37th Conference on Hurricanes and Tropical Meteorology

Wave–Wind Misalignment and Drag Coefficient Rolloff in High-Wind Tropical Cyclones

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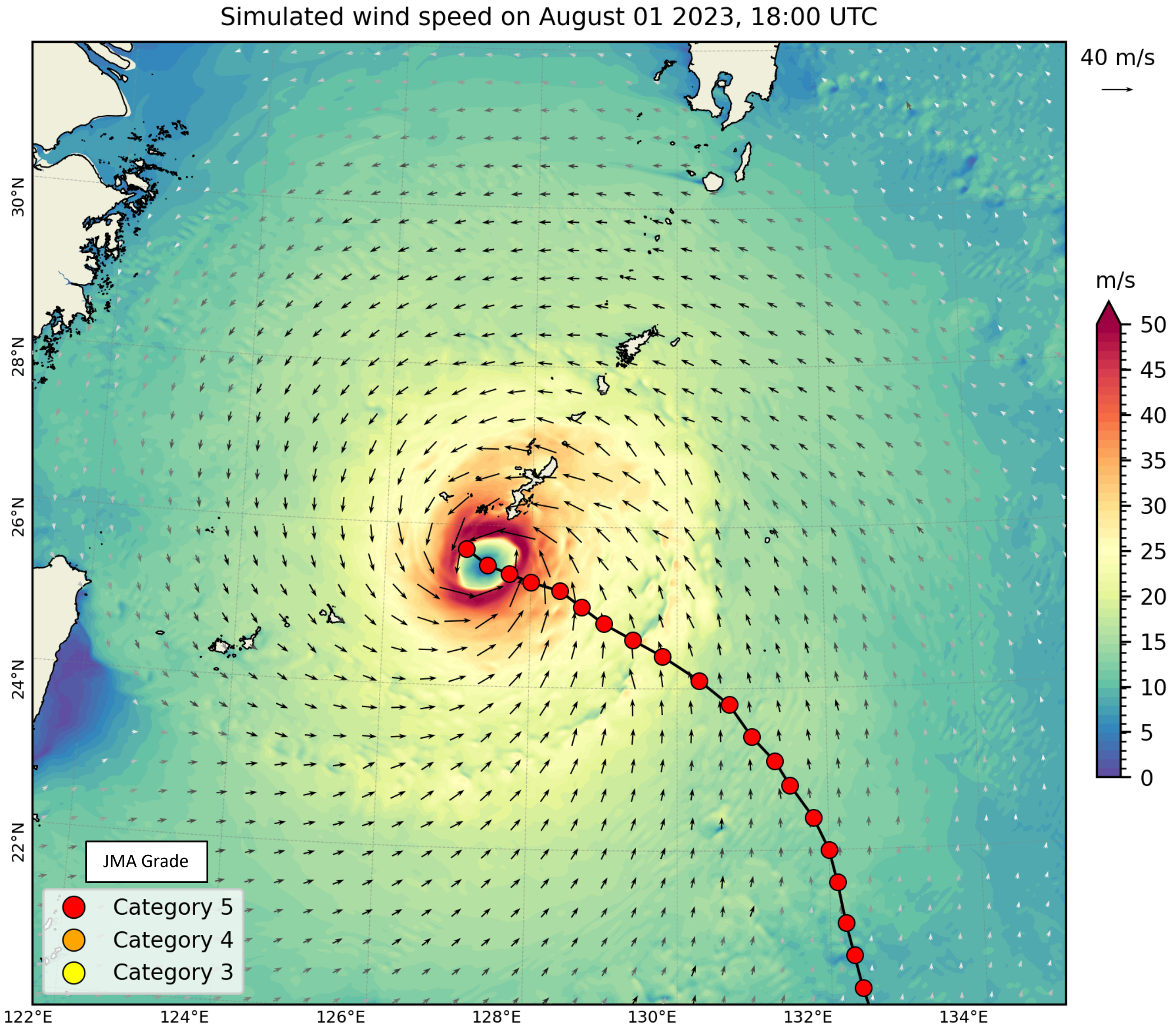
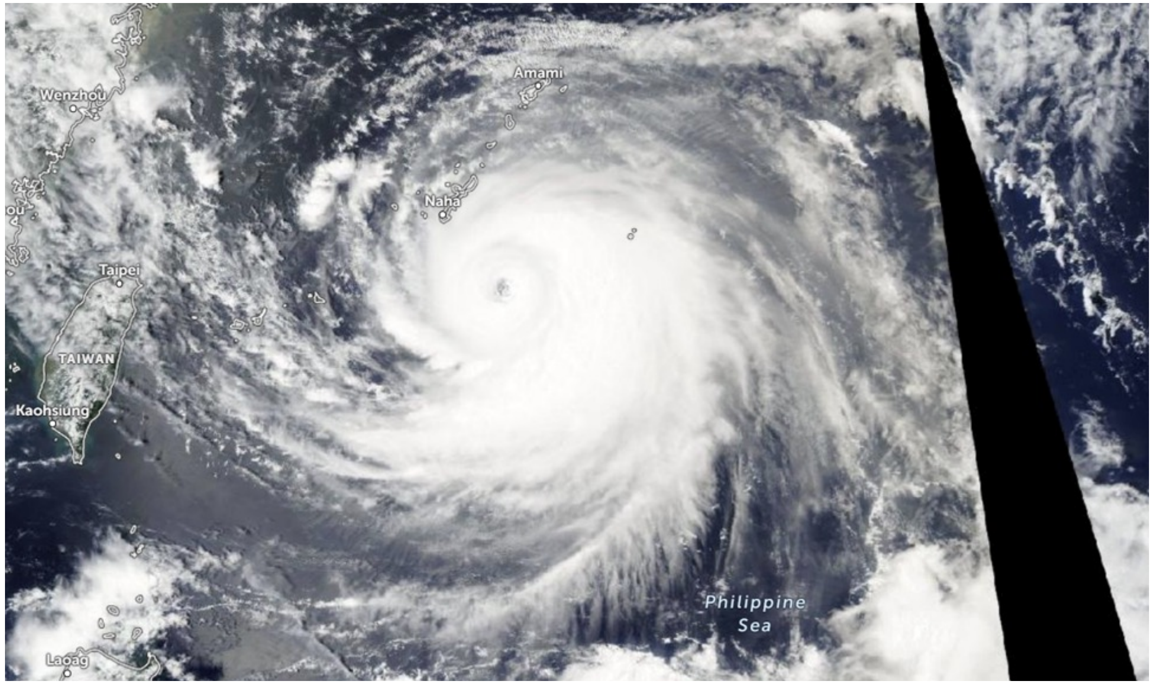
Coupled Modeling of Typhoon Khanun 2023



Typhoon Khanun on August 1st 2023



WRF nested configuration: OUTER domain at 7.5 km

WRF-ROMS-WW3 COUPLED domain at 2.5 km

Simulation from July 28, 2023 to Aug 11, 2023.

Drag Coefficient formulations

Because of lack of observations there is a large uncertainty of the drag coefficient behavior at very high winds.

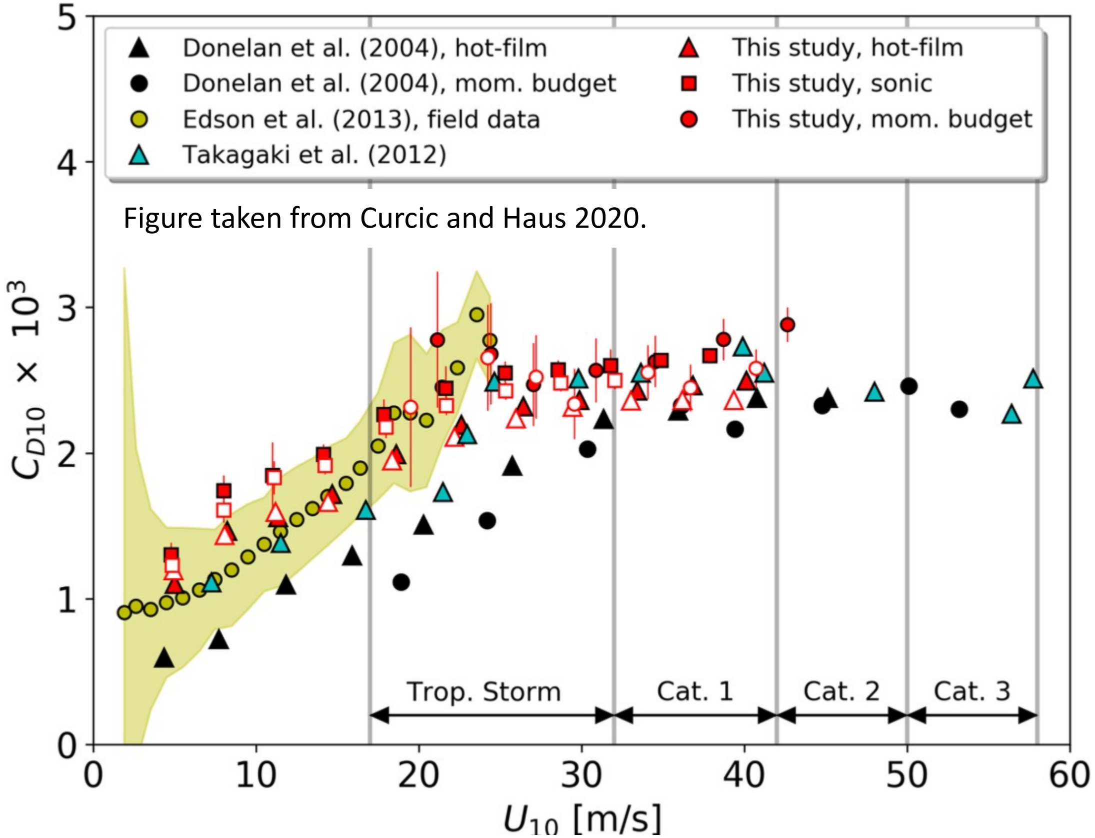
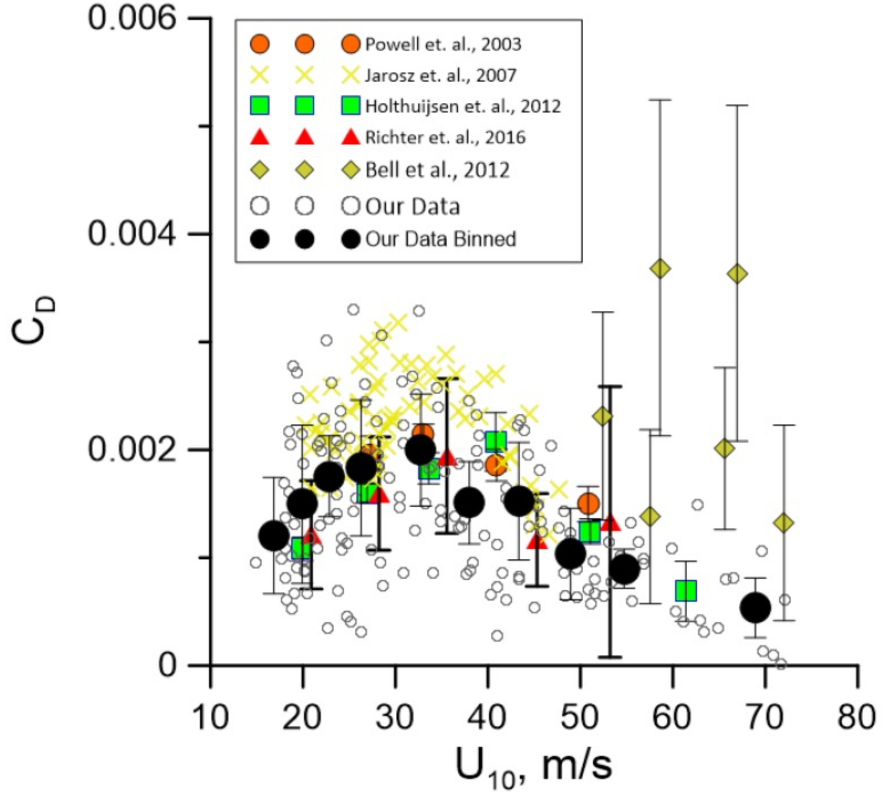


Figure taken from Ermakova et al. 2023.



