Updates to WAM Cycle 4.5.+

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MOTIVATION

- WAM Cycle 4 has undergone modifications over the last release under the WAM umbrella
- These modifications have been performed mainly in an isolated mode
- Generally not publicized
  - (Internal Reports, Conference Presentations, Journal Articles)
- Better inform the modeling community of these changes
- Summary of work over the past 3-years
- Portions are from WISE-2007
- Portions are from work at ECMWF and USACE

Outline

- Introduction
- What is new
- What is different
- Some results
- Where to go next
- Summary

Introduction: Historical Perspective

- Pre-1983: Computers: slow / little memory
- The WAM Group's Challenges:
  - Use state-of-the-art physics
  - Build an operational global wave model
  - Combine data assimilation system (ERS-1)
  - Include time invariant shallow water mechanisms

WAM-Cycle4

The WAM Wave Model

$$\frac{\partial F}{\partial t} + (\cos\phi)^{-1}\frac{\partial}{\partial \phi}\left(\dot{\phi}\cos\phi F\right) + \frac{\partial}{\partial \lambda}\left(\dot{\lambda} F\right) + \sigma\frac{\partial}{\partial \sigma}\left(\dot{\sigma}\frac{F}{\sigma}\right) + \frac{\partial}{\partial \theta}\left(\dot{\theta} F\right) = S$$

Where

$F(\lambda,\phi,\sigma,\theta,t)$ wave energy density spectrum

(λ, ϕ) longitude, latitude

(σ, θ) intrinsic frequency, wave direction

$$\dot{\phi} = \left(c_g \cos\theta + u_{North}\right)/R$$

$$\dot{\lambda} = \left(c_g \sin\theta + u_{East}\right)/\left(R\cos\phi\right)$$

$$\dot{\theta} = c_g \sin\theta \tan\phi / R + \dot{\theta}_D + \dot{\theta}_C$$

$$\dot{\sigma} = \dot{\sigma}_C$$

Leap to the Present

- Wind field quality improvements
- Computer's speed/memory increased
  - Higher resolution global implementation
  - Local applications
- Basic studies on wave physics / numerics
- Reliable directional wave measurements ?
- Data assimilation techniques developed / implemented
- New demands for wave modeling
  - Shallow water
  - New group of users
- Programming paradigm and platforms have made significant progress

Model Users

- Met-Ocean Forecast Centers
  - Global to local
  - Degrees to minutes
  - Deep to shallow water
- Research Institutes
  - Modifying, testing, implementing
  - All temporal and spatial domains
  - Multi-nesting
  - Coupling with ocean / atmospheric processes and interaction mechanisms

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WAM Cycle 4.5.1

- Standard FORTRAN 95
- Free format code
- Modular rather than common blocks
- Dynamic allocation arrays
- Application of intrinsic functions
- IMPLICT none
- INTERFACE Blocks
- USE module, ONLY

ONE EXECUTABLE FOR ALL APPLICATIONS

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Source Functions

- Integration method is fully implicit

$$F_{n+1} = F_n + \frac{\Delta t S}{1 - \Delta t G}$$

- Growth limited as given by Hersbach and Janssen, (1999)
- Diagnostic tail is defined by Cycle 4

$$Max\{2.5\, f_{mean}; 4\, f_{PM}\}$$

- Optional wave breaking source function defined by Battijes and Janssen (1978)

New Options

- Spectral direction modifications
- Sea Ice
- Multiple sub-nest domain
- Time interpolation of BC spectra included in main routine
  - Significant reduction of I/O
- Blocked grid computation removed
- Cold-start removed

REDUCTION IN PARTS and SYSTEM I/O

Research Activities

- High winds and the C_D :
  - Elevated wave heights in Charlie (2004)
  - Original tests on Camille
  - Extended tests
    - Dennis, Ivan, Katrina, Lili and Rita
  - Limited the drag based on these tests
    - *IS TO SOME EXTENT A LEAP IN THE DARK*
  - Tests also included WAM 4.5.2 modification of S_{ds} (Bidlot et al., 2006)

