

International Workshop on Tropical Cyclone–Ocean Interaction in the Northwest Pacific
Busan, South Korea, October 21-23, 2026

Directional Wave–Wind Coupling, Drag Coefficient Rolloff, and Air-Sea Fluxes Under Tropical Cyclones

Hyodae Seo & César Sauvage
Uehiro Center for the Advancement of Oceanography (UC•AO)
University of Hawai‘i at Mānoa

In collaboration with
Tunggul Bhirawa & Satoshi Mitarai
Okinawa Institute of Science and Technology



UNIVERSITY
of HAWAII®
MĀNOA

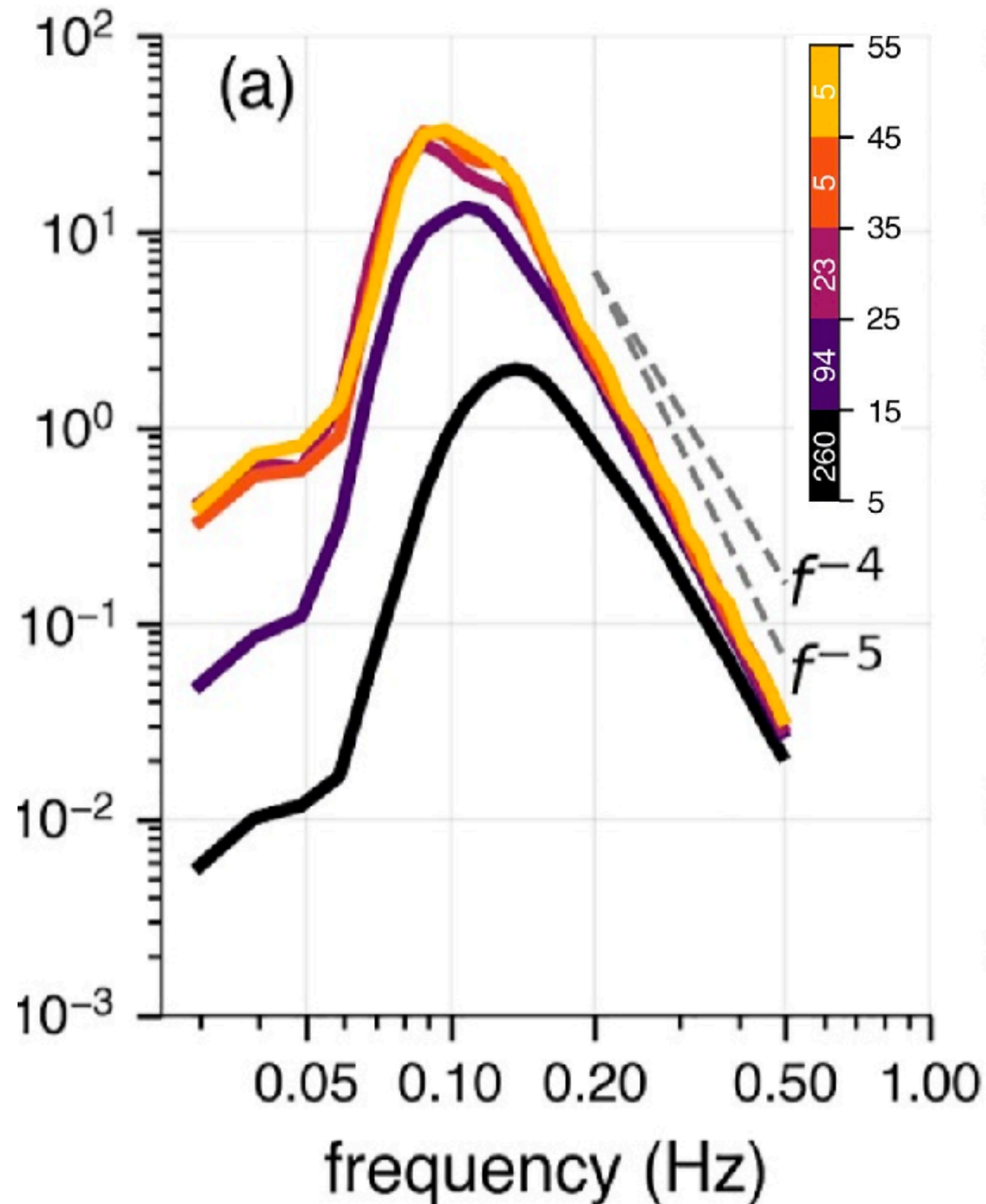


Saturation of wave energy and directional wind-wave

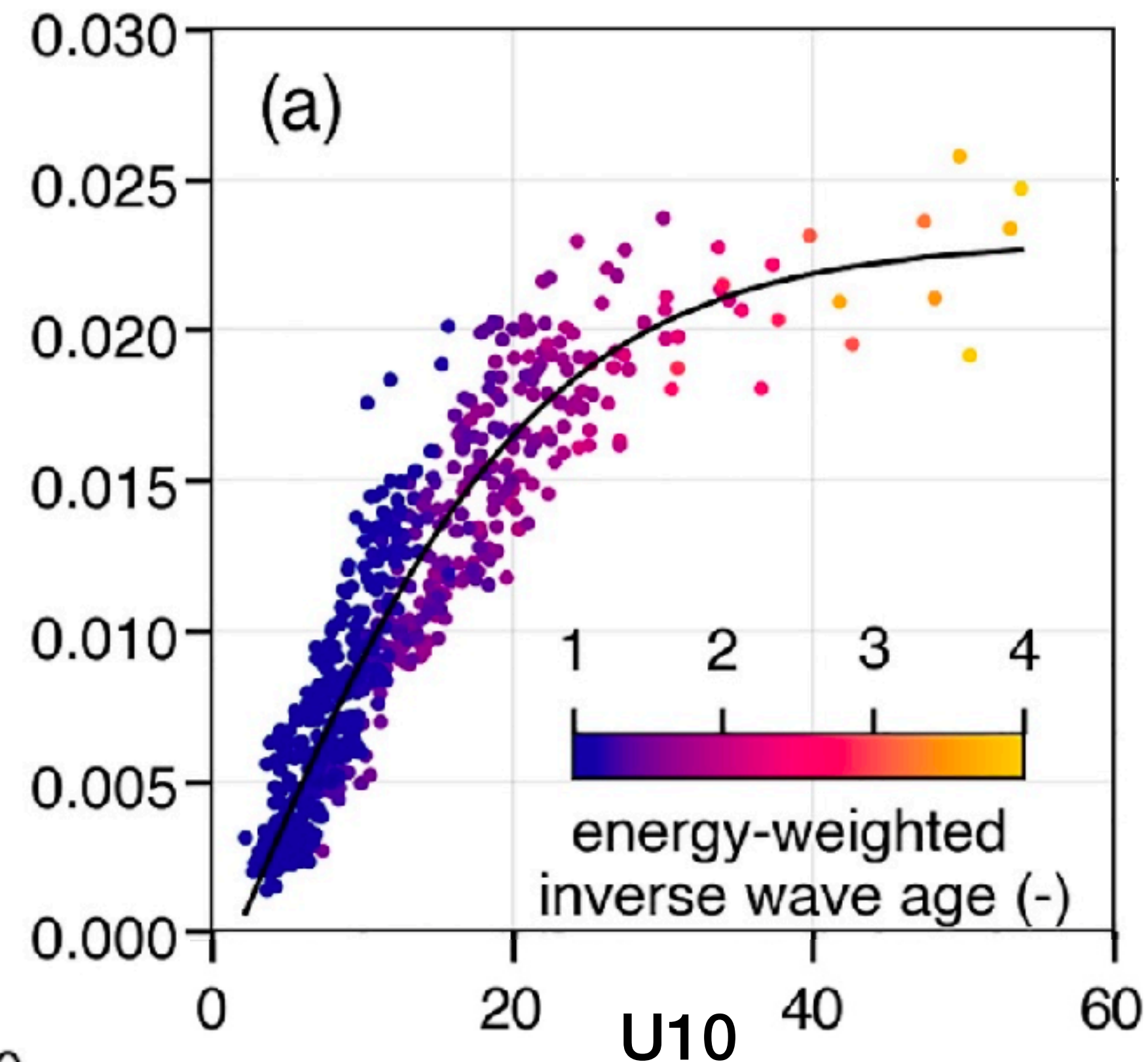
Directional wind-wave coupling

Hurricane Idalia (2023)

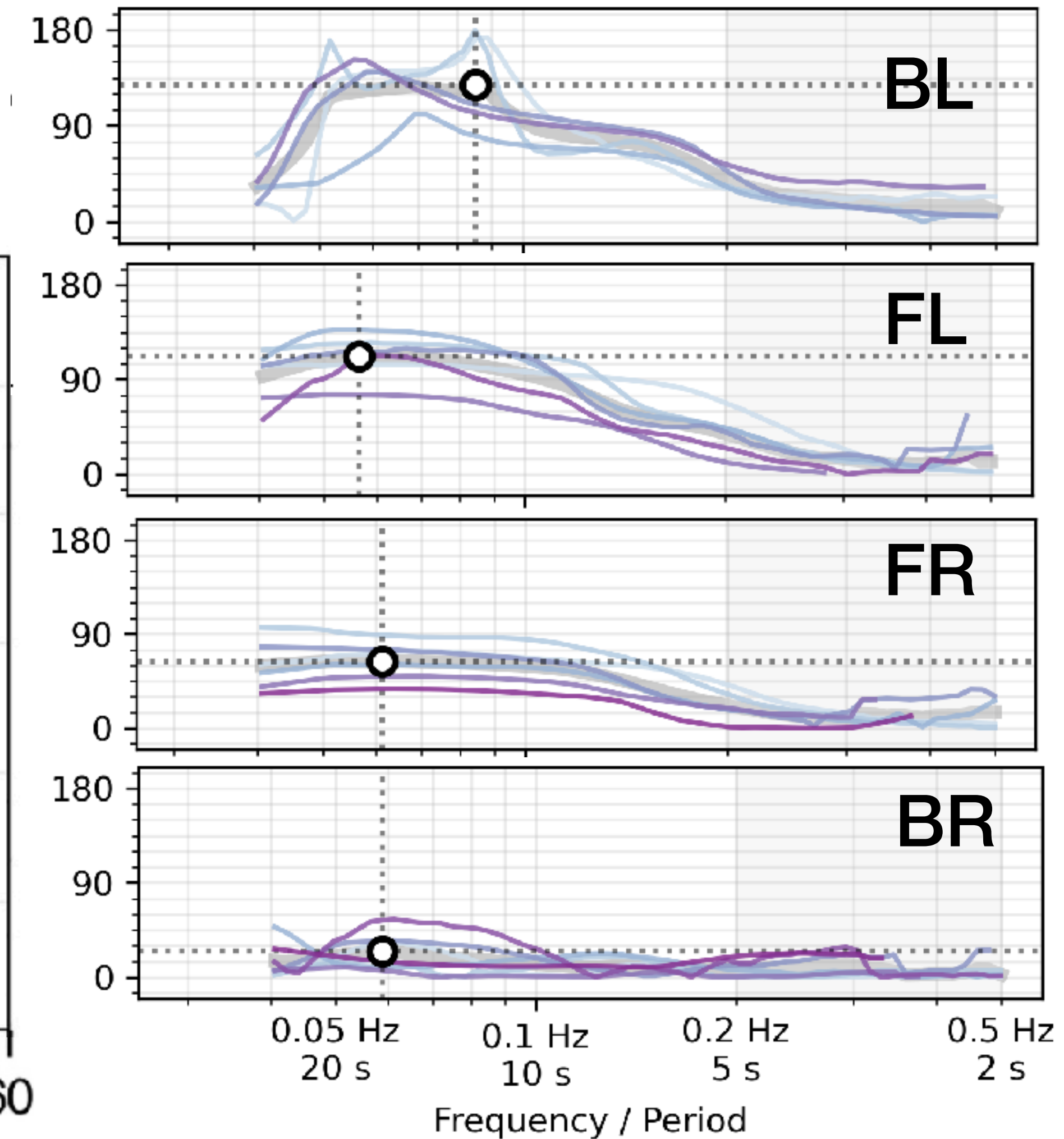
Mean energy density



Mean square slope



Davis et al. (2025)



Pauly et al. (in prep)



Wyn Pauly's poster: Typhoon Saudel (2026)

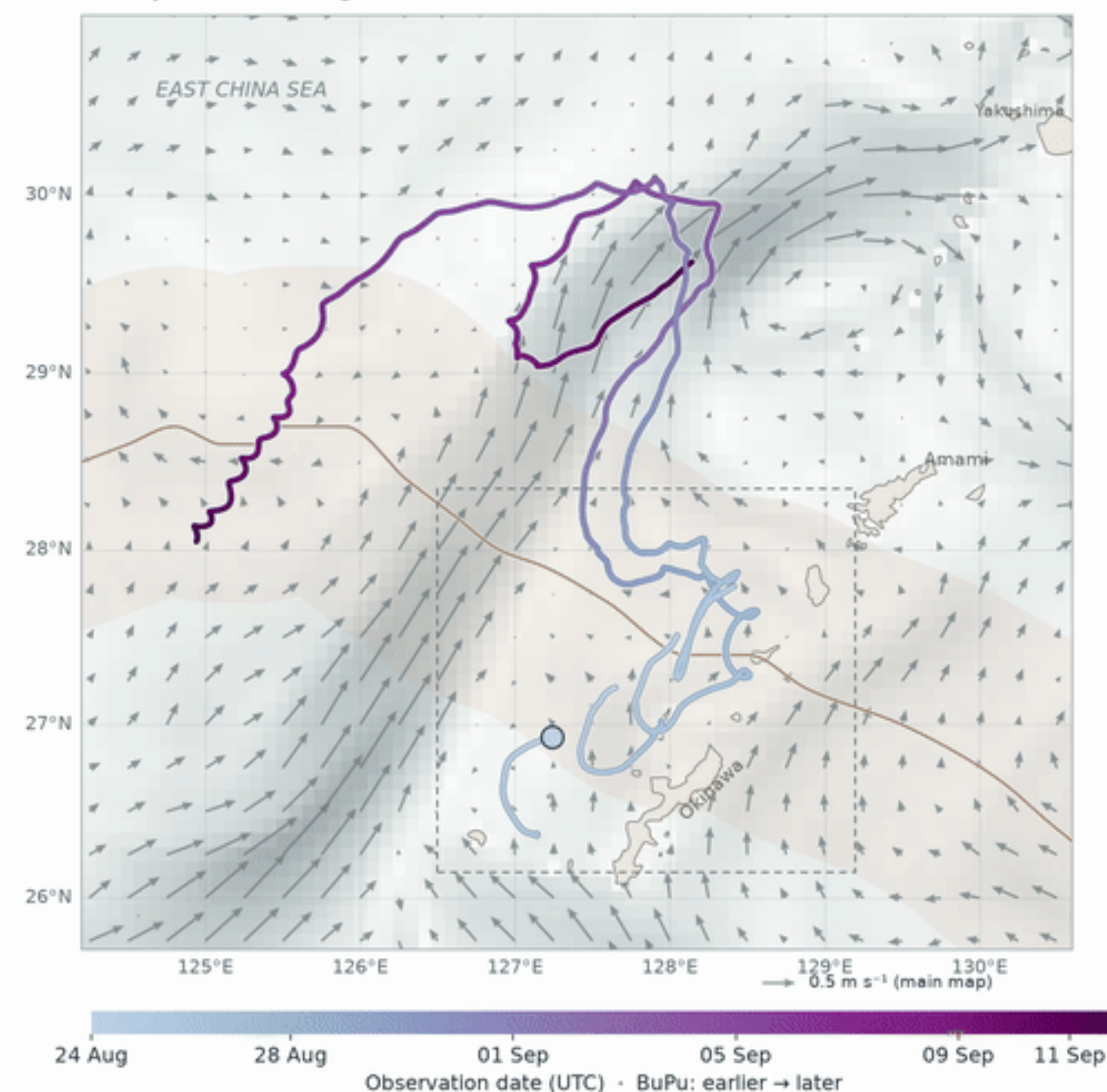
From Inherited Waves to Local Forcing: Frequency-Dependent Wave Adjustment during Typhoon Saudel

**How do we reconstruct
directional wave
evolution under a moving
tropical cyclone?**

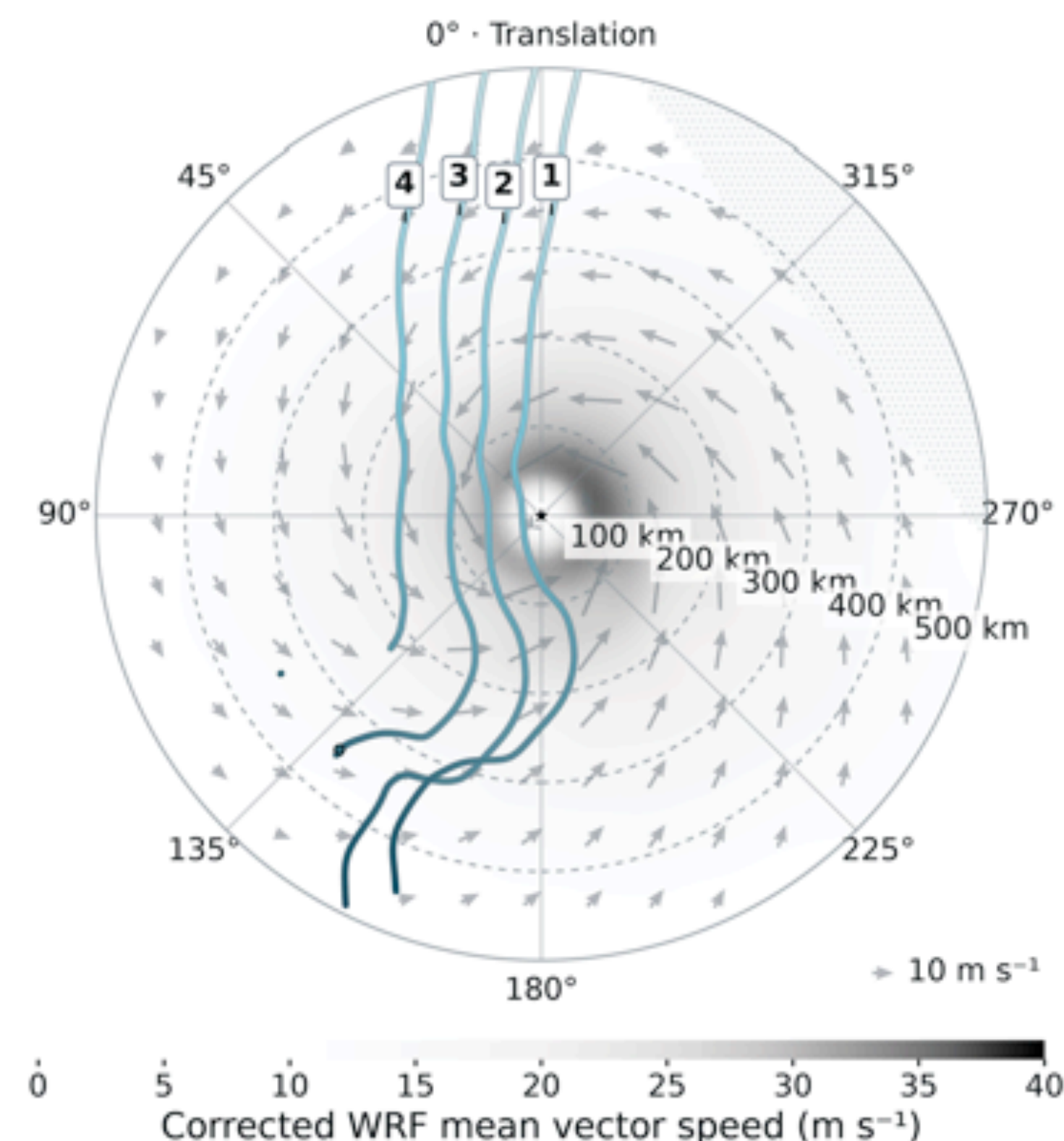
Four drifting Spotter buoys sampled the evolving wave field during Typhoon Saudel (24-28 August 2026).

Directional spectra are reconstructed from measured Fourier moments using the maximum entropy method (MEM), then corrected for Doppler shifts associated with buoy motion. The resulting spectra resolve frequency-dependent wave energy and directional spreading.

