# On the misaligned wind waves behind the atmospheric cold fronts


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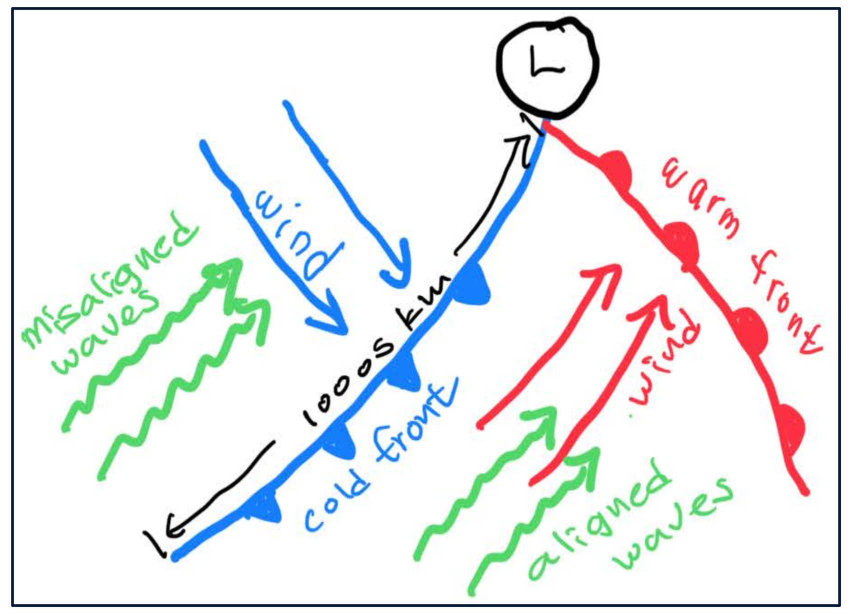
## ① Summary


**Background**: Atmospheric cold fronts have along-frontal scales of many 1000s km, but much shorter cross-frontal scales of 10-100s km. At the sea surface, the high winds near the fronts generate strongly coupled short wind-waves, while the abrupt shift in wind direction across the front, combined with the rapid translation of the frontal system, produces a large area of misaligned surface waves behind the cold fronts.

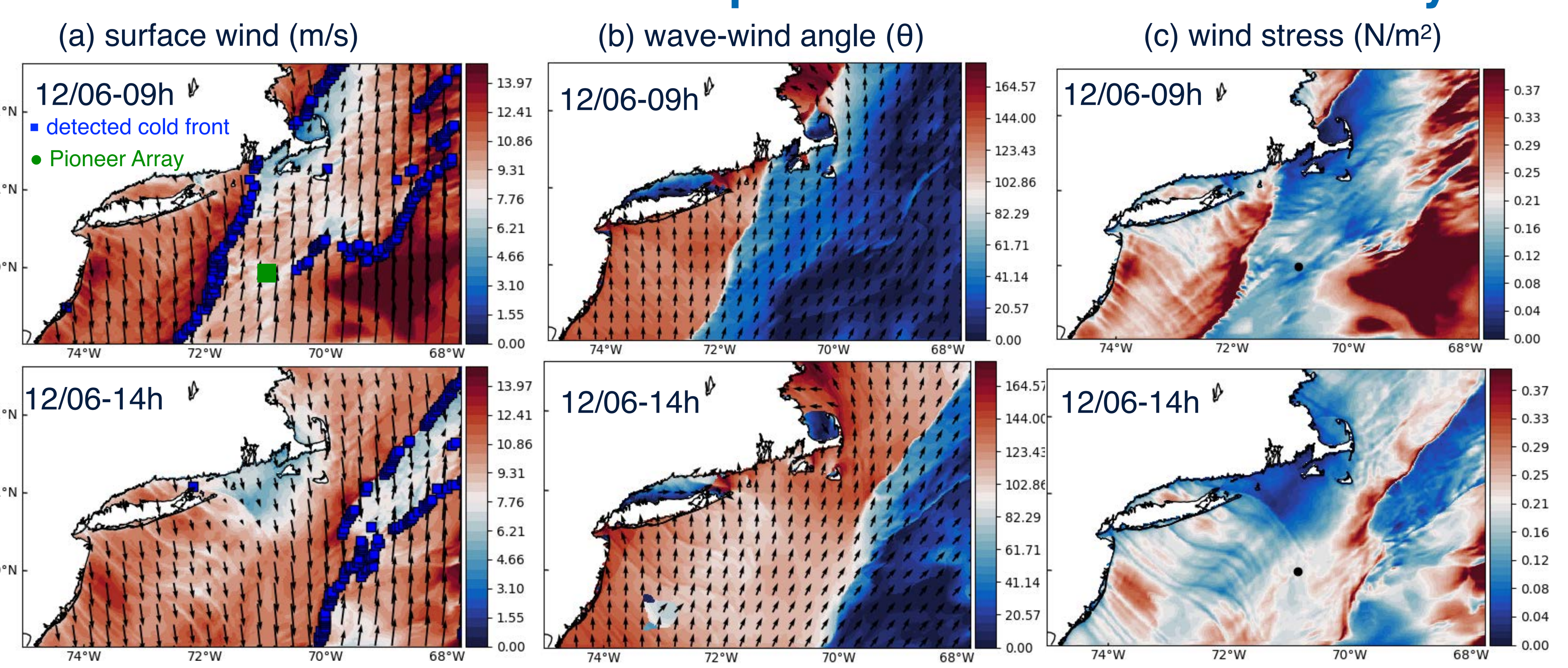
**Objectives**: To characterize the sea state associated with the misaligned waves and evaluate their impacts on surface drag, air-sea momentum fluxes, and wind profiles.



