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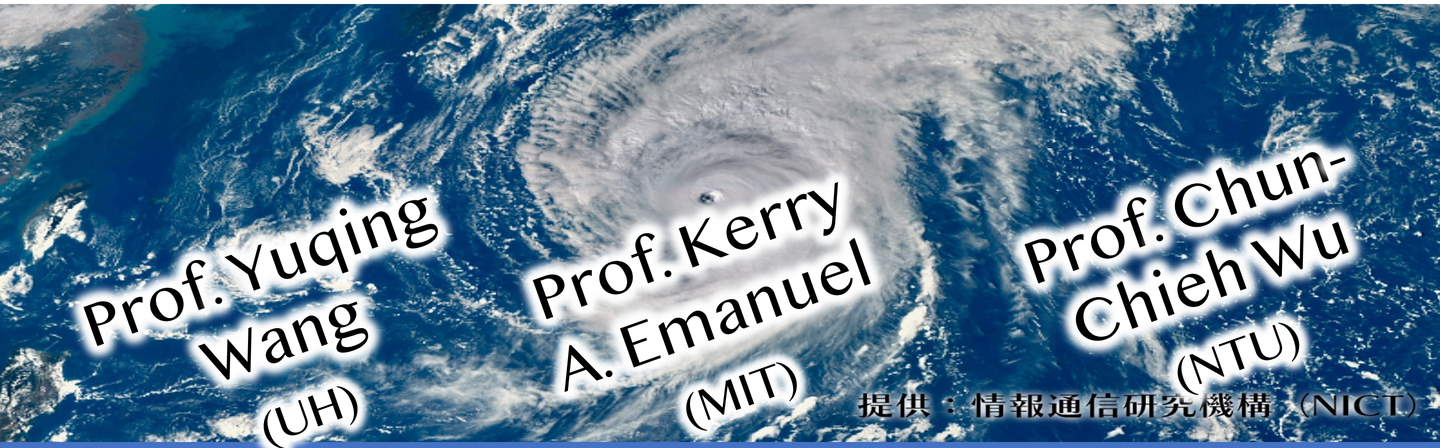

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Ocean subsurface suppresses tropical cyclone genesis during El Niño

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The vast tropical Pacific is home to the majority of tropical cyclones (TCs) which threaten the rim countries every year. The TC genesis is nourished by warm sea surface temperatures (SSTs). During El Niño, the western Pacific warm pool extends eastward. However, the number of TCs does not increase significantly with the expanding warm pool and it remains comparable between El Niño and La Niña. Here, we show that the subsurface heat content change counteracts the favorable SSTs in the tropical central-north Pacific. Due to the anomalous positive wind stress curl, the 26 °C isotherm shoals during El Niño over this region and the heat content diminishes in the tropical central-north Pacific, even though warm SST anomalies prevail. This negative correlation between SST and 26 °C isotherm depth anomalies is opposite to the positive correlation in the tropical eastern and western Pacific. This is critical because quantifying the dynamics of the subsurface ocean provides insight into TC genesis. The trend in TC genesis continues to be debated. Future projections must account for the net effect of the surface-subsurface dynamics on TCs, especially given the expected El Niño-like pattern over the tropical Pacific under global warming.

Our work has been published in *Nature Communications* recently (https://www.nature.com/articles/s41467-022-35530-9).

Environmental characteristics of western North Pacific tropical cyclone onset in neutral ENSO years

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This study investigates the inter-annual changes in tropical cyclone season onset (TCSO) over the western North Pacific (WNP) in neutral El Niño-Southern Oscillation (ENSO) conditions during 1979–2019. The average TCSO during early TCSO years (~ March 27) is significantly earlier than during late TCSO years (~ June 18). In response to inter-annual changes of TCSO in neutral ENSO years, TC activity shows distinct seasonal features. Although there are no significant differences in total TC counts, more TCs occur in March–May while fewer TCs occur in September–November during early TCSO years. Additionally, TC genesis locations tend to move eastward and equatorward during early TCSO years. These TCs are also found to have stronger lifetime maximum intensities. Changes in seasonal TC activity are closely associated with changes in the large-scale environmental pattern changes, which are driven by the seasonal evolution of sea surface temperature anomalies (SSTAs). Low-level vorticity and mid-level humidity changes are found likely to be the two primary factors inducing the seasonal feature differences between early and late TCSO years. Further analyses suggested that the seasonal evolution of sea surface temperature anomaly patterns over the tropical Indian Ocean and tropical Pacific accompanied by TCSO in neutral years is closely linked to changes in the spring Pacific Meridional Mode. Observational analyses and numerical simulations suggest that the Pacific Meridional Mode mainly causes changes in the low-level large-scale circulation over the tropical WNP via a Rossby wave Gill-type response, thus affects inter-annual variability of TCSO during neutral ENSO years. This response is found to be distinct from the previously documented strong relationship between TCSO and strong ENSO events.

Atmospheric modes fiddling the simulated ENSO impact on tropical cyclone genesis over the Northwest Pacific

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The El Niño-Southern Oscillation (ENSO) is crucial to the interannual variability of tropical cyclone (TC) genesis over the western North Pacific (WNP). However, most state-of-the-art climate models exhibit a consistent pattern of uncertainty in the simulated TC genesis frequency (TCGF) over the WNP when we focus on ENSO years. Here, we analyze large ensemble simulations of TC-resolved climate models to identify the source of this uncertainty. Results show that large uncertainty appears in the South China Sea and east of the Philippines, primarily arising from two distinct atmospheric modes: the "Matsuno-Gill-mode" and the Pacific-Japan-like pattern ("PJ-mode"). These two modes are closely associated with anomalous diabatic heating linked to tropical precipitation bias in model simulations. By conditionally constraining either of these atmospheric modes, we can significantly improve the simulated TCGF, confirming that it is the atmospheric circulation bias in response to tropical precipitation bias that causes the uncertainty in the simulated WNP TCGF.

Influence of the Atlantic Multidecadal Oscillation on the rapid intensification of tropical cyclones over the western North Pacific

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Rapid intensification (RI) of tropical cyclones (TCs), defined as an explosive increase of TC intensity over a short time period exceeding a given threshold (e.g., 30 knots in 24 hours), poses a great challenge to both forecasting and disaster prevention. Some recent studies have documented a significant increase in TC RI magnitude (RIM, measured as the mean intensification rate of all TC RI records in a TC season) over the western North Pacific (WNP) since 1979, and attributed it to the influence of global warming. In this study, results from statistical analysis show that the JTWC TC RIM over the WNP during 1951 2021 exhibits significant interdecadal variability, which is found to be closely related to the Atlantic Multidecadal Oscillation (AMO). During the positive AMO phase, the TC RIM increased over the most of the WNP. And the JMA best-track data verified the impact of AMO on TC RIM. Further analyses indicate that the response of the local thermodynamic conditions to the AMO plays a dominant role in such a relationship. The positive AMO phase favors the large TC RIM over the WNP by producing significant warm sea surface temperature (SST) anomalies, increasing TC heat potential and the mid-tropospheric relative humidity in the main occurrence region of TC RI.

Mechanism analysis revealed how AMO remotely affects the WNP environment, especially the whole basin SST warming on the WNP, and then regulates the interdecadal variation of WNP TC RIM. AMO remotely controls the large-scale environmental conditions and then the RIM over the WNP through modulating the local surface heat fluxes and the Ekman heat transport by the Matsuno-Gill-type response and Walker circulation. Through such a response, the warm SST anomaly over the North Atlantic can lead to the low-level convergence and upper-level divergence over the WNP. On one hand, this results in an increase in cloud cover over the tropical Pacific and thus enhances the longwave radiative flux from the atmosphere to the ocean, resulting in SST warming over the WNP. On the other hand, this induces anomalous surface easterly wind over the tropical WNP, which transports warm water northward by the Ekman heat transport, also contributing to SST warming over the WNP. The results are confirmed by results from the AMO sensitivity experiments in the Decadal Climate Prediction Project Component C in the framework of the Coupled Model Intercomparison Project Phase 6.

Climatology and characteristics of rapidly intensifying tropical cyclones over the North Indian Ocean

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Rapid Intensification (RI) of a tropical cyclone (TC) is defined as an increase in the wind speed by 30 knots within 24 hrs. It is a less understood process, particularly for TCs over the North Indian Ocean. We considered data for the past 39 years (1982-2020) from the JTWC and studied the climatology of TCs to understand the frequency and patterns of rapid intensification and identify the key atmospheric and oceanic factors influencing it. The study aims to enhance our understanding of TC behavior in this region, contributing to improved forecasting and disaster preparedness. We found that, out of 197 cases, 44 TCs (22%) experienced RI. There is a significant increasing trend in RI TCs frequency and duration over the Arabian Sea (AS). Lifetime maximum intensity (LMI) is significantly higher, and genesis to LMI duration is also significantly longer for TCs undergoing RI over the AS. LMI is double for RI TC than for Non RI (NRI) TC. The longer duration to achieve the higher maximum intensity resulted in a longer total lifespan for RI TCs. All TCs reaching a super cyclonic storm category underwent RI and generally, RI onset happens in the depression stage. During the Pre-monsoon season, April and May are the most prominent months for RI over the Bay of Bengal, whereas, the May and June months are prominent over the Arabian Sea. During the Post-monsoon season October and November months are the prominent ones over both the basins.

