**Japan Geoscience Union Meeting 2012**
(May 20-25 2012 at Makuhari, Chiba, Japan)


AAS02-01 Room:101A Time:May 25 09:00-09:15

# Measurement of momentum flux across the air-water interface in high-speed wind-wave tank

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Since typhoons wreak catastrophic damages to a local society, it is of great importance to predict the development and decay mechanisms of typhoons accurately. To get reliable predictions, momentum transfer across the air-sea interface should first be estimated accurately. However, in the high wind-speed region with intensive wave breaking, there remains much uncertainty in the trend of drag coefficient and roughness length ($z_0$), and the momentum transfer mechanism has not been clarified. The purpose of this study is therefore to precisely estimate the momentum flux across the breaking air-water interface under strong wind conditions, and to investigate the momentum transfer mechanism.

A high-speed wind-wave tank with 15 m long was used. Wind waves were driven in the water tank at wind speeds of $U_{10}$ = 7 - 67 m/s. A laser Doppler anemometry (LDA) was used to measure the wind-velocity fluctuations. The wind-velocity under breaking wind-wave conditions was measured using a phase Doppler anemometry instead of the LDA. The air friction velocity ($u*$) was directry measured by an eddy-correration method, and the roughness length ($z_0$) were estimated using the logarithmic law of the wind profile. The water level fluctuation was also measured by a resistance type wave height meter.

The results show that $z_0$ monotonically increases with $u*$ in the normal wind-speed region, whereas $z_0$ approaches to a constant value in the high wind-speed region. In previous field and laboratory experiments, the trends of $z_0$ under high wind-speed conditions are controversial among three groups (increase, decrease, and constant with $u*$). The values of momentum flux across the air-sea interface, in whole previous studies, were indirectly estimated by a wind profile method or a momentum budget method. Thus, the precision of these previous data seems to be lower than the present data based on the direct measurements of the Reynolds stress. This supports that the $z_0$ has a constant value under high wind-speed condition. In additon, we derived a new relationship between wind wave shape and $z_0$ applicable in the whole wind speed region, and we expect that the present finding will be useful to improve predictions of typhoons.

Keywords: wind-wave, drag coefficient, roughness length

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AAS02-02 Room:101A Time:May 25 09:15-09:30

# Ocean waves by typhoons and a perspective of their role in interaction

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Extremely strong winds by typhoons generate very high waves in ocean, which is quite dangerous to voyaging vessels and gives much damage to beach structures. Since wave information is crucial for disaster prevention both in seas and coasts, Japan Meteorological Agency (JMA) operates wave models and issues information on ocean waves.

JMA now operates two wave models: one is the Global Wave Model (GWM) for the whole sea area and the other is the Coastal Wave Model (CWM) which covers the seas around Japan. The wave model is the third generation wave model MRI-III, which was originally developed in Meteorological Research Institute (MRI) of JMA. The third generation wave model explicitly calculates the non-linear energy transfer (Snl) values, which is one of three source functions like energy input and dissipation. Operational wave models usually calculate the change of wave spectra, energy of many components divided in many frequency and direction. It is important to calculate accurate Snl values are crucial for quick development of waves or windsea-swell interaction. Multi directional waves usually exist in seas under typhoons, and thus accurate estimation of Snl is necessary.

An Example of high waves by typhoons and wave model prediction, we show a high waves by Typhoon Roke (1115) in 2011. Ty Roke moved eastward in the sea south of Japan main land, with strong intensity and high waves over than 8m height were generated in the central part of the typhoon. Irozaki coastal wave recorder, located in the tip of Izu Peninsula in Shizuoka Prefecture, observed the maximum wave height of 10.6m (wave period was 12.8 sec.) at 06UTC on 21 Sep. The Irozaki wave recorder also observed 2 dimensional wave spectra at that time. The CWM of 12UTC on 20 initial predicted the maximum wave height of 10.5m and wave period of 14.5 seconds at 09UTC. The predicted time of peak wave was 3hours later than the observation but the wave height was fairly compared. The predicted wave spectra were similar to the observed spectra too. The wave model may satisfactory predict wave conditions by typhoons.

