PRELIMINARY REPORT

VIRGINIA BEACH, VA

by

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1. INFORMATION ABOUT THE DEM

Xmin (deg)	-76.600046296295
Xmax (deg)	-75.399954
Ymin (deg)	36.449953719105
Ymax (deg)	37.500046
Zmin (m)	-47.13
Zmax (m)	37.73
Cell size (deg)	0.00009259258999999
Cell size (arc-sec)	1/3 (≈ 10 m)
Zonal Cell size (m)	≈ 8
Meridional Cell size (m)	≈ 10
# columns	12,961
# rows	11,341
# nodes	146,990,701
East-West dimension (km)	106.599
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

Figure 1 shows a Google Earth view of the approximate area covered by the DEM. Figure 2 shows a filled contour plot of the DEM at full resolution. Figure 3 shows a shaded relief plot of the DEM with less resolution. Notice the very complicated bathymetry just east of the Delmarva Peninsula at the top of the figures (1 to 4), in what appears to be tidal flats cut by deep, and steep, channels. This area was the source of instabilities in Grid A, while the presence of entrance channels to Chesapeake Bay, with very steep slopes, was the source of instabilities in Grid C.

The location of the Warning Point is:

Warning Point at:
-75.9420° N, 36.7490° W.

2. REFERENCE GRIDS

Grid A:

The reference Grid A was chosen to have exactly the same geographical dimensions (i.e., Xmin, Xmax, Ymin, Ymax) as the Virginia Beach 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

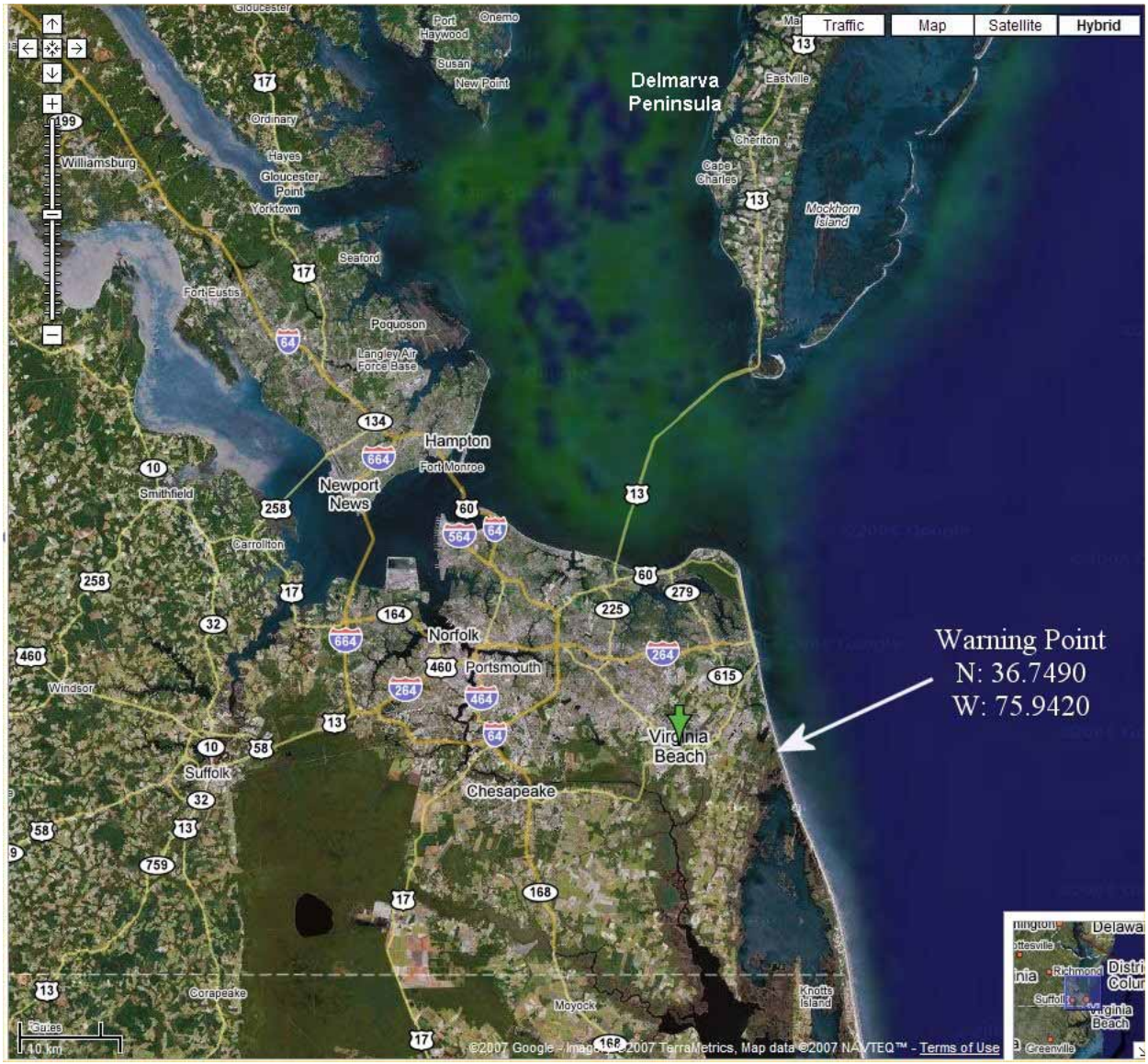

Figure 1 – Google Earth view of the approximate area for which the DEM was made available.

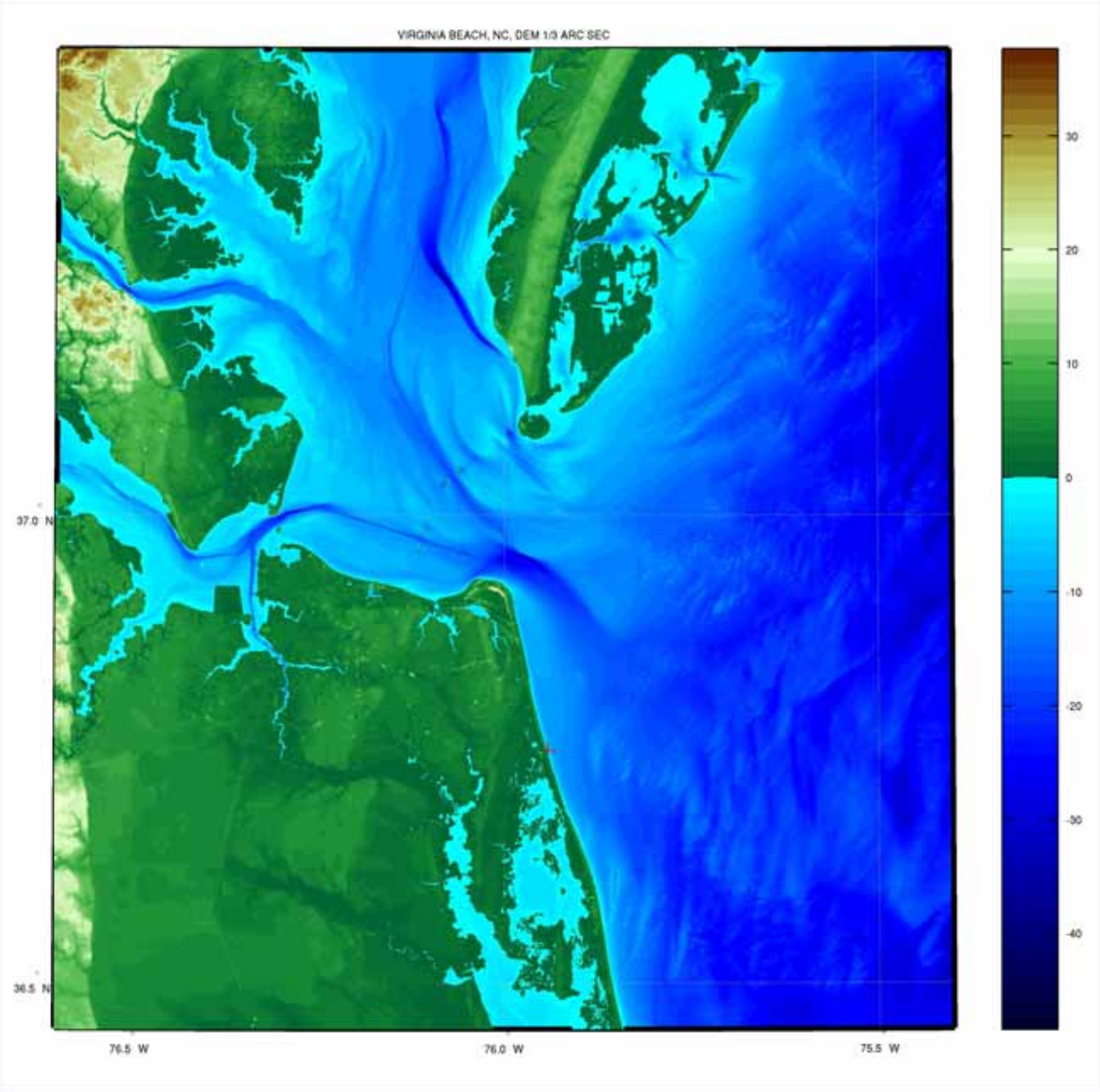

Figure 2 – Filled contour plot at full grid resolution of the DEM. Red cross marks the location of the Warning Point (WP). Note the very irregular bathymetry east of Delmarva Peninsula, and the deep and narrow channels in it. Also note the deep and narrow channels inside Chesapeake Bay, and the bridge, shown as Hwy 13 in Figure 1.

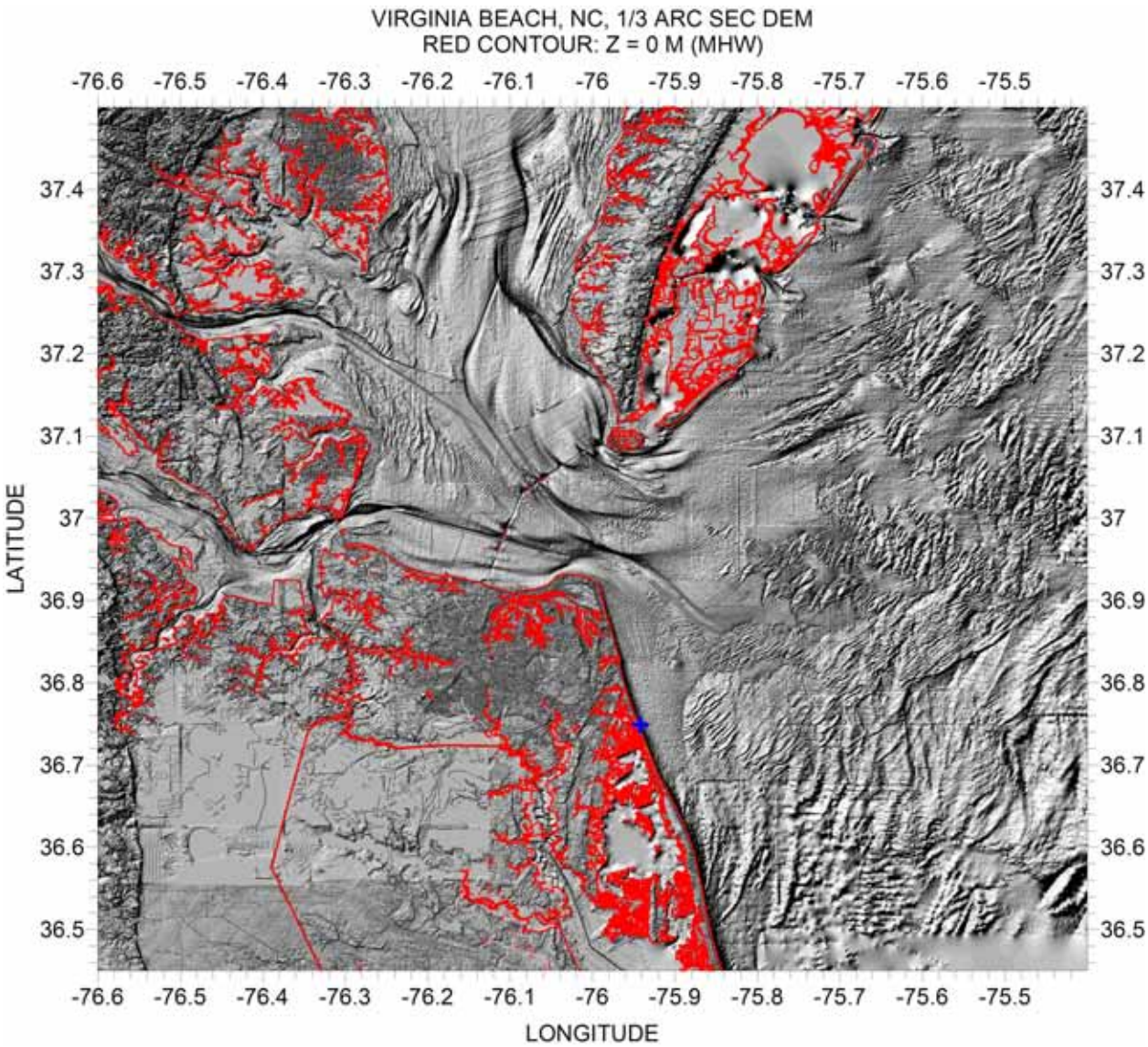

Figure 3 – Shaded relief plot of DEM. Blue cross marks the location of the Warning Point (WP). Note the deep and narrow channels that lead to Chesapeake Bay and east of Delmarva Peninsula. Also note the narrow channel below the bridge shown as Hwy 13 in Figure 1. The z = 0 elevation contour (MHW) is shown in red.

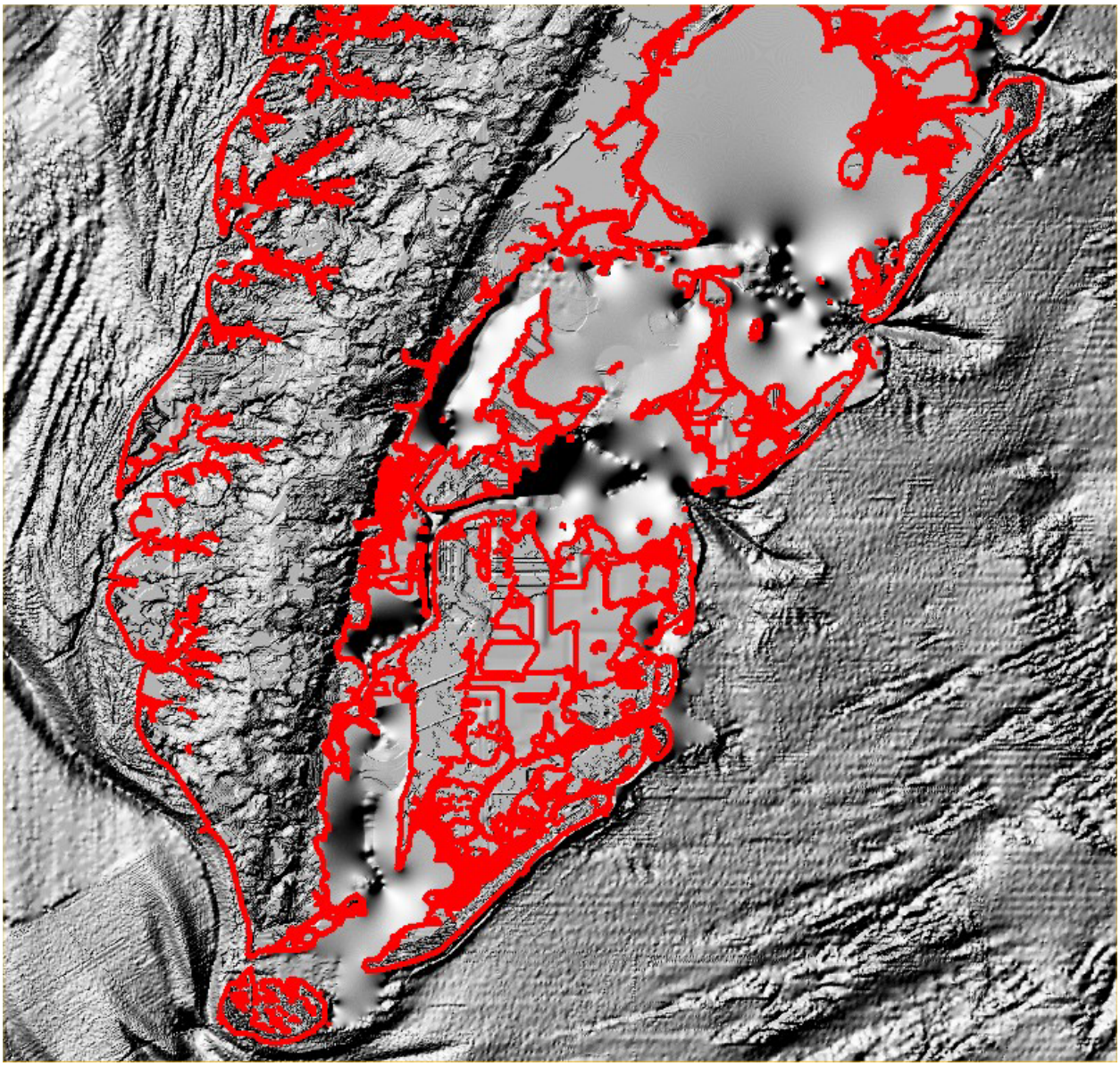

Figure 4 – Zoom of the Delmarva Peninsula. The z = 0 elevation contour (MHW) is shown in red.

re-grid the NGDC DEM from 1/3 sec to 12 sec using the function interp2 with linear interpolation.