The composites are prepared to understand the characteristics of RI TCs in contrast to NRI TCs. For the RI TC composite, the period includes 12 hours before and 24 hours after the RI onset. For the NRI TC, we considered 36 hours starting from the initial intensification stage. The analysis shows the RI TCs are embedded in the warm water regions with ocean heat content of 90–100 KJ cm^{-2} and strong latent heat flux transport. RI TCs also have higher positive low-level relative vorticity, higher upper-level divergence, and higher mid-level relative humidity, with higher moisture content around the TC center. Deep clouds with 208K <IRBT < 240K dominate in RI TCs. The total surface rainfall for RI cases is symmetric around the center. RI TCs have higher rainfall fractions with intense surface rain rates for stratiform and convective rainfall during the pre-monsoon. These findings are derived from composite plots, and while they provide valuable insights, they may not be universally applicable to every cyclone, as there could be variations in the favorable parameters leading to rapid intensification of a cyclone.

Keywords: tropical cyclones, North Indian Ocean, rapid intensification, climatology, characteristics

Applying a time-dependent theory of tropical cyclone intensification for predicting tropical cyclone intensity

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Accurate prediction of tropical cyclone (TC) intensity has proven to be a challenging task due to the complex multiscale physical processes involved in TC intensity change. In this study, we developed a new prediction scheme for TC intensity over the western North Pacific (WNP) based on a state-of-the-art time-dependent theory of TC intensity change, namely an energetically based dynamical system (EBDS) model, together with the use of the Long Short-term Memory (LSTM) neural network, or in short, the EBDS_LSTM. In the EBDS model, TC intensity change is controlled by both the internal dynamics determined by the given favorable ocean and atmospheric thermodynamic conditions and the detrimental environmental effect, with the latter being collectively contributed by various environmental factors, such as environmental vertical wind shear. The LSTM neural network is used to predict the environmental dynamical efficiency in the EBDS model. To minimize the issue of limited-data records, we employed transfer learning to train the scheme using the best-track TC data, the global reanalysis data during 1982–2017 and the data from the NCEP (National Centers for Environmental Prediction)'s Global Forecast System (GFS) during 2019–2021, respectively. The developed scheme is evaluated for TC intensity prediction in 2017 using reanalysis data and 2021-2022 using the GFS data. The prediction by the new scheme shows better skill than the official prediction from the China Meteorological Administration and those by other state-of-art statistical and dynamical forecast systems, particularly for long lead-time forecasts.

Comparisons between the predictability of tropical cyclone track forecasts in WNP and ATL basins

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It is well recognized that there has been great improvement in tropical cyclone (TC) track forecasts over the past decades. In recent years, however, the decreasing trend of perceived error (errors between forecasts and observed positions) has flattened out, and some studies suggested that "the approaching limit of predictability for tropical cyclone track prediction is near or has already been reached". Noting that there remains error in best track dataset, the track forecast errors (short for TFE) published by forecast centers are actually not true track forecast errors (short for TTFE). In this study, a recently proposed forecast error analysis method called SAFE was used to estimate the TTFE of tropical cyclone in Western North Pacific (WNP) Ocean. Using several assumptions and just four parameters, a multi-year forecast error model was constructed to describe TTFE behavior of lead time 24-120 h in WNP basin over the TC seasons from 2011 to 2021, and the variation was extrapolated into the future. The results showed that the TC track forecast in WNP has not yet reached the limit of predictability, with an improvement of about two days in 16-17 years. Furthermore, comparing our WNP results with previous studies for Atlantic (ATL) Ocean basin, it was found that the TTFE in WNP grows faster than in ATL. This is probably because TCs in WNP basin have averagely larger size and intensity, resulting in greater difficulty in forecasting the surrounding winds and therefore larger TTFE growth rate.

Factor analysis and prediction of typhoon intensification using explainable AI

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Typhoon discrimination and development prediction using AI technology have been actively carried out in recent years. Deep learning such as convolutional neural networks (CNNs) is mainly used for AI technology. While deep learning provides high prediction accuracy, it has the disadvantage that it is difficult to understand the prediction reasons and to utilize known meteorological knowledge for prediction.

Against this background, this study examines the application of explainable AI (XAI) to prediction of typhoon intensification. XAI is an AI technology that can explain the reasons of judgment or prediction, and in recent years it has been given importance from the viewpoint of ensuring the reliability of prediction results. In this study, we aim to link the predictive reasons for XAI outputs with meteorological knowledge.

In this study, we use Wide Learning as XAI. Wide Learning is an XAI technology developed by Fujitsu that comprehensively discovers hypotheses expressed by combinations of variables and makes predictions based on those hypotheses. In addition to ensuring explainability of AI, it is capable of discovering new knowledge that humans cannot find.

This study uses the dataset of tropical cyclogenesis in a cloud-resolving global atmospheric simulation. Field data in this dataset, such as longwave radiation and sea level pressure, are subjected to principal component analysis and the top principal components are used as variables.

As a first step, a model for determining the state of a tropical cyclone was learned by Wide Leaning. Tropical cyclones have three types: precursor(preTC), tropical cyclone(TC), and extratropical cyclone(exTC). The accuracy of the determination of tropical cyclone types was 78.2% for precision and 76.8% for recall. Many variables such as longwave radiation, sea-level pressure, and east-west wind were identified as the reasons for the prediction of TC.

Then, using the same dataset, a model for predicting rapid intensification(RI) of tropical cyclones was learned by Wide Learning. The accuracy of RI prediction was 78.6% for accuracy and 64.1% for recall, when the central pressure dropped by 10hPa or more after 24 hours. Many variables, such as the principal component of sea level pressure and the within-field variance value, appeared as the reasons for prediction of RI. The variables appearing in the reasons are the features related to RI. In the future, we will improve our understanding of these characteristics and compare them with existing knowledge of meteorology, and examine whether they can provide new knowledge on typhoon development.

Weighted analog intensity prediction (WAIP) guidance for Philippine tropical cyclones: Initial assessment in intensity bifurcation cases

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The performance of the intensity forecasts generated by the bifurcation version of the seven-day Weighted Analog Intensity Prediction technique for the Western North Pacific (WAIP) was evaluated for 13 tropical cyclone (TC) events that occurred within the Philippine Area of Responsibility (PAR) in 2022 using the preliminary best track intensities from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) as verifying dataset. The method generates a rank-weighted average of intensity evolutions of 16 historical analogs from the 1945-2018 Joint Typhoon Warning Center (JTWC) best track data that closely resemble the PAGASA official track forecast and initial intensity at the time WAIP was run. Furthermore, hierarchical cluster analysis is used to separate analog intensity evolutions into two clusters, provided, that a substantial intensity bifurcation (e.g., threshold intensity difference ≥ 15 kt at each forecast time) is observed.

For the 2022 test cases comprising 105 WAIP intensity forecasts with forecast length of up to 120 hours, the 16-analog WAIP showed generally increasingly negative bias errors with increasing forecast time and root mean square error (RMSE) ranging from 7.5 kt at 12-hour to 23.4 kt at 120-hour. In 36 of 105 WAIP intensity forecasts where substantial intensity bifurcation was observed, there was a considerable improvement in the intensity RMSE relative to the original 16-analog WAIP if an always perfect selection of the correct intensity cluster is made. The "perfect-cluster selection" WAIP forecasts had generally smaller bias errors and lower RMSE across nearly all forecast times, with percent decrease in RMSE ranging from 14.1 to 33.1% relative to those observed in the intensity forecasts from all 16 analogs. While further verification will be performed for TC cases from the 2018 to 2023 seasons, this preliminary evaluation demonstrated the viability of the WAIP as an operational intensity forecast guidance tool within the PAR region compared to the original 10-analog, seven-day WAIP in operational use at PAGASA, especially in intensity bifurcation situations.

Typhoon seasonal forecasting by a high-resolution coupled GCM (NICOCO)

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To mitigate the impact of typhoons, it is needed to precisely predict typhoon activity before the beginning of the typhoon season (June). Some research institutes, operational centres, and insurance companies abroad issue seasonal forecasts of typhoons. In Japan, a part of private weather companies provide an outlook of typhoon activities, but no official seasonal typhoon forecast is issued by JMA.

