Validation of the Unstructured, Highly-Scalable, Integrally-Coupled, ADCIRC-UnSWAN Model

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‘Loose’ Coupling

‘Loose’ Coupling:

- Models coupled through input files
    - Water levels and currents passed to wave model
    - Wave-driven forces passed to circulation model

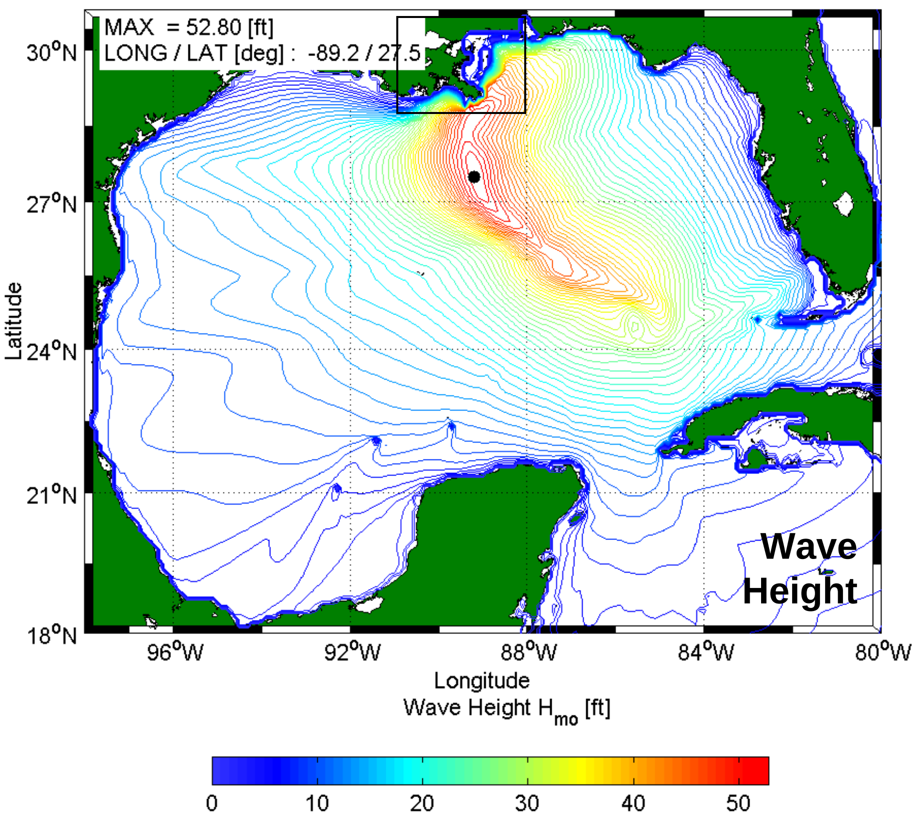
ADCIRC Coupled to Wave Models:

- Basin/region scale: WAM, WaveWatch III
- Nearshore: STWAVE, SWAN

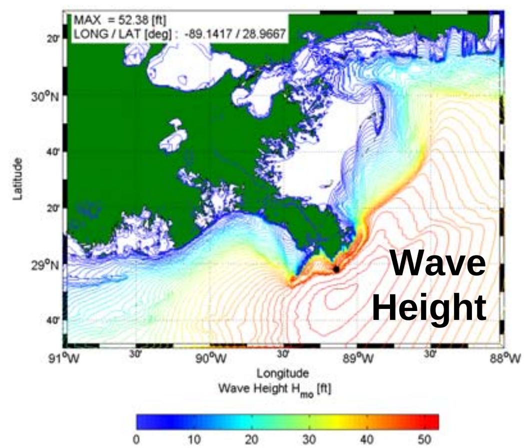
'Loose' Coupling

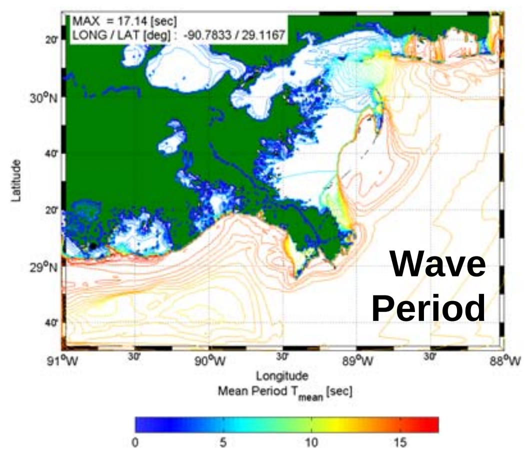
Example: Louisiana Storm Surge Modeling

Basin-Scale WAM Model



Region-Scale WAM Model

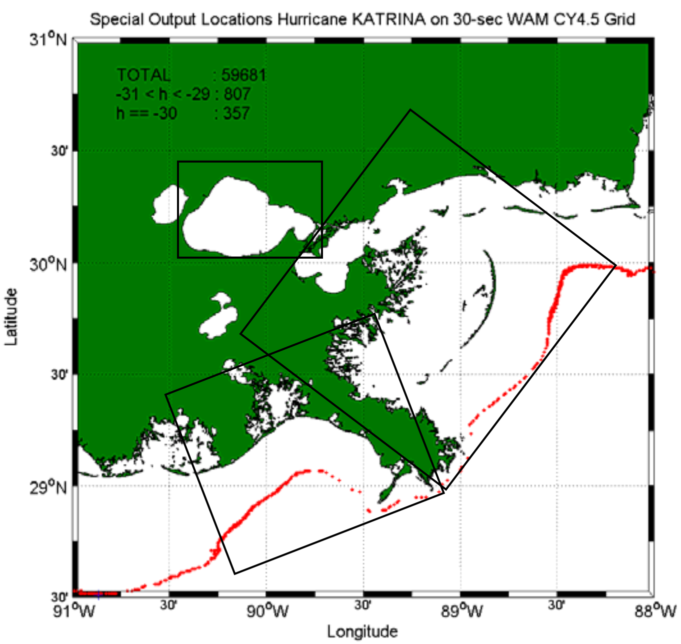


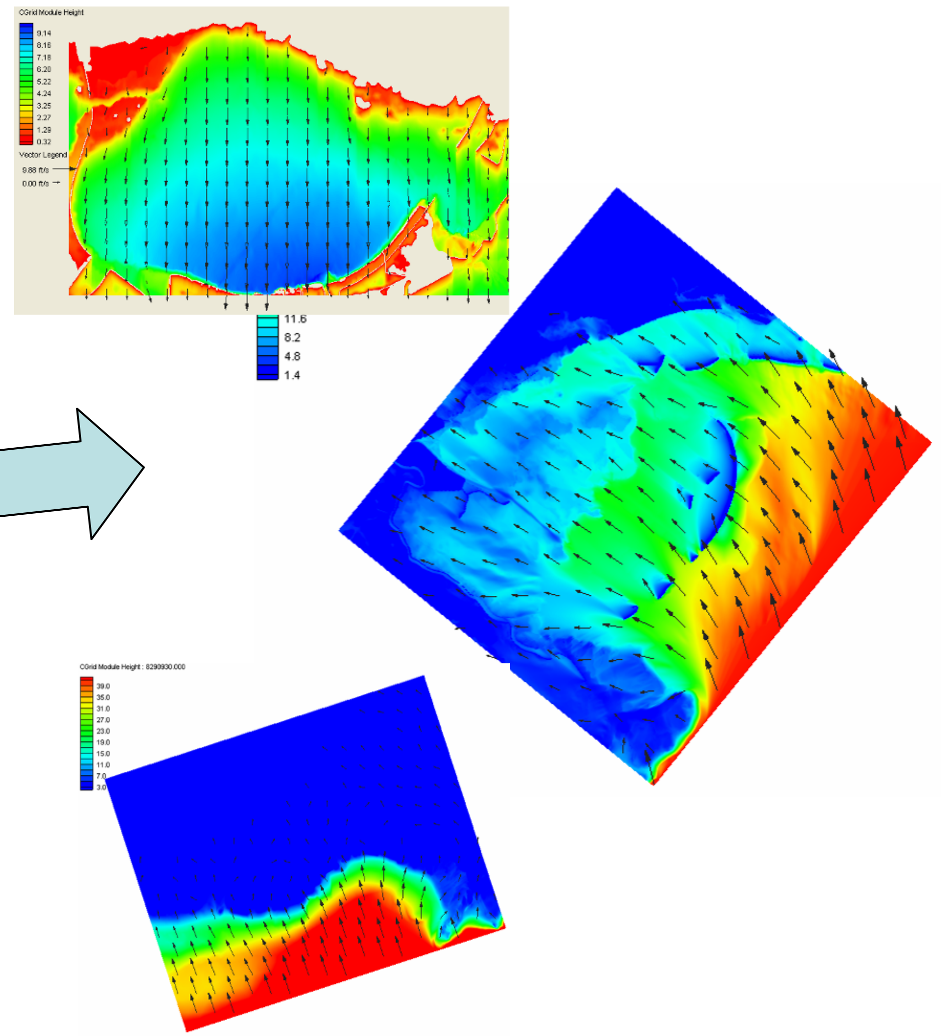


‘Loose’ Coupling

Example: Louisiana Storm Surge Modeling

Nearshore STWAVE Model

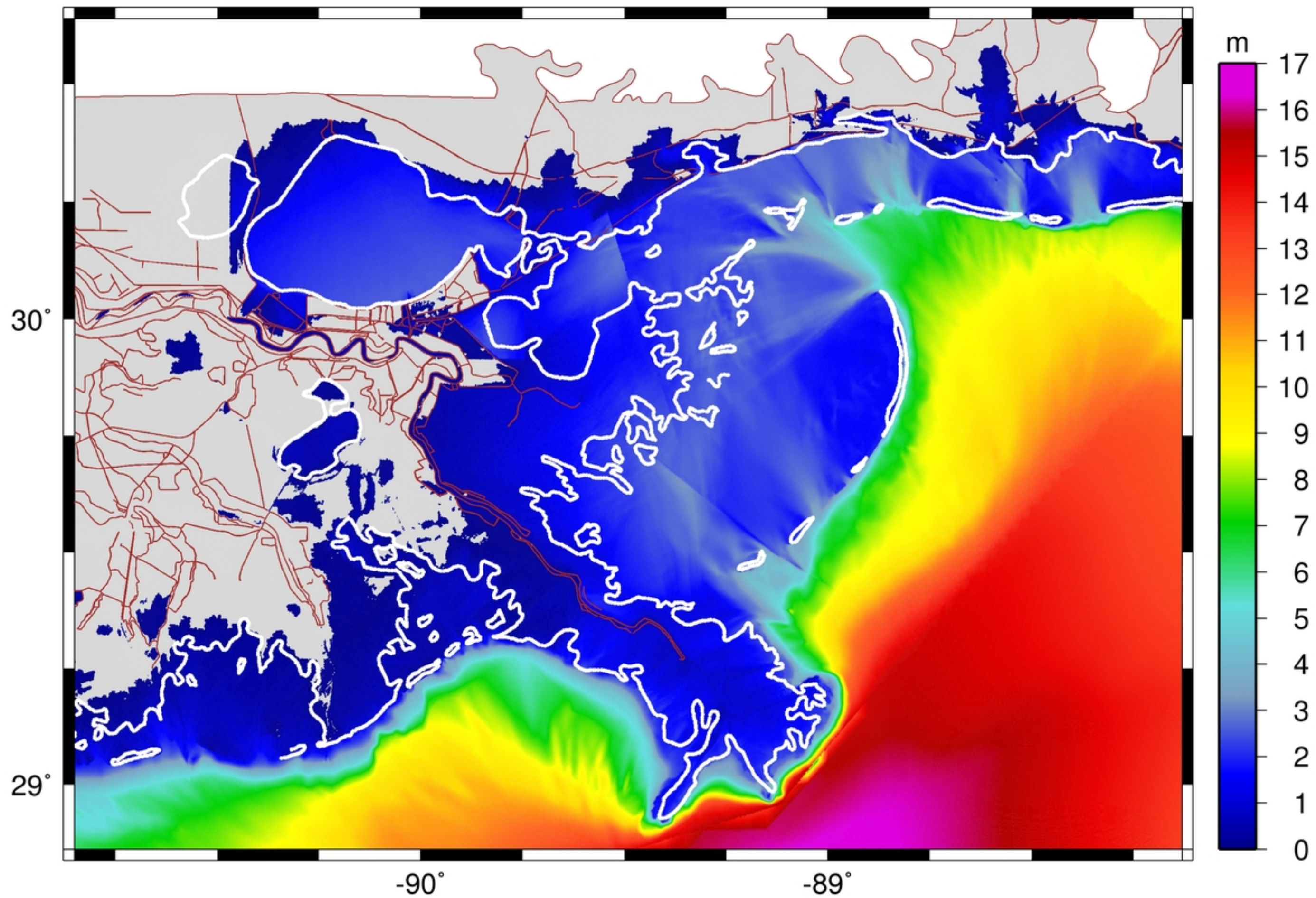




‘Loose’ Coupling

It Works!

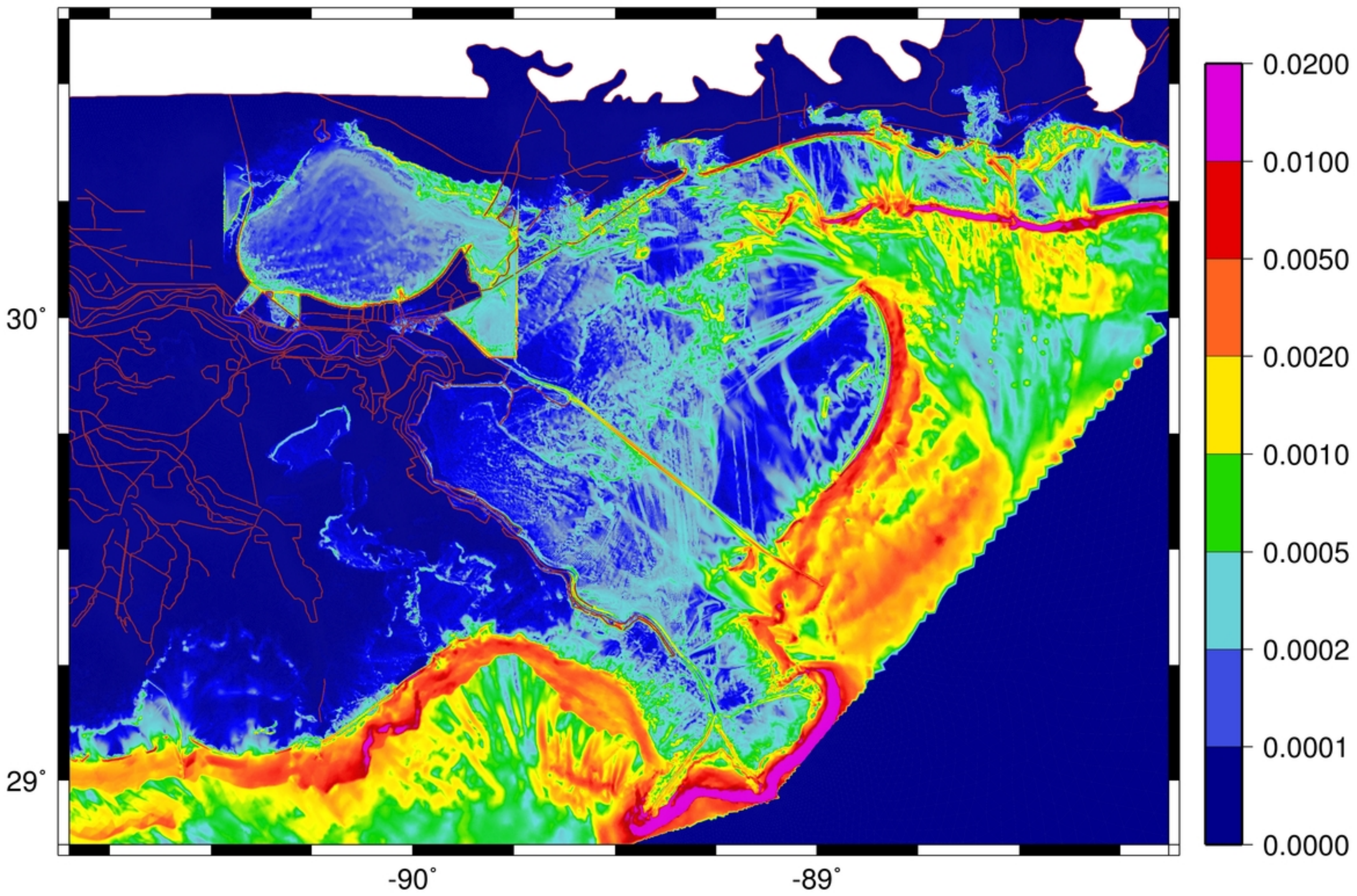
- Maximum significant wave heights in Hurricane Katrina



'Loose' Coupling

It Works!

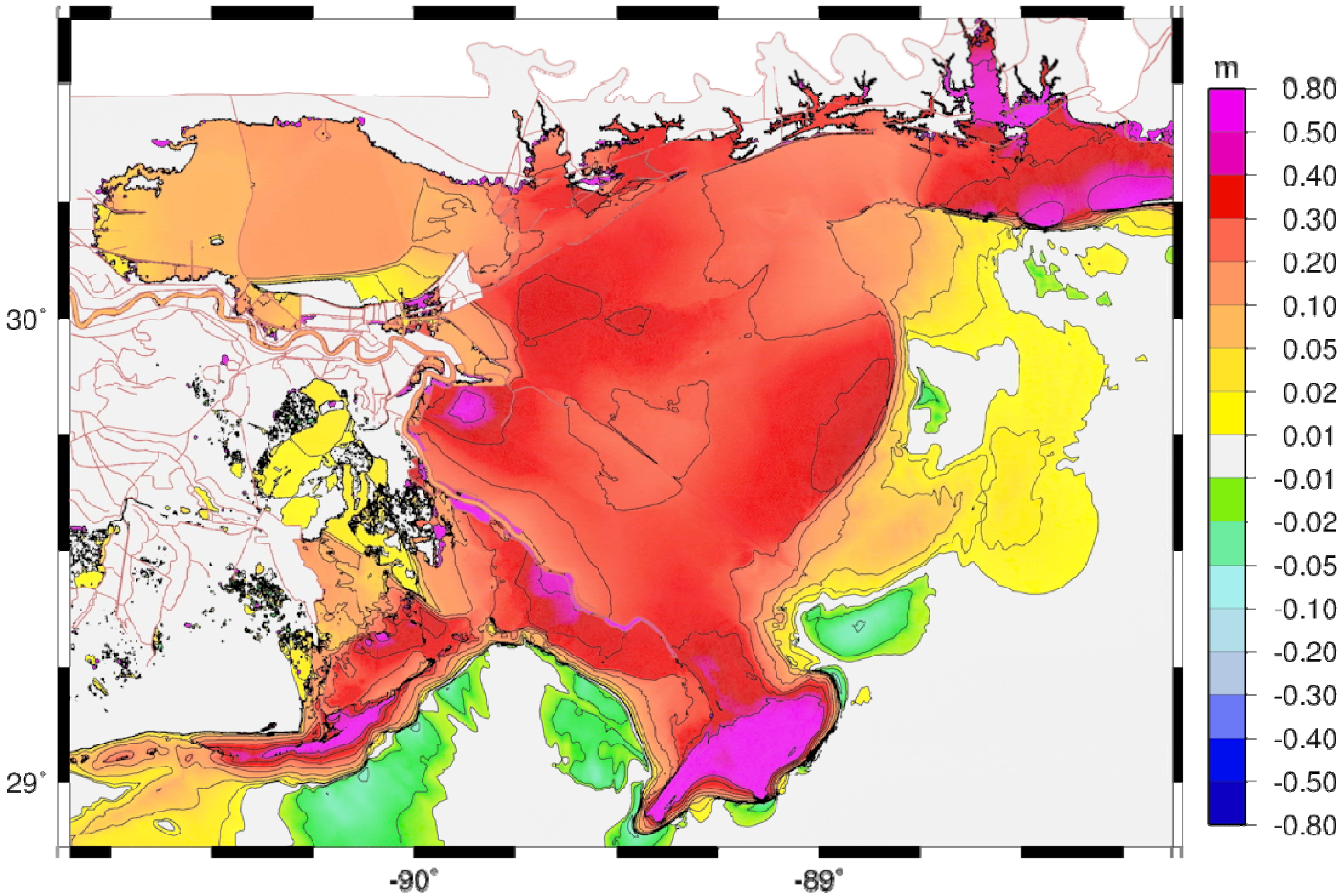
- Maximum wave-driven forces in Hurricane Katrina



'Loose' Coupling

It Works!

- Effect of waves on water levels in Hurricane Katrina



‘Tight’ Coupling

Advantages:

- ADCIRC and wave model run on the same mesh
  - No nesting of meshes
  - No overlapping of meshes
- ADCIRC and wave model run on the same processor
  - No interpolation
  - No global message passing
  - Information is passed through memory
- Optimization of code
  - No overhead for coupling modeling framework
  - Utilize shared memory on multi-core processors
- Optimization of physics
  - No need for directionality in waves model
  - Dynamic *h*- and *p*-adaptivity

‘Tight’ Coupling

Introducing … AdcSwan!

- ADCIRC coupled to Simulating WAves Near-shore (SWAN)
- SWAN:
  - Developed by Booij, Holthuijsen, Zijlema at Delft University
  - Non-phase-resolving, wave energy propagation model

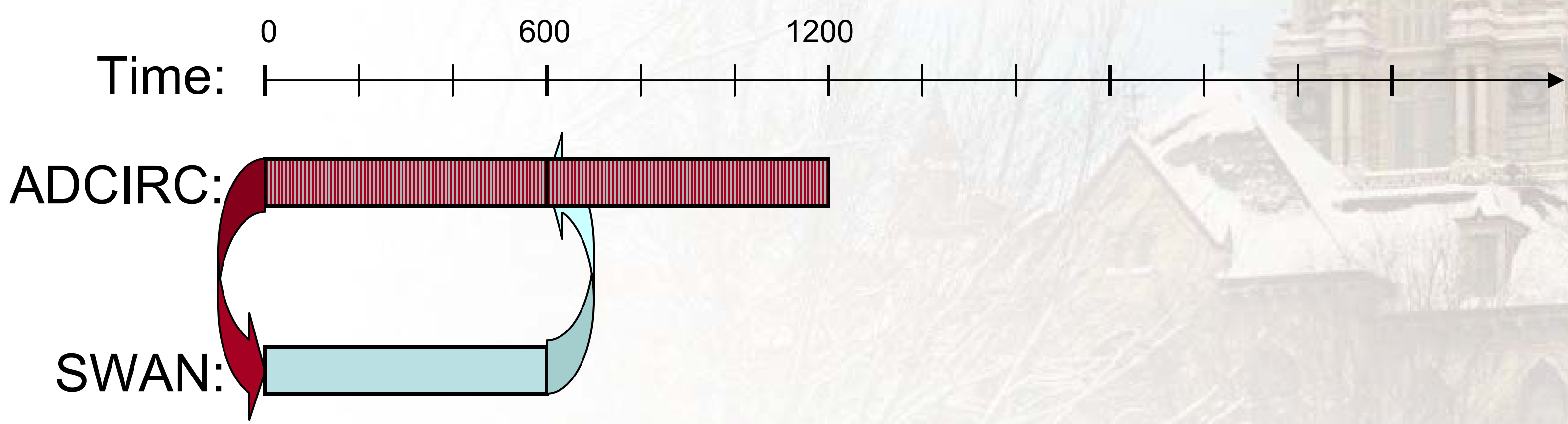
Progress:

- SWAN converted to unstructured meshes (UnSWAN)
- UnSWAN implemented in parallel (PUnSWAN)
- ADCIRC and PUnSWAN compiled into PAdcSwan
  - Pass node-based information between models
  - Run on same local mesh
  - Leapfrog through time

ADCIRC-SWAN

Schematic of Coupling:

- ADCIRC is run for 600 seconds (Δt = 1 sec)
- Water levels (ζ) and currents (u,v) are passed to Swan
- SWAN is run for 600 seconds (Δt = 600 sec)
- Radiation stresses (S_{xx}, S_{xy}, S_{yy}) and wave-driven forces (F_x, F_y) are computed; forces are passed to ADCIRC
- Repeat



- SWAN and ADCIRC are always extrapolating in time

ADCIRC-SWAN

How to Compile and Run:

1. Compile ‘`padcirc`’
   - PUnSWAN uses the parallel infrastructure of PADCIRC
   - The SIZES and MESSENGER object files must exist already
2. Compile PUnSWAN
   - Done inside the ‘`swan`’ subdirectory
   - Follow instructions in ‘`INSTALL.README`’
   - Our makefile uses the compiler flags in the SWAN ‘`macros.inc`’
3. Compile ‘`padcswan`’
   - Done inside the ‘`work`’ directory
   - ADCIRC and UnSWAN will be compiled into the same executable:

```
make padcswan
```

ADCIRC-SWAN

How to Compile and Run:

4. Compile a SWAN-compatible version of ‘`adcprep`’
   - Add a flag inside your ‘`cmplrflags.mk`’ file:

```
# Portland Group compiler on TU Ranger (AMD Opteron 8356, Barcelona Core)  Seizo
ifeq ($(compiler),pgi-ranger)
  PPFC          :=  pgf95
  FC            :=  pgf95
  PFC           :=  mpif90
  FFLAGS1       :=  $(INCDIRS) -fast -tp barcelona-64 -Mextend
  FFLAGS2       :=  $(FFLAGS1)
  FFLAGS3       :=  $(FFLAGS1)
  DA            :=  -DREAL8 -DLINUX -DCSCA
  DP            :=  -DREAL8 -DLINUX -DCSCA -DCMPI
  DPRE          :=  -DREAL8 -DLINUX -DADCSWAN
  IMODS         :=  -I
  CC            := gcc
  CCBE          := $(CC)
  CFLAGS        := $(INCDIRS)  -DLINUX
  CLIBS         :=
  LIBS          :=
  MSGLIBS       :=
  $(warning (INFO) Corresponding machine found in cmplrflags.mk.)
  ifneq ($(FOUND),TRUE)
     FOUND := TRUE
  else
     MULTIPLE := TRUE
  endif
endif
```

   - Prepares boundaries for use by SWAN
   - Still compatible with non-coupled ADCIRC runs

ADCIRC-SWAN

How to Compile and Run:

5. Make two changes to the ‘`fort.15`’ file
    - Set NWS = +/- 3XX
    - Set RSTIMINC equal to the SWAN time step

```
1   ! NCOR - VARIABLE CORIOLIS IN SPACE OPTION PARAMETER
1   ! NTIP - TIDAL POTENTIAL OPTION PARAMETER
-312 ! NWS - WIND STRESS AND BAROMETRIC PRESSURE OPTION PARAMETER
2   ! NRAMP - RAMP FUNCTION OPTION
9.81   ! G - ACCELERATION DUE TO GRAVITY - DETERMINES UNITS
-3.0 ! TAU0 - WEIGHTING FACTOR IN GWCE
 1.0   ! DT - TIME STEP (IN SECONDS)
0.00   ! STATIM - STARTING TIME (IN DAYS)
0.00    ! REFTIM - REFERENCE TIME (IN DAYS)
900 600    ! WTIMINC = TIME INTERVAL (IN SECONDS) BETWEEN WIND AND PRESSURE DATA IN UNIT 22
25.00   ! RNDAY - TOTAL LENGTH OF SIMULATION (IN DAYS)
12.0 0.5 2.0   ! DRAMP - DURATION OF RAMP FUNCTION (IN DAYS)
```

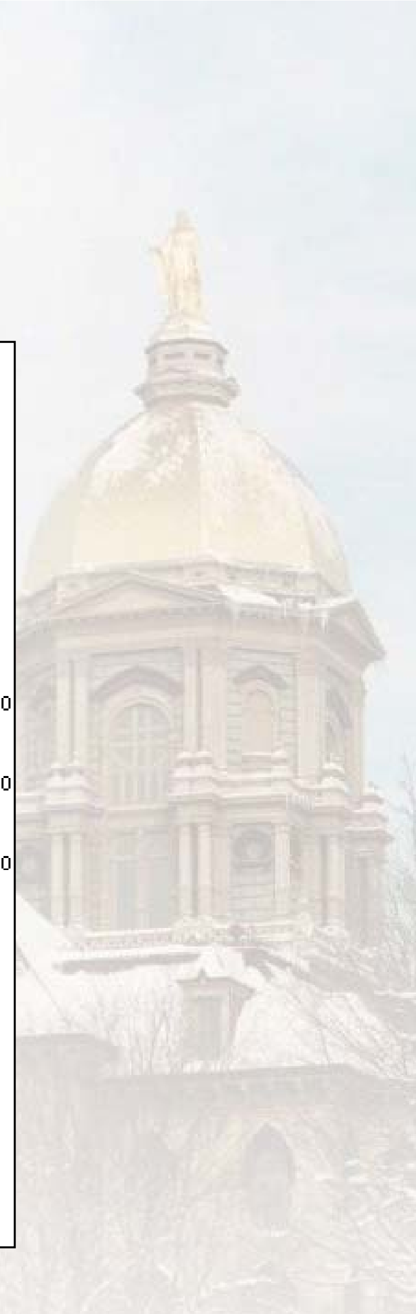
    - Now wave-driven forces are passed from SWAN to ADCIRC

