HURRICANE METOCEAN HINDCASTING

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25 years of wind/wave modeling expertise
oceanweather inc.

Oceanweather Profile

- Founded in 1977 of Prof. Pierson’s NYU group that developed and transferred first SOWM to US Navy FNOC
- Apply high technology to metocean climate for infrastructure design
- Hindcast studies first addressed Gulf of Mexico hurricanes
- Recent focus on global scale multi-decade wave climate simulations
- Intensive focus on specification of accurate atmospheric forcing
- Government supported research on remote sensing system evaluation and applications, modeling, climate trend and variability,

GULF OF MEXICO JIPS

- ODGP: Ocean Data Gathering Program (1969–71) Camille (1969)
- OCMP: Ocean Current Measurement Program (1974–1977)
- ORTAH: Ocean Response To a Hurricane: 1980s
- GUMSHOE (1990): GUoM Storm Hindcasts metOcean Extremes
- GOMOS (2002; update planned for release during 2009)
- Case Studies of Recent Severe Storms:

Hurricane Andrew (1992)	OTC # 7473
Hurricane Lili (2002)	OTC # 16821
Hurricane Ivan (2004)	OTC # 17736
Hurricanes Katrina/Rita (2005)	OTC # 18652
3G Model Performance	Jensen, Cardone, Cox (2006)
Validation of OWI 3G	Forristall (2007)
Marco Polo Validation	R. Dijk, MARIN (2007)

GOMOS
Spec Study Offered 2002

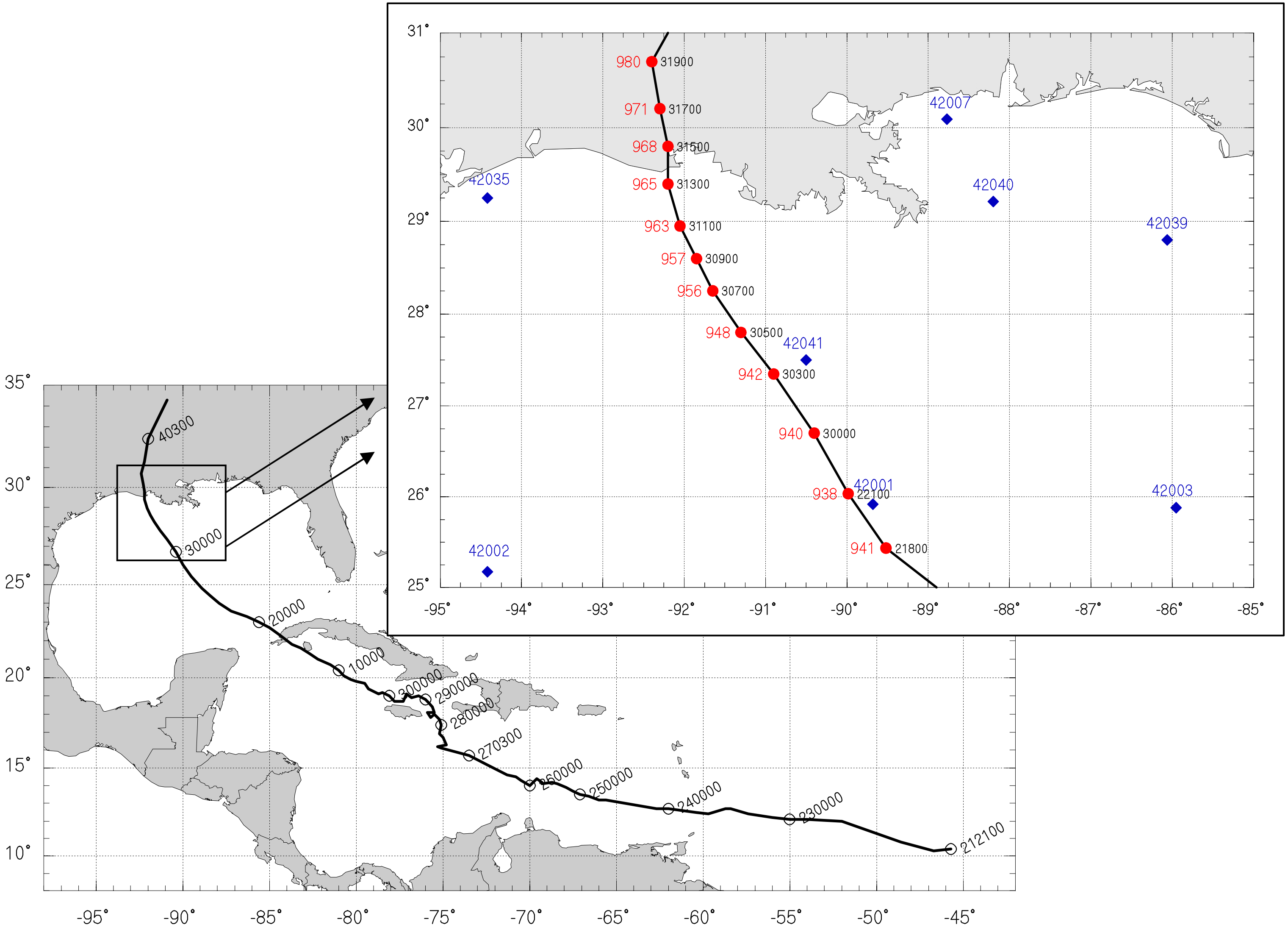
- GUMSHOE Update and Expansion
- ODGP2 Model – an advanced 2G wave model
- 6 NM Grid Spacing
- Hindcast 300+ Hurricanes and Storms 1900–2006
- Kinematic analysis of winds in complex storms
- Confirmed skill of ODGP/GUMSHOE
- Results fed into ABS MODU JIP and API INT/MET

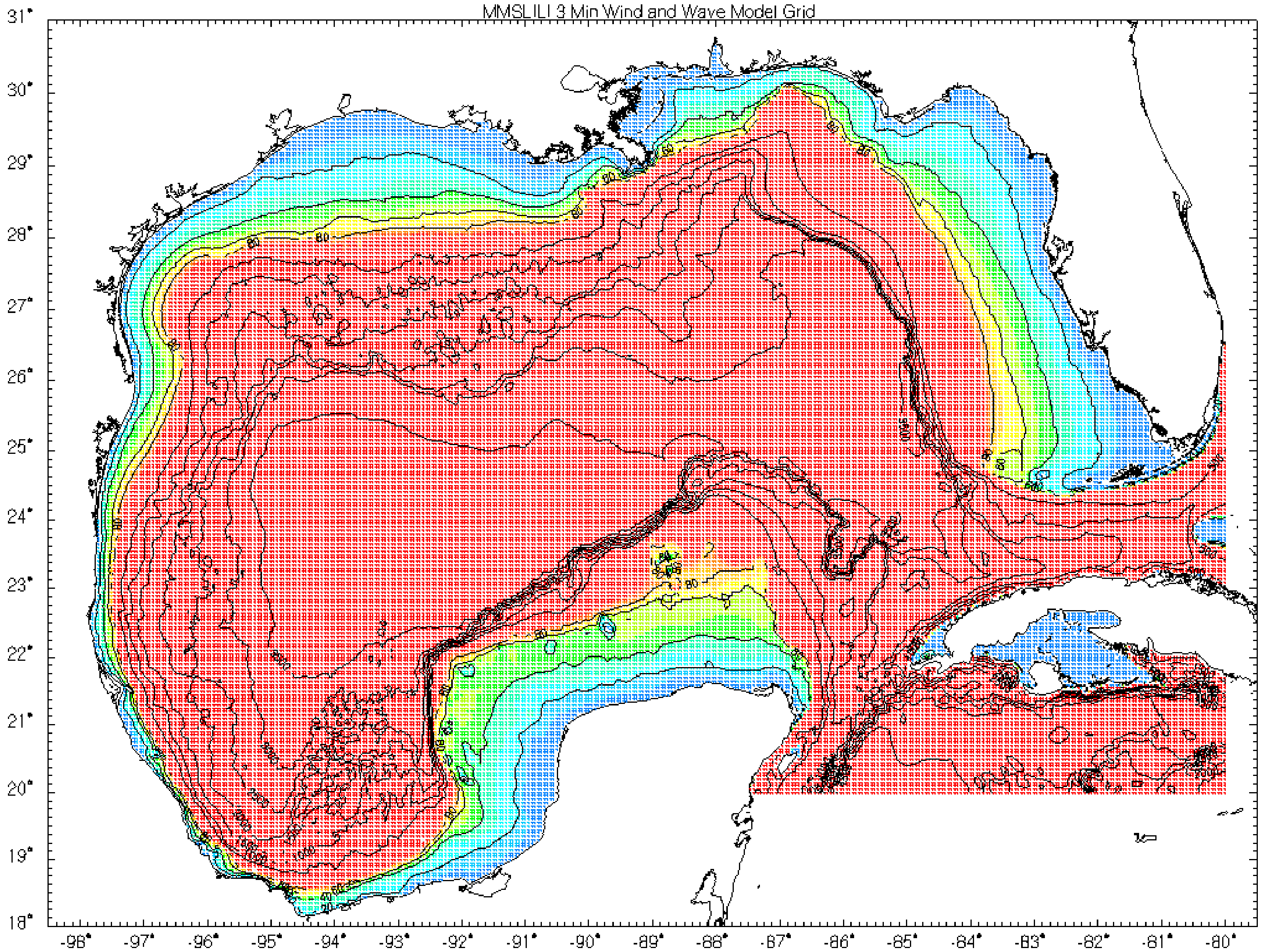
Latest Hindcast Methodology

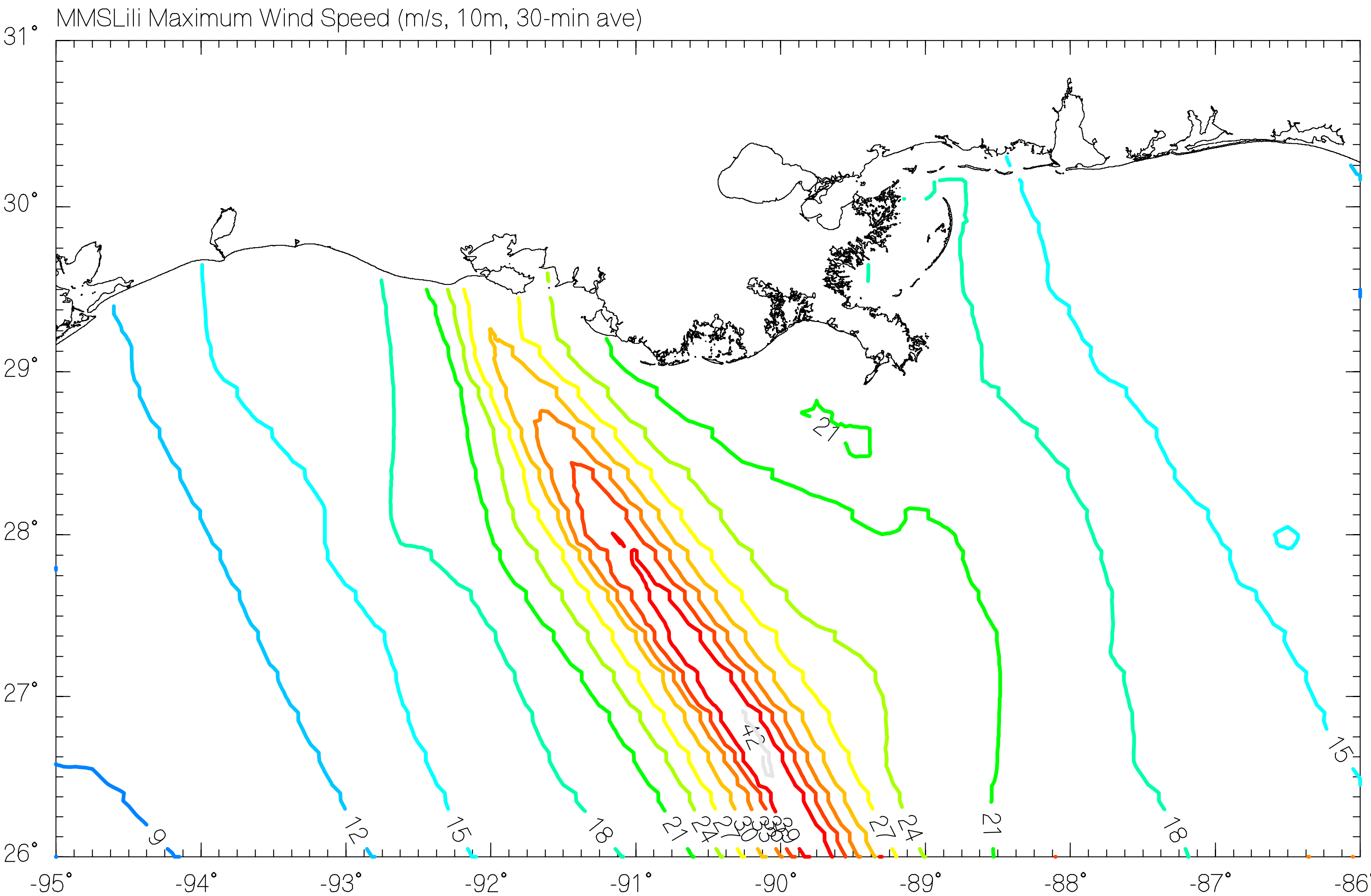
- Specify time and space evolution of the wind field – 30-minute average wind speed and direction at 10-m elevation over water using measured data, model (TC96 PBL) and man-machine mix approach (kinematic analysis systems such as IOKA and HWnd)
- Drive an advanced hydrodynamic model (ADCIRC) to specify time varying storm driven vertically averaged currents and storm surge with tides included. Use storm surge solution to modulate water depth for the wave run
- Drive a third-generation (OWI 3-G) spectral wave model to yield time and space evolution of the wave response – validate against available measured data and calibrate source terms if necessary
- Hindcast Deep Water Current Profile with a 1-D Mixed Layer Model

