The Madden-Julian Oscillation in GCMs

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Using AVHRR OLR and model simulated OLR we analyze intraseasonal convection in the AMIP models and coupled ocean-atmosphere models to determine the extent to which the Madden-Julian Oscillation (MJO; Madden and Julian 1971, 1972) is simulated, and the influence that air-sea interaction has on the representation of the MJO. All data are bandpassed with a 20-100 day Lanczos filter.

Sperber and Slingo (2003) identified seven years when the boreal winter MJO was notably active as a well-defined eastward propagating mode. Using these periods, the eastward propagation of convection was isolated via EOF analysis of filtered AVHRR OLR. For EOF-1 (EOF-2) enhanced convection covers 105^{o}E-180^{o}E, 20^{o}N-20^{o}S (60^{o}E-140^{o}E, 15^{o}N-20^{o}S). In the present study, filtered AVHRR OLR and the model OLR is projected onto the afore-mentioned EOF’s. Thus, all models are evaluated relative to a common metric. The analysis is confined to the months November-March, for 1979/80-1994/95 for the observations and the AMIP II models, and for 9-19 winters from the coupled models.

The amplitude of the OLR perturbations are directly proportional to the standard deviations of the PC’s (Table 1). For the AVHRR OLR data, a one standard deviation perturbation of PC-1 and PC-2 gives rise to convective anomalies of about +/-25Wm^{-2}. The vast majority of models have much weaker MJO convective signals. Also given in Table 1 is the maximum positive correlation, R, between PC-2 and PC-1, and the time lag at which it occurred. For the AVHRR OLR, on average, PC-2 leads PC-1 by 12 days with a maximum positive correlation of 0.67. For all models, R is smaller than observed indicating that eastward propagation is not as coherent as observed. The characteristic timescale of propagation exhibits a wide-range of variability, with some models incorrectly exhibiting weak westward propagation. Comparing AMIP II and AMIP I we find that HADAM3 has a weaker MJO amplitude and less coherent eastward propagation compared to HADAM2. Importantly, air-sea interaction has a beneficial influence. Three of the coupled models have an AMIP II atmospheric component. In each case the coupled models have a larger R, indicating that the MJO convection has a more realistic propagating structure. That coupling to an ocean yields improvement to the representation of the MJO is consistent with Waliser et al. (1999), Inness and Slingo (2003) and Inness et al. (2003).

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Table 1: Observed and simulated MJO characteristics. The columns give the observation/ model designation (the last 4 entries are from the coupled models), the standard deviations of PC-1 and PC2, the maximum positive correlation, R, between PC1 and PC-2, and the time lag at which it occurred. Positive time lags correspond to eastward propagation. Shaded entries highlight models for which an AMIP II integration and a coupled ocean-atmosphere simulation using the same atmospheric model are available.

Model	PC-1	PC-2	R	Lag (days) PC-2 leads PC-1 (positive)
AVHRR	211.3	205.6	0.67	12
CCCMA-99a	100.3	107.0	0.26	11
CCSR-98a	106.4	91.7	0.30	13
CNRM-00a	155.1	143.3	0.42	14
COLA-00a	100.5	85.7	0.16	26
DNM-98a	63.0	67.1	0.16	25
ECMWF-98a	102.5	97.5	0.20	-11
ECMWF-98b	121.8	105.7	0.29	-13
GFDL/DERF-98a	159.0	182.1	0.36	12
GISS-98a	64.0	54.6	0.23	-7
GISS-02a	37.1	37.1	0.17	-15
HADAM2 (AMIP I; 1979/ 80-1987/88)	166.5	130.9	0.40	18
HADAM3 (L58) (UGAMP-98a)	117.1	102.8	0.28	14
JMA-98a	165.3	155.3	0.29	10
MPI-98a (ECHAM4)	222.2	215.8	0.35	12
MRI-98a	174.2	164.1	0.31	9
NCAR-98a (CCM3)	91.9	100.2	0.18	10
NCAR-02a (CAM2)	95.3	95.8	0.19	-24
NCEP-99a	108.9	108.6	0.24	12
NCEP-99b	104.1	98.4	0.22	24
HADCM3 (L30)	104.4	96.0	0.45	8
IAP/LASG GOALS	123.8	129.2	0.42	9
NCAR CCSM2	91.5	115.9	0.28	20
SINTEX (ECHAM4/OPA8.1)	231.2	201.5	0.44	12

