Tropical Cyclone Cd over Shallow Water

(a JHT project)

Mark Powell,
NOAA-AOML-HRD

NOAA's AOML Hurricane Research Division

AOML, Miami

NOAA's Oceanic and Atmospheric Research
Atlantic Oceanographic and Meteorological Laboratories
Hurricane Research Division
Virginia Key, Miami FL (about 20 miles east of the Tropical Prediction Center)

Resources: ~35 scientists and support staff from NOAA, University of Miami Cooperative Institute for Marine and Atmospheric Studies, and other Universities

MOTIVATION:

Modeling

Does sea surface drag increase near the coast?

If so NWP, Wave and Surge model parameterizations will need to change

Impacts

US wind load standards assume open terrain drag (~4.75 x 10^{-3}) near the coast

High drag implies lower wind loads than over open ocean

If Cd is similar over open ocean and coastal waters, US wind load standards and risk modeling will need to change

Cd in Tropical Cyclones

2003: Powell-Vickery-Reinhold first profile-method measurements of Cd, U*, and Zo in tropical cyclones

330 profiles were distributed into four MBL groups of 40-100 sondes per group

Cd was shown to level off or possibly decrease after an initial increase with increasing wind speed

2004: Donelan et al. similar results from flume experiments

Now there are nearly 4 times more sonde profiles

Modeling

- For many models momentum flux in strong winds based on extrapolating Cd (U10) from field studies in < 25 m/s winds

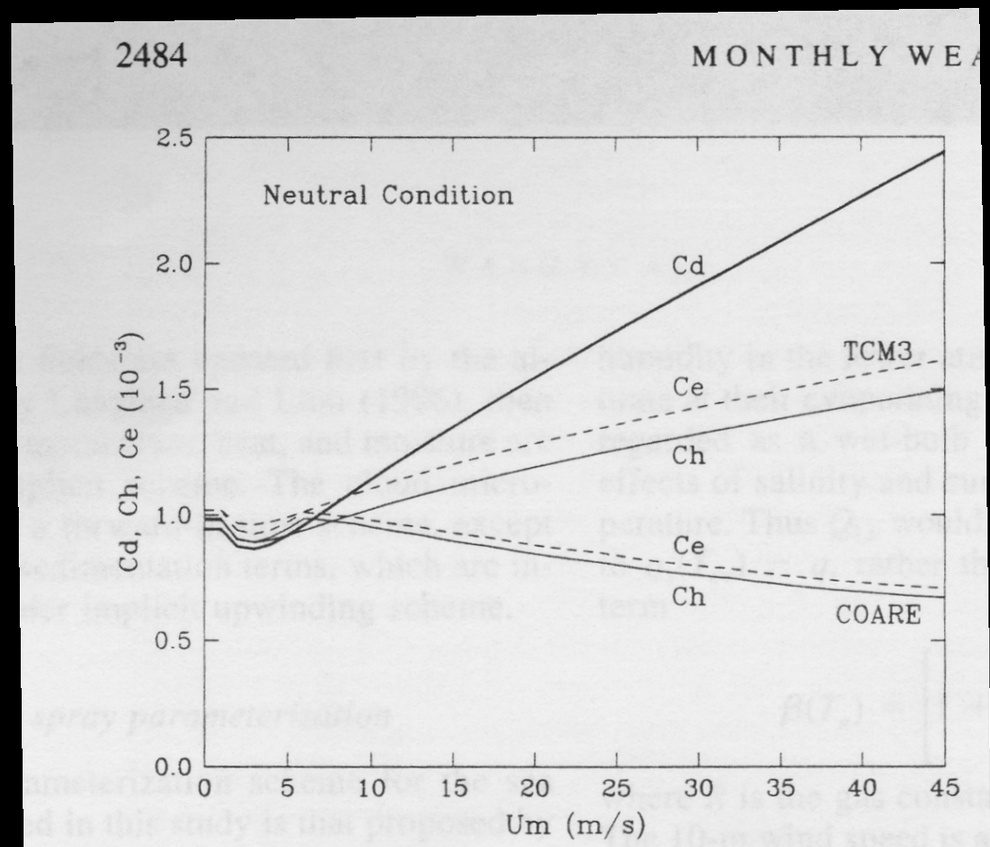


FIG. 1. Comparison of drag coefficient (Cd), exchange coefficients for heat (Ch), and moisture (Ce) as a function of wind speed at 26.5 m above the sea surface under neutral conditions, obtained by the standard TCM3 algorithm (Wang 1999) and by the COARE algorithm (Fairall et al. 1996).

Impact on TC Modeling

- Model parameterizations of momentum flux in the hurricane boundary layer are changing to limit or cap increase in Cd (Andreas 2004, Moon et al., 2004, Wang and Wu 2004, Chen 2007)

Analysis Methods: GPS Sonde

- Hock and Franklin (1999)
- 10-12 m/s fall speed
- 2 Hz Samples P, T, RH, Position
- Accuracy 0.5-2m/s, 2 m height

- Filtered by 5 s low pass filter to remove undersampled scales and noise from satellite switching
- Corrected for acceleration bias
- Wind errors large below 5-8 m

Organizing:

MBL: Avg. of lowest 500 m, contains max in profile, easily determined, 10 m/s bins for similar conditions.

Height bins: Staggered to preserve detail, 8-12 m, 13-20, 21-30,...

Ergodic hypothesis: Each profile is an instance from an ensemble of profiles in identical conditions...average of profiles within an MBL group ~ ensemble average.

Profile Method:

