Role of Ocean Surface Waves in Modulating Tropical Cyclone Intensity

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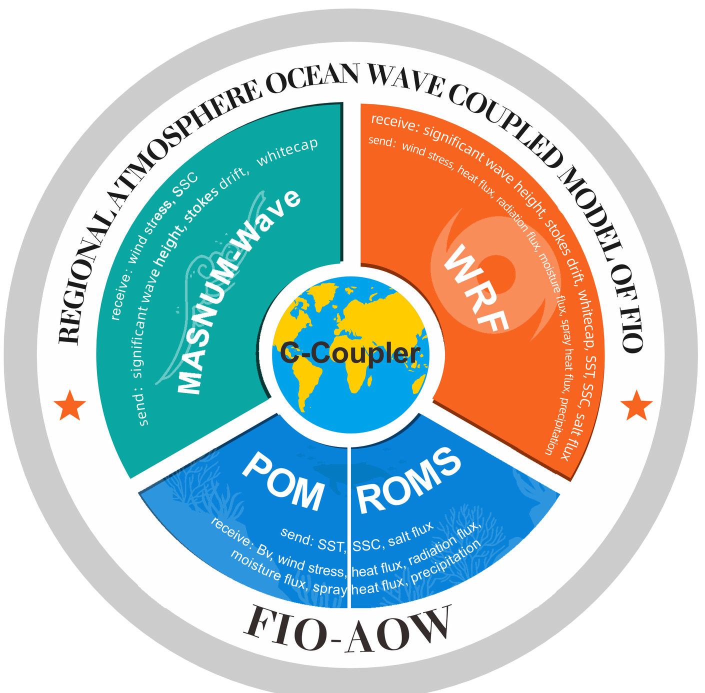
The work presented in this poster was mainly carried out during my time at the [2]**First Institute of Oceanography**

Motivation

Tropical cyclone (TC) stands as one of the most damaging natural hazards in the world, posing threats to lives and property in coastal areas through strong winds, heavy rain, storm surges and landslides upon landfall. Despite significant progress in forecasting the TC tracks, improving the forecast of TC intensity remains a significant challenge. A TC can be conceptualized as a Carnot engine that draws energy from the warm ocean through the flux exchanges at the air-sea interface. Theoretical and observational evidence points to the potential critical role of ocean surface waves in modulating the air-sea fluxes, suggesting these wavy surfaces may help shape the intricate feedback mechanisms between TCs and the underlying ocean. However, these processes are not well-represented in numerical models.

Modelling Approach



FIO-AOW (Zhao et al., 2017; 2022; 2024) is a fully coupled Atmosphere-Ocean-Wave model. It consists of atmosphere component WRF, the 3rd generation ocean surface wave model MASNUM, and ocean circulation components POM&ROMS. These three components are integrated through a community coupler known as C-Coupler. The code of FIO-AOW are publicly assessable at https://github.com/Biao-Zhao/FIO-AOW.

Wave Coupling

The atmospheric and oceanic models in FIO-AOW are tightly coupled through ocean surface waves. Currently, the following wave-related physical processes have been considered to represent the physical interplay between air and ocean, including:

1.Sea-state-dependent air-sea momentum flux

A new air-sea momentum flux scheme considering both wave state (Janssen, 1989) and saturation (decrease) effect at high winds is introduced by

$$z_o = \alpha_{ch}\frac{u_*^2}{g} + \frac{0.11\nu}{u_*}$$

$$\alpha_{ch} = \frac{1}{\sqrt{1-\frac{\vec{\tau}_{in}}{\vec{\tau}_a}}}\begin{cases} 0.011 & U_{10} \le 30 \\ exp(-0.005755U_{10}^2 + 0.3225U_{10} - 8.956) & 30 < U_{10} \le 55 \\ 0.0002 & U_{10} > 55 \end{cases}$$

$$\vec{\tau}_{in} = \rho_w g \int_0^{2\pi}\int_0^{\infty}\frac{\vec{k}}{\omega}S_{in}(\omega,\theta)\,d\omega d\theta$$

