# Observations of Air-Sea Interactions over the Tropical Oceans

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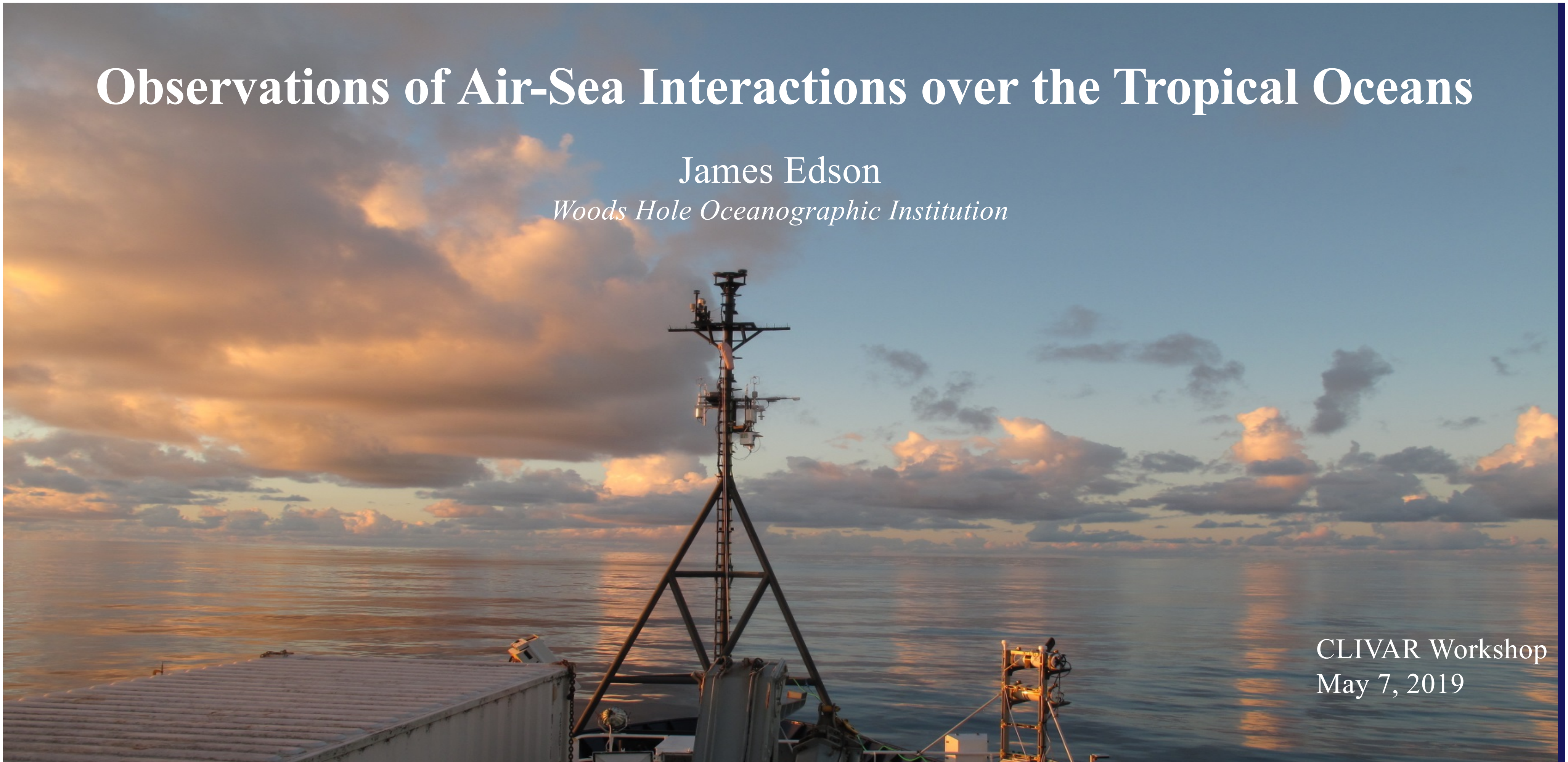
*Woods Hole Oceanographic Institution*



CLIVAR Workshop
May 7, 2019

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## Workshop Goals & Outline

To identify key scientific problems that could be tackled through coordinated modeling and observational efforts and potentially motivate future process studies involving the tropical convection and air-sea interaction communities.

- Recent progress - Direct covariance momentum, heat and moisture fluxes from moving platforms.
- Lesson learned – Latent heat fluxes from buoys
- New approaches – Flow distortion reduction on ships.
- Dalton and Stanton numbers from ships and buoys.
- An example - Parameterizations versus state variables.
- High wind processes in the tropics
- Future Plans

## Direct measurement of momentum, heat and moisture exchange (fluxes) in the marine surface layer

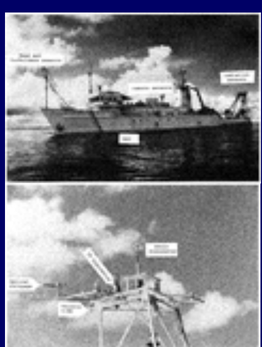
Momentum Flux: $\tau_o = \rho_a \overline{uw} = \rho_a C_D S_r \Delta U$ — Drag Coefficient

Sensible Heat Flux: $Q_H = \rho_a c_p \overline{wT} = \rho_a c_p C_H S_r \Delta\Theta$ — Stanton Number

Latent Heat Flux: $Q_E = \rho_a L_v \overline{wq} = \rho_a L_v C_E S_r \Delta Q$ — Dalton Number

- Moving platforms require motion correction of anemometers
- Minimize flow distortion
- Add capabilities

$$\mathrm{E} = Q_E/(\rho_w L_v)$$



1992 TOGA COARE

2017 NASA SPURS

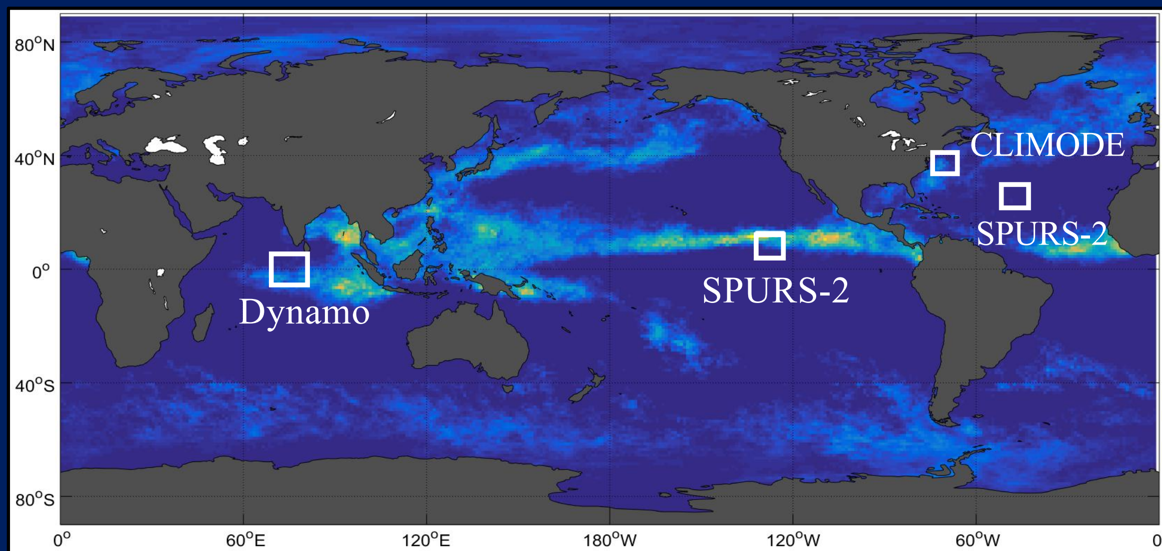
Air-Sea Interaction Spar (ASIS)

CLIMODE Year long

SPURS Latent Heat Flux

OOI & TPOS Real-time Fluxes

# Air-Sea Interaction Field Studies




## Heat Fluxes

$$Q_H = \rho_a c_p \overline{wT} \quad = \rho_a c_p C_H S_r \Delta\Theta \quad \Rightarrow \quad C_{HN} = -\frac{\overline{wT}}{\Delta\Theta \Delta U_N G} = C_D^{1/2}\left(\frac{\kappa}{\ln(\frac{z}{z_T})}\right)$$

$$Q_E = \rho_a L_v \overline{wq} \quad = \rho_a L_v C_E S_r \Delta Q \quad \Rightarrow \quad C_{EN} = -\frac{\overline{wq}}{\Delta Q \Delta U_N G} = C_D^{1/2}\left(\frac{\kappa}{\ln(\frac{z}{z_q})}\right)$$

