Meteorology and oceanography computational work at HPC²

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I. Background
II. Some hurricane examples (4DVAR, model coupling, storm surge)

Background

- Atmospheric modeling (MM5, COAMPS, WRF), operational and research
- Model coupling
- Data assimilation (OI, 3DVAR, 4DVAR), collaborations with NCAR
- Hurricanes
- Severe weather
- Sea breeze, coastal thunderstorm climatology
- Storm surge, ocean wave, and ocean circulation modeling

Although the following examples involve hurricanes, we perform research on a variety of meteorology and oceanography issues

Hurricane Lili's unexpected weakening

HURRICANE LILI DISCUSSION NUMBER 46
NATIONAL WEATHER SERVICE MIAMI FL
5 PM EDT WED OCT 02 2002

LILI WENT THROUGH ANOTHER BURST OF INTENSIFICATION THIS AFTERNOON... WITH THE CENTRAL PRESSURE FALLING FROM 954 MB TO 941 MB IN ABOUT 5 HR. THE HURRICANE HAS CONTINUED TO DEEPEN AT A SLOWER RATE SINCE 16Z...WITH THE CENTRAL PRESSURE FALLING TO 938 MB AT 20Z. THE MAXIMUM FLIGHT LEVEL WINDS FOUND BY THE VARIOUS AIRCRAFT SAMPLING LILI SO FAR ARE 136 KT...SO THE INITIAL INTENSITY IS SET TO 120 KT. LILI IS SHOWING SIGNS OF PEAKING...AS THE AIRCRAFT AND SATELLITE IMAGERY INDICATE THE BEGINNING OF AN OUTER EYEWALL THAT WILL LIKELY BRING A HALT TO THE CURRENT INTENSIFICATION.
(TEXT DELETED)

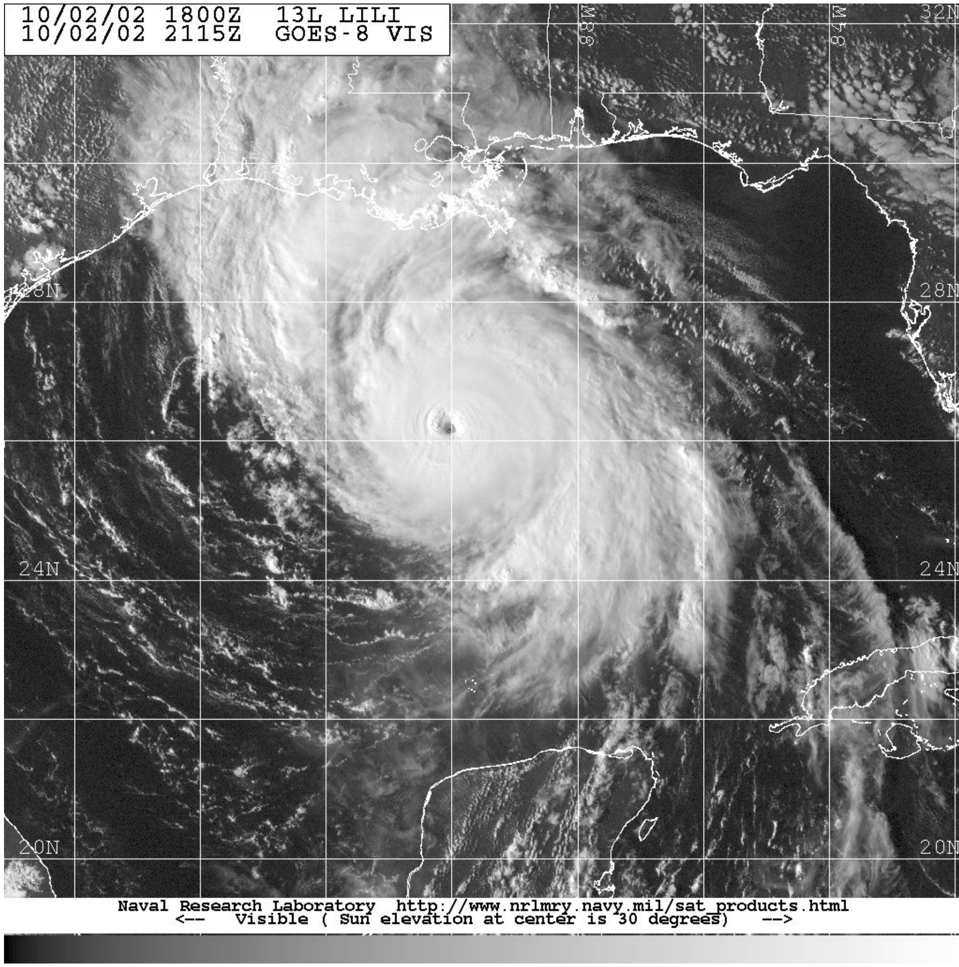
IN ADDITION TO THE CONCENTRIC EYEWALLS...THE ACTUAL INTENSITY IS CATCHING UP WITH THE SATELLITE SIGNATURE AND THE OUTFLOW IS BEING RESTRICTED TO THE WEST AND SOUTHWEST BY AN UPPER-LEVEL TROUGH. THESE THINGS SUGGEST THAT LILI SHOULD PEAK IN THE NEXT 6-12 HR THEN UNDERGO FLUCTUATIONS IN STRENGTH UNTIL LANDFALL. REGARDLESS OF THE EXACT INTENSITY...LILI SHOULD MAKE LANDFALL AS A MAJOR HURRICANE.

FORECASTER BEVEN

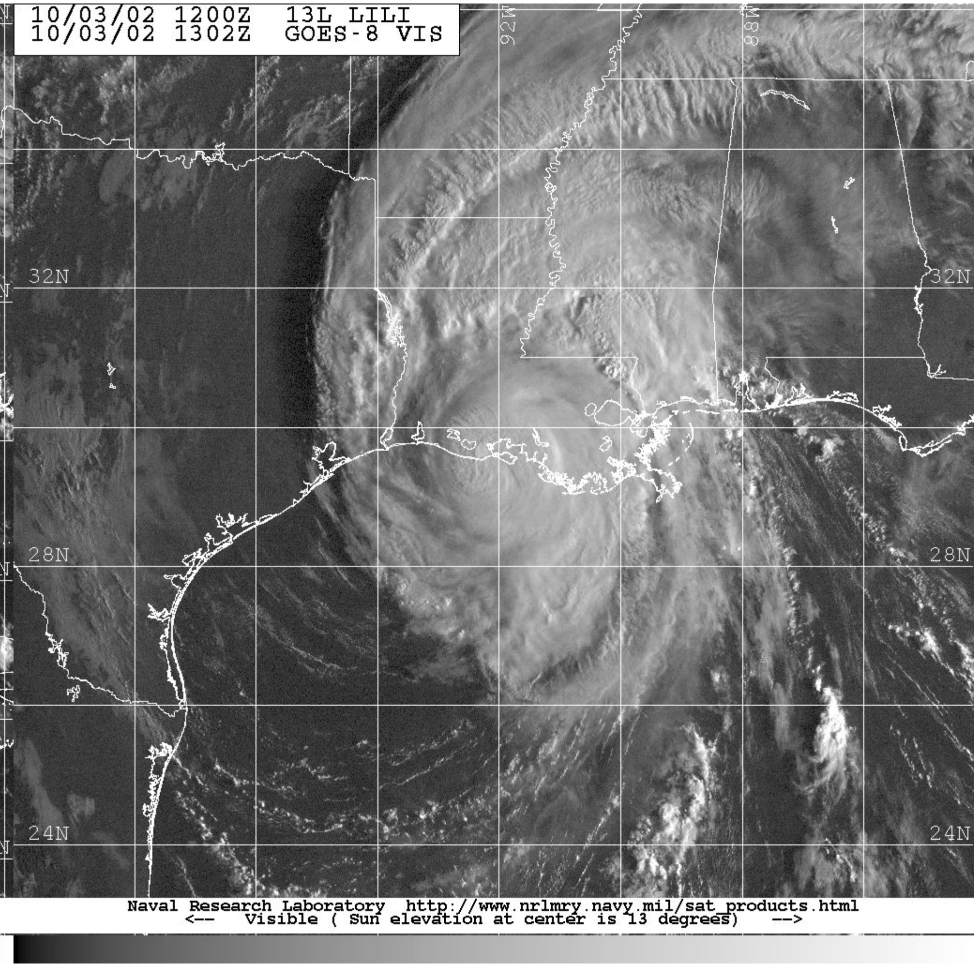
FORECAST POSITIONS AND MAX WINDS

INITIAL	02/2100Z	25.9N	90.0W	120 KTS
12HR VT	03/0600Z	27.5N	91.4W	125 KTS
24HR VT	03/1800Z	29.8N	92.3W	125 KTS...INLAND
36HR VT	04/0600Z	32.2N	91.9W	65 KTS...INLAND
48HR VT	04/1800Z	36.1N	89.0W	35 KTS...INLAND EXTRATROPICAL
72HR VT	05/1800Z	45.0N	74.0W	30 KTS...INLAND EXTRATROPICAL