Developing coupled ocean-atmosphere global climate model for the Earth Simulator and its preliminary physical validation

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ABSTRACT

Our objective here is to introduce coupled global climate models for the Earth Simulator (CFES) with ultra high resolution to carry out century time integration within reasonable time. It is composed of oceanic general circulation model for the Earth Simulator (OFES) and atmospheric general circulation model for the Earth Simulator (AFES). We provide fully parallelized coupling structure to transfer physical data from one component model to the other component through a coupler and back again. CFES is also able to control concurrent performance by changing the number of nodes which employed each component of atmospheric and oceanic models. In addition, we will show that interpolation scheme introduced in this coupler well conserves the physical values.

1. INTRODUCTION

Coupled Atmosphere-Ocean-Sea Ice model for Earth Simulator (:CFES) is composed of oceanic general circulation model for the Earth Simulator (OFES) with sea ice component and atmospheric general circulation model for the Earth Simulator (AFES). Both of component models have been improved computational performance on the Earth Simulator. Coupling feature might be considered as additional freedom in the interface causes disagreement with observed data, because the interface between atmosphere and ocean should be taken into account to maintain a self consistent representation. To remove causative artificial factor of the inconsistent through coupling, we have developed CFES that individual component can run independently. In this framework, each component is linked by fully parallelized coupling interface, so that each component can run independently to avoid drift due to the feedback timing. Furthermore, its computational performance efficiency of CFES has improved due to fully parallelized coupling scheme. In this paper, we will introduce preliminary results from CFES on the Earth Simulator.

2. Parallelization on coupler interface of CFES

In coupling frame work, we focused on developing self consistent interface structure between atmosphere and ocean. Ordinarily, each component was coupled with simple serial scheme as shown in Fig 2. In this coupling scheme, the systematic bias might be caused due to ordering of execution. Atmospheric component at time (t+1) is driven by the results from oceanic component at time (t). It does not allow us to model a self consistent of air-sea interactions.

We have been parallelized structure of CFES by assigning separate groups of nodes to the atmosphere and oceanic components. Each component model can run independently, so that we are able to control parallel performance with changing the number of processors for each component. At the same time, interface for coupling was also fully parallelized. This framework enables us to archive by allowing con current execution for exchanging data between AFES and OFES. This concurrency entails executing all components from time (t) to (t+1) at the same time as shown in Fig.1. A self consistent representation was provided comparing with simple serial coupling scheme.Decomposition of data exchange throughout the coupling has achieved reduction of communication costs. In ordinarily used coupling scheme, gathering/broadcasting for exchanging wasexecuted with low cost. We are now executing experiments with horizontal resolution of 106, T319, T639 under 1 to 1

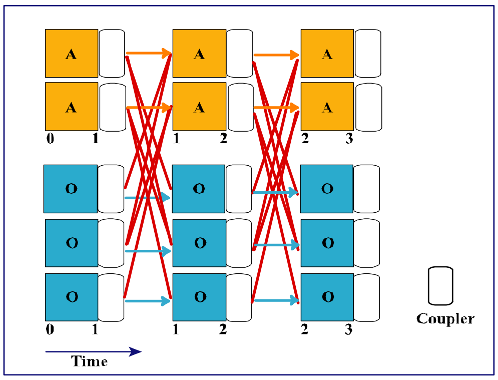

Figure 1. Structure of coupling schemes of CFES. A, O" and "coupler" represent atmospheric/oceanic, oceanic, and schemes for coupling components, respectively.

grid correspondence condition between AFES and OFES. For one month integration, they took about 11 minutes for T106 on the Earth Simulator. As wall clock time for one month 328 CPUs, about 1 hour for T319 on 1368 CPUs, and about 2.8 hours for T639 on 2808 CPUs of the Earth Simulator.

