Overview of the Advanced Circulation (ADCIRC) Coastal Ocean Modeling Framework

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ADCIRC Development Group (www.adcirc.org)

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- **C.D.,** UT Austin
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- **Jason Fleming,** Seahorse Consulting
- **Chris Massey,** ERDC
- **Major contributors:** Arcadis, Inc.; Naval Research Laboratory, Stennis; U.S. Army Corps of Engineers ERDC and New Orleans District office.

ADCIRC design philosophy

- Accurately define the physical system
- Include all of the physical processes
- Numerically resolve the flow
- Ensure accuracy of the solution to the PDE's

ADCIRC design criteria

- High grid resolution to define and capture
  - Local topography and bathymetry
  - Local roughness
  - Critical hydraulic conveyances
  - Structures and raised features that impede or focus flow
  - Wind wave transformation scales

- Accurate numerical algorithms that
  - Are not numerically dissipative
  - Are phase accurate
  - Accommodate high spatial gradients
  - Are robust for high velocity flows

ADCIRC design criteria

- Fully integrate all important processes into the model
  - Accurate winds
  - Accurate momentum transfer to the water column
  - Riverine flows
  - Tides
  - Short wind waves
- Validation

Overview of the modeling system

- **ADCIRC - Circulation model**
- SWAN - Wind wave model (TU Delft)
- Various Wind inputs (NOAA, Whirlwinds, OWI, NHC forecasts, NCEP forecasts)

- Finite element discretizations on unstructured meshes

- Scalable parallel implementation

Models : ADCIRC : ADvanced CIRCulation

- Solves the Generalized Wave Continuity Equation (GWCE):

$$\frac{\partial^2 \zeta}{\partial t^2} + \tau_0 \frac{\partial \zeta}{\partial t} + \frac{\partial \tilde{J}_x}{\partial x} + \frac{\partial \tilde{J}_y}{\partial y} - UH \frac{\partial \tau_0}{\partial x} - VH \frac{\partial \tau_0}{\partial y} = 0$$

where:

$$\tilde{J}_x = -Q_x \frac{\partial U}{\partial x} - Q_y \frac{\partial U}{\partial y} + fQ_y - \frac{g}{2} \frac{\partial \zeta^2}{\partial x} - gH \frac{\partial}{\partial x}\left[\frac{p_s}{g\rho_0} - \alpha\eta\right] + \frac{\tau_{sx} + \tau_{bx}}{\rho_0} + \left(M_x - D_x\right) + U \frac{\partial \zeta}{\partial t} + \tau_0 Q_x - gH \frac{\partial \zeta}{\partial x}$$

$$\tilde{J}_y = -Q_x \frac{\partial V}{\partial x} - Q_y \frac{\partial V}{\partial y} - fQ_x - \frac{g}{2} \frac{\partial \zeta^2}{\partial y} - gH \frac{\partial}{\partial y}\left[\frac{p_s}{g\rho_0} - \alpha\eta\right] + \frac{\tau_{sy} + \tau_{by}}{\rho_0} + \left(M_y - D_y\right) + V \frac{\partial \zeta}{\partial t} + \tau_0 Q_y - gH \frac{\partial \zeta}{\partial y}$$

- Solves the vertically-integrated momentum equations:

$$\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} - fV = -g \frac{\partial}{\partial x}\left[\zeta + \frac{p_s}{g\rho_0} - \alpha\eta\right] + \frac{\tau_{sx} + \tau_{bx}}{\rho_0 H} + \frac{M_x - D_x}{H}$$

$$\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} + fU = -g \frac{\partial}{\partial y}\left[\zeta + \frac{p_s}{g\rho_0} - \alpha\eta\right] + \frac{\tau_{sy} + \tau_{by}}{\rho_0 H} + \frac{M_y - D_y}{H}$$

Models : SWAN : Simulating Waves Nearshore

- Solves the action balance equation:

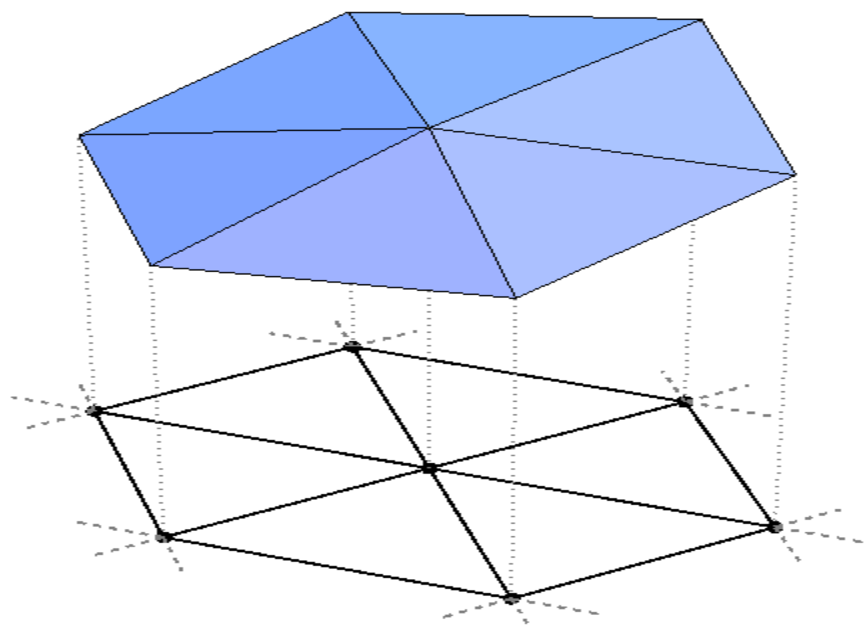
$$\frac{\partial N}{\partial t} + \nabla_{\vec{x}} \cdot \left[\left(\vec{c}_g + \vec{U} \right) N \right] + \frac{\partial c_\theta N}{\partial \theta} + \frac{\partial c_\sigma N}{\partial \sigma} = \frac{S_{tot}}{\sigma}$$

- Computes significant wave heights and returns wave radiation stresses to ADCIRC

Spatial Discretization: the FEM method

- Both ADCIRC and SWAN are discretized using a continuous Galerkin method on unstructured triangular elements

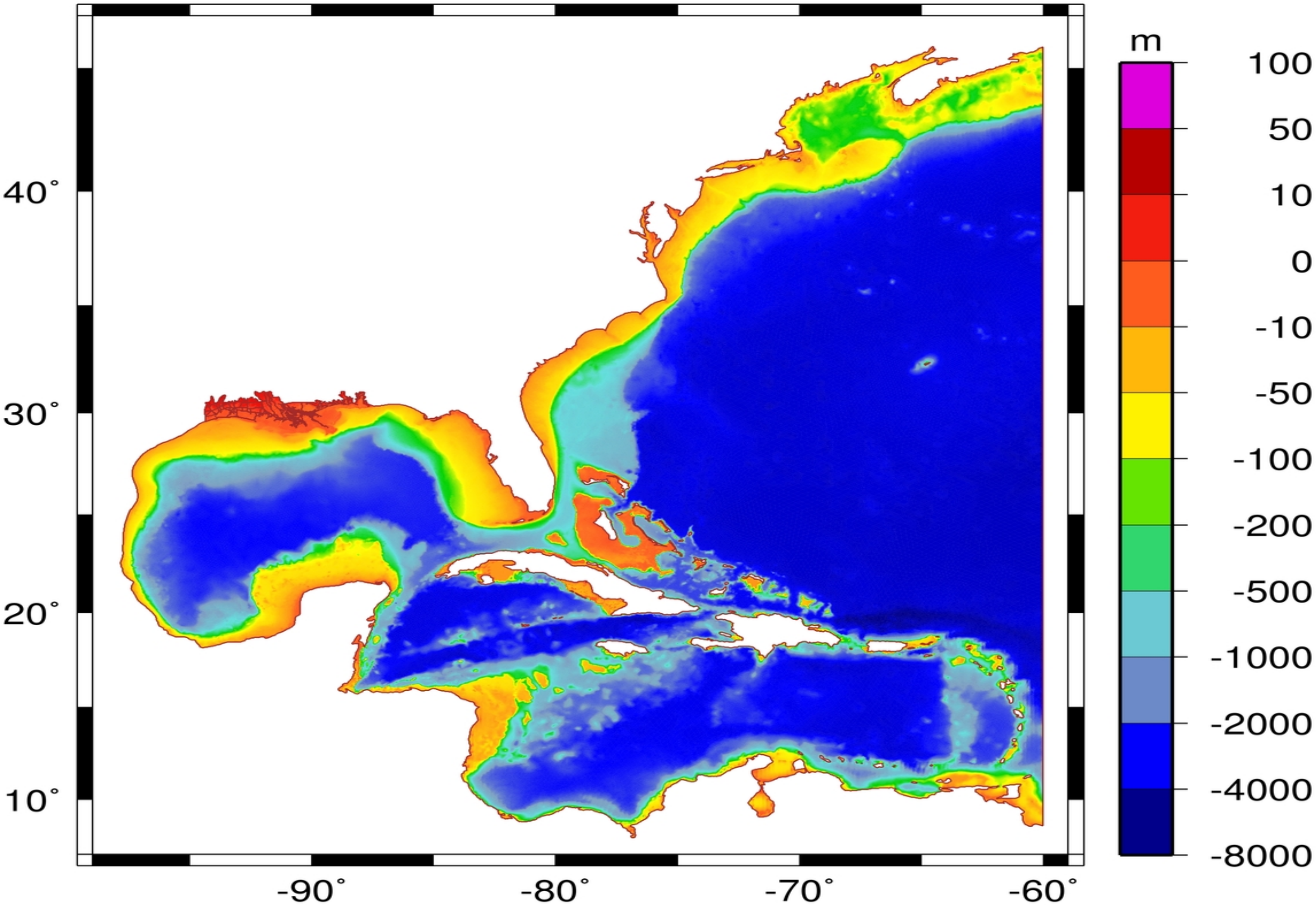
- All unknowns are approximated at the vertices of triangles



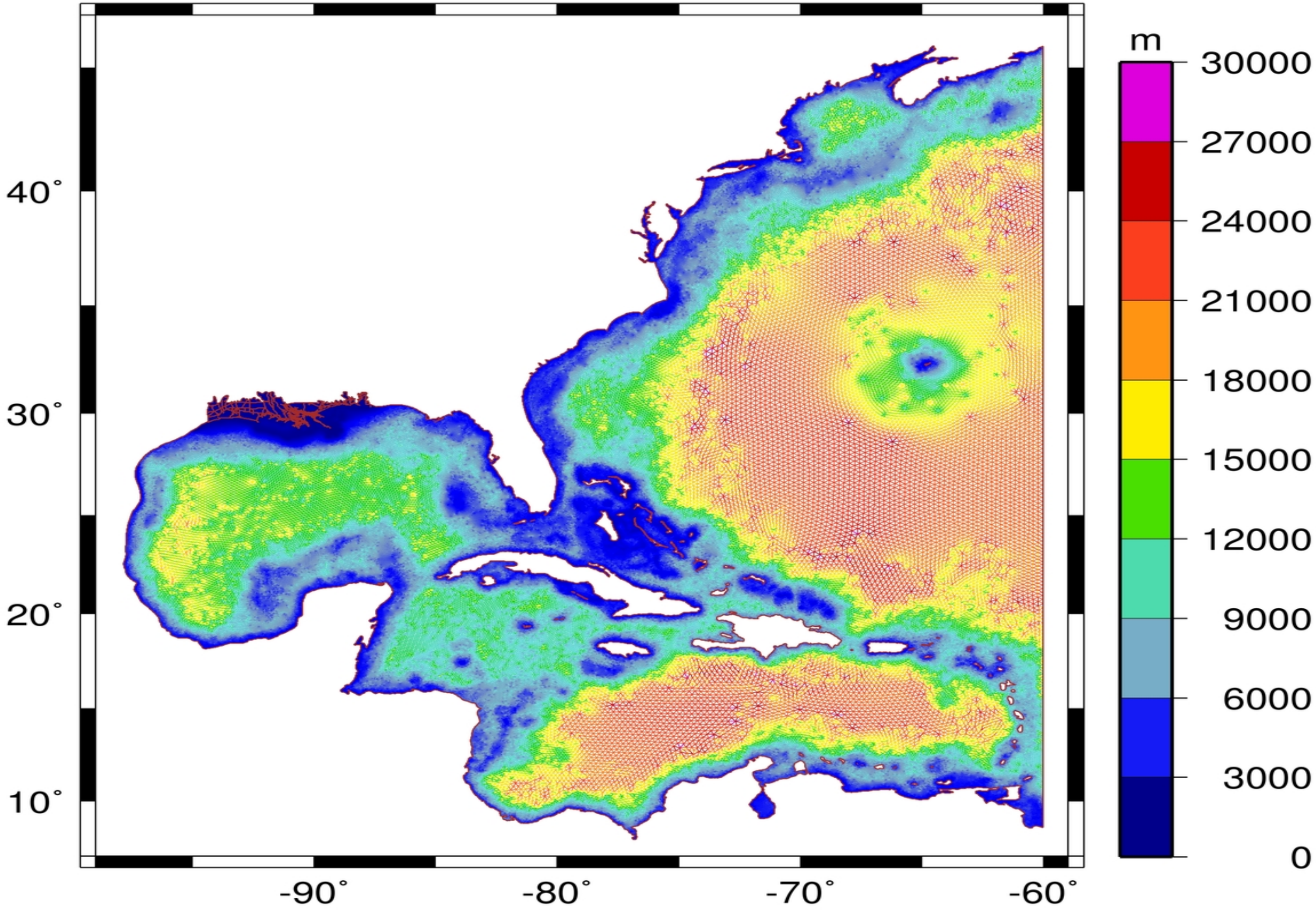
Applications of ADCIRC

- Tidal data base for U.S. East Coast and Gulf of Mexico
- Hindcasts of major Gulf and East Coast Hurricanes
- Water levels for all **levee designs** in Southern Louisiana are based on models developed by our team
- Water levels for the **FEMA DFIRMS** (Digital Flood Insurance Rate Maps) for Louisiana, Texas, Mississippi, Florida, Georgia, South Carolina and North Carolina are based on ADCIRC models (our team developed the TX and LA models)
- ADCIRC is used as a **hurricane forecasting** tool by an LSU-UNC-UT team to provide emergency response information for the States of Louisiana and Texas
- Used to study DH oil spill

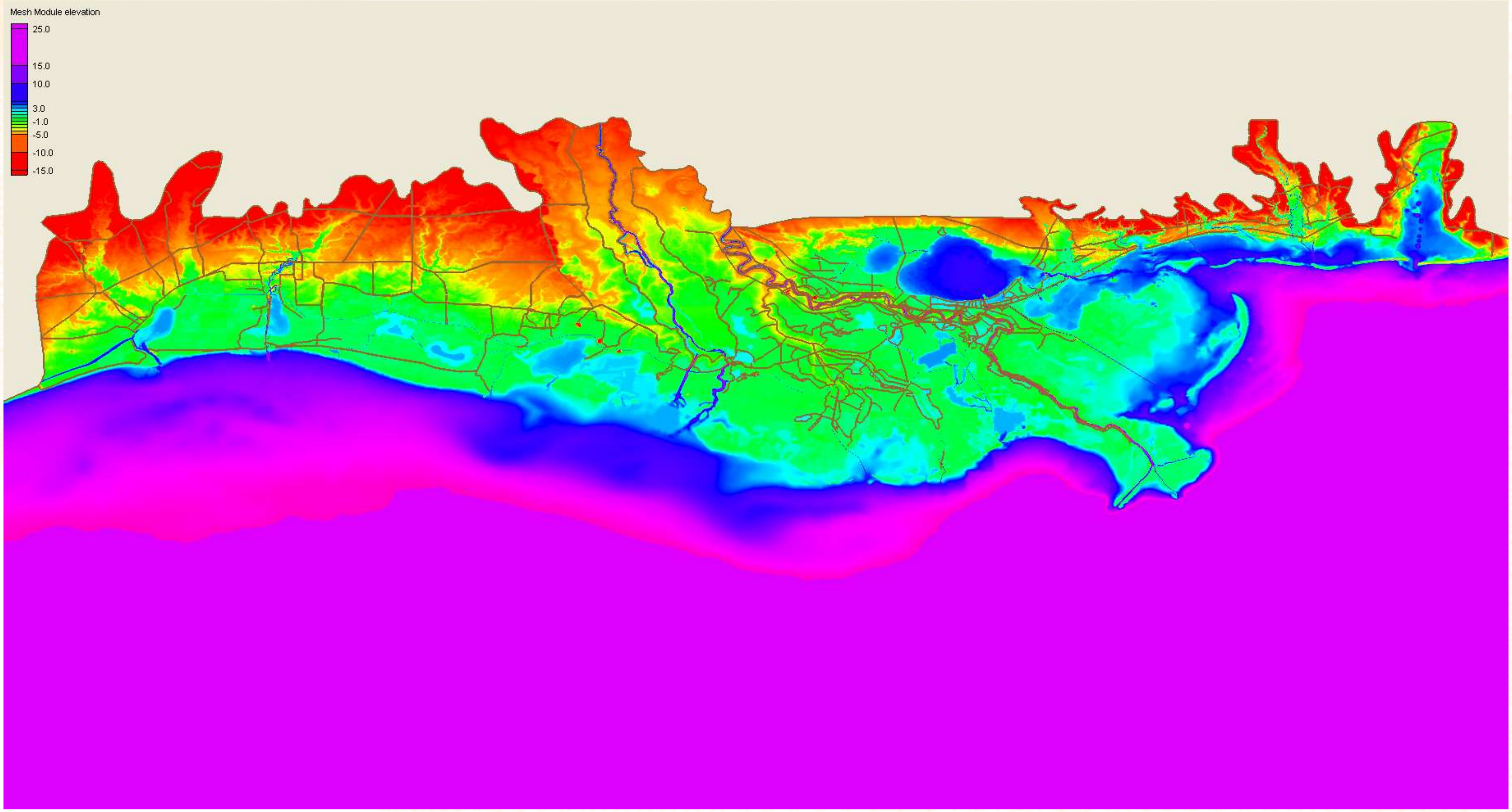
Western North Atlantic ADCIRC Model



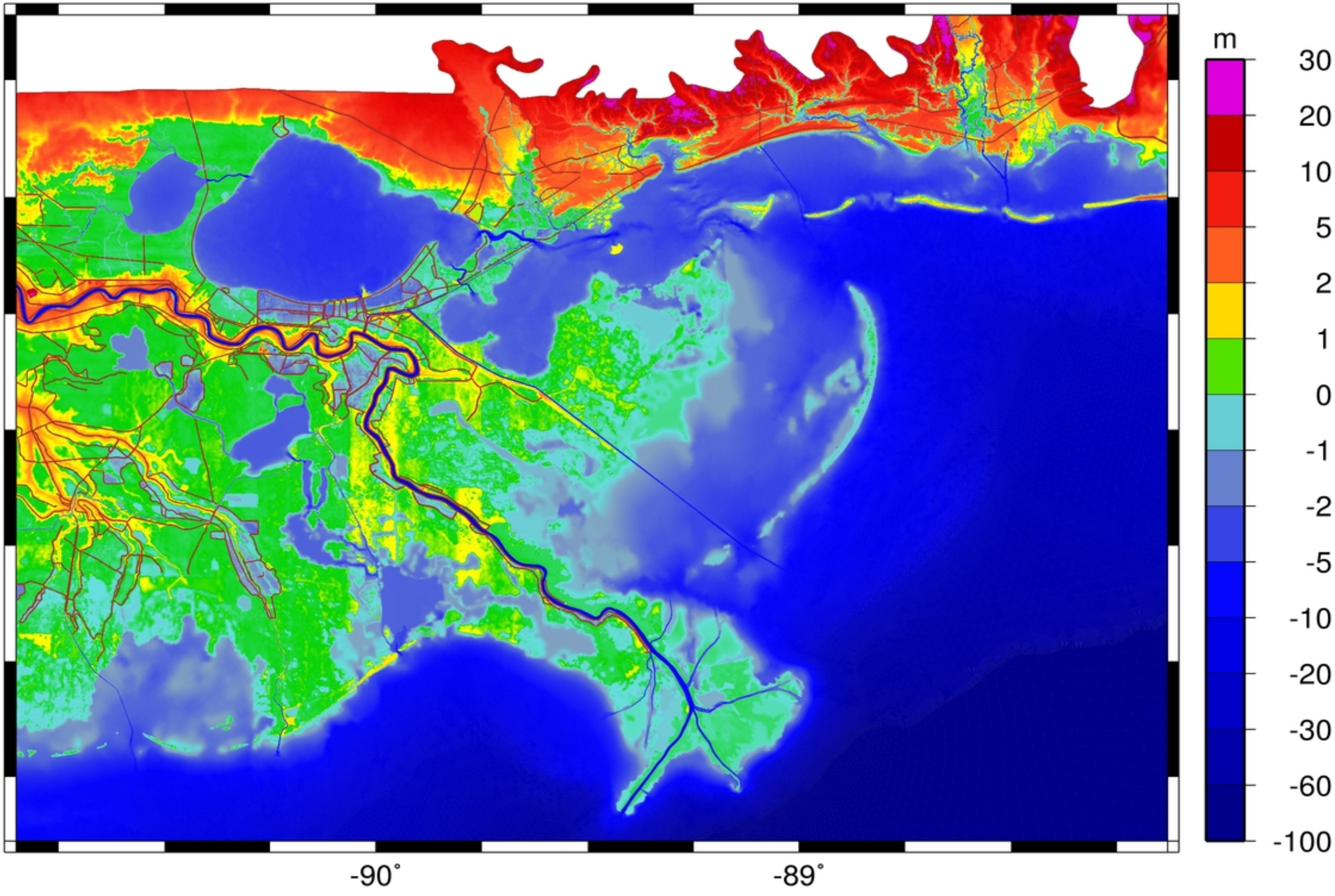
Western North Atlantic—finite element mesh



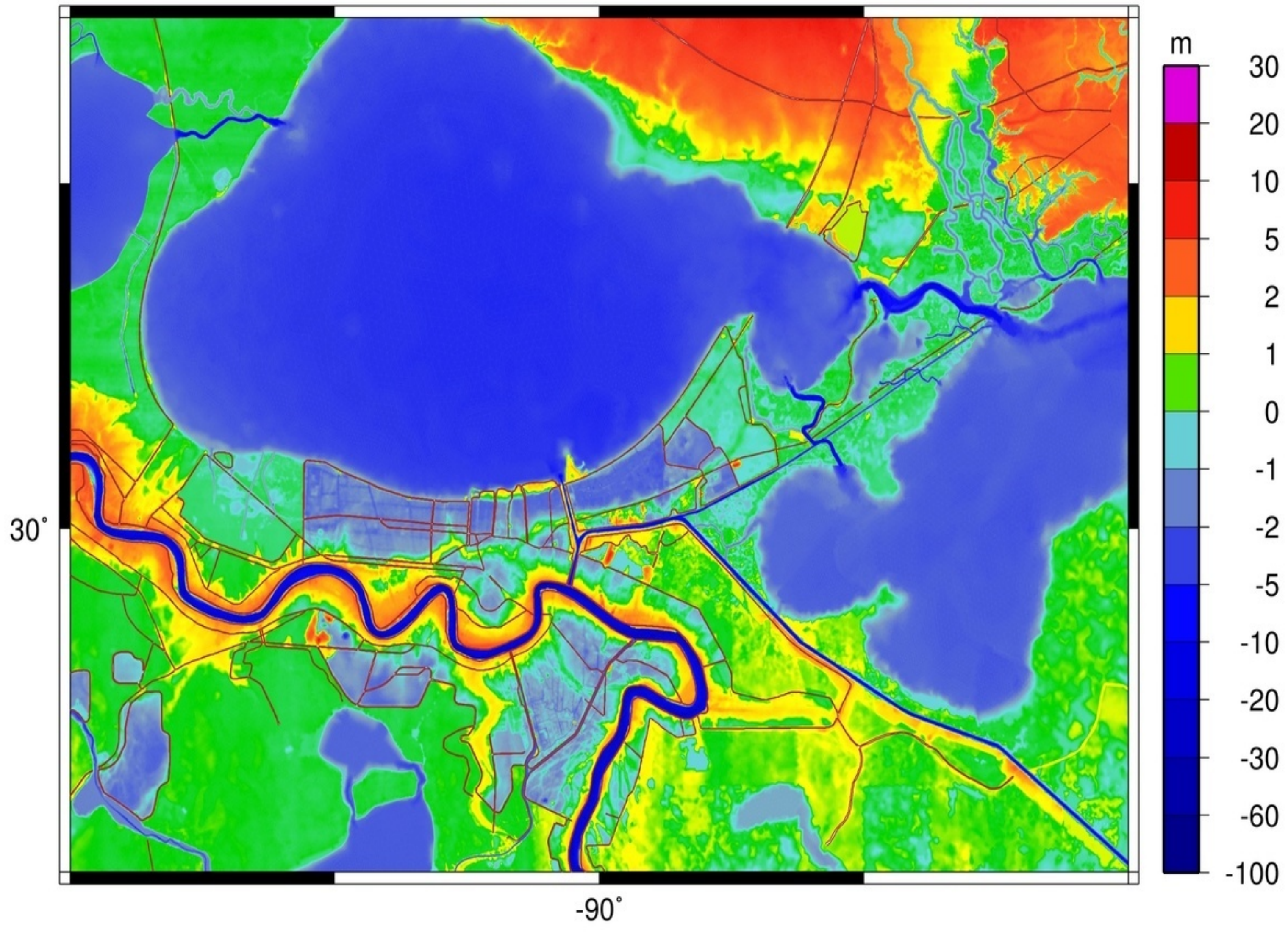
Zoom: Southern Louisiana and Mississippi



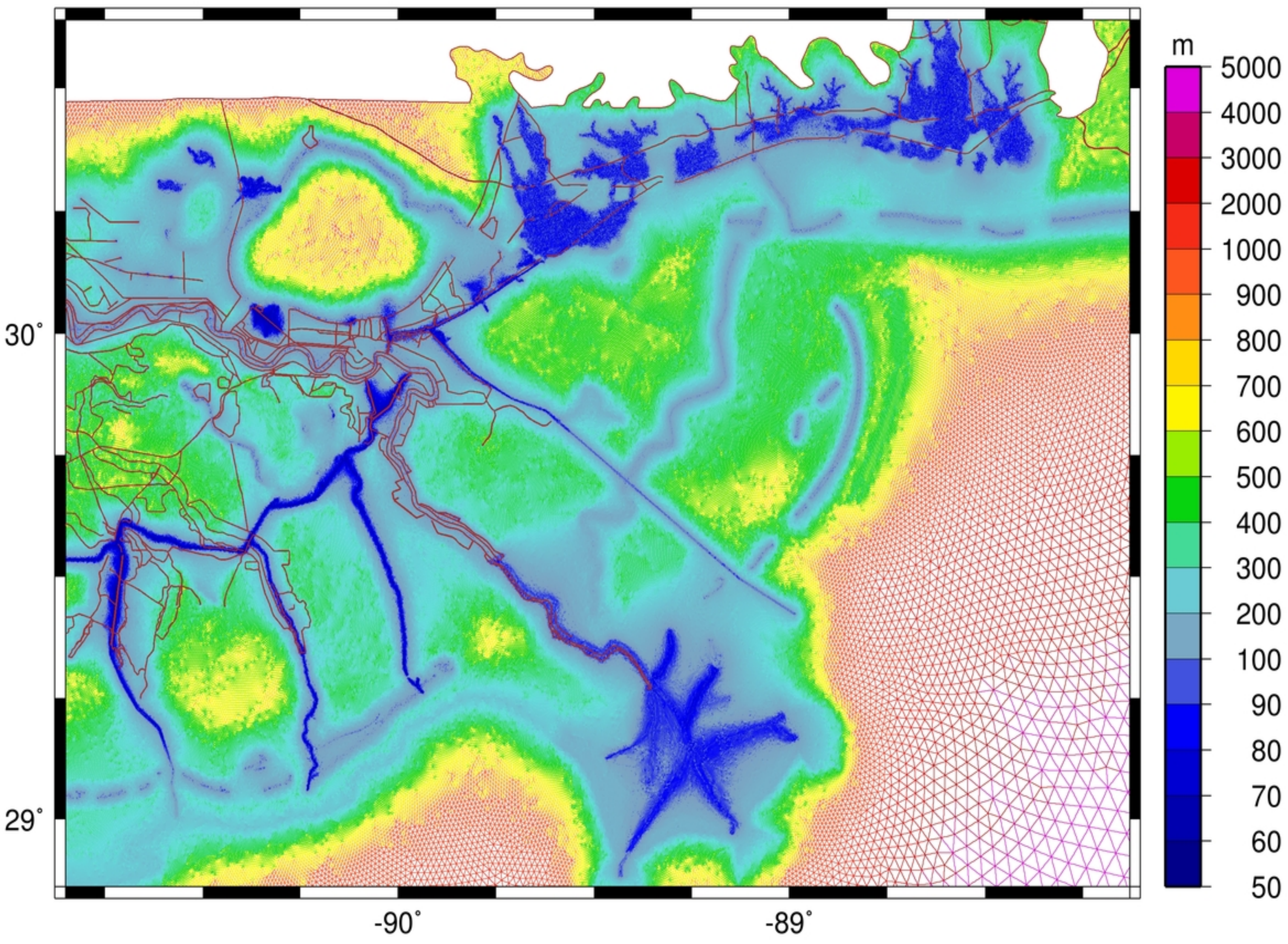
Southeastern Louisiana



New Orleans

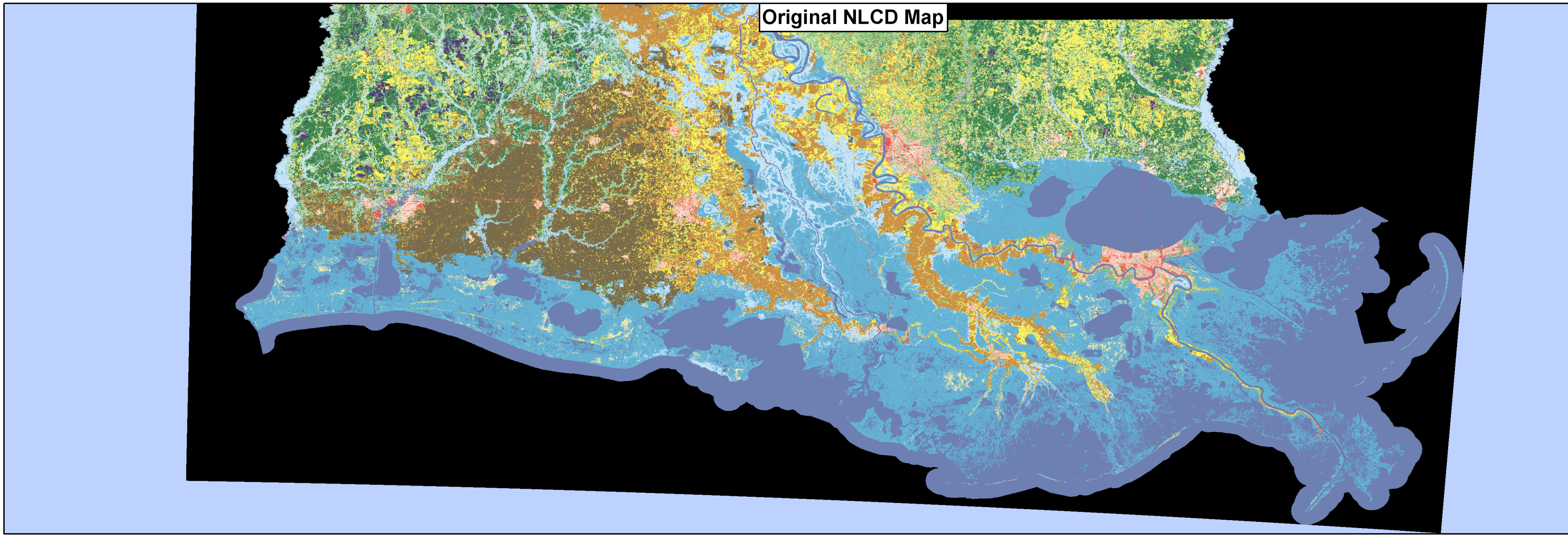


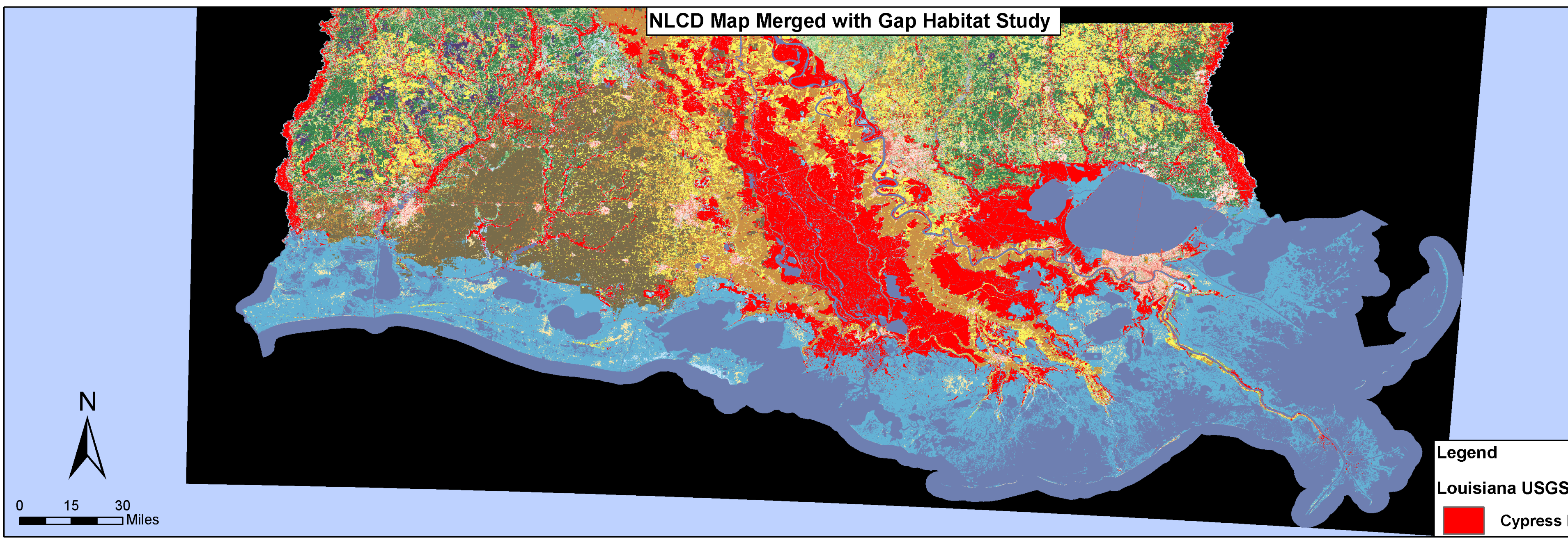
Southern LA and MS finite element mesh



Bottom Friction

- Surface roughness is based on USGS NLCD and GAP land cover/use data
- Standard Manning n values are assigned

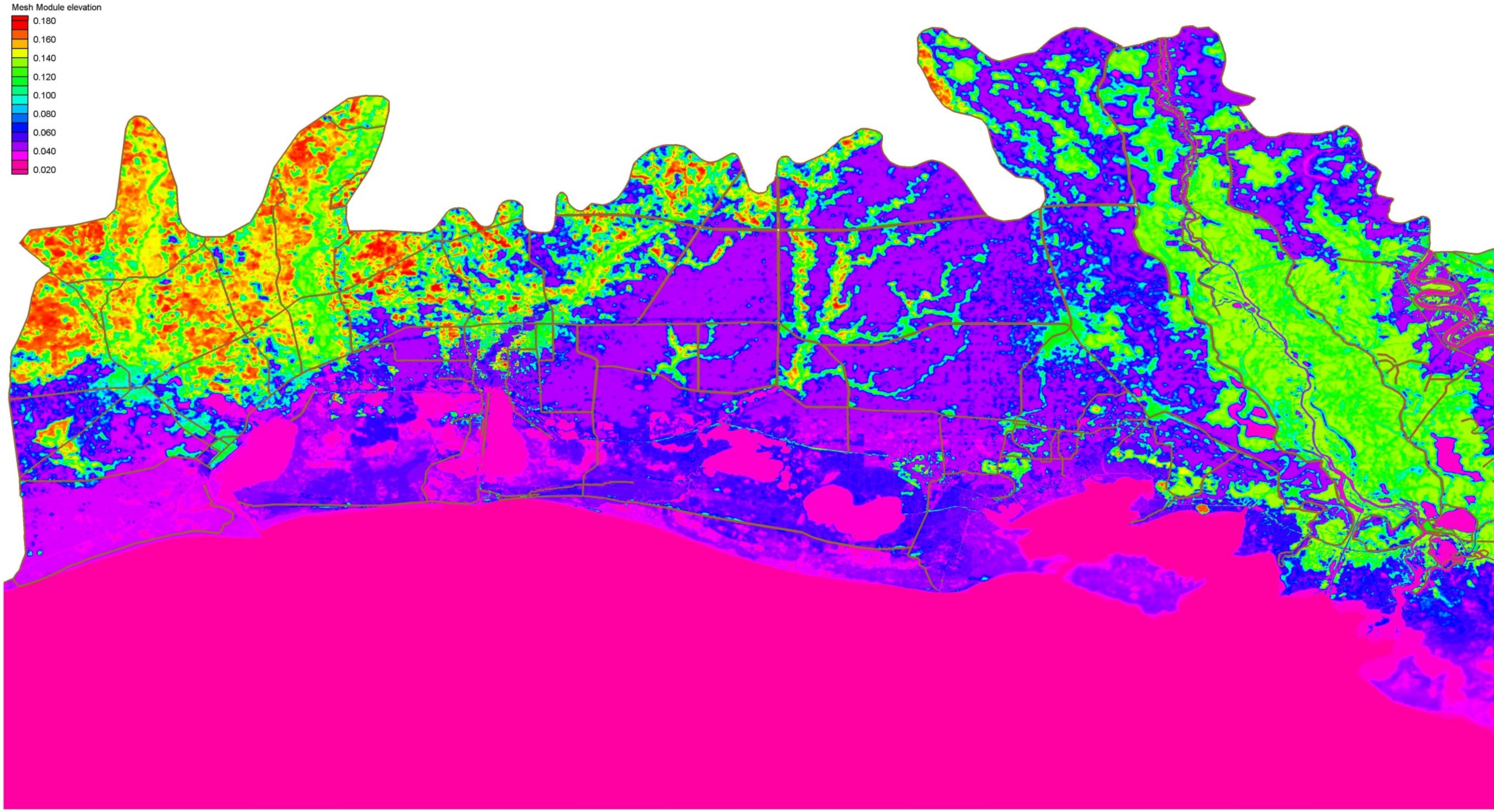

Original NLCD Map

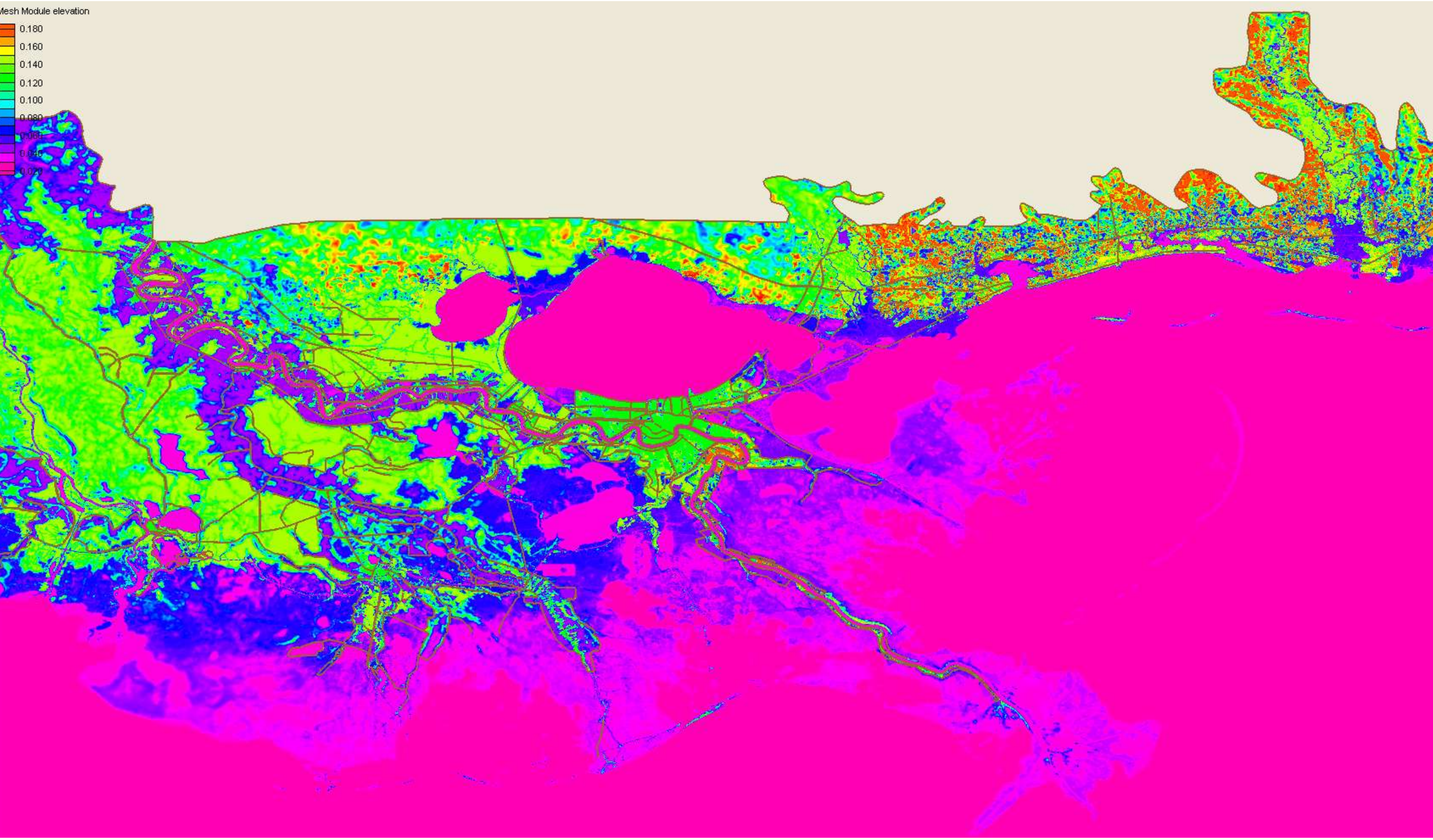

NLCD Map Merged with Gap Habitat Study
N
0
15
30
Miles
Legend
Louisiana USGS
Cypress

National Land Cover Dataset Classification System Legend

Color Key	RGB Value	Class Number and Name
	102, 140, 190	11 - Open Water
	255,255,255	12 - Perennial Ice/Snow
	253, 229, 228	21 - Low Intensity Residential
	247, 178, 159	22 - High Intensity Residential
	231, 86, 78	23 - Commerical/Industrial/Transportation
	210, 205, 192	31 - Bare Rock/Sand/Clay
	175, 175, 177	32 - Quarries/Strip Mines, Gravel Pits
	83, 62, 118	33 - Transitional
	134, 200, 127	41 - Deciduous Forest
	26, 129, 78	42 - Evergreen Forest
	212, 231, 177	43 - Mixed Forest
	220, 202, 143	51 - Shrubland
	187, 174, 118	61 - Orchards/Vineyards
	253, 233, 170	71 - Grasslands/Herbaceous
	252, 246, 93	81 - Pasture/Hay
	202, 145, 71	82 - Row Crops
	121, 108, 75	83 - Small Grains
	244, 238, 203	84 - Fallow
	240, 156, 054	85 - Urban/Recreational Grasses
	201, 230, 249	91 - Woody Wetlands
	144, 192, 217	92 - Emergent Herbaceous Wetlands

NLCD Class	Description	Manning-n
11	Open Water	0.022
12	Ice/Snow	0.020
21	Low Residential	0.120
22	High Residential	0.140
23	Commercial	0.050
31	Bare Rock/Sand	0.040
32	Gravel Pit	0.060
33	Transitional	0.100
41	Deciduous Forest	0.140
42	Evergreen Forest	0.160
43	Mixed Forest	0.140
51	Shrub Land	0.050
61	Orchard/Vineyard	0.100
71	Grassland	0.034
81	Pasture	0.030
82	Row Crops	0.035
83	Small Grains	0.035
84	Fallow	0.030
85	Recreational Grass	0.025
91	Woody Wetland	0.120
92	Herbaceous Wetland	0.035
95	Cypress Forest	0.120


Mesh Module elevation
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020



Mesh Module elevation
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0.120
0.100
0.080
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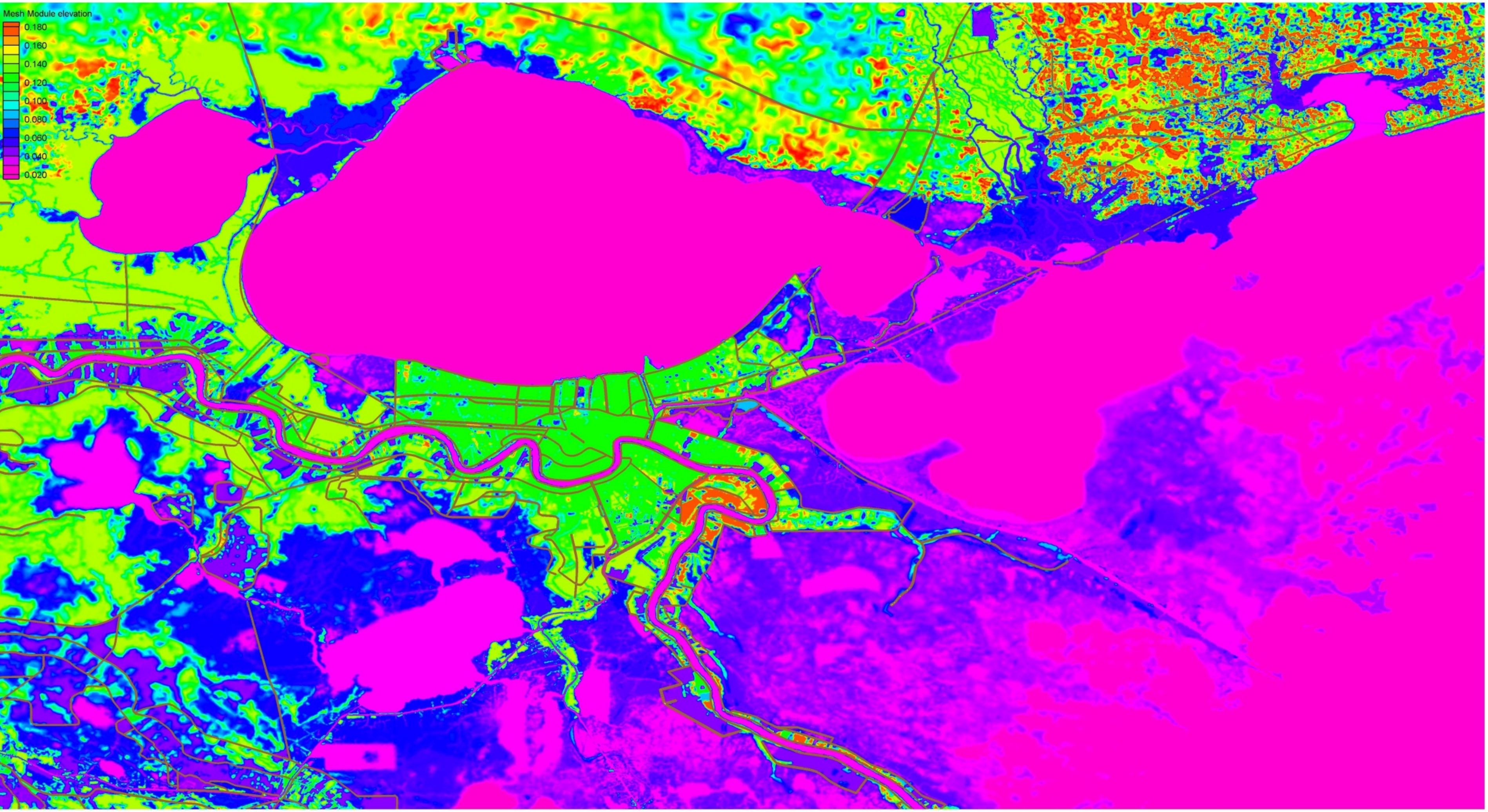
0.040
0.020


Mesh Module elevation
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0.160
0.140
0.120
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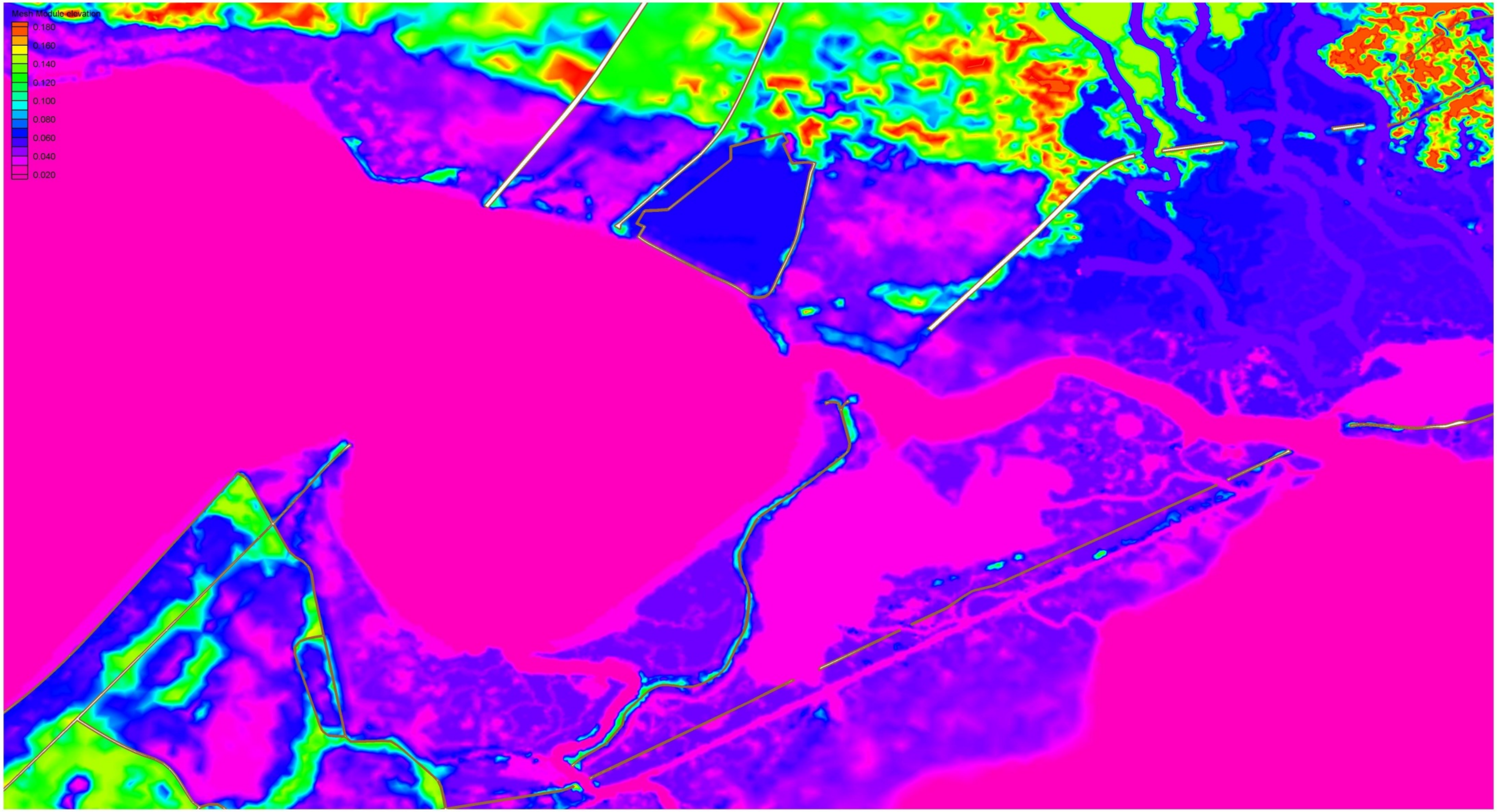
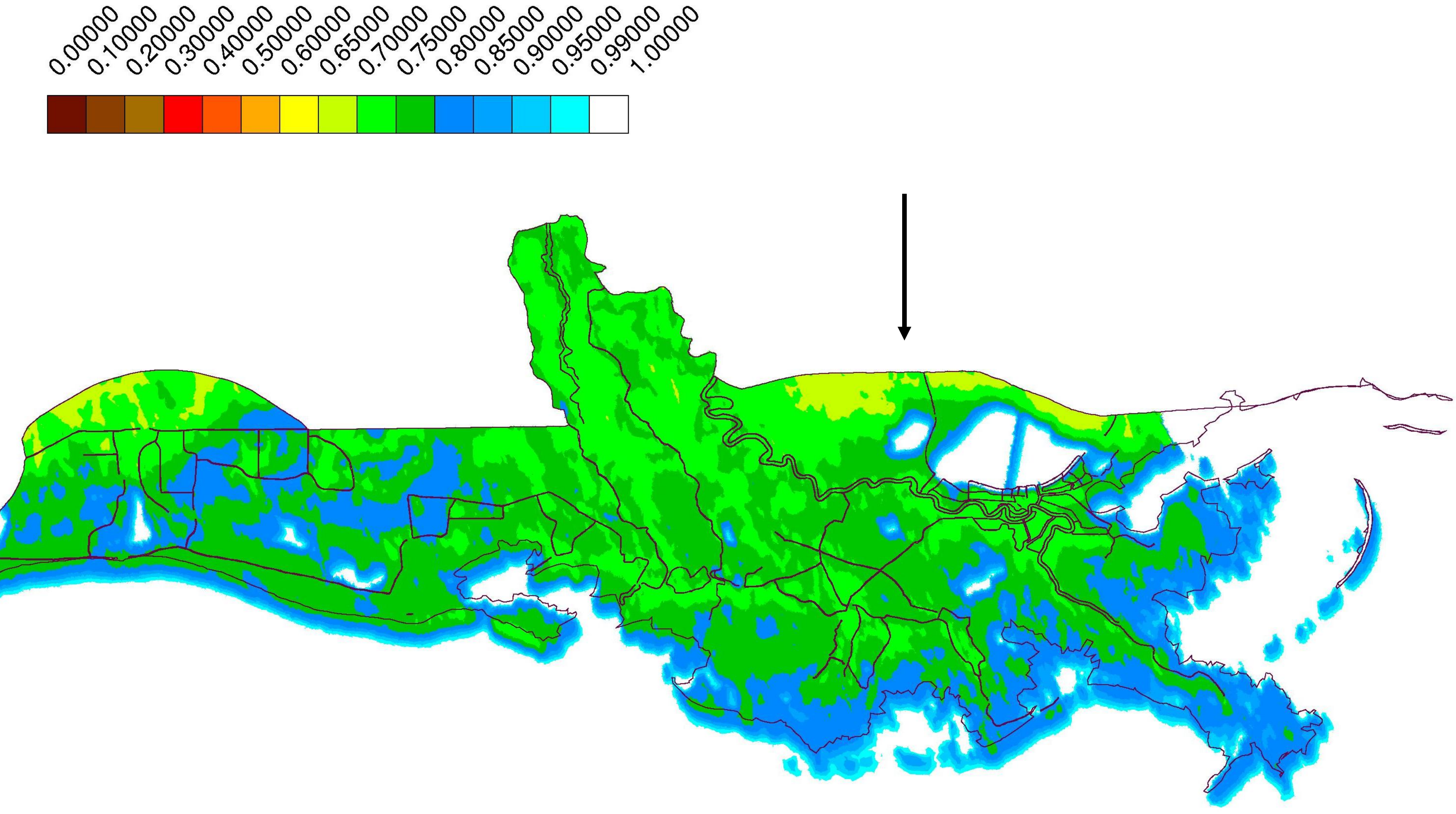


Mesh Module elevation
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020

Wind stress

- Improvements in winds by incorporating directional land roughness to adjust the overland/near-shore wind boundary layer
- Incorporation of canopies where winds are zeroed due to loss of momentum propagating through the canopy.
- Dynamic wind drag coefficient variation between land and sea values as region becomes inundated.

NLCD Class	Description	$Z_{0\text{-land}}$
11	Open Water	0.001
12	Ice/Snow	0.012
21	Low Residential	0.330
22	High Residential	0.500
23	Commercial	0.390
31	Bare Rock/Sand	0.090
32	Gravel Pit	0.180
33	Transitional	0.180
41	Deciduous Forest	0.650
42	Evergreen Forest	0.720
43	Mixed Forest	0.710
51	Shrub Land	0.120
61	Orchard/Vineyard	0.270
71	Grassland	0.040
81	Pasture	0.060
82	Row Crops	0.060
83	Small Grains	0.050
84	Fallow	0.050
85	Recreational Grass	0.050
91	Woody Wetland	0.550
92	Herbaceous Wetland	0.110
95	Cypress Forest	0.550


0.00000
0.10000
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0.30000
0.40000
0.50000
0.60000
0.65000
0.70000
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0.80000
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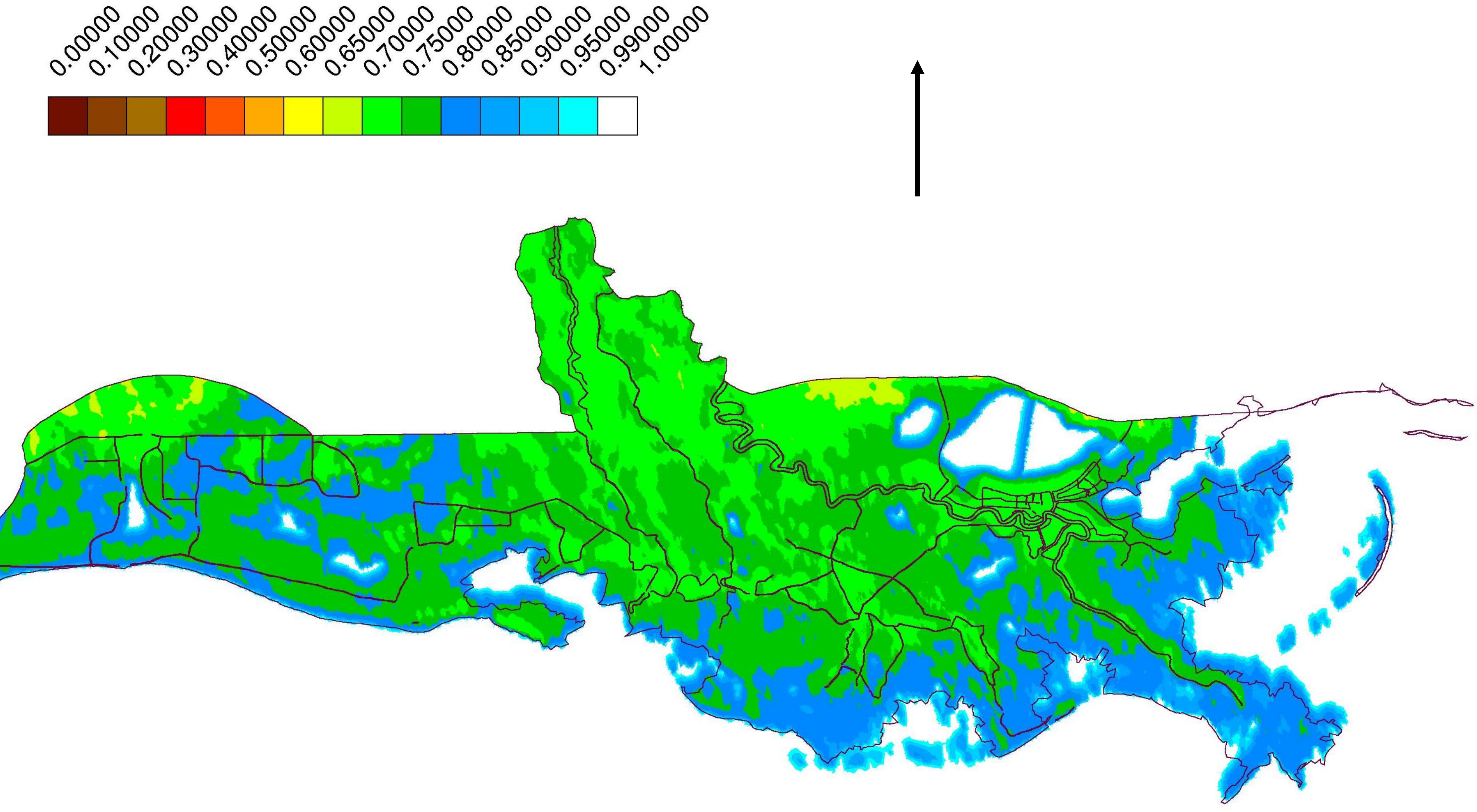
0.90000
0.95000
0.99000
1.00000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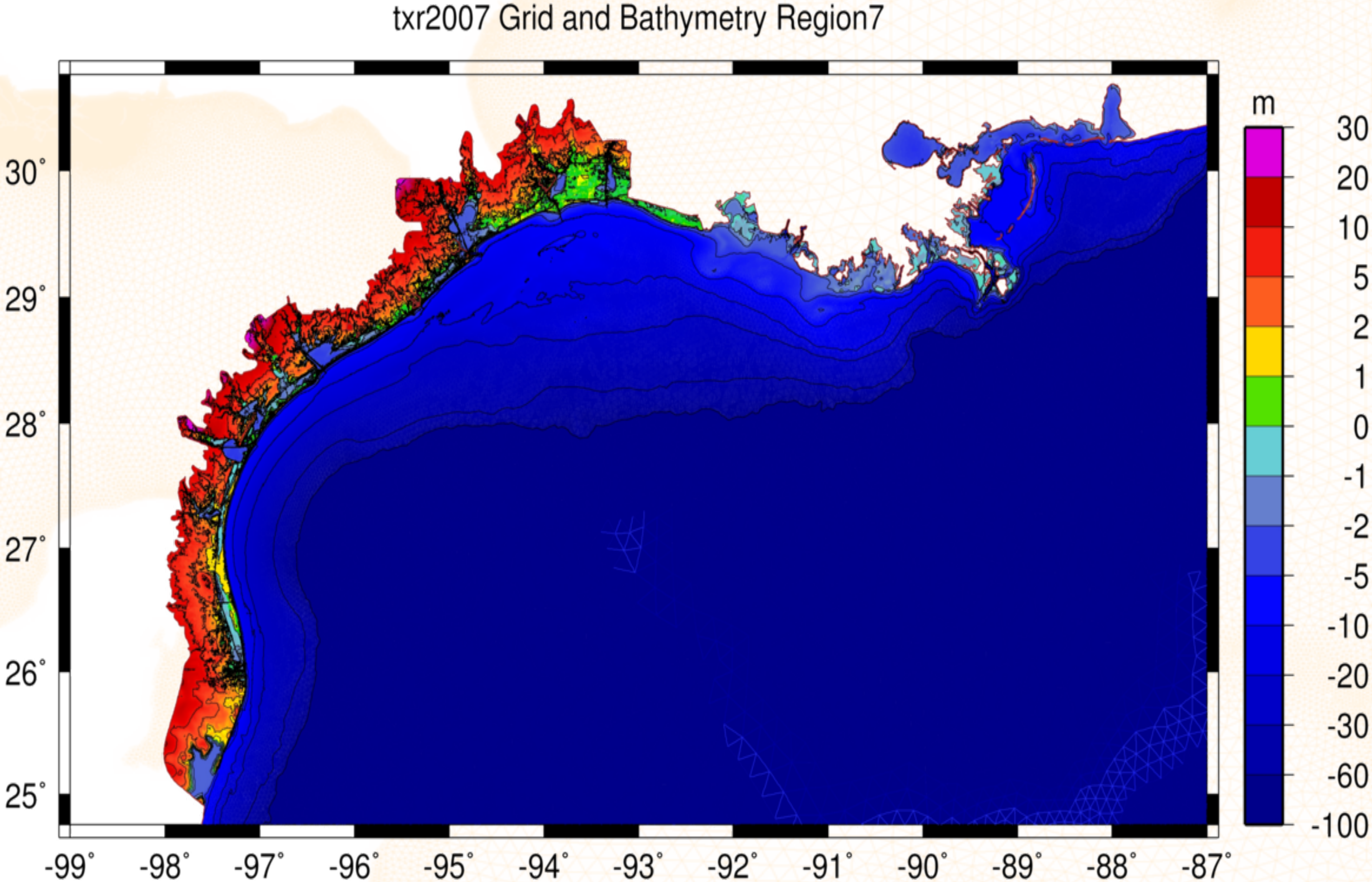
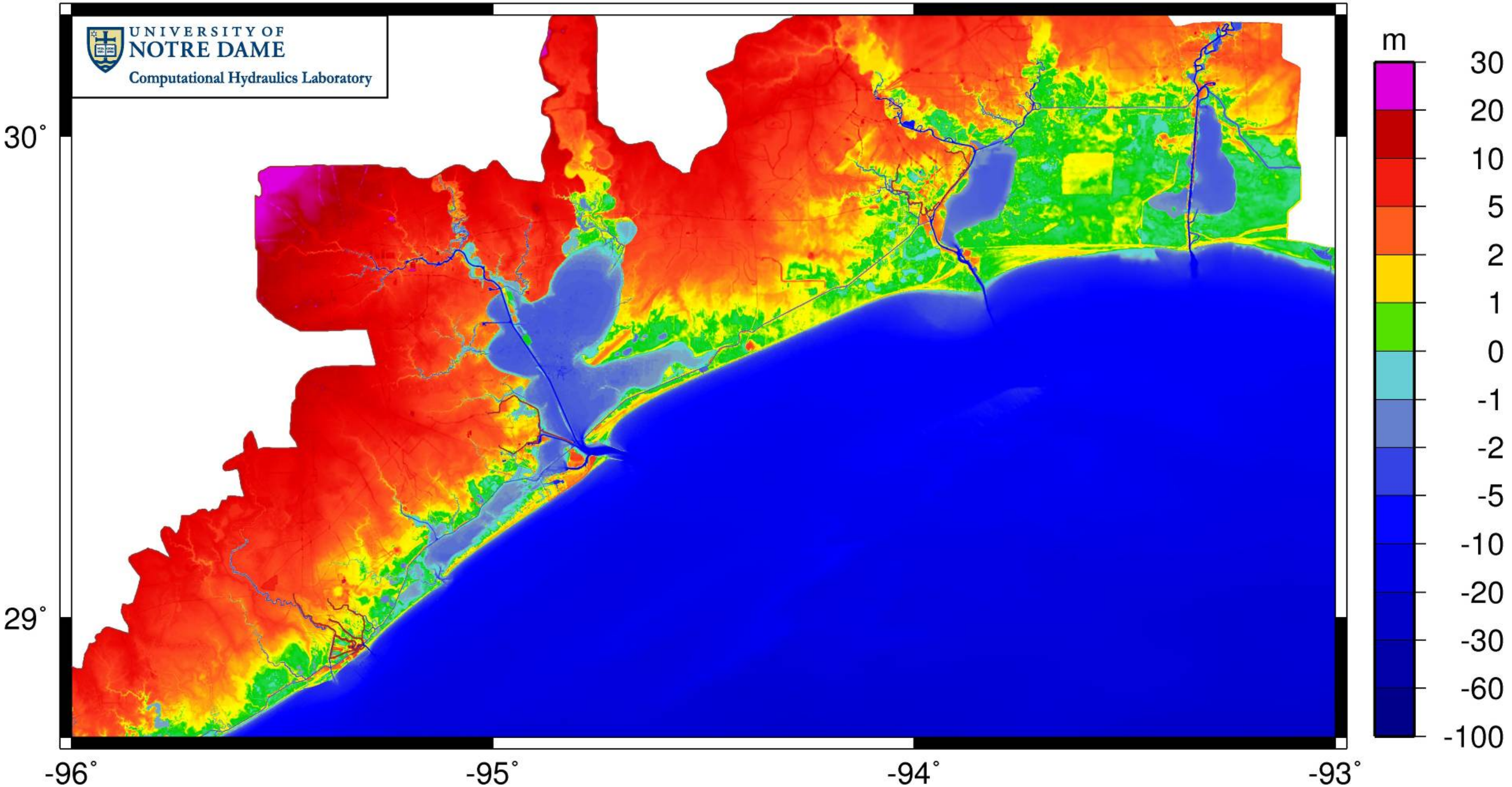
0.75000
0.80000
0.85000
0.90000
0.95000
0.99000
1.00000

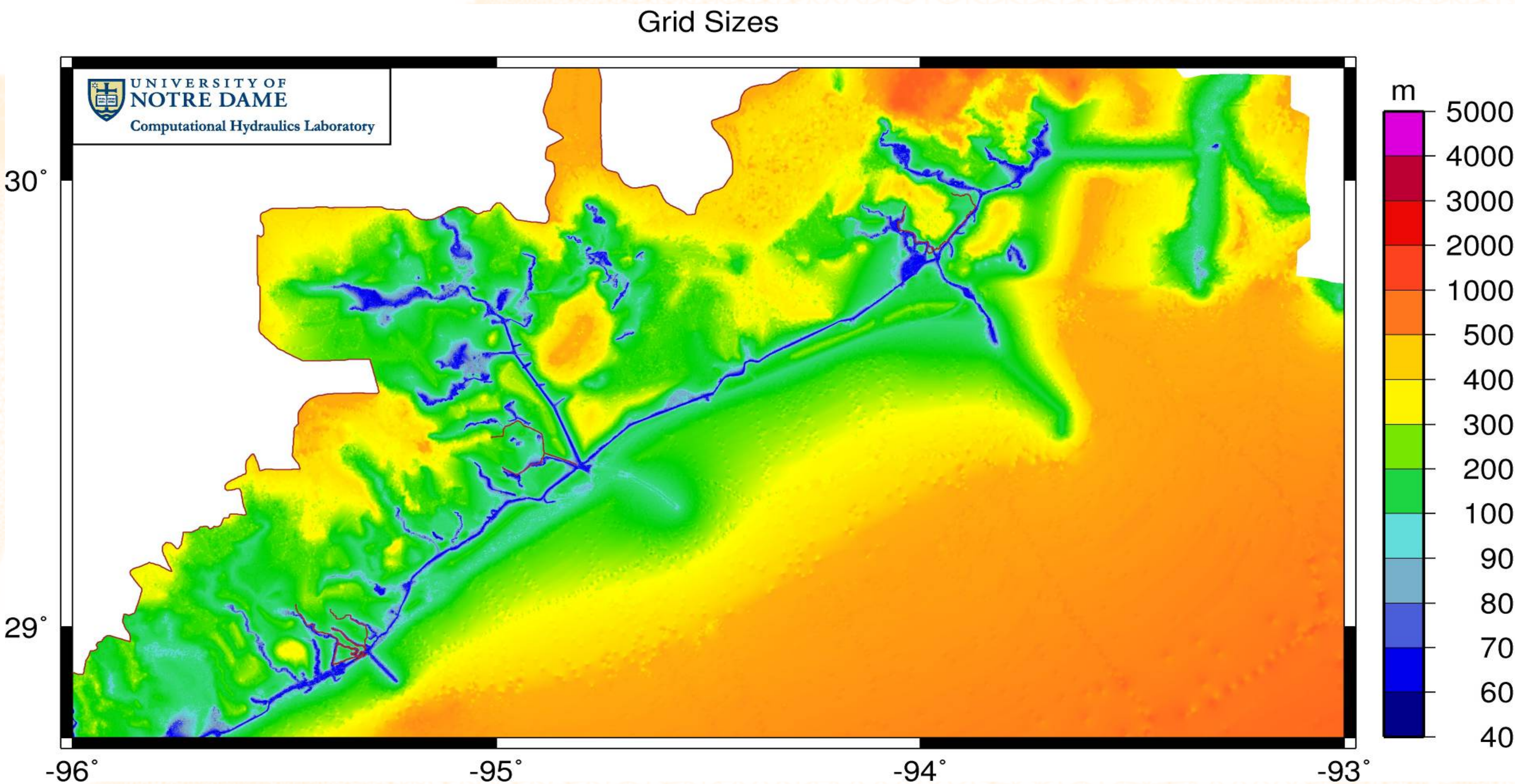
ADCIRC Texas Model



Bathymetry & Topography of the Upper Texas Gulf Coast



Upper Texas Coast Model Resolution



Storm Surge Simulations

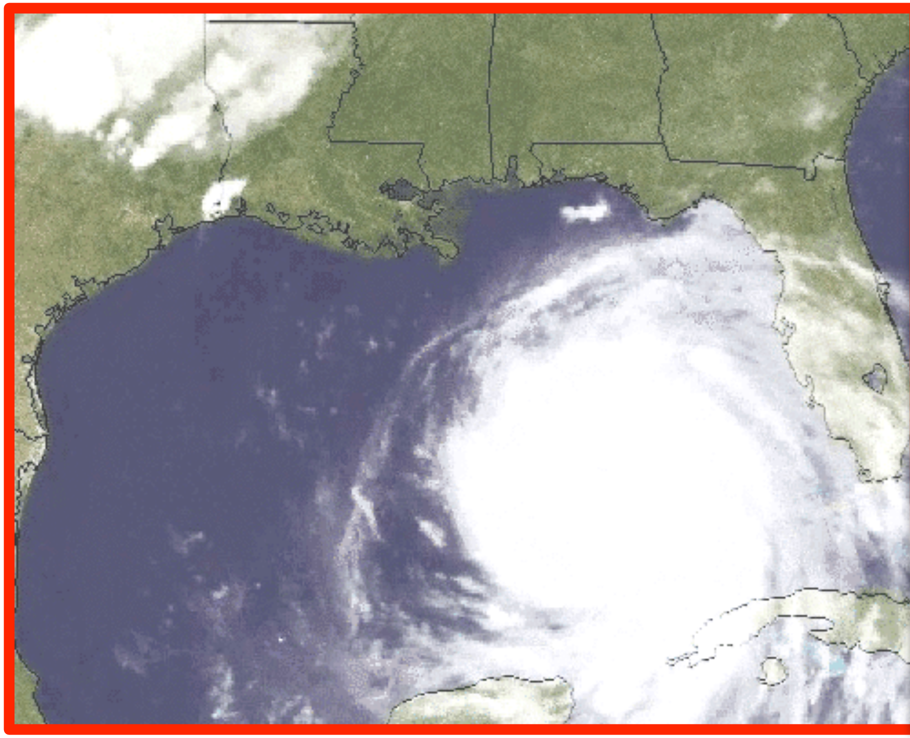
Hindcasting: Studying historical hurricanes

- Evaluate inundation risk in coastal areas
  - High impact – low probability events in an evolving system
- Critical to design of protection and mitigation systems in order to reduce that risk
  - Structures may in fact adversely impact components of the system and increase the risk of flooding

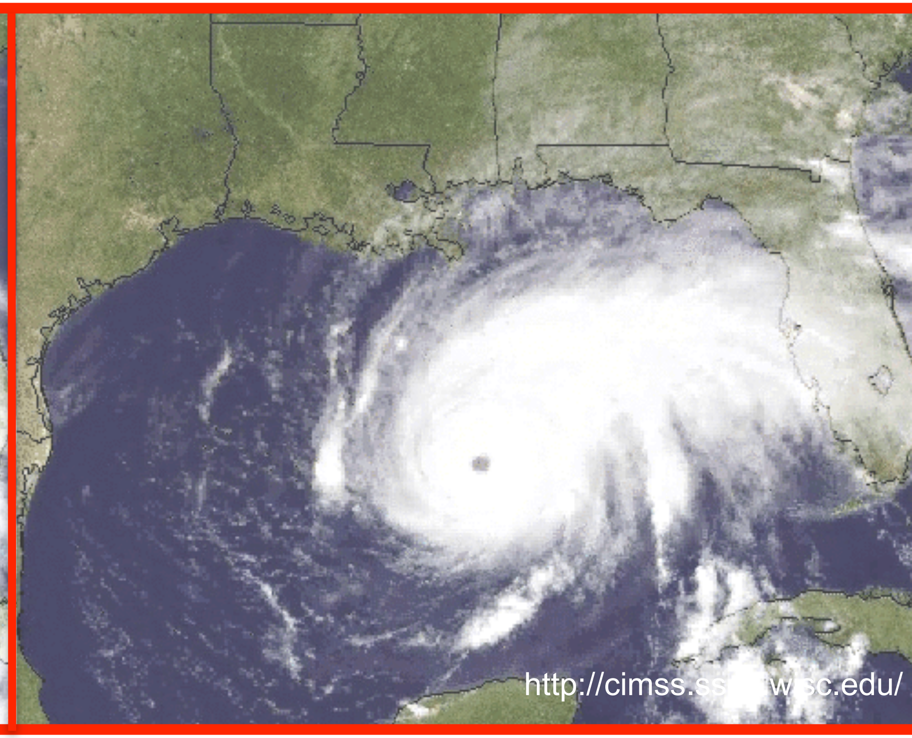
Forecasting: As storms approach land, estimate maximum surge and extent of inundation for emergency management. Must be done in "real-time"

2005 Hurricane Season

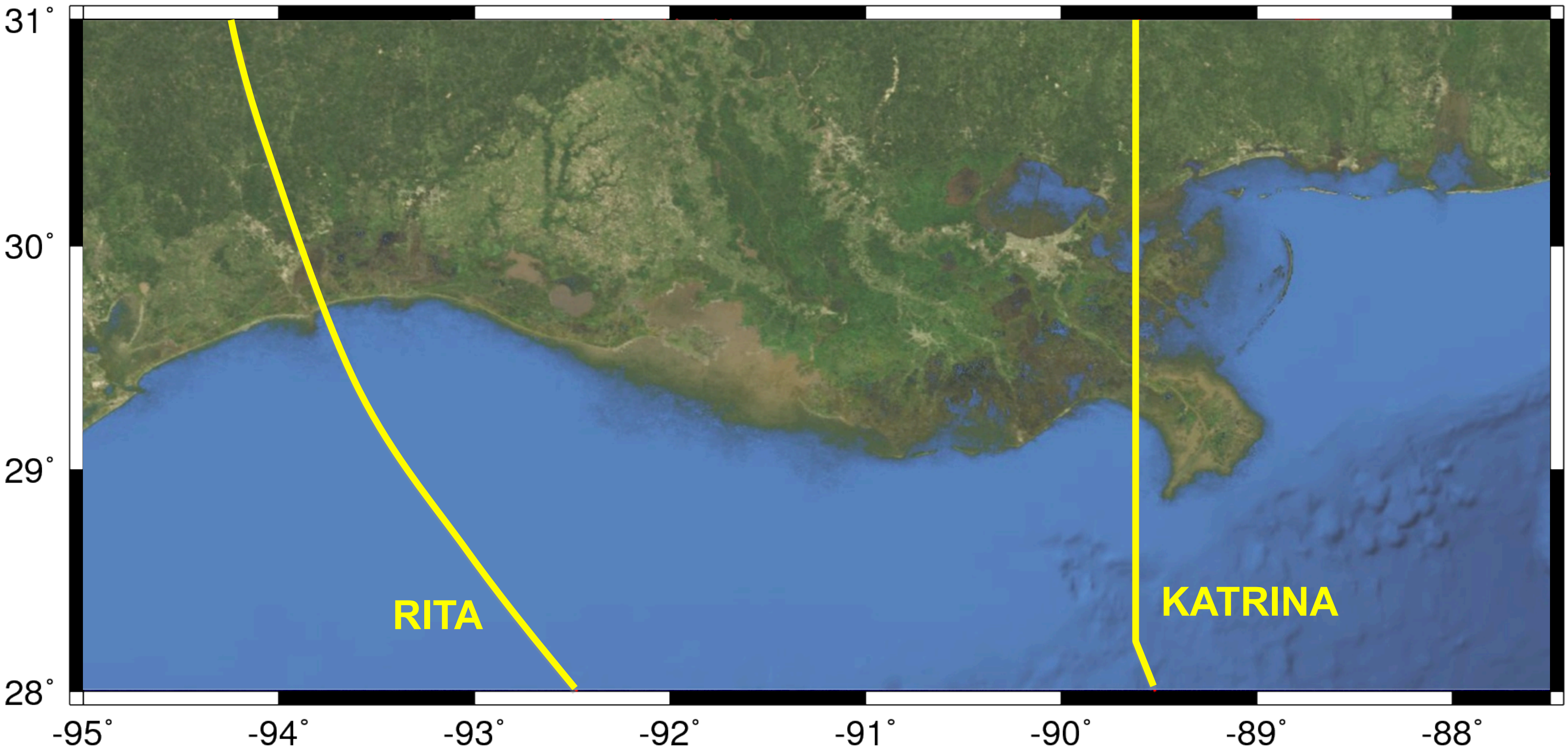
Katrina : 08/28 – 08/29



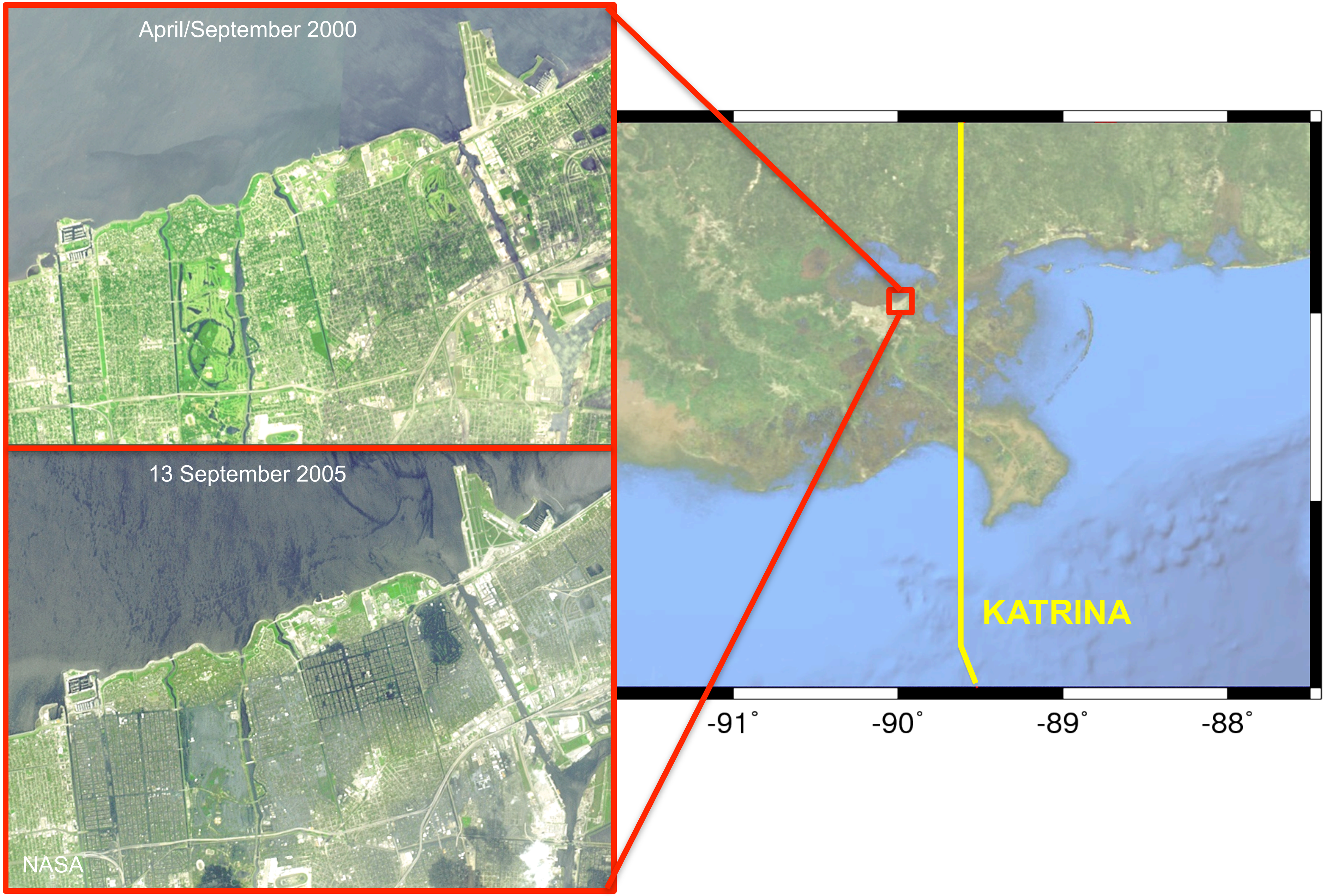
Rita : 09/22 – 09/24



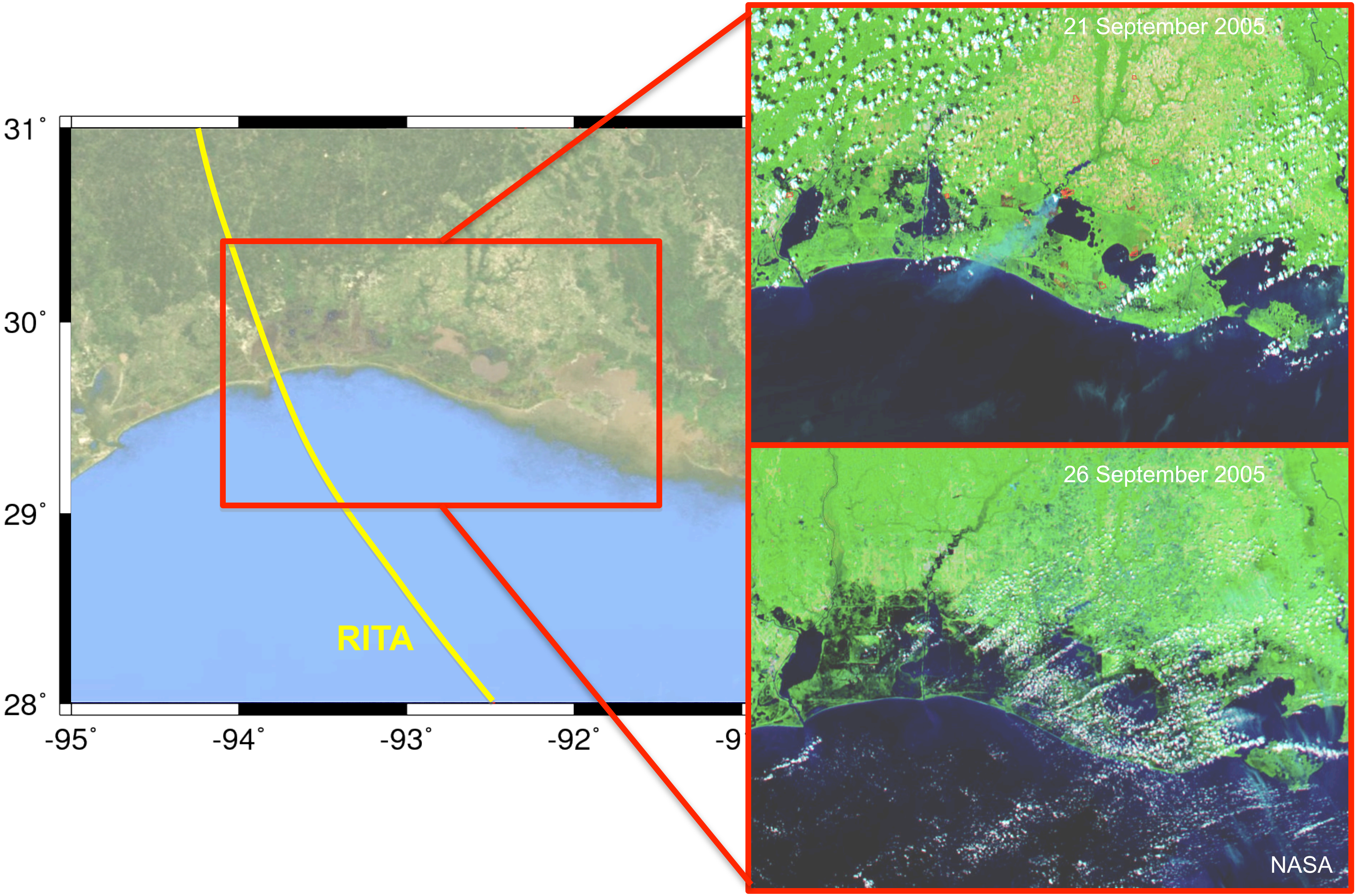
2005 Hurricane Season



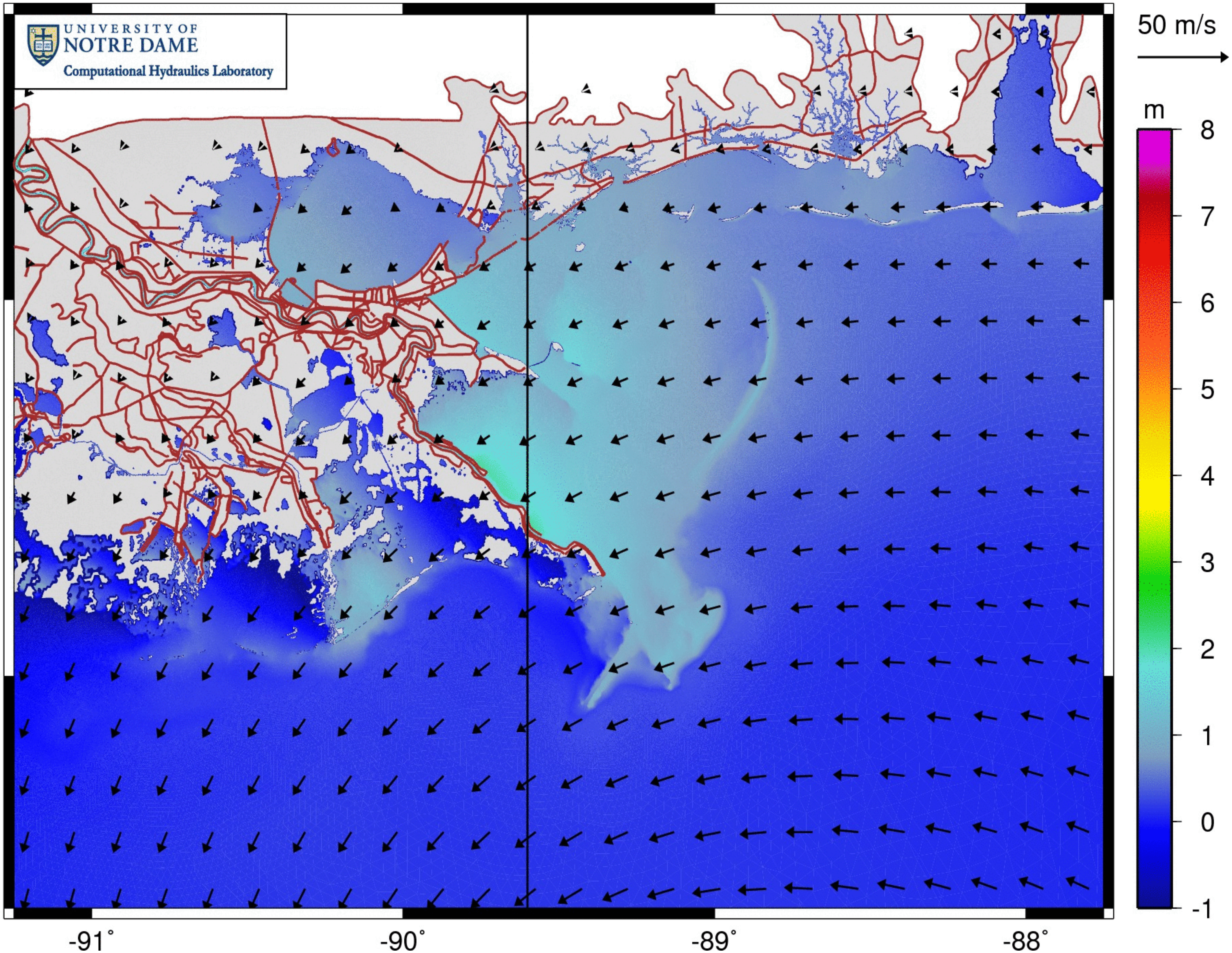
2005 Hurricane Season : Katrina : Inundation of New Orleans



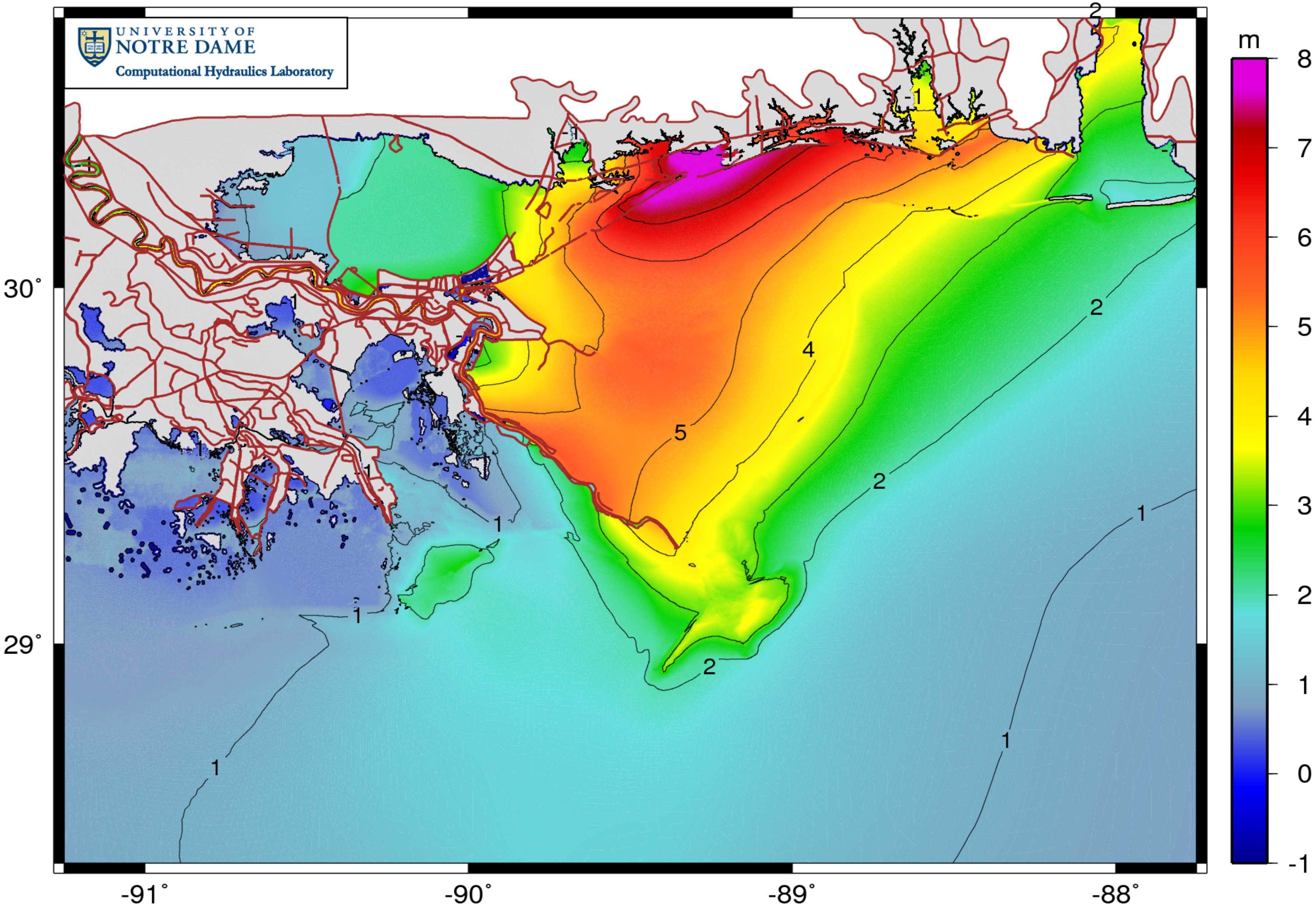
2005 Hurricane Season : Rita : Inundation of Cameron Parish



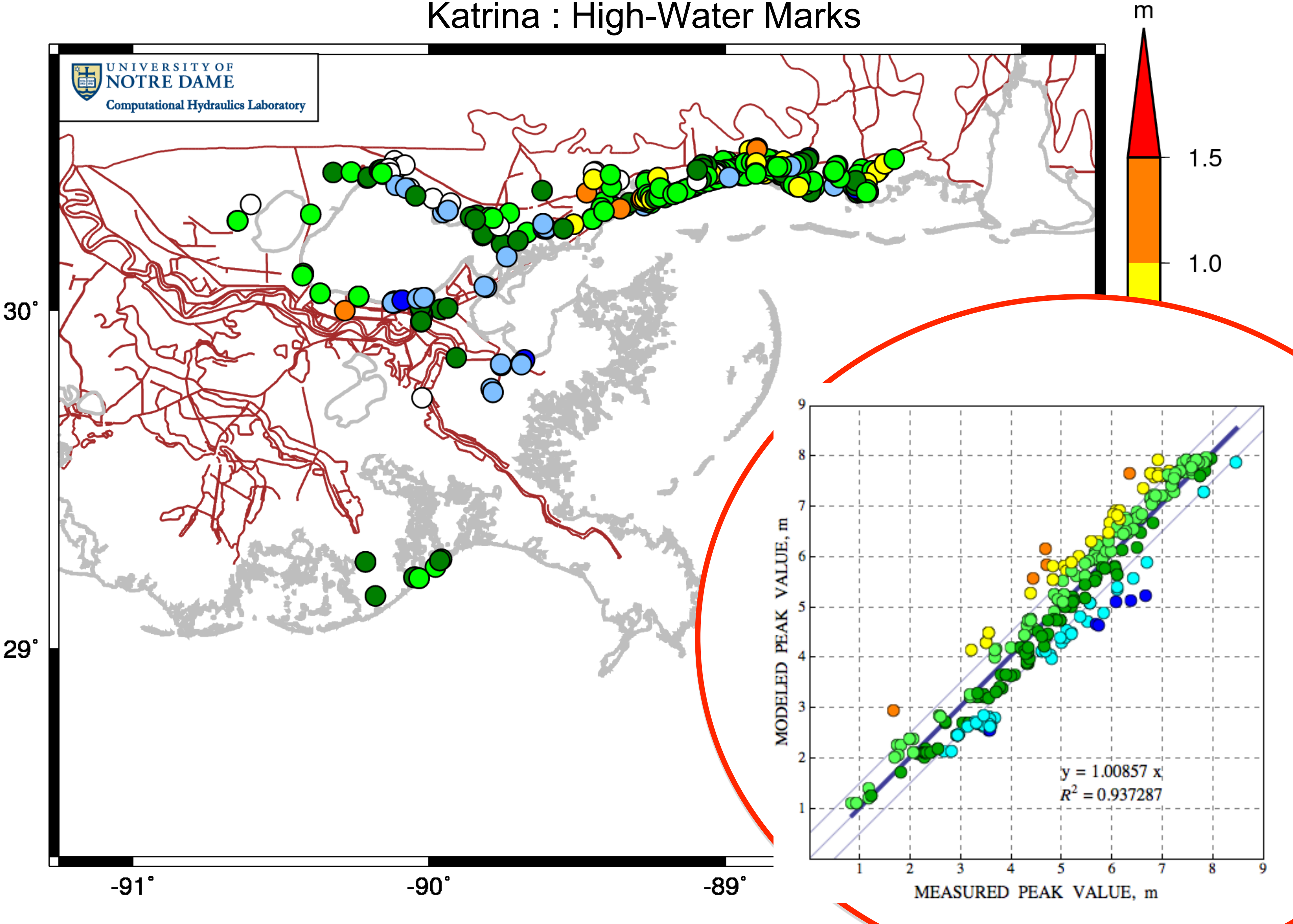
Katrina : Water Levels : 2005/08/29



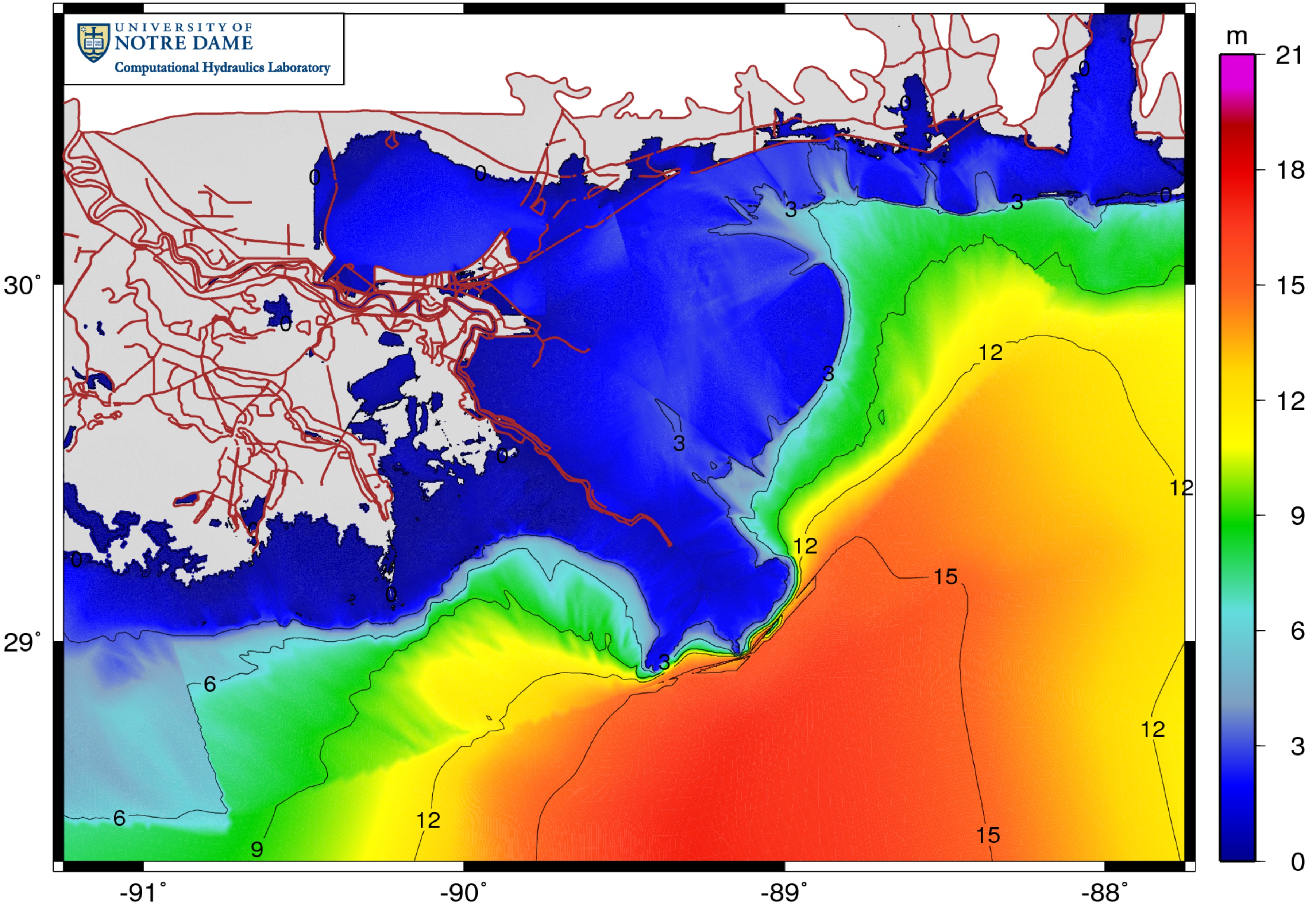
Katrina : Water Levels : Maximum



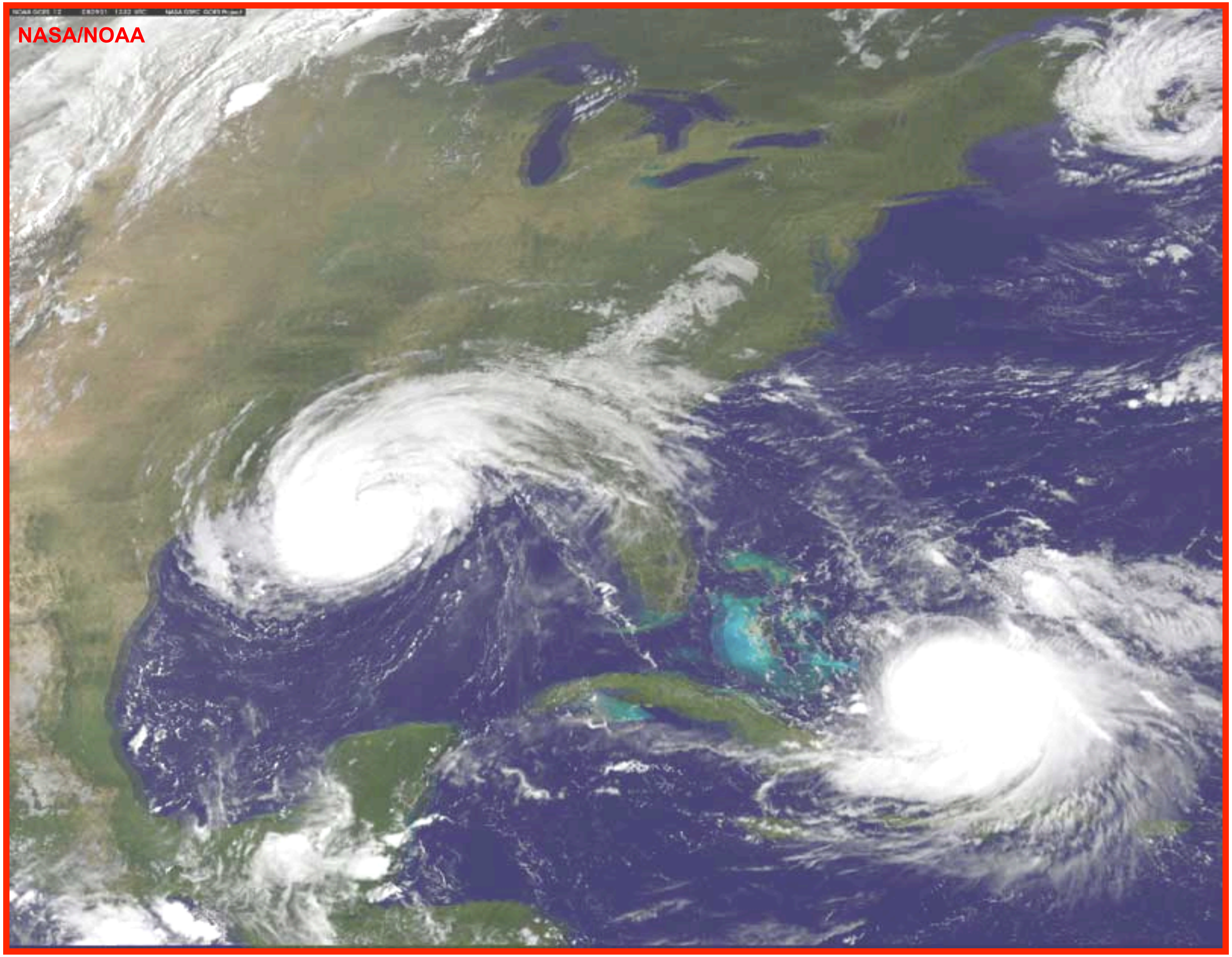
Katrina : High-Water Marks



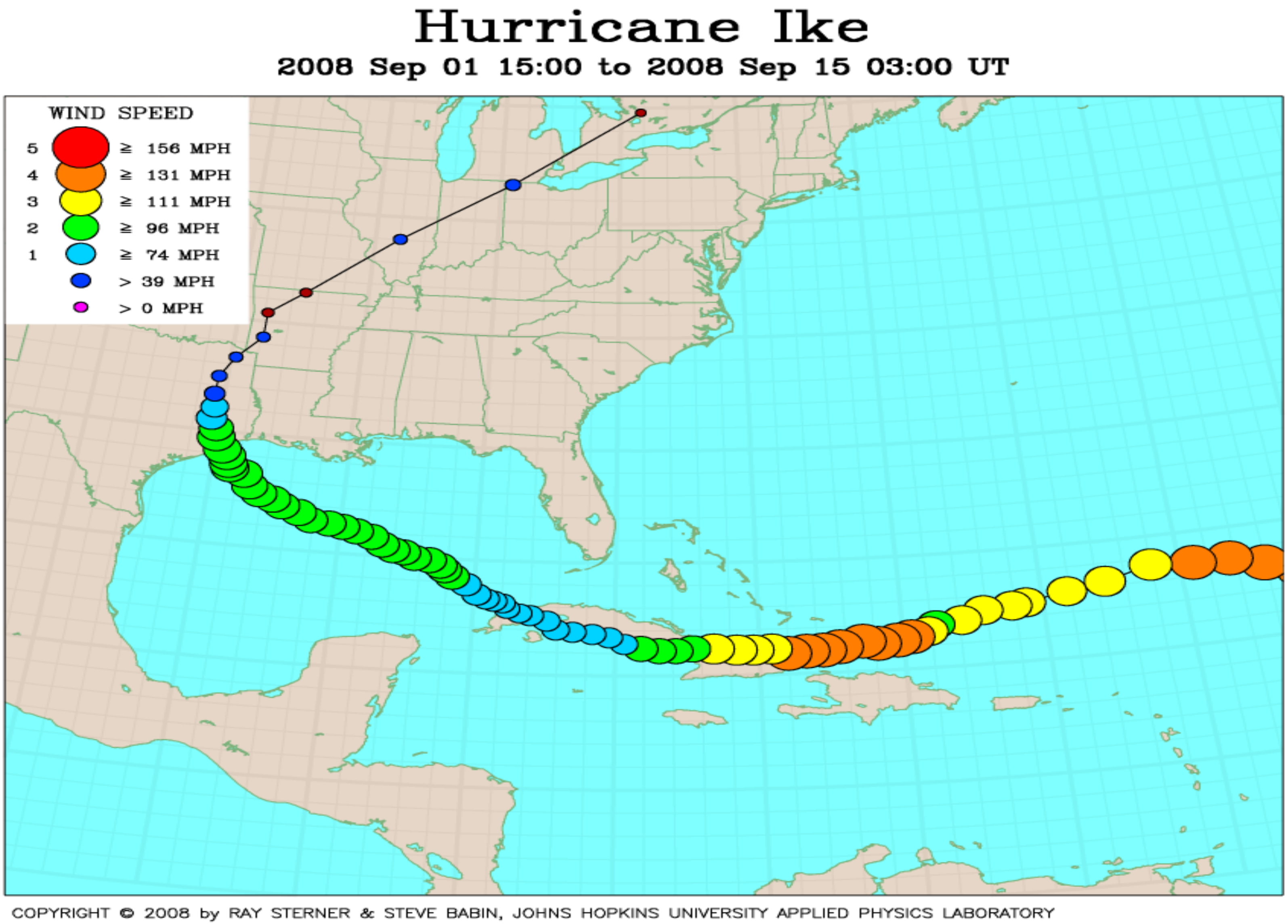
Katrina : Significant Wave Heights : Maximum



