Air-sea Fluxes: BOMEX to EUREC4A/ATOMIC

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- What are fluxes?
- Why do we want fluxes?
- Measurement
- Issues
- BOMEX
- Modern

Fluxes In General

Budget equation for variable
x=X+x’

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

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

Volume source becomes an area flux $S_x = \int_z^\infty Q_x(z)dz$

<w’x’> turbulent transport

Source Examples:

Temperature – radiative flux, condensation

Water vapor – evaporation

Liquid water – condensation, sea spray

Ozone – chemical reactions in air or water, e.g. $Q_x=-C_{xy}XY$

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

Applications for Surface Fluxes

A few examples

- Model lower boundary conditions (LES, PBL, Mesoscale, NWP, GCM)
- Ocean budgets (stress, heat, waves, sea-ice)
- Carbon budgets (uptake CO2 by oceans)
- Pollution deposition (particle, ozone)
- Cloud microphysics (aerosol source, DMS source of sulfur)
- Hurricane intensity
- Global warming

Turbulent Flux Definitions

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

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

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

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

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

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

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

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

Surface Energy and Mass Budgets

$$Net\ Surface\ Energy = -H_s - H_l + R_{sd} - R_{su} + R_{ld} - R_{lu} + H_{Rain}$$

$$Net\ Water = Rain - H_l/(\rho_a L_e)$$

Surface Turbulent Flux Parameterization

Turbulent Fluxes: Parameterization using U, Ts, T, etc.

Flux= Mean correlation of turbulent variables, <w'x'>

MetFlux – Dominated by **atmospheric** turbulent transfer physics

GasFlux – Dominated by **oceanic molecular** transfer physics;

Enhanced by whitecap bubbles

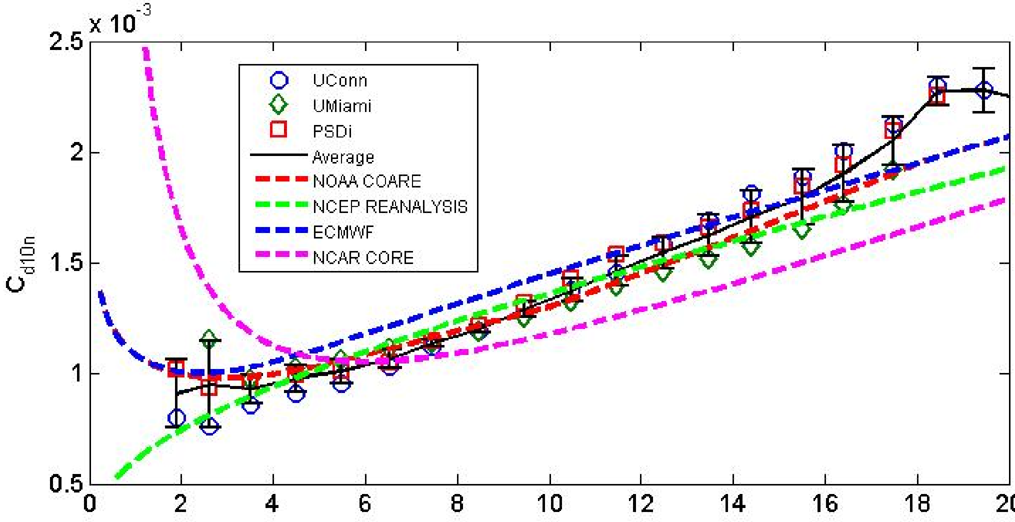
$$Met\ Flux: \overline{w'x'} = C_x U (X_s - X_r) = C_x U \Delta X$$

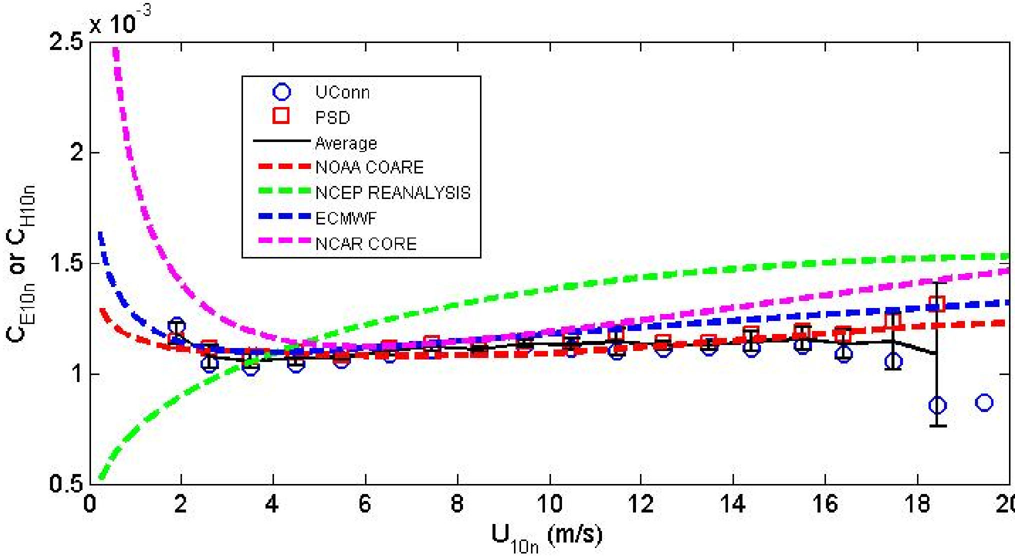
$$Gas\ Flux: \overline{w'x'} = k_x \alpha_x \Delta X \qquad \alpha = sol.$$