Dynamical-based typhoon seasonal forecast using conventional coupled GCMs has been intensively examined along with the progress of high-performance computers in the recent couple of decades. However, horizontal resolution is not high enough to represent observed typhoon intensity and some bias correction technique is needed to predict the intensity-related index (e.g., ACE) quantitatively.

Here, we used a 14-km-mesh global nonhydrostatic atmospheric model coupled with a 0.25-deg-mesh global ocean model (NICOCO; an AGCM NICAM coupled with an OGCM COCO) for 10-year (2010-2019) typhoon seasonal forecast experiments. The model is initialized on 20 May of each year and integrated to 1 November. The initial conditions for the atmosphere are made by interpolating the ensemble analysis data of ALERA (the first 5 members only are used because of computational resources). The initial conditions for the ocean are created by driving COCO using JRA-55do. Thus, the ensemble size of the experiments is five and the initial condition for the ocean is common among the ensemble members. We also performed NICAM (atmosphere-only) experiments. For NICAM experiments, the observational SST of OISSTv2.1 is given.

The results show that NICOCO performed better in predicting seasonal (June–October) numbers of typhoons and seasonal ACE than NICAM. For example, the correlation coefficients between simulated and observed seasonal numbers of typhoons are higher in NICOCO experiments (0.41) than that in NICAM experiments (0.31). The absolute value of mean error is lower in NICOCO (–2.18) than in NICAM (3.86). The model showed the best performance in predicting the seasonal number of typhoons in the eastern south part of the WNP (0°–18°N, 140°–180°E), where intense typhoons often form. The correlation coefficients between simulated and observed seasonal (June-October) numbers of typhoons are higher in NICOCO experiments (0.77) than that in NICAM experiments (0.70). For ACE in the eastern south part of the WNP, the correlation coefficient for NICOCO experiments is 0.80 and that for NICAM experiments is 0.67. The correlation coefficient between simulated and observed numbers of typhoons in June–August is higher in NICOCO experiments (0.36) than that in NICAM experiments (0.34). In September–October, however, the correlation is lower in NICOCO (0.24) than in NICAM (0.35). These results demonstrate NICOCO's good performance in typhoon seasonal forecasting.

Relative timing of rapid intensification and rapid contraction of the radius of maximum wind in tropical cyclones

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Based on the balanced vortex dynamics, it has long been known that tropical cyclone (TC) intensification often occurs simultaneously with contraction of the radius of maximum wind (RMW). However, some recent studies have found that rapid contraction (RC) of RMW could precede rapid intensification (RI) of TC in both observations and simulations, and the understanding of the involved dynamics is incomplete.

In this study, this phenomenon is first revisited based on ensemble axisymmetric numerical simulations. Consistent with previous studies, because the absolute angular momentum (AAM) is not conserved following the RMW, the phenomenon cannot be understood based on the AAM-based dynamics. Both budgets of tangential wind and the rate of change in the RMW are shown to provide dynamical insights into the simulated relationship between RI and RC. During the RC stage, due to the weak TC intensity and large RMW, the moderate negative radial gradient of radial vorticity flux and small curvature of the radial distribution of tangential wind near the RMW favor RC but weak diabatic heating far inside the RMW leads to weak low-level inflow and small radial absolute vorticity flux near the RMW and thus a relatively small intensification rate. As RMW contraction continues and TC intensity increases, diabatic heating inside the RMW and radial inflow near the RMW increase, leading to a substantial increase in radial absolute vorticity flux near the RMW and thus the RI. However, the RMW contraction rate decreases rapidly due to the rapid increase in the curvature of the radial distribution of tangential wind near the RMW as the TC intensifies rapidly and RMW decreases.

The analysis above suggests that RC tends to precede RI. To verify it, the statistical relationship between RC and RI is further examined based on the extended best track dataset for the North Atlantic and eastern North Pacific during 1999–2019. Results show that, as expected, for more than ∼65% of available TCs, the time of the peak contraction rate precedes the time of the peak intensification rate, on average, by ∼10–15 h. With the quantitatively defined RC and RI, results show that ∼50% TCs with RC experience RI, and TCs with larger intensity and smaller RMW and embedded in more favorable environmental conditions tend to experience RI more readily following an RC. Among those TCs with RC and RI, more than ∼65% involve the onset of RC preceding the onset of RI, on average, by ∼15–25 h. The preceding time tends to be longer with lower TC intensity and larger RMW and shows weak correlations with environmental conditions. The qualitative results are insensitive to the time interval for the calculation of intensification/contraction rates and the definition of RI. The results from this study can improve our understanding of TC structure and intensity changes.

Helicity evolution during the life cycle of tropical cyclones formed over the North Indian Ocean

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Tropical cyclones (TCs) are violent meso-β scale convections occurring in the atmosphere. The destructive impact of the TCs commensurate to the helicity associated with their evolution. The evolution of helicity of three TCs viz. Fani, Luban, and Ockhi formed over the north Indian ocean have been analyzed in this study. The analysis of kinetic energy density of primary (EP), secondary (ES) circulation and total helicity has shown that TCs showed helical features when the secondary overturning circulation knotted with primary tangential circulation in a moist convective situation. This condition can be considered a starting of the self-sustained helical feedback process. At this time, the core region became a rotation-dominated region that suppressed strain-dominated surroundings. The Okubo-Weiss parameter demonstrates the similar qualitative behavior of deep convection as total helicity. The local maximas in helicity time series commensurate with the changes in tropical cyclones' stages (intensification/dissipation). Therefore, consideration of helicity analysis is essential to analyze the TC intensification and dissipation.

Exploring aerosol effects on tropical cyclone dynamics and cloud microphysics

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Cyclonic storms are relatively common in the Arabian Sea, but extremely severe cyclonic storms, especially in the pre-monsoon season, are rare. Recently, an exceptionally severe cyclonic storm named "Tauktae" occurred from May 14 to 19, 2021 in the Arabian Sea. Climatological records indicate that such a deadly cyclonic storm has not been observed in the last 60 years. Cyclone Tauktae had a devastating impact on the west coast of India. In this analysis, we examined the dynamics and microphysics of Cyclone Tauktae. Additionally, we explored the role of aerosols in influencing the storm's dynamics and cloud microphysics. Our analysis utilized CERES observations for aerosols and the ERA5 reanalysis dataset for dynamics. The primary factors contributing to the intensification of Cyclone Tauktae included unusual warming in the Arabian Sea, significant latent heat release, and the buildup of cyclone heat potential. We also explored additional factors i.e., mixing of aerosols for this cyclone's intensification. As Cyclone Tauktae matured and progressed, it drew in a substantial amount of aerosols from the surrounding region. The northern tail of the cyclone brought in aerosols from the foothills of the Himalayas, while the southern tail pulled them from the Arabian Peninsula. This mixing of aerosols in the environment strengthened cyclone dynamics and cloud microphysics, leading to increased precipitation during its later stages around the time of landfall. This role of aerosols in storm dynamics we explored by conducting numerical simulations using the Weather Research & Forecasting regional model in the convection-permitting scales. Further research is needed to gain a deeper understanding of cloud microphysics and the precise influence of aerosols on cloud droplets.

Towards a new conceptual understanding of the decay of landfalling typhoons

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The most significant impact of typhoons on human lives is felt when they make landfall. Violent winds, heavy rain, and storm surges accompany landfalling typhoons as they decay over land. A textbook understanding of the decay of landfalling typhoons is achieved by the classical spin-down theory, where the decay is conceptualized using a simple framework: an axisymmetric vortex decaying due to friction with the land underneath. The simplicity of the theory allows an analytical expression predicting the decay of the vortex's azimuthal velocity with time.

We critically examine two aspects of the spin-down theory. First, we consider a key parameter that determines the decay rate: the vortex height. For a real landfalling typhoon, there is no clear analog for the vortex height used in the model and its common practice to use it as a free parameter to obtain a best-fit between model and observational data. We examine this practice by comparing the intensity decay predicted by the theory against results obtained from axisymmetric simulations of landfalling typhoon. We show that the vortex height can have a wide range of values that allows the theory to fit almost any kind of simple decay curve, giving a false impression of utility.

In the second part of this work, we look at the core idea of the spin-down theory through the perspective of total angular momentum budget. We show that the theory uses a strong assumption of no net flux of angular momentum across a vertical surface at any radial position, implying that frictional torque acts as the sole source or sink of the typhoon's total angular momentum. We demonstrate using numerical simulations that there is, in fact, a non-negligible contribution of the flux of angular momentum and discuss its implication in terms of the decay of the landfalling typhoon.

