



Wave–Wind Misalignment and Drag Coefficient Rolloff in Tropical Cyclones

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1: UH Manoa, 2: NCAR, 3: WHOI, 4:OIST



1. Summary

We investigate wave-mediated air–sea exchange processes in a TC using the SCOAR fully coupled model simulations with modified COARE bulk flux parameterizations. Targeting Typhoon Khanun (2023), three different C_D rolloff formulations are considered evaluated against best-track intensity and drifting Spotter buoy wave observations.

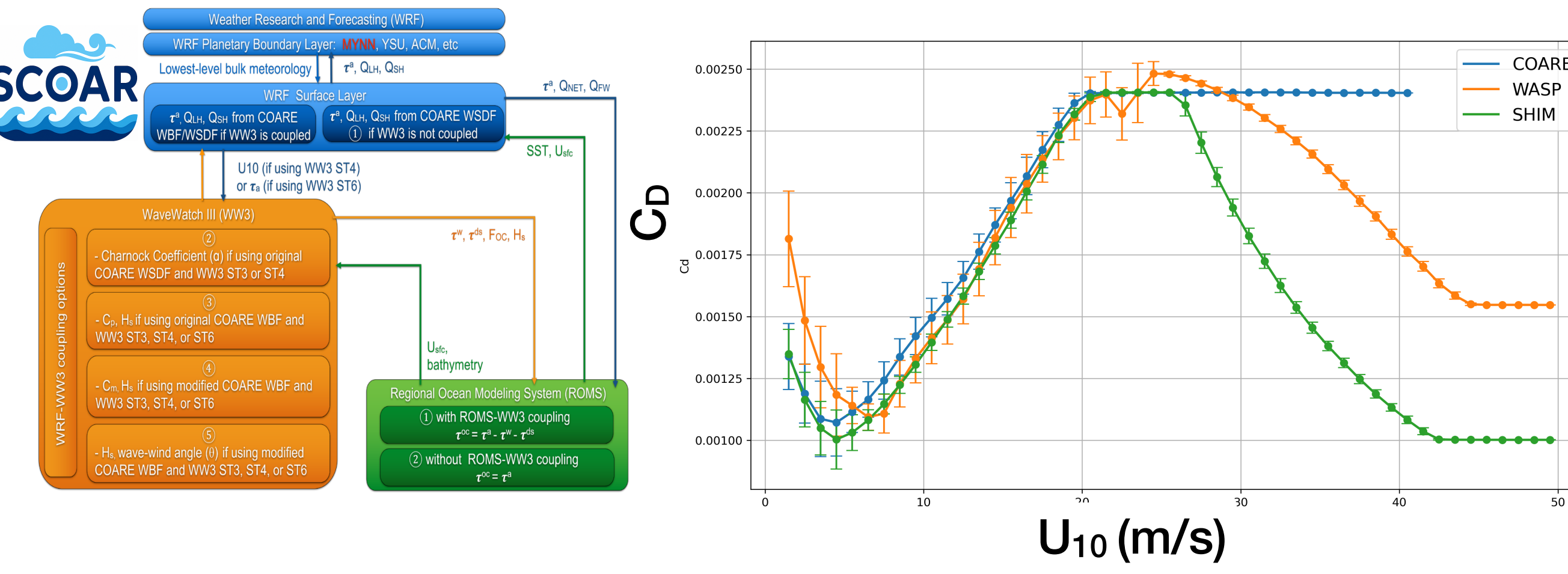
The analysis focuses on two mechanisms:
(1) drag rolloff associated with MSS saturation
(2) directional modulation of surface stress by wind–wave misalignment.

The main results are

- Among the parameterizations tested, the observationally constrained formulation of Shimura et al. (2024) produces the best agreement with observed storm intensity and wave characteristics, with pronounced quadrant-dependent reductions in C_D and MSS.
- The simulations capture an observed secondary relationship between wind–wave misalignment and MSS for wind speeds of 20–45 m/s, suggesting that cross-swell conditions reduce the efficiency of air–sea momentum transfer under extreme winds.
- Three competing TC feedbacks are identified:
 - (1) reduced C_D accelerates near-surface winds, favoring storm intensification;
 - (2) reduced momentum transfer weakens upper-ocean cooling by suppressing turbulent mixing and TKE production, further supporting intensification; and
 - (3) reduced enthalpy exchange coefficient (C_K) decreases together with C_D , reducing upward enthalpy fluxes despite stronger winds, favoring a weaker storm.→ Overall, (1) & (2) dominate, yielding stronger storms characterized by higher maximum wind speeds and lower minimum sea-level pressure.