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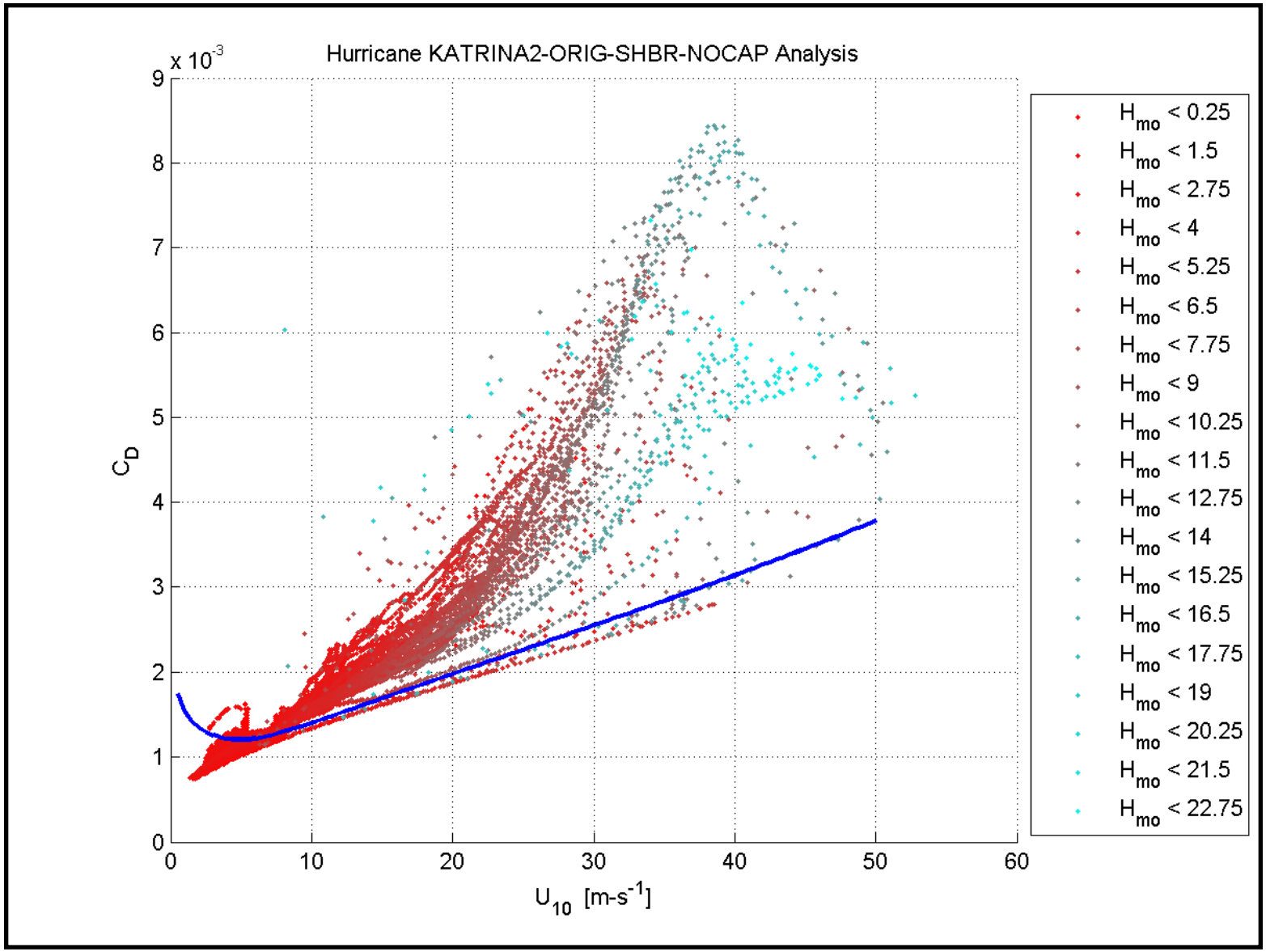
