Tropical Cyclone Atmospheric Forcing[1] for Ocean Response Models: Approaches and Issues

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DEFINITION:

[1]Specification of time and space evolution of the hurricane marine boundary layer wind field (and surface stress) and sea level atmospheric pressure field (for HD models only)

Motivation

Explore response of ocean wave and surge models with proven performance in tropical cyclone regimes to alternative quality wind fields (we have come a long way since SWAMP 1980, Chapter 6)

In storms well monitored by aircraft, radar, satellite and in-situ data, (as in NATL) do alternative dynamical and kinematic wind analysis methods exhibit significant differences in specification of inner core wind intensity and structure – study gives optimistic result vs other basins

What are critical remaining issues in specification of atmospheric forcing for tropical cyclones

Set up this session!

Thanks Andy, Mark, Peter, Chris, Greg, Shuyi (And Tom)

Methodology

Adapt OWI3G wave model and ADCIRC HD model to Gulf of Mexico

Drive with five alternative high resolution wind fields of Hurricane Katrina (2005) developed by dynamical, kinematic and blended approaches

Compare envelope solutions of peak winds, waves and coastal surge, assess skill and high frequency variability

Validate alternative wave hindcasts against measurements at NDBC buoys

Talk up issues!

Conclusions

All wind fields tested adequate for most practical applications but critical issues remain for design criteria

Alternative reanalyzed wind fields exhibited greater differences offshore than on the shelf

All methods suffer from lack of high quality in-situ measured winds in cyclone inner core of intense.

One indirect estimate of surface wind (e.g. reduced aircraft winds) is often used to tune transformation of another indirect method (e.g. SFMR).

Where reconn data not available recent studies report sophisticated uses of satellite data (Vis, IR, Active and Passive Microwave) to estimate storm intensity and structure in aid of all cyclone analysis methods (see paper).

Full 3D NWP forecasting models (e.g. WRF, MM5,GFDL….) may emerge as soon powerful hindcasting ("reanalysis") tools but much more work needed.

Approaches to Surface Wind Analysis

Parametric radial wind profile

e.g Myers-Malkin, HP, SLOSH, Holland, Cooper, Toro…

Dynamical approaches

Steady state: Chow(1971); Cardone, Greenwood and Greenwood, (1978), Thompson & Cardone, 1996 (TC96); Shapiro (1983), Vickery et al., 2000
Non-steady: GFDL, MM5, COAMPS, WRF….

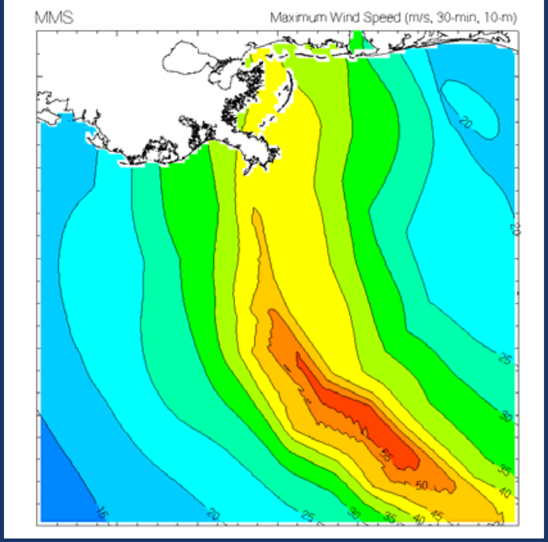
Kinematic approaches

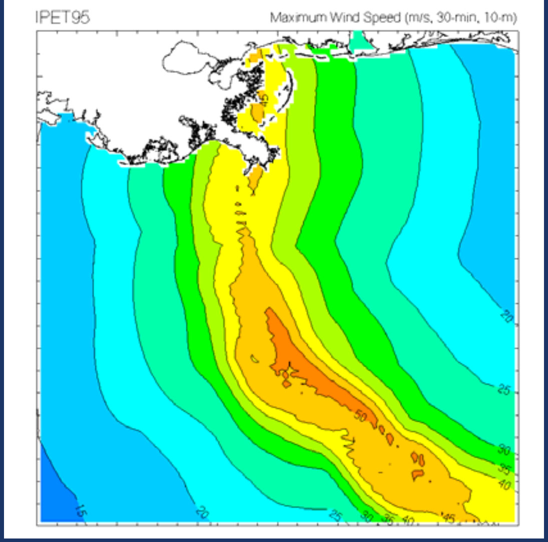
OWI IOKA: Cardone, Greenwood, Cox….
NHRD - HWnd Powell

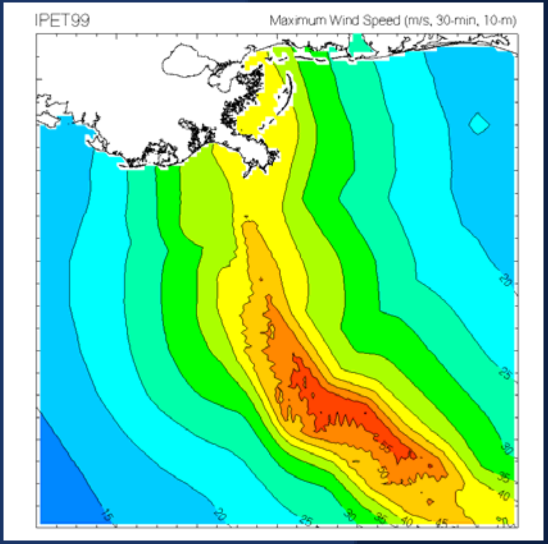
Blend

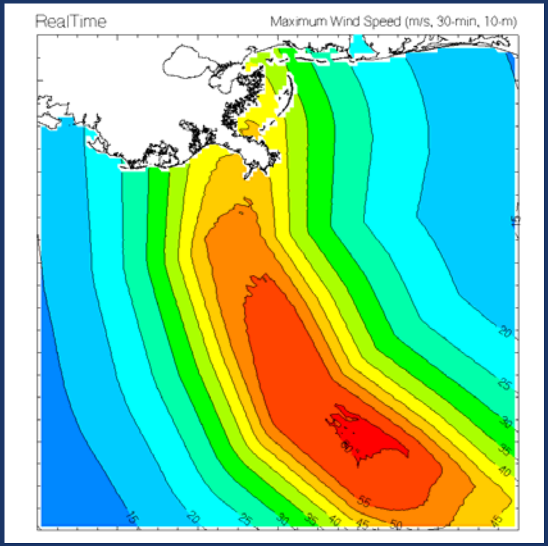
e.g. assimilate HWnd into PBL solution using IOKA

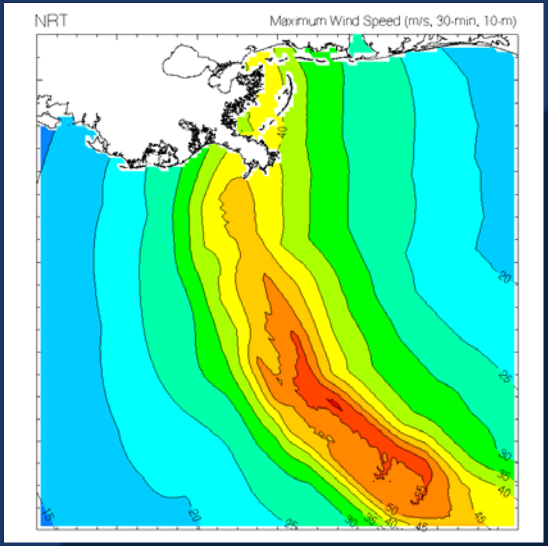
Maximum Wind Speed (m/s)