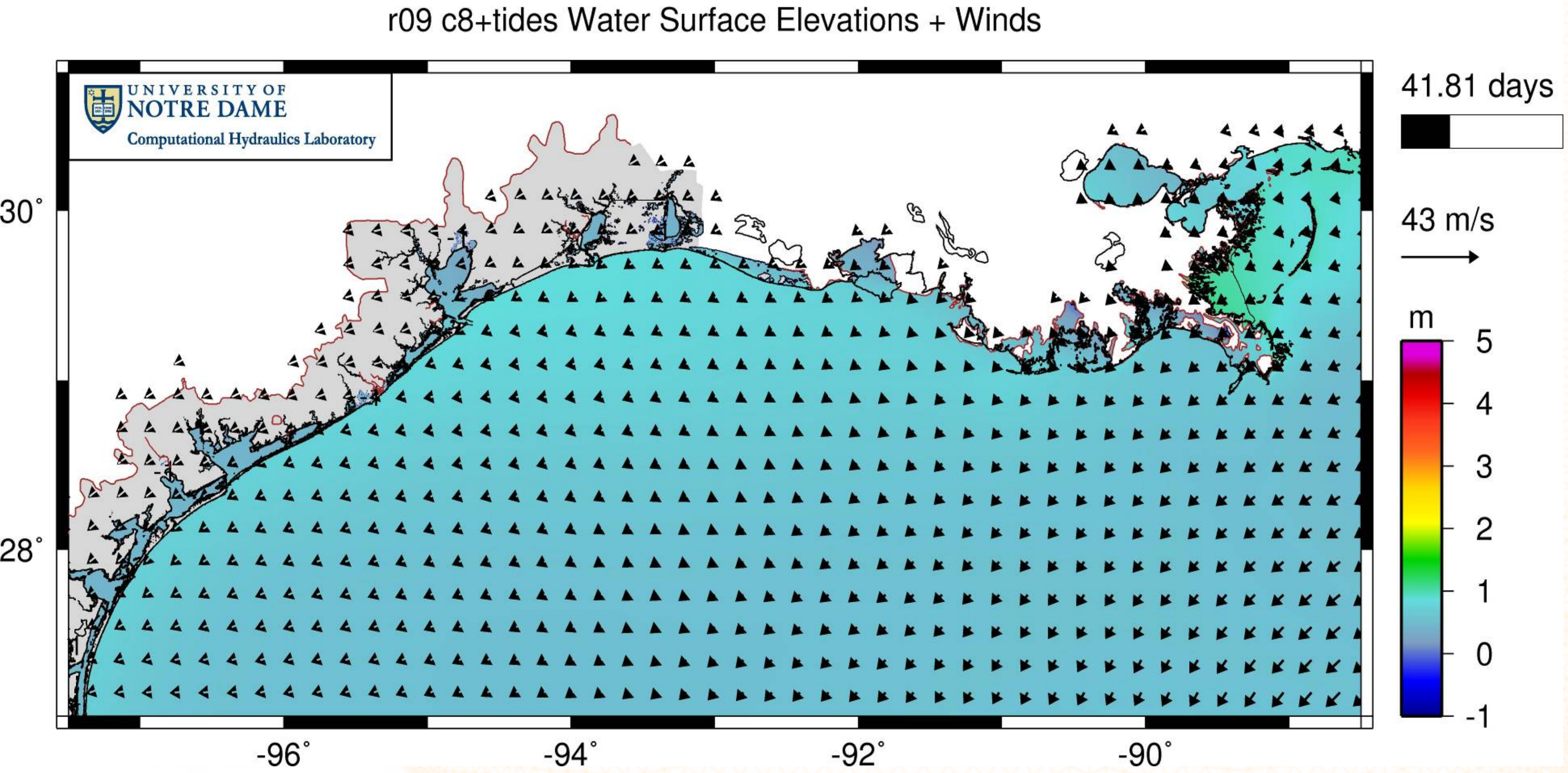
Hurricane Season 2008



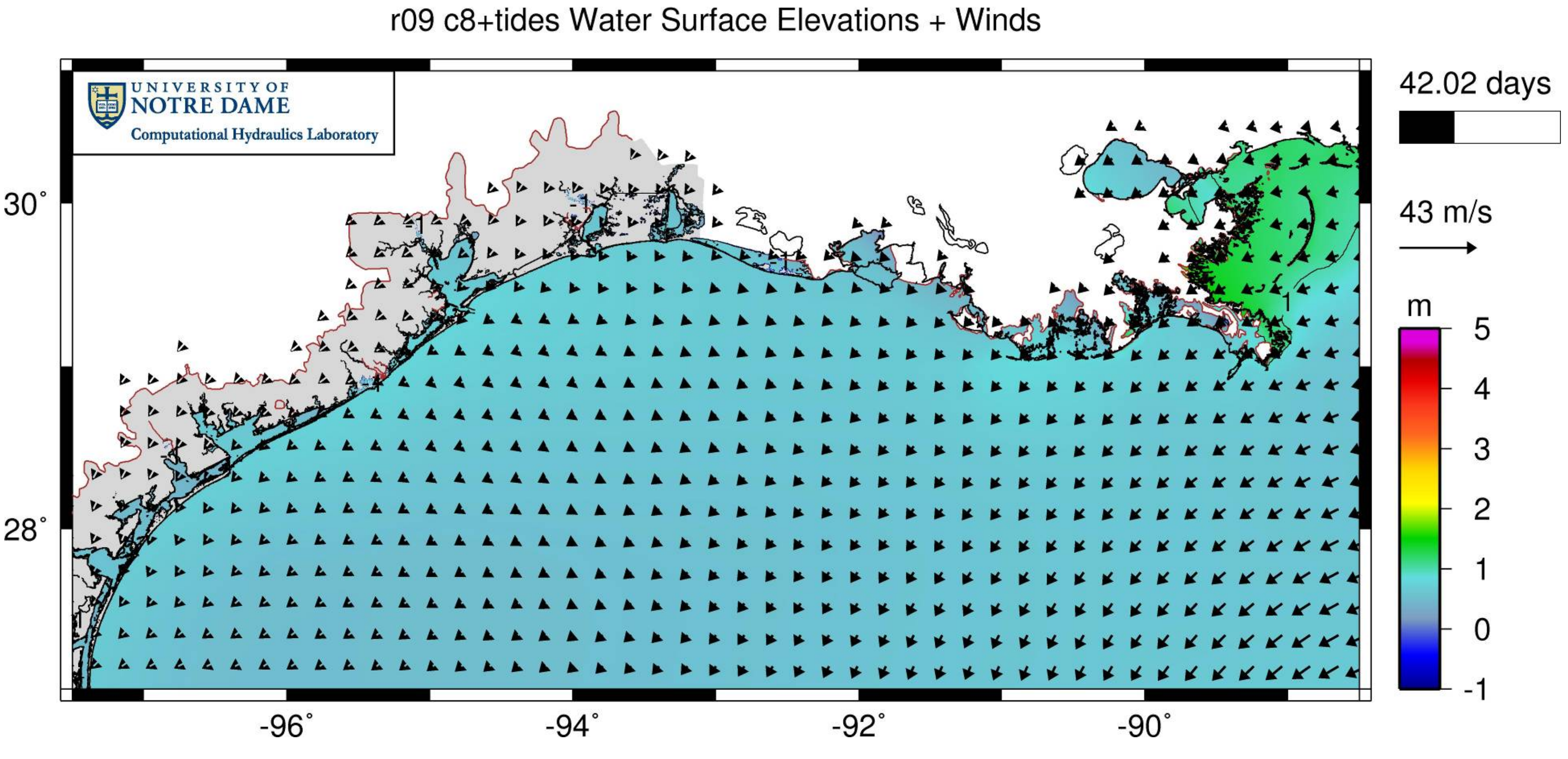
Hurricane Ike



Hindcast Study of Hurricane Ike

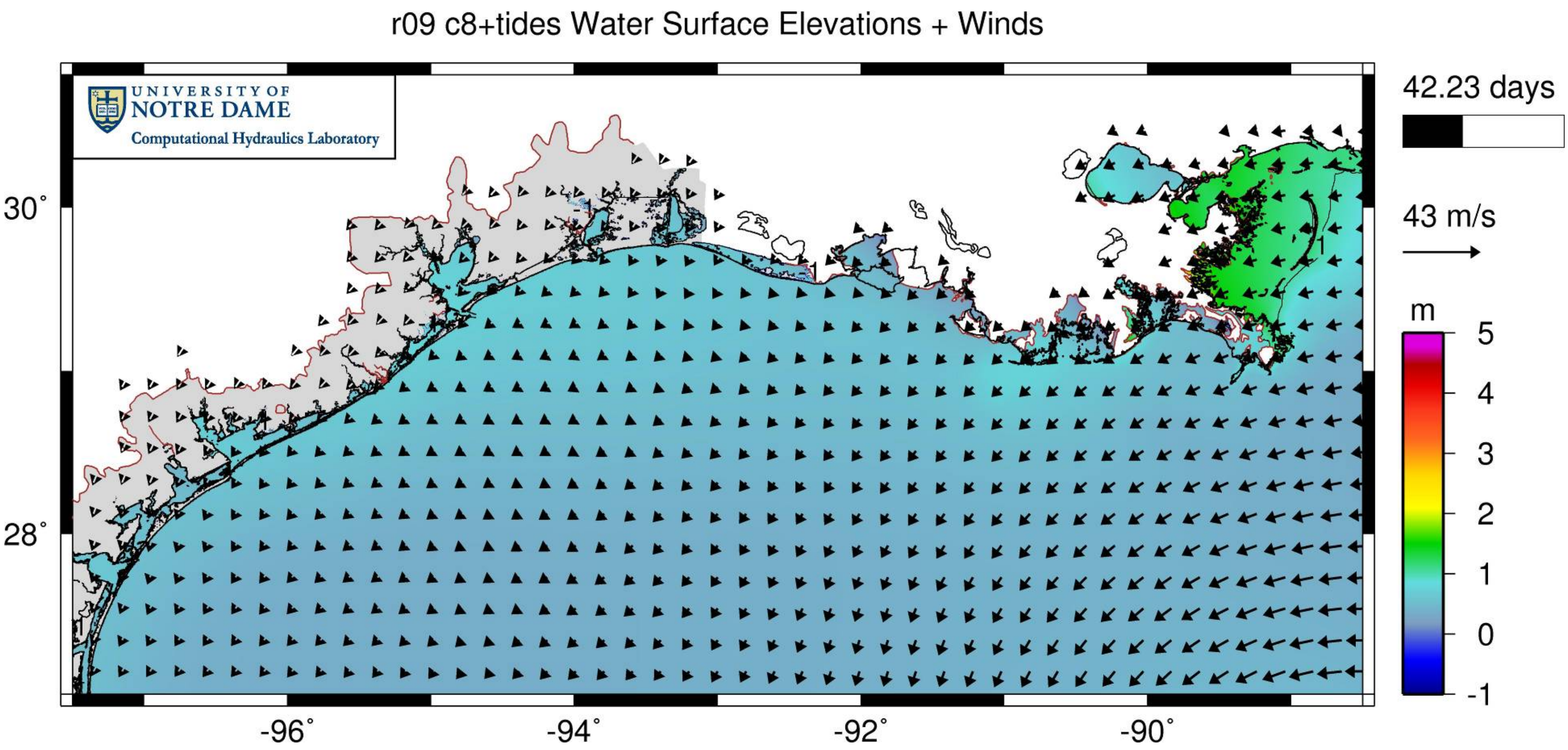


Ike surge contours (m) and wind vectors (m/s)



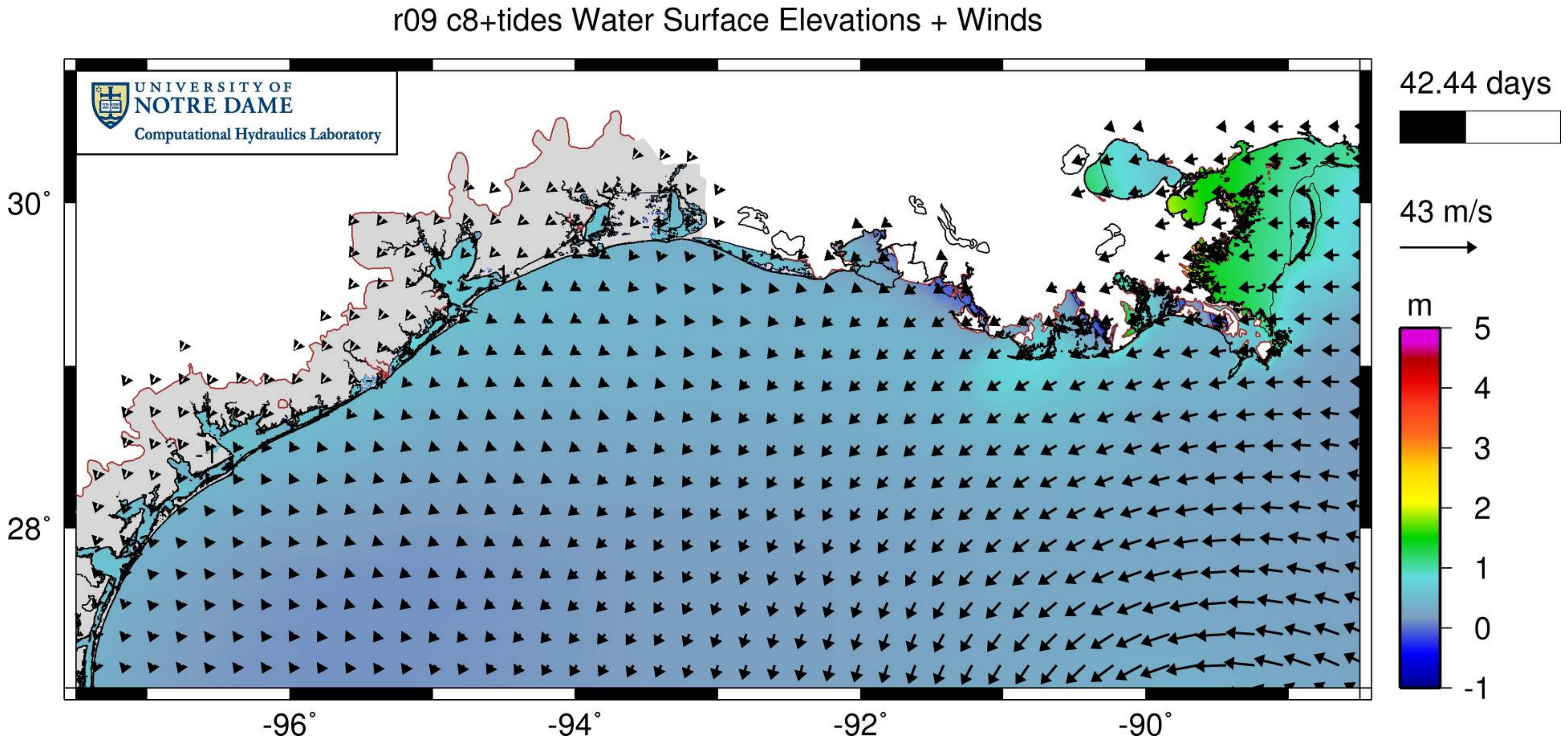
- 43 hrs

Ike surge contours (m) and wind vectors (m/s)



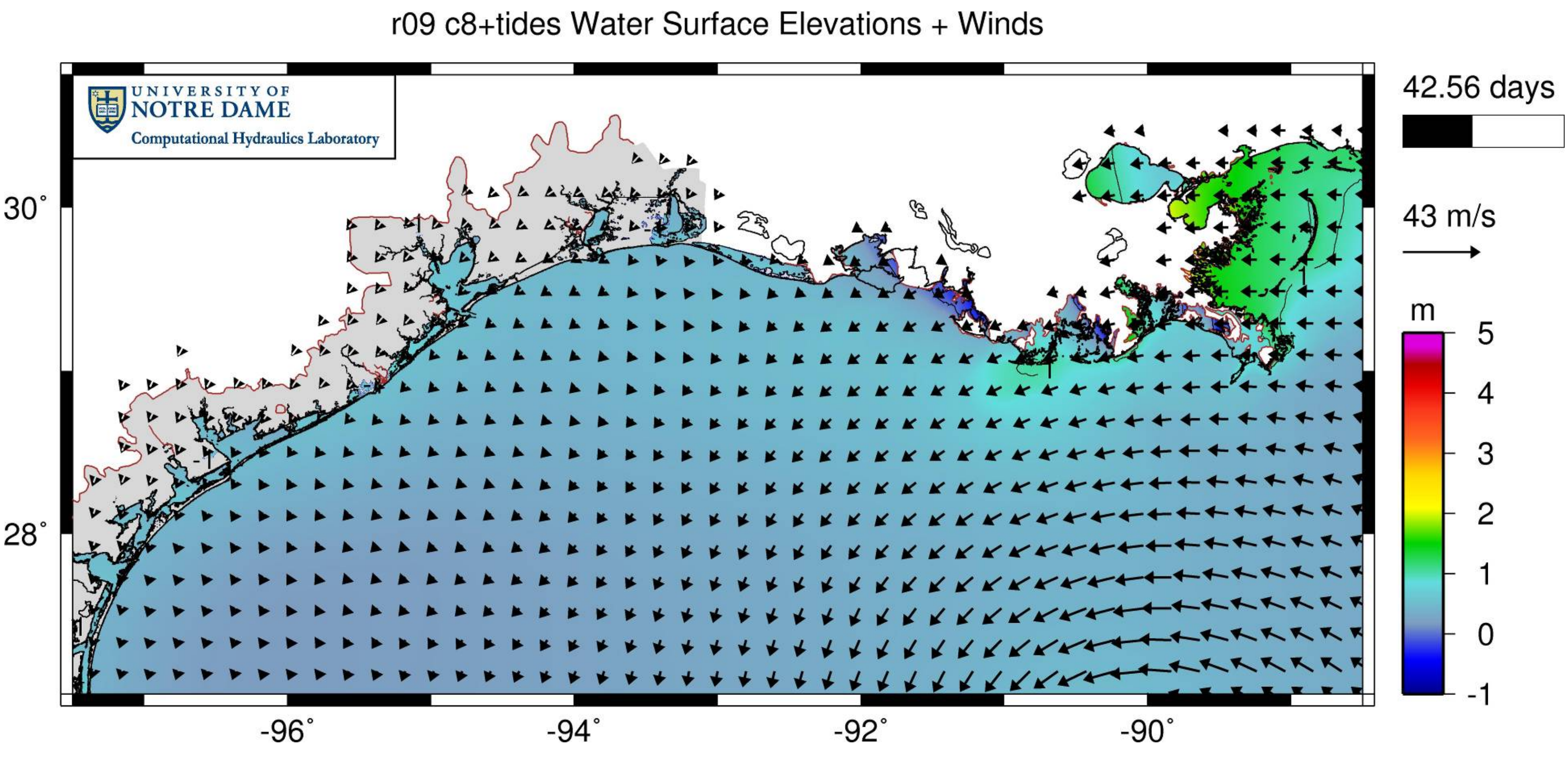
- 38 hrs

Ike surge contours (m) and wind vectors (m/s)



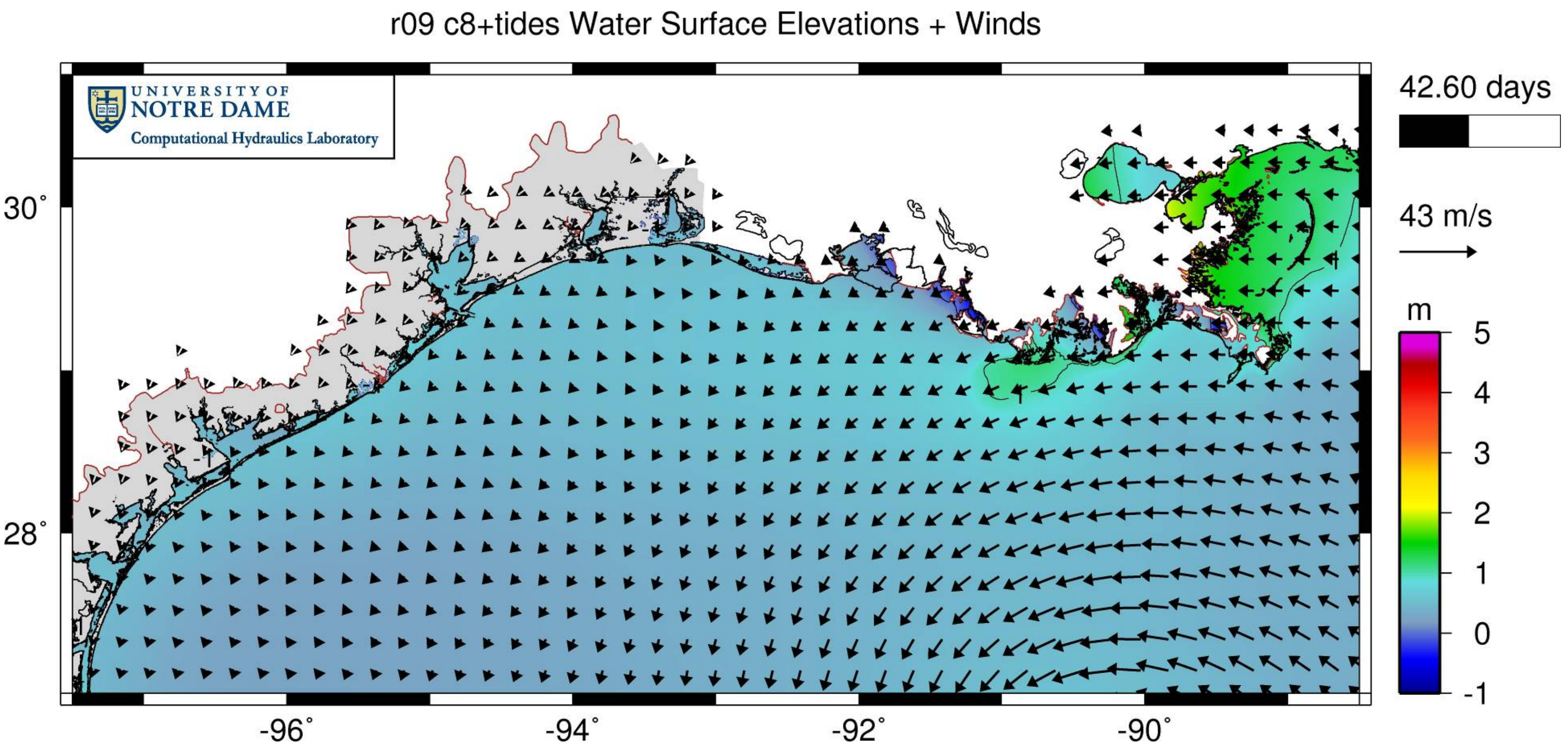
- 33 hrs

Ike surge contours (m) and wind vectors (m/s)



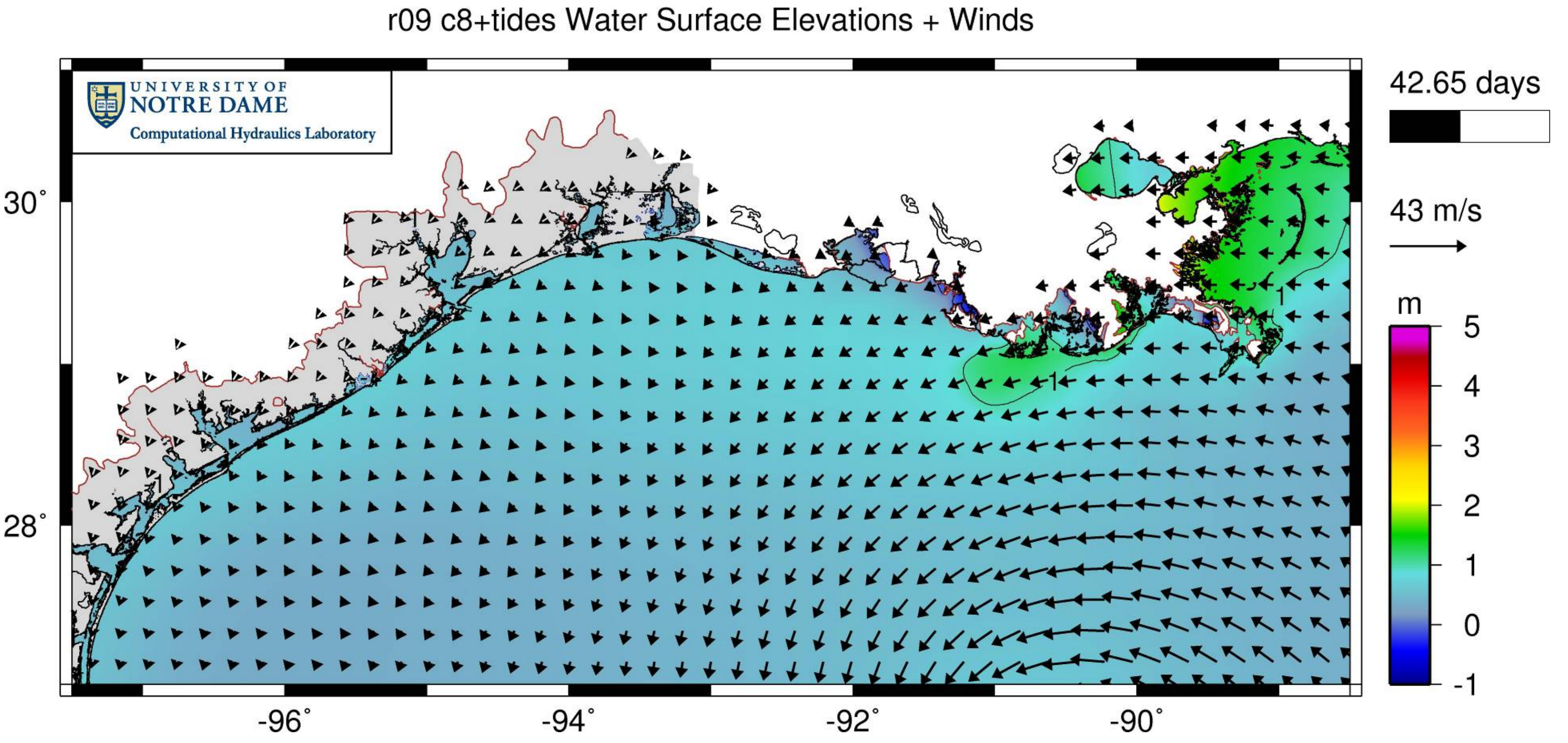
- 30 hrs

Ike surge contours (m) and wind vectors (m/s)



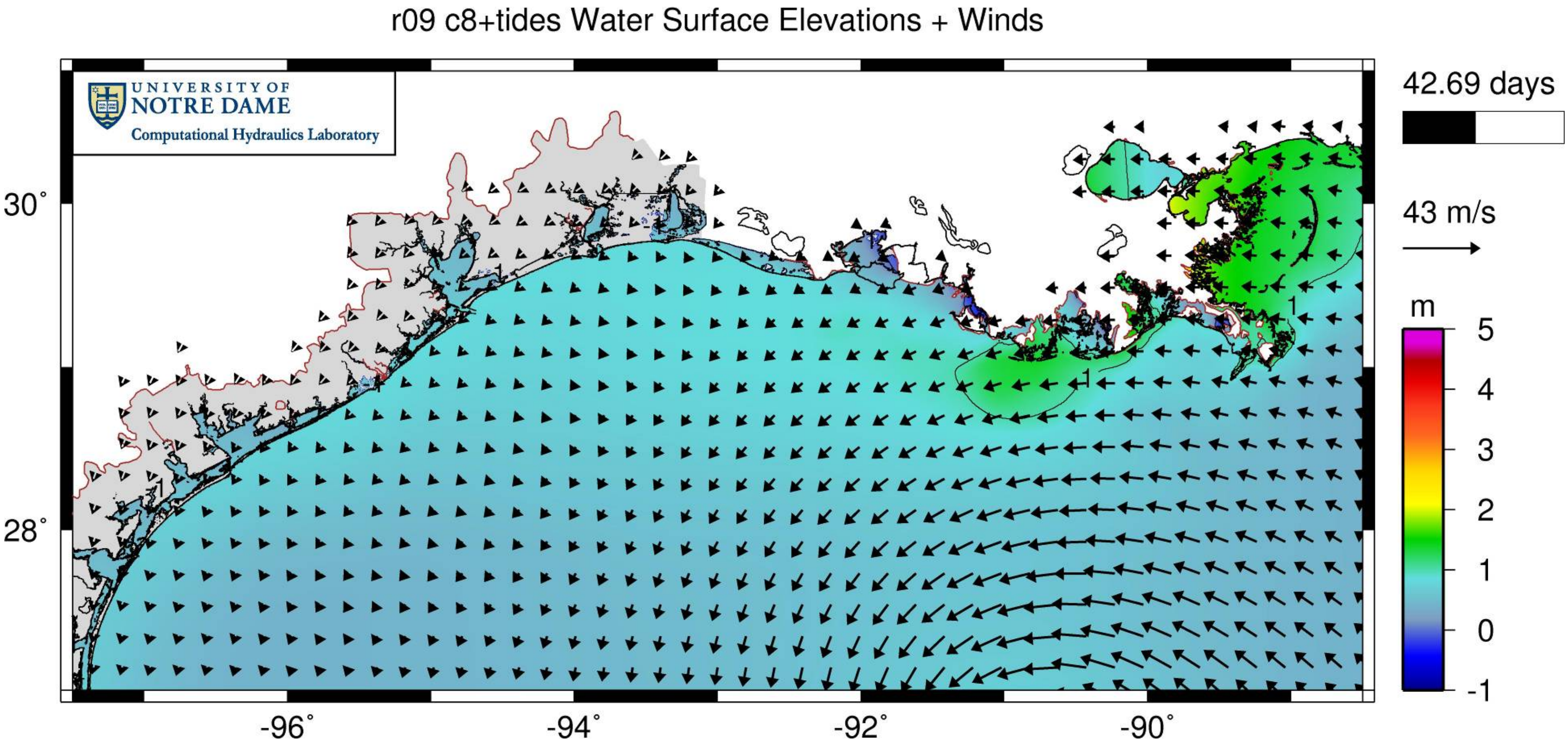
- 29 hrs

Ike surge contours (m) and wind vectors (m/s)



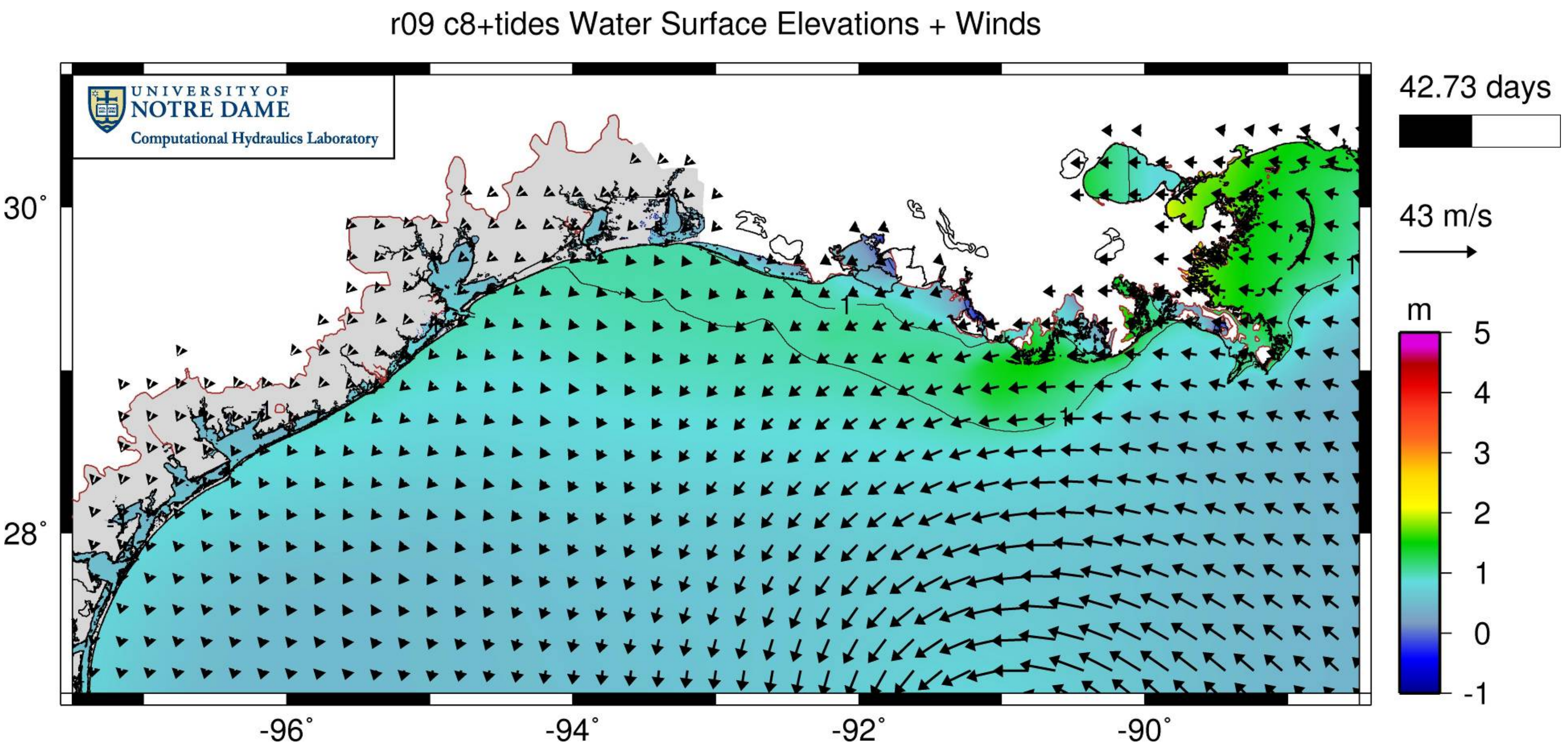
- 28 hrs

Ike surge contours (m) and wind vectors (m/s)



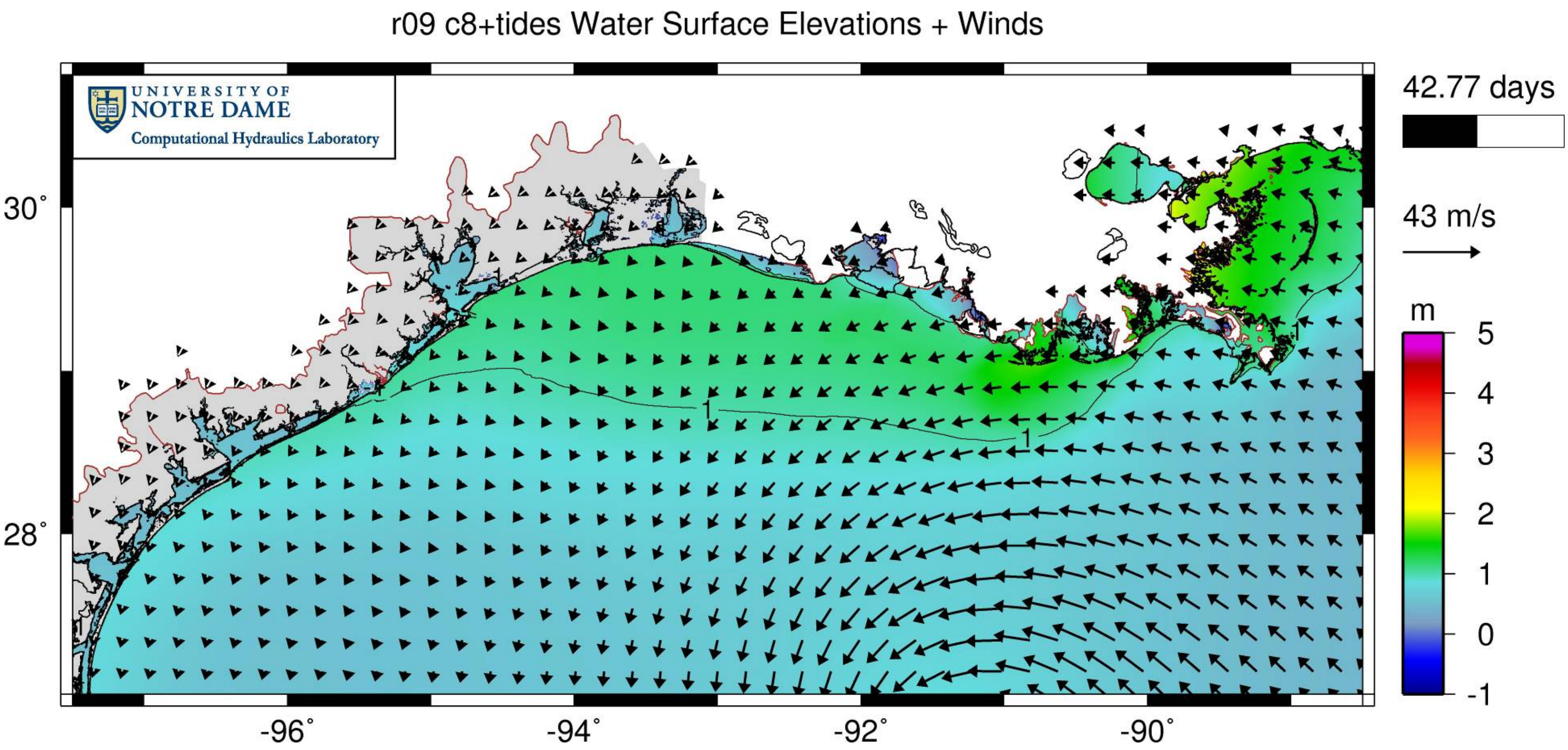
- 27 hrs

Ike surge contours (m) and wind vectors (m/s)



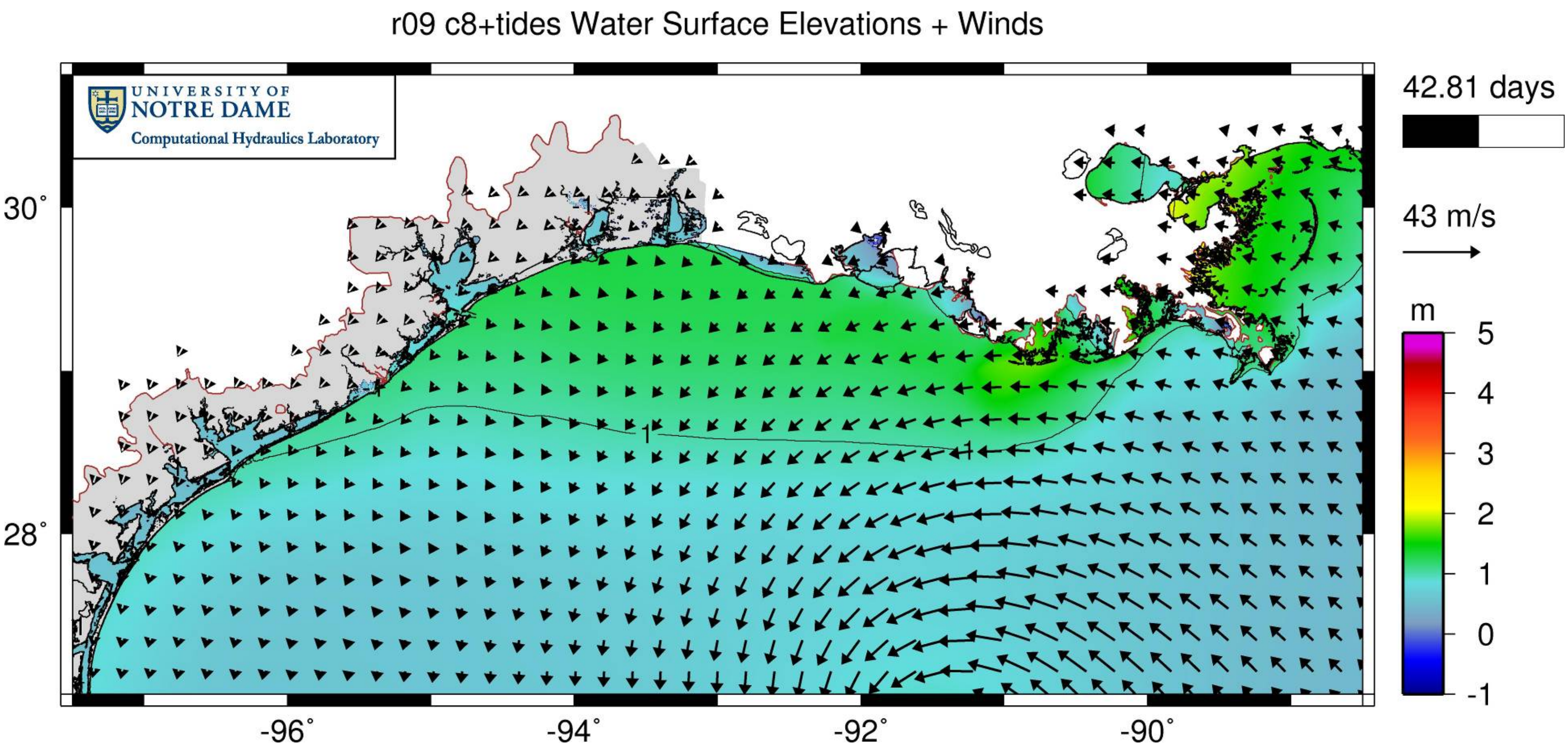
- 26 hrs

Ike surge contours (m) and wind vectors (m/s)



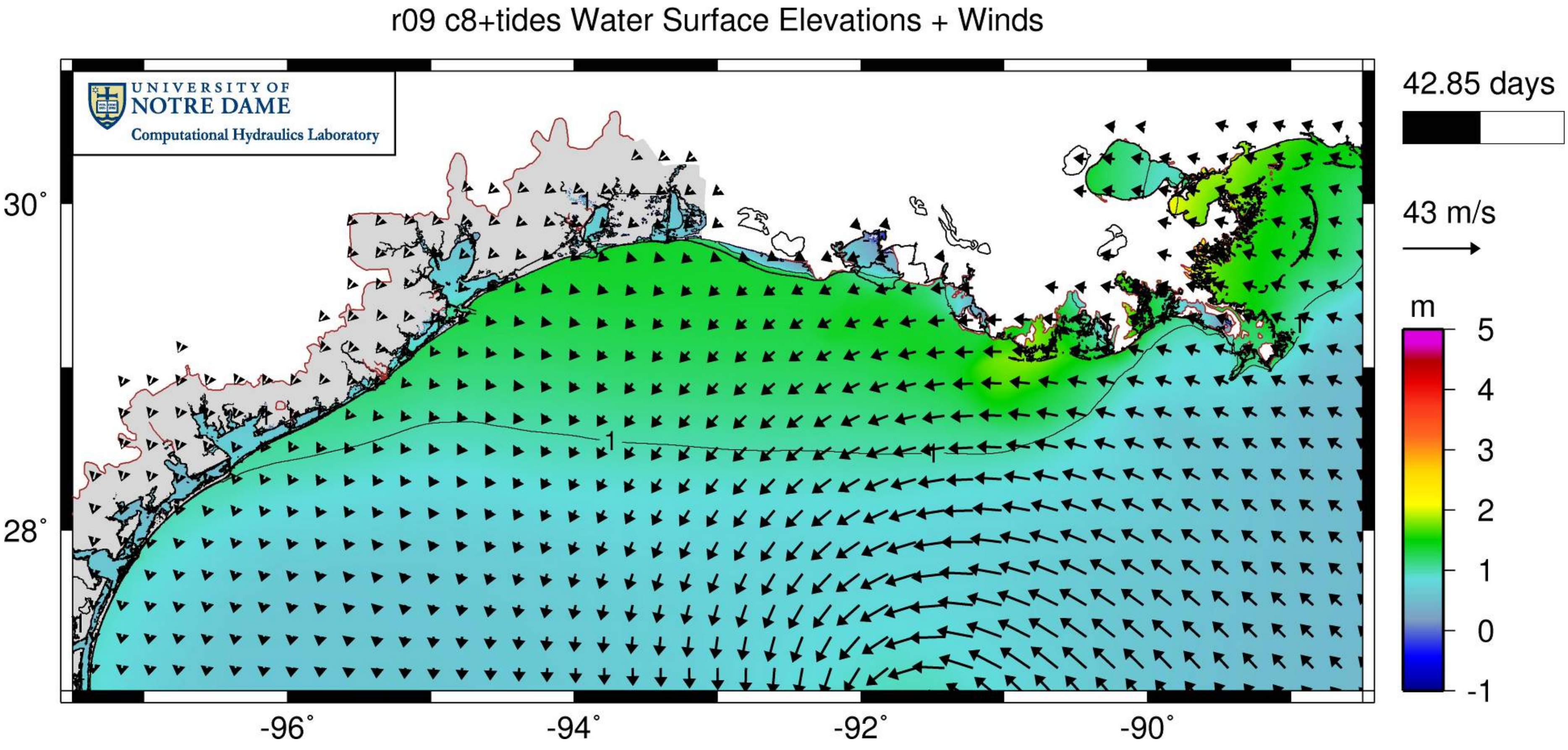
- 25 hrs

Ike surge contours (m) and wind vectors (m/s)



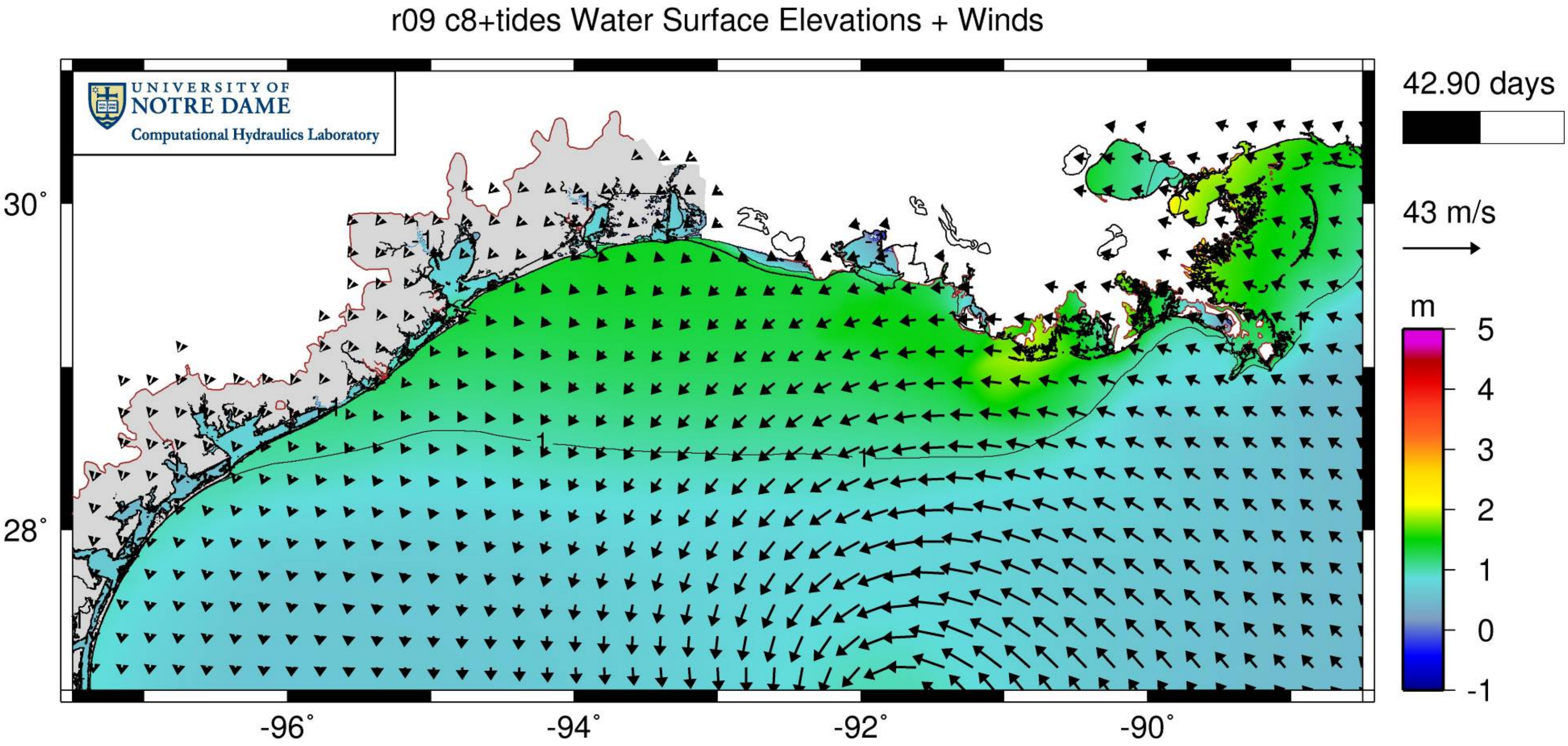
- 24 hrs

Ike surge contours (m) and wind vectors (m/s)



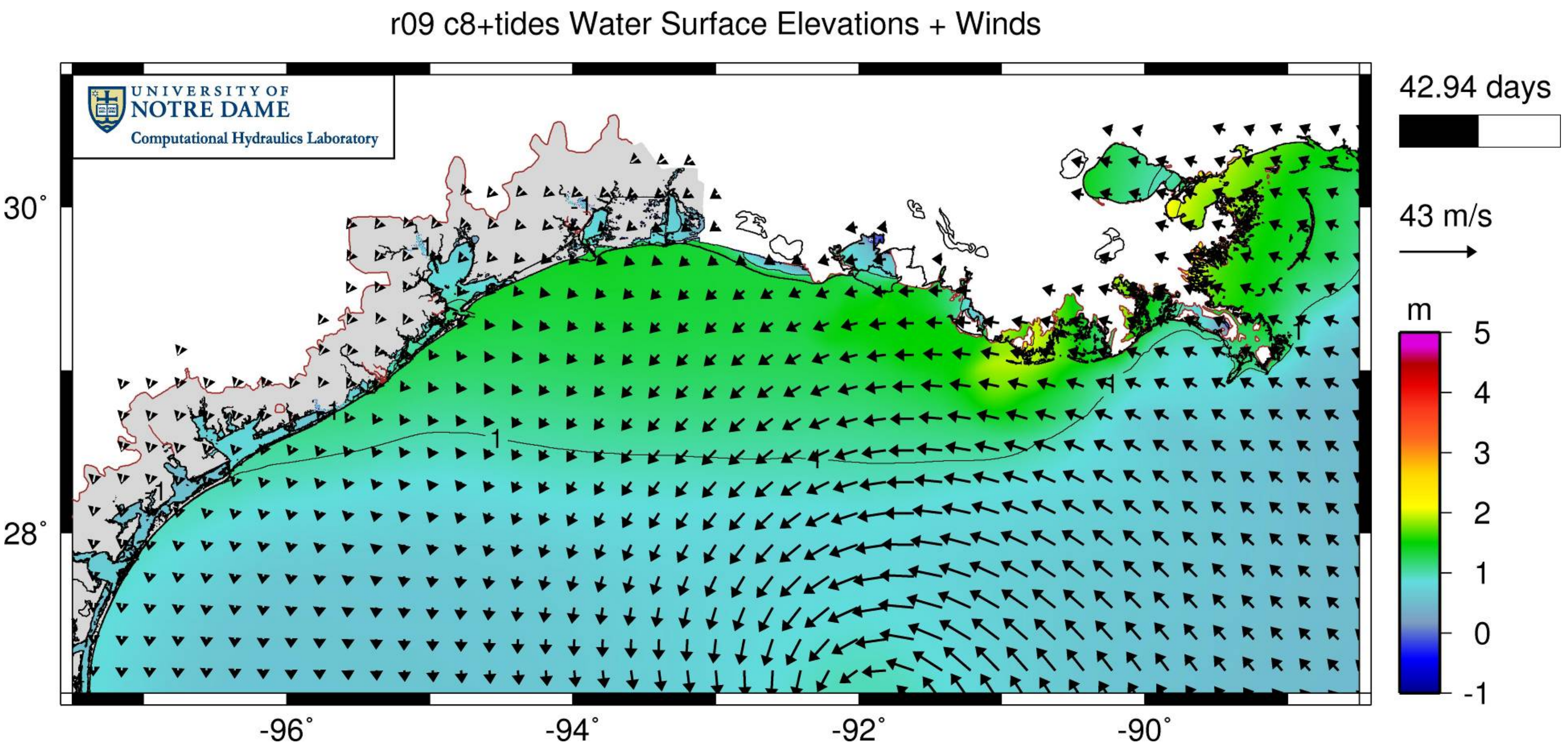
- 23 hrs

Ike surge contours (m) and wind vectors (m/s)



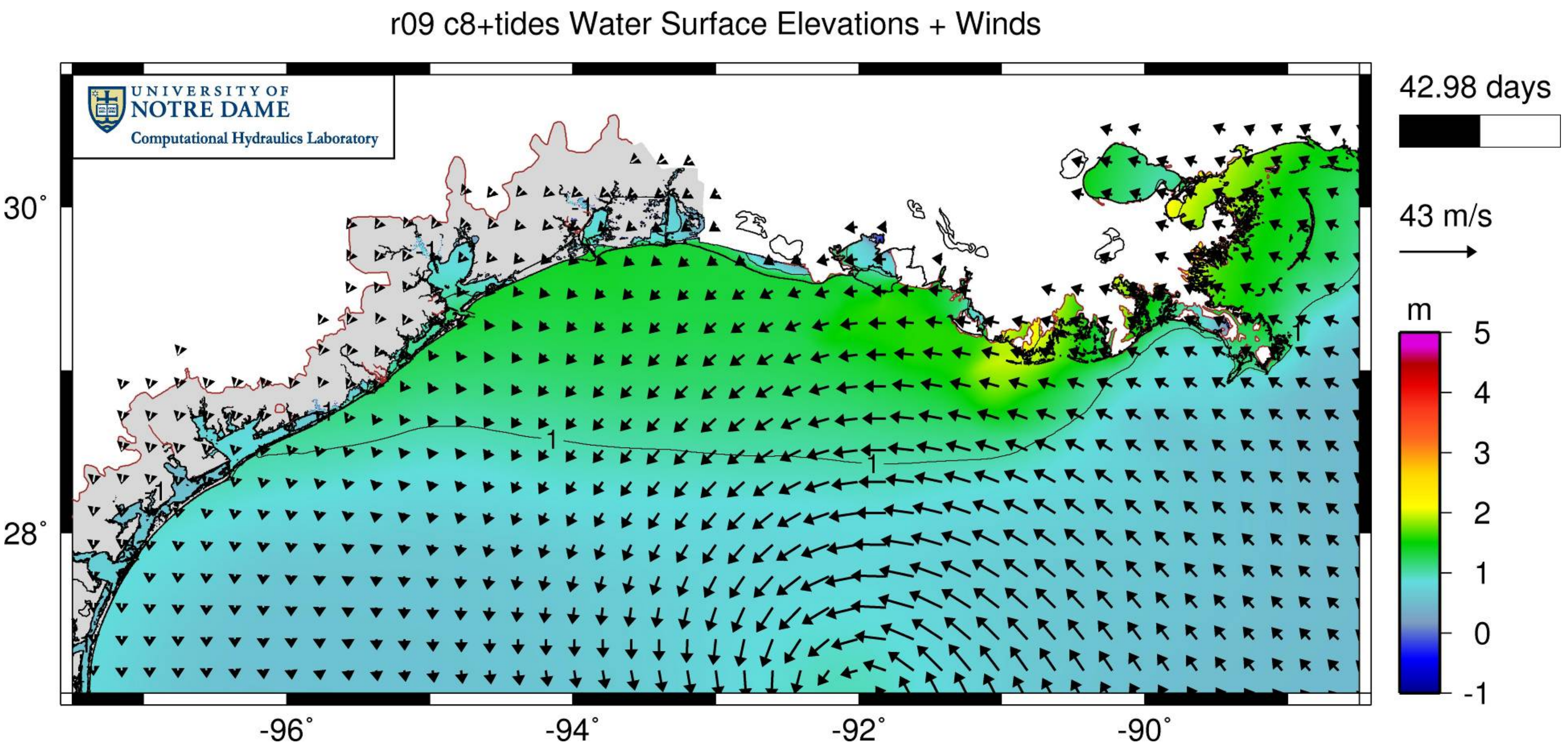
- 22 hrs

Ike surge contours (m) and wind vectors (m/s)



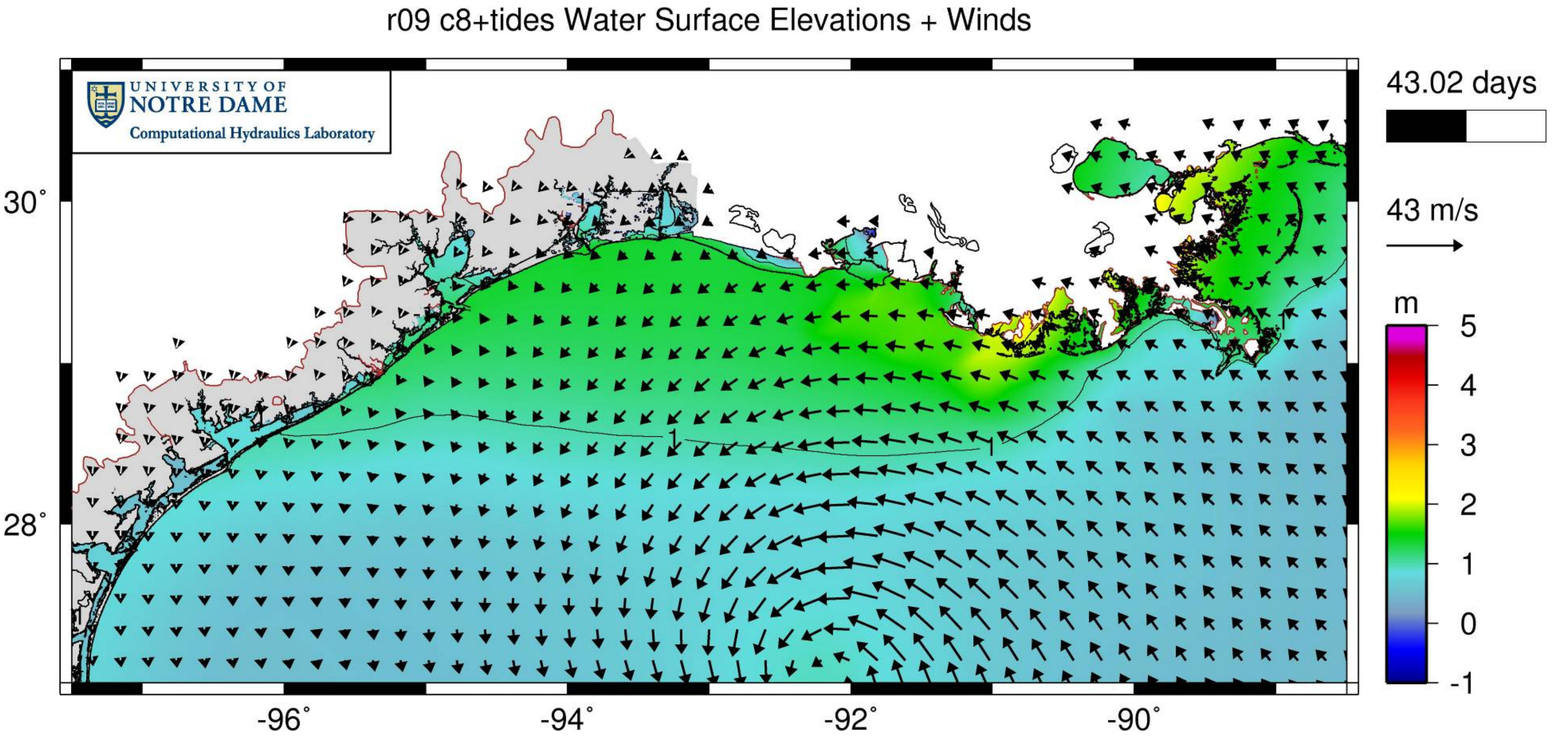
- 21 hrs

Ike surge contours (m) and wind vectors (m/s)



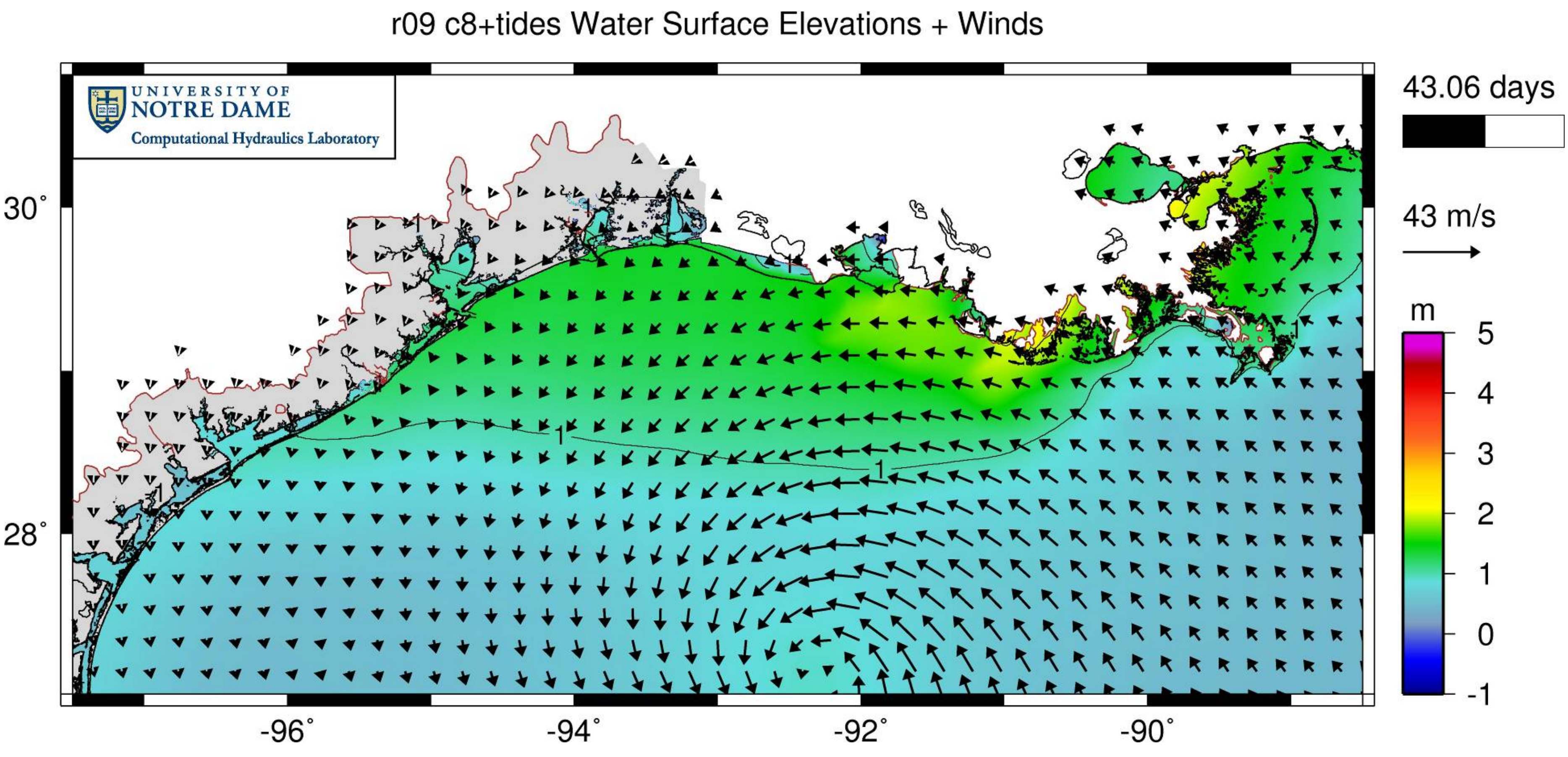
- 20 hrs

Ike surge contours (m) and wind vectors (m/s)



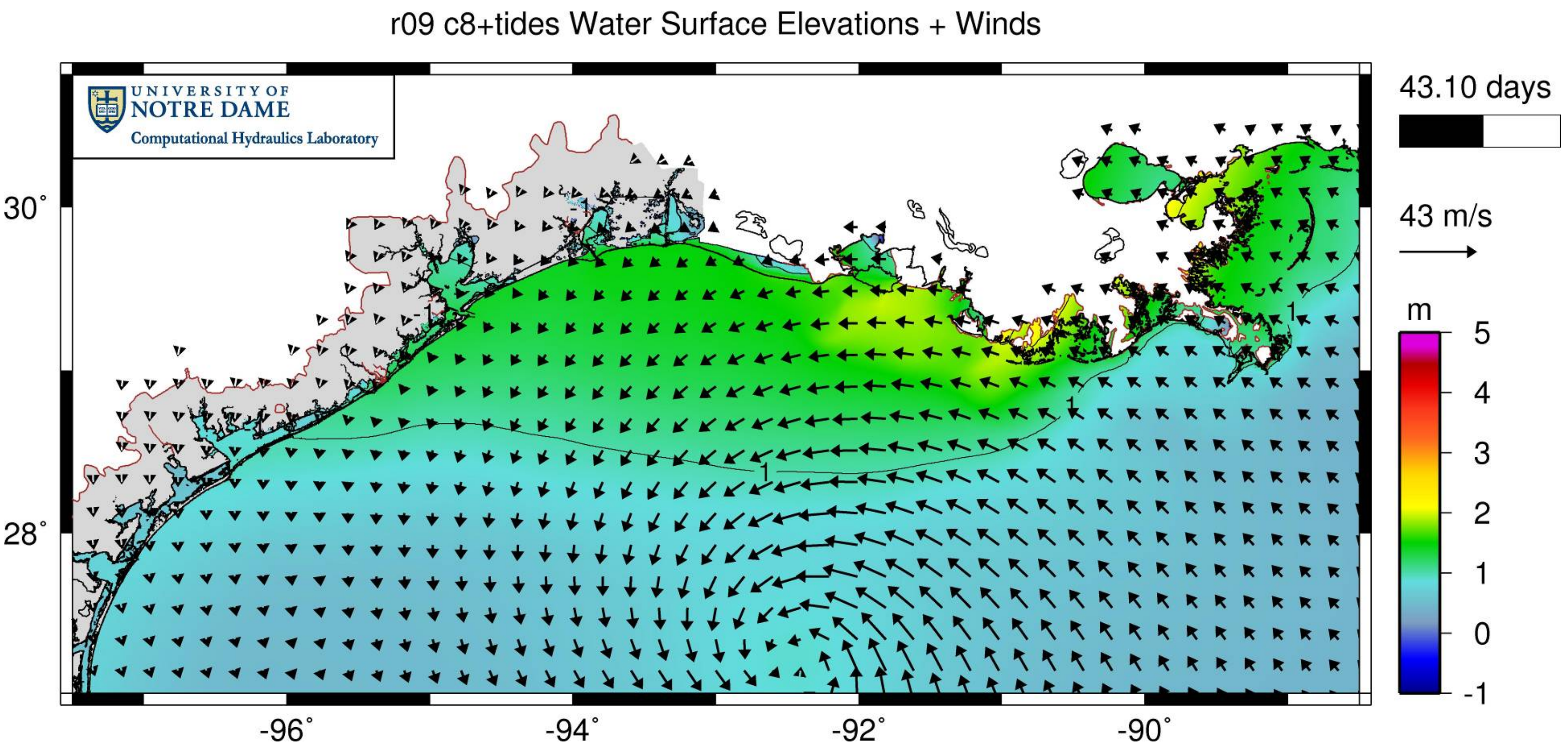
- 19 hrs

Ike surge contours (m) and wind vectors (m/s)



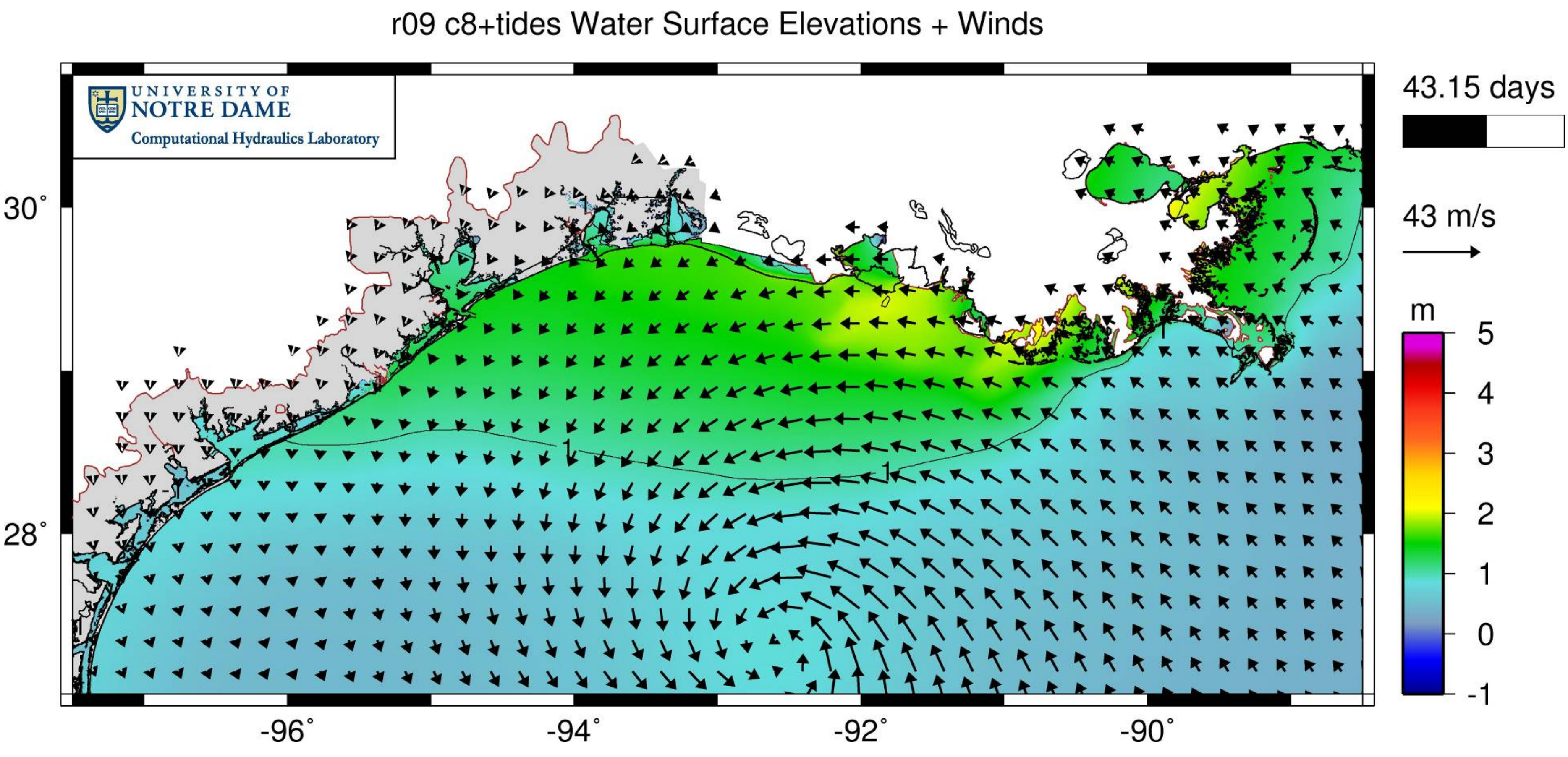
- 18 hrs

Ike surge contours (m) and wind vectors (m/s)



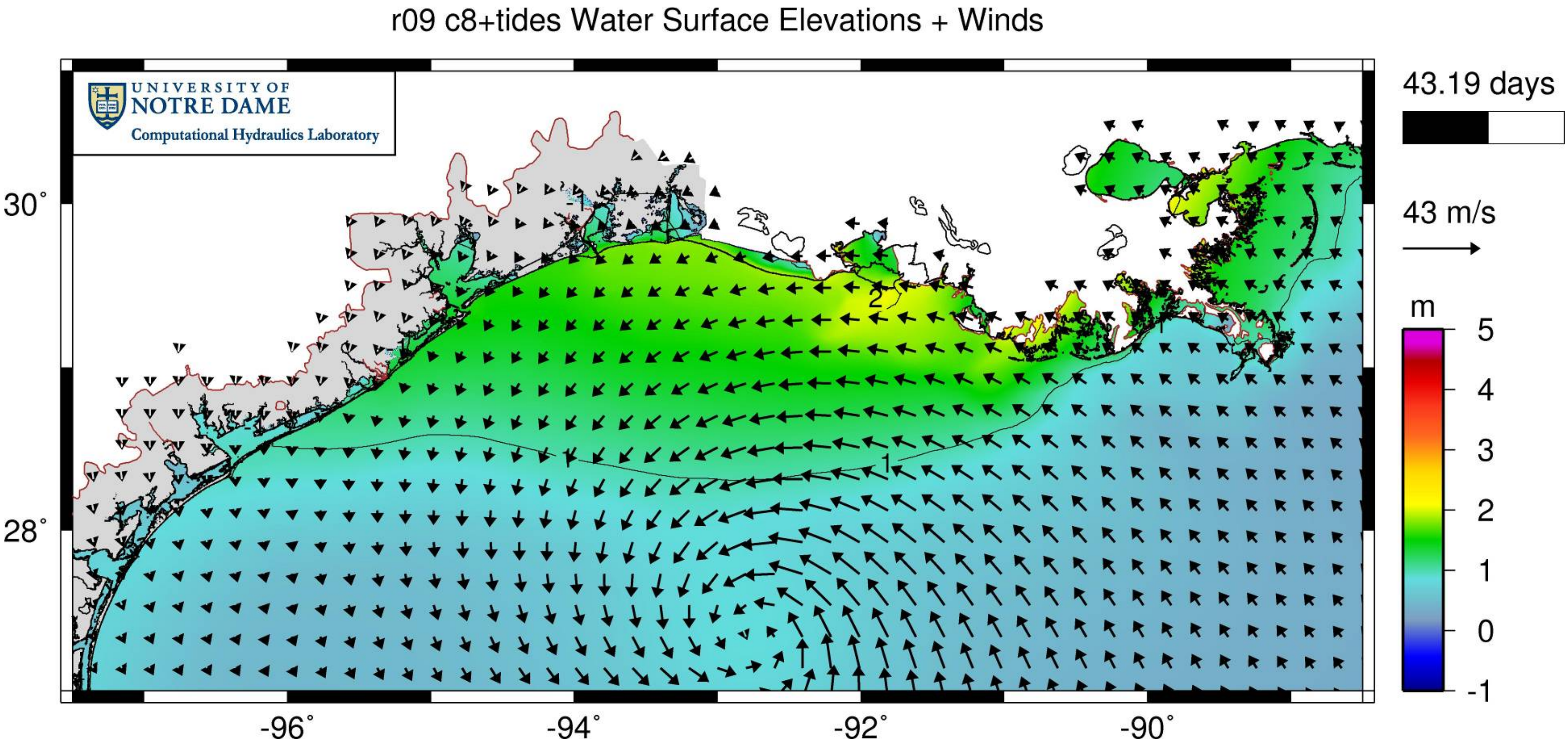
- 17 hrs

Ike surge contours (m) and wind vectors (m/s)



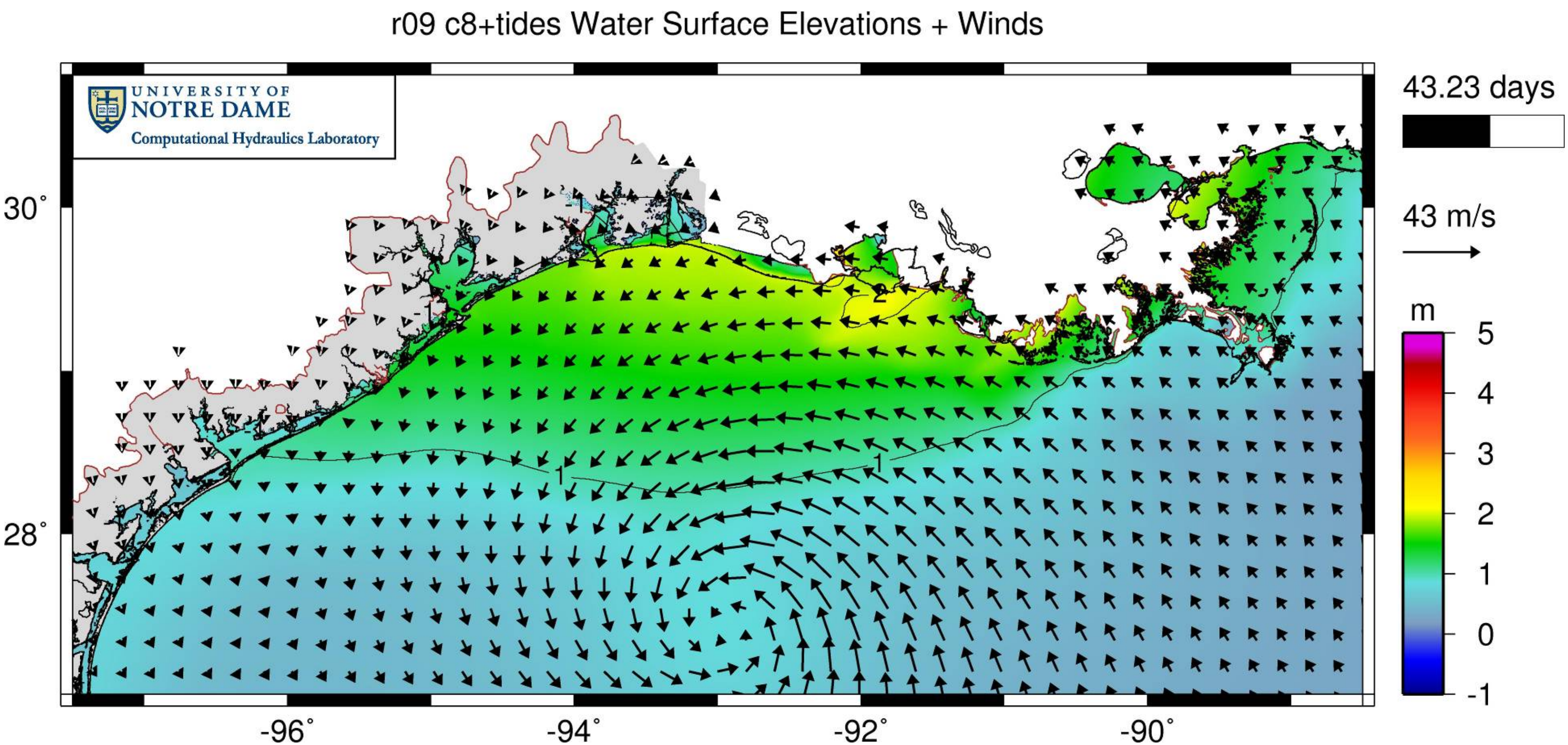
- 16 hrs

Ike surge contours (m) and wind vectors (m/s)



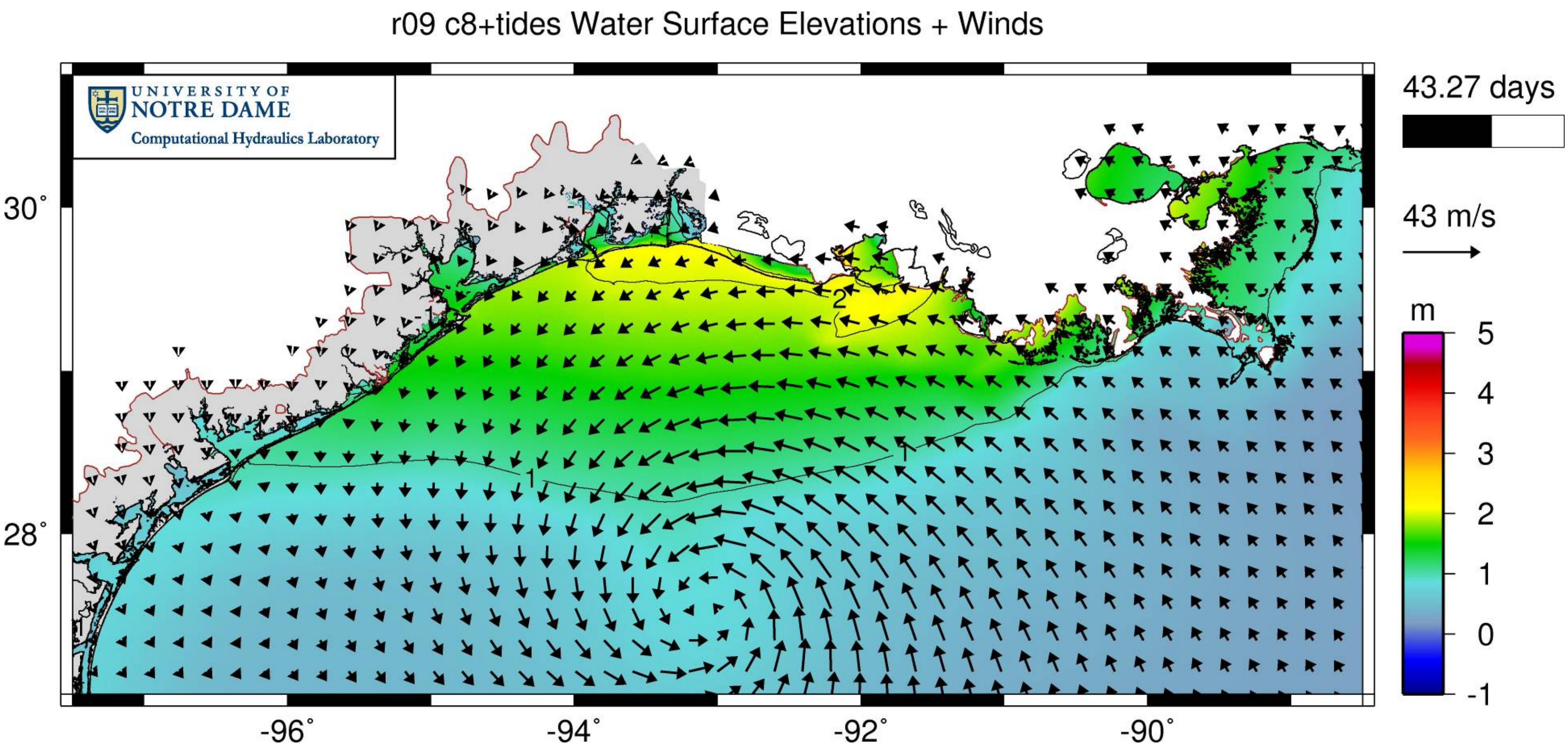
- 15 hrs

Ike surge contours (m) and wind vectors (m/s)



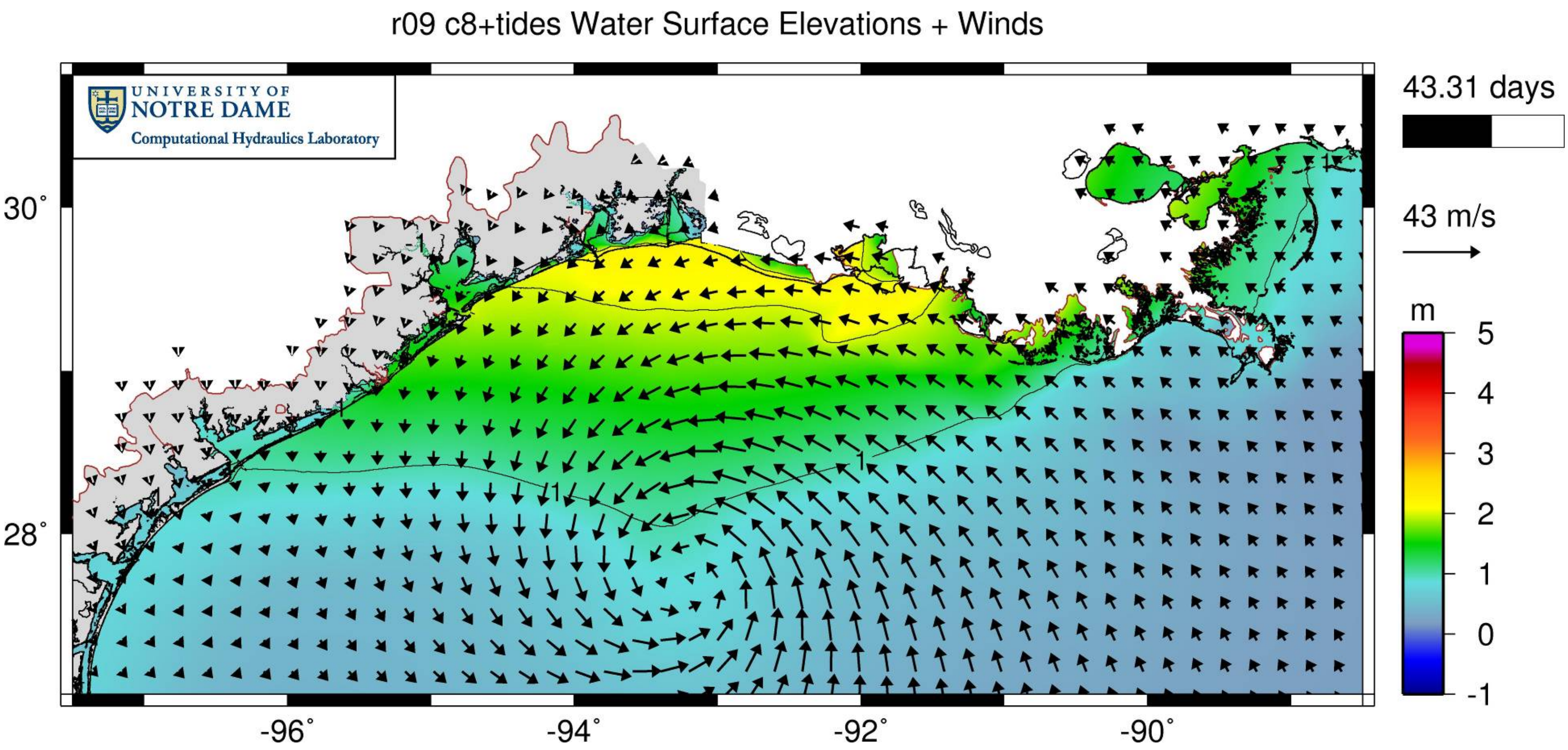
- 14 hrs

Ike surge contours (m) and wind vectors (m/s)



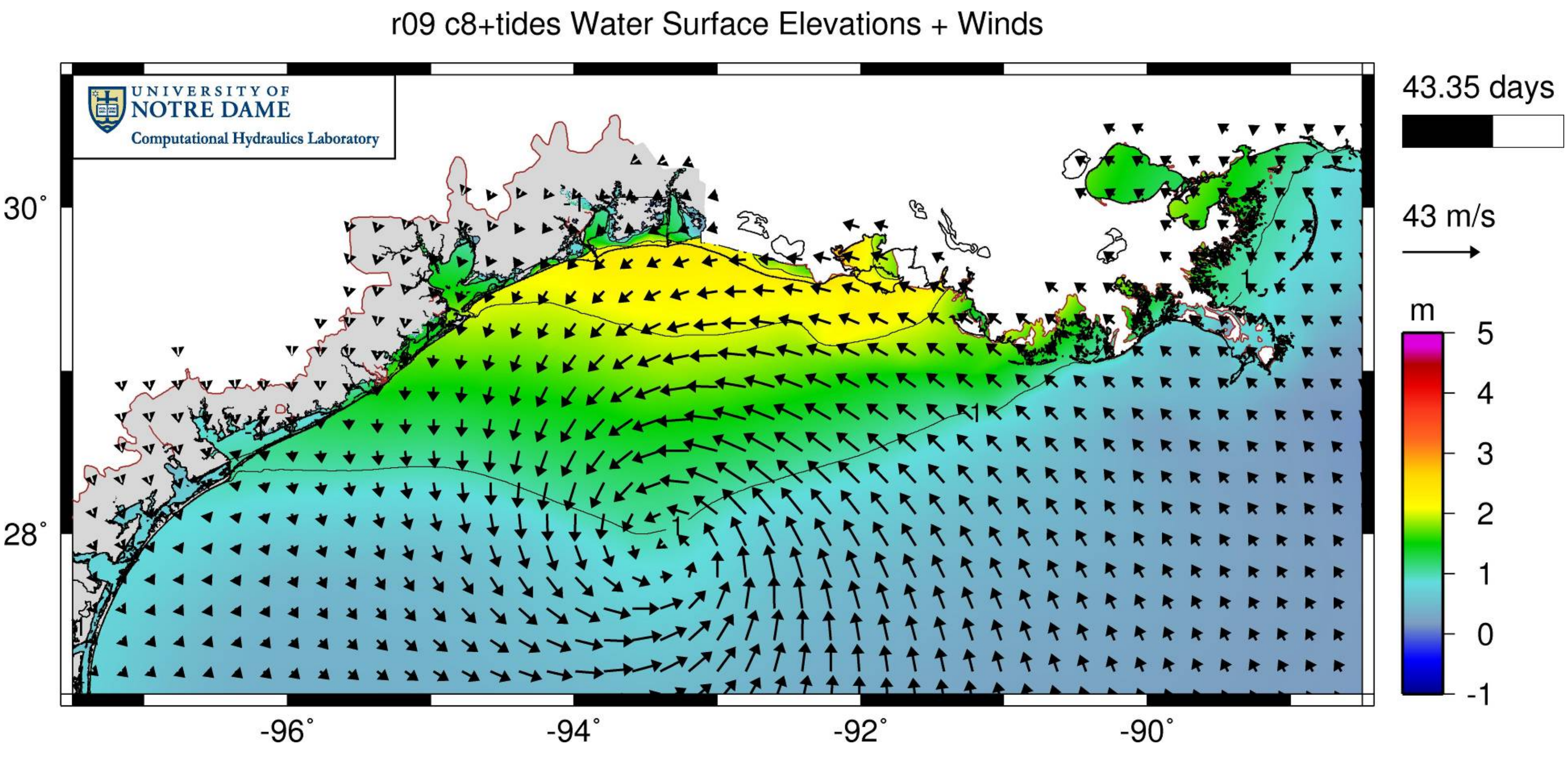
- 13 hrs

Ike surge contours (m) and wind vectors (m/s)



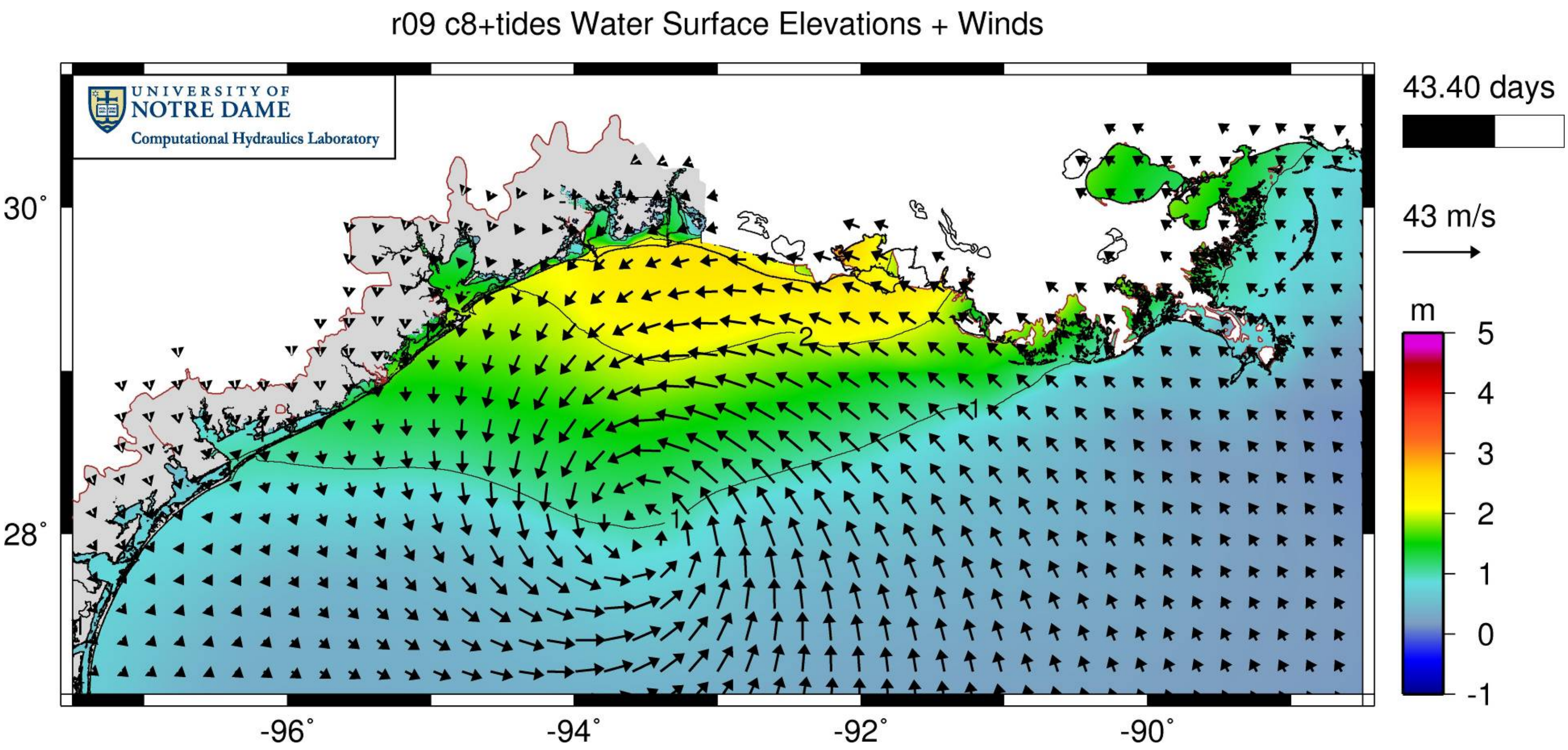
- 12 hrs

Ike surge contours (m) and wind vectors (m/s)



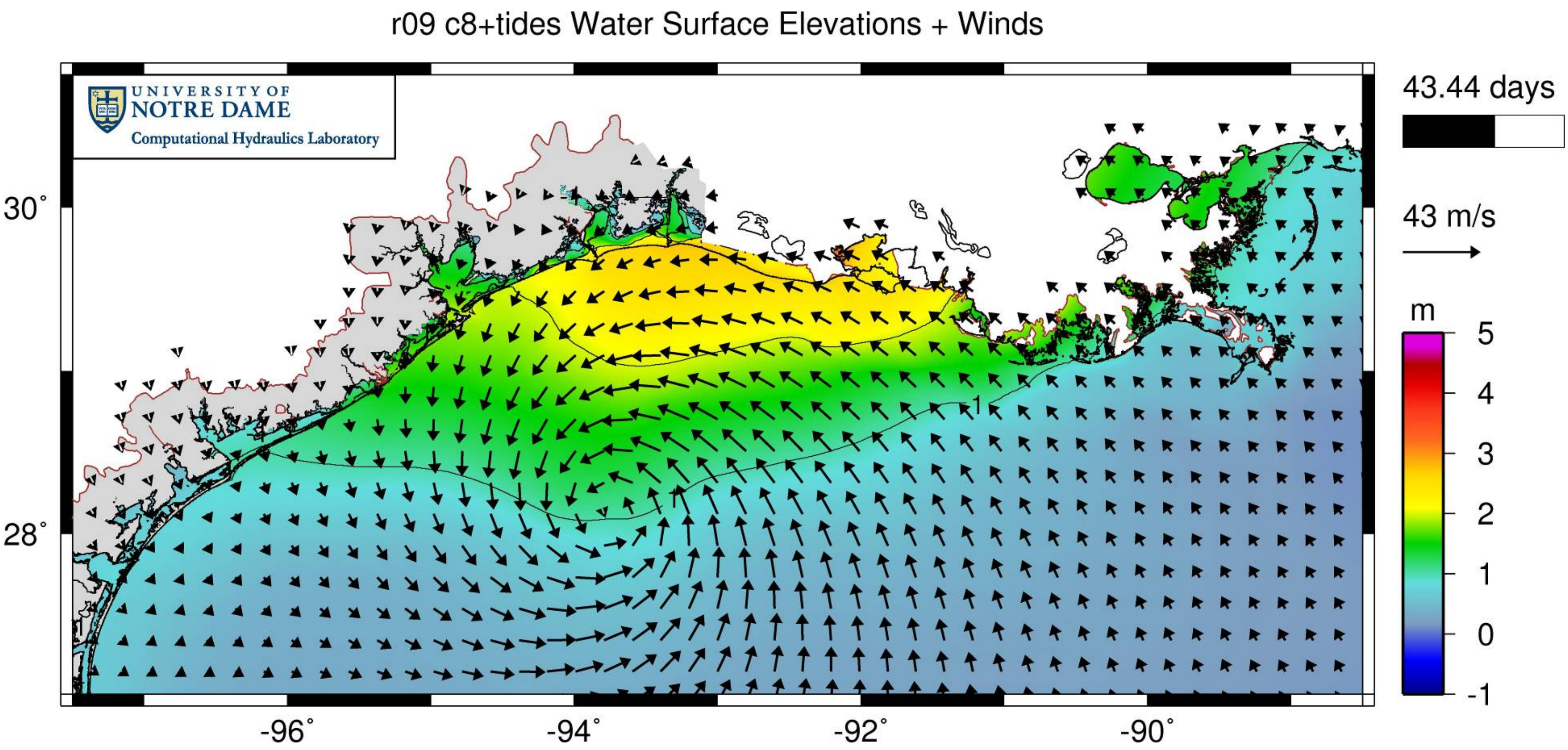
- 11 hrs

Ike surge contours (m) and wind vectors (m/s)



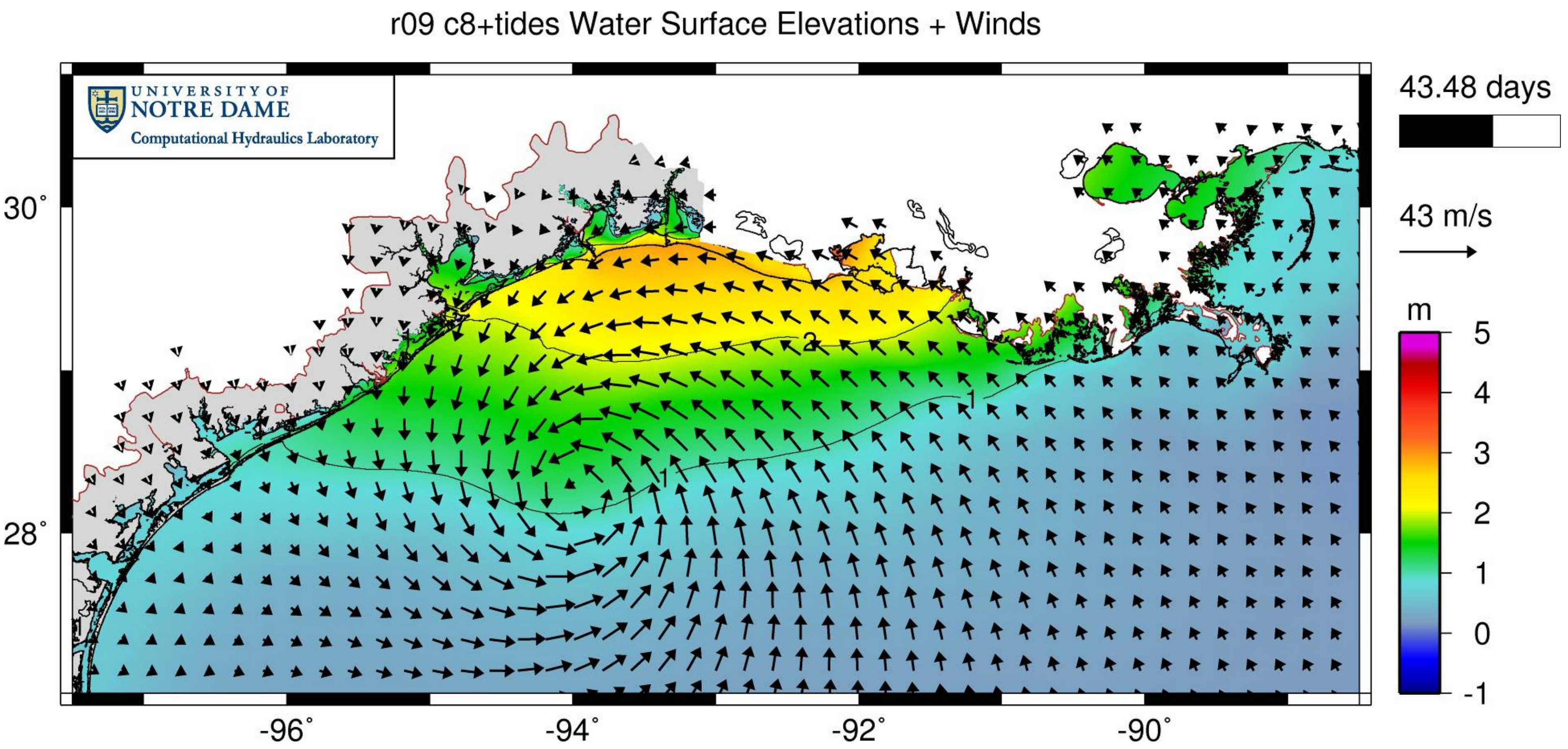
- 10 hrs

Ike surge contours (m) and wind vectors (m/s)



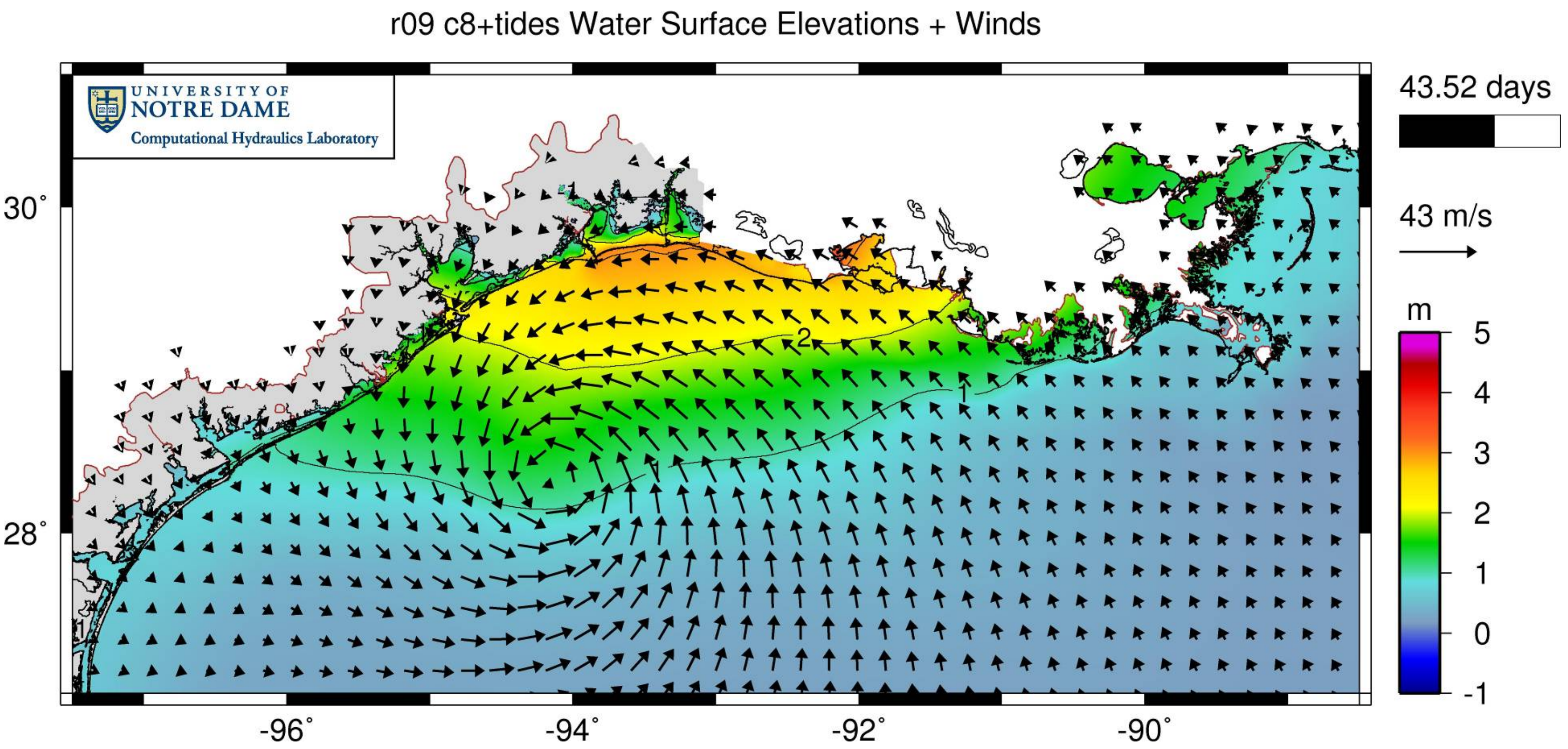
- 9 hrs

Ike surge contours (m) and wind vectors (m/s)