However evidences have shown a saturation or even a decrease of the drag coefficient at high wind speed

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-> Multiple ways exist to represent the surface drag saturation / decrease at very high winds

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Here we explore 3 methods:

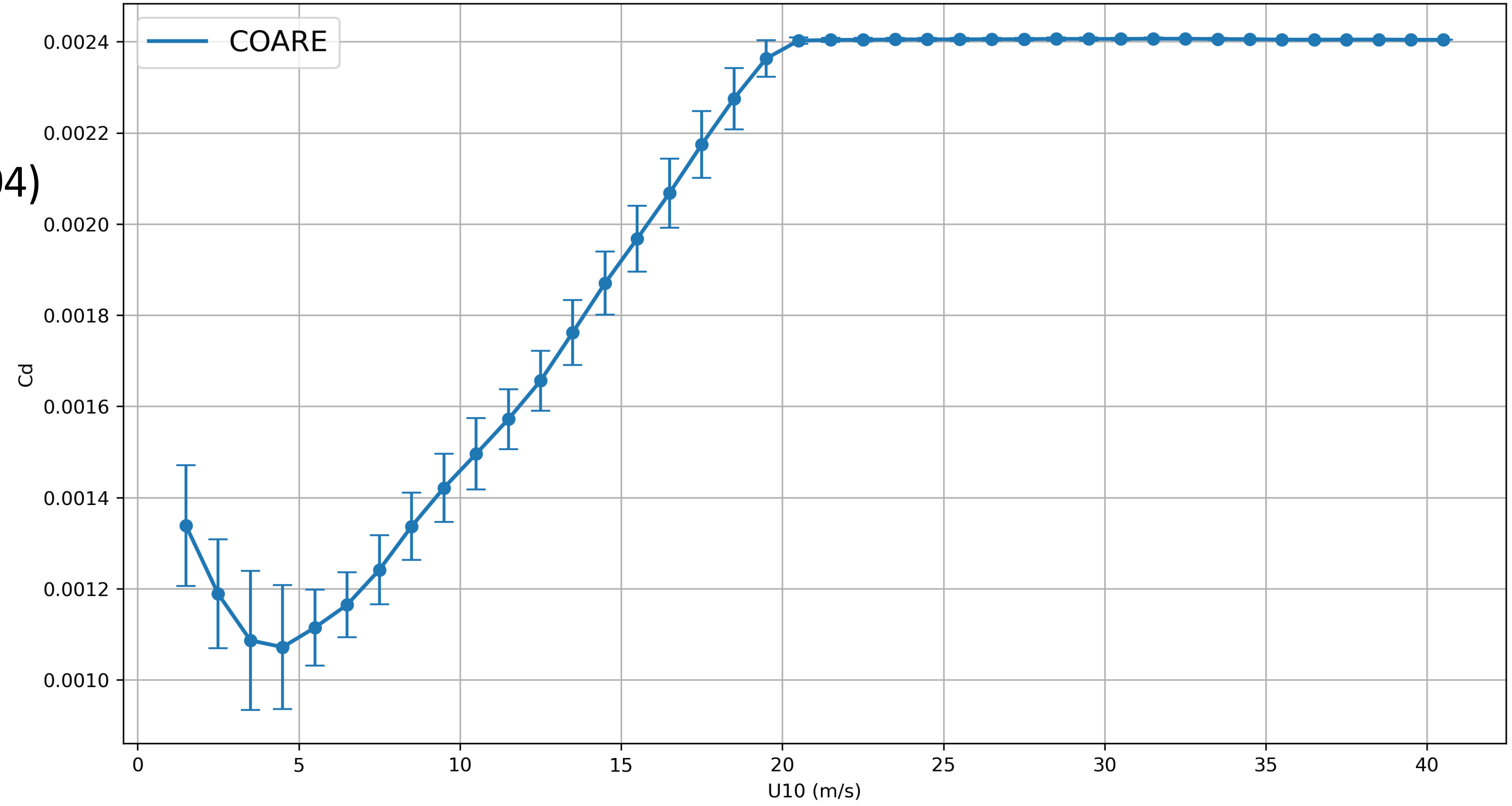
- COARE 3.6 (Edson et al. 2013)

(+ roughness cap following Donelan et al. 2004)

Wave formulation using mean wave age (Sauvage et al. 2023) until cap is reached ($CD \sim 2.4 \; 10^{-3}$)

$$z_{rough} = H_s D \left(\frac{u_*}{c_m} \right)^B, \quad B=2.6, D=0.39$$

Drag Coefficient (CD)



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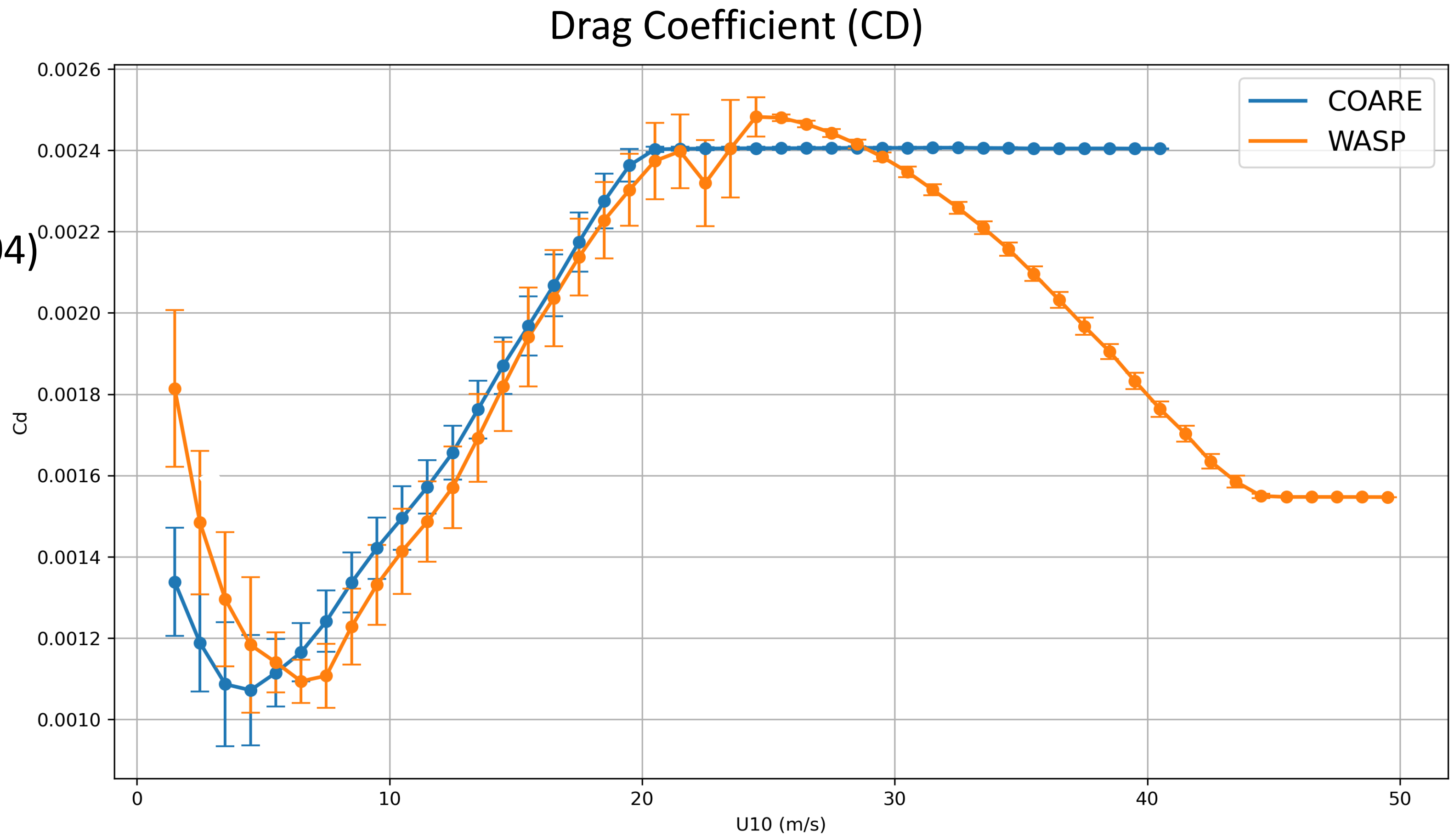
(+ roughness cap following Donelan et al. 2004)

- WASP (Bouin et al. 2024)

Wave formulation with mean wave age
It is meant to follow COARE3.6 until ~20 m/s
then decreases based on observations