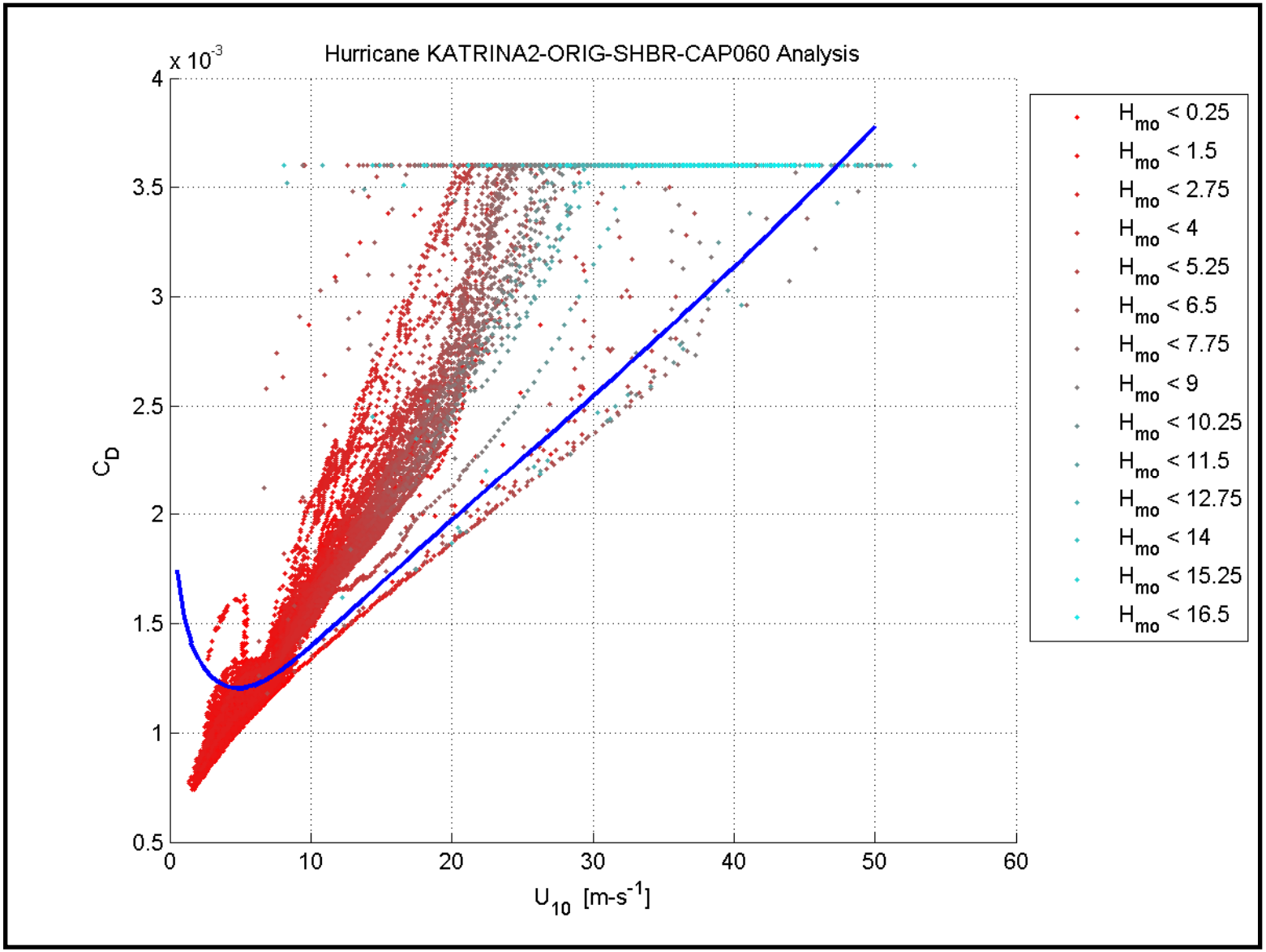
