Wave Modeling New Orleans - Mississippi River Gulf Outlet

Hurricane Katrina August 2005

APPENDICES

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APPENDIX A: Brief introduction to SWAN

SWAN is a third-generation wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters. The present version of SWAN is supported by Rijkswaterstaat (as part of the Ministry of Transport, Public Works and Water Management, The Netherlands). Previous releases of SWAN have been supported mostly by Office of Naval Research (USA) and partly Rijkswaterstaat (The Netherlands). The development of SWAN is in the hands of Delft University of Technology in the Netherlands. The model is based on the wave action balance equation. In SWAN the waves are described with the two-dimensional wave action density spectrum. The independent variables are the frequency and the wave direction. The spectrum may vary in time and space as a function of frequency and direction.

The following wave propagation processes are represented in SWAN:
- propagation through geographic space
- refraction due to spatial variations in bottom and current
- shoaling due to spatial variations in bottom and current
- blocking and reflections by opposing currents
- transmission through, blockage by reflection against obstacles

The following generation and dissipation processes are represented in SWAN:
- generation by wind
- dissipation by whitecapping
- dissipation by depth-induced wave breaking
- dissipation by bottom friction
- wave-wave interactions (quadruplets and triads)

The basic scientific philosophy of SWAN is identical to that of WAM (Cycle 3 and 4). SWAN is a third-generation wave model and it uses the same formulations for the source terms. However, SWAN contains some additional formulations primarily for shallow water. Moreover, the numerical techniques are very different.
For this study, SWAN version 40.51AB is used in the stationary mode.
See also:
SWAN team (Booij, N. IJ.G.Haagsma, L.H.Holthuisen, A.T.M.M. Kieftenburg, R.C.Ris, A.J.van der Westhuysen, M.Zijlema): SWAN Cycle III version 40.51A user manual 2007, http://www.fluidmechanics.tudelft.nl/swan/index.htm

Definition of some variables:

HSIGN $H_s = 4\sqrt{\int\int E(\omega,\theta)d\omega d\theta}$ where $E(\omega,\theta)$ is the variance density spectrum

DIR $[DIR] = \arctan\left[\int \sin(\theta)E(\sigma,\theta)d\sigma d\theta / \int \cos(\theta)E(\sigma,\theta)d\sigma d\theta\right]$

This direction is the mean wave direction in degrees, where the waves come from, normal to the wave crests.

APPENDIX B: Attenuation of wave energy by vegetation

(source: http://cozone.org.uk/nott%5Crturner.pdf)

Adapting the SWAN model to predict the attenuation of wave energy caused by marsh vegetation

Rosalind Turner
CCRU

What is SWAN?

The SWAN (Simulating Waves Nearshore) model is a third generation spectral model developed by a team at Delft University of Technology (Netherlands). The SWAN model was created in an effort to extend the success of deep ocean wave models (e.g. WAMDI, Komen *et al.* 1994) into coastal areas. The SWAN model was designed to fill in the modelling gap in the dynamic area between 20-30m depth and the coast itself.

One of the important advances from second generation wave models to third generation wave models is the addition of prediction of wave-wave interaction and exchange of energy. SWAN is a Eulerian model and is based on the action balance equation (Booij et al. 1999).

$$\frac{\partial}{\partial t}N+\frac{\partial}{\partial x}C_x N+\frac{\partial}{\partial y}C_y N+\frac{\partial}{\partial \sigma}C_\sigma N+\frac{\partial}{\partial \theta}C_\theta N=\frac{S}{\sigma}$$

From the left the first term represents local rate of change of N in time, the second and third terms represent the propagation in x and y (space) with C_x and C_y (the propagation velocities in space).

The fourth term represents the shifting of relative frequency due to variations in water depth and currents while the fifth term represents depth induced refraction.

The right hand term is the energy source term, which accounts for:

- generation;
- dissipation; and
- non-linear interactions between waves (triads and quadruplets).

The aim of this project was to extend the use of SWAN into shallow intertidal zones such as saltmarshes, also calculating additional wave energy dissipation from vegetation baffling.

How was the model adapted?

The SWAN model allows friction to be defined on the basis of the Collins' friction coefficient (1972). This friction coefficient aims to describe the change in wave spectra in relatively shallow water areas where deep-water wave conditions are known. This coefficient was adapted to represent the height, flexibility and density of the vegetation.

The Collins friction coefficient value entered into the model was calculated based on the following equation:

$$Cf_{veg} = C_w \cdot d \cdot n \cdot h_{veg}$$

Where d is plant diameter in metres, n is the number of plants per m^2, C_w is a measure of stem rigidity and h_{veg} is the stem height of the vegetation.

What empirical data was used to test the model?

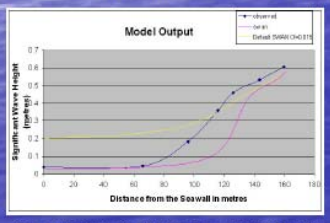
The model was tested using wave measurements derived from observation across the Tillingham marshes and mudflats of the Dengie peninsula in Essex. Dengie is located between the estuaries of the Blackwater and Crouch on the northern margin of the Thames estuary, southern North Sea (see location map). At this site Saltmarshes form a narrow belt of approximately 250 metres between low-lying, seawall-protected agricultural land and intertidal mudflats which extend for up to 4 km offshore. Gently sloping marsh surfaces lie at elevations of 2.4 to 2.7 m O.D. with water depths of up to 1 m at the lower marsh elevations during spring tides. The marshes support a floristically diverse vegetation community including Limonium vulgare, Puccinellia maritima, Atriplex portulacoides and Suaeda maritima (Möller and Spencer (2002), Möller et al. (2002)).

Wave data collected during two years of field work by Möller and Spencer (1999-2001) were used in this model. During those two years 24 tidal events were recorded with full marsh inundation, so only these 24 events were used to test the model.

Map 1: Location of the field site: Tillingham, the Dengie Peninsula, Essex

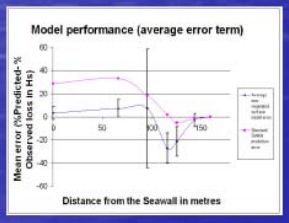


Results: performance of modified friction factor



This graph shows in blue the data observed from field observations, the yellow line shows how the unmodified SWAN model predicts wave dissipation to occur, and the pink line shows the results for the SWAN model with the modified Collins coefficient.

The difficulties in the centre 70 metres of the marsh (approximately 70 to 140 m from the seawall) arise from the model predicting wave energy reduction prematurely. It is hoped that this will be corrected as more accurate bathymetric data and vegetation data are used in the model, and as the C_w (stem rigidity) term is more accurately developed.



The above graph shows the error terms of the standard SWAN prediction (pink) and the adjusted model (blue). It highlights that the model has some problems predicting wave energy loss in the mid marsh region – but shows that it is very accurate at calculating overall energy loss (i.e. the loss by the time the waves are near to the sea wall).

What improvements are being made?

During the past 12 months another data set has been collected at Bridgewick, a site 4 km south of the Tillingham site. This marsh has a cliffed edge rather than the ramped (sloping) marsh edge morphology observed at Tillingham. The data collected includes waves dissipated by the cliffed morphology and by the vegetation covering the marsh above the cliffed edge.

The model will be adapted to take into account the differing bathymetry and vegetation.

It is hoped that the data collected at the Bridgewick field site which includes both hydrodynamic data and data from sensors deployed within the cliff to detect when the cliff suffers failure, that some connections will be observed between hydrodynamics, cliff edge failure, vegetation and seasonality, all of which can be included within the model.

This work will be most useful for those working on marsh restoration and recreation schemes. As shown in the model output graphs to the left, the model is already giving reliable estimations of wave attenuation in proximity to the seawall.

References:

Booij N. Ris RC. and Holthuijsen LH. (1999) A third generation wave model for coastal regions 1. Model description and validation. **Journal of Geophysical Research** 104: pp 7649-7666

Collins JI. (1972) Prediction of shallow-water spectra **Journal of Geophysical Research** 77: pp 2693-2707

Komen GJ. Cavaleri L. Donelan M. Hasselmann K. Hasselmann S. and Janssen PAEM. (1994) **Dynamics and Modelling of Ocean Waves** Cambridge University Press, Cambridge

Möller, I. and Spencer, T. (2002) 'Wave dissipation over macro-tidal saltmarshes: effects of marsh edge typology and vegetation change.' **Journal of Coastal Research**, Special Issue 36: 606-621.

Möller, I., Spencer, T., and Rawson, J. (2002). 'Spatial and temporal variability of wave attenuation over a UK saltmarsh.' **Proceedings of the International Conference on Coastal Engineering** (Institution of Civil Engineers) 7-12 July, Cardiff, U.K.: Thomas Telford Publishing : London, 362.

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APPENDIX C: Scenario 2A "virgin no-MRGO scenario, no levees

C.1 Introduction Scenario 2A

This appendix deals with Scenario 2A, the "virgin no-MRGO scenario". In order to interpret the full impacts of the MRGO we decided to run a Katrina storm with a scenario run modified to a condition as if the MRGO had never existed, nor its levees. For this, we have to envision a situation similar to the late 1950s.

Through the discovery process the Corps of Engineers has admitted that if the LPV levees had not been built along the banks of the MRGO, they would have used the 40 Arpent levee alignment. The levees on the 40 Arpent Avenue would then have had an elevation of 17.5 ft. The surge does not overtop these levees and as a result the water levels in the area of interest of the wave computations would be higher.

Accordingly, we simulate surge along the shores of Lake Borgne in a model in which we change the current model input in the following ways:

(1) 90% reduction in cross-section area of MRGO Reach 1 to the dimensions of the GIWW;
(2) MRGO Reach 2 is removed and replaced with land at normal marsh or swamp elevations;
(3) The spoil disposal area and LPV EBSB is degraded to natural swamp or marsh elevation based on the 1958 habitat map;
(4) Bayou LaLoutre ridge is restored to plug the hole dredged for MRGO Reach 2;
(5) The 40 Arpent/Florida Avenue levee has a pre-Katrina crest elevation of 17.5 ft (NAVD88);
(6) The influence of the Cypress trees originally present between the MRGO and the 40 Arpent levees is taken into account in the spatial roughness field.

For the SWAN wave simulations only items (2), (3) and (6) play a role. Like Scenario 1, the six time steps 4a, 5am, 6am, 7am, 8am, 9am (local time on August 29th, 2005) are considered.

The position and resolution of the computational grids is equal to those in Scenario 1. Also the wave boundary conditions, numerical settings, output locations and most physical settings are the same. Since the difference between this Scenario and Scenario 1 is limited to the area within computational grid C, the Scenario 1 results on the base grid (A) are valid for Scenario 2A.

Input for Scenario 2A that differs from Scenario 1:
- Bathymetry
- Bottom friction
- Wind
- Water levels

Besides Scenario 2A there are also SWAN results available for Scenario 2B which has the 40 Arpent levee at 6.5 ft (see Appendix D).

C.2 Input Scenario 2A

Bathymetry Scenario 2A

The bathymetry for Scenario 2A is modified to represent the conditions prior to the construction of the MRGO. Starting from the bathymetry of Scenario 1, Reach 2 of the MRGO is filled up to the height of the surrounding marshes and swamps in the bathymetry. The levees and spoil disposal area next to MRGO Reach 2 are degraded to the height of the surrounding marshes and swamps, being at 2ft NAVD88 in the western part, and 1.5 ft NAVD88 in the eastern part. A land-water map provided by the Robinson experts has been used to construct the original small water streams in the marshes (elevation set at -1ft NAVD88). The resulting depths in the model area are shown in Figure C1.

The adjusted bathymetry for Scenario 2A is only included in computational grids C, M, F and G.

Bottom friction Scenario 2A

Originally, the area between the MRGO and the 40 Arpent levees was covered with Cypress trees (data provided by the Robinson experts) which would considerably reduce wave propagation. The influence of the trees on the waves is included by locally enlarging the friction coefficient.

For Scenario 2A the friction coefficient is locally (the areas of Figure 4.5) set to 0.2. Figure C2 shows the friction coefficient as input for the SWAN computations. Note that this is different from Scenario 2C. The larger bottom friction is only included in computational grids M and F.

Wind Scenario 2A

Inside the cypress forest the influence of the wind is reduced by the trees. Therefore the wind velocities are reduced by 80% (percentage provided to us by the Robinson experts) inside the Cypress forests. For Scenario 2A the same wind files are used as for Scenario 2C version g, see Figure 4.7.

Water levels Scenario 2A

The computed water levels resulting from the FINEL Scenario 2A-runs (de Wit, 2008) have been used to locally modify the ADCIRC water level fields of Scenario 1 to Scenario 2A. The FINEL simulations have a high resolution and cover fully the F-grid. The water level field for the M-grid has been completed with the ADCIRC Scenario 1 data.

The water levels for Scenario 2A are only included in computational grids M, F and G. Figure C.3 shows the water levels as input for the SWAN computations.

C.3 SWAN results Scenario 2A

General

In this scenario we simulate the situation before the MRGO was constructed, with Cypress swamps, no MRGO-levees and with the 40 Arpent Avenue levees having an elevation of 17.5 ft. The absence of the deep and wide MRGO prevents the waves growing as they did in Scenario 1. Furthermore, the Cypress forests suppress the waves and reduce the wind velocity so that there is less driving force for the waves to grow. The water levels of Scenario 2A are less, and in shallower water the waves will be smaller. The general outcome of the SWAN simulations of Scenario 2A is that the waves on the location of the present levee would be lower if there were no MRGO.

Scenario 2A: SWAN results at output locations

The significant wave height, wave direction and peak period as computed by SWAN on the output locations for the six time steps are presented in Table C.1. The water levels are also included in this table.

Time step 8 am shows the largest wave heights and periods. On Ray 2, the maximum significant wave height is 5.8 ft. The largest period occurs on ray 6 and is 6.2 seconds (however, in combination with a smaller wave height of 4.6 ft).

Since the levees have been removed in Scenario 2A, the locations "levee", "toe" and "deep" should be comparable. Still, small differences occur caused by local variations in depth, friction, wind and water level.

Rays 1 and 2 have no limiting influence of Cypress woods and reduced wind.

On all rays the wave height of Scenario 2A is considerably lower than in Scenario 1.

Scenario 2A: 2d-overview of significant wave height - Hs

Figures C.4.a-c reflect the significant wave height in 2d-plots. One can see the higher waves on Lake Borgne (up to 9 ft on 8:00am), and smaller waves on the marshes. The Cypress forests can be recognized as the area with lower waves. When comparing these plots with the ones from Scenario 1, the main difference is the absence of the MRGO and the levees.

Scenario 2A: 2d-overview of peak wave period - Tp

Figures C.5.a-b present the peak wave period in 2d-plots. The peak period is a measure of how the wave energy is divided over the wave frequencies, rather than a measure for the amount of energy (which would be the significant wave height).

Scenario 2A: Wave parameters along the rays

Figure C.6a-b shows the wave height, peak period, wave direction, water depth (including surge level) and friction coefficient along rays through the pre described output locations, perpendicular to the MRGO. These plots show the variation in wave parameters and water depth. The location of the rays can be found in Figure 2.6. The colored dots have the same

position as the ones in Scenario 1, but since the MRGO and the levees have been removed in Scenario 2A, their vertical elevation is almost the same now for the five locations. Only the plots of time step 8:00 local time are presented.

Due to the absence of the MRGO and the levees, the variation in depth is less than in Scenario 1. The variation in friction coefficient depends on the presence of the Cypress trees causing additional friction. One can see that the wave height reduces as the friction coefficient increases.

Conclusion Scenario 2A

In Scenario 2A the situation before the MRGO was constructed has been simulated, with Cypress trees growing in the marshes, and no MRGO-levees. The absence of the deep and wide MRGO prevents the waves to grow as they did in Scenario 1. Furthermore, the Cypress forests suppress the waves and reduce the wind velocity so that there is less driving force for the waves to grow. The general outcome of the SWAN simulations of Scenario 2A is that the waves on the location of the present levee would be lower if there were no MRGO.

