Impacts of surface waves on air-sea flux and marine boundary layer processes in the North Atlantic Oceans

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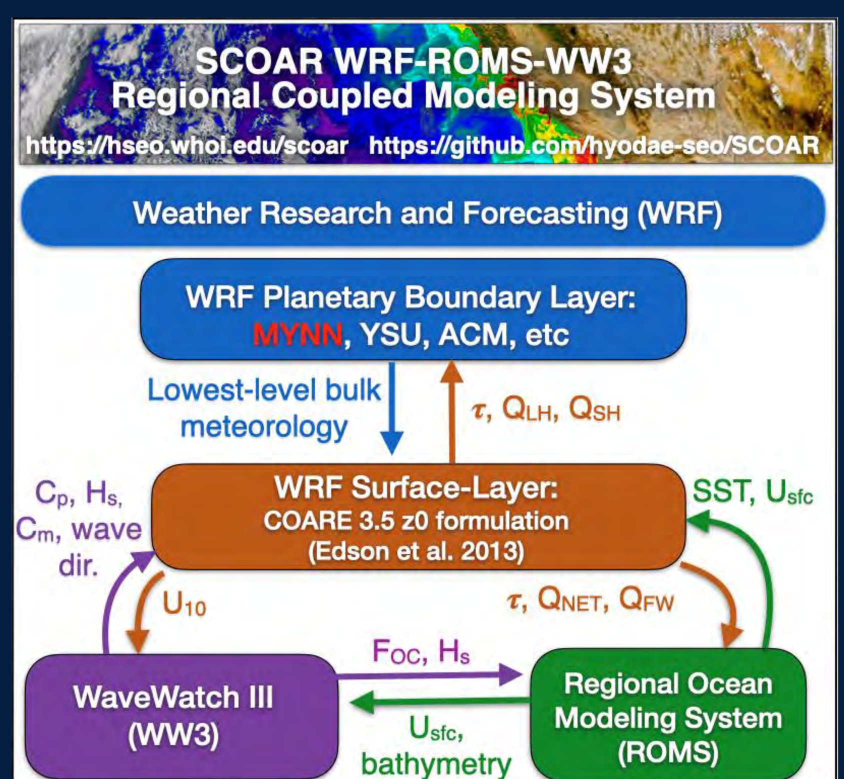
INTRODUCTION

The US East Coast region features a multitude of oceanic and surface wave processes that, through air-sea interaction, are critical for the atmosphere and an accurate description of the surface wind stress. The surface stress is defined by:

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

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 this region of highly variable wind regimes and sea states.

REGIONAL COUPLED MODEL



10 km horizontal resolution

Experiments	Coupling	Z0 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)

COARE3.5

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, it is currently formulated in several different ways, the simplest and the most broadly used is to parameterize it as a function of wind speed only:

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

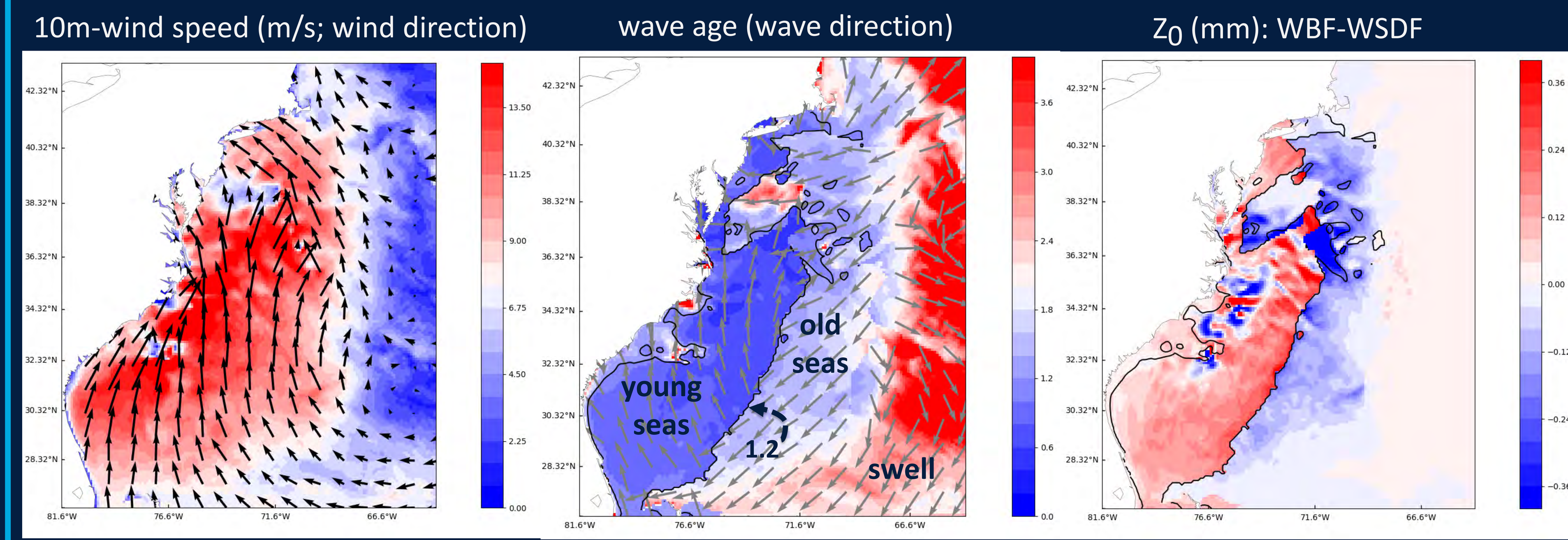
In this case a wind wave equilibrium is assumed: wind seas under high wind and swell under low wind, also it is assumed that wind and waves are aligned.

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

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

where u_*/Cp is the inverse wave age. In this formulation it is still assumed that wind and waves are aligned. Note that the phase speed (Cp) is defined using the peak period of the waves (Tp).