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

Transfer coefficients computed from direct flux measurements

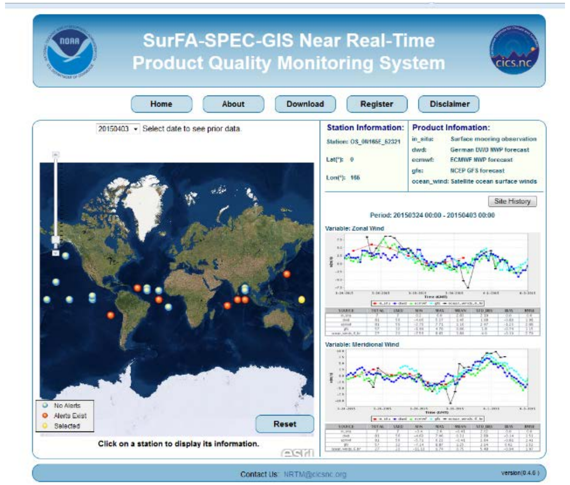
$$C_x = -\overline{w'x'}/[U\Delta X]$$



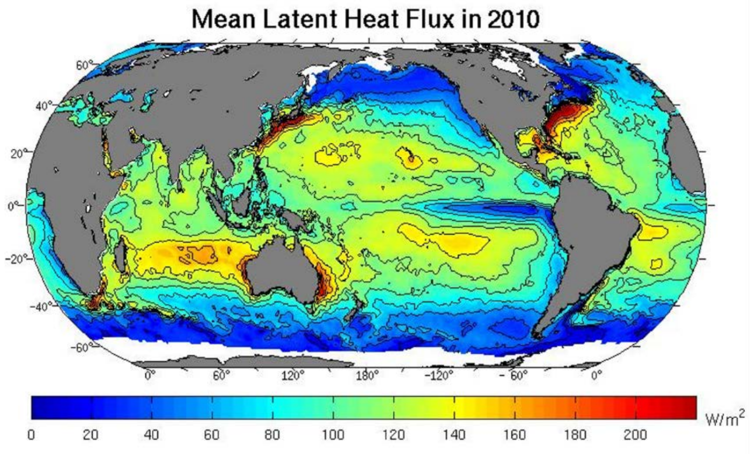


Community Flux Products Using Bulk Estimates

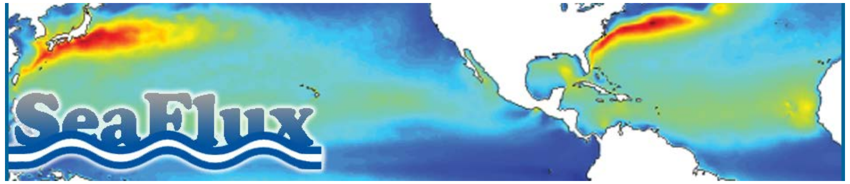
- NWP: SURFA Archived flux fields from ECMWF, DWD, JMA

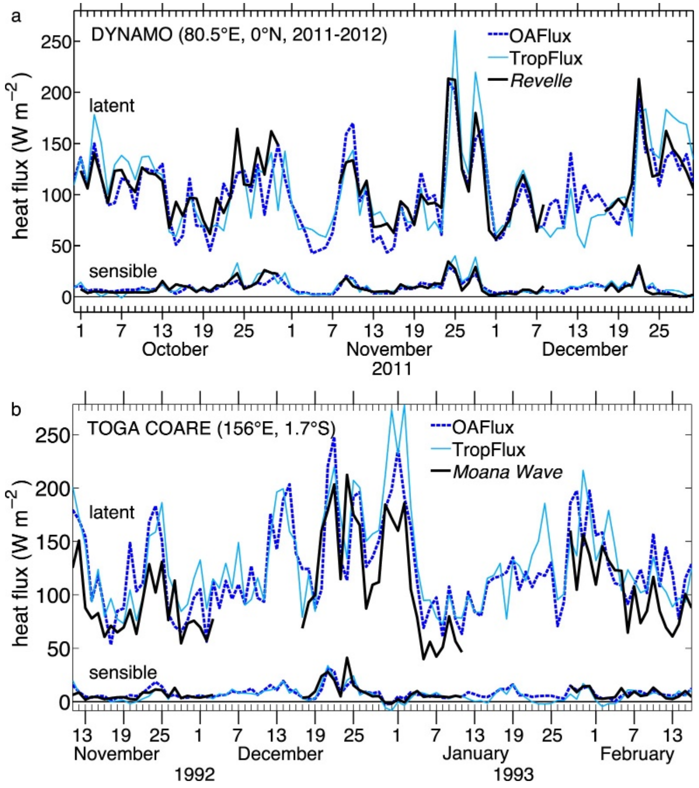


- Blended: WHOI OAFlux, CORE,..



Satellite: SEAFLUX, GSSTF, HOAPS, JOFURO, IFREMER





Measurement Near-Surface Turbulent Fluxes <w'x'>

- Sensors (w', x')
  - 10 Hz, 3 digit resolution, 2.5% accuracy, withstand marine environment
- Platform
  - Ship, buoy, aircraft, pier, ocean- or land-based tower
- Processing
  - Fast DAS, time synchronization, high pass filtering (x=X+x'), averaging, motion corrections, coordinate transform
- Dirt effects
  - Sensor crosstalk, Sea salt and biochemical, ship effluent, radio/radar interference, flow distortion, flow distortion, birds
- Ancillary
  - All variables relevant to parameterization, platform navigation, food

BOMEX Research Vessel with Flux Sensors

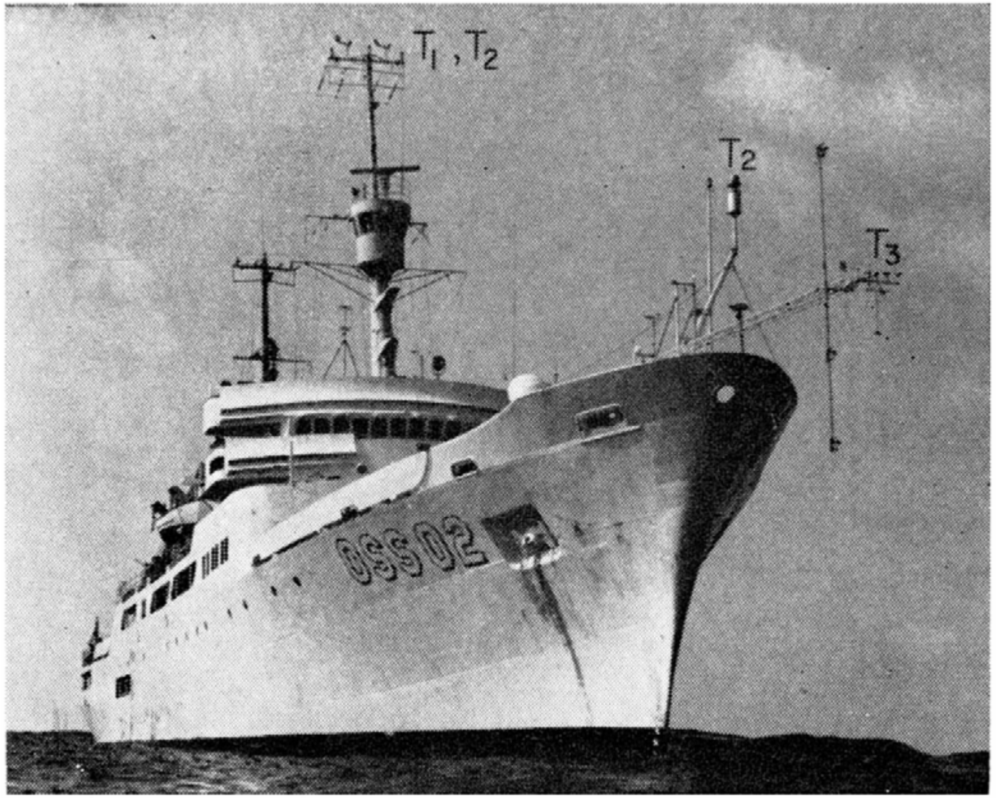


FIG. 1. United States Coast and Geodetic Survey Ship *Discoverer*. Type 1 and Type 2 winds from the aerovanes marked T1 and T2, Type 2 wet and dry bulb temperatures from hygrothermometer marked T2 and Type 3 temperatures and winds at the end of the horizontal boom marked T3. Meteorological data collected on the vertical mast on the boom were not used in this study.

