

PAPER • OPEN ACCESS

Numerical Simulation Analysis of Typhoon Moving Track on Sea Surface Cooling

To cite this article: Jiagen Li *et al* 2024 *J. Phys.: Conf. Ser.* **2718** 012002

View the [article online](#) for updates and enhancements.

You may also like

- [Upper ocean response to typhoon Megi \(2010\)](#)
Yiding Wang, Qiang Liu and Yongshuai Ma
- [Influence of Typhoon Hinnamnor-induced near-inertial gravity waves on the suppression of marine heatwave](#)
J S Saranya, Panini Dasgupta and SungHyun Nam
- [A simulation of Typhoon In-Fa \(2021\) using the coupled ocean- atmosphere-wave model COAWST](#)
Wei Chen, Jie Chen, Jian Shi et al.

Numerical Simulation Analysis of Typhoon Moving Track on Sea Surface Cooling

Jiagen LI¹, Hanshi WANG^{1*}, Huizan WANG¹

¹ College of Meteorology and Oceanography, National University of Defense Technology, Changsha, Hunan 410073, China

Email: lijiaagen@nudt.edu.cn; wanghanshi@nudt.edu.cn; wanghuizan@126.com

Abstract. Typhoons are mainly generated in the tropical ocean where the temperature is higher than 26°C. When typhoons move on the ocean, they will cause obvious sea surface cooling (SSC) along their track. The translation speed and moving direction of typhoons are two important components of the typhoons track, and they are also important factors affecting SSC. SSC reduces the heat flux from ocean to typhoons, and thus weakens the intensity of typhoons. Because the air-sea heat exchange mainly occurs in the inner-core region of typhoons, the SSC in the inner-core plays a crucial role in weakening the intensity of typhoons. Based on the numerical experiments, this study analysed the distribution of SSC caused by typhoons under different moving tracks. The results show that under the same ocean environment, typhoon intensity and translation speed, the inner-core SSC caused by sharp-right-turning typhoons is significantly stronger than that caused by the straight-moving typhoons (about 1.34 times) and sharp-left-turning typhoons (about 1.45 times). Without considering the air-sea heat flux, the contribution of vertical mixing to inner-core SSC is about 93.1% and that of advection is about 6.9% when typhoon is moving straight, and the contribution of advection is increasing with the increase of typhoon right turning angle.

1. Introduction

Tropical cyclones are generated mainly near the tropics, known as typhoons in the northwest Pacific, which have caused serious population death and property damages around the globe [1-3]. The track of a typhoon is largely controlled by large-scale atmospheric flows [4], due to the development and progress of satellite remote sensing technology and numerical model, typhoon track forecasting accuracy has been greatly improved in recent years [5-7]. However, compared to track forecasting, the intensity forecasting skills of typhoons have improved slowly in the past few decades [5, 8], one of the important reasons is that the response and feedback process of the upper ocean to typhoons is still not fully understood [9, 10].

The sea surface temperature cooling (SSC) response to typhoons has been a of research focus in recent decades [11, 12], including SSC caused by an individual typhoon [13,14] and composite analysis of observed SSC [15, 16]. As the SSC response has a lagging time, the maximum SSC will generally lag the typhoon inner-core area, which is also the reason why it is called cold wake. The negative feedback of SSC to typhoon intensity requires that typhoon can have a long enough residence time on the cold wake. Therefore, past studies have shown that the translation speed of typhoons [17-18] and other related factors [19] together become important factors affecting the intensity of typhoons. In order to improve typhoon intensity forecasting skills, the numerical simulations are applied to explore the negative feedback mechanism of SSC to typhoon intensity [20].



However, previous numerical simulation experiments and composite of SSC almost assume that typhoons move under a straight-line track. In the actual ocean, typhoons do not all move under the straight-line track. Statistic results show that more than 50% of typhoons in the northwest Pacific will have a track turning, but previous studies have paid little attention to the effects of typhoon track turning on the SSC response and feedback process. Only a few individual cases of typhoon have been studied [21, 22] to show that the response and feedback process will be significantly enhanced when typhoon is turning. However, the generality and mechanism are still unclear. Therefore, based on the numerical experiments, this study analysed the distribution of SSC caused by typhoons under different moving tracks.

