Improved Parameterization of Heat, Mass and Momentum Exchange for Process Studies in Numerical Models

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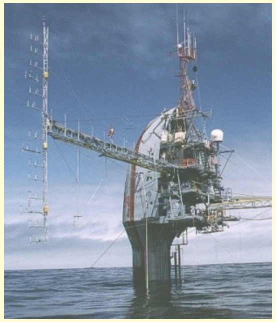
Outline

- Momentum Exchange
  - COARE 3.5
  - Hockey Stick
  - Climate Models
  - Waves
- Energy Exchange & Waves
- Heat Exchange
  - Ship
  - Buoys
- Uncertainty in Drag & Transfer Coefficients
- Future of DC Fluxes for Process Studies

Momentum Fluxes



Surface Stress

$$\tau = -\rho\overline{uw} \approx \rho C_{DN} U_r^2 G$$

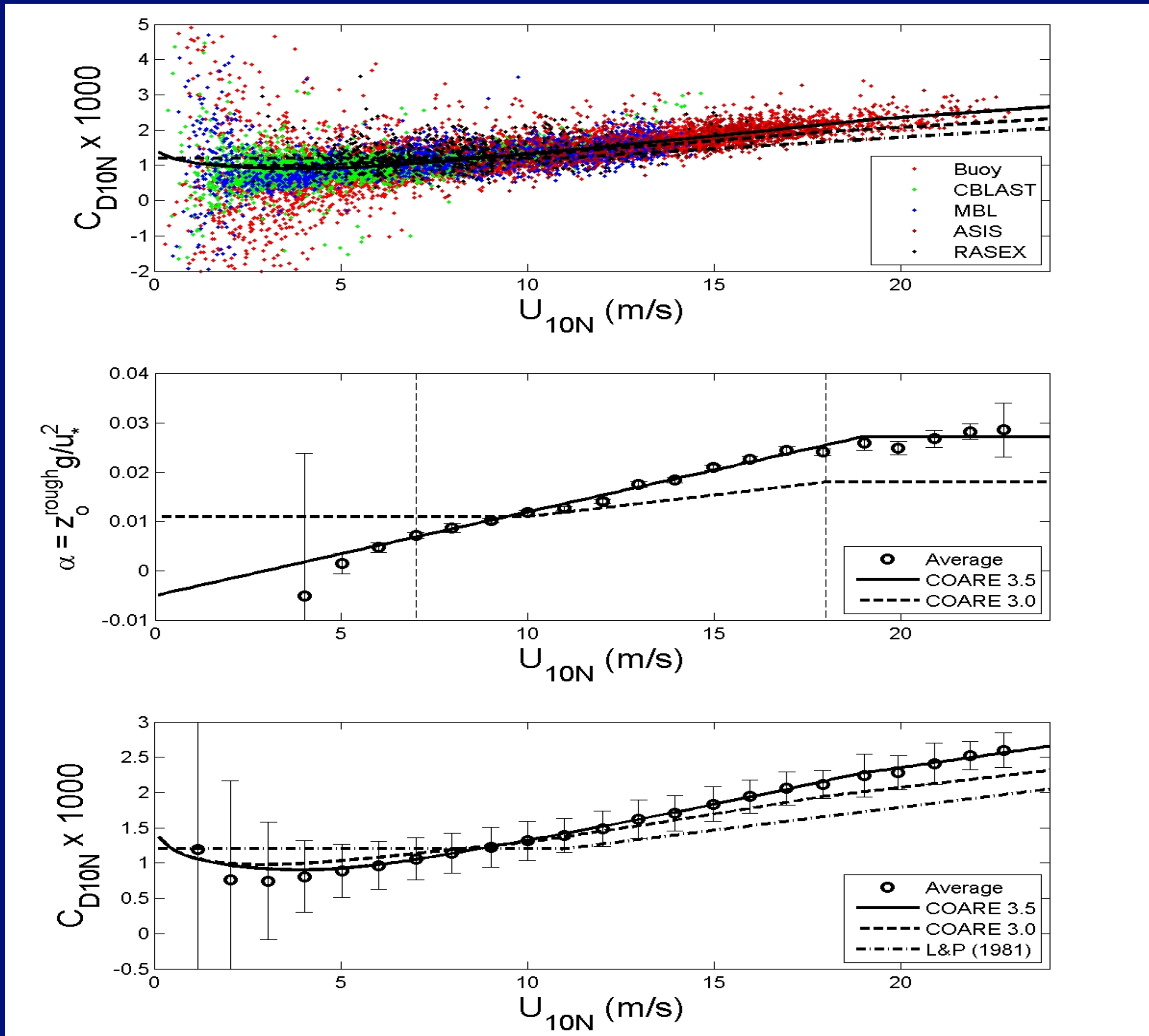
Drag Coefficient

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

Roughness Length

$$z_o = \alpha\frac{\nu}{u_*} + \beta\,(U_{N10})\frac{u_*^2}{g}$$

MBL/CBLAST/CLIMODE Drag Coefficients



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

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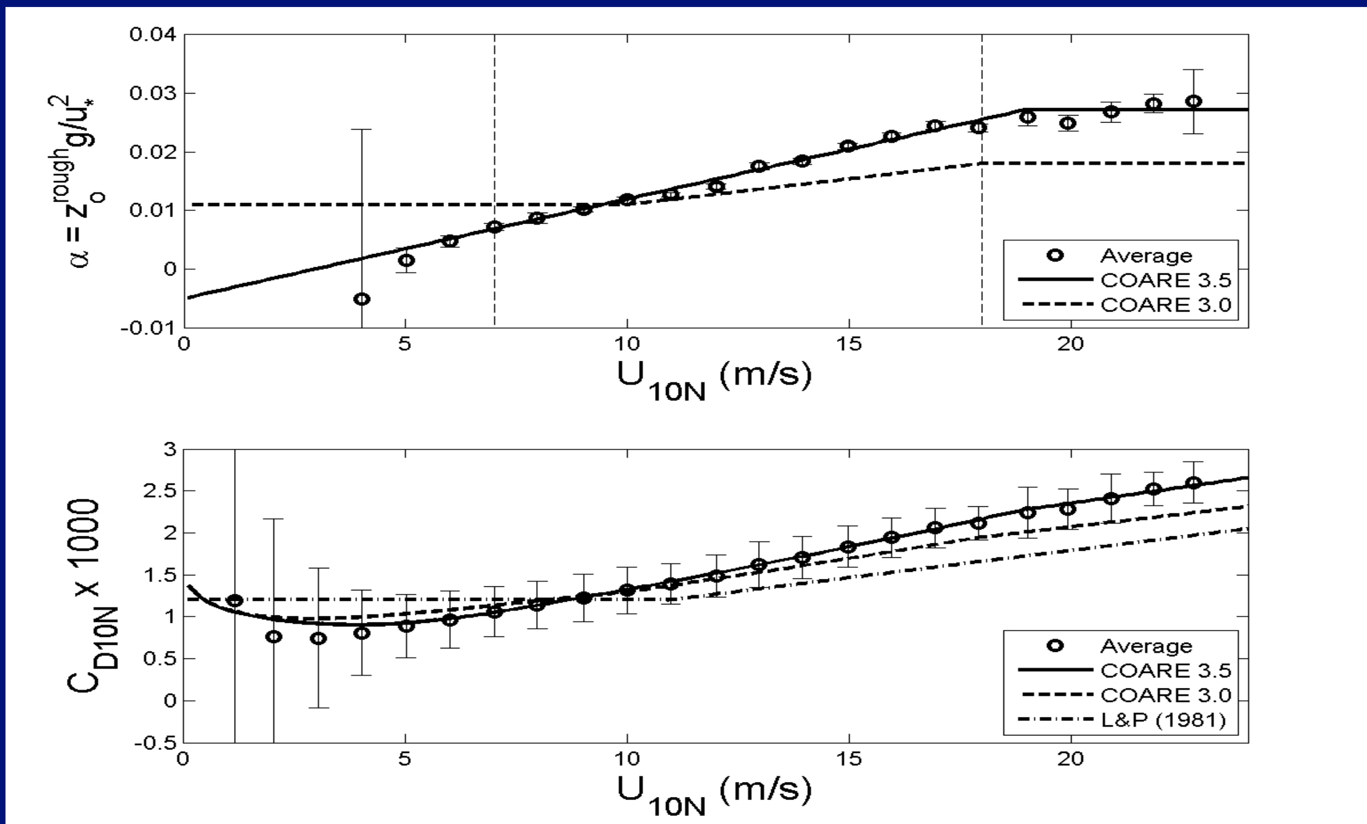
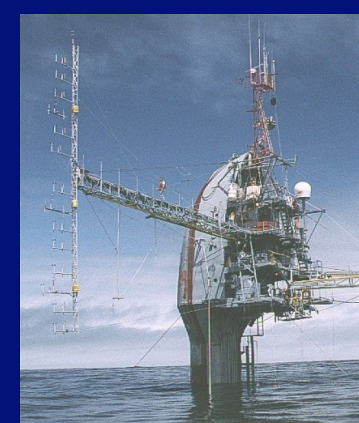
MBL/CBLAST/CLIMODE Drag Coefficients