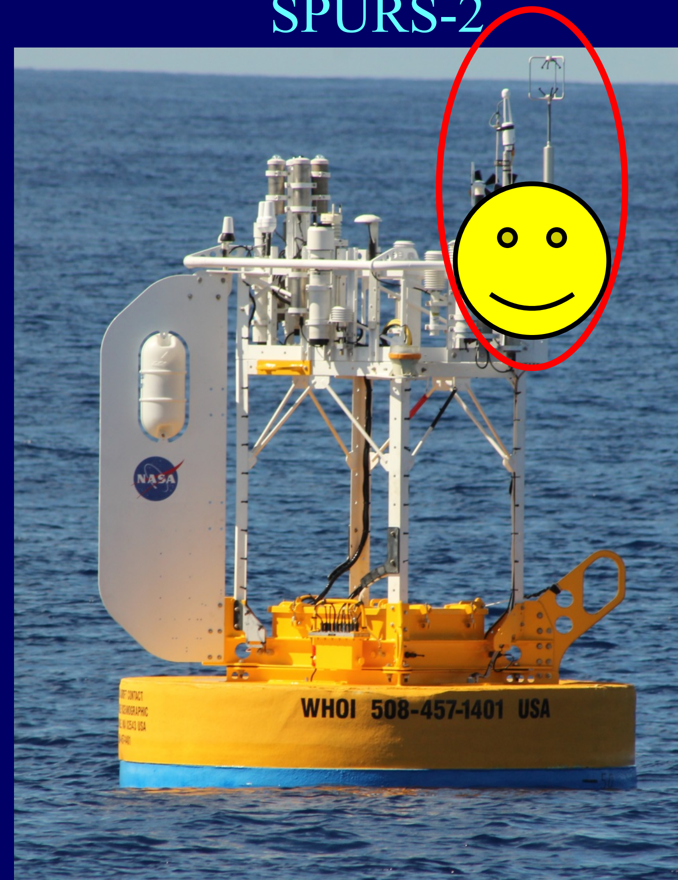
$$z_q = z_T = \mathrm{f}\left(\frac{z_o u_*}{\nu}\right)$$

# Challenge: Latent Heat Flux from Buoys

SPURS-1


Closed Path

SPURS-2




Open Path

# Ship-based Flux Systems

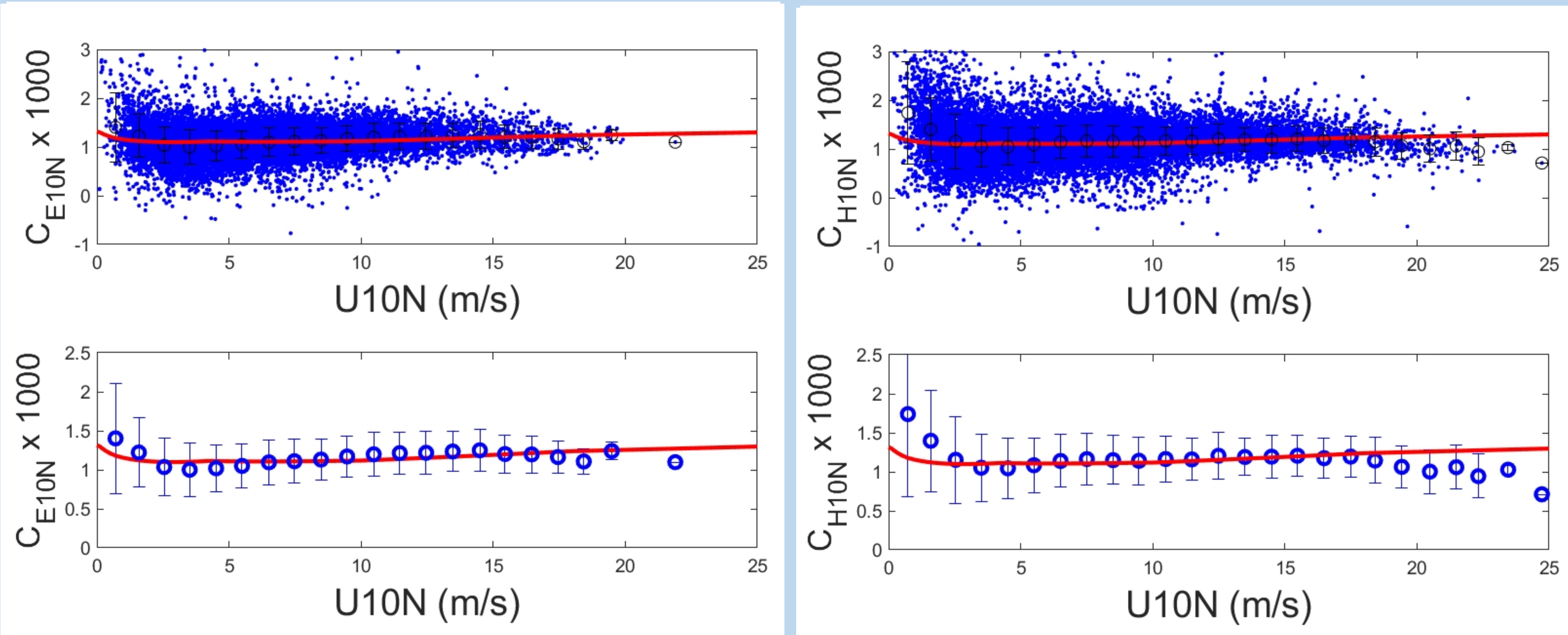
- DCFS.
- Open path hygrometers
- Closed path hygrometer
- Aspirated RH/T sensors
- Solar/IR sensors
- Optical rain gauge
- Self-siphoning rain gauge

# Challenge: Reduce Flow Distortion

- Optimal placement of sensors based on wind tunnel results and high-resolution models.
- Empirical corrections for flow distortion on the means based on LIDAR and other measurements.
- New methodologies for reduced flow distortion such as
- Landwehr, S., N. O'Sullivan, and B. Ward, 2015: Direct flux measurements from mobile platforms at sea: Motion and airflow distortion corrections revisited. J. Atmos. Oceanic. Tech., 32, 1163- 1178.
- Approximately half the flux bias have been removed on ships.

# Combine Buoy & Ship Fluxes to Parameterize the Dalton & Stanton Numbers

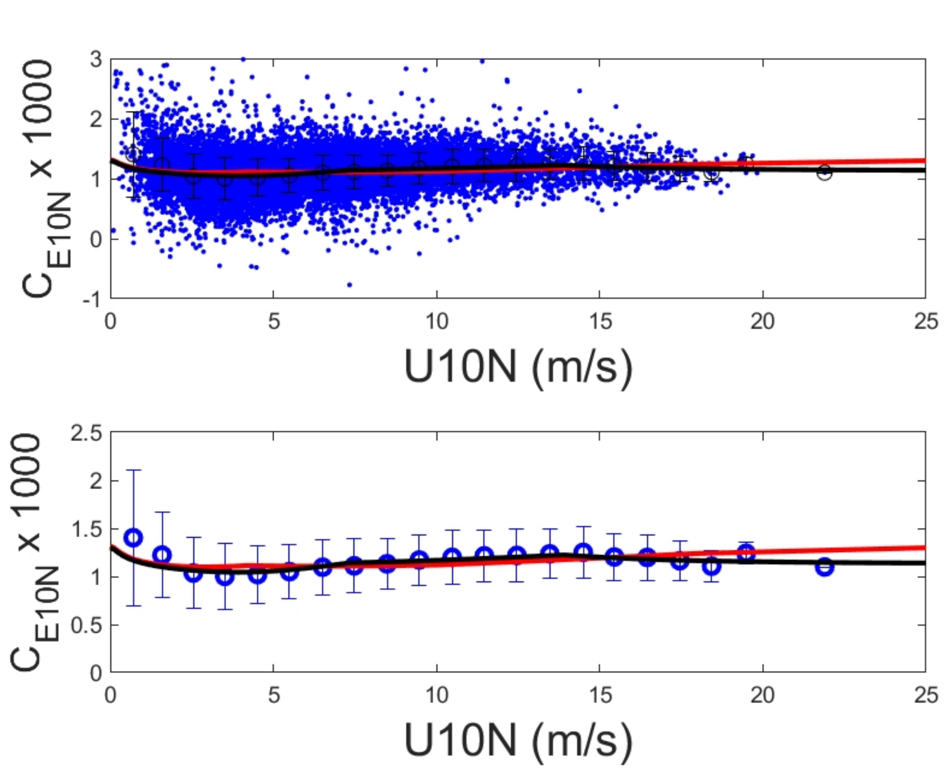
# Ship & Buoy-based Transfer Coefficients