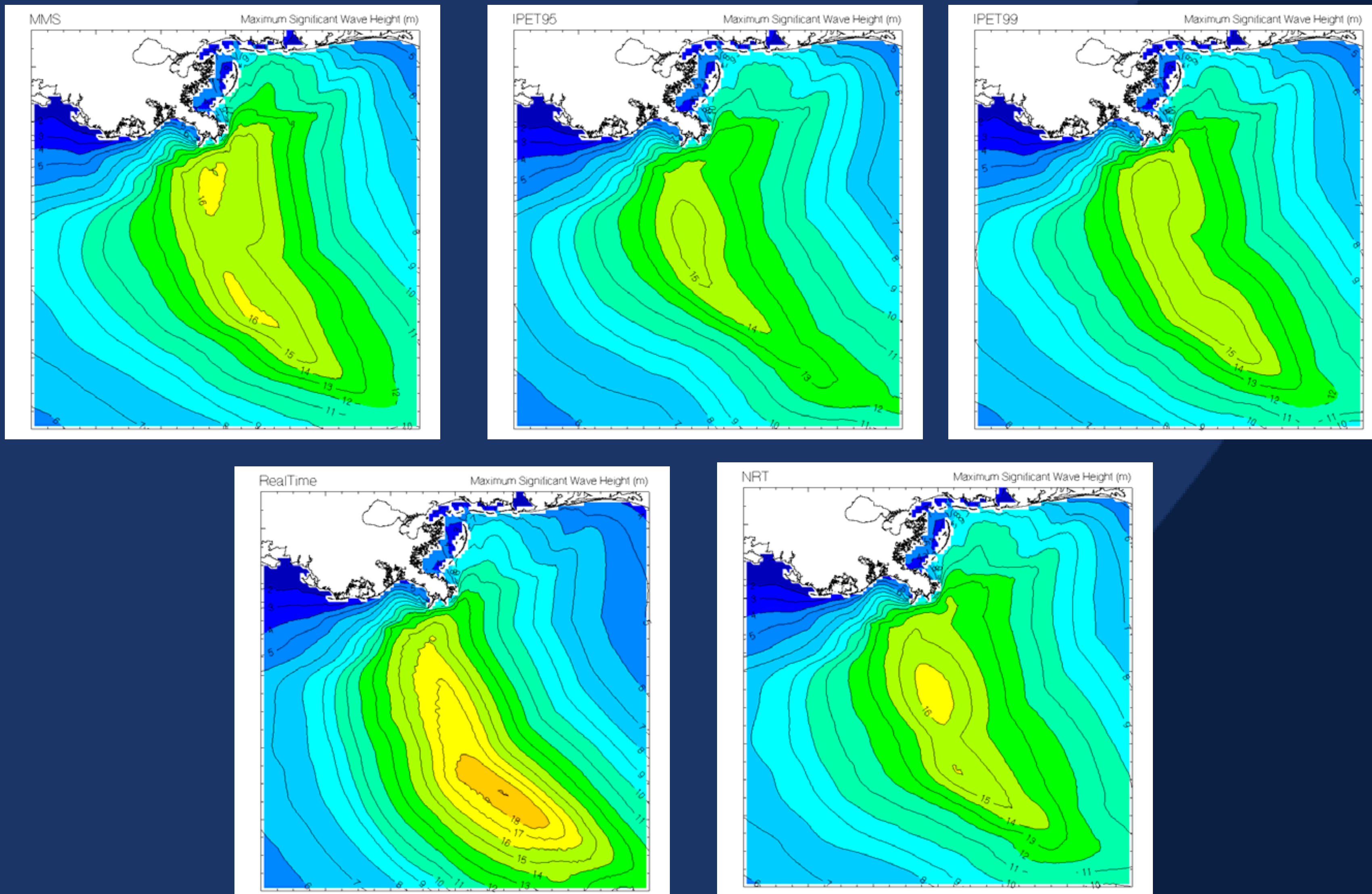




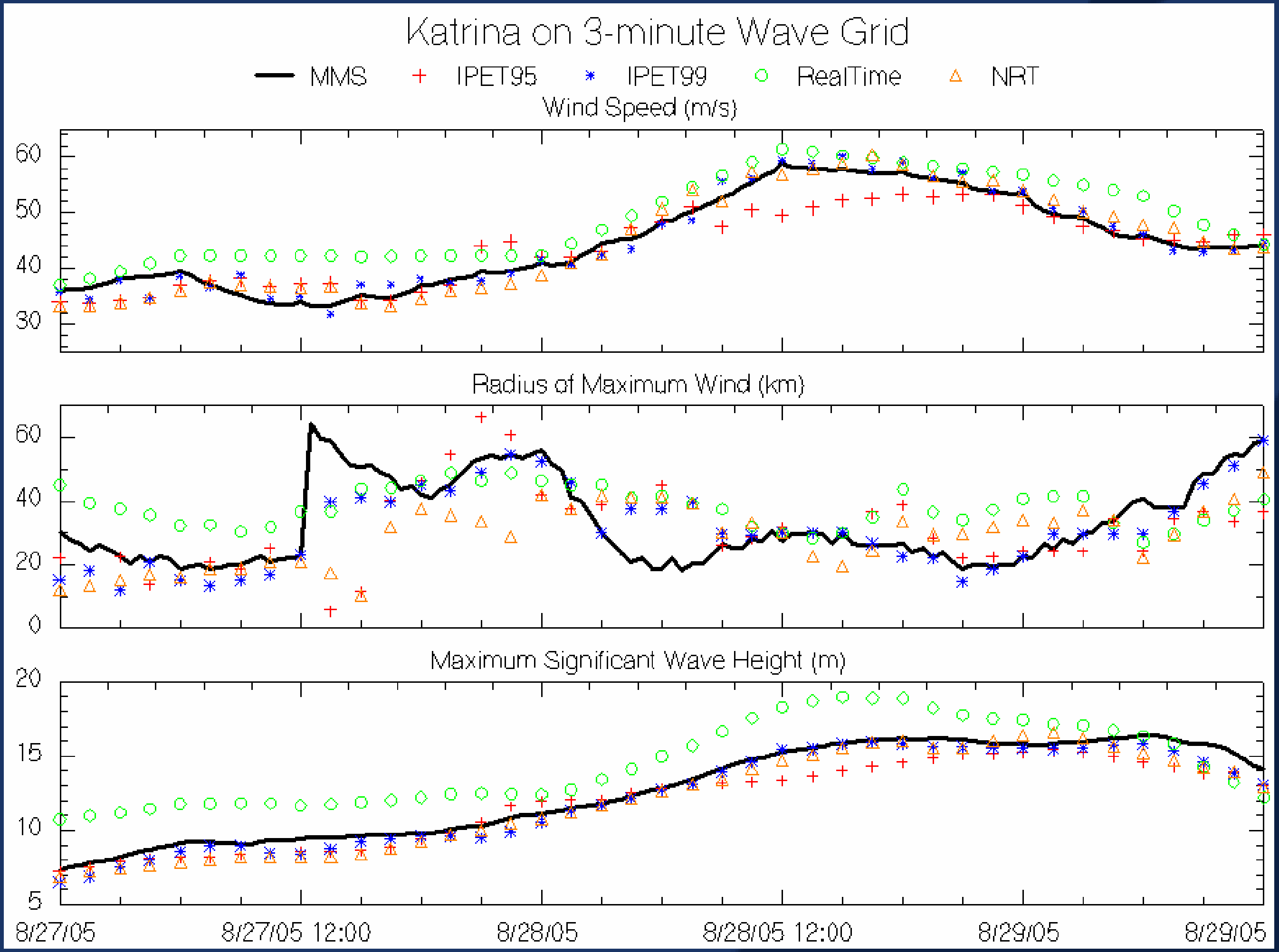




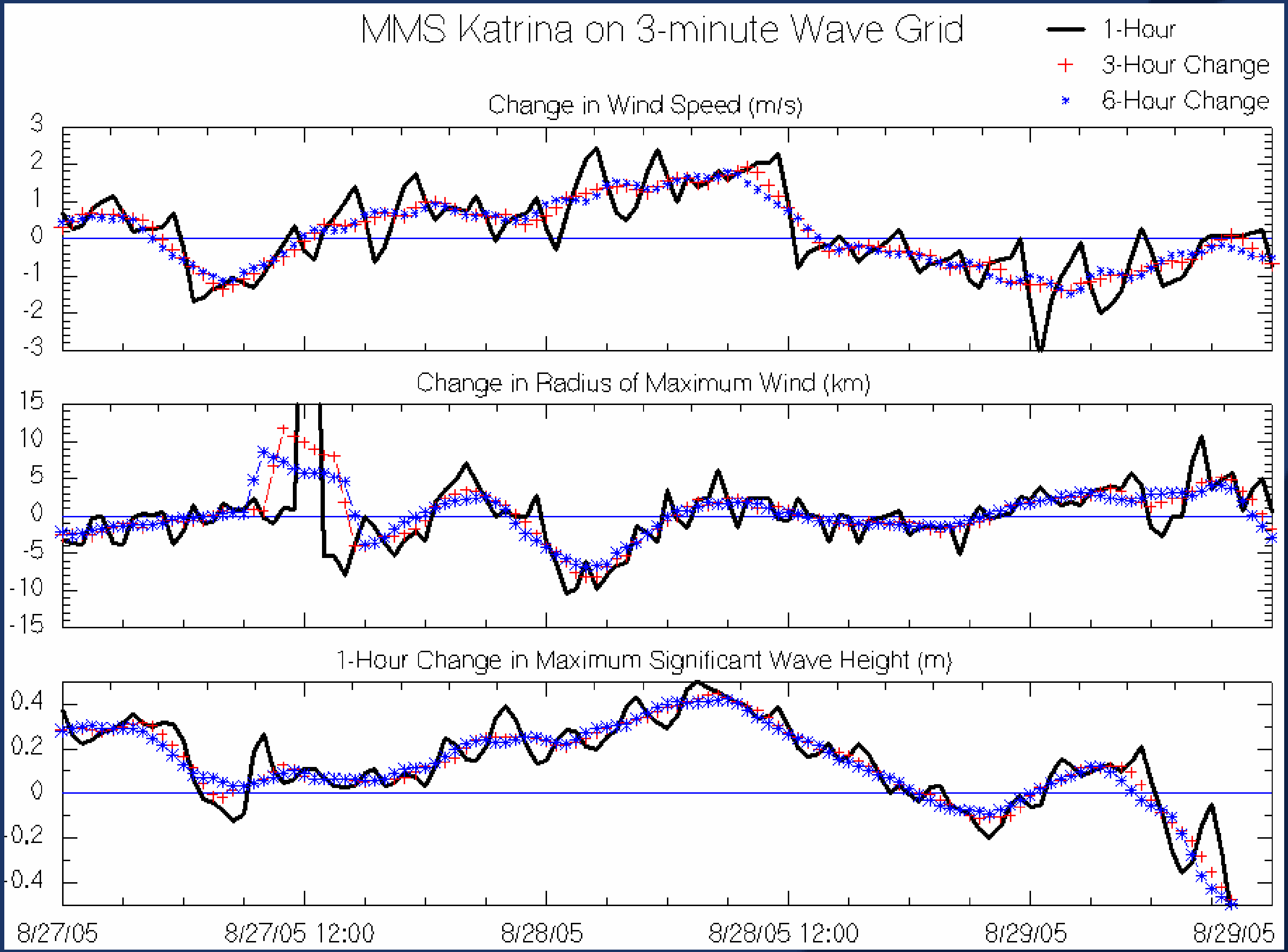
Maximum Significant Wave Height (m)



