Drifting Buoys Observation of Typhoon Generated Extreme Ocean Waves and the Reduced Drag Coefficient

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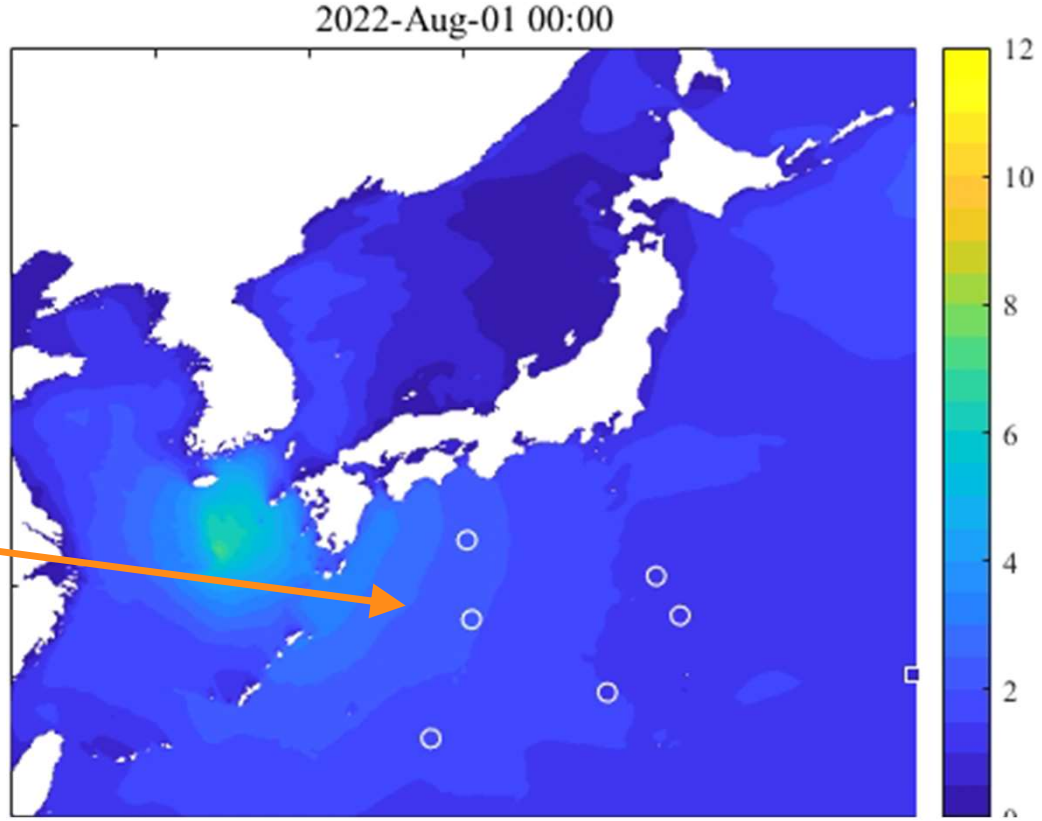
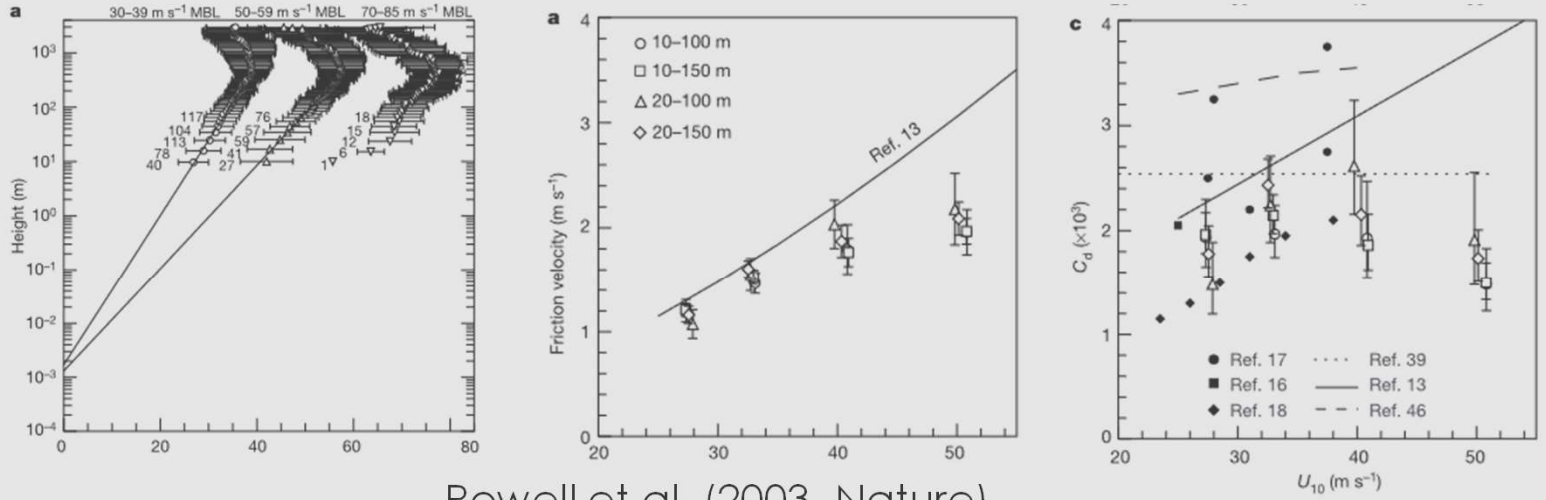
Small GPS wave buoy
SPOTTER (Sofar Ocean)



Observed air-sea momentum flux in tropical cyclone winds

Air observation
(Drop sonde)



