Tropical cyclone-ocean interactions on Typhoon Haiyan (2013) simulated by a coupled atmosphere-wave-ocean model

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Typhoon Haiyan, the deadliest tropical cyclone (TC) ever recorded in the Philippines, made landfall in the central Philippines on 8 November 2013. To understand roles of TC-ocean interactions on Haiyan, numerical simulations of Haiyan and analogous Typhoon Mike (1990) were performed using a 2-km-mesh nonhydrostatic atmosphere model (NHM) and its atmosphere-wave-ocean coupled model (CPL). Comparison between Haiyan and Mike revealed that relatively rapid translation and small sea surface cooling (SSC) were the factors critical for simulating the extraordinary intensity of Haiyan. Without SSC, Mike might have become stronger than Haiyan. To evaluate uncertainties of TC intensity predictions under different oceanic initial conditions, ensemble simulations for thirty-three oceanic conditions were performed with a 7-km mesh NHM and its CPL for the two TCs. Uncertainties of preexisting oceanic conditions directly affected the central pressures simulated by the NHM. In addition, uncertainties of simulated central pressures were reduced via modification of the secondary circulation due to reduction in the uncertainties of sea surface temperature, irrespective of geographical location, even though wave coupling resulted in some uncertainties of drag coefficients, surface winds, and latent heat fluxes near the TC centers. The ensemble simulations also indicate the importance of TC moving speed and thereby sea surface cooling on TC predictions.

Keywords: Tropical cyclone-ocean interaction , Atmosphere-wave-ocean coupled model, sea surface cooling, Oceanic environment

Interaction of storm surge and waves along the Indian coastline using a coupled atmosphere-ocean-wave model

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Interaction between the tropical cyclone (TC) induced waves, storm surge, and associated coastal inundation along the east coast of India investigated using a coupled atmosphere-ocean-wave model. The fully coupled Ocean-Atmosphere-Wave model (COAWST model components) was configured over the Bay of Bengal (BoB), a semi-enclosed basin in the northern Indian Ocean. To understand the impact of waves on storm surge, two numerical experiments were performed with different coupling configuration. In the experiment with wave model coupled to atmosphere and ocean models, the ocean circulation model includes depth dependent wave stress terms, Stokes drift, vertical transfer of wave-generated pressure transfer to the mean momentum equation, wave dissipation as a source term in the turbulence kinetic energy equation, mean current advection, and refraction of wave energy. Wave induced forces were considered to affect the cyclone induced storm surge. Role of storm surge on the nearshore wave-field was analysed from coupled model simulations. Model results showed that the extent of simulated inundation area increased when the effects of waves were included. The study highlights importance of inclusion of the wave effects for the hindcast of the water levels during the storm surge.

Keywords: tropical cyclone, COAWST, surge-wave interaction

Development of the stretch-atmosphere and ocean model to study air-sea interaction associated with tropical cyclones

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The tropical cyclones have the large impacts on our lives. While the track of tropical cyclone is mainly controlled by wind fields associated with the Pacific high, development is influenced by heat flux from the oceans. A global nonhydrostatic atmospheric model (NICAM) can simulate the tropical cyclones and deep convection in the tropical regions. In order to understand the interactions between atmosphere and ocean associated with tropical cyclone, we need develop the atmosphere-ocean coupling model.
We select the stretched-version NICAM (Tomita et al., 2008) as an atmospheric model and also select the CCSR Ocean Component Model (COCO) as an ocean model. The Stretch-NICAM saves computational resources by focusing on a specific region at high resolution. However, the horizontal resolution becomes coarser for the region outside of the target region. The horizontal spacing of stretched-version NICAM and COCO is about 6 km and 1 degree grid, respectively. This is the first time to use the stretched atmospheric model as a coupling model. Hereafter we call this new coupling model as stretched-version NICOCO. The horizontal grid configuration is difference between stretched-version NICAM and COCO. Here we insert the coupler model (called Jcup) between the two models and exchange fluxes with every 1 hour. The initial condition of the NICAM is prepared by NCEP Tropospheric Analysis data.
In this study, we chose the tropical cyclone generated at 28 August 2004 near Japan and investigate the air-sea interaction associated with the tropical cyclone. The model integration was performed with 7 days. To compare the real ocean, we also use the 4-dimensional Ocean Reanalysis dataset (FORA) and Argo floats data. For a comparison, we also performed simulation by only oceanic model (COCO) with 33 days (18 Aug. 2004 to 19 Sep. 2004). In this simulation, atmospheric forcing is given by ERA-Interim (1.25degree). Horizontal resolution of atmospheric forcing is different from stretched-version NICOCO. Our new model shows that sea surface temperature near tropical cyclone drops and which is 1 K colder compared with FORA data. The sea surface height (SSH) and mixed layer depth (MLD) are also changed. These variables decreased associated with tropical cyclone. Mei et al. (2013) showed that SSH decreases associated with tropical cyclone. The negative anomaly reached 6 cm at maximum. While FORA shows the good results, stretched-version NICOCO shows the rapid recovery of SSH compared with observations. In stretched-version NICOCO and FORA, MLD becomes deepen associated with tropical cyclones. However, similar with SSH, recovery is rapid in stretched-version NICOCO. Compared with COCO, stretched-version NICOCO shows the large amplitude of SSH and MLD variation, it may be caused by difference of horizontal resolution of atmospheric forcing.
In the presentation, we will discuss the results about the boundary layer and state in the sea.

