NC STATE UNIVERSITY

Sensitivity of Storm Surge Predictions to Meteorological Forcing for Hurricane Isaac (2012)

JC Dietrich[1], A Muhammad[2], M Curcic[3], A Fathi[2], CN Dawson[2], S Chen[3], RA Luettich Jr[4]

[1]Dep't of Civil, Construction, and Environmental Engineering, NC State University
[2]Inst. for Computational Engineering and Sciences, University of Texas at Austin
[3]Rosenstiel School of Marine and Atmospheric Science, University of Miami
[4]Inst. of Marine Sciences, University of North Carolina at Chapel Hill

CARTHE-II All-Hands Meeting
Coral Gables FL, 19-21 October 2015

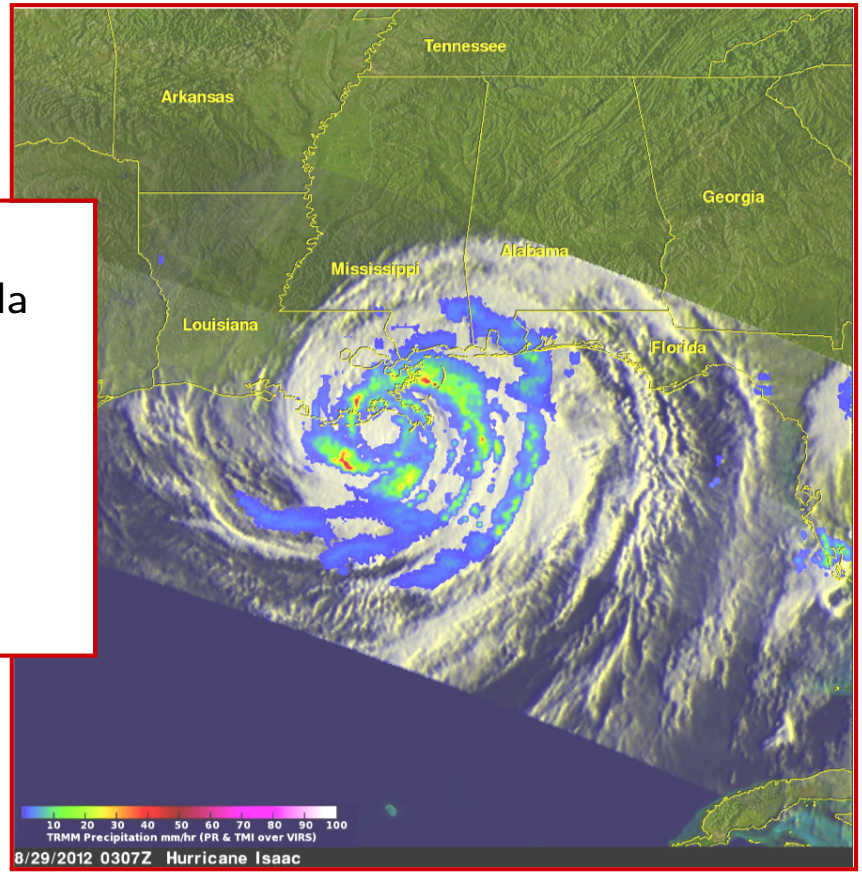
CARTHE CONSORTIUM for ADVANCED RESEARCH on TRANSPORT of HYDROCARBON in the ENVIRONMENT

Hurricane Isaac (2012)

Challenges of Forecasting

Uncertainties in storm track:
- Early NHC advisories had landfall in Florida
- Forecast shifted westward on 26 August
- Less than 48 hr warning to Louisiana

Uncertainties in forward speed:
- Extremely slow-moving at landfall
- 20 in of rain in New Orleans

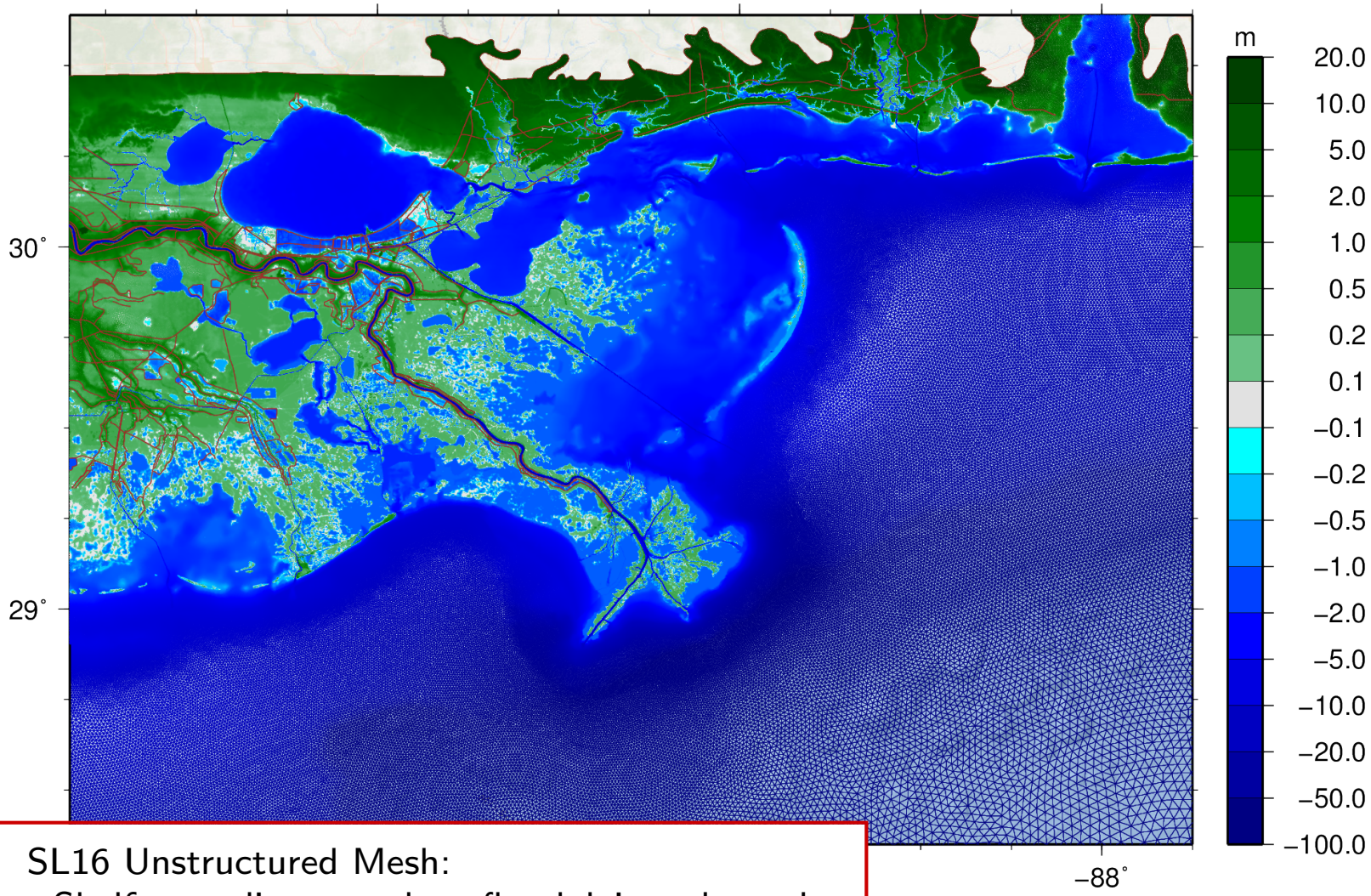


Surge pushed into marshes:
- 3.4 m near Shell Beach LA
- 2.5 m in Mississippi

Tested protection system near New Orleans:
- No flooding in city proper
- Overtopped levees around nearby communities

Hurricane Isaac (2012)

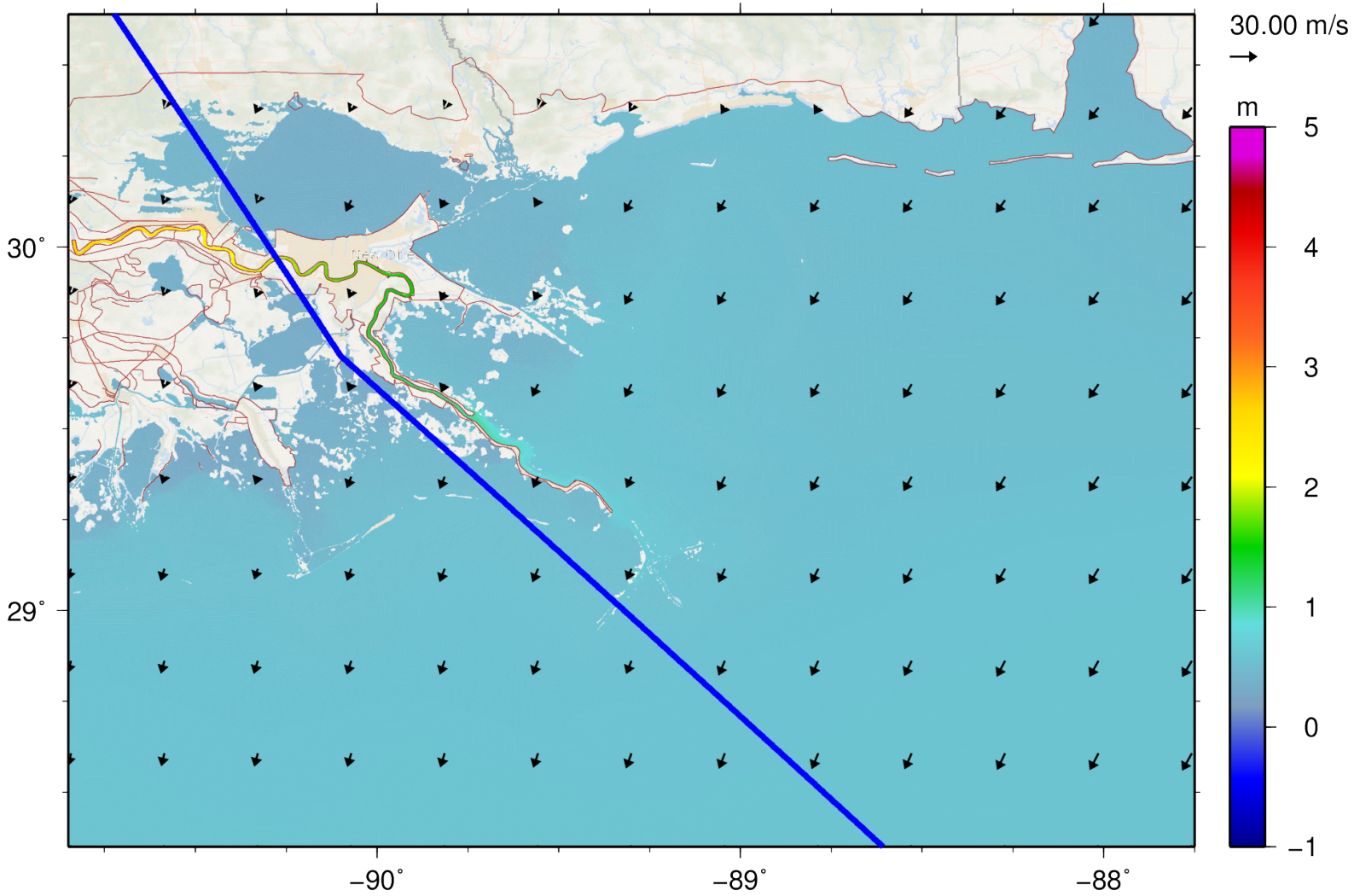
Representation of SE Louisiana



SL16 Unstructured Mesh:
- Shelf, coastline, marshes, floodplains, channels
- Resolution varies downward to 10m

Hurricane Isaac (2012)

Predictions of Coastal Flooding



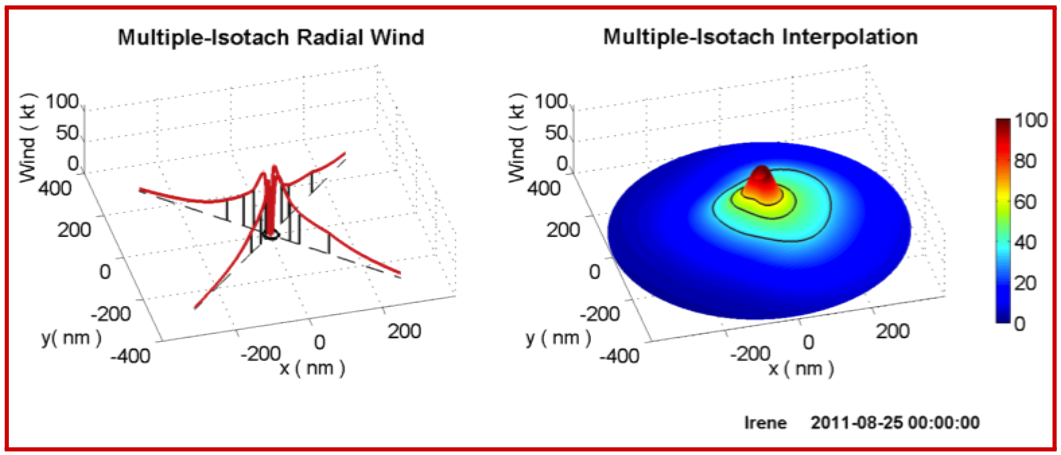
ADCIRC Surge Guidance System (`http://coastalemergency.org/`):
- Automated forecast guidance for waves, storm surge and flooding
- Example during Isaac advisory 25, issued 39 hr before landfall

Forecasting of Winds and Surge

Generalized Asymmetric Holland (GAH)

For tropical cyclones, this system represents the pressure and wind fields with a parametric vortex model:

- Originally based on Holland (1980)
- Updated to account for storm asymmetry (Mattocks *et al.* 2006, Mattocks and Forbes 2008)
- Updated recently as **Generalized Asymmetric Holland (GAH)** model (Gao *et al.* 2015)
  - Eliminates assumption of cyclostrophic balance
  - Uses all storm isotachs to construct wind field
  - Better representation of forecast advisories



Significant limitation:

- Accuracy depends on the forecast advisories issued by the NHC

Forecasting of Winds and Surge

Weather Research and Forecasting (WRF)

Obvious alternative is to use process-based meteorological models

- Consider the models within the Unified Wave INterface Coupled Model (UWIN-CM):
  - Atmosphere - **Weather Research and Forecasting (WRF)**
  - Waves - University of Miami Wave Model (UMWM)
  - Ocean circulation - HYbrid Coordinate Ocean Model (HYCOM)
- Models are tightly coupled
  - Wind fields include the effects of storm-induced ocean cooling
  - Wind-wave stress computed directly from the wave model
- For each forecast, UWIN-CM relies on the National Center for Environmental Prediction (NCEP) Global Forecasting System (GFS)
  - IC - GFS and HYCOM analyses fields
  - BC - GFS and HYCOM forecast fields (6-hourly)

We can now read and interpolate directly these WRF wind fields onto the ADCIRC unstructured mesh

Forecasting of Winds and Surge

GAH and WRF Forecasts

Goal: To evaluate the performance of WRF in coastal Louisiana, and its impacts on predictions of storm surge and flooding during Isaac (2012)

- How will coupling with WRF change our surge predictions?

