Hurricanes Ike Forerunner Surge and Damage

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R. Dean; *University of Florida at Gainesville*

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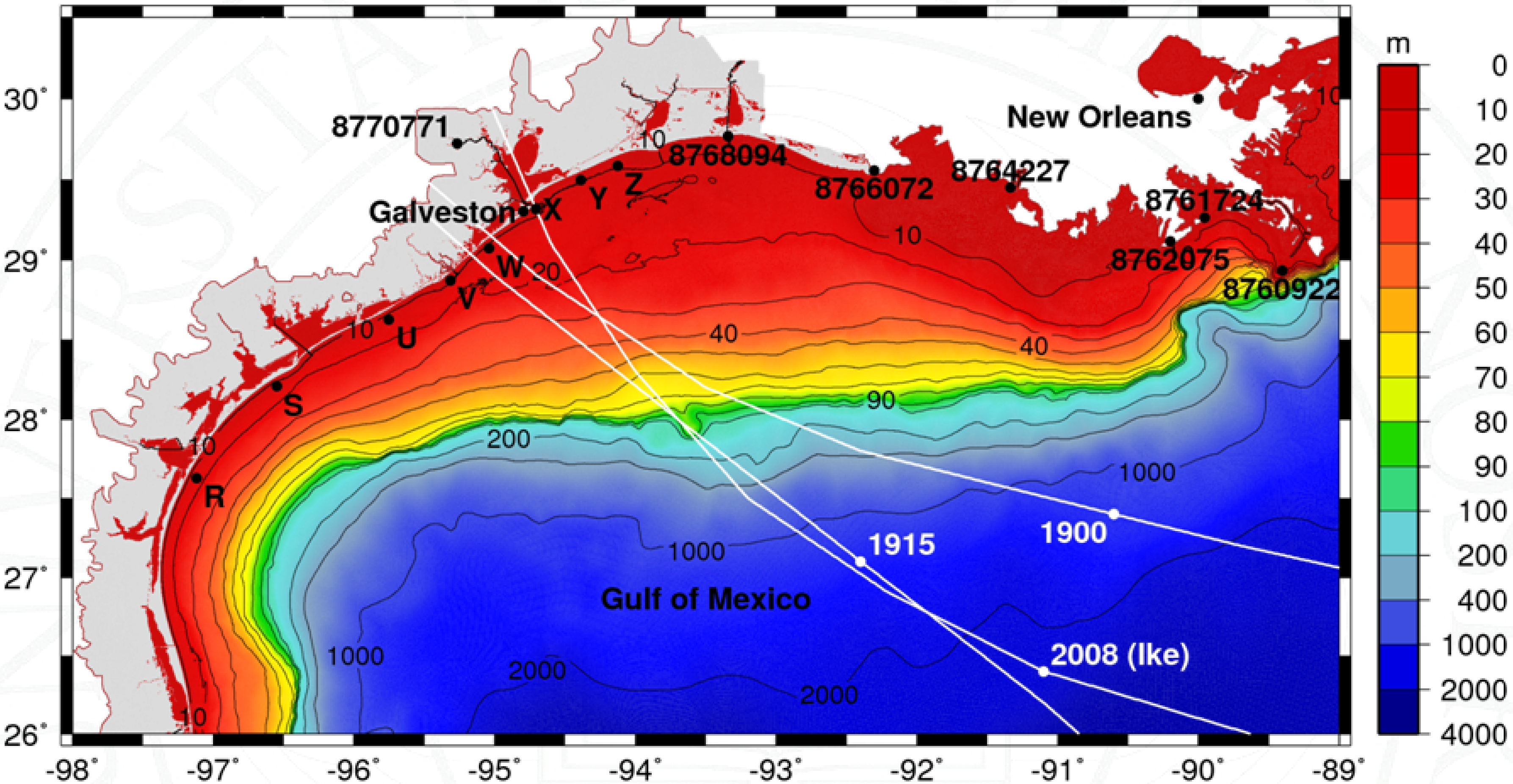
Waves 2011, Kohala Coast Hawaii

November 1, 2011

Motivation

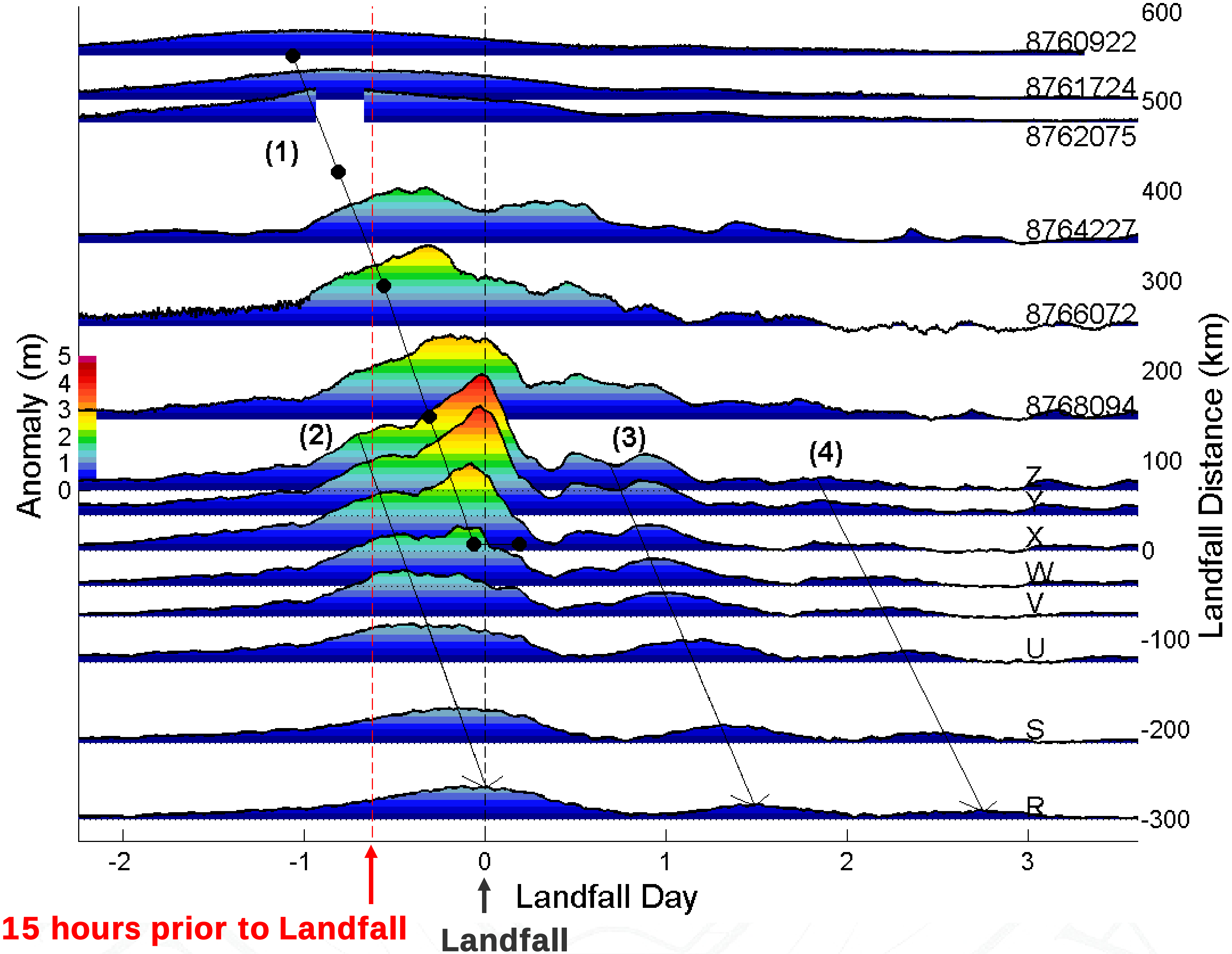
- Hurricane Ike (2008) produced an *early forerunner of 2^{+} m* along the Louisiana-Texas shelf and coast
  - 15 hours prior to landfall
  - The hurricane was located off the shelf in the deep Gulf of Mexico
  - Winds were directed shore parallel or offshore
- The forerunner penetrated deep into Galveston Bay into the heart of Houston
- A major portion of Ike's surge propagated as a free wave along the LATEX shelf down the Texas coast

Tracks of ***major storms*** and ***bathymetry*** showing LATEX shelf

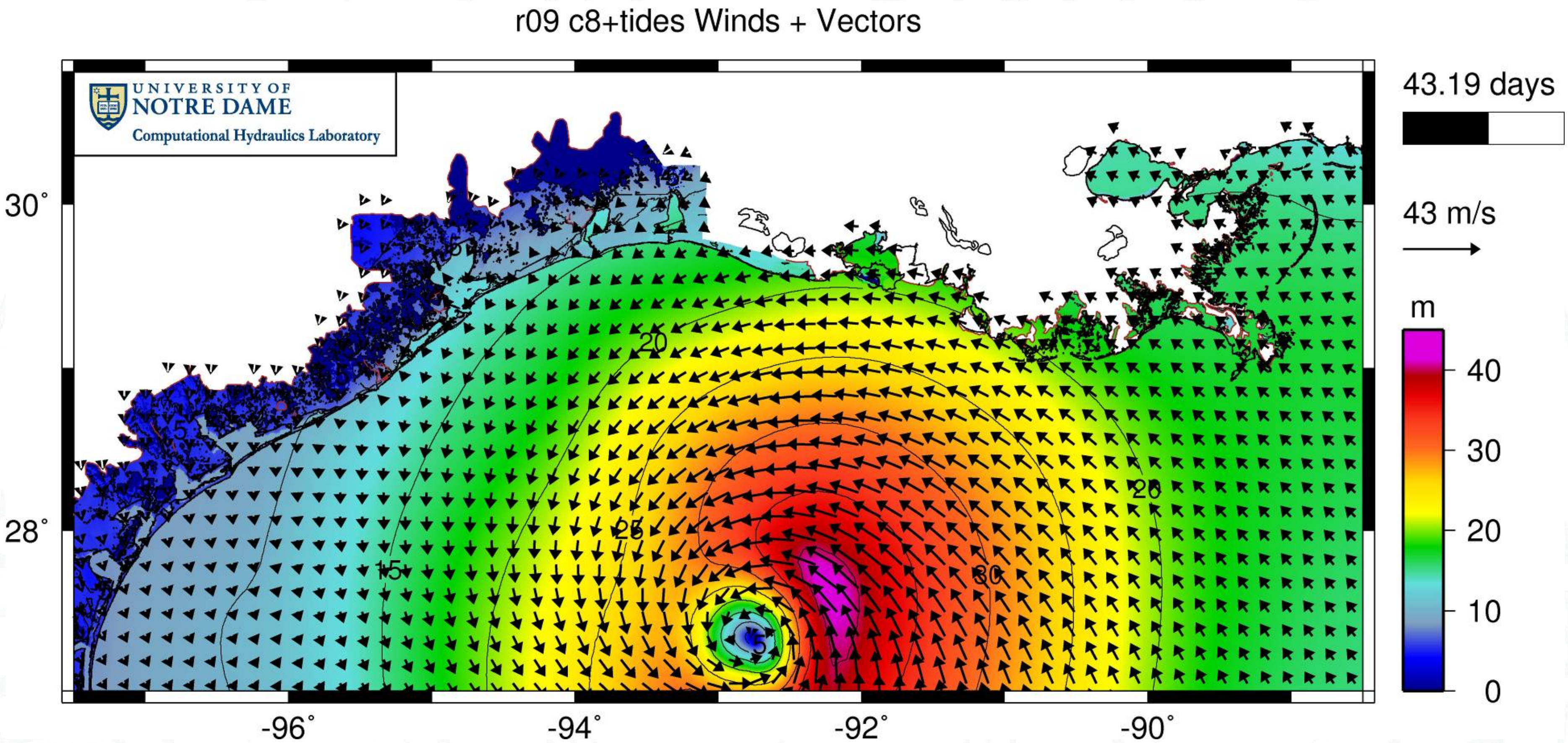


NOAA stations 8701724, 8760922, 8762075, 8764227, 8766072, 8766094, 8770771
Andrew Kennedy gauges Z – R

Ike water surface elevation ***anomaly*** (measured water level – predicted tides) from eastern Louisiana to western Texas



Wind vectors ***15 hours prior to landfall*** from H*Wind/OWI data assimilated models



Extent of hurricane force winds are contoured in red
Extent of tropical storm force winds are contoured in yellow and green

Eye and hurricane force winds are ***off*** the shelf
Winds are directed ***shore parallel or offshore***

Question ?

- Hurricane Ike *forerunner* origin
  - Wave radiation gradient induced stress ?
  - Gulf of Mexico wide resonant modes ?
  - Geostrophic set up ?

Conclusions & Implications

- Hurricane Ike *forerunner* originates from *Geostrophic setup* and requires
  - Fast shore parallel shelf currents
  - Low shelf friction
  - A wide shelf
- Hurricane Ike *forerunner* has a slow time scale and its implications include
  - Early dune degradation
  - Efficient inland coastal floodplain and bay penetration
  - Very fast shore parallel shelf currents that destroy offshore energy infrastructure

Bolivar Peninsula, Pre-Ike

Bolivar Peninsula, Post-Ike

Hurricane Ike Forerunner Surge

- Methods
  - SWAN+ADCIRC Wave & Circulation Model Coupling
  - TX2008-r09 SWAN+ADCIRC Model for Texas
  - Air-sea interaction
  - Validation data
- Ike Hindcast and Validation
  - Winds, Waves, Surge, Shelf velocities
- Ike Analysis
  - Origin of the forerunner – Coriolis effect
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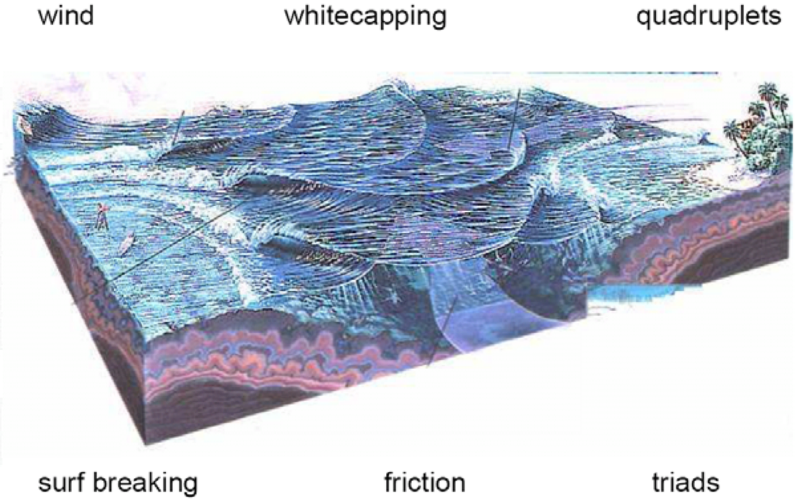
SWAN+ADCIRC Model – Coupled waves and current on identical unstructured grids

- ADCIRC solves for water surface elevations and currents in two and three dimensions

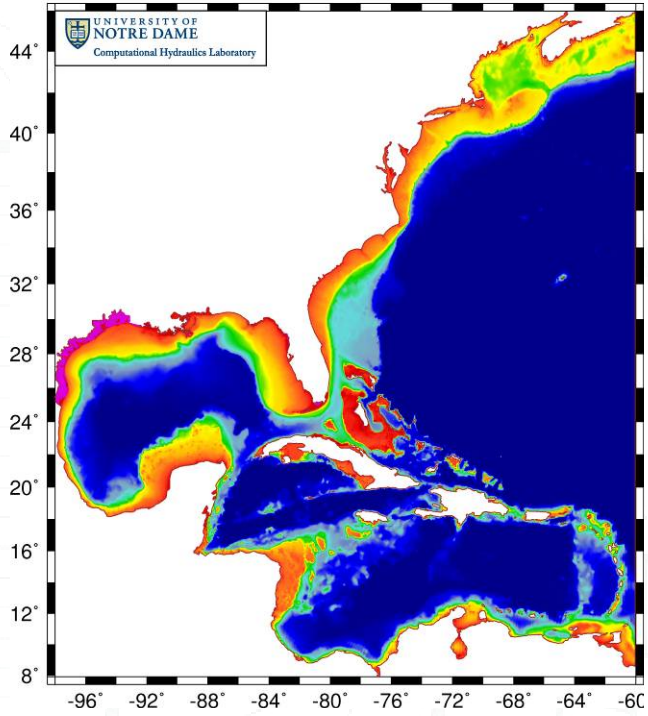
- SWAN solves the wave action density and is a non-phase resolving wave model with wave energy represented by a spectrum



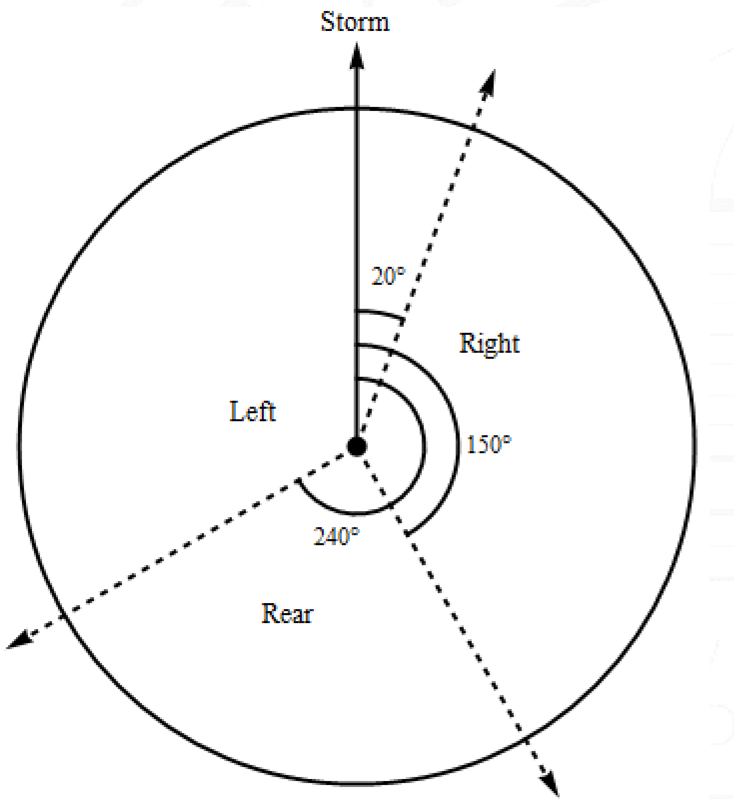
- ADCIRC and SWAN interact
  - Water levels and currents effect waves
  - Wave breaking forces water level setup and currents

TX2008-r09 Bathymetry and topography

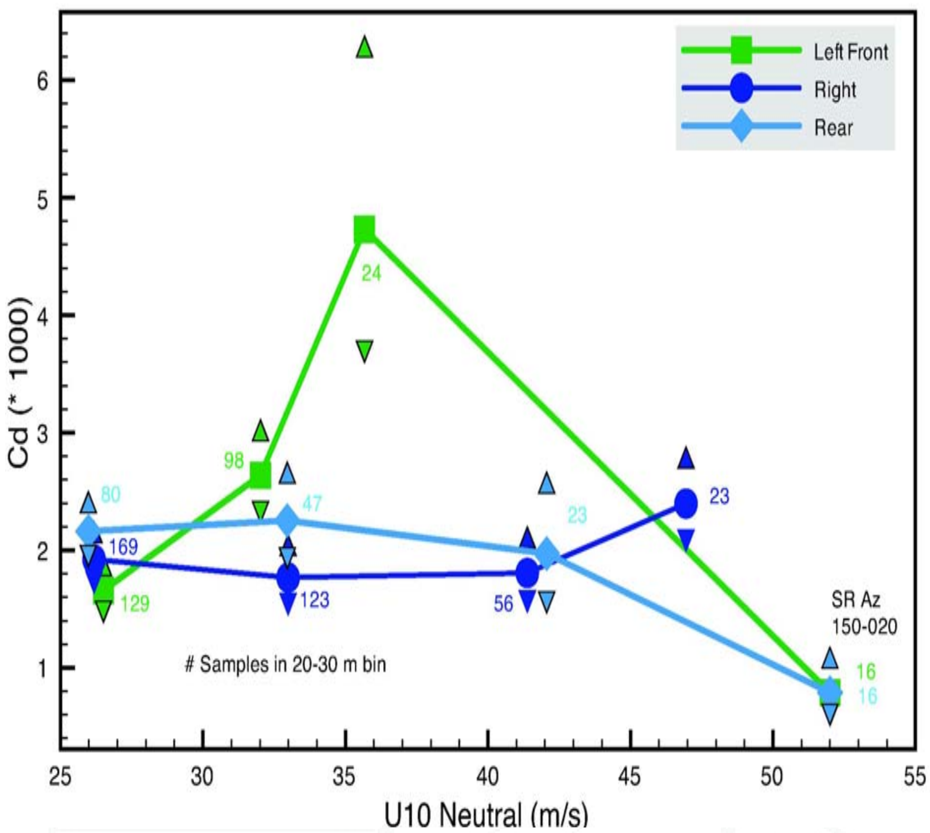
- Western North Atlantic – Gulf of Mexico
- Floodplain from Brownsville to Lake Calcasieu
- Resolution down to 30m
- Fully incorporates high resolution features, channels, barrier islands and wave breaking zones
- 3,323,388 nodes
- Time steps: ADCIRC 1 sec
SWAN 10 min
- Tx2008_r09 Performance on Diamond
  - SWAN+ADCIRC-CG: 14 wall clock minutes per day of simulation on 4096 cores



Sector based drag laws

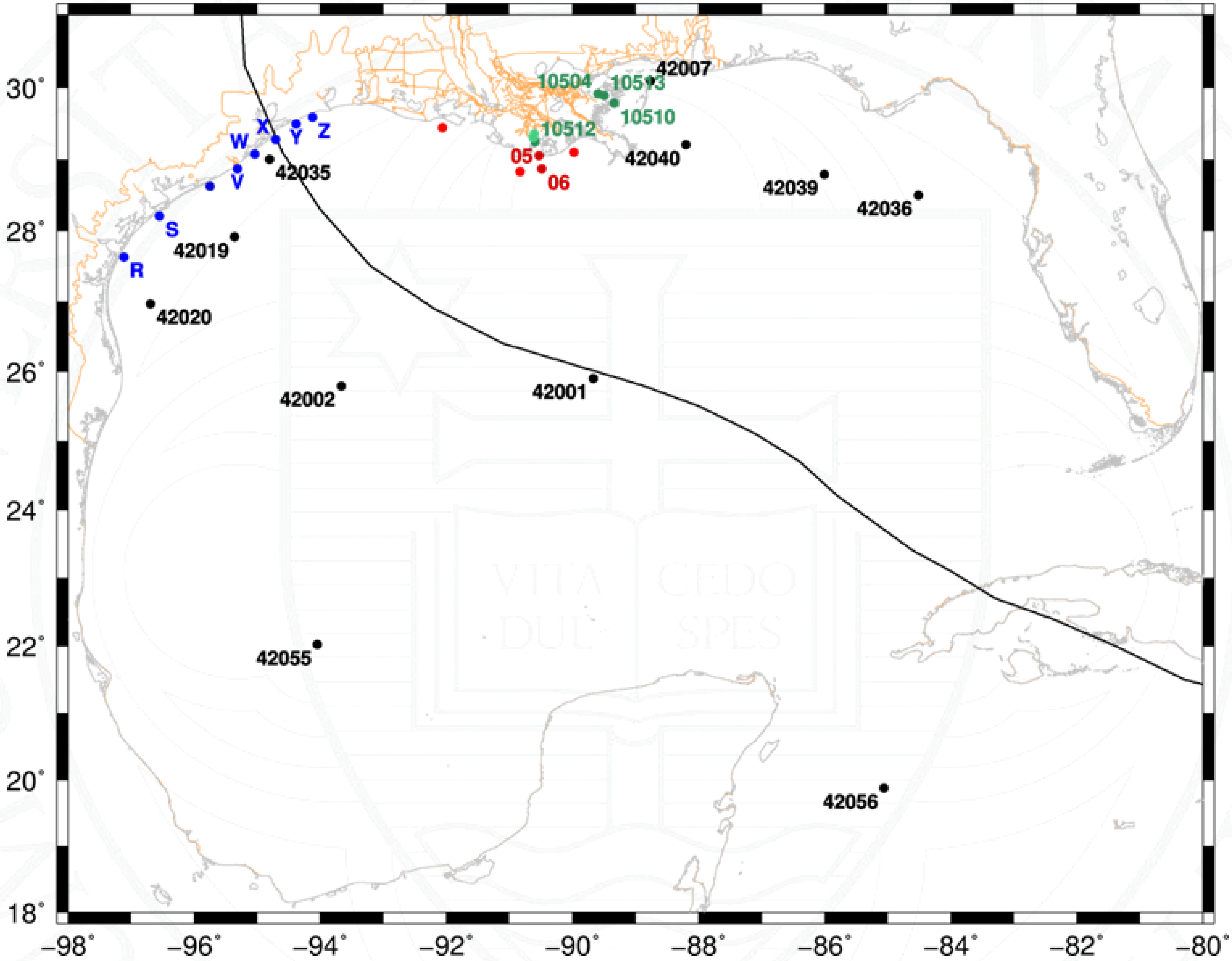


Extents of sectors in relation to direction of storm movement; Powell (2006)

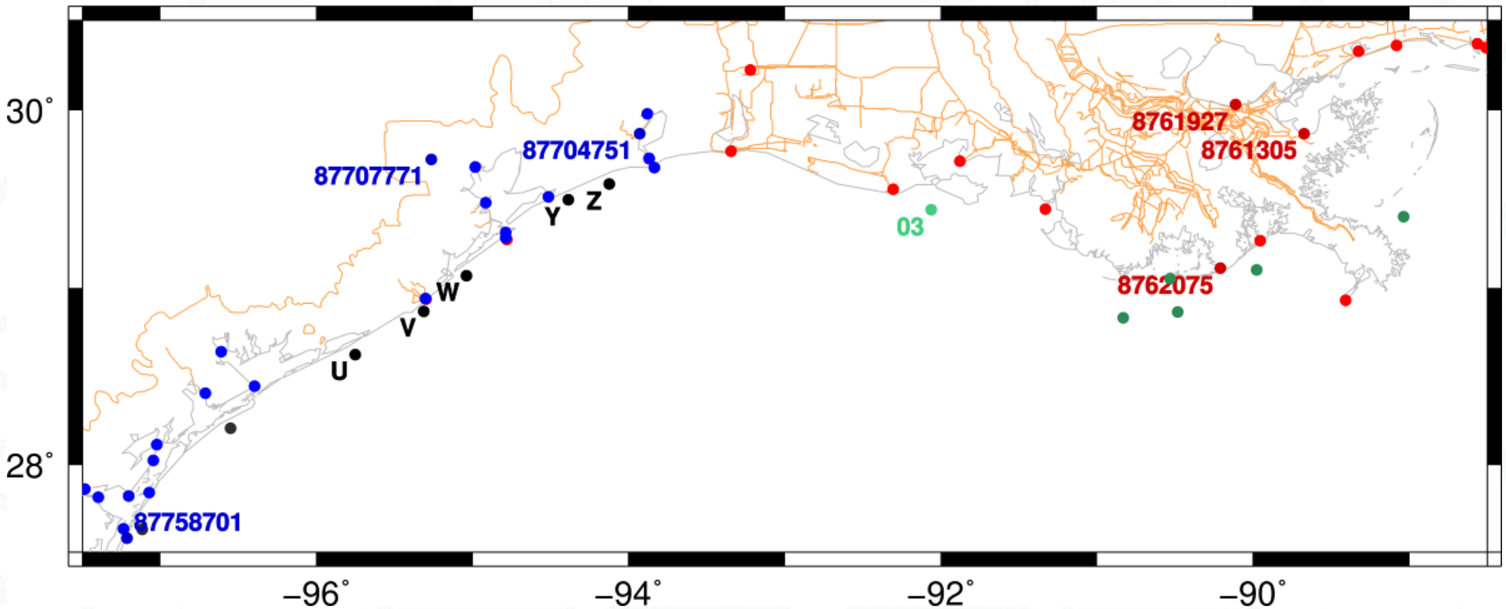


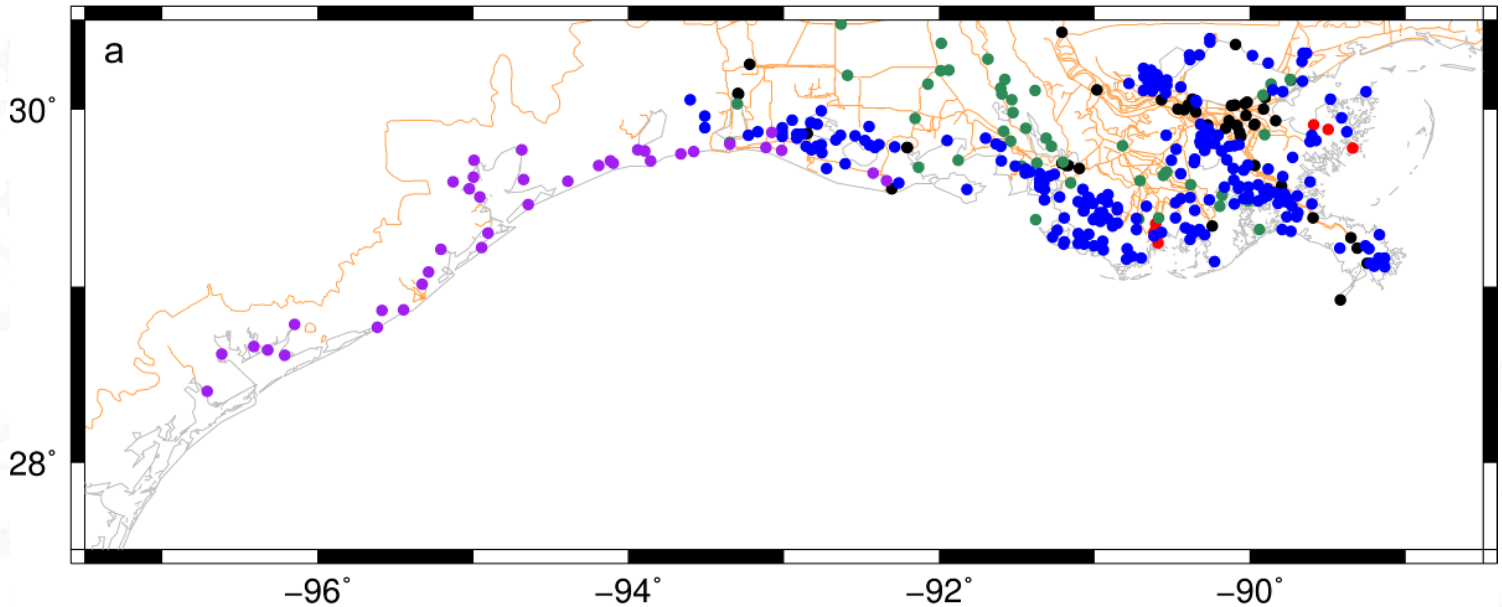
Wind drag coefficient variability by storm sector; Powell (2006)

Validation Data: Wave parameter time histories



Validation Data: Water level time histories





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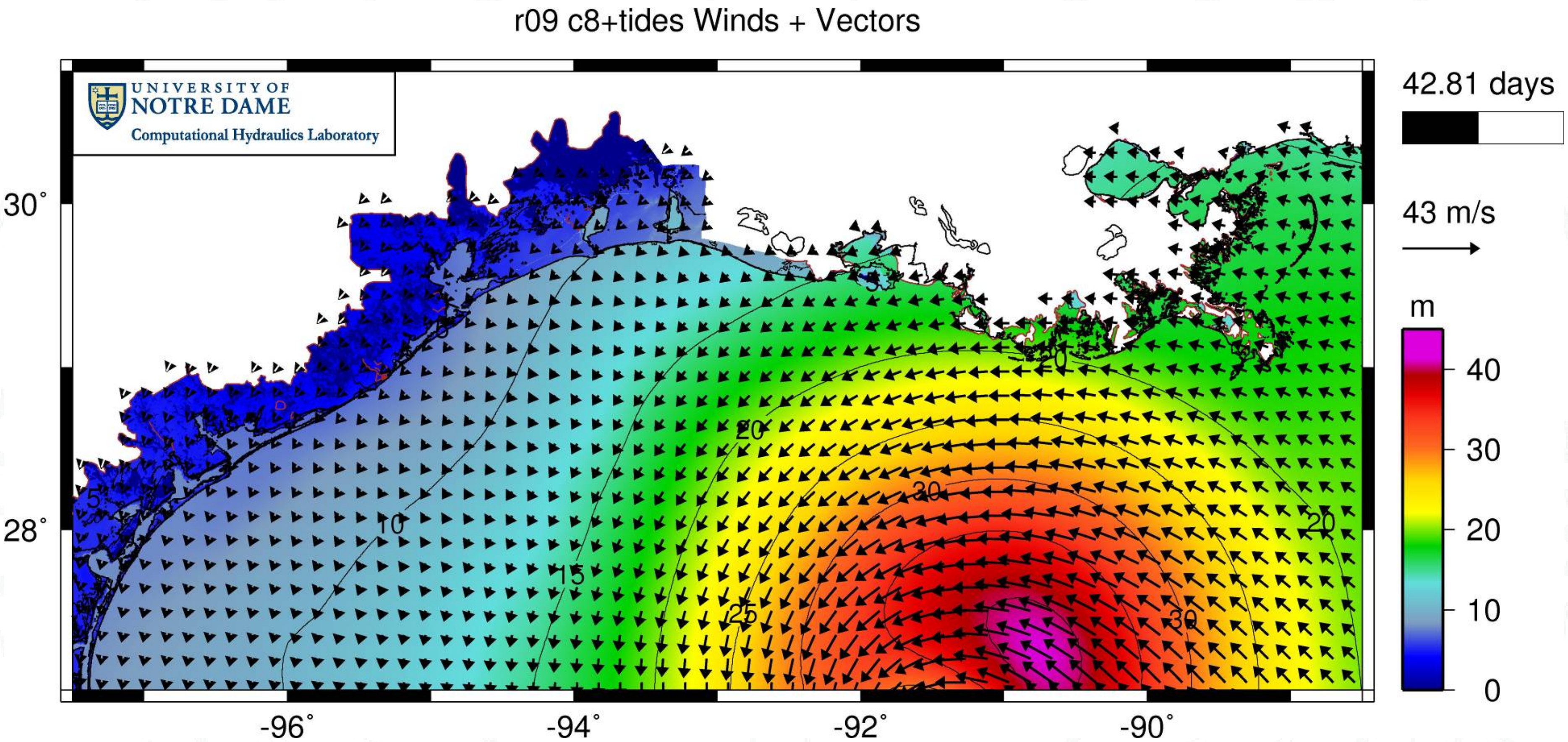
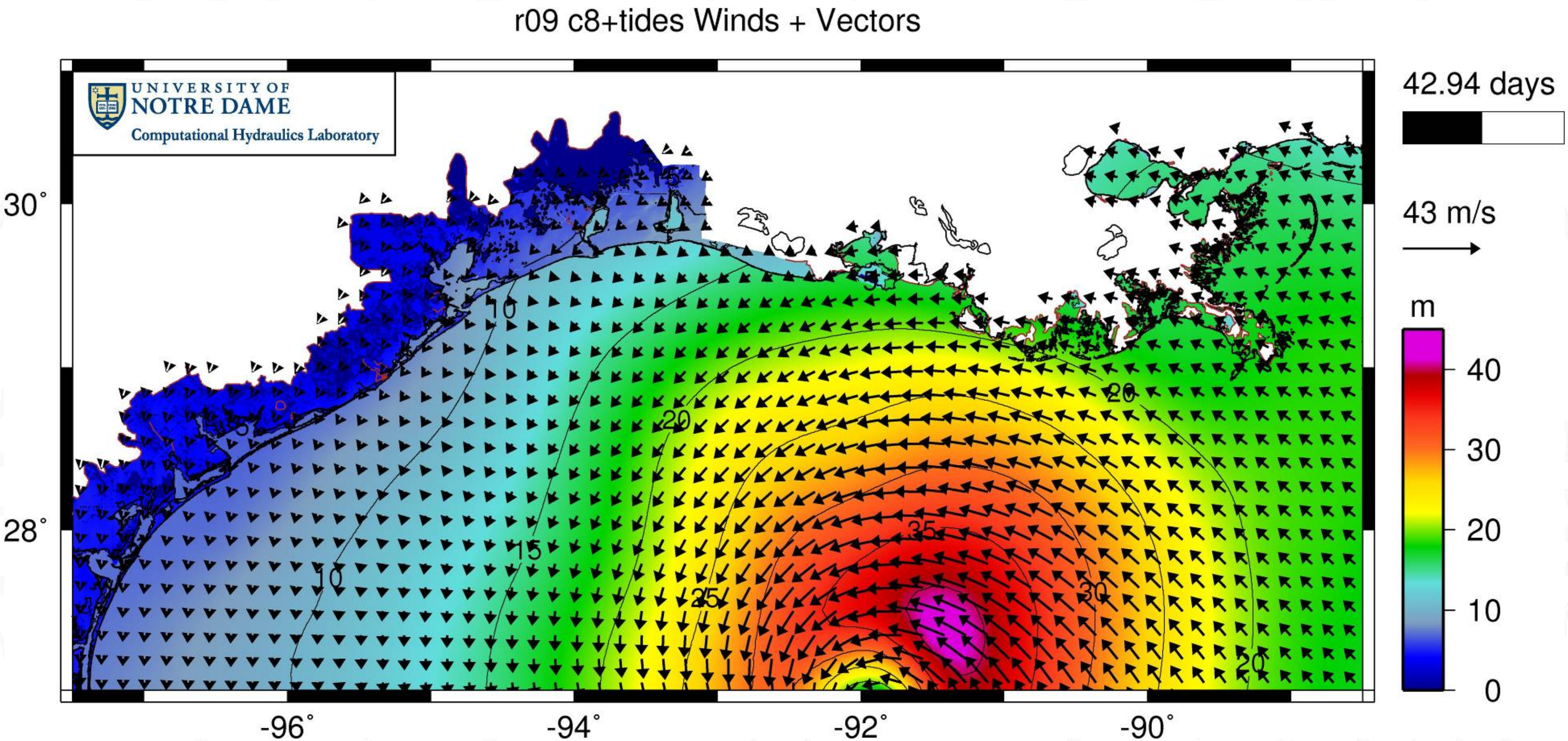
Ike wind contours and vectors (m/s)



- 24 hrs

Ike wind contours and vectors (m/s)



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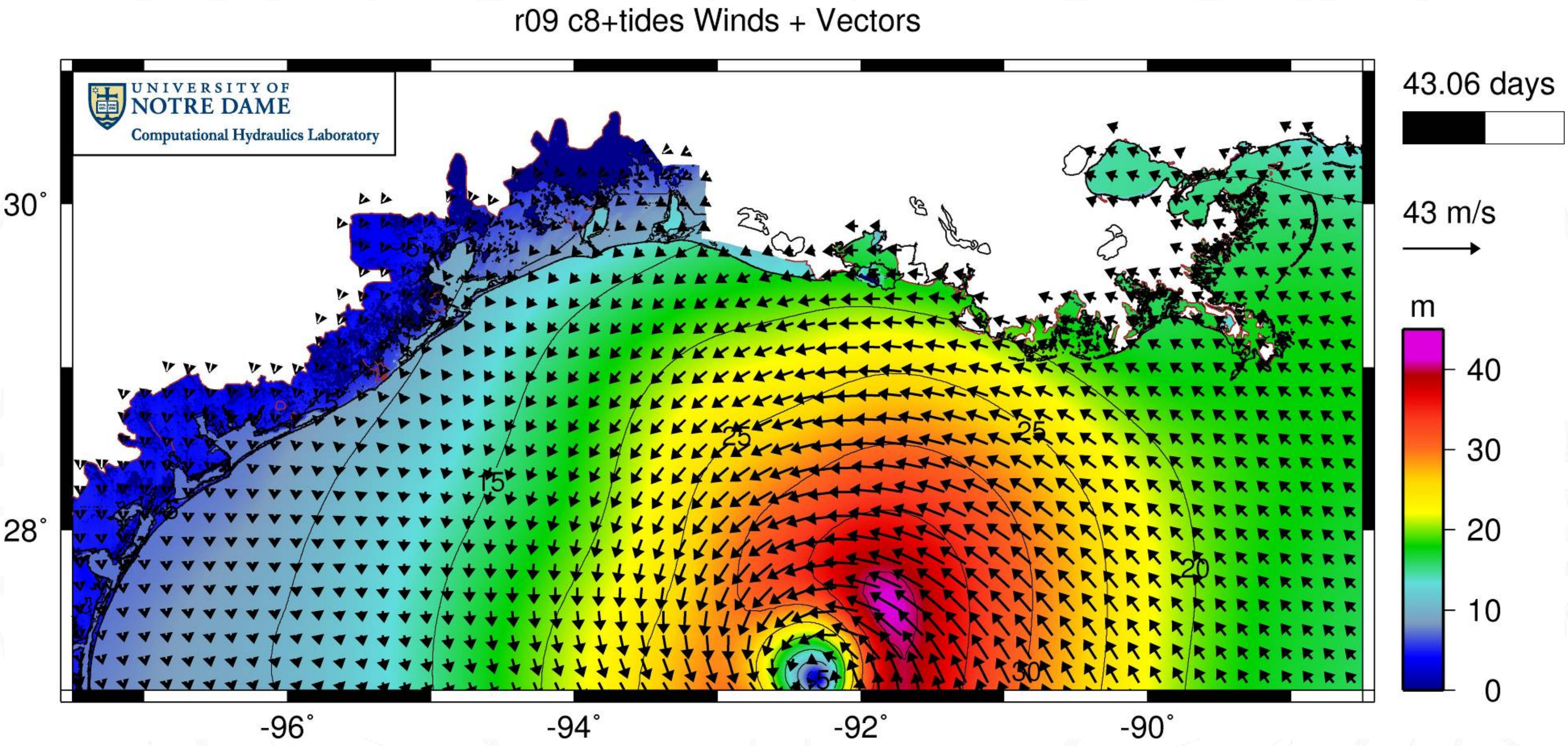

- 18 hrs

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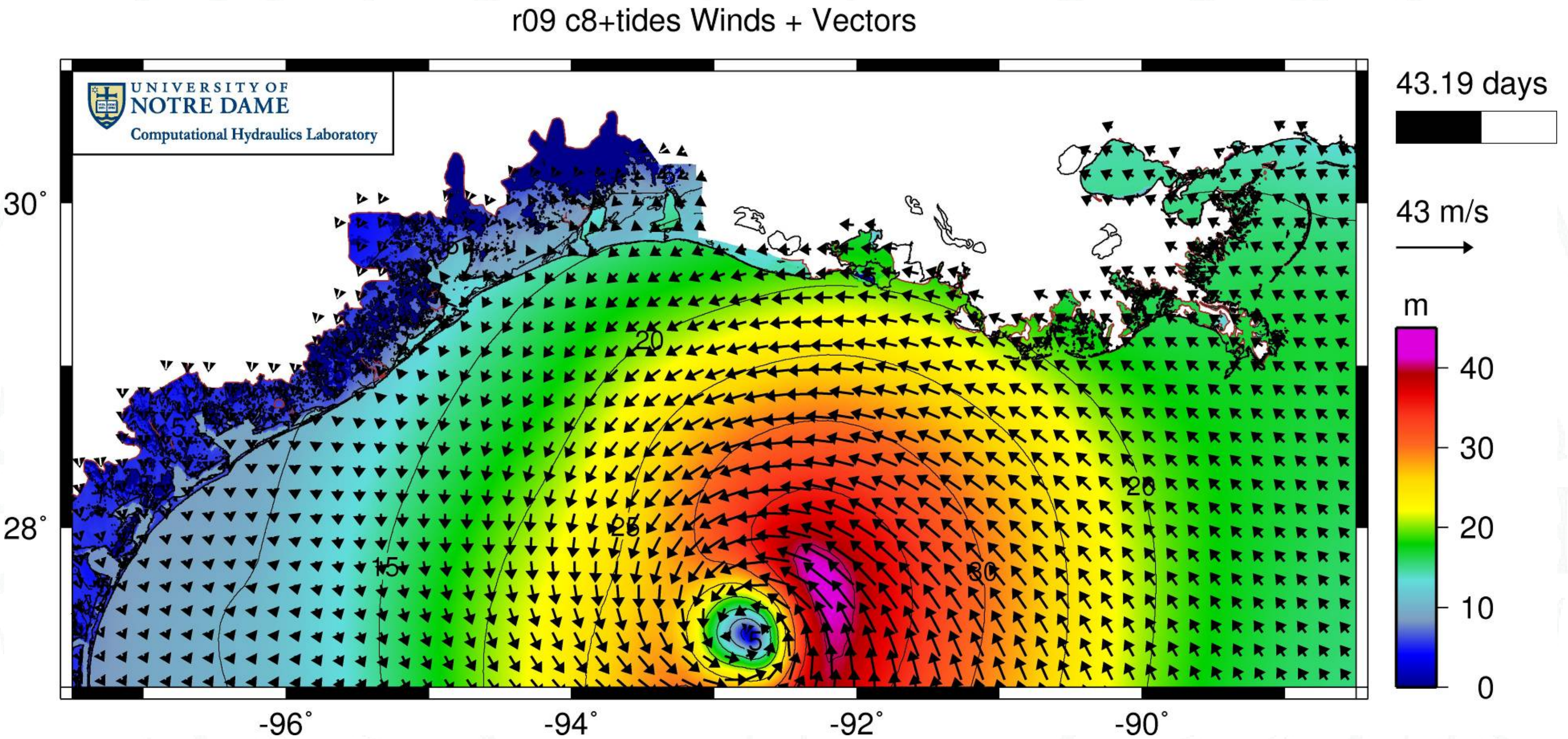

- 15 hrs

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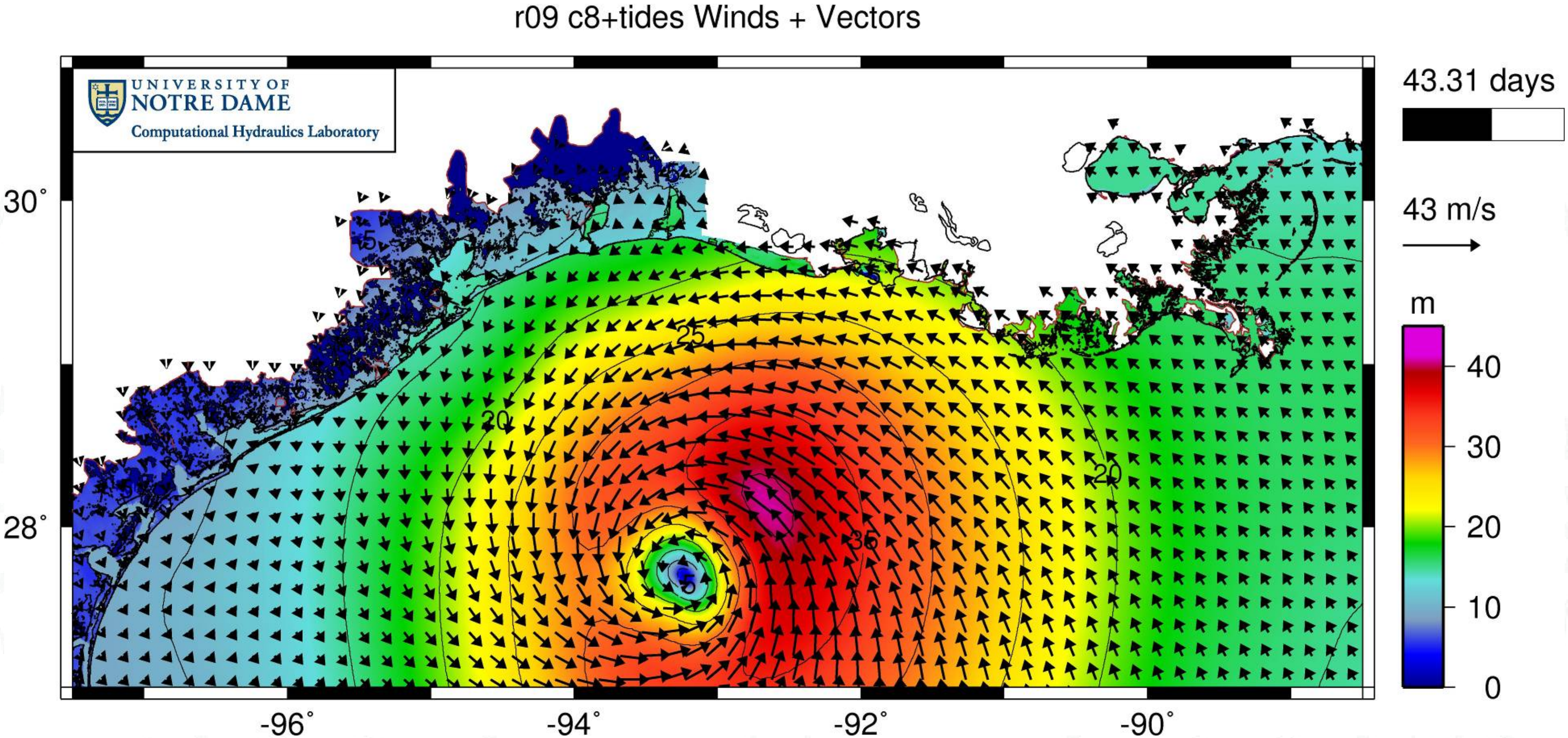
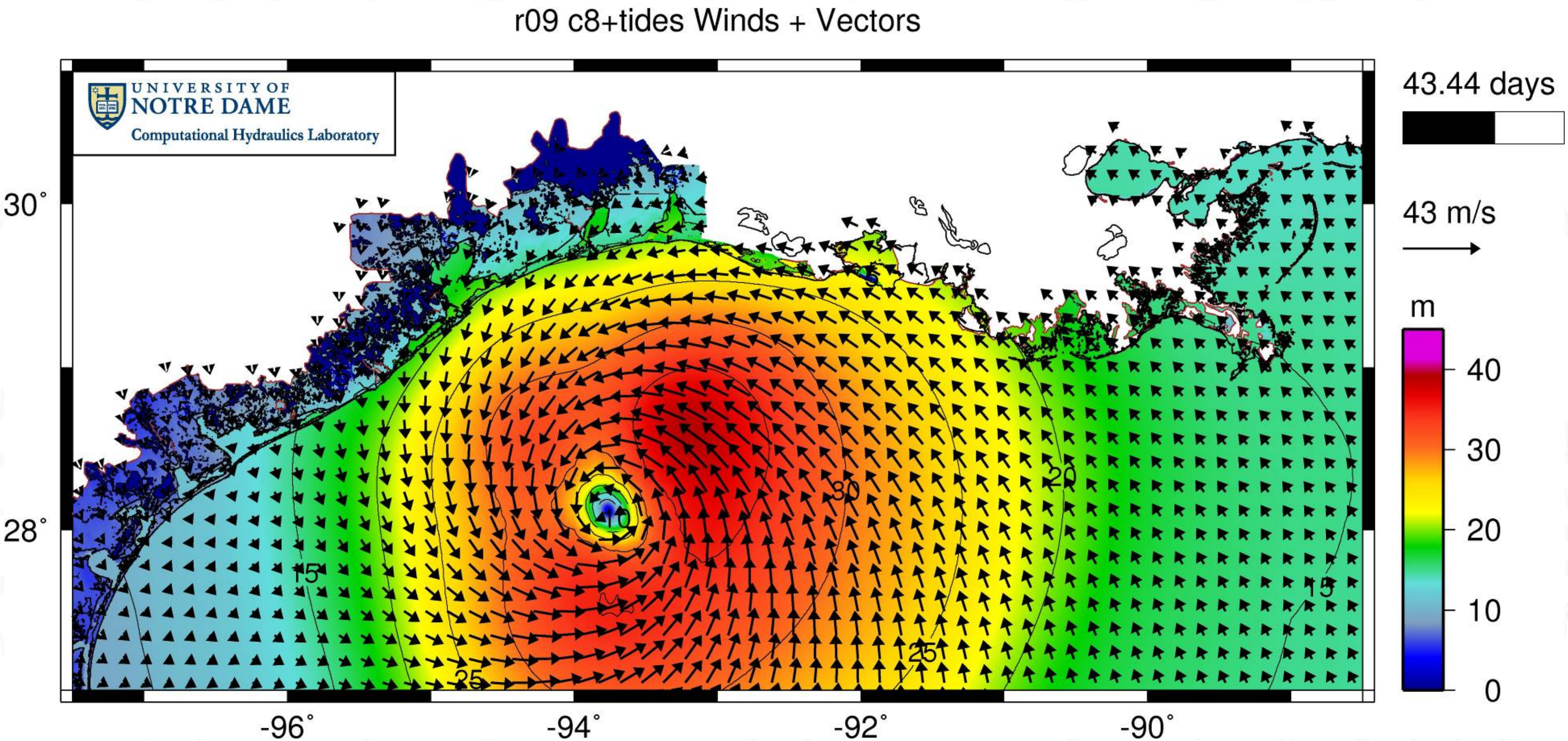