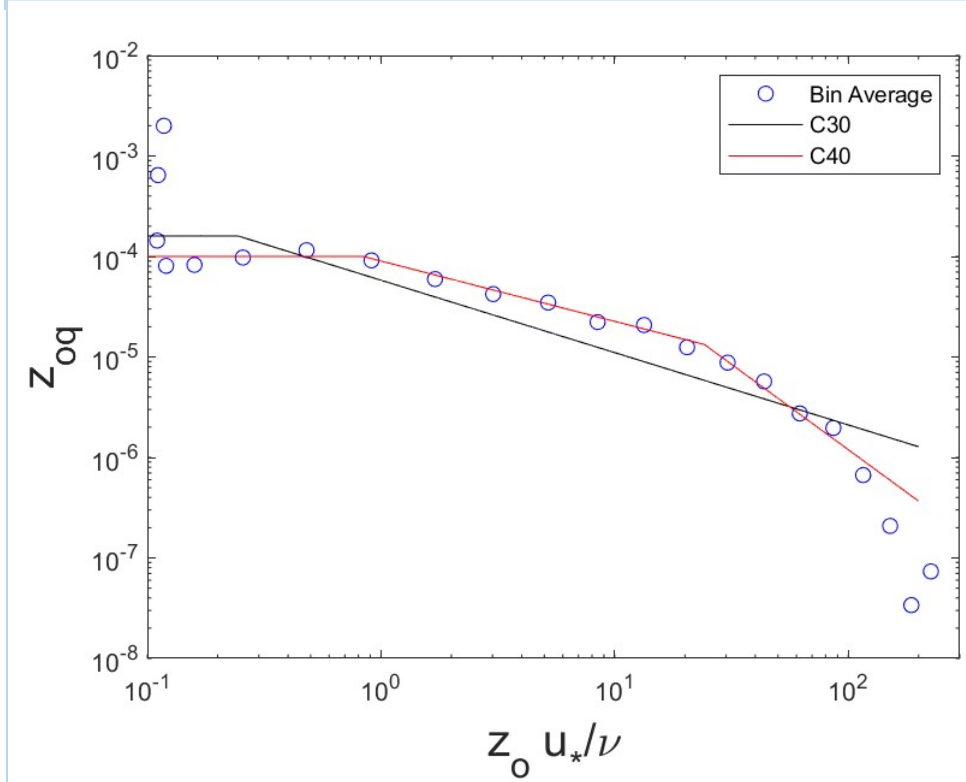



$$C_{EN} = -\frac{\overline{wq}}{\Delta Q \Delta U_N G} = C_{DN}^{1/2}\left(\frac{\kappa}{\ln(z/z_{oq})}\right)$$

$$C_{HN} = -\frac{\overline{wT}}{\Delta\Theta\, \Delta U_N G} = C_{DN}^{1/2}\left(\frac{\kappa}{\ln(z/z_{oT})}\right)$$

# Ship & Buoy-based Transfer Coefficients

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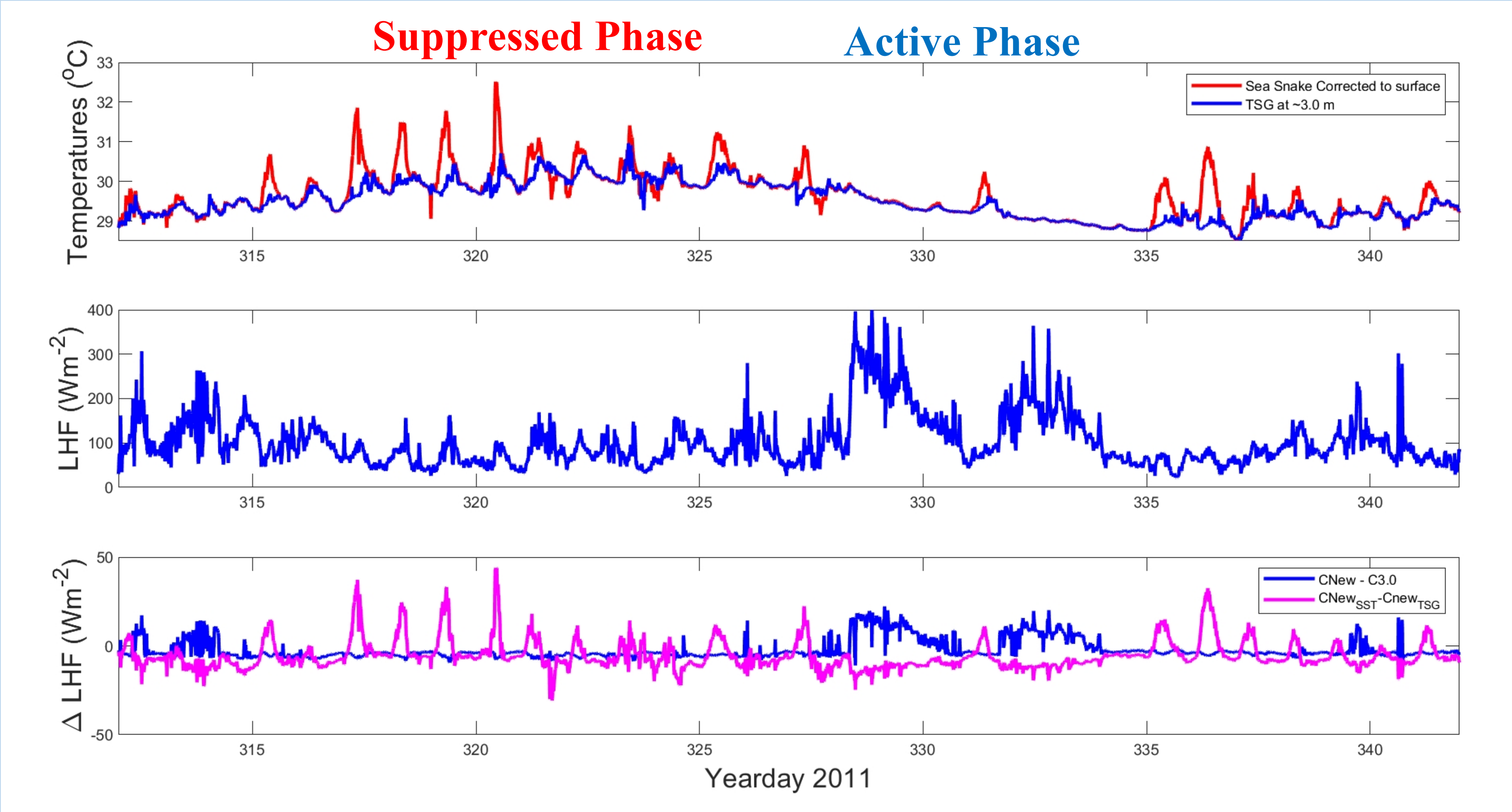
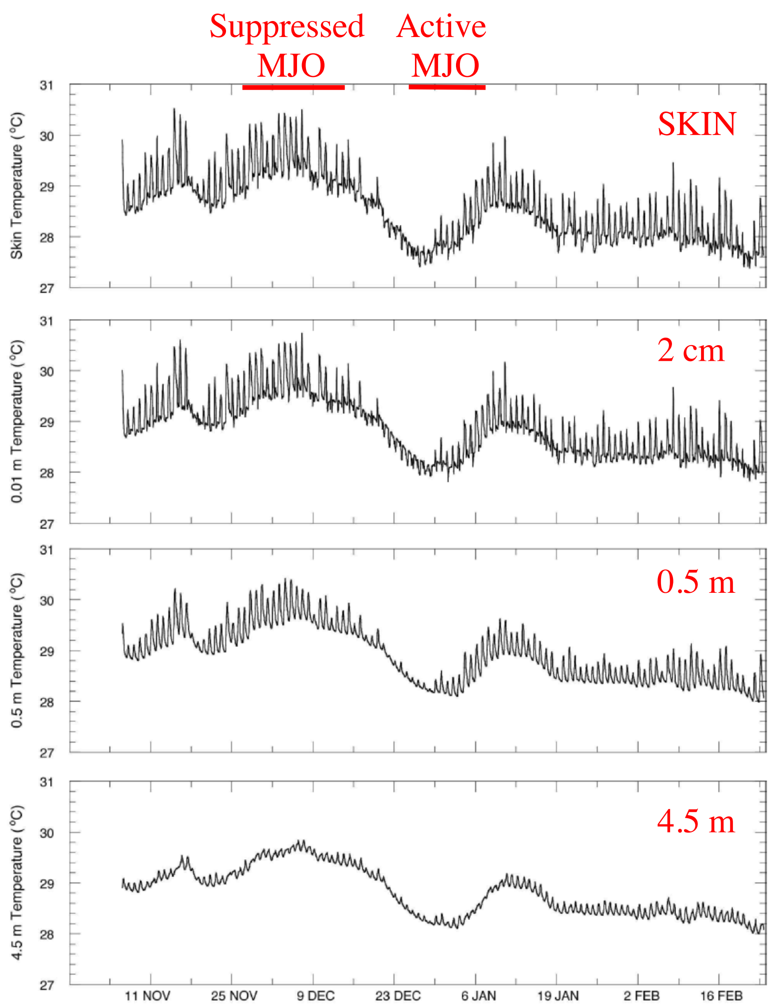
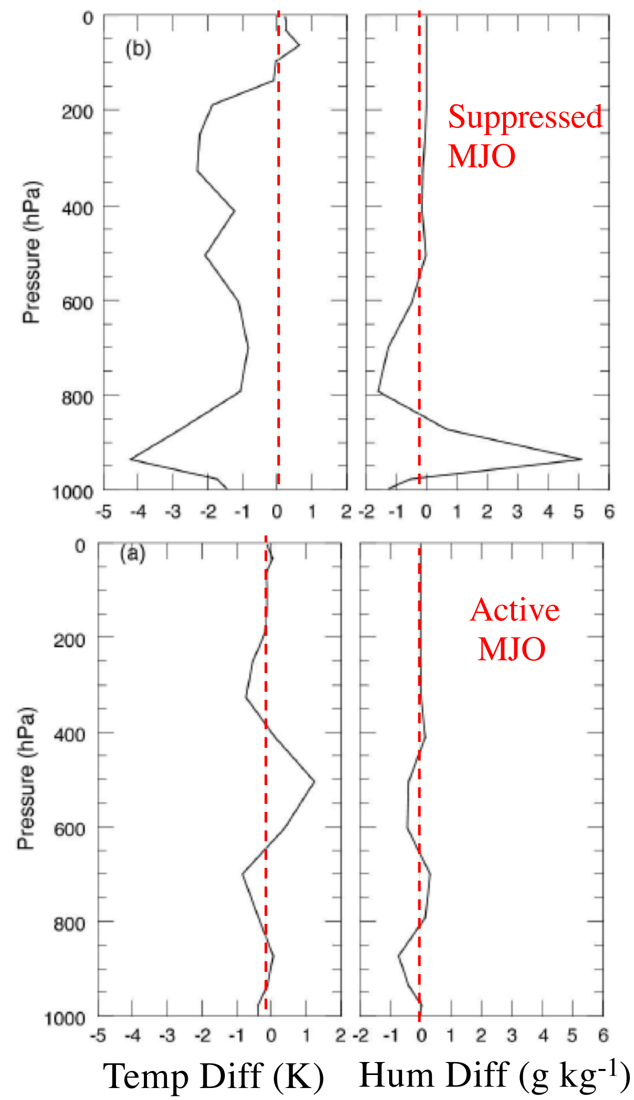
$$z_q = z_T = \mathrm{f}\left(\frac{z_o u_*}{\nu}\right)$$