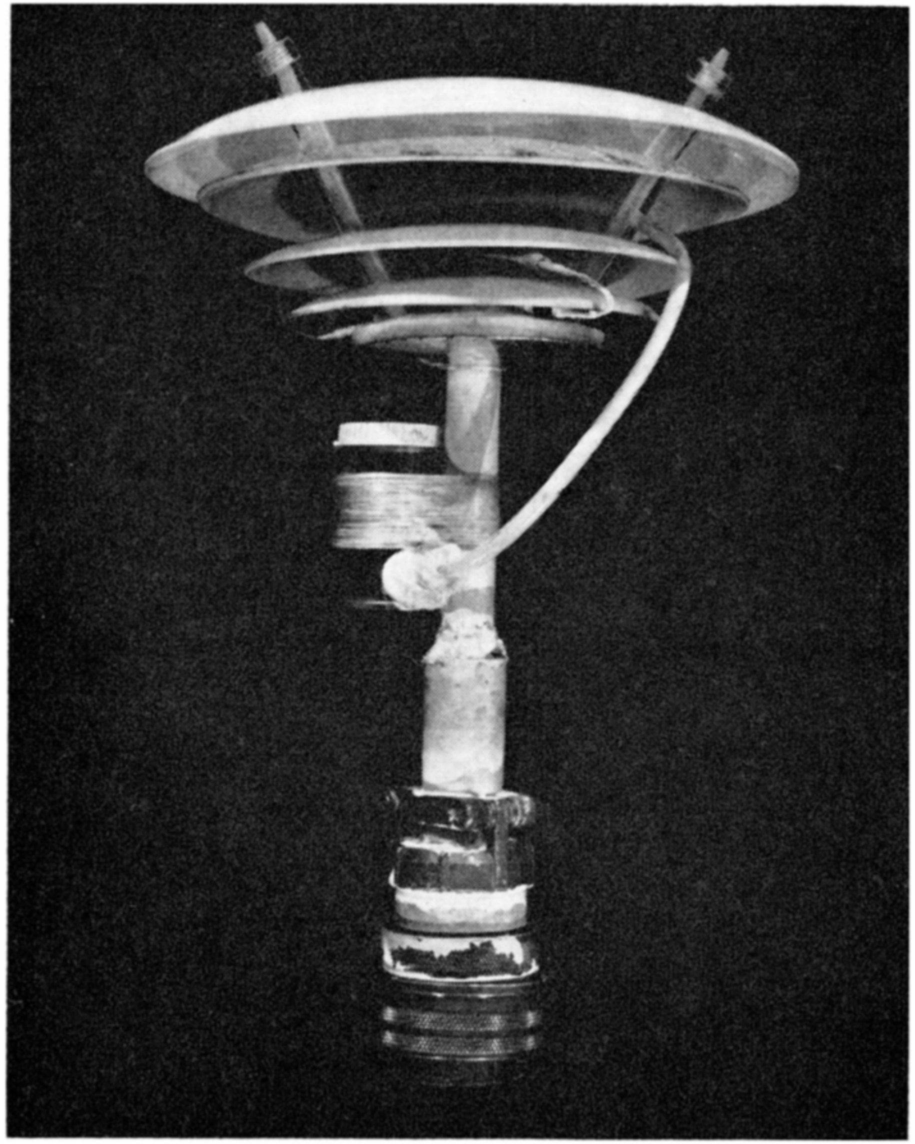
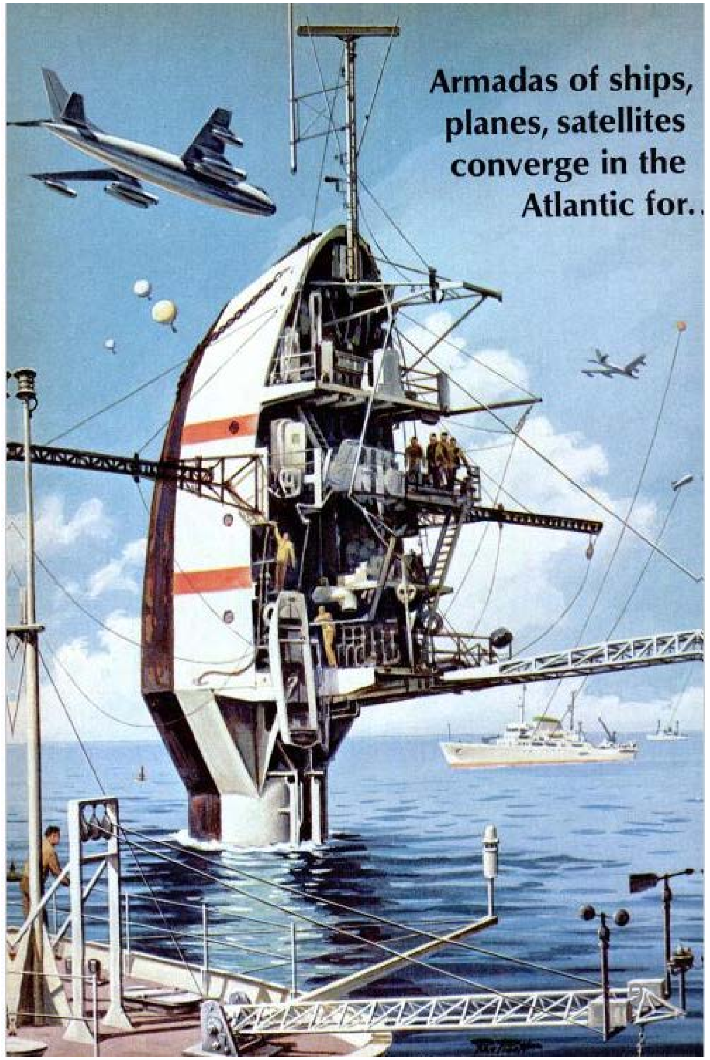
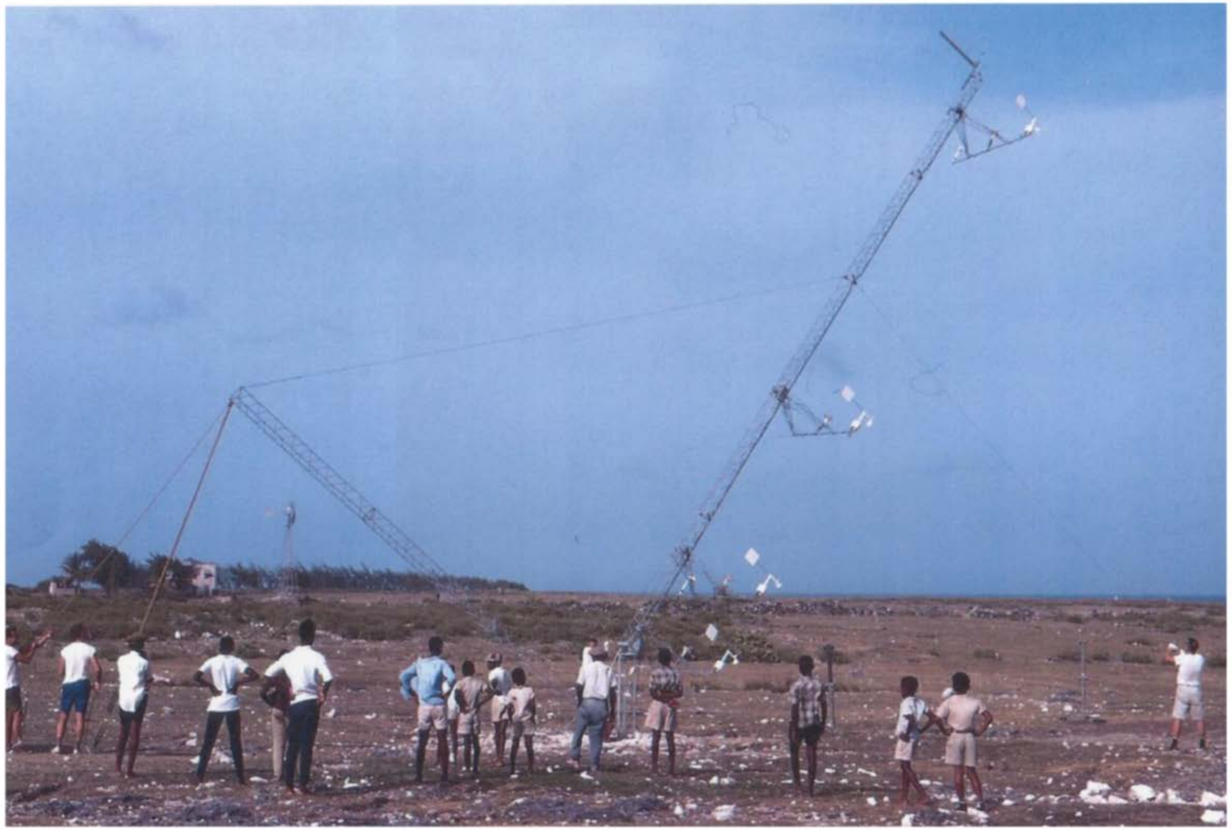


