Issues in Wave-Circulation Coupling

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ADCIRC Workshop, Stennis Space Center

Monday, 18 April 2011

SWAN+ADCIRC(CG):
‘Tight’ Coupling of Hurricane Waves and Surge

M. Zijlema (2010). “Computation of Wind-Wave Spectra in Coastal Waters with SWAN on Unstructured Grids.” *Coastal Engineering*, 57, 267-277.

J.C. Dietrich, *et al*. (2011). "Modeling Hurricane Waves and Storm Surge using Integrally-Coupled, Scalable Computations." *Coastal Engineering*, 58, 45-65.

J.C. Dietrich, *et al*. (2011). “Hurricane Gustav (2008) Waves and Storm Surge: Hindcast, Synoptic Analysis and Validation in Southern Louisiana." *Monthly Weather Review*, in press.

A.B. Kennedy, *et al.* (2011). "Origin of the Hurricane Ike Forerunner Surge.” *Geophysical Research Letters*, in press.

J.C. Dietrich, *et al.* (2011). “Performance of the Unstructured-Mesh, SWAN+ADCIRC Model in Computing Hurricane Waves and Surge.” *Journal of Scientific Computing*, in preparation.

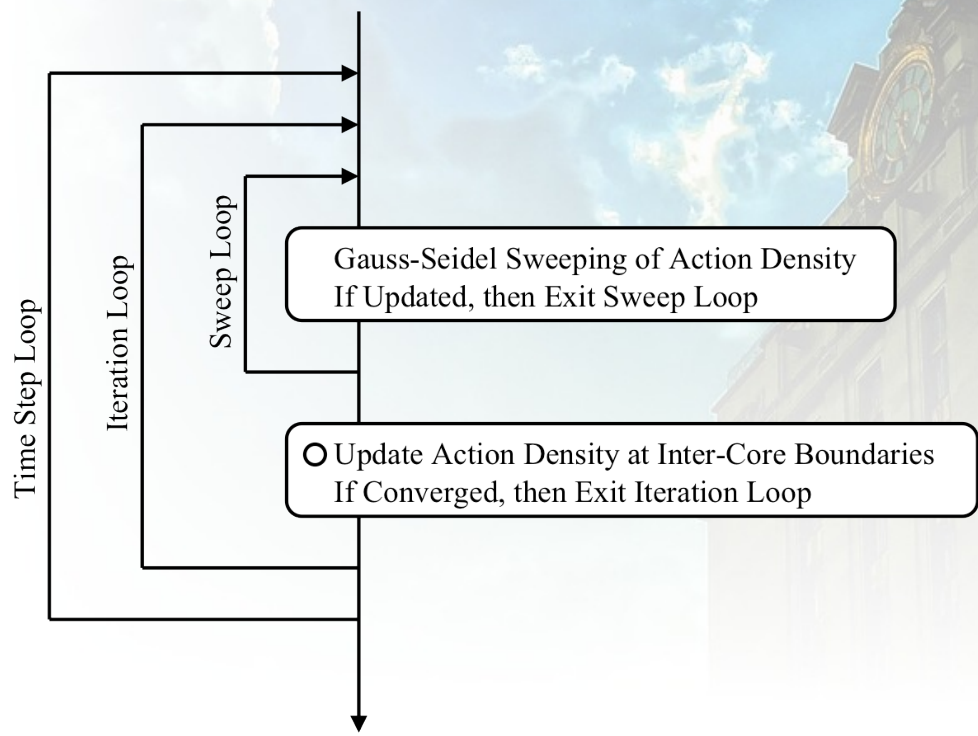
SWAN+ADCIRC

Simulating WAves Nearshore (SWAN):

- Solves the action balance equation:

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

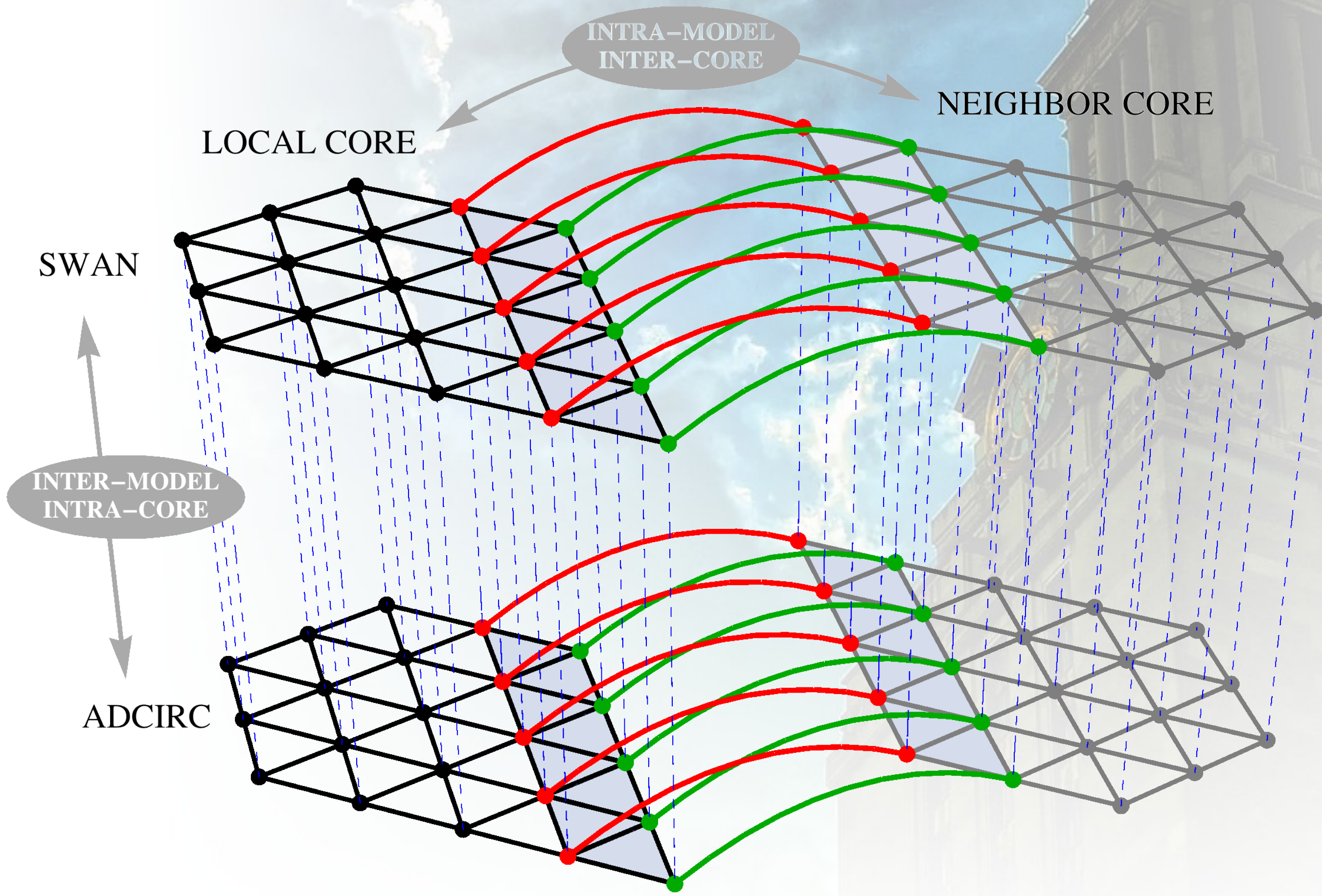
- Sweep the action densities throughout the domain:



SWAN+ADCIRC

'Tight' Coupling:

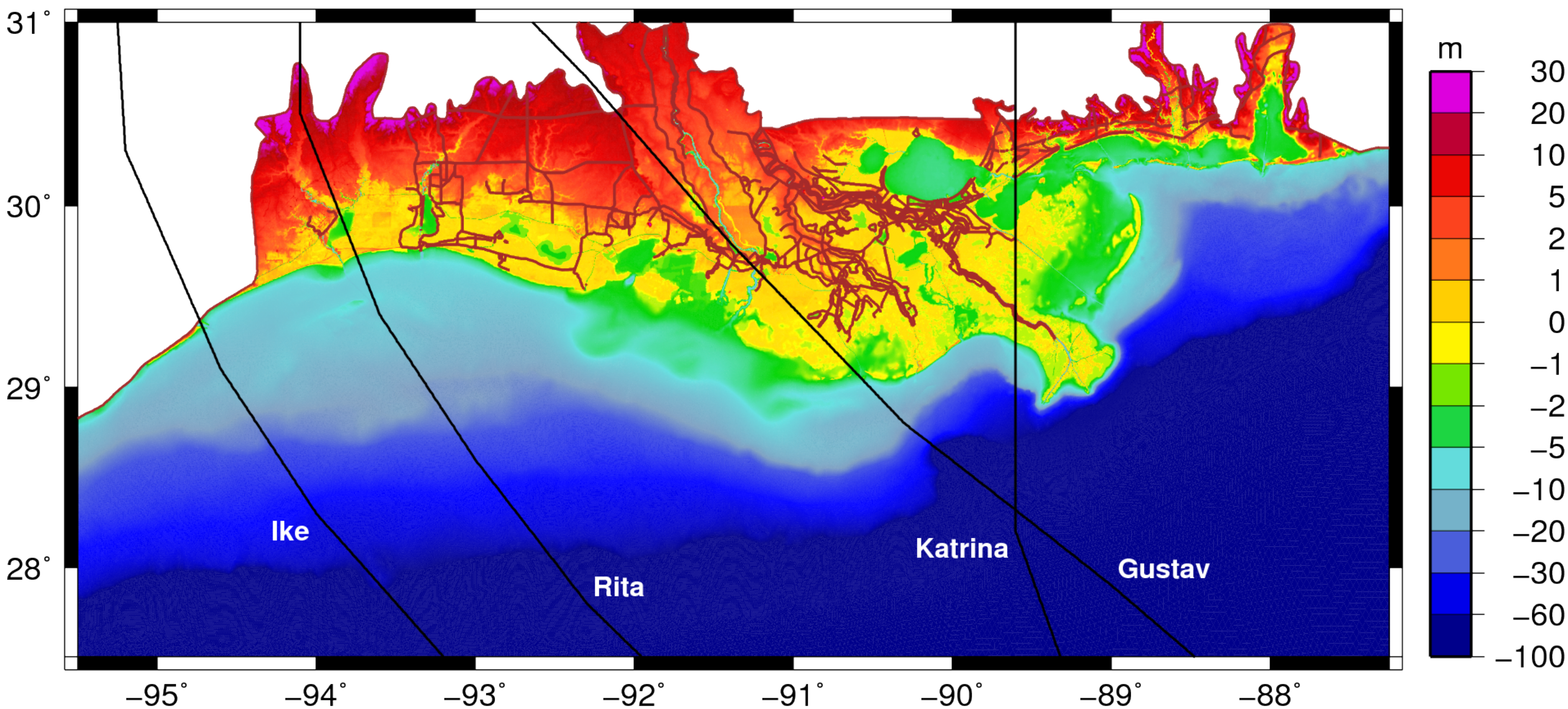
- Models share same local sub-meshes, communicate locally:



SWAN+ADCIRC

SL16 Mesh:

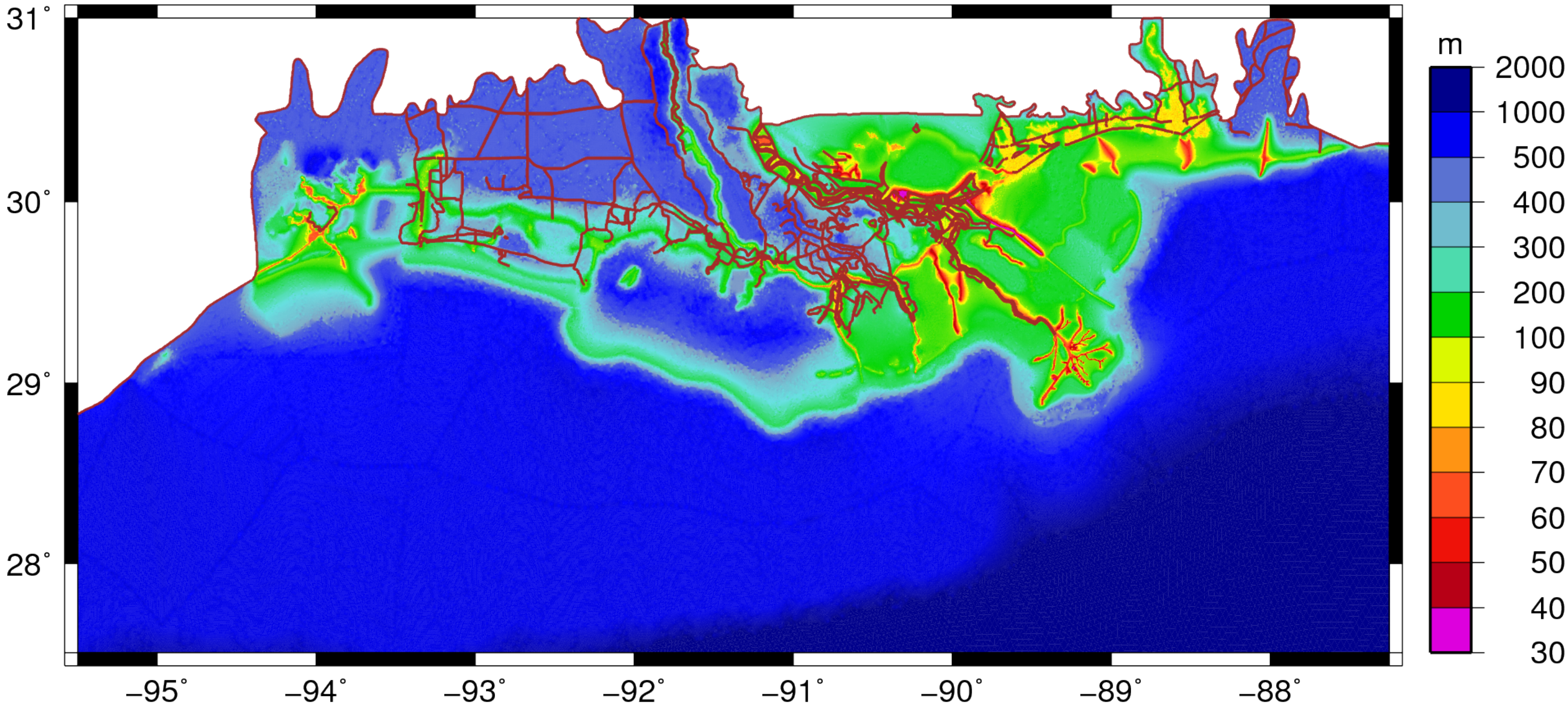
- Bathymetry and Topography:



SWAN+ADCIRC

SL16 Mesh:

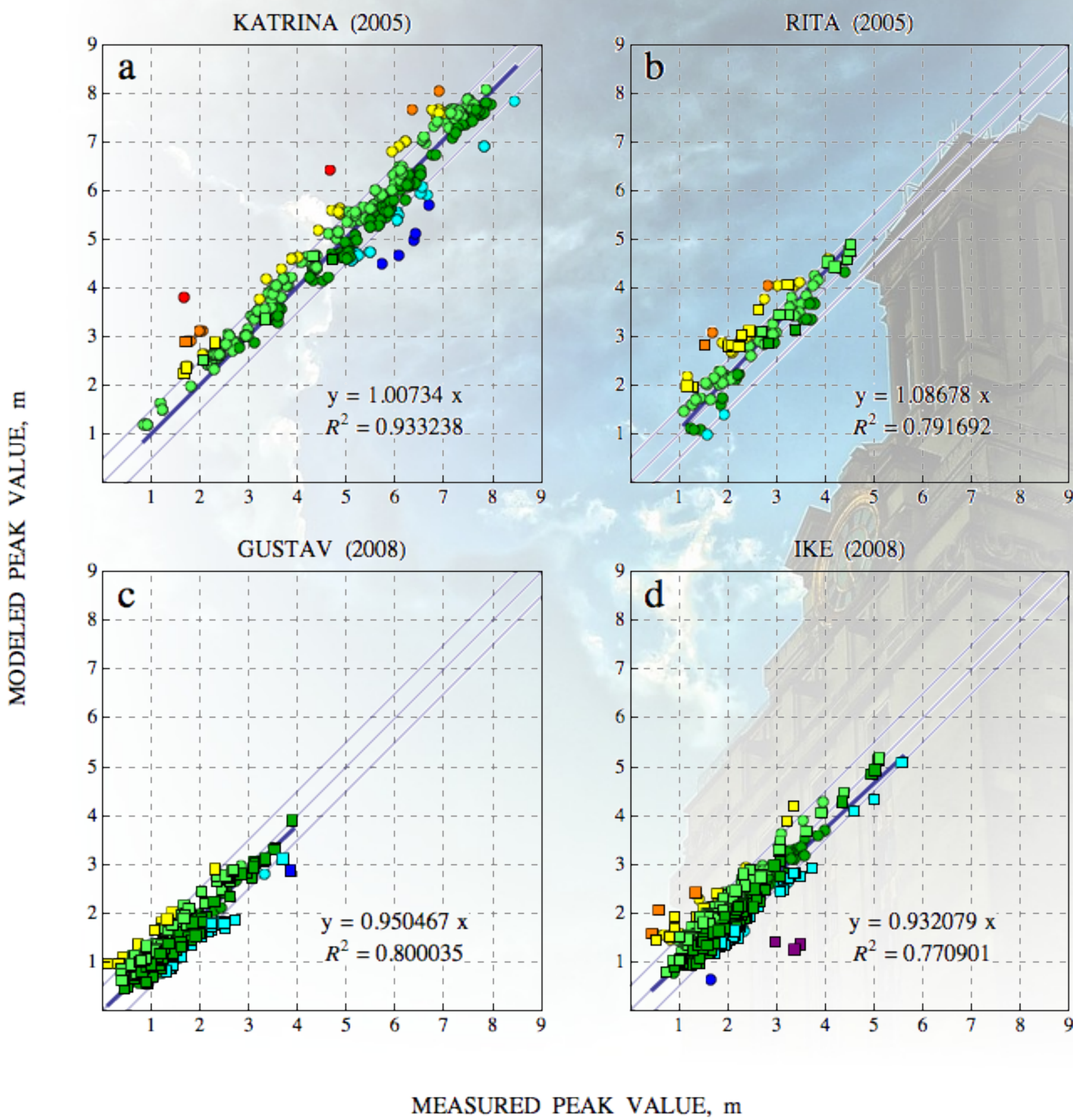
- Mesh Sizes:



SWAN+ADCIRC

		Katrina	Rita	Gustav	Ike
High-Water Marks	USACE	206			
	URS/FEMA	193	84	82	177
Water Levels	CRMS			232	240
	USGS (Perm)	6		18	22
	USGS (Depl)		23	24	16
	USACE			39	41
	USACE-CHL			6	6
	NOAA	3		23	23
	Kennedy			16	
	CSI			5	5
Waves	USACE-CHL			6	6
	Kennedy			16	
	CSI	3	2	5	5
	NDBC	14	11	12	12

SWAN+ADCIRC



KATRINA (2005)
a
y = 1.00734 x
R^2 = 0.933238
RITA (2005)
b
y = 1.08678 x
R^2 = 0.791692
GUSTAV (2008)
c
y = 0.950467 x
R^2 = 0.800035
IKE (2008)
d
y = 0.932079 x
R^2 = 0.770901
MODELED PEAK VALUE, m
MEASURED PEAK VALUE, m