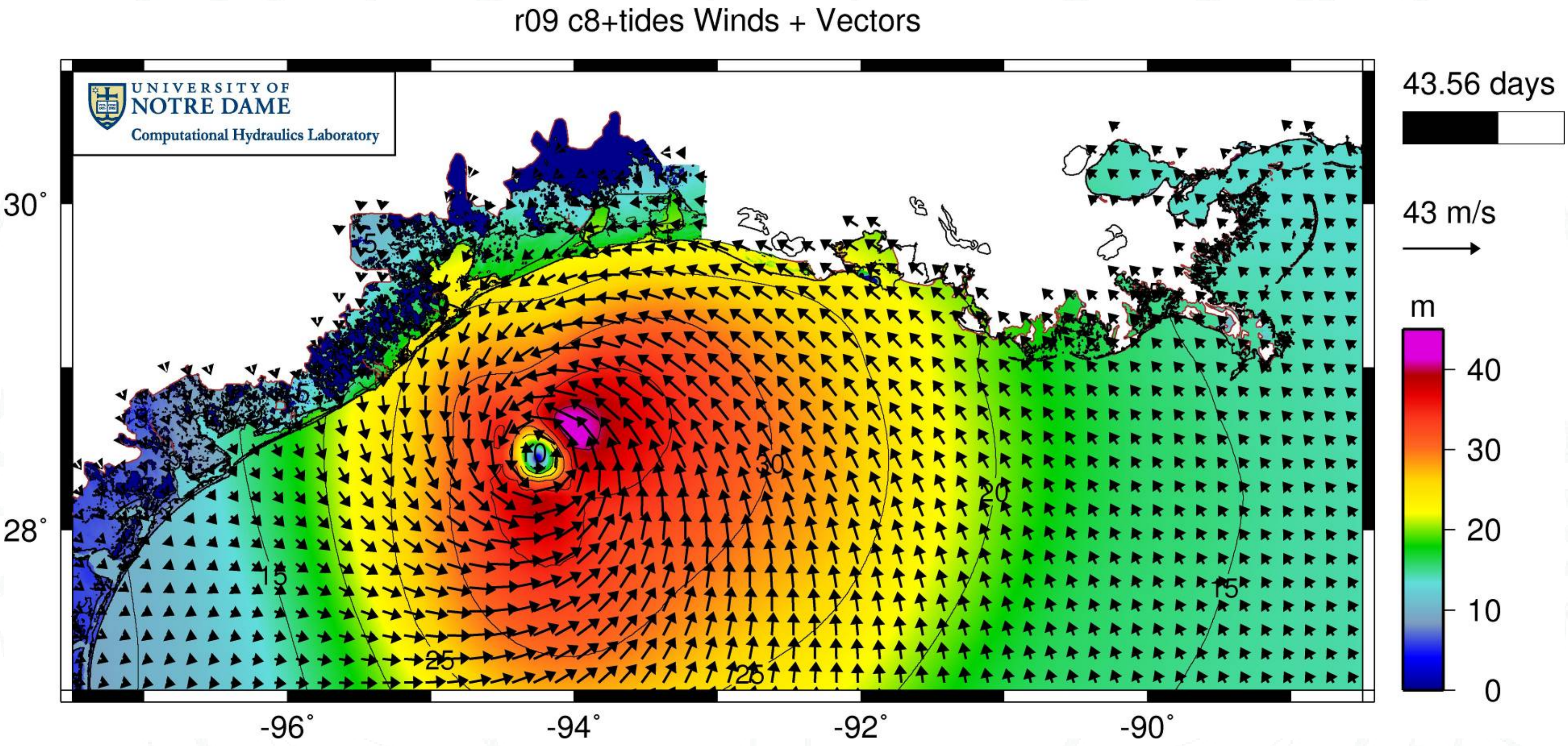
- 12 hrs

Ike wind contours and vectors (m/s)



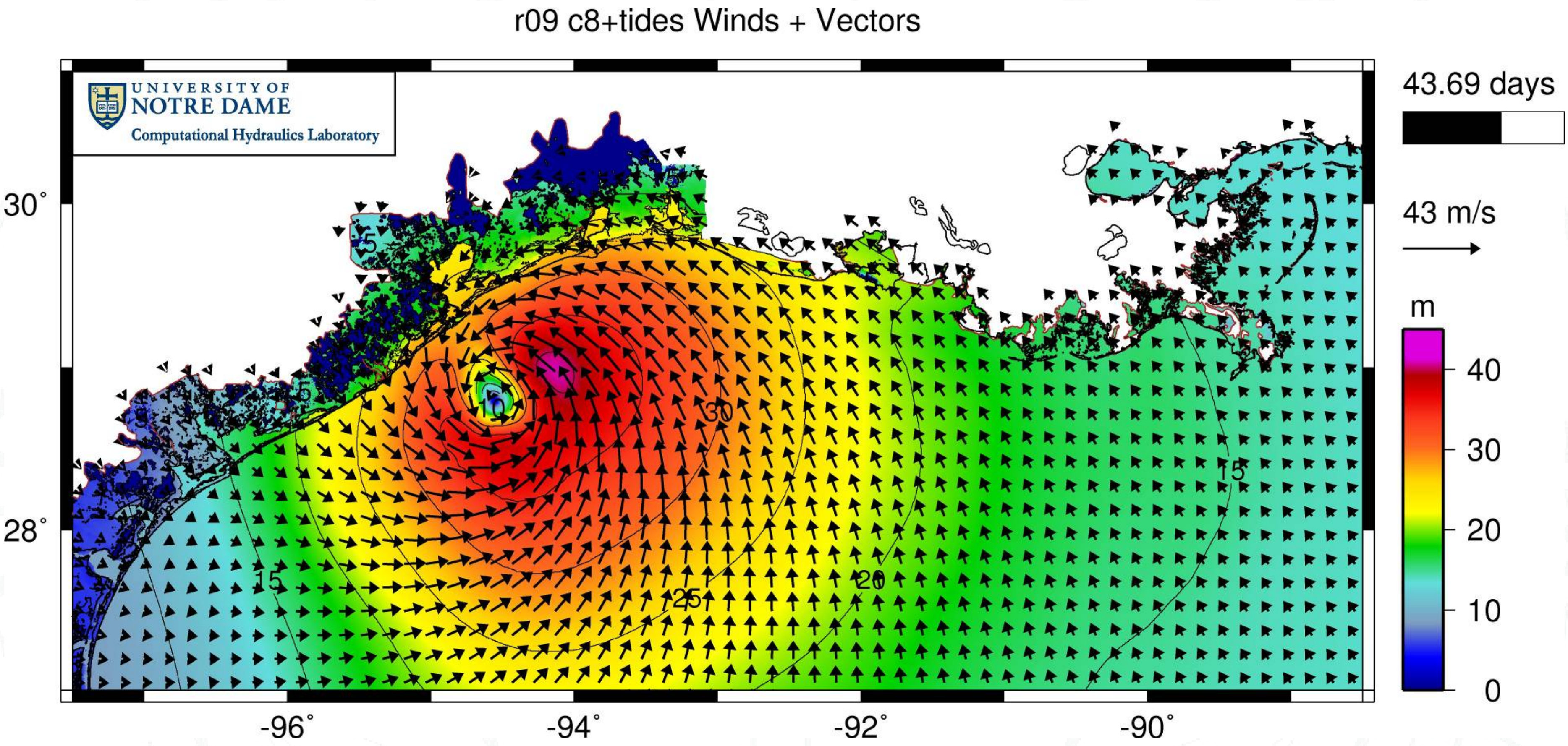
- 9 hrs

Ike wind contours and vectors (m/s)



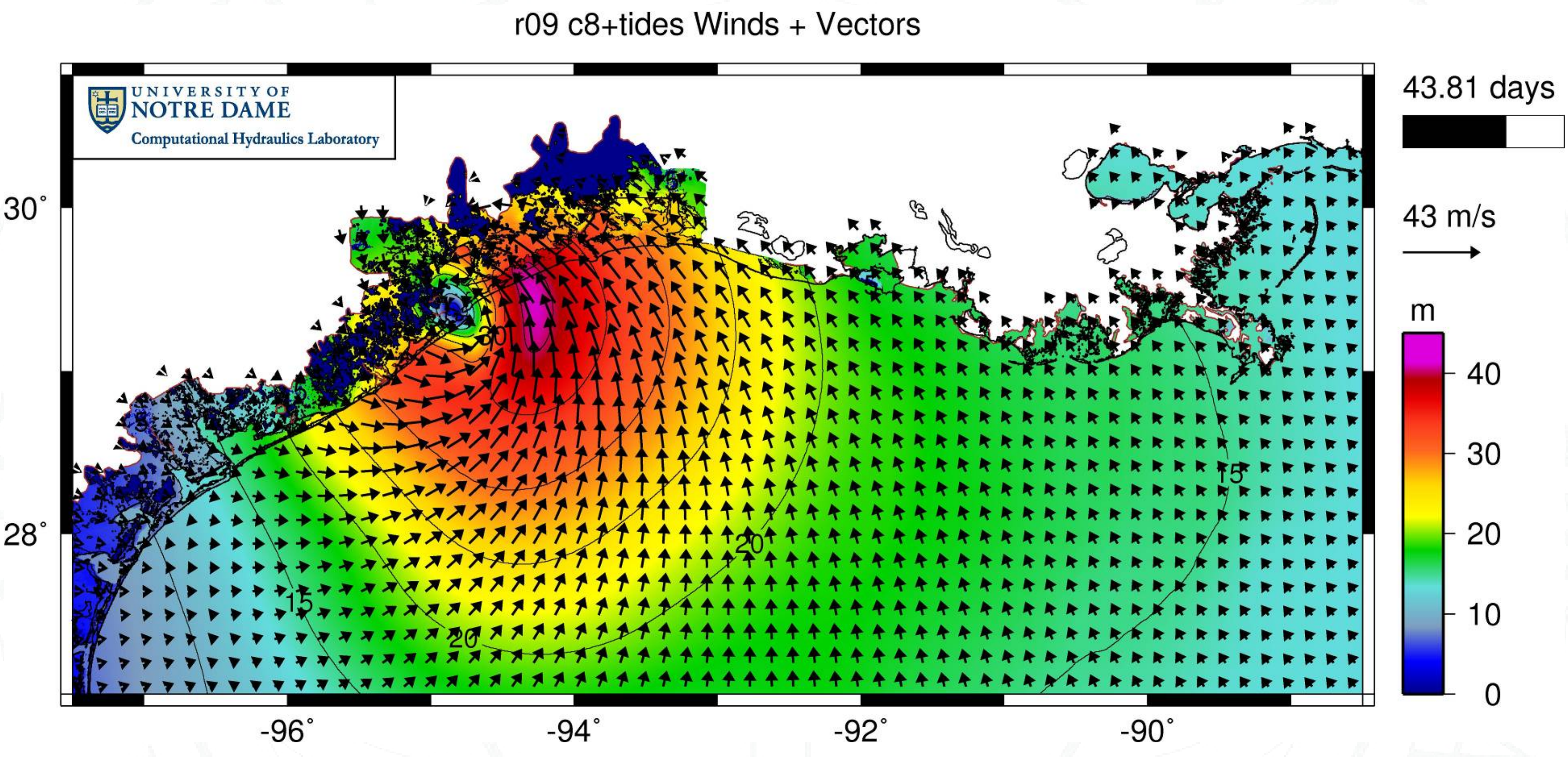
- 6 hrs

Ike wind contours and vectors (m/s)



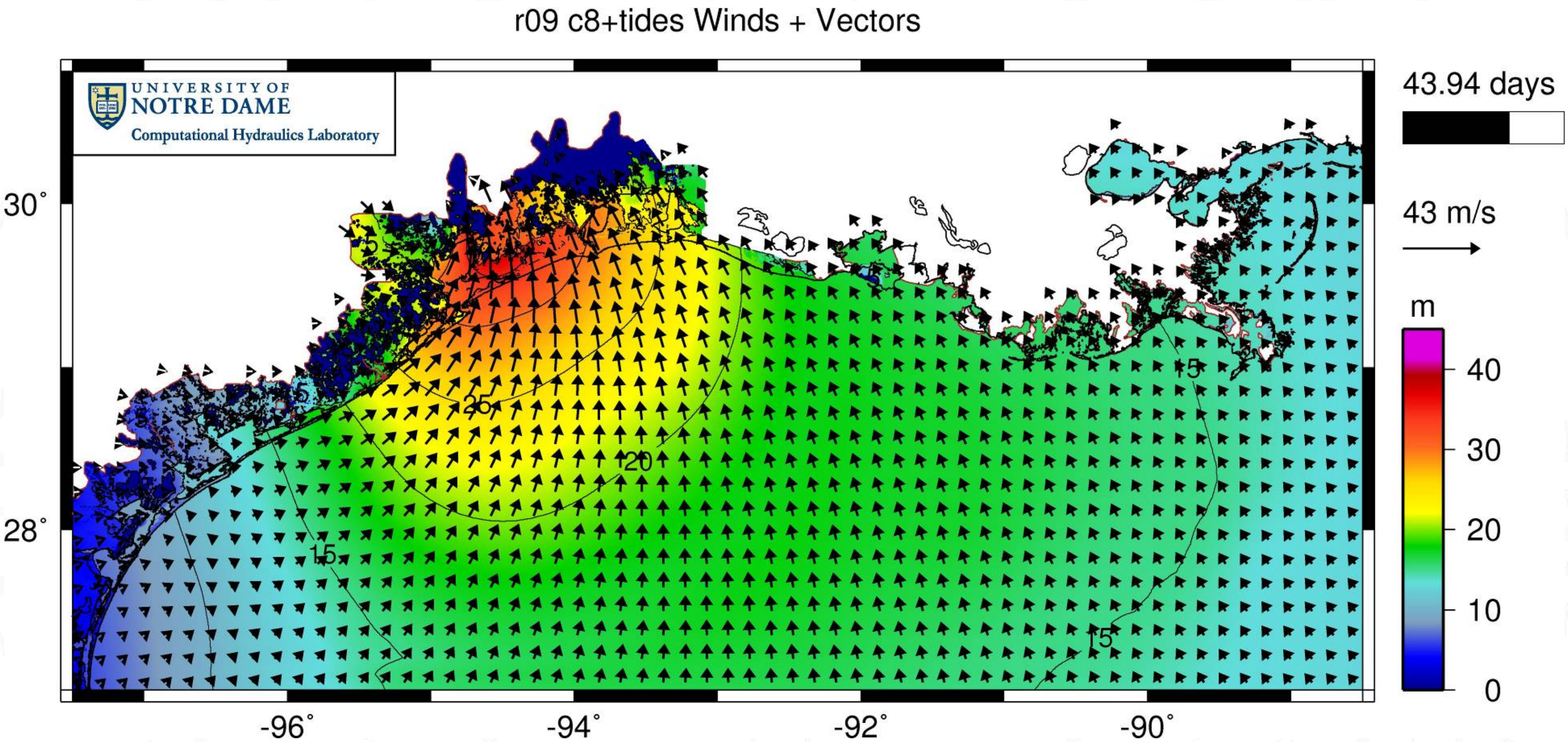
- 3 hrs

Ike wind contours and vectors (m/s)



LANDFALL = 0 hrs

Ike wind contours and vectors (m/s)



+ 3 hrs

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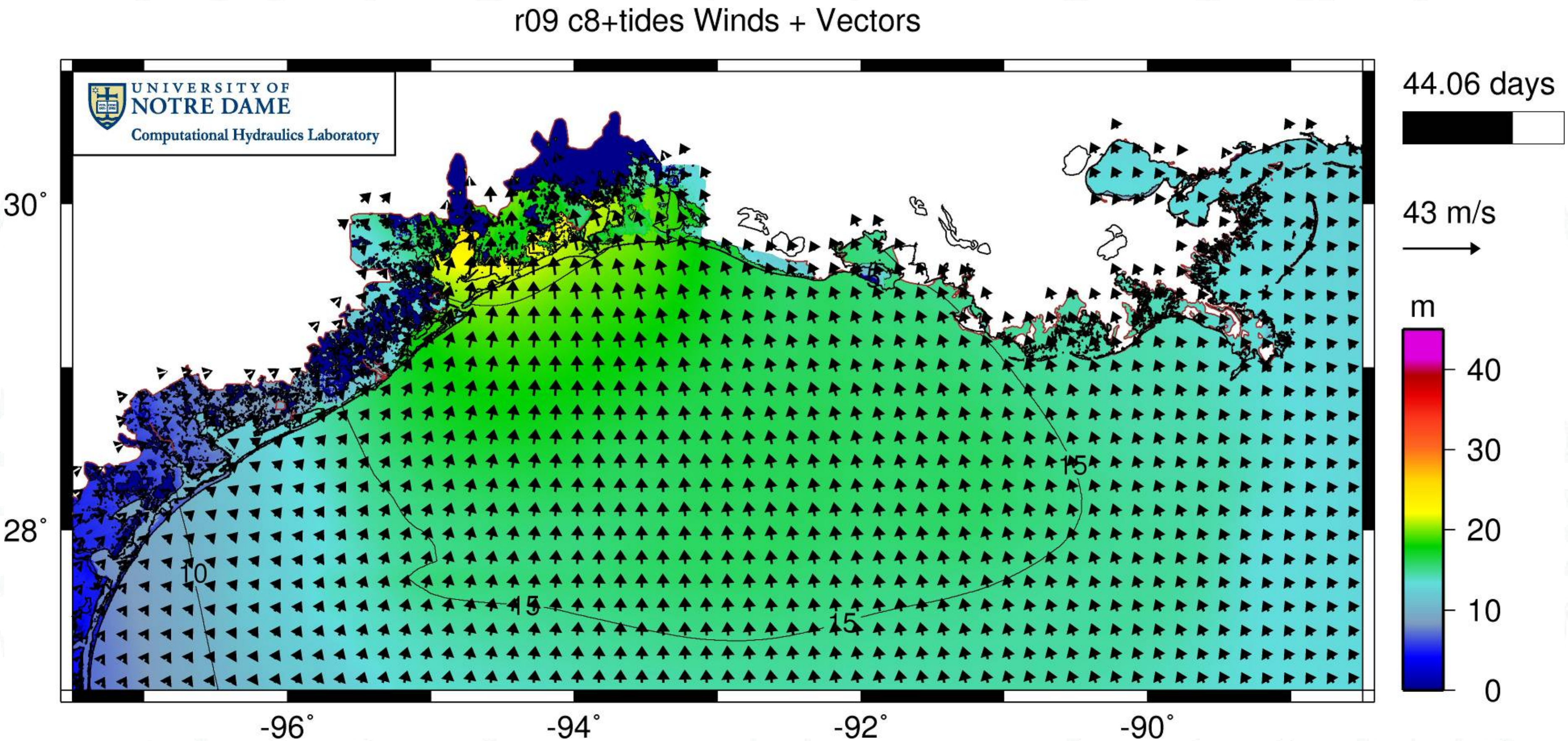

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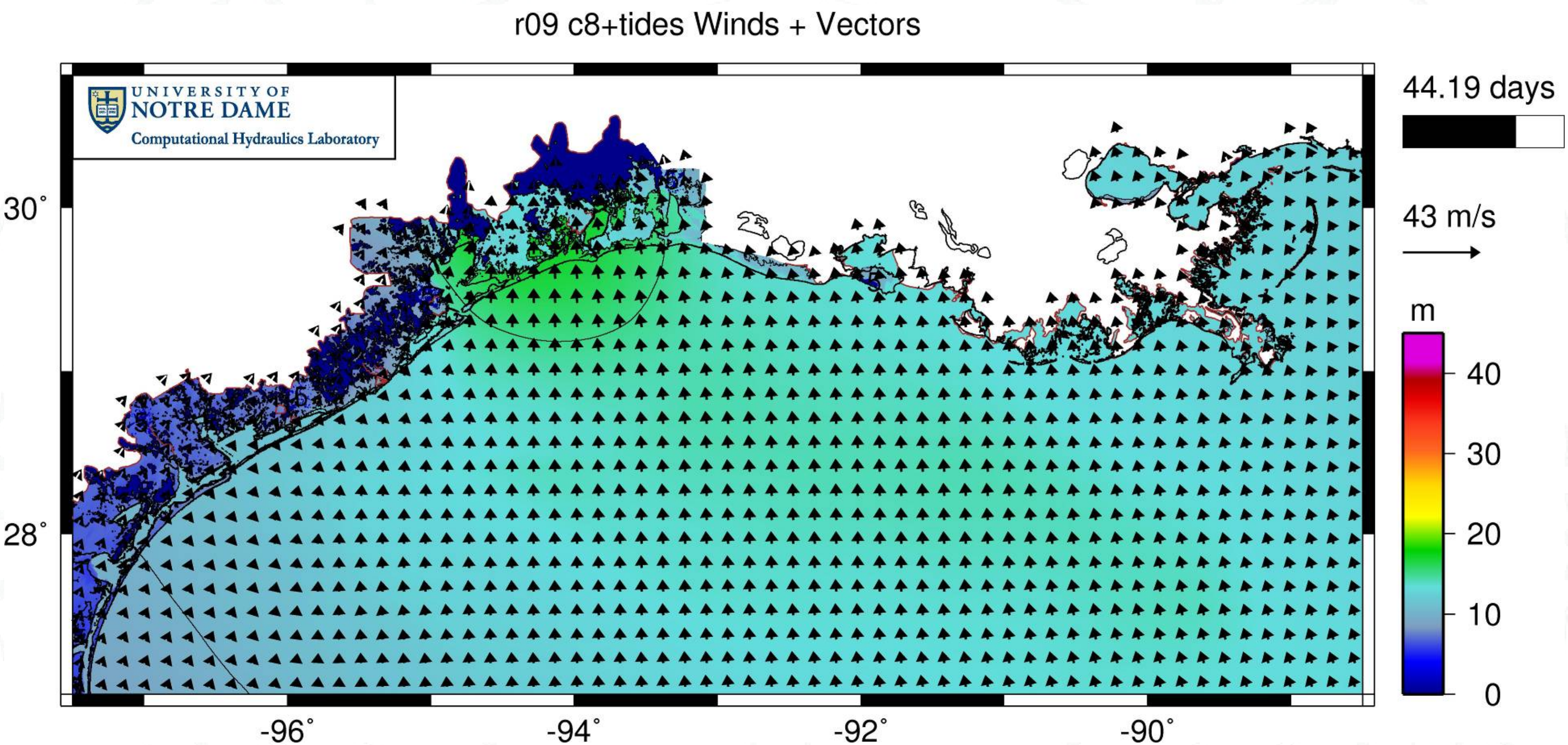

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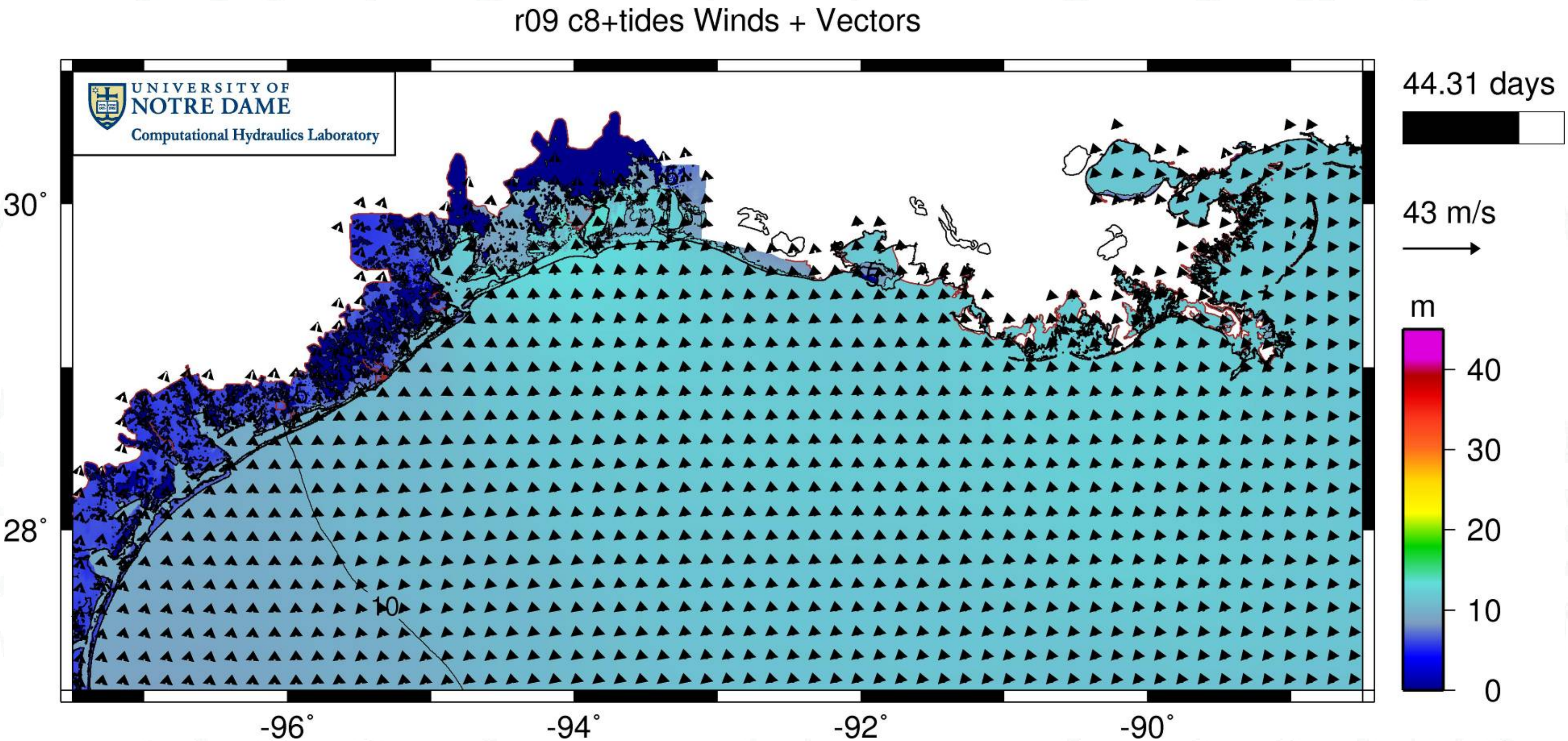
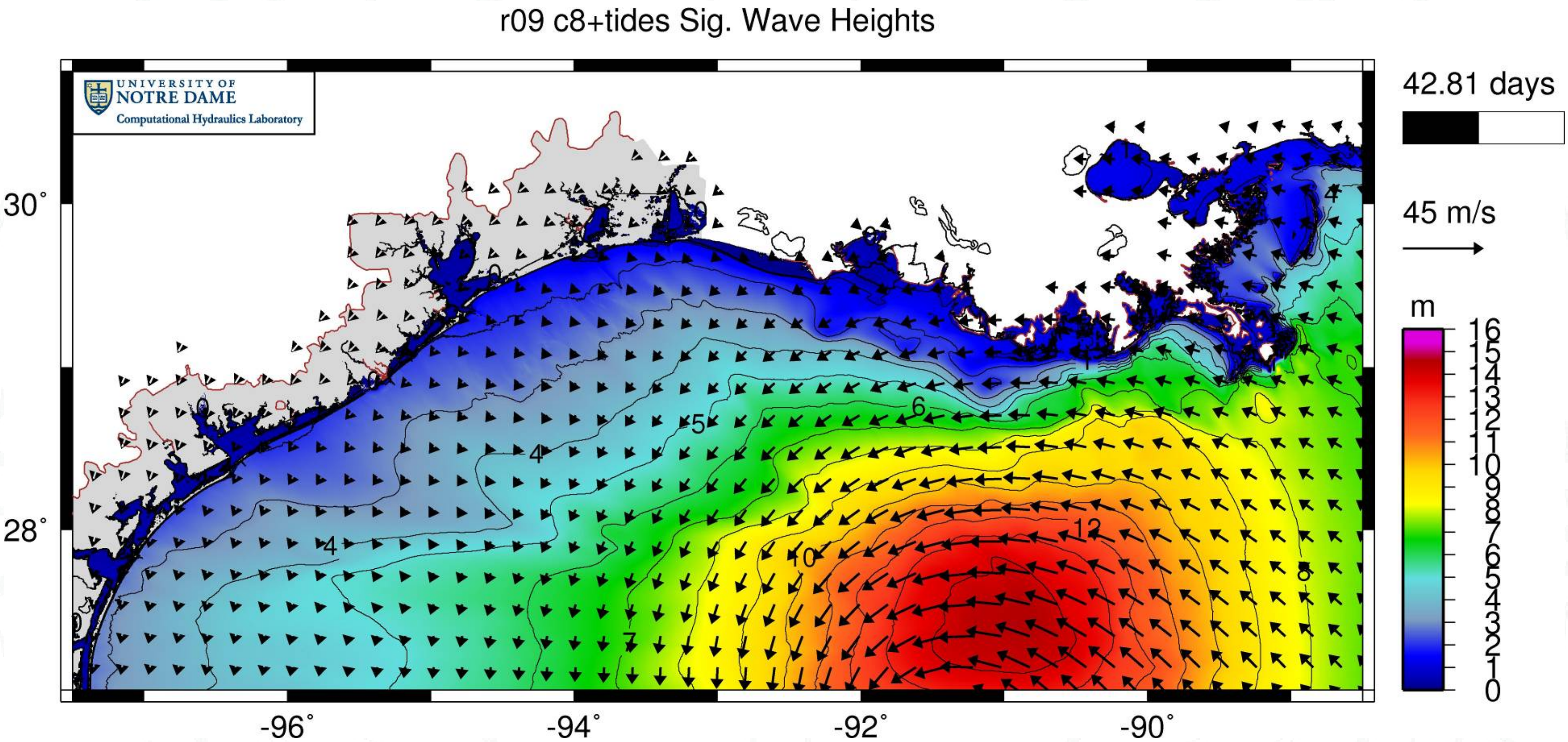


+ 12 hrs

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



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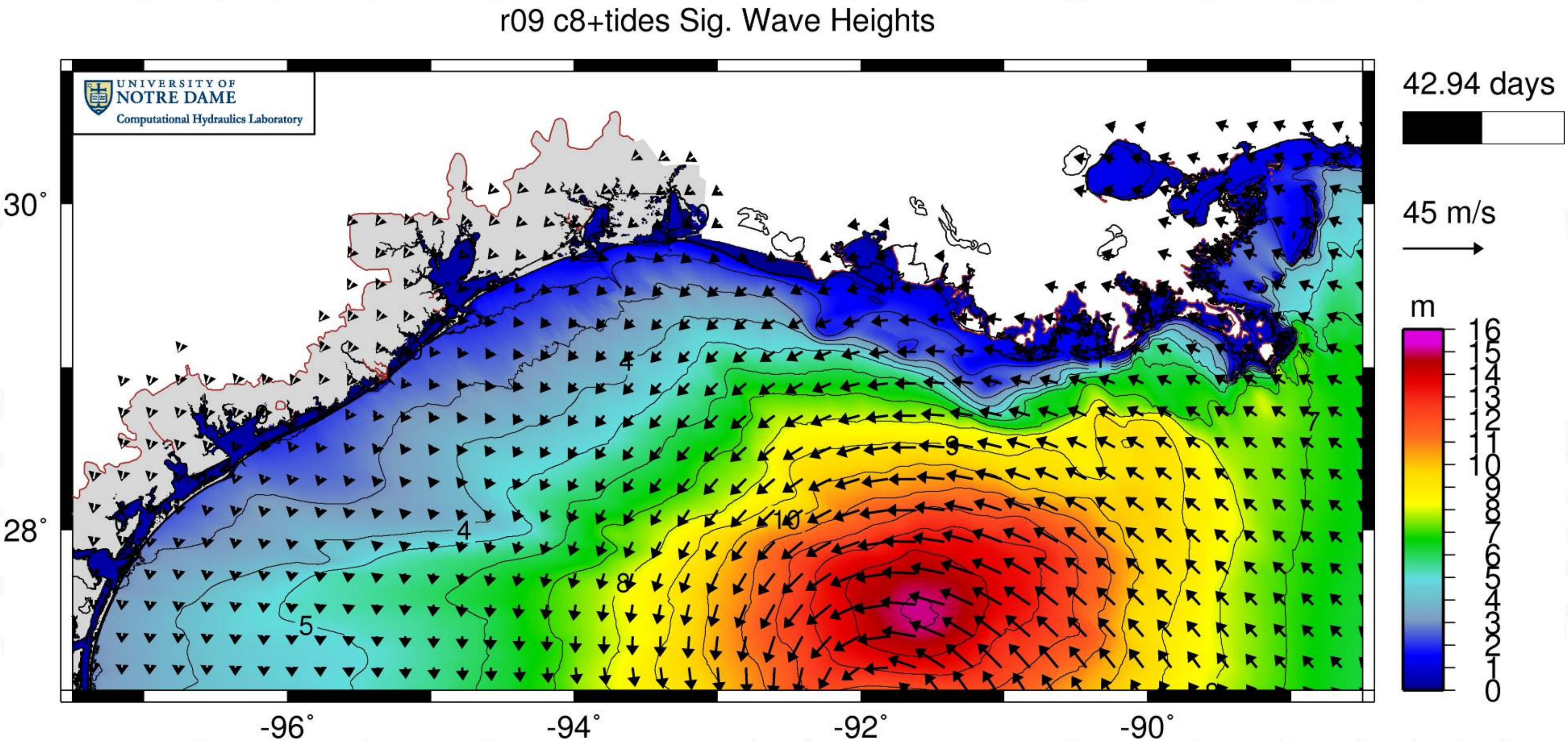

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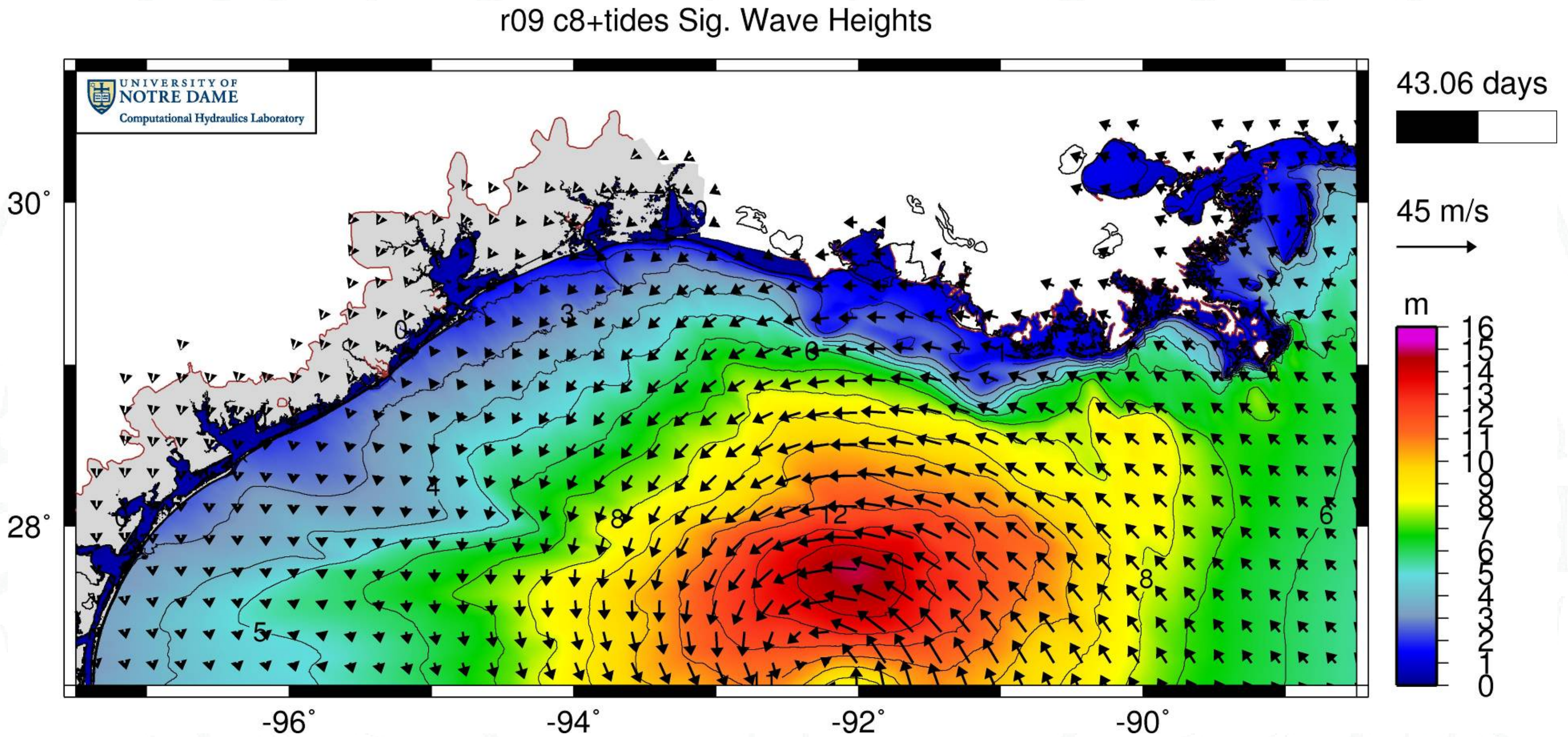

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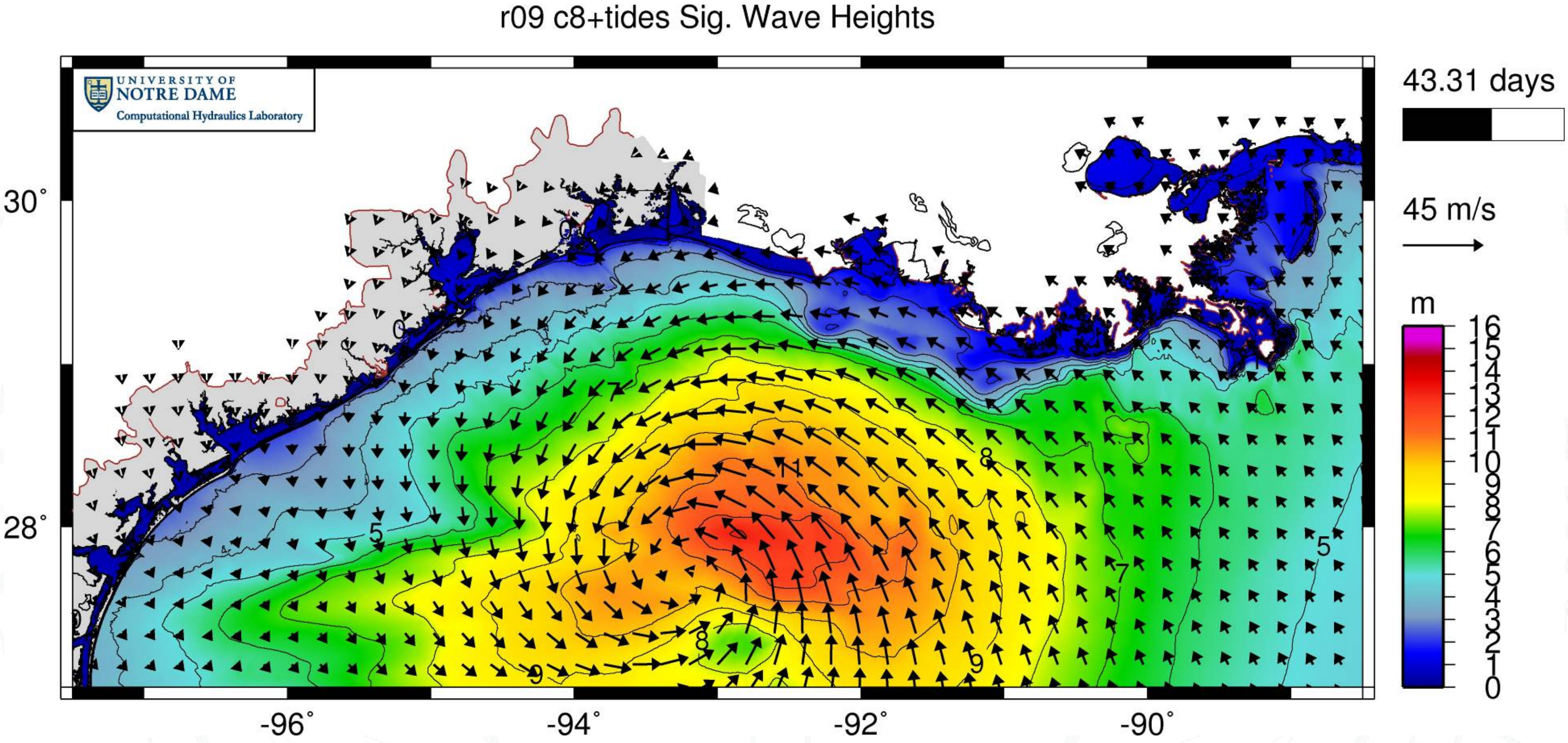

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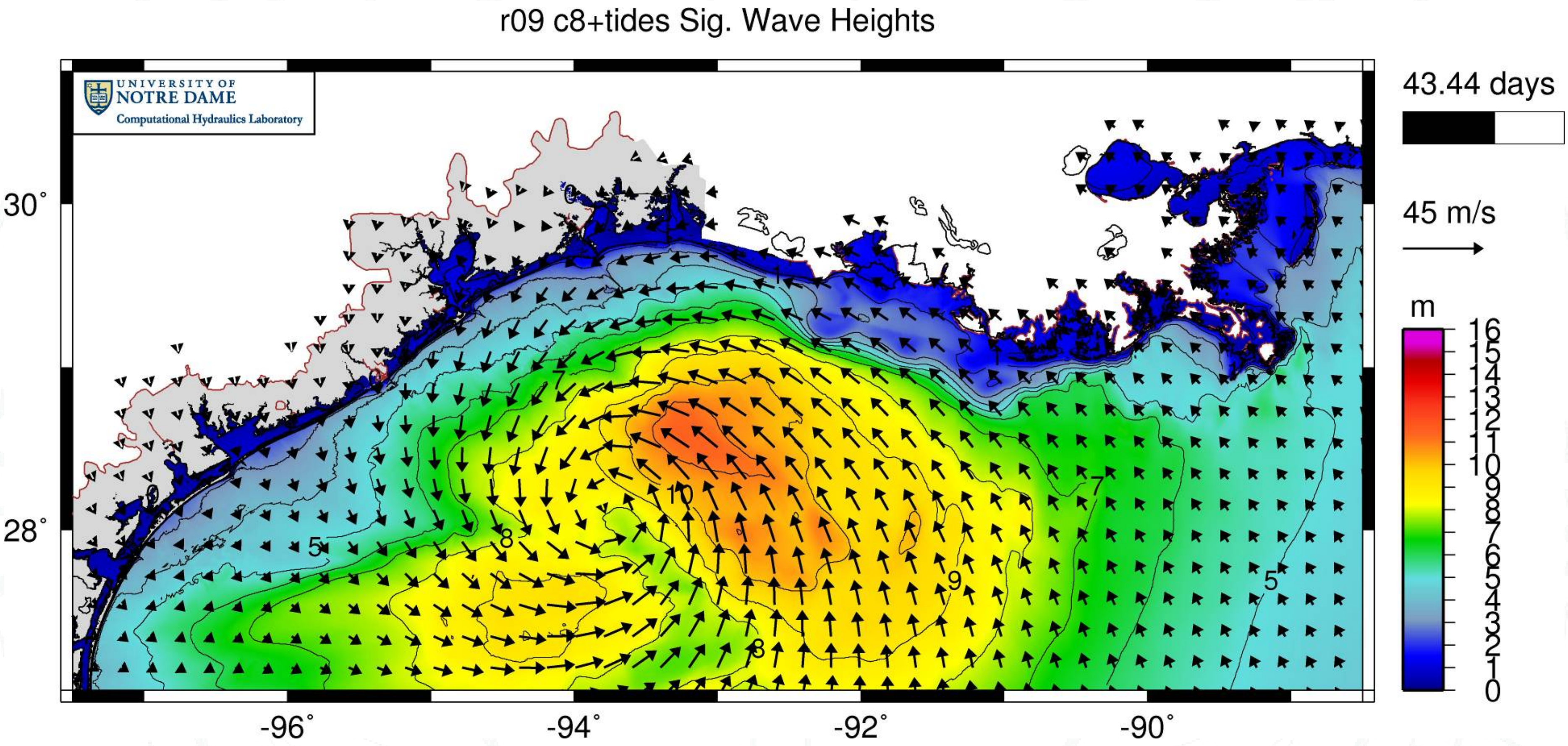

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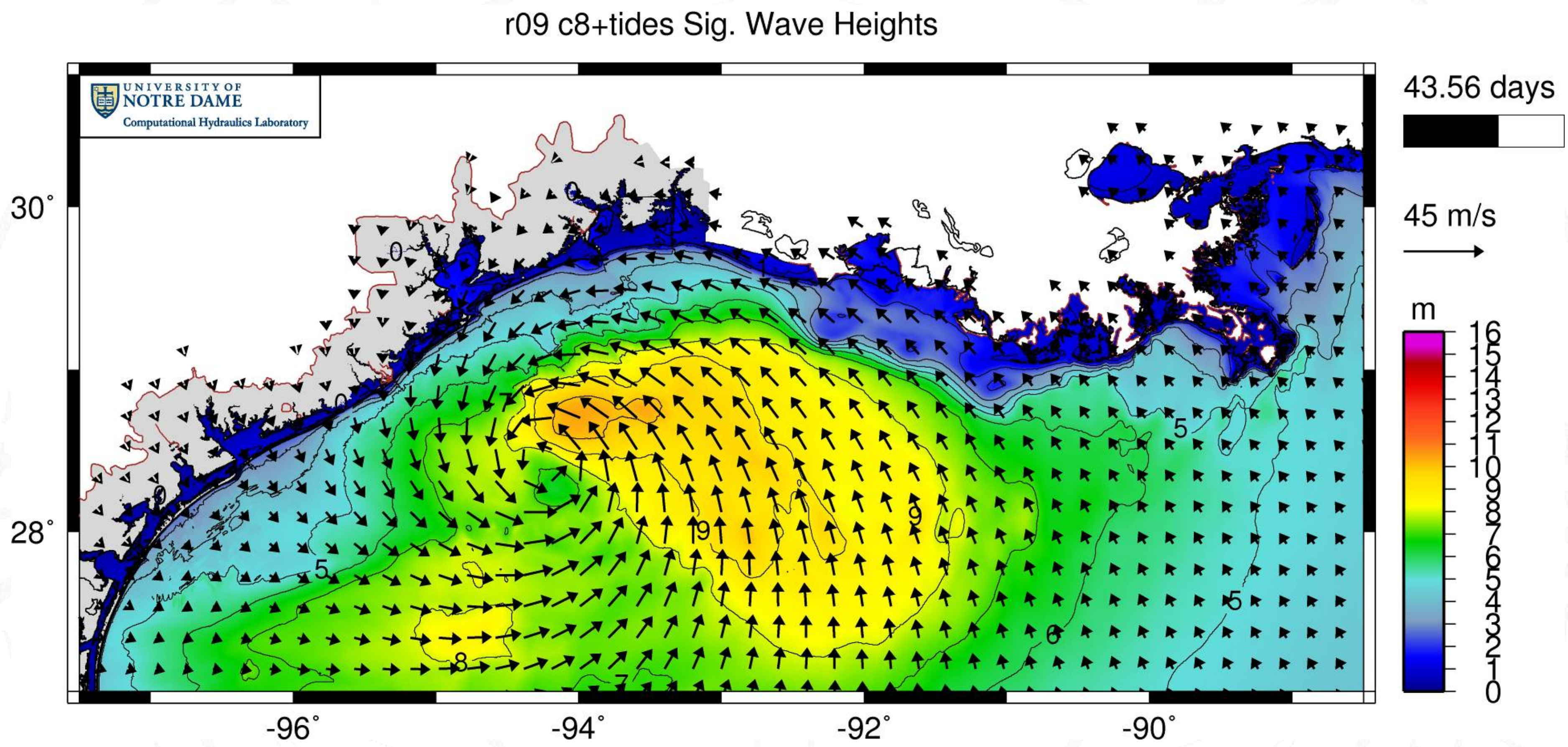

