Section 9

Development of and studies with coupled ocean-atmosphere models

Variability in the Southern Annular Mode due to decadal variations in tropical heating

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The Southern Annular Mode (SAM) is the dominant pattern of variability in monthly anomalies of atmospheric circulation in the Southern Hemisphere. While the SAM captures temporal variations in the meridional mass distribution, its shape is far from fixed. The Melbourne University General Circulation Model is used to determine the dependence of the SAM on spatial variations in tropical heating. The model is configured at T42 spectral resolution, and forced with four sets of SST anomalies, each formed as 12-month climatologies for both El Niño and La Niña conditions, during first the epoch 1944-1973 when the PDO was in the negative phase, and second during the epoch 1974-2003 when the PDO was in the positive phase. This choice, which produces SST anomalies that differ spatially, is motivated by the study of Lachlan-Cope and Connolley (2006) who showed that differences in the location of tropical heating give rise to substantial differences in the high southern latitude time-mean circulation due to changes in location and strength of Rossby wave generation and subsequent propagation.

Figure 1 shows the leading EOF of simulated surface pressure from the four simulations. The SAM is a transient feature, and thus arises from changes to the transient flow. While the differences in the time-mean circulation between the four experiments largely confirm Lachlan-Cope and Conelley's findings, here we show that changes in the mean flow alter the transient circulation. Changes in vertically integrated transient meridional momentum flux explain the differences in gradients (and geostrophic flow) between experiments. Indeed, Figure 2 shows that baroclinic growth rates tend to be larger slightly upstream of increased momentum fluxes, and that local ridges in the SAM pattern are coincident with reduced instability. The influence of the tropical SST variability is explained as follows. Tropical sources of Rossby waves produce enhancement of the mid-latitudes westerly jet in locations controlled by the trajectory of the wave propagation. A stronger jet increases the likelihood of baroclinic instability and thus preconditions the flow to transient eddy generation. The generation of baroclinic eddies yields a poleward momentum flux, and consequently modifies the structure of the SAM. This mechanism is strongest in wintertime when the baroclinicity is generally stronger, however, the mechanism also occurs in summertime. Indeed, Figure 1 suggests that the variation in the structure of the SAM is greatest in the summertime, when the mean shape of the SAM is less robust.

These experiments provide some insight to the reason behind the apparently large difference in model simulations of the SAM. Specifically, coupled climate models are unlikely to reproduce the observed SAM unless the temporal and spatial variations in tropical SSTs, and thus teleconnection patterns, are also reproduced reliably. On the other hand, it is likely that models capture the mechanism well since it is fundamental to the development of mid-latitude storms.

References

Lachlan-Cope T., and W. Connolley, 2006: Teleconnections between the tropical Pacific and the Amundsen-Bellinghausen Sea: Role of the El Niño/Southern Oscillation. *Journal of Geophysical Research*, **111**, D23101, doi:10.1029/2005JD006386.