Long-term analysis of tropical cyclone intensity using MPI theory based on CMIP6 HighResMIP projections

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In addition to sea level rise, other effects of global warming have already been observed. The intensification of tropical cyclones (TC) is also no exception. This study shows how TCs will change in the future worldwide using MPI (Maximum Potential Intensity) theory, which estimates the maximum development of TCs for given climatological environmental conditions. This study used the CMIP6 HighResMIP (High-Resolution Model Intercomparison Project) experiment, which was evaluated specifically for TCs in IPCC AR6. This data set focuses on the intercomparison of TC intensities under the RCP8.5 scenario, providing high-resolution data and estimating the effect of atmosphere-ocean coupling with AGCM (Atmospheric Global Climate Model) and AOGCM (Atmosphere-Ocean Global Climate Model). The differences in projection between the AGCM and the AOGCM for MPI were analyzed in detail.

The scenario-based projections show significantly intensified TC trends in the monthly mean MPI in WNP (Western North Pacific) and NA (North Atlantic), especially for AOGCM, although each model of HighResMIP has different characteristics. As a most significant linear trend of monthly mean MPI, in NA, it was -0.76 hPa/10 years for AOGCM. As for future changes in MPI, in WNP, most GCMs suggested TC intensity changes are -1~-3 hPa by 2050. You can also easily guess a spatial difference between MPI and the maximum development value of TCs from track data of HighResMIP mainly because TC translation is not considered in MPI theory. Therefore, it is important to reveal the north-south difference when applying MPI to calculating MPS (Maximum Strom Surge height)[1)]. We can accurately predict future changes in maximum storm surge risk by quantifying and filling this difference. The details of the result will be presented at the conference.

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Refined tropical cyclone genesis potential index for enhanced tropical cyclone projection in the western North Pacific region

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The research utilized high-resolution atmospheric general circulation models (AGCM) to simulate tropical cyclones (TCs) and assessed two TC genesis potential indices concerning their ability to depict projected TC changes in the western North Pacific (WNP) under a warming scenario. Both indices effectively captured the seasonal variations in TC genesis frequency (TCGF) and its spatial distribution in historical simulations and observational data.The commonly used TC genesis potential index (χGPI) projected a substantial increase in TCGF in response to a warmer ocean surface. However, this projection contradicted the significant reduction in the model projection due to the predominant influence of sea surface temperature (SST) on χGPI. Higher SST in distant ocean basins often overshadowed the destabilizing effect of locally warmer SST, resulting in more stable atmospheric conditions in the WNP and fewer TC occurrences.In contrast, the revised index (χMqGPI), which takes gross moisture condensation into account, projected a decrease in TCGF that more accurately represented the declining trend of TCGF in the warming simulations by AGCM. Although the reduction was milder than that directly derived from the TC detection scheme, these results suggest the feasibility of using χMqGPI, based on multimodel coarse-resolution CMIP6 climate model outcomes, to forecast future changes in TCGF in the WNP.

The role of cloud-radiation interactions in accelerating tropical cyclone development

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This study uses CERES satellite measurements and WRF model simulations to examine the importance of radiative heating in promoting tropical cyclone (TC) genesis and modulating the prediction skills of TC intensification in an operational hurricane forecasting model. There is a growing recognition that radiative heating plays a critical role in accelerating the development of tropical mesoscale convective systems through cloud-radiation interactions. Therefore, investigating the role of radiative heating that contributes to TC development can advance our understanding of how the large-scale forcing influences TC genesis.

A series of experiments have been conducted using numerical model simulations to address how cloud-radiation interactions modulate the development of TCs. Both satellite measurements and model simulations demonstrate consistent signals of TC genesis that tropical waves (TWs) that develop into the TC category tend to have stronger cloud radiative heating than those that don’t, especially within 500 km of the circulation center. While latent heating is known to provide a higher magnitude of energy for TCs, our study finds that radiative heating also contributes substantially to TC genesis. Our numerical simulations reveal that when cloud-radiation interactions are included, the likelihood of TC genesis increases, particularly for storms at the weaker end of the intensity spectrum. The structural differences in cloud radiative heating within and around the TC area created by cloud-radiation interactions are found to be the key driver of this increase in genesis chances. In addition to the importance of radiative heating to TC genesis, the model’s ability to capture radiative heating also directly influences the prediction skills of TC intensification in numerical weather forecasting. Our findings suggest that cloud-radiation interactions play a crucial role in triggering the development of TWs and TCs at the early stage of their lifetime.

Sensitivity Analysis of Assimilating Doppler Radar Radial Winds Within the Inner- and Outer-Core Regions of Tropical Cyclones

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The assimilation of Doppler radar radial wind observations is important for improving tropical cyclone (TC) prediction. However, the specific impacts and contributions of these observations over different areas are still unclear. In this study, the impact of assimilating radar radial winds within the innerand outer-cores of TCs is evaluated. For TC Mujigae (2015), analyses suggest that although the outer-core observations better improve the upper-level outflow of the TC, the inner-core observations contribute more to enhancing tangential wind and updraft near the eyewall as well as correcting the TC size, warm core structure, and asymmetrical eyewall convection. The improvements conferred by the assimilating the total observations in the analysis and forecasting of TC tracks and intensities are mainly contributed by the inner-core observations. This is probably because: (a) the model has a higher deficiency in simulating the TC inner-core structure, which leads to a larger background deviation relative to the observations and the assimilation increment contributed by the inner-core observations; (b) as determined by the stronger nonlinearity of the physical processes, the ensemble spread (i.e., model uncertainty) around the inner core is larger, resulting in a more distinct impact of data assimilation. The significant improvements in the inner-core observations are further consolidated by analyses of two other TCs of different sizes and intensities, in which the number of inner-core observations accounts for only 1/3 of the total on average. The TC inner-core area should be a major consideration of future TC observation projects.

Reference:

Feng, J., Duan, Y., Sun, W., & Zhou, Y. (2023). Sensitivity Analysis of Assimilating Doppler Radar Radial Winds Within the Inner- and Outer-Core Regions of Tropical Cyclones. *Journal of Geophysical Research: Atmospheres*, *128*(8).

Angular momentum transport and instability in the eye: observational evidence from a 30-second imaging with Himawari-8

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I will be presenting views and results from a recent paper, Horinouchi, T., S. Tsujino, M. Hayashi, U. Shimada, W. Yanase, A. Wada, and H. Yamada, (2023) Stationary and transient asymmetric features in tropical cyclone eye with wavenumber-one instability: Case study for Typhoon Haishen (2020) with atmospheric motion vectors from 30-second imaging. *Mon. Wea. Rev.*, 151(1), 253-273. https://doi.org/10.1175/MWR-D-22-0179.1, whose abstract is as follows:

Dynamics of low-level flows in the eye of Typhoon Haishen (2020) in its late phase of intensification are investigated with a special rapid-scan observation of the Himawari-8 geosynchronous satellite conducted every 30 s. This is accomplished by deriving storm-relative atmospheric motion vectors at an unprecedentedly high spatiotemporal resolution by tracking clouds across five consecutive visible-light reflectivity. The overall low-level circulation center was situated several kilometers away from the storm center defined in terms of the inner edge of the lower part of eyewall clouds. The shift direction is rearward of the storm translation, consistently with a numerical study of the tropical cyclone (TC) boundary layer. Over the analysis period of 10 h, azimuthal-mean tangential wind around this center was increased at each radius within the eye, and the rotational angular velocity was nearly homogenized. The instantaneous low-level circulation center is found to orbit around the overall circulation center at distances around 5 km. Its orbital angular speed was close to the maximum angular speed of azimuthal-mean tangential winds. This rotating transient disturbance is found to transport angular momentum inward, which explains the tangential wind increase and the angular velocity homogenization in the eye. These features are consistent with an algebraically growing wavenumber-1 barotropic instability, whose impact on TC structures has not been explored. This instability enhances wavenumber-1 asymmetry in ring-shaped vorticity, which can be induced by various processes such as translation, environmental shear, and exponential barotropic instability. Therefore, it may appear broadly in TCs to affect wind distribution in their eyes.

Typhoon-generated extreme wave reanalysis by data assimilation with drifting buoy observations

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In recent years, many coastal disasters have been caused by typhoons. Furthermore, typhoon intensity is predicted to increase due to global warming, which is expected to increase the intensity of typhoon waves. Therefore, it is important to improve the accuracy of wave models for extreme high waves around typhoons. Also, in recent years, it has become relatively easy to observe the open ocean using small drifting wave buoys.
This study aims to develop a system to improve the accuracy of wave height prediction for typhoon waves by assimilating observation data from drifting wave buoys into a wave model.