FIG. 2. Radiation shield for dry and wet bulb thermistor.

Floating Instrument Platform FLIP
World's Largest Spar Buoy



BOMEX Platforms: Land and Air

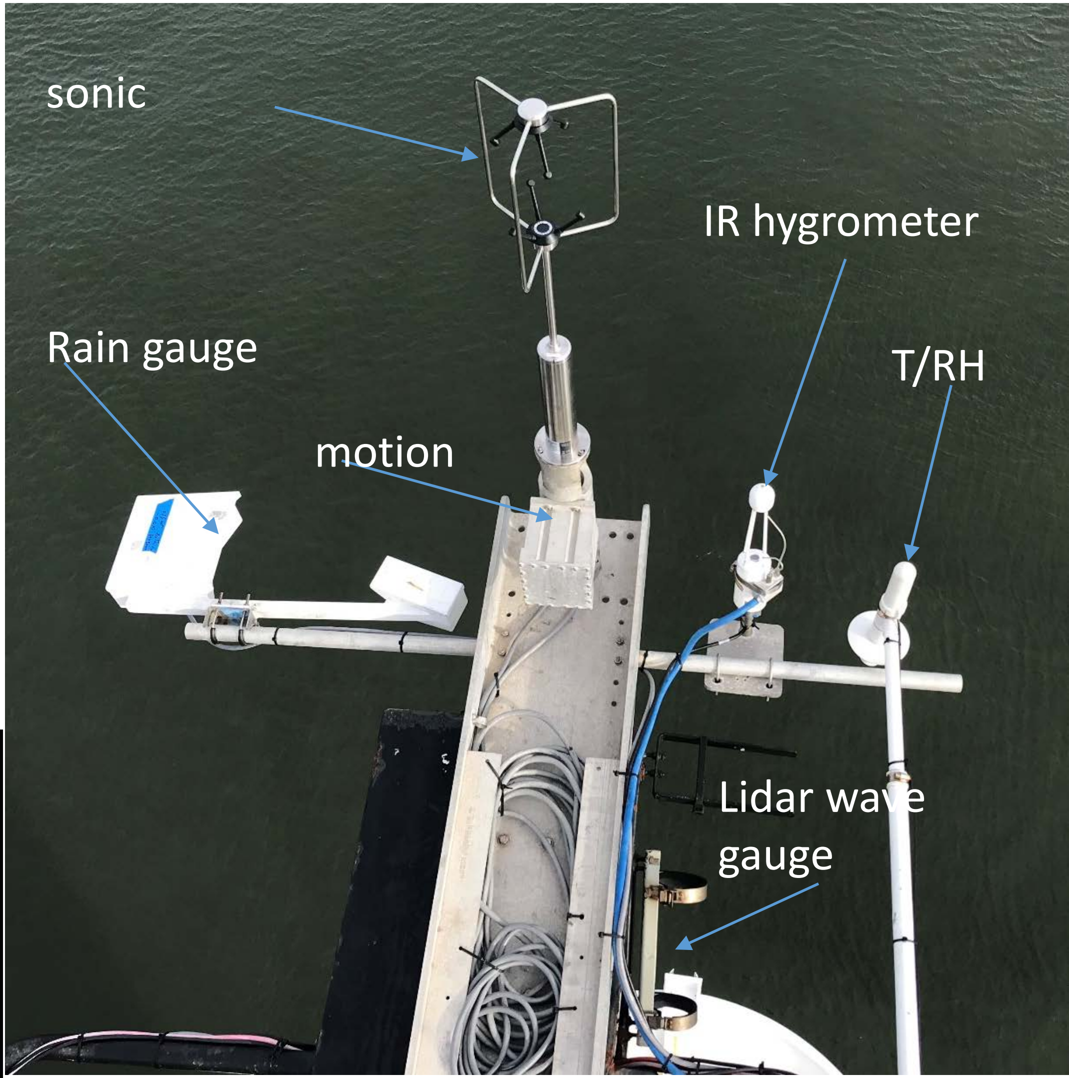


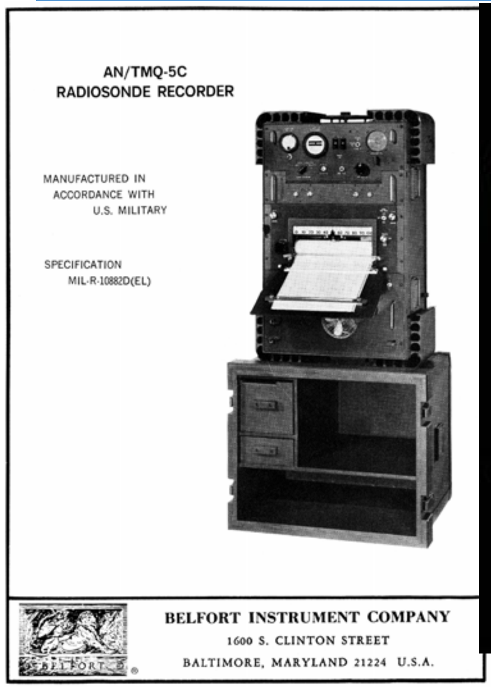
Tower on Barbados

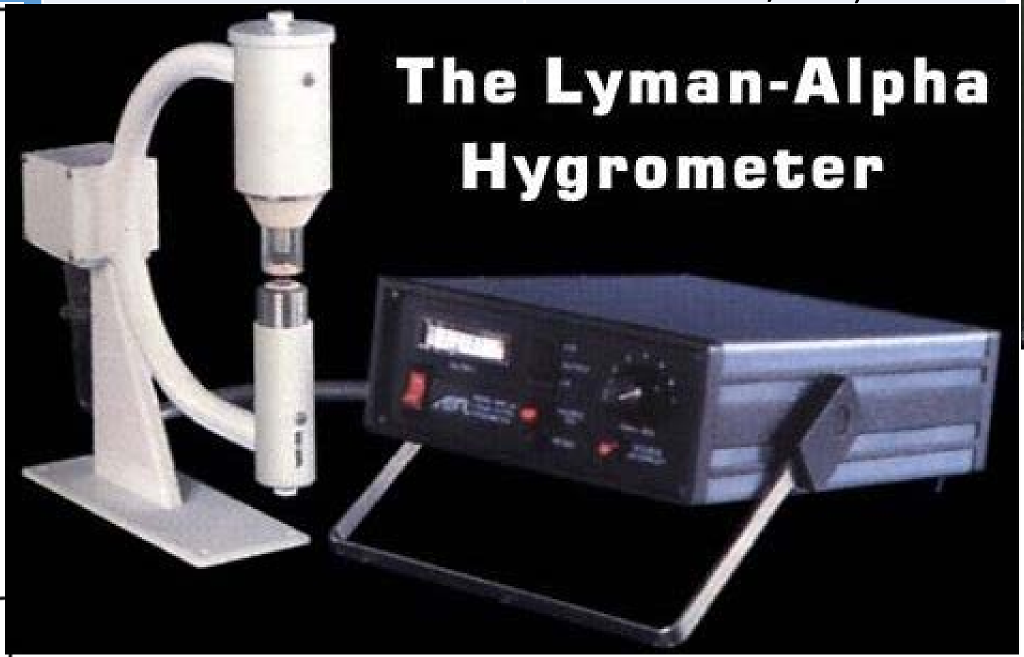
NOAA DC-6

BOMEX vs Modern

	BOMEX	EUREC4A/ATOMIC
Flux Platforms	Ships, FLIP, 2 A/C, Tower	4 ship, 4 A/C, UAS, UAV
u', v', w'	Sonic anemometer, gust vanes, propellers, hot wire anemometer	Sonic anemometer, 5-hole pressure ports
T'	Microthermal wires	Sonic anemometer, Microthermal (UAS)