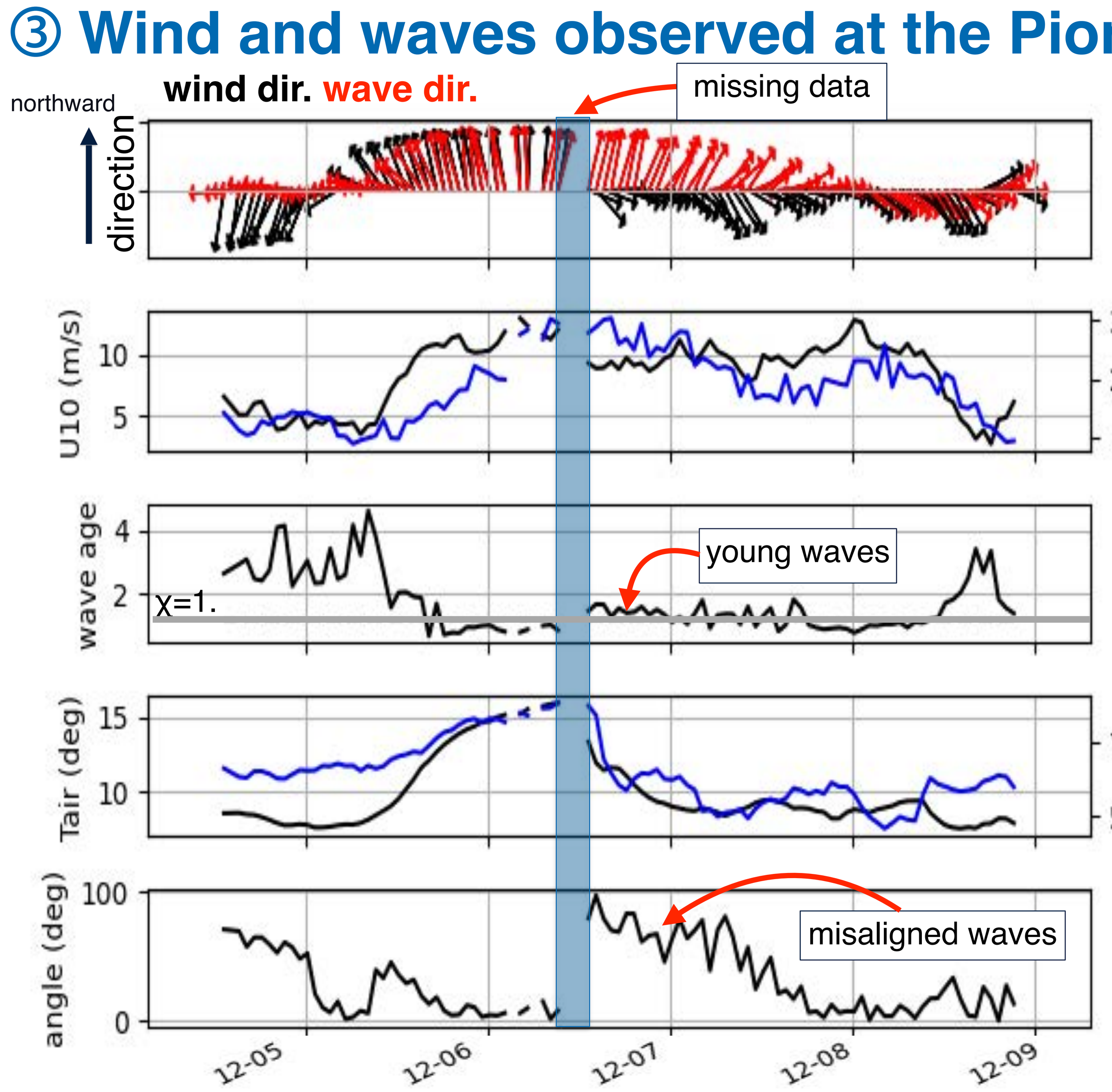
**Results:** Misaligned waves increase the surface drag and wind stress, reducing wind speed in the MABL. Despite the transient nature of the phenomena (hours to days), because the cold fronts are ubiquitous and have large along-frontal length scales, the area impacted by the misaligned wind waves can be significant. The misaligned waves are continuously generated/disappear as the fronts translate eastward.