Charnock -> $\alpha = A\chi^{B},$

A and B are polynomial functions of U_{10}



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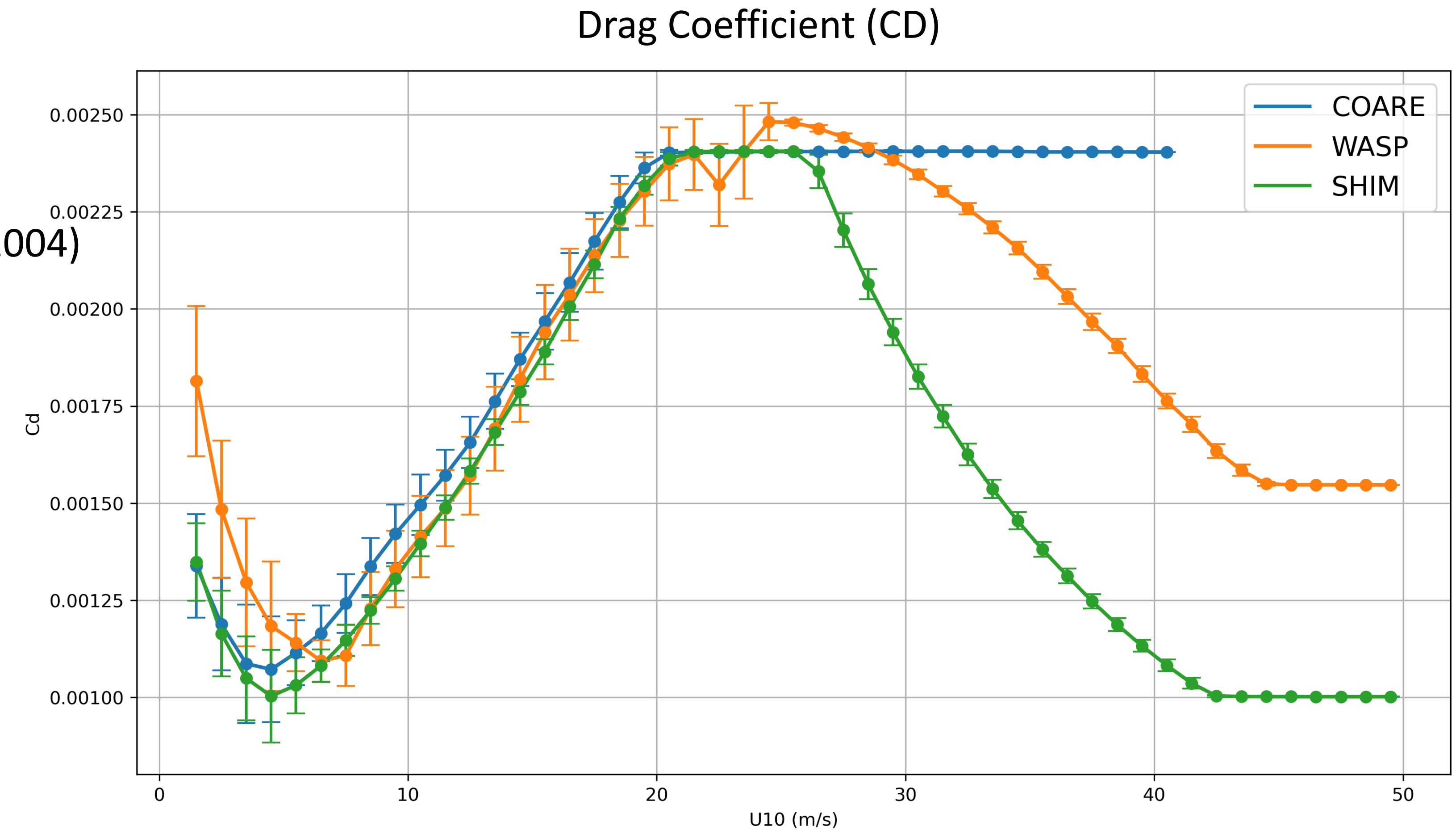
Here we explore 3 methods:

- COARE 3.6 (Edson et al. 2013)

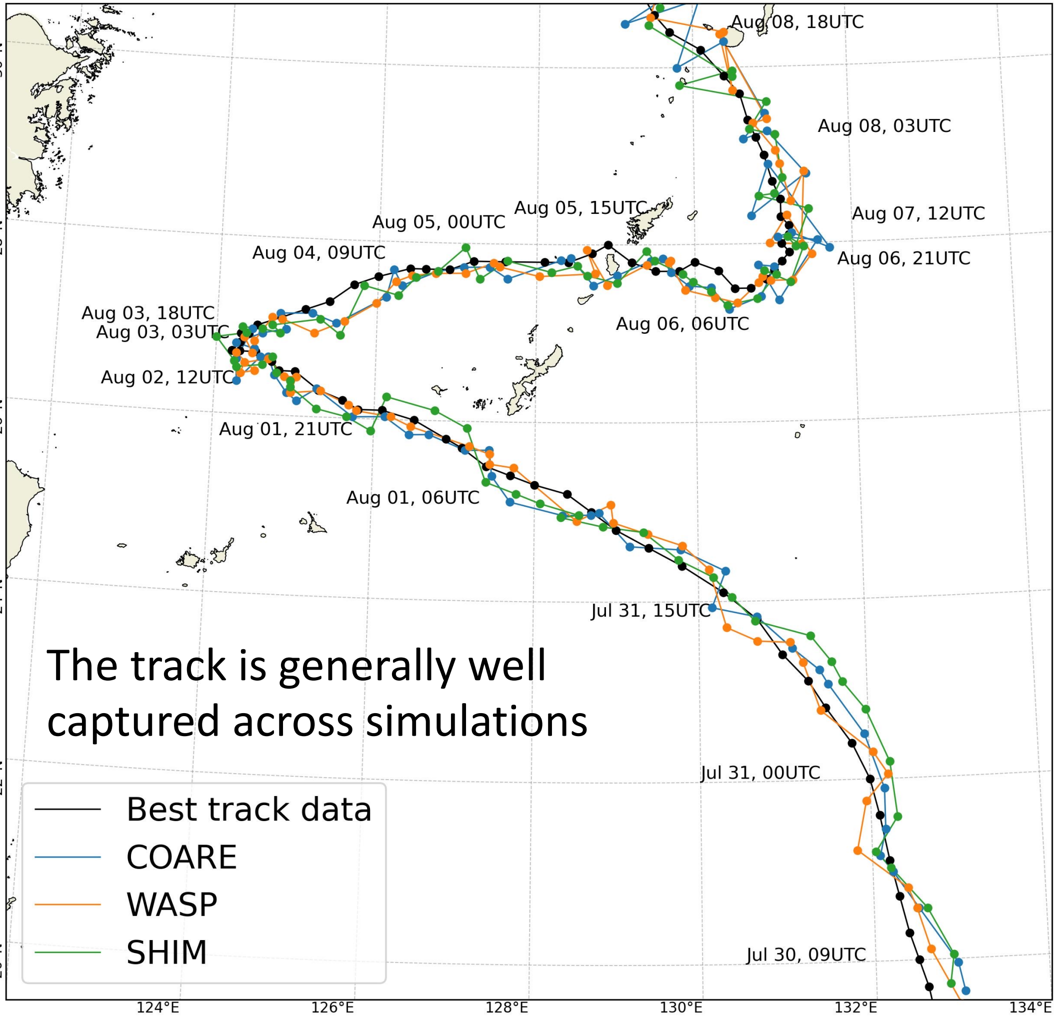
(+ roughness cap following Donelan et al. 2004)

- WASP (Bouin et al. 2024)
- SHIM (Shimura et al. 2024)

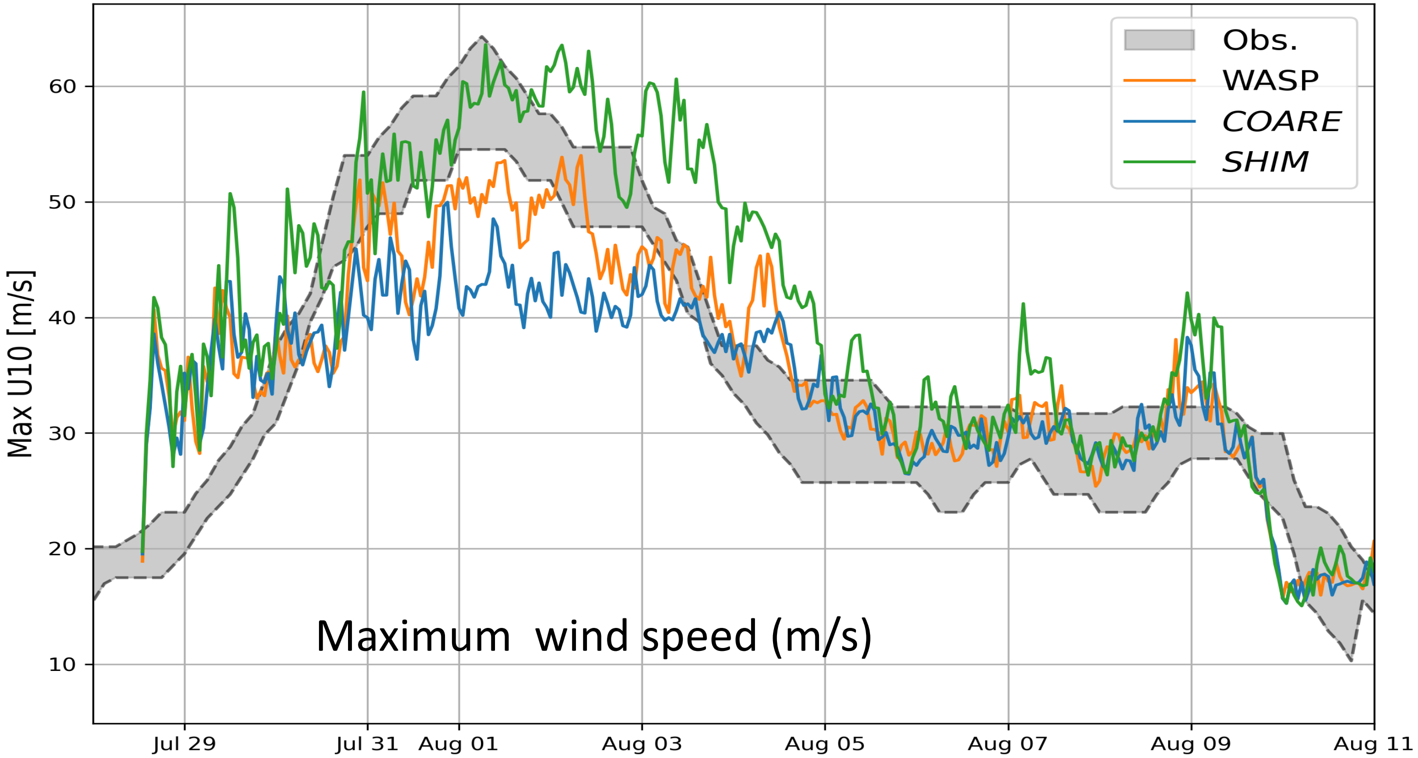
It follows COARE3.6 until ~20 m/s then cap u*~1.75 m/s for winds above 25 m/s



Comparison to observations



The track is generally well captured across simulations

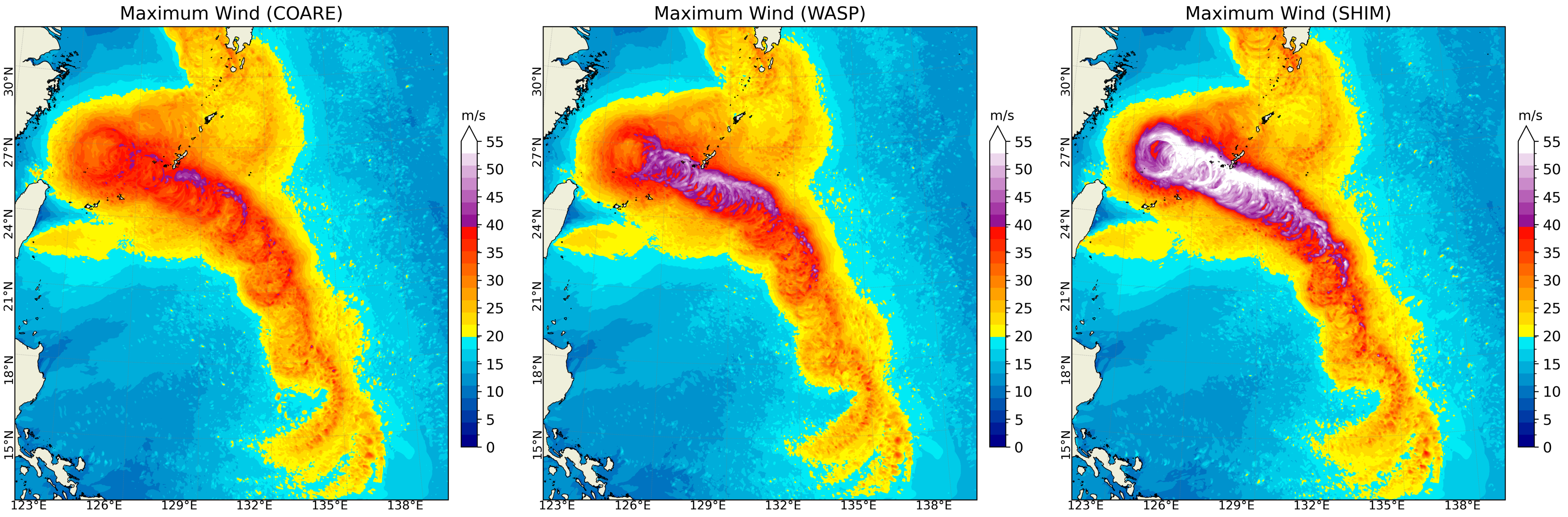


The maximum wind speed is generally well capture while being underestimated when using COARE and WASP.