3. Preliminary results

From results of various resolution experiments, we show preliminary results of CFES with T106 after two years integration on the Earth Simulator. Fig.2. and Fig.3 present SST and SSS, respectively. Although integration term is too short to validate its physical performance, those distributions are reasonable and it shows that coupling is executed with conserved flux values on the whole region. Furthermore, we present annual averaged precipitation of CFES with T106 in Fig.4. In Fig. 5, vertical distribution of temperature on equator band between 2 degree of North and 2 degree of South is showed. Those distributions are also acceptable at present state.

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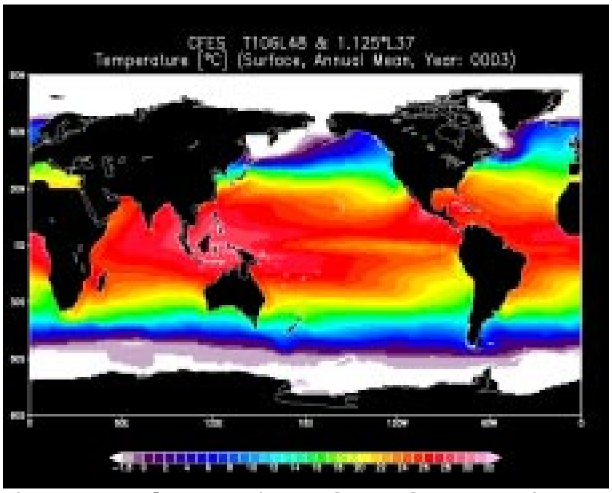

Figure 2. Annual averaged SST of CFES after 2 years integration of CFES with T106 horizontal resolution.

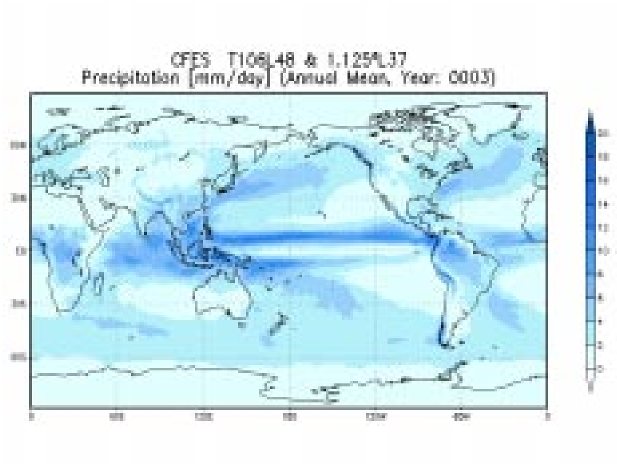

Figure 4 Annual mean of precipitation after 2 years integration of CFES with T106 horizontal resolution.

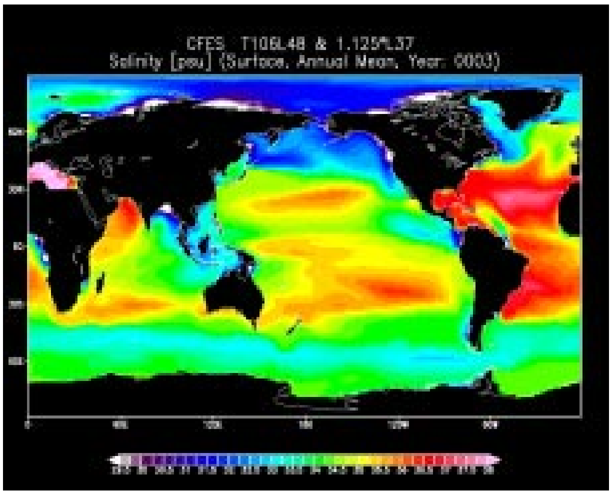

Figure 3. Annual mean of SSS after 2 years integration of CFES with T106 horizontal resolution.

