Climate, Weather and Water Science

Earth System Research Laboratory

Chris Fairall

Air Sea/Ice Fluxes

Air-Sea Ice Fluxes

Light Winds to Hurricanes Poles to Tropics
Momentum, Heat, Moisture, Trace Gases, Aerosol Particles, Radiation, Precipitation

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Approach

Direct Flux Observations
Tech Development, Near-surface, Boundary-Layer Observations

Fundamental Physics
Navier-Stokes, Turbulent Kinetic Energy budget equations, scalar conservation

Flux Parameterization
Similarity scaling, cloud-radiative coupling, deposition velocities

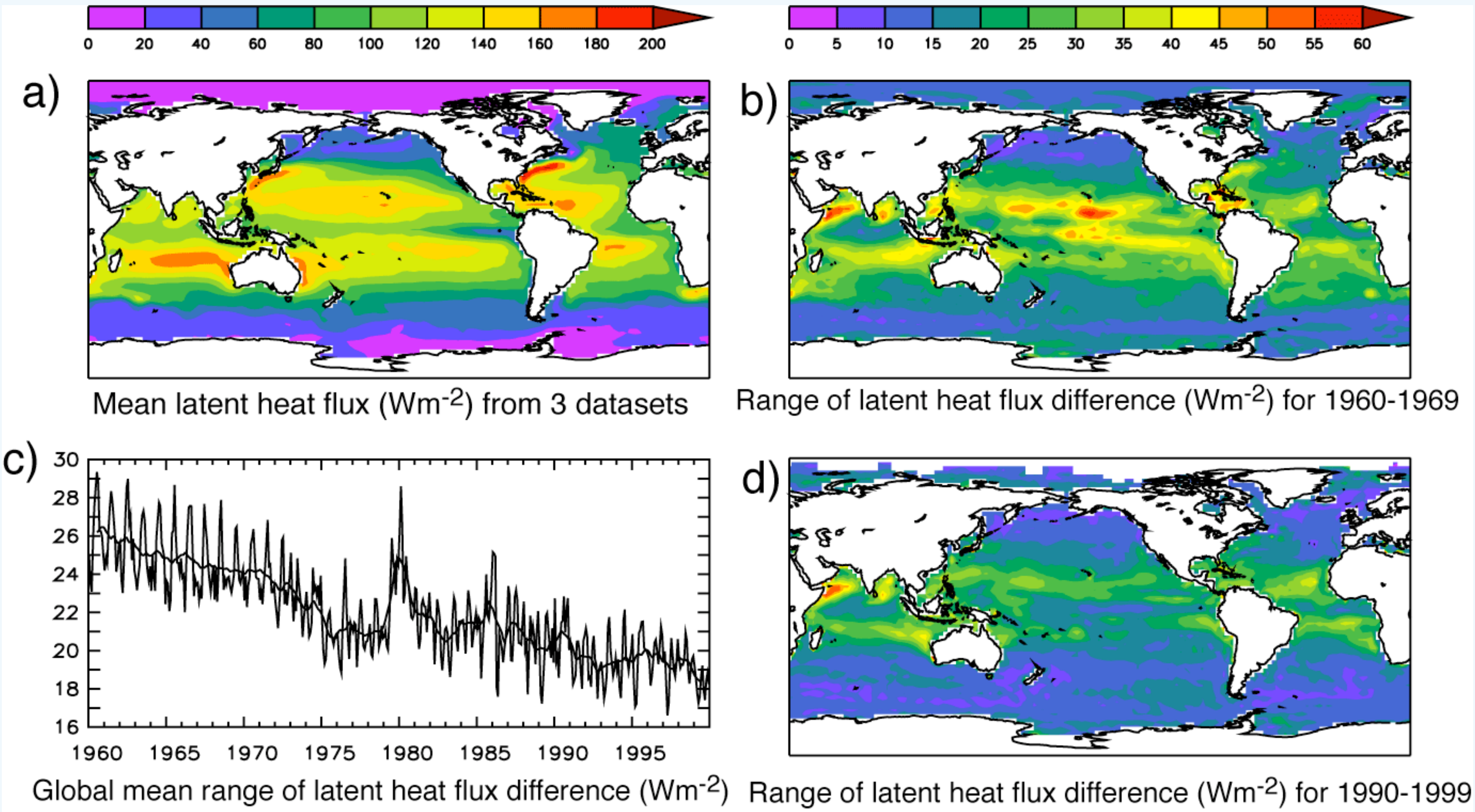
Research Numerical Models
1-D Closure, Large Eddy Simulation, Mesoscale, Cloud Resolving, Regional