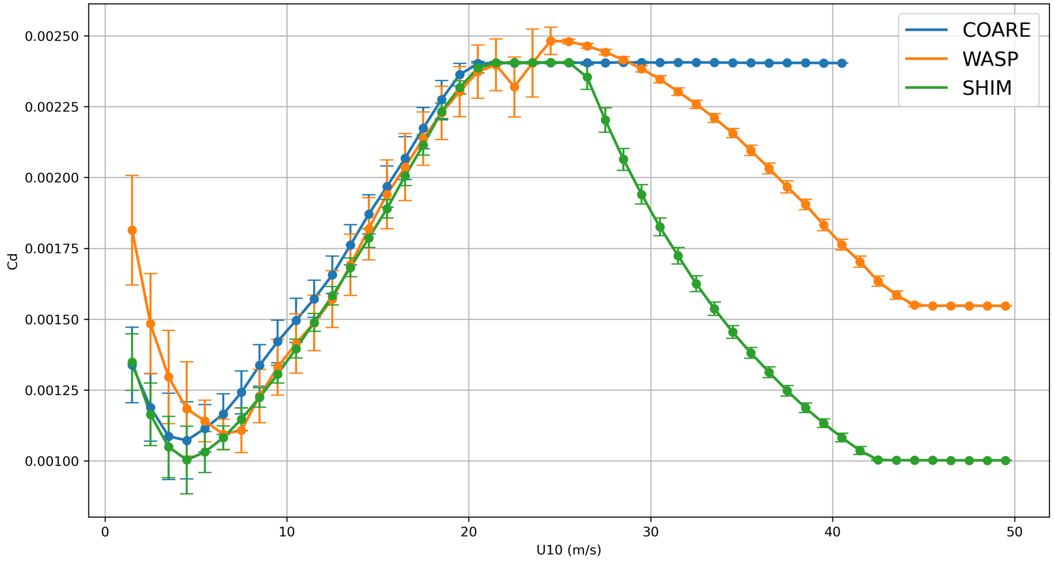
Using SHIM drag formulation gives higher wind speed and reaches close to observed wind at the peak.

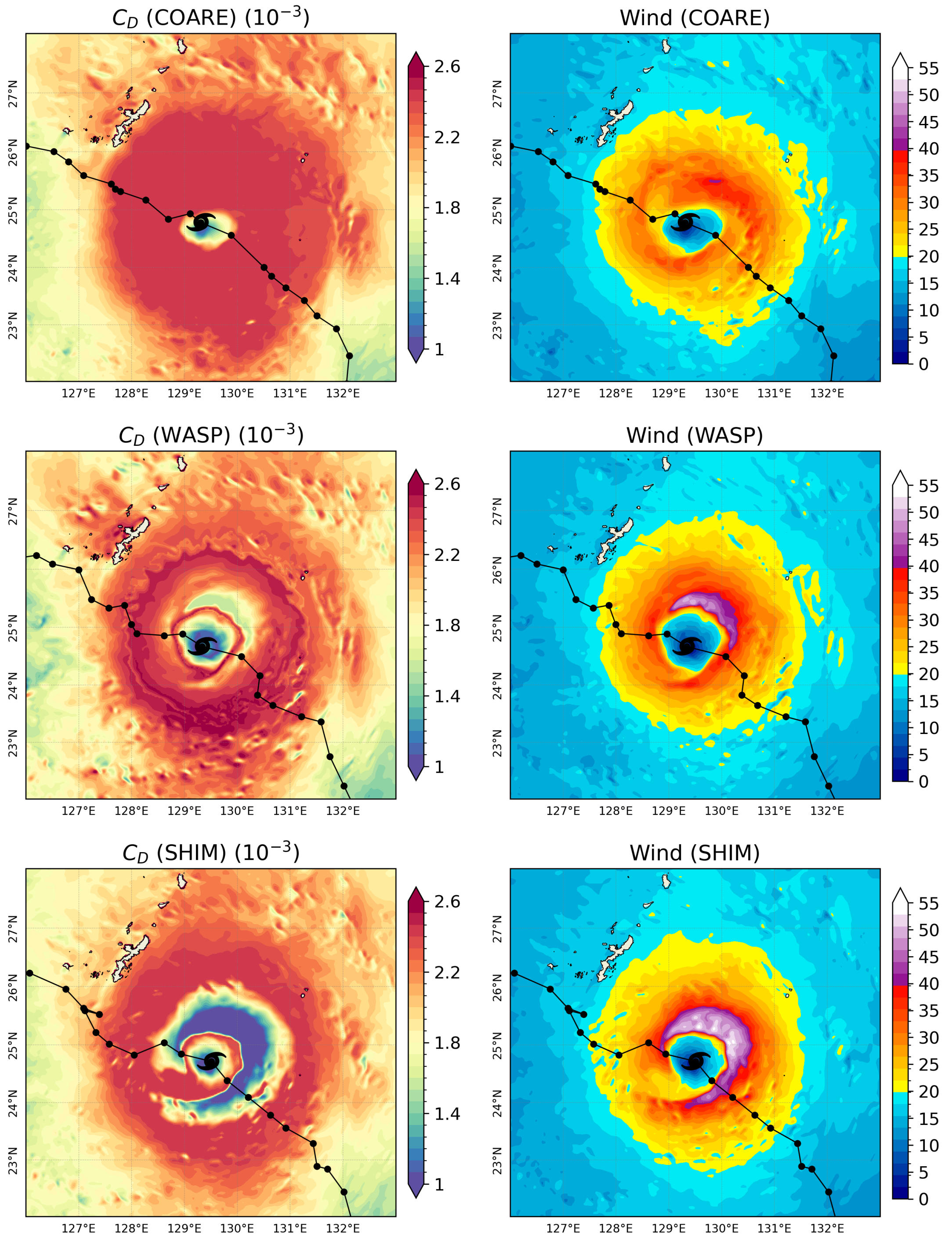
Maximum wind speed simulated

Maximum wind speed simulated between July 28 and Aug 11, 2023.



Drag and Wind impacts

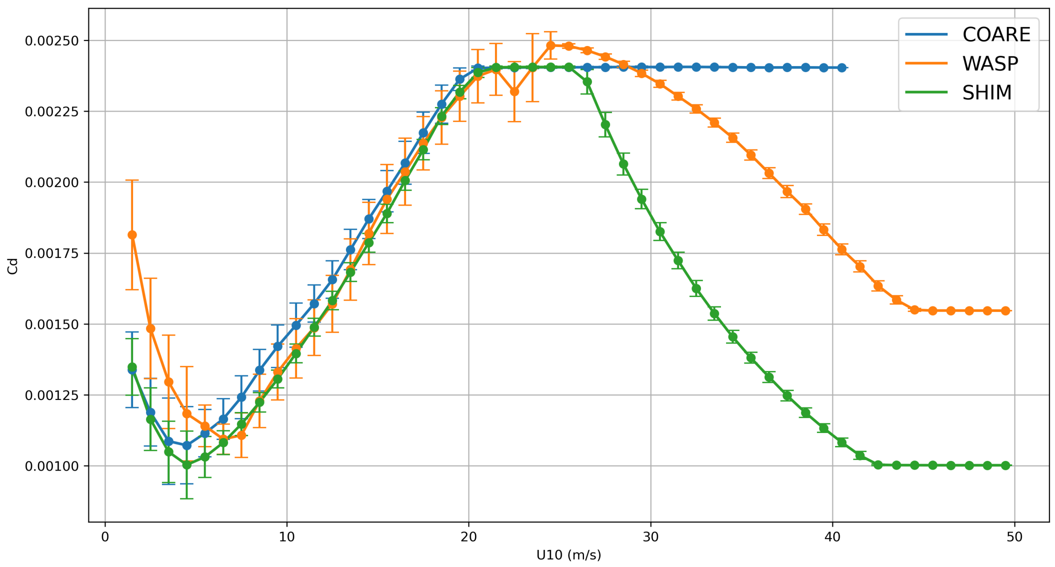




Quicker saturation of the drag (CD) in COARE but at a higher value resulting in lower wind speed.

The decrease of drag in WASP and SHIM creates an asymmetry in CD, which emphasize the typhoon wind asymmetry increasing wind on the right side.