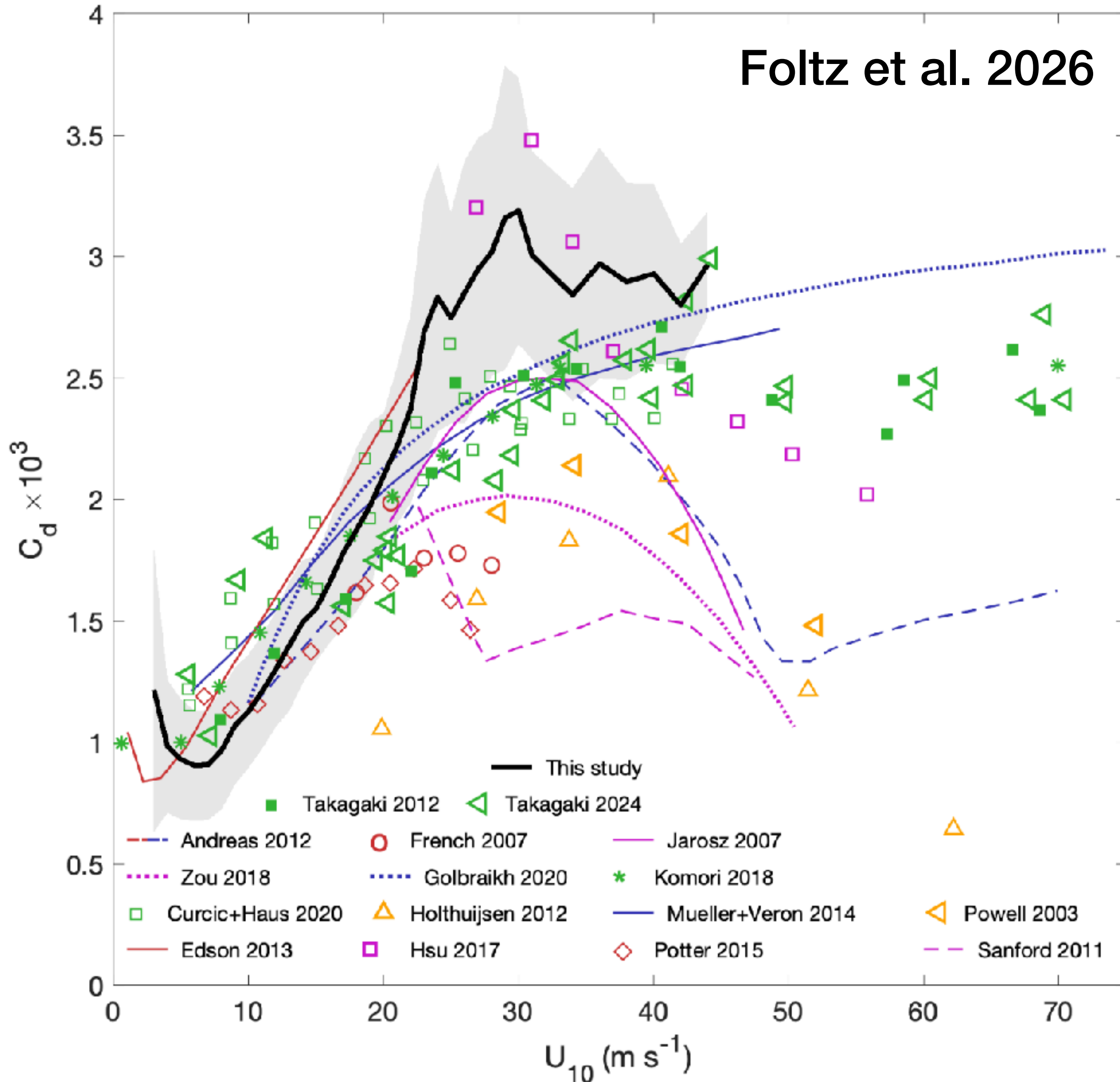
24 August-11 September 2026 · Okinawa and the East China Sea
Currents and positions: 24 Aug 2026 10:06 UTC



b Storm-relative coordinates



Drag coefficient (C_D) and roughness length (z_0) parameterizations



$$C_D = \left[\frac{\kappa}{\ln(z/z_0) - \psi_m(\zeta)} \right]^2$$

$$\left. \begin{aligned} z_0^{\text{rough}} &= \alpha \frac{u_*^2}{g} \\ z_0^{\text{rough}} &= H_s 0.09 \left(\frac{u_*}{C_p} \right)^2 \end{aligned} \right\} \text{Edson et al. (2013)}$$

$$z_0^{\text{rough}} = H_s 0.09 \cos(0.45\theta) \left(\frac{u_*}{C_p} \right)^{2\cos(-0.32\theta)} \quad \left. \vphantom{z_0^{\text{rough}}} \right\}$$

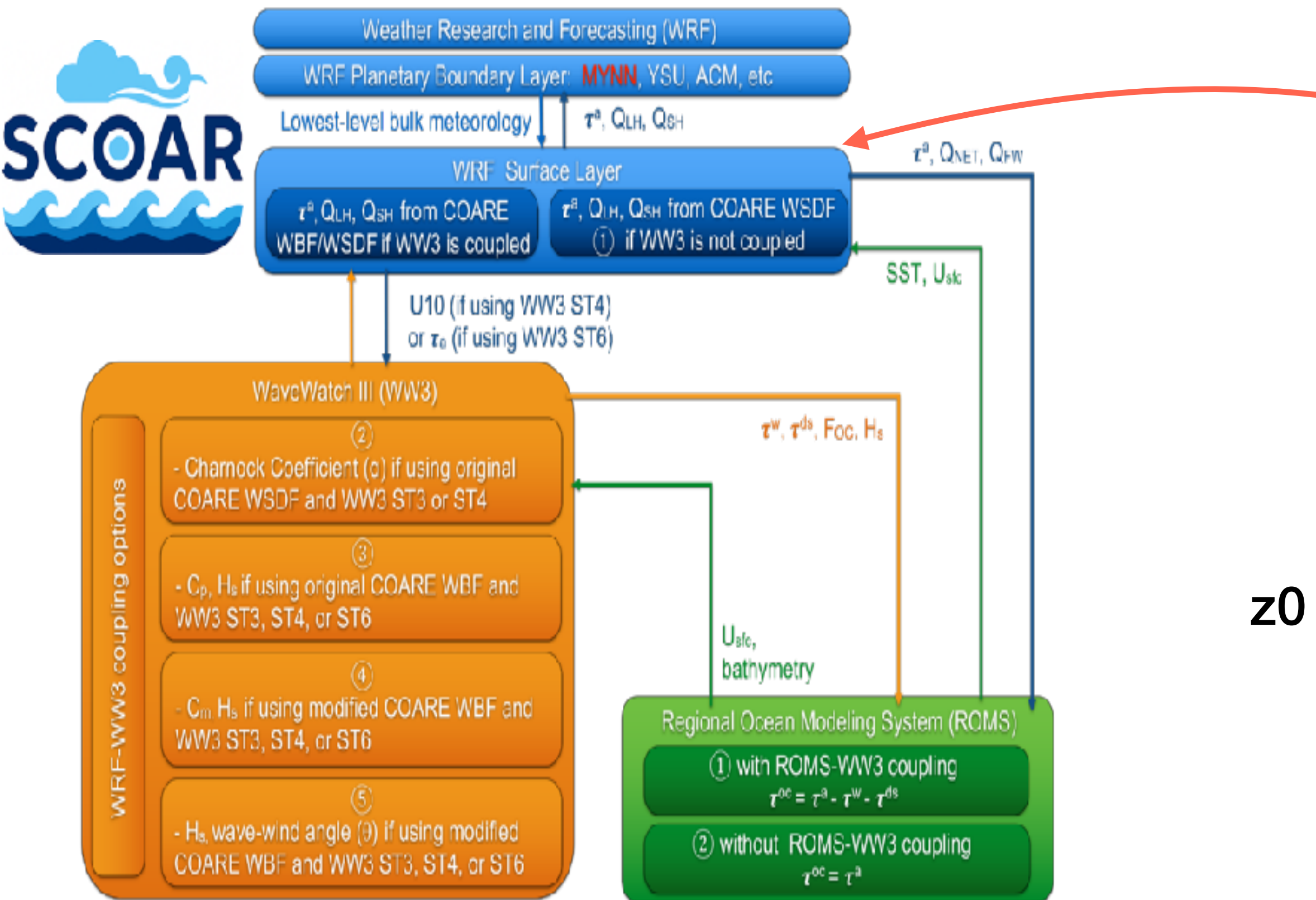
$$z_0^{\text{rough}} = H_s 0.09 \left(\frac{u_*}{C_m} \right)^2 \quad \text{Sauvage et al. (2023)}$$

$$C_h = \left[\frac{\kappa}{\ln(z/z_0) - \psi_m(\zeta)} \right] \left[\frac{\kappa}{\ln(z/z_{0t}) - \psi_h(\zeta)} \right]$$

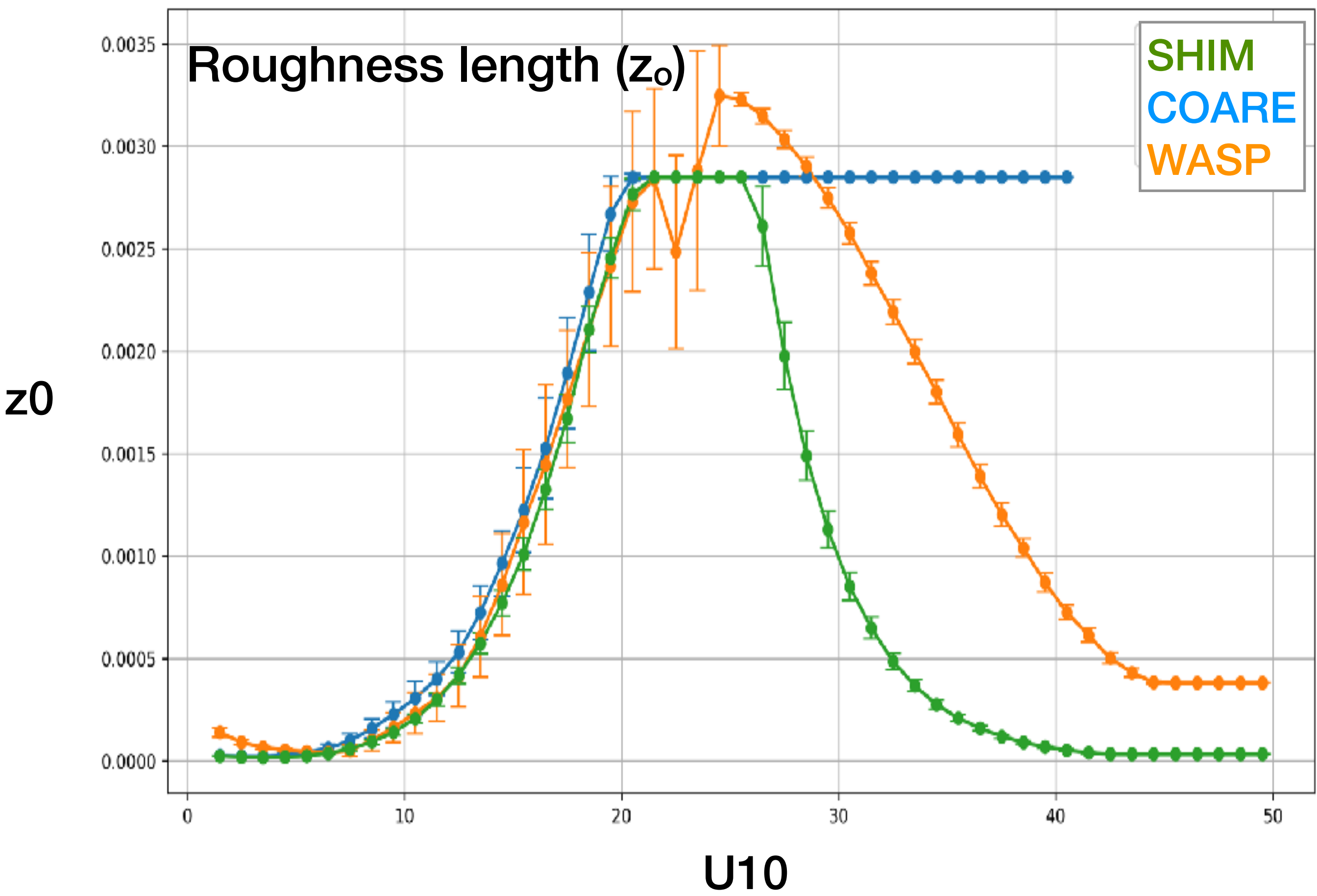
SCOAR WRF-ROMS-WW3 fully coupled simulations

using 3 different z_0 scenarios

$$z_o^{rough} = H_s 0.09 \frac{u_*^2}{C_m}$$



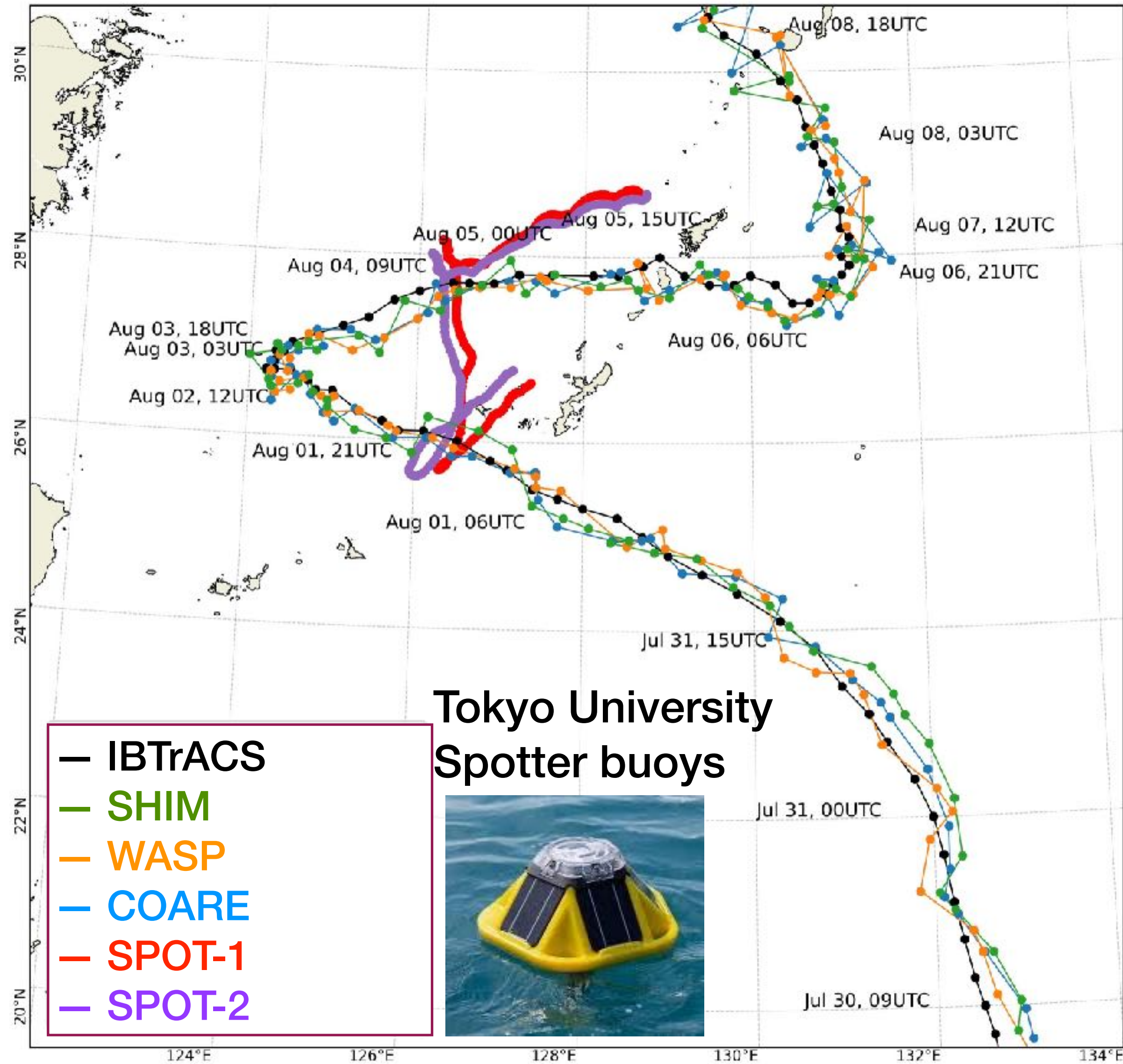
- COARE (Edson et al. 2013; Sauvage et al. 2023)
- WASP (Bouin et al. 2024)
- SHIM (Shimura et al. 2024)



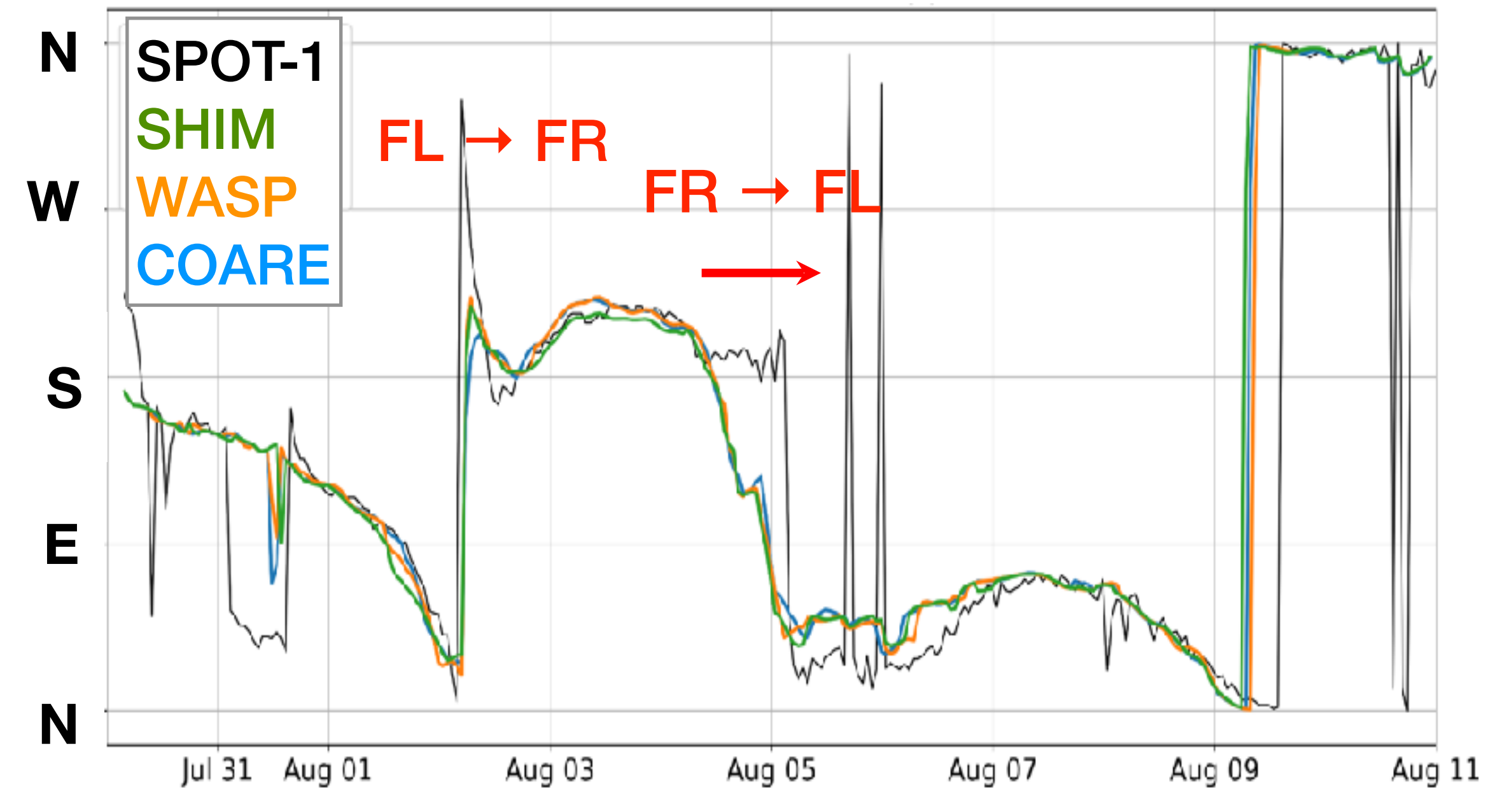
Seo et al. (2007, 2016); Sauvage et al. (2023, 2024)