Model simulations using the guidance available during the storm

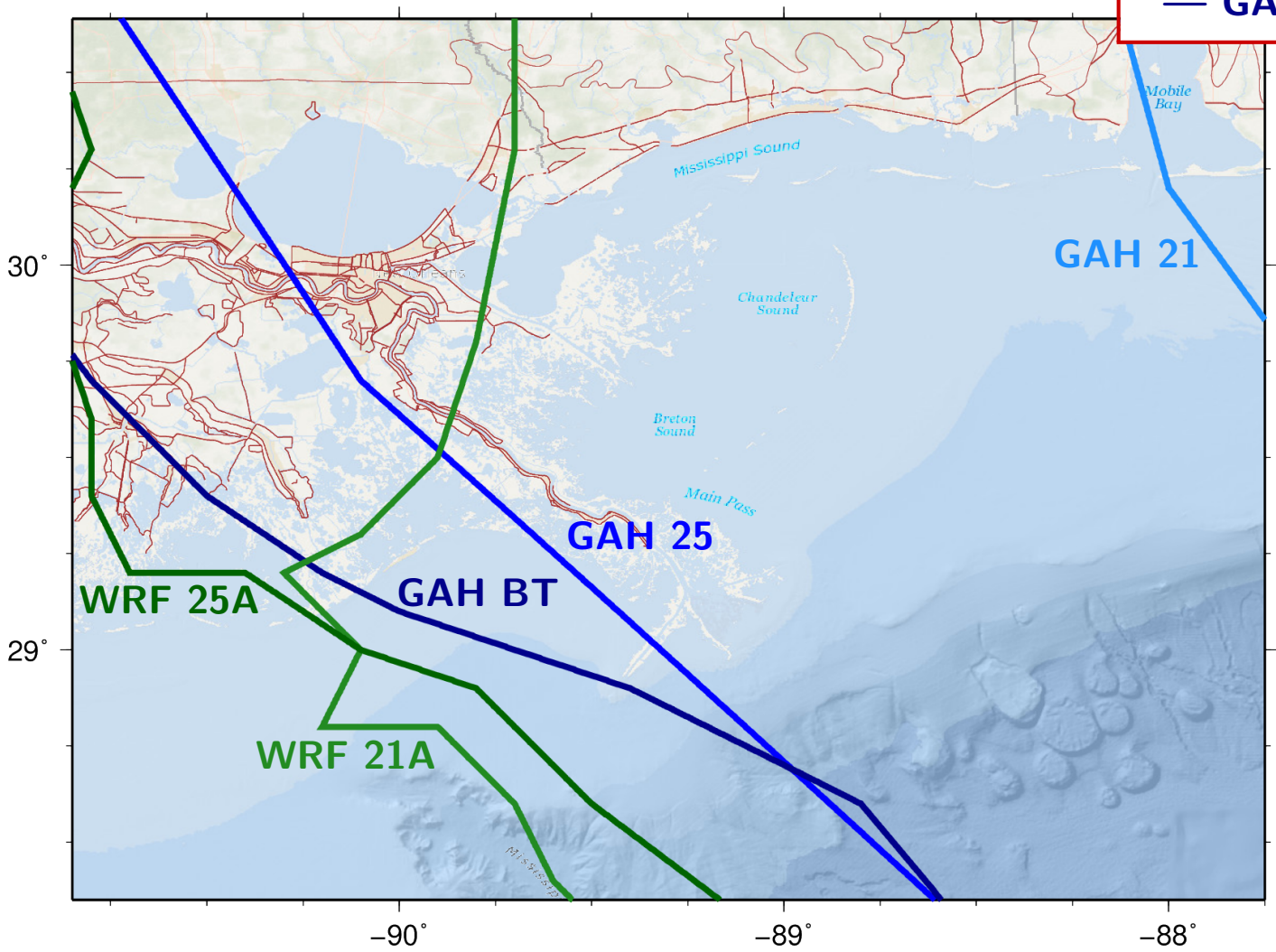
- Evaluate the forecast predictions:

Model	Start (UTC)	To Landfall
GAH 21	2012/08/26/0900	63 hr
GAH 25	2012/08/27/0900	39 hr
WRF 21A	2012/08/26/1200	60 hr
WRF 25A	2012/08/27/1200	36 hr

- Compare against the NHC best-track guidance (**GAH BT**)