Ocean Flux Observing System
Research Vessels (*SAMOS*), Ship Opportunity (*COADS*), Flux Reference Buoys (*OceanSites*), Satellites (*SEAFLUX*)

NOAA Models
Operational Numerical Weather Prediction
Climate Models

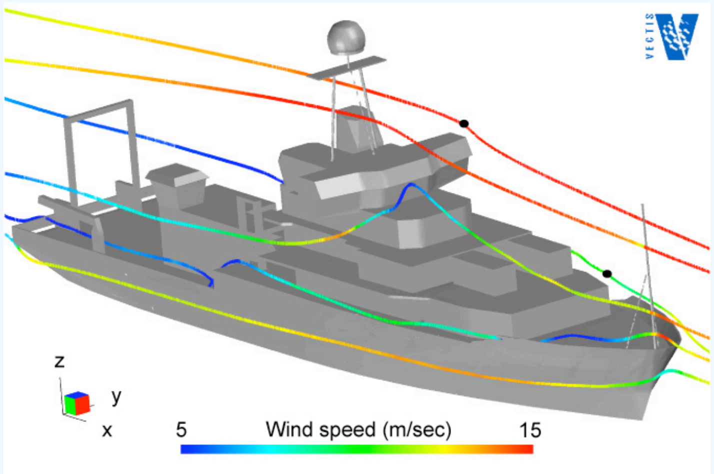
- **Direct data used principally to develop parameterizations, improve the observing system, and 'verify' model results**

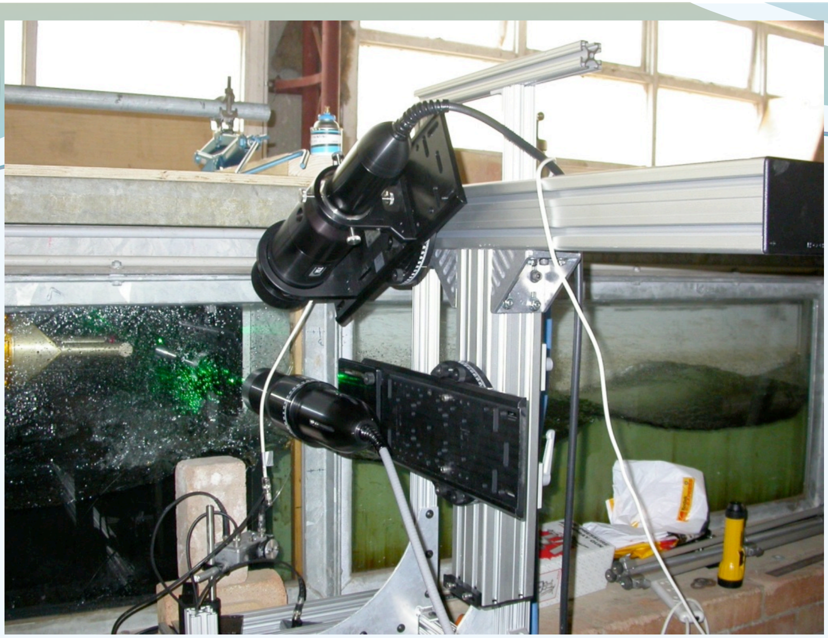
Range of Estimates of Evaporation Rates From Three Global Products



