Japan Geoscience Union Meeting 2012
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AAS02-01 会場:101A 時間:5 月 25 日 09:00-09:15

高速風洞水槽を用いた風波気液界面上における抗力測定
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.

キーワード: 風波, 抗力, 界面粗度
Keywords: wind-wave, drag coefficient, roughness length

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台風による波浪とその相互作用に関する展望
Ocean waves by typhoons and a perspective of their role in interaction

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台風のような極限的強風下においては、非常に高い波浪が生成され、船舶の航行や海岸部に大きな影響を与える。このため、波浪情報は外洋・沿岸何れの防災取っても重要であり、気象庁は波浪モデルを運用し、波浪についての情報発表を行っている。気象庁では、現在、極域を除いた全球を対象とした全球波浪モデル、日本近海を対象とした沿岸波浪モデル、の二つの波浪モデルを運用している。このモデル MRI-III は気象研究所で開発された第 3 世代波浪モデルである。第 3 世代波浪モデルとは、波浪の発達に関わる、エネルギー入力、エネルギー散逸、非線形エネルギー輸送の 3 過程のうち、非線形エネルギー輸送を陽に計算するモデルである。波浪スペクトル（通常波浪モデルでは、周波数・方向別エネルギーである波浪スペクトルを物理量としいる）間でのエネルギーの交換は、波浪の安定的な発達にとって重要であるとともに、風浪・うねり間でのエネルギー交換による、急発達等を正しく推算する上で重要となる。台風中心域においては通常、多方向の波が存在していることが多く、この過程を正しく見積もることが重要である。

台風による波浪と波浪モデルの予測例として、2011 年台風第 15 号による東海沖の波浪について紹介する。台風第 15 号は、勢力を維持したまま日本の南海上を東進し、台風中心付近では波高 8m を超える高波となった。2011 年 9 月 21 日 15 時（JST）には、静岡県にある石廊崎波浪計で波高 10.6m、周期 12.8 秒の高波を観測した。また、石廊崎の沿岸波浪計は、この高波の波浪スペクトルも観測した。沿岸波浪モデルは、この高波を、時間的には若干位相の遅れはあるものの、10m 強という観測とほぼ同じ最大波高を予測しており、更に、推算された波浪スペクトルは、観測値とよく一致していた。台風による波浪の予測技術は十分満足できるものといえよう。

一方で、台風の強度予測には、海との熱・運動量フラックスを正しく評価することが重要である。これらの交換は海面を通した現象であるが、台風中心の海面は高波により荒れた状態となり、波しぶきが飛び交っている。海面での交換過程は、波浪の状況（一般的には「海面状態」）に依存するであろうというのが通説である。現在では、大気モデルに海洋モデルと波浪モデルを結合し、総合的な観点で台風に対する強度変化の影響を評価する調査は多数行われている。

しかし、波浪の影響そのものについては、根本的な問題も含めて解明されているとは言い難い。素過程の評価には、大気モデルと波浪モデルを結合し、そのインパクトを調査することが必要である。本発表では、現時点での波浪依存性についての知見をまとめつつ、気象モデルと波浪モデルを結合させた場合に、台風強度にどの程度影響を与えうるのかについて、代表的な抵抗係数の決定式によるインパクトの違いを紹介する。

キーワード: 波浪, 台風, 海気相互作用
Keywords: ocean waves, typhoons, air-sea interaction

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台風および冬季対流時における新型鉛直混合スキームの性能
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.

キーワード: 乱流混合, 新型鉛直混合, 台風, 冬季対流, 日本海
Keywords: turbulent mixing, improved mixed layer scheme, typhoon, winter convection, Japan Sea

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AAS02-04 会場:101A 時間:5 月 25 日 09:45-10:00

大気海洋結合・非結合実験における海洋に対する台風強度の違い
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.

キーワード: 熱帯低気圧, 台風, 大気海洋相互作用, 大気海洋結合モデル, 雲解像メソスケール領域モデル, 数値実験
Keywords: tropical cyclone, typhoon, air-sea interaction, atmosphere-ocean coupled model, cloud resolving mesoscale regional model, Numerical experiment

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台風域の海面粗度長と抵抗係数に関する数値シミュレーション
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.

キーワード: 台風, 抵抗係数, 高風速, 海面粗度長, 大気波浪海洋結合モデル
Keywords: Typhoon, Drag coefficient, High wind, Surface roughness length, Atmosphere-wave-ocean coupled model

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台風通過が貧栄養海域の生物群集構造に及ぼす影響の評価
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.

キーワード: 台風, 熱帯性低気圧, 亜熱帯, 植物プランクトン, 動物プランクトン, 栄養塩
Keywords: Typhoon, Tropical cyclone, Subtropics, Phytoplankton, Zooplankton, Nutrients

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海洋環境の基礎生産への台風の影響
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 会場:101A 時間:5 月 25 日 11:05-11:20

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

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.

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ITOP ドロップウィンドゾンデを使用した台風進路予測のための観測システム実験
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.

キーワード: 数値予報, 台風進路, データ同化
Keywords: Numerical Weather Prediction, Typhoon Track, Data Assimilation

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発達した熱帯低気圧の海面フラックス有効半径
An effective radius of the sea surface enthalpy flux for the maintenance of a tropical cyclone

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本研究では、準定常状態にある熱帯低気圧（Tropical Cyclone: TC）には、海面エンタルピーフラックスの有効半径（それより内側のフラックスのみによって TC の強度が維持される）が存在することを示した。まず著者らの構築した軸対称非静力学モデルを用いて準定常状態の熱帯低気圧を計算し、ある半径より外側のフラックスを切った実験を繰り返し行った結果、有効半径は約 100 km（最大風速半径の 7-8 倍）に位置していることが分かった。加えて、エンタルピー収支解析の結果、有効半径は、境界層内で半径と動径方向流速の積の動径方向微分が値を持ち始める半径であることが示唆された。この微分は水平収束を表すため、典型的な熱帯低気圧では眼の壁雲直下で極大値を持つ。この値が存在する範囲は、熱帯低気圧が海面から得たエンタルピーを運動エネルギーに変換する上で重要な二次循環の上昇流域の下端に相当する。つまりこの微分が値を持つ領域で、海洋からのエンタルピーが絶たれると、熱帯低気圧は強度を維持できなくなるわけである。

キーワード: 熱帯低気圧, 海面フラックス
Keywords: Tropical Cyclones, Sea surface fluxes

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熱フラックス偏差が短時間で台風強化に影響を与えるメカニズム
Short-time-scale typhoon intensification as a response to anomalous surface heat fluxes

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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.

キーワード: 台風海洋相互作用, 渦力学, 感度解析
Keywords: Typhoon-ocean interaction, vortex dynamics, sensitivity analysis