AFTER QUICKLY STRENGTHENING TO A STRONG CAT. 4 HURRICANE, LILI WEAKENED EVEN MORE RAPIDLY THAN IT HAD INTENSIFIED



LILI NEAR ITS MAXIMUM INTENSITY OF 145 MPH

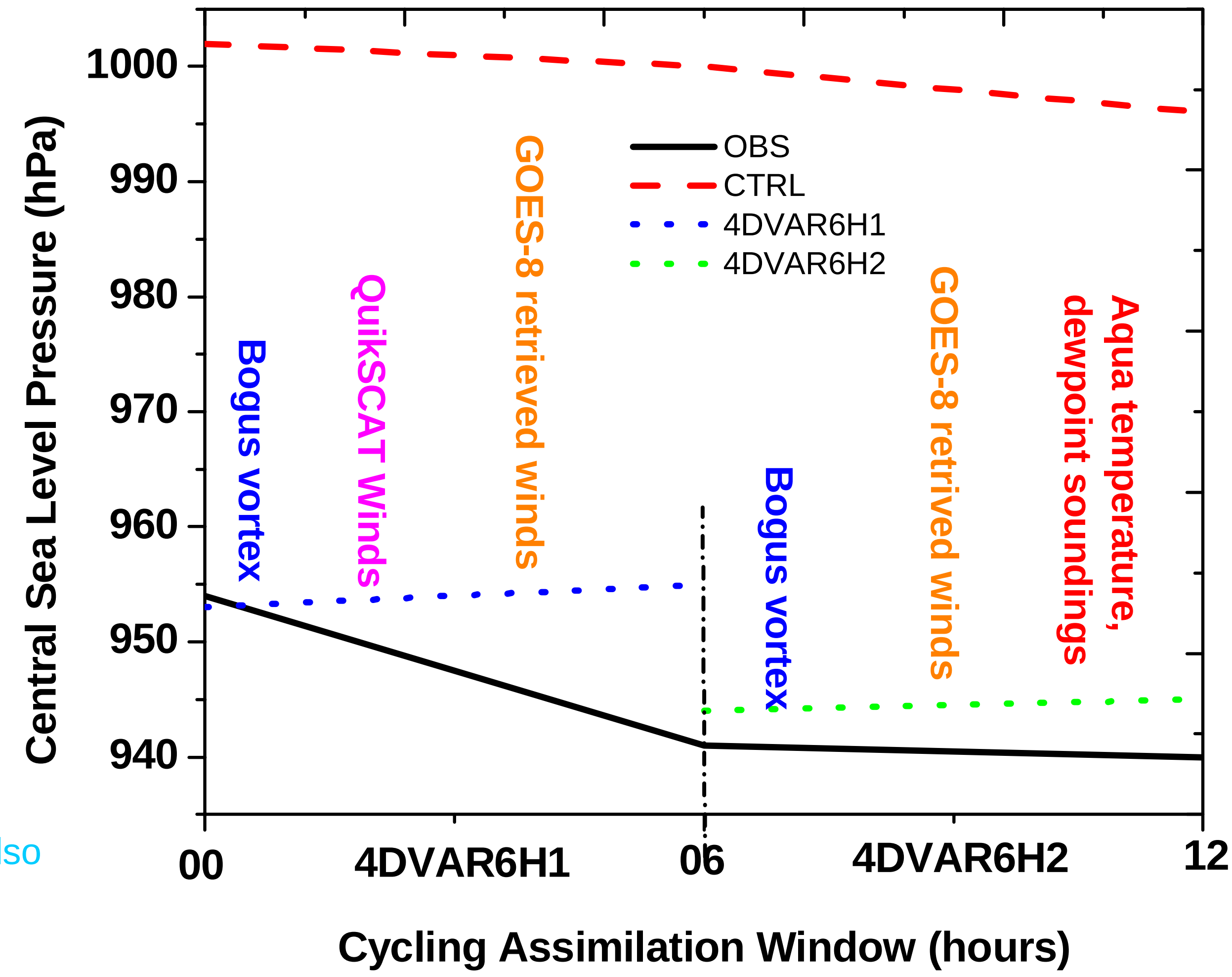


LILI MAKING LANDFALL AS A CAT. 1 HURRICANE

Sensitivity of Lili to NASA satellite data

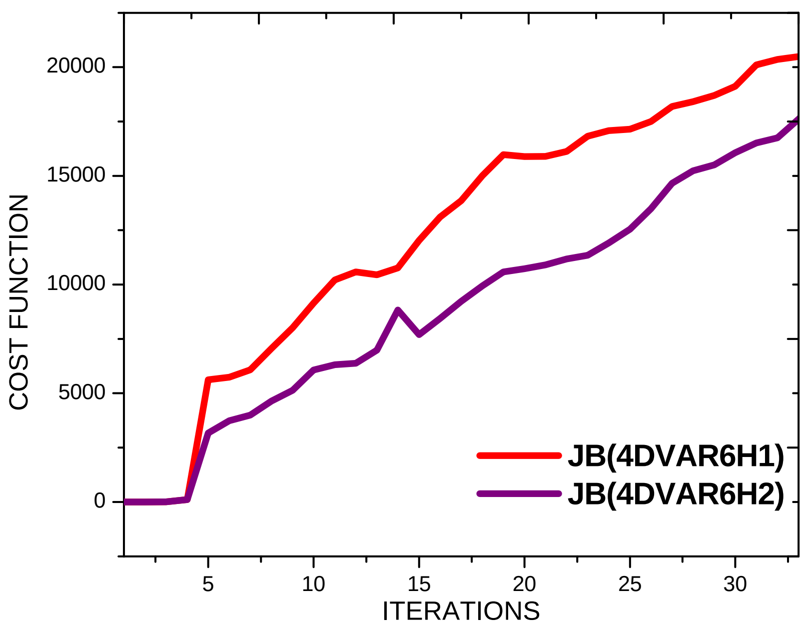
(to be published in AMS journal Monthly Weather Review)