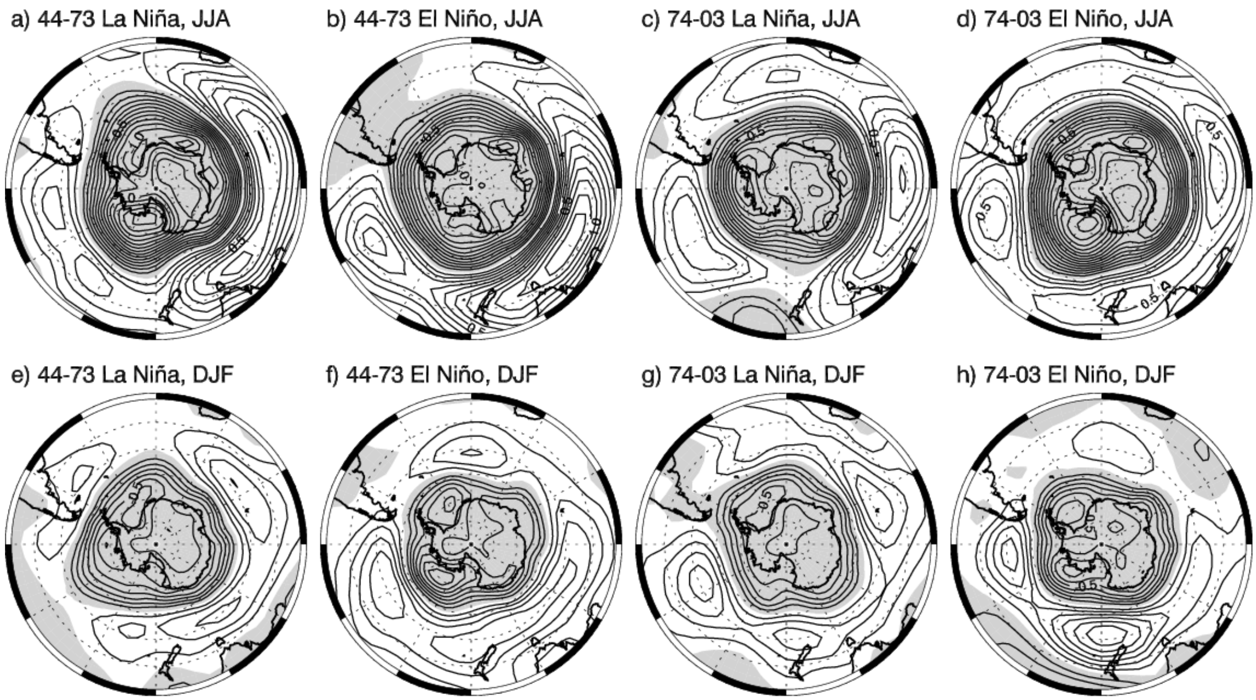

Figure 1: First EOF of monthly anomaly surface pressure for each season DJF (upper panels) and JJA (lower panels). The contour interval is 1 hPa. Negative values are shaded and the zero contour has been omitted. Results are from the final 30 years of 40-year simulations.

