Ocean Seminar Series
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Air-sea fluxes - light winds to hurricanes

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Physics of air-surface interactions and coupling to ocean-ice/atmosphere BL

Aspects:

- Emphasize surface fluxes
- Similarity Scaling
- Bulk Flux Parameterizations
- Surface/subsurface processes
- Improve Observing Technologies
- Flux climatologies

Applications:

•Model lower BC (PBL, Meso, NWP, GCM)
•Ocean budgets (stress, heat, waves, sea-ice)
•Carbon budgets
•Pollution deposition (particle, ozone)
•Cloud microphysics (aerosol source, DMS)
•Atmos Propagation (Cn^2, ducting, extinction)
•Hurricane intensity

Why A Flux?

Budget equation for concentration x=X+x'

$$\frac{DX}{Dt} = -\frac{\partial}{\partial z}\left[\overline{w'x'} - D_x\frac{\partial X}{\partial z} - V_g X + \overline{w_s'x'}\right] + Q_x$$

Rate change = [turbulent + molecular + mean fall + slip covariance] + Source

Put source term inside derivative

$$\frac{DX}{Dt} = -\frac{\partial}{\partial z}\left[\overline{w'x'} - D_x\frac{\partial n}{\partial z} - V_g X + \overline{w_s'x'} + S_x\right]$$

Volume source becomes an area flux

$$S_x = \int_z^\infty Q_x(z)dz$$

Generalized flux variable

$$F_x = \left[\overline{w'x'} - D_x\frac{\partial X}{\partial z} - V_g X + \overline{w_s'x'} + S_x\right]$$

Source Examples:

Temperature – radiative flux, condensation

Water vapor – evaporation

Liquid water – condensation, sea spray

Ozone – reactions is air or water, eg Q_x=-$C_{xy}XY$

Particles – gas-particle, coalescence, sea spray, blowing dust, meteors

Flux Definitions

$$Sensible\ Heat: H_s = \rho_a c_{pa} \overline{w'T'}$$

$$Latent\ Heat: H_l = \rho_a L_e \overline{w'q'}$$

$$Stress: \vec{\tau} = \rho_a \overline{w'u_x'}\hat{i} + \rho_a \overline{w'u_y'}\hat{j}$$

$$Rain\ Heat: H_p = c_{pw} P(T_s - T_{wet})$$

$$BuoyAir: F_b = H_s / \rho_a c_{pa} + 0.61T\ H_l / \rho_a L_e$$

$$BuoyWater: F_b = -\alpha g H_{net} / \rho_w c_{pw} + \beta g (E - P)$$

$$Gas\ Exchange: F_x = \overline{w'r_x'}$$

$$Particle\ Exchange: F_n = \overline{w'n(r)'} - w_g \overline{n(r)} + \overline{w_s' n(r)'}$$

Present Status of *Surface* Flux Parameterizations

Turbulent Fluxes: Bulk Parameterization

Mean correlation of turbulent variables represented in terms of mean flow variables – wind speed, surface-to-air variable difference

MetFlux – Dominated by atmospheric turbulent xfer

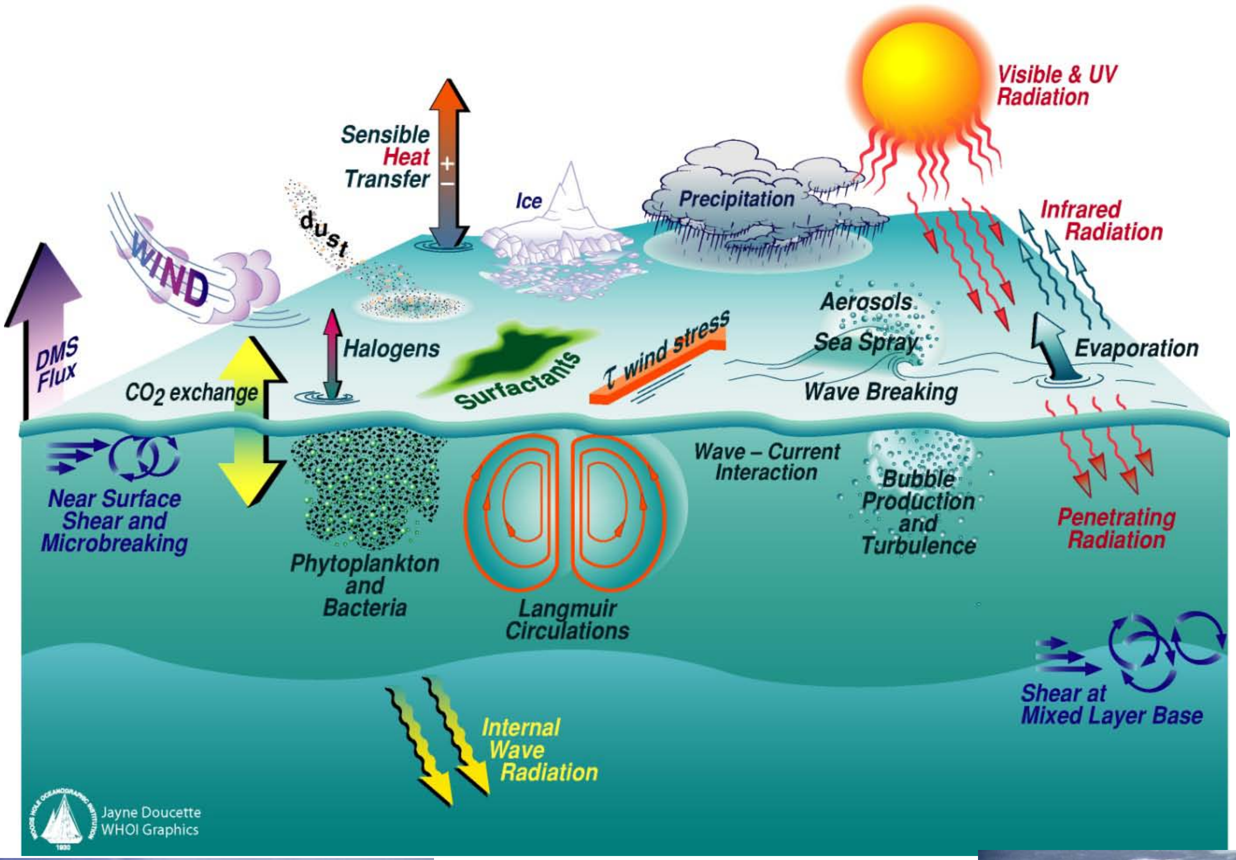
GasFlux – Dominated by oceanic molecular xfer; Enhanced by whitecap bubbles