It is well known that momentum and heat fluxes from seas are very important for typhoon intensity changes. These values are transferred through sea, whose surface under typhoon is quite rough by high waves and covered by drifting sea sprays. Flux values might be supposed to be influenced by wave condition, or more generally ”sea state”. There are many works which investigate the impact of the effect on tropical cyclone intensity by using integrated numerical models, namely a weather-ocean-wave coupled model.

However, wave influence itself has not been sufficiently cleared yet; rather even principle mechanism is still unknown. It would be necessary to couple a wave model with a weather model and to investigate the effect intensively. We show some results of impact of typhoon intensity by a weather-wave coupled model. The influence change by the different drag coefficients is also shown.

Keywords: ocean waves, typhoons, air-sea interaction

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AAS02-03 Room:101A Time:May 25 09:30-09:45

# The performances of improved vertical mixing scheme in the typhoon and winter convection cases in Japan Sea

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The vertical turbulent mixing in ocean mixed layer plays a crucial role in transferring momentum and heat across the air-sea interface. Therefore, the turbulent mixing scheme to parameterize this process is very important in the ocean mixed layer modeling.

The mixed layer scheme by Mellor and Yamada (1982) (hereafter MY82 scheme) has been widely used in a variety of numerical models. However, numerous numerical studies indicate a significant defect of the MY82 scheme, which is a slow growth and shallow mixed layer because the dependency of turbulent length scale on stability is ignored (Sun and Ogura, 1980; Martin, 1985; Kantha and Clayson, 1994). To fix this problem, Nakanishi and Nino (2009) developed an improved MY82 scheme (hereafter MYNN scheme) which incorporated the effects of buoyancy and stability on the turbulent length scale. Another improvement is that the empirical constants are determined by LES database. The MYNN scheme has been applied in various atmospheric circulation models successfully. In this study, we apply the MYNN scheme as an ocean mixed layer scheme in an ocean circulation model and check its performance.

We consider two situations. One is to study the response of the mixed layer to a super typhoon 'Maemi' which passed through the Japan Sea in September, 2003. The other is to study the response of the mixed layer to the strong cooling and wind forcing in winter from November in 2010 to February in 2011, which induce strong convection in the northern part of the Japan Sea. A 3D z-coordinate ocean circulation model, the RIAM Ocean Model (RIAMOM), with 1/12 degree horizontal resolution and 36 vertical levels is used to investigate the performances of the MYNN scheme for typhoon and winter convection cases.

For the typhoon case, hourly MSM-JMA forcing data (wind stress, humidity, air temperature and so on) are used in the model. The surface heat flux is estimated by bulk method without surface relaxation. While, for the winter convection case, the model is run from November 2010 to February 2011 during which the winter weather condition is very hard due to the strong La Nina event. The other conditions are same with the typhoon cases.

The results in both cases show that in experiments with the MY82 scheme, the SSTs are obviously warmer than those in experiments with the MYNN scheme, which were still warmer than observations. The area-averaged SST with the MY82 scheme is about 0.25 degree higher than that of MYNN experiment in the typhoon case. Meanwhile, in the winter convection case, the improved mixing scheme generates a 0.2 degree colder area-averaged SST than the MY82 scheme. The higher SST in the experiments with the MY82 scheme implies that downward transports of the momentum and heat from the surface layer are generally weaker than the experiments with the MYNN scheme. Further analyses show that the mixed layer and the turbulent kinetic energy develop very well in the experiments with the MYNN scheme. As a summary, the MYNN scheme contributes to a certain extent to overcome the weak points of the MY82 scheme such as an insufficient growth of the mixed layer and underestimate of the turbulent kinetic energy through the enhanced transports of the momentum and heat downward from the surface layer. The results in this study imply that the MYNN scheme has a good performance compared with the original MY82 scheme in the ocean mixed layer modeling.