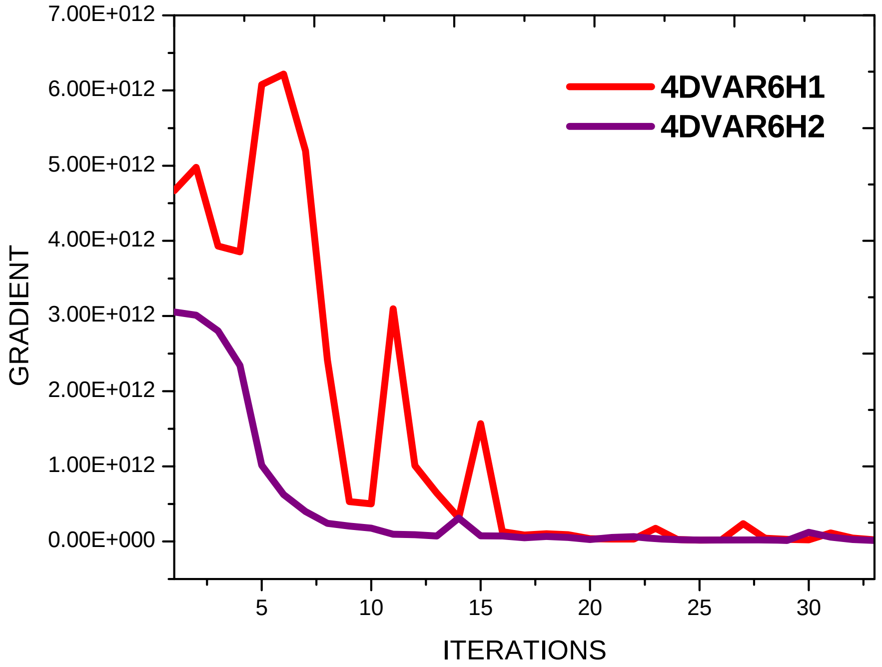
4DVAR strategy



Conventional observations also assimilated

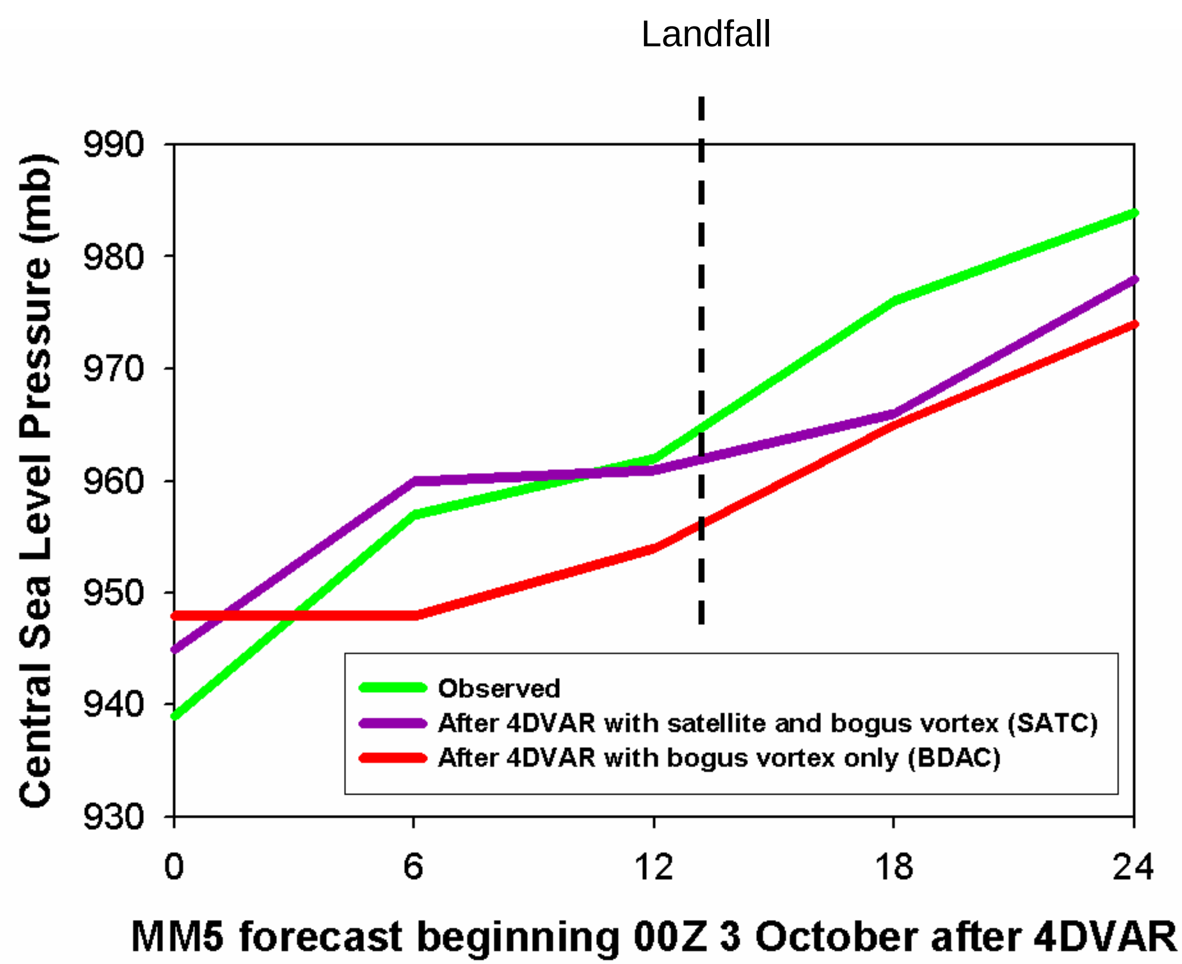
Cost function and gradient in 4DVAR6H1 and 4DVAR6H2





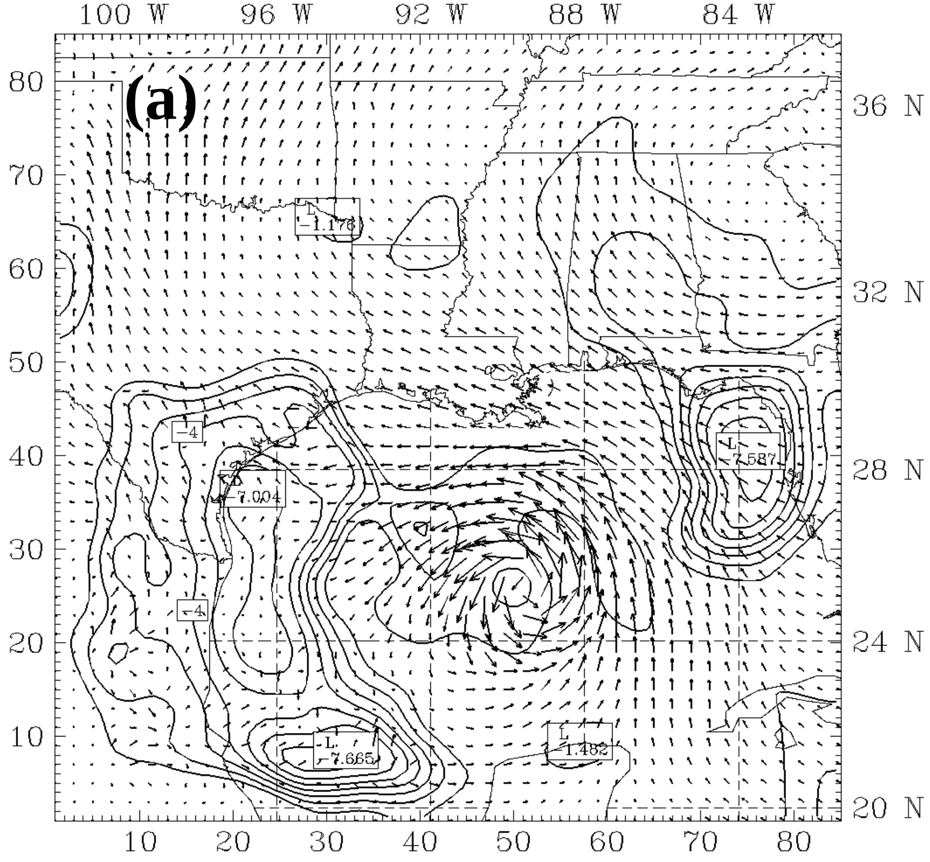
Gradient for both 4DVAR6H1 and 4DVAR6H2 have good convergence, which show all data were assimilated well.

30 iterations were integrated in each 4DVAR assimilation window. Each iteration takes about 5 hours!


Landfall
Central Sea Level Pressure (mb)
990
980
970
960
950
940
930
0
6
12
18
24
Observed
After 4DVAR with satellite and bogus vortex (SATC)
After 4DVAR with bogus vortex only (BDAC)
MM5 forecast beginning 00Z 3 October after 4DVAR

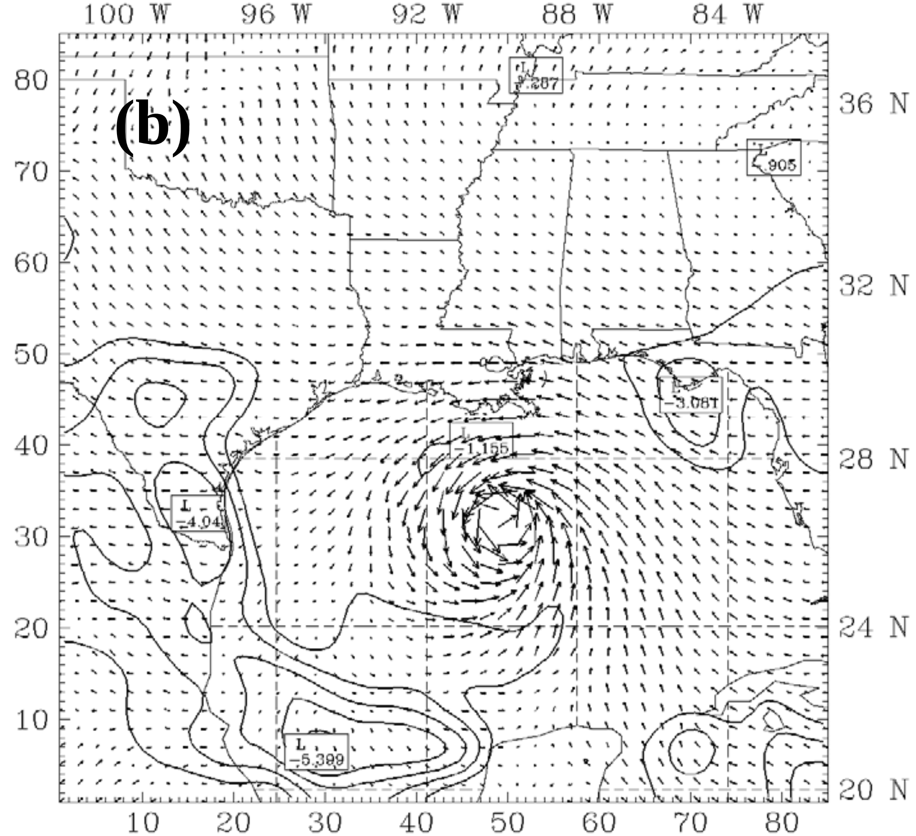
Difference of mixing ratio (solid line) and wind vectors at 950 mb between first 6-h 4DVAR and second 6-h 4DVAR

(4DVAR6H2 - 4DVAR6H1)