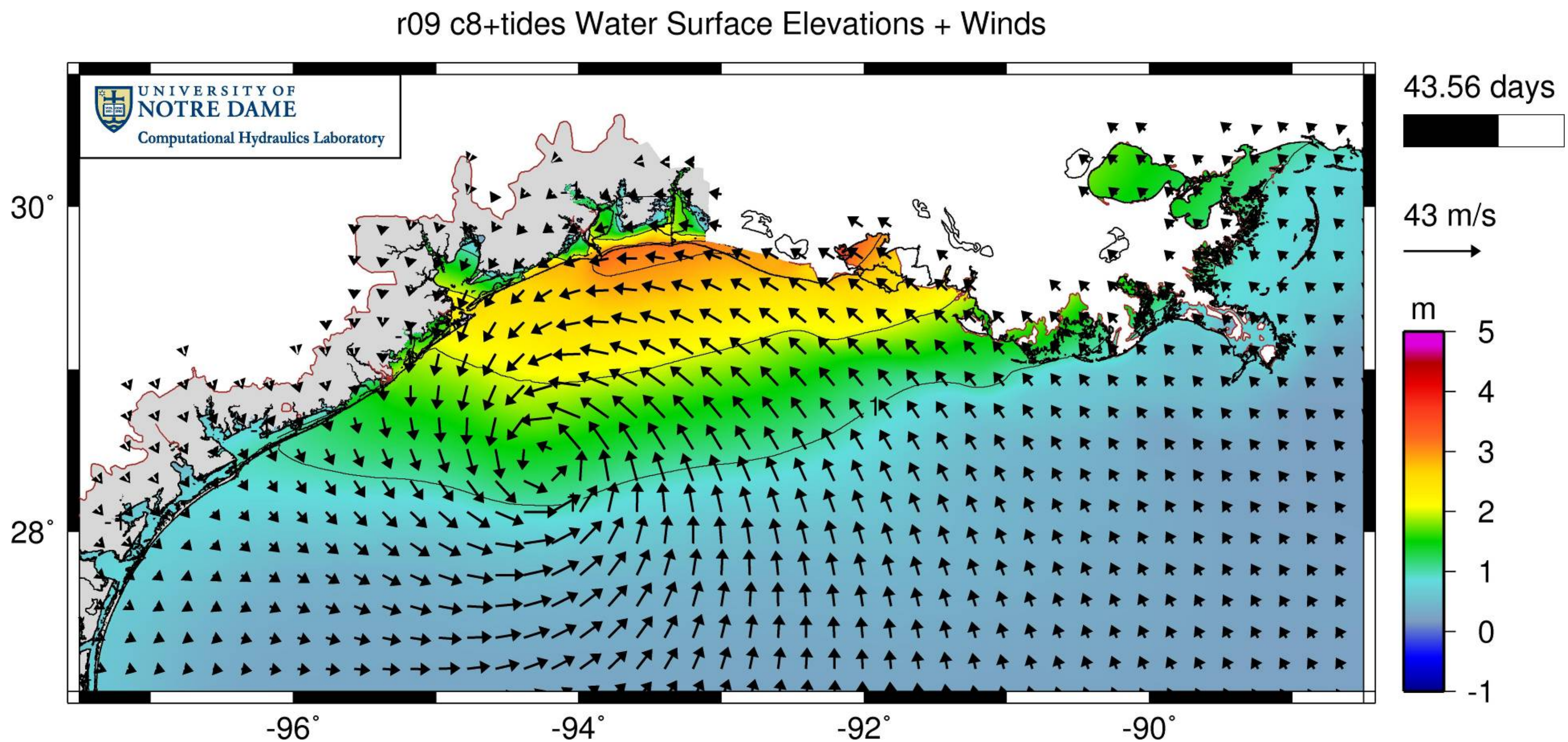
- 8 hrs

Ike surge contours (m) and wind vectors (m/s)



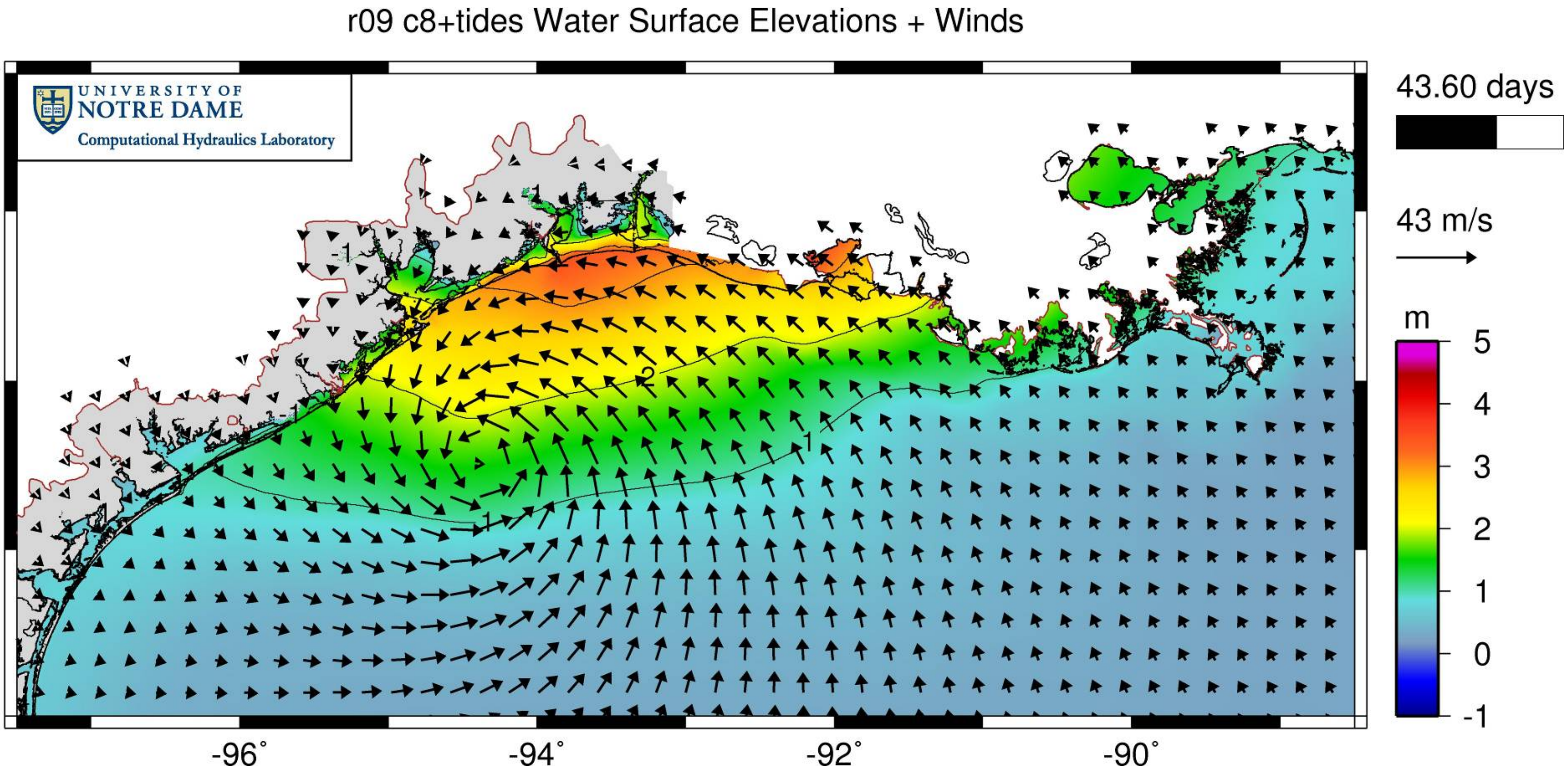
- 7 hrs

Ike surge contours (m) and wind vectors (m/s)



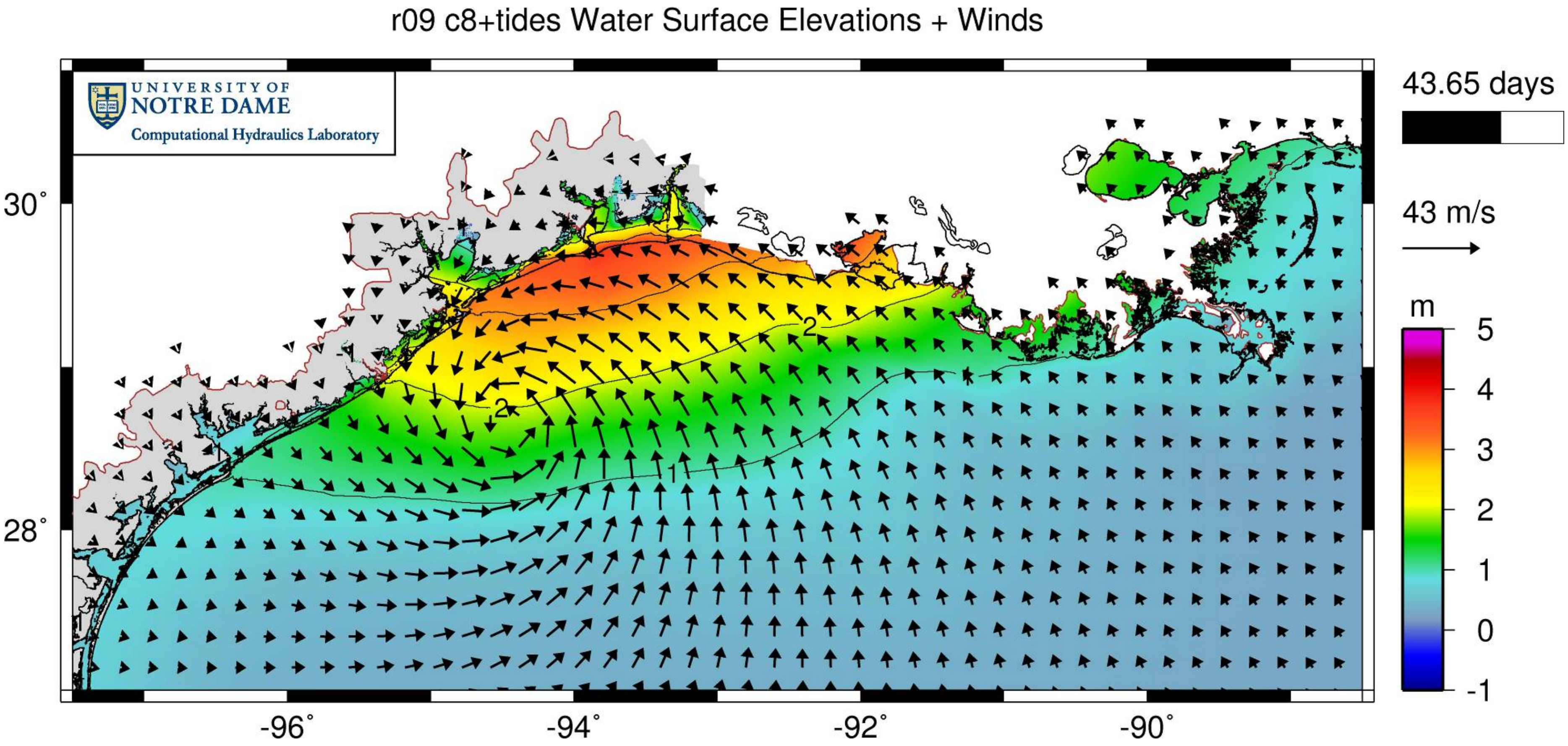
- 6 hrs

Ike surge contours (m) and wind vectors (m/s)



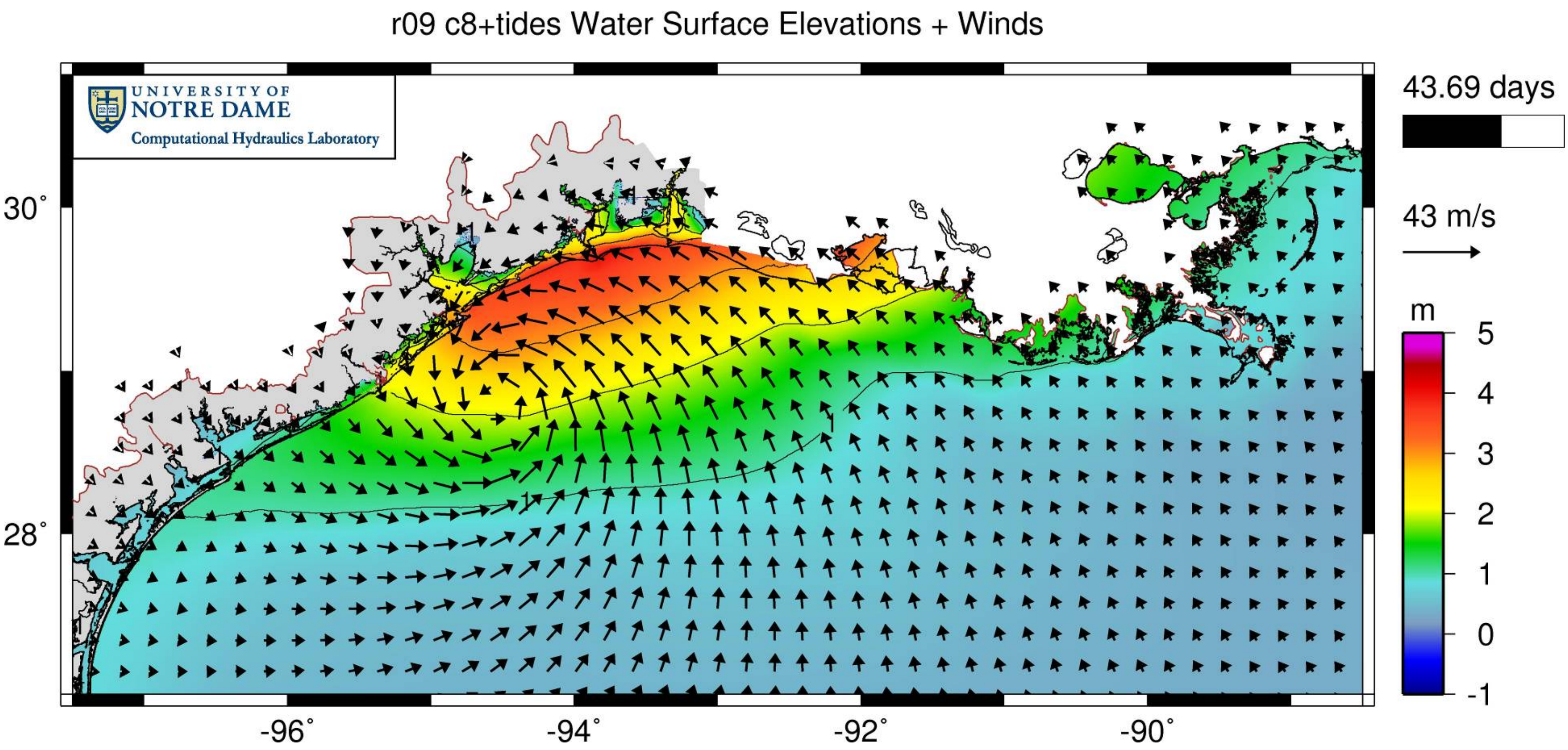
- 5 hrs

Ike surge contours (m) and wind vectors (m/s)



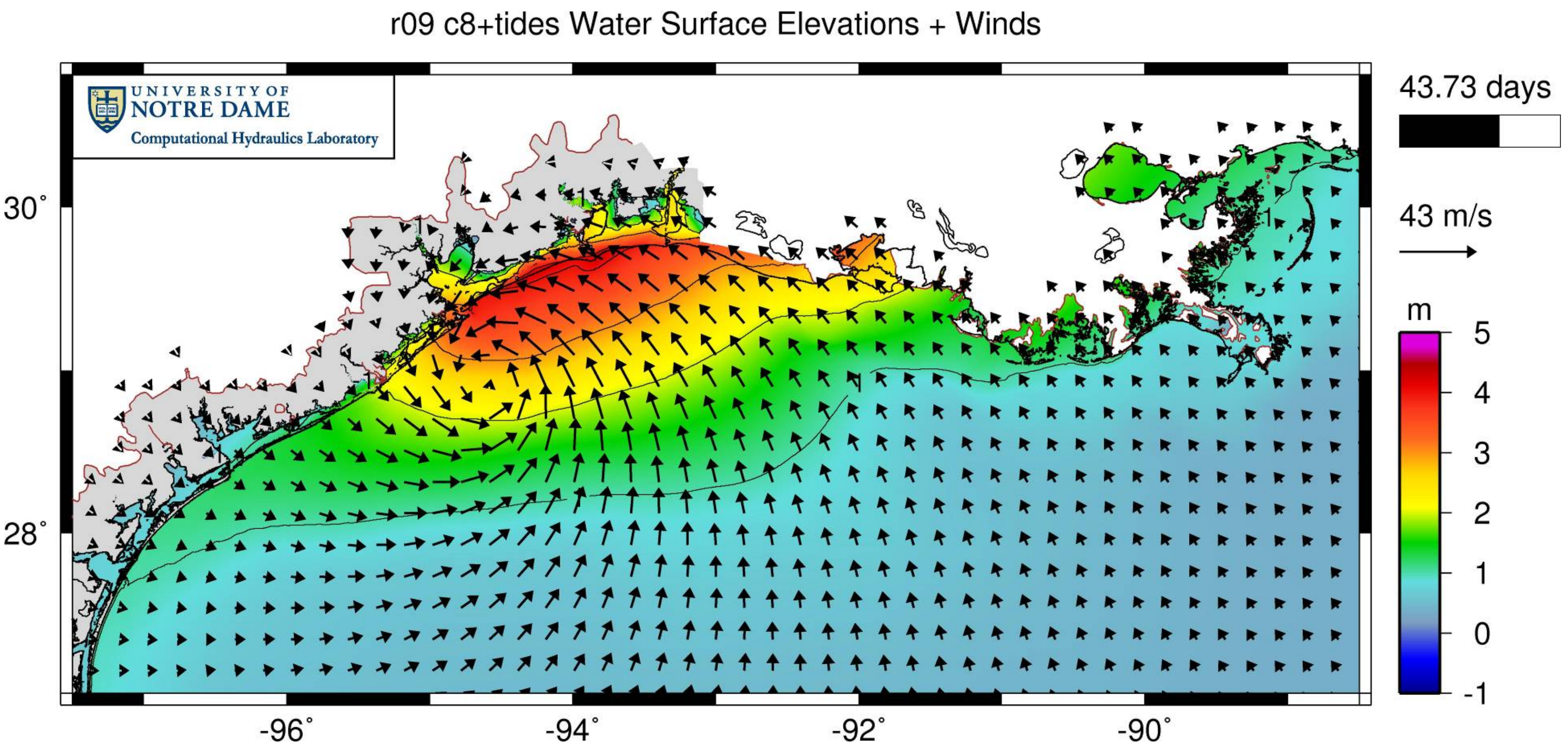
- 4 hrs

Ike surge contours (m) and wind vectors (m/s)



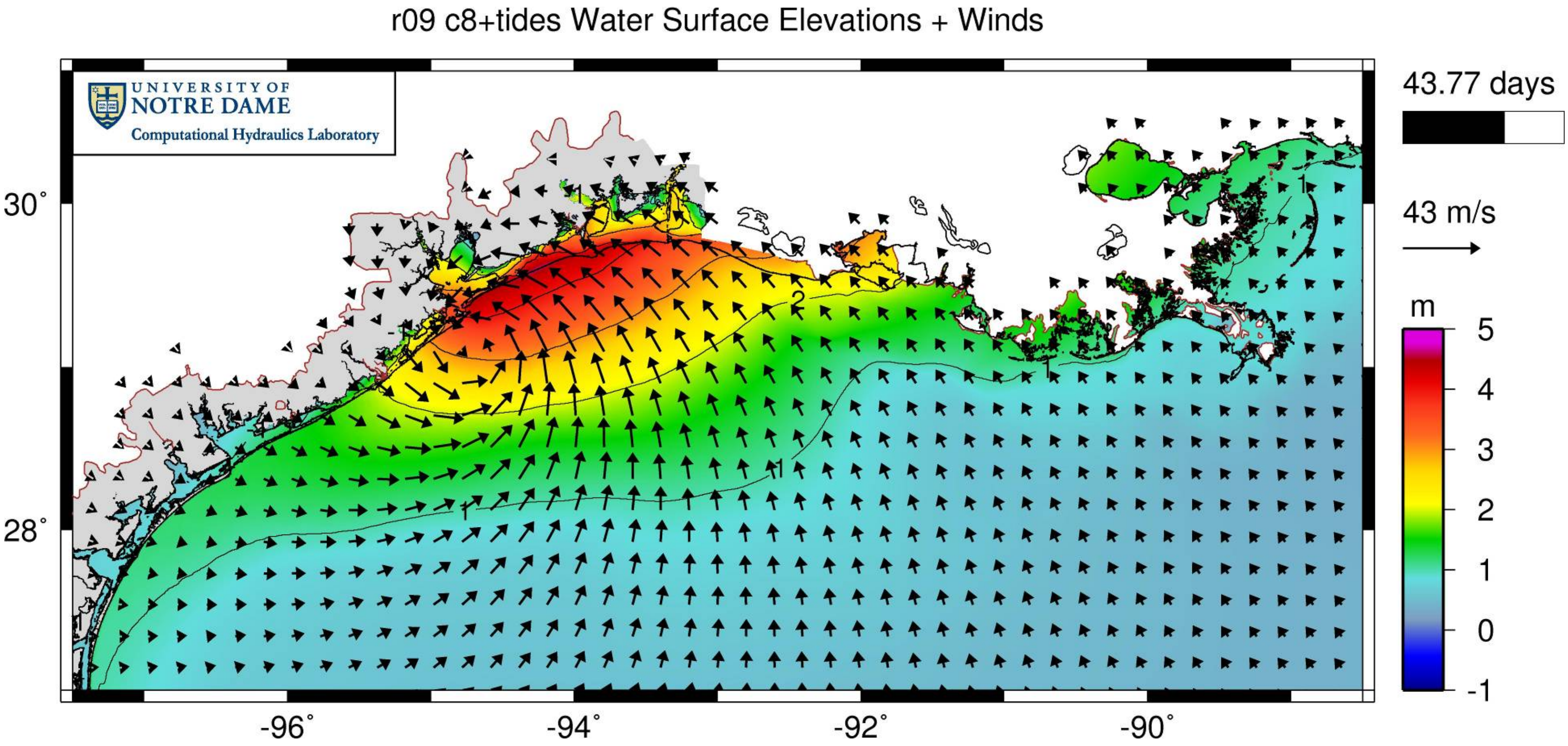
- 3 hrs

Ike surge contours (m) and wind vectors (m/s)



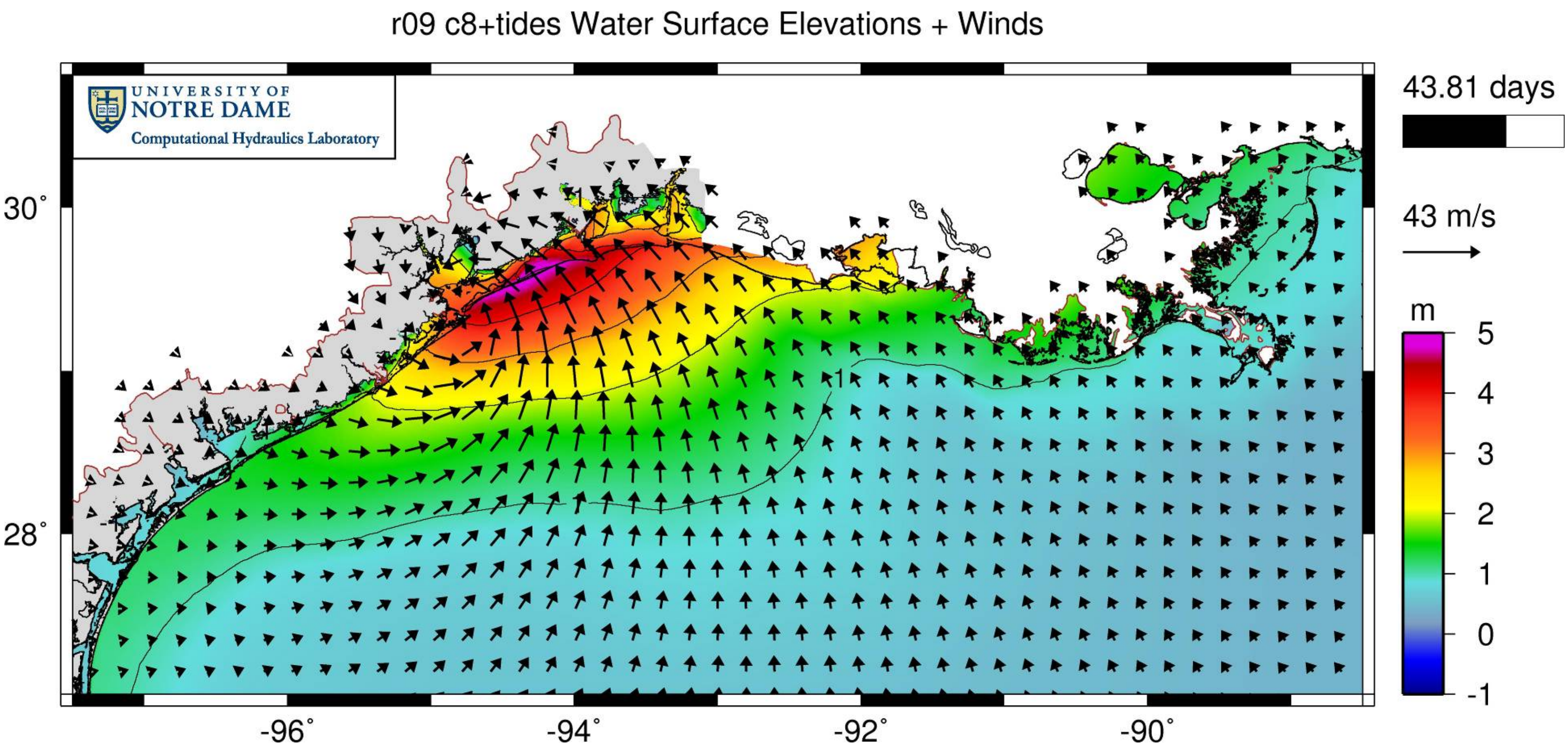
- 2 hrs

Ike surge contours (m) and wind vectors (m/s)



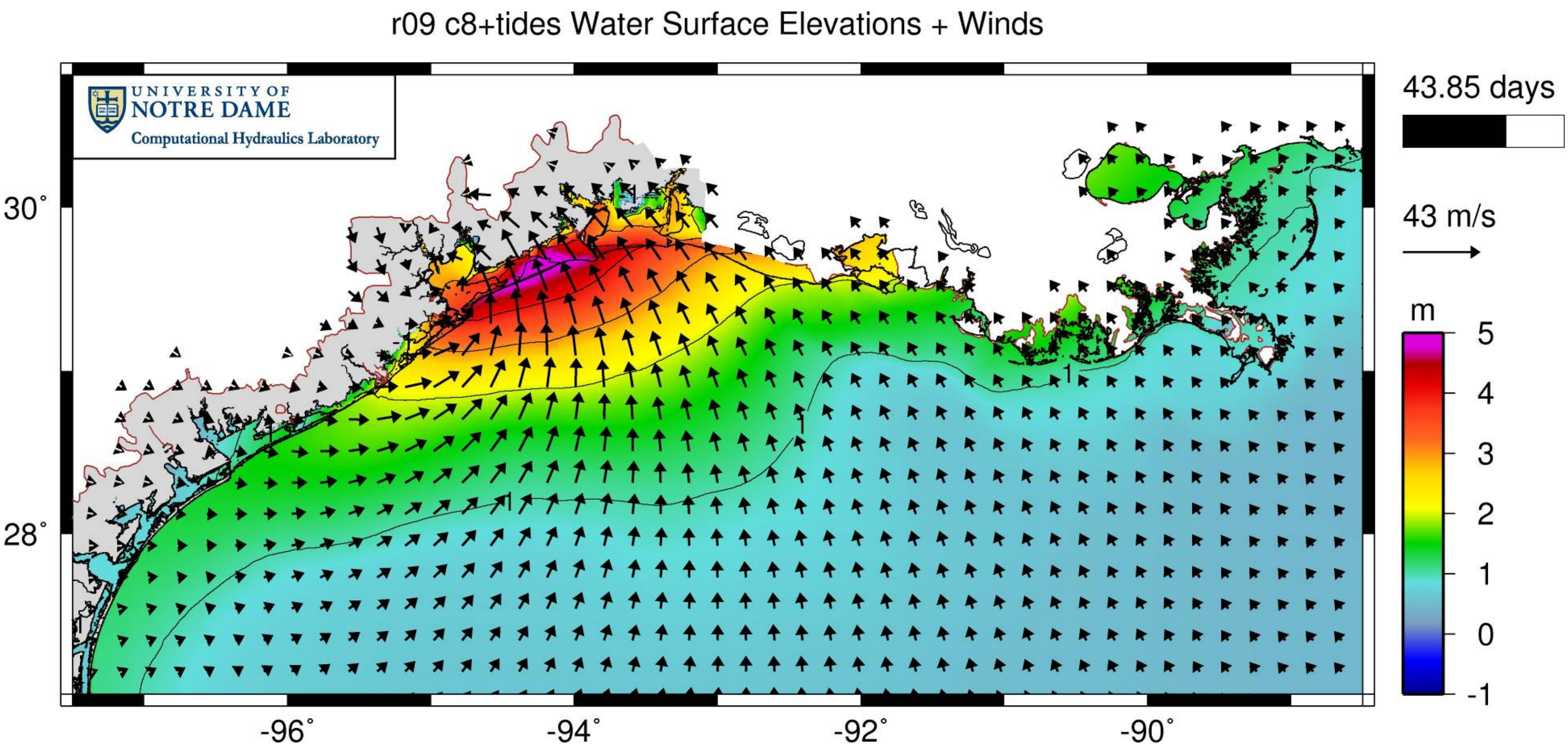
- 1 hrs

Ike surge contours (m) and wind vectors (m/s)



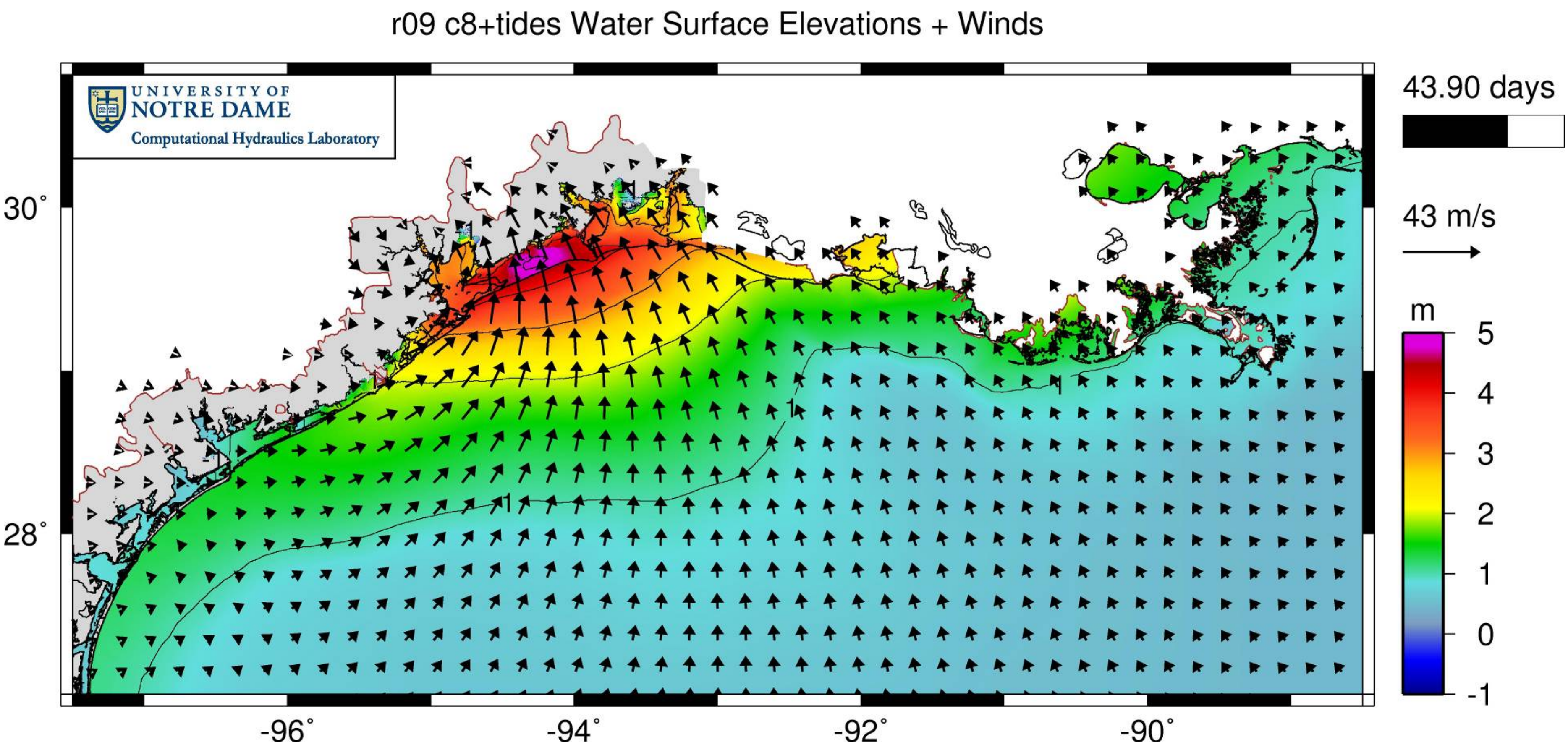
LANDFALL 0 hrs

Ike surge contours (m) and wind vectors (m/s)



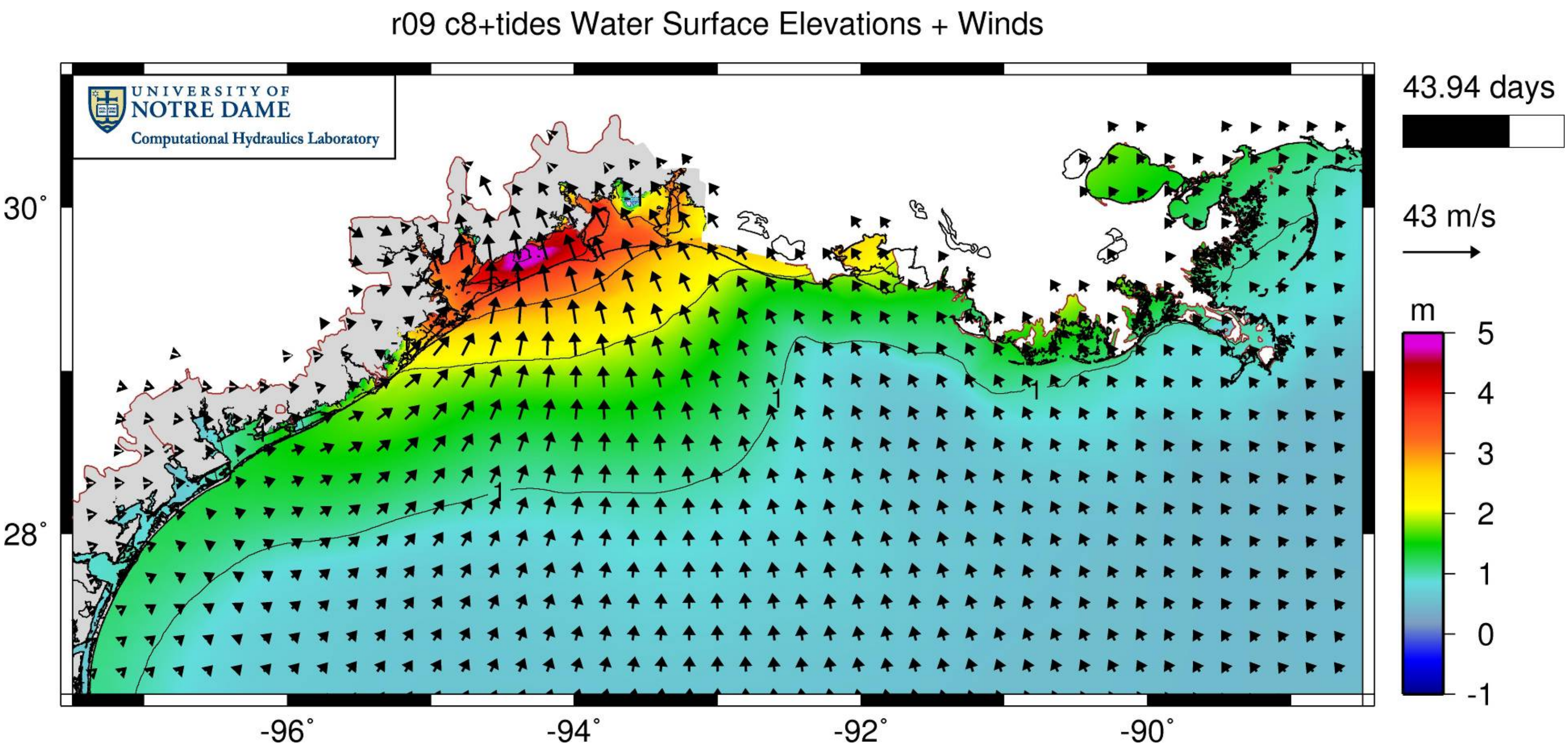
+ 1 hrs

Ike surge contours (m) and wind vectors (m/s)



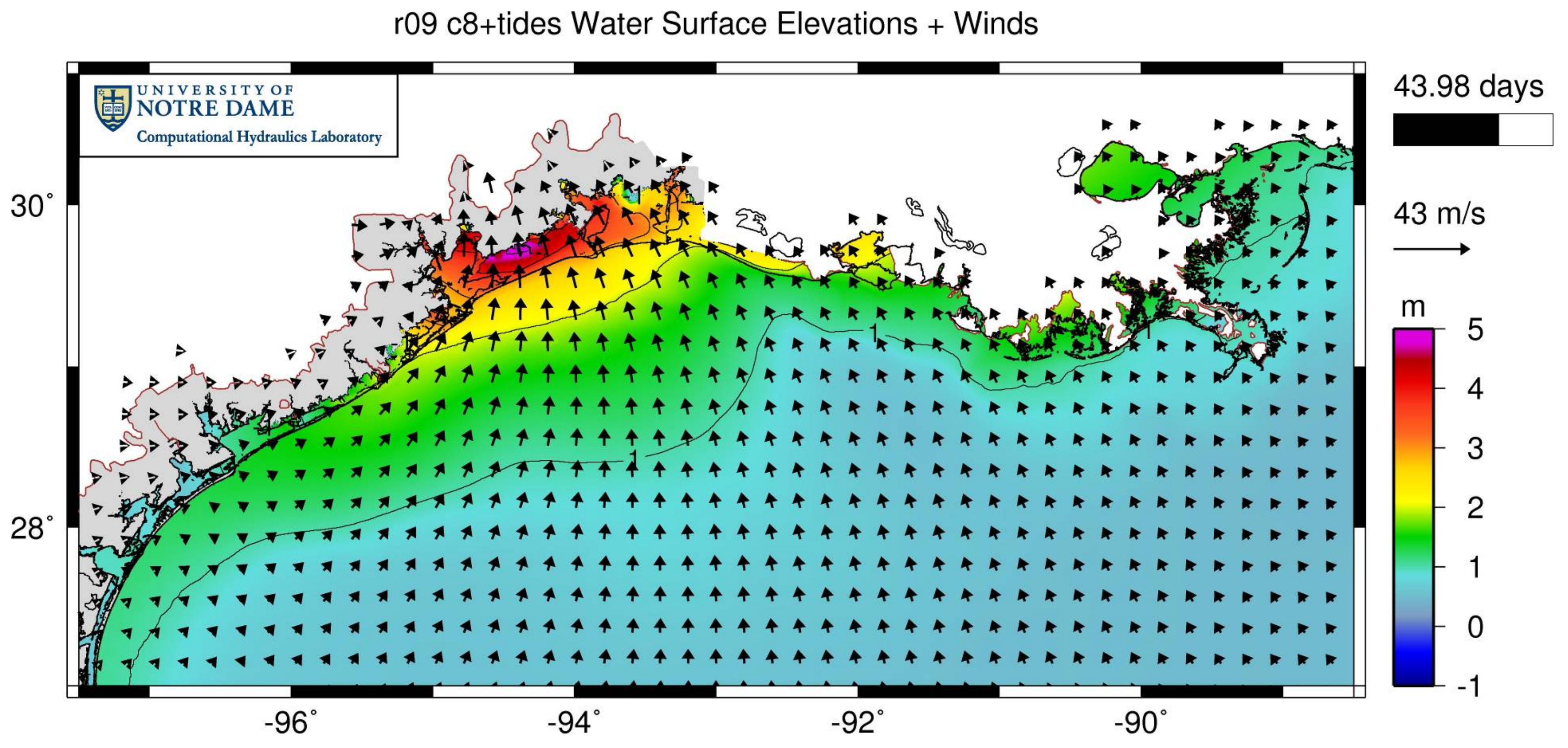
+ 2 hrs

Ike surge contours (m) and wind vectors (m/s)



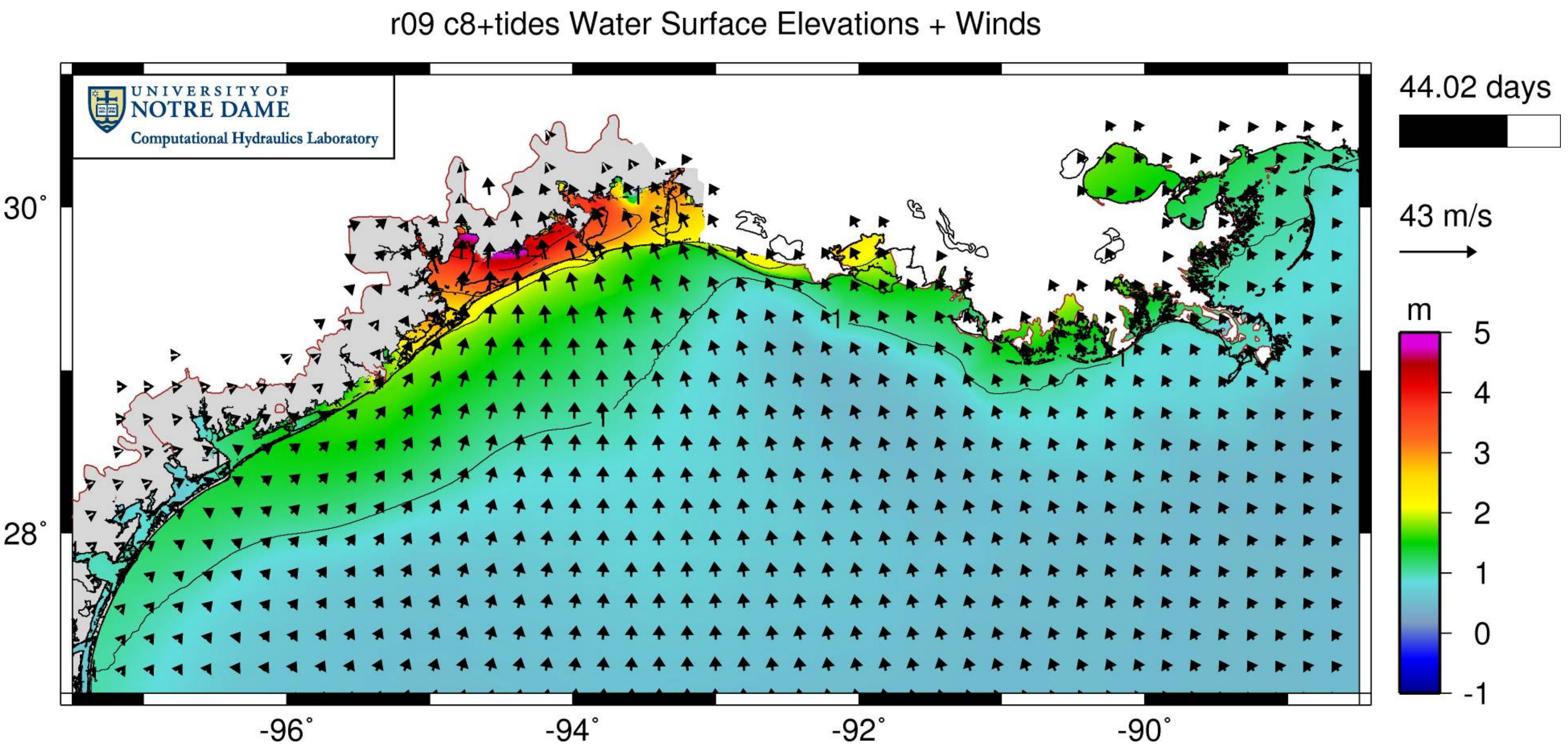
+ 3 hrs

Ike surge contours (m) and wind vectors (m/s)



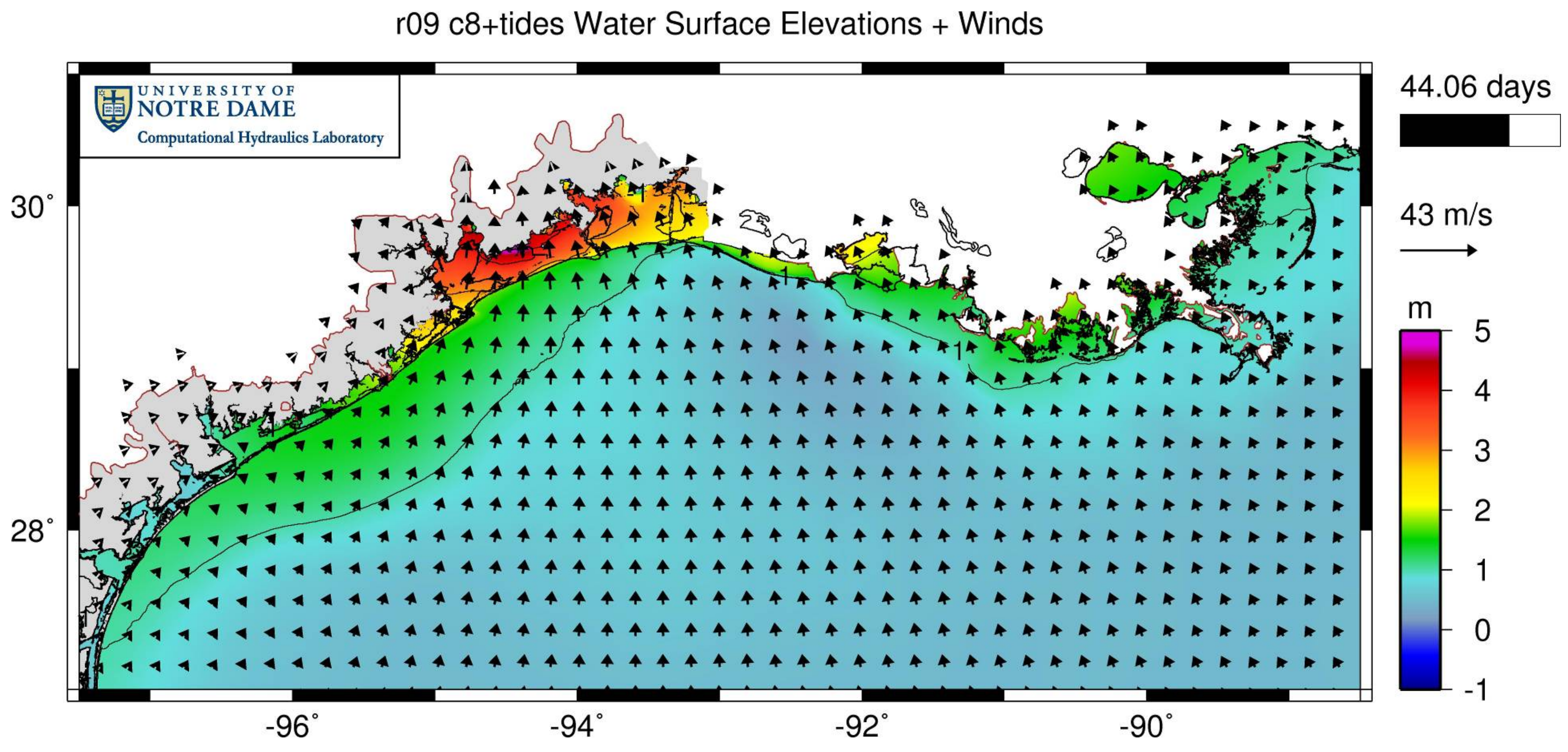
+ 4 hrs

Ike surge contours (m) and wind vectors (m/s)



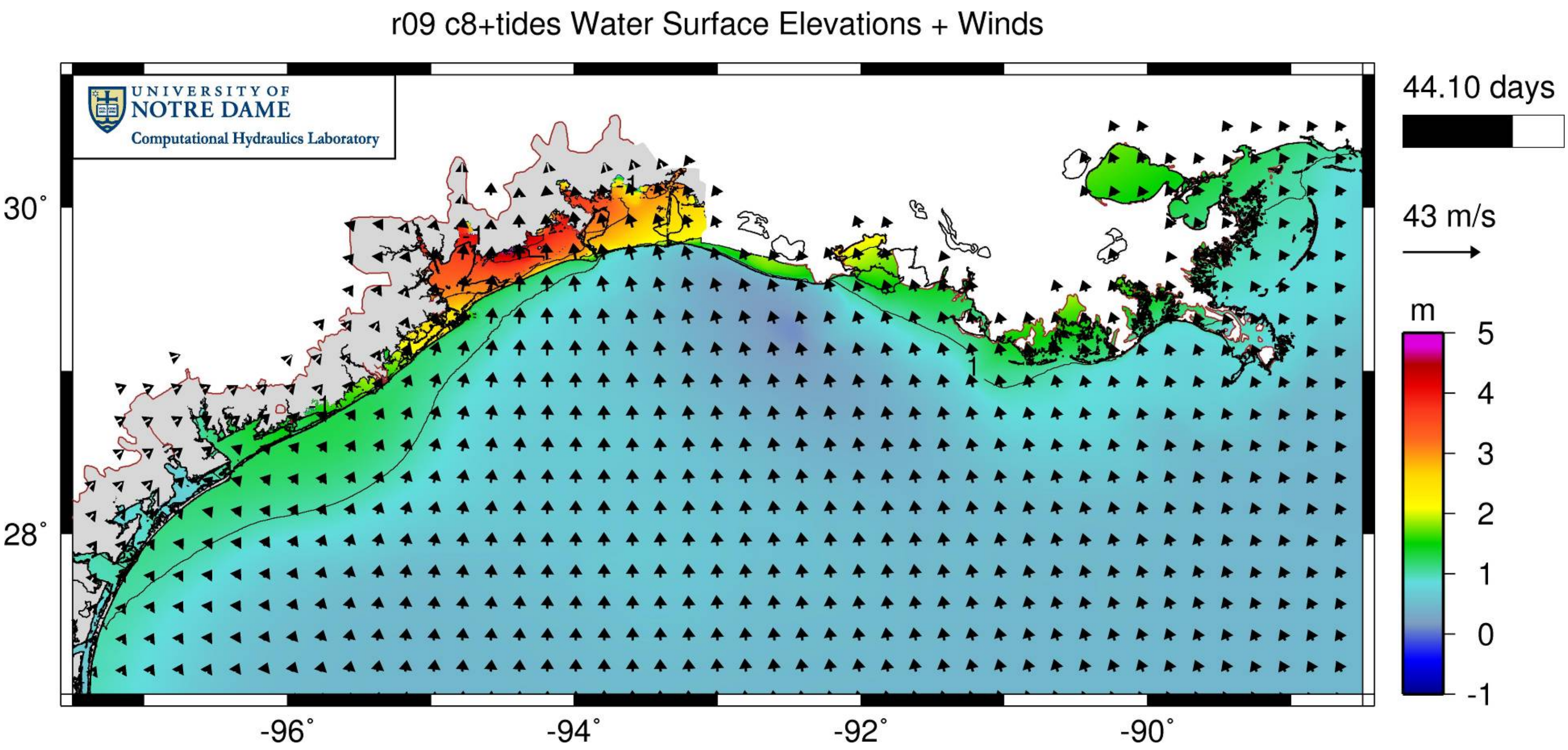
+ 5 hrs

Ike surge contours (m) and wind vectors (m/s)



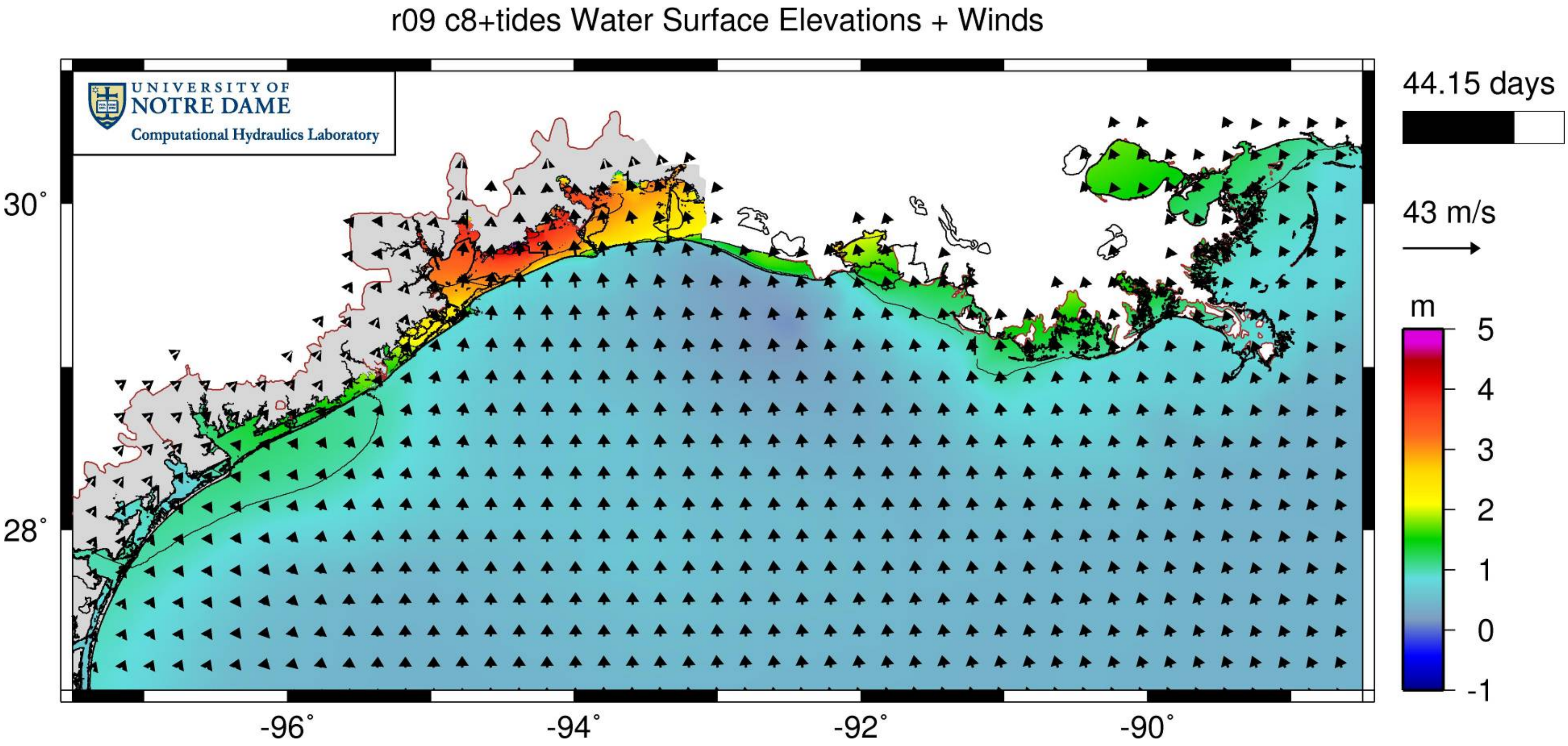
+ 6 hrs

Ike surge contours (m) and wind vectors (m/s)



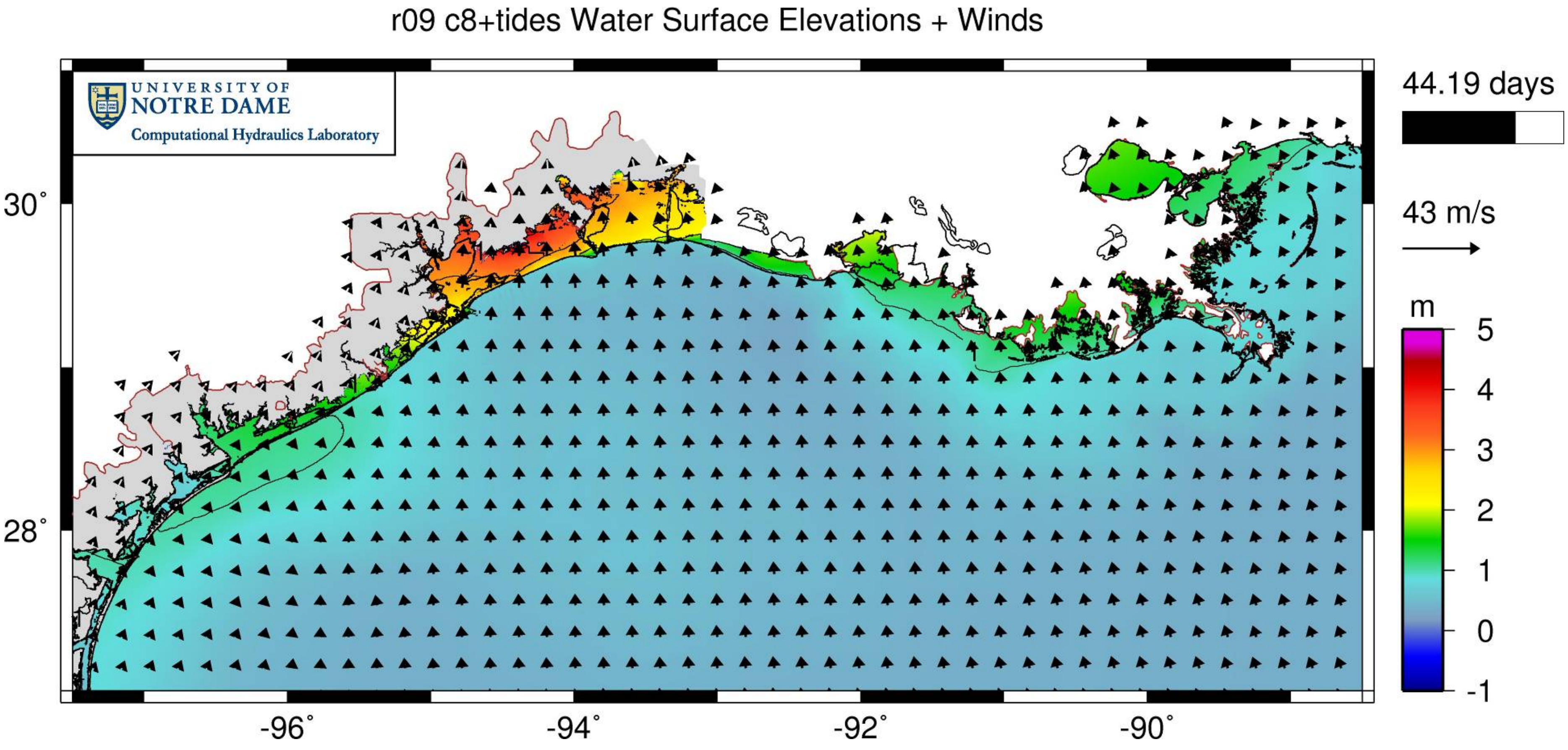
+ 7 hrs

Ike surge contours (m) and wind vectors (m/s)



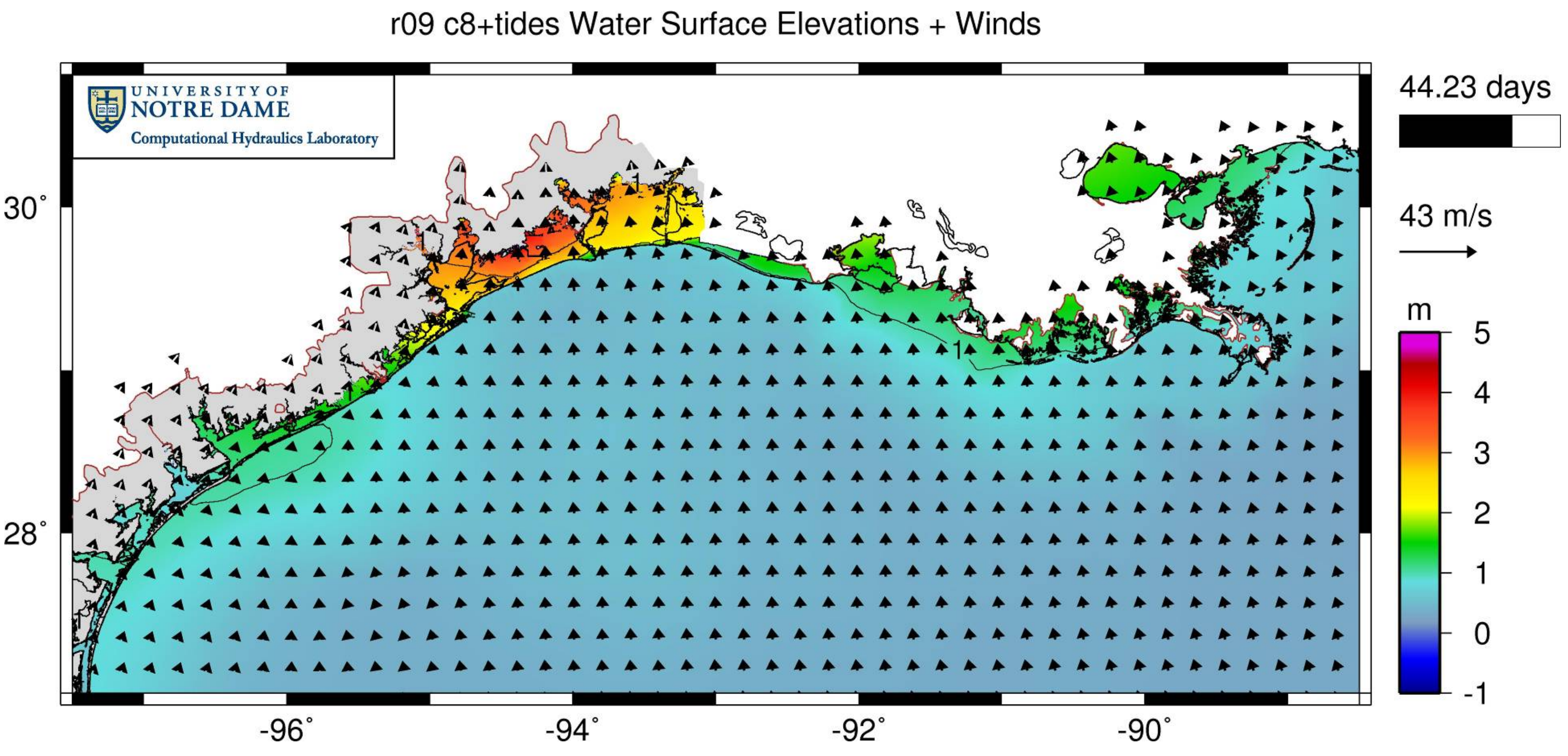
+ 8 hrs

Ike surge contours (m) and wind vectors (m/s)



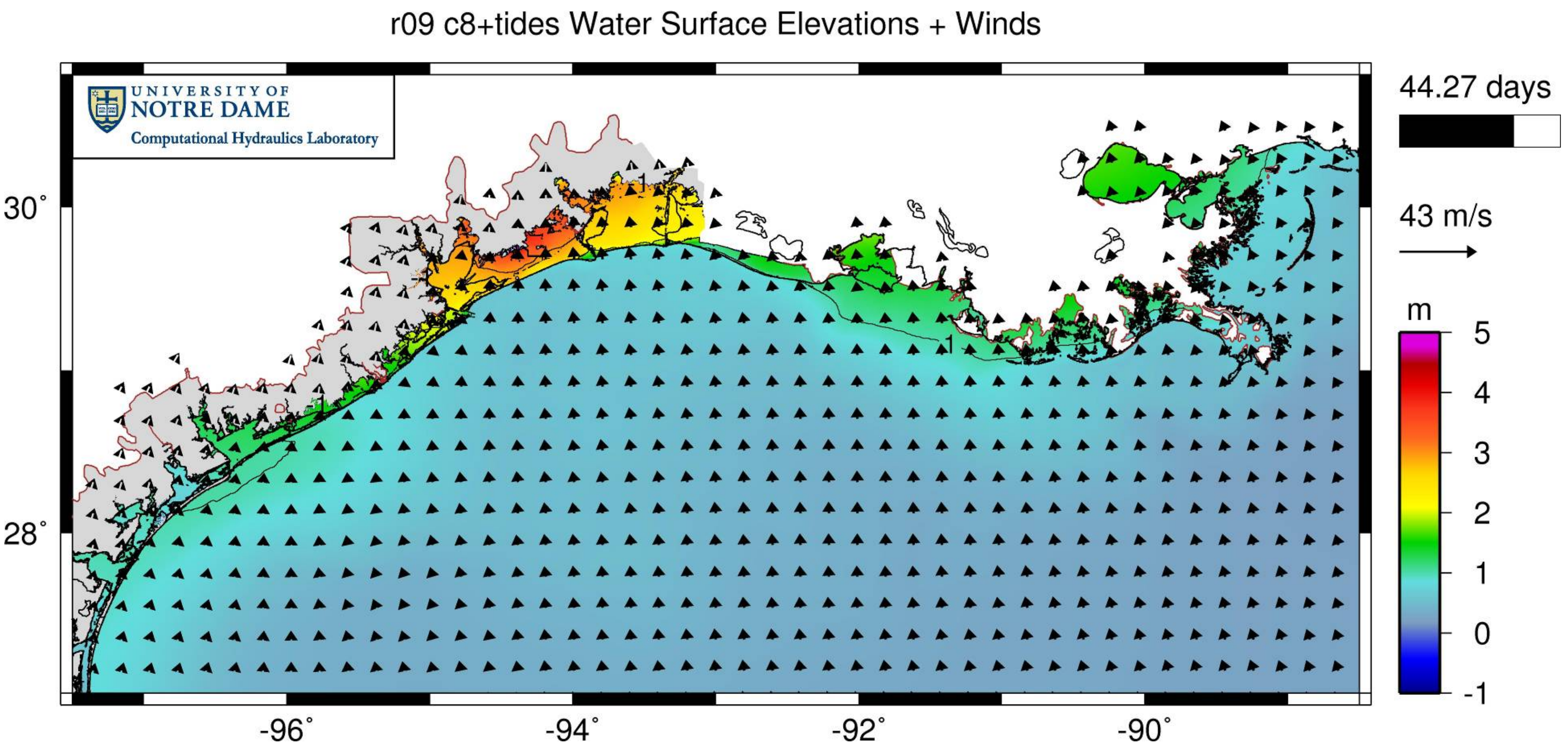
+ 9 hrs

Ike surge contours (m) and wind vectors (m/s)



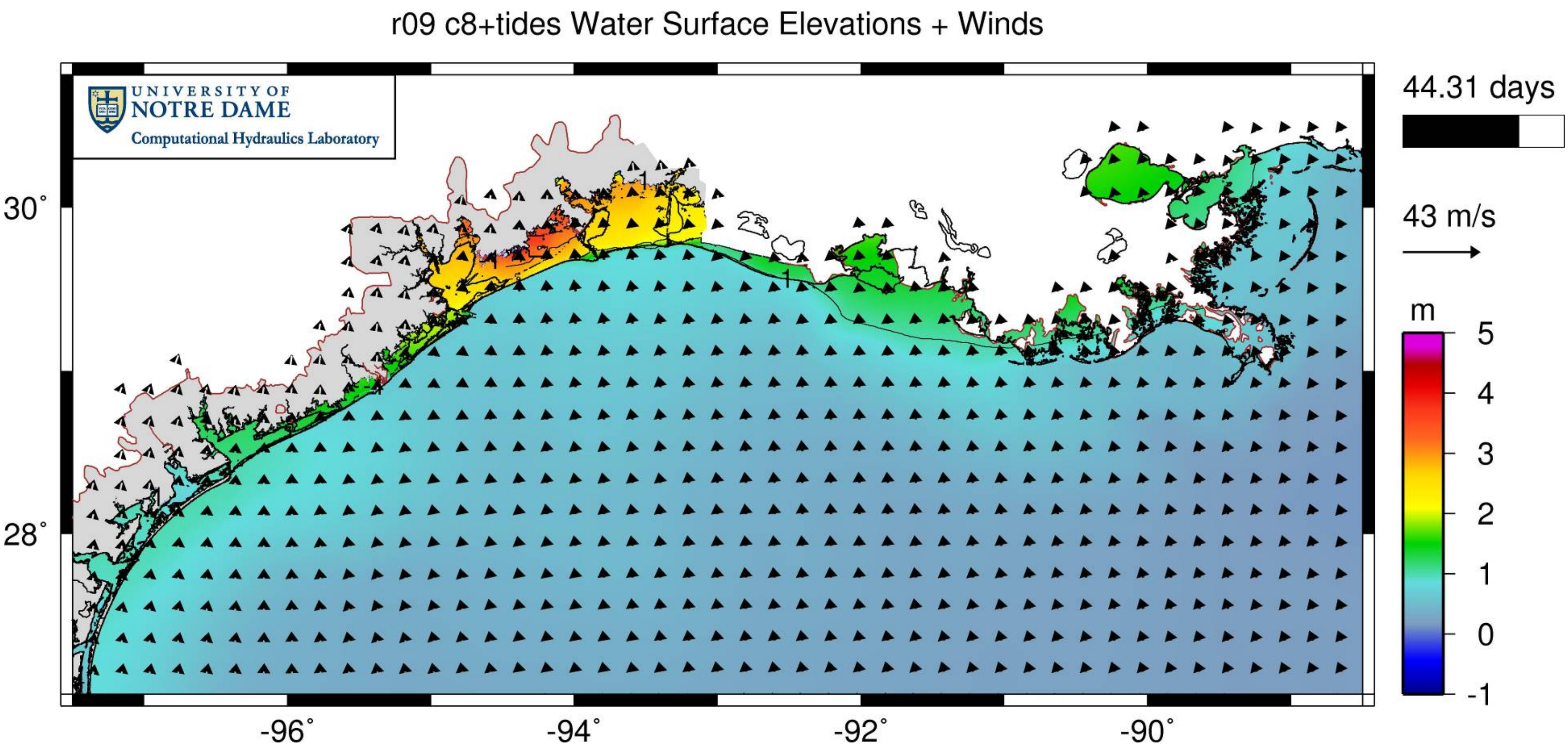
+ 10 hrs

Ike surge contours (m) and wind vectors (m/s)



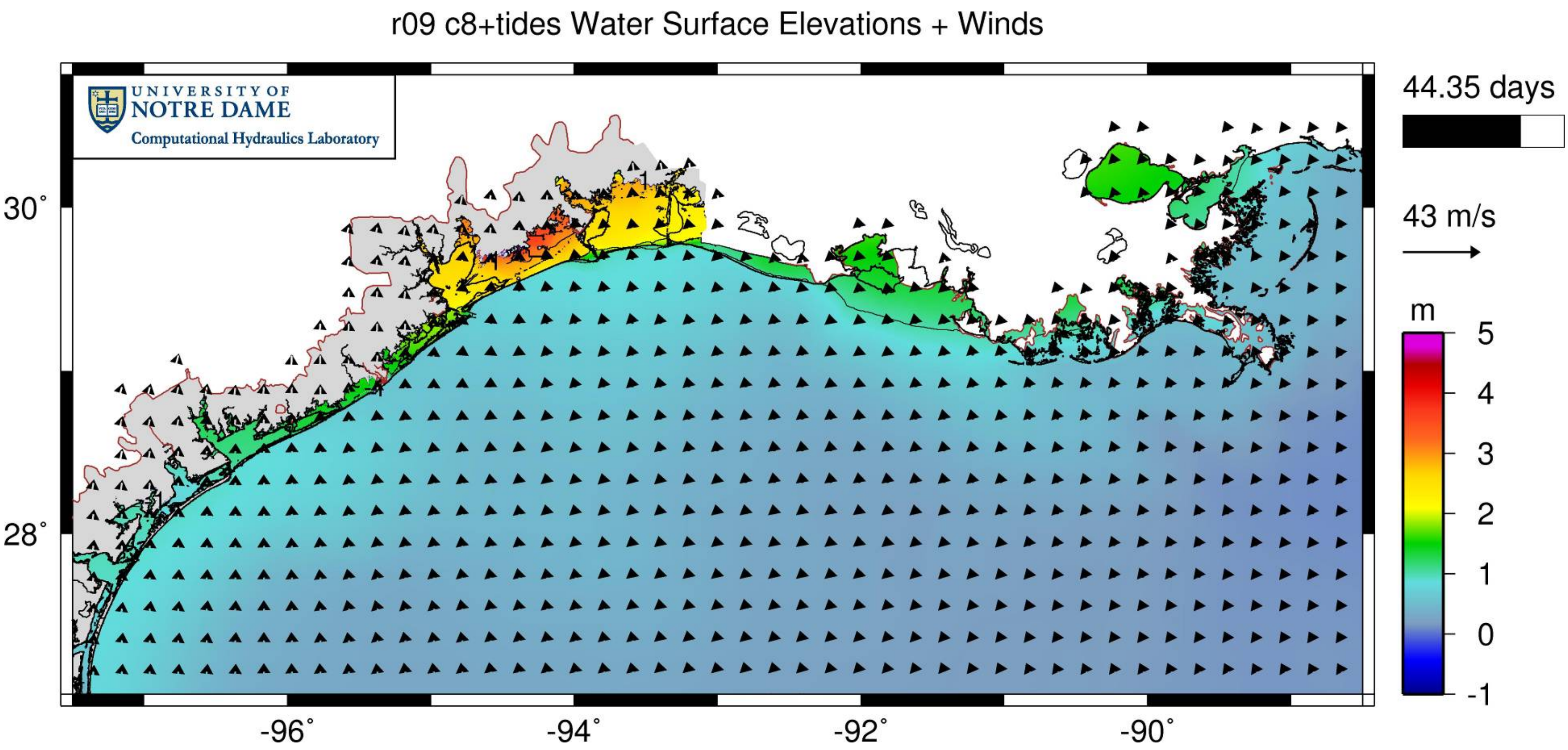
+ 11 hrs

Ike surge contours (m) and wind vectors (m/s)



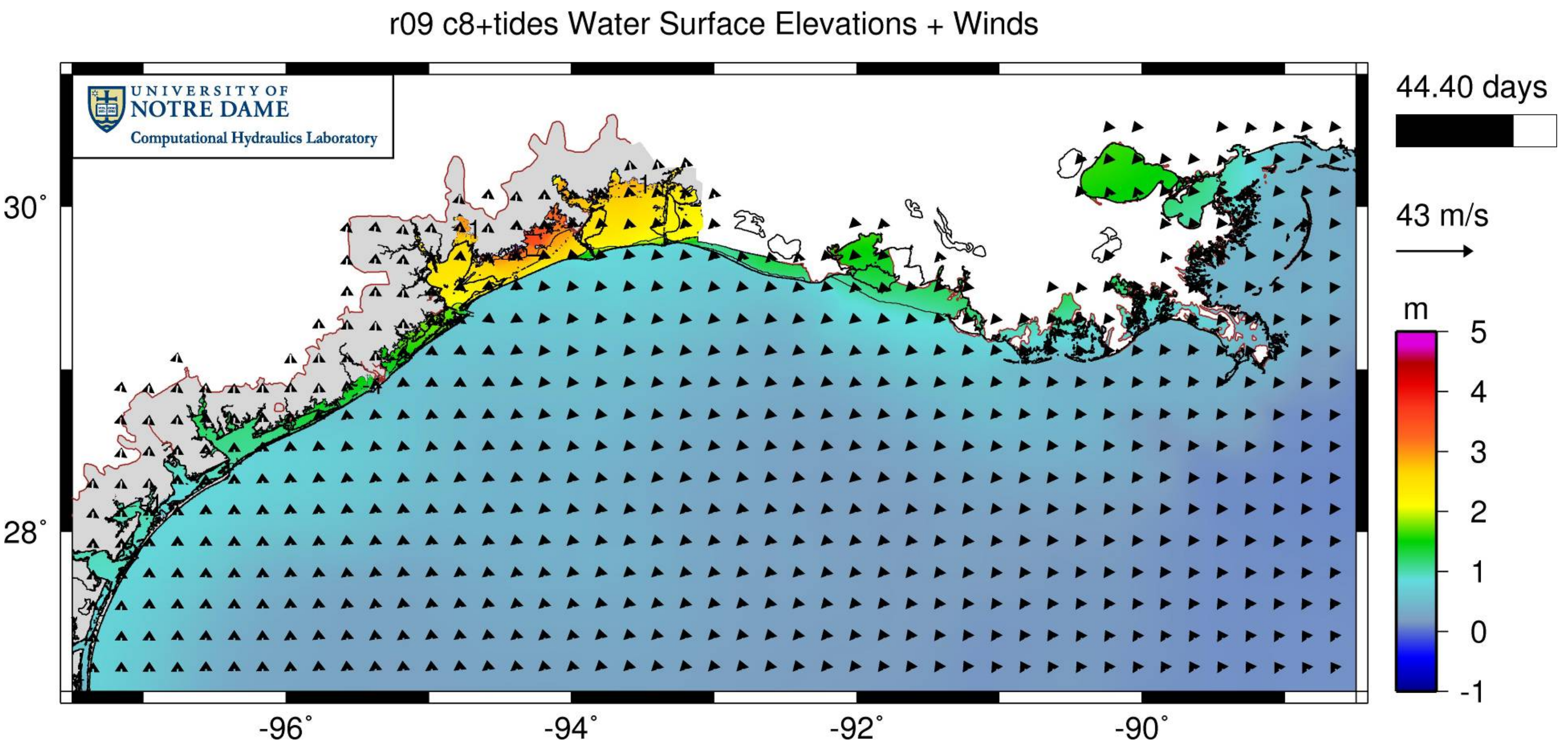
+ 12 hrs

Ike surge contours (m) and wind vectors (m/s)



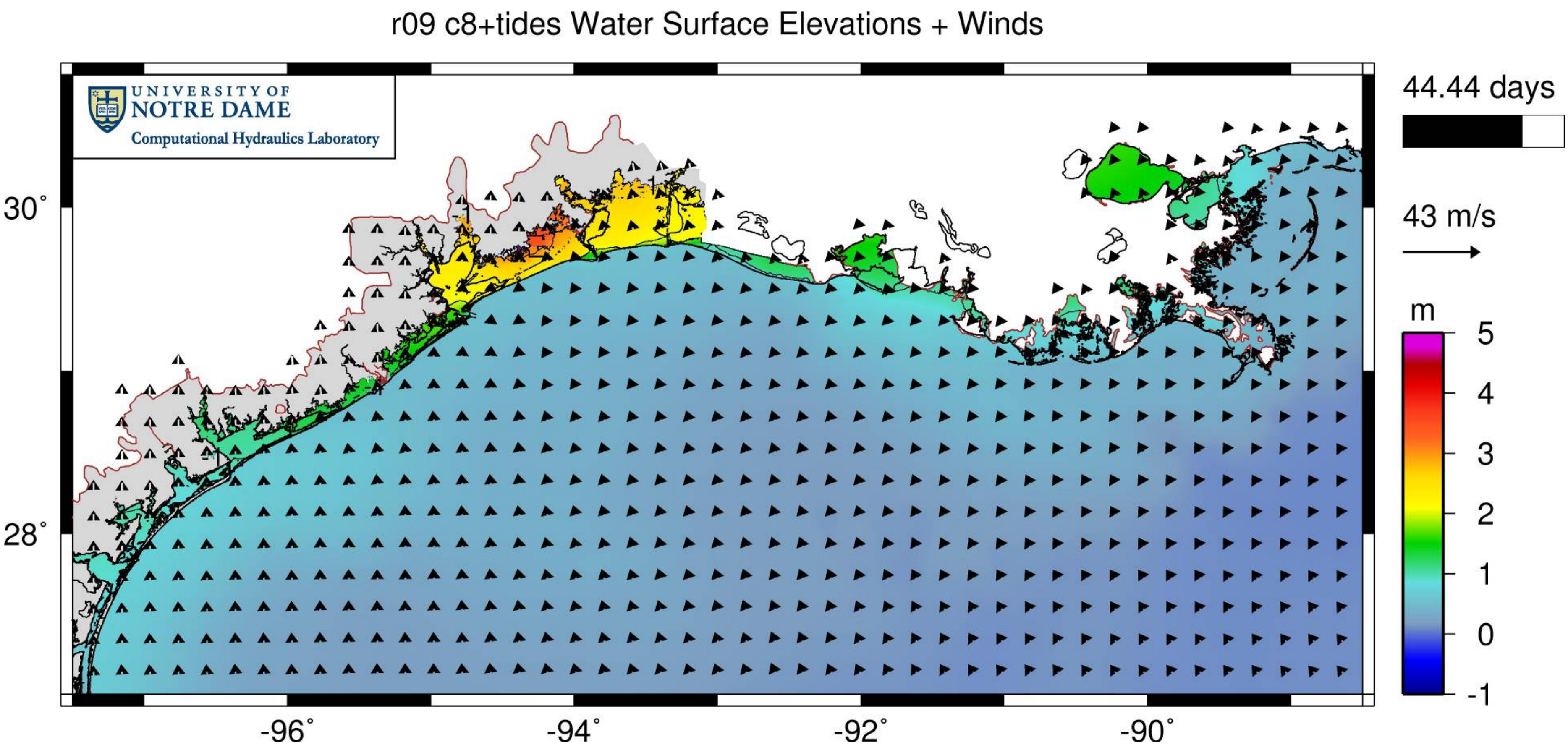
+ 13 hrs

Ike surge contours (m) and wind vectors (m/s)



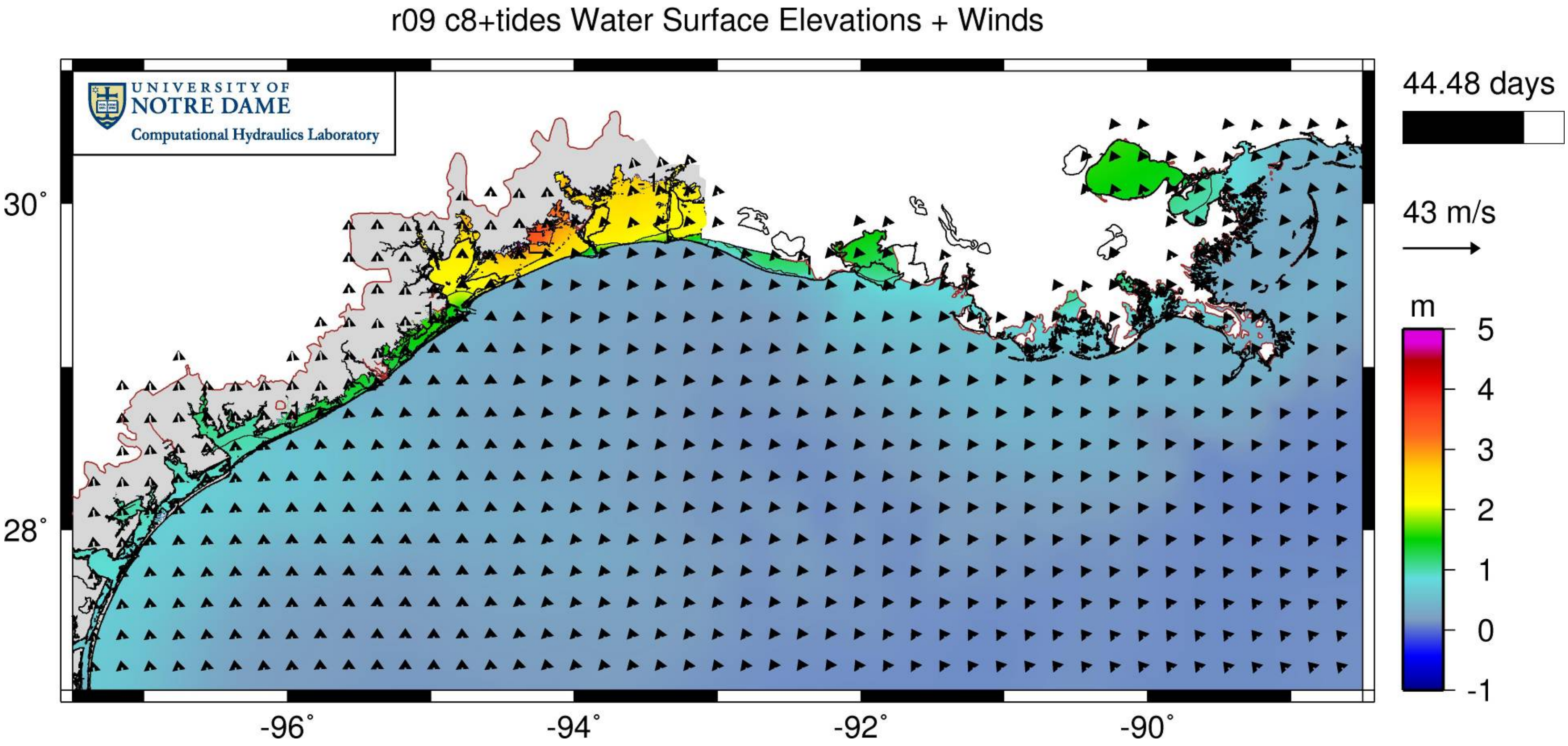
+ 14 hrs

Ike surge contours (m) and wind vectors (m/s)



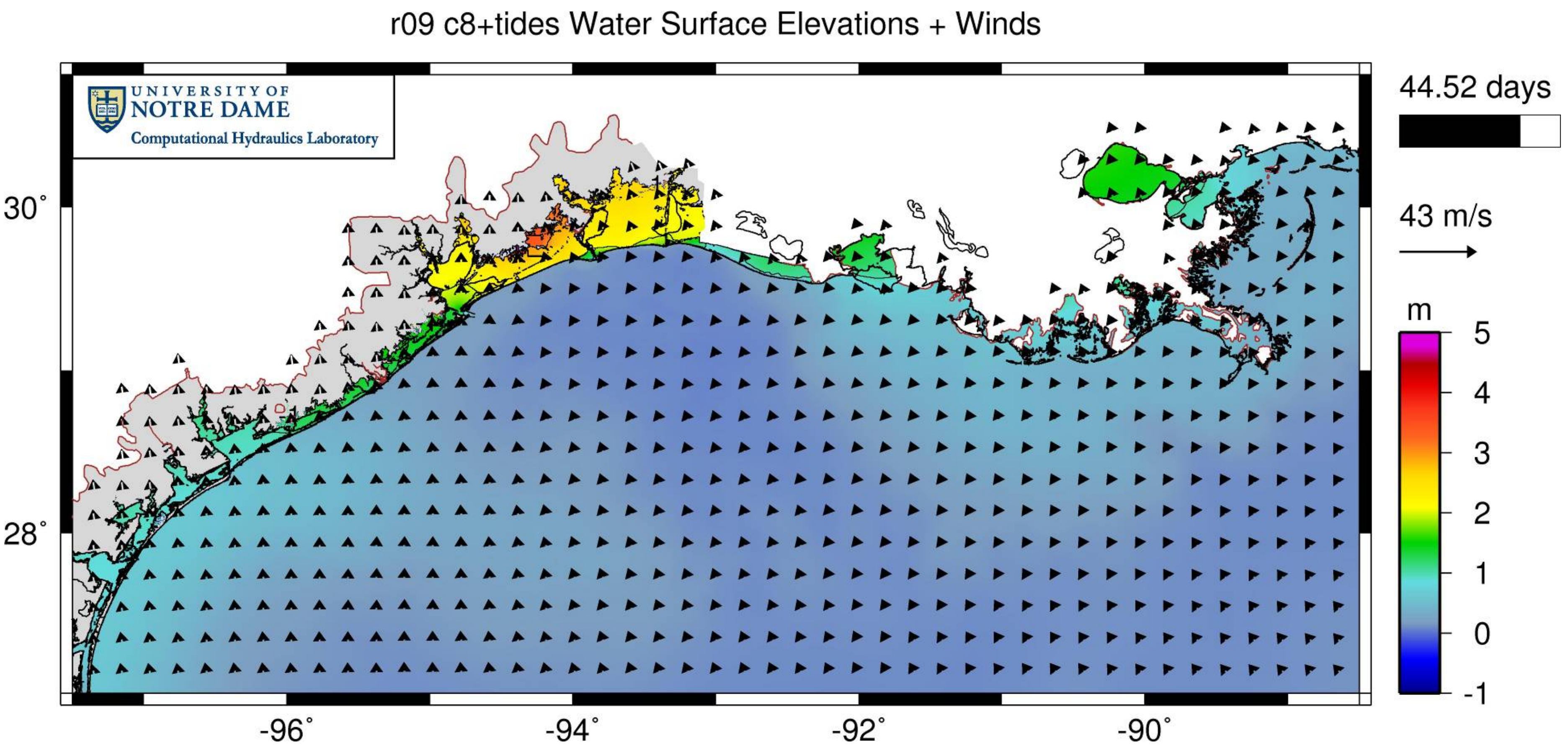
+ 15 hrs

Ike surge contours (m) and wind vectors (m/s)



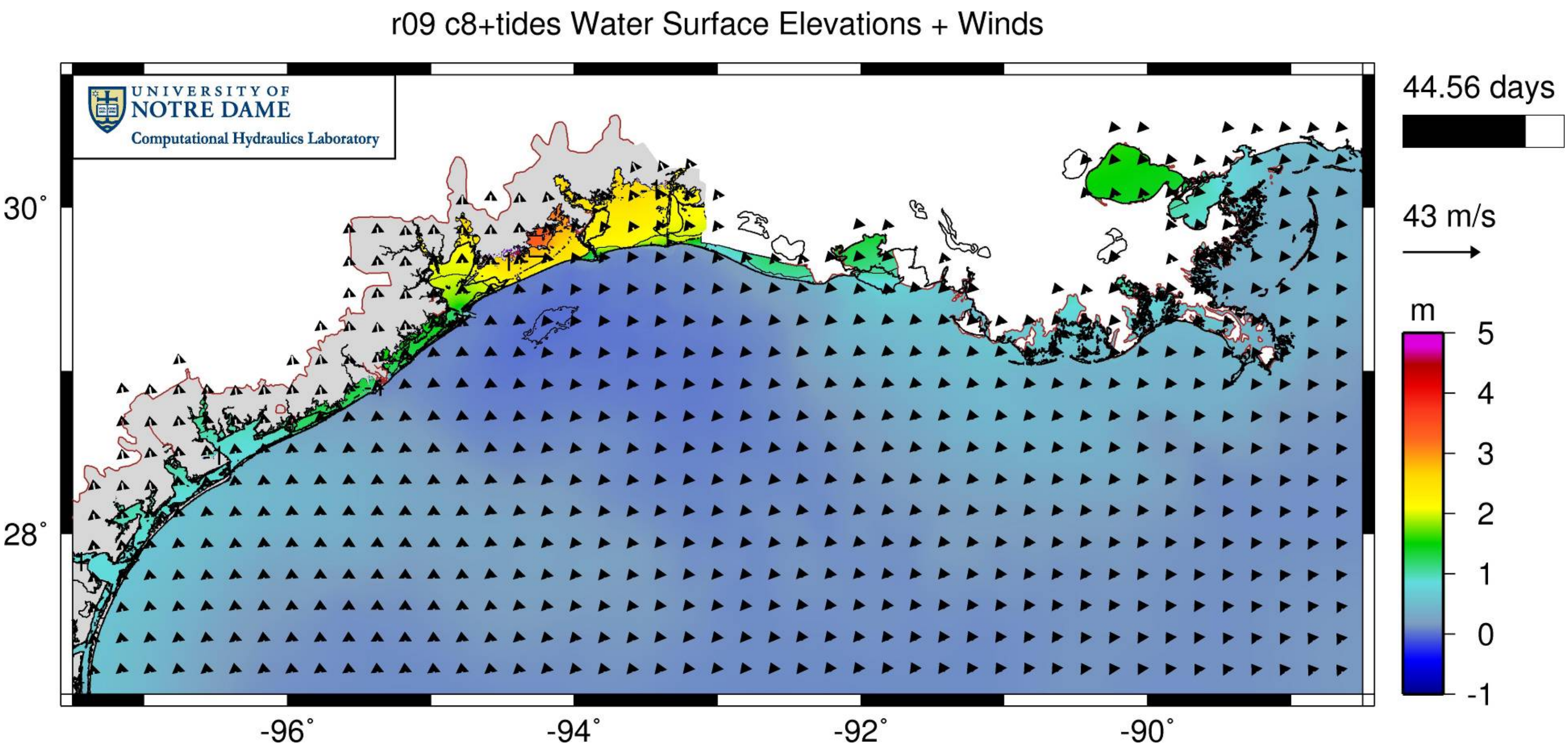
+ 16 hrs

Ike surge contours (m) and wind vectors (m/s)

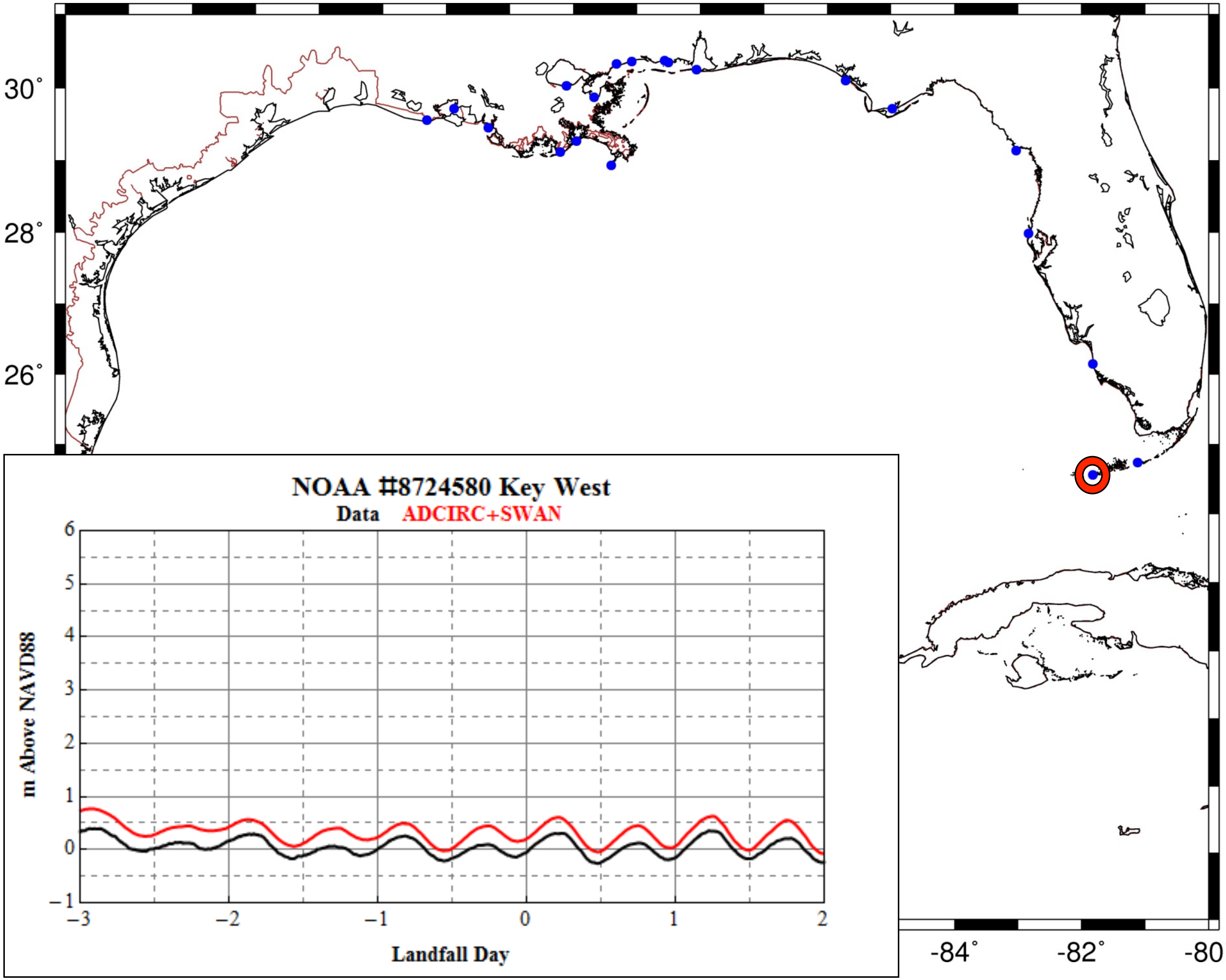


+ 17 hrs

Ike surge contours (m) and wind vectors (m/s)



+ 18 hrs



30°
28°
26°
-84°
-82°
-80°
NOAA #8724580 Key West
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
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−1
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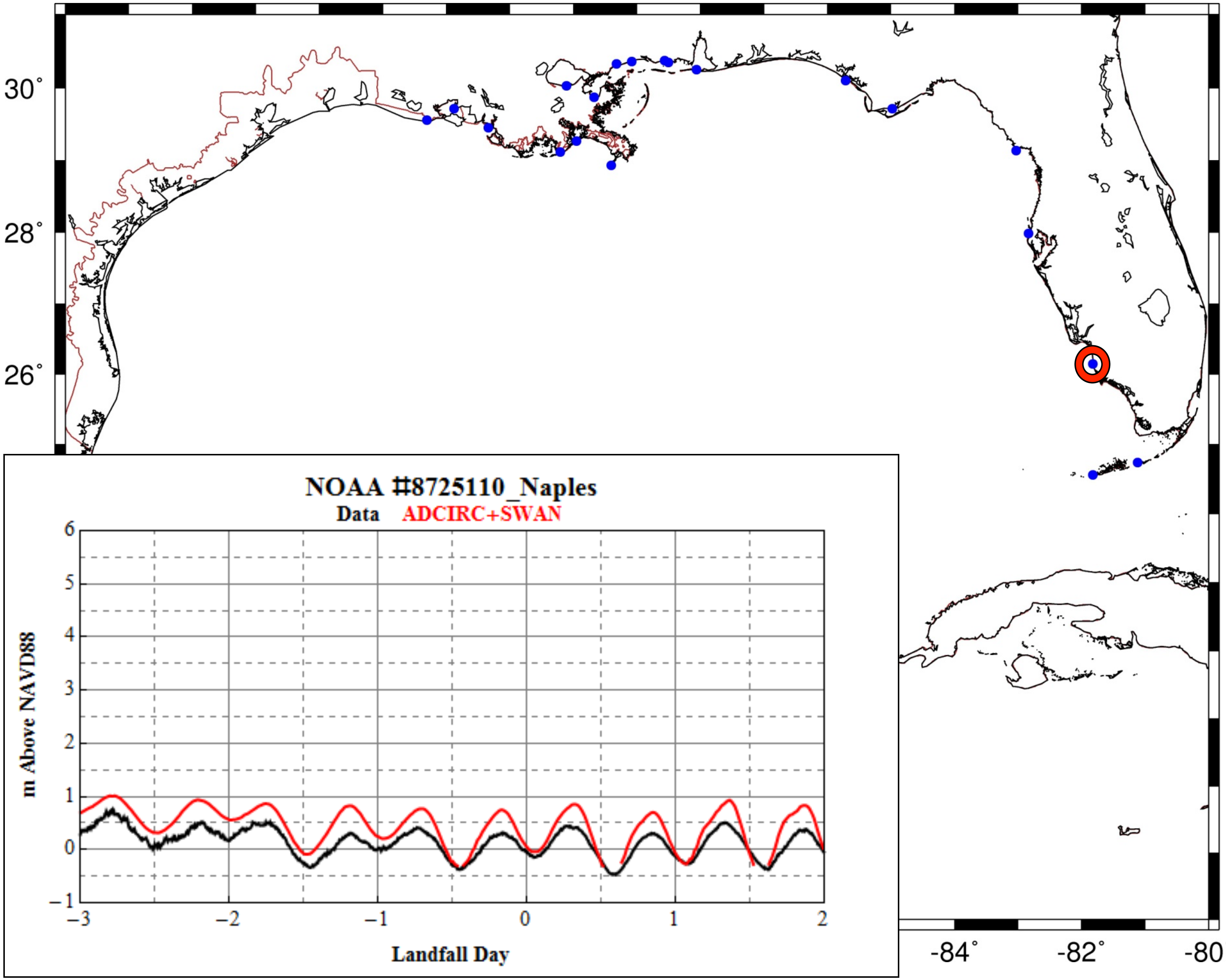
1
2



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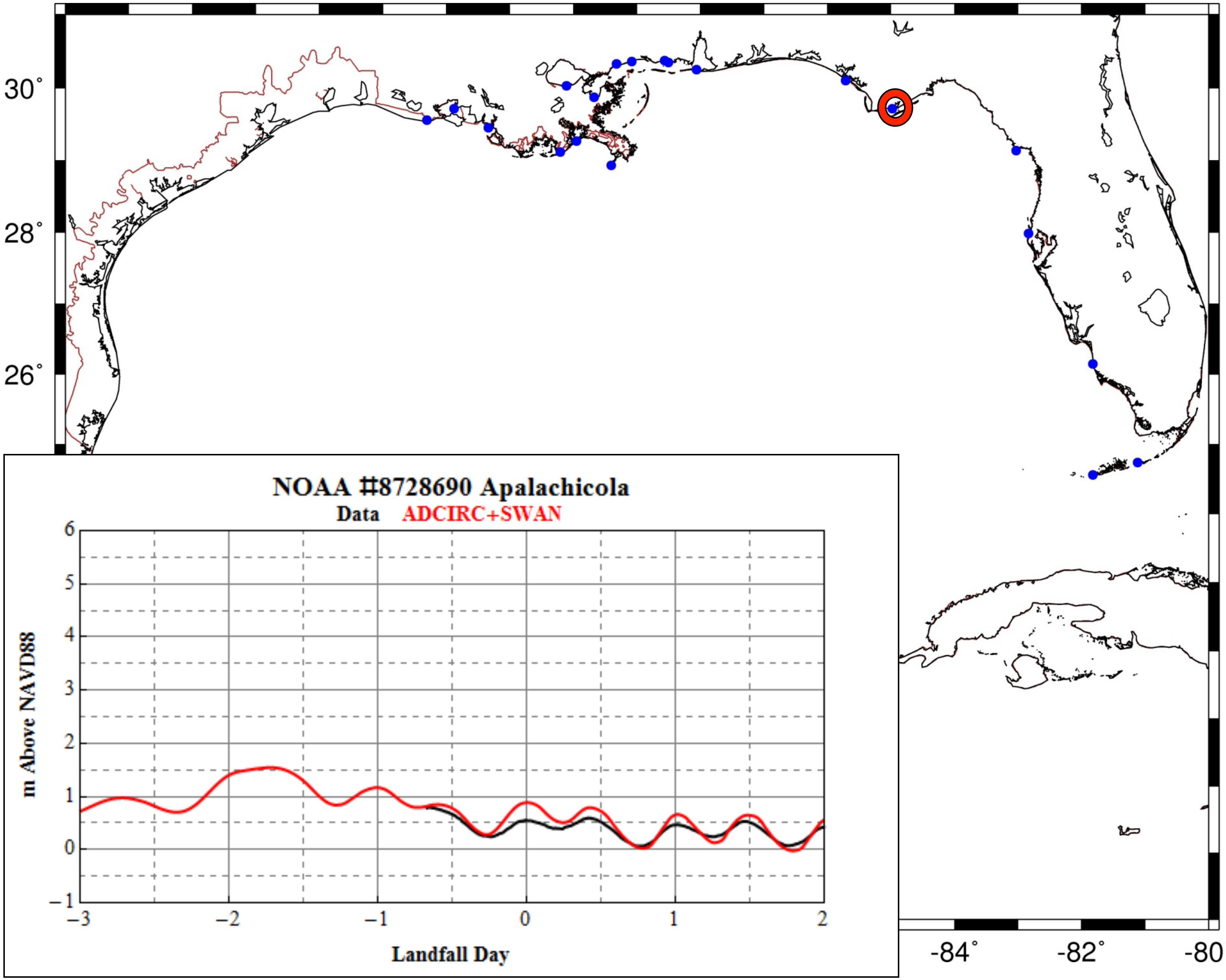
-82°
-80°
NOAA #8725110_Naples
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day



30°
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-84°
-82°
-80°
NOAA #8728690 Apalachicola
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
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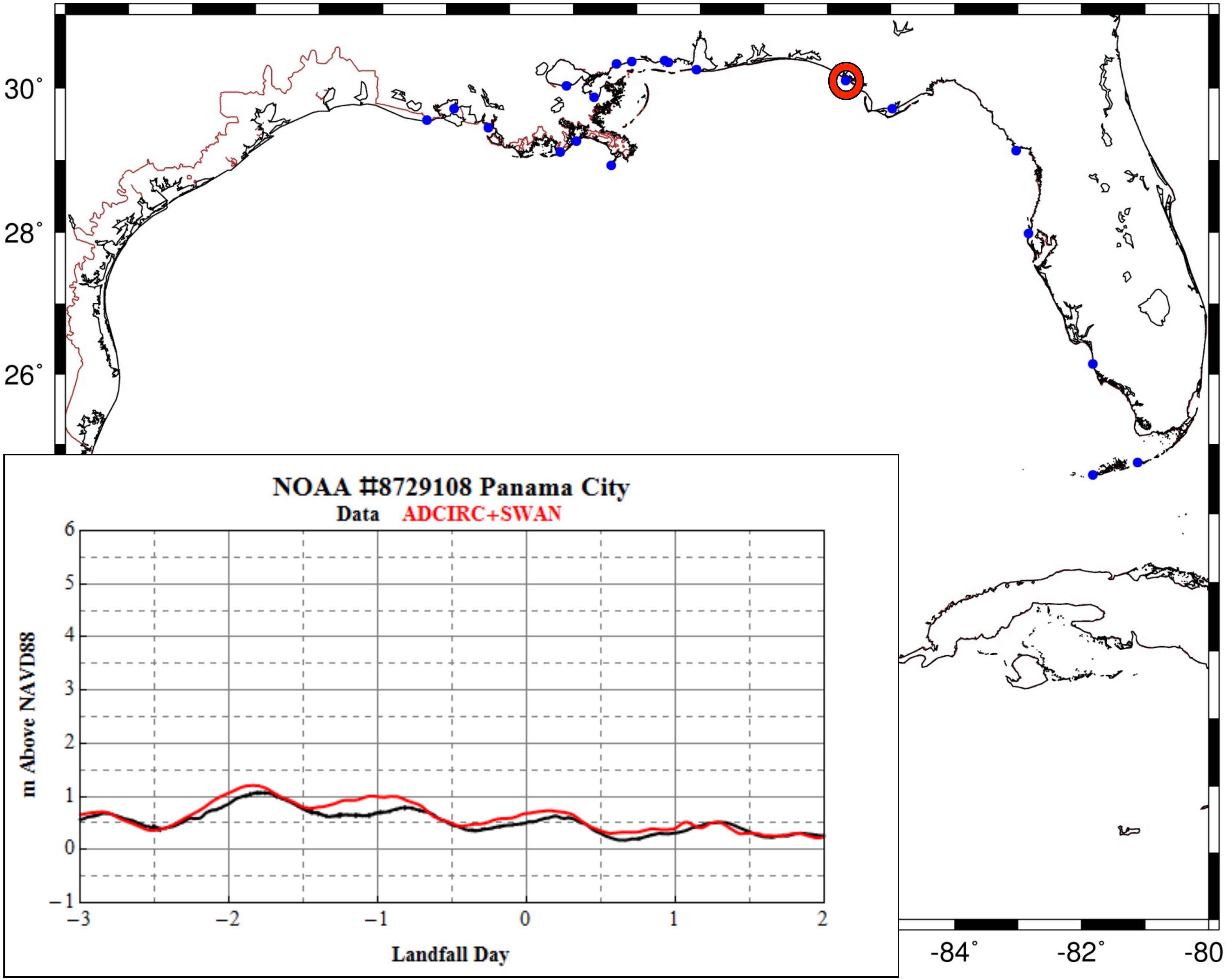
2