$$Met\ Flux: \overline{w'x'} = C_x U (X_s - X_r) = C_x U \Delta X$$

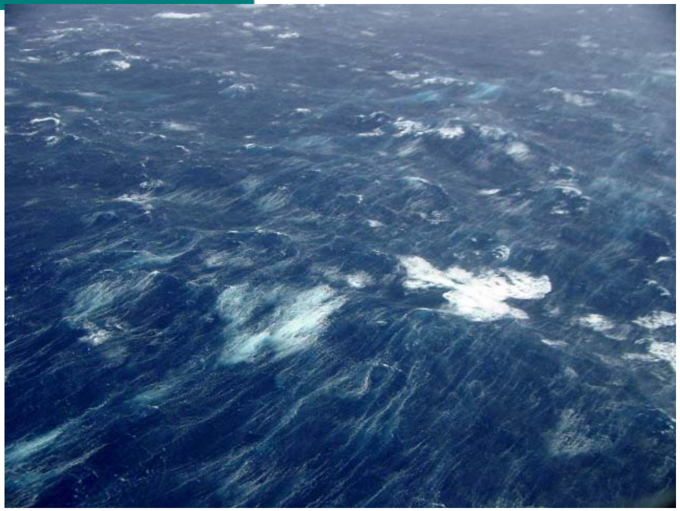
$$Gas\ Flux: \overline{w'x'} = k_x \alpha_x \Delta X \qquad \alpha = sol.$$

$$Particles: F_{deposition} = -V_d(r)\overline{n(r)};$$

$$F_{source} = F(f_{whitecap}, U, u_*, wave\,breaking, slope)$$



Do You Feel Lucky?
C_d=Constant



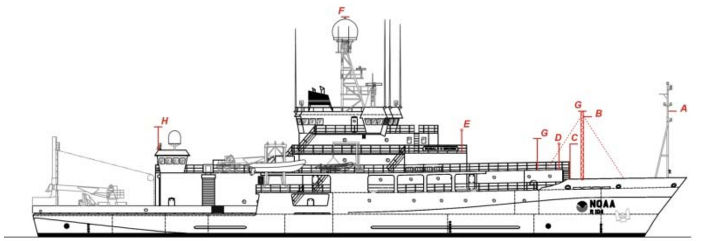
Sensing Technologies

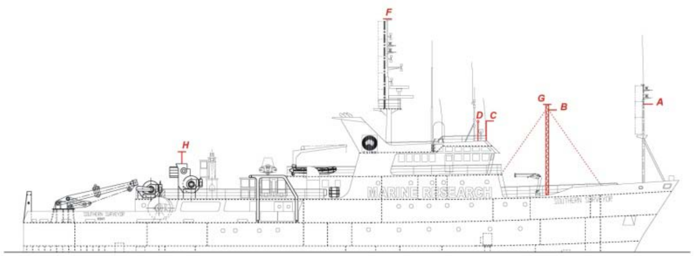
- Near-surface in situ
  - Sonic anemometer/thermometer
  - IR fast hygrometer, fast CO_2
  - Chemilum. Fast ozone, DMS
  - High quality mean T, q, Ts
  - Eppley solar/IR radiometers
  - Surface waves
- Boundary Layer/column
  - Ceilometer
  - Wind profiling radar
  - Rawindsonde
  - Microwave radiometer
  - Doppler cloud radar

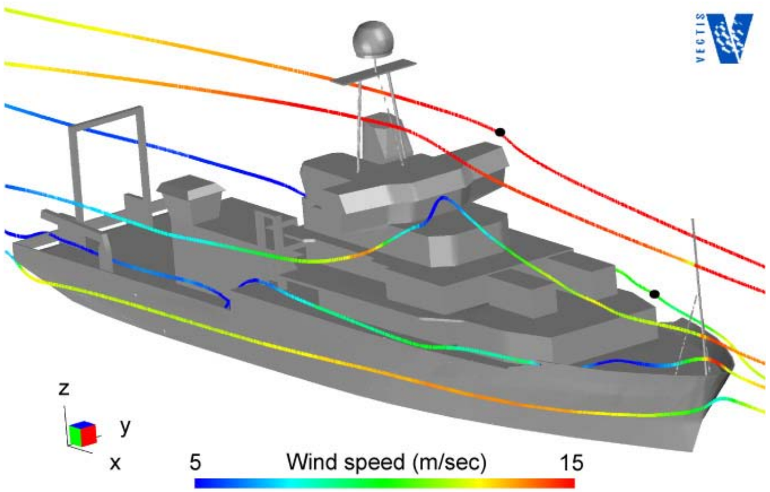
Unbelievable Number of Dirt Effects

- Motion corrections
- Contamination by salt, ship exhaust, sea gulls, …
- Flow distortion (Ship, tower, other sensors)
- Sensor separation, time delays, decorrelation, frequency response, path averaging,…
- Surface boundary conditions (currents, ocean/snow gradients)
- Extreme cold, icing, frost formation, fog/rain impact
- Poor signal to noise, weak stratified turbulence
- Sensor-variable crosstalk (Webb, motion, chemical)
- Artificial (self-) correlation

Turbulence Measurements from Ships

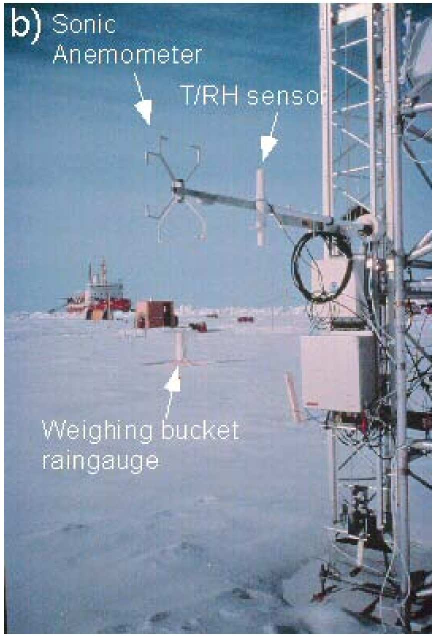


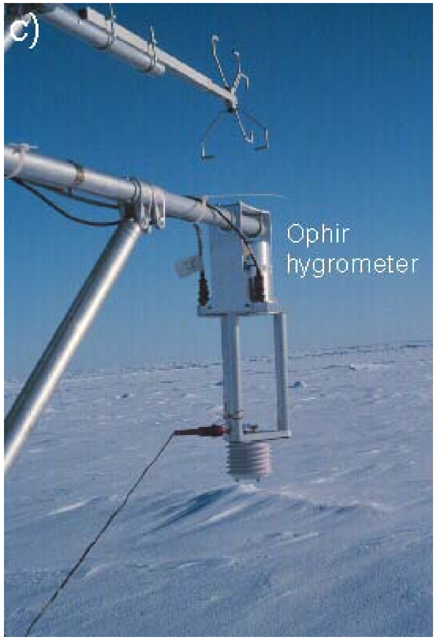




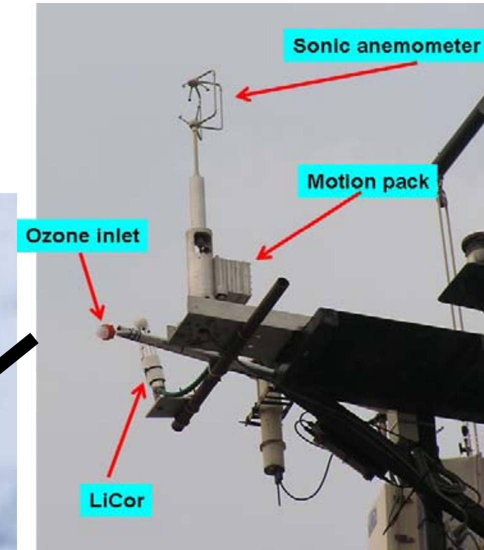
ASFG Air-Ice Flux Instrumentation SHEBA Field Program 1998-1999