Example: Validation of the MMS Supported Hindcast of Lili (2002) (OTC#16821)

Track of Lili




MMSLILI 3 Min Wind and Wave Model Grid
31°
30°
29°
28°
27°
26°
25°
24°
23°
22°
21°
20°
19°
18°
-98°
-97°
-96°
-95°
-94°
-93°
-92°
-91°
-90°
-89°
-88°
-87°
-86°
-85°
-84°
-83°
-82°
-81°
-80°



MMSLili Maximum Wind Speed (m/s, 10m, 30-min ave)
31°
30°
29°
28°
27°
26°
-95°
-94°
-93°
-92°
-91°
-90°
-89°
-88°
-87°
-86°
9
12
15
18
21
24
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30
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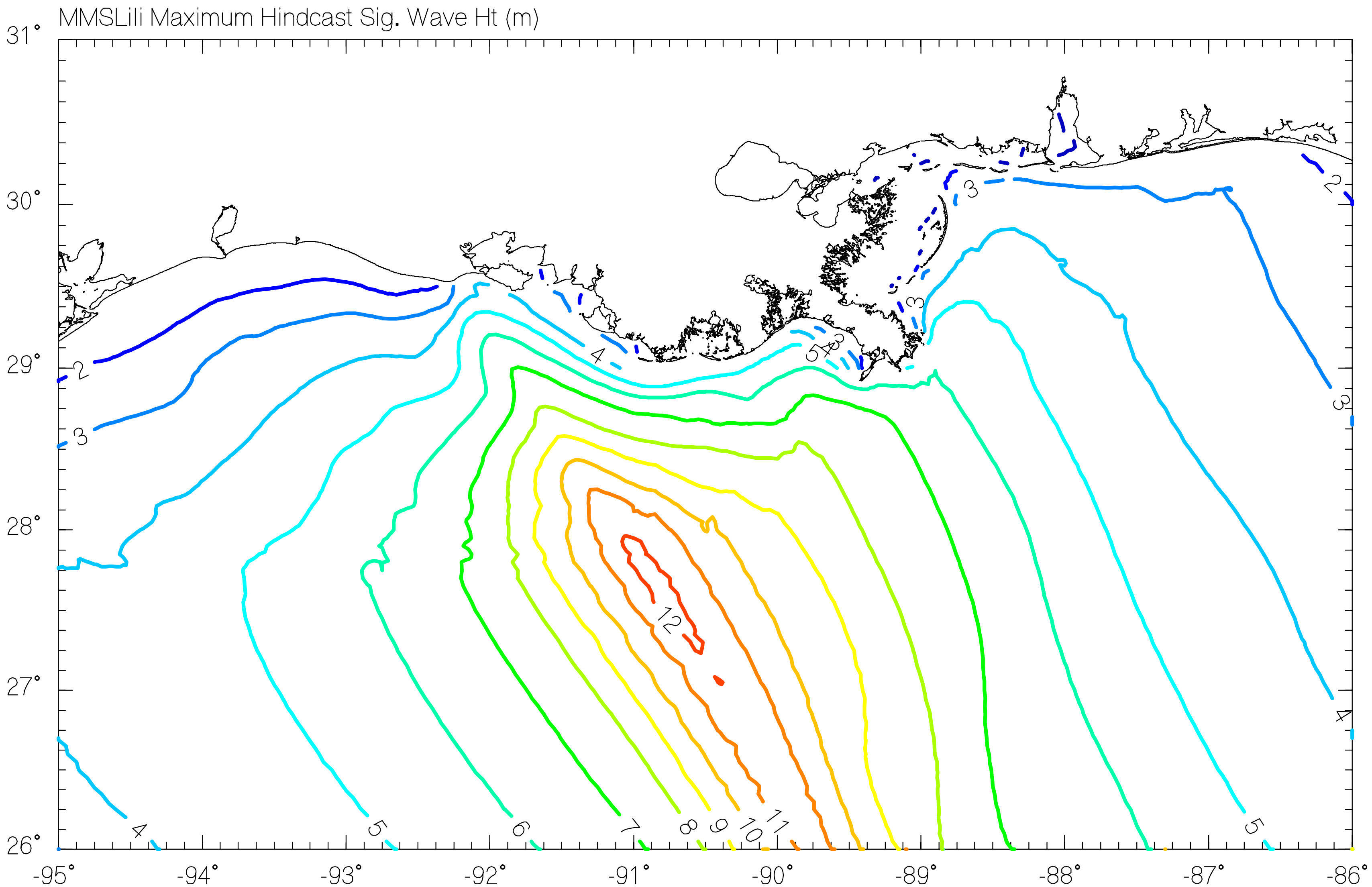
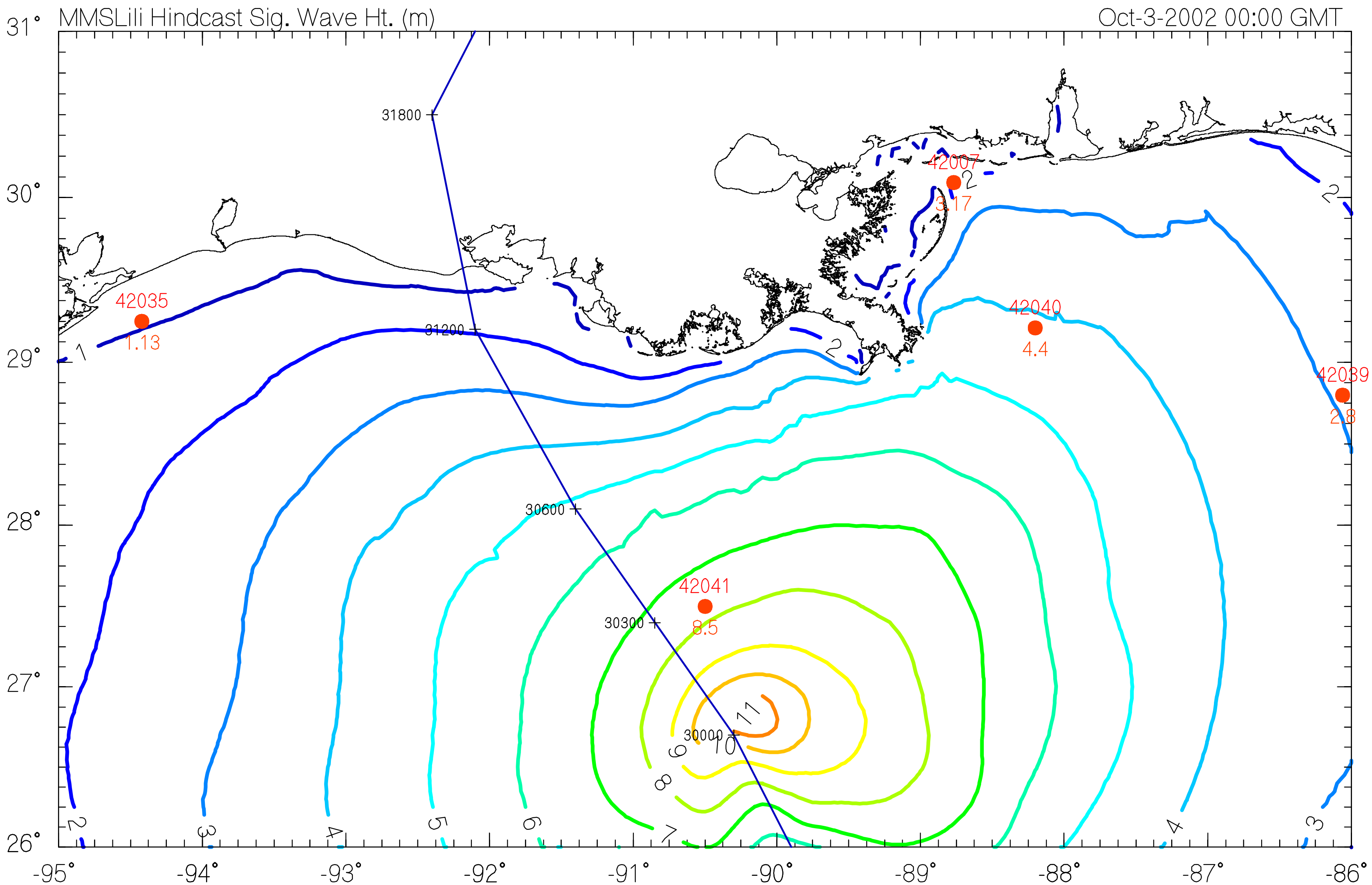
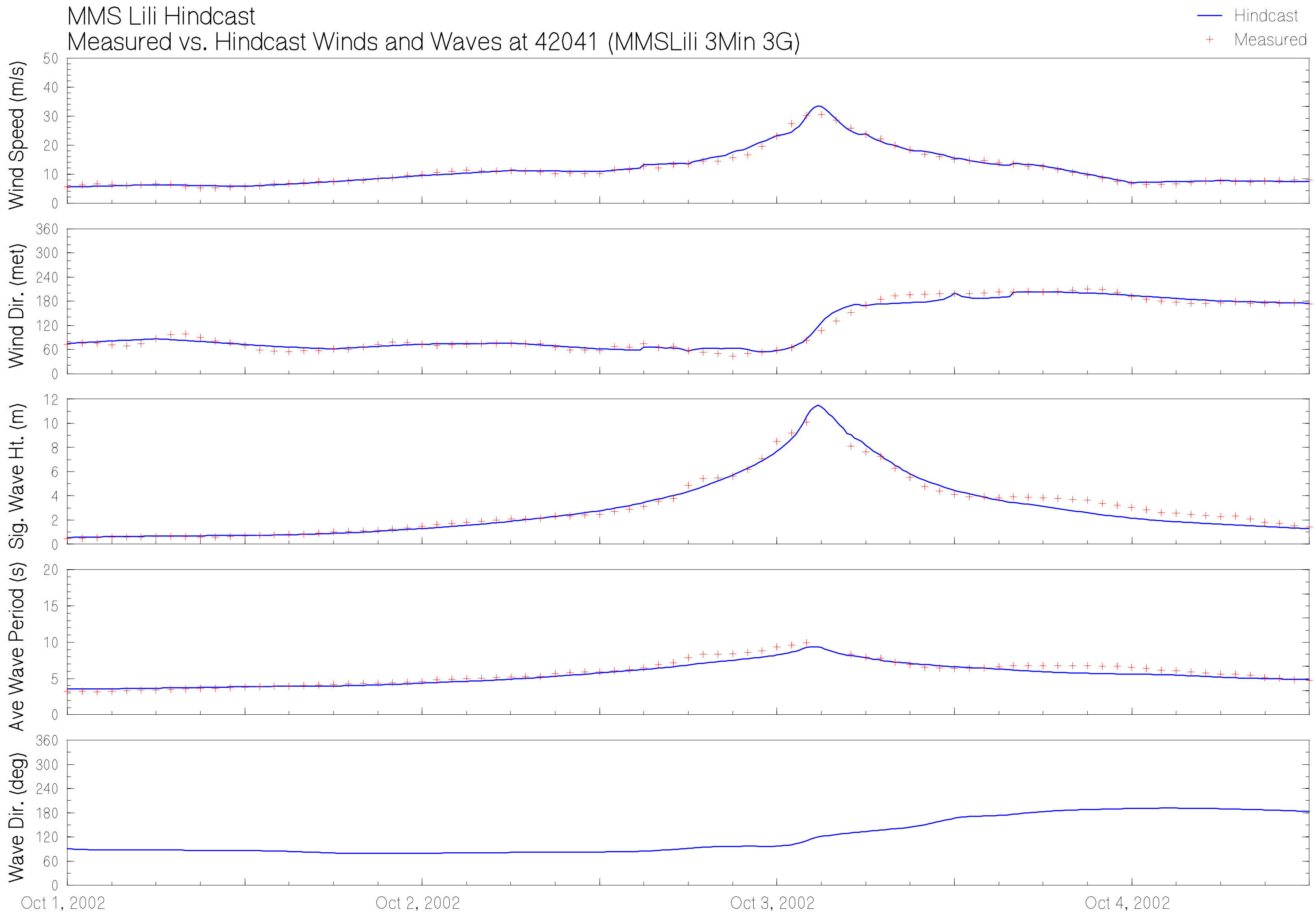
24
21
18
15
21

