CBLAST (Coupled Boundary Layer Air-Sea Transfer)
ITOP (Impact of Typhoon on Ocean in Pacific)

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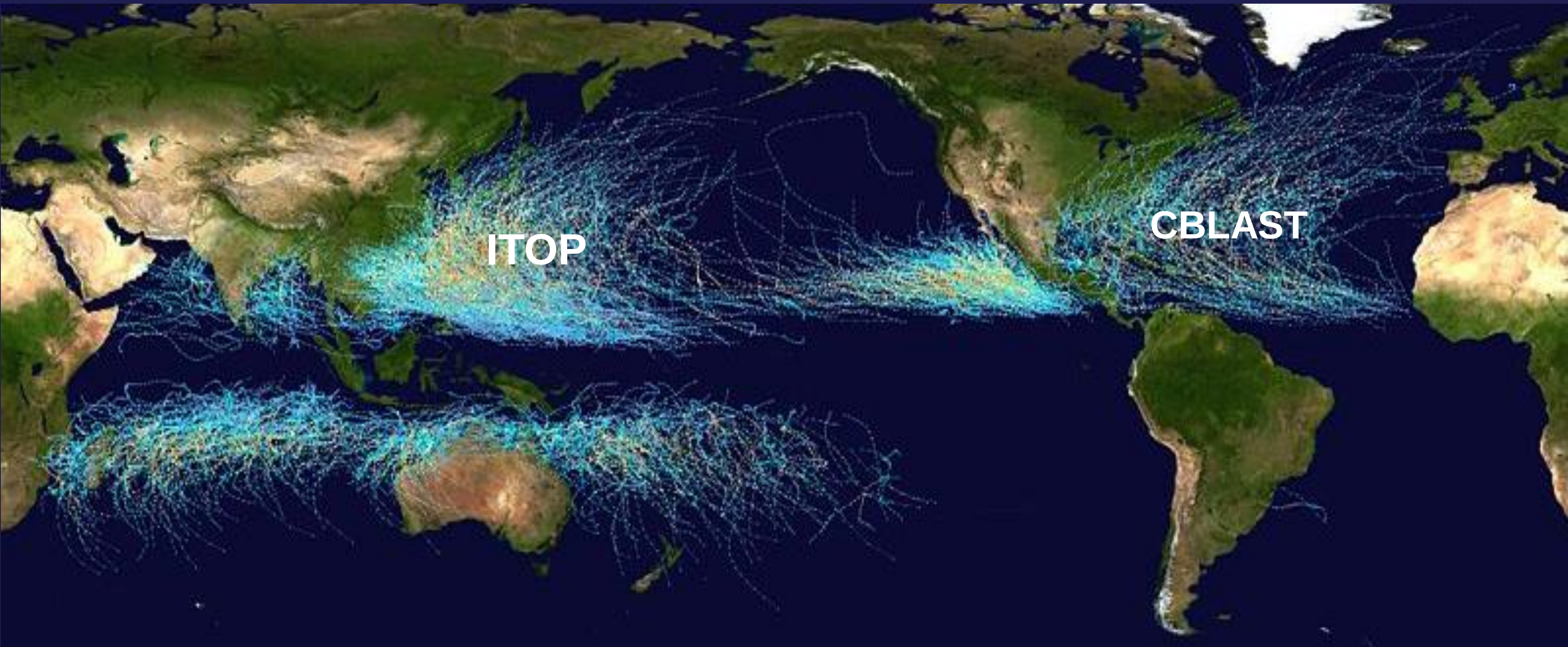
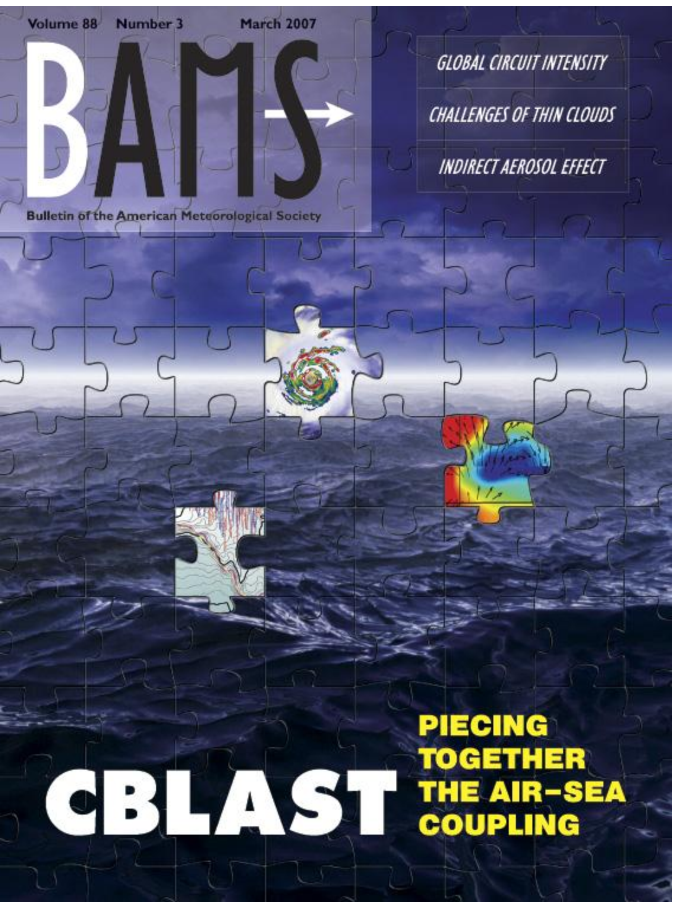


- **A goal of CBLAST is to better understand how hurricanes interact with the ocean and to improve hurricane forecast models.**

- **Through CBLAST we have improved our knowledge about the processes that fuel hurricanes (heat from the ocean) and the frictional forces (drag on the sea surface) that mix the ocean and result in extreme ocean waves.**

- **Objectives: Atmosphere-Wave-Ocean coupling, effects of sea spray, etc.**



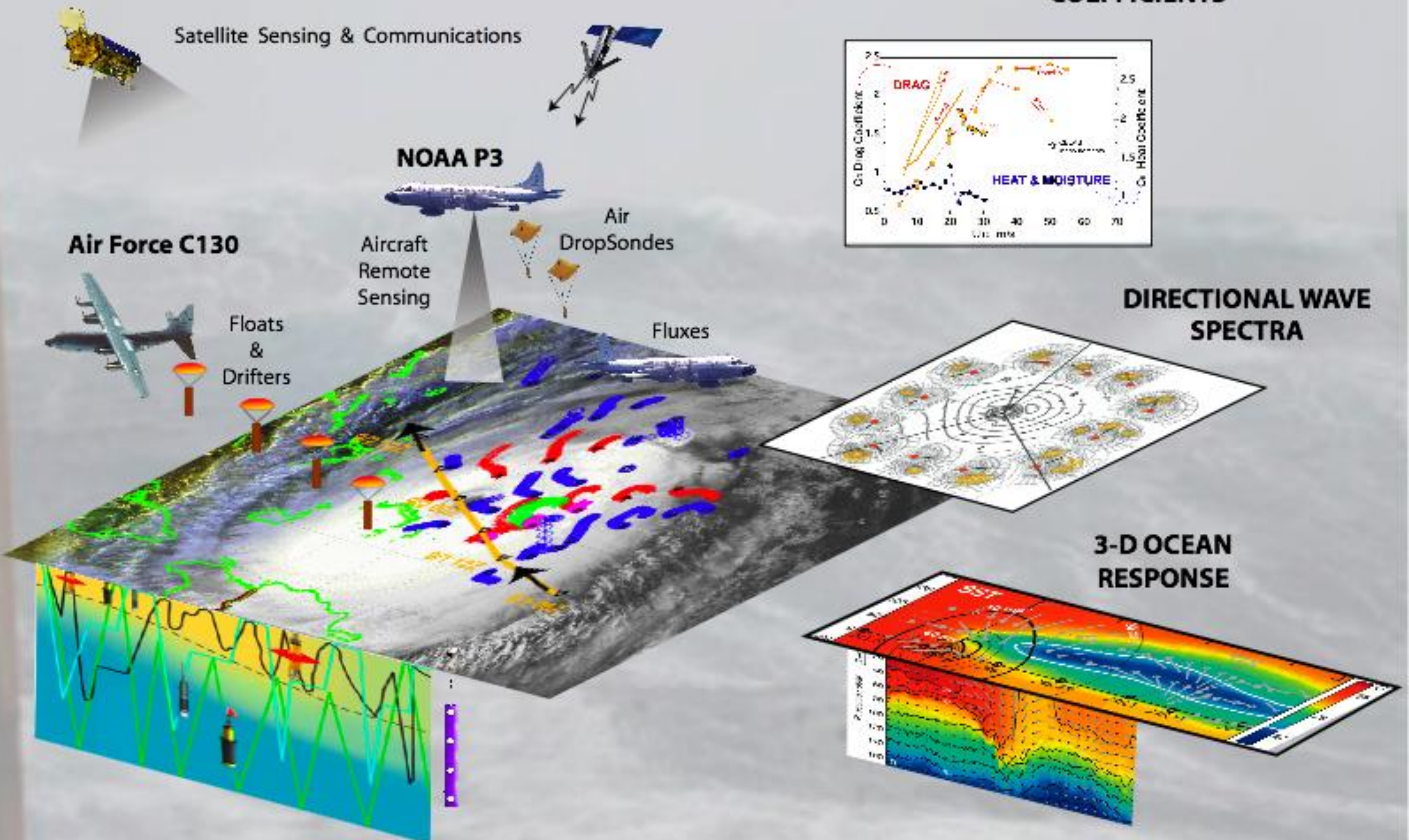
<u>BAMS issue on CBLAST:</u>

Chen et al. 2007**:** The CBLAST-Hurricane Program and the next-generation fully coupled atmosphere-wave-ocean models for hurricane research and prediction. *BAMS, 311-317*.

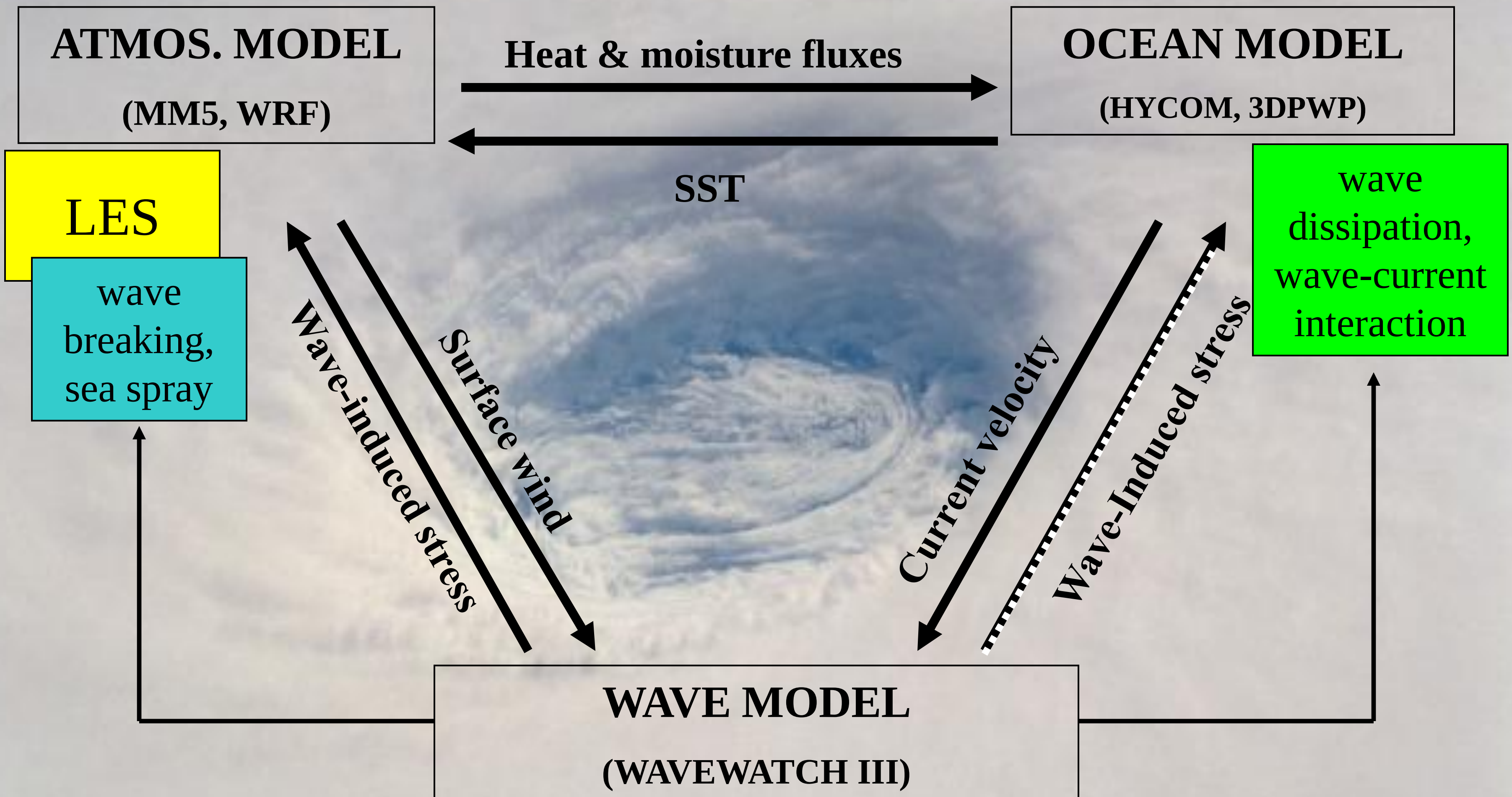
Black et al. 2007**:** Air-Sea Exchange in Hurricanes: Synthesis of Observations from the Coupled Boundary Layer Air-Sea Transfer Experiment, *BAMS*, 357-374.