30°
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-84°
-82°
-80°
NOAA #8729108 Panama City
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
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1
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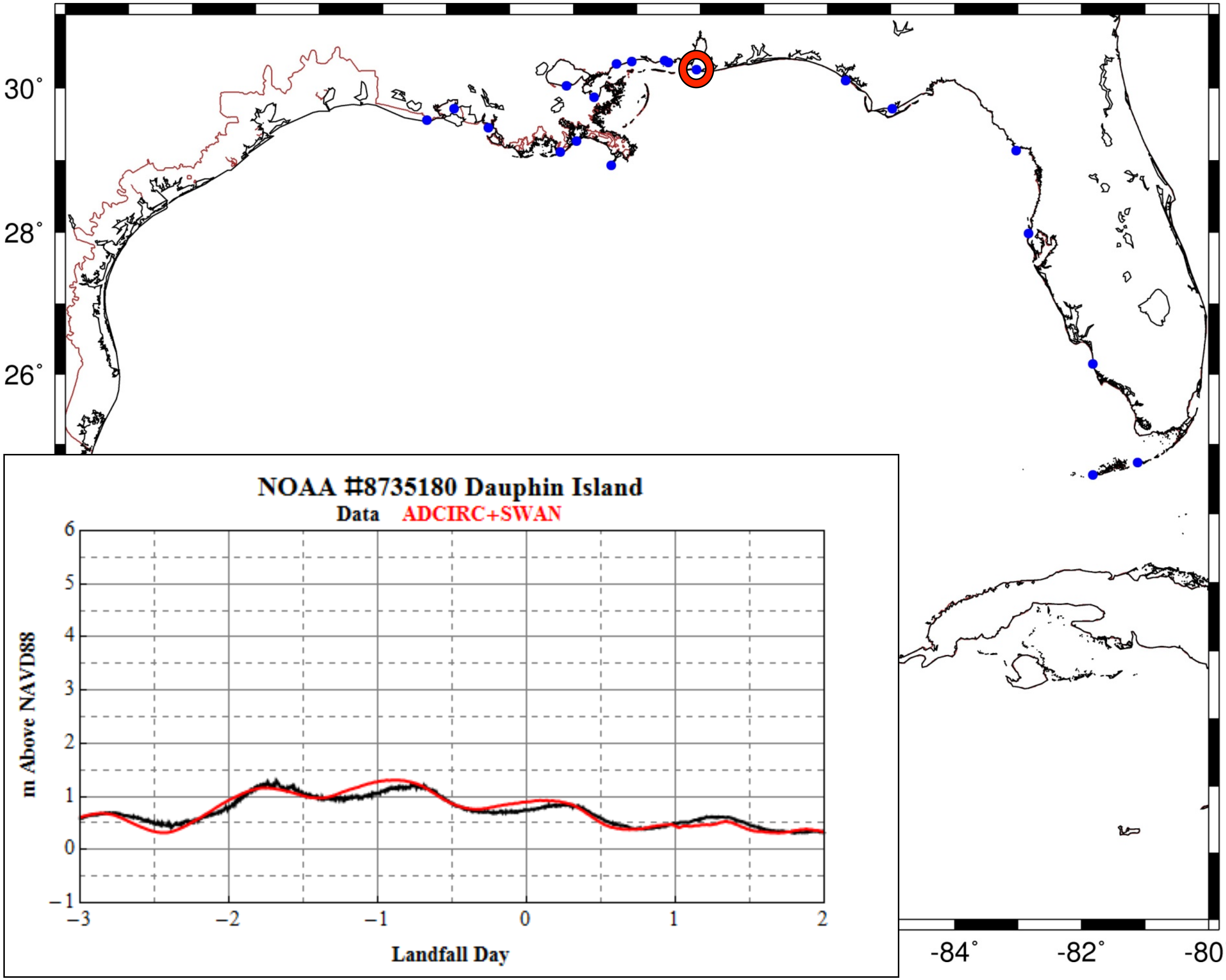

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-84°
-82°
-80°
NOAA #8735180 Dauphin Island
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
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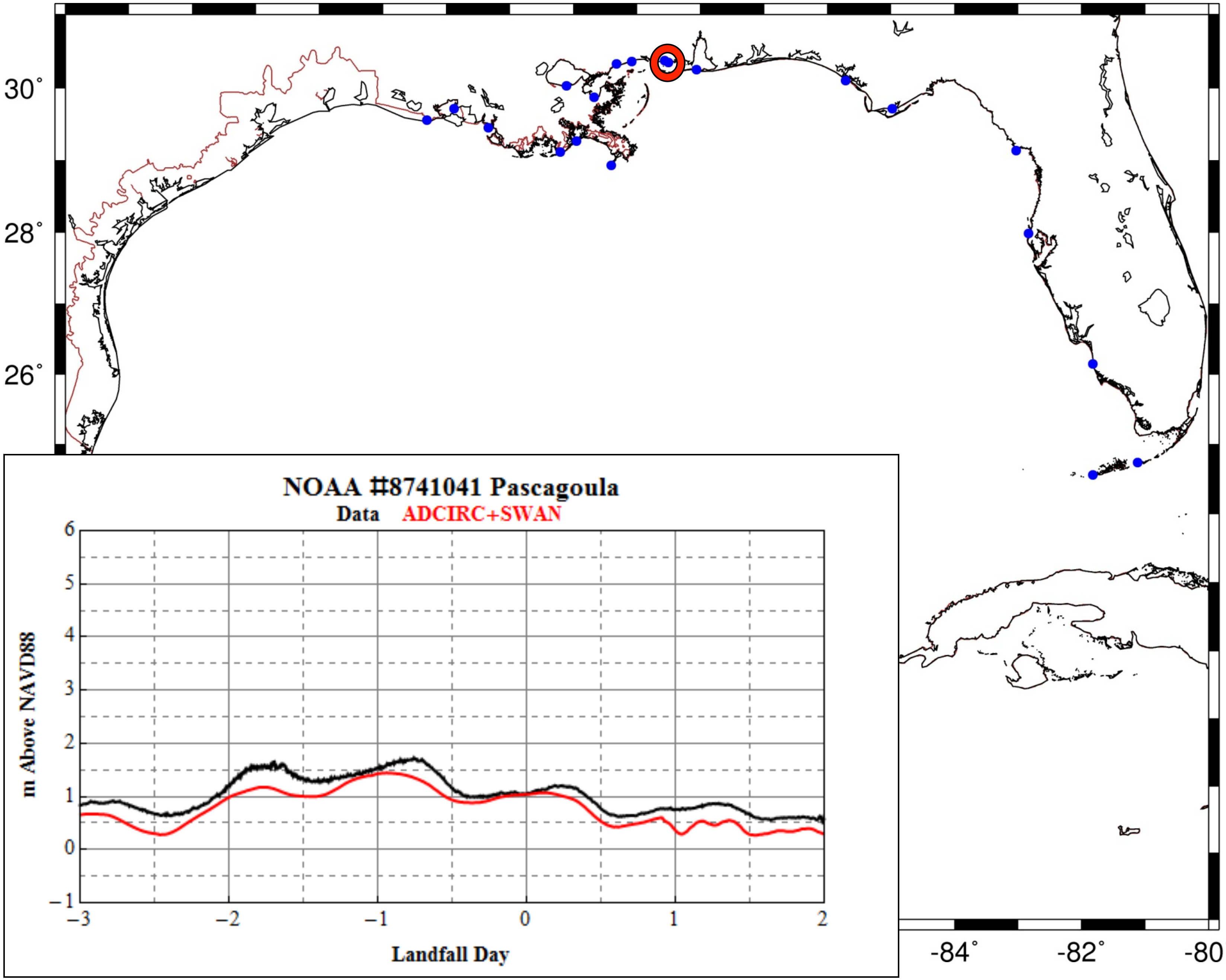

30°
28°
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-84°
-82°
-80°
NOAA #8741041 Pascagoula
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
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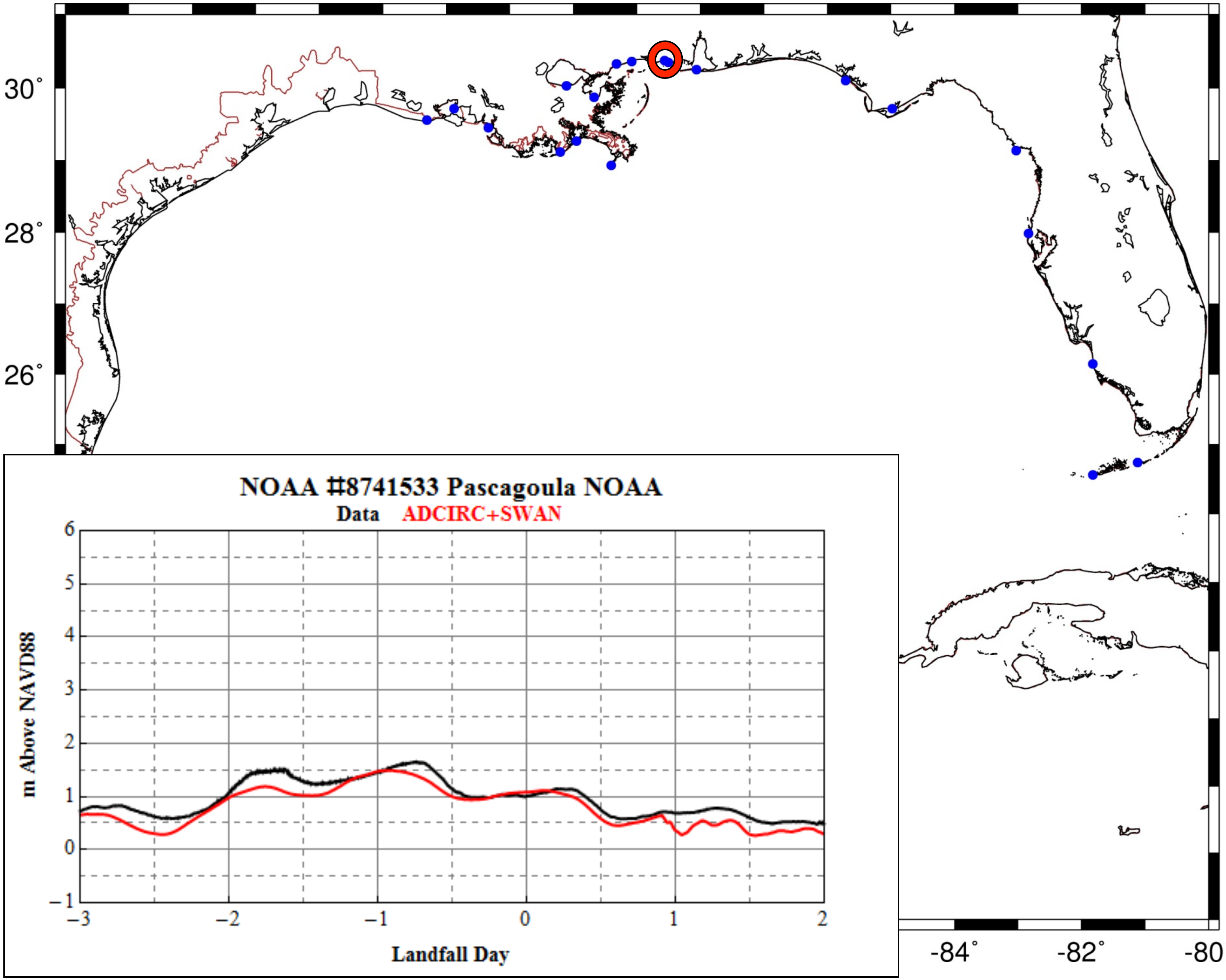

30°
28°
26°
-84°
-82°
-80°
NOAA #8741533 Pascagoula NOAA
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
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5
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3
2
1
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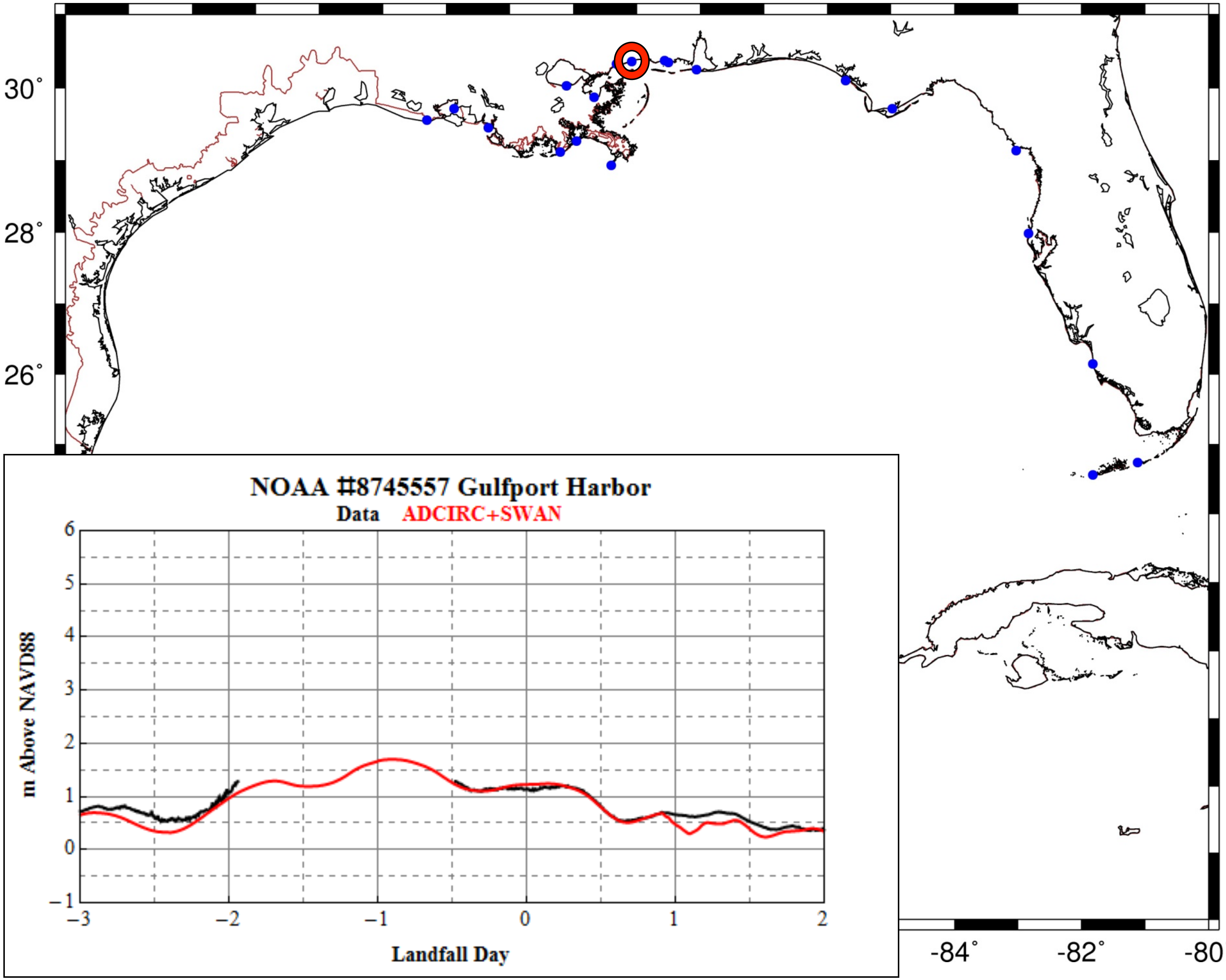
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-84°
-82°
-80°
NOAA #8745557 Gulfport Harbor
Data ADCIRC+SWAN
m Above NAVD88
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−1
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−2
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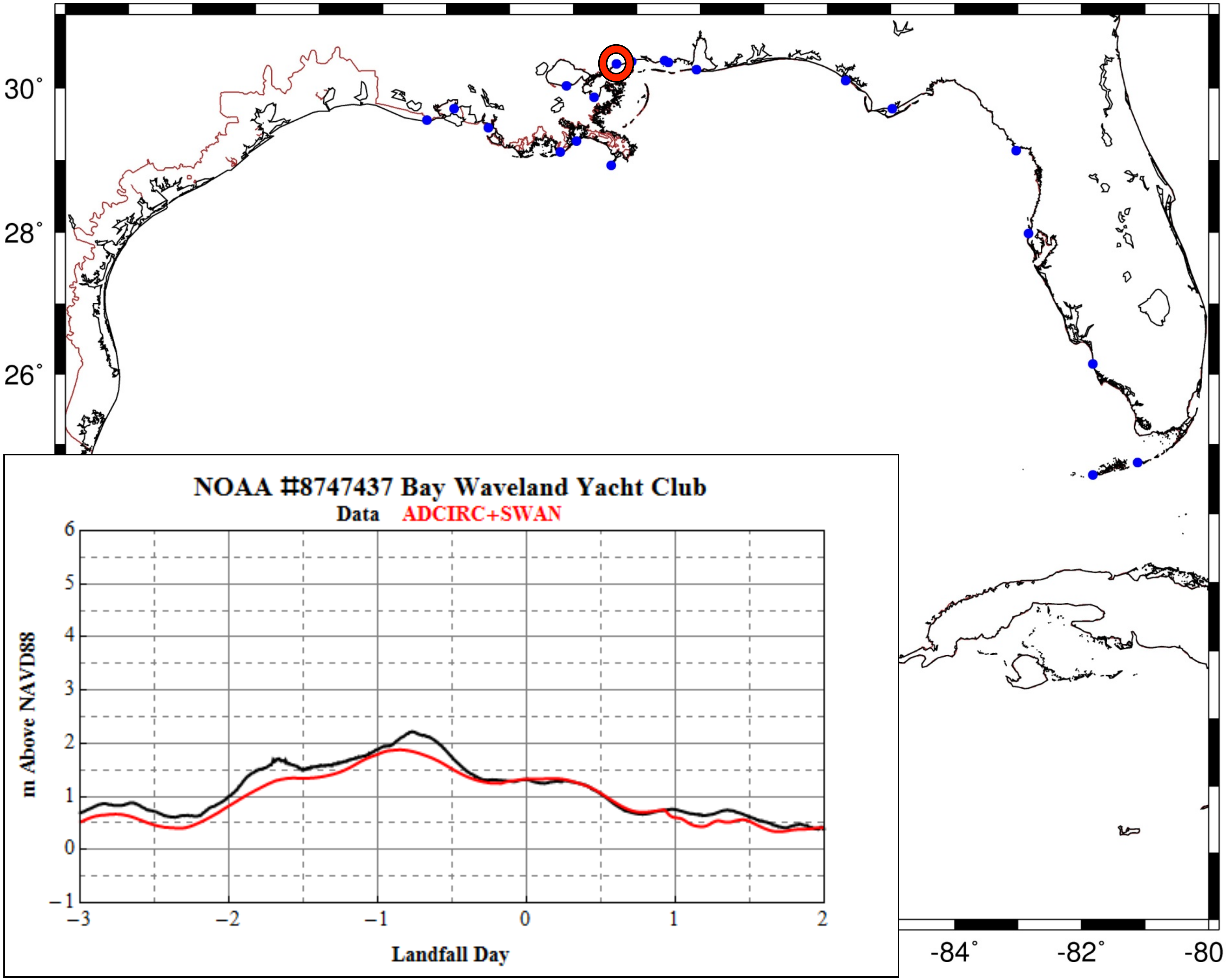
1
2
Landfall Day



30°
28°
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-84°
-82°
-80°
NOAA #8747437 Bay Waveland Yacht Club
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
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−1
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0
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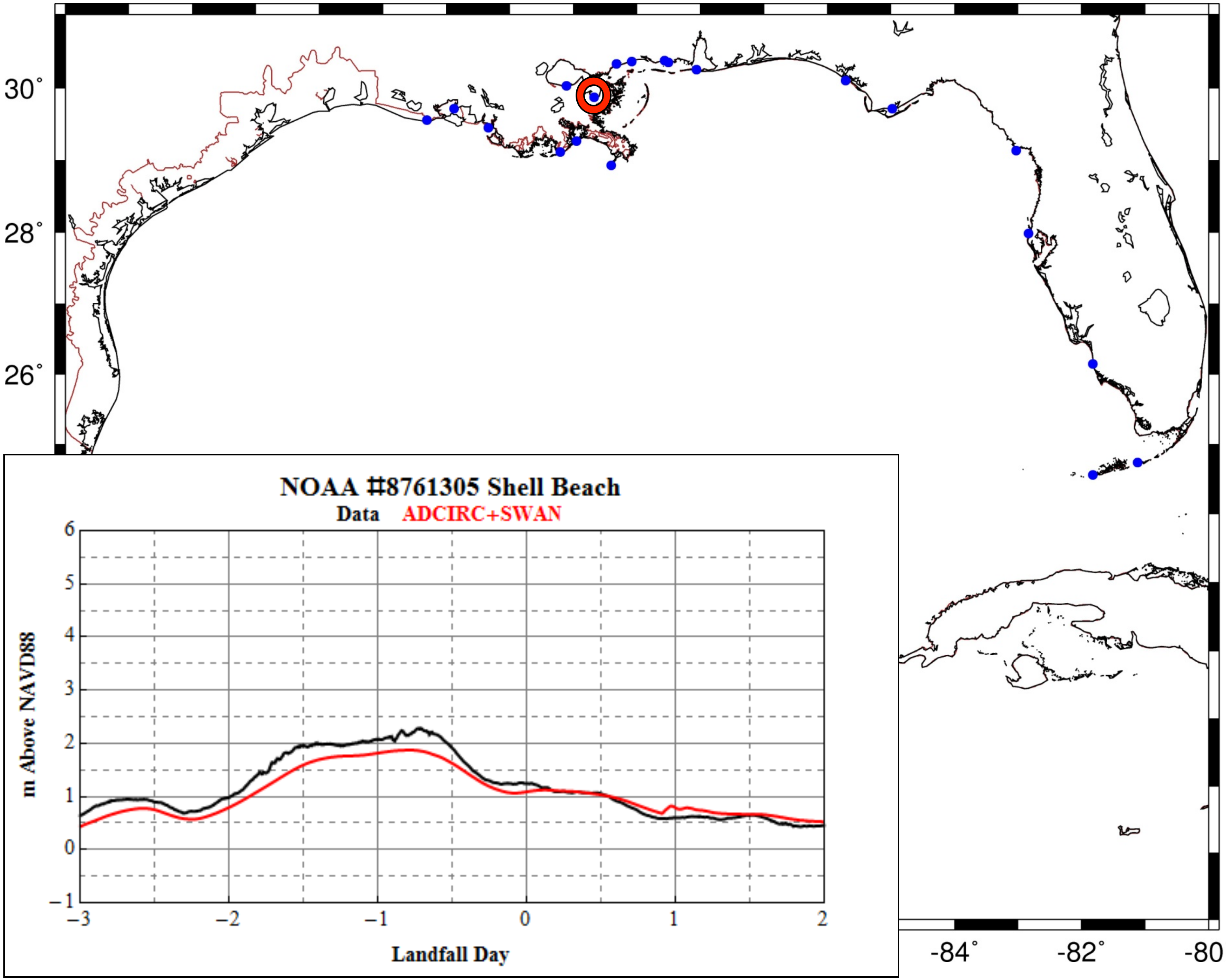
2


30°
28°
26°
-84°
-82°
-80°
NOAA #8761305 Shell Beach
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
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3
2
1
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−1
−3
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−1
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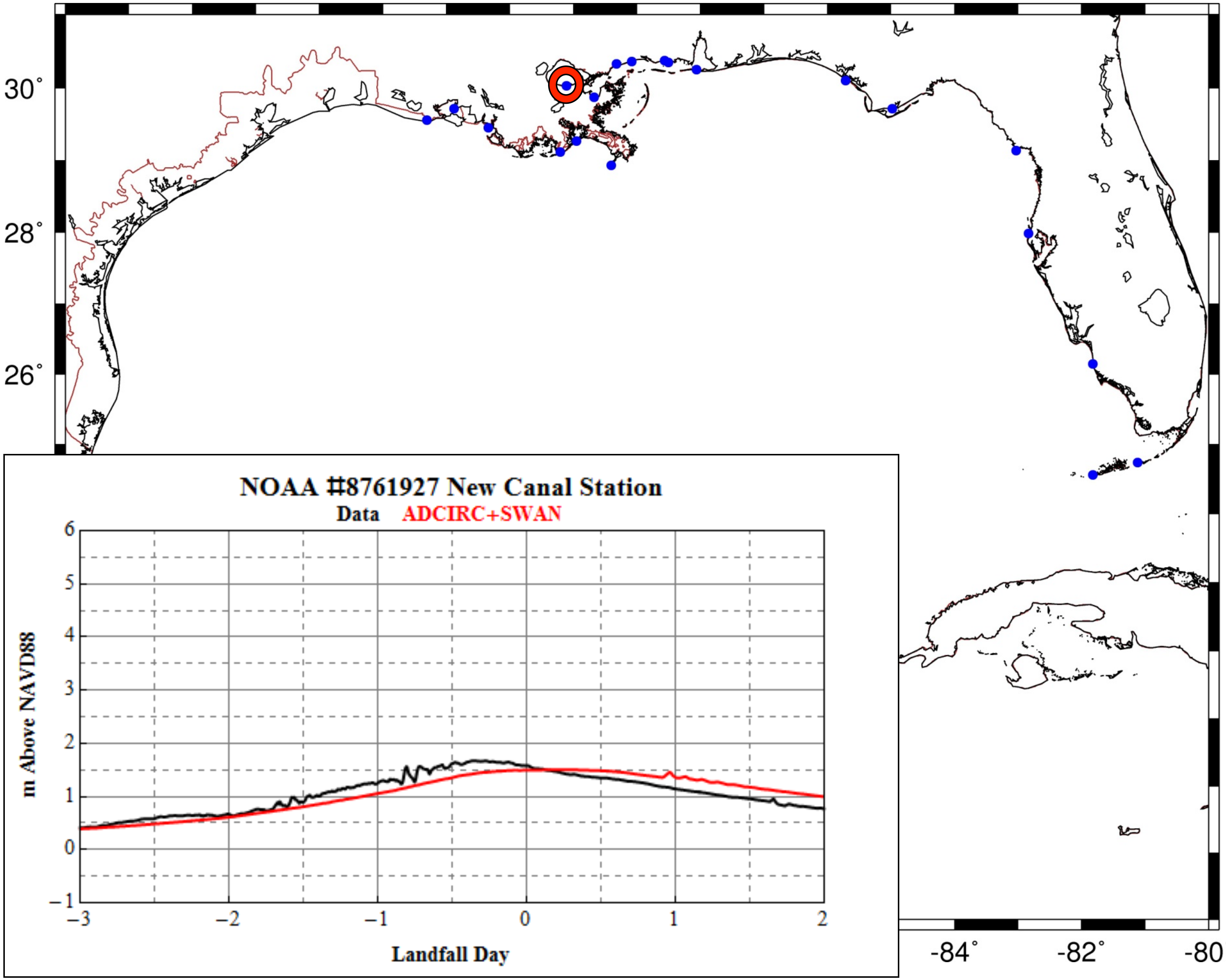
30°
28°
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-84°
-82°
-80°
NOAA #8761927 New Canal Station
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
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−1
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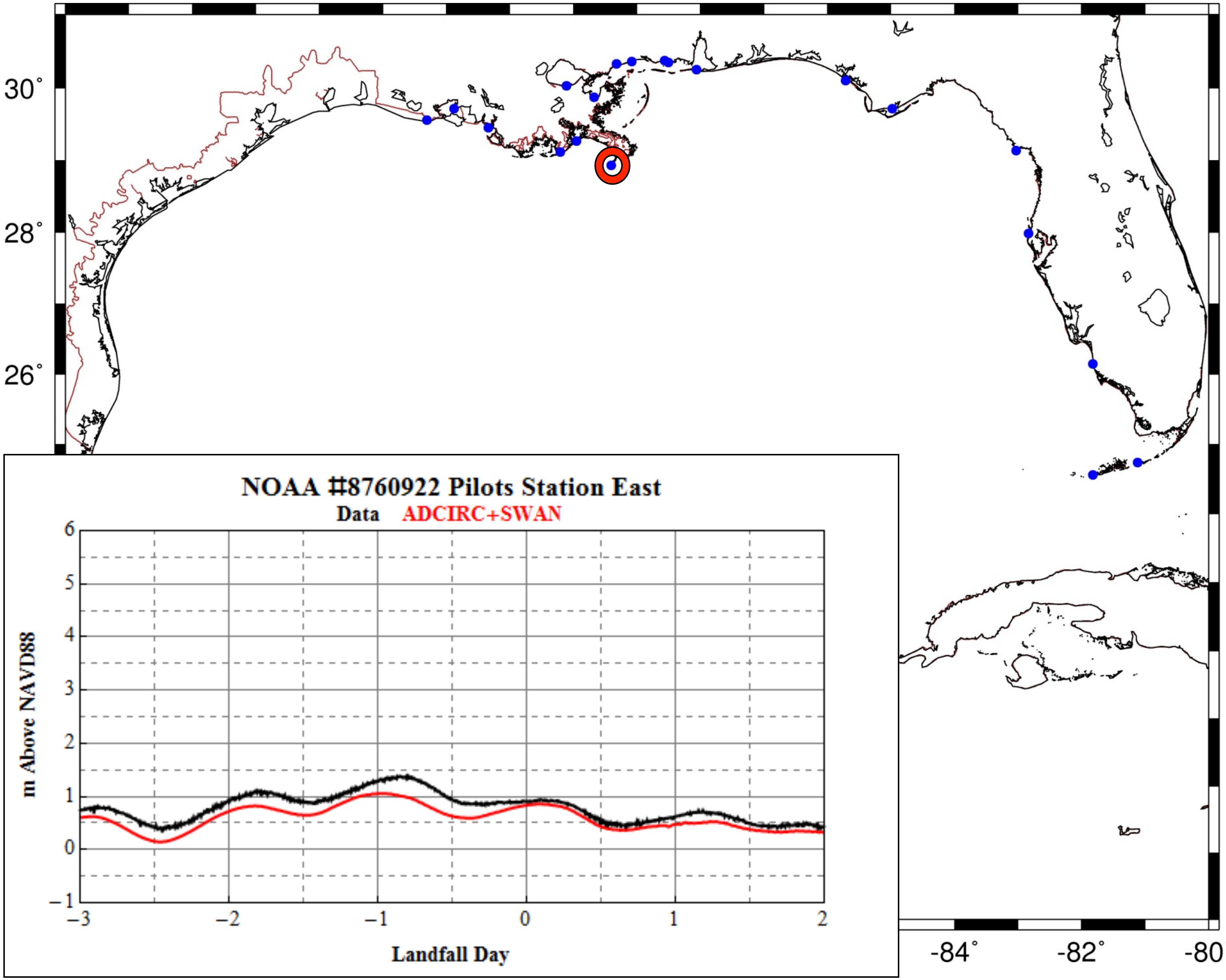
2



30˚
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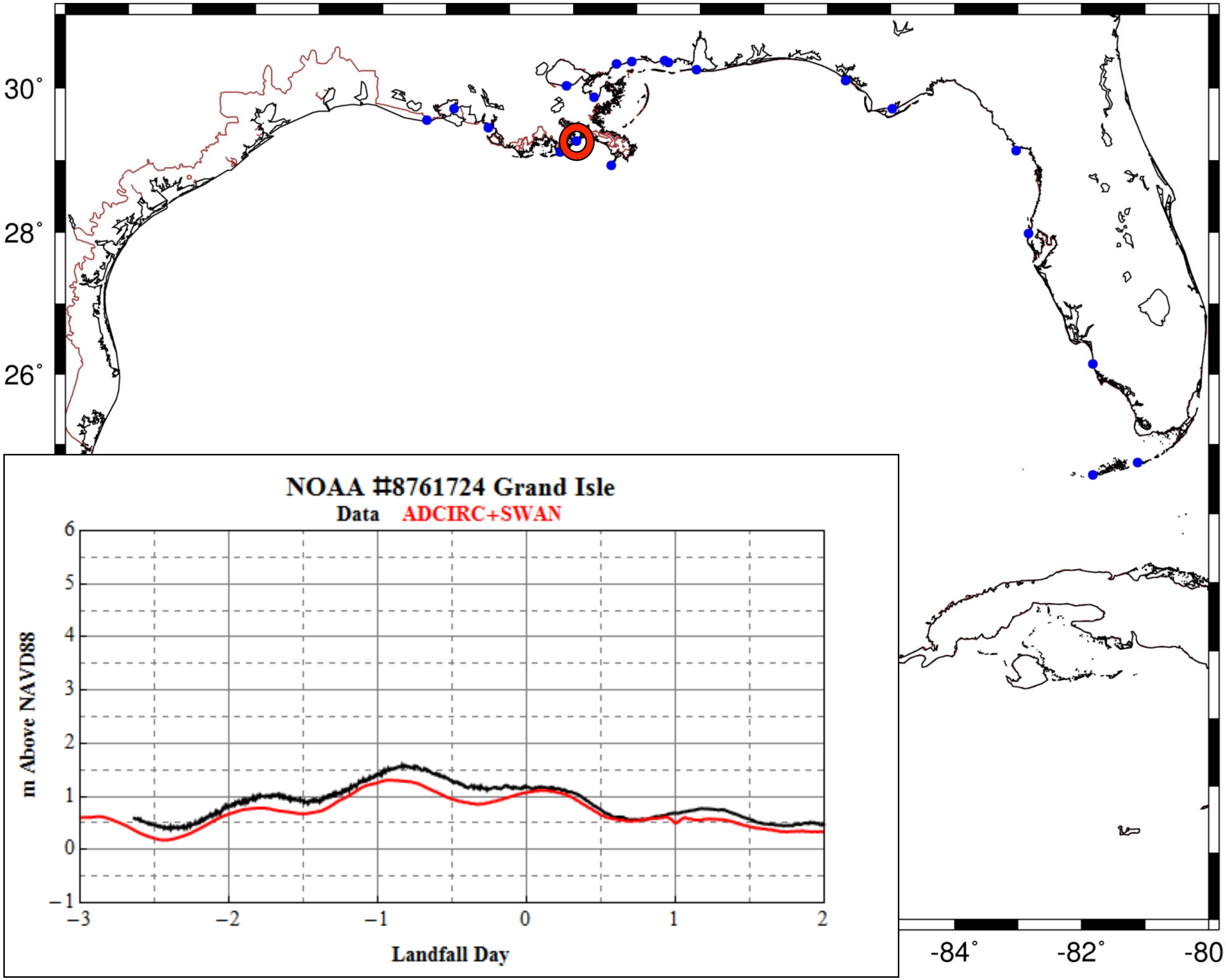
-84˚
-82˚
-80˚
NOAA #8760922 Pilots Station East
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day


30°
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-84°
-82°
-80°
NOAA #8761724 Grand Isle
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
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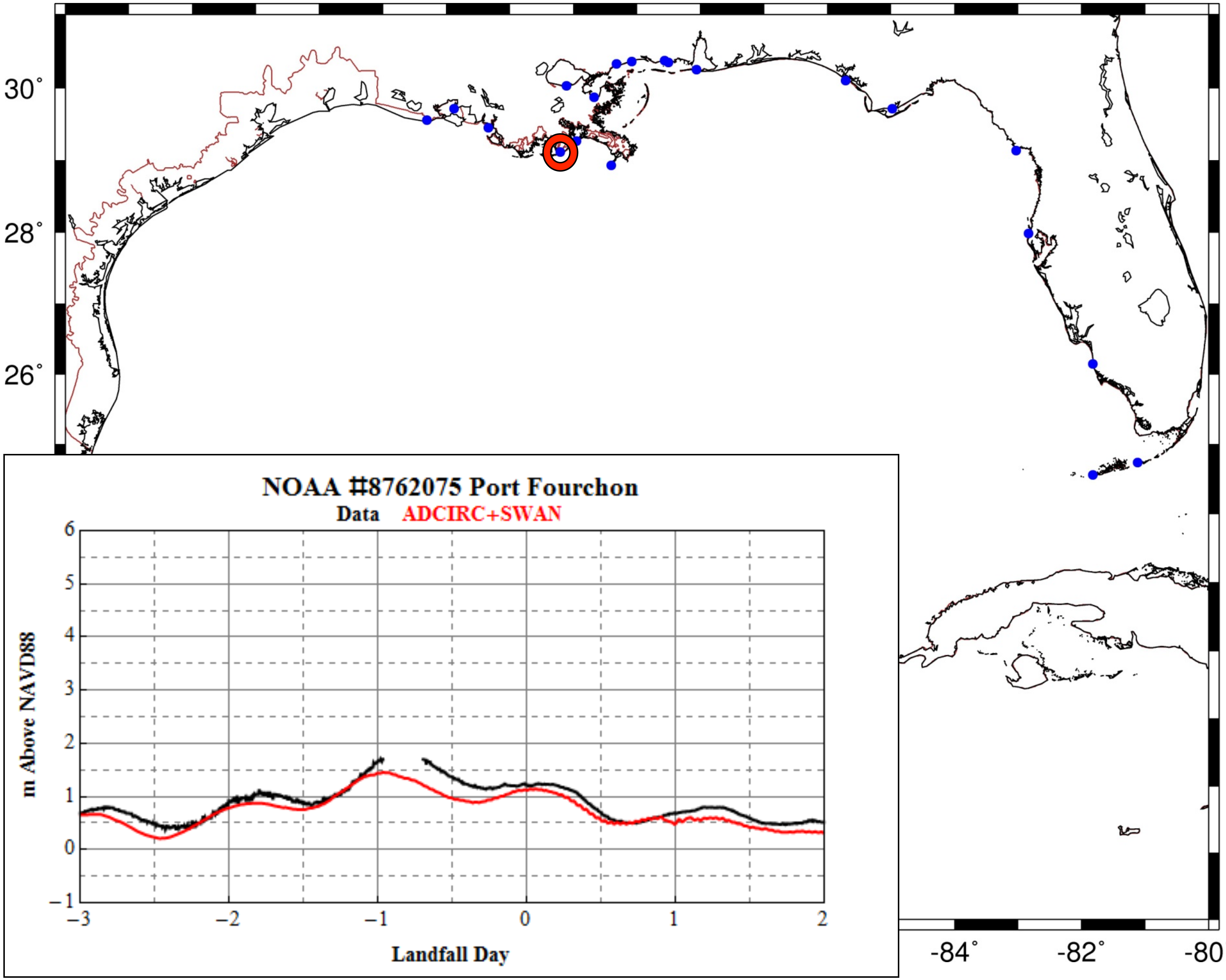
30˚
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-80˚
NOAA #8762075 Port Fourchon
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
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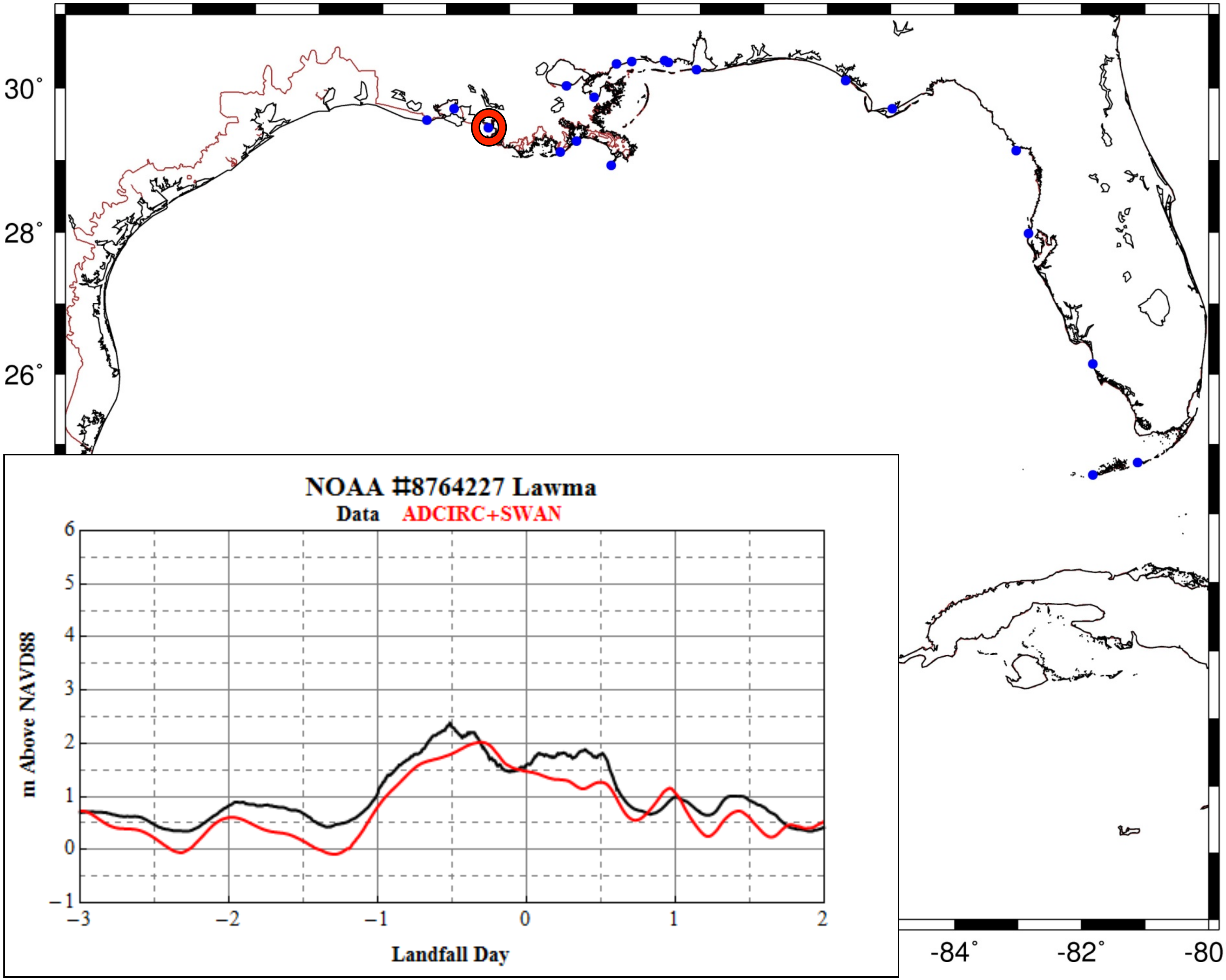
30˚
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NOAA ♯8764227 Lawma
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
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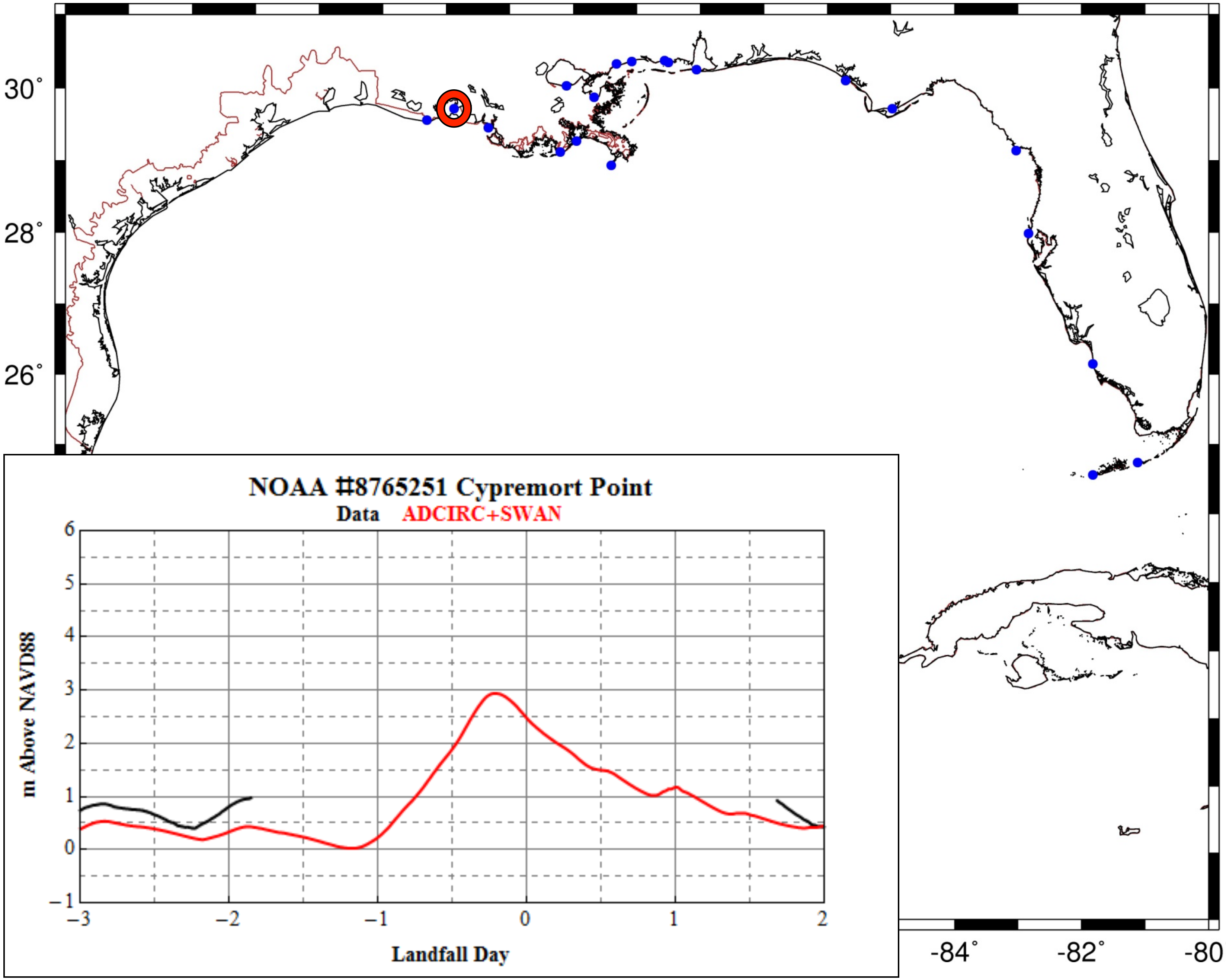

30°
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NOAA #8765251 Cypremort Point
Data ADCIRC+SWAN
m Above NAVD88
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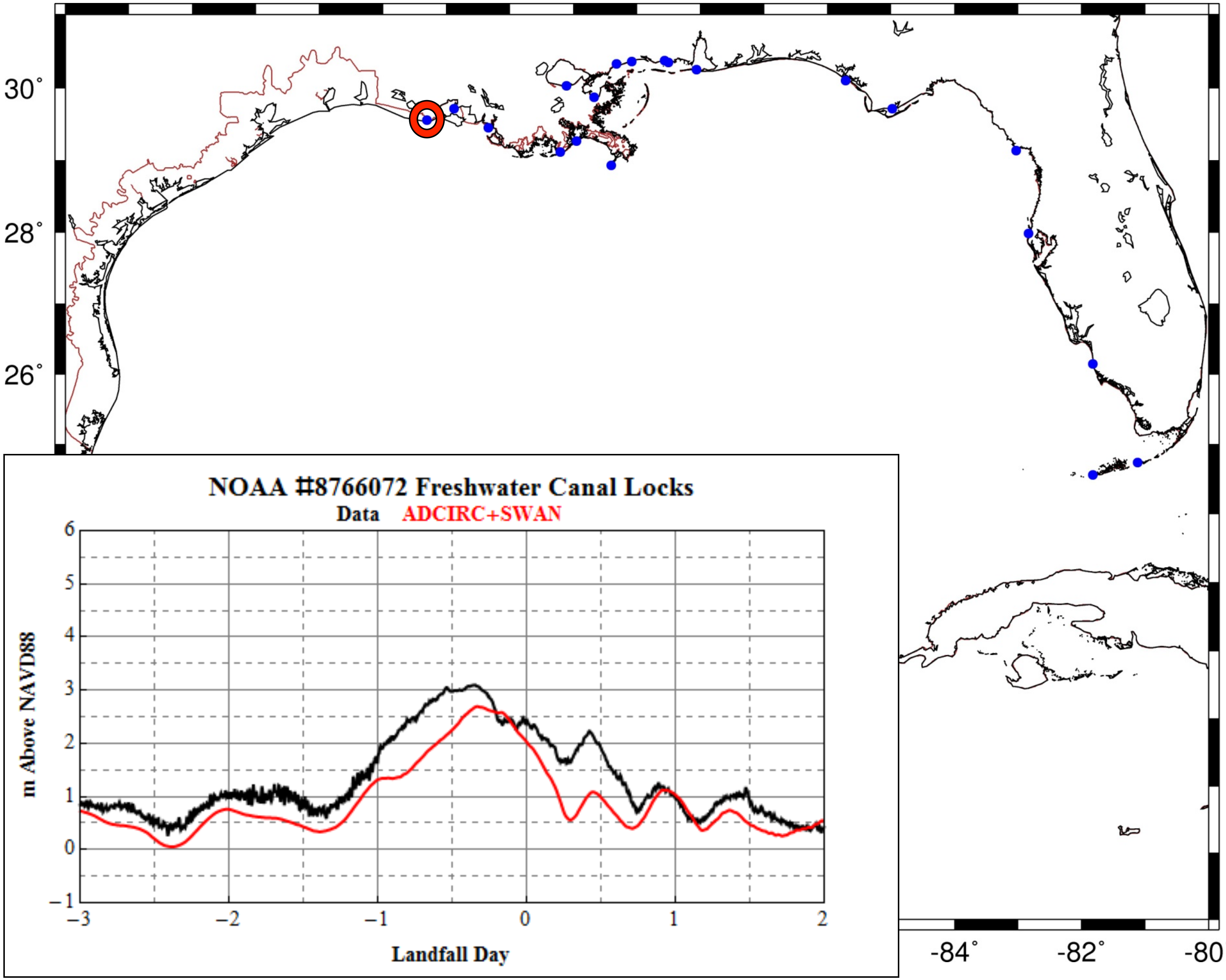
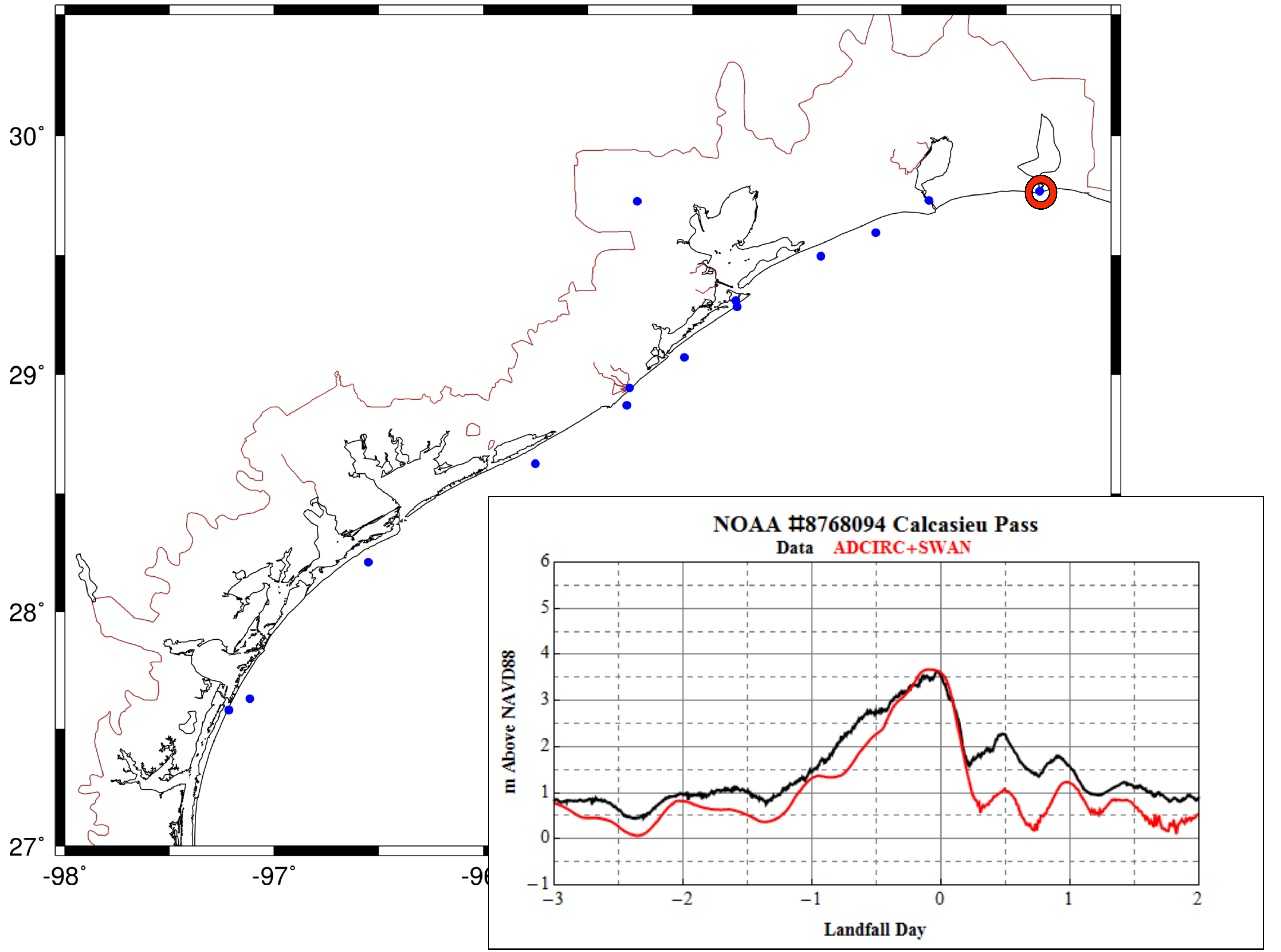
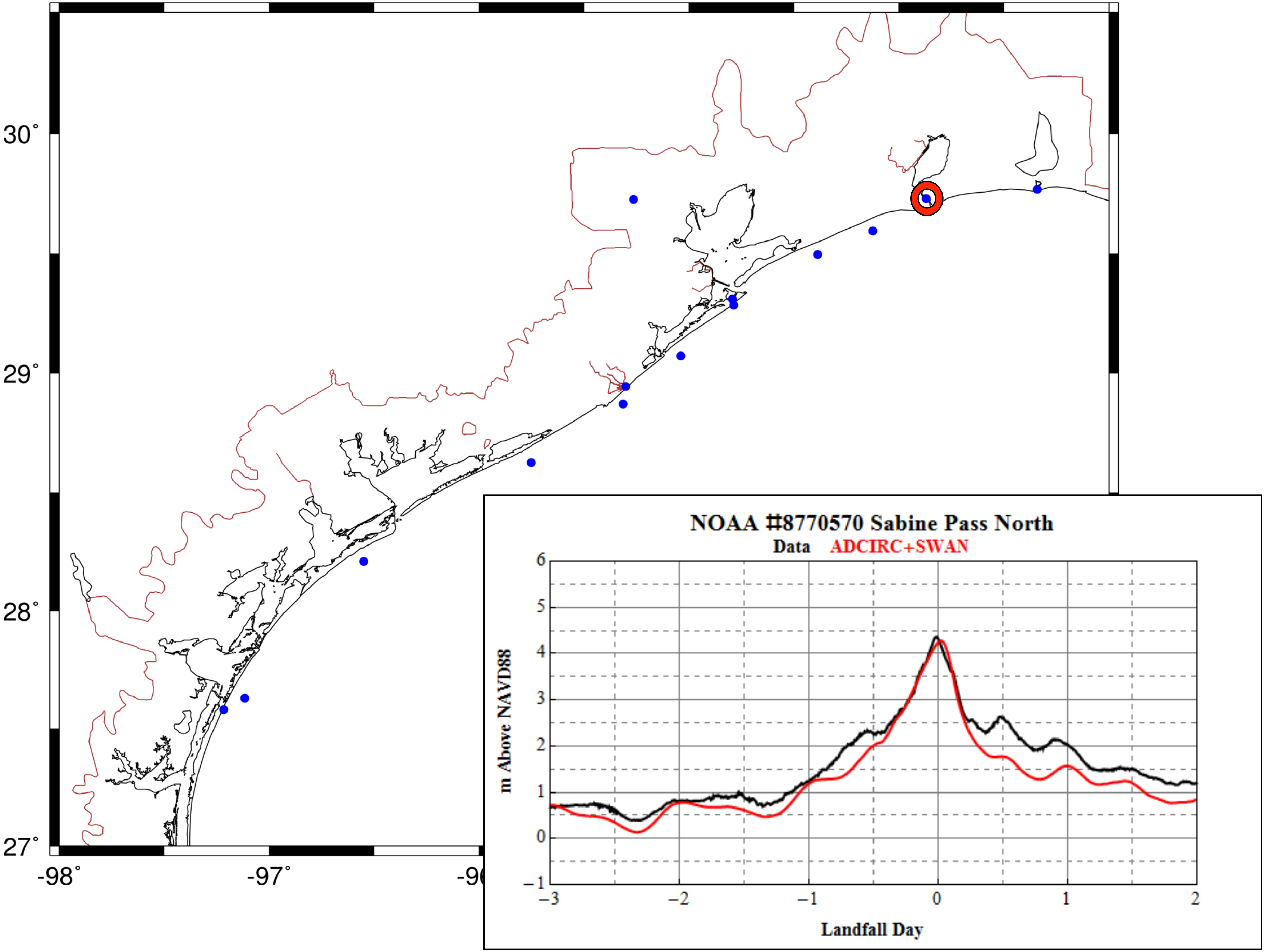
Landfall Day



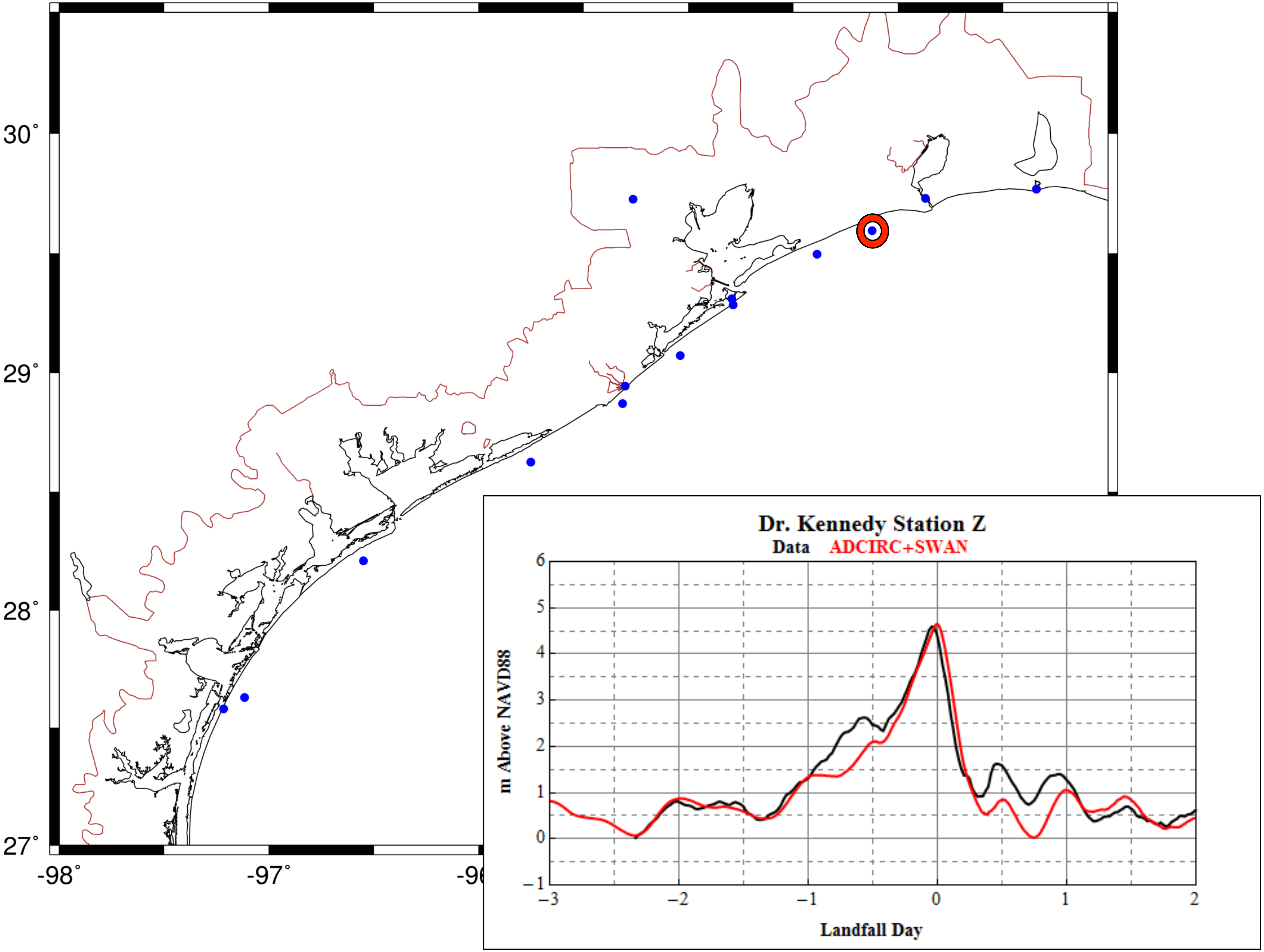
30˚
28˚
26˚
-84˚
-82˚
-80˚
NOAA #8766072 Freshwater Canal Locks
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day



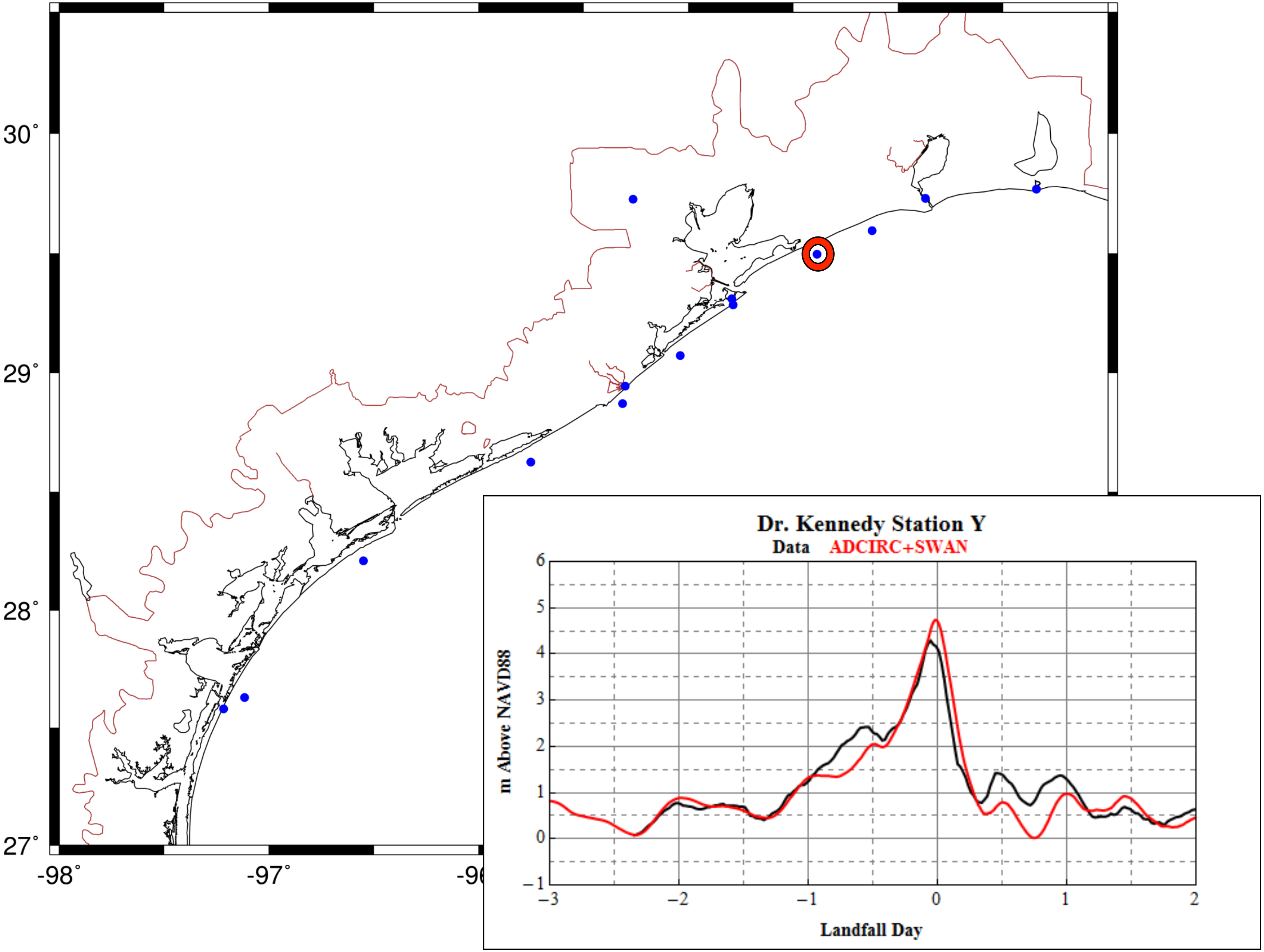
30°
29°
28°
27°
-98°
-97°
NOAA #8768094 Calcasieu Pass
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day

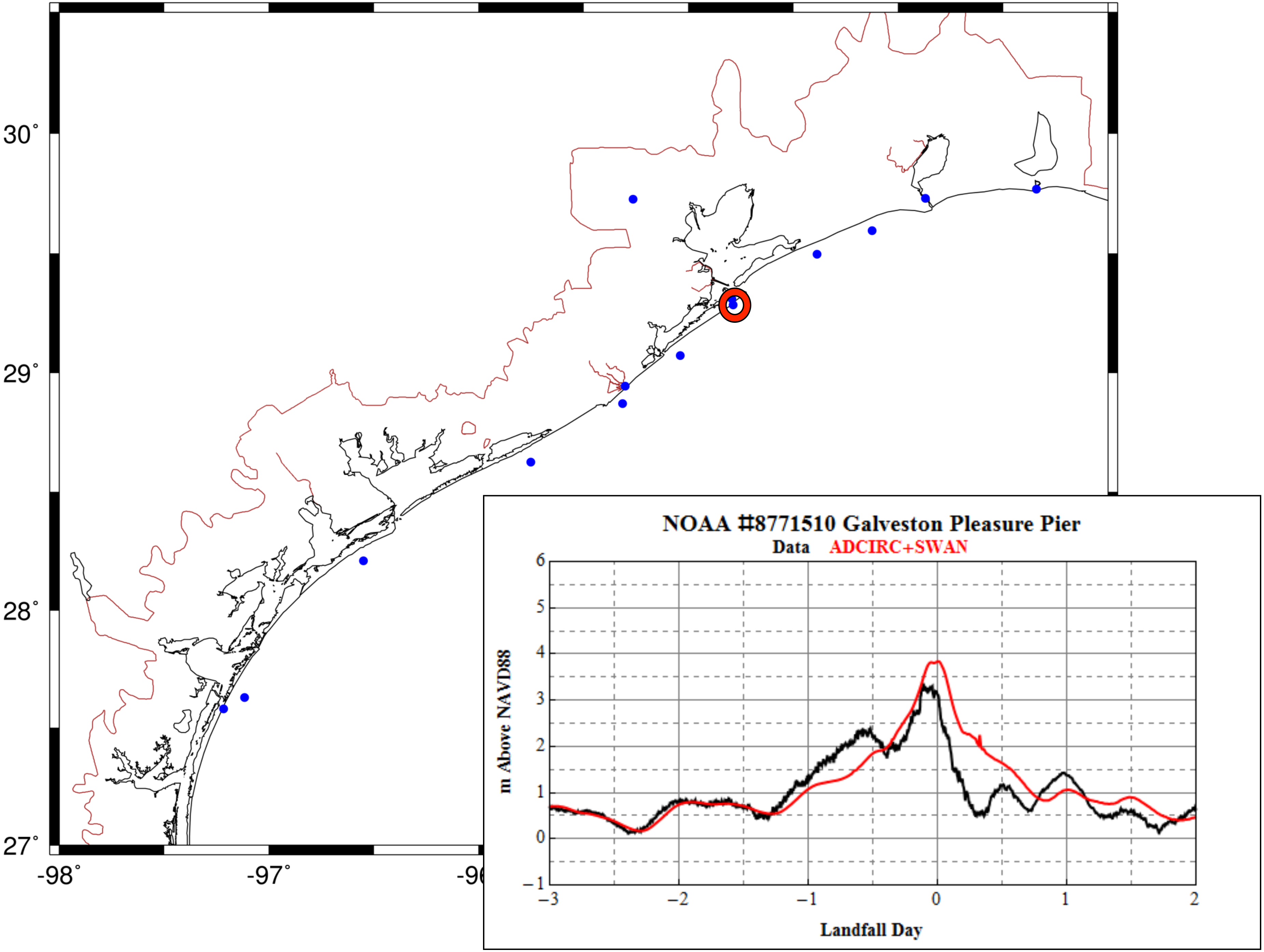


30°
29°
28°
27°
-98°
-97°
NOAA #8770570 Sabine Pass North
Data
ADCIRC+SWAN
m Above NAVD88
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2
Landfall Day

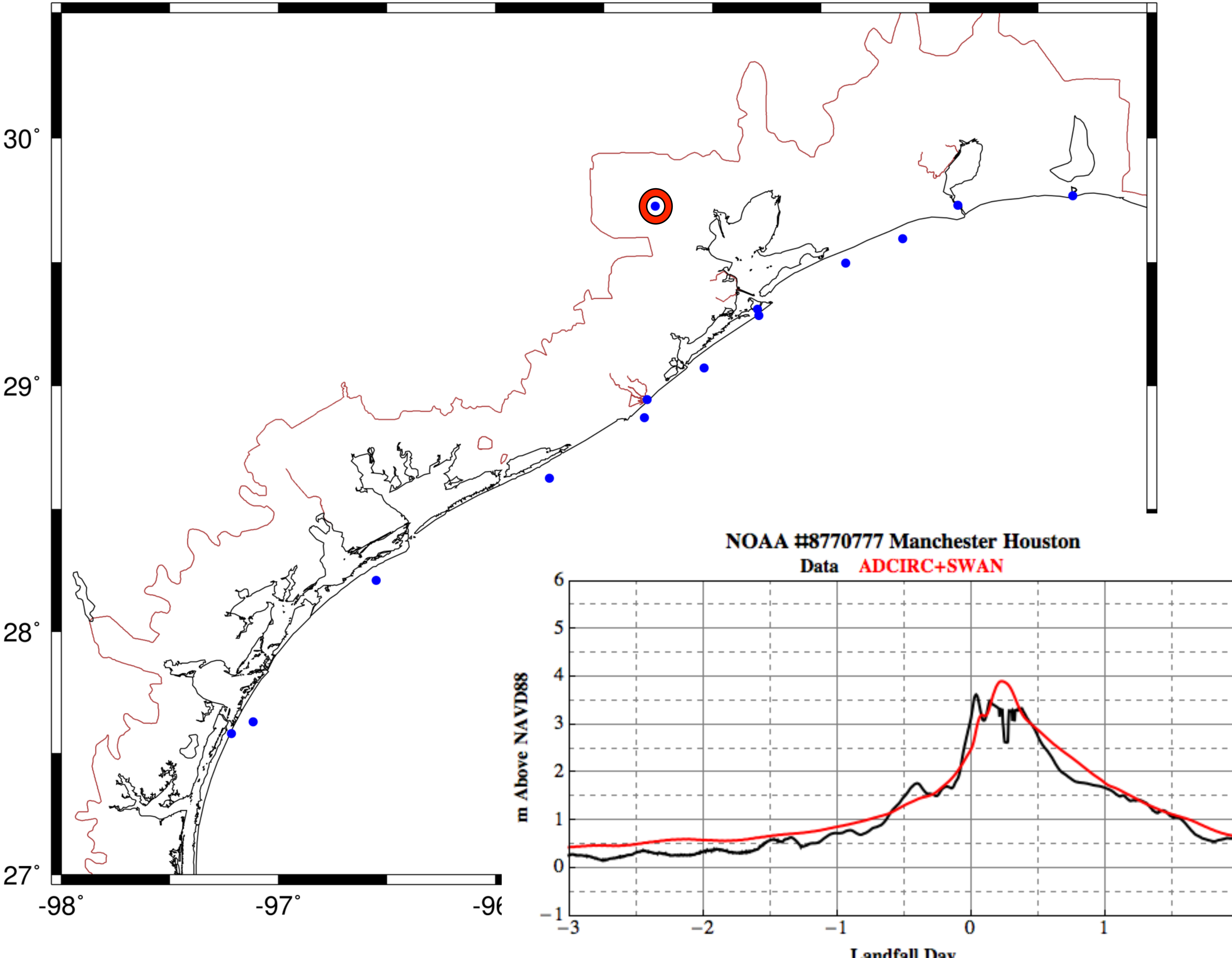


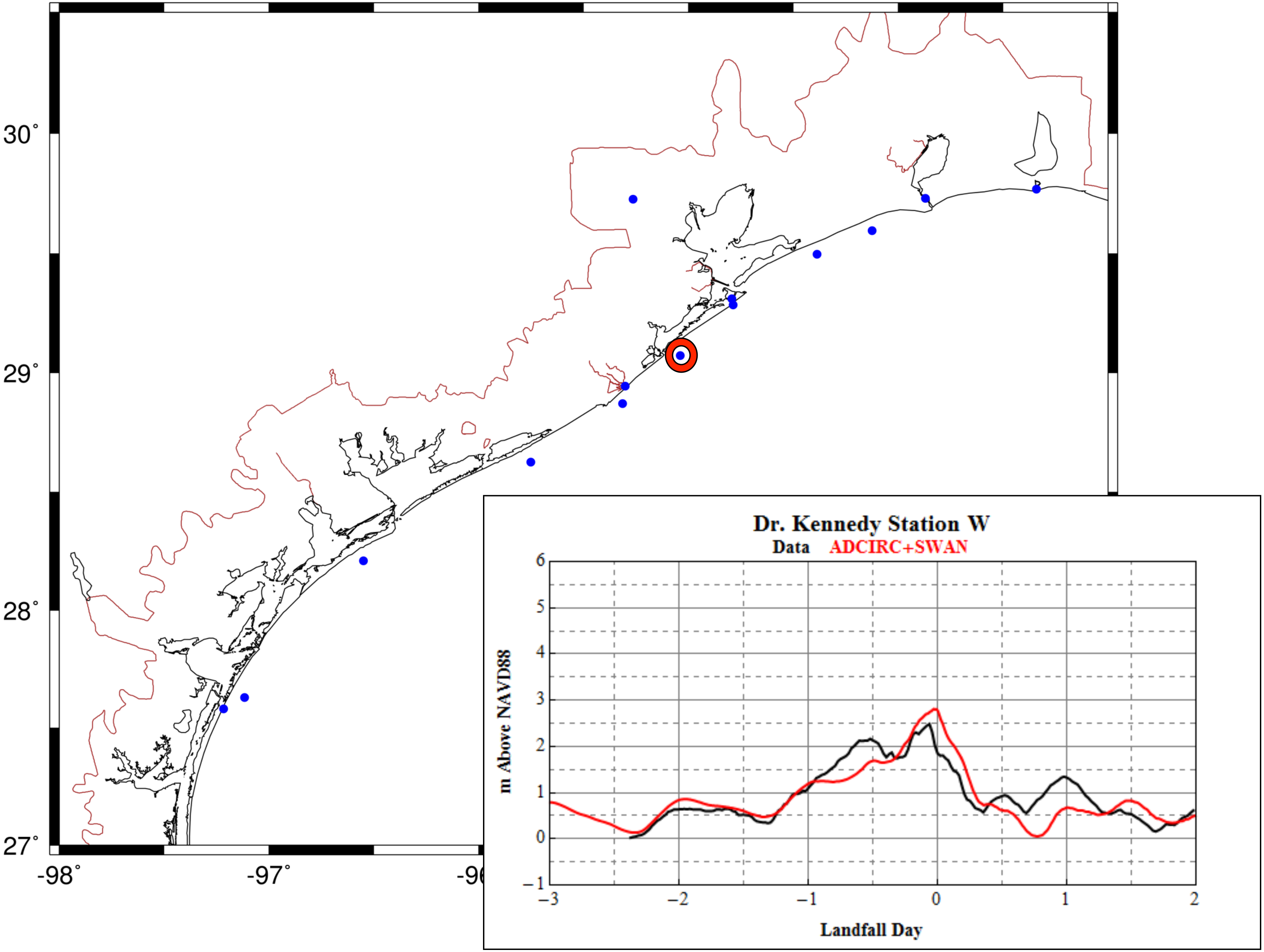
30°
29°
28°
27°
-98°
-97°
Dr. Kennedy Station Z
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2

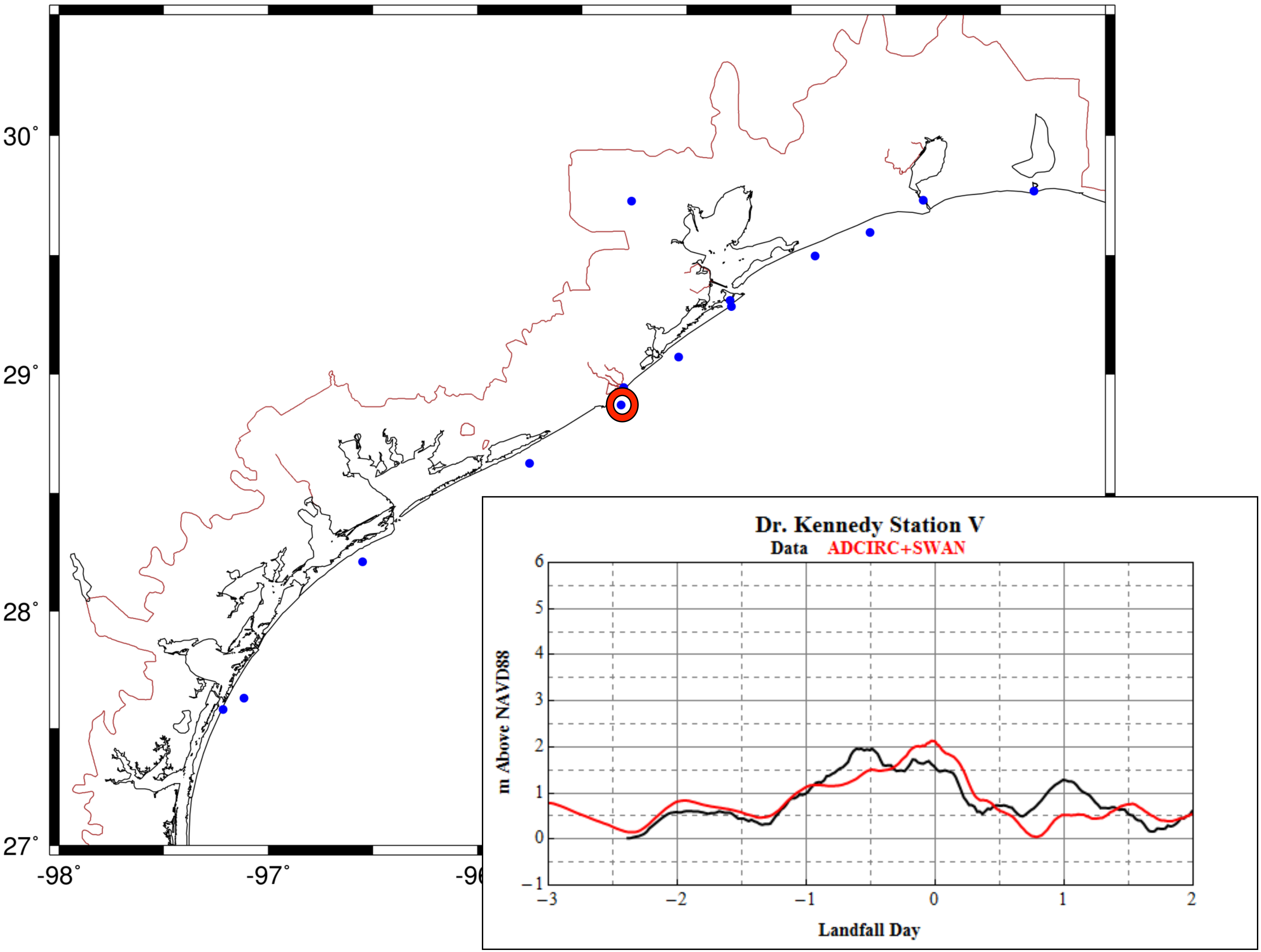

30°
29°
28°
27°
-98°
-97°
-96
Dr. Kennedy Station Y
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2

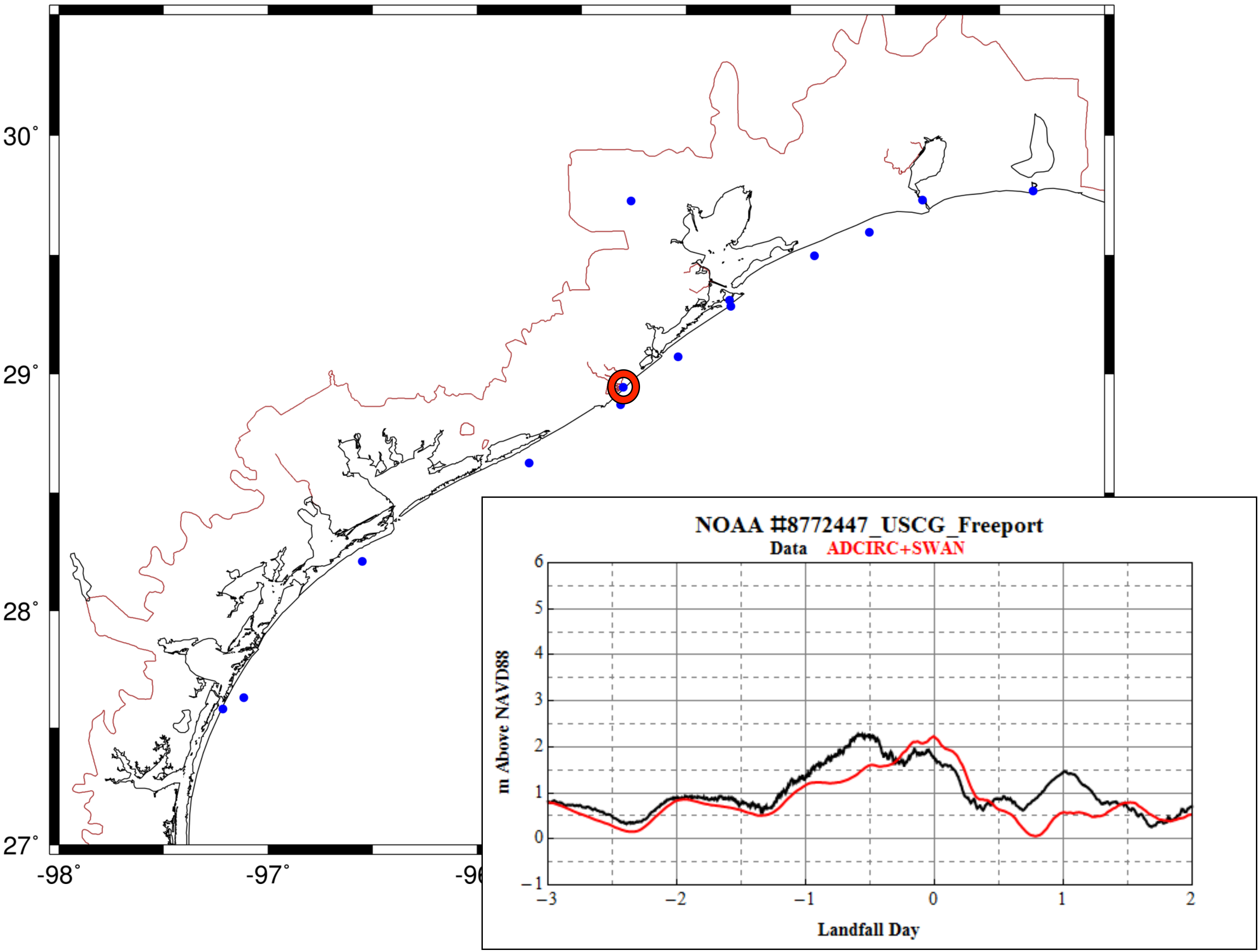


30°
29°
28°
27°
-98°
-97°
NOAA #8771510 Galveston Pleasure Pier
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day

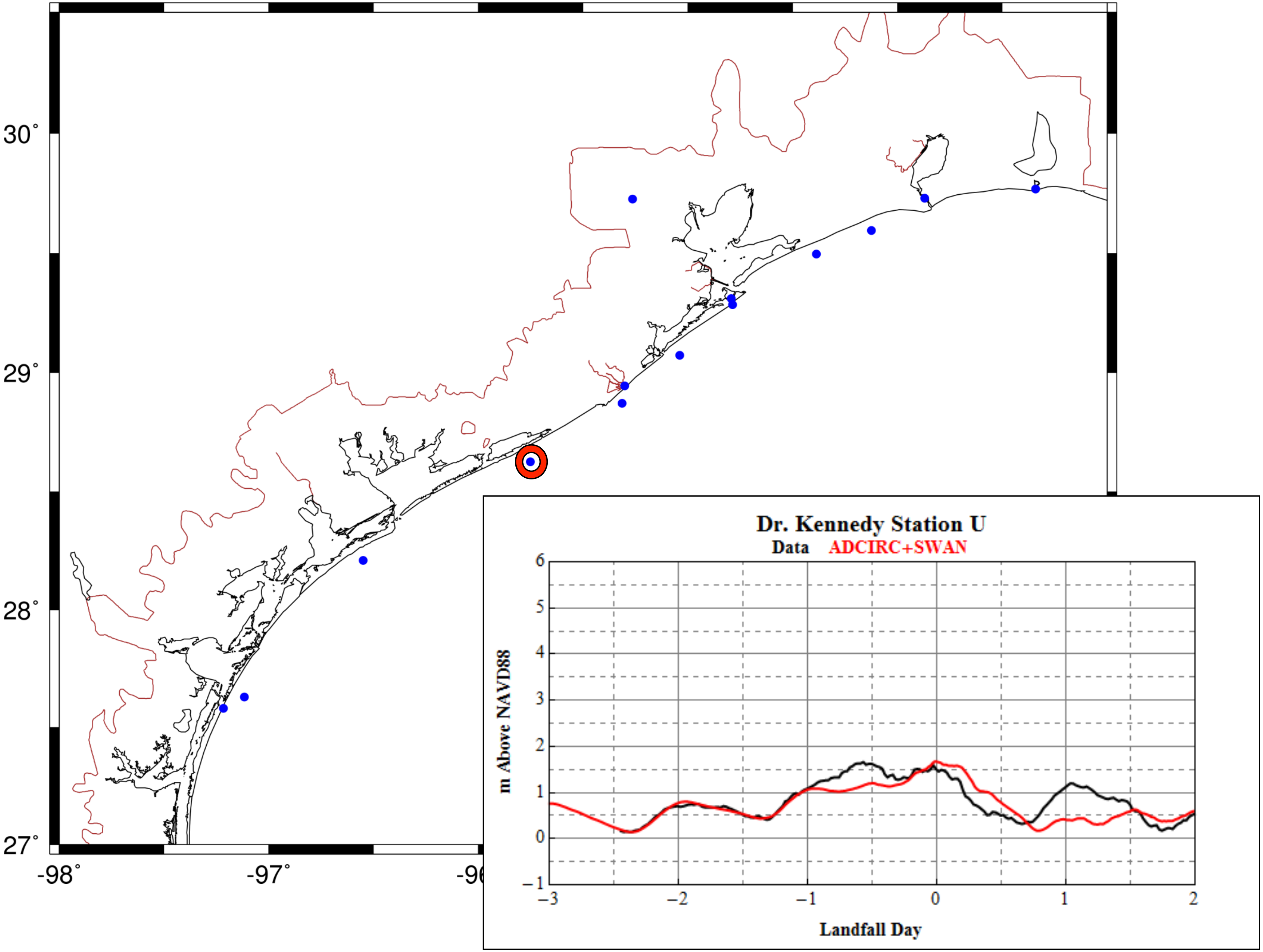

30°
29°
28°
27°
-98°
-97°
-96
NOAA #8770777 Manchester Houston
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2


30°
29°
28°
27°
-98°
-97°
Dr. Kennedy Station W
Data
ADCIRC+SWAN
m Above NAVD88
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2
Landfall Day

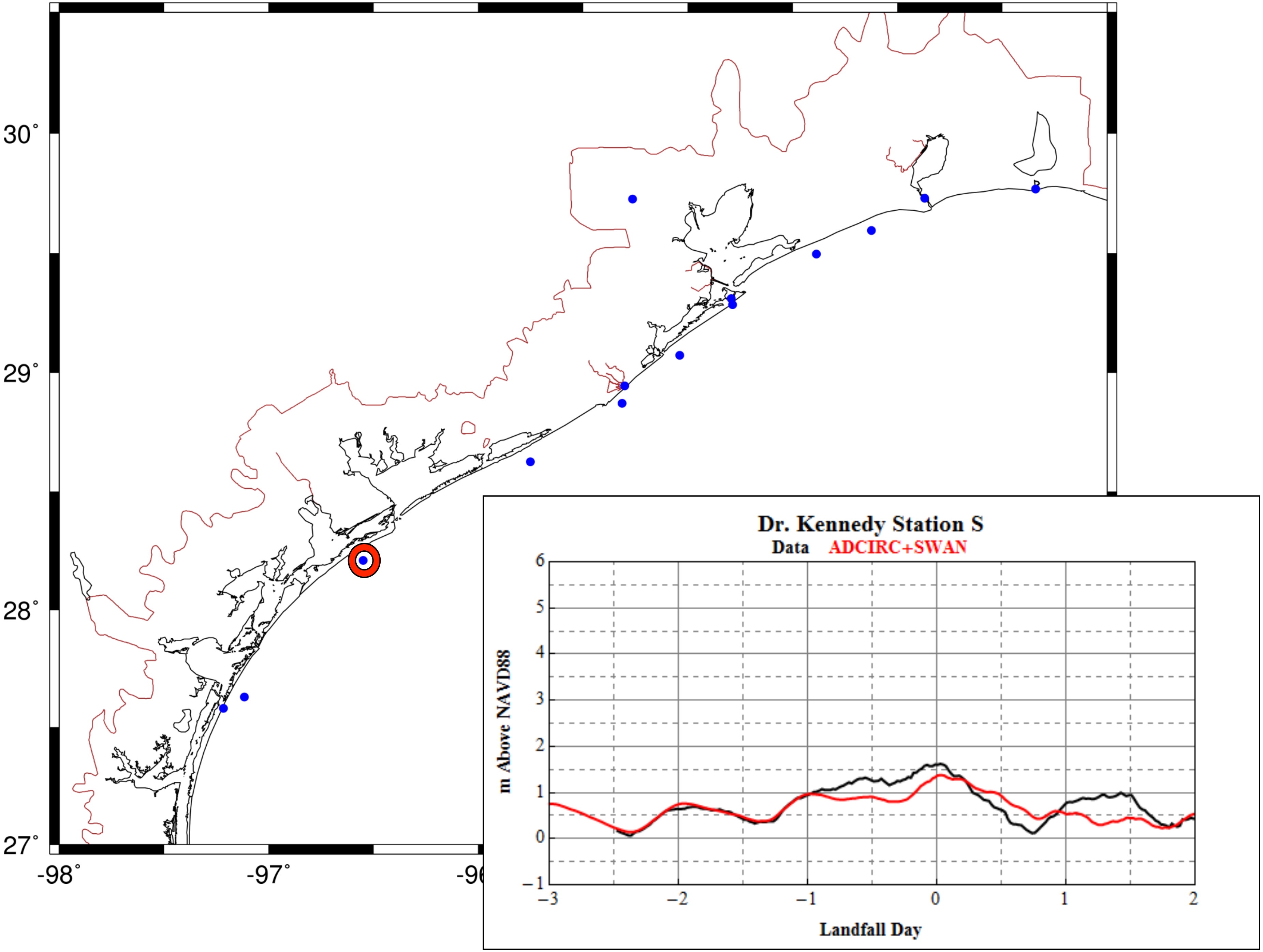

30°
29°
28°
27°
-98°
-97°
-96
Dr. Kennedy Station V
Data
ADCIRC+SWAN
m Above NAVD88
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2
Landfall Day



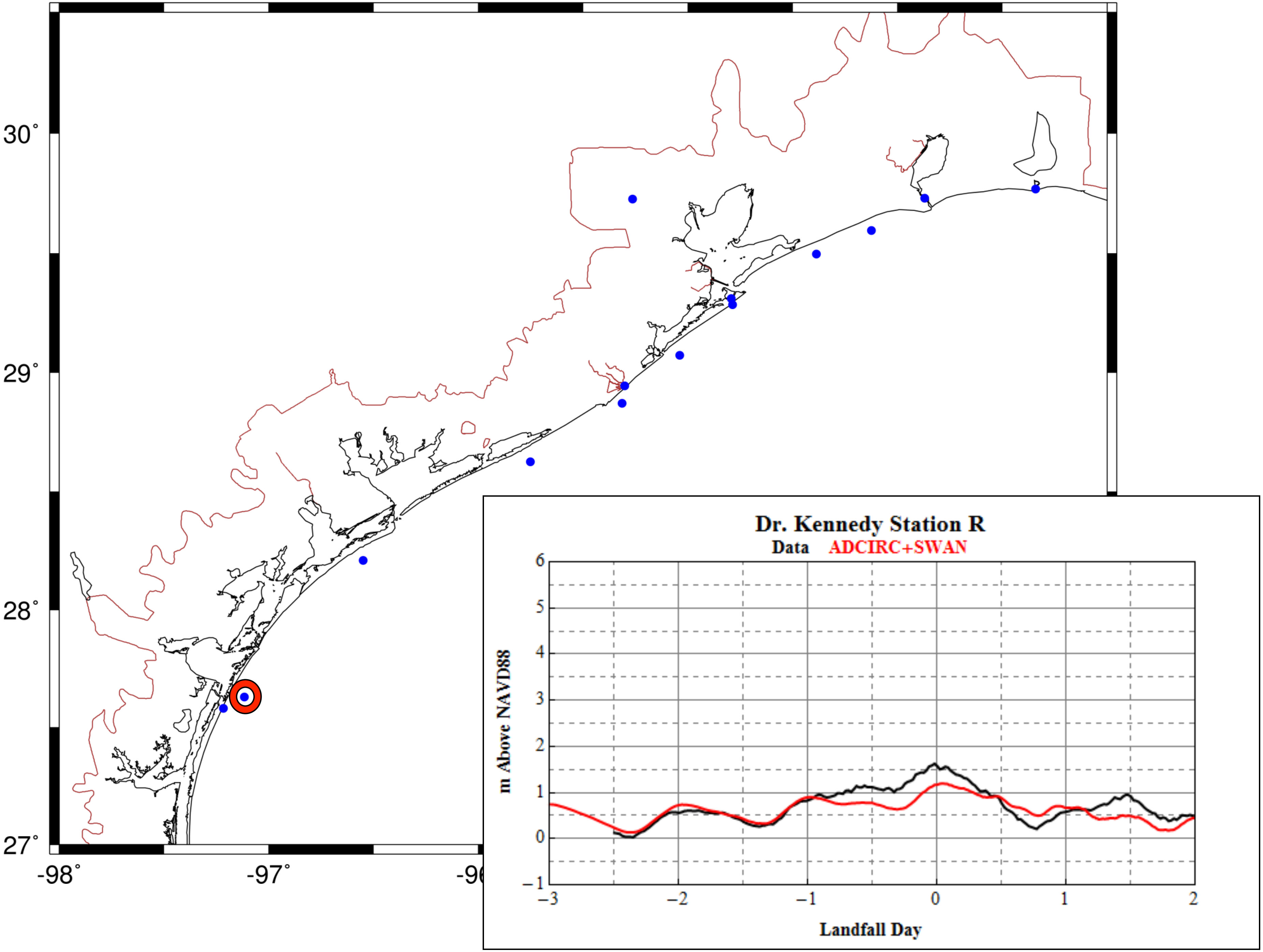
30°
29°
28°
27°
-98°
-97°
-96
NOAA #8772447_USCG_Freeport
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day



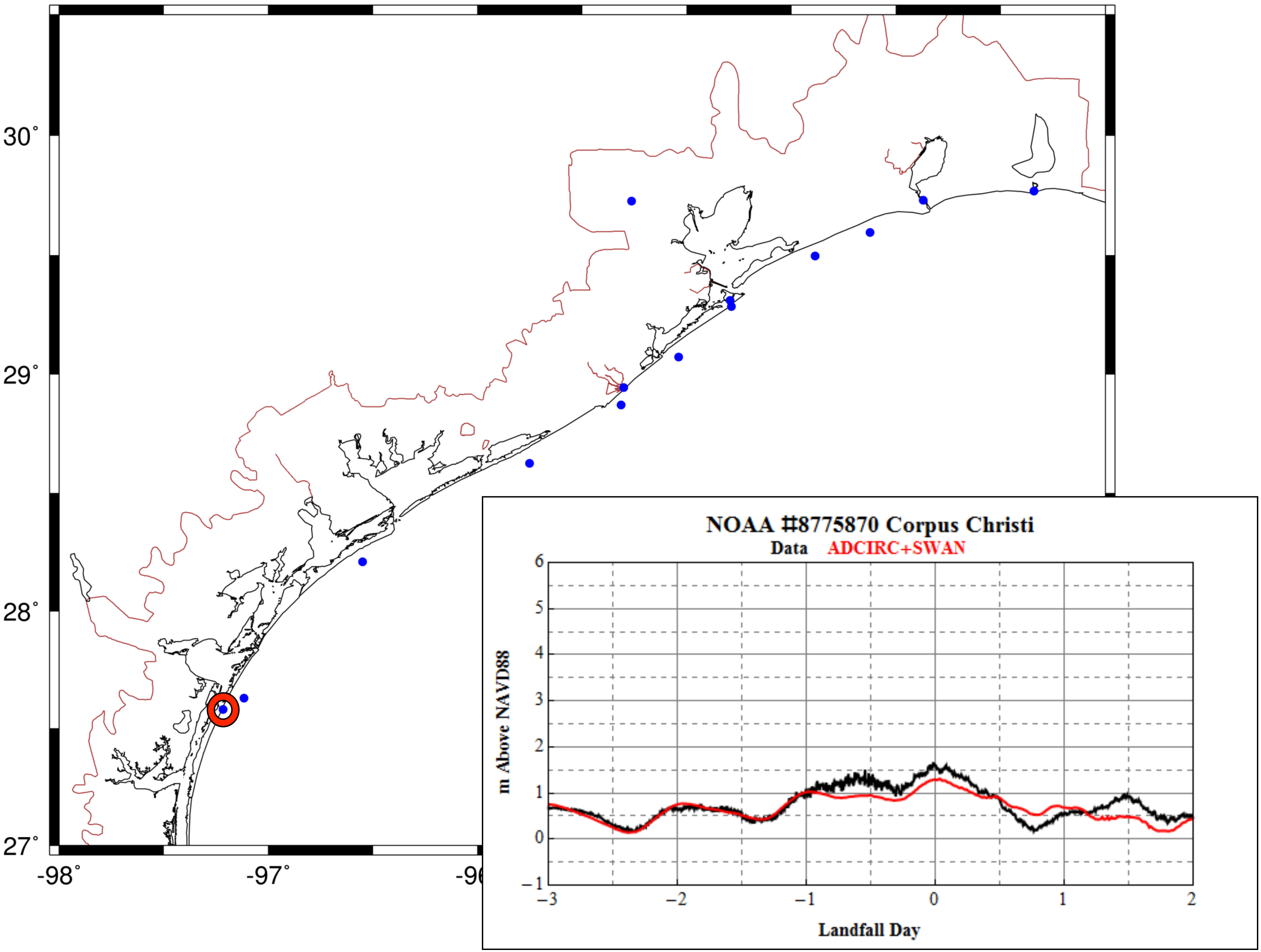
30°
29°
28°
27°
-98°
-97°
-96
Dr. Kennedy Station U
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day



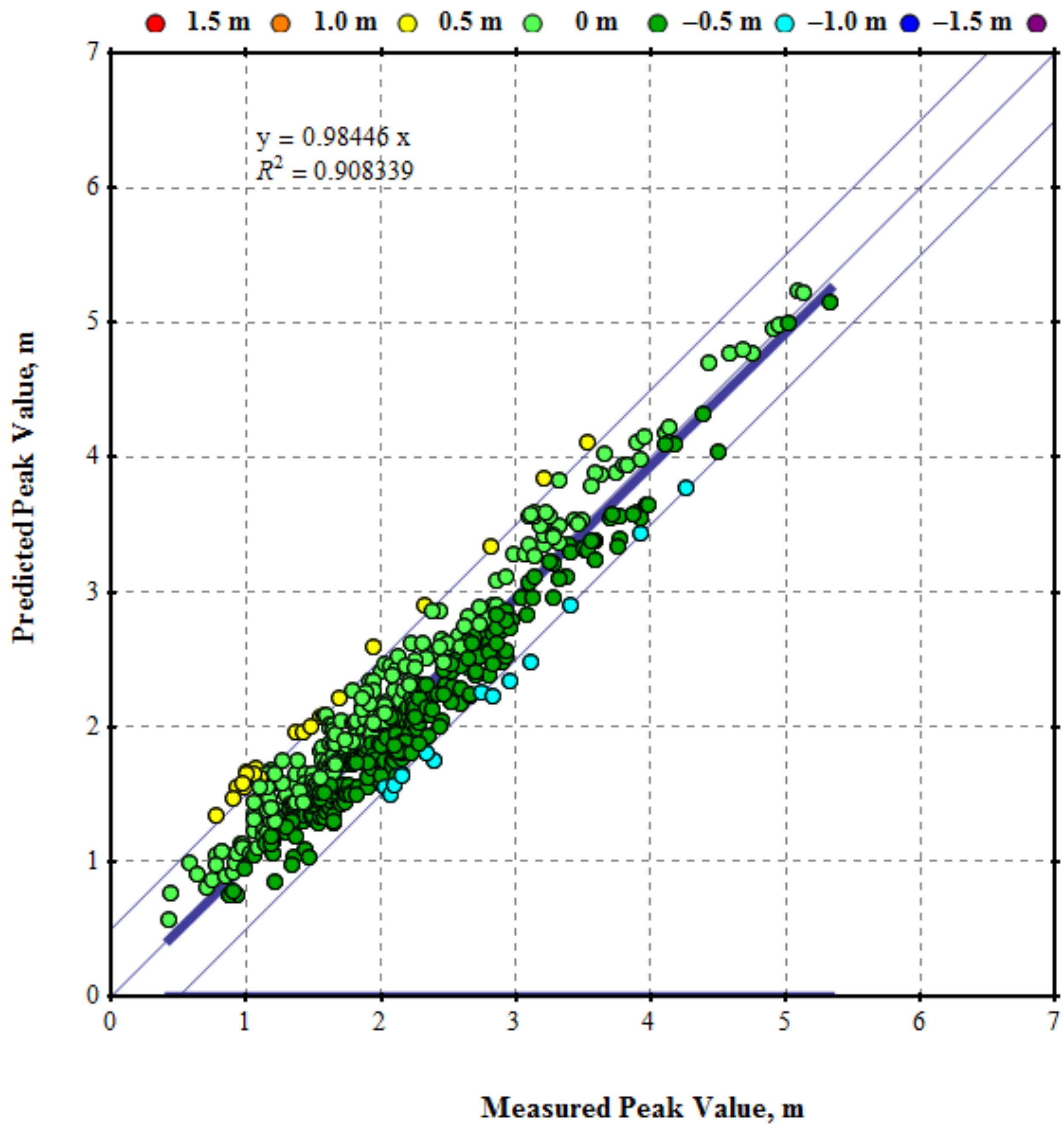
30°
29°
28°
27°
-98°
-97°
-96
Dr. Kennedy Station S
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2



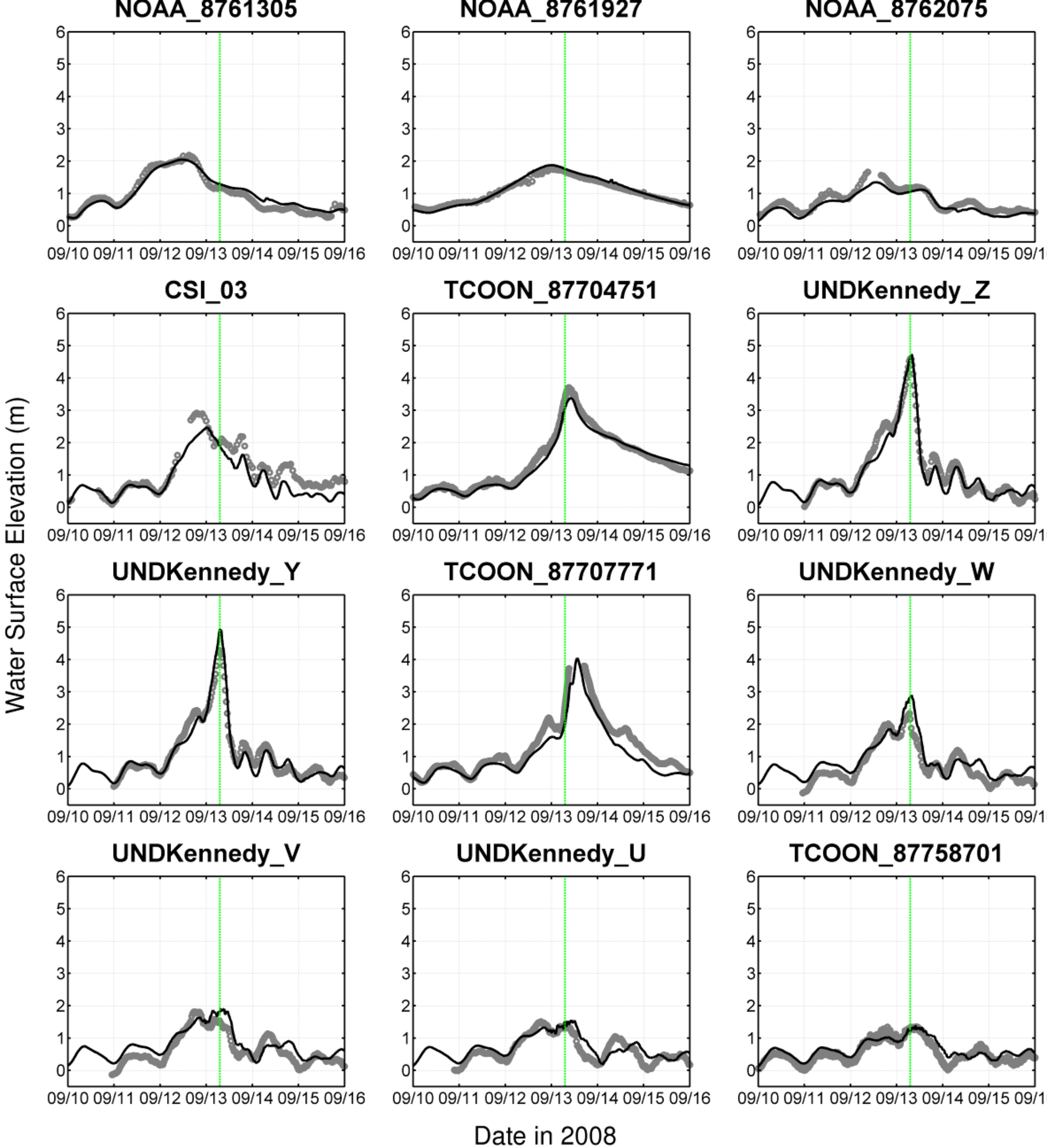
30°
29°
28°
27°
-98°
-97°
Dr. Kennedy Station R
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2