## ② Wind and waves under atmospheric cold fronts: Case study




(a) v10 (vectors, m/s) and wind speed (shading); (c) angle (θ,°) between wind and wave direction (shading), overlaid with peak wave direction (vectors); (d) parameterized wind stress (N/m²) using the default COARE3.5 wave-based formulation. Blue squares indicate the detected cold front following Parfitt et al. (2017).

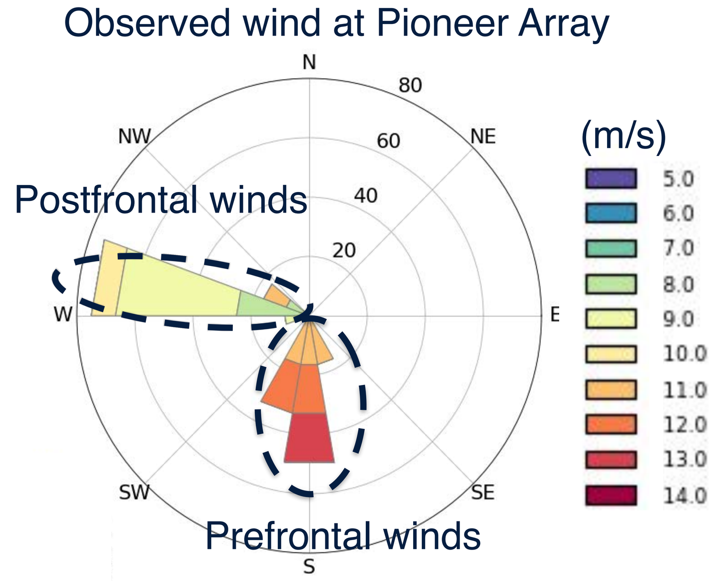
## ③ Wind and waves observed at the Pioneer Array




Measurements indicate a passage of a cold front around Dec 6, with abrupt shifts in wind direction, a rapid drop in Tair, and an increase in Hs.