The first attempts to run MOST for the reference run was made using 0 as the "Minimum Depth for Offshore" (MDO from now on), that is, the location of the perfectly reflecting wall was placed at the MHW line, while allowing runup to occur at both grids A and B. For the first attempt the input bathymetry/topography file was passed through BATHCORR.F with 0 for the wave height, 0 for the depth up to which to smooth (and this value was kept like this for all BATHCORR.F runs, so it won't mentioned anymore), and a value of 1 for the Steepness parameter (SP). And MOST blew up as soon as the tsunami wave penetrated through the channels in the tidal flats east of the Delmarva Peninsula. So BATHCORR.F was again applied with SP = 0.6, and the problem persisted at the same location. BATHCORR.F was again applied, now with SP = 0.5, and the problem persisted. The data was again passed through BATHCORR.F, but with SP = 0.3, and the problem persisted.

So the data (the one coming out after using BATHCORR.F with SP = 0.3) was next smoothed with a 3x3 Gaussian low-pass filter, by means of a Surfer (Golden Software; Grid → Filter) script which applied the Gaussian to just the bathymetry. The Gaussian weights were was as follows (and they were kept like this for all smoothing attempts):

TABLE 1: Low-pass Gaussian Weights

1	2	1
2	4	2
1	2	1

The Gaussian was passed through the whole bathymetry values, but just one pass (one can apply as many passes as one wants). The problem persisted at the same location.

So a fresh start was made in which the 12 s resolution non-corrected data was passed through BATHCORR.F with wave height = 0, and SP = 0.5, and then filtered with the Gaussian just in the problematic area alone. Another Surfer script was made in which one gives the coordinates of the corners of the rectangle inside of which one wants the filter to be applied, and one also supplies how many passes to apply within that rectangle (call it rectangle 1). One also supplies to the program the coordinates defining a slightly larger rectangle (call it rectangle 2) in which the filter is passed a smaller amount of times than inside the first rectangle. This second, and larger, rectangle serves as a transition area that smoothly merges the filtered data inside the first rectangle to the unfiltered data outside the second rectangle. This helps in not producing discontinuities in depth between rectangle 1 and the area outside rectangle 2. Inside rectangle 1 the Gaussian was passed twice, while inside rectangle 2 it was passed only once. It should be emphasized that if land values fall inside the rectangles, these are not smoothed.

After this was done the output was passed through BATHCORR.F with wave height = 0, and SP = 0.5. Another attempt was made with this version of Grid A, and now it did run longer than with the previous version, but now the instability moved the southern end of the grid, somewhere between the location of the Warning Point (WP) and the south boundary of the grid. And it occurred very close to the MHW shoreline. So the grid (A) was again passed through

BATHCORR.F with wave height = 0, and SP = 0.3, and the output was passed once more through the Gaussian filter (the whole grid, but just the bathymetry), and again supplied to MOST. And the problem at the new location still persisted.

In the next attempt I took the grid prior to the last pass through the Gaussian filter (which, as described in the above paragraph, was applied to all of the bathymetry), and now the Gaussian was applied to just the southern part of the bathymetry, since this is where the new problem was arising. And it still blew out. I should add that the problem, right from the first blow outs, manifested itself in that apparently the wave height became infinite at some point and time, since the string "Inf" appeared written near the bottom of the *.lis output. And this change in height went directly from values smaller than 0.5 m. That is, in the movies you could see the tsunami arriving with height less than 0.5 m, and right away it went to "Inf" in the following snapshot, with no 'ringing" effect that one could notice before the blow up.

I should also add that whenever a grid is smoothed a check is made that no discontinuities are generated at the boundaries with the "parent" grid (the immediately outer grid). This is checked with grid B also (its boundary with Grid C and Grid A).

So the last version of Grid A was again passed through BATHCORR.F, but now with wave height = 0.5, and SP = 0.3, and additional values (relative to when wave height = 0) were corrected by BATHCORR.F (I should also recall that whenever BATHCORR.F is used the output is again passed through it again until no depth values are corrected). So where no changes were made with wave height = 0, new changes came out with wave height = 0.5. But the problem still persisted.

Again, I started from "square one" by taking the uncorrected grid and passing it through BATHCORR.F with wave height = 0.5, and SP = 0.3, but the problem still persisted. At this point, since the instability was occurring near shore at the southern end of Grid A, I decided to change the MDO value from 0 to 5, and the problem disappeared. So next I reduced MDO to 1, and the problem did not appear. That is, the program did run the 10 hours of simulation I had given it.

Since having MDO = 1 solved the problem, and since the goal is to have the model run with bathymetry as close to the original (unsmoothed, or not corrected) as possible, I took the uncorrected, 12 sec resolution, grid A data, passed it through BATHCORR.F with wave height = 0.5, but with SP =1 (no smoothing), and supplied the output to MOST, now with MDO = 1. And it did run, and so this was finally used as my reference Grid A. Table 2 gives some basic statistics of the Reference Grid A, including the maximum time step, Δt_A, in seconds for the grid as given by BATHCORR.F.

TABLE 2

Grid Information: Reference Grid A 12 s

Grid File Name:	Grid_A_reference_12s_MOST_v7.grd
Grid Size:	316 rows x 361 columns
Total Nodes:	114076

Grid Geometry	
X Minimum:	-76.600046296295
X Maximum:	-75.400046329895
X Spacing:	0.0033333332399999 = 12 arc sec ≈ 360 m
Y Minimum:	36.449953719105
Y Maximum:	37.499953689705
Y Spacing:	0.00333333324 = 12 arc sec ≈ 360 m
Grid Statistics	
Z Minimum:	-44.48
Z Maximum:	35.2025
Δt_A = 14.147 s	

Figure 5 shows a surface plot of Reference Grid A. The figure also shows the rectangles outlining the finally adopted Reference Grids B and C. To see how the final Reference 12 s Grid A differs from the uncorrected 12 s Grid A, Figure 6 shows a plot where a contour plot of the final Reference 12 s Grid A (red contours) is overlaid over a contour plot of the uncorrected 12 s Grid A (black contours). The MHW shoreline for both is shown as a thicker contour. We can see that the changes are minimal and are located where the bathymetry is very irregular (to be noticed where the black contours do not coincide with the red contours).

Grid B:

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 possible. Figure 5 shows the outline of the Reference Grid B. Based on previous work, it was chosen to have a grid cell size of 6 arc seconds.

The way the 6 s Reference Grid B was prepared is as follows. The 1/3 s DEM was reduced in size (re-gridded to a resolution of 6 s ≈ 180 m) with regrid_ngdc.m using Matlab. Then it was cropped to the desired size using Surfer's Grid → Extract function. In the same way as for Reference Grid A, several attempts were made with BATHCORR.F using wave height = 0, and different SP values. The final version used was the outcome of SP = 0.6. This grid never gave any problem. Figure 7 shows a surface plot of the final Reference 6 s Grid B. Table 3 gives some basic statistics of Reference Grid B, including the maximum time step based on the CFL condition.

TABLE 3

Grid Information: Reference Grid B 6 s

Grid File Name:	Grid_B_reference_6s_MOST_v2.grd
Grid Size:	481 rows x 481 columns
Total Nodes:	231361
Grid Geometry	
X Minimum:	-76.4
X Maximum:	-75.6
X Spacing:	0.0016666666666666 = 6 arc sec ≈ 180 m

Y Minimum:	36.5
Y Maximum:	37.3
Y Spacing:	0.0016666666666667 = 6 arc sec ≈ 180 m
Grid Statistics	
Z Minimum:	-46.93
Z Maximum:	18.4652
Δt_B = 6.88 s	

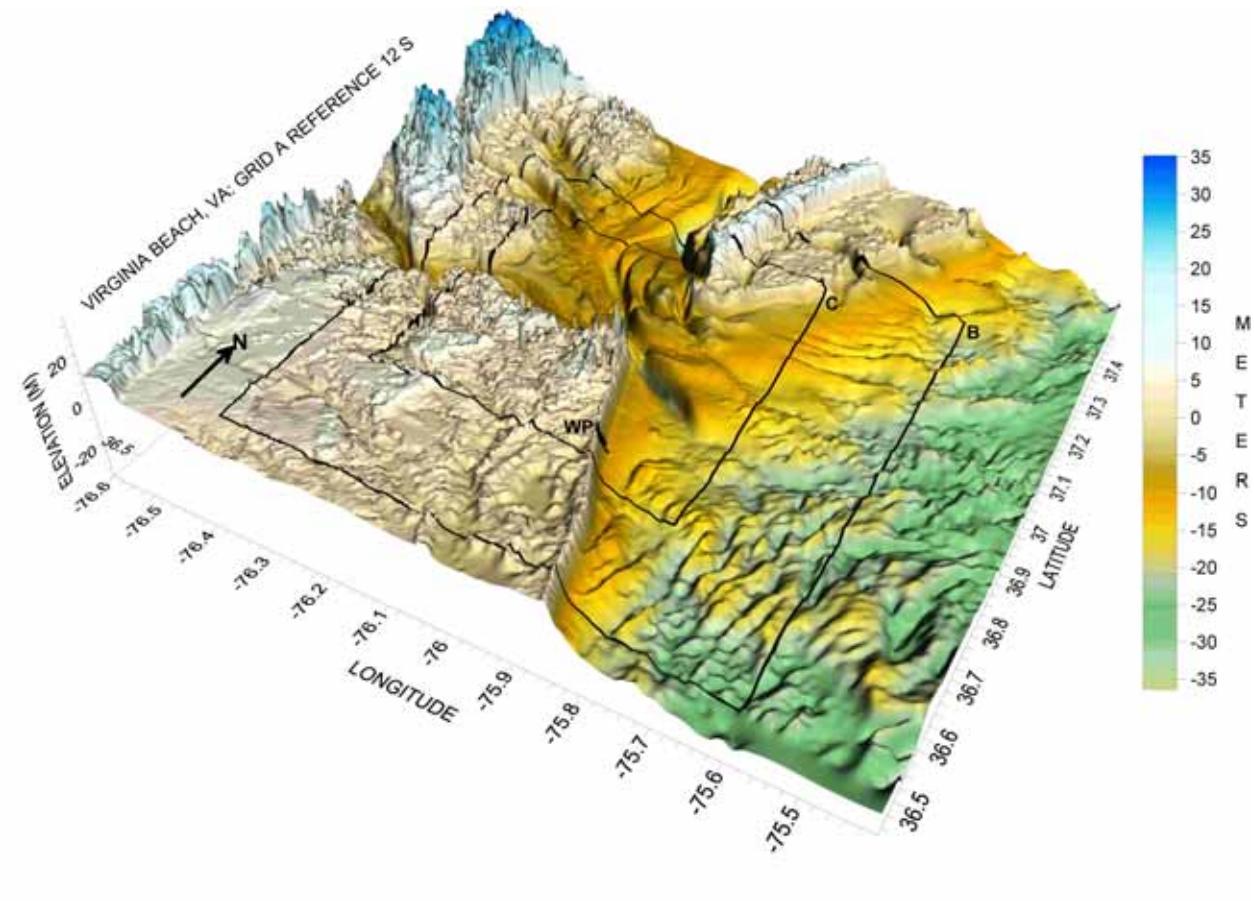

Figure 5 – Surface plot of Reference Grid A 12 s, looking from the SE. The outline of the finally adopted Reference Grids B and C are also shown.

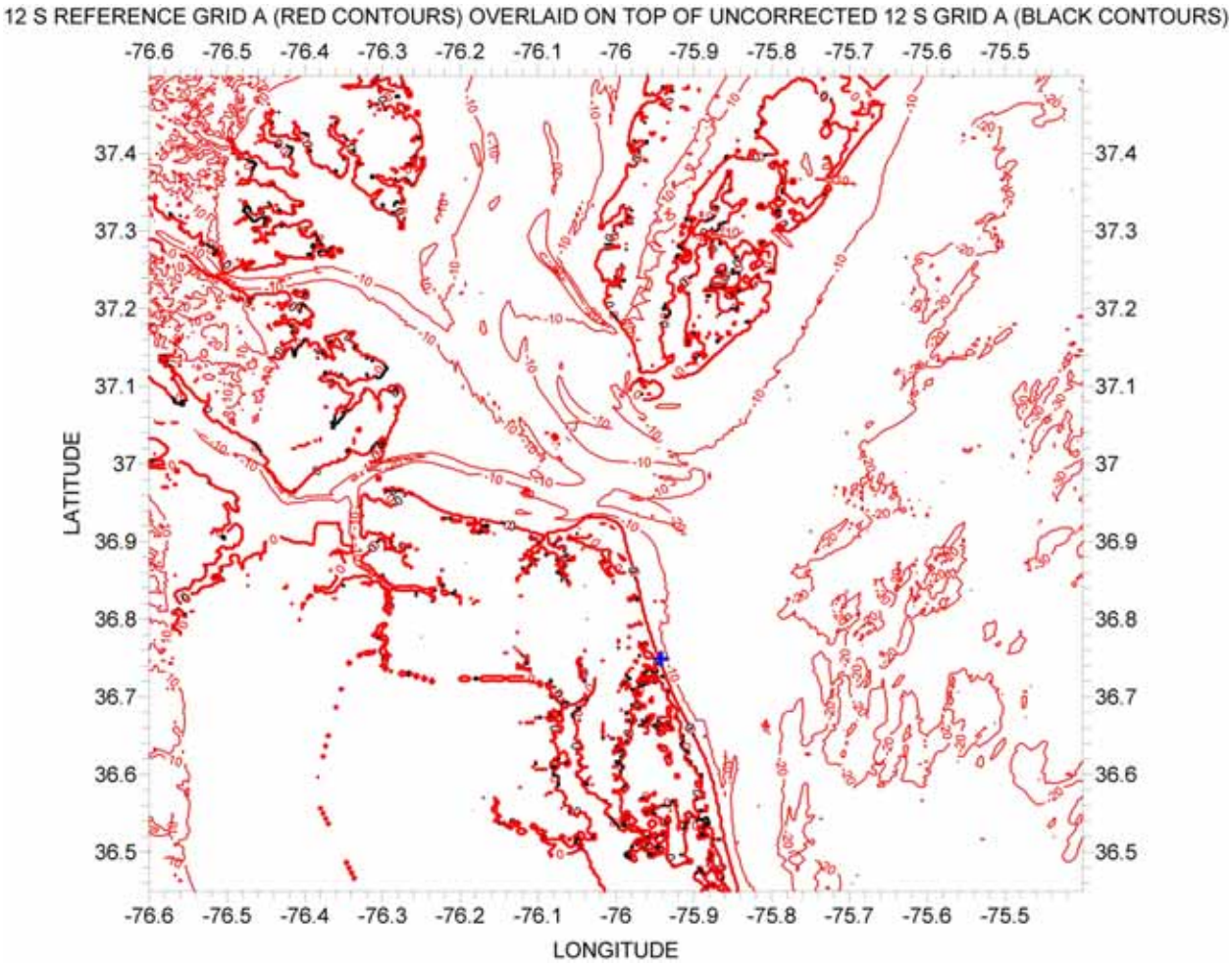

Figure 6 – Comparison of 12 s uncorrected (as obtained from the re-gridding of the original DEM) grid A (black contours) versus the finally adopted Reference 12 s Grid A (red contours). The MHW contour line is shown as a thicker contour for both.

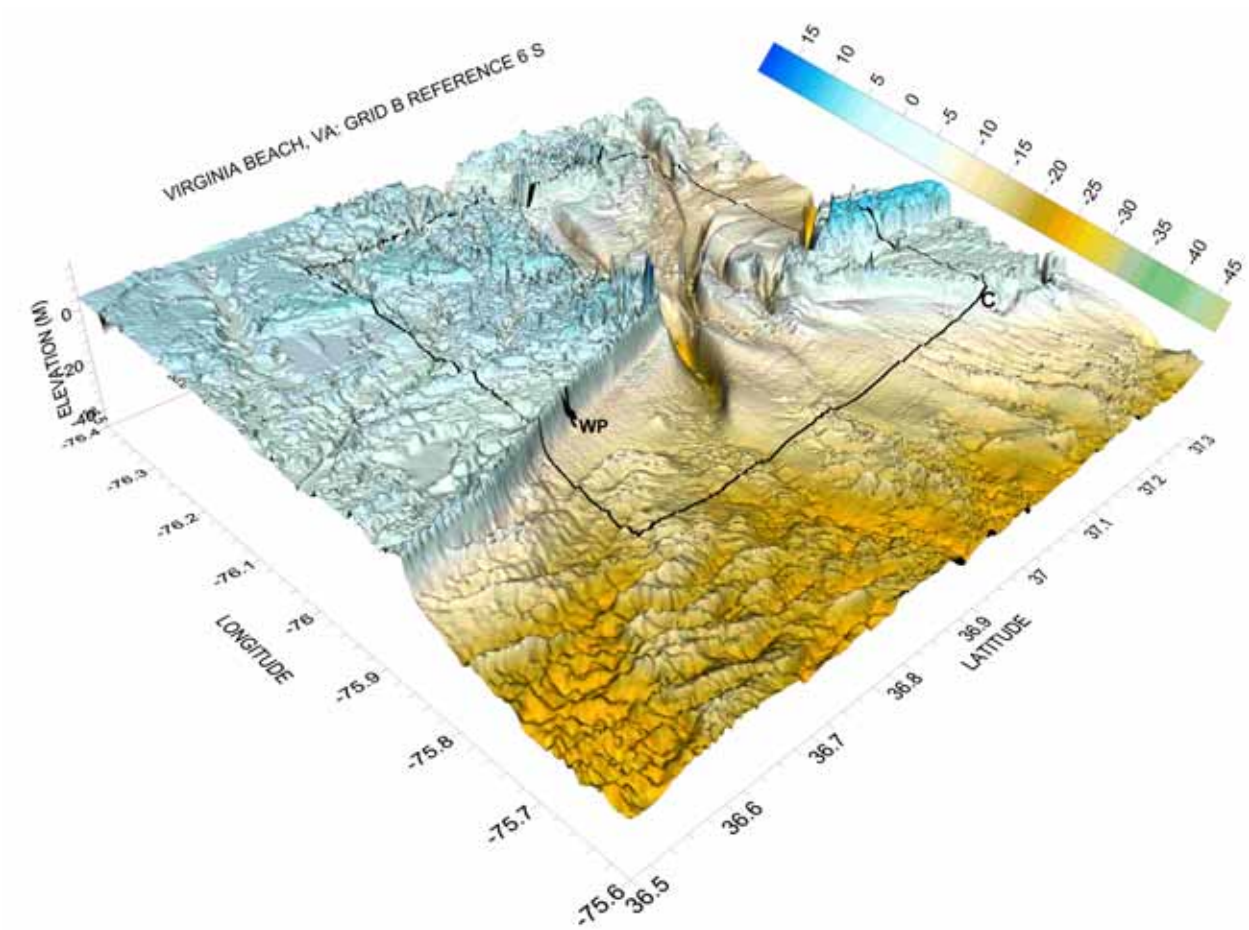

Figure 7 – Surface plot of the finally adopted Reference 6 s Grid B, looking from the SE. The outline of the finally adopted Reference Grid C is also shown.