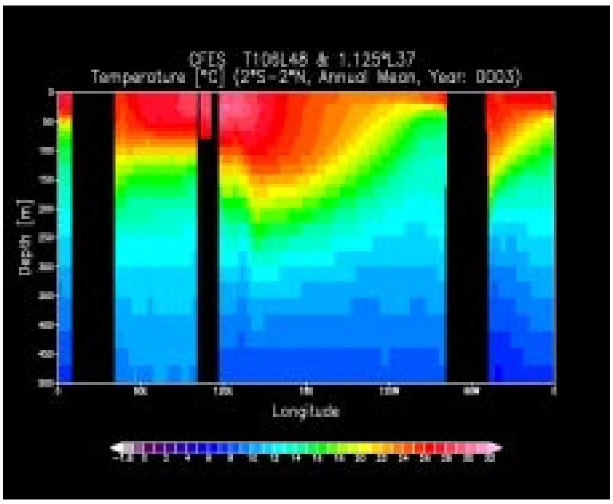

Figure 5. Annual averaged distribution of temperature on equator of ocean after 2 years integration.

Validation of typhoon intensity prediction by MRI typhoon-ocean coupled model

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1. Introduction

The typhoon-ocean coupled model has been developed at Meteorological Research Institute (MRI) in Japan Meteorological Agency (JMA) (Wada and Mino 2002). On a parallel with the development, a mixed layer model, which is an ocean part of the coupled model, has also developed (Wada 2002a). Owing to the improvement of turbulent mixing processes in mixed layer model, decreases of sea surface temperature (SST) could be simulated greater than those of previous model (Wada 2002a). Using this upgraded mixed layer model, numerical simulations for typhoons during 2000-2002 seasons are conducted. Here, we focus on typhoon intensity prediction and validate it by upgraded typhoon-ocean coupled model.

2. Numerical Simulations

Numerical simulations are conducted by both typhoon-ocean coupled model (CM) and operational typhoon model (TYM20) for the sake of comparison. Both models have 20km horizontal resolution of the typhoon center. Solar radiation, long-wave radiation and turbulent mixing processes near the surface are included in CM. Of numerical experiments over 100 cases, 27 cases are selected on the criteria of the errors of tracking prediction of typhoons from JMA best track positions: within 20km at T+0h, 100km at T+24h, 200km at T+48h, 300km at T+72h, which T is the initial time. The tracking limit is set for the sake of reliance of typhoon intensity prediction. The tracking map of all selected typhoons is shown in Fig.1.

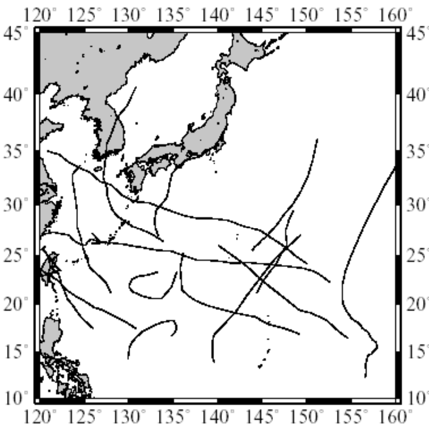

Fig.1 Japan Meteorological Agency (JMA) best track of selected typhoons during 2000-2002 seasons under the criteria of prediction of typhoon movement by coupled model of which position is within 20km at T+00h, 100km at T+24h, 200km at T+48h, and 300km at T+72h from JMA best track positions

Table 1 shows the list of 27 typhoons selected of all simulated typhoons on the criteria of tracking prediction. The range of JMA best track minimum sea level pressure (MSLP) during 72 hours integration is from 920hPa to 985hPa, while the MSLP by coupled model is from 921hPa to 979.8hPa. *Italic* characters in table 1 represent that minimum MSLP is detected at the initial time. For the purpose of investigating the ocean coupling effect, the maximum MSLP rising is defined as maximum MSLP (CM) - MSLP (TYM20) during 72 hours integration. The greatest deference of maximum MSLP rising is 10.1hPa on Typhoon PODUL at 12UTC in October 22 2001. The ocean coupling effects can be recognized from these results, however they seem to be smaller in comparison with related results by Bender and Ginis (2000).

