Improving wave-based air-sea momentum flux parameterization in mixed seas

César Sauvage*, Hyodae Seo, Carol Anne Clayson and James B. Edson (WHOI) | * csauvage@whoi.edu

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INTRODUCTION

Oceanic and surface processes, through various regimes of interactions among ocean current, surface wind and wind waves, are critical for the atmosphere and an accurate description of the wind stress. The focus of this study is on the impact of the ocean surface waves through the drag coefficient (C_D) on momentum flux. More especially how does the air-sea flux parameterization behave in swell and mixed seas conditions.

COARE 3.5

$$\tau = \rho_a C_D (U_a - U_o)^2$$

C_D is defined using the surface roughness length (Z_0). Z_0 can be expressed as the sum of a smooth and a rough part. For smooth flow, τ is mainly supported by viscous shear. As for the rough part one way is to parameterize it as a function of wind speed only (**WSDF**):

$$z_{rough} = \alpha \frac{u_*^2}{g} \quad \text{with} \quad \alpha = 0.0017\, U_{10} - 0.005$$

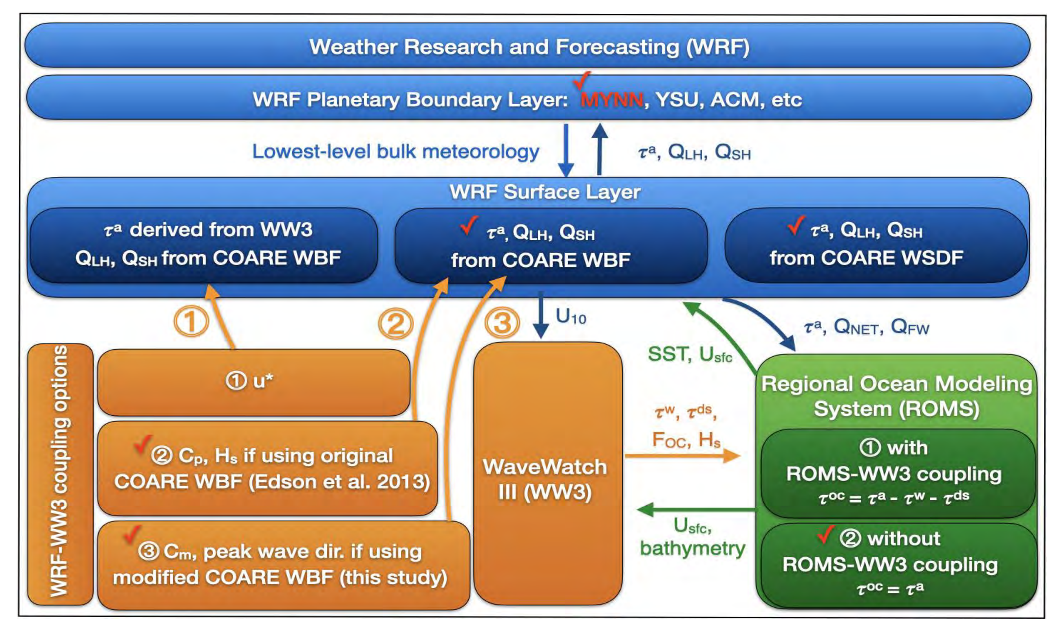
In this case a wind wave equilibrium is assumed: wind seas under high wind and swell under low wind, also it is assumed that wind and waves are aligned.

An alternative way to define Z_{rough} in COARE3.5 is to use a wave-based formulation (**WBF**), which requires contemporaneous information about wave and sea states, such as significant wave height (Hs) and phase speed of the dominant waves (Cp):

$$z_{rough} = H_s \cdot 0.09 \cdot \left(\frac{u_*}{C_p}\right)^2$$

where u_*/Cp is the inverse wave age. In both of these formulations it is assumed that wind and waves are aligned. Hereafter wave age is defined as C_p/U_{10}.