<https://www.hyodaeseo.com/scoar/>

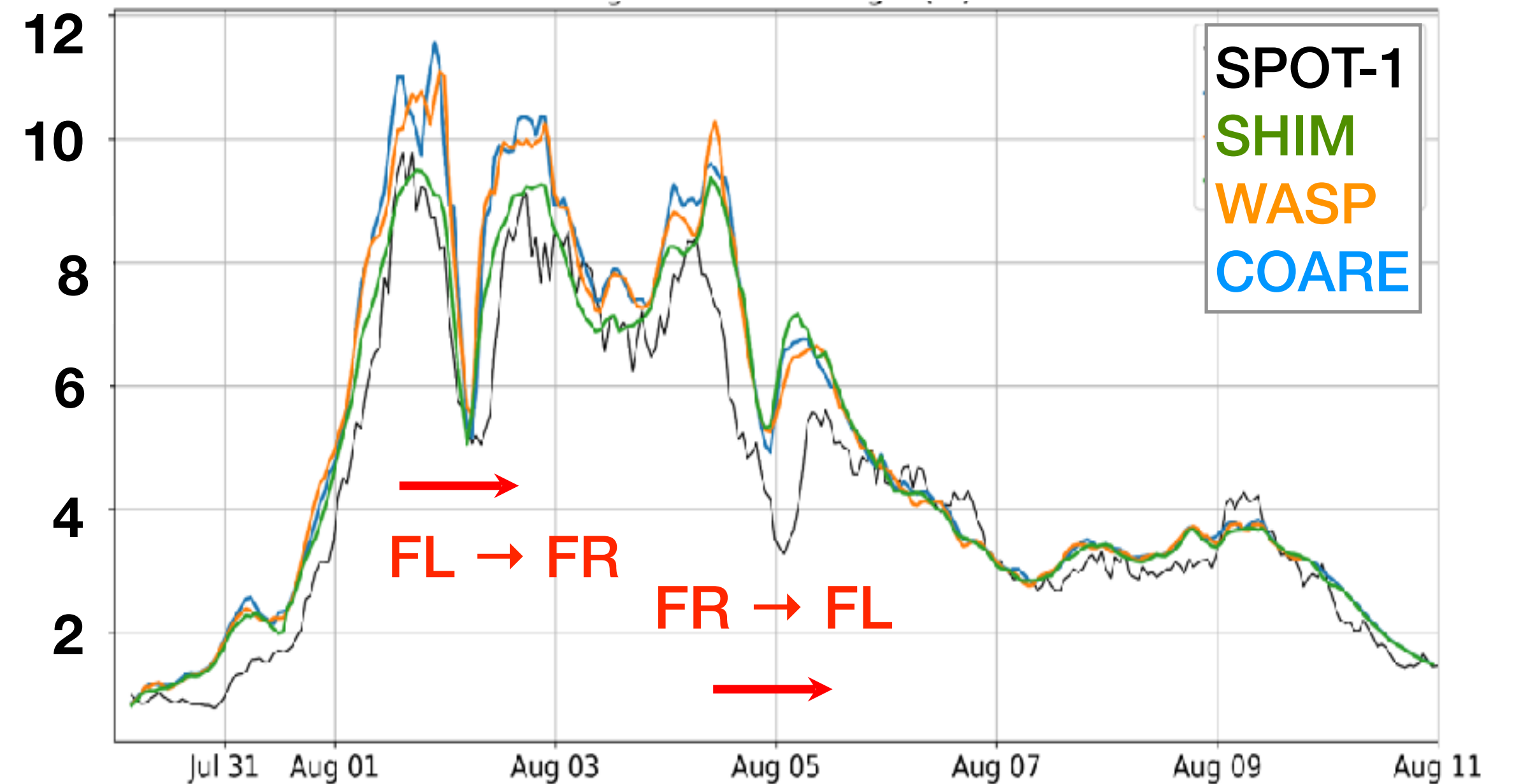
① Khanun's Sea State



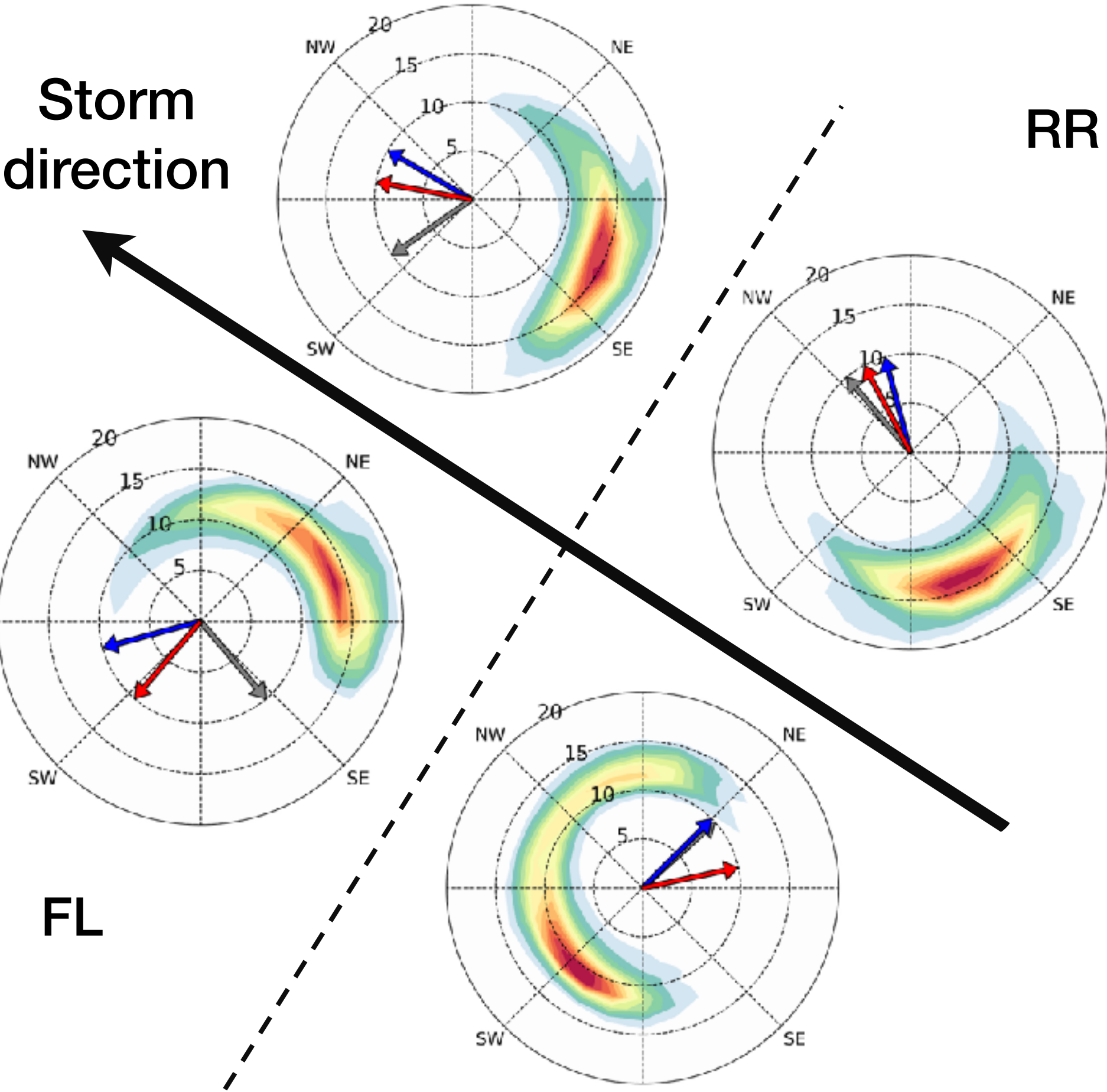
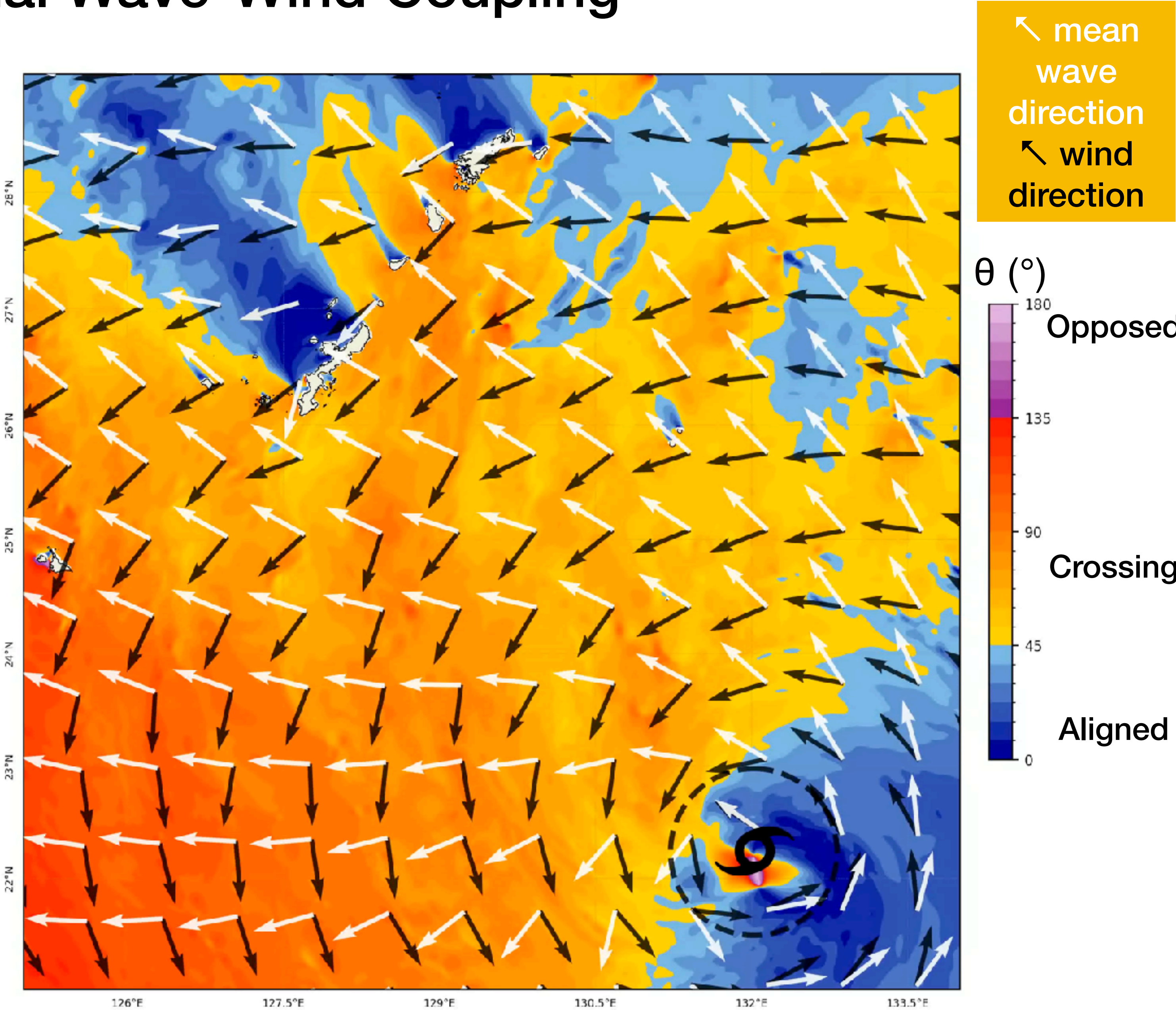
Peak wave direction



Significant wave height



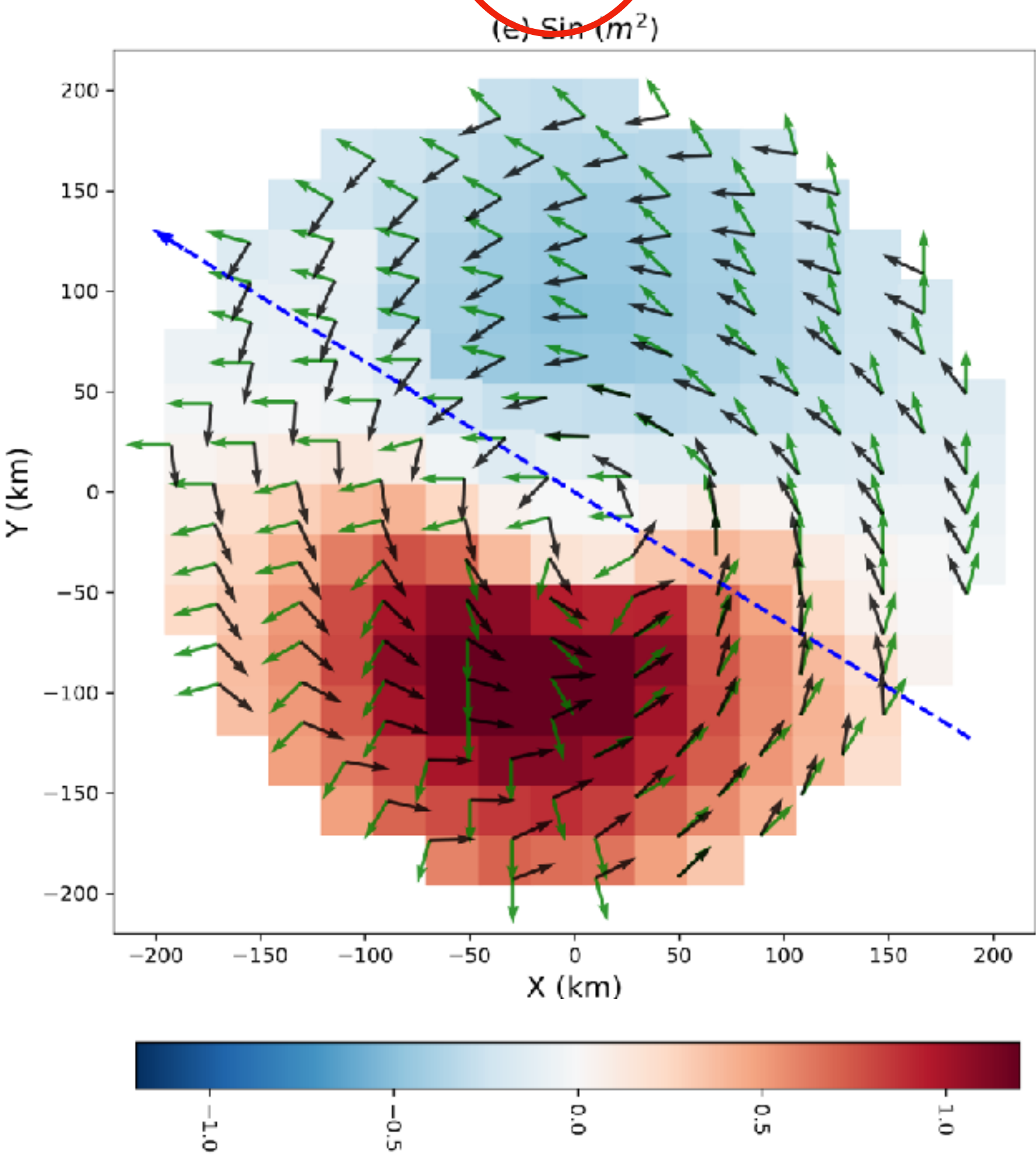
Directional Wave-Wind Coupling



July 31 — Aug 2

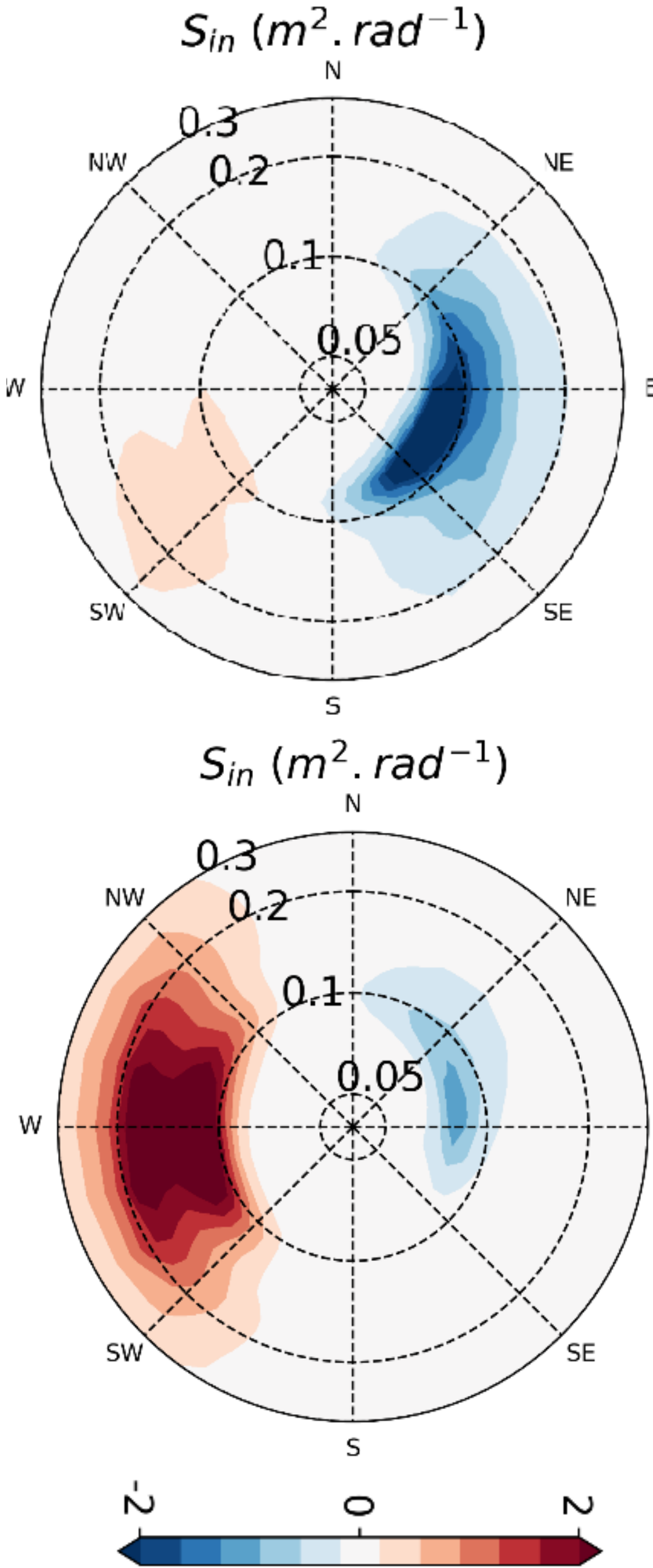
Spectral Source Term Diagnostics

$$\frac{\partial N}{\partial t} + \nabla \cdot cN = \frac{S_{tot}}{\sigma} = \frac{S_{in}}{\sigma} + \frac{S_{ds}}{\sigma} + \frac{S_{nl}}{\sigma}$$