q'	1 channel UV absorption, wet/dry bulbs	3-channel IR absorption
Motion	FLIP (cheating), INS	IMU (combined accelerations/GPS)





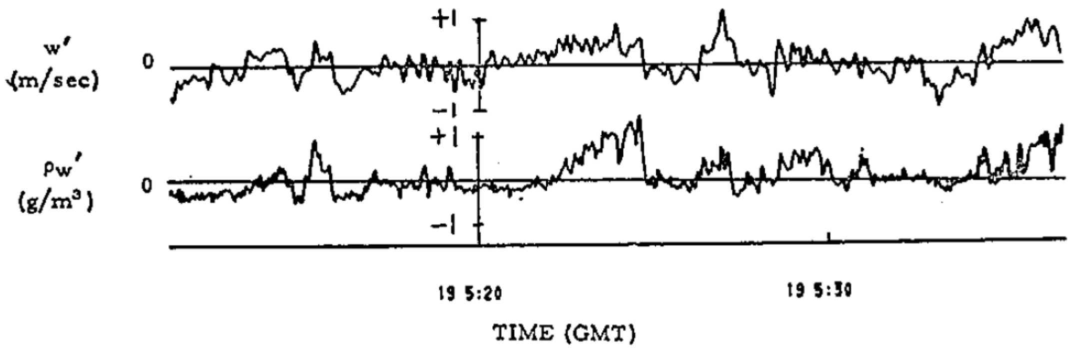


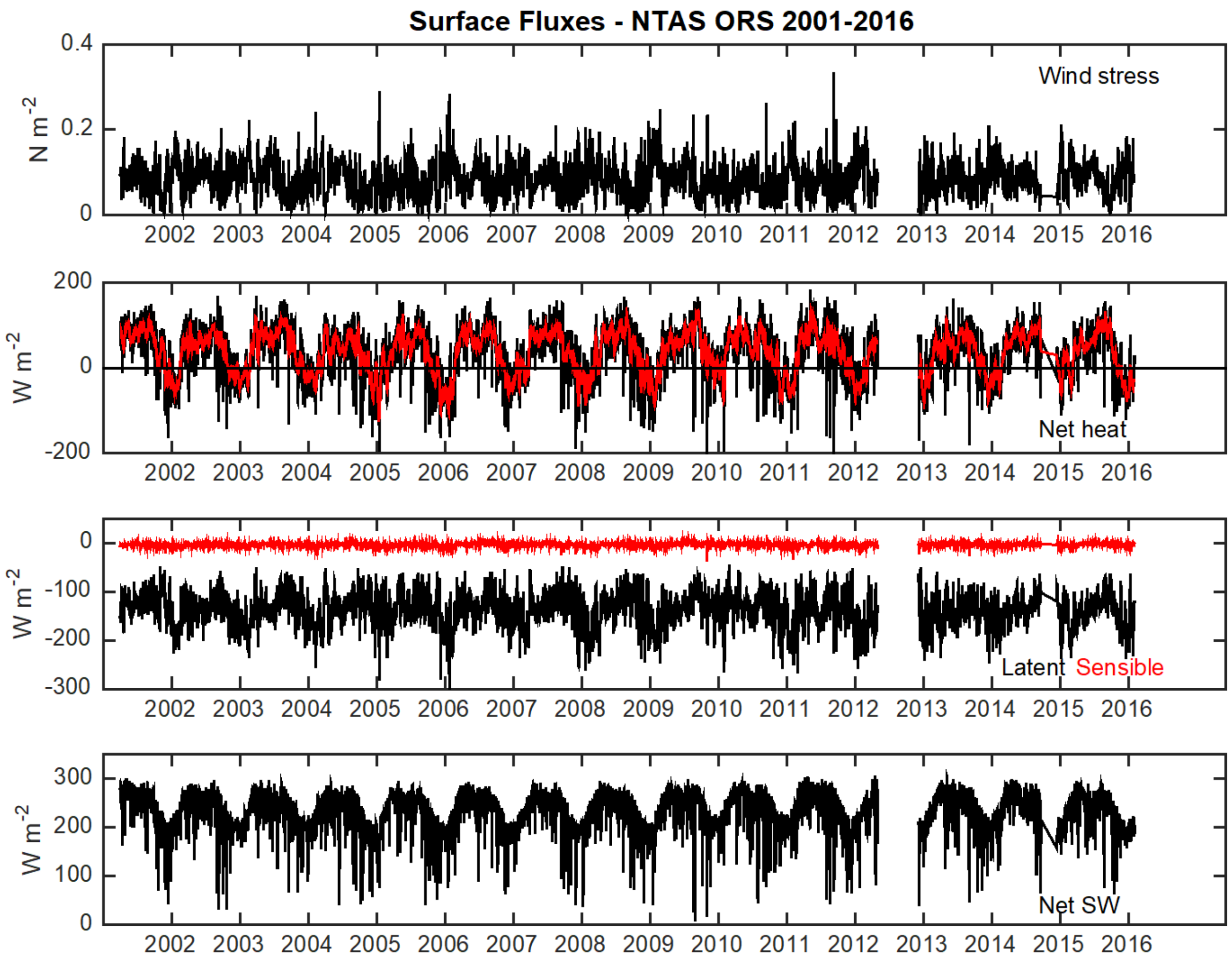
BOMEX Latent Heat Flux Estimates

Table 3. BOMEX average evaporation rates, mm day^{-1}

	May 5-12	June 20-26	June 28 - July 2
Atmospheric budget (rawinsondes)		6.0	
Ocean heat budget		5.8	6.1
Covariance: NOAA aircraft	5.8		6.1
Covariance: FLIP (OSU;UBC)	4.9		
Profile: FLIP (UW)	6.0		
Bulk aerodynamic (Deacon-Webb)	6.3	5.6	