Forecasting of Winds and Surge

SE Louisiana and Storm Tracks

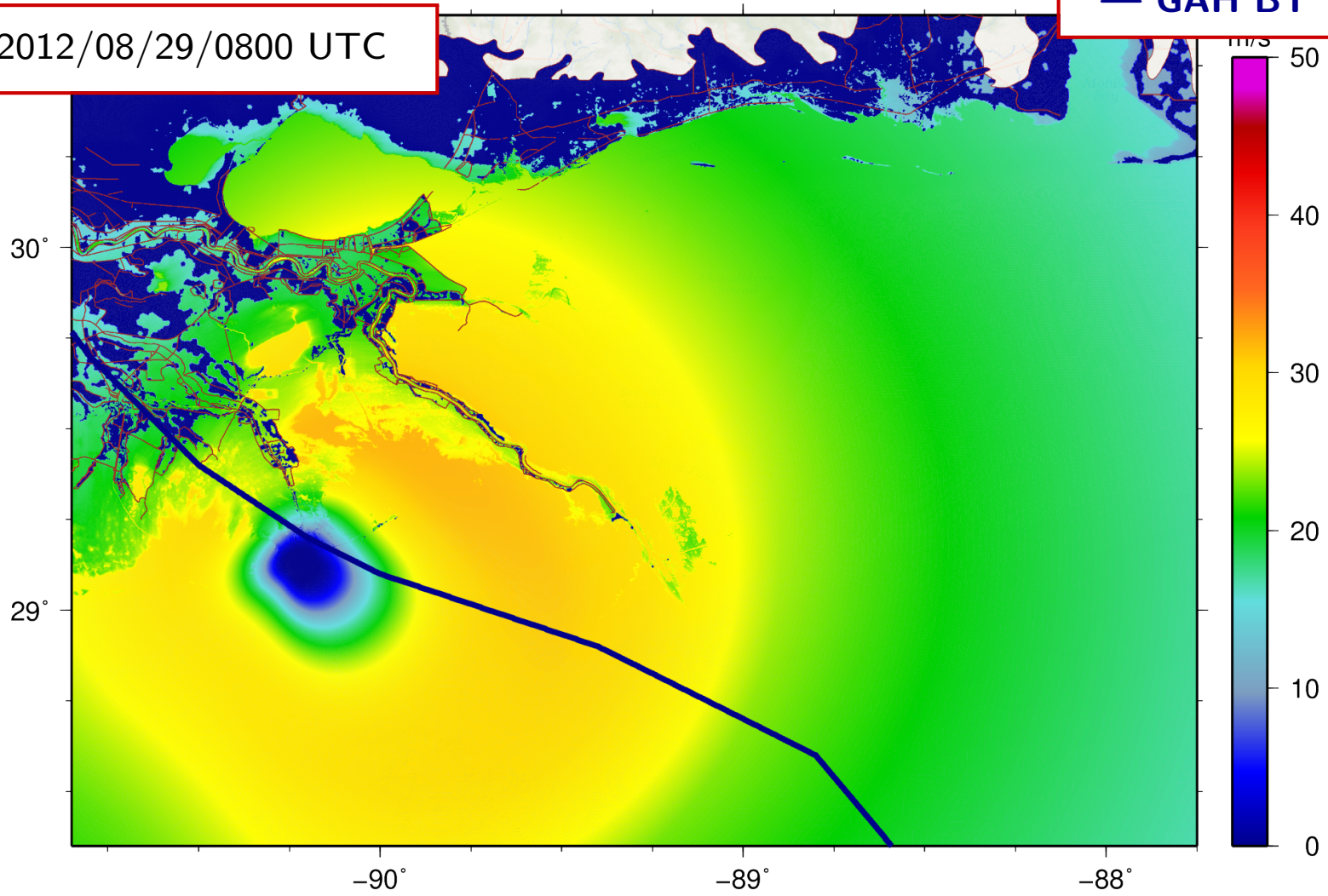


Meteorological Forcing

Wind Field at Second Landfall near Grand Isle LA

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— **GAH BT**

2012/08/29/0800 UTC

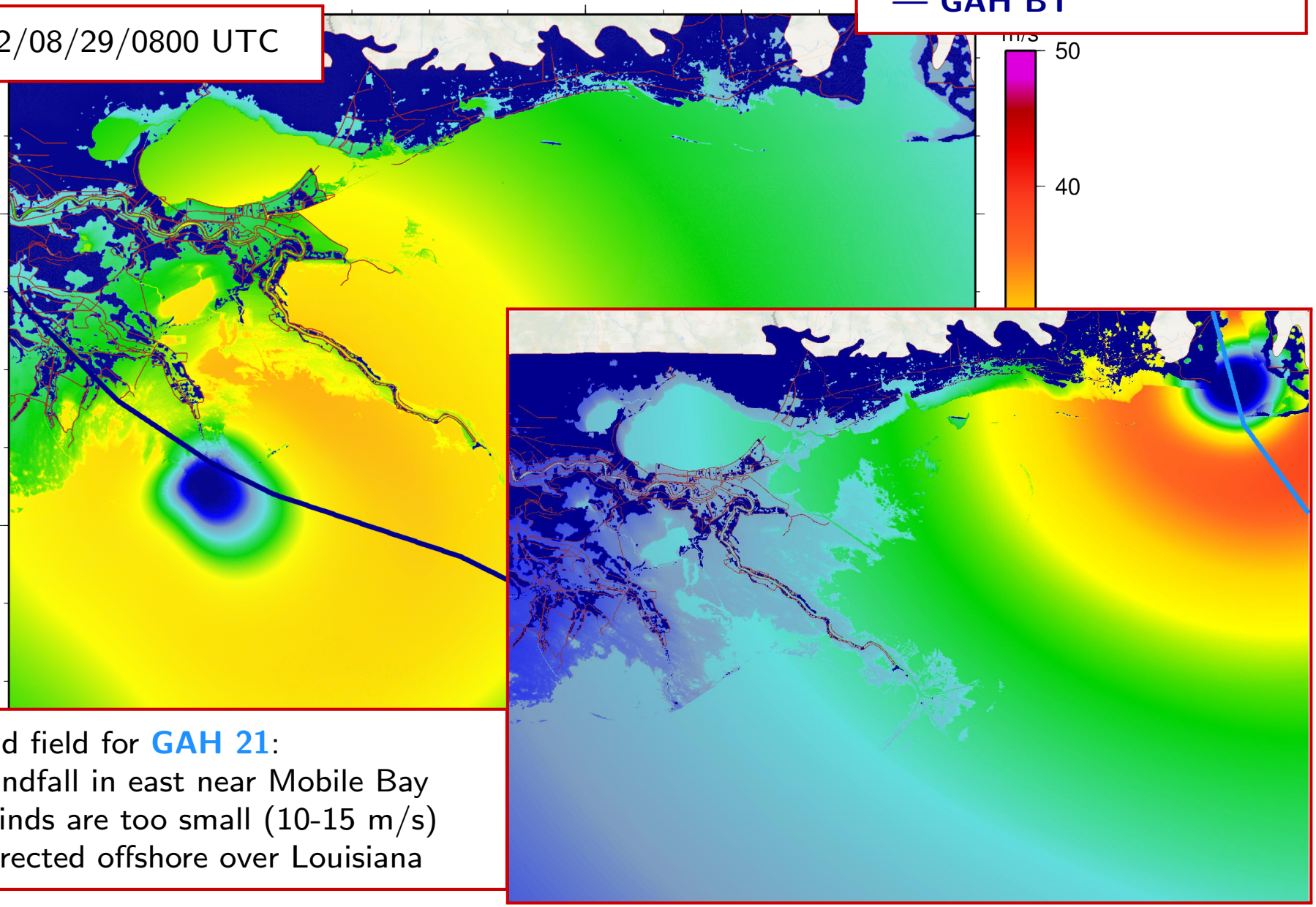


Meteorological Forcing

Wind Field at Second Landfall near Grand Isle LA

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— GAH BT

2012/08/29/0800 UTC



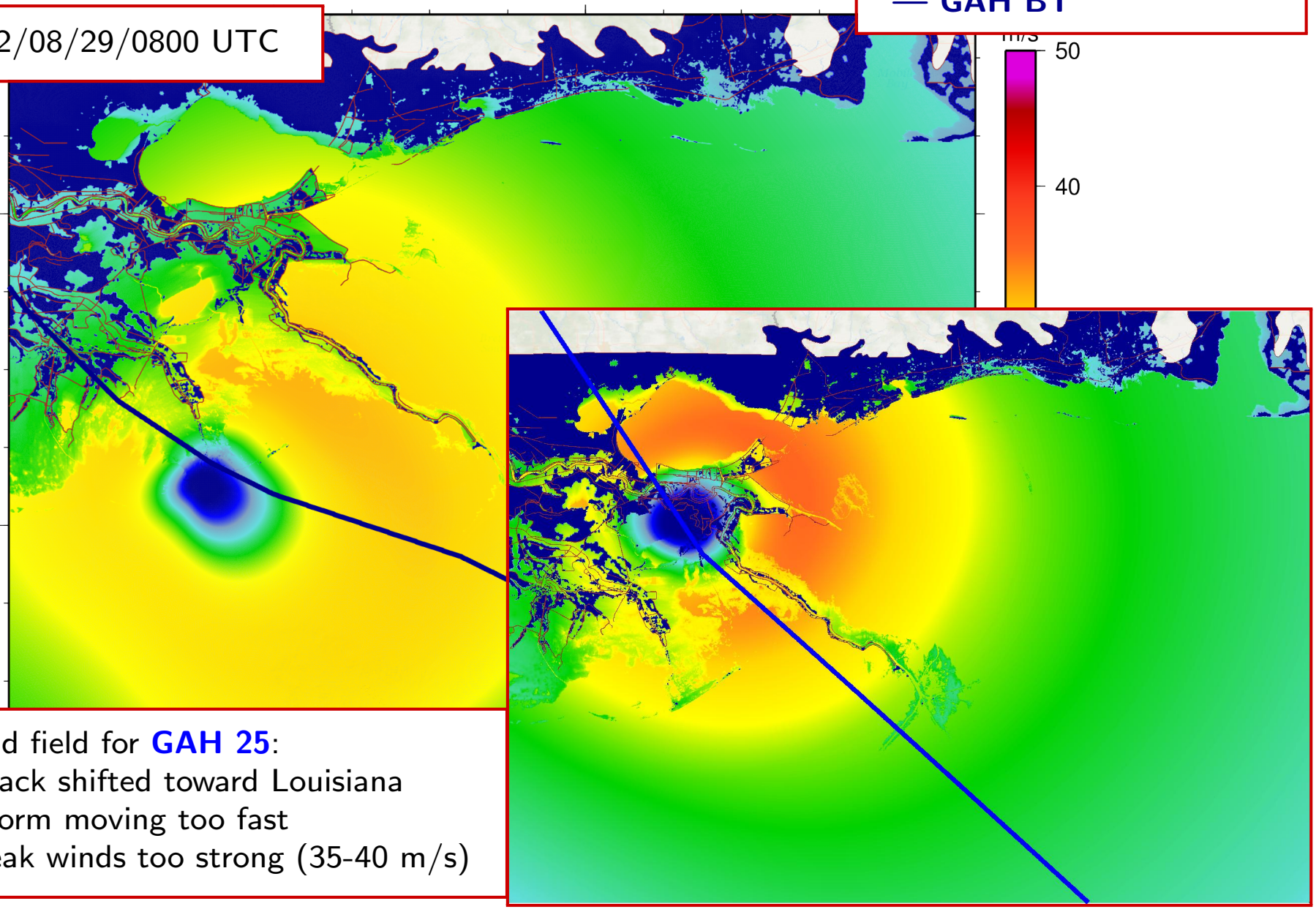
Wind field for **GAH 21**:
- Landfall in east near Mobile Bay
- Winds are too small (10-15 m/s)
- Directed offshore over Louisiana

Meteorological Forcing

Wind Field at Second Landfall near Grand Isle LA

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— GAH BT

2012/08/29/0800 UTC



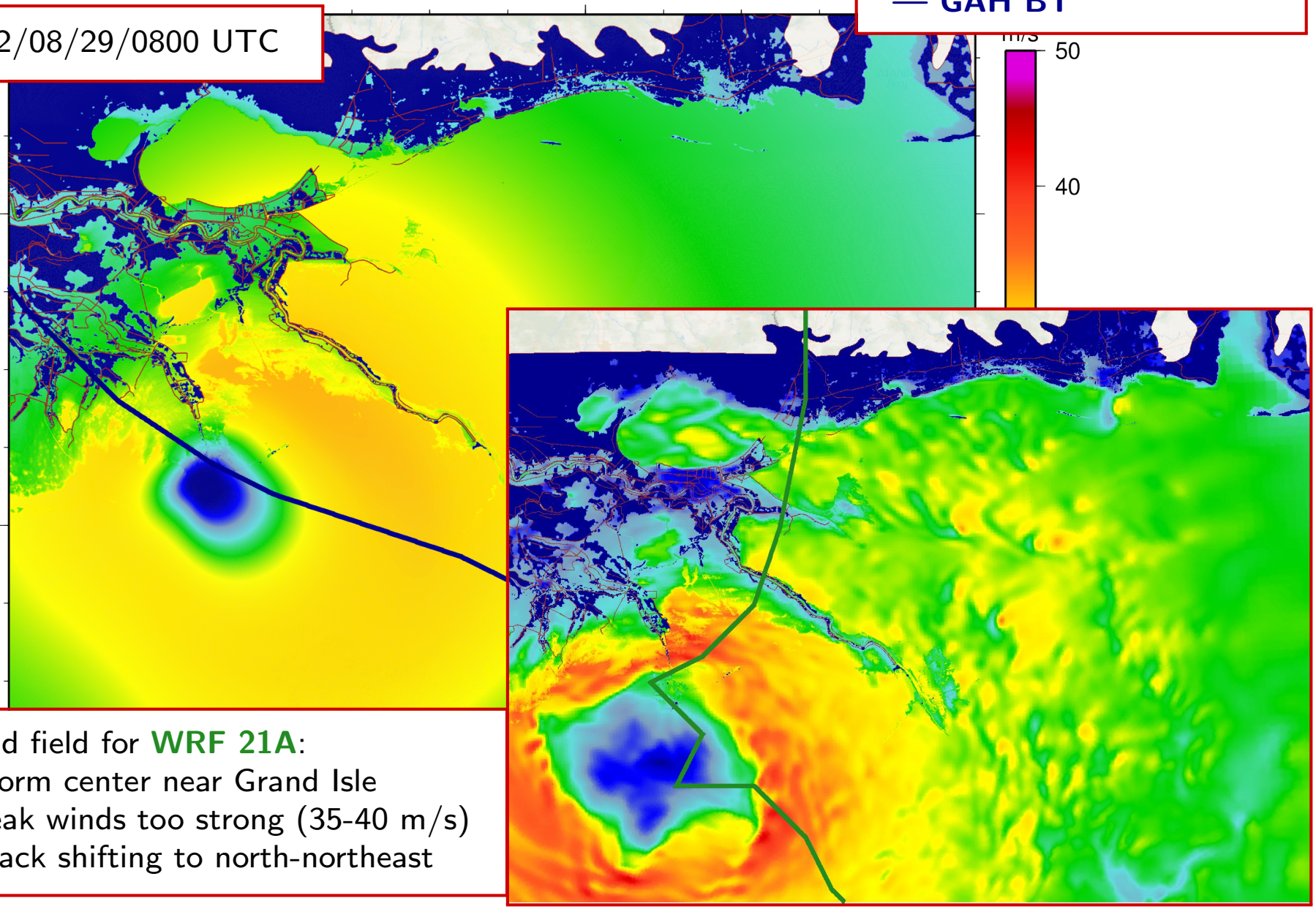
Wind field for **GAH 25**:
- Track shifted toward Louisiana
- Storm moving too fast
- Peak winds too strong (35-40 m/s)

Meteorological Forcing

Wind Field at Second Landfall near Grand Isle LA

— GAH 21 — **WRF 21A**
— GAH 25 — WRF 25A
— **GAH BT**

2012/08/29/0800 UTC



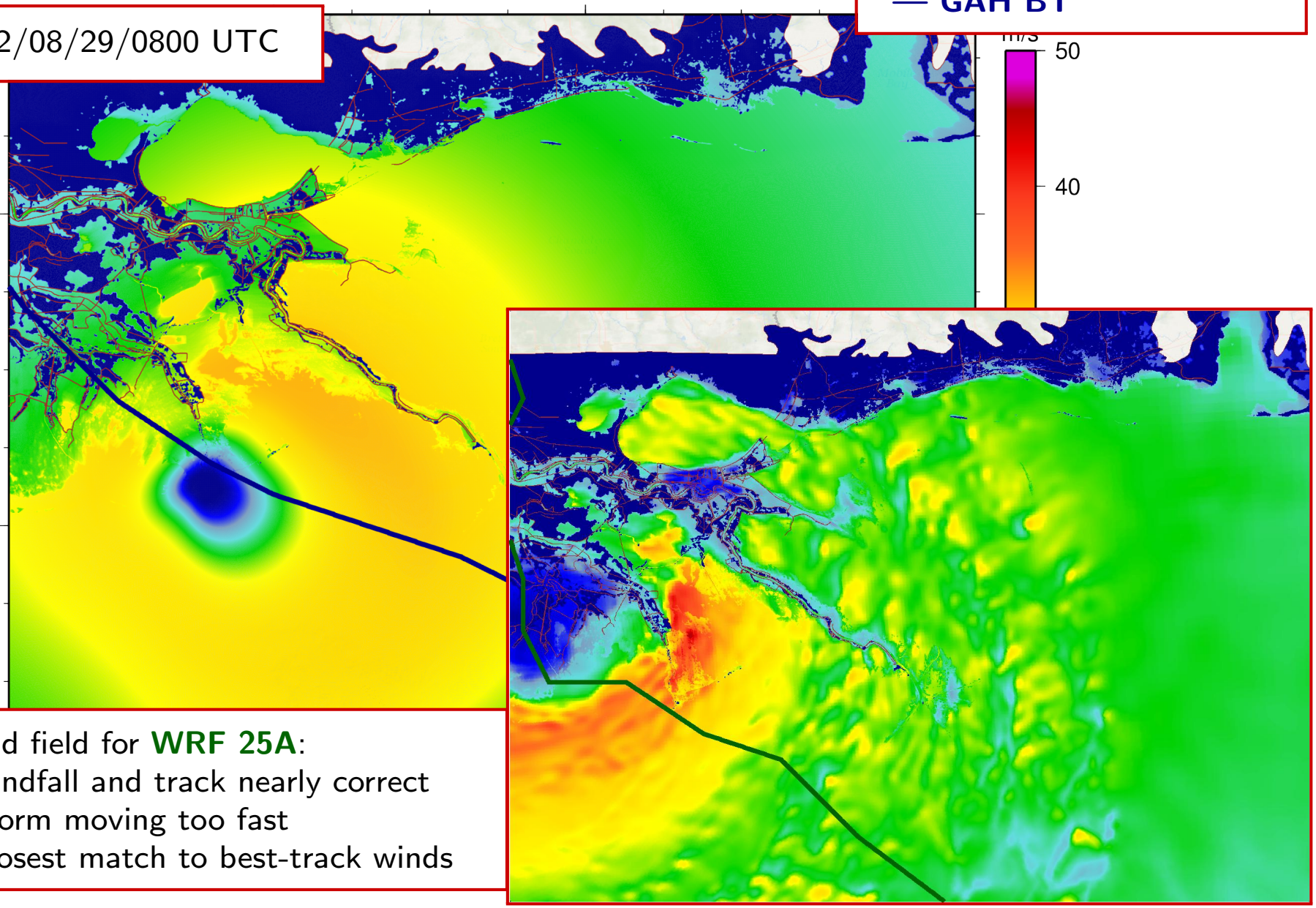
Wind field for **WRF 21A**:
- Storm center near Grand Isle
- Peak winds too strong (35-40 m/s)
- Track shifting to north-northeast