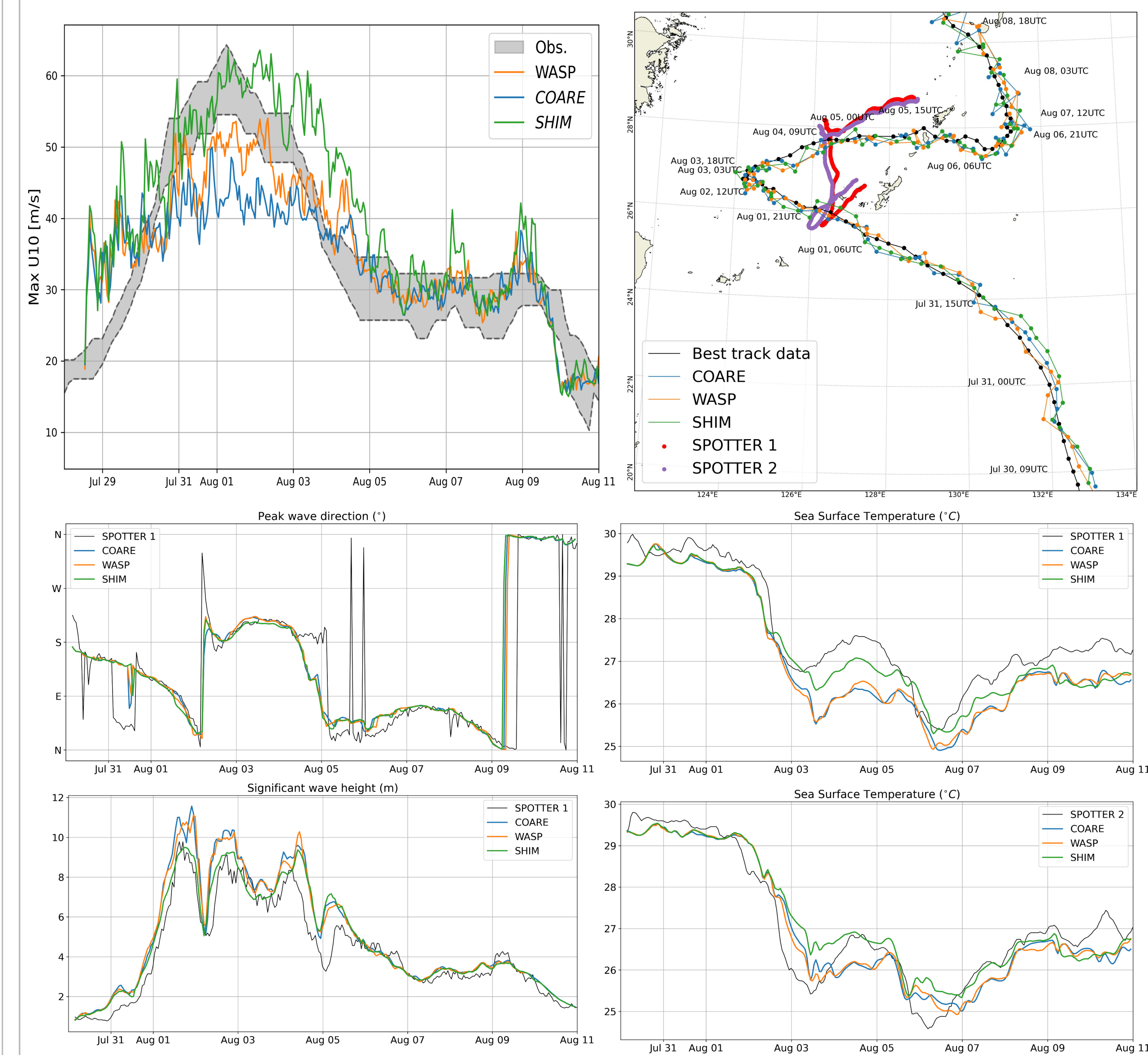
2. Model and Experiments

2.5km WRF-ROMS-WW3 simulations for Typhoon Khanun (2023) with 3 different drag coefficient rolloff cases