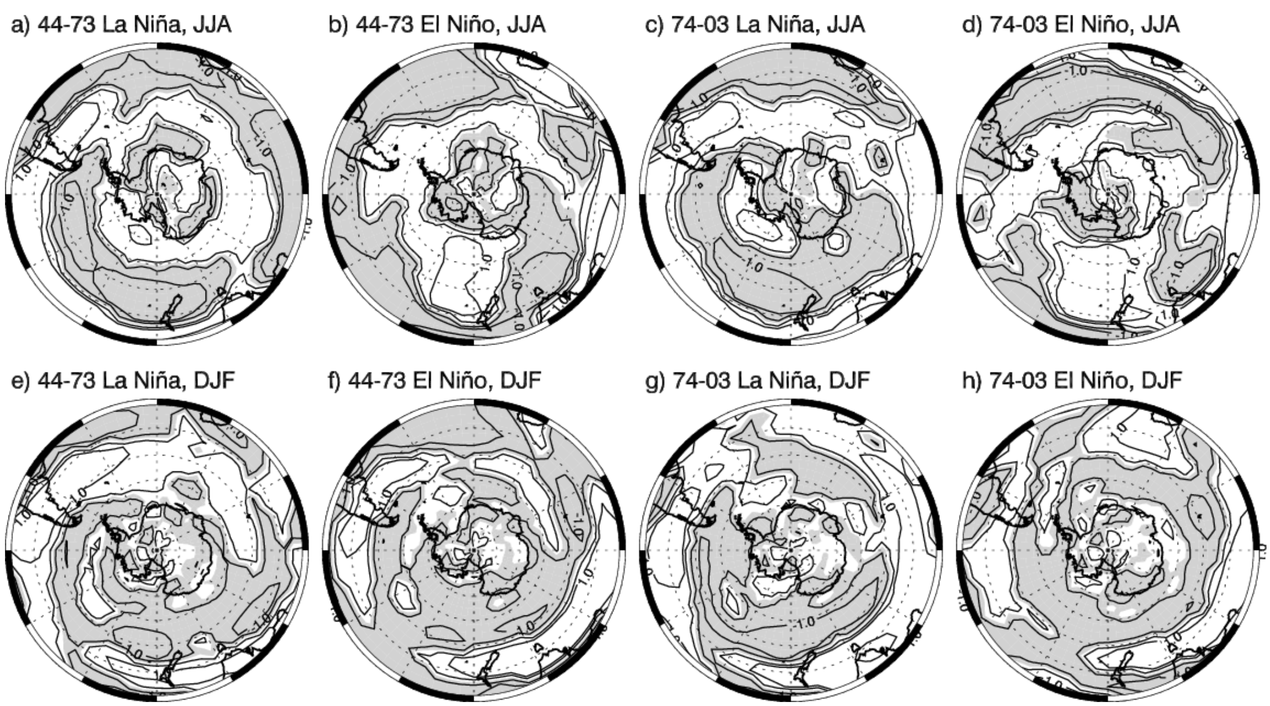

Figure 2: Experiment minus control difference in baroclinic growth rate (e-folding time) for the locally most unstable 2-layer baroclinic wave. Negative values indicate faster growth (shaded), positive indicates slower growth. Contour interval is 0.5 days. The zero contour has been omitted.

The impact of oceanic observations on tropical cyclone intensity prediction in the case of Typhoon Namtheun (2004)

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1. Introduction

Local sea surface cooling (SSC) caused by a passage of a tropical cyclone (TC) plays a significant role in TC intensity predictions by using atmosphere-ocean coupled models. However, whether or not environmental oceanic conditions affect TC intensity predictions has not been clear. The quality of environmental oceanic reanalyzed dataset depends on the frequency of observations. The frequency of observations has been still insufficient even though nearly three-thousand ARGO floats have been deployed in the world ocean. Here we show the impact of oceanic observations such as in situ observations by voluntary ships, research vessels, buoys and floats, and satellite altimeters on the TC intensity prediction in the case of Typhoon Namtheun (2004).

2. Methods

The outline of numerical predictions in the case of Typhoon Namtheun (2004) has been already reported in Wada and Murata (2007). The computational domains consist of two regional nests: an outer nest with a grid spacing of 6 km and inner nest with a grid spacing of 2 km. In the outer-nest domain, a cumulus parameterization was conjunctively used with a cloud microphysics. After 30-hour integration in the outer-nest domain, a calculation in the inner-nest domain was initiated to be started without using a cumulus parameterization. The atmosphere-ocean coupled model used in the present study was modified in the following manners: The entrainment formulation of Deardorff (1983) was updated from Wada and Murata (2007) and sea surface boundary process was also modified as the magnitude of diurnal sea surface temperature (SST) variations could be realistically reproduced compared with observations.

Using the North Pacific version of Meteorological Research Institute multivariate ocean variational estimation system, three types of oceanic reanalysis dataset were prepared for TC intensity predictions by the coupled model:

a. no assimilation of both in situ observations and sea surface height observations by satellite altimeters
b. no assimilation of in situ observations and assimilation of sea surface height observations by satellite altimeters
c. assimilation of both in situ observations and sea surface height observations by satellite altimeters

Figure 1 depicts the locations of in situ observations on July 2004. The number of in situ observations was not always sufficient in the computational domain (Fig.2a), while sea surface height data by satellite altimeters (JASON1 and ENVISAT) covered in the computational domain (Fig. 2b).

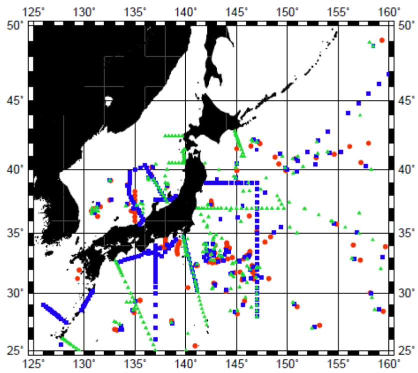

Fig. 1 Locations of in situ observations on July 2004. Red circles show the locations on the early July, blue squares show the locations on the middle July, and green triangles show the locations on the late July.