Keywords: turbulent mixing, improved mixed layer scheme, typhoon, winter convection, Japan Sea

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AAS02-04 Room:101A Time:May 25 09:45-10:00

# Sensitivity of typhoon intensity to the ocean in atmosphere-ocean coupled/non-coupled experiments

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Intensity of typhoons is greatly controlled by air-sea interaction with the ocean through the sea surface, with affecting the sea temperature distribution through mixing/upwelling in the upper layer in the ocean. To investigate the intensity change of typhoons with air-sea interaction, umerical experiments were performed utilizing with atmosphere-ocean regional coupled/non-coupled model; slab ocean model was for one dimensional coupled experiments and CReSS-NHOES was for three dimensional coupled experiments.

In the comparison of the results, remarkable differences of intensities resulting from air-sea interaction were represented, with successfully simulating typical structures of typhoons. Especially, the deepening of the central minimum pressure of typhoons was suppressed resulting in the ocean circulation caused by the typhoons. The magnitude of the central pressure deepening in the mature stage was more in the three-dimensional ocean coupled experiment including upwelling, compared to that in a slab ocean experiment of one-dimensional vertical mixing heat transfer in the ocean upper layer, and was much more compared to that in fixed sea surface temperature experiment without time variation.

In the western North Pacific, passing typhoons are greatly affected the local sea surface temperature around the warm Kuroshio currents where meridional sea temperature gradient is sharp. Sensitivity experiments employed meridionally smoothed sea surface temperature were performed to investigate to consider the effect by the Kuroshio currents in addition to the coupled/non-coupled experiments. The intensity of the typhoon was suppressed passing around the Kuroshio current and showed weak deepening of the central minimum pressure in the experiment with smoothing sea surface temperature. The experiment employed zonally averaged meridionally smoothed showed quite weak deepening of the central minimum pressure toward the mature stage. These appeared in the typhoons, especially ones which moved slowly around the Kuroshio currents.

We will discuss intensity suppression of typhoons, not only the difference of the sea surface temperature but also the difference of the latent/sensible heat flux around the center of the typhoons and the ocean heat content in the ocean surface layer.

Keywords: tropical cyclone, typhoon, air-sea interaction, atmosphere-ocean coupled model, cloud resolving mesoscale regional model, Numerical experiment

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AAS02-05 Room:101A Time:May 25 10:00-10:15

# Numerical simulations on surface roughness lengths and drag coefficients under typhoons

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Numerical simulations for Typhoons Choi-wan in 2009 and Fanapi in 2010 were performed using a nonhydrostatic atmosphere model coupled with wave and multi-layer ocean models to investigate the variation in surface roughness length under typhoons. Surface roughness lengths were calculated by the formulation which is a function of wave steepness proposed by Taylor and Yelland (2001). This study addresses surface roughness lengths and drag coefficient under the two typhoons.

The computational domain was 3240 km x 3960 km with a horizontal grid spacing of 6 km for Choi-wan and was 2000 km x 1800 km with a horizontal grid spacing of 2 km for Fanapi. The model had 40 vertical levels with variable intervals from 40 m for the lowermost (near-surface) layer to 1180 m for the uppermost layer for both typhoon simulations. The model had maximum height approaching nearly 23 km. The time step of the nonhydrostatic atmospheric model was 15 s for Choi-wan and 6 s for Fanapi. The length of the time step of the ocean model was six times that of the nonhydrostatic atmospheric model. The initial depth of the mixed layer was determined from oceanic reanalysis data, calculated using the MRI ocean variational estimation (MOVE) system (Usui et al., 2006). The integration time was 96 hours for Choi-wan and 72 hours for Fanapi.

The dependency of 10-m wind speed indicated that surface roughness lengths and drag coefficients were saturated or leveled off when a 10-m wind speed was high. These saturated or capped level of surface roughness lengths and drag coefficients varied on the intensity of the typhoon and its phase. This implies that the saturated or capped level of surface toughness lengths and drag coefficients are not determined from the magnitude of 10-m wind speed but the structure and phase of (simulated) typhoon.