Edson et al. 2007**:** The Coupled Boundary Layers and Air-Sea Transfer Experiment in Low Winds (CBLAST-LOW). *BAMS, 346*-356.

CBLAST 2003-2004 Hurricanes
Measurements and Results



Coupled Atmosphere-Wave-Ocean Modeling System for Hurricane Predictions



Wind-Wave Coupler: wave model spectra+spectral tail, wave-induced stress, wave dissipation

Uncoupled Atmosphere Model

Charnock Relationship: $z_o = \alpha\, u_*/g$

Coupled Atmosphere-Wave Model

- **Roughness Length (non-directional)**

$$\tau = \tau_t + \tau_w \longrightarrow z_o$$

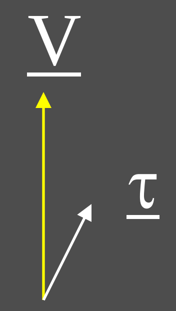
(e.g., Janssen at ECMWF)

z_o - wave-age dependent

- **Stress Vector (directional)**

$$M_x = -\tau_x$$

$$M_y = -\tau_y$$



τ_x , τ_y - components of stress from integral of momentum input to the wave spectrum.

Wind-Wave Coupling Parameterization (Chen et al. 2009a)

Wave-induced stress (WW3 spectrum + spectral tail):

$$\tau_x = g\rho_w \int_0^{\infty}\int_{-\pi}^{\pi} \frac{\gamma}{\omega} F(k,\vartheta) k_x k\, dk\, d\vartheta$$

X-component of stress from integral of momentum input to the spectrum:

$$\frac{\gamma}{\omega} = S\frac{\rho_a}{\rho_w}\left[\frac{U_{(\pi/k)}\cos\theta}{C(k)} - 1\right] \cdot \left|\frac{U_{(\pi/k)}\cos\theta}{C(k)} - 1\right|$$

Growth rate of each component from measurement of pressure-slope correlation (S-shelter coefficient, C-phase speed, U(π/k)-half wavelengh height wind speed)

$$F(k,\vartheta) = \alpha k^{-5} \sec h^2(\beta(\vartheta_k))$$

Spectrum of long waves from WAVEWATCH III (cutoff at $3f_p$); spectrum of short waves from fit to tail given below. α is adjusted to fit the highest modeled wavenumbers.

$$\beta = \frac{1.2}{\cos^{-1}(C/U)}; C/U < 0.9$$

β is the spreading function for the short waves.

Wind-Wave Coupling Parameterization (Chen et al. 2009a)

$$\frac{\gamma}{\omega} = S\frac{\rho_a}{\rho_w}\left[\frac{U_{(\pi/k)}\cos\theta}{C(k)} - 1\right] \cdot \left|\frac{U_{(\pi/k)}\cos\theta}{C(k)} - 1\right|$$

where $U_{(\pi/k)}$ is the wind speed at the height of the 1/2 wavelength,

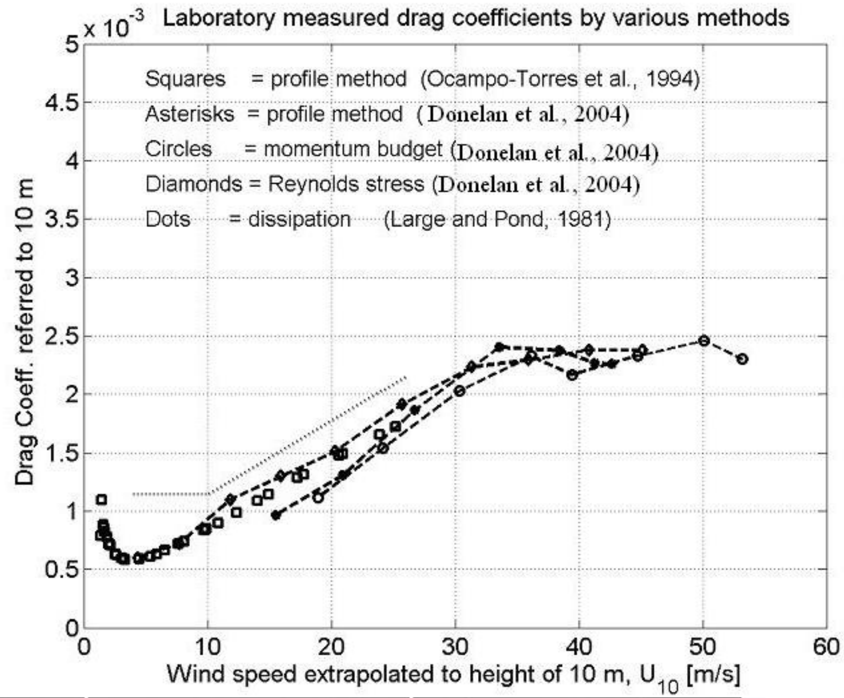
$$U_{(\pi/k)} = \begin{cases} U_{10}, & \pi/k > 10m \\ U_{10} + \frac{u_*}{\kappa}\ln\left(\frac{\pi/k}{10}\right), & \pi/k < 10m \end{cases}$$

C the phase speed, and S is the sheltering coefficient,

$$S = \begin{cases} S_1, & U_{10} < U_{10s} \\ S_2 + (S_1 - S_2)e^{-\frac{U_{10} - U_{10s}}{2U_{10s}}}, & U_{10} > U_{10s} \end{cases}$$

S_1=0.28 and S_2=0.11 for growth and attenuation, respectively, based on Donelan (1999). U_{10} is the wind speed at 10 m and U_{10s} the threshold value at which the flow saturation occurs.

Drag coefficient in high-wind conditions (Donelan et al. 2004)



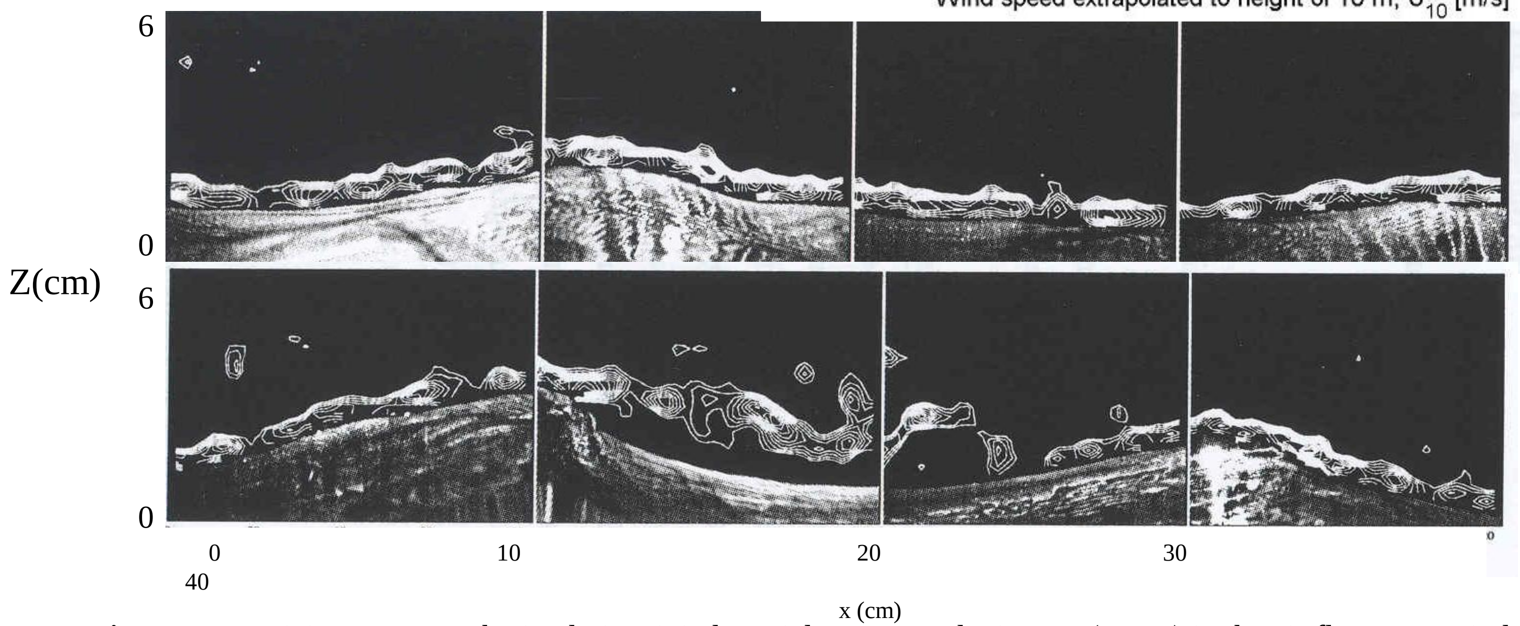
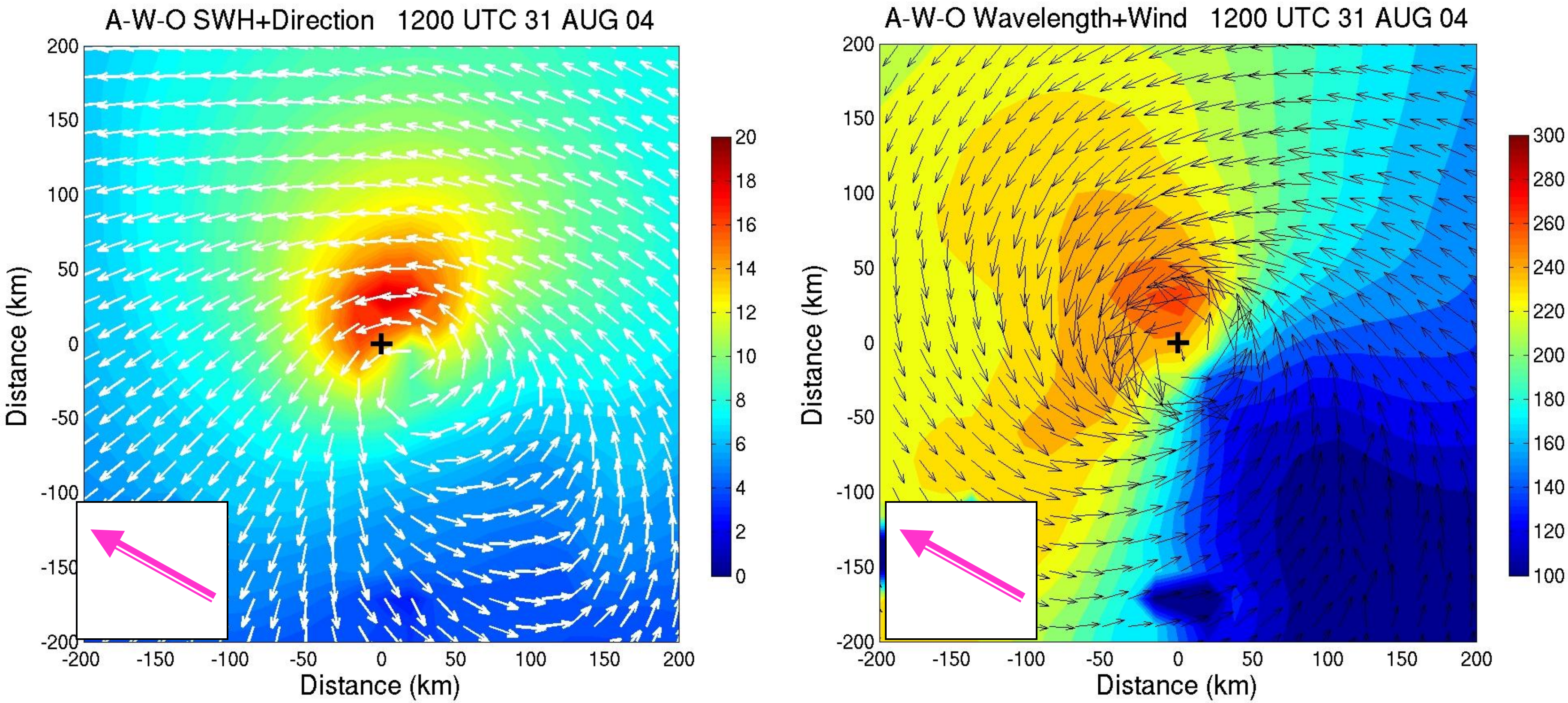
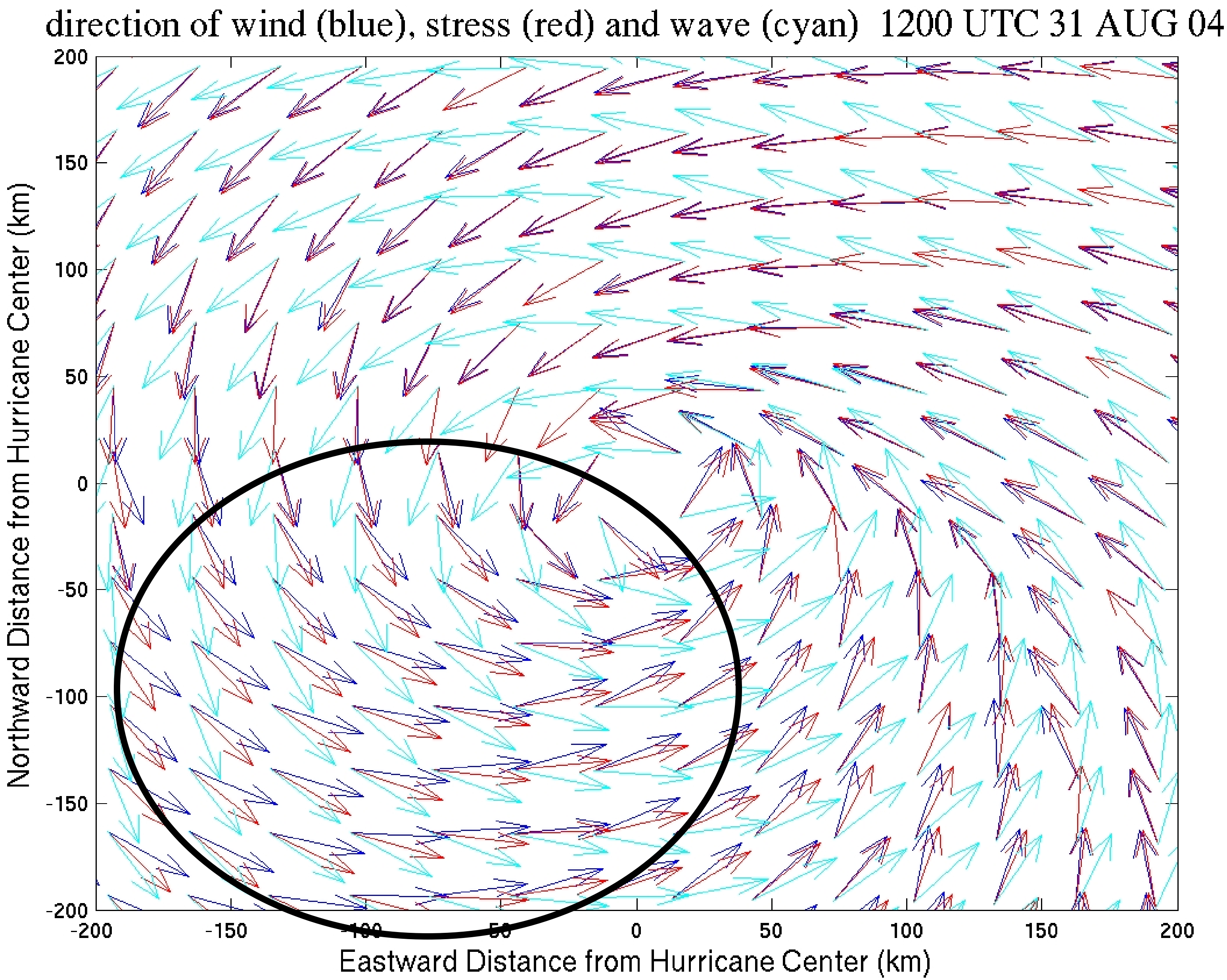


