P1.8 OCEANIC IMPACTS ON TROPICAL CYCLONE INTENSITY PREDICTION USING JMA HIGH-RESOLUTION GLOBAL NWP MODEL

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1. INTRODUCTION

The Japan Meteorological Agency (JMA) has developed a high-resolution global atmospheric model (JMA-GSM) for purposes of the numerical weather prediction (NWP) and the future extreme weather projection. JMA-GSM has a horizontal resolution of approximately 20km and 60 vertical layers, and it is in operation for NWP at JMA since November 2007. Such a high-resolution global model should have a greater potential for severe weather forecasting, including direct predictions of tropical cyclone intensity.

Ocean is a primary energy source of tropical cyclones. Therefore, good parameterizations for air-sea interactions and ocean are essential to accurate simulations of tropical cyclone using numerical models. Thus, it could be expected that for many tropical cyclones a high resolution global model makes it possible to directly simulate their intensities or tendencies at least. In this study, the revised atmospheric boundary layer scheme and parameterization for air-sea fluxes for JMA-GSM are examined on the simulation of tropical cyclones, especially focusing on their intensities. Impacts of coupling with an oceanic model are also investigated.

2. JMA GLOBAL NWP MODEL

The JMA high-resolution global NWP model, JMA-GSM, became operational in November 2007. Figure 1 shows an outline of the current global NWP system at JMA. The global model uses the hydrostatic and the shallow-atmosphere approximations in the governing equations. The horizontal representation is spectral using spherical harmonics as basis functions, and the horizontal resolution is spectral triangular 959 (T959), roughly equivalent to 0.1875 x 0.1875 degree latitude-longitude. The vertical coordinate is a hybrid pressure-based coordinate, and the vertical domain extends over surface to 0.1hPa (topmost atmospheric level). For a surface pressure of 1000hPa, the lowest level is set at a pressure of about 998.5hPa. The model has 60 unevenly spaced hybrid levels.

In the horizontal, the transform method is used to compute non-linear terms. The corresponding grid in physical space is non-staggered. For the time integration, a two-time-level semi-Lagrangian semi-implicit scheme is used. A constant time step length (600sec) is applied to both dynamics and physics, except for radiation computations. In order to reduce the amplitude of the shortest scales of motion, a linear fourth-order horizontal diffusion is applied to the prognostic variables.

3. EXPERIMENT ON OCEANIC IMPACTS

3.1 *Atmospheric Boundary Layer*

Over ocean, atmospheric boundary layer (ABL) has a crucial role that transports large amount of moisture upward from the ocean surface. The JMA global NWP model employs a first order turbulence closure scheme to handle effects of atmospheric turbulence. In the scheme vertical diffusivities both within and