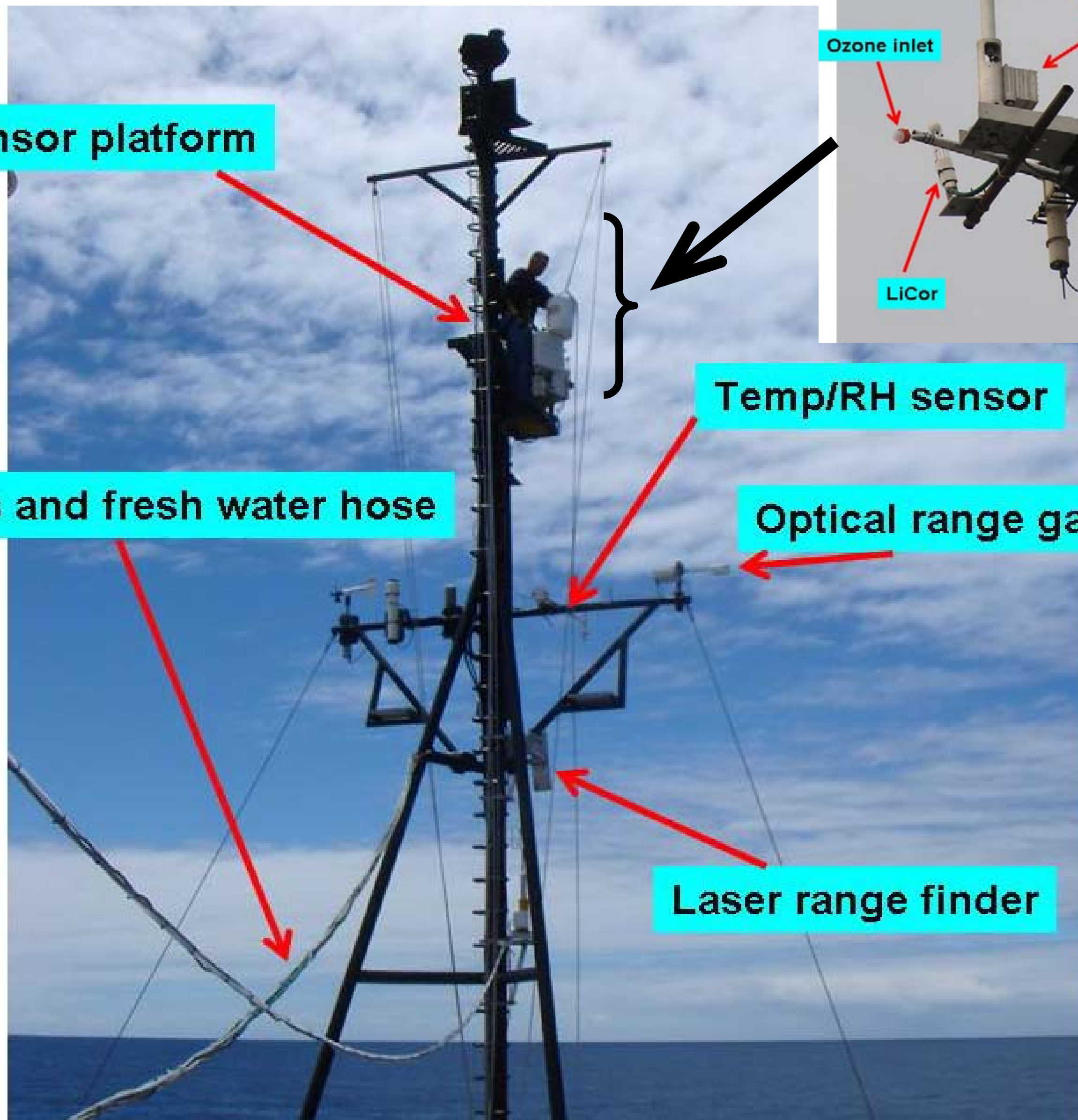
- The Atmospheric Surface Flux Group (ASFG) deployed a 20-m main micrometeorological tower, two short masts, and several other instruments on the surface located 280 – 350 m from the *Des Groseilliers* at the far edge of the main ice camp.
- Turbulent and mean meteorological data were collected at five levels, nominally 2.2, 3.2, 5.1, 8.9, and 18.2 m (or 14 m during most of the winter).
- Each level had a Väisälä HMP-235 temperature/relative humidity probe (T/RH) and identical ATI three-axis sonic anemometers/thermometers.
- An Ophir fast infrared hygrometer was mounted on a 3-m boom at an intermediate level just below level 4 (8.1 m above ice).