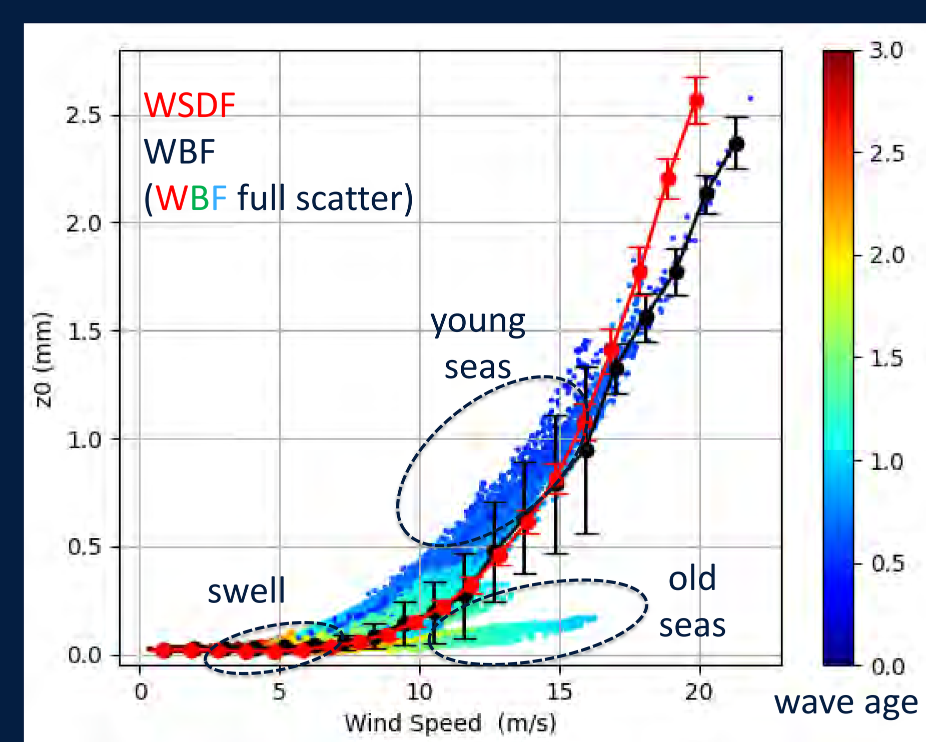
WBF vs WSDF

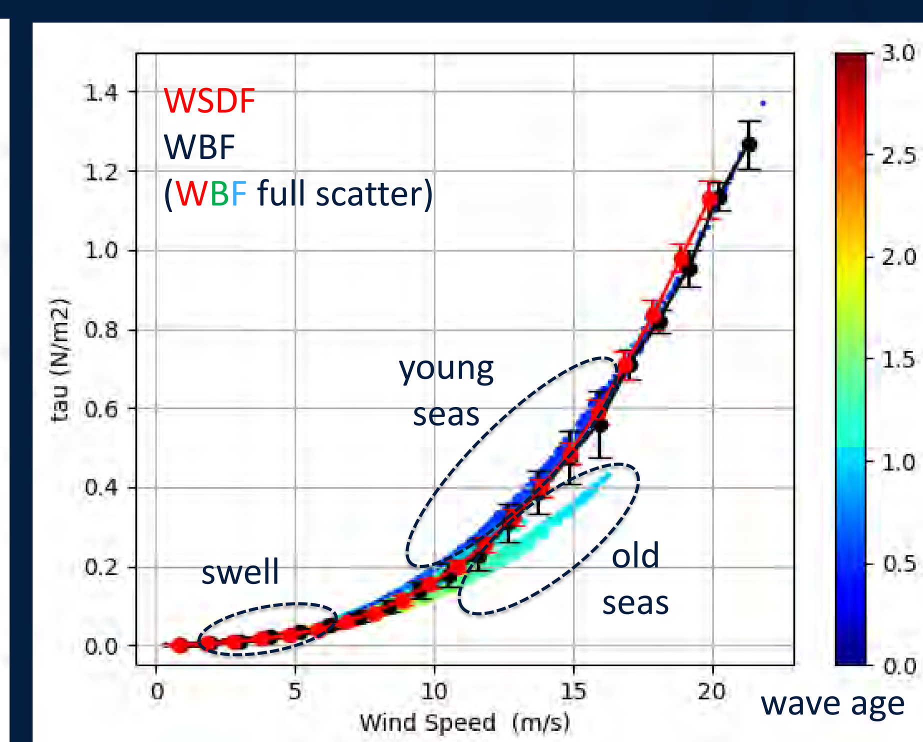


Snapshot of December 3, 2018 at 1200UTC ; Hereafter wave age is defined as Cp/U_{10} .