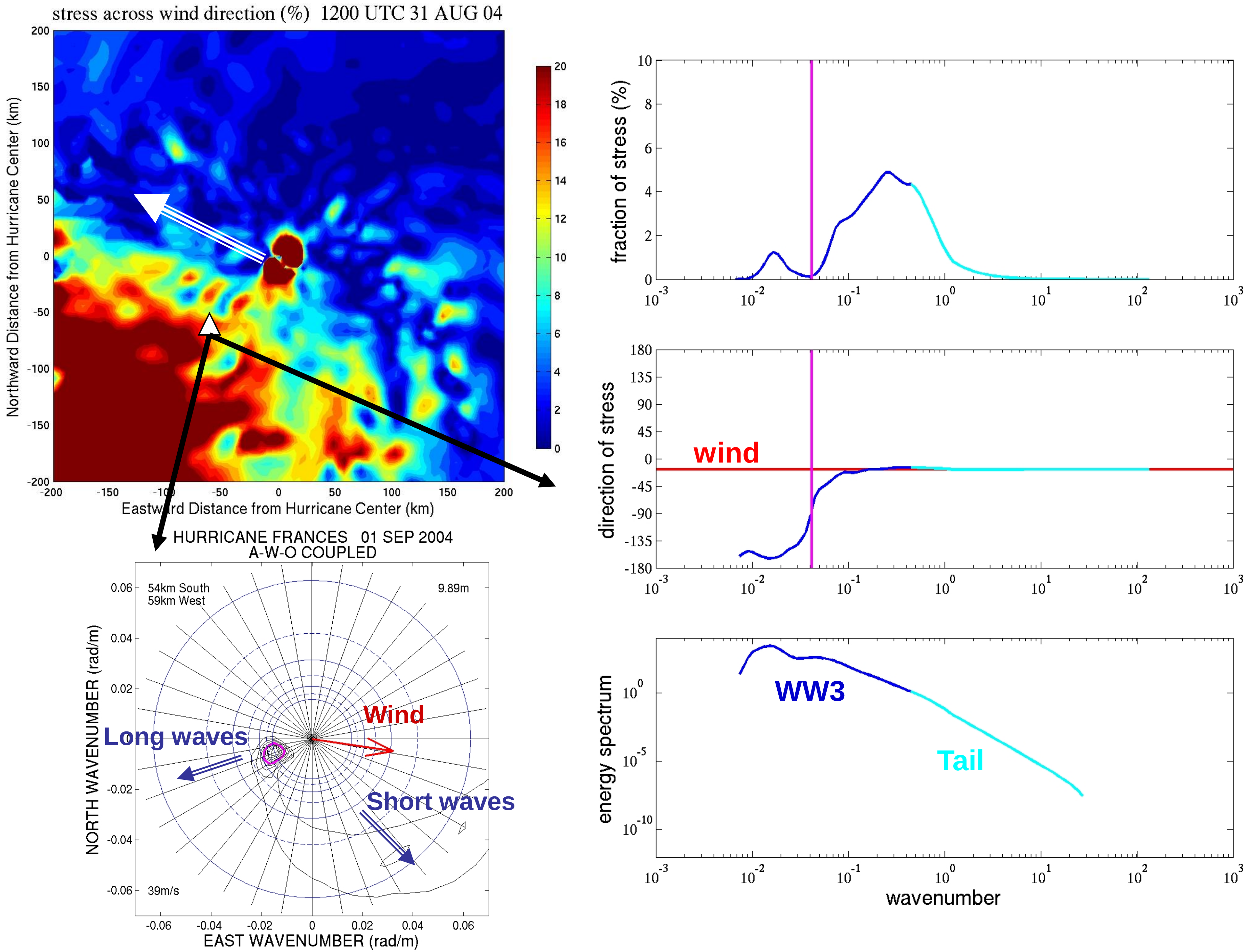
Figure 4. Vorticity contours obtained via Digital Particle Image Velocimetry (DPIV) in the air flow over wind driven waves [Reul, 1998]. Both wave and air flow are from left to right. (Top) waves of gentle slope – non-separated flow. (Bottom) waves of steep slope – separated flow.

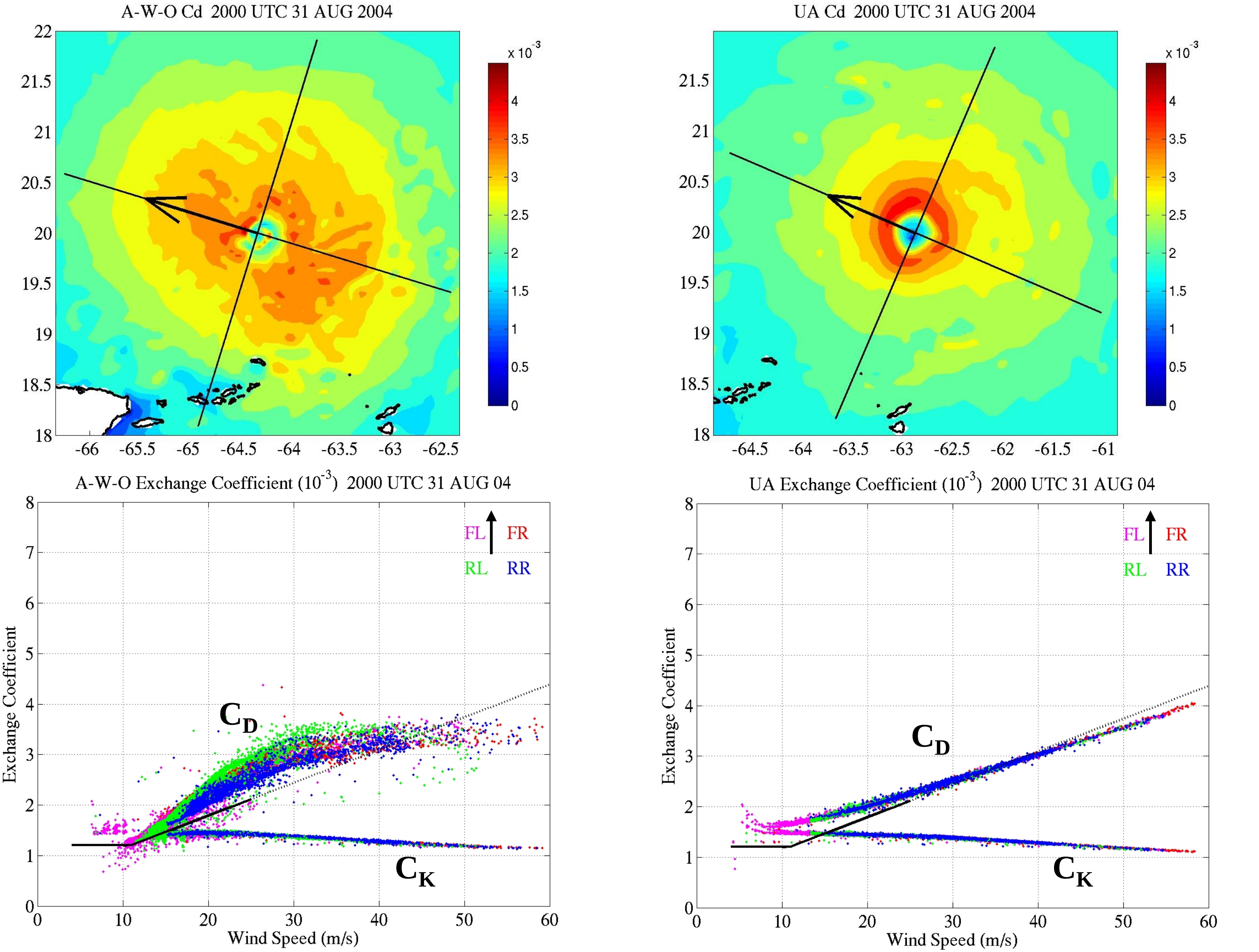
Ocean surface waves in Hurricane Frances (2004)



A few key results from the directional win-wave coupling




stress across wind direction (%) 1200 UTC 31 AUG 04
Northward Distance from Hurricane Center (km)
Eastward Distance from Hurricane Center (km)
HURRICANE FRANCES 01 SEP 2004
A-W-O COUPLED
54km South
59km West
9.89m
39m/s
NORTH WAVENUMBER (rad/m)
EAST WAVENUMBER (rad/m)
Long waves
Wind
Short waves
fraction of stress (%)
direction of stress
wind
energy spectrum
WW3
Tail
wavenumber



