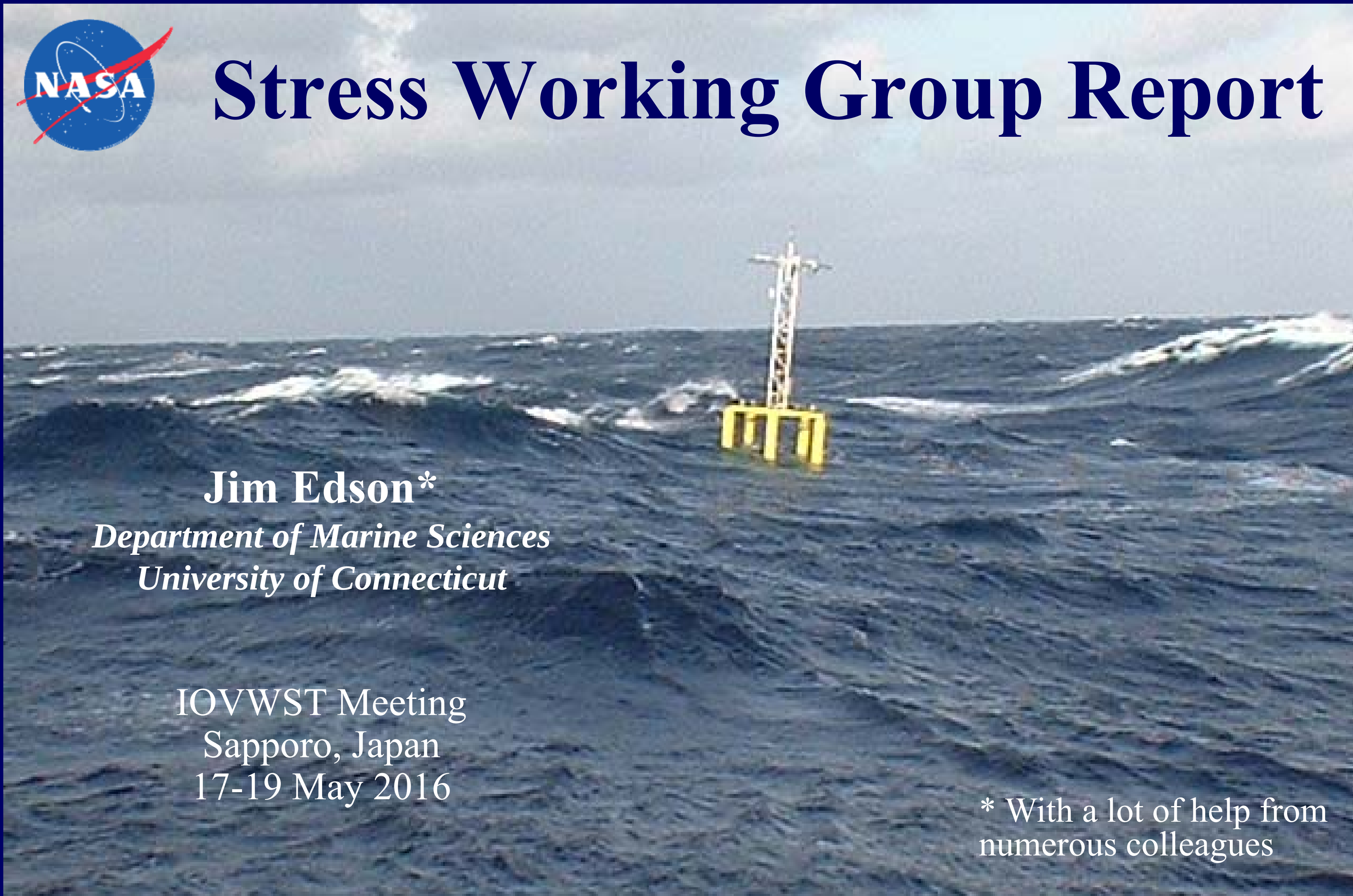
Stress Working Group Report



Jim Edson*

Department of Marine Sciences

University of Connecticut

IOVWST Meeting
Sapporo, Japan
17-19 May 2016

* With a lot of help from numerous colleagues

Research supported by grants from the NASA ONR, and NSF

Background

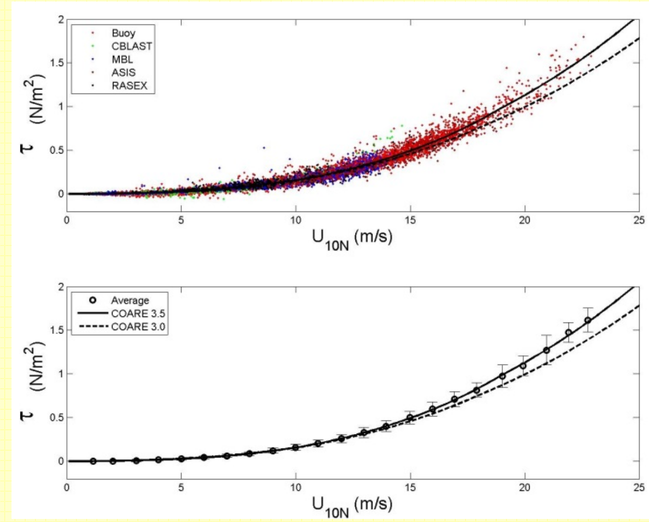
Motivation for the working group can be found in a recent ocean flux remote sensing survey paper by Bourassa et al. (2010 TOS):

- *Recent studies find that scatterometers, and presumably other wind-sensing instruments, respond to stress rather than wind, accounting for variability due to **wind, buoyancy, gustiness, surface currents, waves, and air density**.*
- *The basis for this is that radar backscatter is proportion to surface roughness, and we generally assume that surface roughness is most closely correlated with wind stress, τ.*
- *Wind stress is most closely correlated with the equivalent neutral wind speed (squared) relative to the sea surface, computed at a height of 10-m, U_{r10N}.*
- *The relationship between U_{r10N} and τ given found using a neutral drag coefficient C_{D10N}:*

$$\tau = \rho_a \overline{uw} \cong \rho_a C_{D10N} U_{r10N}^2 G \quad \Rightarrow \quad C_{D10N} = \left(\frac{\kappa}{\ln(z / z_0)} \right)^2$$

- *Therefore, the stress can be estimated from scatterometer-derived winds through a drag coefficient without the need for stability corrections.*

Momentum Fluxes

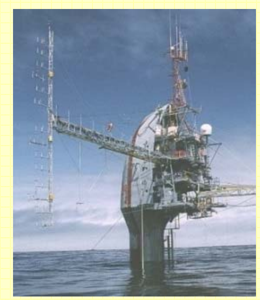


Surface Stress

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

Drag Coefficient

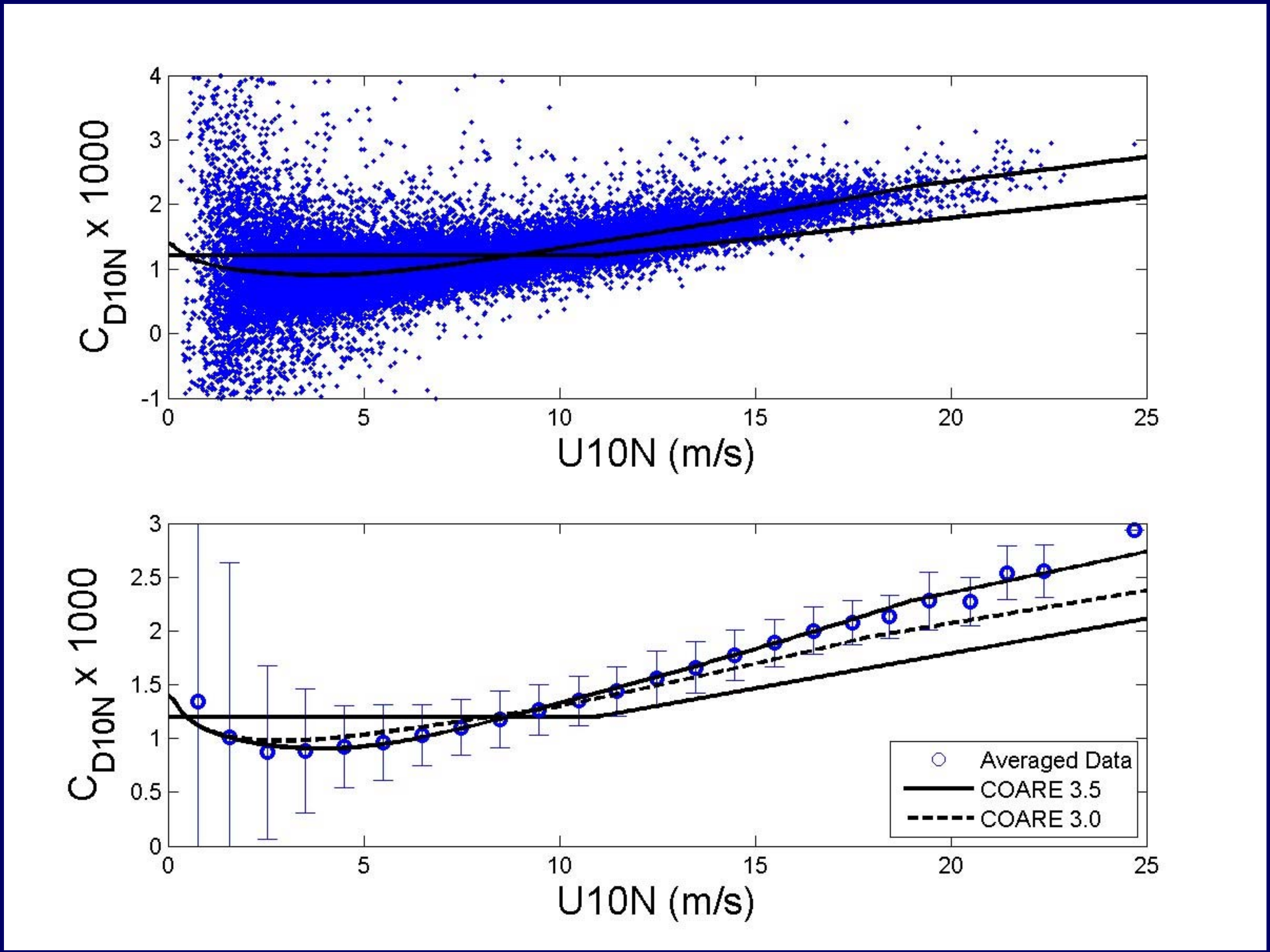
$$C_{DN} = \frac{-\overline{uw}}{\Delta U_{Nr}^2 G} = \left(\frac{\kappa}{\ln(z / z_o)} \right)^2$$



Roughness Length

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

MBL/CBLAST/CLIMODE Drag Coefficients



Long time series data sets are found at:

http://tds-opal.sr.unh.edu/thredds/catalog/opal_ts/opal_asflux/catalog.html

Momentum Fluxes

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$$\tau = -\rho_a \overline{uw} \approx \rho_a C_{DN} U_{rN}^2 G$$