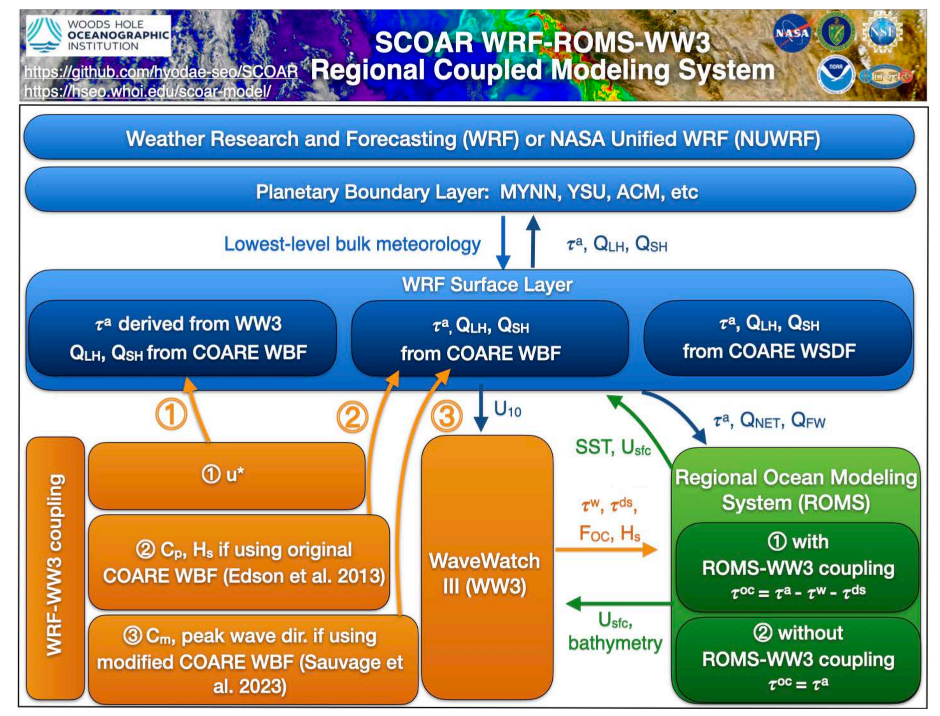
The strongly misaligned young waves lasted, in this case, for ~24 hours after the passage of the cold front.