SCOAR REGIONAL COUPLED MODELING



Experiments (Δx = 10km)	Coupling	Z_0 in COARE3.5
WSDF	WRF-ROMS	Wind speed only
WBF	WRF-ROMS-WW3	Wave based (Tp, Hs)
WBF_θ	WRF-ROMS-WW3 (modified WBF)	With misaligned wave (θ ≠ 0)
WBF_Tm		With Tm (instead of Tp)

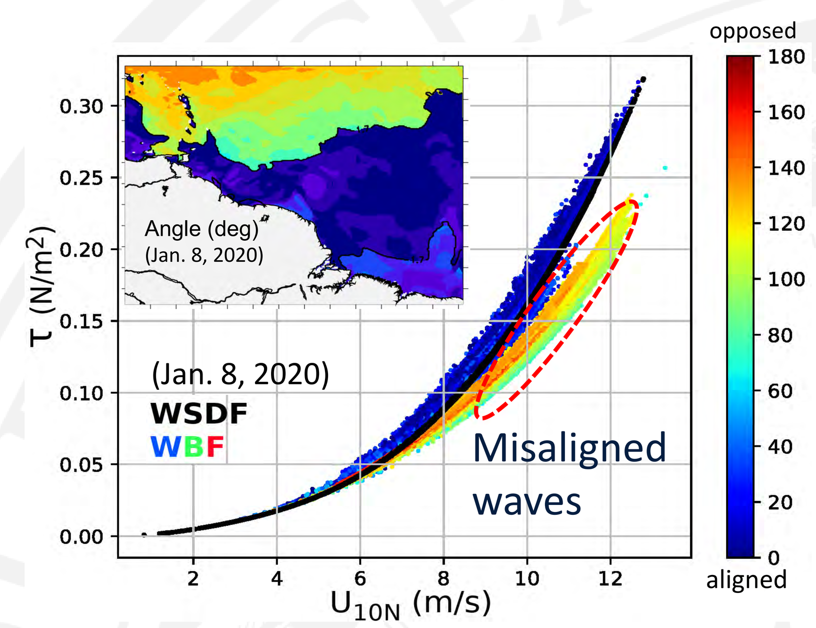
INCLUDING WAVES DIRECTIONALITY

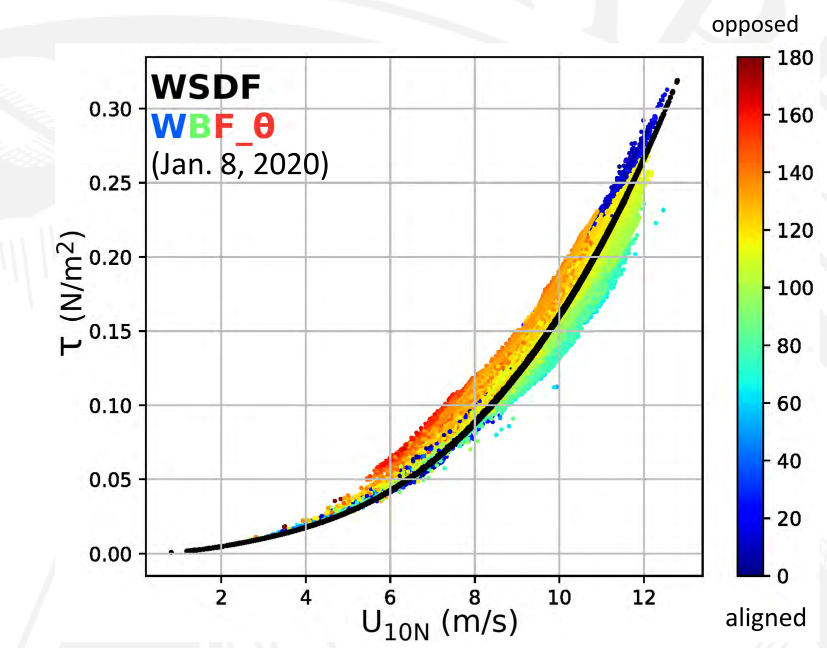
During the study case of January 8, 2020 in the Northwest Tropical Atlantic Ocean, the sea state leading to the strong decrease of surface wind stress appears to be strongly misaligned with the trade winds.