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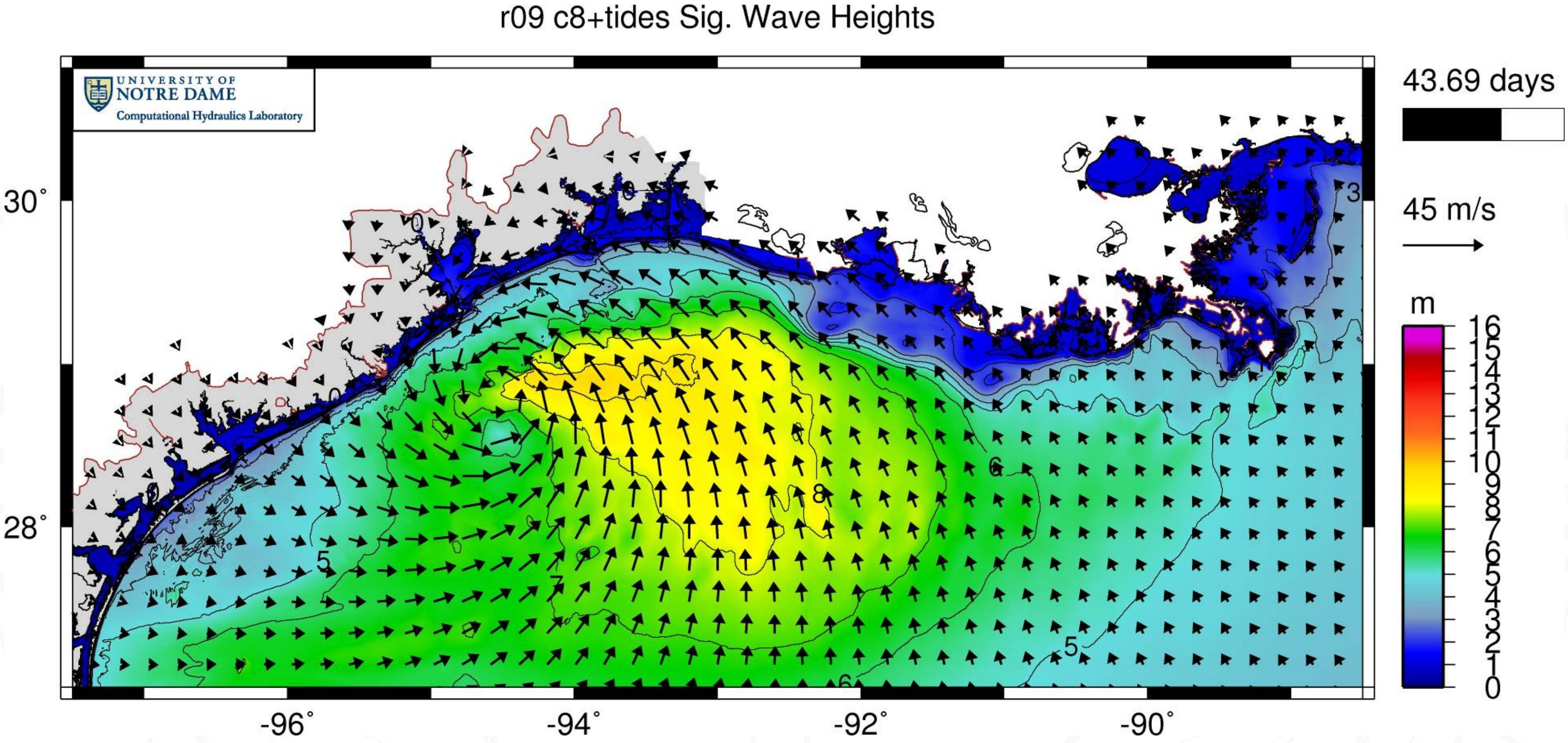

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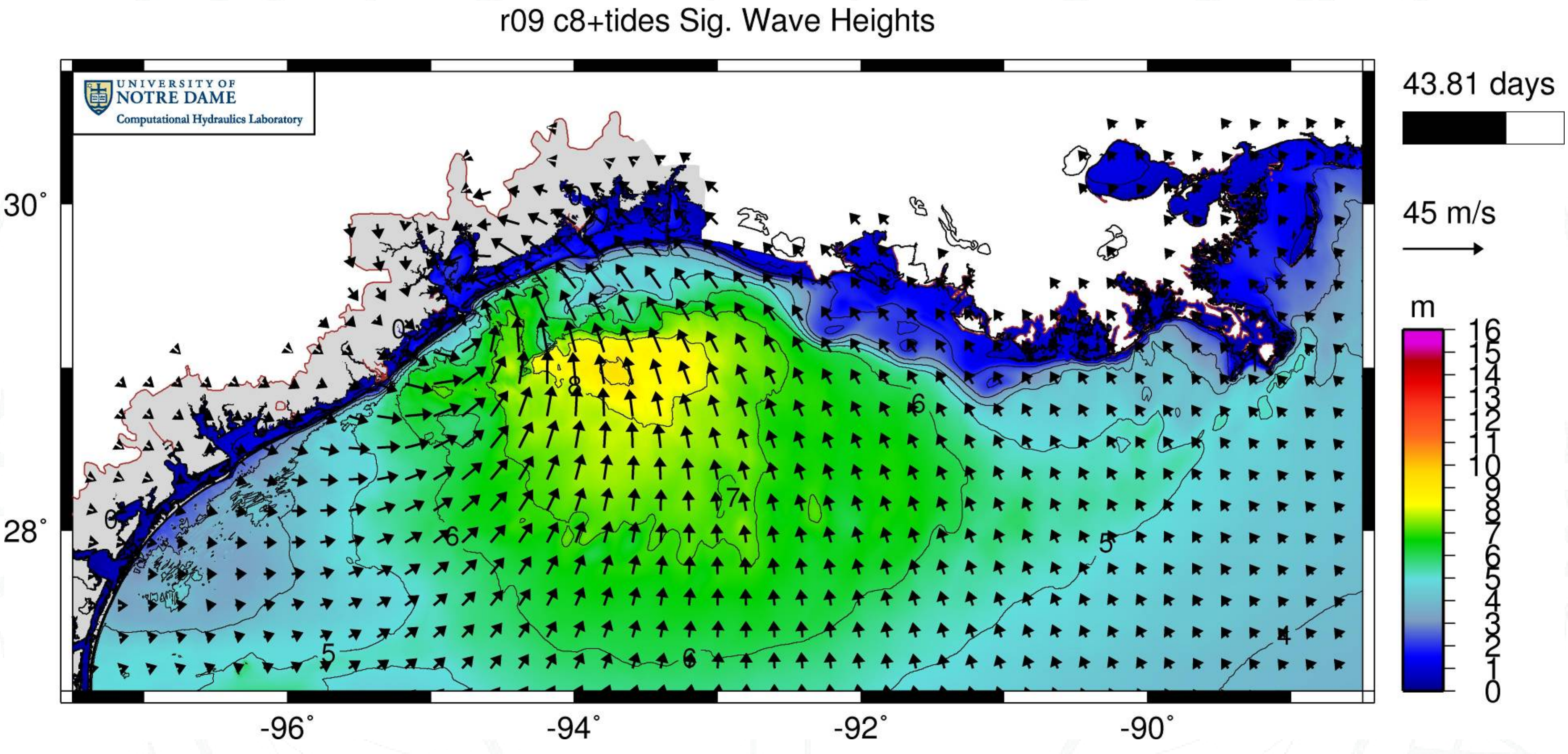

LANDFALL = 0 hrs

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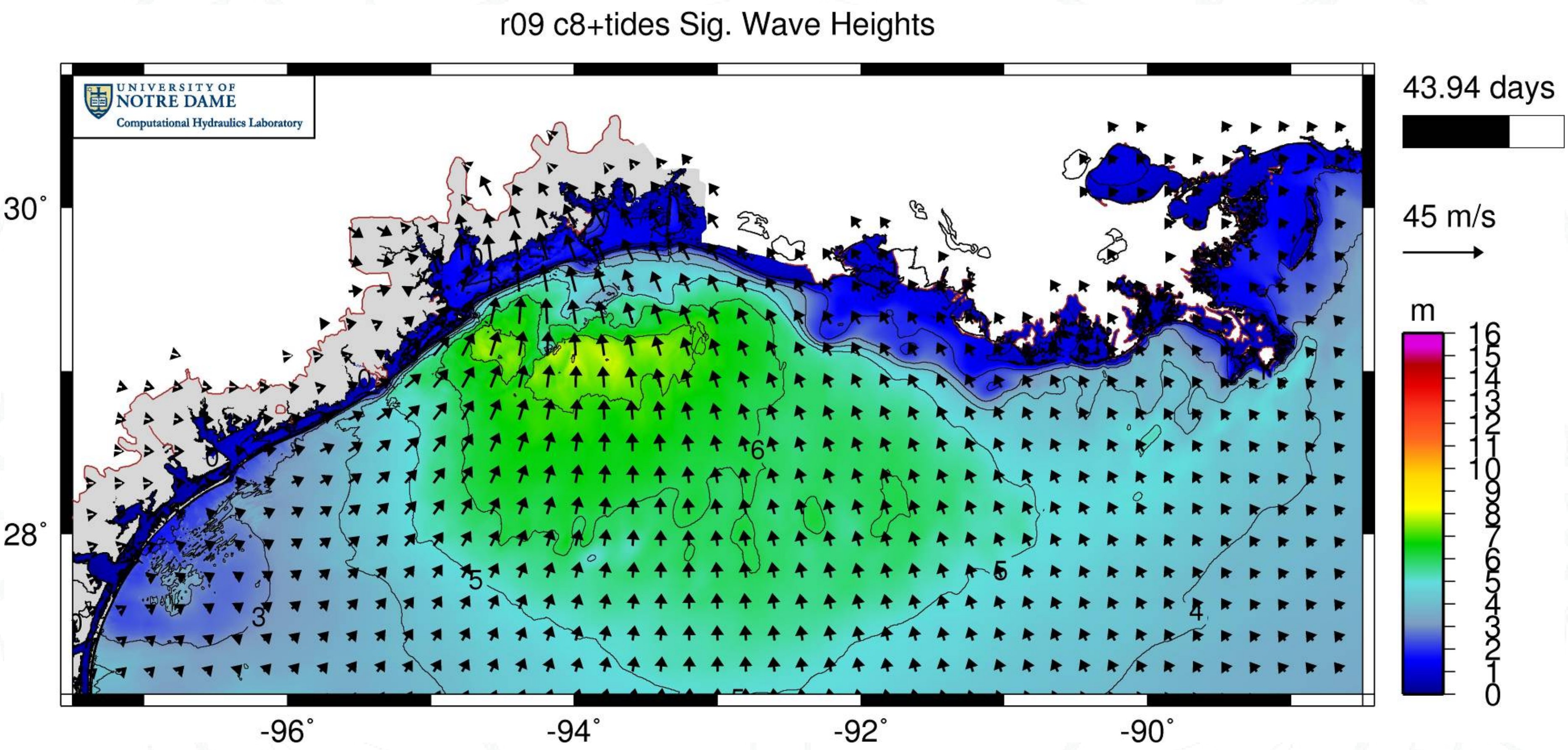

+ 3 hrs

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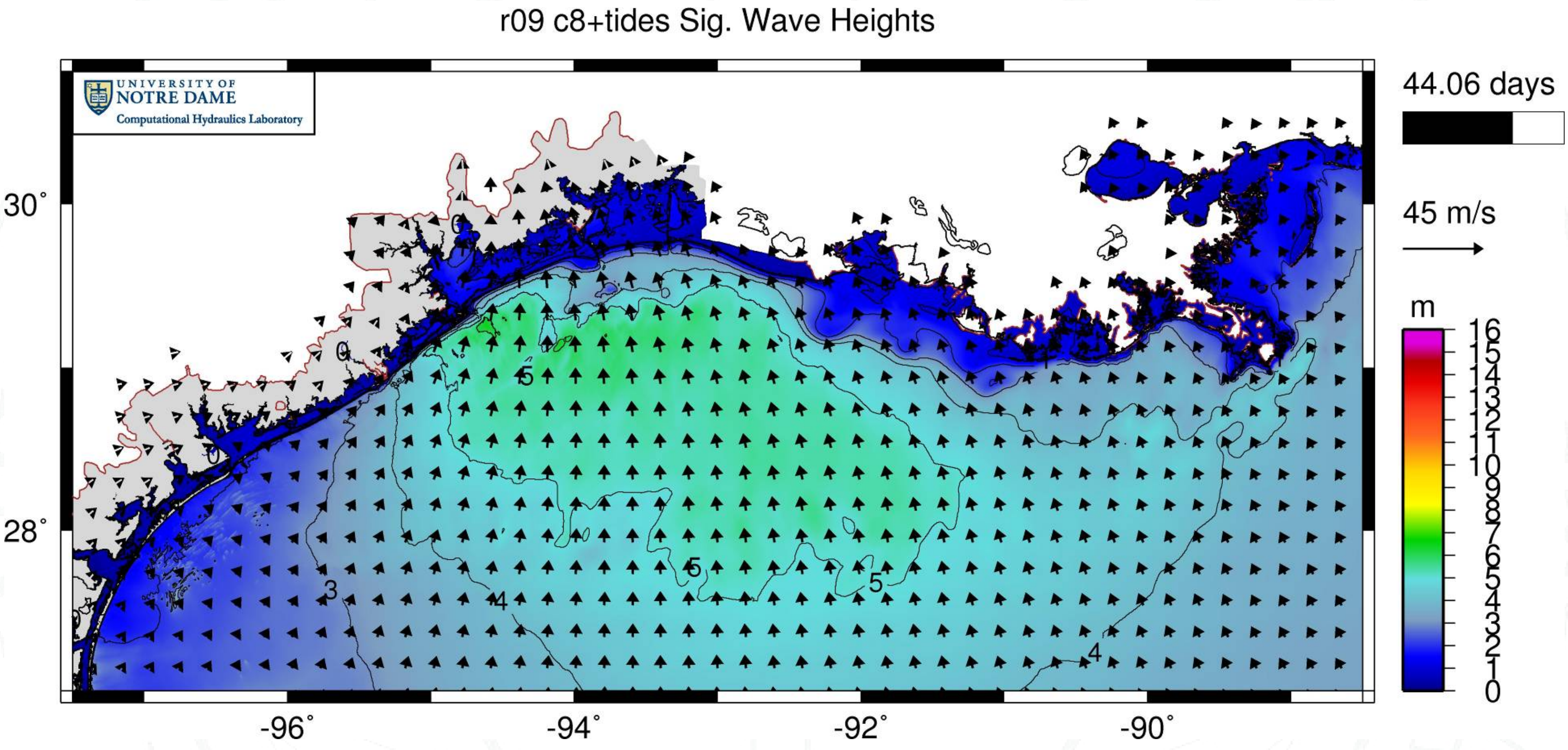

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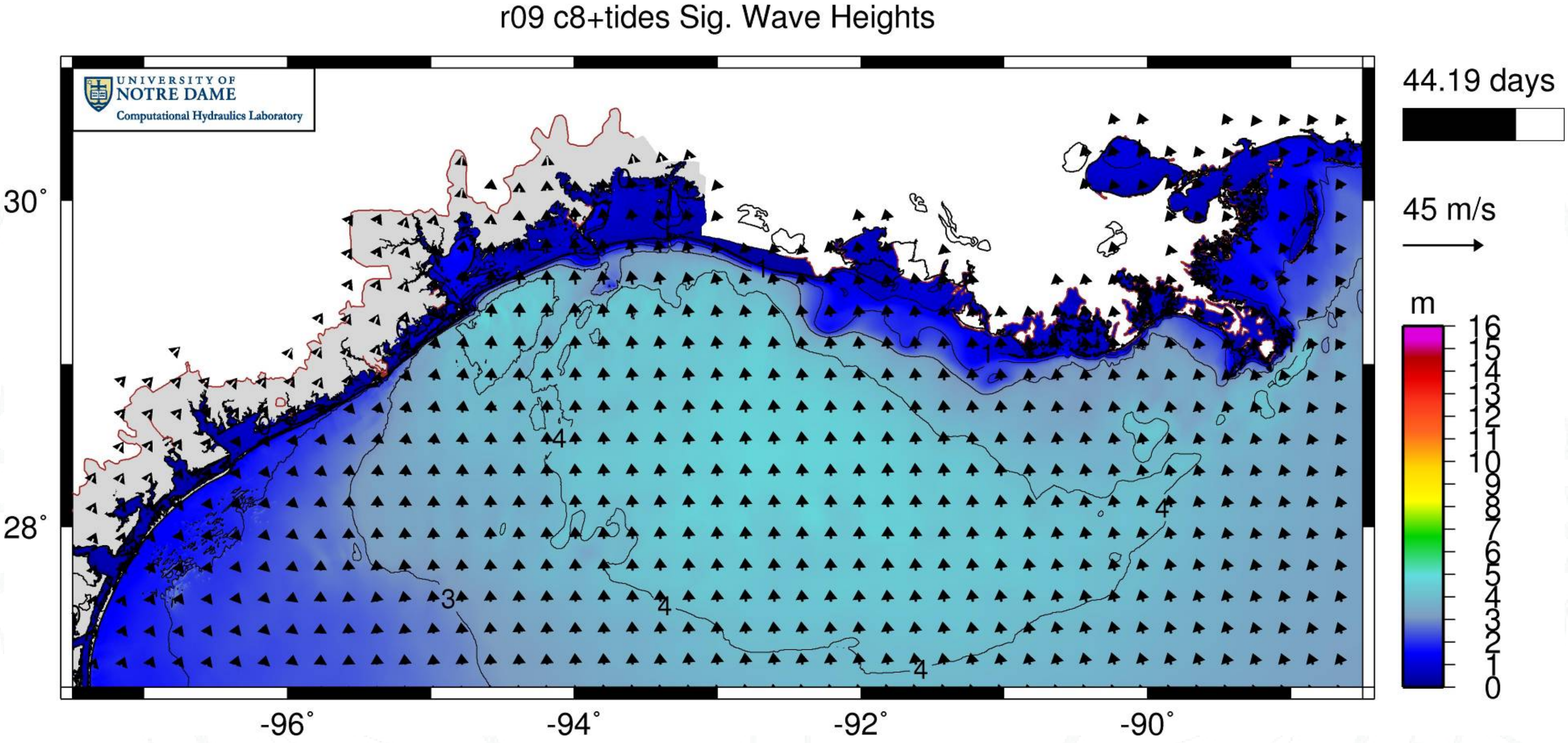

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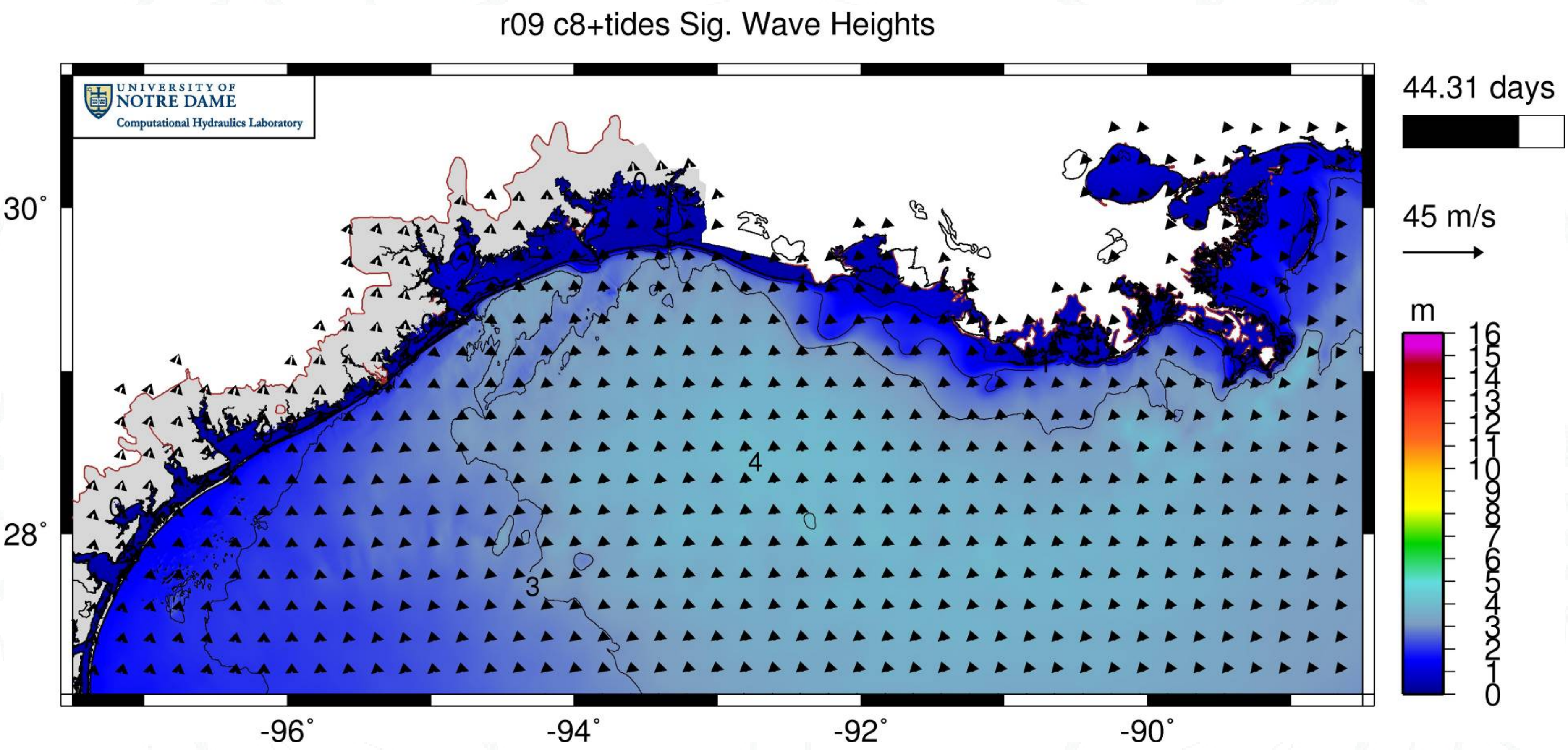

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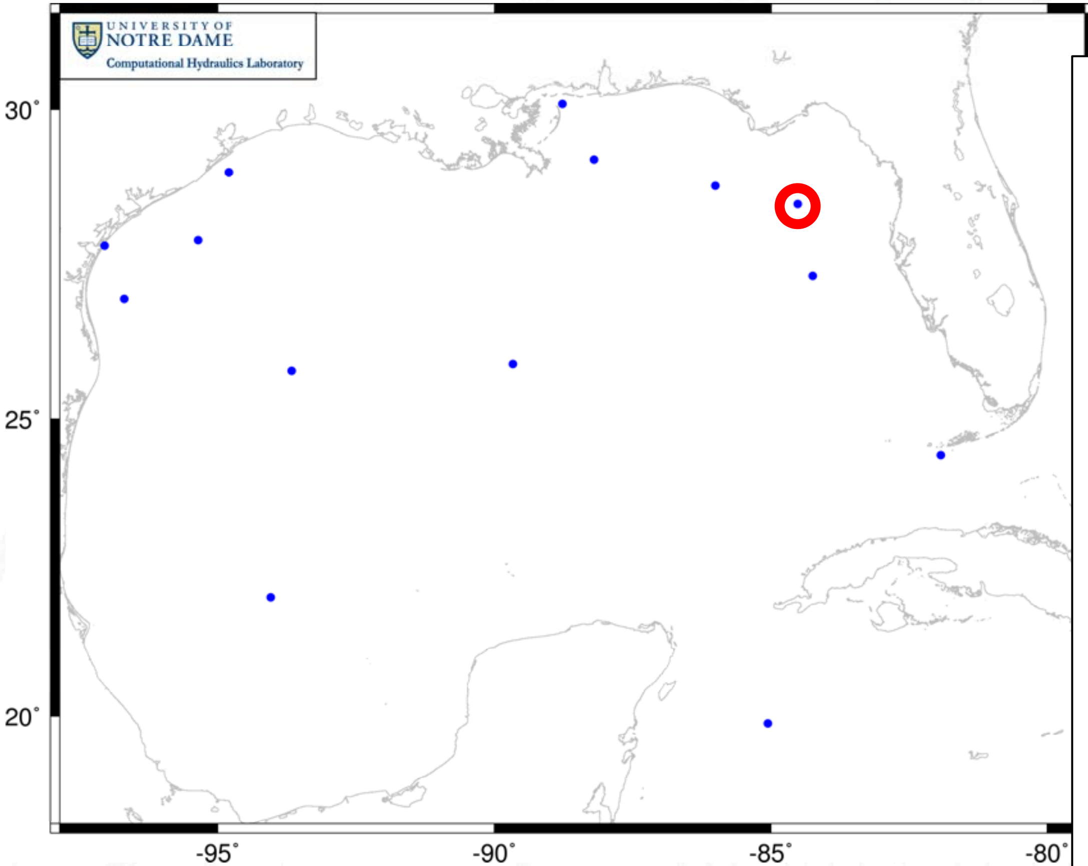
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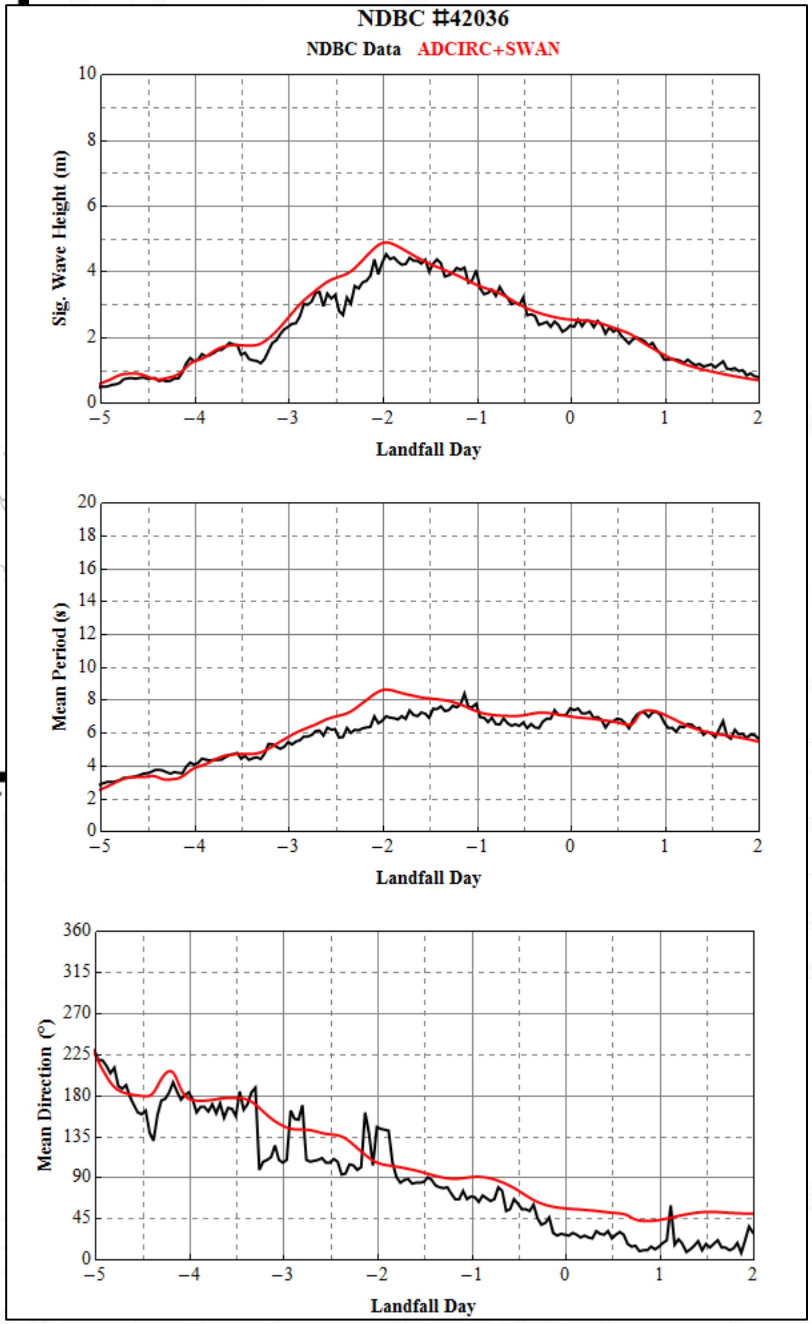
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ADCIRC+SWAN
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Landfall Day
Mean Period (s)
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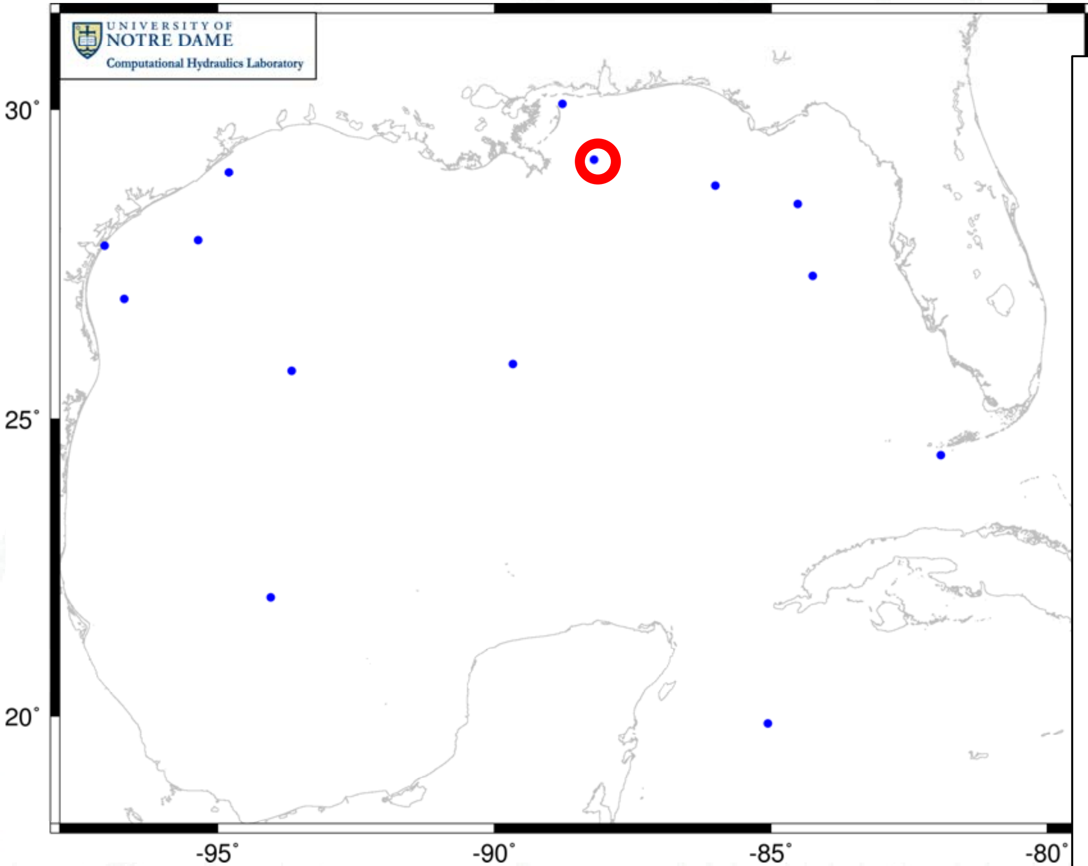
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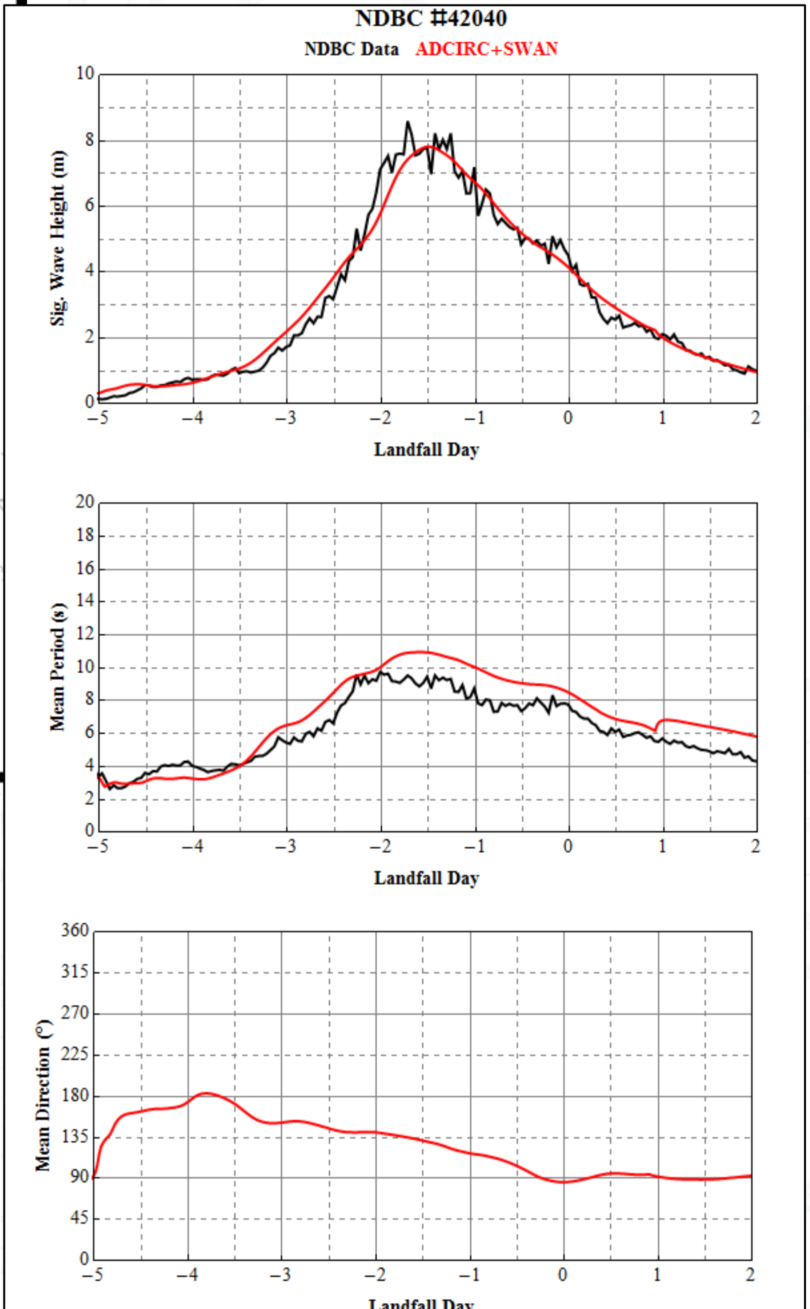
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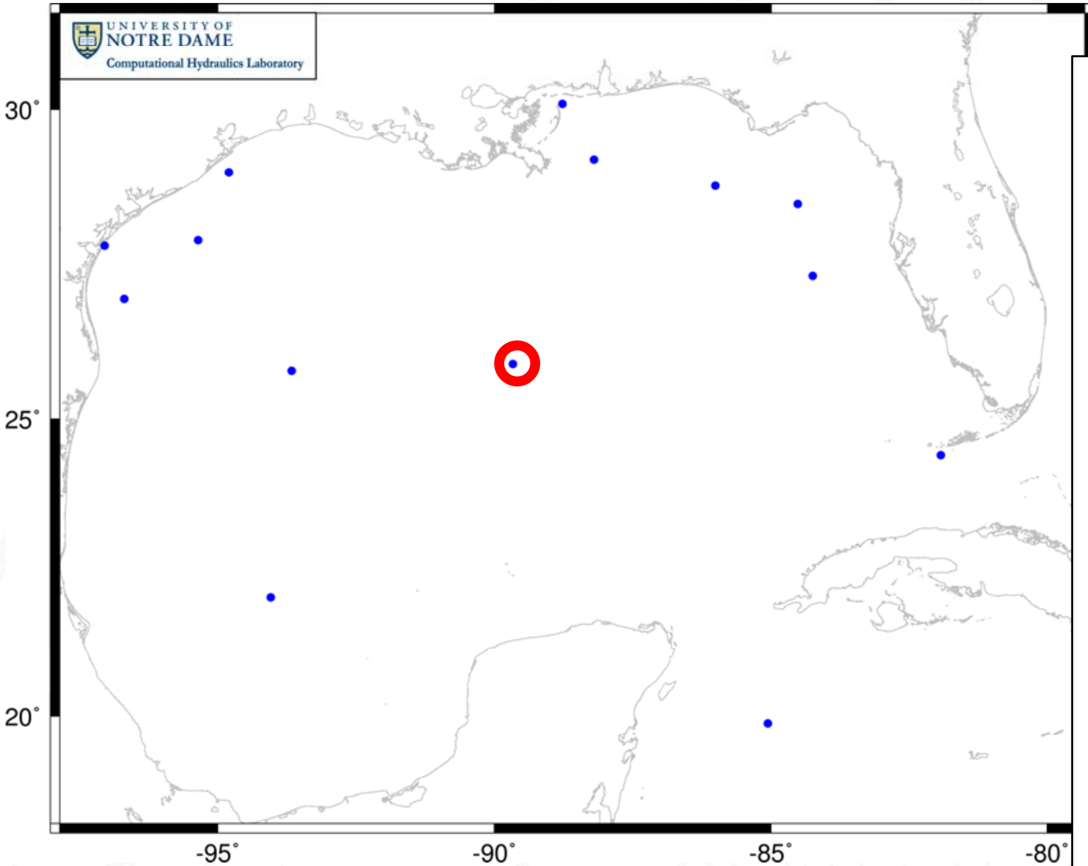
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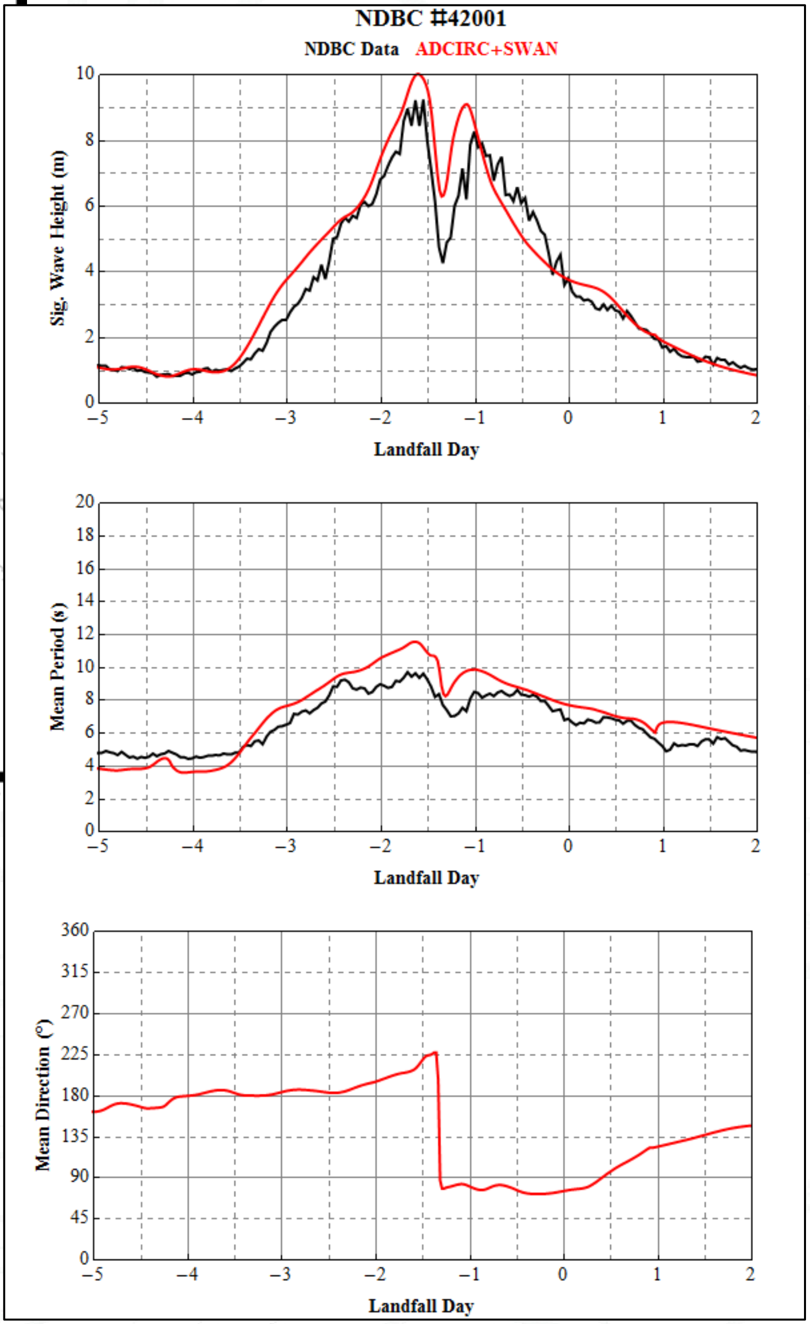
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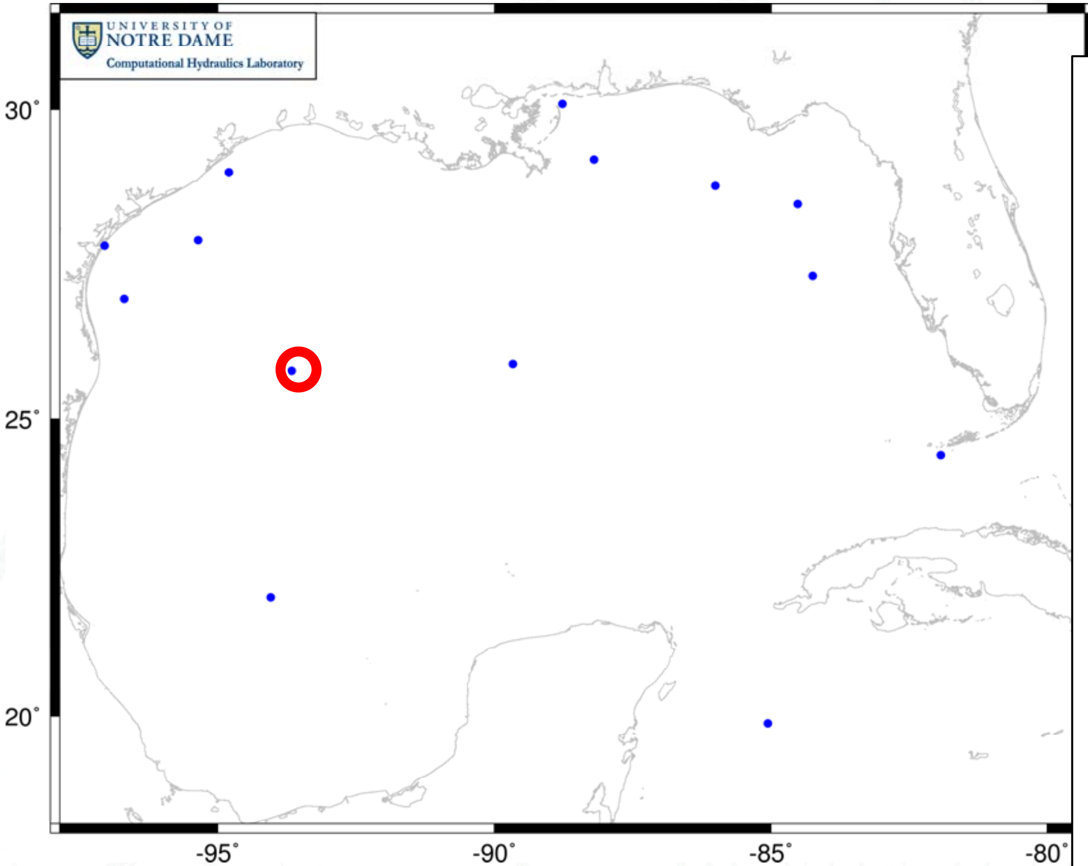
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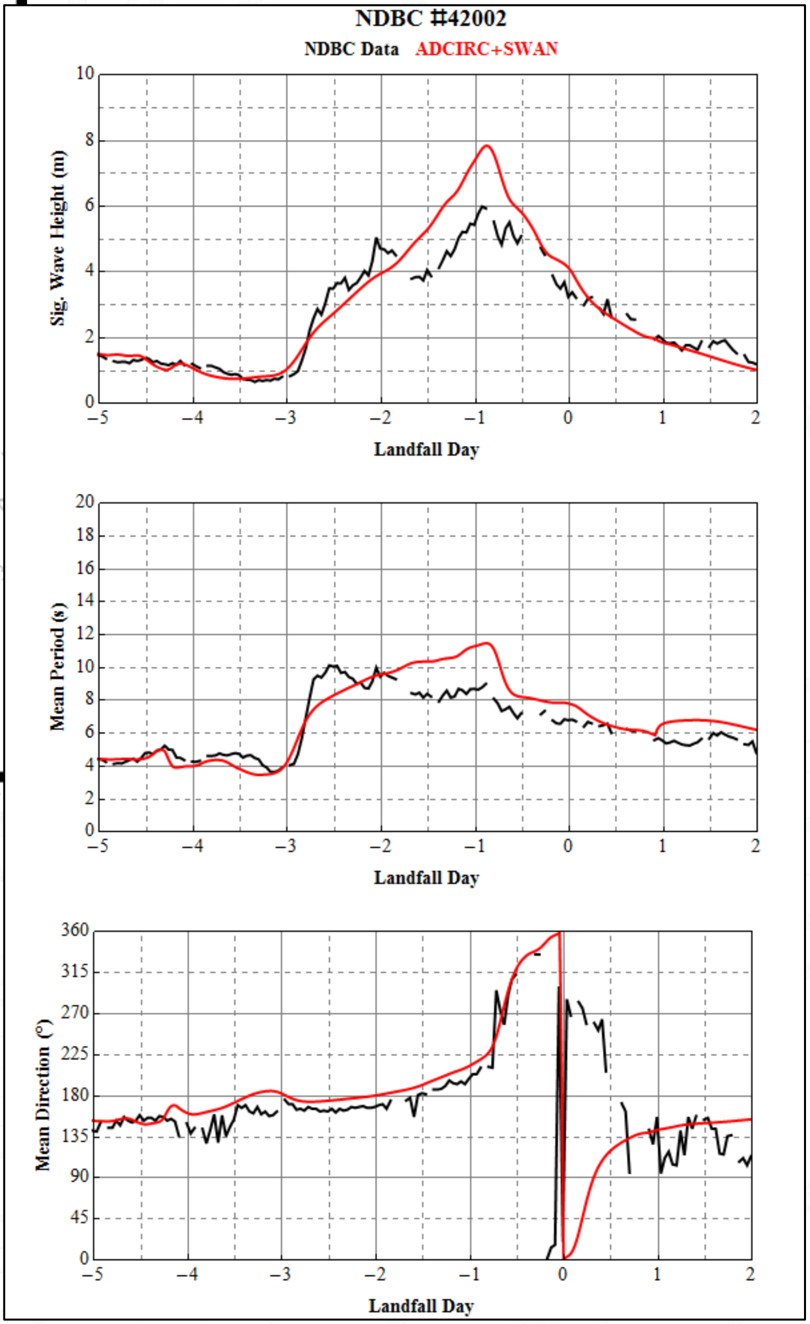
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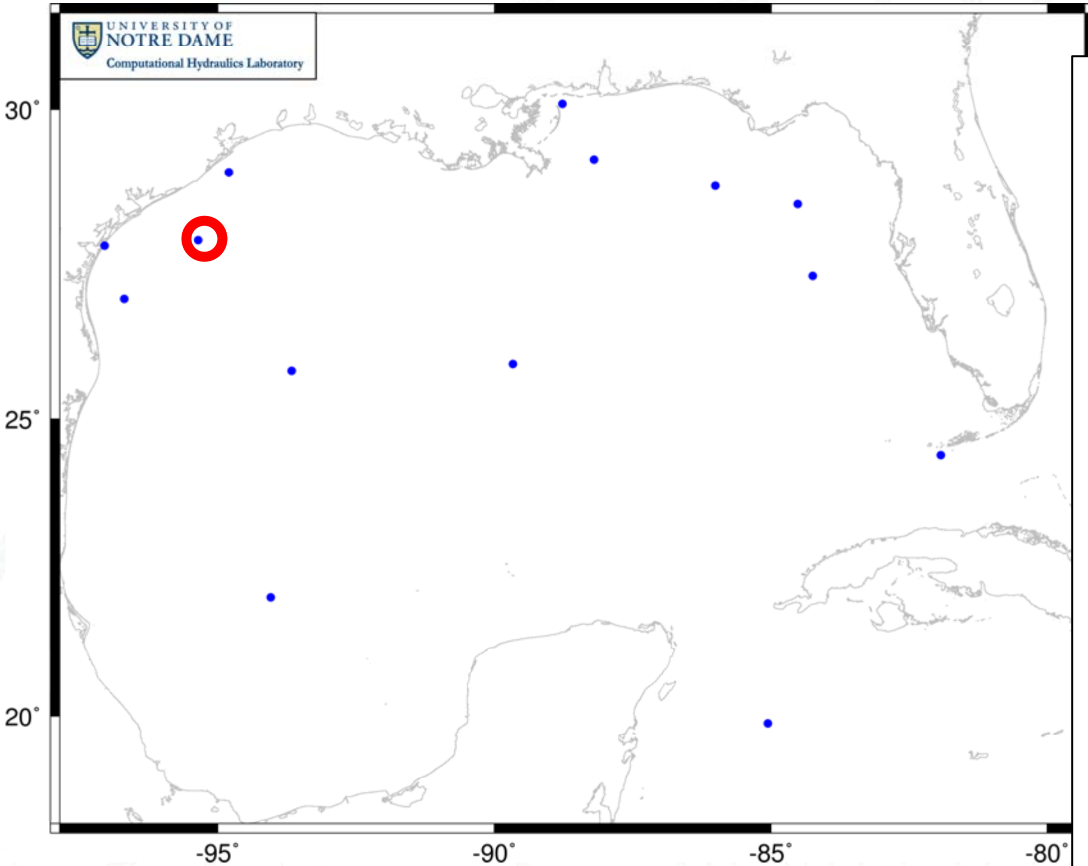
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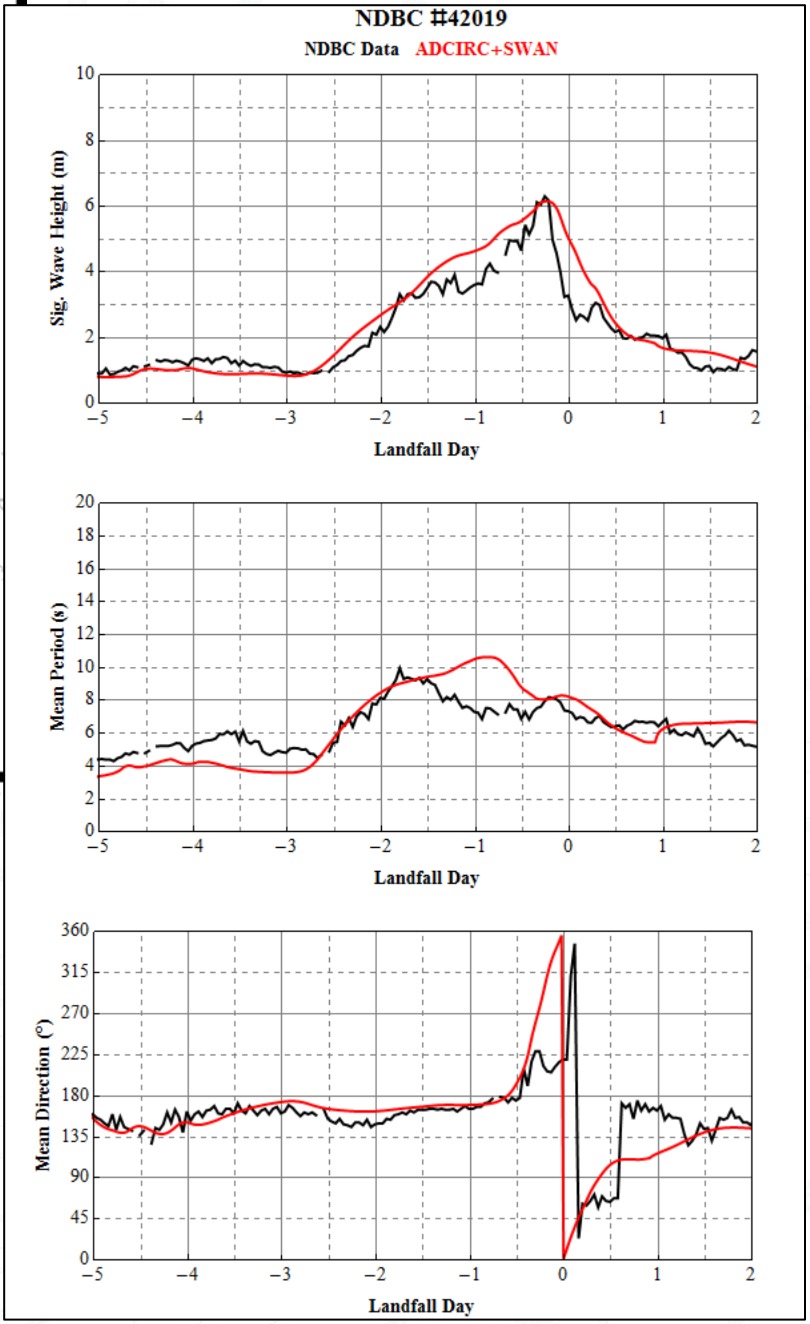
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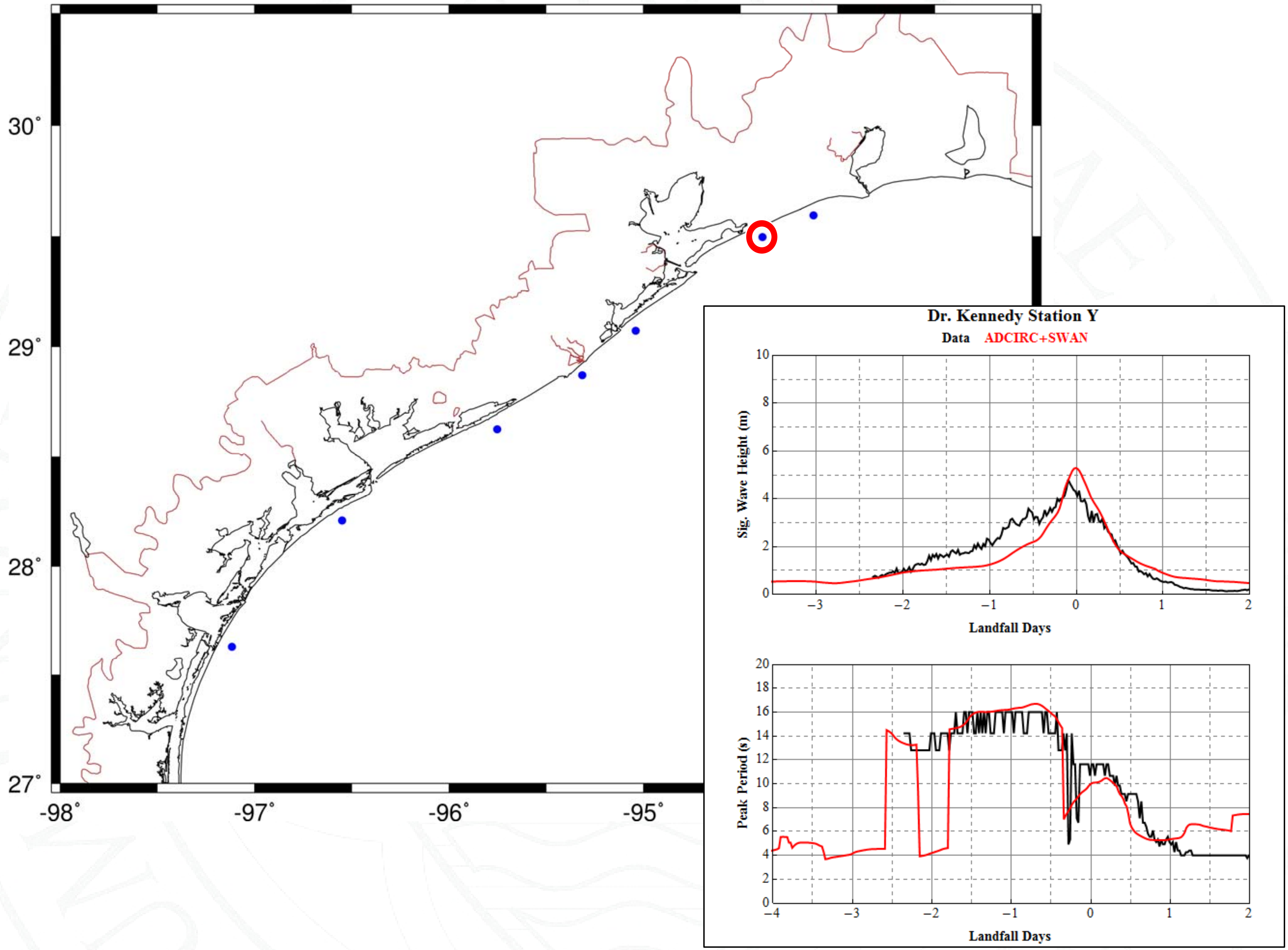
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Dr. Kennedy Station Y
Data
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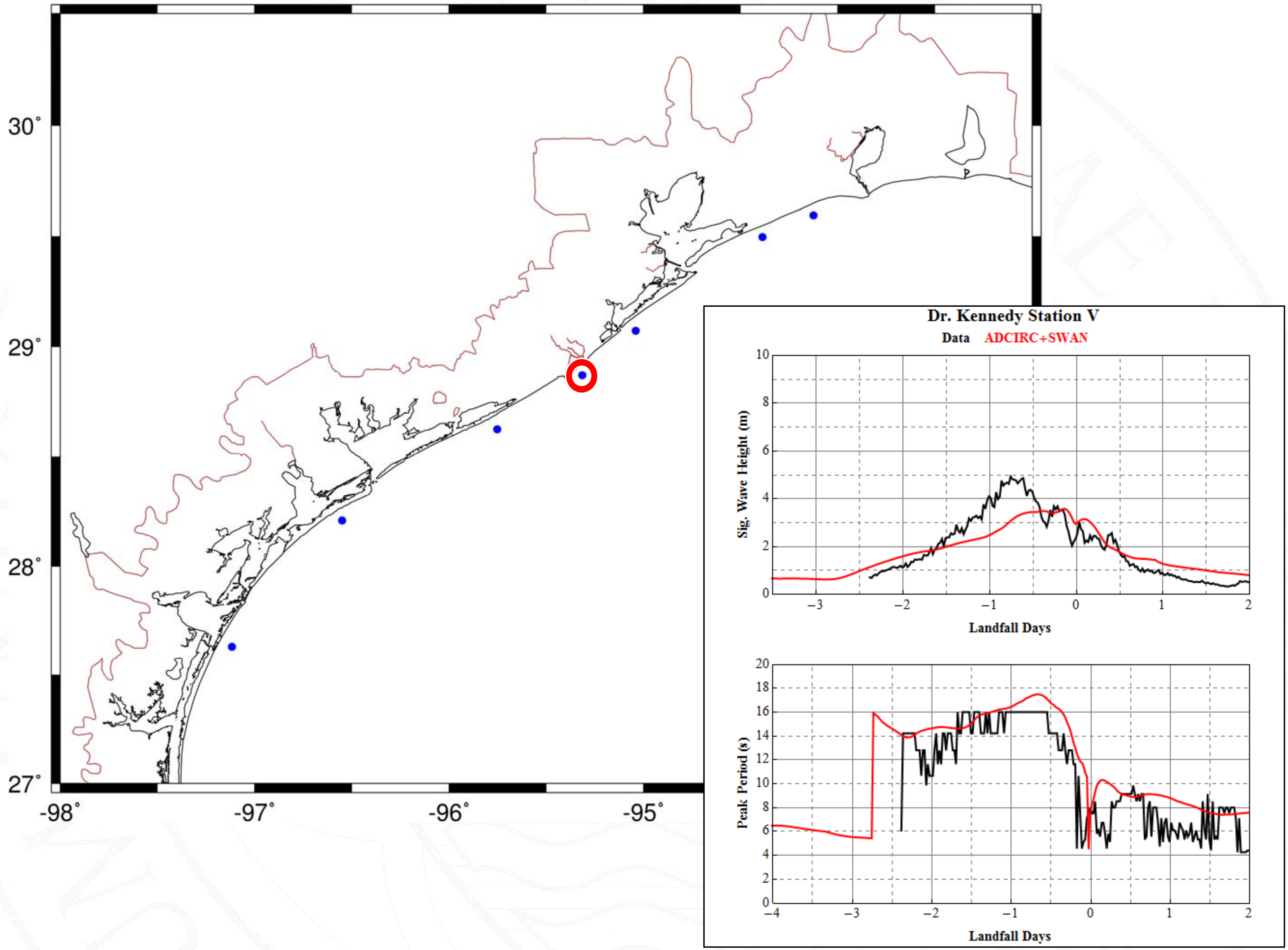
Sig. Wave Height (m)
Landfall Days
Peak Period (s)
Landfall Days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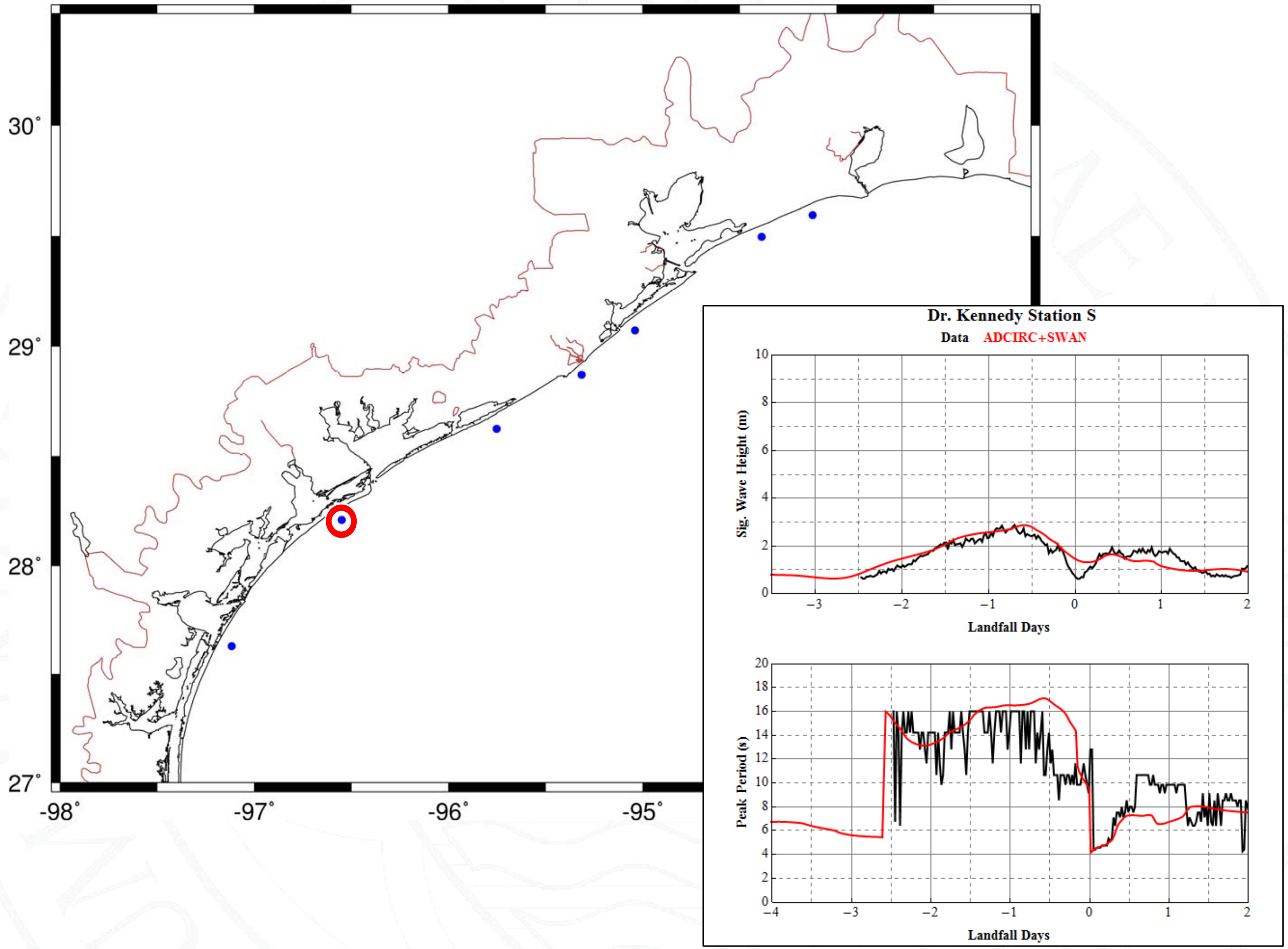
Peak Period (s)
Landfall Days



