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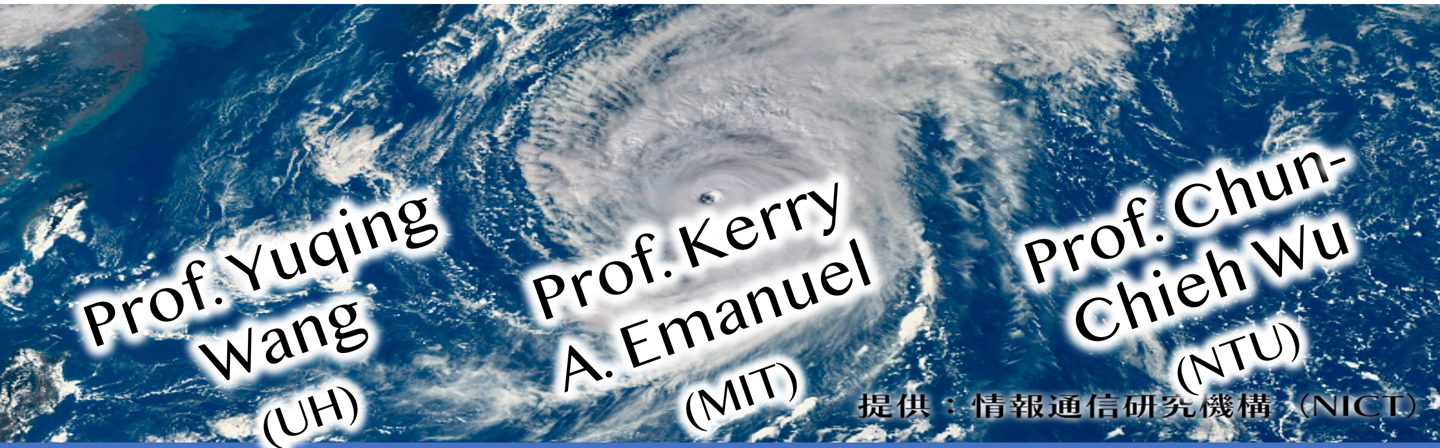
ABSTRACTS (SESSION 1)



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Tropical cyclone characteristics over the western North Pacific stratified by genesis environment

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A tropical cyclone (TC) forms under large-scale environmental conditions favorable for cyclogenesis (TCG), which are generally found where higher sea surface temperatures (SSTs) and supportive largescale flow patterns coexist. Ritchie and Holland (1999) grouped the lower-tropospheric large-scale atmospheric flow patterns contributing to TCG over the western North Pacific (WNP) into five TCG factors: shear line (SL), confluence region (CR), monsoon gyre (GY), easterly waves (EW), and Rossby wave energy dispersion from a preexisting cyclone (PTC). Yoshida and Ishikawa (2013), following their study, developed a method of detecting the five TCG factors, named Typhoon Genesis Score (TGS). The TGS methodology is currently available on TRC's website, providing real-time analysis results. The advantages of releasing real-time TGS results are twofold: 1) differences in the TCG factors that lead to characterization of TCs and 2) differences in the TCG factors could be considered key determinants of whether a TC develops to tropical storm strength.

Fudeyasu and Yoshida (2017) determined the statistical characteristics of TCs over the WNP, stratified by five TCG environmental factors in the summer and autumn during 1979–2013, using TGS. TCs that formed in large-scale flows mainly associated with a GY (hereafter, GY-TCs, and similar terms) tended to develop slowly. The average lifetime maximum intensity of PTC-TCs is larger than those of other factors, due to their longer development stage. On average, TC size of GY-TCs is larger at the TCG time than other TCG factors, whereas those of EW-TCs and PTC-TCs are smaller. These results provide important information for use in disaster prevention.