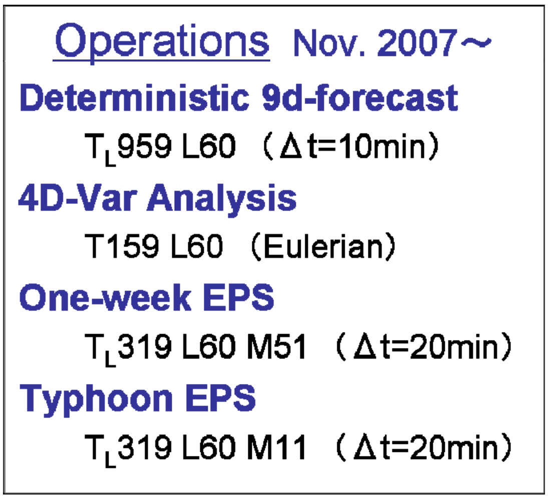

FIGURE 1. An outline of the current global NWP system at JMA

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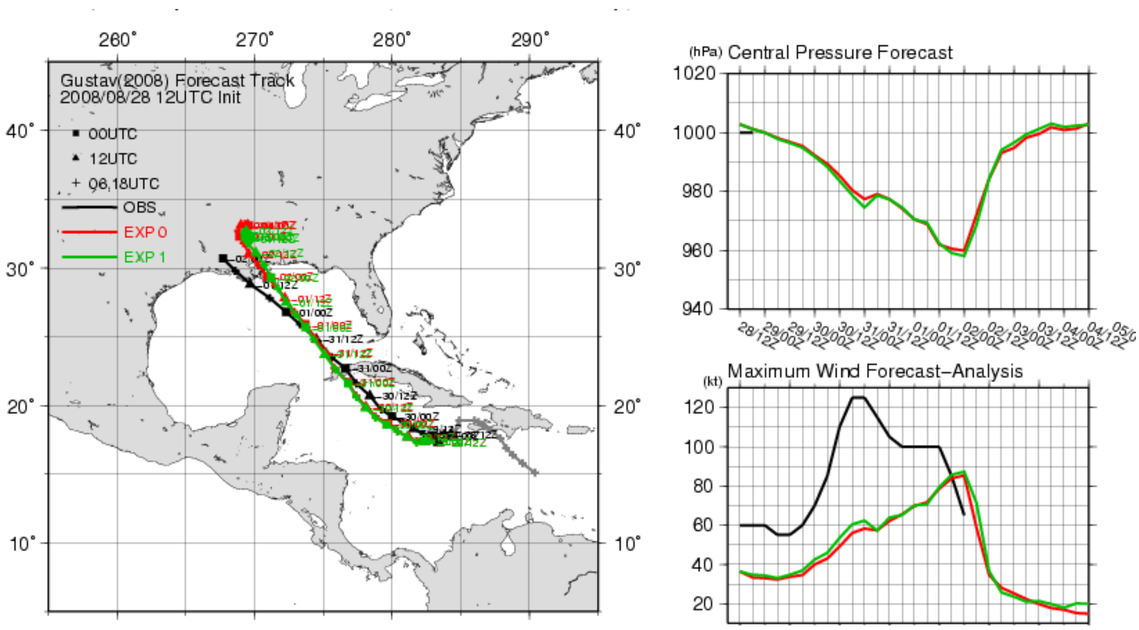

FIGURE 2. Tropical cyclone track and intensity for the hurricane GUSTAV 2008. Black lines show analyzed track and intensity, and red and green lines do those predicted by Exp0 and Exp1 models, respectively. Exp0 model uses a local ABL scheme and a usual Charnock's relation for the ocean roughness parameterization. Exp1 model uses a non-local ABL scheme and a modified Charnock's relation based on Makin (2005). Left panel shows cyclone track, and upper and lower right panels do central pressure (in hPa) and maximum wind speed (in knots) of the cyclone, respectively. Concerning numerical predictions, time integrations are carried out from Aug. 28th 12UTC, 2008 as an initial time to 168 hours (7 days) later.

above ABL are determined in terms of the local Richardson number ("local closure scheme"). Under unstable conditions, however, so-called "a non-local mixing" may efficiently transport heat and moisture upward and make structures of ABL more vertically homogeneous.

On surface drag over ocean, some observational studies pointed out that under extreme wind conditions the Charnock's relation may overestimate sea surface roughness length and wind stress (e.g., Powell et al., 2003). Considering improvements on predicting tropical cyclone intensities, a revision is introduced to the surface roughness length parameterization over hurricane wind range.

The improved atmospheric boundary layer scheme, including non-local turbulent mixing and revised air-sea flux, brings a modification of tropical cyclone intensity (Figure 2). However, their impact on the track prediction is quite less. By introducing a modified sea surface roughness parameterization based on Makin (2005), while the model simulates somewhat stronger surface winds, its impact on the intensity is relatively small.

The non-local mixings transport more moisture upward compared to those by the local scheme within well-mixed ABLs. Then evaporative moisture supply from ocean is efficiently activated, and sub-grid scale convection activities are relatively suppressed and grid scale condensations and motions become more dominant. As a consequence of that, a cyclone intensity is enhanced. A modified roughness length parameterization reduces both ocean roughness and surface drag even at moderate wind speeds as well as hurricane winds. However, a modified parameterization scheme shows larger surface stress than original one because of stronger winds due to more intense cyclone (not shown).

3.2 *Coupling With Oceanic Model*

In order to further improve intensity prediction of tropical cyclones, simple ocean models, such as a layered reduced gravity model and a one-dimensional (1D) ocean model, have been developed to be coupled to the JMA global atmospheric model. A 1D ocean model is designed with relatively higher vertical resolution than the layered model. The oceanic vertical mixing is expressed by a simple eddy kinetic