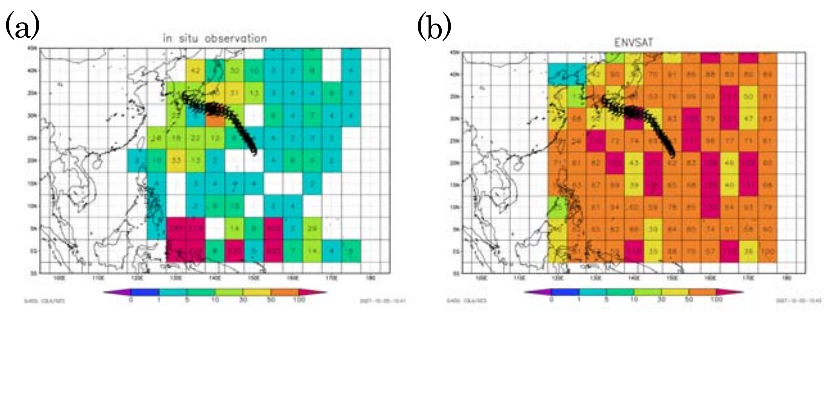

Fig.2 The horizontal distribution of the number of (a) in situ oceanic observations and (b) sea surface height observations by satellite altimeters on the late July with a grid spacing of 5°. Typhoon Marks shows the track of Typhoon Namutheun (2004).

3. Results

3-1 Environmental oceanic conditions

Figure 3 shows the horizontal distribution of SSTs on 29 July 2004 and predicted TC positions depicted every six hours during the 40-hour integrations. A cold eddy off Kii peninsula, the area over 29℃ and local SSC around 33° N,140° E were calculated in three SST fields, respectively. However, there was no significant difference among the track predictions. This indicates that environmental oceanic conditions hardly affect the TC track prediction.

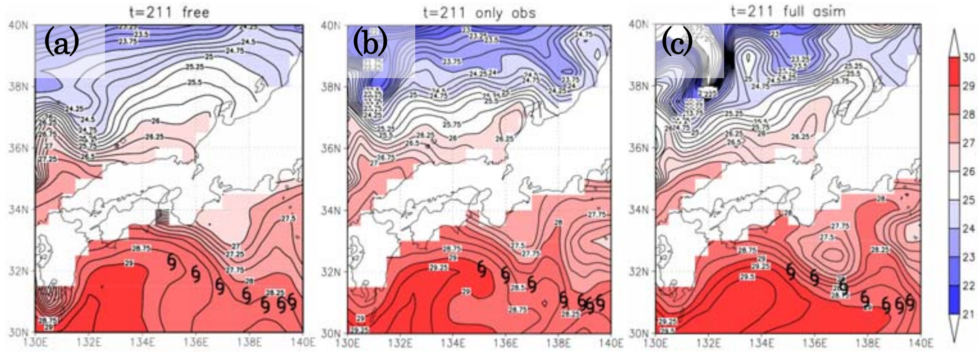

Fig. 3 Horizontal distribution of SST (Shades and contours) on 29 July 2004 and predicted TC positions (typhoon marks) every six hours during the 40-hour integration. (a) Case a, (b) Case b, and (c) Case c.

3-2 Tropical cyclone predictions

Figure 4 shows the results of TC track and intensity predictions by using the atmosphere-ocean coupled model. During the early integrations, minimum central pressure in Case c was the lowest of three numerical predictions probably due to eastward extension of SST higher than 29℃. However, the results of TC intensity prediction were almost all the same at 27-hour integration again. After that, minimum central pressure in Case b was the lowest.

Figure 5 shows the results of TC intensity prediction by using the non-coupled (atmosphere-only) model. Minimum central pressure in Case c continued to be the lowest of three numerical experiments during the integration, which was clearly different from the results shown in Fig. 4. The difference in minimum central pressure among the three environmental oceanic conditions was at most 5 hPa at 15-hour integration (Fig. 4), while the difference of minimum central pressure between coupled (Fig. 4) and non-coupled (Fig. 5) simulations were nearly 15 hPa.