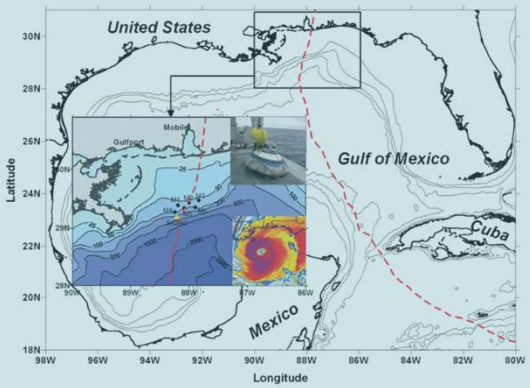
Vickery et al. (2009, JAMC)
Holthuijsen et al. (2012, JGR)
Ermakova et al. (2023, JMSE)

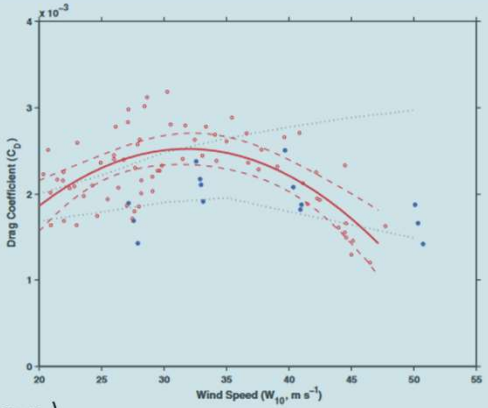
Powell et al. (2003, Nature)

Reduced drag coefficient for high wind speeds in tropical cyclones

Ocean observation
(Ocean current)

$$\frac{\partial U}{\partial t} - fV = \frac{\tau_{sx}}{\rho H} - \frac{rU}{H}$$





Zou et al. (2018, Tellus)

Jarosz et al. (2007, Science)

Bottom-Up Determination of Air-Sea Momentum Exchange Under a Major Tropical Cyclone

Observed air-sea momentum flux in tropical cyclone winds

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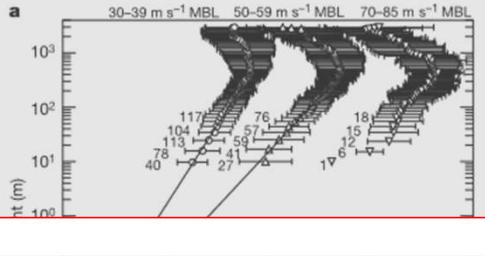

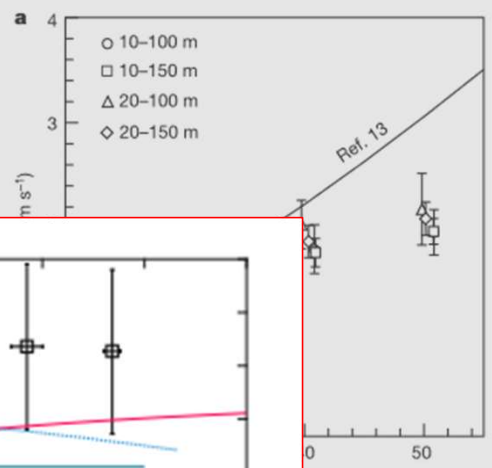

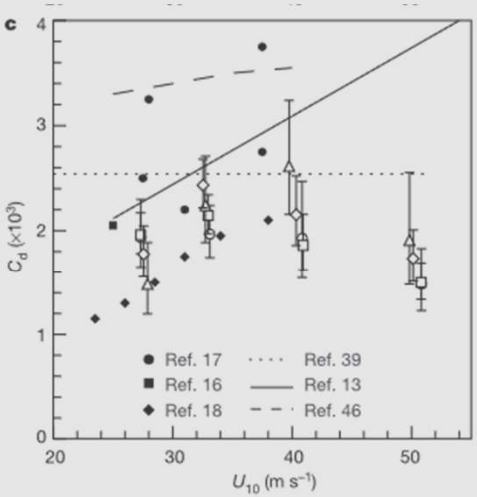

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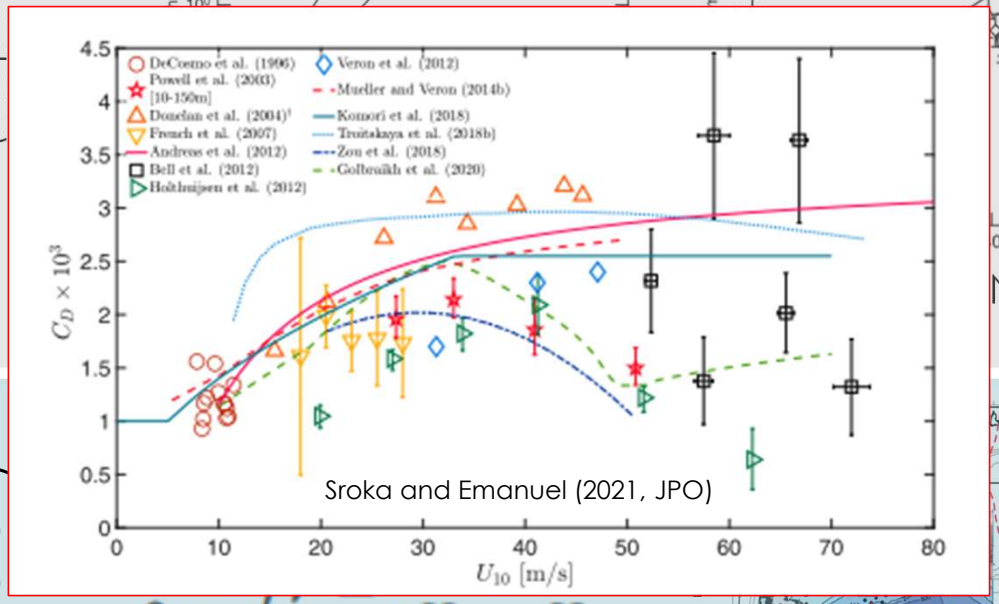
Holthuijsen et al. (2012, JGR)
Ermakova et al. (2023, JMSE)