Hs [ft]	4am (local)				5am (local)		
loc	L	T	D		L	T	D
1	1.7	1.7	1.7		2.1	2.1	2.2
2	2.5	2.5	2.1		3.1	3.1	2.7
3	1.2	1.2	1.4		1.7	1.6	1.9
4	1.6	1.3	1.3		2.1	1.7	1.7
5	1.6	1.2	1.1		2.0	1.6	1.5
6	1.6	1.8	1.9		2.1	2.4	2.5
7			3.4				4.0

dir come from [°N]	4am (local)				5am (local)		
loc	L	T	D		L	T	D
1	59	58	58		57	56	56
2	51	55	70		50	54	67
3	71	65	72		68	63	69
4	38	33	41		37	33	41
5	50	51	50		46	47	49
6	54	53	53		53	52	52
7			54				53

Tp [s]	4am (local)				5am (local)		
loc	L	T	D		L	T	D
1	2.6	2.4	2.4		2.9	2.6	2.6
2	2.6	2.6	2.9		2.9	2.9	3.2
3	2.4	2.4	2.4		2.9	2.9	3.2
4	2.4	2.4	2.4		2.9	2.9	2.6
5	2.0	2.0	2.9		2.2	2.4	3.2
6	2.9	5.1	5.1		3.2	5.1	5.1
7			3.2				3.5

wl [ft]	4am (local)				5am (local)		
loc	L	T	D		L	T	D
1	5.7	5.7	5.8		6.7	6.7	6.8
2	5.9	6.0	6.2		7.1	7.2	7.4
3	6.5	6.6	6.9		7.9	8.0	8.3
4	6.6	6.7	6.9		8.1	8.1	8.3
5	6.6	6.6	7.0		8.0	8.1	8.4
6	8.1	8.4	8.4		9.7	10.0	10.0
7			7.2				8.6

Table C1.a: Results SWAN Scenario 2A: 4am and 5 am on output locations (Hs, Direction, Tp, Water level; for output locations, see Paragraph 2.5; L="levee", T="toe", D="deeper parts")

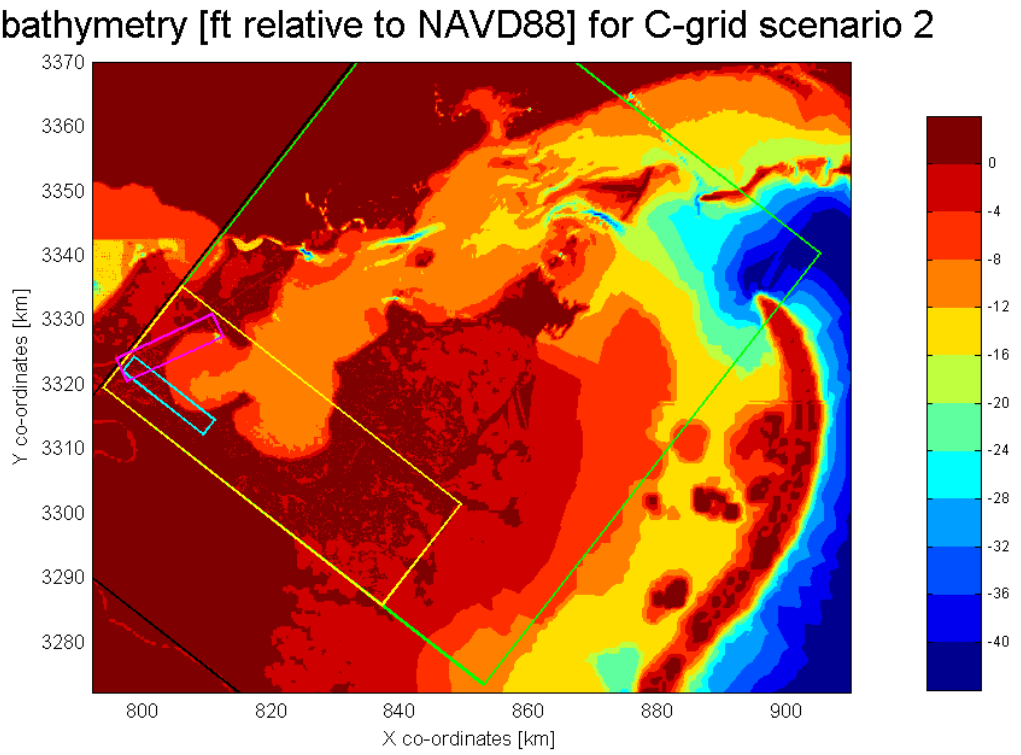
Hs [ft]	6am (local)				7am (local)				8am (local)				9am (local)		
loc	L	T	D		L	T	D		L	T	D		L	T	D
1	2.8	2.8	2.8		3.7	3.7	3.7		4.9	4.9	4.9		4.9	4.9	4.9
2	3.8	3.8	3.4		4.8	4.8	4.4		5.8	5.8	5.5		4.9	4.9	4.9
3	2.2	2.2	2.4		3.0	2.9	3.1		3.8	3.7	3.9		3.1	3.1	3.2
4	2.7	2.2	2.3		3.5	3.0	3.1		4.1	3.6	3.8		3.5	3.4	3.4
5	2.6	2.1	2.0		3.4	2.7	2.7		3.9	3.3	3.4		3.1	2.9	3.1
6	2.8	3.1	3.3		3.7	4.1	4.2		4.2	4.6	4.8		2.6	2.9	3.0
7			4.8				5.8				6.8				4.6

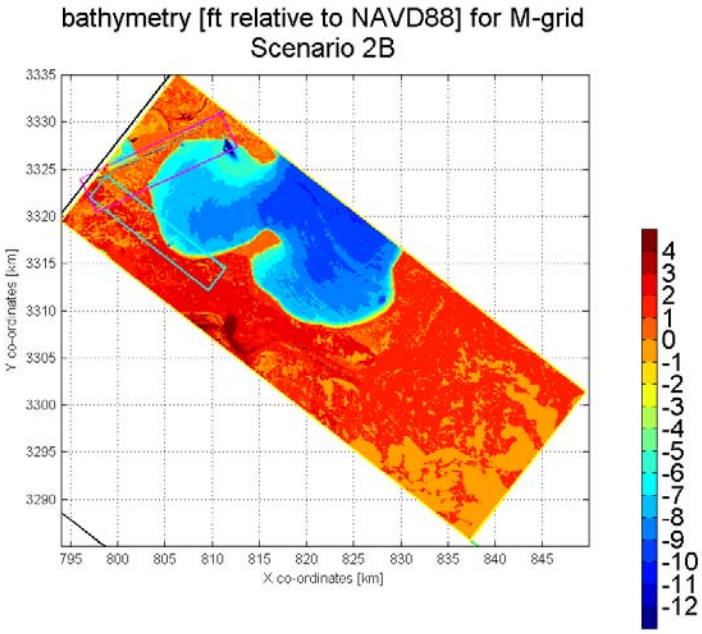
dir come from [°N]	6am (local)				7am (local)				8am (local)				9am (local)		
loc	L	T	D		L	T	D		L	T	D		L	T	D
1	54	53	53		52	51	51		52	51	51		33	33	34
2	49	52	63		49	51	60		50	52	59		21	22	25
3	65	60	66		64	59	63		65	60	64		17	16	17
4	36	33	40		37	35	41		39	38	43		10	10	11
5	42	43	47		41	42	47		43	44	48		8	10	18
6	51	50	51		51	51	51		54	54	54		21	20	19
7			51				50				54				34

Tp [s]	6am (local)				7am (local)				8am (local)				9am (local)		
loc	L	T	D		L	T	D		L	T	D		L	T	D
1	3.2	2.9	2.9		3.2	3.2	3.2		3.8	3.5	3.8		5.1	5.1	5.1
2	3.2	3.2	3.5		3.8	3.8	3.8		4.2	4.2	4.7		5.1	5.1	5.1
3	3.2	3.2	3.8		3.8	3.5	4.2		4.2	4.2	4.7		4.7	4.7	4.7
4	3.2	3.2	3.2		3.5	3.5	3.5		3.8	3.8	3.8		4.7	4.7	4.7
5	2.6	2.9	3.5		2.9	3.2	4.2		3.5	3.8	4.7		4.7	4.7	4.7
6	4.2	5.1	5.1		4.7	4.7	4.7		5.1	6.2	6.2		4.7	4.7	4.7
7			3.5				3.5				3.8				4.2

wl [ft]	6am (local)				7am (local)				8am (local)				9am (local)		
loc	L	T	D		L	T	D		L	T	D		L	T	D
1	8.0	8.1	8.1		9.8	9.9	9.9		12.7	12.7	12.7		15.6	15.6	15.5
2	8.7	8.7	8.9		10.7	10.7	10.8		13.5	13.5	13.5		15.5	15.5	15.4
3	9.6	9.7	10.0		11.8	11.9	12.1		14.5	14.5	14.6		15.4	15.4	15.3
4	9.8	9.9	10.0		12.1	12.1	12.2		14.7	14.7	14.7		15.4	15.3	15.3
5	9.8	9.8	10.2		12.1	12.1	12.4		14.7	14.7	14.9		15.4	15.3	15.3
6	11.6	11.9	12.0		14.0	14.2	14.3		15.9	16.1	16.1		14.9	14.8	14.8
7			10.0				11.5				13.9				14.0

Table C1.b: Results SWAN Scenario 2A: 6-9am on output locations (Hs, Direction, Tp, Water level; for output locations, see Paragraph 2.5; L="levee", T="toe", D="deeper parts")





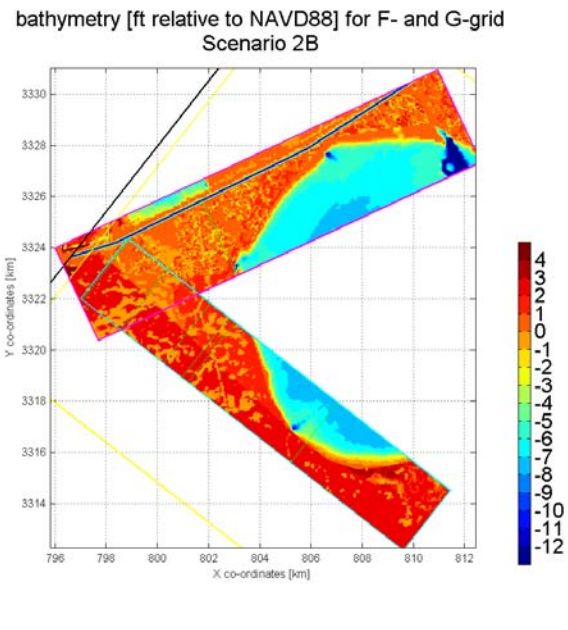


Figure C1: Bathymetry for Scenario 2A=2B, for grids C, M, F and G.

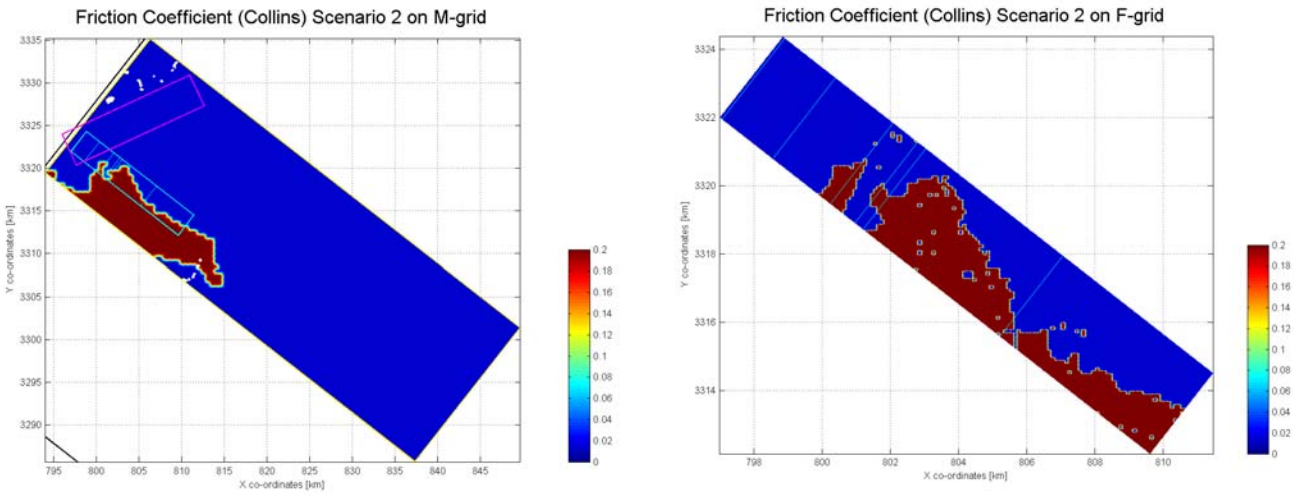


Figure C2: Scenario 2A=2B; Applied friction coefficient for SWAN computations on M-grid and F-grid

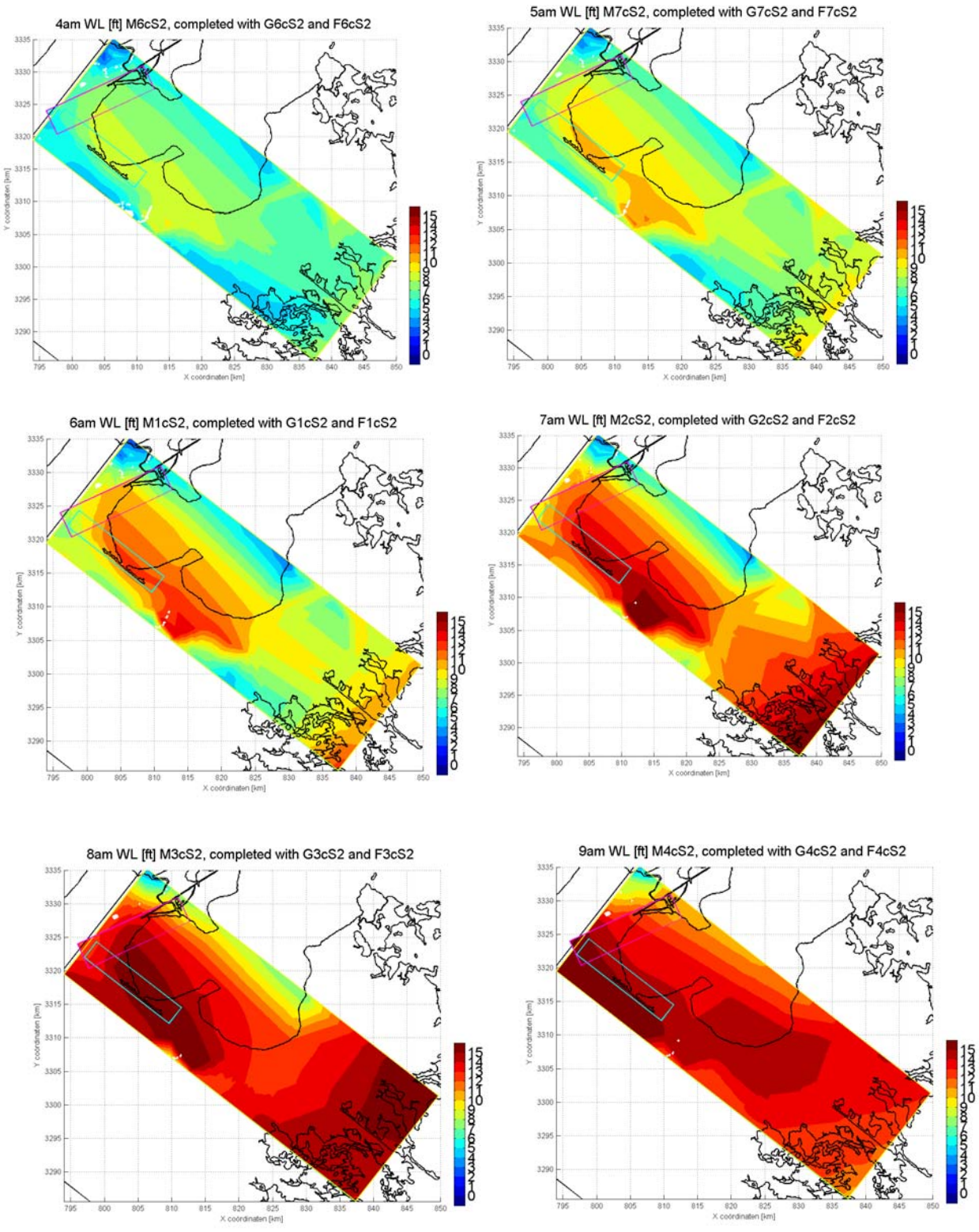


Figure C3: Scenario 2A: Water levels based on the combination of FINEL Scenario 2A and ADCIRC Scenario 1

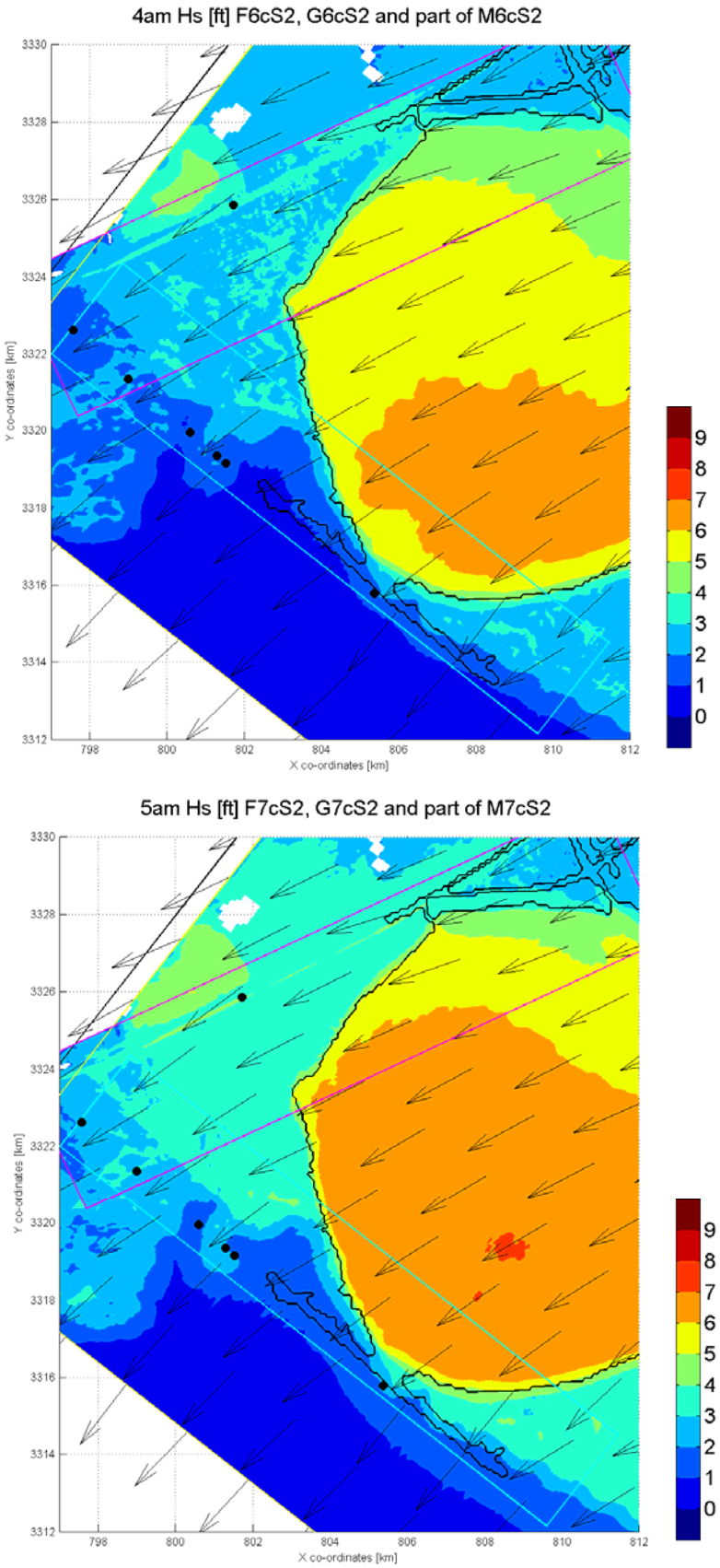


Figure C4.a: Scenario 2A; SWAN results significant wave height (Hs [ft]) and wave direction, 4:00 am and 5:00 am LT on grid F, G, and part of grid M