Log Law for neutral stability

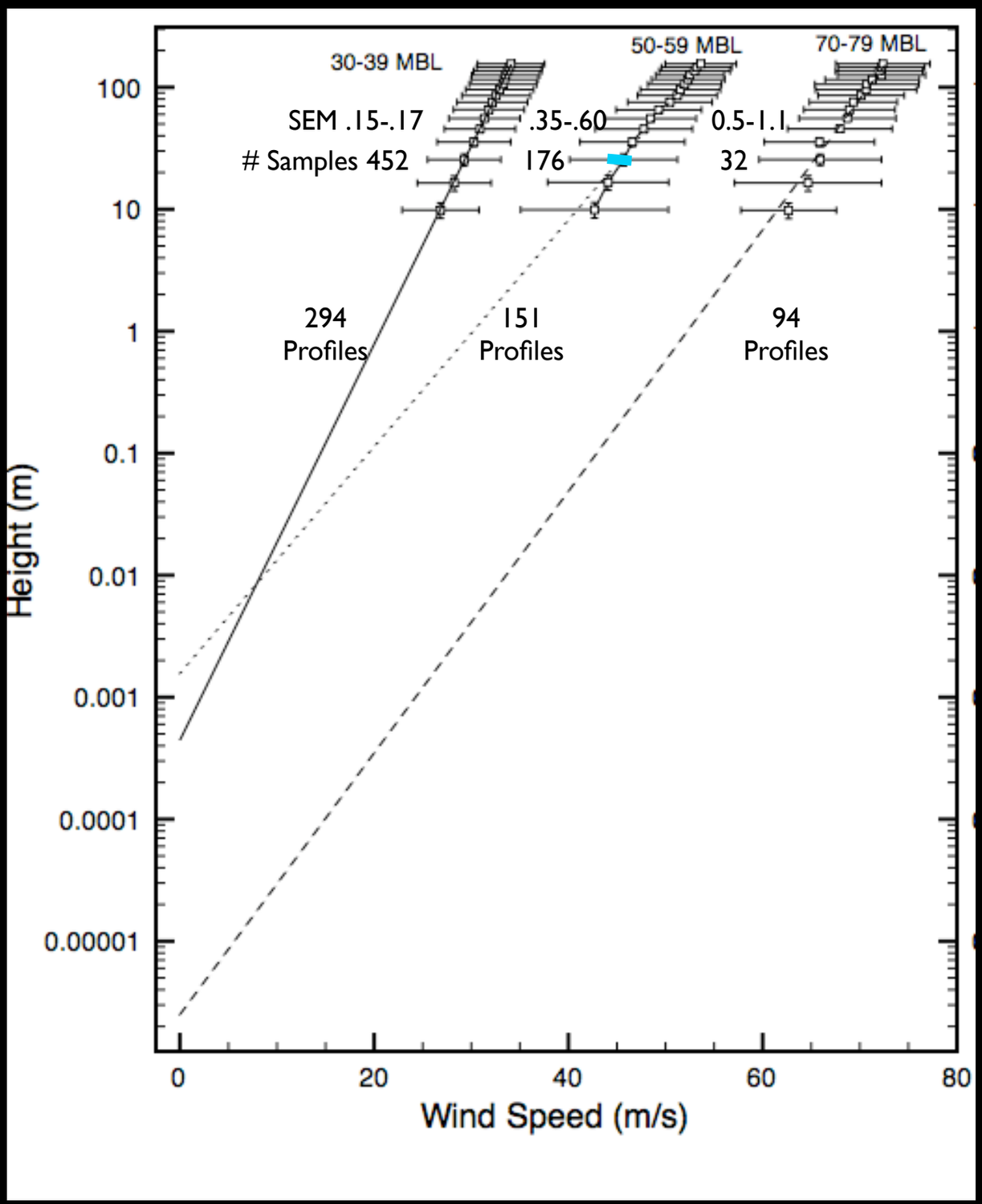
$U = U_* / k \quad Ln\ (Z / Zo)$

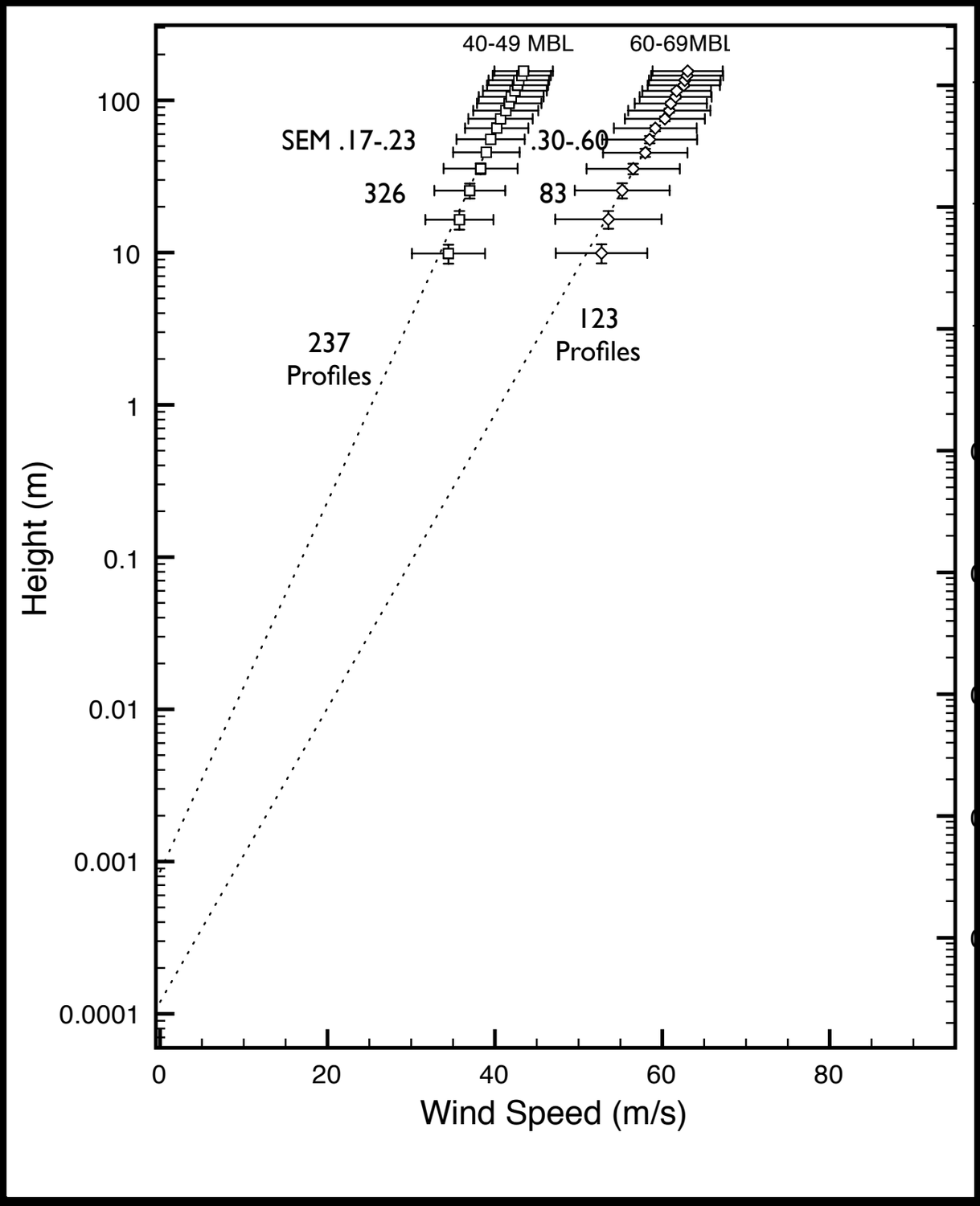
$Ln\ (Z) = (k / U_*)\ U + Ln\ (Zo)$

slope intercept

$$\tau = \rho\, U*^2 = \rho\, C_d\, U_{10}^2$$

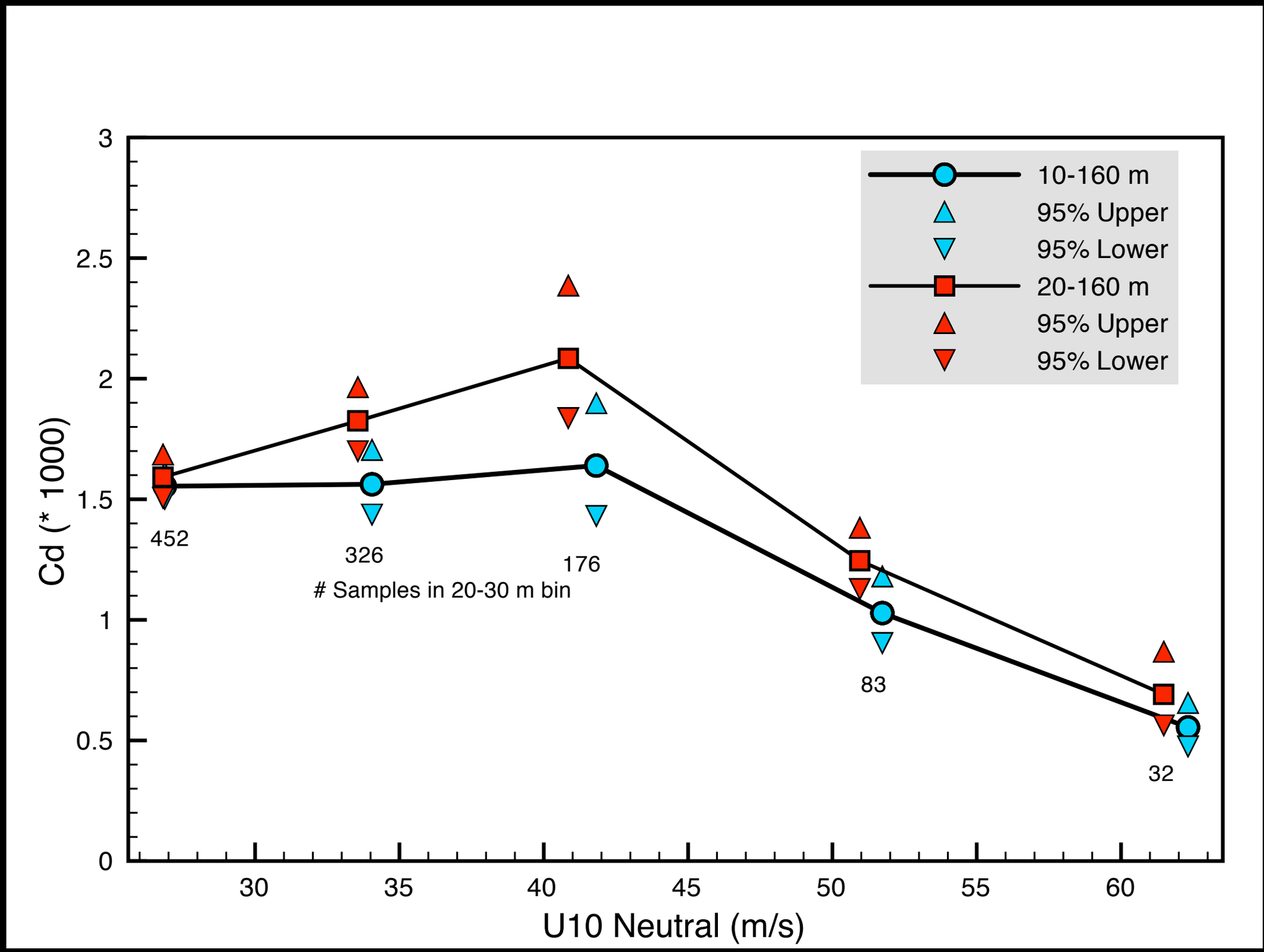
$$Cd = \left(\frac{.4}{Ln\left(\frac{Zo}{10}\right)} \right)^2$$


30-39 MBL
50-59 MBL
70-79 MBL
SEM .15-.17
.35-.60
0.5-1.1
Samples 452
176
32
294
Profiles
151
Profiles
94
Profiles
Height (m)
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0
20
40
60
80
Wind Speed (m/s)


40-49 MBL
60-69MBL
SEM .17-.23
.30-.60
326
83
237
Profiles
123
Profiles
Height (m)
100
10
1
0.1
0.01
0.001
0.0001
0
20
40
60
80
Wind Speed (m/s)