Keywords: stretch-atmosphere and ocean coupling model

Improvement in TWRF and Its Impact on Tropical Cyclones Predictions over the Western North Pacific

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With violent wind and severe rainfall, the tropical cyclone is one of the most disastrous weather system over ocean and the coastal area. To provide accurate tropical cyclone track and intensity forecasts is one of the most important task of the national weather service of countries affected. Taiwan is one of the area frequently influenced by tropical cyclones. Improving the tropical cyclone forecast is the highest priority task of Taiwan’ s Central Weather Bureau (CWB).
Recent improvement of the tropical cyclone forecast is due to the improvement of the numerical weather prediction. A version of the Advanced Research Weather Research and Forecasting Model (ARW WRF), named TWRF (Typhoon WRF), was developed and implemented in CWB for operational tropical cyclones forecasting from 2011. During the years, partial update cycling, cyclone bogus scheme, relocation scheme, 3DVAR with outer loop, field blending scheme, new trigger Kain–Fritsch cumulus scheme, and so on have been studied and applied in TWRF (Hsiao et al. 2010, 2012, 2015) to improve the model. The averaged 24/48/72 hours cyclone track forecast errors of TWRF are 91/152/210, 91/147/223, and 84/133/197km in year 2013, 2014, and 2015 respectively.
In this study, we try to improve the model by changing the TWRF configuration from a triple nested to a double nested one, and increasing the model resolution from 45/15/5 km, 45-levels (here TWRFd5) to 15/3 km, 52-levels (here TWRFd3). Results of the track, intensity, and rainfall predictions from both TWRFd5 and TWRFd3 for tropical cyclones over the Western North Pacific Ocean in 2016 are analyzed and compared. The quantitative rainfall predictions over high terrain area are also studied. The preliminary results show increasing the model resolution improving the track, intensity and rainfall forecast. However, the 3 km resolution model TWRFd3 has a tendency to over predict the intensity of the tropical cyclones. The detail will be presented in the conference.

Keywords: tropical cyclone forecast, Typhoon WRF, rainfall predictions

Additional Arctic observations improved forecast skill of a typhoon over midlatitude

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In summer and autumn 2016, a remarkable meandering of the jet stream occurred over the Northern Hemisphere. During August, the special radiosonde observations were made on the German RV Polarstern, Korean RV Araon and Russian land station Baranova although these data were not sent to the Global Telecommunication System. The impact of the additional radiosonde data on forecasting the atmospheric circulations over the Arctic and beyond, in particular a case of typhoon1610 (LIONROCK) over East Asia, was investigated using the AFES-LETKF data assimilation system and its ensemble reanalysis data set (ALERA2). We used the ALERA2 as the reference reanalysis (CTL) and the observing-system experiment (OSE) reanalysis in which the same observational data set was assimilated, including the radiosonde data obtained by the RVs and land station. Using these CTL and OSE reanalysis data as initial values, ensemble forecasting experiments were conducted as the CTL and OSE forecasts, respectively. Comparing these ensemble forecasts, there were large differences in the position of the predicted typhoon over Japan. The OSE forecast well predicted the northward movement of the typhoon which is controlled by a trough with strong wind at the upper level. In the CTL forecast, in contrast, the more southward shift of the trough was found over west of Japan, which caused failure of predicting of the typhoon position. Moreover, it is found that forecasting the trough was affected by the special observations in the Arctic regions. This result suggested that the radiosonde observations over the Arctic would improve the skill of weather forecasts at midlatitude during summer.