Meteorological Forcing

Wind Field at Second Landfall near Grand Isle LA

— GAH 21 — WRF 21A
— GAH 25 — **WRF 25A**
— **GAH BT**

2012/08/29/0800 UTC

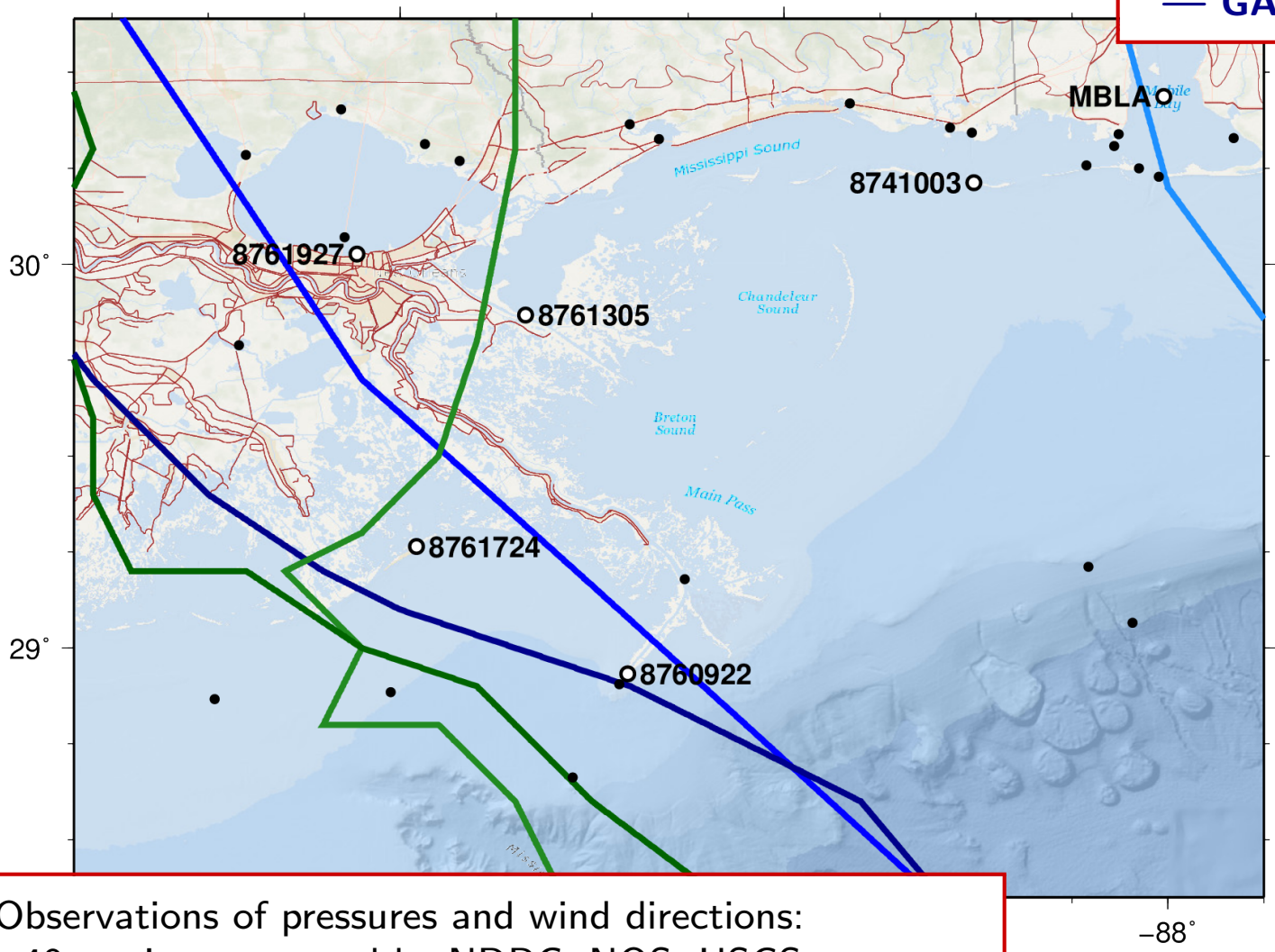


Wind field for **WRF 25A**:
- Landfall and track nearly correct
- Storm moving too fast
- Closest match to best-track winds

Meteorological Forcing

Time Series Comparisons to Observations

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— GAH BT

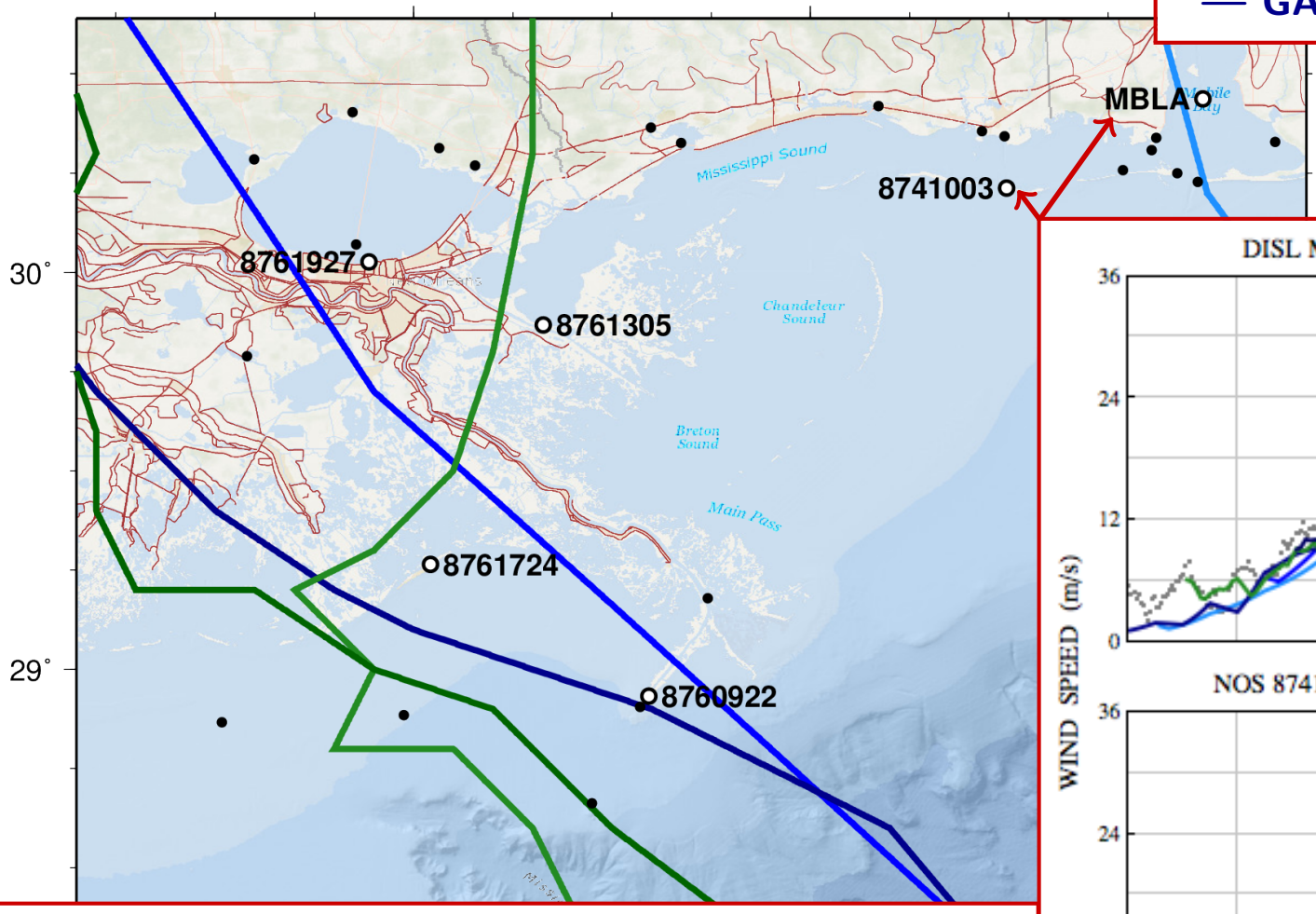


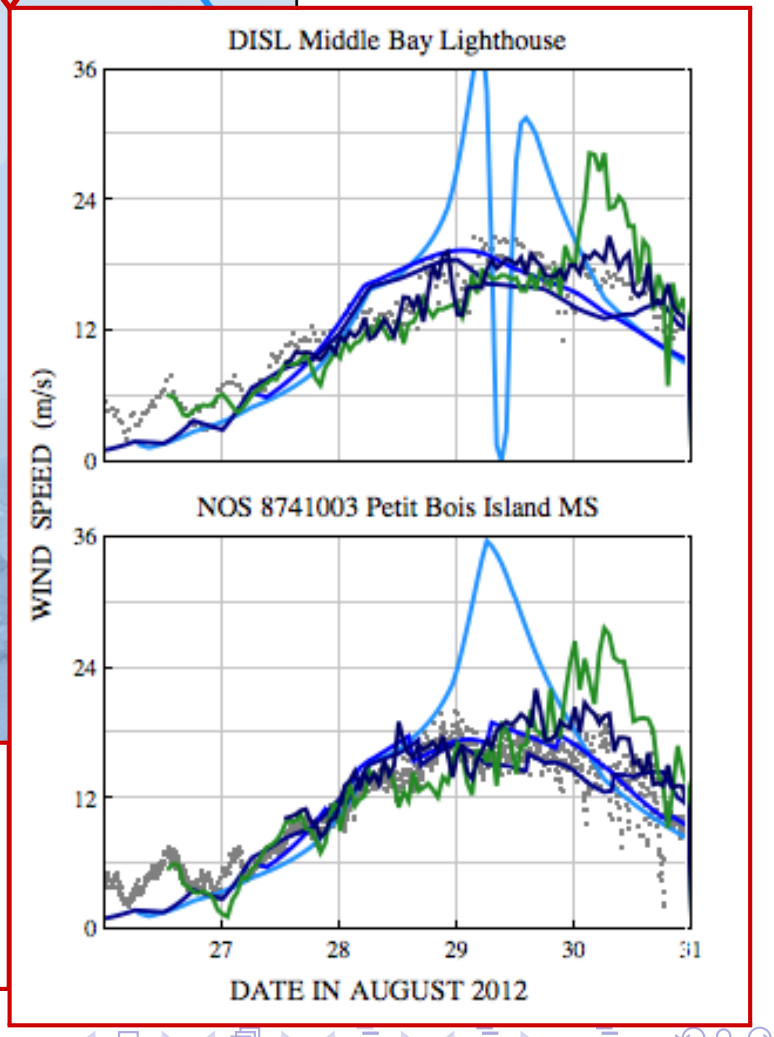
Observations of pressures and wind directions:
- 40 stations operated by NDBC, NOS, USGS, etc.
- Compare observations and predictions at all stations
- Selected stations illustrate the model performance

