Development of an Atmosphere-wave coupled model

Nadao Kohno and Yuhei Takaya

Department of Atmosphere, Ocean, and Earth System Modeling Research
Meteorological Research Institute, Japan Meteorological Agency (JMA)
E-mail: nkohno@mri-jma.go.jp. nkono@met.kishou.go.jp

○ Introduction

It is expected that an atmosphere-wave coupled model can deal with detailed boundary process, such as momentum flux, although scientific mechanism is not yet well cleared to satisfactory level. Wave coupling became popular in high-resolution regional models especially for tropical cyclones, where extremely high waves may exist, but global atmosphere-wave coupled model is not so commonly used in National Meteorological/Hydrological services. Wave coupling is supposed to give large impact on high resolution models, especially for week-range and later forecasts, development of a global atmosphere-wave coupled system was started at JMA.

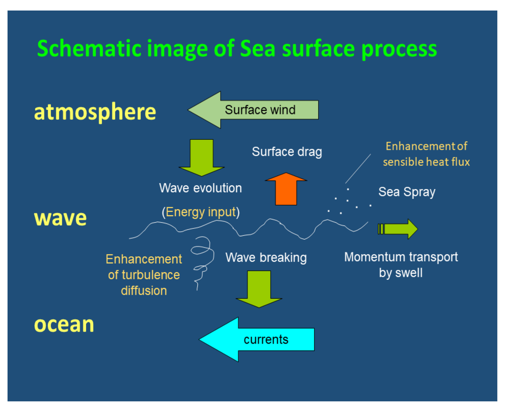


Figure 1 Schematic image of sea surface processes

○Model design

In the coupled system, the base model components are

- JMA Global Spectral Model (GSM) with resolution T319L100
- JMA wave model MRI-III with gird resolution of 0.5 degree.

The parameters are exchanged via coupler (S-CUP), which was developed at MRI. The way of coupling is typical two-way interaction same as Janssen and Viterbo (1996).

Parameters are exchanged every 30 minutes. Only the change of momentum flux by waves is considered, not heat flux.

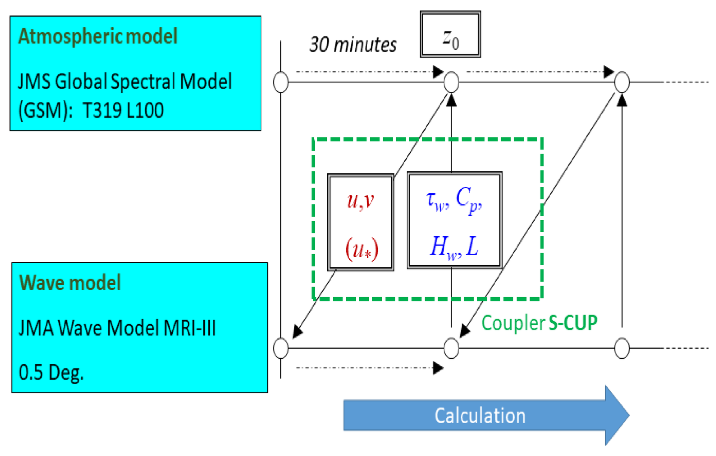


Figure 2 Coupling scheme

○Wave characteristics and impact to roughness

Before the coupling, it is necessary for evaluating the wave effects on momentum fluxes. However, the wave dependency on roughness is not yet satisfactorily cleared: there are many opinions on the relation and many formulae are proposed in its long research history.

Our aim is not discussing about the dependency process itself, but checking impact of coupling. Therefore, four typical dependency formulae, listed in Table 1, were selected for checking wave sensitivity of roughness (drag coefficient). Although there are so many formulae and coefficients, we first compare the basic qualitative characteristics among the three formulae, with Charnock's wind dependency.