2. Model configurations and experimental design

2.1. Model settings

The Regional Ocean Modeling System (ROMS) model is used in this study for the simulation of typhoon moving tracks on sea surface cooling. The flat bottom square sea basin is used in the model domain, the water depth is 4000 meters, the latitude range is 15°N to 35°N, and the longitude range is 20°. The grid adopts closed boundary conditions and cannot penetrate the boundary with directional flow, the horizontal resolution is 1/10°, and the vertical layer is 20 layers, gradually encrypted from the bottom to the surface. During the experiment, only the constructed momentum forcing field is applied in the ocean basin, the thermohaline forcing term is closed, and only the cooling process caused by the pure dynamic response of the ocean to the wind field process is simulated.

2.2. Experimental design

The initial ocean flow field and sea surface height of the ocean model are 0, and the thermohaline profile of every point in the ideal rectangle is the same. The initial temperature and salinity fields are set as the global climatological temperature and salinity from 15°N to 35°N, as shown in Figure 1. The ideal typhoon wind field is built by rankine vortex model, the typhoon parameters are shown in Table 1.

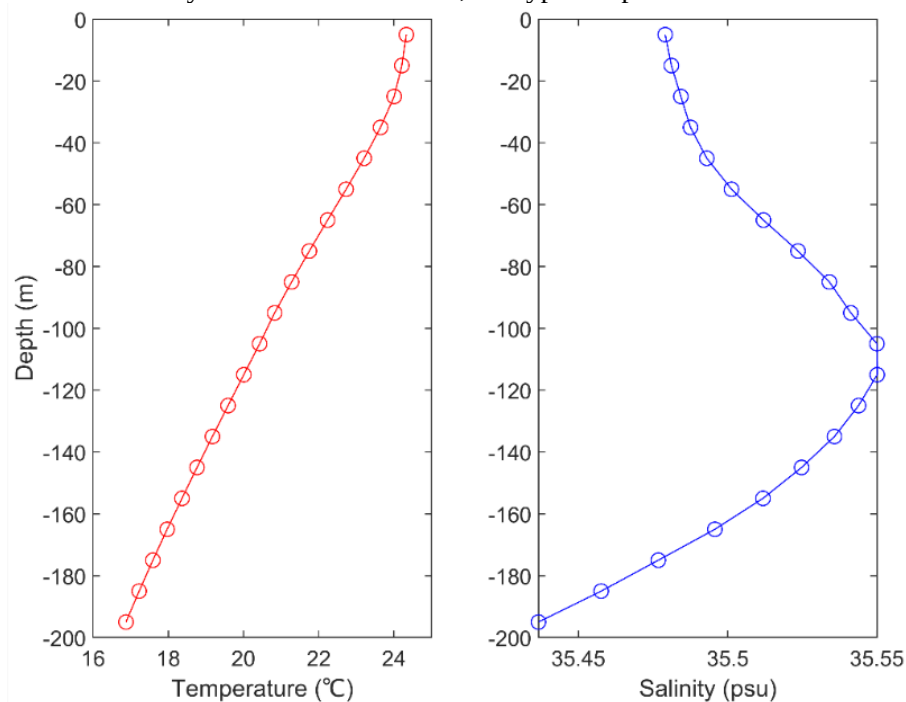


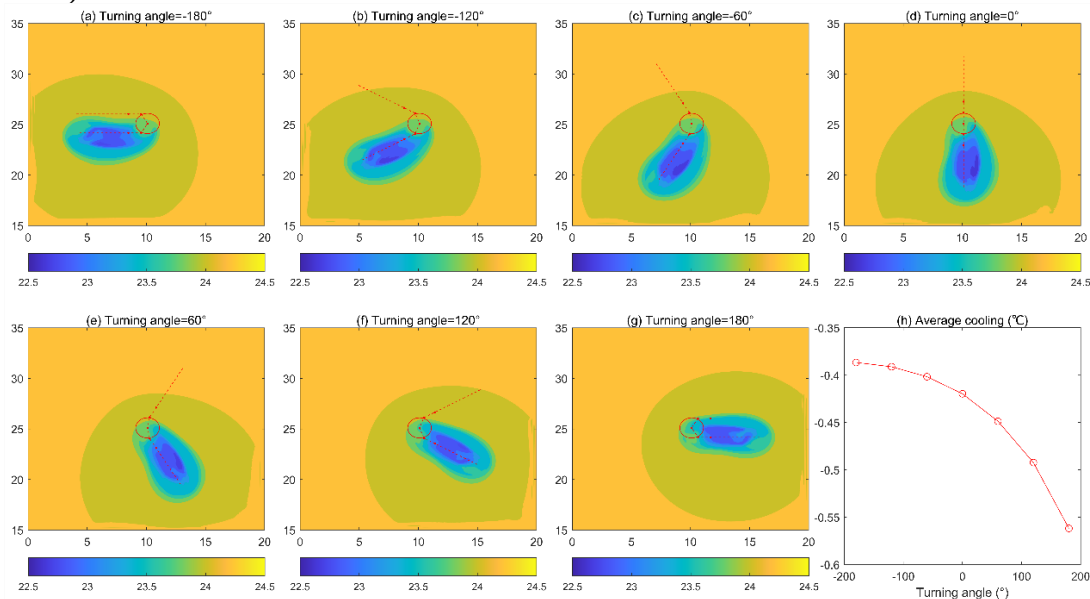
Figure 1. Initial temperature and salinity profiles.