Keywords: Arctic, Radiosonde, Ensemble forecast

Global 7-km mesh nonhydrostatic Model Intercomparison Project for improving TYphoon forecast (TYMIP-G7)

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The Global 7-km mesh nonhydrostatic Model Intercomparison Project for improving TYphoon forecast (TYMIP-G7; Nakano et al. 2016) is designed to understand and statistically quantify the advantage of high-resolution nonhydrostatic global atmospheric models for improvement of tropical cyclone (TC) prediction. The 137 sets of 5-day simulations using three next-generation nonhydrostatic global models with horizontal resolution 7 km, and conventional hydrostatic global model with horizontal resolution 20 km are run on the Earth Simulator. The three 7-km mesh nonhydrostatic models are the nonhydrostatic global spectral atmospheric Model using Double Fourier Series (DFSM; Yoshimura, 2012), Multi-Scale Simulator for the Geoenvironment (MSSG; Takahashi et al., 2006, 2013), and Nonhydrostatic ICosahedral Atmospheric Model (NICAM; Satoh et al. 2014). The 20-km mesh hydrostatic model is the operational Global Spectral Model (GSM; Japan Meteorological Agency, 2013) of the Japan Meteorological Agency. Compared with the 20-km mesh GSM, the 7-km mesh models reduce systematic errors in the TC track, intensity and wind radii predictions. The benefits of the multi-model ensemble method were confirmed for the 7-km mesh nonhydrostatic global models. While the three 7-km mesh models reproduce the typical axisymmetric mean inner-core structure, including the primary and secondary circulations, the simulated TC structures and their intensities in each case are very different for each model. In addition, the simulated track is not consistently better than that of the 20-km mesh GSM. These results suggest that the development of more sophisticated initialization techniques and model physics is needed to further improve the TC prediction.

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Keywords: typhoon, numerical weather prediction

Effects of the Coriolis Force on Intensity of Hurricane PALI in Ensemble Experiments

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Tropical cyclones (TCs) observations are unusual in the equatorial region from 5˚N to 5 ˚S. Therefore, previous studies studied the effects of the Coriolis force on TC in ideal experiments. These studies, however, have not shown the mechanisms for the TC intensification for realistic settings. Thus, the aim of this study is to clarify the mechanisms of the intensification of Hurricane PALI and the effects of the Coriolis force using a regional atmospheric model. PALI occurred at 4.4˚N where is nearly 200 km southeast of Oahu island, USA, on 18Z 7 January 2016 and developed to 43.7 $m \times s^{-1}$ at the mature stage (Category-2) on 18Z 12.

We conducted ensemble downscale experiments to deal with initial uncertainty. The non-hydrostatic mesoscale numerical model, WRF, with horizontal resolution of 10 km is used in the present study. To identify the effects of the Coriolis force, sensitivity experiments with Coriolis parameters are conducted. The sensitivity experiments were conducted by inputting the Coriolis forces relatively north to 10˚ every 1˚ from the calculation domain. The initial states were derived from 11 ensemble members of NOAA’s 2nd-generation global ensemble reforecast dataset. NCEP FNL (Final) Operational Global Analysis data is used as common soil data for all ensemble members and sea surface temperature fixed at the initial time. Among other settings, we used the Kain-Fritsch scheme for cumulus convection parameterization. For the initial time of 00Z 6 January, 36 hours before PALI genesis, all ensemble members forecast a cyclone with TC intensity of 17 $m \times s^{-1}$. The simulated Hurricanes move continuously toward the northwest and locate from the equator to 10˚N during forecast time.

We examined the differences of the intensity of simulated Hurricanes among different Coriolis forces. By changing Coriolis force, the intensity of hurricanes changed, but the tracks were almost the same. The result of sensitivity experiments show that larger Coriolis force does not necessarily make TCs stronger. Furthermore, it is found that the spread of TC intensity varies with the Coriolis force.