A-W-O Cd 2000 UTC 31 AUG 2004
UA Cd 2000 UTC 31 AUG 2004
x 10^-3
A-W-O Exchange Coefficient (10^-3) 2000 UTC 31 AUG 04
UA Exchange Coefficient (10^-3) 2000 UTC 31 AUG 04
Exchange Coefficient
Wind Speed (m/s)
FL FR
RL RR
C_D
C_K

D. Jeung (MS Thesis/UM, 2008)

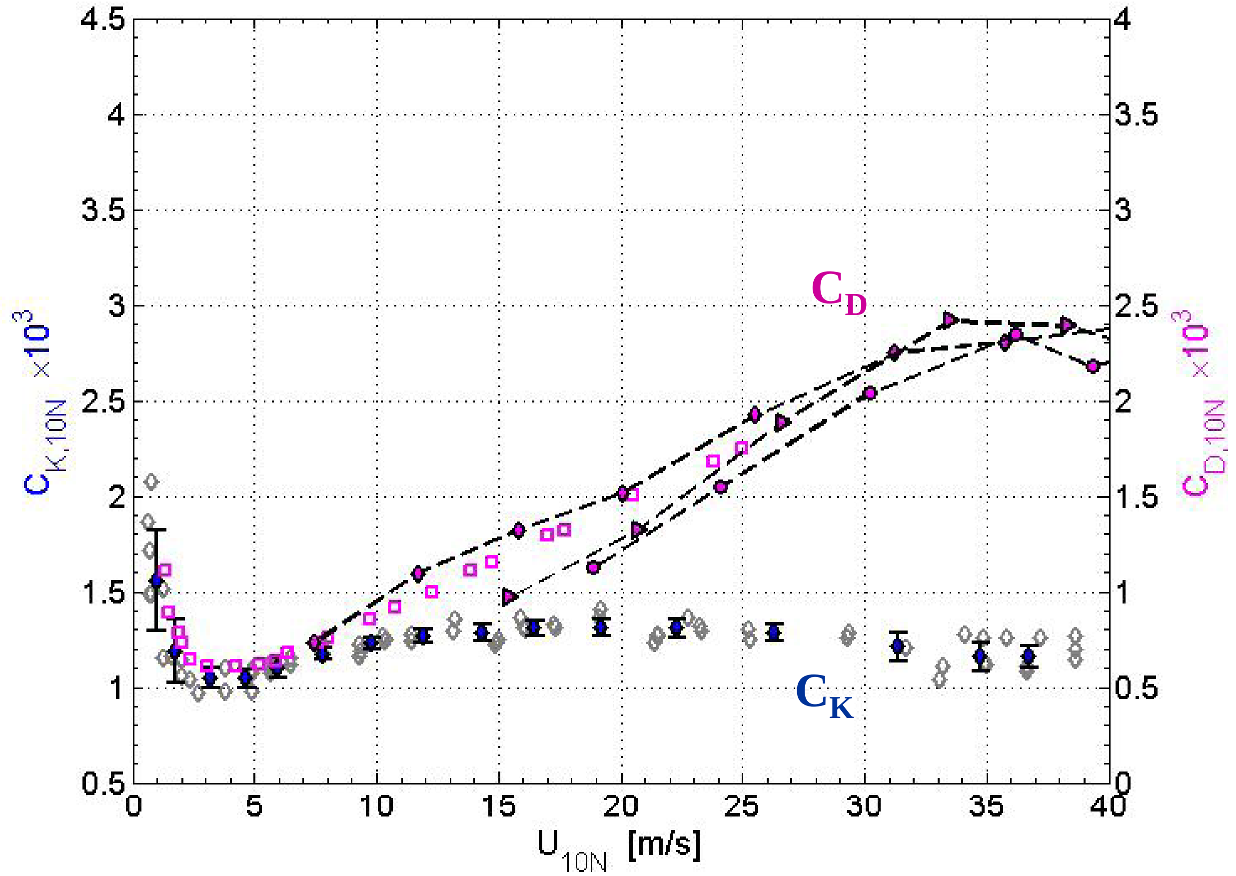
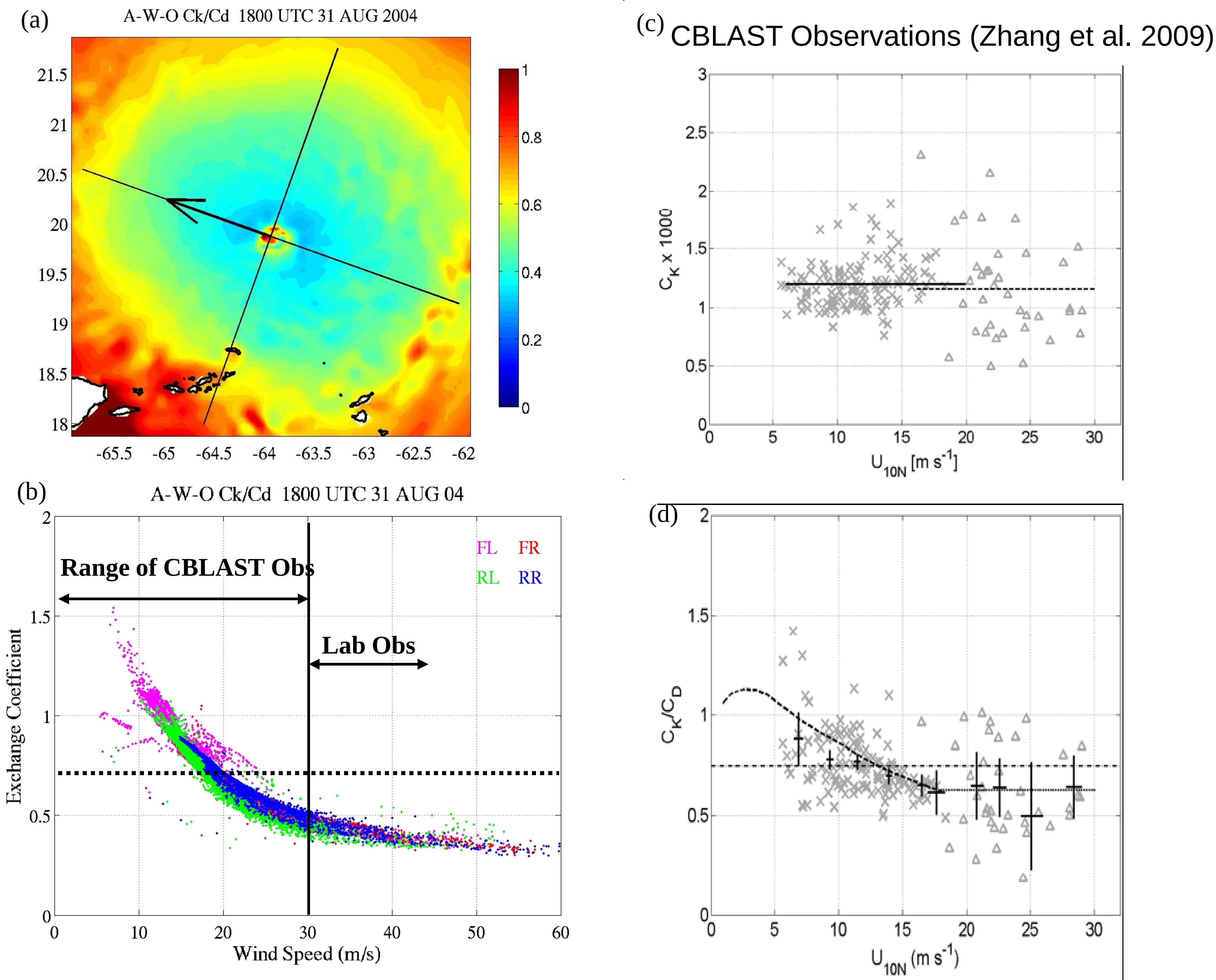
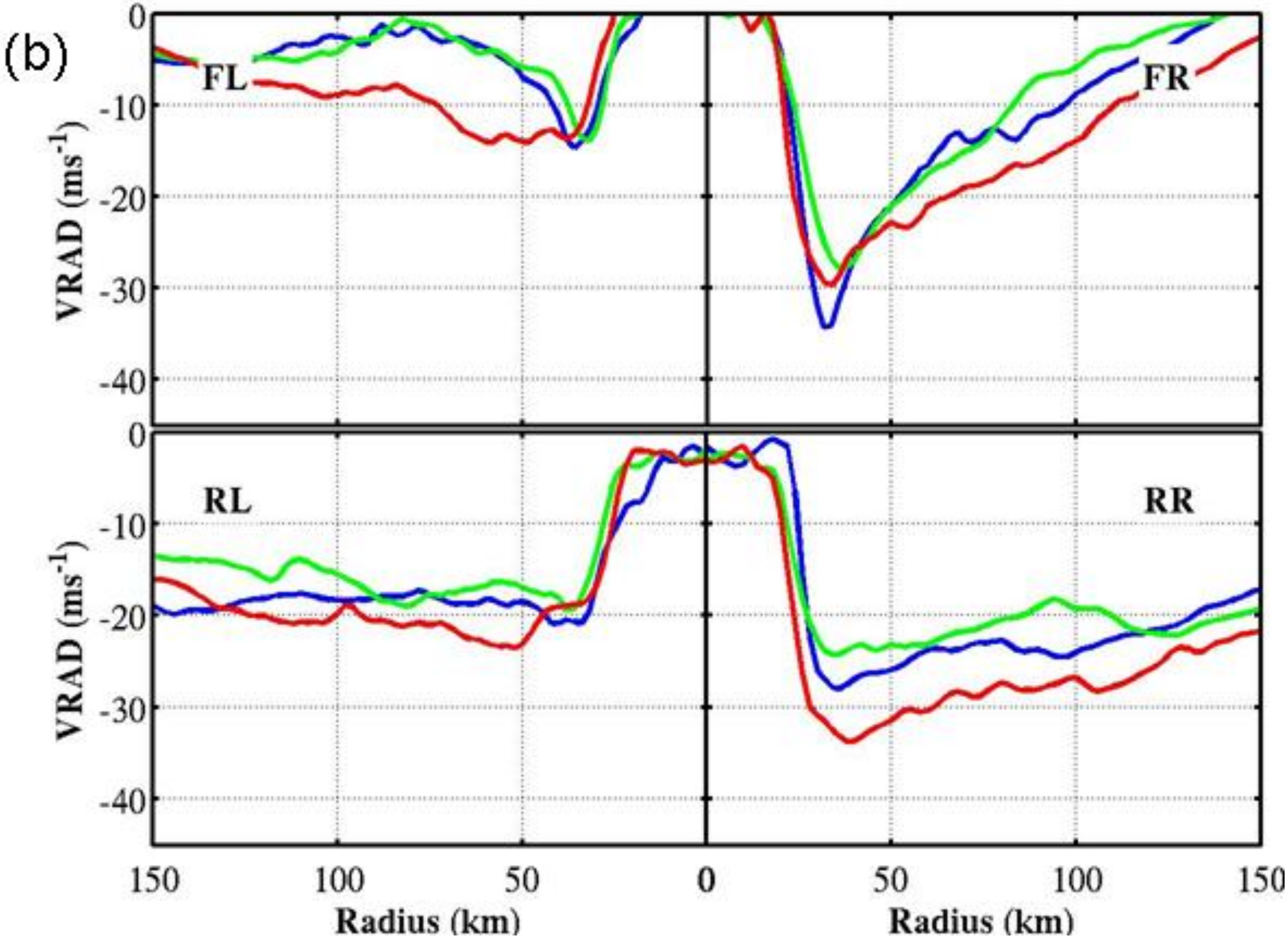
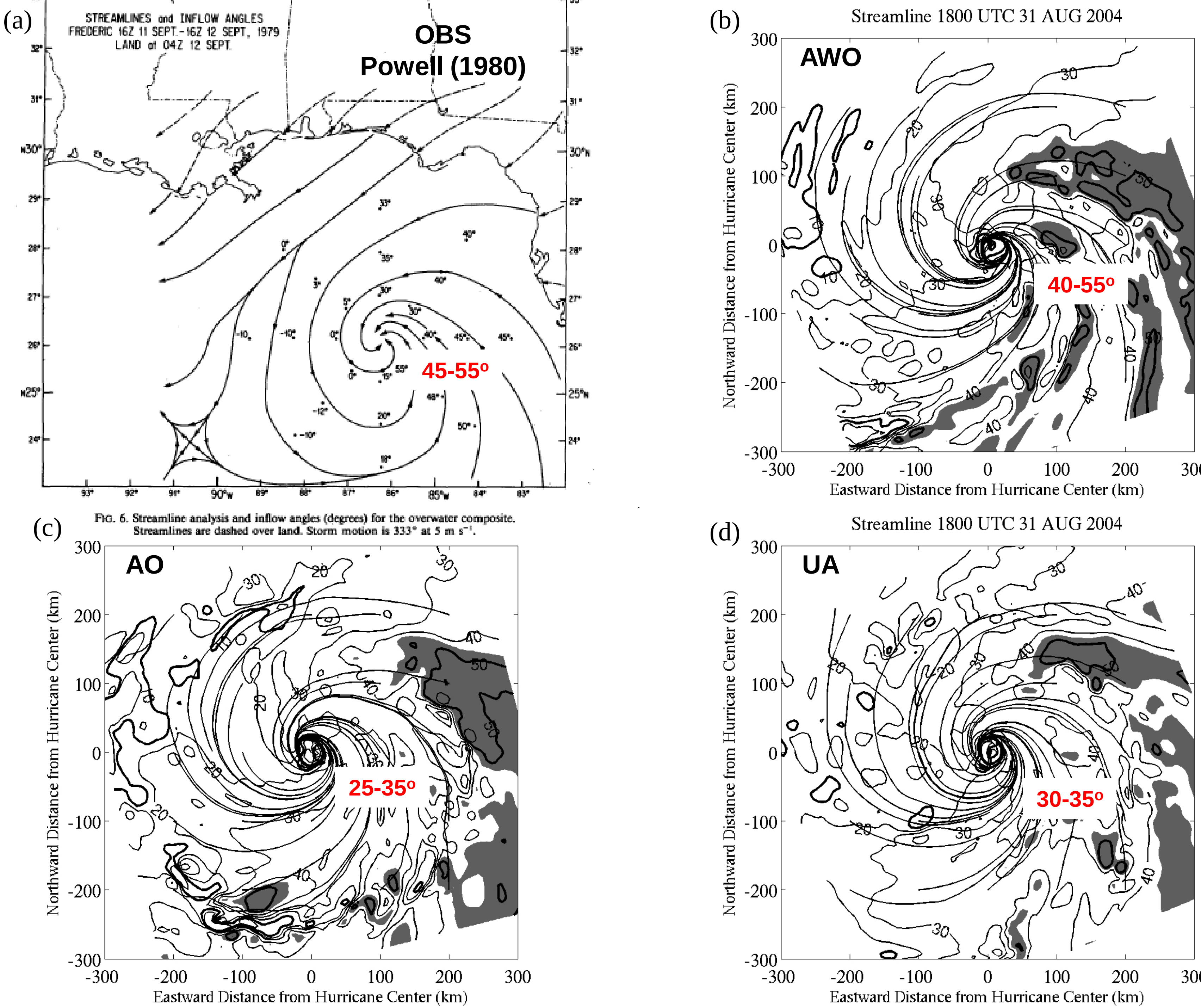