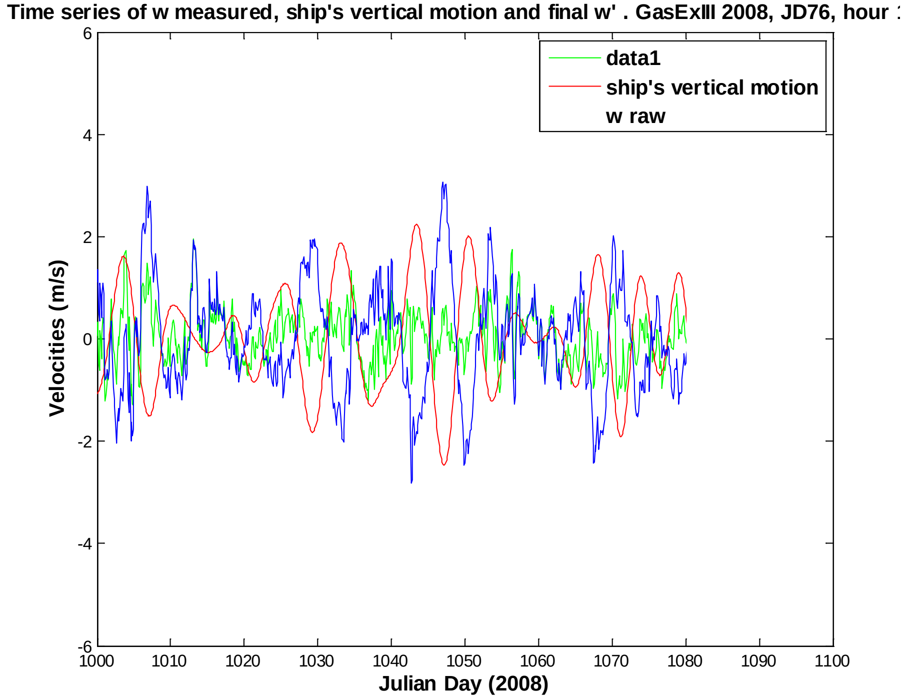


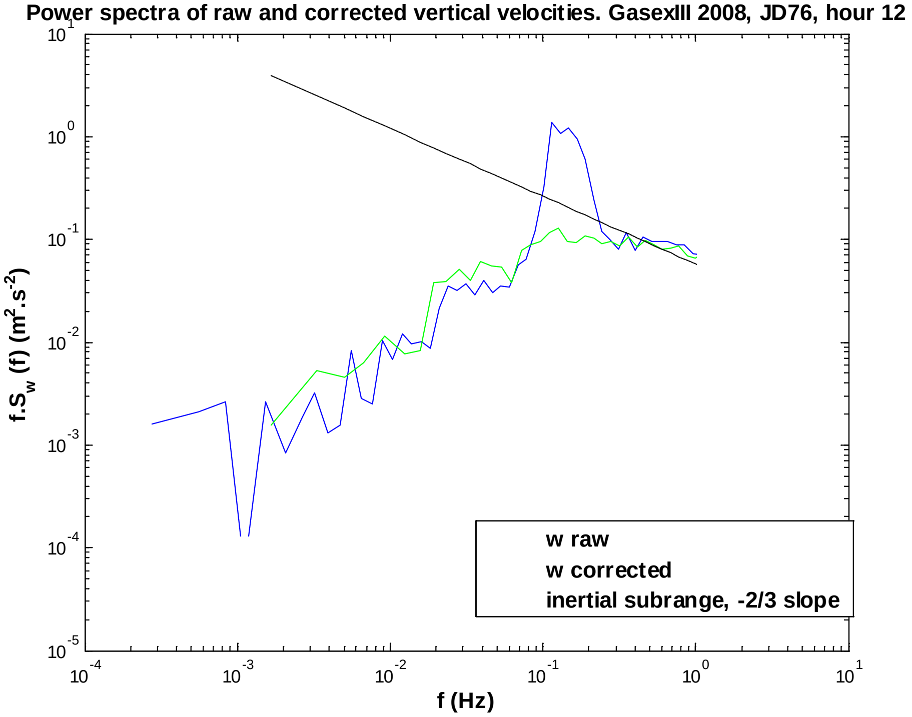
Example of Instrumented Mast



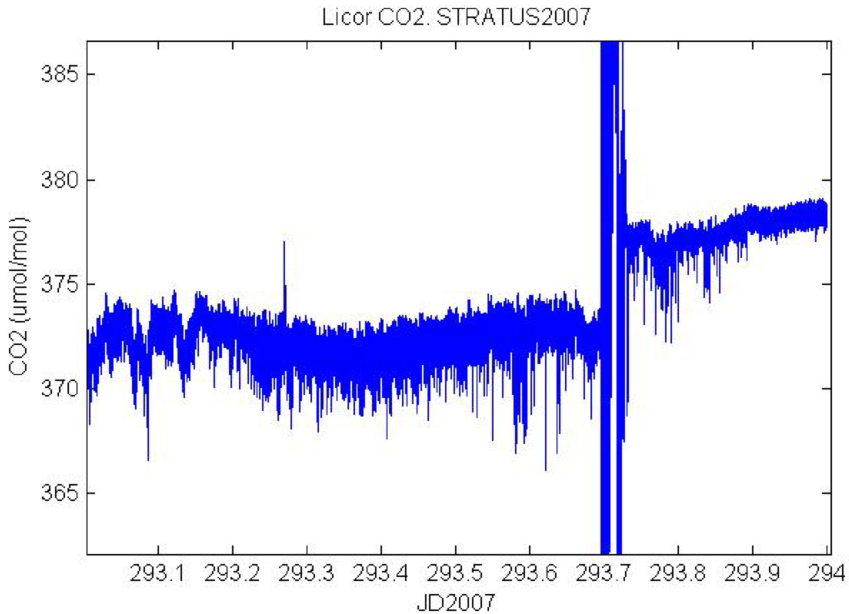


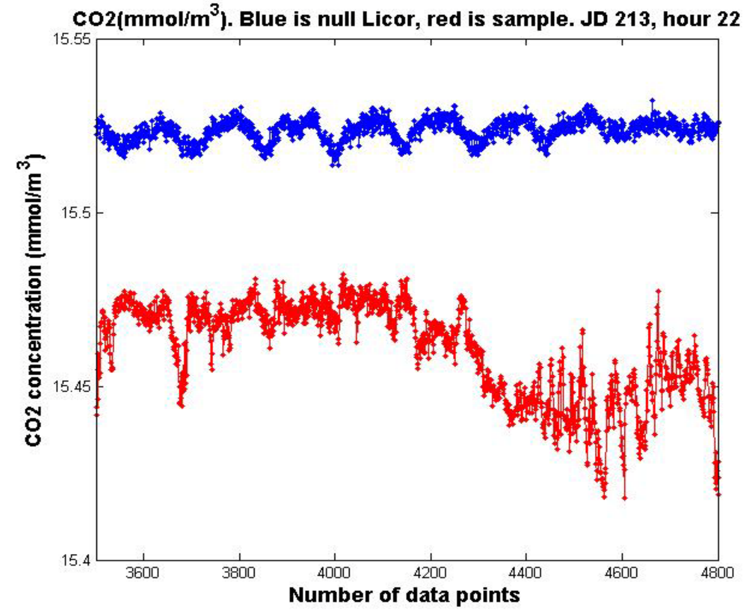
Ship Motion Corrections

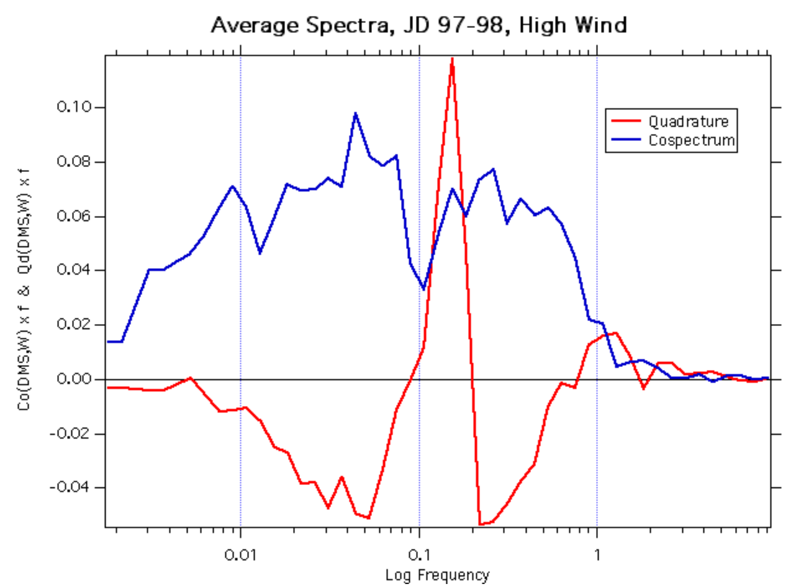




Sample Dirt/Crosstalk Effects







Historical perspective on turbulent fluxes: Typical moisture transfer coefficients