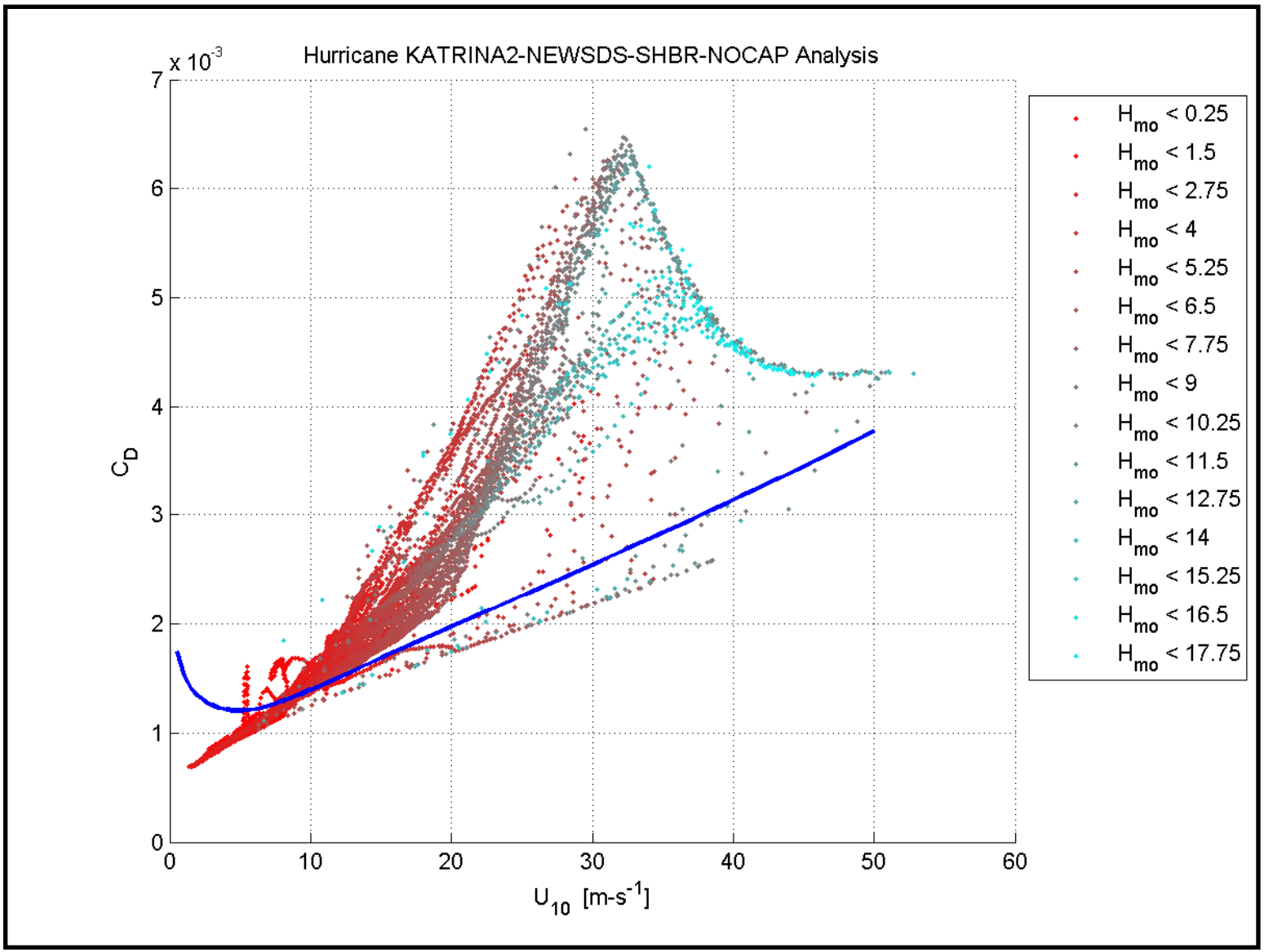
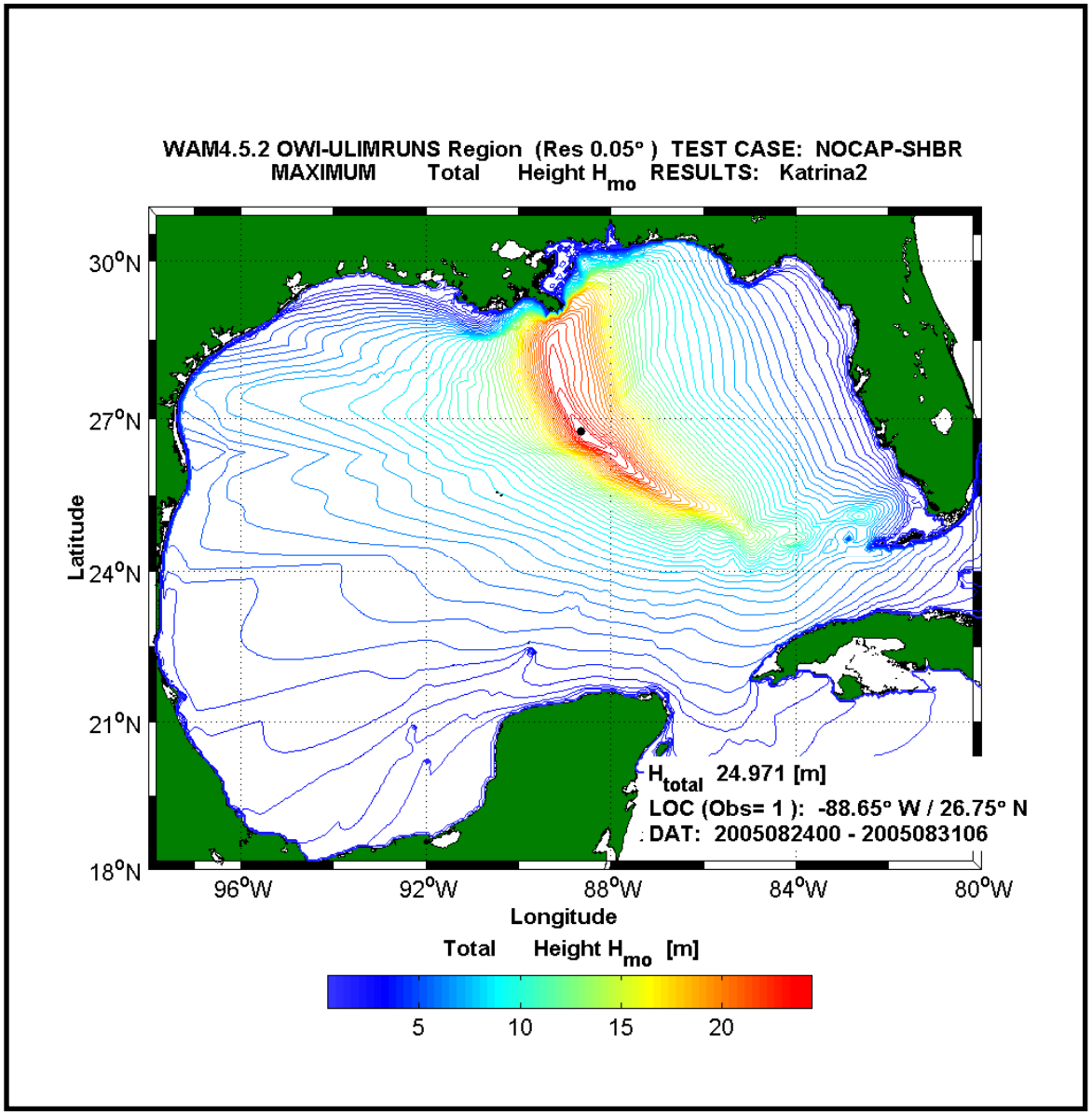