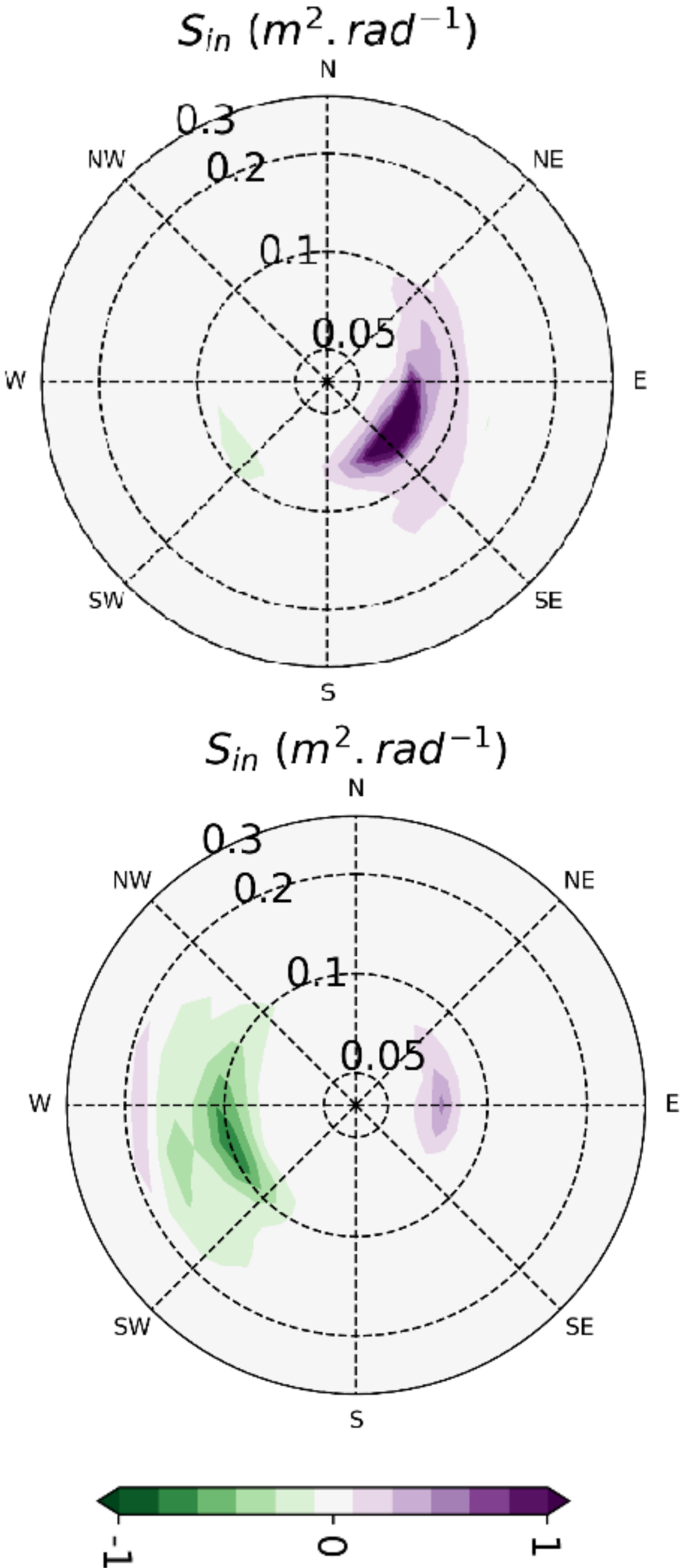


Right

S_{in} : SHIM

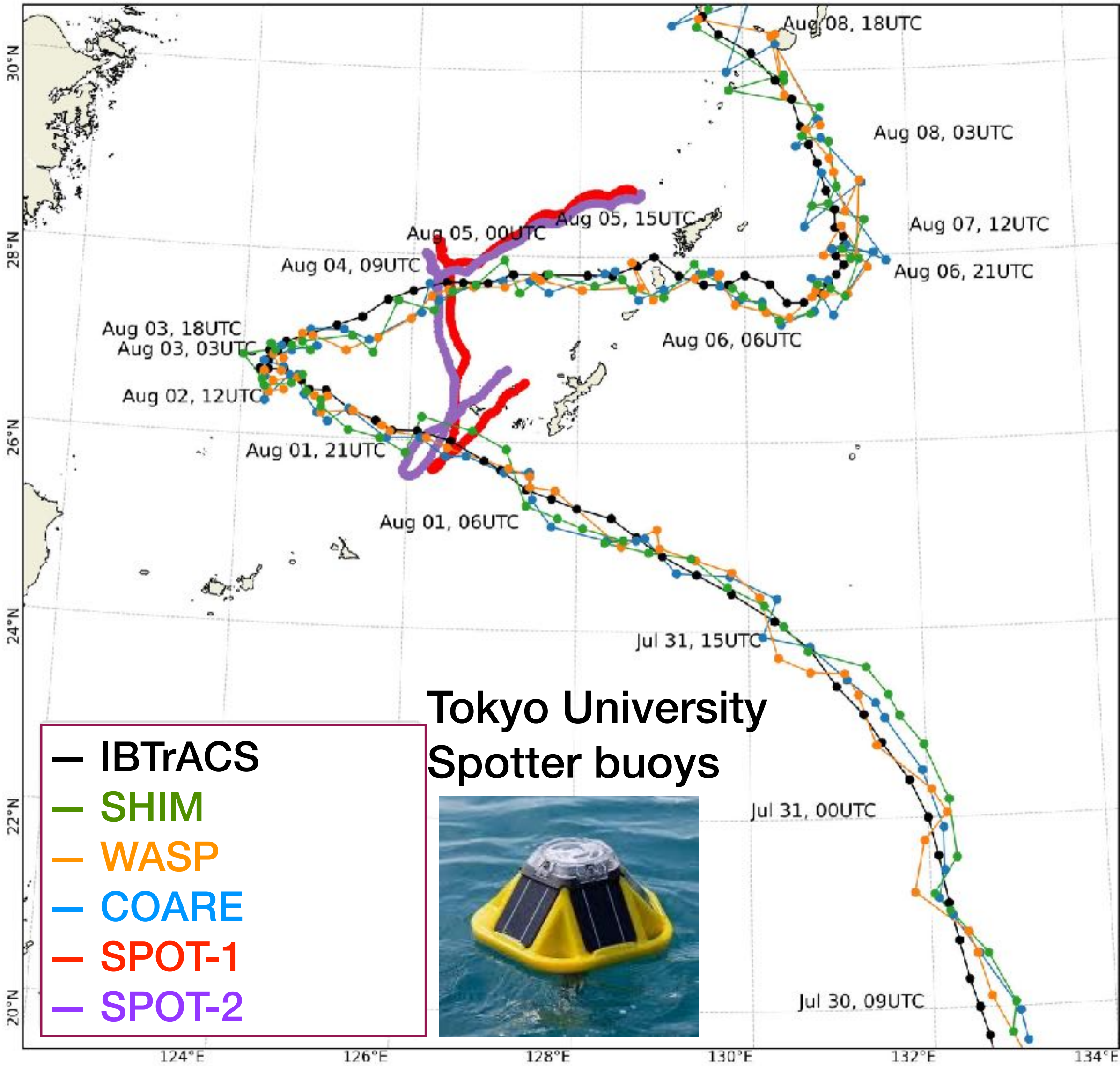


S_{in} : SHIM-COARE

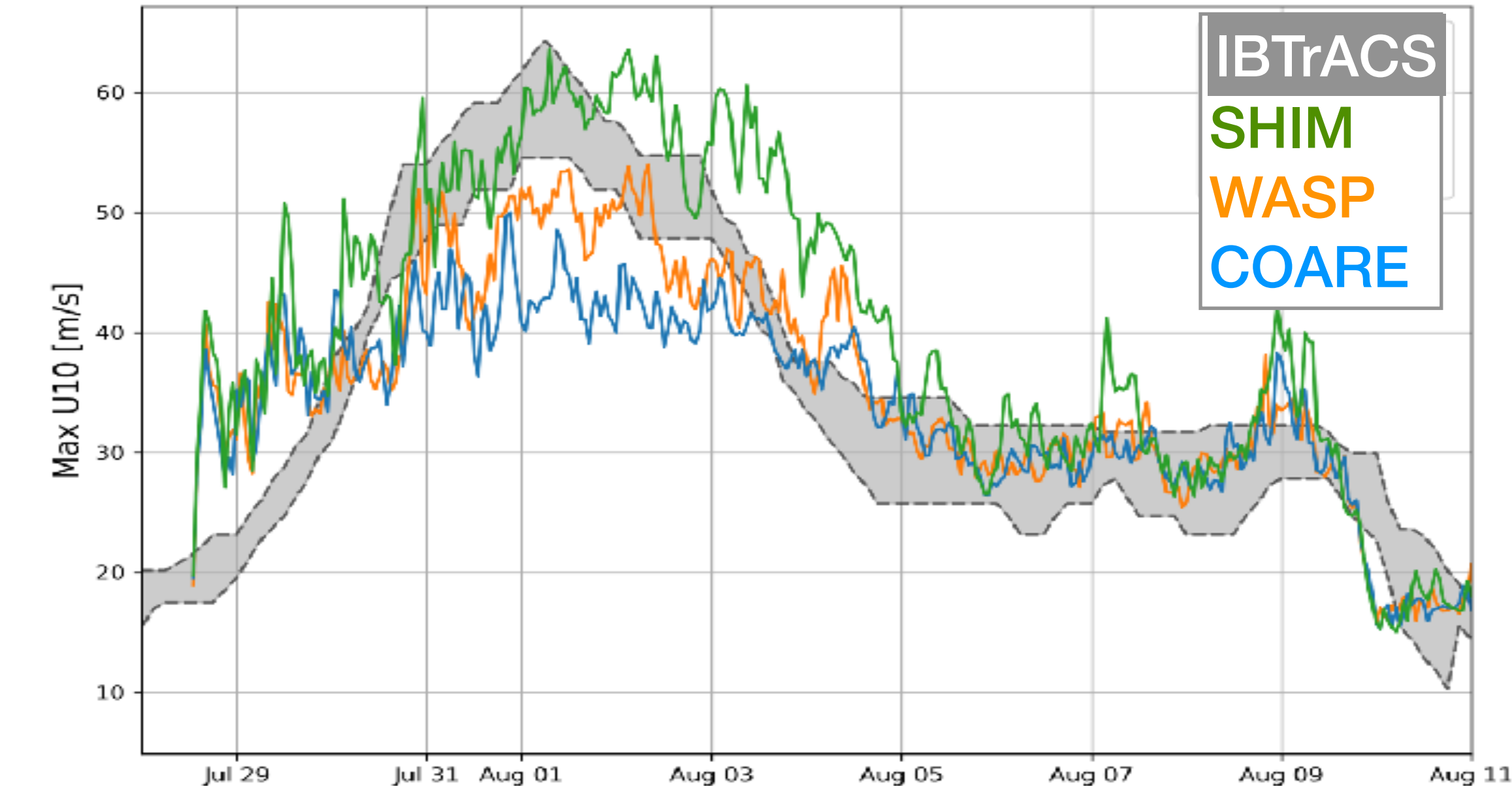


Left

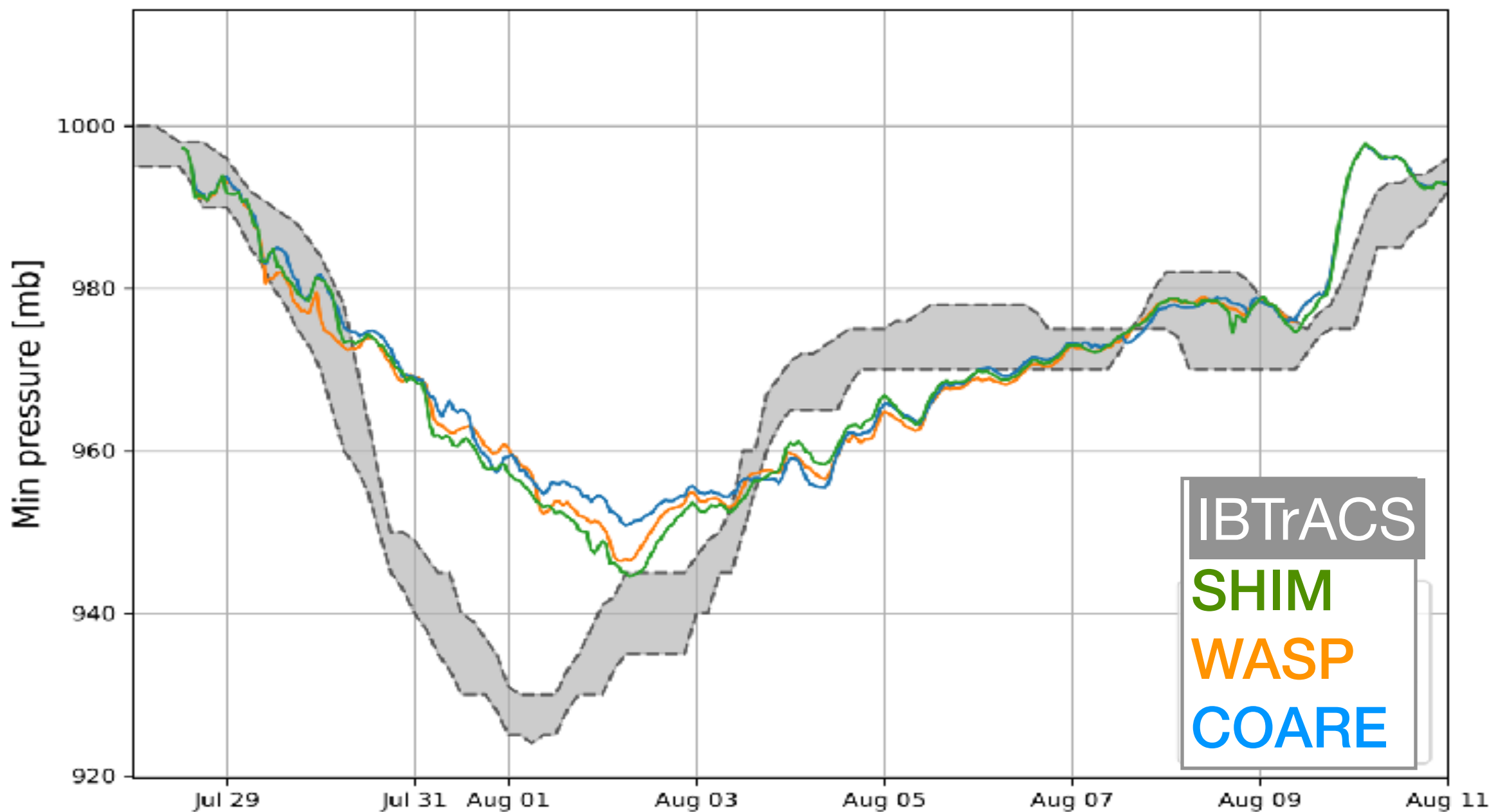
② Khanun's Intensity



Maximum wind speed (m/s)



Minimum Sea level pressure



Simulated Storm Intensity

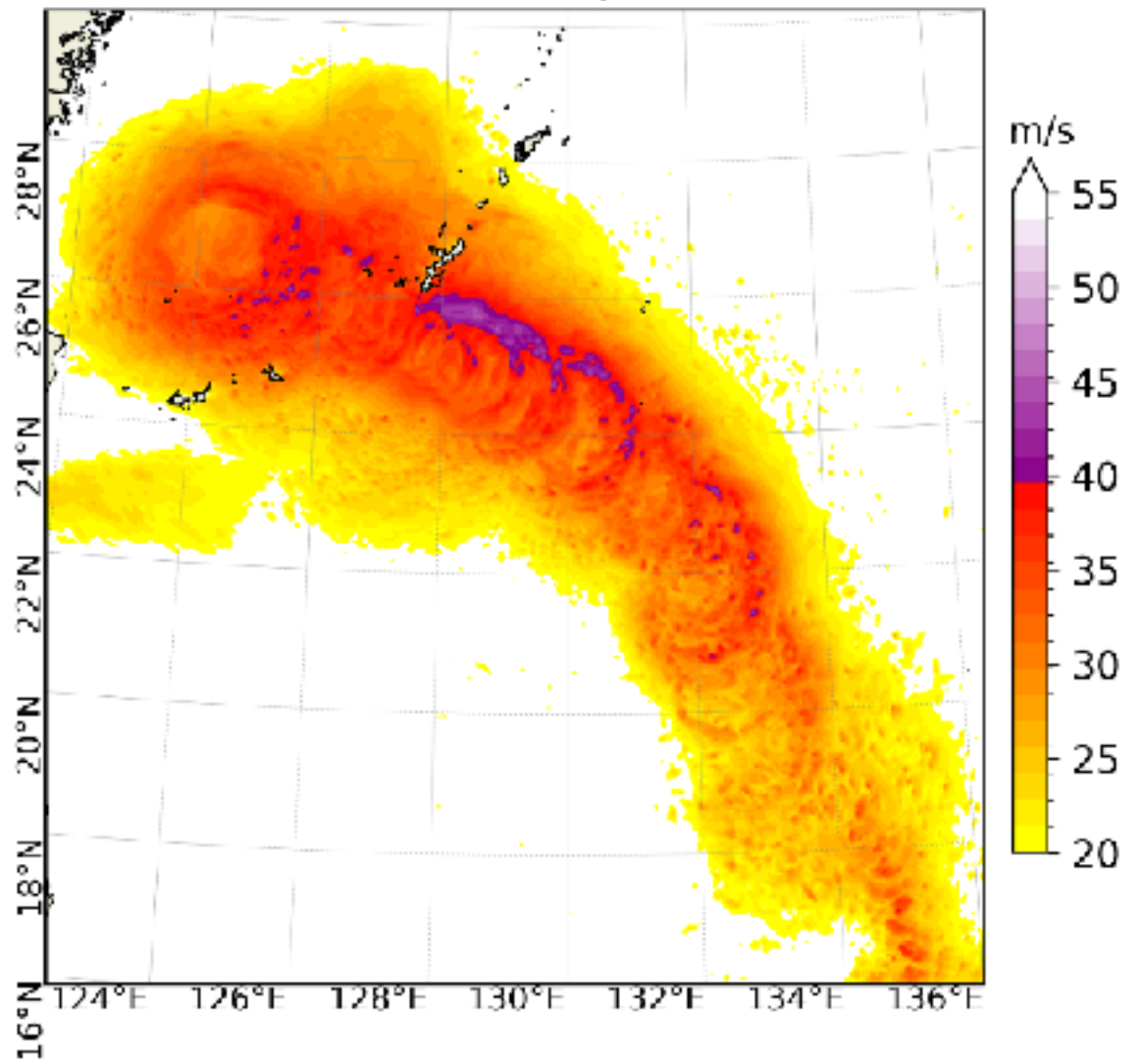
COARE

WASP

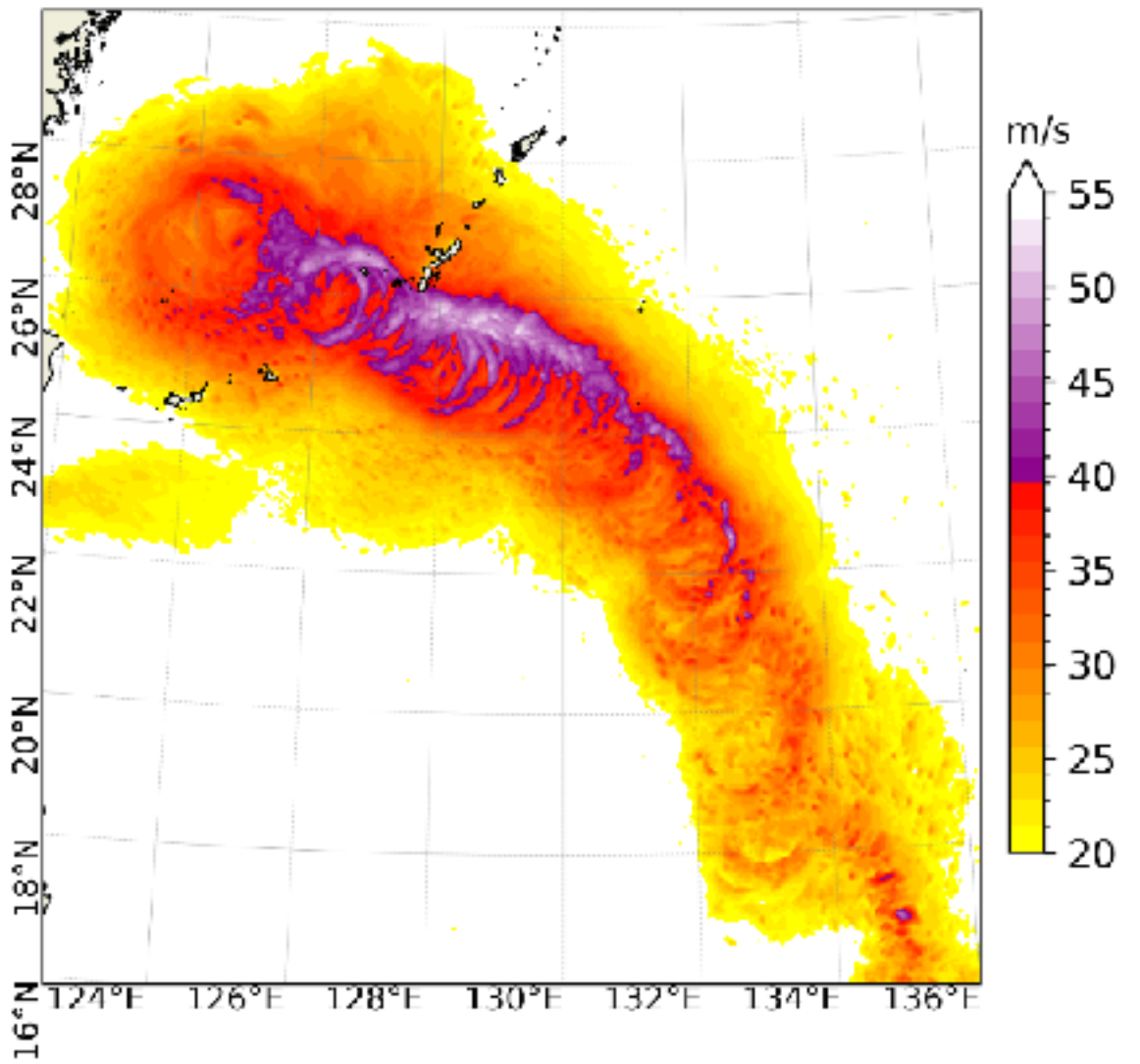
SHIM

$V_{\max}$

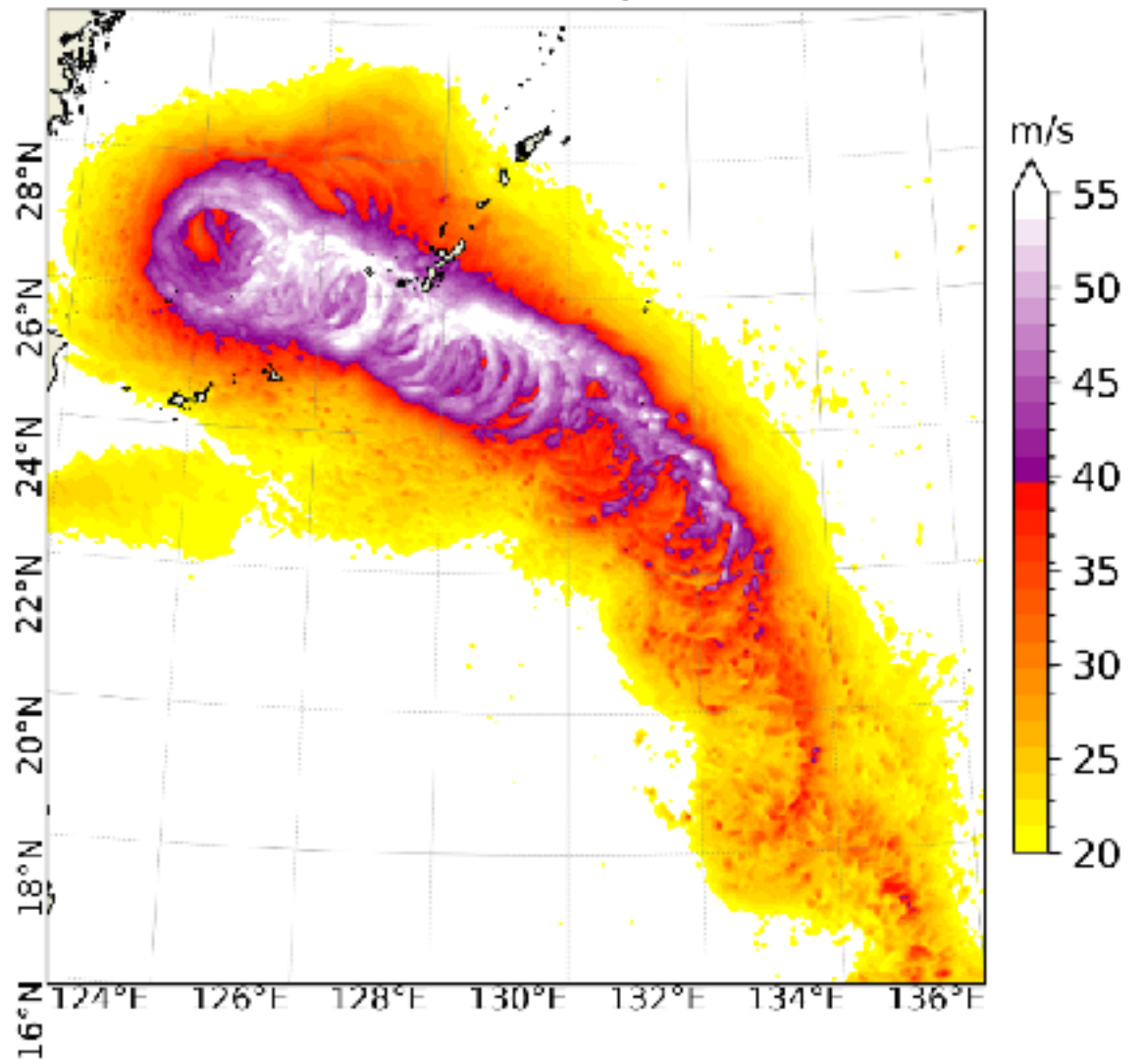
(a) Maximum Wind Speed (COARE)



(b) Maximum Wind (WASP)

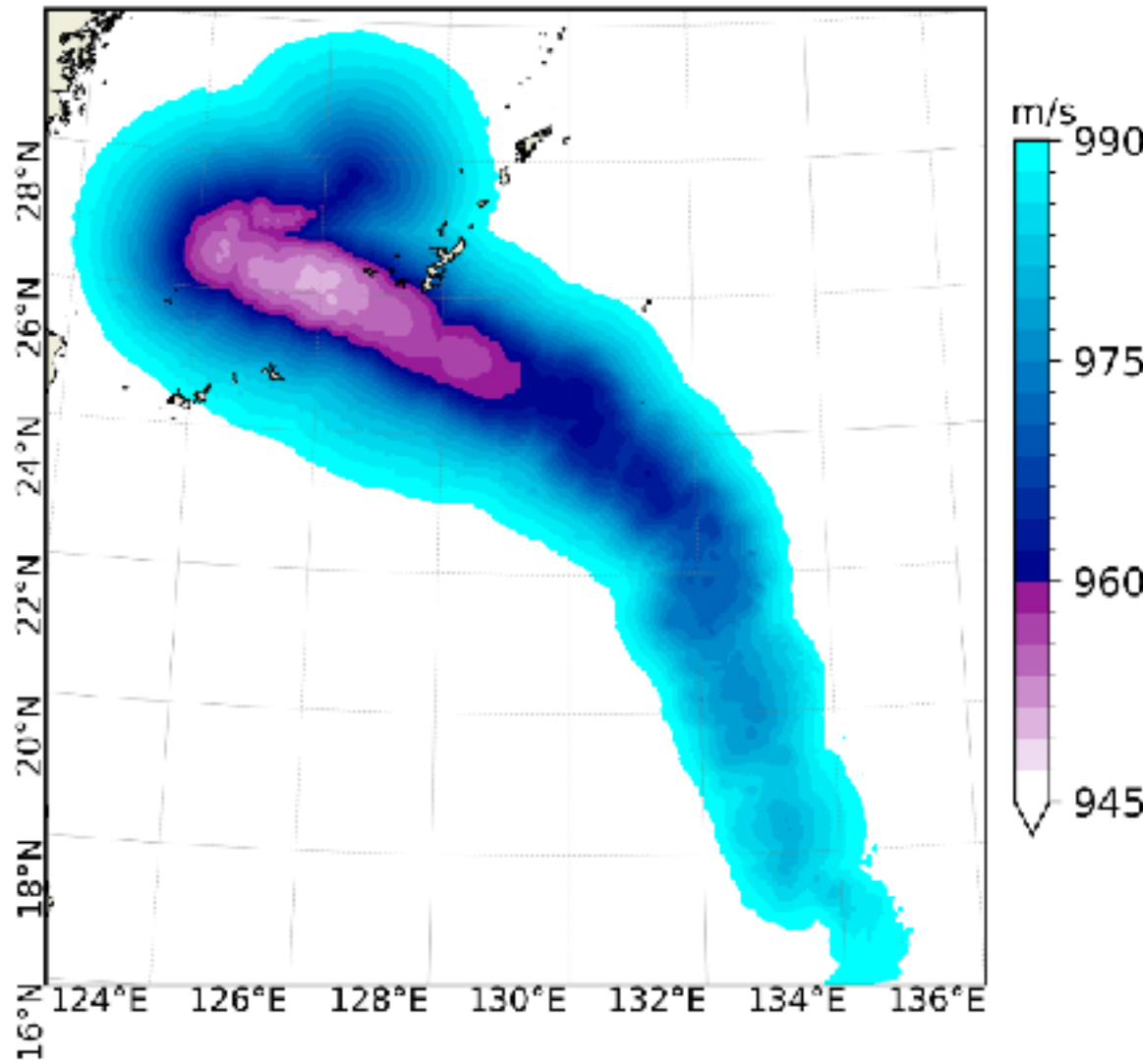


(c) Maximum Wind Speed (SHIM)