ADCIRC-SWAN

How to Compile and Run:

6. SWAN is controlled by the new ‘`fort.26`’ file …

```
PROJ 'KatrinaWW' 'KWW'
$
SET LEVEL 0.0
SET DEPMIN 0.1
MODE NONSTATIONARY
$
COORDINATES SPHERICAL CCM
$
CGRID UNSTRUCTURED CIRCLE MDC=32 FLOW=0.031384 MSC=32
READ UNSTRUCTURED
$
INIT ZERO
$
INPGRID WLEV UNSTRUCTURED EXCEPTION 0.1 NONSTAT 20070101.000000 600 SEC 20070108.000000
READINP ADCWL
$
INPGRID  CUR UNSTRUCTURED EXCEPTION 0.  NONSTAT 20070101.000000 600 SEC 20070108.000000
READINP ADCCUR
$
INPGRID WIND UNSTRUCTURED EXCEPTION 0.  NONSTAT 20070101.000000 600 SEC 20070108.000000
READINP ADCWIND
$
GEN3 KOMEN AGROW
WCAP KOMEN 2.36E-5 3.02E-3 2.0 1.0 1.0
BREAKING
FRICTION
TRIADS
PROP BSBT
OFF REFRAC
NUM STOPC DABS=0.005 DREL=0.01 CURVAT=0.005 NPNTS=101 NONSTAT MXITNS=2
$
TEST 1,0
COMPUTE 20070101.000000 600 SEC 20070108.000000
STOP
```



ADCIRC-SWAN

How to Compile and Run:

7. … and by the new ‘`swaninit`’ file
   - The command file name is ‘`fort.26`’

```
    4                                       version of initialisation file
Delft University of Technology              name of institute
    3                                       command file ref. number
fort.26                                     command file name
    4                                       print file ref. number
KatrinaWW.prt                               print file name
    4                                       test file ref. number
                                            test file name
    6                                       screen ref. number
   99                                       highest file ref. number
$                                           comment identifier
                                                   TAB character
\                                           dir sep char in input file
/                                           dir sep char replacing previous one
    1                                       default time coding option
```

ADCIRC-SWAN

How to Compile and Run:

8. Run ‘`padcswan`’ like you would run ‘`padcirc`’
   - The command is something like:

     ```
     mpirun –np 512 ./padcswan –W 10
     ```

   - The run looks something like:

```
 TIME STEP = 1555300     ITERATIONS =   13     TIME = 0.15553000E+07
  ELMAX = 0.2448E+00 AT NODE     787  SPEEDMAX = 0.4780E-01 AT NODE     780   ON MYPROC =     0
 TIME STEP = 1555400     ITERATIONS =   12     TIME = 0.15554000E+07
  ELMAX = 0.2448E+00 AT NODE    1365  SPEEDMAX = 0.4823E-01 AT NODE     780   ON MYPROC =     0
 TIME STEP = 1555500     ITERATIONS =   13     TIME = 0.15555000E+07
  ELMAX = 0.2448E+00 AT NODE    1365  SPEEDMAX = 0.4882E-01 AT NODE     780   ON MYPROC =     0
 TIME STEP = 1555600     ITERATIONS =   12     TIME = 0.15556000E+07
  ELMAX = 0.2446E+00 AT NODE    1365  SPEEDMAX = 0.4957E-01 AT NODE     780   ON MYPROC =     0
 TIME STEP = 1555700     ITERATIONS =   12     TIME = 0.15557000E+07
  ELMAX = 0.2444E+00 AT NODE    1365  SPEEDMAX = 0.5036E-01 AT NODE     780   ON MYPROC =     0
 TIME STEP = 1555800     ITERATIONS =   13     TIME = 0.15558000E+07
  ELMAX = 0.2442E+00 AT NODE    1365  SPEEDMAX = 0.5114E-01 AT NODE     780   ON MYPROC =     0
+time 20070101.001000    , step     1; iteration     1; sweep    1
+time 20070101.001000    , step     1; iteration     1; sweep    2
+time 20070101.001000    , step     1; iteration     2; sweep    1
+time 20070101.001000    , step     1; iteration     2; sweep    2
 TIME STEP = 1555900     ITERATIONS =   12     TIME = 0.15559000E+07
  ELMAX = 0.2440E+00 AT NODE    1365  SPEEDMAX = 0.5200E-01 AT NODE     780   ON MYPROC =     0
 TIME STEP = 1556000     ITERATIONS =   13     TIME = 0.15560000E+07
  ELMAX = 0.2439E+00 AT NODE    4092  SPEEDMAX = 0.5292E-01 AT NODE     780   ON MYPROC =     0
 TIME STEP = 1556100     ITERATIONS =   12     TIME = 0.15561000E+07
  ELMAX = 0.2440E+00 AT NODE    4092  SPEEDMAX = 0.5389E-01 AT NODE     780   ON MYPROC =     0
```

ADCIRC-SWAN

How to Compile and Run:

9. New SWAN output files will be created
   - Tied to meteorological output:

```
-4 18.0 25.0 3600 ! NOUTGE,TOUTSGE,TOUTFGE,NSPOOLGE : GLOBAL ELEVATION OUTPUT INFO (UNIT  63)
-4 18.0 25.0 3600 ! NOUTGV,TOUTSGV,TOUTFGV,NSPOOLGV : GLOBAL VELOCITY  OUTPUT INFO (UNIT  64)
-4 18.0 25.0 3600 ! NOUTGW,TOUTSGW,TOUTFGW,NSPOOLGW : GLOBAL WIND OUTPUT INFO (UNIT 73/74)
```

   - Many global output files will be generated:
     - Pressure: ‘`fort.73`’
     - Wind speed: ‘`fort.74`’
     - Wave-driven forces: ‘`rads.64`’
     - Significant wave heights: ‘`swan_HS.63`’
     - Mean wave directions: ‘`swan_DIR.63`’
     - Mean wave periods: ‘`swan_TM02.63`’
     - Peak wave periods: ‘`swan_TPS.63`’