COARE 3.5

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

doi: http://dx.doi.org/10.1175/JPO-D-12-0173.1





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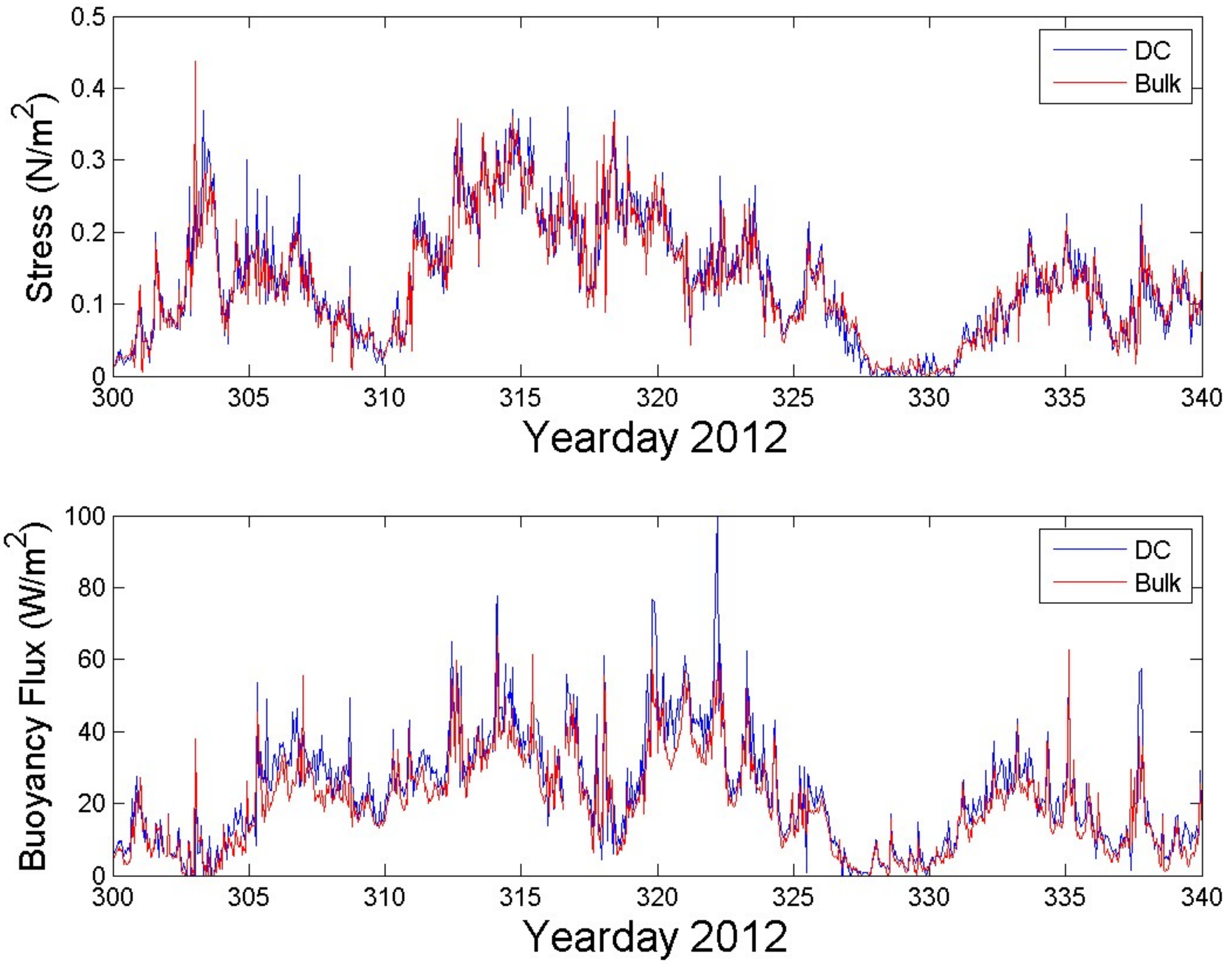
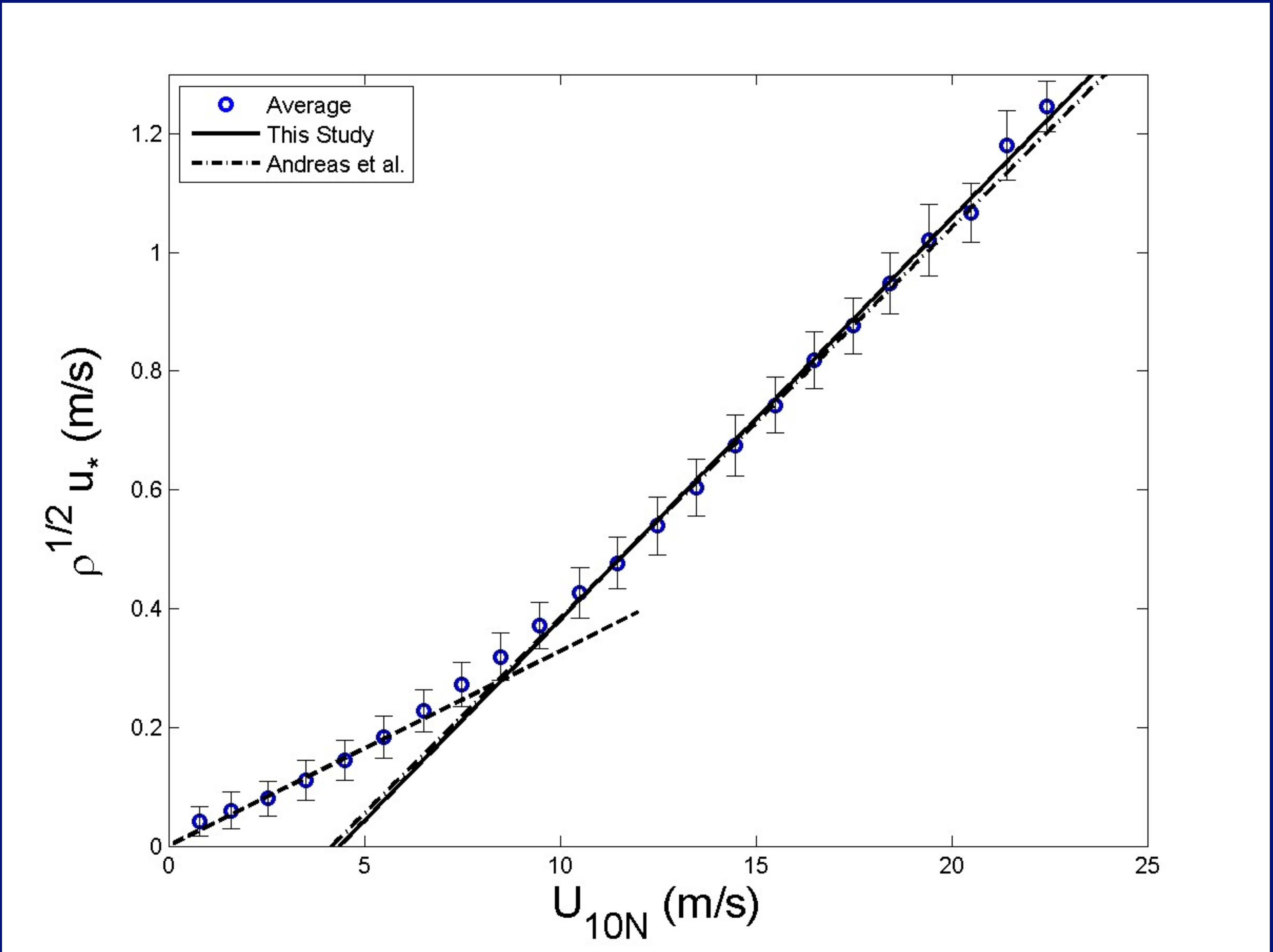
Flux Time Series