6 mm/day = 173 W/m^2





10-m Evaporation Coefficient

Post BOMEX

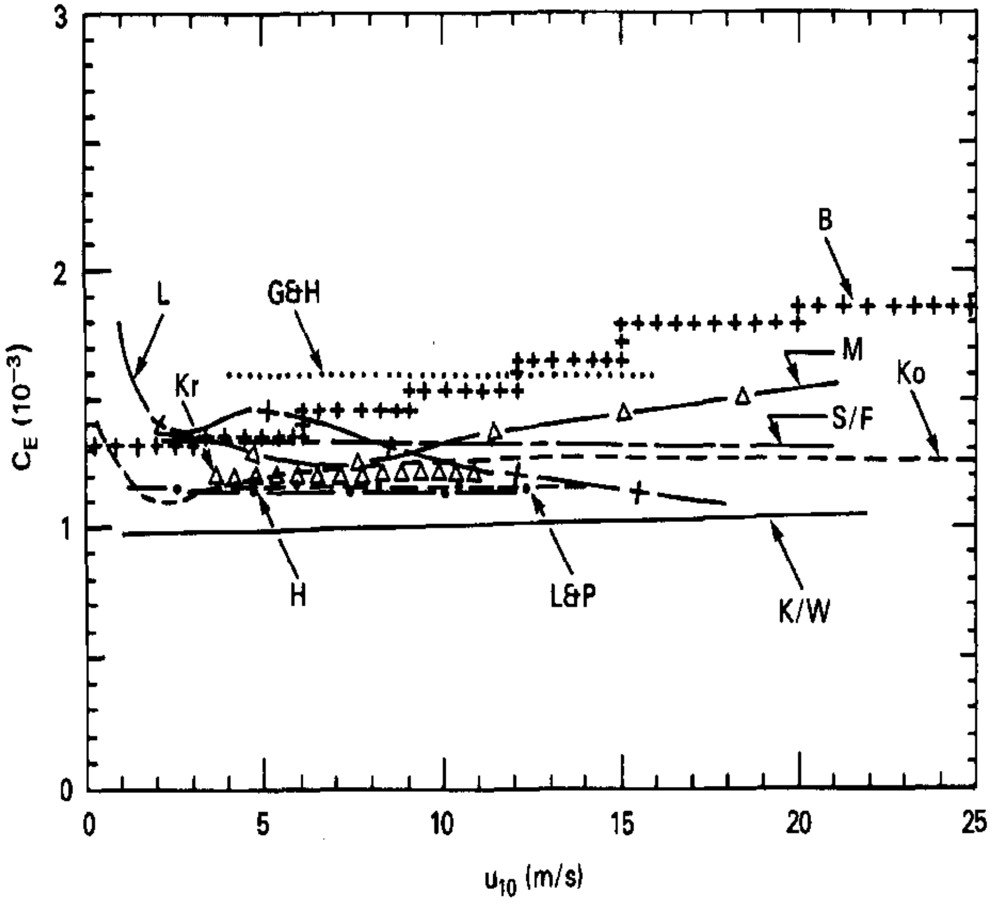
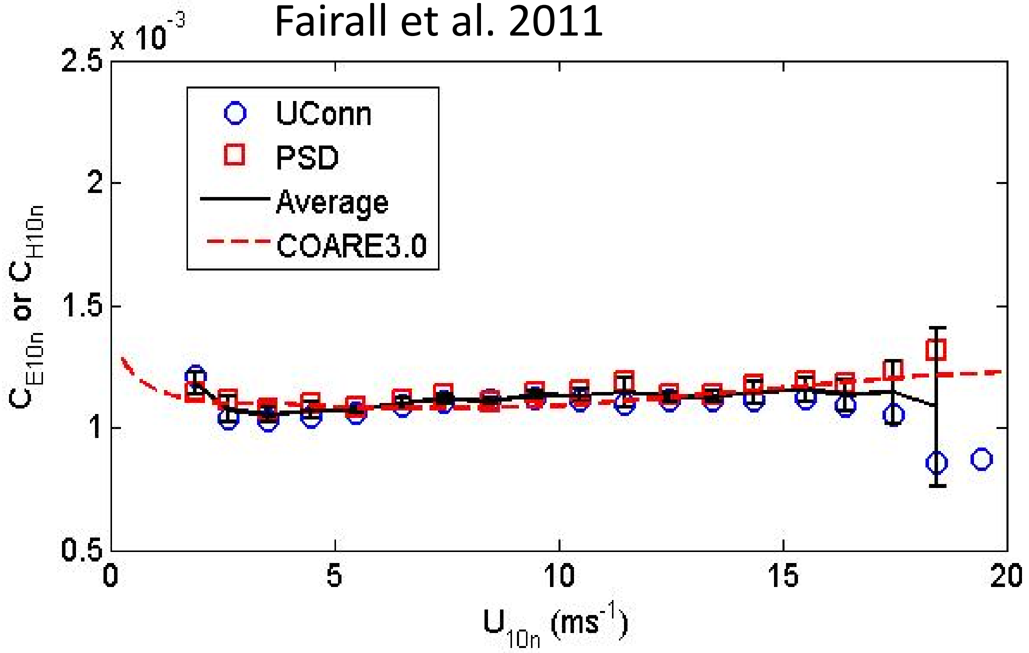
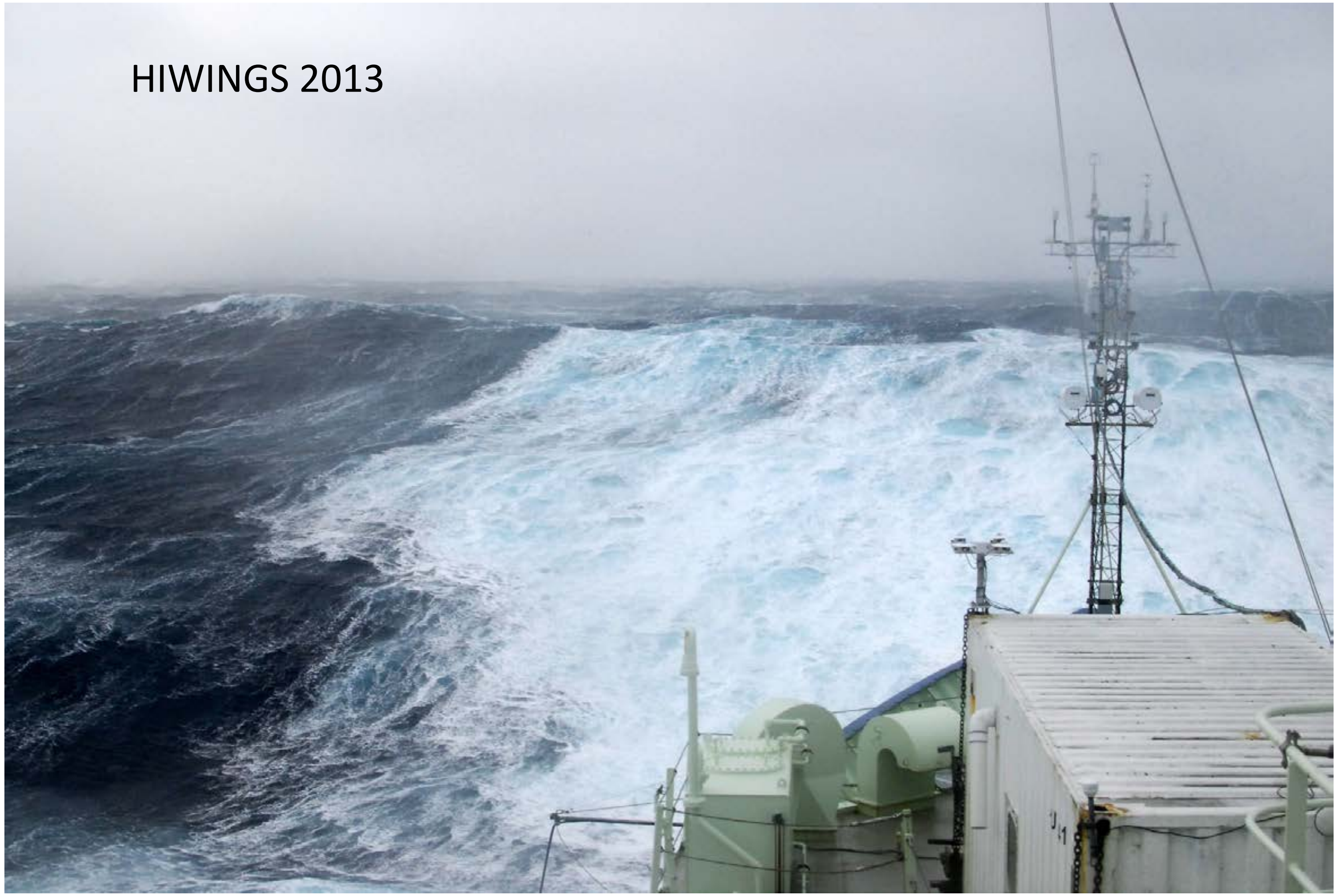