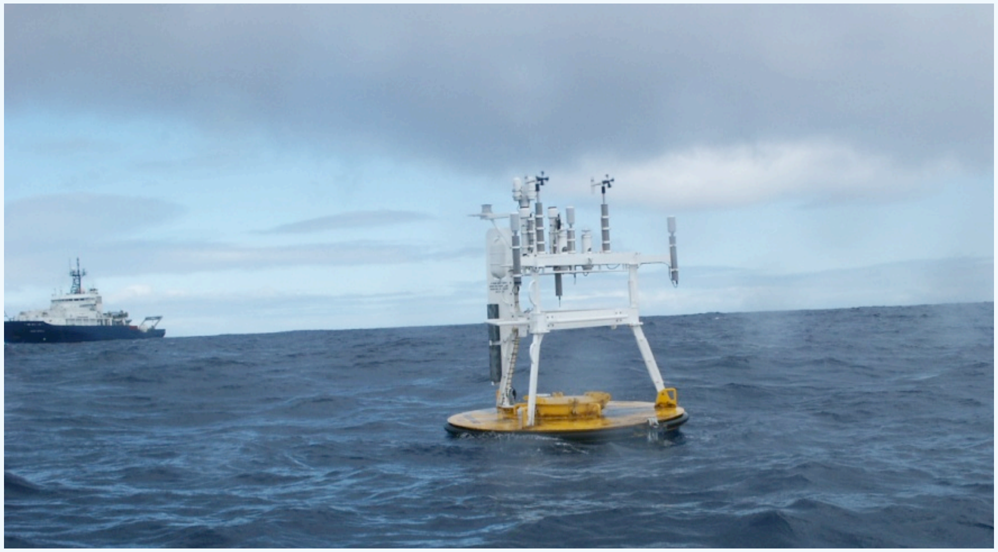
Comparison of monthly mean latent heat fluxes from NCEP (Kalnay et al. 1996), ERA-40 (Uppala et al. 2005), and Optimal Analysis Flux (Yu and Weller, 2007).

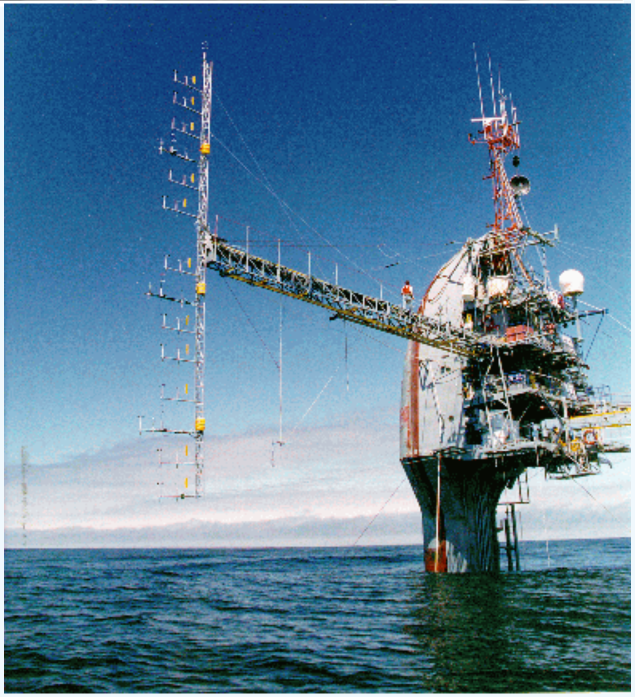
TECHNOLOGY EXAMPLE: Motion-Corrected Eddy-Covariance Turbulence Measurements from Ships