Drag Coefficient

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

Neutral Winds

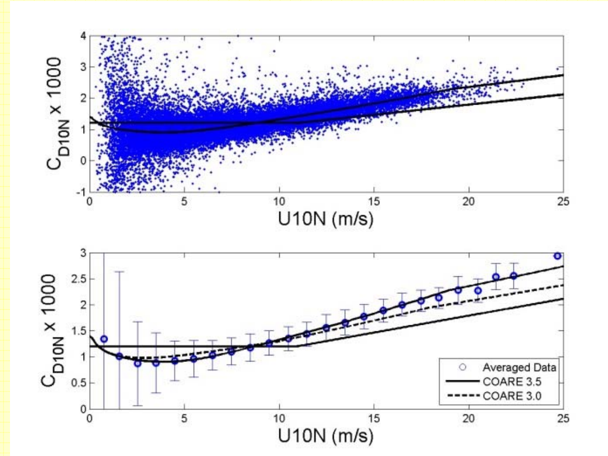
$$U_{rN} = U_r - \frac{u_*}{\kappa G}\psi(z/L)$$

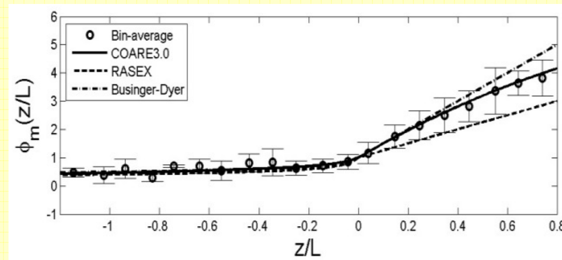
Relative Winds

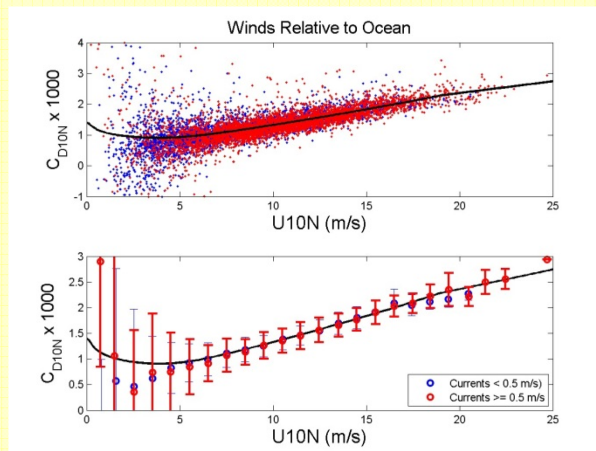
Density Effects

Gustiness

Buoys generally provide vector averaged winds and we need to parameterize the missing gustiness in the actual wind speed.

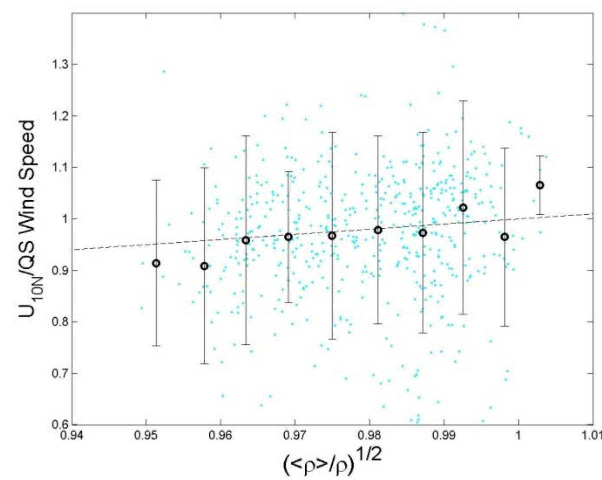






Density Effects

- Ocean surface wind stress depends on the atmospheric density. The GMF has been constructed using the average surface atmospheric density, $<\rho_a>$, above the oceans, but if the actual value, ρ_a, is taken into account the result becomes better suitable to be compared to NWP v



$$\tau_0 = <\rho_a> C_{D10N} \left(U_{r10N}^{retrieval}\right)^2 = \rho_a C_{D10N} U_{r10N}^2$$

$$U_{r10N} = \sqrt{\frac{<\rho_a>}{\rho_a}}\, U_{r10N}^{retrieval}$$

- Here we have assumed that the Drag Coefficients are the same.
- Of course, this could be adjusted as well using the latest generation of drag coefficients.

Stress-equivalent Winds, U10S

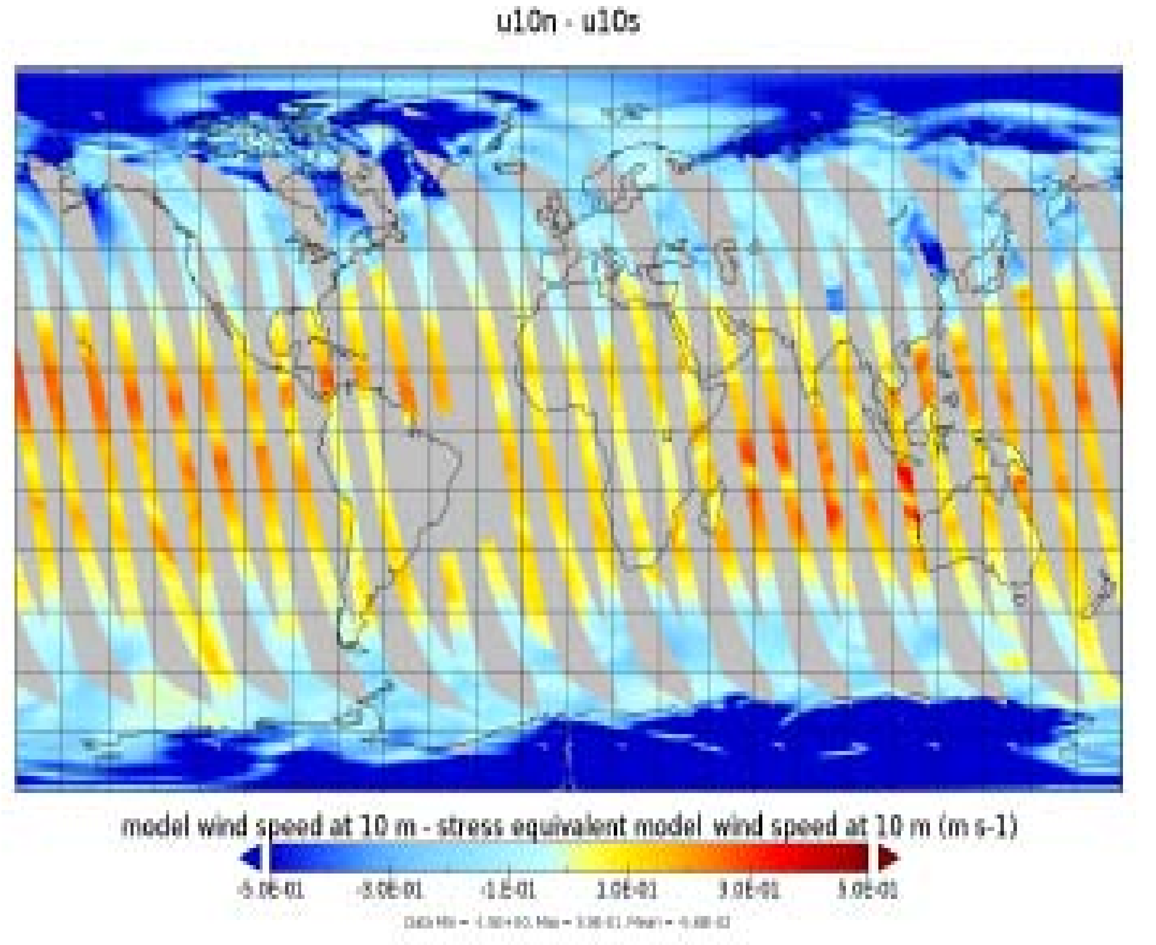
Equivalent neutral winds, $\boldsymbol{u}_{r10N}$, depend only on $\boldsymbol{u}_*$, surface roughness and the presence of ocean currents and were used for backscatter geophysical model functions (GMFs)

Stress-equivalent wind is a better input for backscatter GMFs:

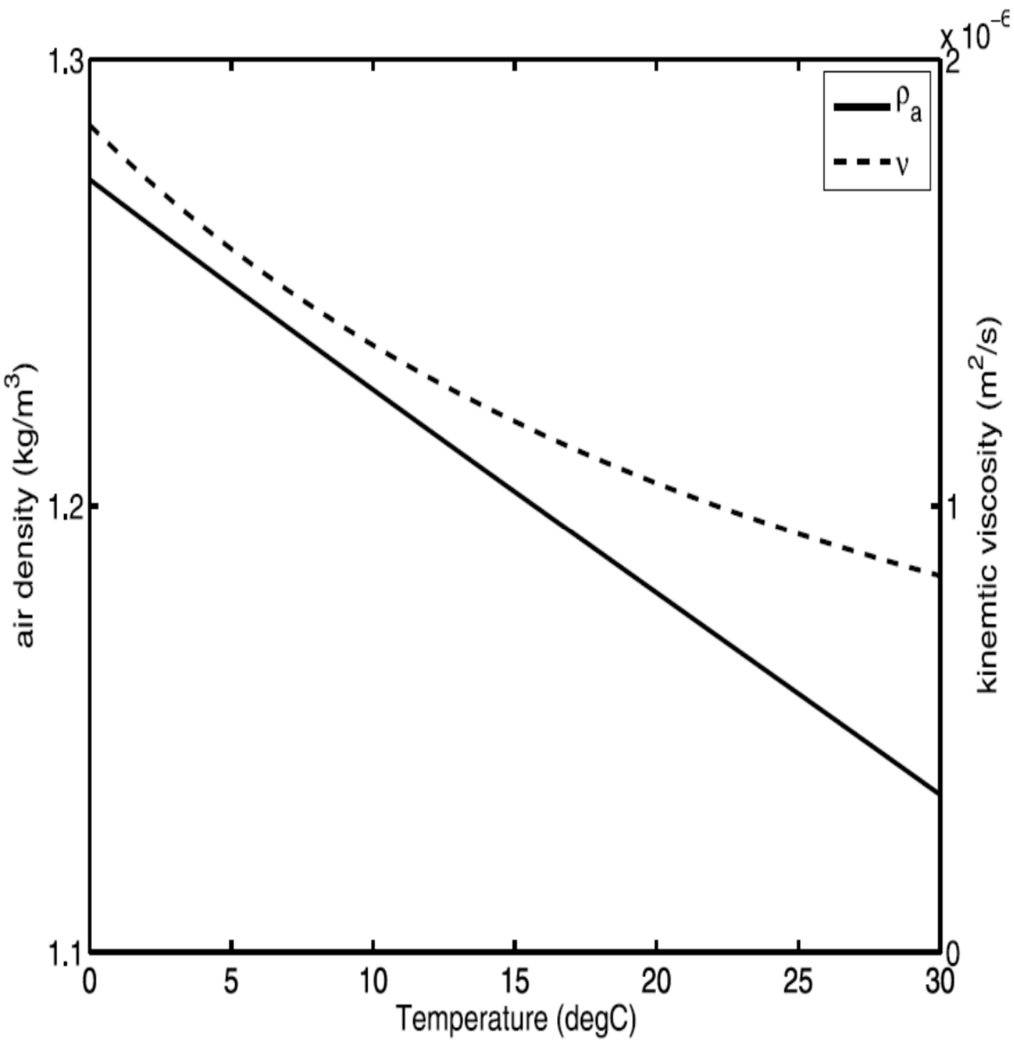
$$u_{r10N} = \sqrt{\frac{<\rho_a>}{\rho_a}}\, u_{r10S}$$

Implemented in MyO FO v5 and under evaluation in the IOVWST

Jos de Kloe et al. (KNMI)



Air density and sea water kinematic viscosity versus temperature. Air density is calculated at the normal air pressure and relative humidity of 75%. Kinematic viscosity is calculated at constant salinity of 35 psu. (Senya Grodsky)