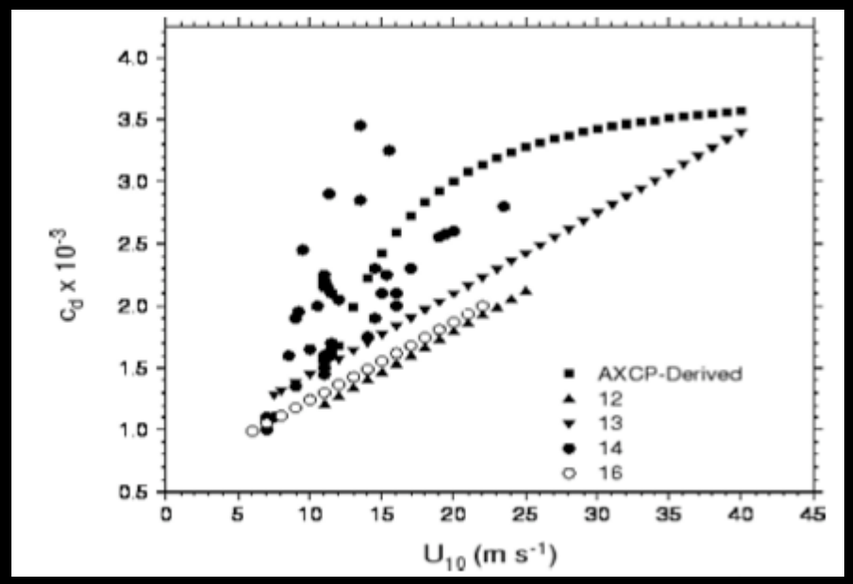
Review of 2007 JHT Results

20-160 m surface layer



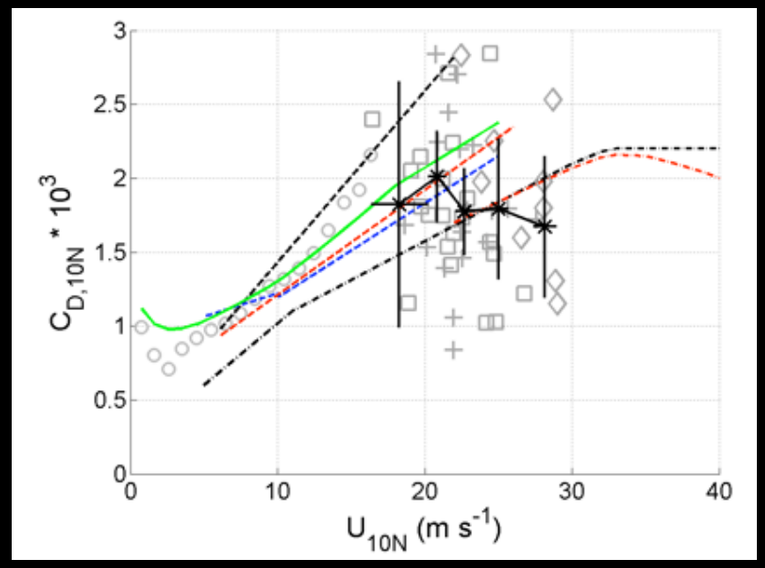
Recent Hurricane Cd Measurements

Shay and Jacob 2006



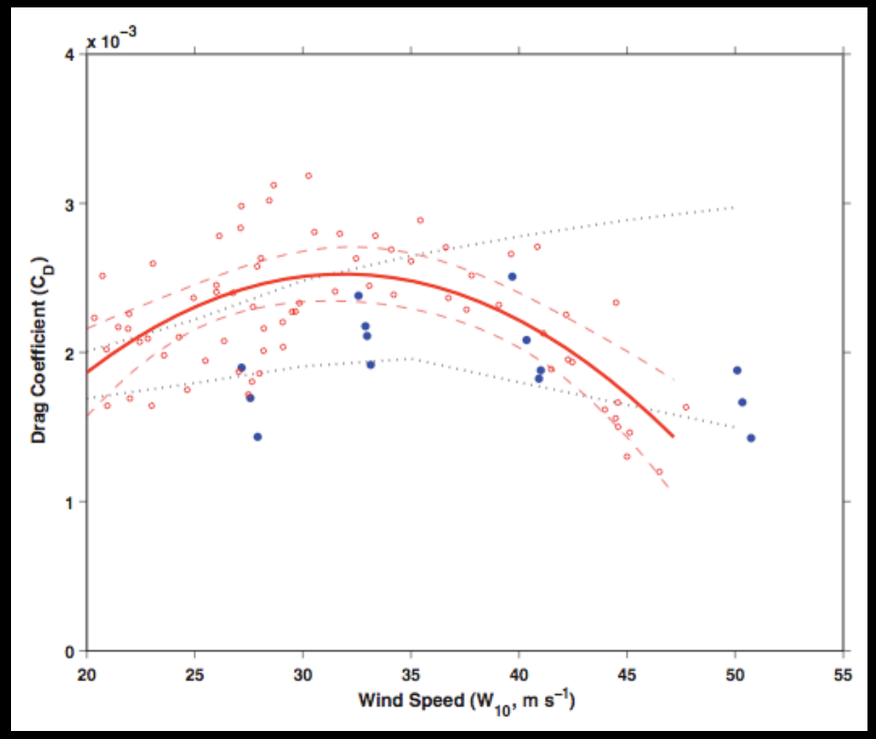
AXCP, sfc winds

CBLAST
Black et al., French et al 2007



Eddy correlation 70-400 m
Sfc stress extrapolated
U10 from SFMR

Hurricane Ivan Jarosz et al
2007



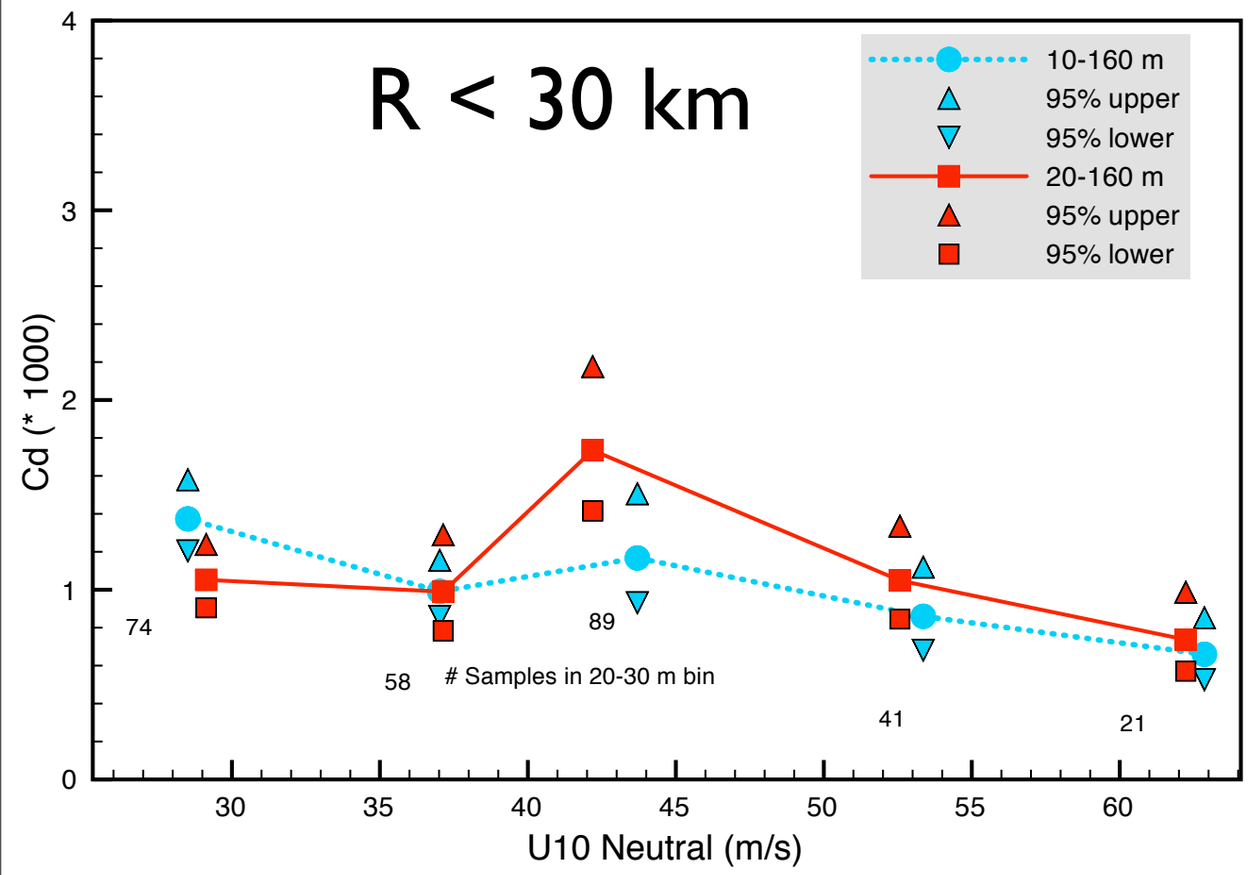
ADCP, Surface winds

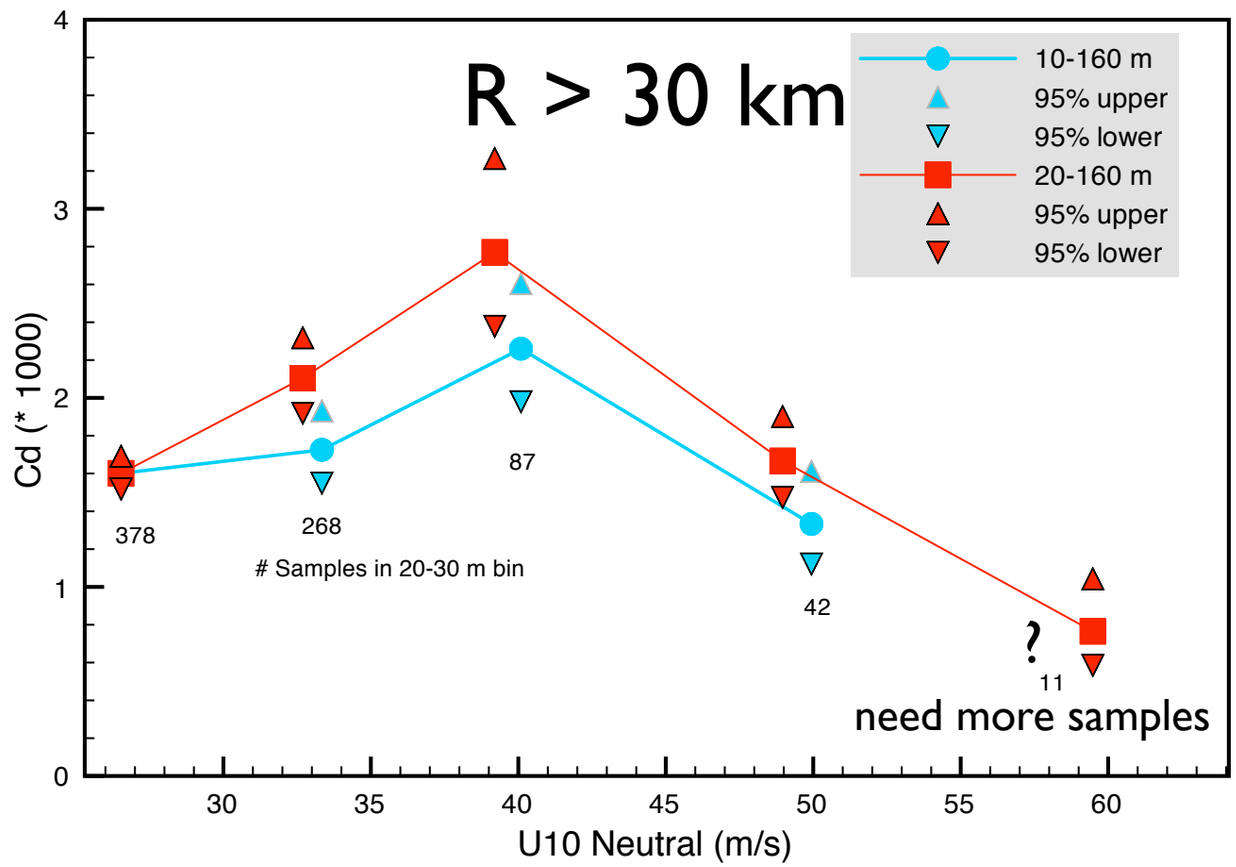
Bubbles: Sfc. tension/tensile strength too small for supporting stress (Andreas 2004)