Error Norms for Time Series Data:

- Scatter Index (SI):

$$SI = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(E_i - \overline{E}\right)^2}}{\frac{1}{N}\sum_{i=1}^{N}\left|O_i\right|}$$

- Bias:

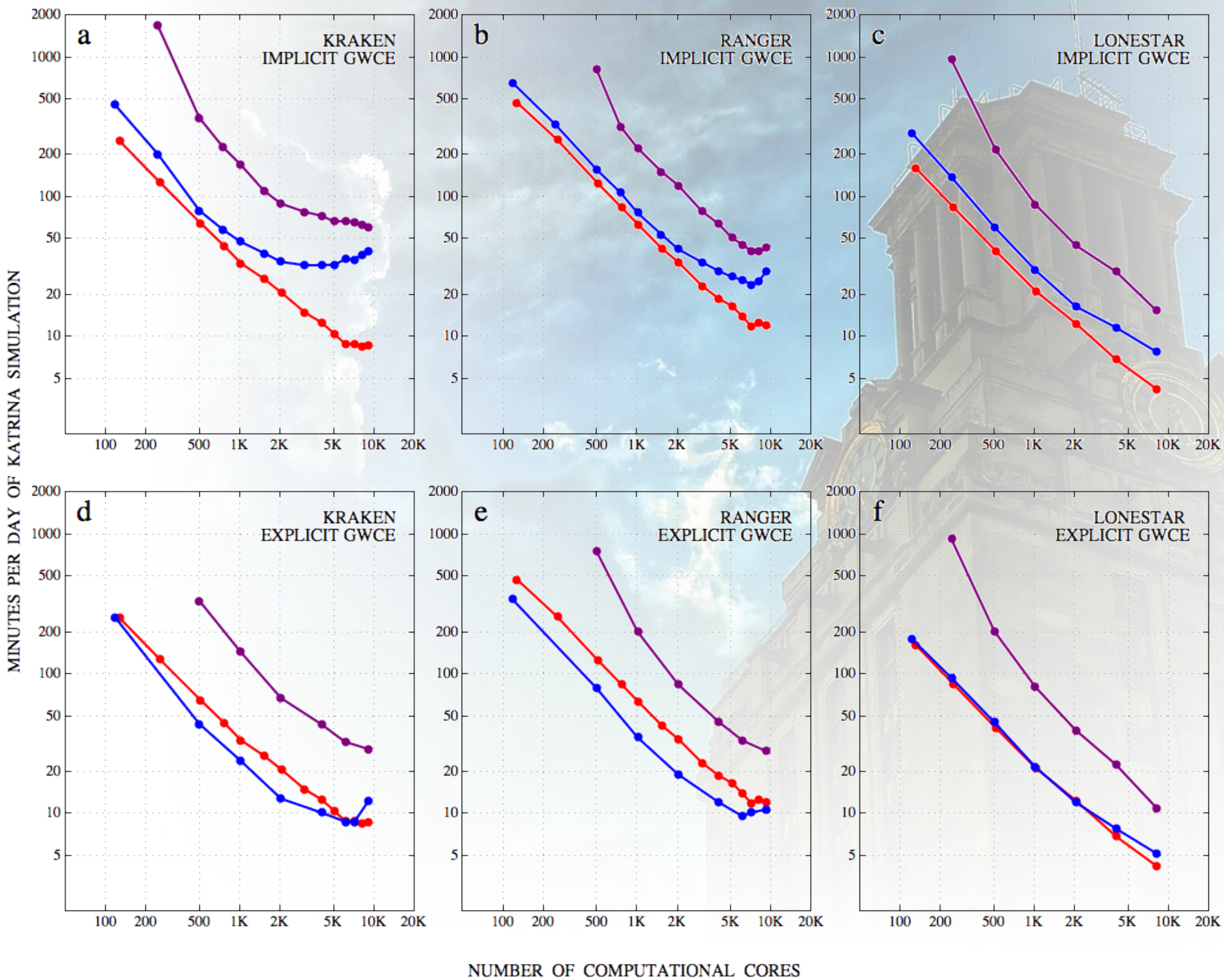
$$Bias = \frac{\frac{1}{N}\sum_{i=1}^{N}E_i}{\frac{1}{N}\sum_{i=1}^{N}\left|O_i\right|}$$

where: N is the number of observations, $E_i = S_i - O_i$ is the error between the modeled (S_i) and measured (O_i) values, and $\overline{E}$ is the mean error.

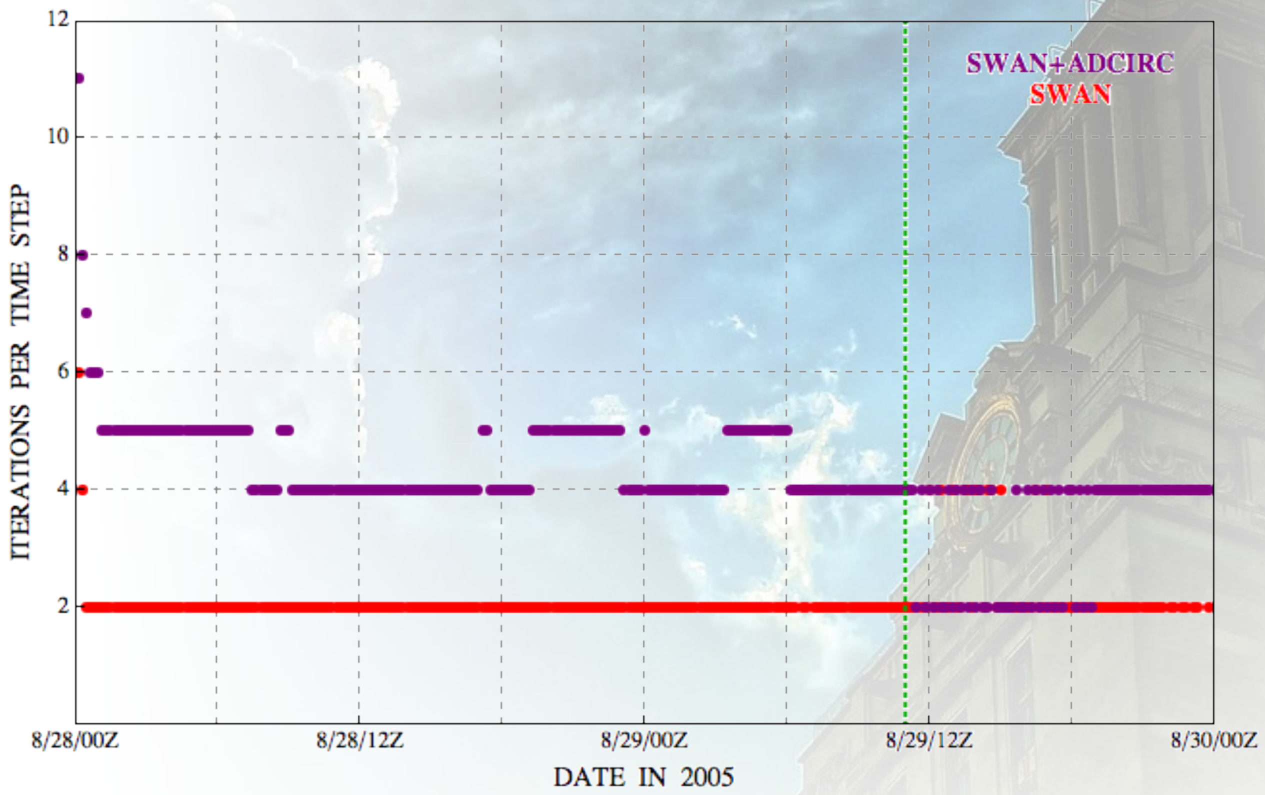
SWAN+ADCIRC

			Katrina	Rita	Gustav	Ike
Water Levels	ς	*m*	1.01	1.09	0.95	0.93
		R^2	0.93	0.79	0.80	0.77
		SI	0.19	0.28	0.24	0.16
		Bias	0.14	0.15	0.14	-0.07
Waves	H_s	*SI*	0.23	0.23	0.34	0.29
		Bias	0.05	0.43	0.35	0.09
	T_p	*SI*	0.22	0.25	0.53	0.57
		Bias	0.07	0.25	-0.03	0.02
	T_{m-10}	*SI*	0.15	0.12	0.22	0.16
		Bias	0.09	0.18	-0.03	0.13