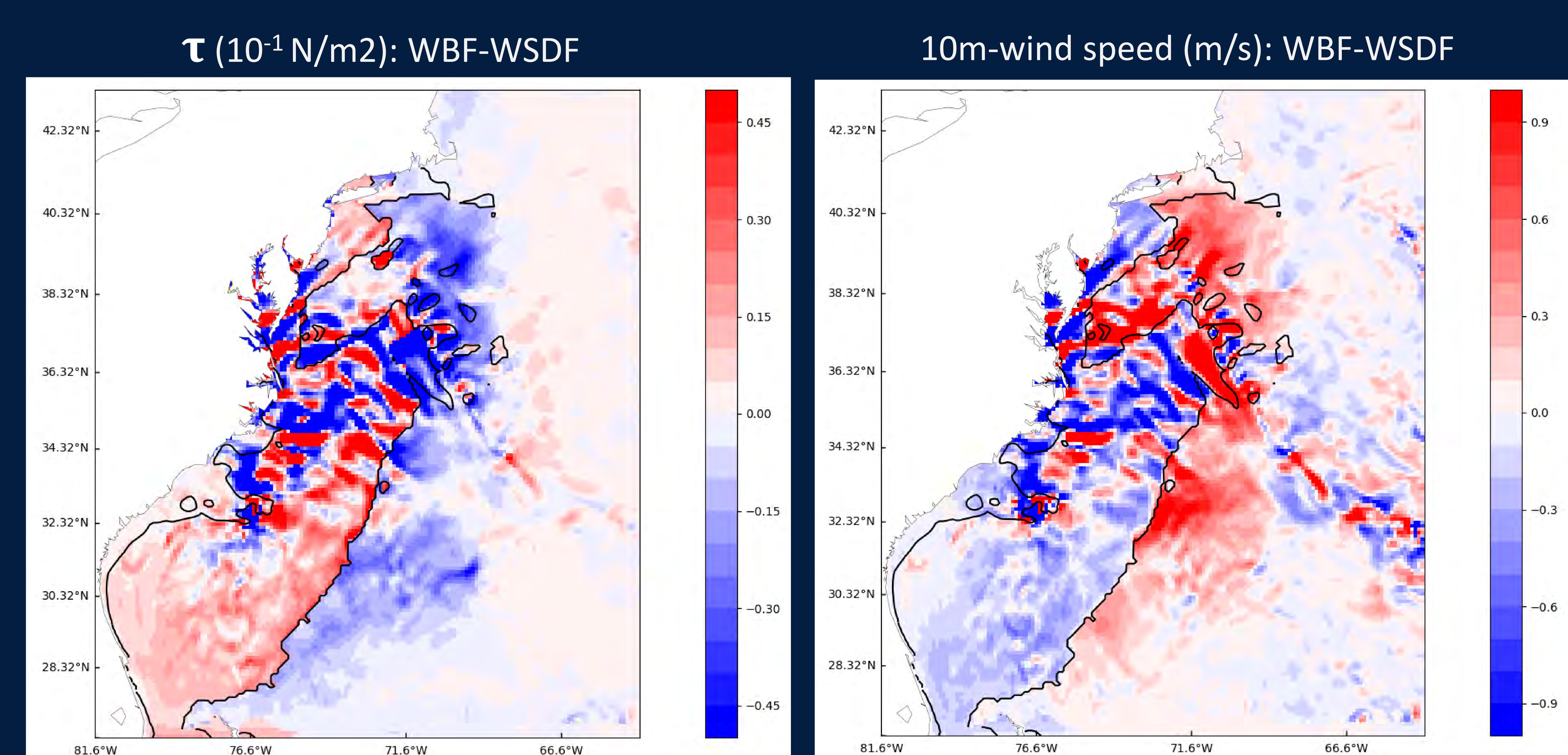
Under moderate to high wind conditions Z_0 is increased above young seas (wave age < 1.2) whereas it is decreased above old seas (wave age > 1.2).

Under low wind conditions pure swell generally occurs, with large wave age >3, which is well captured by the assumptions in WSDF.