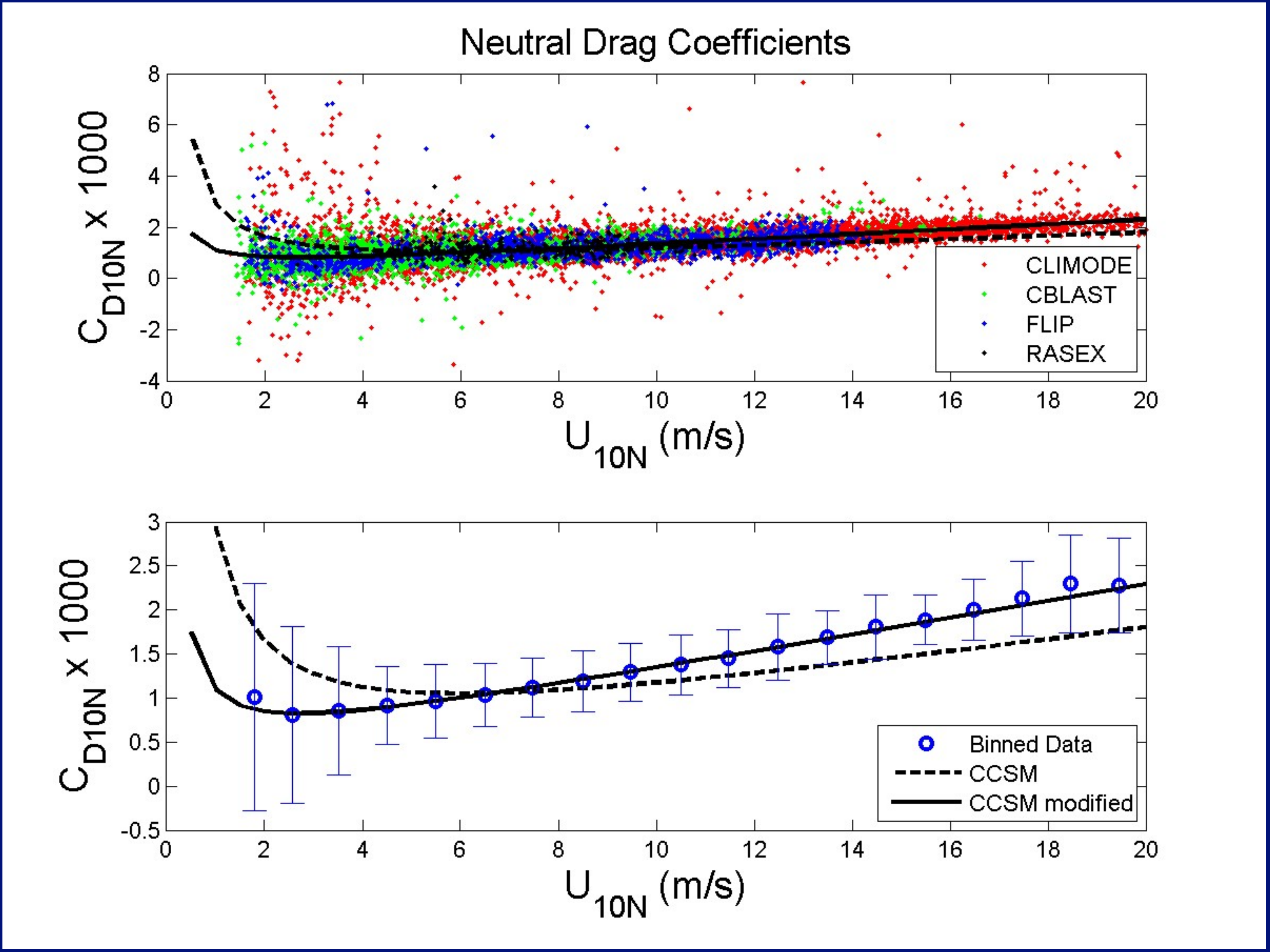
COARE 3.5

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

The Hockey Stick

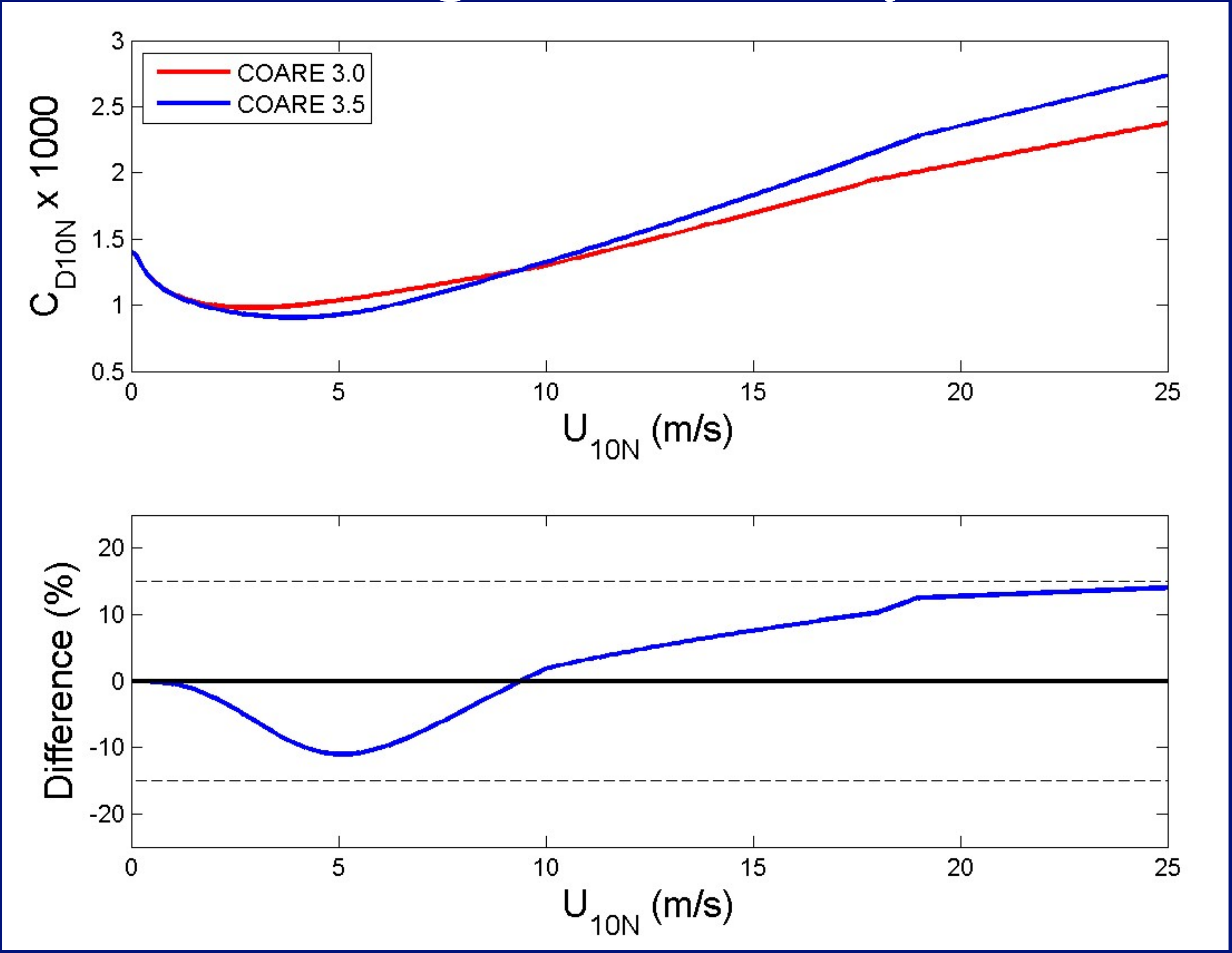


CCSM Drag



Neutral Drag Coefficients
$C_{D10N} \times 1000$
U_{10N} (m/s)
CLIMODE
CBLAST
FLIP
RASEX
$C_{D10N} \times 1000$
U_{10N} (m/s)
Binned Data
CCSM
CCSM modified

Drag Uncertainty



Surface Momentum Exchange & Waves

- **Above the Wave Boundary Layer – MO Similarity expected to hold.**

$$\rho\overline{uw} = \rho\overline{u'w'}$$

- **Within the Wave Boundary Layer – MO Similarity begins to break down.**

$$\rho\overline{uw} = \rho\overline{u'w'} + \rho\overline{\tilde{u}\tilde{w}}$$

- **At the surface**

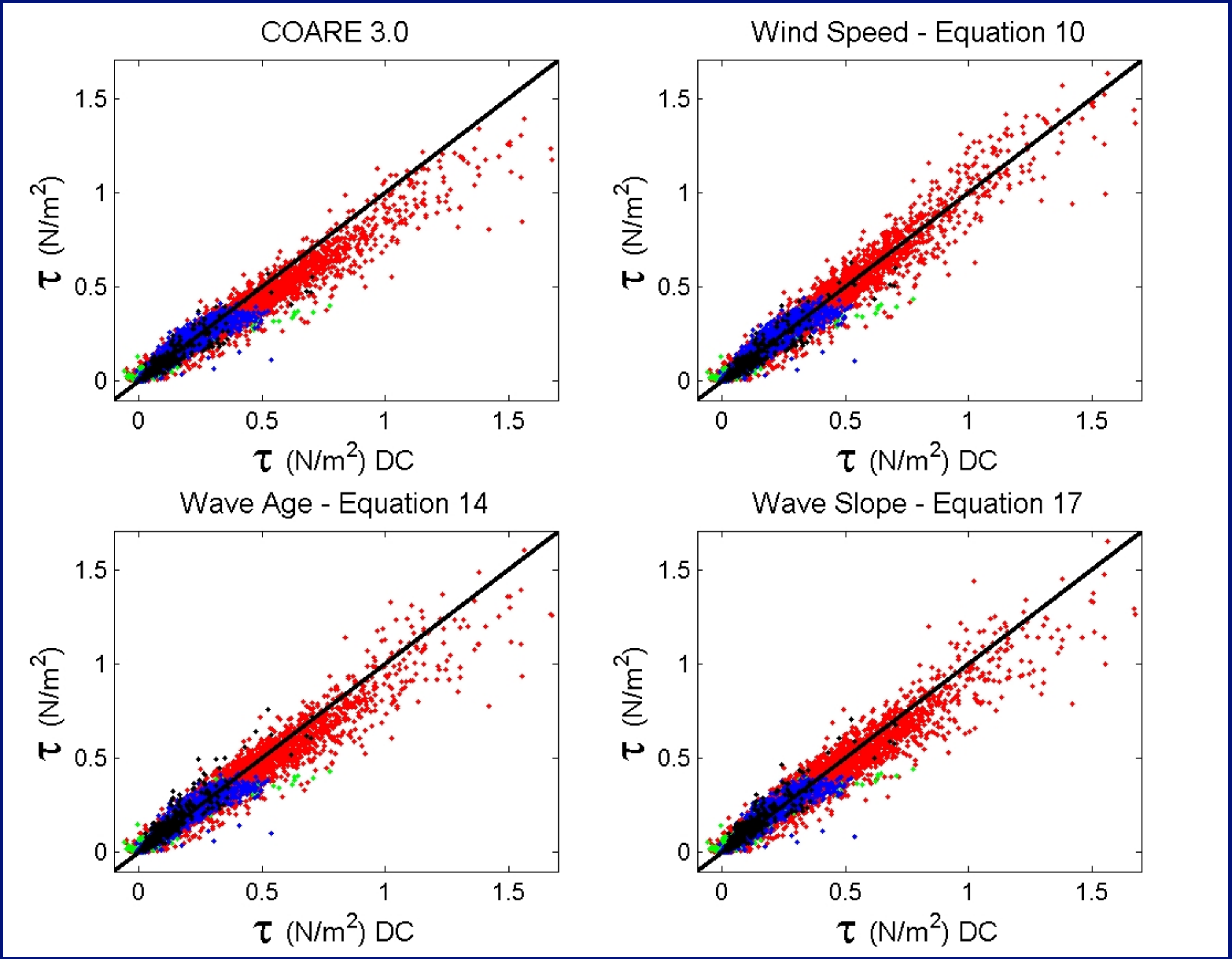
$$\rho\overline{uw} = \nu\frac{dU}{dz} + \rho\overline{\tilde{u}\tilde{w}} = \underbrace{\nu\frac{dU}{dz}}_{\text{Viscous Stress}} + \underbrace{\overline{p_0\frac{\partial\eta}{\partial x}}}_{\text{Form Drag}}$$