Meteorological Forcing

Time Series Comparisons to Observations

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— GAH BT



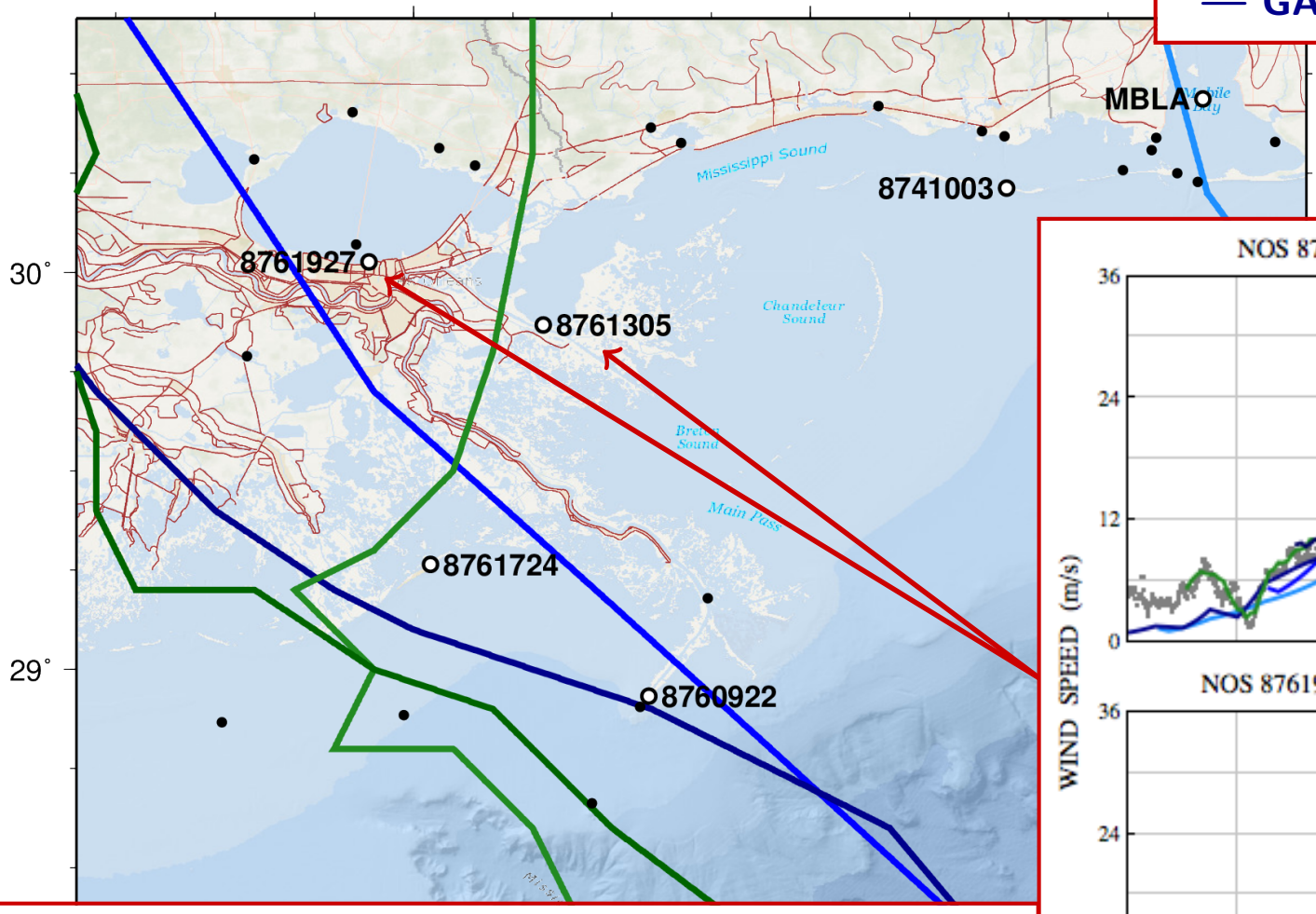


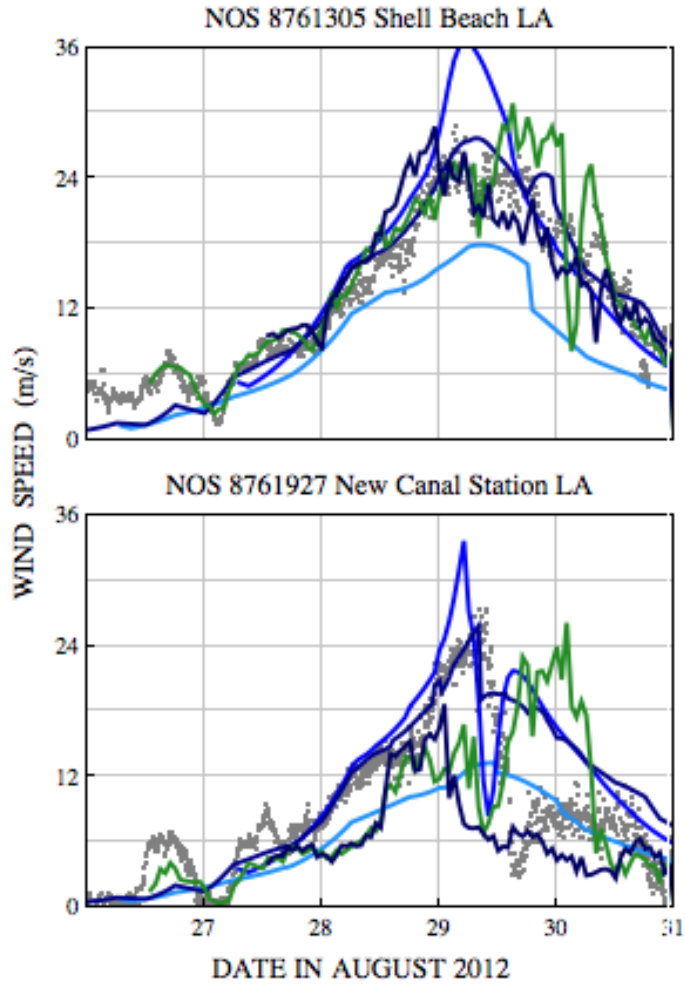
Stations along Mississippi-Alabama coastlines:
- Storm passes too close in **GAH 21**
- Incorrect strengthening after storm in **WRF 21A**
- Later forecasts match well to observations

Meteorological Forcing

Time Series Comparisons to Observations

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— GAH BT



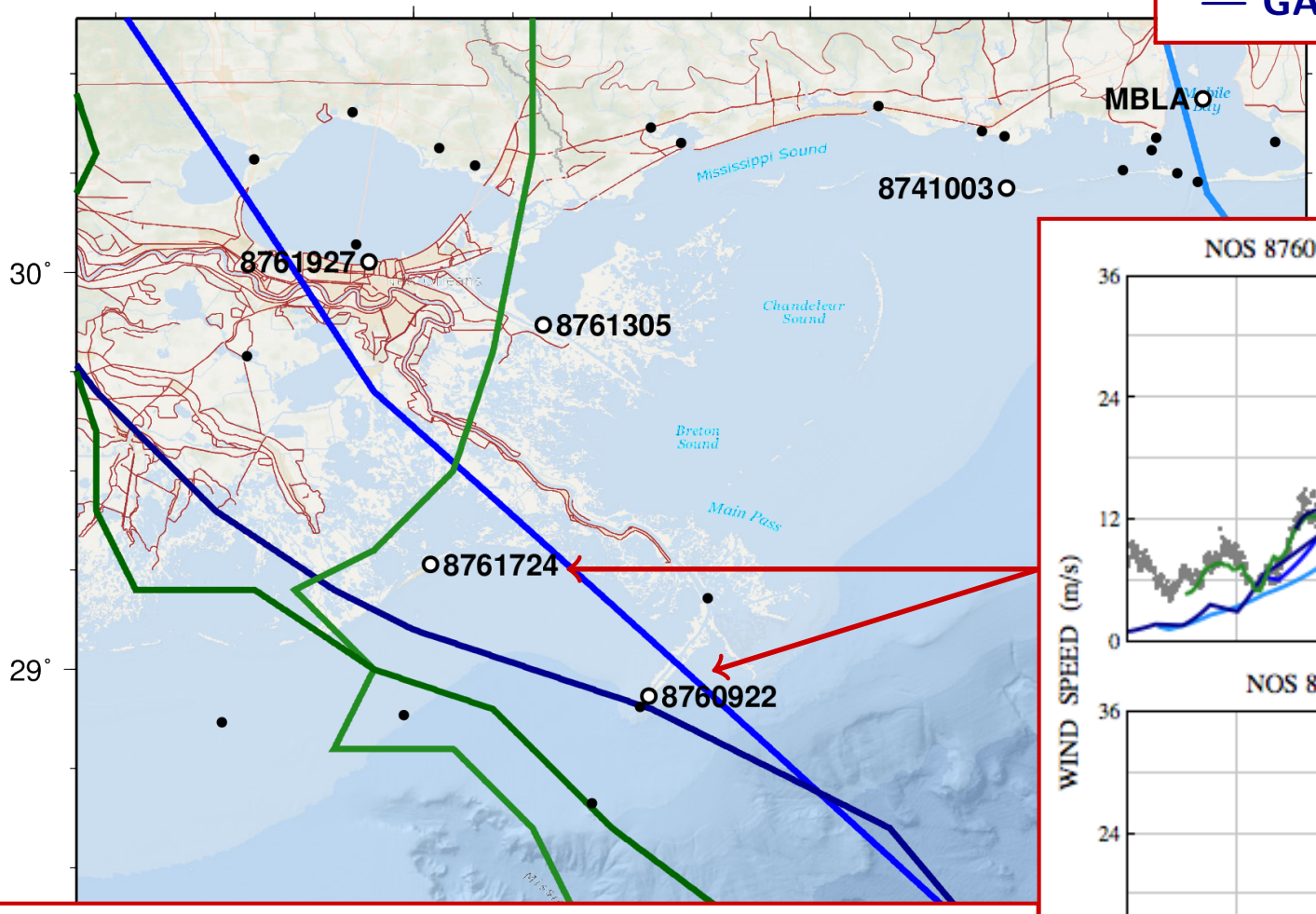


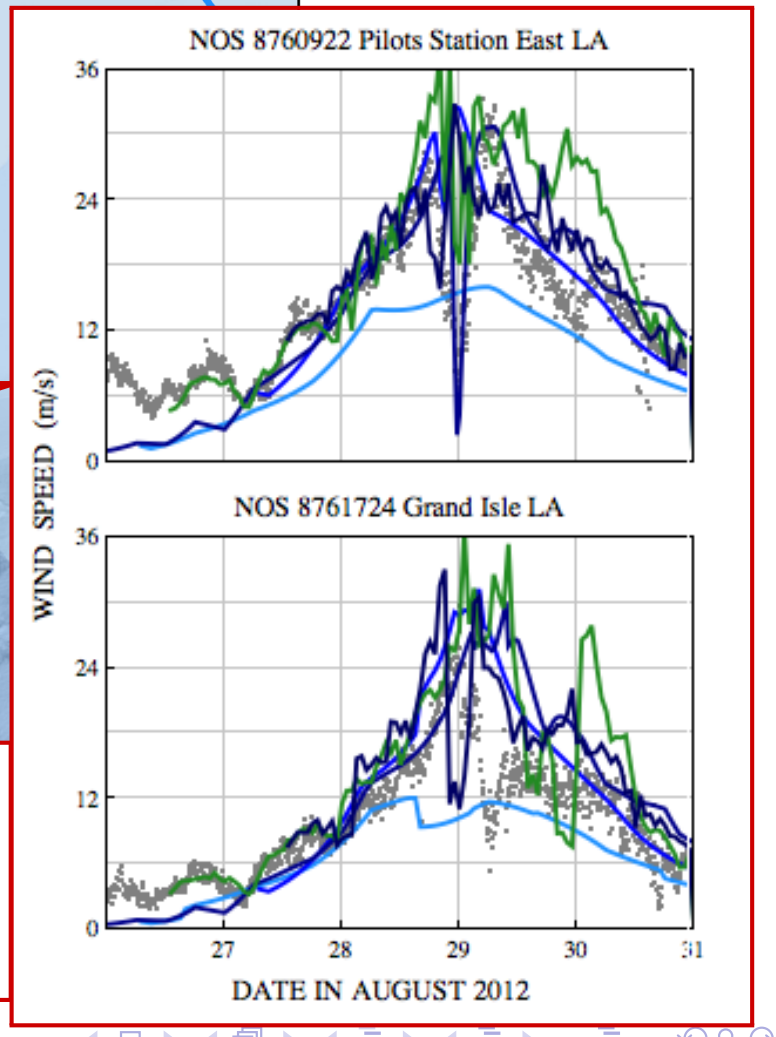
Stations near New Orleans:
- **GAH 25** overpredicts peak winds by 5-10 m/s
- Winds too small in Lake Pontchartrain by **WRF 25A**
- Even the **GAH BT** winds are too strong after landfall

Meteorological Forcing

Time Series Comparisons to Observations

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— GAH BT





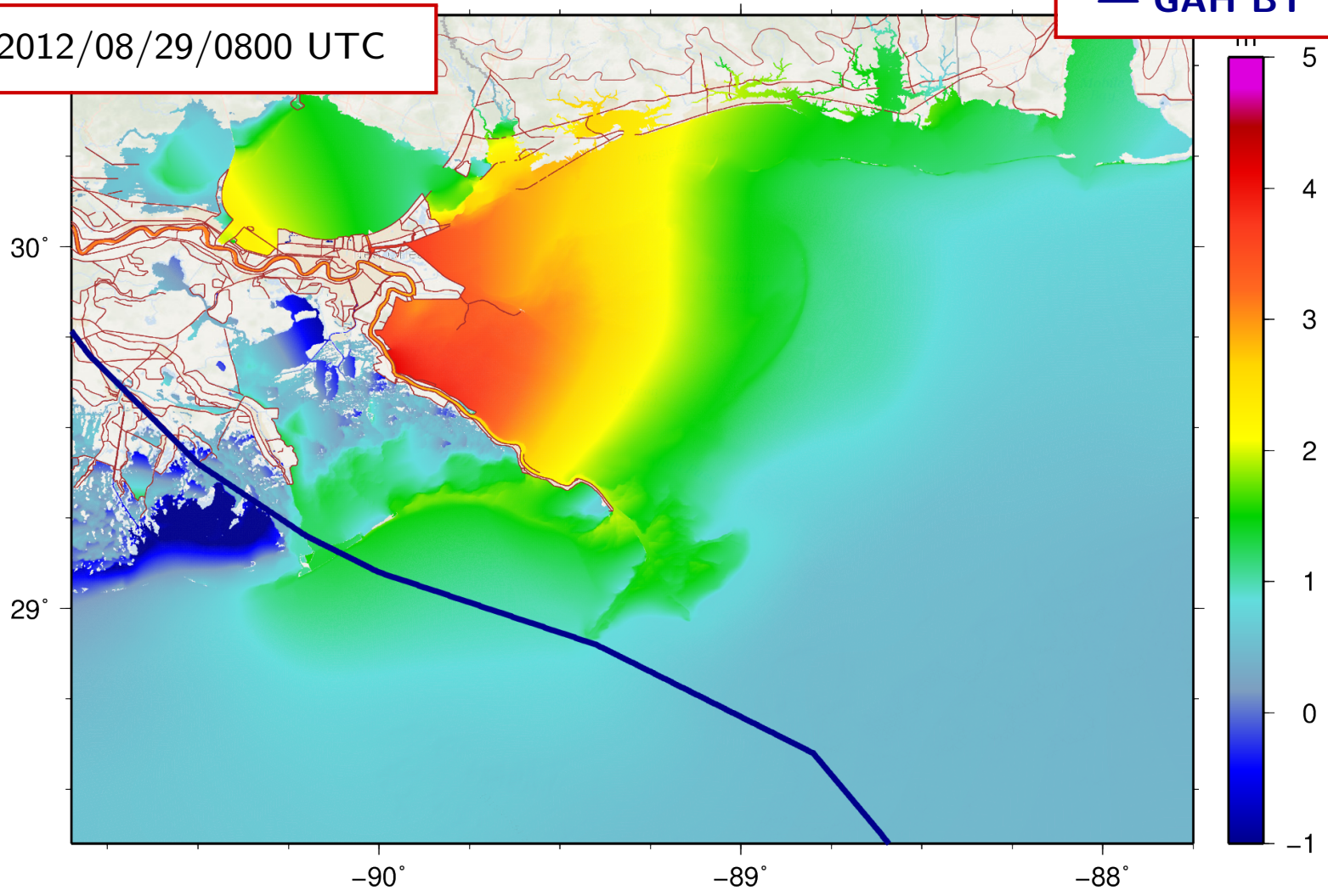
Stations south of Mississippi River:
- Good match to minimum pressure of 970 mbar
- Peak wind of 33 m/s matched by later advisories
- **WRF 25A** too strong by 5-10 m/s after landfall