During the intensification of Fanapi (at 24-hour integration), surface roughness lengths and drag coefficients were high where both 10-m wind velocity and wave heights were high. Each horizontal distribution of 10-m wind velocity, surface roughness lengths, drag coefficients and hourly precipitation had a wave-number-1 pattern. When Fanapi approached the Miyako island, south of Japan, at 48-hour integration, surface roughness lengths and drag coefficients were high on the north side from the Fanapi's center, while 10-m wind velocity and 1-hour precipitation were high on the east from the center, against the moving direction of the storm. Wave heights were high along and on the right side of the track behind the storm, probably due to wave-near-inertial current interactions. A difference of the location between high surface roughness lengths/drag coefficients and high wave heights was also found at 60-hour integration when the storm approached the Ishigaki island.

In fact, simulated central pressures tended to be low compared with the best track central pressures for Choi-wan. In addition, simulated tracks had a northward bias and simulated central pressures tended to be high compared with the best track and its central pressures for Fanapi. Nonetheless, it is of importance that surface roughness lengths are closely related to drag coefficients in spite that the drag coefficients are calculated not only by surface roughness length, but also by wave heights and 10-m wind velocity. However, we need to validate the results of numerical simulations for Choi-wan and Fanapi using the in situ observations.

Keywords: Typhoon, Drag coefficient, High wind, Surface roughness length, Atmosphere-wave-ocean coupled model

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AAS02-06 Room:101A Time:May 25 10:15-10:30

# Evaluation of floral and faunal shifts in the oligotrophic ocean after typhoon passage

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Typhoon can induce vertical mixing, upwelling, or sometimes both of them in the water column because of the strong wind stress. These events can induce phytoplankton blooms after typhoon passages in the oligotrophic ocean. However, little is known about community structure and succession in lower trophic organisms following the passage of typhoons. Therefore, we tried to evaluate the community successions in the East China Sea and the northwest Pacific Ocean through on deck bottle incubation experiments simulating the hydrographic conditions after the passage of typhoon.

In all experimental conditions we designed, chlorophyll *a* concentrations increased, and the increased algal cells were mainly composed of large diatoms. Although nano-sized ciliates also increased, the abundance of possible diatom grazers such as dinoflagellates and nauplii little changed throughout our incubations. These results suggest that the increased diatom may sink and enhance biogenic carbon flux in the water column. Typhoons can affect not only phytoplankton productivity, but also the composition of lower trophic organisms and biogeochemical processes in the oligotrophic ocean.

Keywords: Typhoon, Tropical cyclone, Subtropics, Phytoplankton, Zooplankton, Nutrients

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AAS02-07 Room:101A Time:May 25 10:45-11:05

# Influence of typhoon to primary production in the marine environment

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Response of ocean primary production to typhoon, which is not easy to study by ship observation, is becoming clear using ocean color remote sensing data. Here, we will review studies of influence of typhoon to primary production in the marine environment, including our studies in the eastern Asian marginal seas. Often phytoplankton biomass and primary production enhance by upwelling and mixing caused by passage of typhoon. Using ocean color and other satellite data, changes of not only biomass but also primary production and new production by typhoon can be estimated, and profiles of Argo float are useful to estimate changes of nutrients. Multiple regression analysis of the changes of primary production with typhoon translation speed, maximum wind speed and depth of the pass is useful to estimate the enhancement from the basic typhoon parameters. Differences of basic oceanographic structures give different magnitude of primary production response, and in some region responded phytoplankton can be carried significant distance with current.