New Z_0 formulation based on previous studies (Patton et al. 2015, Porchetta et al. 2019):

$$z_{rough} = H_s \cdot 0.09\cos(0.4\theta) \cdot \left(\frac{u_*}{C_p}\right)^{2\cos(0.32\theta)} \quad \text{where } \theta \text{ in } [0:180]$$

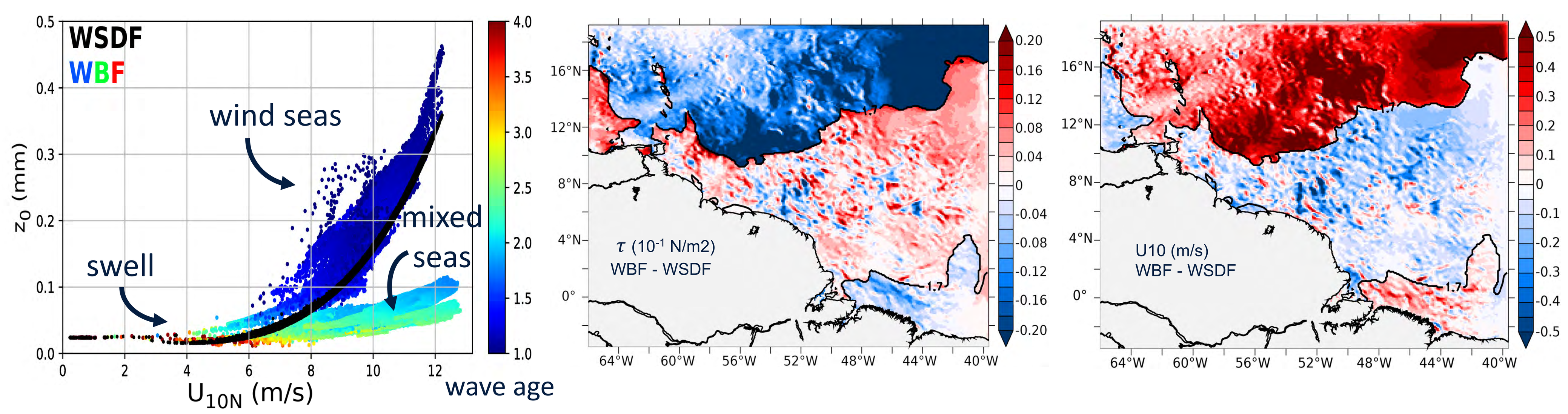
This allows the surface stress to increase in case of strong wave misalignment with the local wind.