30°
29°
28°
27°
-98°
-97°
NOAA #8775870 Corpus Christi
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2

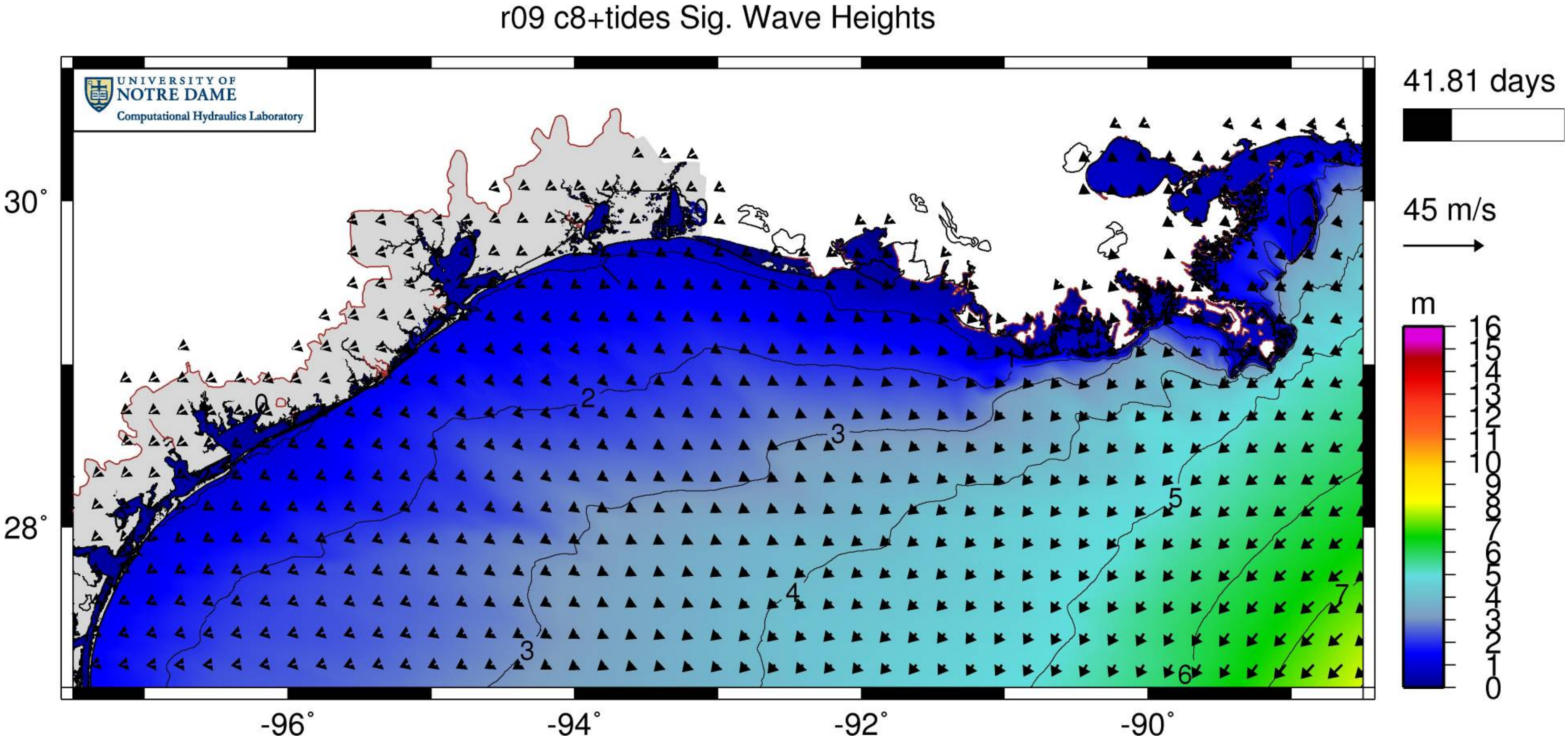


1.5 m
1.0 m
0.5 m
0 m
–0.5 m
–1.0 m
–1.5 m
y = 0.98446 x
R² = 0.908339
Predicted Peak Value, m
Measured Peak Value, m
0
1
2
3
4
5
6
7



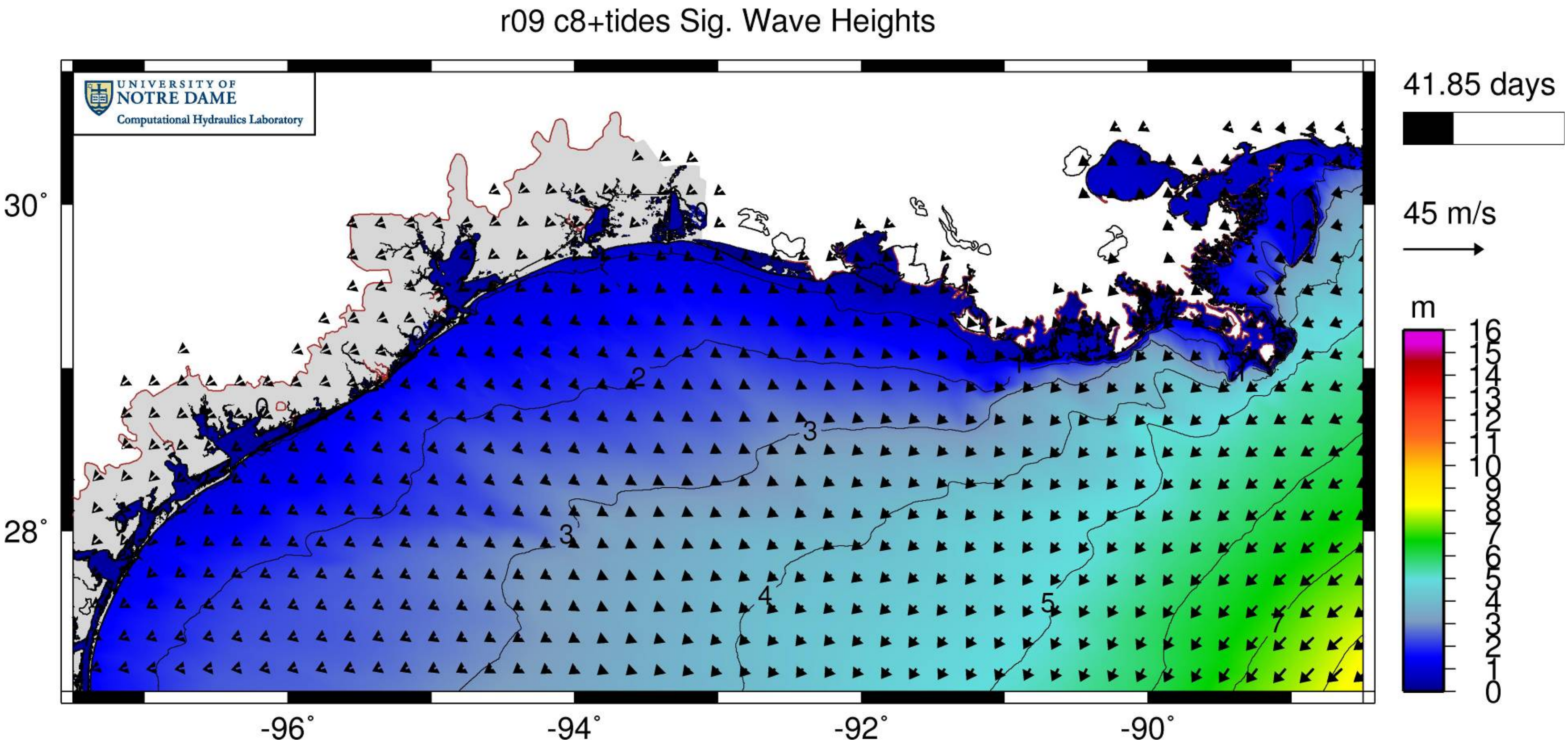
NOAA_8761305
NOAA_8761927
NOAA_8762075
CSI_03
TCOON_87704751
UNDKennedy_Z
UNDKennedy_Y
TCOON_87707771
UNDKennedy_W
UNDKennedy_V
UNDKennedy_U
TCOON_87758701
Water Surface Elevation (m)
Date in 2008
09/10 09/11 09/12 09/13 09/14 09/15 09/16
0 1 2 3 4 5 6

Ike significant wave height contours (m) and wind vectors (m/s)



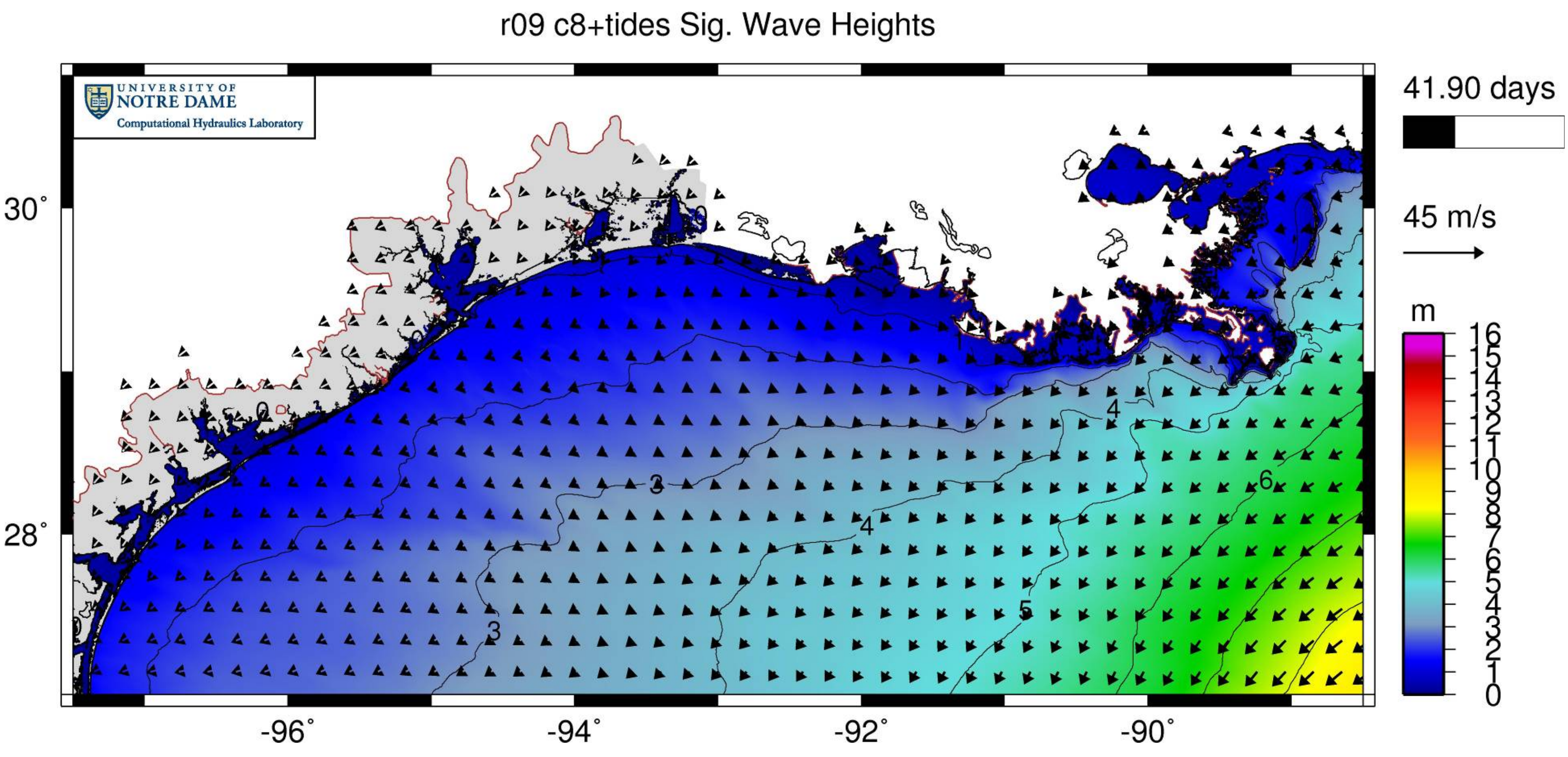
- 48 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



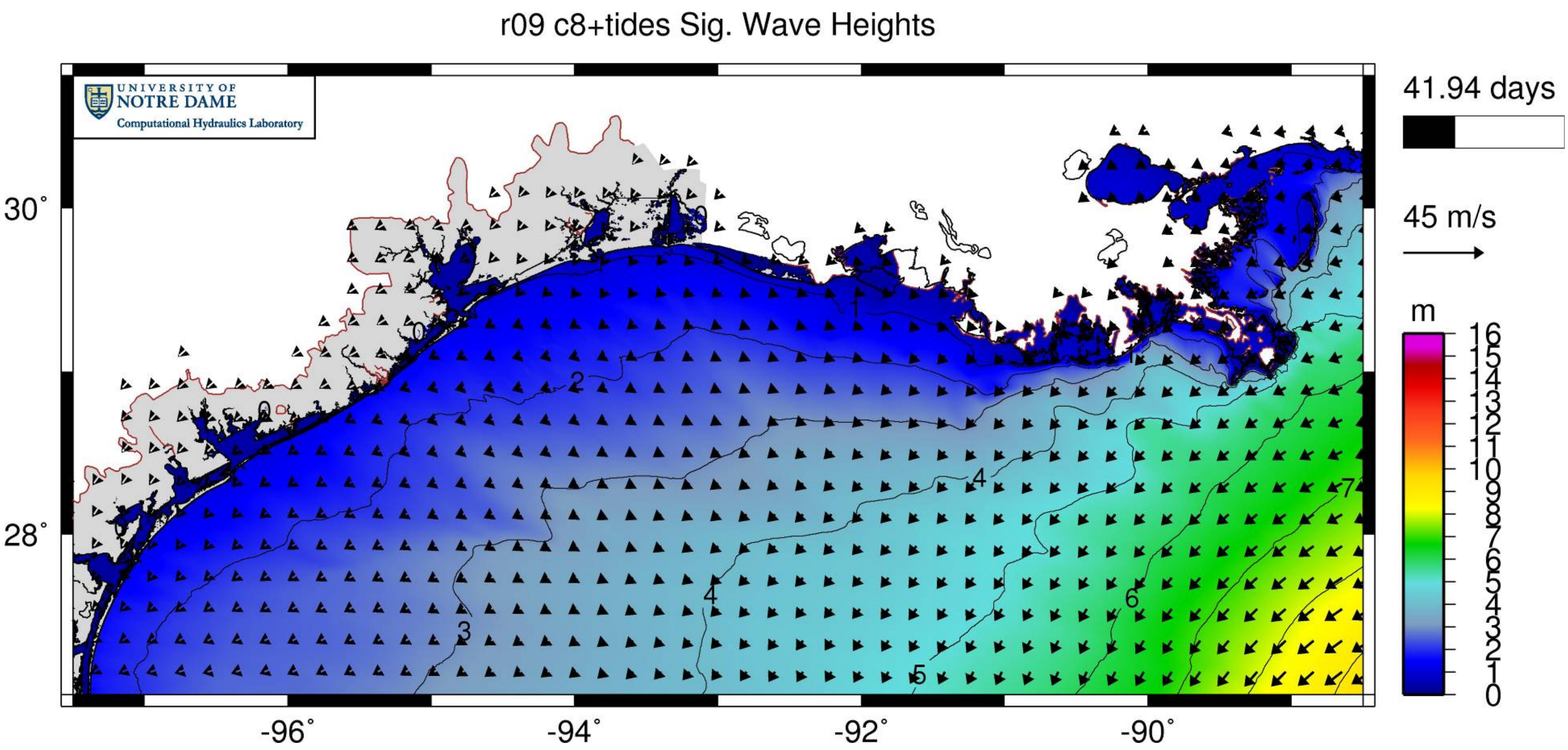
- 47 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



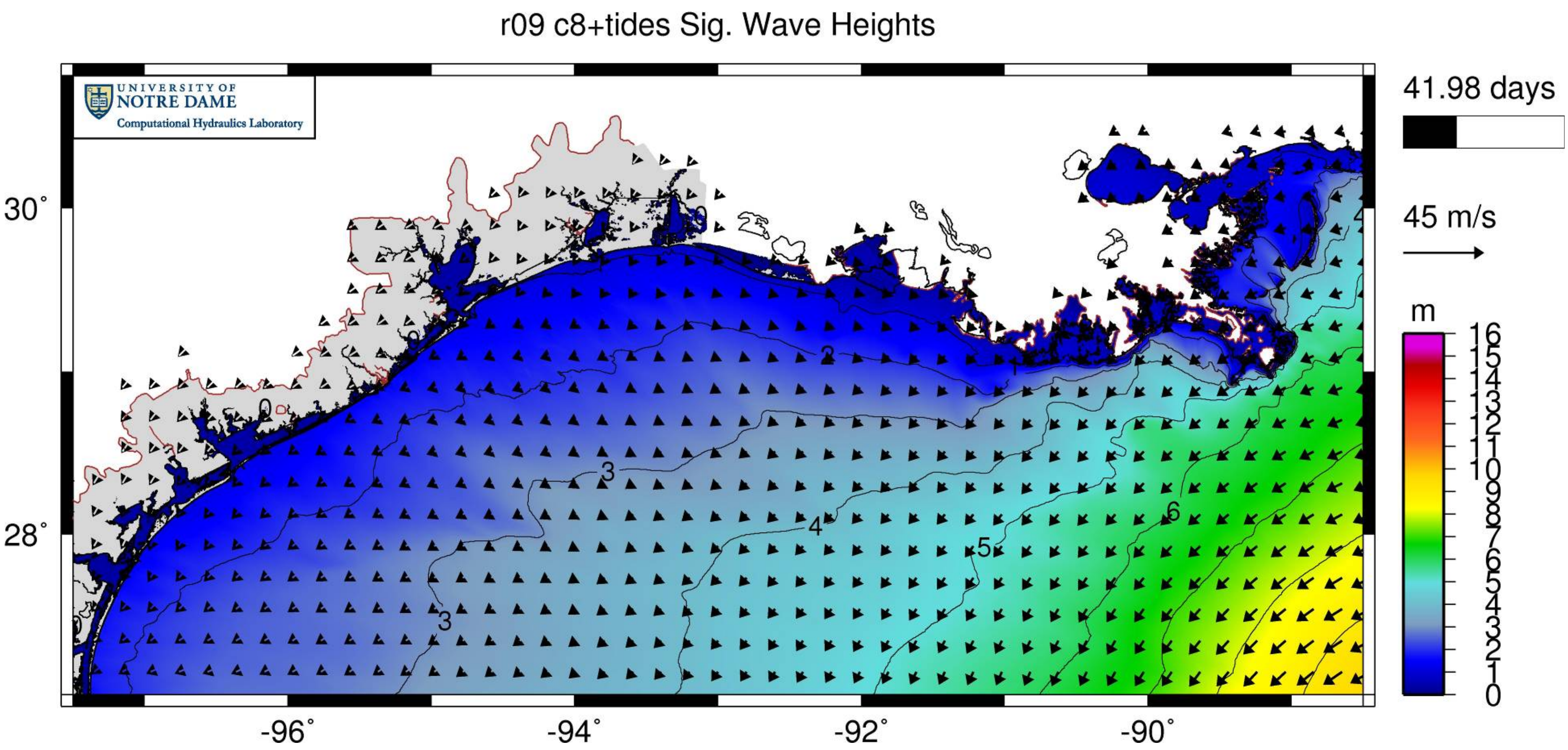
- 46 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



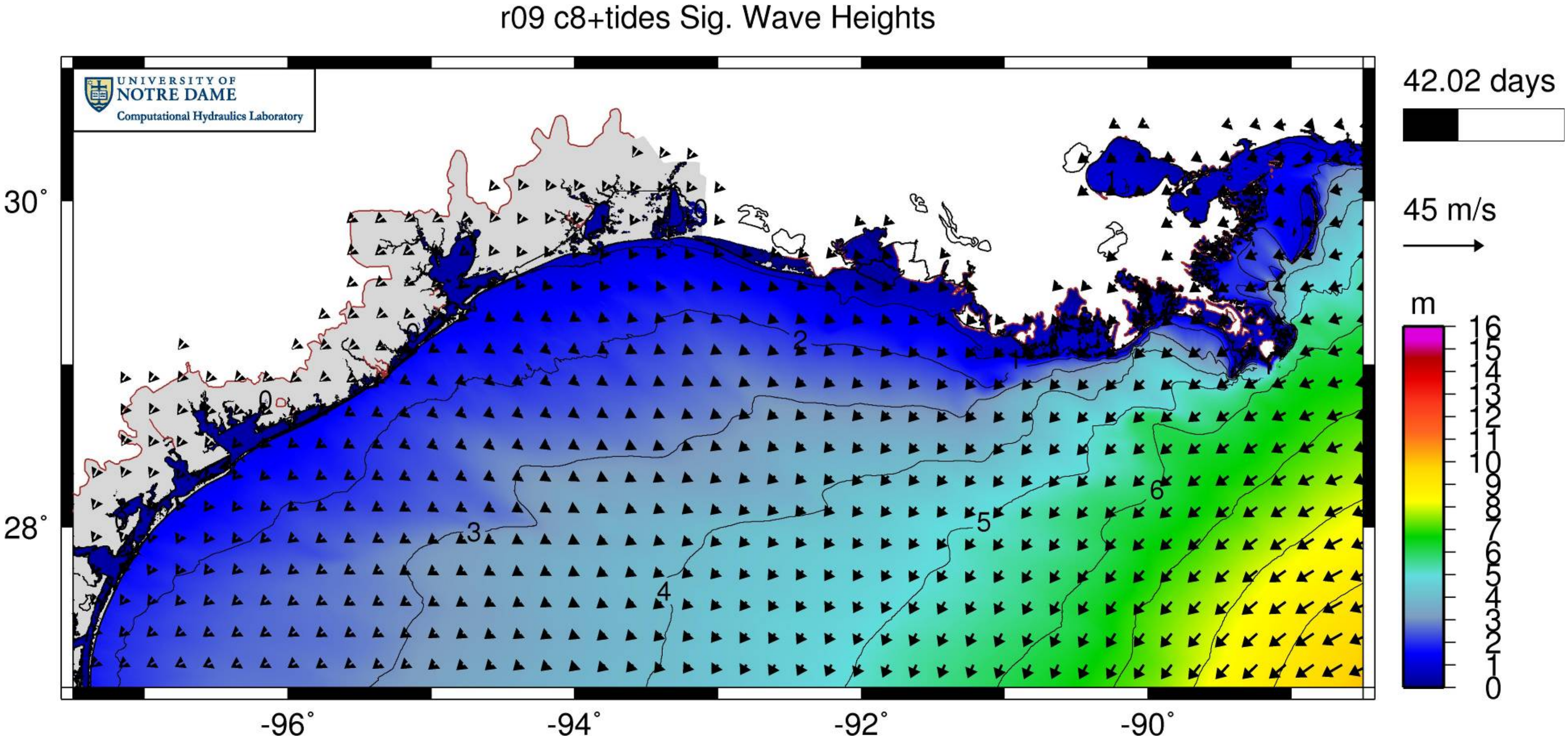
- 45 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



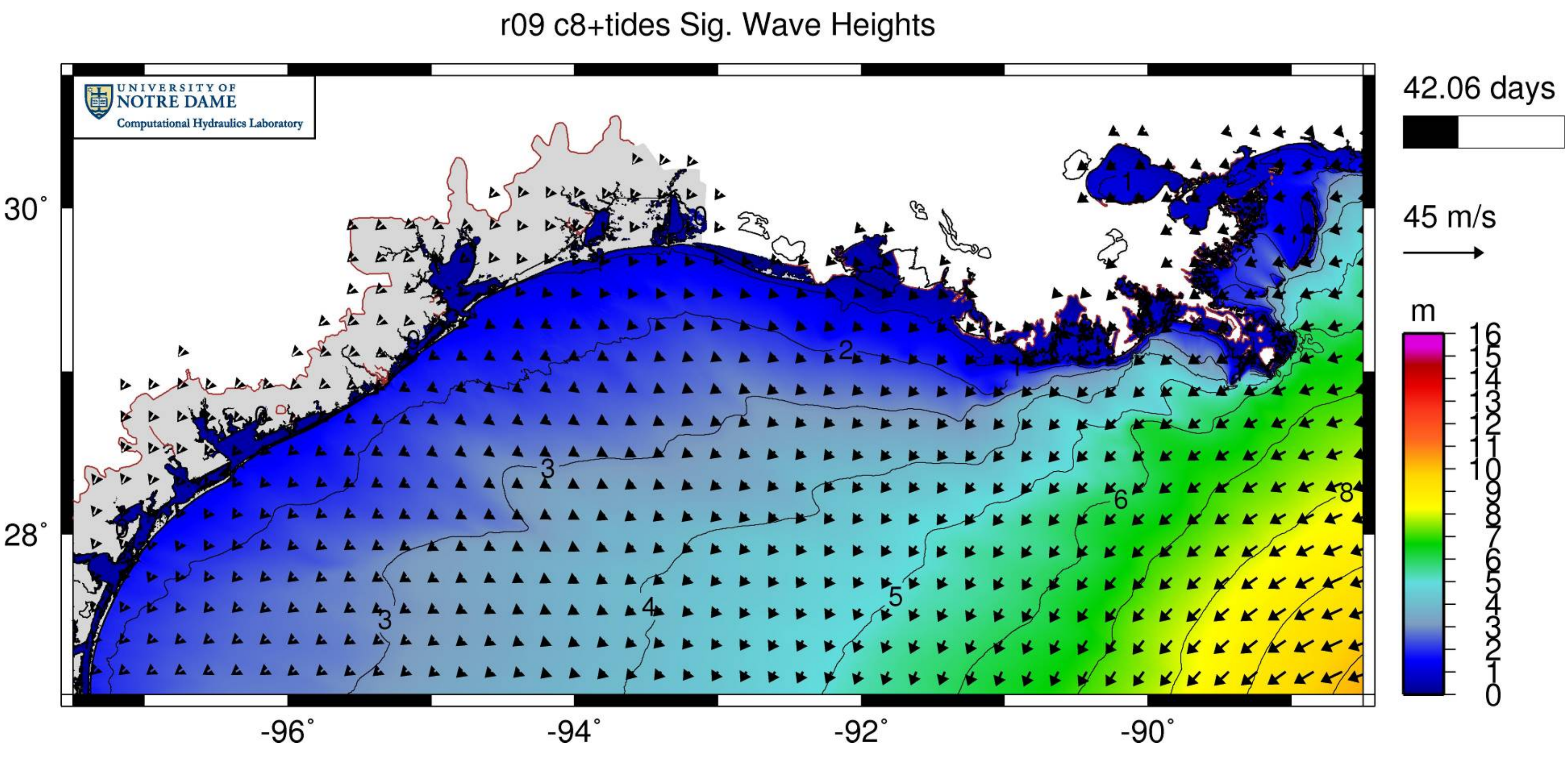
- 44 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



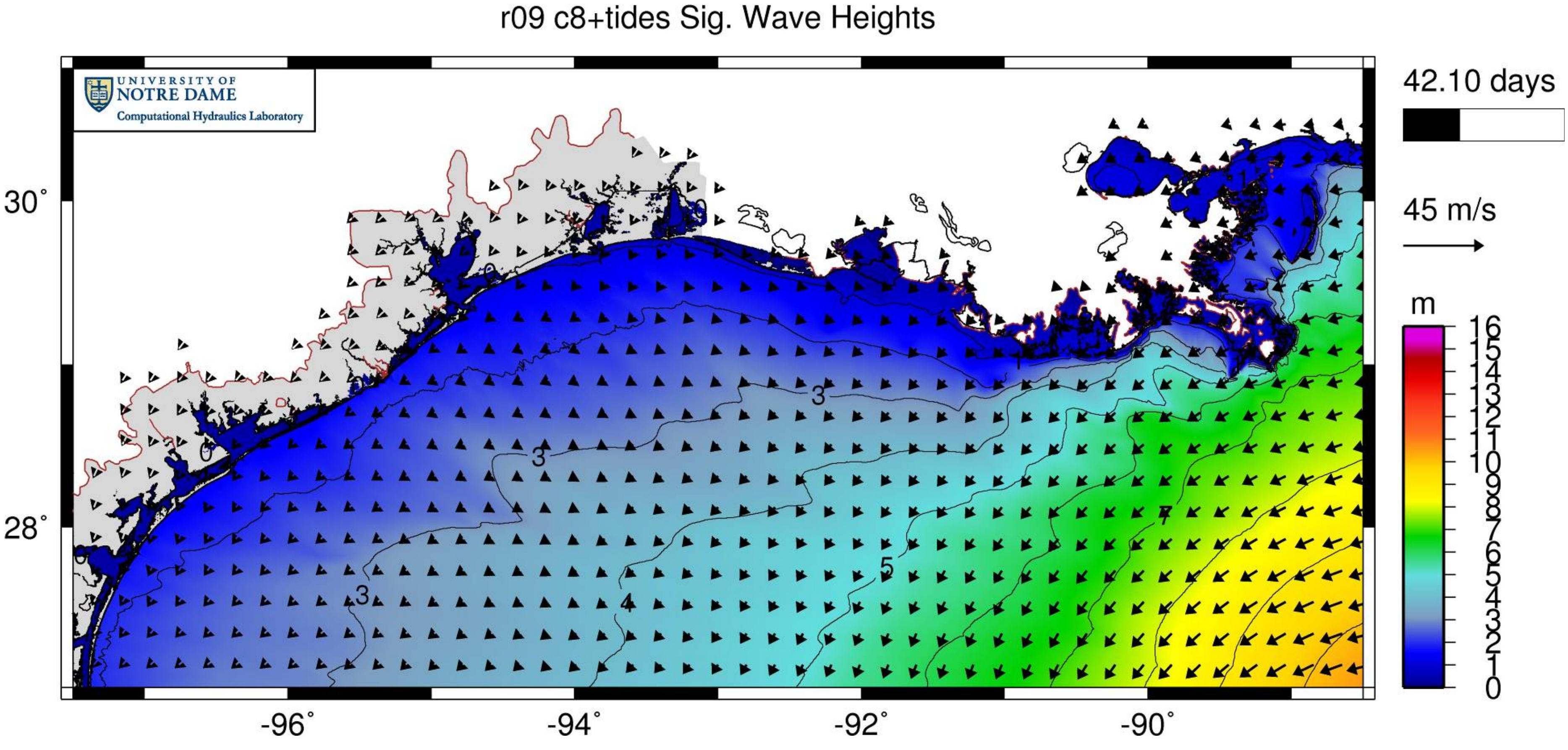
- 42 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



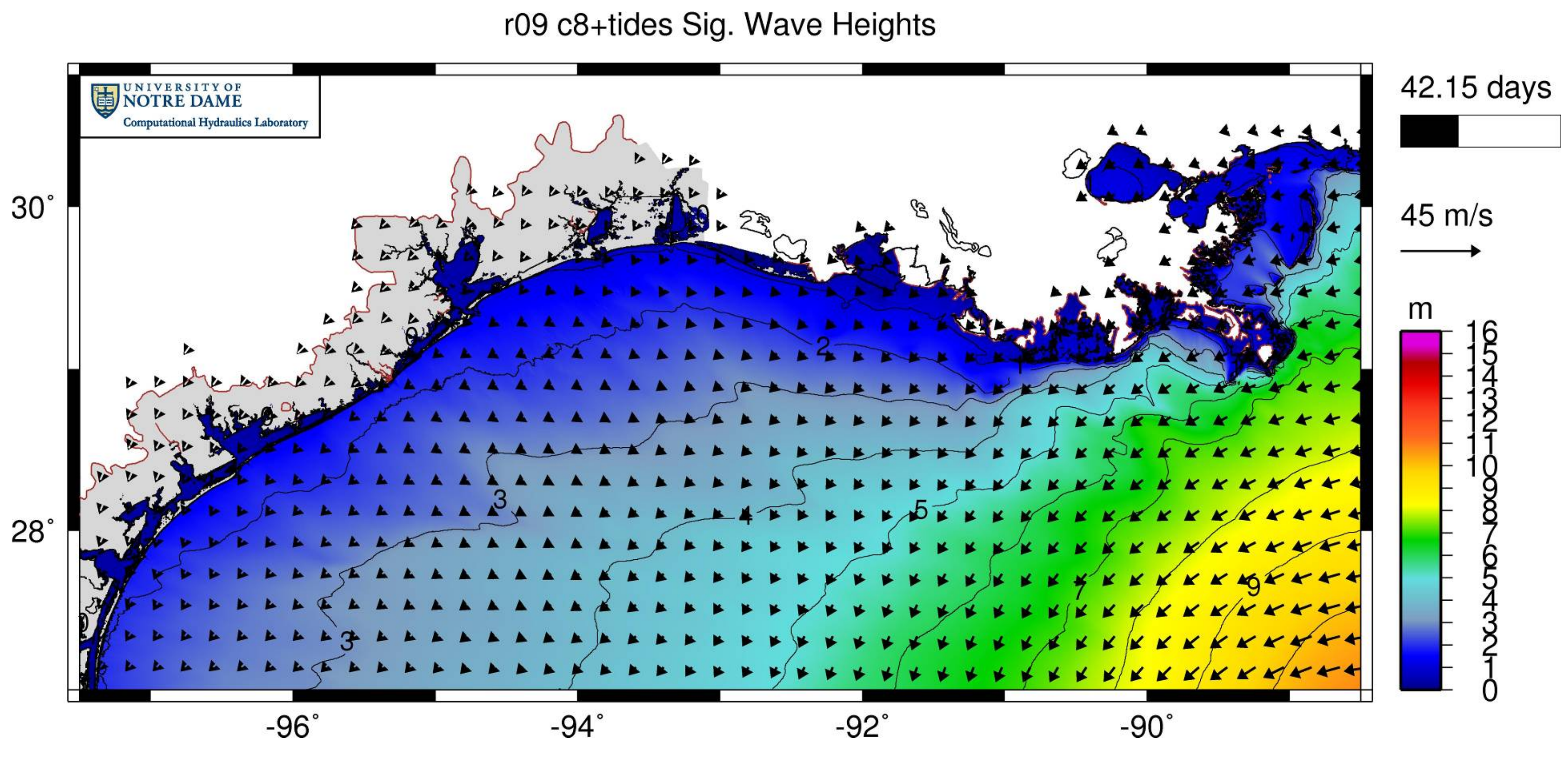
- 41 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



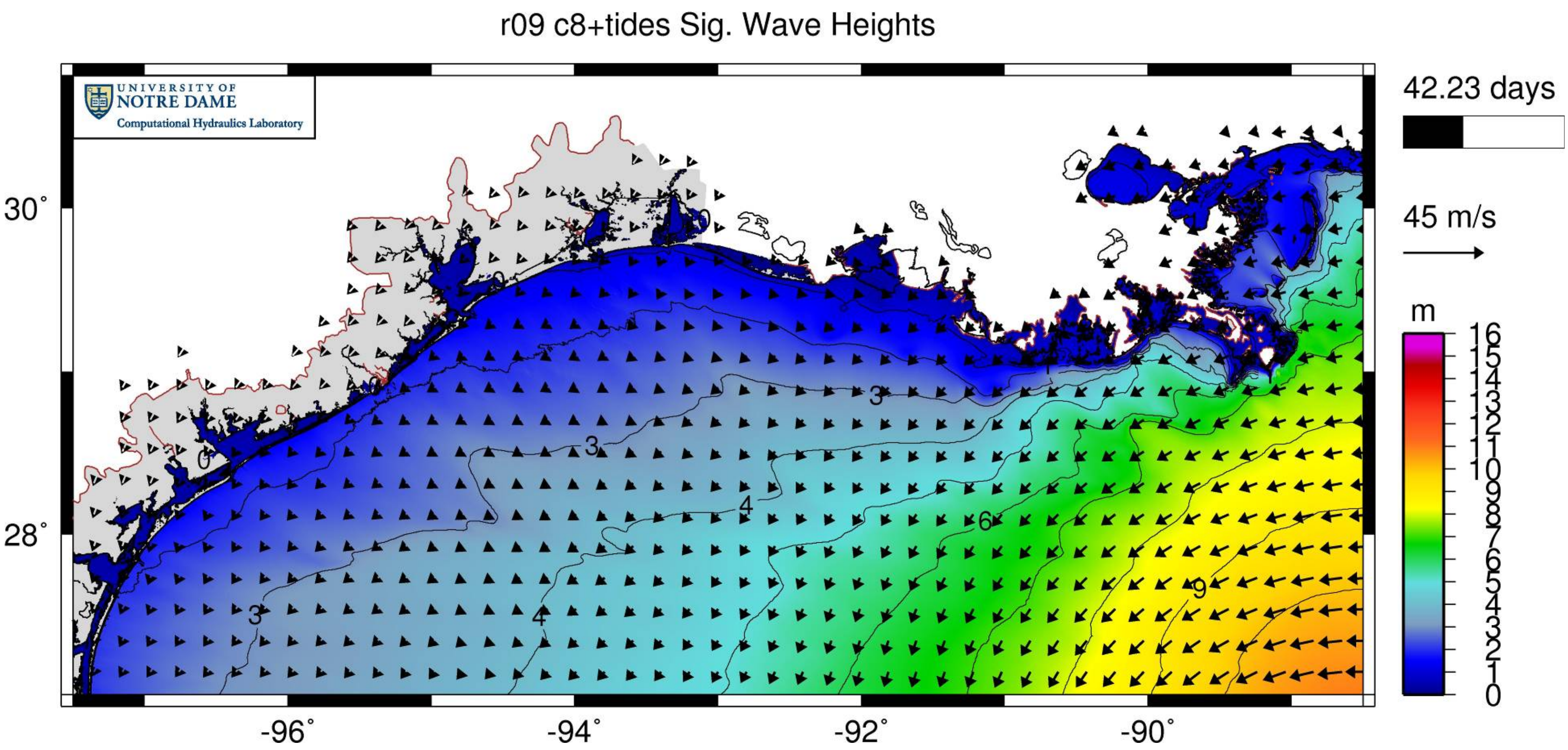
- 40 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



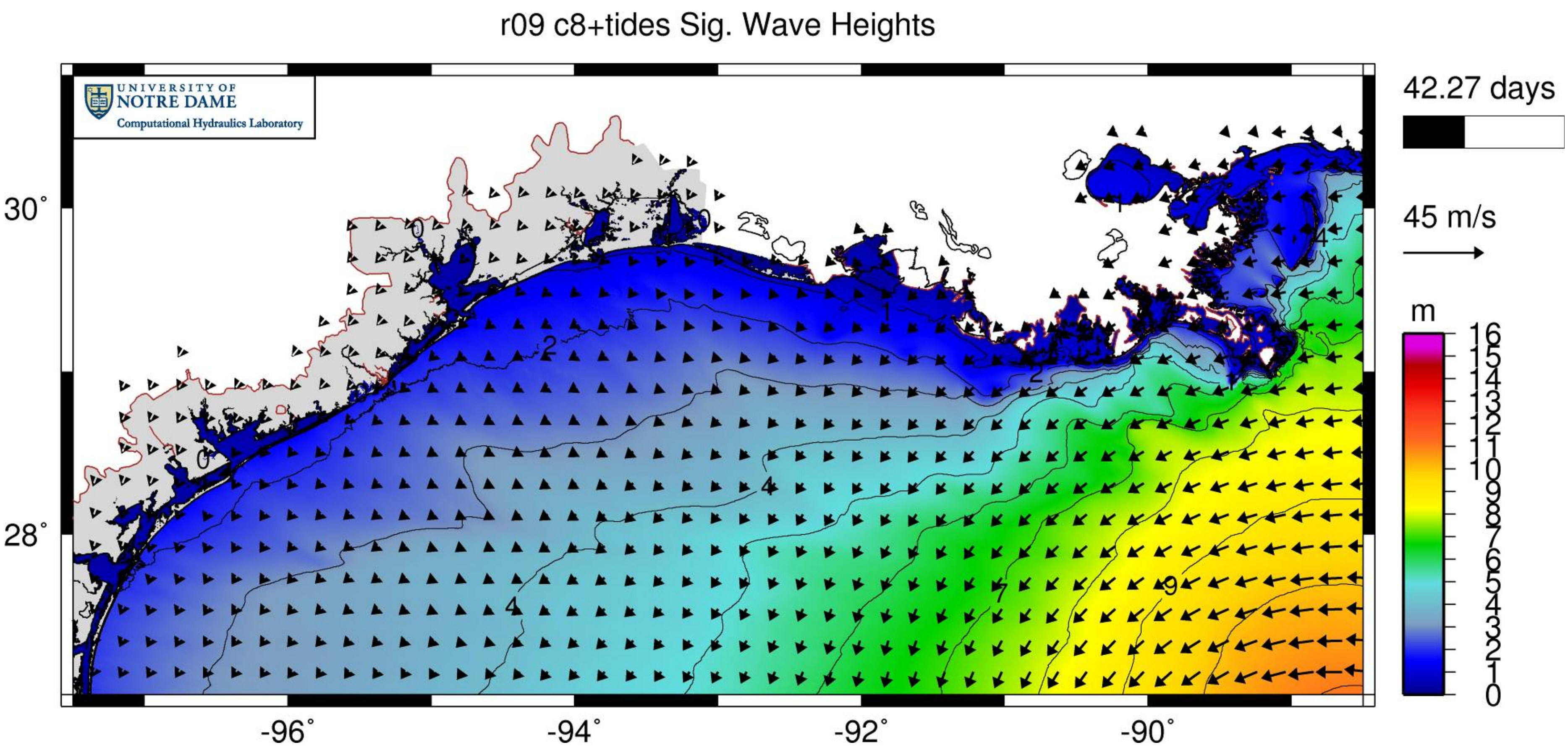
- 39 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



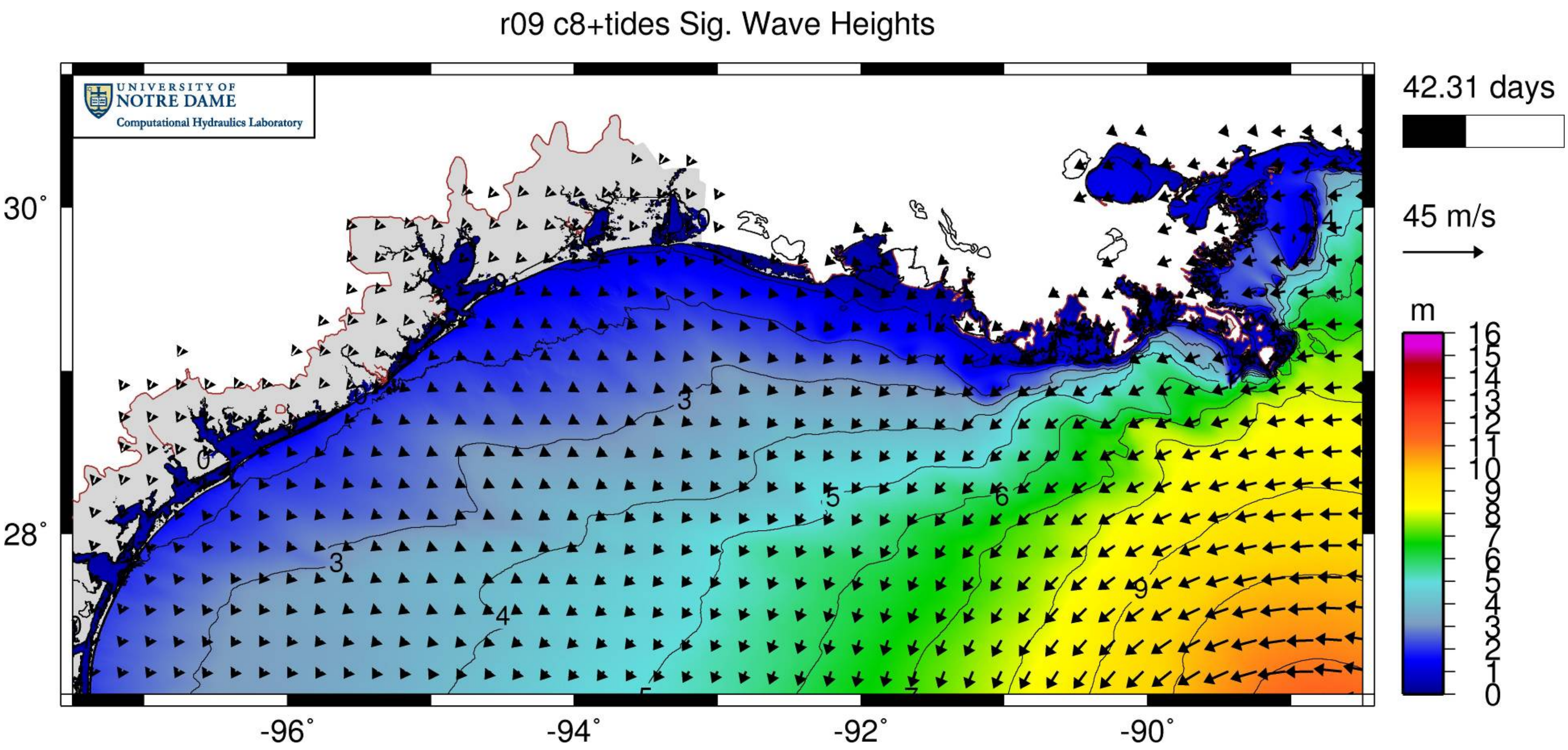
- 38 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



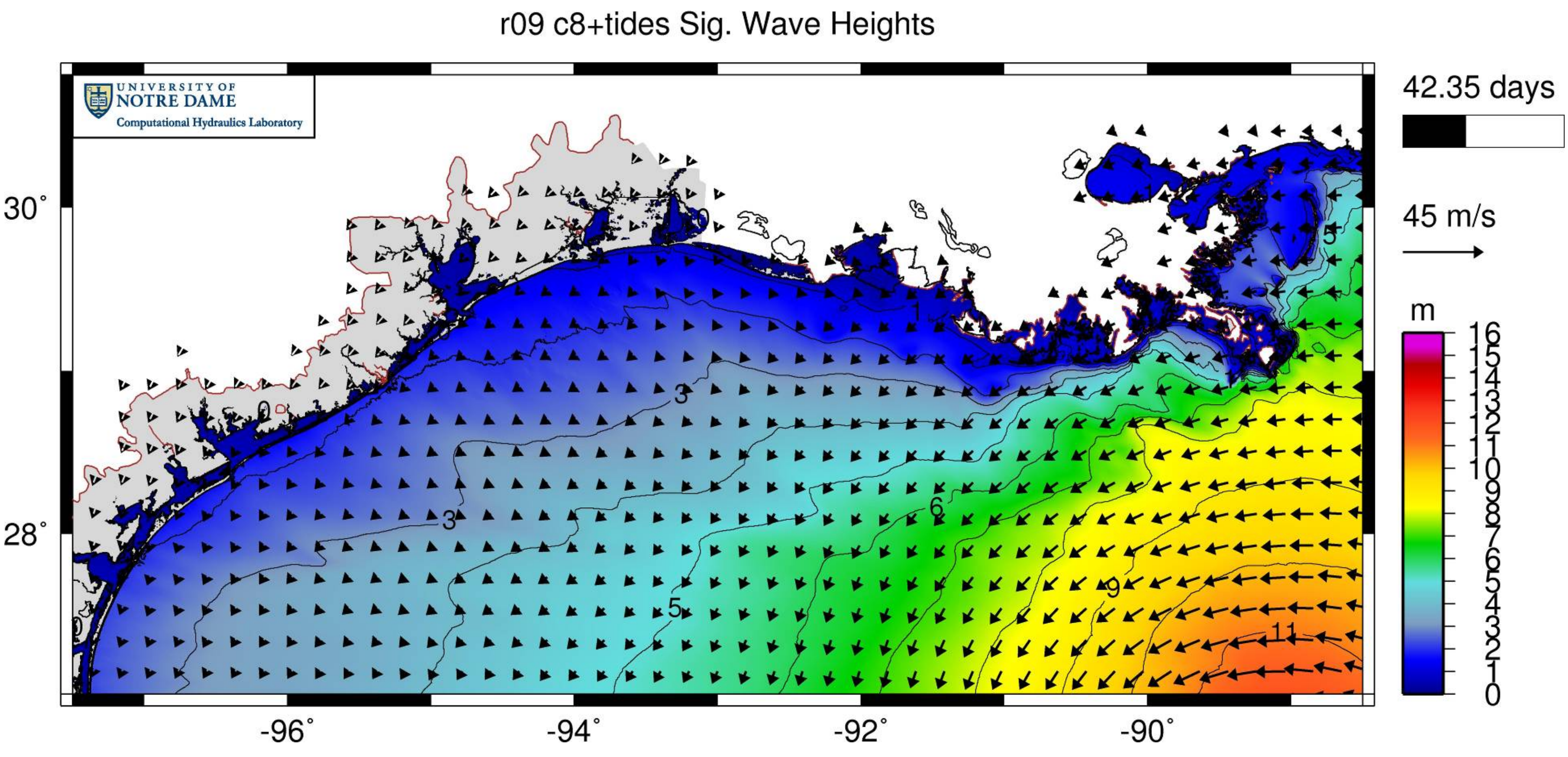
- 37 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



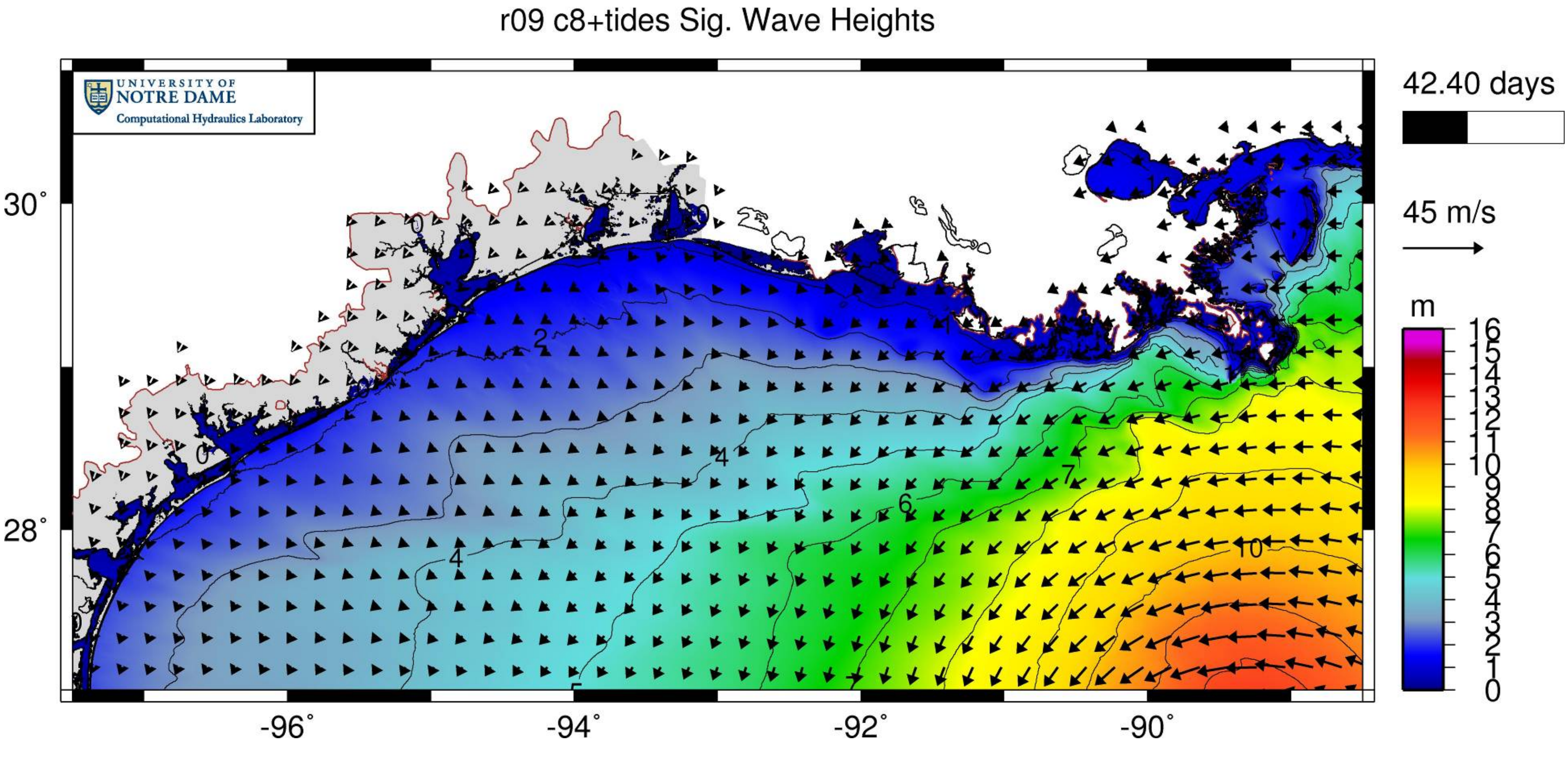
- 36 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



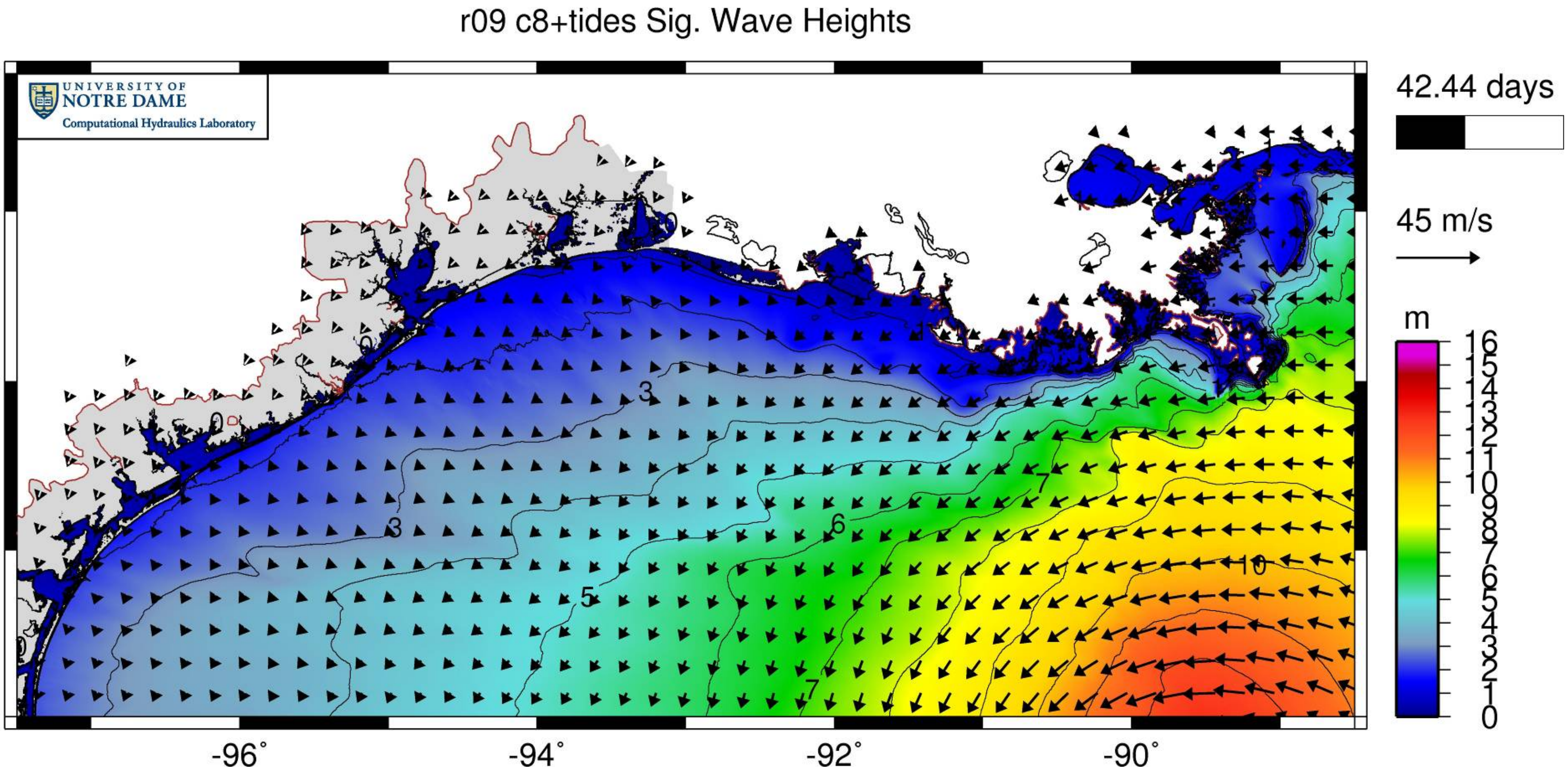
- 35 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



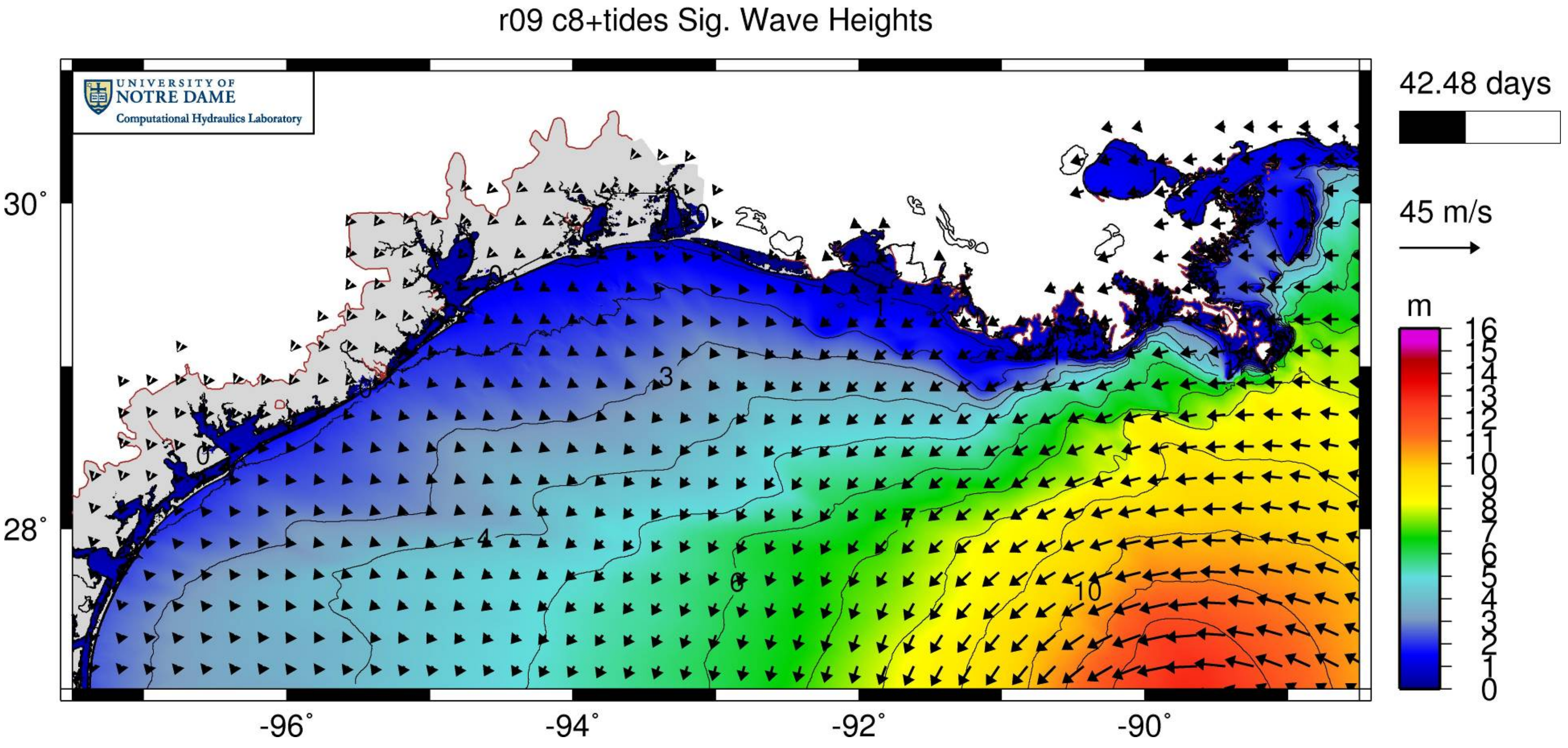
- 34 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



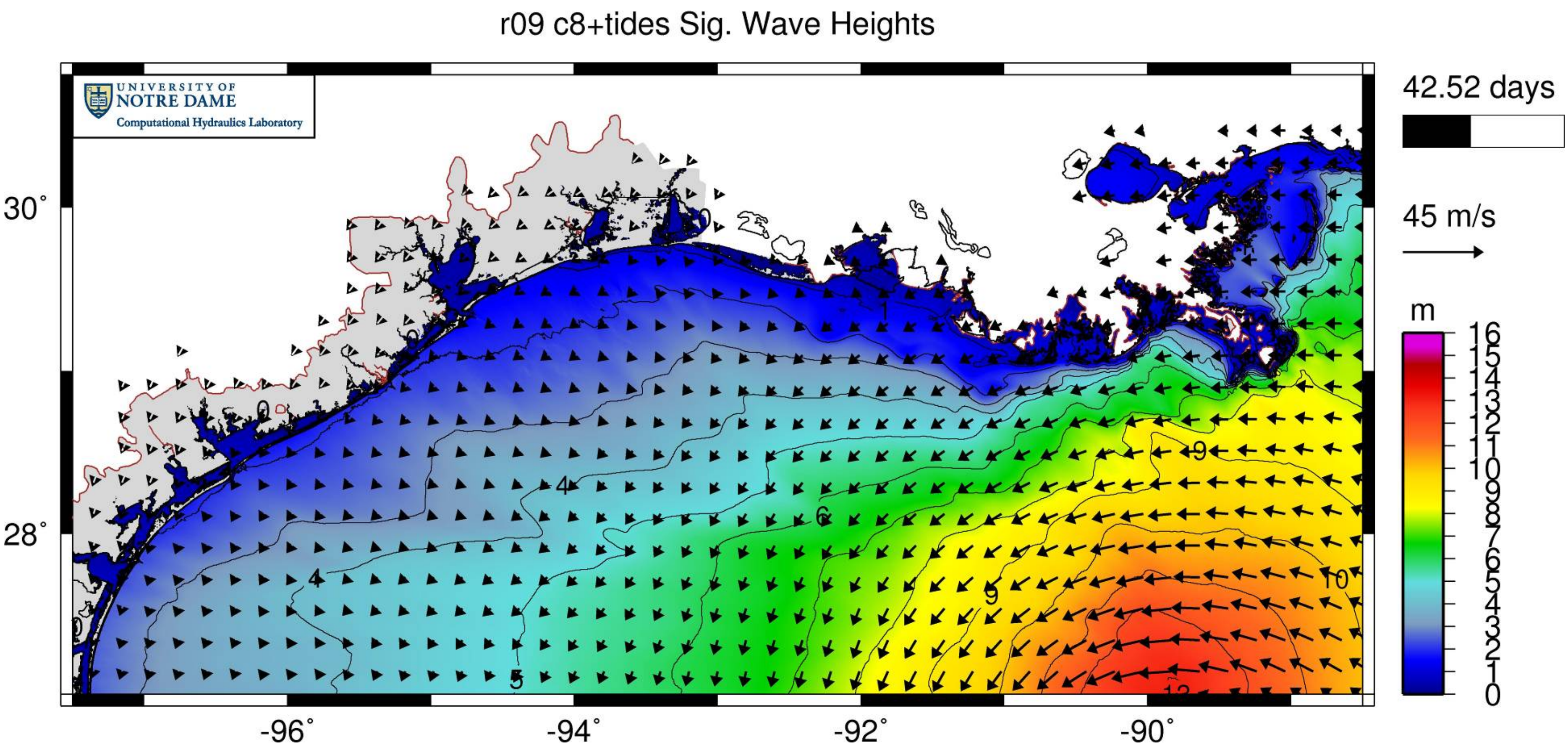
- 33 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



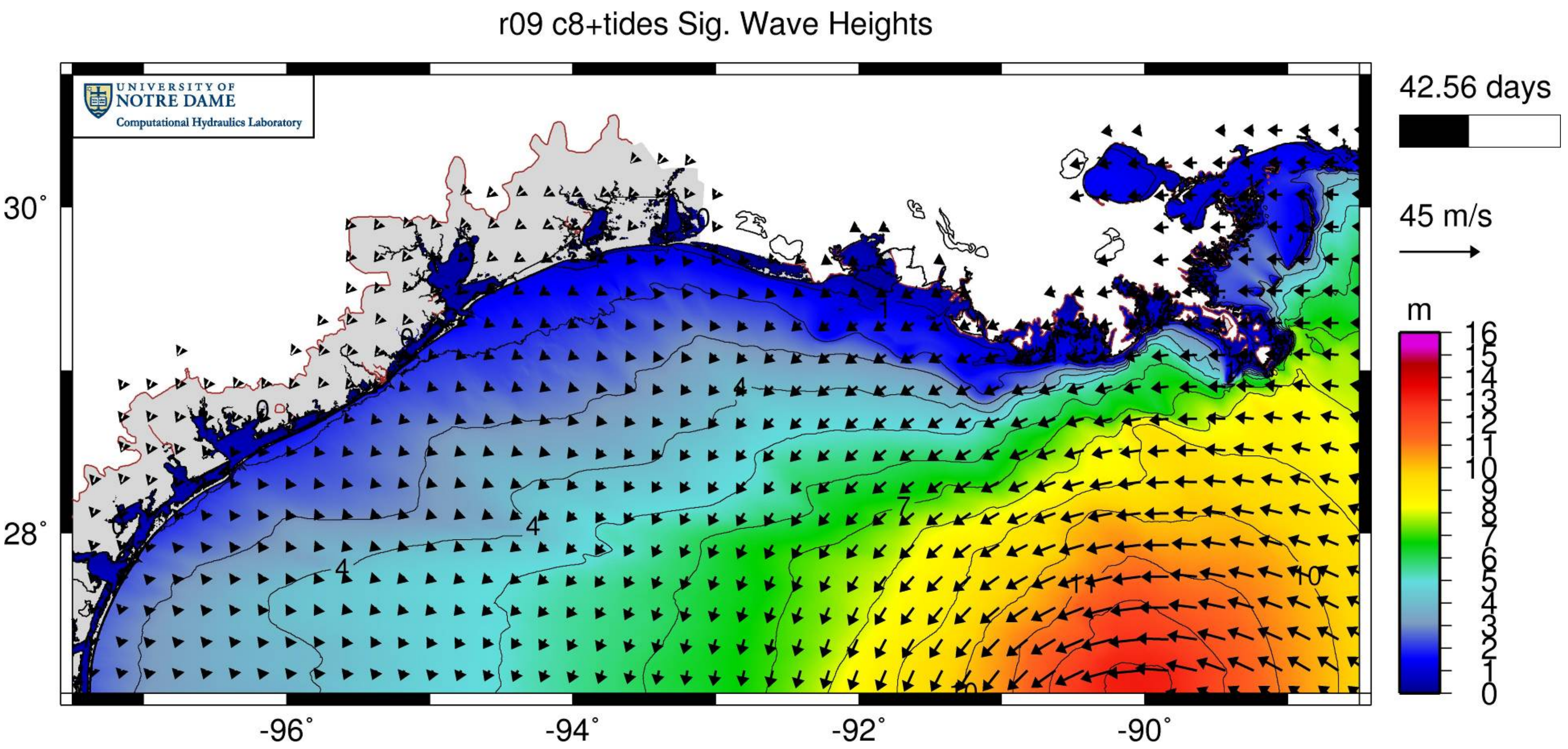
- 32 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



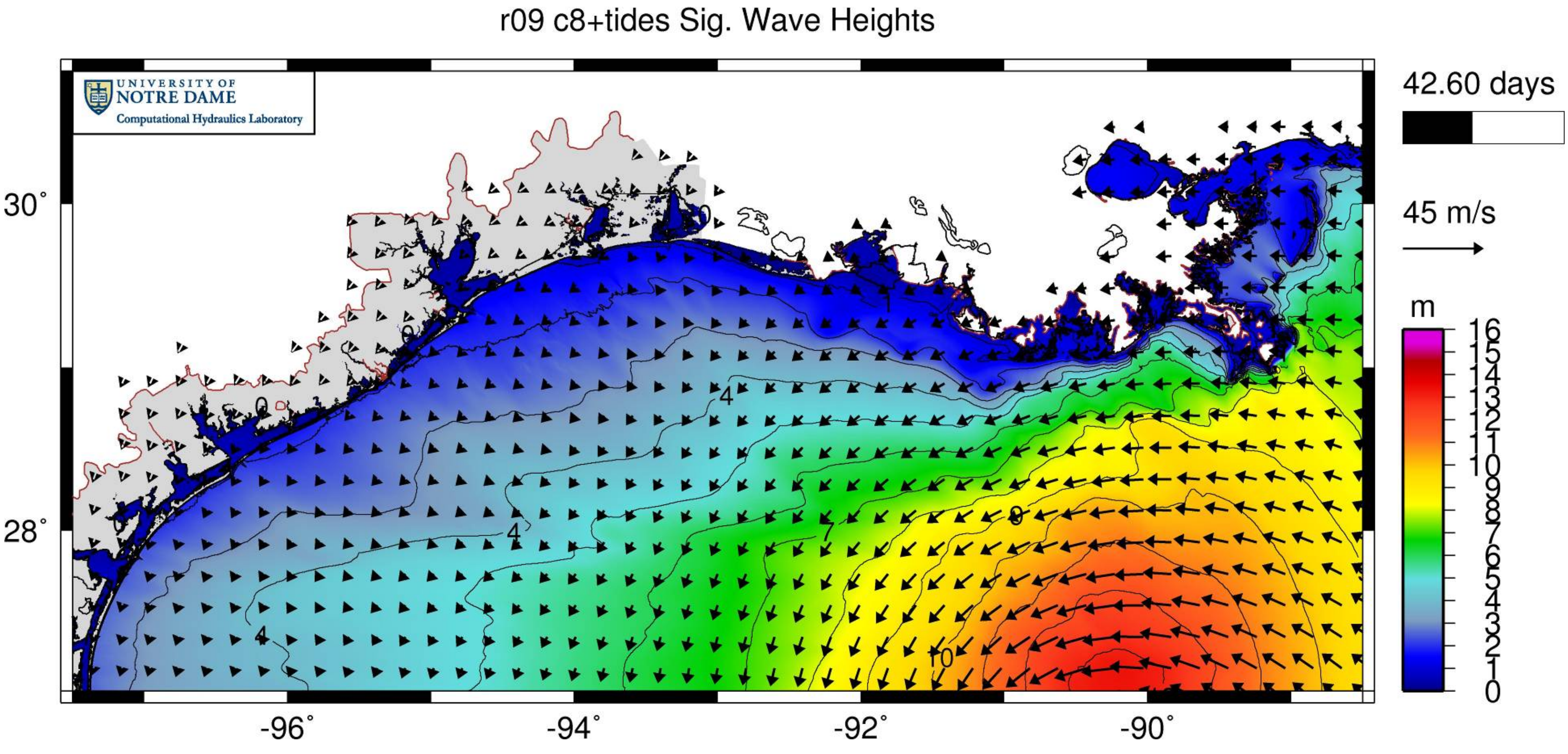
- 31 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



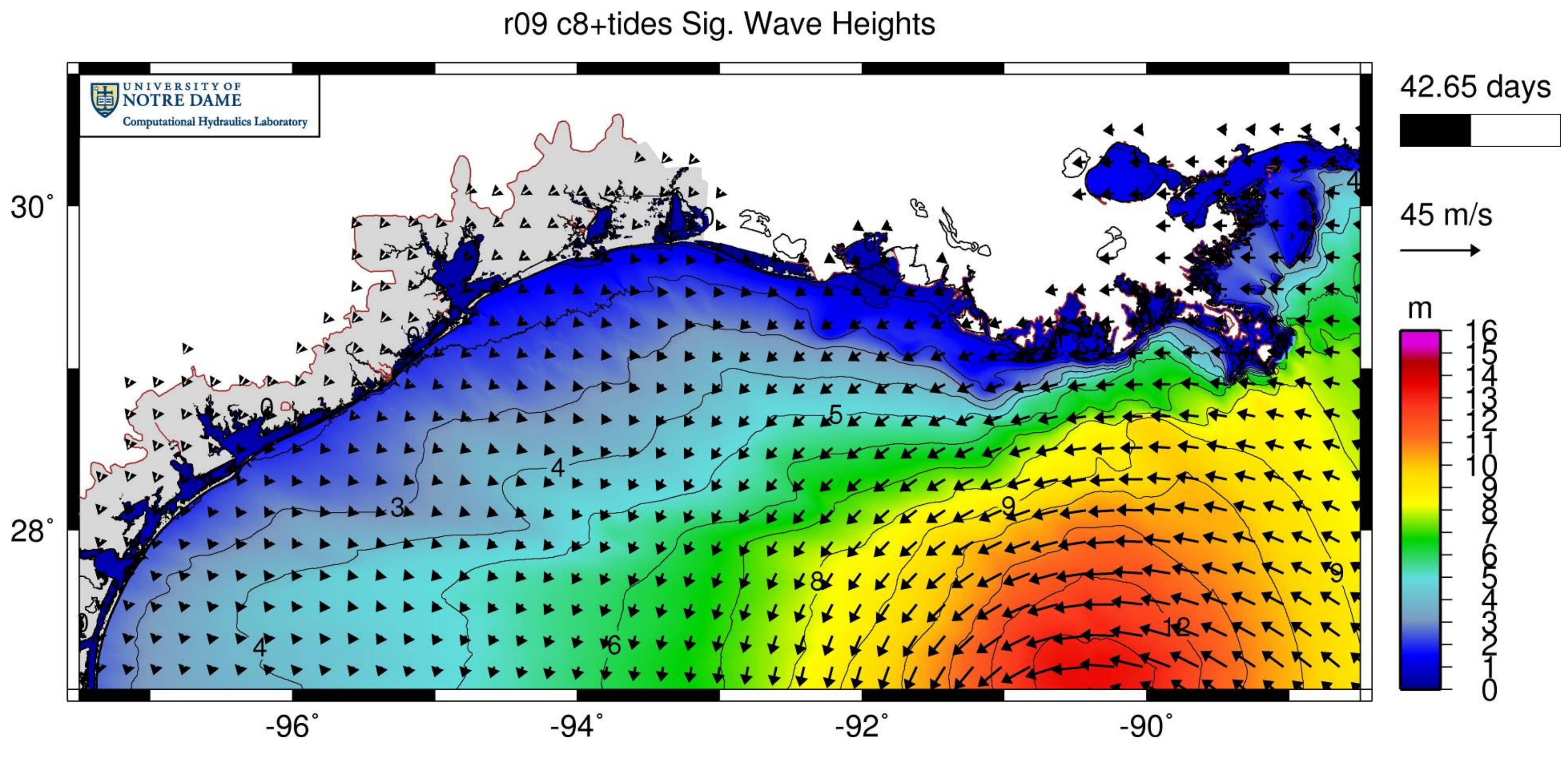
- 30 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



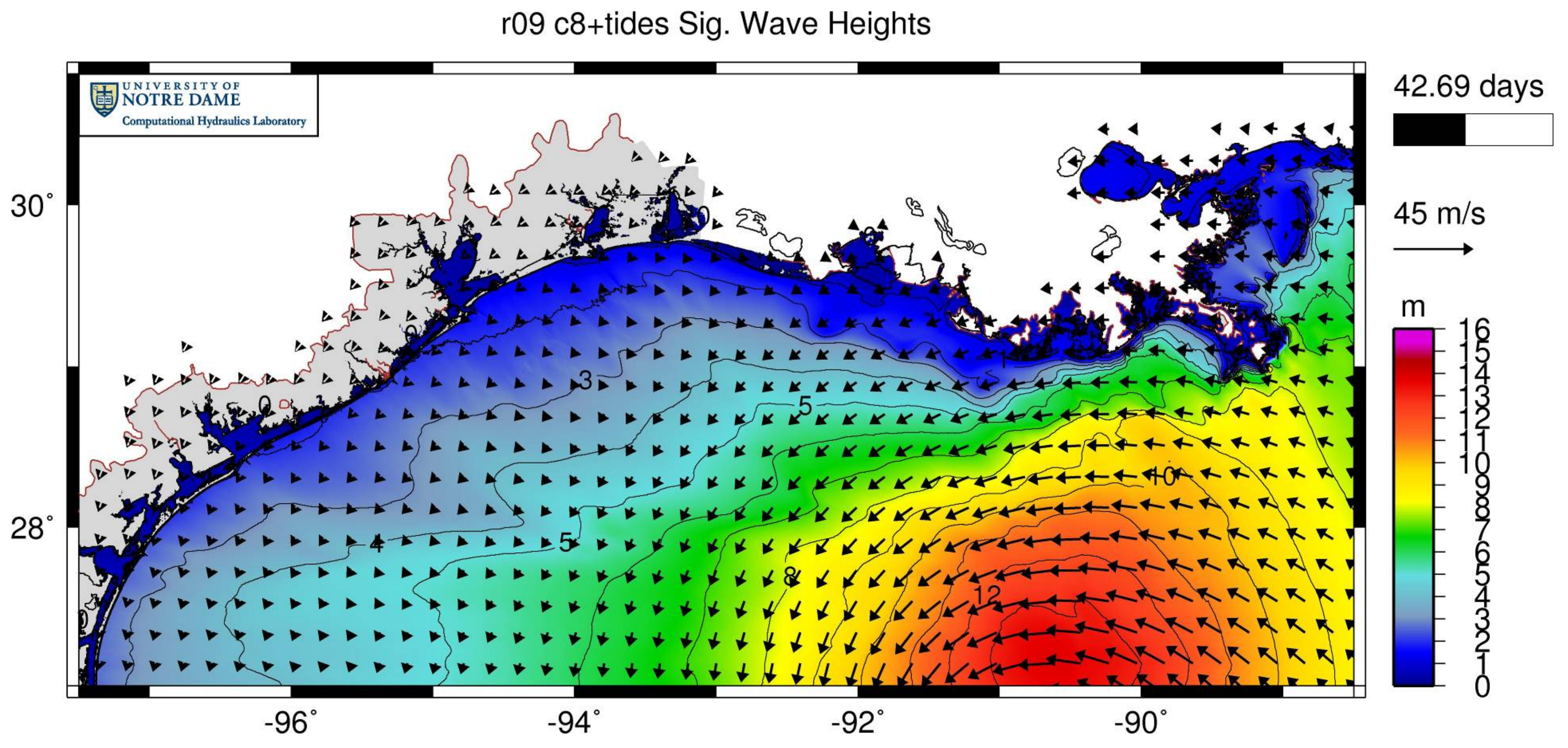
- 29 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



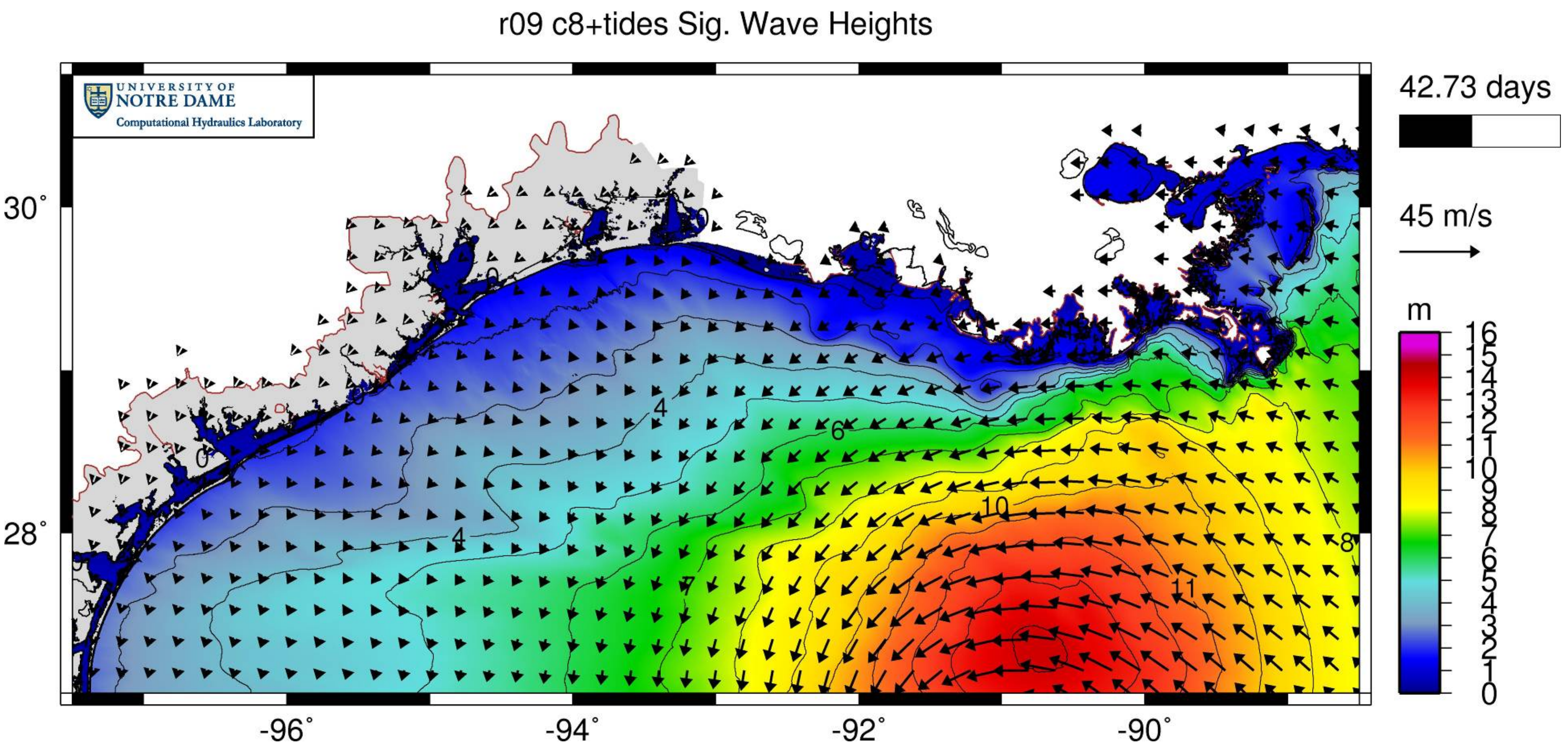
- 28 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



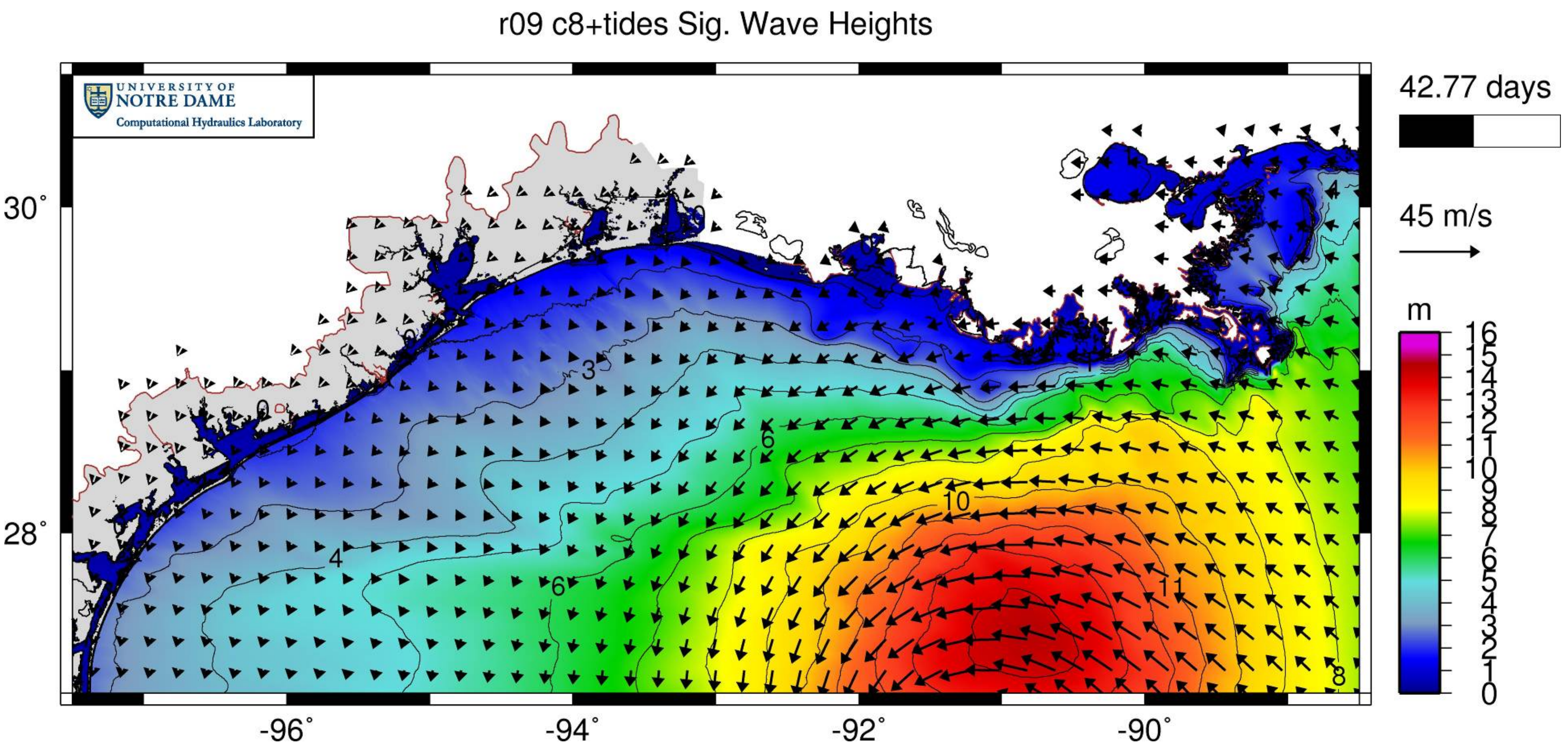
- 27 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



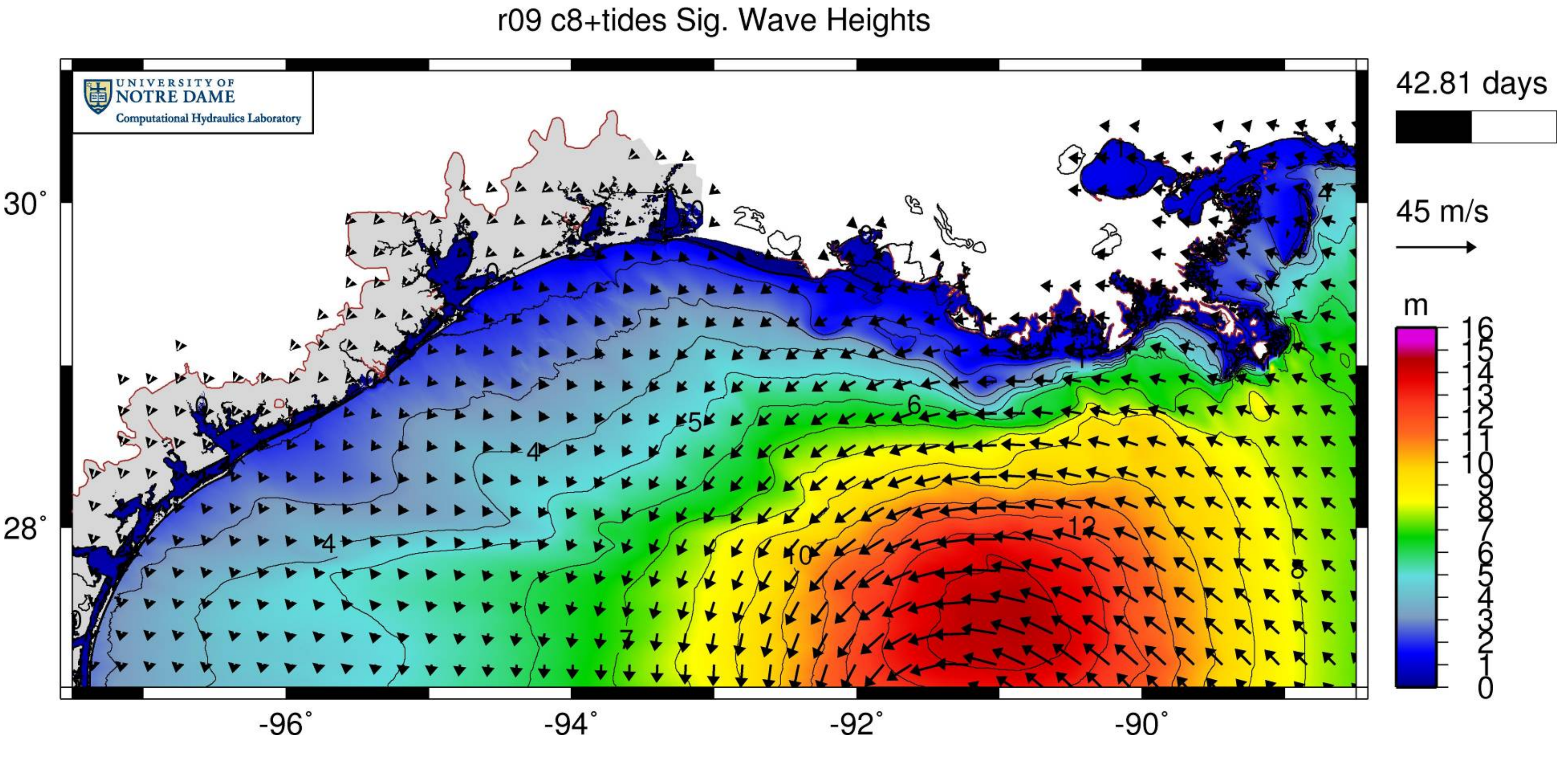
- 26 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



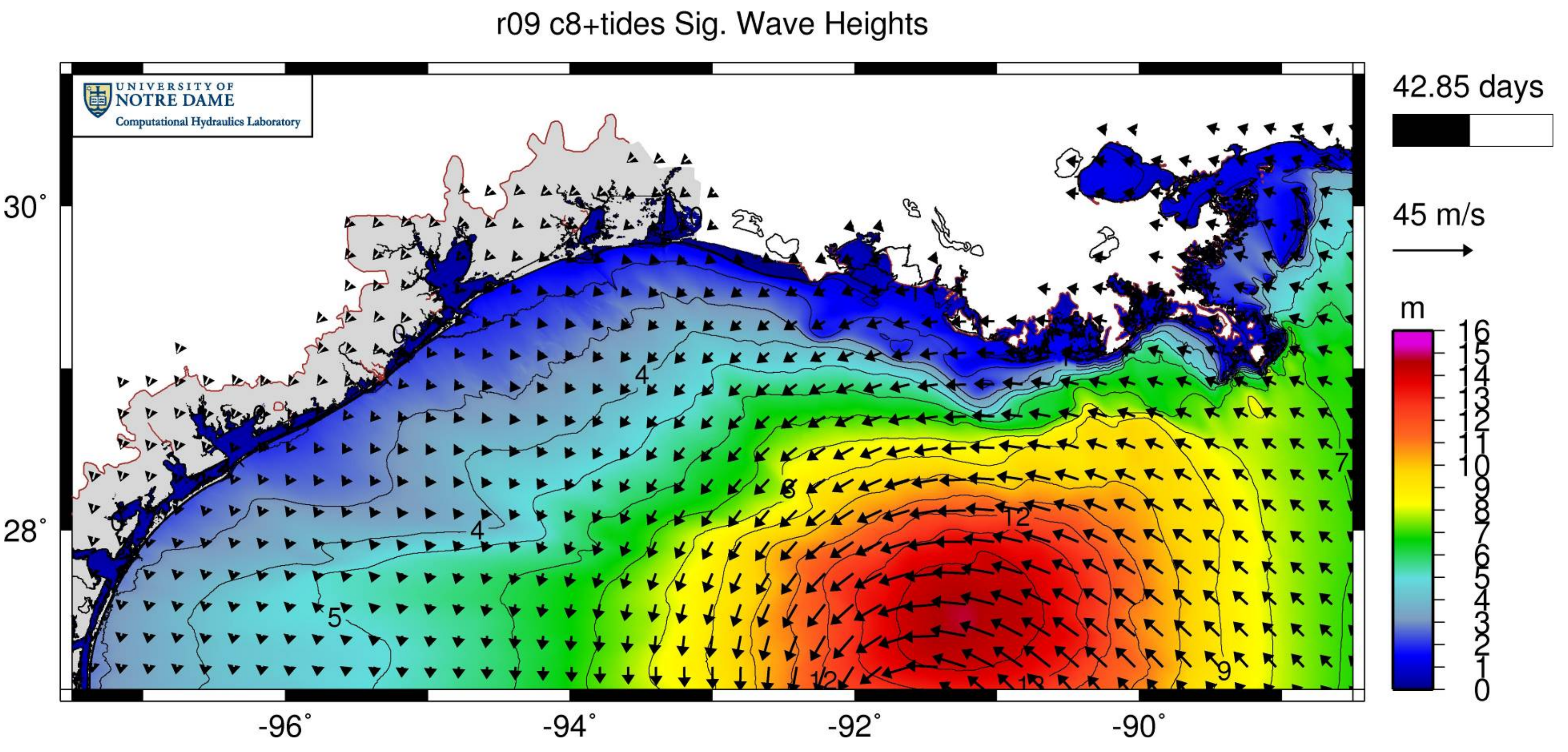
- 25 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



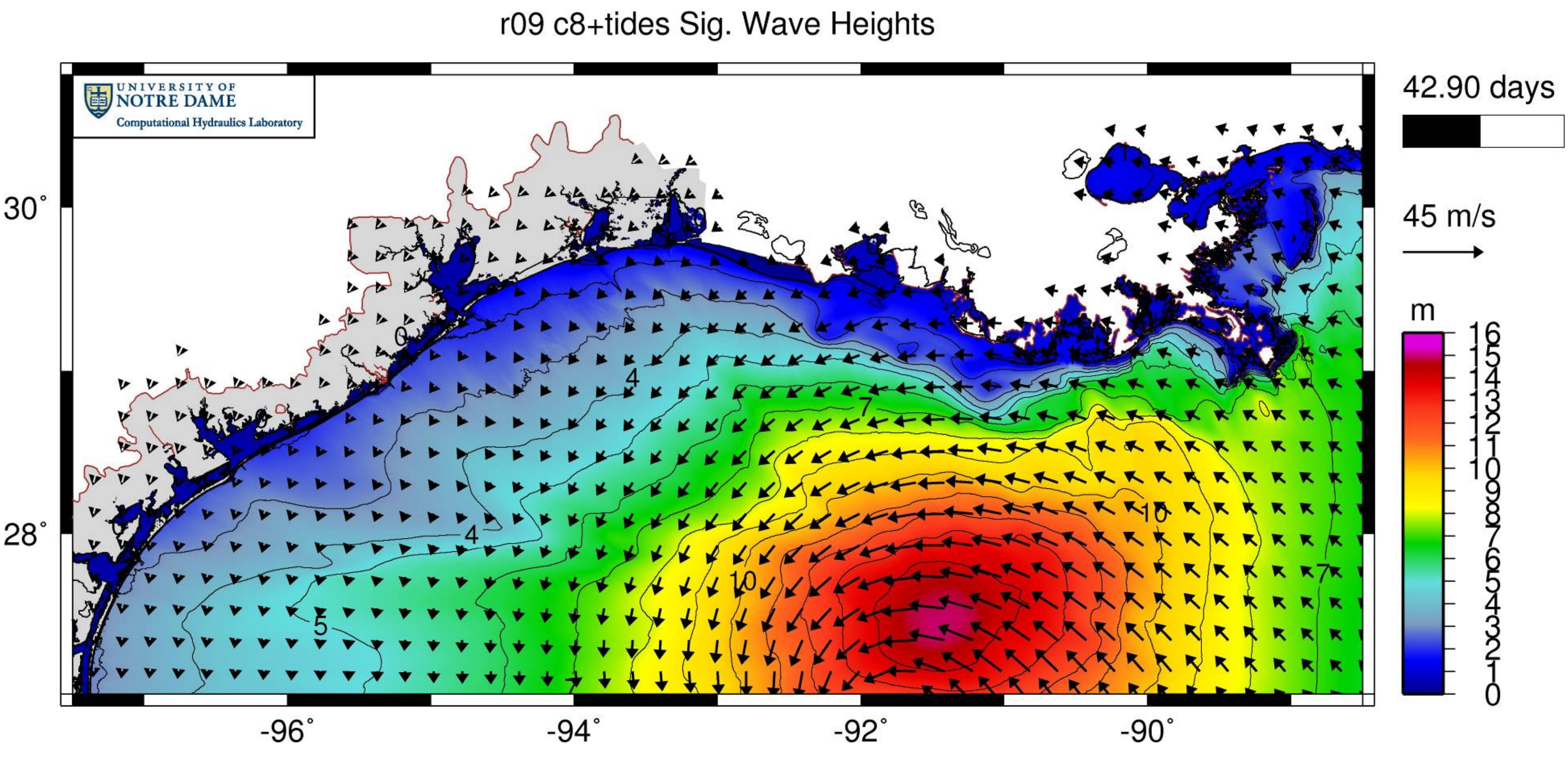
- 24 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



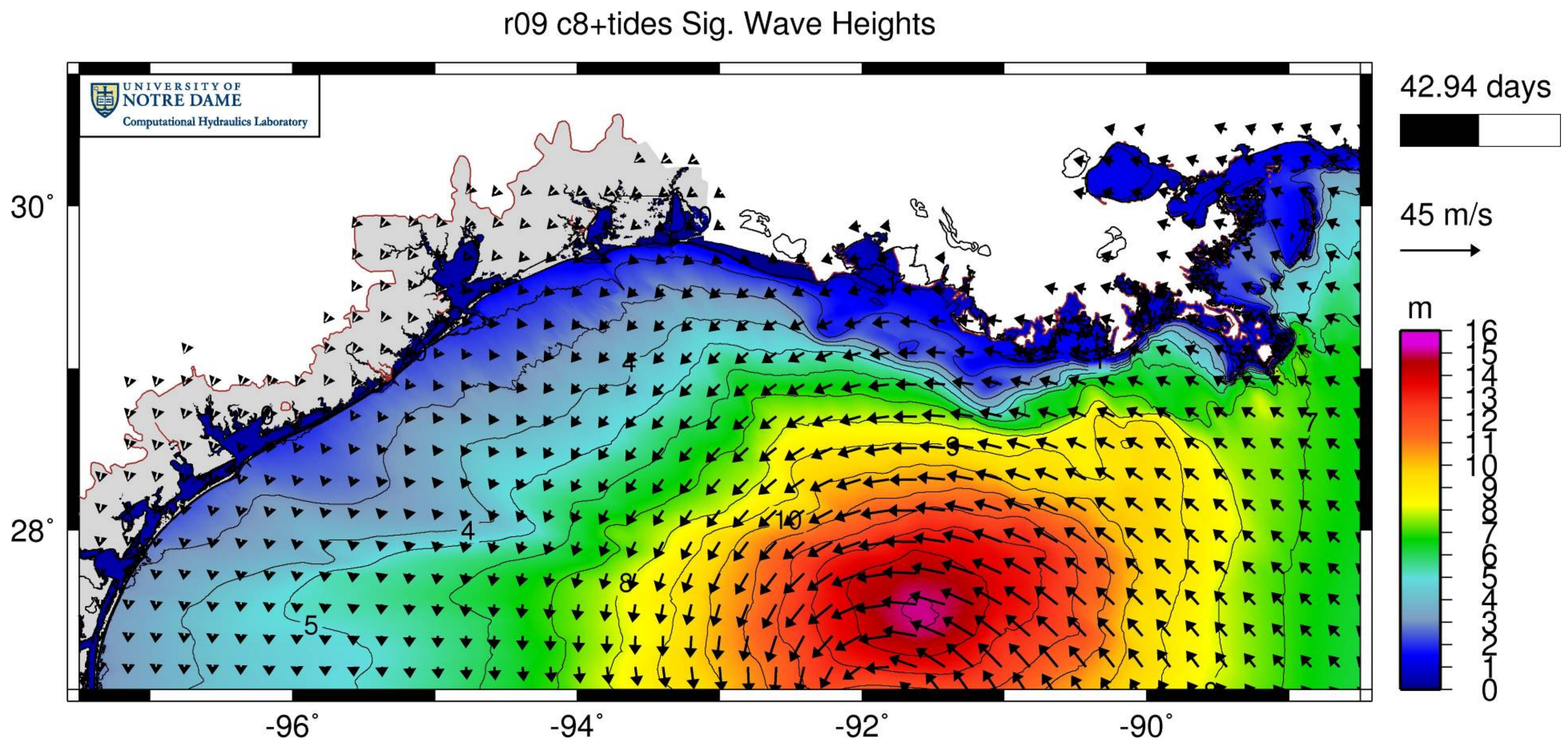
- 23 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



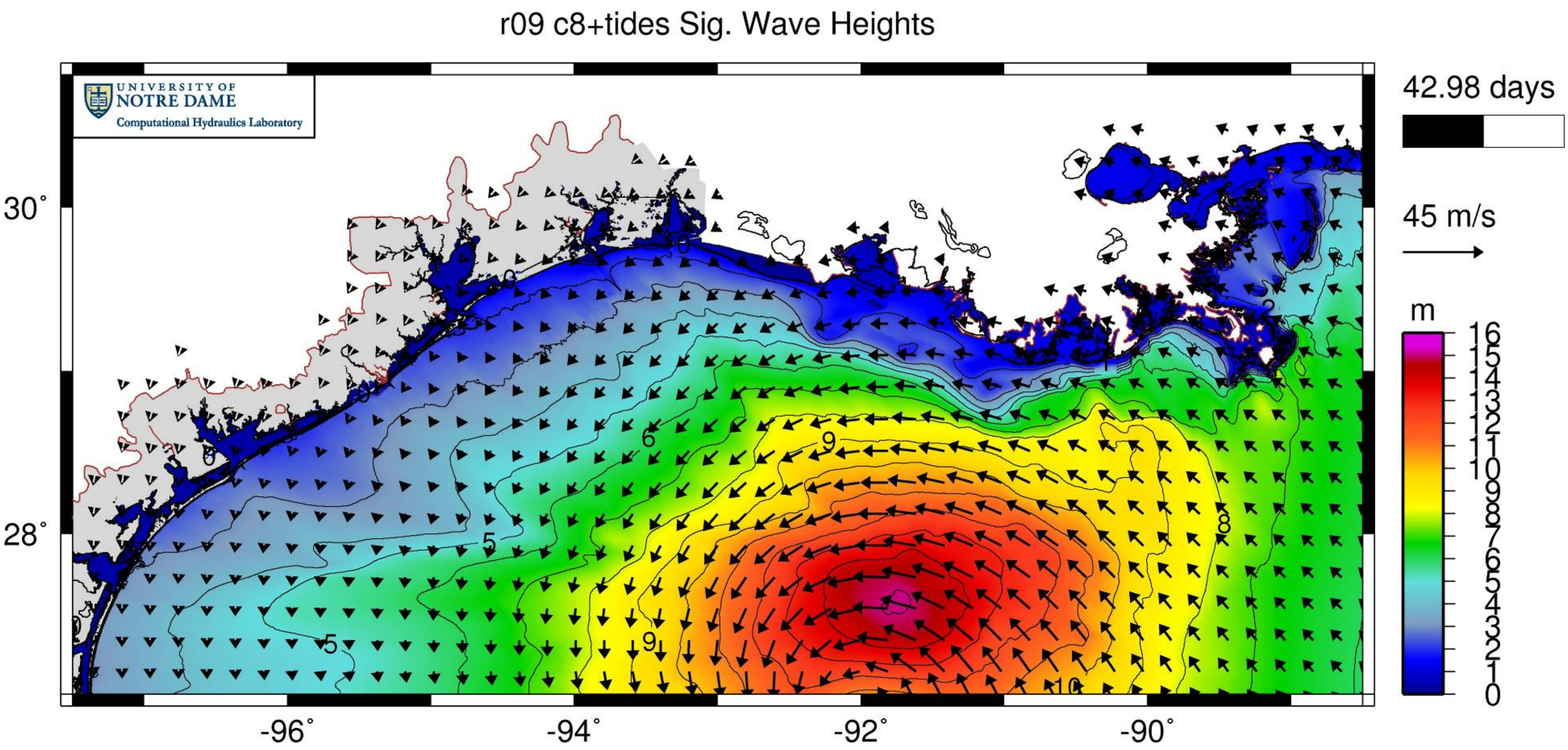
- 22 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



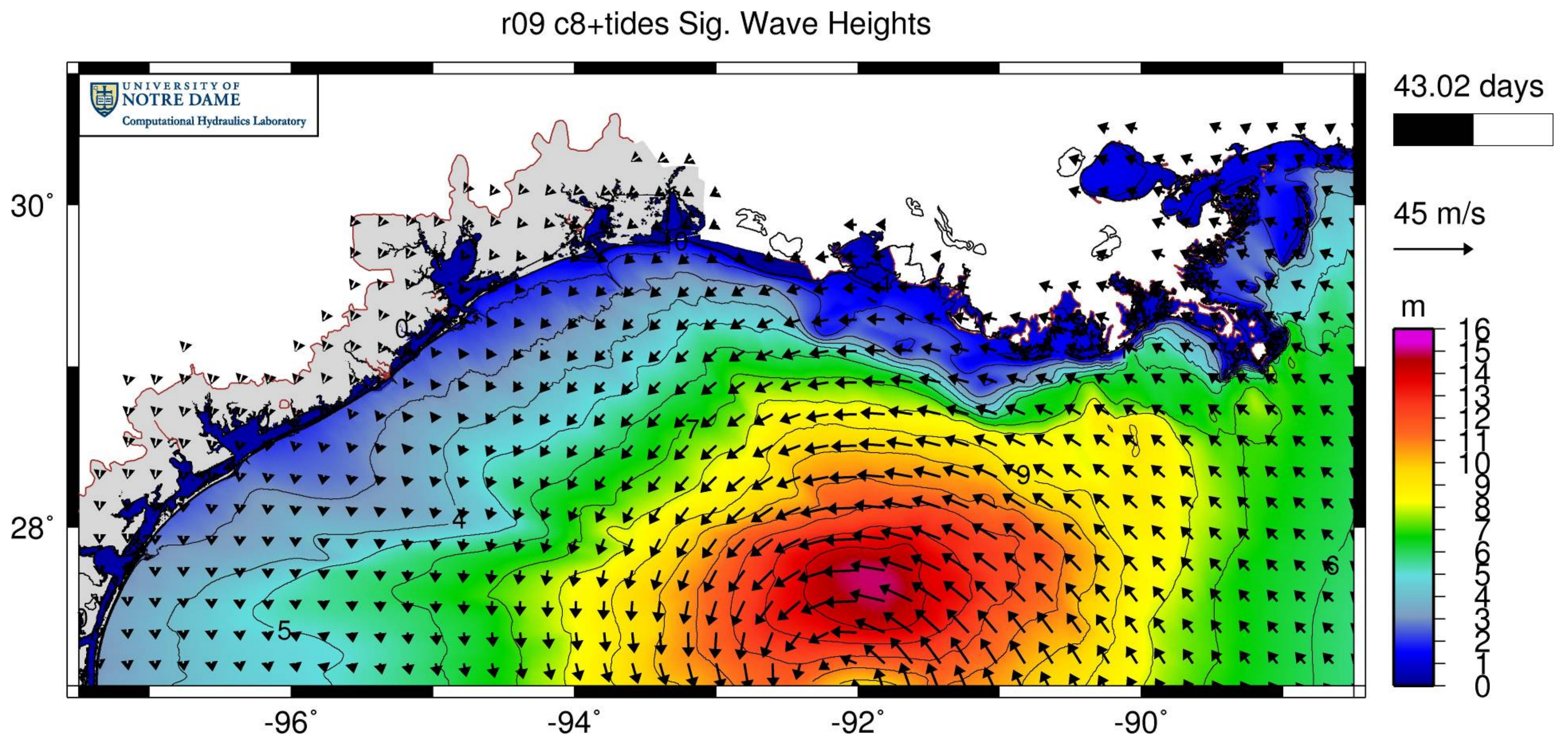
- 21 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