SST cooling by CM is from -0.41℃ to -2.23℃ of which temperatures are smaller in comparison with observed SST cooling by Black (1983) or Bender et al.(1993) of which range is from -1℃ to -6 ℃ and observed SST cooling by TRMM/TMI of which range is from -2.7℃ to -7.2℃ in Table 1. SST cooling by CM seems to be underestimated as well as maximum MSLP rising.

One of the reasons of weaker SST cooling is that TYM20 cannot simulate the real intensity of strong typhoons such as Typhoon WUTIP on August 28 and Typhoon Higos on September 27.

Table 1 List of selected typhoons (name and initial time), their minimum MSLP and maximum SST cooling by JMA best track and coupled model and maximum MSLP rising between typhoon model and coupled model.

Typhoon NAME	INITIAL TIME (12UTC)	BEST TRACK MSLP (hPa)	MIN. MSLP by coupled model (hPa)	MAX. MSLP RISING (hPa)	MAX. SST COOLING (℃) by coupled model	MAX. SST COOLING by TRMM/TMI (℃)
BILIS	2000/08/20	920	922.2	7	-1.79	-4.80
TORAJI	2001/07/27	960	959.1	3.8	-1.15	-4.05
MAN-YI	2001/08/05	955	954.4	5.7	-2.14	-5.10
PABUK	2001/08/19	960	947.8	2.6	-2.03	-3.45
WUTIP	2001/08/28	930	950.7	4.6	-1.56	-6.90
NARI	2001/09/10	960	967	1.7	-1.51	-4.50
NARI	2001/09/16	970	979.8	0.9	-0.48	-3.59
LEKIMA	2001/09/25	970	961.8	1.4	-1.19	-2.70
LEKIMA	2001/09/26	985	979.1	1.8	-1.06	-3.15
PODUL	2001/10/21	930	959.9	6.5	-1.09	-3.60
PODUL	2001/10/22	925	943.1	10.1	-1.40	-4.20
PODUL	2001/10/24	925	935	9.5	-1.53	-4.05
MITAG	2002/03/05	930	940.4	0.3	-0.64	-3.60
HAGIBIS	2002/05/17	935	959.2	6	-0.41	-3.30
RAMMASUN	2002/07/02	945	937.4	4.4	-2.16	-5.25
FENGSHEN	2002/07/22	925	921	2.1	-1.31	-5.10
FUNG-WONG	2002/07/22	960	969.6	2.4	-1.09	-3.30
FENGSHEN	2002/07/23	945	942.4	1.6	-0.92	-3.75
FENGSHEN	2002/07/24	965	966.4	0.5	-0.69	-2.70
PHANFONE	2002/08/13	940	926.8	7	-1.89	-4.35
RUSA	2002/08/28	950	940.8	3.6	-2.19	-4.20
RUSA	2002/08/29	950	947.9	3.8	-2.23	-4.65
SINLALU	2002/08/30	950	961.2	2.7	-0.64	-2.40
SINLALU	2002/08/31	950	947.4	3.3	-1.08	-2.70
SINLALU	2002/09/01	950	935.5	1	-1.28	-2.84
SINLALU	2002/09/04	955	950.6	5.4	-2.11	-5.10
HIGOS	2002/09/27	930	943	3.6	-0.55	-7.20

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This issue is related to modeling of initial condition and physical processes in TYM20. Intensity errors at the initial time in TYM20 often occur because the structure at the typhoon center, particularly of strong typhoon, has too sharp pressure gradient to be fully expressed with 20km horizontal resolution. Concerning with the underestimation of strong typhoon, maximum wind velocity of TYM20 is smaller than that of JMA best track under the same MSLP. The weaker wind stress causes weak ocean response to typhoons and leads to small SST cooling after the passage of typhoons. The issue is closely related with atmospheric physical processes of TYM20 and CM. Actually, the parameterizations in the planetary boundary layer and cumulus parameterization in TYM20 are different from those of Bender and Ginis (2000).