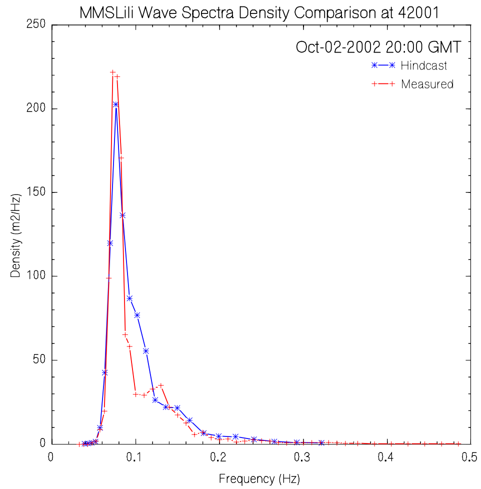


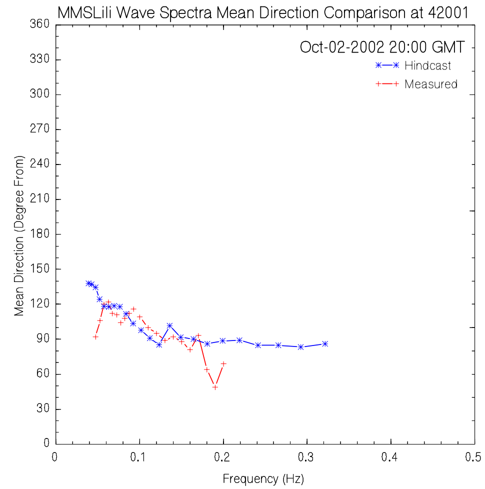
MMSLili Maximum Hindcast Sig. Wave Ht (m)
31°
30°
29°
28°
27°
26°
-95°
-94°
-93°
-92°
-91°
-90°
-89°
-88°
-87°
-86°
2
3
4
5
6
7
8
9
10
11
12

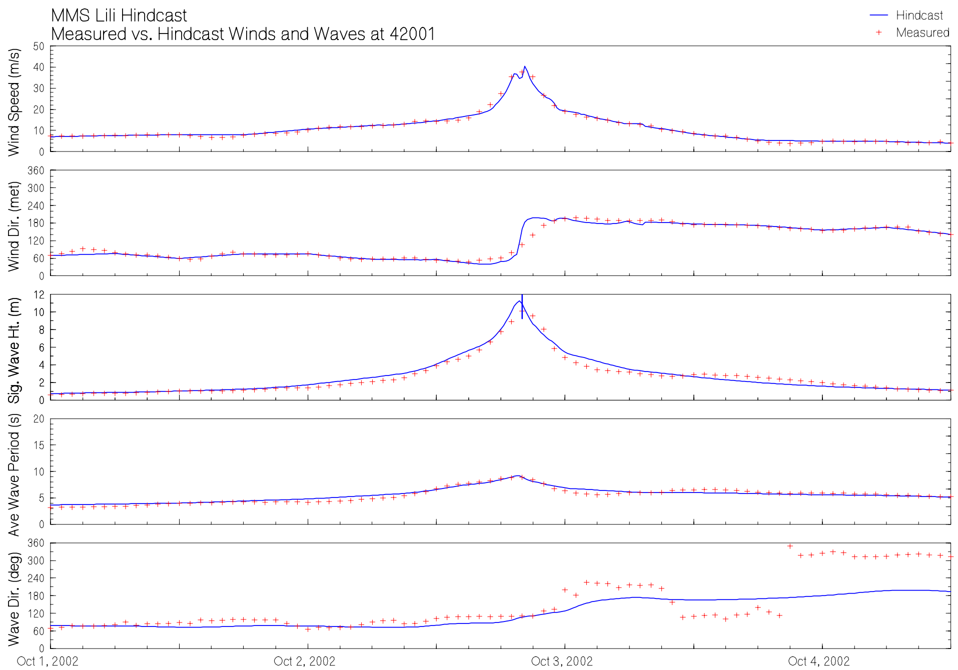


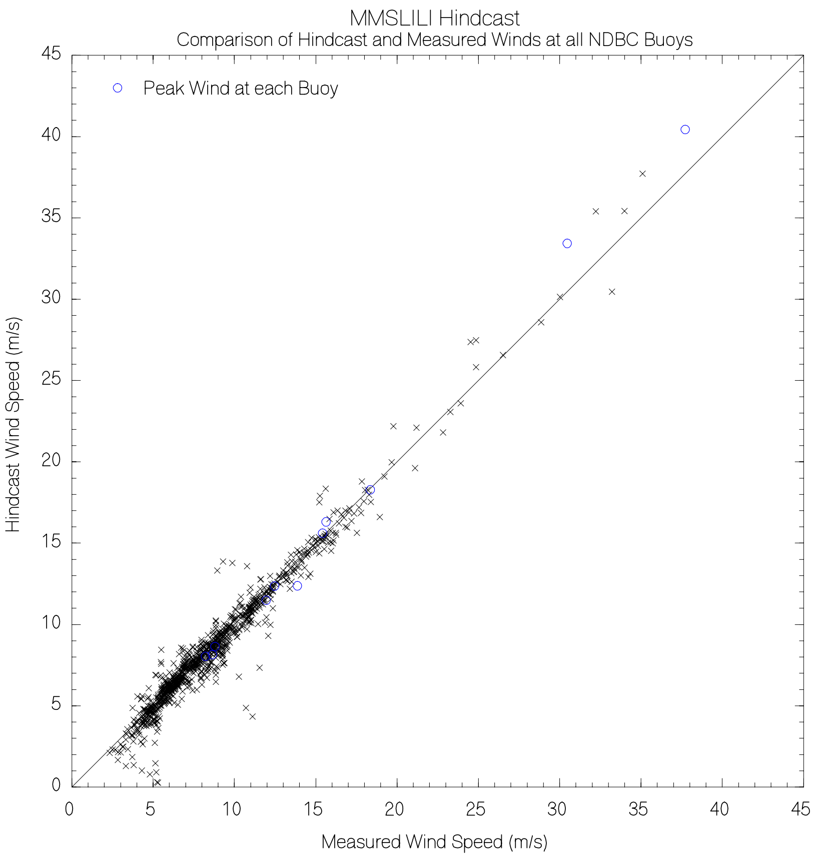
MMSLili Hindcast Sig. Wave Ht. (m)
Oct-3-2002 00:00 GMT
31°
30°
29°
28°
27°
26°
-95°
-94°
-93°
-92°
-91°
-90°
-89°
-88°
-87°
-86°
31800
31200
30600
30300
30000
42035
1.13
42007
3.17
42040
4.4
42039
2.8
42041
8.5
1
2
3
4
5
6
7
8
9
10
11

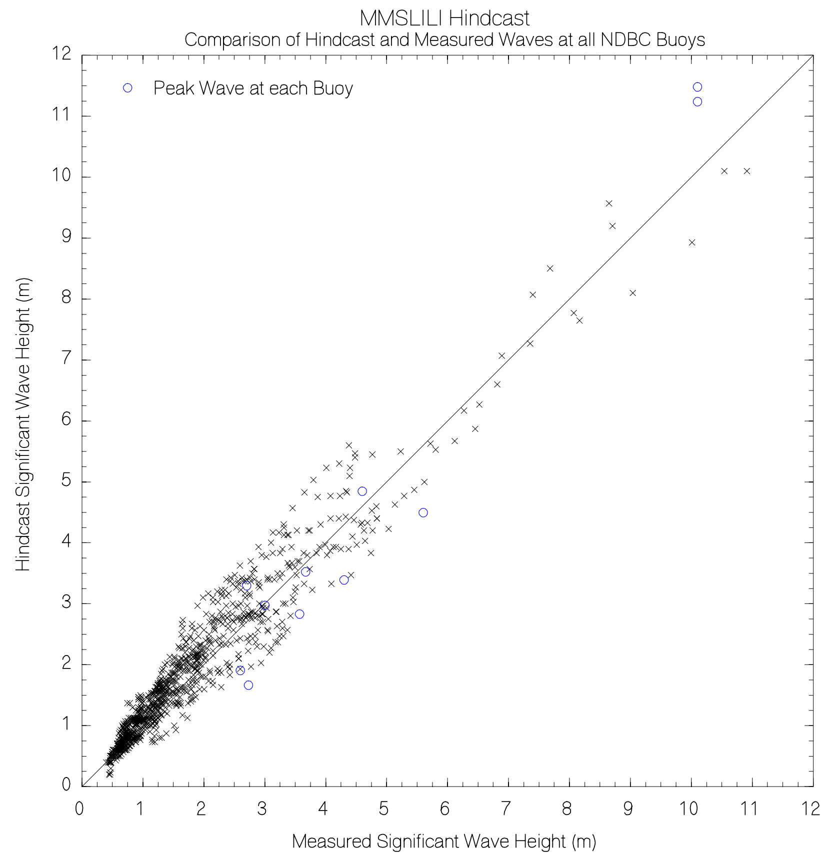

MMS Lili Hindcast
Measured vs. Hindcast Winds and Waves at 42041 (MMSLili 3Min 3G)
Hindcast
Measured
Wind Speed (m/s)
Wind Dir. (met)
Sig. Wave Ht. (m)
Ave Wave Period (s)
Wave Dir. (deg)
Oct 1, 2002
Oct 2, 2002
Oct 3, 2002
Oct 4, 2002