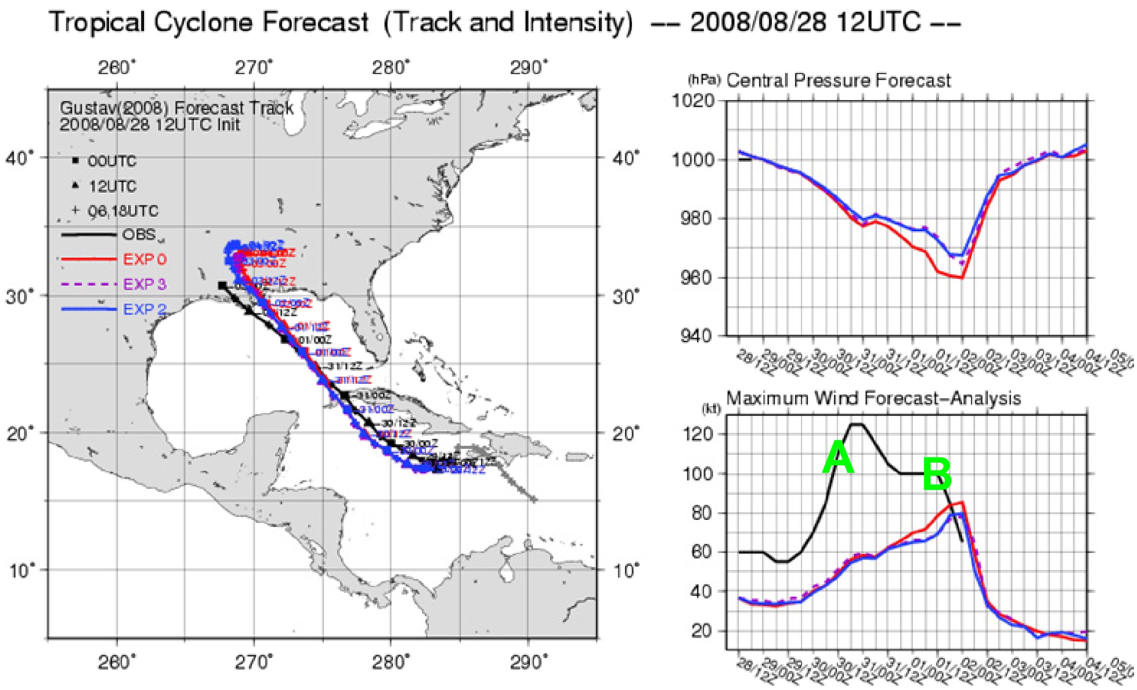

FIGURE 3. Same as Figure 2, except that numerical predictions using Exp2 (blue line) and Exp3 (purple dash line) models are shown instead of Exp1 model. Exp2 model uses same boundary layer parameterizations as Exp0 model and but coupled with the 1D ocean model. Exp3 model is also coupled to the ocean model with same boundary layer scheme as Exp1. The indications “A” and “B” correspond to typical development and weakening stages of the cyclone, respectively.

energy parameterization based on Gaspar et al. (1990). The parameterization scheme used includes a single prognostic equation for the turbulent kinetic energy. For some tropical cyclone cases, coupling with an oceanic mixed-layer model modifies a prediction of cyclone intensity through consuming heat energy of the ocean. It is also suggested that oceanic effects related to the heat content are dominative for cyclone intensity predictions rather than modifications in the surface drag.

In a development stage of the cyclone (for example, indicated as “A” in figure 3), the model coupled with the ocean (Exp2) simulates a similar change in cyclone intensity to that of the non-coupled model (Exp0). On the other hand, during a cyclone weakening stage (for example, indication “B”), the coupled model can predict an obvious suppression of cyclone development and fairly reduce enhancing intensities of the cyclone. The improvement may be due to proper evaluations of a consumption of ocean heat content (OHC) and changes in sea surface temperature (SST) by coupling with the oceanic model. While the model with the modified atmospheric boundary layer schemes (Exp1) brings an improvement on predicting cyclone developments, the coupled model (Exp2) shows a large modification of intensity predictions for the cyclone weakening stage.

Around the location “A”, ocean has large heat content (more than 150kJ/cm^2) depending both on relatively higher temperature of upper ocean and on deeper mixed layer structure (figure 4). Abundant OHC may effectively assist cyclone developments, and change in SST due to the passing cyclone is relatively small. On the contrary, developments of the cyclone are fairly alleviated around the location “B” where decrease in SST is significant due to less OHC (about 50kJ/cm^2, see figure 5).

A false re-development near the landfall may come from insufficient treatments in some parameterizations of the atmospheric model (cumulus convection, surface flux, etc.) and inaccurate predictions of OHC in the oceanic model.