2. Sea spray-mediated air-sea enthalpy flux

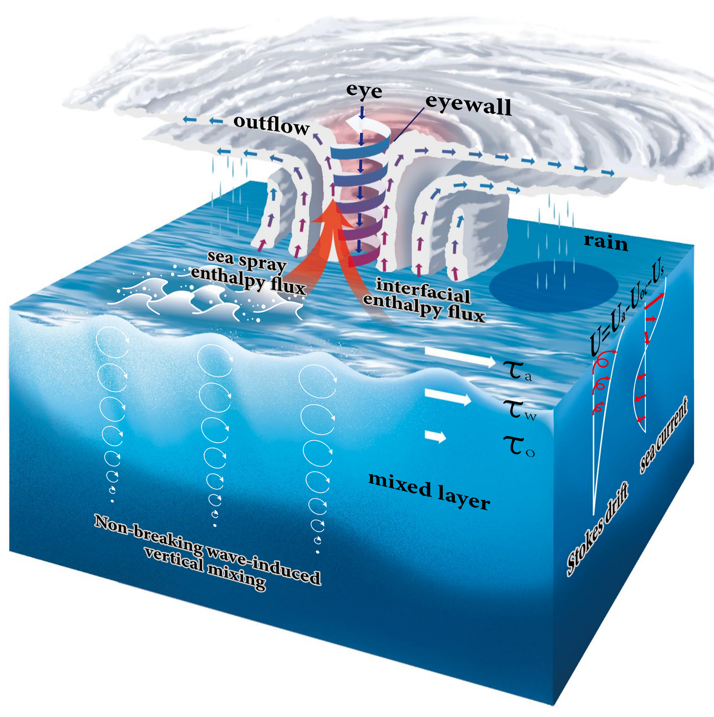
The sea spray-mediated sensible and latent fluxes (Andreas et al., 2015) have been added to the boundary layer interfacial heat fluxes in the atmosphere model boundary layer like

$$H_{S,T} = H_S + H_{S,sp}$$

$$H_{L,T} = H_L + H_{L,sp}$$

$$H_{S,sp} = \rho_s c_{ps}(T_s - T_{eq,100})V_S(u_*)$$

$$H_{L,sp} = \rho_s L_v\left\{1 - \left[\frac{r(\tau_{f,50})}{50\mu m}\right]^3\right\}V_L(u_*)$$



3. Non-breaking wave-induced vertical mixing

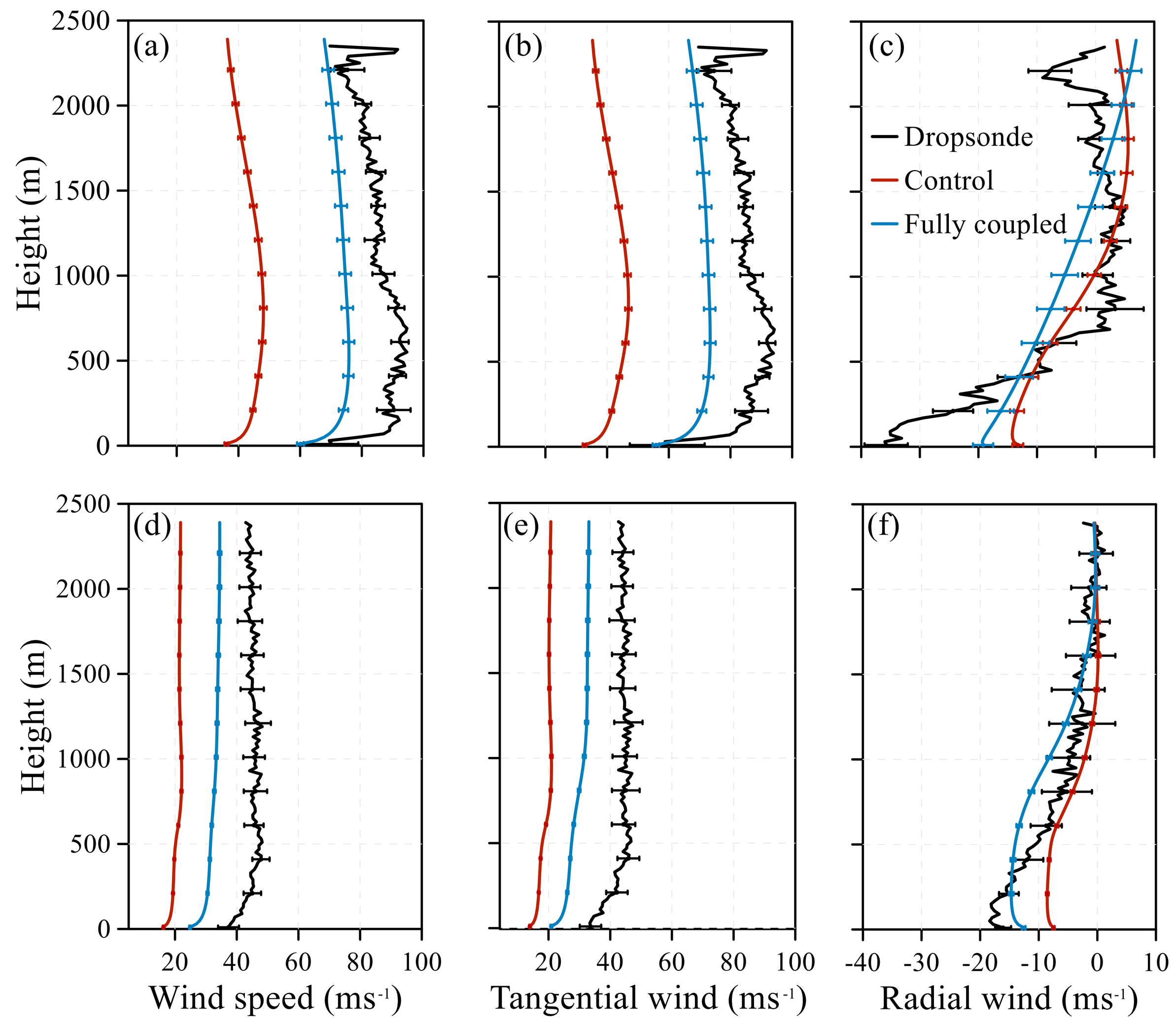
Turbulence generated by non-breaking waves (Qiao et al, 2010) is calculated by integrating wave spectrum as follows