Observed wind at Pioneer Array



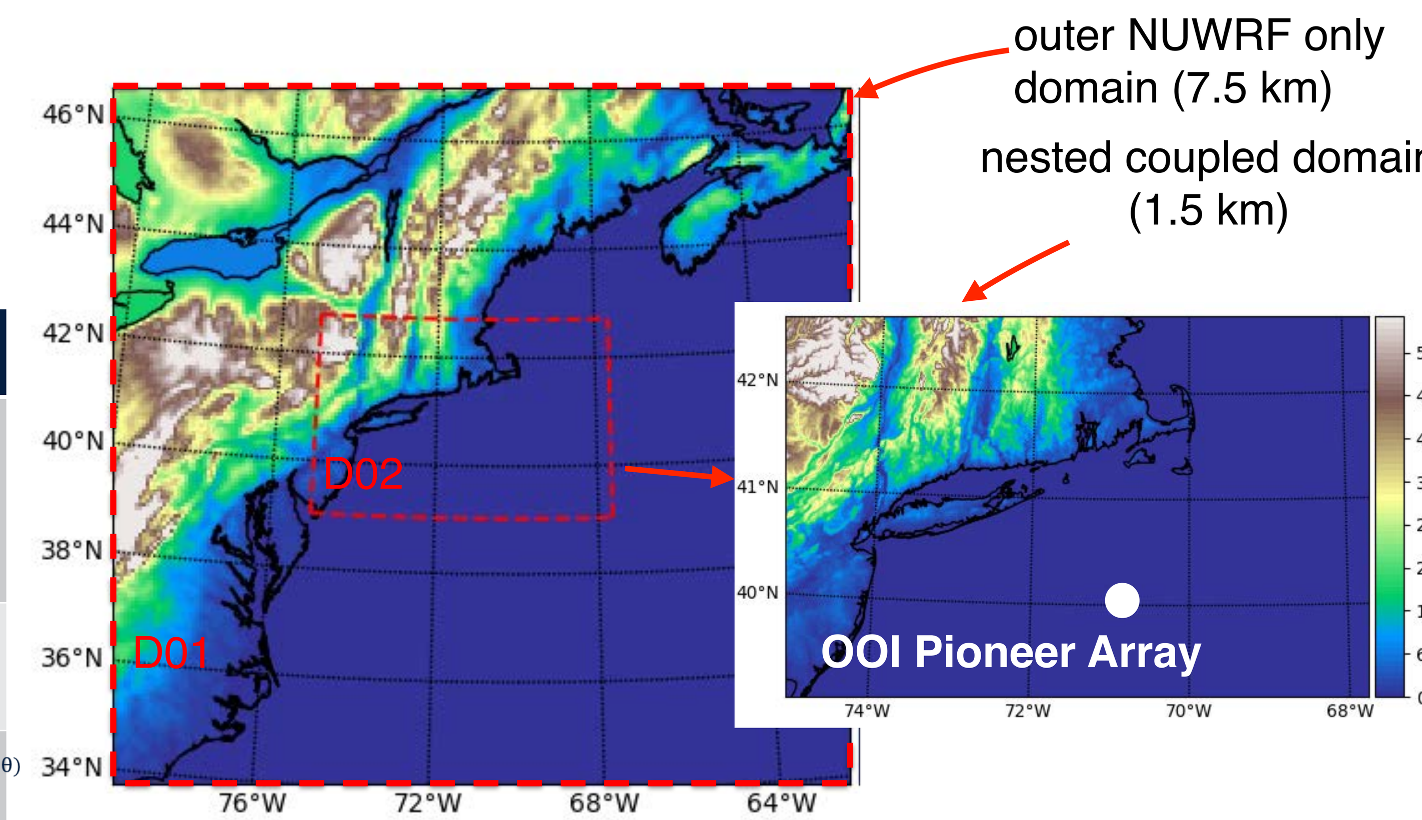

## ④ Coupled model and experiments

Seo et al. 2007; 2014; Sauvage et al. 2023 ;
https://hseo.whoi.edu/scoar-model/

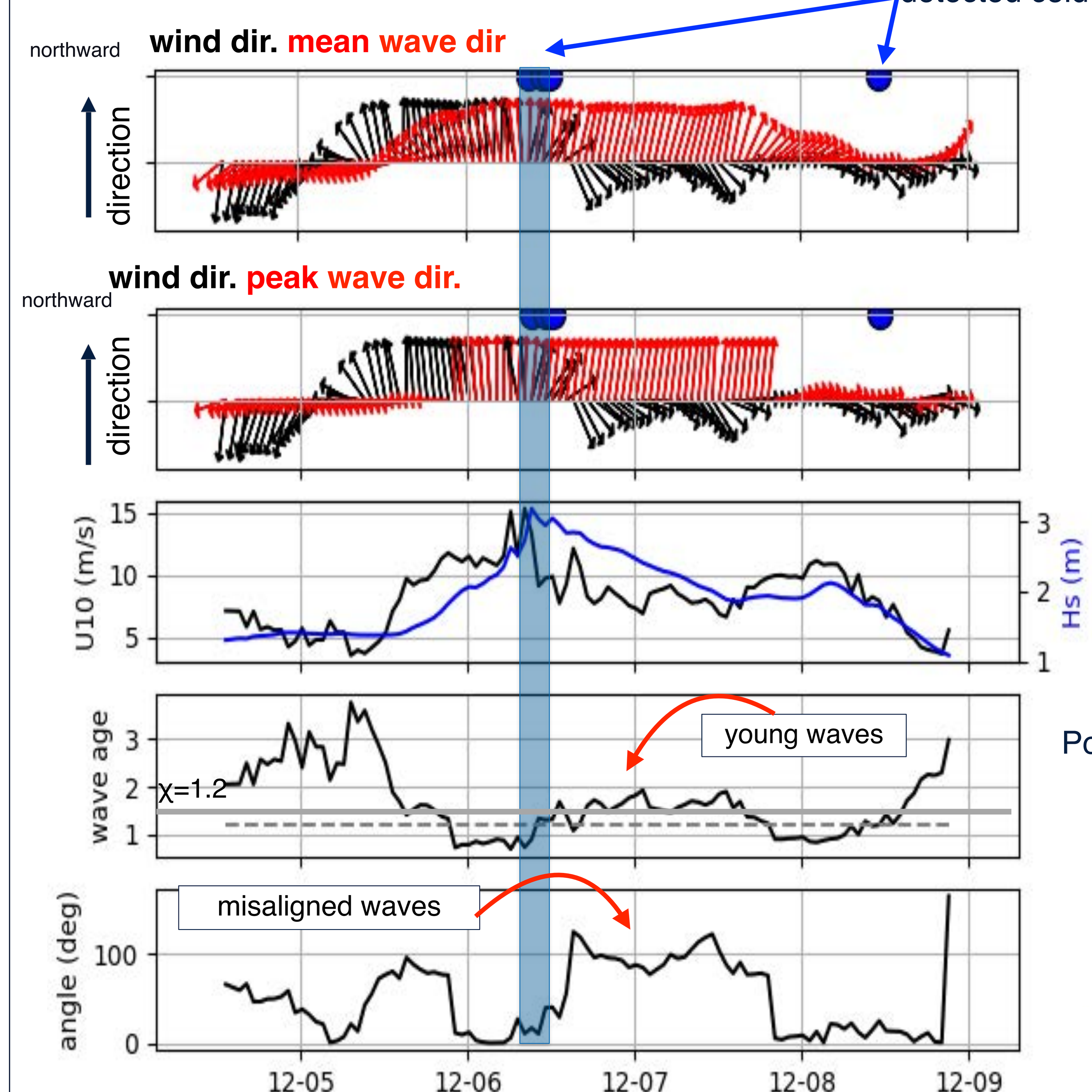



Case study simulations using the NUWRF-ROMS-WW3 coupled model with different z0 formulations

| Exps | WBF | WBFθ |
|---|---|---|
| COARE3.5 | Default COARE3.5 wave-based formulation (θ=0) | Modified COARE3.5 wave-based formulation (θ≠0) |
| Reference | Edson et al. (2013) | Sauvage et al. (2023) |
| formulation $z_{rough} =$ | $H_s \cdot 0.09 \cdot \left(\frac{u_*}{C_p}\right)^2$ | $H_s \cdot 0.09\cos(0.4\theta) \cdot \left(\frac{u_*}{C_p}\right)^{2\cos(0.32\theta)}$ |