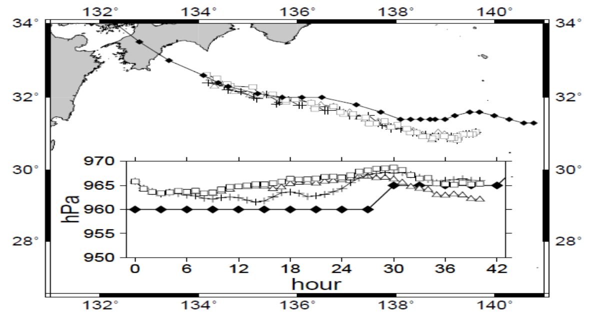

Fig. 4 Predicted tropical cyclone positions and time series of minimum central pressure. Circles show the result of Case a. Triangles show the result of Case b. Crosses show the result of case c.

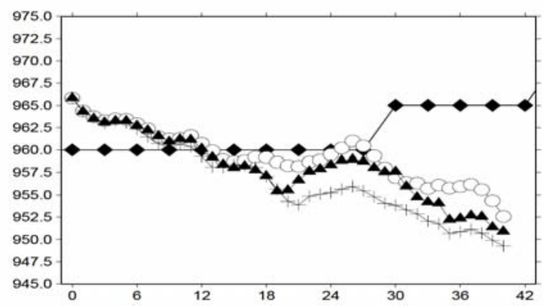

Fig. 5 Time series of minimum central pressure predicted by non-coupled model. Circles show the result of Case a. Triangles show the result of Case b. Crosses show the result of case c.

4. Concluding remark

The result of relatively small impact of environmental oceanic condition on TC intensity predictions suggests that environmental oceanic conditions play a minor role in TC intensity predictions compared with the role of local SSC. However, we should note that uncertainty of environmental oceanic condition possibly inhibits the improvement of tropical cyclone intensity predictions by atmosphere-ocean coupled models. The uncertainty of environmental oceanic condition may increase where in situ observations are scarce (Fig. 3a). We need to further investigate the impact of oceanic observations of TC intensity predictions for many TCs.

References

Deardorff、J. W. (1983): A multi-limit mixed-layer entrainment formulation. J. Phys. Oceanogr., 13, 988-1002.

Wada and Murata (2007): Effect of horizontal resolution and sea surface cooling on simulations of tropical cyclones in case of Typhoon Namtheun (2004) by a coupled MRI tropical cyclone-ocean model. WMO CAS/JSC WGNE Report. 9-09.

Numerical experiments of intensification of an idealized typhoon-like vortex under various sea surface temperatures by a nonhydrostatic atmosphere-ocean coupled model

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1. Introduction

We investigated the impact of environmental sea surface temperature (SST) and local sea surface cooling (SSC) caused by the typhoon-like vortex on its intensity and intensification using a nonhydrostatic atmosphere-ocean coupled model. The coupled model was a nonhydrostatic atmosphere-slab mixed-layer ocean model developed by the first author. We examined the process of intensification in detail under various environmental SSTs and their local SSCs caused by the vortex. The process of interaction between local SSC and intensification has not been clarified even though the impact of local SSC on vortex's warm-core temperature and maximum wind speeds have been studied.

2. Methods

Table 1 shows the specification of numerical experiments. In the present report, three values of SST (28, 30, and 32℃) were used as an initial environmental SST. An initial wind field was assumed to be cyclonically axisymmetric (Nasuno and Yamasaki,1997). A radius of initial maximum wind was set to be 80 km and initial maximum wind speed was set to 20 m s^{-1}(Fig. 1). An atmospheric thermodynamic condition was horizontally homogeneous. The thermodynamic profile was obtained from the regional objective analysis dataset on 26 July in 2004 when Typhoon Namutheun in 2004 was located around 25°N, 150°E. The homogeneous initial field was made by extracting and averaging the domain of Typhoon Namutheun (600 km X 600 km) centered at the storm center.