Wave height and slope impacts



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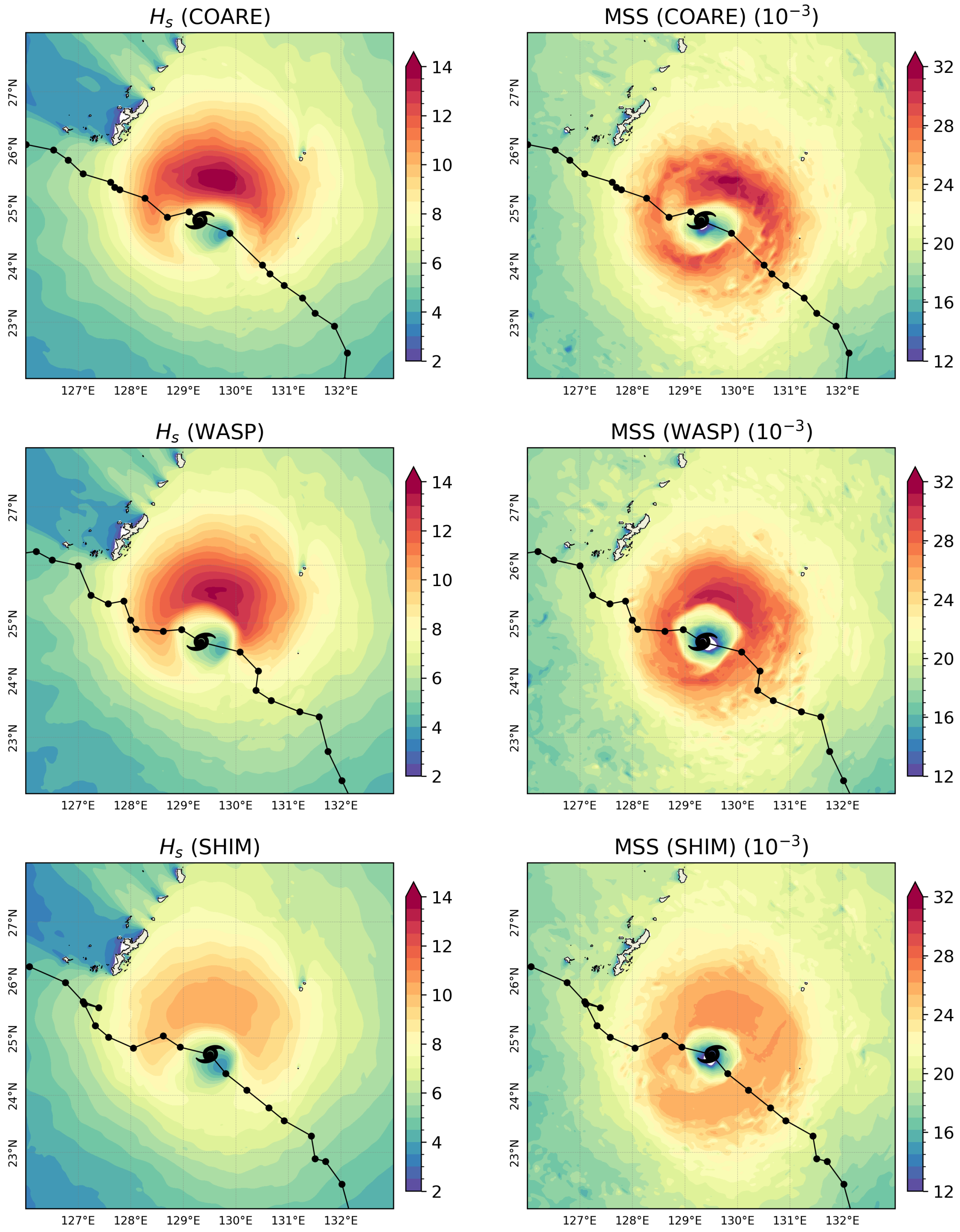
The decrease and saturation in CD helps to reproduce the saturation of MSS and Hs



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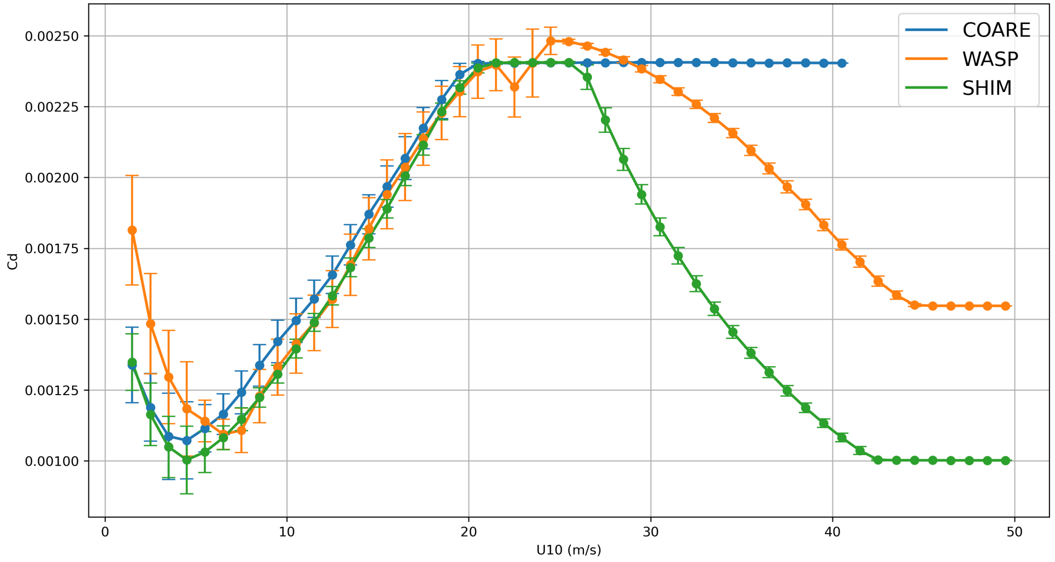

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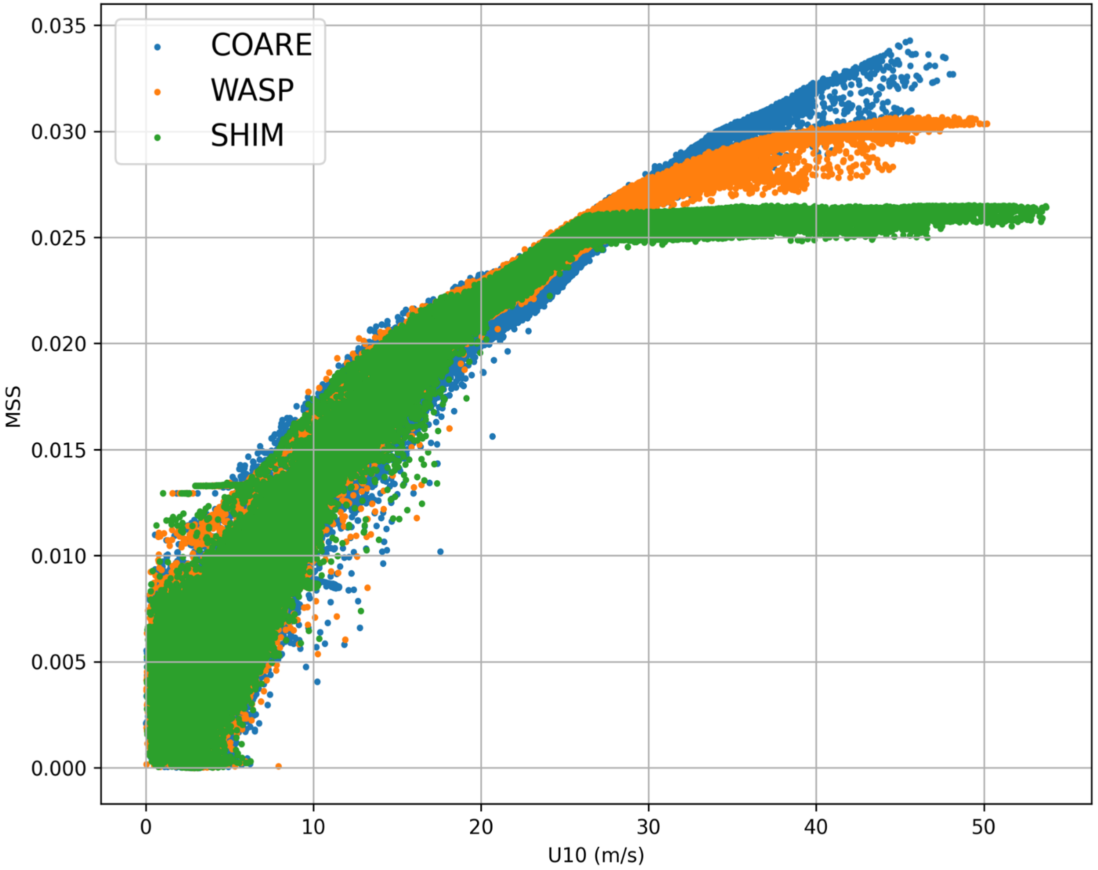
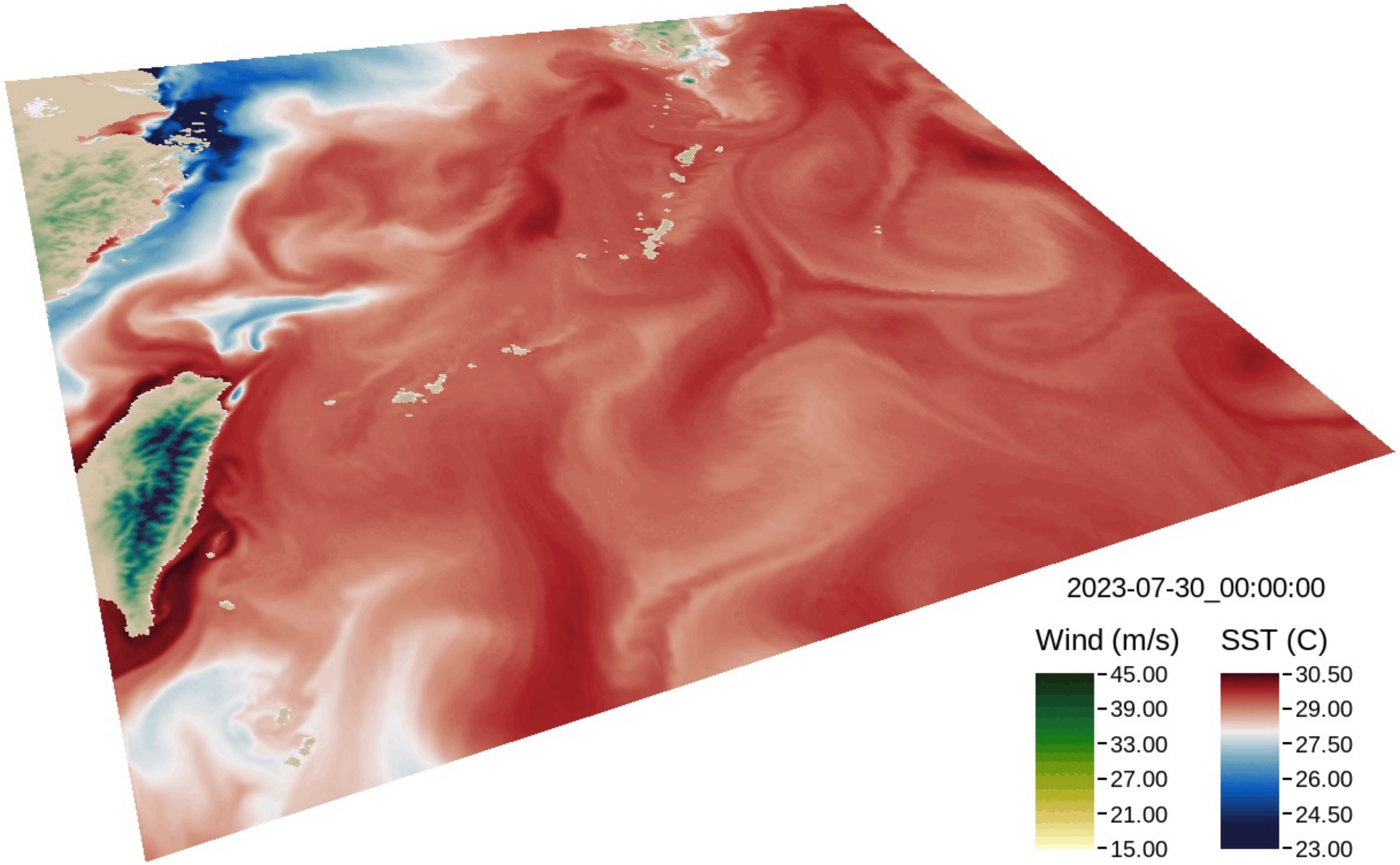