Table 1. Parameter setting of ideal TC intensity, translation speed and turning angle in numerical experiments.

TC Intensity (kts)	Translation speed (m/s)	Turning angle (°)
64	2	-180, -160, -140, -120, -100, -80, -60, -40, -20, 0, 20, 40, 60, 80, 100, 120, 140, 160, 180
	3	-180, -160, -140, -120, -100, -80, -60, -40, -20, 0, 20, 40, 60, 80, 100, 120, 140, 160, 180
	4	-180, -160, -140, -120, -100, -80, -60, -40, -20, 0, 20, 40, 60, 80, 100, 120, 140, 160, 180
	5	-180, -160, -140, -120, -100, -80, -60, -40, -20, 0, 20, 40, 60, 80, 100, 120, 140, 160, 180
	6	-180, -160, -140, -120, -100, -80, -60, -40, -20, 0, 20, 40, 60, 80, 100, 120, 140, 160, 180
	7	-180, -160, -140, -120, -100, -80, -60, -40, -20, 0, 20, 40, 60, 80, 100, 120, 140, 160, 180
	8	-180, -160, -140, -120, -100, -80, -60, -40, -20, 0, 20, 40, 60, 80, 100, 120, 140, 160, 180

3. Results

Figure 2 shows the net SSC lags behind far right-behind the TC centre, and the SSC is generally right-bias, which is consistent with previous studies. The mean inner-core (defined as within 100km of the TC center) SSC induced by typhoon with the turning angle of -180° , -120° , -60° , 0° , 60° , 120° and 180° are -0.387°C , -0.391°C , -0.402°C , -0.42°C , -0.449°C , 0.492°C and 0.562°C , respectively (Figure 2a-g). In summary, the inner-core SSC caused by right-turning typhoons is stronger than that caused by straight-moving typhoons (about 1.34 times), and stronger than that caused by left-turn typhoons (about 1.45 times).

**Figure 2.** Model-simulated SSC caused by typhoons under the turning angle from -180° to 180° when typhoon intensity is 64 kts and translation speed is 5m/s.

To characterize the processes responsible for the thermal responses, the ocean temperature budget analysis is carried out using the thermodynamic equation [23]. The net SSC is determined by horizontal advection, vertical advection, vertical mixing and horizontal diffusion. In general, the magnitude of horizontal diffusion is much smaller than advection and vertical mixing [24] and thus will be neglected in our analysis. Past numerous studies have suggested that vertical mixing accounts for a large fraction of TC-induced SSC up to 70%–85% [19]. In this study, the mean inner-core SSC caused by vertical mixing under the turning angle from -180° to 180° are -0.365 , -0.37 , -0.378 , -0.391 , -0.41 , -0.439 and -0.487°C , respectively (Figure 3a-g). It can be seen from Figure 3(h) that the change trend of vertical mixing is

consistent with the net SSC in Figure 2(h), and the vertical mixing under right-turning typhoon is stronger than that under straight-turning and left-turning typhoon. For sharp-left-turning typhoons, straight-moving typhoons and sharp-right-turning typhoons, the contribution of vertical mixing to net SSC is 94.3%, 93.1% and 86.7%, respectively.