Figure 8 shows a plot where a contour plot of the final Reference 6 s Grid B (red contours) is overlaid over a contour plot of the uncorrected 6 s Grid B (black contours). The MHW shoreline for both is shown as a thicker contour. As for grid A, we can see that the changes are minimal and are located where the bathymetry is very irregular.

Grid C:

The reference Grid C was chosen to be as large as possible for the reason explained above fro Grid B. Based on previous work, the cell size adopted for Reference Grid C was 1 arc sec. And based on the population information shown in Figure 1, and the location of the WP, its area coverage was chosen as shown in Figure 5. Again, using regrid_ngdc.m the 1/3 sec DEM was re-interpolated to 1 arc sec, and Surfer was used for cropping to the desired size and location.

In the attempts to obtain running versions of the Reference Grids it was noticed that, while MOST never blew out in Grid C, the results right from the beginning were unrealistic. Right from the first movie snapshot (see Figures 9 and 10) wave heights up to 2 m were seen right on top of the steeply sloped entrance channels to Chesapeake Bay before the first tsunami wave crest had even entered Grid A. One could actually delineate the location of the channels, and the bridge, by looking at the first few snapshots. And as time evolved the wave evolution looked very unrealistic. Actually, after a certain time step the maximum and minimum wave heights over the whole grid ranged consistently between 2 – 3 m down to -2 to -3 m, at all snapshots. It was obvious that the model was unstable, but it never blew up. So it was obvious that the problem was the steep sides of the channels.

BATHCORR.F was used to try to smooth out these channels, using wave height = 0.5, and SP = 0.3, but the problem still persisted. I did not try to use BATHCORR.F with smaller values of SP since it is not clear to me what the program does to the bathymetry. And I remember that in the Puerto Rico Grid A it created a notch right at the shelf break just south of southwestern Puerto Rico. So, after passing the data through BATHCORR.F with SP = 0.3, the output was passed through the Gaussian Surfer filter (1 pass – all of the bathymetry), and given to MOST. It continued with the unrealistic results. So the output was again passed again through the Gaussian, with 4 passes (which in addition to the 1st pass, implies a total of 5 passes). The problem still persisted. Ten additional passes were applied (a total of 15), and the problem still persisted. Finally, after 20 additional passes (a total of 35 passes) the problem disappeared. The resulting data was again passed though BATHCORR.F, but with SP = 1 and only 1 point was modified. Figure11 shows a surface plot of the final Reference 1 s Grid C. Table 4 gives some basic statistics of Reference Grid C, including the maximum time step based on the CFL condition.

A look at Figure 11 shows the presence a row of alongshore “spikes” very close to the MHW line, which is not clear to me what they represent, but they obviously present an impediment to inland flooding even for a tsunami signal 3-4 meters high. This can be better seen in Figure 12. A contour plot of a small area (see Figure 13) shows the alongshore features in closer detail. Slices 1 and 2, taken across the grid are shown in Figure 14. Are these real topographic features (sand dunes?); vegetation?; or beach houses on stilts?, is unknown to me.

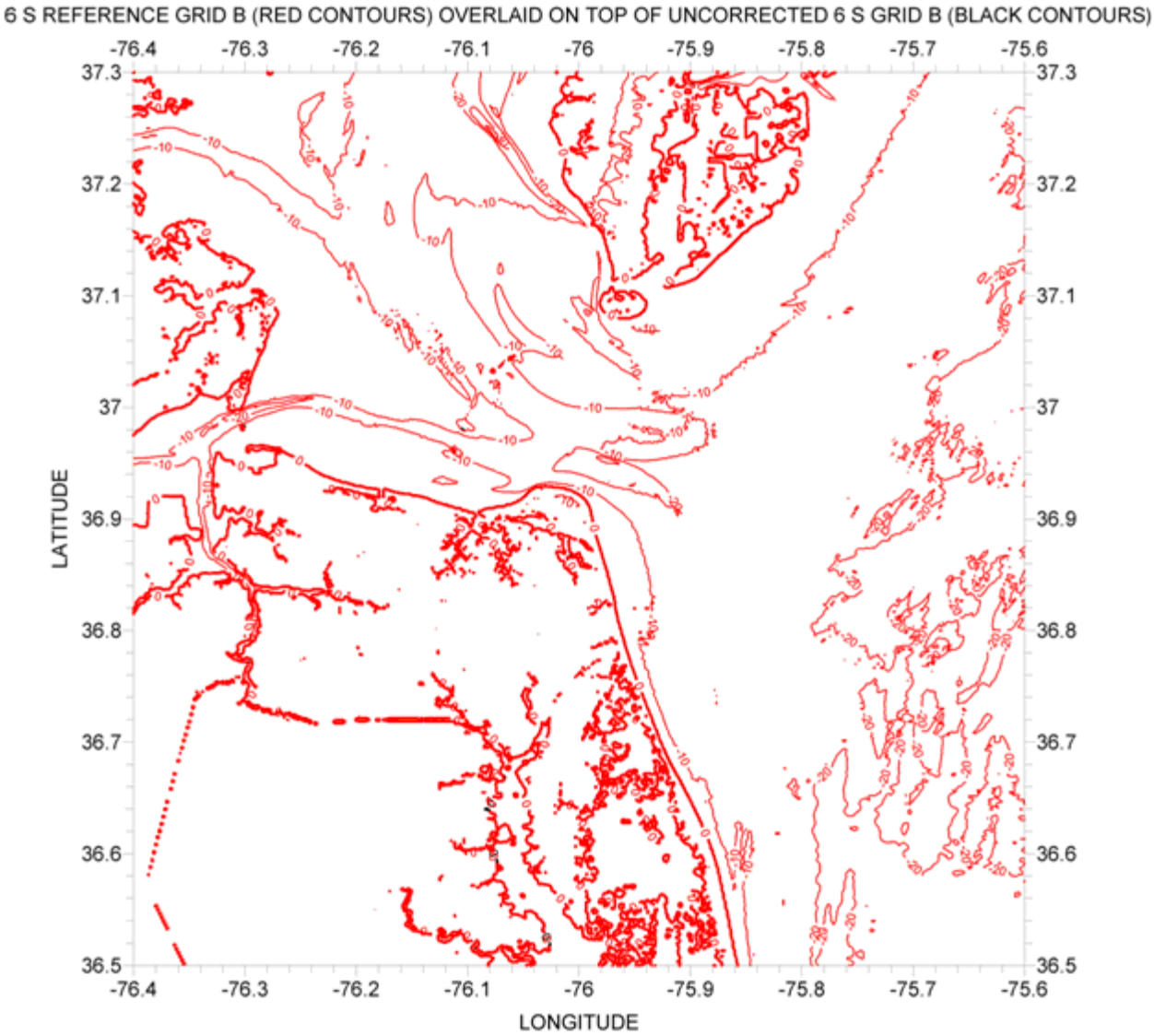

Figure 8 – Comparison of 6 s uncorrected (as obtained from the re-gridding of the original DEM) grid B (black contours) versus the finally adopted Reference 6 s Grid B (red contours). The MHW contour line is shown as a thicker contour for both.

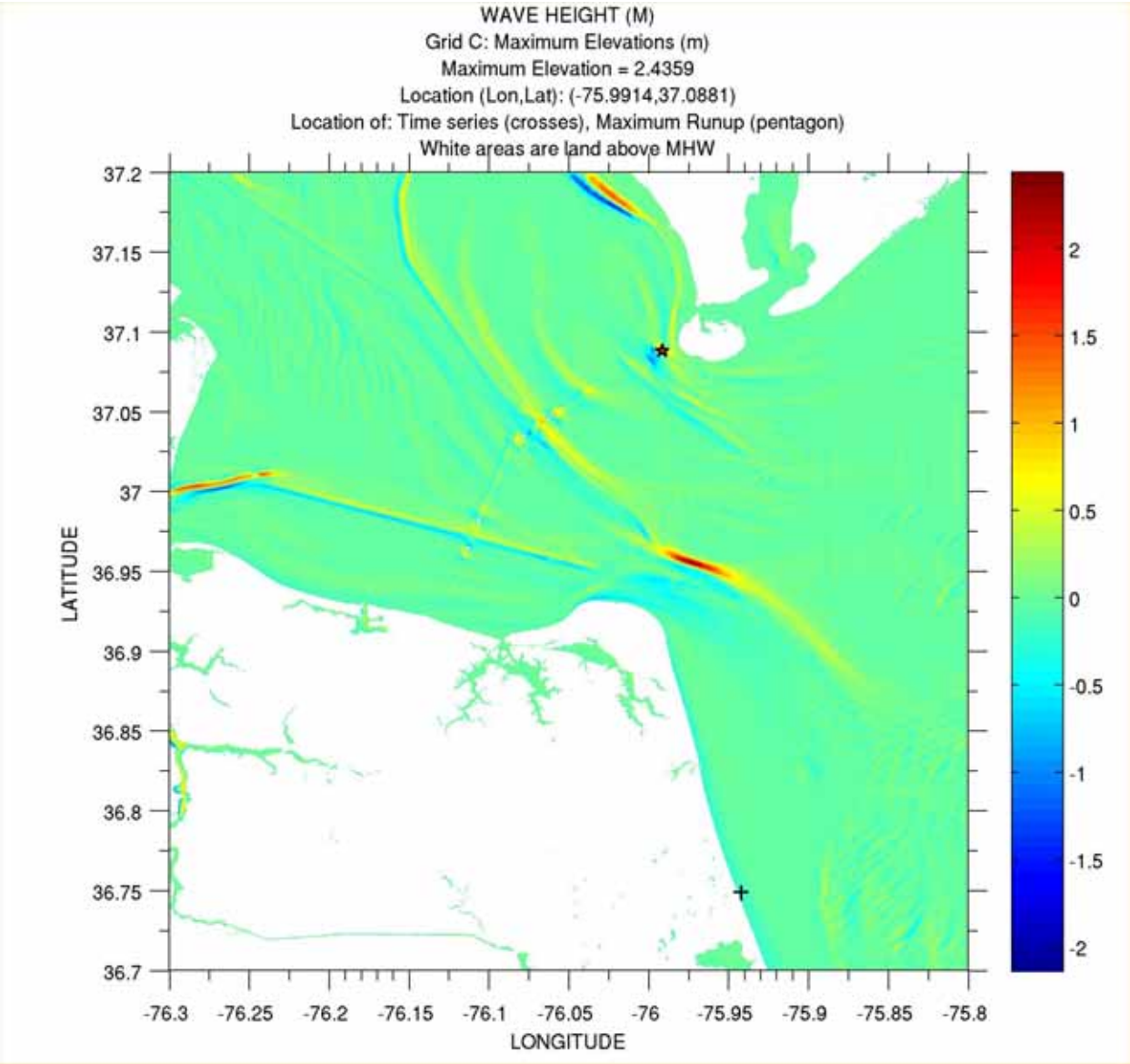

Figure 9 – Snapshot 1 for reference 1 s Grid C showing instabilities occurring right at the beginning of the computations in Grid C apparently due to the steep and narrow channels appearing in the grid. This was solved after several smoothing attempts. The instabilities are formed right on top of the channels, including the bridge crossing the entrance to the Bay, shown in Figures 2 and 3.

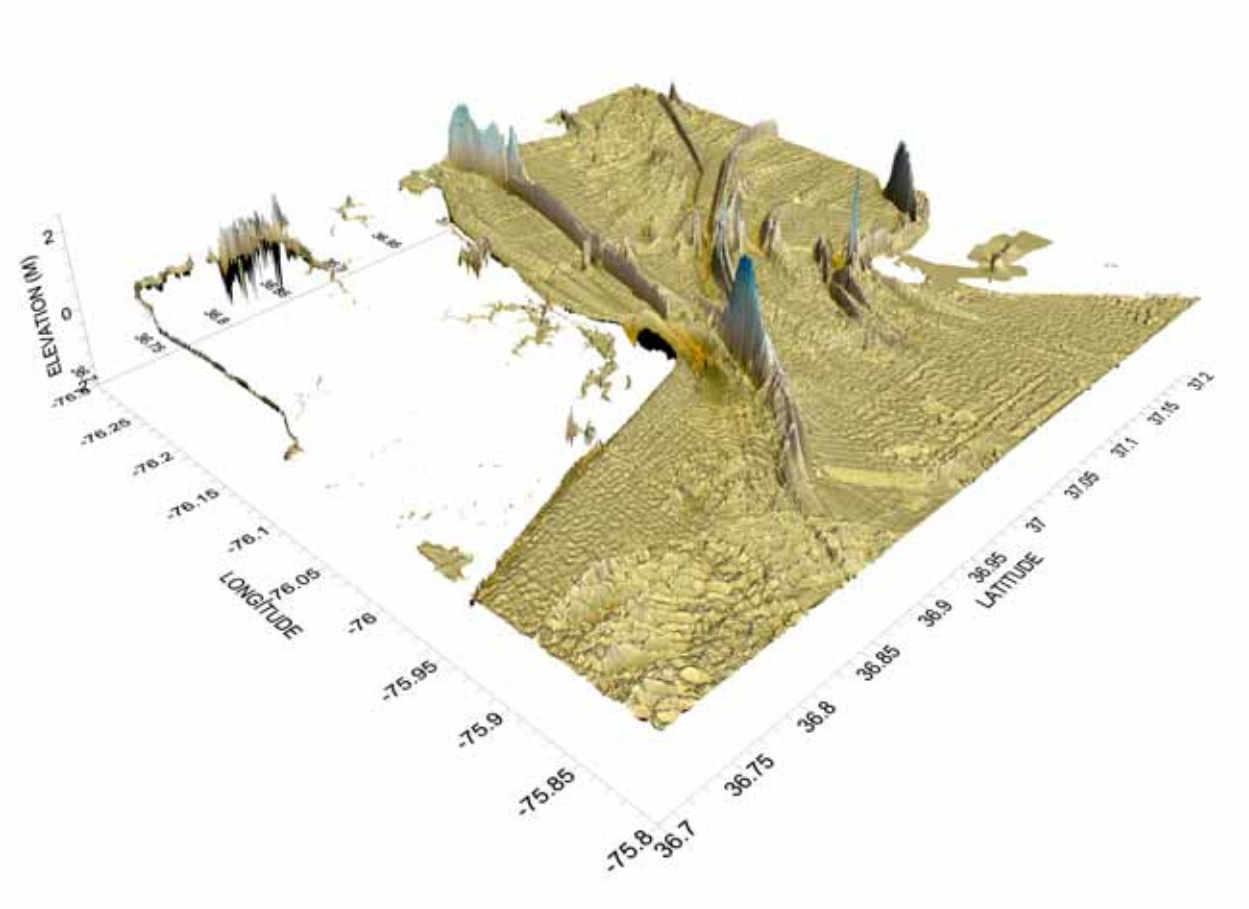

Figure 10 – Another view of the instabilities in Grid C.