Important if 10^3 increase in bubble generation (Kudryavtsev 2007)

Spray/spume: stable layer, spray supports stress, sea sfc flattens
(Andreas, Kudryavtsev, Makin 2005, Bye and Jenkins 2006)

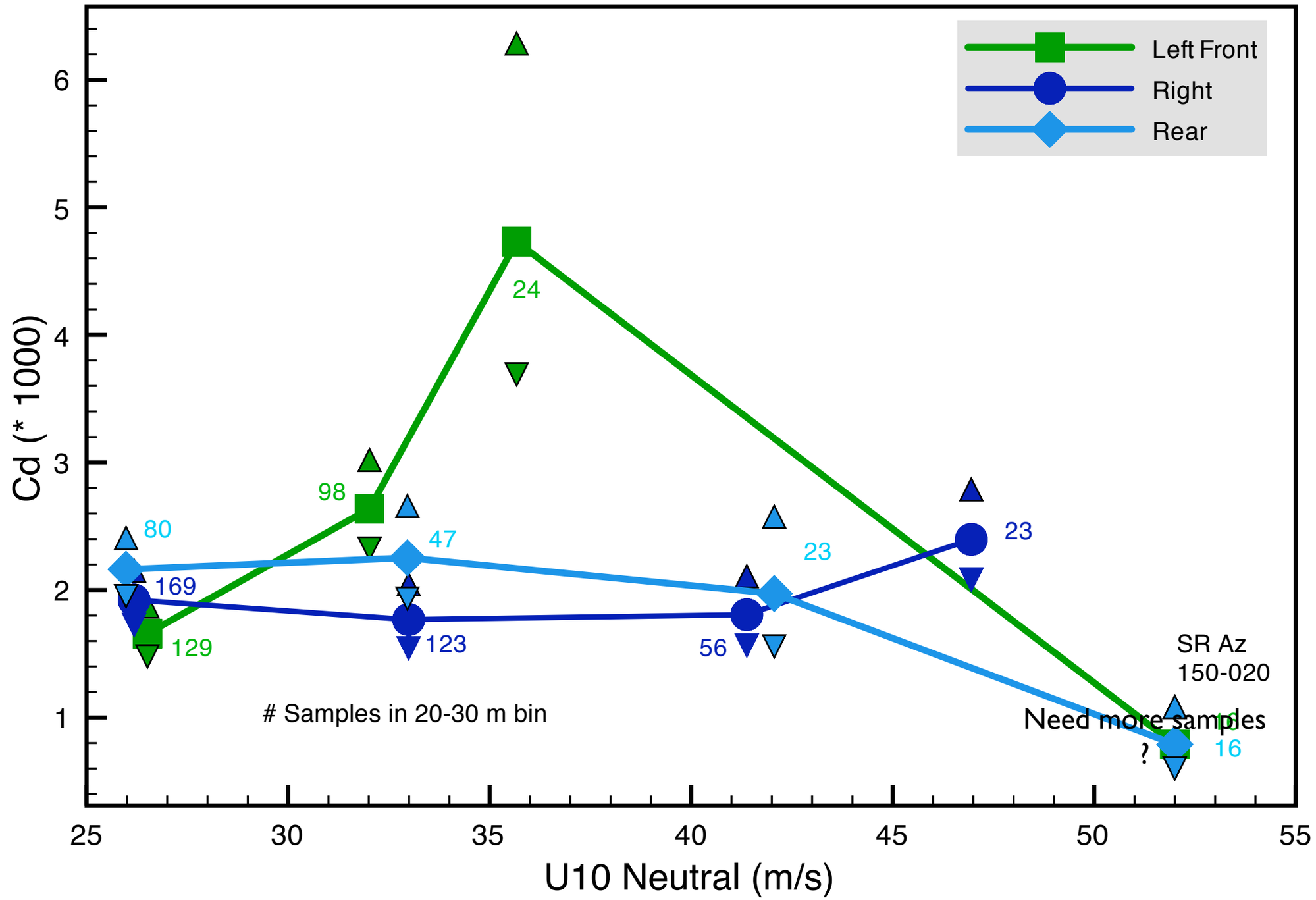
Cd : Radius

30 km is median for MBL wind groups > 50 m/s





Cd: Storm rel. azimuth



Shallow water (< 50 m) profiles were organized into onshore, offshore, inland, and alongshore flow regimes

Wind Profile sample counts

MBL group (m/s)	Sonde profiles in deep water	Shallow water profiles	Onshore / Open
20-29	224	32	19
30-39	252	65	42
40-49	307	30	19
50-59	187	18	9
60-69	118	5	
70-79	94	0	
80-89	26	0	