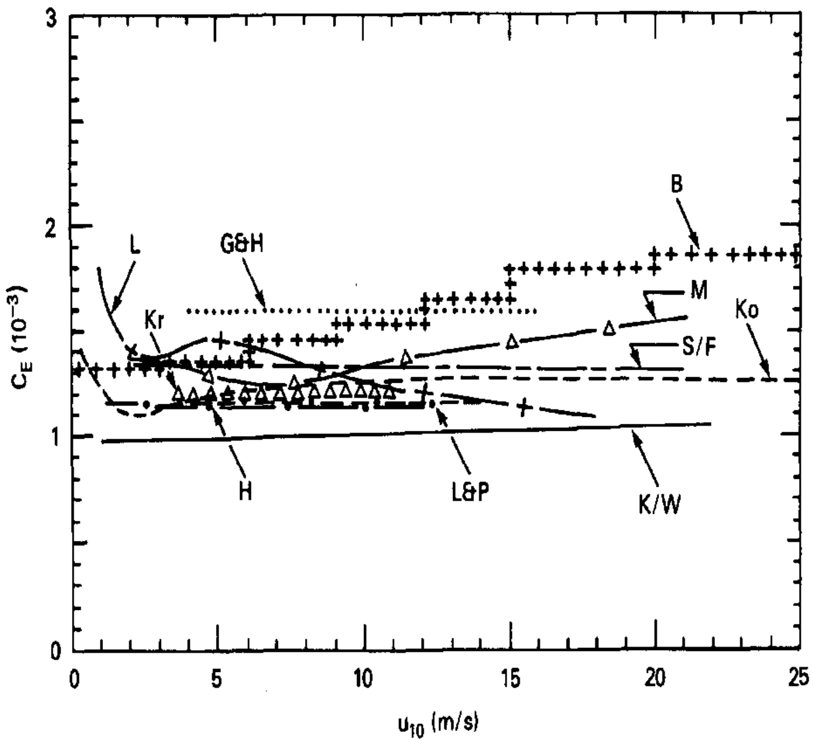
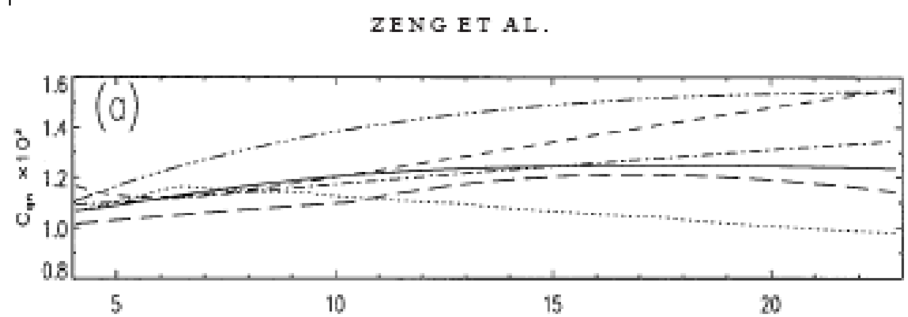
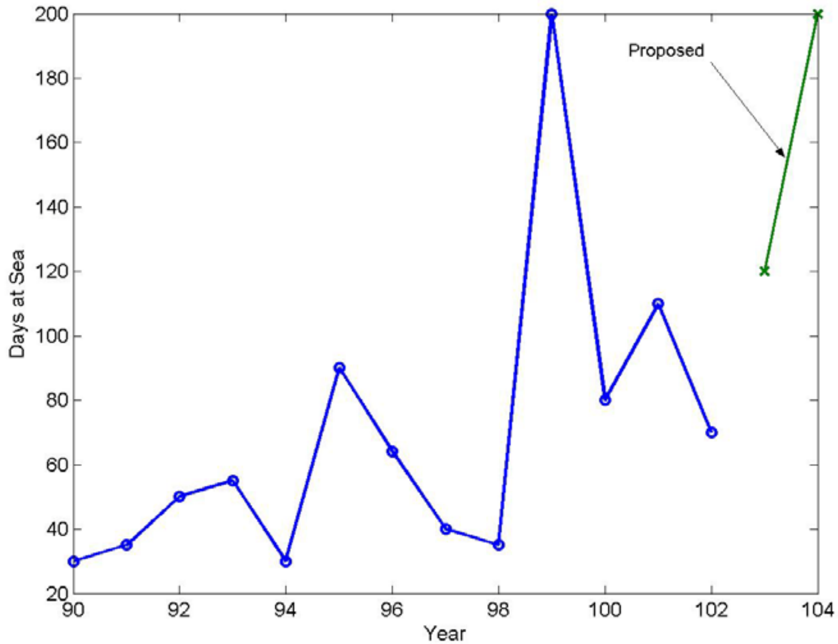


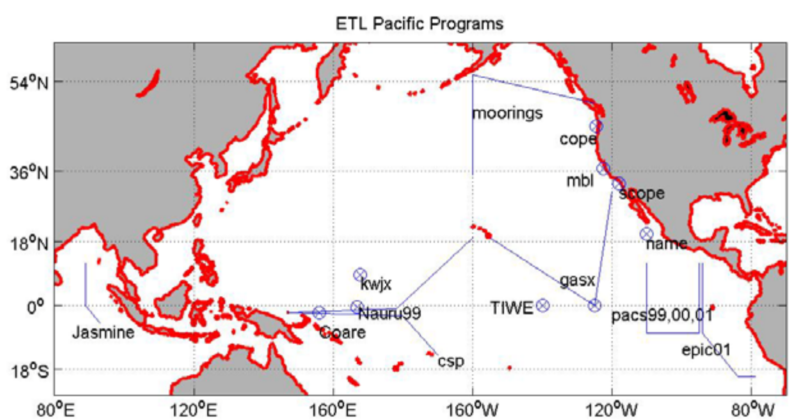
FIG. 3. Humidity coefficients (C_E) for the ten selected schemes under neutral or slightly unstable conditions as a function of the wind speed (u_{10}) at an altitude of 10 m. Scheme acronyms are given in Table 1.

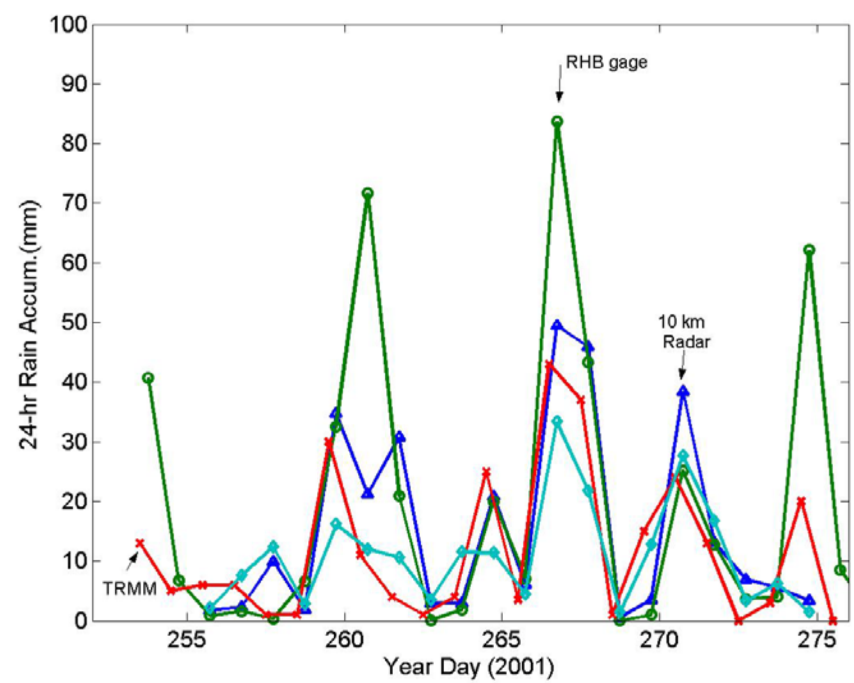


Algorithms of UA (solid lines), COARE 2.5 (dotted lines), CCM3 (short-dashed lines), ECMWF (dot-dashed lines), NCEP (tripledot-dashed lines), and GEOS (long-dashed lines) .