Table 1 **The roughness formulae used in dependency check**

Charnock (1955) (no wave dependency)	$\frac{gz_0}{{u_*}^2} = \alpha\ (\alpha = 0.020, constant)$ (The constant is modified from 0.185, and is used in GSM.)
Janssen (1989) (wave induced stress)	$\frac{gz_0}{{u_*}^2} = 0.010\left(1-\frac{\tau_w}{\tau}\right)^{-1/2}, \tau = \rho_a {u_*}^2,\ \tau_w = \rho_w g \iint \frac{S_{in}}{c_p} df d\omega$
Smith et al. (1992) (wave age)	$\frac{gz_0}{{u_*}^2} = 0.48\left(\frac{u_*}{c_p}\right)$
Taylor and Yelland (2001) (wave steepness)	$\frac{z_0}{H_w} = 1200\left(\frac{H_w}{L}\right)^{4.5}$

z_0: roughness length, u_*: friction velocity, g: gravitational acceleration, ρ_a/ρ_w: density of air / water.
$H_w, L,$ and c_p are wave height, wave length and phase speed of waves, respectively.
Sin indicates energy input by wind..

Wave / wind condition and their impact on drag coefficients. (Case: 00UTC on 28 Dec 2012.)

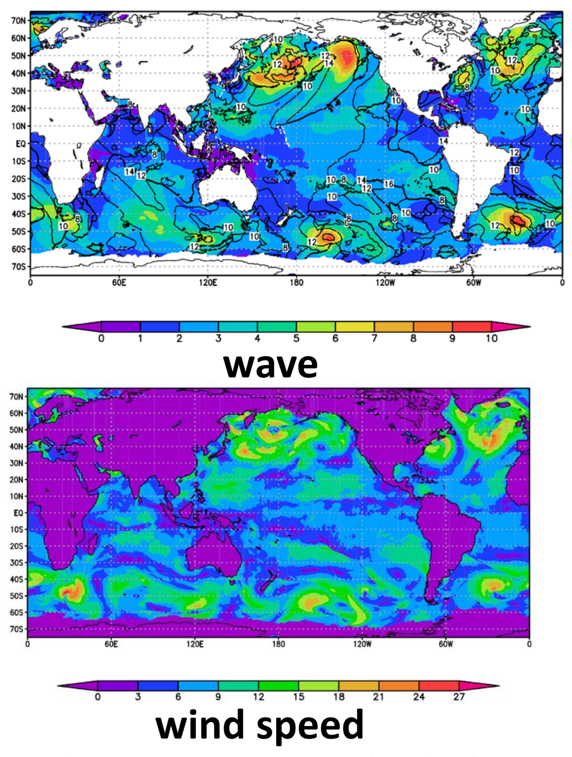


Figure 3 Wave and wind

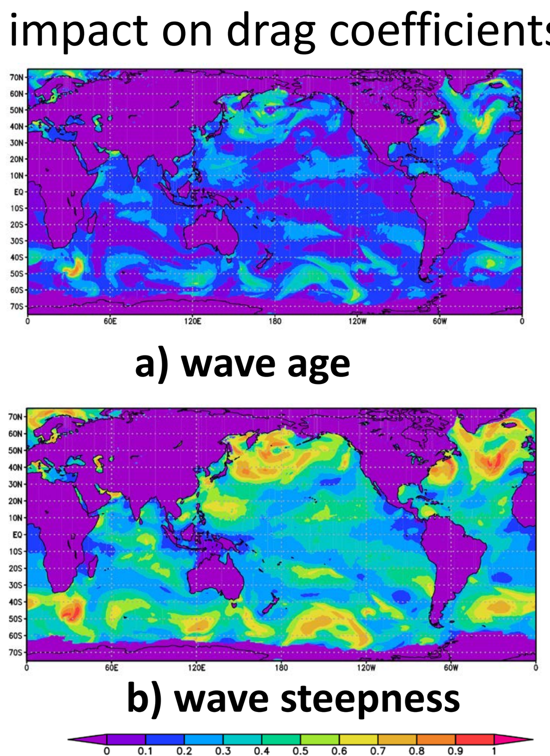


Figure 4 Normalized wave age and wave steepness.