Table 1 Specification of numerical experiments

Numerical model	Wada and Murata (2007) (NHM + slab mixed-layer ocean coupled model)
Grid number	301 x 301 x 40 (600 km x 600 km x ~23km)
Horizontal resolution	2 km
Vertical resolution	40 m – 1180 m
Coriolis parameter	5.0×10^{-5}
Cumulus parameterization	None
Cloud physics	3-ice bulk
Integration time	81 hours (after 27 hours, both non-coupled and coupled experiments are performed)
Initial sea temperature profile	2nd level: SST – 1 ℃, 3rd level: SST – 12℃, bottom level: 5℃
Number of oceanic layer	3
Initial layer thickness	30 m in a mixed layer, 170 m in a thermocline, 800 m below a thermocline

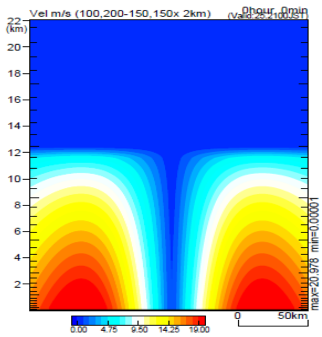

Figure 1 Initial wind field used in the present numerical experiments

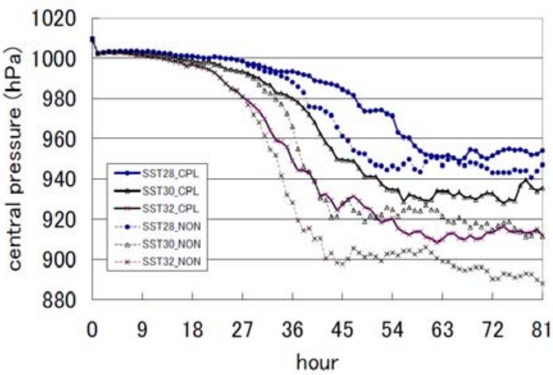

Figure 2 Time series of simulated minimum sea level pressure. CPL indicates a coupled experiment, while NON indicates a non-coupled experiment. The figures 28, 30, and 32 are values of initial sea surface temperature.

3. Results

3.1 Sea surface temperature

Time series of minimum sea level pressure (Fig. 2) indicated that the intensity and intensification of typhoon-like vortex depended on a value of initial environmental SST. From the result shown in Fig. 2, high initial environmental SST led to decrease in minimum sea level pressure. In particular, a typhoon-like vortex rapidly intensified from 27 to 45 hours integration when the initial environmental SST was 32℃, while the intensification of typhoon-like vortex comparably delayed when the initial environmental SST was 28℃. The difference in minimum sea level pressure between sea surface temperatures of 28℃ and 32℃ was nearly 50 hPa (Fig. 2).

Intensification of typhoon-like vortex is related to the development of warming area formed around the center of typhoon-like vortex. High potential vorticity (PV) on the 345K-isotherm concentrated on the vortex center when the initial environmental SST was 30 ℃ (Fig. 3a). However, high PV area was not overlapped with the warming area indicated by the low height on the 345-K isotherm. In contrast, high PV area was overlapped with the area of low height on the 345K-isotherm when the initial SST was 32℃ (Fig. 3b). The result suggests that high initial environmental SST leads to easily establish a warm-core ring formed around the center of typhoon-like vortex.

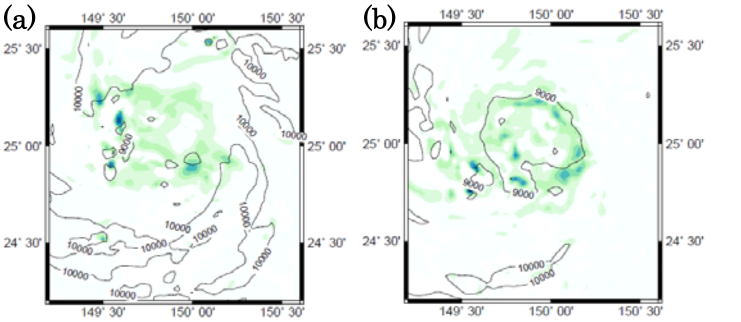

Figure 3 Contours show a height on the isotherm of 345 K at 27-hour. Shades show potential vorticity on the isotherm of 345K. Color bars in Fig. 3 are also used. (a) sea surface temperature is 30℃. (b) sea surface temperature is 32℃.