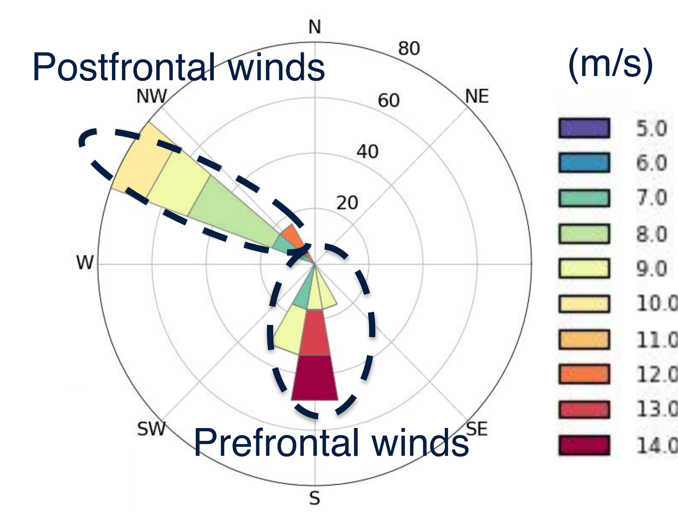

## ⑤ Simulated wind and wave conditions



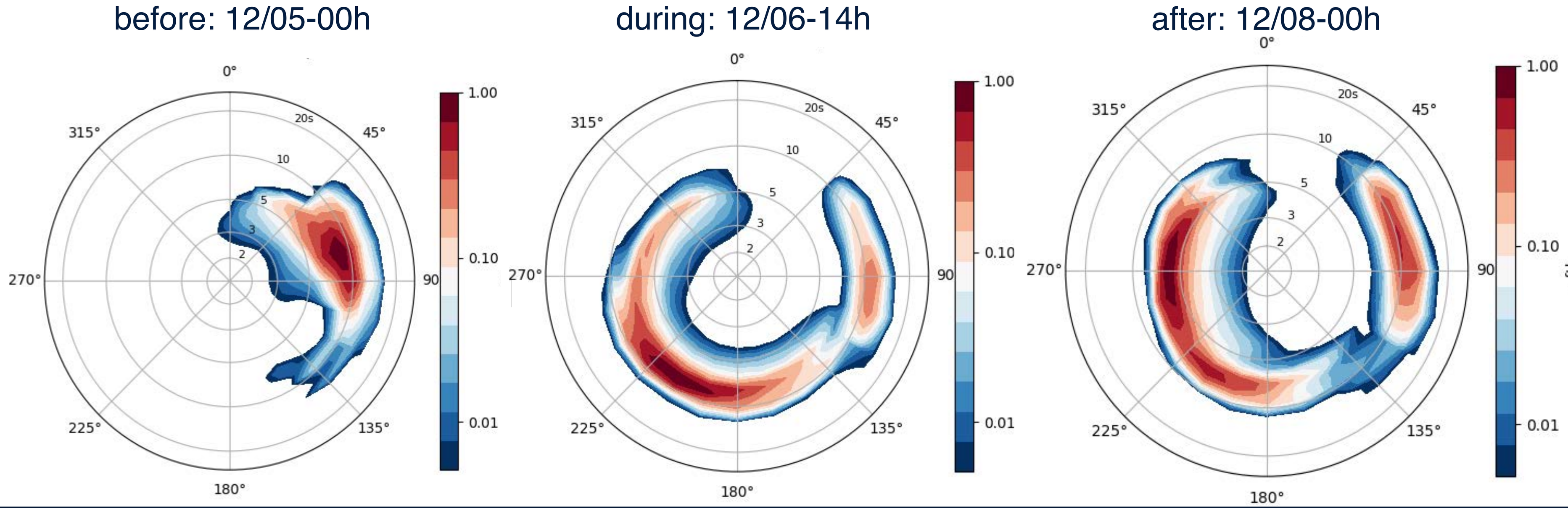

The misaligned young waves after the front are also well captured.

The peak (mean) wave direction produces more abrupt (gradual) shifts in the wave direction. The mean wave direction agrees better with the Pioneer array data (though it uses peak wave direction).