Time History of Wind and Wave Parameters

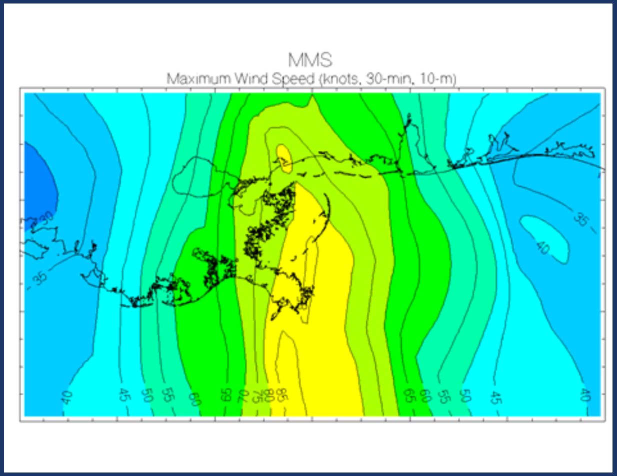


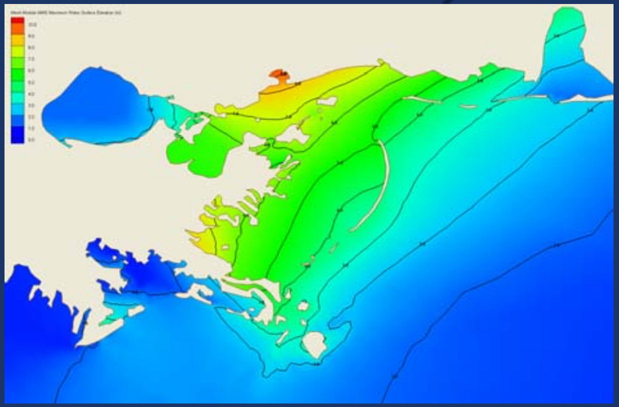
Change in Wind/Wave Parameters

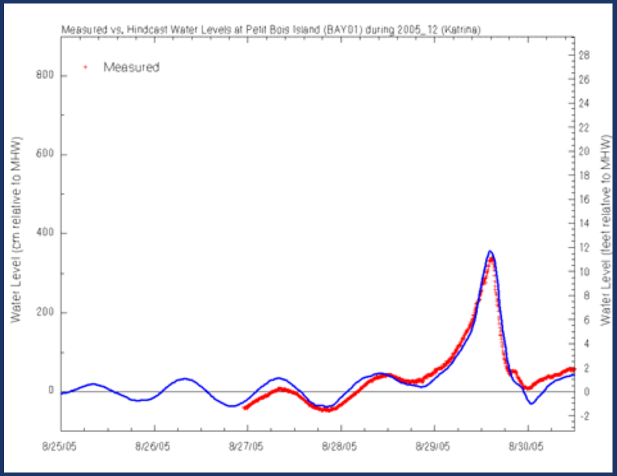


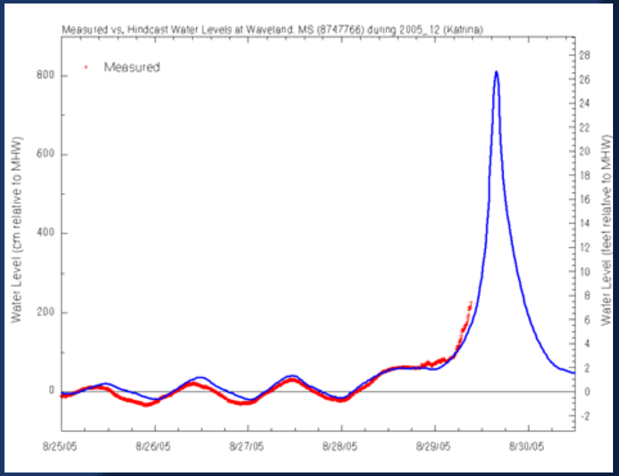
Results for MMS Wind – "Best"

peak surge at coast within 5%









See Cardone and Cox (2007)

JCOMM Seoul Storm Surge Symposium

25 years of wind/wave modeling expertise
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WHAT ARE THE MAIN ISSUES

STEADY STATE PBL APPROACH

- ***physics –mainly surface roughness parameterization***
- ***initialization – simple Holland type profile insufficient***
- ***lack of in-situ measured data for calibration/validation***

KINEMATIC APPROACHES

- ***transformation of wind data from moving sensors and satellites into optimum Eulerian representation***
- ***optimization of analysis spatial scale filter***
- ***homogenization of archive over historical period of record***
- ***lack of in-situ measured data for calibration/validation***

3D MODELS (COUPLED OR UNCOUPLED)

- ***for hindcasts, constrain solution to move storm along correct track***
- ***data assimilation***
- ***can you have too much physics and resolution?***
- ***lack of in-situ measured data for calibration/validation***

PBL - TC96 Based on Chow (1971) NYU MS

A moving Cartesian coordinate system (x, y) is now defined such that its origin always coincides with the moving low center of p_c. In terms of the moving system, (6) is transformed into

$$\frac{d\mathbf{V}}{dt} + f\mathbf{K} \times (\mathbf{V} - \mathbf{V}_g)$$

$$= -\frac{1}{\rho} \nabla p_c + \nabla \cdot (K_H \nabla \mathbf{V}) - \frac{C_D}{h} |\mathbf{V} + \mathbf{V}_c| (\mathbf{V} + \mathbf{V}_c) \qquad (7)$$

where $\mathbf{V}$ = horizontal wind velocity relative to the low center; $= \hat{\mathbf{V}} - \mathbf{V}_c$; $\mathbf{V}_g$ = effective geostrophic flow relative to the low center; $= \hat{\mathbf{V}}_g - \mathbf{V}_c$; and $\mathbf{V}_c$ = velocity of the moving reference system relative to the fixed earth

$$\frac{d}{dt} = \left(\frac{\partial}{\partial t}\right)_c + \mathbf{V} \cdot \nabla$$

where $(\partial/\partial t)_c$ = time derivative local to the moving coordinate system

$$= \frac{\partial}{\partial t} + \mathbf{V}_c \cdot \nabla$$

Eq. (7) can be expanded from vector form into equations involving the scalar components of horizontal velocity. After some rearranging of terms, the equations to be solved are

$$\frac{\partial u}{\partial t} = fv - \left(u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y}\right) - P_u + H_u - F_u \qquad (8)$$

$$\frac{\partial v}{\partial t} = -fu - \left(u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y}\right) - P_v + H_v - F_v \qquad (9)$$

where u, v = x- and y-components of $\mathbf{V}$

zontally homogeneous and quasi-stationary.

A particularly convenient form of the parameterization, first proposed by Deardorff (1972) and updated by Arya (1977), expresses the PBL fluxes in terms of layer-averaged mean PBL properties. Parametric relations in this generalized theory may be written in the form

$$\frac{k\tilde{u}}{u_*} = -(\ln \hat{z}_o + A_m); \quad \frac{k\tilde{v}}{u_*} = -B_m \frac{f}{|f|} \qquad (13, 14)$$

$$\frac{k(\theta_v - \theta_o)}{\theta_*} = -(\ln \hat{z}_o + C_m) \qquad (15)$$

where $\tilde{u}$, $\tilde{v}$ = vertically integrated [as in (8) and (9)] horizontal wind components in the direction of the surface shear and perpendicular to it, respectively; u_* = friction velocity; θ_v = mean layer virtual potential temperature at desired elevation; $\hat{z}_o = z_o/h$, where z_o is the roughness length; k = von Karman's constant; θ_o = potential temperature at z_o; θ_* = potential temperature scale; A_m, B_m, C_m = universal functions of dimensionless similarity parameters; and $f/|f|$ = sign of f (+ or −).