- **COARE parameterizes this through the roughness length:**

$$z_0 = \alpha\frac{\nu}{u_*} + \boxed{\beta}\frac{u_*^2}{g}$$

Charnock Parameter

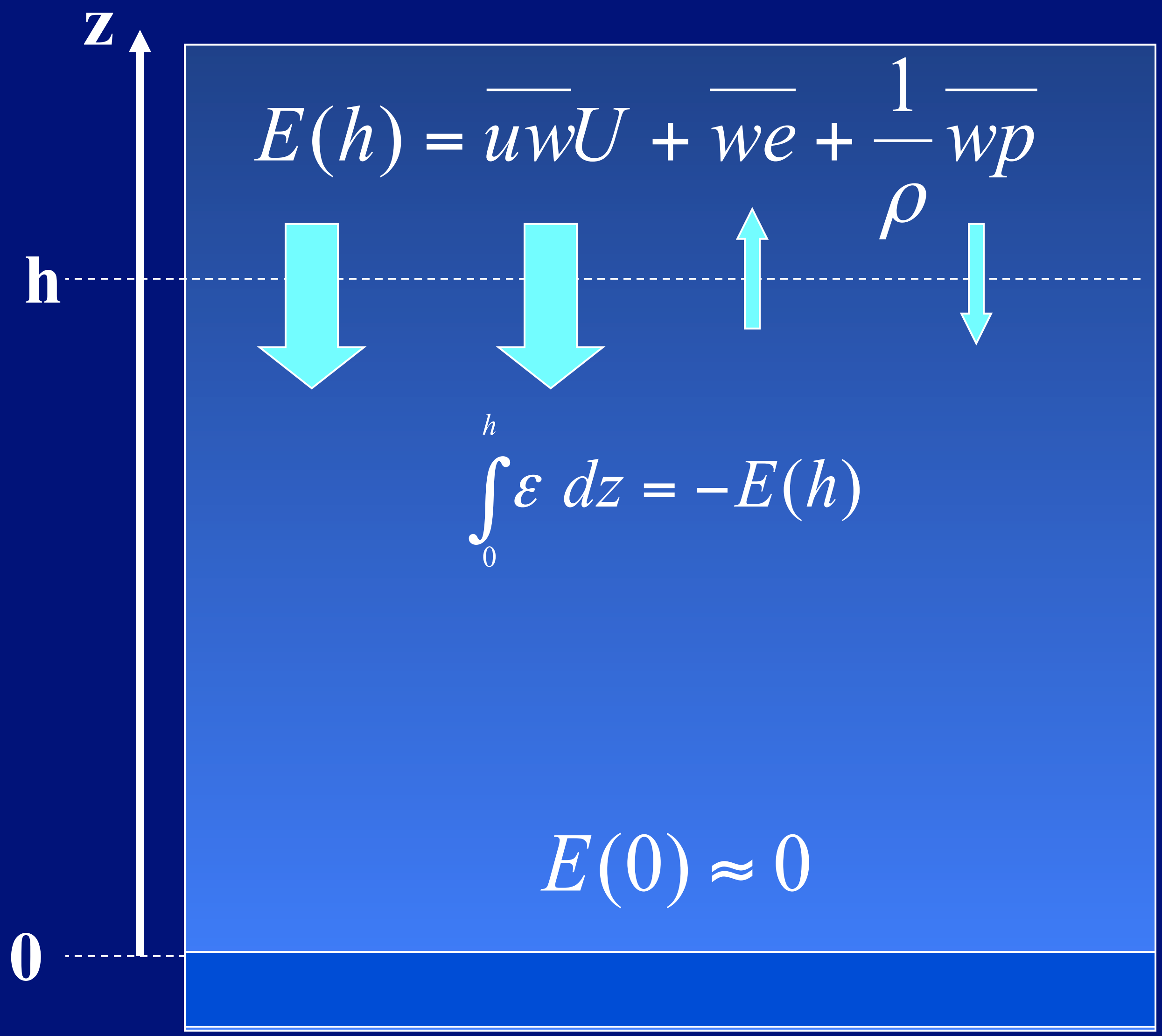
Wind Speed, Wave Age, Wave Slope



ENERGY EXCHANGE & WAVE GROWTH

Energy Flux Into the Marine Surface Layer

(Neutral & Horizontally Homogeneous)



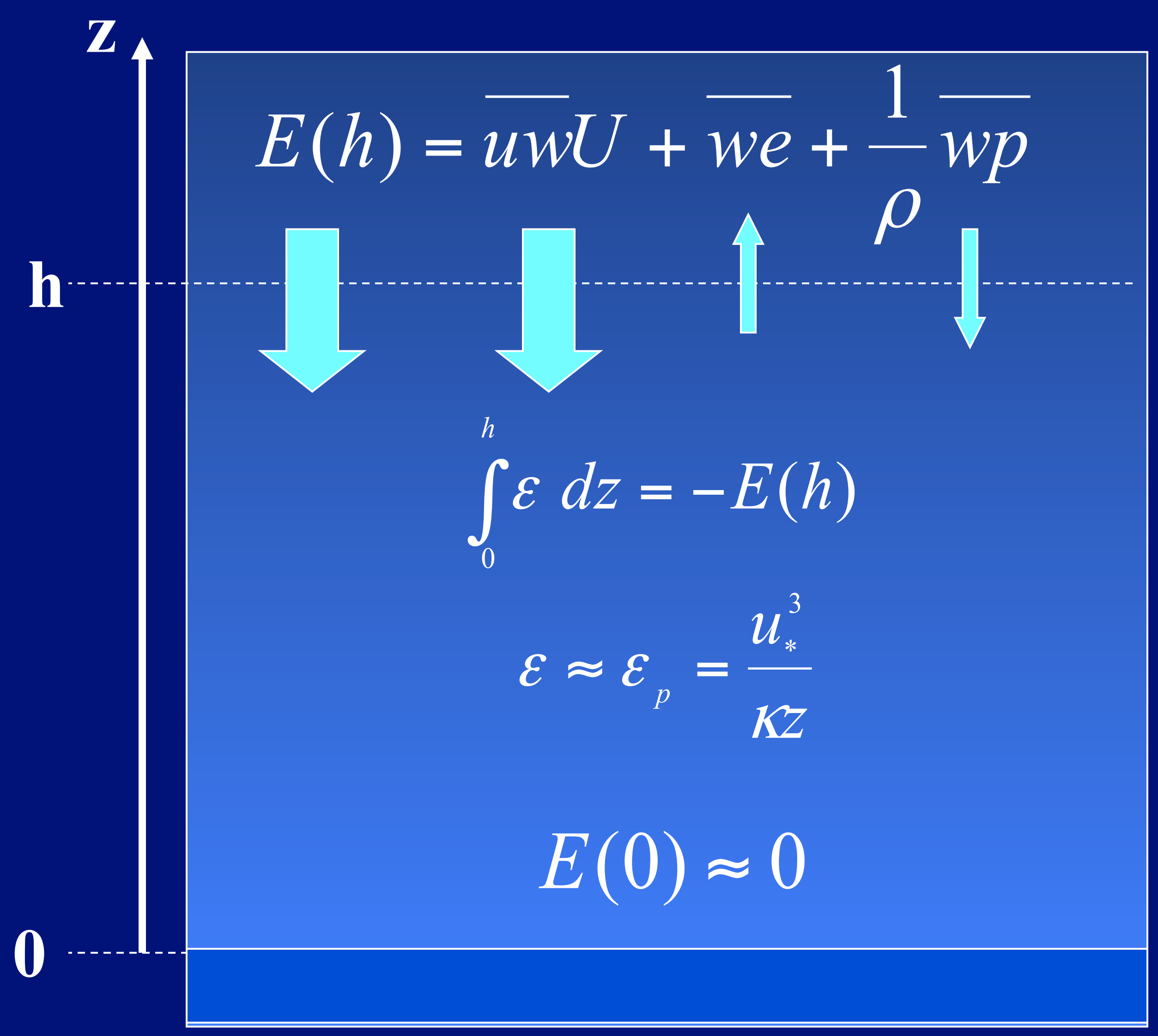
$$E(h) = \overline{uwU} + \overline{we} + \frac{1}{\rho}\overline{wp}$$

$$\int_0^h \varepsilon \, dz = -E(h)$$

$$E(0) \approx 0$$

Energy Flux Into the Marine Surface Layer

If there is no energy out the bottom, then the law-of-the-wall is expected.