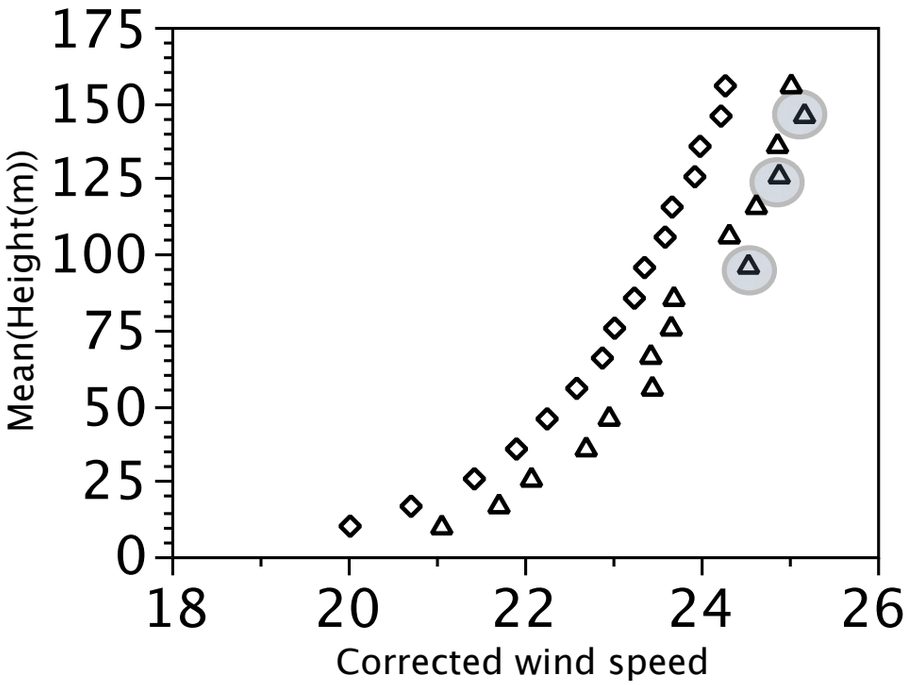
Note: excludes post-2000 A/F sondes, post-2006 NOAA and Wilma sondes