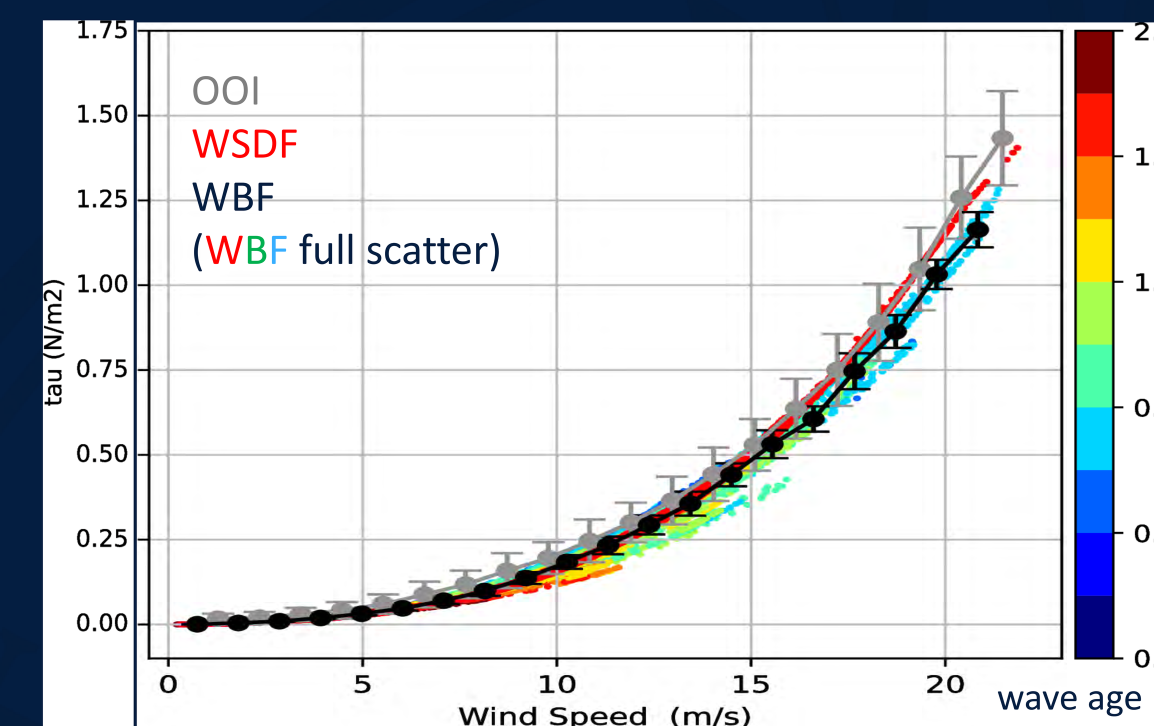


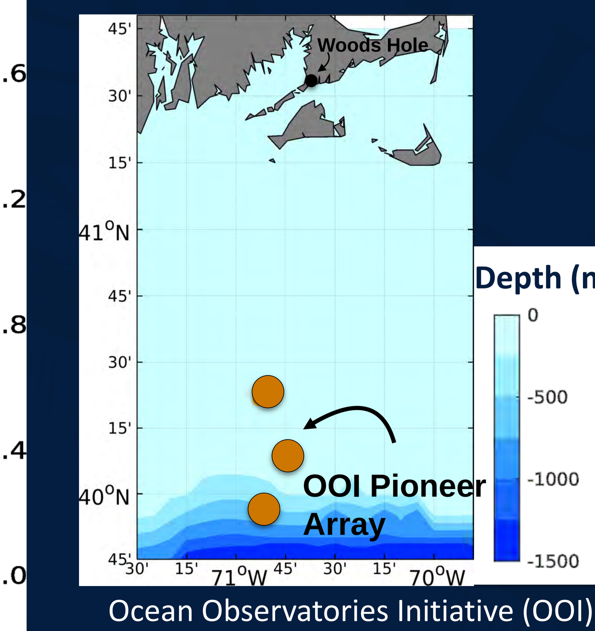


The differences found in Z_0 directly impact the C_D and τ (10-15%), resulting in an instant increase/decrease of the near-surface wind speed (5%) above the constant flux layer.



MODEL vs OBSERVATIONS





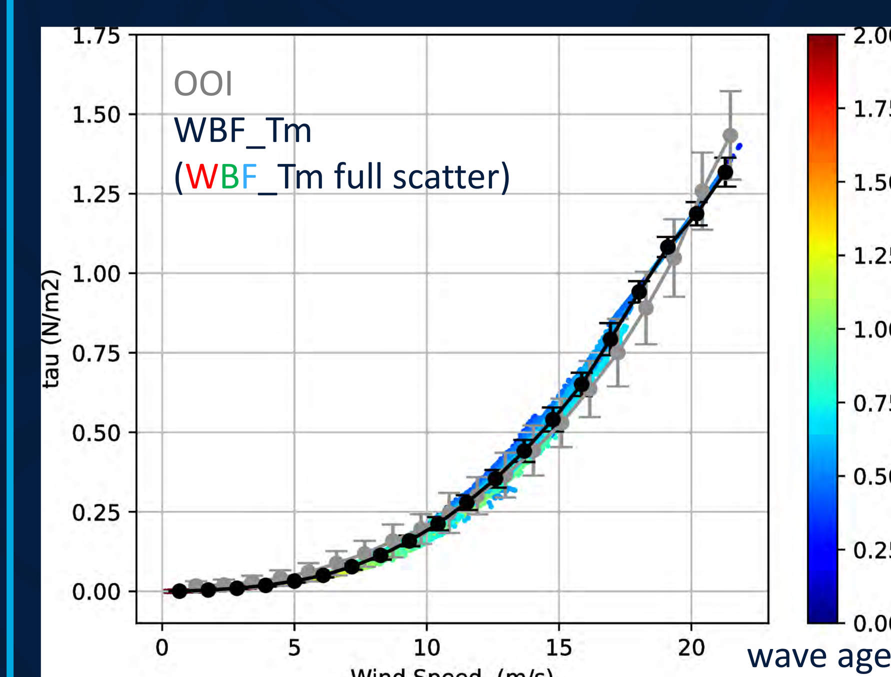
Ocean Observatories Initiative (OOI)

