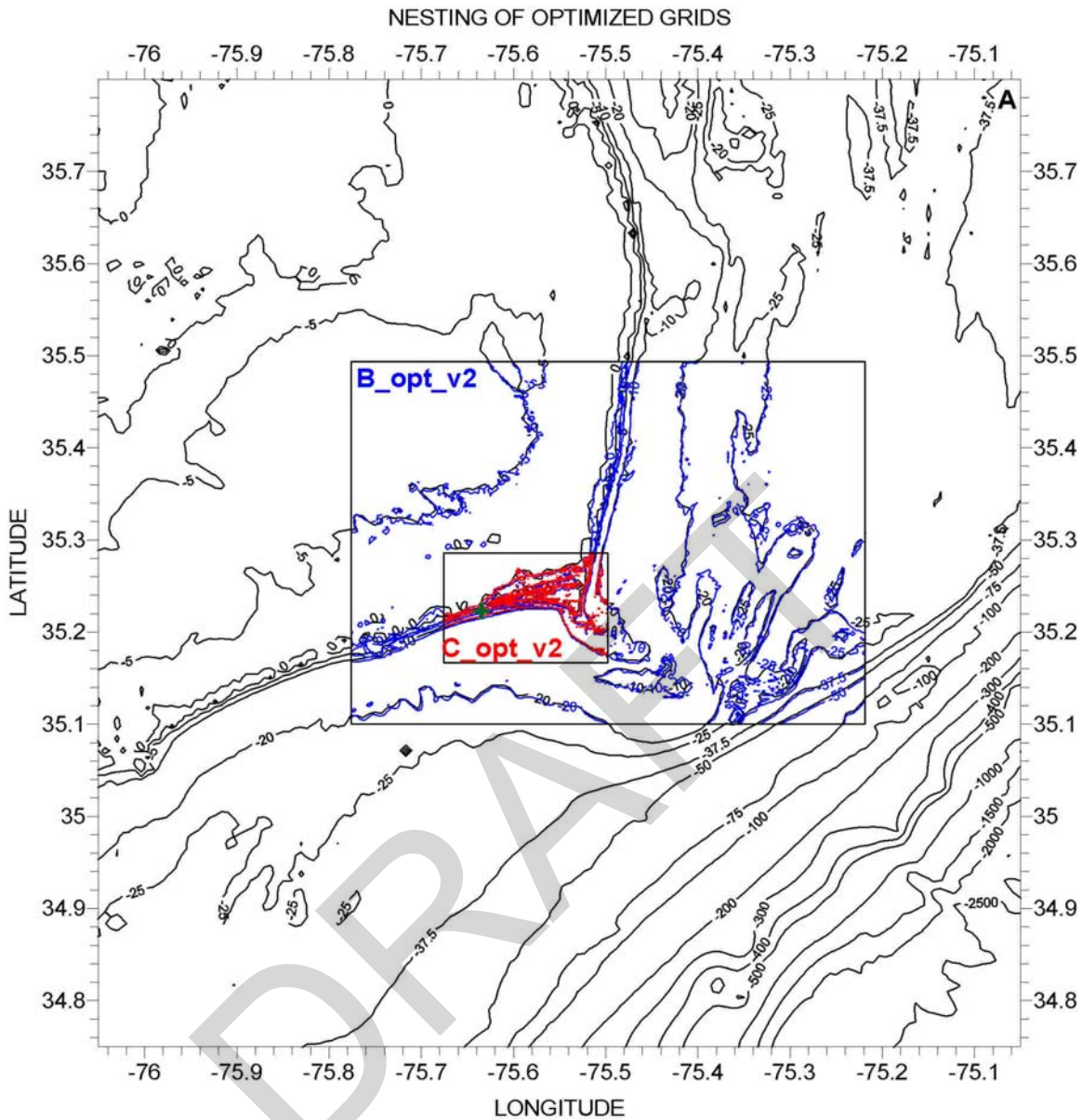
Figure 15 – Nesting of optimized grids. Grids C (red) on top of Grid B (blue), and Grid B on top of Grid A (black). This is to show the absence of depth discontinuities along the grid boundaries.