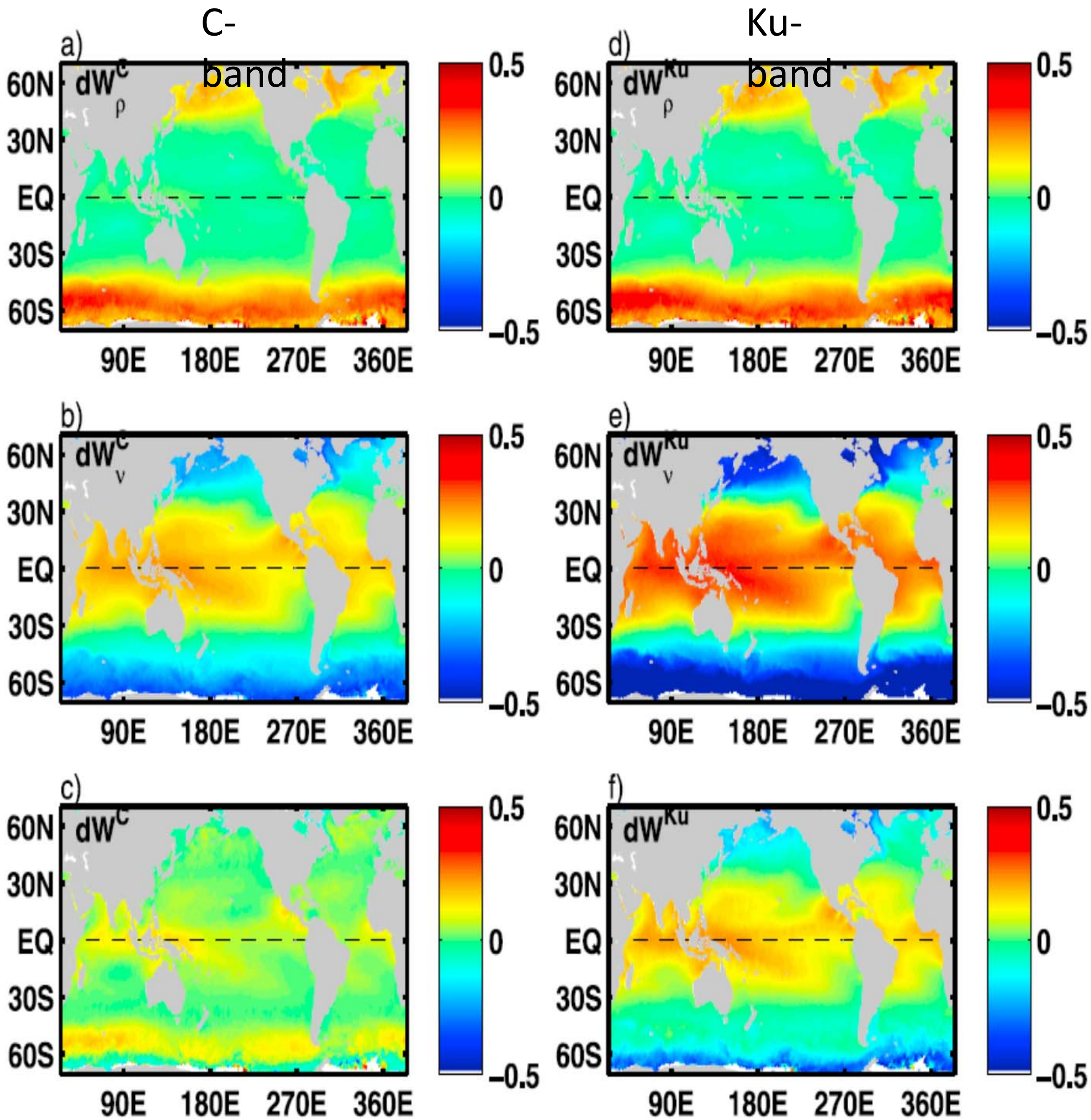


(1) Colder (more dense) air generates waves more effectively.

(2) Higher viscosity at cold SST leads to stronger wave dissipation

The above two effects work opposite ways and partially compensate each other.

Spatial distribution of model wind retrieval errors (m/s) at theta=45deg. Calculations are done using the Kudryavtsev et al (2005) Radar Imaging Model assuming that GMF corresponds to global mean SST=19C



Air density

Water viscosity

Combined

Grodsky, S. A., et al (2012), Does direct impact of SST on short wind waves matter for scatterometry?, Geophys. Res. Lett., 39, L12602, doi:10.1029/2012GL052091.

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Surface Stress

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Drag Coefficient

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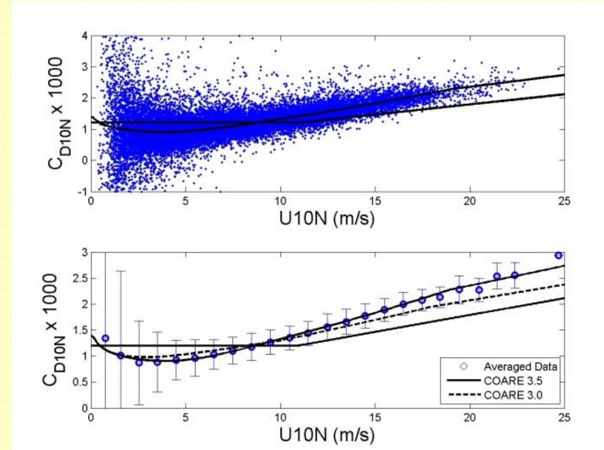
Neutral Winds

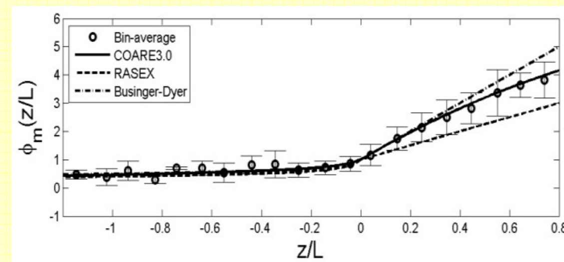
$$U_{rN} = U_r - \frac{u_*}{\kappa G} \psi(z/L)$$

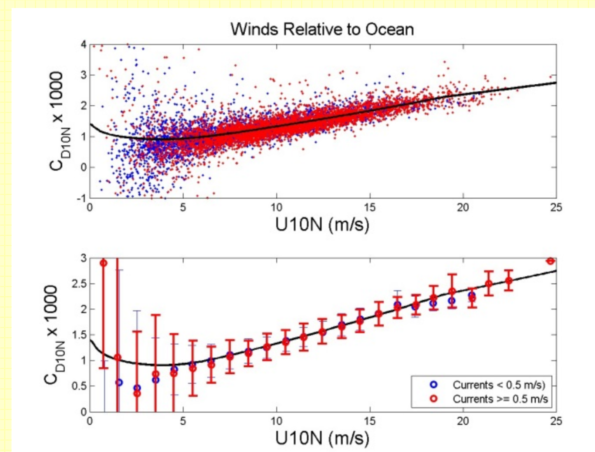
Relative Winds

Density Effects

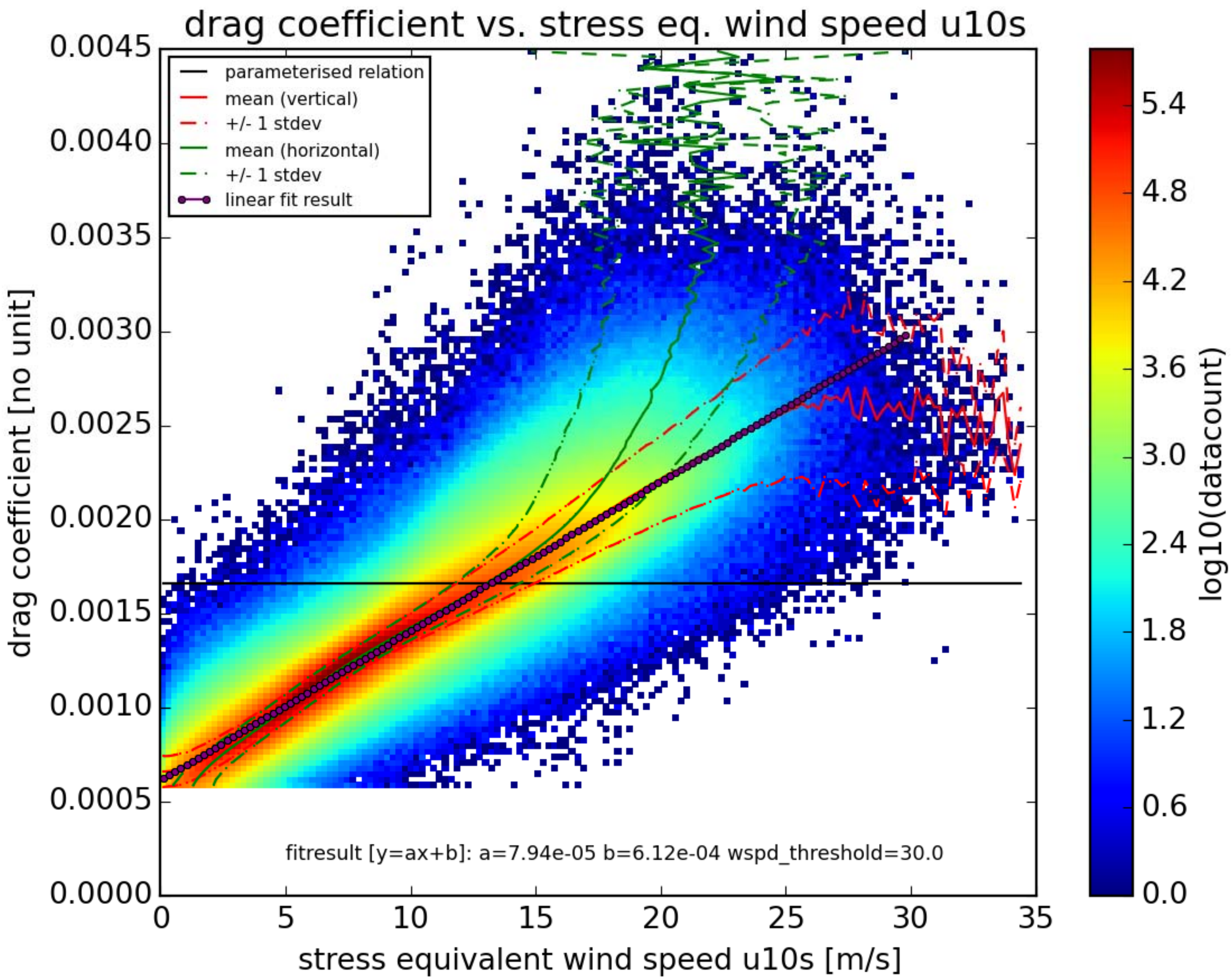
Gustiness Buoys generally provide vector averaged winds and we need to parameterize the missing gustiness in the actual wind speed.