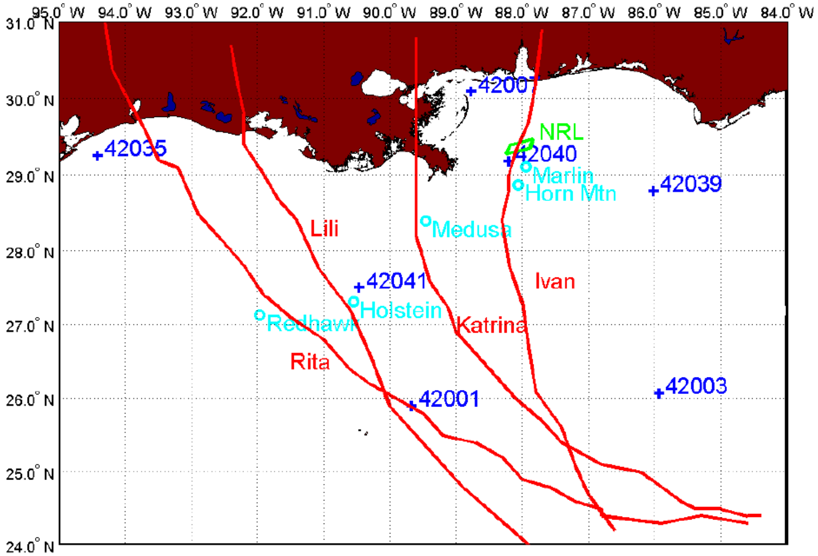

MMSLili Wave Spectra Density Comparison at 42001
Oct-02-2002 20:00 GMT
Hindcast
Measured
Density (m2/Hz)
Frequency (Hz)
0
50
100
150
200
250
0
0.1
0.2
0.3
0.4
0.5

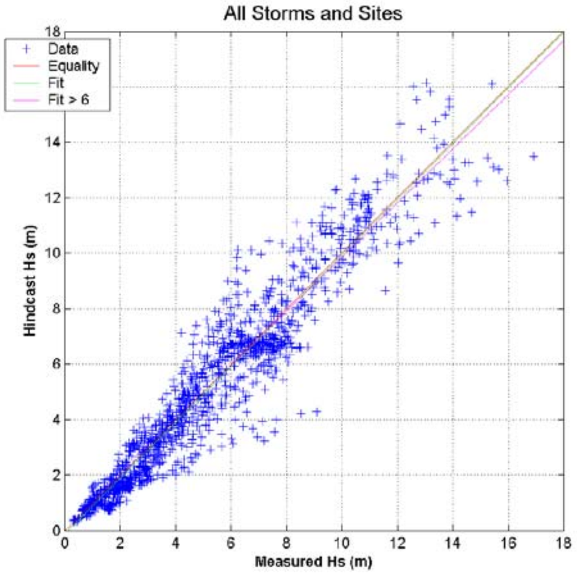

MMSLili Wave Spectra Mean Direction Comparison at 42001
Oct-02-2002 20:00 GMT
Hindcast
Measured
Mean Direction (Degree From)
Frequency (Hz)
0
30
60
90
120
150
180
210
240
270
300
330
360
0
0.1
0.2
0.3
0.4
0.5

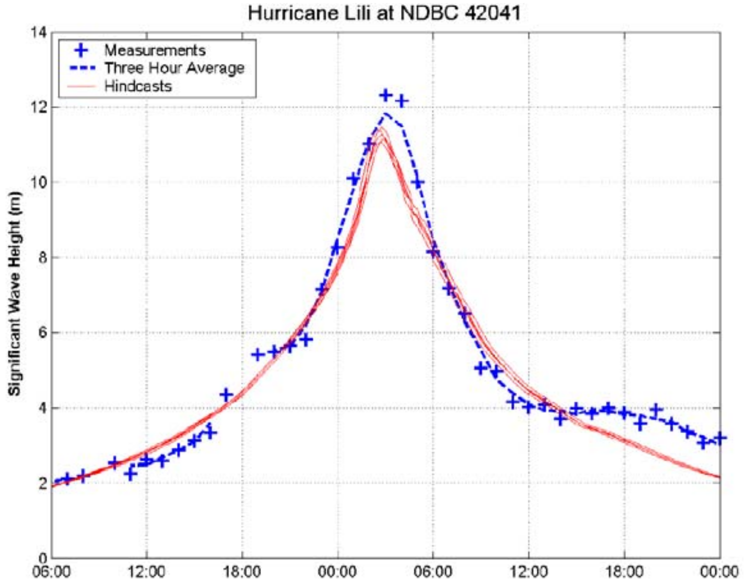

MMS Lili Hindcast
Measured vs. Hindcast Winds and Waves at 42001
Hindcast
Measured
Wind Speed (m/s)
Wind Dir. (met)
Sig. Wave Ht. (m)
Ave Wave Period (s)
Wave Dir. (deg)
Oct 1, 2002
Oct 2, 2002
Oct 3, 2002
Oct 4, 2002

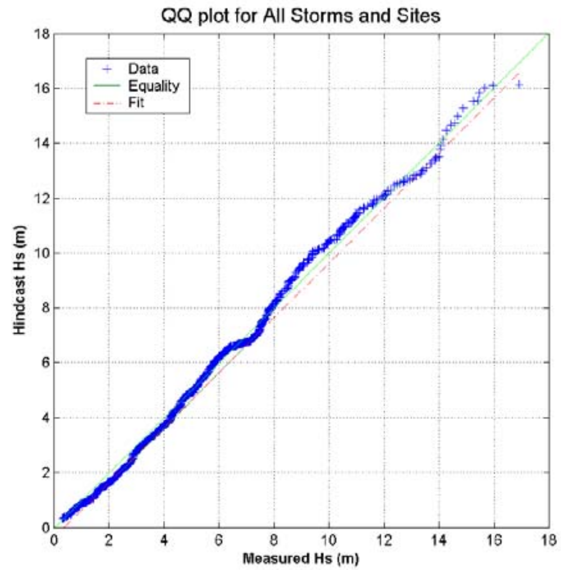

MMSLILI Hindcast
Comparison of Hindcast and Measured Winds at all NDBC Buoys
Peak Wind at each Buoy
Hindcast Wind Speed (m/s)
Measured Wind Speed (m/s)
0
5
10
15
20
25
30
35
40
45


MMSLILI Hindcast
Comparison of Hindcast and Measured Waves at all NDBC Buoys
Peak Wave at each Buoy
Hindcast Significant Wave Height (m)
Measured Significant Wave Height (m)
0
1
2
3
4
5
6
7
8
9
10
11
12









From Forristall 2007

Hindcast Skill with Best Wind Fields and 3G Wave Model

For Significant Wave Height (HS) and storm peaks:

Bias < 10 cm (Bias is mean difference between hindcast and measured data)

Scatter Index < 0.15 (SI is rms difference / mean of measurement sample)

For Peak Spectral Period (TP) associated with storm peak HS

Bias less than +/- 1 second

Scatter Index less than 15%

Conditioned on well documented storms such as, say, post 1 955 GMEX Storms
Errors will be larger for earlier storms

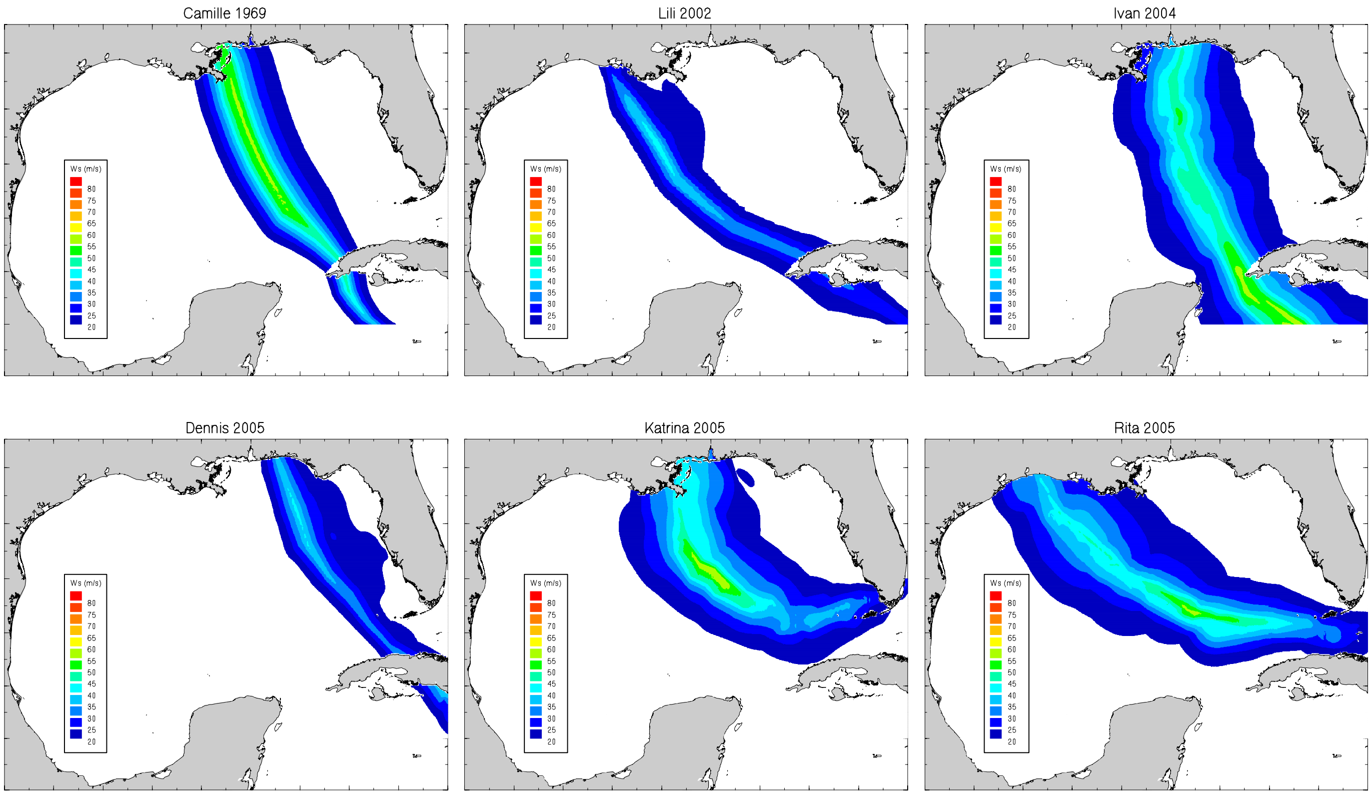
For details see OTC #4323 1982 (Reece and Cardone); Cardone et al. 1996; Jensen et al. 2006; Forristall 2007

A Recent Intercomparison of 3G Wave Model Variants (Jensen et al. 2006)

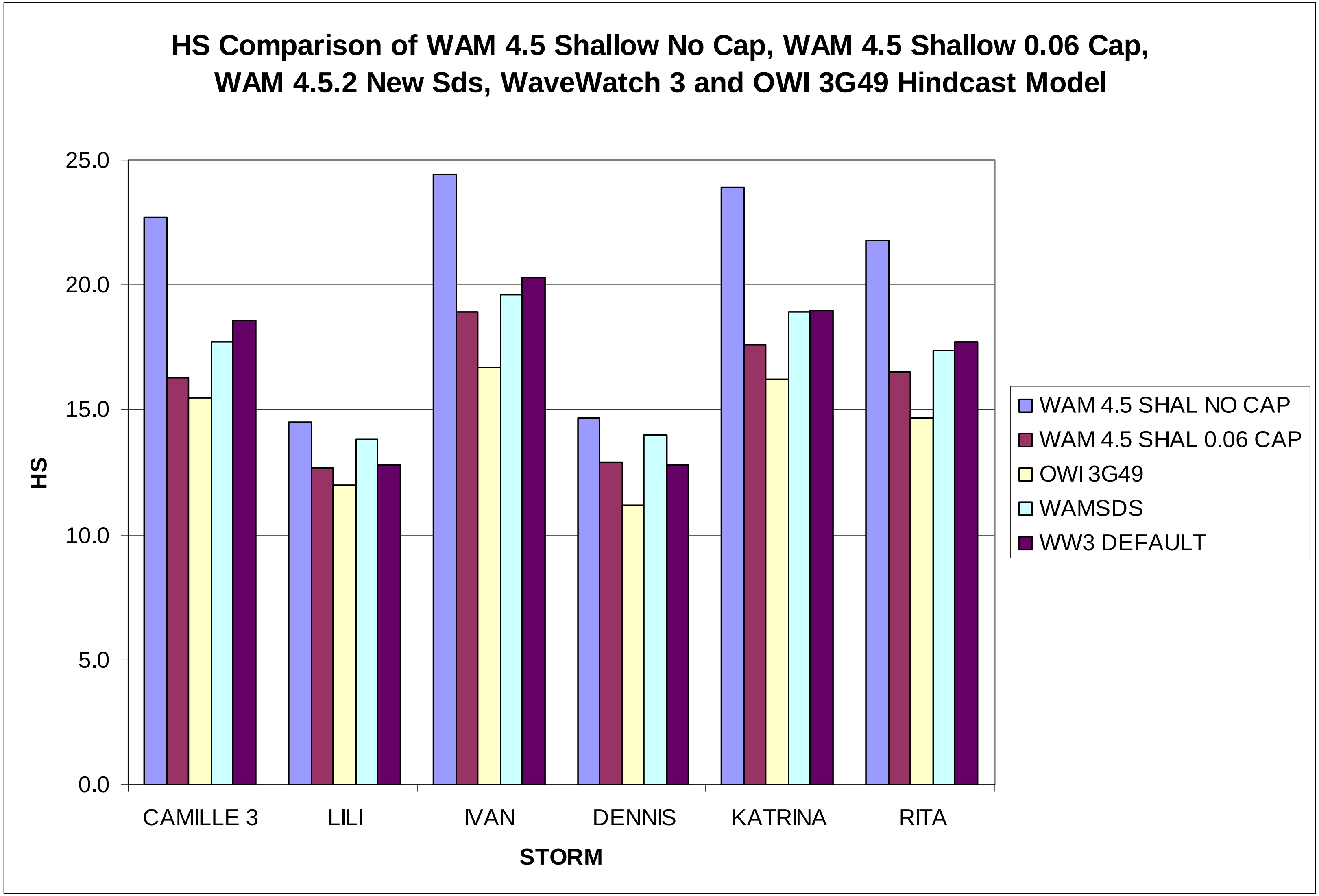
Apply "best" wind fields for:

	SS#	Peak Winds (30-min)
• Camille (1969)	5	56 m/s
• Lili (2002)	4	48 m/s
• Ivan (2004)	5	58 m/s
• Dennis (2005)	3	41 m/s
• Katrina (2005)	5	57 m/s
• Rita (2005)	5	58 m/s

Envelope of Modeled Wind Fields in Small, Medium and Large Hurricanes (“Daisy” to “Helene” types after Colon 1964)



Not All 3G Wave Models Unbiased



	HS				**TP**			
	BIAS	STD DEV.	SCATTER INDEX	CC	BIAS	STD DEV.	SCATTER INDEX	CC
WAM 4.5 Shallow No Cap	0.89	1.81	0.24	0.93	3.62	2.50	0.23	0.57
WAM 4.5 Shallow 0.06 Cap	-0.08	1.81	0.17	0.93	2.45	2.34	0.22	0.62
OWI 3G49	0.03	1.06	0.14	0.95	-0.72	0.96	0.09	0.95

WIND FIELD MODELLING CHALLENGES

- Accurately describe along track variability of:
  - Peak 10-m average wind speed
  - Primary radius of maximum wind
  - Evolution of concentric wind radii
  - Evolution of wind maxima over azimuth
  - Far field structure
- Historical data homogenization and consistent data reanalysis

TropPBL History & Inputs

1978 Version restricted B=1, single exponential profile
1996 Version allowed variable B, double exponential profile
2007 Version allows Dp, B to vary by quadrant
2008 Reformulate PBL physics and drag law

$$P(r) = Po + \sum_{i=2}^{n} dp_i e^{-\left(\frac{R_{pi}}{r}\right)^{Bi}}$$

Storm Position – Latitude/Longitude

Storm Motion – Speed/Direction

Po - Central Pressure of Storm

Available from standard sources such as HURDAT but we reexamine these as well

Rp_i – Scale Pressure Radius

Related to the Radius of Maximum Wind (RMW) expressed as a inner and outer radii

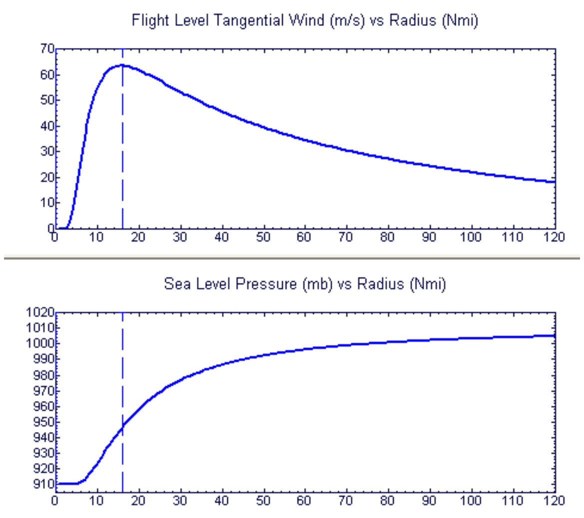
Dp_i – Total Pressure Drop (*Pfar-Po*)

Pfar may be derived from synoptic maps or atmospheric model output, however the % associated with each Rp_i must be determined

B_i – Holland's B associated with each Rp_i

Controls the peakedness of the pressure and resultant wind profile

TropPBL Inputs: Single vs. Double Exponential Profile

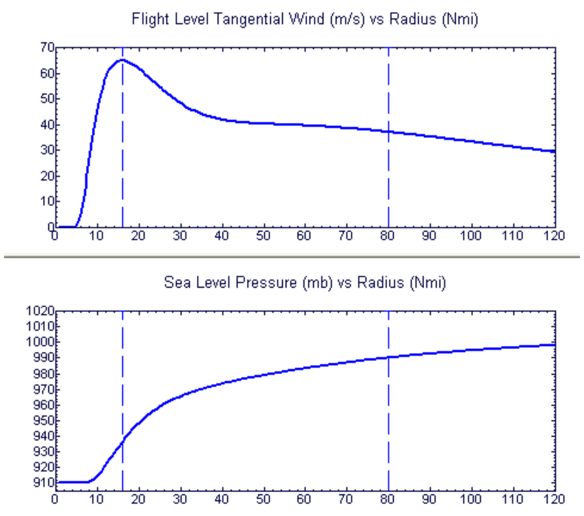


Cp=910, Pfar=1010, Dp=100 mb

Rp1=16 Nmi

B1=1.45

The Storm?

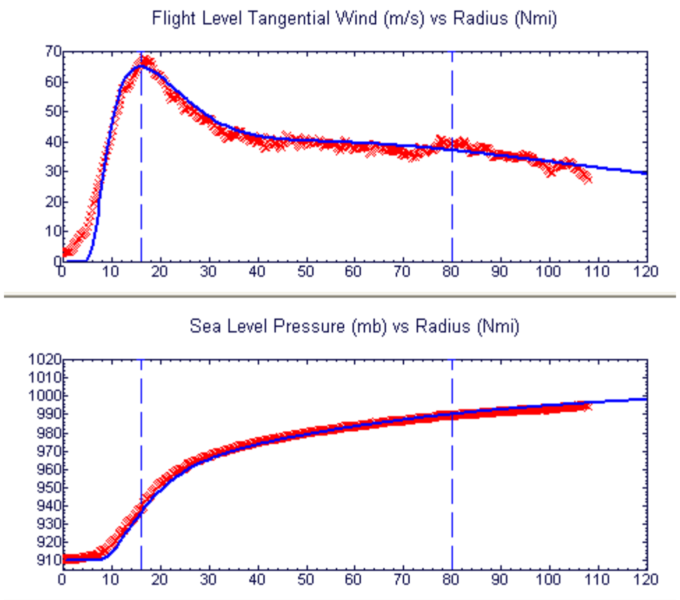


Cp=910, Pfar=1010, Dp=100 mb

Rp1=16 Nmi Rp2=80 Nmi

B1=2.1 B2 = 1.7

Katrina 2005

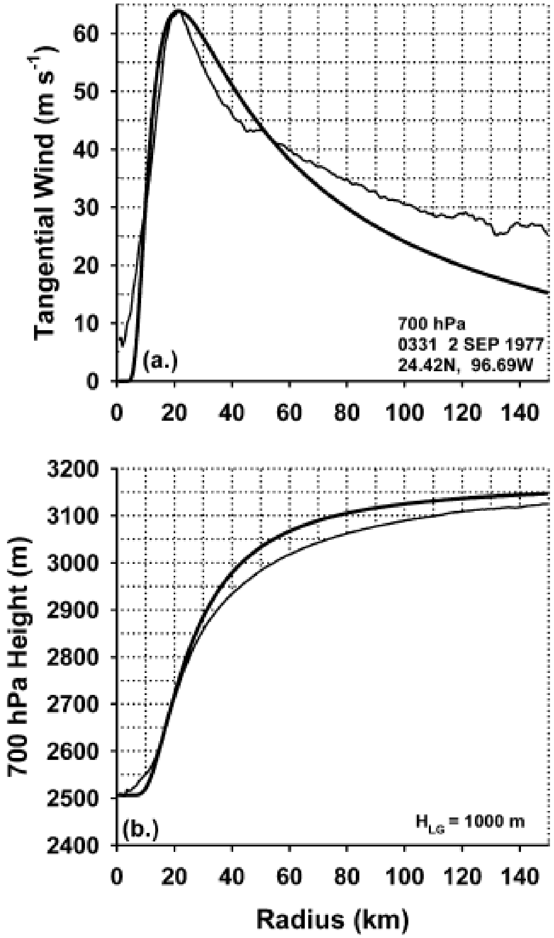


Willoughby and Rahn (2004) Methodology

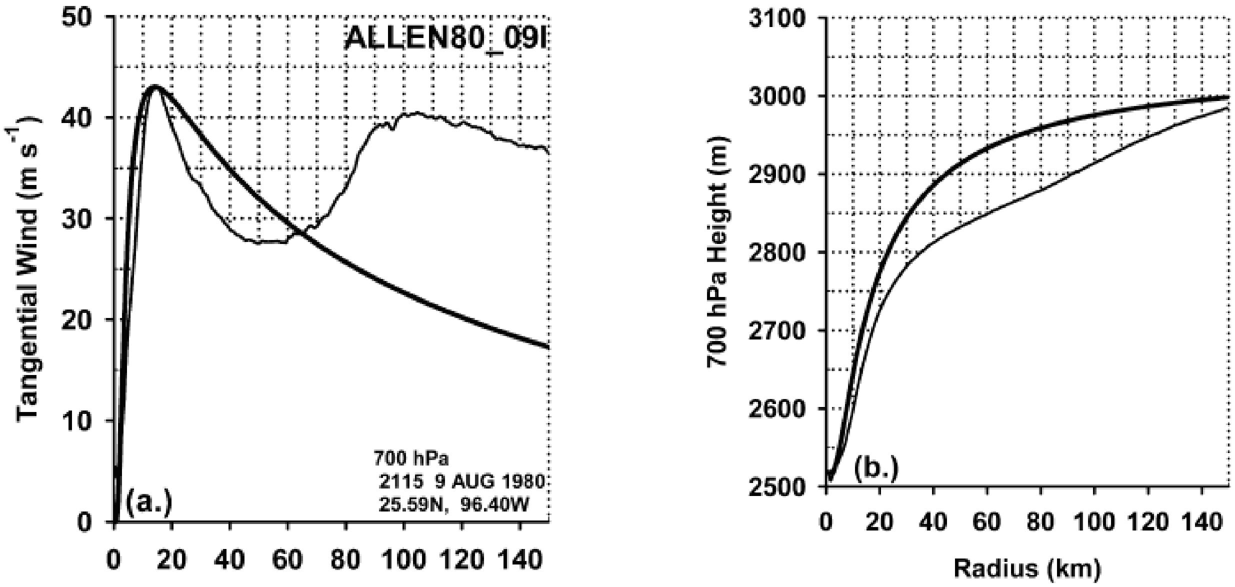
$$S^2 = \sum_{k=1}^{K} \{[v_o(r_k) - v_g(r_k, B)]^2 + g[z_o(r_k) - z(r_k, B)]^2 L_z^{-1}\}$$