18Z, 2 October

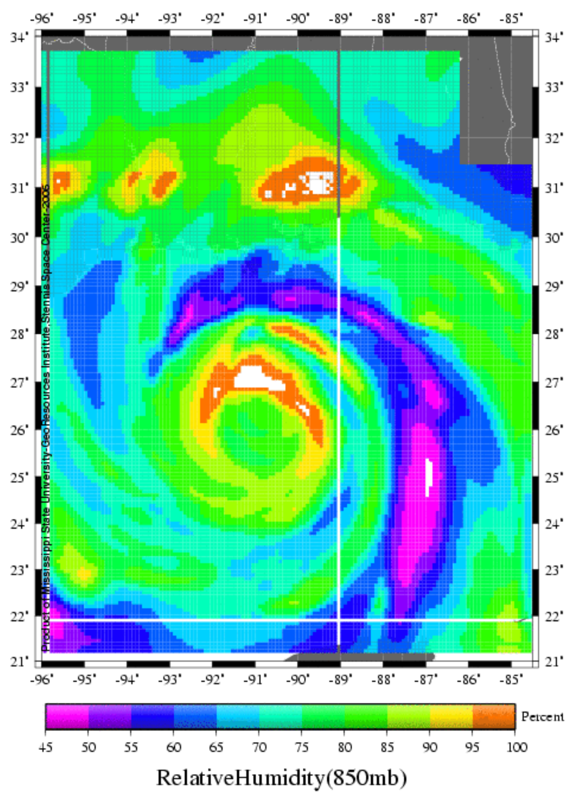
(4DVAR6H2 - 4DVAR6H1)



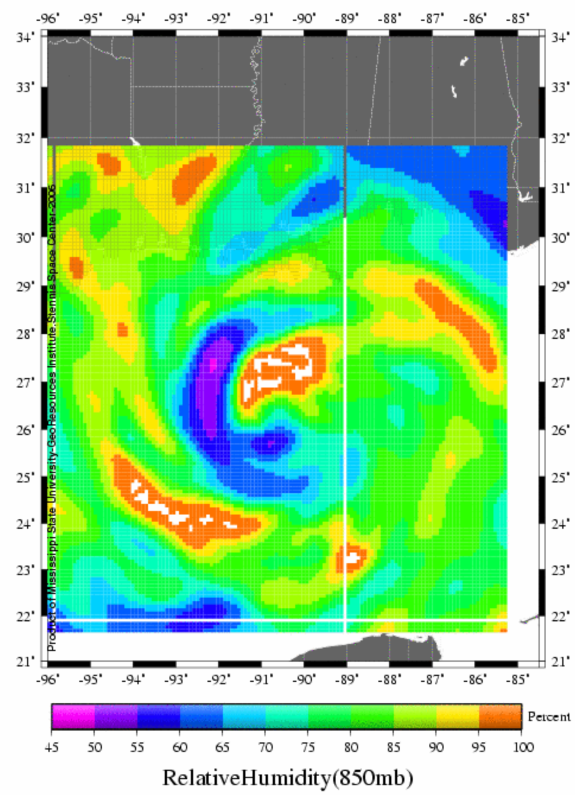
00Z, 3 October

MM5 Simulation, Relative Humidity at 850mb on Oct 3, 2002 00Z

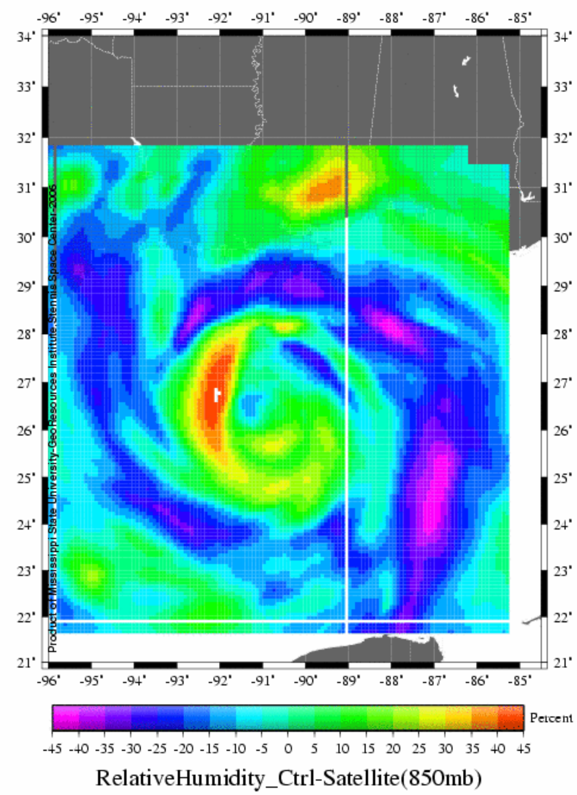
MM5_SIM_RH_850 (no_satellite) October 3, 2002 00Z



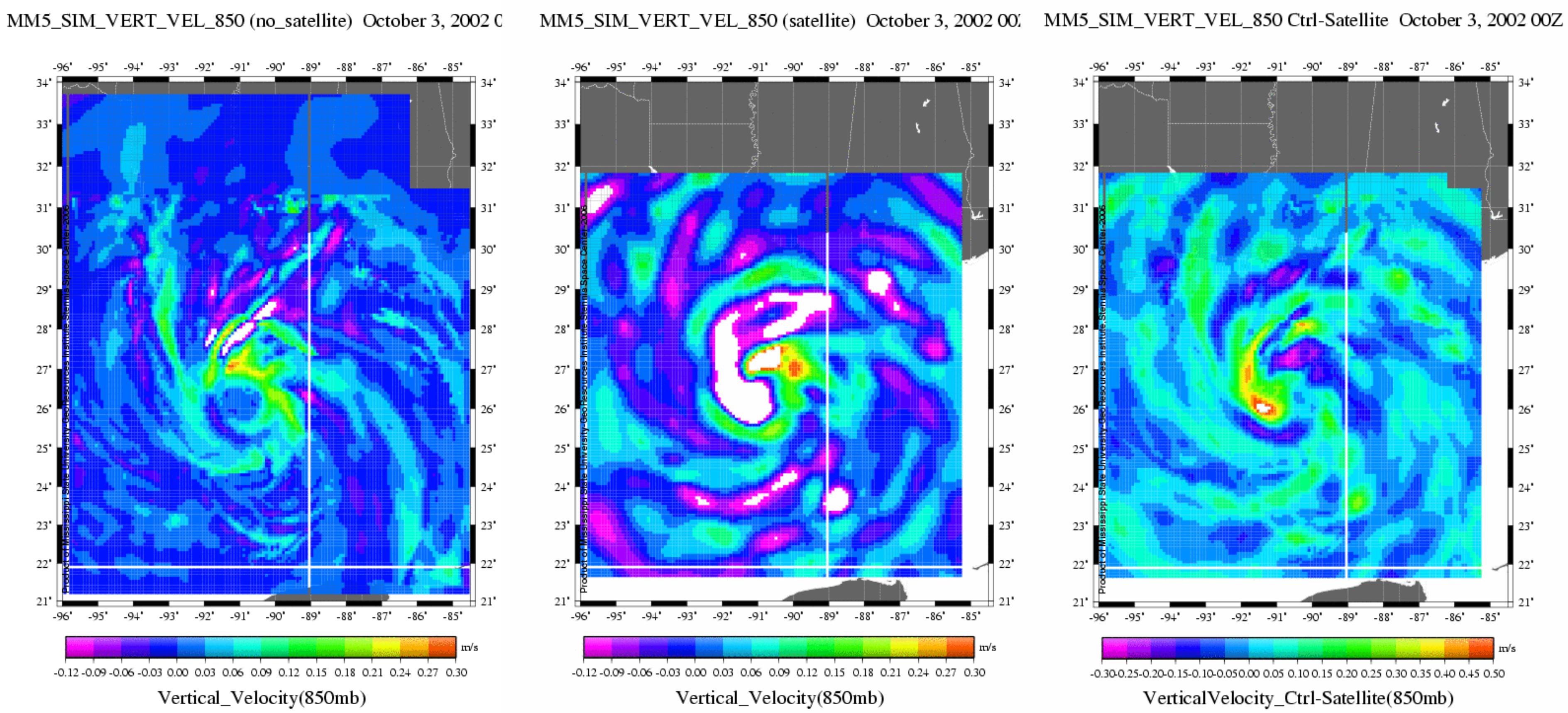
MM5_SIM_RH_850 (satellite) October 3, 2002 00Z