The potential temperature scale is expressed in terms of the heat flux as

$$\theta_* = \frac{H}{\rho c_p u_*} \qquad (16)$$

where c_p = specific heat of air at constant pressure; and H = heat flux. The presence of boundary layer turbulence due to both shear and buoyancy leads to the Monin-Obukov length scale L, expressed in terms of θ_* and u_* as

$$L = \frac{-u_*^3 \theta_v \rho c_p}{kgH} = \frac{-u_*^2 \theta_v}{kg\theta_*} \qquad (17)$$

TC96 Physics and Initialization

Parameterizations

Kh – horizontal eddy diffusivity

Kv - expressed in term of Cm – drag coefficient w/s/t to mean pbl Ws/Wd

Zo – deep water, shallow water

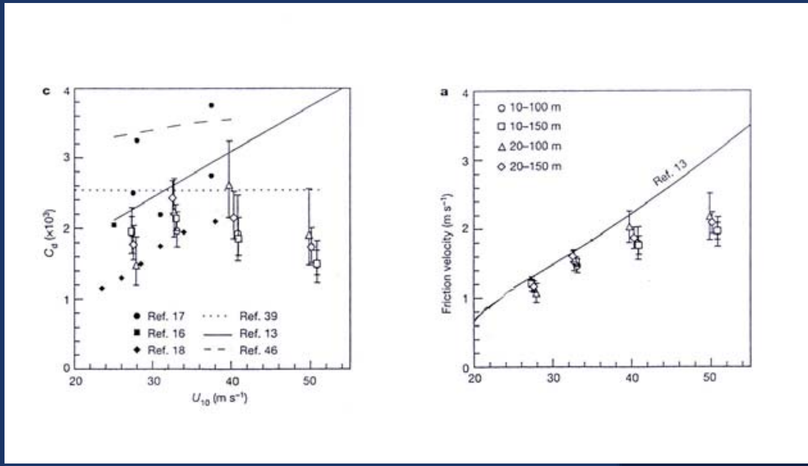
Am, Bm, Cm – from Arya/Deardoff mean layered PBL parameterization

Initialization

Po	central	Vg	ambient flow , uniform?
Rp	scale radius	Vf	storm motion
B	peakedness parameter		azimuthal variability of B, Pfar
Pfar	far field pressure		temporal variability of Po, Rp, B, Pfar, H
H	PBL depth		stratification

Fig.3a, 3c below from Powell et al. (Nature, 2003)
Supporting evidence from more recent wind profile data (“top-down approach”) and and “bottom-up” estimates of Jarosz et al. (Science, 2007)

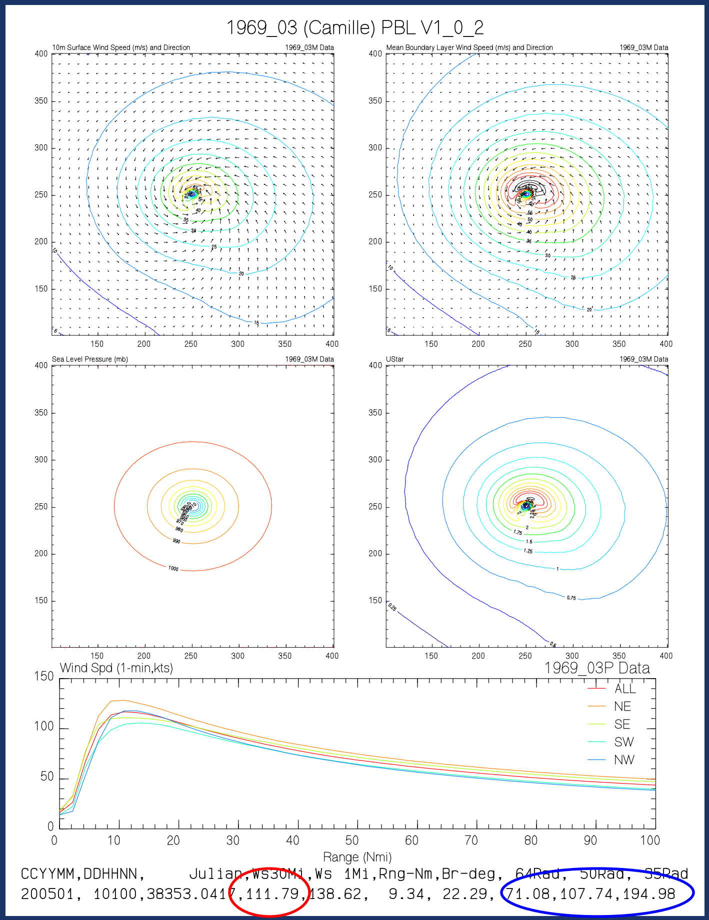
- ***Wave response: C10 cap already in OWI3G since 1992 and version of WAM4.5 used in the RSMAS NOPP program on hurricane forecasting (Graber et al, 2006)***
- ***But evidence that C10 decreases again >40 m/s and stress itself may be ultimately capped?***

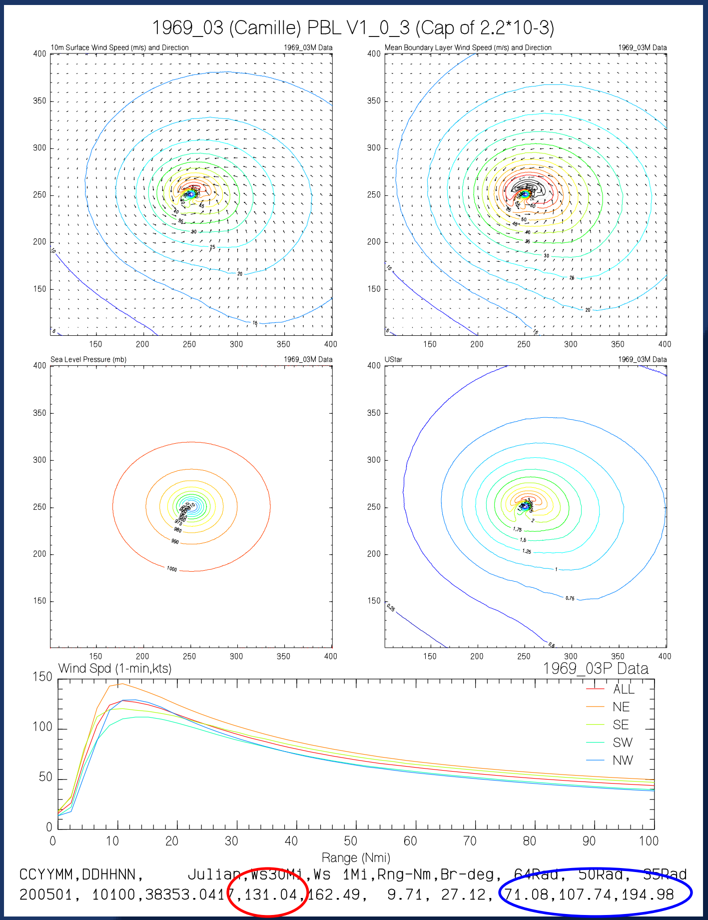


ISSUE: modeled inner core wind field for Cat 2or greater TCs very sensitive to drag law