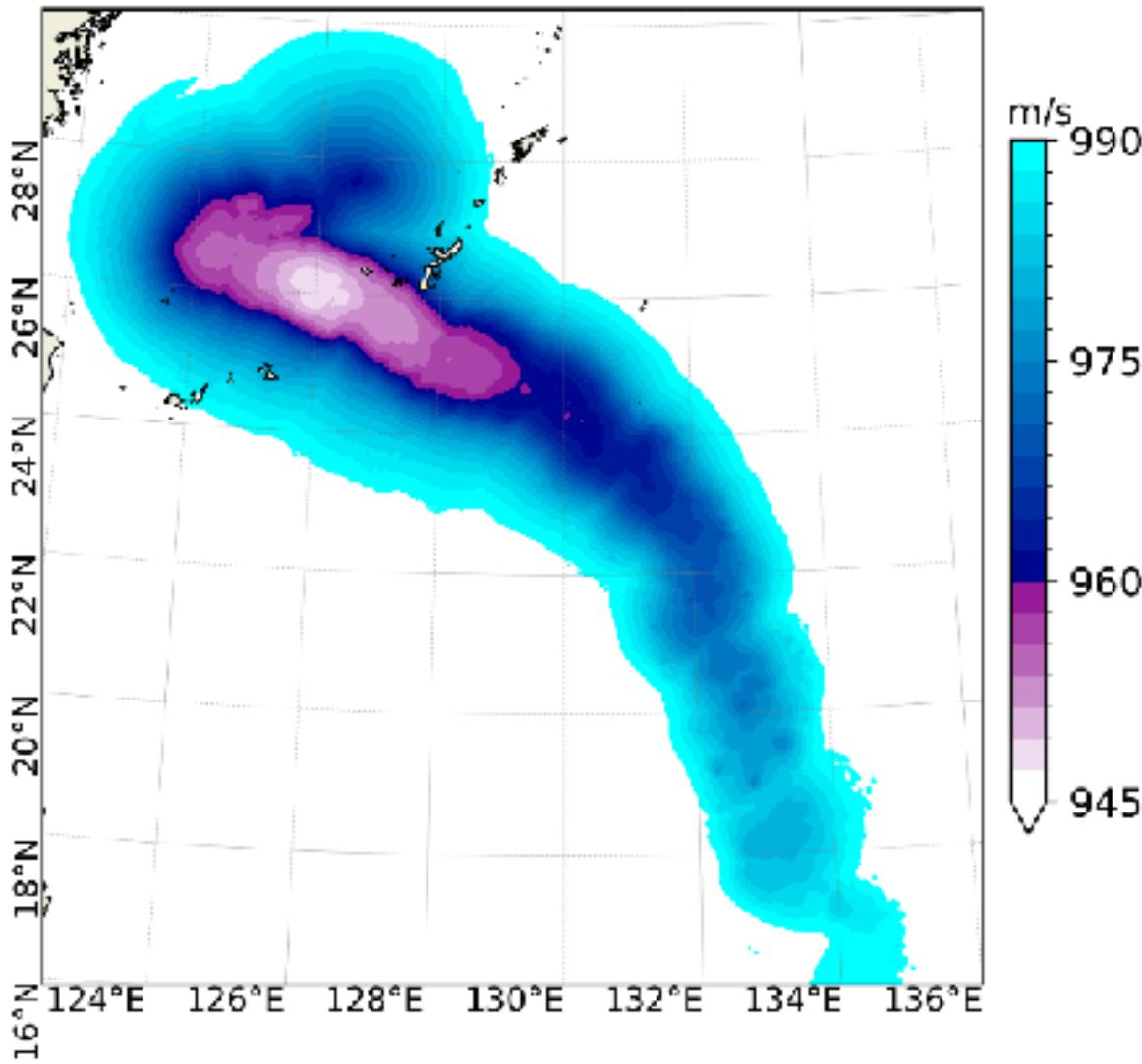


$SLP_{\min}$

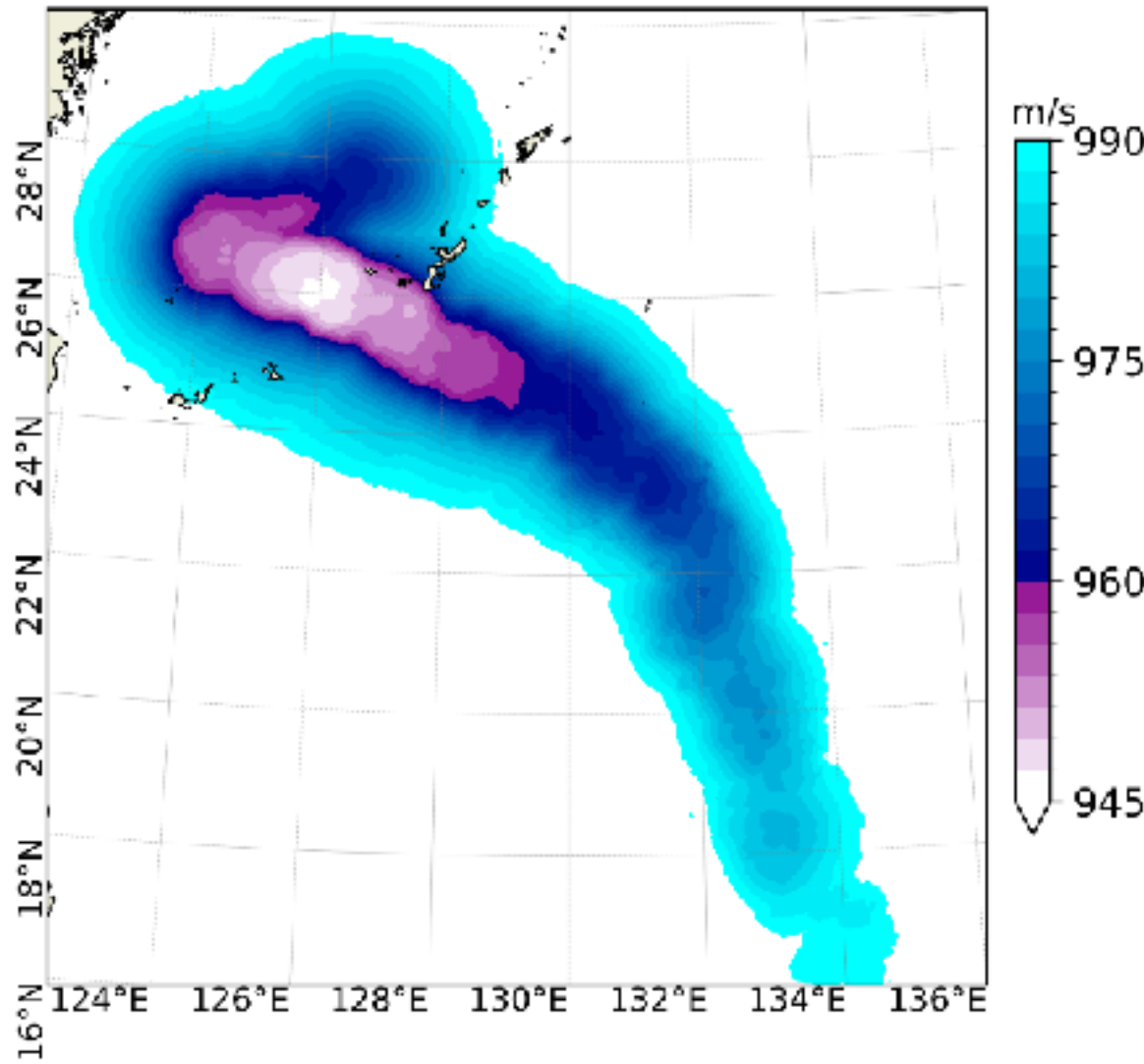
(d) Minimum Sea Level Pressure (COARE)



(e) Minimum Sea Level Pressure (WASP)



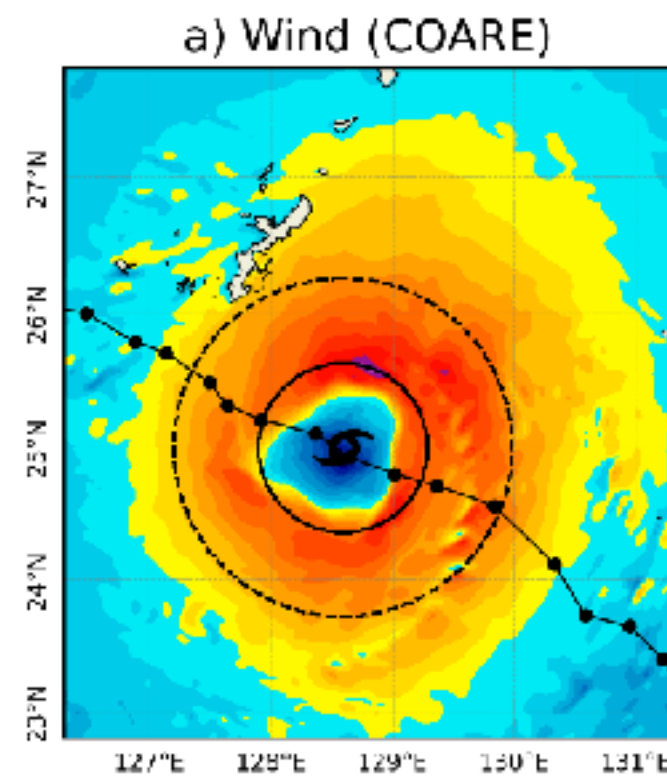
(f) Minimum Sea Level Pressure (SHIM)



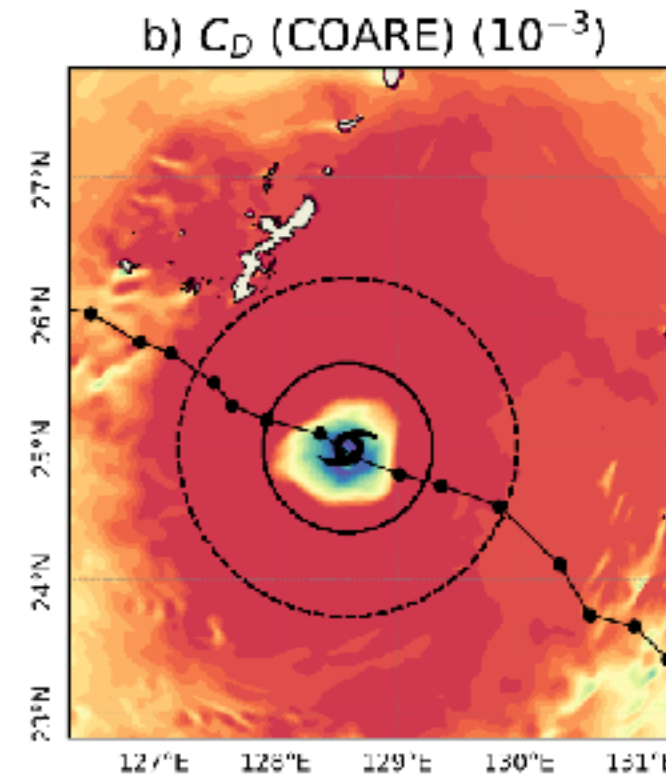
Drag Coefficients, Wave Energies, and Air-Sea Momentum Exchanges

COARE

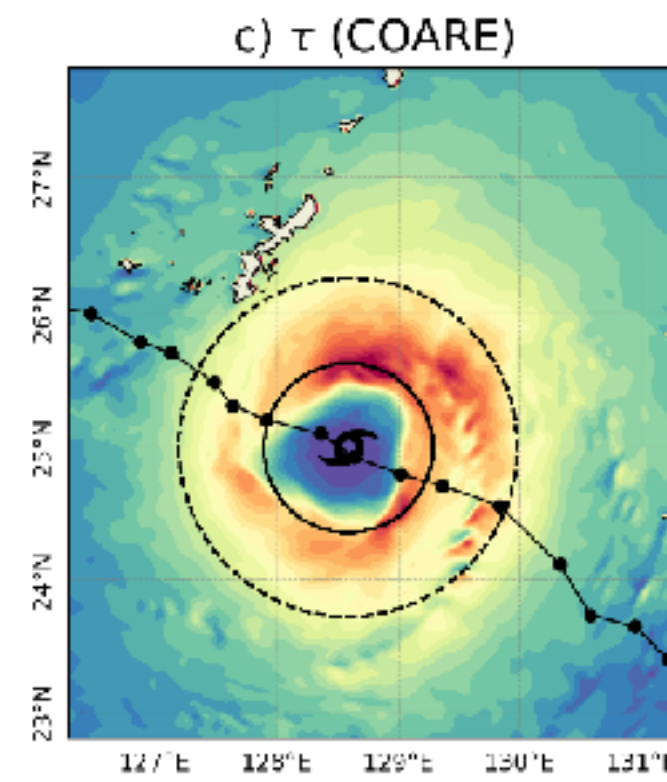
U_{10}



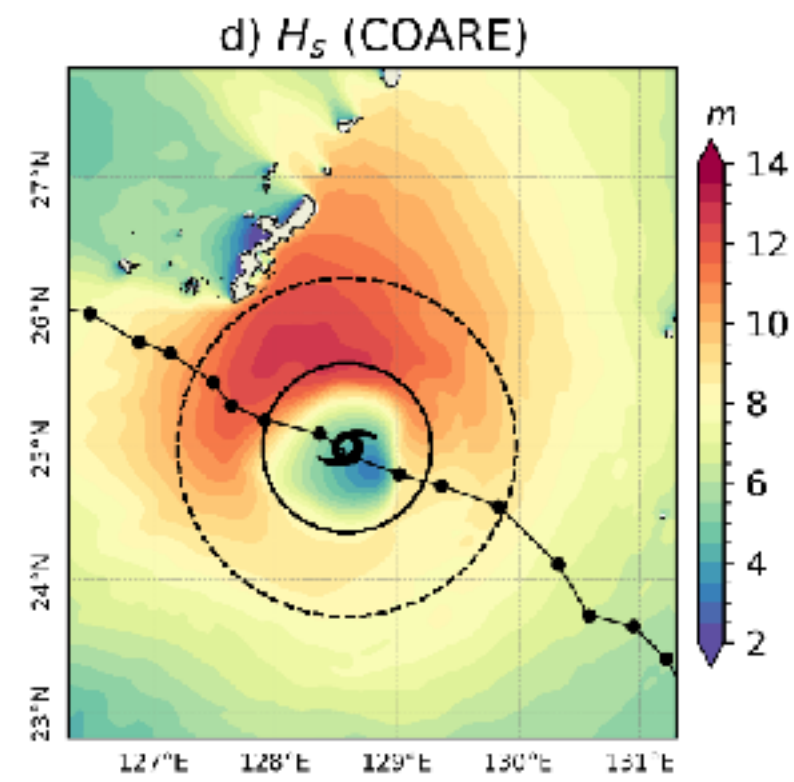
C_D



τ

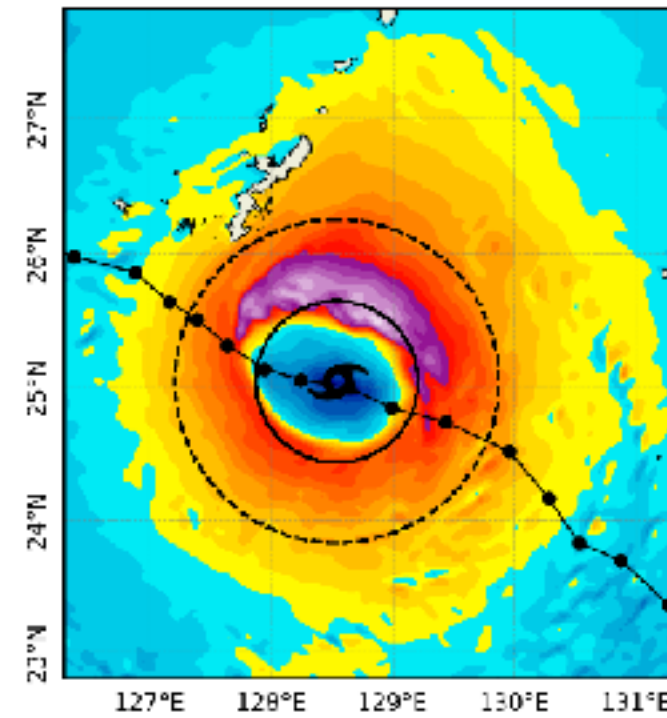


H_s

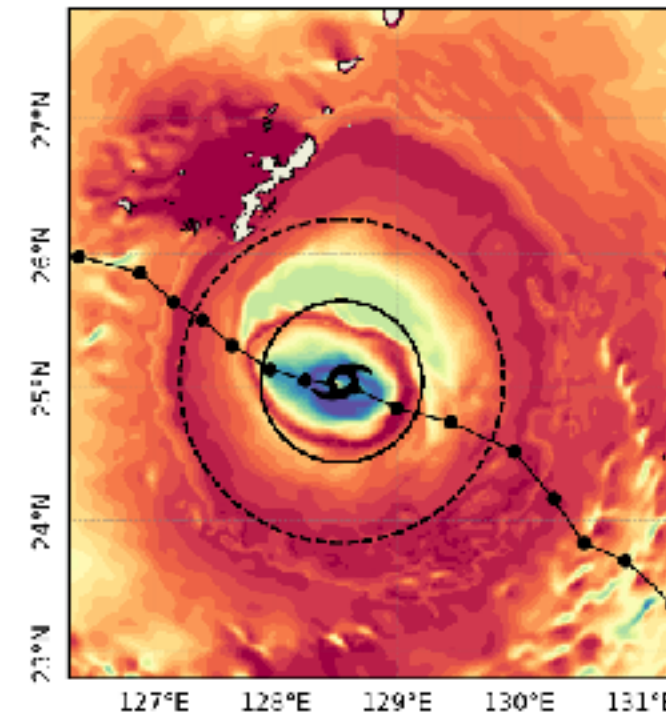


WASP

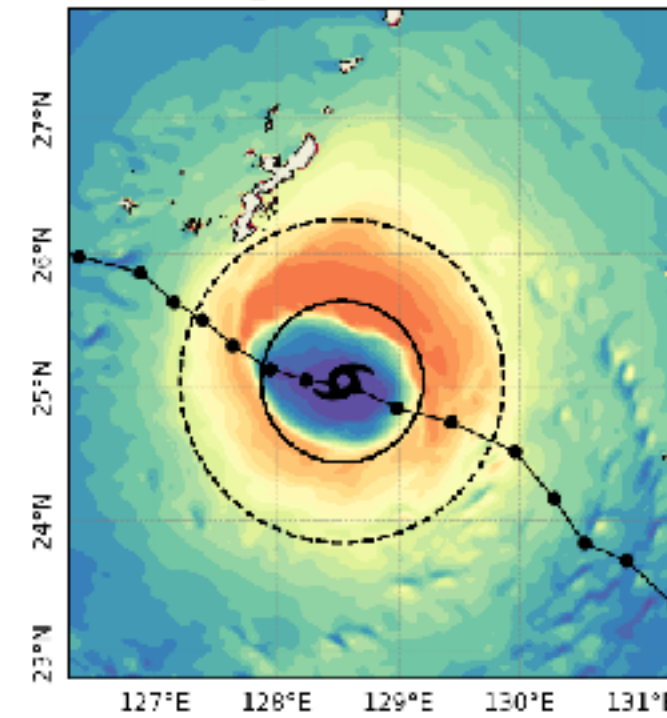
e) Wind (WASP)



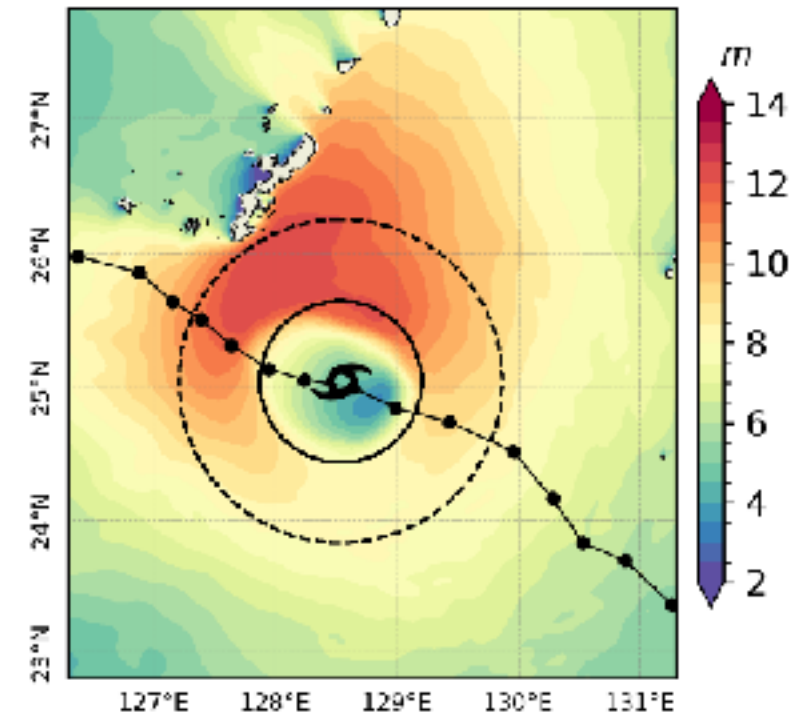
f) C_D (WASP) (10^{-3})



g) τ (WASP)

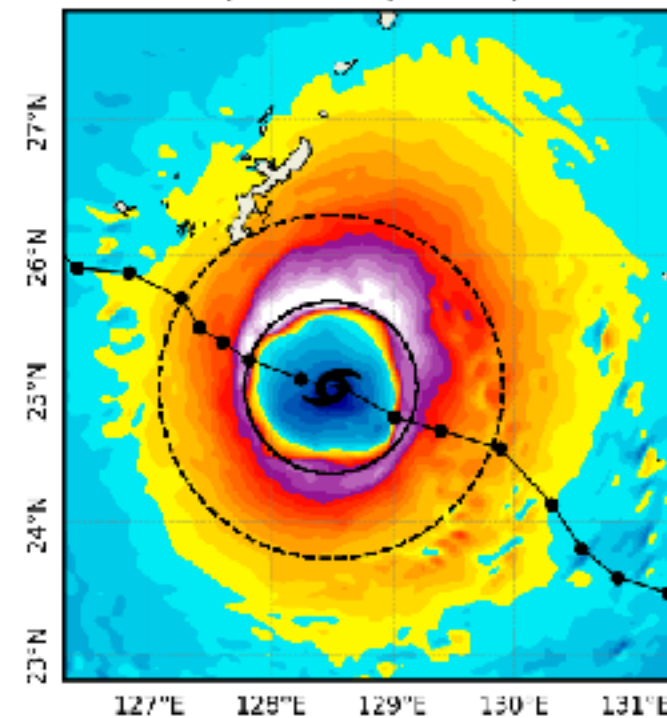


h) H_s (WASP)