Figure 5.2. Comparison between the characteristic behaviors of enthalpy and drag coefficients; Present work (enthalpy coefficients; gray and blue diamonds; vertical bars represent the range of estimates based on 95% confidence limits), from Ocampo-Torres et al. (1994; drag coefficients; magenta squares), and from Donelan et al. (2004; drag coefficients; magenta diamonds, right-pointing triangles, circles)


(a)
A-W-O Ck/Cd 1800 UTC 31 AUG 2004
(b)
A-W-O Ck/Cd 1800 UTC 31 AUG 04
Range of CBLAST Obs
Lab Obs
FL
FR
RL
RR
Exchange Coefficient
Wind Speed (m/s)
(c)
CBLAST Observations (Zhang et al. 2009)
C_K x 1000
U_10N [m s^-1]
(d)
C_K/C_D
U_10N (m s^-1)

Radial Inflow





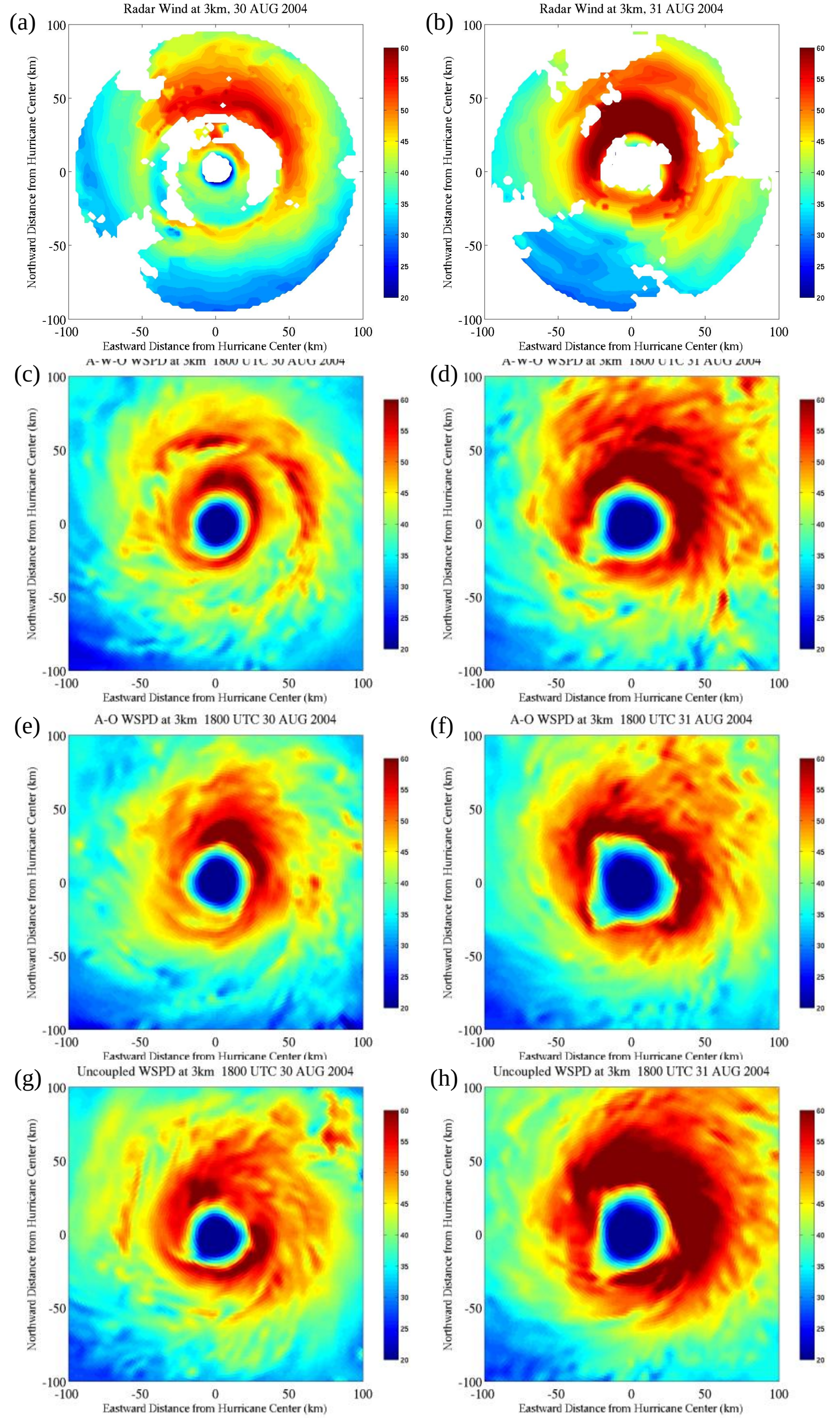
(a)
STREAMLINES and INFLOW ANGLES
FREDERIC 16Z 11 SEPT.-16Z 12 SEPT, 1979
LAND at 04Z 12 SEPT.
OBS
Powell (1980)
45-55°
FIG. 6. Streamline analysis and inflow angles (degrees) for the overwater composite. Streamlines are dashed over land. Storm motion is 333° at 5 m s⁻¹.
(b)
Streamline 1800 UTC 31 AUG 2004
AWO
40-55°
(c)
AO
25-35°
(d)
Streamline 1800 UTC 31 AUG 2004
UA
30-35°
Northward Distance from Hurricane Center (km)
Eastward Distance from Hurricane Center (km)