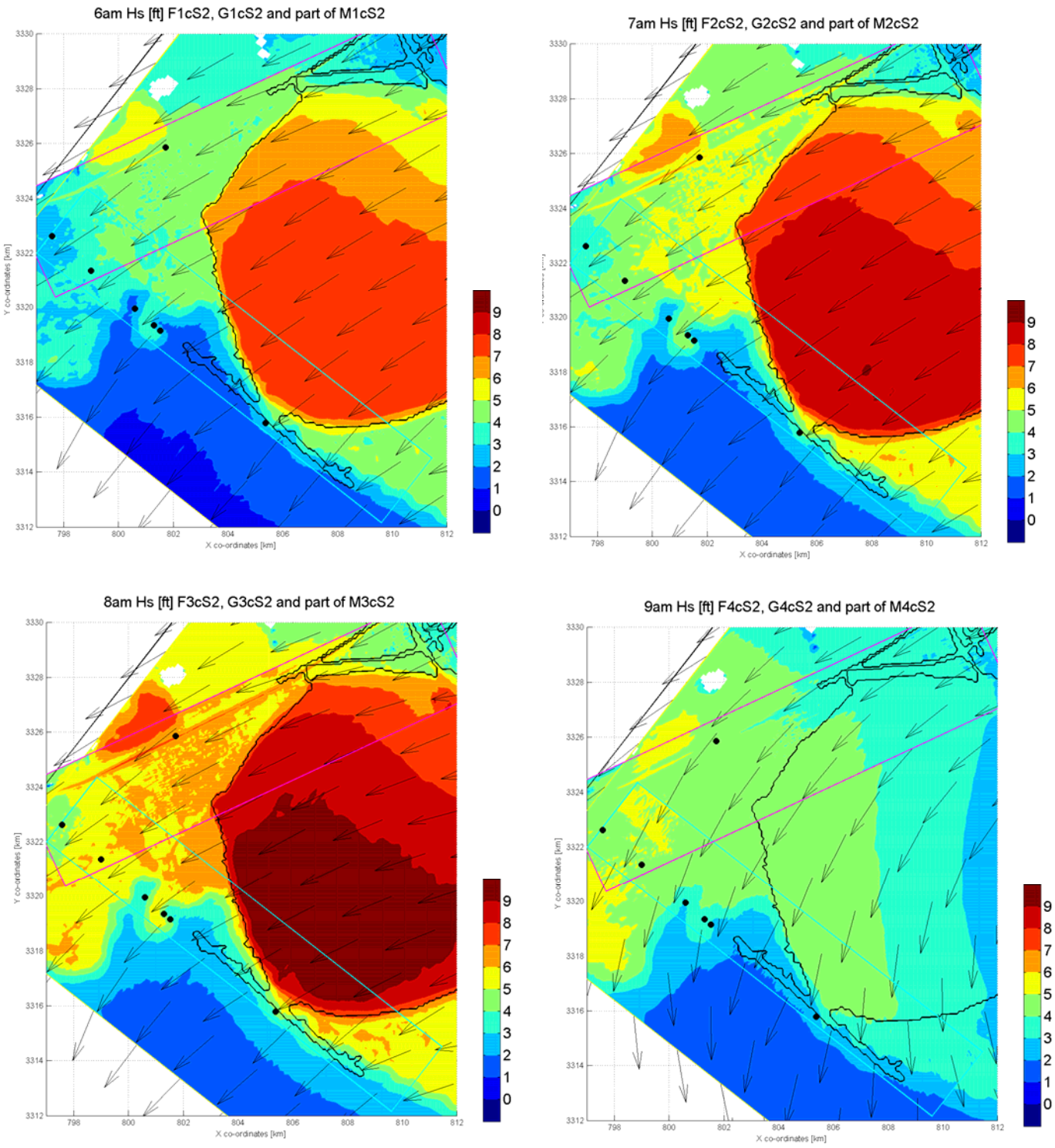


Figure C4.b: Scenario 2A; SWAN results significant wave height (Hs [ft]) and wave direction, 6:00 am - 9:00 am LT on grid F, G, and part of M

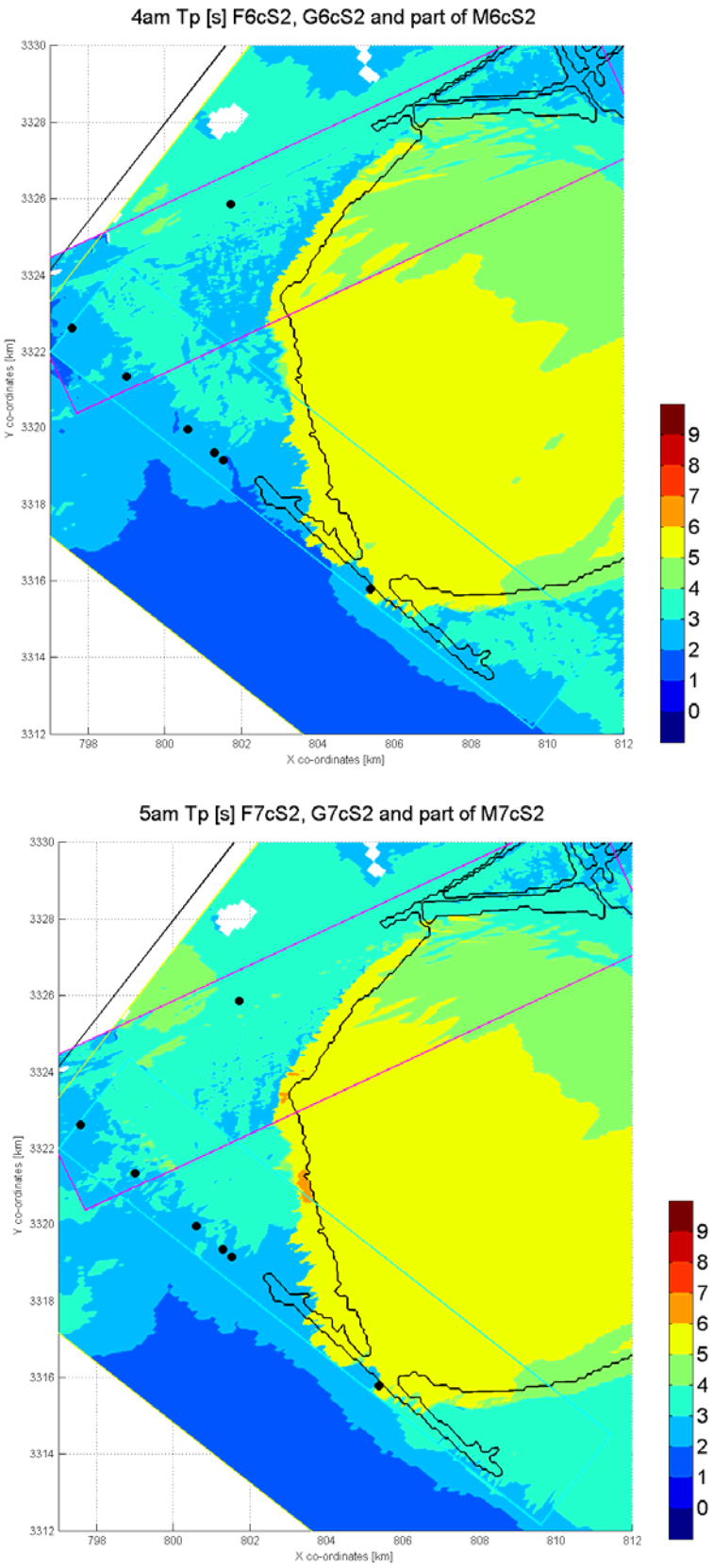


Figure C5.a: Scenario 2A; SWAN results peak wave period (Tp [s]), 4:00 am and 5:00 am on grid F, G and part of M

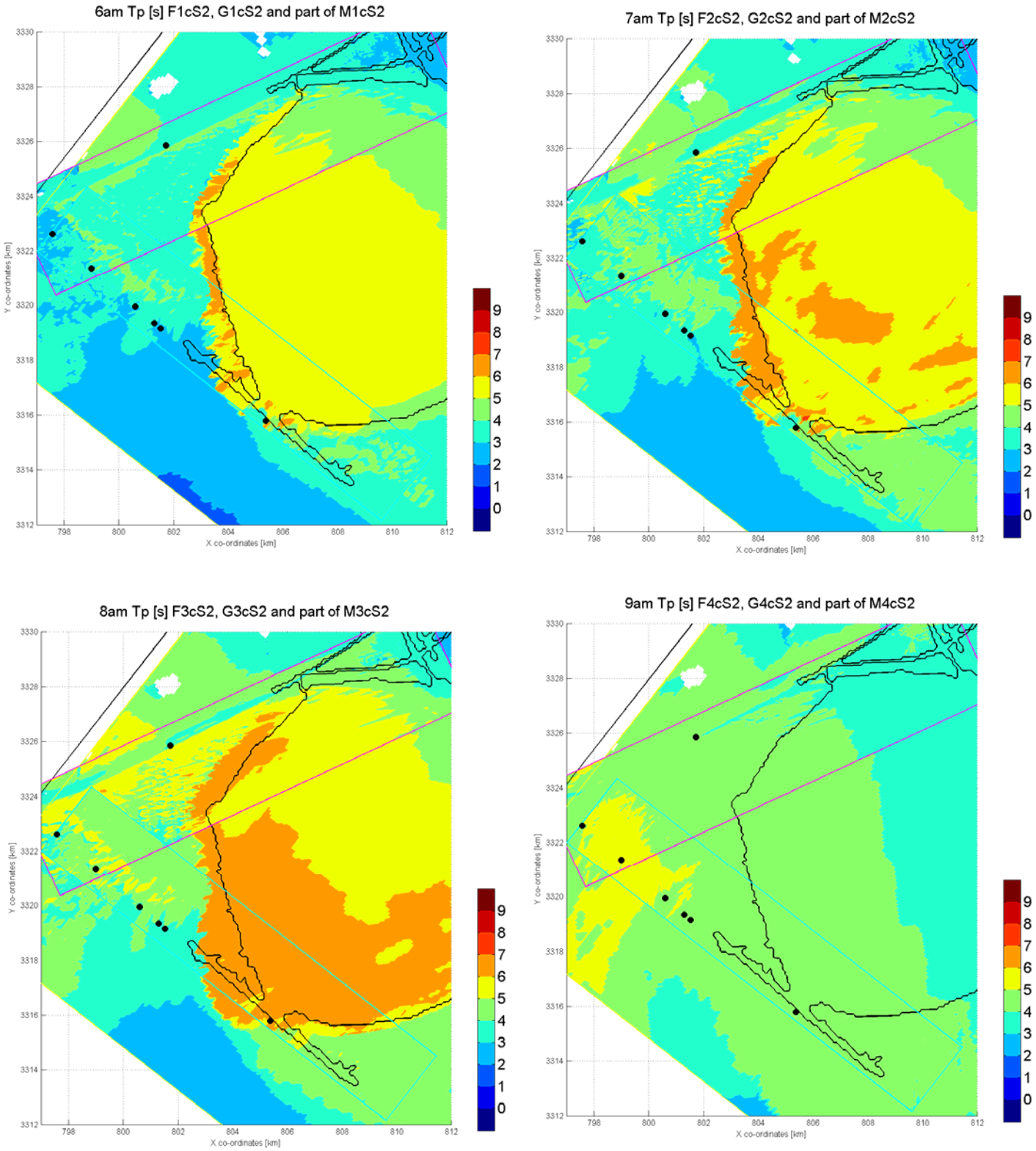


Figure C5.b: Scenario 2A; SWAN results peak wave period (Tp [s]), 6:00 am - 9:00 am on grid F, G and part of M

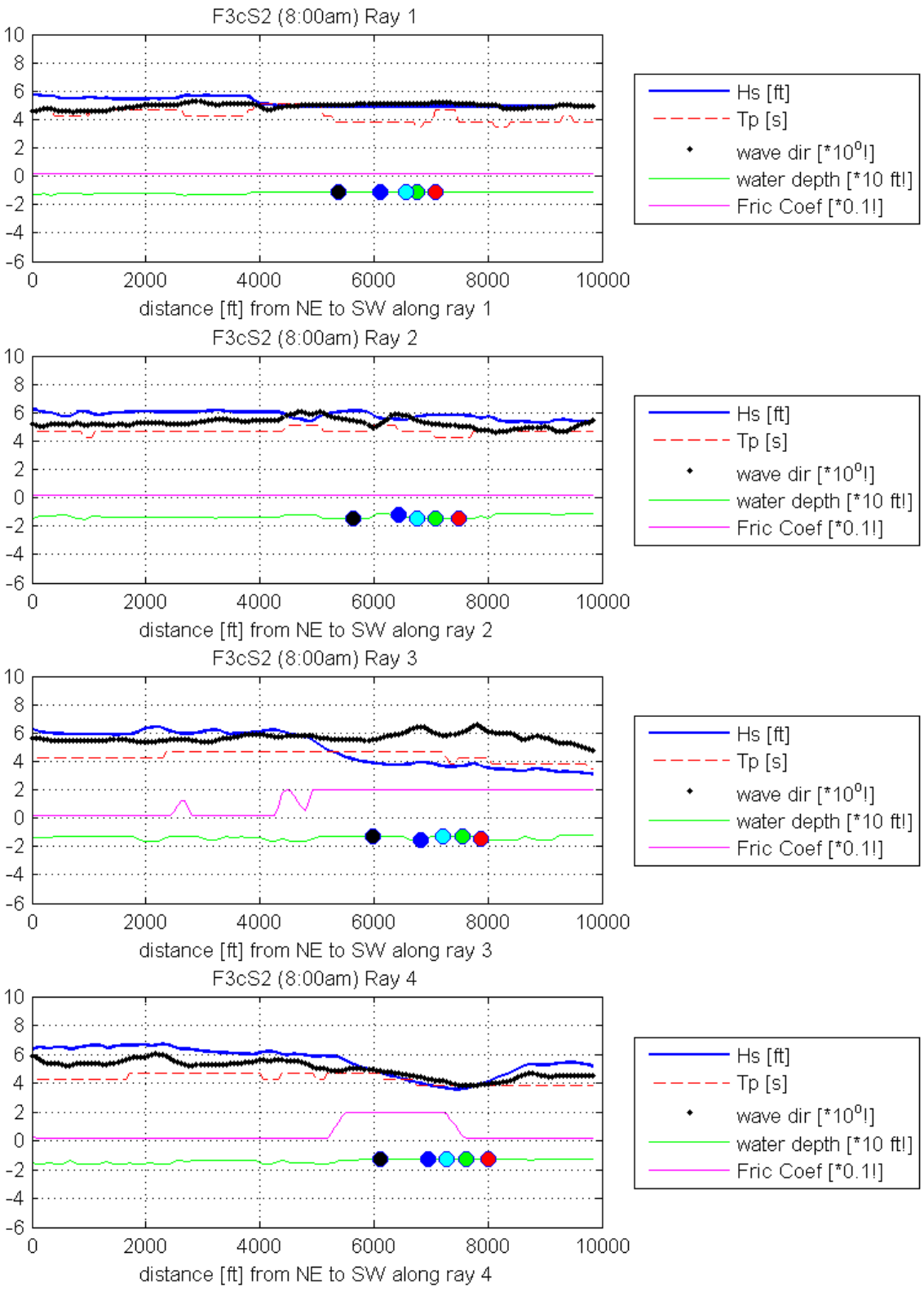


Figure C6.a: Wave parameters on rays 1-4 at 8:00 am LT Scenario 2A

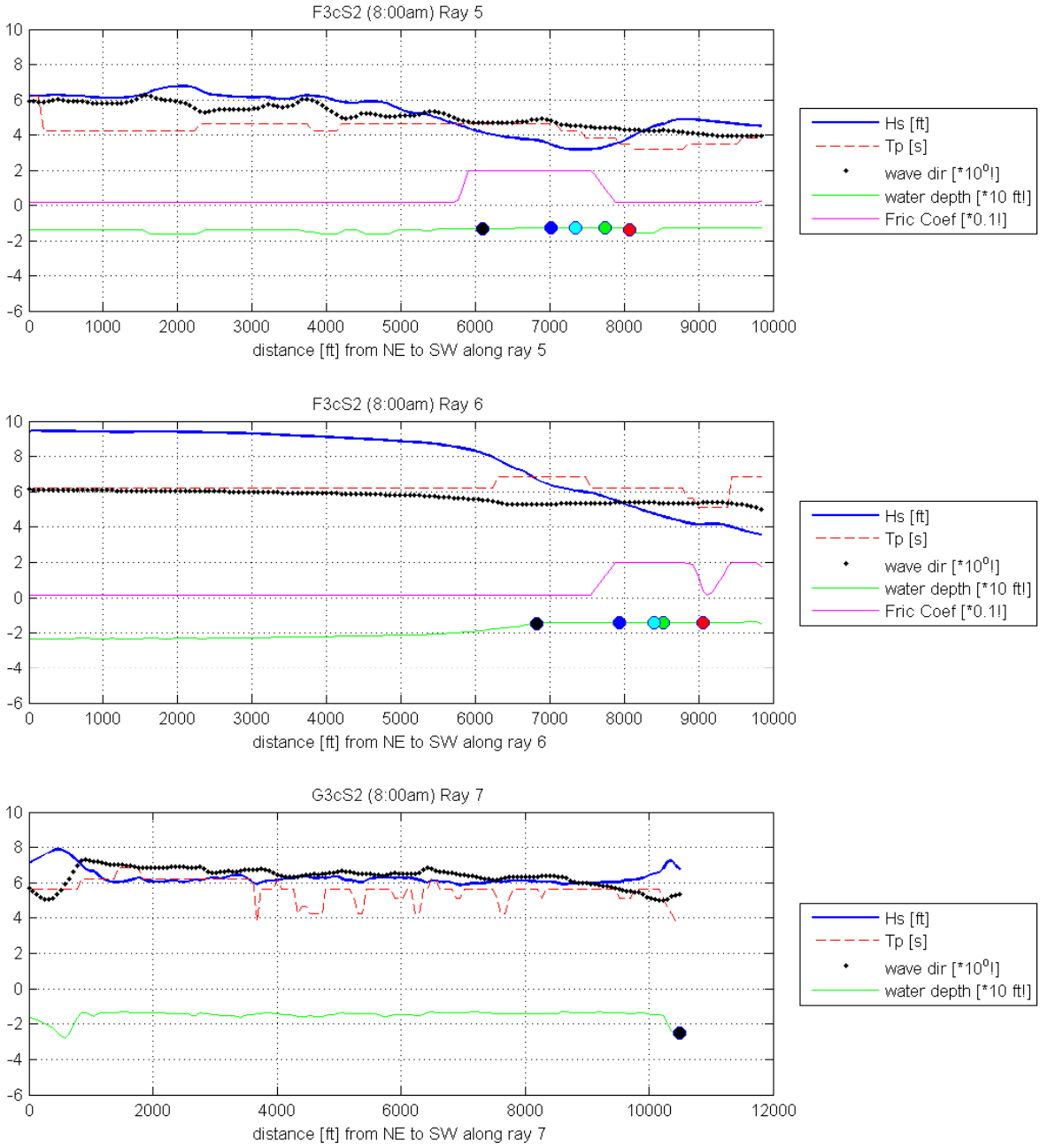


Figure C6.b: Wave parameters on rays 5-7 at 8:00 am LT Scenario 2A

APPENDIX D: Scenario 2B "virgin no-MRGO scenario, no levees"

D.1 Introduction Scenario 2B

Scenario 2B is the situation as if the MRGO nor its levees had ever existed. In this scenario the 40 Arpent Avenue levee has a pre-Katrina crest elevation of 6.5 ft (NAVD88).