Using the TGS and early stage Dvorak analysis (EDA) provided by the Japan Meteorological Agency, Fudeyasu et al. (2020) investigated the characteristics and environmental conditions of TCs over the WNP from 2009 to 2017 that dissipated before reaching tropical storm strength (TDs) under unfavorable environmental conditions. We compared TDs with TCs that reached tropical storm strength (TSs) in terms of modulations of the five TCG factors. The environments around TDs were less favorable for development than those around TSs, as there were significant differences in atmospheric (oceanic) environmental parameters between TDs and TSs in the factors of CR, EW, and PTC (SL, GY, and PTC). The environmental conditions for reaching tropical storm strength over their genesis stage, using five factors, can be summarized as follows: higher tropical cyclone heat potential in the SL and GY, weak vertical shear in the CR, wet conditions in the EW, and higher SSTs and an intense preexisting cyclone in PTC. Thus, the development conditions stratified by environmental factors using TGS can be used for operational forecasting.

Counterbalancing impacts from historical anthropogenic aerosols and greenhouse gases on global-scale tropical cyclone genesis potential

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How anthropogenic forcing could change tropical cyclones (TCs) is a keen societal concern owing to its significant socio-economic impacts. However, a global picture of the anthropogenic aerosol and greenhouse gas effect on TCs has not yet emerged. Here we show that anthropogenic aerosol emission can reduce northern hemisphere (NH) TCs, represented by genesis potential index (GPI), but increase southern hemisphere (SH) TCs primarily through altering vertical wind shear and mid-tropospheric upward motion in the TC formation zones using the single anthropogenic forcing experiments from the 14 Coupled Model Intercomparison Project phase 6 (CMIP6) models.

These circulation changes are driven by anthropogenic aerosol-induced NH-cooler-than-SH and NH-increased versus SH-decreased meridional (equator to mid-latitudes) temperature gradients. The cooler NH produces a low-level southward cross-equatorial transport of moist static energy, weakening the NH ascent in the TC formation zones; meanwhile, the increased meridional temperature gradients strengthen vertical wind shear, reducing NH TC genesis. The opposite is true for the SH. The results may help to constrain the models' uncertainty in the future TC projection. Reduction of anthropogenic aerosol emission may increase the NH TCs threat. Further, we quantify the relative contributions of anthropogenic aerosol and greenhouse gas (GHG) to global TCF.

We find that the two forcings have comparable but opposite impacts on GPIs due to their influences on the TC environment, leading to an insignificant change in GPIs in the historical period (1850-2014). Notably, the aerosol radiative forcing's intensity is only about one-third of that of GHG, suggesting a more effective modulation of aerosol forcing on GPIs. The stable global TC frequency during the past decades could be attributable to the similar pace of the two anthropogenic emissions. The results highlight that a reliable global TC projection depends on both the aerosol and GHG emission policies.

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.

On the Intensification of Typhoon Damrey with the Monsoon Gyre

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Typhoon Damrey, the first named tropical cyclone (TC) of the year 2000 in the western North Pacific, was embedded in a monsoon gyre (MG) during its intensification period. We explored the mechanisms of its rapid development and the contribution of the MG using a localized, instantaneous energetics diagnostic tool: the multiscale window transform (MWT) and MWT-based multiscale energetics analysis. We used the ERA5 reanalysis dataset to obtain the fields on three temporal scales: TC-scale fields; MG-scale fields; and large-scale background fields. The canonical transfer of kinetic energy from the large-scale background fields to the tropical cyclone was negligible, whereas the MG increased the TC-scale kinetic energy in the precipitation active quadrant and weakened its kinetic energy in the precipitation inactive quadrant. Barotropic canonical transfer therefore did not contribute to the development of this tropical cyclone. Kinetic energy was produced in Damrey mainly through buoyancy conversion and pressure work. In the upper troposphere, the available potential energy converted to TC-scale kinetic energy, but this was mostly offset by the negative work done by the pressure gradient force with the updraught near the eyewall. In the lower troposphere, TC-scale kinetic energy was produced by horizontal pressure work due to the inflow. This new finding helps us to understand the impact of the MG on the TC intensification and the underlying mechanisms governing TC evolution.