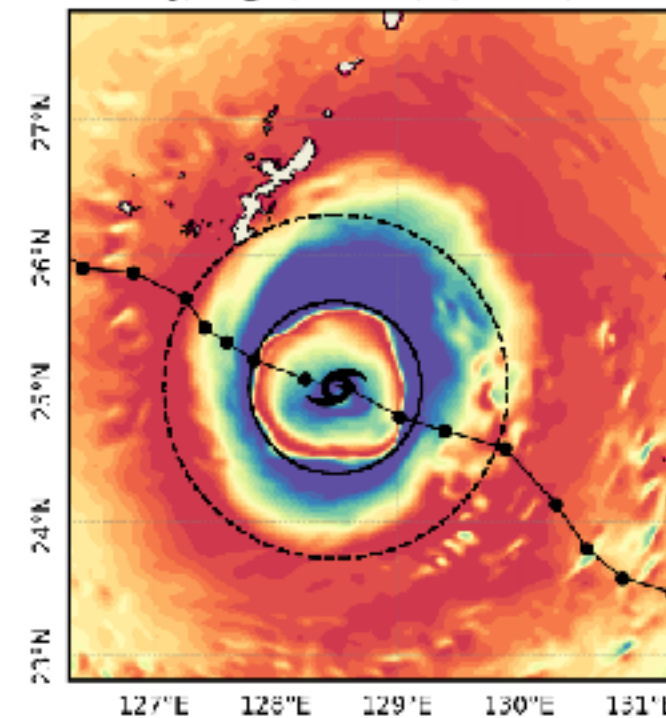


SHIM

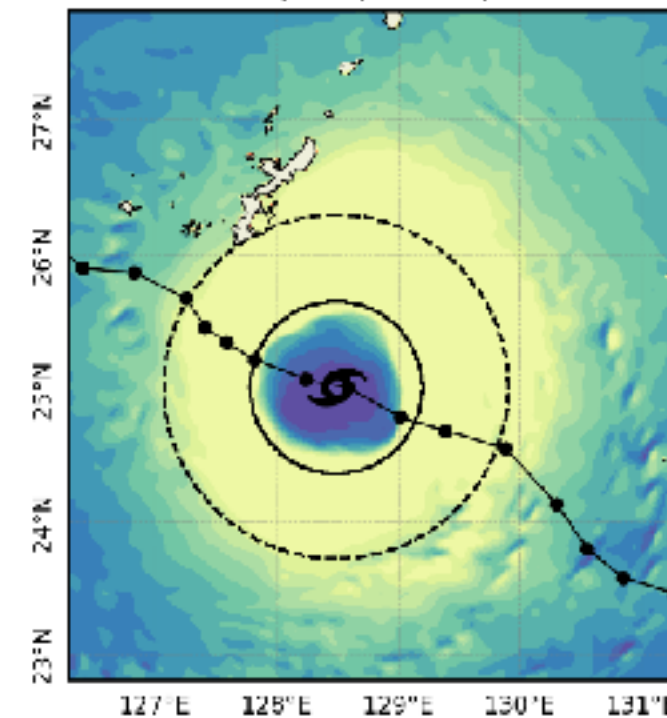
i) Wind (SHIM)



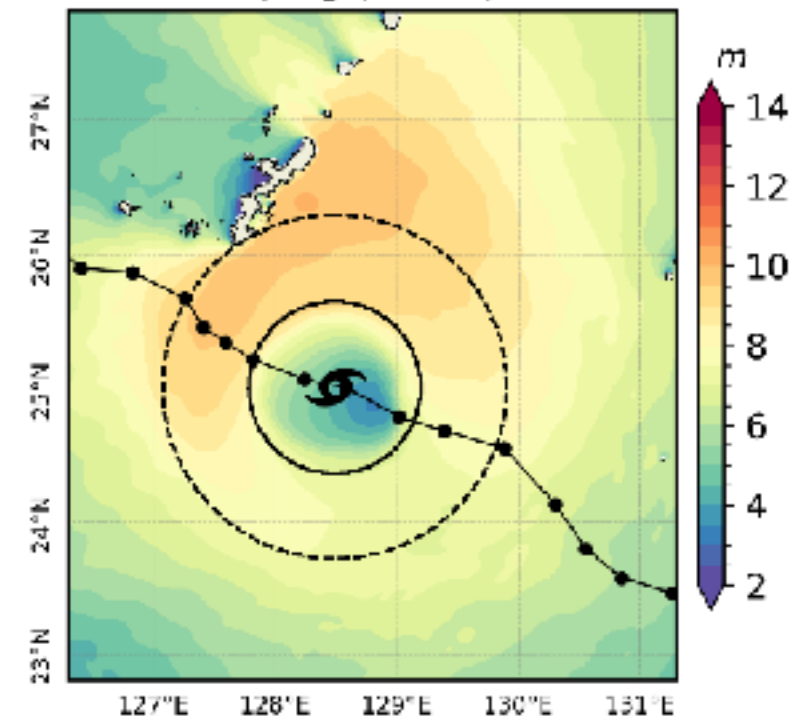
j) C_D (SHIM) (10^{-3})



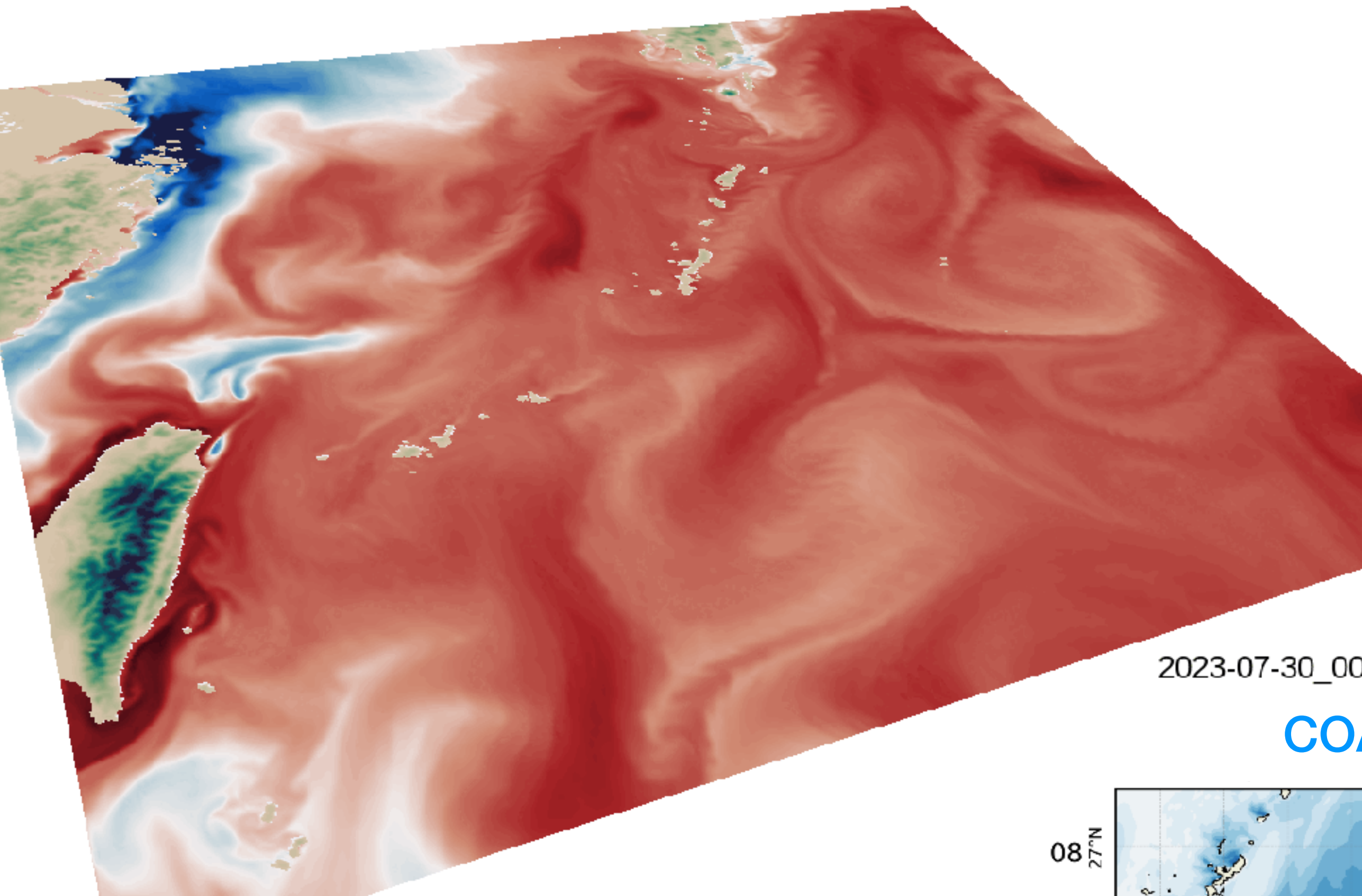
k) τ (SHIM)



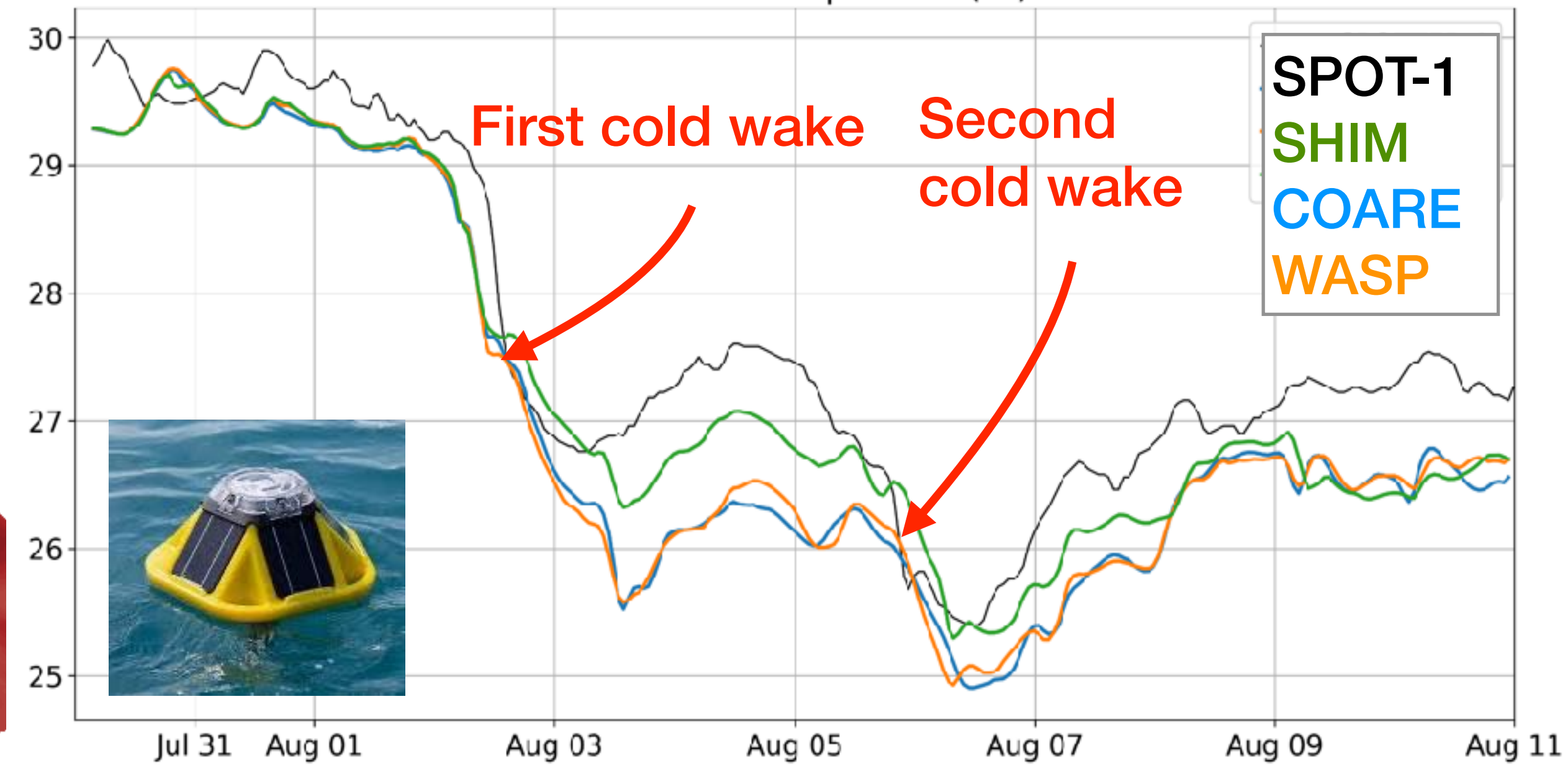
l) H_s (SHIM)



③ Khanun induced cold wake



Sea surface temperature



2023-07-30_00:00:00

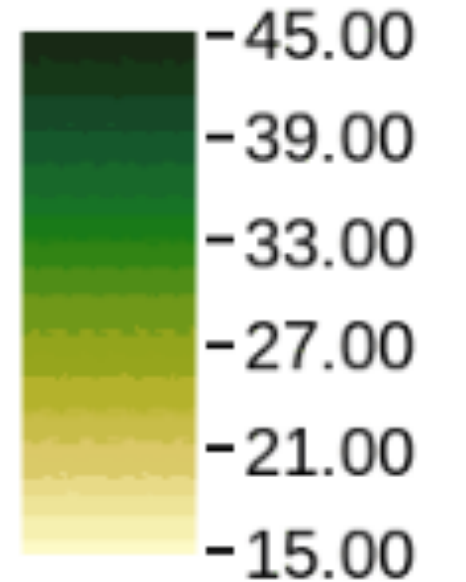
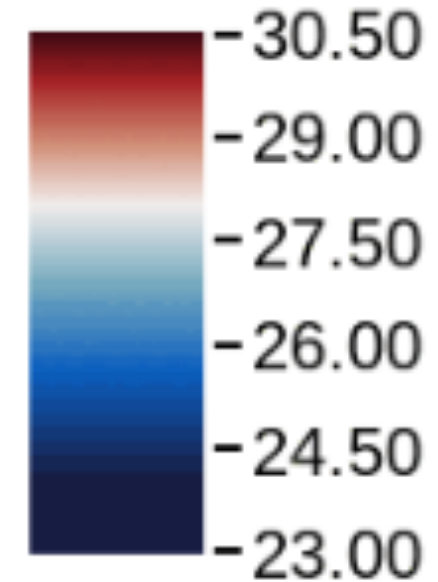
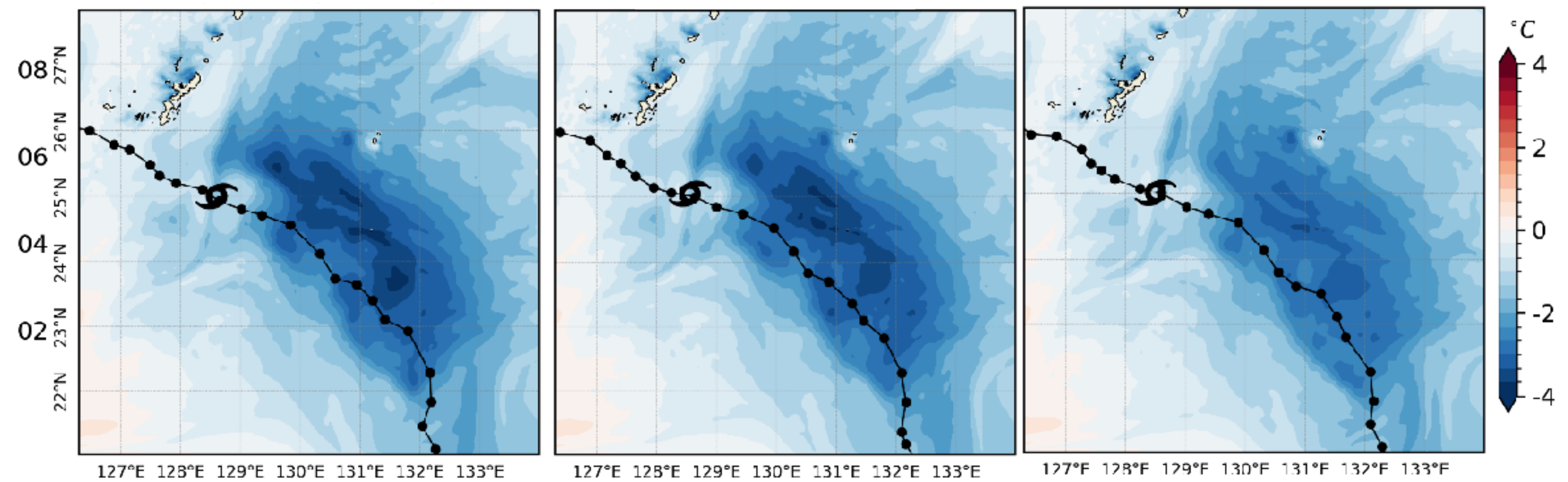
COARE

WASP

SHIM

Wind (m/s)

SST (C)