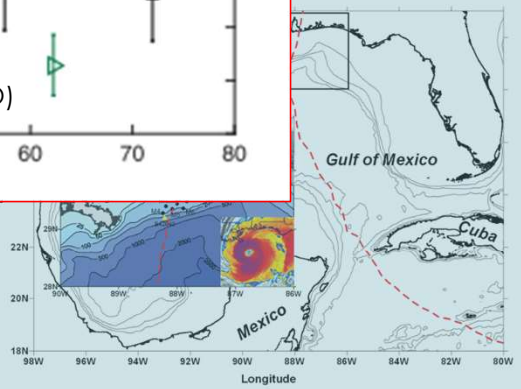
Sroka and Emanuel (2021, JPO)

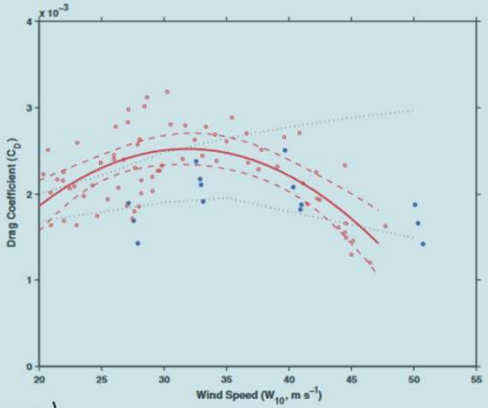
Nature)

speeds in tropical cyclones

Ocean observation (Ocean current)

$$\frac{\partial}{\partial t} \qquad \rho H \qquad H$$



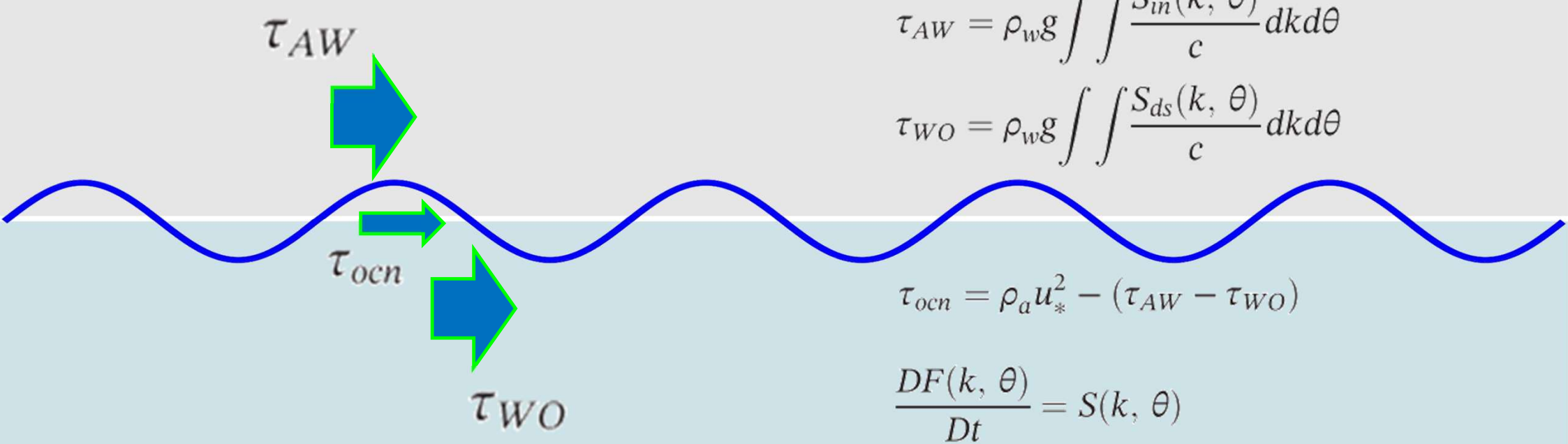


Zou et al. (2018, Tellus)

Jarosz et al. (2007, Science)

Bottom-Up Determination of Air-Sea Momentum Exchange Under a Major Tropical Cyclone

Momentum transfer through waves



$$\tau_{AO} = \rho_a u_*^2 = \rho_a C_m U^2$$

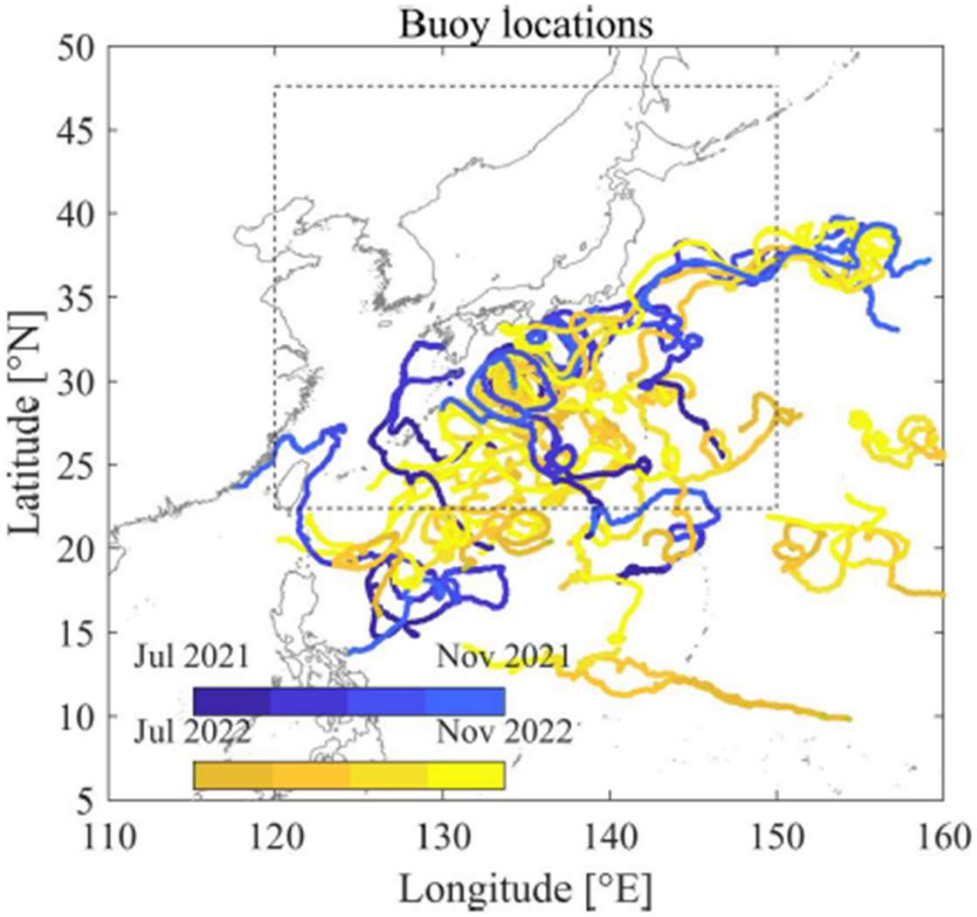
$$\tau_{AW} = \rho_w g \int\int \frac{S_{in}(k,\,\theta)}{c} dk d\theta$$