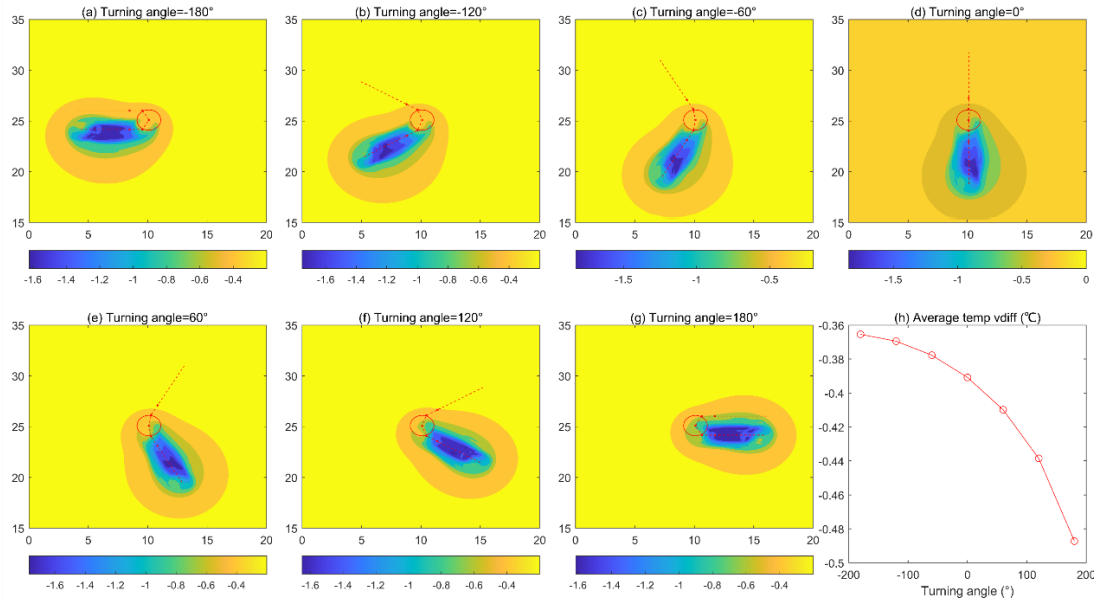


Figure 3. Model-simulated SSC caused by vertical mixing under the turning angle from -180° to 180° when typhoon intensity is 64 kts and translation speed is 5m/s.

The advection has usually been regarded as the secondary important process responsible for the TC-induced SSC, but it can play a nonnegligible role in some cases [25]. The advection is important as a nonlocal process to extend or redistribute the SSC, determining the spatial pattern of SST [26]. Figure 4 shows the mean inner-core SSC caused by advection under the turning angle from -180° to 180° are -0.0215, -0.0219, -0.0242, -0.0291, -0.0391, -0.0541 and -0.075°C. Although the change trend of advection is consistent with the net SSC, it contributes relative smaller to the net SSC, especially when the typhoons occur a sharp-left-turning. For sharp-left-turning, straight-moving and sharp-right-turning typhoons, the contribution of advection to net SSC is 5.7%, 6.9% and 13.3%, respectively.