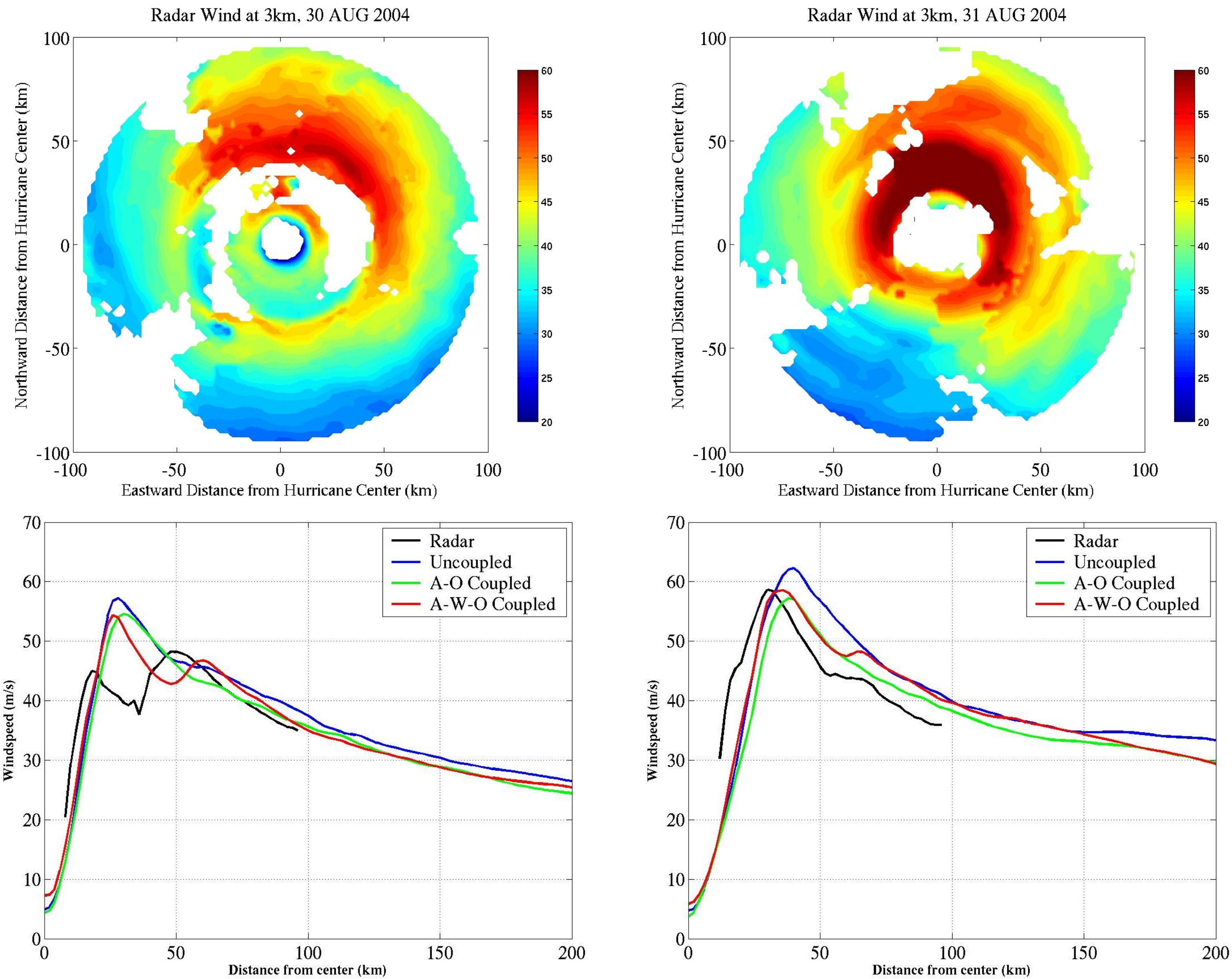
Radar Obs

A-W-O

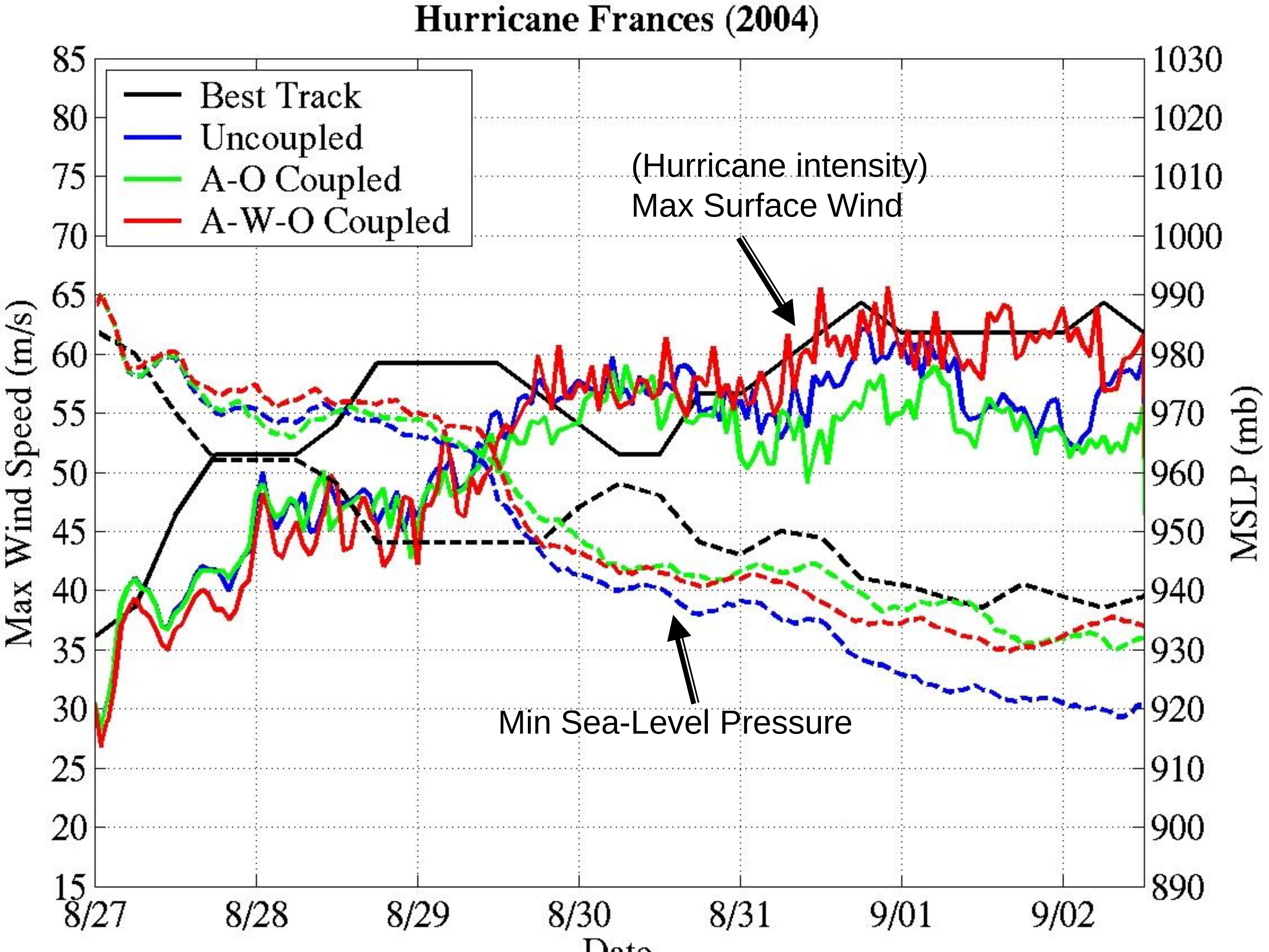
A-O

UA

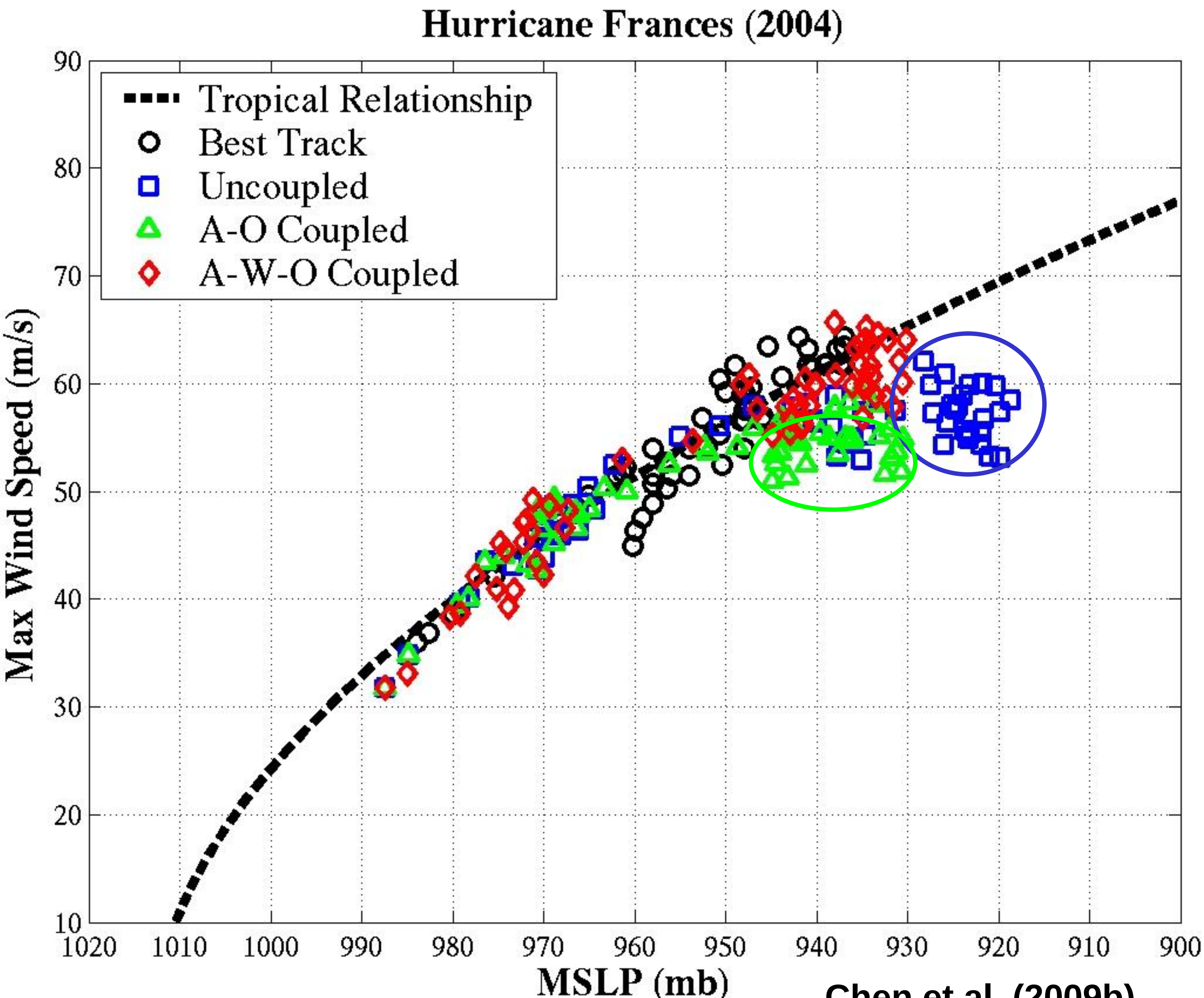




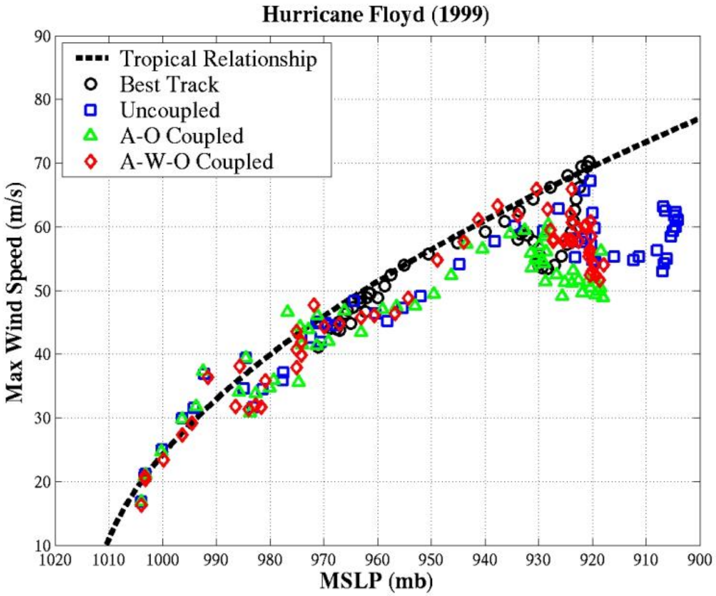
Radar Wind at 3km, 30 AUG 2004
Radar Wind at 3km, 31 AUG 2004
Northward Distance from Hurricane Center (km)
Eastward Distance from Hurricane Center (km)
100
50
0
-50
-100
60
55
50
45
40
35
30
25
20
Radar
Uncoupled
A-O Coupled
A-W-O Coupled
Windspeed (m/s)
Distance from center (km)
70
10
150
200

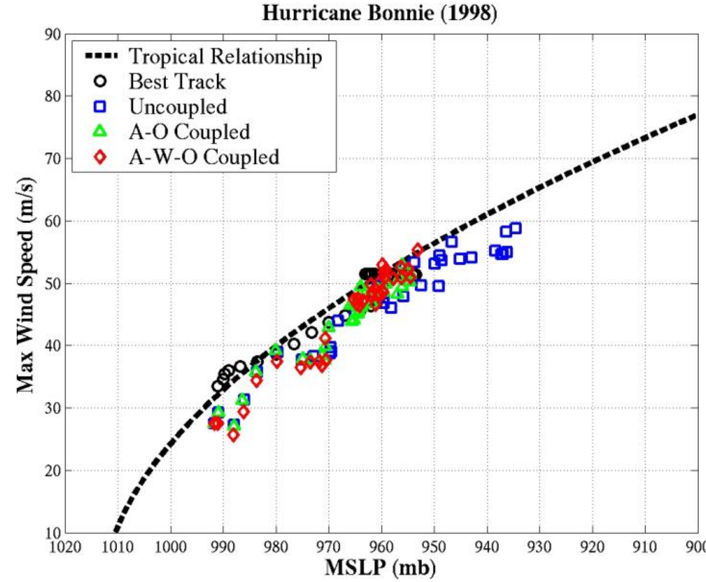


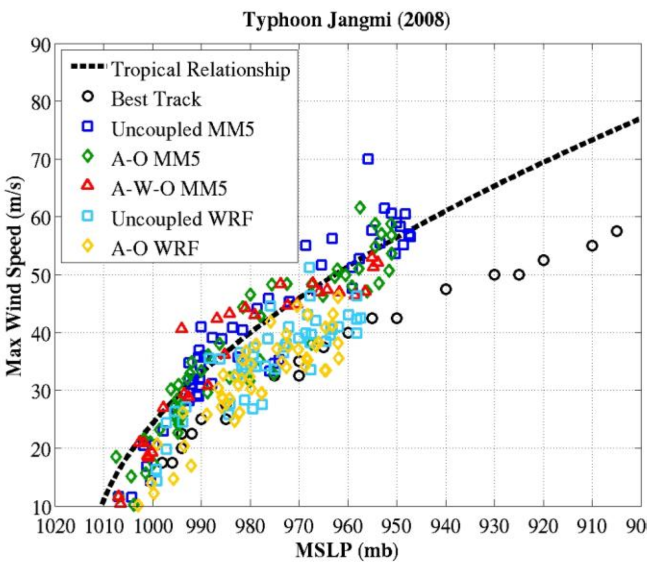
Chen et al. (2009b)

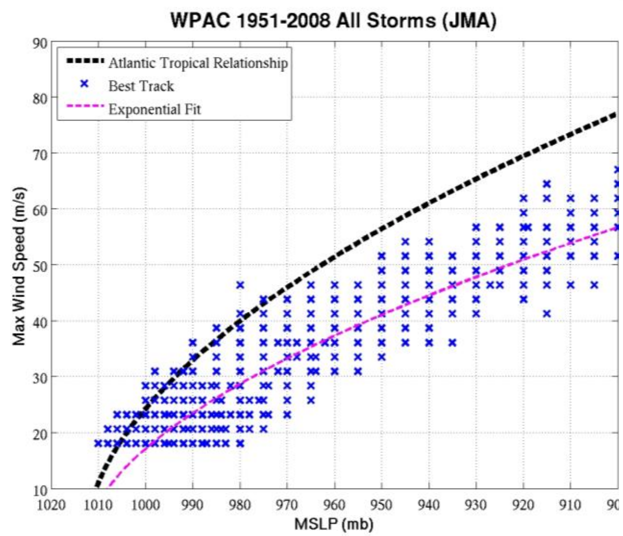


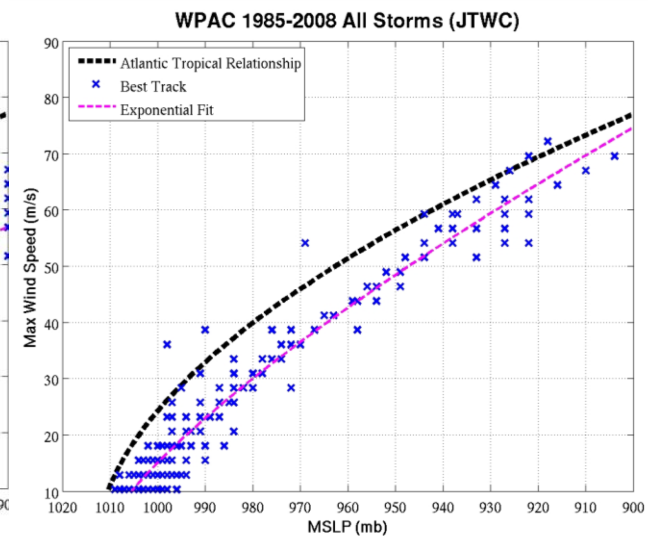
Chen et al. (2009b)