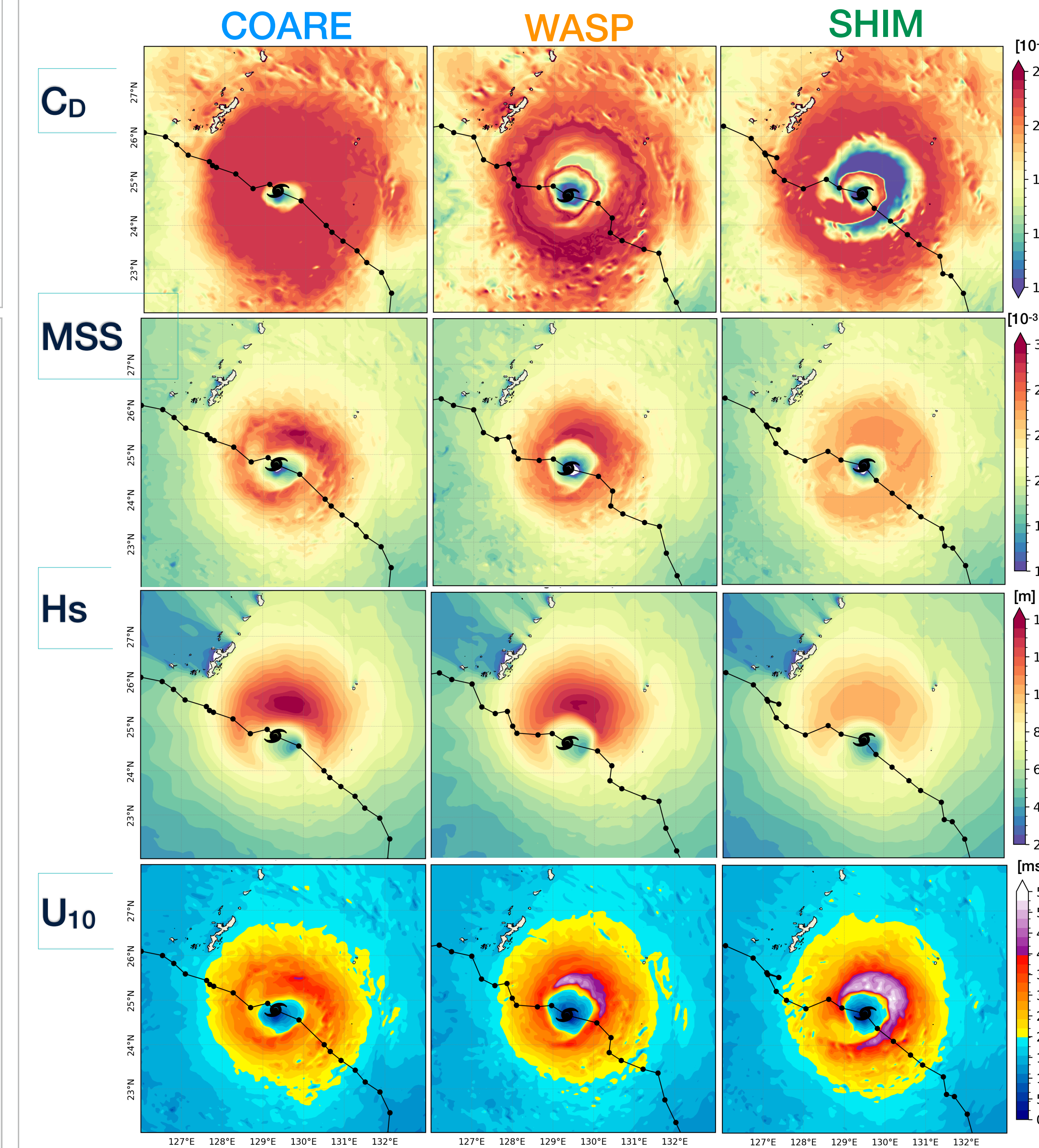


- COARE3.5** (Edson et al. 2013; Sauvage et al. 2023):
 $z_{rough} = H_s D (u_* / c_m)^B$ until cap ($C_D \sim 2.4 \cdot 10^{-3}$)
- WASP** (Bouin et al. 2024): $\alpha = A \chi^B$ until ~20 m/s, then decreases following observations
- SHIM** (Shimura et al. 2024): COARE3.6 up to ~20 m/s; and cap $u^* \sim 1.75$ m/s for $U_{10} > 25$ m/s