‘Planes, Trains, and Automobiles’ - A Diversity of Experimental Approaches





Surface Turbulent Flux Parameterizations

Turbulent Fluxes: Bulk Parameterization

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

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

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

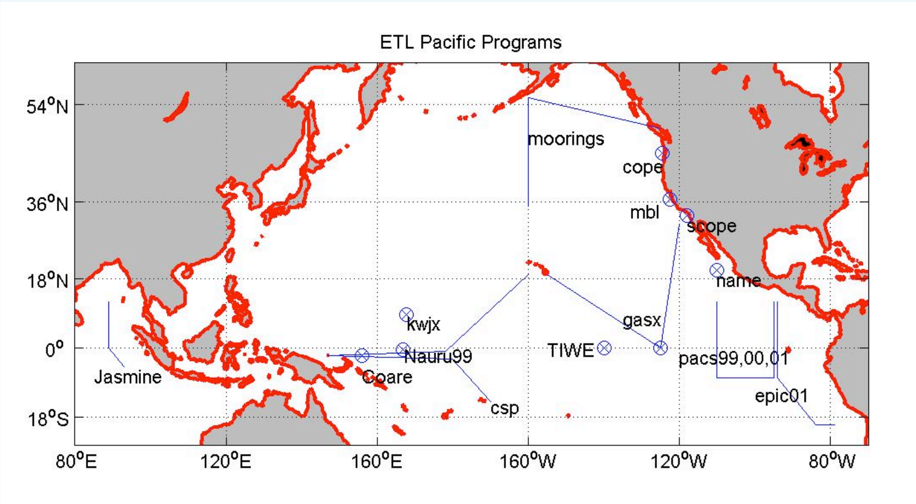
$$Particles: F_{deposition} = -V_d(r)\overline{n(r)}$$

Transfer coefficients computed from direct flux measurements

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

SAMPLE PRODUCT: NOAA COARE AIR SEA TURBULENT FLUX MODEL

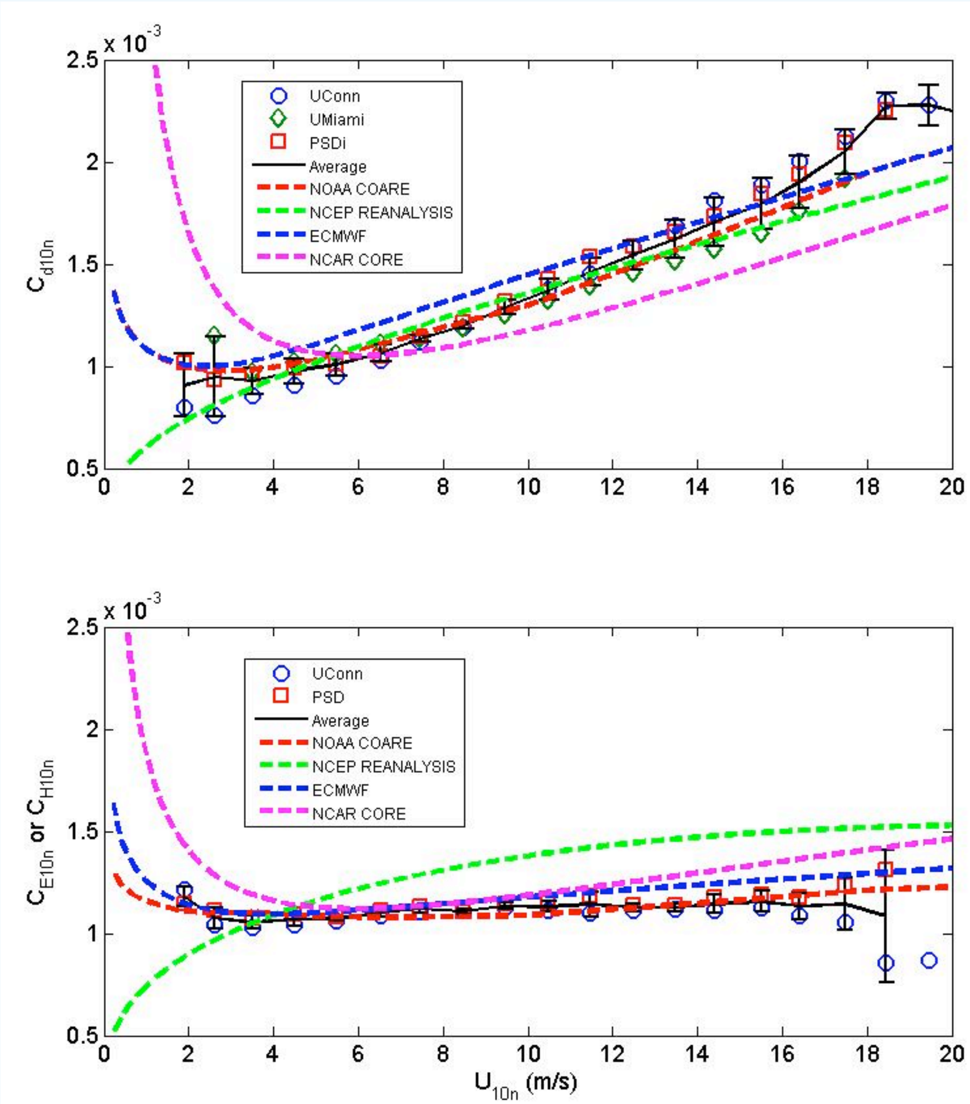
- 1996 Bulk Meteorological fluxes
  - Update 2003 (7200 covariance obs*)
  - Oceanic cool skin
  - Ocean diurnal warm layer
- 2000 CO_2 [*U. Conn* and *Columbia U*]
- 2003 Hurricane Sea Spray
- 2004 DMS [*U. Hawaii*]
- 2005 Snow/Ice [US Army *CRREL*]
- 2006 Ozone [*U. Colorado*]
- 2009 Hurricanes [*UNSW* Australia]