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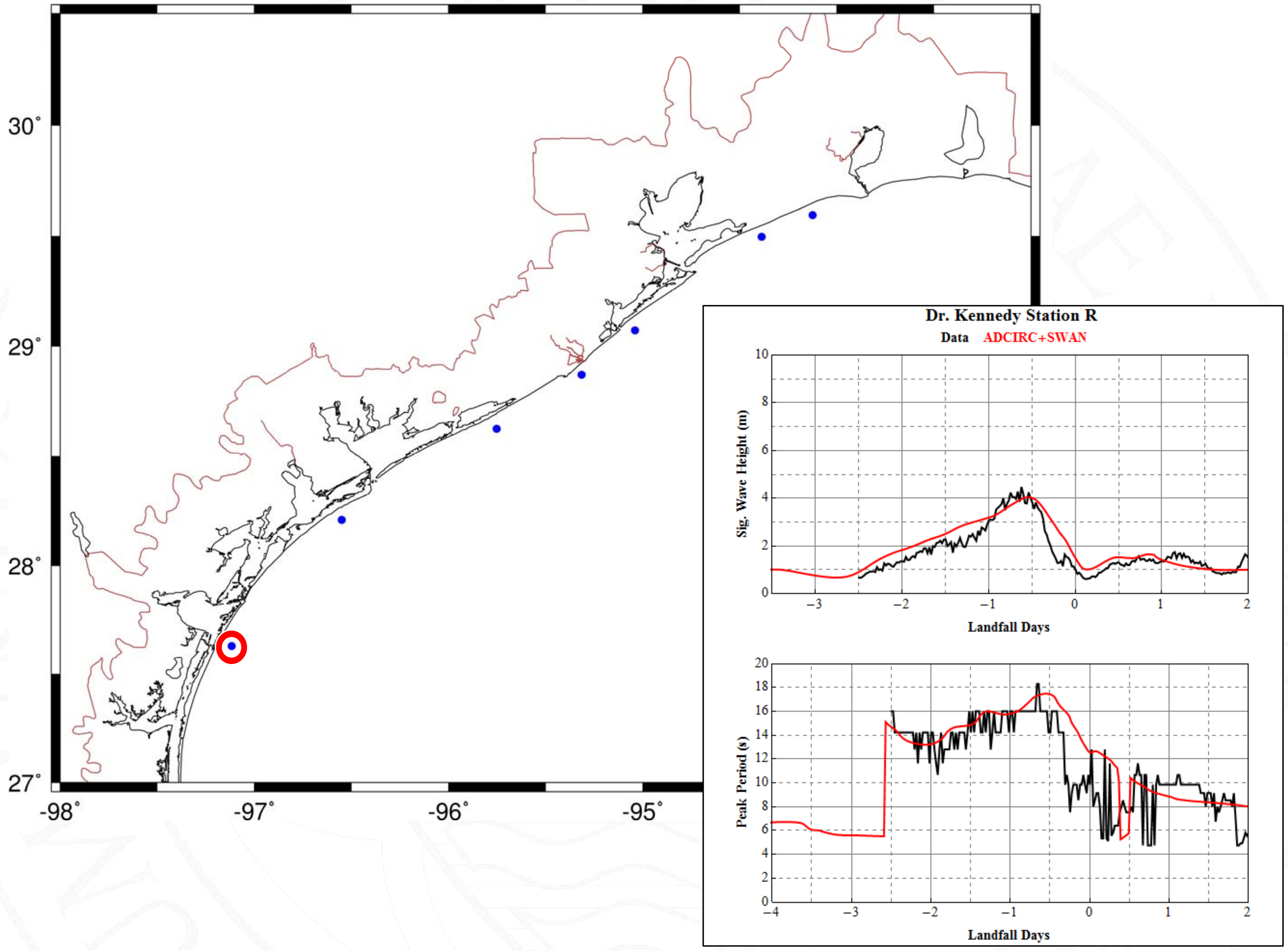
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Dr. Kennedy Station R
Data
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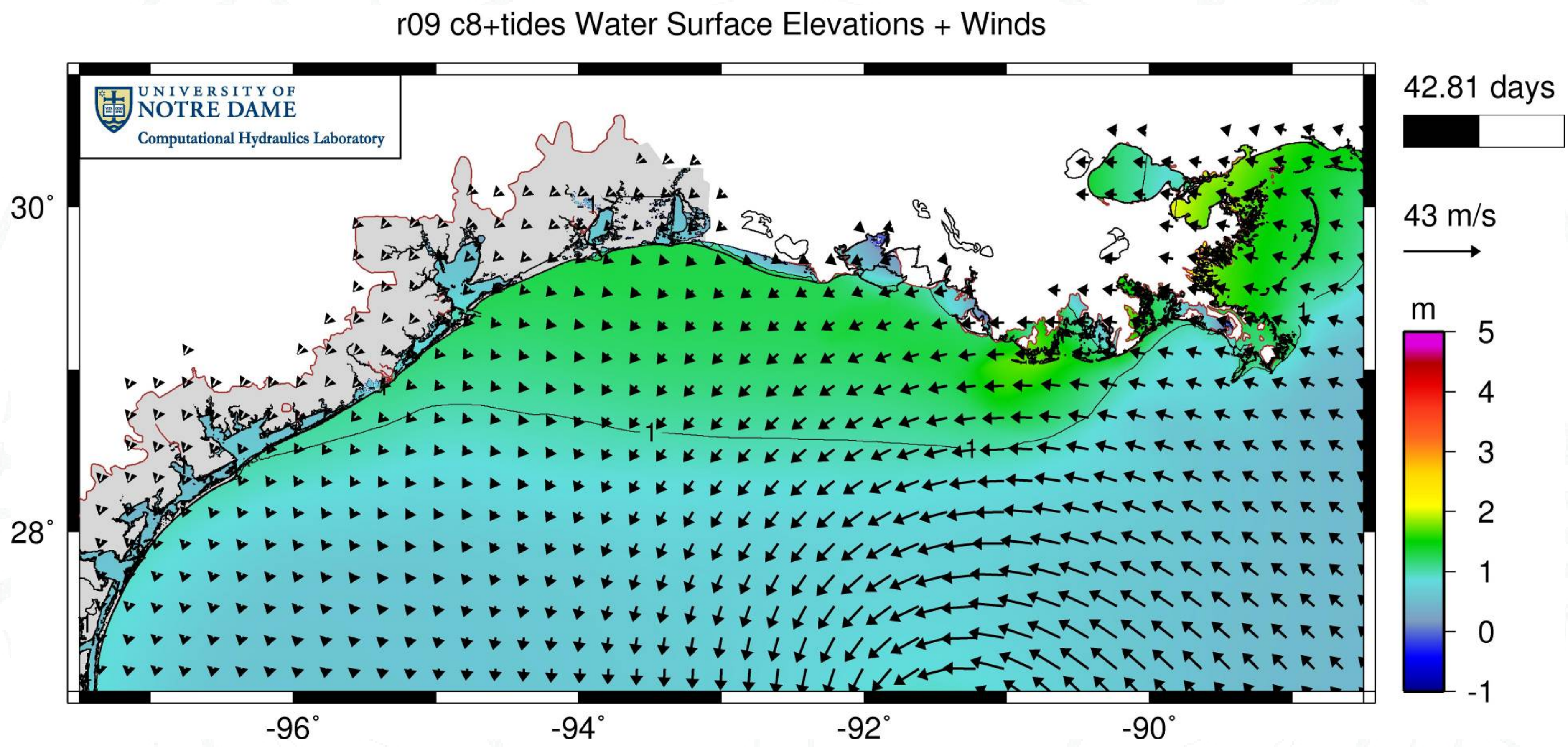
Ike surge contours (m) and wind vectors (m/s)



- 24 hrs

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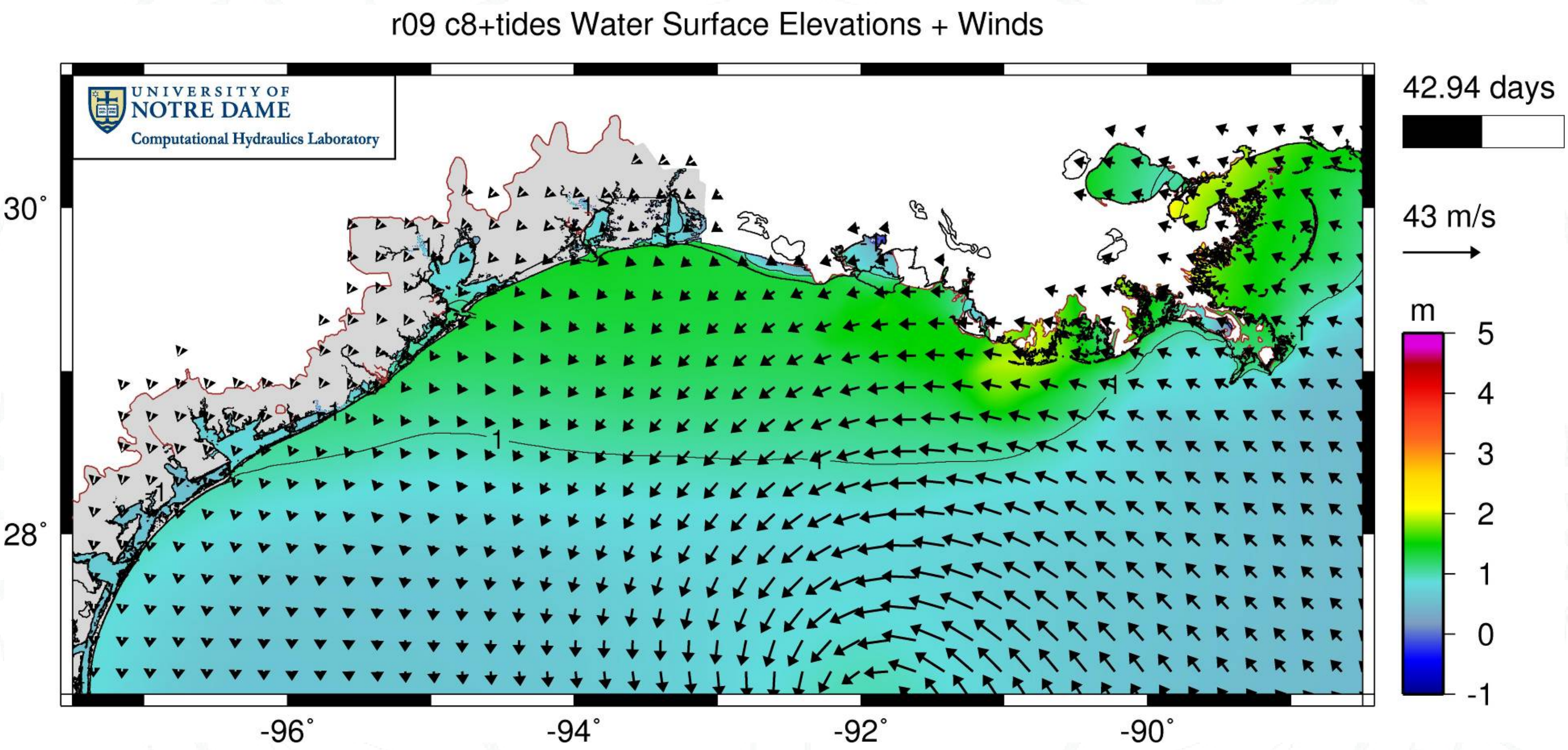

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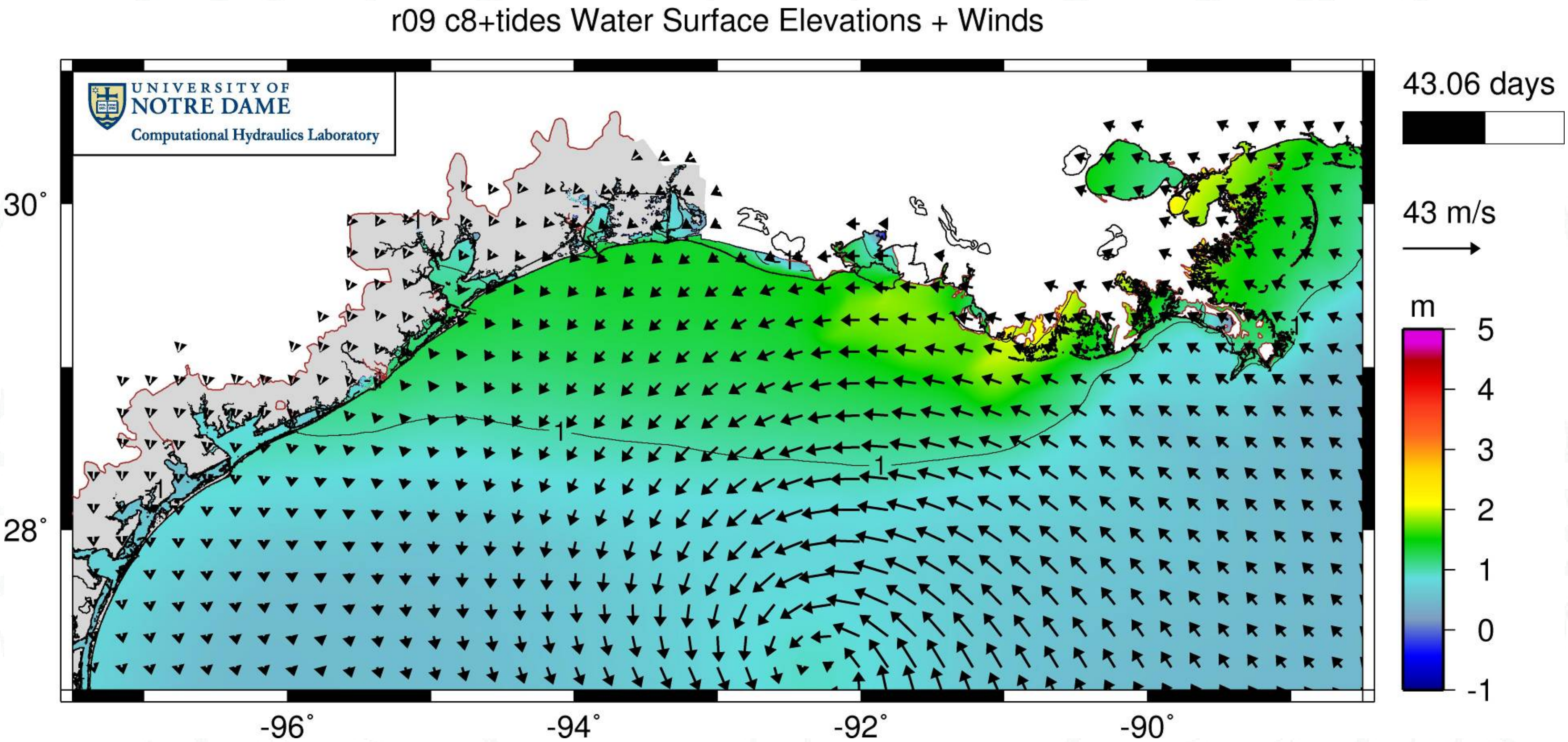
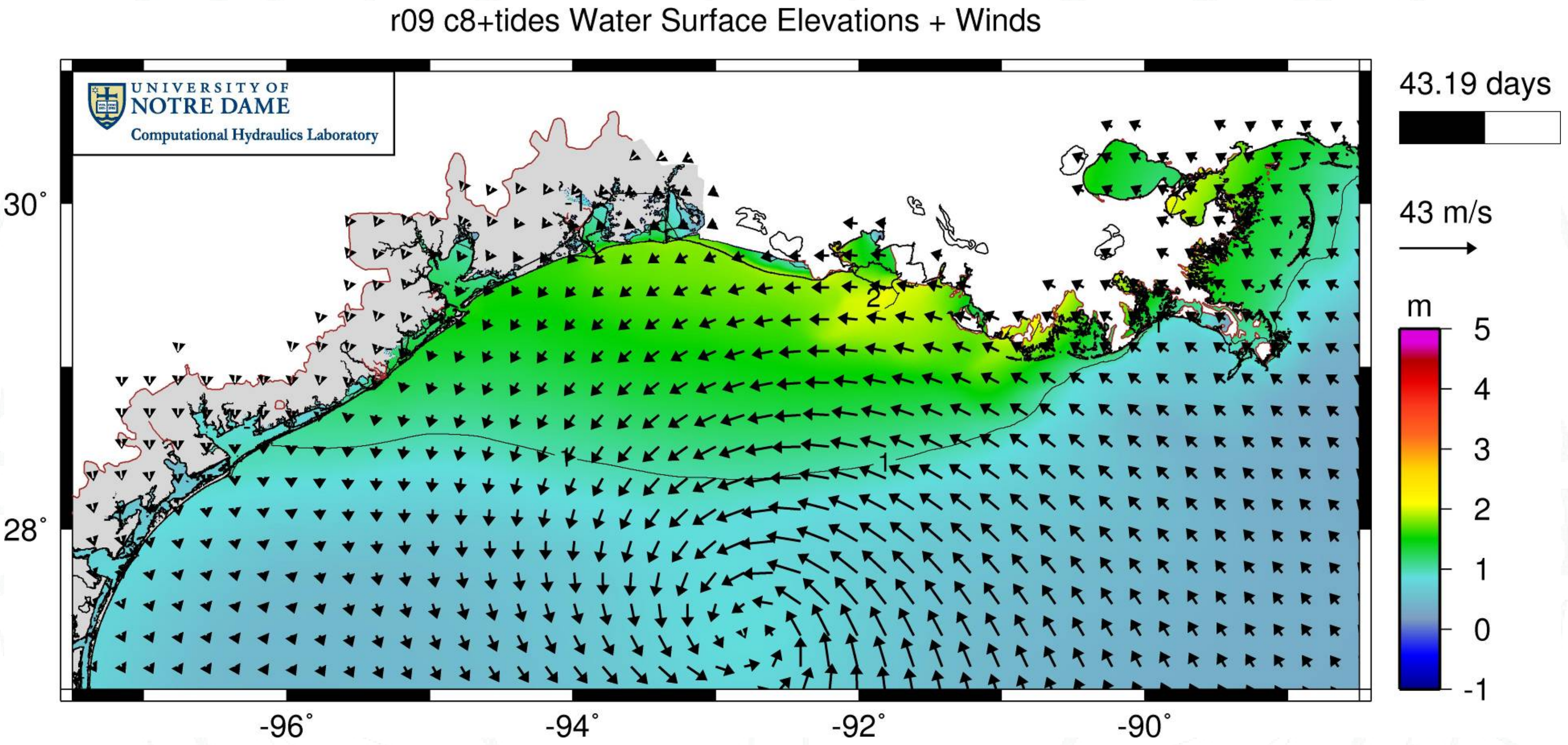