Hurricane Floyd (1999)
Tropical Relationship
Best Track
Uncoupled
A-O Coupled
A-W-O Coupled
Max Wind Speed (m/s)
MSLP (mb)


Hurricane Bonnie (1998)
Tropical Relationship
Best Track
Uncoupled
A-O Coupled
A-W-O Coupled
Max Wind Speed (m/s)
MSLP (mb)

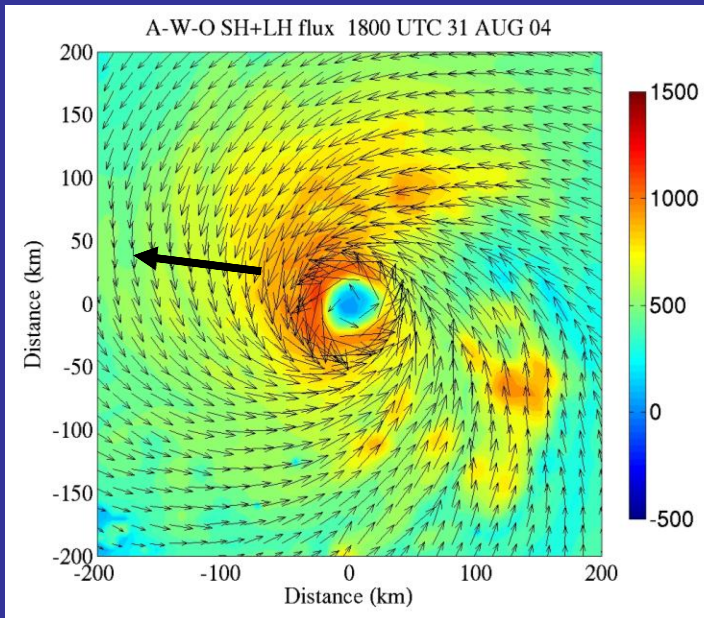

Typhoon Jangmi (2008)
Tropical Relationship
Best Track
Uncoupled MM5
A-O MM5
A-W-O MM5
Uncoupled WRF
A-O WRF
Max Wind Speed (m/s)
MSLP (mb)


WPAC 1951-2008 All Storms (JMA)
Atlantic Tropical Relationship
Best Track
Exponential Fit
Max Wind Speed (m/s)
MSLP (mb)

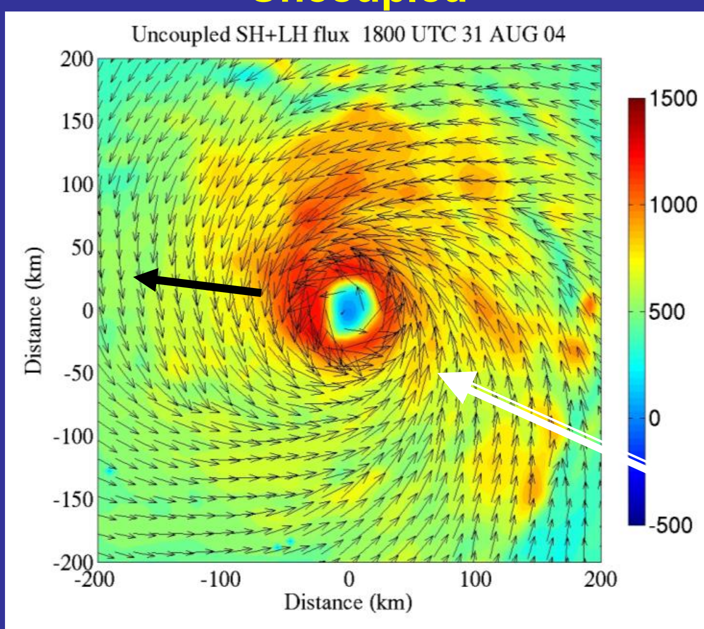

WPAC 1985-2008 All Storms (JTWC)
Atlantic Tropical Relationship
Best Track
Exponential Fit
Max Wind Speed (m/s)
MSLP (mb)

Enthalpy (SH+LH) Flux

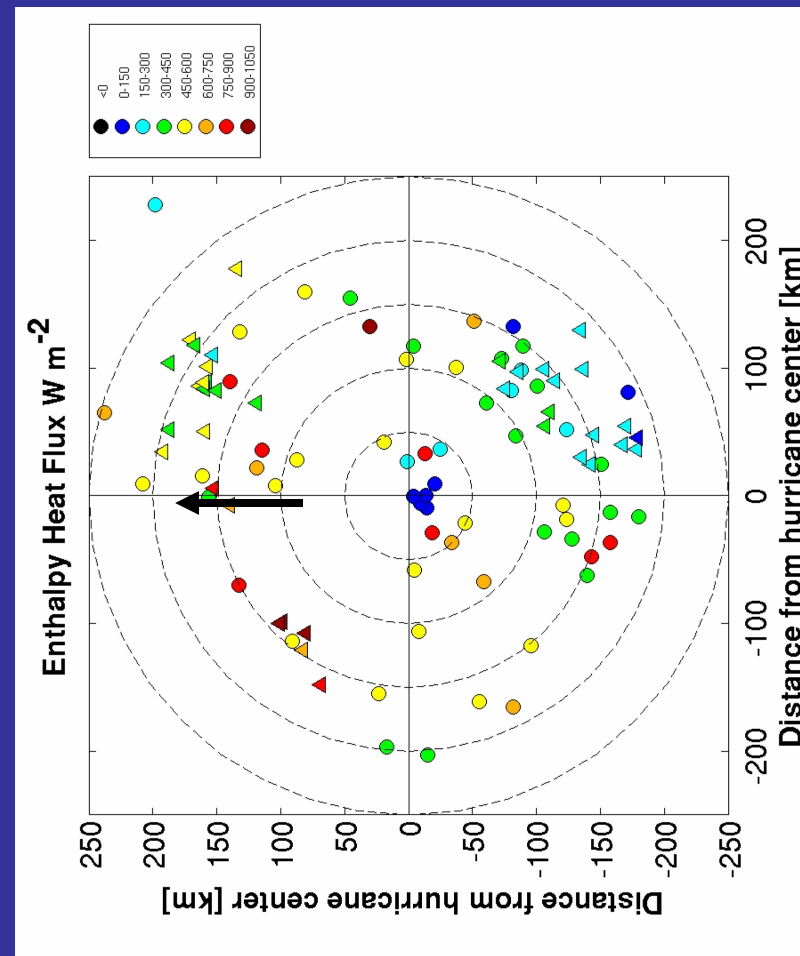
Coupled Atmos-Wave-Ocean



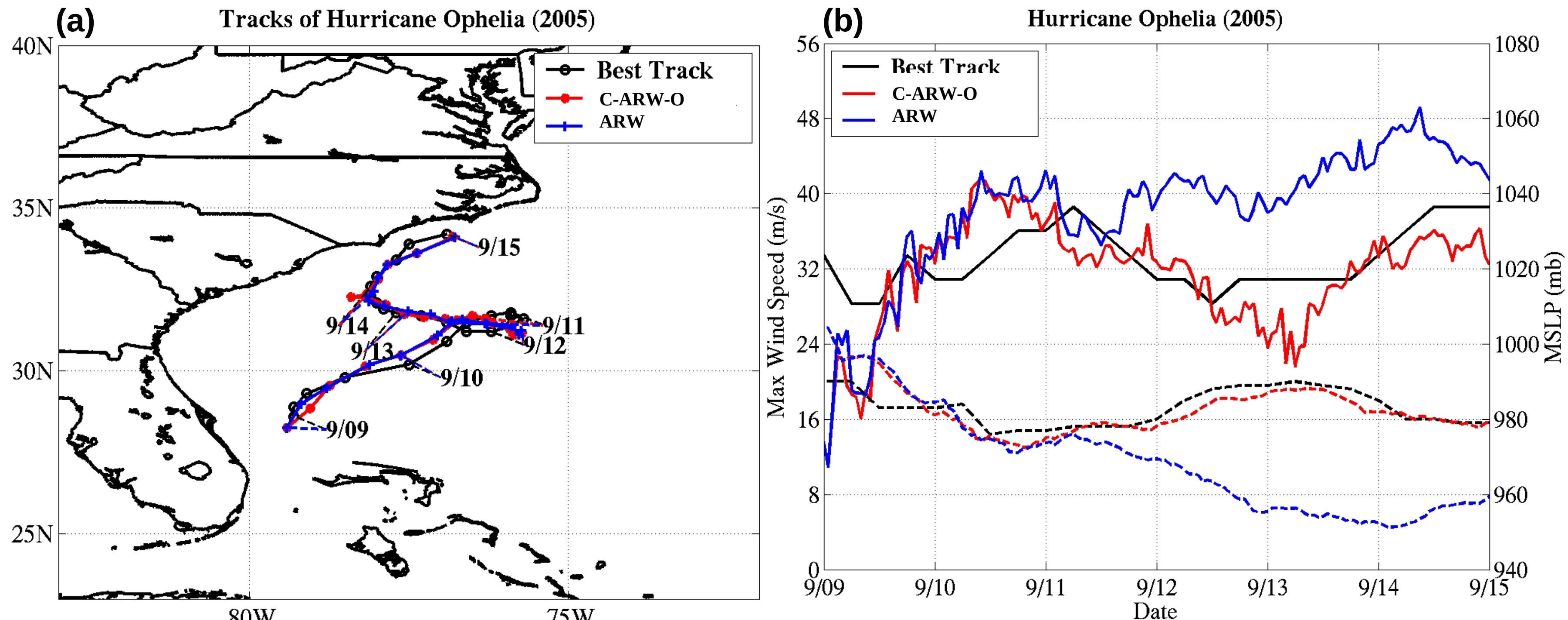
Uncoupled



Observed form 6 hurricanes using GPS dropsondes plus 2 from CBLAST turbulence flux measurement (triangles)



~30% greater than observed



(c)