$$E(h) = \overline{uwU} + \overline{we} + \frac{1}{\rho}\overline{wp}$$

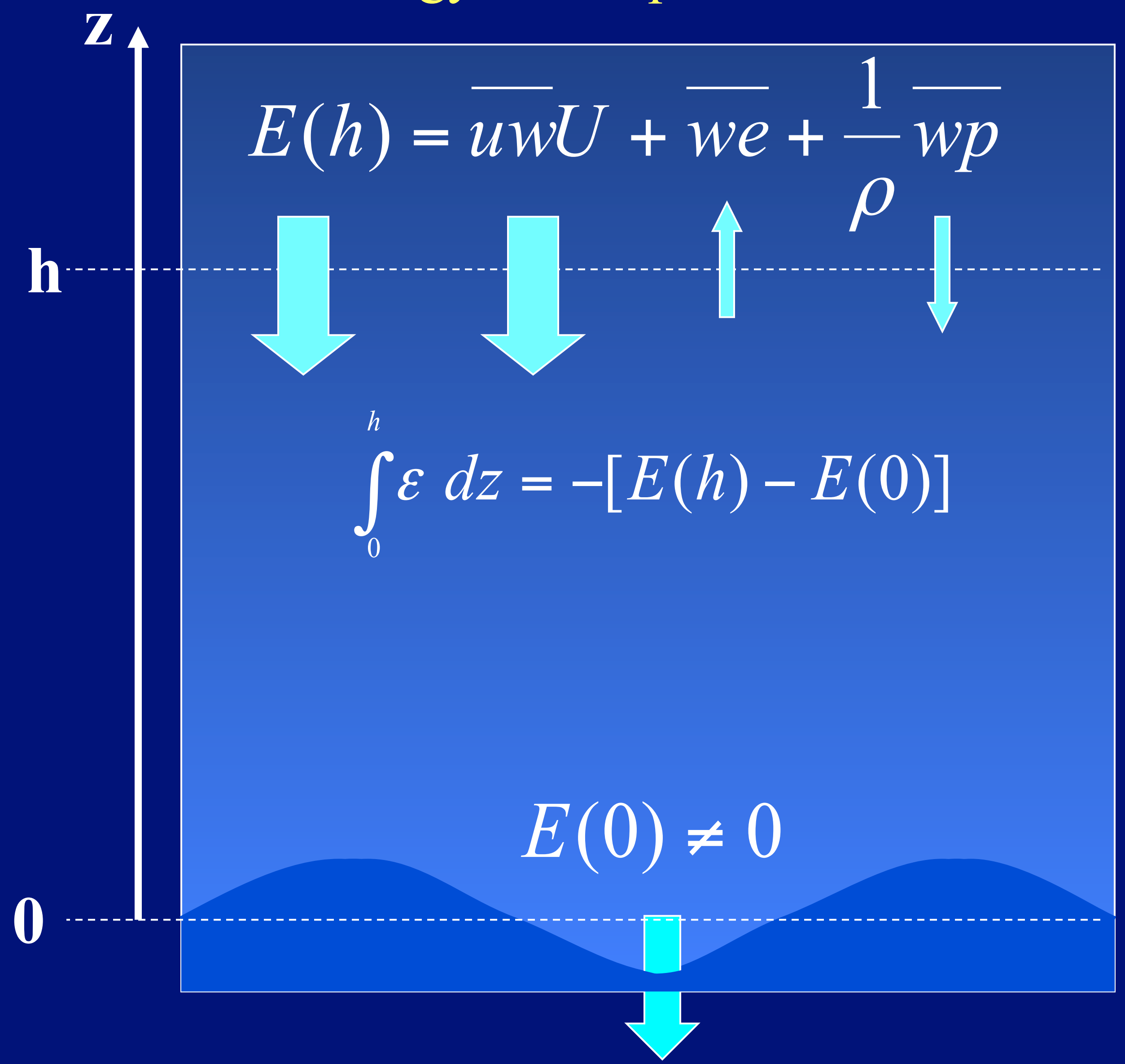
$$\int_0^h \varepsilon \, dz = -E(h)$$

$$\varepsilon \approx \varepsilon_p = \frac{u_*^3}{\kappa z}$$

$$E(0) \approx 0$$

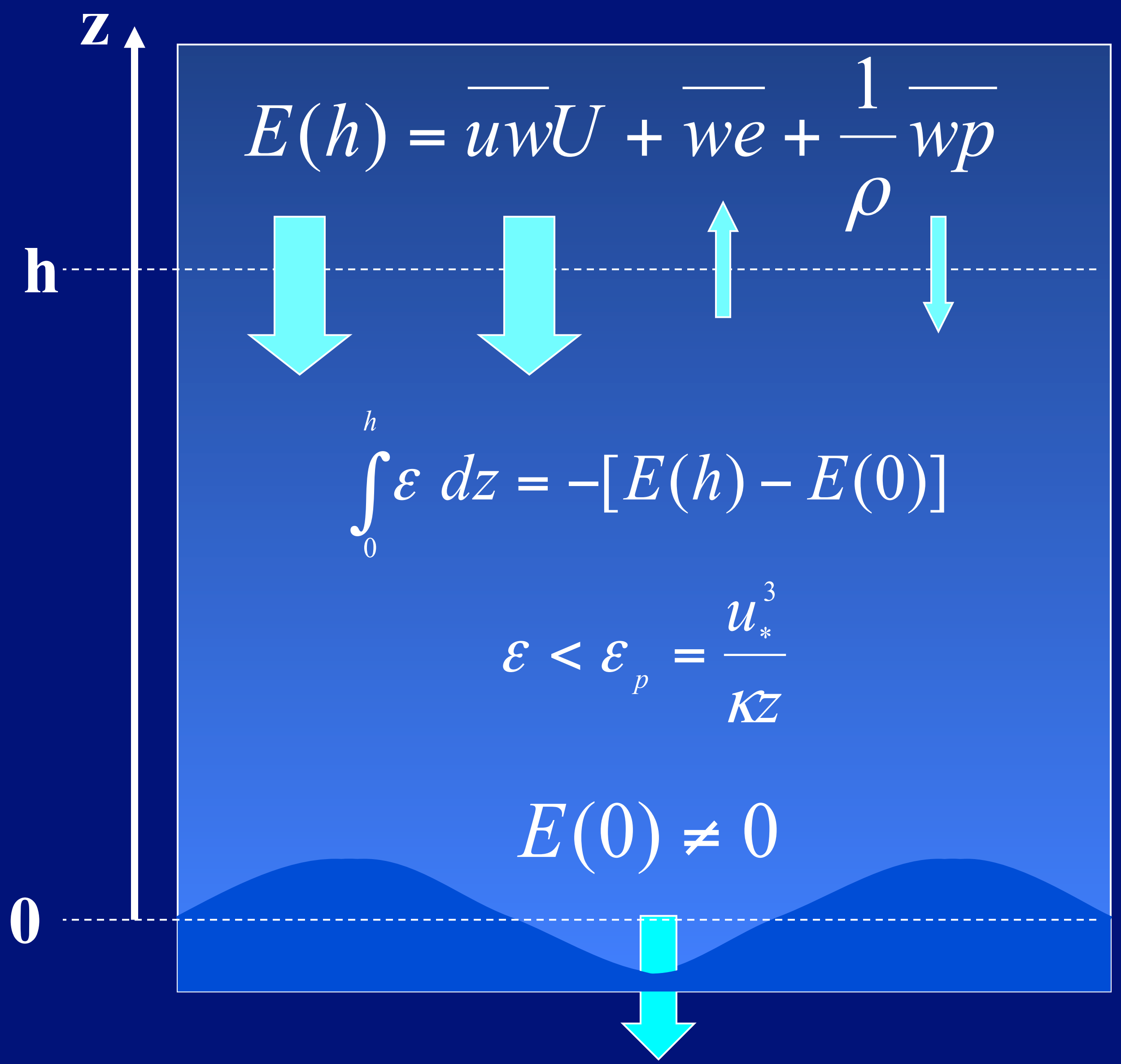
Energy Flux Into the Marine Surface Layer

However, if some of the energy is transported to the ocean then less energy is dissipated & ...

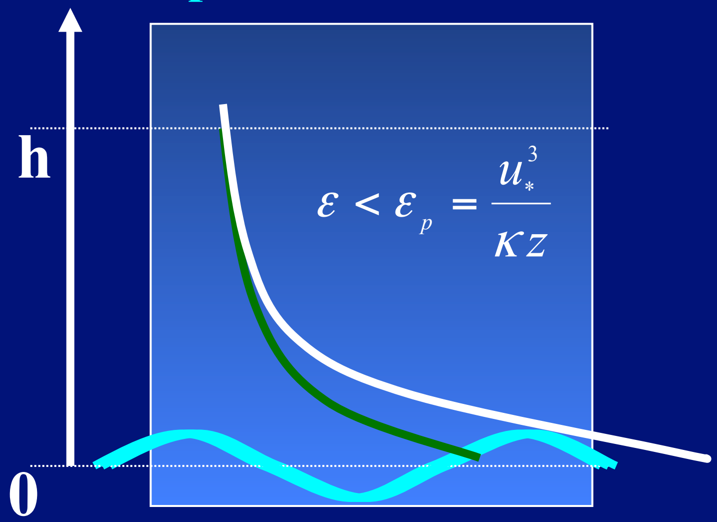


Energy Flux Into the Marine Surface Layer

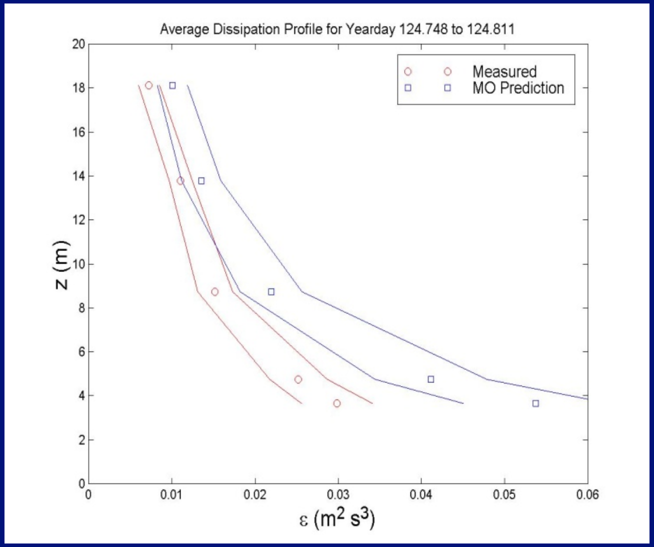
The measured dissipation should be less than predicted by the law-of-the-wall.