D.2 Input SWAN simulations Scenario 2B

The only difference between Scenario 2A and 2B are the water levels of grids M, F and G. Instead of FINEL run 2A, the water levels are based on the results of FINEL run 2B.

Figure D1 shows the water levels as input for the SWAN computations.

D.3 SWAN results Scenario 2B

SWAN results at output locations

Table D.1 gives the significant wave height, peak wave period, wave direction and surge water level for the seven pre-described output locations. At time 8:00 am (t3) the wave conditions are most severe. The location where the levee used to be in Scenario 1 has the following maxima: 5.5 ft as significant wave height at ray 2, 5.1 seconds as peak period at ray 6 and 15.6 ft as water level at ray 6.

On the levee, the significant wave height in Scenario 2B is 0.1 till 0.5 ft lower than in Scenario 2A. The water levels are in the order of 1 ft lower.

2d-overview of significant wave height - Hs

Figures D2 present the significant wave height on the the F and G grids, completed with parts of the M-grid. In the Cypress forest the wave height is less than in the swamp areas without trees, due to the presence of the trees and the reduced wind velocity. Note that in Scenario 2B, the MRGO has been removed.

2d-overview of peak wave period - Tp

Figure D3 shows the peak wave period on the F and G grids, completed with parts of the M-grid.

Wave parameters along the rays

Figure D4 presents the wave parameters along the seven rays in the area of interest, for time step 8:00 am.

Conclusion Scenario 2B

In Scenario 2B the situation before the MRGO was constructed has been simulated, with Cypress trees growing in the marshes, and no MRGO-levees. The absence of the deep and wide MRGO prevents the waves to grow as they did in Scenario 1. Furthermore, the Cypress forests suppress the waves and reduce the wind velocity so that there is less driving force for the waves to grow. The general outcome of the SWAN simulations of Scenario 2B is that the waves on the location of the present levee would be lower if there were no MRGO.

Hs [ft]	4am (local)				5am (local)		
loc	L	T	D		L	T	D
1	1.7	1.7	1.7		2.1	2.1	2.2
2	2.5	2.5	2.1		3.1	3.1	2.7
3	1.2	1.2	1.4		1.7	1.6	1.9
4	1.6	1.3	1.3		2.1	1.7	1.7
5	1.6	1.2	1.1		2.0	1.6	1.5
6	1.6	1.8	1.9		2.1	2.4	2.5
7			3.4				4.0

dir come from [°N]	4am (local)				5am (local)		
loc	L	T	D		L	T	D
1	59	58	58		57	56	56
2	51	55	70		50	54	67
3	71	65	72		68	63	69
4	38	33	41		37	33	41
5	50	51	50		46	47	49
6	54	53	53		53	52	52
7			54				53

Tp [s]	4am (local)				5am (local)		
loc	L	T	D		L	T	D
1	2.6	2.4	2.4		2.9	2.6	2.6
2	2.6	2.6	2.9		2.9	2.9	3.2
3	2.4	2.4	2.4		2.9	2.9	3.2
4	2.4	2.4	2.4		2.9	2.9	2.6
5	2.0	2.0	2.9		2.2	2.4	3.2
6	2.9	5.1	5.1		3.2	5.1	5.1
7			3.2				3.5

wl [ft]	4am (local)				5am (local)		
loc	L	T	D		L	T	D
1	5.7	5.7	5.8		6.7	6.7	6.8
2	5.9	6.0	6.2		7.1	7.2	7.4
3	6.5	6.6	6.9		7.9	8.0	8.3
4	6.6	6.7	6.9		8.1	8.1	8.3
5	6.6	6.6	7.0		8.0	8.1	8.4
6	8.1	8.4	8.4		9.7	10.0	10.0
7			7.2				8.6

Table D1.a: Results SCENARIO 2B SWAN simulations 4am and 5 am on output locations (Hs, Direction, Tp, Water level; for output locations, see Paragraph 2.5; L=levee, T=toe, D=deeper parts)

Hs [ft]	t1=6am (local)				t2=7am (local)				t3=8am (local)				t4=9am (local)		
loc	L	T	D		L	T	D		L	T	D		L	T	D
1	2.8	2.8	2.8		3.5	3.5	3.6		4.4	4.4	4.5		4.3	4.3	4.4
2	3.8	3.8	3.4		4.7	4.7	4.3		5.5	5.5	5.2		4.5	4.5	4.6
3	2.2	2.2	2.4		2.9	2.9	3.1		3.5	3.5	3.8		2.8	2.8	2.9
4	2.7	2.2	2.3		3.4	2.9	3.1		4.0	3.5	3.7		3.3	3.1	3.2
5	2.6	2.1	2.0		3.3	2.7	2.7		3.8	3.2	3.3		2.9	2.7	2.8
6	2.8	3.1	3.3		3.6	4.0	4.2		4.1	4.5	4.7		2.4	2.7	2.8
7			4.8				5.8				6.7				4.6

dir come from [°N]	t1=6am (local)				t2=7am (local)				t3=8am (local)				t4=9am (local)		
loc	L	T	D		L	T	D		L	T	D		L	T	D
1	54	53	53		52	51	51		52	51	51		32	32	33
2	49	52	63		49	51	60		50	52	59		22	23	27
3	65	60	66		64	59	63		65	61	65		19	17	19
4	36	33	40		37	35	41		40	38	43		10	9	10
5	42	43	47		41	42	47		44	45	49		8	11	18
6	51	50	51		51	51	51		54	54	54		22	20	20
7			51				50				54				34

Tp [s]	t1=6am (local)				t2=7am (local)				t3=8am (local)				t4=9am (local)		
loc	L	T	D		L	T	D		L	T	D		L	T	D
1	3.2	2.9	2.9		3.2	3.2	3.2		3.5	3.5	3.5		4.7	4.7	4.7
2	3.2	3.2	3.5		3.8	3.8	3.8		4.2	4.7	4.2		4.7	4.7	5.1
3	3.2	3.2	3.8		3.5	3.5	4.2		4.2	3.8	4.7		4.7	4.7	4.7
4	3.2	3.2	3.2		3.5	3.5	3.5		3.8	3.8	3.8		4.7	4.7	4.7
5	2.6	2.9	3.5		2.9	3.2	4.2		3.2	3.8	4.7		4.7	4.7	4.7
6	4.2	5.1	5.1		4.7	4.7	4.7		5.1	6.2	6.2		4.7	4.7	4.7
7			3.5				3.5				3.8				4.2

wl [ft]	t1=6am (local)				t2=7am (local)				t3=8am (local)				t4=9am (local)		
loc	L	T	D		L	T	D		L	T	D		L	T	D
1	8.0	8.0	8.1		9.5	9.5	9.6		11.5	11.5	11.6		13.4	13.5	13.5
2	8.6	8.7	8.8		10.4	10.4	10.6		12.4	12.5	12.6		13.7	13.7	13.8
3	9.6	9.7	9.9		11.5	11.6	11.9		13.6	13.7	13.9		14.0	14.0	14.0
4	9.8	9.9	10.0		11.8	11.9	12.0		13.9	14.0	14.1		14.1	14.1	14.1
5	9.8	9.8	10.2		11.9	11.8	12.2		13.9	13.9	14.2		14.1	14.1	14.1
6	11.6	11.9	11.9		13.9	14.1	14.2		15.6	15.8	15.8		14.1	14.1	14.1
7			10.0				11.5				13.7				13.5

Table D1.b: Results SCENARIO 2B SWAN simulations 6-9am on output locations (Hs, Direction, Tp, Water level; for output locations, see Paragraph 2.5; L=levee, T=toe, D=deeper parts)

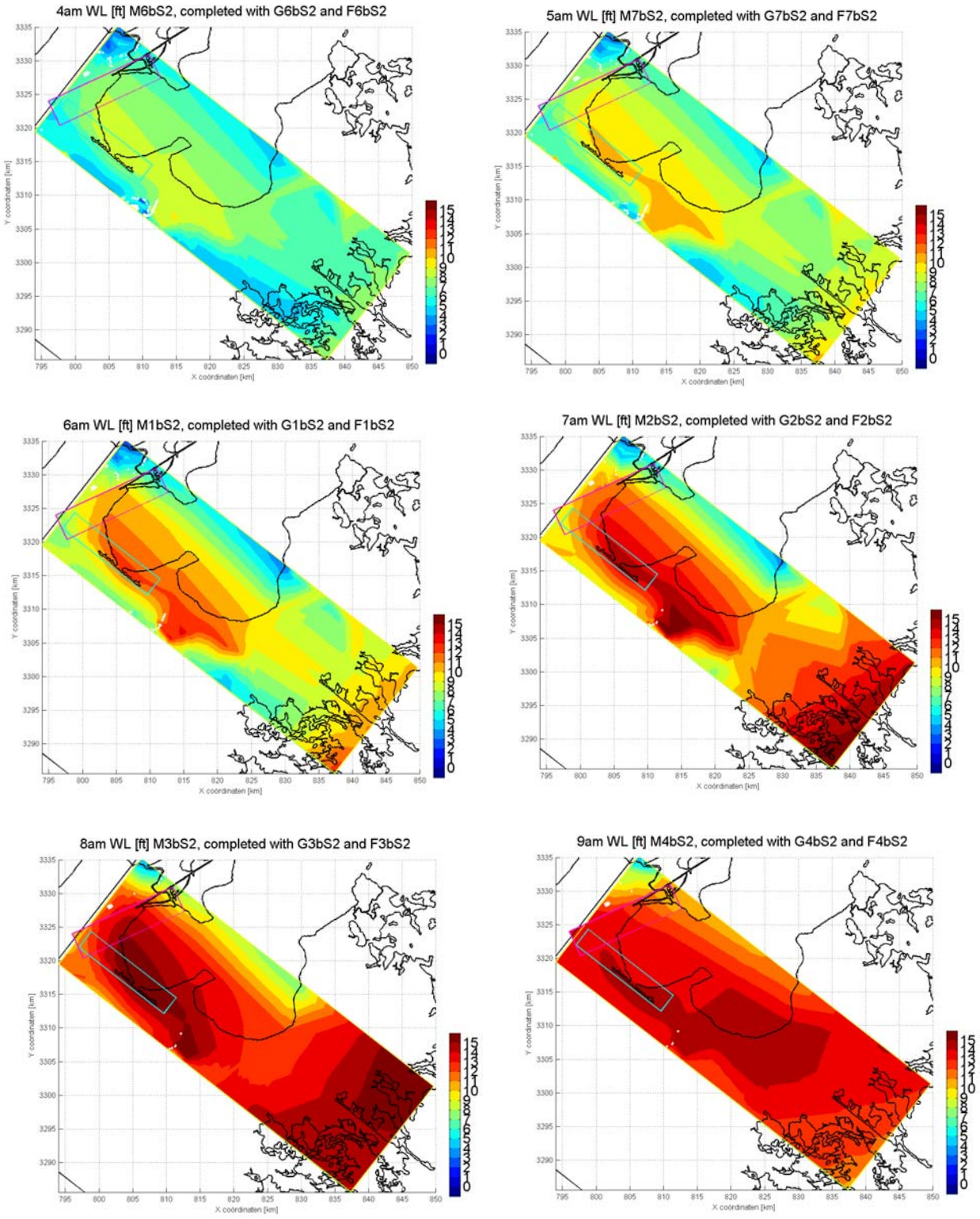


Figure D1: Scenario 2B: Surge water level fields [ft relative to NAVD88] 4am, 5am, 6am, 7am, 8am, 9am LT based on data from FINEL and ADCIRC

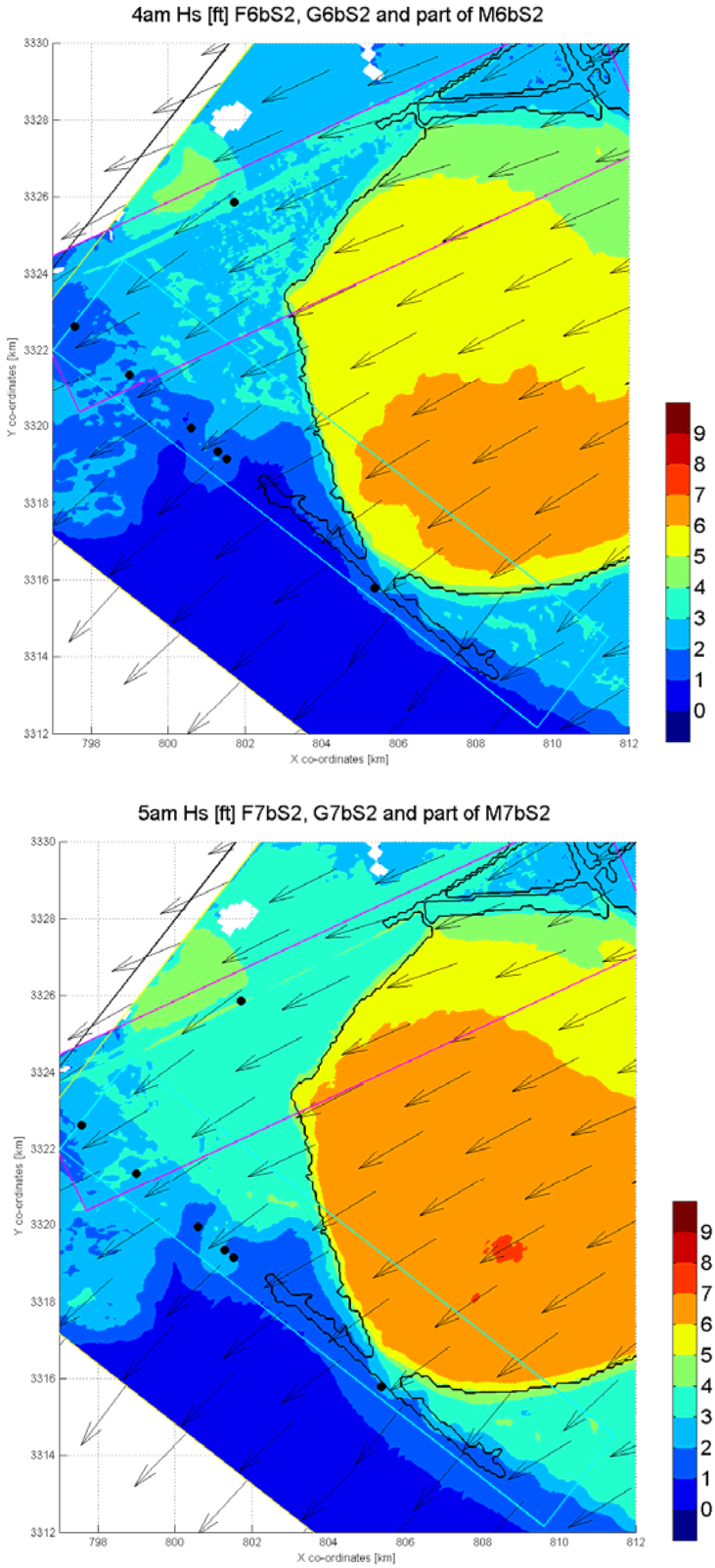


Figure D2.a: Scenario 2B: SWAN results significant wave height Hs [ft] and wave direction 4am and 5am LT on grid F, G and part of M