We developed a system to assimilate the drifting buoy observations into the spectral wave model, WAVEWATCH III. We implemented Optimal Interpolation as a data assimilation method. We conducted typhoon wave simulations in the Western North Pacific, targeting the typhoon waves in the summer of 2022. The accuracy of wave simulations was estimated using the Japanese coastal wave observation network. At first, we conducted the initialized experiment in which the initial condition is assimilated with drifting buoy observations, and the model runs for three days without assimilation. As a result, the model improves immediately after data assimilation (initial condition), and the improvement continues for 71 hours. Next, we conducted a sequential data assimilation experiment in which the assimilation process was operated every 1 hour. The sequential data assimilation reduced the wave model error by up to 2.63 m when drifting buoys observed extreme typhoon waves near the center. Even when the assimilation process is operated every 3 hours, the wave model error was reduced by up to 2.36 m. Our results show that the assimilation of drifting buoy observation data can meaningfully improve the wave model for extreme typhoon waves.

Simultaneous observations of atmosphere and ocean directly under typhoons using autonomous surface vehicles

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In recent years, damage to structures and facilities due to extreme weather, such as typhoons, has been increasing. For implementing appropriate, proactive responses to expected damage, it is essential to predict typhoons more quickly and accurately. Therefore, in order to enhance the lead-time for responses, accurate prediction is indispensable while typhoons are forming and moving over the sea before they make landfall. Aircraft observations equipped with a dropsonde have advanced our understanding of the vertical structure of typhoons and confirmed that the accuracy of typhoon intensity prediction is improved by atmosphere-ocean coupled models, suggesting that information on the ocean, which is the energy source of typhoons, is also essential.

This study presents experimental observations to improve typhoon prediction accuracy and to understand interactions between atmosphere and ocean directly under typhoons. Two Wave Gliders (WGs) equipped with interchangeable sensors were sailed toward the path of an approaching Category 5 typhoon “Hinnamnor” in August 2022 in the north-west Pacific Ocean. Sensors on WGs measured atmospheric pressure, wind, atmospheric and seawater temperature, waves, currents, salinity, and chlorophyll-a concentrations in different parts of typhoons. For Hinnamnor, observations were made at 2 locations 11 km and 100 km from the typhoon’s center.

These observations made it possible to clarify changes in various phenomena as typhoons approached and to compare differences in storm characteristics measured by the two WGs. Sea surface pressure in the core of a typhoon is useful as an initial predictor of its intensity. Data assimilation into numerical models and other observations are expected to improve prediction accuracy of typhoon phenomena. Furthermore, simultaneous observations of atmosphere and ocean will also be useful for modeling interactions.

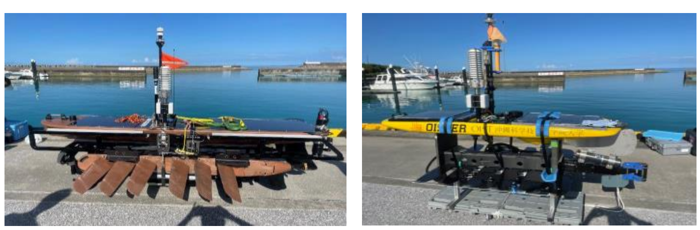

Fig. Observation equipment.
WG/SV3 named “Seiuchi-san” (left) and WG/SV2 named “OISTER” (right).

Impacts of assimilating sea surface observation directly under super typhoon Hinnamnor (2022) in the Northwest Pacific

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It is important to obtain observation over the ocean, to improve typhoon forecast accuracy and to understand typhoon development. Many attempts have been made to observe meteorological conditions near the typhoon centers [1,2], but it is not easy to observe typhoons due to the severe conditions. In 2022, we succeeded in simultaneous observation of the atmosphere and ocean directly under the typhoon Hinnamnor [3].

In this study, we assimilate the observation and forecast with the Weather Research and Forecasting Model's three-dimensional variational data assimilation system (WRFDA for 3DVAR) to see the effect of the observation on improving forecast accuracy.

In the first attempt, we assimilated the observation for the simulation where the typhoon weakened unlike the Japan Meteorological Agency (JMA) analysis, where the typhoon maintained its strength. Then it was found that the resulting pressure drop of 20 hPa approaches the analytical value by assimilating sea level pressure (SLP) and temperature (SLT). However, since in this attempt, the observation is limited at a single point and a single time and the simulation accuracy is low due to the rough resolution, the observation may be overestimated in this assimilation system. The next step is to increase the number of observation points and frequency of data to be assimilated.

Therefore, this time, we would like to assimilate and forecast with both atmospheric and oceanic data at multiple points and multiple times to evaluate the value of our sea surface observation. The results will be compared to the control run and to the JMA Best Track and we discuss the typhoon intensity with the atmospheric pressure obtained by the simulation.

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Atmospheric turbulence observation and simulation in typhoon circulation

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Atmospheric turbulence, characterized by rapid and irregular changes in wind speed and direction, presents significant challenges to aviation, weather forecasting, and simulation. Accurate monitoring and understanding of atmospheric turbulence are crucial for improving flight safety and weather prediction. However, traditional observation methods such as aircraft observations are not suitable for Taiwan, which has complex terrain and terrain compression characteristics. Balloon soundings, on the other hand, cannot provide sufficient spatial and temporal resolution for specific regions. Therefore, we propose the use of unmanned aerial vehicles (UAVs) and research jets as observation platforms to measure the in-situ turbulence in typhoon circulation. UAVs offer flexibility, safety and cheaper solution and maneuverability, allowing them to fly at lower altitudes and in specific regions, collecting real-time in-situ data with high spatial resolution, including aircraft coordinates, inertial navigation data, flight attitudes, and turbulence indicators such as eddy dissipation rate to identify convective regions. The research jets we approach are Gulfstream-100 (ASTRA, AIDC, Taiwan) and Gulfstrea-400 (G-4, DAS, Japan) for tropical storm dropsonde observation. We create a onboard toolkits including a Mateksys FC H743-WLite flight controller unit, and GPS sensor and Mission planner software to record the 50-Hz onboard flight information (latitude, longitude, time, height, pitch/yaw/roll and vertical velocity of aircraft) to estimate the atmospheric turbulence. In addition, we use numerical weather models (WRF) as the environmental base and simulate UAV flights using the X-Plane flight simulator under different weather conditions. Finally, we did an field testing flight experiments 2020 in the Yi-Lan of Taiwan. One UAV combine our toolkits hanged by weather balloon released at 2000m height to played kind of “re-turn” glider recoveried this UAV well. Our toolkits alao took a good testing cases in AIDC-ASTRA jet cabins during Typhoon DOKSURI and any possible typhoon cased in western Pacific Ocean during summer-autumn of 2023. We expect tour toolkit could help us collecting lots of atmospheric turbulence in real typhoon weather condition and to validate the numerical model simulation results.

Optimization of a numerical weather model for the supercomputer Fugaku

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Typhoons and torrential downpours often cause disastrous damage to society. To prevent them, understanding and predicting the mechanisms of these meteorological phenomena is an important social issue at present.

An important method to reveal these mechanisms is the weather simulation. CReSS (Cloud Resolving Storm Simulator) and NICAM (Nonhydrostatic ICosahedral Atmospheric Model) are examples of such simulators. Simulating high-resolution problems is essential for understanding the details of the mechanism and improving prediction accuracy. HPC (High Performance Computing) plays a significant role in executing them. However, there are challenges in computing large-scale weather simulations, such as computational speed, scalability, and data transportation. We are researching technology to enable large-scale weather simulations and use highly efficient computing resources with HPC.

In this study, we conducted performance profiling of CReSS on the supercomputer Fugaku. This mainly includes strong scaling and bottleneck analyses. In terms of strong scale analyses, we confirmed that CReSS has scalability, i.e., increasing the number of computation nodes led to a decrease in computation time. However, the scalability was slower when using more than 16 computation nodes. In terms of the bottleneck analyses, the process of “saturation adjustment” accounted for about 20% and had the maximum computation time among all processes when using intra-node computation. Furthermore, in MPI (Message Passing Interface) communication, the process of “AllReduce” including error information collection accounted for about 80% when using inter-node computation.

As the next step in our research, we will analyze the performance of SCALE (Scalable Computing for Advanced Library and Environment), which adopts similar models to CReSS, and compare them. Additionally, we will identify points for optimizing CReSS and develop novel technology to effectively execute CReSS on Fugaku.

Near landfall intensification of tropical cyclones in the South China Sea: Coastal shallow water responses

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Over a quarter of TCs experienced rapid intensification in the South China Sea (SCS), which is comparatively higher than those in western north Pacific. As most of those intensification occurred over the shallow continental shelf in the northern SCS, it is important to find out the possible favorable oceanic responds during the passage of Near-landfall Intensification (NLI) TCs. The coastal shallow water dynamic and thermal process during the passage of three NLI TCs and other non-NLI ones is studied.