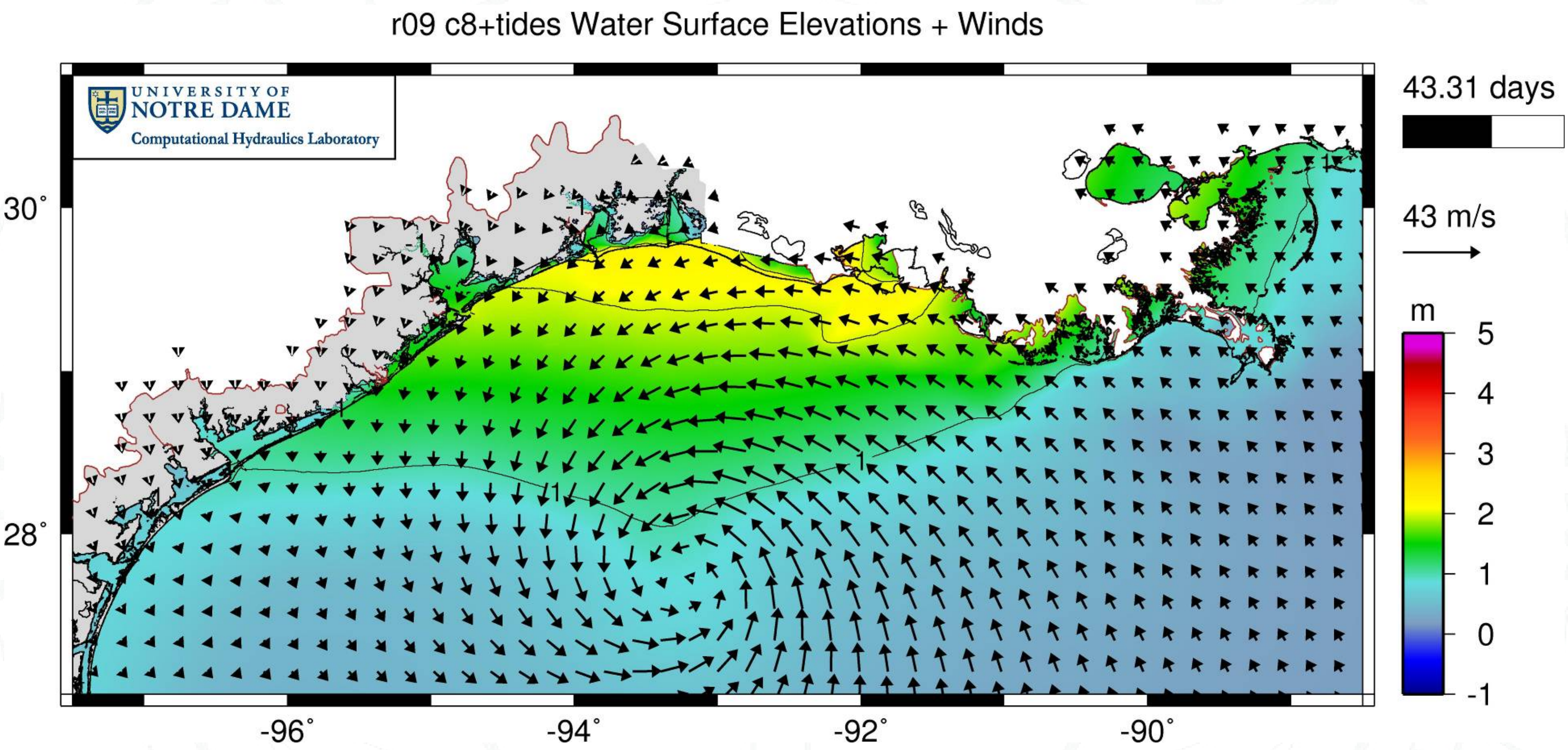
- 18 hrs

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



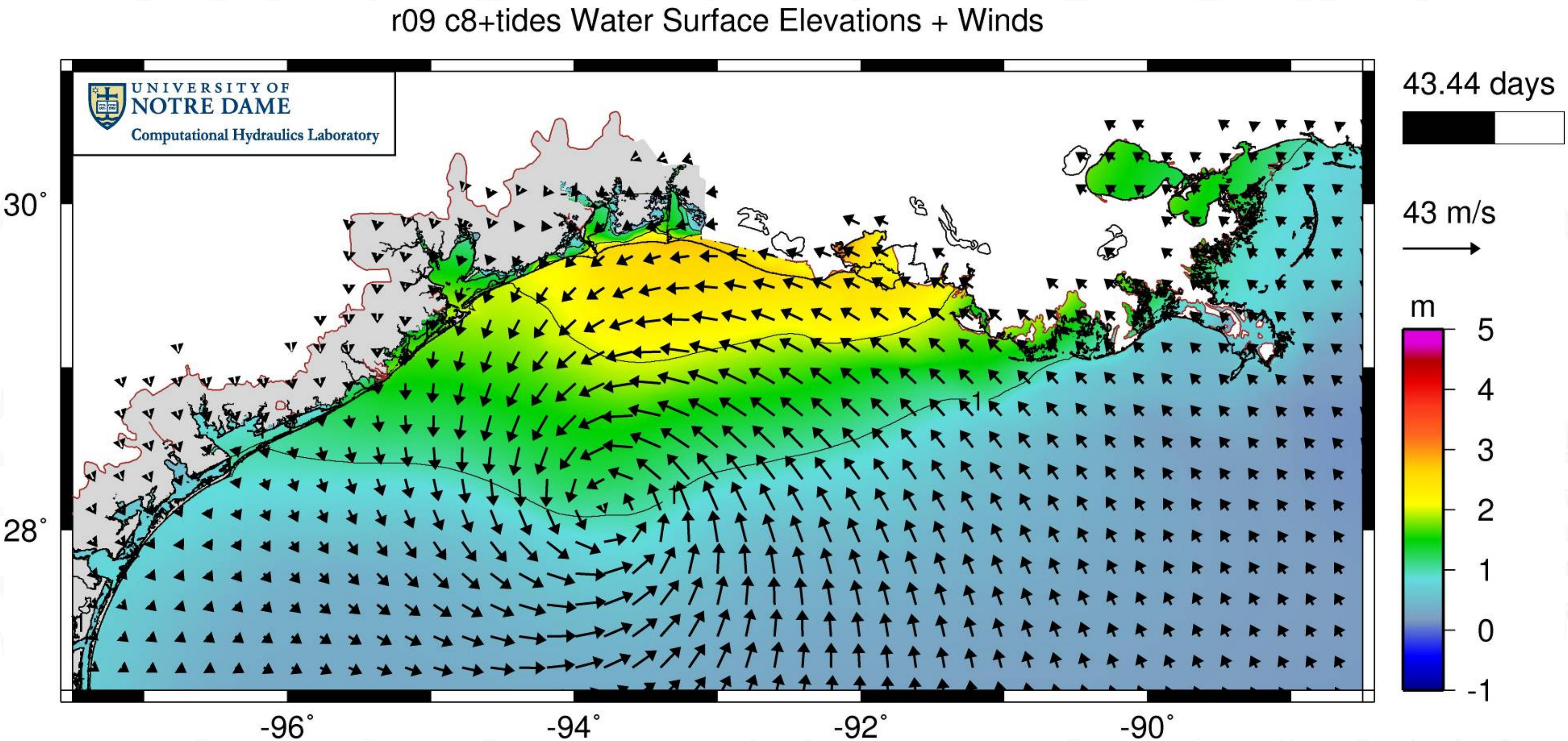
- 15 hrs

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



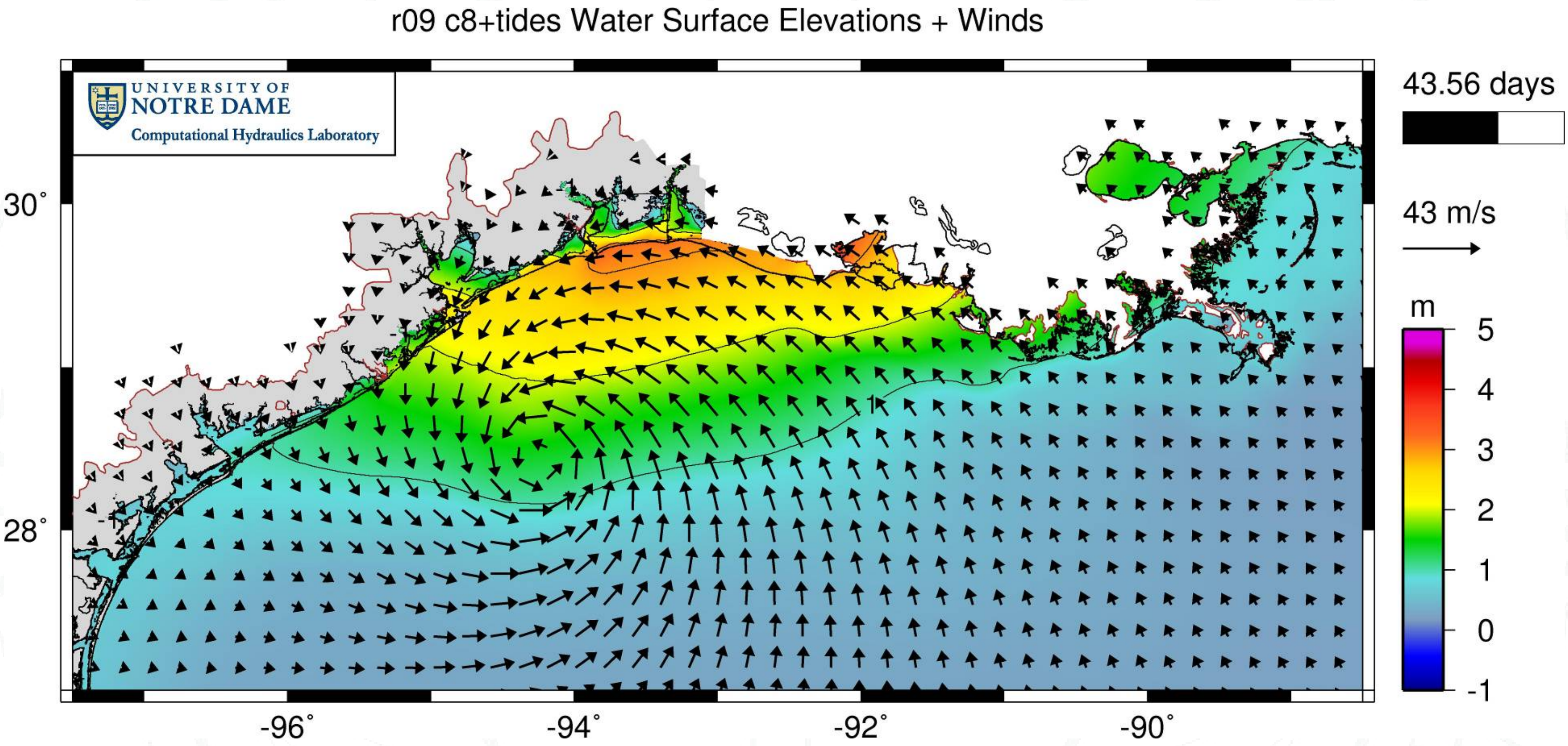
- 12 hrs

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



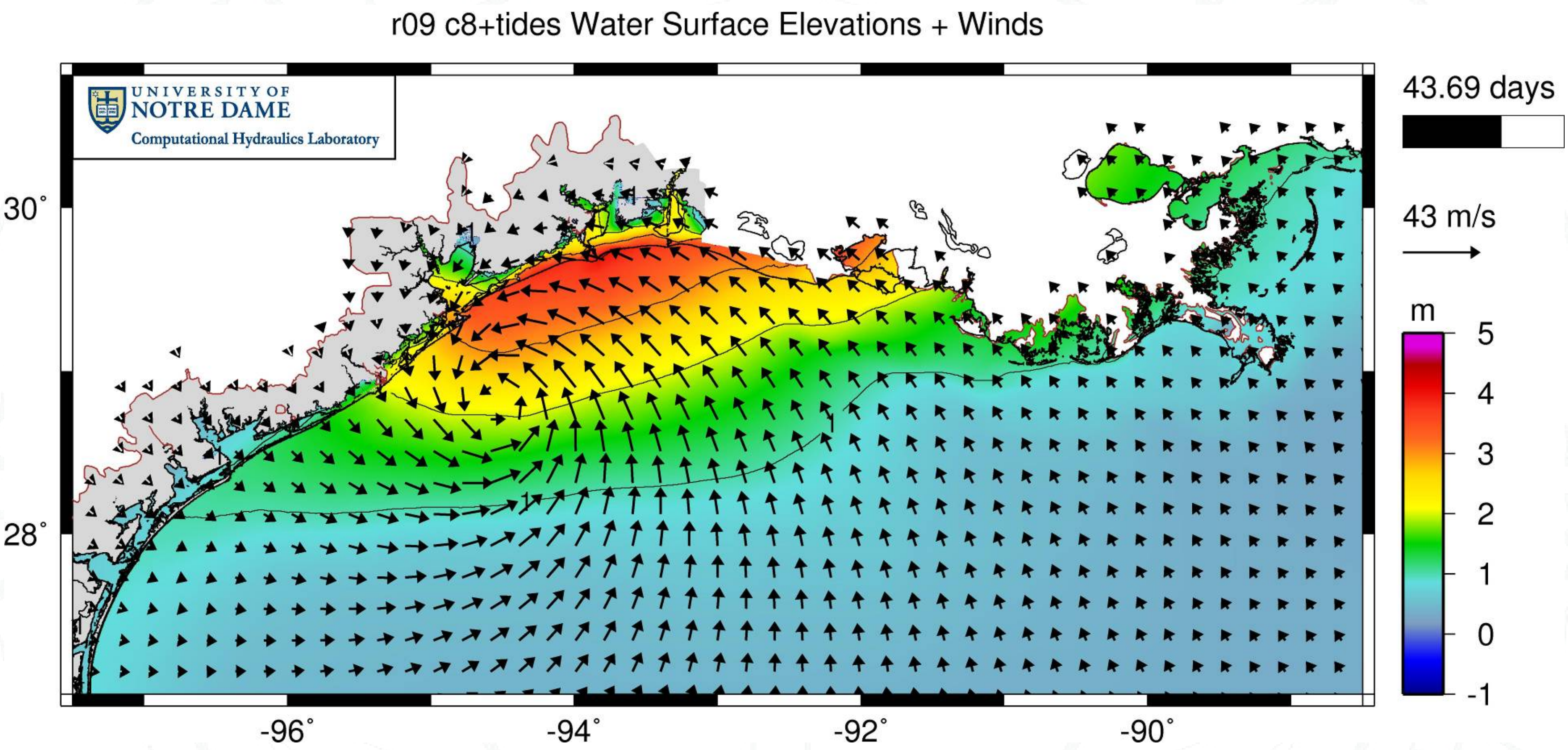
- 9 hrs

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



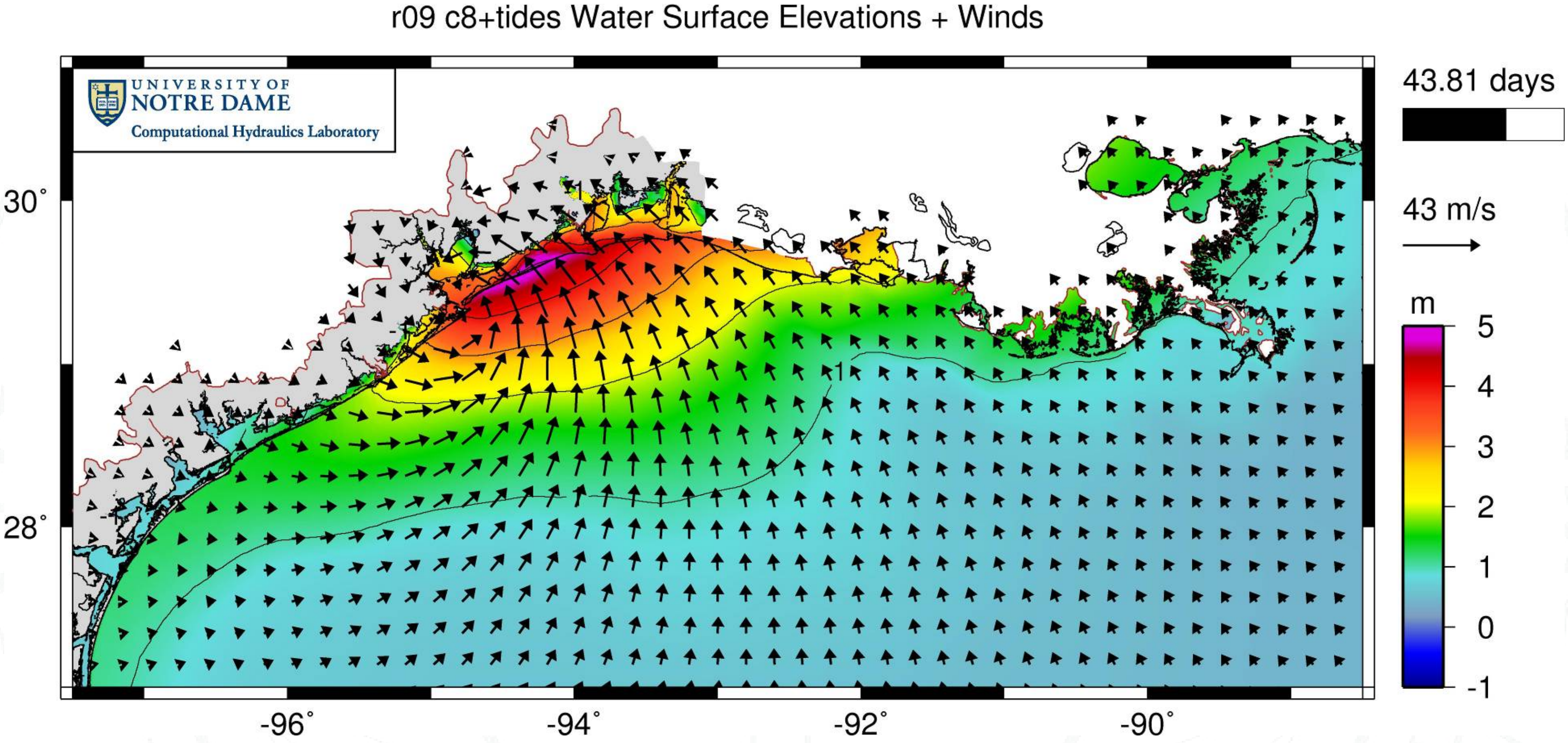
- 6 hrs

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



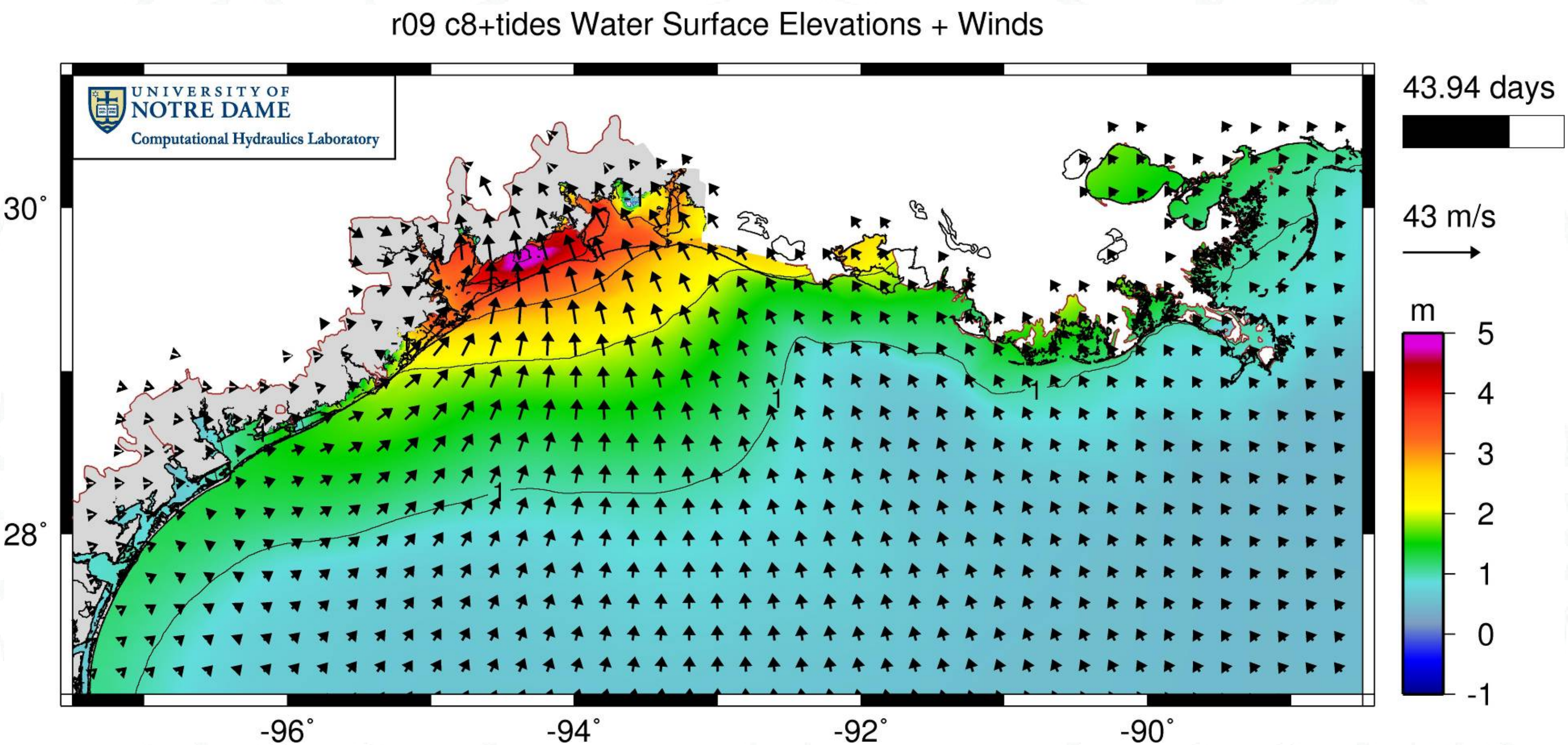
- 3 hrs

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



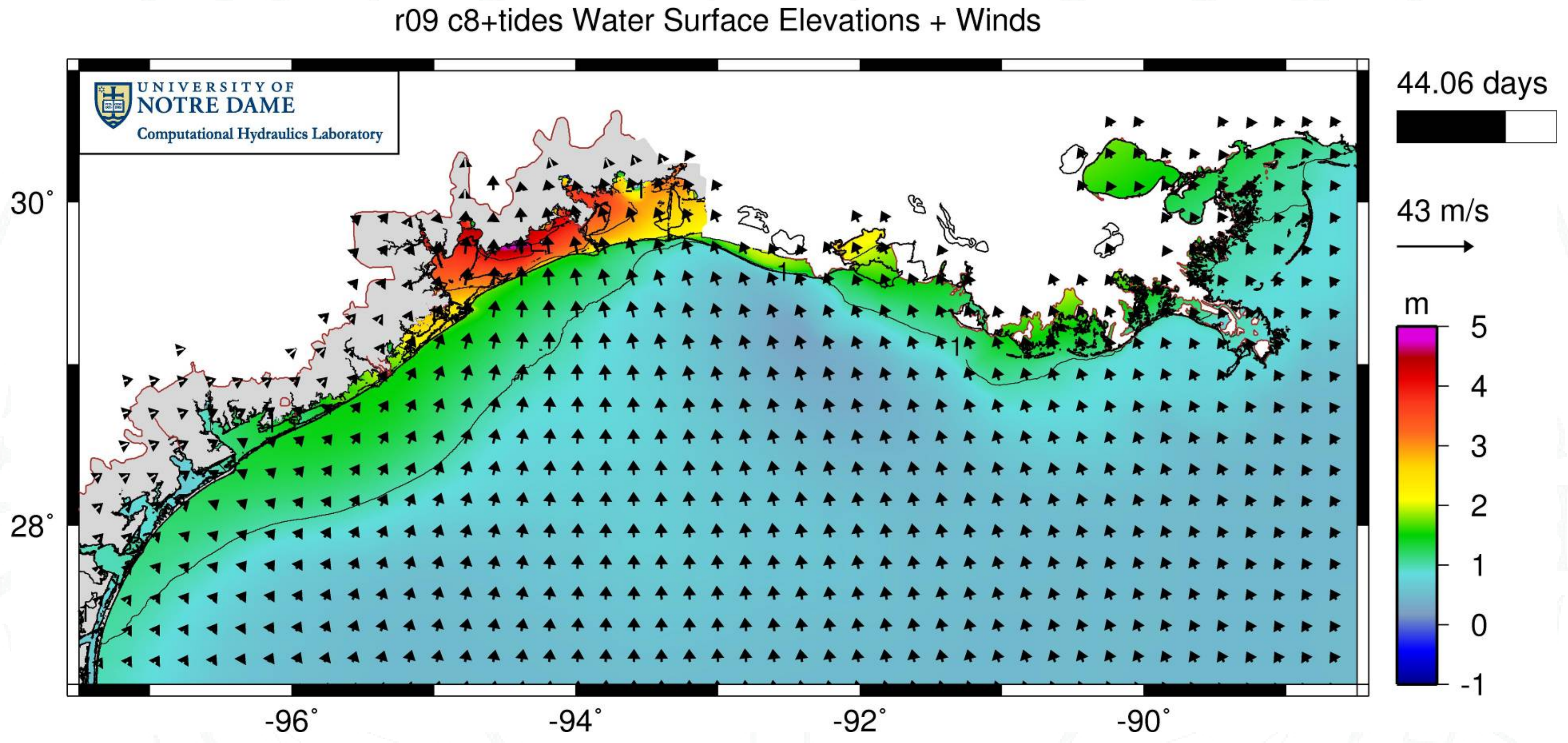
LANDFALL 0 hrs

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



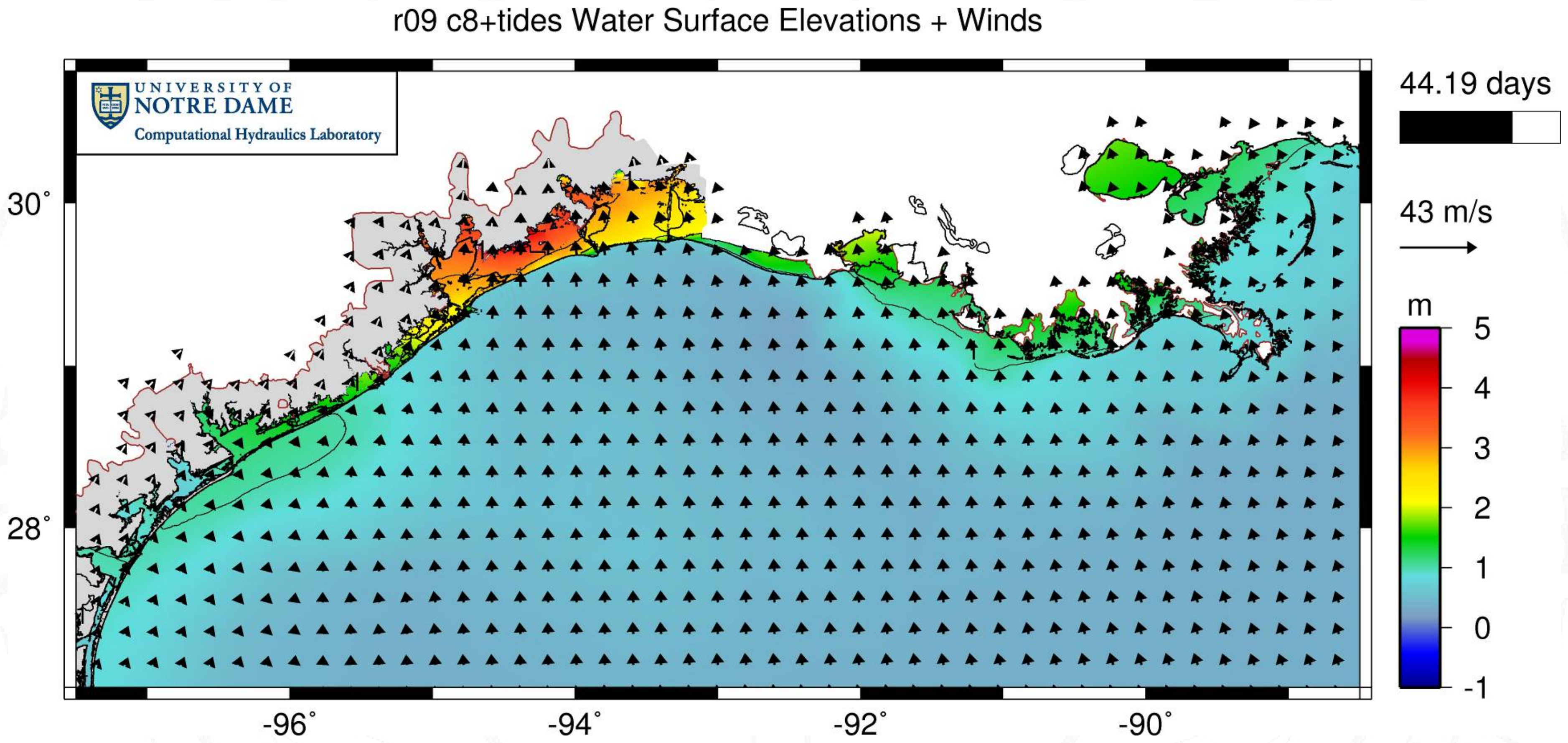
+ 3 hrs

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



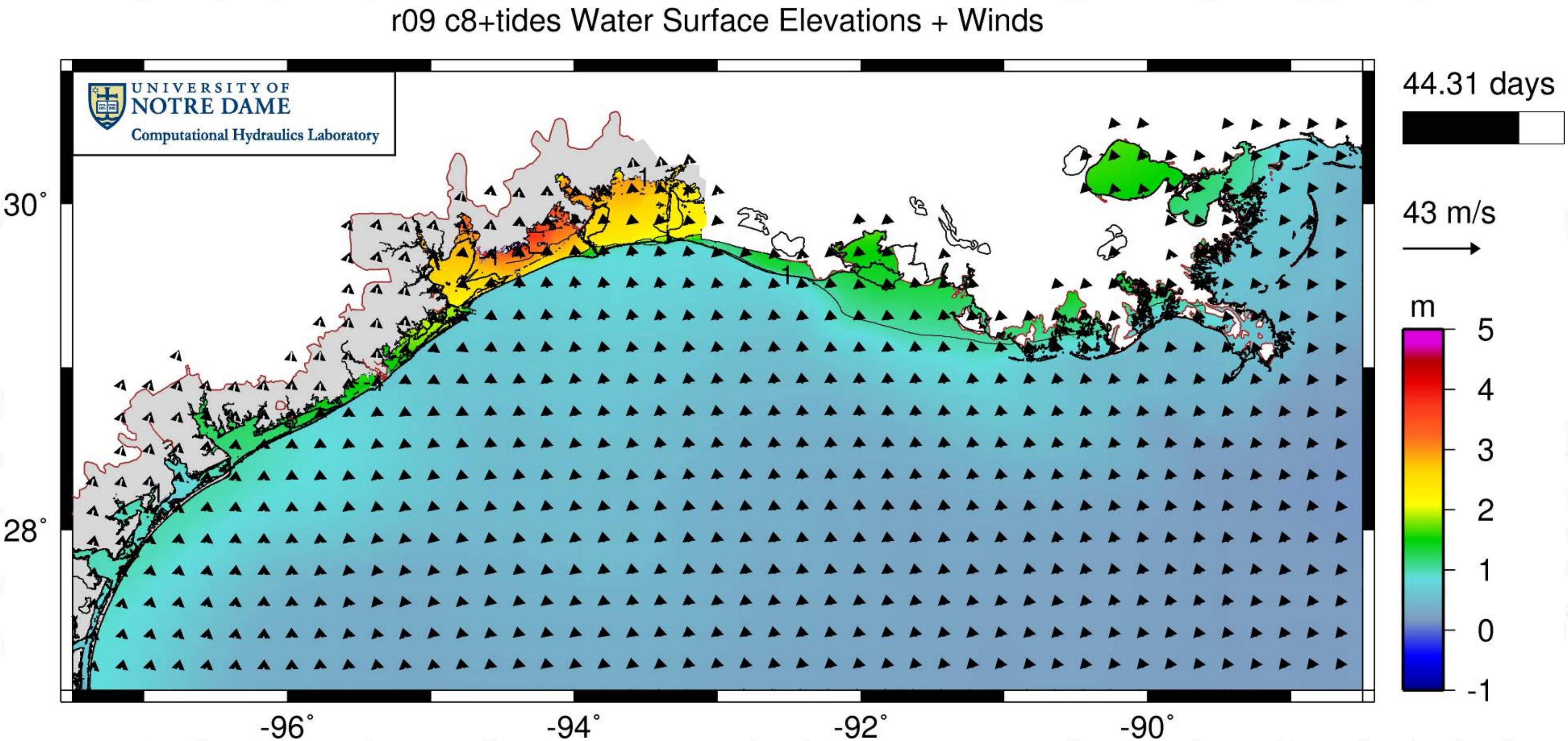
+ 6 hrs

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

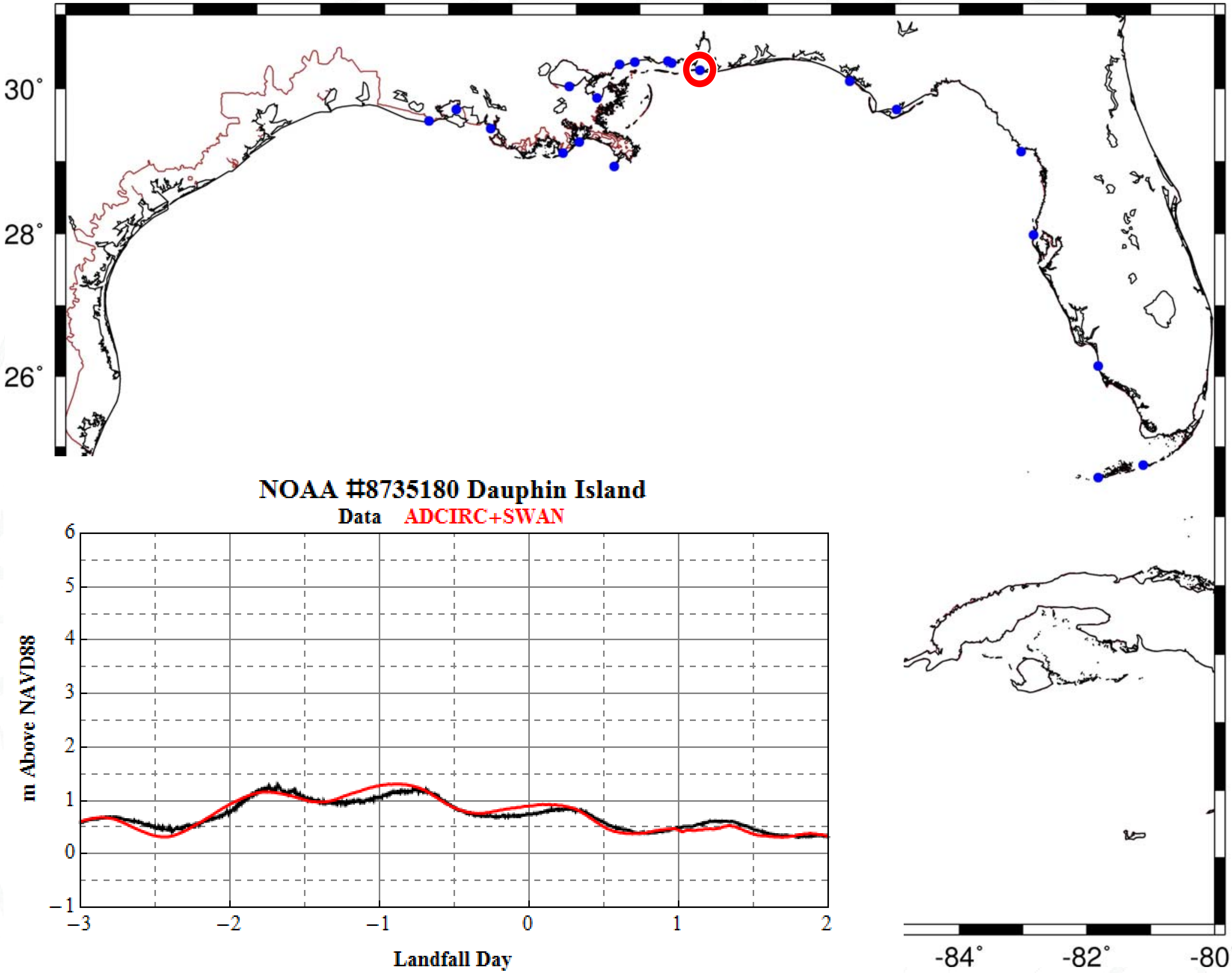


+ 9 hrs

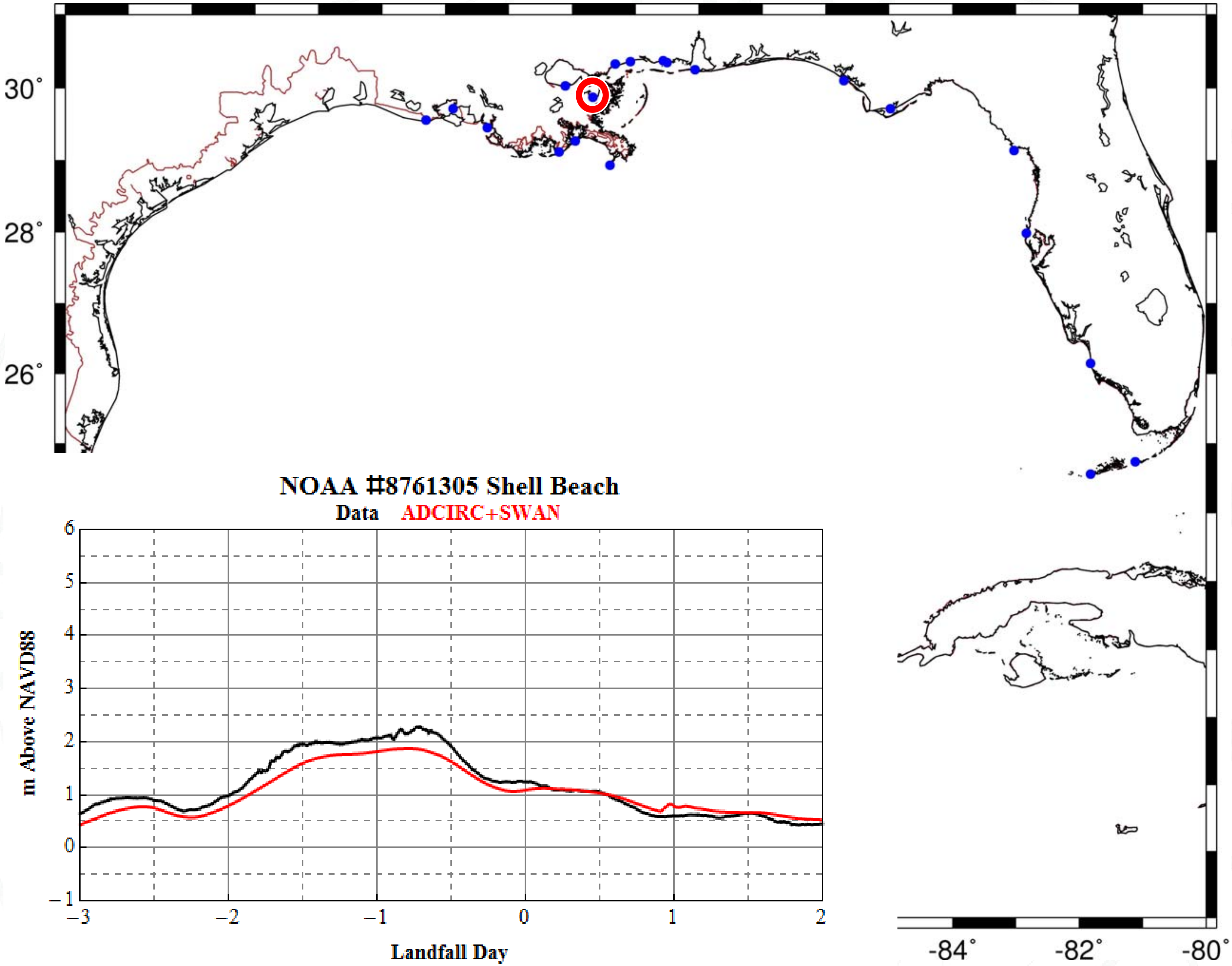
Ike surge contours (m) and wind vectors (m/s)

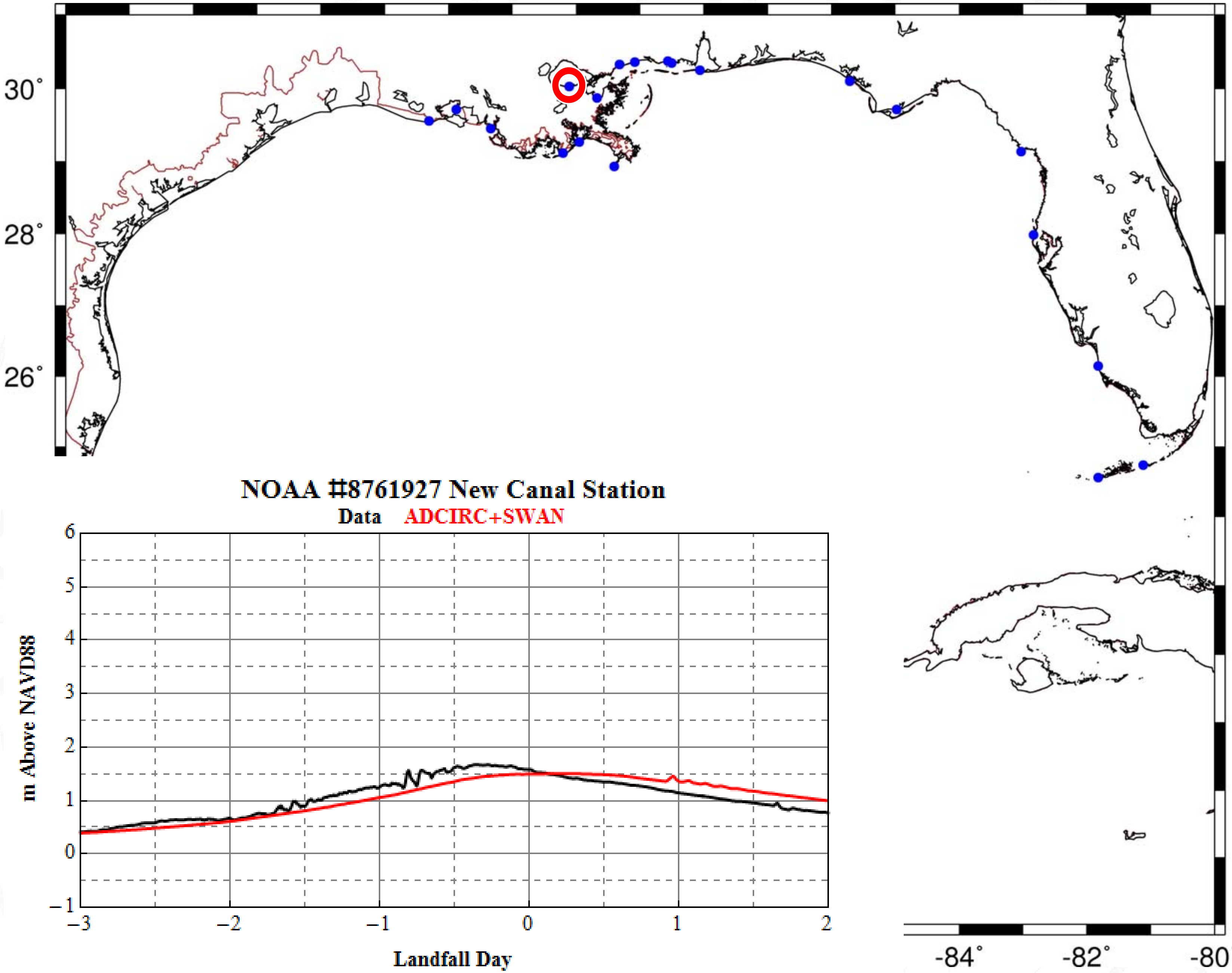


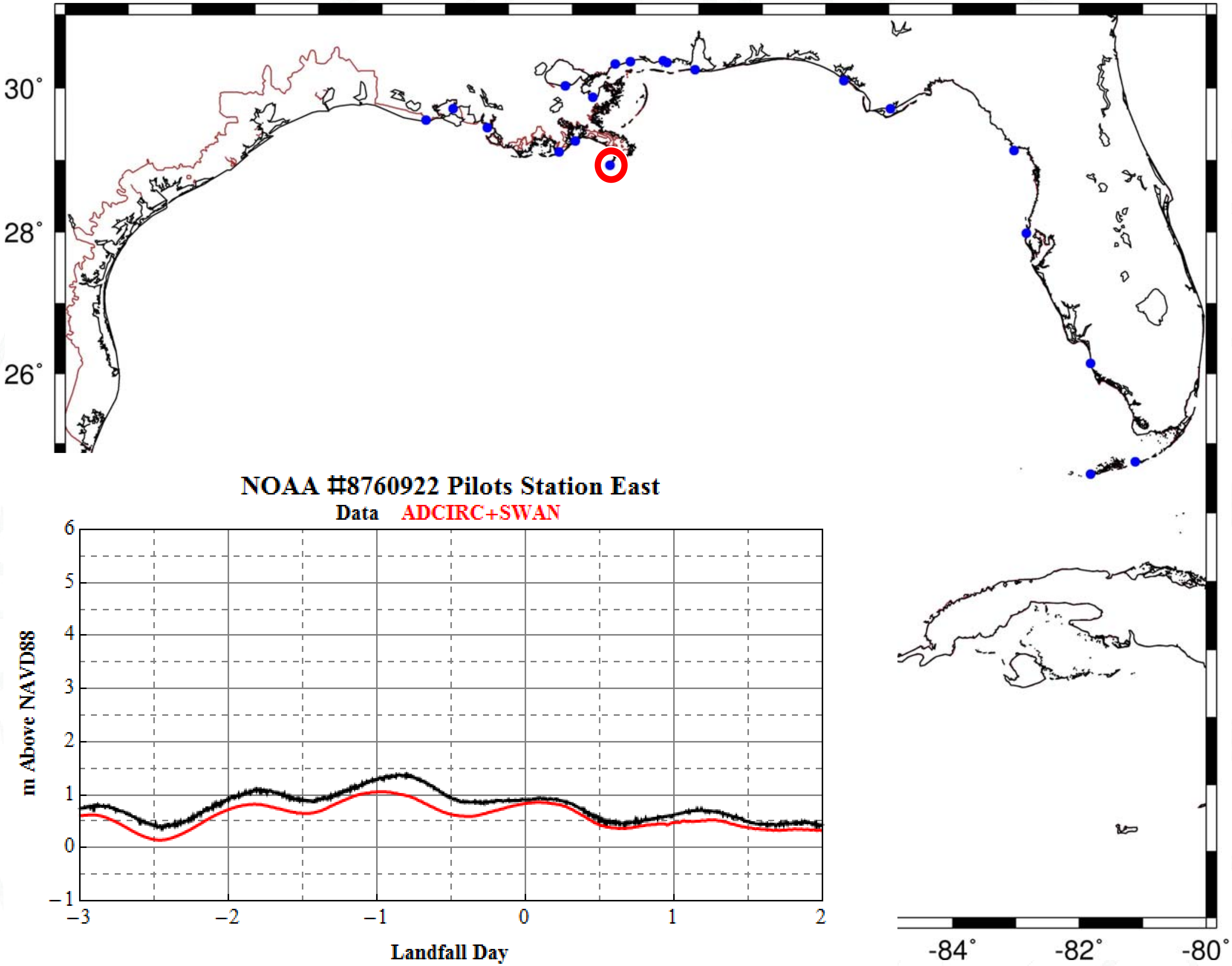
+ 12 hrs



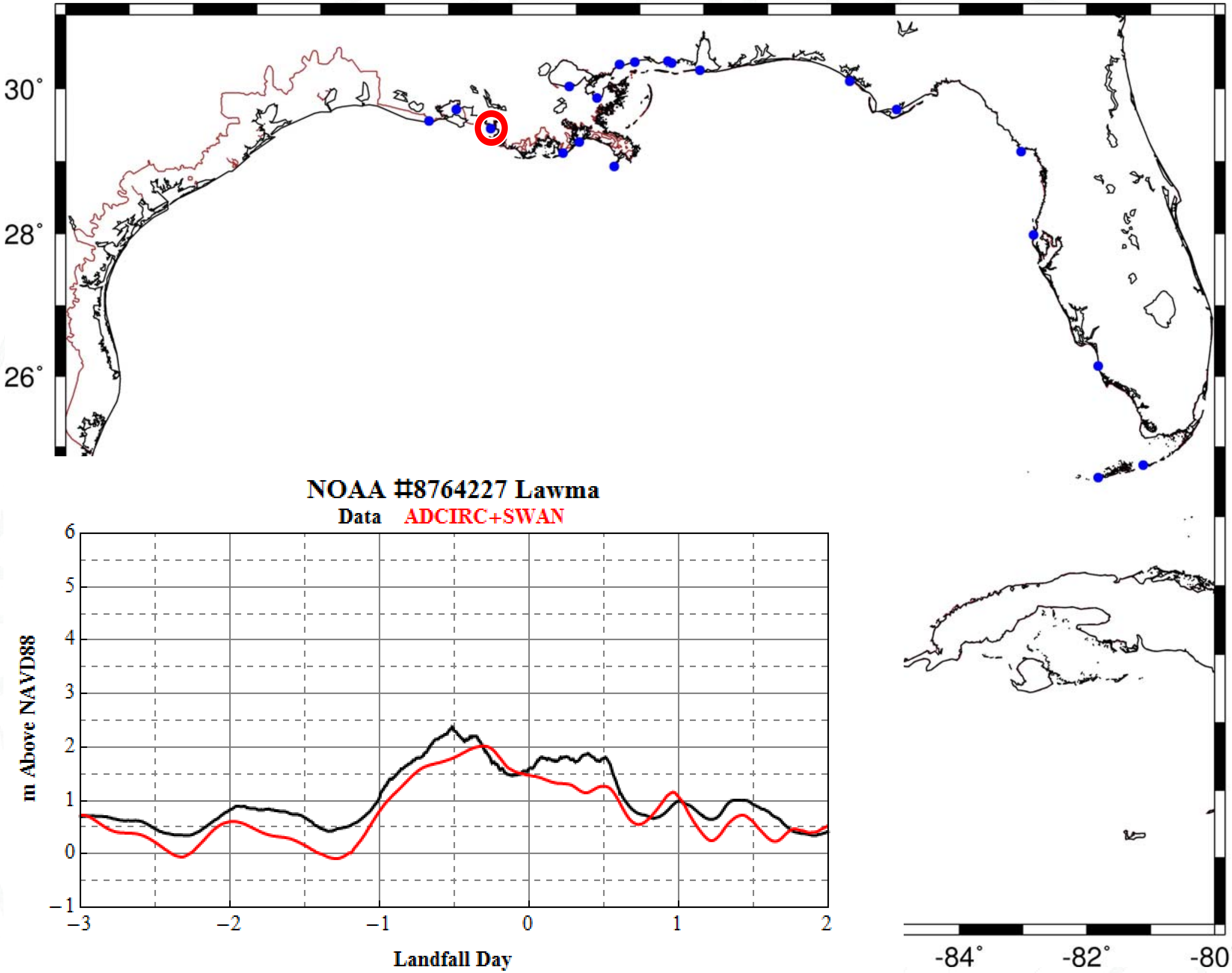
30°
28°
26°
-84°
-82°
-80°
NOAA #8735180 Dauphin Island
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2

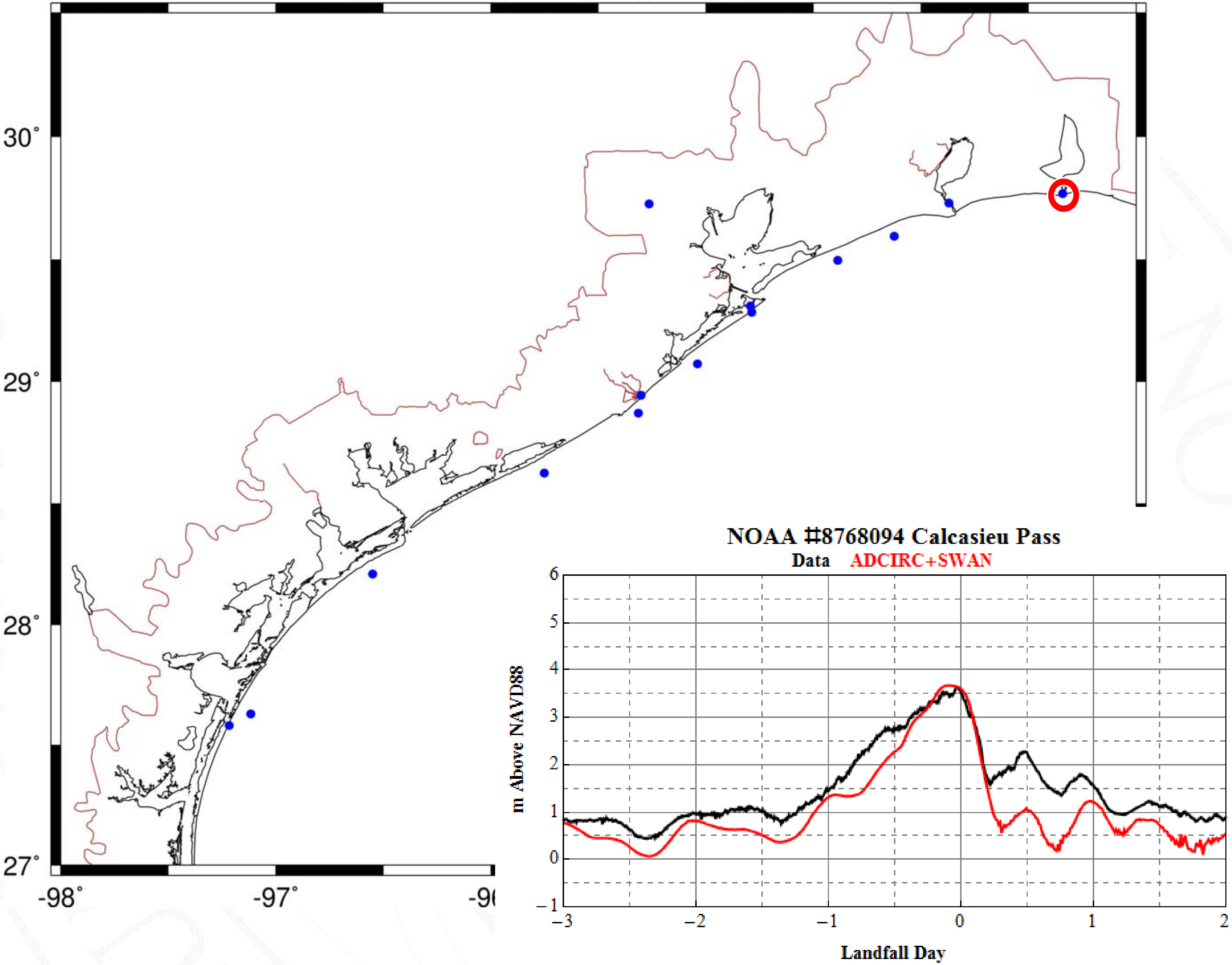

30°
28°
26°
-84°
-82°
-80°
NOAA #8761305 Shell Beach
Data
ADCIRC+SWAN
m Above NAVD88
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2
Landfall Day

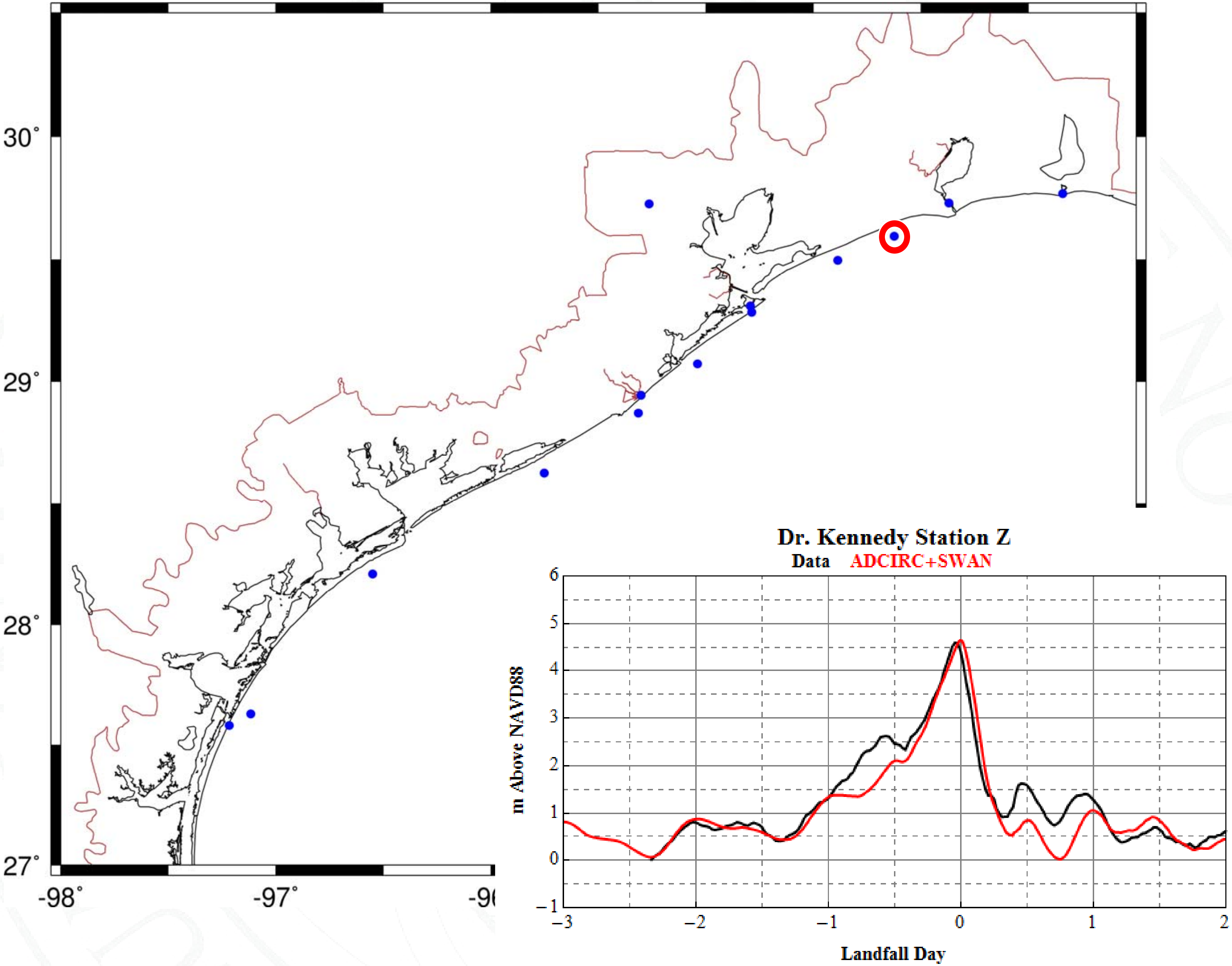

30°
28°
26°
-84°
-82°
-80°
NOAA #8761927 New Canal Station
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2



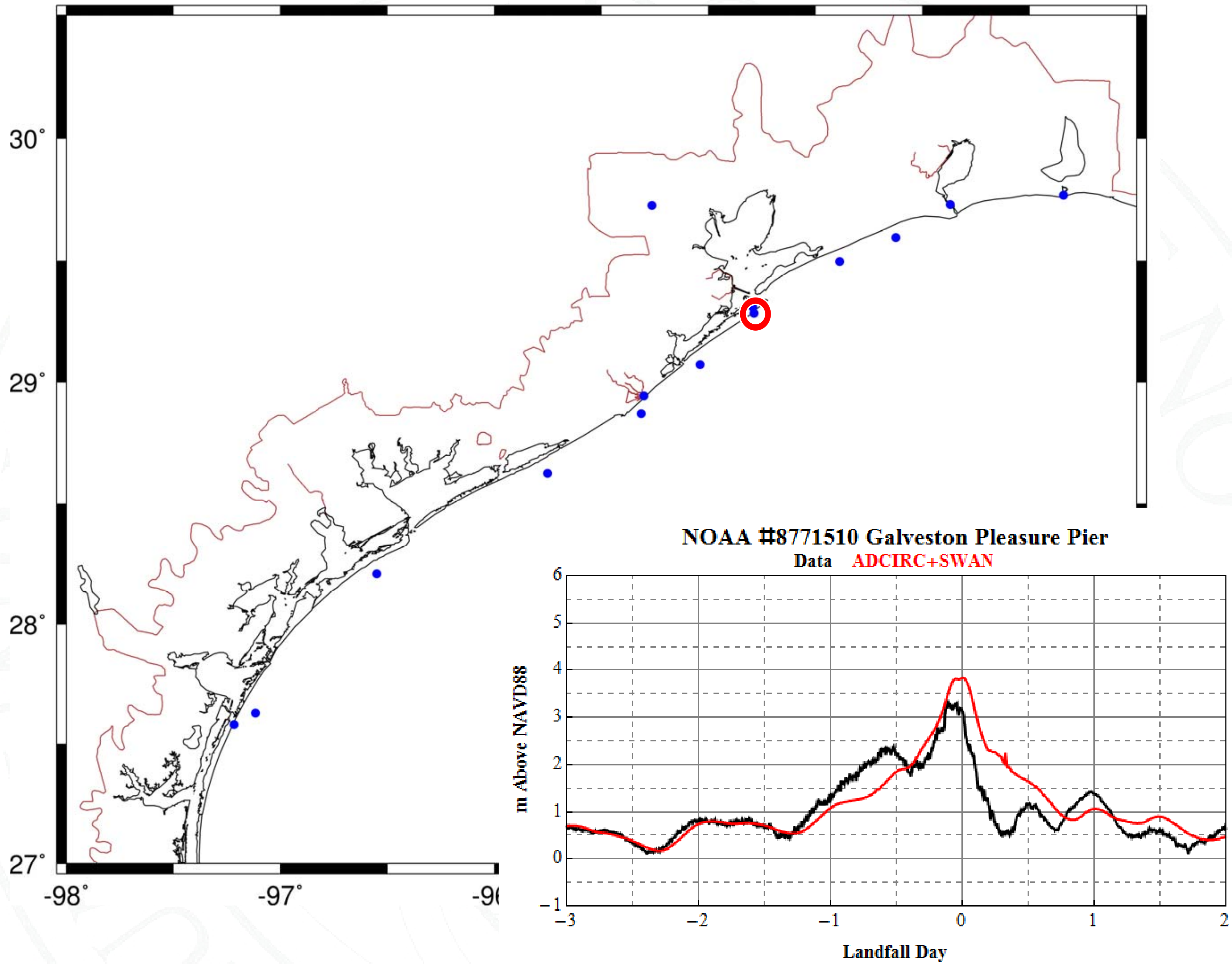
30°
28°
26°
-84°
-82°
-80°
NOAA #8760922 Pilots Station East
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2


30°
28°
26°
NOAA #8764227 Lawma
Data ADCIRC+SWAN
m Above NAVD88
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2
Landfall Day
-84°
-82°
-80°

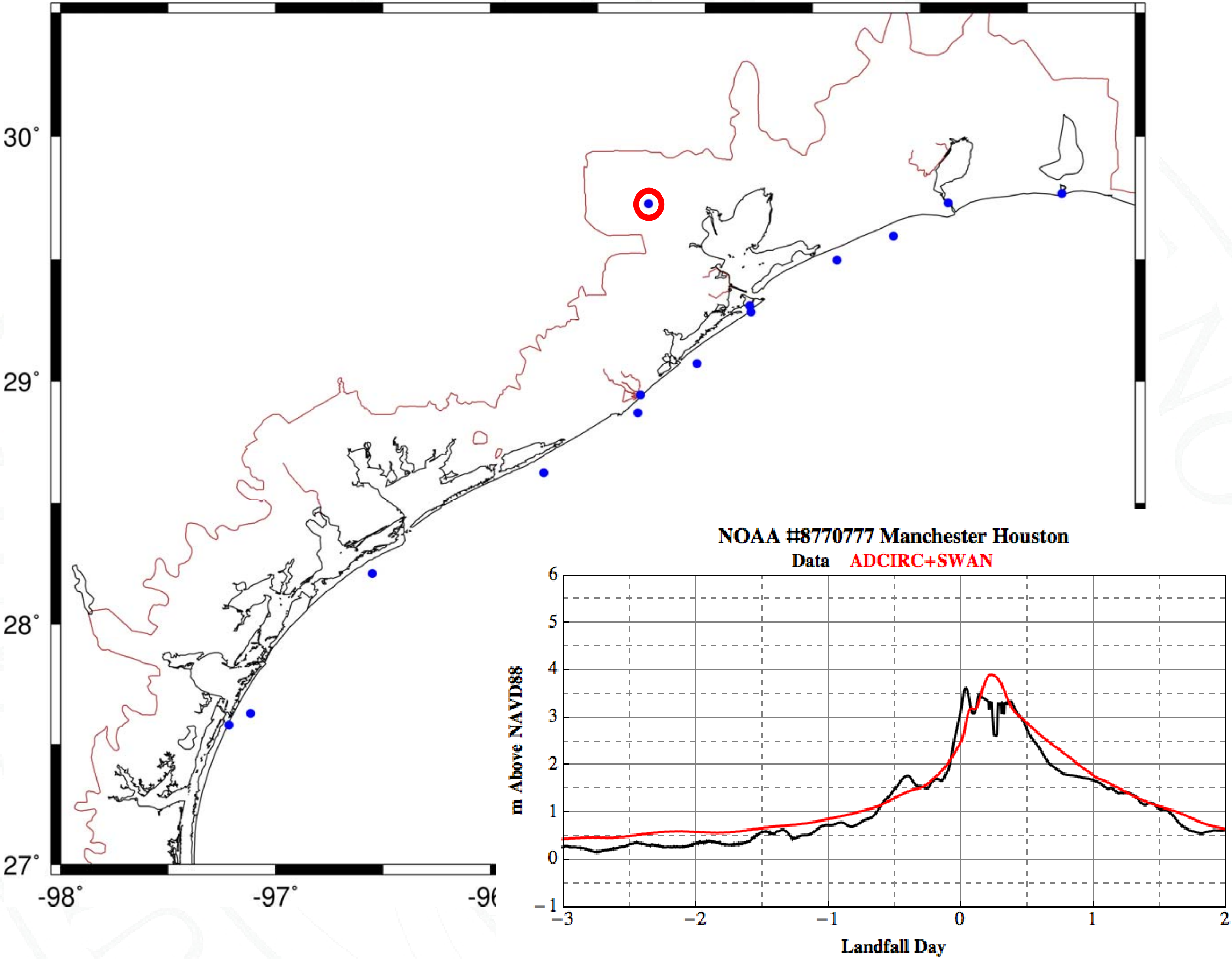

30°
29°
28°
27°
-98°
-97°
NOAA #8768094 Calcasieu Pass
Data
ADCIRC+SWAN
m Above NAVD88
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2
Landfall Day

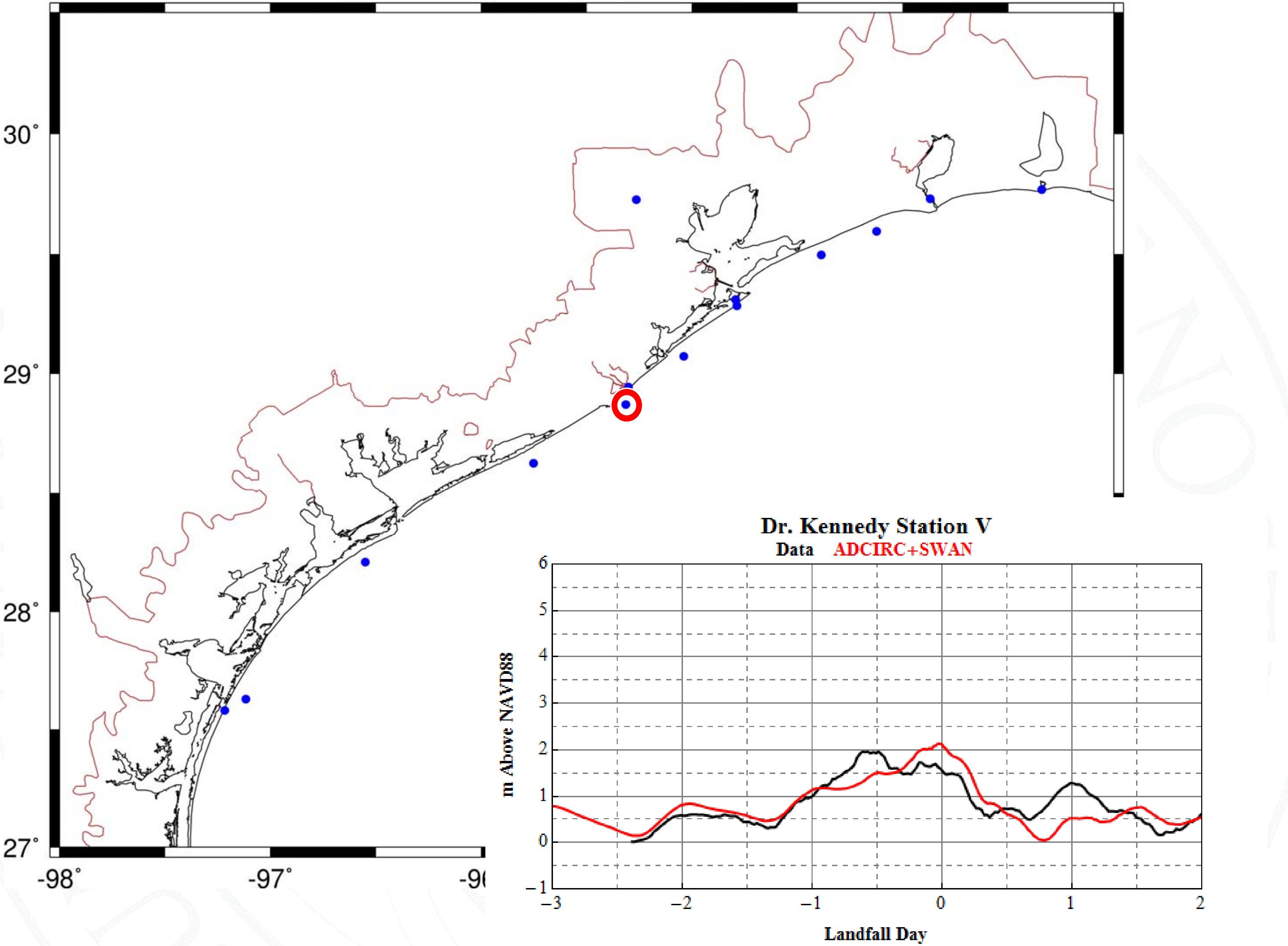


30°
29°
28°
27°
-98°
-97°
-96
Dr. Kennedy Station Z
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2