PSD cruises Pacific Ocean 1991-2001

*Complete flux data time series publically available under 'Data Sets' at http://www.esrl.noaa.gov/psd/psd3/wgsf/

Synthesis on Turbulent Flux Parameterizations: Combined Observations from ESRL, UConn, UMiami



Neutral turbulent transfer coefficients at z=10 m as a function of wind.

Symbols are **Direct Data** (14,450 observations; 90% between 3 and 17 m/s)

Dash Lines are **Parameterizations**

***Observations of 3 Research Groups Agree Closely (with 5%) But Need More High Speed Data**

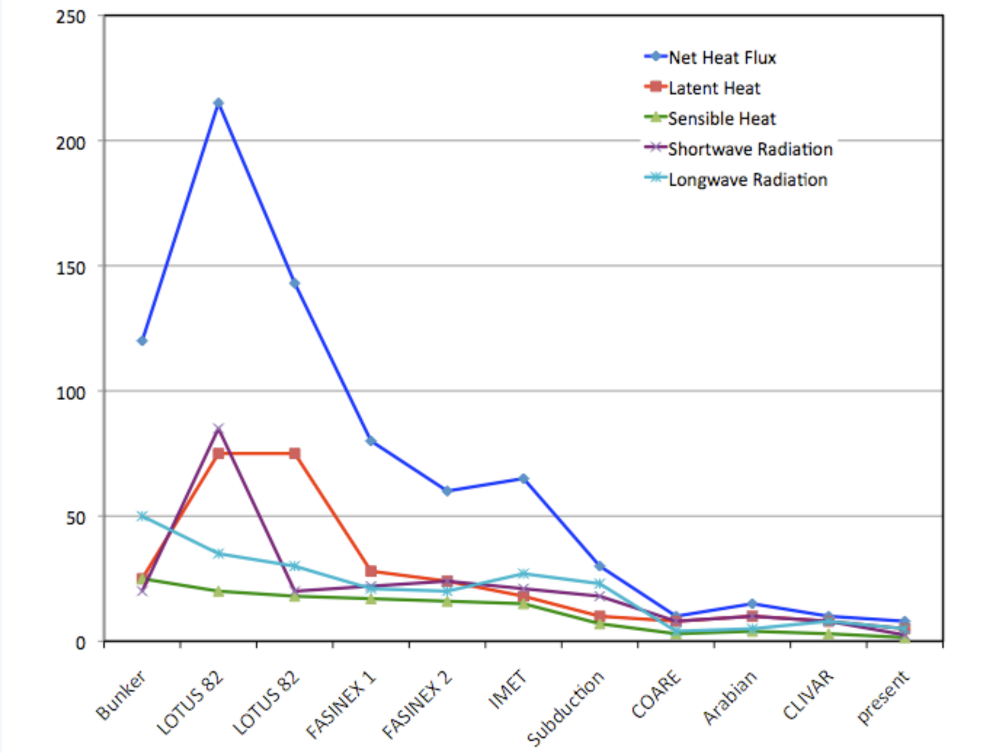
***Spread of Parameterizations is Greater Than Spread of Observations**