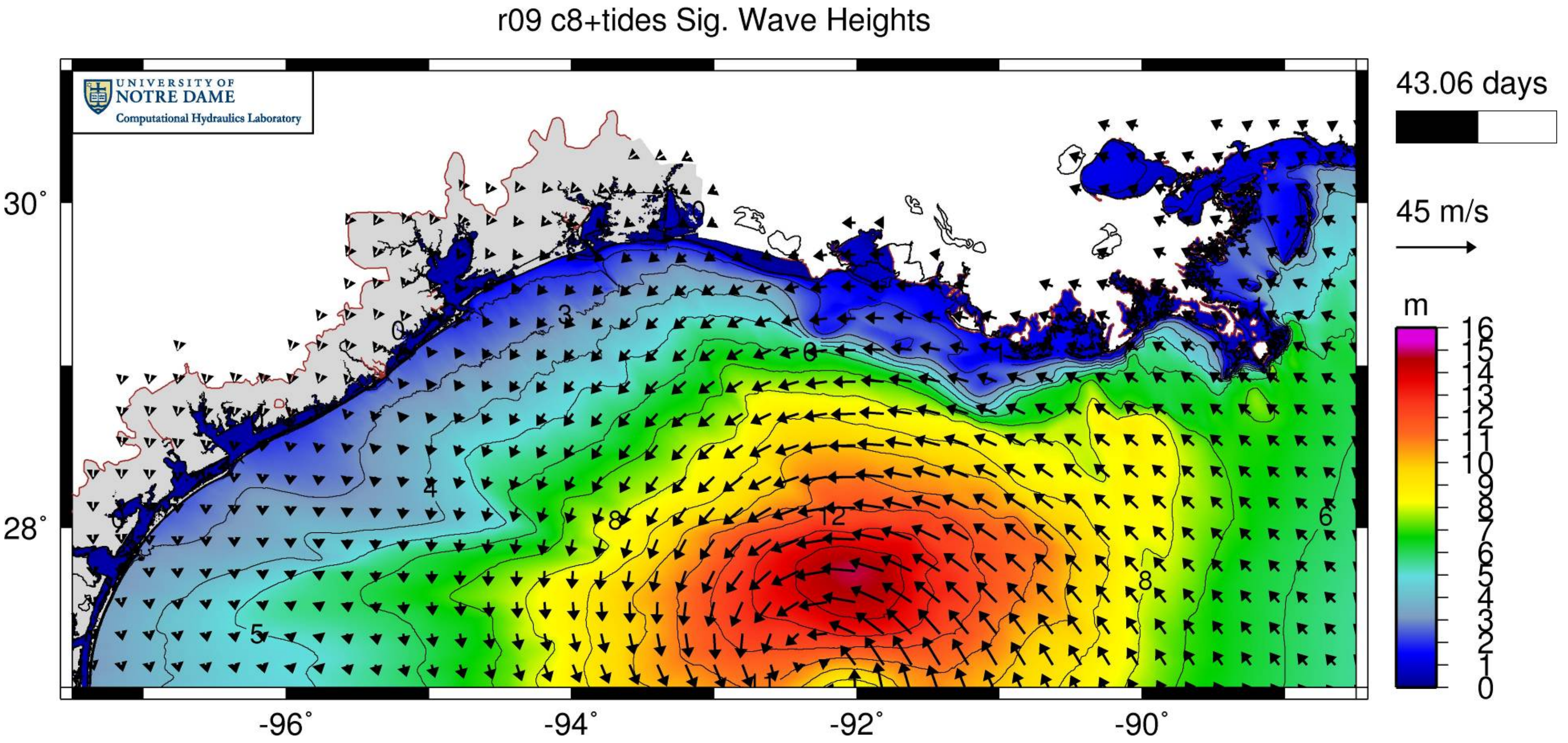
- 20 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



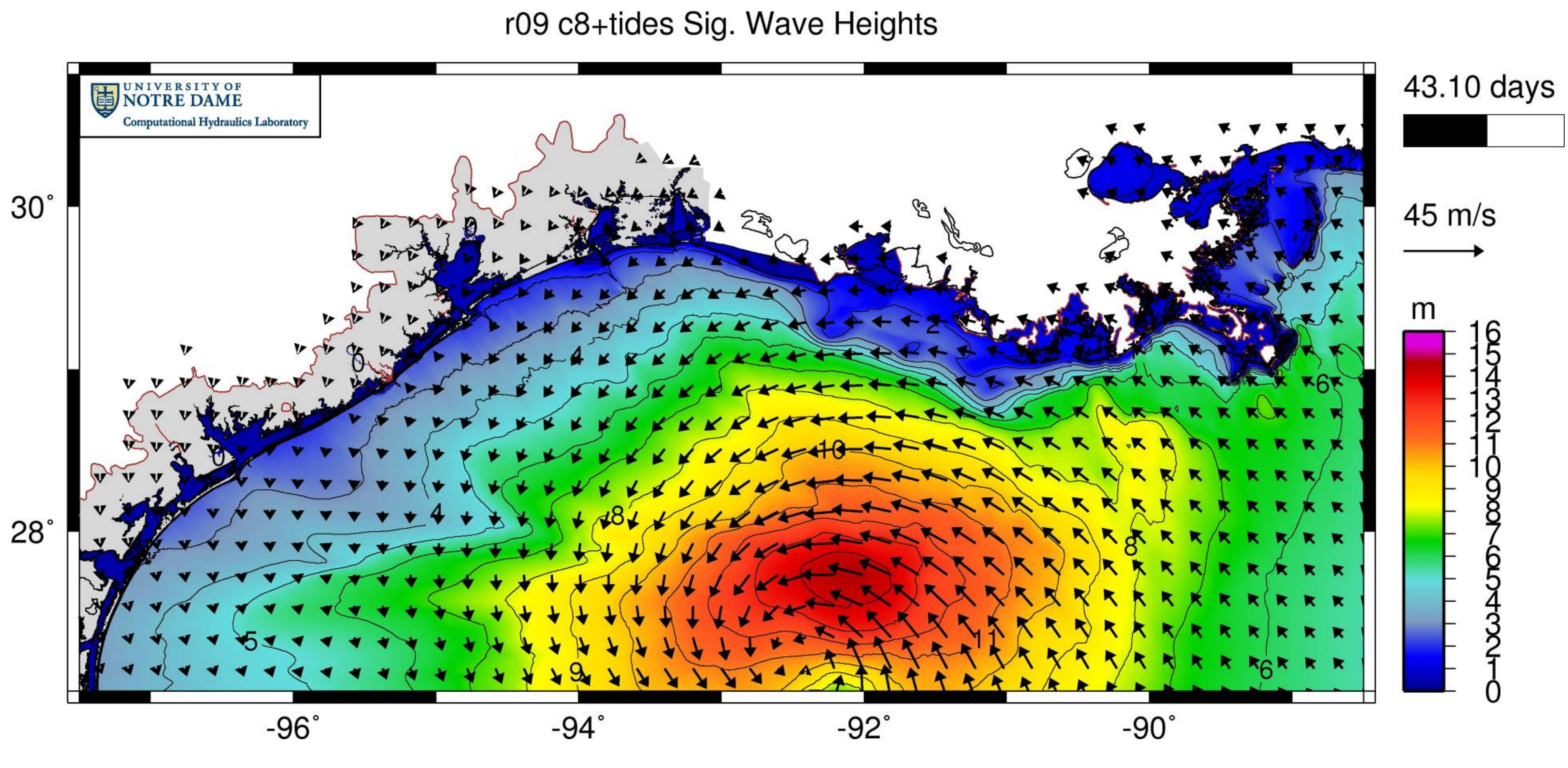
- 19 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



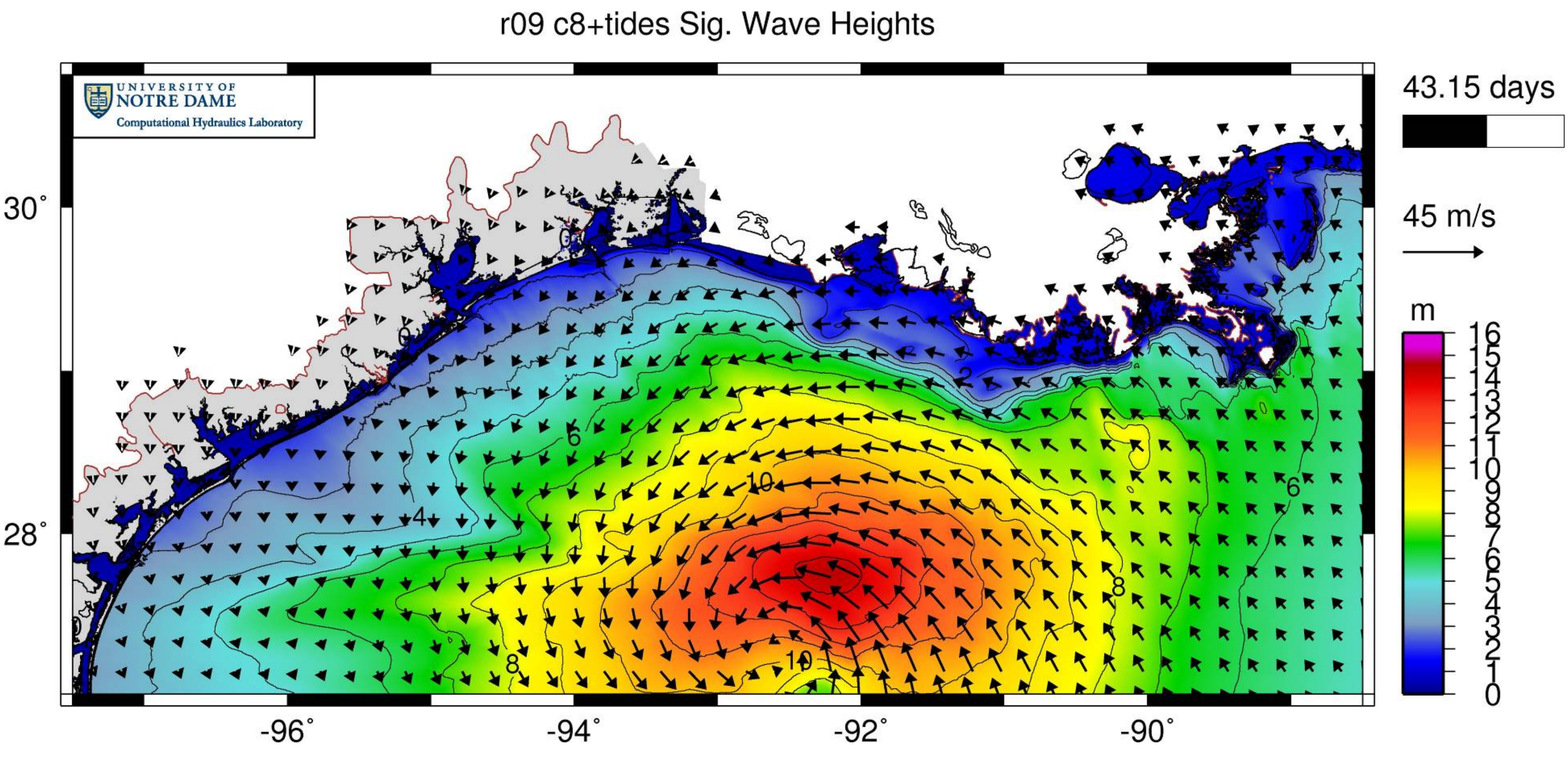
- 18 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



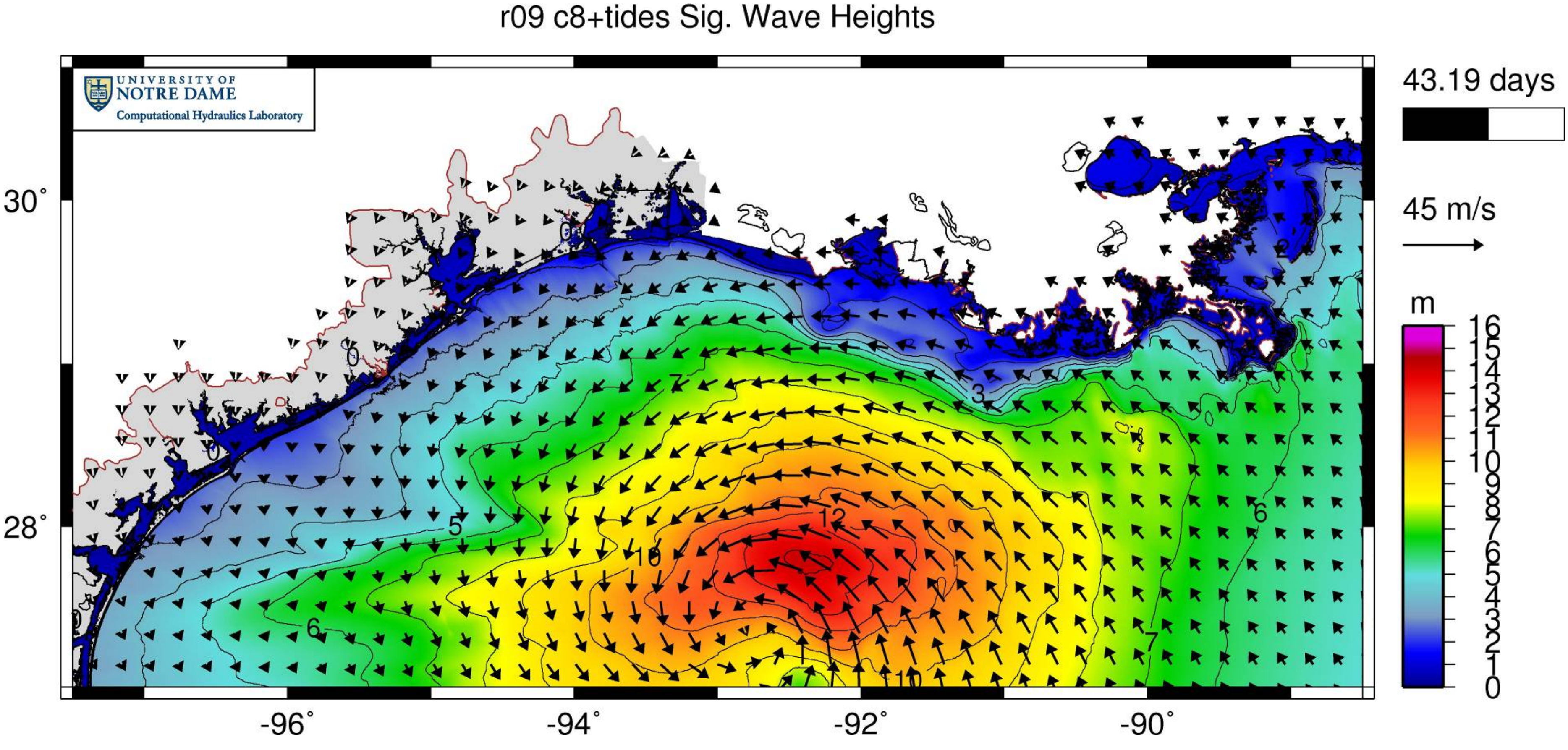
- 17 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



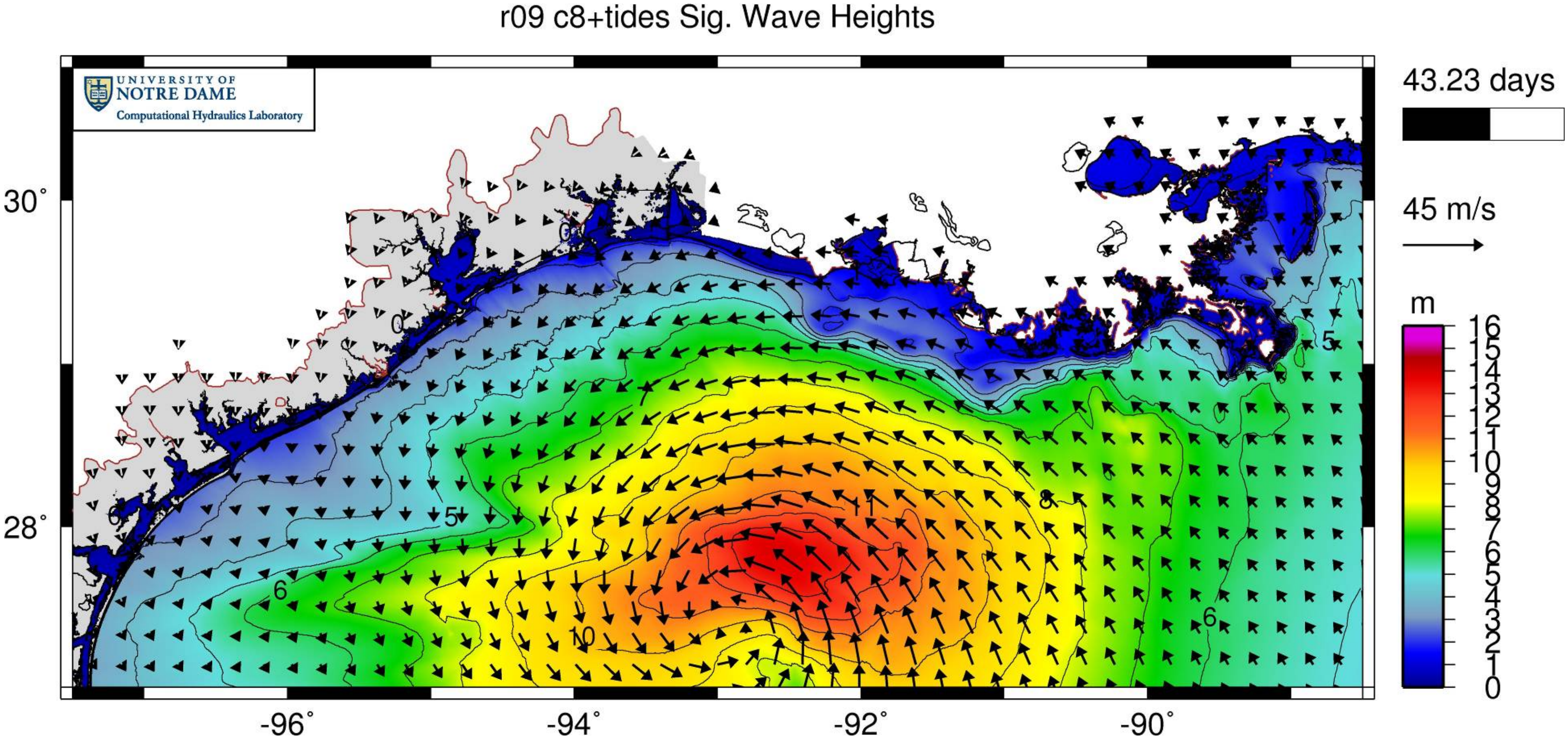
- 16 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



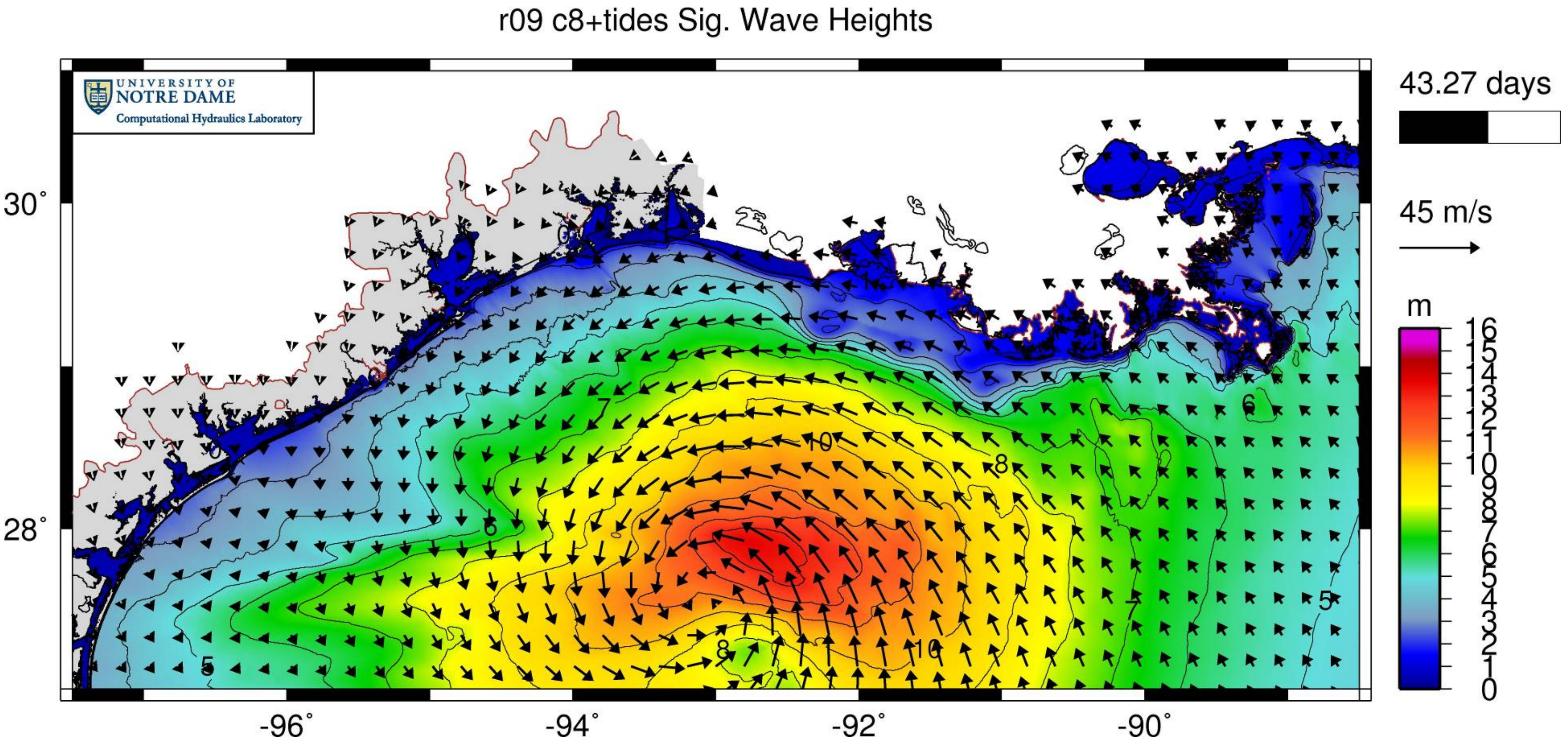
- 15 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



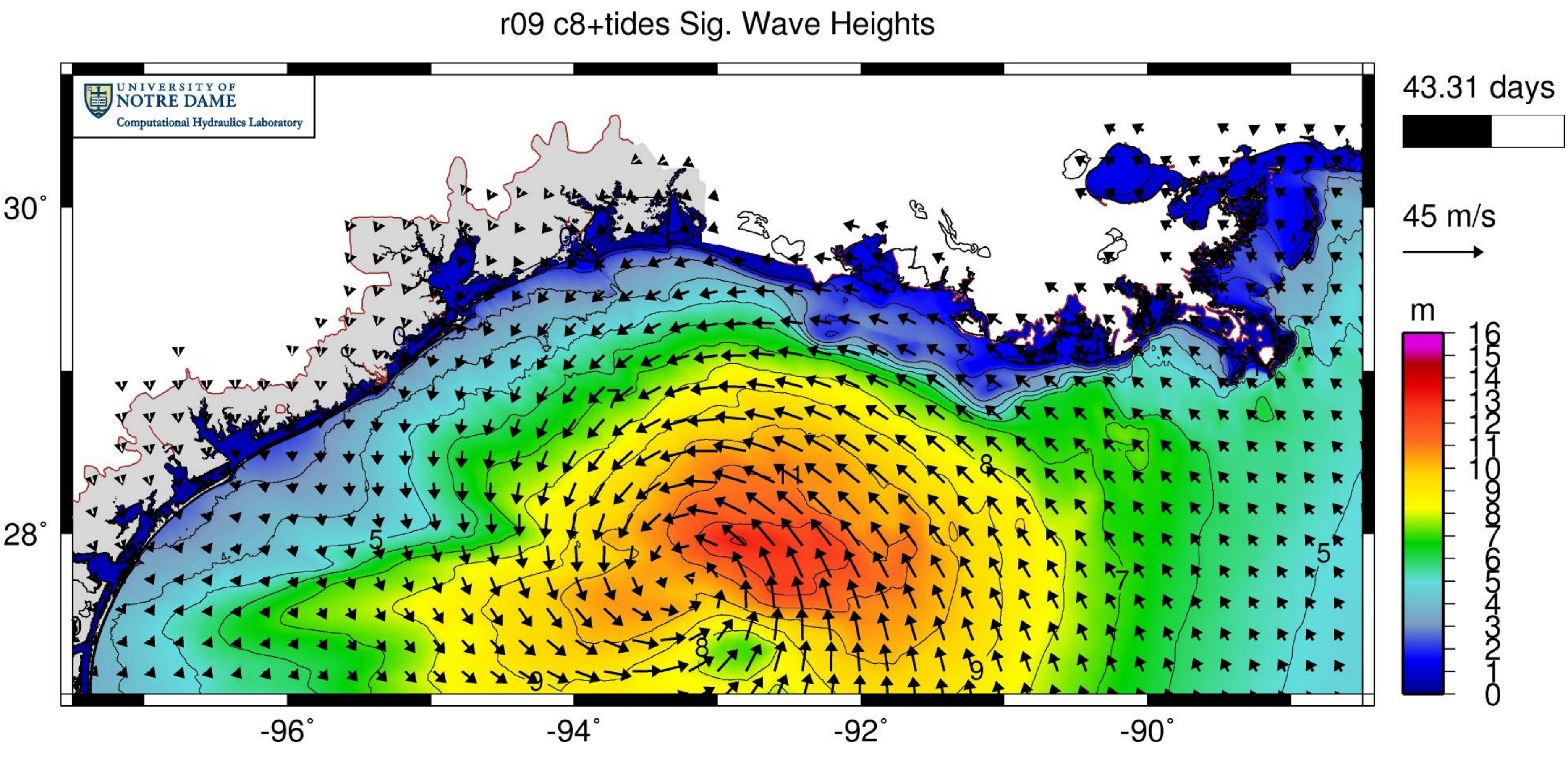
- 14 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



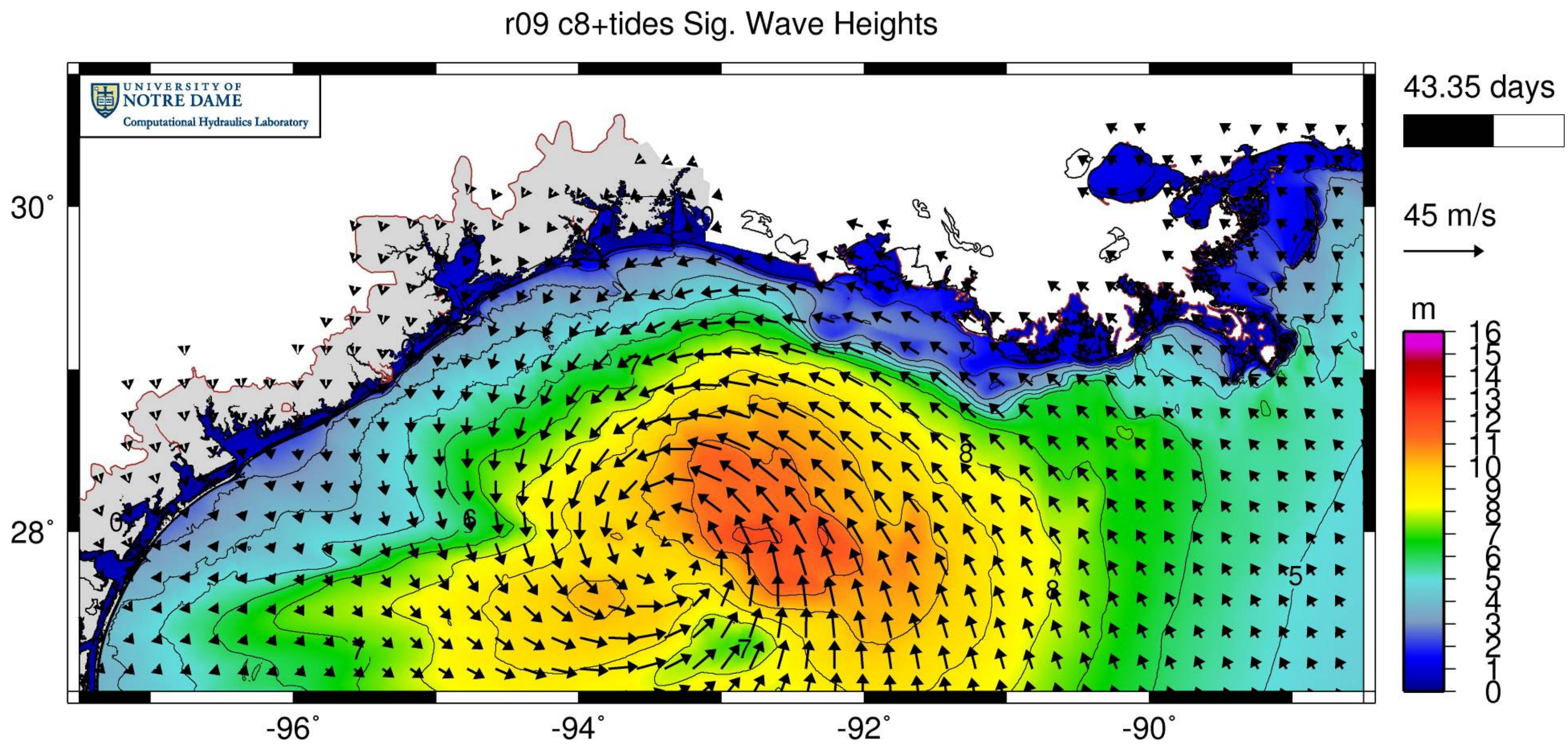
- 13 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



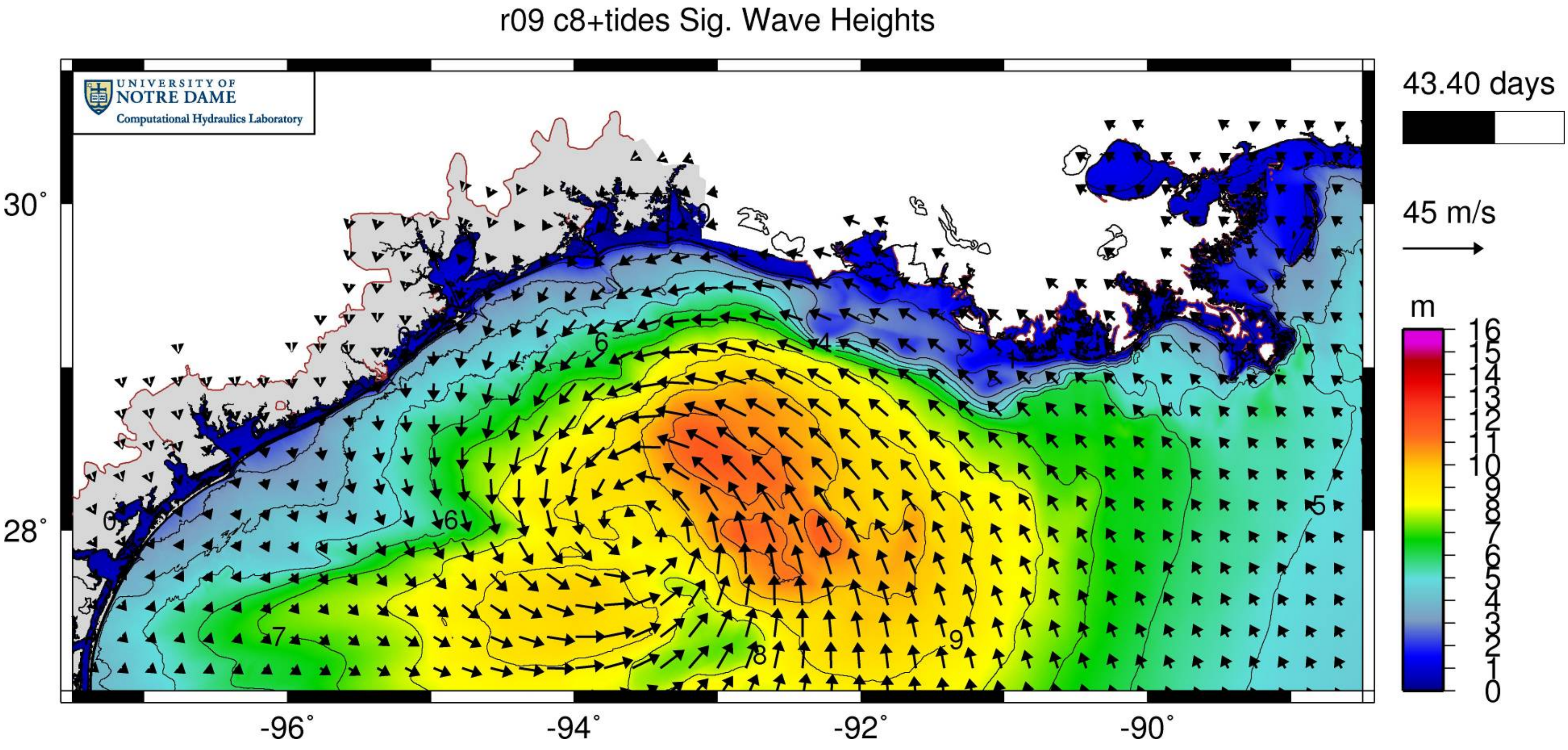
- 12 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



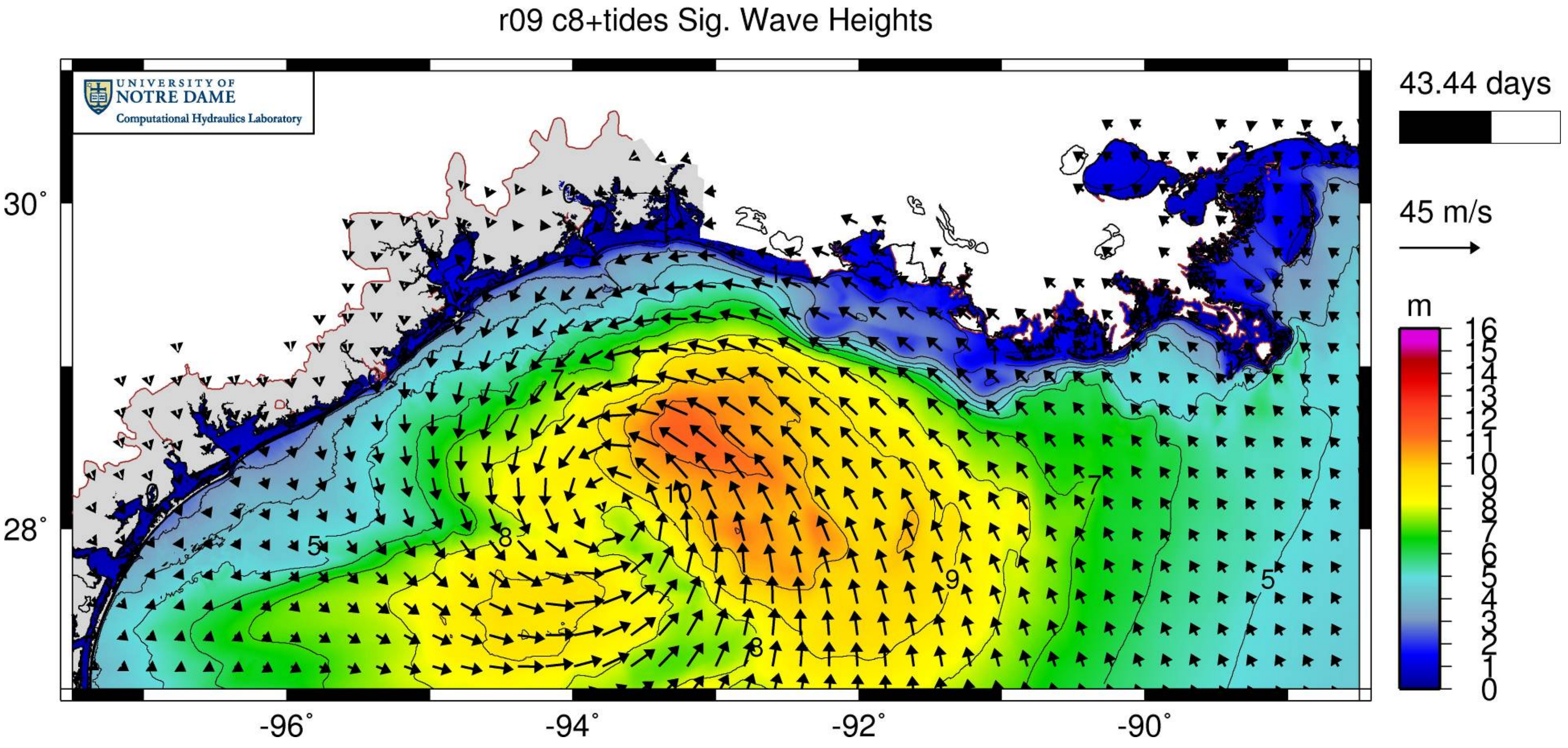
- 11 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



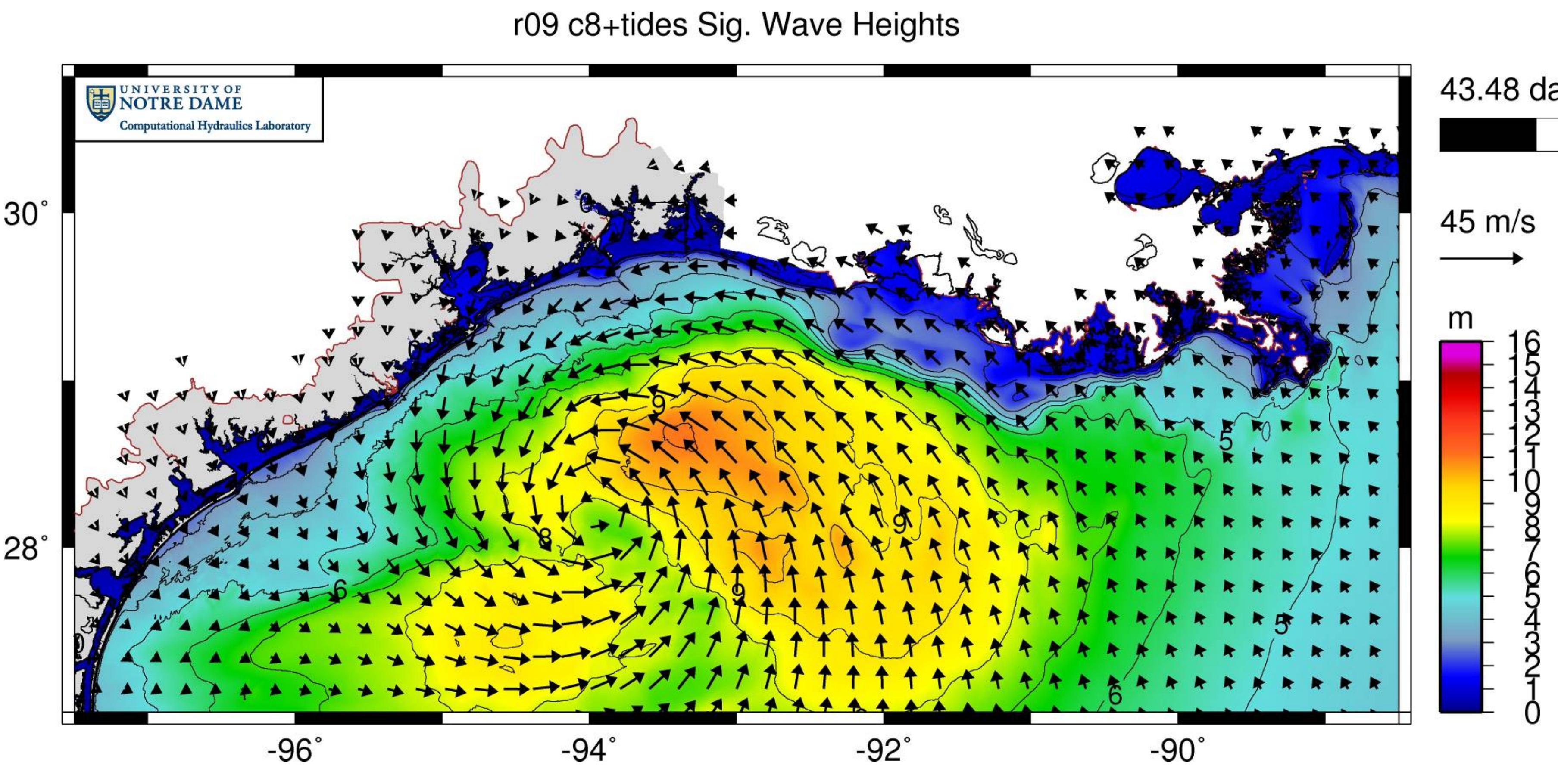
- 10 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



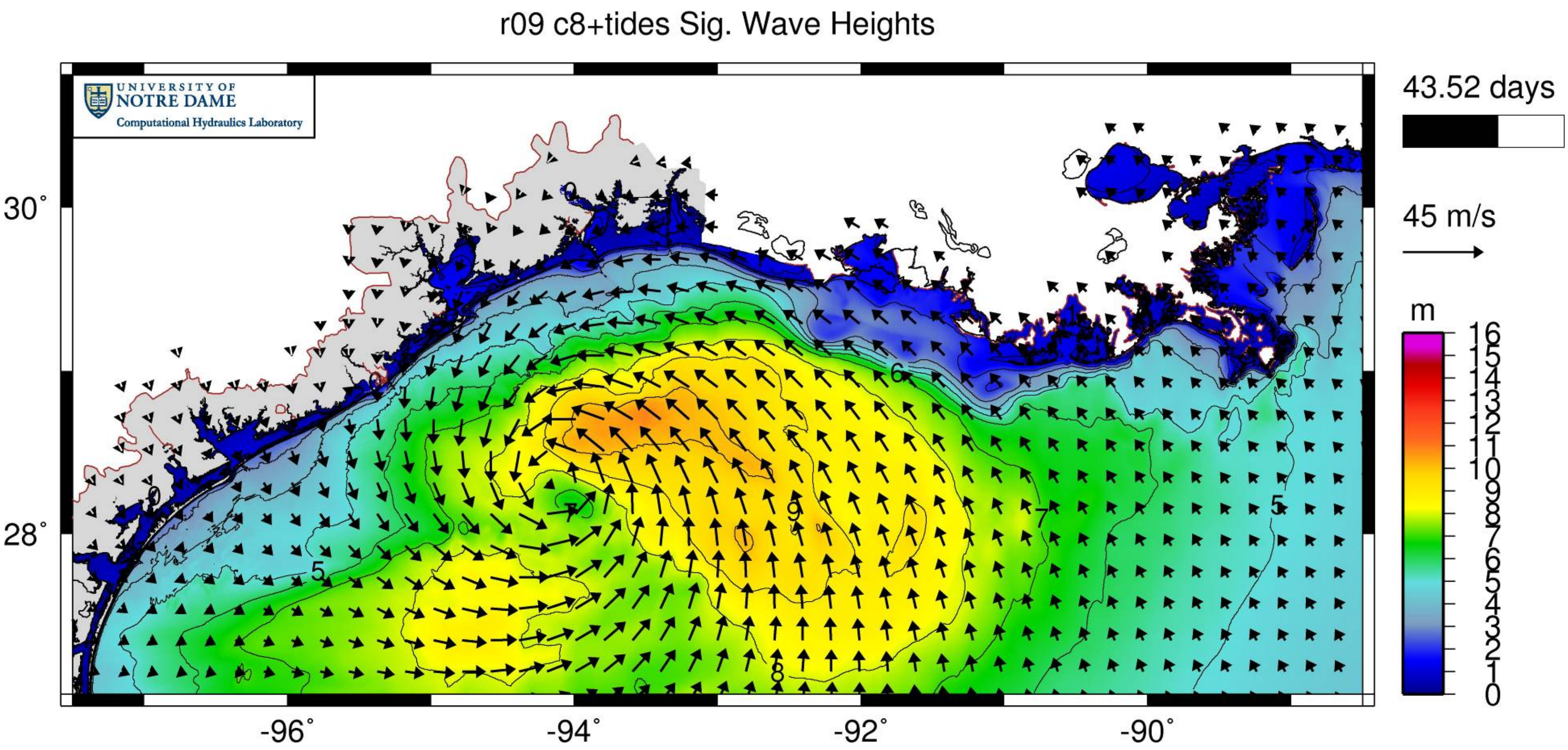
- 9 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



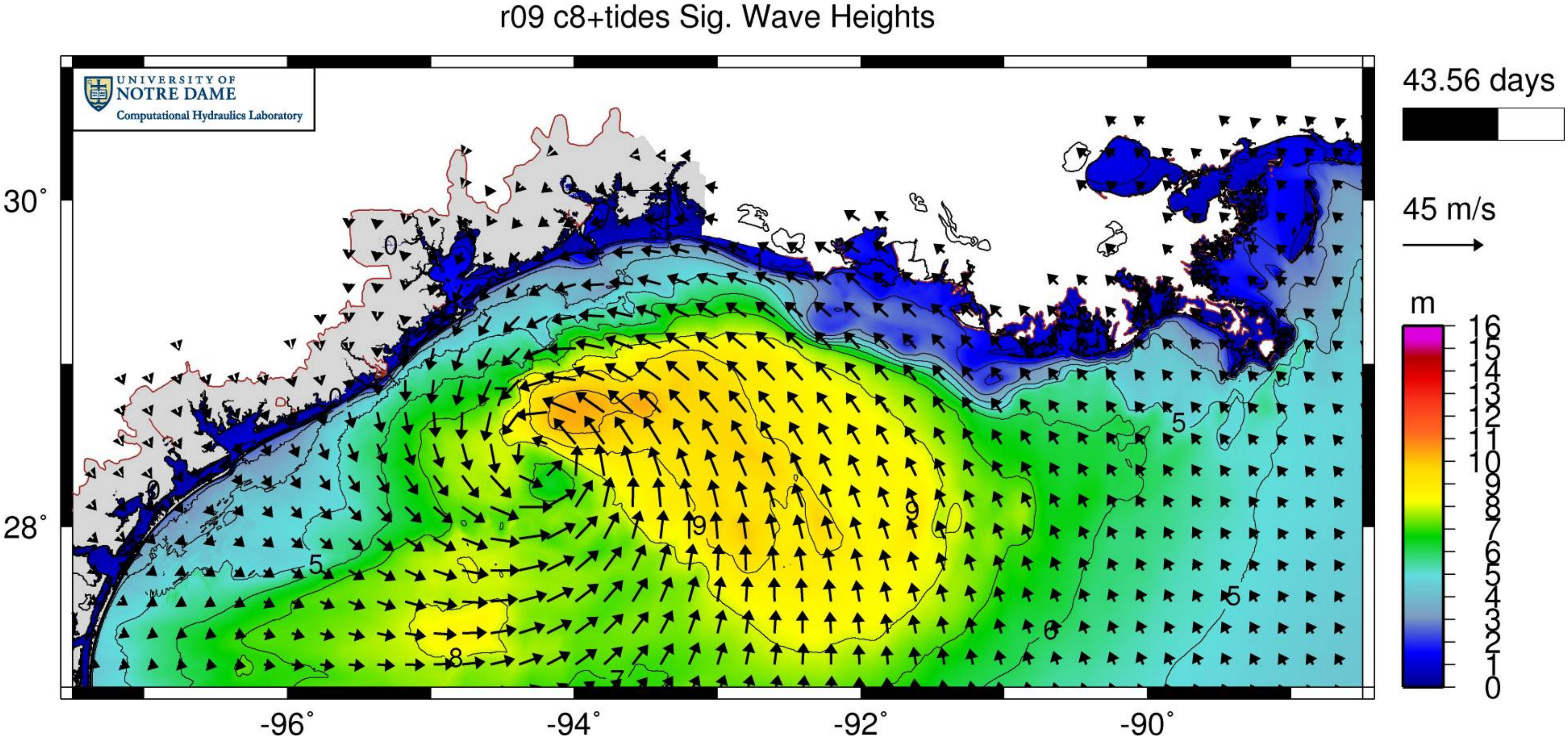
- 8 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



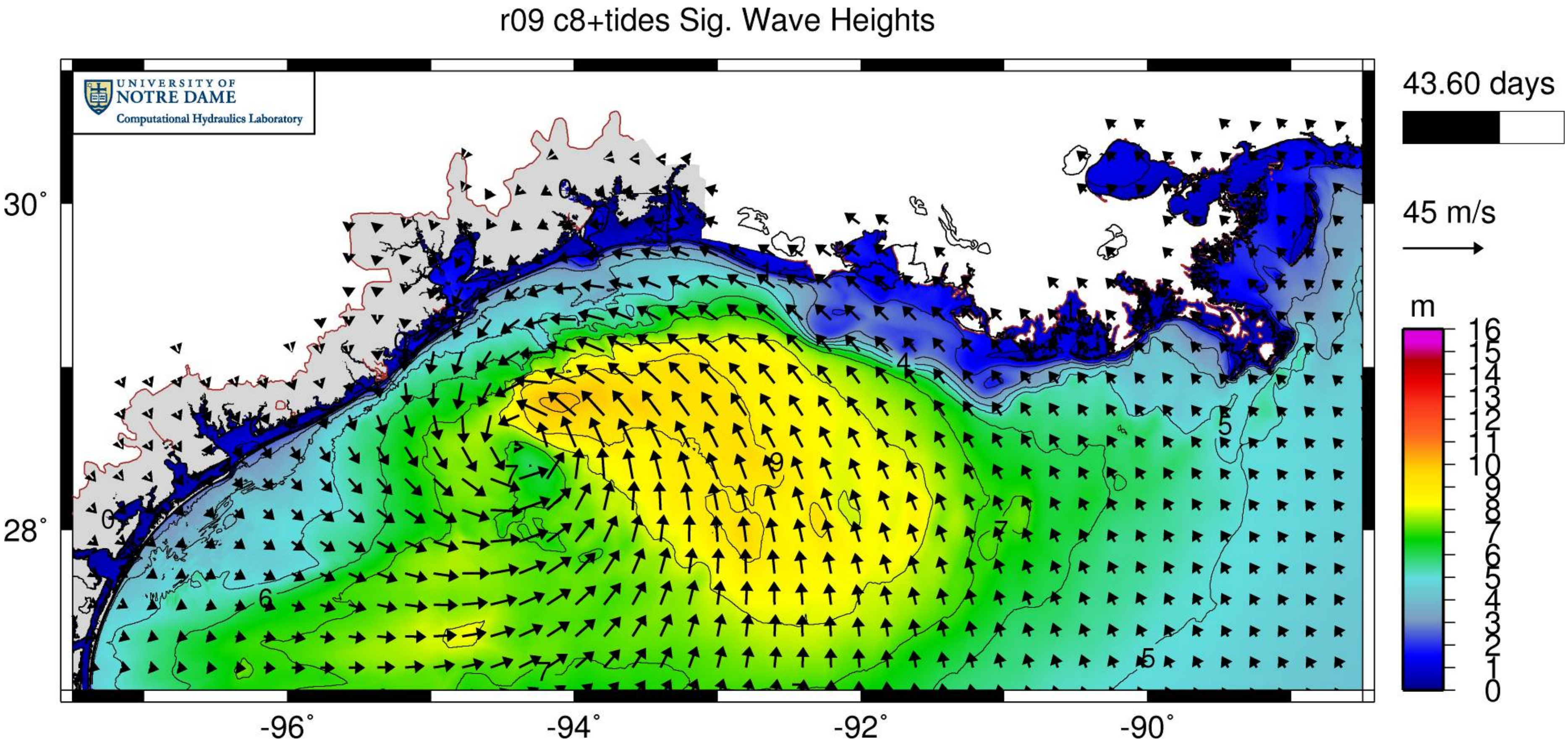
- 7 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



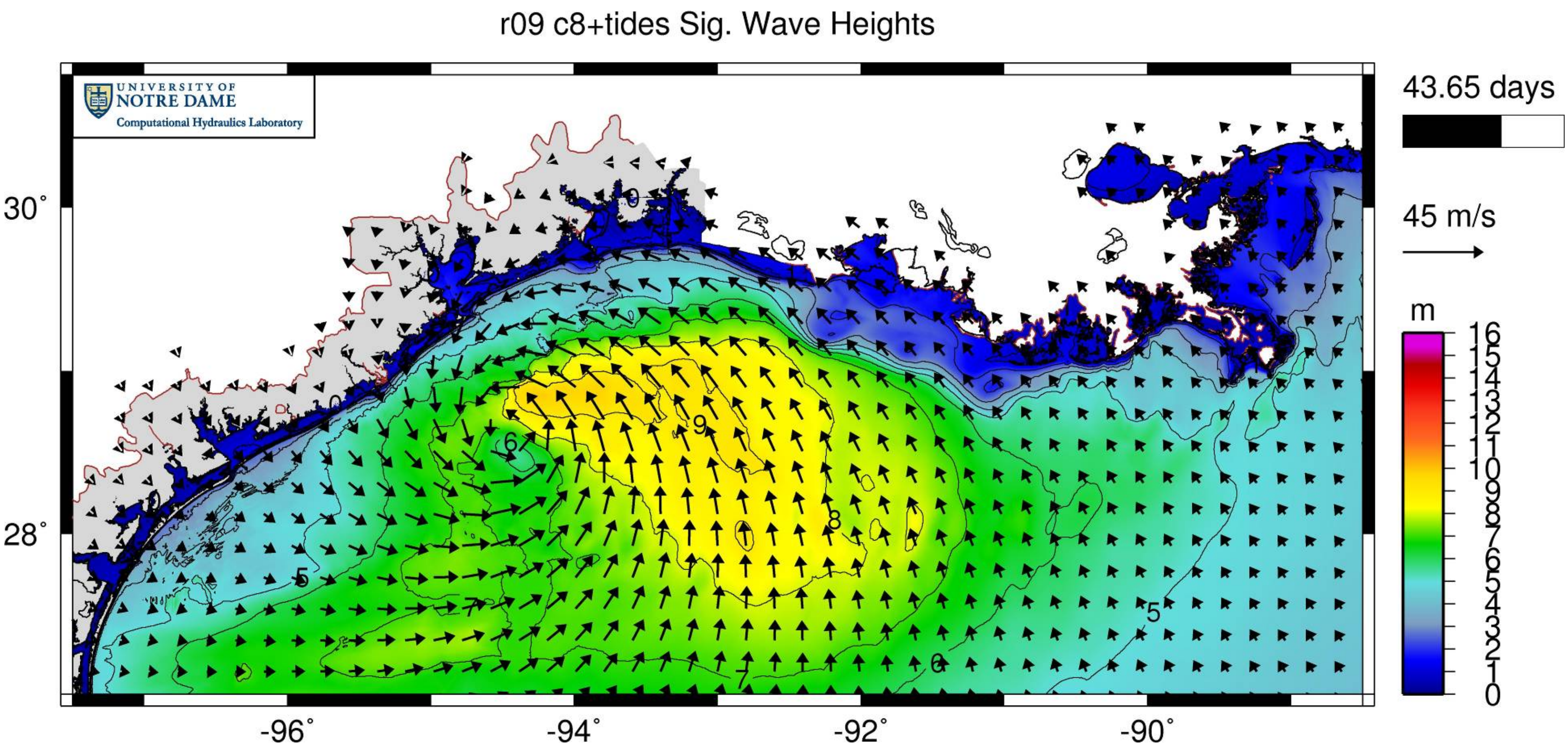
- 6 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



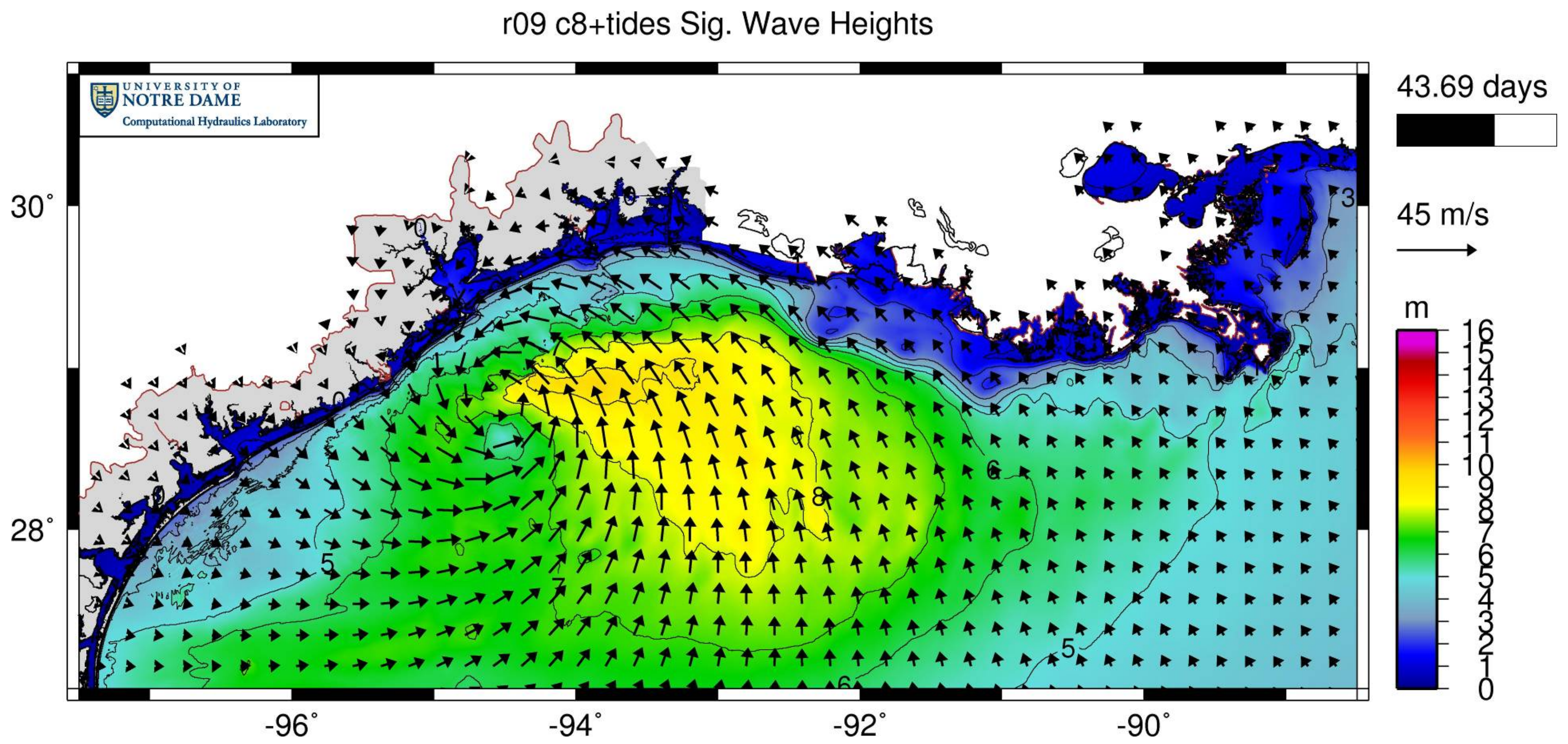
- 5 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



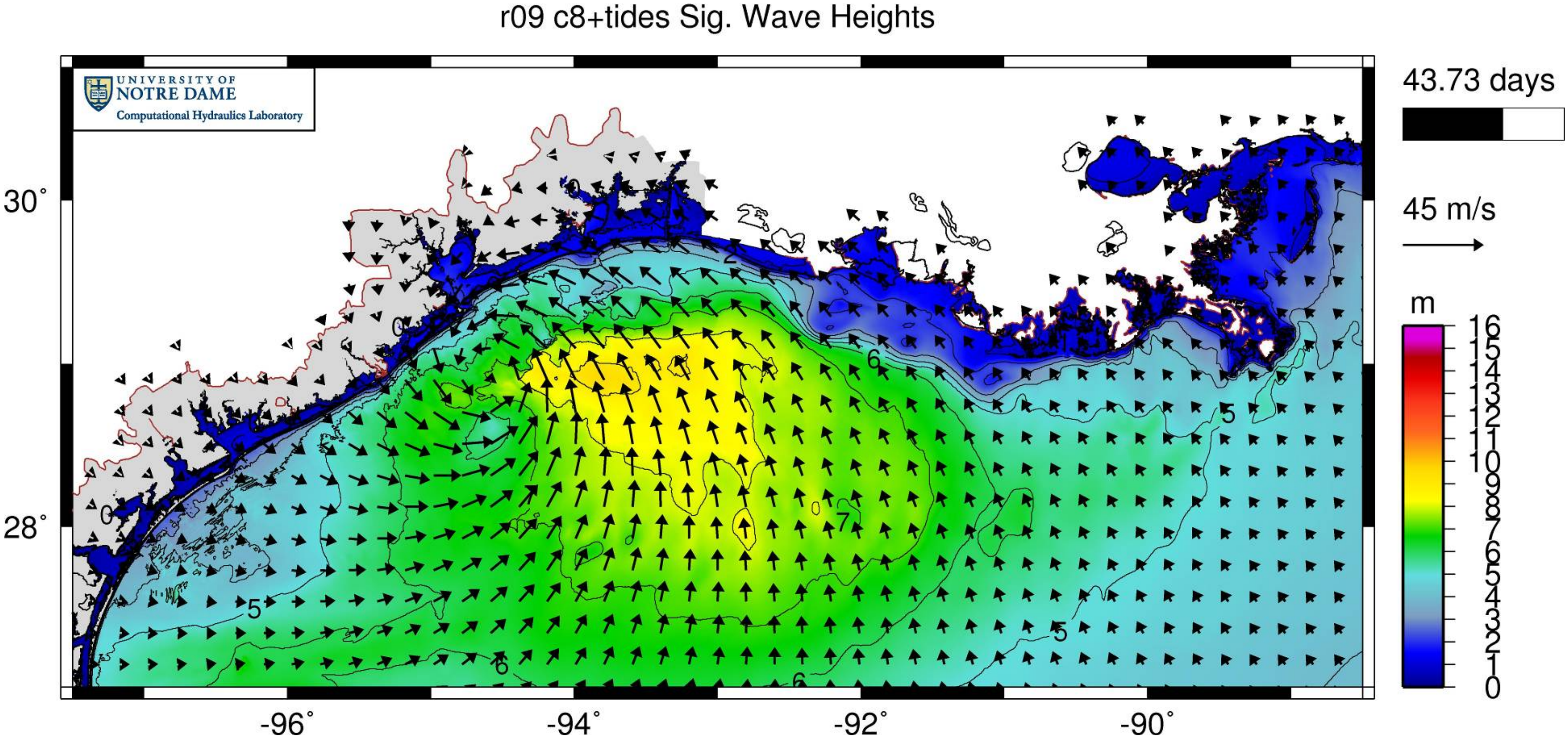
- 4 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



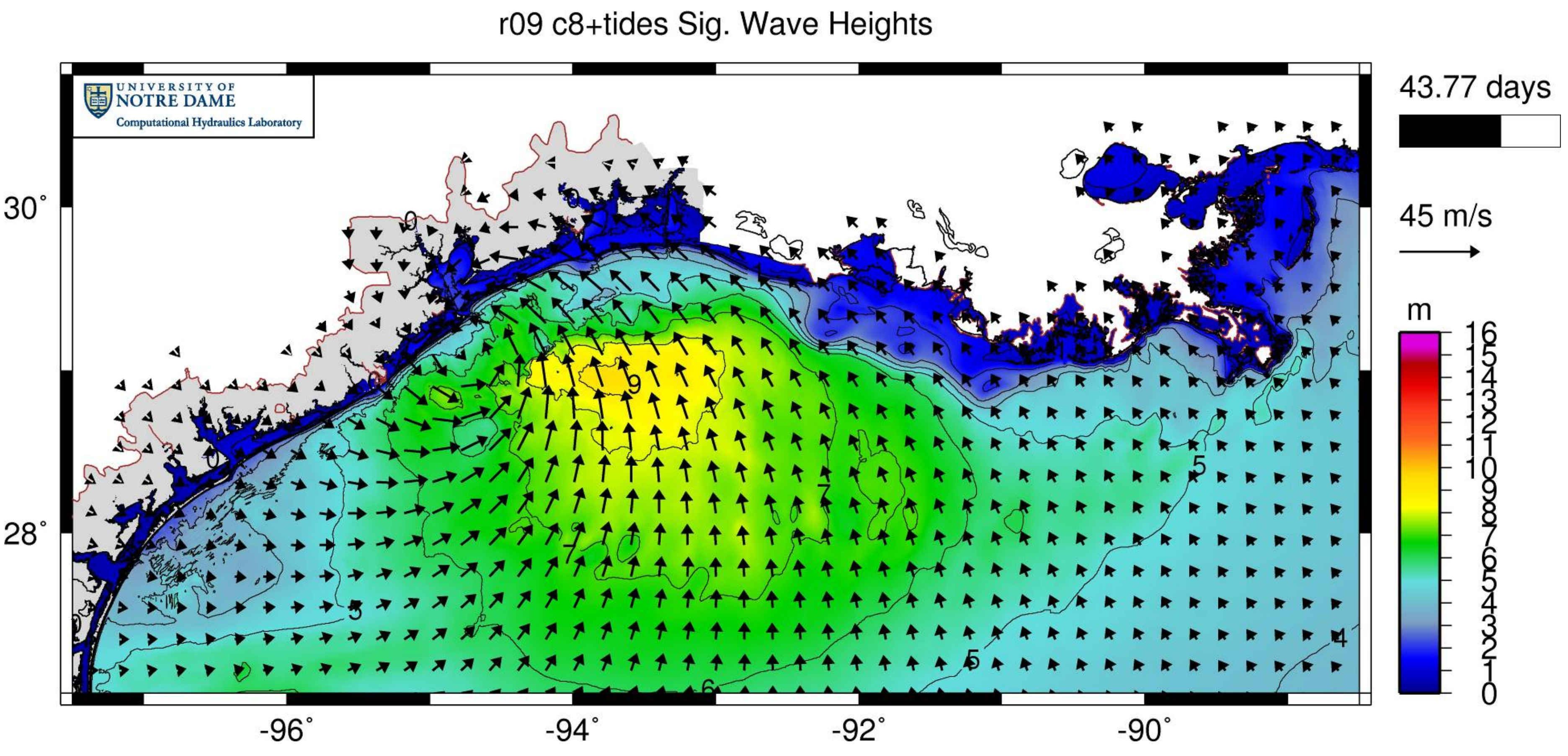
- 3 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



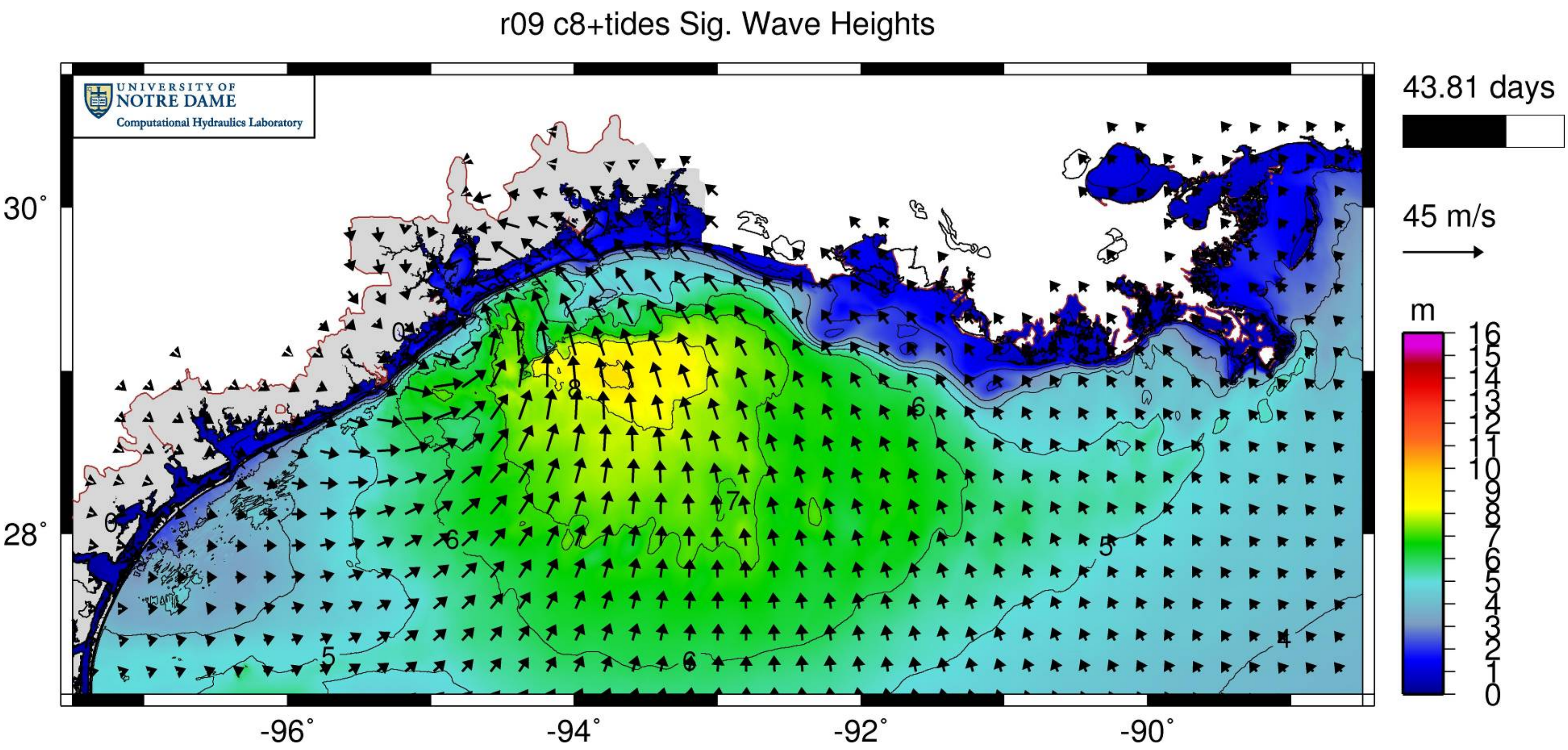
- 2 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



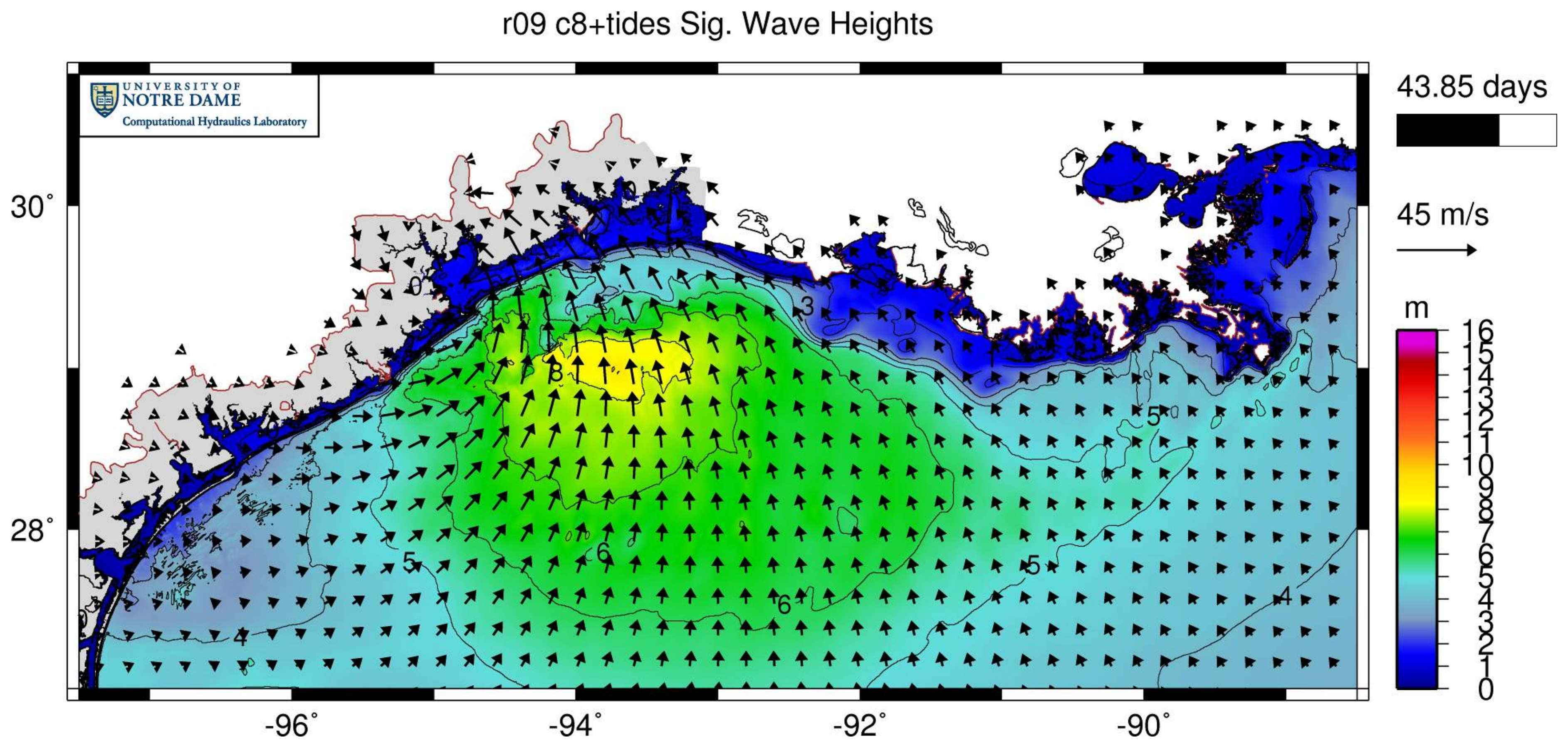
- 1 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



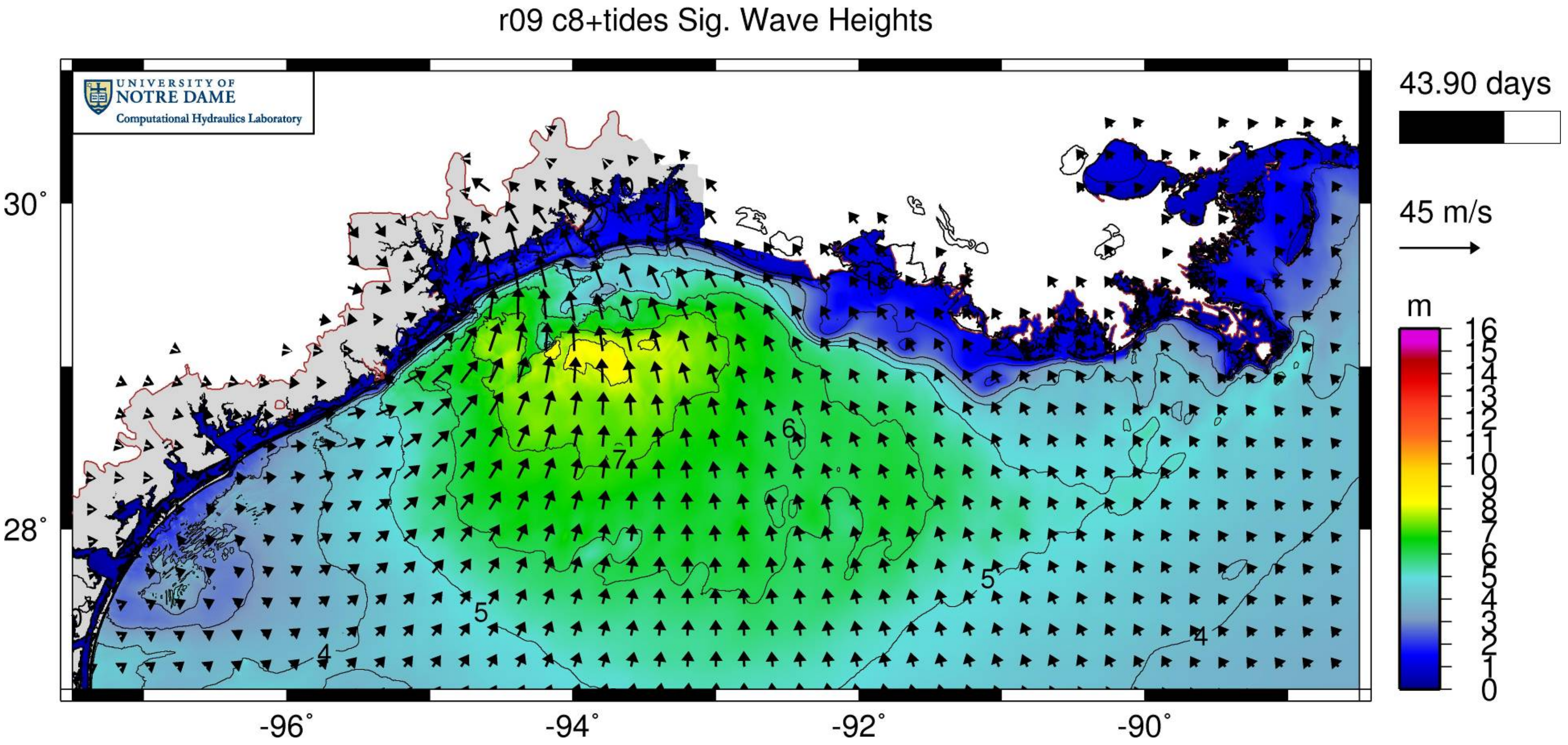
LANDFALL = 0 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



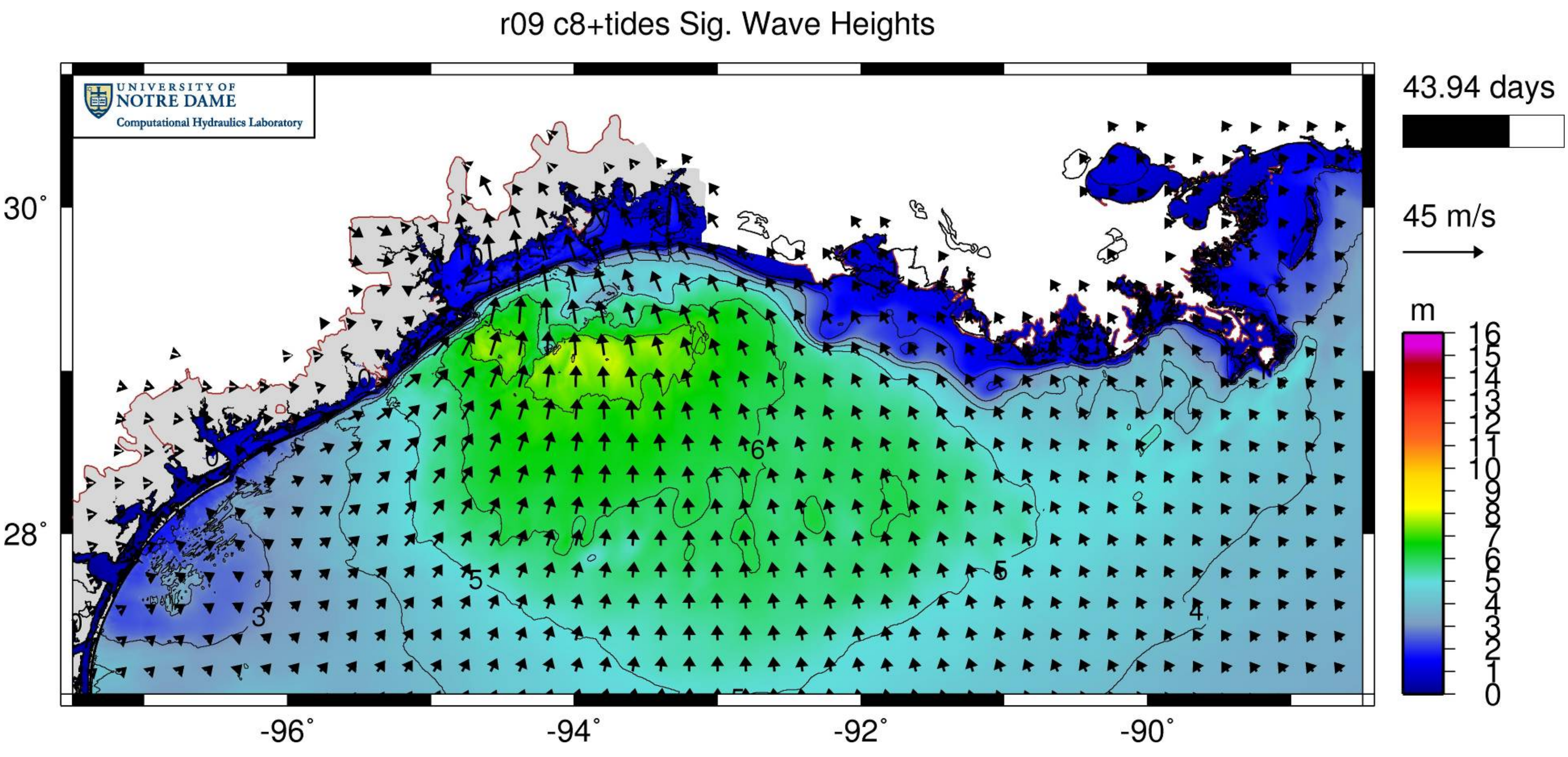
+ 1 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



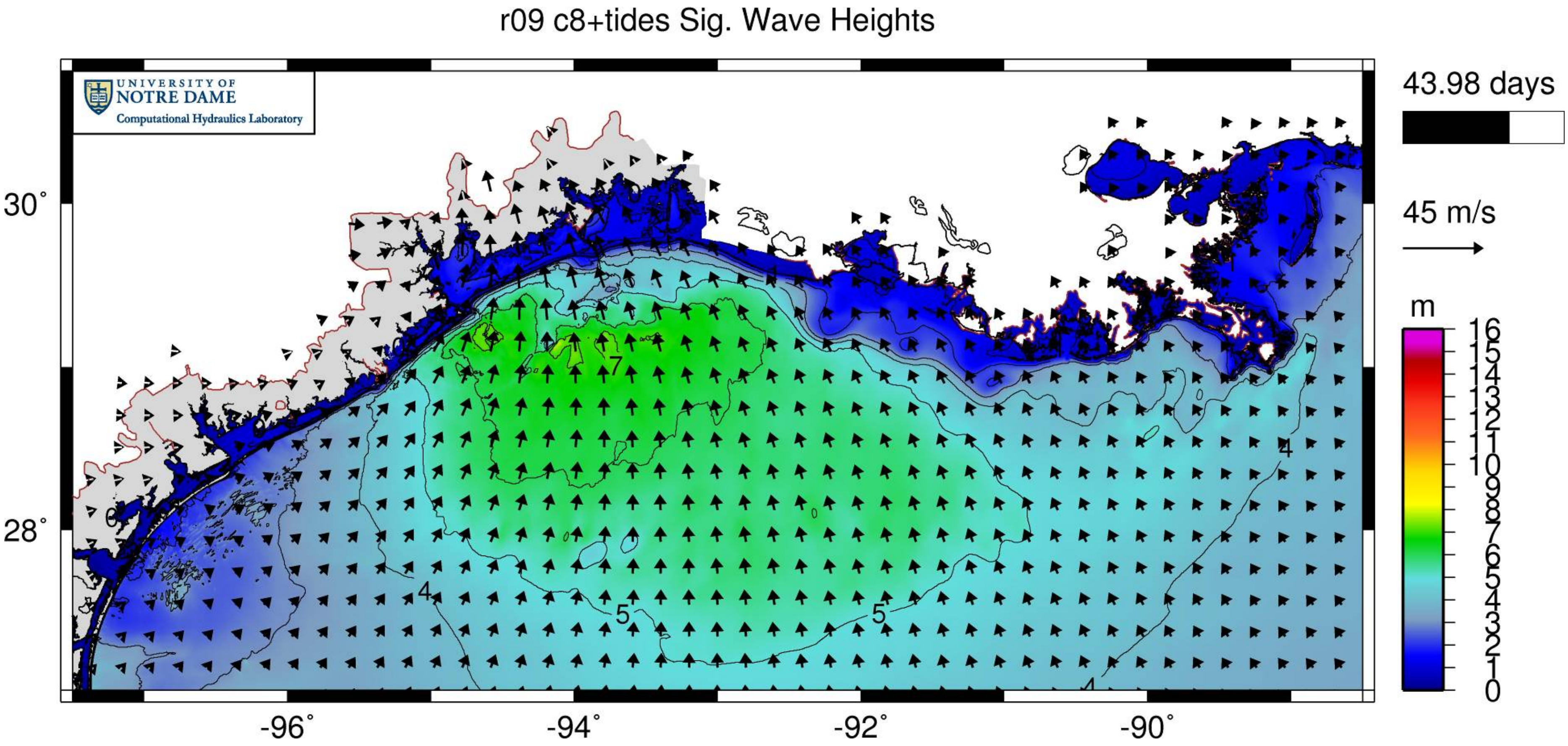
+ 2 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



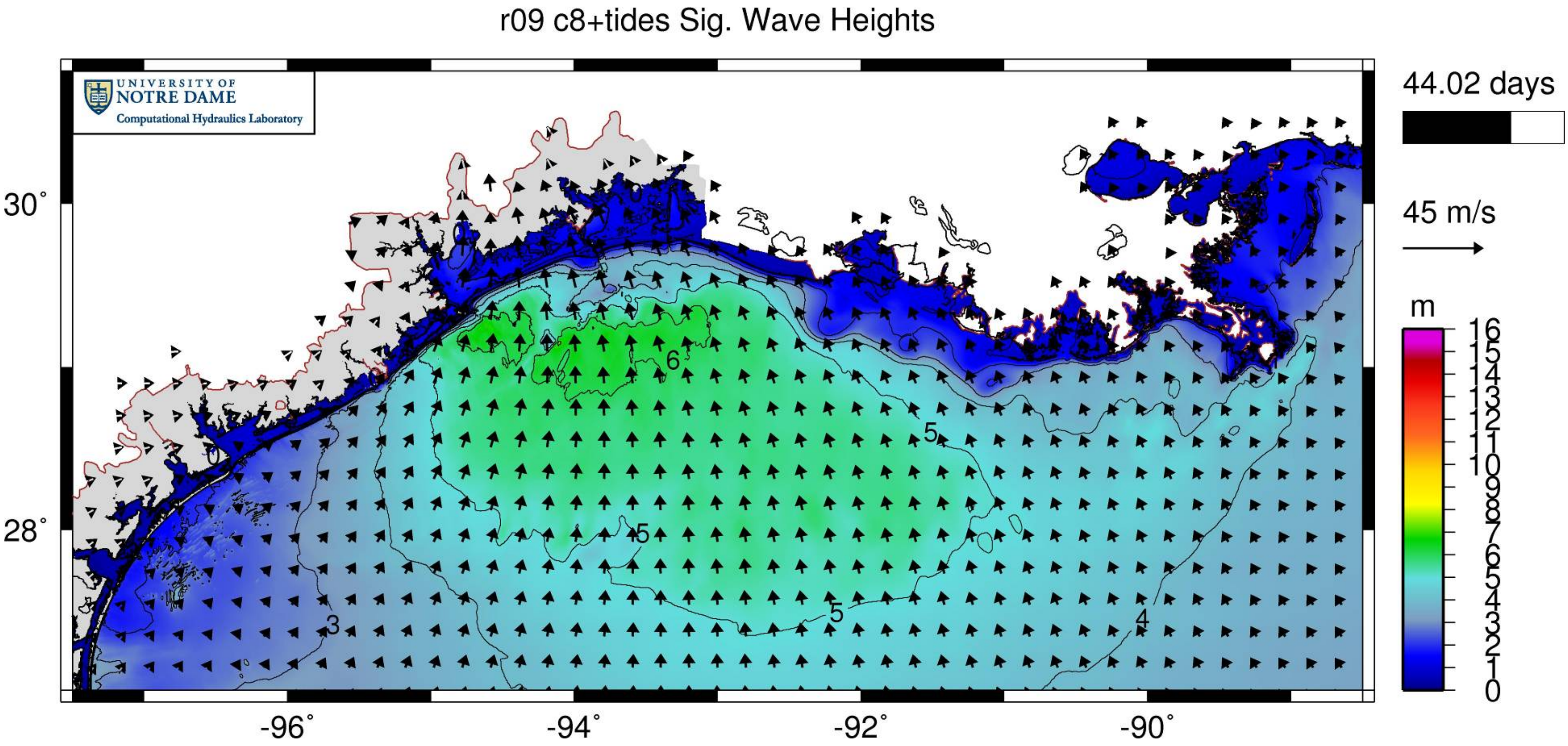
+ 3 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



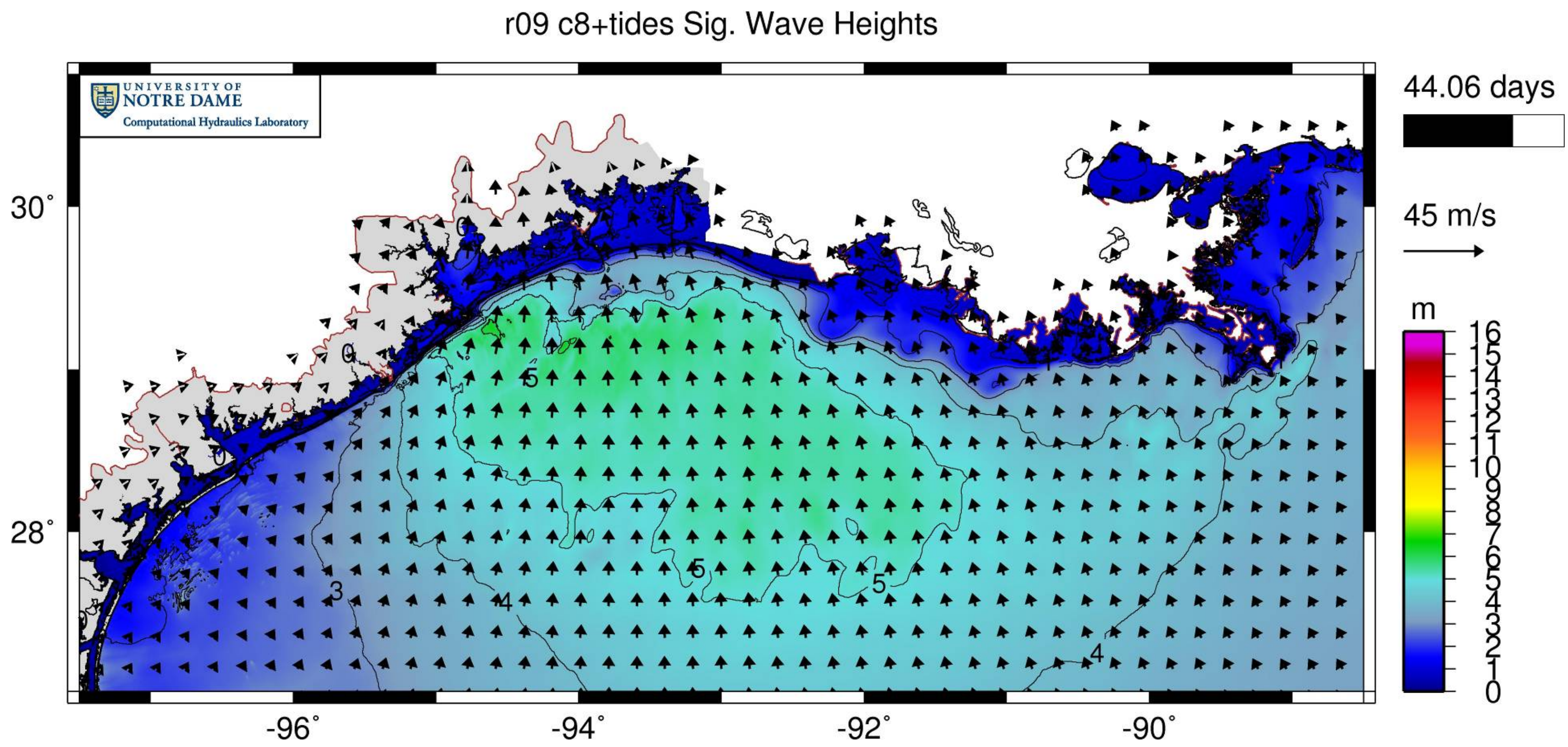
+ 4 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



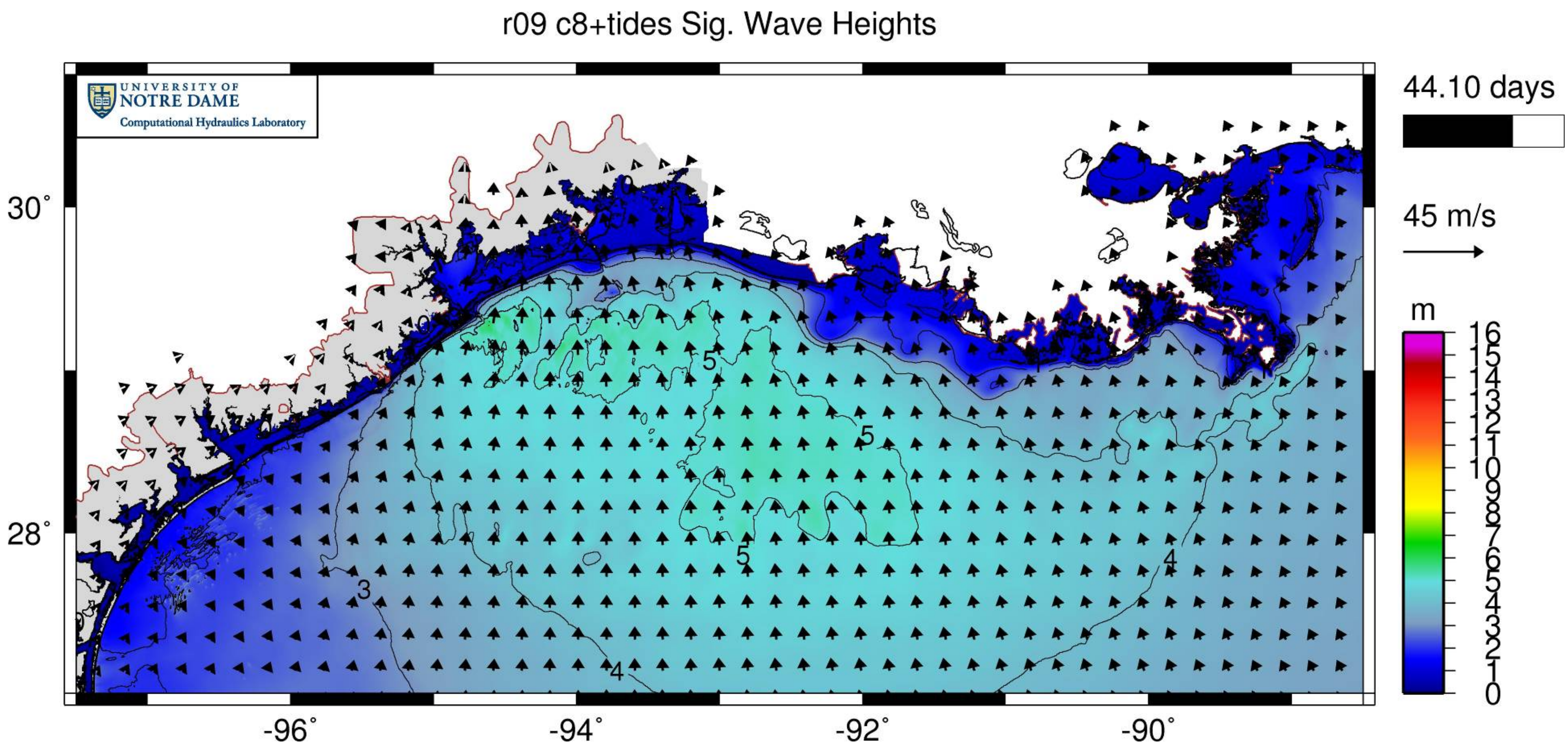
+ 5 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



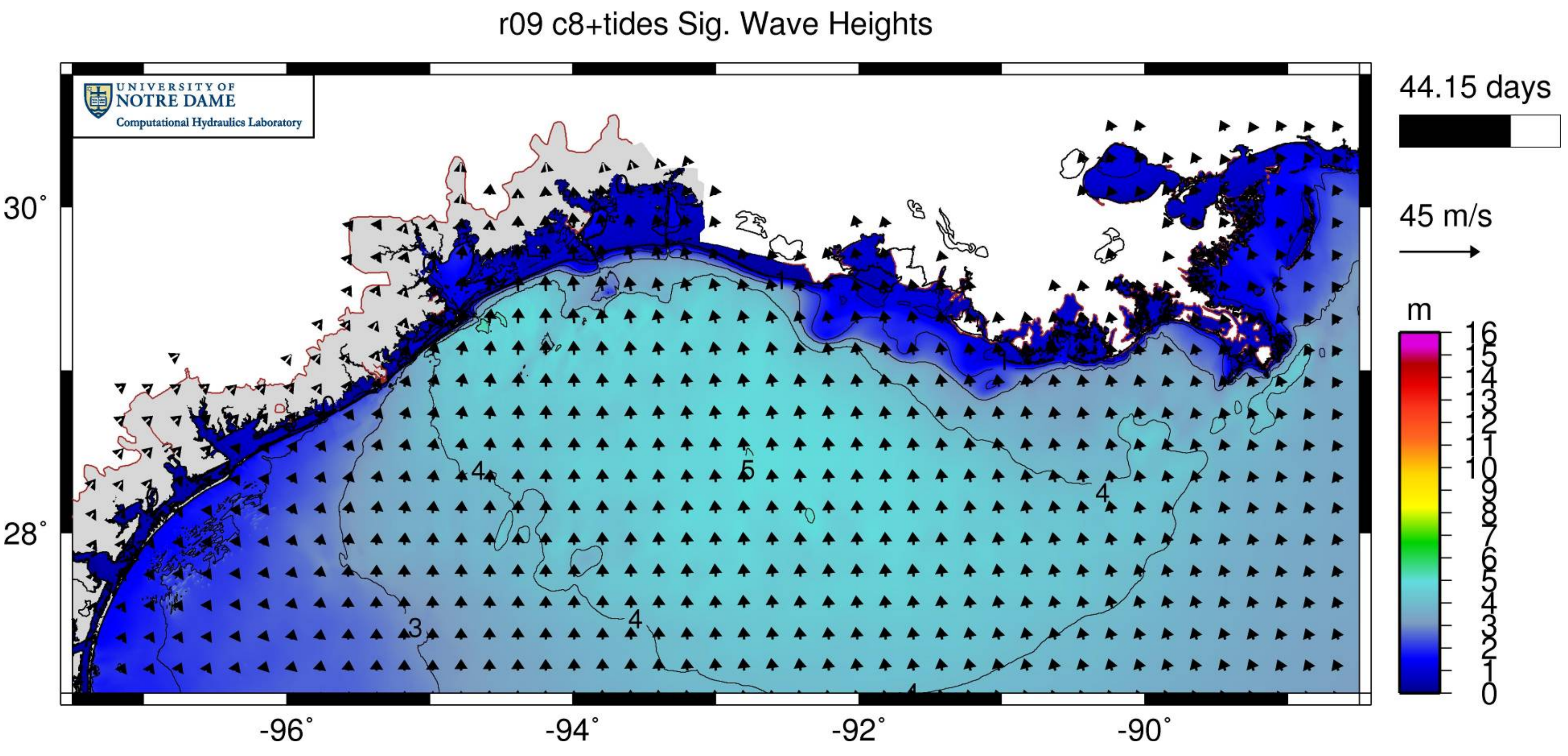
+ 6 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



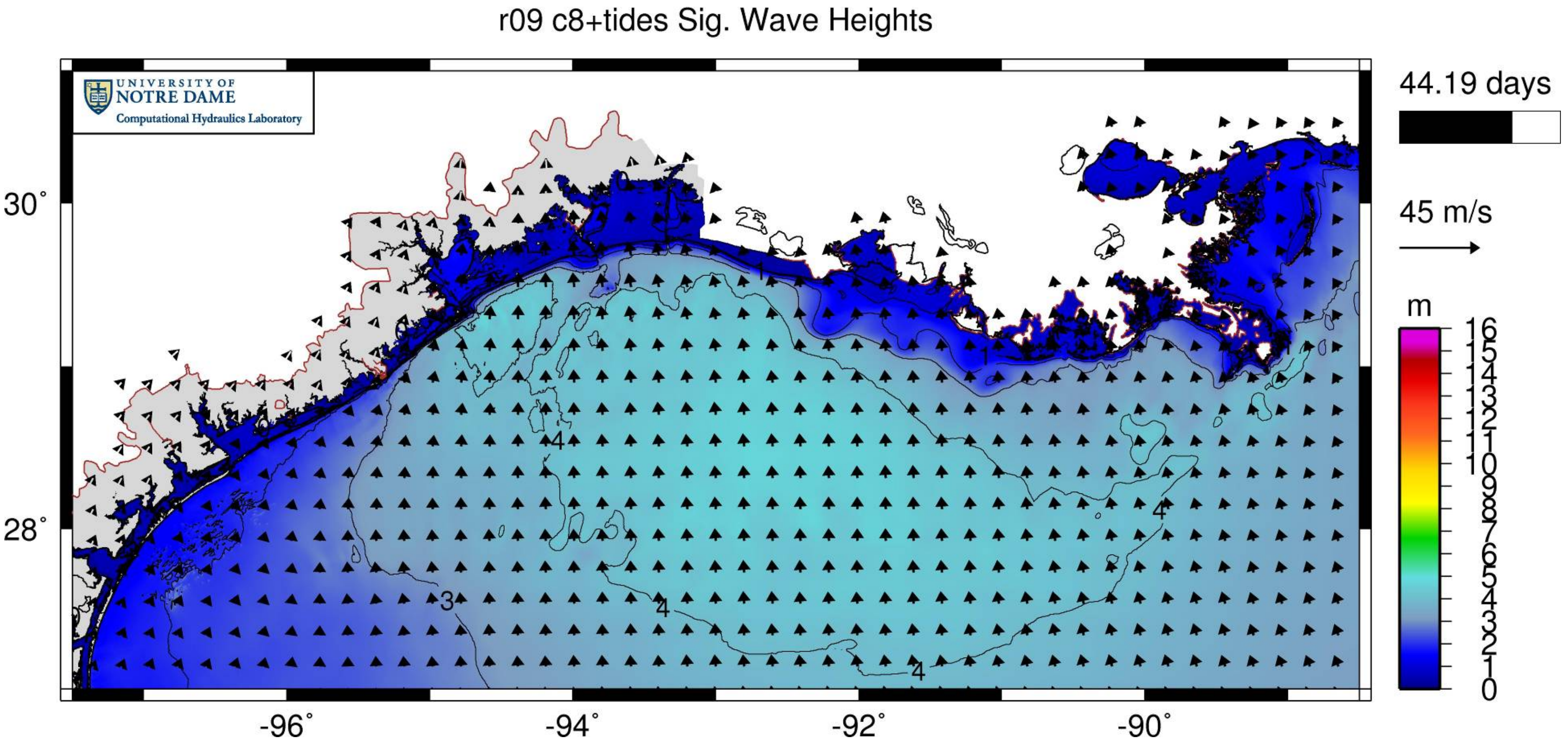
+ 7 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



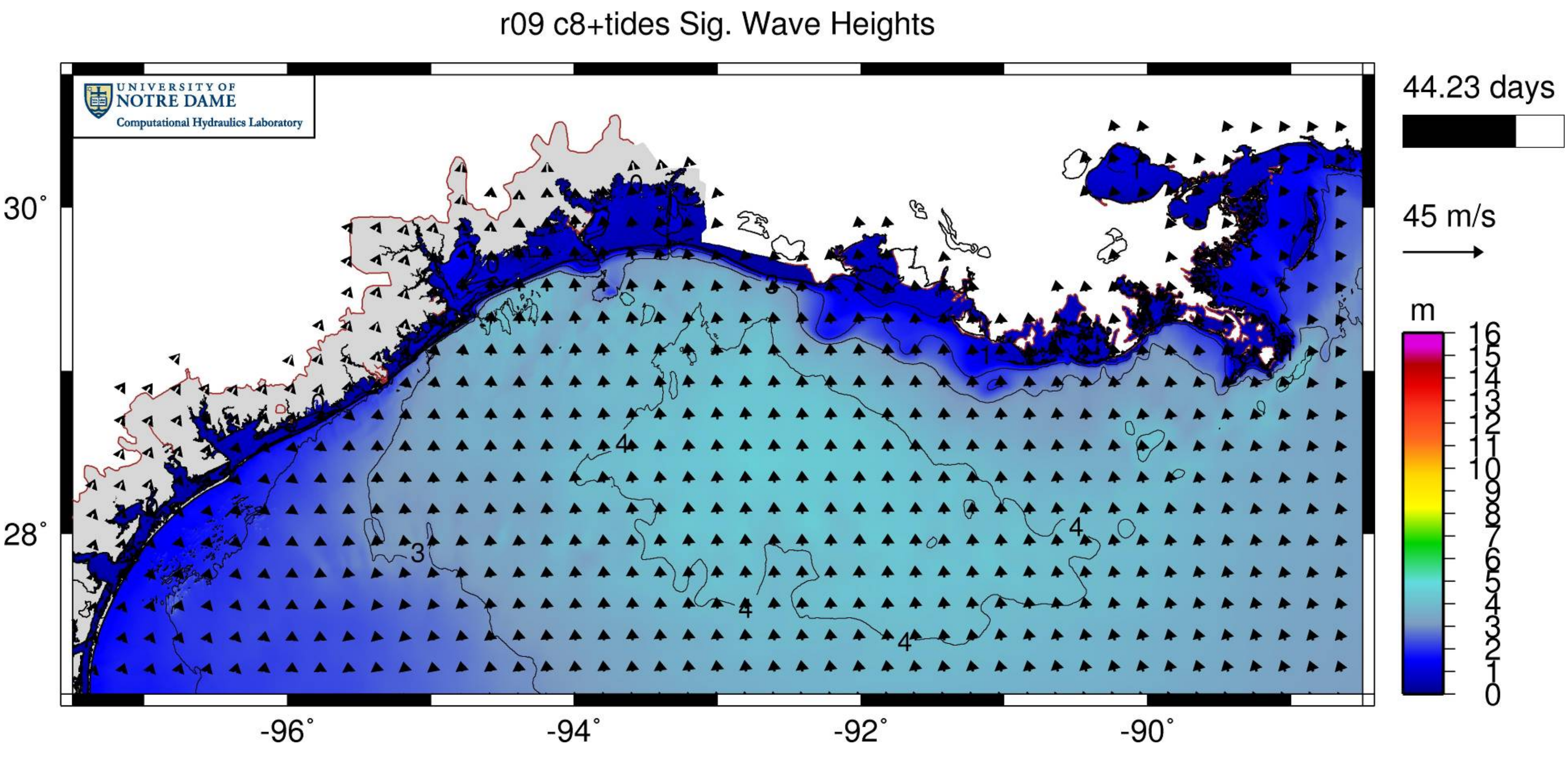
+ 8 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