Keywords: Tropical cyclone, Hurricane, WRF, Ensemble forecast, Coriolis force

The influence of asymmetric convection on typhoon motion near Taiwan

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This study focus on the influence of asymmetric convection on typhoon motion near the east coast of Taiwan. Eighty-four typhoons that made landfall on the east coast of Taiwan are analyzed. There are 49 cases which experience deflection tracks turning to the left-hand side relative to the typhoon moving direction before landfall. Eighteen of them are with very large deflection angles (DA) (> 20˚) and another 7 cases are with looping tracks (LTs). We found most of the large DA and LT cases are occurred north of 23 ˚N near Taiwan and has significant stronger convection in the north of the storm. The Weather Research and Forecasting (WRF) Model was used to simulate the typhoon motion approaching Taiwan. We use the potential vorticity (PV) tendency diagnosis to analyze the mechanisms which affect the storm movements. The wave number one component (WN1) of PV tendencies are decomposed into horizontal advection (HA), vertical advection (VA) and diabatic heating (DH) terms. The northern landfall typhoons have significant heating asymmetries for the storm structure before landfall, and thus modify the storm track through the DH PV tendency. The vorticity stretching effect also occurred to south of the storm. This vorticity stretching (VA effect) and diabatic heating asymmetries (DH effect) lead to the track deflections before landfall. Our results highlight the importance of asymmetric convection and its impact to typhoon track deflections which occurred north of 23 ˚N near the east coast of Taiwan.

Keywords: Typhoon track, Potential vorticity tendency diagnosis, Diabatic heating asymmetries

Interannual variation and prediction of spring precipitation over southeast China

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The interannual variations and the prediction of the leading two empirical orthogonal function (EOF) modes of the spring (April-May; AM) precipitation over southeast China for the period from 1951 to 2014 are examined using both observational data and the output from six atmosphere-ocean coupled climate models. A positive phase of the leading EOF mode of the spring precipitation over China (EOF1-prec) features enhanced rainfall in southern China. The ENSO-related tropical Pacific SST anomalies in the previous season can serve as a precursor for EOF1-prec. The second EOF mode of spring precipitation (EOF2-prec) over China is characterized by a dipole structure with one pole near the Yangtze River and another one with opposite sign over the Pearl River Delta. An equivalent barotropic Rossby wave train pattern associated with EOF2-prec can be observed, originating from the Ural Mountains across the Eurasian continent reaching the Japan Sea, causing anomalous moisture convergence over the Yangtze River alongside divergence conditions in southern China. A North Atlantic sea surface temperature (SST) dipole in the preceding March can contribute to the wave train-like pattern. An empirical model, constructed based on the observational analysis, can significantly improve the seasonal forecast skill of spring precipitation over China, especially over the Yangtze River area.

Keywords: precipitation, spring, numerical model

Interannual variations of tropical cyclone frequency over South China Sea

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This study attempts to investigate the interannual changes of tropical cyclone (TC) frequency over South China Sea (SCS) in the different seasons of summer (May-August) and winter (September-December) during 1977-2012. The spectral analysis indicate that during the summer, there is a periodicity of 4-8 years between 1993-2003 and an obvious interdecadal signal while during the winter the periodicity of 2-8 yeas is dominated between 1980 and 1992. The differences of characteristic between the summer and winter is related to the role of Indian Ocean. During the winter the subtropical Indian Ocean Dipole (IOD) around 20ºS induces a cyclone circulation over the North Indian Ocean that leads to a upper-level divergence and low-level cyclone with updraft over SCS that is favorable for TC formation. The impact of subtropical IOD becomes weaker during the summer, however the colder sea surface temperature still can be found in the western part of Indian Ocean. Meanwhile western North Pacific warm pool also results in an ascending flow over the SCS and enhances MJO activity there that increases the numbers of SCS TCs.

Keywords: tropical cyclone , interannual change, South China Sea

How well do global climate models simulate the variability of Western North Pacific Tropical Cyclones Associated with ENSO?