Keywords: marine ecosystem, primary production, typhoon, cyclone, phytoplankton, nutrient

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AAS02-08 Room:101A Time:May 25 11:05-11:20

# Typhoon-induced Phytoplankton Blooms and Primary Productivity Increase in the Western North Pacific Subtropical Ocean

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Using multiple satellite observations and series of numerical experiments, this work systematically studied phytoplankton blooms induced by tropical cyclones in the western North Pacific subtropical Ocean (WNPSO), because WNPSO is among the world oceans where most number of intense tropical cyclones are found. All eleven typhoon cases passing the study domain in 2003 were examined in detail. It was observed that only two typhoons (18%) were able to induce phytoplankton blooms (chlorophyll-a concentration increased from<=0.1 mg $m^{-3}$ to 0.4-0.8 mg $m^{-3}$) and strong sea surface temperature cooling of -2.5 to -6 degrees Centigrade. The other nine typhoons, including the most intense tropical cyclone on earth in 2003 (i.e., super-typhoon Maemi), were not able to induce phytoplankton blooms and the associated sea surface temperature cooling was weak (0 to -1.5 degrees Centigrade). Using series of numerical experiments, it was found that the presence of warm ocean eddy can effectively isolate the cold, nutrient-rich water to be entrained to the surface ocean. Under this situation, even category-5 typhoon Maemi at its peak intensity of 150kts could not induce phytoplankton bloom in the WNPSO. The weak responses of the other eight typhoons were due to insufficient wind intensity and transit time (caused by relatively small storm size and fast translation speed) in this deep nutricline/mixed layer ocean. As a result, the total annual primary production increase induced by typhoons in the WNPSO was estimated to be ˜ 3.27x1012g C (0.00327 Pg), equivalent to 0.15% of the global annual anthropogenic $CO_2$ uptake. This suggests that though WNPSO has the highest number and intensity of tropical cyclones among the world oceans, tropical cyclones in the WNPSO have little contribution to enhance biological carbon fixation in the context of global carbon-climate system.

Reference:

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AAS02-09 Room:101A Time:May 25 11:20-11:35

# Observing System Experiments for Typhoon Track Prediction using ITOP Dropwindsonde Data

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An international field campaign, Impact of Typhoons on the Ocean in the Pacific (ITOP), was conducted in 2010. While ITOP aimed to study the ocean response to typhoons in the western Pacific, a number of dropwindsondes were released from research aircrafts during the field experiment. The dropwindsonde data was provided in real time via the Global Telecommunications System (GTS) in order for operational numerical weather prediction (NWP) centers to assimilate the data.

In this study, the impact of the dropwindsonde data collected during the ITOP field campaign on typhoon track prediction is investigated. For this purpose, the global forecasting system at the Japan Meteorological Agency (JMA), which consists of the Global Spectral Model (GSM) and Four-dimensional variational assimilation (4D-Var), is used. The resolutions of GSM and the inner model of the 4D-Var are TL319L60 and T106L60, respectively, while those of the operational system are TL959L60 and TL319L60, respectively. Two sets of numerical experiments are performed; one is that all dropwindsonde data is assimilated in the 4D-Var, and the other is no dropwindsonde data is assimilated. The period of the numerical experiments is 3 months, 22nd Jul. to 22nd Oct., which cover the whole ITOP period. The total number of dropwindsondes used in the experiments is 656.

The results of the data denial experiments show that the dropwindsonde data has a small impact on typhoon track prediction. It is found through detailed analyses that many of the dropwindsonde data are rejected in the data assimilation due to large differences between the observations and the first-guess fields. In addition, the displacement of typhoon central position in the first-guess field is also found to be the cause of the rejection of observational data. Different from airborne observations targeted on typhoon track prediction, where the dropwindsondes are deployed not only around typhoons but also in the synoptic environment, most of the dropwindsondes are collected near the center of typhoons in ITOP. Besides the horizontal resolutions of GSM and the inner model of the 4D-Var used in this study are about 60 km and 120 km, respectively, which is not enough to resolve the typhoon structure near the center. It would be needed to improve the representation of the first-guess fields to assimilate the dropwindsonde data near the center of typhoons. Increasing the horizontal resolution of GSM and the 4D-Var or using a regional forecasting system such as the JMA Non-Hydrostatic Model (NHM) may be a promising approach. At the same time, a study on adaptive observation techniques is of great importance because the observations near the typhoon center may not necessarily have a large impact on the reduction in the typhoon track prediction errors.