# Parameterizations and State Variables

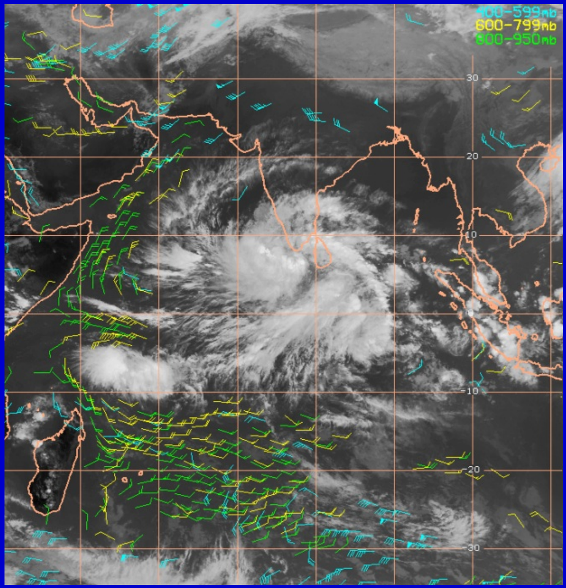





*Clayson and Chen, 2002*

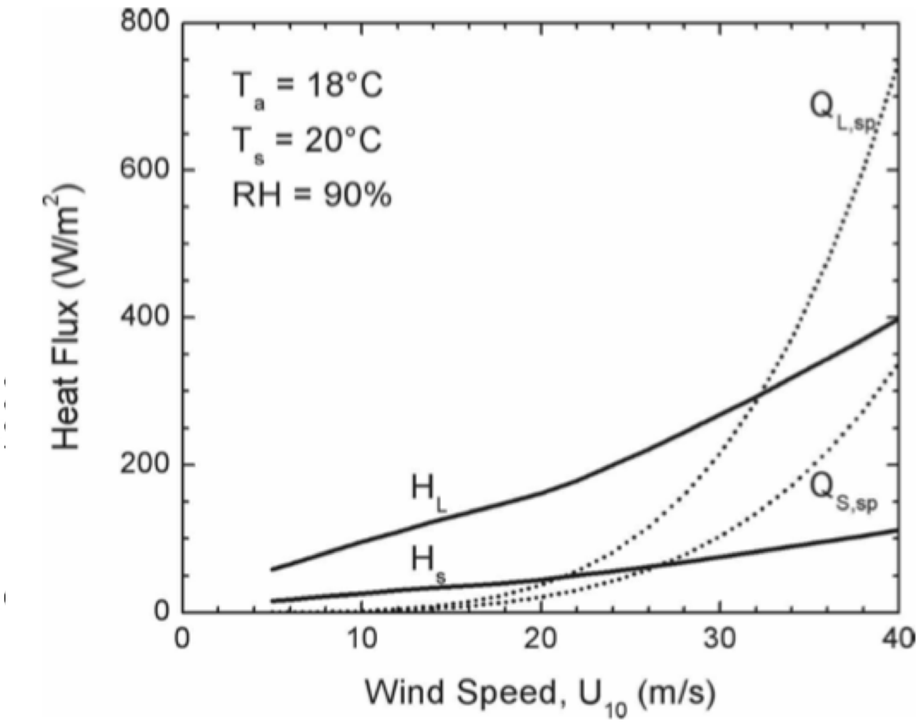


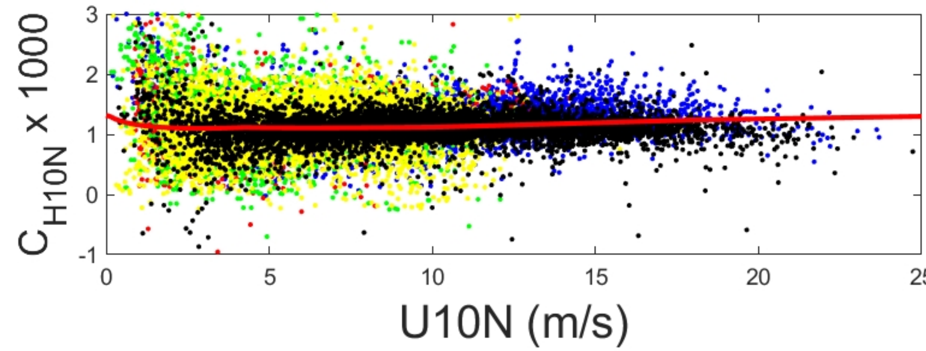
# High Winds in the Tropics

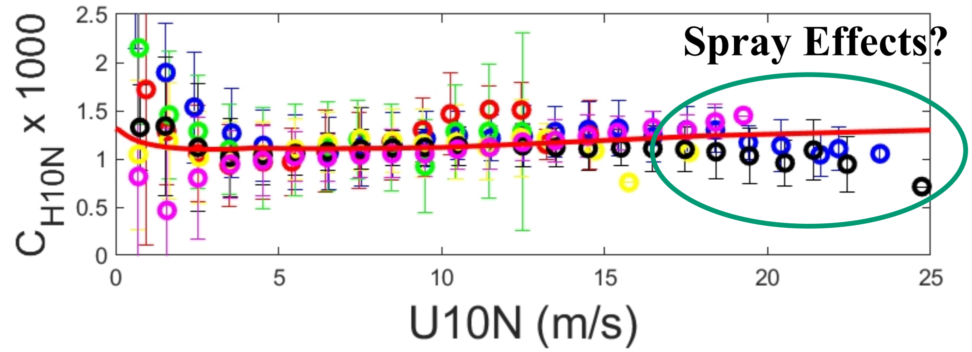


# Ship & Buoy-based Transfer Coefficients

From model of Andreas et al. 2008




$$C_{EN} = -\frac{\overline{wq}}{\Delta Q \Delta U_N G} = C_{DN}^{1/2}\left(\frac{\kappa}{\ln(z/z_{oq})}\right)$$

$$C_{HN} = -\frac{\overline{wT}}{\Delta \Theta \, \Delta U_N G} = C_{DN}^{1/2}\left(\frac{\kappa}{\ln(z/z_{oT})}\right)$$