Proposed
Days at Sea
200
180
160
140
120
100
80
60
40
20
90
92
94
96
98
100
102
104
Year


NOAA
R 104

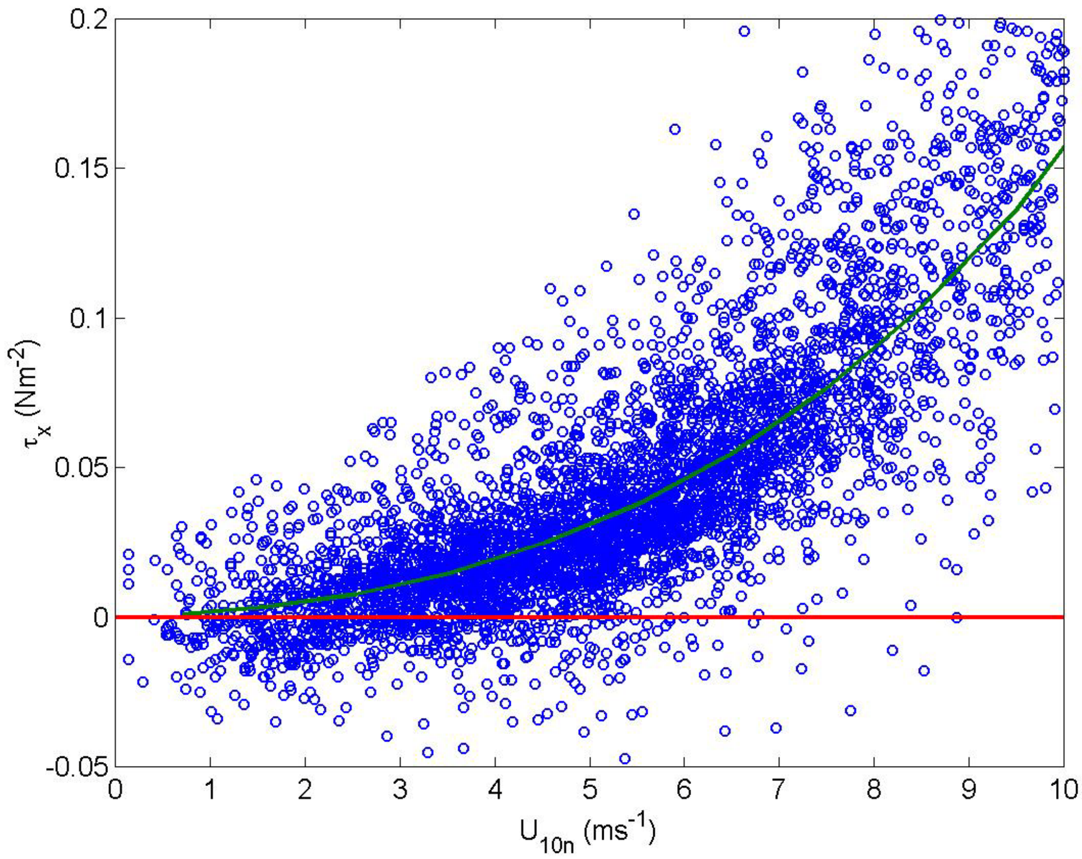

ETL Pacific Programs
54°N
36°N
18°N
0°
18°S
80°E
120°E
160°E
160°W
120°W
80°W
moorings
cope
mbl
scope
name
kwjx
Nauru99
Coare
csp
TIWE
gasx
pacs99,00,01
epic01
Jasmine


RHB gage
10 km
Radar
TRMM
24-hr Rain Accum.(mm)
100
90
80
70
60
50
40
30
20
10
0
255
260
265
270
275
Year Day (2001)