Keywords: Numerical Weather Prediction, Typhoon Track, Data Assimilation

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AAS02-10 Room:101A Time:May 25 11:35-11:50

# An effective radius of the sea surface enthalpy flux for the maintenance of a tropical cyclone

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The present study found that there is a radius within which the sea surface flux for moist enthalpy plays a vital role in determining the intensity of a tropical cyclone. From the results of the numerical experiments using an axisymmetric nonhydrostatic model, it was shown that when the sea surface fluxes are modified within the radius the intensity suddenly changes on a short time scale.

As long as the surface enthalpy flux diminishes outside this radius the tropical cyclone intensity does not decrease. In the simulated tropical cyclone, this radius locates 7–8 times the radius of maximum wind speed. The effective radius seems to be located near where the radial gradient of the quantity, radius times radial velocity, in the inflow layer sharply changes. This is because within this radius, the radial flux divergence in the conservation equation of enthalpy has nonzero values and contributes to the local balance.

Keywords: Tropical Cyclones, Sea surface fluxes

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AAS02-11 Room:101A Time:May 25 11:50-12:05

# Short-time-scale typhoon intensification as a response to anomalous surface heat fluxes

ITO, Kosuke[1*], Yoichi Ishikawa[2], Yoshiaki Miyamoto[3], Toshiyuki Awaji[2]

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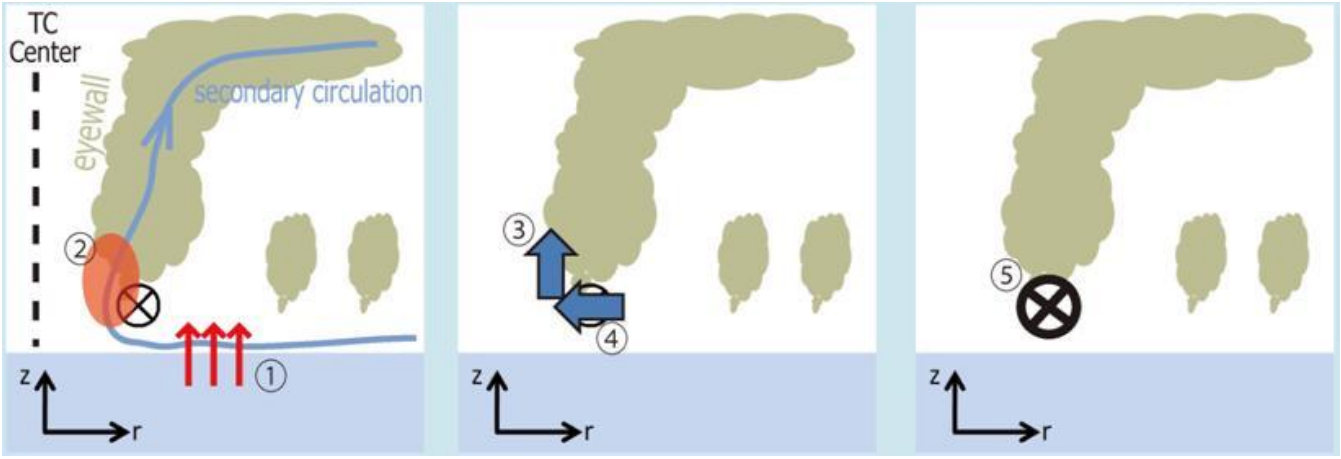
The typhoon often encounters small scale oceanic variabilities due to oceanic mesoscale warm eddies and warm western boundary currents. These features act to enhance heat fluxes at the sea surface [Lin et al. 2008, MWR]. According to the energy balance obtained from the theoretical framework, these oceanic factors can potentially have an impact on maximum tangential velocity [Emanuel et al. 2004, JAS; Lin et al. 2008, MWR].