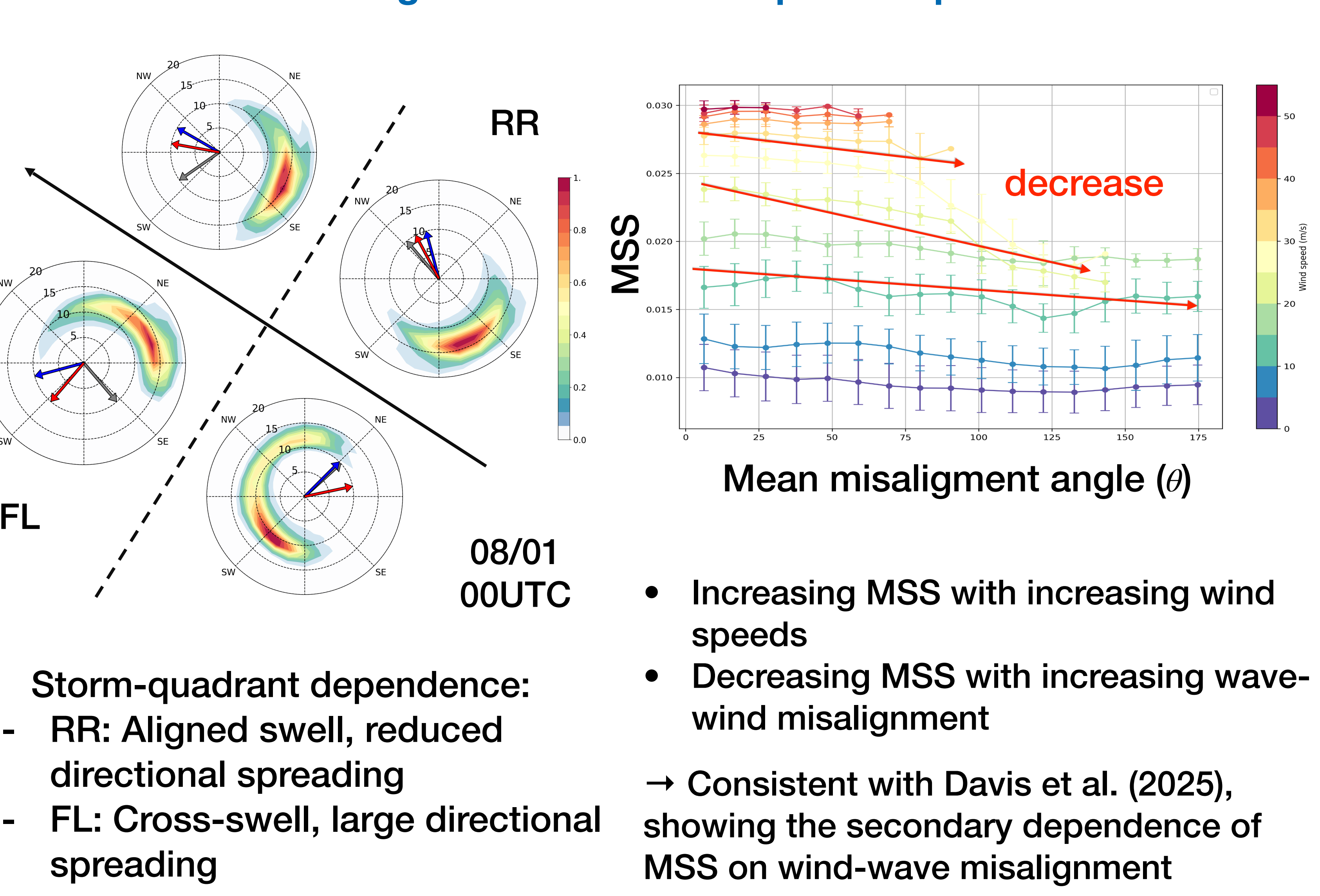
3. Typhoon Khanun (2023): Validation & Sensitivity