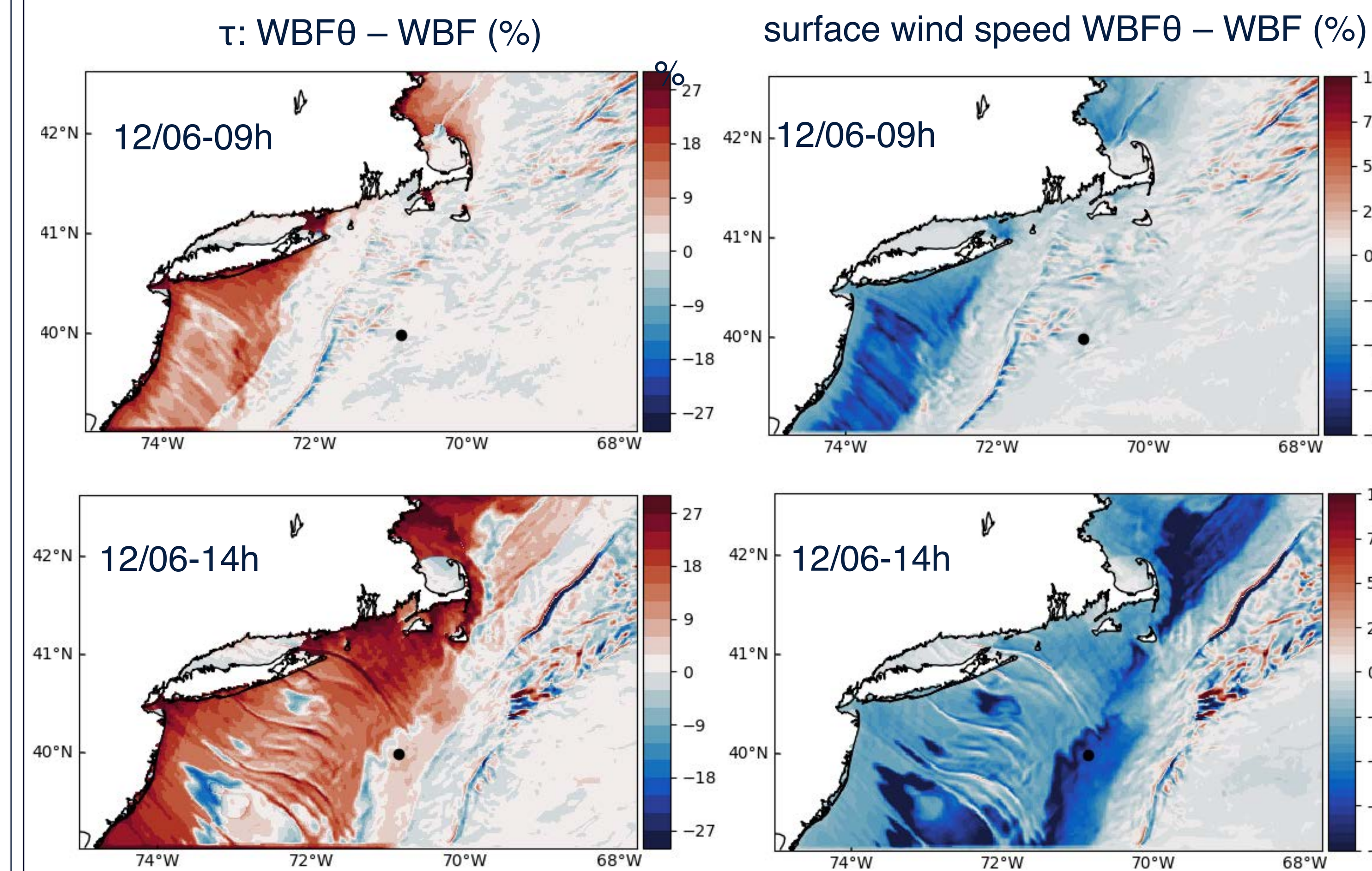
Simulated wind sampled at Pioneer Array




**Normalized wave spectrum energy density (m².s.deg⁻¹) on period space**

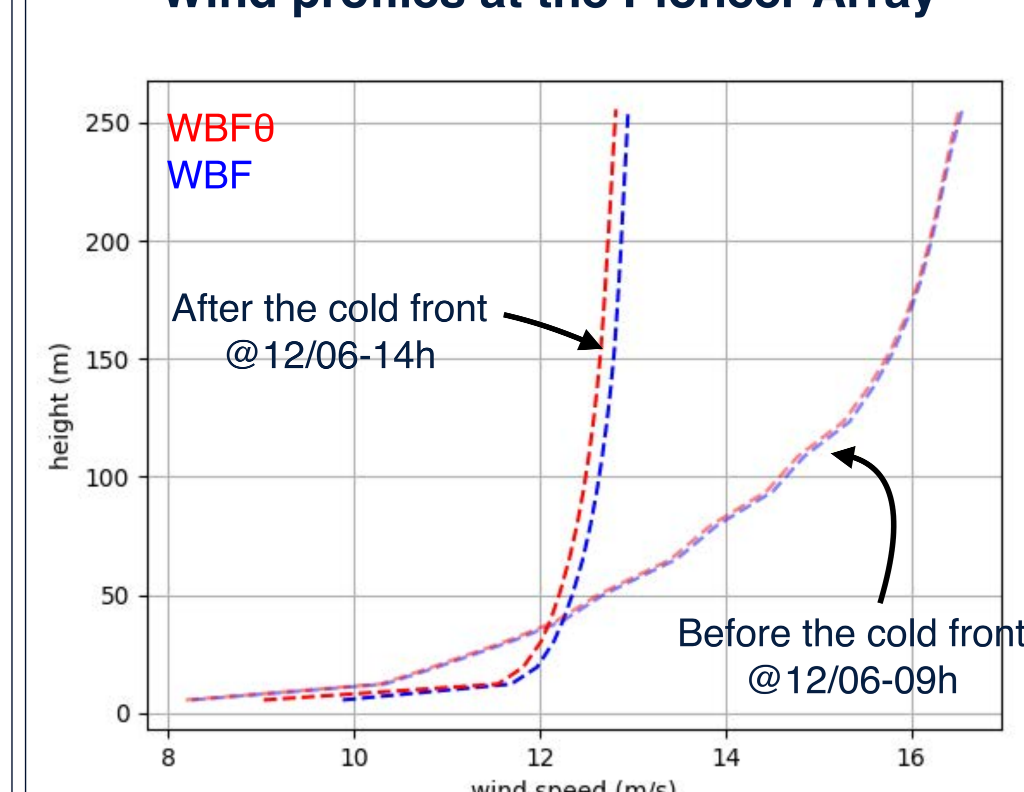



## ⑥ Effects on air-sea fluxes and MABL winds




Including the misaligned wave effect in the bulk formula increases the stress by up to 30%, and decreases wind speeds by up to 10% over a large area behind the cold front.

**Wind profiles at the Pioneer Array**




Before the passage of the cold front, the wind profiles were identical between the two runs.

As the cold front passed, the increased stress due to misaligned waves in WBFθ produced distinctly weaker wind.

The strongest differences are found at the surface, but the systematic (although it's small) wind speed reduction in WBFθ is found throughout the MABL.