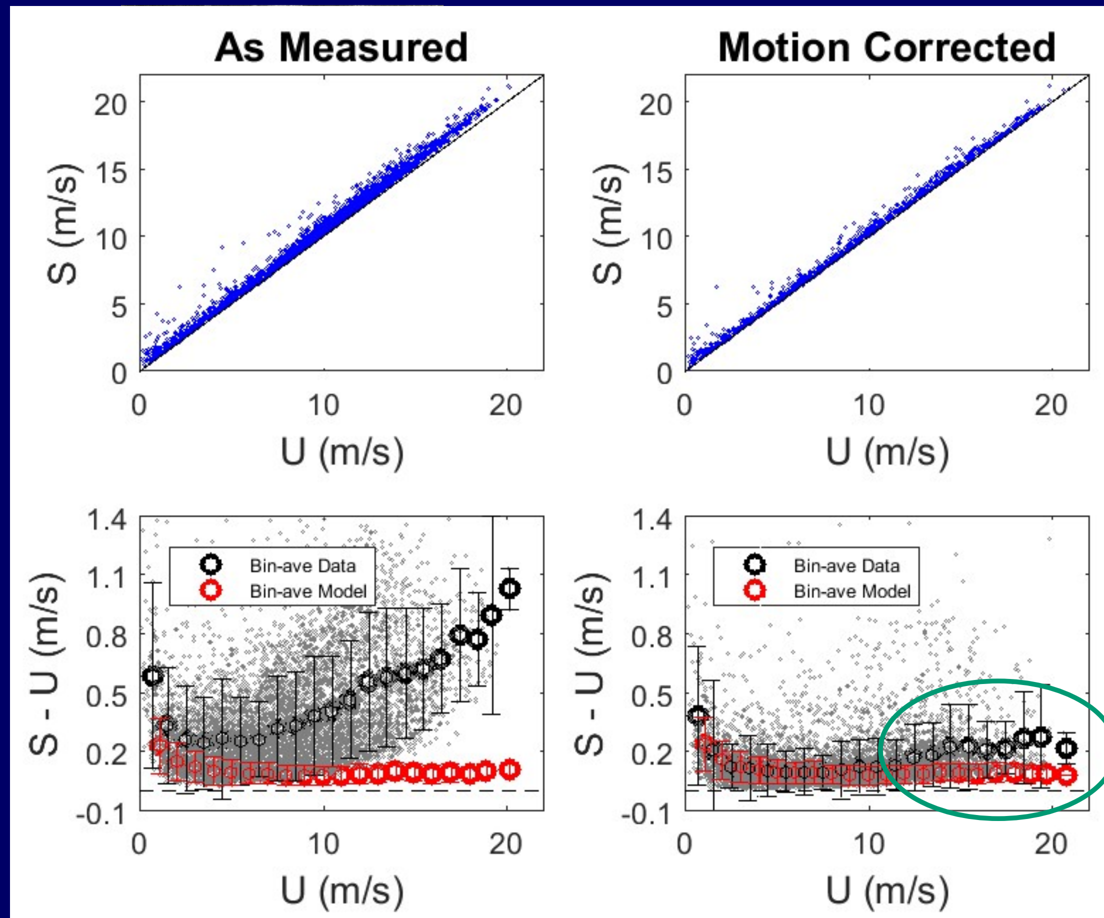
# Gustiness

- We have a pretty good handle on near surface gustiness in convective conditions.

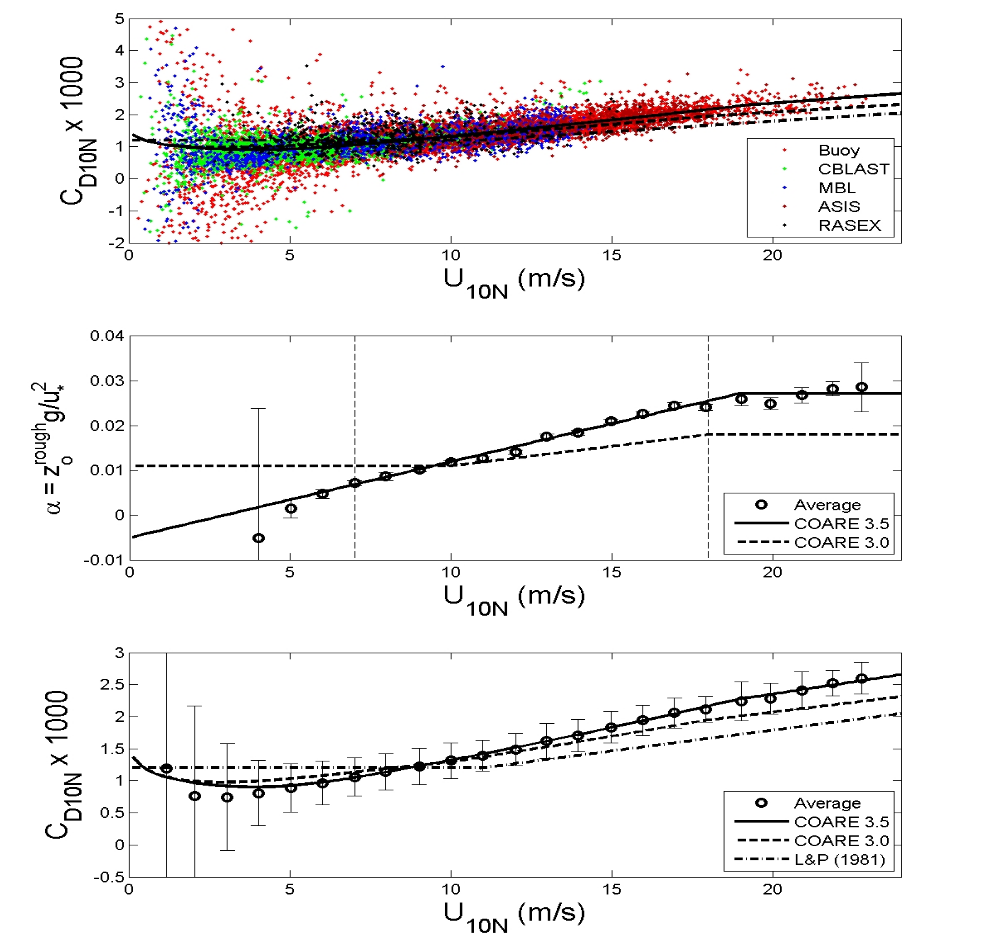
$$\tau_o = \rho_a \overline{uw} = \rho_a C_D S_r \Delta U$$

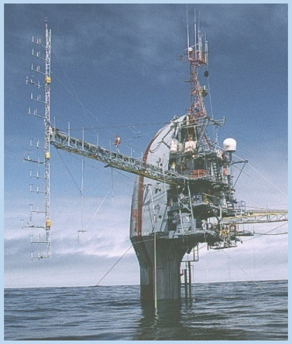
$$G = \frac{S_r}{\Delta U} = \frac{\overline{(U^2 + V^2)^{1/2}}}{\left(\overline{U}^2 + \overline{V}^2\right)^{1/2}} = f(w_*)$$

- We have less confidence on how to account for gustiness above the surface layer.
- And even less confidence on how to parameterize "gustiness" caused by coherent structures such as roll vortices at higher wind speeds.