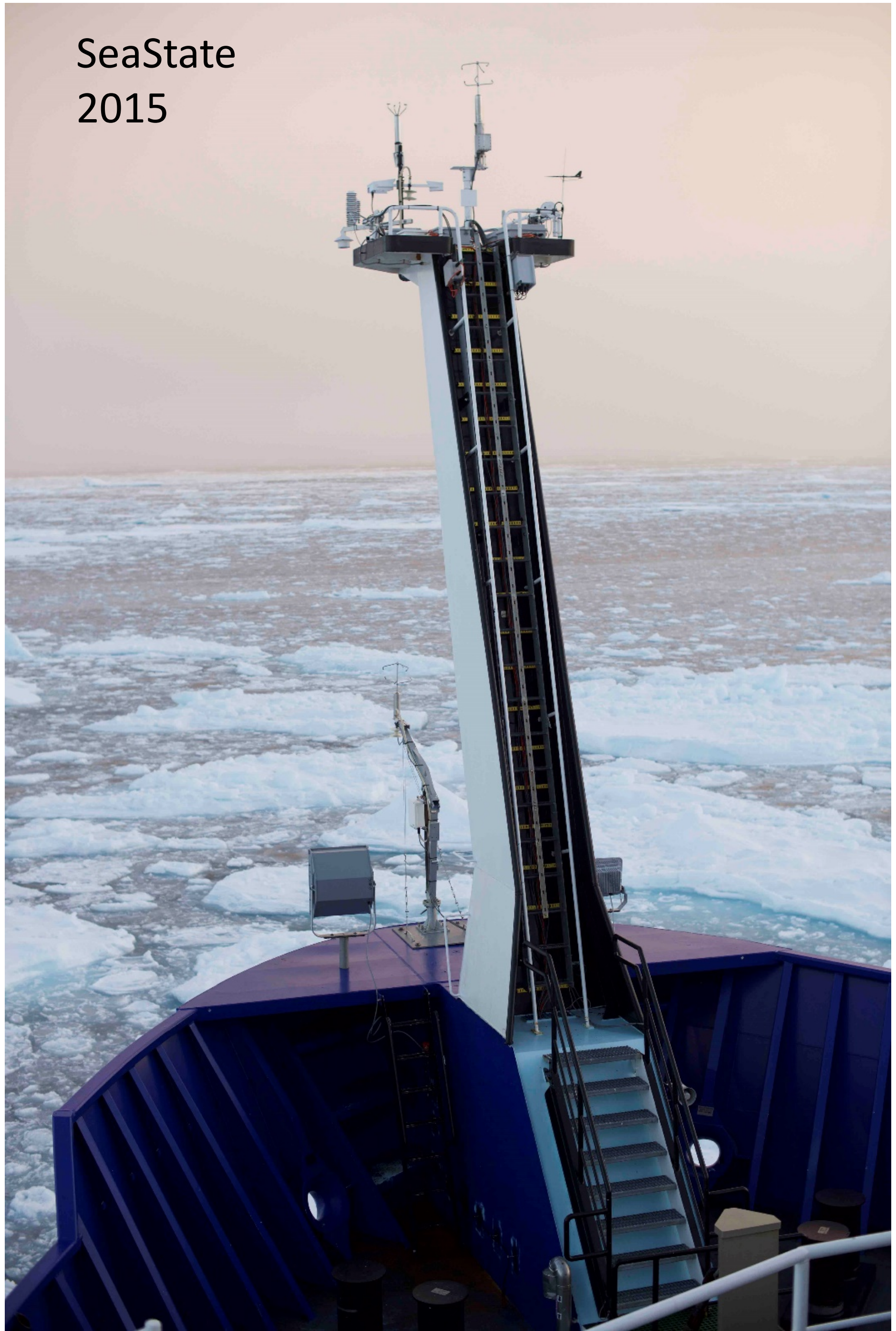
FIG. 3. Humidity coefficients (C_E) for the ten selected schemes under neutral or slightly unstable conditions as a function of the wind speed (u_{10}) at an altitude of 10 m. Scheme acronyms are given in Table 1.