***NOAA *COARE* model is the best fit**

Real Progress!

$$NetHeatFlux = Solar_{net} + IR_{net} + Latent + Sensible$$

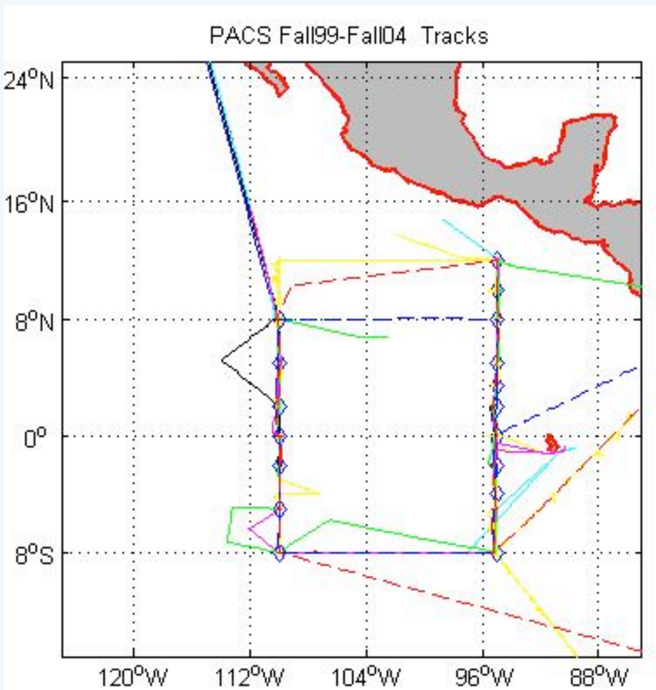
- Dramatic improvements in surface flux observations
- Gas transfer work featured as a highlight in the *WCRP* report on 30 years of accomplishments
- Major contributor to NOAA's Office of Climate Observations



Time series of surface flux component **accuracies** for Flux Reference Buoys from 1970's to today (Colbo and Weller, 2009)

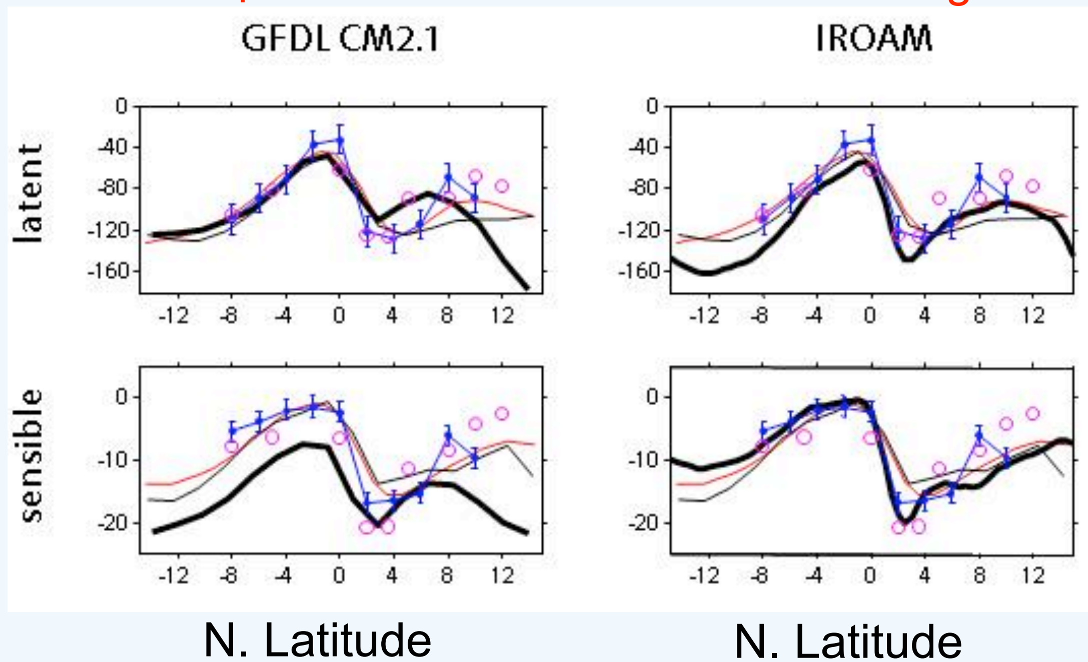
Models vs. Data 'Climatology'