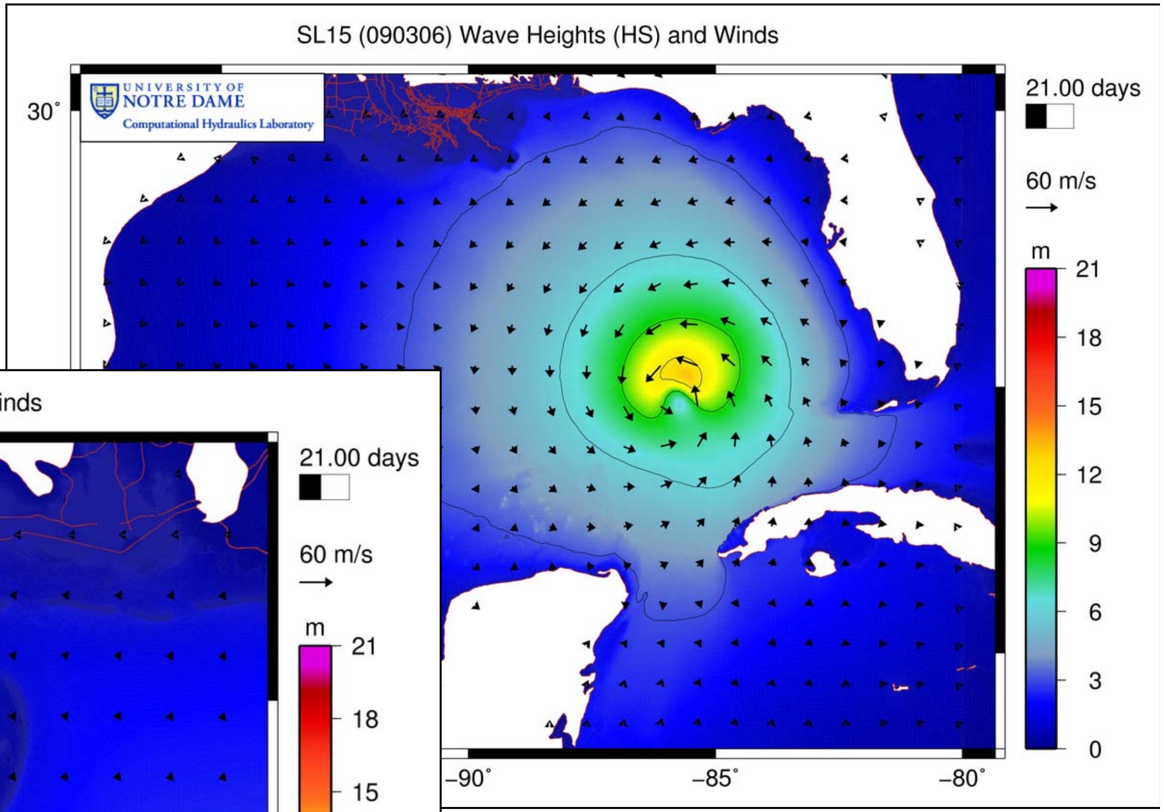
Hurricane Katrina

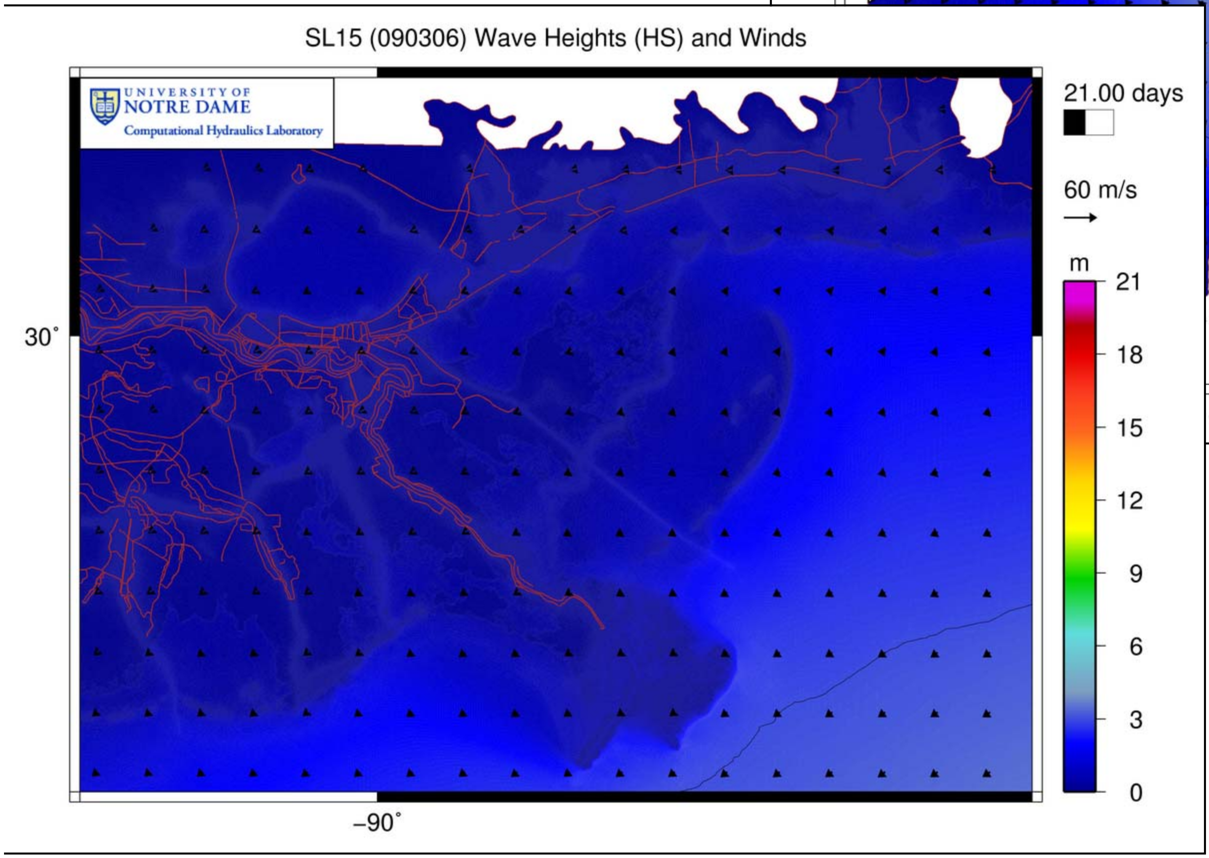
Wave Heights

Hurricane Katrina

Wave Heights

- 2005/08/28/0000Z

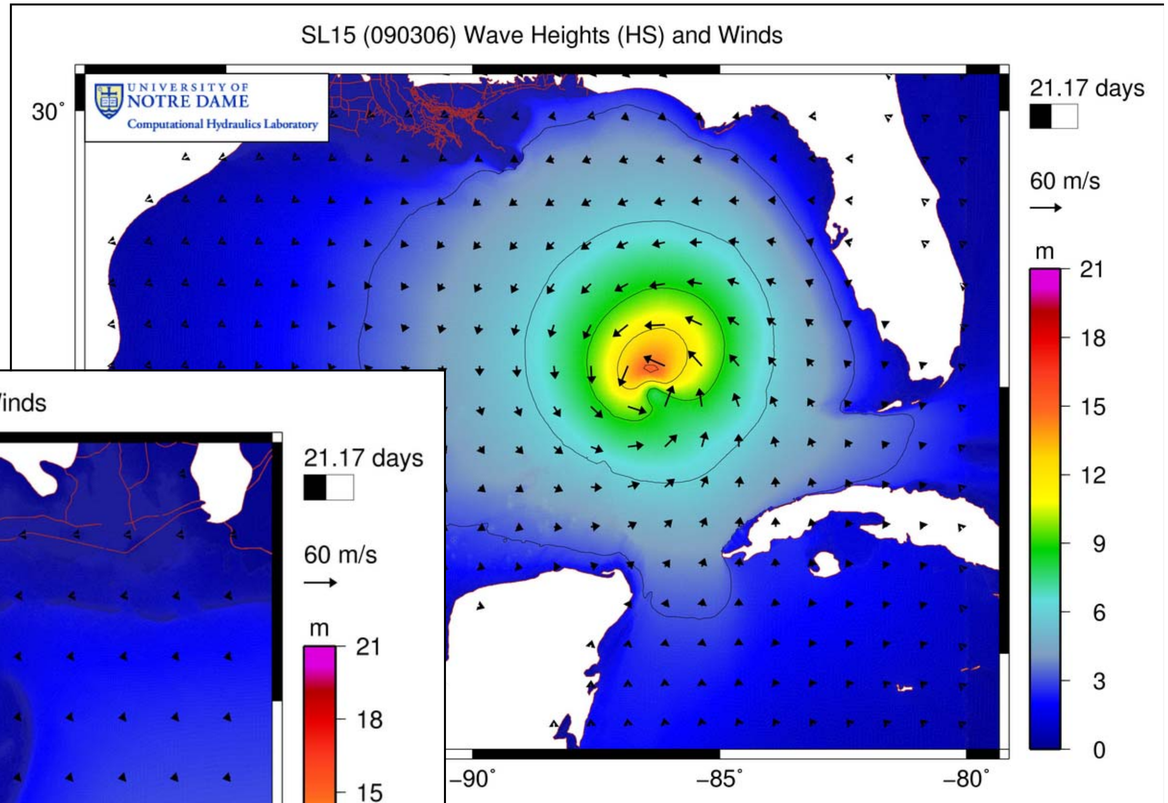


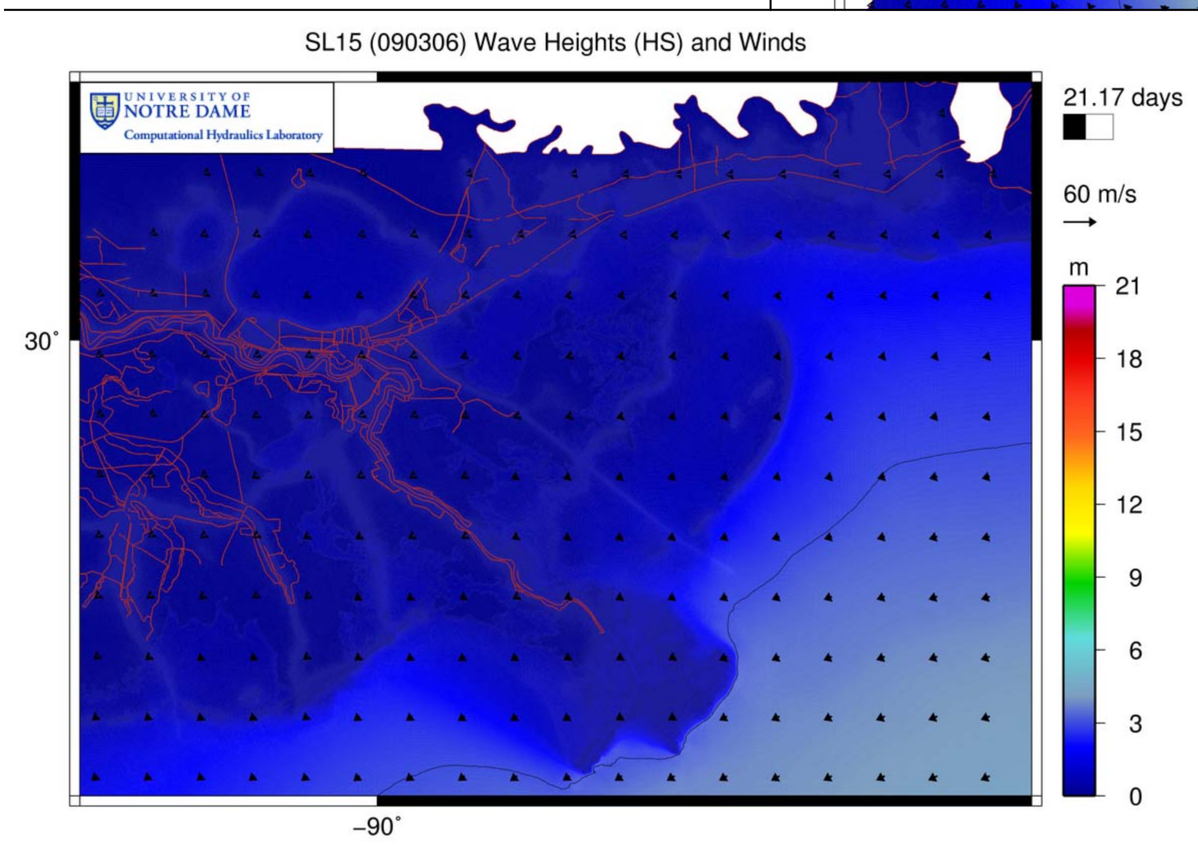


Hurricane Katrina

Wave Heights

- 2005/08/28/0400Z

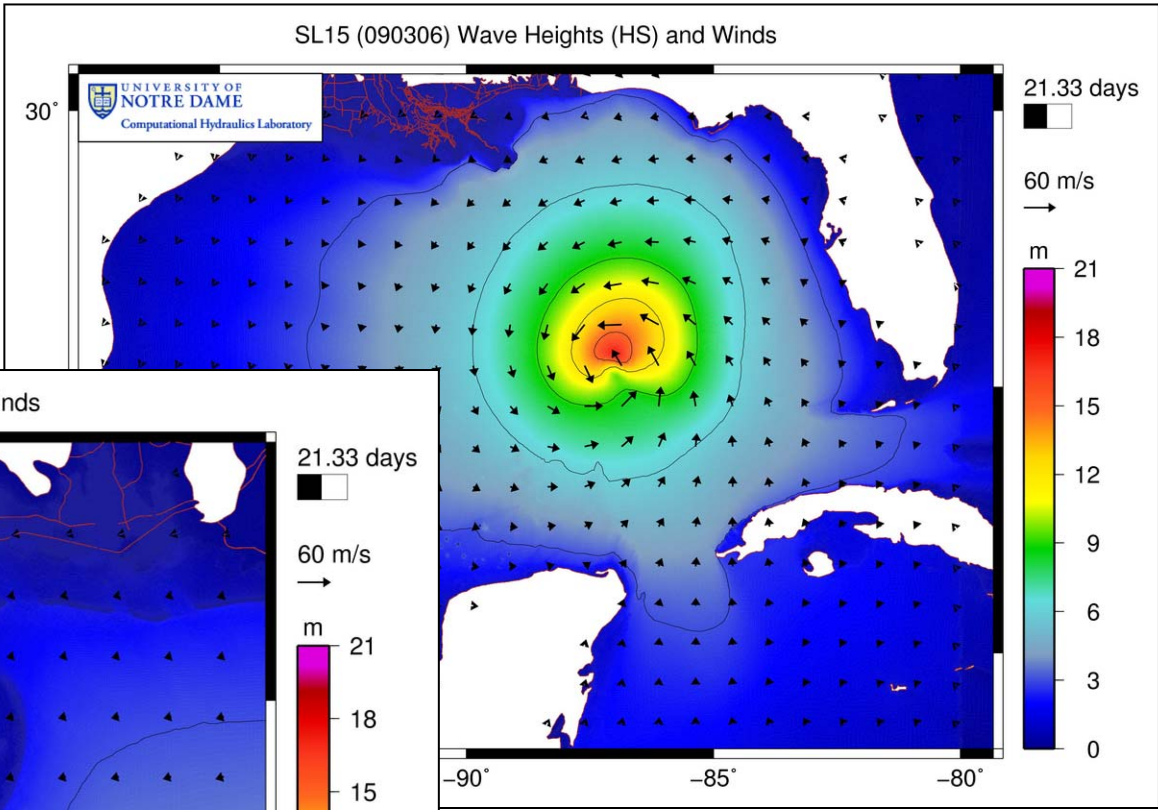


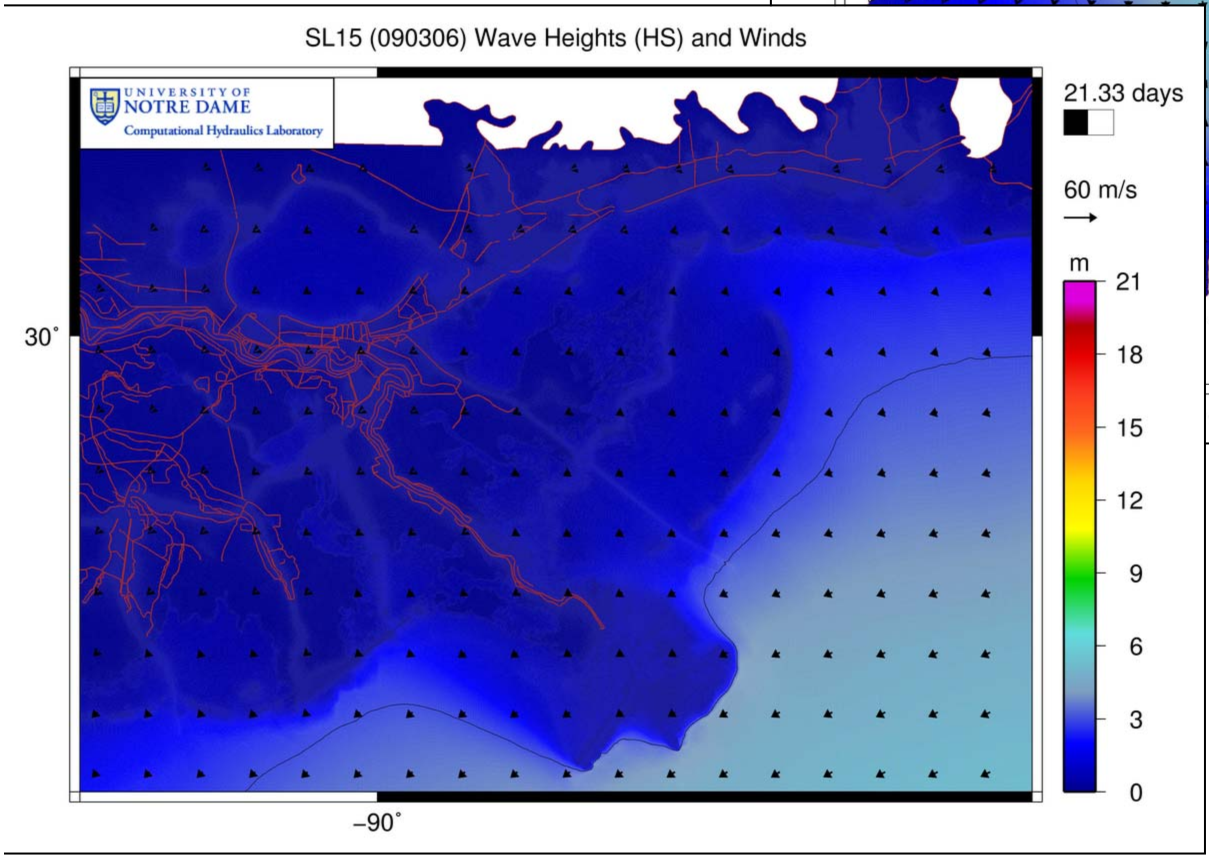


Hurricane Katrina

Wave Heights

- 2005/08/28/0800Z

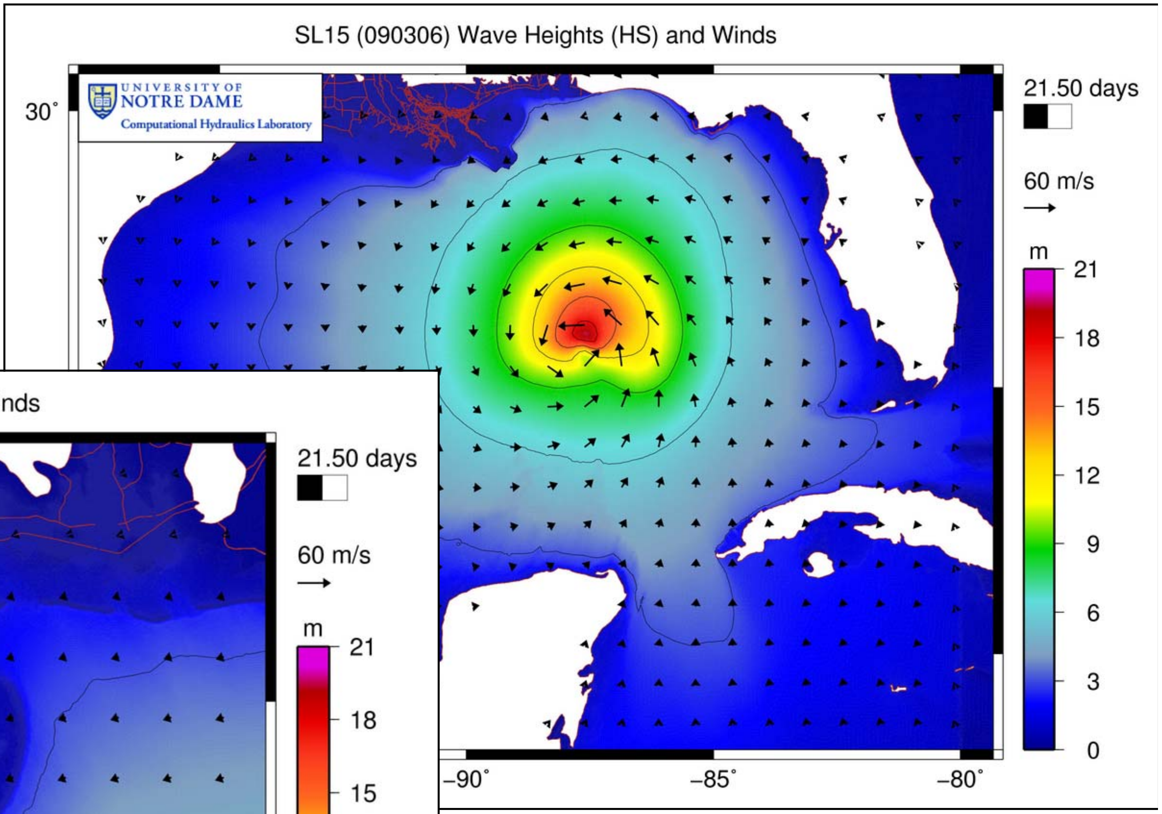


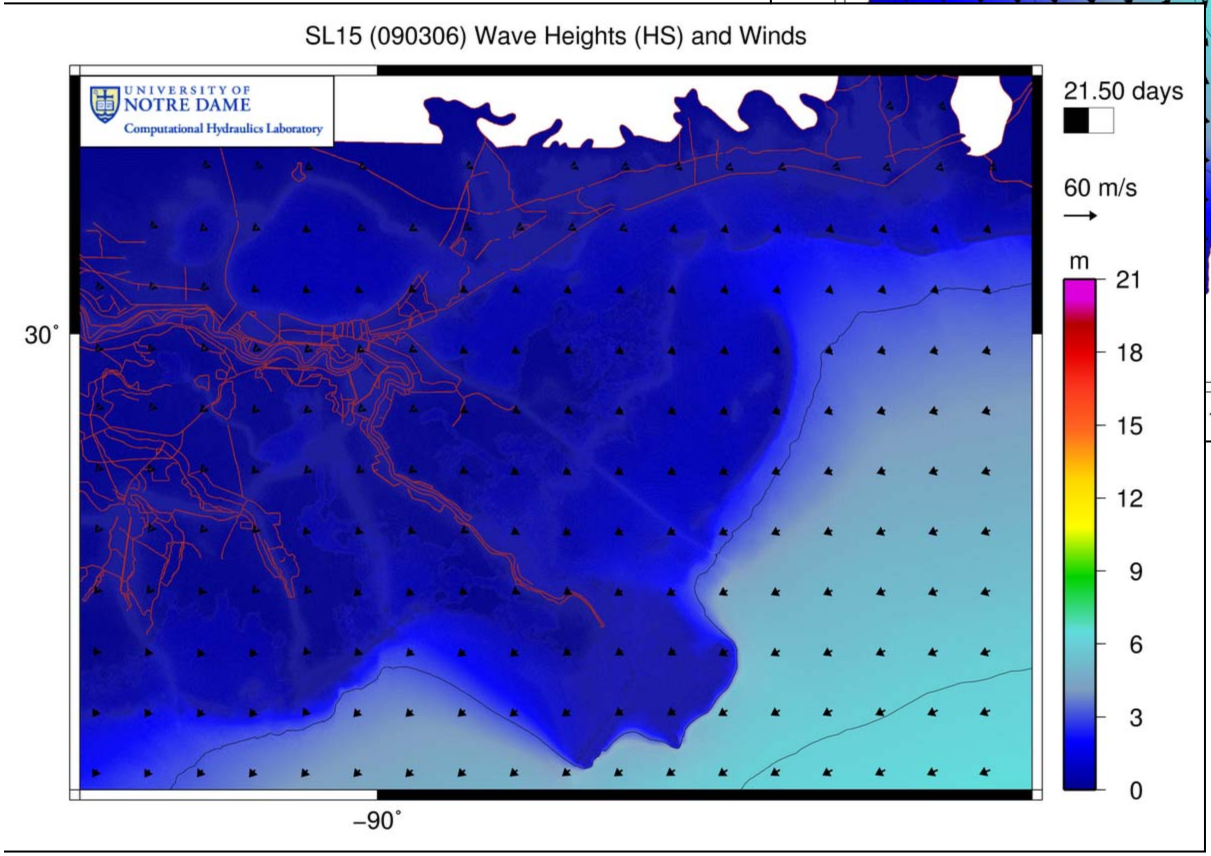


Hurricane Katrina

Wave Heights

- 2005/08/28/1200Z

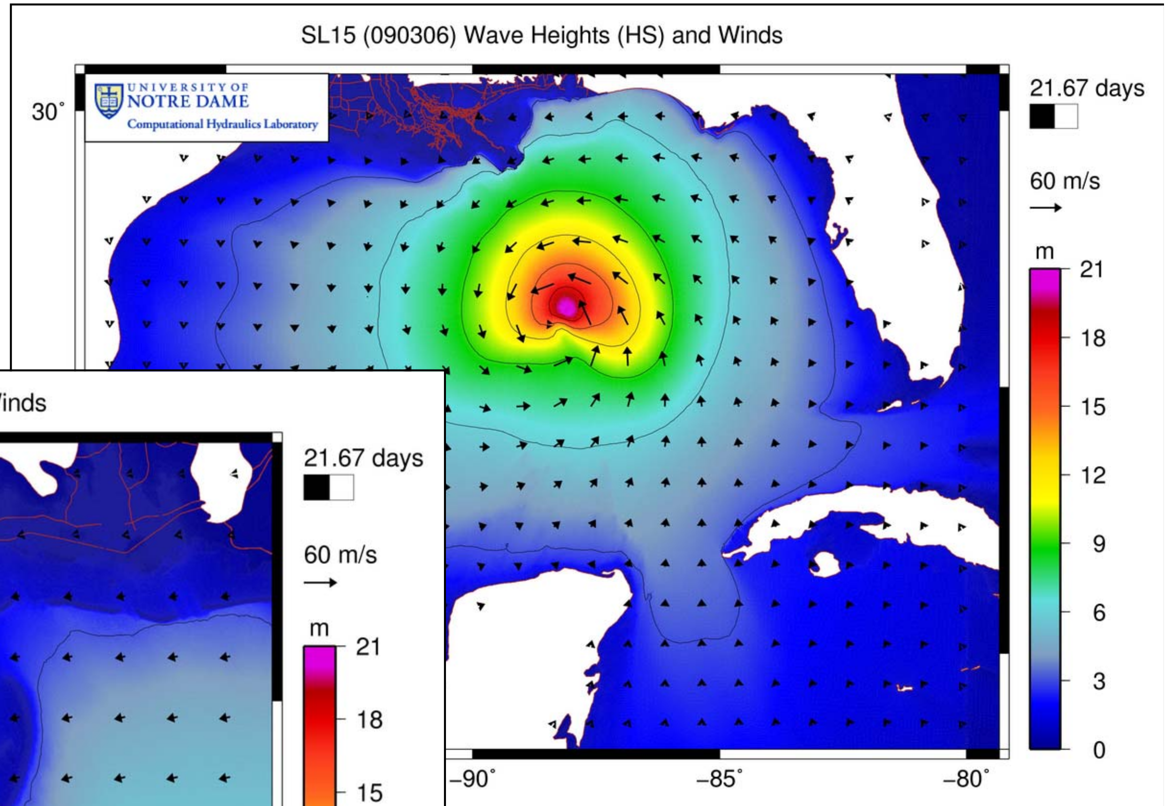


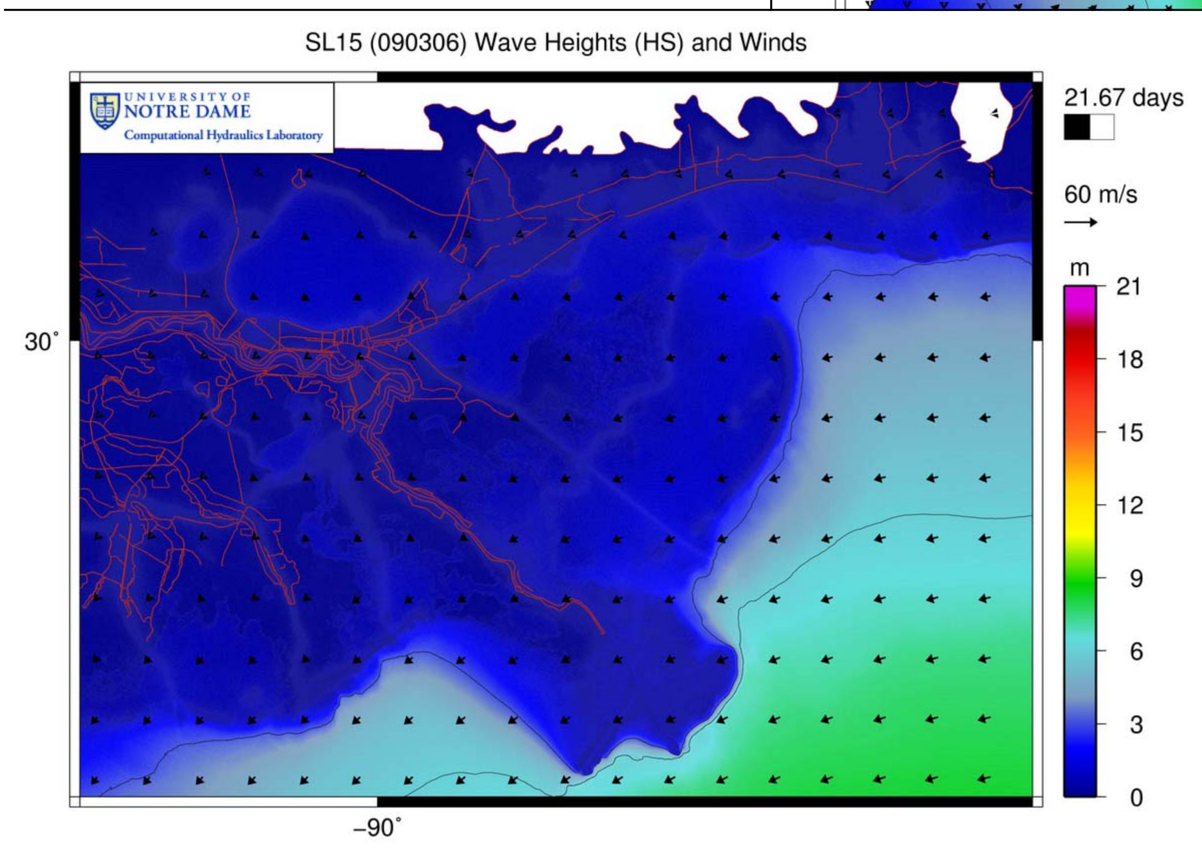


Hurricane Katrina

Wave Heights

- 2005/08/28/1600Z

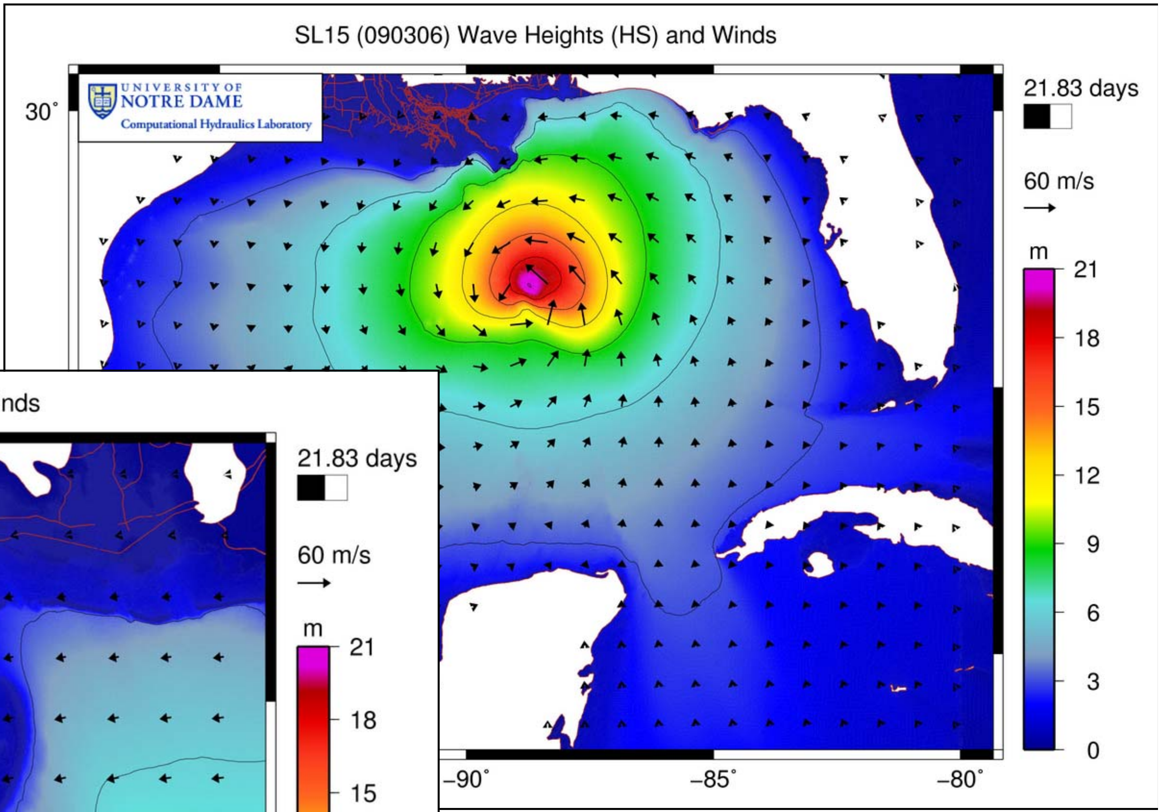


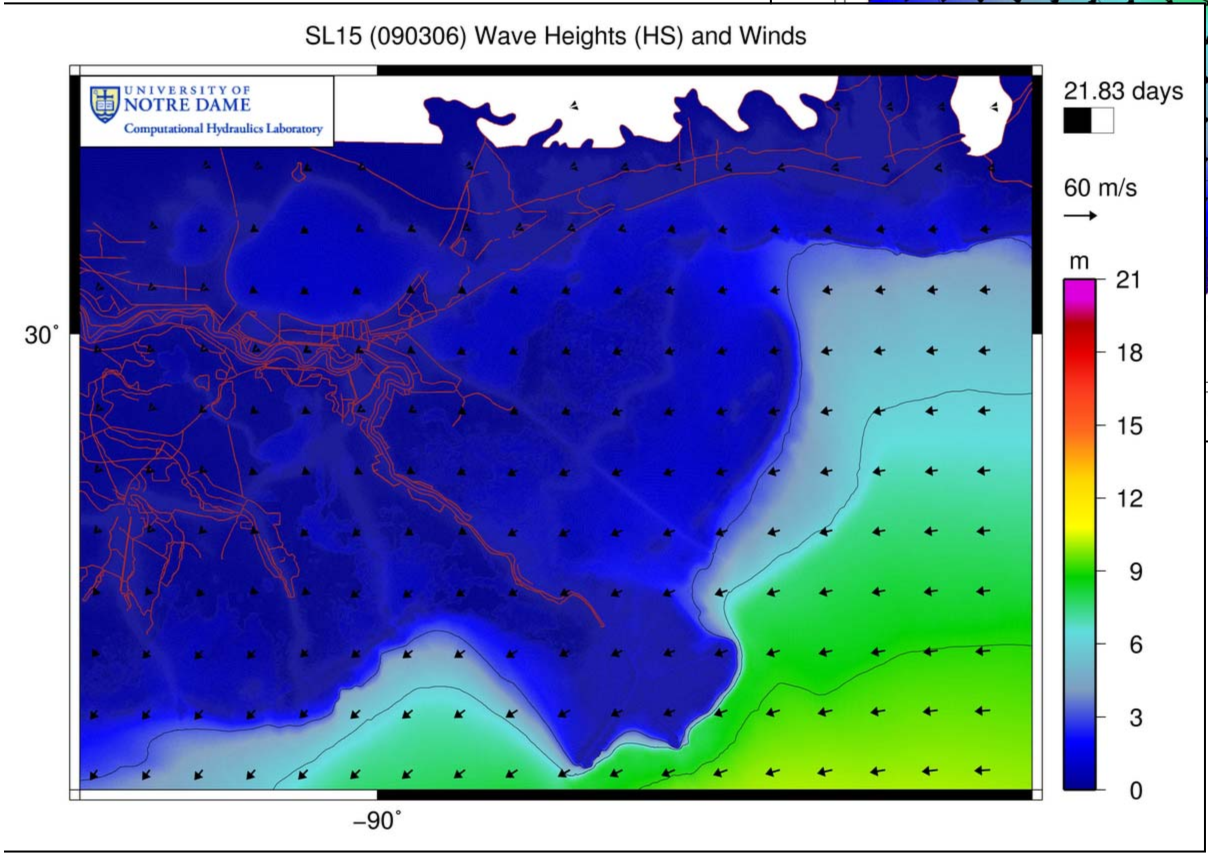


Hurricane Katrina

Wave Heights

- 2005/08/28/2000Z

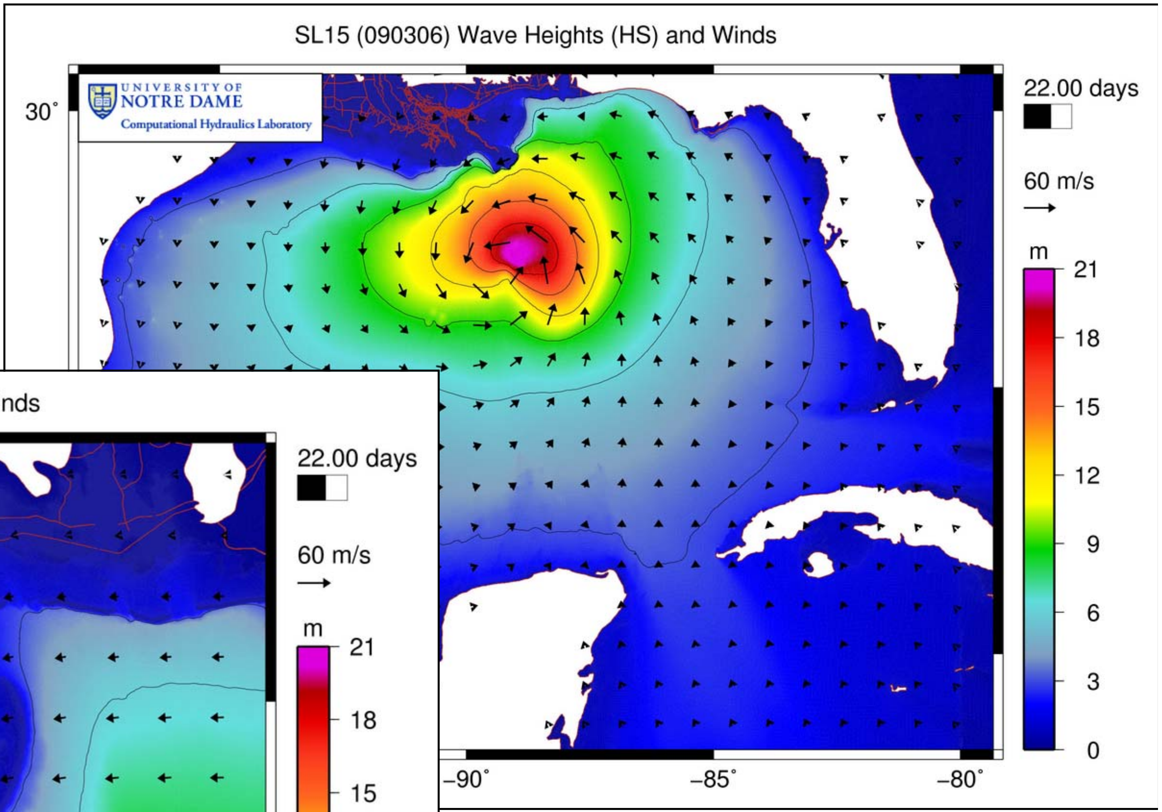


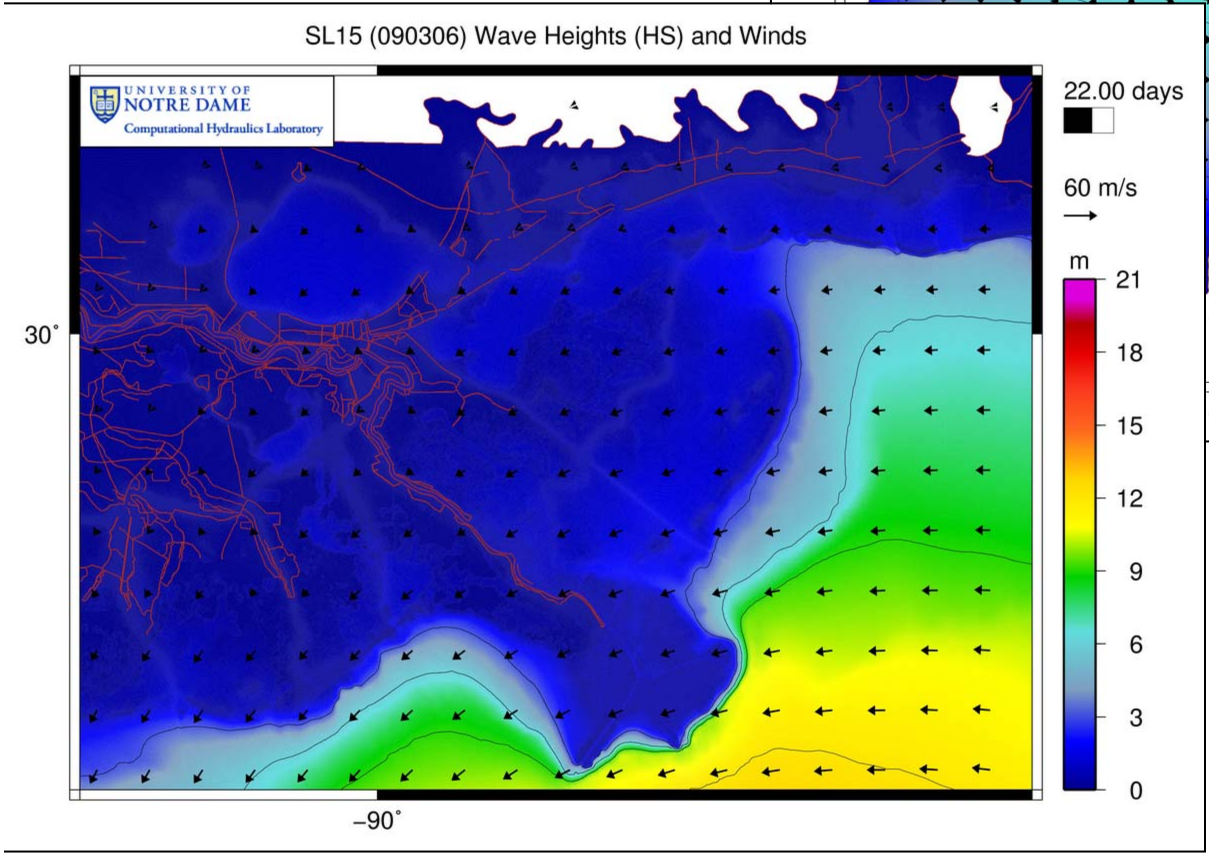


Hurricane Katrina

Wave Heights

- 2005/08/29/0000Z

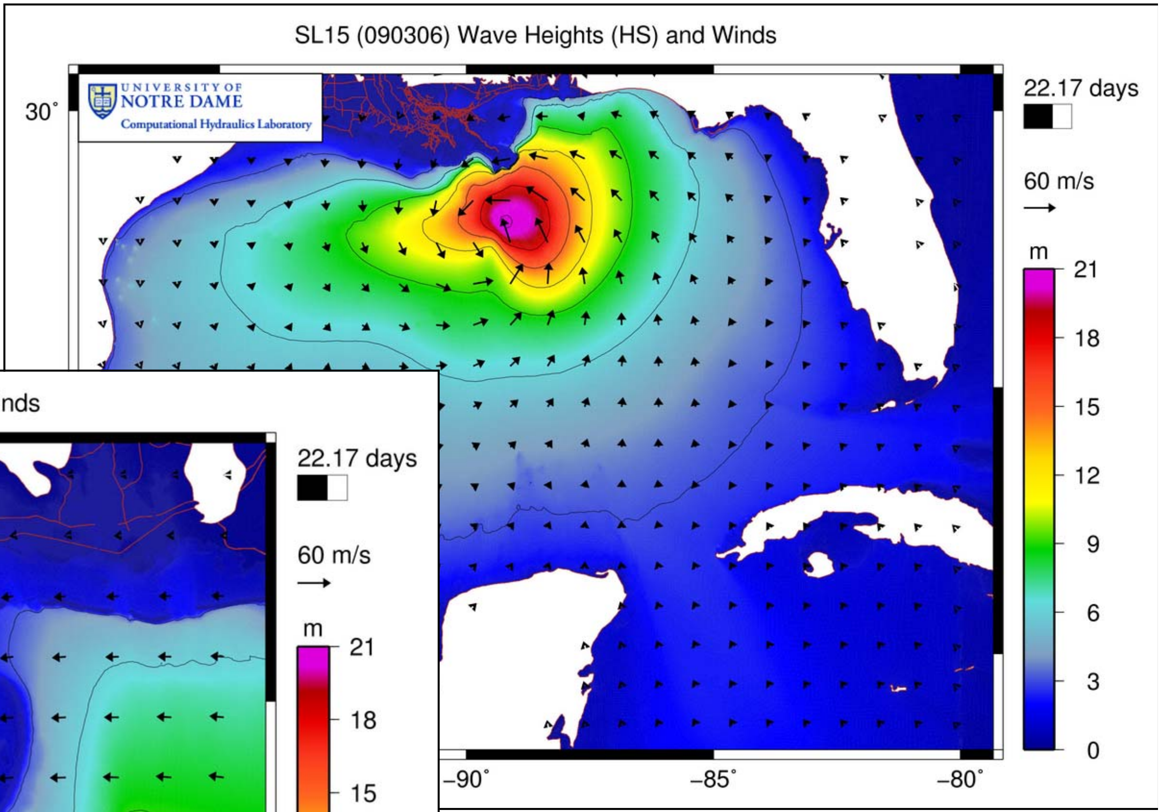


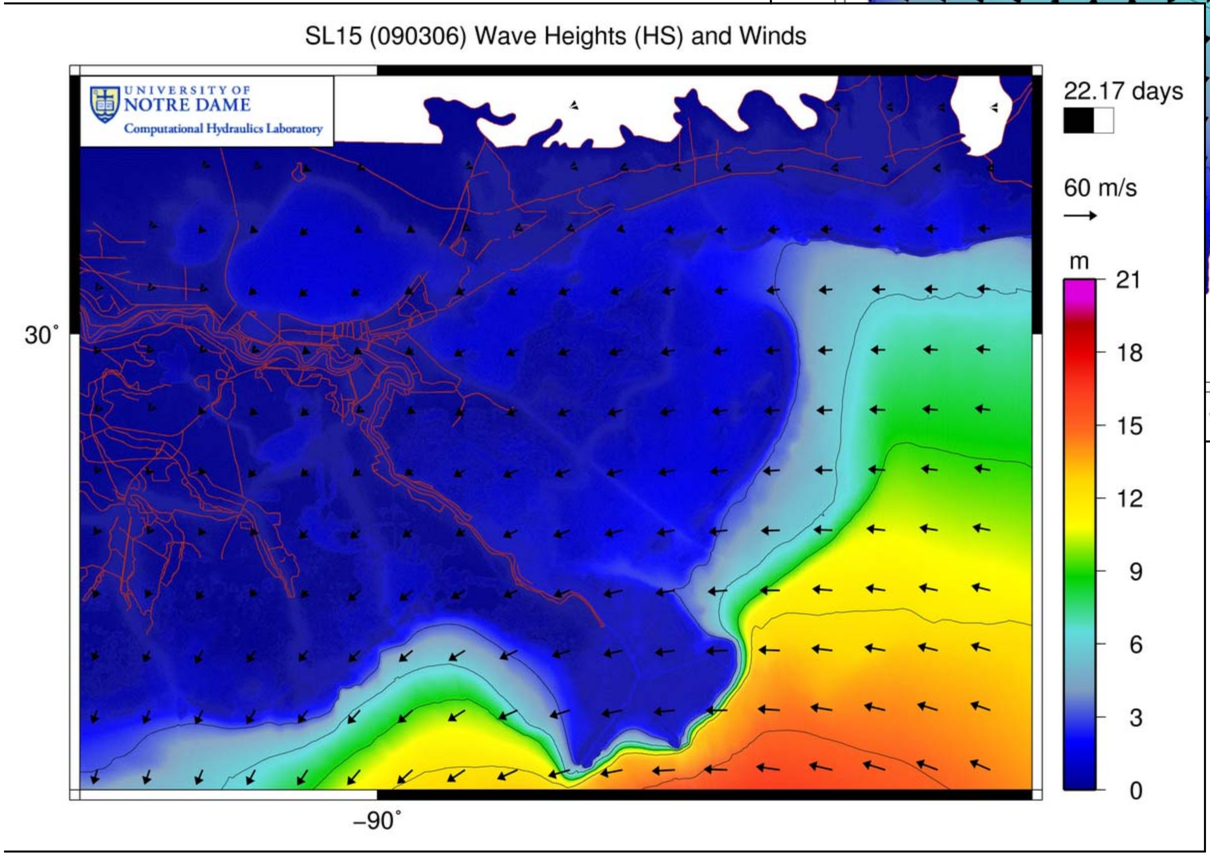