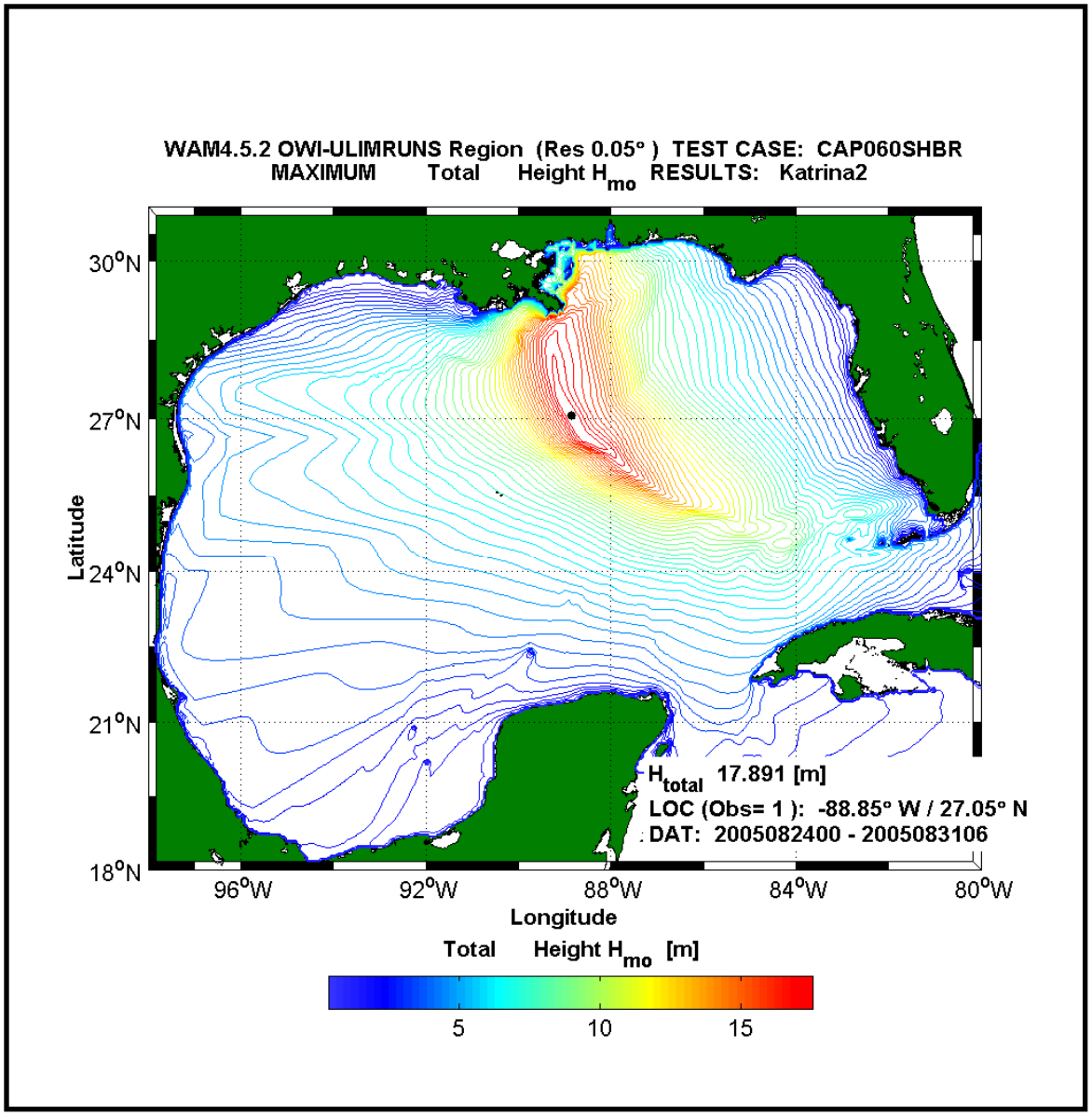
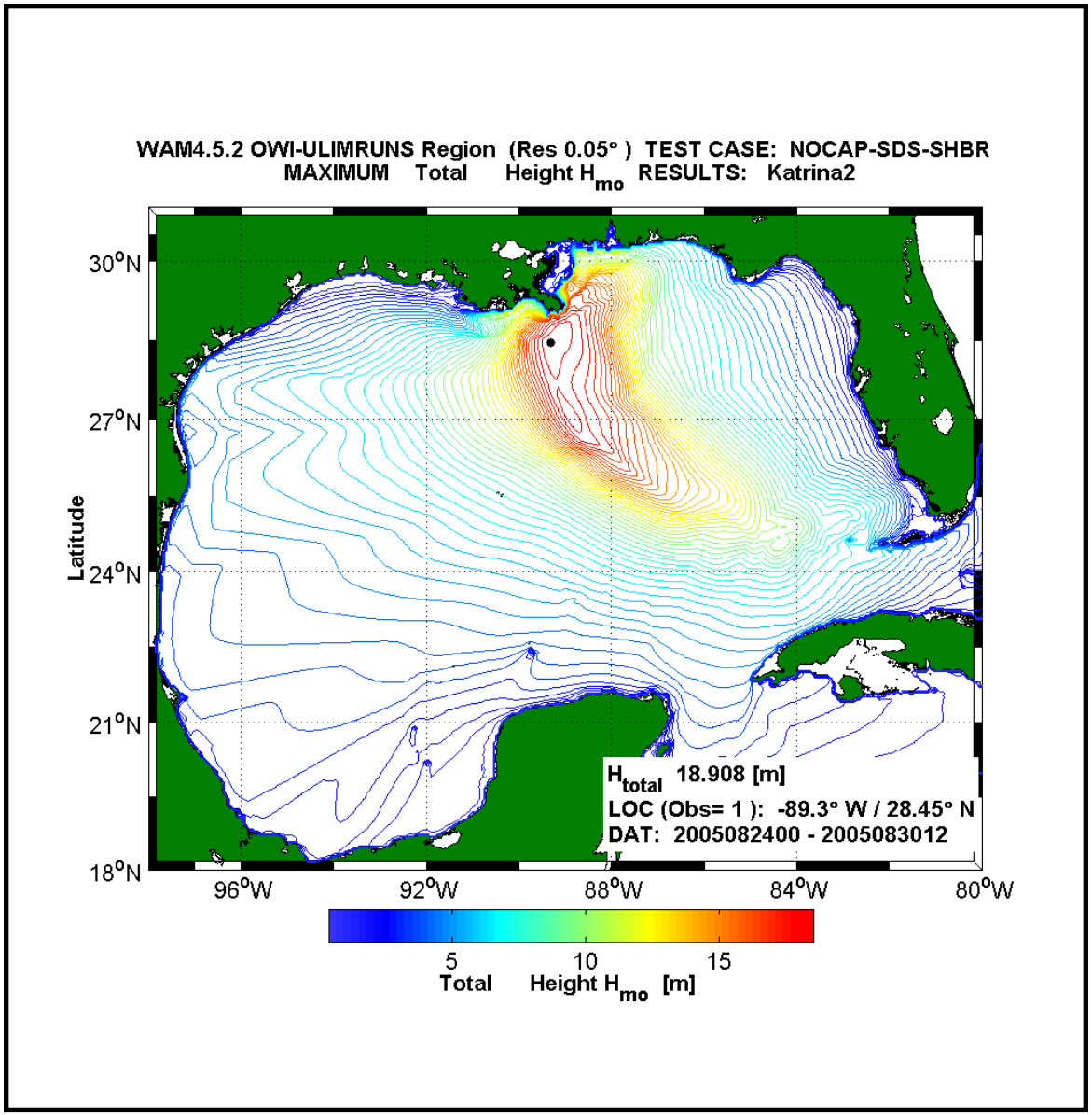