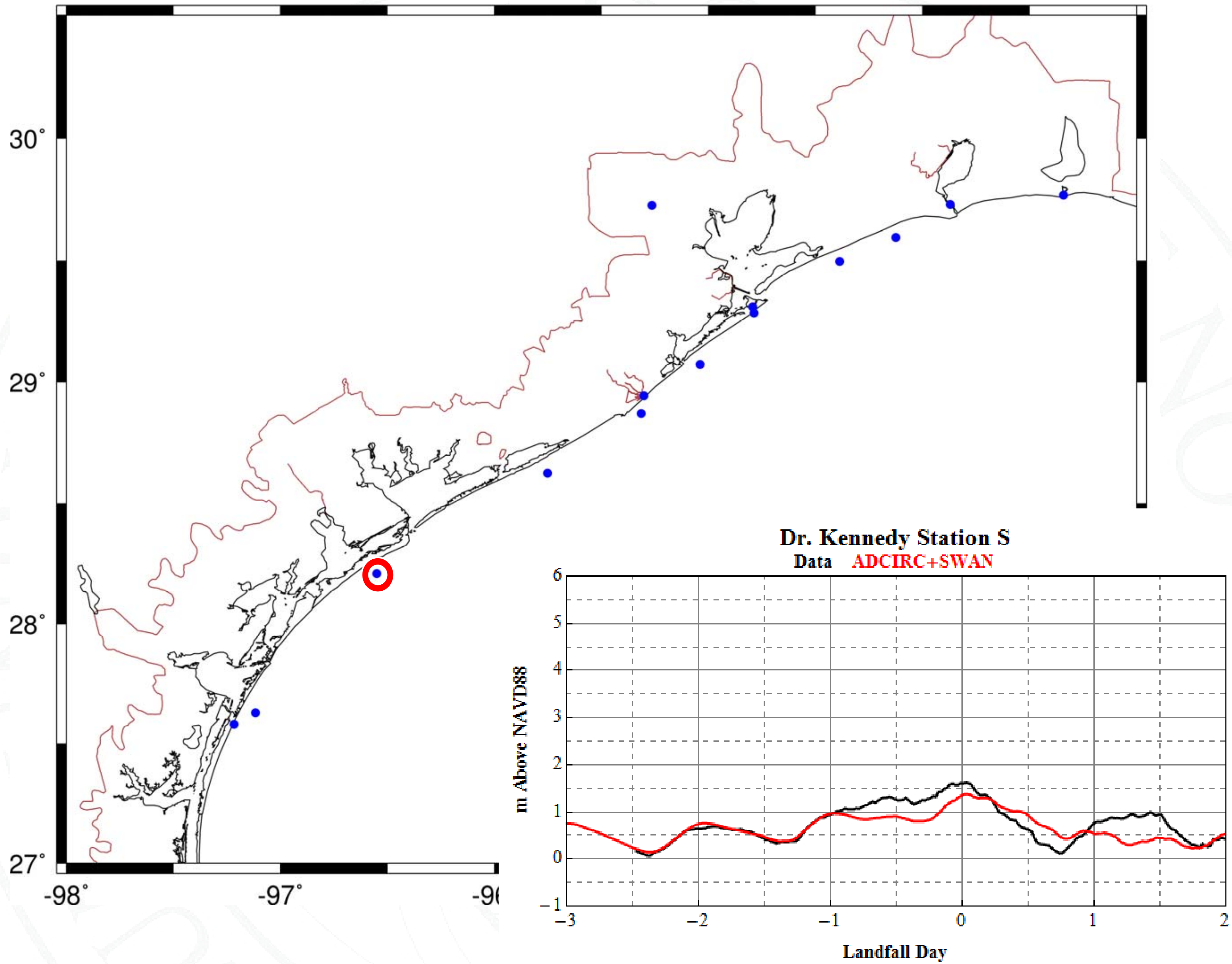


30˚
29˚
28˚
27˚
-98˚
-97˚
NOAA #8771510 Galveston Pleasure Pier
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2

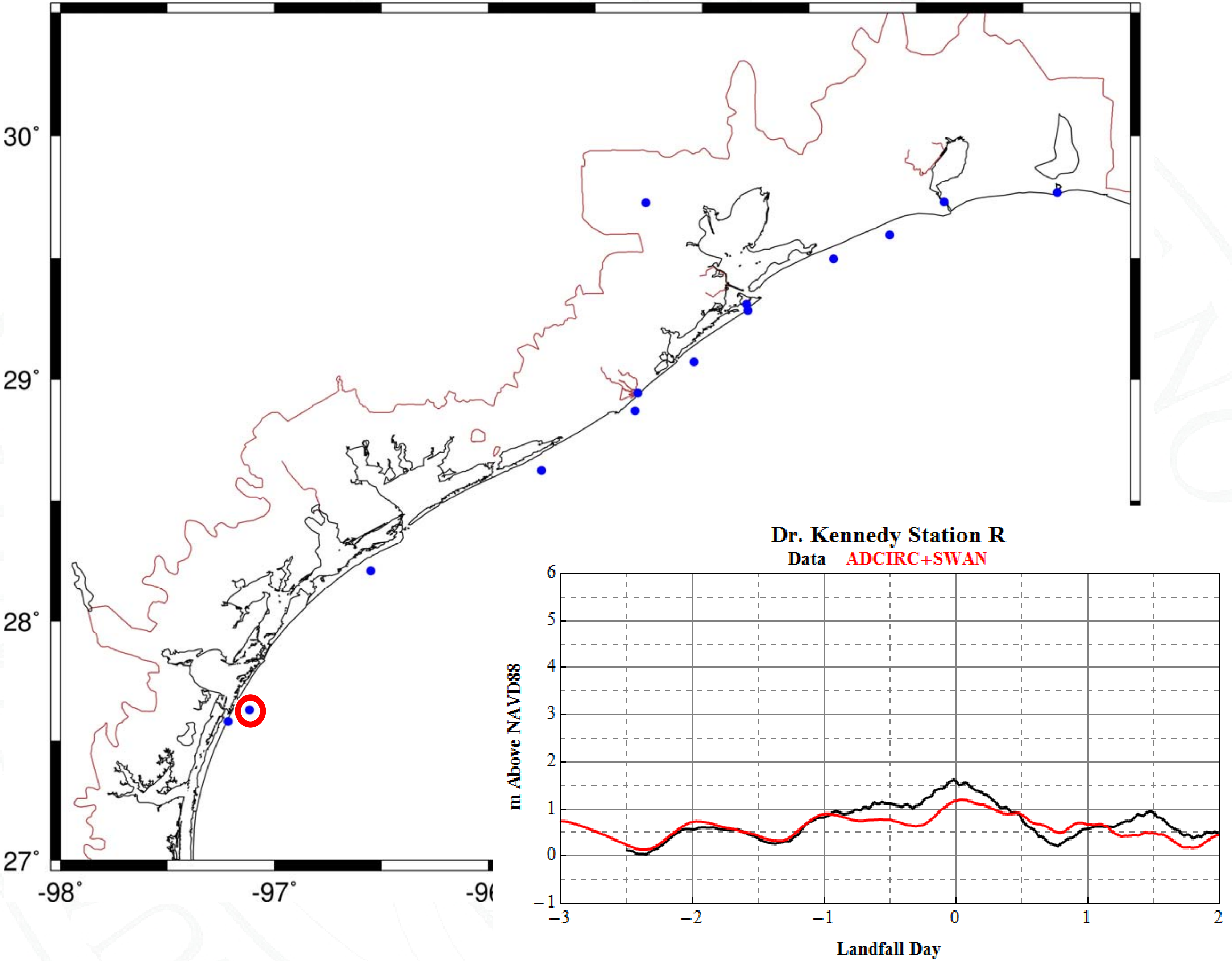

30°
29°
28°
27°
-98°
-97°
-96
NOAA #8770777 Manchester Houston
Data ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2



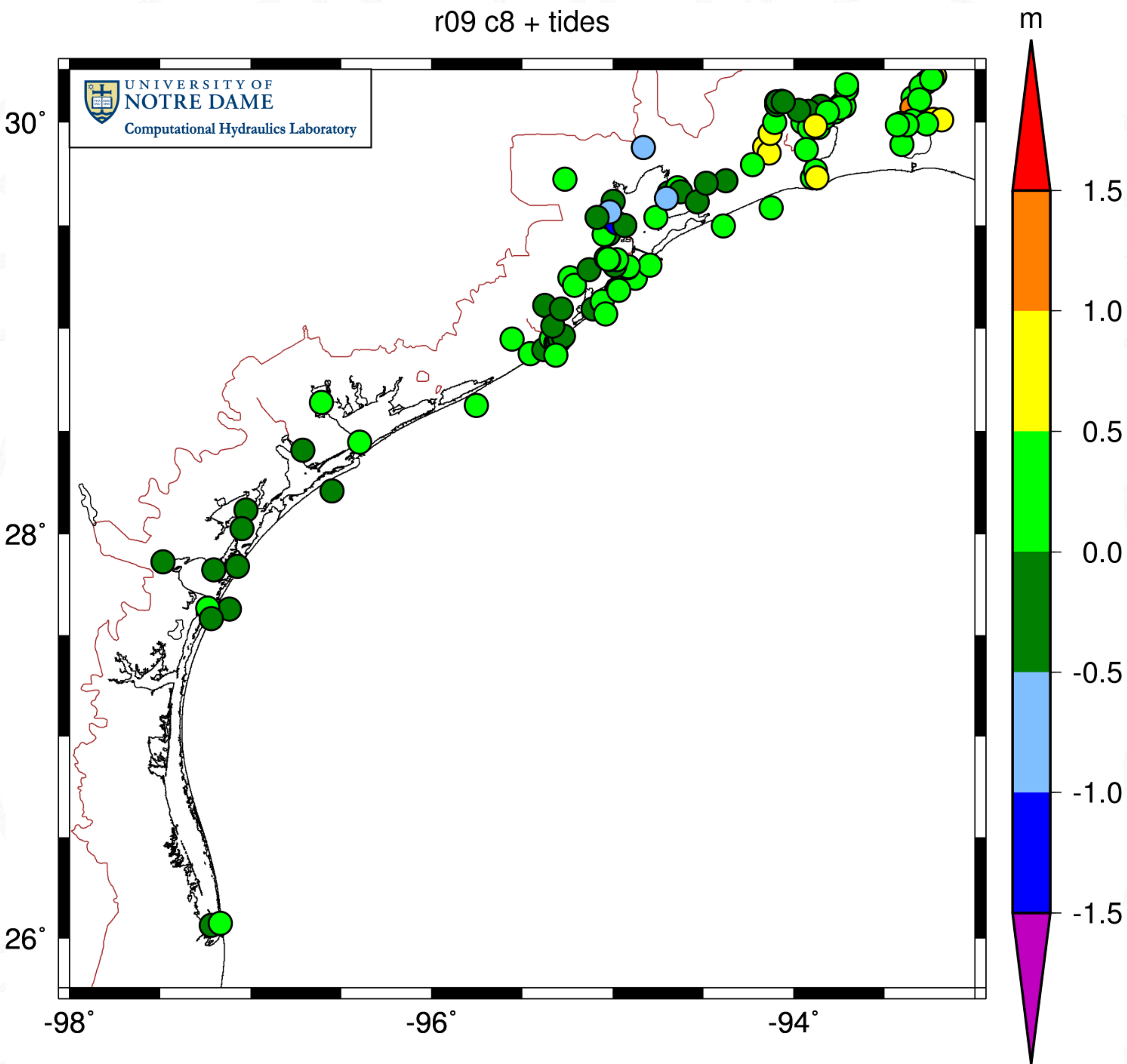
30°
29°
28°
27°
-98°
-97°
Dr. Kennedy Station V
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2



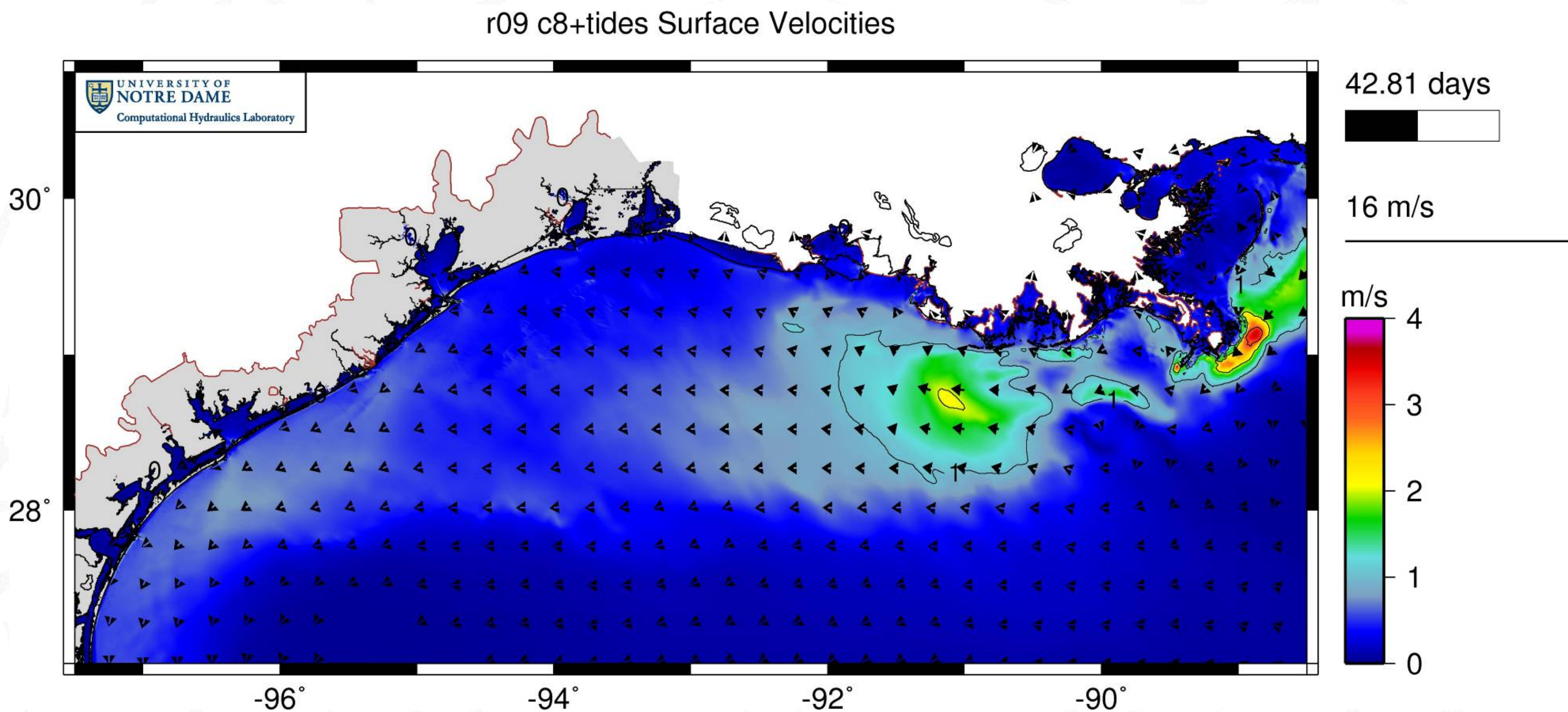
30°
29°
28°
27°
-98°
-97°
Dr. Kennedy Station S
Data
ADCIRC+SWAN
m Above NAVD88
Landfall Day


30°
29°
28°
27°
-98°
-97°
-96
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

Ike Hindcast – HWM Comparisons – URS/FEMA Data

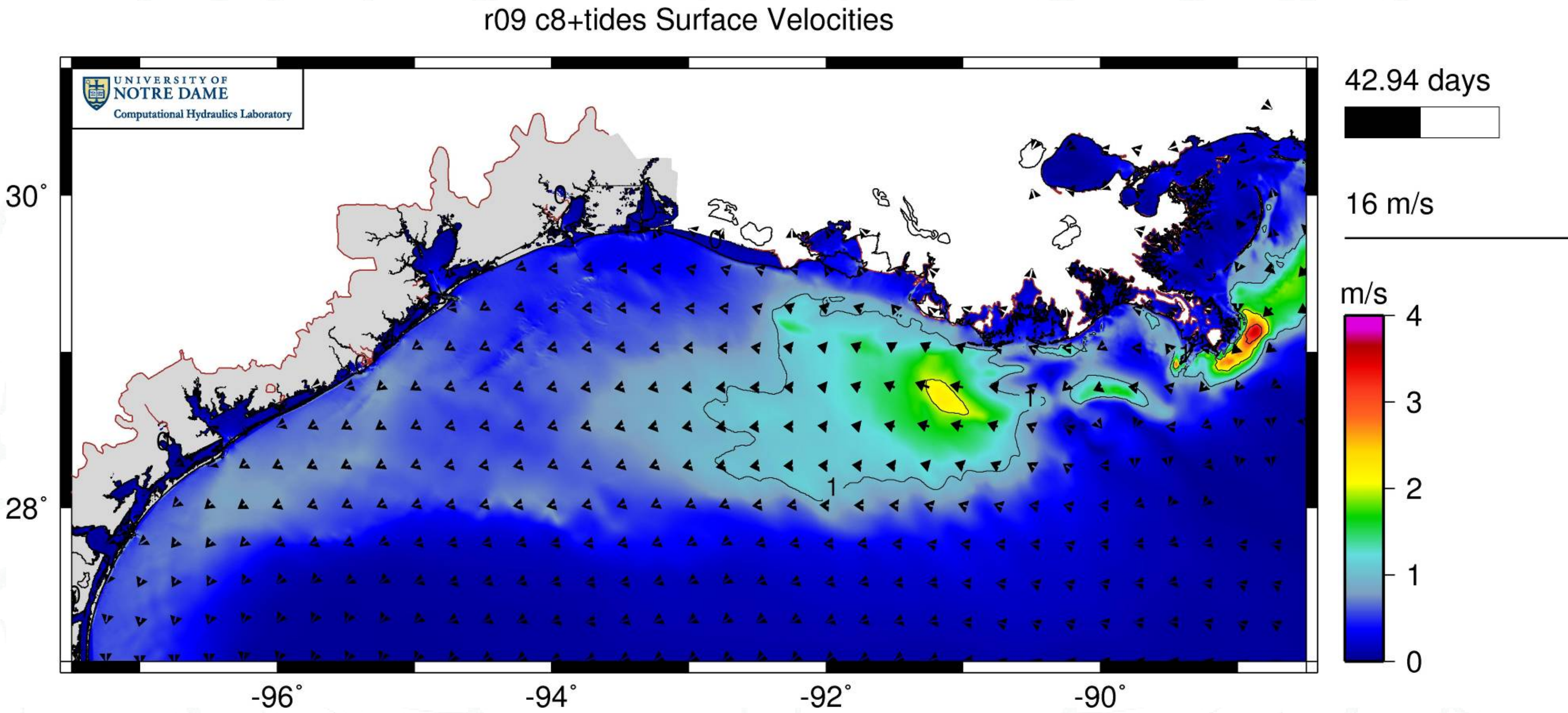


Ike significant surface current contours and vectors (m/s)



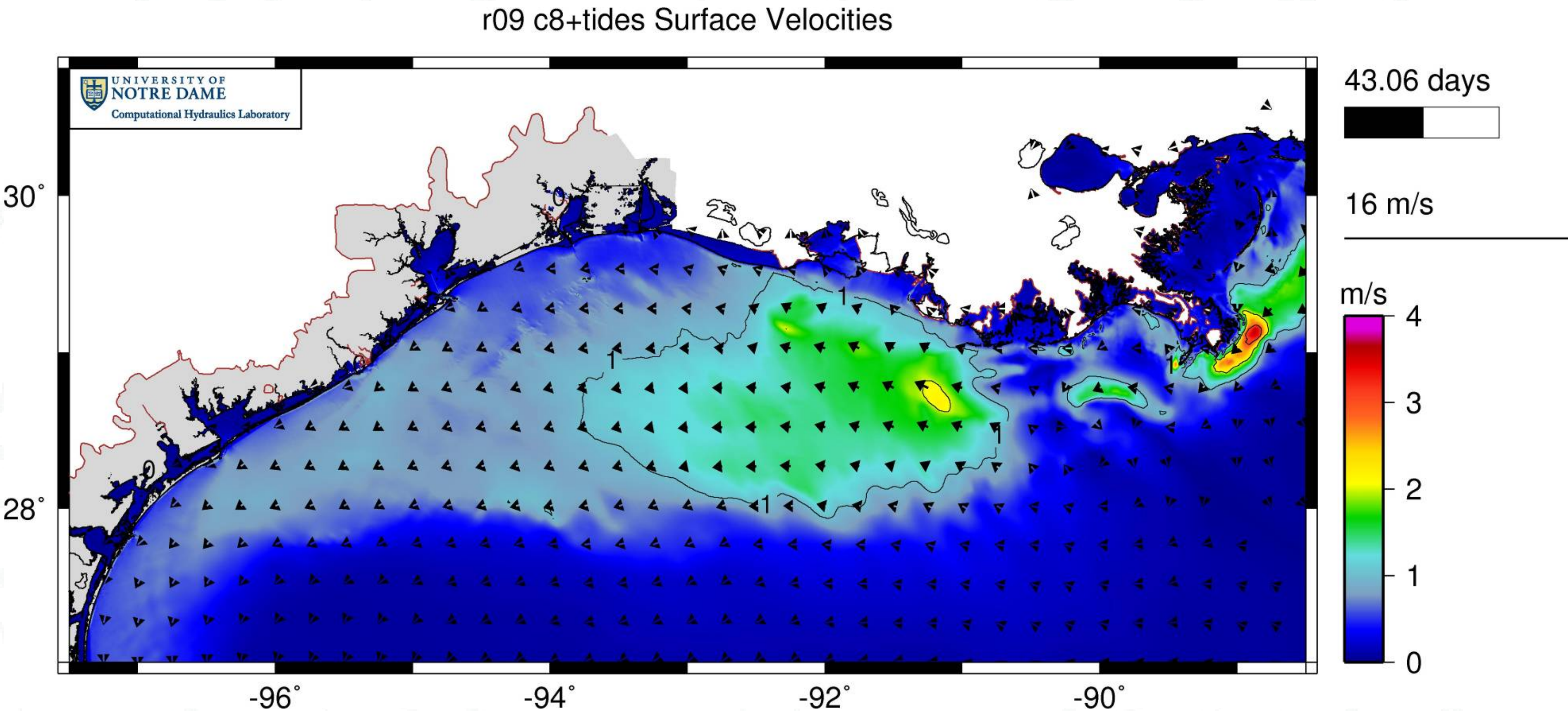
- 24 hrs

Ike significant surface current contours and vectors (m/s)



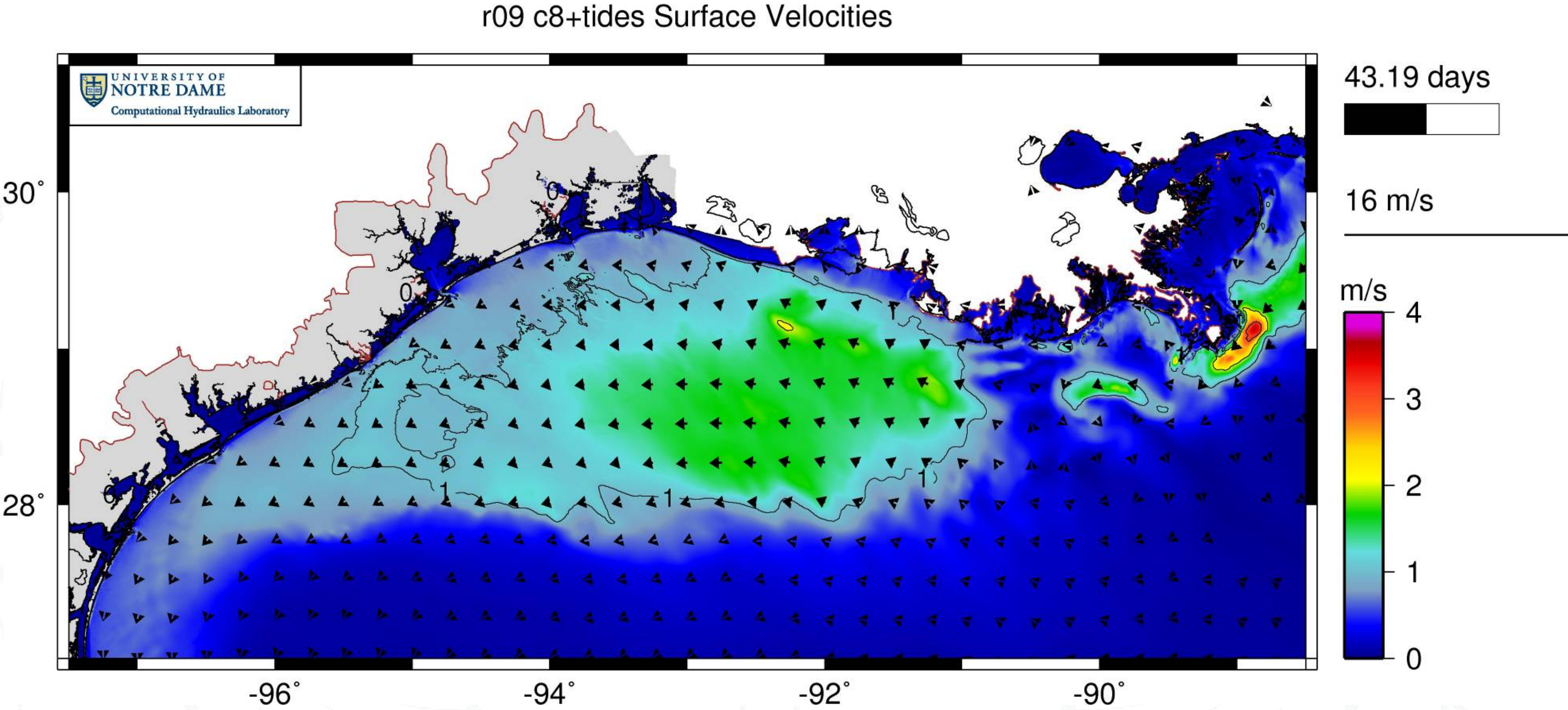
- 21 hrs

Ike significant surface current contours and vectors (m/s)



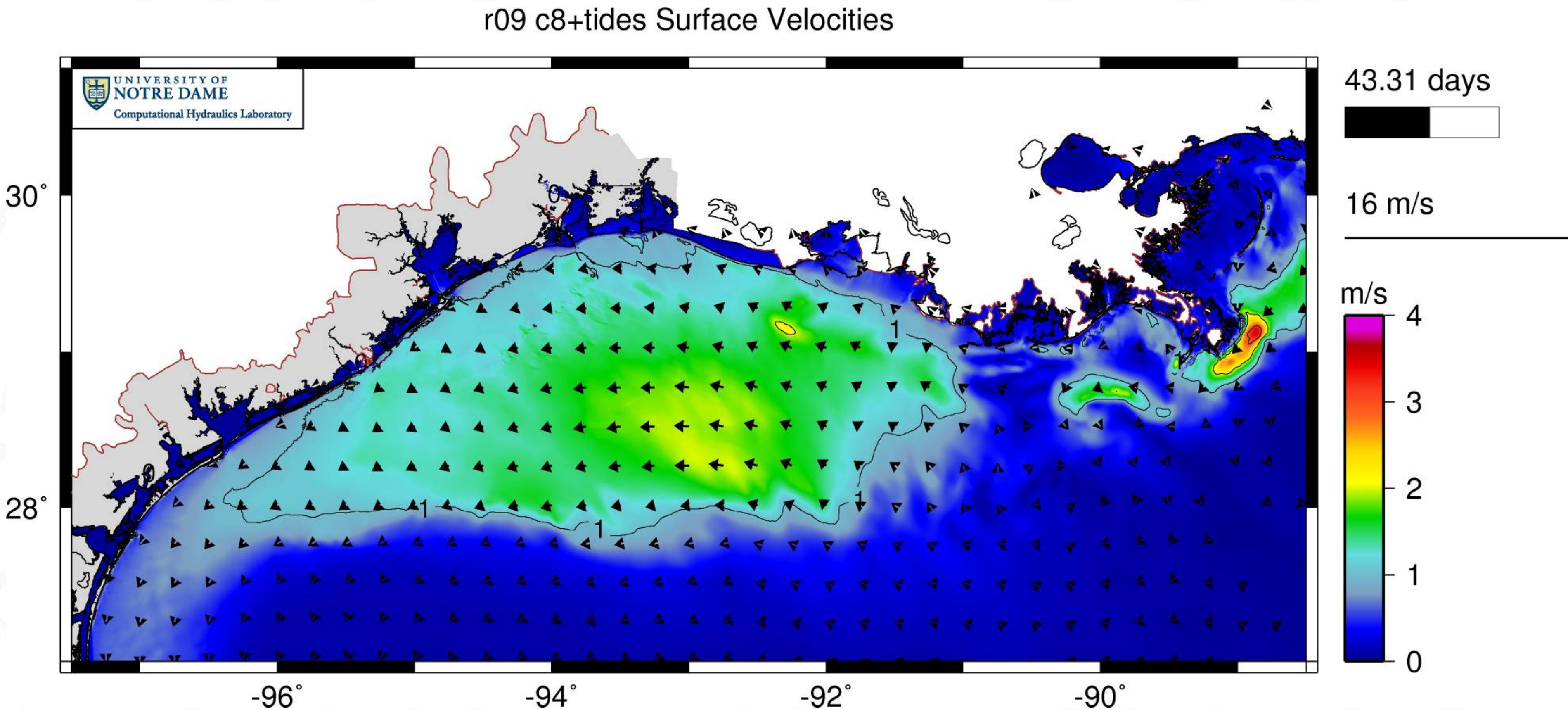
- 18 hrs

Ike significant surface current contours and vectors (m/s)



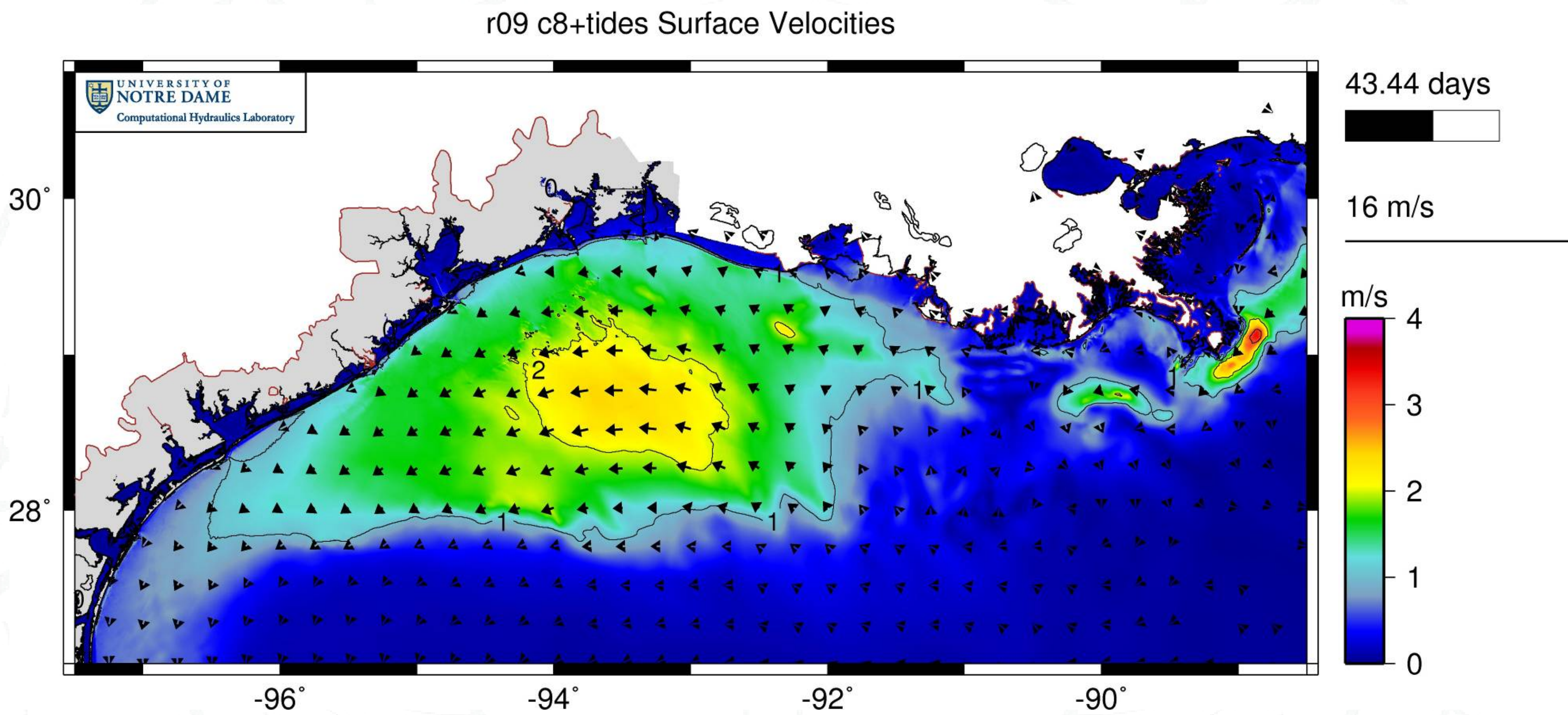
- 15 hrs

Ike significant surface current contours and vectors (m/s)



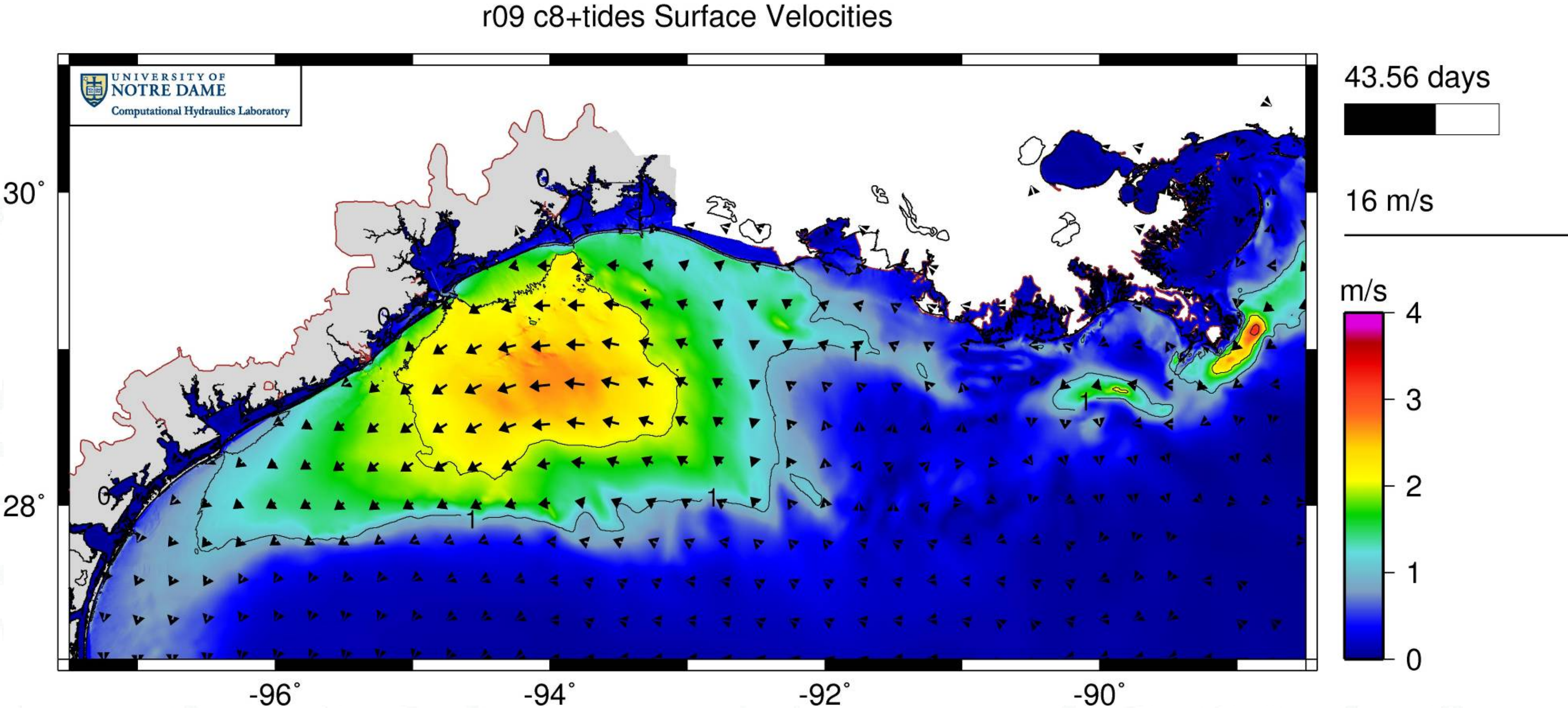
- 12 hrs

Ike significant surface current contours and vectors (m/s)



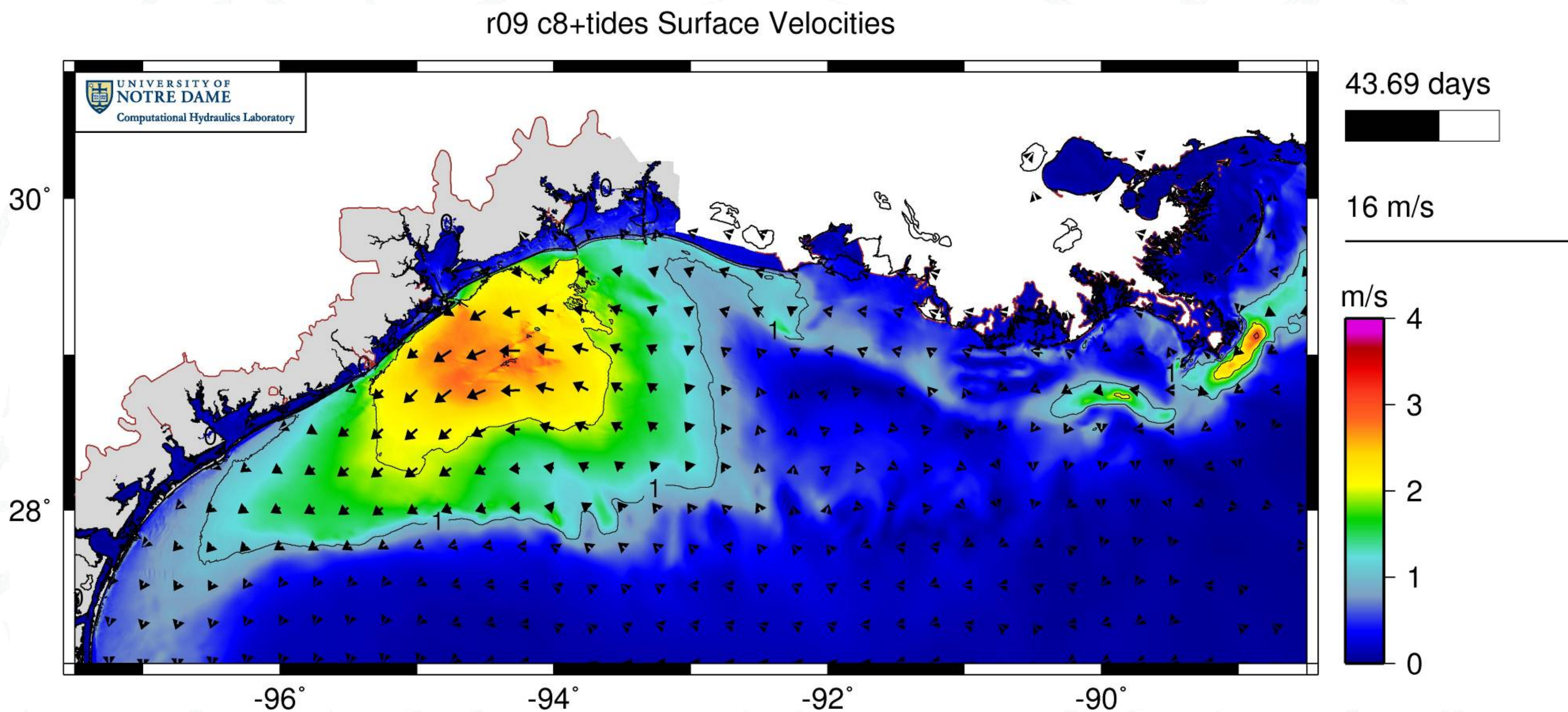
- 9 hrs

Ike significant surface current contours and vectors (m/s)



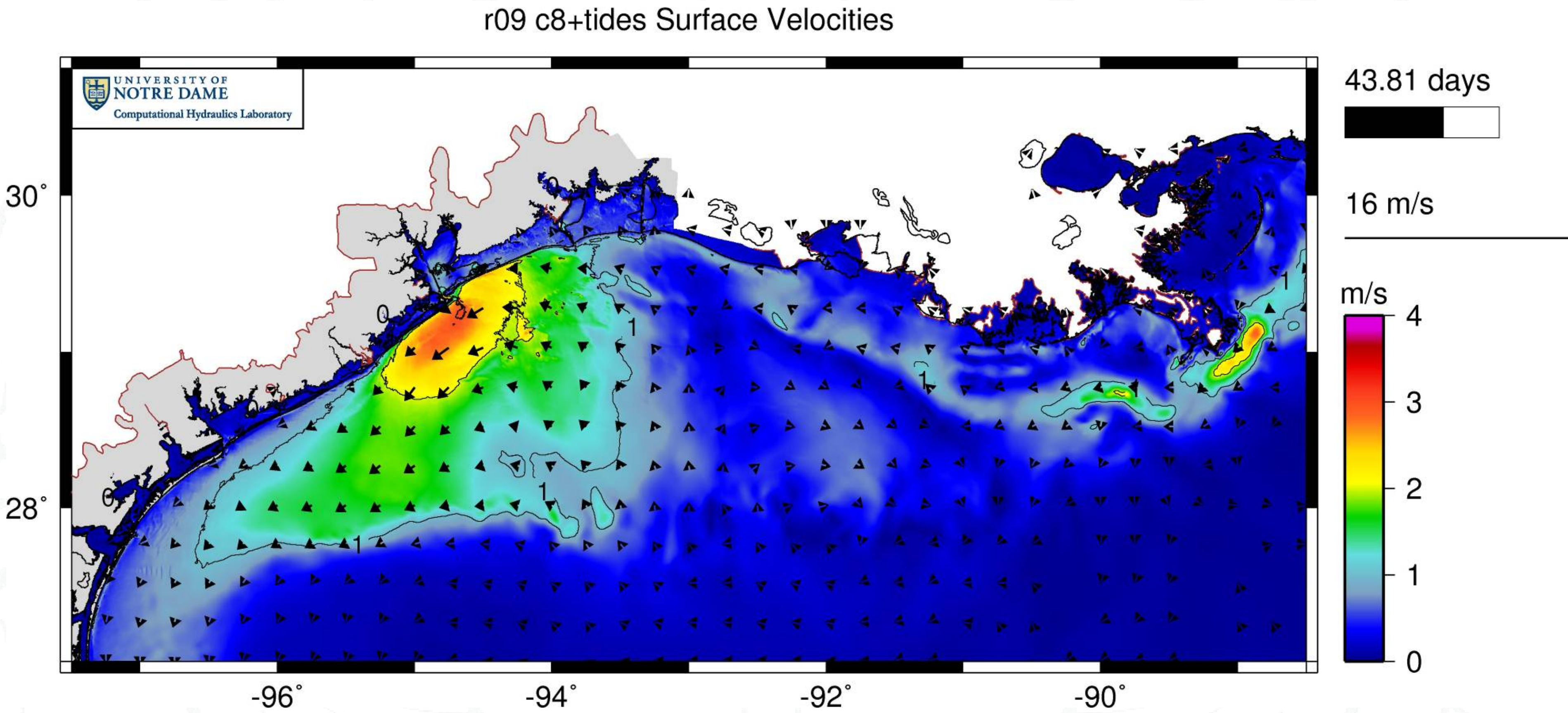
- 6 hrs

Ike significant surface current contours and vectors (m/s)



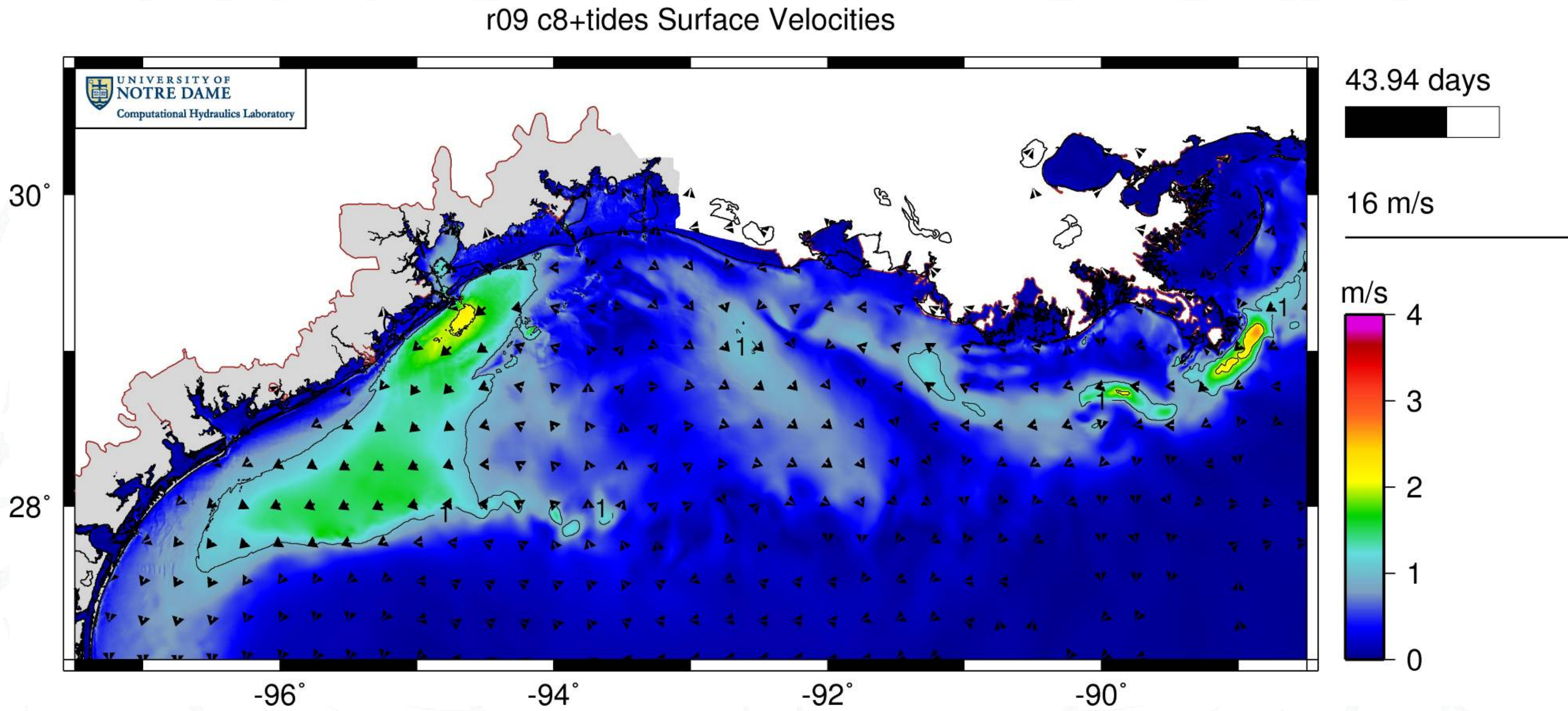
- 3 hrs

Ike significant surface current contours and vectors (m/s)



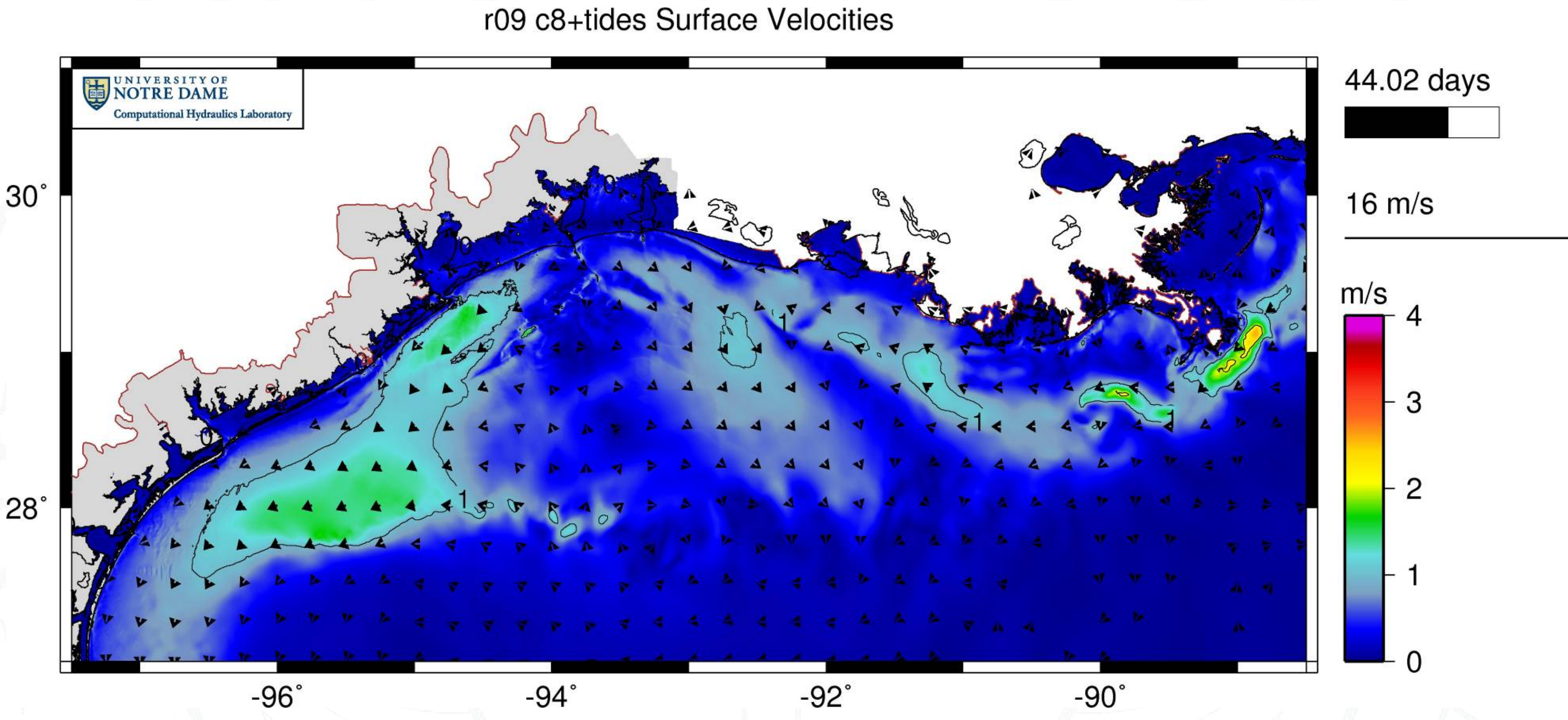
LANDFALL 0 hrs

Ike significant surface current contours and vectors (m/s)