Hurricane Katrina

Wave Heights

- 2005/08/29/0400Z

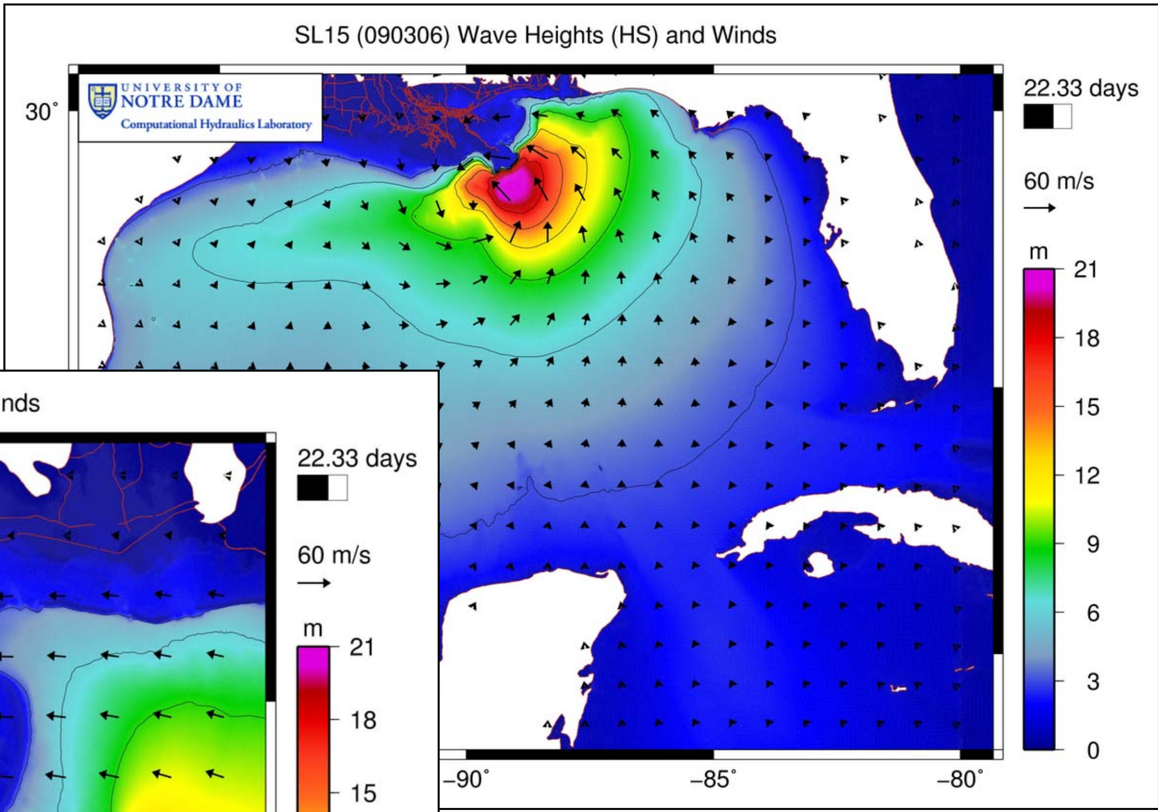


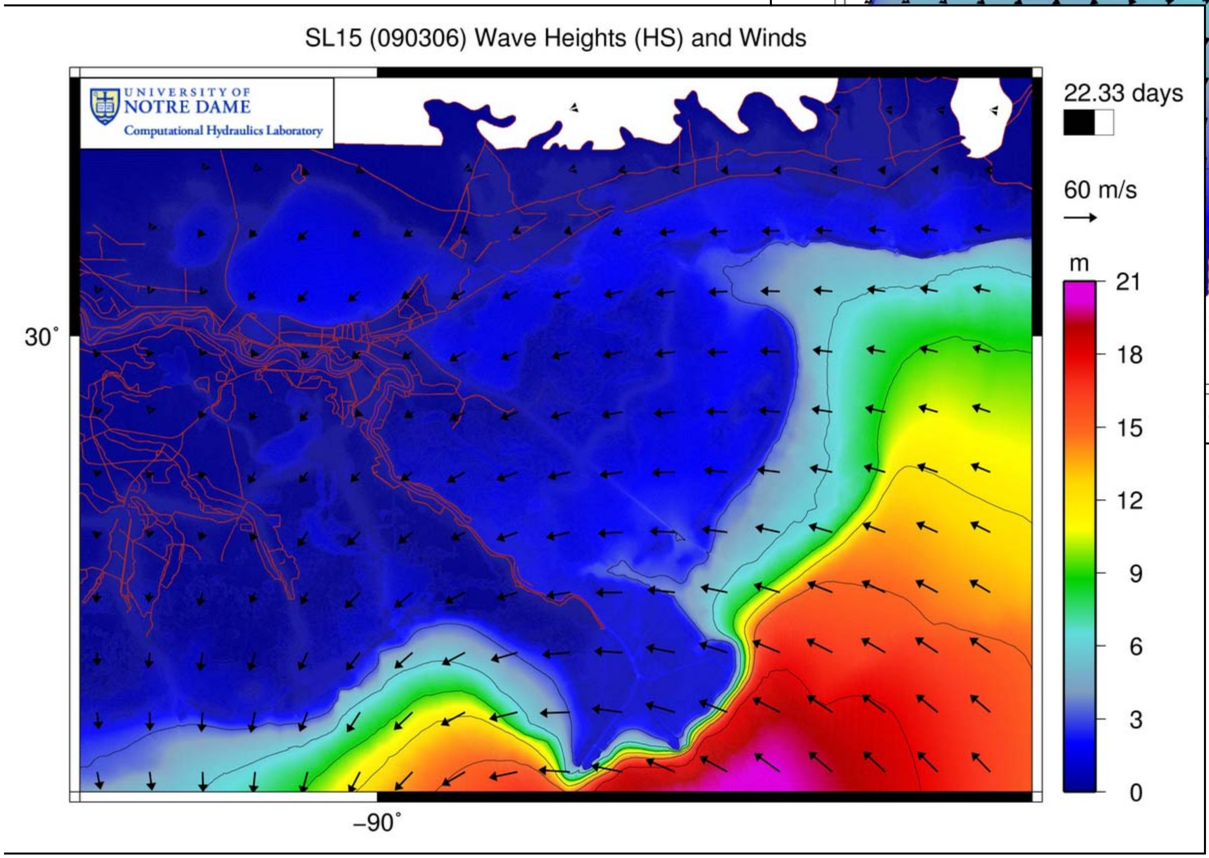


Hurricane Katrina

Wave Heights

- 2005/08/29/0800Z

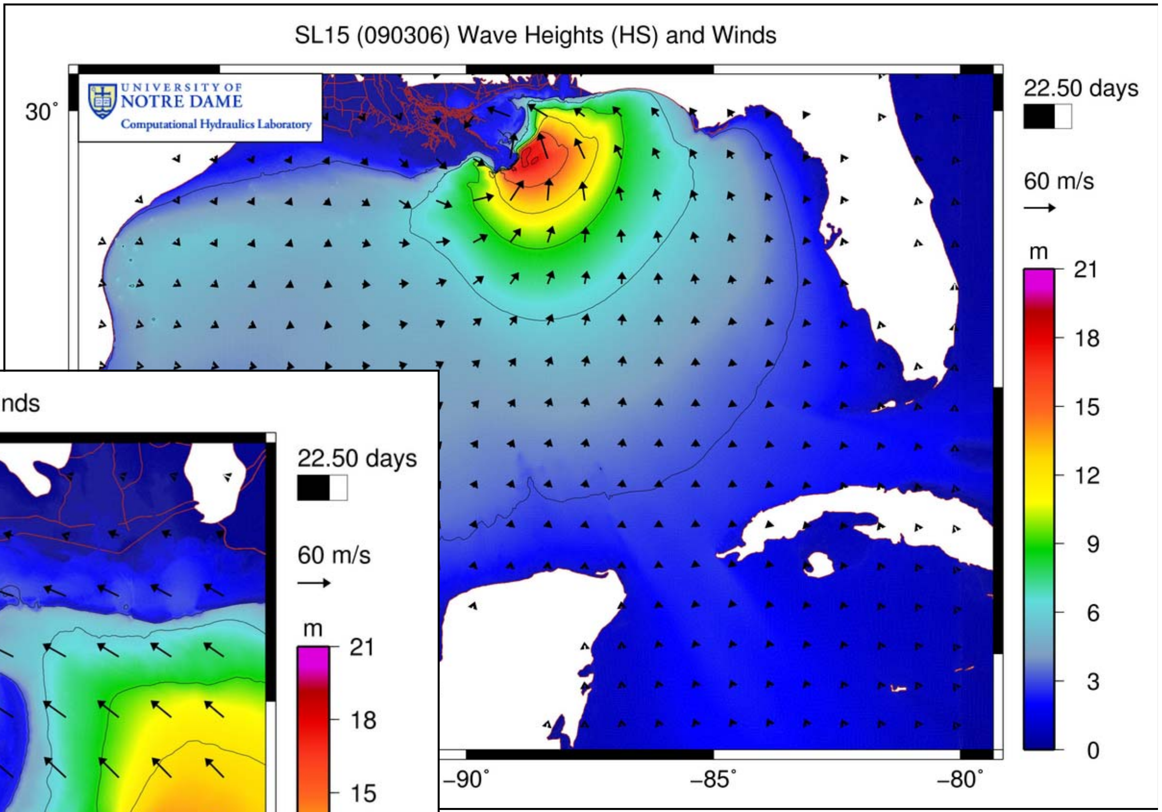


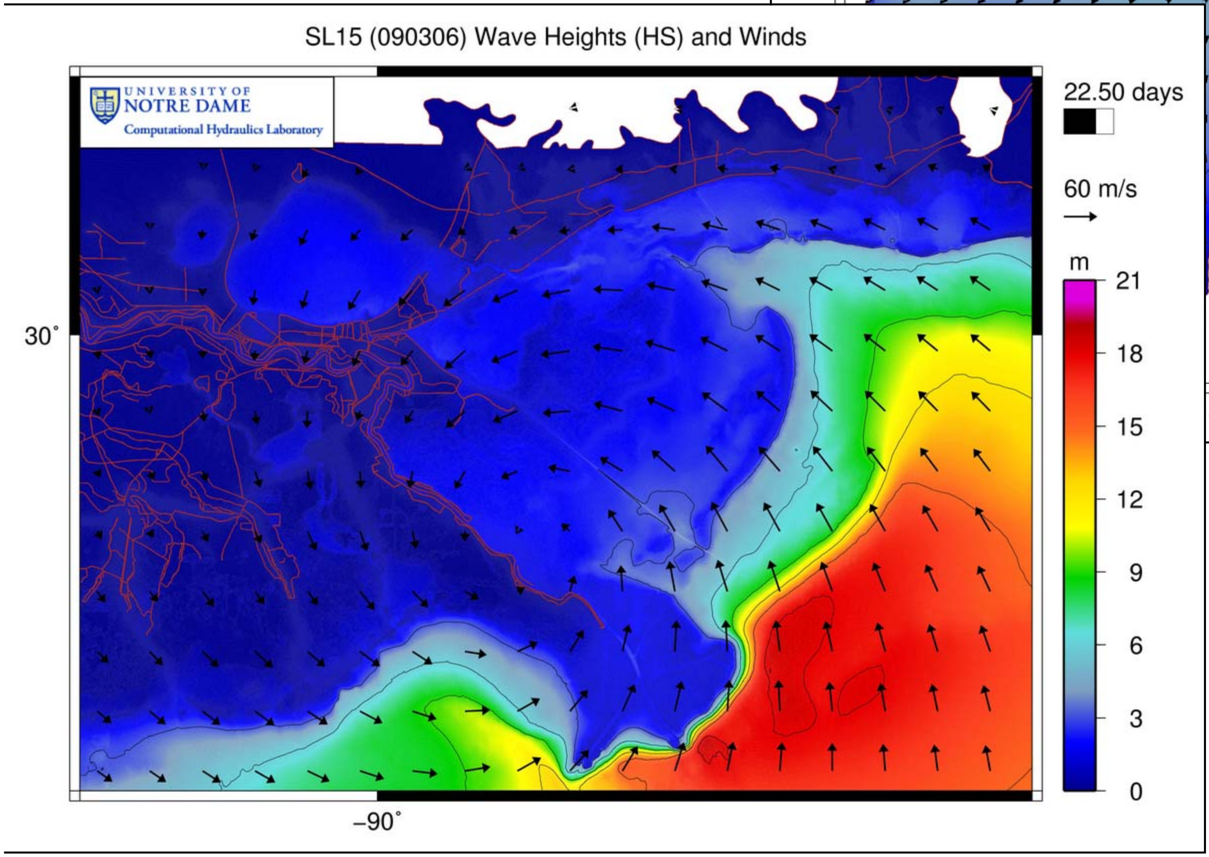


Hurricane Katrina

Wave Heights

- 2005/08/29/1200Z

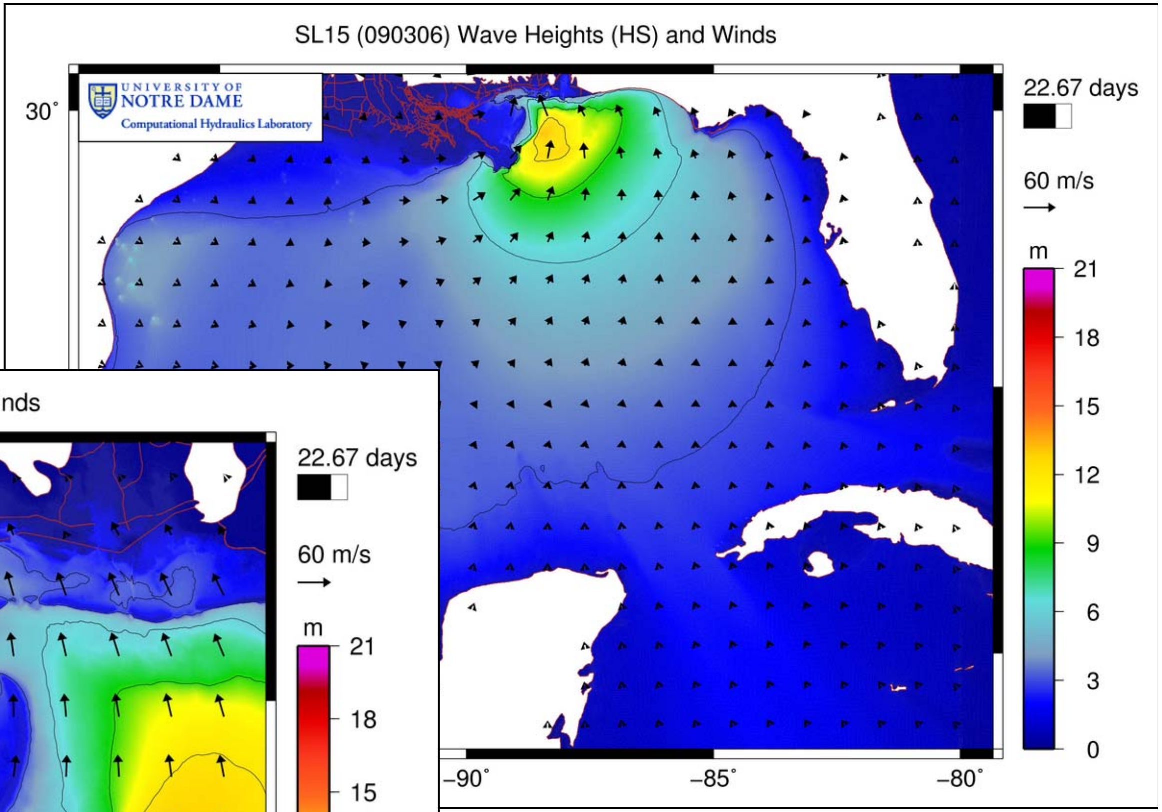


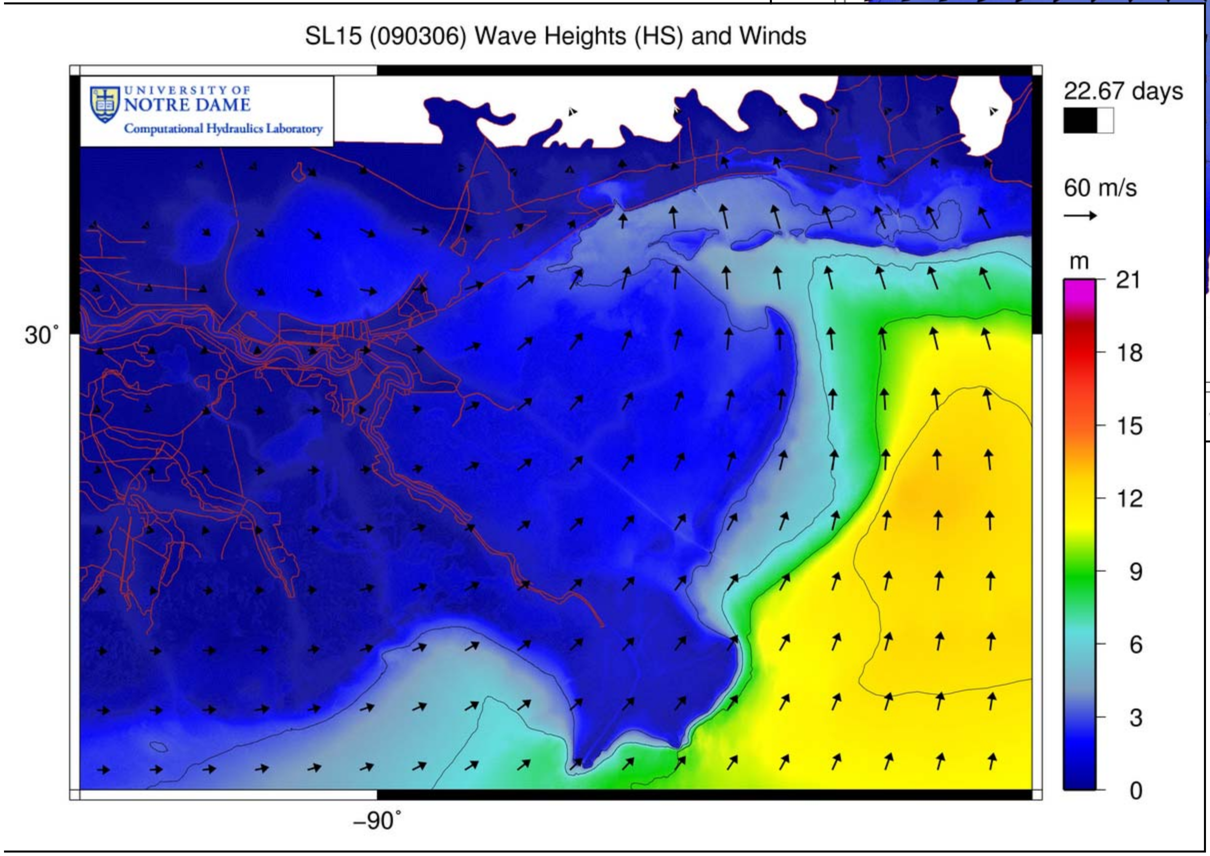


Hurricane Katrina

Wave Heights

- 2005/08/29/1600Z

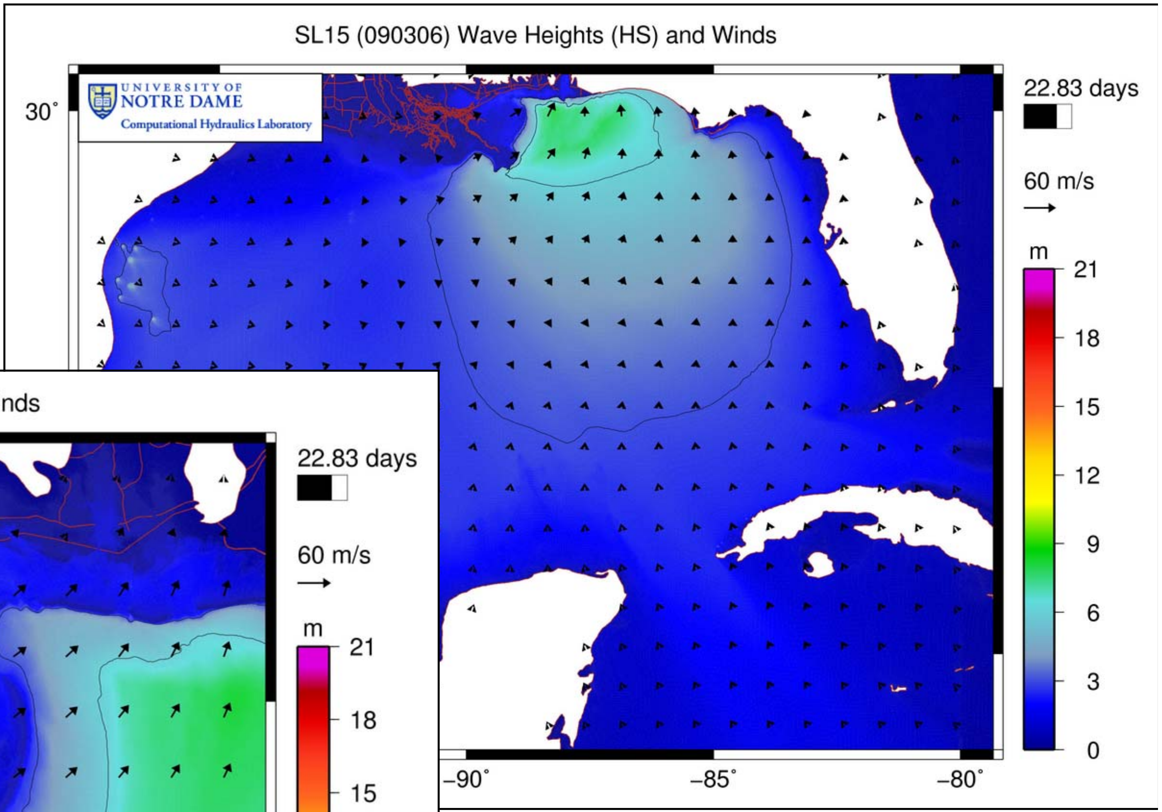


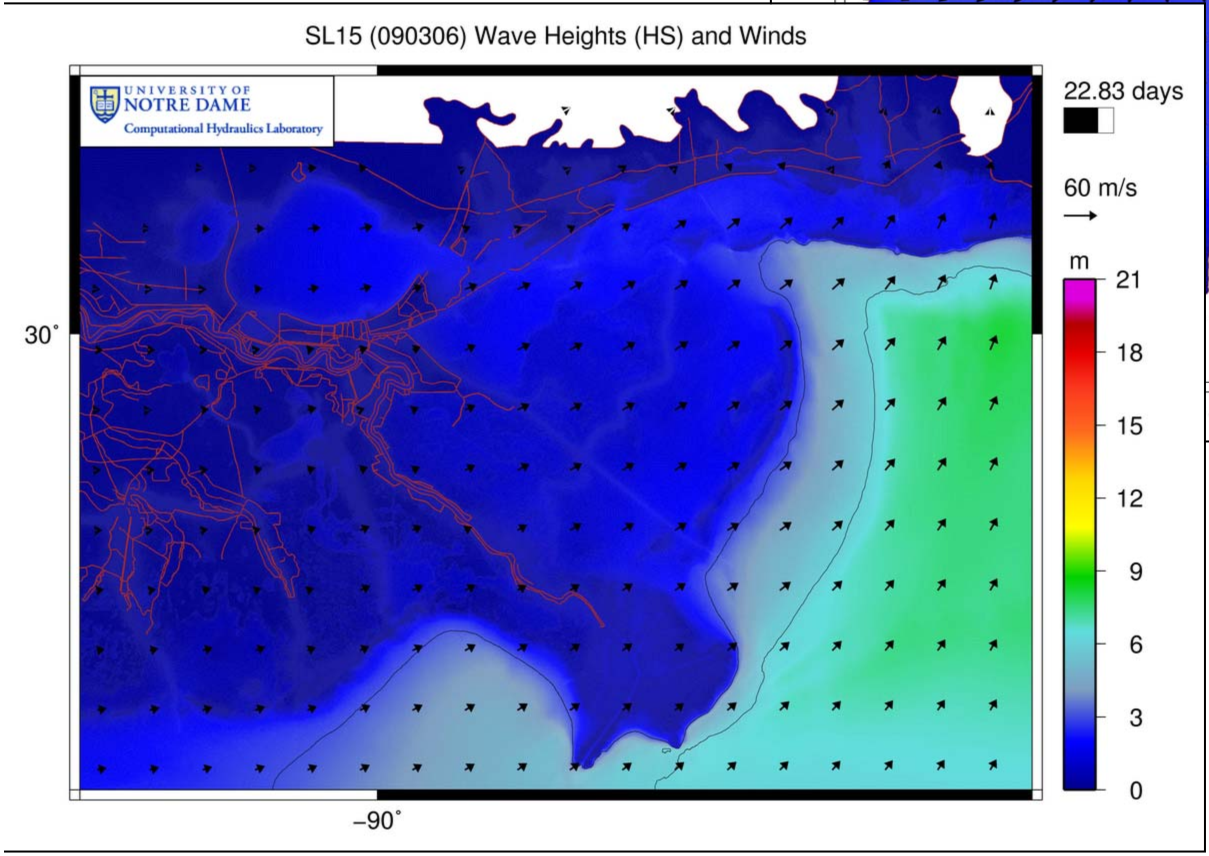


Hurricane Katrina

Wave Heights

- 2005/08/29/2000Z

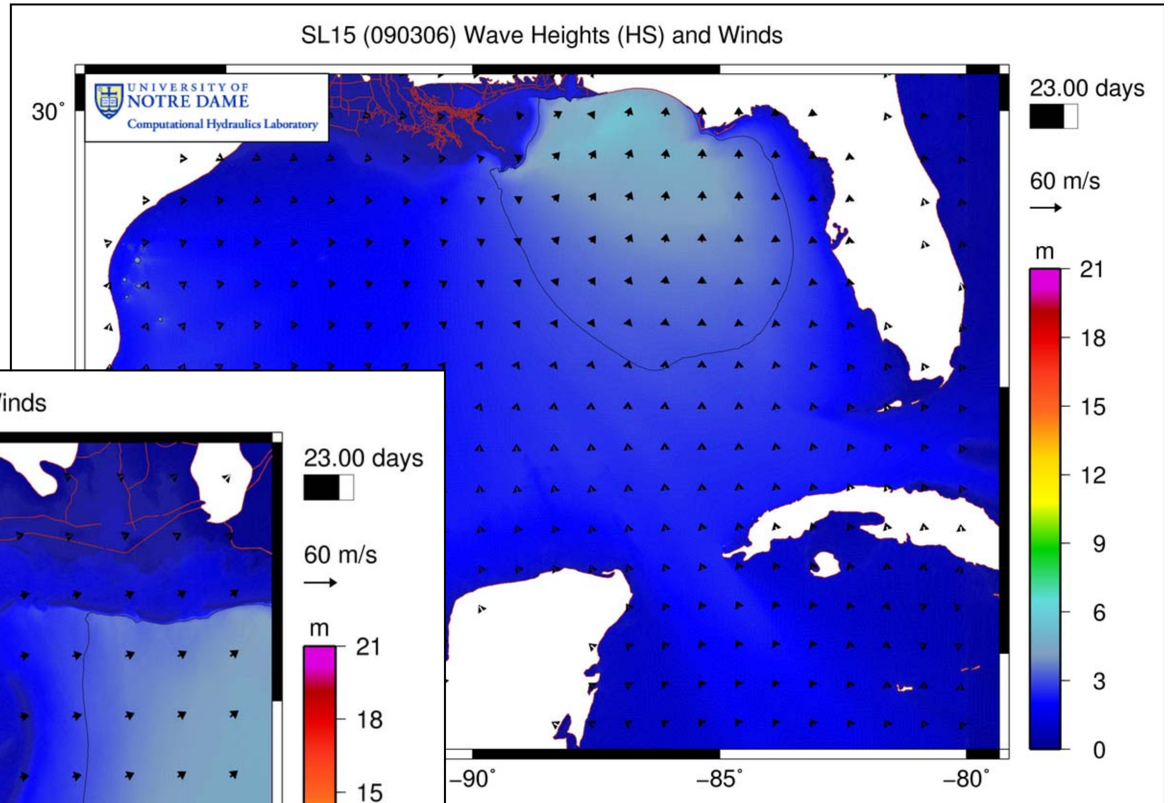


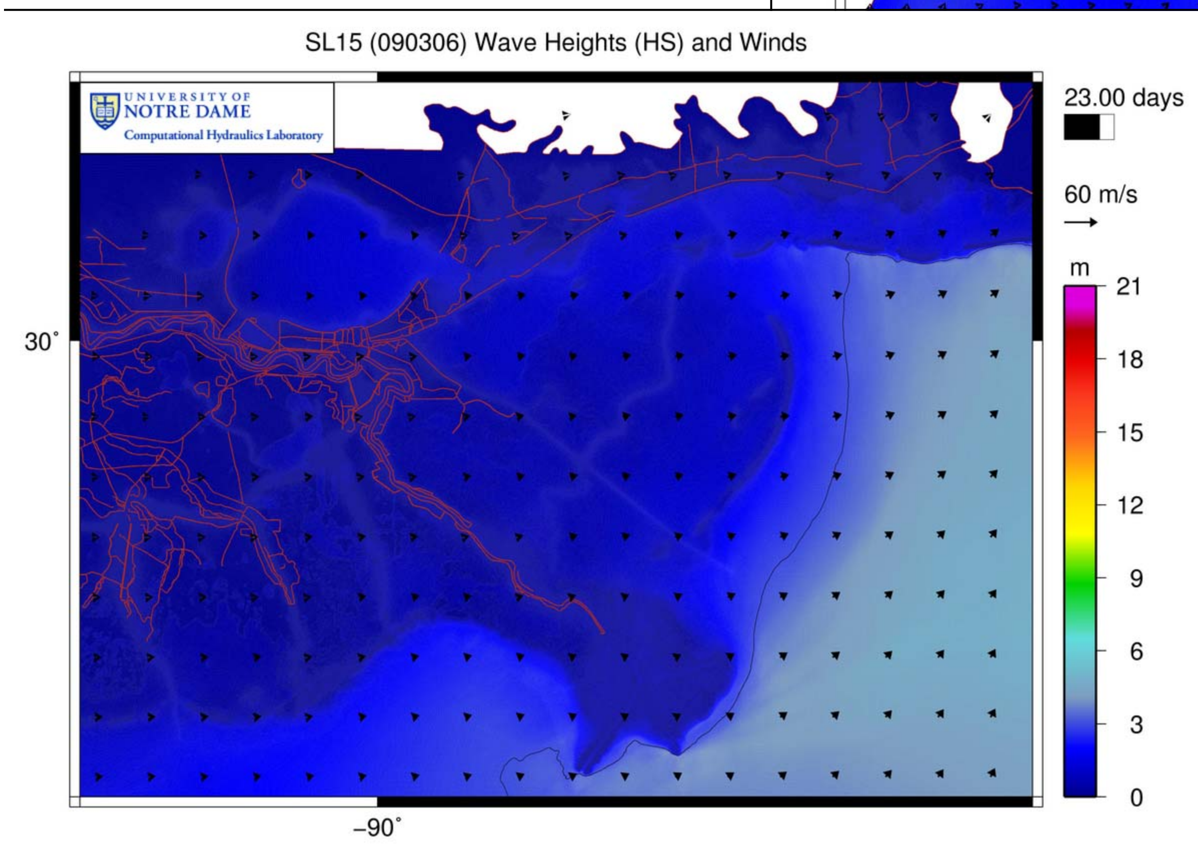


Hurricane Katrina

Wave Heights

- 2005/08/30/0000Z





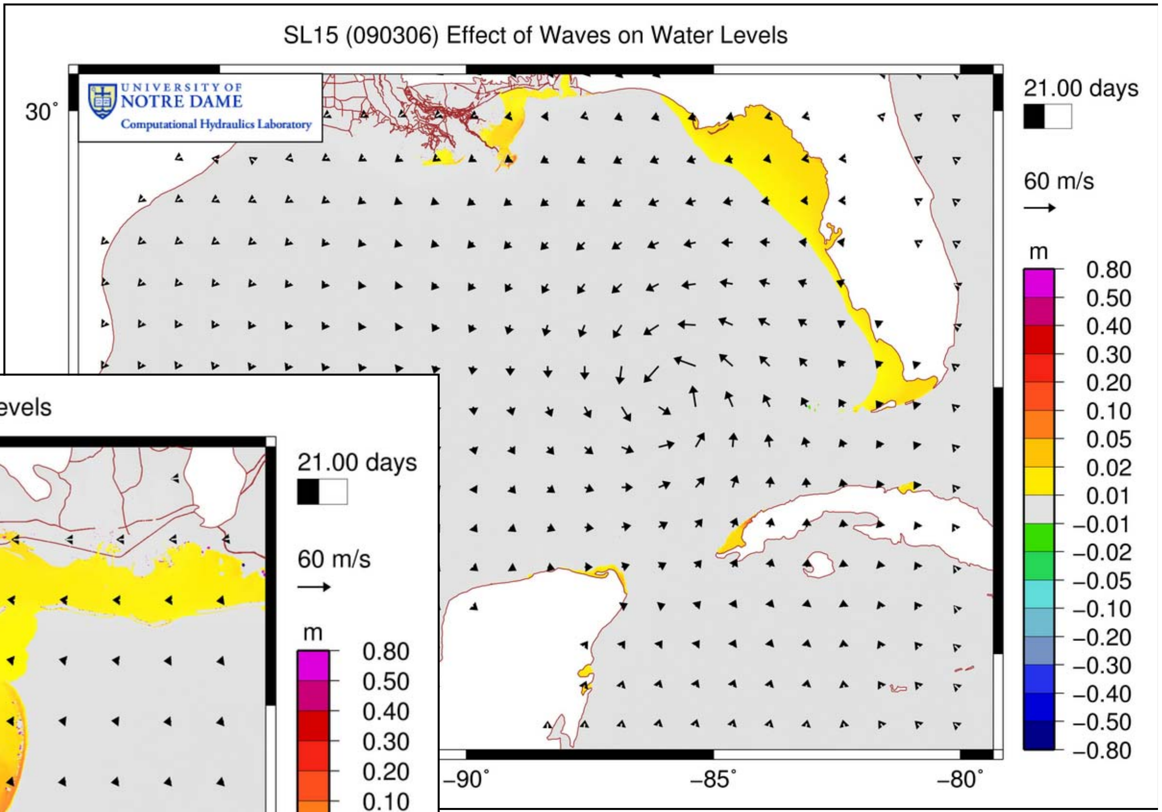
Hurricane Katrina

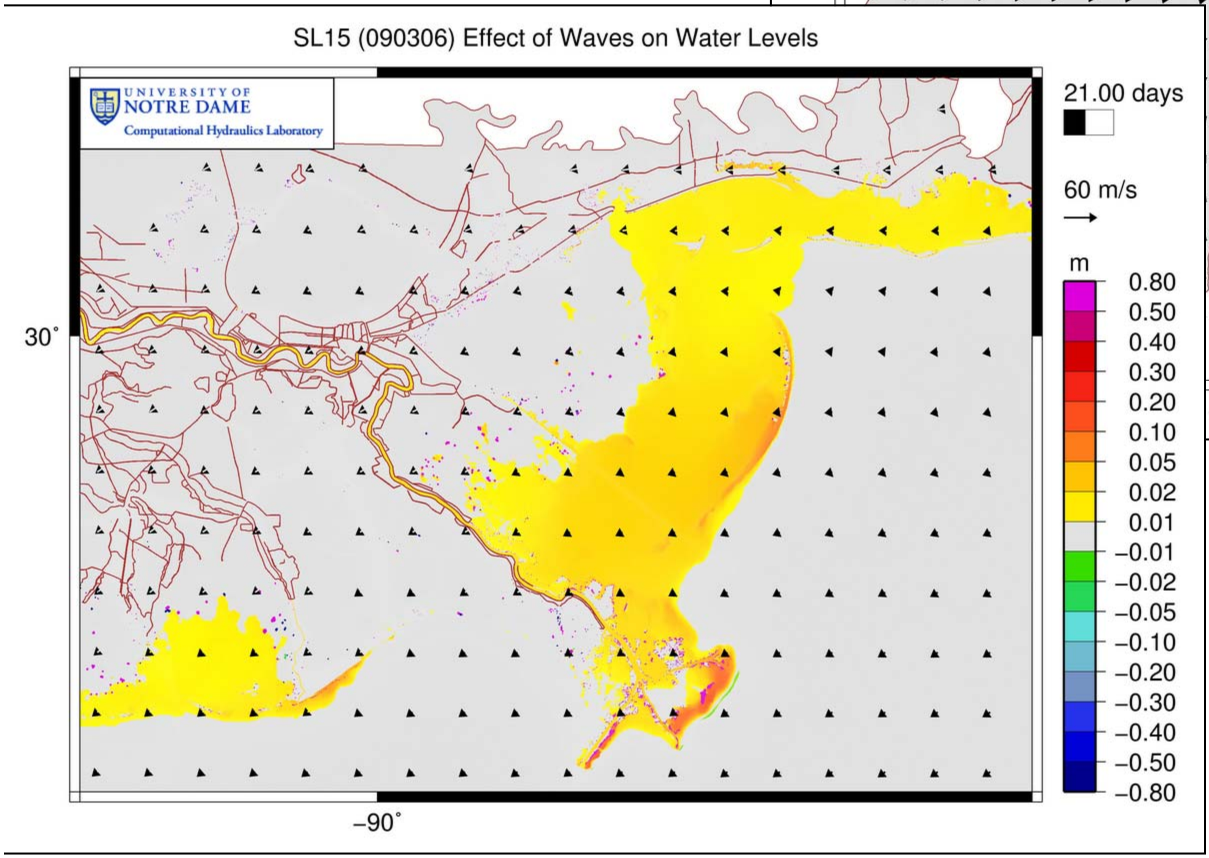
Waves on Water Levels

Hurricane Katrina

Waves on Water Levels

- 2005/08/28/0000Z

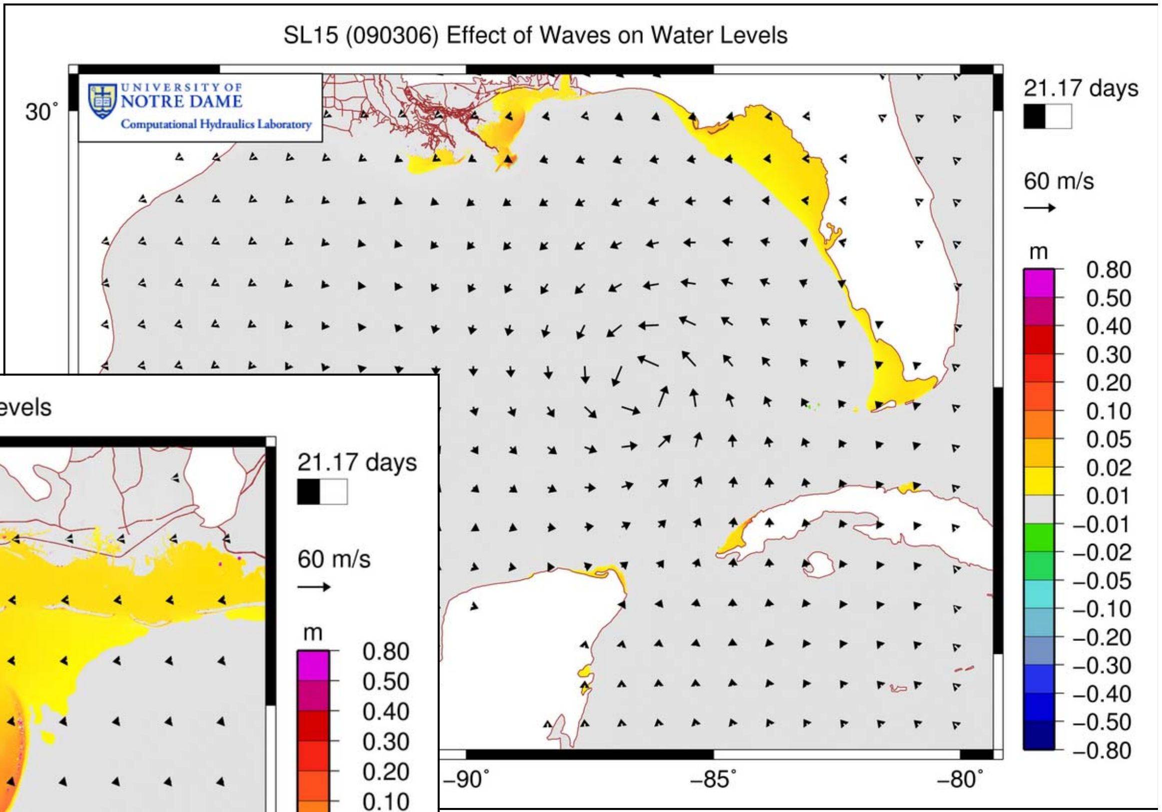


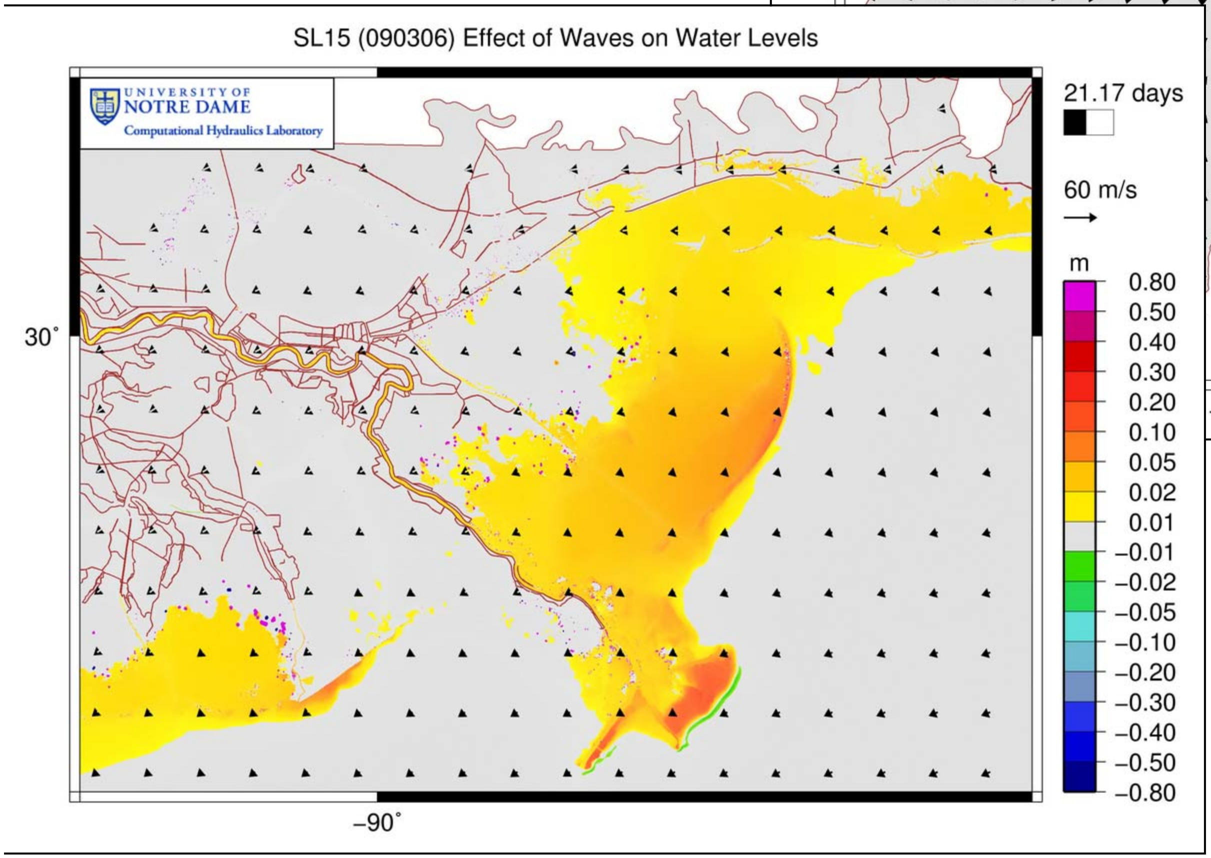


Hurricane Katrina

Waves on Water Levels

- 2005/08/28/0400Z