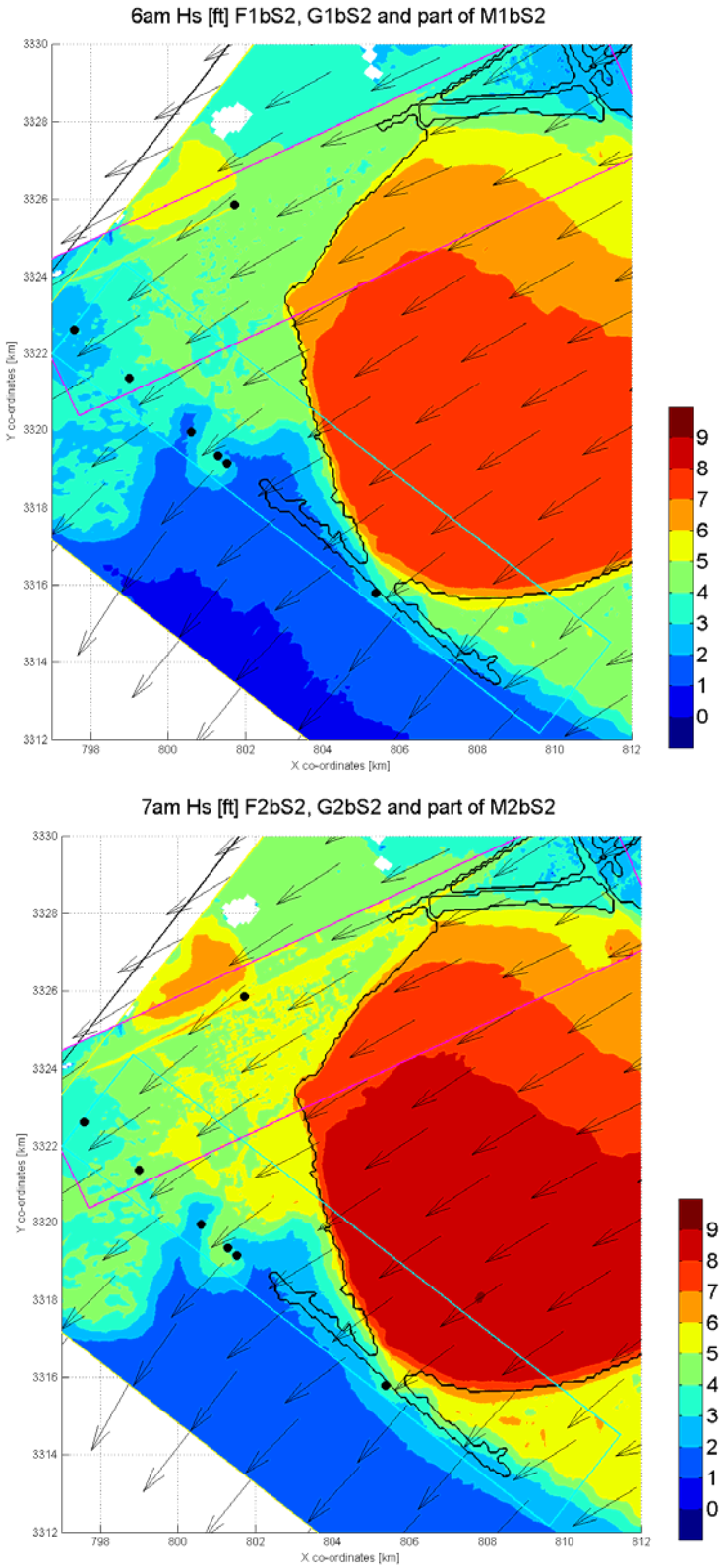


Figure D2.b: Scenario 2B: SWAN results significant wave height Hs [ft] and wave direction 6am and 7am LT on grid F, G and part of M

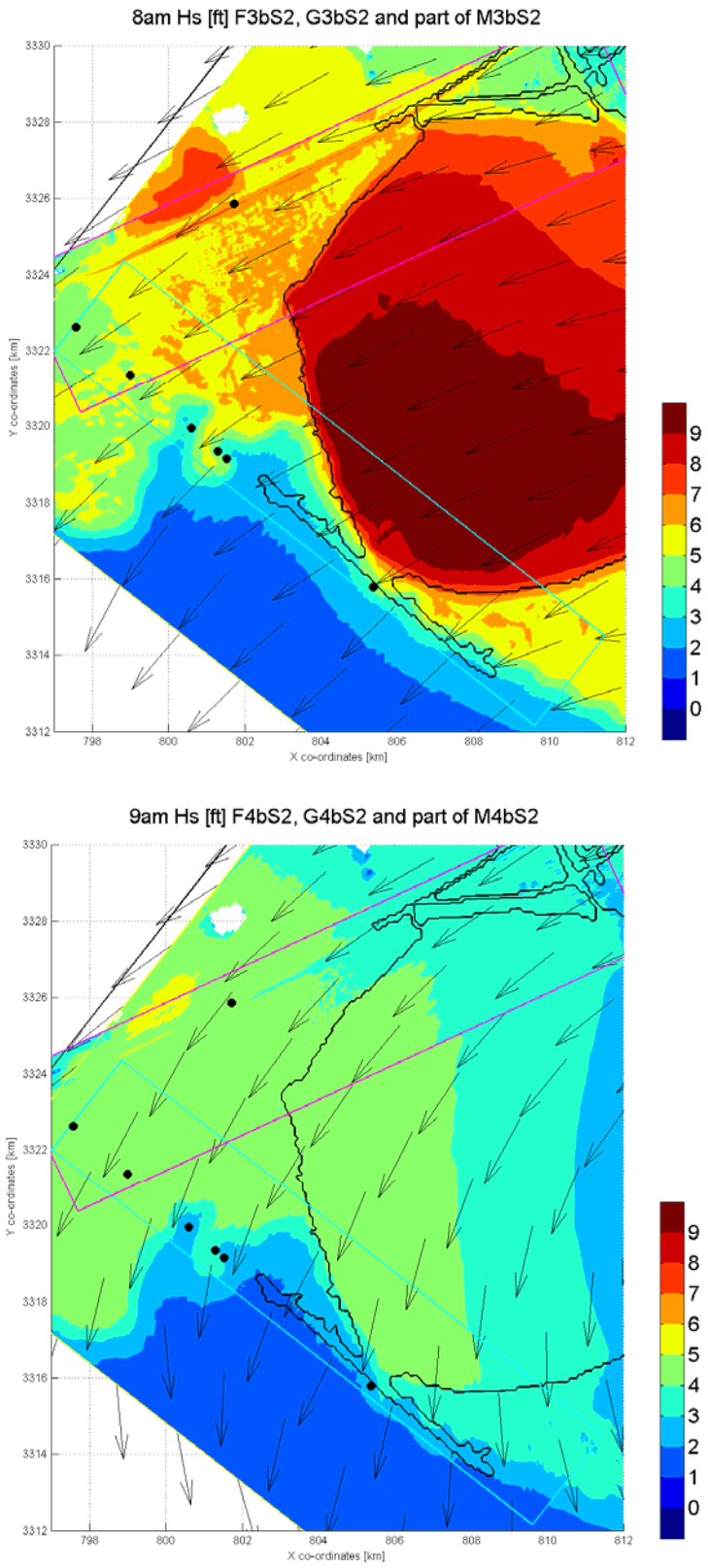
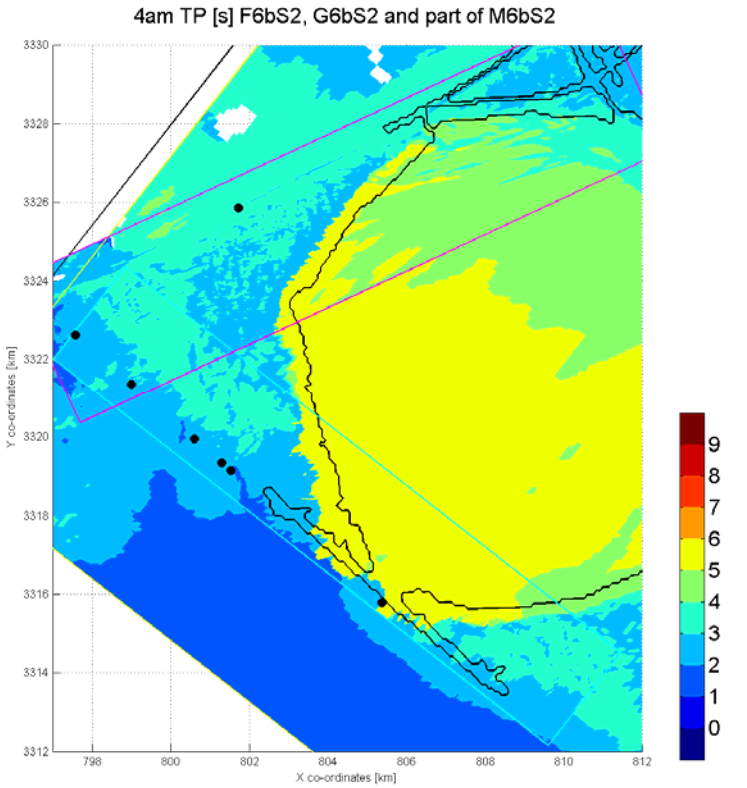


Figure D2.c: Scenario 2B: SWAN results significant wave height Hs [ft] and wave direction 8am and 9am LT on grid F, G and part of M



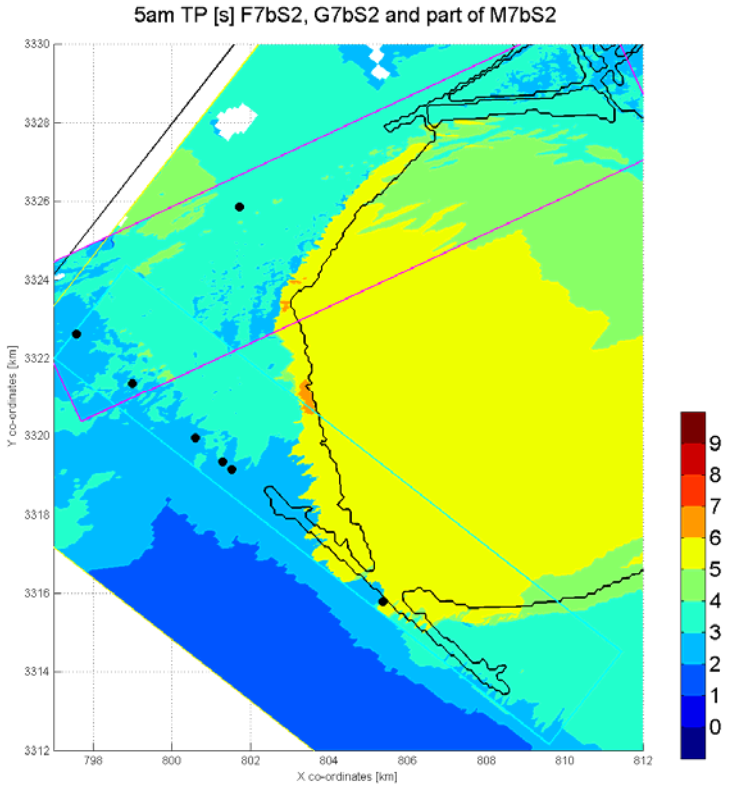


Figure D3.a: Scenario 2B: SWAN results peak wave period Tp [s] 4am and 5am LT on grid F, G and part of M

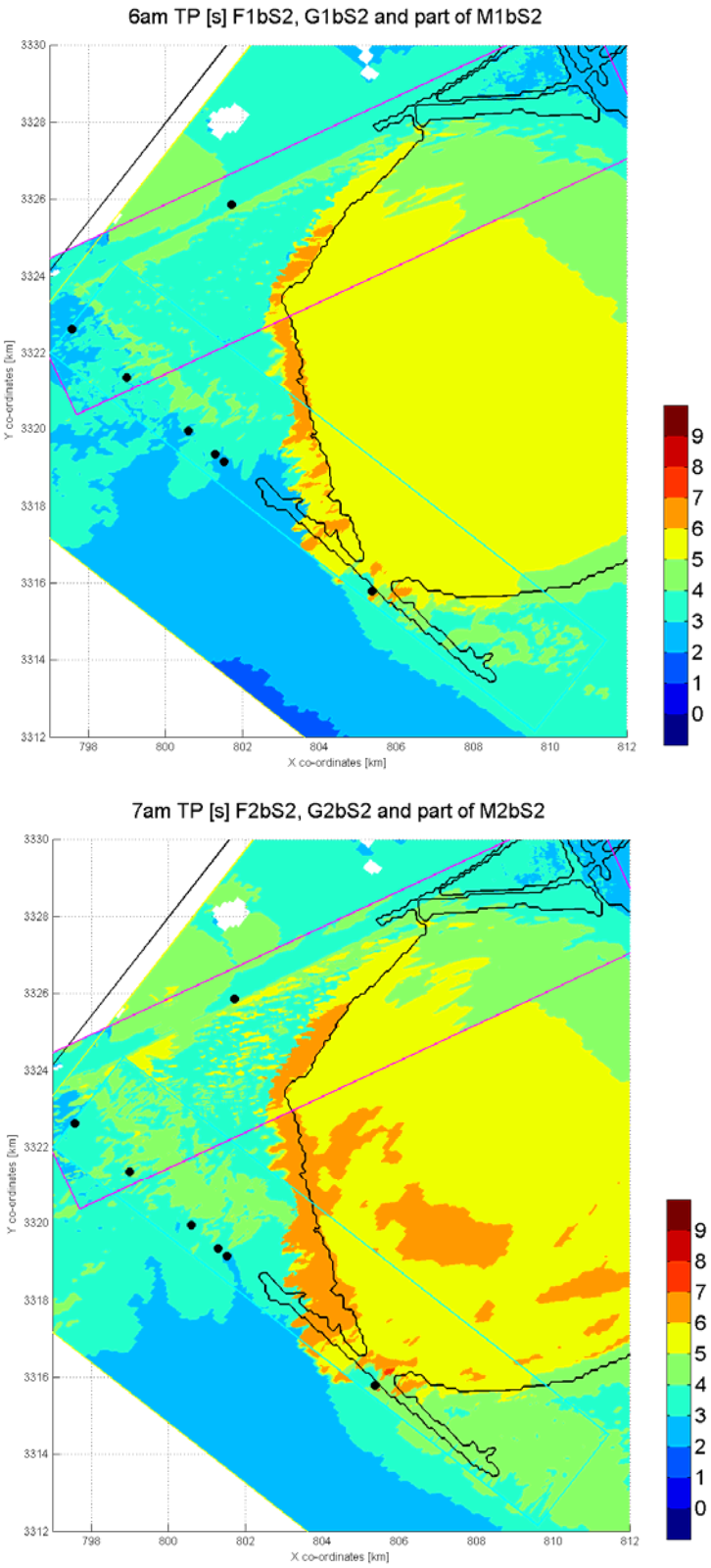


Figure D3.b: Scenario 2B: SWAN results peak wave period Tp [s] 6am and 7am LT on grid F, G and part of M

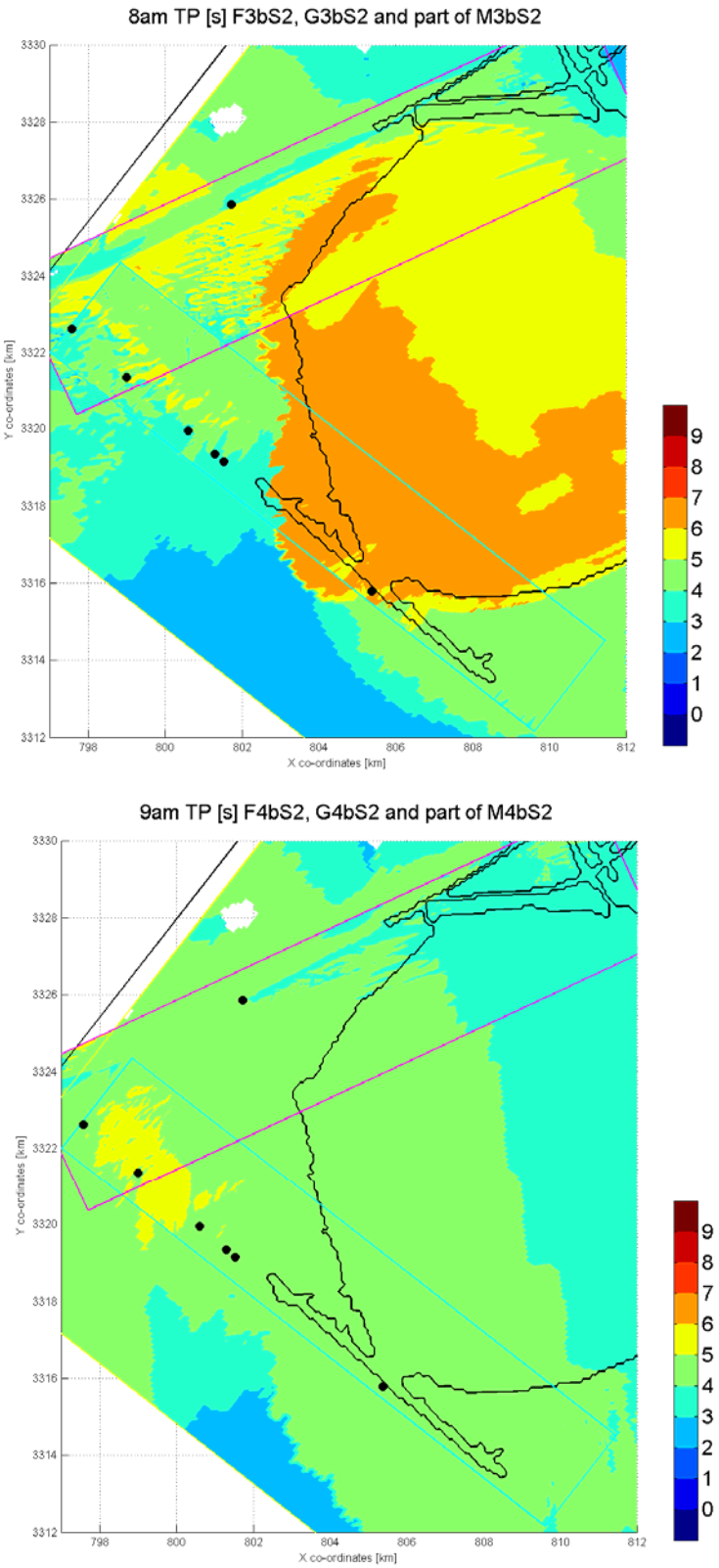


Figure D3.c: Scenario 2B: SWAN results peak wave period Tp [s] 8am and 9am LT on grid F, G and part of M