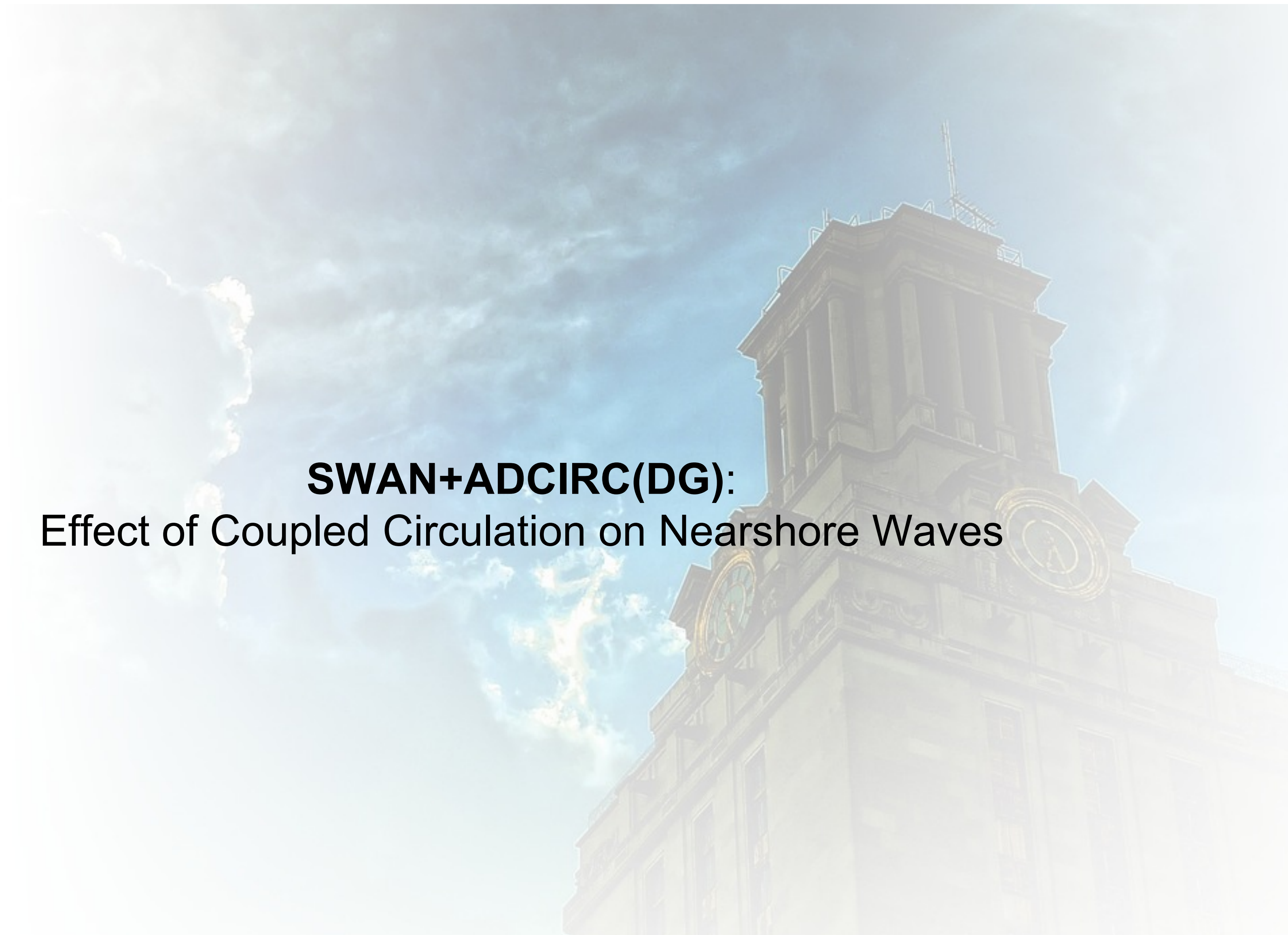
SWAN+ADCIRC


a
KRAKEN
IMPLICIT GWCE
b
RANGER
IMPLICIT GWCE
c
LONESTAR
IMPLICIT GWCE
d
KRAKEN
EXPLICIT GWCE
e
RANGER
EXPLICIT GWCE
f
LONESTAR
EXPLICIT GWCE
2000
1000
500
200
100
50
20
10
5
100
200
500
1K
2K
5K
10K
20K
MINUTES PER DAY OF KATRINA SIMULATION
NUMBER OF COMPUTATIONAL CORES

SWAN+ADCIRC



SWAN+ADCIRC
SWAN
12
10
8
6
4
2
ITERATIONS PER TIME STEP
8/28/00Z
8/28/12Z
8/29/00Z
8/29/12Z
8/30/00Z
DATE IN 2005



SWAN+ADCIRC(DG):
Effect of Coupled Circulation on Nearshore Waves

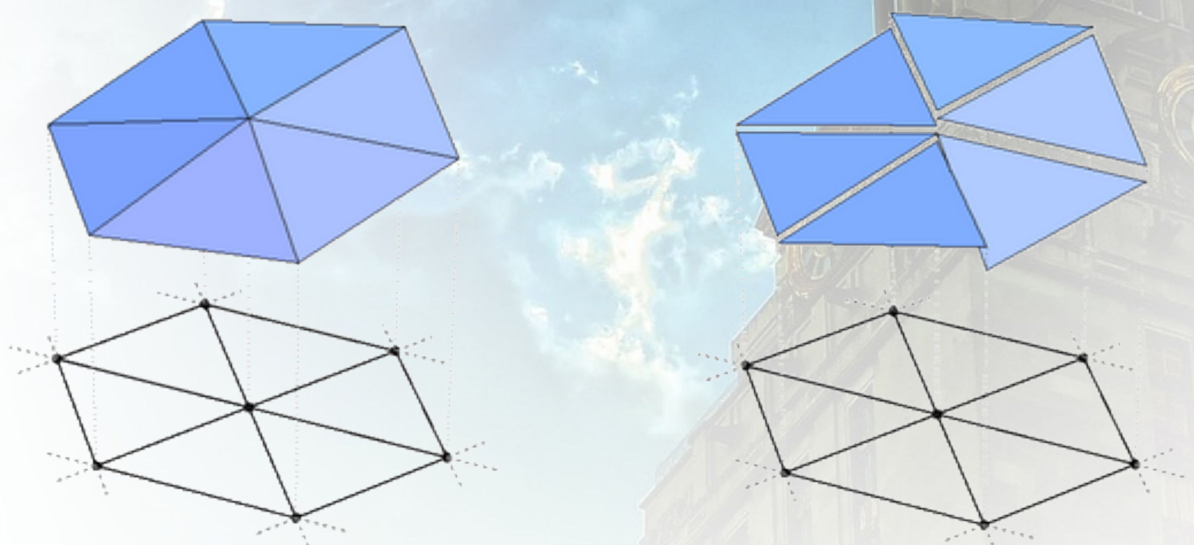
E.J. Kubatko, *et al.* (2006). “*hp* Discontinuous Galerkin Methods for Advection Dominated Problems in Shallow Water Flow.” *Computer Methods in Applied Mechanics and Engineering*, 196, 437-451.

C.N. Dawson, *et al.* (2011). ”Discontinuous Galerkin Methods for Modeling Hurricane Storm Surge.” *Advances in Water Resources*, in press.

J.C. Dietrich, *et al.* (2011). “Effect of Coupled Circulation on a Nearshore Wave Model.” *Coastal Engineering*, in preparation.

Discontinuous Galerkin (DG):

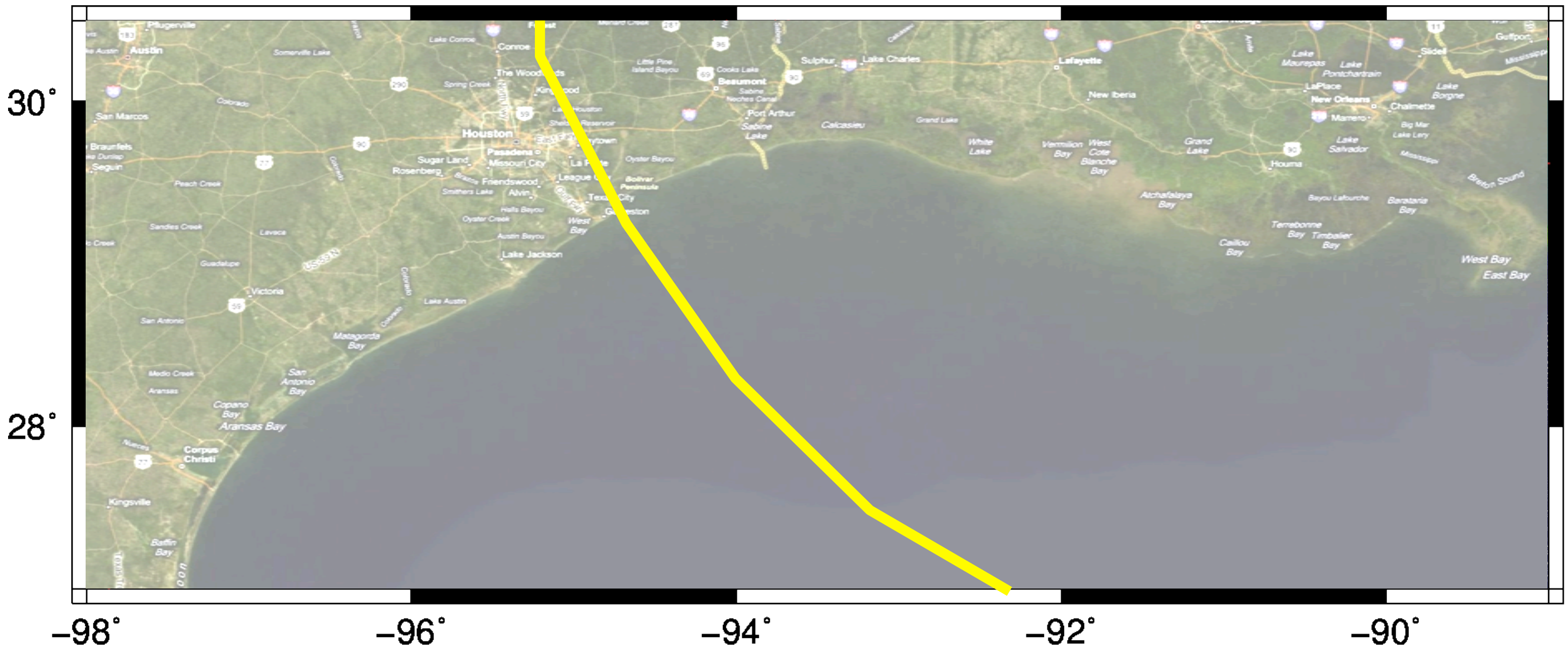
- Uses local basis functions that can be *p*-adaptive.
- Solution can be discontinuous along element edges:



Ike on the LATEX Shelf

Hurricane Ike (2008):