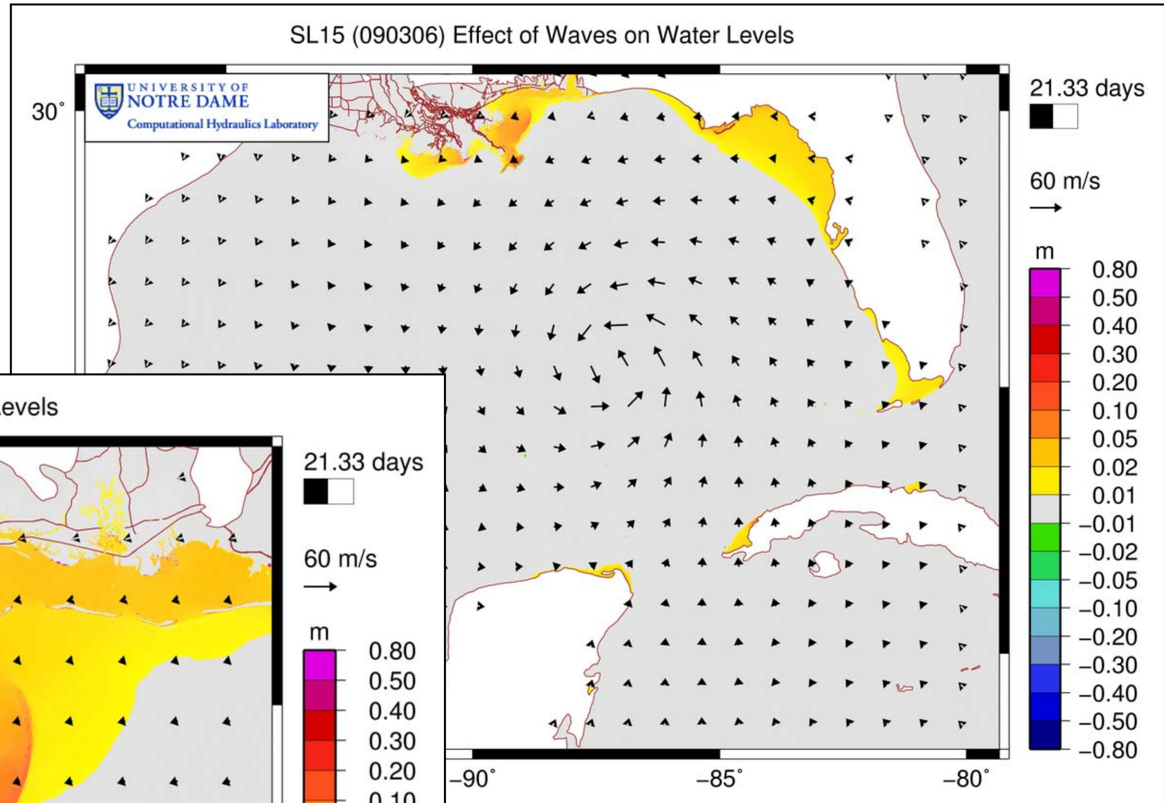


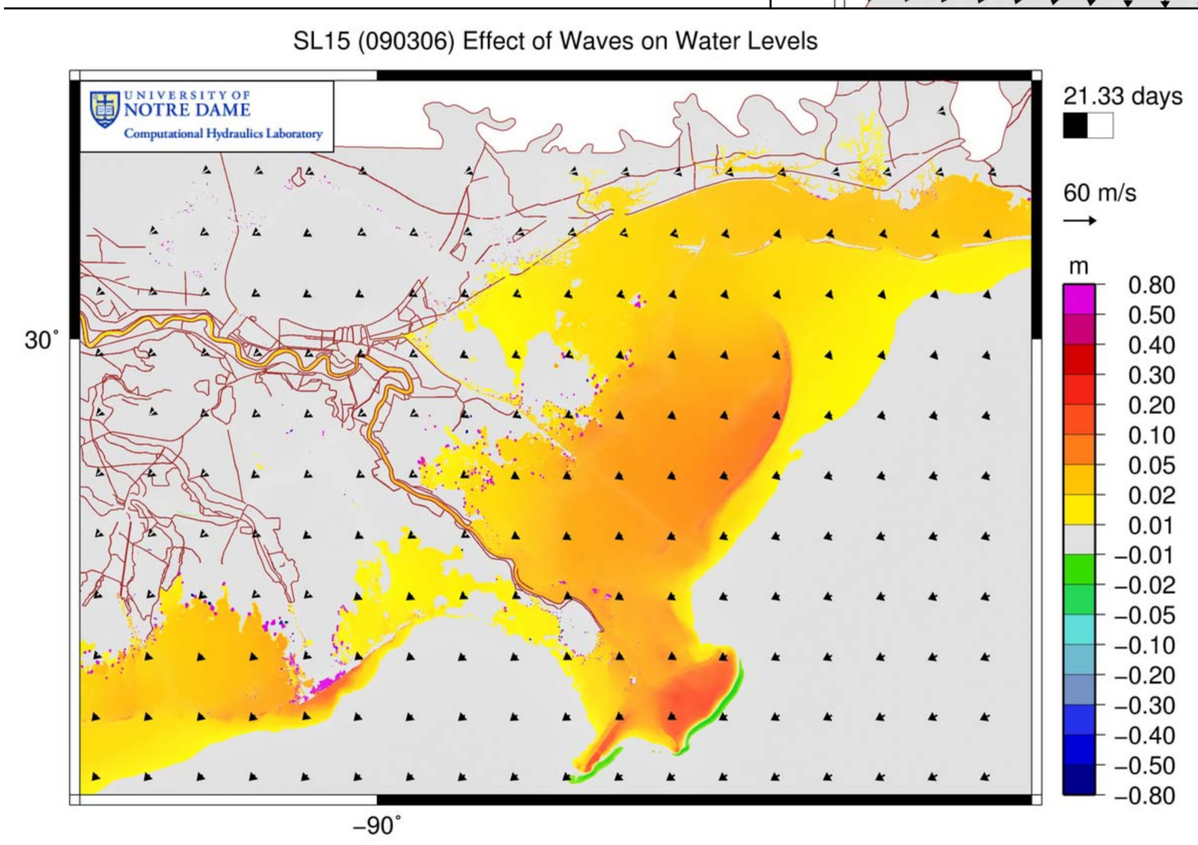


Hurricane Katrina

Waves on Water Levels

- 2005/08/28/0800Z

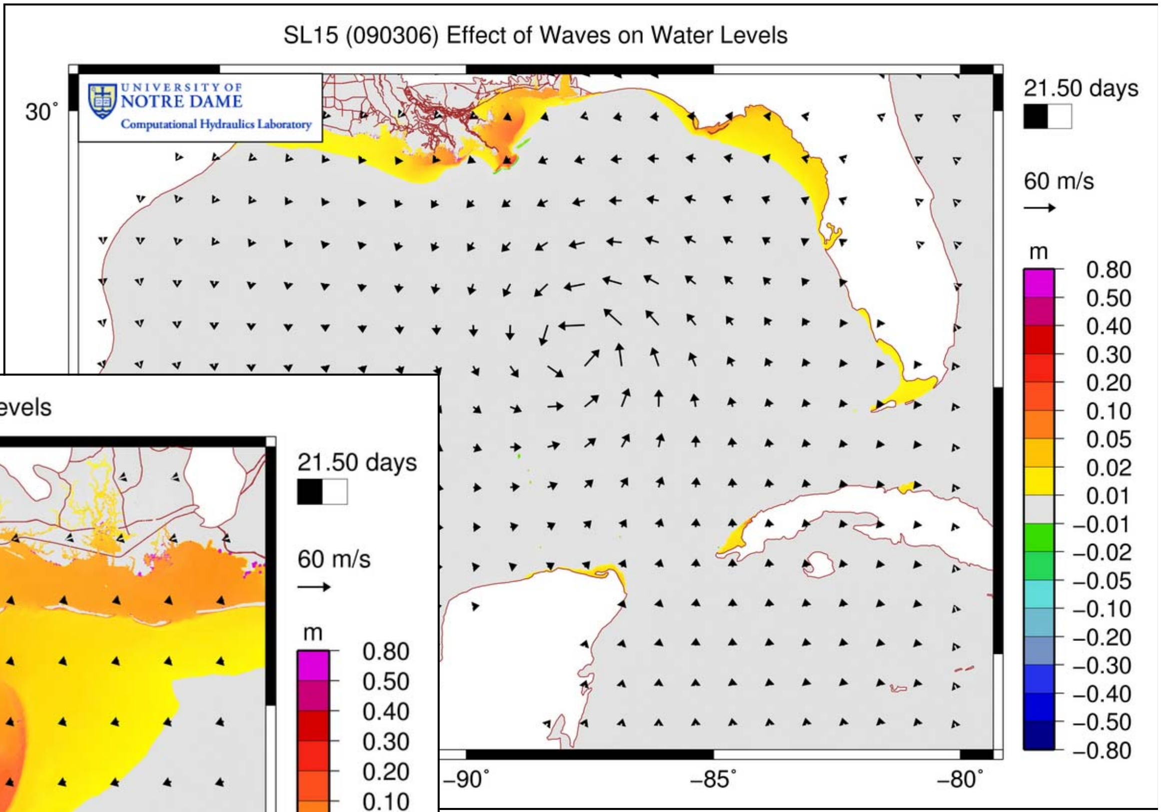


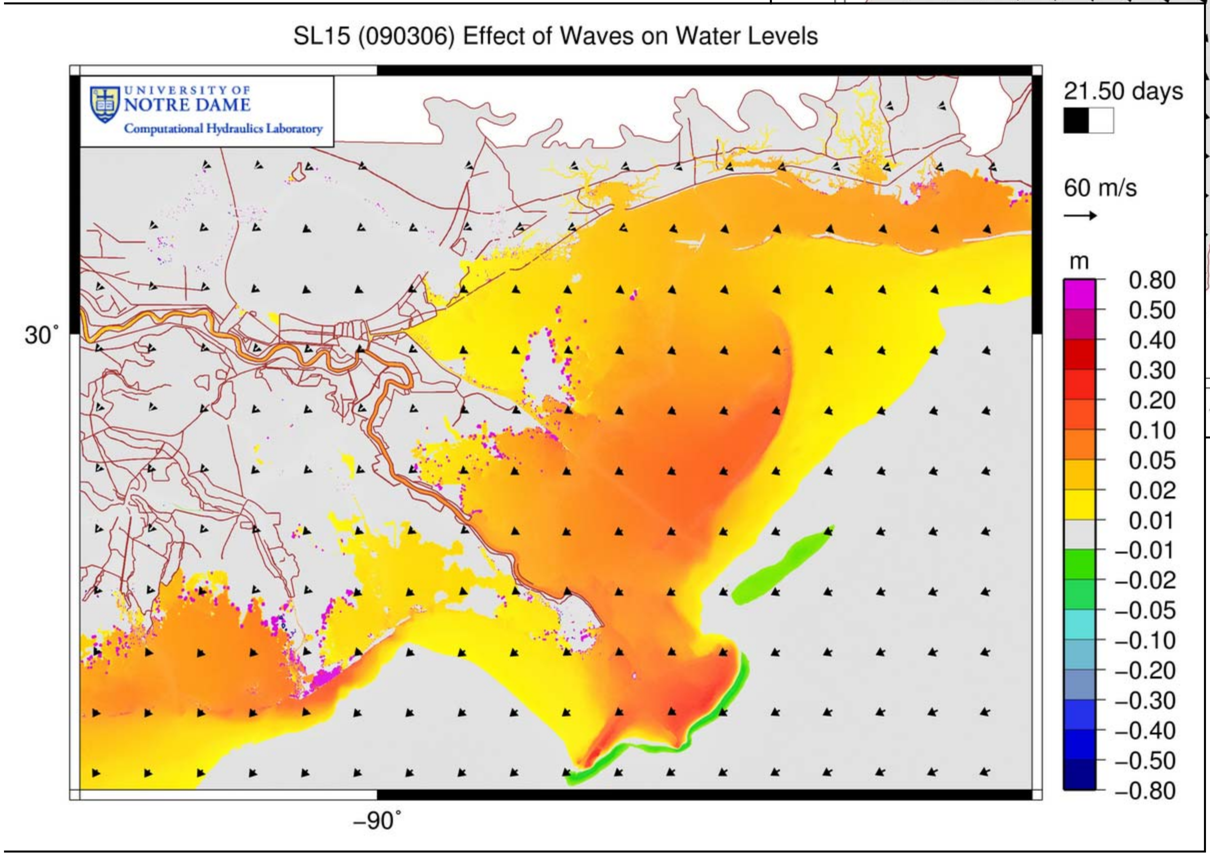


Hurricane Katrina

Waves on Water Levels

- 2005/08/28/1200Z

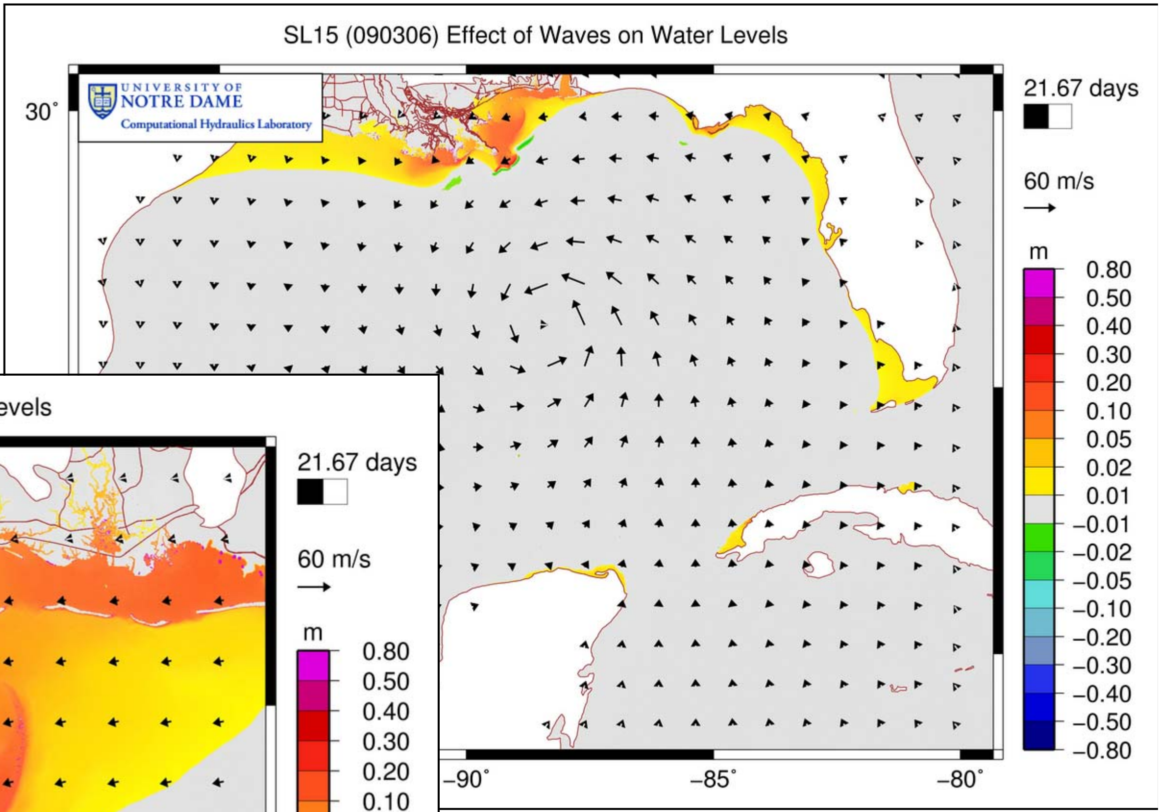


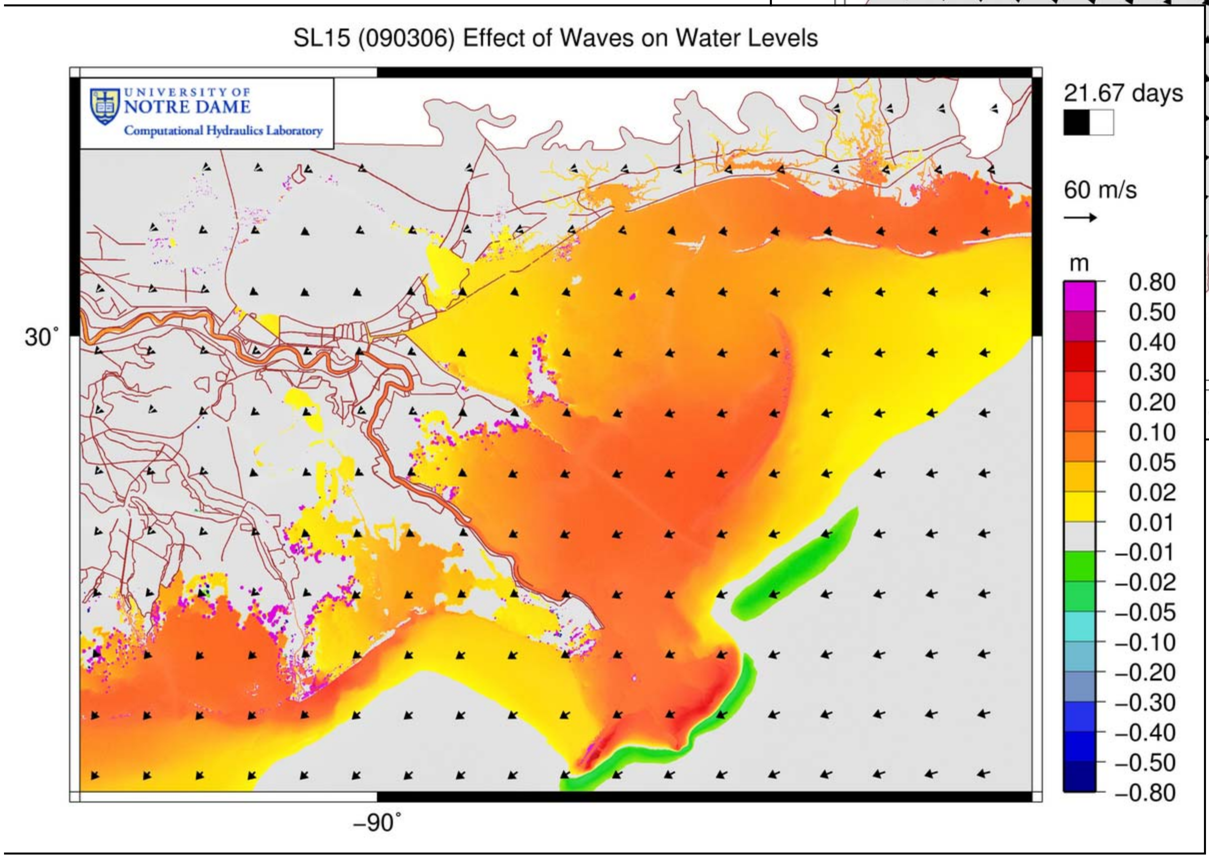


Hurricane Katrina

Waves on Water Levels

- 2005/08/28/1600Z

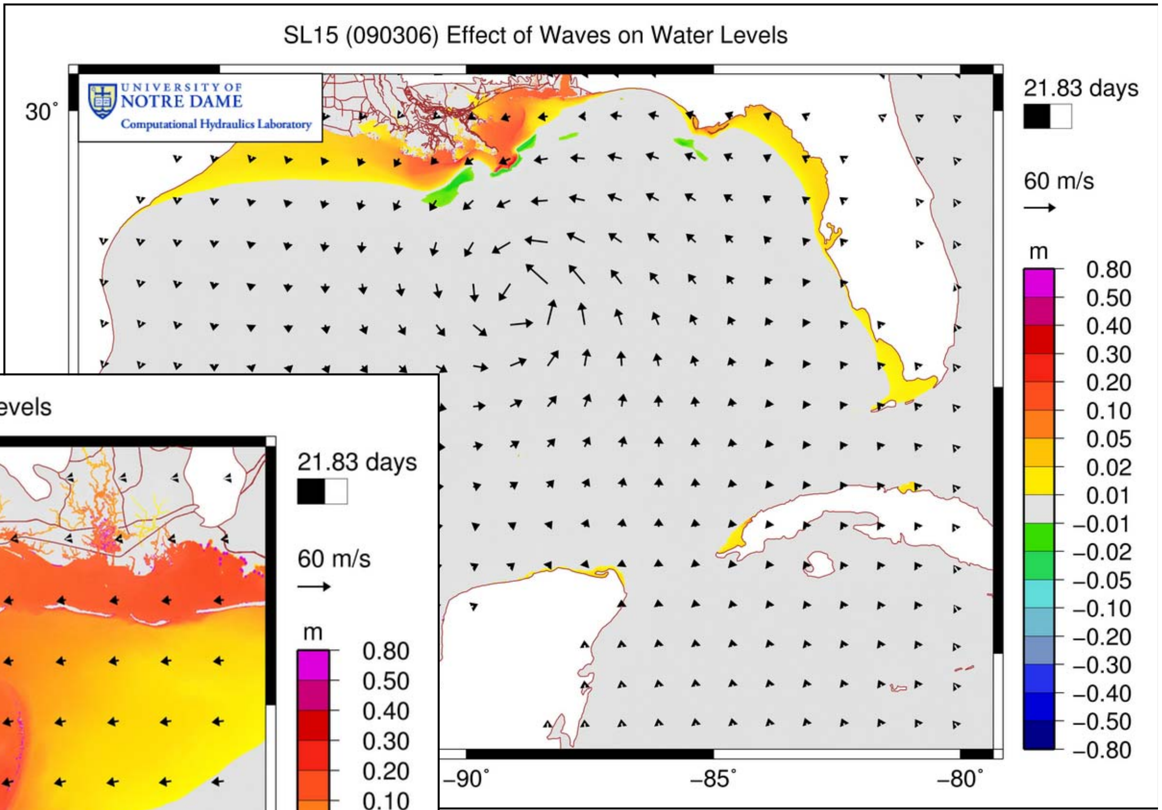


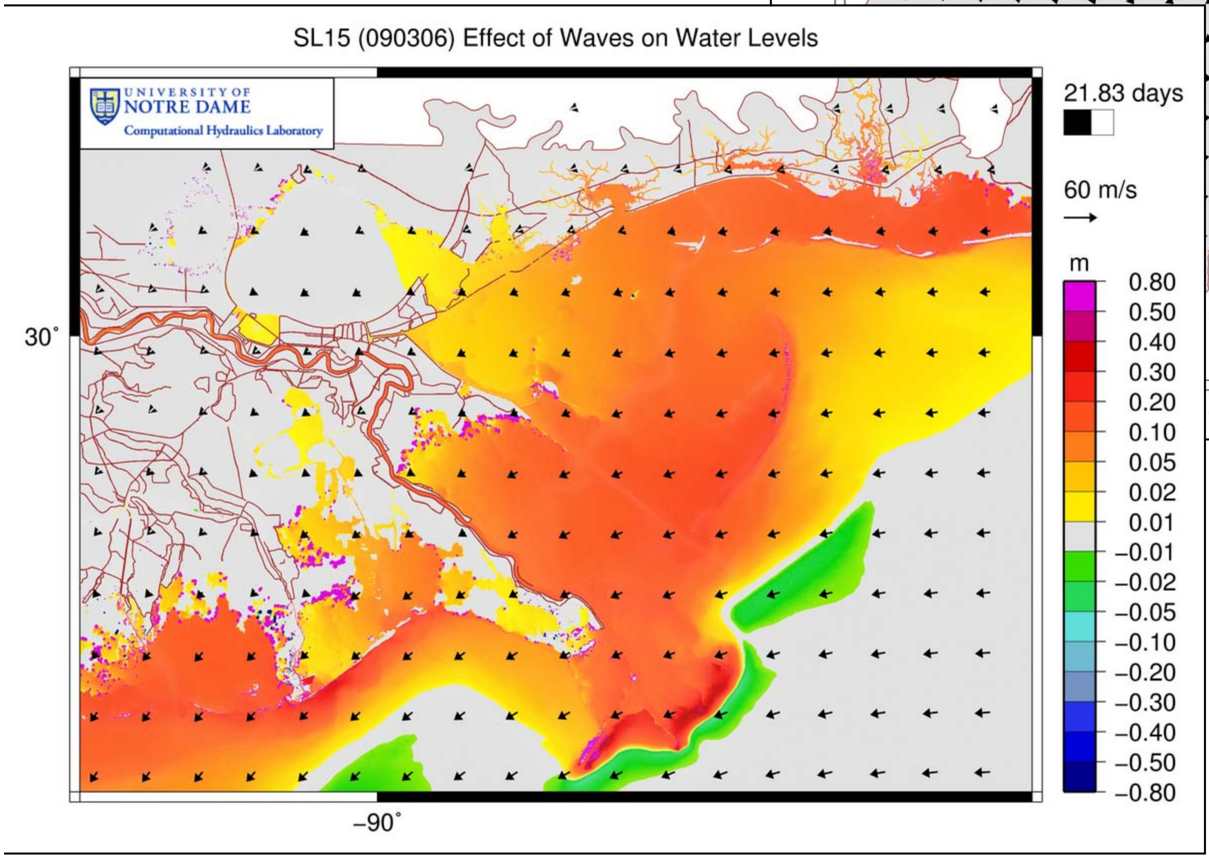


Hurricane Katrina

Waves on Water Levels

- 2005/08/28/2000Z

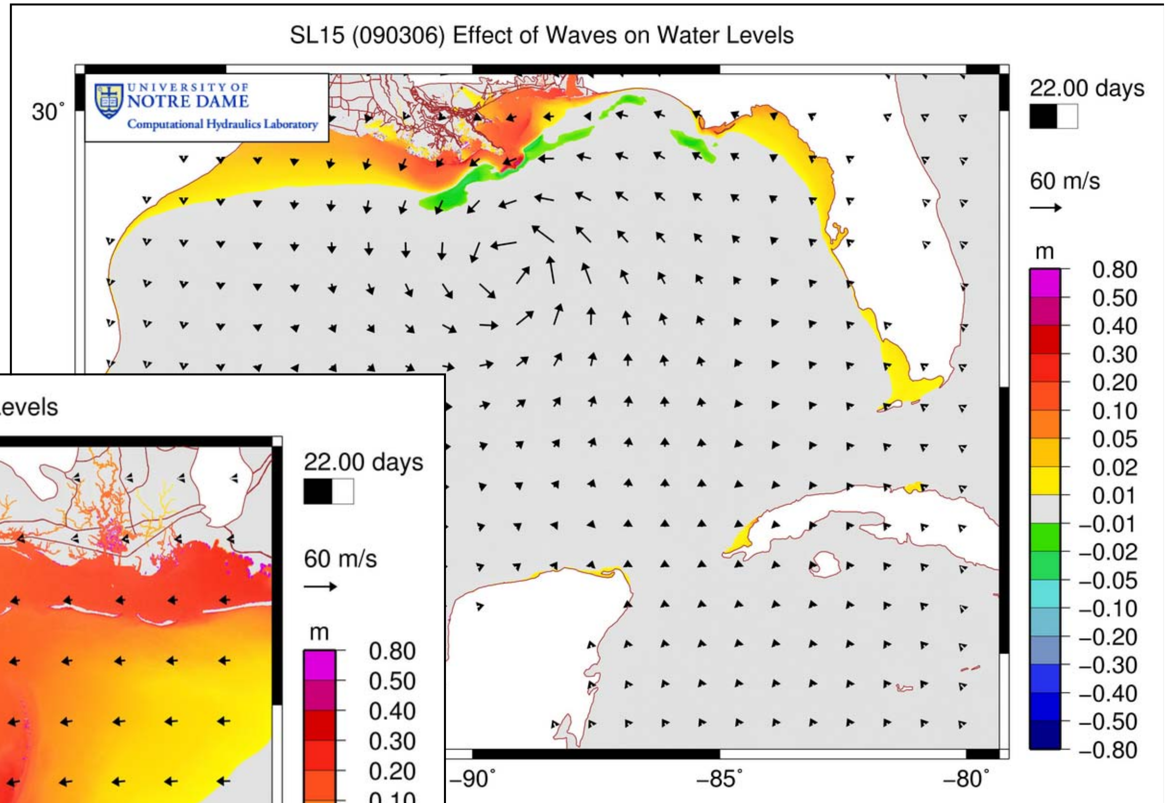


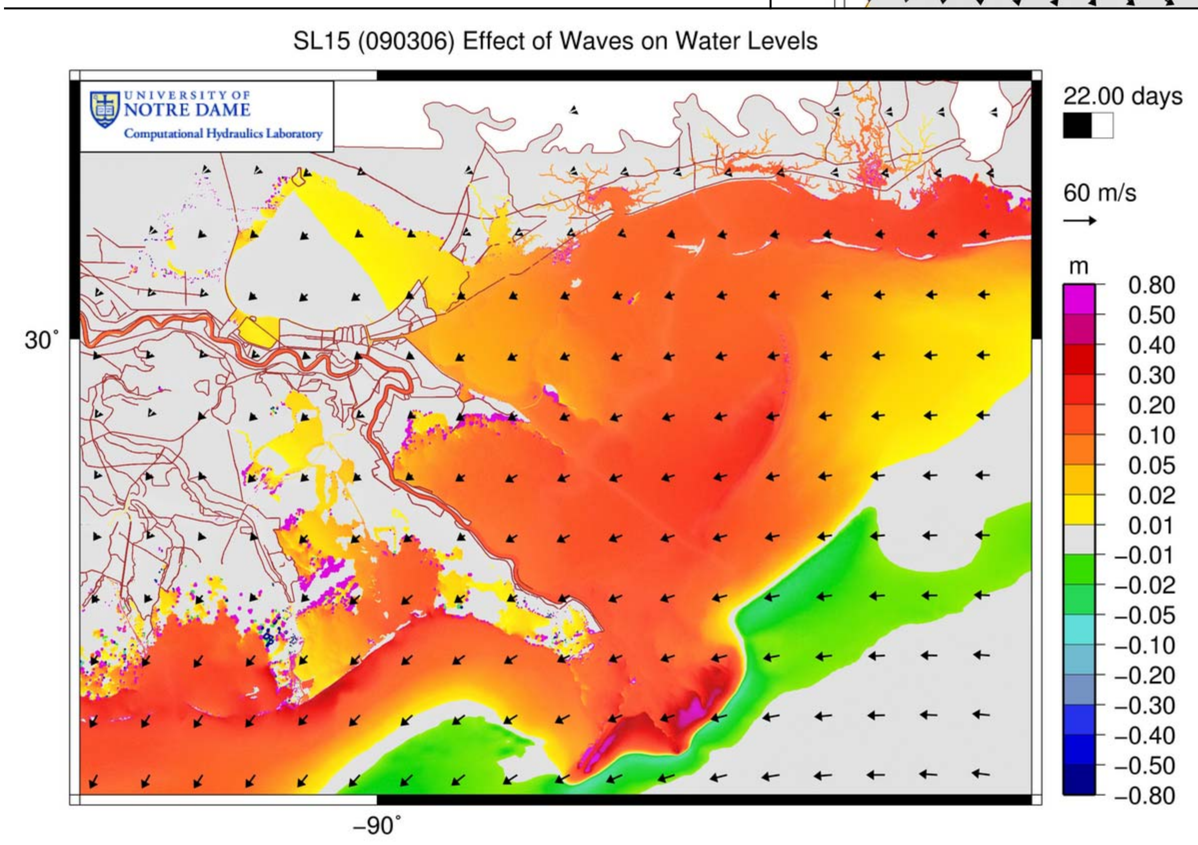


Hurricane Katrina

Waves on Water Levels

- 2005/08/29/0000Z

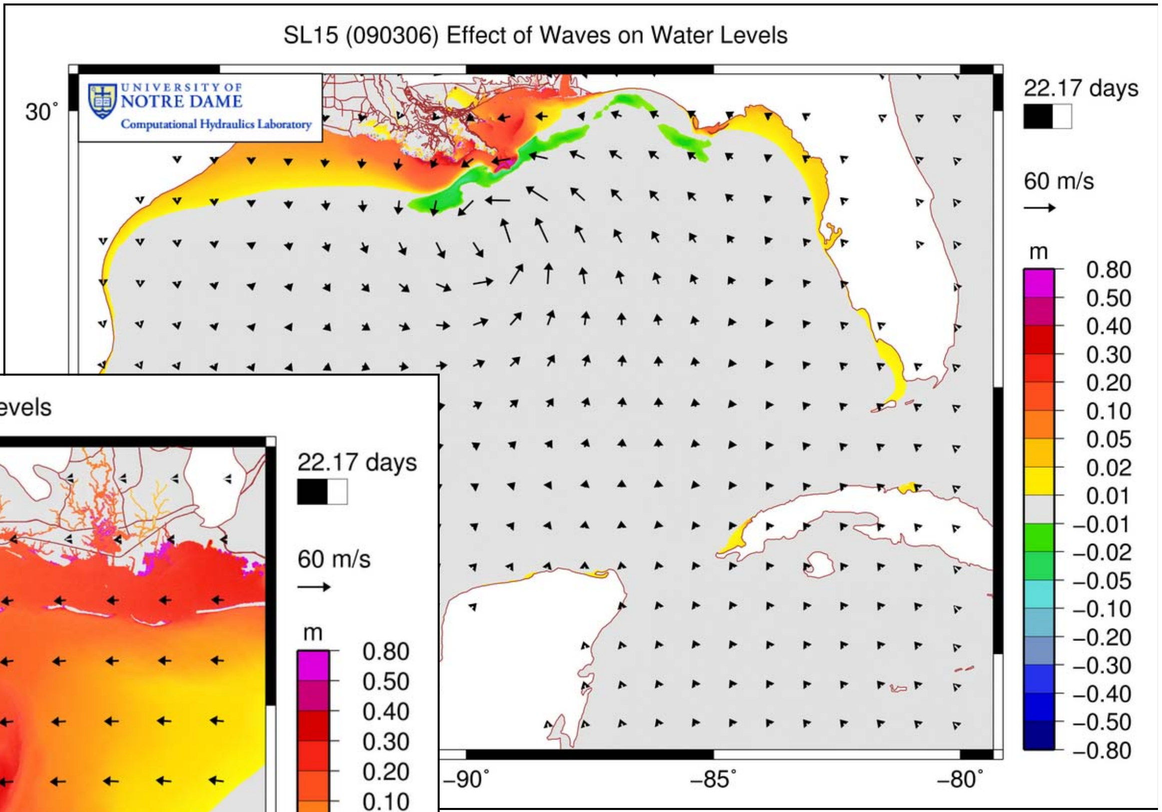


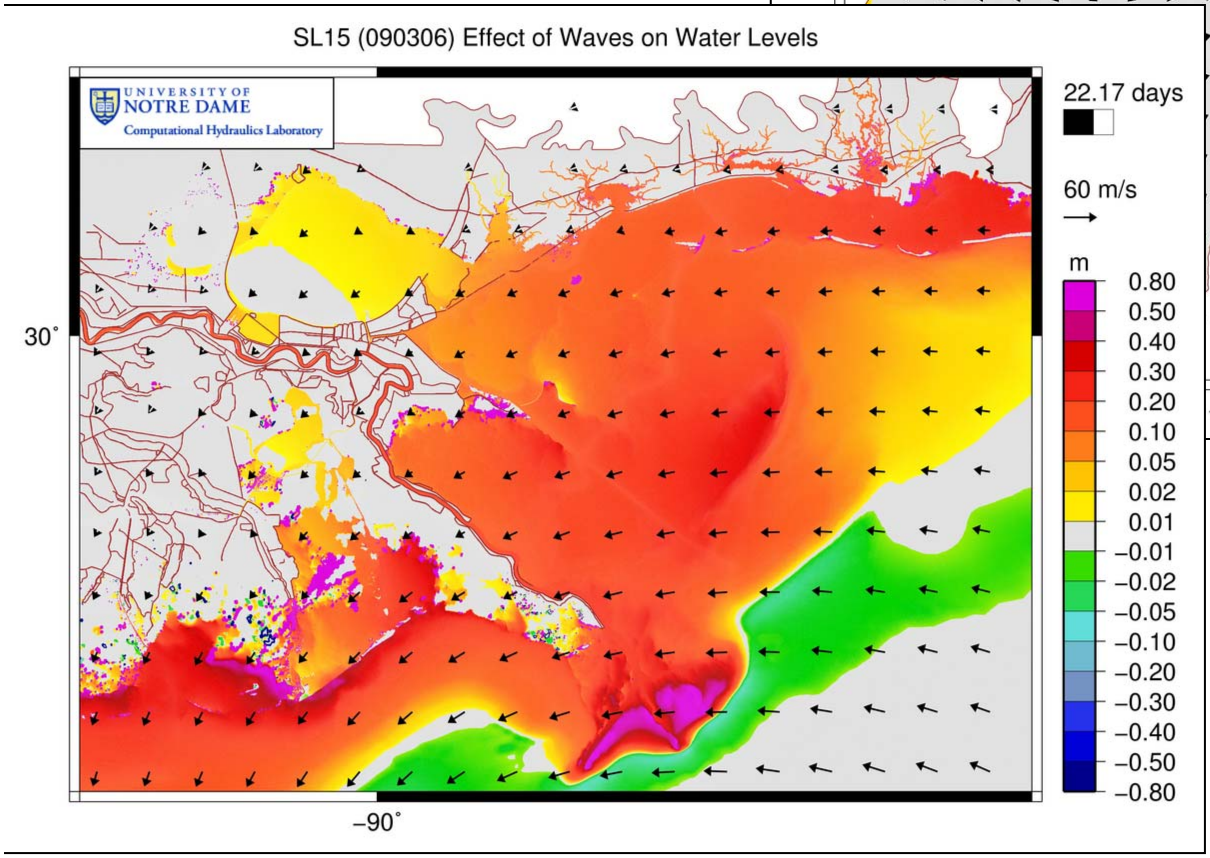


Hurricane Katrina

Waves on Water Levels

- 2005/08/29/0400Z

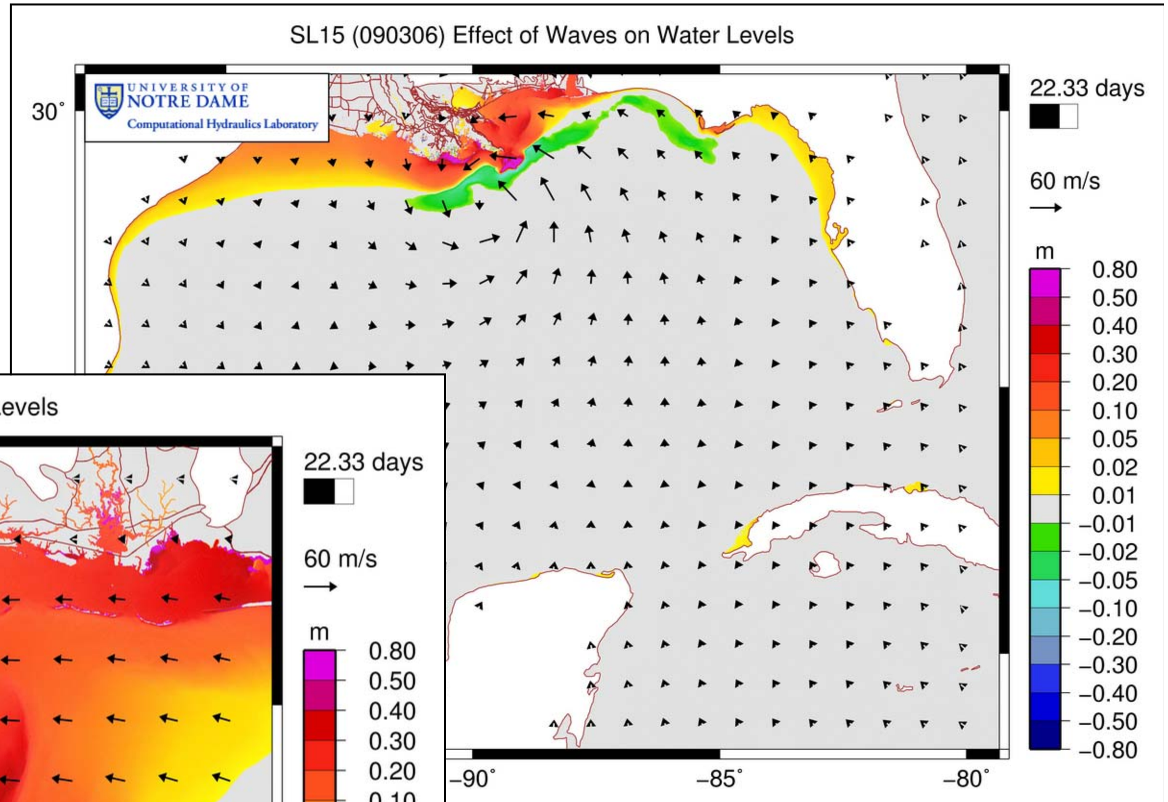


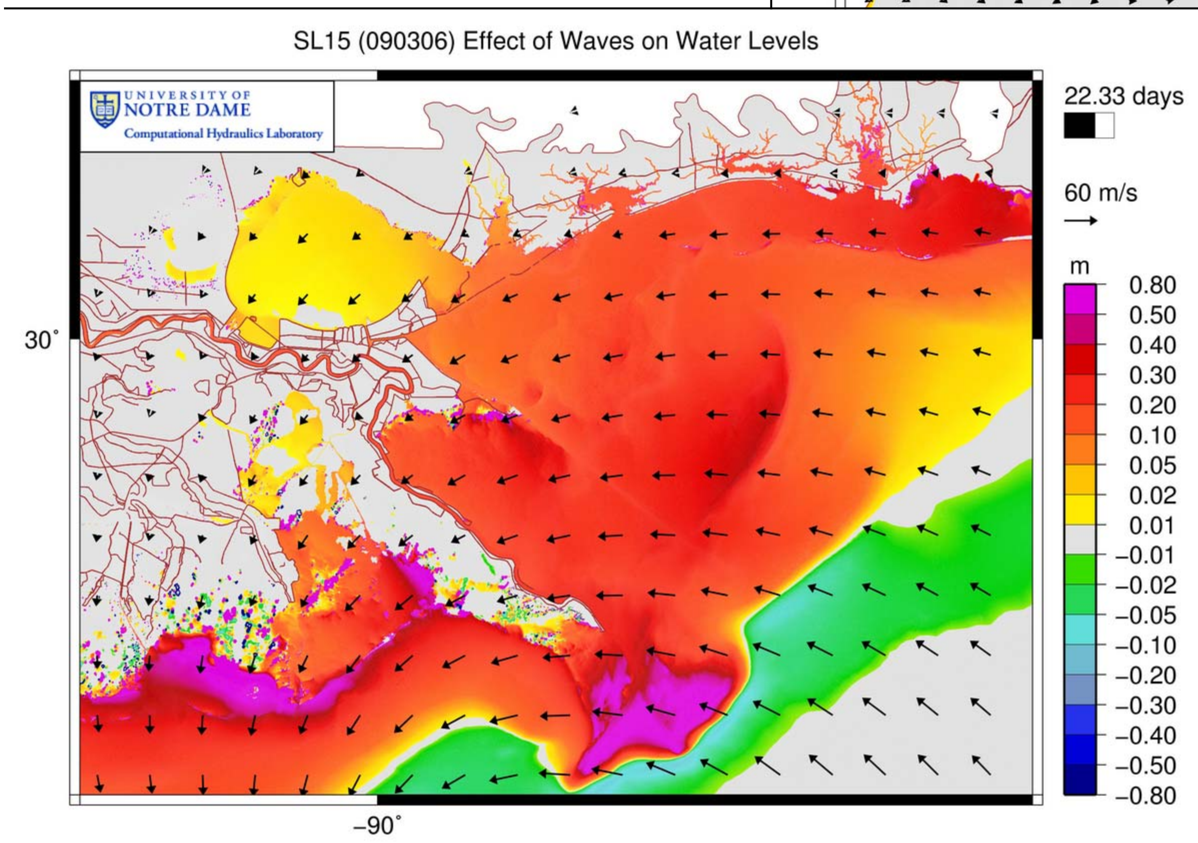


Hurricane Katrina

Waves on Water Levels

- 2005/08/29/0800Z

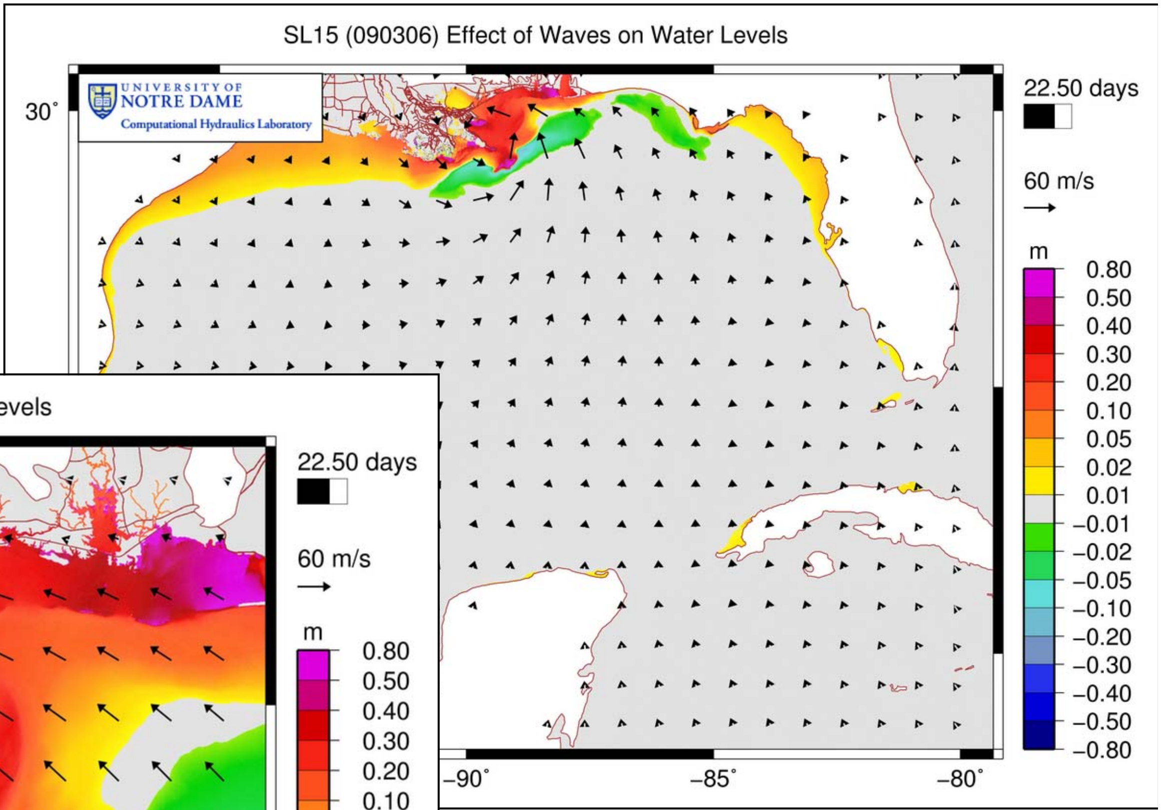


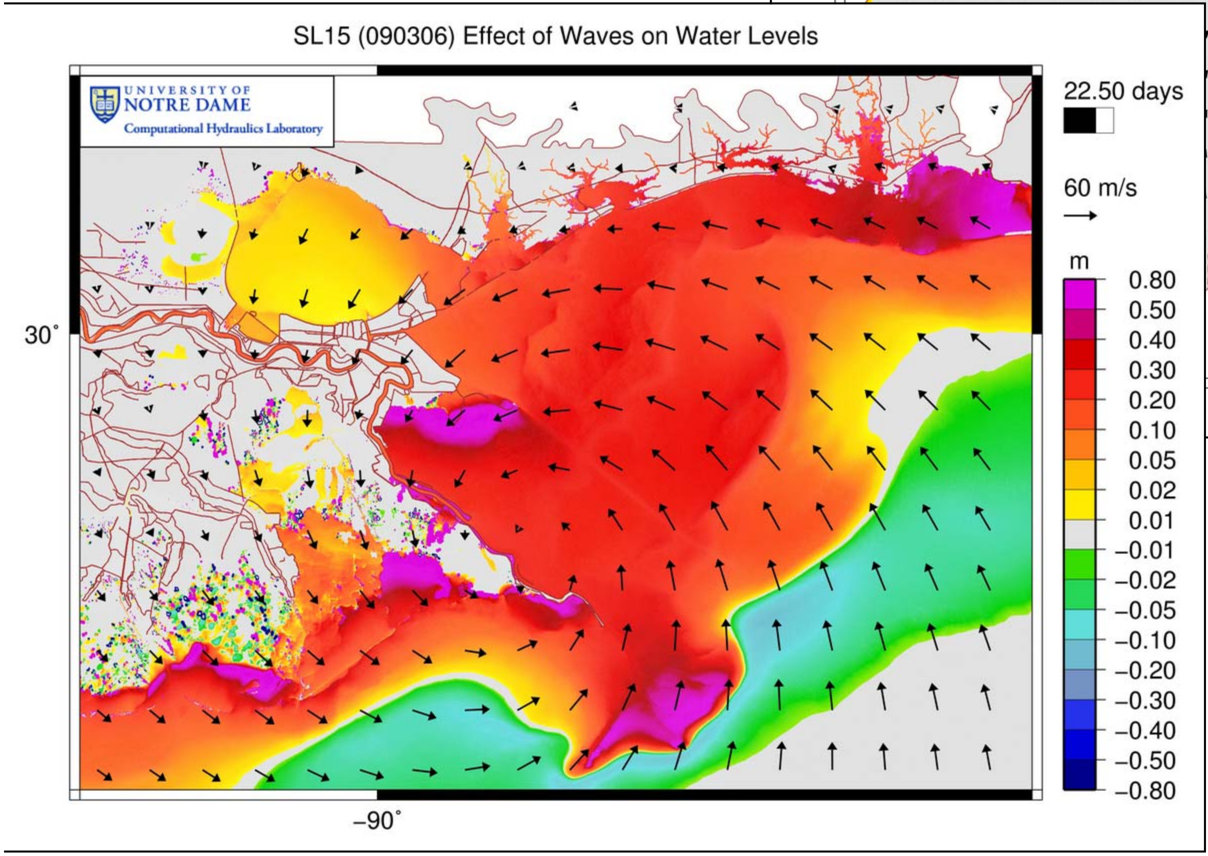