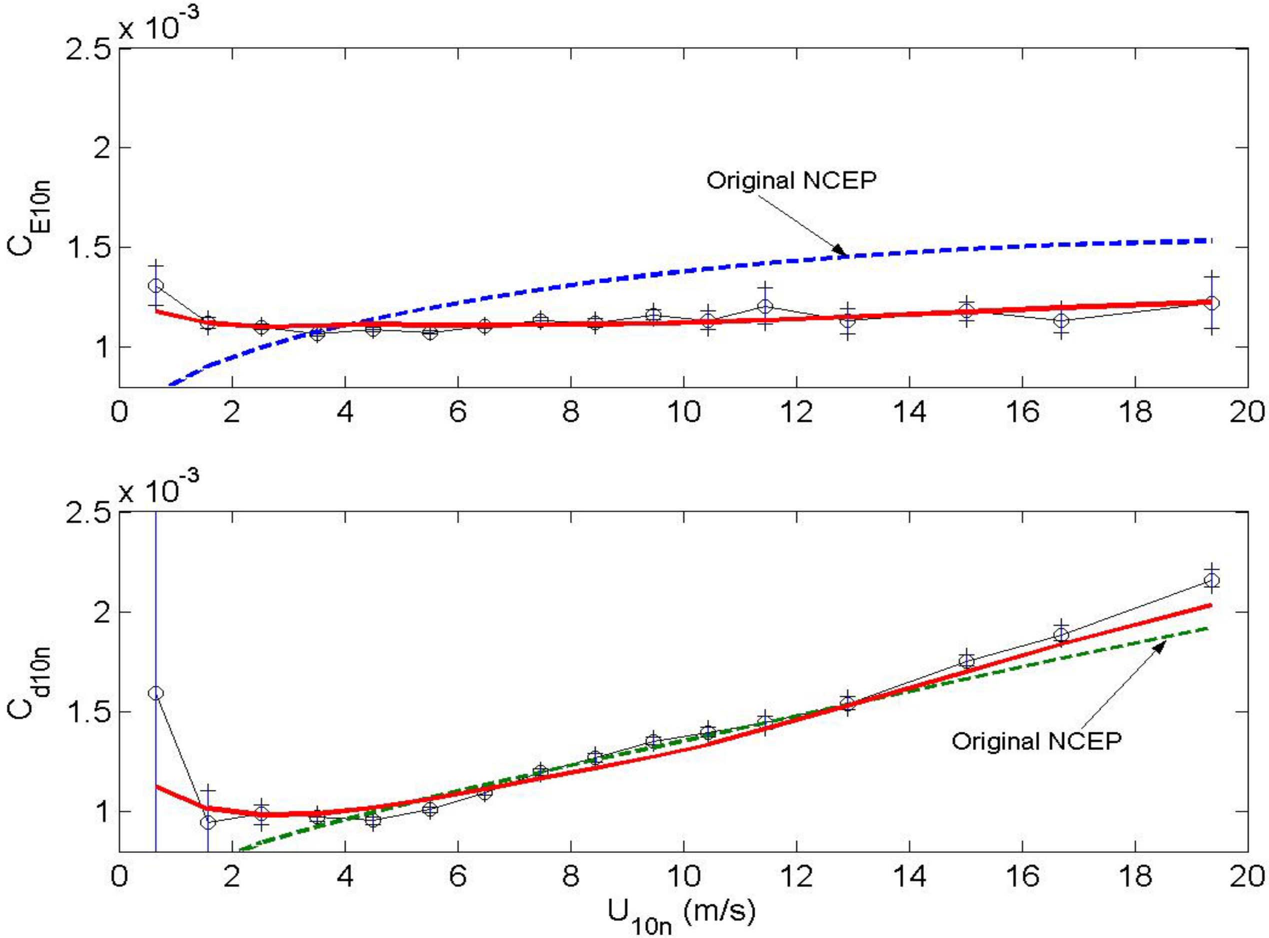
COARE MODEL HISTORY

- 1996 Bulk Meteorological fluxes ($k_u = u^* C_d$)
  - Update 2003 (8000 eddy covariance obs)
  - Oceanic cool skin module – molecular sublayer
- 2000 CO_2
- 2004 DMS
- 2006 Ozone