See Powell (2007) this session

SAMPLE RESULTS from TC96 FROM NUMERICAL EXPERIMENTS WITH C10 CAP



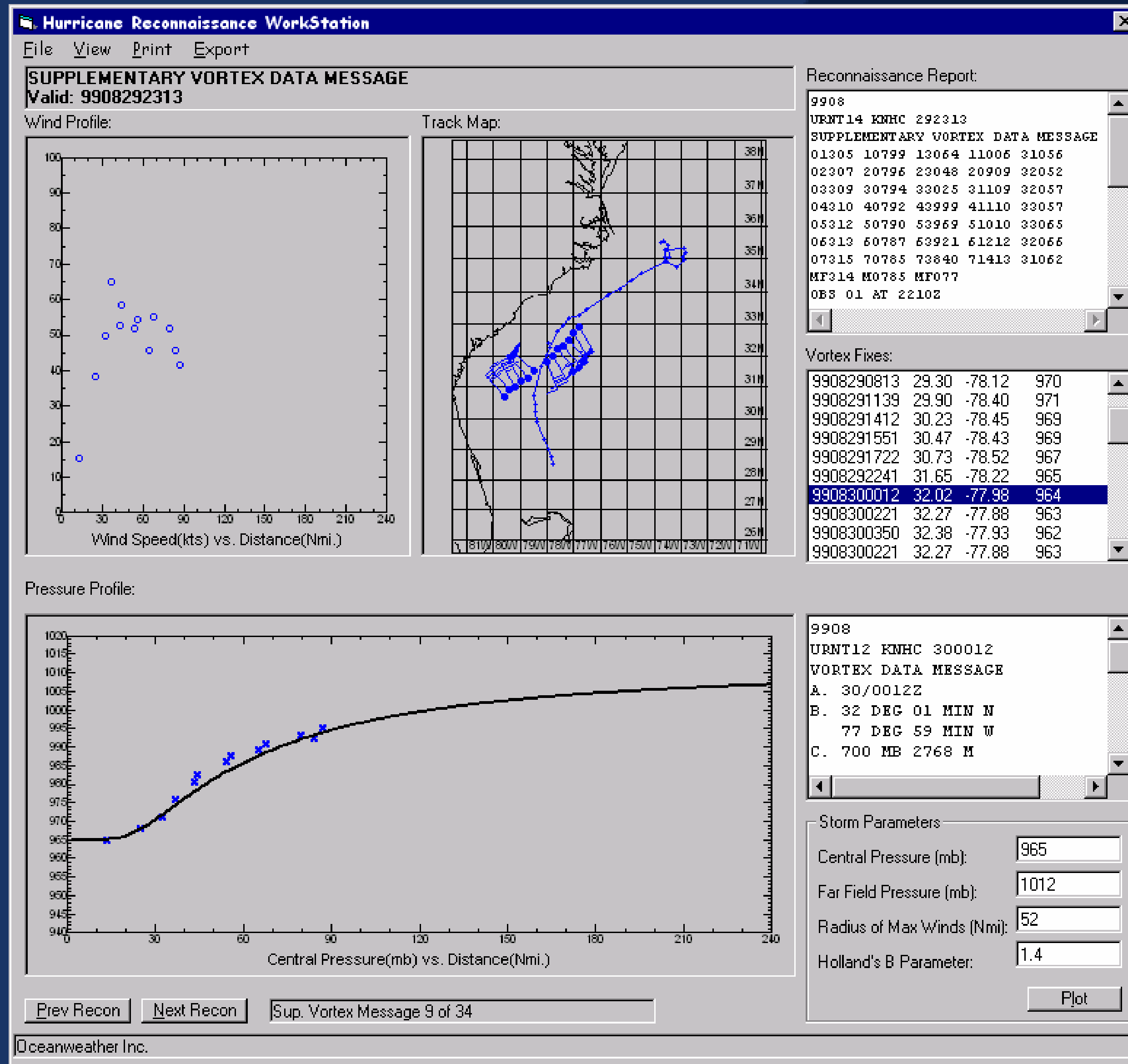


ISSUE: Initialization of PBL

Many storms do not fit the simple single exponential representation of the radial pressure field (SEE Cox and Cardone (2007 this session for more)

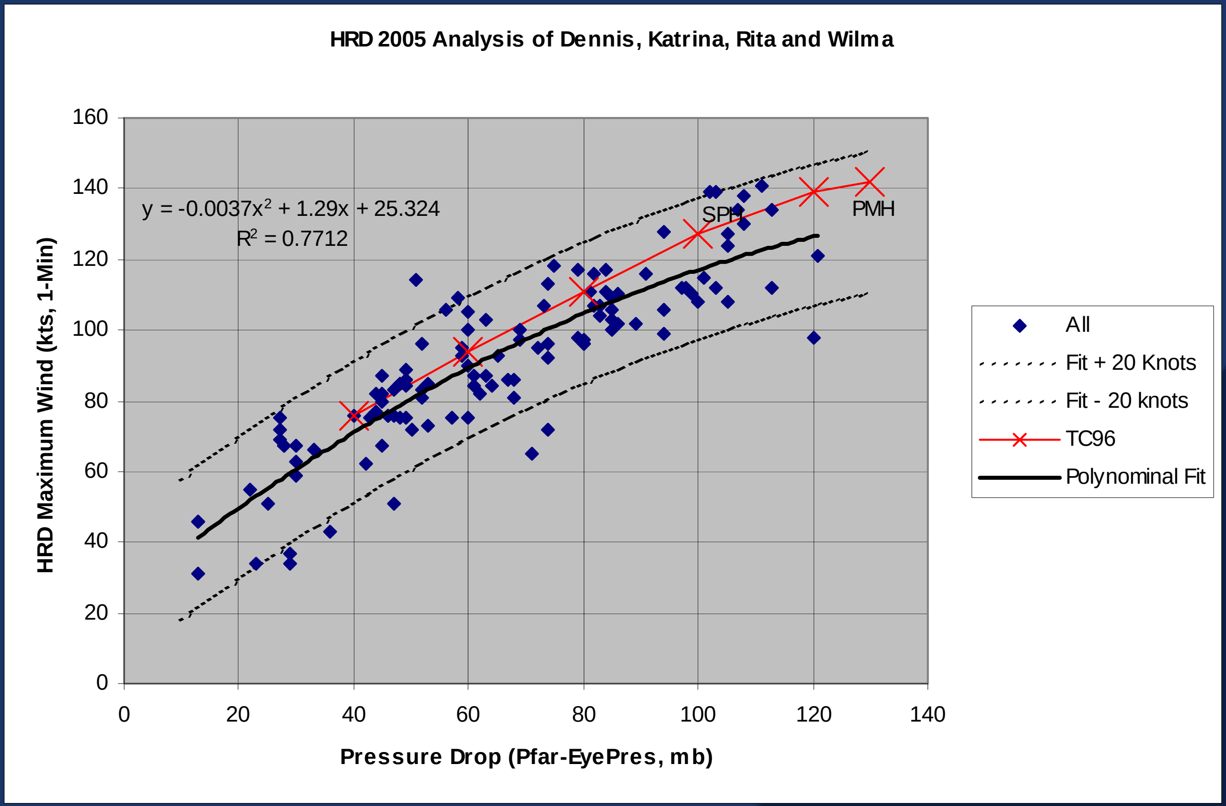
Pressure Profile Fit to Aircraft Data

$$p(r) = p_0 + \sum_{i=1}^{n} dp_i \, e^{-\left(\frac{Rpi}{r}\right)^{Bi}}$$



ISSUE: mean "growth curve" of model depends critically on mean synoptic climatological behavior of B – See Vickery (2007) this session

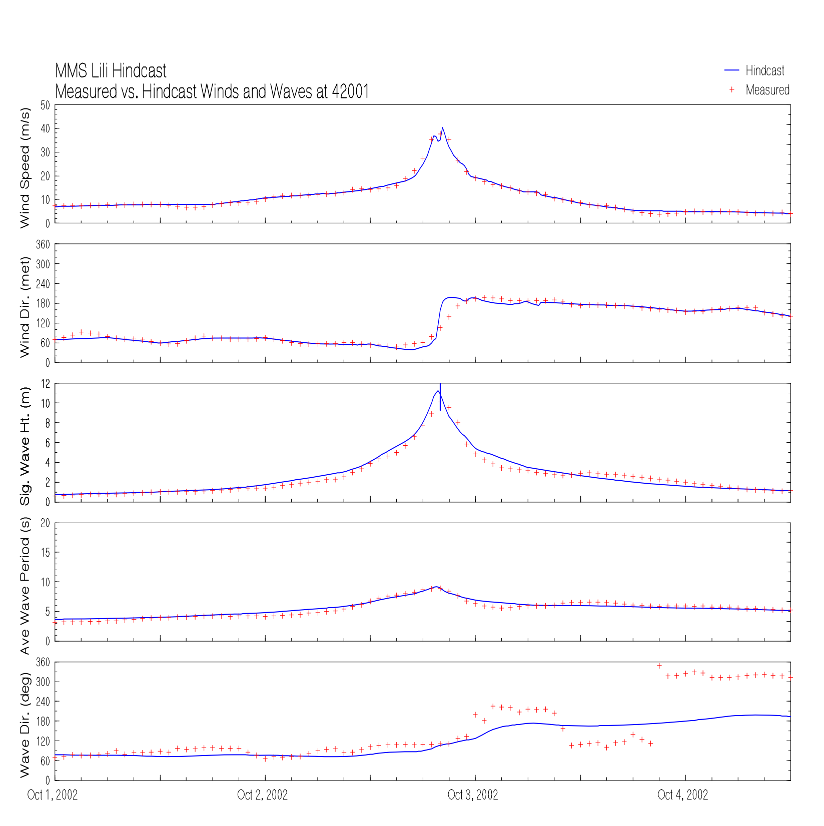
Plot below shows from library of HWnd snapshots produced for NHC between 1998 and 2006 peak snapshot wind speed peaks plotted versus Po in Katrina, Rita, Dennis, Wilma and Po vs Vmax mean prediction of TC96 with simple inversely modeled B (red line) vs polynomial fit to data points