Hurricane Katrina

Waves on Water Levels

- 2005/08/29/1200Z

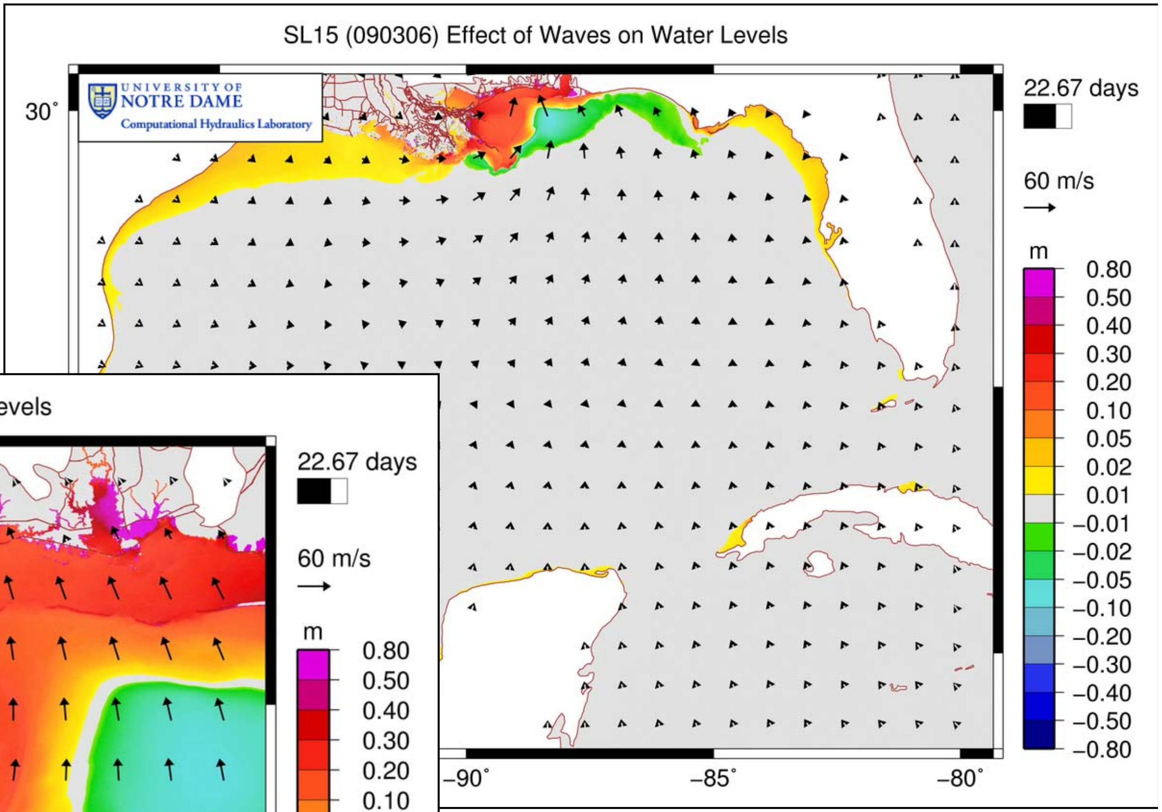


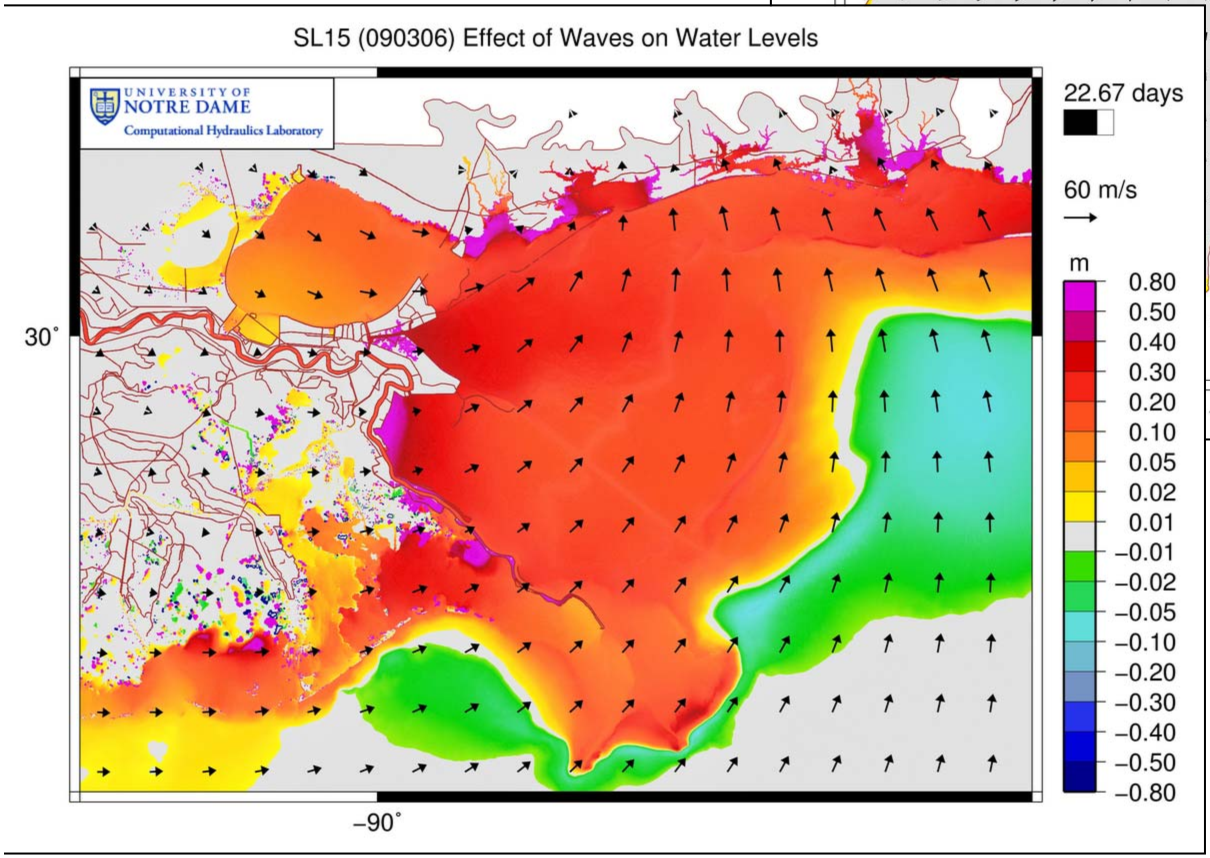


Hurricane Katrina

Waves on Water Levels

- 2005/08/29/1600Z

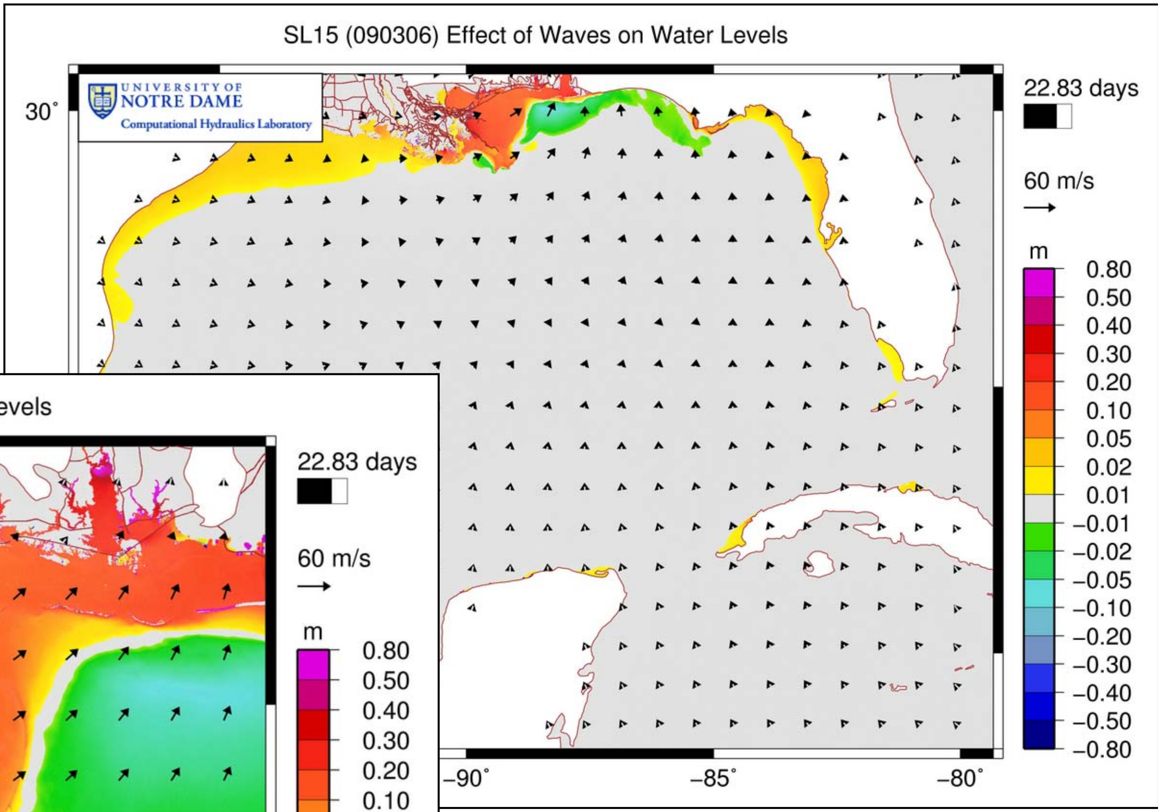


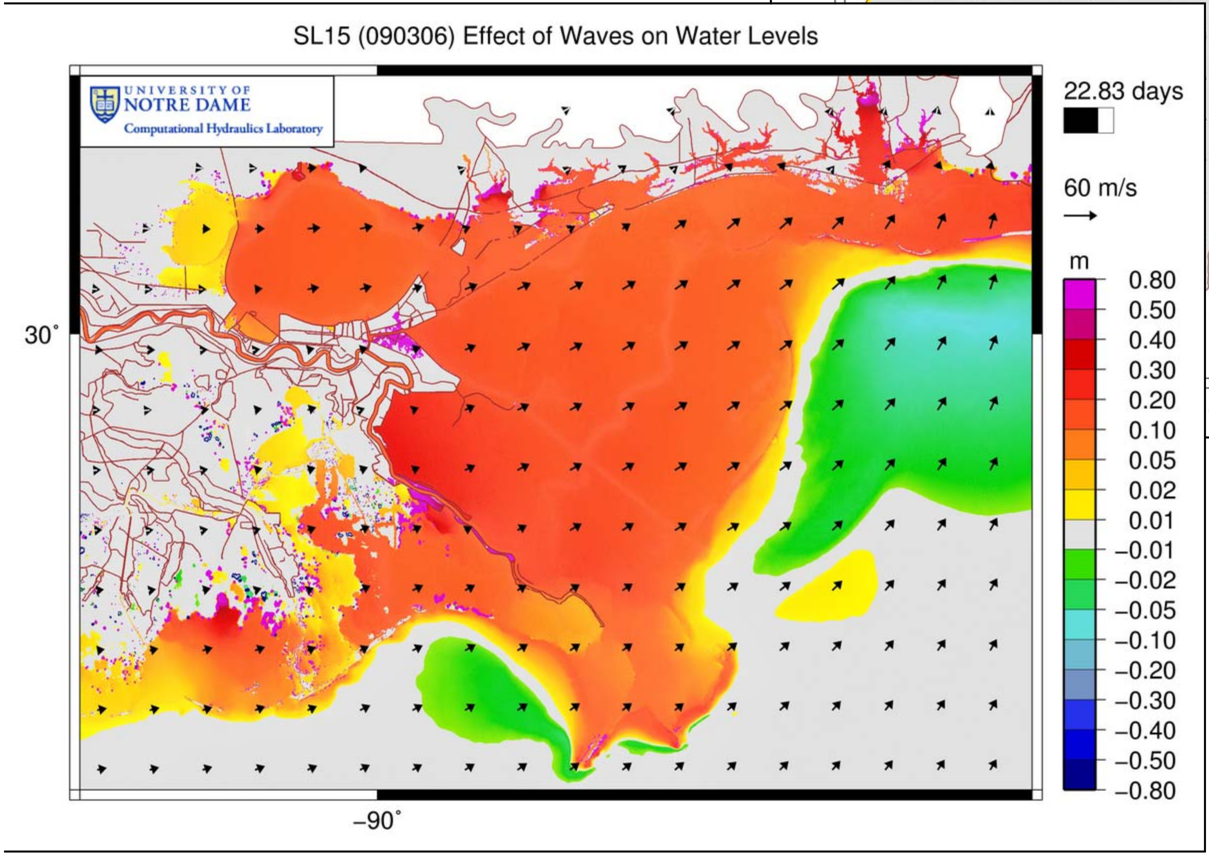


Hurricane Katrina

Waves on Water Levels

- 2005/08/29/2000Z

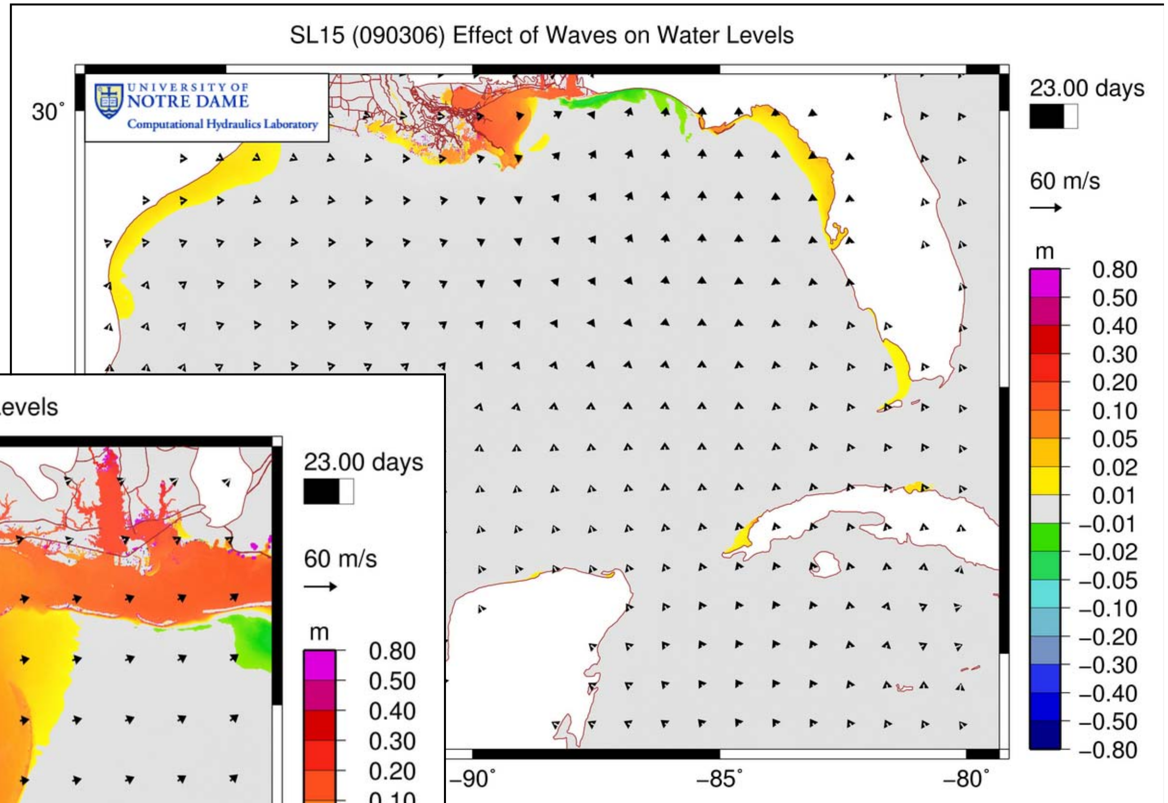


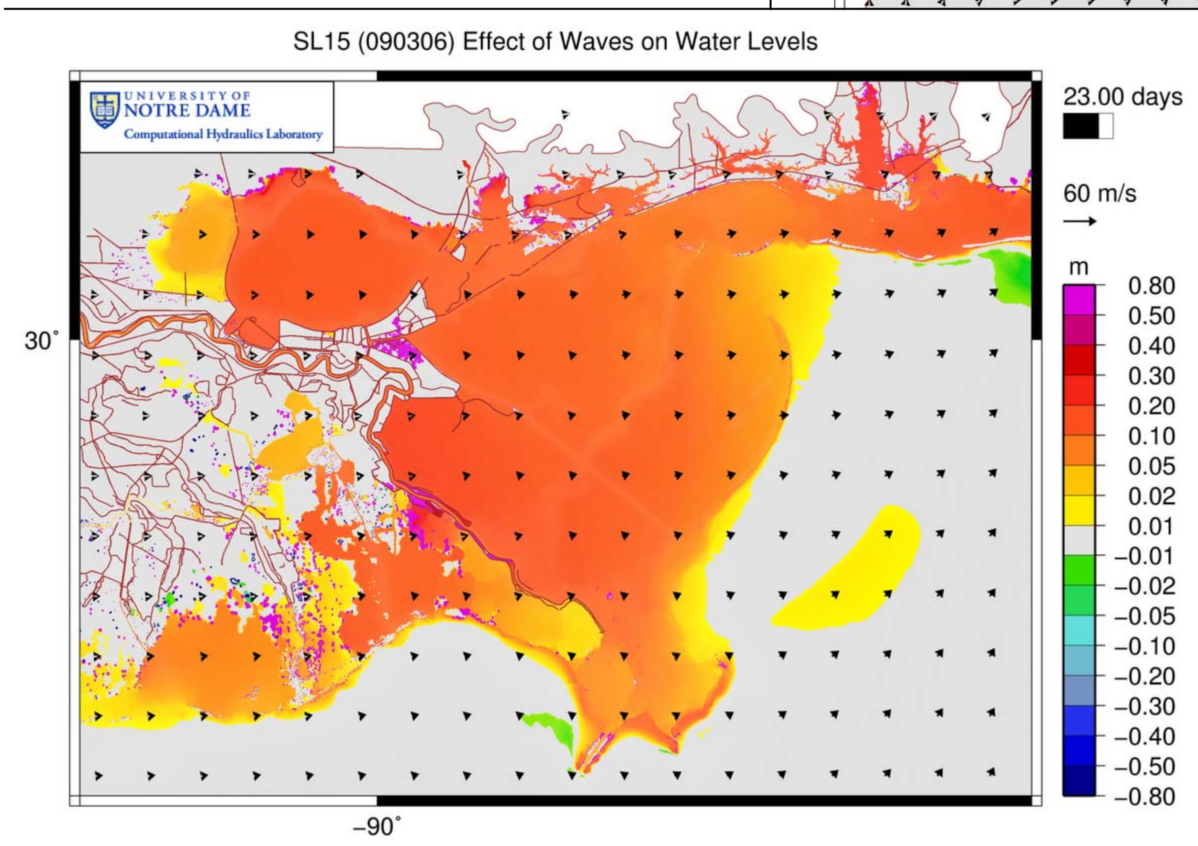


Hurricane Katrina

Waves on Water Levels

- 2005/08/30/0000Z





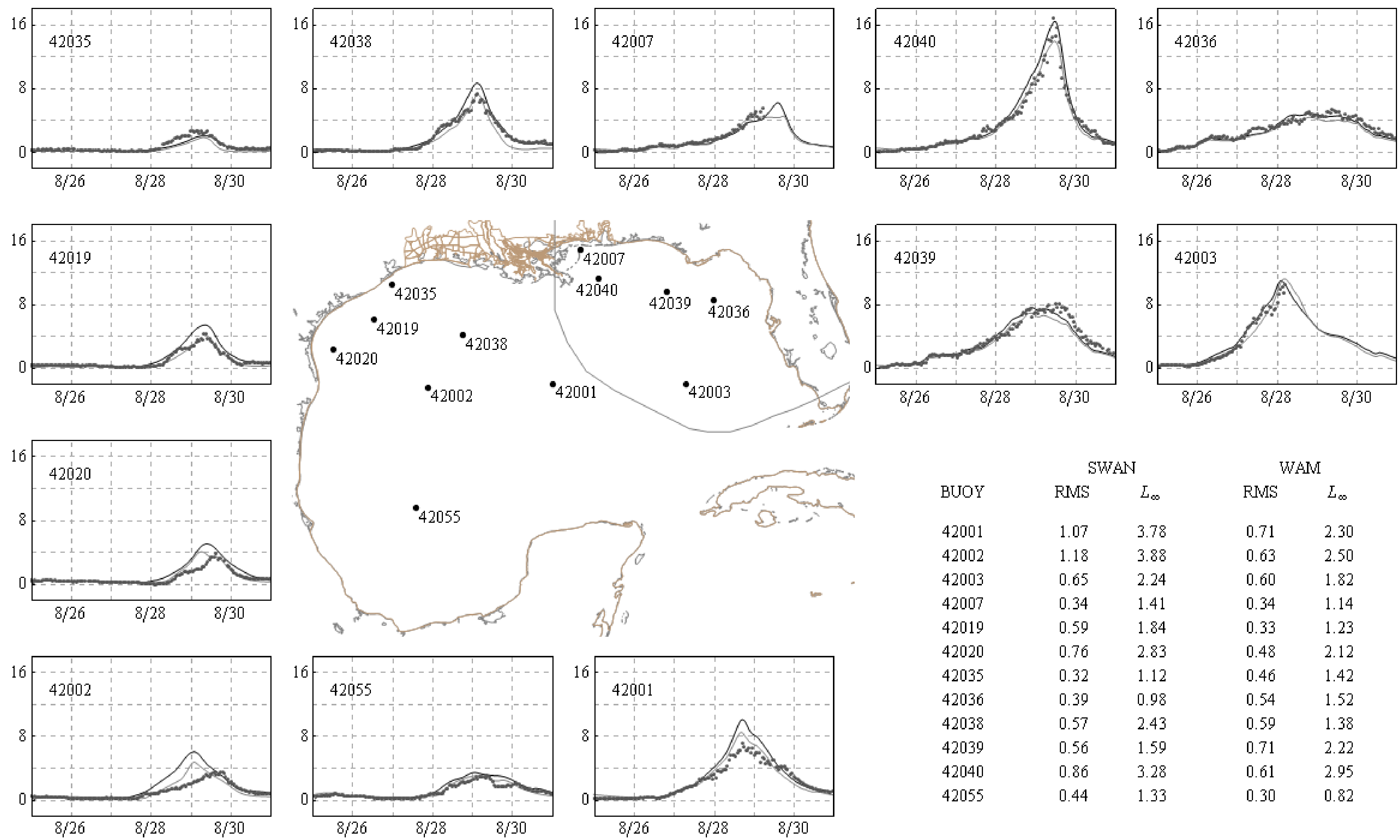
Hurricane Katrina

Comparison to Measured Data

- NDBC buoy data
- USACE high-water marks
- FEMA/URS high-water marks

Hurricane Katrina

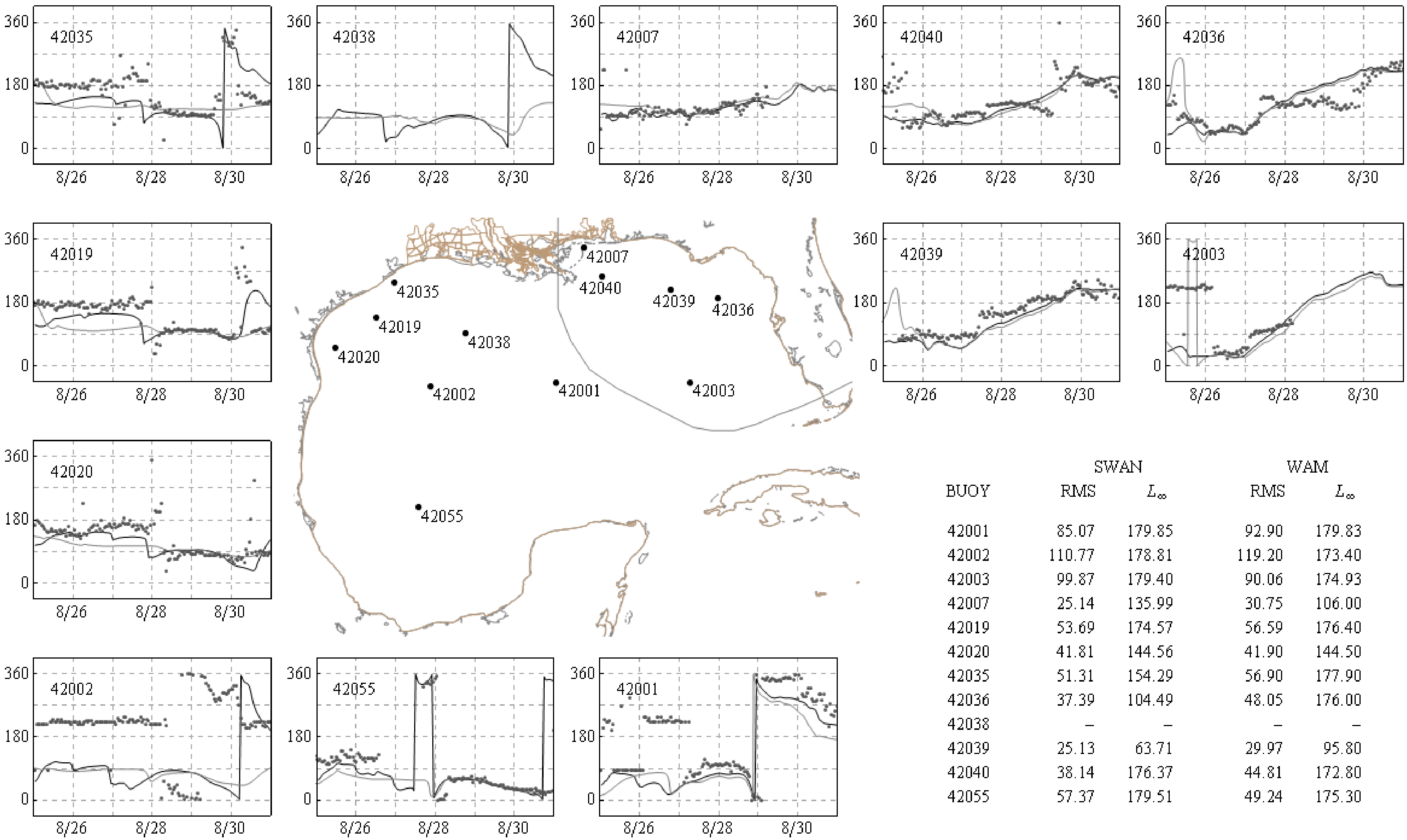
SIGNIFICANT WAVE HEIGHTS (HS) AT NDBC BUOYS



BUOY	SWAN RMS	SWAN L_∞	WAM RMS	WAM L_∞
42001	1.07	3.78	0.71	2.30
42002	1.18	3.88	0.63	2.50
42003	0.65	2.24	0.60	1.82
42007	0.34	1.41	0.34	1.14
42019	0.59	1.84	0.33	1.23
42020	0.76	2.83	0.48	2.12
42035	0.32	1.12	0.46	1.42
42036	0.39	0.98	0.54	1.52
42038	0.57	2.43	0.59	1.38
42039	0.56	1.59	0.71	2.22