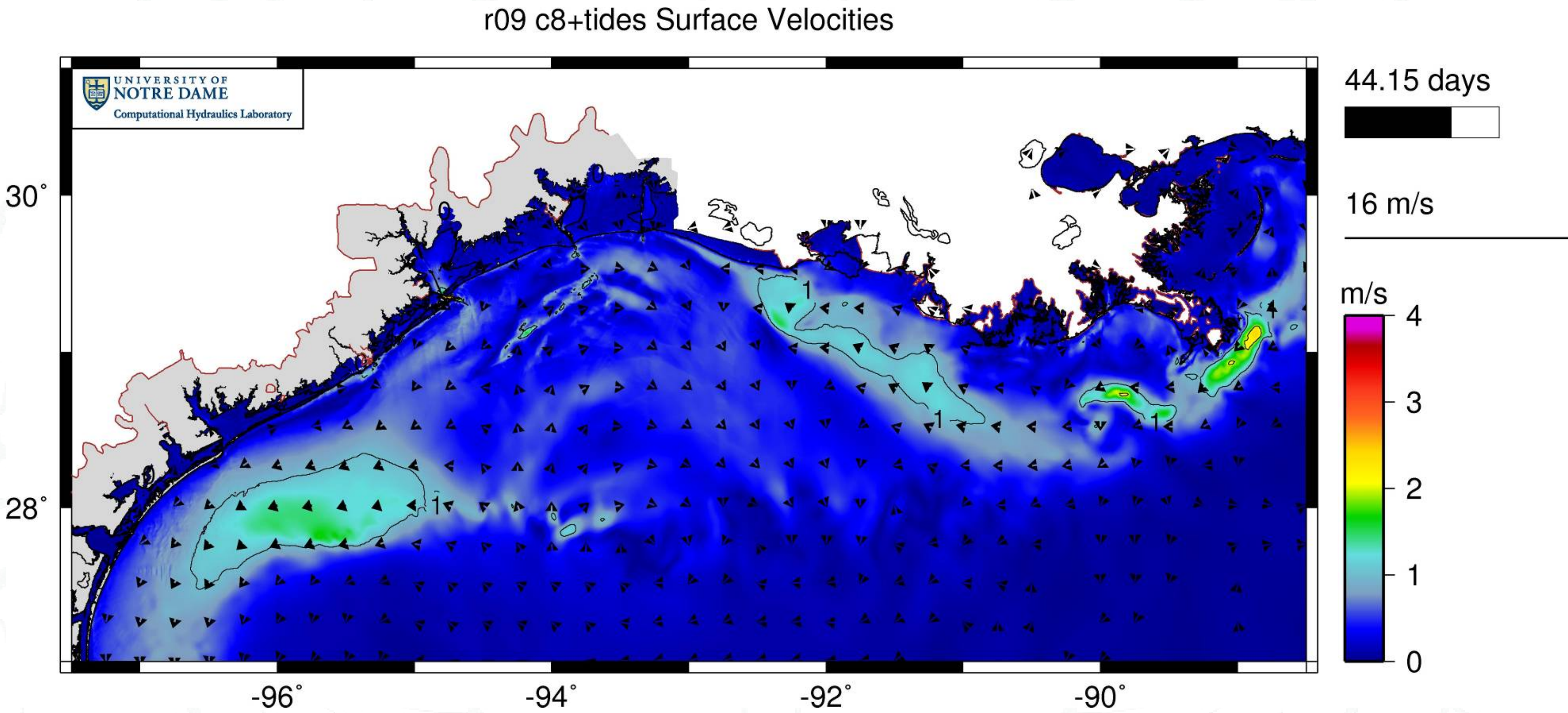
+ 3 hrs

Ike significant surface current contours and vectors (m/s)



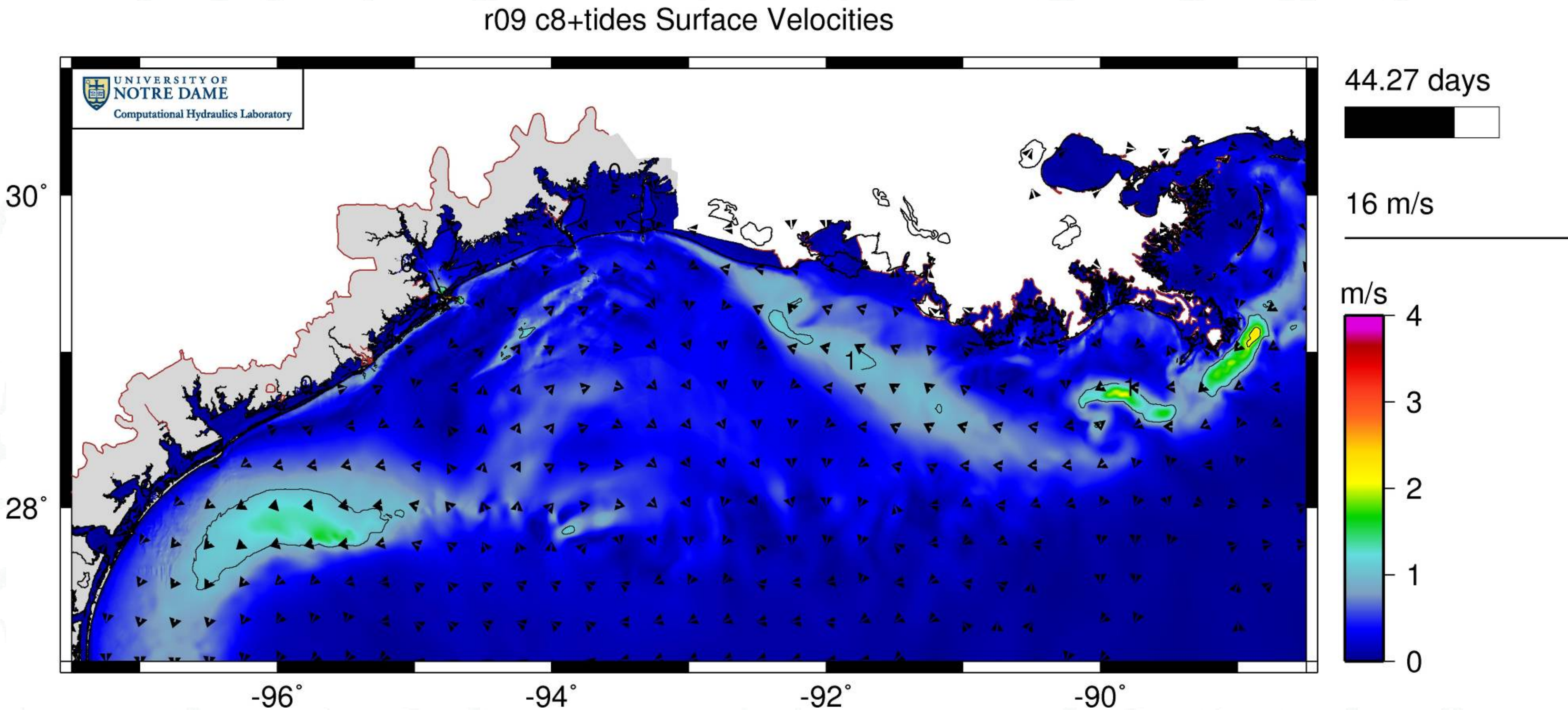
+ 6 hrs

Ike significant surface current contours and vectors (m/s)



+ 9 hrs

Ike significant surface current contours and vectors (m/s)

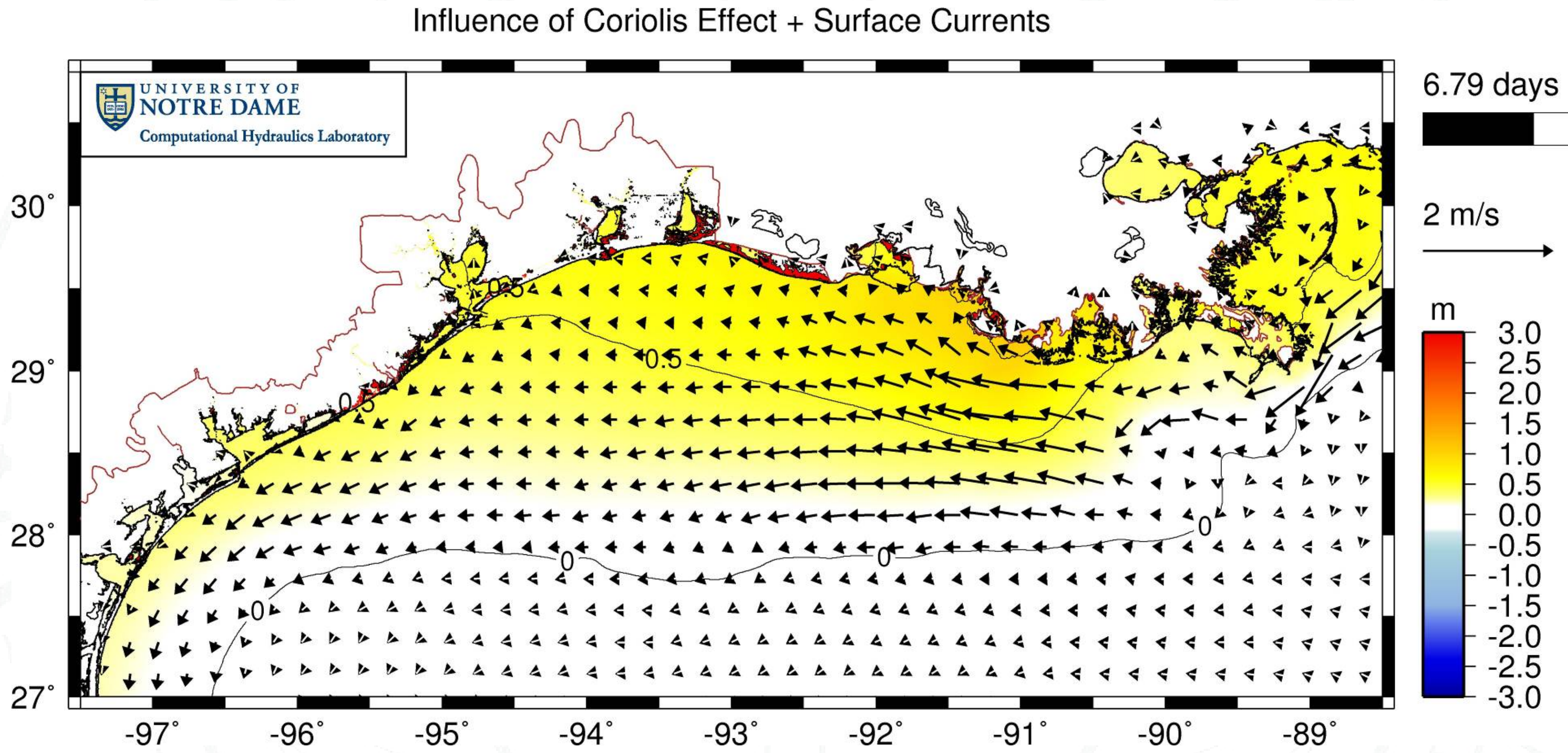


+ 12 hrs

Hurricane Ike Forerunner Surge

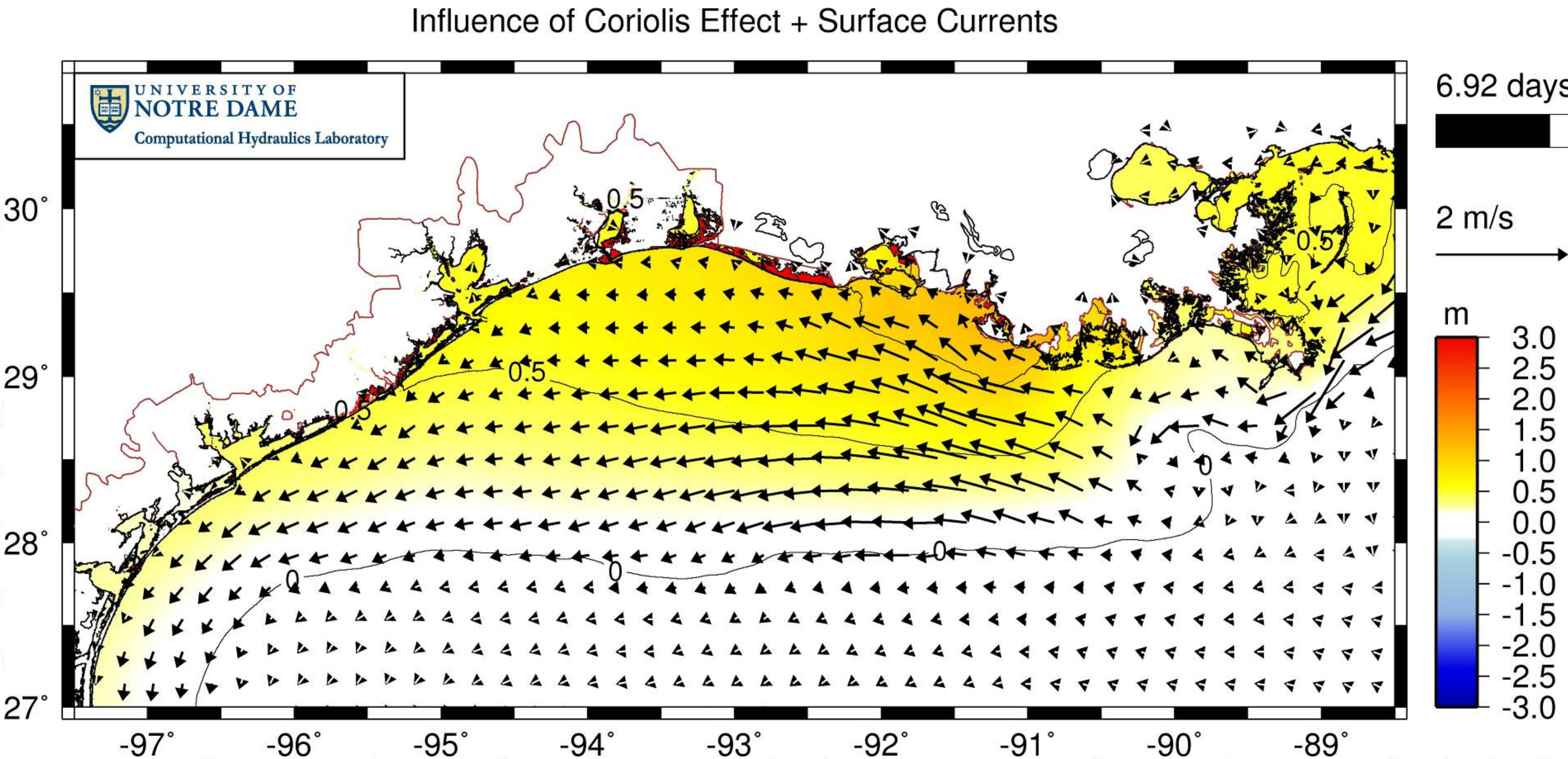
- Methods
  - SWAN+ADCIRC Wave & Circulation Model Coupling
  - TX2008-r09 SWAN+ADCIRC Model for Texas
  - Air-sea interaction
  - Validation data
- Ike Hindcast and Validation
  - Winds, Waves, Surge, Shelf velocities
- Ike Analysis
  - Origin of the forerunner – Coriolis effect
- Conclusions & Implications