# MBL/CBLAST/CLIMODE Drag Coefficients

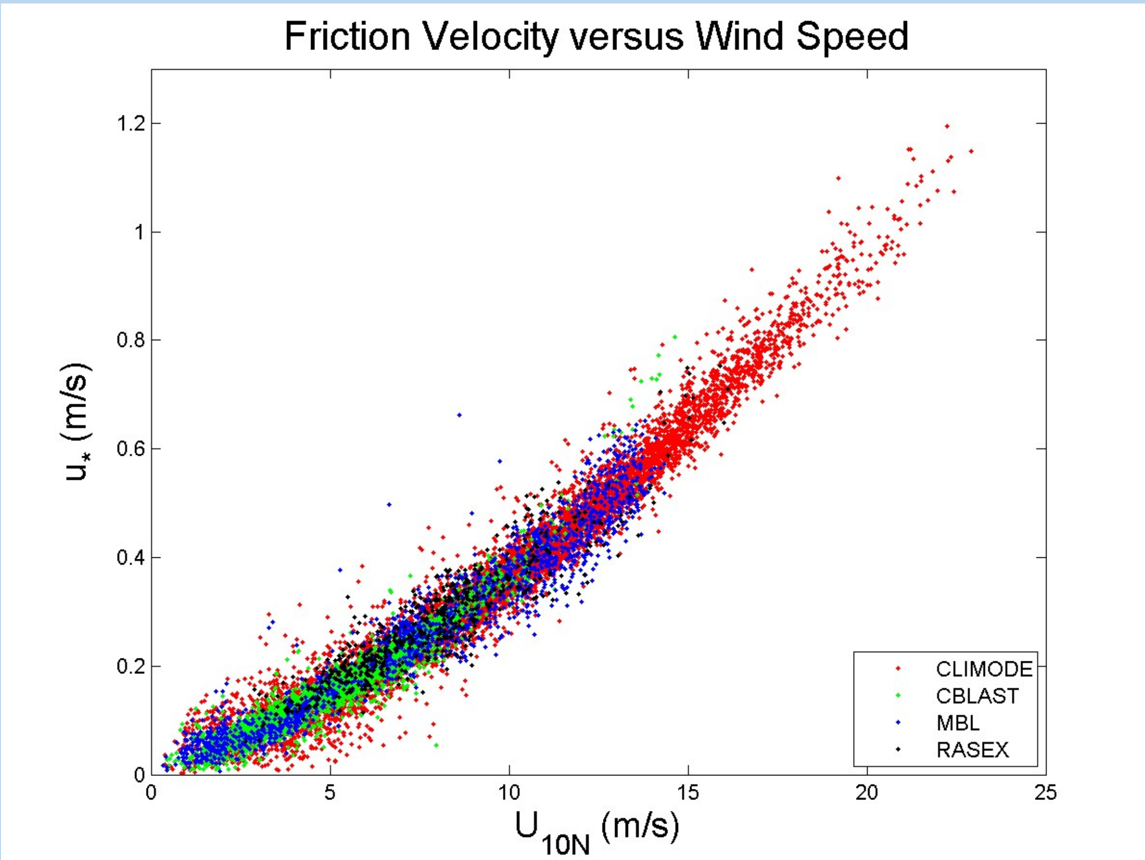


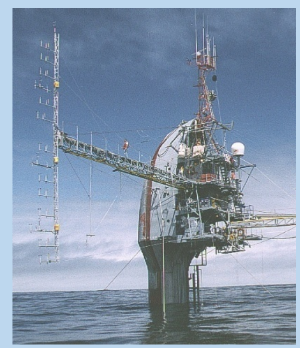



**COARE 3.5**

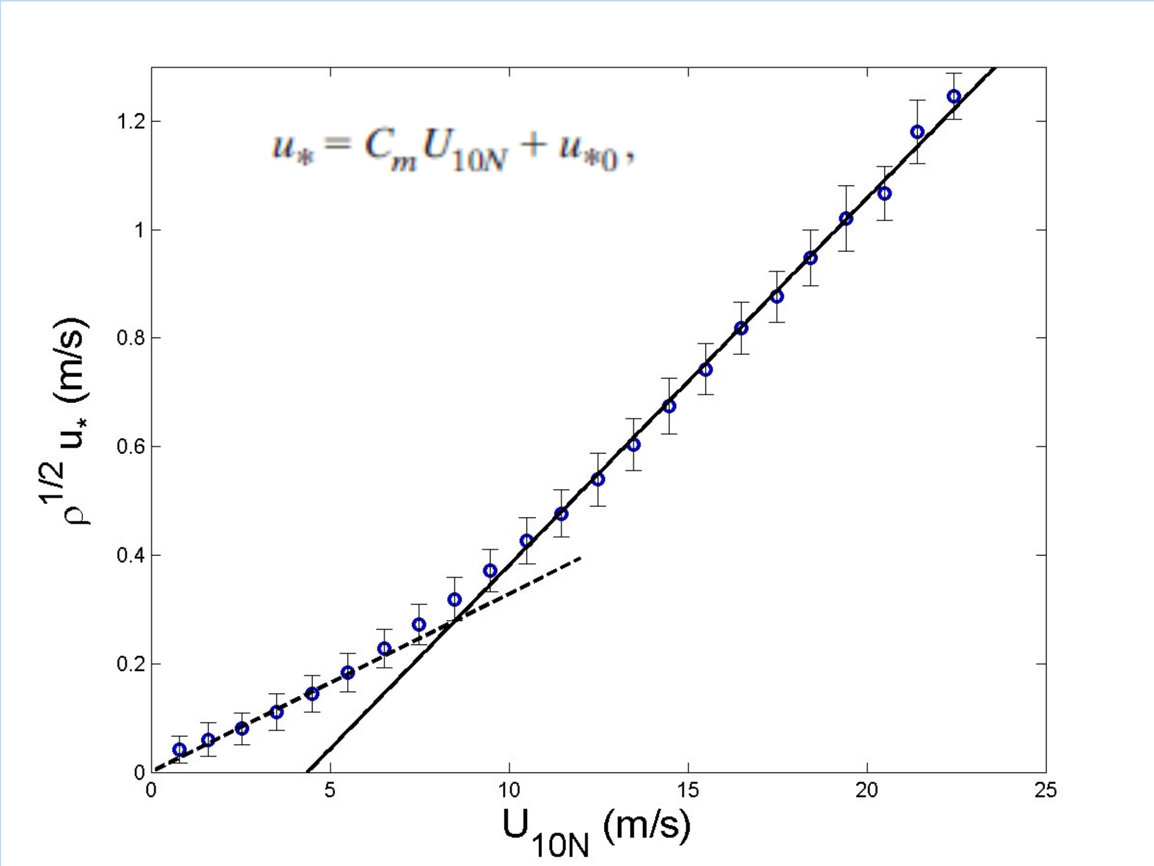
Edson, James B., and Coauthors, 2013: On the Exchange of Momentum over the Open Ocean. *J. Phys. Oceanogr.*, **43**, 1589–1610.