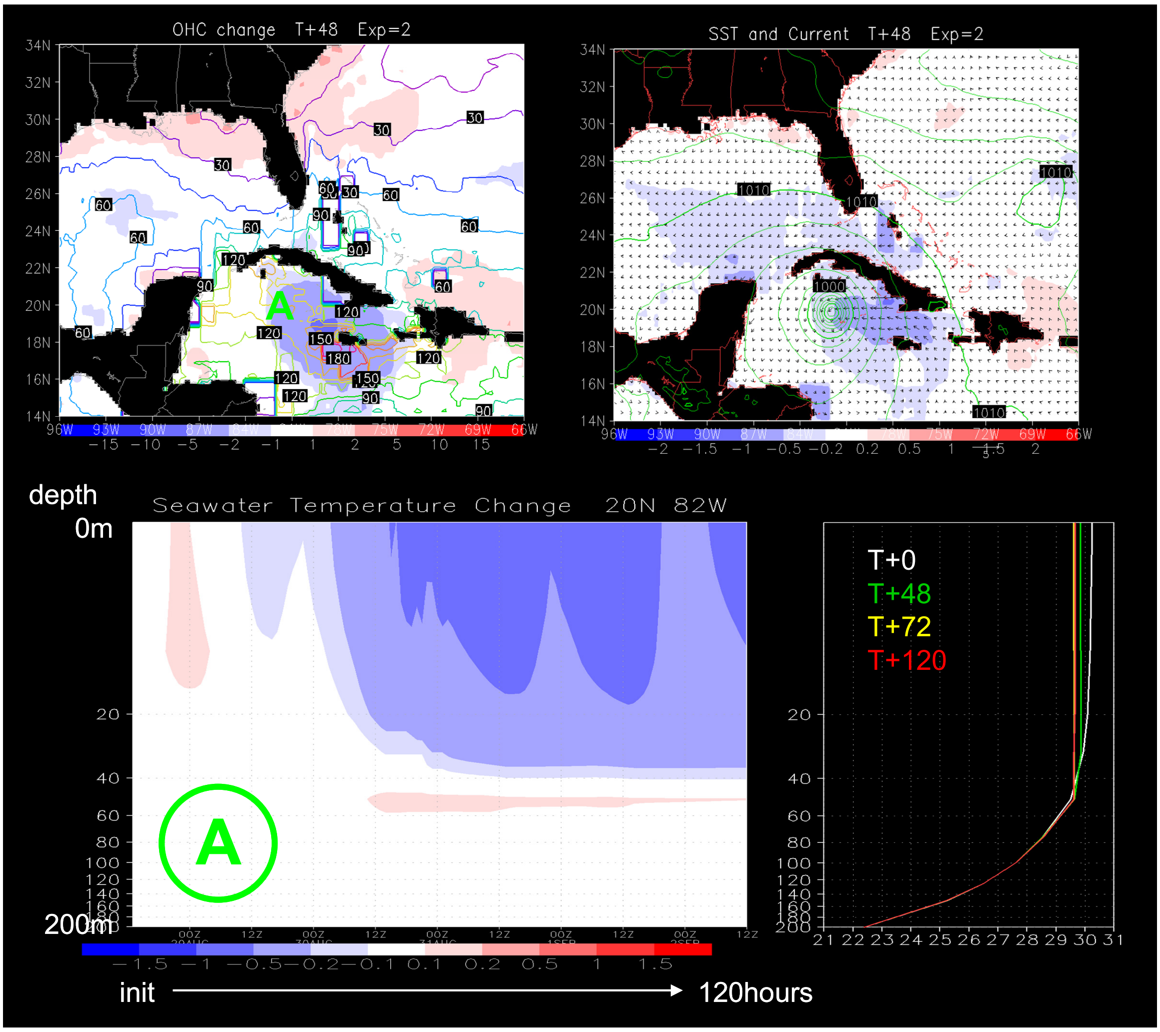

FIGURE 4. Impacts of coupling with the ocean model in the cyclone development stage. Upper left panel shows ocean heat content (contour, in kJ/cm^2) and its change from initial time to 48hours integration (by shaded). Upper right panel shows SST change (in degree C) from initial time to 48hours integration as shaded. Lower panels show changes in seawater temperature up to 200m depth (in degree C) at the location "A" indicated in the upper left panel.

4. CONCLUSIONS

Ocean is a primary energy source of tropical cyclones, and good parameterizations for air-sea interactions and ocean are essential to accurate simulations of tropical cyclone by numerical models. The revised atmospheric boundary layer scheme and parameterization for air-sea fluxes in JMA-GSM are examined on the simulation of tropical cyclones focusing on their intensities. Impacts of coupling with a 1D oceanic model are also studied.

The improved atmospheric boundary layer scheme, including a non-local turbulent mixing and a revised air-sea flux, brings a clear modification of tropical cyclone intensity for the case of hurricane Gustav (2008). On surface drag over ocean, introducing a modified sea surface roughness parameterization after Makin, the model simulates somewhat stronger surface winds, while its impact on the intensity is relatively small.