Ike – difference between surface water anomaly (m) with and without Coriolis



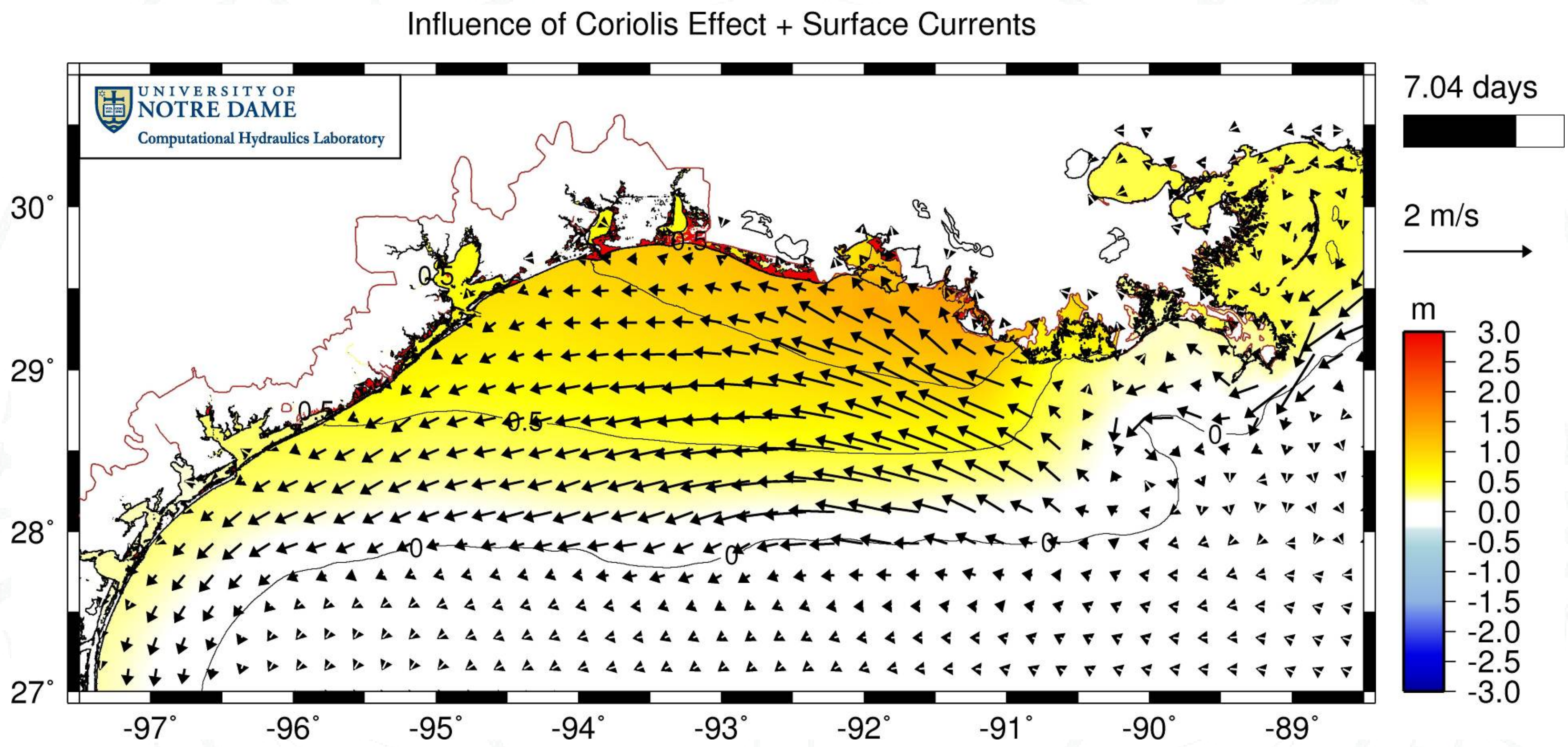
- 24 hrs

Ike – difference between surface water anomaly (m) with and without Coriolis



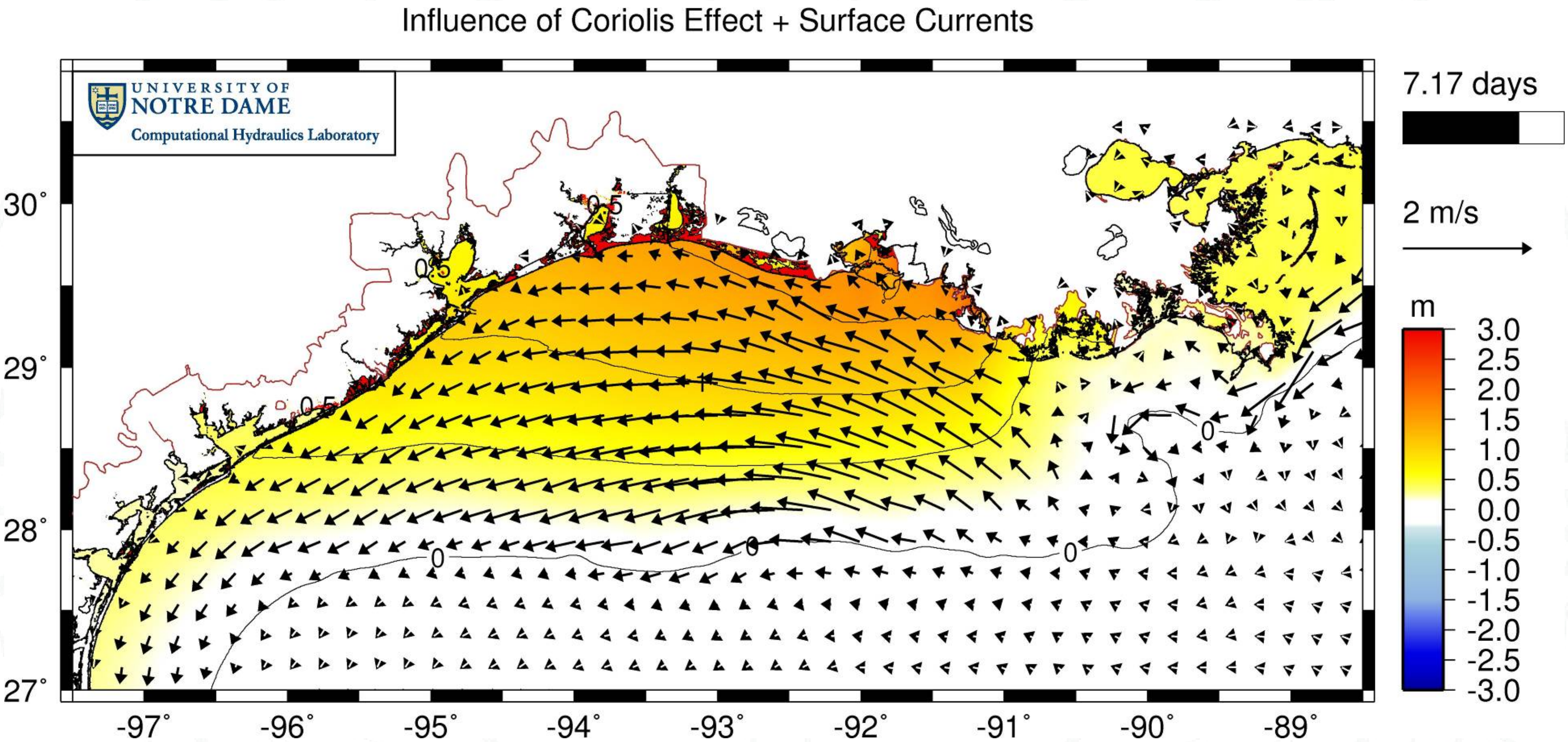
- 21 hrs

Ike – difference between surface water anomaly (m) with and without Coriolis



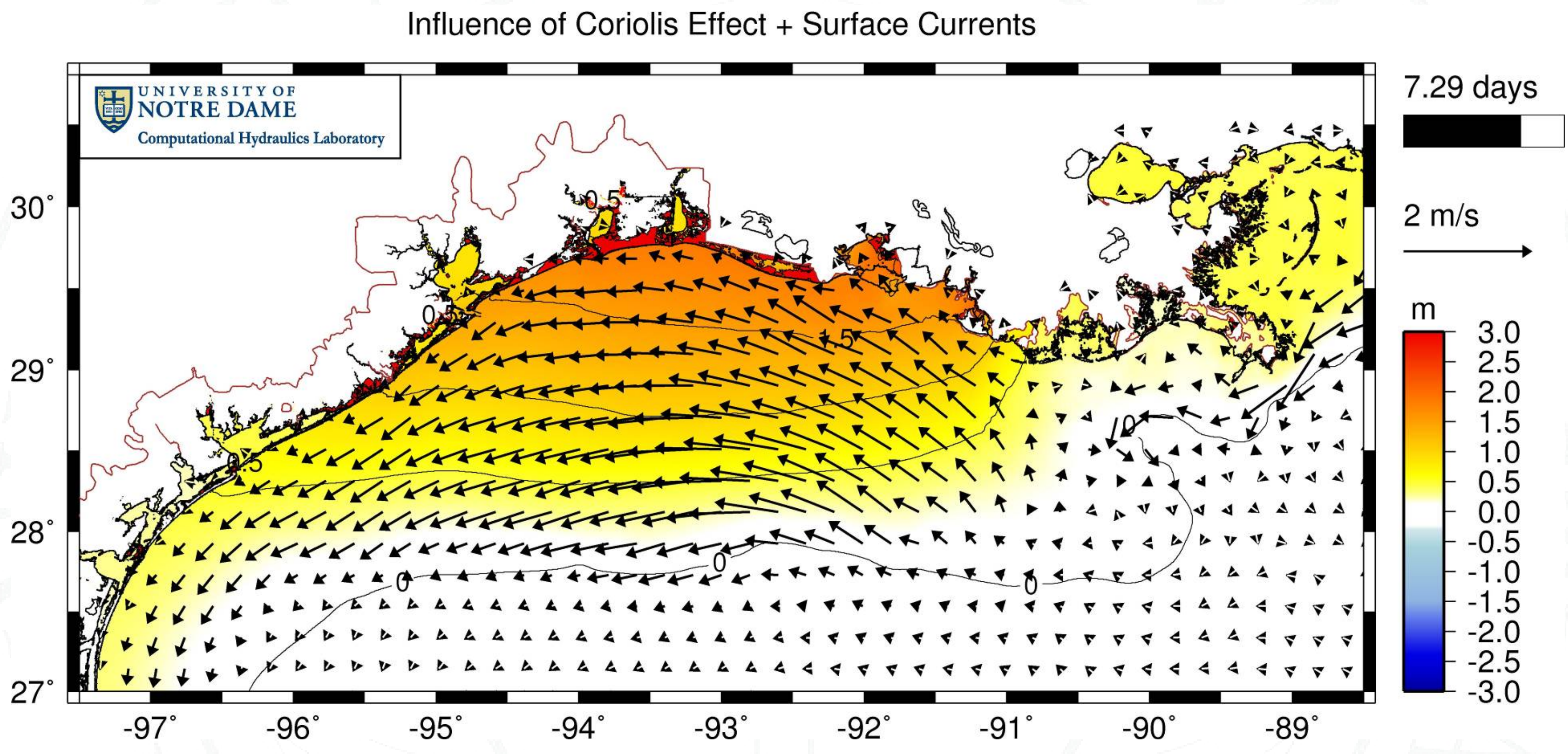
- 18 hrs

Ike – difference between surface water anomaly (m) with and without Coriolis



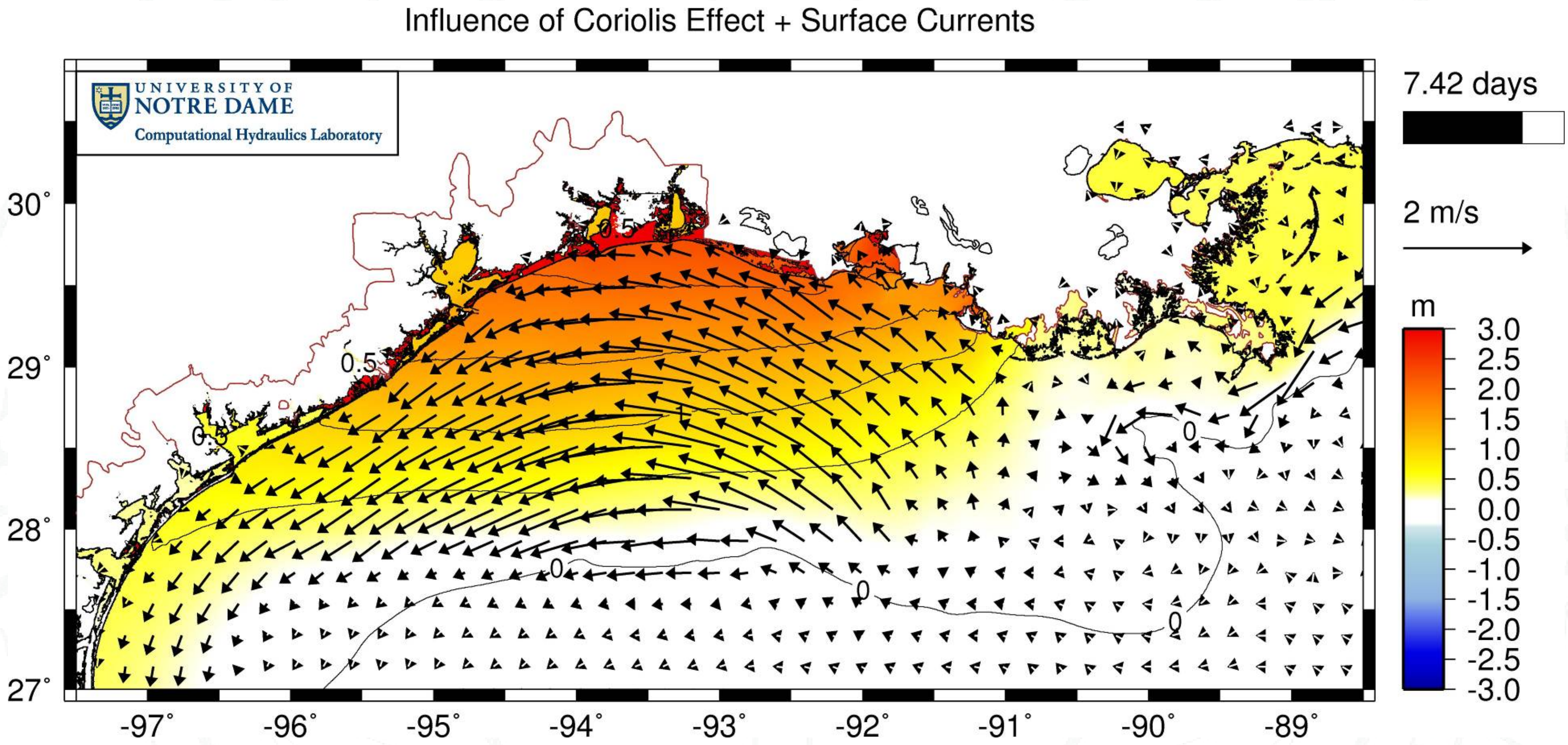
- 15 hrs

Ike – difference between surface water anomaly (m) with and without Coriolis



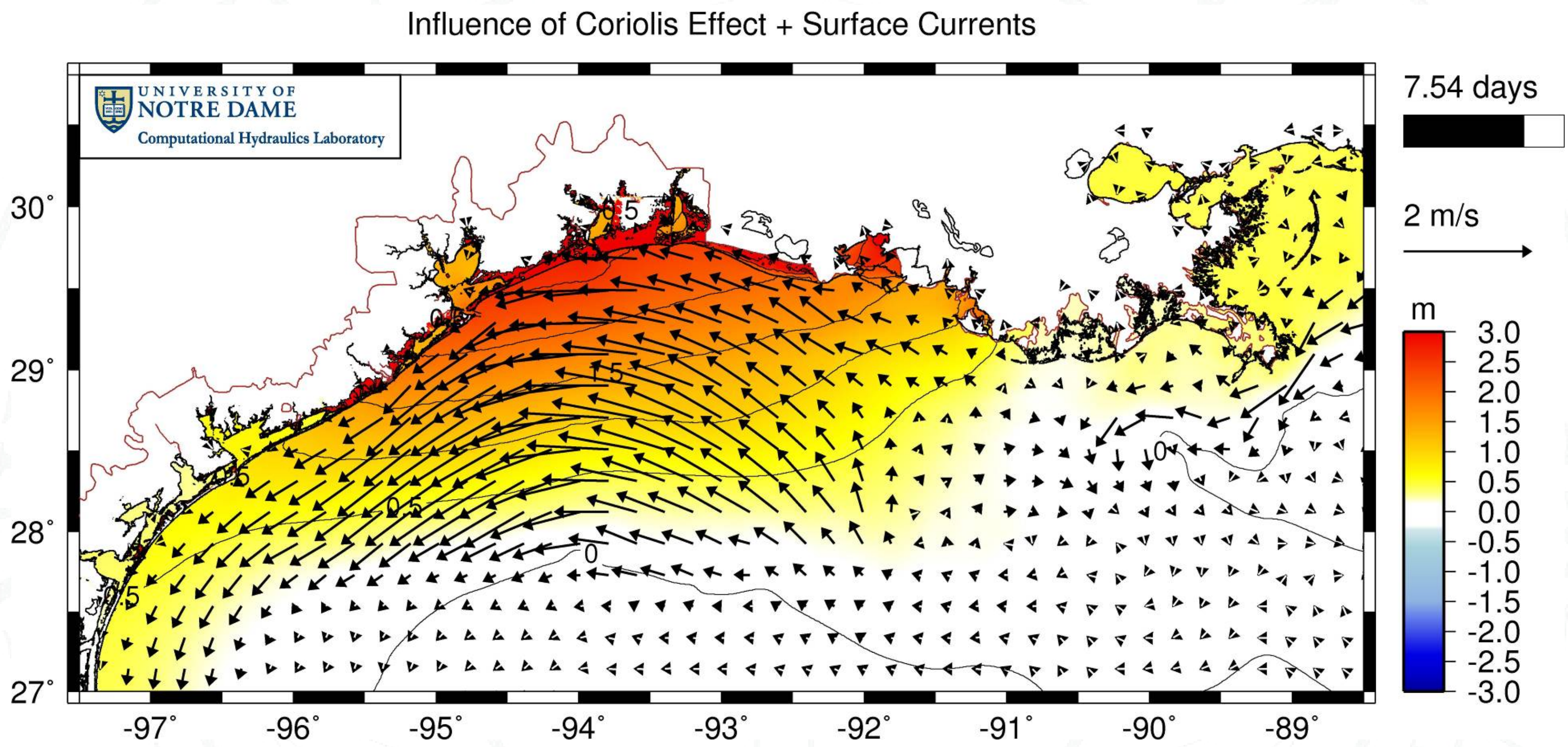
- 12 hrs

Ike – difference between surface water anomaly (m) with and without Coriolis



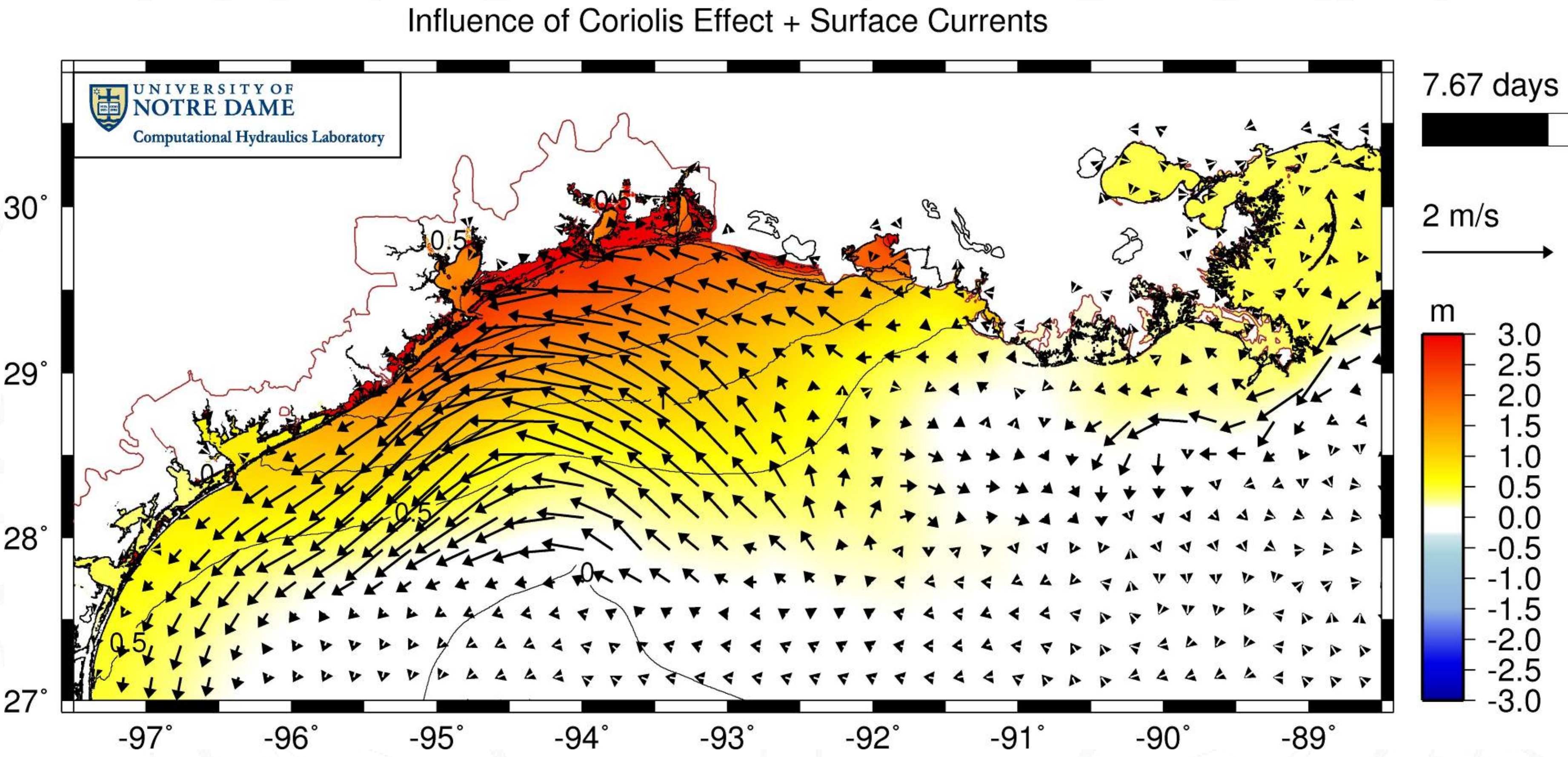
- 9 hrs

Ike – difference between surface water anomaly (m) with and without Coriolis



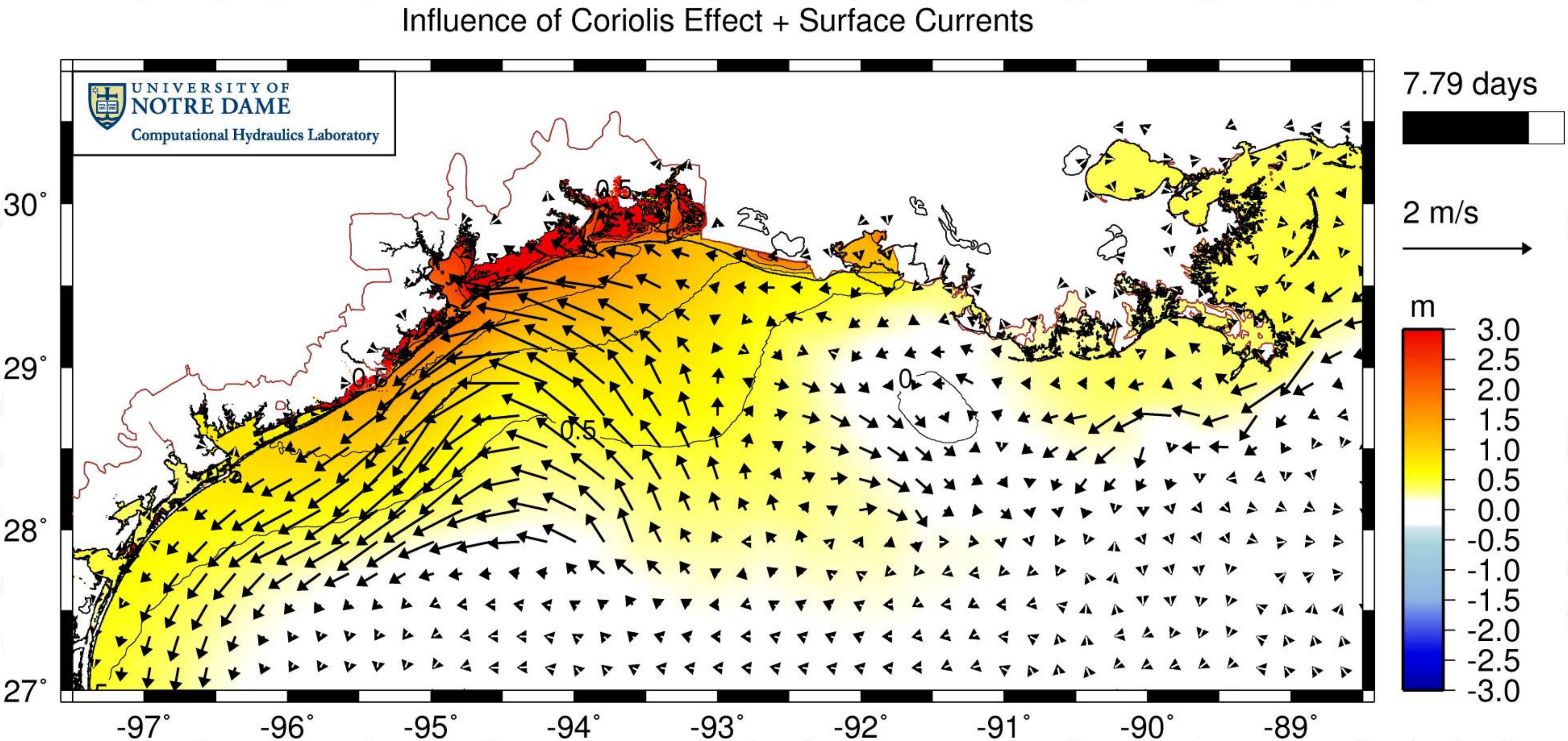
- 6 hrs

Ike – difference between surface water anomaly (m) with and without Coriolis



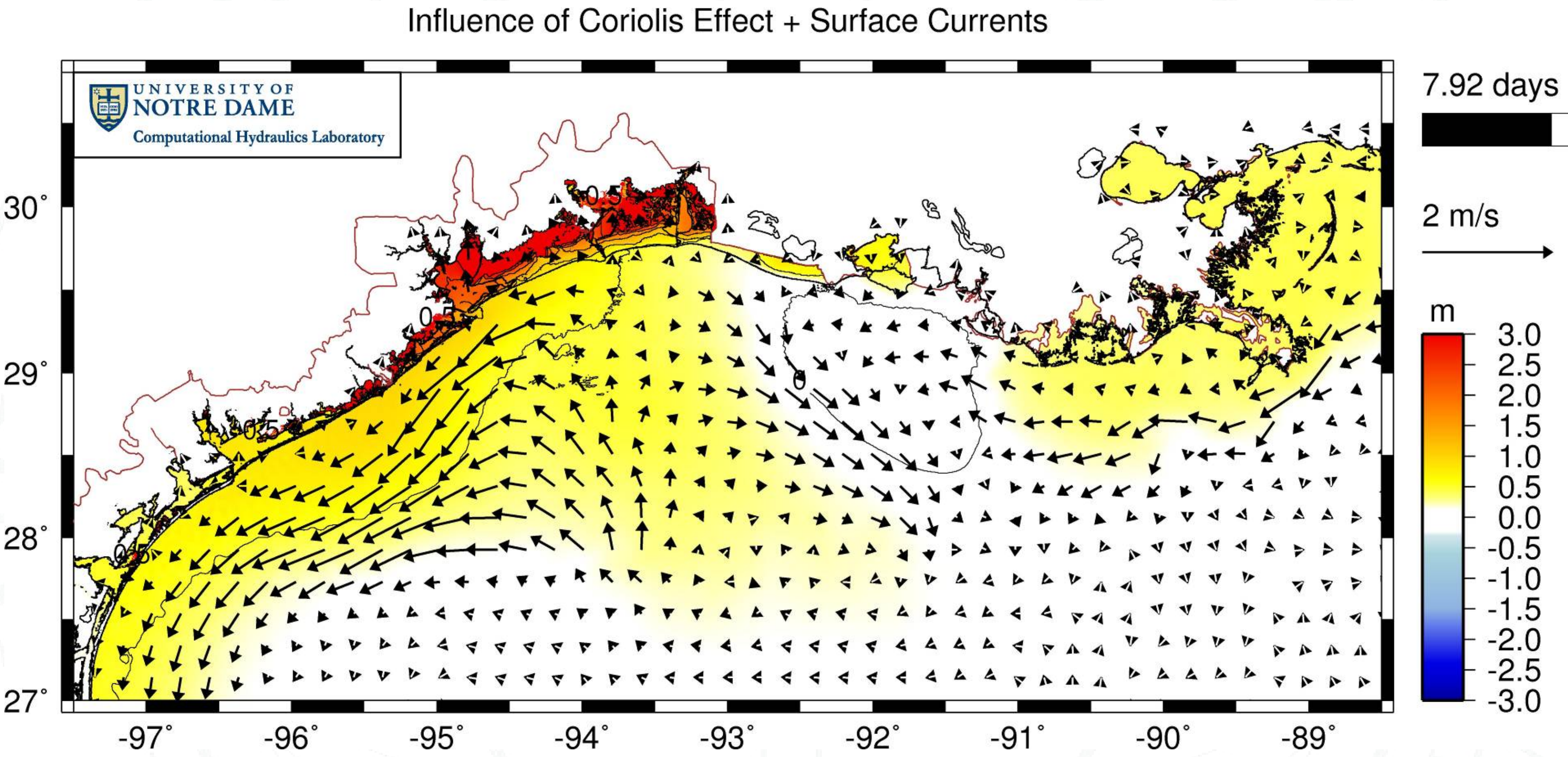
- 3 hrs

Ike – difference between surface water anomaly (m) with and without Coriolis



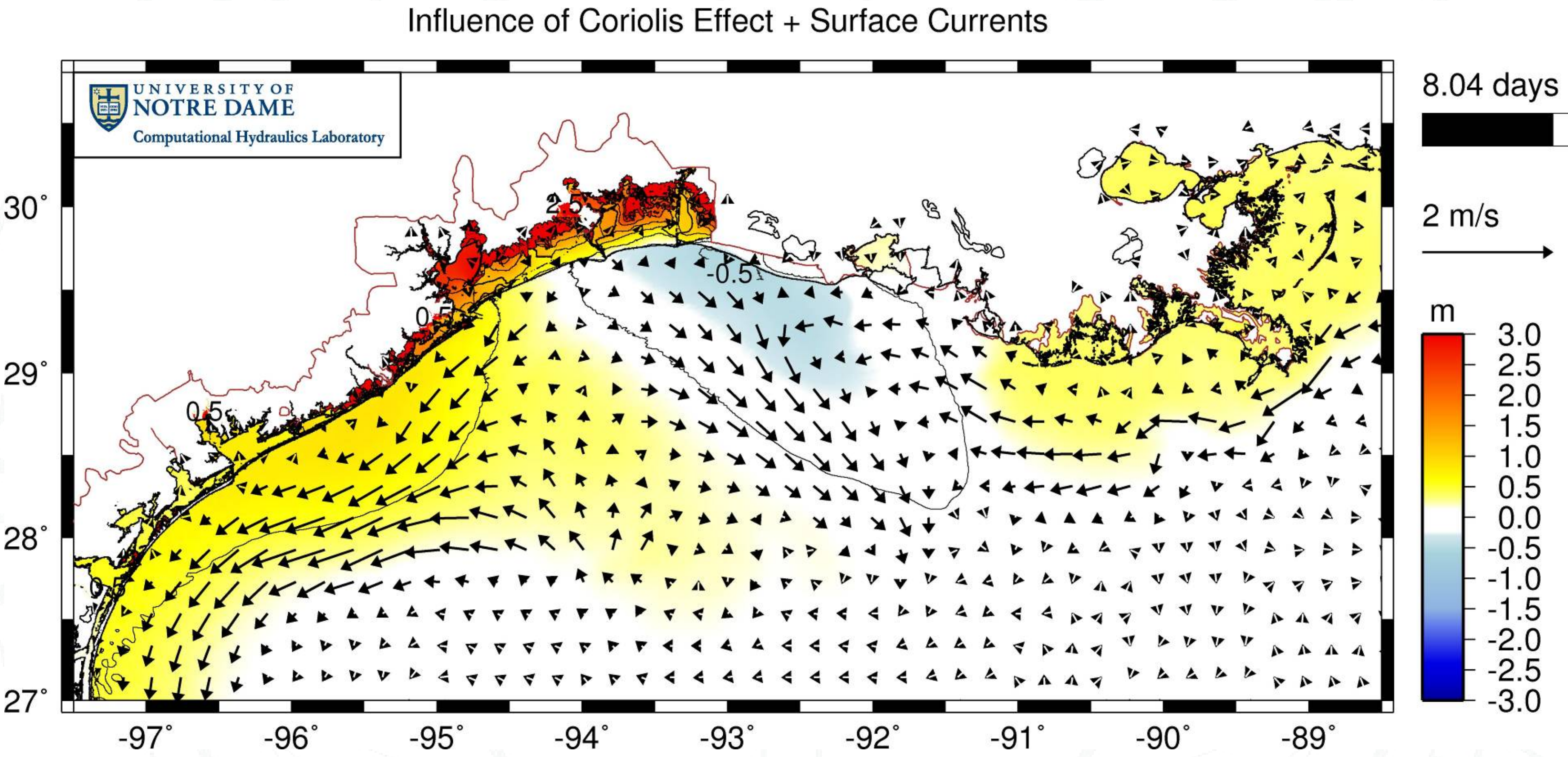
LANDFALL 0 hrs

Ike – difference between surface water anomaly (m) with and without Coriolis



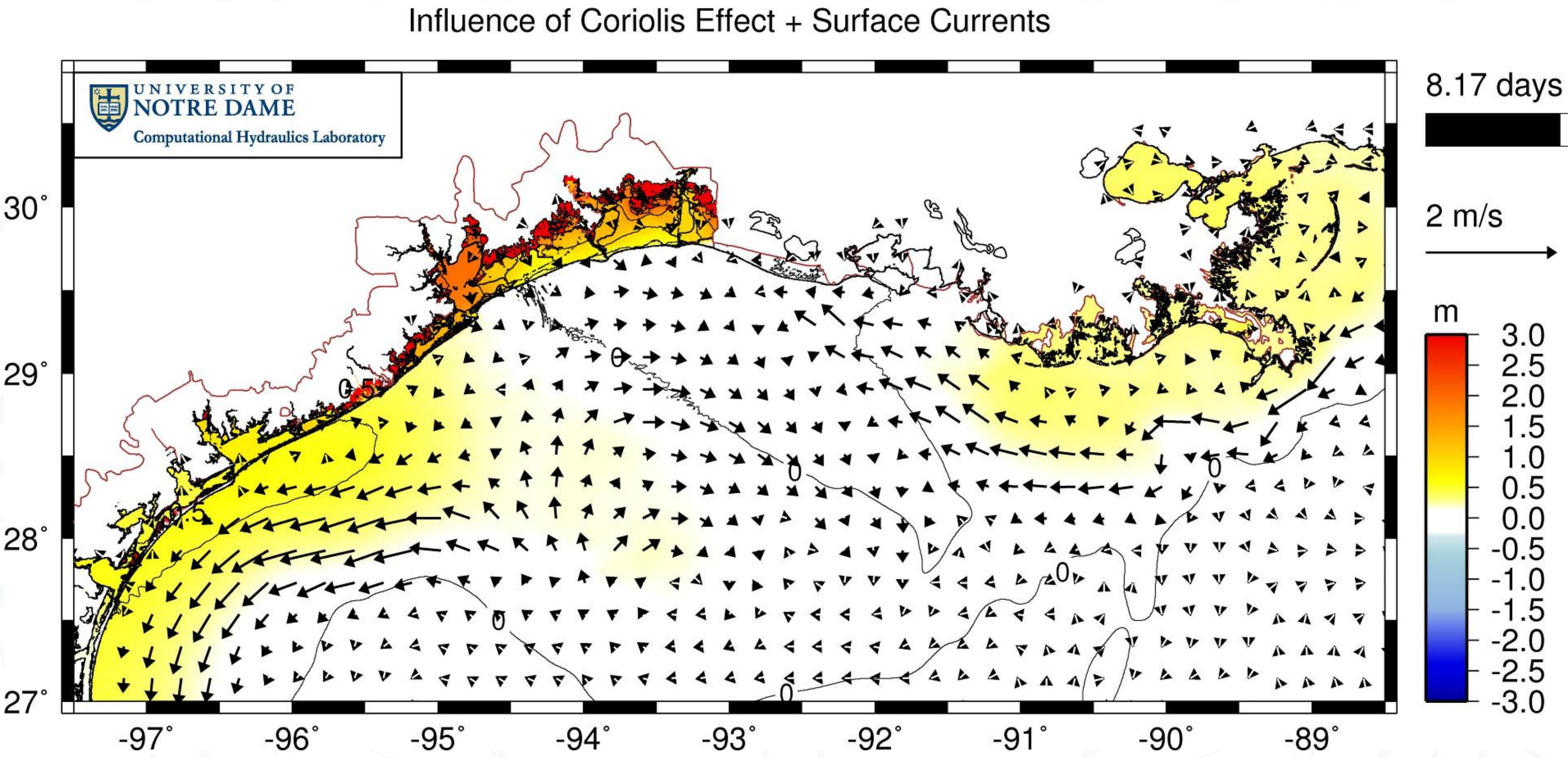
+ 3 hrs

Ike – difference between surface water anomaly (m) with and without Coriolis



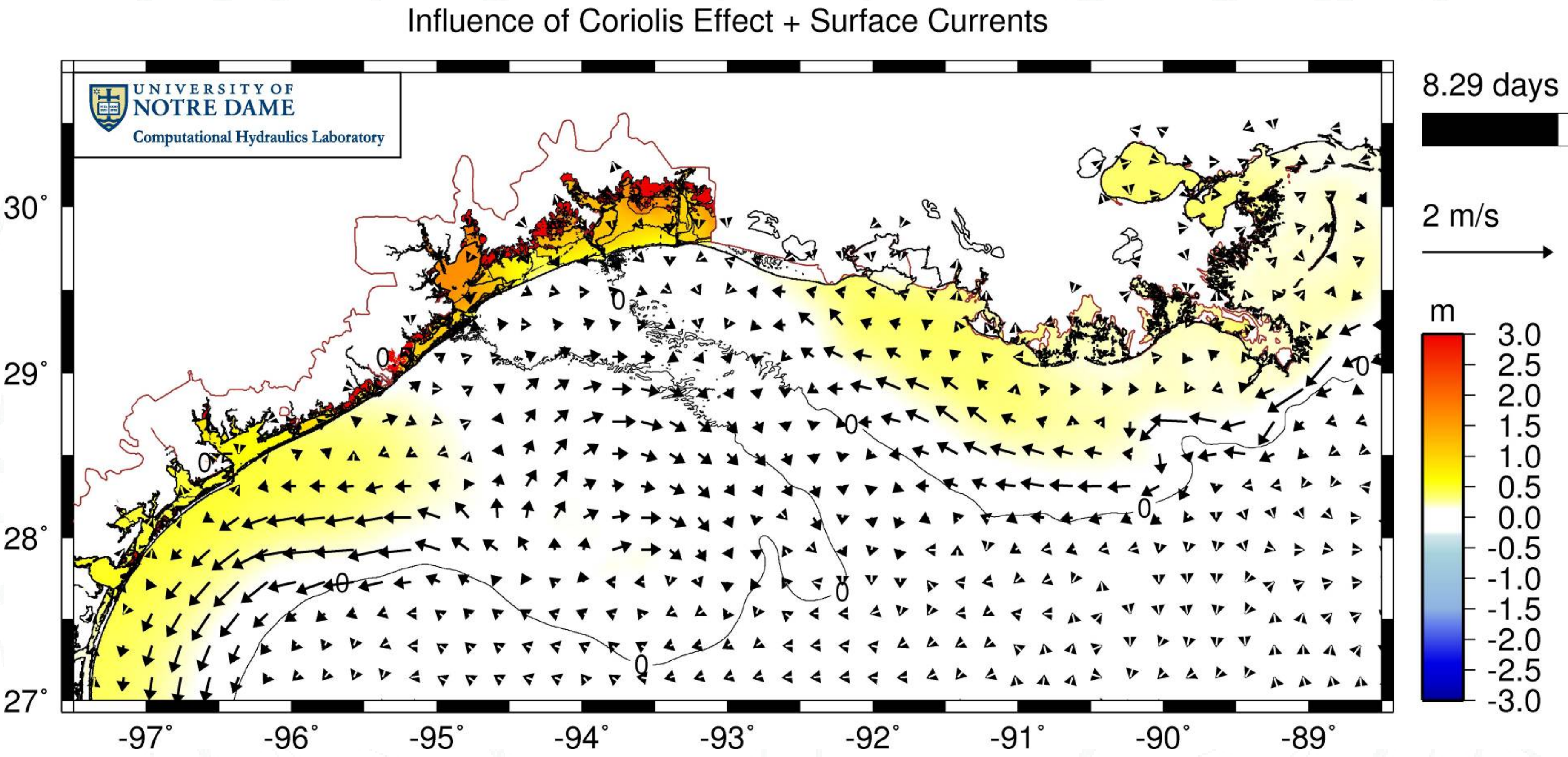
+ 6 hrs

Ike – difference between surface water anomaly (m) with and without Coriolis

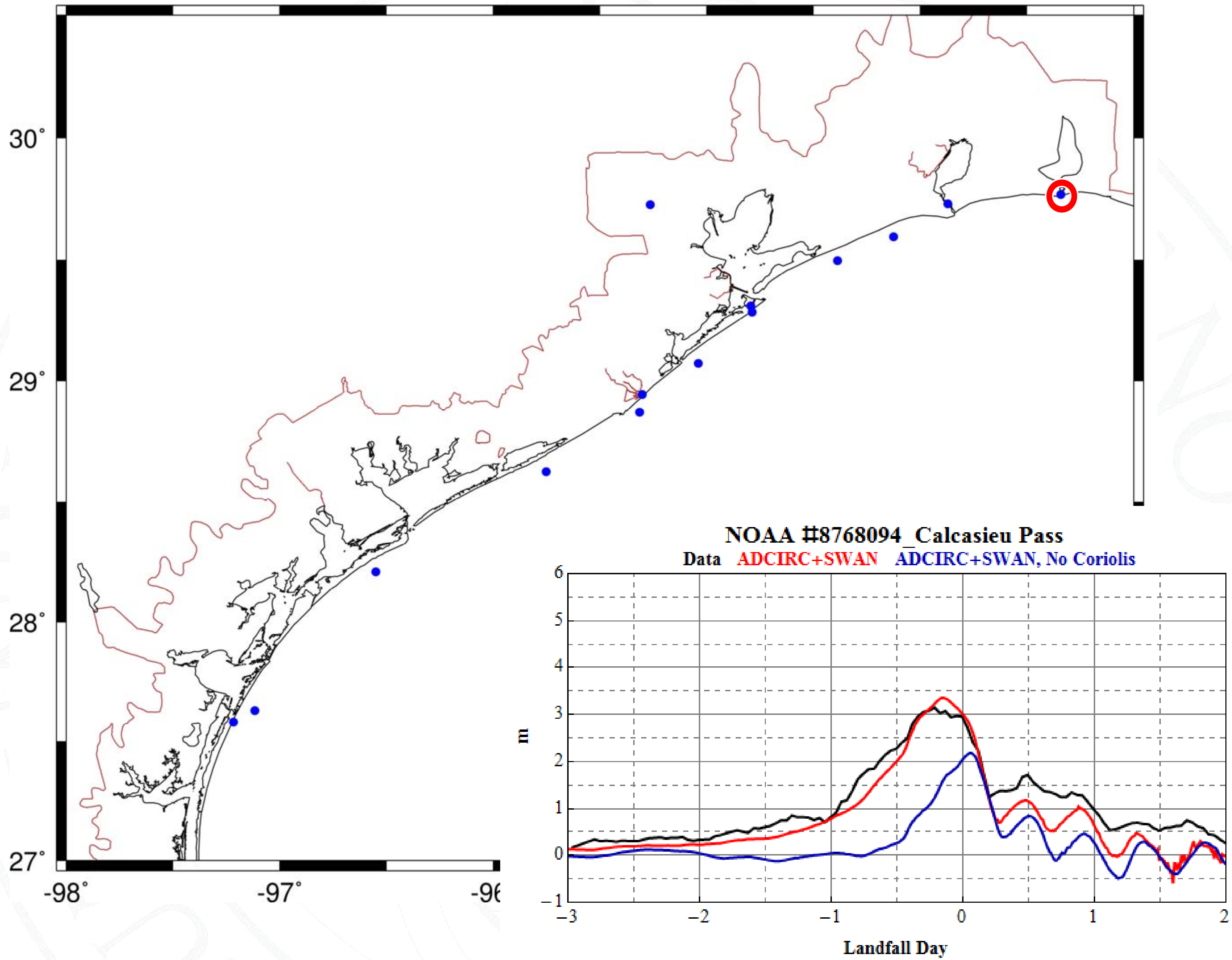


+ 9 hrs

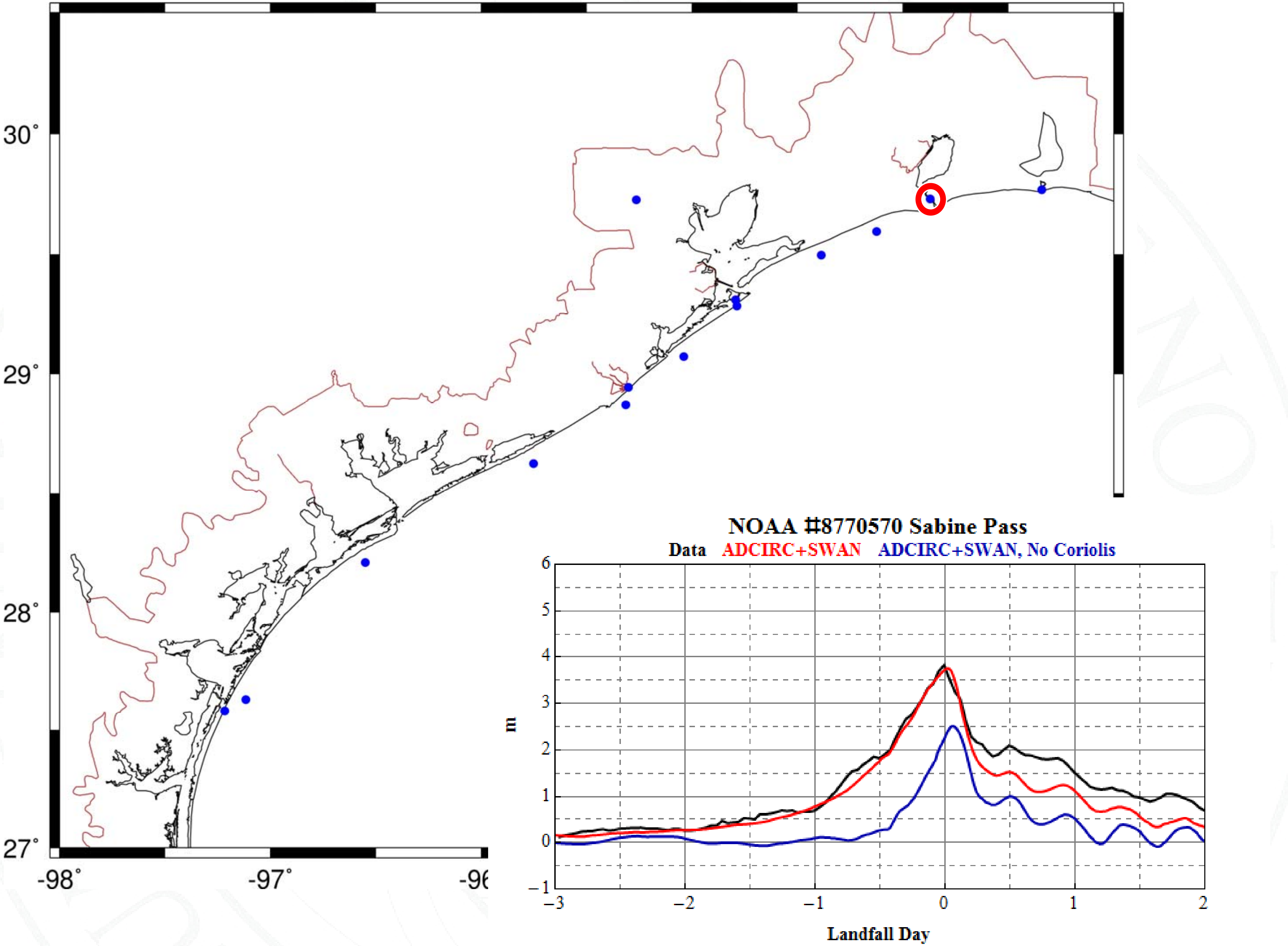
Ike – difference between surface water anomaly (m) with and without Coriolis



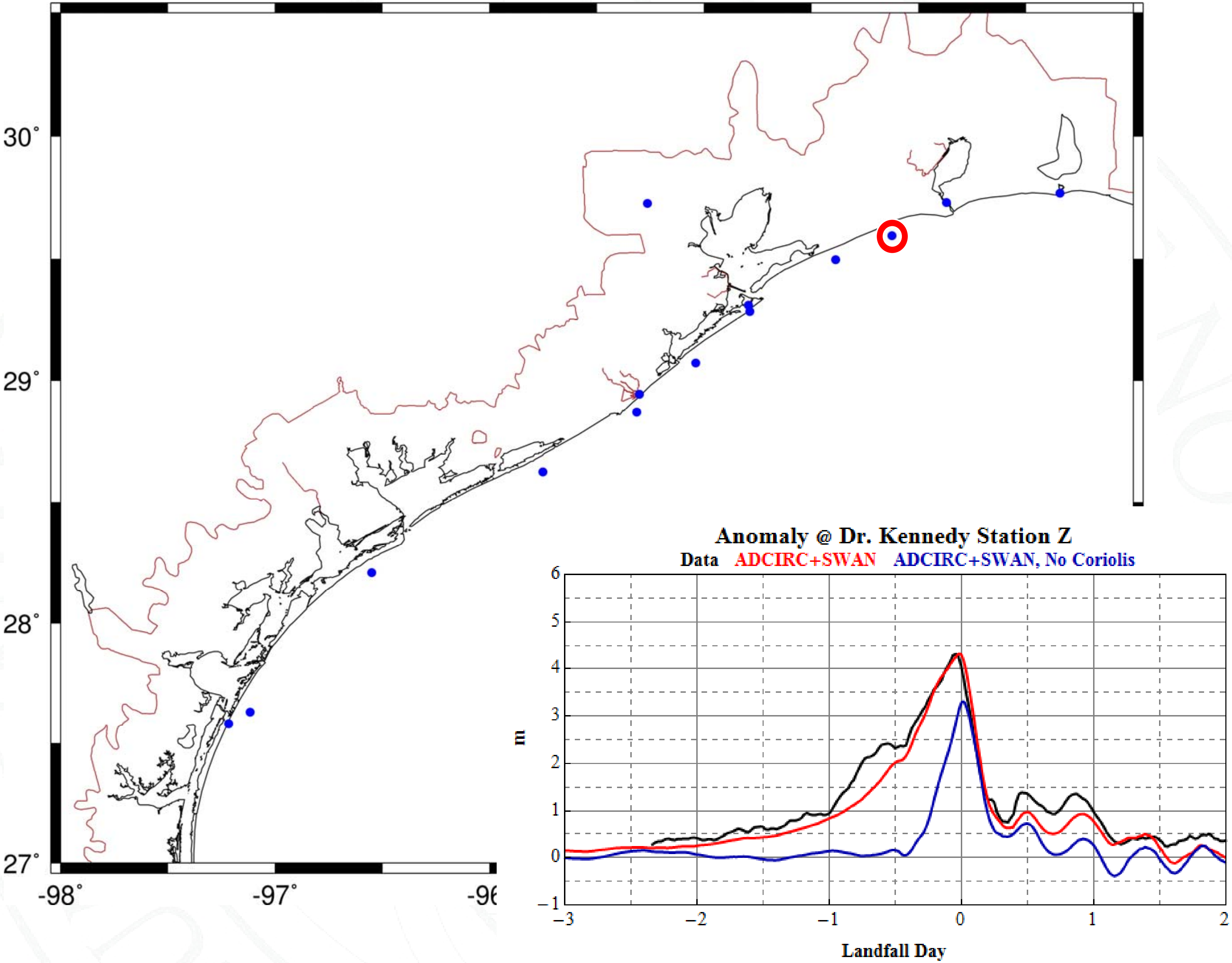
+ 12 hrs



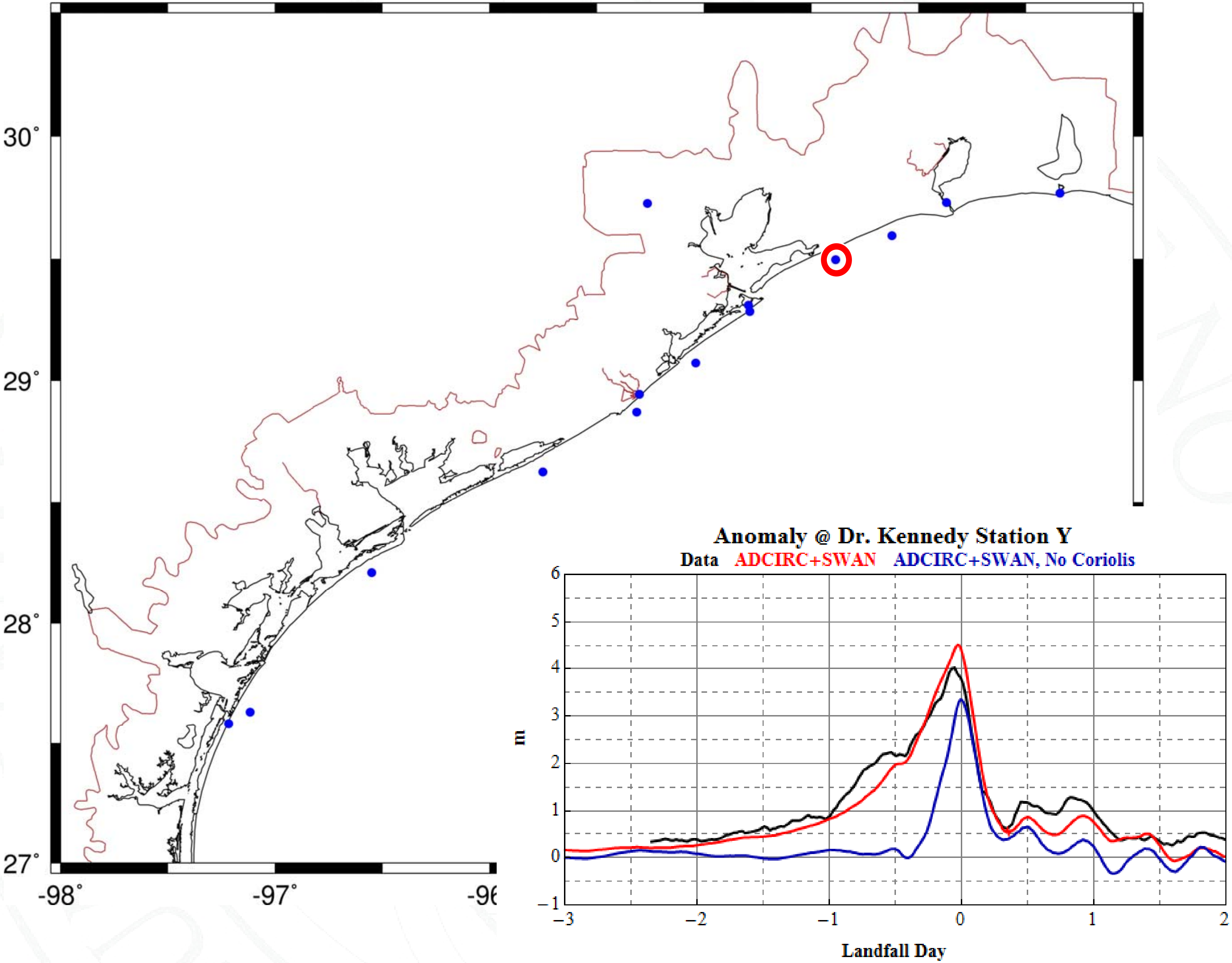
30°
29°
28°
27°
-98°
-97°
NOAA #8768094_Calcasieu Pass
Data
ADCIRC+SWAN
ADCIRC+SWAN, No Coriolis
m
Landfall Day

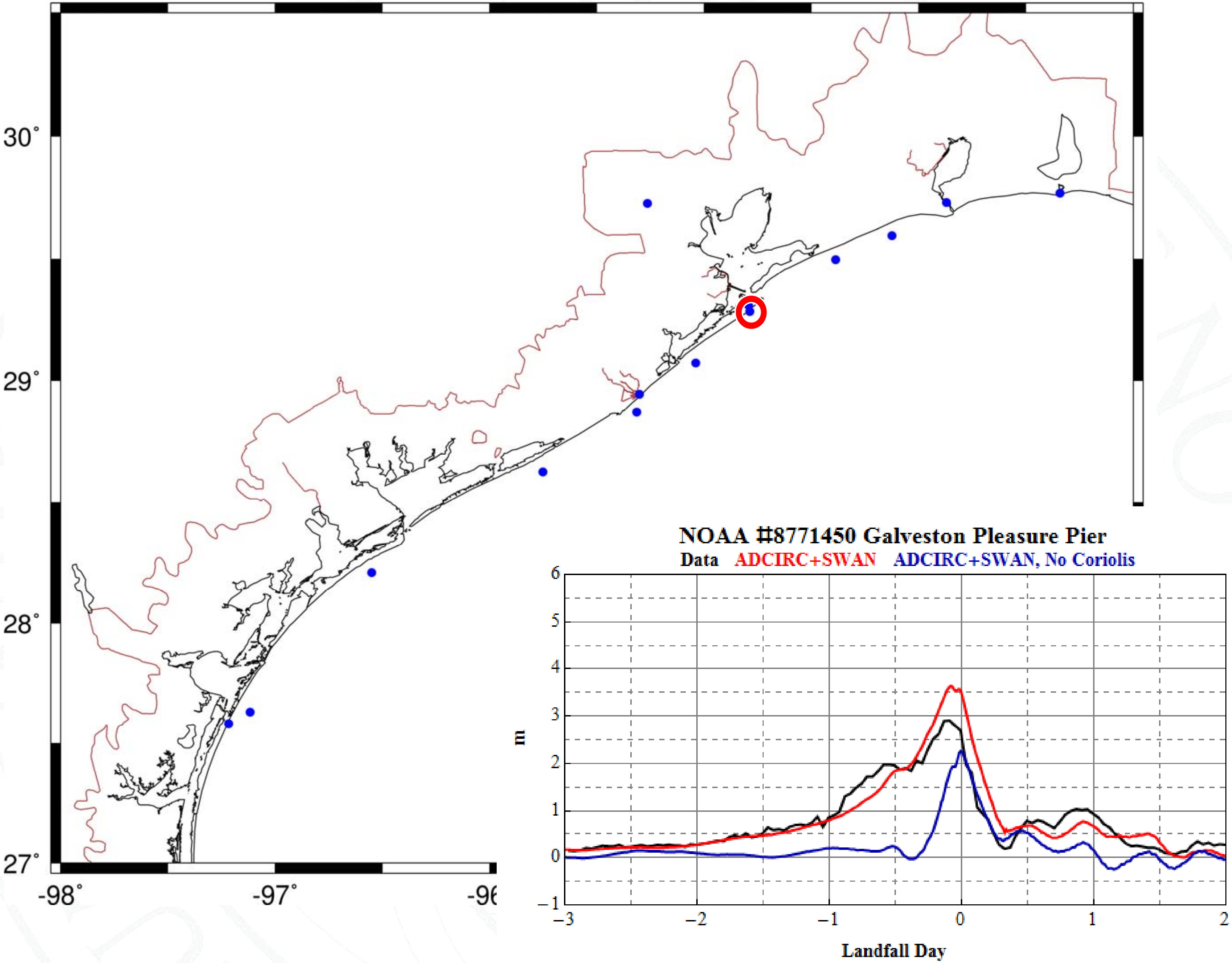


30°
29°
28°
27°
-98°
-97°
-96
NOAA #8770570 Sabine Pass
Data
ADCIRC+SWAN
ADCIRC+SWAN, No Coriolis
m
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2



30°
29°
28°
27°
-98°
-97°
-96
Anomaly @ Dr. Kennedy Station Z
Data
ADCIRC+SWAN
ADCIRC+SWAN, No Coriolis
m
Landfall Day


30°
29°
28°
27°
-98°
-97°
Anomaly @ Dr. Kennedy Station Y
Data ADCIRC+SWAN ADCIRC+SWAN, No Coriolis
m
Landfall Day
6
5
4
3
2
1
0
−1
−3
−2
−1
0
1
2


30°
29°
28°
27°
-98°
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NOAA #8771450 Galveston Pleasure Pier
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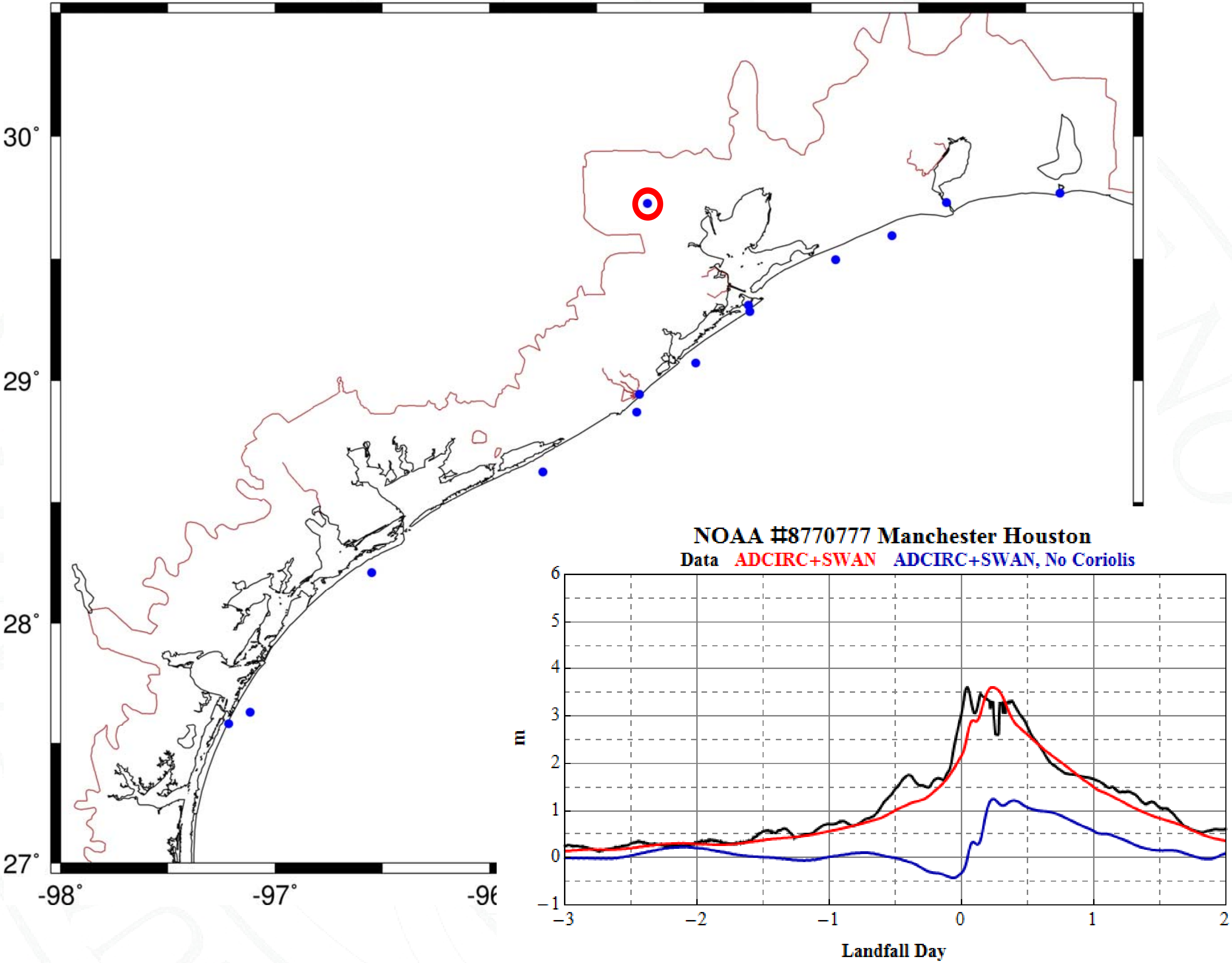
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NOAA #8770777 Manchester Houston
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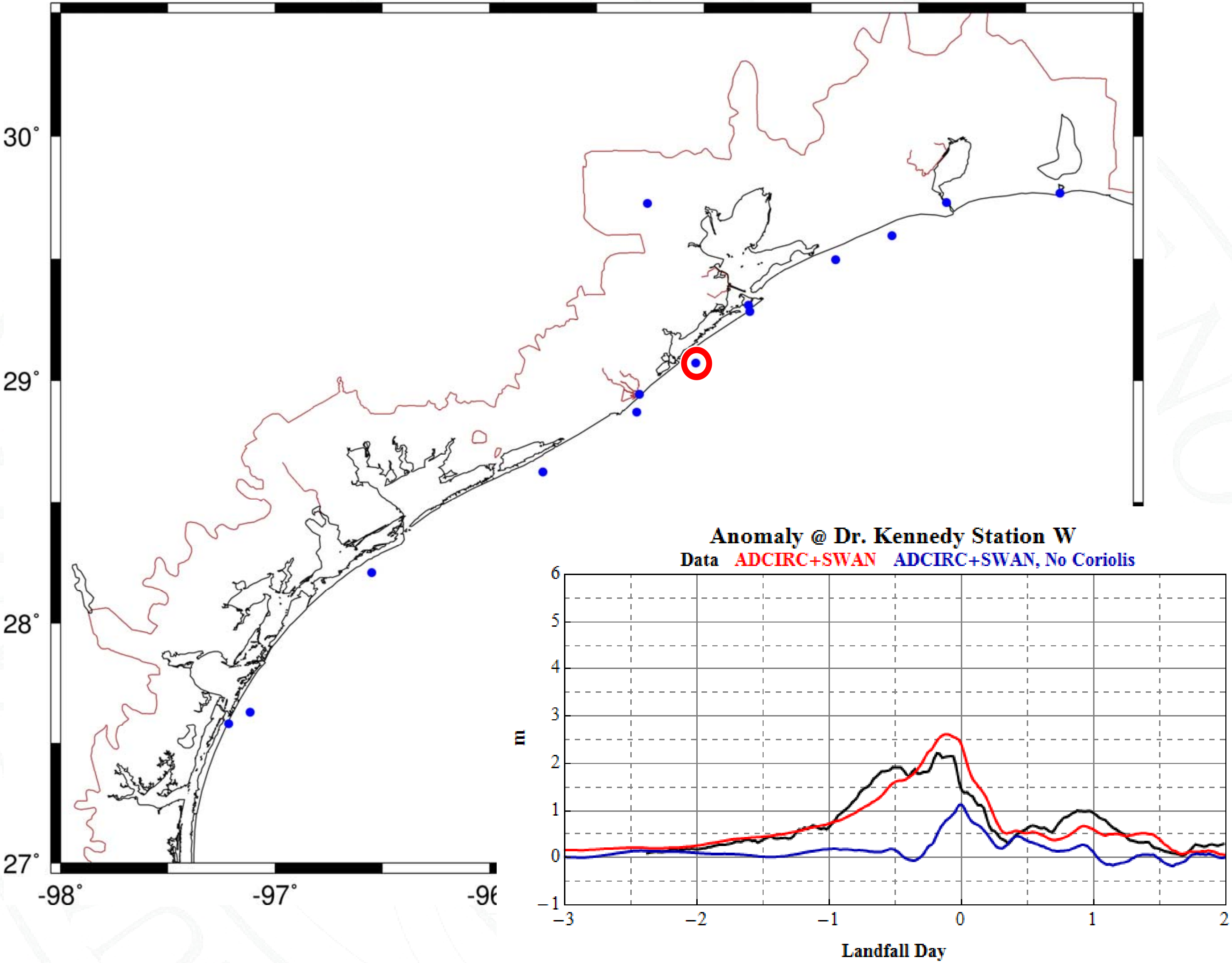
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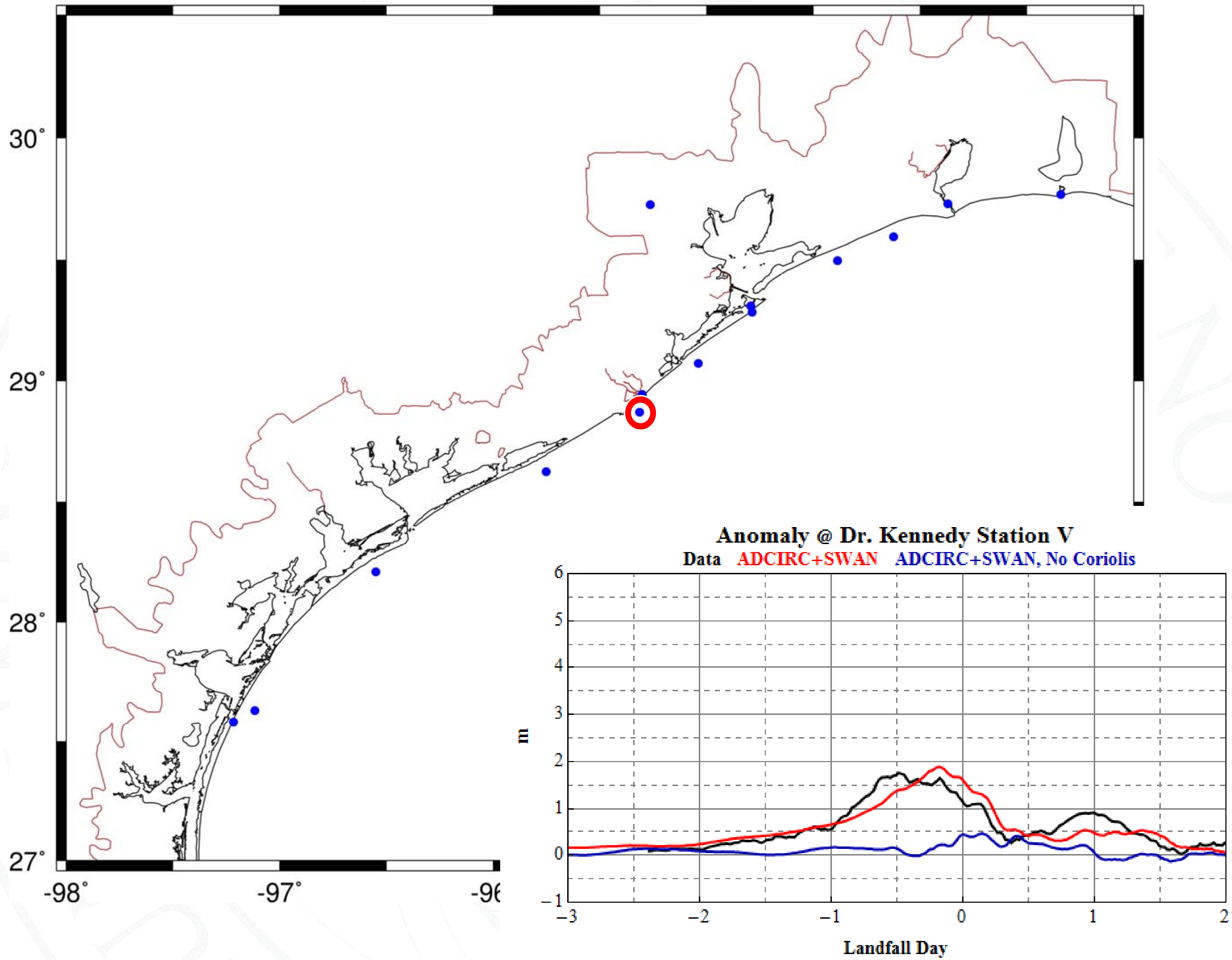

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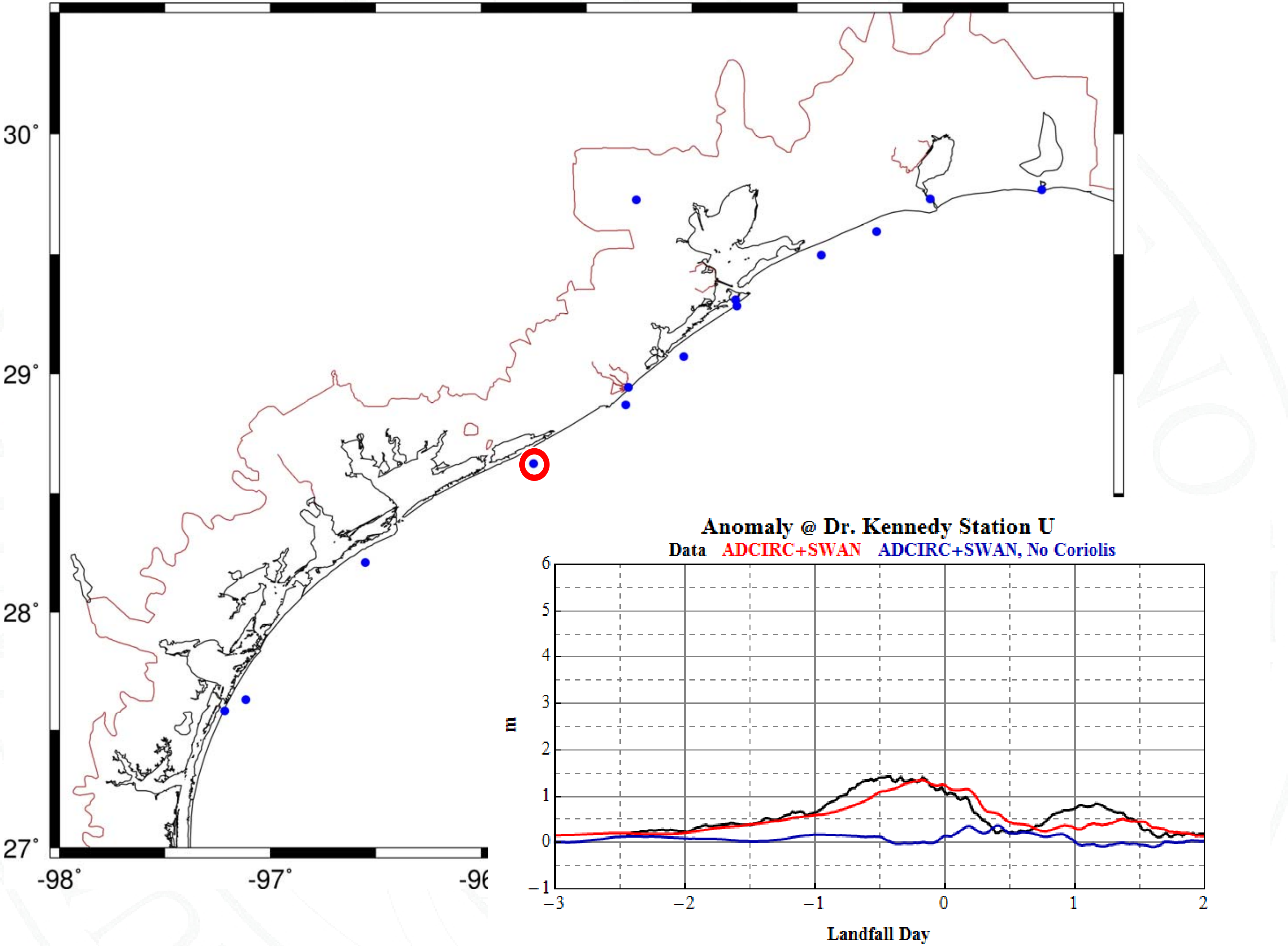

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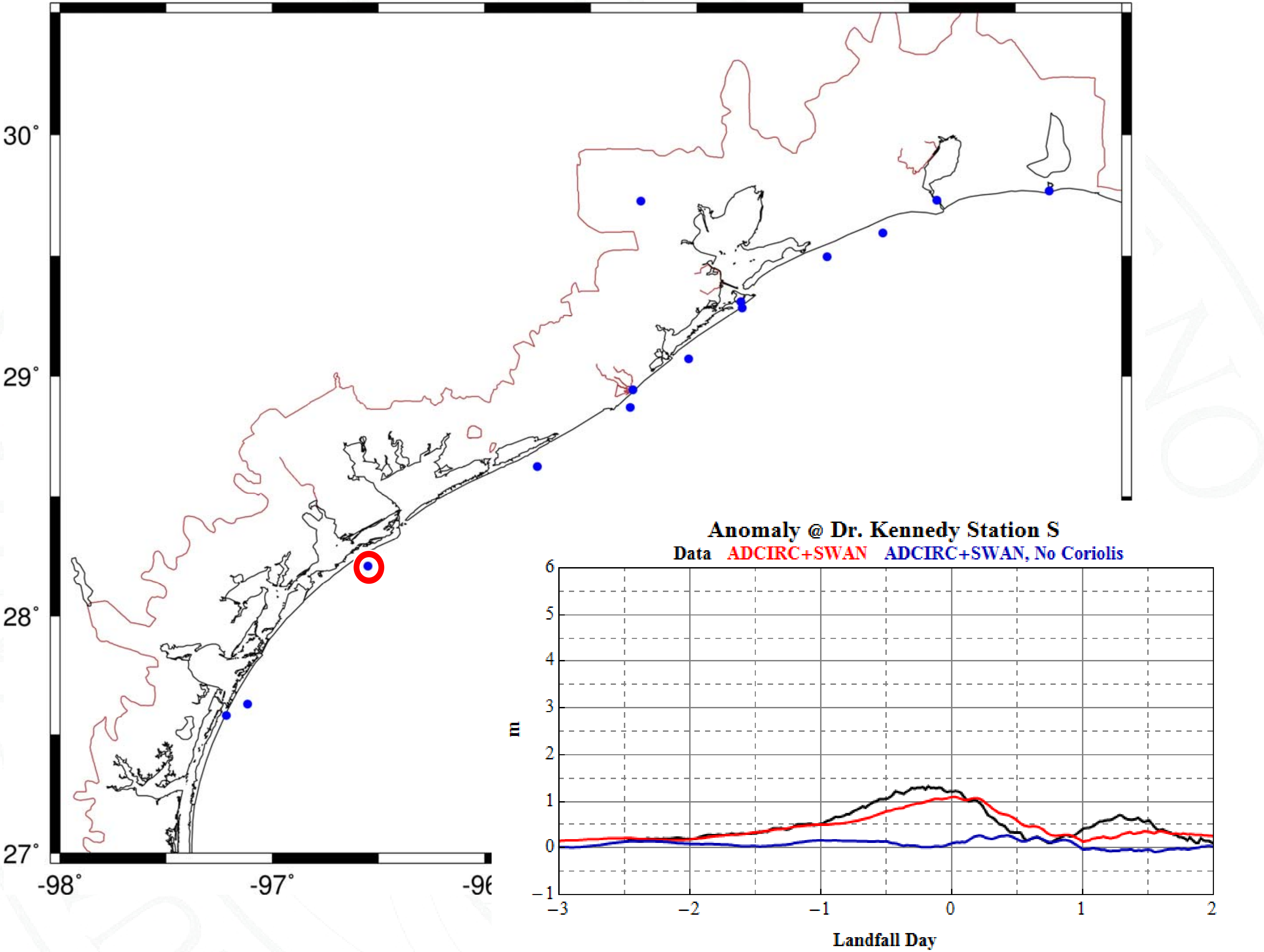

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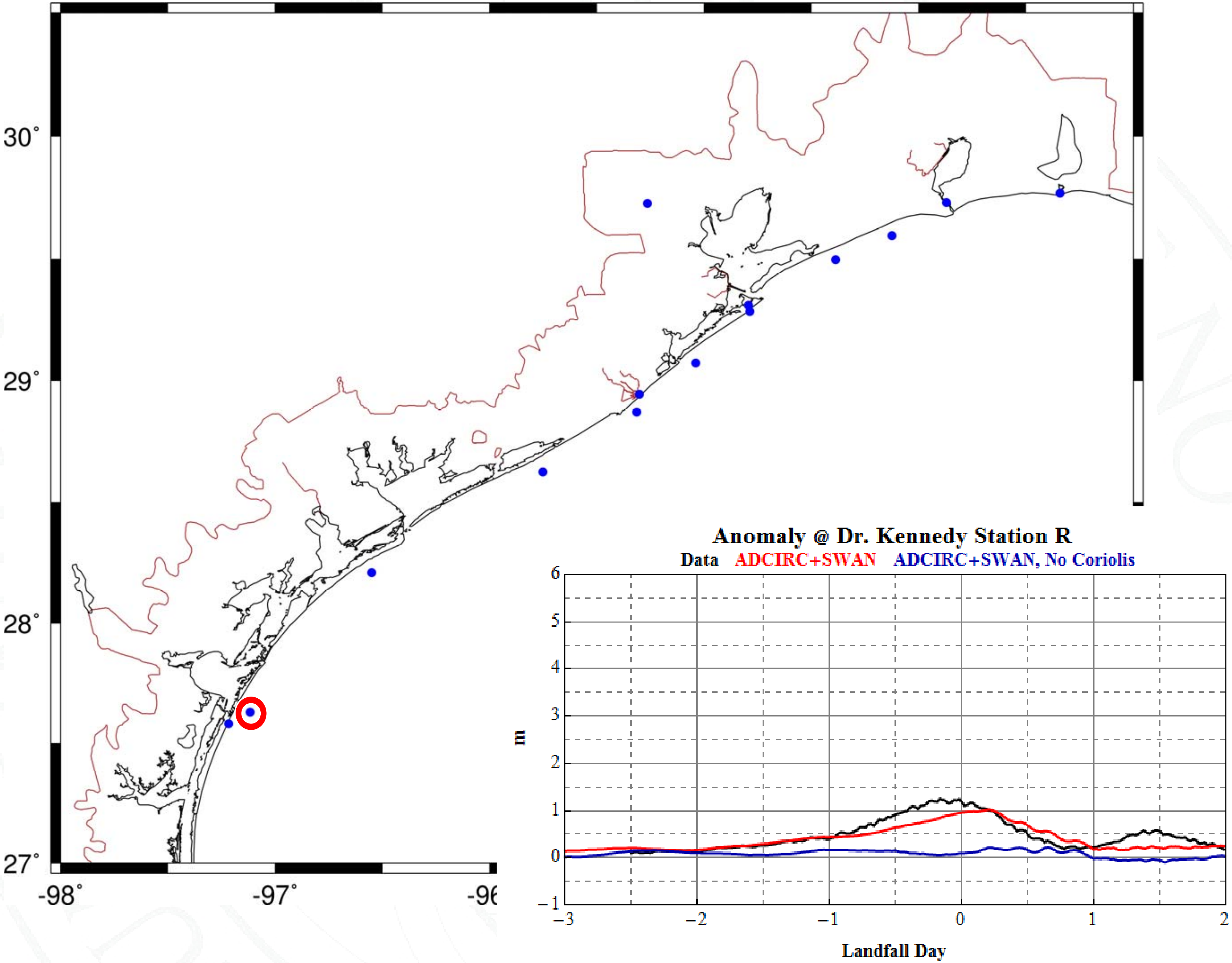

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Anomaly @ Dr. Kennedy Station R
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Hurricane Ike Forerunner Surge

- Methods
  - SWAN+ADCIRC Wave & Circulation Model Coupling
  - TX2008-r09 SWAN+ADCIRC Model for Texas
  - Air-sea interaction
  - Validation data
- Ike Hindcast and Validation
  - Winds, Waves, Surge, Shelf velocities
- Ike Analysis
  - Origin of the forerunner – Coriolis effect
- Conclusions & Implications

Conclusions

- Coupled wave + current simulations faithfully forecast deep water, coastal and inland waves and surge
  - Integrated wave + current models
  - Large domains
  - Appropriate levels of local grid resolution
  - Excellent winds
  - Wave and surge data to validate

Conclusions

- Large scale and early Forerunner is generated through fast shore parallel currents and Coriolis driven tilt
  - Is possible due to the wide LATEX shelf, smooth bottom and large size of storms
  - Is a slow process allowing plenty of time to penetrate far inland
  - Can propagate as a free shelf wave from the LA coast past Corpus Christi

Acknowledgments

- National Science Foundation
- Office of Naval Research
- U.S. Army Engineer Research and Development Center
- U.S. Army Corps of Engineers MVN
- FEMA
- Department of Homeland Security
- Naval Research Laboratory
- Army Research Office
- NOAA

For more information coast.nd.edu

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