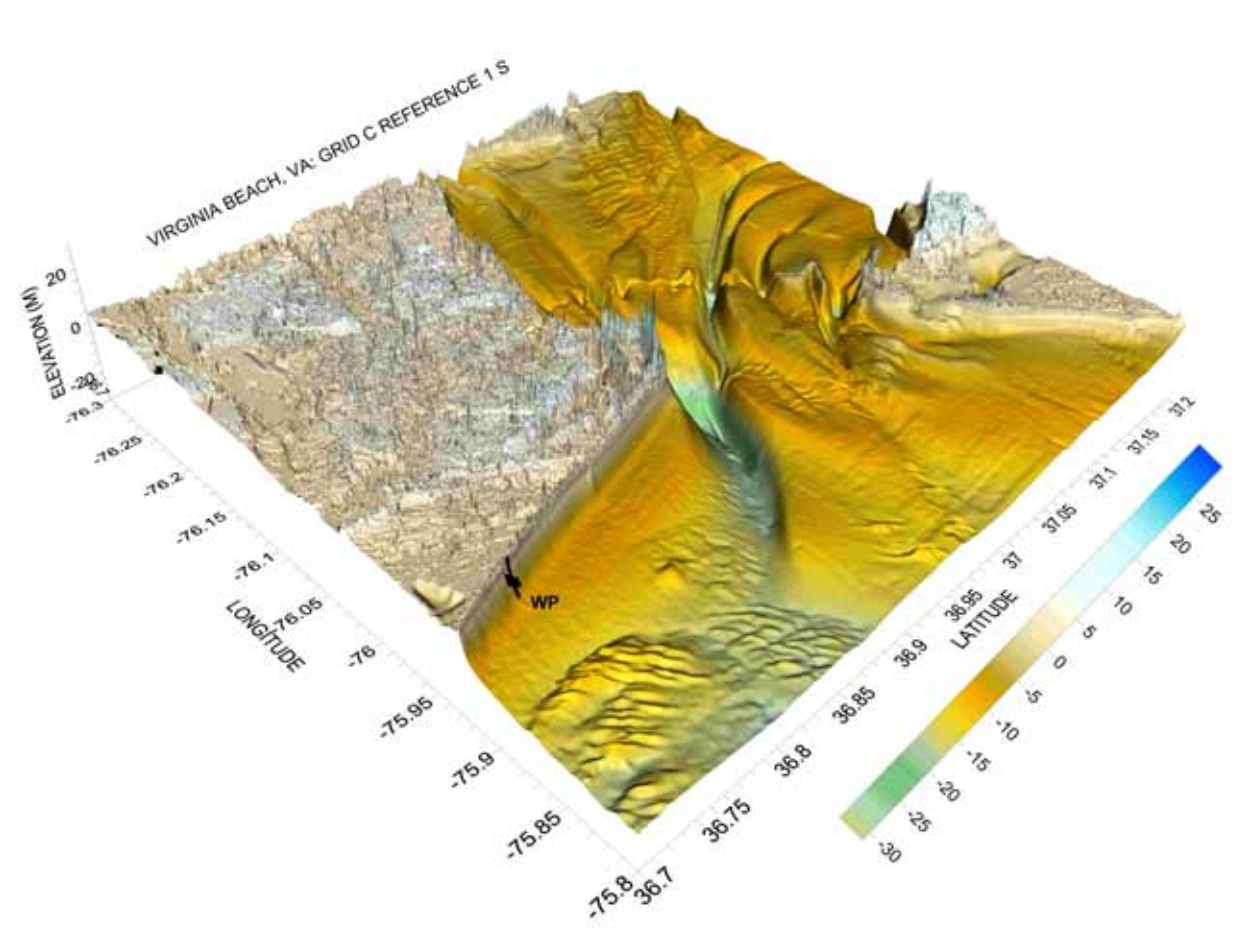

Figure 11 – Surface plot of the finally adopted Reference 1 s Grid C, looking from the SE. Even though this grid was low-pass filtered, the presence of the steeply sloping channels can still be seen.

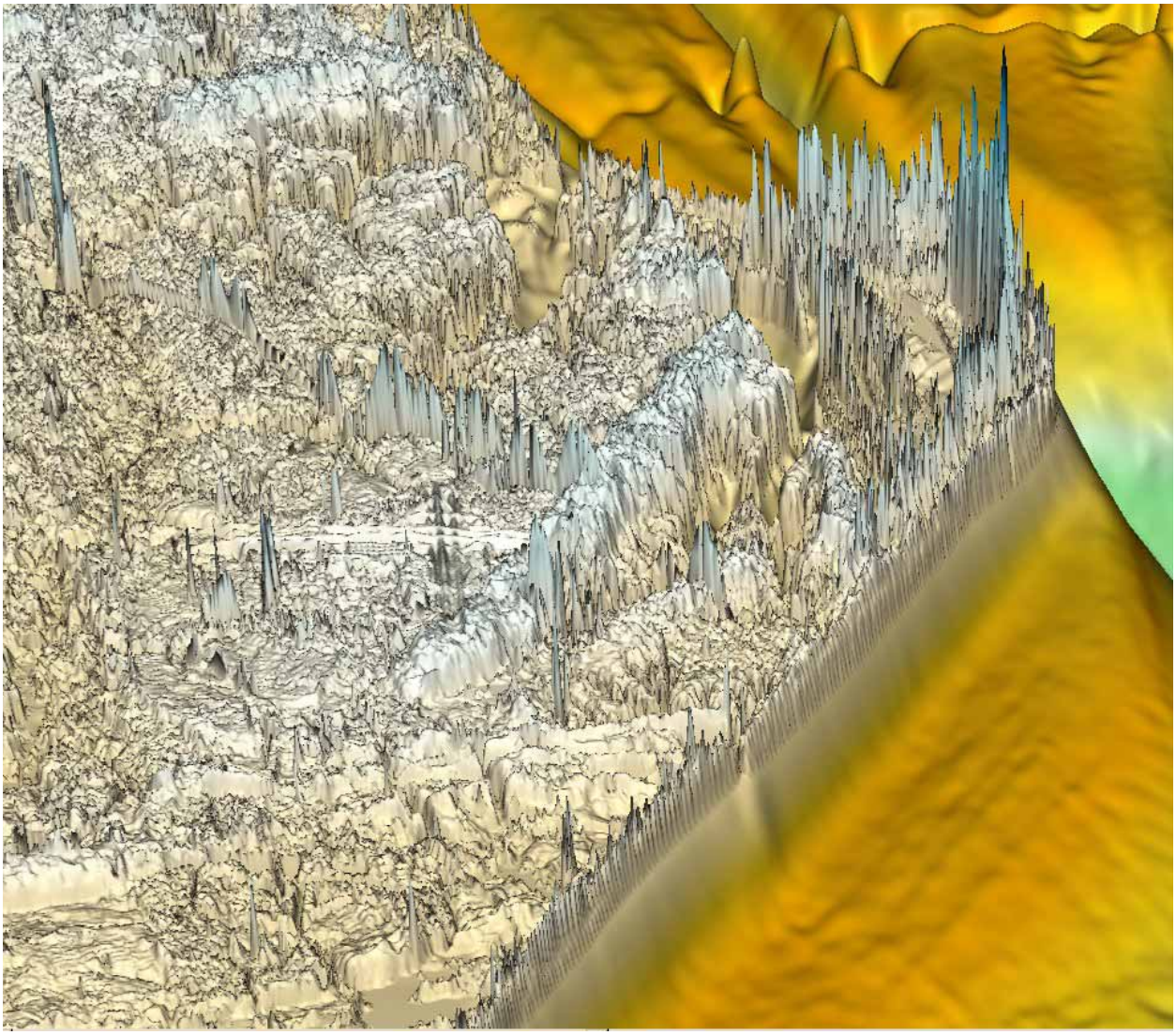
Figure 12 – Zoom in showing the presence of a “spiky” seawall.

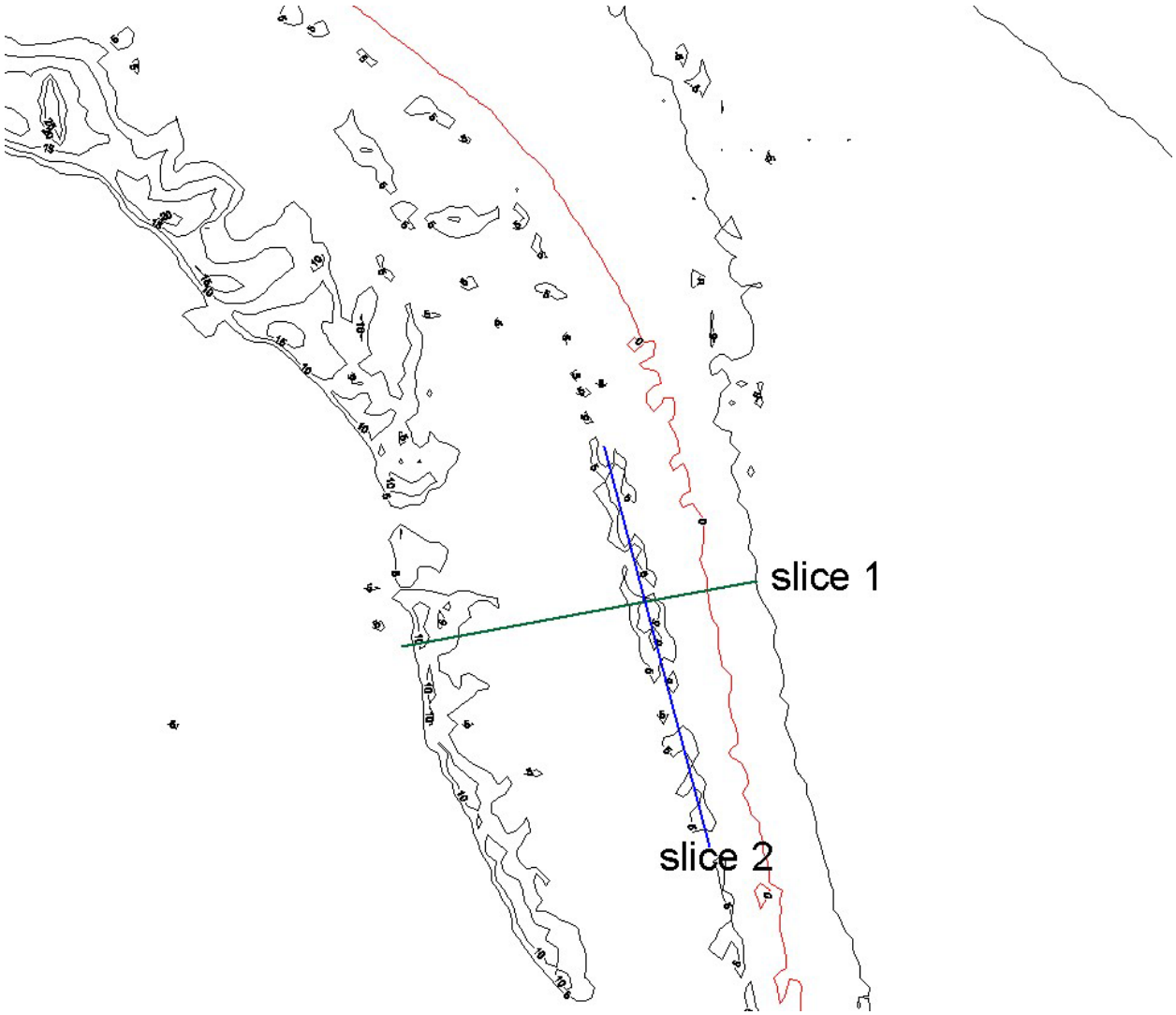

Figure 13 – Contour plot of a section of the nearshore topography, and the location of two slices taken across the topography. Red contour is z = 0 (MHW line).

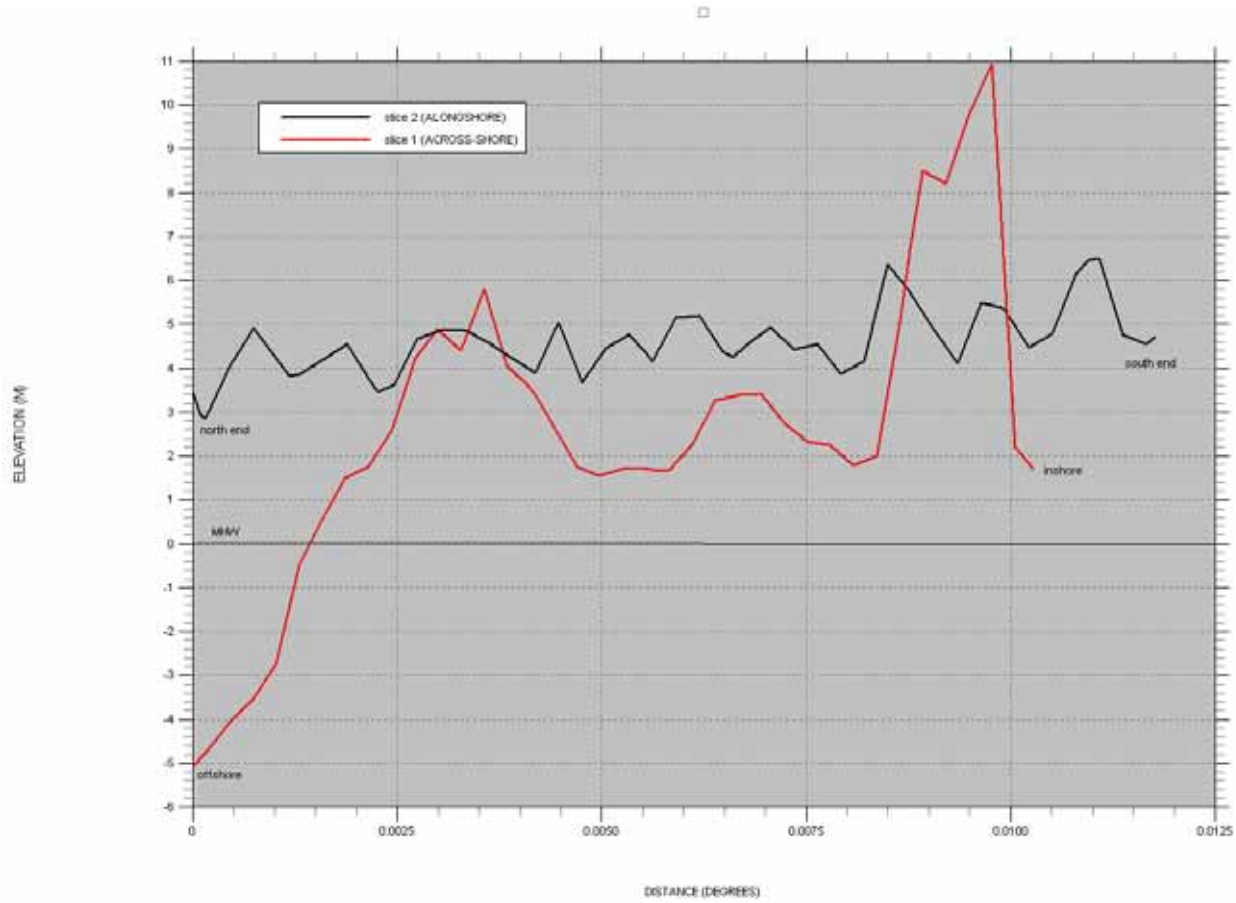

Figure 14 – Topographic variation along the two slices shown in Figure 12.

TABLE 4	
Grid Information: Reference Grid C 1 s	
Grid File Name: Grid_C_reference_1s_MOST_v7.grd	
Grid Size:	1801 rows x 1801 columns
Total Nodes:	3243601
X Minimum:	-76.3
X Maximum:	-75.8
X Spacing:	0.00027777777777778 = 1 arc sec ≈ 30 m
Y Minimum:	36.7
Y Maximum:	37.2
Y Spacing:	0.00027777777777778 = 1 arc sec ≈ 30 m
Grid Statistics	
Z Minimum:	-31.2766
Z Maximum:	29.8783
Δt_C = 1.41 s	

Figure 15 shows a plot where a contour plot of the final Reference 1 s Grid C (red contours) is overlaid over a contour plot of the uncorrected 1 s Grid C (black contours). The MHW shoreline for both is shown as a thicker contour. As for grids A and B, we can see that the changes are minimal and are located where the bathymetry is very irregular. The figure shows that red contours are less 'noisy' than the black contours.

Finally, Figure 16 shows a contour plot of the nested grids, showing that the pre-processing has not introduced significant depth discontinuities along the grid boundaries.

3. OPTIMIZED GRIDS

Once the above discussed problems in the different reference grids were taken care off, the preparation of the optimized grids went smoothly. And as before, in the attempt to get the optimized grids I was guided by the previous work done in Puerto Rico, where the optimized grids came out with 70,146 (A: San Juan and Mayaguez), 31,275 (B: Mayaguez), 16,986 (B: San Juan), 16,422 (C: Mayaguez), and 33,740 (C: Mayaguez) computational cells. And the resolutions were: A (24 s for both Mayaguez and San Juan), B (8 s for both Mayaguez and San Juan), and C (3 s for both Mayaguez and San Juan).

Grid A:

The Reference 12 s Grid A was passed through Surfer → Extract in order to regrid it from 12 s resolution to 24 s resolution. 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). The Optimized 24 s Grid A came out with 180 columns and 158 rows. The output was passed through BATHCORR.F with wave

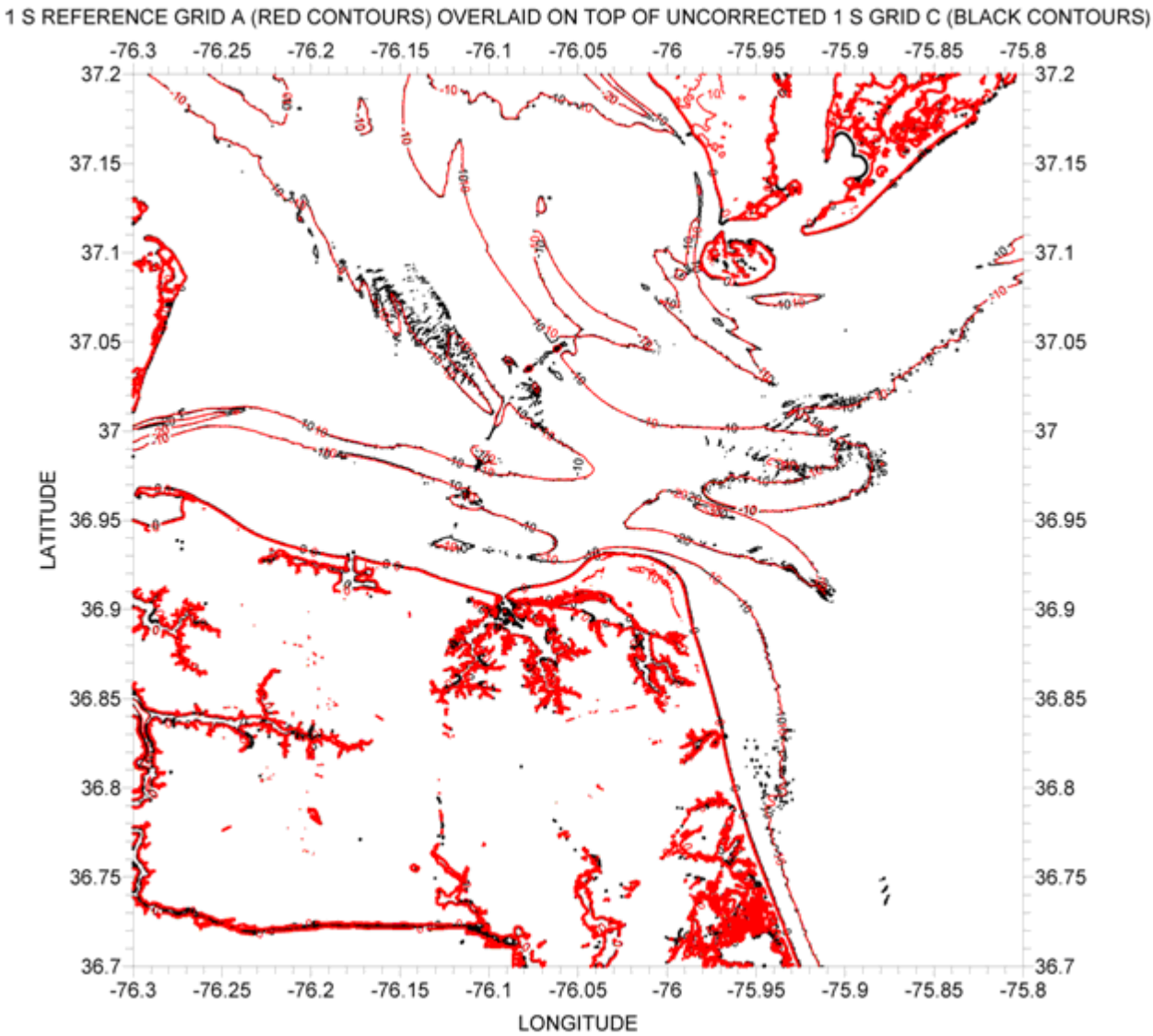

Figure 15– Comparison of 1 s uncorrected (as obtained from the re-gridding of the original DEM) grid C (black contours) versus the finally adopted Reference1 s Grid C (red contours). The MHW contour line is shown as a thicker contour for both. Note that the "noise" in the black contours has been decreased drastically.