MM5_SIM_RH_850 Ctrl-Satellite October 3, 2002 00Z

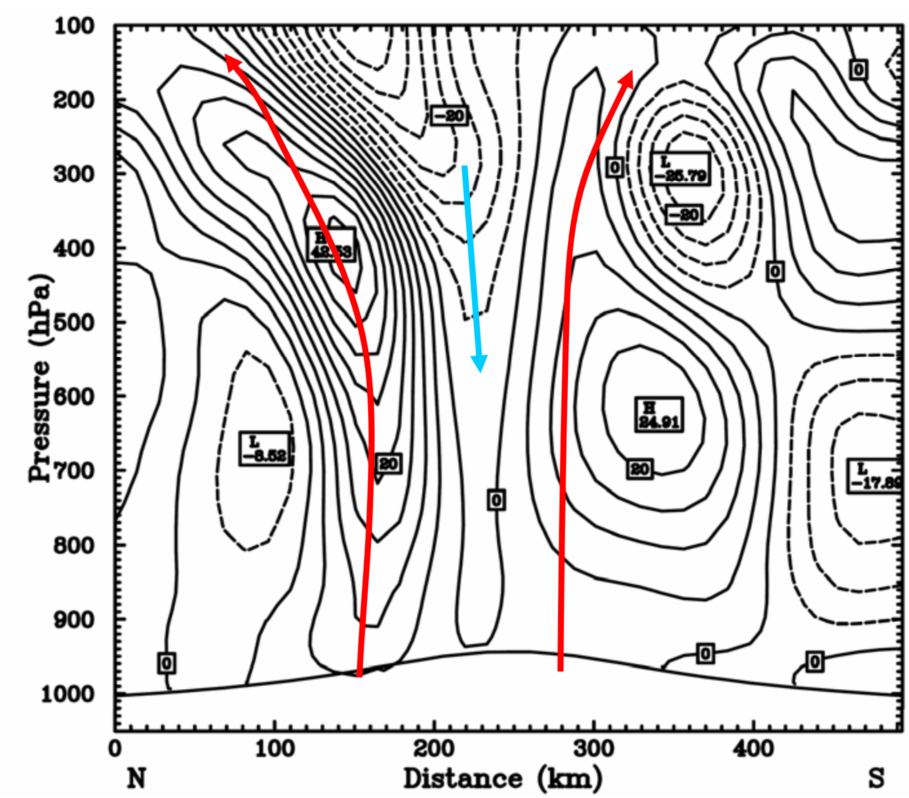


MM5 Simulation, Vertical Velocity at 850mb on Oct 3, 2002 00Z

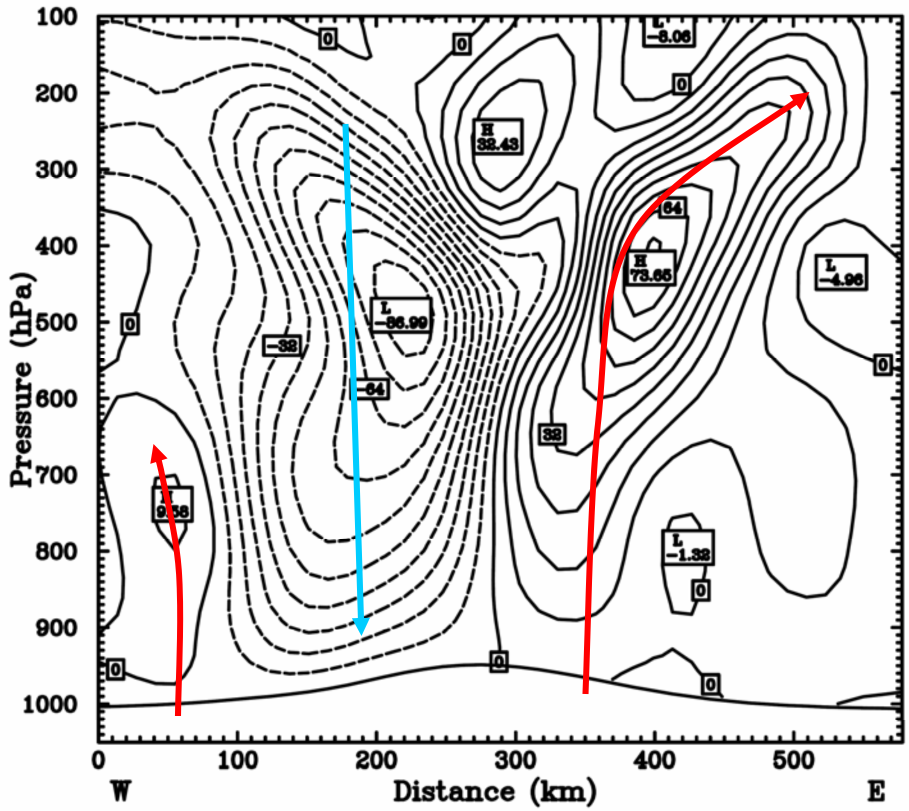


Cross sections of vertical velocity

18Z, 2 October



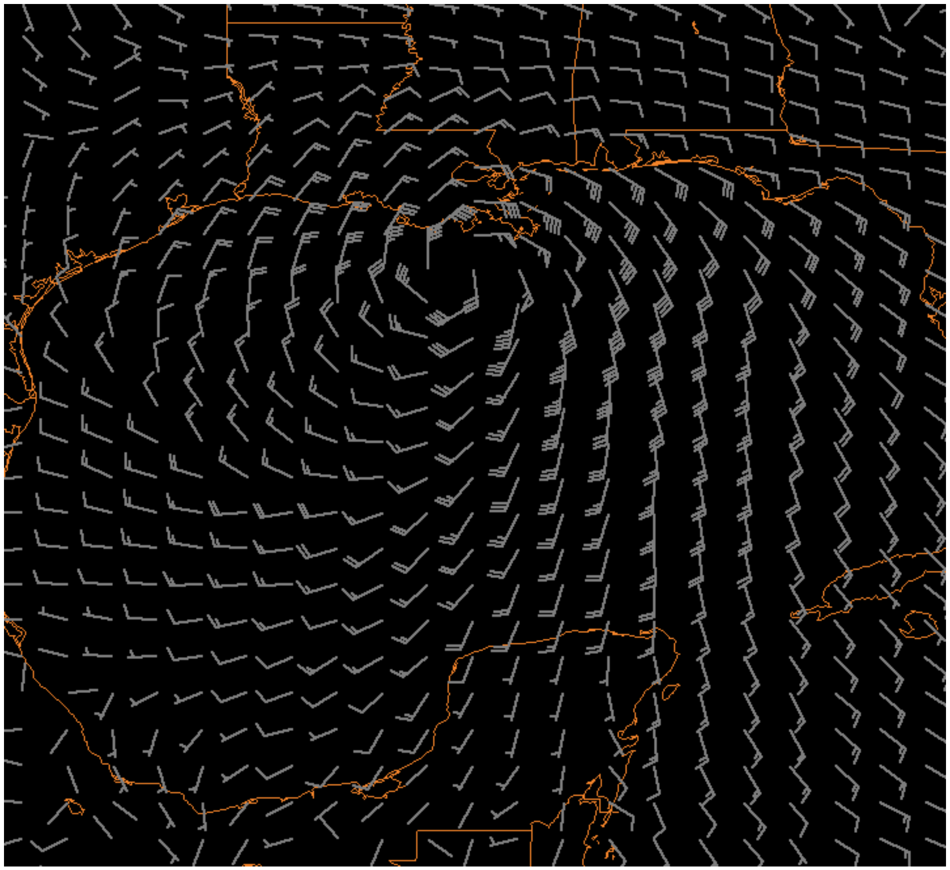
00Z, 3 October



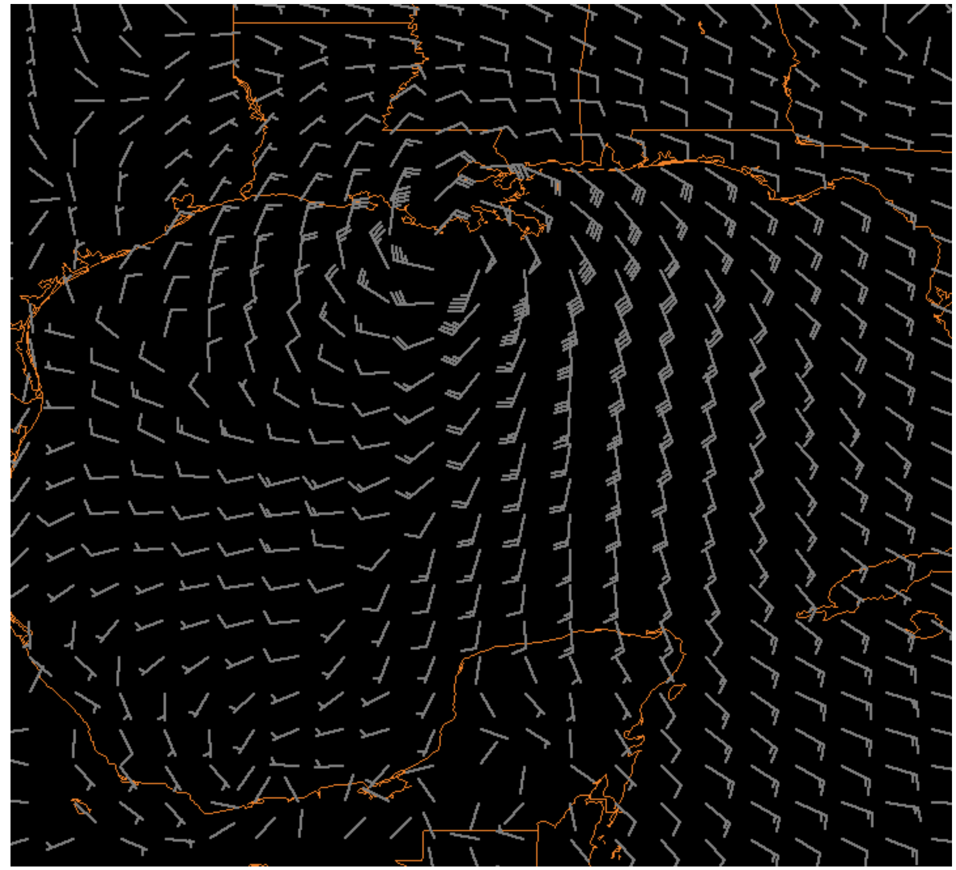
Western eyewall has collapsed

Study of ocean influence on Hurricane Lili using model coupling

MM5 winds (m/s), no coupling

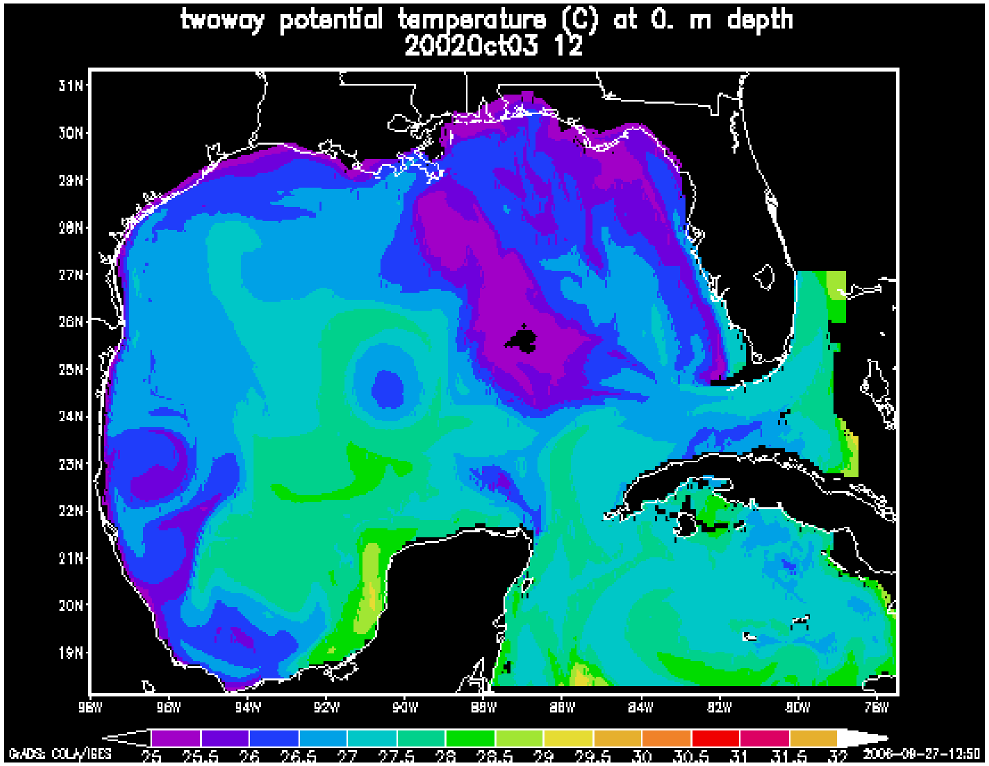


MM5 coupled to ocean model HYCOM



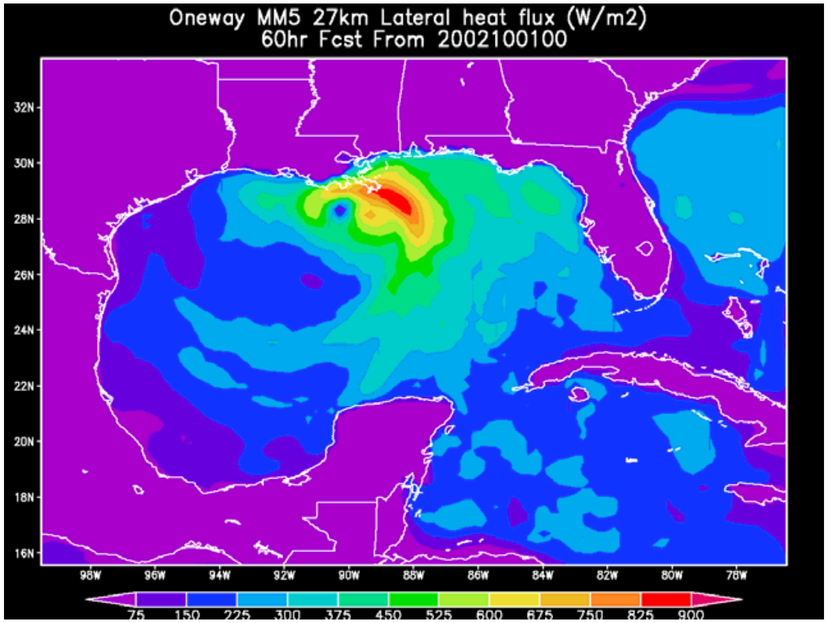
MM5 simulated Lili weaker with coupling

HYCOM ocean model
Sea surface temperature

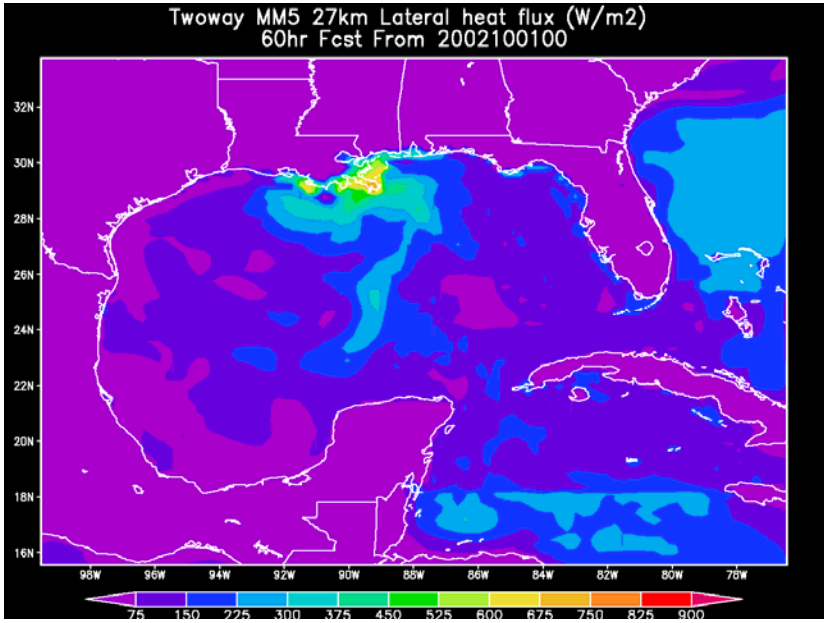


Note cool wake from ocean mixing

Latent heat flux, no coupling



Latent heat flux, with coupling



Conclusions on Lili's weakening

- Dry air intrusion caused western eyewall to collapse, and also impacted moisture field around hurricane
- Ocean mixing near coast reduced fluxes

Simulation of Hurricane Katrina’s storm surge

ADCIRC Storm Surge Implementation

- **The ADvanced CIRCulation (ADCIRC) Model for Shelves, Coasts, and Estuaries (ADCIRC) is a multi-dimensional, finite-element-based hydrodynamic circulation code.**
- **Typical applications include:**
  - Modeling tidally and wind-driven circulation in coastal waters
  - Forecasting hurricane storm surge and flooding

  Used by major governmental bodies in the United States

  - Extensively applied by the U.S. Army Corps of Engineers and U.S. Navy
  - Recently adopted by National Ocean Service for U.S. East coast
  - Certified by FEMA for National Flood Insurance Program
  - Adopted by several state offices