$$\tau_{WO} = \rho_w g \int\int \frac{S_{ds}(k,\,\theta)}{c} dk d\theta$$

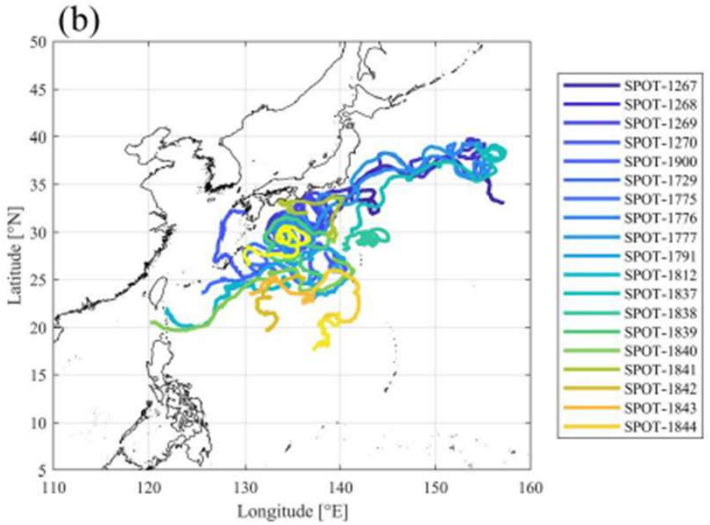
$$\tau_{ocn} = \rho_a u_*^2 - (\tau_{AW} - \tau_{WO})$$

$$\frac{DF(k,\,\theta)}{Dt} = S(k,\,\theta)$$

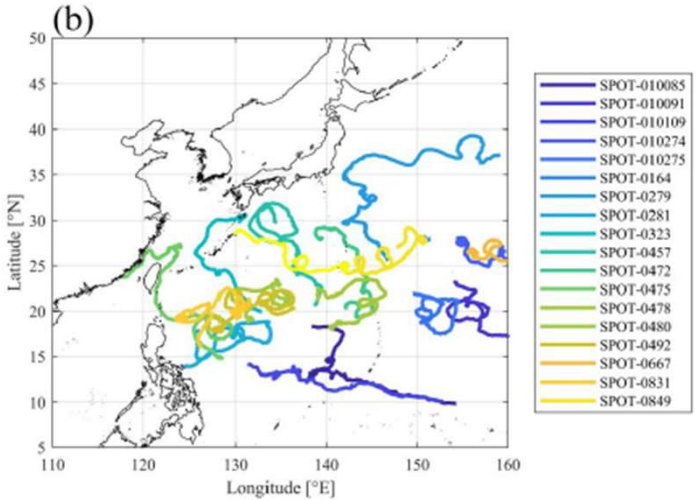
$$S(k,\,\theta) = S_{in}(k,\,\theta) + S_{ds}(k,\,\theta) + S_{nl}(k,\,\theta)$$