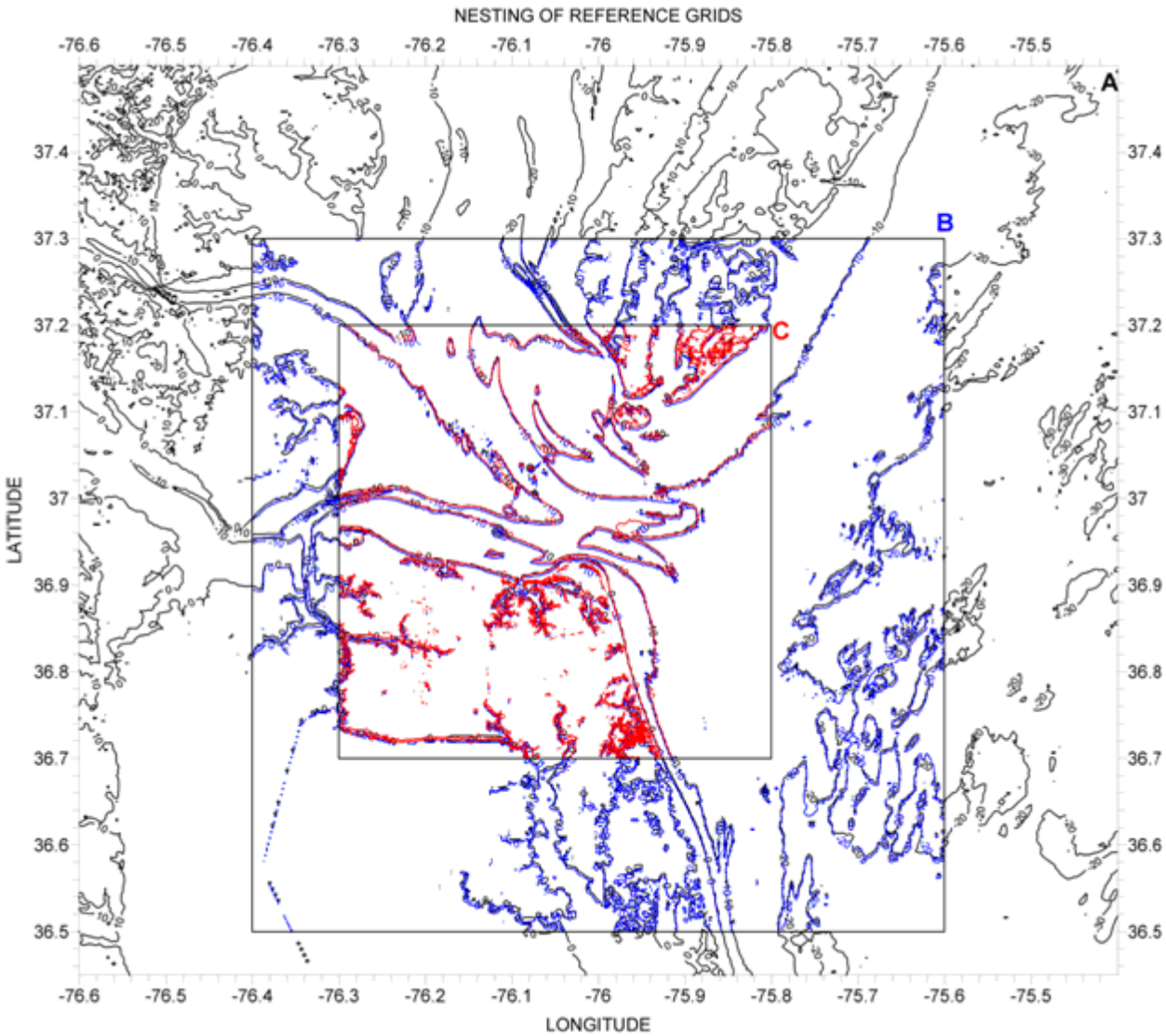

Figure 16 – Nesting of reference grids. Grids C (red) on top of Grid B (blue), and Grid B on top of Grid A (black). This is to show the absence of depth discontinuities along the grid boundaries.

height = 0.5, and SP = 1, through two iterations. Table 5 gives some basic statistics of Optimized 24 s Grid A, including the maximum time step based on the CFL condition.

TABLE 5

Grid Information: Optimized Grid A 24 s

Grid File Name: Grid_A_opt_24s_v2.grd	
Grid Size:	158 rows x 180 columns
Total Nodes:	28440
Grid Geometry	
X Minimum:	-76.600046296295
X Maximum:	-75.400046329895
X Spacing:	0.0067039104268154 = 24 arc sec ≈ 720 m
Y Minimum:	36.449953719105
Y Maximum:	37.499953689705
Y Spacing:	0.0066878979019109 = 24 arc sec ≈ 720 m
Grid Statistics	
Z Minimum:	-35.134
Z Maximum:	35.2859
Δt_A = 32.013 s	

Figure 17 shows a surface plot of Optimized 24 s Grid A, and the outline of the finally adopted Optimized Grids B and C.

Grid B:

The Reference 6 s 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 and the west boundary was moved eastward (cropping of the grid along its west boundary) until the number of columns came to 252. The eastern boundary was left the same as for the Reference 6 s Grid B. Next the northern boundary was moved south and southern boundary was moved north, until the number of rows came down to 226, a total of 44,856 nodes. The output was passed through BATHCORR.F with wave height = 0.5, and SP = 1, where only 1 point was corrected. Table 6 gives some basic statistics of Optimized 8 s Grid B, including the maximum time step based on the CFL condition.

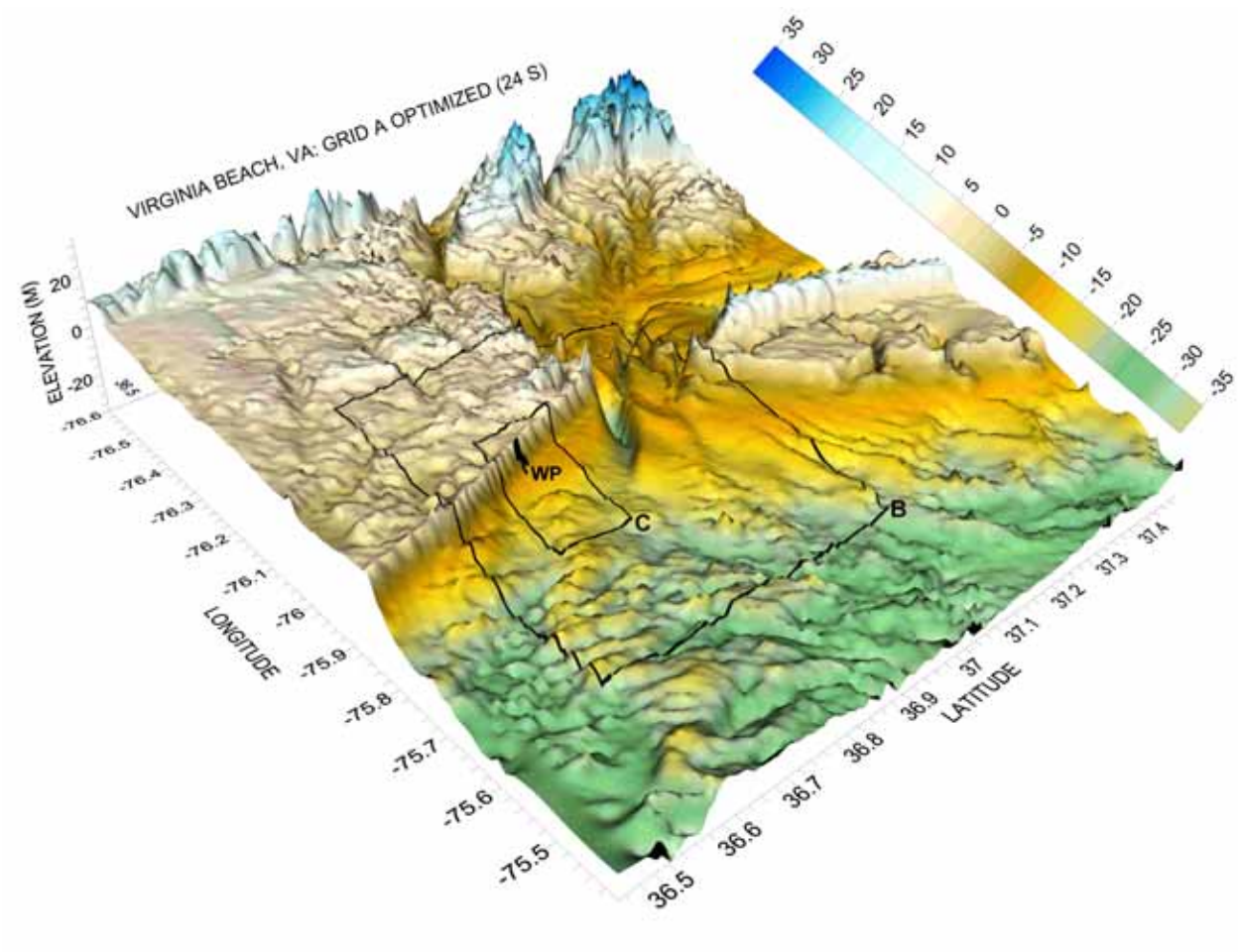

Figure 17– Surface plot of the finally adopted Optimized 24 s Grid A, looking from the SE.

TABLE 6	
Grid Information: Optimized Grid B 8 s	
Grid File Name: Grid_B_opt_8s_v1.grd	
Grid Size:	226 rows x 252 columns
Total Nodes:	56952
Grid Geometry	
X Minimum:	-76.157777777778
X Maximum:	-75.6
X Spacing:	0.0022222222222231 = 8 arc sec ≈ 240 m
Y Minimum:	36.6
Y Maximum:	37.1
Y Spacing:	0.0022222222222222 = 8 arc sec ≈ 240 m
Grid Statistics	
Z Minimum:	-31.856486361534
Z Maximum:	16.710823632545
Δt_B = 11.19 s	

Figure 18 shows a surface plot of Optimized 8 s Grid B, and the outline of the finally adopted Optimized Grid C.

Grid C:

The Reference 1 s Grid C was passed through Surfer → Extract in order to regrid it from 1 s resolution to 3 s resolution and then was cropped along its western and northern boundaries (that is, the eastern and southern boundaries were left as in the Reference 1s Grid C) until the number of columns came down to 215 and rows to 145, a total of 31,175 nodes. The output was passed through BATHCORR.F with wave height = 0.5 and SP = 1. Table 7 gives some basic statistics of Optimized 3 s Grid C, including the maximum time step based on the CFL condition.

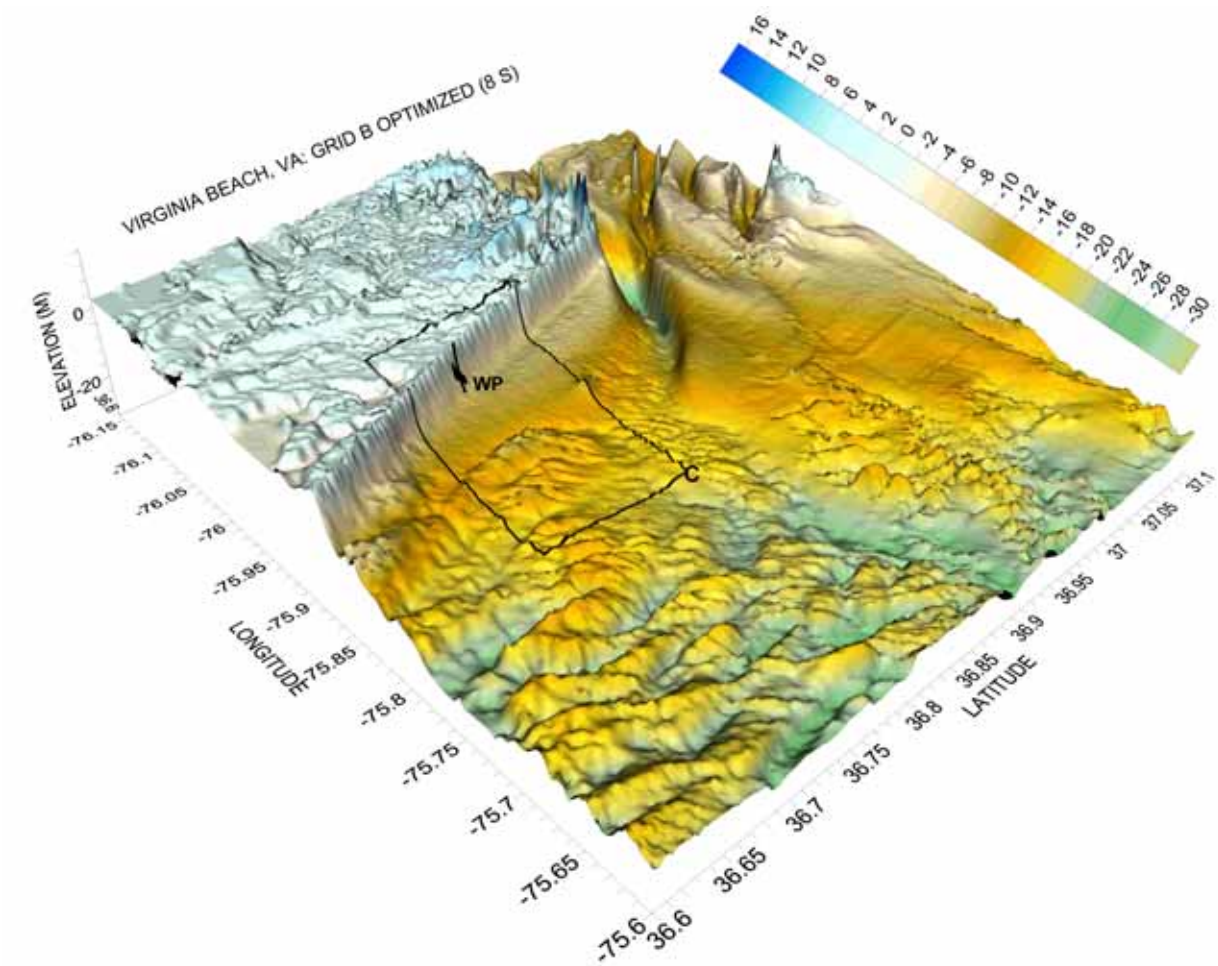

Figure 18– Surface plot of the finally adopted Optimized 8 s Grid B, looking from the SE. The outline of the finally adopted Optimized Grid C is also shown.

TABLE 7

Grid Information: Optimized Grid C 3 s

Grid File Name: Grid_C_opt_3s_v1.grd	
Grid Size:	145 rows x 215 columns
Total Nodes:	31175
Grid Geometry	
X Minimum:	-75.978631051753
X Maximum:	-75.8
X Spacing:	0.00083472454090187 = 3 arc sec ≈ 90 m
Y Minimum:	36.7
Y Maximum:	36.82020033389
Y Spacing:	0.00083472454090276 = 3 arc sec ≈ 90 m
Grid Statistics	
Z Minimum:	-19.541680952062
Z Maximum:	7.2068934454809
Δt_C = 5.38 s	

Figure 19 shows a surface plot of Optimized 3 s Grid C. Finally, Figure 20 shows a contour plot of the nested grids, showing that the pre-processing has not introduced significant depth discontinuities along the grid boundaries.