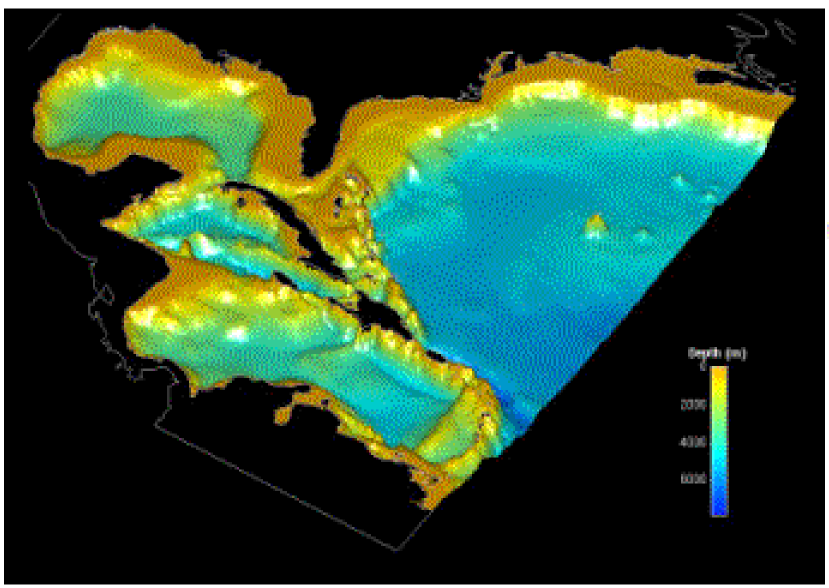
WorldWinds

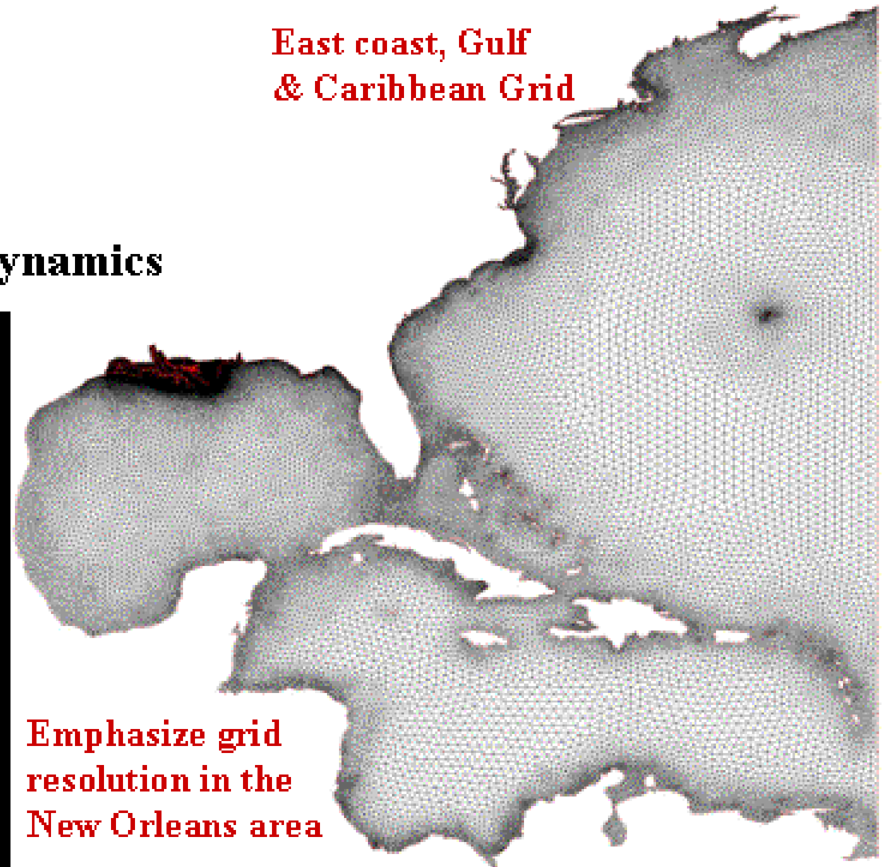
ADCIRC Storm Surge Implementation

Simulation of coastal regions – Large Domain Strategy

Correctly capture

- **Basin to basin interactions**
- **Basin to shelf dynamics**
- **Shelf to adjacent coast/land dynamics**