The cooling effect of Sea Surface Temperature (SST) happens after the passage of TCs, while the SST in the forward direction of NLI TCs track is maintaining or even increasing when approaching land. The coastal mixed layer warming along the coastline can be explained by Ekman transport under sustained wind stress under easterly surface winds forcing on the right side of TC tracks. The magnitude of easterly wind stress during the passage of NLI TCs is 3 times more than those without intensification. Successive deepening of coastal boundary layer and increasing warming up of density mixed layer, where the vertical integrated temperature increase up to 0.3℃ on average, could maintain oceanic heating before landfall.

Coastal Ekman transport could favor coastal downwelling to compensate the loss of warm water, indicating the critical importance of coastal ocean dynamics and air-sea interactions.

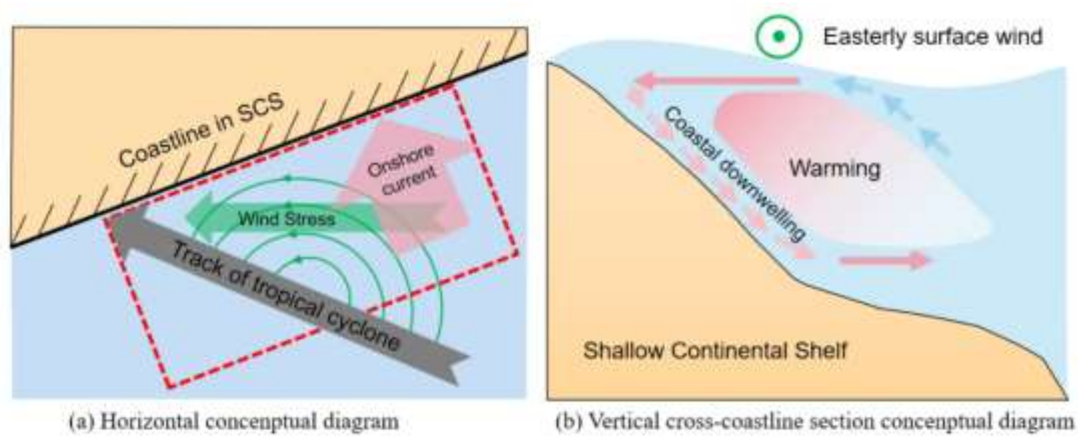

Figure. Conceptual diagram of (a) Horizontal and (b) vertical cross-coastline section of shallow water responds during the passage of NLI TCs.The red dashed box is defined as shallow continental shelf area in SCS. The gray thick arrow indicates the prevailing track in the SCS. The green vectors represent the surface wind by TC forcing; Pink vectors and shading areas denotes coastal downwelling and corresponding warming averaged in red dashed box.

The impact of varying SSTs on the track and intensity of Tropical Storm WASHI (2011)

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High sea surface temperatures (SSTs) supply thermodynamic energy to tropical cyclones (TCs). As global SSTs increase, it is essential to understand how SST affects TC track and intensity. This study investigates the effects of changing the SST magnitude over the Philippine Sea (125°E to 150°E and 5°N to 15°N) on the track and intensity of TC WASHI (2011), a catastrophic TC that hit Mindanao Island, southern Philippines, using the Weather Research and Forecasting (WRF) model. This TC exhibited an almost linear and westerly track that passed through warmer than normal waters. Simulations were conducted wherein the SST over the Philippine Sea was adjusted uniformly with the following magnitudes: ±0.5K, ±1.0K, and ±2.0K. The results show that as the SST magnitude increases (decreases), the TC intensity strengthens (weakens), the translational speed increases (decreases), and the track deflects northwards (southwards) when the TC is still on open waters and without topographic interaction. This is attributed to the fact that higher (lower) SST facilitates (impedes) evaporation, which leads to enhanced (reduced) latent heat transfer, condensation, and adiabatic heating. This results in greater (lesser) surface wind circulation, increased (decreased) translational speed, and a stronger (weaker) maximum sustained wind speed of the TC. The impact of SST on the track was further analyzed in terms of potential vorticity (PV) and its tendency (PVT), which was decomposed into its horizontal advection, vertical advection, and diabatic heating components. The results show a larger contribution of the horizontal advection component than the vertical advection and diabatic heating components to the TC track, such that a northward (southward) deflection occurs when SST magnitude increases (decreases). Specifically, the TC tends to move to an area with higher values of the horizontal advection component of the PVT. These findings provide additional insights into the effects of SST variability and future changes on TCs within the Philippine Sea.

Keywords: WRF, Tropical Cyclone, TS WASHI, sea surface temperature, carnot engine, Mindanao Island

Changes in intensity and tracks of tropical cyclones crossing the central and southern Philippines from 1979 to 2020: an observational study

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Observational studies on the characteristics of tropical cyclones (TCs) crossing Mindanao and Visayas Islands, in the southern and central Philippines, respectively, remain limited. To address this research gap, this study investigates the changes in the translational speeds, the direction of motion, and intensities of 8 and 39 landfalling TCs crossing Mindanao and Visayas Islands, respectively, from 1979 to 2020. The intensities, translational speeds, and direction of motions of the TCs were characterized by their position before (approaching point; AP), during (landing point; LP), and after (departing point; DP) traversing through Mindanao and Visayas Islands. The results show a significant linear relationship in the intensity change between AP and DP, indicating a general weakening of TCs as they traverse both island groups. About 5 (29) TCs showed a decrease in intensity based on the maximum sustained wind speed (MSW) after crossing Mindanao (Visayas). The intensity of TCs with at least Typhoon category upon landfall, decreased on average (percentage) by about 23.33 kts (− 25.4%) and 24.29 kts (− 45.5%) after crossing Mindanao and Visayas, respectively. The MSW of weaker TCs decreased on average by about 6.67 kts (− 25.0%) and 8.13 kts (− 20.5%) after traversing Mindanao and Visayas, respectively. Cases with increased (1 TC for Mindanao and 6 TCs for Visayas) and no change in intensities (2 TCs for Mindanao and 4 TCs for Visayas) after crossing the island were also found. Landfalling TCs over Mindanao exhibited a characteristic where those defected rightward (leftward) at AP tend to be defected rightward (leftward) at DP, while no pattern was found for the TCs traversing Visayas. Furthermore, TCs moving across Mindanao and Visayas tend to decelerate as they approach and move away from the island. The findings of this study are essential for disaster mitigation and a greater understanding of the TCs behavior in terms of intensity, translational speed, and defection.

Numerical simulation of topographic influence on the heavy rainfall of Typhoon Rammasun

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The heavy rainfall caused by Super Typhoon Rammasun (2014), the strongest typhoon that has landed in China since meteorological records began, has caused huge economic and social losses to China. Preliminary analysis showed that the intensity and area of the rainfall were closely related to Wuzhi Mountain, China. However, the physical mechanisms need to be analyzed in depth. Using the WRF V3.9 model, a high-resolution numerical simulation of topographic influence on the heavy rainfall of Typhoon Rammasun was carried out. The results show that the topographic rise significantly weakened the rainfall intensity and changed the location of the heavy rainfall center of Typhoon Rammasun. If the topography of Hainan Island increased to twice the original altitude, the maximum daily rainfall caused by Rammasun decreased by 35.2%, and the heavy rainfall center shifted from western Hainan Island (WHI) to southwestern Hainan Island (Fig. 1).

On one hand, the topographic rise increased the friction of the topography and weakened the intensity of Rammasun, resulting in a weaker rainfall in WHI (the observed heavy rainfall center). On the other hand, the topographic rise changed the structure of Rammasun. The control experiment showed that the heavy rainfall in WHI was mainly caused by meso-micro scale systems on an outer spiral cloud belt of Rammasun. If the altitude rose, the low-level convergence and the mid-low level ascending movement in WHI were weakened, making it difficult to form long-lasting, quasi-stationary meso-micro scale systems, eventually leading to the rainfall center transferring to southwestern Hainan Island.