2.6 Sources tested

The Puerto Rico Trench is the only potential source appearing in the FACTS page that could significantly impact Cape Hatteras, NC. A 9.0 Mwt earthquake and tsunami was used to test the grids for Virginia Beach, as shown below:

I also used another source file which was more compactly defined around Grid A and, therefore, of smaller size.

Source Location	Unit Sources	Slip for each unit source (m)	Mw
Atlantic	49 through 55 Rows A and B	11	9.0

The area covered was

Xmin = -79 W
Xmax = -73 W
Ymin = 34 N
Ymax = 40 N

A Mwt of 9.0 is above what experts think could occur in the region, but it should offer a good test.

3.0 Results

Four hours of simulation were carried out, followed by testing 10 hours of simulation. Figures 16 to 18 show the maximum elevations obtained for the reference grids, while Figures 19 to 21 show the same information for the optimized grids. And Figure 22 shows a comparison of the elevation time series obtained at the WP for the reference and the optimized Grid C. In addition, the root-mean-square-error (RMSE; assuming that the results for the reference grids are the correct ones) is also computed. This came out to 0.144 meters (rounding to 3 decimal places). Figures 23 to 29 show the corresponding maximum elevations and time series for 10 hours of simulation. The RMSE came out to 0.001 m.

Tables 5 and 6 show a listing of the *.in and *.lis files used in the Reference runs for the 4 hours of simulation, respectively. The corresponding tables for the Optimized 4 hours runs are shown in Tables 7 and 8. Table 9 shows the summary of the results for 4 hours of simulation.

```
0.001Minimum amplitude of input offshore wave (m): CAPE HATTERAS REFERENCE
0Input minimum depth for offshore (m)
0.1Input "dry land" depth for inundation (m)
0.0009Input friction coefficient (n**2)
1      let a and b run up
30.0    max eta before blow up (m)
0.8Input time step (sec)
18000Input amount of steps (4 hrs)
2Compute "A" arrays every n-th time step, n=
1Compute "B" arrays every n-th time step, n=
76Input number of steps between snapshots (every 60.8 s)
0...Starting from
1...Saving grid every n-th node, n=
Cape Hatteras reference run (4 hrs)
```

Table 5 Cape Hatteras *.in file for 4 hour reference run

```
Site:  Cape_Hatteras
Input prefix:  31028
Read Computational parameters:
Minimum amplitude of input offshore wave (m):   1.0000000000000000E-003
Input minimum depth for offshore (m):    0.000000000000000
Input "dry land" depth for inundation (m):    0.1000000000000000
Input friction coefficient (n**2):   9.0000000000000000E-004
Input runup switch (0 - runup only in gridC, 1 - runup in all grids):          1
Max allowed eta (m):    30.00000
Input time step (sec):    0.8000000000000000
Input amount of steps:        18000
Compute "A" arrays every n-th time step, n=          2
Compute "B" arrays every n-th time step, n=          1
elapsed secs:    30945.02    , user:    30725.81    , sys:     219.2100
clock sec:        30974 , minutes:    516.2333
```

Table 6 Cape Hatteras *.output file for reference run (4 hours)

```
0.001Minimum amplitude of input offshore wave (m): CAPE HATTERAS
0Input minimum depth for offshore (m)
0.1Input "dry land" depth for inundation (m)
0.0009Input friction coefficient (n**2)
1      let a and b run up
30.0    max eta before blow up (m)
3Input time step (sec)
4800Input amount of steps (4 hrs)
1Compute "A" arrays every n-th time step, n=
2Compute "B" arrays every n-th time step, n=
20Input number of steps between snapshots (every 60.0 s)
0...Starting from
1...Saving grid every n-th node, n=
Cape Hatteras optimized v8 run (4 hrs)
```

Table 7 Cape Hatteras *.in file for Optimized run

```
 8-08-2007  13:29:38.311
Site:  Cape Hatteras
Input prefix:  31028
Minimum amplitude of input offshore wave (m):   1.0000000000000000E-003
Input minimum depth for offshore (m):     0.000000000000000
Input "dry land" depth for inundation (m):   0.1000000000000000
Input friction coefficient (n**2):   9.0000000000000000E-004
Input runup switch (0 - runup only in gridC, 1 - runup in all grids):        1
Max allowed eta (m):     30.00000
Input time step (sec):    3.000000000000000
Input amount of steps:        4800
Compute "A" arrays every n-th time step, n=        1
Compute "B" arrays every n-th time step, n=        2
Input number of steps between snapshots (should be a    multiple of A,B and C time steps) :  20
 elapsed secs:   216.2100    , user:   214.9200    , sys:   1.290000
 clock sec:         217 , minutes:   3.616667
```