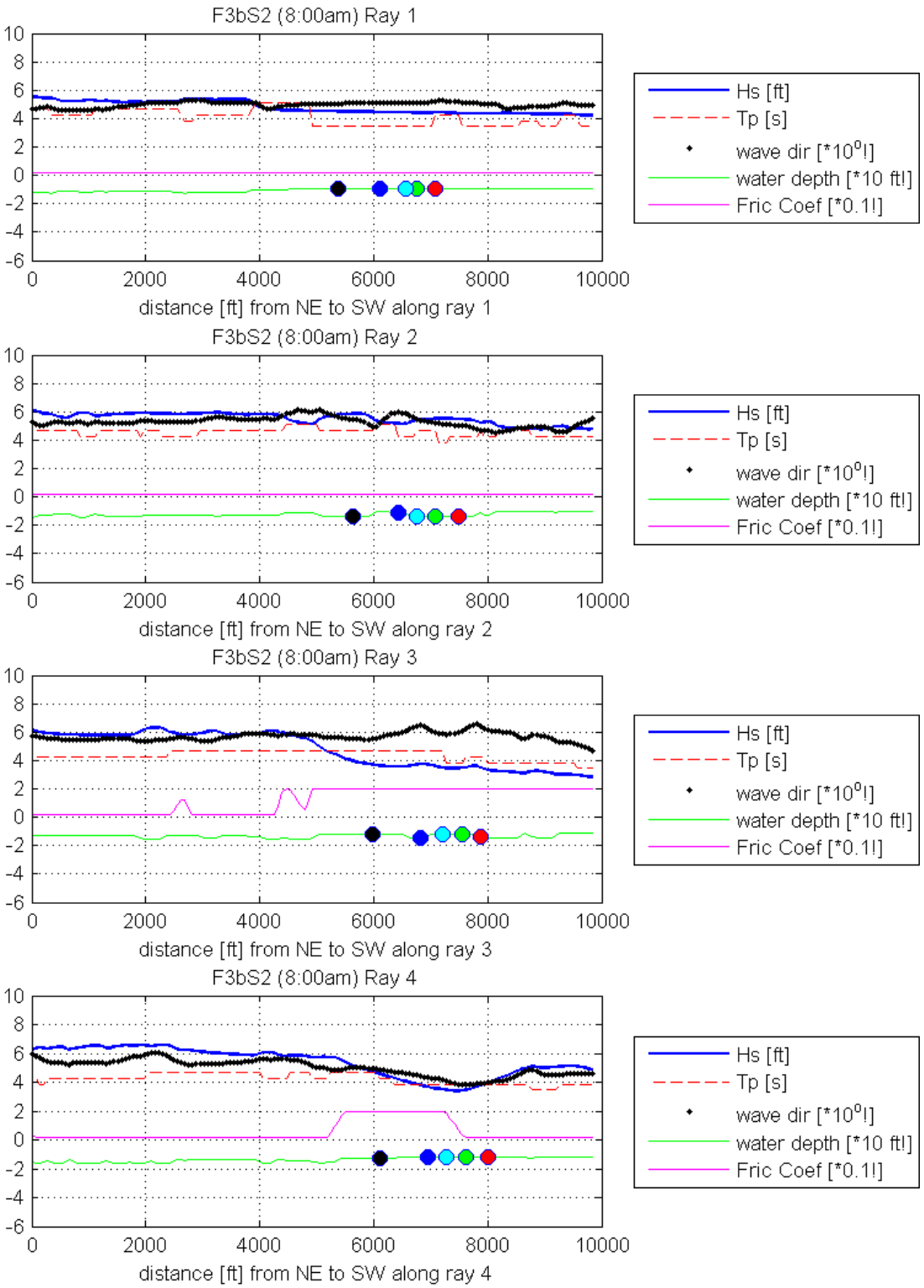


Figure D4.a: Scenario 2B; Wave parameters on rays 1-4 at 8am LT (colored circles indicate output locations)

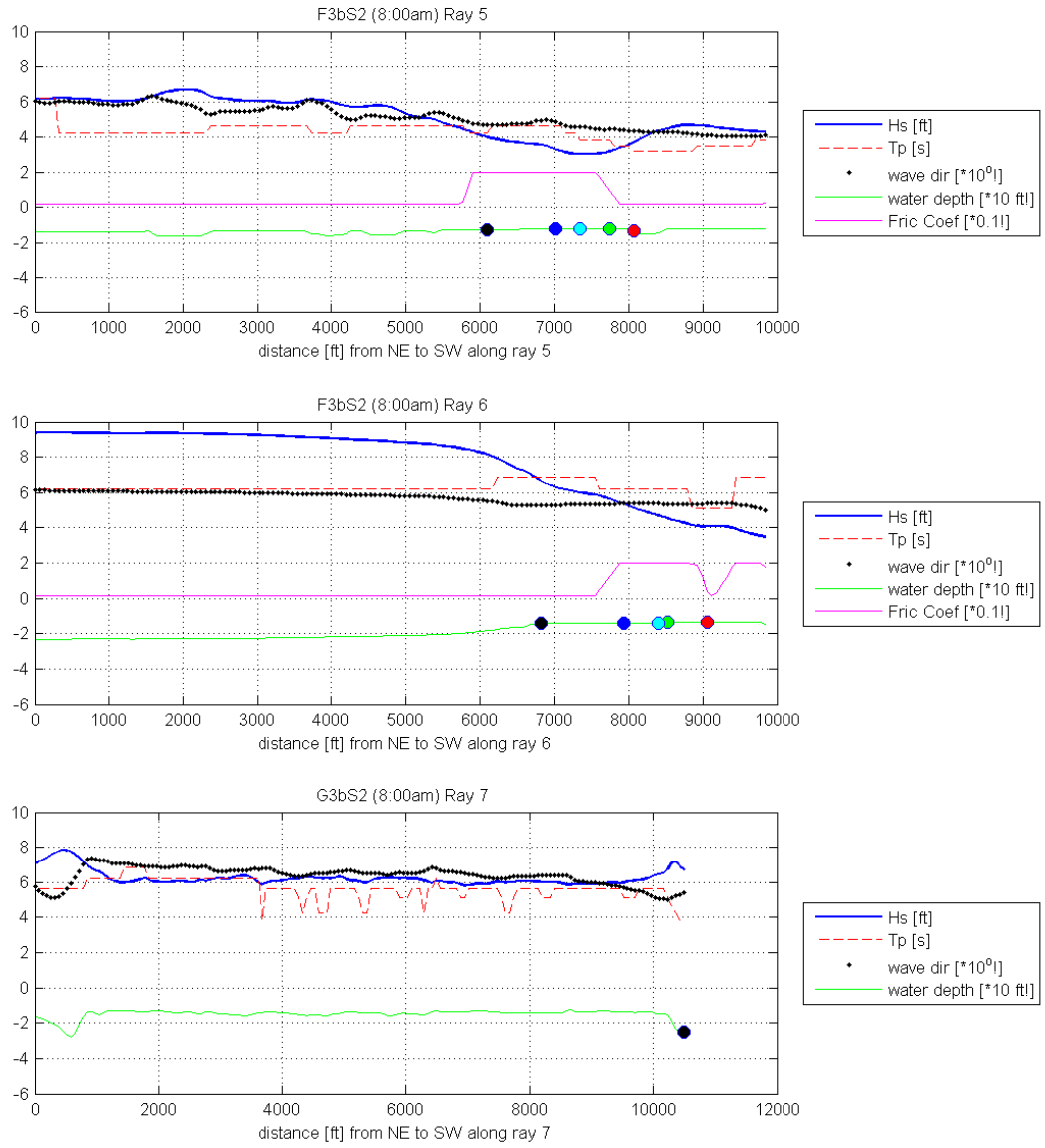


Figure D4.b: Scenario 2B; Wave parameters on rays 5-7 at 8am LT (colored circles indicate output locations)

APPENDIX E: Scenario 3 "MRGO-as-designed scenario"

E.1 Introduction Scenario 3

This chapter deals with Scenario 3, the "MRGO-as-designed scenario". We run a Katrina storm with a scenario run modified with a MRGO channel as originally designed.

Scenario 3 consists of the Katrina storm in combination with:
- the MRGO levees along their current alignment at their pre-Katrina elevations,
- the MRGO channel (Reach 1 and reach 2) at its authorized width, depth, and alignment and with
- the pre-MRGO (1958) wetlands/swamps (incl trees where they used to be) and shoreline.

The authorized dimensions of the MRGO, as originally designed, refer to a bottom width of 500 ft, slopes 1:2 and a depth of 36 ft.

E.2 Input Scenario 3

The position and resolution of the computational grids is equal to those in Scenario 1. Also the wave boundary conditions, numerical settings, output locations and most physical settings are the same. Since the difference between the scenarios are limited to the area within computational grid C, the Scenario 1 results on the base grid (A) are valid for Scenario 3 too.

Input for Scenario 3 that differs from Scenario 1:
- Bathymetry
- Bottom friction
- Wind
- Water levels

Bathymetry Scenario 3

The bathymetry for Scenario 3 consists of the Scenario 2A-bathymetry to which the MRGO at its design dimensions is added. MRGO Reach 1 and 2 have dimensions of 36 feet deep, 500 feet wide at the bottom and 650 feet wide at the top, as provided by the Robinson experts.

The levees along the MRGO Reach 1 and 2 are at the actual pre-Katrina crest heights, as provided by the Robinson experts. These were also present in the bathymetry of Scenario 1.

The GIWW has the dimensions of 150 feet wide and 12 feet deep (similar as in Scenario 1), as provided by the Robinson experts.

The resulting depths in the model area are shown in Figure E1. The adjusted bathymetry for Scenario 3 is only included in computational grids C, M, F and G.

Bottom friction Scenario 3

In Scenario 3 the Cypress forest south west of Lake Borgne is included albeit that it is cut by the MRGO. Where trees are present, the bottom friction coefficient is raised from 0.015 to 2.0 (see also explanation for bottom friction of Scenario 2C and Figure 4.5). The marshes have a friction coefficient of 0.49. In the MRGO and on its levees we did not include any vegetation ; hence the friction coefficient is 0.015 here.

There are three different values for the friction coefficient (Cfr=stem rigidity * Diameter [m] * number/m^2 * Height [m]):

- Cypress forest	Cfr= 0.9	* 0.5	*	0.9	*	5	= 2.0
- Spartina (moderate)	Cfr= 0.5	* 0.01	*	49	*	2	= .49
- Flat (Lake, Channel, Ocean)	Cfr= 0.015 (SWAN's default value)						

The perimeter of the Cypress forest is as we received it from the Robinson experts (Ivor van Heerden), see Figure 4.5. The larger bottom friction is only included in computational grids M and F. Figure E2 shows the friction coefficient as input for the SWAN computations.

Wind Scenario 3

Inside the cypress forest the influence of the wind is reduced by the trees. Therefore the wind velocities are reduced by 80% (percentage provided to us by the Robinson experts) inside Cypress forests. Along the MRGO channel, the wind is not reduced, which makes the wind for this scenario different from Scenario 2A/B/C.

The reduced wind is only included in computational grids M and F. Figure E3 shows the wind velocities as input for the SWAN computations. The resolution of the wind file for Scenario 3 is 500 m x 500 m (1640 ft x 1640 ft) which is twice as fine as in Scenario 1.

Water levels Scenario 3

The water level data consists of non-uniform data fields based on the combination of ADCIRC S08 simulations for Scenario 3 performed by the Robinson experts and FINEL simulations for Scenario 3 (Wit, de 2008). The water levels for Scenario 3 are only included in computational grids M, F and G. Figure E.4 shows the water levels as input for the SWAN computations.

E.3 SWAN results Scenario 3

General

NB:
When comparing the results of Scenario 3 with other scenarios one should keep in mind that the output locations have the same coordinates, but not necessarily the same elevation. The names "levee", "toe" etc are based on Scenario 1.

In Scenario 3 the MRGO has its authorized dimensions which are smaller than its actual size. The Cypress forest is present south west of Lake Borgne. The levees are in place.

Scenario 1 revealed that the waves grow as they cross the MRGO; we expect smaller waves in Scenario 3 as the MRGO is narrower. Also the trees and marh vegetation will dampen the waves since they reduce the wind velocity and physically obstruct the waves. The water

levels of Scenario 3, using a combination of FINEL and ADCIRC output, are more or less similar to the ones from Scenario 1.

Scenario 3: SWAN results at output locations

Tables E1.a and b present the significant wave height, peak period, wave direction and water level for a few locations on the seven output rays. On the levee the significant wave height of Scenario 3 is roughly 1 ft less than of Scenario 1. The maximum significant wave height at a levee output location is 6.0 ft on location 1. The maximum period occurs on locations 1,2,6 and is 4.2 s.

Scenario 3: 2d-overview of significant wave height - Hs

Figures E5.a-c show 2d-plots of the significant wave height. One can recognize the MRGO with higher waves and the Cypress trees with lower waves. The larger waves on the MRGO are present over a narrower width than in Scenario 1.

Scenario 3: 2d-overview of peak wave period - Tp

Figure E6a-c shows 2d-plots of the peak period. The period varies between circa 3 and 7 seconds. On 8 am the wave periods are highest.

Scenario 3: Wave parameters along the rays

Figures E7a-b present the wave parameters (including bottom friction coefficient and water levels) along the seven rays in the area of interest at 8:00 am local time.

The location of the rays can be found in Figure 2.6. The colored dots have the same position as the ones in Scenario 1, but since the MRGO has been changed in Scenario 3, their vertical elevation is different. One can see that the cross section of the MRGO is smaller than in Scenario 1.

The variation in friction coefficient depends on the presence of the vegetation causing additional friction. One can see that the wave height reduces as the friction coefficient increases.

Hs [ft]	4am (local)			5am (local)		
loc	L	T	D	L	T	D
1	0.0	2.7	3.0	0.0	3.5	3.7
2	0.0	3.1	3.1	2.4	3.8	3.8
3	0.0	2.5	1.9	0.0	3.1	2.4
4	1.9	2.5	2.3	2.6	3.1	2.9
5	0.0	2.2	1.6	0.0	2.8	2.0
6	2.2	2.6	3.0	2.8	3.3	3.7
7			3.6			4.3

dir come from [°N]	4am (local)			5am (local)		
loc	L	T	D	L	T	D
1	0	45	45	0	44	42
2	0	47	50	49	45	47
3	0	52	59	0	49	54
4	35	41	40	35	39	37
5	0	42	42	0	39	37
6	45	47	51	44	47	50
7			53			51

Tp [s]	4am (local)			5am (local)		
loc	L	T	D	L	T	D
1	0.0	2.9	2.6	0.0	3.2	3.2
2	0.0	2.9	2.9	3.2	3.2	3.2
3	0.0	2.6	2.2	0.0	2.9	2.4
4	2.6	2.4	2.4	2.9	2.6	2.6
5	0.0	2.4	2.2	0.0	2.6	2.4
6	2.9	2.6	2.9	3.2	2.9	3.2
7			3.2			3.5

wl [ft]	4am (local)			5am (local)		
loc	L	T	D	L	T	D
1	0.0	8.8	8.7	0.0	10.6	10.5
2	0.0	9.0	9.0	10.9	10.8	10.8
3	0.0	9.2	9.1	0.0	11.0	10.9
4	9.3	9.2	9.2	11.1	11.0	11.0
5	0.0	9.3	9.2	0.0	11.0	11.0
6	9.5	9.4	9.4	11.2	11.1	11.1
7			8.2			9.7

Table E1.a: Results SWAN Scenario 3: 4am and 5 am on output locations (Hs, Direction, Tp, Water level; for output locations, see Paragraph 2.5; L="levee", T="toe", D="deeper parts")

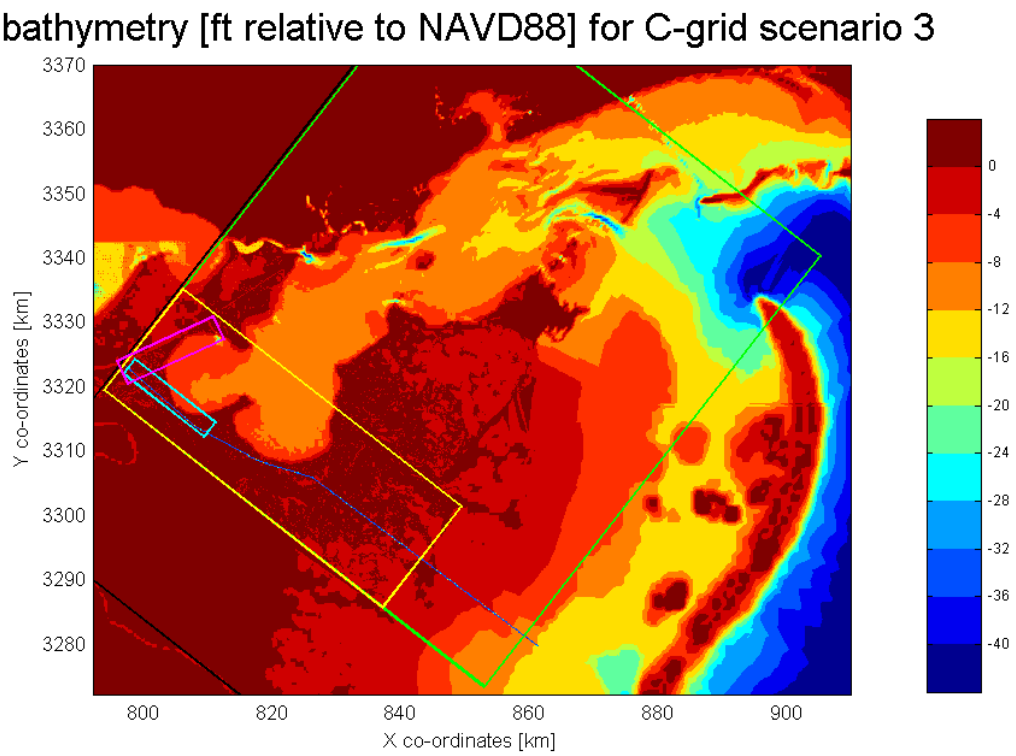
Hs [ft]	6am (local)			7am (local)			8am (local)			9am (local)		
loc	L	T	D	L	T	D	L	T	D	L	T	D
1	-	4.3	4.7	-	5.5	6.0	6.0	6.4	6.9	-	3.9	3.9
2	3.4	4.7	4.8	4.5	5.9	6.1	5.5	6.8	7.0	3.1	3.6	3.7
3	2.9	4.0	3.1	4.1	5.0	3.9	5.0	5.7	4.4	2.6	2.7	2.2
4	3.5	3.9	3.7	4.6	4.9	4.8	5.4	5.6	5.3	2.7	2.8	2.7
5	-	3.5	2.6	-	4.4	3.4	4.9	4.9	3.7	-	2.4	2.1
6	3.6	4.2	4.7	4.7	5.4	6.0	5.2	5.9	6.4	2.0	2.2	2.4
7			4.6			6.3			6.6			4.0