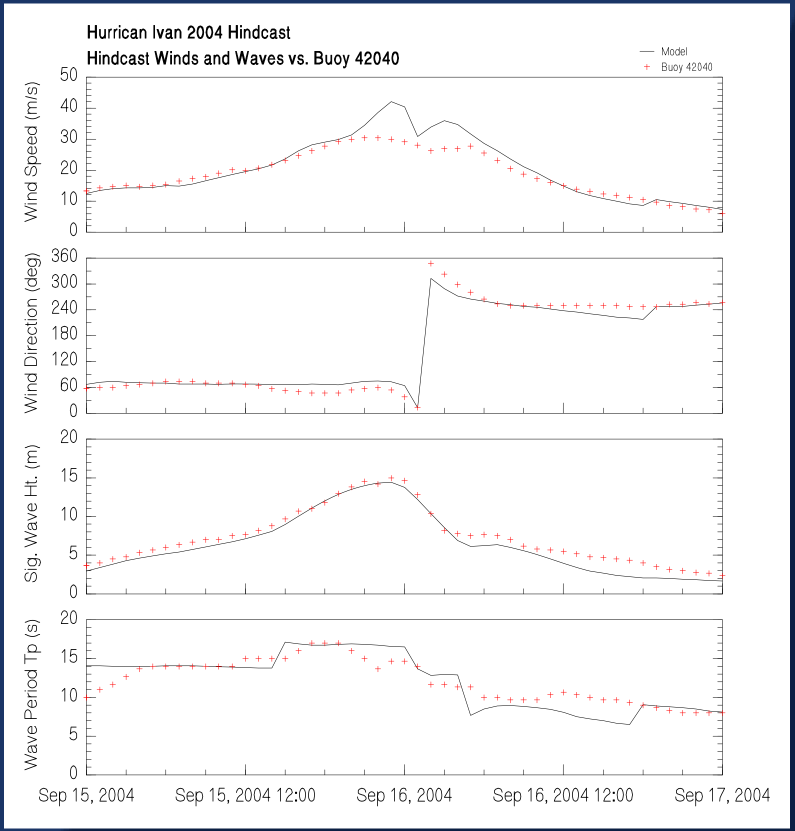
ISSUE: lack of in-situ turbulence filtered Eulerian frame validation wind data

- ***Well initialized model solutions tend to agree with NDBC 10-meter discus buoy winds in inner core, but not with 3-meter buoy winds in high sea states (effect seems to kick in at HS>8 m and WS > 30 m/s) as exemplified below:***

Left: Lili hindcast at 42001



Right: Ivan hindcast at 42040



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ISSUE: how to get high quality in-situ Eulerian winds in inner core

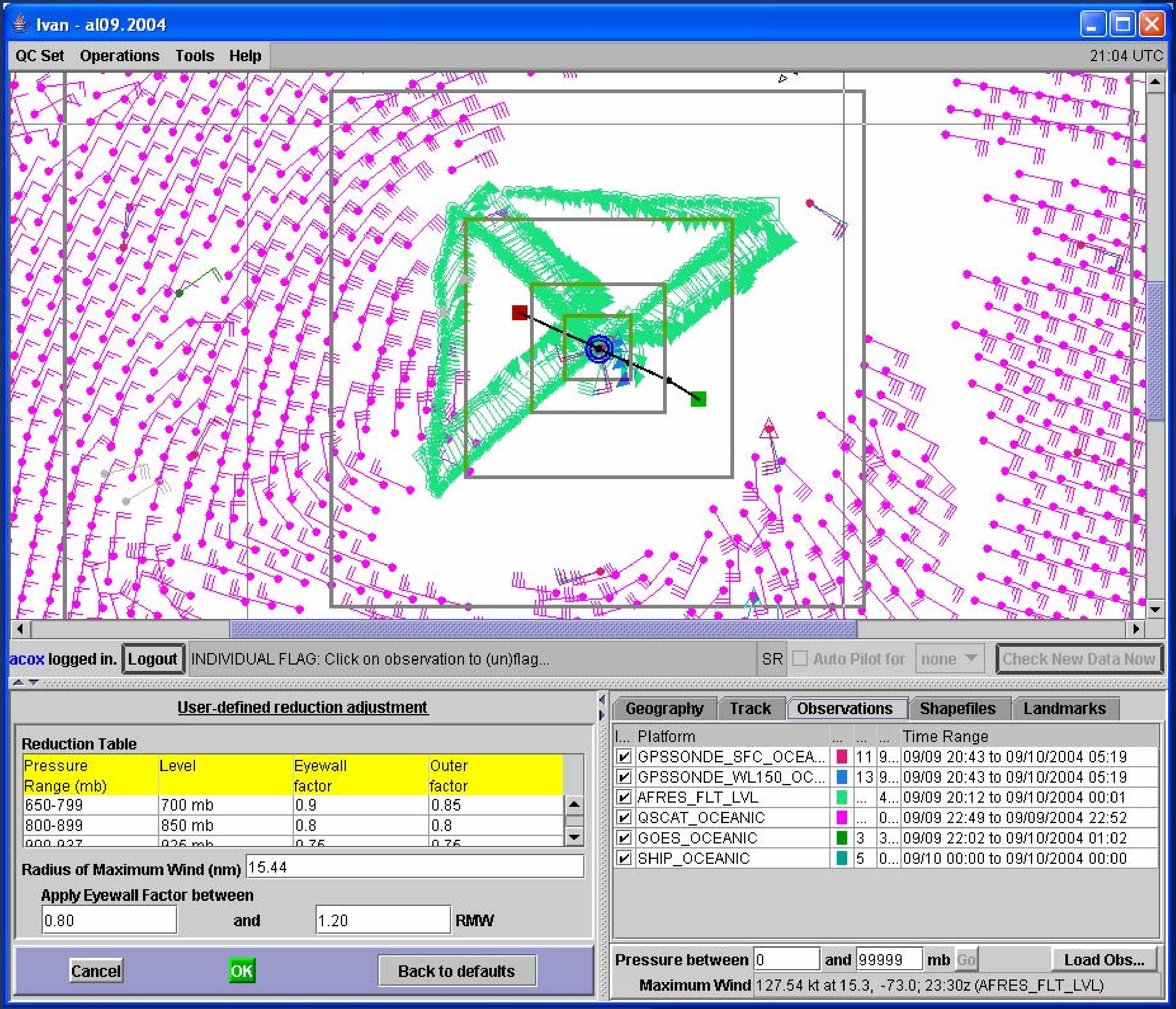
KORDI TOWER – Korea

WIND FARM TOWER

TOP OF DRILLING DERRICK

NDBC – Back to 10-Discus
(Image courtesy NDBC)

KINEMATIC APPROACH: NOAA NHRD HWnd (Powell et al, 1998)



ISSUE: Aircraft flight level winds and GPS dropwindsonde are moving point sensors and conversion to peak 1-minute sustained wind is problematic

GPS Drops Mean Profiles
Franklin et al. (2003)

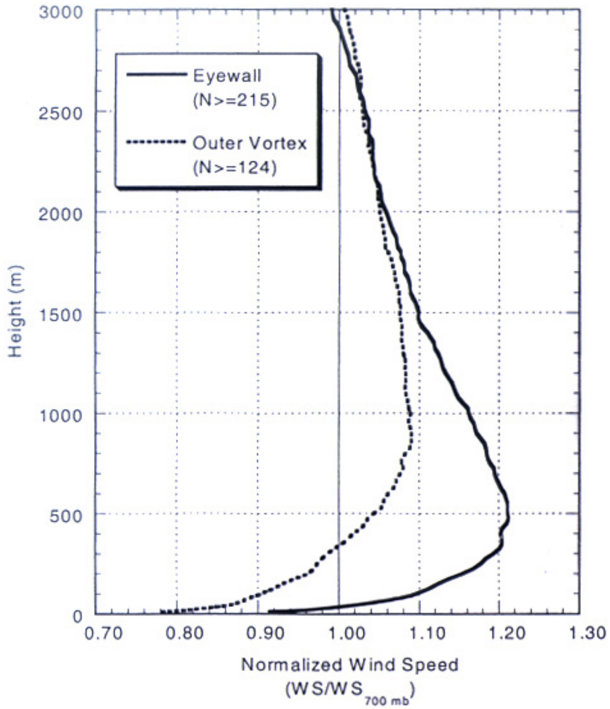


FIG. 8. Mean hurricane wind speed profiles for the eyewall and outer-vortex regions. Wind speeds are averaged and expressed as a fraction of the profile wind speed at 700 hPa. The minimum number of profiles used to construct the averages is also indicated.

TABLE 2. Recommended operational wind adjustment factors for adjusting reconnaissance flight-level winds to the surface, for the hurricane-eyewall and outer-vortex regions.