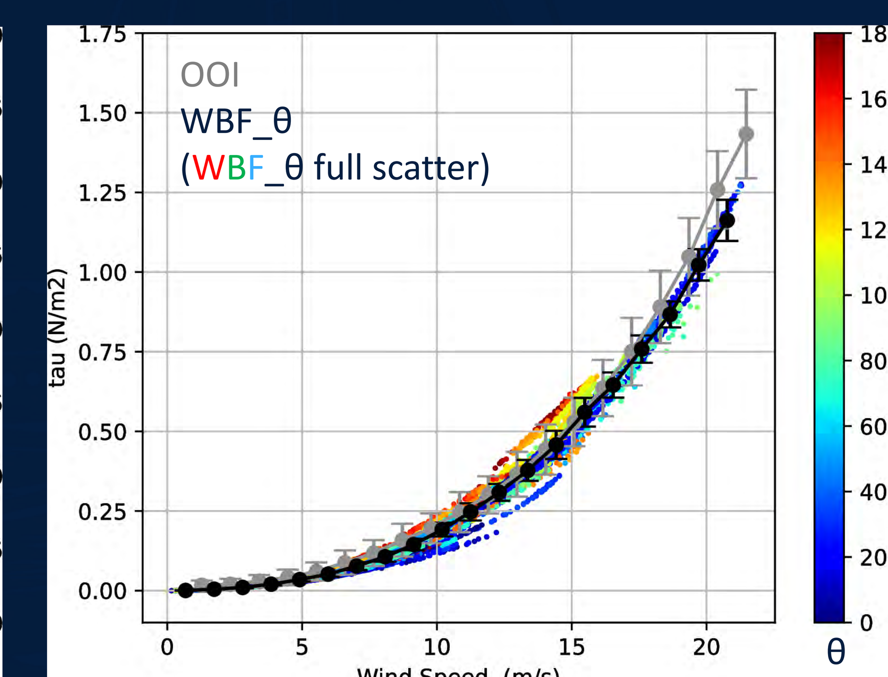
Model validation against direct eddy covariance flux measurements at the OOI mooring during December 2018 and January 2019.

- WBF alleviates the low stress bias over short wind-waves.
- WBF over-emphasizes the old seas and swell impacts on Z_0 and τ under moderate to high wind.

Modification of the calculation of Z_0 depending on the wave's mean phase speed (Cm) or on the angle between wind and waves (θ) allows to alleviates the low stress bias induced by old seas.

$$z_{rough} = H_s\, 0.39 \left(\frac{u_*}{Cm}\right)^{2.6} \qquad z_{rough} = H_s\, 0.09 \cos(0.45\theta) \left(\frac{u_*}{Cp}\right)^{2\cos(-0.32\theta)}$$





SUMMARY

1. WBF alleviates the low stress bias over young seas but substantially underestimates the stress in high winds and high wave age.
2. Tp does not accurately describe a mixed-sea state where swell and wind-sea co-exist and tends to overestimate the impact of decaying seas under moderate to high winds. Two ways to mitigate this:
   - introducing directional alignments of wind and waves
   - using wave mean period instead of spectral peak wave period to compute the wave age.
3. Further refinements of the coefficients used here need to be considered to generalized these parametrizations.