Ck

Enthalpy flux

Enthalpy flux: Feedback effect

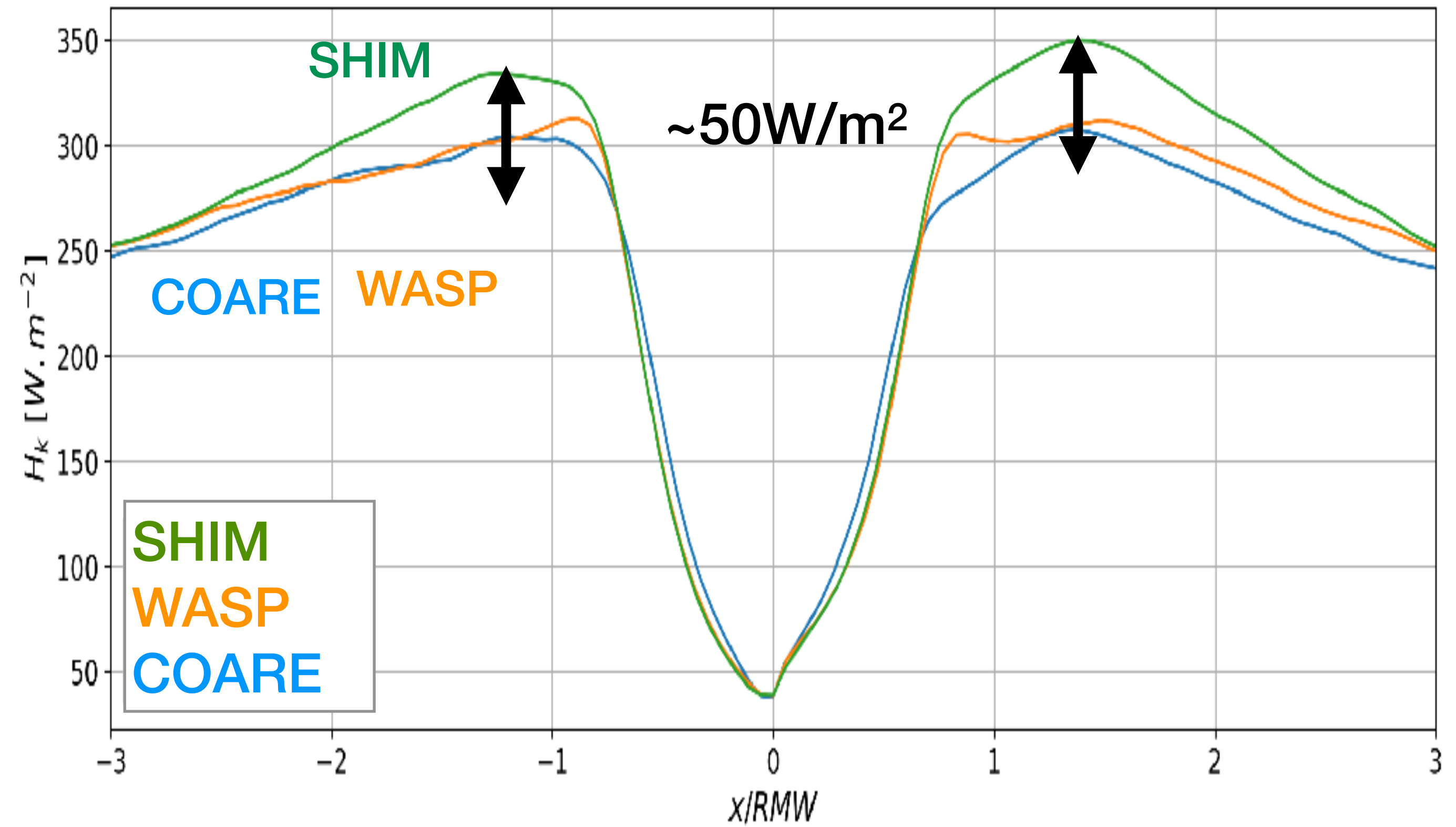
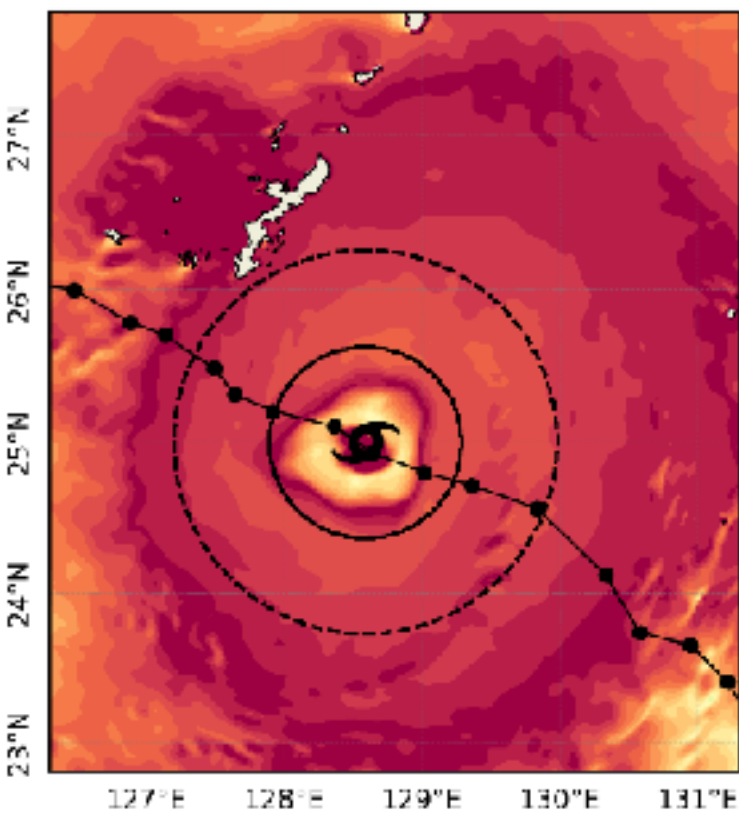
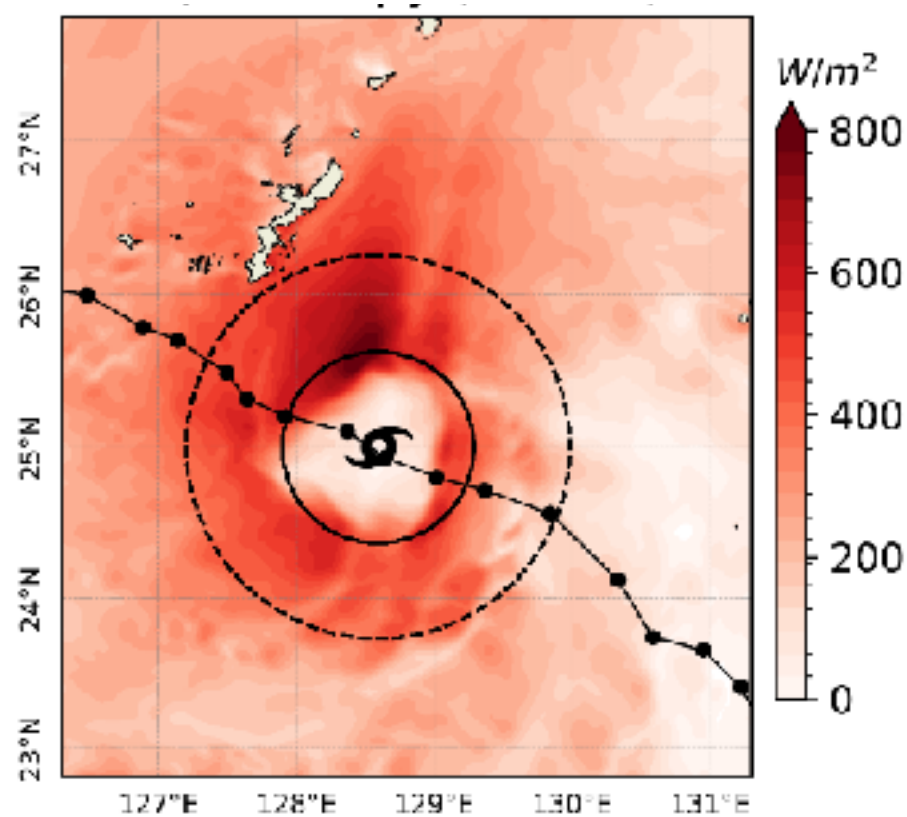
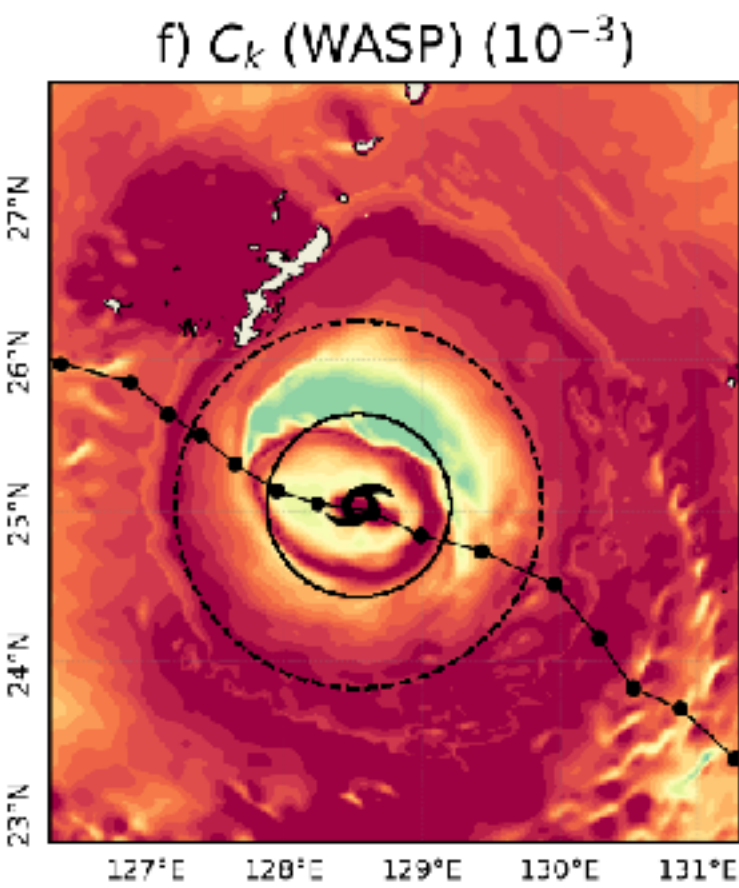
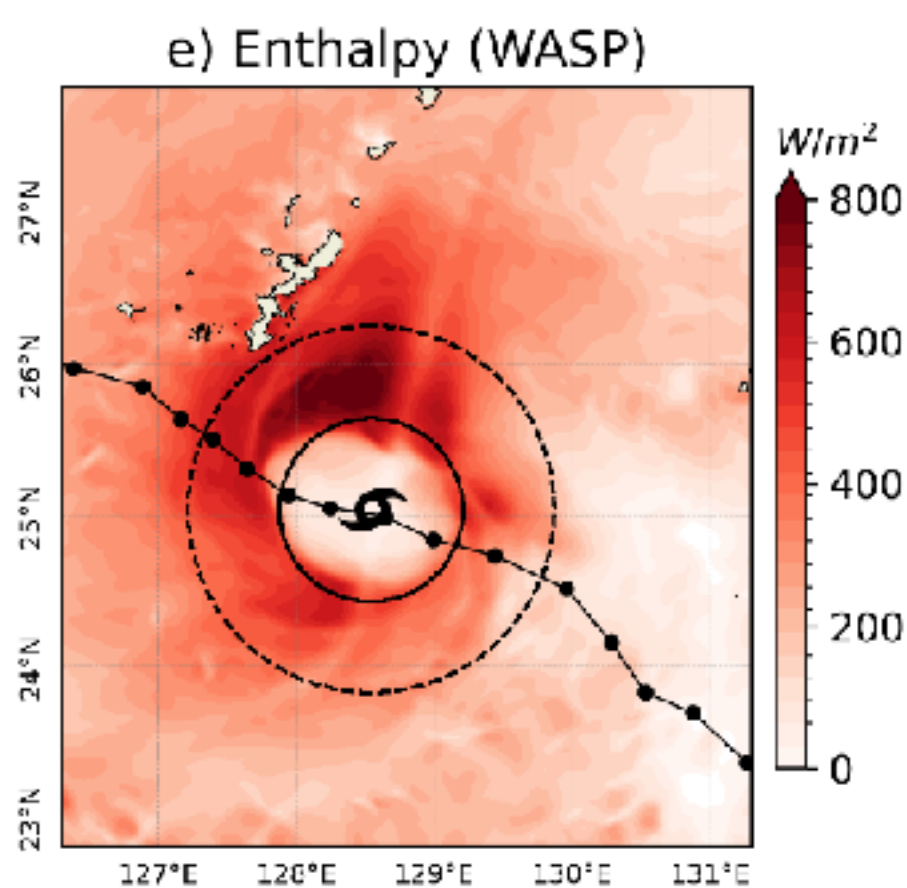
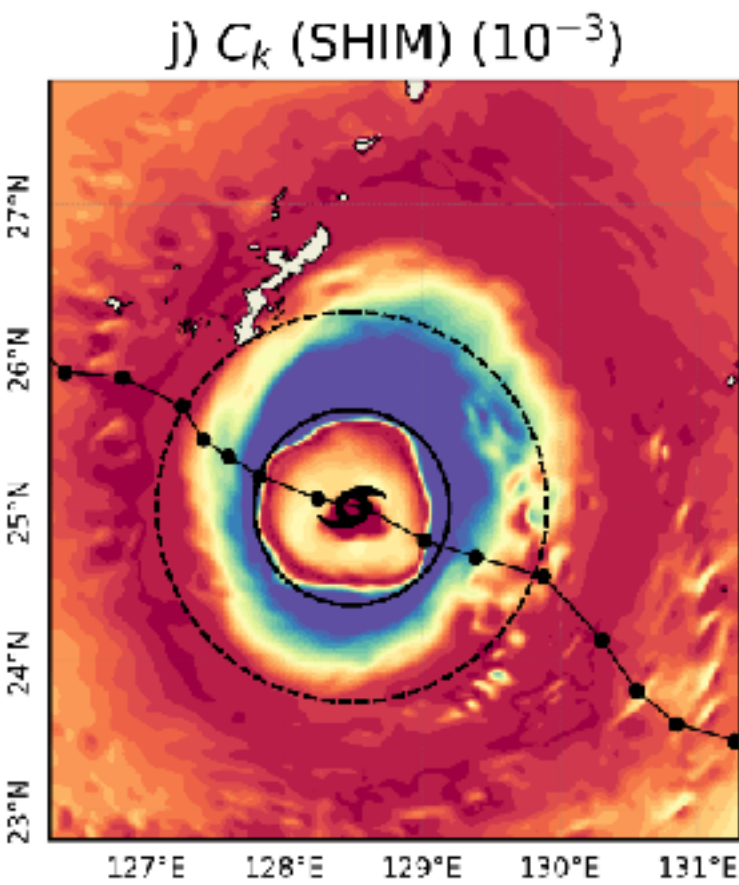
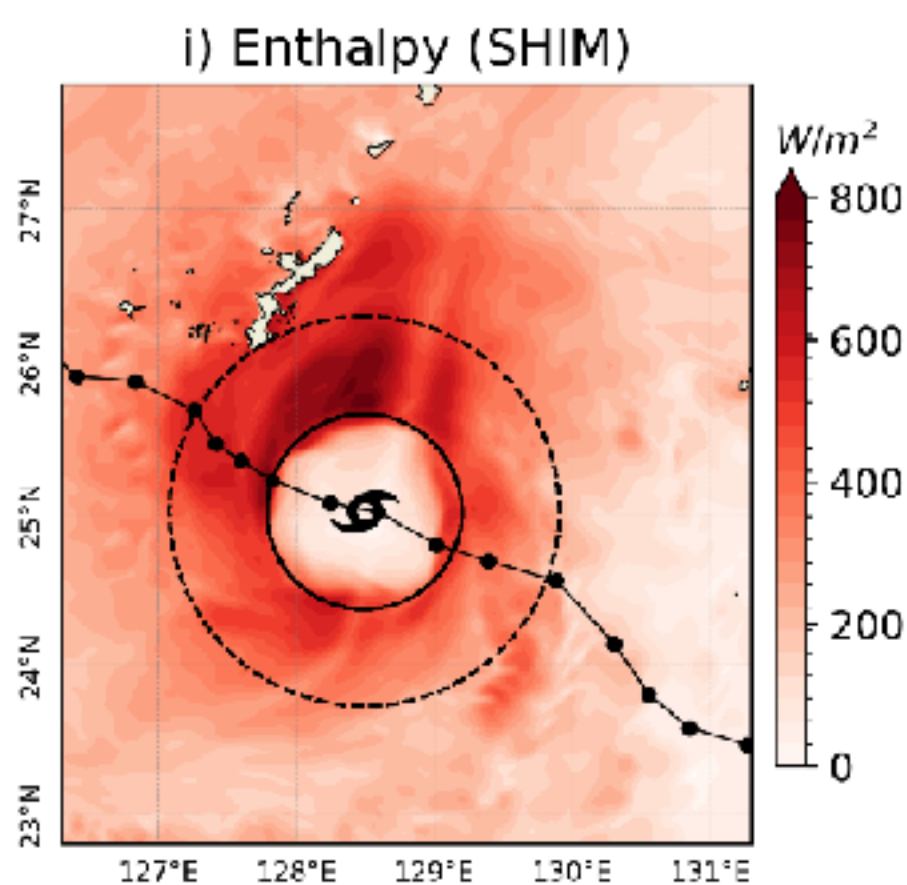
COARE

Time-averaged Enthalpy flux

WASP

SHIM

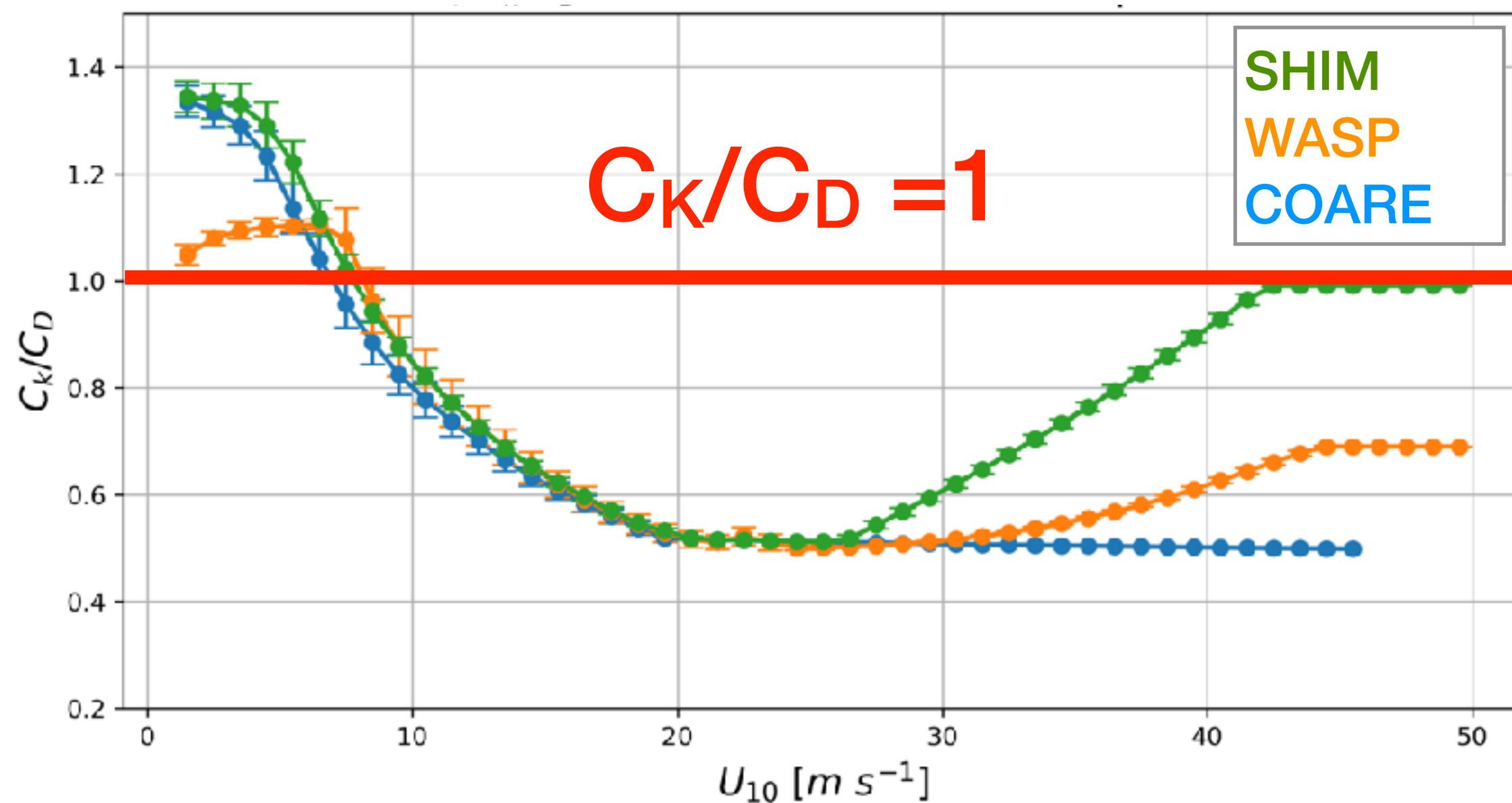
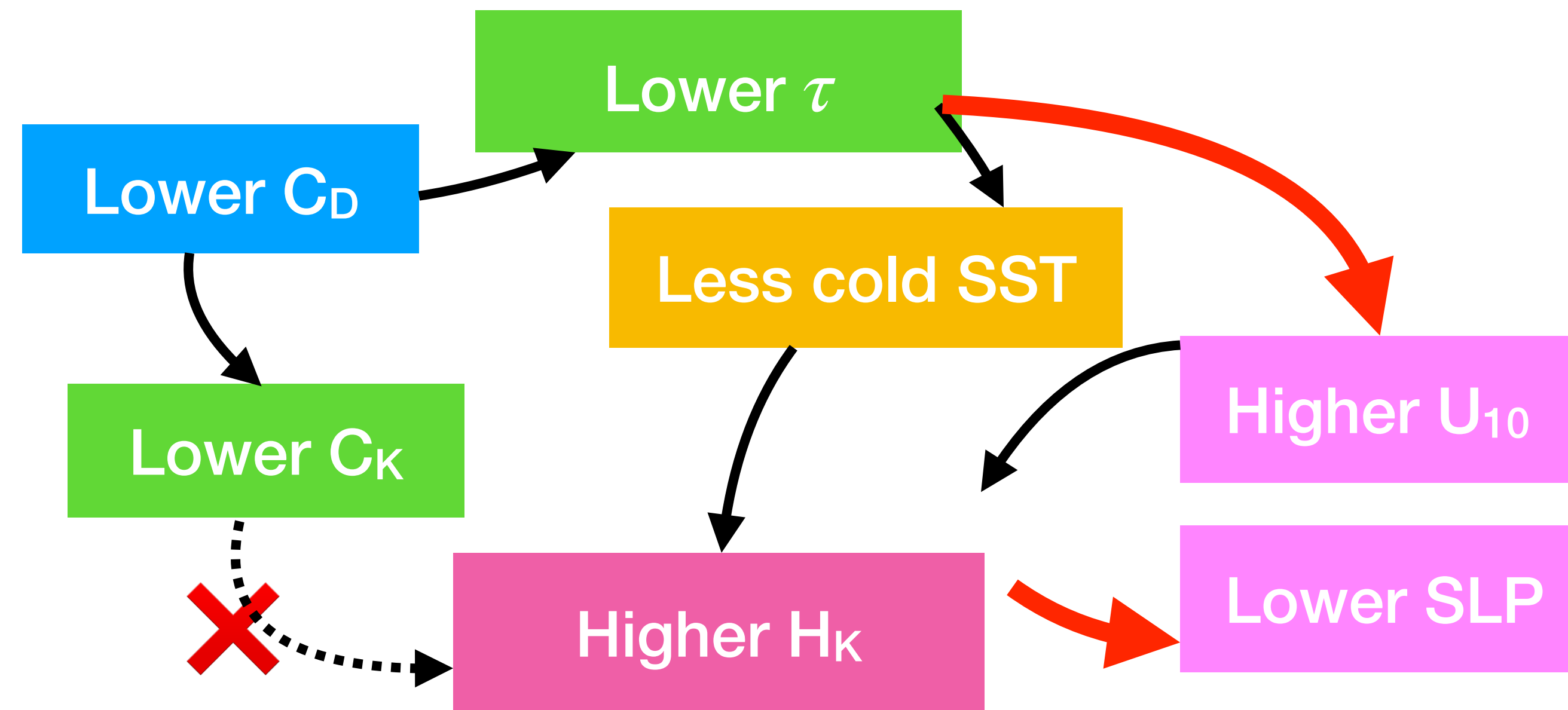
$\sim 50 \text{ W/m}^2$



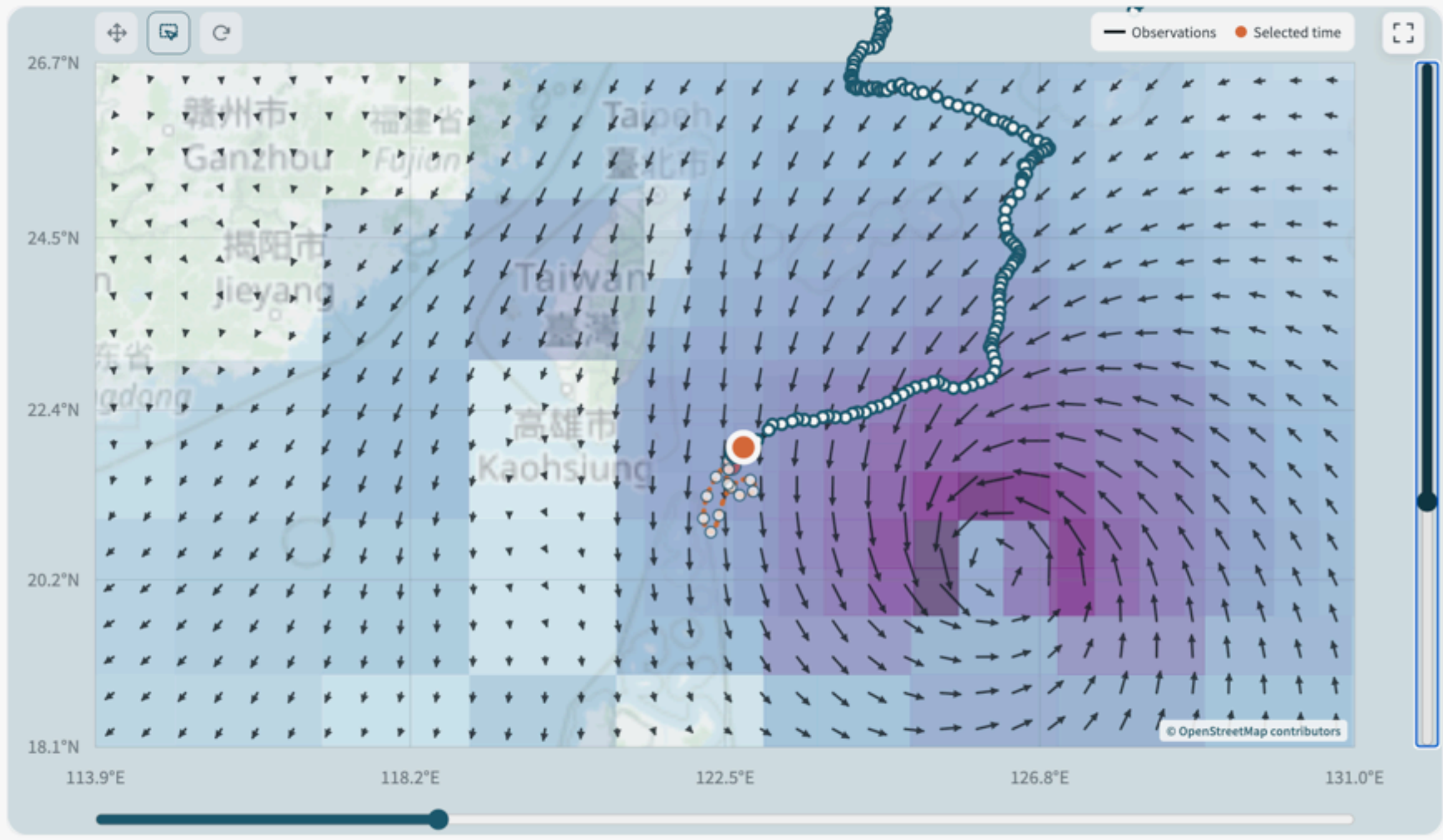
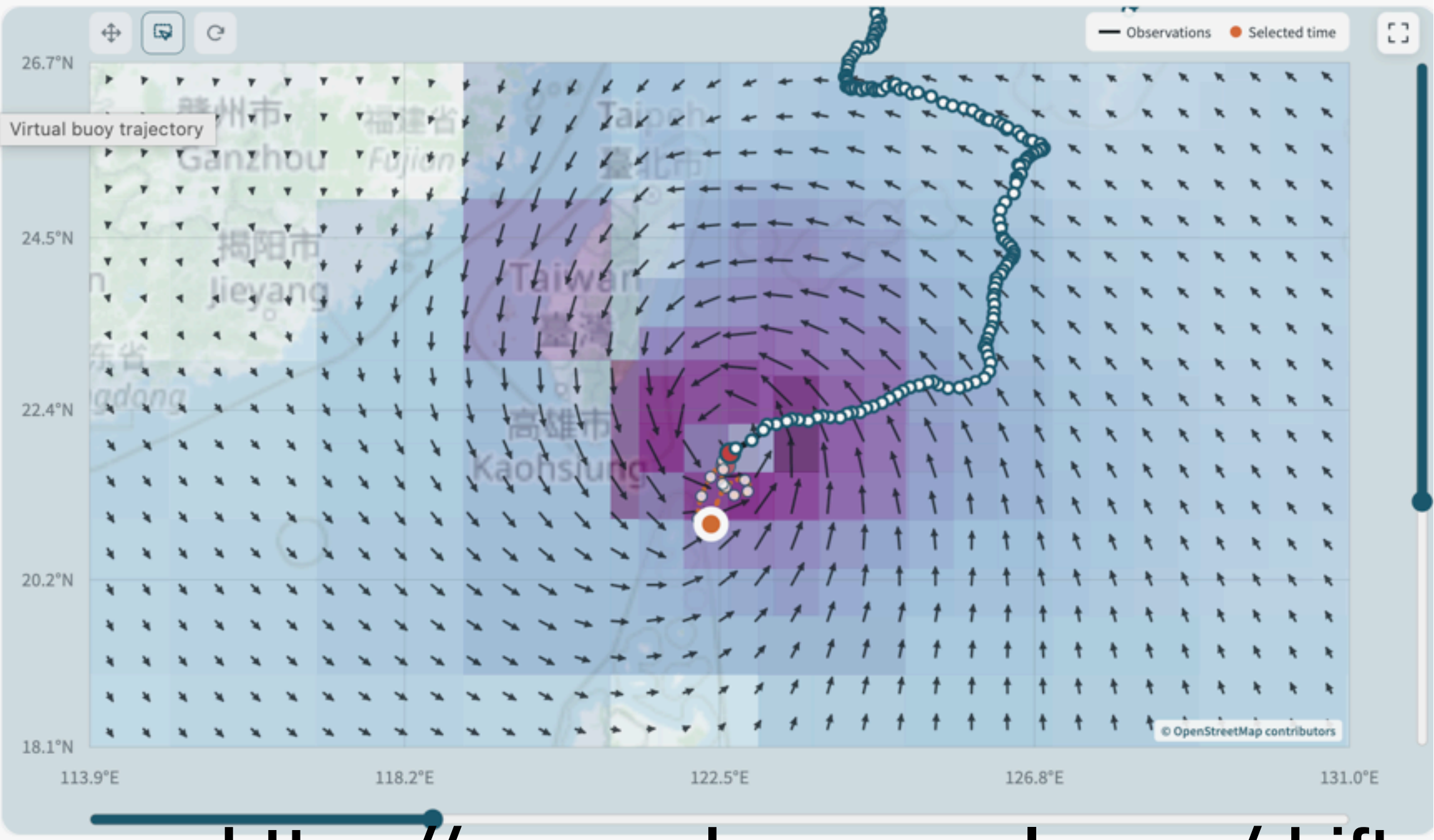
Summary and Discussion

C_D behavior in high winds (>30 m/s) represents the strong spatial variability in sea states and wave-wind directional coupling, which feed back on storm intensity by modulating air-sea fluxes.