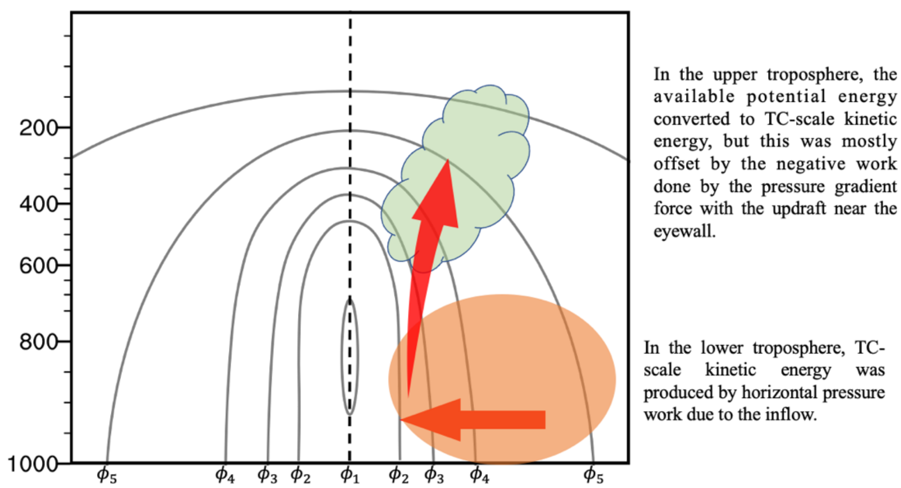

Fig. 1 Schematic diagram of the intensity changes of Typhoon "Damrey" in 2000.

Relationship between tropical cyclone intensity and SST

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The primary importance of the sea surface temperature (SST) to the tropical cyclone (TC) activity is well known. In the western North Pacific (WNP) anomalous SST significantly modulates the TC activity through the atmospheric responses. Occurrences of the intense TCs are the community's major concern. Here we discuss how the SST anomalies affect the frequency and distribution of the TC lifetime maximum intensity (LMI) in the WNP.

We focus on how the modulation of SST in the specific subdomains of the WNP (e.g., tropics, subtropics) can affect the TC LMI, by sensitivity experiments using a global atmospheric model (Nonhydrostatic ICosahedral Atmospheric Model, NICAM[1]) for the 2018 boreal summer season[2],[3]. A horizontal mesh size of 14 km, which marginally resolve TC structure, was employed. Each sensitivity case consists of 24 members.

The 2018 summer is characterized by warm SST anomalies over the central subtropical Pacific, central the eastern Pacific, and south of Japan, and enhanced TC activity in the eastern part of the WNP. By sensitivity experiments removing the subtropical/tropical SST anomalies, it was found that the tropical (subtropical) SST anomalies contribute to the overall TC activity including the occurrence of intense TCs (eastward extension of the occurrence of intense TCs), by maintaining the strong monsoon circulation and associated local Hadly/Walker circulations.

Comparison of the historical pre-TC environment factors between the strong and weak LMI TCs shows that SST and vertical wind shear are the leading two factors in all sensitivity cases. Comparison between the strong and moderate LMI TCs suggests that the middle tropospheric vertical velocity was comparable to the above leading two factors in the cases without subtropical warm SST anomalies. These results highlight common and specific aspects of the impacts of SST anomalies on the TC LMI in the WNP.

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Multi-scale interaction and predictability/controllability of the tropical cyclone intensification

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Predicting tropical cyclone intensity changes, especially the onset of rapid intensification, has been a challenging topic because of its chaotic nature in multi-scale physical process with significant contributions from convective-scale phenomena. The forecast uncertainty in the intensification onset process is particularly limited. This may also indicate the potentials of effective controllability.

In this study, we have explored the contribution of moist convective activity to influence/modify the predictability and variability of TC intensification onset. Our recent investigation in Minamide and Posselt (2022) proposed a Lagrangian-based approach to identify the potential signals of individual convective occurrence. Using the technique, we conducted sensitivity experiments to intervene in specific convective activities within the inner-core of early-stage TCs with convection-permitting Weather Research and Forecasting model (WRF-ARW). The results indicate that the spatiotemporal variability of convective activity had significant impacts on whether early-stage vortex completes precession and initiates RI. Given the strong nonlinearity of the onset process of RI, the advancement of our understanding of the uncertainty sources will provide an insight to explore the TC predictability/controllability.

Reference: Minamide, M., D. J. Posselt, 2022: Using Ensemble Data Assimilation to Explore the Environmental Controls on the Initiation and Predictability of Moist Convection, Journal of the Atmospheric Sciences, doi:10.1175/JAS-D-21-0140.1.