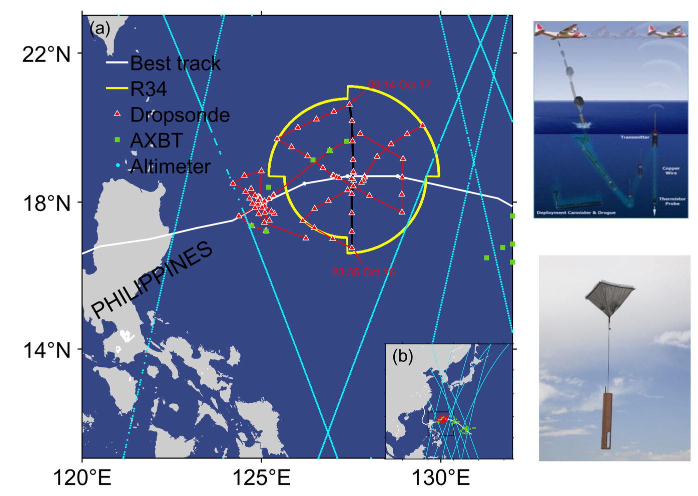
$$B_v = \alpha\int E(\vec{k})\exp\{2kz\}\,d\vec{k}\,\frac{\partial}{\partial z}\left(\iint_{\vec{k}}\omega^2 E(\vec{k})\exp\{2kz\}\,d\vec{k}\right)^{\frac{1}{2}}$$

This coefficient is added to the vertical viscosity and diffusivity of ocean model by