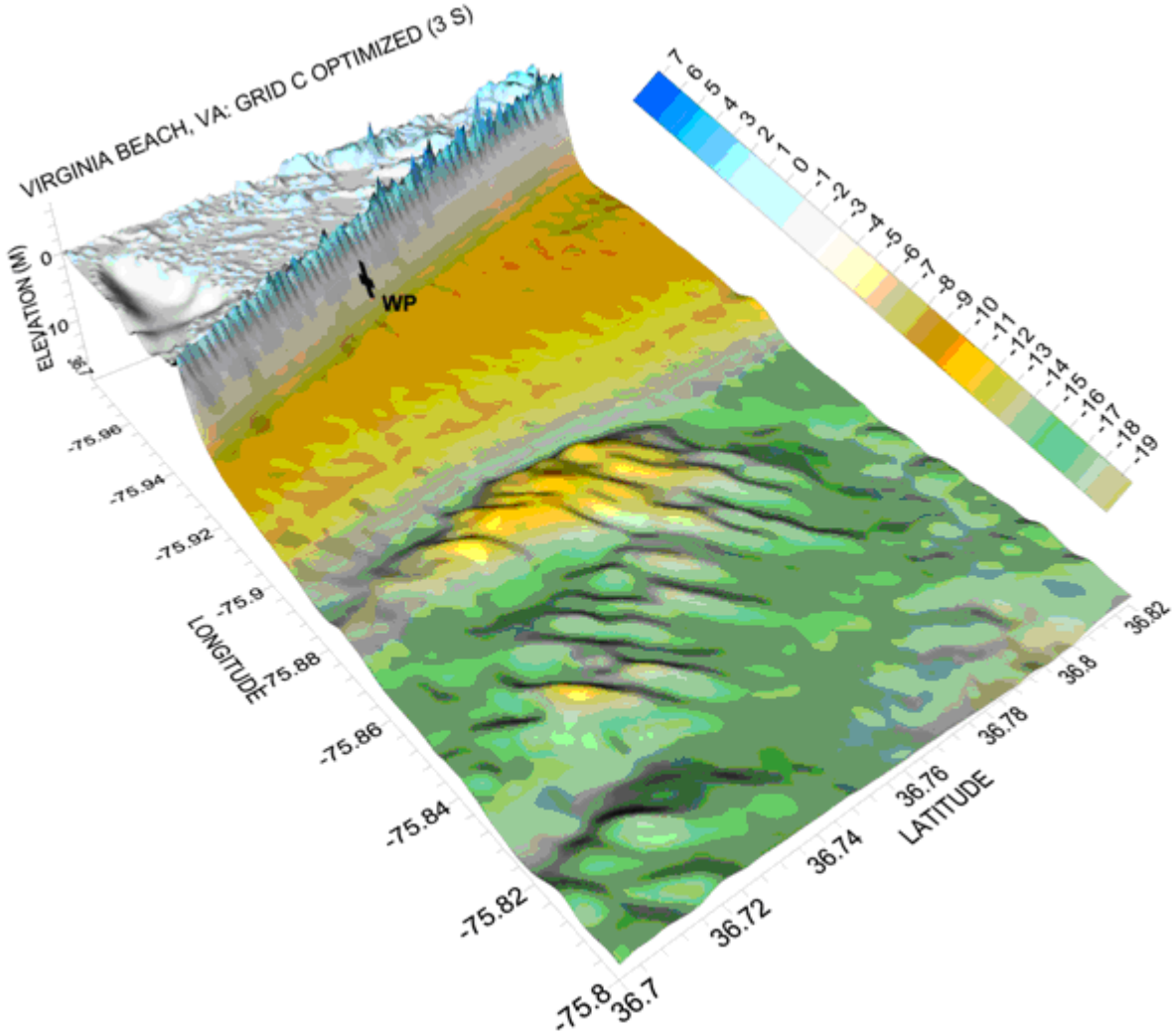

Figure 19 – Surface plot of the finally adopted Optimized 3 s Grid C, looking from the SE.

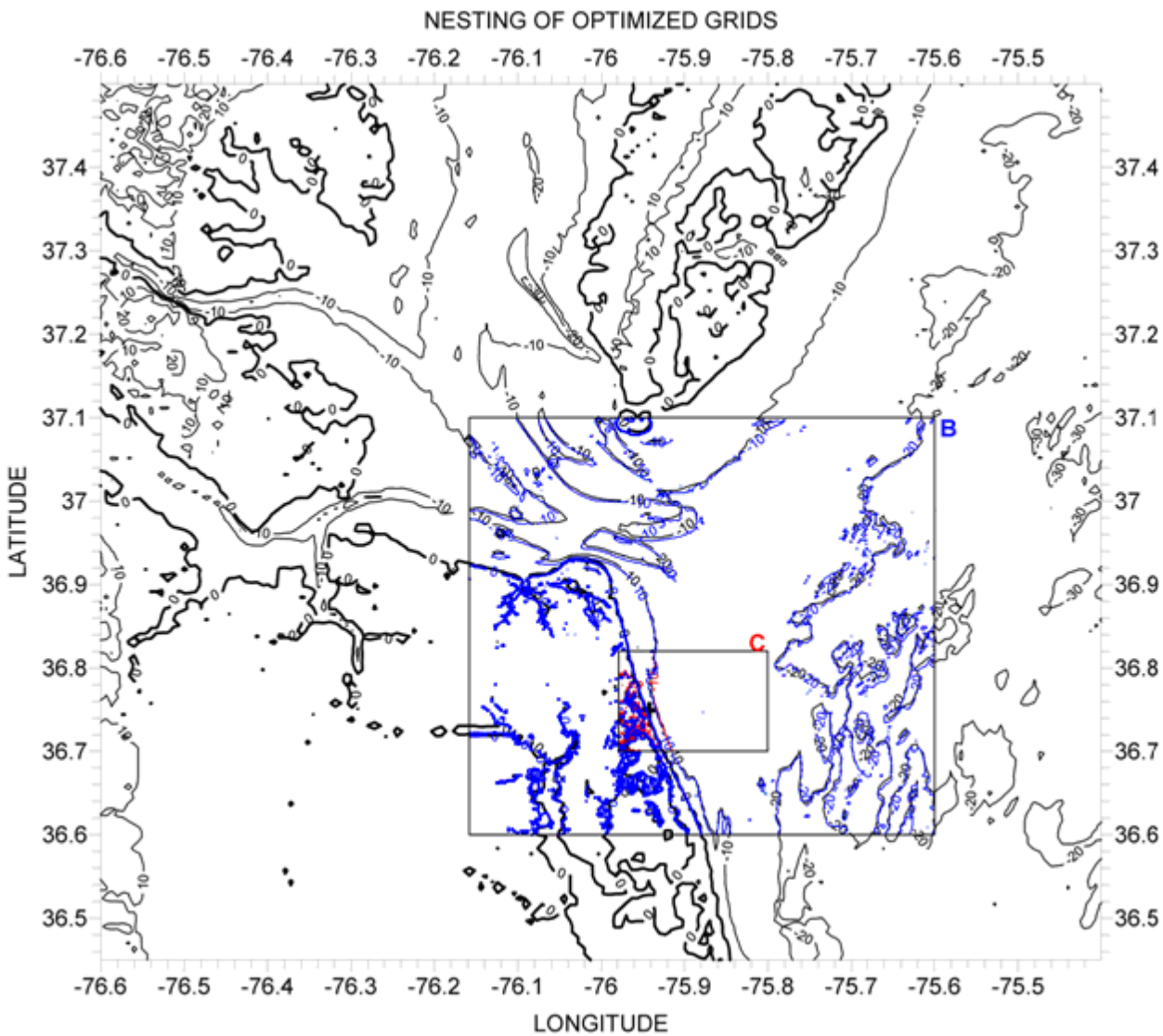

Figure 20 – Nesting of optimized grids. Grids C (red) on top of Grid B (blue), and Grid B on top of Grid A (black). This is to show the absence of depth discontinuities along the grid boundaries.

4. SOURCES

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

"Data output for source: Atlantic Mwt 9.0,
11.00*a48+11.00*b48+11.00*a49+11.00*b49+11.00*a50+11.00*b50+11.00*a51+11.00*b51+11.00*a52+11.00*b52+11.00*a53+11.00*b53+11.00*a54+11.00*b54+11.00*a55+11.00*b55"
"output/10359h.nc"
"output/10359u.nc"
"output/10359v.nc"

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

"Data output for source: Atlantic Mwt 9.0,
11.00*a48+11.00*b48+11.00*a49+11.00*b49+11.00*a50+11.00*b50+11.00*a51+11.00*b51+11.00*a52+11.00*b52+11.00*a53+11.00*b53+11.00*a54+11.00*b54+11.00*a55+11.00*b55"
"output/11594h.nc"
"output/11594u.nc"
"output/11594v.nc"

The area covered by this source is defined by

Xmin = -79
Xmax = -73
Ymin = 31
Ymax = 40

A Mwt of 9.0 is is above what experts think that could happen there, but it should offer a good test.

5. RESULTS

Four hours of simulation were carried out. Figures 21 to 23 show the maximum elevations obtained for the reference grids, while Figures 24 to 26 show the same information for the optimized grids. And Figure 27 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 0.001 meters (rounding to 3 decimal places).

The *.in input file and the *.lis output file for the reference run are shown in Tables 8 and 9, respectively. The *.in input file and the *.lis output file for the optimized run are shown in Tables 10 and 11, respectively. Table 12 shows the summary of results for 4 hours of simulation.

TABLE 8: *.IN INPUT FILE FOR REFERENCE RUN (4 HOURS)

```
0.001   Minimum amplitude of input offshore wave (m): VIRGINIA BEACH REFERENCE
1       Input minimum depth for offshore (m)
0.1     Input "dry land" depth for inundation (m)
0.0009 Input friction coefficient (n**2)
1     let a and b run up
300.0   max eta before blow up (m)
1.12    Input time step (sec)
12857   Input amount of steps (10 hrs)
10      Compute "A" arrays every n-th time step, n=
5       Compute "B" arrays every n-th time step, n=
60      Input number of steps between snapshots (67.2 s)
0       ...Starting from
1       ...Saving grid every n-th node, n=
Grid_A_ref_12s_v7.dat
Grid_B_ref_6s_v2.dat
Grid_C_ref_1s_v7.dat
/home2/amercado/DATA/sources/PR_Trench/
/home2/amercado/DATA/VB/MOST_runs_1/MOST_output_1/

Virginia Beach reference run (4 hrs)
```

TABLE 9: *.LIS OUTPUT FILE FOR REFERENCE RUN (4 HOURS)

```
  8-04-2007  13:30:44.155
 Site:  Virginia_Beach
 Input prefix:  31028
 Input Directory:  /home2/amercado/DATA/VB/MOST_runs_1/
 Read Computational parameters:
 /home2/amercado/DATA/VB/MOST_runs_1/most3_facts_nc.in
  Minimum amplitude of input offshore wave (m):   1.0000000000000000E-003
  Input minimum depth for offshore (m):     1.000000000000000
  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):     300.0000
  Input time step (sec):     1.120000000000000
  Input amount of steps:         12857
  Compute "A" arrays every n-th time step, n=           10
  Compute "B" arrays every n-th time step, n=            5
  Input number of steps between snapshots (should be a    multiple of A,B and C time steps) :
60
  ...Starting from:            0
```

```
 ...Saving grid every n-th node, n=          1
Reading Bathymetry
  1-ST LEVEL:
Bathymetry:  /home2/amercado/DATA/VB/MOST_runs_1/Grid_A_ref_12s_v7.dat
  2-ND LEVEL:
Bathymetry:  /home2/amercado/DATA/VB/MOST_runs_1/Grid_B_ref_6s_v2.dat
  3-RD LEVEL:
Bathymetry:  /home2/amercado/DATA/VB/MOST_runs_1/Grid_C_ref_1s_v7.dat
 DODS URL:  /home2/amercado/DATA/sources/PR_Trench/
 Input FACTS files:
zonal U:  /home2/amercado/DATA/sources/PR_Trench/31028u.nc
meridial V:  /home2/amercado/DATA/sources/PR_Trench/31028v.nc
amplitudes H:  /home2/amercado/DATA/sources/PR_Trench/31028h.nc
size of input array:          24          35        1441
 Longitude:    280.8999666666667       to    287.0333000000000
  Latitude:    31.03333000000000       to    40.10000000000000
      Time:    0.000000000000000       to    86400.00000000000
NetCDF array size for grid C:         1801        1801
NetCDF array size for grid B:          481         481
NetCDF array size for grid A:          361         316
  output directory:  /home2/amercado/DATA/VB/MOST_runs_1/MOST_output_1/
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_1/MOST_output_1/Virginia_Beach_runupC_ha.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_1/MOST_output_1/Virginia_Beach_runupC_ua.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_1/MOST_output_1/Virginia_Beach_runupC_va.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_1/MOST_output_1/Virginia_Beach_runupB_ha.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_1/MOST_output_1/Virginia_Beach_runupB_ua.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_1/MOST_output_1/Virginia_Beach_runupB_va.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_1/MOST_output_1/Virginia_Beach_runupA_ha.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_1/MOST_output_1/Virginia_Beach_runupA_ua.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_1/MOST_output_1/Virginia_Beach_runupA_va.nc
  netCDF initialization complete
 input          171  wave detected at    10200.00000000000       amp:
   0.1016055718064308      cm at     284.3666333333333       ,
    36.63333000000000
 Initial surface is read at t=    10200.00000000000
  Run finished
```

```
 8-04-2007  19:10:39.429
elapsed secs:    20361.39     , user:    20220.30     , sys:    141.0900
clock sec:        20395 , minutes:    339.9167
```

TABLE 10: *.IN INPUT FILE FOR OPTIMIZED RUN (4 HOURS)

```
0.001   Minimum amplitude of input offshore wave (m): VIRGINIA BEACH OPTIMIZED
1       Input minimum depth for offshore (m)
0.1     Input "dry land" depth for inundation (m)
0.0009 Input friction coefficient (n**2)
1      let a and b run up
300.0   max eta before blow up (m)
4.3     Input time step (sec)
3349    Input amount of steps (10 hrs)
7       Compute "A" arrays every n-th time step, n=
2       Compute "B" arrays every n-th time step, n=
14      Input number of steps between snapshots (60.2)
0       ...Starting from
1       ...Saving grid every n-th node, n=
Grid_A_opt_24s_v2.dat
Grid_B_opt_8s_v1.dat
Grid_C_opt_3s_v1.dat
/home2/amercado/DATA/sources/PR_Trench/
/home2/amercado/DATA/VB/MOST_runs_2/MOST_output_2/

Virginia Beach optimized run (4 hrs)
```

TABLE 11: *.LIS OUTPUT FILE FOR OPTIMIZED RUN (4 HOURS)

```
 8-04-2007  13:30:52.097
Site:  Virginia_Beach
Input prefix:  31028
Input Directory:  /home2/amercado/DATA/VB/MOST_runs_2/
Read Computational parameters:
/home2/amercado/DATA/VB/MOST_runs_2/most3_facts_nc.in
 Minimum amplitude of input offshore wave (m):   1.0000000000000000E-003
 Input minimum depth for offshore (m):     1.000000000000000
 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):     300.0000
 Input time step (sec):     4.300000000000000
 Input amount of steps:         3349
 Compute "A" arrays every n-th time step, n=           7
 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) :
14
```

```
 ...Starting from:            0
 ...Saving grid every n-th node, n=           1
Reading Bathymetry
  1-ST LEVEL:
Bathymetry:  /home2/amercado/DATA/VB/MOST_runs_2/Grid_A_opt_24s_v2.dat
  2-ND LEVEL:
Bathymetry:  /home2/amercado/DATA/VB/MOST_runs_2/Grid_B_opt_8s_v1.dat
  3-RD LEVEL:
Bathymetry:  /home2/amercado/DATA/VB/MOST_runs_2/Grid_C_opt_3s_v1.dat
 DODS URL:  /home2/amercado/DATA/sources/PR_Trench/
 Input FACTS files:
zonal U:  /home2/amercado/DATA/sources/PR_Trench/31028u.nc
meridial V:  /home2/amercado/DATA/sources/PR_Trench/31028v.nc
amplitudes H:  /home2/amercado/DATA/sources/PR_Trench/31028h.nc
size of input array:          24          35         1441
 Longitude:    280.8999666666667       to    287.0333000000000
  Latitude:    31.03333000000000       to    40.10000000000000
      Time:    0.000000000000000       to    86400.00000000000
NetCDF array size for grid C:          215          145
NetCDF array size for grid B:          252          226
NetCDF array size for grid A:          180          158
 output directory:  /home2/amercado/DATA/VB/MOST_runs_2/MOST_output_2/
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_2/MOST_output_2/Virginia_Beach_runupC_ha.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_2/MOST_output_2/Virginia_Beach_runupC_ua.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_2/MOST_output_2/Virginia_Beach_runupC_va.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_2/MOST_output_2/Virginia_Beach_runupB_ha.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_2/MOST_output_2/Virginia_Beach_runupB_ua.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_2/MOST_output_2/Virginia_Beach_runupB_va.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_2/MOST_output_2/Virginia_Beach_runupA_ha.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_2/MOST_output_2/Virginia_Beach_runupA_ua.nc
netCDF output:
/home2/amercado/DATA/VB/MOST_runs_2/MOST_output_2/Virginia_Beach_runupA_va.nc
  netCDF initialization complete
 input          171  wave detected at    10200.00000000000       amp:
   0.1016055718064308      cm at     284.3666333333333       ,
    36.63333000000000
 Initial surface is read at t=    10200.00000000000
  Run finished
```

```
 8-04-2007  13:33:06.491
elapsed secs:    133.7200     , user:    132.1100     , sys:    1.610000
clock sec:          134 , minutes:    2.233333
```

TABLE 12: SUMMARY OF RUNS

Grid	Region	Reference Model			Optimized Model		
		Coverage Lon. (°W) ---------- Lat. (°N)	**Cell Size (arc sec)**	**Time Step (sec)**	**Coverage Lon. (°W) ---------- Lat. (°N)**	**Cell Size (arc sec)**	**Time Step (sec)**