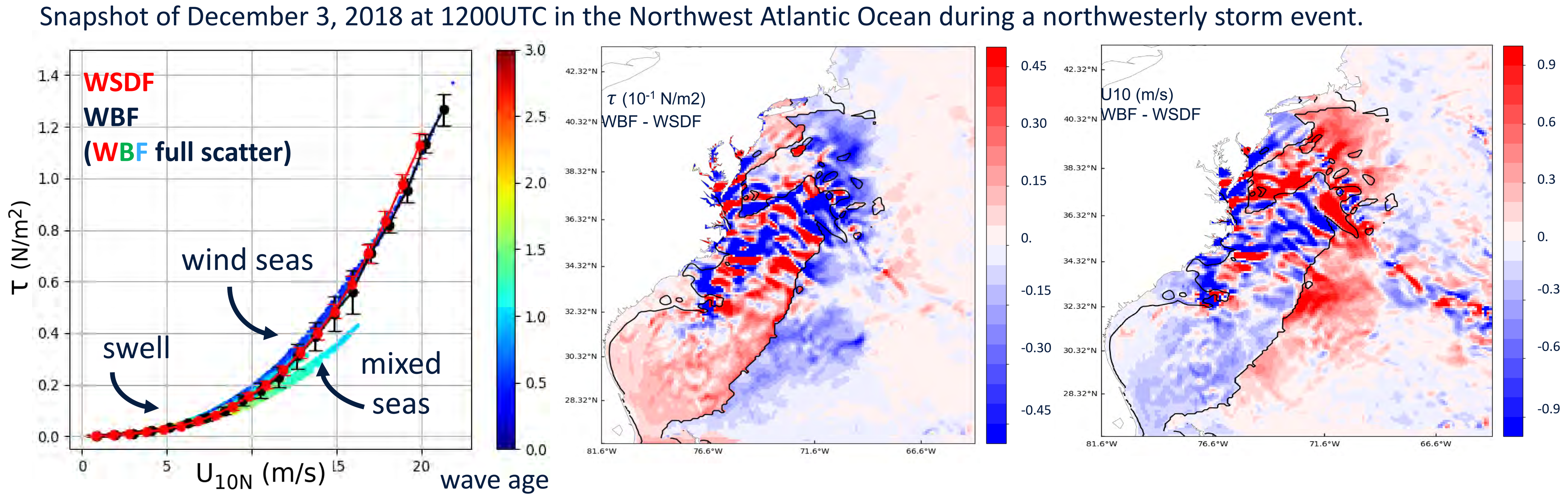


WBF vs WSDF

Snapshot of January 8, 2020 at 0600UTC in the Northwest Tropical Atlantic Ocean during a northwesterly swell event.



Snapshot of December 3, 2018 at 1200UTC in the Northwest Atlantic Ocean during a northwesterly storm event.



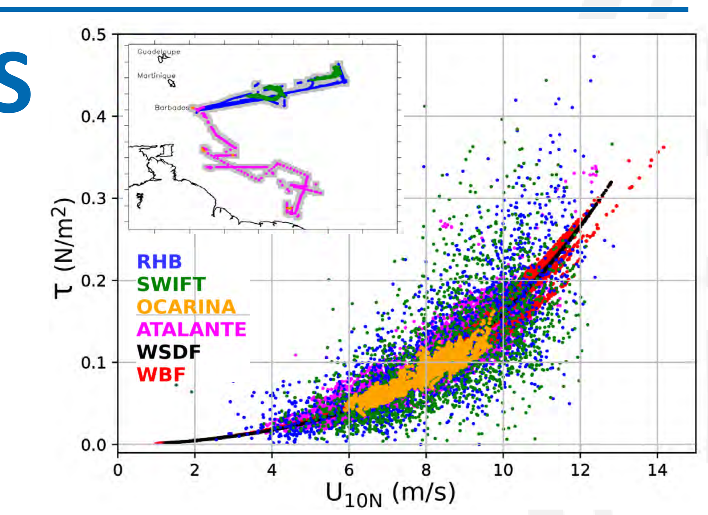
Under moderate to high wind conditions Z_0 is increased above young seas (wave age < 1.2) whereas it is decreased above mixed seas (wave age > 1.2).

The differences found in Z_0 directly impact the C_D and τ (10-15%), resulting in an instant increase/decrease of the near-surface wind speed (5%) above the constant flux layer.