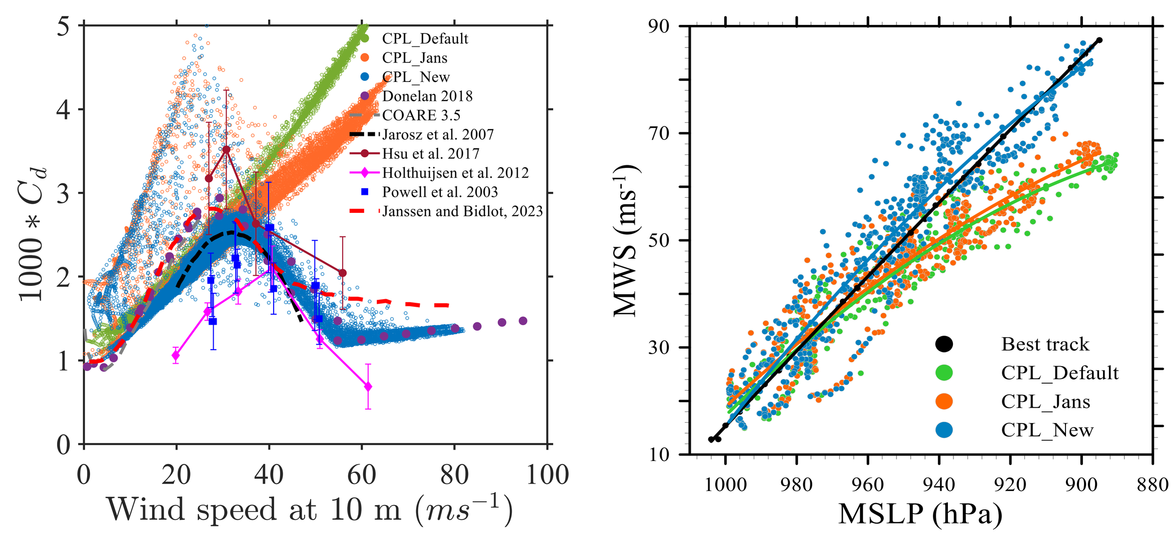
$$K_m = K_{mc} + B_v, \qquad K_h = K_{hc} + B_v$$

Tropical Cyclone Intensity





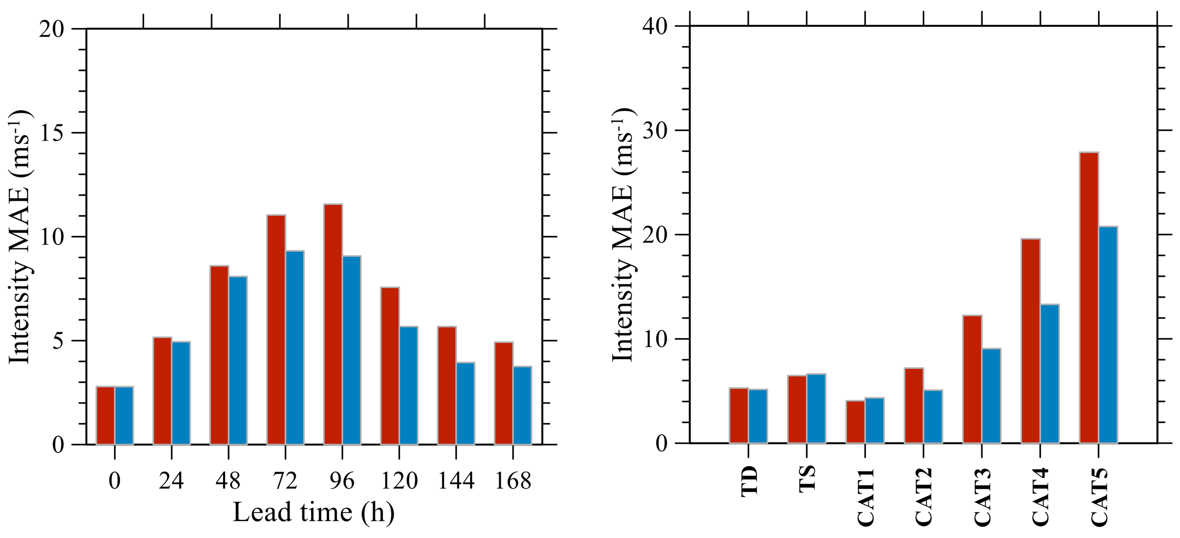
The azimuthally averaged vertical profiles of simulated wind speeds are compared with dropsonde in the eyewall (0.75≤r/RMW≤1.25, RMW stands for Radius of Maximum Wind) and outer core (3≤r/RMW≤5) regions. The introduction of surface wave related physical processes leads to improved wind speeds and TC structure in terms of boundary layer height and inflow strength.