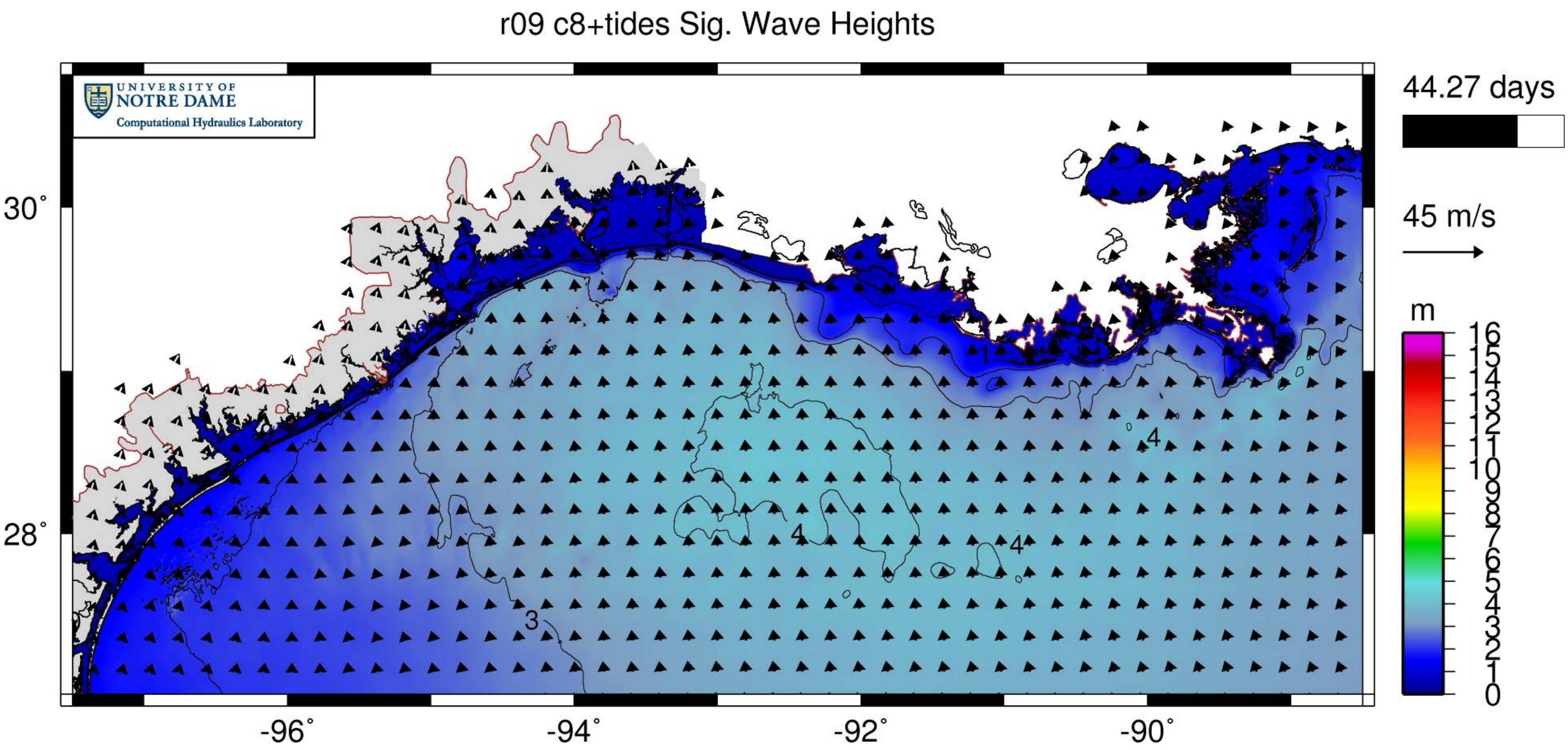
+ 9 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



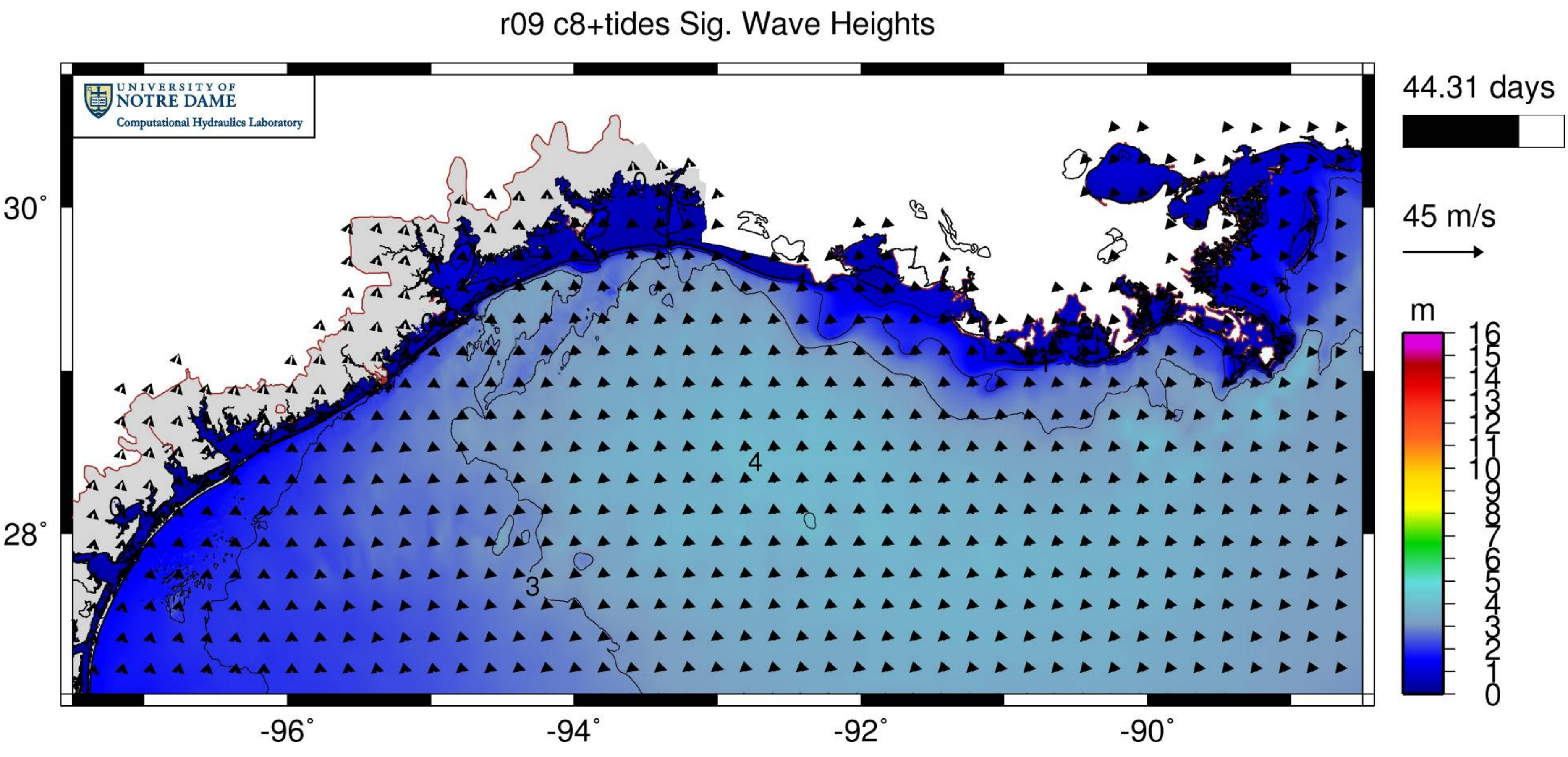
+ 10 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



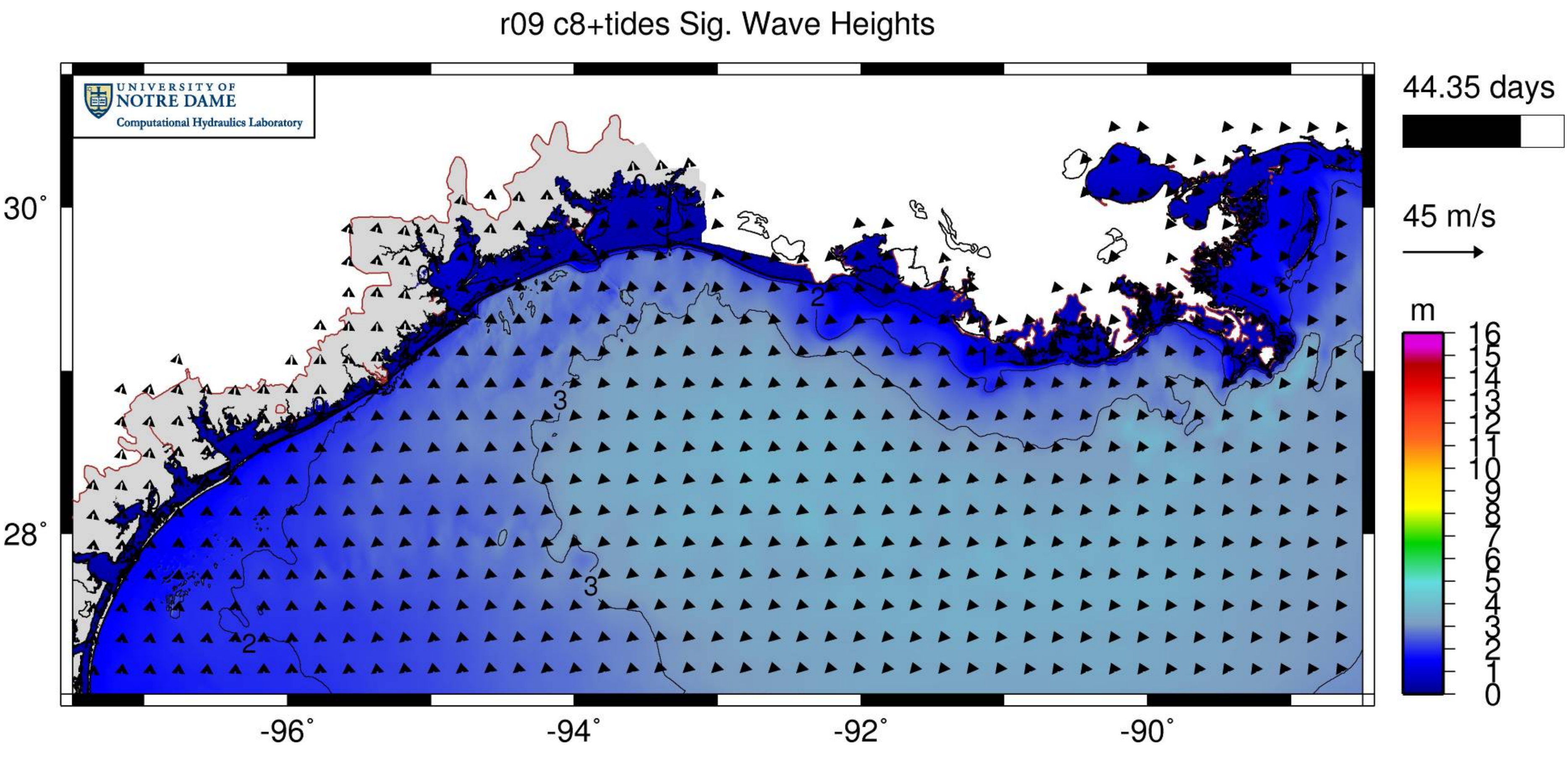
+ 11 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



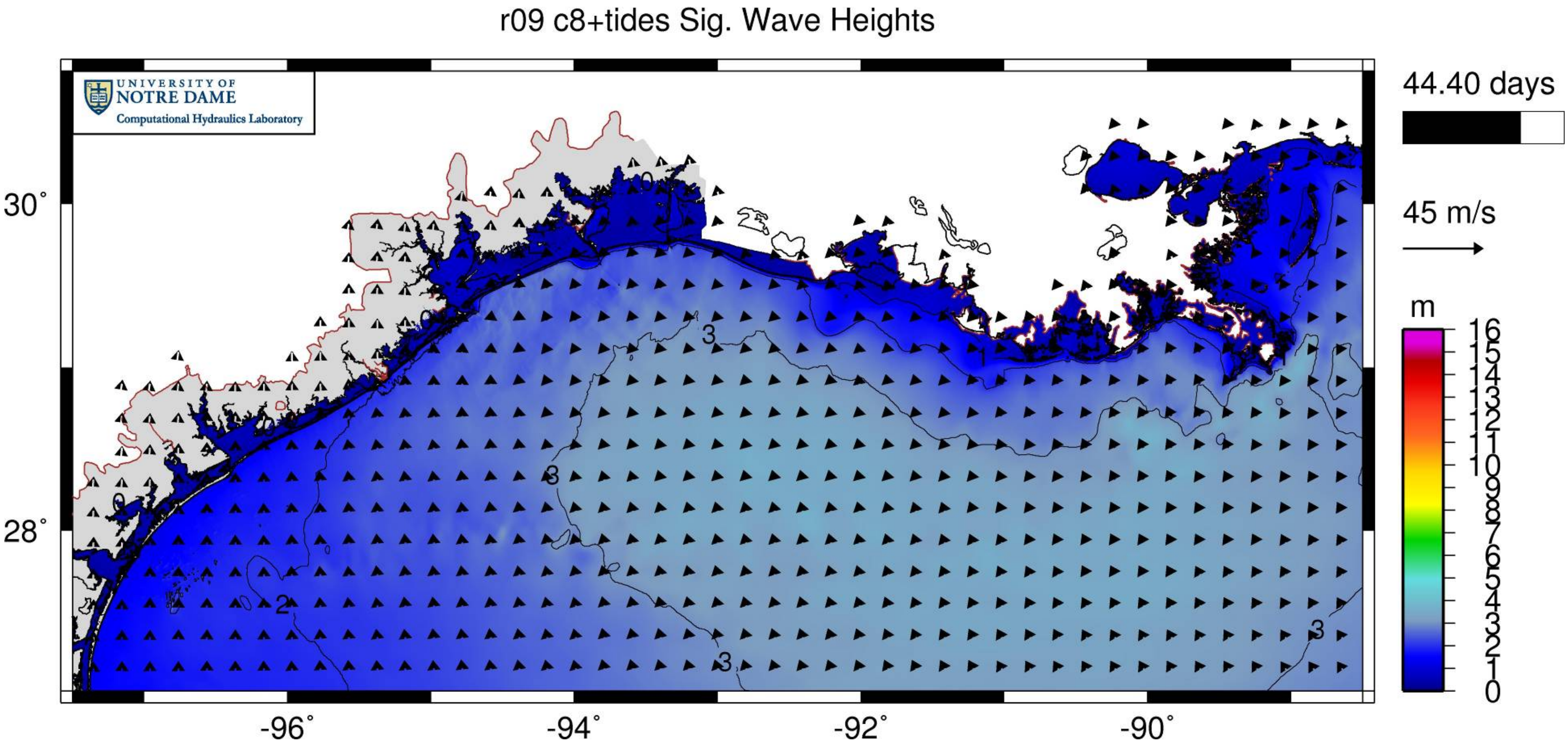
+ 12 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



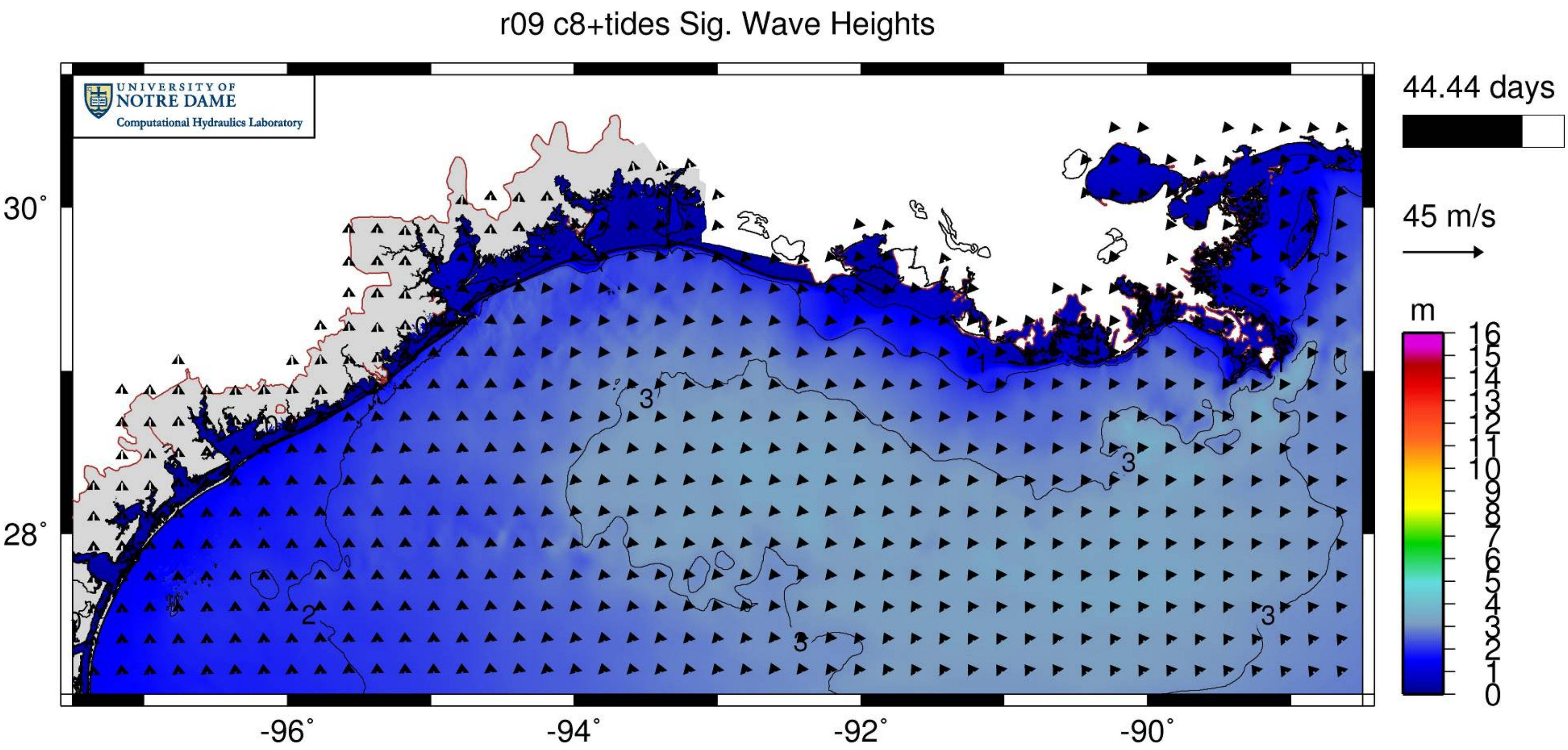
+ 13 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



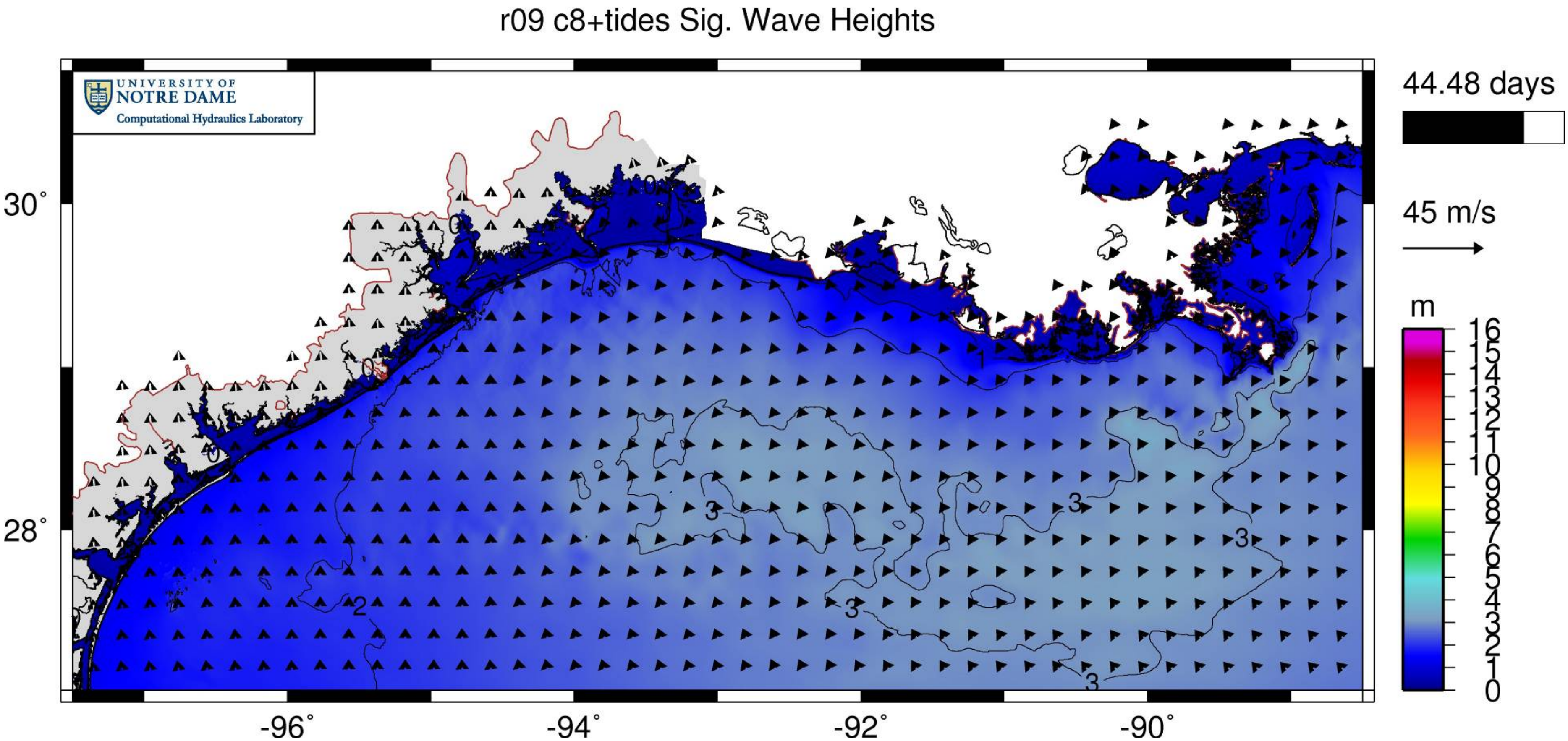
+ 14 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



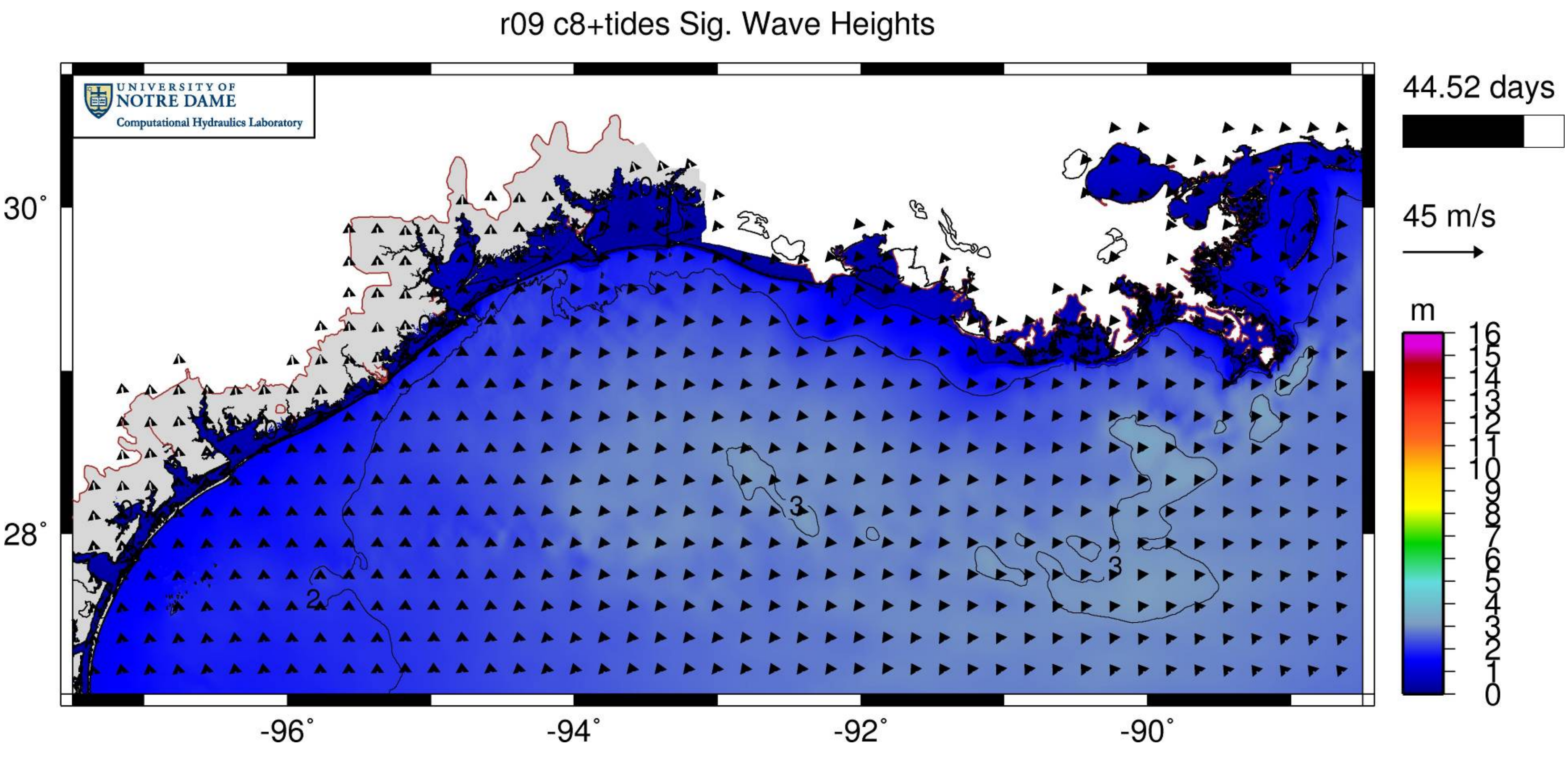
+ 15 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



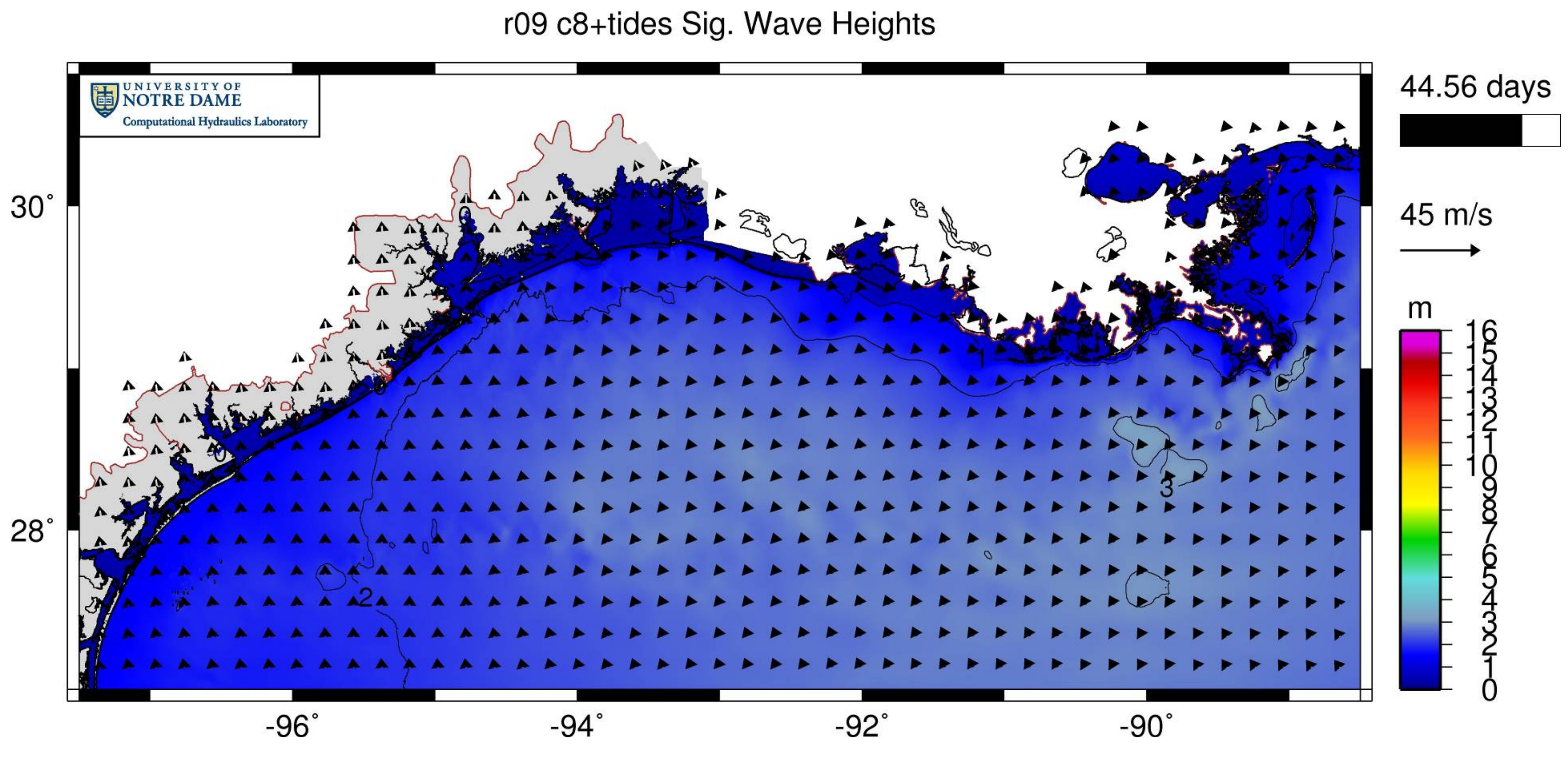
+ 16 hrs

Ike significant wave height contours (m) and wind vectors (m/s)

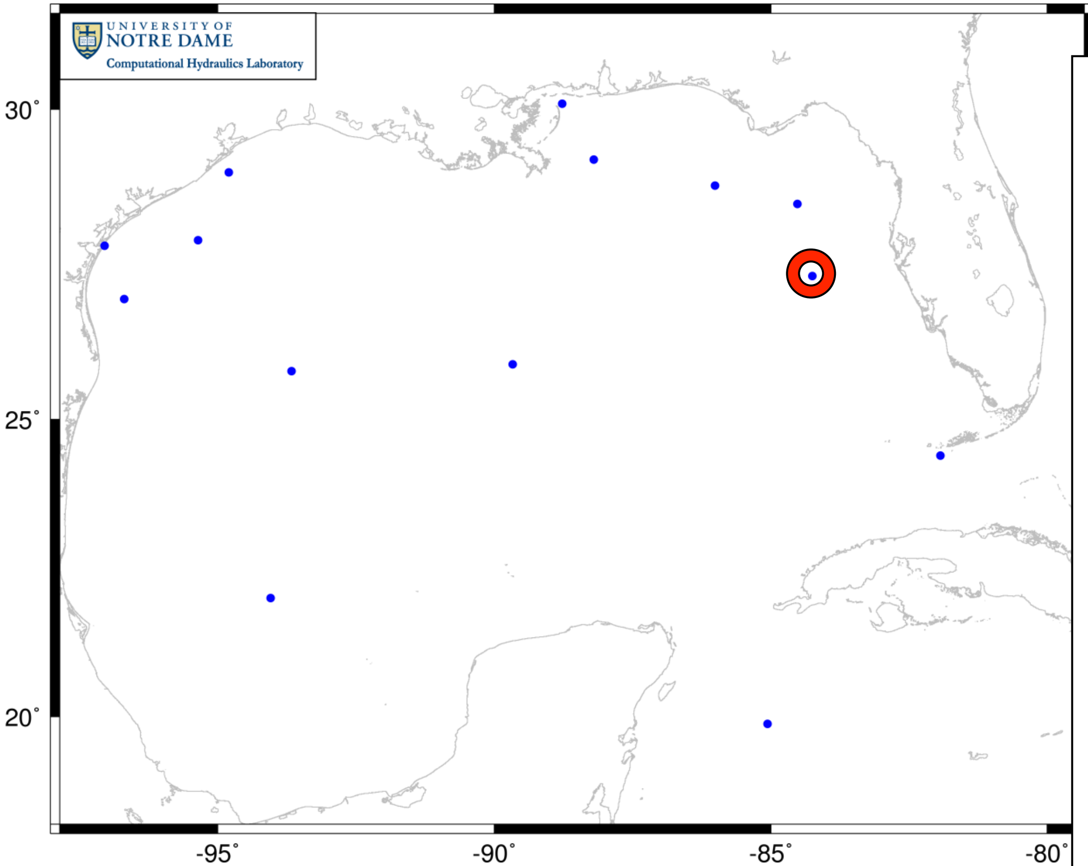


+ 17 hrs

Ike significant wave height contours (m) and wind vectors (m/s)



+ 18 hrs


UNIVERSITY OF
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Computational Hydraulics Laboratory
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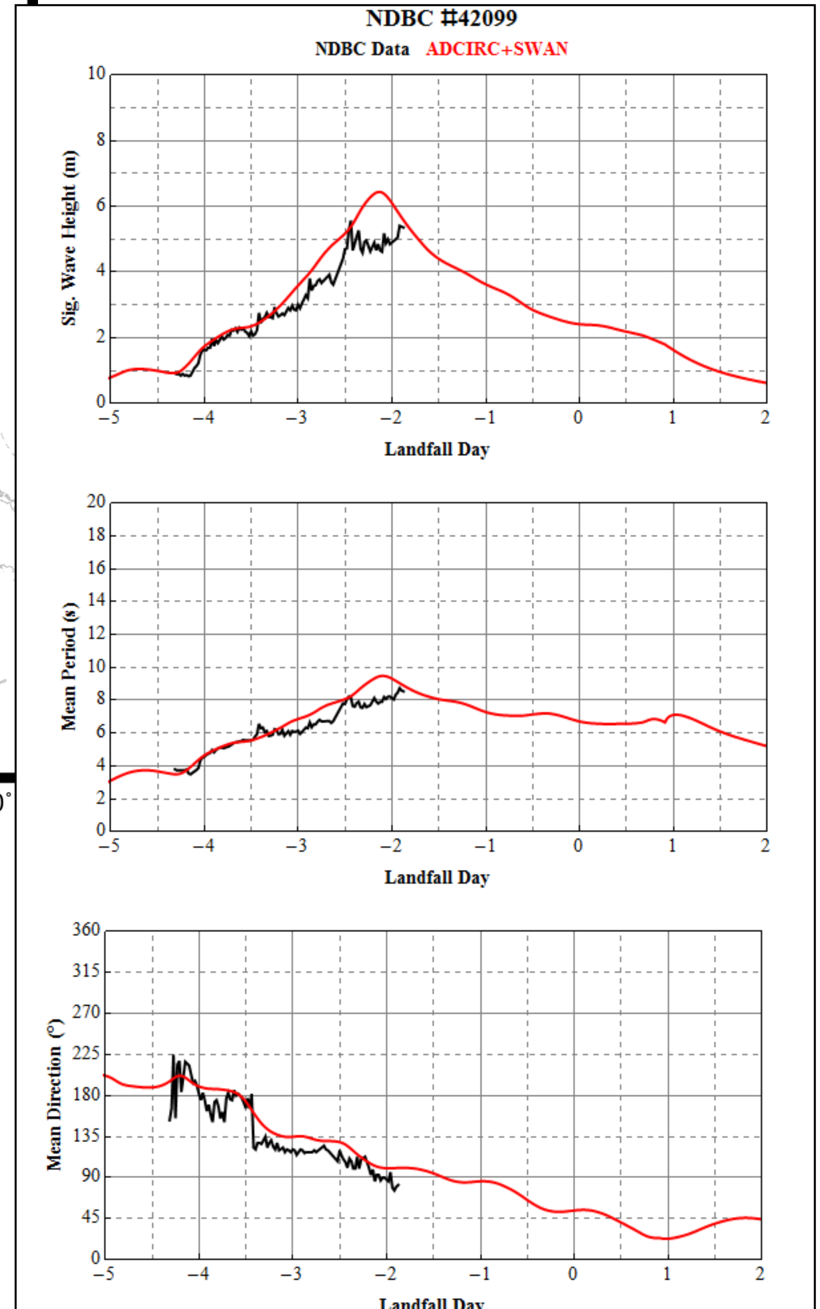
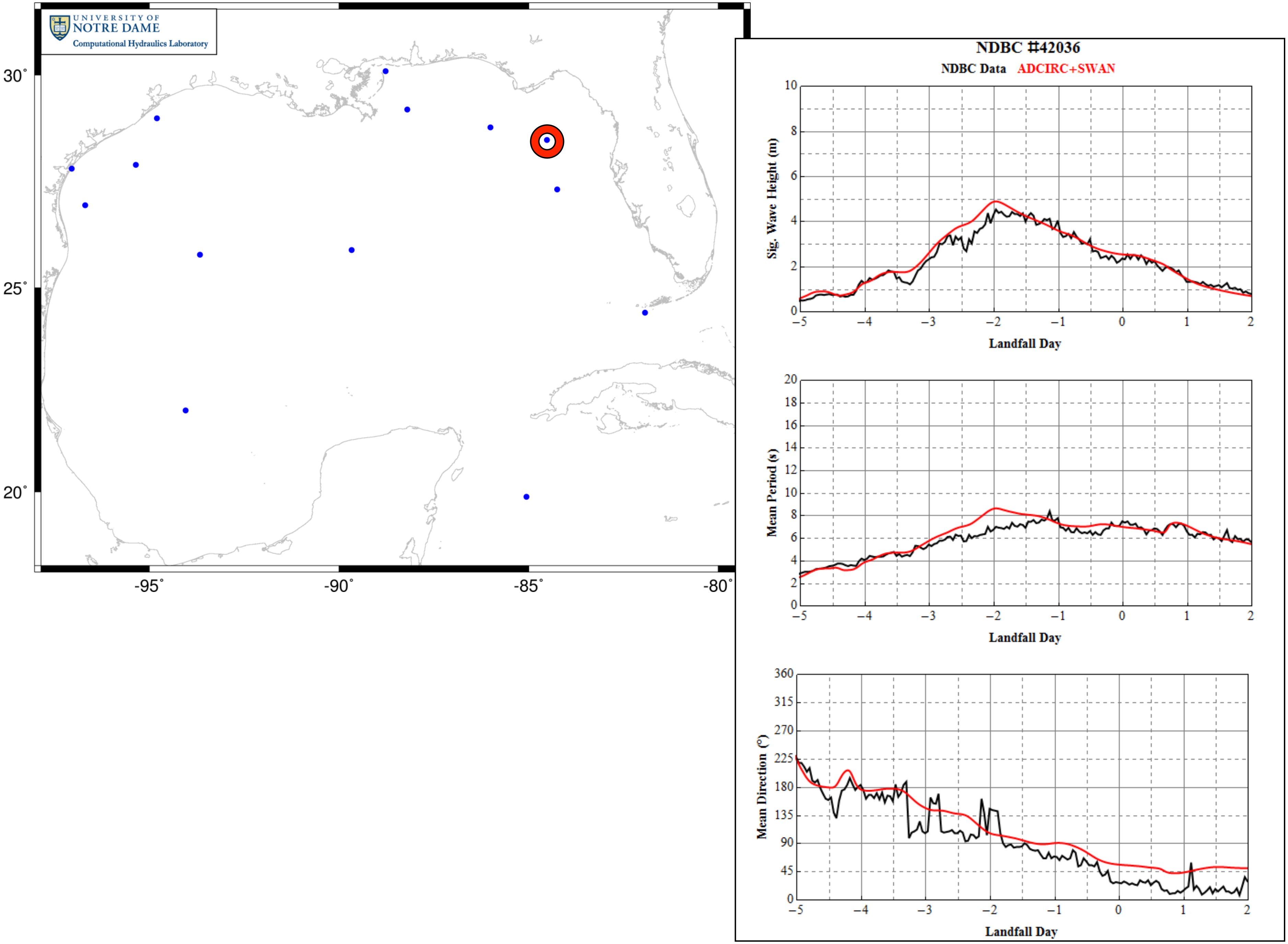

NDBC #42099
NDBC Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Day
Mean Period (s)
Landfall Day
Mean Direction (°)
Landfall Day



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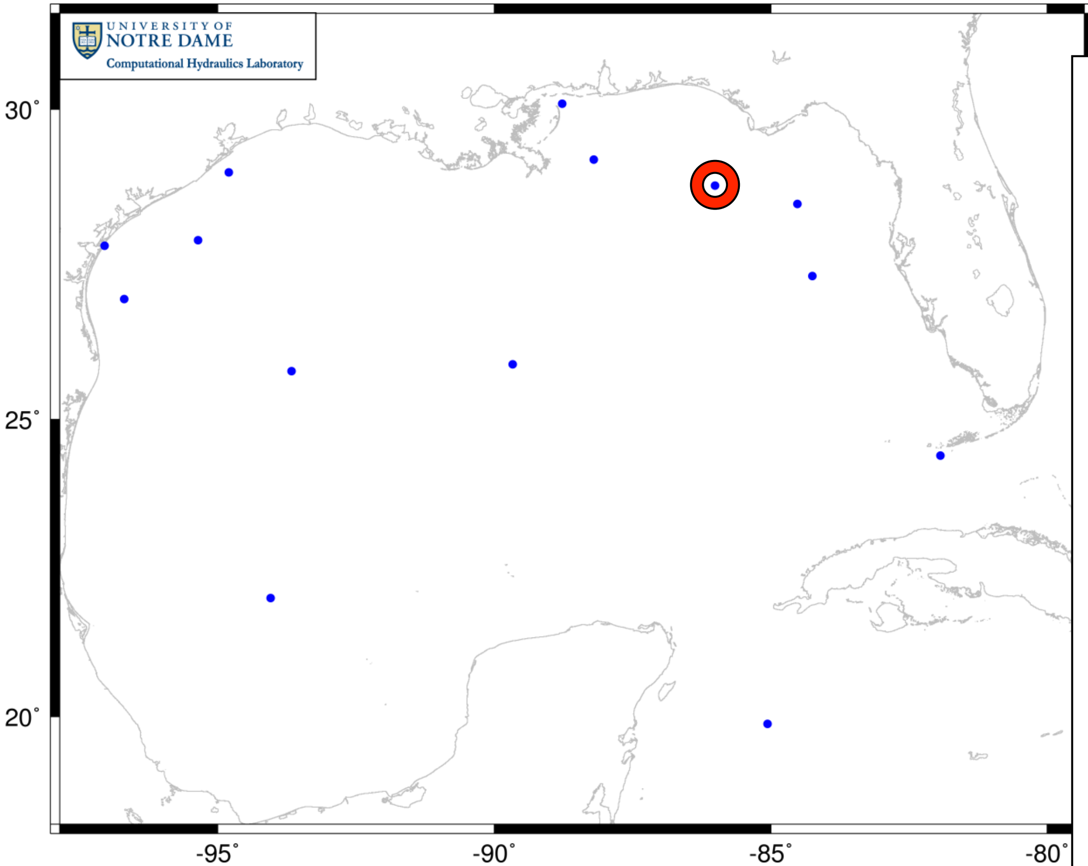
NDBC #42036
NDBC Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Day
Mean Period (s)
Landfall Day
Mean Direction (°)
Landfall Day


UNIVERSITY OF
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Computational Hydraulics Laboratory
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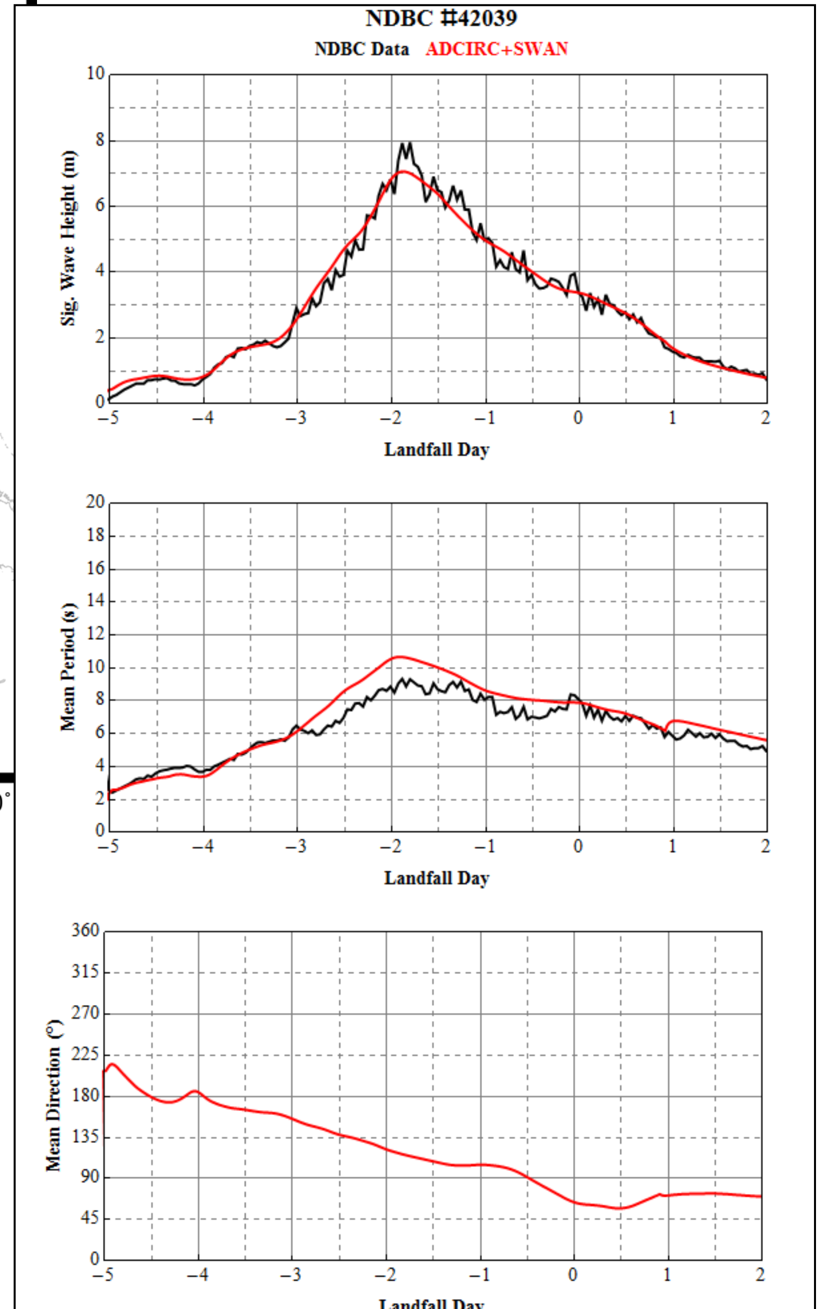
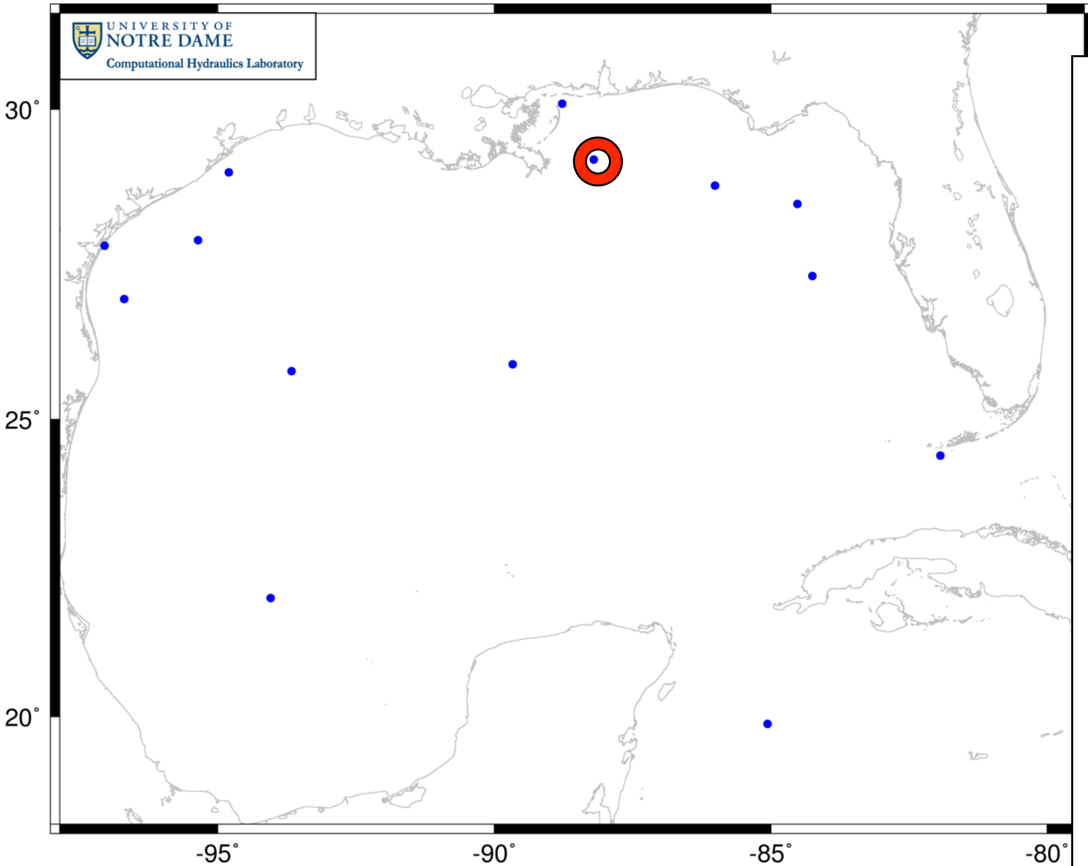

NDBC #42039
NDBC Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Day
Mean Period (s)
Landfall Day
Mean Direction (°)
Landfall Day


UNIVERSITY OF
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Computational Hydraulics Laboratory
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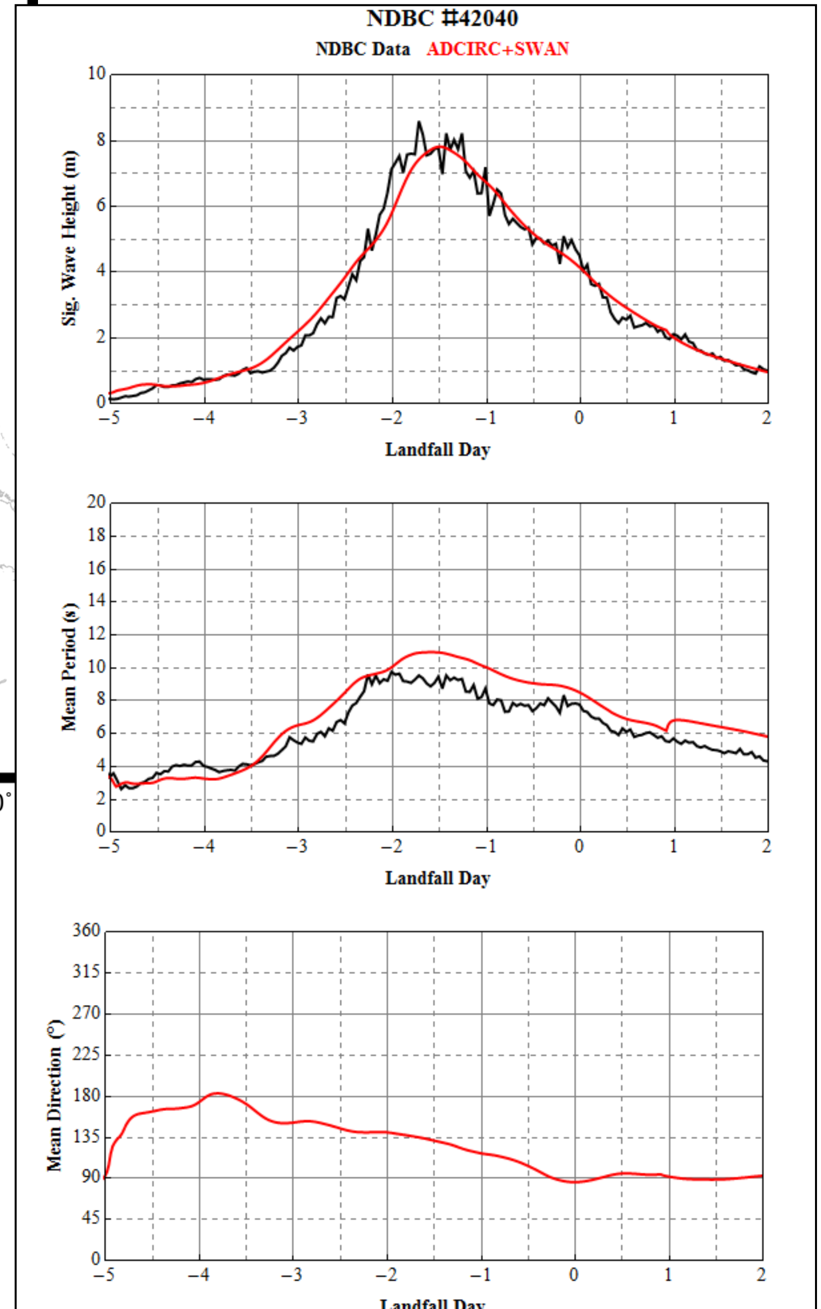
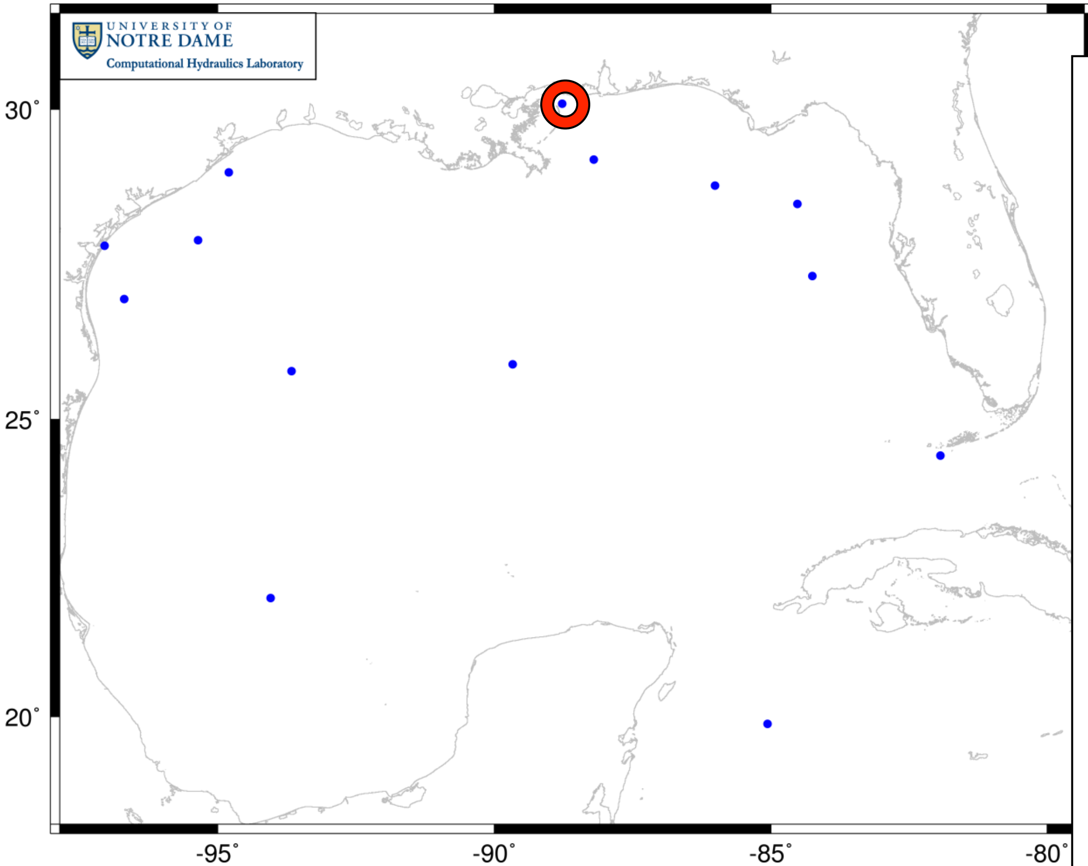

NDBC #42040
NDBC Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Day
Mean Period (s)
Landfall Day
Mean Direction (°)
Landfall Day


UNIVERSITY OF NOTRE DAME
Computational Hydraulics Laboratory
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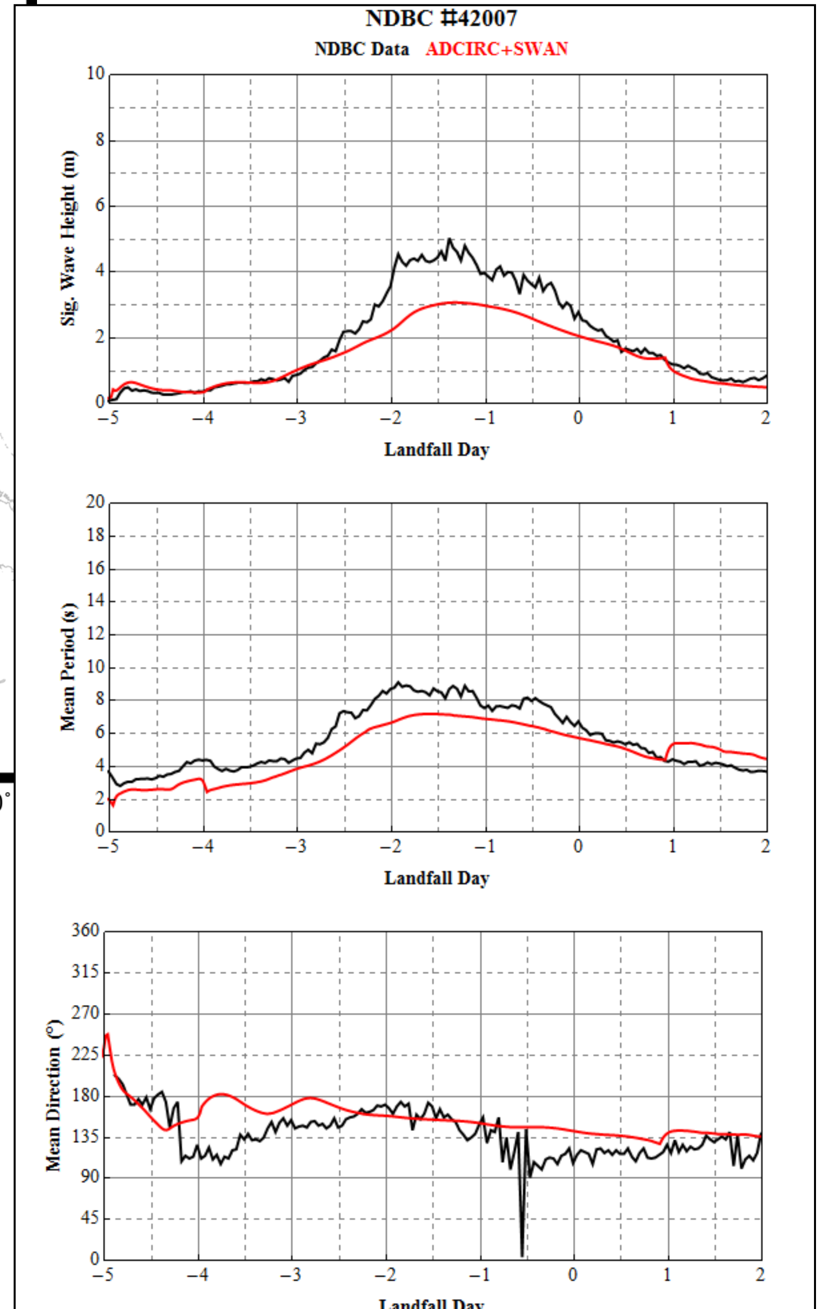
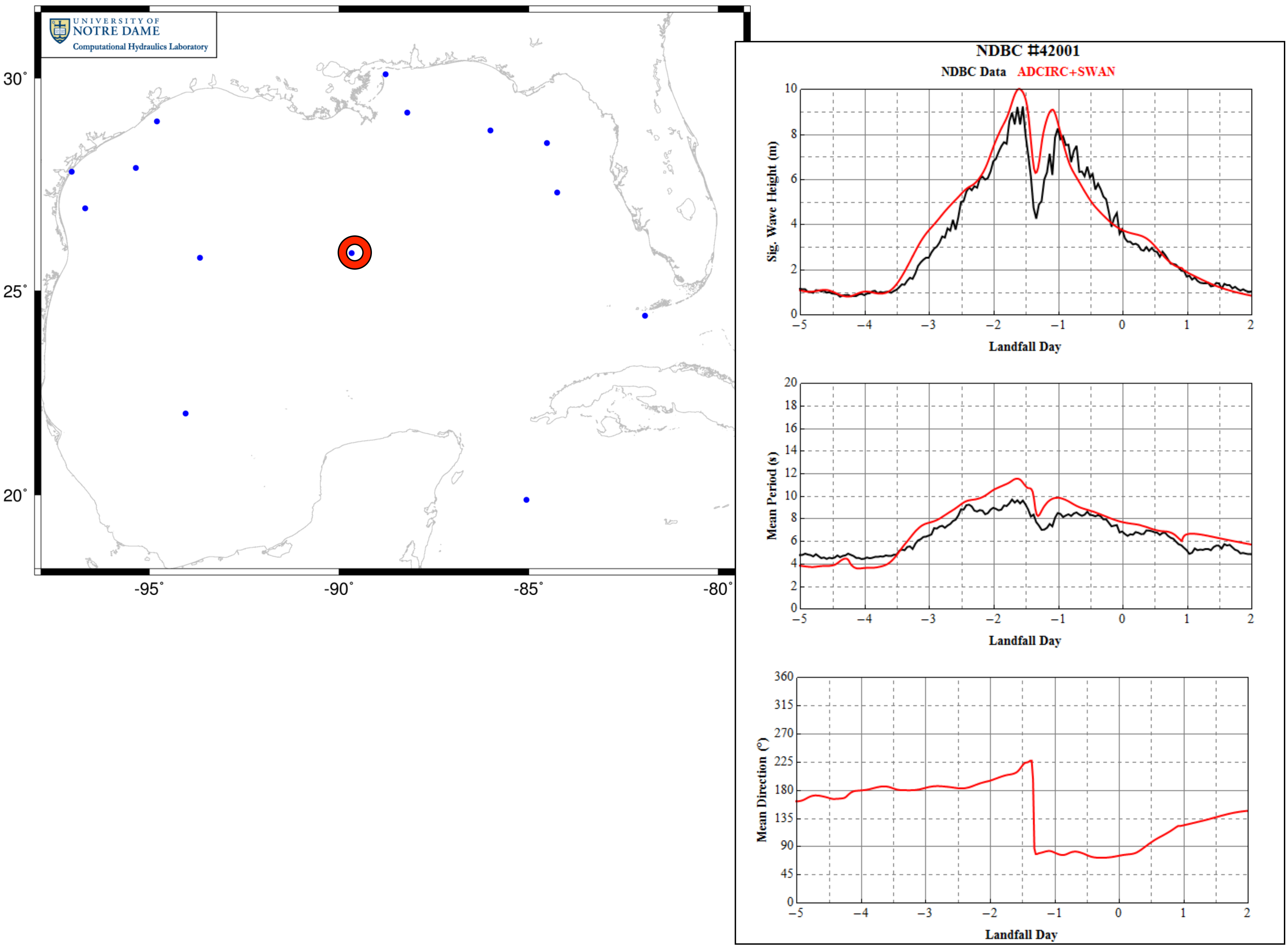

NDBC #42007
NDBC Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Day
Mean Period (s)
Landfall Day
Mean Direction (°)
Landfall Day



UNIVERSITY OF NOTRE DAME
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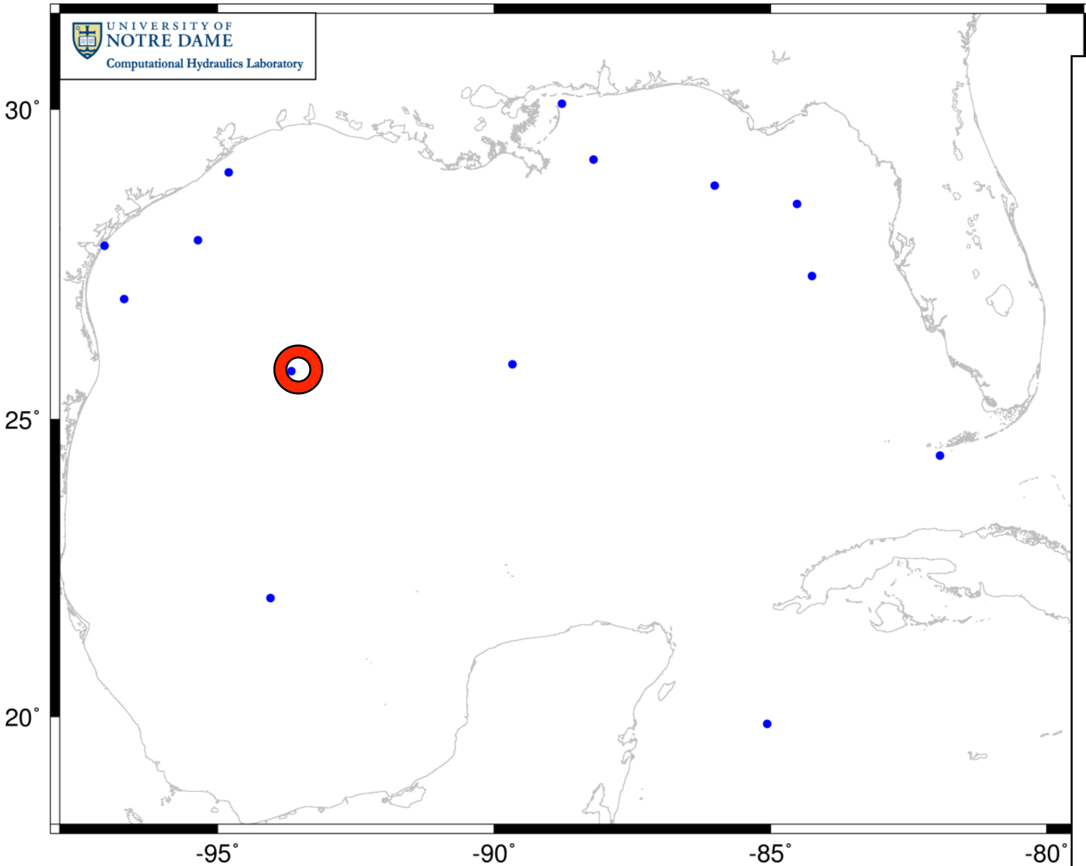
NDBC #42001
NDBC Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Day
Mean Period (s)
Landfall Day
Mean Direction (°)
Landfall Day


UNIVERSITY OF NOTRE DAME
Computational Hydraulics Laboratory
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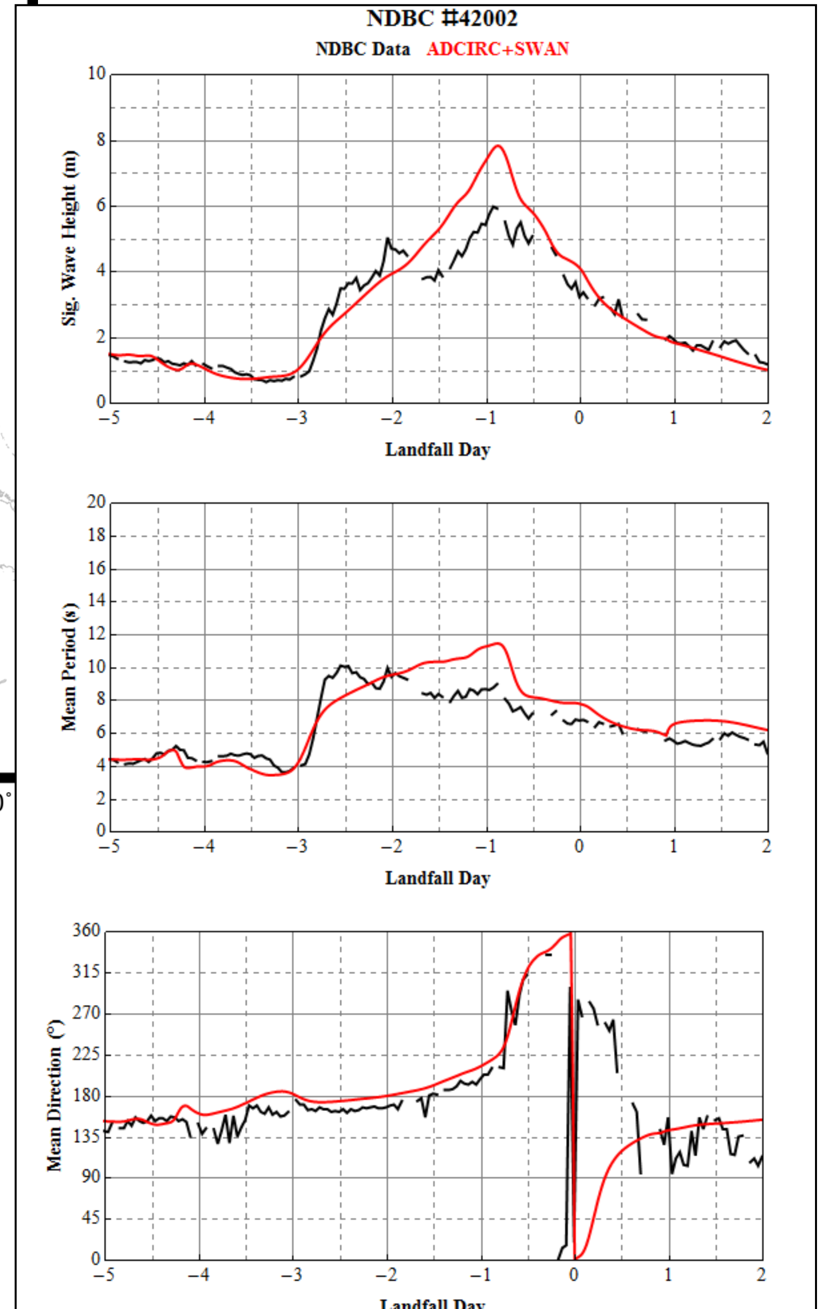
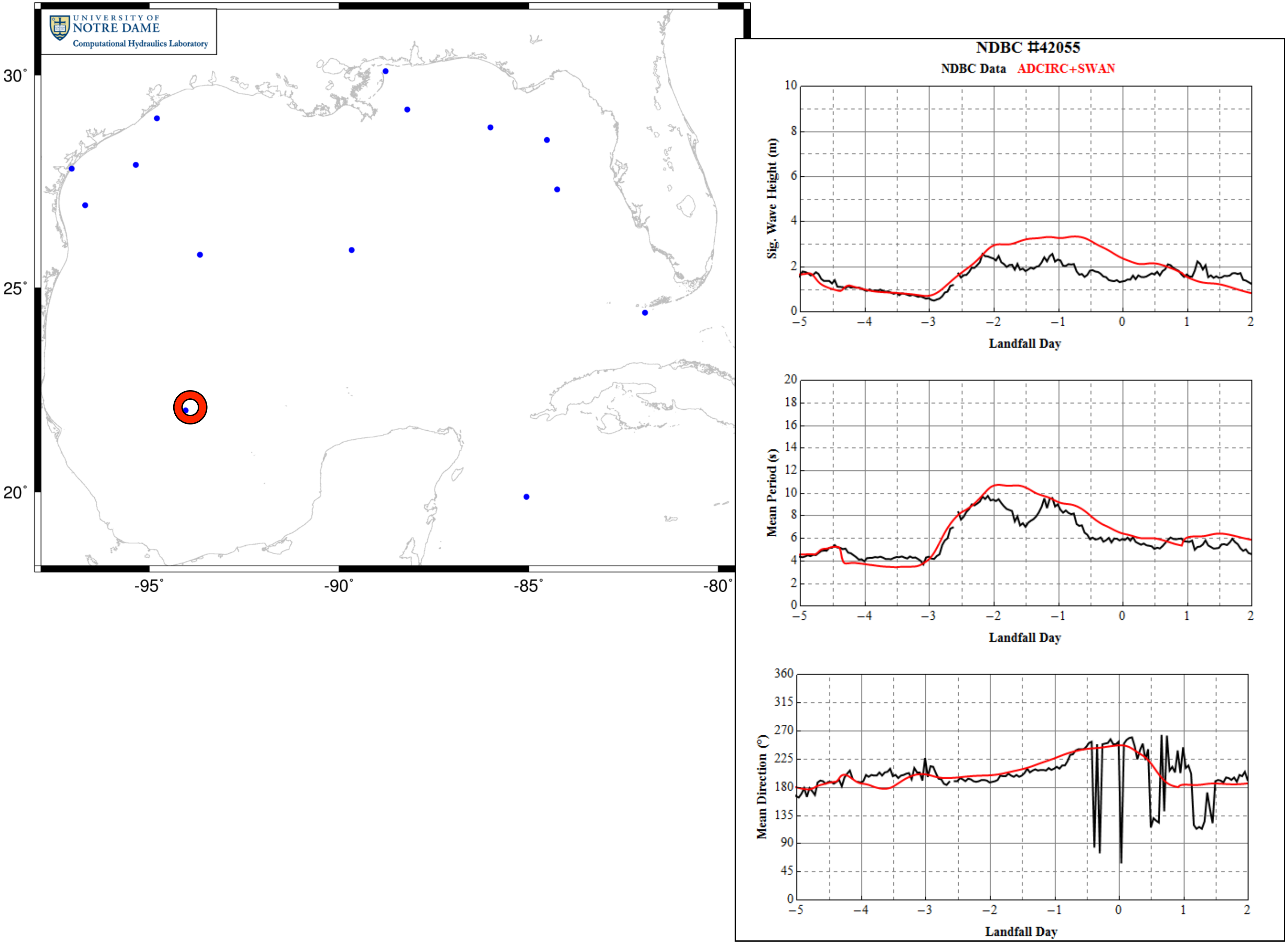

NDBC #42002
NDBC Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Day
Mean Period (s)
Landfall Day
Mean Direction (°)
Landfall Day


UNIVERSITY OF NOTRE DAME
Computational Hydraulics Laboratory
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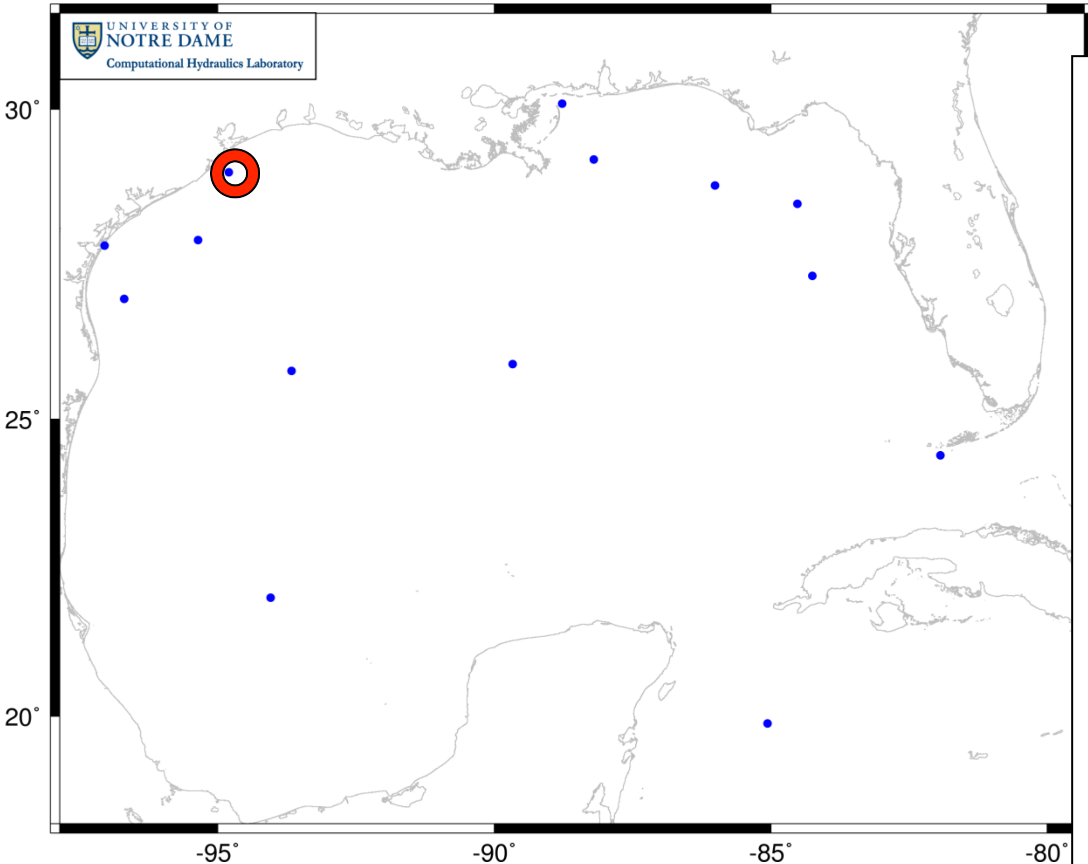
NDBC #42055
NDBC Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Day
Mean Period (s)
Landfall Day
Mean Direction (°)
Landfall Day


UNIVERSITY OF
NOTRE DAME
Computational Hydraulics Laboratory
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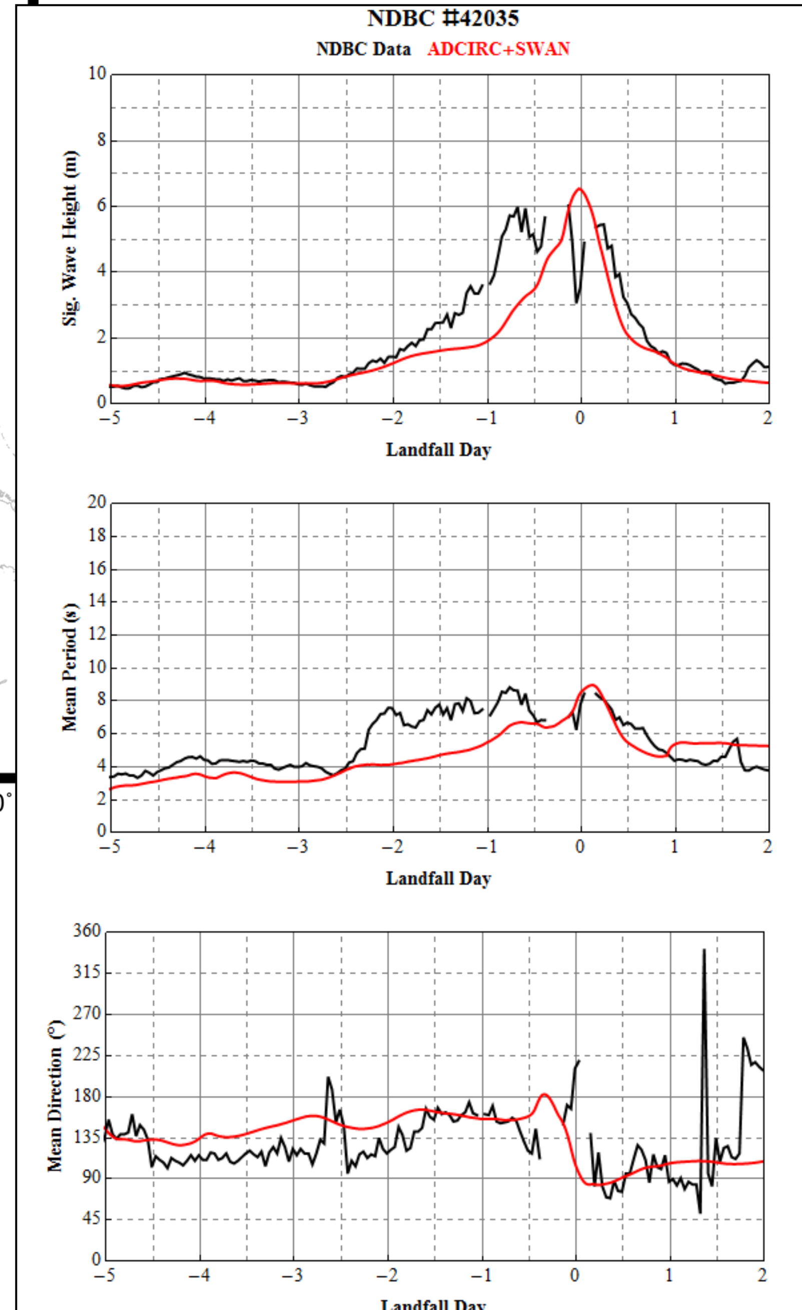
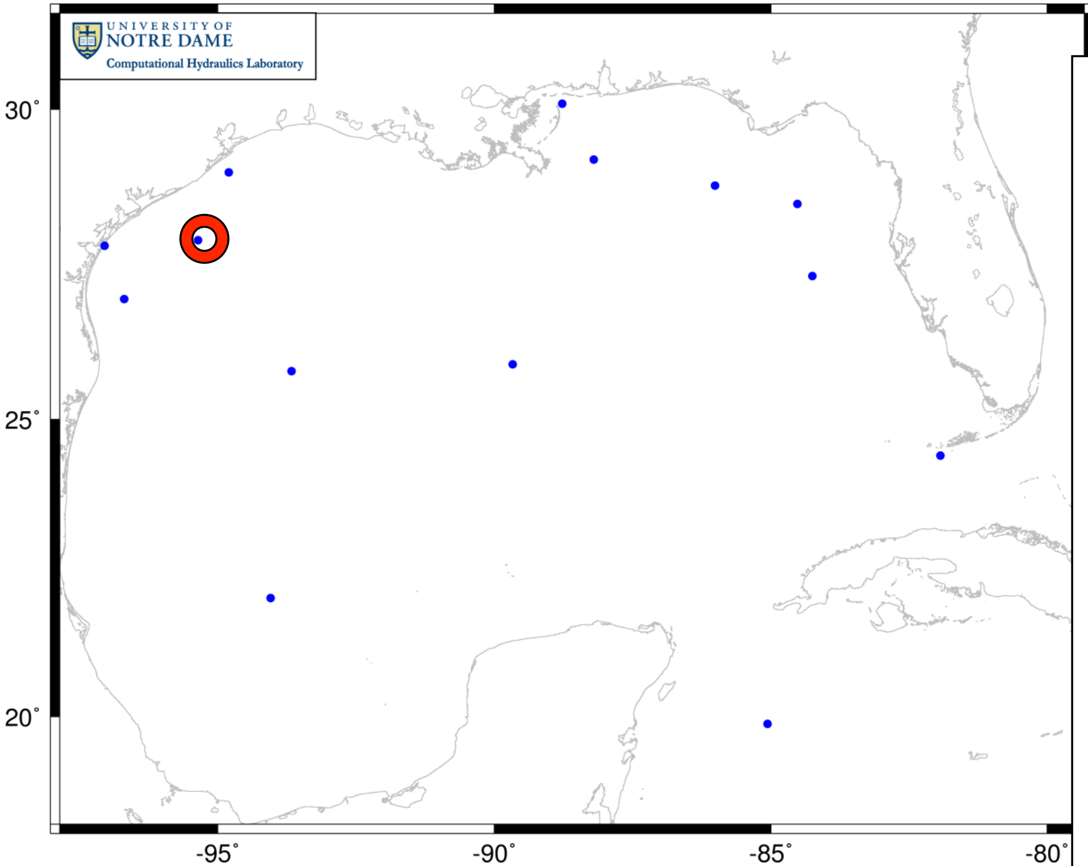

NDBC #42035
NDBC Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Day
Mean Period (s)
Landfall Day
Mean Direction (°)
Landfall Day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Computational Hydraulics Laboratory
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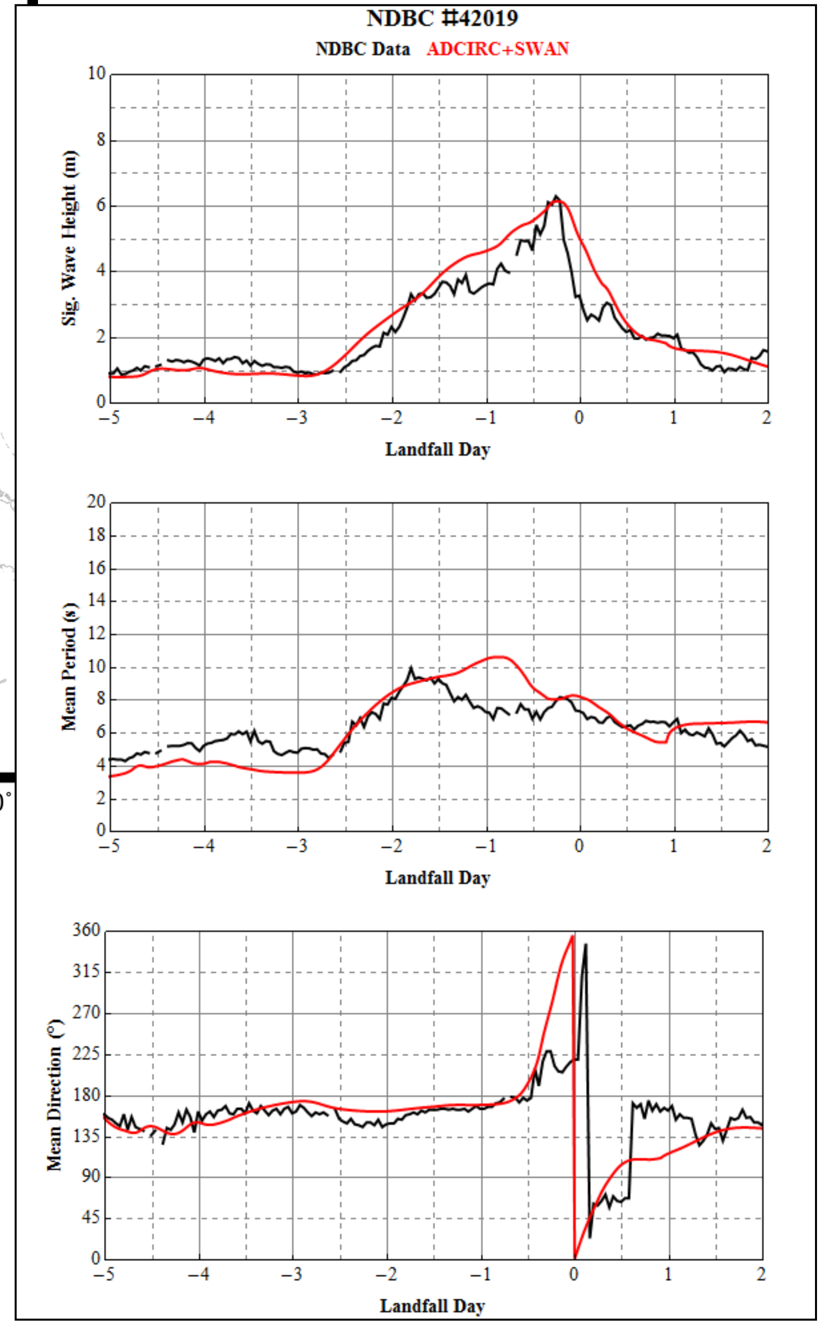
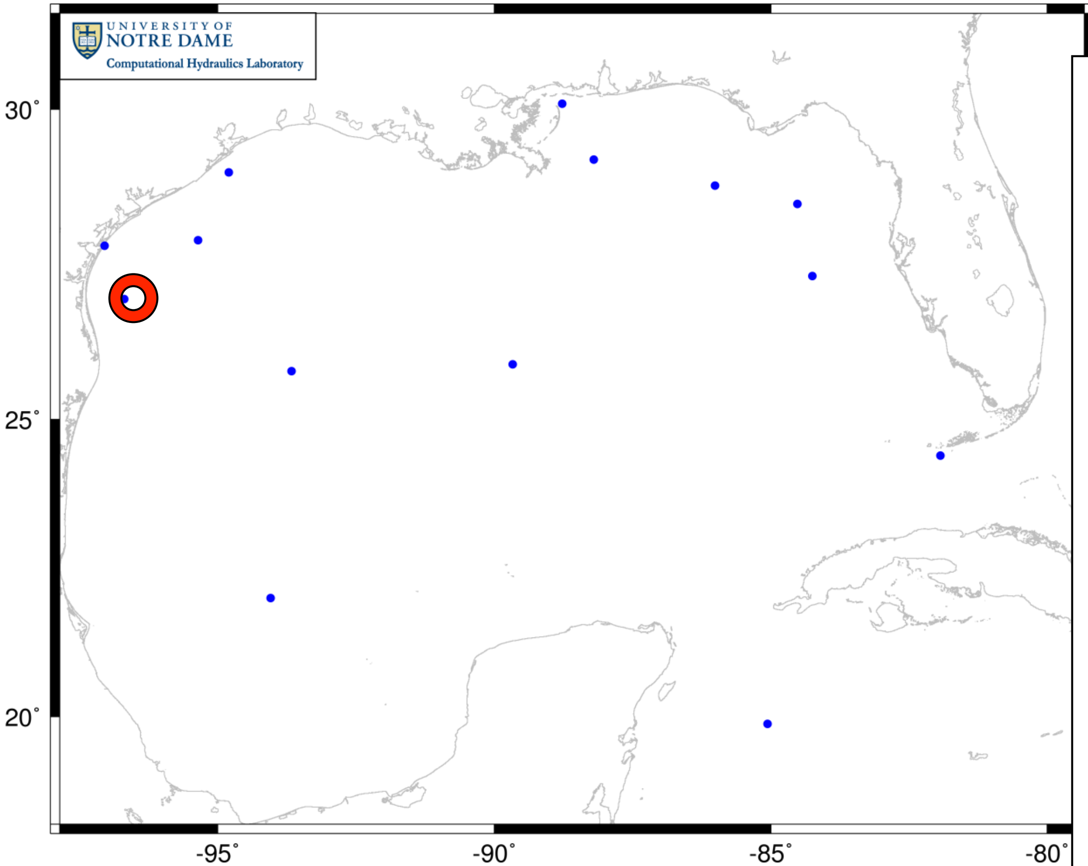

NDBC #42019
NDBC Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Day
Mean Period (s)
Landfall Day
Mean Direction (°)
Landfall Day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Computational Hydraulics Laboratory
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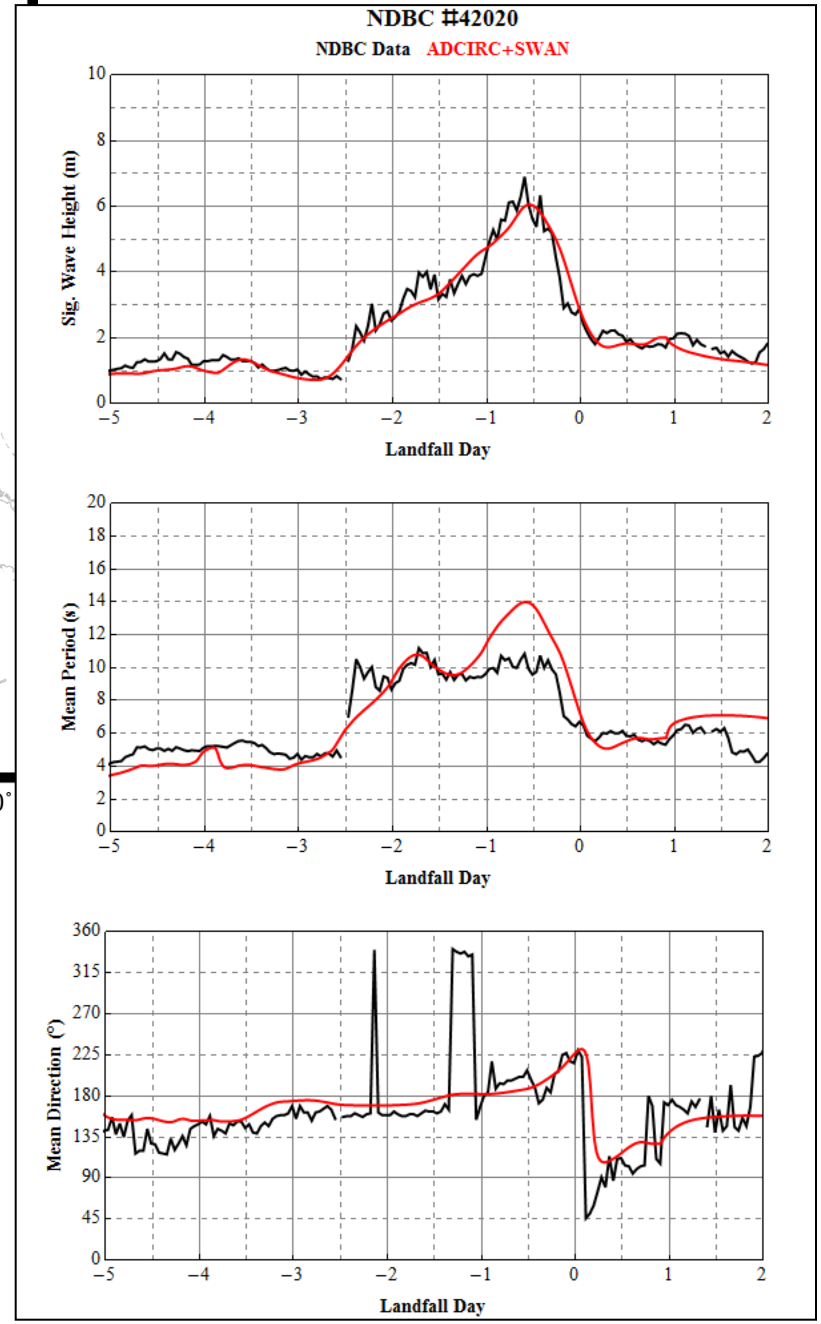
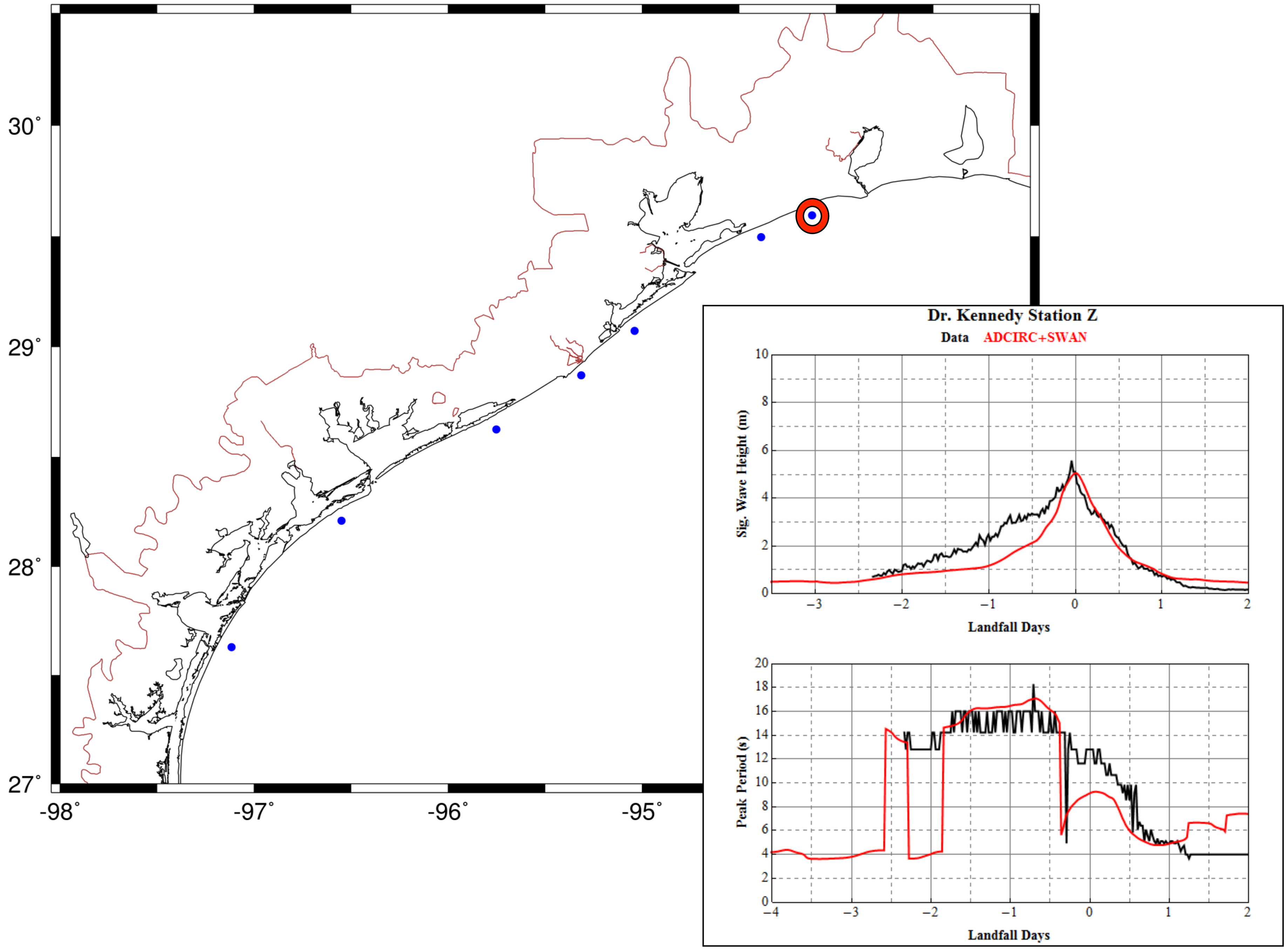

NDBC #42020
NDBC Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Day
Mean Period (s)
Landfall Day
Mean Direction (°)
Landfall Day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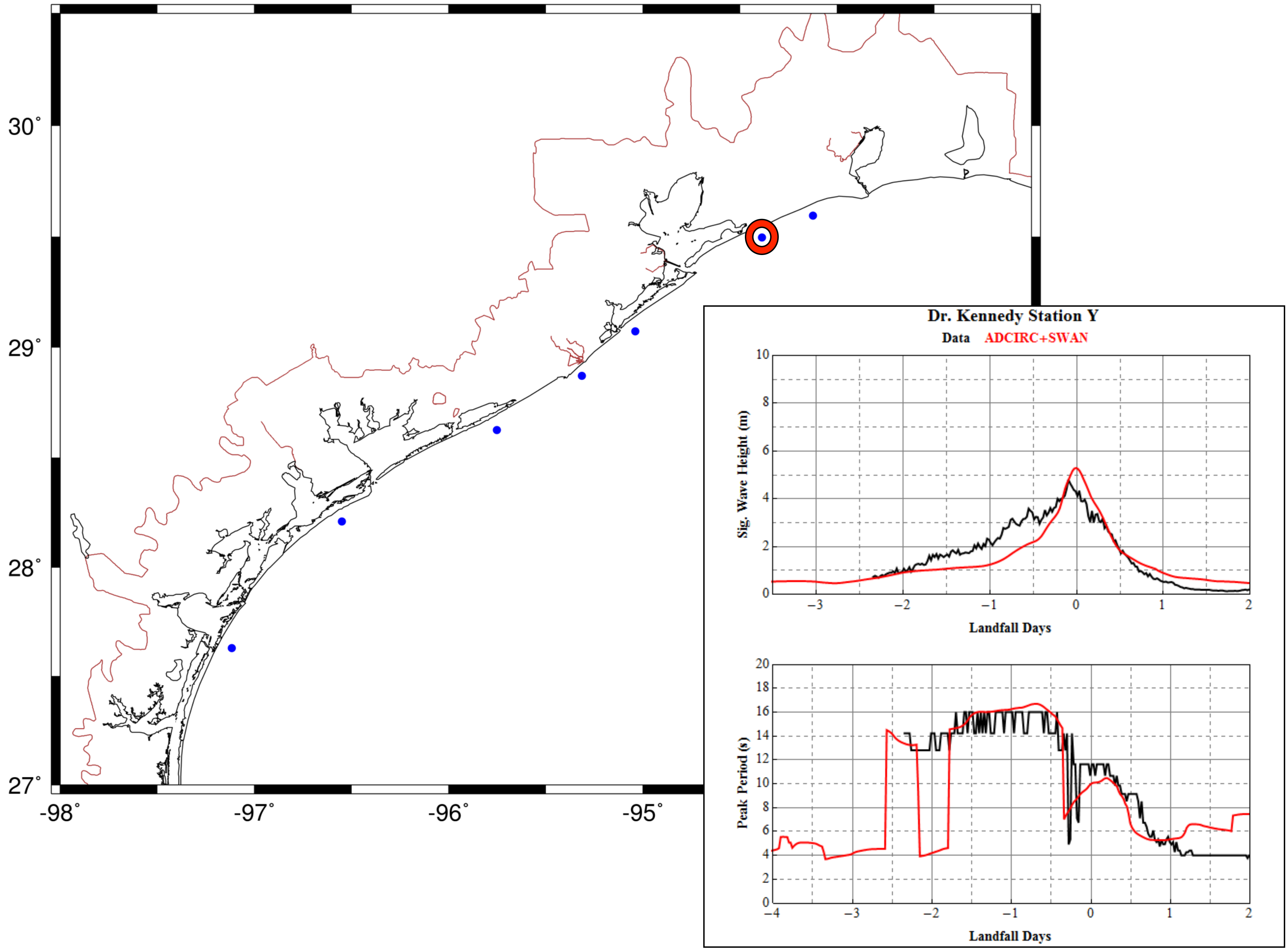
Dr. Kennedy Station Z
Data ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Days
Peak Period (s)
Landfall Days



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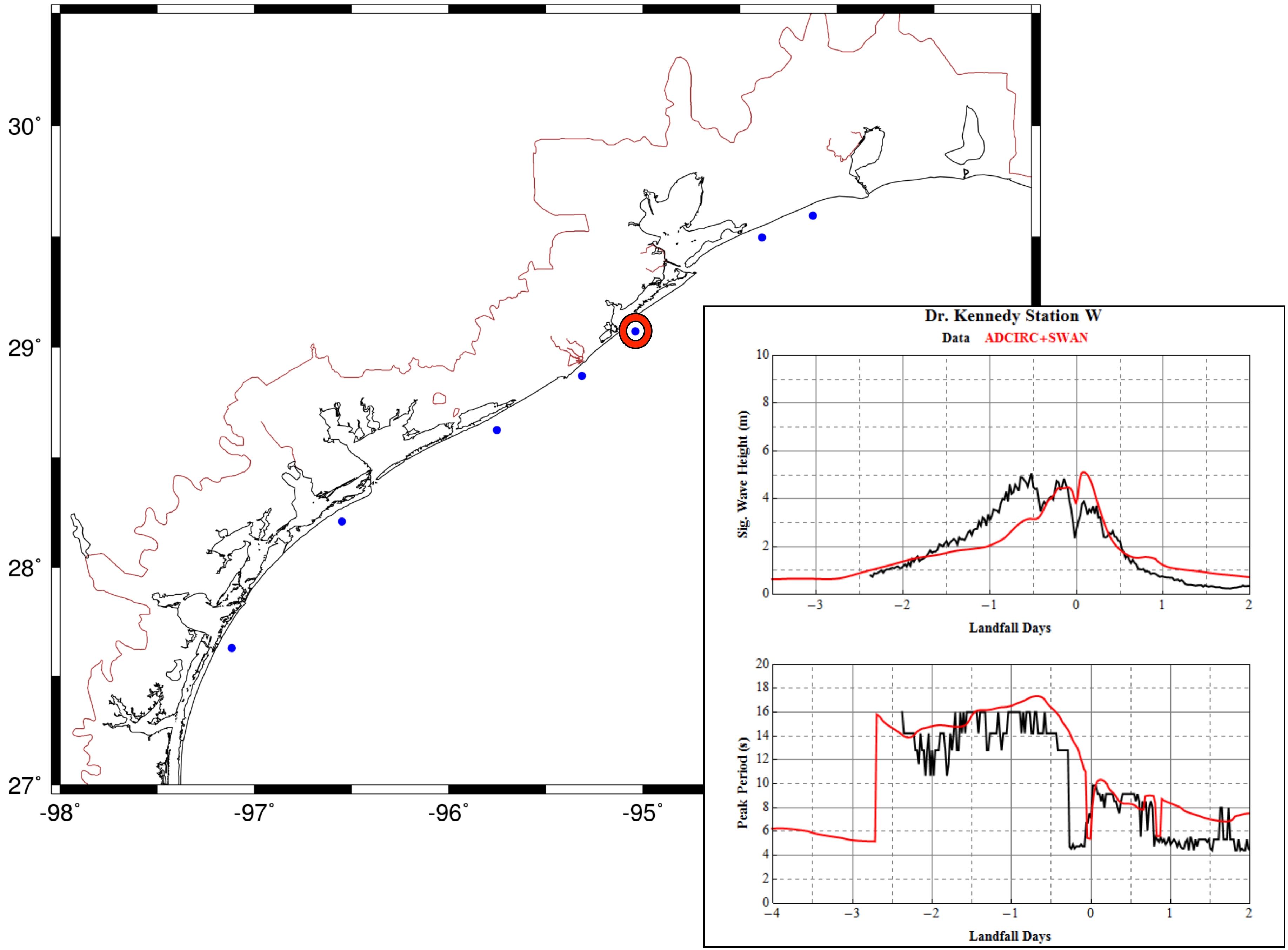
Dr. Kennedy Station Y
Data ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Days
Peak Period (s)
Landfall Days



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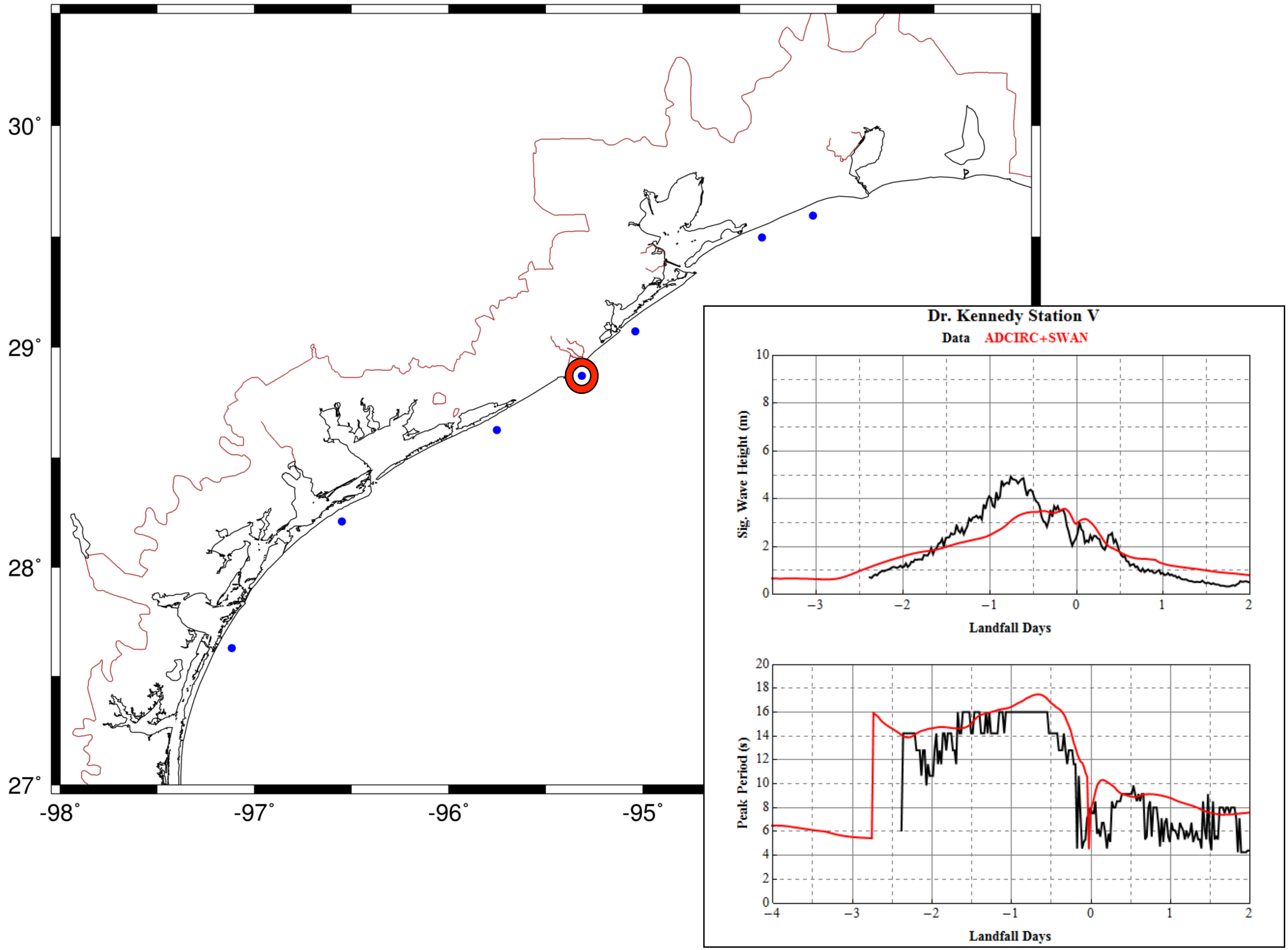
Dr. Kennedy Station W
Data
ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Days
Peak Period (s)
Landfall Days