Mean Wind Profiles

Shallow △ Deep ◇

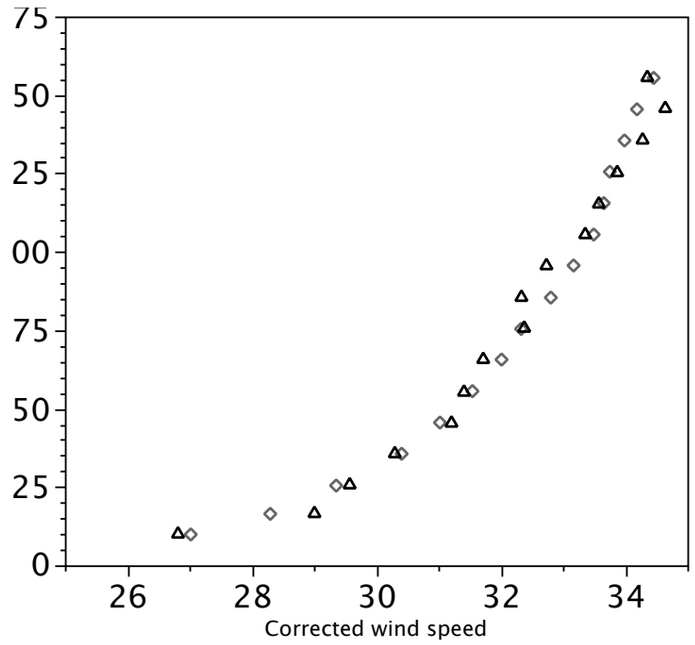
Onshore / Open

20-29 MBL



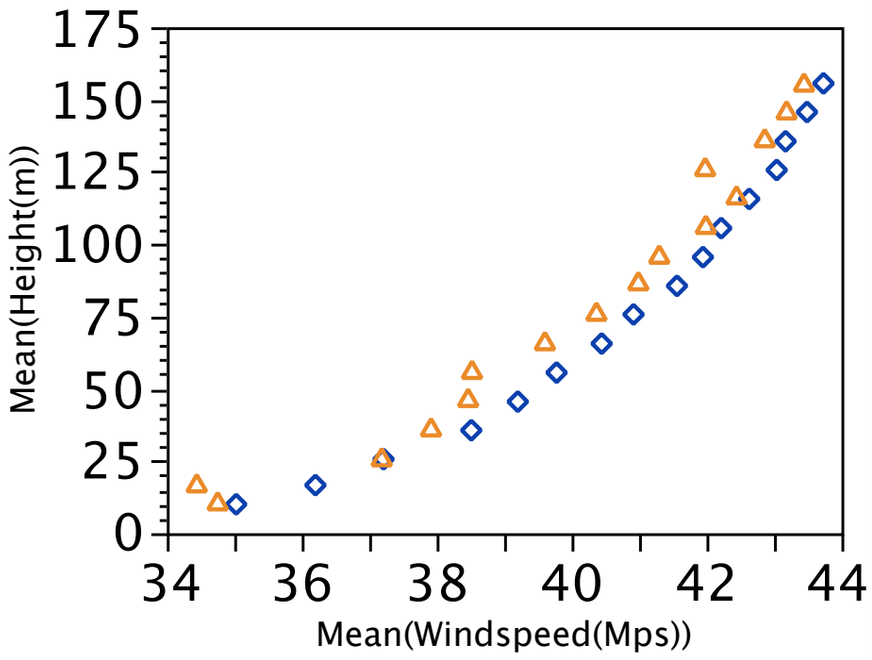
Shallow water winds stronger

30-39 MBL



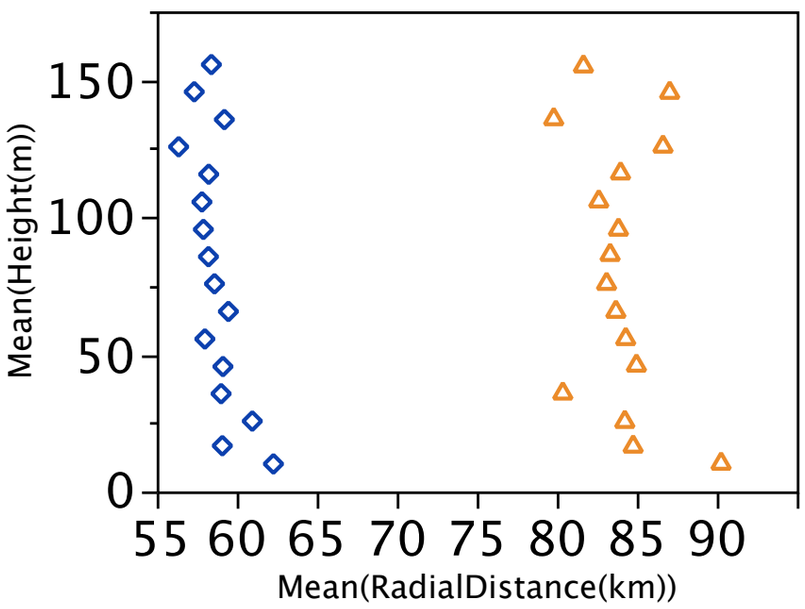
Shallow / Deep about same

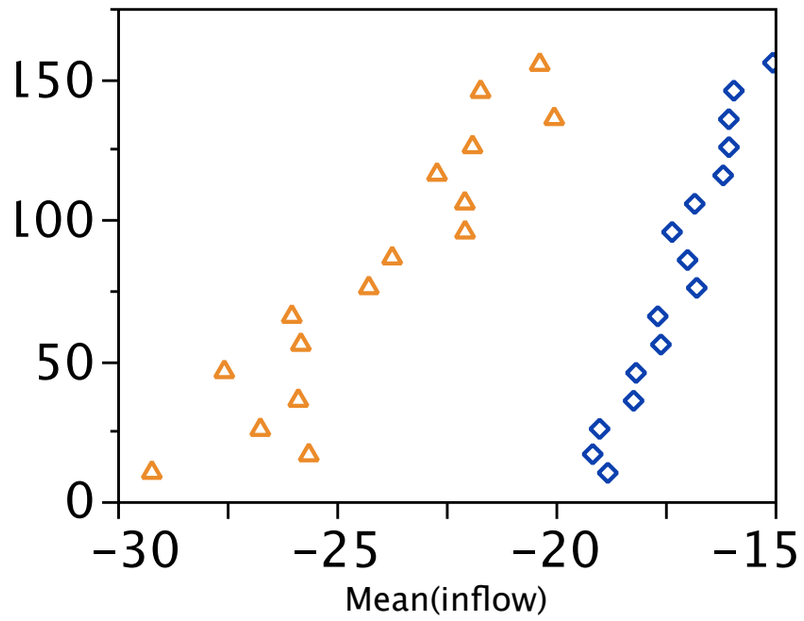
40-49 MBL

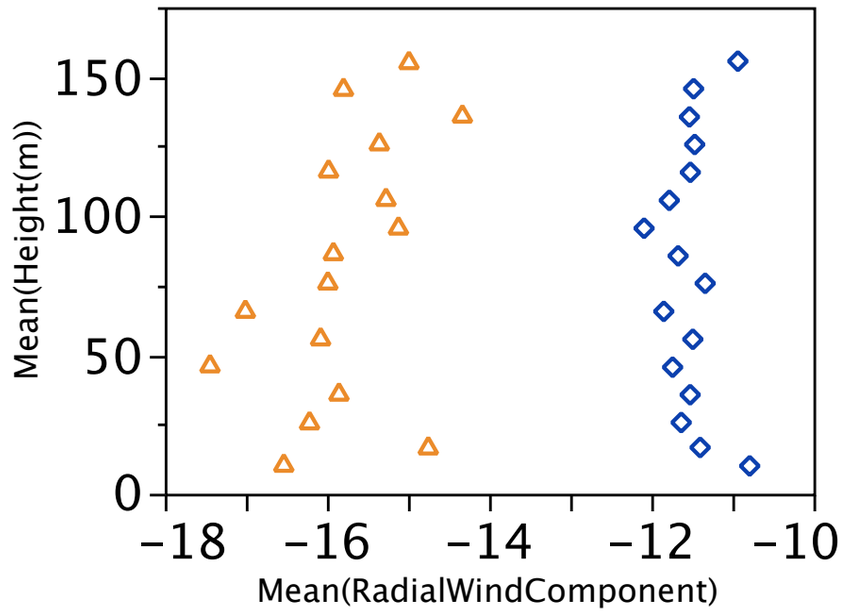


Deep water winds stronger

At any level, a null hypothesis of zero difference could not be rejected for 30-39 and 40-49 MBL groups but significant differences for 20-29 MBL at 95, 125, 145 m levels

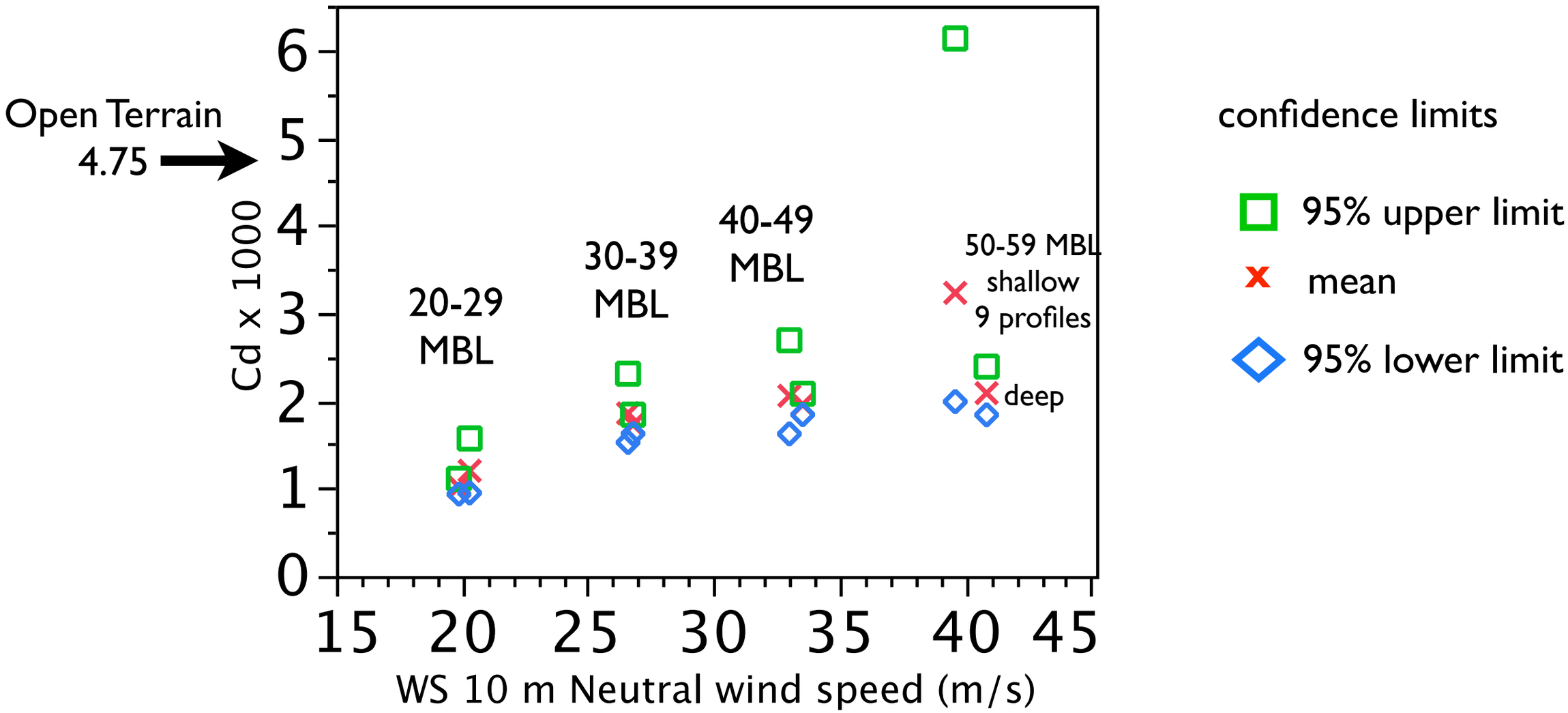






Shallow water sondes profiles are associated with stronger radial velocities and larger inflow angles at larger radial distance

Cd in Shallow and deep water



No significant differences between shallow and deep water Cd
need more samples, especially for > 50 m/s MBL winds

- **Conclusions**
  - V: shallow stronger 20-29MBL, same 30-39 MBL, weaker 40-49 MBL
  - Significant differences for some 20-29 MBL levels
  - No significant difference between shallow and deep water Cd for MBL winds < 50 m/s
  - Shallow water Cd's significantly different from open terrain*

The End

Questions?