A	Virginia Beach	-76.6000463
		-75.4000463
		---------- 	
		36.4499537
		37.4999537
		------- 	
		# cols = 361
		# rows = 316
		nodes = 114,076
			12
			(≈ 360 m)
			
			Lx≈106,811 m (east-west dimension)
			
			Ly≈116,526 m (north-south dimension)
				14.15	-76.6000463
					-75.4000463
					---------- 	
					36.4499537
					37.4999537
					------- 	
					# cols = 180
					# rows = 158
					nodes = 28,440
						24
						(≈ 720 m)
						
						Lx≈106,811 m (east-west dimension)
						
						Ly≈116,526 m (north-south dimension)
							32.01

B	Virginia Beach	-76.4000000
		-75.6000000
		---------- 	
		36.5000000
		37.3000000
		---------- 	
		# cols = 481
		# rows = 481
		nodes = 231,361
			6
			(≈ 180 m)
			
			Lx≈71,302 m (east-west dimension)
			
			Ly≈88,781 m (north-south dimension)
				6.88	-76.1577778
					-75.6000000
					---------- 	
					36.6000000
					37.1000000
					------- 	
					# cols = 252
					# rows = 226
					nodes = 56,952
						8
						(≈ 240 m)
						
						Lx≈49,746 m (east-west dimension)
						
						Ly≈55,487 m (north-south dimension)
							11.19

C	Virginia Beach	-76.3000000
		-75.8000000
		---------- 	
		36.7000000
		37.2000000
		-------- 	
		# cols = 1801
		# rows = 1801
		nodes = 3,243,601
			1
			(≈ 30 m)
			
			Lx≈44,535 m (east-west dimension)
			
			Ly≈55,488 m (north-south dimension)
				1.41
				
				Finally adopted: 1.12
					-75.9786311
					75.8000000
					---------- 	
					36.7000000
					36.8202003
					------- 	
					# cols = 215
					# rows = 145
					nodes = 31,175
						3
						(≈ 90 m)
						
						Lx≈15,952 m (east-west dimension)
						
						Ly≈13,339 m (north-south dimension)
							5.38
							
							Finally adopted: 4.3

Min offshore depth (m) grids A & B		1			1		
Water depth for dry land (m)		0.1			0.1		
Friction coefficient		0.0009			0.0009		
CPU time for 4 - hours simulation		> 339 min			2.23 < 10 min		
CPU time for 10 - hours simulation		= 962 min			= 5.53 min		

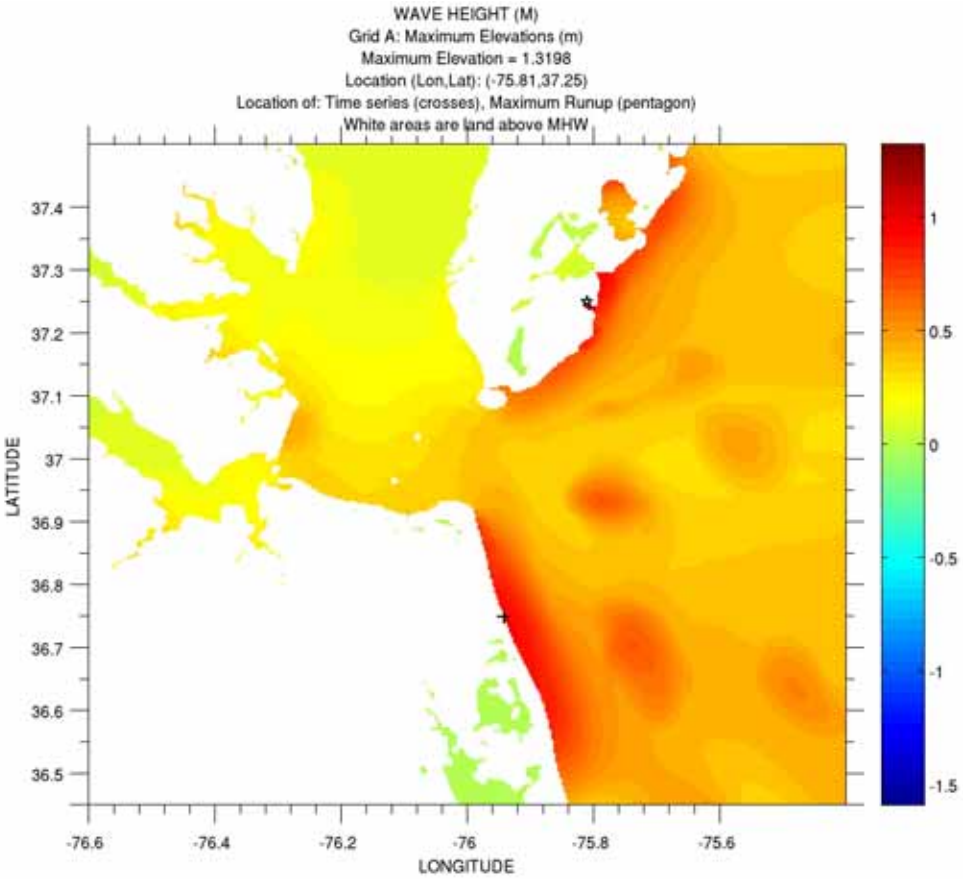

Figure 21 – Reference 12 s Grid A. Four hours of simulation. Black cross shows the location of the WP.

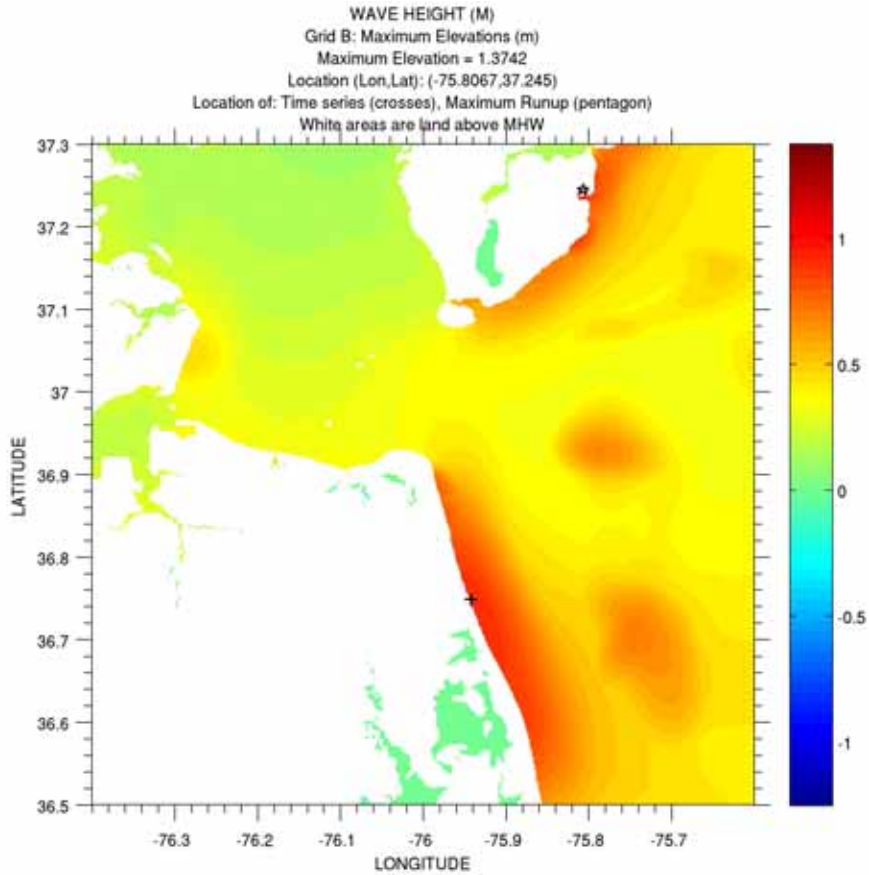

Figure 22 – Reference 6 s Grid B. Four hours of simulation. Black cross shows the location of the WP.

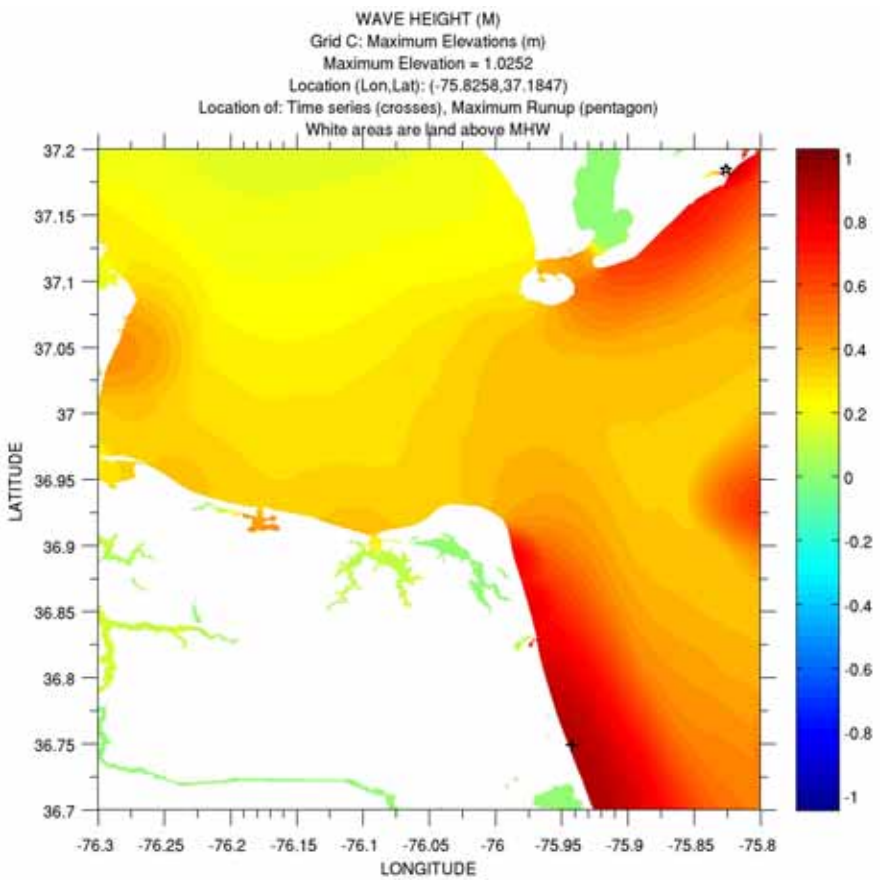

Figure 23 - Reference 1 s Grid C. Four hours of simulation. Black cross shows the location of the WP.

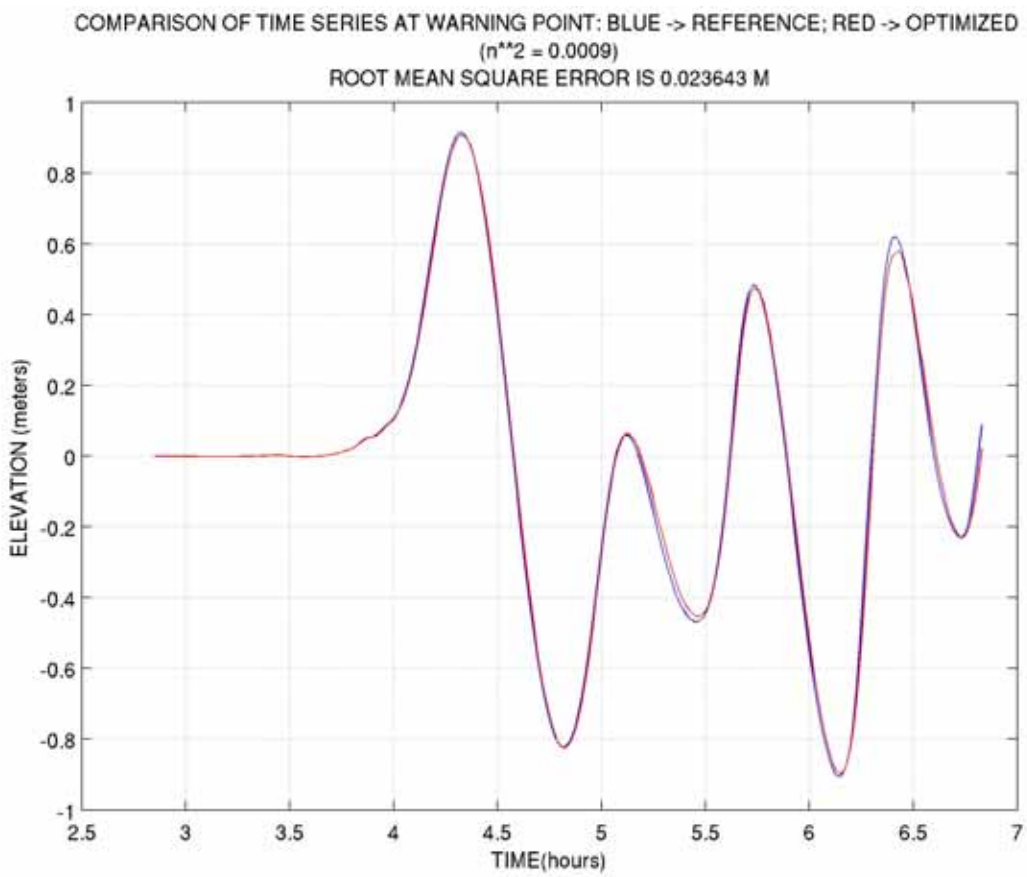

Figure 24 – Plot comparing the time series at the WP in Grid C for both the Reference and the Optimized grids. Four hours of simulation.

Figures 25 to 31 show the corresponding figures after 10 hours of simulation. The RMSE is 0.021 (rounding to three decimal places) for the 10 hours of simulation. The wall clock time was 5.53 minutes for the optimized grids.

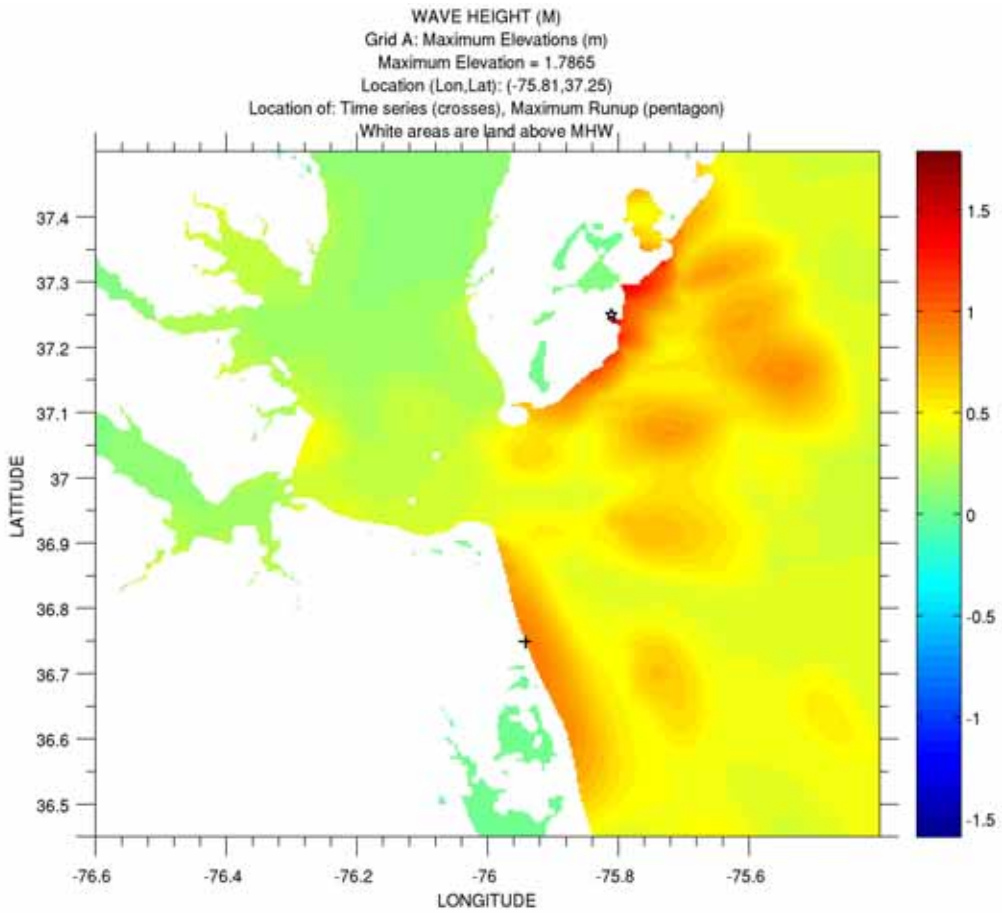

Figure 25 – Reference 12 s Grid A. Ten hours of simulation. Black cross shows the location of the WP.