MSS saturation consistent with previous studies (e.g. Shimura et al. 2024, Davis et al. 2023,2025)

Cold wake response to Drag formulation



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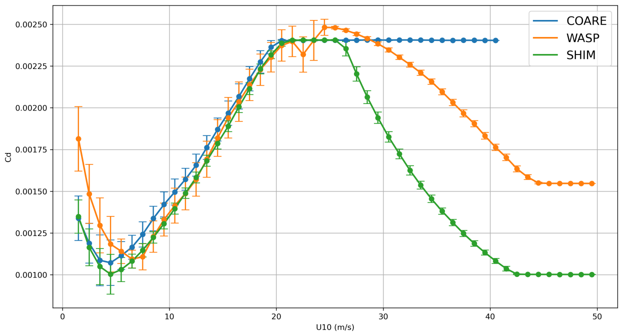
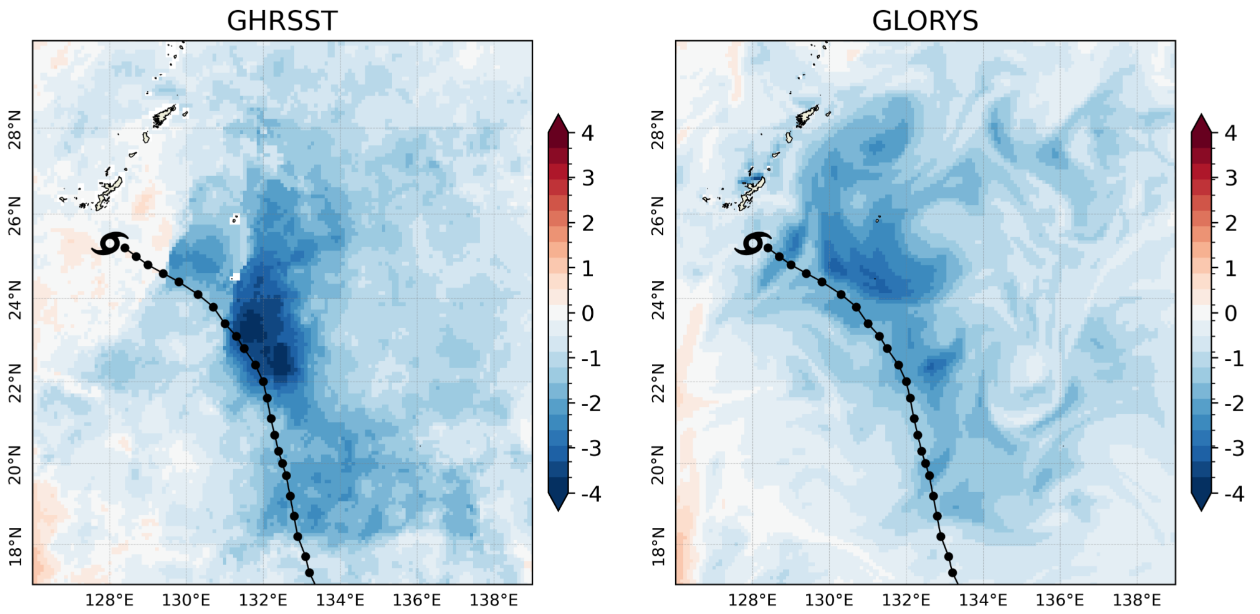


SST differences:
Aug. 1st - July 28
(12UTC)



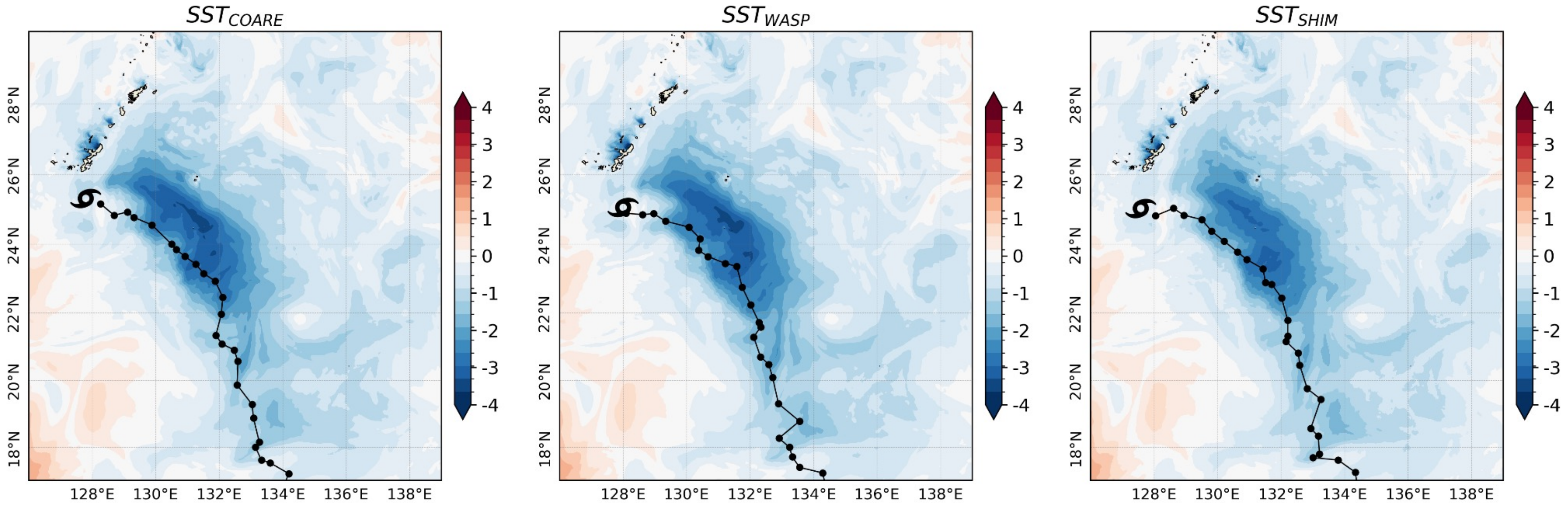
Higher drag

↓

stronger mixing

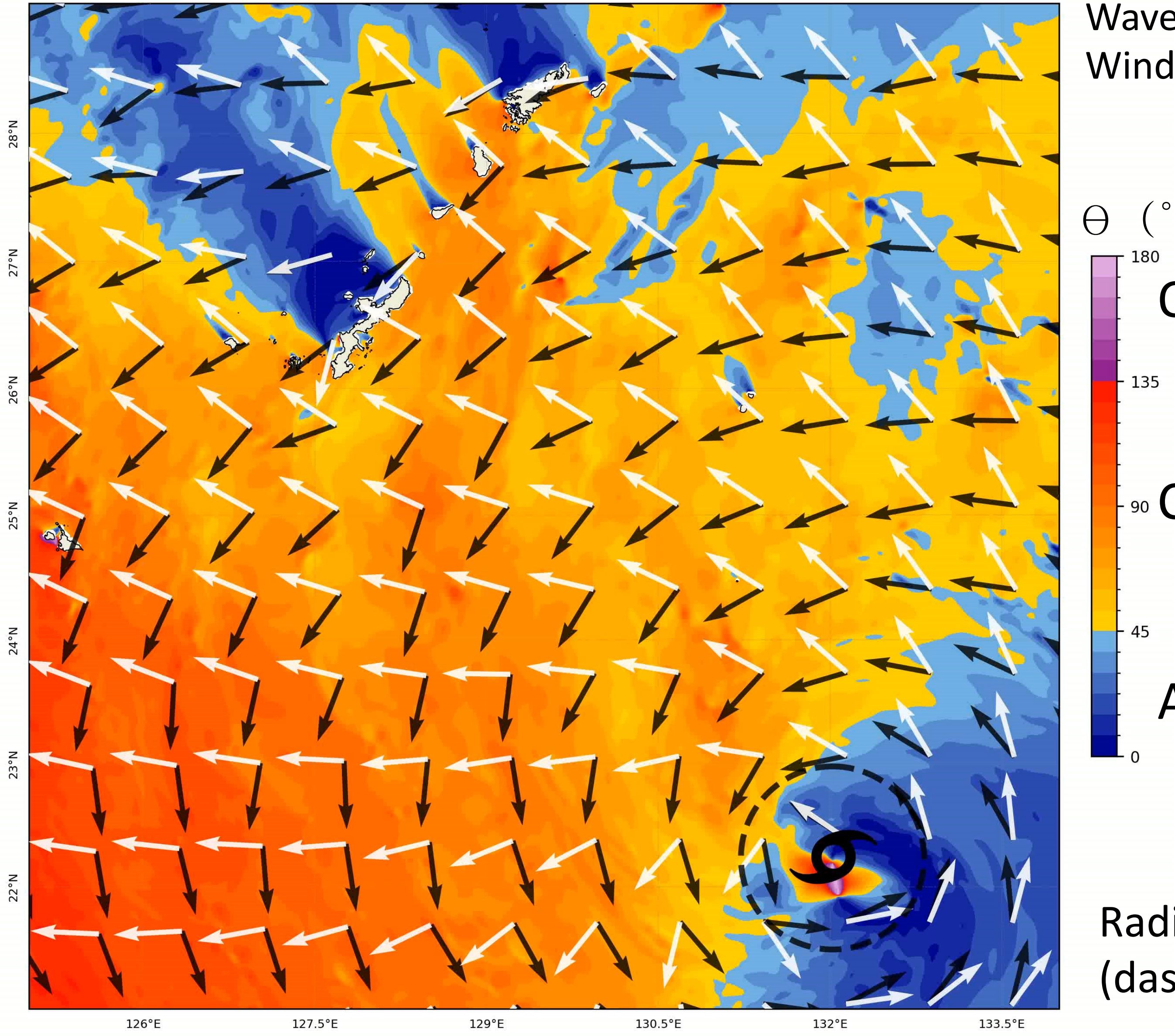
↓

stronger cold wake



-> cold wake modulation of about 0.5 to 1 ° C between COARE and SHIM

July 31 to Aug. 2, Mean wind wave misalignment evolution



Wave mean dir. (white arr.)
Wind dir. (black arr.)