Flight level	Eyewall	Outer vortex (convection)	Outer vortex (not in convection)
700 hPa	0.90	0.85	0.80
850 hPa	0.80	0.80	0.75
925 hPa	0.75	0.75	0.75
1000 ft (305 m)	0.80	0.80	0.80

Mean Profiles for Individual Hurricanes

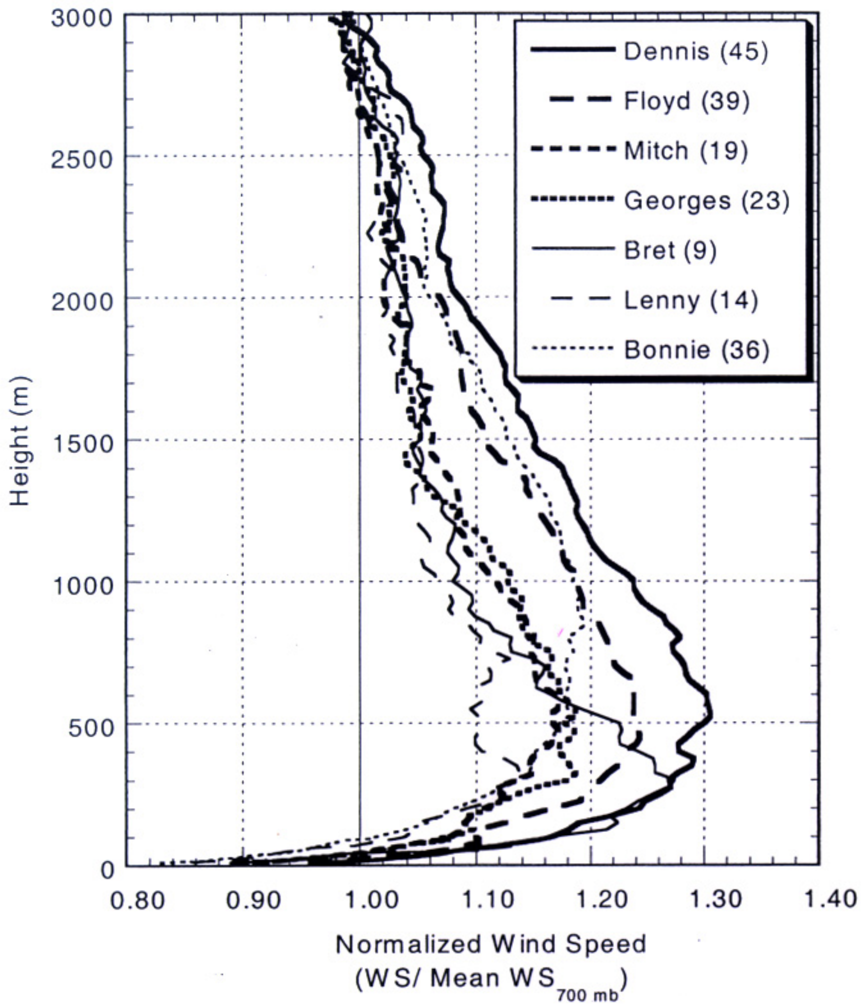


FIG. 11. Mean eyewall wind speed profiles for individual hurricanes. All winds are averaged and are expressed as a percentage of the profile 700-hPa wind speed. The number of soundings used to construct the mean profile for each storm is given in parentheses in the figure legend.

ISSUE: SFMR is a moving point area-average wind remote sensor and GMF and conversion to peak 1-minute sustained wind is problematic
SEE Cox and Cardone (2007) and Powell (2007) this session

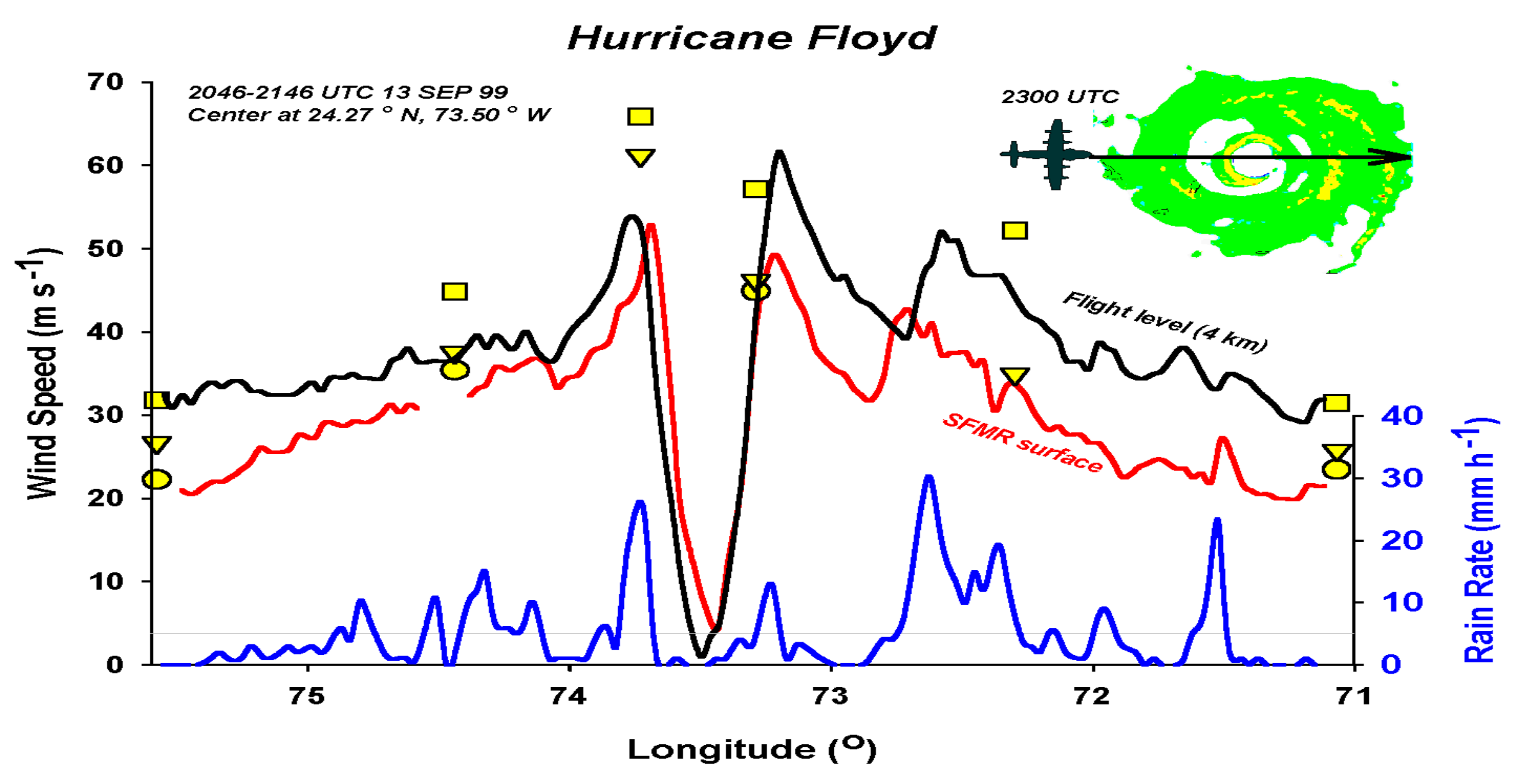


Image courtesy of HRD

ISSUE: Wind speed transformations have evolved over time; historical archive of HWnd analyses do not form a homogeneous historical database