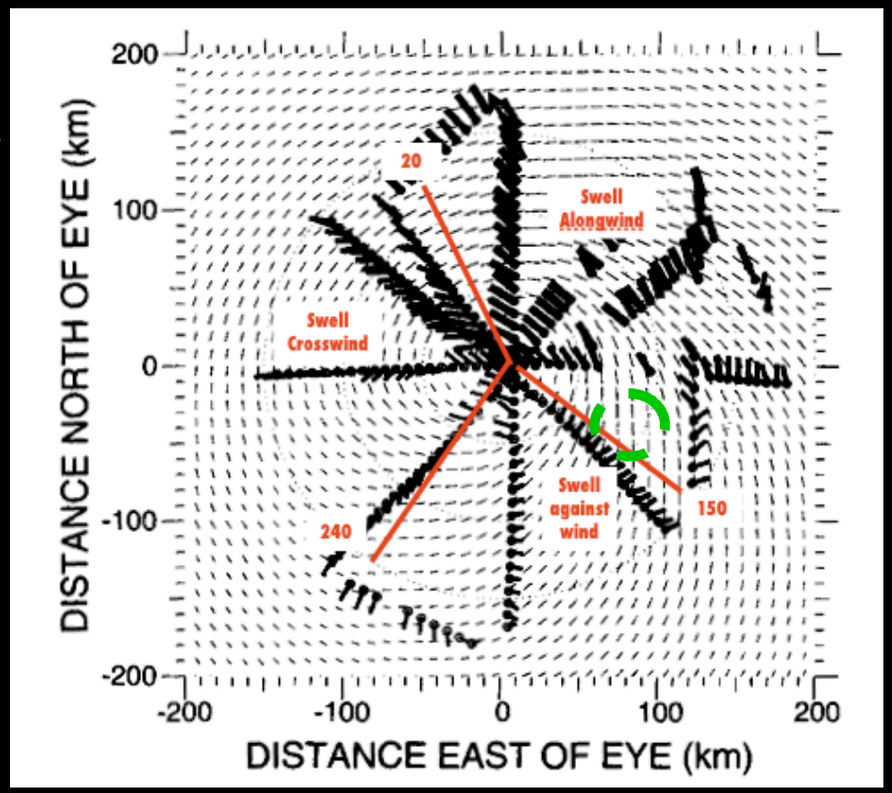
Conclusions

Storm motion

Left Front> 30km: waves propagate to right of wind, move faster than storm, Cd increase with U10

higher Cd than rear, right

Need more data for MBL > 60 m/s



Within 30 km Cd smaller

From Wright et al., 2001

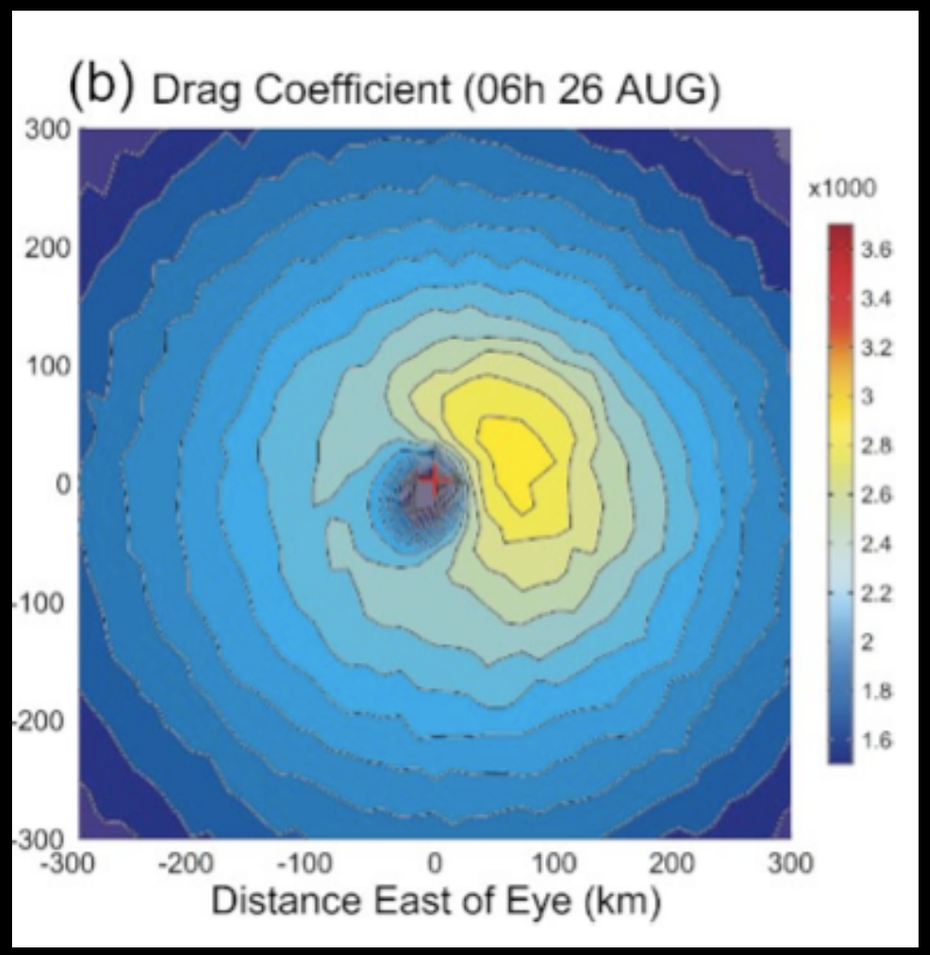
Right side > 30 km: waves / wind coincident

High ratio of wind to wave phase speed

Cd ~ constant with U10

Cd < left front slightly < than rear

Need more data for MBL > 60 m/s



Moon et al., 2004 Coupled ocean wave -wave BL model

Rear > 30 km: waves / wind can oppose
Cd ~ constant with U10
Cd slightly > right < left front

Bias in shear correction

- One sided (upward) finite difference underestimates shear and overestimates wind
  - 1) Mean profile from 8-160 m for each MBL group
  - 2) Bias estimated from sonde "launched" into mean profile
  - 3) Bias removed from mean profile
  - 4) New profile fit to estimate slope (U*) and intercept (Zo)