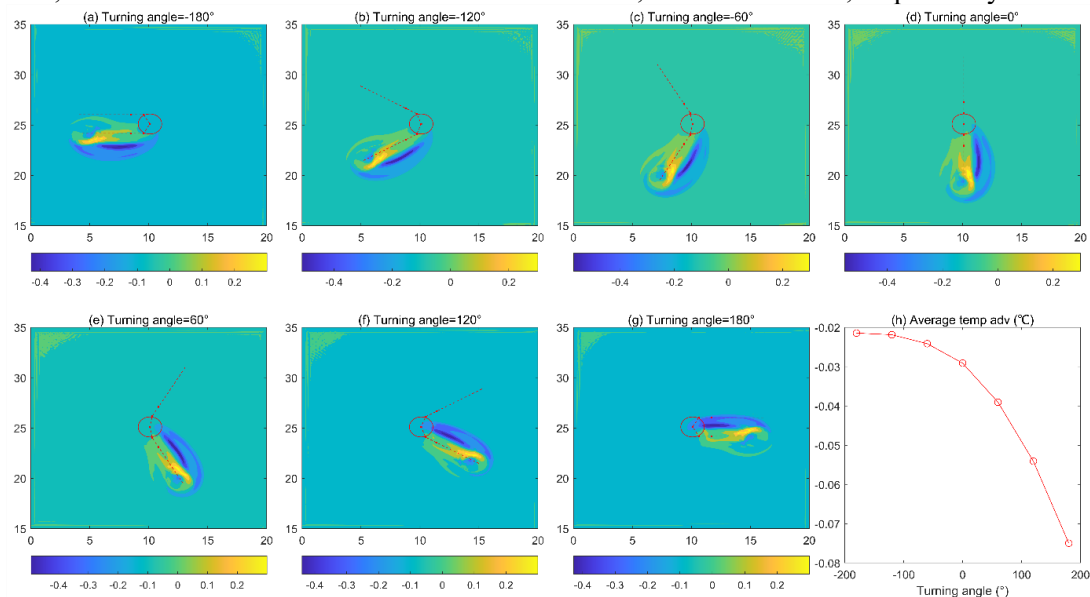


Figure 4. Model-simulated SSC caused by advection under the turning angle from -180° to 180° when typhoon intensity is 64 kts and translation speed is 5m/s.

Figure 5 showed that the relationship of net SSC (black), advection (blue), mixing (red) with turning angle and translation speed. As shown in Figure 5(a), the larger the right turning angle of typhoon, the more significant the inner-core SSC. When the typhoon turns at -180° , 0° and 180° , the inner-core temperature drop is -0.387°C , -0.42°C and -0.562°C . For the slope of SSC versus turning angle, when the typhoon moves from sharp-left-turning to straight-moving, the SSC change slope is $-1.83 \times 10^{-4}^\circ\text{C}/^\circ$. When the typhoon moves from straight-moving to sharp-right-turning, the SSC change slope increases to $-7.89 \times 10^{-4}^\circ\text{C}/^\circ$.

For translation speed, the slower the typhoon moves, the more significant the inner-core SSC. When the typhoon moves at a fast (8 m/s), moderate (5 m/s) and slow (2 m/s) translation speed, the inner-core SSC is -0.322°C , -0.42°C and -0.931°C . For the slope, when the typhoon moves from fast to moderate translation speed, the SSC change slope is about $-0.026^\circ\text{C}(\text{m/s})^{-1}$. When the typhoon moves from moderate to slow translation speed, the SSC change slope increases to $-0.177^\circ\text{C}(\text{m/s})^{-1}$.

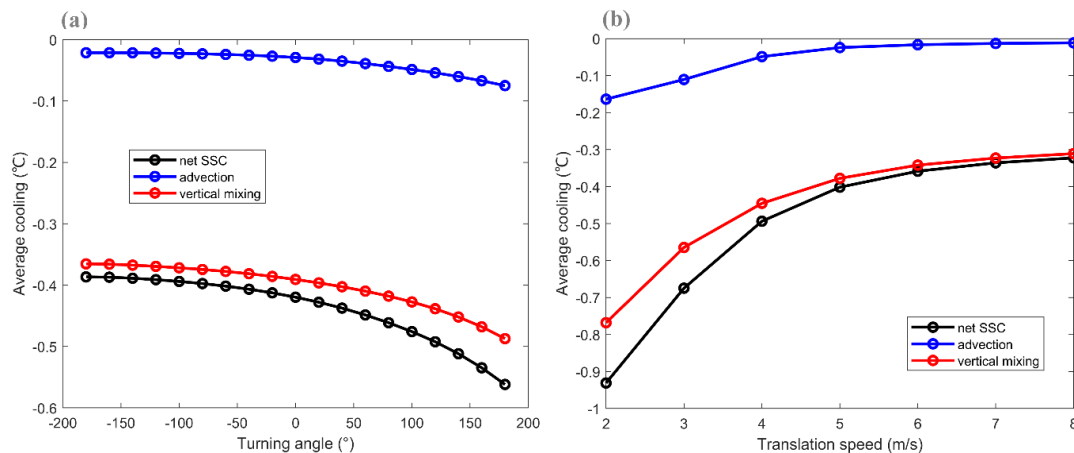


Figure 5. The relationship of net SSC (black), advection (blue), mixing (red) with (a) turning angle and (b) translation speed.

4. Discussions

Past studies have illustrated that SSC usually biased to the right side of the TC track in the Northern Hemisphere. Figure 6 showed the right bias of SSC caused by typhoons under different tracks, which showed that when the typhoon moved straight, the maximum SSC caused by the typhoon (-0.69°C) is about 100 km to the right of the typhoon track, and the maximum SSC on the left is -0.33°C , which is only half of the SSC on the right. When the typhoon turned 180° to the right, the SSC caused by the typhoon is significantly enhanced to -1.44°C , which located at 360 km on the right side of the typhoon track. When the typhoon turned left, the maximum SSC caused by the typhoon is weakened, and the amplitude of right bias is also weakened. When the left-turning angle increased to 180° , the SSC caused by the typhoon is significantly enhanced to -0.81°C , which located at 330 km on the left side of the typhoon track.