Attempts to minimize the difference between the observed flight level tangential wind and flight level heights to obtain a RMW and B combination

Applied for a single exponential wind profile



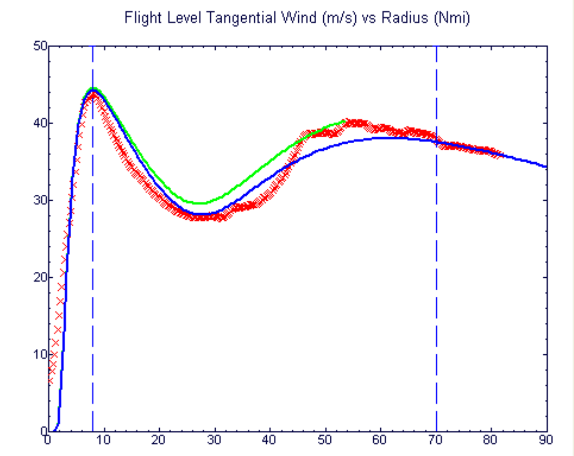
Willoughby and Rahn (2004) Methodology

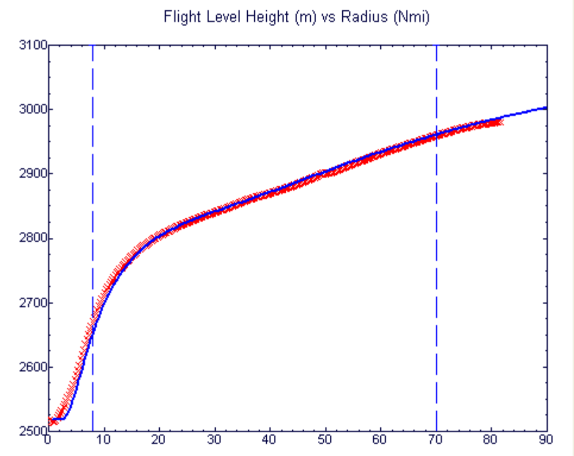


Large discrepancies observed when attempting to fit a single exponential wind profile to a storm displaying a double wind maxima

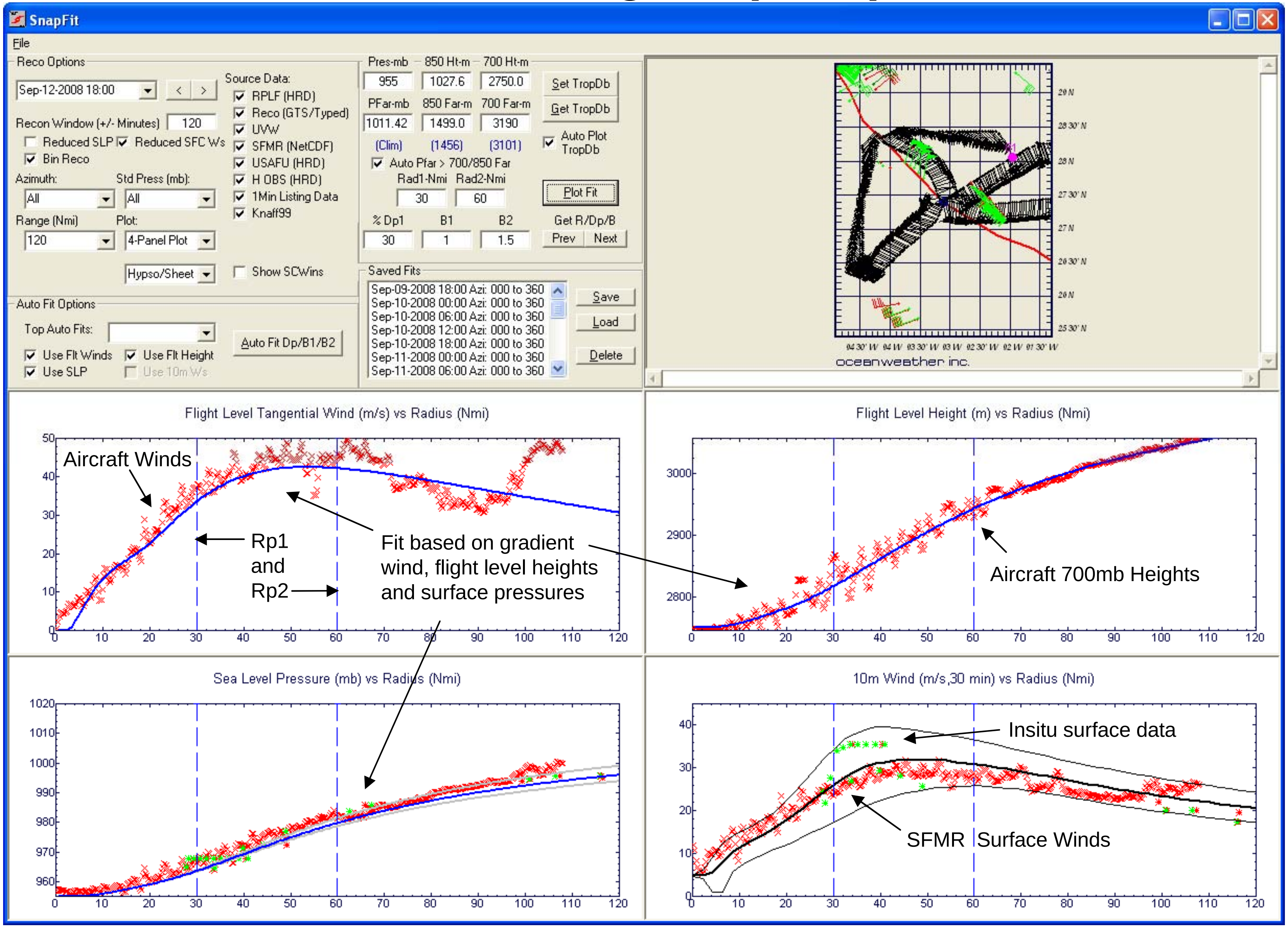
GOMOS Update Methodology

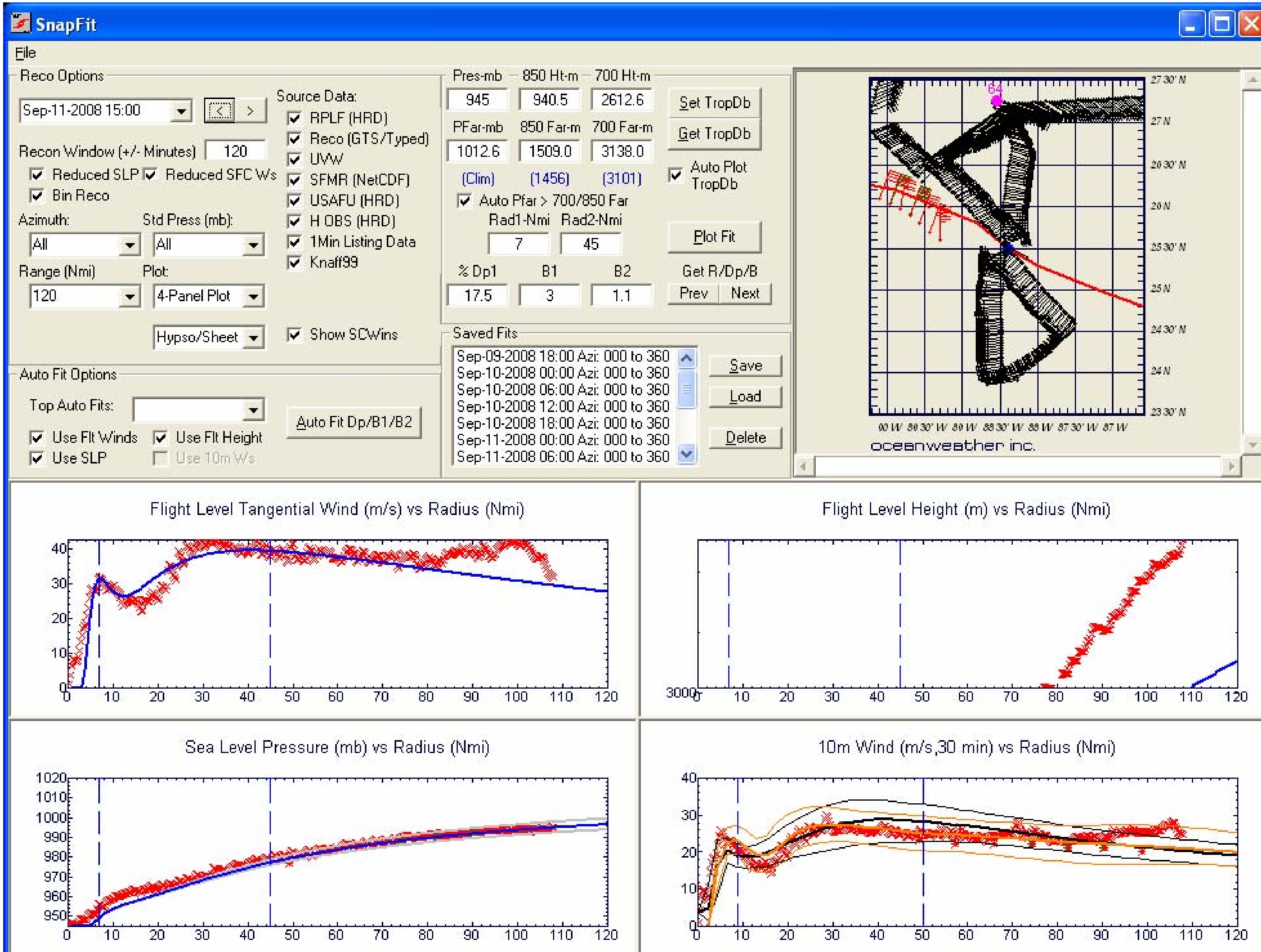
- *Apply double exponential pressure profile as implemented in TropPBL*
- *Expand cost function to allow sea level pressure measurements as well as flight level tangential wind and height*
- *Display available fit information in work station to allow storm analysis which tracks the parameter set throughout the storm life cycle*



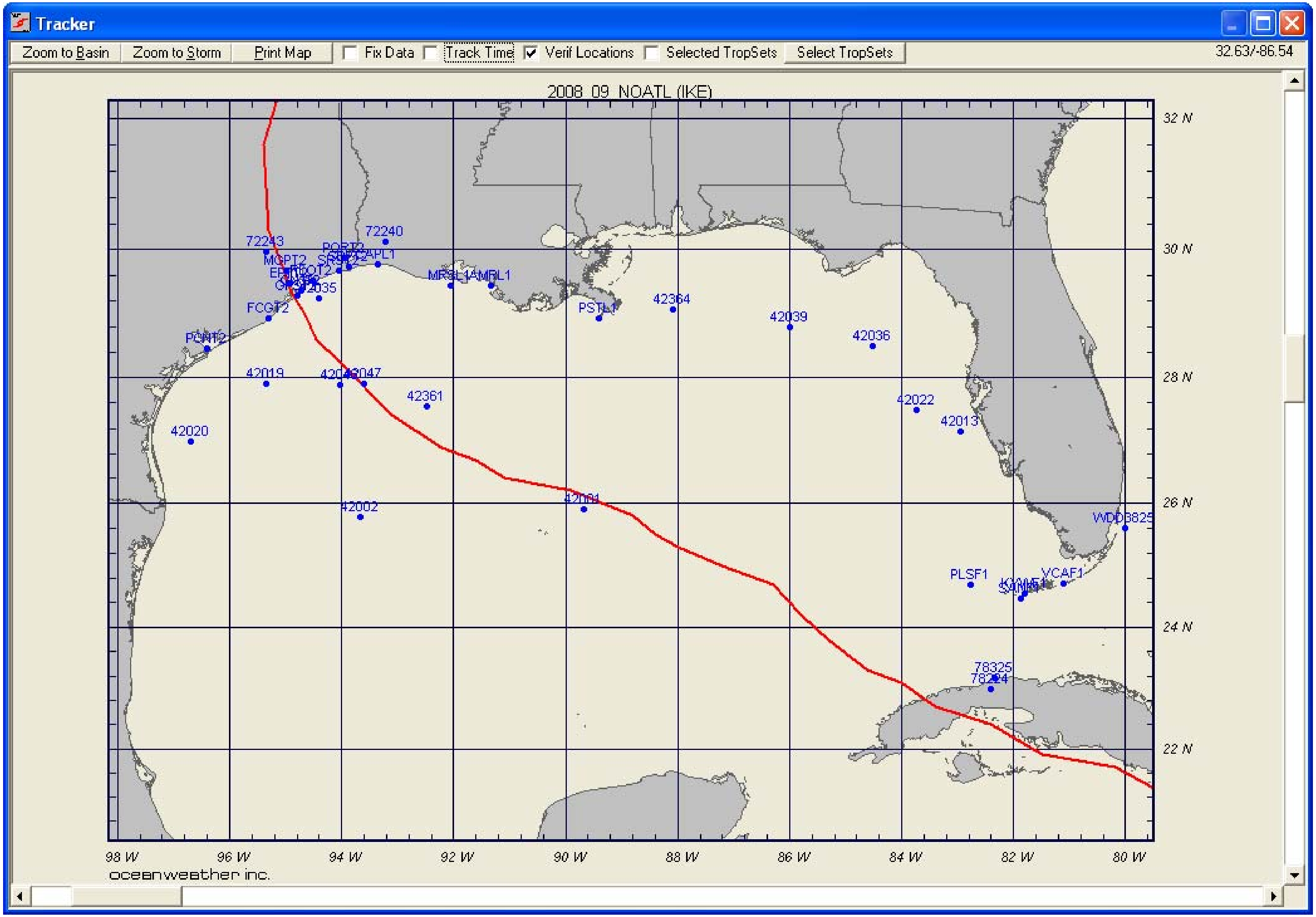


Fit During Ike (2008)