The other reason is associated with oceanic conditions. The amount of SST cooling shown in Table 1 isn't proportional to the amount of maximum MSLP rising between TYM20 and CM. That is because SST cooling after the passage of typhoons is related to not only the magnitude of wind stresses but also the translation speed of typhoons and ocean conditions such as the thickness of the mixed layer and the vertical gradient of sea temperature in the thermocline (Wada 2002b). The mixed layer temperature with deep mixed layer is difficult to decrease, while the temperature with shallow mixed layer is easy to decrease.

3. Improvement of Intensity Prediction

Here, we focus on the tendency of MSLP during and every 6 hours in 72 hours. As a typhoon has been developing (weakening) during 6 hours, the tendency has a minus (plus) sign. If a typhoon doesn't change its intensity during 6 hours, the tendency will be zero. Therefore, using the tendency of MSLP to validate the typhoon intensity prediction is significant. For the purpose of investigating the similarity of model tendency to JMA best track tendency, correlation coefficients between in MSLP tendency as it is by both TYM20 and CM and JMA best track MSLP tendency are examined. Fig 2. shows time series of the correlation coefficients of MSLP tendencies of 27 typhoons every 6 hours. It should be noted that JMA best track MSLP is recorded every 5 hPa unlike outputs as it is by both models. Here, the MSLP tendency by both models is converted as below formulas.

$$P'_{tend} = Round(P_{tend}/5)\times 5$$

P_{tend} is the MSLP tendency. *Round* is a function for half adjust. The time series of correlation coefficients by converted MSLP tendency (not shown) is almost the similar to that shown in Fig. 2. The correlation coefficients of CM are greater than that of TYM20 after T+42h. This result suggests that the prediction of MSLP tendency during 6 hours by CM is more accurate after T + 42h than that by TYM20. However, the correlation coefficient at T+24h is the worst in the integration time.

4. Concluding Remarks

The results suggest that CM has the possibility of improving the intensity prediction of typhoons. Through the numerical simulations for typhoons, however, physical processes in the planetary boundary layer and cumulus parameterization will need to be further improved to simulate greater SST cooling after the passage of typhoons.

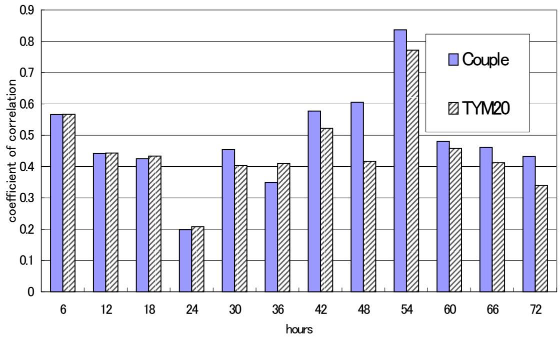

Fig.2 Correlation coefficients of tendency of minimum sea level pressure (MSLP) during 6 hours between models and JMA best track data

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Typhoon-ocean coupled model with upgraded mixed layer model

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1. Introduction

Local sea surface temperature (SST) cooling underneath typhoons and occurred after their passage has an influence on intensity of typhoons through air-sea interaction. To predict intensity of typhoons more accurately, the typhoon-ocean coupled model has been developed at Meteorological Research Institute (MRI) in Japan Meteorological Agency (JMA). According to the report by Wada (2003a), the ocean coupling was effective after T+42h for intensity prediction of typhoons, which T was the initial time of the integration. However, SST cooling by MRI typhoon-ocean coupled model has been still underestimated. One of the reasons is that turbulent mixing processes in the mixed layer model are not enough to simulate SST variations under various wind conditions. Consequently, Wada (2003b) improved the turbulent mixing processes in the mixed layer model. As the result of the improvement, the mixed layer model can successfully simulate SST variations under various wind conditions including local SST cooling after the passage of Typhoon REX on August 1998. Using the mixed layer model with upgrade turbulent mixing processes, MRI typhoon-ocean coupled model (Wada 2003a) has reconstructed. In the present report, the atmospheric response of Typhoon BILIS to local SST cooling will be represented through the difference of horizontal distribution or vertical profile of physical elements between typhoon model and typhoon-ocean coupled model.