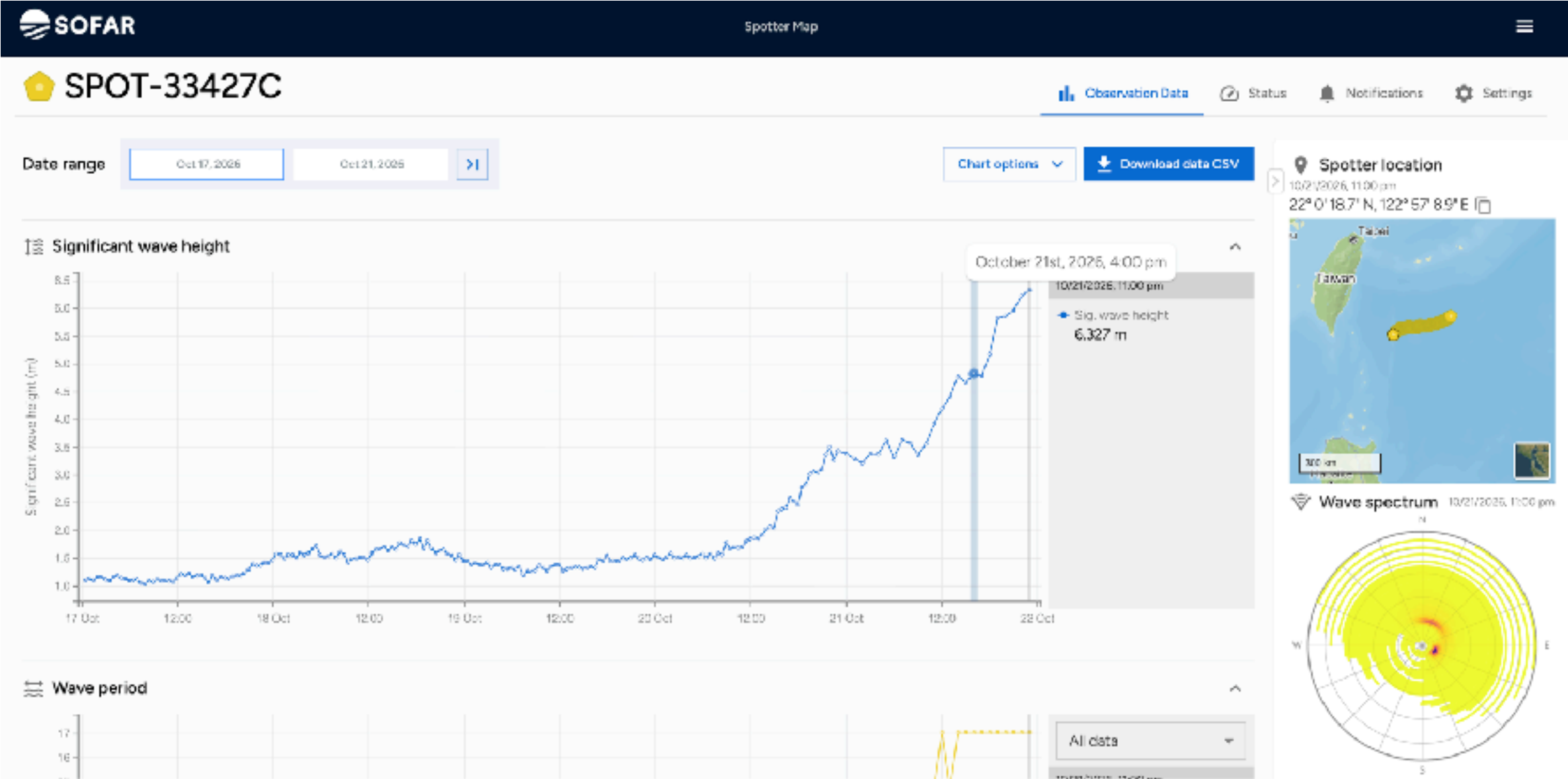
C_K/C_D ratio



Typhoon Champi



<https://research.wynpaully.com/driftcaste>

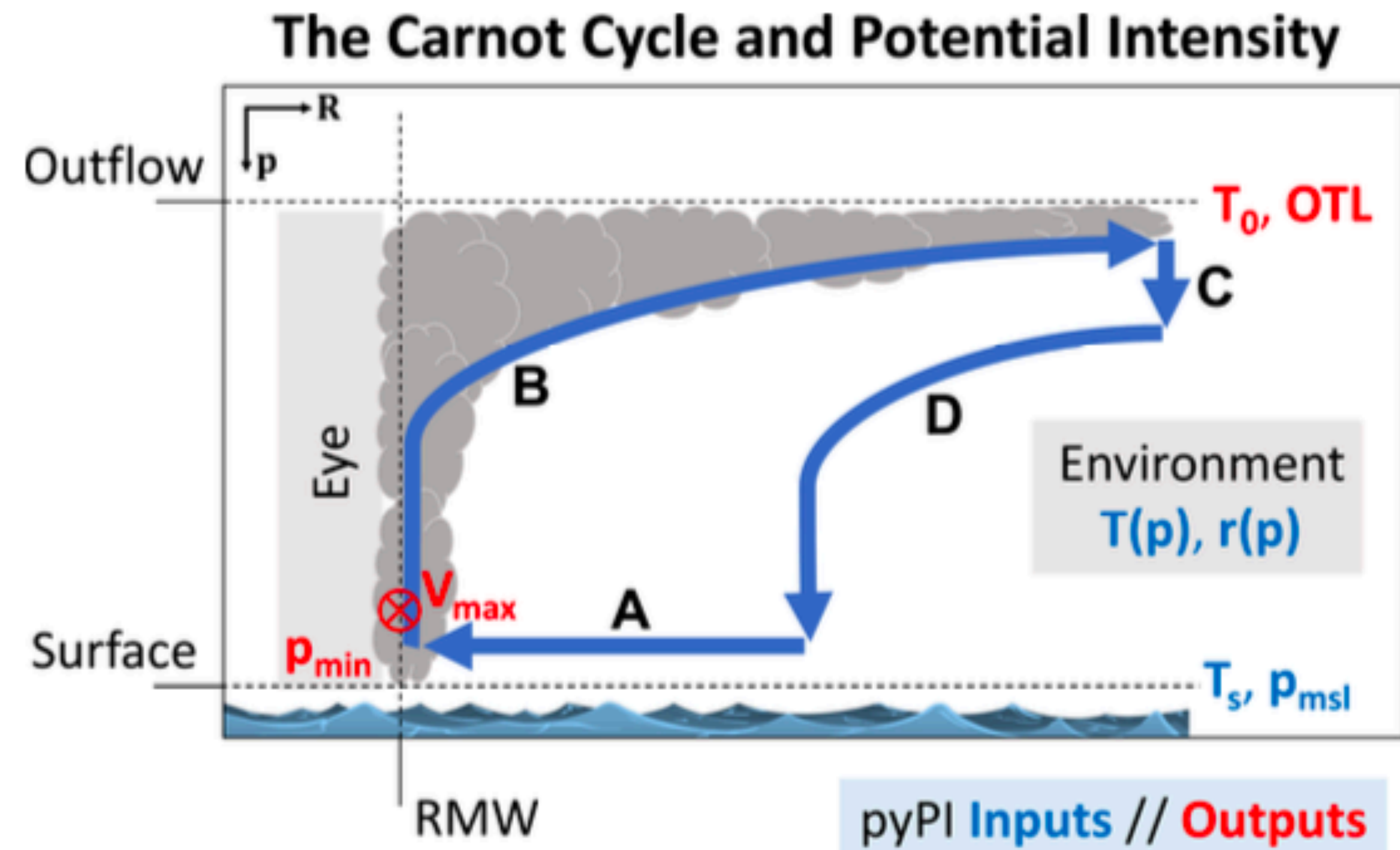


Drag Coefficient and Storm Potential Intensity

In the equilibrium condition, TC intensity is constrained by the balance between energy added at the warm ocean surface and energy lost in the cool outflow region aloft (Emanuel 1988)

$$V_{max}^2 = \frac{(\bar{T} - T_o)}{T_o} \frac{C_K}{C_D} (K_{SST} - k)$$

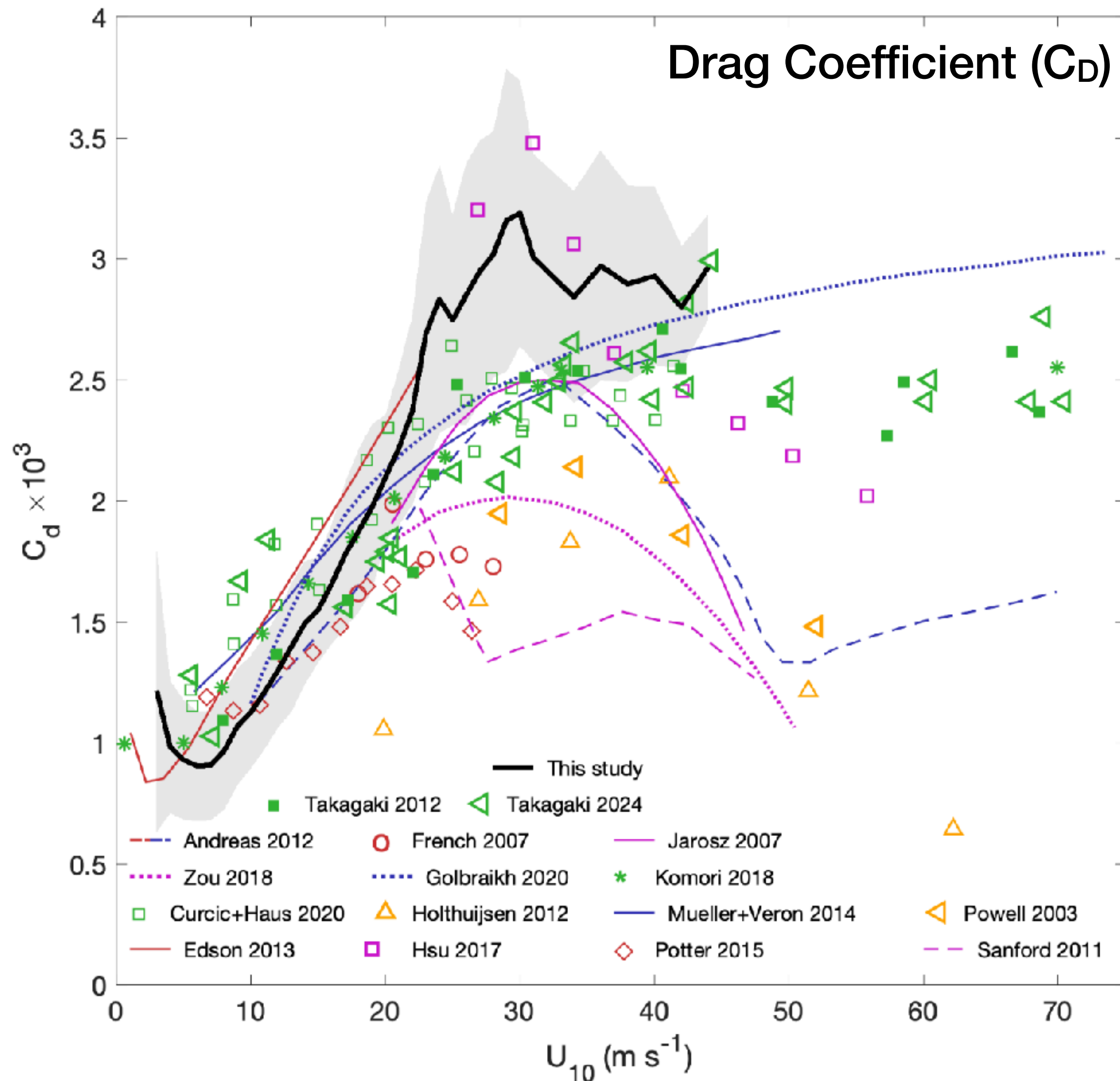
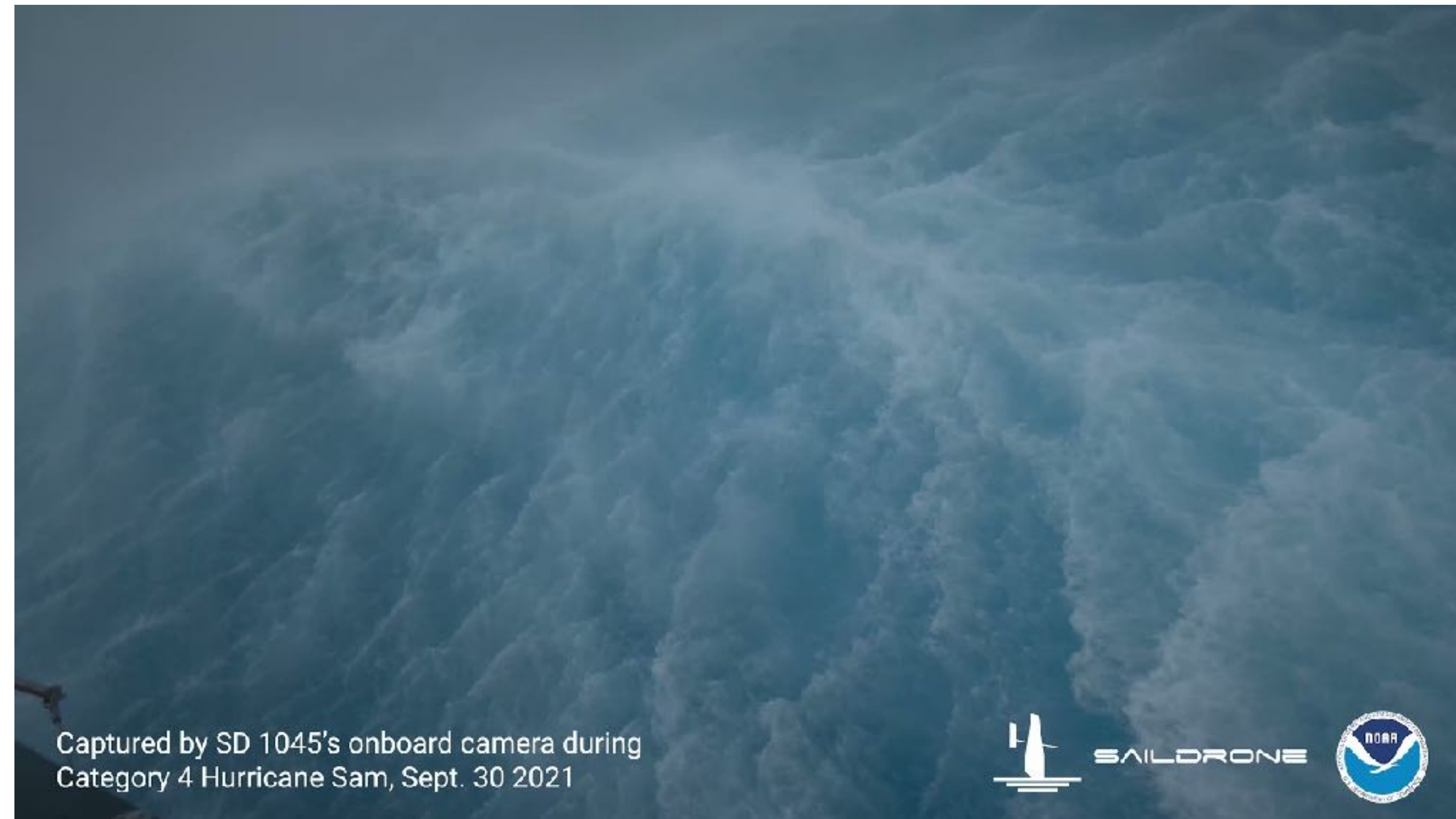
pre-storm ocean temp. $\rightarrow \bar{T}$
TC outflow temperature $\rightarrow T_o$
air-sea enthalpy difference $\rightarrow K_{SST} - k$



Gilford 2021

C_K , C_D , k , & K_{SST} all vary with sea state and its spatial variability under high wind. Sea states and wave-supported roughness length are key parameters.

Sea state and drag coefficient under very high winds



https://www.youtube.com/results?search_query=https%3A%2F%2Fwww.youtube.com%2Fwatch%3Fv%3DTzgdSSb0T98

The hurricane foam coverage and sea spray form a slippery surface: Wind energy input to waves ceases to increase while wind speeds increase

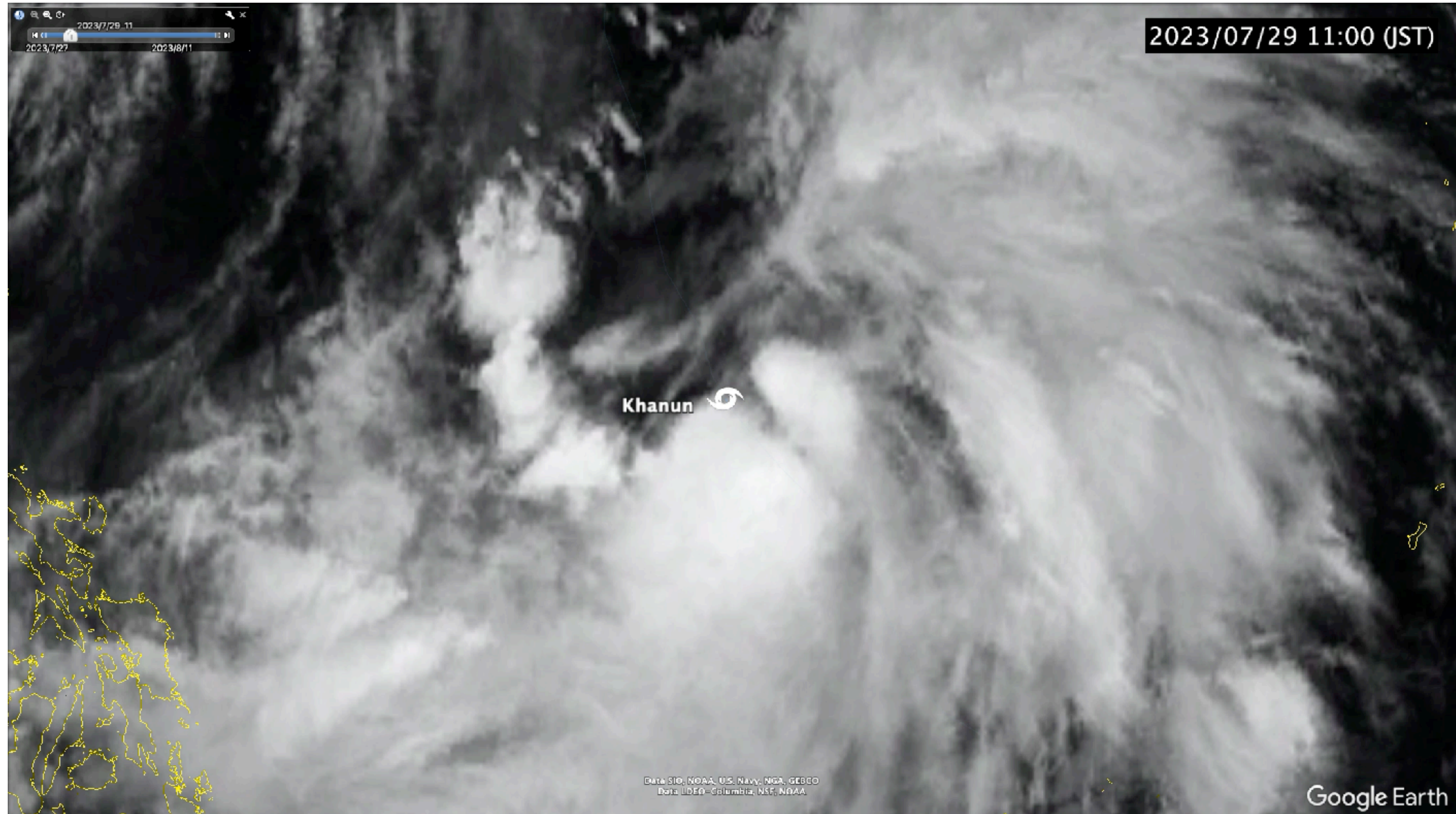
Typhoon Khanun (2023)

5x



(2 survived and
neared the storm
center twice)

2x



Courtesy: Prof. Satoshi Mitarai (OIST)