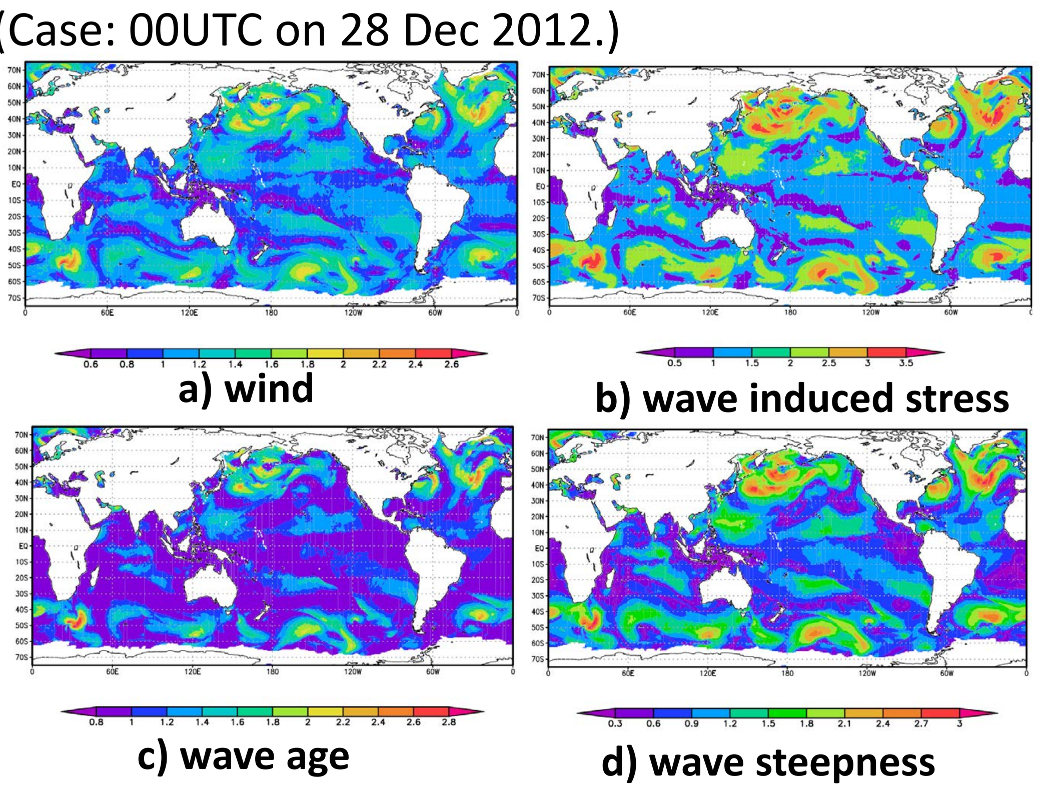
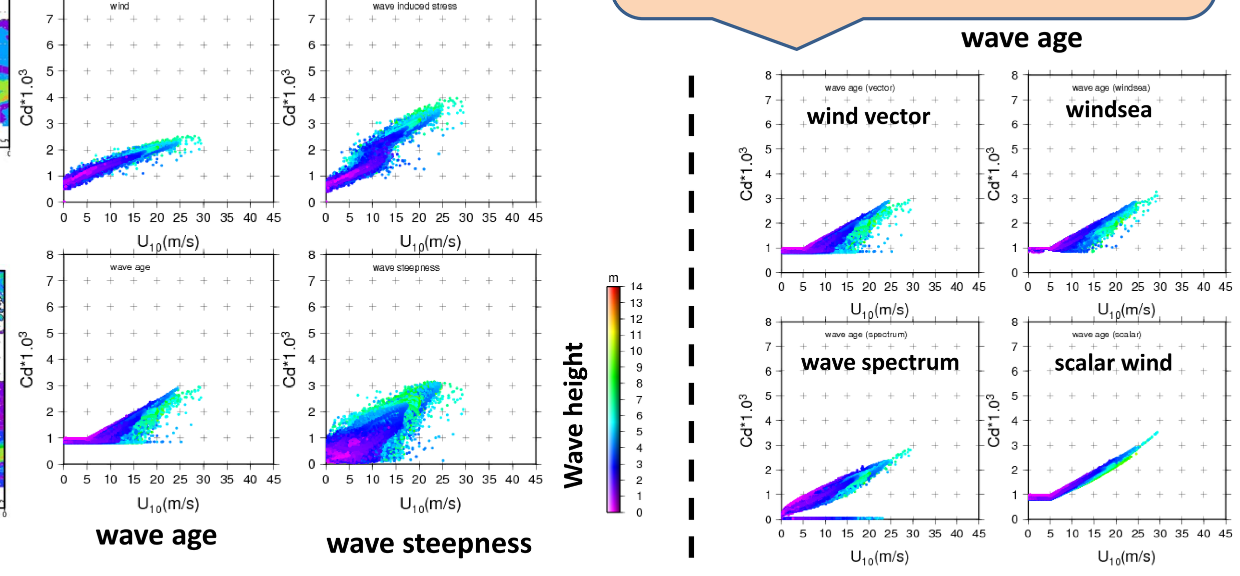