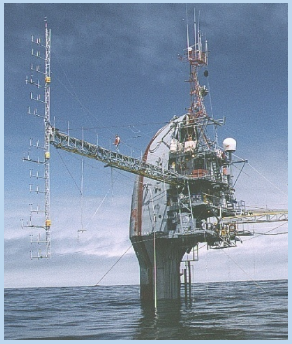
# MBL/CBLAST/CLIMODE/RASEX



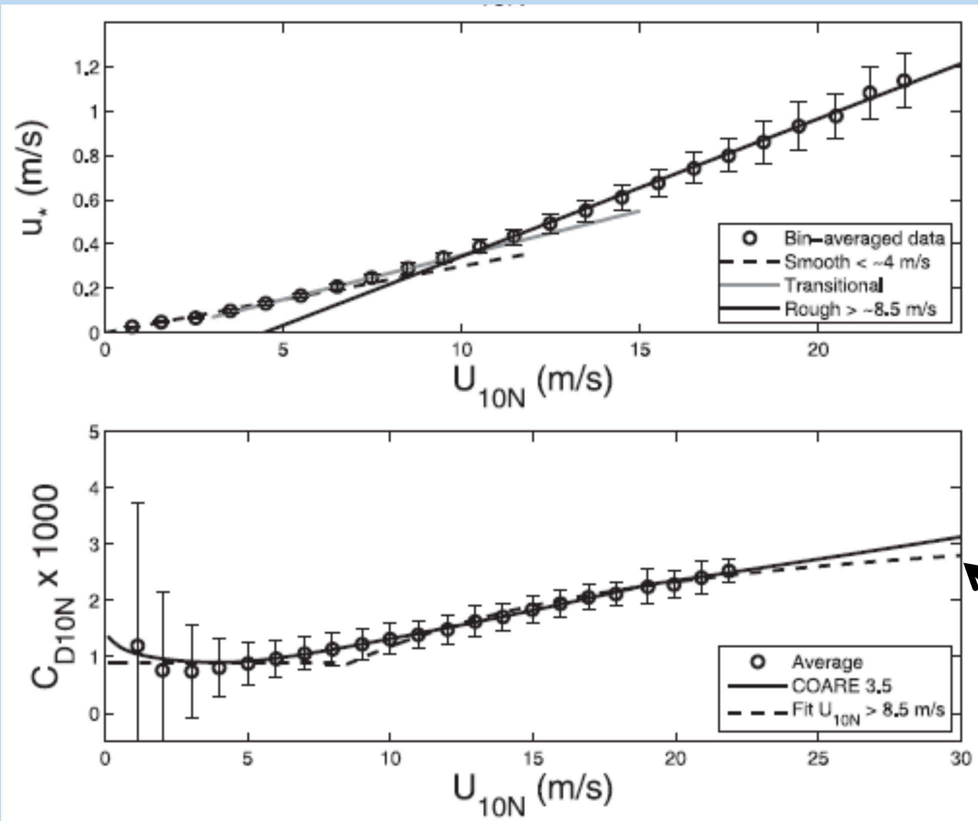



# Another Hockey Stick

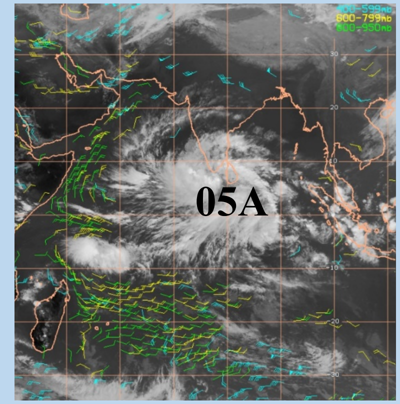


# Drag Coefficient at High Winds



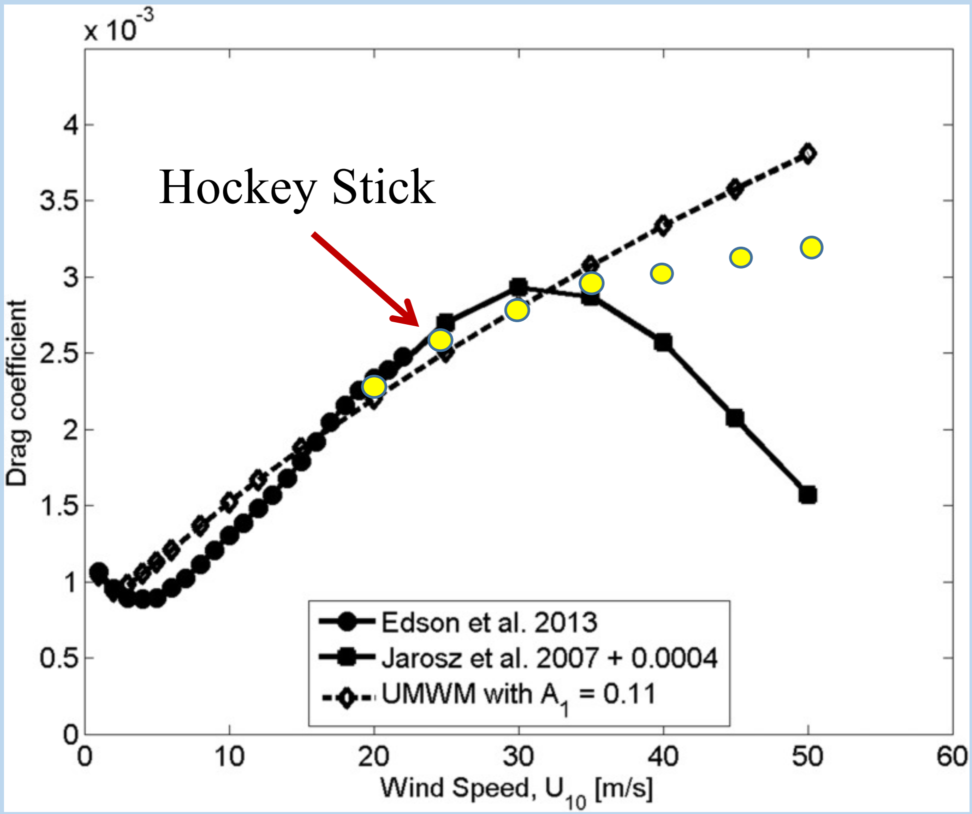

$$u_* = C_m U_{10N} + u_{*0},$$

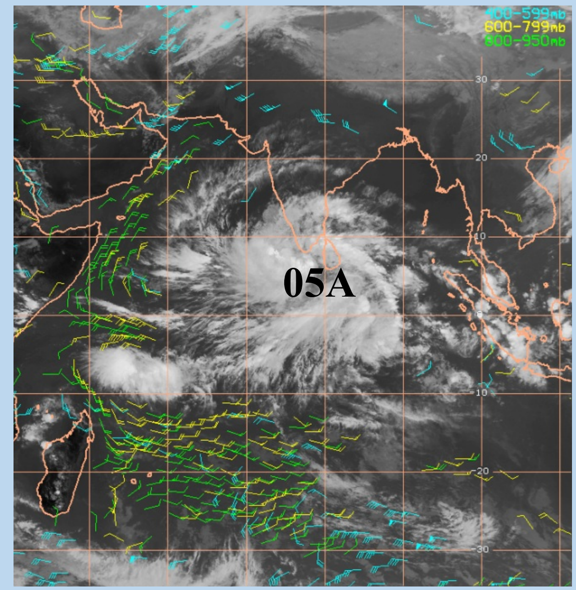



$$C_{D10N} = \left(\frac{u_*}{U_{10N}}\right)^2 = \left(C_m + \frac{u_{*0}}{U_{10N}}\right)^2$$

Hockey Stick

# Drag Coefficient at High Winds

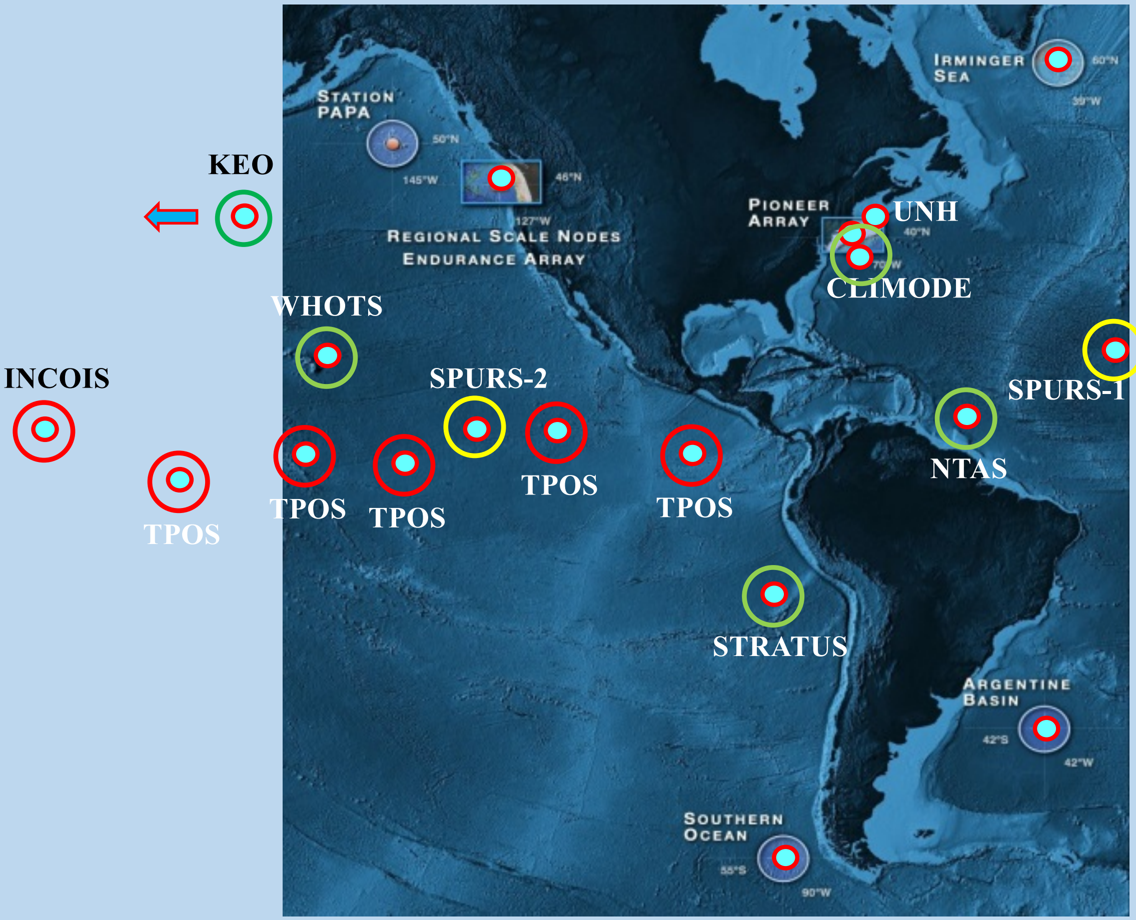


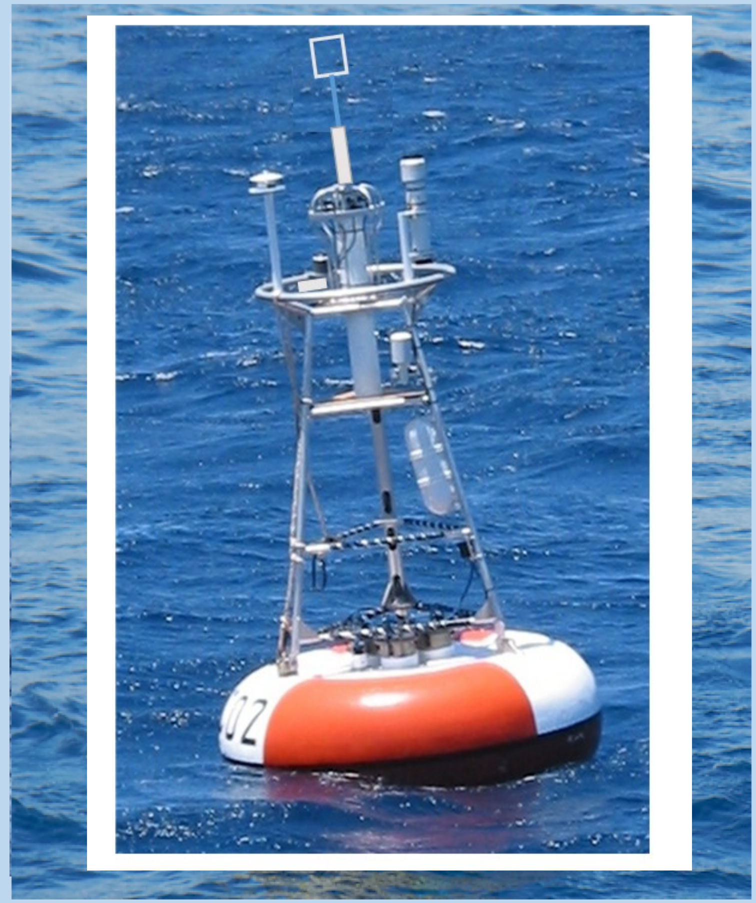




Donelan, M. A. ( 2018). On the decrease of the oceanic drag coefficient in high winds. *Journal of Geophysical Research: Oceans*, 123, 1485–1501. https://doi.org/10.1002/2017JC013394