Storm Surge and Flooding

Water Levels at Second Landfall near Grand Isle LA

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— **GAH BT**

2012/08/29/0800 UTC

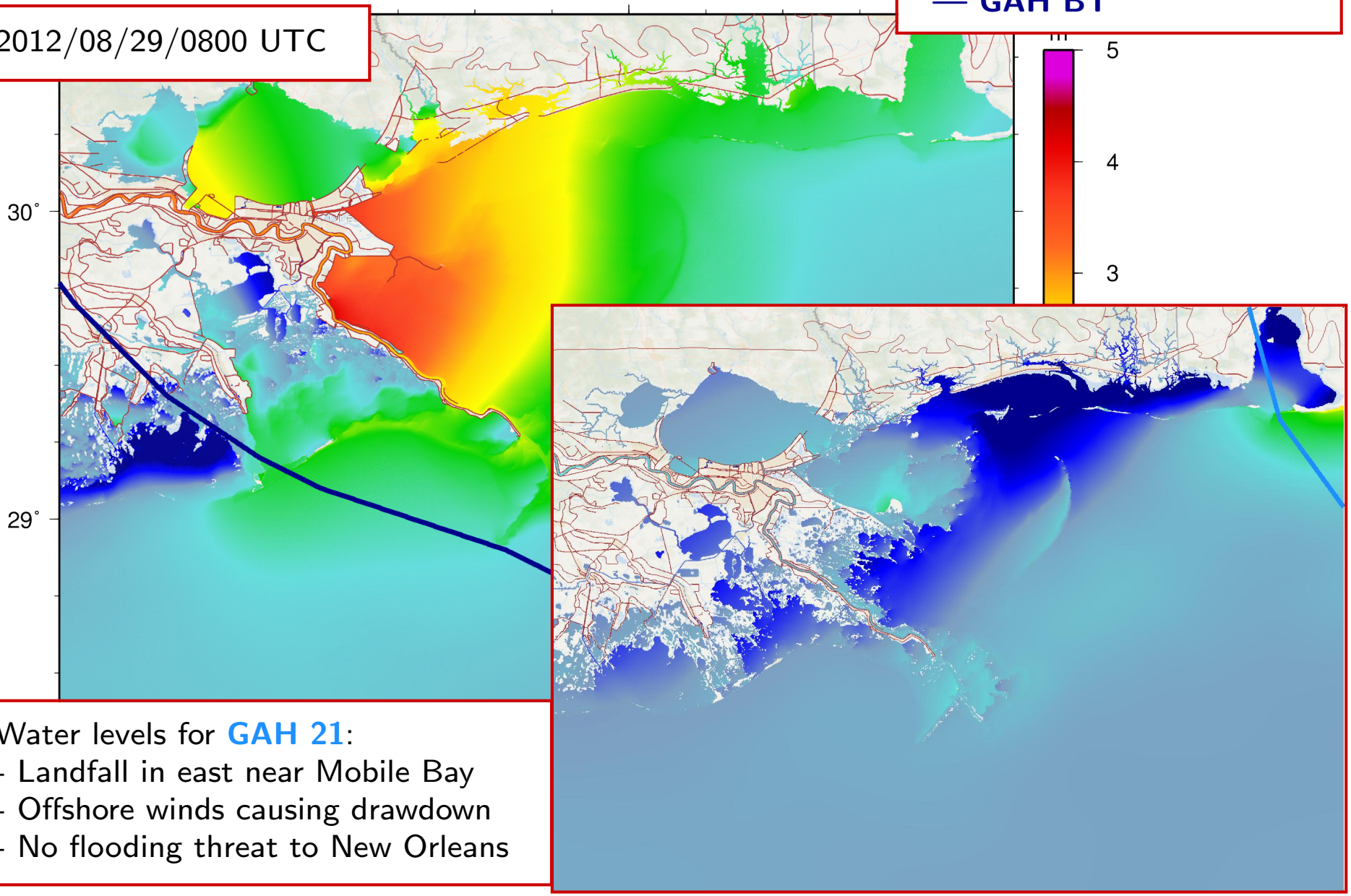


Storm Surge and Flooding

Water Levels at Second Landfall near Grand Isle LA

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— GAH BT

2012/08/29/0800 UTC



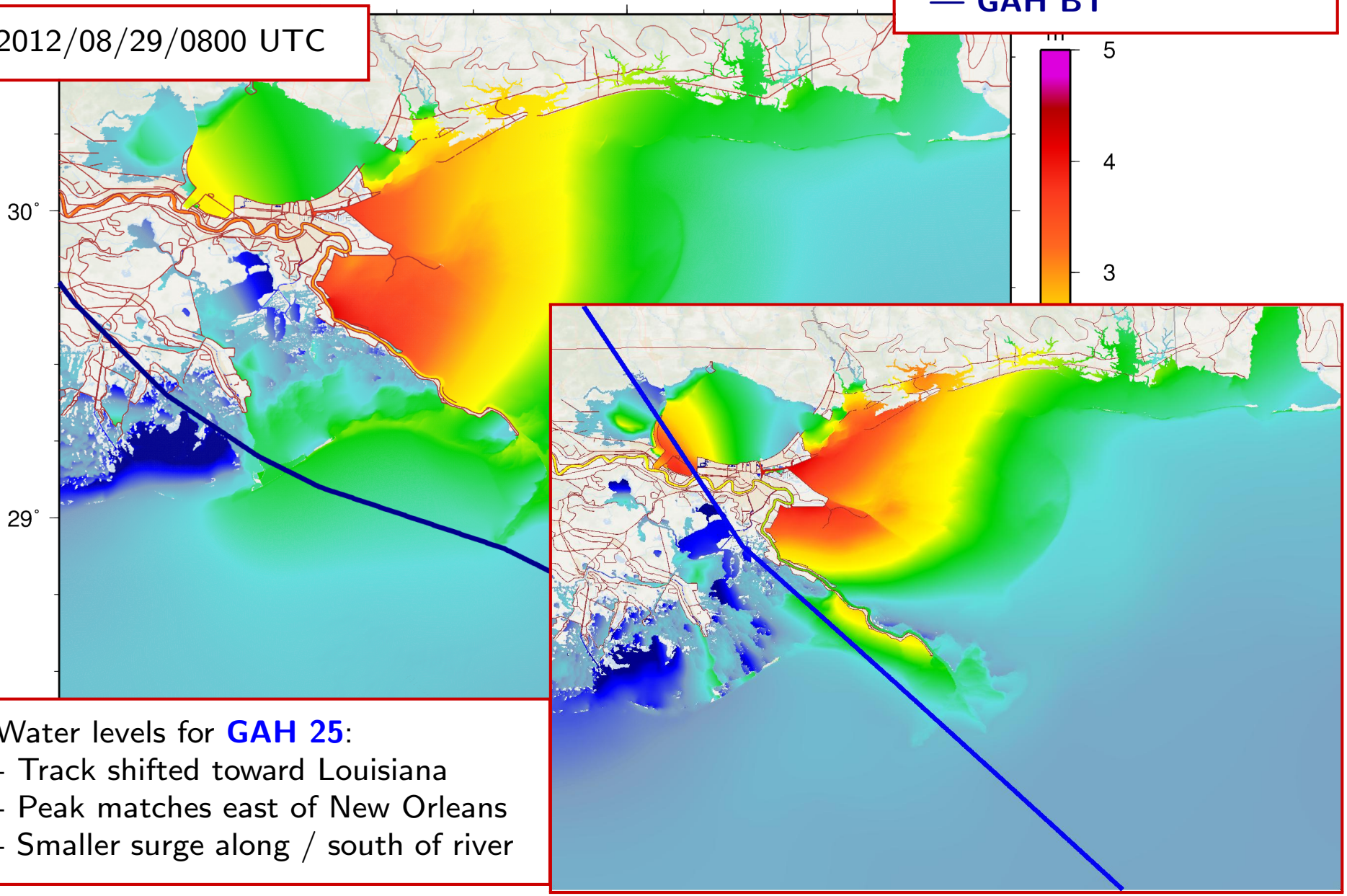
Water levels for **GAH 21**:
- Landfall in east near Mobile Bay
- Offshore winds causing drawdown
- No flooding threat to New Orleans

Storm Surge and Flooding

Water Levels at Second Landfall near Grand Isle LA

— GAH 21 — WRF 21A
— **GAH 25** — WRF 25A
— **GAH BT**

2012/08/29/0800 UTC



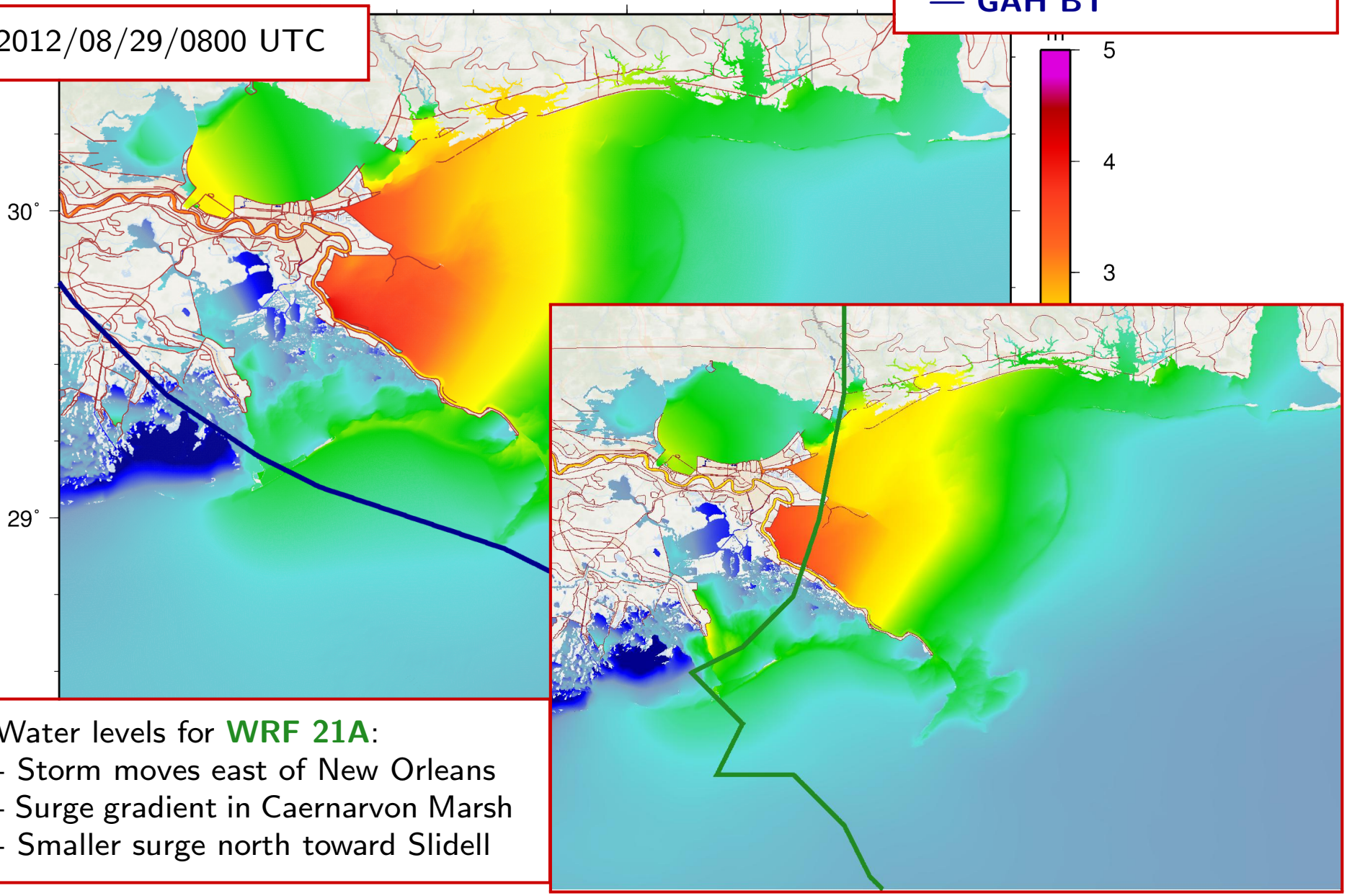
Water levels for **GAH 25**:
- Track shifted toward Louisiana
- Peak matches east of New Orleans
- Smaller surge along / south of river