Opposed waves

Crossing waves

Aligned waves

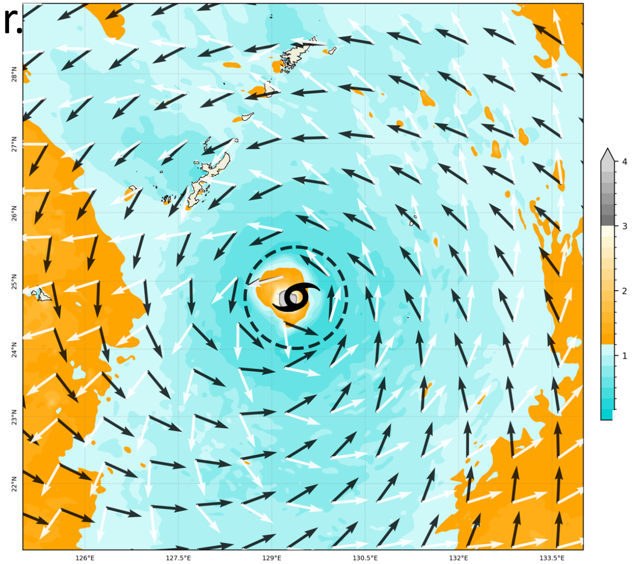
Radius Max. Wind
(dashed circle)

Aug 1st 00UTC, Normalized wave energy

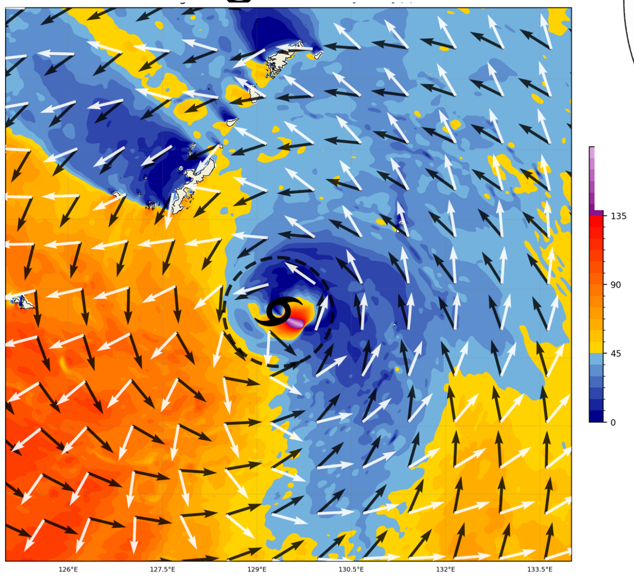
Mean wave age

Wave mean dir.
(white arr.)

Wind dir.
(black arr.)

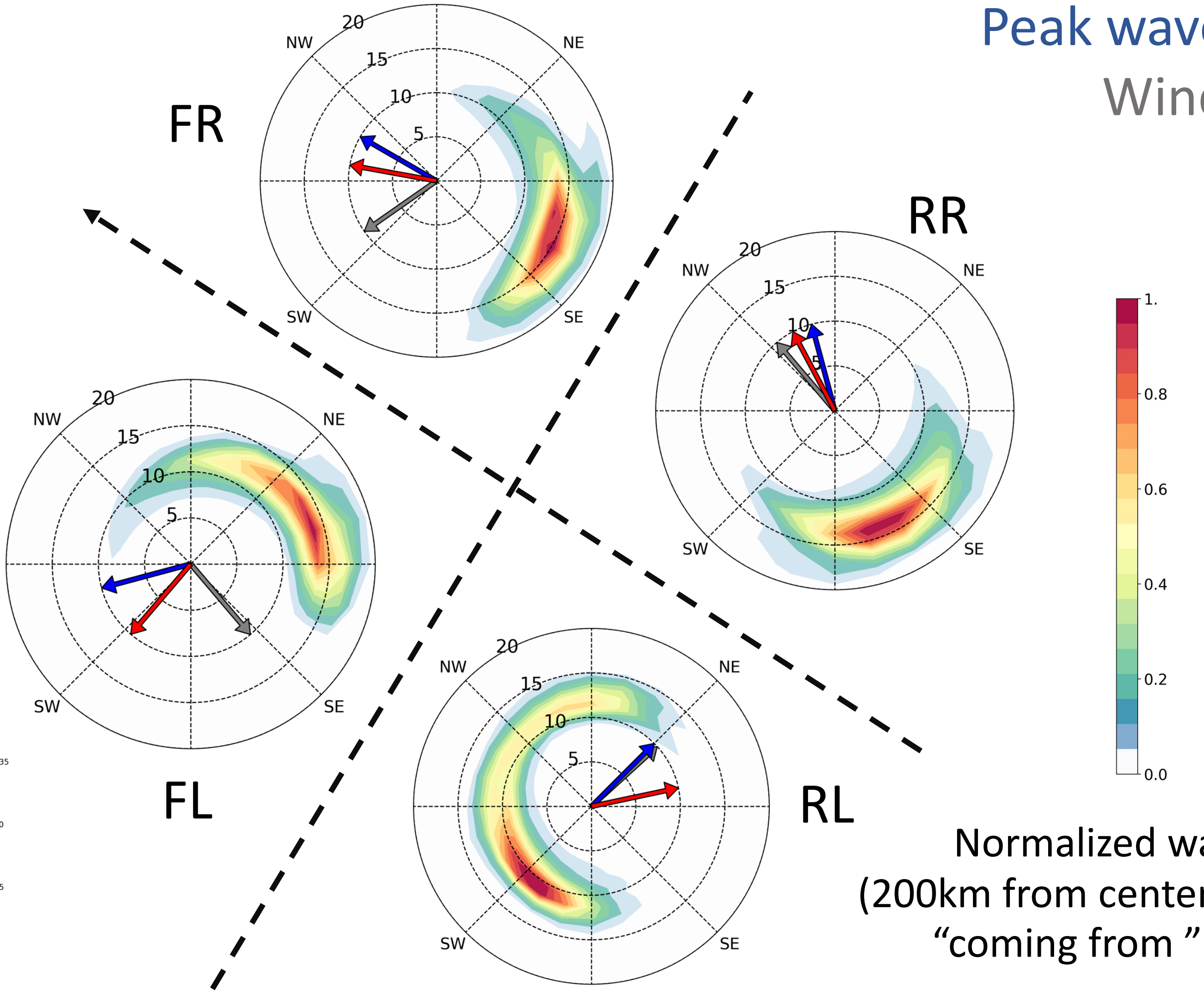


Mean angle



RMW
(dashed circle)

Mean wave direction
Peak wave direction
Wind direction



Normalized wave spectra
(200km from center ~ 2 RMW)
"coming from " convention

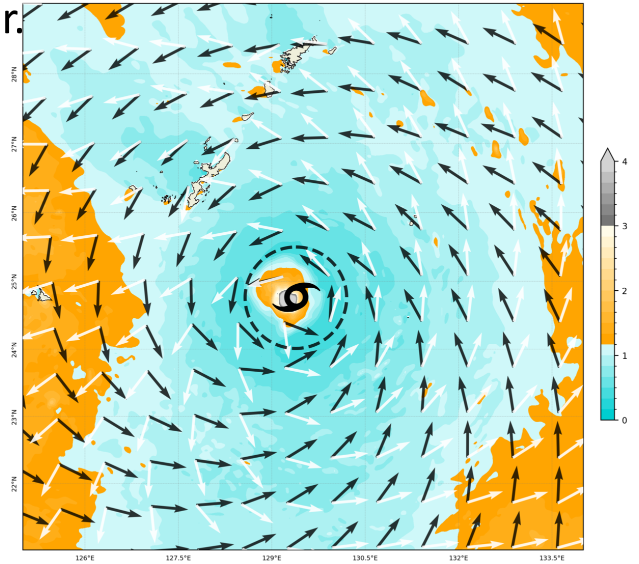
Aug 1st 00UTC, Normalized wave energy

Wave mean dir.
(white arr.)

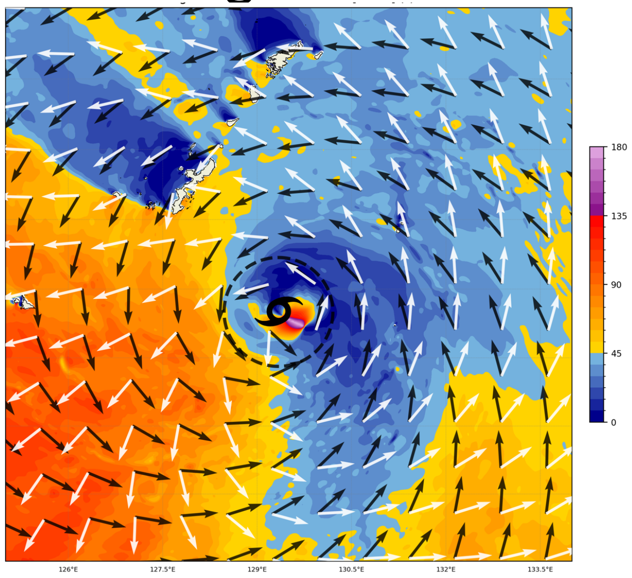
Wind dir.
(black arr.)

RMW
(dashed circle)

Mean wave age



Mean angle



Normalized wave spectra
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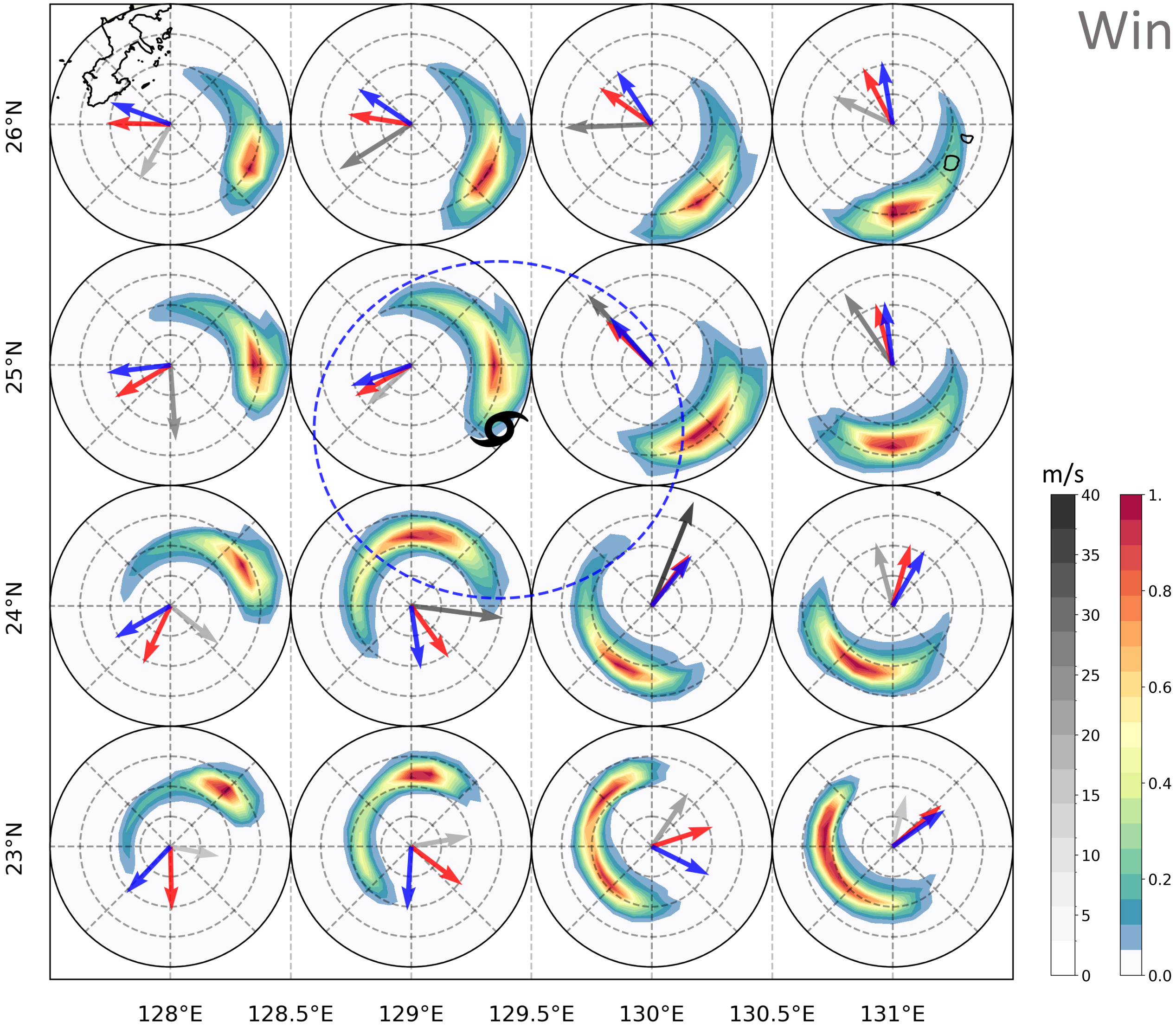
Mean wave direction
Peak wave direction
Wind direction