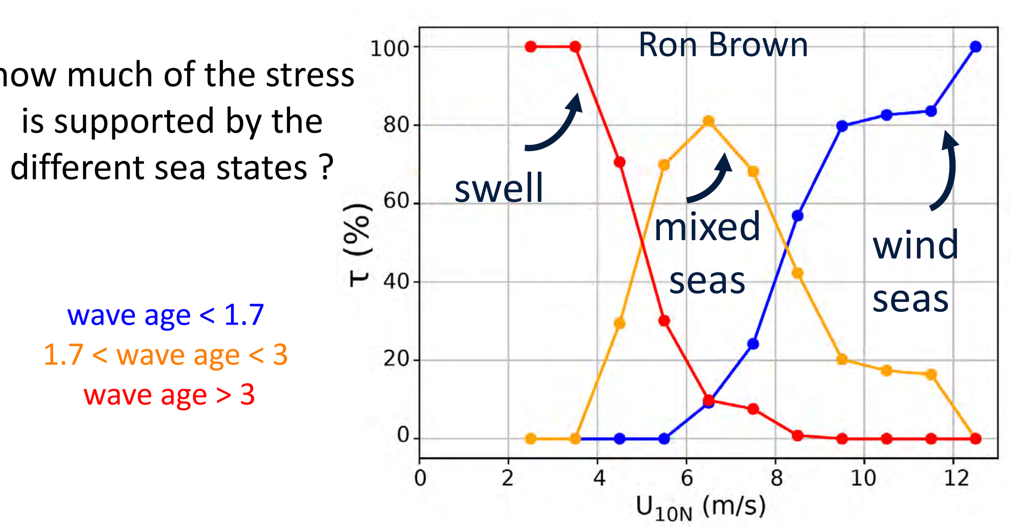
MODEL vs OBSERVATIONS

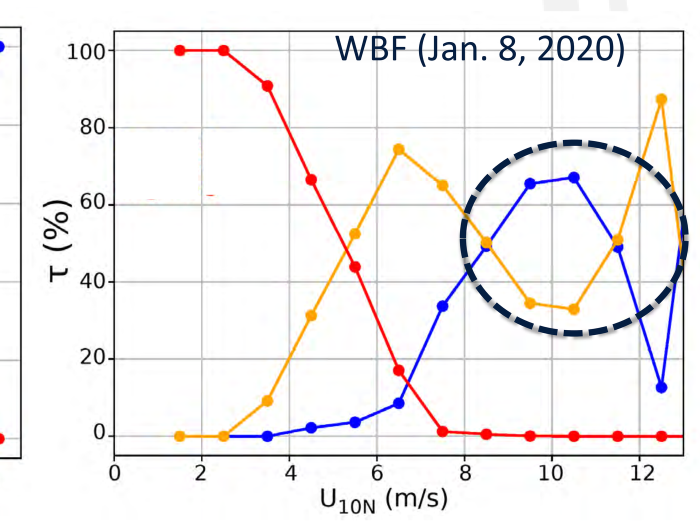
- Comparison against direct measurement of the momentum flux during the EUREC4A-ATOMIC campaign in Jan.-Feb. 2020.

Ron Brown and Ocarina → eddy covariance method
Atalante → inertial dissipation method
SWIFT → estimation of friction velocity from the equilibrium frequency range of the wave spectrum



how much of the stress is supported by the different sea states ?

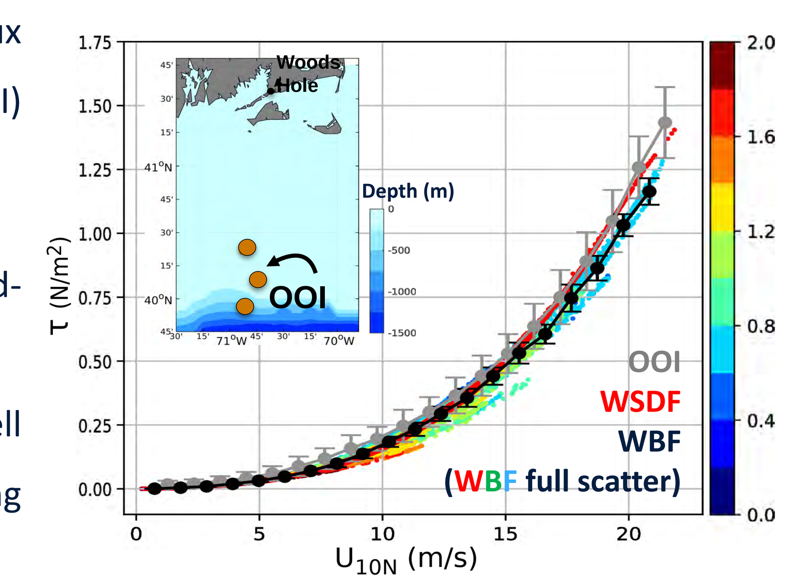




- Comparison against direct eddy covariance flux measurements at the Ocean Observatories Initiative (OOI) mooring during Dec. 2018 and Jan. 2019.