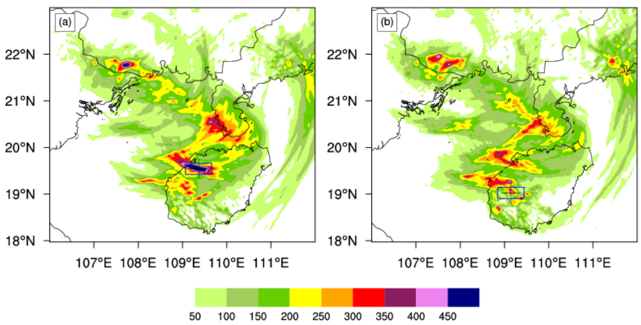

Fig. 1 The simulated daily rainfall of Typhoon Rammasun on 19 July 2014 in domain 1 (unit: mm, The black crosses in (a) and (b) represent the heaviest rainfall position of CTRL (P1) and that of SEN2 (P2), respectively. The rectangular boxes in (a) and (b) represent the heaviest rainfall area of CTRL (A1) with P1 as the center and that of SEN2 (A2) with P2 as the center, respectively.)
(a) CTRL experiment; (b) SEN2 experiment

Tropical cyclone wind field reconstruction for hazard estimation via Bayesian hierarchical modeling

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Tropical cyclones (TCs) are one of the biggest threats to life and property around the world. Usually, TC wind hazard is quantified in terms of return periods/levels of wind fields. Accurate estimation of TC wind hazard, especially for extreme TC wind, requires estimation of catastrophic TCs having a very low occurrence probability, or equivalently a very long return period spanning up to thousands of years. Since reliable TC data are available only for recently decades, stochastic modeling and simulation turned out to be an effective approach to achieve more stable hazard estimates, particularly for regions where little or no historical TC records exist.

The common practice consists of two stages. The first stage is to fit a basin-wide TC full-track model to TC track data, to generate hundreds of thousands of synthetic TCs that can make up for the sparseness of TC observations while still complying with the statistical characteristics of the observed TCs. The second stage is to couple these synthetic TCs with TC wind field models, either to simulate landfall TC wind fields for wind hazard estimation, or to further drive storm surge models for coastal flood hazard estimation. The performance of the synthetic TCs is crucial to the subsequent hazard estimation. The authors have developed a novel approach to the full-track TC modeling and simulation via multivariate functional principal component analysis (Yang et al. 2021), which shows high performance and high efficiency for the first-stage task.

Here, we present a Bayesian hierarchical modeling approach to TC wind field reconstruction to fulfil the second-stage task, based on synthetic TCs generated from the first stage. The reconstructed TC wind fields are ready for hazard estimation. Through this and our previous works, we have completed a systematic approach to TC wind hazard estimation. As an illustration, we applied our approach to western North Pacific basin yielding a 10,000-year TC wind field series, and estimated TC wind hazards for China coastal cities and offshore waters. Our proposed approach has the following advantages:

- From full-track simulation to wind field reconstruction, only minimal dataset, i.e. the TC best-track data, is used throughout our approach, whose sources are usually stable and consistent.
- Only one single model is used for each stage task, so that aspects of a synthetic TC and its wind field are consistent with each other, and correlations between them are considered.
- Our approach is computationally efficient and can run on a modern desktop PC, therefore the turnaround time can be greatly reduced, especially when newly available TC data are incorporated periodically into the model, so that it can be used for various purposes relating to TC wind hazard estimation.

Yang C, Xu J, Yin J. (2021). Stochastic Simulation of Tropical Cyclones for Risk Assessment at One Go: A Multivariate Functional PCA Approach. *Earth and Space Science*, 8(8). https://doi.org/10.1029/2021EA001748.

Impacts of Typhoons, Western Pacific Subtropical Highs, and Upper-Level Jets on a predecessor rain event in Central China

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Based on high-resolution WRF simulation results, this study mainly utilizes the Piecewise Potential Vorticity Inversion (PPVI) method to quantitatively analyze the influence of Typhoon "In-Fa" (2021), the Western Pacific Subtropical High (WPSH), and the Upper-Level Jet Stream (ULJ) on a predecessor rain event (PRE) in Central China. The patterns of the WPSH, Typhoon "In-Fa", ULJ and precipitation are well reproduced in the control experiment (CTL). The magnitude of potential vorticity anomaly associated with the WPSH (Typhoon "In-Fa") is increased and decreased by 50% in the initial condition based on the PPVI method, namely SH150 and SH050 (TC150 and TC050), respectively. The analysis shows that the 54-h rainfall accumulations in TC150 and TC050 are reduced by 39.5% and 31.8% compared to CTL, respectively, more than 28.8% in SH150 and 20.1% in SH050, indicating that Typhoon "In-Fa" plays a more critical role in the rainfall amplification than the WPSH. This result also confirms that this PRE occurs within the quite favorable configuration of WPSH and Typhoon "In-Fa" circulations. The WPSH and Typhoon "In-Fa" majorly control the meridional and zonal moisture transports, respectively. The diagnosis of moist ageostrophic ω turns out that diabatic heating is closely related to the vertical motion during this PRE. Besides, the heavy rainfall region is also closely attributed to the distributions of equivalent potential temperature and divergence.

Additionally, we also discussed the implications of ULJ for this PRE. In the sensitivity experiment (NOULJ), the ULJ is largely suppressed by mitigating the adjacent upper-level troughs and ridges according to the PPVI method. As a result, the upper-level divergence, secondary circulation, lower-level jet (LLJ), and precipitation in NOULJ are weaker than those in CTL. A forward trajectory analysis further indicates that the secondary circulation is suppressed in NOULJ, mainly due to the weakening of upper-level pumping effect. The 54-h accumulated rainfall in NOULJ is 31% lower than that in CTL, which can be attributed to three facets: 1) the moisture accumulation is majorly controlled by wind convergence, which is closely related to the ULJ and LLJ; 2) the upward motion is primarily organized by the thermally direct secondary circulation on the right-entrance region of ULJ, with a minor contribution from the baroclinic trough; 3) the atmosphere instability and slantwise vorticity development are weakened in NOULJ.

Tropical cyclone induced remote precipitation over Yangtze River Basin during the last stage of Meiyu Period

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1. Introduction

The precipitation associated with a tropical cyclone can be broadly classified into two primary categories: precipitation induced by the TC's circulation, and Tropical Cyclone Remote Precipitation (TRP). Under favorable atmospheric conditions, it has been discovered that the interaction between TC with mid-latitude weather systems tends to result in substantially higher levels of precipitation than those produced solely by the TC body circulation, which has become one of the most important forms of summer rainstorm in mid-latitude regions. This study will focus on a significant rainstorm event took place towards the end of the Meiyu season in 2016 over the Yangtze river basin (YRB) in China, which potentially influenced by Typhoon Nepartak and recognized as a TRP event.

2. Data & Method

The NCEP FNL data were prepared operationally produced every six hours and consist of 1°x1° grids. The numerical simulation was conducted using WRF-ARW v4.4. Typhoon best track data are provided by JMA and JWTC. The CMORPH data was utilized for the systematic evaluation and validation of simulated precipitation results. China Ground station dataset were employed to observe the intensity of precipitation over YRB. We applied the TC isolation and removal algorithm on the WRF run to further investigate the remote effect of TC. The anomalous features were removed using the following 9-point smoothing operator.

3. Results

Around July 6th, extreme precipitation occurred over Wuhan and part of Anhui Province over YRB in China. To further investigate characteristics of TRP process, we utilized the WRF model for numerical simulation experiment. The following analysis are based on the simulation results.

The moisture over rainfall area supplied by two moisture channels from the south China sea and the Pacific to the rainfall area, which is primarily driven by TC Nepartak and West Pacific Subtropical High circulation. Over the rainfall area, a distinct correlation can be discerned with positive Moisture Flux Convergence (MFC) region.

Following the removal of the TC, a marked reduction in precipitation was observed within the rainfall region (Fig.1 (a)). While the effects of the TC were not entirely eliminated, the precipitation over YRB still significantly decreased by approximately 25%. Accompanied by this, though the moisture channel hasn't change, the MFC was substantially reduced over YRB and two moisture channels (Fig.1 (b)). The removal of the TC led to an increase in geopotential height on the southwest and south flank of the WSPH, resulting in a corresponding weakening of the wind fields. Such change significantly reduced the transport of moisture towards the YRB direction resulting in the decreasing of precipitation.