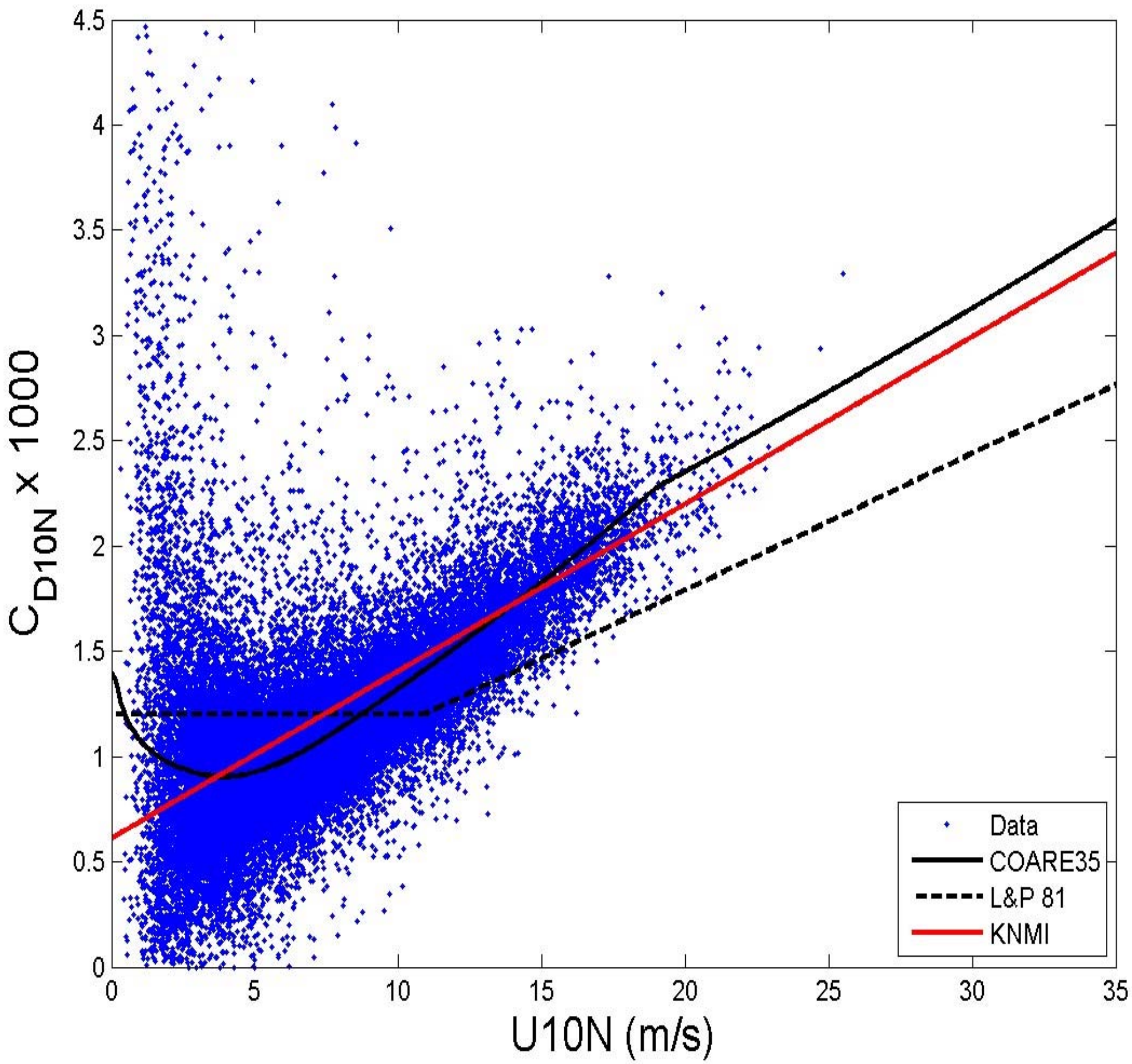


Observations vs Model Drag



The drag parameterization currently used to calculate wind stress in the KNMI L3 products is based on a fit on ERA-Interim (year 2012) data of u10s against drag coefficient

Observations vs Model Drag



Synthesis Paper on Surface Stress & Scatterometry

Surface Stress

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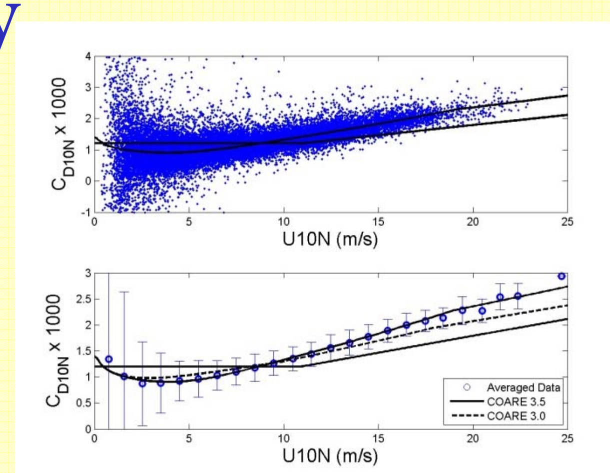
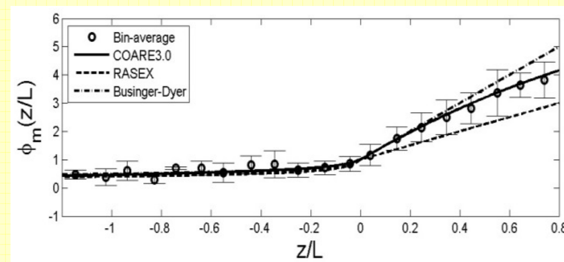


Neutral Winds

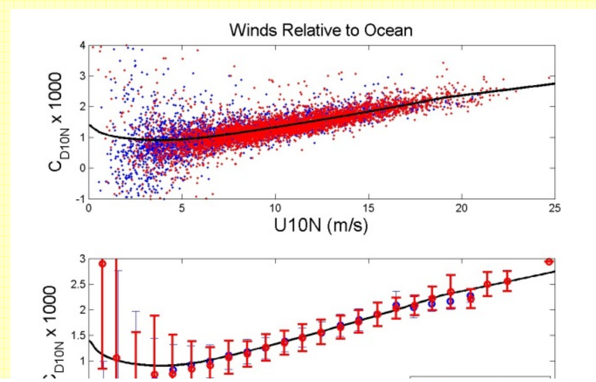
$$U_{rN} = U_r - \frac{u_*}{\kappa G} \psi(z / L)$$



Relative Winds

Density & Viscosity Effects

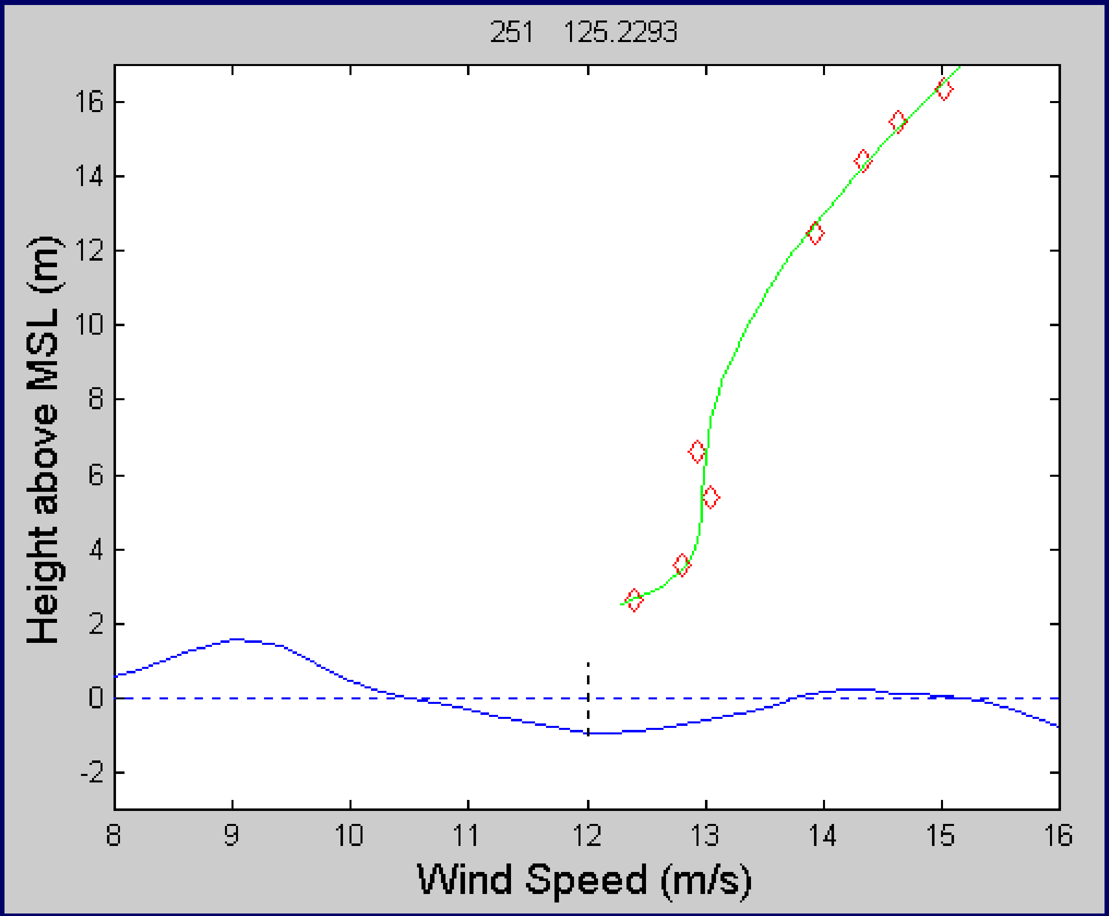
Gustiness

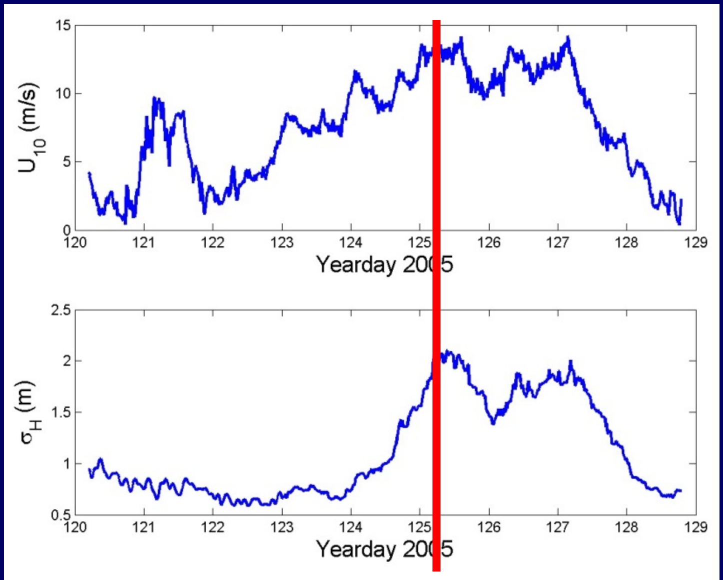


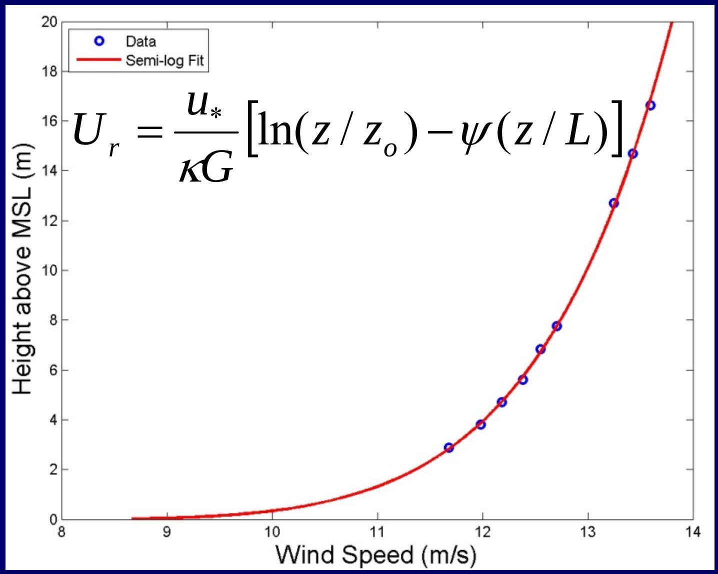
Modulation by Long Waves, Fetch, Shallow Water, U>25m/s