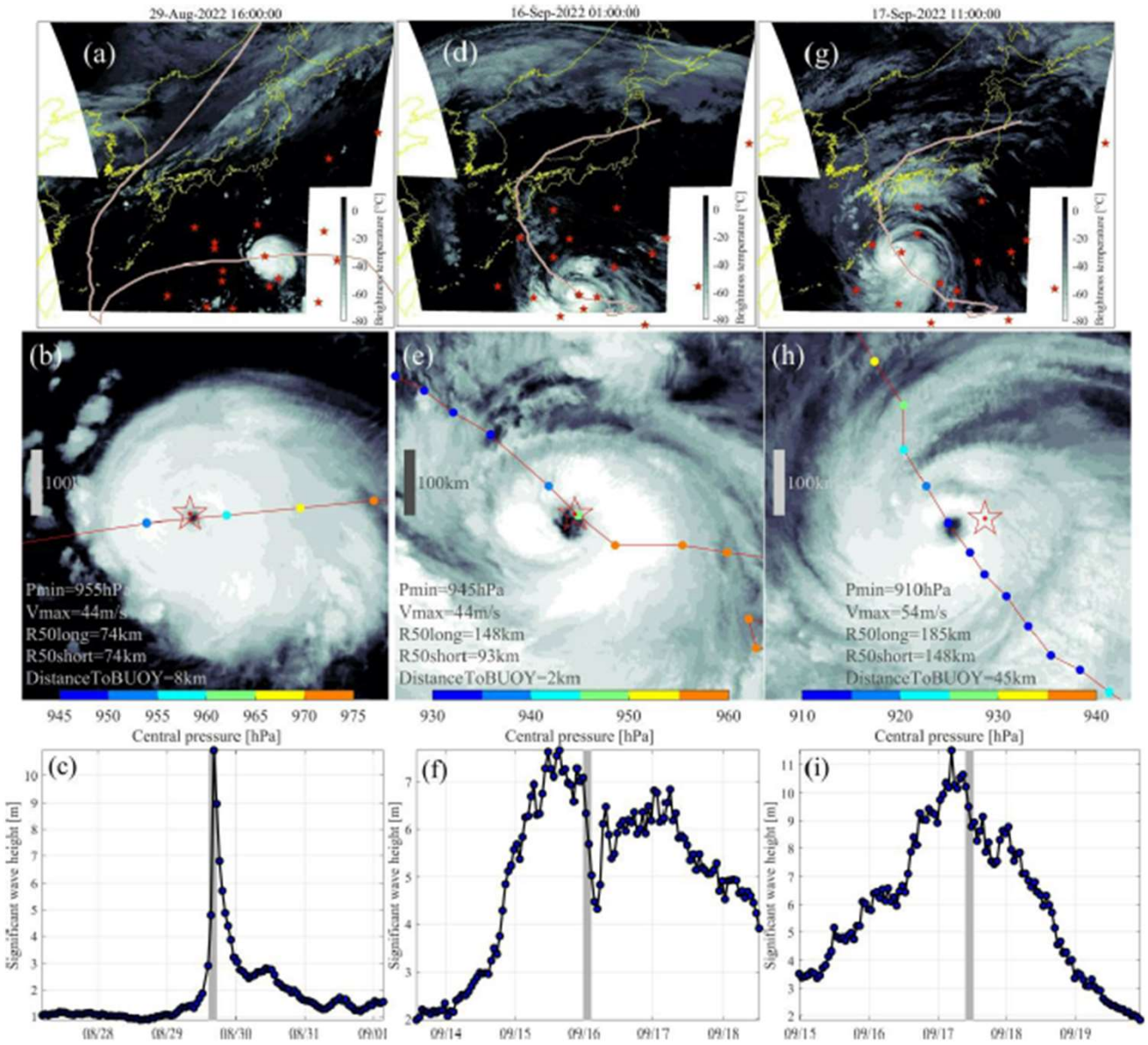
Drifting wave buoy paths
Target period: summer in 2021 and 2022



Kyoto Univ. deployed buoys

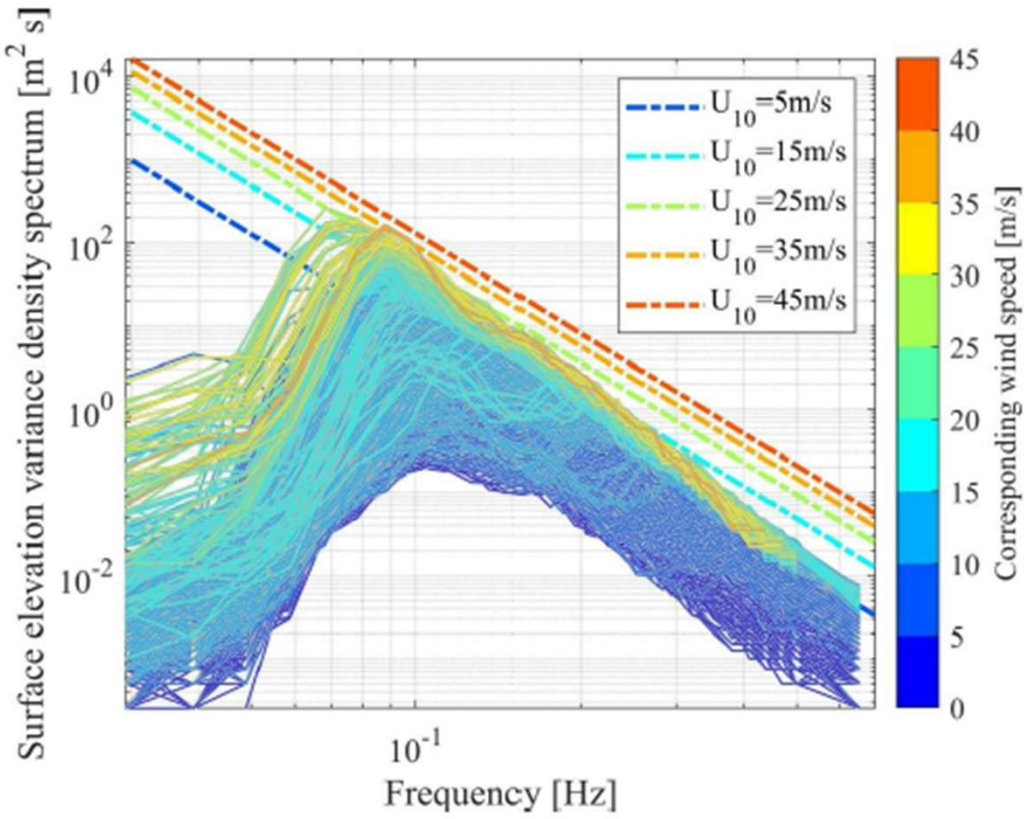


Sofar Ocean deployed buoys


29-Aug-2022 16:00:00
16-Sep-2022 01:00:00
17-Sep-2022 11:00:00
(a)
(d)
(g)
Brightness temperature [°C]
(b)
(e)
(h)
100km
Pmin=955hPa
Vmax=44m/s
R50long=74km
R50short=74km
DistanceToBUOY=8km
Pmin=945hPa
Vmax=44m/s
R50long=148km
R50short=93km
DistanceToBUOY=2km
Pmin=910hPa
Vmax=54m/s
R50long=185km
R50short=148km
DistanceToBUOY=45km
Central pressure [hPa]
(c)
(f)
(i)
Significant wave height [m]
08/28
08/29
08/30
08/31
09/01
09/14
09/15
09/16
09/17
09/18
09/19