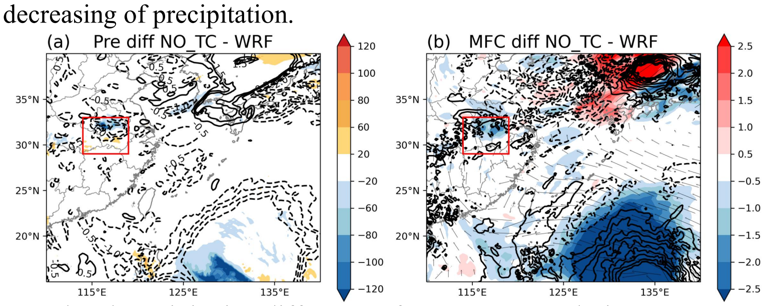

Fig.1 Accumulated precipitation difference of NO_TC – F06 during TRP **Contour**: MFC difference (b) Vertical integrated MFC difference of NO_TC – F06 at peak time of rainfall **Arrow**: Moisture flux in NO_TC run **Contour**: Geopotential height difference

The association of West Pacific subtropical high with Typhoons over the western North Pacific Ocean and its impact on Indian summer monsoon rainfall

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The present study examined the interrelationship between the Indian summer monsoon (ISM) rainfall, west Pacific subtropical high (WPSH) and Tropical cyclone (TC) activity over the western north Pacific (WNP) Ocean during the peak summer monsoon season in 1951-2019. When WNP TCs are inactive (active), there is a noticeable 10° westward (eastward) shift observed in intense (weakened) WPSH. The WPSH and WNP TC activities divided into four categories: Eastward shift of WPSH with active TCs (EA) and inactive TC (EI), westward shift of WPSH with active TCs (WA) and inactive TCs (WI) in order to investigate the combined influence of WPSH and WNP TCs on ISMR during NonENSO. In EA, surplus (deficit) rainfall noticed over the central (southern peninsular) India as result of moderate cold PDO pattern and moisture convergence (low CAPE, abnormal moisture divergence and downdraft). The eastward shift of WPSH and inactive WNP TCs during NonENSO helps to increase (decrease) the regional convective activity over east central India and parts of north India (southern peninsular India) through regional changes in atmospheric circulations and mid-tropospheric vertical velocity. In contrast, westward shift of WPSH along with inactive (active) TCs, the majority of India (southern peninsular and northeast India) experiences excessive precipitation while east central India (east and west central India) undergoes deficit rainfall in WI (WA) cases. These rainfall patterns are consistent with spatial distribution of moisture flux convergence, CAPE and mid-tropospheric vertical velocity over the region. In the cases of NonENSO, the westward shift of WPSH associated with inactive TCs is a more favourable condition for ISMR than active TCs.

Quantification and attribution of ocean cooling induced by the passages of Typhoons Faxai (2019) and Hagibis (2019) over the same region using a high-resolution ocean model and cooling parameters

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A typhoon develops by receiving thermal energy from the ocean. It is also known that the sea surface temperature (SST) decreases with the passage of typhoons, which is important to predict typhoon intensity. In this study, we quantitatively evaluated the typhoon-induced SST cooling caused by typhoons Faxai (2019) and Hagibis (2019) using a high-resolution ocean model (Tanaka et al., 2018) and the cooling parameter (Co) proposed by Miyamoto et al. (2017).

Co is a non-dimensional number that theoretically indicates the magnitude of SST cooling during the passage of a typhoon. The model is based on the ocean general circulation model MRI.COM Ver. 4.7 (Tsujino et al., 2017). The horizontal resolution is $1/60^\circ$ and the vertical is 35 layers.

Faxai and Hagibis both passed over the same ocean region south of Japan with similar tracks, but the associated average SST cooling differed. Mean SST cooling by Faxai was less than 2 degrees, while Hagibis was more than 2 degrees. The average Co value was 1.6 for Faxai and 3.6 for Hagibis, indicating that SST was more easily cooled by Hagibis than by Faxai. This is consistent with the observations. In the impact of ocean conditions in Co, Hagibis was 2.6 times larger than Faxai. It indicates that the ocean before Hagibis passes is less hard to cool ocean than Faxai. In short, it is important for ocean cooling not only ocean conditions but also typhoon characteristics because in fact, Hagibis cooled the ocean more than Faxai. In addition, the impact of typhoon characteristics in Hagibis was 4.8 times larger than in Faxai. Thus, SST was more likely to cool by typhoon characteristics in the case of Hagibis. Especially, typhoon size in the horizontal direction had the most efficient effect on SST cooling.

Therefore, Co can estimate the effects of typhoon characteristics and ocean conditions separately. This study quantitatively shows differences in the attribution of typhoon-induced SST cooling caused by Faxai and Hagibis. We propose that Co is a practical indicator for estimating SST cooling caused by a typhoon and comparing factors of typhoon-induced SST cooling in multiple cases although Co does not consider the effects of upwelling and advection.

Rainfall strength and area from landfalling tropical cyclones over the North Indian and western North Pacific oceans under increased CO2 conditions

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To understand the characteristics and changes in rainfall associated with landfalling tropical cyclones (TCs) from various perspectives, several studies have been conducted: 1) examining the characteristics and future projections of TC-induced rainfall in the North Indian Ocean (NIO) and western North Pacific (WNP), 2) investigating the influence of environmental factors on TC-induced rainfall and its future changes in the NIO, and 3) exploring the impact of environmental factors on TC-induced rainfall and its future changes in the WNP.

Firstly, the rainfall characteristics of TCs were divided into rainfall strength (RS) and rainfall area (RA). Currently, the WNP exhibits higher intensity and larger area of TC-induced rainfall compared to the NIO. Moreover, the changes in rainfall characteristics under different scenarios of increasing carbon dioxide (CO_2) varied across different regions. Particularly, in the NIO, there was a greater increase in RS, while in the WNP, the RA showed a larger increase. This indicates that TC-induced rainfall and the associated environmental conditions differ between regions.

Secondly, the temporal and spatial relationships between TC-induced rainfall and environmental variables were examined in the NIO, focusing on the pre- and post-monsoon periods and dividing the region into the Arabian Sea and the Bay of Bengal. Regardless of the region, there was a close relationship between TC intensity and RS. It was observed that the frequency of TCs in the Arabian Sea. These findings suggest an increased risk due to the higher frequency and intense RS associated with TCs in the Arabian Sea, highlighting the need for appropriate measures.

Lastly, in the WNP, the temporal analysis revealed that TC-induced rainfall predominantly occurs from July to October, while the spatial analysis divided the region into the South China Sea and East Asia. In terms of RA, all environmental variables showed significant relationships in the South China Sea, while in East Asia, mid-level relative humidity was not a significant factor and vertical shear played a particularly important role. This highlights the importance of understanding the regional variations and mechanisms that regulate TC-induced rainfall in the WNP.

In conclusion, the studies provide insights into the characteristics and changes in precipitation associated with landfalling TCs in the NIO and WNP from different perspectives. The findings emphasize the need to improve our understanding of the regional factors that modulate TC-induced rainfall. Furthermore, considering the potential risks associated with increased TC frequency and intense rainfall, appropriate measures and policies should be developed for effective management and response within the affected regions.

Risk assessment for sediment disaster using Typhoon Path Ensemble Simulation

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With the increasing risk of disasters due to climate change, there is an urgent need for local governments and companies in Japan to establish measures to mitigate disaster risks. However, the experience of local governments in disaster prevention largely depends on past disaster experiences, and there is a need to support disaster reduction awareness in municipalities that have not experienced major disasters in the past through unconventional approaches. The purpose of this study is to create a time-series data of alert and warning information related to virtual sediment-related disasters based on the Typhoon Path Ensemble Simulation (TPES, Yamasaki et al., 2017), which is an ensemble dataset that simulates the shift of typhoon paths from east to west for 30 real typhoon cases.

The TPES precipitation data, with a horizontal grid size of 5 km and a time interval of 30 minutes, are converted to a 1 km grid size with a time interval of 10 minutes, similar to the analyzed rainfall. In addition, a frequency bias correction is applied to adjust the occurrence frequency of extreme precipitation values. A newly implemented serial three-tank model, similar to the one used by the Japan Meteorological Agency developed by Ishihara and Kobatake (1979), is used to calculate the soil-water index values from precipitation data. The soil-water indexes are converted to (virtual) Landslide Risk Map.

There are differences in the occurrence frequency of extreme precipitation between the rainfall data calculated using the numerical weather model WRF in Typhoon Path Ensemble Simulation and the Radar-AMeDAS rainfall. To minimize the impact of these differences, the frequency bias correction method (e.g., Matsushita, 2012) is applied based on the historical data of the Japan Meteorological Agency's MSM rainfall from October to March between 2011 and 2020, which has a comparable resolution to TPES despite being a different model. The Radar-AMeDAS rainfall was converted to a 5 km mesh following Urita et al. (2011). The cumulative frequency for thresholds of precipitation was calculated for both the Radar-AMeDAS rainfall and MSM. The precipitation in MSM and TPES is corrected following the corresponding cumulative frequency of the Radar-AMeDAS precipitation

We compared the maximum soil-water index during Typhoon Hagibis event in 2019 between the analysis, the simulation of TPES with and without the frequency bias correction. It seems that TPES underestimates the soil-water indexes compared to the analysis, while the bias-corrected TPES appears to be closer to the analysis. We also found the frequency bias correction works well in other Typhoon cases.

In the future, we plan to apply Typhoon Path Ensemble Simulation to various fields related to risk management, such as the formulation of business continuity plans (BCPs) for private companies and/or local governments. It is also possible to create the multi-hazard index data, including virtual flood and inundation hazards based on the Typhoon Path Ensemble Simulation, which will be a future work.