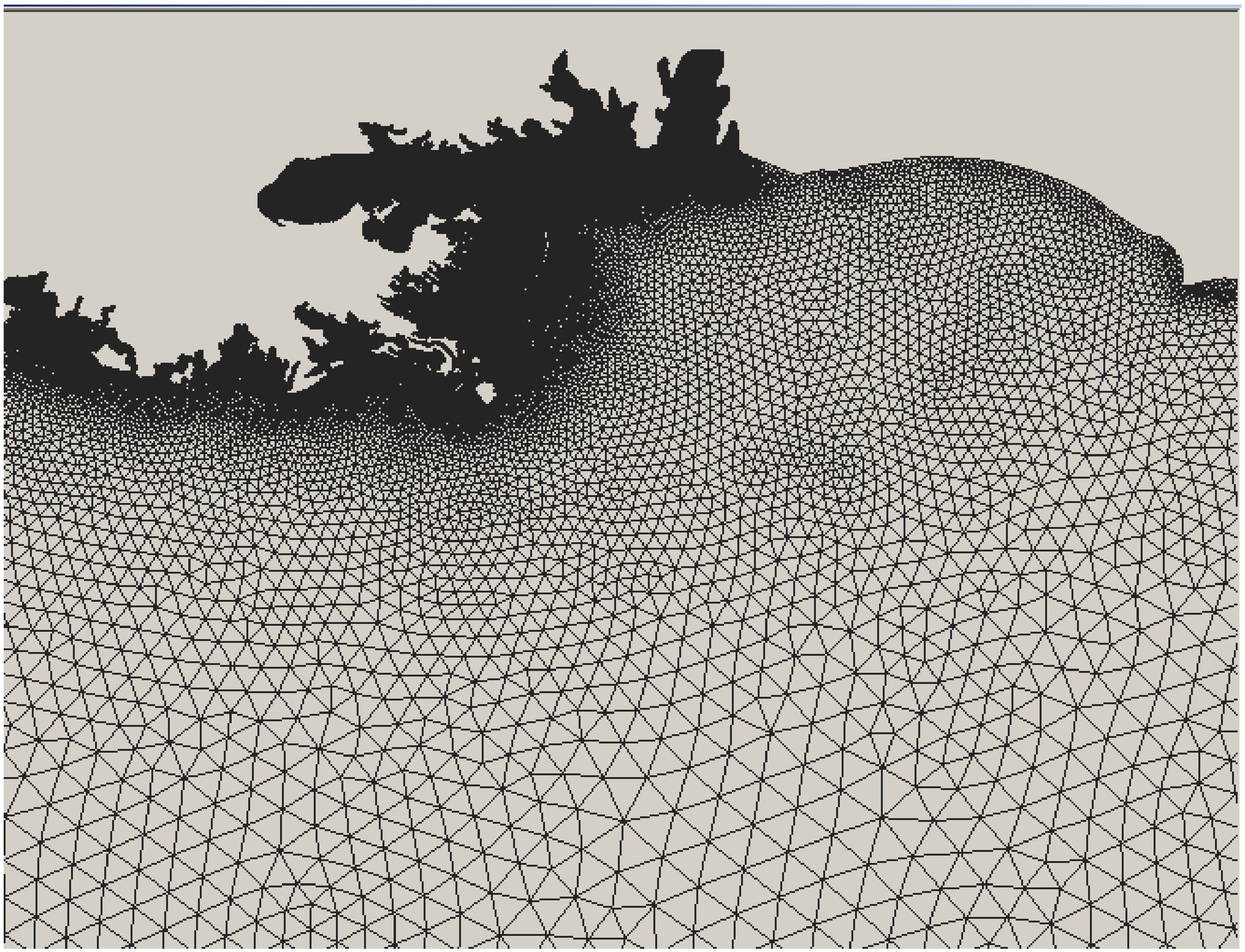


East coast, Gulf & Caribbean Grid

Emphasize grid resolution in the New Orleans area

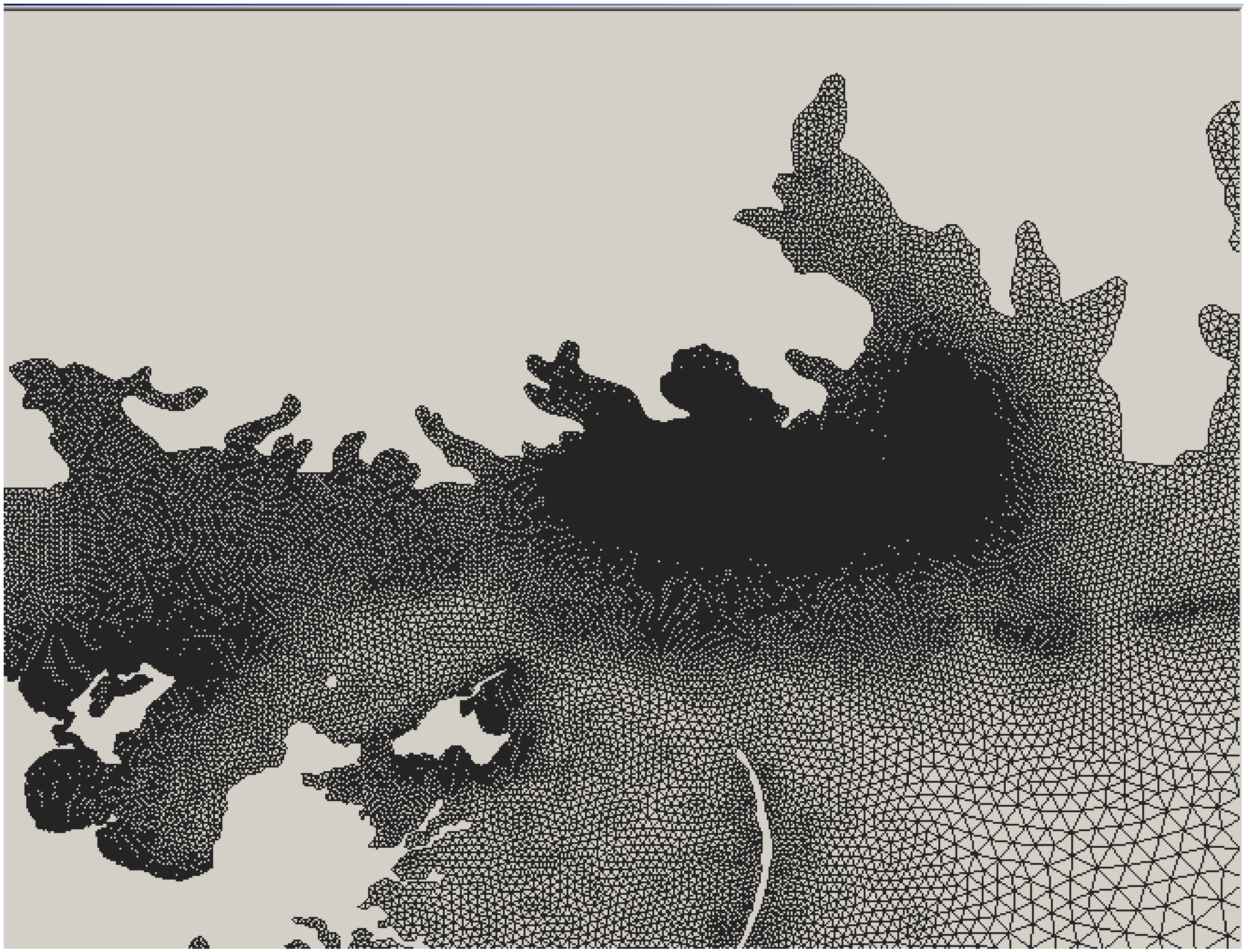
WORLDWINDS

ADCIRC grid – zoom in of North Gulf Coast



Calculations done at each point. Higher resolution done along shoreline, bays, and bayous to accurately simulation storm surge.

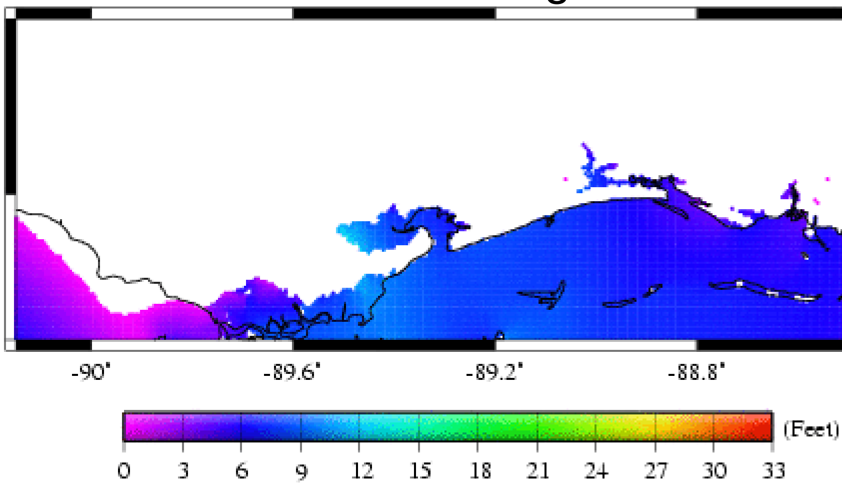
ADCIRC grid zoomed in on coastal bays and marsh



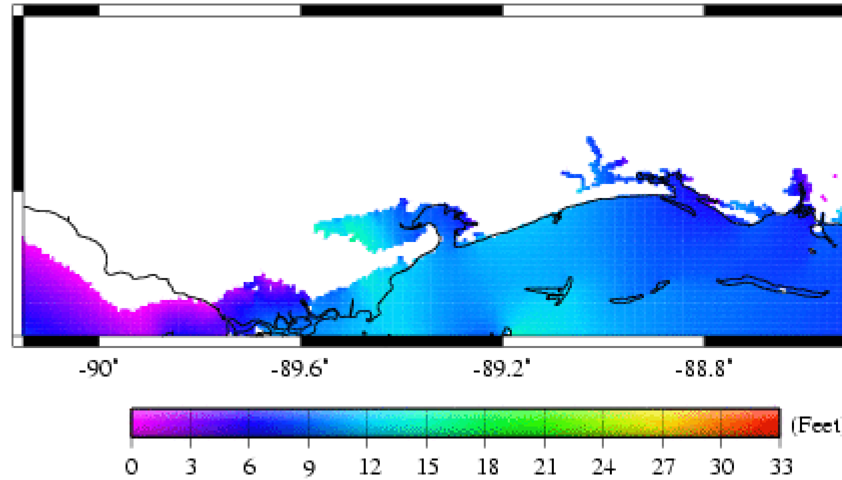
WorldWinds

ADCIRC storm surge simulation

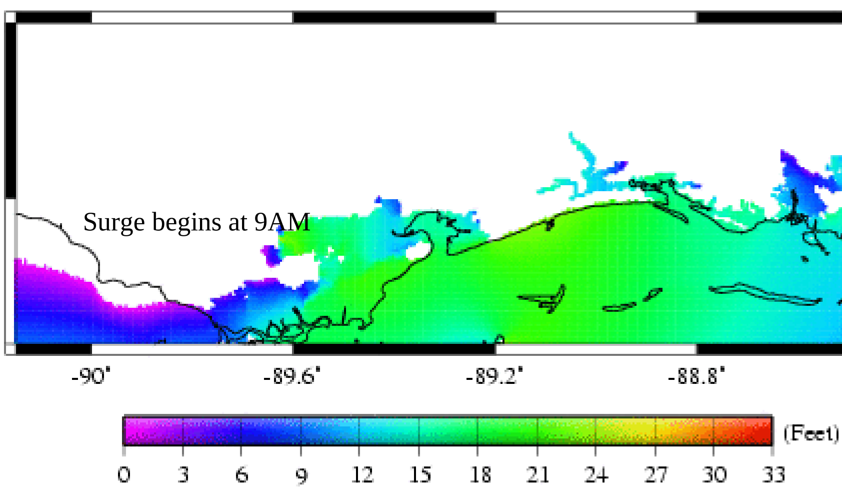
Katrina storm surge at 5AM



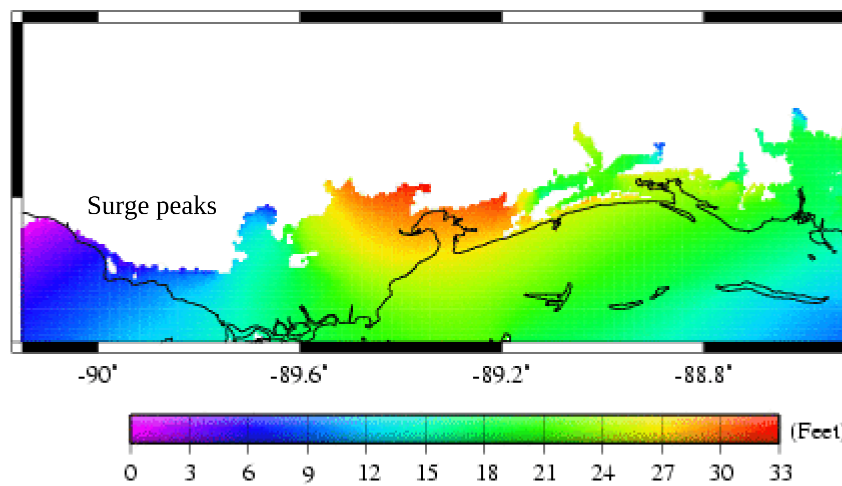
Katrina storm surge at 7AM



Katrina storm surge at 9AM



Katrina storm surge at 11AM



Surge values shown are relative to sea level. Subtract ground elevation to get water inundation values.

Applications

- Study evolution of surge after observations destroyed
- Sensitivity runs for levee design, impact of wetlands
- Timing of wind versus surge
- Surge forecasts and storm surge atlases

Time series of sustained wind, wind gust, and surge in Bay St. Louis

Time (Aug. 29)	*Wind (mph)*	*Wind gust (mph)*	*Storm surge (feet)*
3:00AM	40 (east-northeast)	46	4
5:30AM	75 (east-northeast)	97	6
6:30AM	86 (northeast)	112	6
8:30AM	103 (east)	140	9
9:30AM	120 (southeast)	145	13
10:30AM	100 (south)	115	22
11:30AM	90 (west)	104	19
12:30PM	80 (west)	92	16

Tropical storm-force winds begin after midnight.
Hurricane-force winds begin around 5AM.
Inundation from surge began 9-10:30AM depending on location