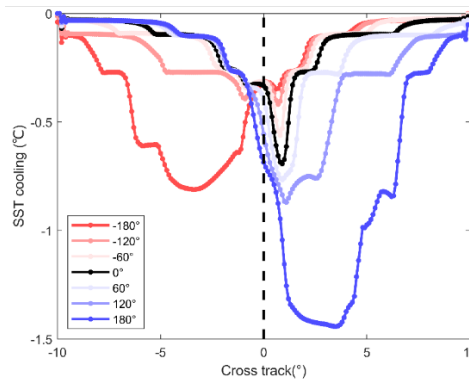


Figure 6. Cross-track SST cooling under the turning angle from -180° to 180° when typhoon intensity is 64 kts and translation speed is 5m/s.

5. Conclusions

This study conducted a series of ideal experiments based on RMOS to analyse the distribution of SSC caused by typhoons under different moving tracks. The model results show that under the same ocean environment and typhoon intensity, the larger right-turning angle and slower translation speed could induce the more significant SSC. The inner-core SSC caused by sharp-right-turning typhoons is significantly stronger than that caused by the straight-moving typhoons (about 1.34 times) and sharp-left-turning typhoons (about 1.45 times). Meanwhile, the inner-core SSC caused by slow-moving typhoons is significantly stronger than that caused by the moderate-moving typhoons (about 2.22 times) and fast-moving typhoons (about 2.89 times).

Based on the ocean temperature budget analysis using the thermodynamic equation. The contribution of vertical mixing to inner-core SSC is about 93.1% and that of advection is about 6.9% when typhoon is moving straight without considering the air-sea heat flux. In addition, the contribution of advection is increasing with the increase of typhoon right-turning angle, and the contribution of vertical mixing is increasing with the increase of typhoon left-turning angle.

The present study indicated that the turning angle of typhoon translation is an effective factor in modulating TC-induced inner-core sea surface cooling based on ideal experiments, which could suggest that it could improve TC intensity forecasting by accounting for the SSC_{IC} associated with TC track turning. In the future, we will combine observational data to reveal the quantitative relationship between SSC_{IC} and translation direction.

6. References

- [1] Dake C, Xiaotu L, Wei W, Guihua W, Guijun H, Lei Z. Upper ocean response and feedback mechanisms to typhoon. **Advances in Earth Science** 2013, 28(10): 1077-1086.
- [2] Emanuel K. Evidence that hurricanes are getting stronger. **Proc Natl Acad Sci U S A** 2020, 117(24): 13194-13195.
- [3] Lin II, Rogers RF, Huang H-C, Liao Y-C, Herndon D, Yu J-Y, *et al.* A Tale of Two Rapidly Intensifying Supertyphoons: Hagibis (2019) and Haiyan (2013). **Bulletin of the American Meteorological Society** 2021, 102(9): E1645-E1664.
- [4] George JE, Gray WM. Tropical cyclone motion and surrounding parameter relationships. **Journal of Applied Meteorology** 1976, 15: 1252-1264.
- [5] Cangialosi JP, Blake E, DeMaria M, Penny A, Latta A, Rappaport E, *et al.* Recent Progress in Tropical Cyclone Intensity Forecasting at the National Hurricane Center. **Weather and Forecasting** 2020, 35(5): 1913-1922.
- [6] Zhou F, Toth Z. On the Prospects for Improved Tropical Cyclone Track Forecasts. **Bulletin of the American Meteorological Society** 2020, 101(12): E2058-E2077.
- [7] Yu H, Chen G, Zhou C, Wong WK, Yang M, Xu Y, *et al.* Are We Reaching the Limit of Tropical Cyclone Track Predictability in the Western North Pacific? **Bulletin of the American Meteorological Society** 2022, 103(2): E410-E428.
- [8] Bender MA, Marchok T, Tuleya RE, Ginis I, Tallapragada V, Lord SJ. Hurricane Model Development at GFDL: A Collaborative Success Story from a Historical Perspective. **Bulletin of the American Meteorological Society** 2019, 100(9): 1725-1736.
- [9] Emanuel KA. Thermodynamic control of hurricane intensity. **Nature** 1999, 401(14).
- [10] Ginis I, Yablonsky RM. Limitation of One-Dimensional Ocean Models for Coupled Hurricane–Ocean Model Forecasts. **Monthly Weather Review** 2009, 137(12): 4410-4419.
- [11] Emanuel KA. 100 Years of Progress in Tropical Cyclone Research. **Meteorological Monographs** 2018, 59: 15.11-15.68.
- [12] Zhang H, He H, Zhang W-Z, Tian D. Upper ocean response to tropical cyclones: a review. **Geoscience Letters** 2021, 8(1).
- [13] Price JF. Upper Ocean Response to a Hurricane. **Journal of Physical Oceanography** 1981, 11: 153-174.
- [14] Pun I-F, Lin II, Lien C-C, Wu C-C. Influence of the Size of Supertyphoon Megi (2010) on SST Cooling. **Monthly Weather Review** 2018, 146(3): 661-677.
- [15] Wang G, Wu L, Mei W, Xie SP. Ocean currents show global intensification of weak tropical cyclones. **Nature** 2022, 611(7936): 496-500.