Predictability of the most long-lived tropical cyclone Freddy (2023) during its westward journey through the southern tropical Indian Ocean

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In 2023, Storm Freddy emerged as the most long-lived tropical cyclone (TC) in record, lasting 35 days over the southern tropical Indian Ocean and spanning both weather and sub-seasonal to seasonal time ranges. The primary objective of this study is to understand the factors contributing to the poor predictability of Freddy in forecasts spanning over two weeks. This holds significant importance as our understanding about the ability of the numerical models to predict long-lived TCs remains limited. Using over 7000 global ensemble forecasts from five global Numerical Weather Prediction centers and a high-resolution regional model, we identified three key factors contributing to the limited predictability of Freddy: the strength of the Mascarene High, the position of Storm Dingani (2023), and the size of Freddy. In large track-error results of the global forecasts and regional simulations for Freddy, the strength of the Mascarene High was underestimated, Dingani was located further northeast, and Freddy was either too large or too small. Our investigation emphasizes the crucial role played by the interaction between the TC and multi-scale systems in TC forecasts. This is meaningful for the improvement of Numerical Weather Prediction models to deal with extreme TC events in the future.

Large eddy simulation of entire tropical cyclone for entire development period

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We have realized a large eddy simulation (LES) of an entire tropical cyclone with time integration longer than 100 hours, which can cover the entire development period from an initial disturbance. In the previous study (Ito et al., 2017), the developed tropical cyclone was interpolated into LES with a grid size of 20000 x 20000 x 60, and only 10 hours of time integration was performed. While the configurations of LES are the same, the state of the art supercomputer "Fugaku" enables to extend the time integration.

A weak vortex is placed as the initial disturbance. The environment exmploys a sounding in the case of Hagibis 2019, which made the rapid intensification The simulated tropical cyclone starts to develop 72 hours after the initiation. After about 100 hours, the simulated tropical cyclone strengthens to ~920 hPa (Fig. 1), which is indicated by the maximum potential intensity.

As similar to the previous LES, the developed TC reveal various fine-scale structures in both the boundary layer and the eyewall cloud (Fig. 2). Temporal evolution of the simulated TC is investigated. Significant temporal variations are found in outer rainbands, azimuthal wave number of significant pattern of eyewall, boundary layer height, and so on.

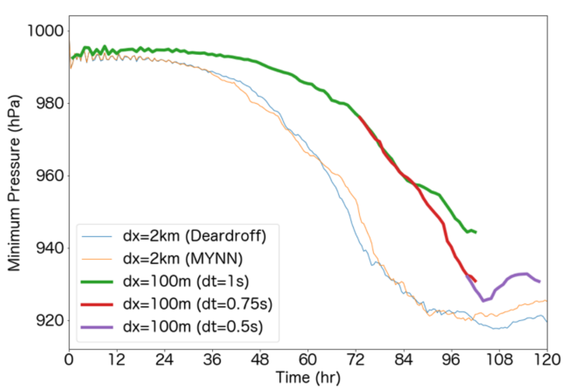

Figure 1: Time series of the minimum surface pressure of simulated tropical cyclone. Both LES (dx=100m) and coarser resolution (dx=2km) results are shown

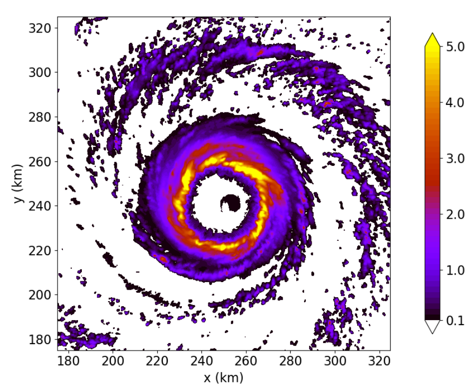

Figure 2: Mixing ratio of hydrometer (g/kg) in the horizontal plane at the height of 39 m in LES at 103 hours after the initiation.

Reference

Ito, J., T. Oizumi, and H. Niino, 2017: Near-surface coherent structures explored by large eddy simulation of entire tropical cyclones. Scientific reports, 7, 3798.