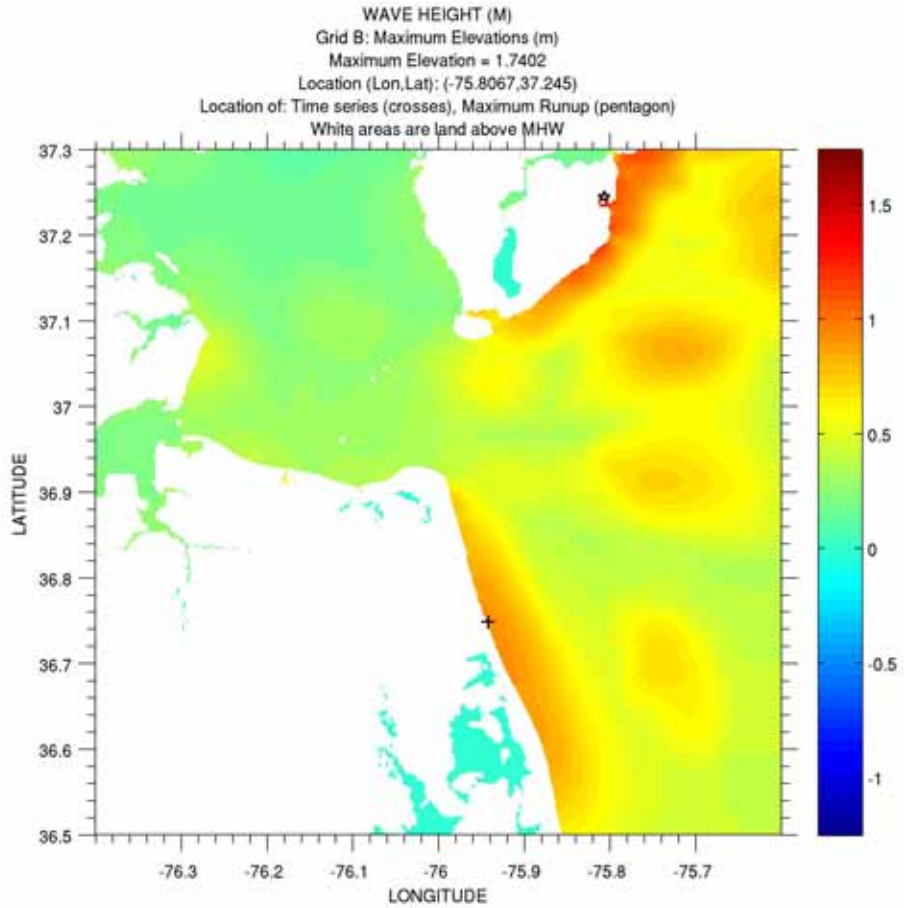

Figure 26 – Reference 6 s Grid B. Ten hours of simulation. Black cross shows the location of the WP.

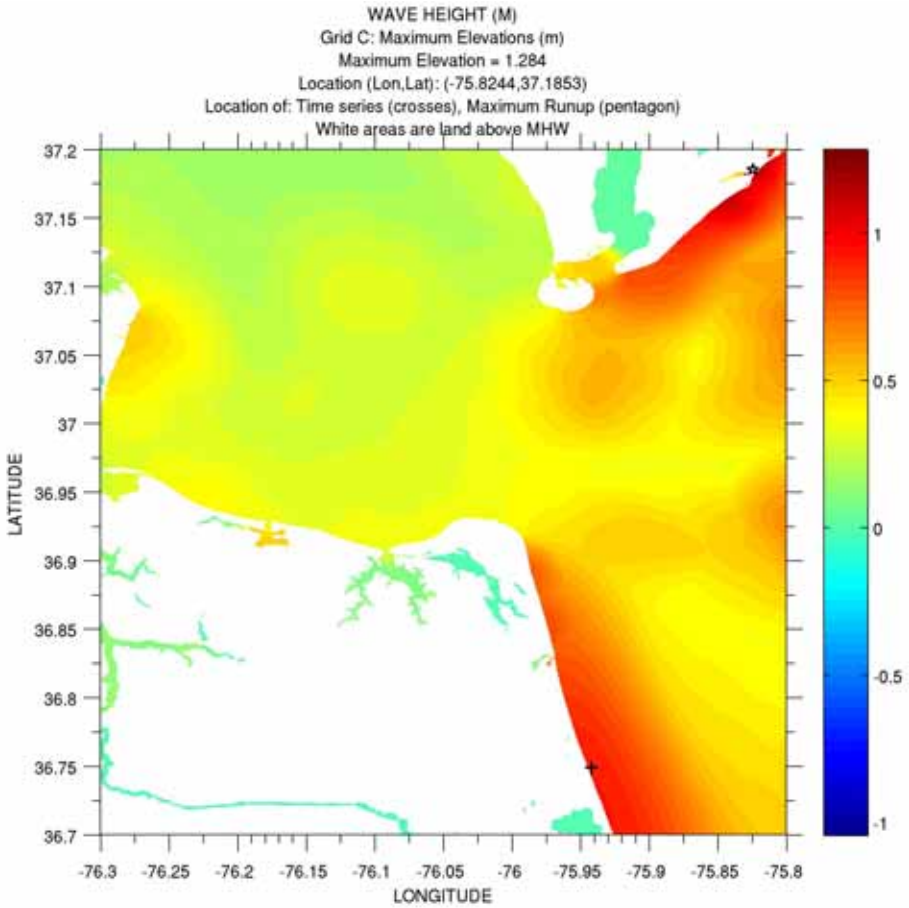

Figure 27 – Reference 1 s Grid C. Ten hours of simulation. Black cross shows the location of the WP.

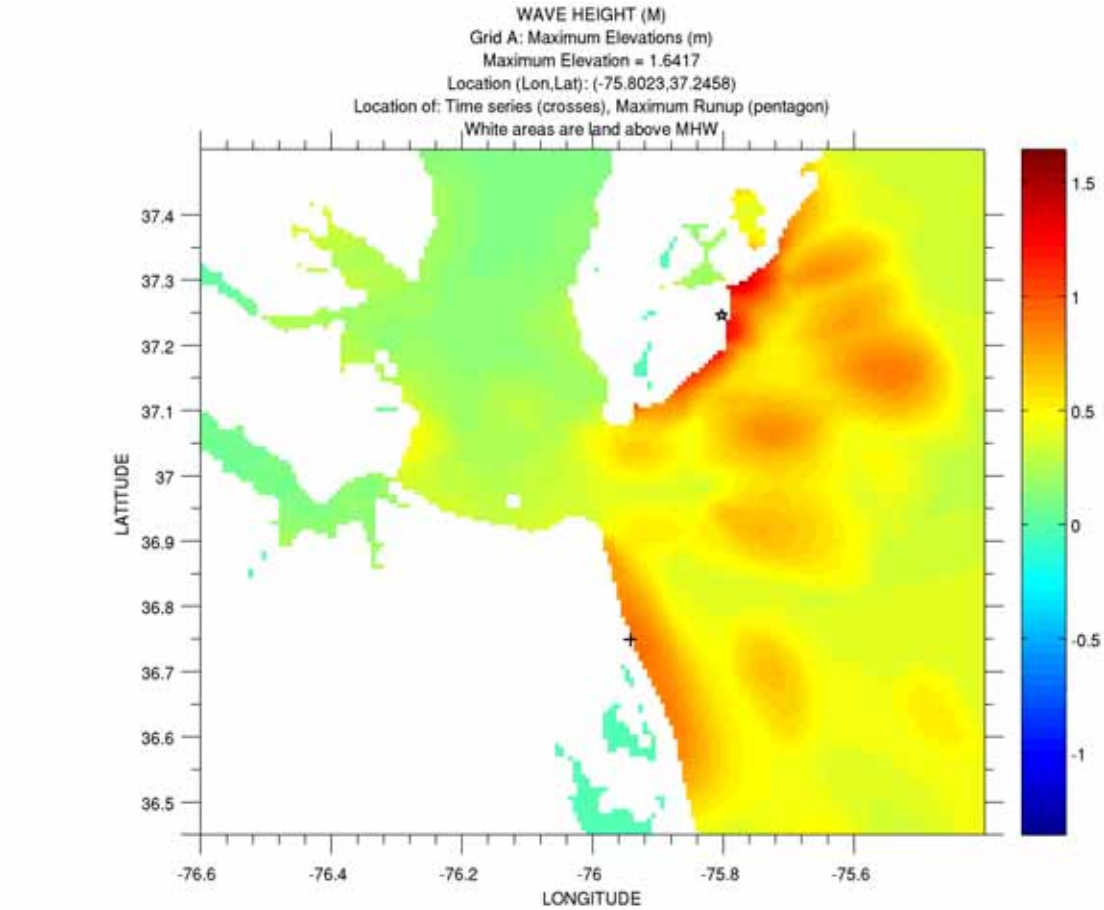

Figure 28 – Optimized 24 s Grid A. Ten hours of simulation. Black cross shows the location of the WP.

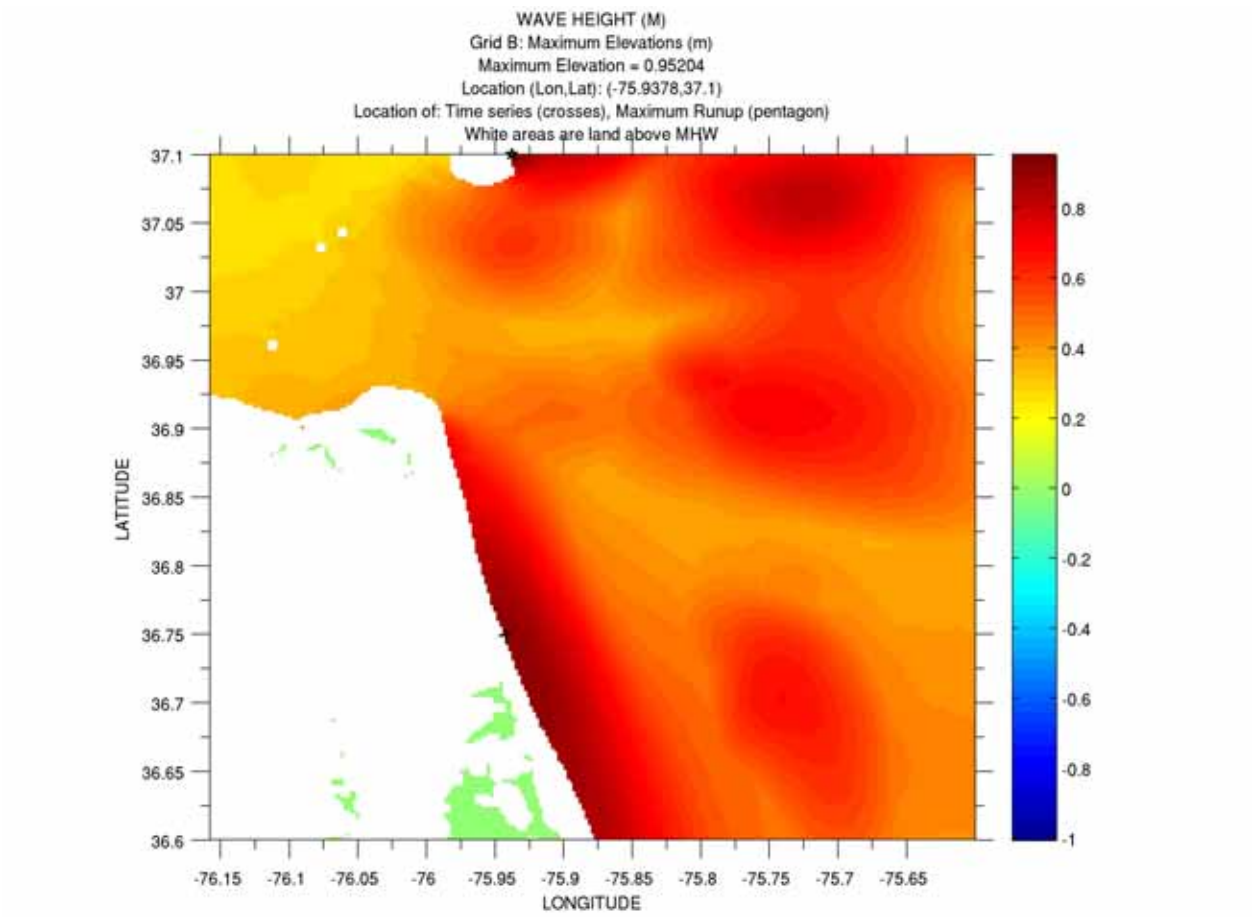

Figure 29 – Optimized 8 s Grid B. Ten hours of simulation. Black cross shows the location of the WP.

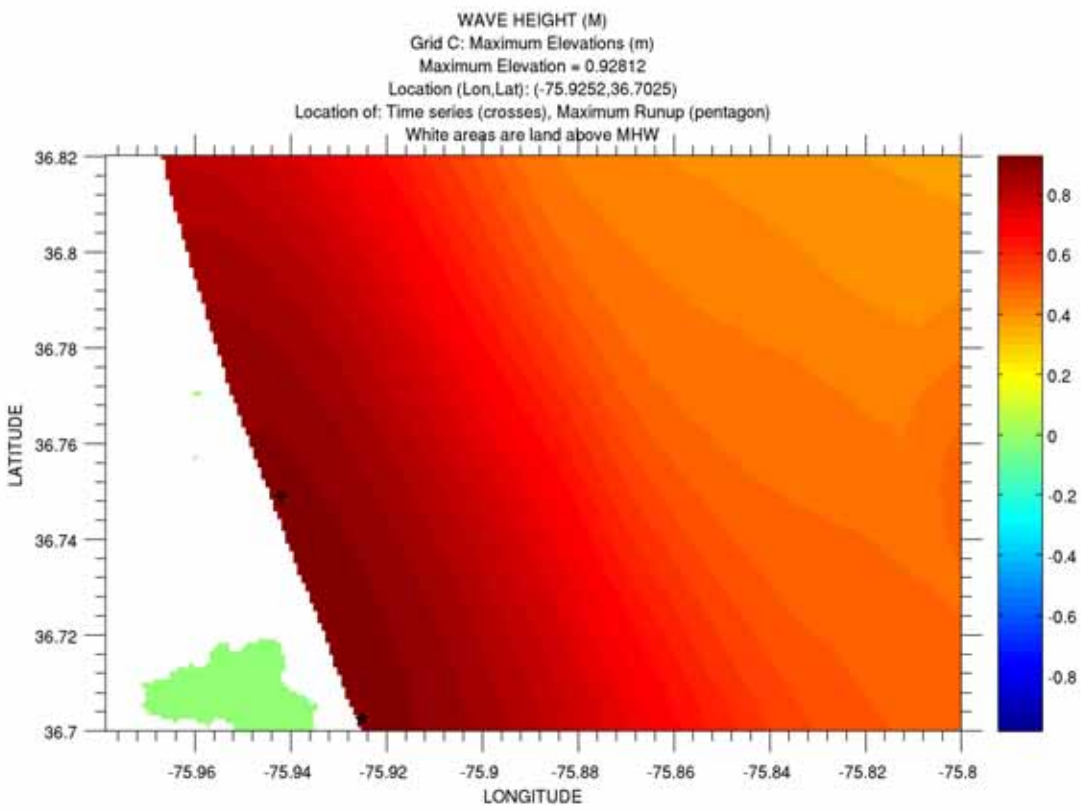

Figure 30 – Optimized 3 s Grid C. Ten hours of simulation. Black cross shows the location of the WP.

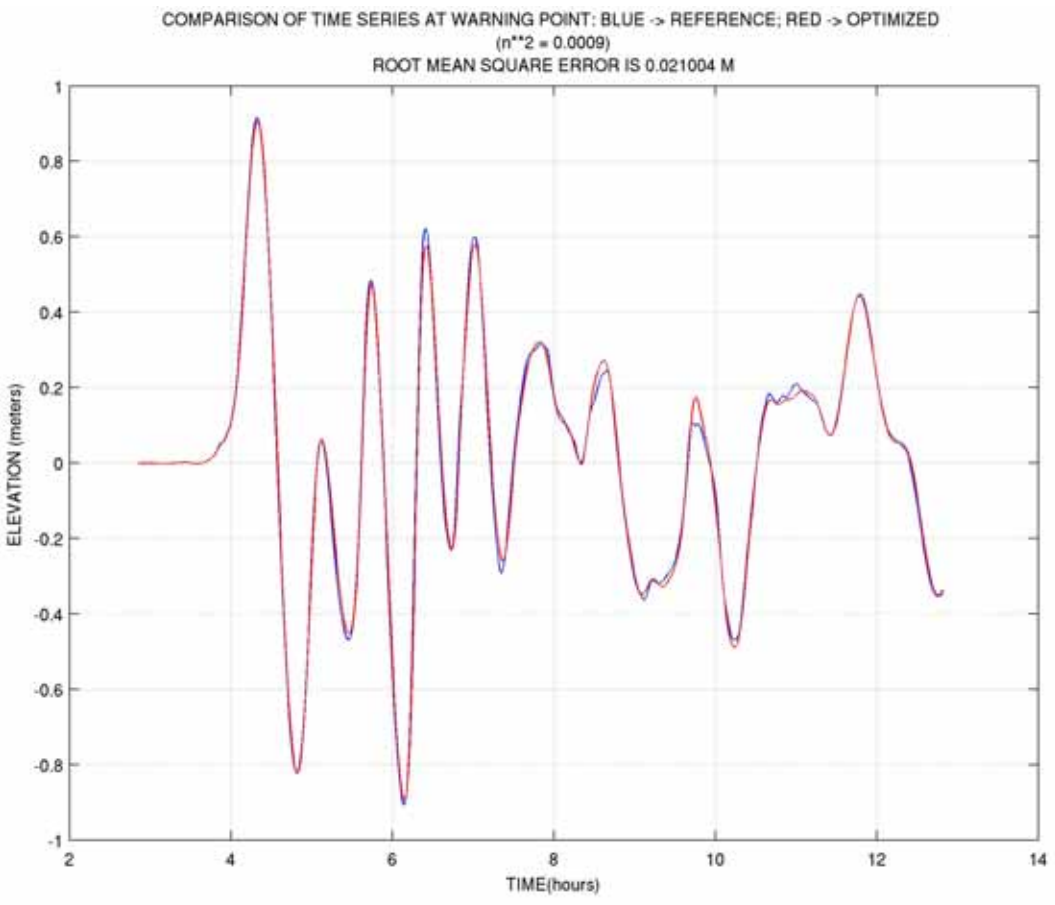

Figure 31 – Plot comparing the time series at the WP in Grid C for both the Reference and the Optimized grids.