Storm Surge and Flooding

Water Levels at Second Landfall near Grand Isle LA

— GAH 21 — **WRF 21A**
— GAH 25 — WRF 25A
— **GAH BT**

2012/08/29/0800 UTC



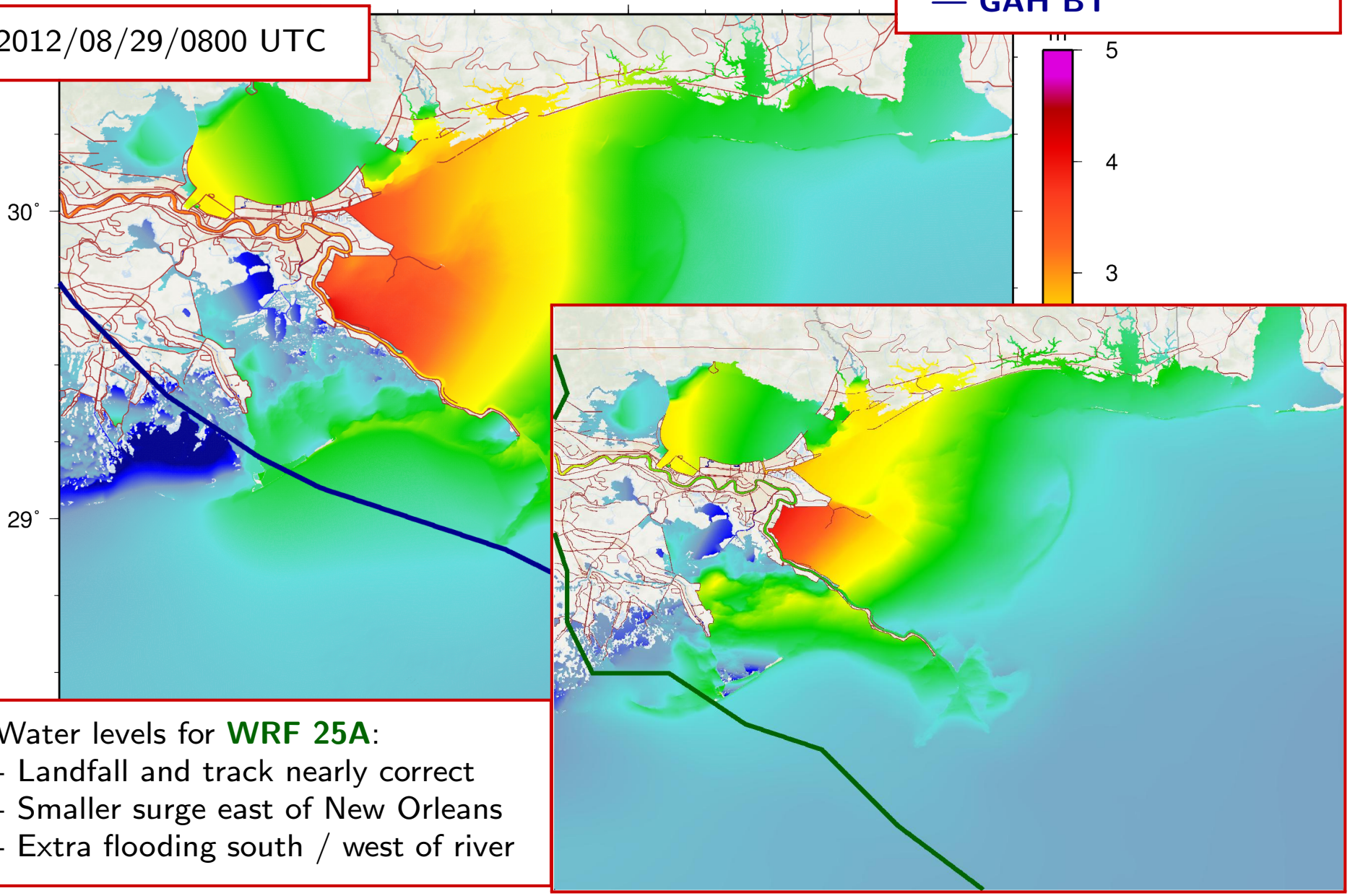
Water levels for **WRF 21A**:
- Storm moves east of New Orleans
- Surge gradient in Caernarvon Marsh
- Smaller surge north toward Slidell

Storm Surge and Flooding

Water Levels at Second Landfall near Grand Isle LA

— GAH 21 — WRF 21A
— GAH 25 — **WRF 25A**
— **GAH BT**

2012/08/29/0800 UTC

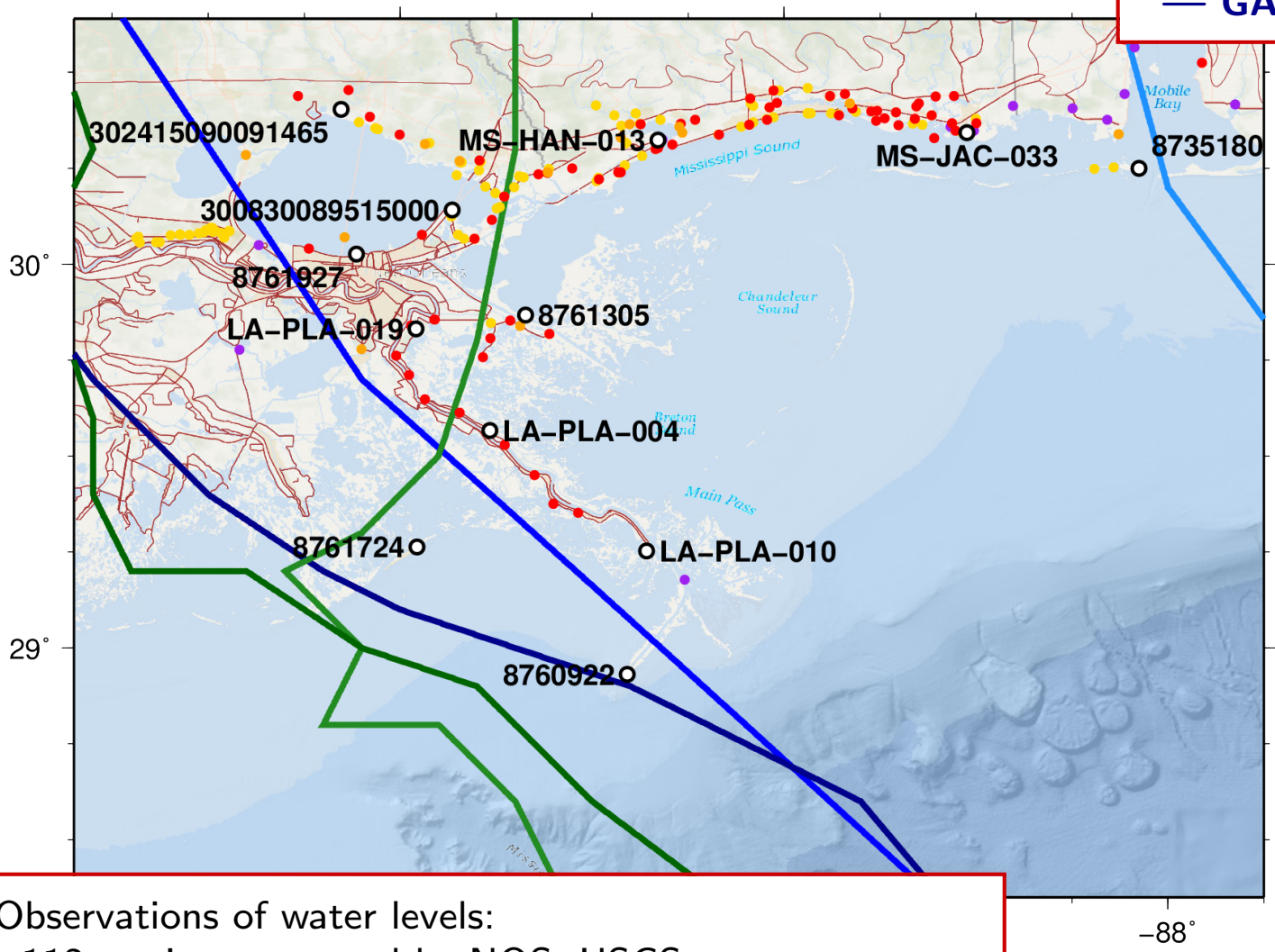


Water levels for **WRF 25A**:
- Landfall and track nearly correct
- Smaller surge east of New Orleans
- Extra flooding south / west of river

Storm Surge and Flooding

Time Series Comparisons to Observations

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— GAH BT

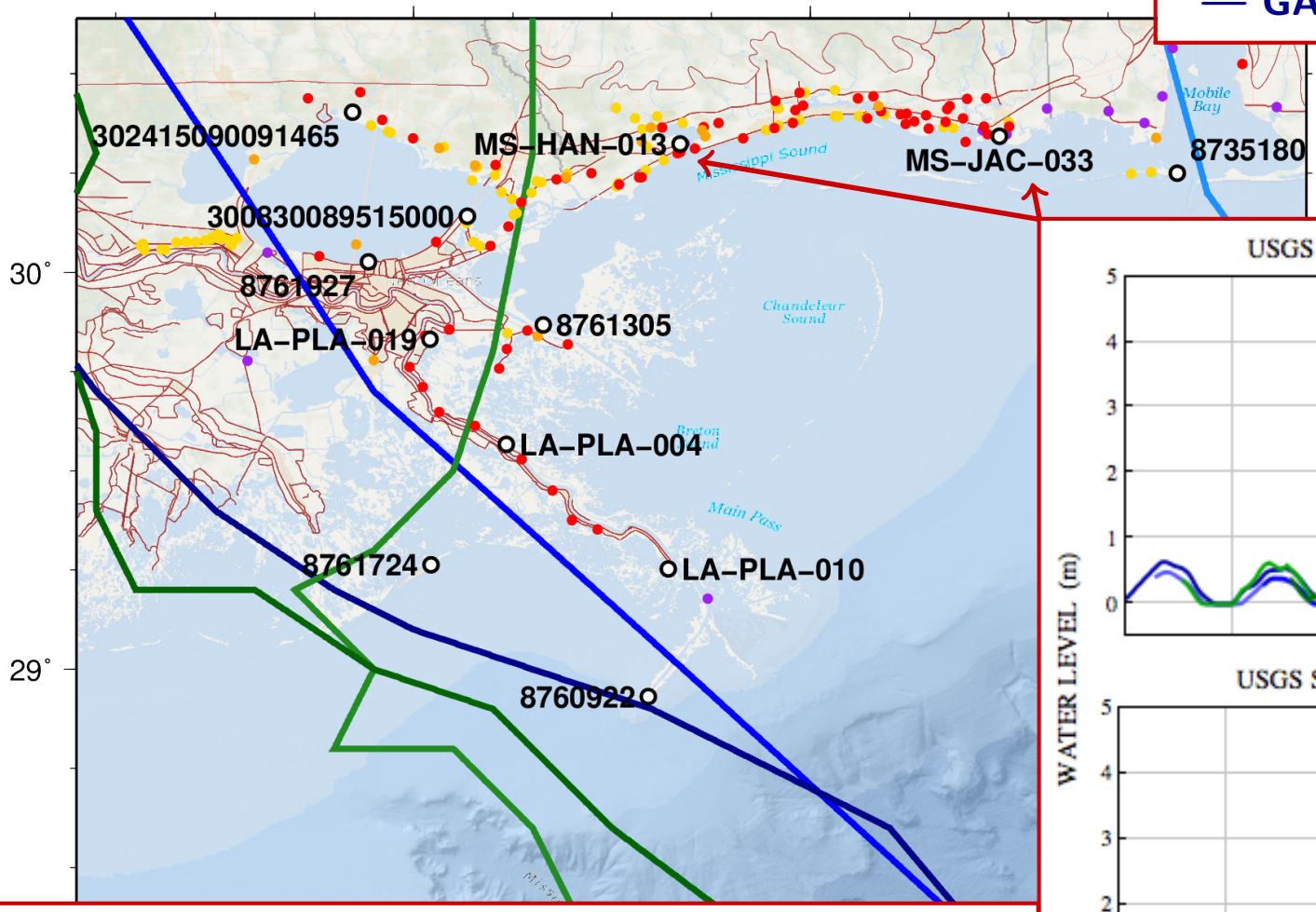


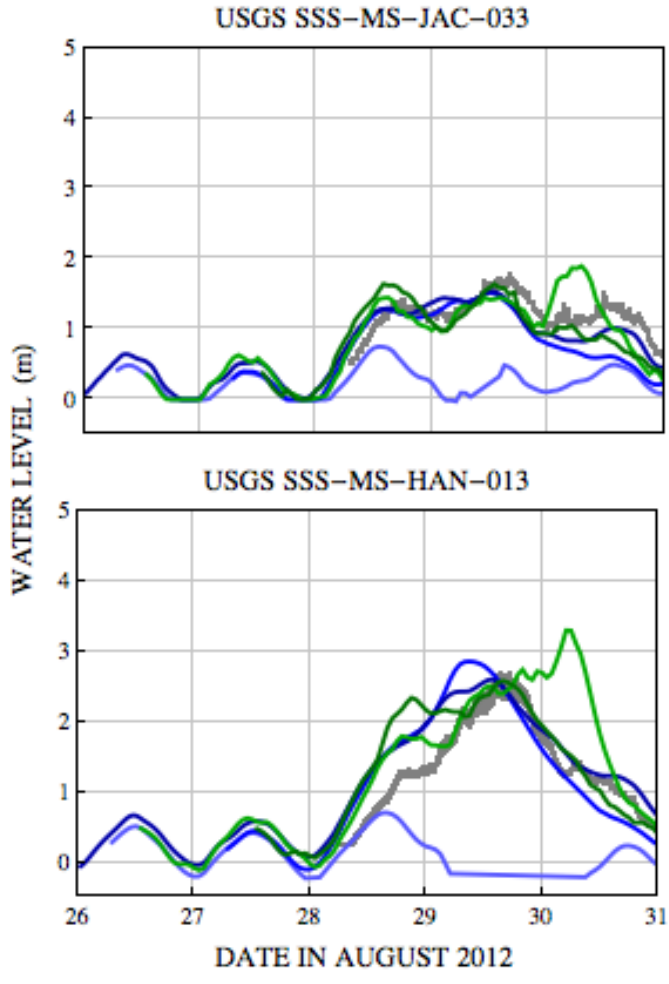
Observations of water levels:
- 112 stations operated by NOS, USGS, etc.
- Another 100 high-water marks collected by USGS
- Selected stations illustrate the model performance