Instantaneous Wind Profile Over Waves

FLIP May 1995

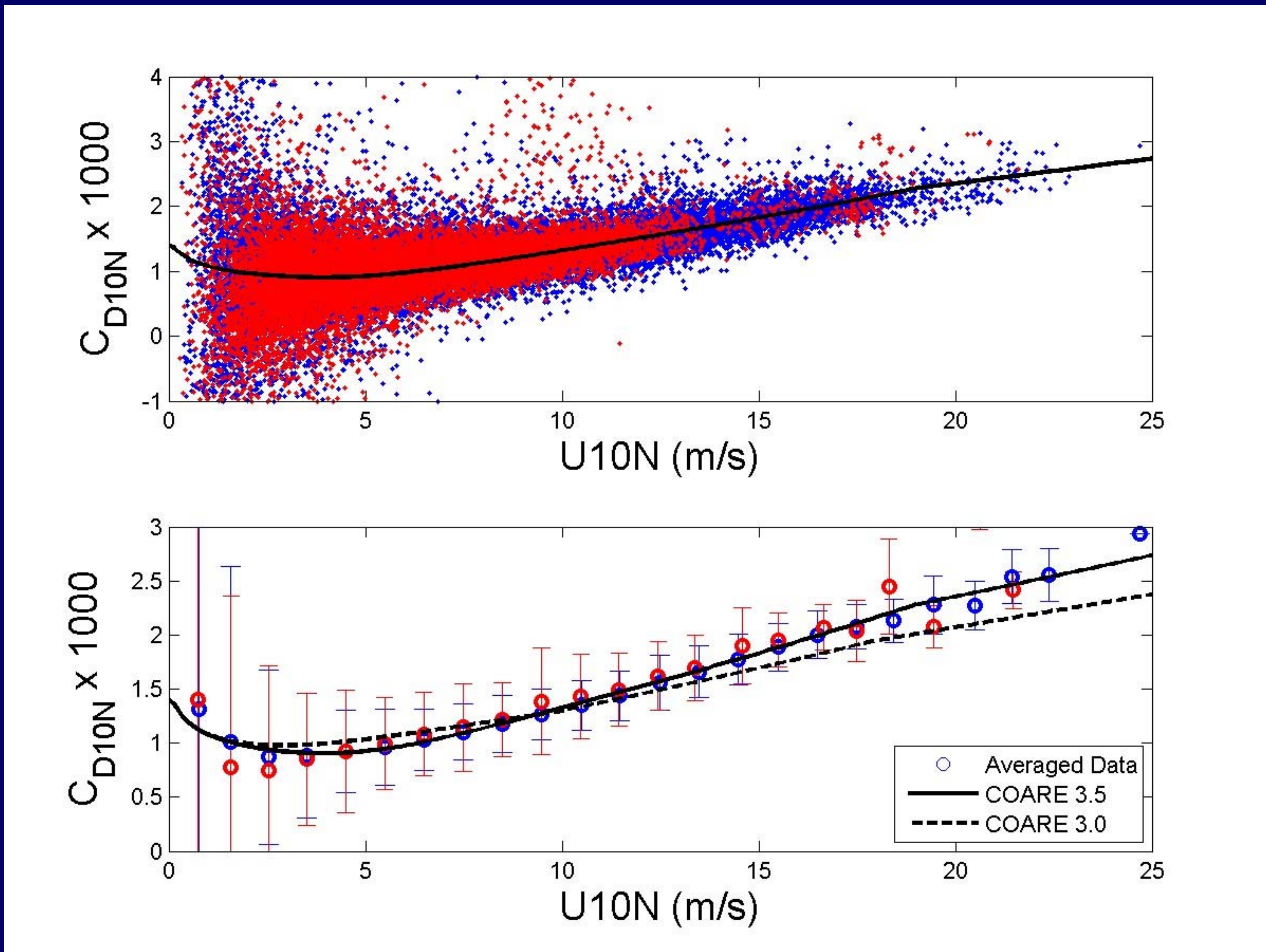






$$U_r = \frac{u_*}{\kappa G}\left[\ln(z/z_o) - \psi(z/L)\right]$$

Shallow Water Drag Coefficients



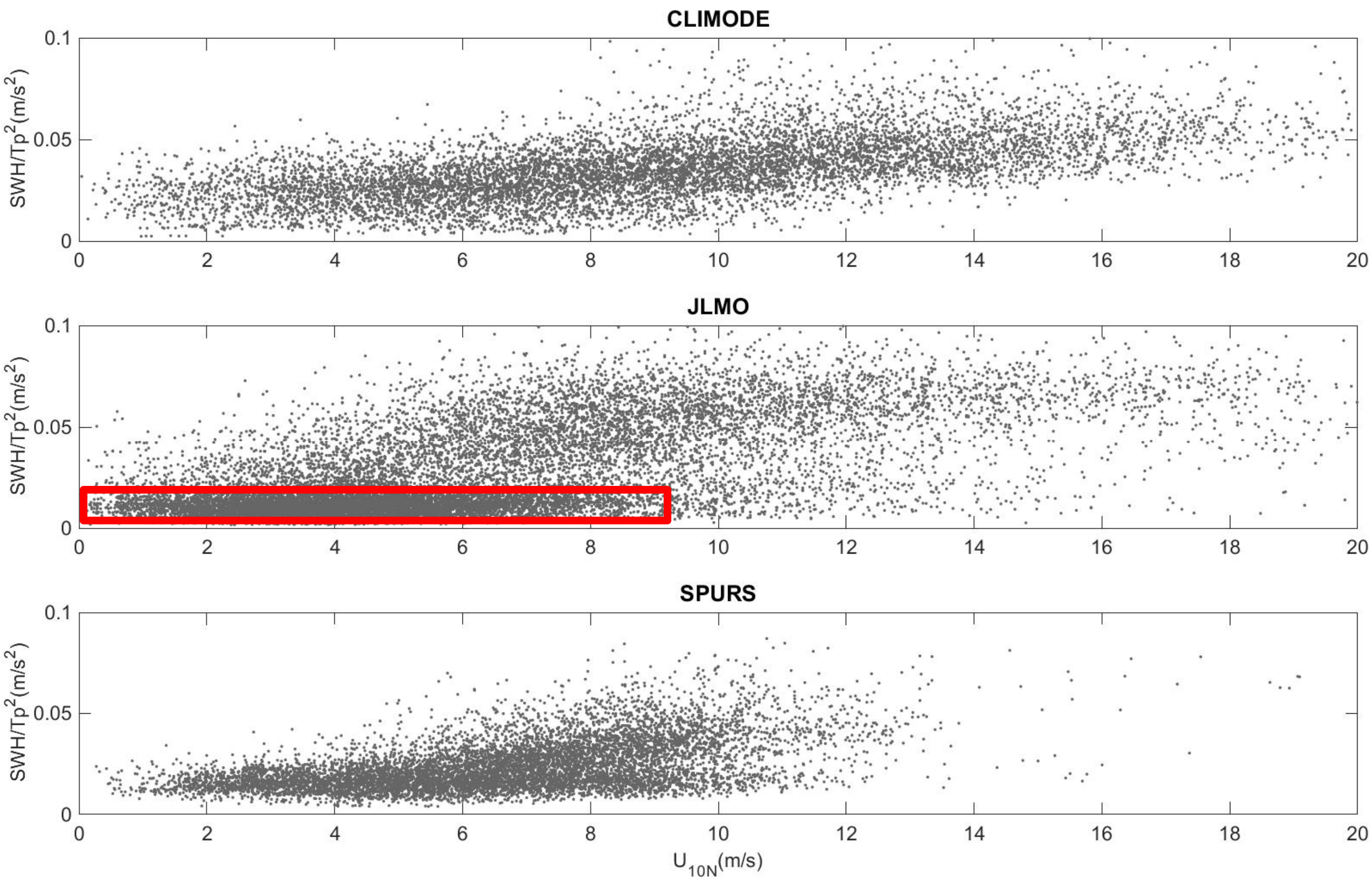
Slight enhancement in shallow water; also seen during RASEX (3-4m) and at MVCO (<15m).