One of the fundamental questions is how perturbations bring about changes in the maximum tangential velocity. Needless to say, diagnostic balance theory does not describe the time-dependent behavior of perturbations. Perhaps one may identify that adjustment processes in a gradient-wind balanced vortex explain the intensification, more specifically, changes in the central pressure field due to enhanced condensation capable of intensifying the vortex. However, Wu et al. (2006, JAS) showed perturbation-like inputs to the central pressure field are not likely to affect the subsequent maximum tangential velocity substantially. This is because the radius of the eyewall is typically smaller than the Rossby deformation radius.

In this study, we trace the sensitivity of maximum tangential velocity backward by using an adjoint model and evaluate the term balances to seek for the responsible physical processes. As a result of integration backwards to four minutes prior to the specified time, a dipole pattern appears in the sensitivity fields with respect to potential temperature and the mixing ratio of water vapor. A positive (negative) sensitivity is found inside (outside) the target region, which exhibits an increase of tangential velocity four minutes after the introduction of positive (negative) perturbations in potential temperature or in the mixing ratio of water vapor inside (outside) the target region. With further backward integration, the sensitivity signals reach down to the surface.

The term balance analysis indicates that the stronger inward motion is induced quite locally following the enhanced convective motion due to the changes in condensation and buoyancy forces. Then, stronger inward motion is quickly turned into the anomaly of tangential wind (that is, the intensification of maximum wind speed) since the timescale of conversion from radial velocity to tangential velocity is relevant to the inverse of the absolute vorticity in a near gradient wind balanced vortex. This short-timescale process is not associated with the changes in the central pressure field. See details in Ito et al.(2011, JAS). If the presentation time allows, we will further discuss the fact that a reduction in moist air supply in the exterior region of the typhoon can serve to strengthen the maximum tangential velocity.

Keywords: Typhoon-ocean interaction, vortex dynamics, sensitivity analysis



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AAS02-P01 Room:Convention Hall Time:May 25 09:00-12:15

# Optimization of air-sea exchange coefficients in a tropical cyclone by use of a variational data assimilation system

ITO, Kosuke[1*], Takuya KAWABATA[3], Yuuki HONDA[2], Teruyuki KATO[2], ISHIKAWA, Yoichi[1], Toshiyuki Awaji[1]

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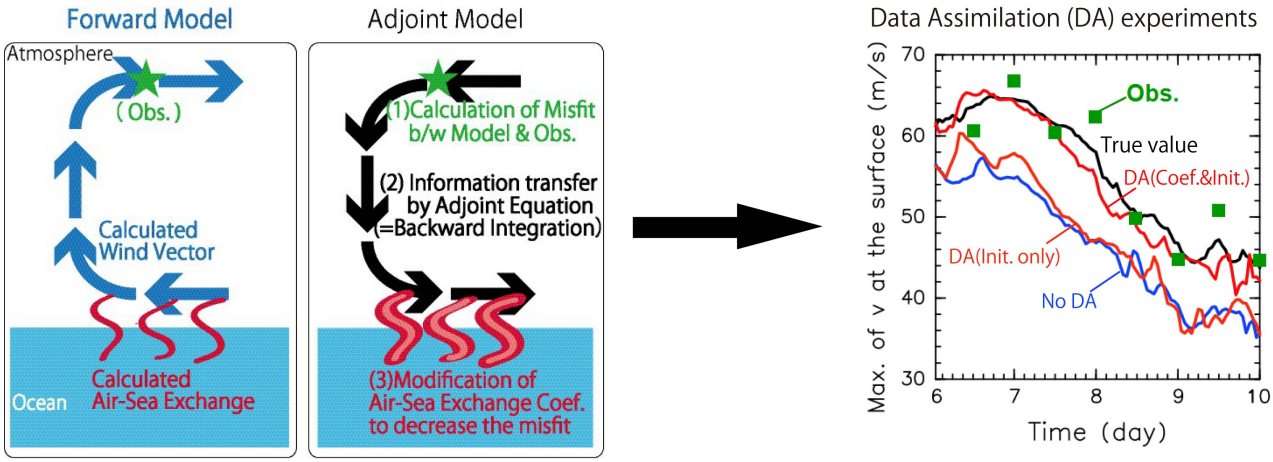
A tropical cyclone (TC) intensifies and maintains its circulation against surface friction through the self-inducement of anomalous heat fluxes from the sea surface. Therefore, uncertainty in the values of air-sea heat and momentum exchange coefficients has a detrimental effect on TC numerical modeling. Since a TC is one of the most destructive disasters, a method is required to reduce such uncertainty with respect to disaster prevention and scientific progress. In this study, impact of optimizing air-sea exchange coefficients by a variational data assimilation system is investigated for TCs. Our results show that the air-sea exchange coefficients are successfully improved by using the available observational data. The updated air-sea exchange coefficients yield improvements in the the maximum wind speed, the inner core structure and the location of vortex center in comparison with the data assimilation experiments in which the initial condition is selected as a control variable. Furthermore, it is implied that the optimization leads to enhanced prediction skill. See more details in Ito et al.(2010, SOLA).