Hurricane Katrina Data from NOAA HRD

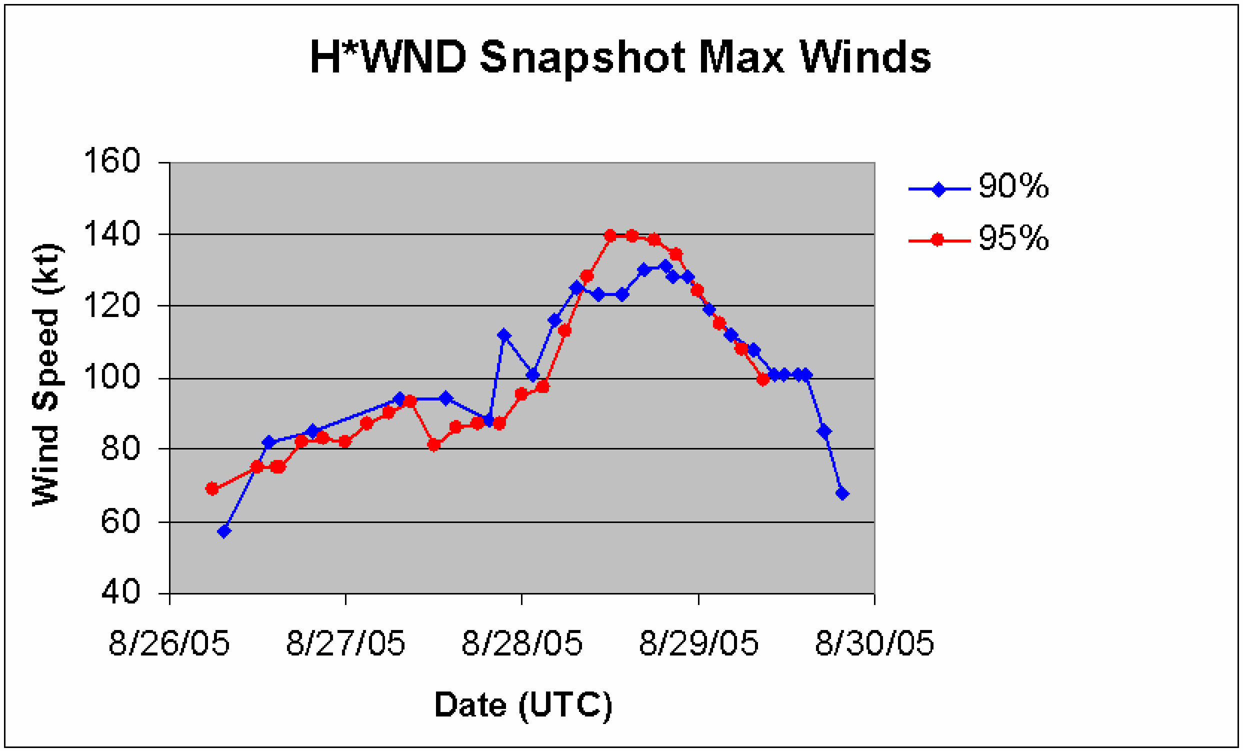
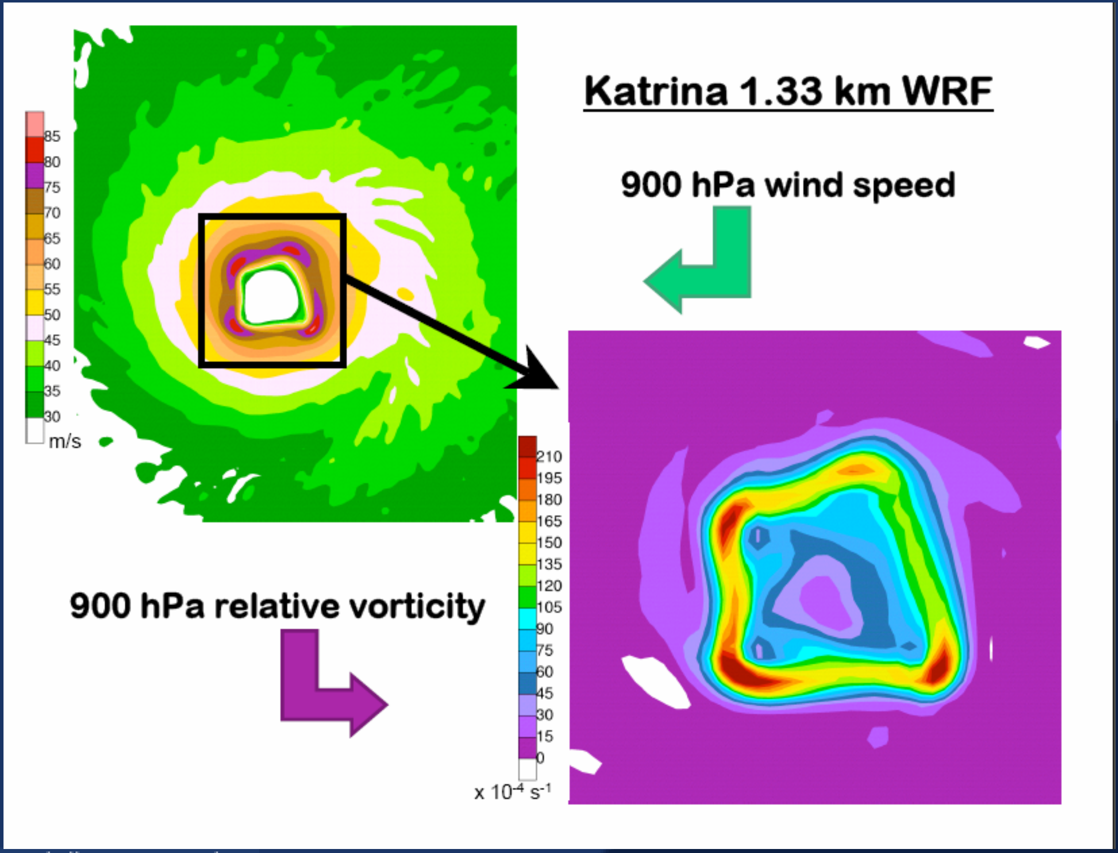


Image courtesy Jeff Hanson

3 D NWP MODELS –WRF, GFDL, WRF

- ***ISSUE: Normally used in predictive mode mainly to forecast storm track and general intensity. Relaxation of steady state, hydrostatic assumption, very high resolution and coupling with sea surface produces interesting and detailed solutions – but are they realistic – see below from Corbiosco et al. (2007)***

- ***SEE: Chen (2007), Davis and Holland (2007), Knutson (2007) this session.***



Way Forward As We See It

1. Stabilize PBL and Kinematic methods, develop an assimilative 3D model analysis approach and apply to "Reanalysis"

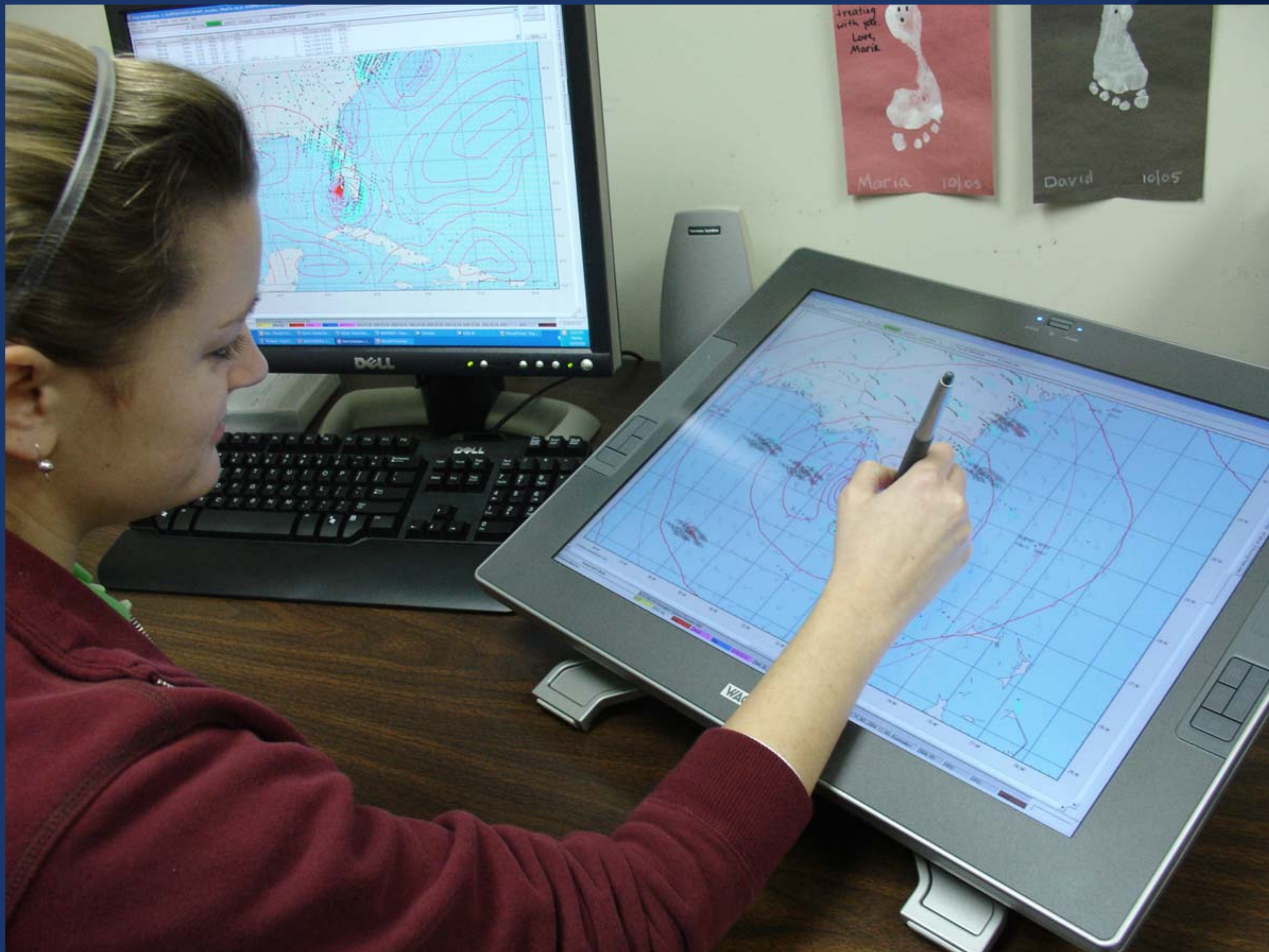
2. Fully rescue, process to digital form and homogenous historical met data, apply new toolbox for PBL initialization and validation of Kinema and homogenized HWnd with that database to all late 19th and 20th century storms

3. Build a library of NATL and WPAC TC surface wind and pressure fields to replace HURDAT and JTWC for use in hindcast, deductive, JPM, synthetic storm etc approaches to development of design criteria and coastal hazard mapping

3. The library will serve to guide application of coupled 3D models to reanalysis

4. Too bad all of the above not available yet for the fine emergency post Katrina hazard assessment studies reported here, but together with ocean response physics advances and climate variability:

THESE STUDIES SHOULD BE REPEATED AT REGULAR INTERVALS!


Love,
Maria
Maria 10/05
David 10/05
DELL
DELL