Table 8 Cape Hatteras *.lis output file for Optimized 4 hour run

Notice that in this location the maximum time step for the reference run is determined by Grid B due to the large depth at the southeast corner. While for the optimized runs is determined by Grid A.

Grid	Region	Reference Inundation Model (RIM)				Stand-by Inundation Model (SIM)		
		Coverage	Cell	Time		Coverage	Cell	Time
		Lat. [°N]	Size	Step		Lat. [°N]	Size	Step
			["]	[sec]		Lon. [°W]	["]	[sec]
A	Outer Banks	34.7499 35.7999 76.05004- 75.05004		1.817		36.4499 - 37.4999 76.600 -75.400		
			12				24	3.64
			(301x316)				(151x158)	
B	Outer Banks	34.8960- 35.7226 75.887 -75.1165		0.961		35.1004 -35.4937 75.7759 -75.218		
			6				8	6.99
			(464x497)				(252x178)	
C	Cape Hatteras	36.70-37.20	1	1.41		35.1660 -35.2861	3	5.58
		76.30-75.80	(1801x1801)			75.676 - 75.497	(245x145)	
Minimum offshore depth [m]		0				0		
Water depth for dry land [m]		0.1				0.1		
Manning coefficient		0.0009				0.0009		
CPU time for a 4-hour simulation		>516				**3.62**		
CPU time for 10 - hours simulation		1049				**9.10**		

Table 9 Summary of Runs for Cape Hatteras, NC

4.0 Summary and Conclusions

This report describes the development of a Standby Inundation Model (SIM) for Cape Hatteras, North Carolina, as a component of the National Oceanic and Atmospheric Administration (NOAA) Short-term Inundation Forecasting for Tsunamis (SIFT) system. The model is validated using numerical results from a high-resolution MOST reference model since there are no historical tsunami instrumental records for the island. The developed SIM is tested against different scenarios of large virtual tsunamis numerically generated the Puerto Rico Trench. A four hour simulation of the inundation ran in 3.62 minutes. Due to the continental shelf and possibility of refractive it is suggested that the SIM allow to be run for a longer period of time to better resolve the later waves.

5.0 References

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6.0 Appendix A

Since the initial development of the Cape Hatteras, NC SIM , the parameters for the input file for running the SIM and RIM in MOST have been changed to reflect changes to the MOST model code. The following appendix lists the new input files for Cape Hatteras.

6.1 RIM *.in file for Cape Hatteras, NC – updated 2009

0.001Minimum amplitude of input offshore wave (m): CAPE HATTERAS REFERENCE

0Input minimum depth for offshore (m)

0.1Input "dry land" depth for inundation (m)

0.0009Input friction coefficient (n**2)

1   let a and b run up

50.0   max eta before blow up (m)

0.85Input time step (sec)

42353Input amount of steps (10 hrs)

1Compute "A" arrays every n-th time step, n=

1Compute "B" arrays every n-th time step, n=

70Input number of steps between snapshots (every 59.5 s)

0...Starting from

1...Saving grid every n-th node, n=

Cape Hatteras reference run (10 hrs) with new Grid A

6.2 SIM *.in file for Cape Hatteras, NC – updated 2009

0.0001Minimum amplitude of input offshore wave (m):CAPE HATTERAS optimized run

0Input minimum depth for offshore (m)

0.1Input "dry land" depth for inundation (m)

0.0009Input friction coefficient (n**2)

1let a and b run up

300.0max eta before blow up (m)

2.55Input time step (sec)

5647Input amount of steps (4 hrs)

1Compute "A" arrays every n-th time step, n=

1Compute "B" arrays every n-th time step, n=

24Input number of steps between snapshots (every 61.2 s)

0...Starting from

1...Saving grid every n-th node, n=