$$\tau_x = C_d U^2 = -\rho_a \overline{w'u'}$$

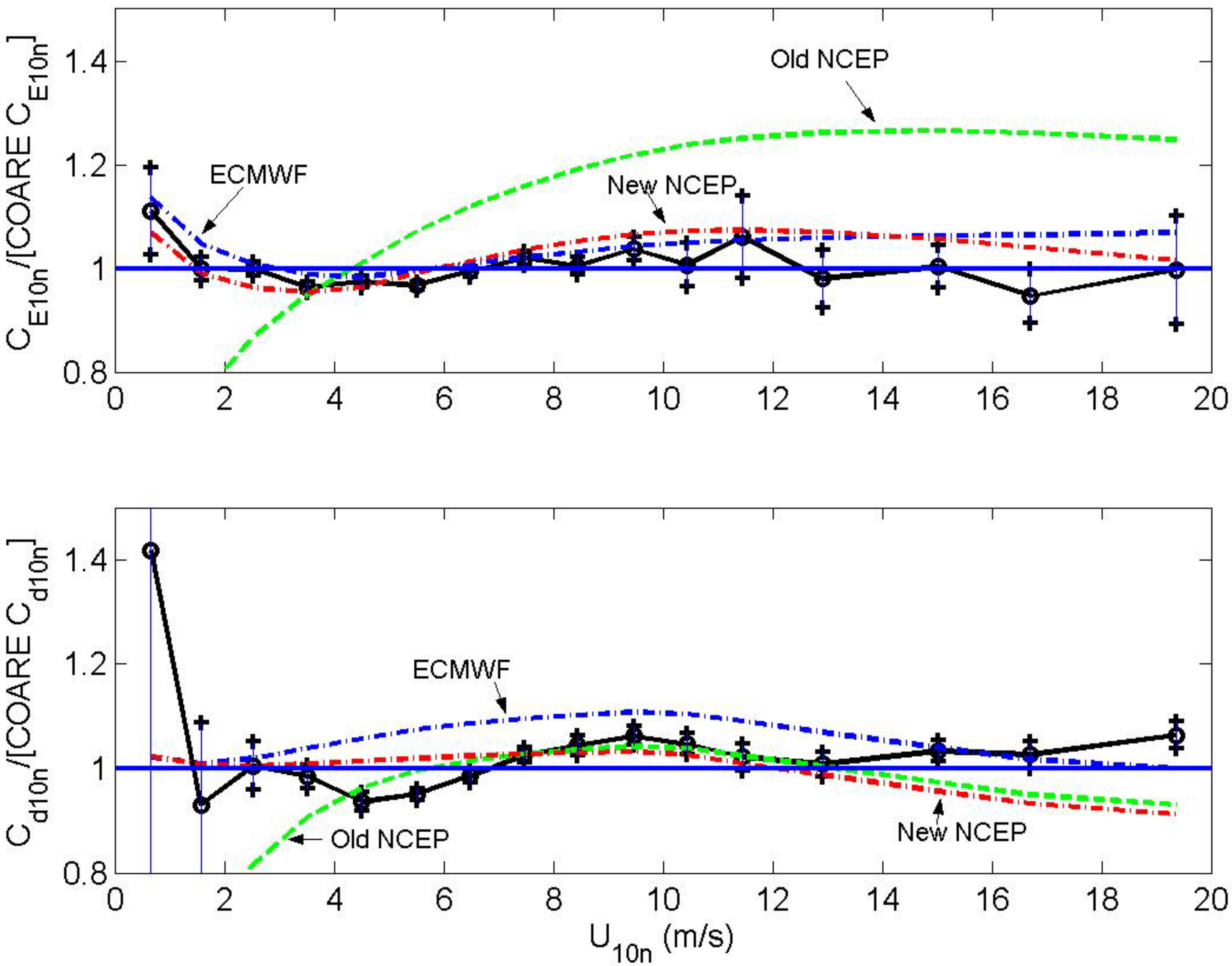


Results from 13 Cruises in 8 years

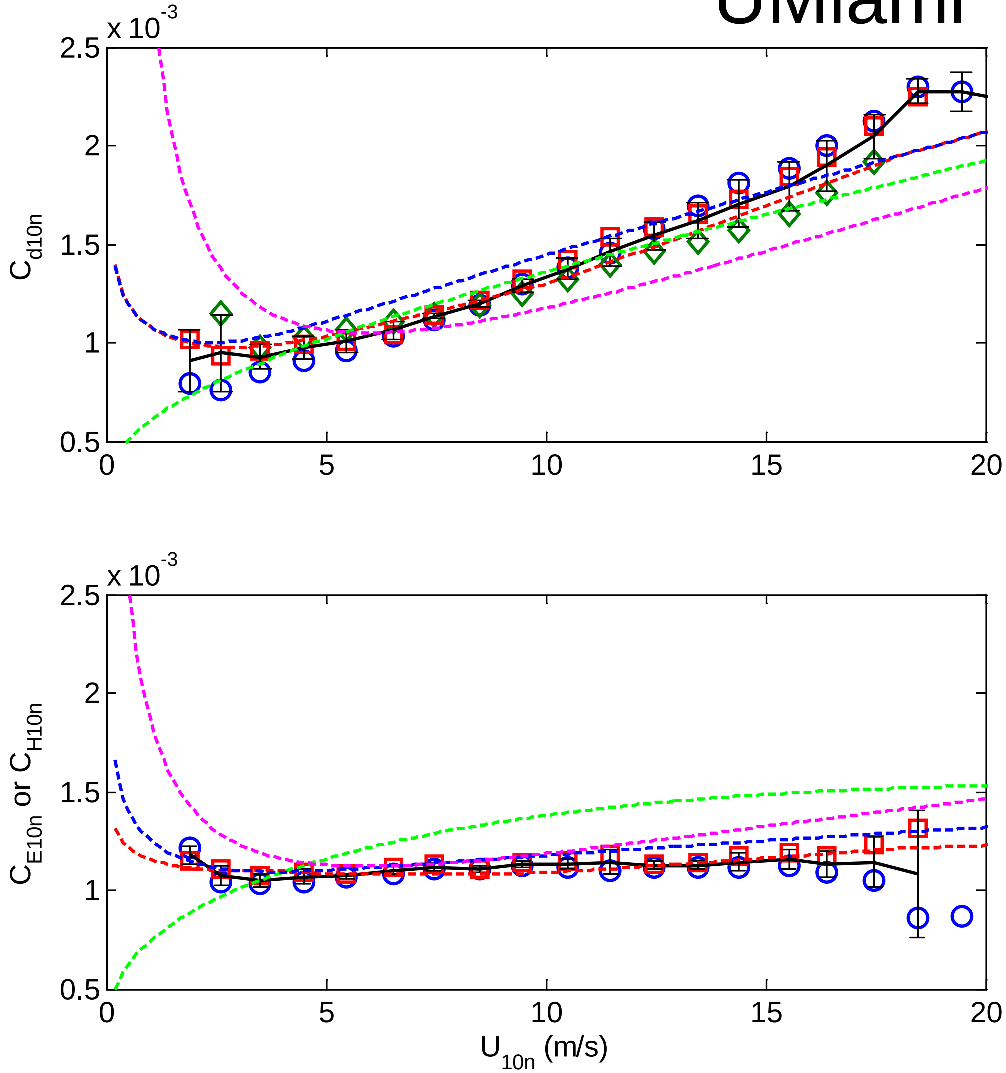


Air-Sea transfer coefficients as a function of wind speed: latent heat flux (upper panel) and momentum flux (lower panel). The red line is the COARE algorithm version 3.0; the circles are the average of direct flux measurements from 12 ETL cruises (1990-1999); the dashed line the original NCEP model.

Observations Normalized by Model

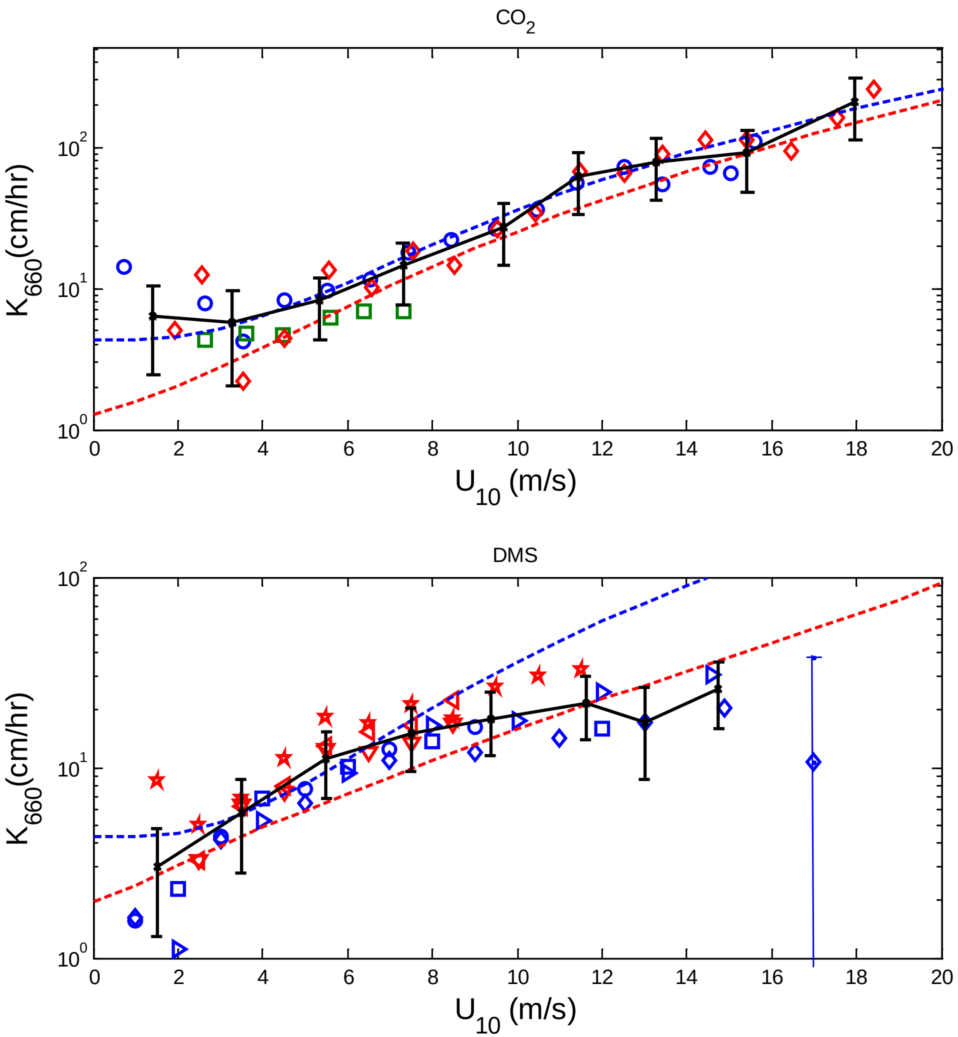


Combined Observations from Three Research Groups: ESRL, UConn, UMiami



10-m neutral turbulent transfer coefficients as a function of 10-m neutral wind speed from direct surface-based observations. Symbols are: circle – U. Connecticut (FLIP, Martha's Vineyard Observatory, and moored buoys), diamond – U. Miami (ASIS spar buoy), and square – NOAA/ESRL (ships). Upper panel: C_{d10n}; Lower panel: C_{E10n} (ESRL) and C_{H10n} (U. Connecticut). The black line is the mean of the data sets; the error bars are statistical estimates of the uncertainty in the mean. The parameterizations shown are **COARE** algorithm (red), **NCEP** reanalysis (green), **ECMWF** (blue), **Large and Yeager** (magenta).

Combined Observations from 6 Research Groups



Gas transfer coefficient coefficients as a function of 10-m neutral wind speed from direct surface-based observations. The black line is the mean of the data sets; the error bars are statistical estimates of the uncertainty in the mean. Upper panel CO_2, symbols are: circle - GASEX98, square - GASEX01, diamond – GASEX08 (data courtesy J. Edson, W. McGillis). The parameterizations shown are: blue dashed line - McGillis et al 2001, red dashed line – NOAA/COARE *CO_2*. Lower panel DMS, symbols are: square- Sargasso, circle - TAO, right triangle – DOGEE, diamond – GASEX08, left triangle - Wecoma04, down triangle - Knorr 06, pentagram - Knorr 07 (data courtesy B. Huebert - blue symbols) and E. Saltzman - red symbols)). The parameterizations shown are: blue dashed line - McGillis et al 2001, red dashed line – NOAA/COARE *DMS*.