Figure 5 Calculated drag coefficients.

However, when parameters for calculation are changed, the scatter can be drastically different even in the same formula. Further performance check is necessary...



(scatter plot of drag coefficients)

○Coupling impact (Fast calculation result)

First calculation with coupled model with wave induced stress was conducted. The initial time is 00UTC on 6 July 2019.

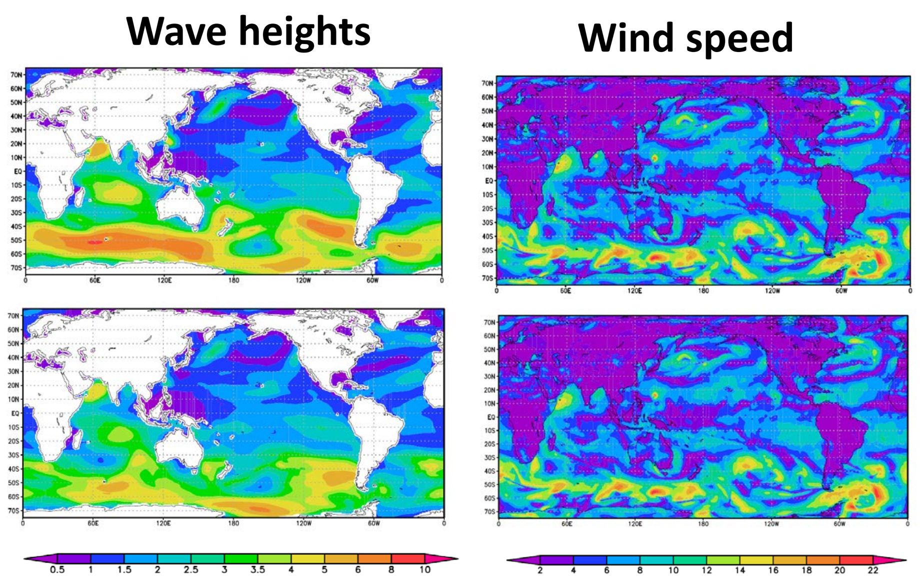


Figure 6 Five-day mean wave heights (left) and u10 (right)
The mean values were for 10-14 day forecasts.