In order to further improve intensity prediction of tropical cyclones, simple ocean models have been developed to be coupled with JMA-GSM. For the Gustav (2008), a coupling with the oceanic model

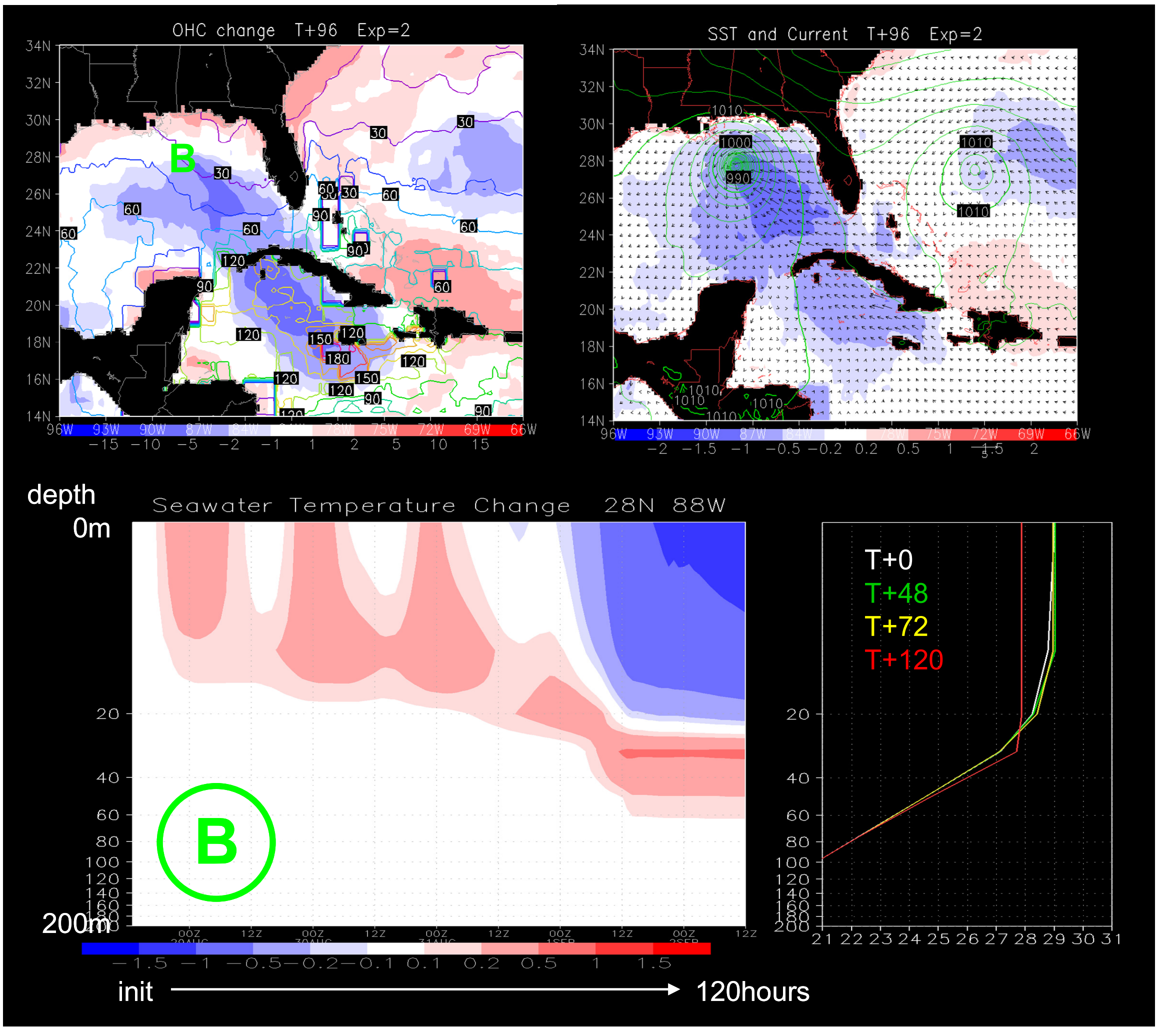

FIGURE 5. Same as figure 4, but for the cyclone weakening stage. Upper left shows OHC and its change up to 96hours integration, and upper right does SST change at 96hours later. Lower panels show changes in seawater temperature for the location "B".

modifies a prediction of cyclone intensity through consuming heat energy of ocean. It is suggested that oceanic effects of heat content are dominative for cyclone intensity predictions rather than modifications in the surface drag.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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