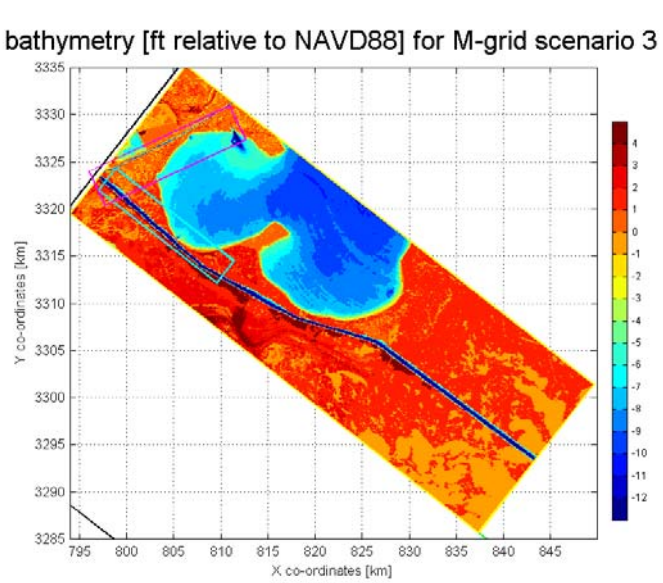
dir come from [°N]	6am (local)			7am (local)			8am (local)			9am (local)		
loc	L	T	D	L	T	D	L	T	D	L	T	D
1	-	41	38	-	39	35	38	39	36	-	23	17
2	48	43	43	46	41	41	46	42	42	32	23	16
3	46	45	47	42	43	43	43	45	46	17	13	1
4	34	36	33	34	35	31	35	36	33	16	14	3
5	-	35	31	-	33	28	42	35	32	-	7	359
6	44	45	47	44	45	47	46	49	51	21	16	12
7			43			47			43			33

Tp [s]	6am (local)			7am (local)			8am (local)			9am (local)		
loc	L	T	D	L	T	D	L	T	D	L	T	D
1	-	3.5	3.5	-	3.8	3.8	4.2	4.2	4.2	-	3.5	3.5
2	3.5	3.5	3.5	3.8	3.8	3.8	4.2	4.2	4.2	3.5	3.5	3.5
3	3.2	3.2	2.6	3.5	3.5	3.2	3.8	3.8	3.2	3.2	3.2	2.9
4	3.2	2.9	2.9	3.5	3.5	3.2	3.8	3.5	3.5	3.2	3.2	2.9
5	-	2.9	2.6	-	3.2	2.9	3.5	3.5	3.2	-	2.9	2.9
6	3.5	3.2	3.5	3.8	3.8	3.8	4.2	3.8	3.8	2.9	2.9	2.9
7			3.5			3.8			4.2			3.5

wl [ft]	6am (local)			7am (local)			8am (local)			9am (local)		
loc	L	T	D	L	T	D	L	T	D	L	T	D
1	-	12.5	12.4	-	14.8	14.7	17.2	17.2	17.2	-	14.6	14.6
2	12.9	12.8	12.7	15.3	15.2	15.1	17.8	17.7	17.6	14.7	14.7	14.7
3	13.0	13.0	12.9	15.4	15.4	15.3	17.8	17.8	17.7	14.7	14.7	14.6
4	13.1	13.0	13.0	15.5	15.4	15.4	17.8	17.7	17.7	14.6	14.6	14.6
5	-	13.0	13.0	-	15.4	15.4	17.8	17.7	17.7	-	14.6	14.6
6	13.2	13.1	13.1	15.7	15.6	15.6	17.7	17.6	17.6	14.4	14.4	14.4
7			11.3			13.1			16.0			14.1

Table E1b: Results SWAN Scenario 3: 6-9am on output locations (Hs, Direction, Tp, Water level; for output locations, see Paragraph 2.5; L="levee", T="toe", D="deeper parts")





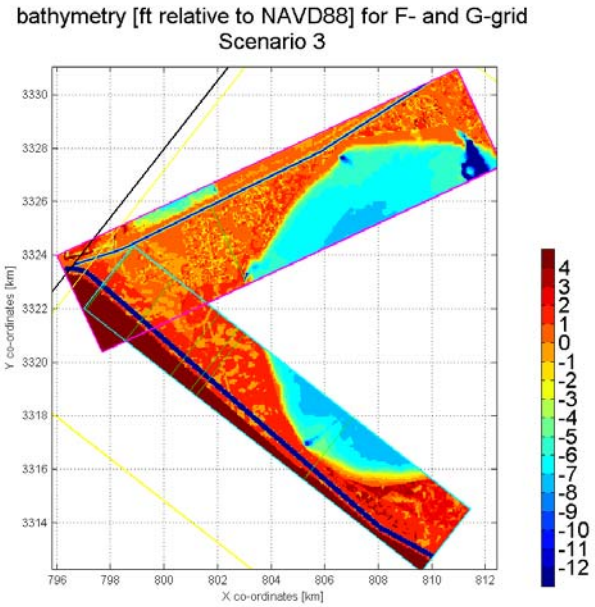


Figure E1: Scenario 3; Bathymetry for C, M, F and G grids [feet relative to NAVD88]

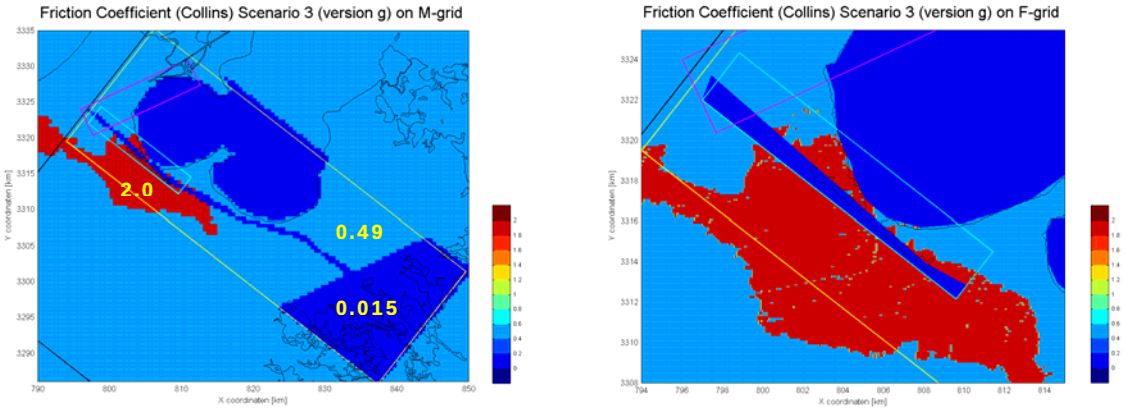


Figure E2: Friction fields Scenario 3g on M-grid and F-grid

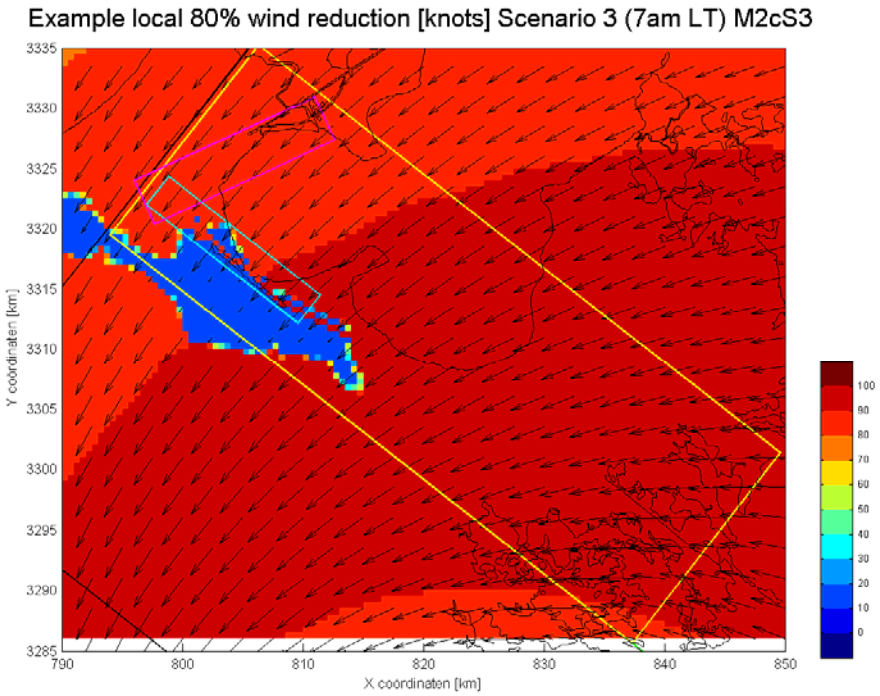


Figure E3: Scenario 3; Example wind field [knots] 7am

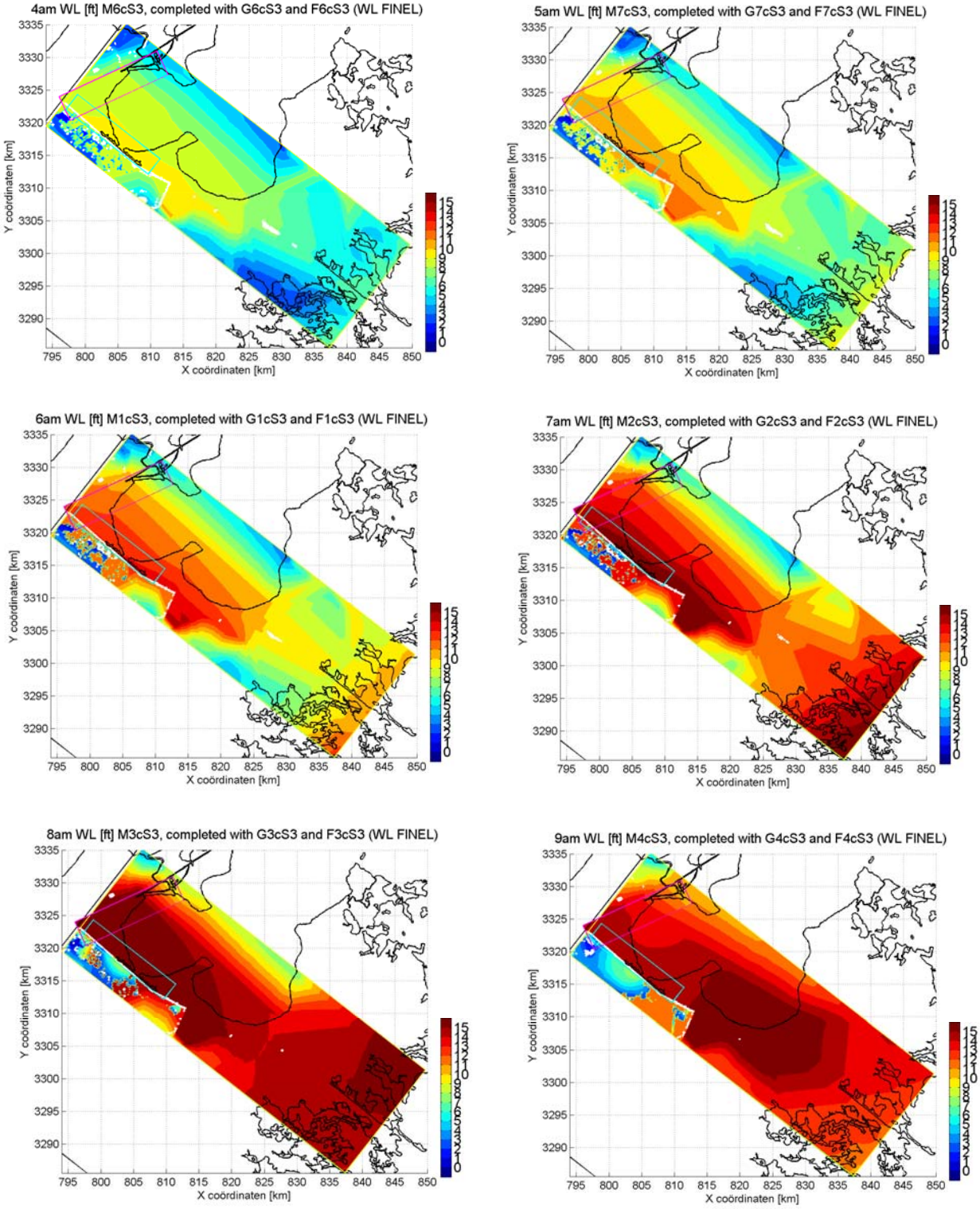


Figure E4: Scenario 3: Water level surge [ft NAVD88]) based on the combination of FINEL Scenario 3 and ADCIRC Scenario 3

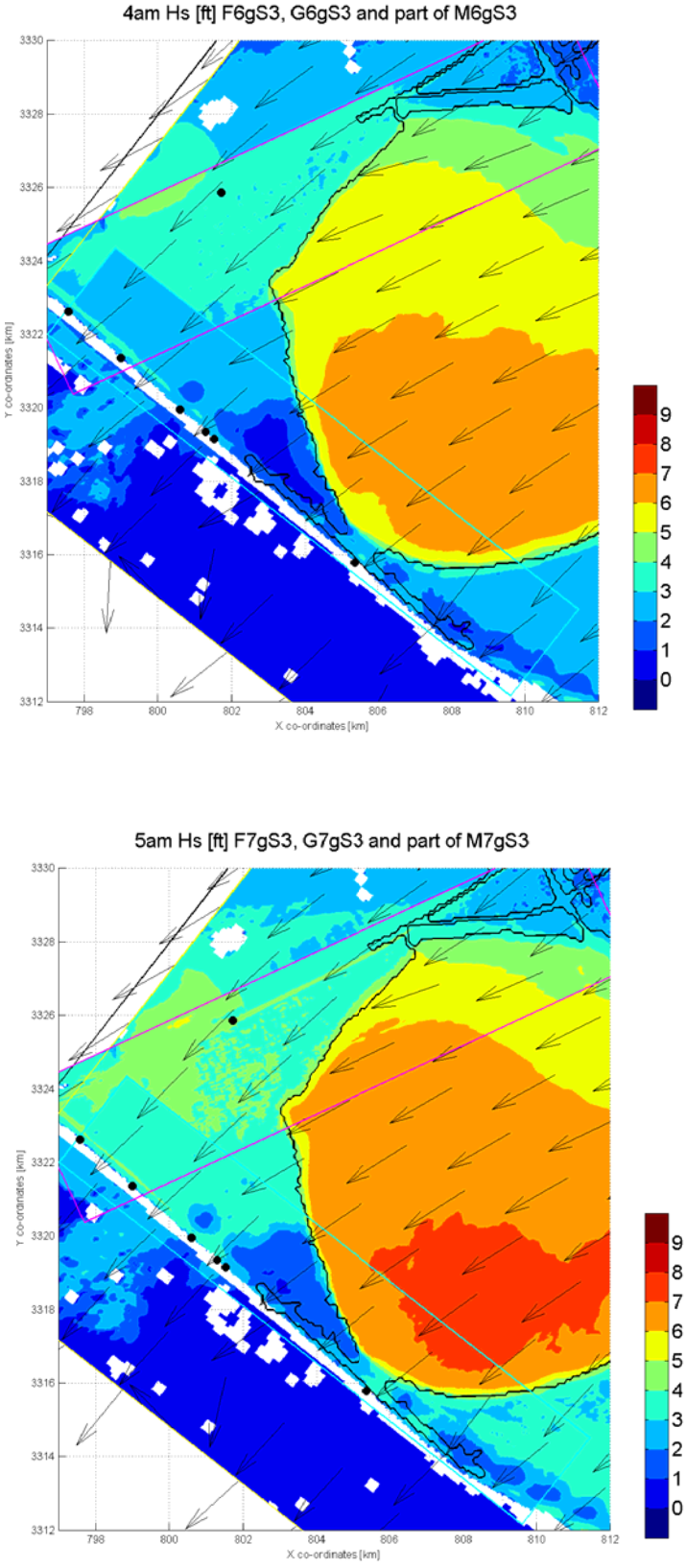


Figure E5.a: Scenario 3: SWAN results significant wave height Hs [ft] and wave direction on grids M, F, G at 4, 5am local time