DCFS Combined Datasets – Expanded Wave Conditions

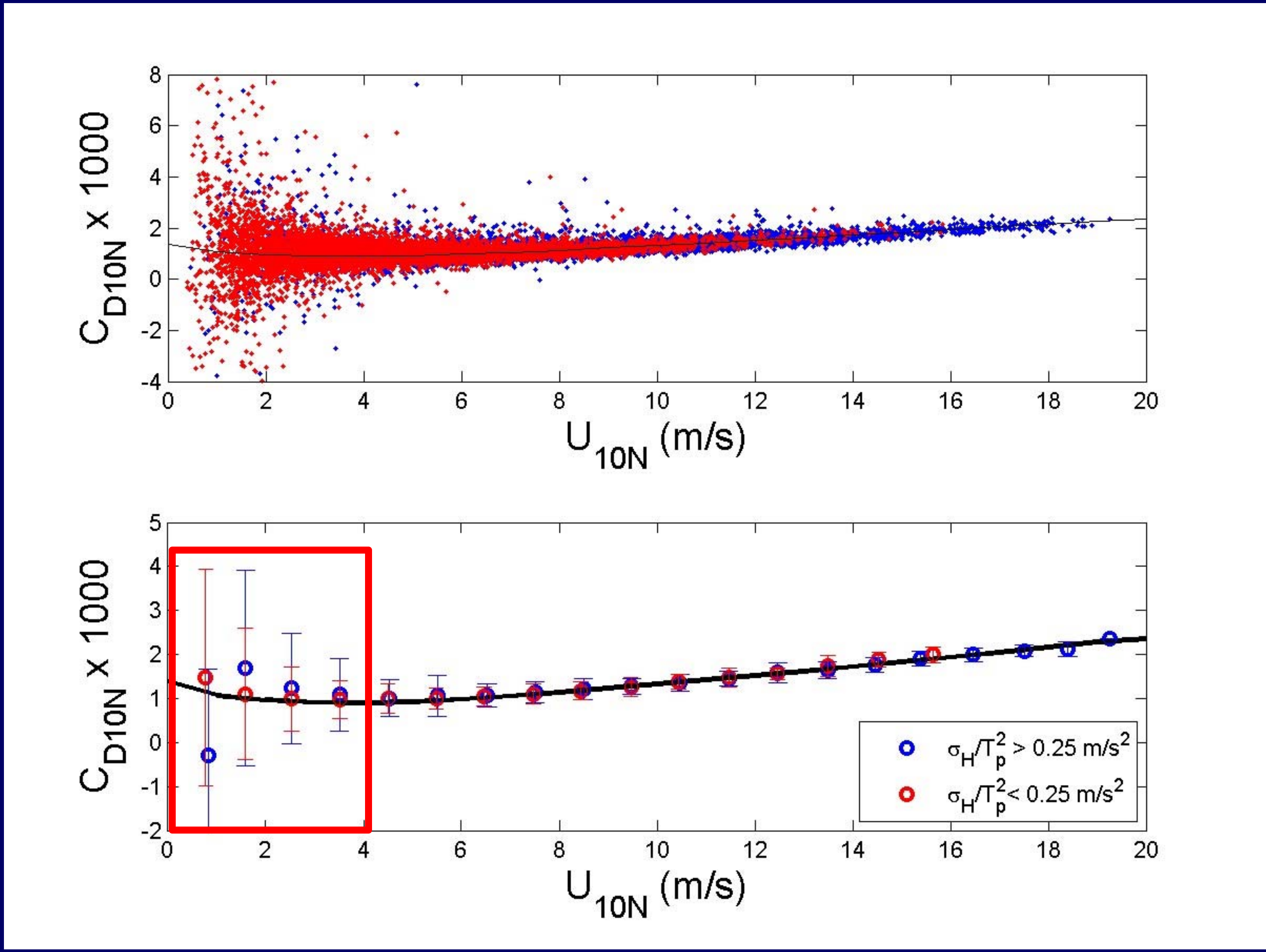
CLIMODE

Coastal NE
- bifurcation in steepness

SPURS I
N. Atlantic 24 N

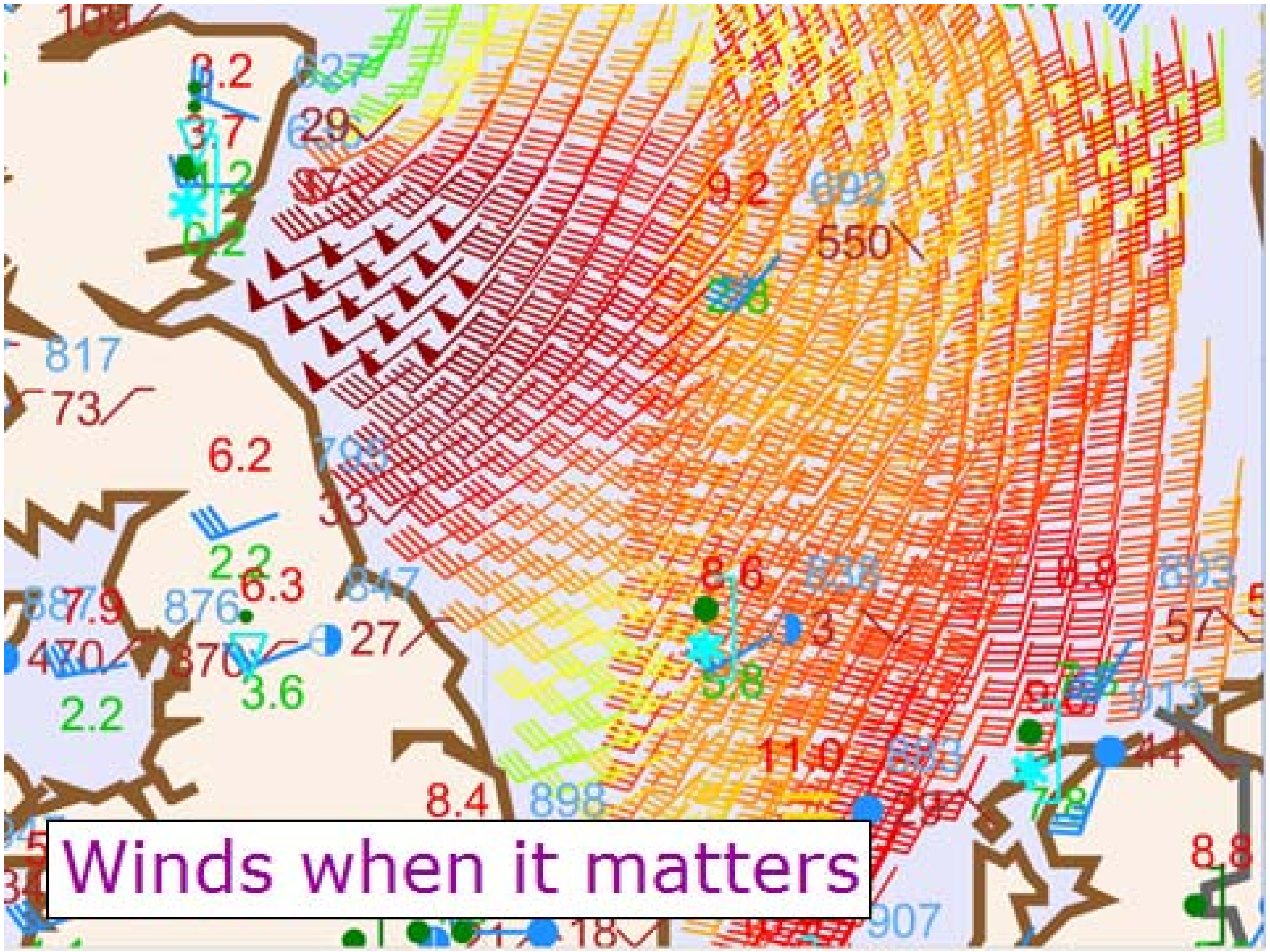


Drag Coefficients



Modulation by long waves is generally limited to low-wind, swell-dominated conditions.

Coastal Winds & Fetch



This slide “expresses the insensitivity of scatterometers to sea state. You may imagine that in the case below sea state is fresh off the coast of Scotland. Nevertheless, the ASCAT winds meet up to their expectations in terms of strength.” - Ad

Scatterometer High Winds Workshop

Motivation

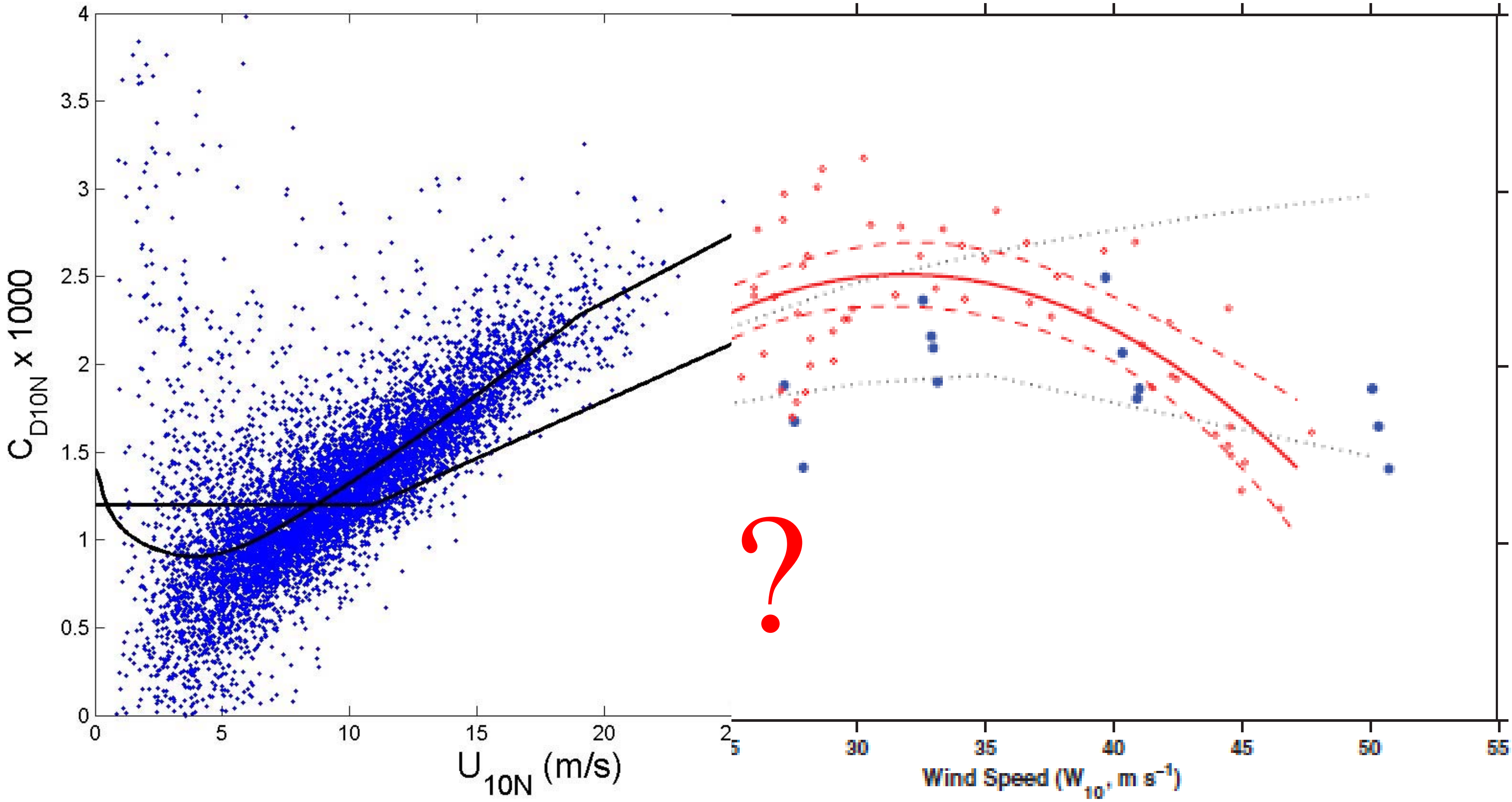
Scatterometer ocean vector wind retrievals are a relatively mature remote-sensing product

However, the validation and understanding of scatterometer retrievals at the very high winds (> 30 m/s) is less well understood

- Has been discussed at the annual IOWVST meetings the past several years
- Recommendation to hold a dedicated workshop made at the May 2015 IOWVST meeting
- Workshop held December 9-10, 2015 at NOAA's National Hurricane Center. Workshop report is being drafted.

For EUMETSAT and ESA, this issue is strategically also relevant, given the additional VH capability planned for the EPS-SG SCA instrument, where good sensitivity to very high wind speeds is expected. Furthermore, the observation of very high winds is also related to the ability of resolving finer spatial scales, which is also a capability that is being further investigated and exploited with ASCAT and will constitute even a more important challenge for SCA

Surface Stress and Roughness at High Winds



Refinement of DC Stress Measurements

How do we quantify the behavior at High Winds?

Liu & Tang 2016

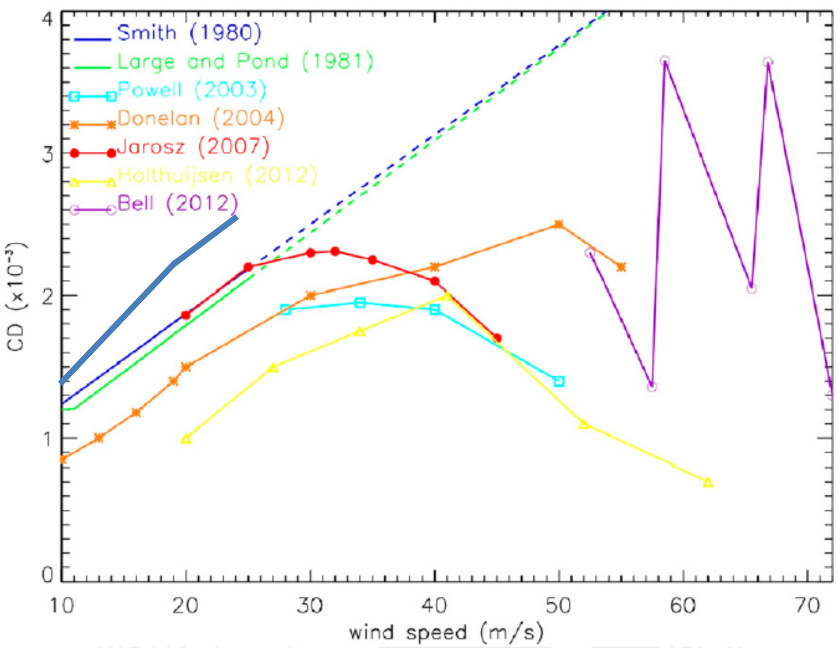


FIG. 1. Drag coefficients as a function of wind speed. Broken lines are extrapolations.