Saffir-Simpson Hurricane Wind Scale

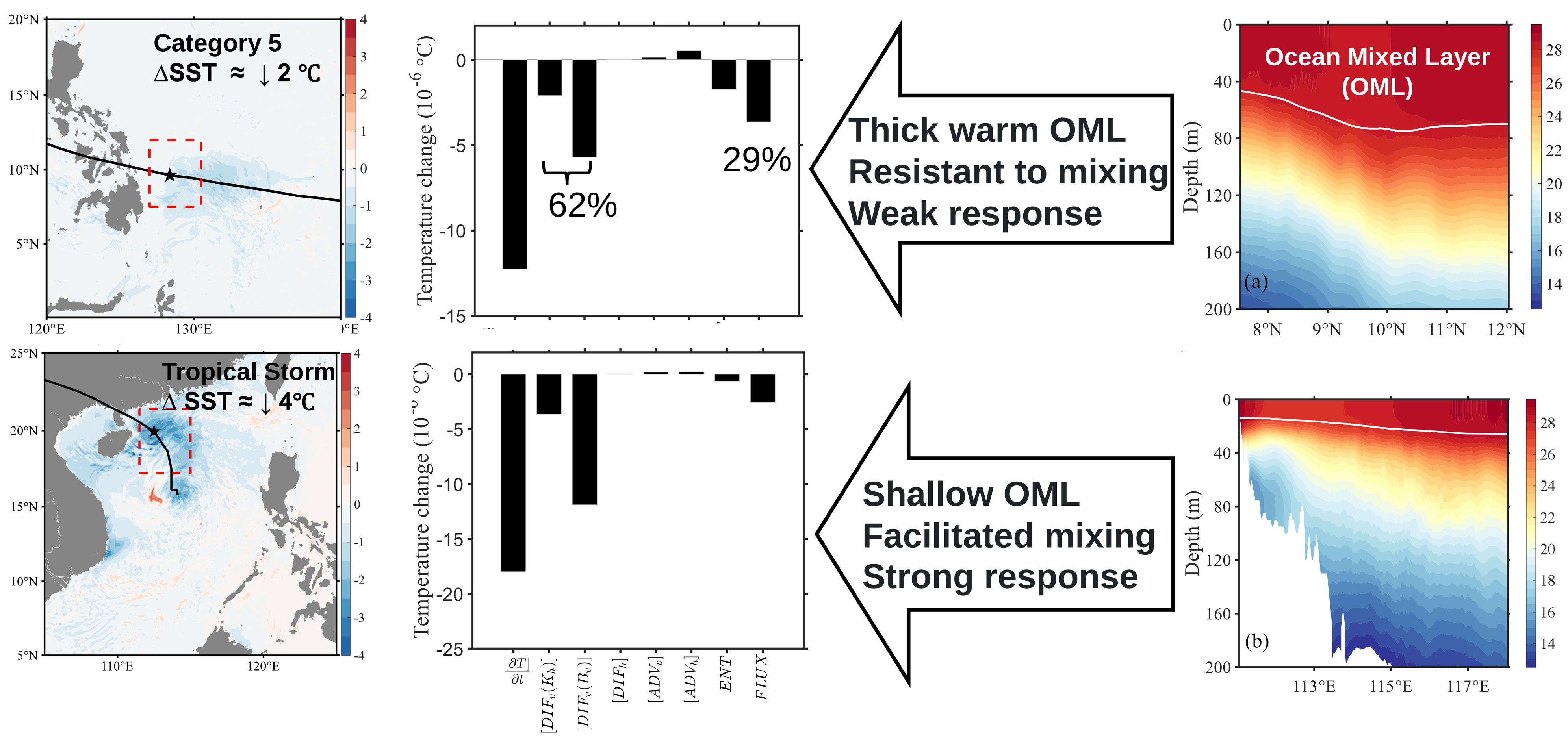
TD, TS and Category 1-5

1	YAGI	28	TS	12	PABUK	46	2
2	LEEPI	18	TS	13	WUTIP	51	3
3	BEBINCA	18	TS	14	SEPAT	21	TS
4	RUMBIA	36	1	15	FITOW	40	1
5	SOULIK	64	4	16	DANAS	62	4
6	JEBI	31	TS	17	NARI	51	3
7	UTOR	67	4	18	WIPHA	62	4
8	TRAMI	39	1	19	FRANCISCO	72	5
9	KONG-REY	26	TS	20	KROSA	54	3
10	TORAJI	26	TS	21	HAIYAN	87	5
11	USAGI	69	4				



TCs of 2013 in western North Pacific are retrospectively simulated. Results suggest that the surface wave related physical processes play an important role in TC intensity and wind-pressure relationship. Wind-pressure relationship is very sensitive to the air-sea momentum flux parameterization at high winds

Ocean Response



References

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