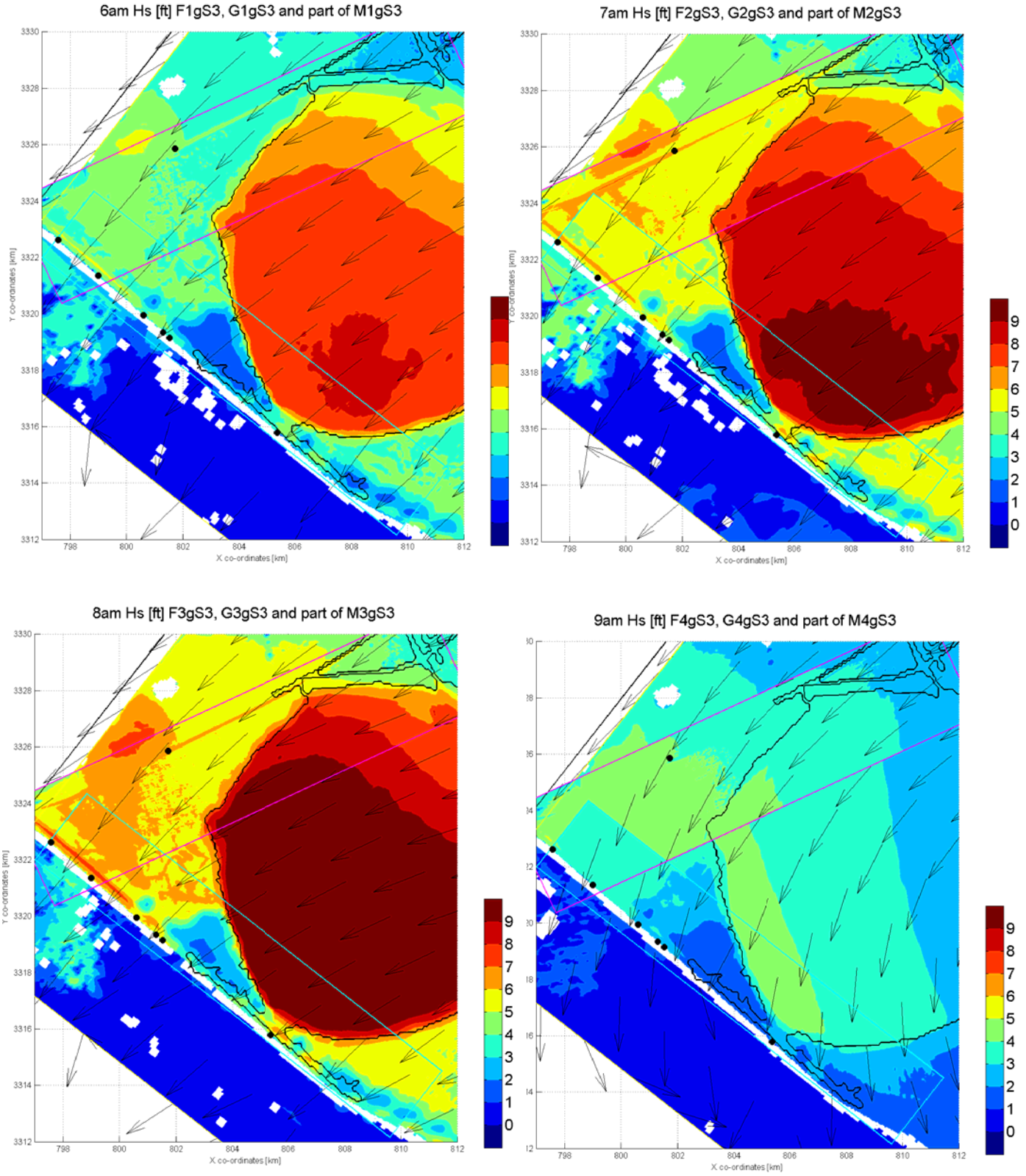


Figure E5.b: Scenario 3: SWAN results significant wave height Hs [ft] and wave direction on grids M, F, G at 6, 7, 8, 9am local time

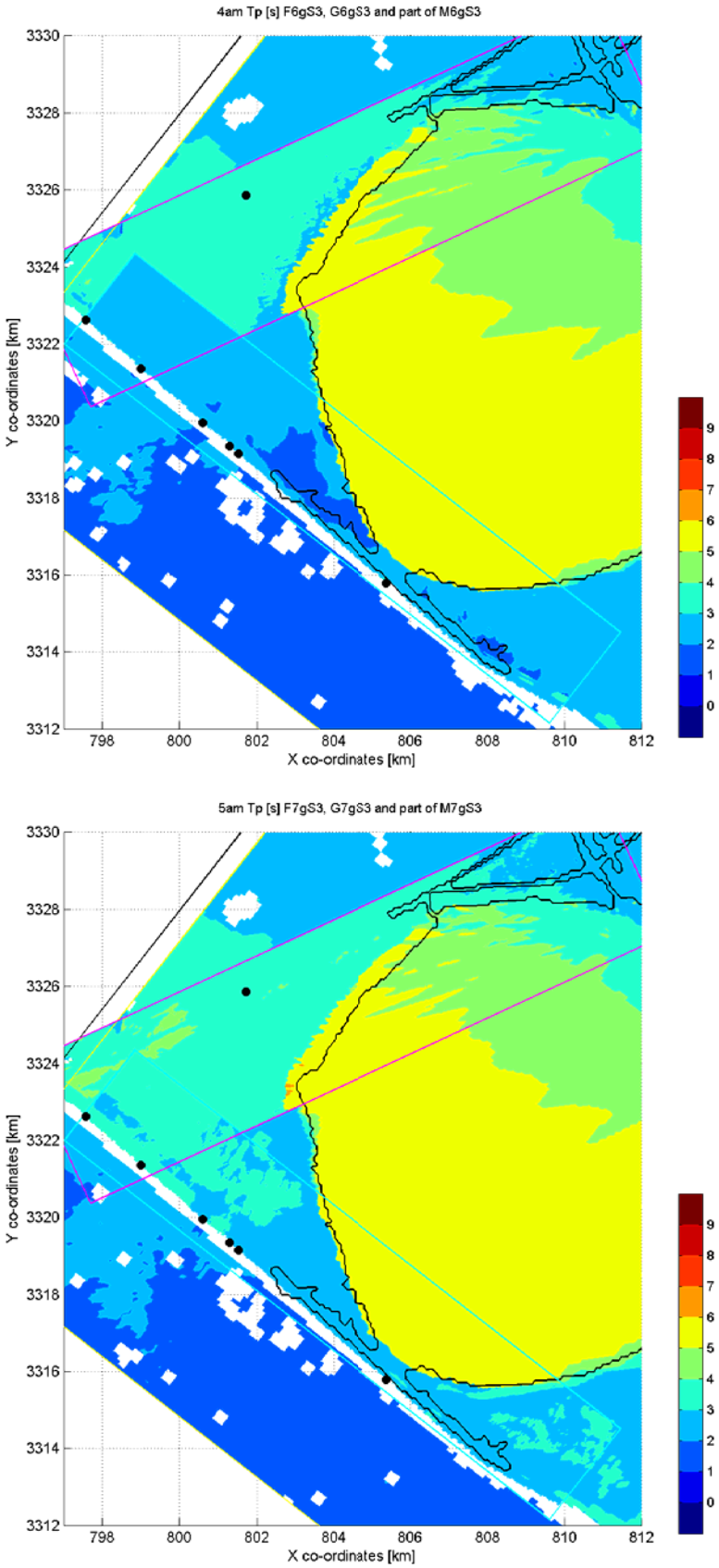


Figure E6.a: Scenario 3, SWAN results peak wave period [s] on grids M, F, G at 4 & 5 am

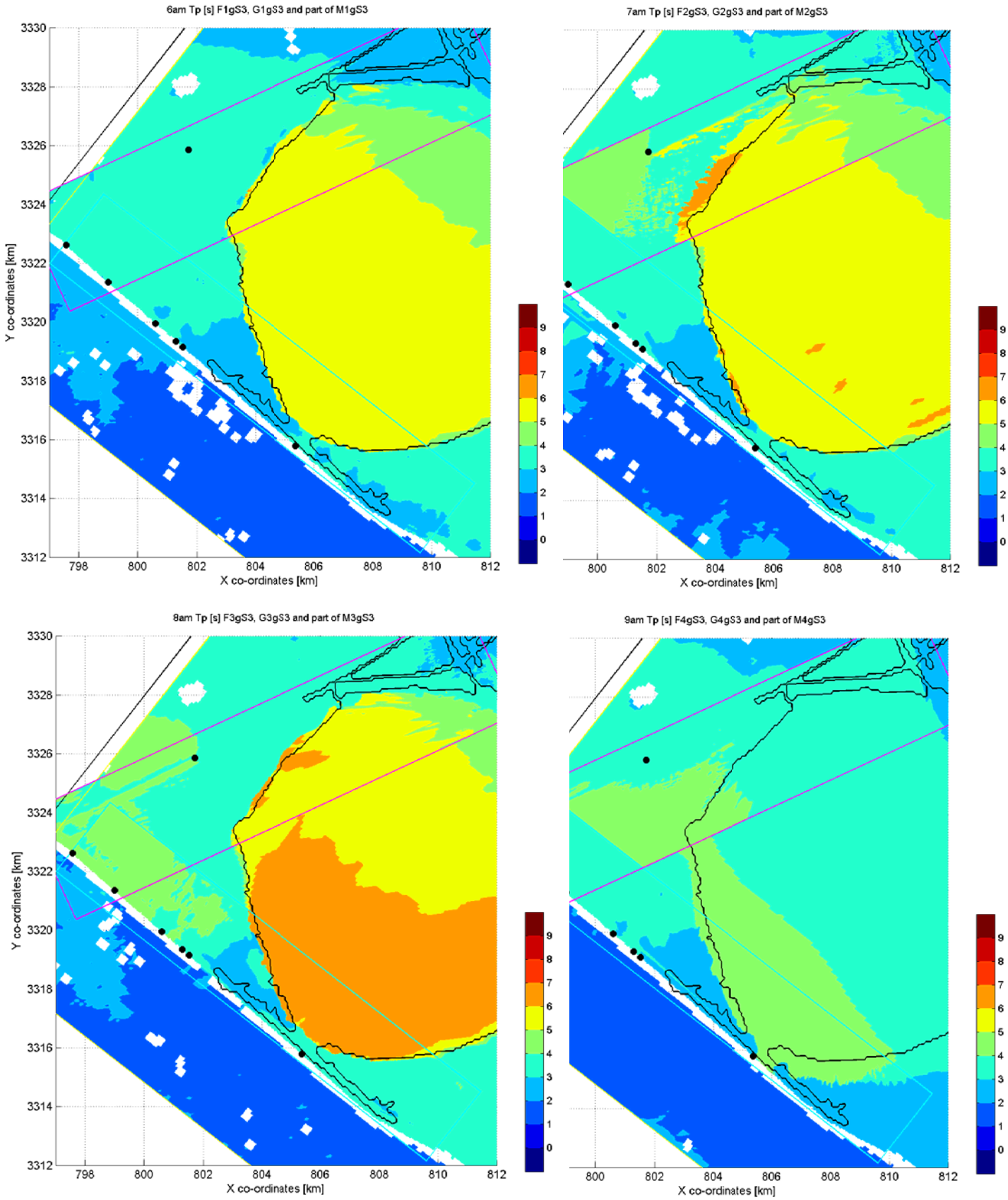


Figure E6.b: Scenario 3, SWAN results peak wave period [s] on grids M, F, G at 6,7,8,9 am

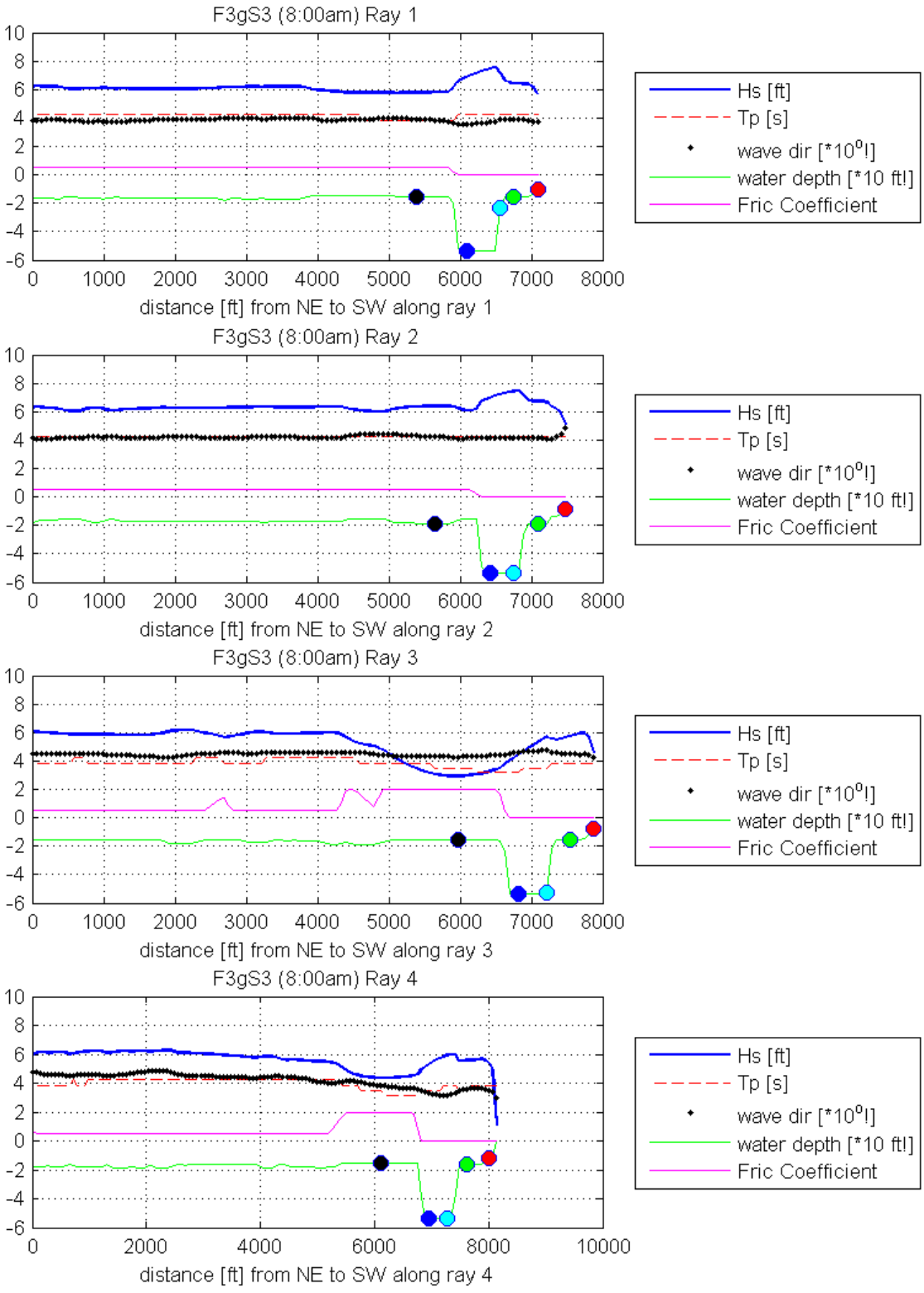


Figure E7.a: Scenario 3, SWAN wave parameters on rays 1-4 at 8:00 am

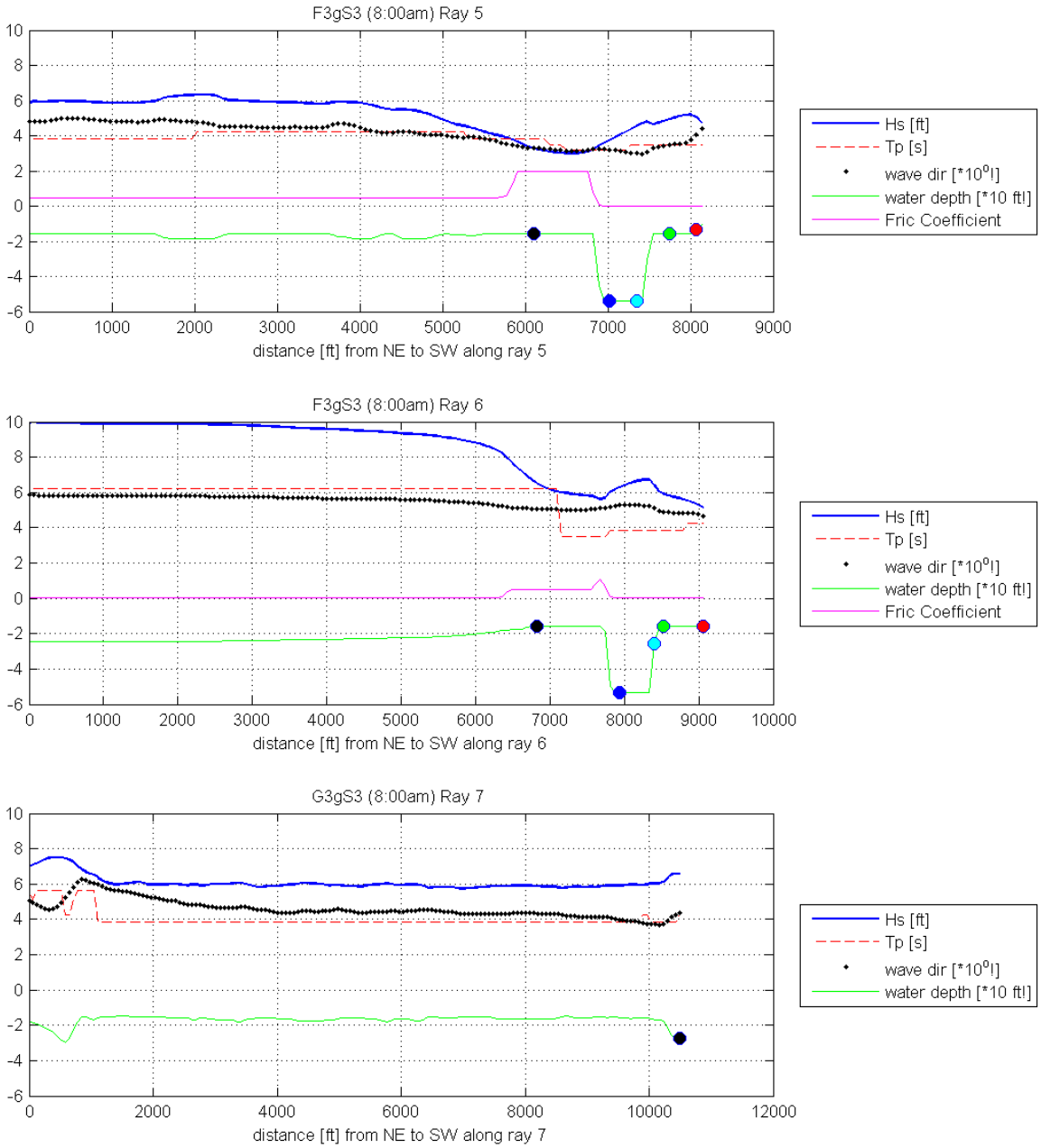


Figure E7.b: Scenario 3, SWAN wave parameters on rays 5-7 at 8:00 am