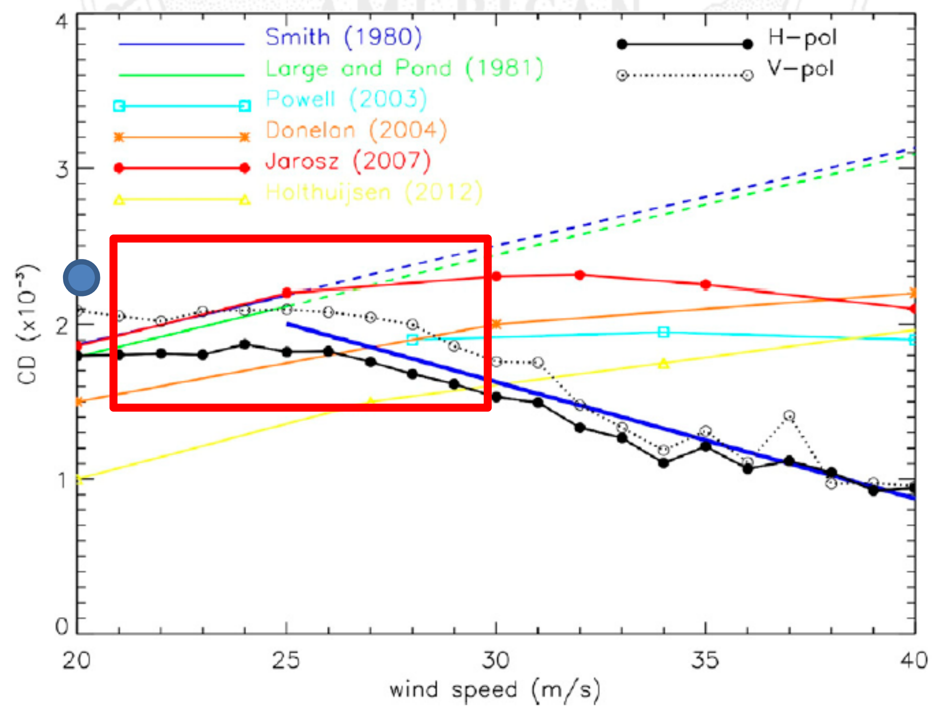


FIG. 5. Drag coefficient as a function of wind speed computed from stress measured by QuikSCAT, with a linear regression of the combined bin averages (thick blue line), superimposed onto the drag coefficients of past studies shown on Fig. 1.

Soloviev et al. 2014

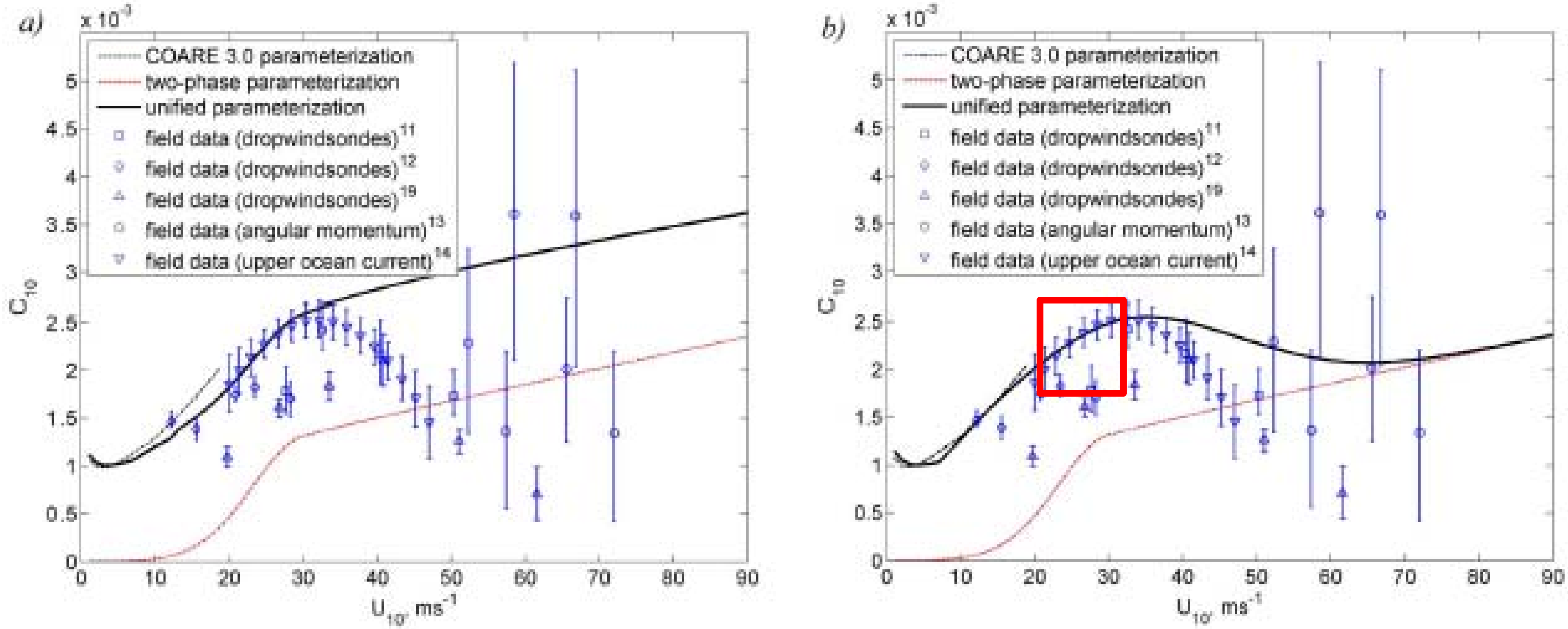


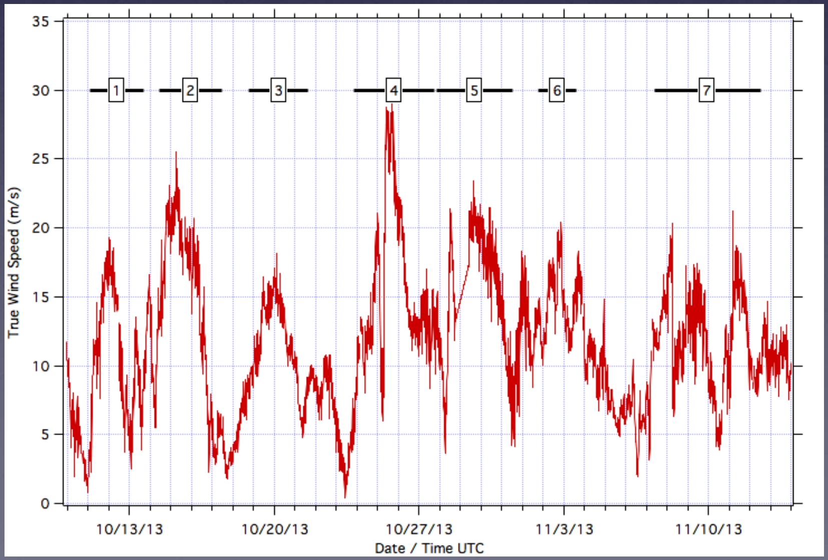
Figure 2 | Comparison of the unified air-sea drag coefficient parameterization calculated with the surface stress method (a) and the surface roughness method (b). The COARE 3.0 parameterization, two-phase parameterization (lower bound on drag coefficient), and available data from field experiments are shown for comparison. We have included only the available field observations that report confidence intervals. The surface stress method and the surface roughness method are different approaches for unifying two-phase, wave-form, and viscous stresses (see Methods). The COARE 3.0 parameterization has been used for verification of the unified parameterizations in the range of wind speeds from 1 to 19 ms^{-1}.

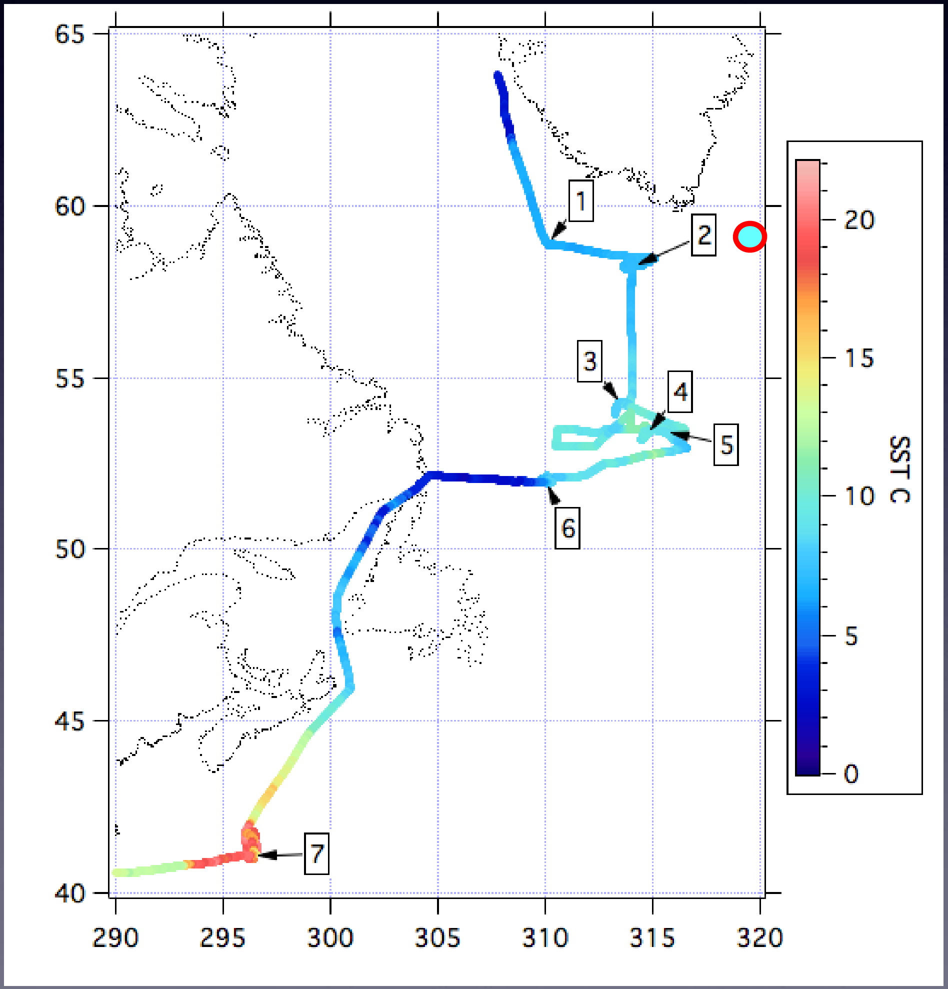
Future Plans: NASA SPURS & NSF's OOI

Observations from the High Wind Gas Exchange Study (HiWinGS)

Byron Blomquist, Barry Huebert, Jeff Hare: Univ. Hawaii
Chris Fairall, Ludovic Bariteau: NOAA / ESRL, CU CIRES