Normalized wave energy

Normalized wave spectra
“coming from ” convention

Mean wave age

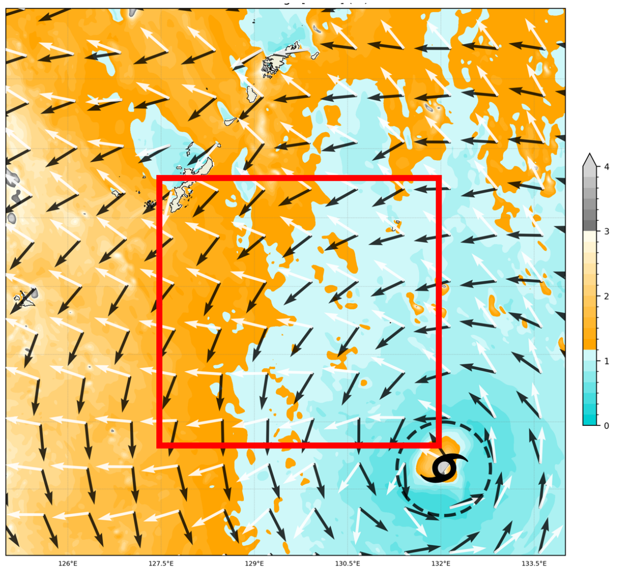
Mean angle

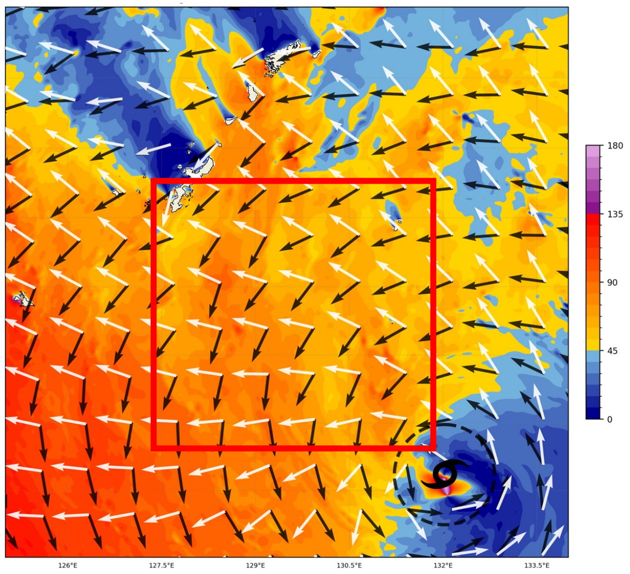
Mean wave direction
Peak wave direction
Wind direction

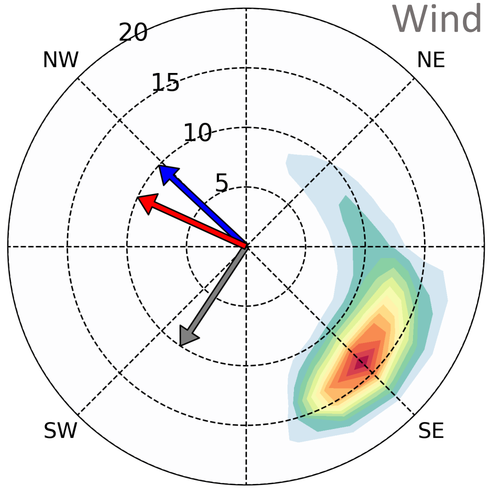
July 31, 00UTC

Wave mean dir.
(white arr.)

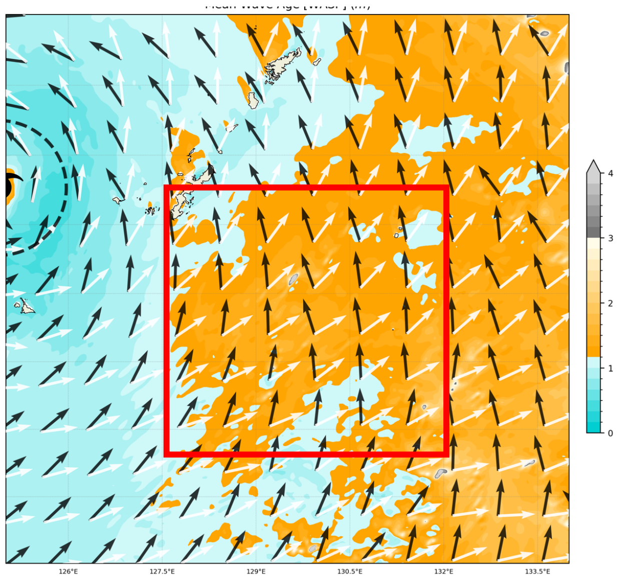
Wind dir.
(black arr.)

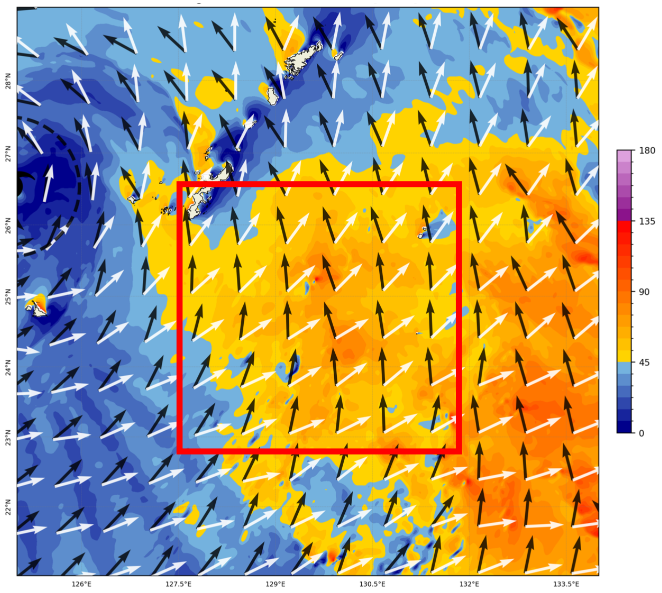


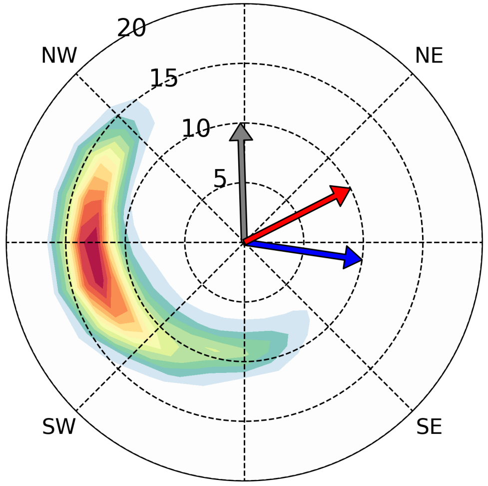


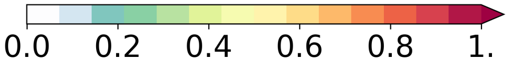


Aug 02, 00UTC



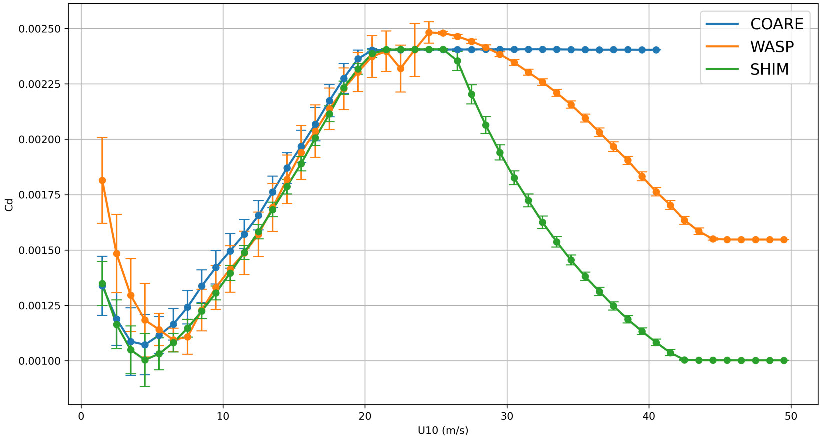


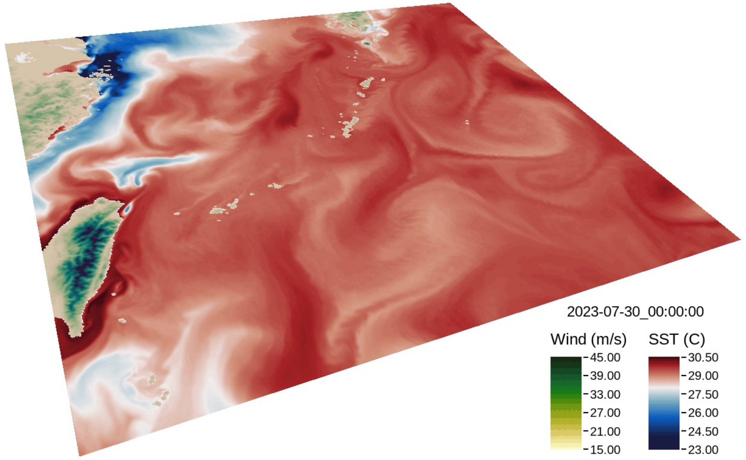




Summary & Perspectives

- We investigated coupled ocean-atmosphere-wave simulations of Typhoon Khanun in 2023 exploring the impact of the Cd decrease and saturation at high wind speed.
- The stronger decrease of the drag coefficient in SHIM gave the strongest wind while also giving the weaker cold wake
- The decrease and saturation in Cd at higher wind helps to reproduce the saturation of MSS and Hs
- Strong misalignment happens before and after the passage of Khanun over a large area.
- How does wind-waves-current misalignment before, during and after Khanun impact the surface drag coefficient and cold wake ?
- How does sea spray mediates Khanun’s intensity, cold wake and heat fluxes exchanges ?





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