3.2 Sea surface cooling

The impact of local SSC on the intensity and intensification of typhoon-like vortex was salient when the initial environmental SST was 32℃ and local SSC was the largest in all initial environmental SSTs. The increase in minimum sea level pressure was nearly 25 hPa at 81-hour integration in the coupled experiment. The amount of increase in minimum sea level pressure in coupled experiments usually decreased as the initial environmental SST was lower. It is because the magnitude of SSC is small and is depended on the value of initial environmental SST and initial oceanic stratification such as mixed-layer depth and vertical gradient of temperature in the thermocline.

The impact of local SSC on the intensification of typhoon-like vortex was represented by the amount of PV production alongside spiral rainbands and around the center of typhoon-like vortex (Fig. 4a-b). In Fig. 4a, both a warming area and high PV concentration were salient, while a warming area was not salient in Fig. 4b. Therefore, local SSC also plays a role in delaying the intensification due to weak PV production and small warming region.

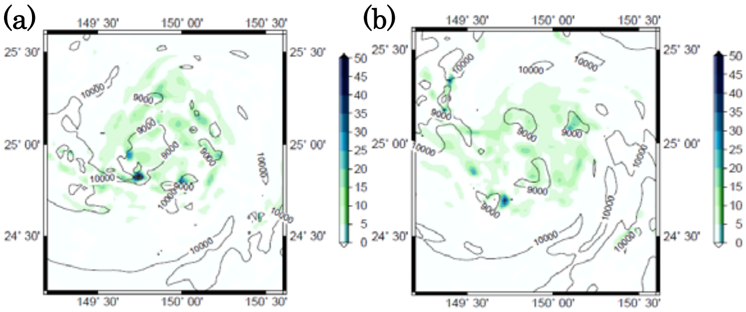

Figure 4 Contours show a height on the isotherm of 345 K. Shades show potential vorticity on the isotherm of 345K. (a) sea surface temperature is 30℃. (b) sea surface temperature is 30℃ but in a coupled experiment.

The axisymmetrical mean PV on the 305K-isotherm (Fig. 5) indicated that a typhoon-like vortex intensified through an inward isothermal transportation of PV, conserving angular momentum. The inward transportation of PV within a typhoon-like vortex simulated by a non-coupled model (Fig. 5a) was much stronger than that by a coupled model (Fig. 5b). In fact, the amplitude of PV production had a direct effect on the structure of typhoon-like vortex during the intensification. Therefore, isothermal transportation of PV in the atmospheric boundary layer (on the 305K-isotherm surface) is related to the intensification and it is sensitive to local SSC.

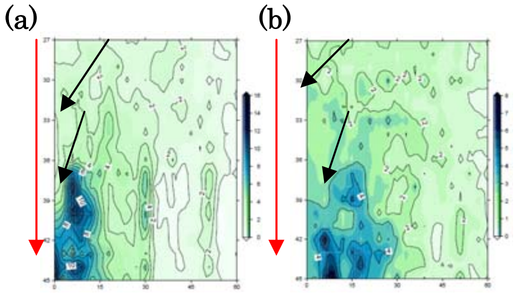

Figure 5 Time series of 2-dimensional axisymmetrical mean potential vorticity. A horizontal axis indicates a distance from the vortex center and a vertical axis indicates the integration hour. (a) the result in the non-coupled experiment. (b) the result in the coupled experiment. Black arrows show inward transportation of potential vorticity on the 305-K isotherm. Red arrows show the temporal transition.

Reference

Nasuno, T and M. Yamasaki (1997): J. Meteor.Soc. Japan, 75, 907-924.