Hurricane KATRINA2-ORIG-SHBR-NOCAP Analysis
x 10^-3
C_D
U_10 [m-s^-1]
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
60
H_mo < 0.25
H_mo < 1.5
H_mo < 2.75
H_mo < 4
H_mo < 5.25
H_mo < 6.5
H_mo < 7.75
H_mo < 9
H_mo < 10.25
H_mo < 11.5
H_mo < 12.75
H_mo < 14
H_mo < 15.25
H_mo < 16.5
H_mo < 17.75
H_mo < 19
H_mo < 20.25
H_mo < 21.5
H_mo < 22.75

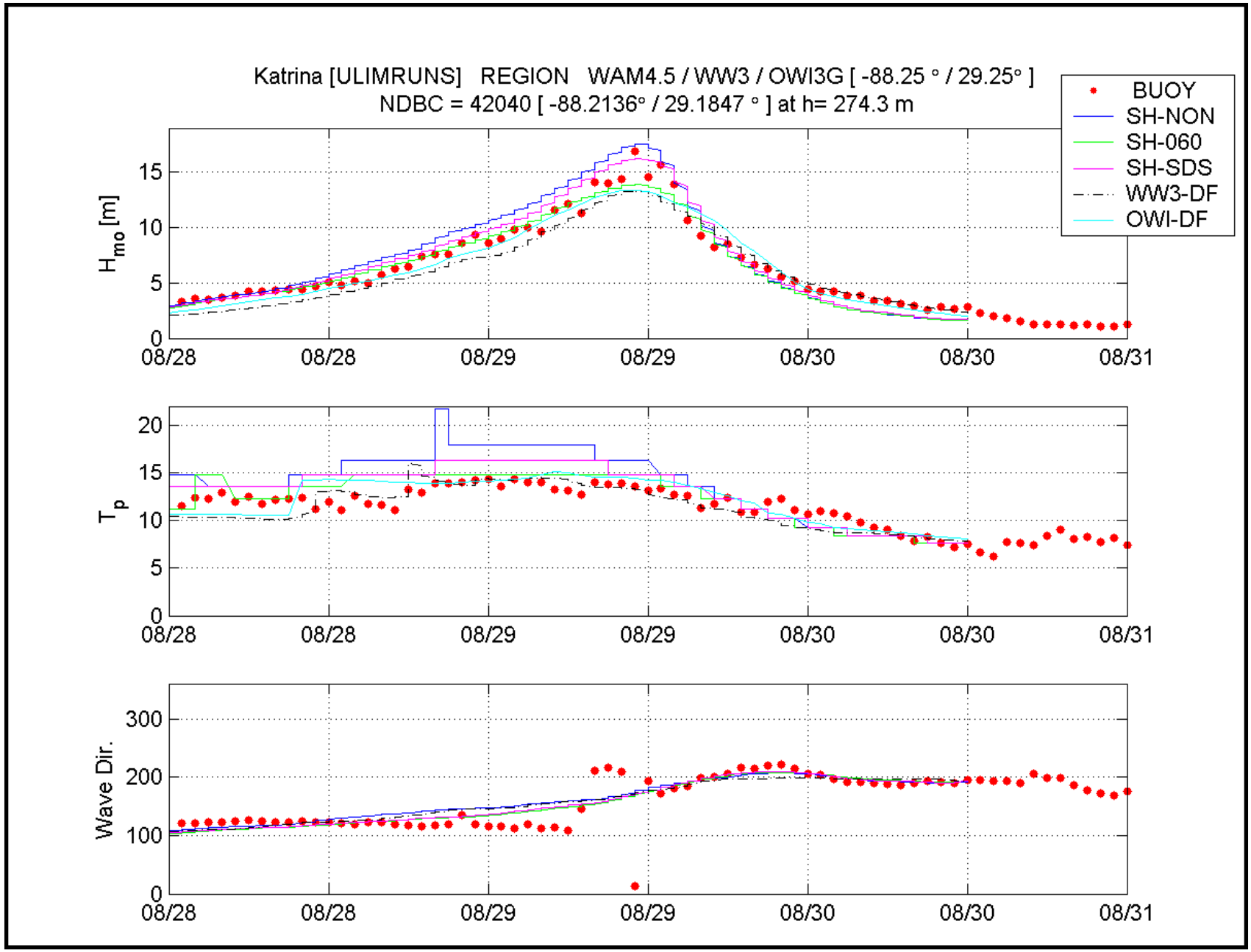

Hurricane KATRINA2-ORIG-SHBR-CAP060 Analysis
x 10^-3
C_D
U_10 [m-s^-1]
0.5
1
1.5
2
2.5
3
3.5
4
0
10
20
30
40
50
60
H_mo < 0.25
H_mo < 1.5
H_mo < 2.75
H_mo < 4
H_mo < 5.25
H_mo < 6.5
H_mo < 7.75
H_mo < 9
H_mo < 10.25
H_mo < 11.5
H_mo < 12.75
H_mo < 14
H_mo < 15.25
H_mo < 16.5