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An assessment on the simulations of interannual variability of tropical cyclones (TCs) over the western North Pacific (WNP) and association with El Niño–Southern Oscillation (ENSO), as well as a subsequent diagnosis for possible causes of the model biases generated from simulating the large scale climate conditions, are documented in the paper. The model experiments are carried out by the Hurricane Work Group under the U.S. Climate Variability and Predictability Research Program (CLIVAR) using five global climate models (GCMs) with a total of 16 ensemble members forced by the observed sea surface temperature, and spanning 28-yr period from 1982 to 2009. The results show GISS and GFDL model ensemble means best simulate the interannual variability of TCs and the multi-model ensemble mean (MME) follows. Also, the MME has the closest climate mean annual number of WNP TCs and the smallest root-mean-square error to the observation.
Most GCMs can simulate the interannual variability of WNP TCs well, with stronger TC activities during two types of El Niño, namely eastern Pacific (EP) and central Pacific (CP) El Niño, and weaker activity during La Niña. However, none of models captures the differences in TC activity between EP and CP El Niño as shown in observations, which may be due to the bias of the circulations in models in response to the westward shift of tropical heating associated with CP El Niño. In addition, a general unrealistic scene exists in model simulations with the underestimated intensities of the convection anomaly over the maritime continent in the western tropical Pacific during each ENSO phase of whatever warm or cold, which may be the important source of biases in simulating WNP TC associated with the ENSO events.

Keywords: Simulations, tropical cyclones, variability, ENSO, global climate models

Unusual growth in intense typhoon occurrences over the Philippine Sea in September after the mid-2000s

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During the global warming hiatus period (1998–present), a pronounced increase in the number of intense typhoon occurrences was identified over the Philippine Sea (PS: 5°–25°N, 125°–140°E) in September after the mid-2000s. Comparing two periods before and after the mid-2000s indicates that intense typhoons rarely occurred over the PS in September before the mid-2000s, with a frequency of fewer than 0.4 per year, but reached up to nearly 1.5 per year after the mid-2000s. The abrupt increase in intense typhoon occurrences over the PS was primarily attributed to increased tropical cyclone (TC) genesis and favorable large-scale conditions for TC intensification. The increase in TC genesis number over the PS was caused by contributory dynamical conditions, including positive low-level relative vorticity anomalies and anomalous ascents, which corresponded to a southwestward shift and strengthening of the monsoon trough. In addition, among the favorable large-scale conditions, the increased relative humidity that resulted from intensified moisture flux convergence exerted essential effect on the TC intensification.

These changes in atmospheric environmental conditions favoring intense typhoon occurrences over the PS were primarily associated with the change in the tropical Indo-Pacific sea surface temperature (SST) around the mid-2000s. Besides that, the positive feedback TCs exerted on the circulation was also conducive to the unusual growth in intense typhoon occurrences over the PS. And note that the role of SST anomalies in the air–sea interaction is the key to interpret why the unique phenomenon only occurred in September

Keywords: tropical cyclone, decadal change

Influence of the IOD on the relationship between El Nino Modoki and the East Asian-western North Pacific summer climate

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The relationship between El Nino Modoki and the East Asian-western North Pacific summer monsoon (EA-WNPSM) has been revealed to be under the influence of Indian Ocean Dipole (IOD). When a pure El Nino Modoki occurs without a positive IOD, a strong EA-WNPSM is observed with a significant anomalous low-level cyclone over the western North Pacific (WNP), excessive rainfall there and deficient Meiyu–Baiu rainfall. In contrast, when an El Nino Modoki happens simultaneously with a positive IOD, the anomalous EA-WNPSM tends to be much weaker. This difference is attributed to a positive IOD effect. The results demonstrate that a positive IOD usually leads to a strong South Asian summer monsoon heating, which further causes easterly anomalies in the western Pacific. These anomalous easterlies tend to strengthen the WNP anticyclonic vorticity leading to a weak EA-WNPSM. Therefore, a positive IOD weakens the relationship between the El Nino Modoki and the EA-WNPSM. In addition, numerical experiments verified that the strong low-level WNP cyclonic anomaly is built through the off-equatorial heating associated with the local cyclonic circulation. The anomalous WNP anticyclonic vorticity induced by a positive IOD weakens this off-equatorial heating, thus leading to a weak EA-WNPSM.