Wind (Momentum flux) estimation from wave spectrum

(Shimura et al., 2022, JGR-Oceans)



$$E(f) = E_0 f^{-4} \qquad E_0 = \frac{4\beta I u_* g}{(2\pi)^4}$$

The analytic expression of the wave energy spectrum in the wind-wave equilibrium range (Phillips, 1985)

$$U(z) = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_0}\right)$$ The law of wall

$$z_0 = 0.11\frac{\upsilon}{u_*} + \alpha\frac{u_*^2}{g}$$

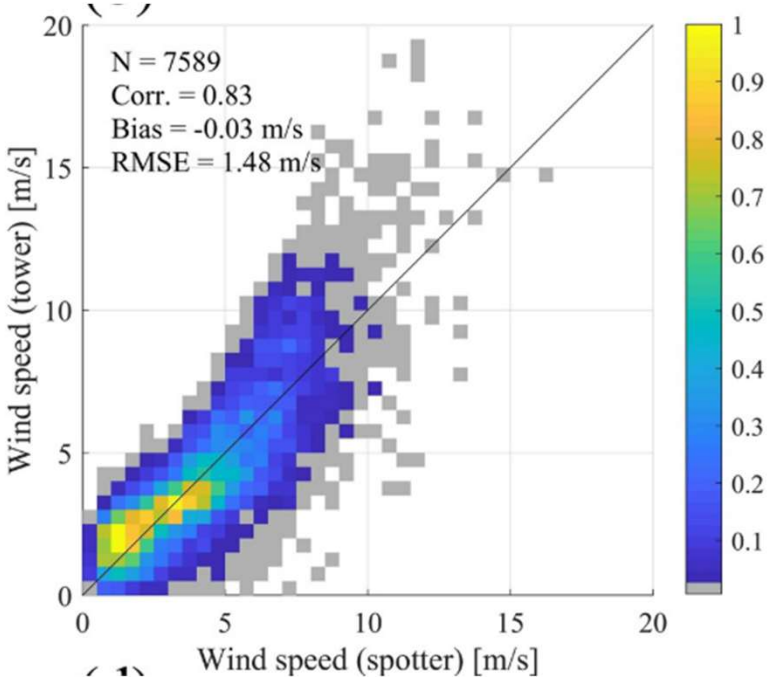
Roughness length by the Charnock relation (Charnock, 1955)

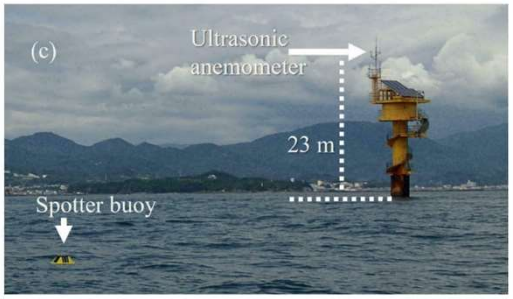
$$E_o = \max E(f) f^4.$$

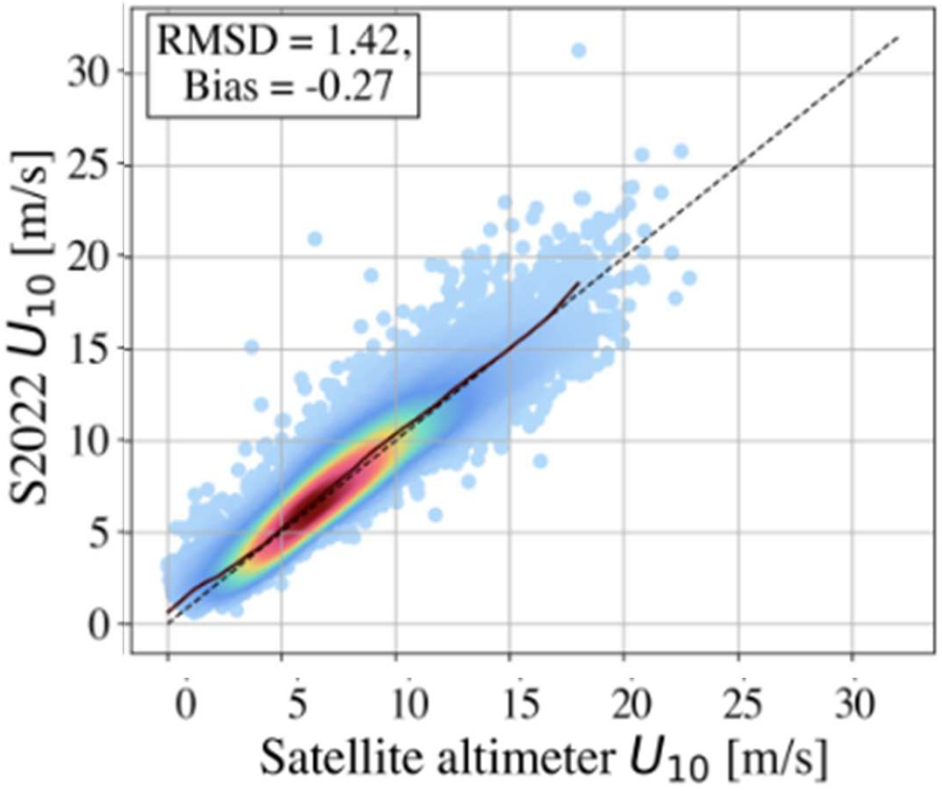
$$E_o = \max E(f)/L^2 \cdot (g/2\pi)^2$$

Wind (Momentum flux) estimation from wave spectrum

(Shimura et al., 2022, JGR-Oceans)