Hurricane KATRINA2-NEWSDS-SHBR-NOCAP Analysis
x 10^-3
C_D
U_10 [m-s^-1]
0
1
2
3
4
5
6
7
0
10
20
30
40
50
60
H_mo < 0.25
H_mo < 1.5
H_mo < 2.75
H_mo < 4
H_mo < 5.25
H_mo < 6.5
H_mo < 7.75
H_mo < 9
H_mo < 10.25
H_mo < 11.5
H_mo < 12.75
H_mo < 14
H_mo < 15.25
H_mo < 16.5
H_mo < 17.75


WAM4.5.2 OWI-ULIMRUNS Region (Res 0.05°) TEST CASE: NOCAP-SHBR
MAXIMUM Total Height H_{mo} RESULTS: Katrina2
30°N
27°N
24°N
21°N
18°N
Latitude
96°W
92°W
88°W
84°W
80°W
Longitude
H_{total} 24.971 [m]
LOC (Obs= 1): -88.65° W / 26.75° N
DAT: 2005082400 - 2005083106
Total Height H_{mo} [m]
5
10
15
20

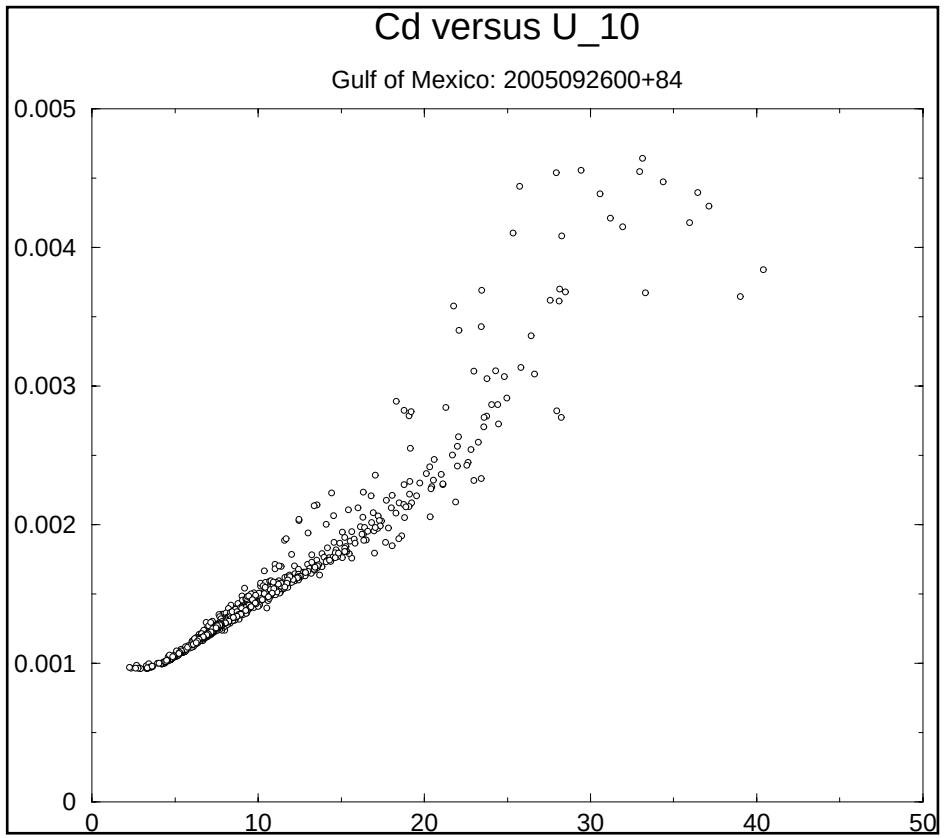

WAM4.5.2 OWI-ULIMRUNS Region (Res 0.05°) TEST CASE: CAP060SHBR
MAXIMUM Total Height H_{mo} RESULTS: Katrina2
30°N
27°N
24°N
21°N
18°N
Latitude
96°W
92°W
88°W
84°W
80°W
Longitude
H_{total} 17.891 [m]
LOC (Obs= 1): -88.85° W / 27.05° N
DAT: 2005082400 - 2005083106
Total Height H_{mo} [m]
5
10
15


WAM4.5.2 OWI-ULIMRUNS Region (Res 0.05°) TEST CASE: NOCAP-SDS-SHBR
MAXIMUM Total Height H_{mo} RESULTS: Katrina2
30°N
27°N
24°N
21°N
18°N
Latitude
96°W
92°W
88°W
84°W
80°W
H_{total} 18.908 [m]
LOC (Obs= 1): -89.3° W / 28.45° N
DAT: 2005082400 - 2005083012
5
10
15
Total Height H_{mo} [m]


Katrina [ULIMRUNS] REGION WAM4.5 / WW3 / OWI3G [-88.25 ° / 29.25°]
NDBC = 42040 [-88.2136° / 29.1847 °] at h= 274.3 m
BUOY
SH-NON
SH-060
SH-SDS
WW3-DF
OWI-DF
H_{mo} [m]
T_p
Wave Dir.
0
5
10
15
20
100
200
300
08/28
08/28
08/29
08/29
08/30
08/30
08/31