- 7 stations
- SST 5 – 20°C
- 37 days, Nuuk to Woods Hole

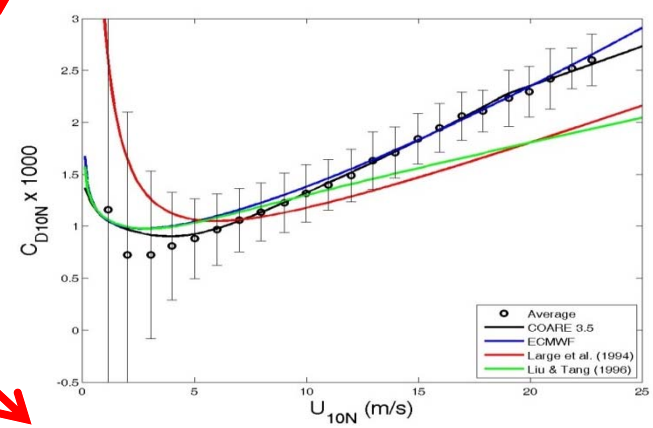




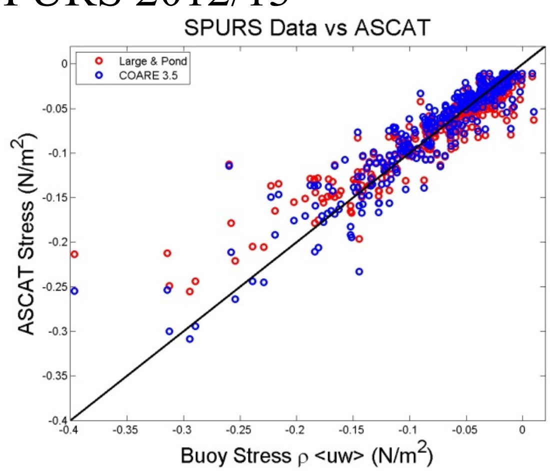
Preliminary Objectives

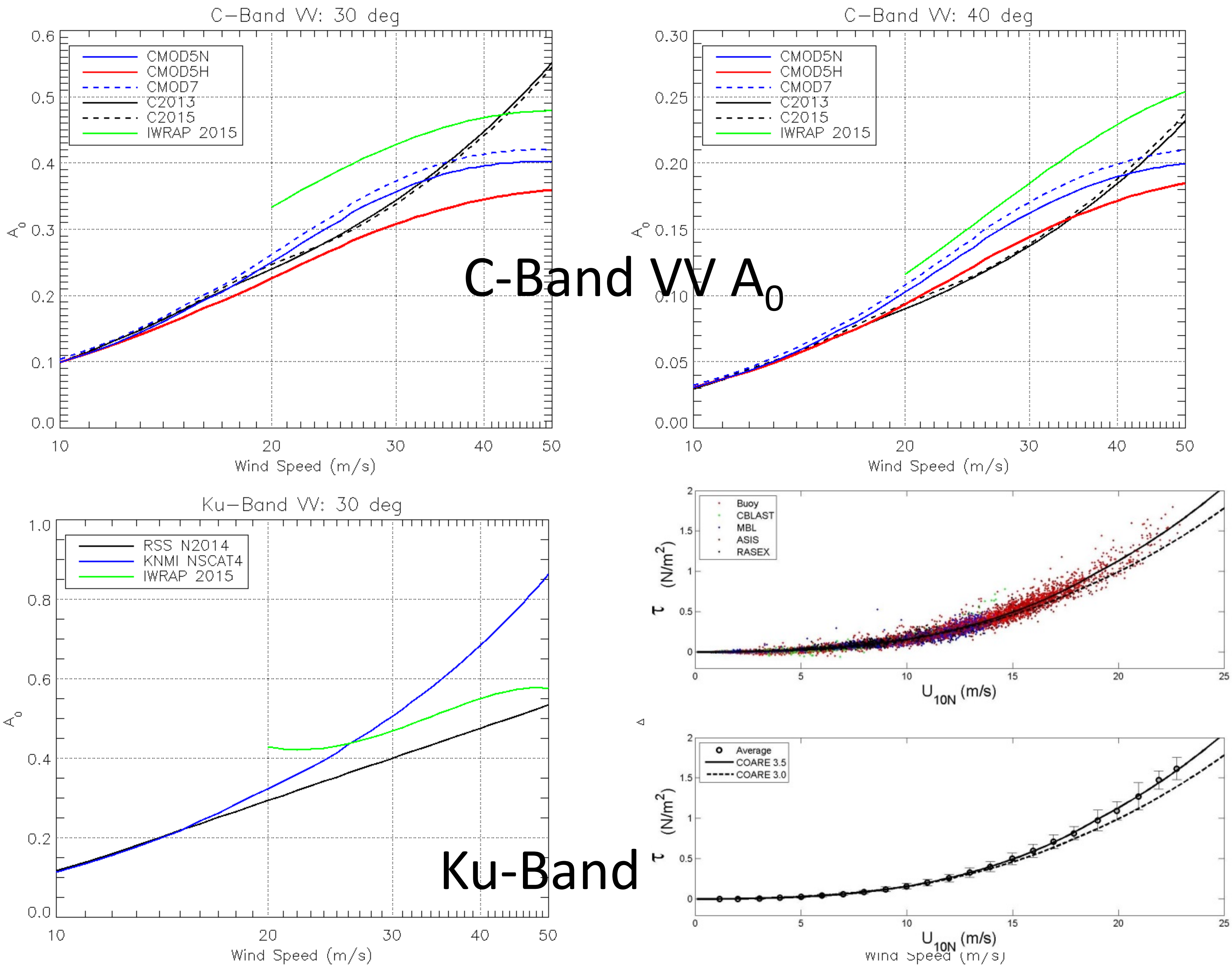
- Improved estimates of wind stress derived from scatterometer estimates of the equivalent neutral wind via a WSWG recommended drag coefficient.
- Investigate the need for more direct estimates of wind stress from scatterometer measurements of backscatter: $\vec{\tau} = f(\vec{\sigma}_0, \ldots)$

CLIMODE 2006



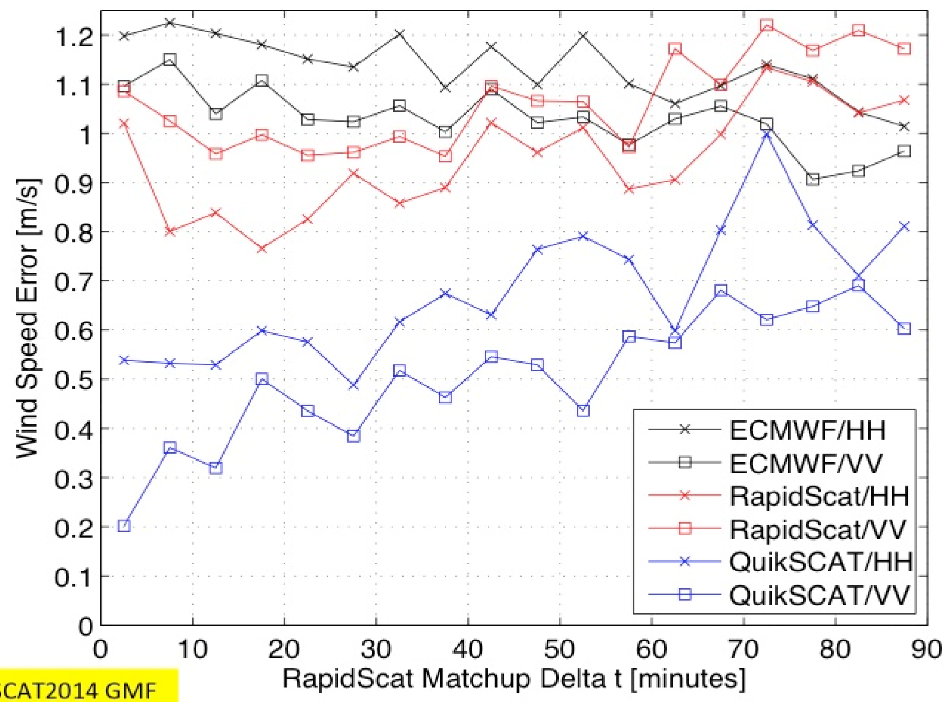
SPURS 2012/13



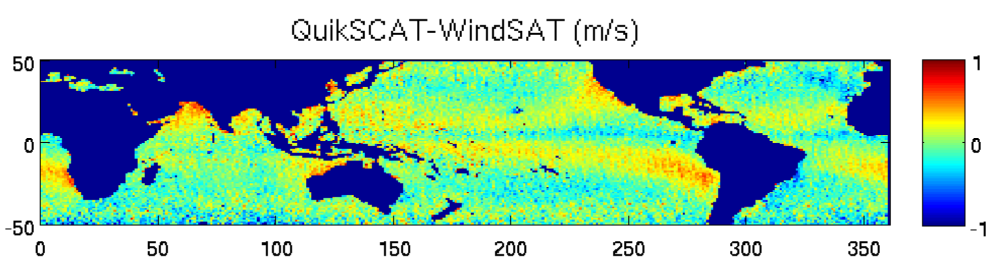

C-Band VV A$_0$
Ku-Band
C−Band VV: 30 deg
C−Band VV: 40 deg
Ku−Band VV: 30 deg
CMOD5N
CMOD5H
CMOD7
C2013
C2015
IWRAP 2015
RSS N2014
KNMI NSCAT4
A_0
Wind Speed (m/s)
Buoy
CBLAST
MBL
ASIS
RASEX
Average
COARE 3.5
COARE 3.0
τ (N/m^2)
U_{10N} (m/s)

QuikSCAT 2010-2015 (nonspinning) wind speed and backscatter data (Available at ftp://podaac.jpl.nasa.gov/allData/quikscat/L1C/)

Triple Colocation random error for ECMWF, RapidScat, and QuikSCAT nonspinning data



NSCAT2014 GMF



- Most precise spaceborne Ku-backscatter and wind speed measurements available
- Individual 25-km measurement precision is 0.1 m/s as evidenced by comparison between consecutive independent measurements.
- Wind speed accuracy is upper bounded by 0.5 m/s by comparison with ECMWF and RapidScat in triple colocation studies.
- Despite use of ECMWF wind direction to determine wind speeds, QuikSCAT nonspinning wind speeds agree much better with WindSAT than ECMWF.
- Backscatter measurements also available; used to calibrate RapidSCAT data
- Their precision makes QuikSCAT nonspinning measurements suitable for examining mesoscale spectra of wind speed fields and sensitivity of backscatter to effects such as SST, currents, and other phenomena difficult to observe in wind fields with 1.0 m/s random error.

Discussion Topics

- Is there interest and are we ready to produce a Synthesis Paper on “Surface Stress and Scatterometry” to summarize our recent work? Topics could include:
  - Role of surface currents and the relative wind
  - Role of atmospheric stability and the equivalent neutral wind
  - Role of air density
  - Role of “long” surface waves on surface stress
  - Role of surface variability and gustiness
  - Role of SST and viscosity
  - Impact of SST gradients
  - Recommendation for drag coefficients
- Can the Coastal Working Group provide any guidance on specific phenomena they’d like to revisit including wave age, wave steepness, enhanced breaking, shallow-water waves, wind-wave directional differences, & fetch limited seas.
- How do we move forward in our attempts to combine scatterometers and observations to improve estimates of wind speed and stress at extreme winds (> 25 m/s)?
- Is there any desire to work on a GMF that directly relates stress measurements with backscatter? The stress measurements could include both DC and bulk derived measurements using our recommended algorithm.