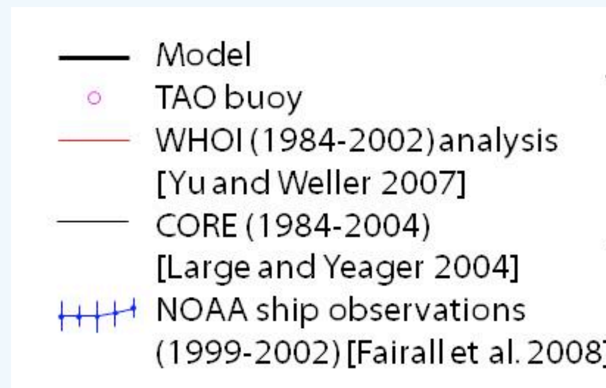
ESRL-PSD Tao Buoy Maintenance Cruises, 6 October and 3 April deployments: flux, boundary-layer, cloud systems



GFDL Coupled Model - IPCC

U. Hawaii Regional

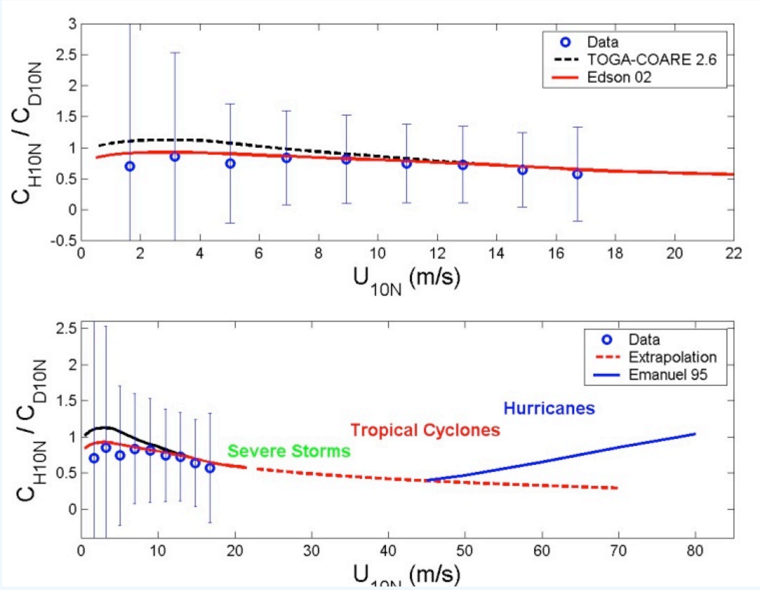




$$NetHeatFlux = Solar_{net} + IR_{net} + Latent + Sensible$$

The Future*

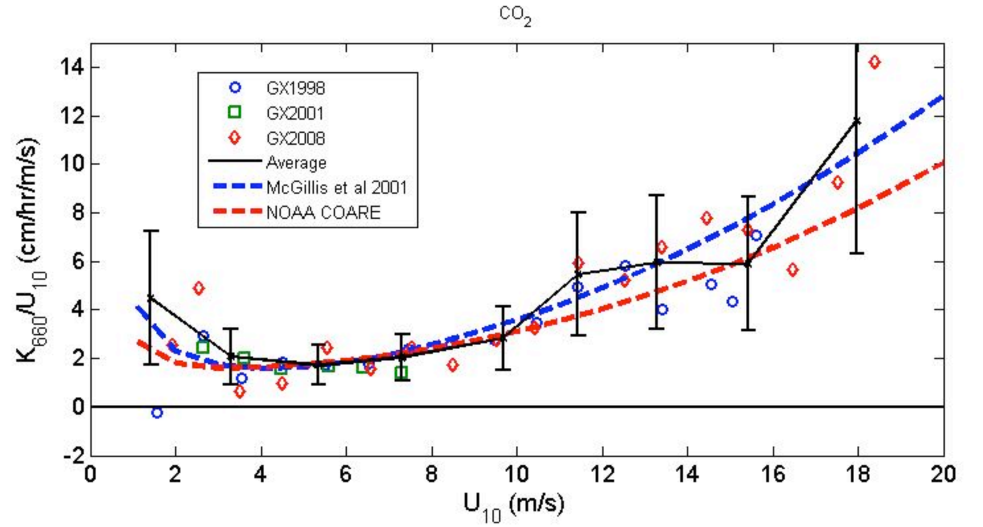
- Regimes
  - High winds (U> 15 m/s)
  - High latitudes
- Processes
  - Wave Effects
  - Sea Spray and Bubbles
- NOAA Process Observing Systems
  - P-3 wave/interface
  - Research Vessels and SAMOS
  - New generation flux buoys
- NWP/Climate Model Fluxes
  - Operational NWP fluxes -SURFA

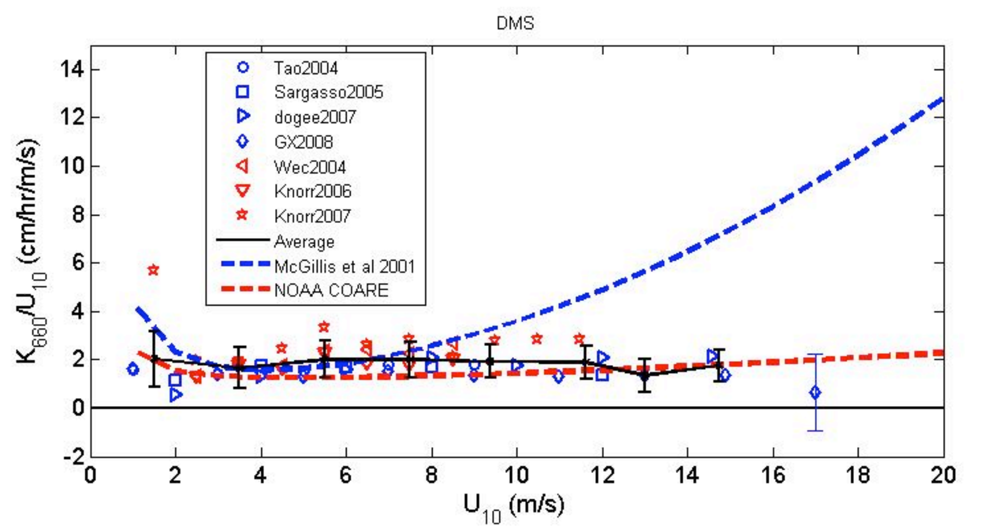


Ratio of heat to momentum transfer coefficients: Equivalent to ratio of energy input to frictional loss.

*Fairall, C. & 18 Co-Authors, 2010: Observations to Quantify Air-Sea Fluxes and Their Role in Climate Variability and Predictability in *Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society (Vol. 2),* Venice, Italy, 21-25 September 2009, Hall, J., Harrison D.E. & Stammer, D., Eds., ESA Publication WPP-306.

Contrast to Stress/Heat Coefficients: Large Uncertainties Remain for Gas Transfer





Gas Transfer Sensitivity to:

- Solubility
- Wave breaking
- Bubbles
- Tangential vs. Pressure (wave) stress
- Surfactants
- Temperature
- Complex chemistry
- Biology