Fairall et al. 2011



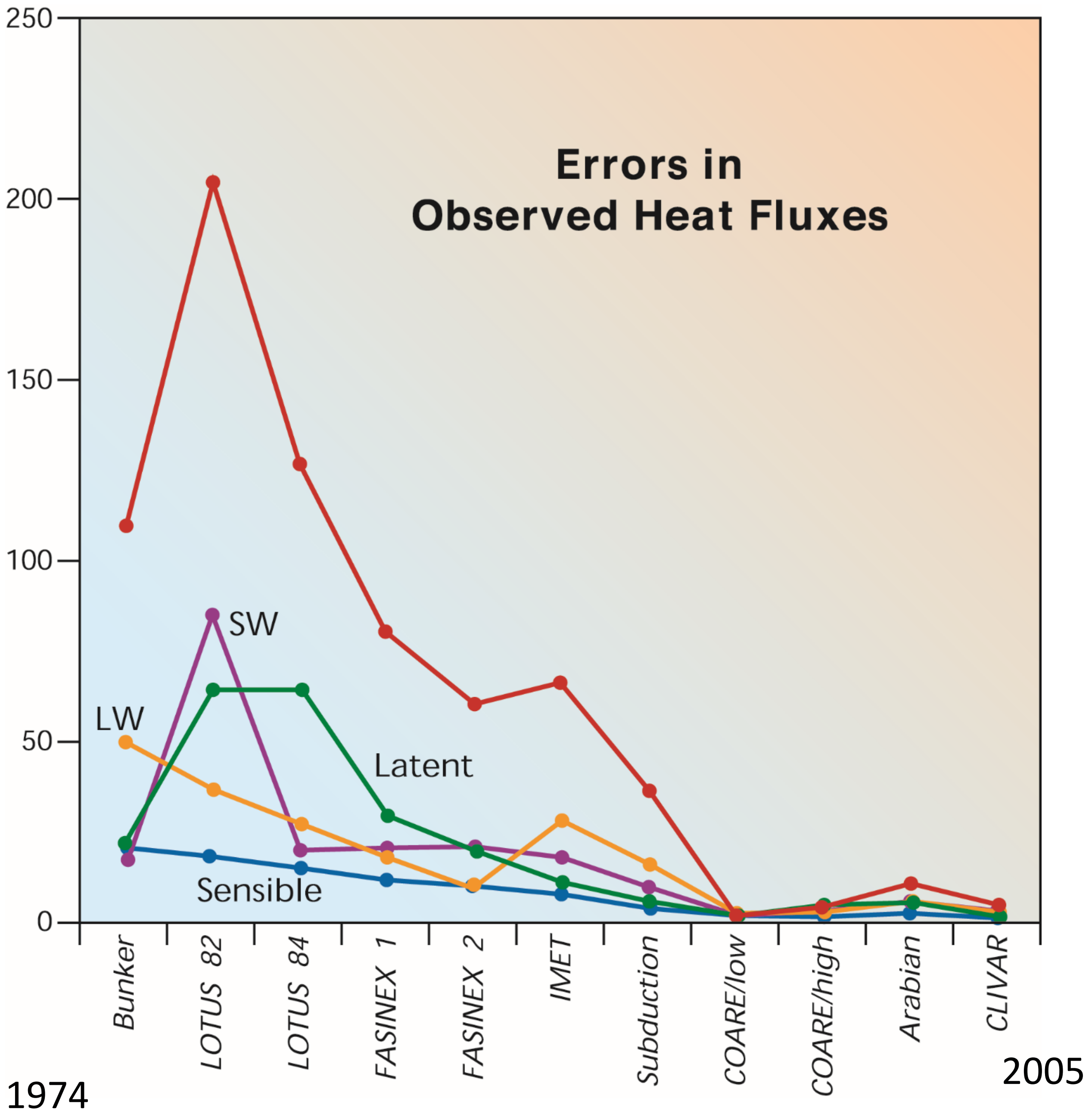
Humidity and heat 10-m transfer coefficients. Average 20,300 observations. Uconn – Hs; PSD – Hl.



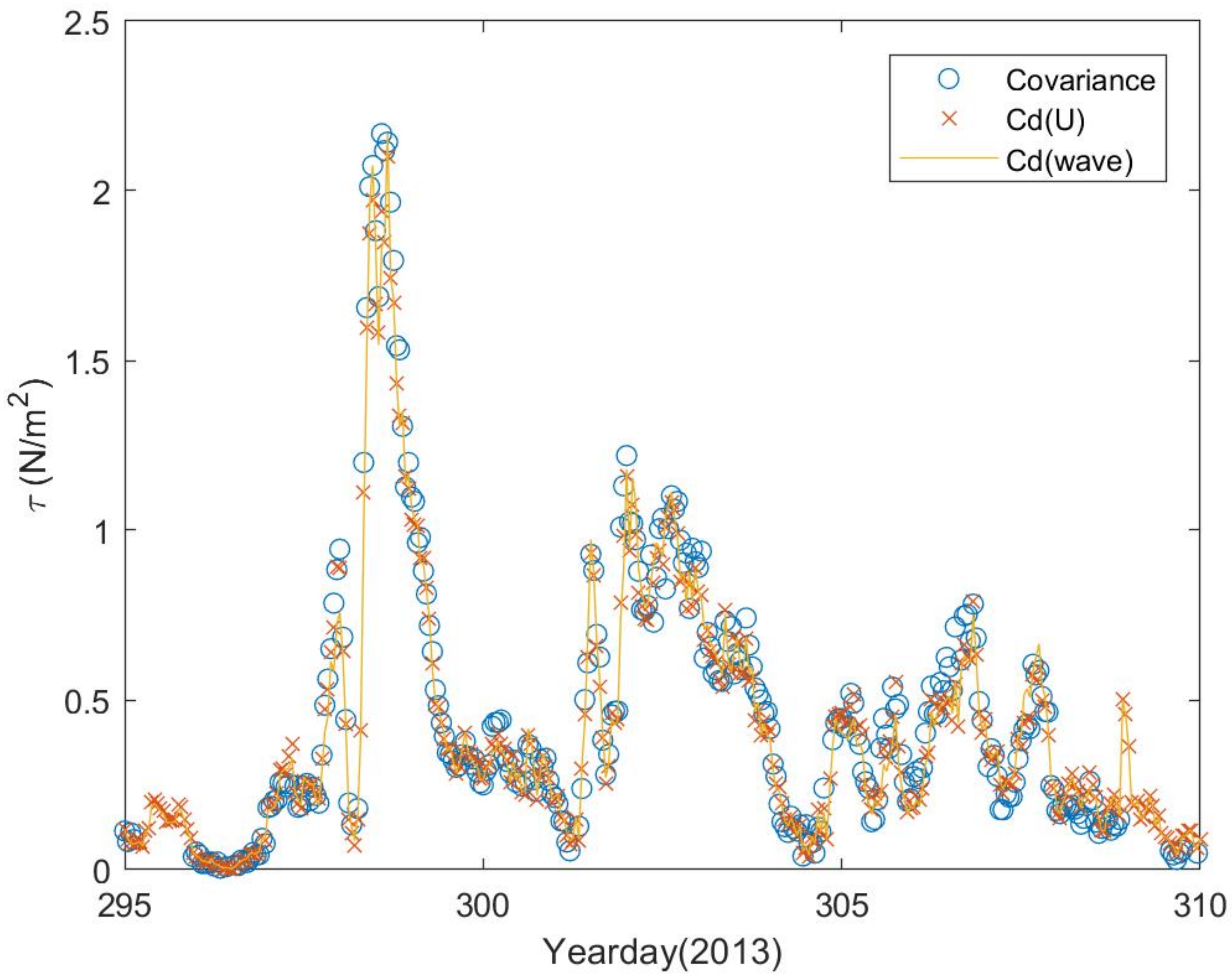


‘You cannot measure fluxes from a ship’ quote from a famous tropical meteorologist

Improved *in situ* air-sea flux observations



‘You cannot measure fluxes from a ship’ - a famous tropical meteorologist



Stress observations
HIWINGS field program
South of Greenland
November 2015.
Covariance measurements vs two versions of COARE model