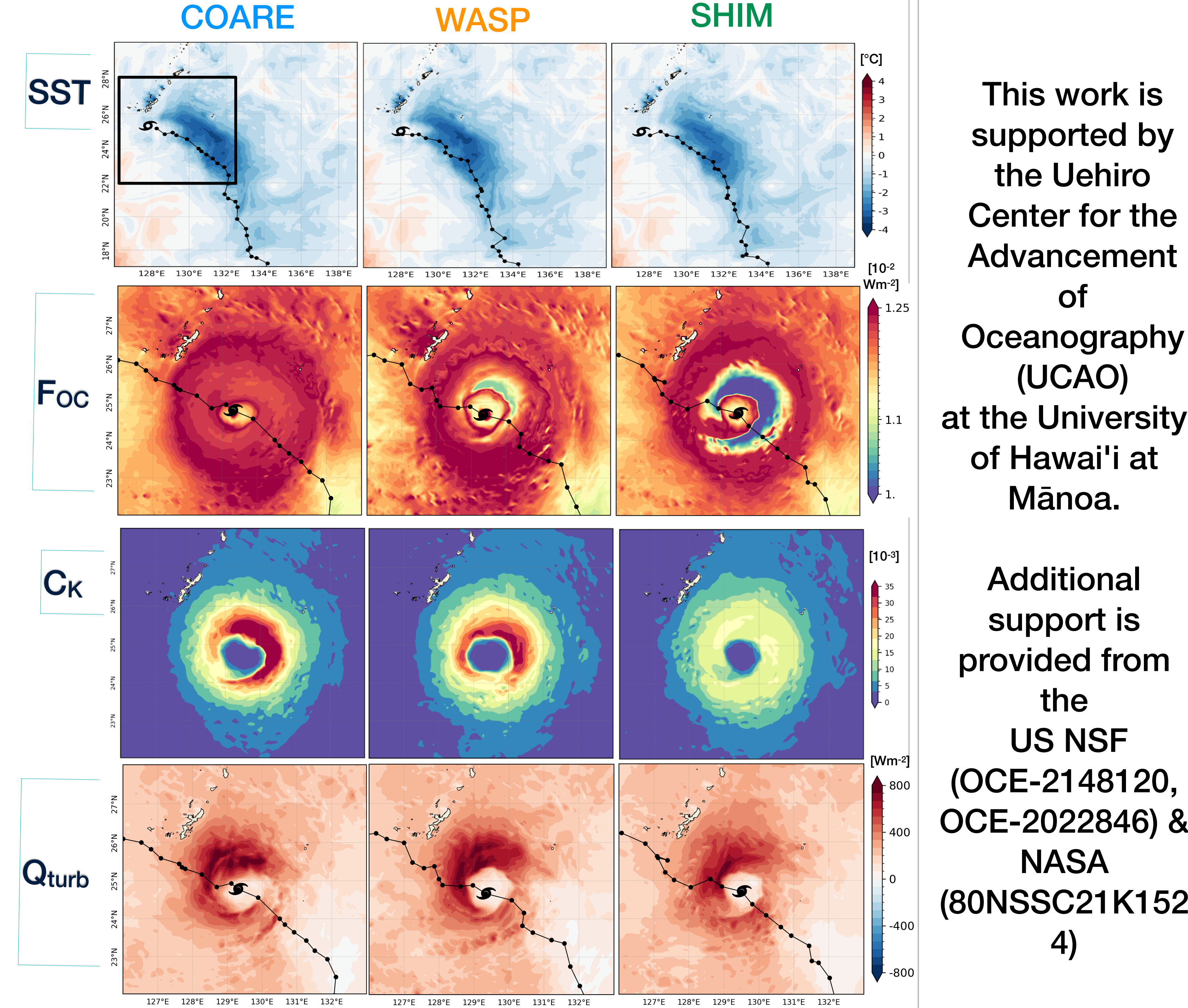
5. Drag coefficient, MSS, and wind speeds



4. Wave-wind misalignment and mean-square slope



6. SST and heat flux



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