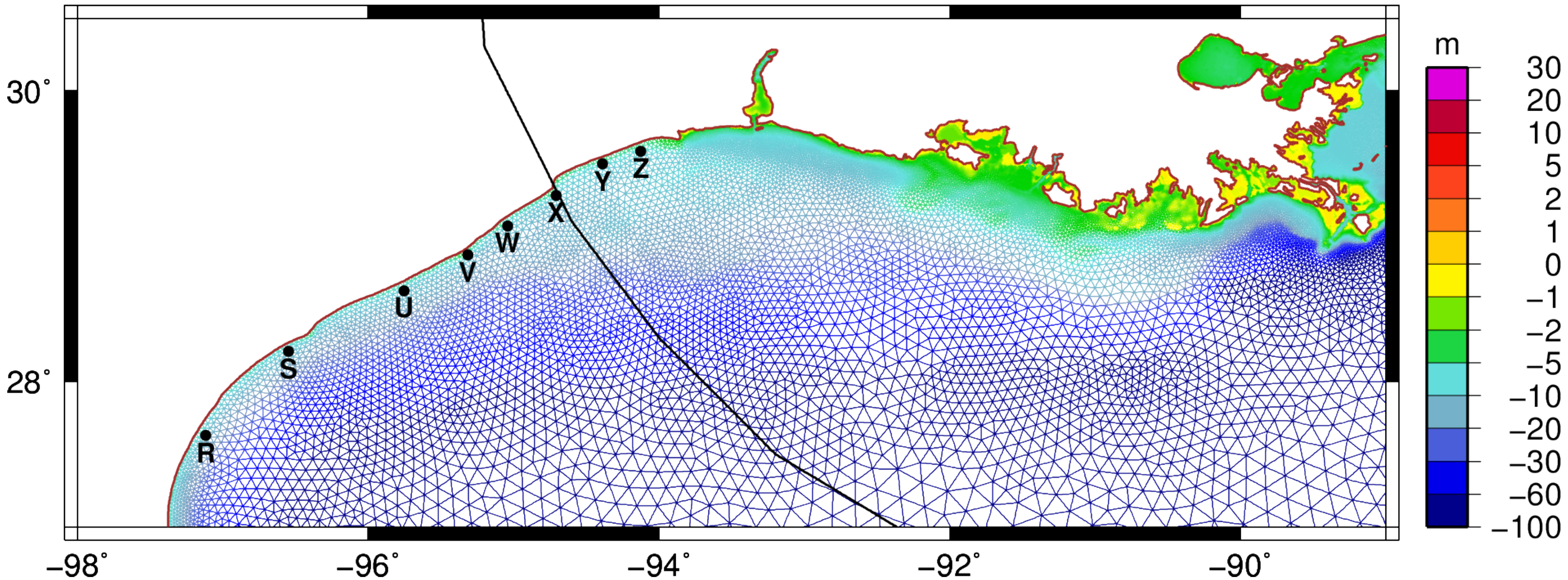
- Made landfall near Galveston, TX:



Ike on the LATEX Shelf

EC2001 Mesh:

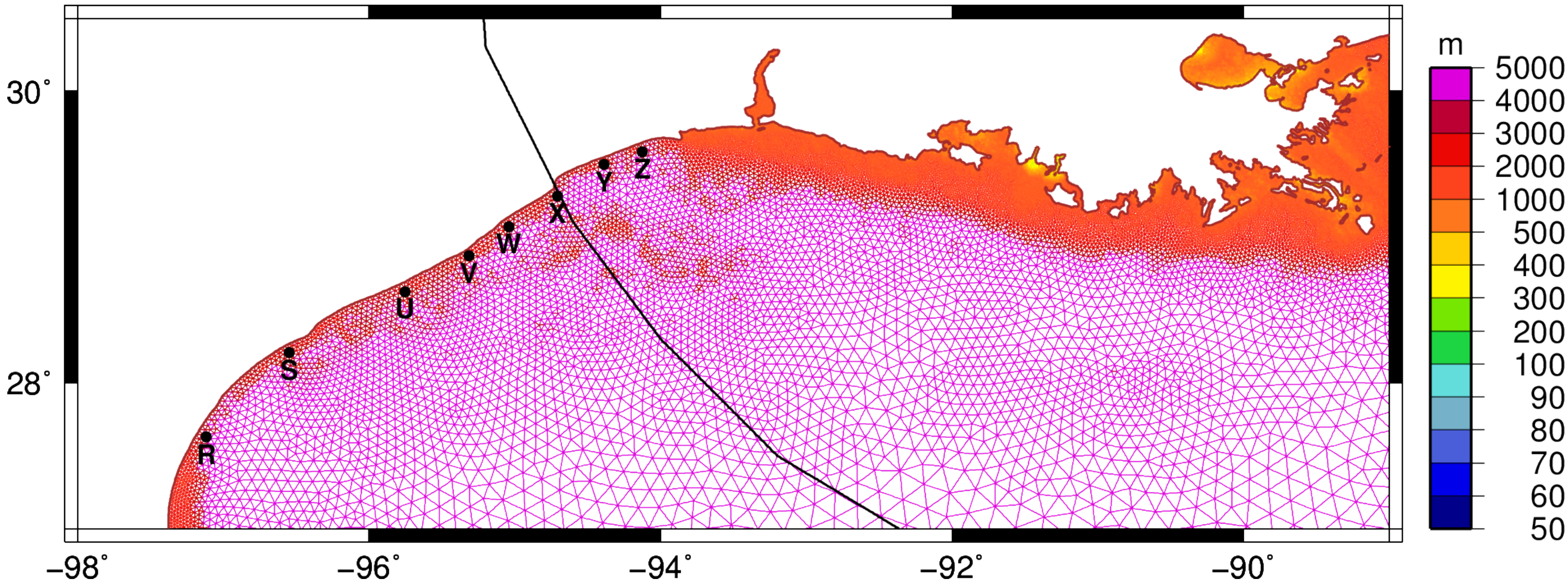
- Bathymetry and Topography:



Ike on the LATEX Shelf

EC2001 Mesh:

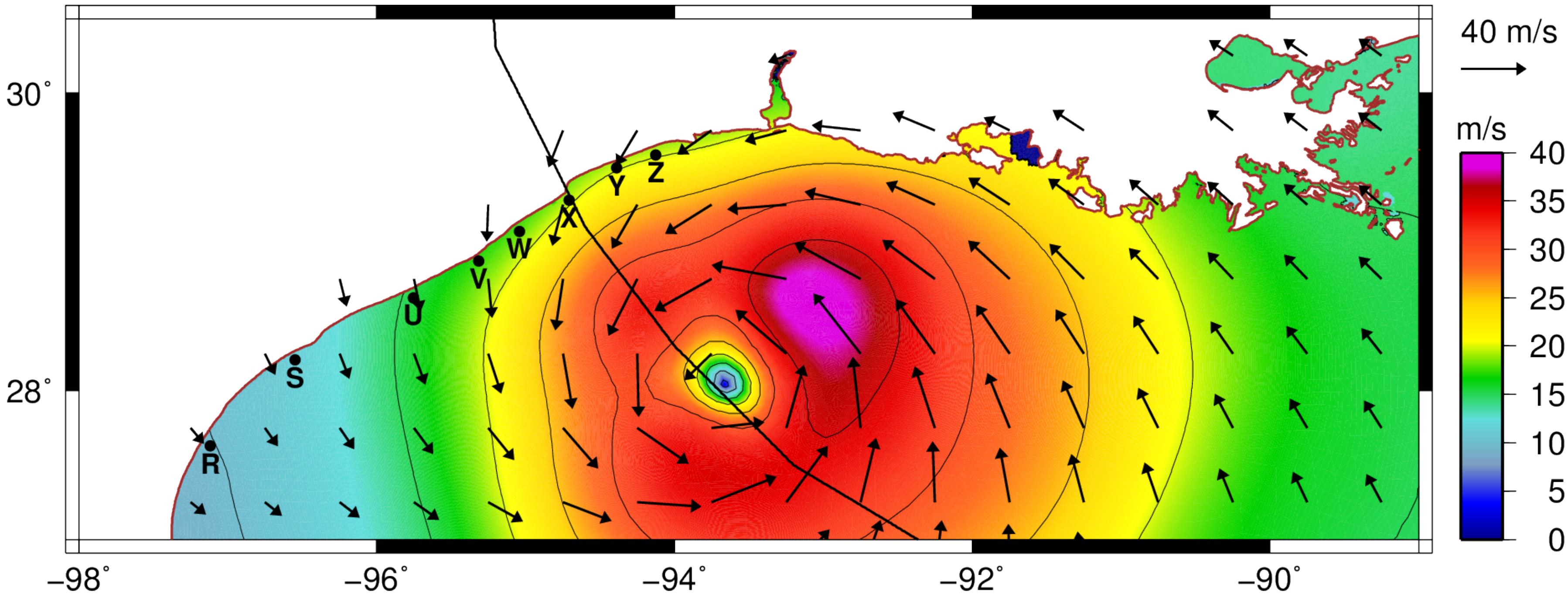
- Mesh Sizes:



Ike on the LATEX Shelf

2008 / 09 / 12 / 2200Z:

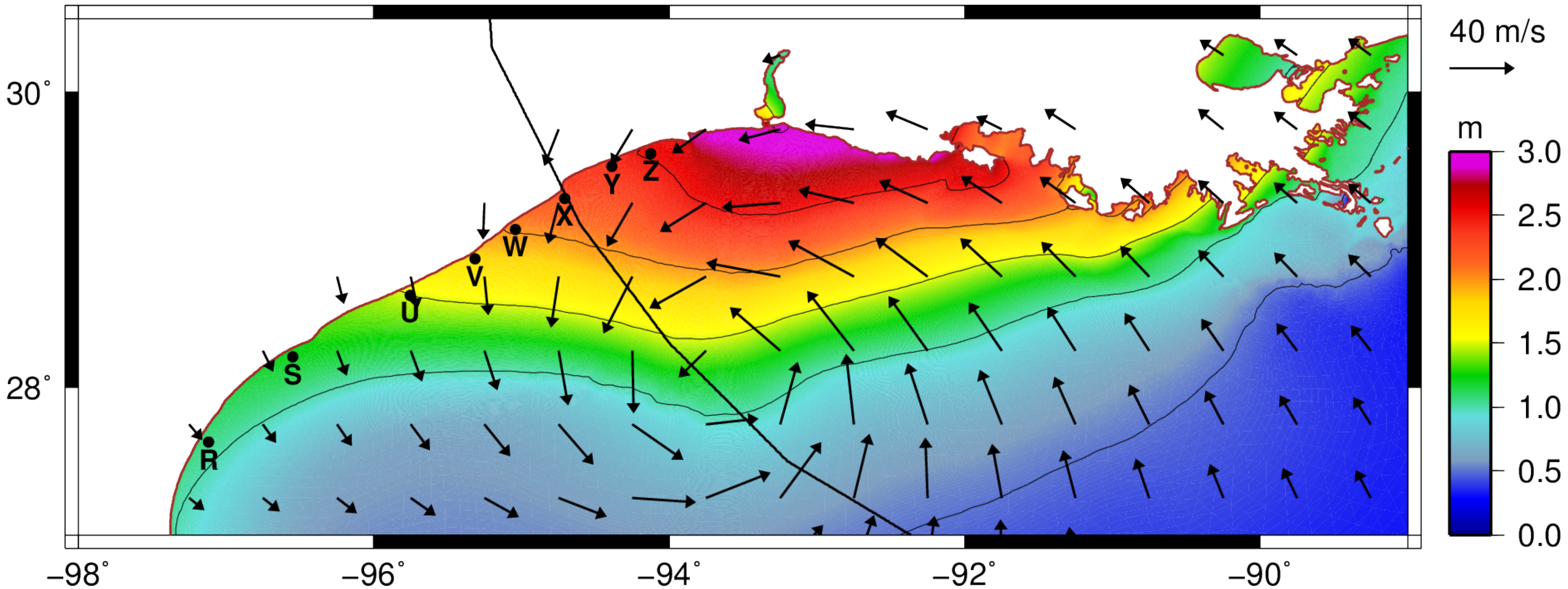
- Wind Speeds:



Ike on the LATEX Shelf

2008 / 09 / 12 / 2200Z:

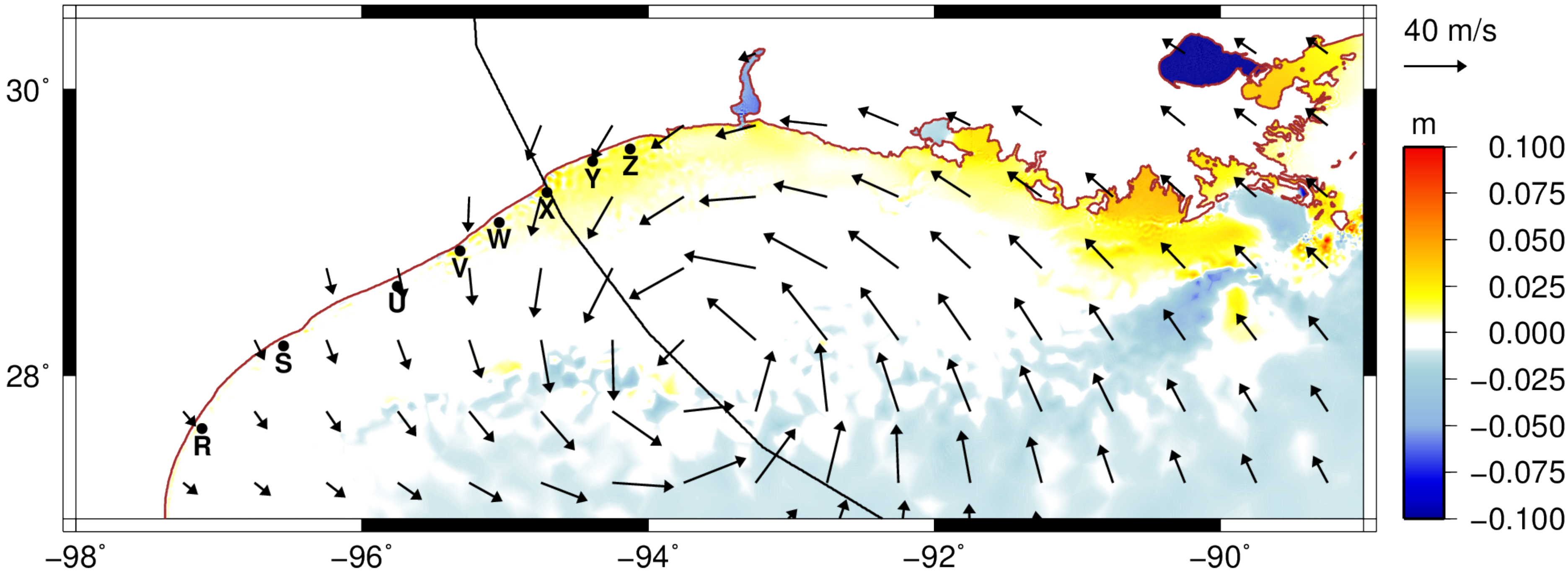
- DG Water Levels:



Ike on the LATEX Shelf

2008 / 09 / 12 / 2200Z:

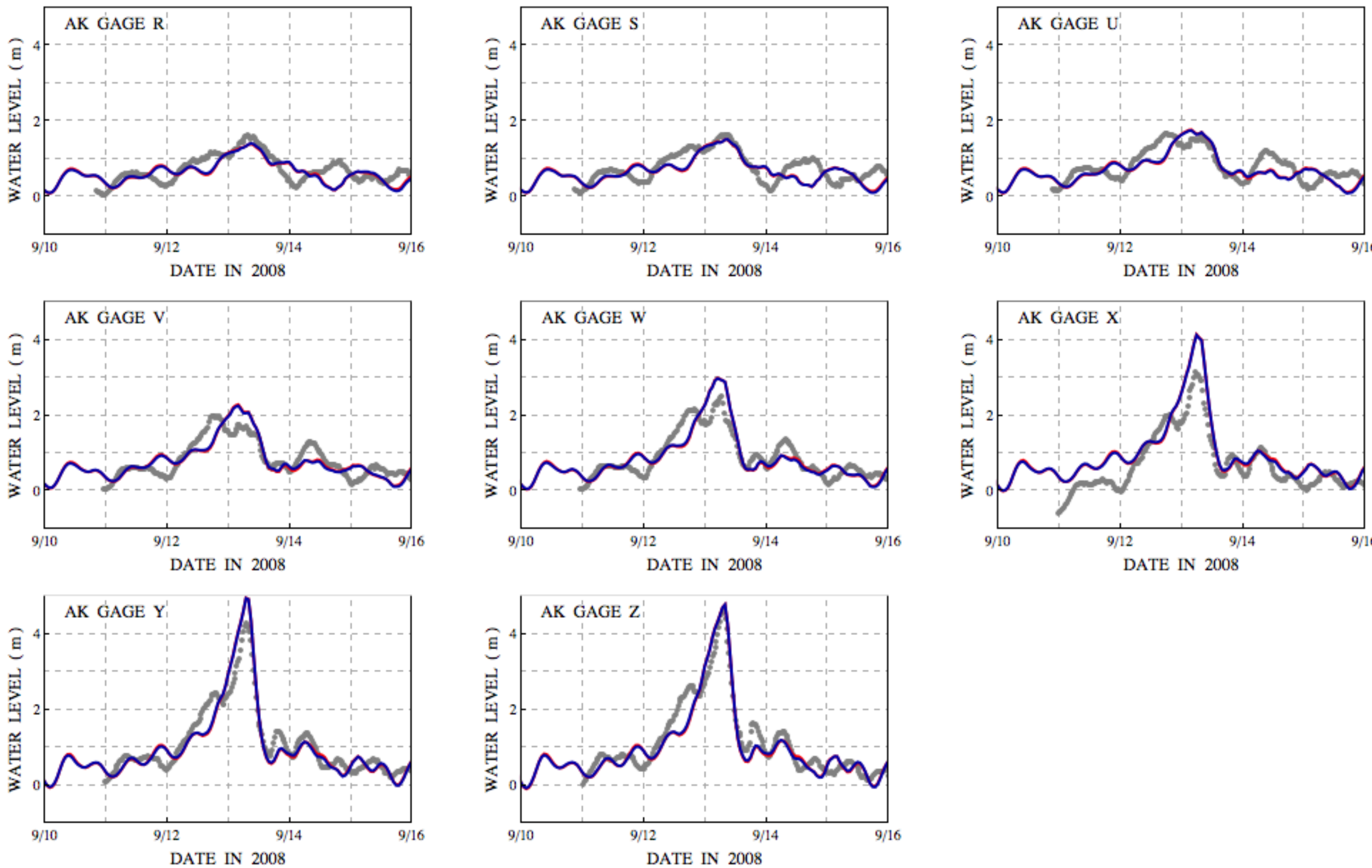
- Difference between DG and ADCIRC Water Levels:



Ike on the LATEX Shelf

Kennedy Gages:

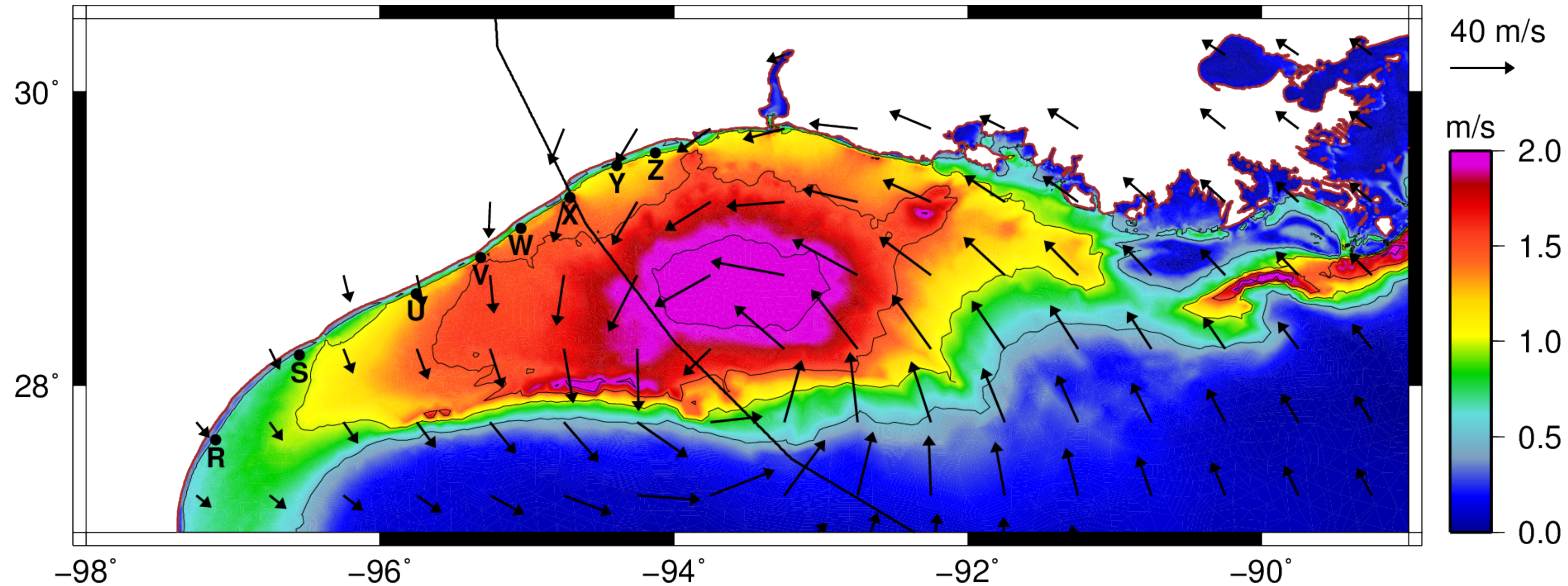
- DG Water Levels:



Ike on the LATEX Shelf

2008 / 09 / 12 / 2200Z:

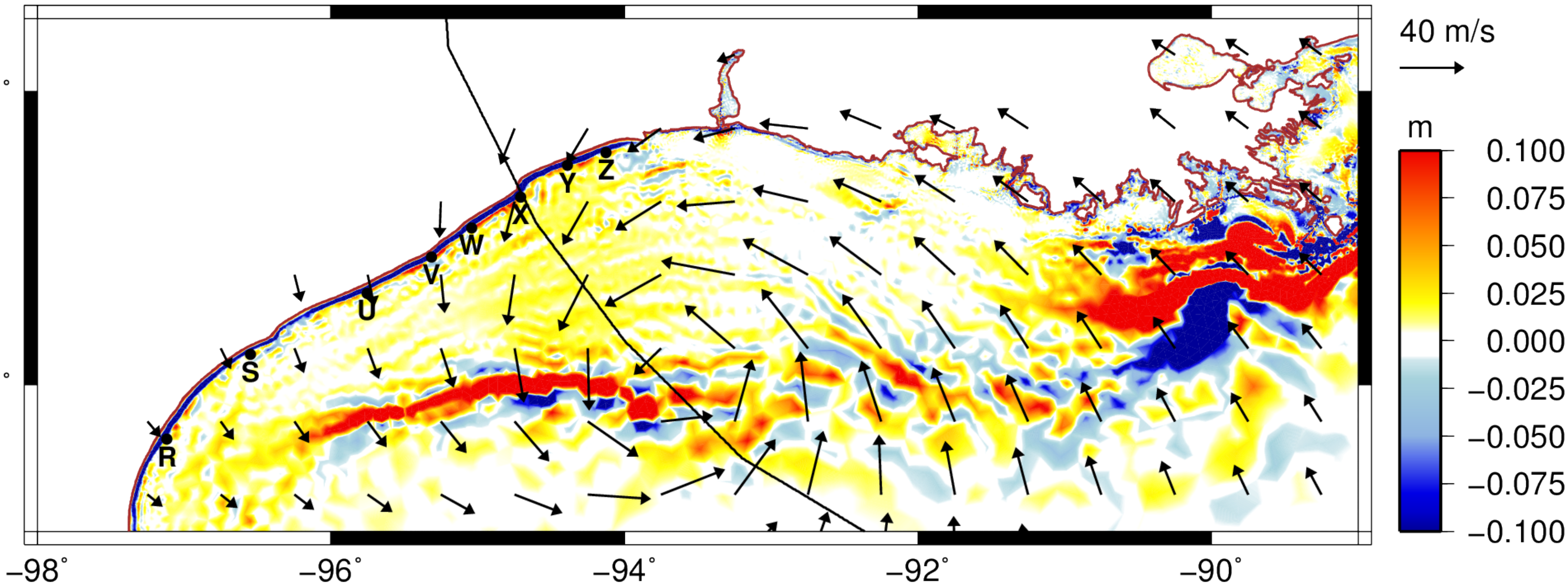
- DG Currents:



Ike on the LATEX Shelf

2008 / 09 / 12 / 2200Z:

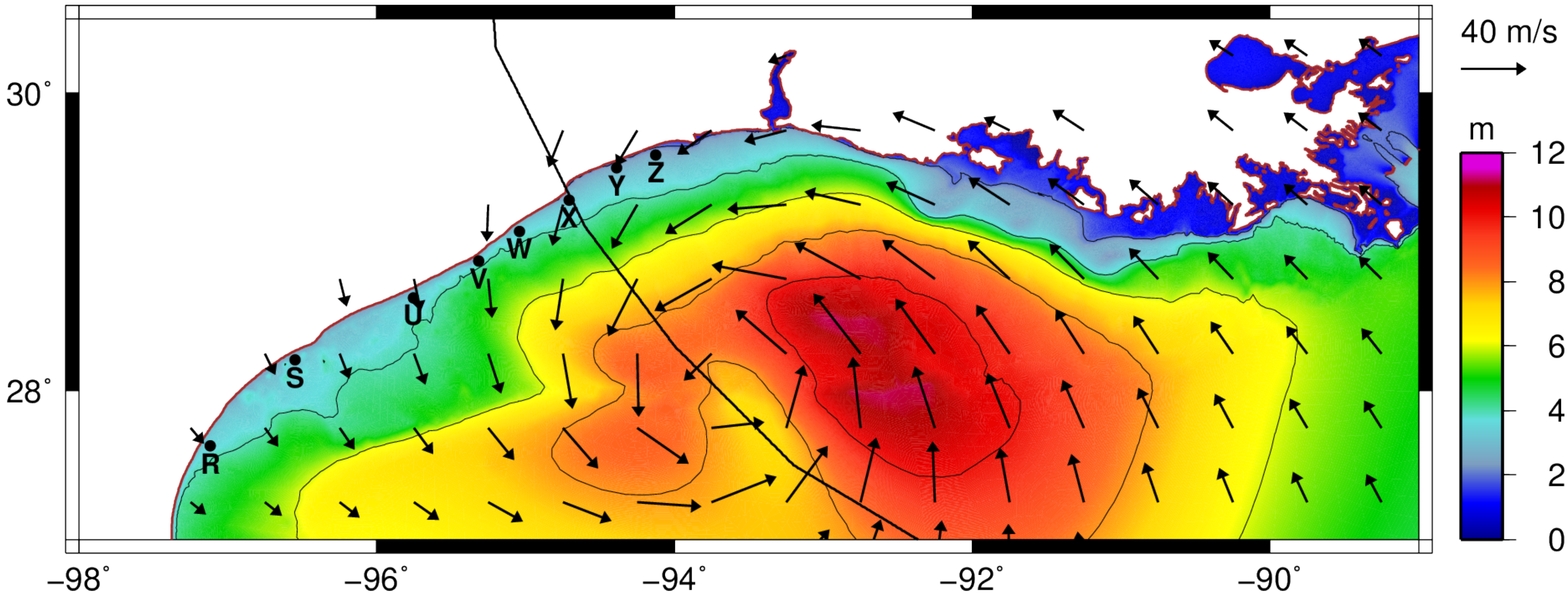
- Difference between DG and ADCIRC Currents:



Ike on the LATEX Shelf

2008 / 09 / 12 / 2200Z:

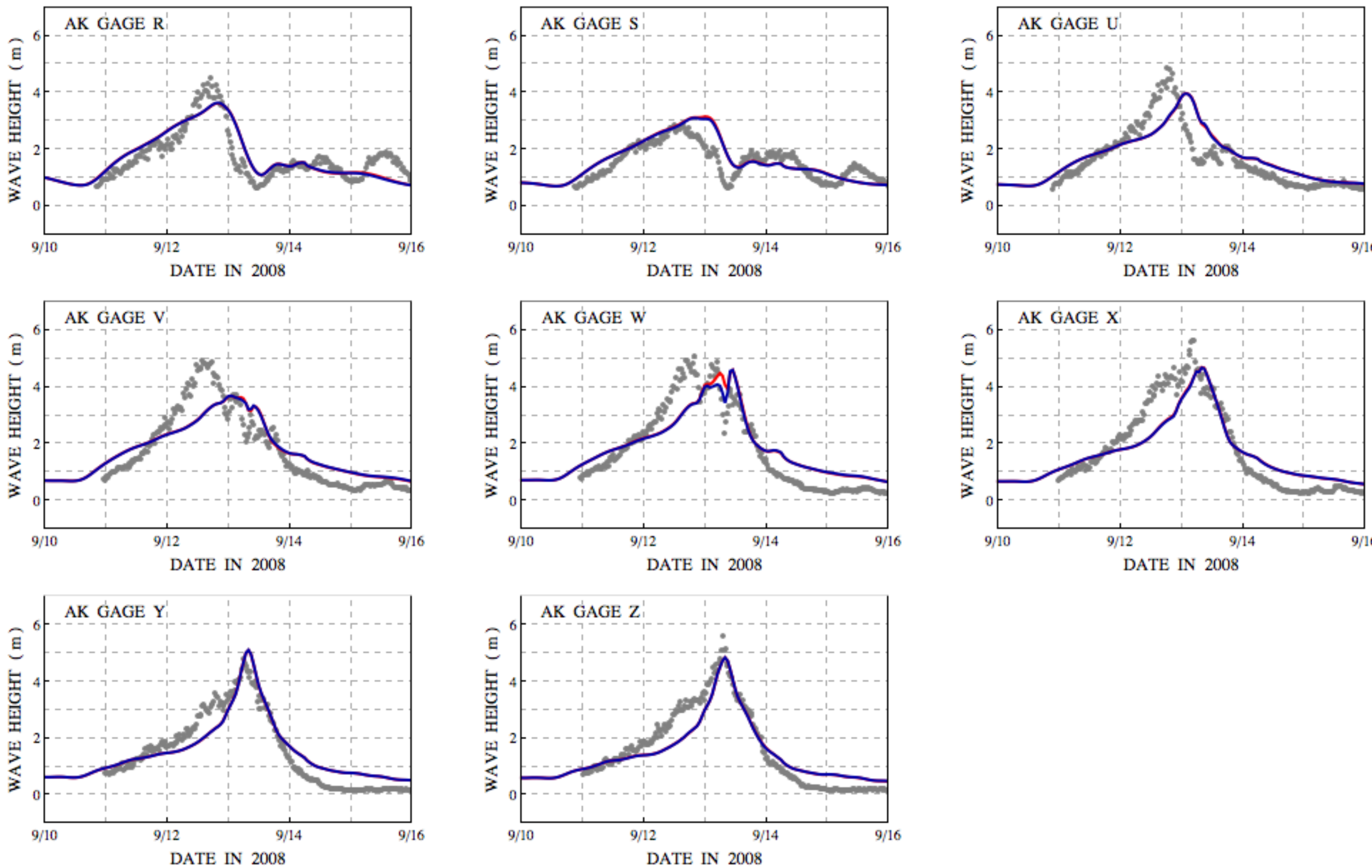
- SWAN+DG Wave Heights:



Ike on the LATEX Shelf

Kennedy Gages:

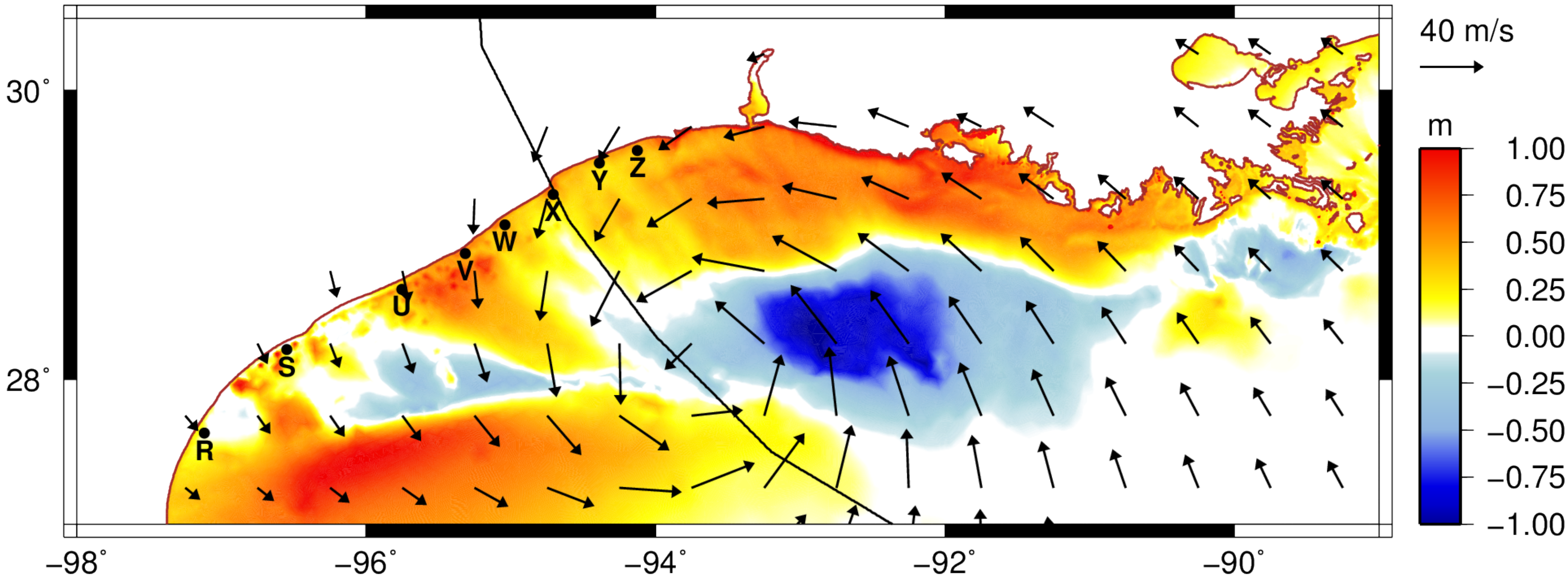
- SWAN+DG Wave Heights:



Ike on the LATEX Shelf

2008 / 09 / 12 / 2200Z:

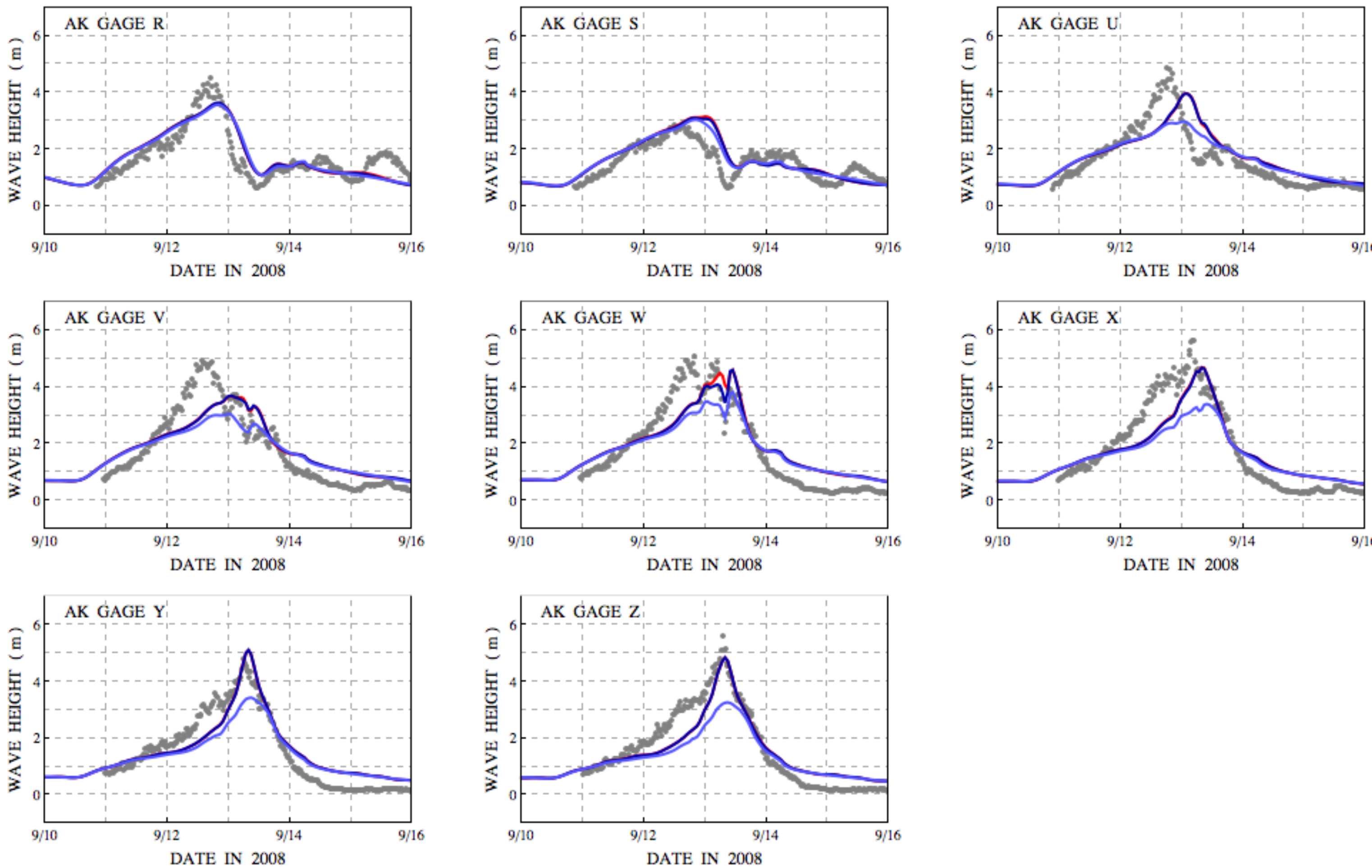
- Effect of Circulation on SWAN+DG Wave Heights:



Ike on the LATEX Shelf

Kennedy Gages:

- Effect of Circulation on SWAN+DG Wave Heights:



The End

Conclusions:

- DG model produces circulation that is very similar to ADCIRC:
  - Water levels are nearly identical.
  - Currents are more peaked in regions with bathymetric gradients.
- SWAN+DG simulates well the waves and storm surge on the shelf.
- SWAN solution is sensitive to circulation:
  - Wave heights increased by 1m.
  - Wave periods increased by 4s (but not shown herein).

Future Work:

- Extend SWAN+DG to high-resolution Texas mesh.