42040	0.86	3.28	0.61	2.95
42055	0.44	1.33	0.30	0.82

Hurricane Katrina

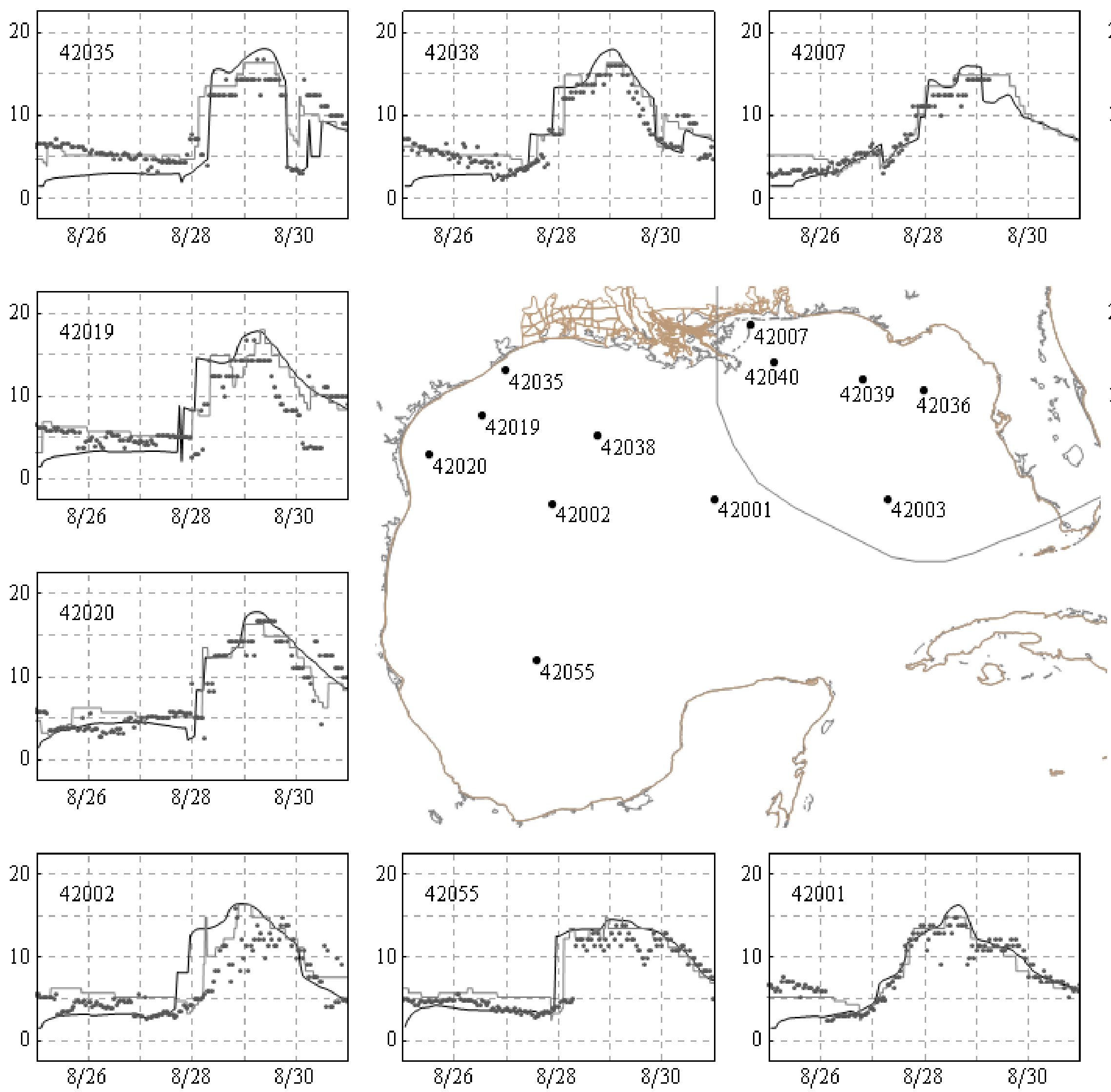
MEAN WAVE DIRECTIONS (DIR) AT NDBC BUOYS



BUOY	SWAN RMS	SWAN L_∞	WAM RMS	WAM L_∞
42001	85.07	179.85	92.90	179.83
42002	110.77	178.81	119.20	173.40
42003	99.87	179.40	90.06	174.93
42007	25.14	135.99	30.75	106.00
42019	53.69	174.57	56.59	176.40
42020	41.81	144.56	41.90	144.50
42035	51.31	154.29	56.90	177.90
42036	37.39	104.49	48.05	176.00
42038	–	–	–	–
42039	25.13	63.71	29.97	95.80
42040	38.14	176.37	44.81	172.80
42055	57.37	179.51	49.24	175.30

Hurricane Katrina

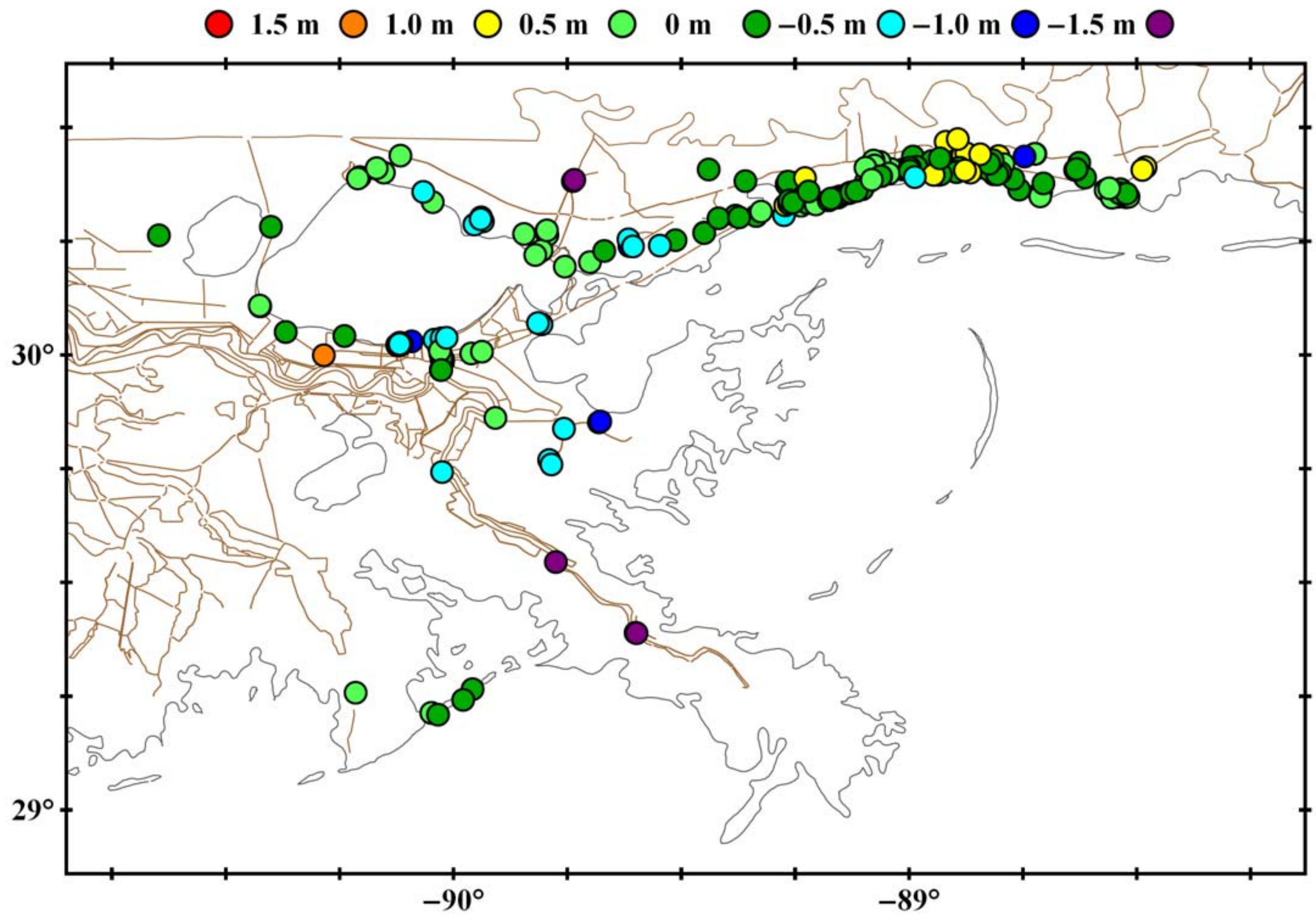
PEAK WAVE PERIODS (TPS) AT NDBC BUOYS



	SWAN		WAM	
BUOY	RMS	L_∞	RMS	L_∞
42001	1.88	5.81	1.30	4.42
42002	3.31	8.83	2.28	8.02
42003	0.88	2.32	1.43	3.18
42007	1.57	4.56	1.58	3.75
42019	3.42	11.61	2.59	7.32
42020	2.13	9.03	2.29	10.88
42035	2.98	10.79	2.18	9.51
42036	1.07	2.87	1.32	3.27
42038	2.50	5.76	1.65	3.98
42039	1.47	5.83	1.25	3.88
42040	2.02	6.18	1.51	4.18
42055	2.33	8.70	1.95	8.96

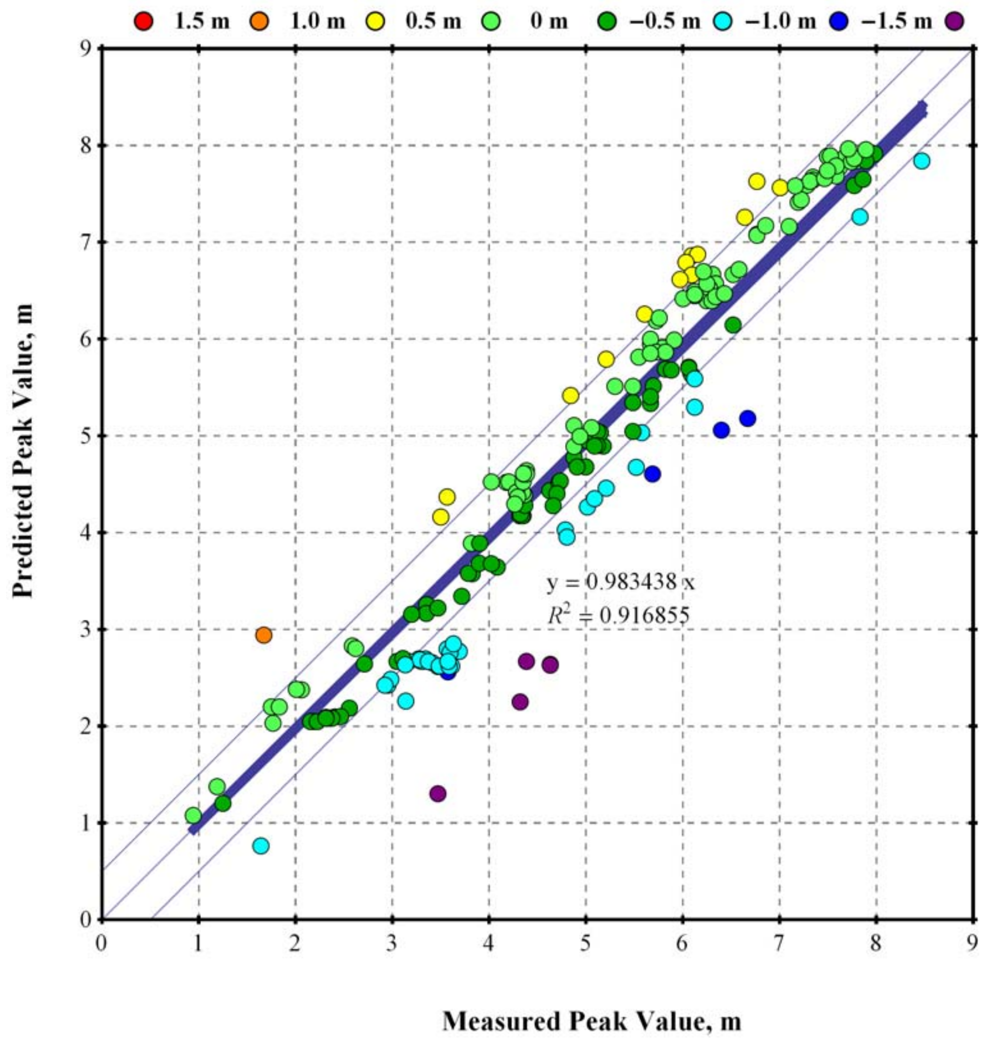
Hurricane Katrina

USACE High-Water Marks