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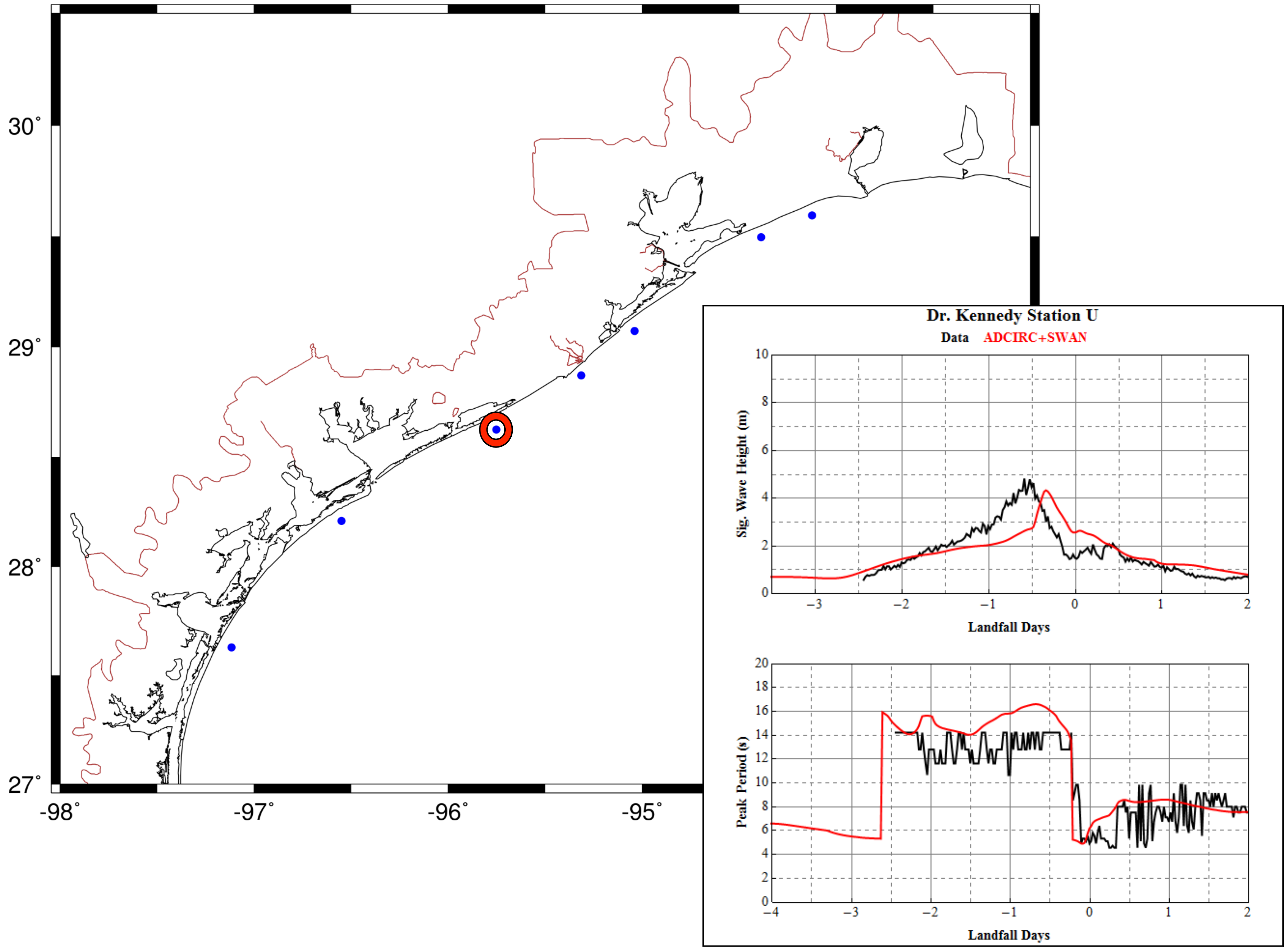
Dr. Kennedy Station V
Data ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Days
Peak Period (s)
Landfall Days



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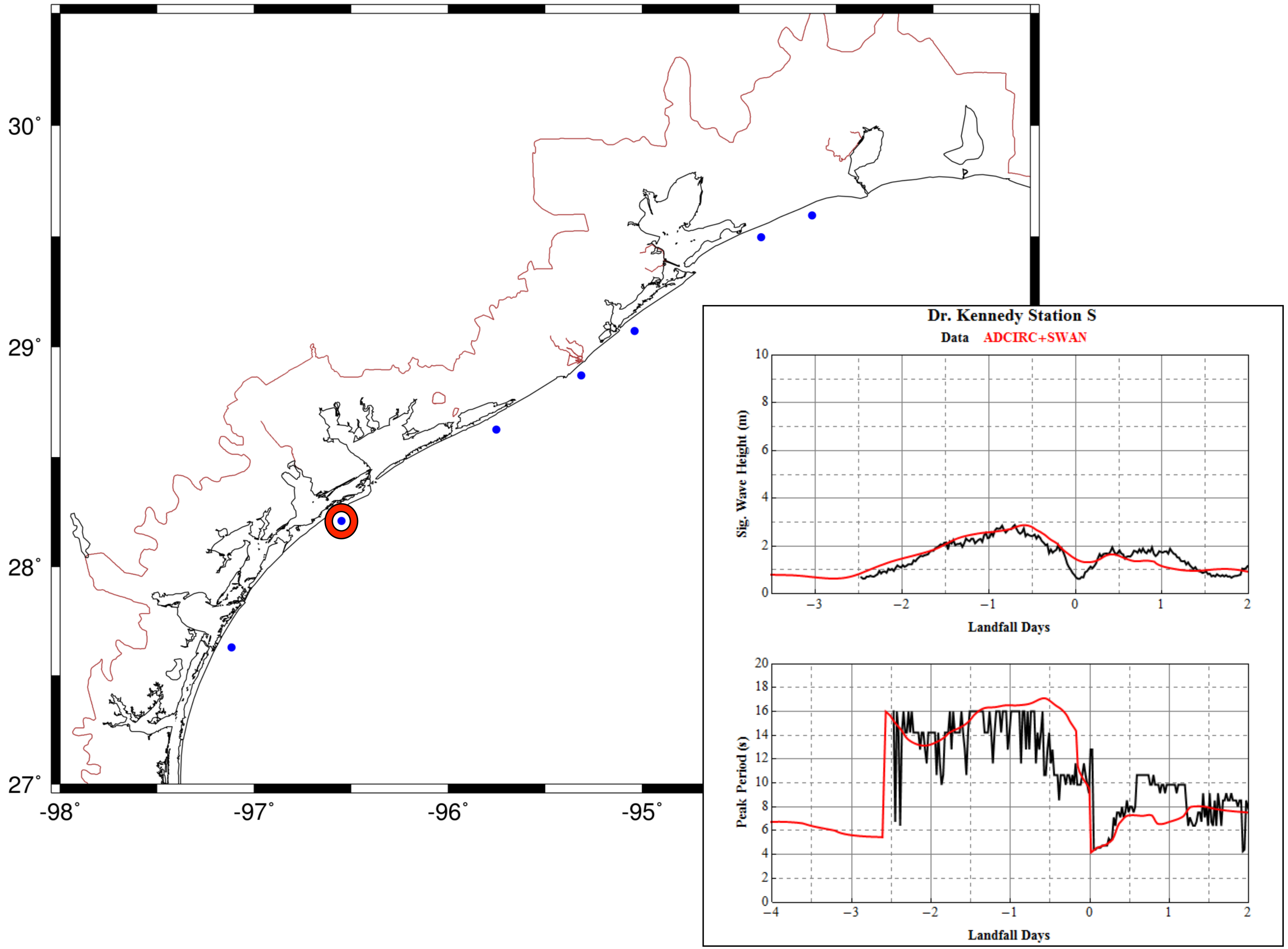
Dr. Kennedy Station U
Data ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Days
Peak Period (s)
Landfall Days



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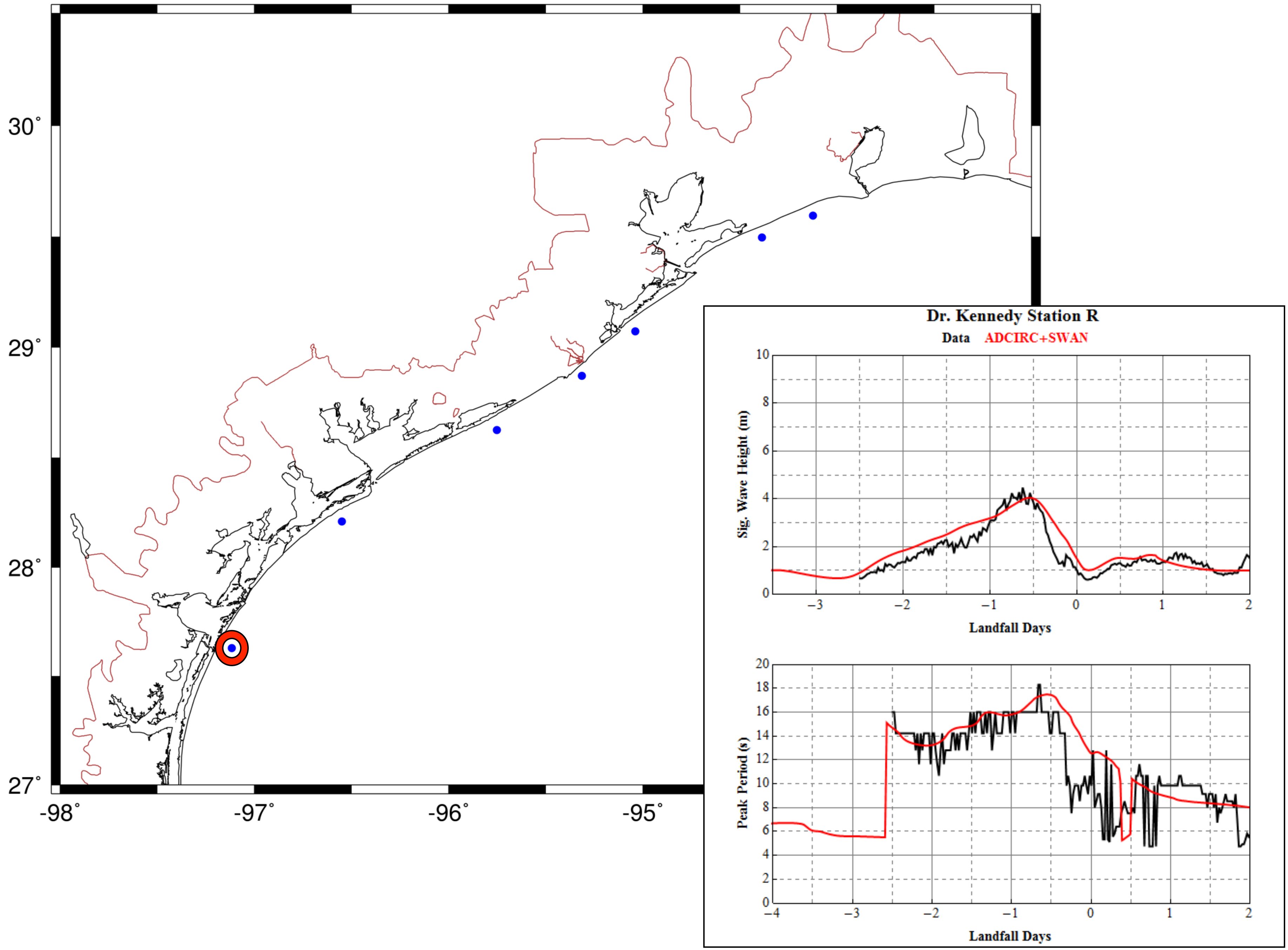
Dr. Kennedy Station S
Data ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Days
Peak Period (s)
Landfall Days



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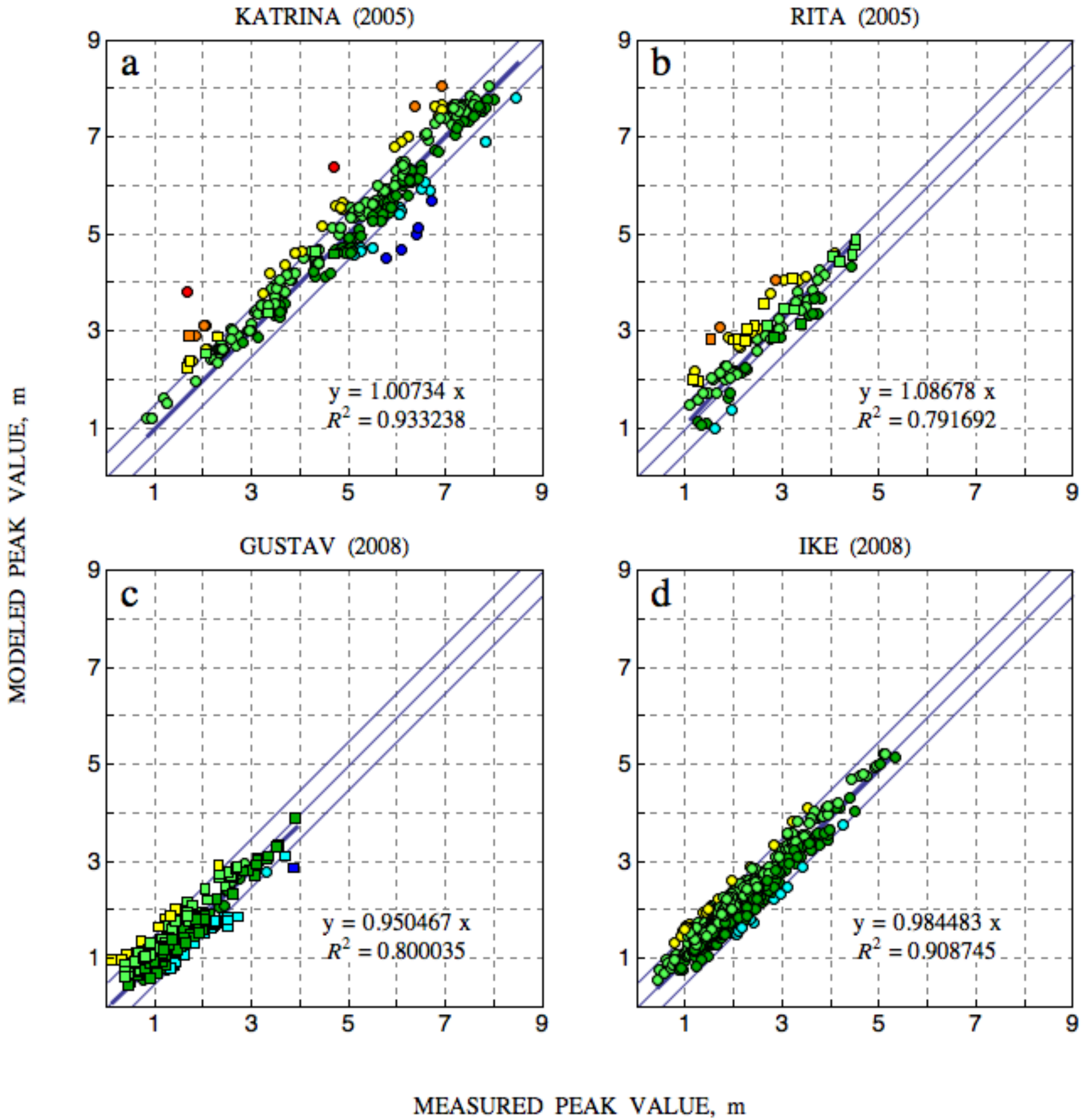
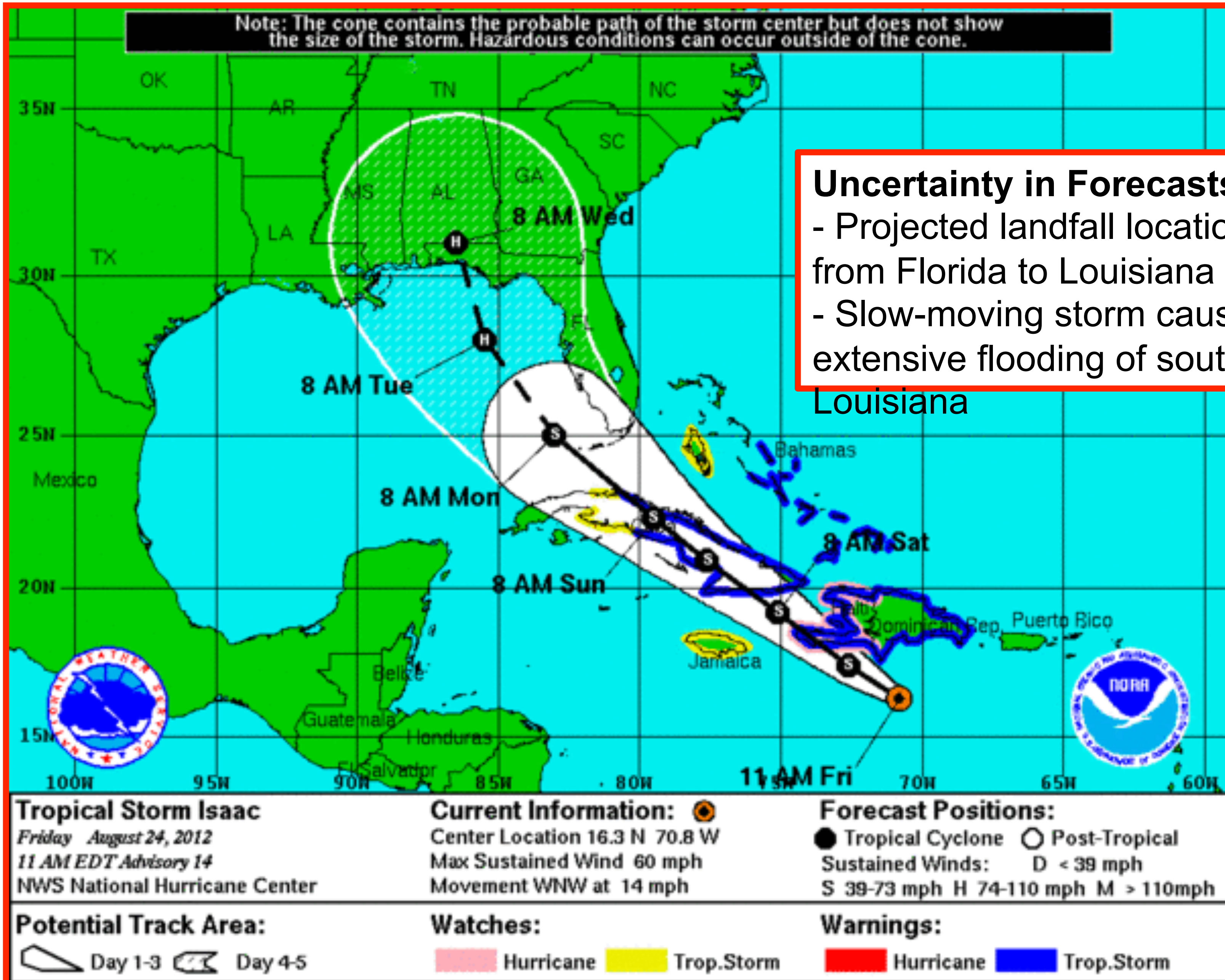
Dr. Kennedy Station R
Data ADCIRC+SWAN
Sig. Wave Height (m)
Landfall Days
Peak Period (s)
Landfall Days

Validation : High-Water Marks



Applications : Hurricane Forecasting :Isaac



Uncertainty in Forecasts

- Projected landfall location shifted from Florida to Louisiana
- Slow-moving storm caused extensive flooding of southeast Louisiana

Applications: Hurricane Forecasting: Isaac (2012)

ADCIRC Surge Guidance System (ASGS)

Runs continuously during hurricane season:

- Uses wind forecasts every 6hr from NHC to force SWAN+ADCIRC
- Portable to any unstructured mesh:
    - UT Austin - Texas floodplain from west Louisiana to Mexico border
    - LSU - entire Louisiana floodplain with focus on New Orleans
    - UNC Chapel Hill - floodplains of the Carolinas

Surge guidance to emergency managers during Isaac (2012):

- LSU and UNC Chapel Hill provided Web-based guidance:

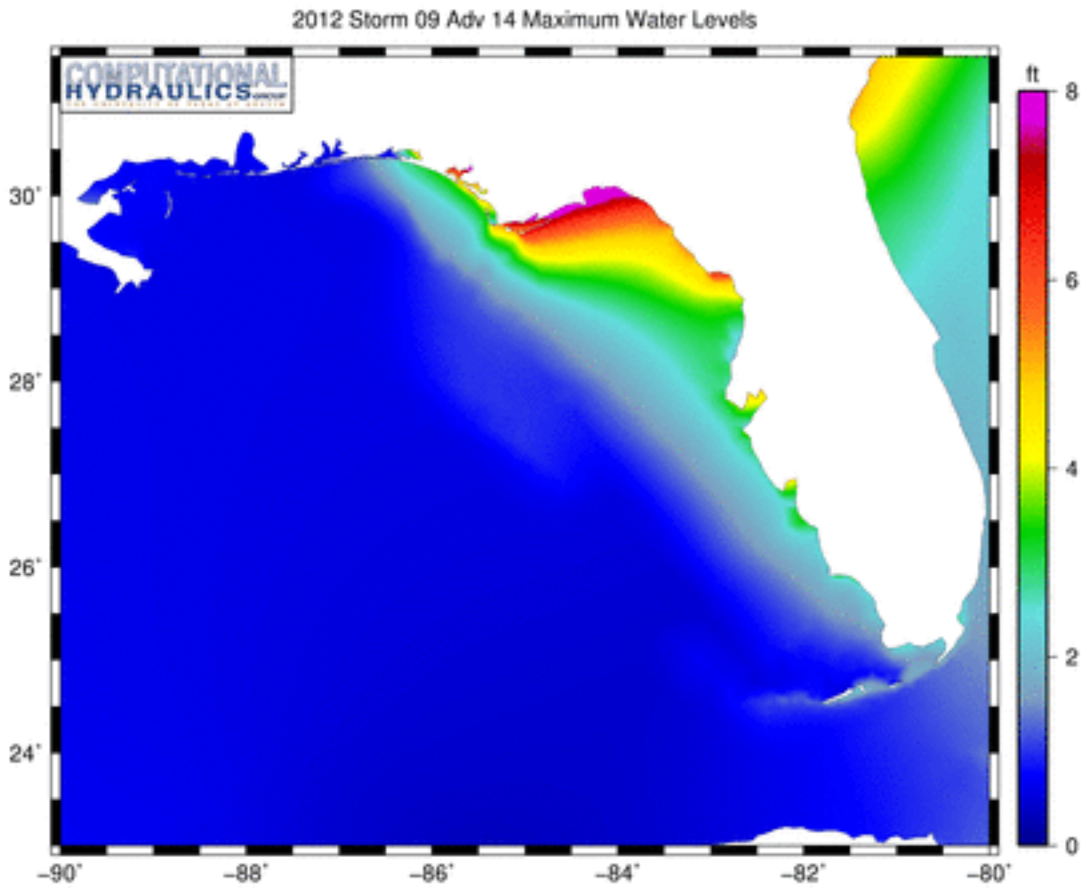
  (http://cera.cct.lsu.edu/cgi-cera-ng/cera-ng.cgi)
- UT Austin also provided ASGS forecasts:
    - TX State Operations Center
    - NWS Fort Worth
    - NWS Miami

Applications : Hurricane Forecasting : Isaac

Evolution of Surge Forecasts

Maximum surge on EC95 mesh at 6hr intervals:

- Advisory 14 : About 105hr before projected landfall at Destin FL
- Advisory 38 : About 39hr after actual landfall at Mississippi River



Deepwater Horizon Oil Spill

Deepwater Horizon was a 9-year-old, mobile offshore drilling unit

Located 66km from the Louisiana coastline, in 1500m of water

Platform was engulfed on 20 April by an explosion of methane gas; structure burned for more than 24hr before sinking on 22 April

Explosion killed 11 workers and injured 17

Oil spill flow rates:

- Estimated to have begun at a rate of 9900 $m^3\ d^{-1}$
- Diminished over time to a final rate of 8400 $m^3\ d^{-1}$ on 15 July 2010

Emergency responders relied on satellite and aerial imagery

Nearshore Oil Transport : Motivation

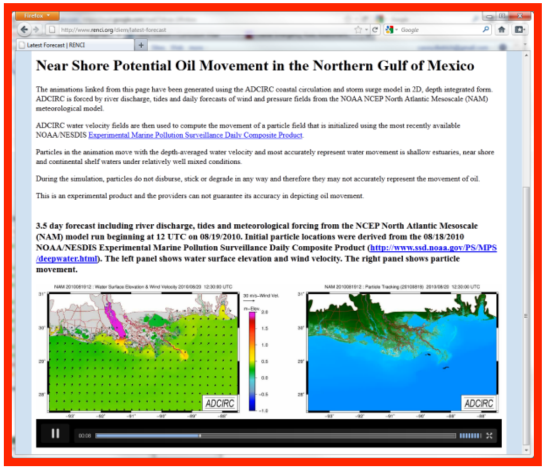
Satellite imagery can only show current location of the slick

- Where will the oil move?
- What happens if a hurricane approaches?

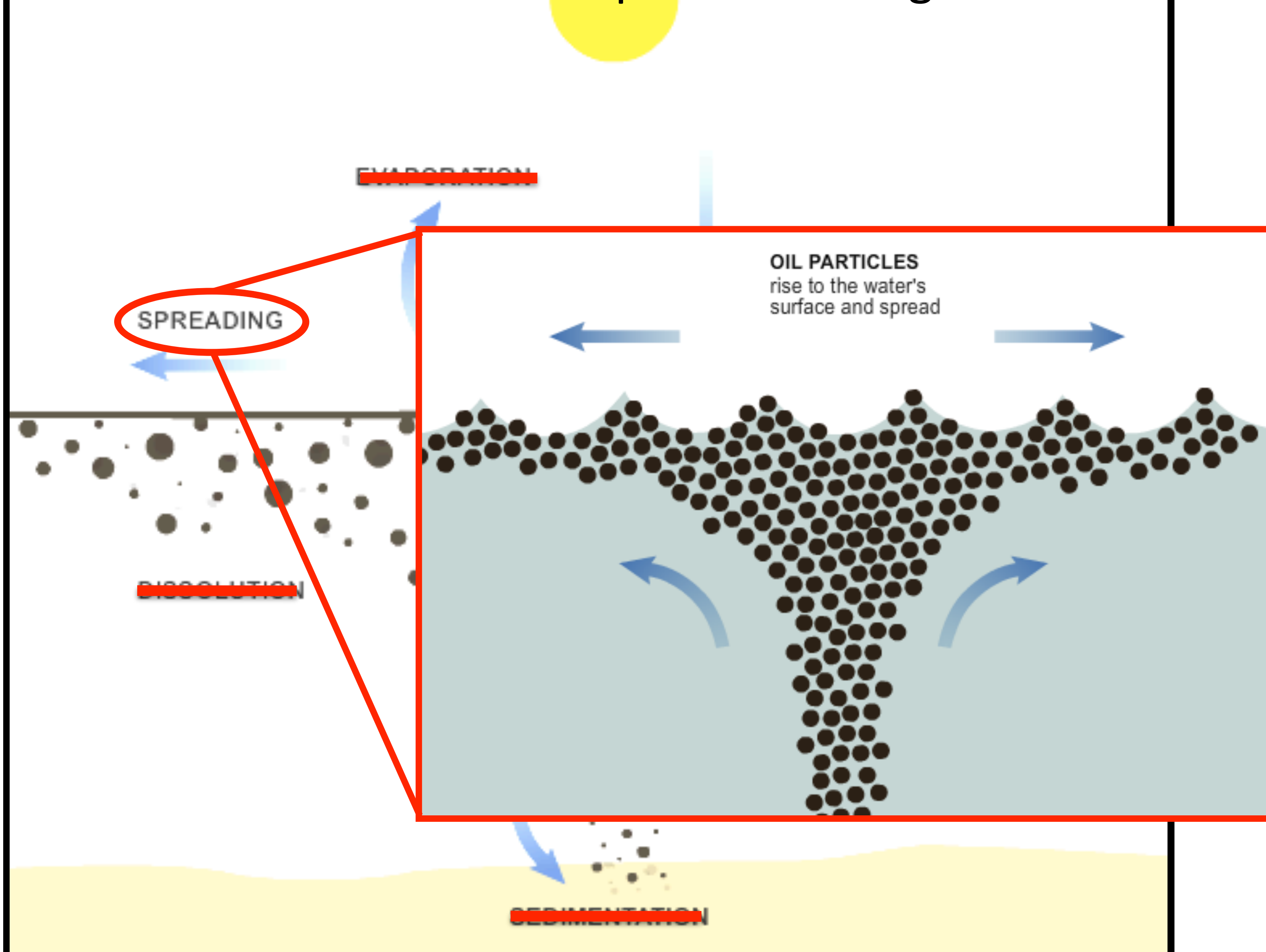
Forecasts of oil transport need to be <u>accurate</u> and <u>fast</u>

- Provide results to NOAA and other spill modelers
- Provide results to emergency managers

in real time (http://adcirc.org/oilspill)



Nearshore Oil Transport : Challenges



Nearshore Oil Transport : Lagrangian Particles

Particle positions are tracked through the unstructured mesh:

$$\vec{x}_p(t+\Delta t) = \vec{x}_p(t) + \vec{u}(\vec{x}_p, t)\Delta t + \vec{D}$$

- where the dispersion uses a stochastic perturbation (Proctor et al., 1994):

$$\vec{D} = (2R-1)\sqrt{\vec{c}\vec{E}_v \Delta t}$$

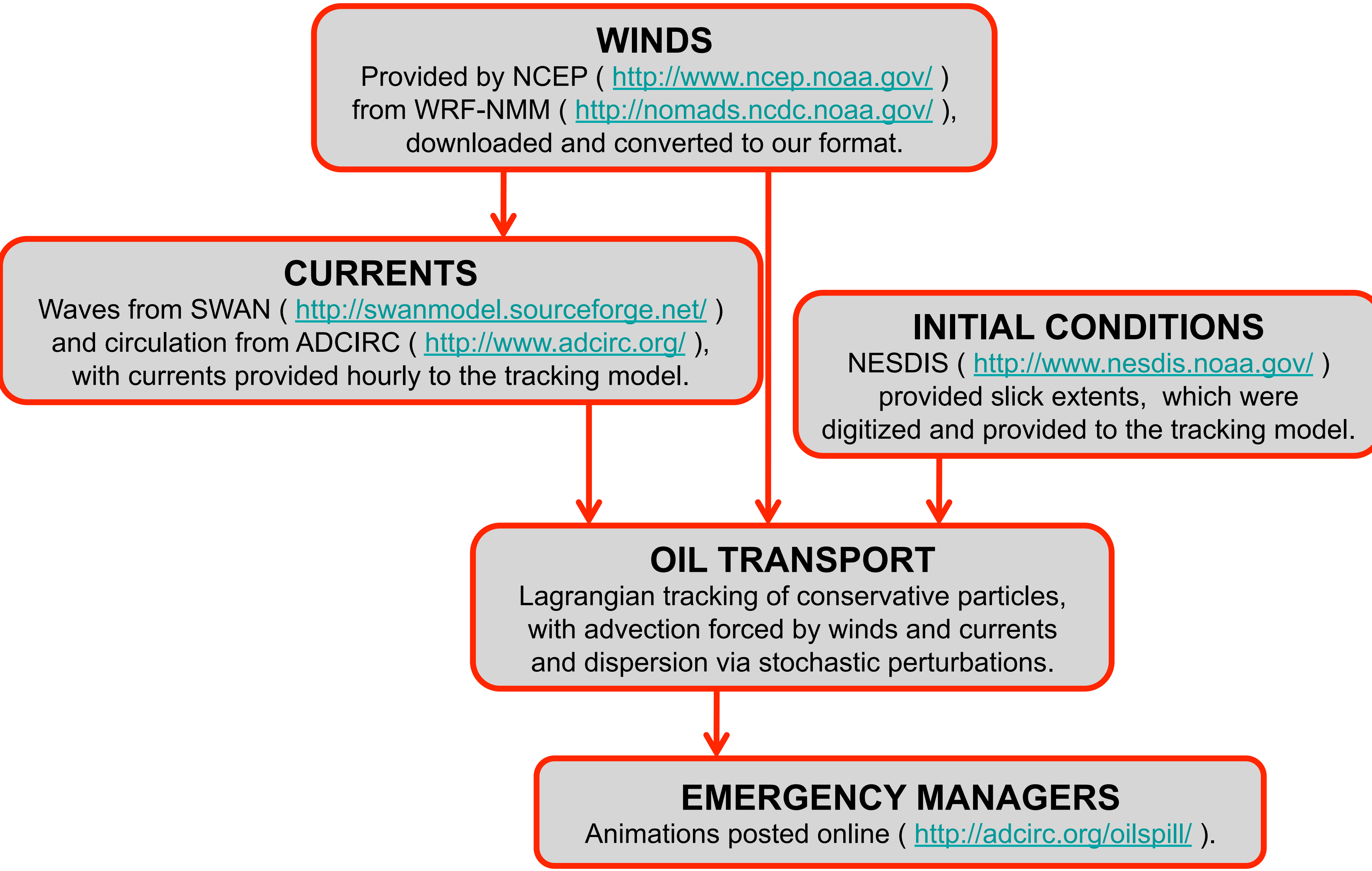
- and where the velocities are a linear combination of currents and winds:

$$\vec{u}(\vec{x}_p, t) = F_c \vec{u}_c(\vec{x}_p, t) + F_w \vec{u}_w(\vec{x}_p, t)$$

.

Using hybrid OpenMP/MPI, 11M particles can be tracked on a 10M-element mesh in about **5.5 min/day** using 256 cores on TACC Ranger.

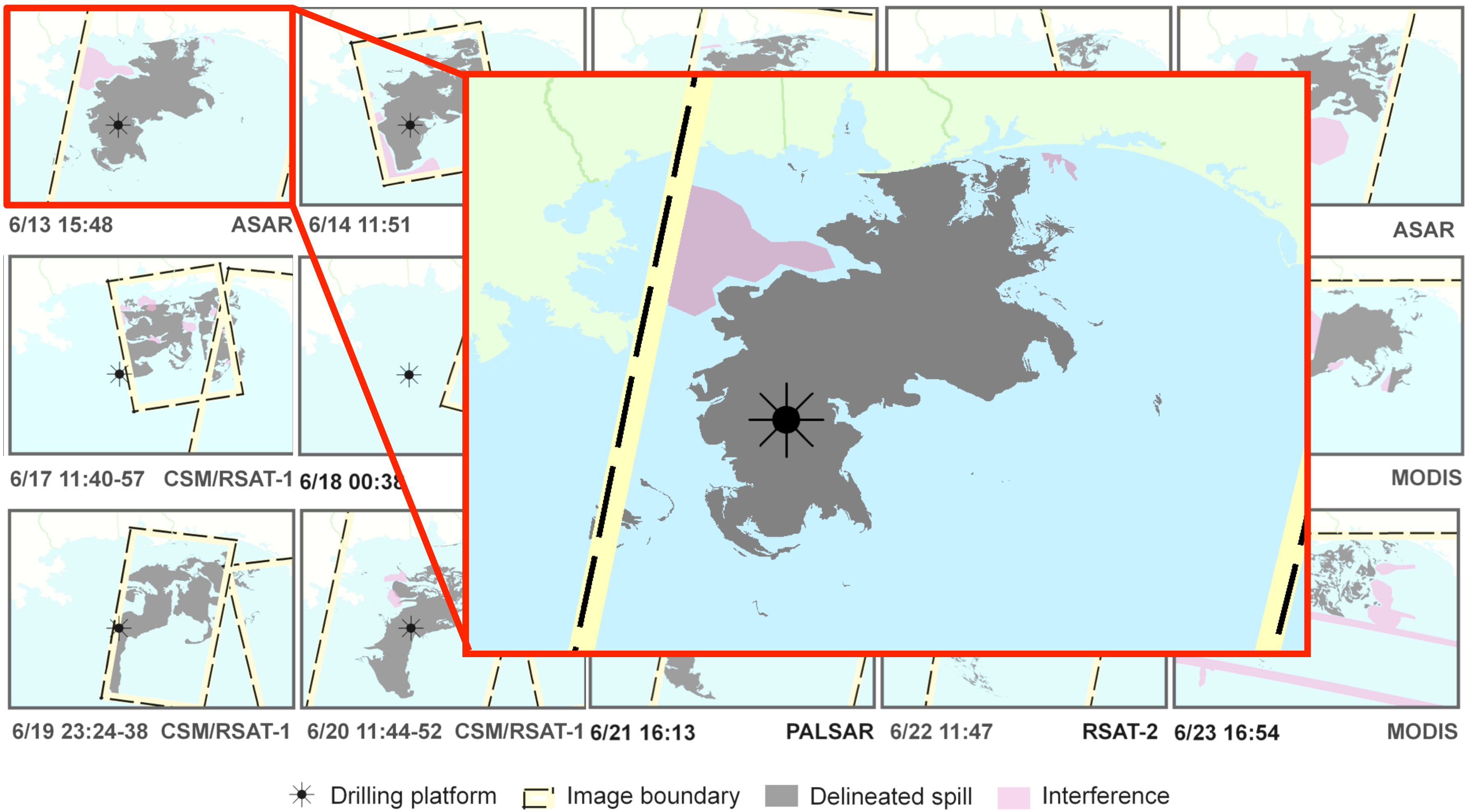
Nearshore Oil Transport : Flow Chart



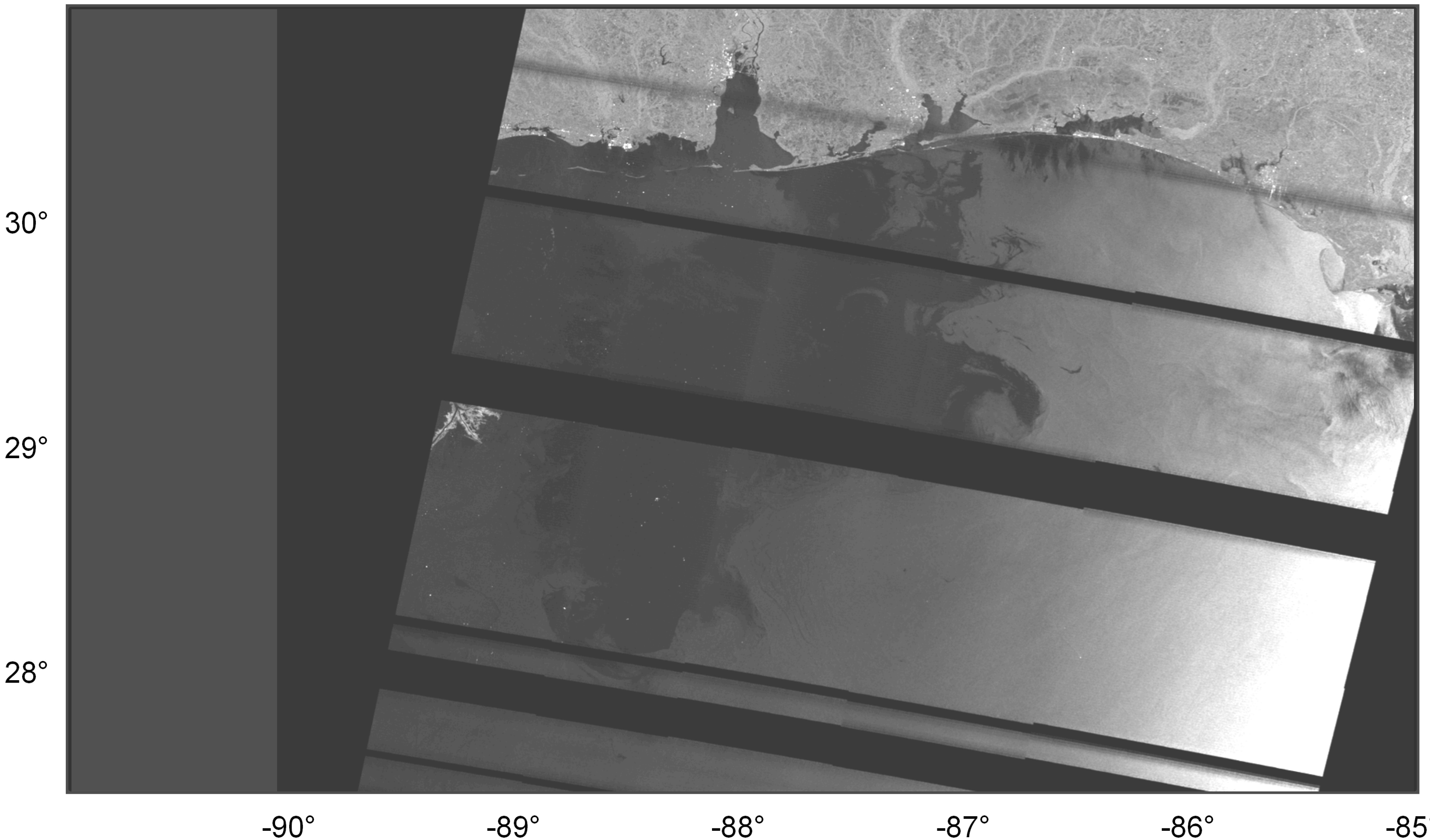
Validation : Mid-June

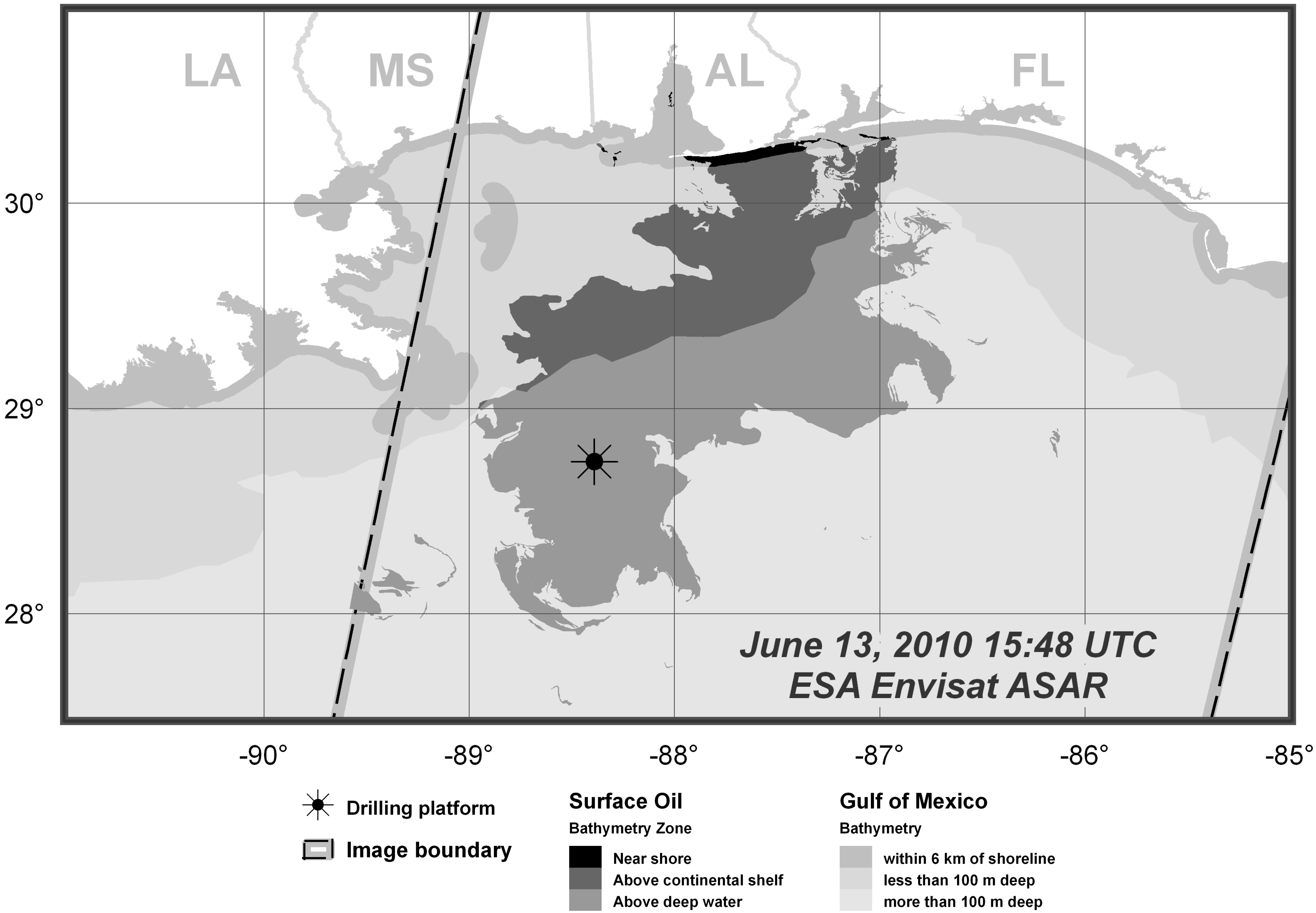
Examples of available imagery during 13-23 June 2010:

- NESDIS consolidated observations from a suite of satellite sensors

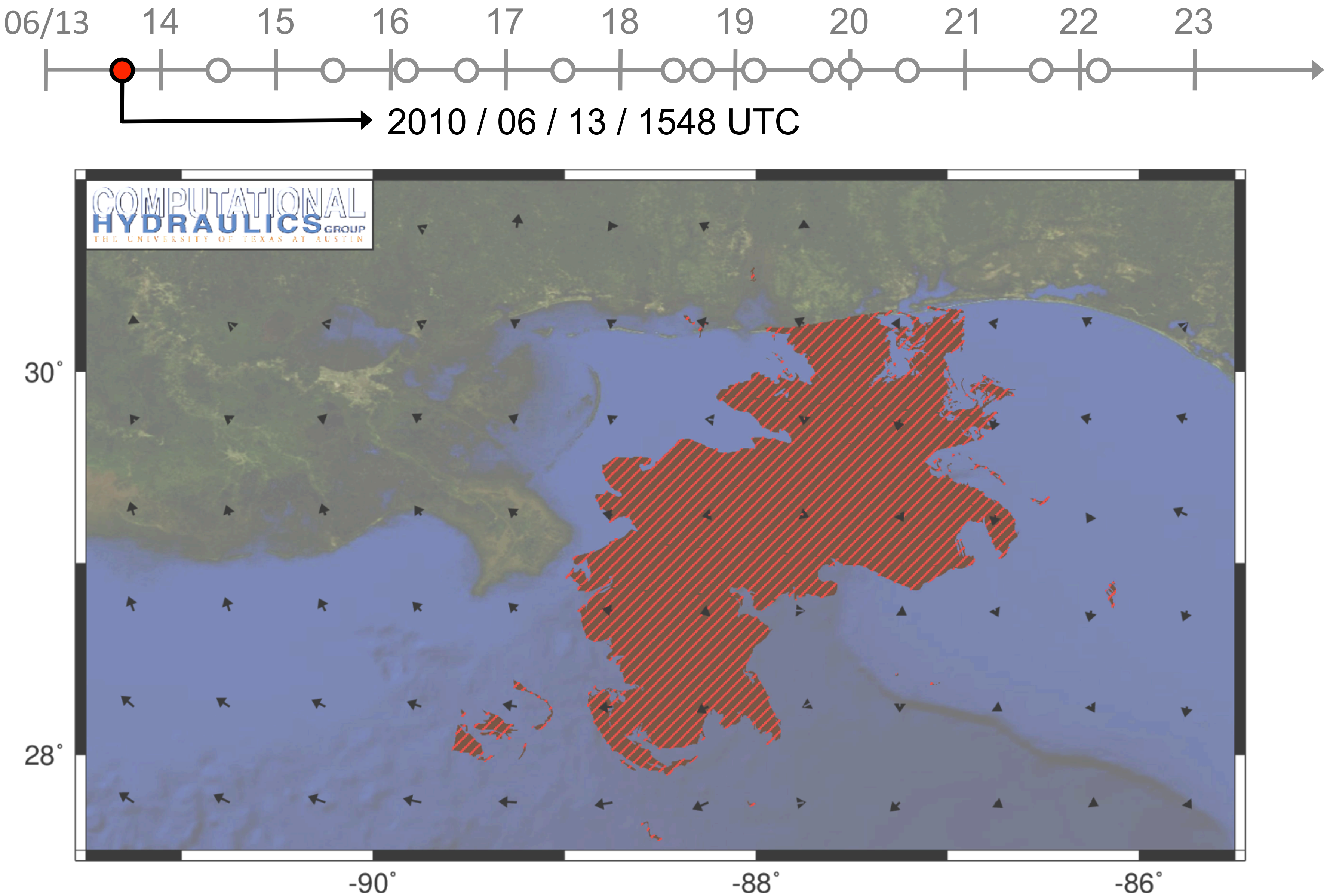


Validation : Mid-June

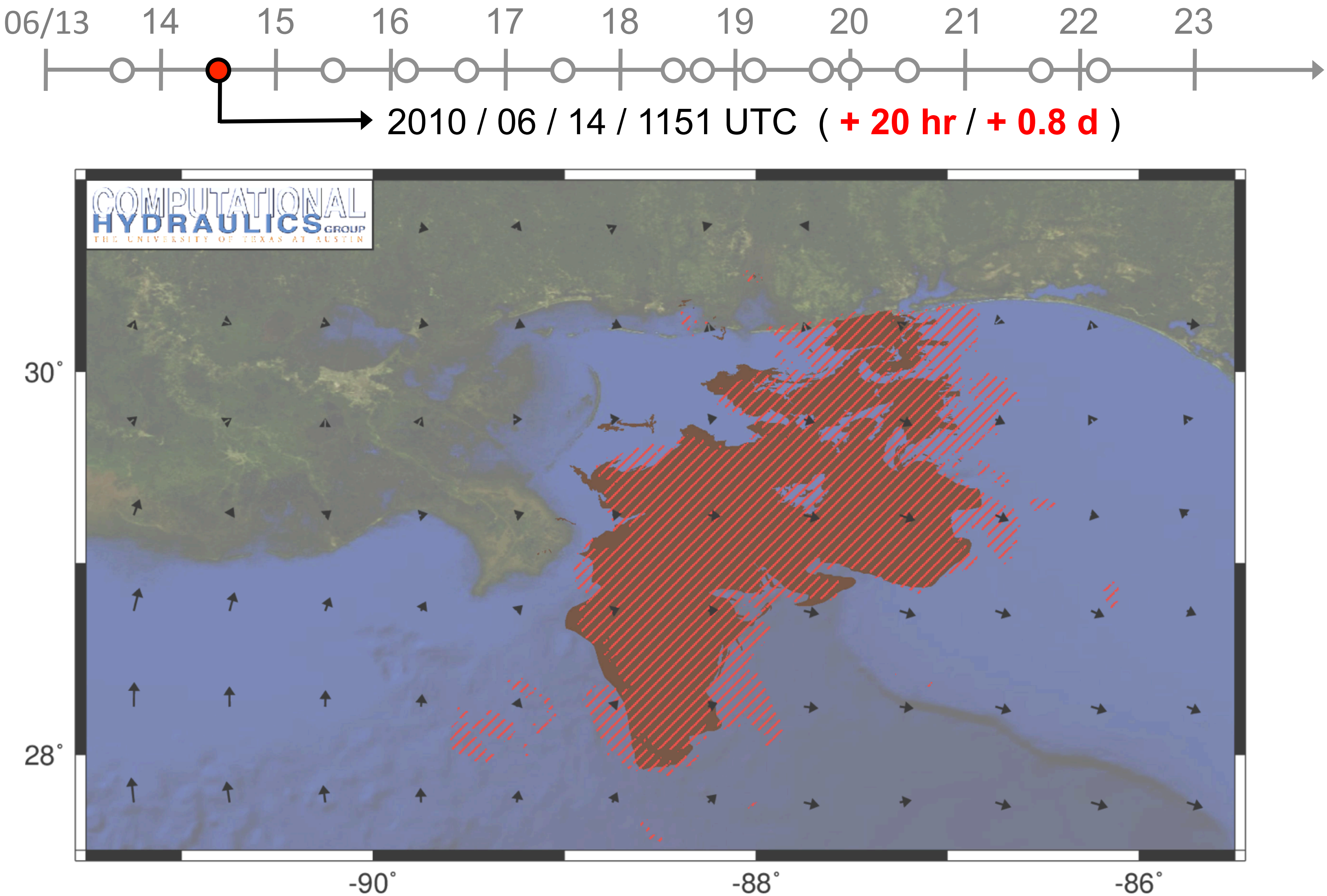




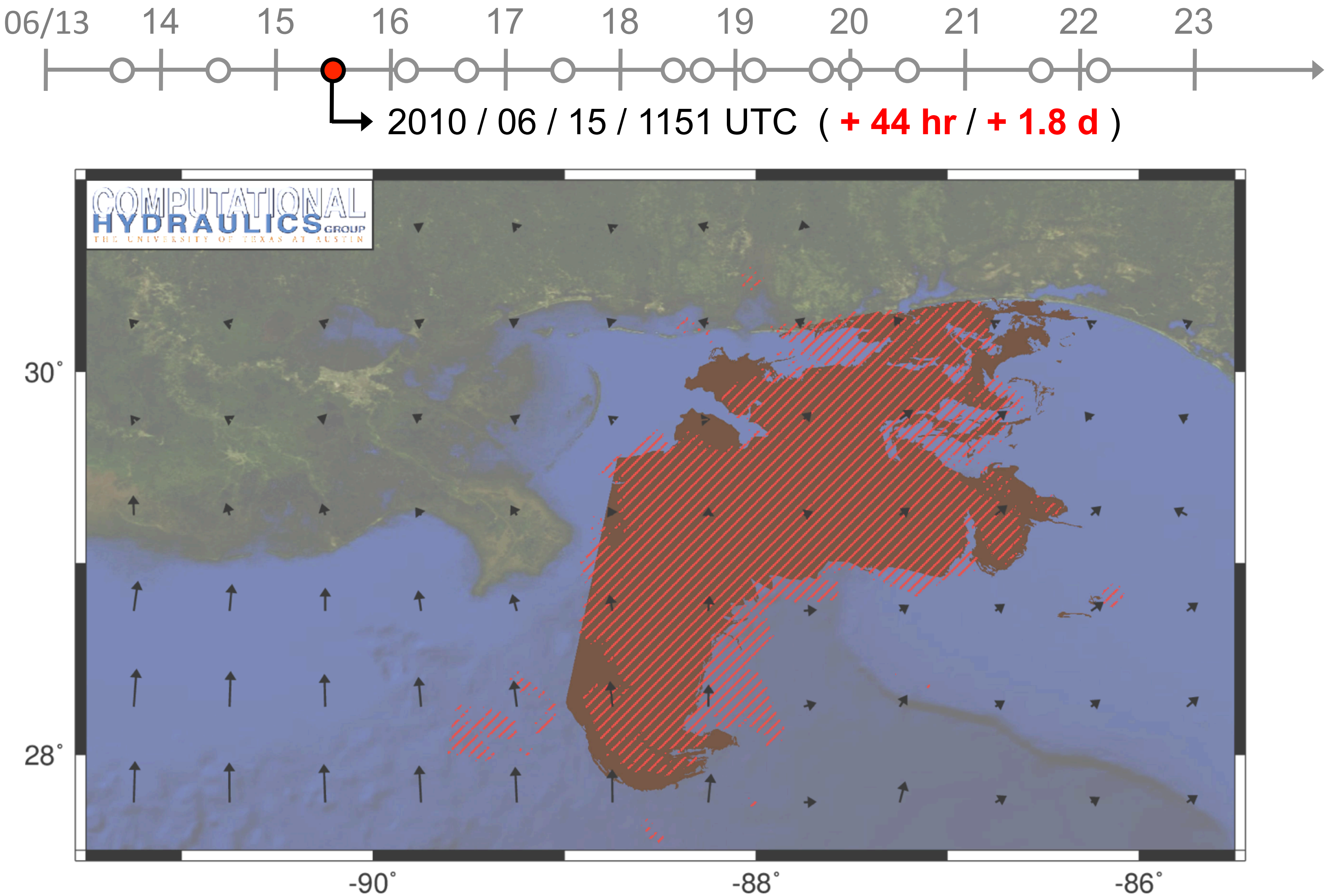
LA
MS
AL
FL
30°
29°
28°
-90°
-89°
-88°
-87°
-86°
-85°
June 13, 2010 15:48 UTC
ESA Envisat ASAR
Drilling platform
Image boundary
Surface Oil
Bathymetry Zone
Near shore
Above continental shelf
Above deep water
Gulf of Mexico
Bathymetry
within 6 km of shoreline
less than 100 m deep
more than 100 m deep



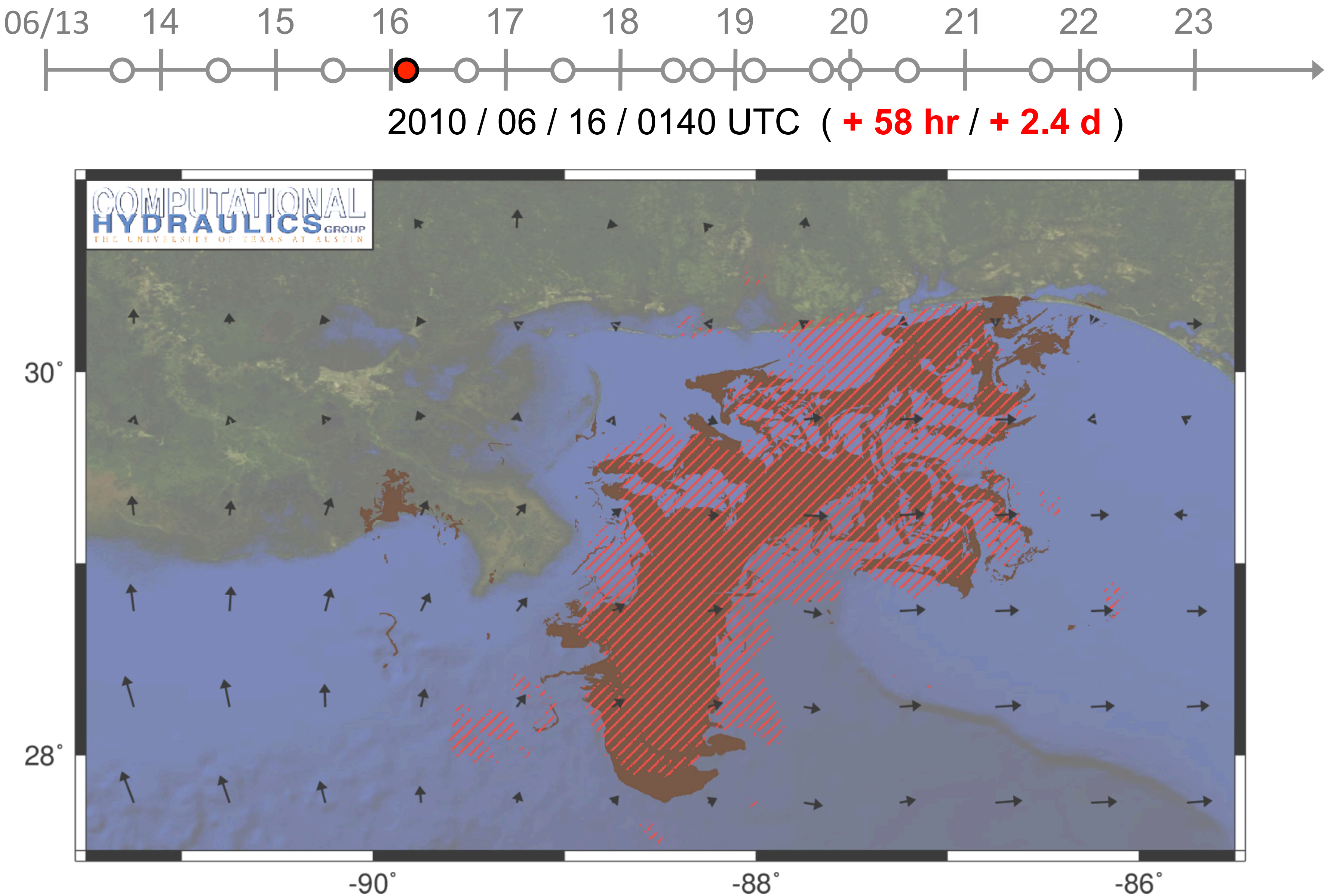
Satellite Observations **Predicted Particle Locations**



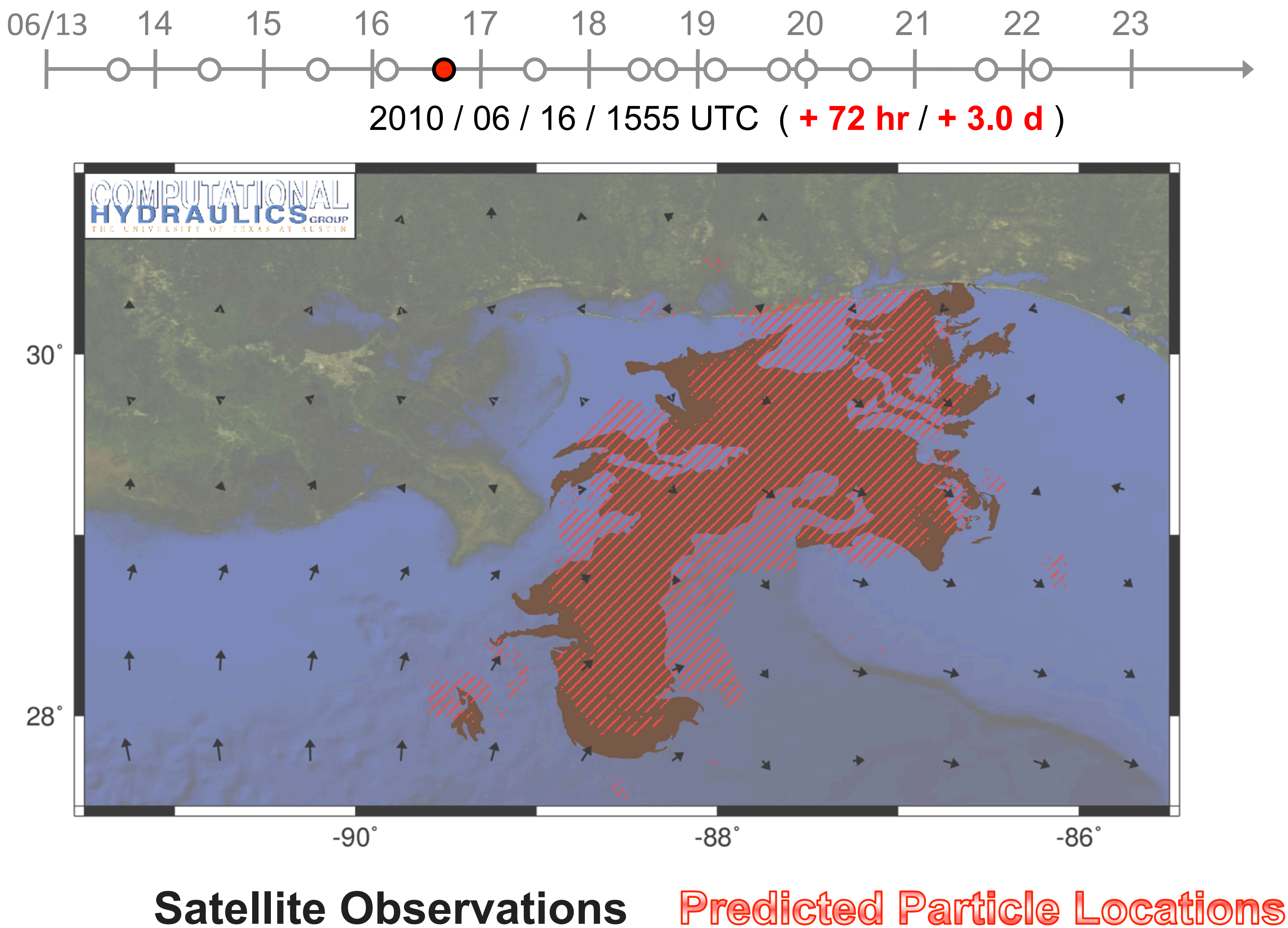
Satellite Observations **Predicted Particle Locations**



Satellite Observations **Predicted Particle Locations**



Satellite Observations **Predicted Particle Locations**


06/13
14
15
16
17
18
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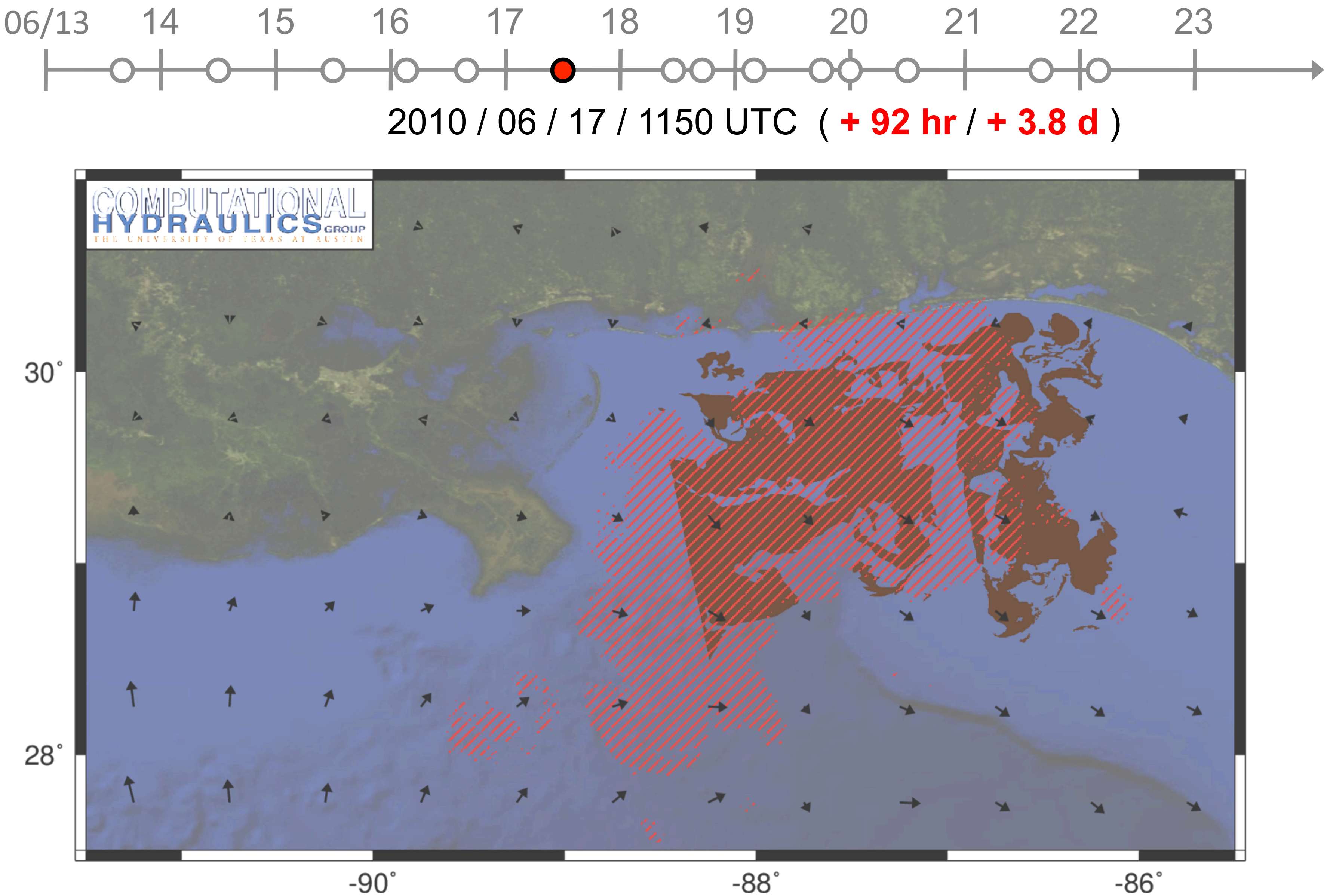
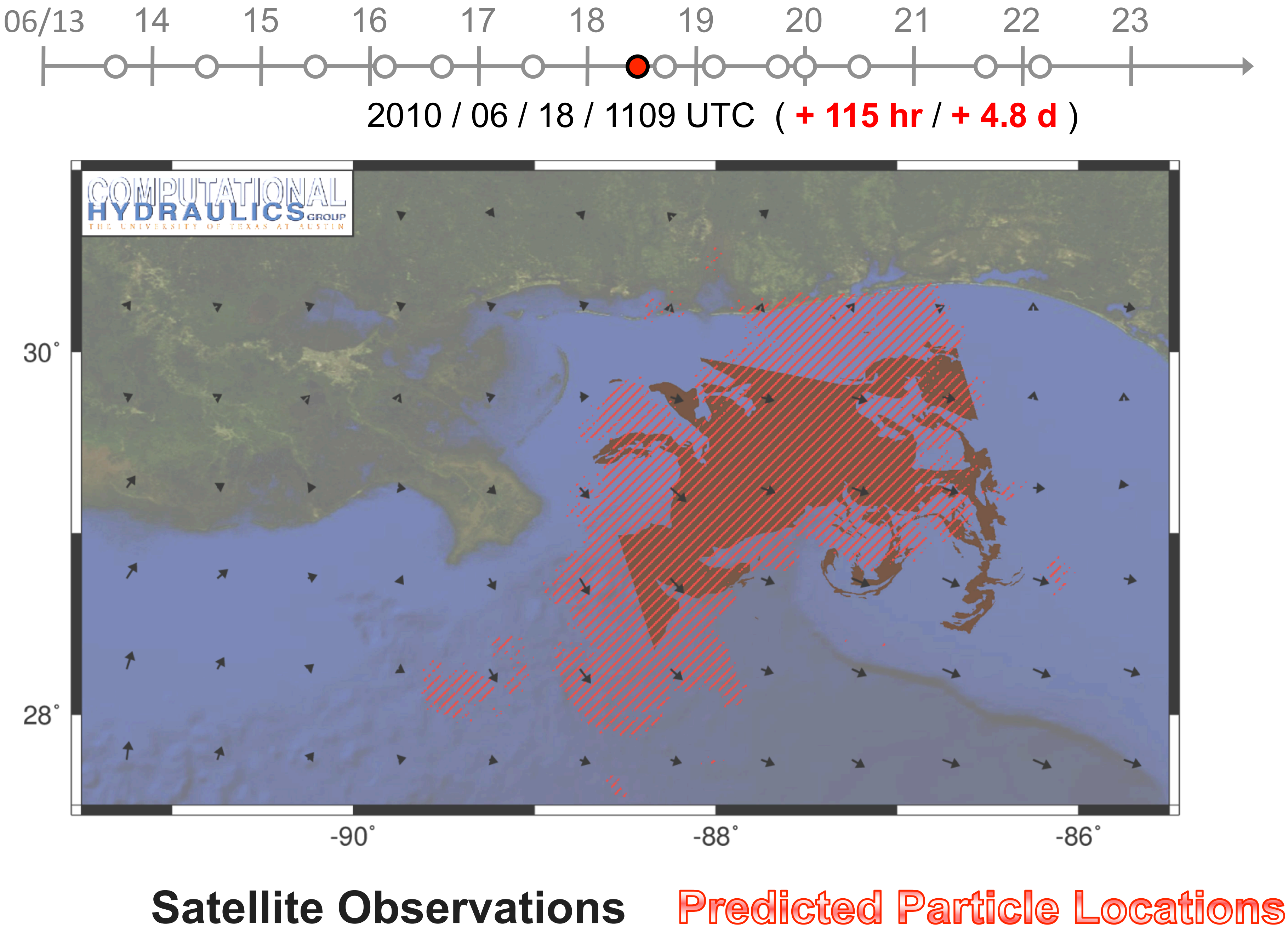
20
21
22
23
2010 / 06 / 16 / 1555 UTC (+ 72 hr / + 3.0 d)
COMPUTATIONAL HYDRAULICS GROUP
THE UNIVERSITY OF TEXAS AT AUSTIN
30°
28°
-90°
-88°
-86°
Satellite Observations
Predicted Particle Locations



Satellite Observations Predicted Particle Locations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19
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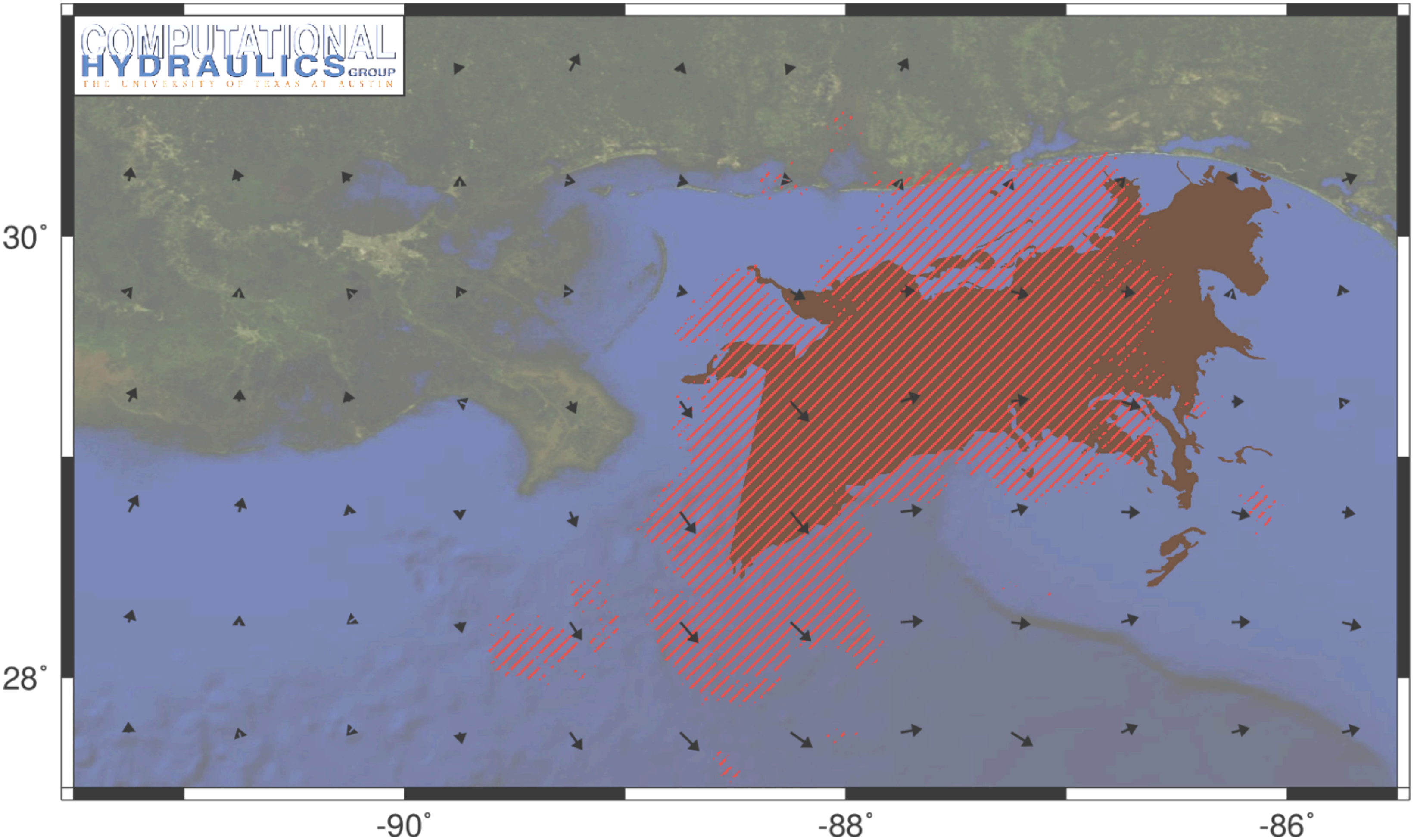
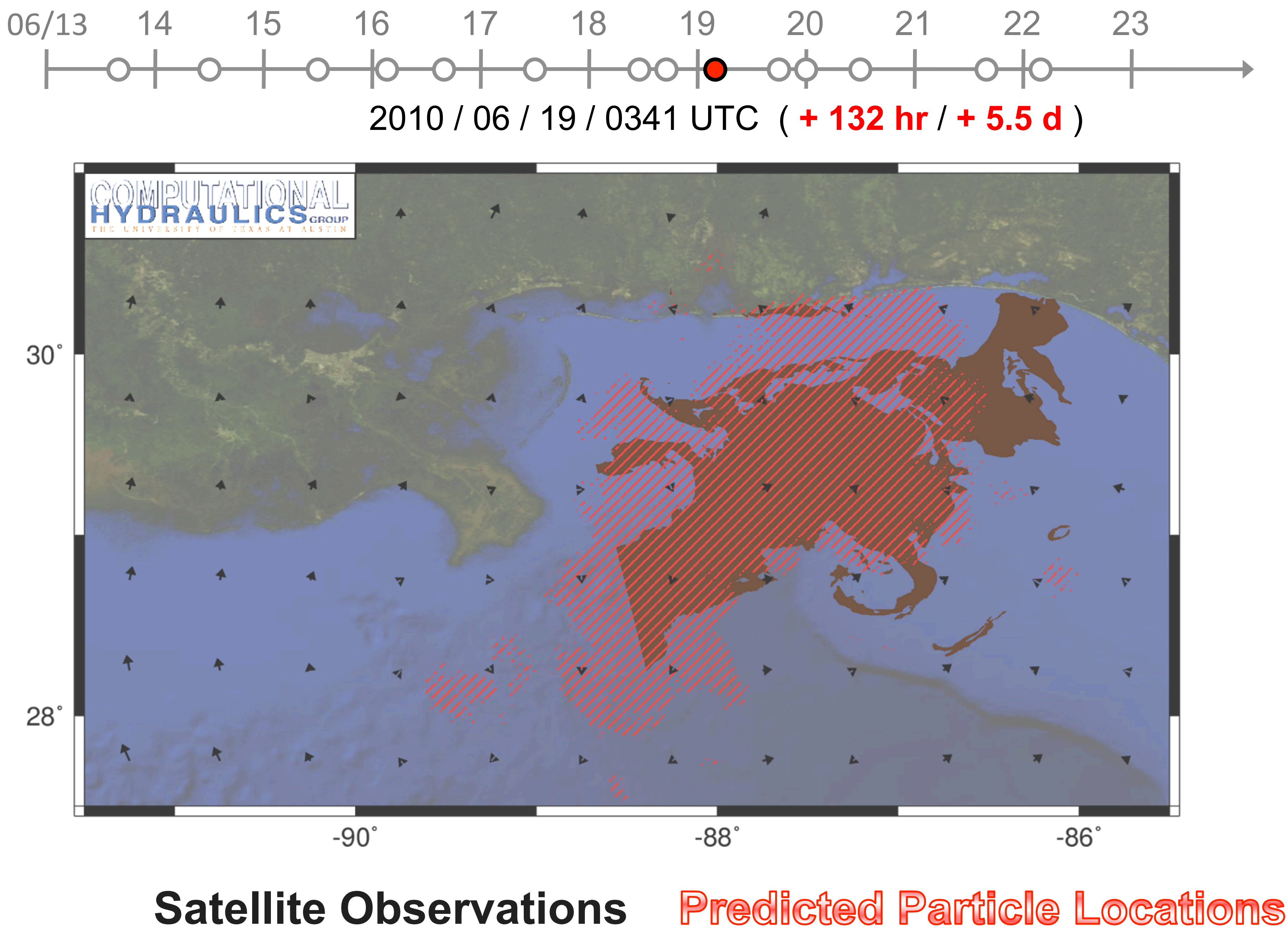
23
2010 / 06 / 18 / 1109 UTC (+ 115 hr / + 4.8 d)
COMPUTATIONAL
HYDRAULICS GROUP
THE UNIVERSITY OF TEXAS AT AUSTIN
30˚
28˚
-90˚
-88˚
-86˚
Satellite Observations
Predicted Particle Locations

06/13 14 15 16 17 18 19 20 21 22 23

2010 / 06 / 18 / 1637 UTC (**+ 121 hr** / **+ 5.0 d**)



Satellite Observations **Predicted Particle Locations**



06/13
14
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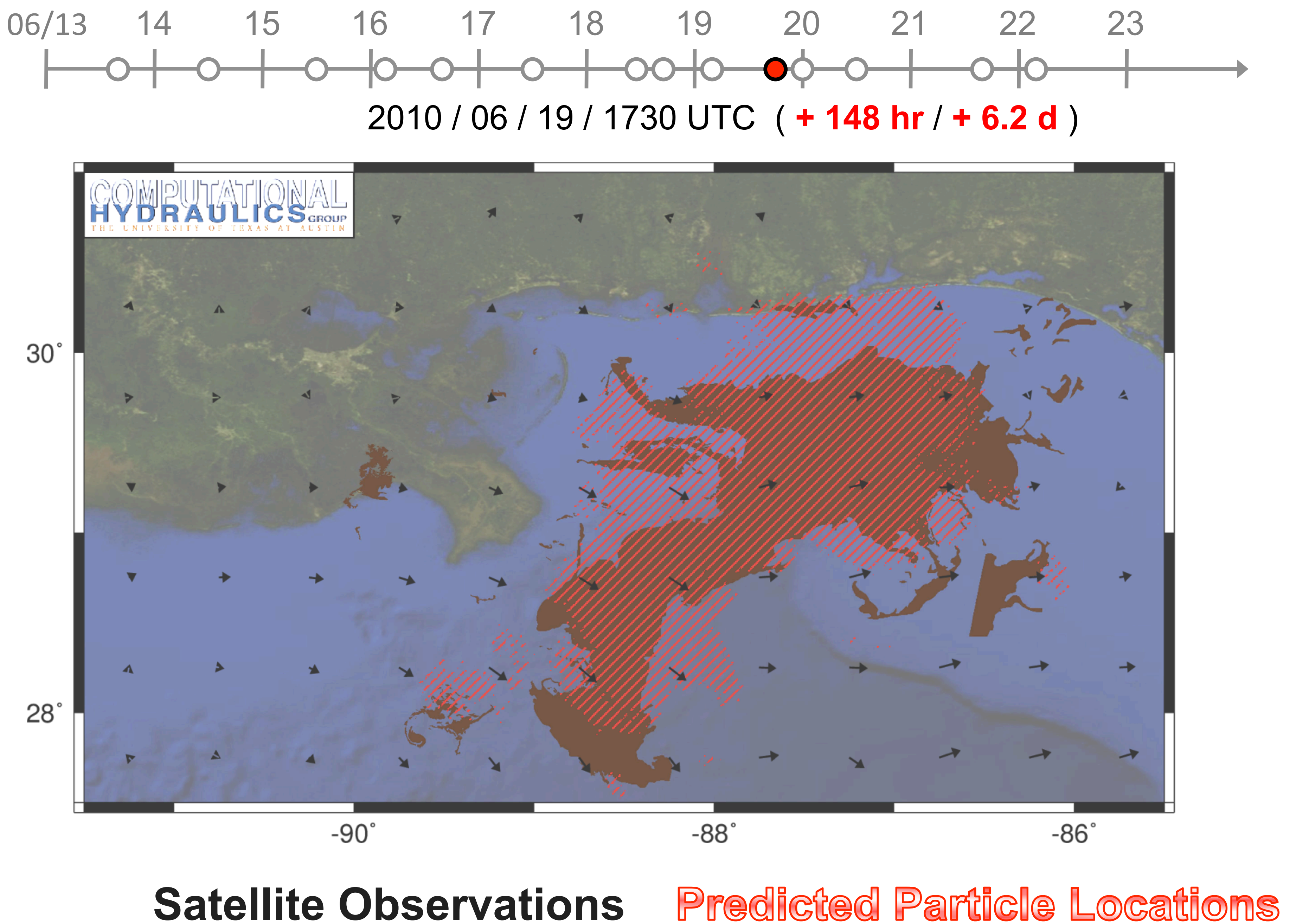
23
2010 / 06 / 19 / 0341 UTC (+ 132 hr / + 5.5 d)
COMPUTATIONAL HYDRAULICS GROUP
THE UNIVERSITY OF TEXAS AT AUSTIN
30˚
28˚
-90˚
-88˚
-86˚
Satellite Observations
Predicted Particle Locations


06/13
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19
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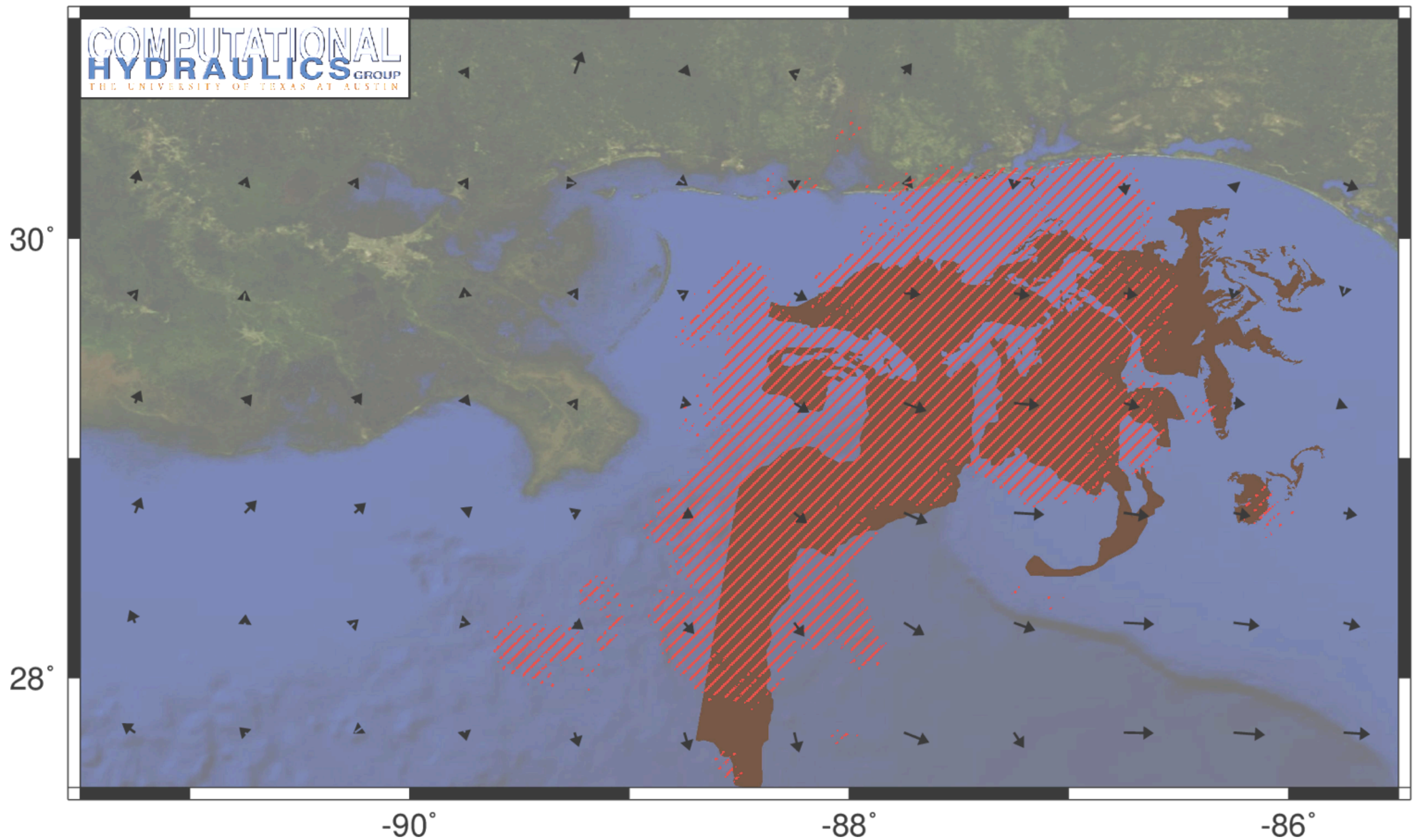
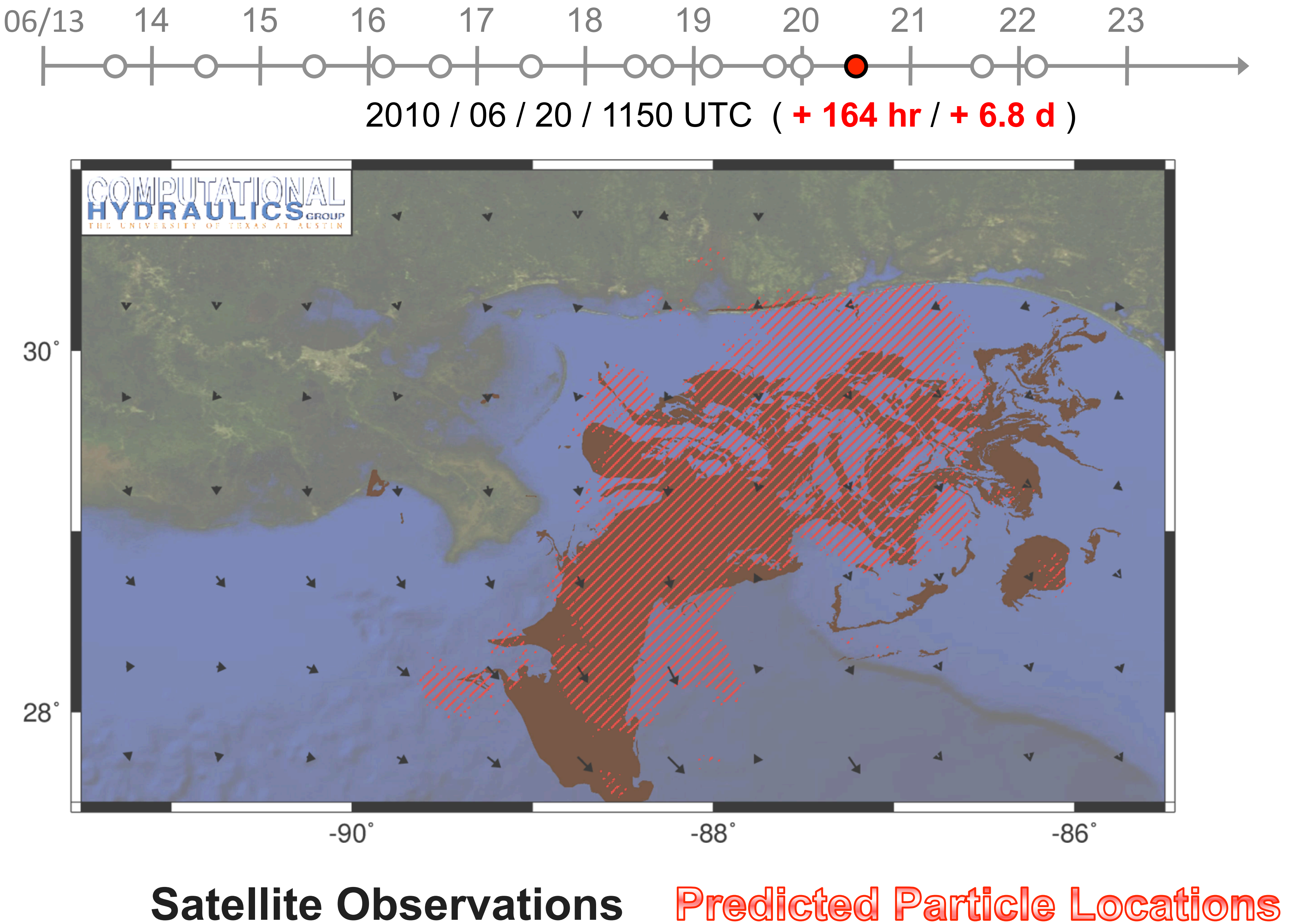
21
22
23
2010 / 06 / 19 / 1730 UTC (+ 148 hr / + 6.2 d)
COMPUTATIONAL
HYDRAULICS GROUP
THE UNIVERSITY OF TEXAS AT AUSTIN
30°
28°
-90°
-88°
-86°
Satellite Observations
Predicted Particle Locations

06/13 14 15 16 17 18 19 20 21 22 23

2010 / 06 / 19 / 2330 UTC (**+ 152 hr** / **+ 6.3 d**)



Satellite Observations **Predicted Particle Locations**



06/13
14
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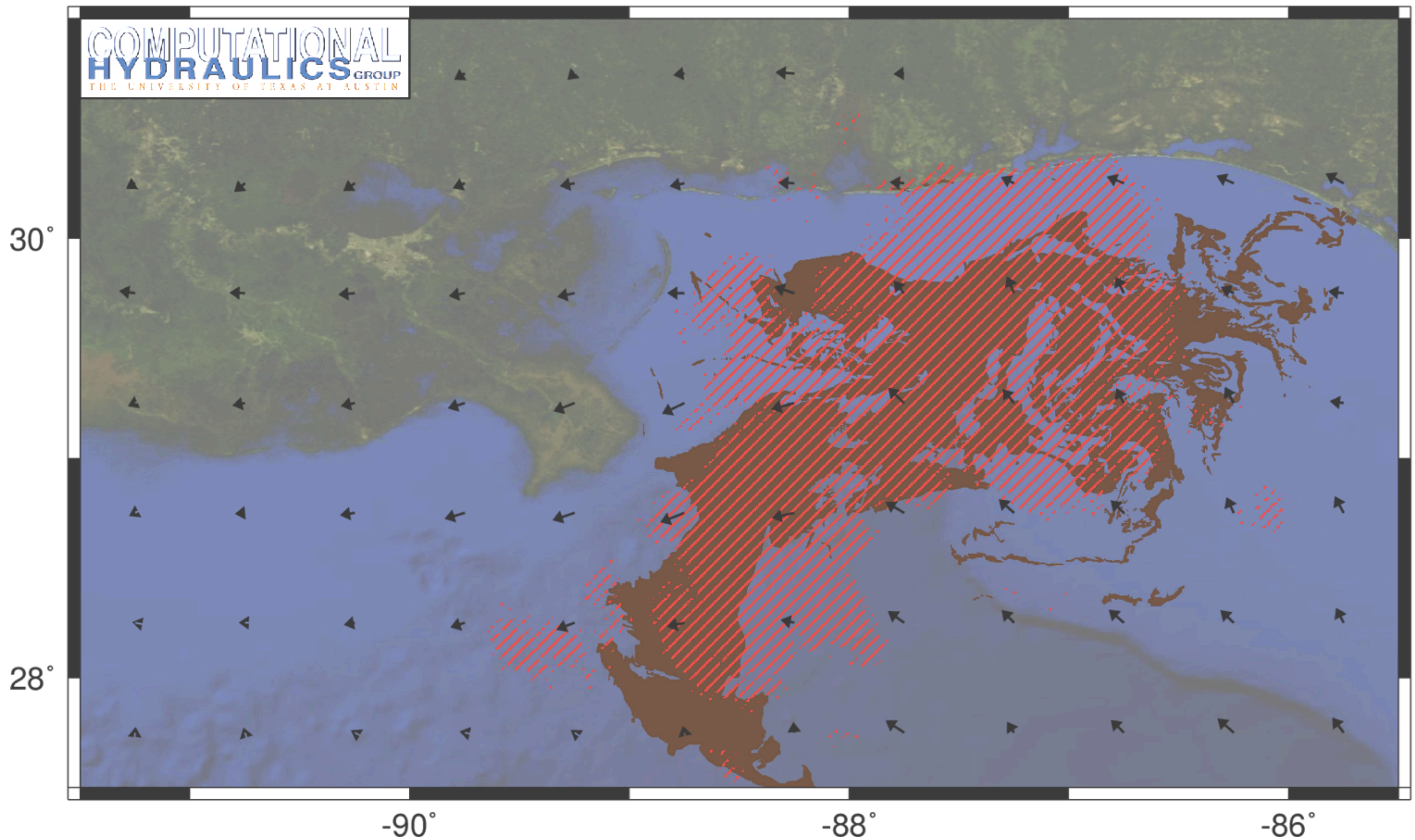
2010 / 06 / 20 / 1150 UTC (+ 164 hr / + 6.8 d)
COMPUTATIONAL
HYDRAULICS GROUP
THE UNIVERSITY OF TEXAS AT AUSTIN
30˚
28˚
-90˚
-88˚
-86˚
Satellite Observations
Predicted Particle Locations

06/13 14 15 16 17 18 19 20 21 22 23

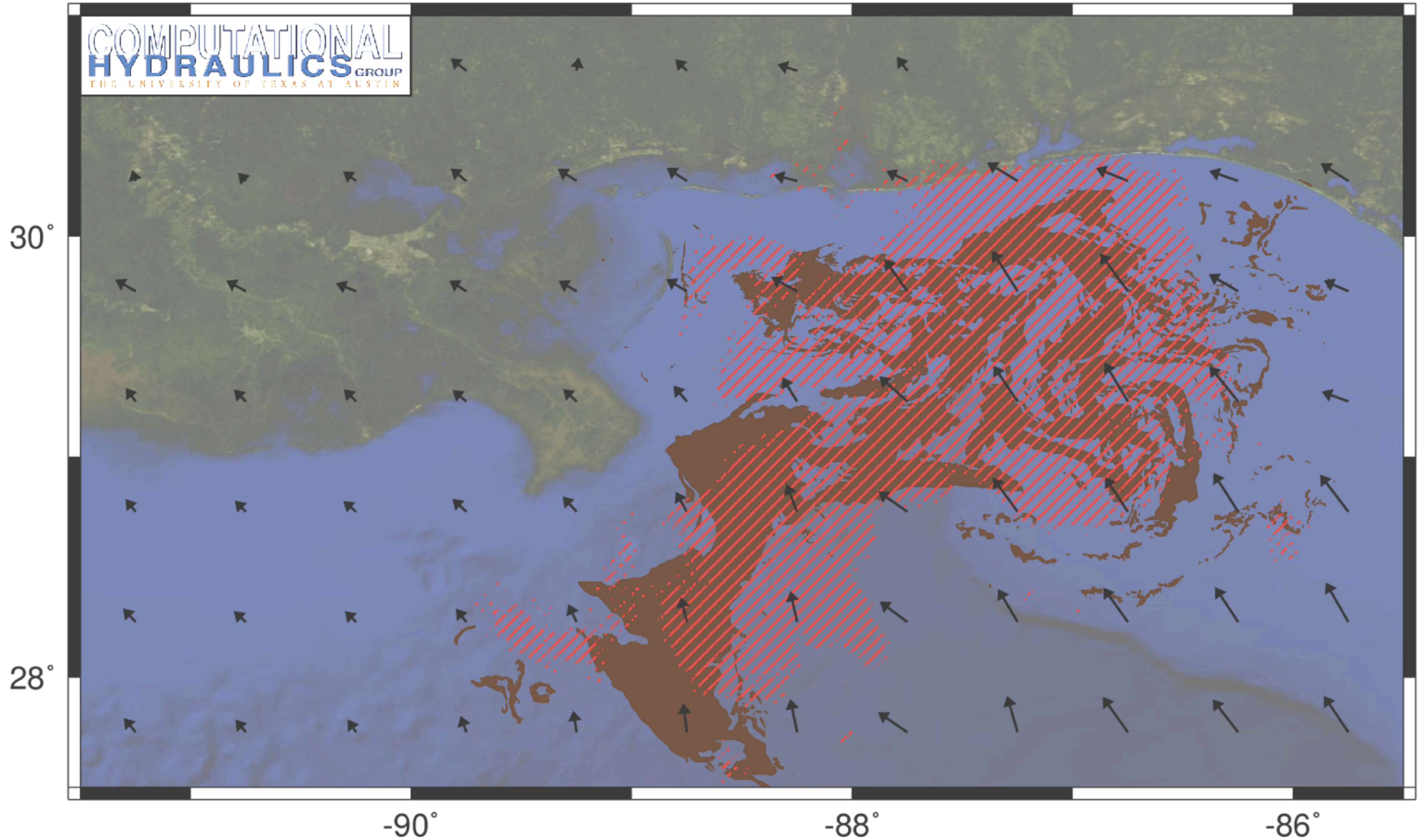
2010 / 06 / 21 / 1613 UTC (**+ 192 hr** / **+ 8.0 d**)



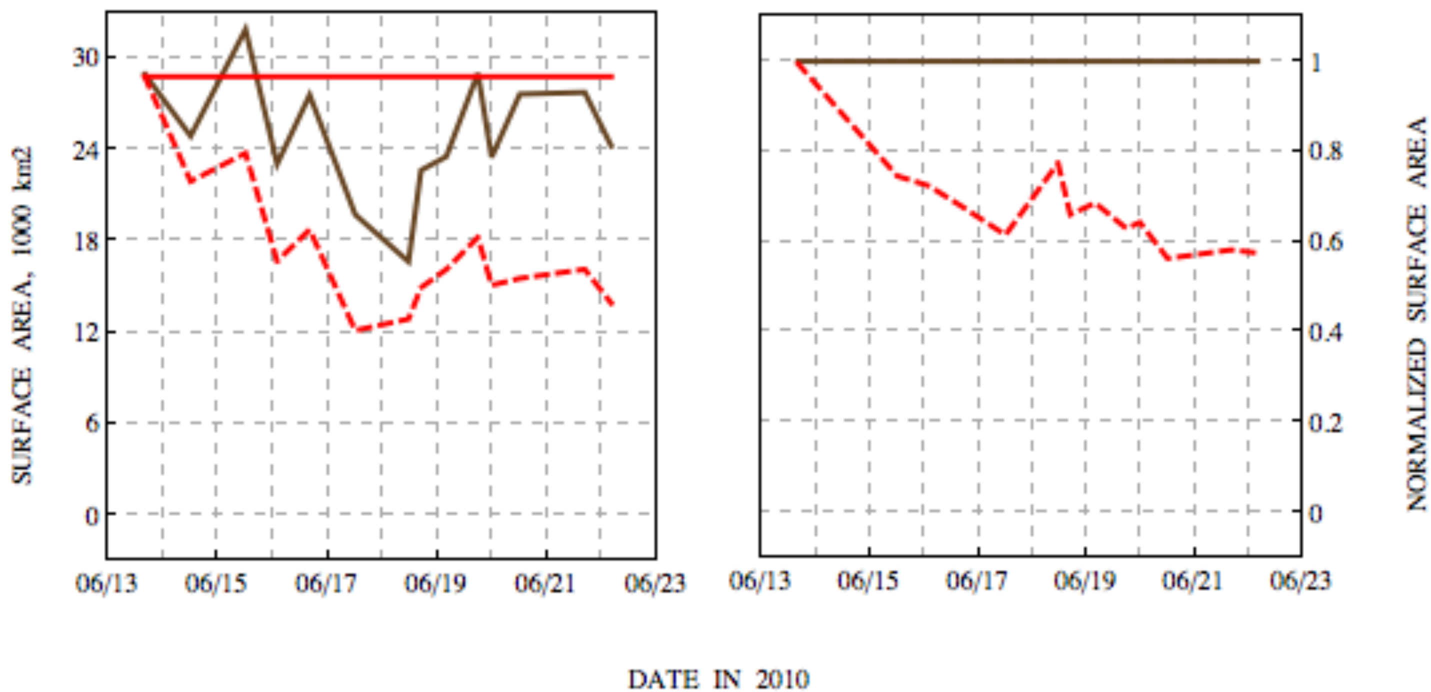
Satellite Observations **Predicted Particle Locations**

06/13 14 15 16 17 18 19 20 21 22 23

2010 / 06 / 22 / 0348 UTC (+ 204 hr / + 8.5 d)



Satellite Observations **Predicted Particle Locations**



Overlap of our predictions to observations:

- **Solid brown** - Total areas of observed oil in satellite imagery
- **Solid red**- Total areas of predicted locations of Lagrangian particles
- **Dashed red** - Overlap between predictions and observations

After one week of simulation, overlap is about 60 percent

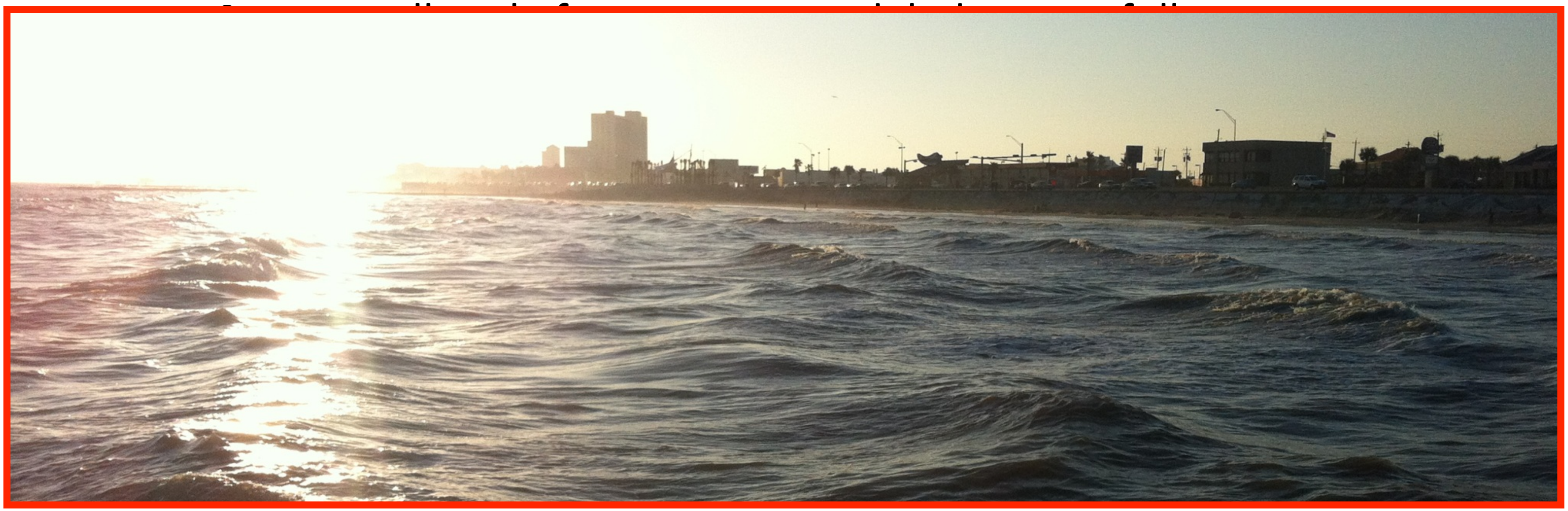
- Good qualitative and quantitative match to observations

Conclusions

ADCIRC model is a verified and validated tool for modeling coastal hydrodynamics, hurricane storm surges and oil spills. This is a great example of how basic algorithmic research can be transitioned into operational models.

ADCIRC forecast system runs successfully in real-time

Good match to overall movement of oil spill



Open Questions

3D baroclinic, deep-water to near-shore to inland coupling (ADCIRC coupled to HYCOM, see Casey Dietrich's talk tomorrow)

3D Oil transport, bioegradation, weathering, etc. (Lagrangian vs. Eulerian methods; collaboration with Juan Restrepo and Shankar V.)