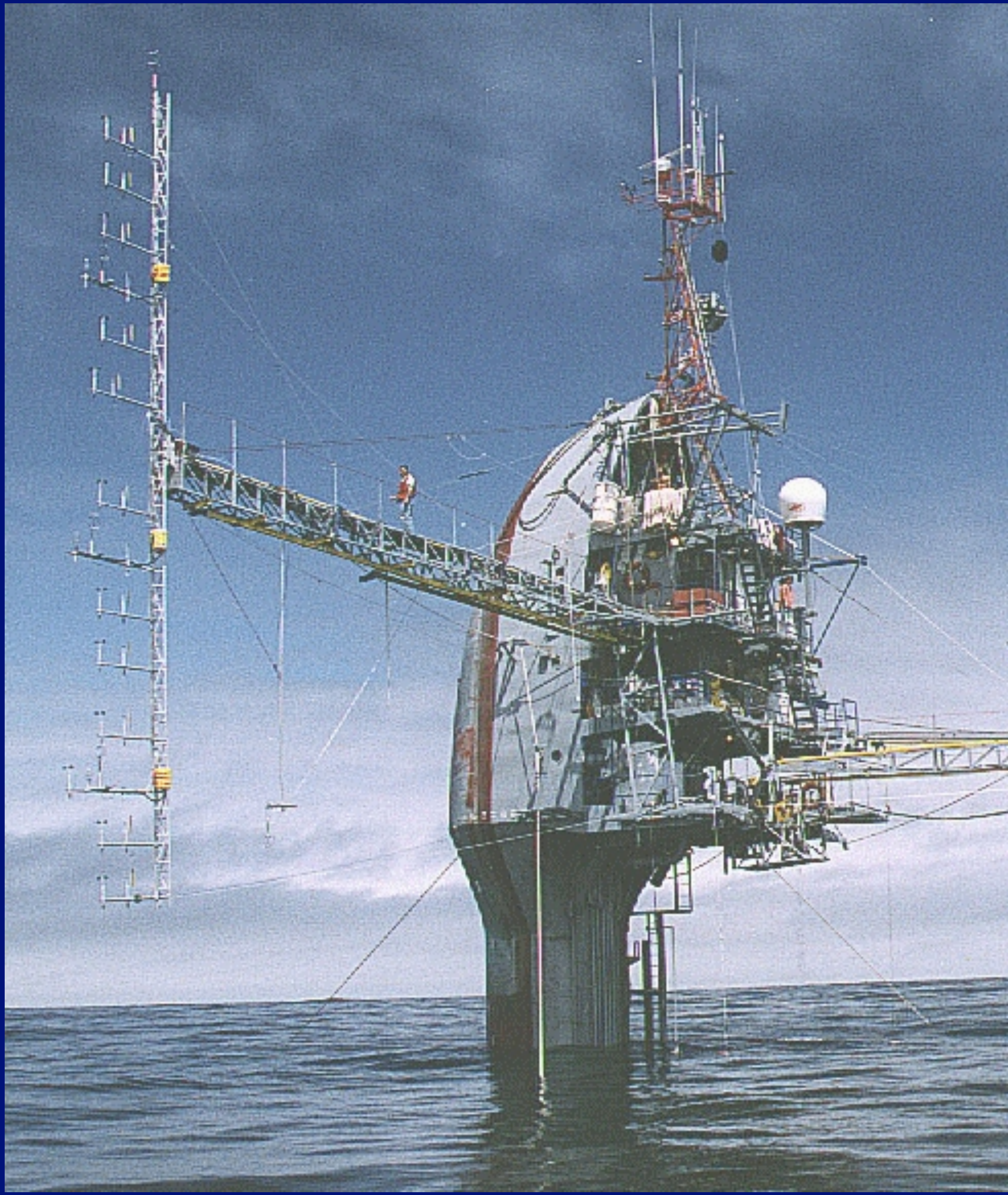
Measured dissipation should be less than predicted.



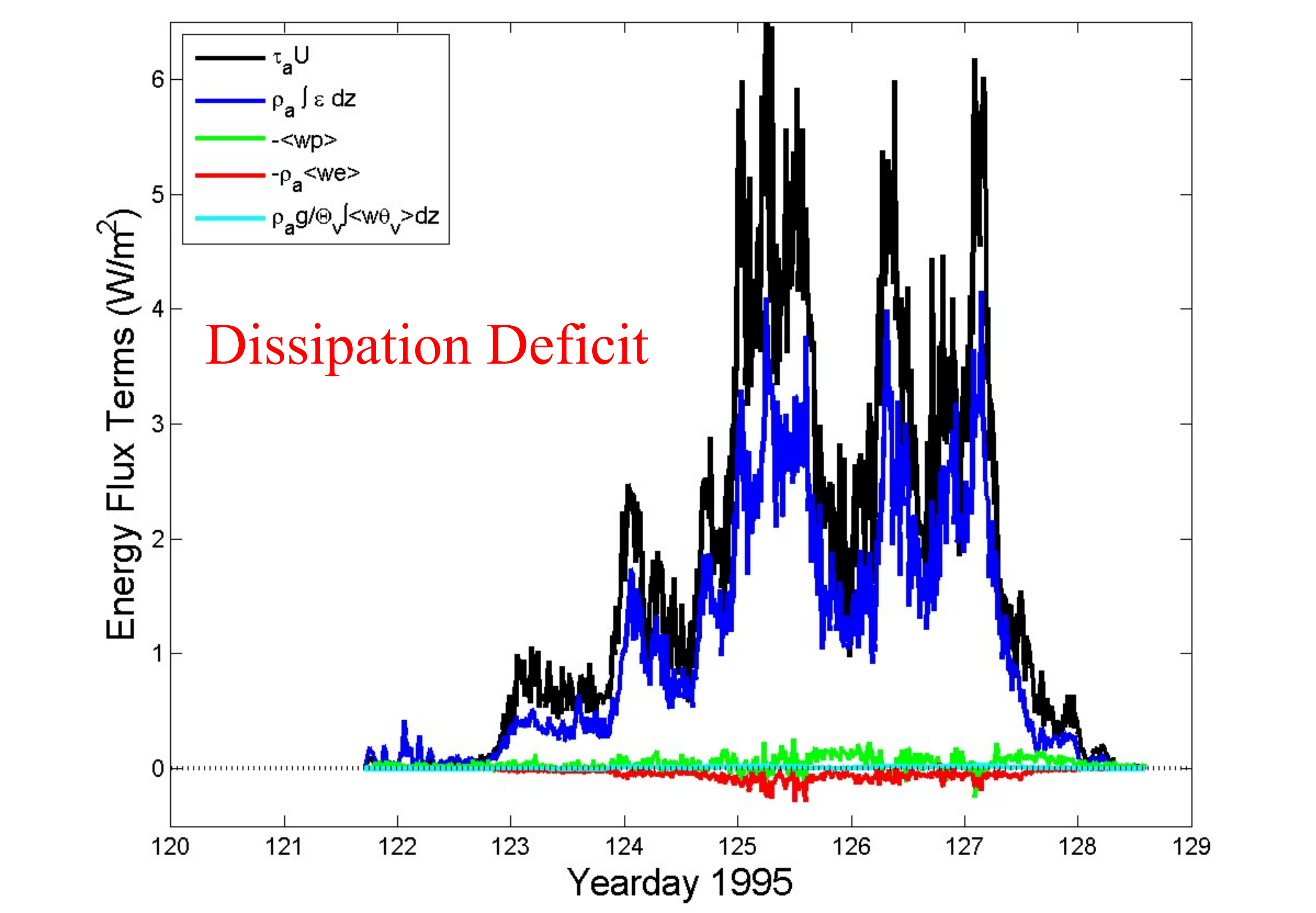
FLIP results



confirm this

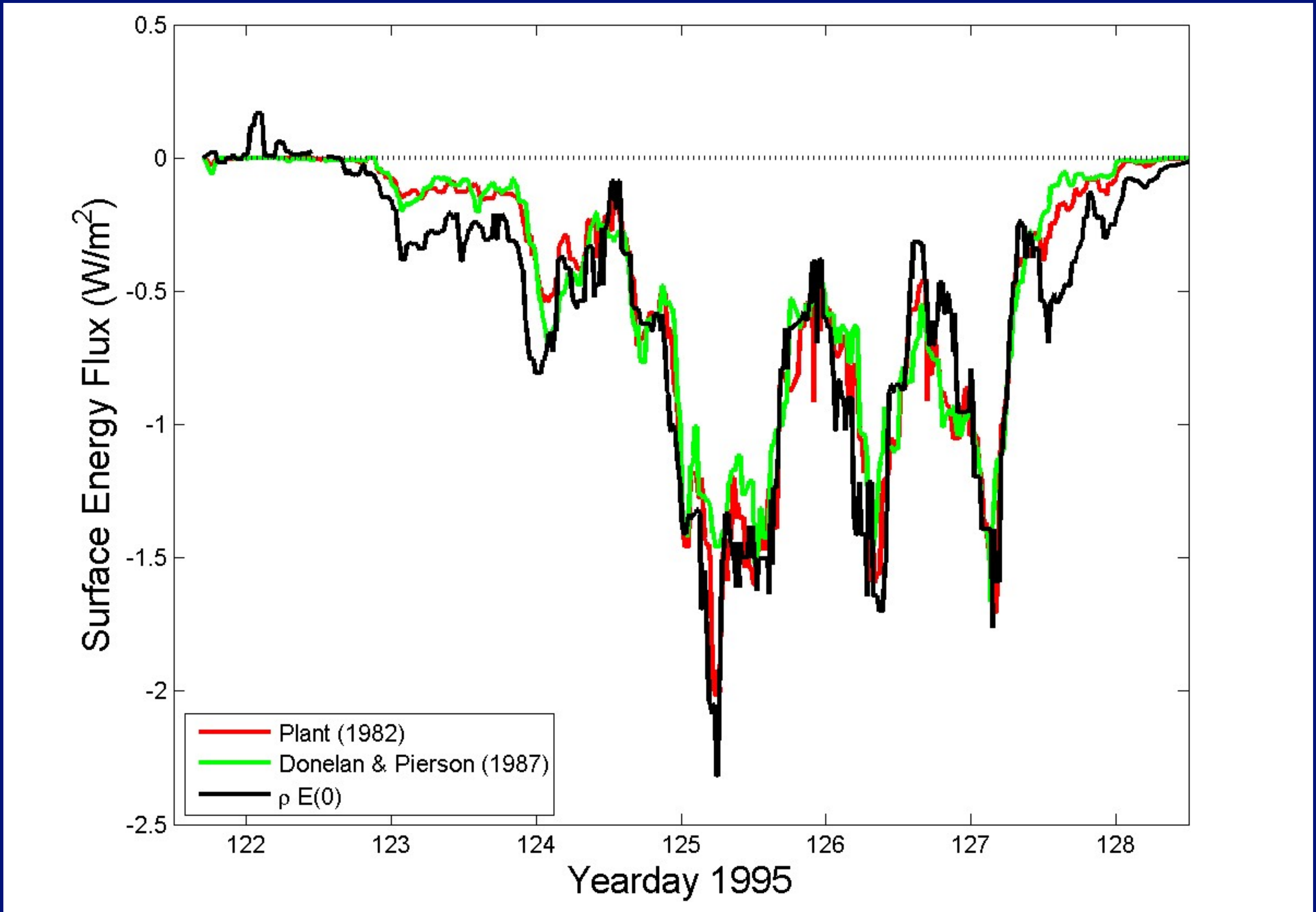


Energy Flux Into the Marine Surface Layer



$$E(0) = \rho_a \int_0^h \varepsilon\, dz - \tau_a U + \rho_a \overline{we} + \overline{wp} - \frac{\rho g}{\Theta_v} \int_0^h \overline{w\theta_v}\, dz$$