→ WBF alleviates the low stress bias over short wind-waves.

→ WBF over-emphasizes the mixed seas and swell impacts on Z_0 and τ under moderate to high wind, leading to the low-stress bias.

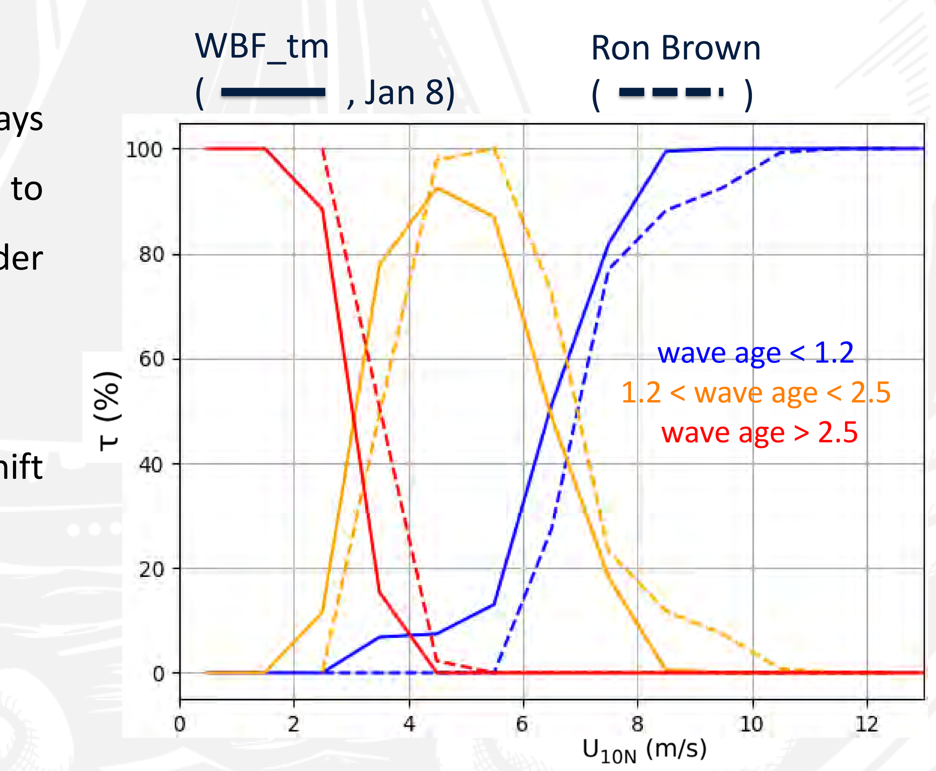


USING THE MEAN PERIOD OF THE WAVES

The peak wave period does not always represents accurately the sea state and tend to overestimate the impact of mixed sea under moderate wind conditions

The mean period is more appropriate and shift the wave age distribution to younger waves.

$$z_{rough} = H_s \cdot 0.39 \cdot \left(\frac{u_*}{C_m}\right)^{2.6}$$



CONCLUSION

→ COARE3.5 with the coupled model against EUREC4A-ATOMIC and OOI data show that WBF over-emphasizes the mixed seas and swell impacts on Z_0 under moderate to high winds.

→ Two possible remedies for low stress bias:

- Wave-wind directional misalignment (θ≠0): increases the drag for misaligned waves
- Mean wave period (T_m): emphasizes the presence of wind waves in the mixed sea state

→ Require more detailed tuning of the parameters (i.e., specific to the coastal and shelf oceans).