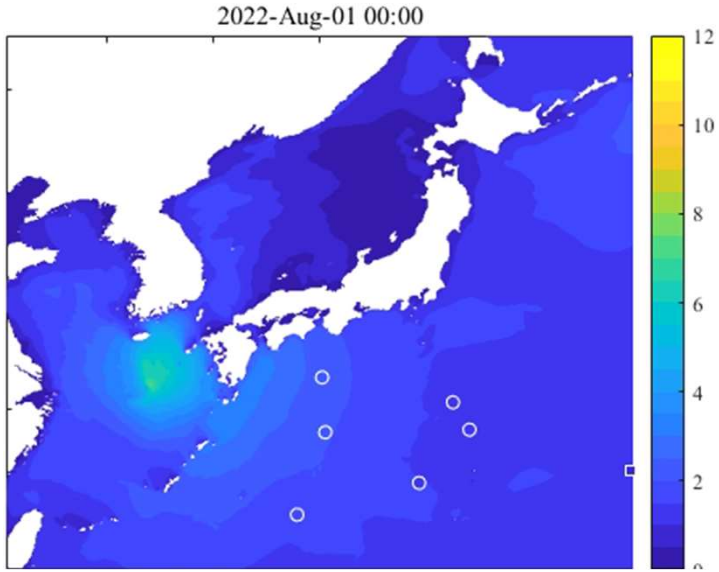


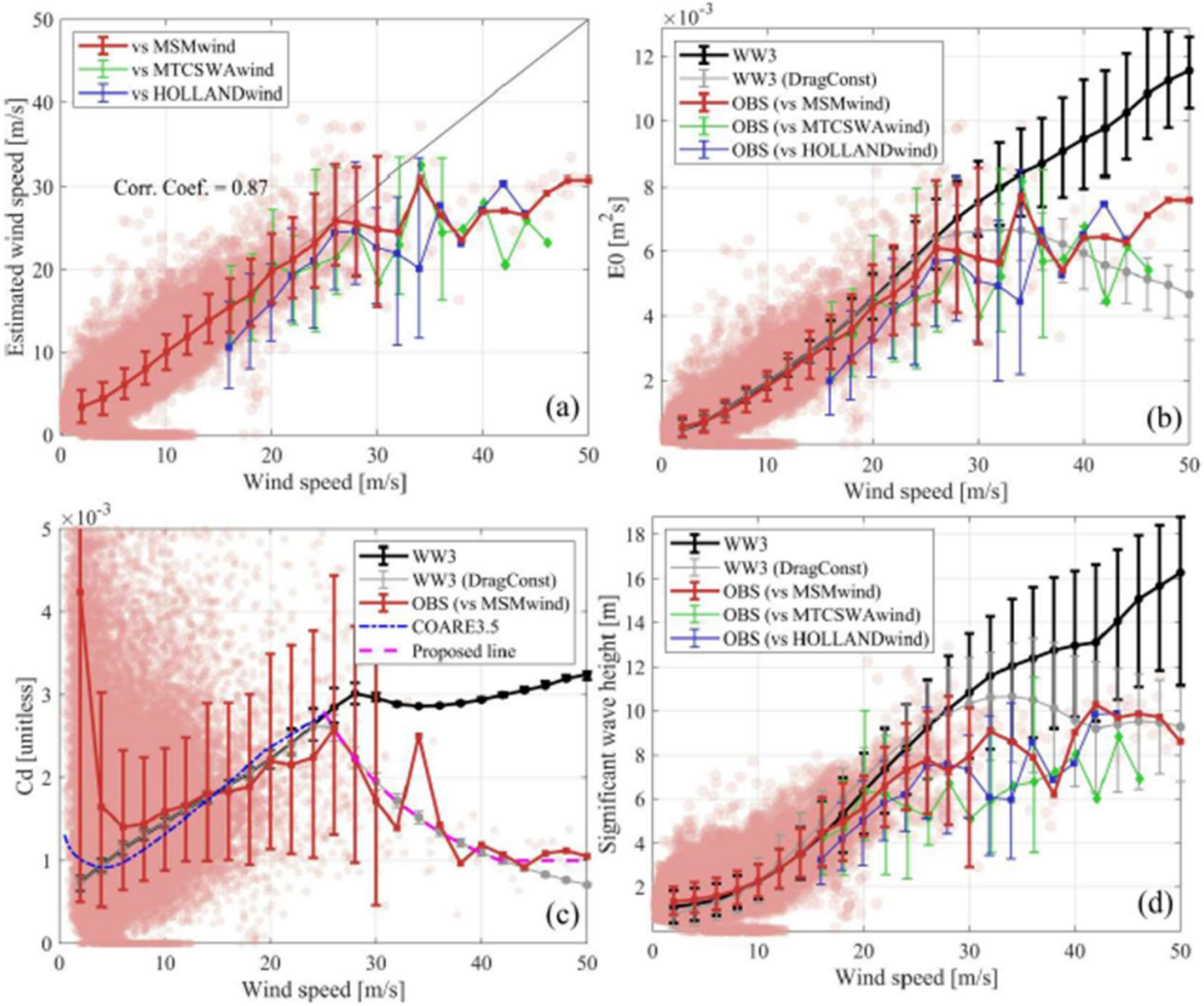


Dorsay et al., (2023)