# Future Plans and Assets for the Tropics

# A Growing Global Array



# Real-time from Mobile Assets


Saildrone

X-Spar

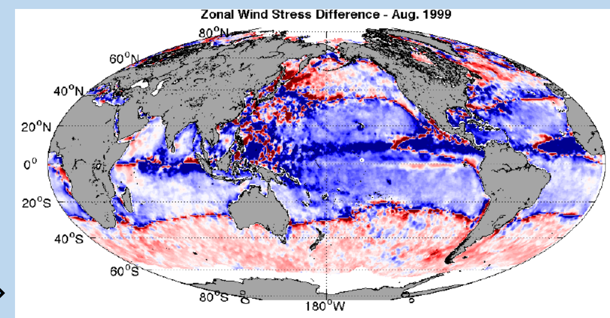

Wave Glider

# Global Stress from Satellites


$$\vec{U}_{10N} = f(\vec{\sigma}_0)$$

$$\tau = C_{D10N} U_{10N}^2$$

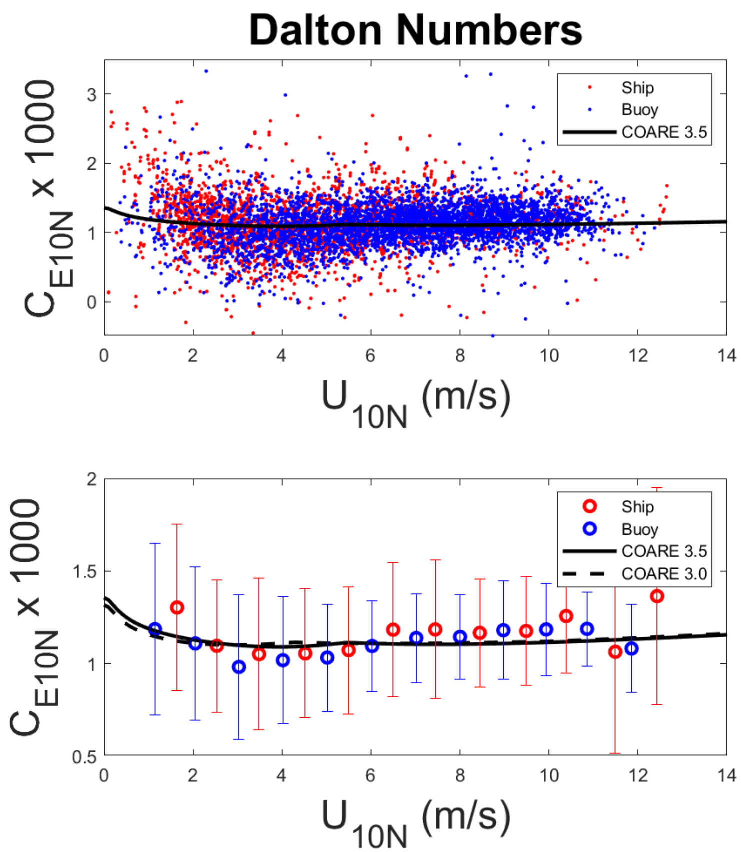
$$\vec{\tau} = f(\vec{\sigma}_0)$$

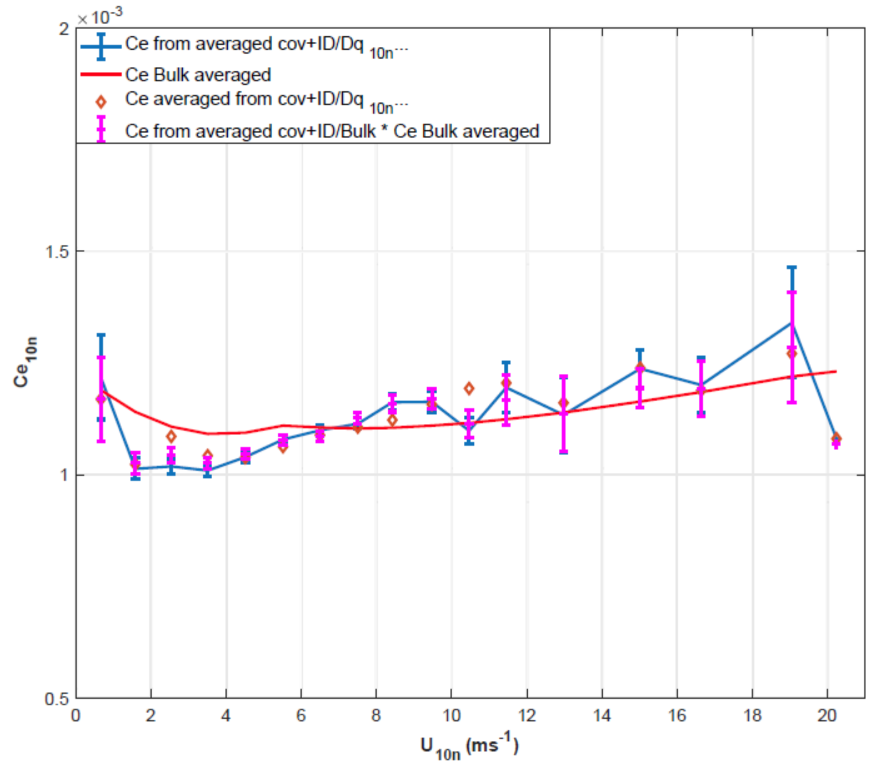


# Summary

- Marine physicists have made significant progress in recent decades in our ability to directly measure surface fluxes from research vessels, moored buoys and, most recently, mobile platfroms.
- These platforms utilize Direct Covariance Flux Systems (DCFS) to remove platform motion from the measured wind speeds to measure the flux directly.
- Over the past decade or so, researchers have begun to collect long time series, O(year), of momentum and buoyancy fluxes from surface moorings that experience less flow distortion over a wider range of conditions.
- This includes sensors to measure latent heat fluxes on research moorings and some mobile platforms
- Improved flow distortion correction on ships is improving flux accuracy and decreasing biases.
- The accuracy of the transfer coefficients continues to improve over a wind range of wind speeds.
- Understanding the relationship of the transfer coefficients to wave driven processes at low winds and their behavior at high to extreme winds remain major objectives.

# Flow Distortion Corrected

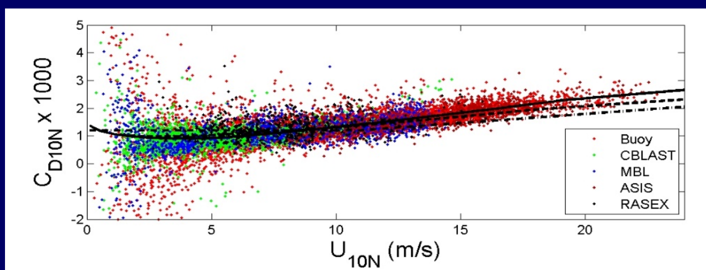


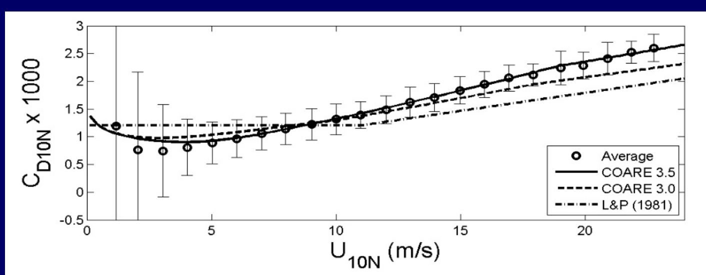



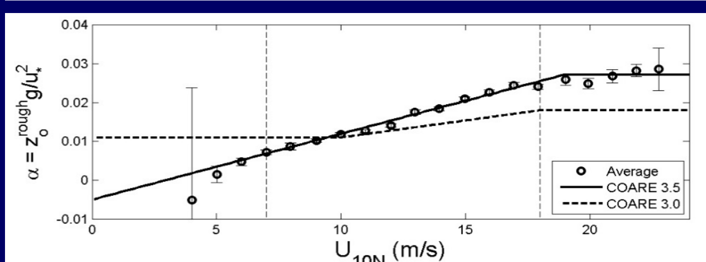
# Accurate parameterization of these fluxes under observed atmospheric stability, sea-state and wave-age

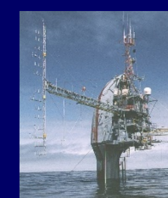
Momentum Flux: $\tau_o = \rho_a \overline{uw} \quad = \rho_a C_D S_r \Delta U$ Drag Coefficient

$$C_{DN} = \frac{\overline{uw}}{\Delta U_N^2 G} = \left(\frac{\kappa}{ln\left(\frac{z}{z_o}\right)}\right)^2$$



- Drag on the ocean surface is commonly parameterized in terms of the roughness length, $z_o$.
- Edson et al. (2013) parameterized $z_o$ as a function of wind speed, wave-age and wave-steepness dependent Charnock variabile.
- It hard to beat a wind-speed dependent form.
- To first order, wind-waves of O(0.1-100 m) support the surface stress.
- Longer waves and swell have a second order effect.