SnapFit
File
Reco Options
Sep-11-2008 15:00
Source Data:
RPLF (HRD)
Reco (GTS/Typed)
UVW
SFMR (NetCDF)
USAFU (HRD)
H OBS (HRD)
1Min Listing Data
Knaff99
Recon Window (+/- Minutes) 120
Reduced SLP
Reduced SFC Ws
Bin Reco
Azimuth:
Std Press (mb):
All
All
Range (Nmi)
Plot:
120
4-Panel Plot
Hypso/Sheet
Show SCWins
Auto Fit Options
Top Auto Fits:
Auto Fit Dp/B1/B2
Use Flt Winds
Use Flt Height
Use SLP
Use 10m Ws
Pres-mb
850 Ht-m
700 Ht-m
945
940.5
2612.6
PFar-mb
850 Far-m
700 Far-m
1012.6
1509.0
3138.0
(Clim)
(1456)
(3101)
Auto Pfar > 700/850 Far
Rad1-Nmi
Rad2-Nmi
7
45
% Dp1
B1
B2
17.5
3
1.1
Set TropDb
Get TropDb
Auto Plot TropDb
Plot Fit
Get R/Dp/B
Prev
Next
Saved Fits
Sep-09-2008 18:00 Azi: 000 to 360
Sep-10-2008 00:00 Azi: 000 to 360
Sep-10-2008 06:00 Azi: 000 to 360
Sep-10-2008 12:00 Azi: 000 to 360
Sep-10-2008 18:00 Azi: 000 to 360
Sep-11-2008 00:00 Azi: 000 to 360
Sep-11-2008 06:00 Azi: 000 to 360
Save
Load
Delete
oceanweather inc.
Flight Level Tangential Wind (m/s) vs Radius (Nmi)
Flight Level Height (m) vs Radius (Nmi)
Sea Level Pressure (mb) vs Radius (Nmi)
10m Wind (m/s,30 min) vs Radius (Nmi)

NDBC Data During Ike (2008)



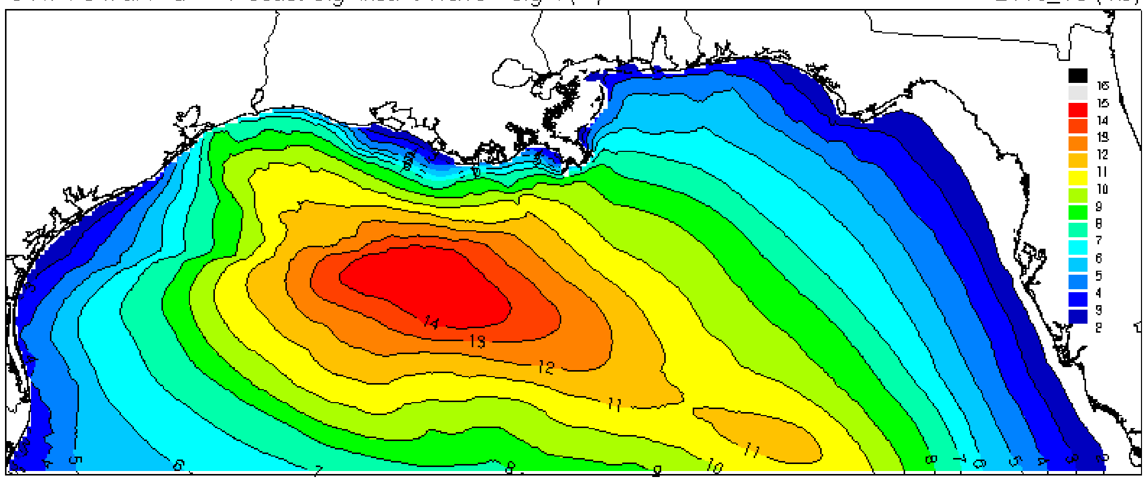
Ike was mainly SS #2 in Gulf BUT Generated Peak Sea States Greater Than Many SS#3 and #4 Storms. The REASON: Shelf-Like Radial Wind Structure

Preliminary Hindcast Ike (2008)

Significant Wave

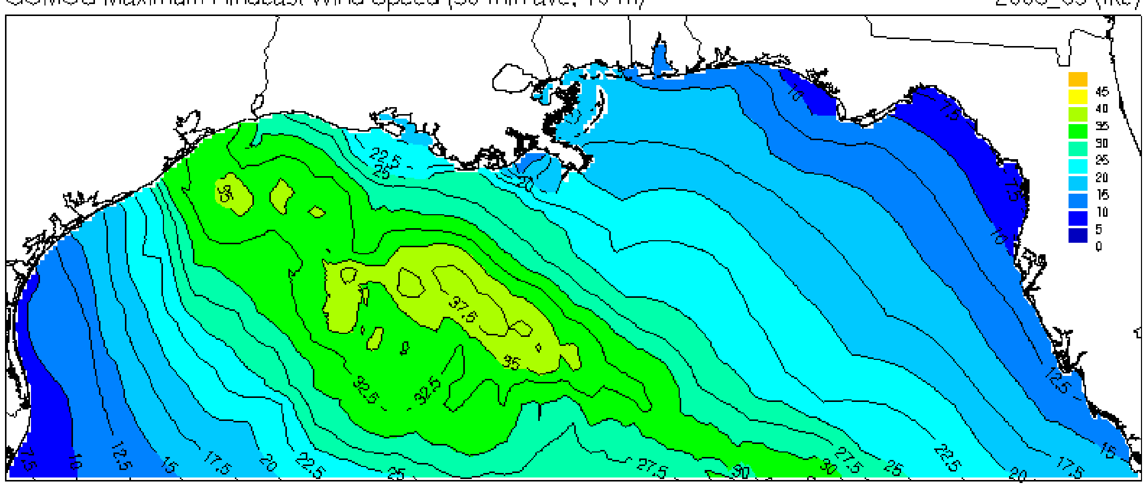
Height (Meters)

GOMOS Maximum Hindcast Significant Wave Height (m) 2008_09 (Ike)

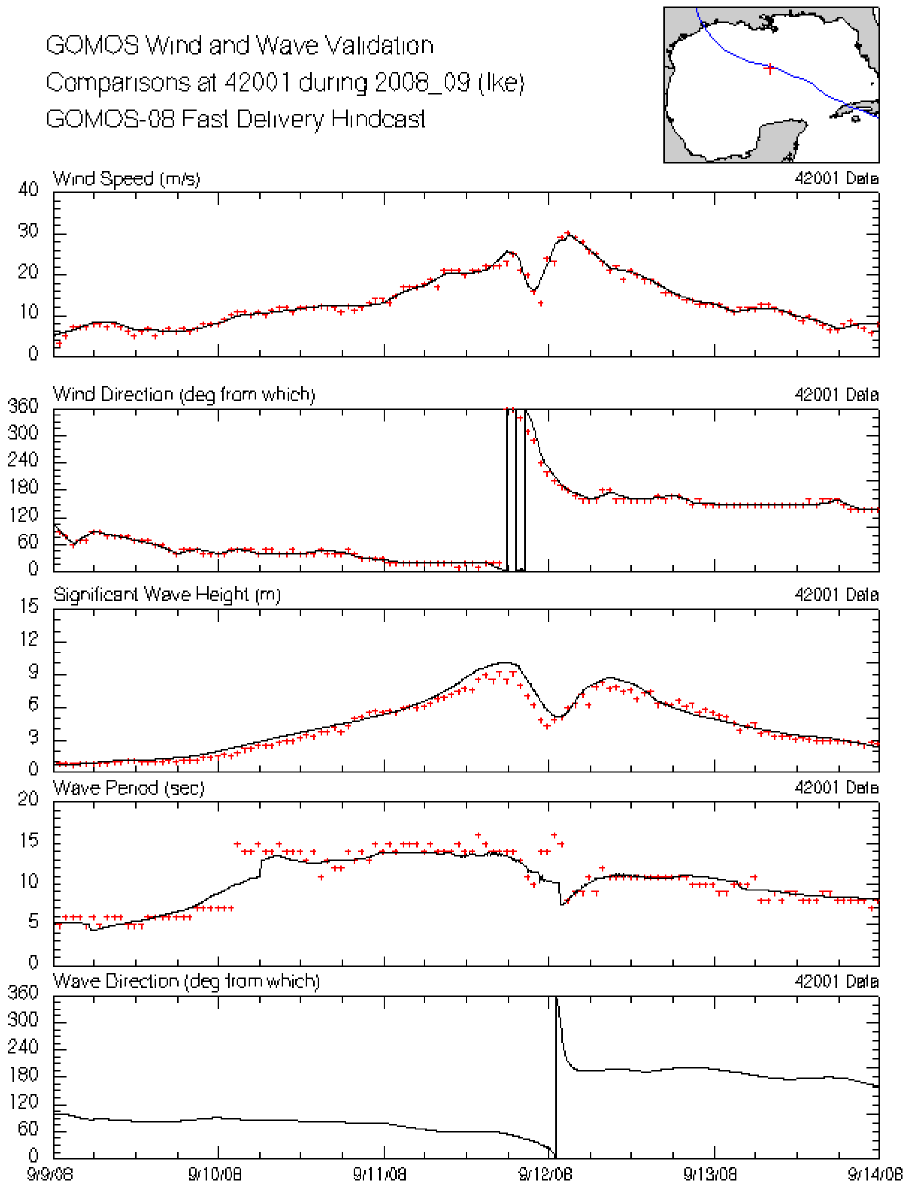


Wind Speed (Meters/Second

GOMOS Maximum Hindcast Wind Speed (30-min ave, 10-m) 2008_09 (Ike)