Energy Flux Into the Marine Surface Layer



$$E(0) = \rho_a \int_0^h \varepsilon \, dz - \tau_a U + \rho_a \overline{we} + \overline{wp} - \frac{\rho g}{\Theta_v} \int_0^h \overline{w \theta_v} \, dz$$

The reduced/enhanced dissipation is caused by:

$$\varepsilon = \boxed{-\overline{uw}\frac{\partial U}{\partial z}} - \frac{g}{\Theta_v}\overline{w\theta_v} - \boxed{\frac{\partial \overline{we}}{\partial z}} - \boxed{\frac{1}{\rho}\frac{\partial \overline{wp}}{\partial z}}$$

- Wave-induced modulation of the shear production term.
  - Momentum Flux → $\rho uw(0) = p(0)\, \partial\eta/\partial x$
- Energy transport
- Wave induced modulation of the energy transport terms.
  - Energy Flux → $wp(0) = p(0)\partial\eta/\partial t$

HEAT EXCHANGE

Heat Fluxes

Latent Heat Flux

$$Q_E = \rho L_v \overline{wq} \approx \rho C_{EN} \Delta Q U_r G$$

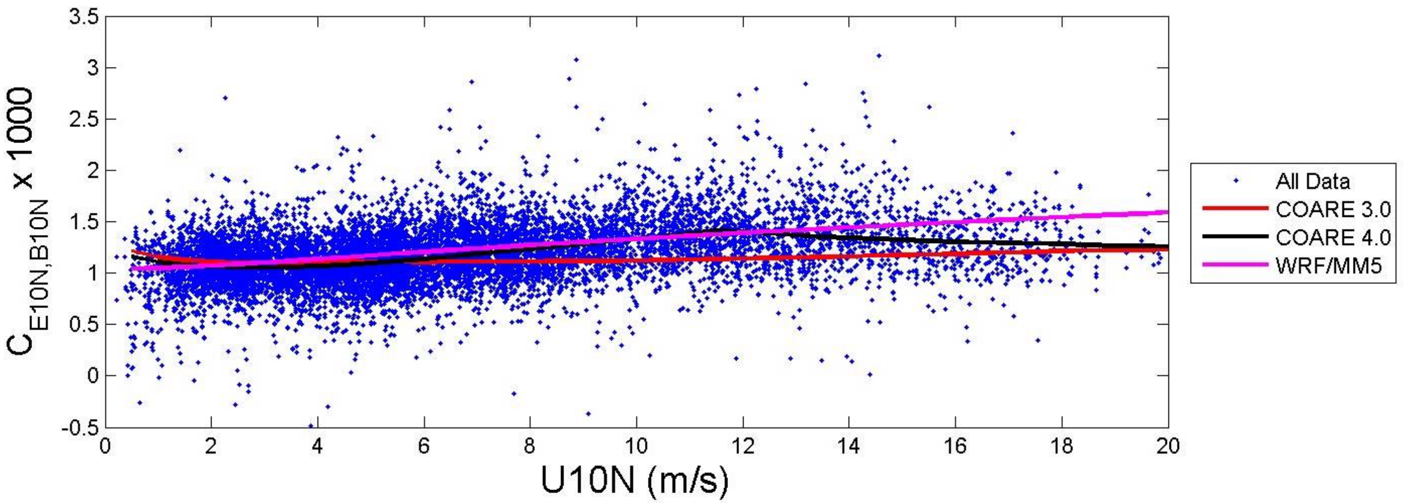
Drag Coefficient

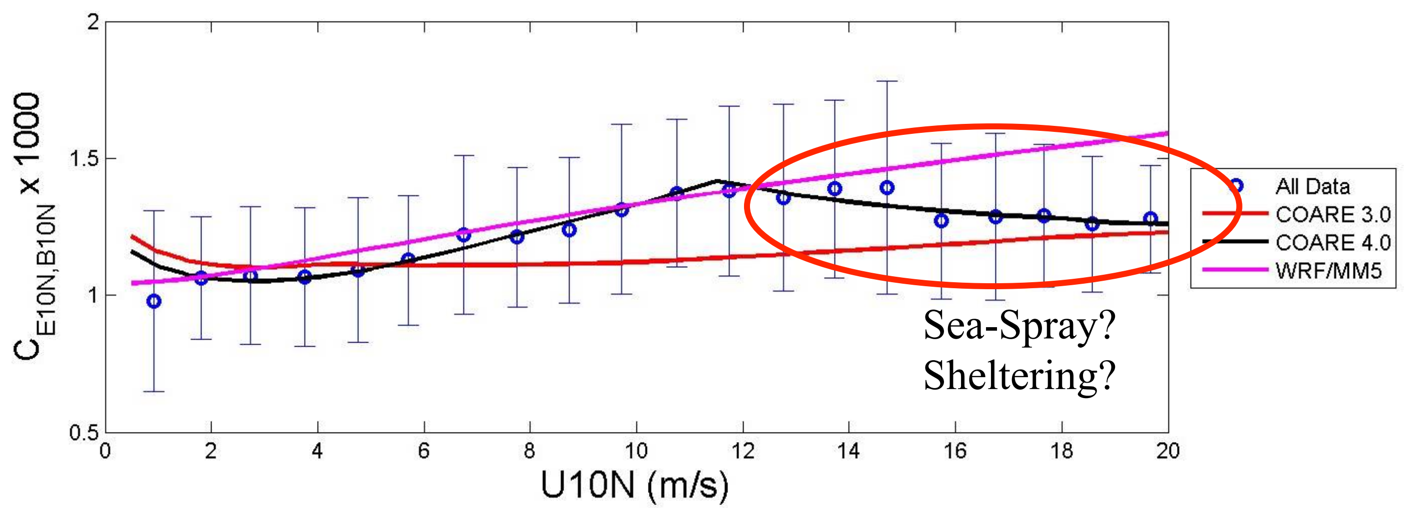
$$C_{EN} = \frac{\overline{wq}}{\Delta Q U_r G} = \left(\frac{\kappa}{\ln(z / z_{0q})} \right)^2$$