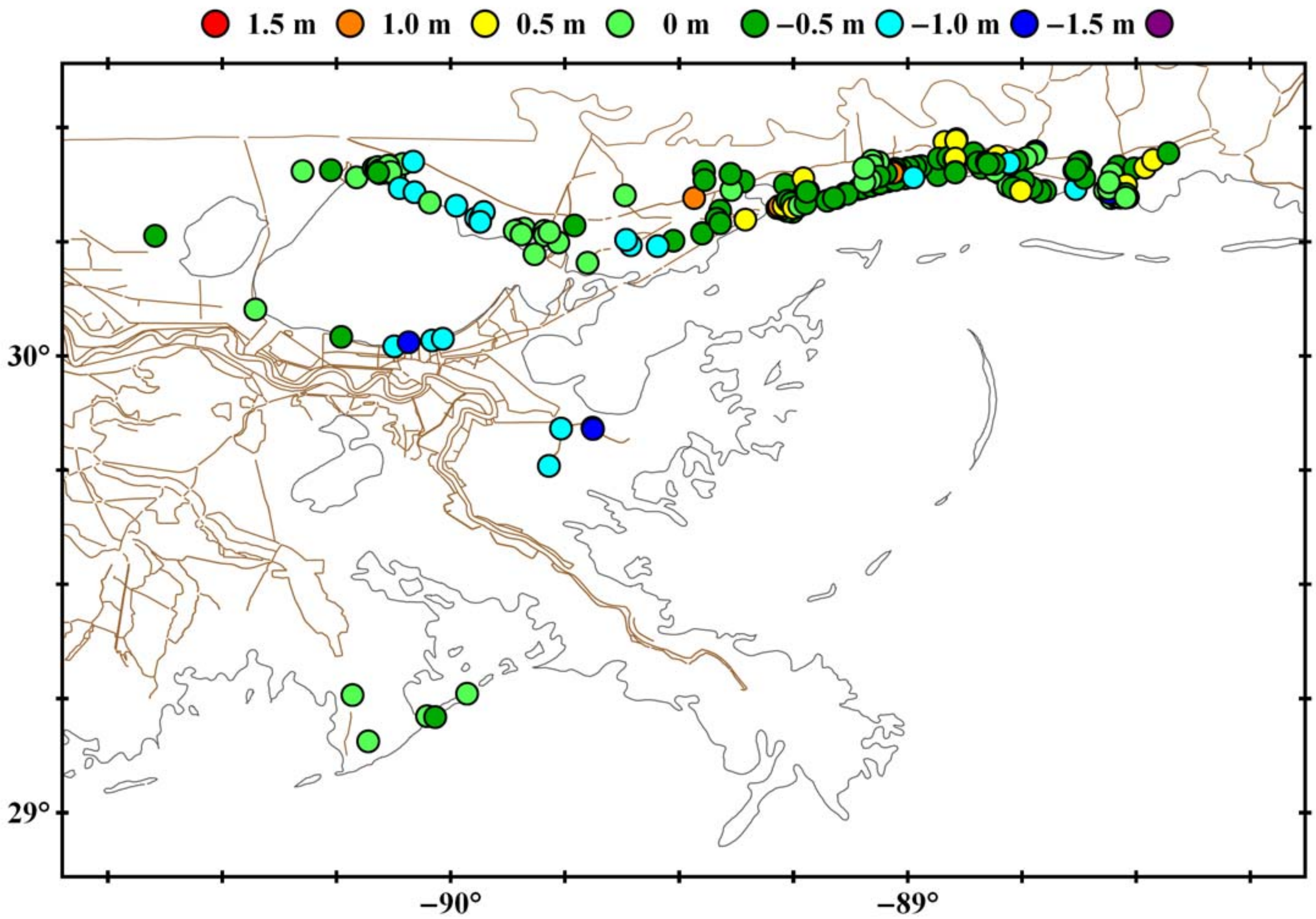
Hurricane Katrina

USACE High-Water Marks



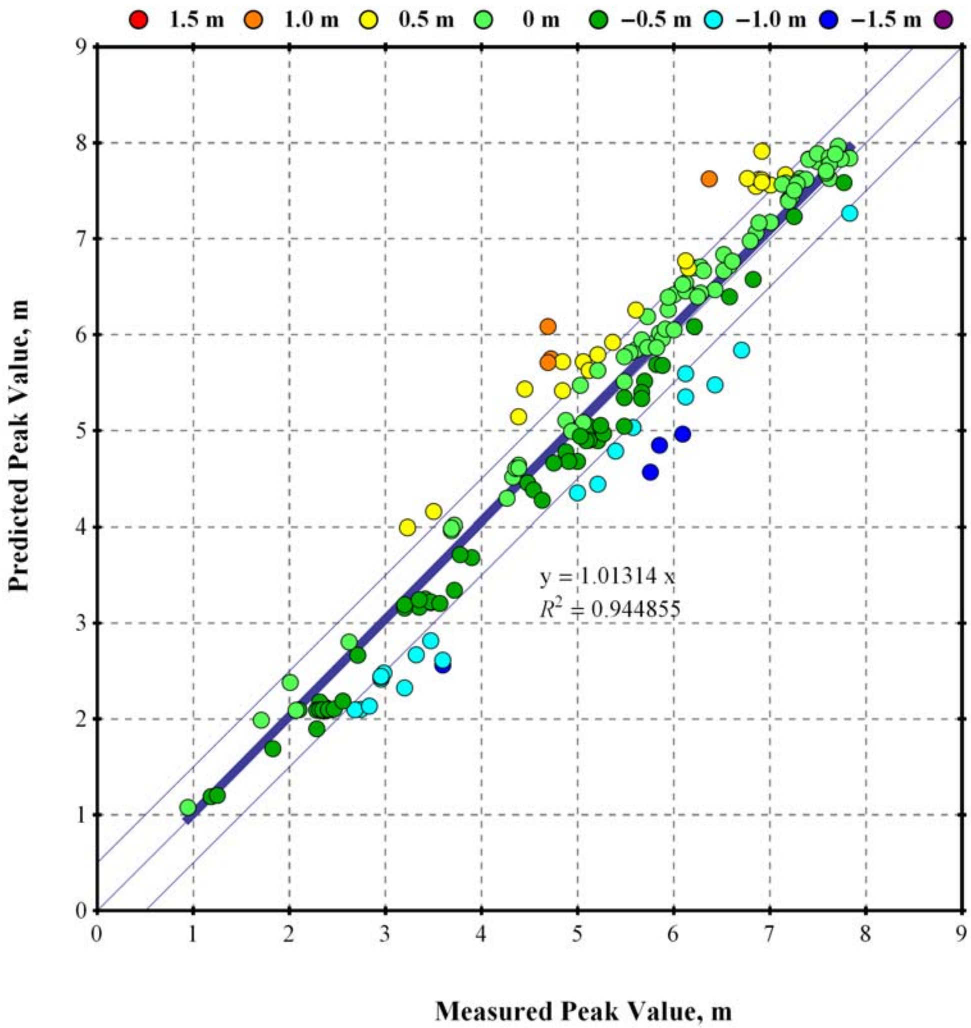
Hurricane Katrina

FEMA/URS High-Water Marks



Hurricane Katrina

FEMA/URS High-Water Marks



Conclusions

Preliminary Implementation

- ADCIRC and SWAN have been coupled so that they:
    - Run on the same processor
    - Run on the same local mesh
    - Share information through memory
- The coupled model is efficient and scalable

Preliminary Validation

- Performed for Katrina (shown) and Rita (not shown)
- The coupled model performs surprisingly well, especially in deep water
- More resolution is needed in the Gulf of Mexico
- More physics (warm-core eddies?) may also be needed

Future Work

Implementation:

- Experiment with different methods of coupling in time
- Utilize multi-core programming environments

Verification:

- Study convergence in geographic space
- Study convergence in all other parameters (σ, θ, Δt, *etc.*)

Validation:

- Run the ADCIRC-SWAN model on the next generation of meshes
- Katrina and Rita (2005)
- Gustav and Ike (2008)