Storm Surge and Flooding

Time Series Comparisons to Observations

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— GAH BT



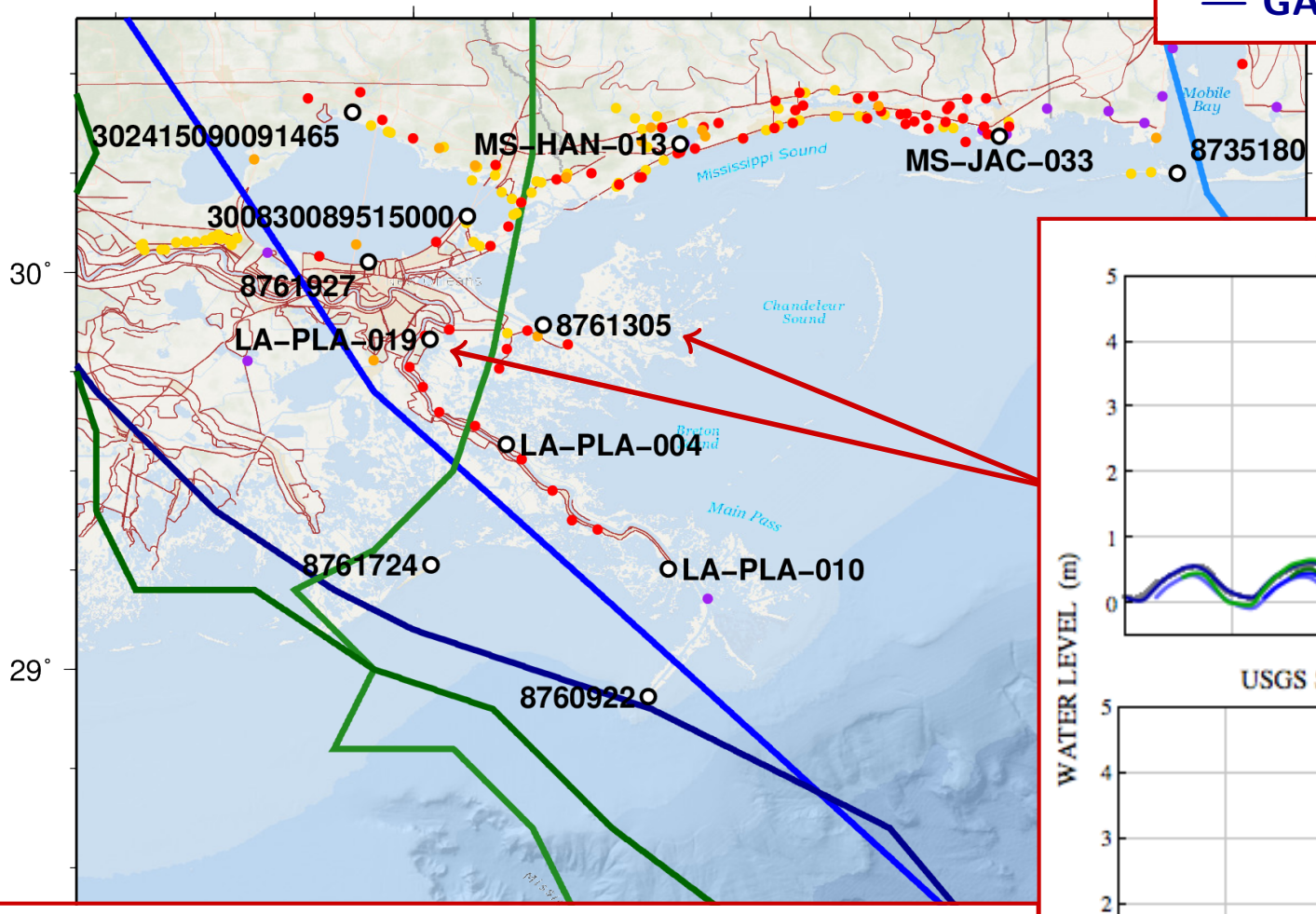


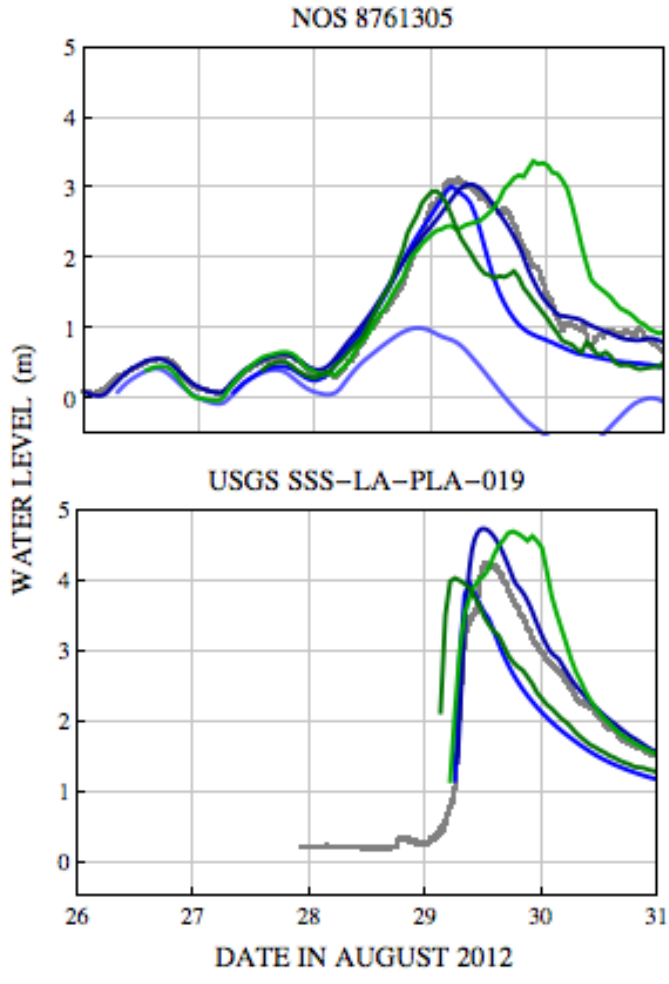
Stations along Mississippi-Alabama coastlines:
- Offshore winds on west side of storm track in **GAH 21**
- Incorrect strengthening after storm in **WRF 21A**
- Later forecasts match better to observations

Storm Surge and Flooding

Time Series Comparisons to Observations

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— GAH BT



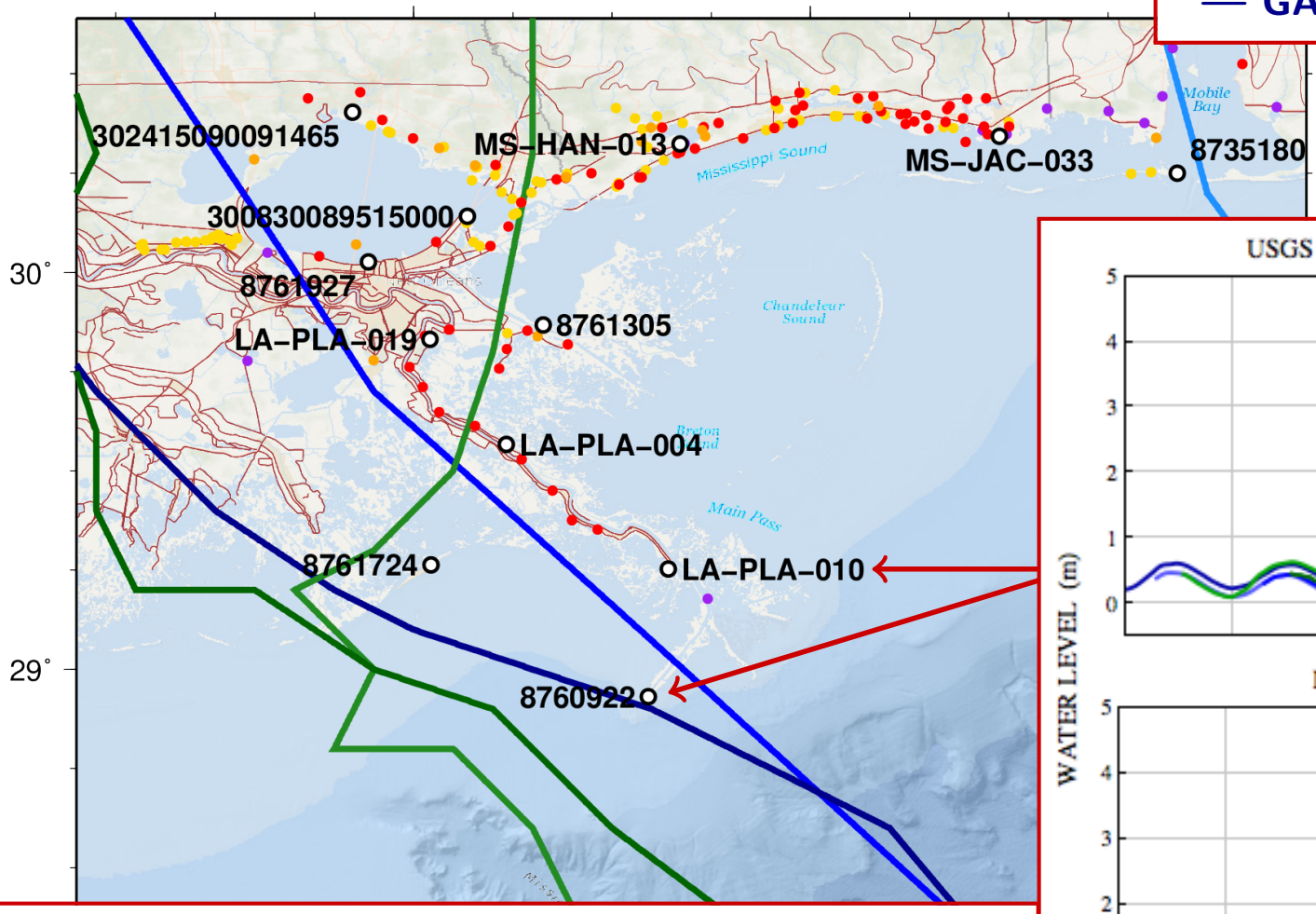


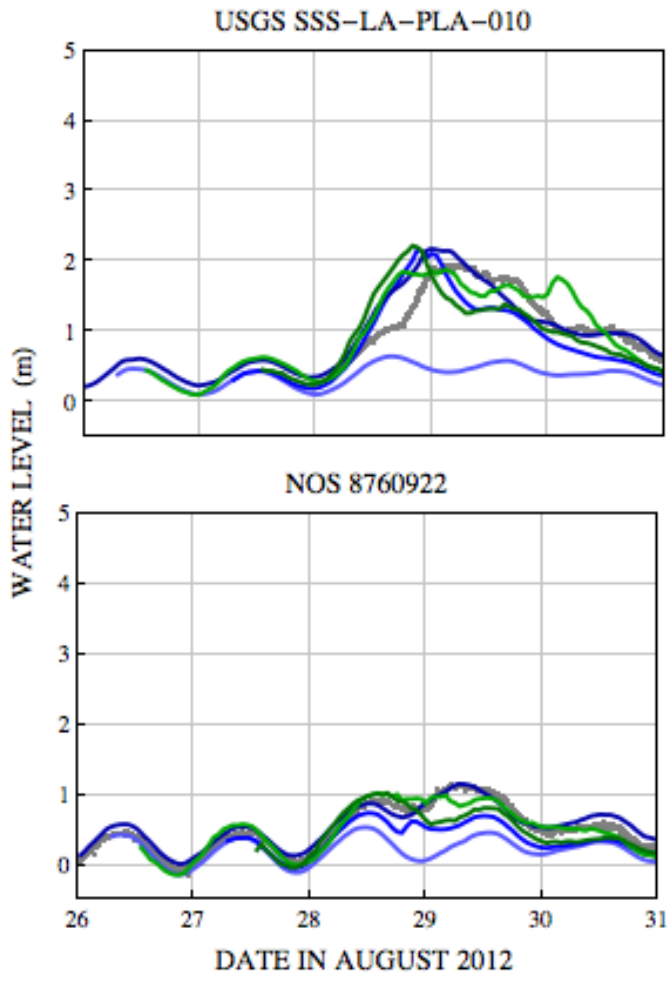
Stations to east of New Orleans:
- **WRF 21A** overpredicts peak surge by 0.5 m
- **GAH 25** and **WRF 25A** underpredict peaks by 0.5 m
- **GAH BT** peak is too large in Caernarvon Marsh

Storm Surge and Flooding

Time Series Comparisons to Observations

— GAH 21 — WRF 21A
— GAH 25 — WRF 25A
— GAH BT





Stations near mouth of Mississippi River:
- **GAH 21** surges are consistently too small
- Other forecasts match well to peaks, but too early
- Even the **GAH BT** occurs too early

Conclusions

Error Statistics for Time Series Comparisons

Comparison of **RMS Errors** for each forecast advisory:

	Pressures (mbar)	Wind Speeds (m/s)	Water Levels (m)
Stations	40	40	112
GAH 21	20.0	5.19	1.32
GAH 25	18.8	4.25	0.49
WRF 21A	9.7	4.59	0.55
WRF 25A	7.8	3.96	0.42
GAH BT	12.1	3.82	0.35

- Pressures – WRF is a much better match to observations
- Wind speeds – Both models improve for later advisories
- Water Levels – Both models improve for later advisories, but the results using WRF forcing are a better match to observations

Conclusions

Summary and Future Work

Evaluated the response of storm surge predictions to wind forcing

- GAH - Parametric vortex model based on Holland (1980), accounting for storm asymmetry and multiple isotachs
- WRF - Process-based meteorological model, accounting for coupling to ocean waves and circulation

Clear advantage to WRF

- GAH limited by NHC forecast errors in storm track and speed
- WRF pushes storm west toward eventual landfall location

Future work for real-time forecasting

- Need to automate the coupling – Scripts to find archive of UWIN-CM results, download the latest WRF output fields
- How will this affect the time to forecast guidance?