WAM 4.5.2

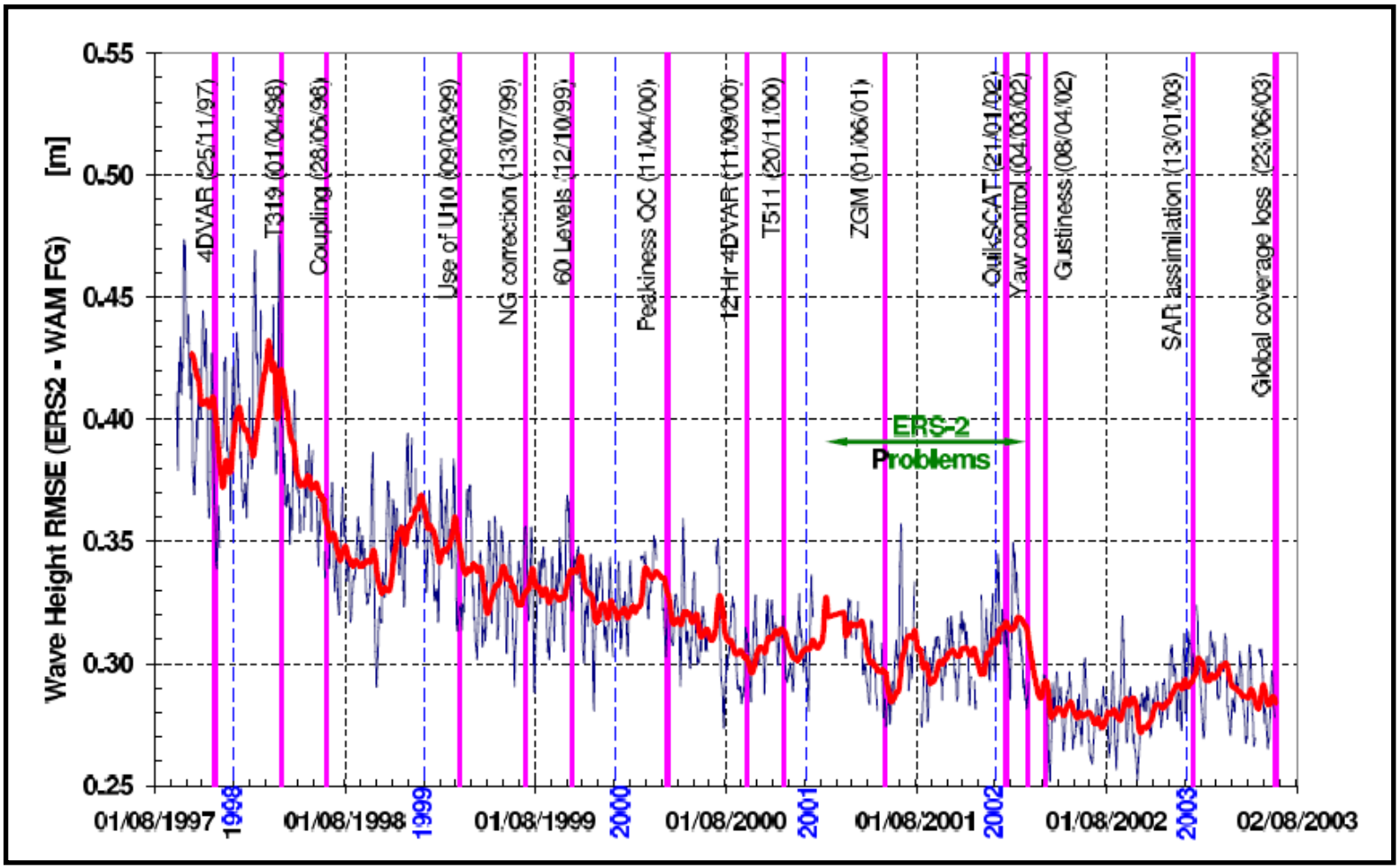
- Pseudo-linear coupling with high-resolution winds (Janssen, 1991)
  - Influence on C_d from wave induced stress term
  - At high winds C_d increases
  - The profile remains time invariant based on PBL
- Pure coupling at the Air-Sea Interface at ECMWF
  - Increasing wave heights
  - Increase in drag
  - Alters the wind profile
  - Decrease the wind speed
- There are differences of these approaches



Data Assimilation

- WAM Model Performance
  - Reduction in the bias, RMSE, SI,…
  - Improved physics
  - Improved Winds
- Data Assimilation (ECMWF)
  - Incorporate altimeter data
  - Incorporates SAR

Data Assimilation (ECMWF)



Summary and Outlook

- Let the atmospheric modeling do all the work
- Model Physics: Source terms
  - Wind input
    - Fully coupled to the atmosphere vs pseudo linear coupling
  - DIA replacement
    - It is coming DTR
  - Dissipation
    - Bidlot et al. (2007) solution have significant merits
  - Depth limited spectral breaking
  - Still needs work

Summary and Outlook

- Data Assimilation is the key
- Operational:
  - Parallel Programming paradigms
    - OpenMP
    - MPI
  - Factors of 10 to 100 decrease run time
    - 8 times faster → Doubling the resolution

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QUESTIONS