Keywords: Data assimilation, Tropical Cyclone, Air-sea exchange coefficient



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AAS02-P02 Room:Convention Hall Time:May 25 09:00-12:15

# Assessment of near-future typhoon risk in the Asia-Pacific region by using Stochastic Typhoon Model

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Typhoons generally trigger disasters, such as floods, landslides, storm winds and so on, often causing severe economic as well as human damages. The fourth assessment report of Intergovernmental Panel on Climate Change showed that tropical cyclones, including typhoons or hurricanes, are likely to become more intense in future due to global warming. Therefore, there is a possibility that damages caused by typhoons will become larger due to increase in number of intense typhoons. It is necessary to project the impact of climate change on typhoon characteristics, and subsequently estimate the risk associated with the typhoons. This study aims to project future typhoon characteristics and to assess the typhoons risk in Asia-Pacific region. There are some studies of numerical models designed to generate artificial typhoon. One example of those is output of General Circulation Model (GCM). GCMs can reproduce typhoon characteristics in principle because GCMs can calculate global climate change based on hydrodynamic equation and parameterized physical processes. However, it is difficult to repeat calculation in GCMs because computational resource is limited. The data extracted from GCMs are insufficient for assessing potential risk associated with typhoon damages. To solve these problems, Stochastic Typhoon Model (STM) based on statistical analysis is employed. STM is a kind of Monte Carlo simulation which stochastically calculates variation of typhoon characteristics from start to end of typhoon life based on observed typhoon statistics. For future typhoon projections, the statistical characteristics of the future typhoon tracks are produced as input data instead of the observed data. The future typhoon tracks are calculated by adding future trends by GCM to observed typhoon statistics. As a result of future projections, the typhoons track shift northeast in Western North Pacific. Especially around the Philippines, there is a remarkable tendency of decrease in number of typhoons in the future. Furthermore, the number of typhoons, with lower minimum central pressure, increases in near-future in WNP. Finally, typhoon risk is assessed stochastically using projection of typhoon characteristics under future climate change. Typhoon damage is determined by the characteristics of the typhoon such as intensity or track of the typhoon, the largeness of area where the typhoon affects, and the vulnerability of the area. In this study, the characteristics is represented as minimum central pressure, the largeness area depend on population and typhoon tracks, and GDP is used as indicator of vulnerability To assess the risk associated with typhoon, expected damage is calculated by using a relation between observed characteristics of a typhoon and the damage caused by it. Typhoon damages are estimated based on total cost of damages, which includes human damage as well as damage to physical infrastructures. The change of social conditions such as population or GDP is not considered to assess only climate change. As a result of typhoon risk, annual damage cost will decrease in almost all countries. For example, in Japan and China, damage cost per a typhoon also decrease. In this study, used parameters are minimum pressure when typhoon made landfall and the distribution of typhoon landfall. In these countries, minimum pressure is not changed. Therefore, the change of distribution of typhoon landfall affects to decrease of the damage cost per a typhoon. As conclusion, the methodological experience in this study will be helpful to build risk management.

Keywords: Stochastic Typhoon Model, General Circulation Model, Risk Assessment, Typhoon damages