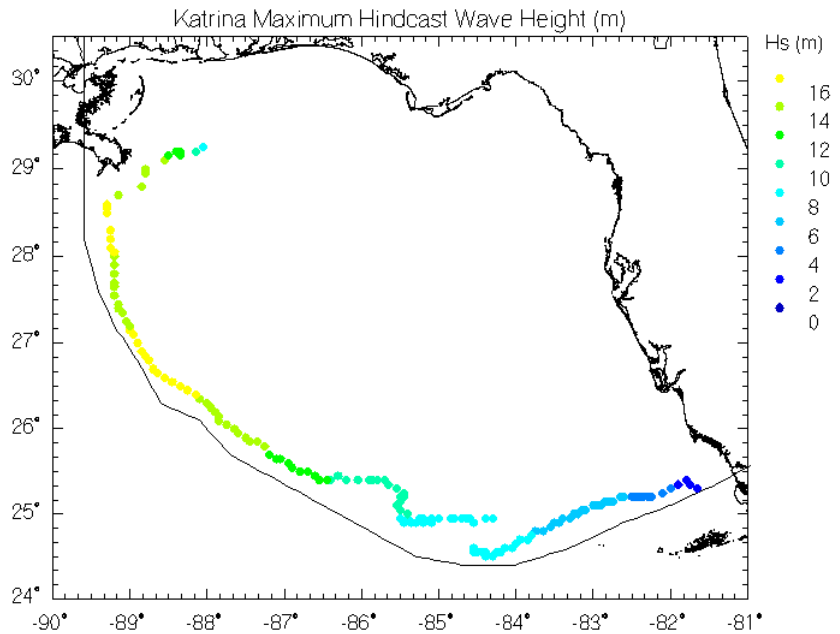


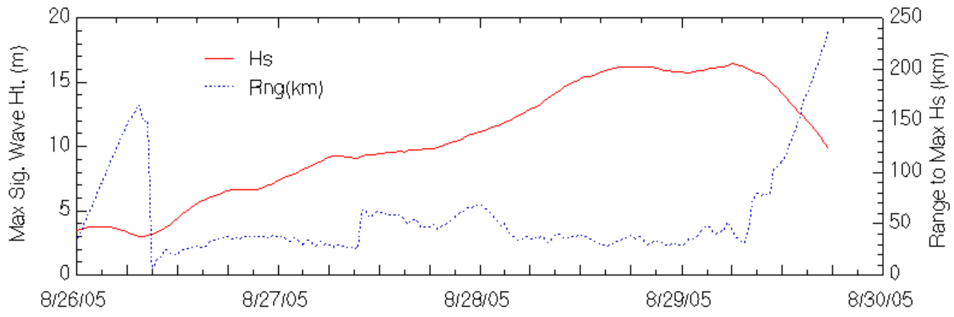
Comparison of preliminary hindcast and measured wind and sea state at NDBC Buoy 42001 in Hurricane Ike (2008)



Evolution of the MSS Supported Hindcast Peak Sea State in Katrina (2004) (OTC # 18652)

Tracking the locus and magnitude of peak HS over the entire hindcast history in Katrina

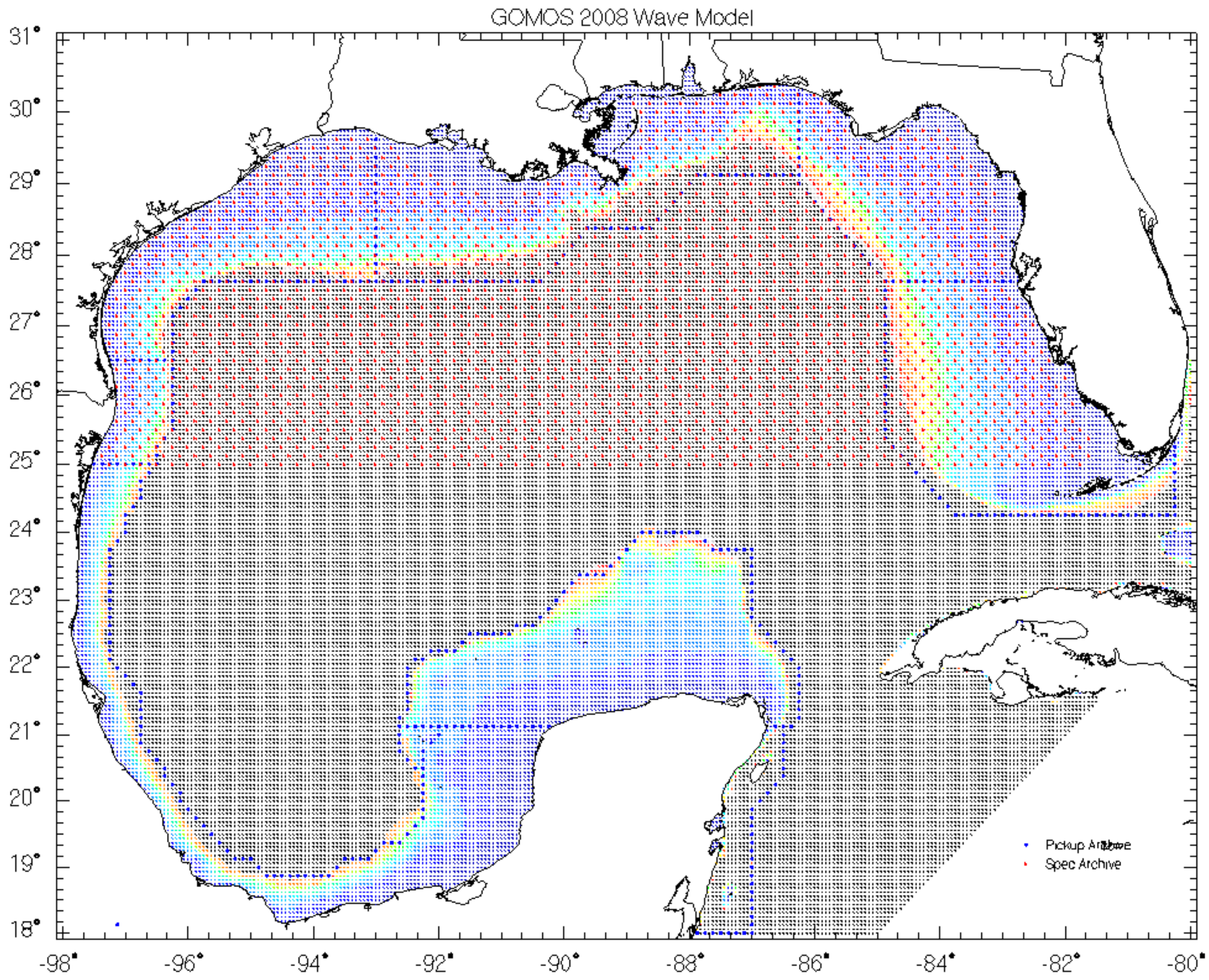




SS# 1 2 3 4 5 4 3 2 1

Saffir-Simpson Scale is a poor measure of ocean response. Evolution of storm track and radial distribution of wind speed are critical — well documented in GOM

GOMOS-USA 2008 Update Wave Model Grid



7km (0.625-deg) Grid

4x Grid Spacing of GOMOS

40,000+ active grid points

OWI-3G Wave Model

Spectral Fits at subset of points (red)

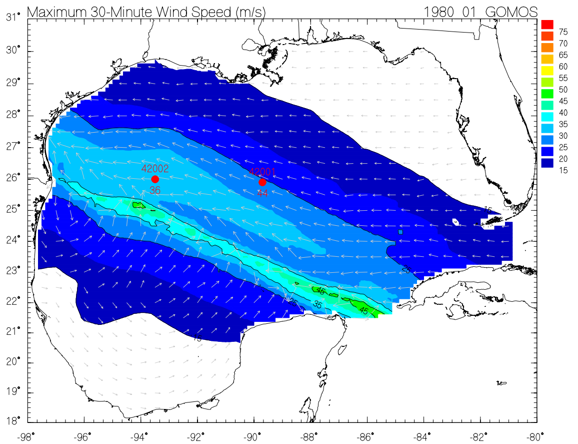
Water Level/2D Currents from ADCIRC (w/tides)

VALIDATION APPROACH

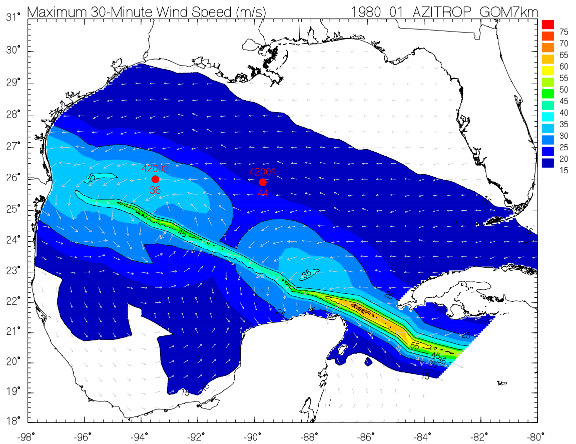
- Compare GUMSHOE, GOMOS and UPDATE Wind and Wave Model Runs for Tier 1 Storms
- Use reanalysis inputs, new wind model
- +2G and 3G Wave Models
- Revalidate and recalibrate as needed
- Classic industry data sets, all NDBC measured data and satellite altimetry within 500 km of track, limited new industry data as used in a recent paper by FOROCEAN

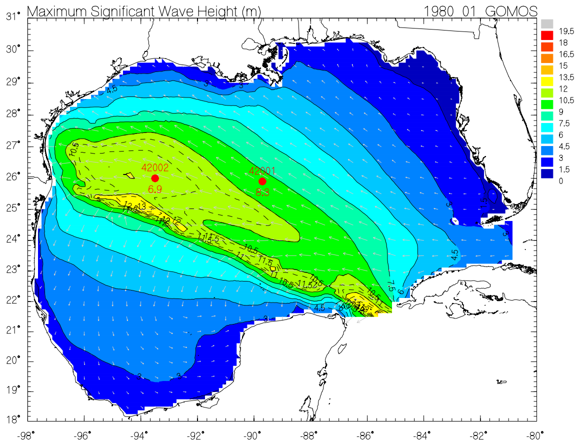
EXAMPLE OF FOUR WAY RUN COMPARISON DURING 1980–01 (Allen)

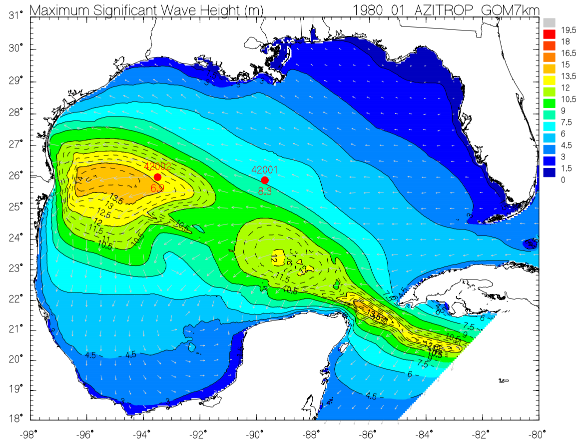
GUMSHOE/GOMOS



GOMOS UPDATE







GOMOS-UPDATE STATUS

ReAnalysis Proceeding in following storm tiers:

Tier 1: 76 Storms – most extreme storms that drive the extremes in the Gulf. Analysis done by full tropical committee – 1980–2007 complete.

Tier 2: 82 Storms – moderate storms in the Gulf – 1970–2007 complete.

Tier 3: Remaining Gulf storms (150+) – tropical storms and weak hurricanes – 1980–2000 complete.

Working back into the earlier 20th century from here

GOMOS-USA Update Available Q2/2009

GOMOS IMPACT ON GULF METOCEAN DESIGN DATA

Deep Water Projects 2004-2013 according to MMS 2007-020 (66 projects)

- Anadarko
- ATP
- BHP
- BP
- ChevronTexaco
- ConocoPhillips
- Dominion
- ENI
- ExxonMobil
- Hydro (Statoil)

Kerr McGee
LLOG
Murphy
Noble
Petrobras
Pioneer
Shell
Total
Walter

- ALL of the above except Pioneer (its last project was in 2004) tap into GOMOS

- About two dozen other smaller operators and independents operating in deep and shallow waters

Critical Issues

- Not all 3G wave models yield the same skill
- Uncertainty on ocean response to "MPI" hurricanes
- Wind fields produced by mesoscale NWP models (MM5, WRF …) "not quite ready for prime time"
- Coupled meso-scale ocean-atmosphere models yielding interesting process knowledge (e.g. variation of effective drag with intensity and azimuth)
- Hindcasts of current response not as skilful as waves

  especially in deep water and in eddies/loop current
- Accurate *in situ* pbl inner core wind data still rare

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