- [16] Wang Y, Xiu P. Typhoon footprints on ocean surface temperature and chlorophyll-a in the South China Sea. **Sci Total Environ** 2022, 840: 156686.
- [17] Chang K-F, Wu C-C, Ito K. On the Rapid Weakening of Typhoon Trami (2018): Strong Sea Surface Temperature Cooling Associated with Slow Translation Speed. **Monthly Weather Review** 2023, 151(1): 227-251.
- [18] Mei W, Pasquero C, Primeau F. The effect of translation speed upon the intensity of tropical cyclones over the tropical ocean. **Geophysical Research Letters** 2012, 39(7): L07801.
- [19] Schade LR, Emanuel KA. The Ocean's Effect on the Intensity of Tropical Cyclones: Results from a Simple Coupled Atmosphere–Ocean Model. **Journal of the Atmospheric Sciences** 1999, 56: 642-651.
- [20] Lu Z, Wang G, Shang X. Inner-core sea surface cooling induced by a moving tropical cyclone. **Journal of Physical Oceanography** 2021, 51: 3385-3400.
- [21] Li J, Yang Y, Wang G, Cheng H, Sun L. Enhanced Oceanic Environmental Responses and Feedbacks to Super Typhoon Nida (2009) during the Sudden-Turning Stage. **Remote Sensing** 2021, 13(14): 2648.
- [22] Zhang H, Liu Y, Liu P, Guan S, Wang Q, Zhao W, *et al.* Enhanced upper ocean response within a warm eddy to Typhoon Nakri (2019) during the sudden-turning stage. **Deep Sea Research Part I: Oceanographic Research Papers** 2023, 199: 104112.
- [23] Jullien S, Menkes CE, Marchesiello P, Jourdain NC, Koch-Larrouy A, Lengaigne M, *et al.* Impact of Tropical Cyclones on the Heat Budget of the South Pacific Ocean. **Journal of Physical Oceanography** 2012, 42(11): 1882-1906.
- [24] Liu X, Zhang DL, Guan J. Parameterizing Sea Surface Temperature Cooling Induced by Tropical Cyclones: 2. Verification by Ocean Drifters. **Journal of Geophysical Research: Oceans** 2019, 124(2): 1232-1243.
- [25] Huang P, Sanford TB, Imberger J. Heat and turbulent kinetic energy budgets for surface layer cooling induced by the passage of Hurricane Frances (2004). **Journal of Geophysical Research** 2009, 114(C12).
- [26] Yang Y-J, Sun L, Liu Q, Xian T, Fu Y-F. The biophysical responses of the upper ocean to the typhoons Namtheun and Malou in 2004. **International Journal of Remote Sensing** 2010, 31(17-18): 4559-4568.

Acknowledgments

This work is supported by the National Key R&D Program of China (2021YFC3101503), Hunan Provincial Natural Science Foundation of China (2023JJ10053), National Natural Science Foundation of China (42276205). We are grateful to the Alaska Outer Continental Shelf Region of the Bureau of Ocean Energy Management, U.S. Department of the Interior, and Rutgers University, Institute of Marine and Coastal Sciences for the free use of the “RMOS” package. We are grateful to the ICFOST 2023 for this nice chance.