2. The atmospheric response to local SST cooling

Numerical simulations on Typhoon Bilis of which initial time is at 12UTC on August 20 2000, are conducted using the upgraded typhoon-ocean coupled model and operational typhoon model for the sake of comparison. Horizontal resolutions of both models are 20km at the typhoon center. Compared with the previous result by Wada and Mino (2002), ocean coupling effects become more prominent for Typhoon Bilis. The ocean coupling effect is recognized from a rise of 16.8hPa at T+42h in minimum sea level pressure (MSLP) of Typhoon BILIS (Fig.1). Fig.1 also shows that the tendency of MSLP during T+24h to T+48h when Typhoon BILIS sustains its intensity is well simulated. However, the coupled model cannot simulate the maximum intensity of Typhoon BILIS. This issue may be associated with the atmospheric physical processes in operational typhoon model (Wada 2003a).

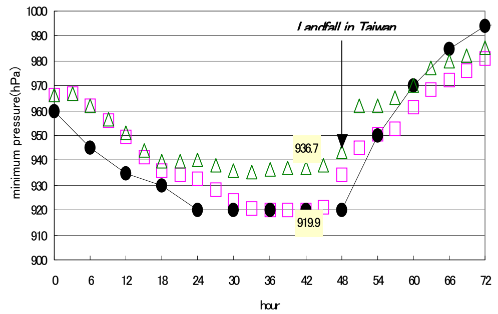

Fig. 1 Time series of minimum sea level pressure (MSLP) on Typhoon BILIS of which initial time is at 12UTC on 20 August 2000. Close circle indicates JMA best track MSLP, triangle MSLP by coupled model, and square MSLP by operational typhoon model.

The ocean coupling effects have influences on simulated inner structure of Typhoon BILIS. Vertical wind profiles concentrically averaged at radius from the typhoon center in the radius-pressure coordinate system indicate that maximum wind velocity of the operational typhoon model (Fig.2a) is greater than that of the coupled model (Fig.2b). Maximum wind velocity of typhoons is generally situated in eyewall region. The position of the maximum wind velocity of the coupled model moves outward from that of the operational typhoon model. To be more precise, maximum wind velocity of the operational typhoon model is situated within 100km from the typhoon center (Fig.2a), while that of the coupled model is situated outside 100km from the typhoon center (Fig.2b). Sharp horizontal gradient of horizontal wind velocity becomes loose particularly at the eyewall. Tangential wind velocity of the coupled model is weaker within 150km radius than that of the operational typhoon model (not shown). Radial velocity of the coupled model represents weak convergence near the surface and weak divergence in the upper layer around 200hPa (not shown). The potential temperature and specific humidity also decrease within 100km radius throughout the layer and in the lower layer from nearly 800hPa to the surface by ocean coupling (not shown).

The horizontal distribution of precipitation is clearly changed by ocean coupling (Fig.3). In the

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typhoon model, precipitation is dominant ahead and on the rightward of the running typhoon (Fig.3a). In contrast, precipitation is dominant behind and on the rightward of the running typhoon in the coupled model (Fig.3b). The difference of horizontal distribution of precipitation is concerned with the difference of the distribution of turbulent heat fluxes associated with SST cooling underneath typhoons. Variations of potential temperature and specific humidity near the surface may reflect the distribution of precipitation through the vertical transport of turbulent heat fluxes.