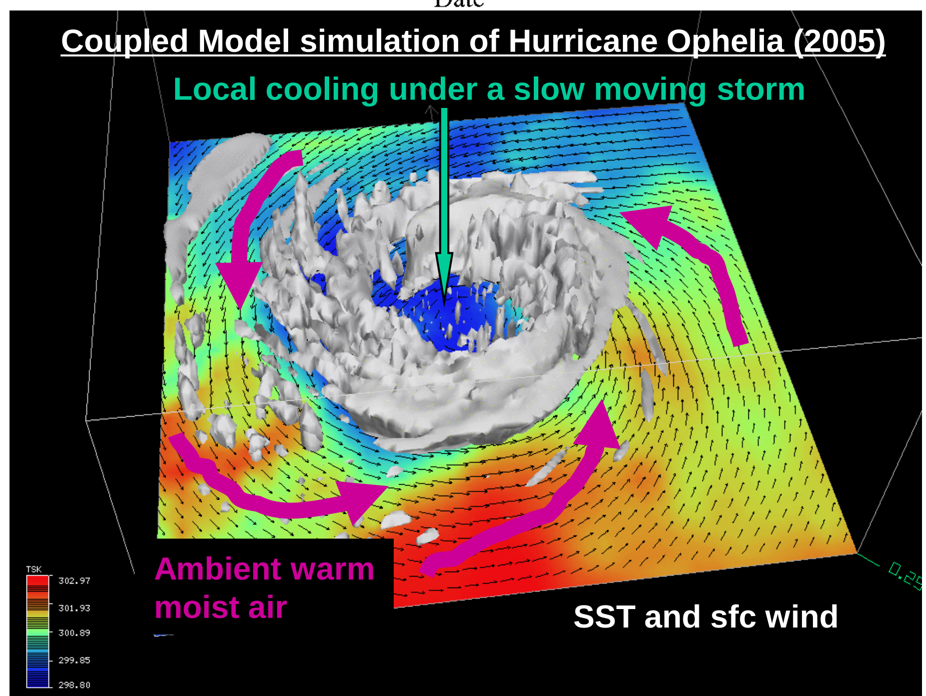
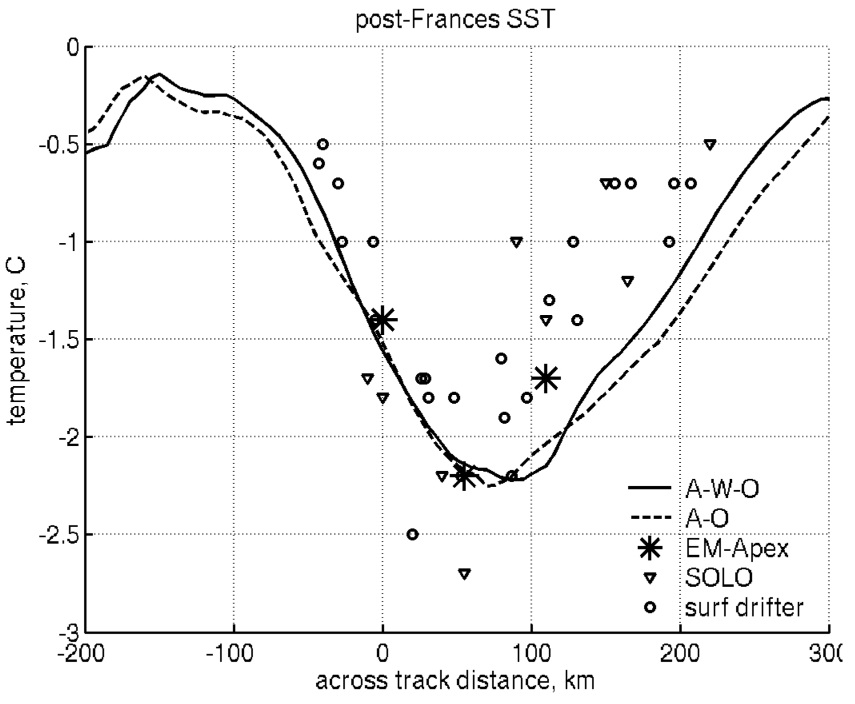
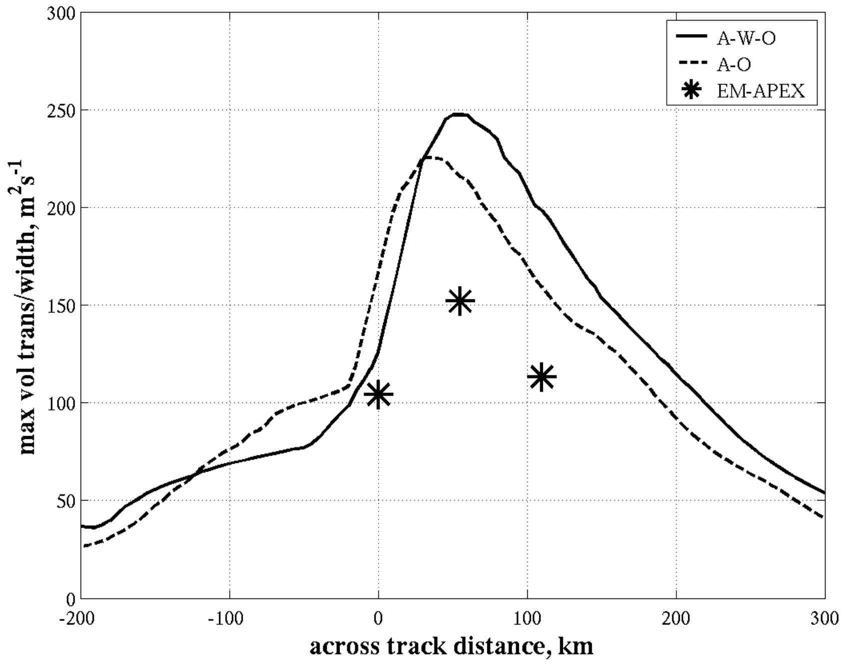


Fig. 1 (a) Uncoupled ARW (blue) and coupled ARW-Ocean model (red) simulated storm tracks, (b) MSLP (dashed) and maximum wind speed (solid) of Hurricane Ophelia (2005) compared with the NHC best track (black) data, and (c) SST, surface wind, cloud water+ice of Ophelia at 0000 UTC Sept 13. The models were initialized at 0000 UTC Sept 9 with the NCEP analysis fields as initial and lateral boundary conditions for ARW and HYCOM Atlantic data assimilation fields for the coupled model. (Chen et al. 2010)

Post-Frances SST

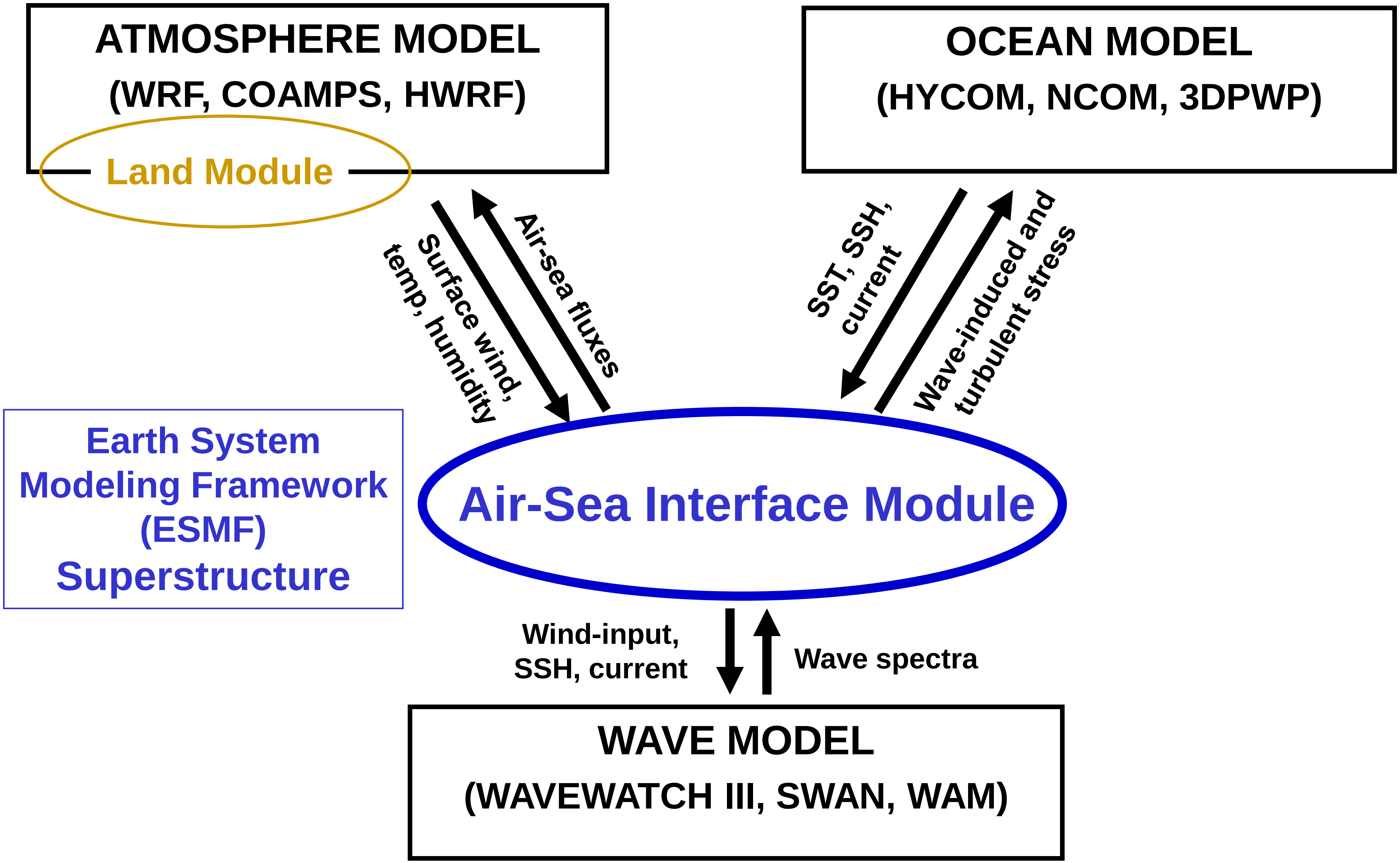


Post-Frances Volume Transport

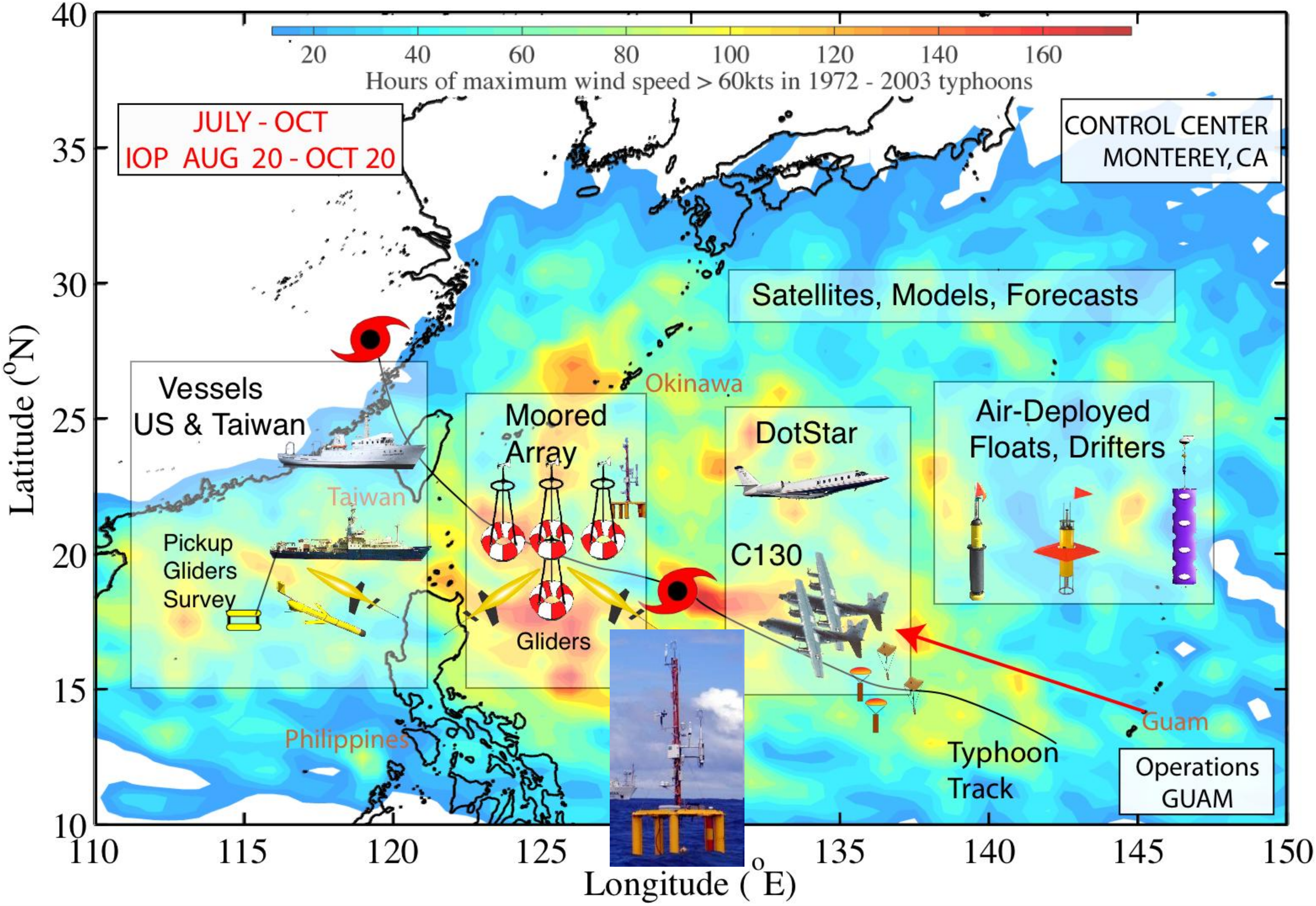


Inconsistent stress/momentum flux?

Atmosphere-Wave-Ocean Coupled Modeling System



ITOP 2010



40
35
30
25
20
15
10
110
115
120
125
135
140
145
150
Latitude (°N)
Longitude (°E)
20 40 60 80 100 120 140 160
Hours of maximum wind speed > 60kts in 1972 - 2003 typhoons
JULY - OCT
IOP AUG 20 - OCT 20
CONTROL CENTER
MONTEREY, CA
Satellites, Models, Forecasts
Okinawa
Vessels
US & Taiwan
Taiwan
Pickup
Gliders
Survey
Moored
Array
Gliders
DotStar
C130
Air-Deployed
Floats, Drifters
Guam
Philippines
Typhoon
Track
Operations
GUAM