Thermal Roughness Length

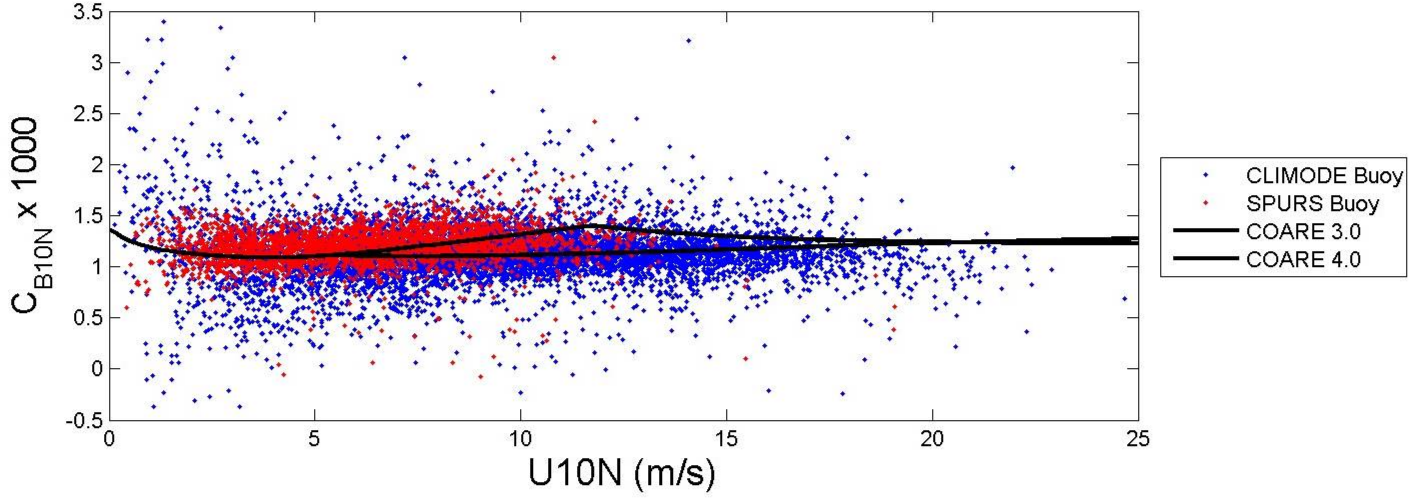
$$z_{0q} = f(z_0 u_* / \nu)$$

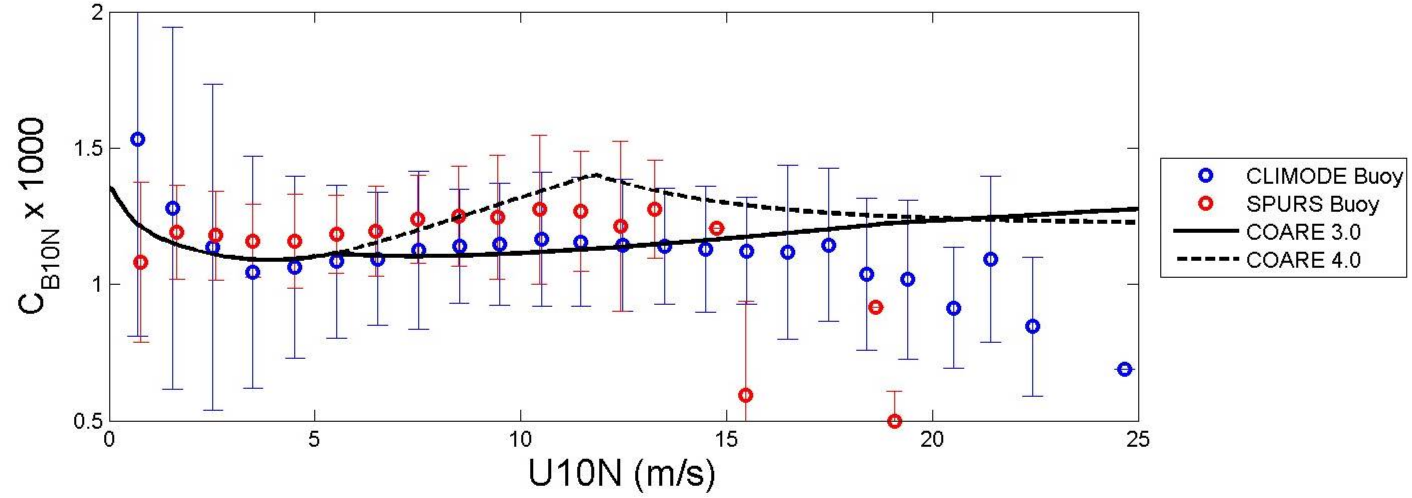
Heat Transfer



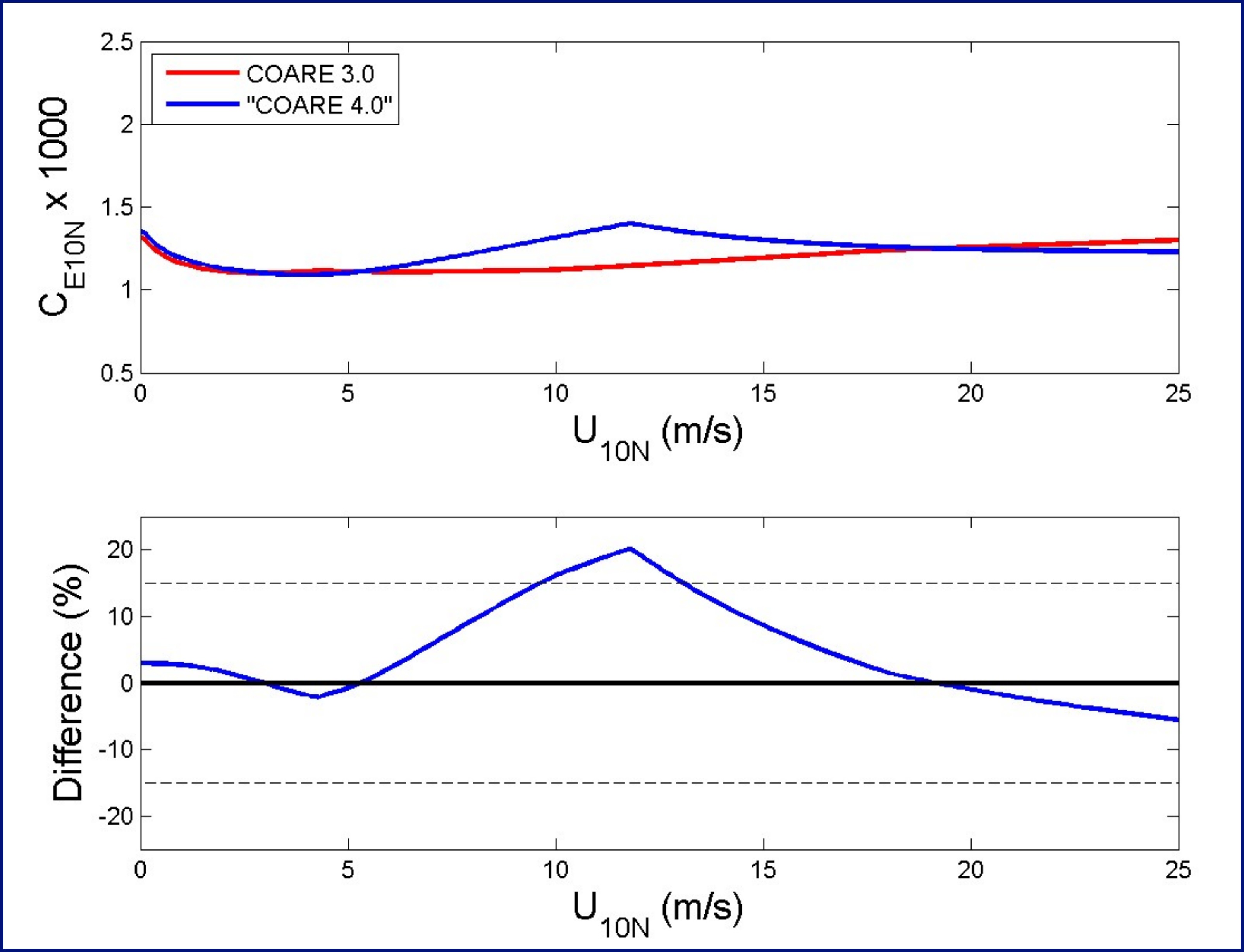


Heat Transfer





Dalton/Stanton Number Uncertainty



FUTURE OF FLUX MEASUREMENTS FOR PROCESS STUDIES

NSF’s Ocean Observing Initiative (OOI)

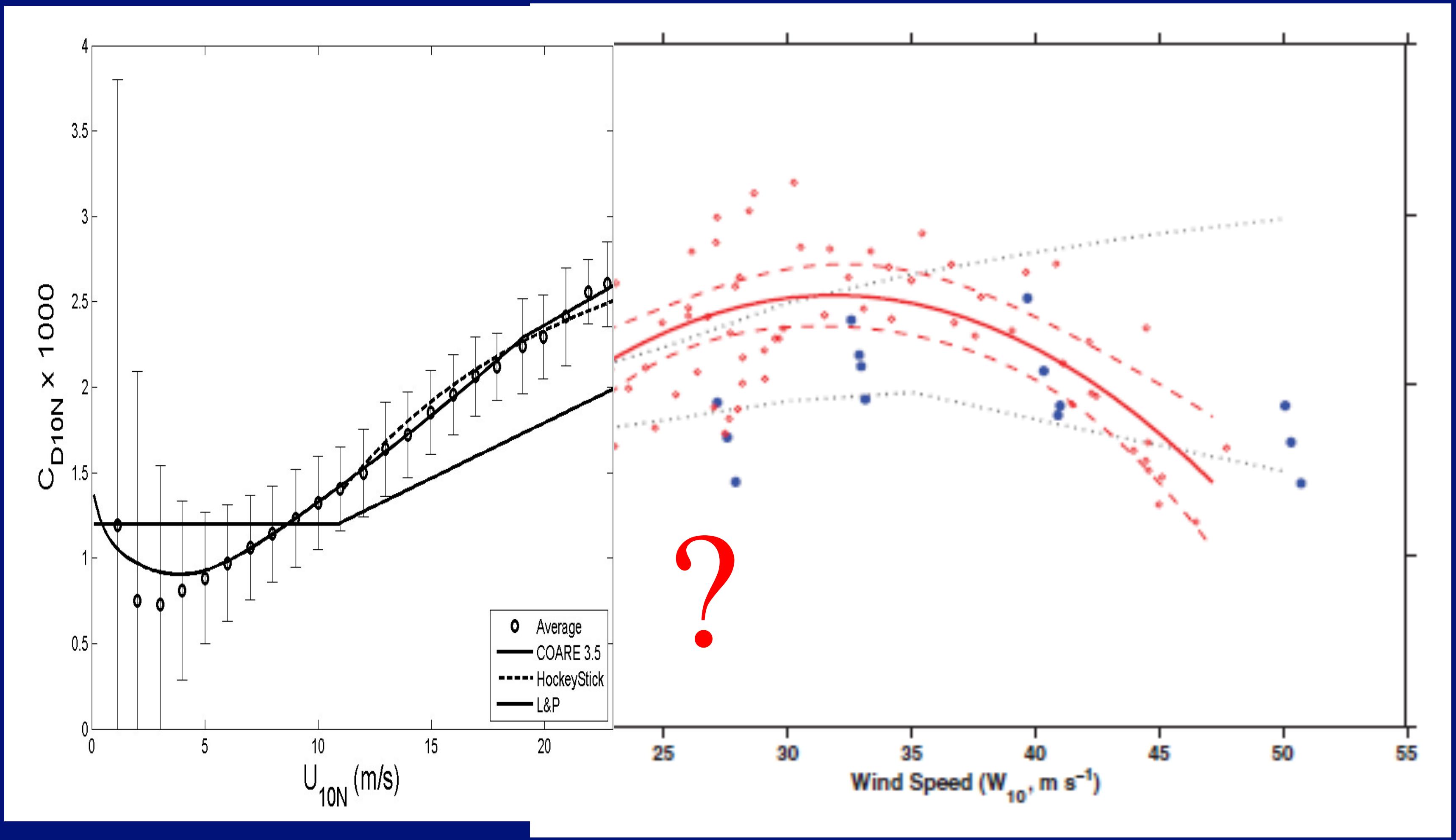
- The community needs to push for access to the raw data.
- One suggestion is for a group of PIs to write a proposal to analyze data from these buoy.
- Hold a workshop to compare techniques, products and discuss scientific findings.
- Post consensus fluxes to the community.

Summary

- The COARE3.5 Drag Coefficient Algorithm gives good agreement with data from a variety of low-distortion, open ocean platforms with greatest uncertainty at low & very high winds.
- While wave-age and sea-state dependent Charnock variables give good agreement with data, it is hard to beat a wind-speed dependent formulation.
- Our investigations of energy transport in the MABL indicate a dissipation deficit over growing seas and a dissipation surplus over swell.
- Somewhat less certainty is seen in the transfer coefficients for heat (i.e., the Stanton and Dalton Numbers) due to the use of ship-based measurements and flow distortion issues, and spray at high winds.
- Disagreement in these transfer coefficients exist between ship- and buoy-based estimates.
- We need to take advantage of the latest buoy-based measurements from OOI and other field programs.

Questions?

Drag Coefficients at High Winds



How do we quantify the behavior at High Winds?

Relative Velocity

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