Reference wind speeds and wave simulations

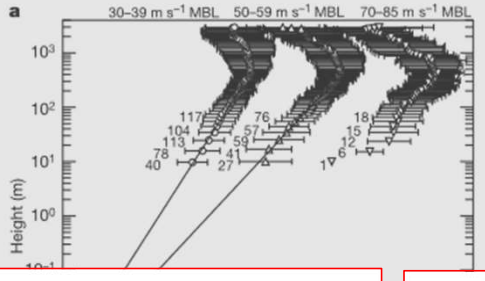
- Reference wind data (Three data sources)
  - Analysis data from Japanese Meteorological Agency's Meso Scale Model (JMA-MSM)
    - 1 hourly
    - 5 km
  - The multi-platform tropical cyclone surface winds analysis (MTCSWA)
    - US National Oceanic and Atmospheric Administration (Knaff et al., 2021).
    - The wind fields are objectively estimated using multiple satellite platforms (sounder data from six satellites and imagery data from four satellites)
    - 3 hourly
    - Since 7th September 2022
  - Parametric tropical cyclone wind
    - Holland (1980)
    - Based on JMA bast track
- Wave numerical simulation
  - WAVEWATCH III (ST4 switch)
  - JMA-MSM wind forcing

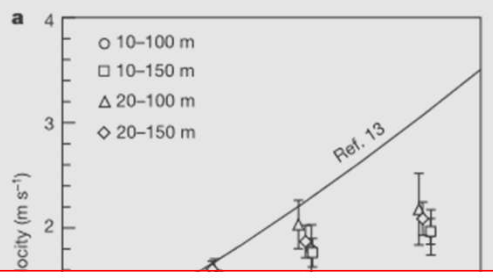


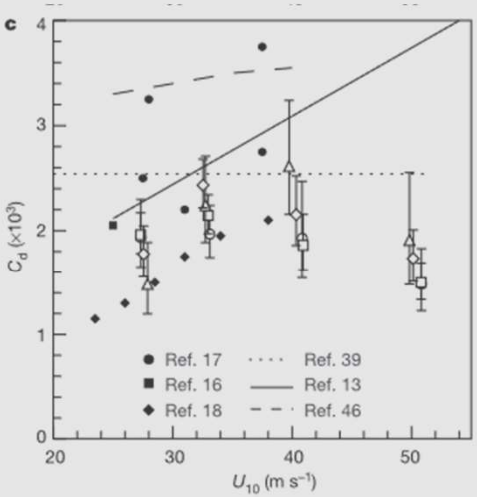

vs MSMwind
vs MTCSWAwind
vs HOLLANDwind
Corr. Coef. = 0.87
Estimated wind speed [m/s]
Wind speed [m/s]
(a)
WW3
WW3 (DragConst)
OBS (vs MSMwind)
OBS (vs MTCSWAwind)
OBS (vs HOLLANDwind)
E0 [m²s]
(b)
Cd [unitless]
COARE3.5
Proposed line
(c)
Significant wave height [m]
(d)

Conclusions

Ocean observation
(Ocean sonde)







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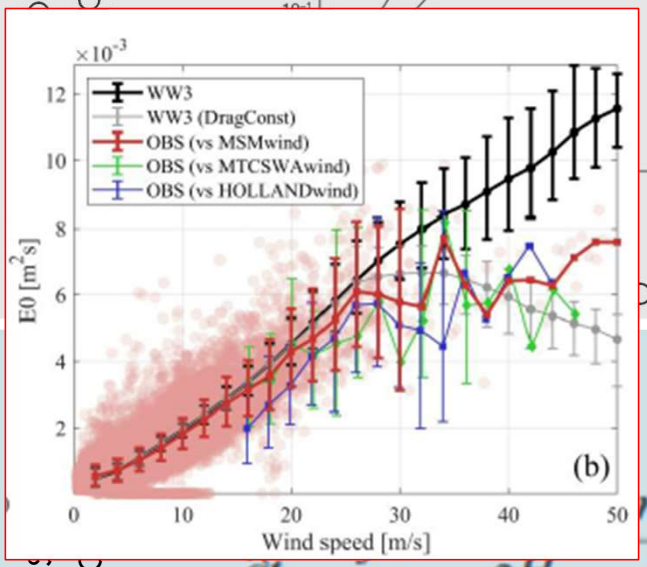
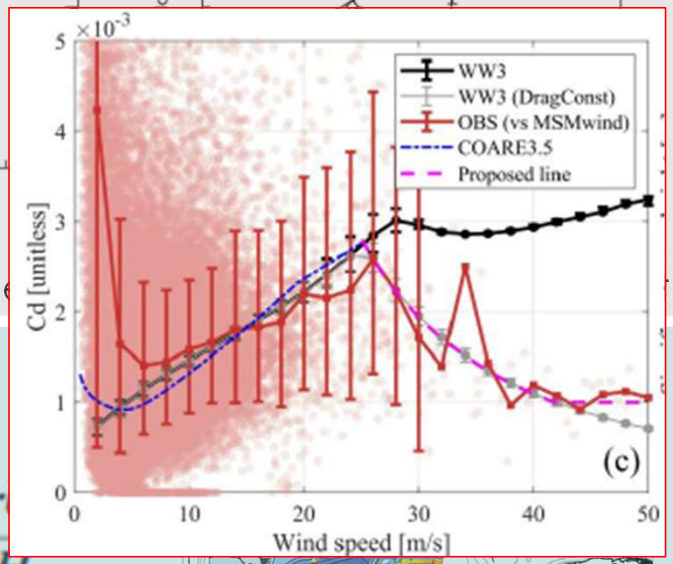
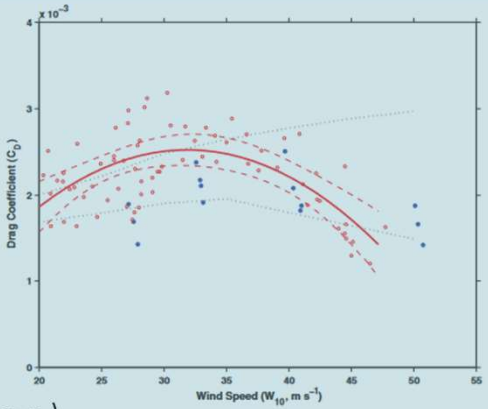




ropical cyclones



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