(a) (b)

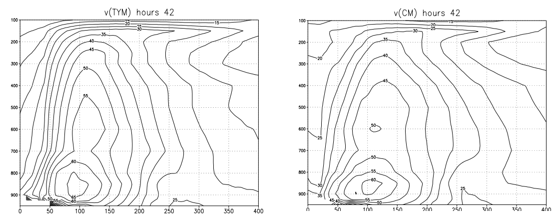

Fig. 2 Vertical profiles concentrically averaged at distances from the typhoon center in the pressure-distance coordinate system: (a) by operational typhoon model,(b) by coupled model

(a) (b)

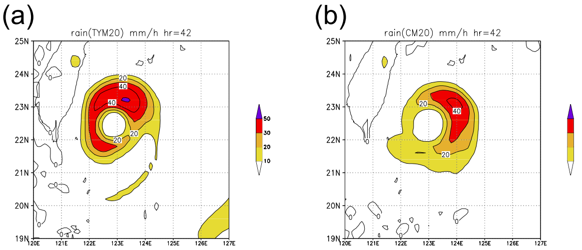

Fig. 3 Horizontal distribution of 1-hour precipitation at T + 42h: (a) by operational typhoon model (b) by coupled model

SST cooling after the passage of Typhoon BILIS is prominent in the rightward of the running typhoon. The maximum SST cooling is -2.8℃ (Fig.4a), which is greater than that of previous study (Wada and Mino 2002, Wada 2003a). Nevertheless, the maximum SST cooling by TRMM/TMI (Fig.4b) is nearly 4.8℃ (Wada 2003a) and greater than that by typhoon-ocean coupled model. To investigate the effect of atmospheric forcing to local SST cooling, SST cooling after the passage of Typhoon BILIS is reexamined using the mixed layer model with Rankin vortex which is produced using JMA best track maximum wind velocity and global analysis data in JMA. SST cooling by upgraded mixed layer model with Rankin vortex is nearly 5℃ (Fig.4c) and close to that by TRMM/TMI. Considering from the results so far obtained, errors of computed SSTs seem to be caused by underestimation of sea surface wind velocity or wind stresses in the typhoon and coupled model.

3. Concluding remark

The ocean coupling effects for Typhoon BILIS are recognized from MSLP (Fig.1), maximum wind velocity and vertical concentric averaged wind profile (Fig.2), and precipitation (Fig.3). The ocean coupling effects can be also found in the averaged vertical profile of potential temperature, specific humidity, and sea surface heat fluxes. All responses represent the negative feedback against typhoon development. The simulated SST cooling by the coupled model (Fig.4) indicates that wind stresses near the surface aren't fully simulated by typhoon and coupled models.

References

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(a) (b) (c)

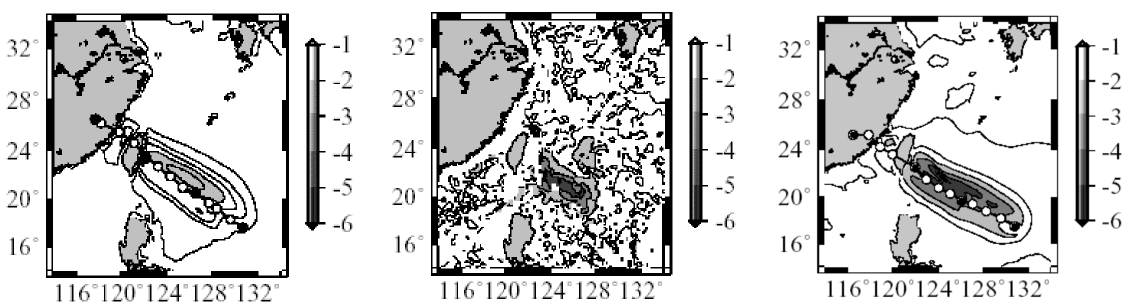

Fig.4 Distributions of SST deviation at T+72h from the initial time: Open and close circles indicate the position of typhoons every 6 hours (open) and every 24 hours (close) (a) SST cooling by coupled model, (b) SST cooling by TRMM/TMI, (c) SST cooling by mixed layer model with Rankin vortex based on JMA best track data.