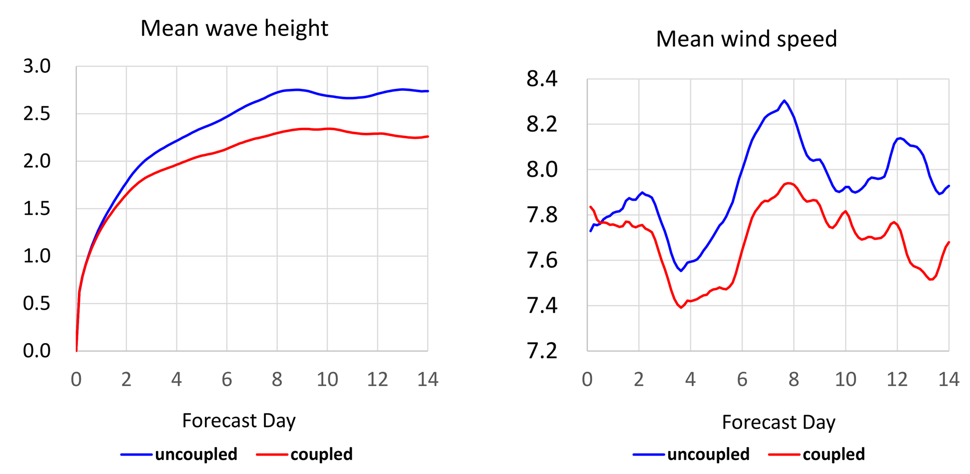


Figure 7 Change of global mean values in time day forecasts.

The current coupled model tends to underestimate strong winds and high waves.

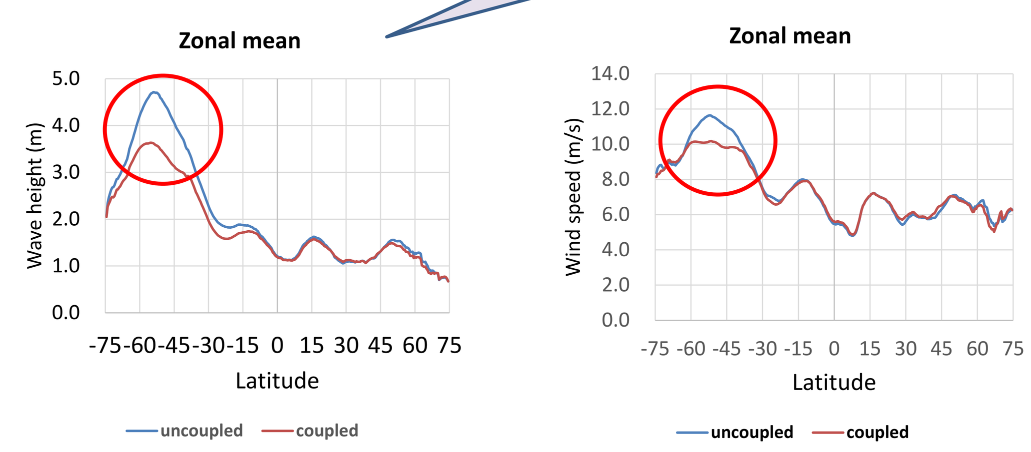


Figure 8 Zonal mean of wave and wind for two-week calculation

○ Conclusion

- ✓ We started developing a global atmosphere-wave coupled model, which will be used in operational at JMA.
- ✓ It seems that the basic characteristic of wave dependency is not so different among typical formula, although parameters used in the formulae are different. It turned out that, way of calculation may change the results drastically, even in the same formula. We may need to further investigate and modify the adequate way of roughness calculation.
- ✓ The first test calculation indicates apparent impact of wave coupling to JMA atmospheric model GSM. However, underestimation of wave was detected in high wave areas, some coefficients in the model should be modified. We are going to further improve the coupling process too.

References

Charnock, H., 1955: Wind stress on a water surface. *Quart.J.Roy.Meteorol. Soc.*, 81, 639-640.
Janssen, P. A. E. M., 1989: Wave-induced stress and the drag of air flow over sea waves. *J. Phys. Oceanogr.*, 19, 745-754.
Janssen. P.A.E.M. and P. Viterbo, 1995:. Ocean waves and the atmospheric climate. J. of Climate, 9, 1269 – 1287.
Smith, S. D., R. J. Anderson, W. A. Oost, C. Kraan, N. Maat, J. DeCosmo, K. B. Katsaros, K. L. Davidson, K. Bumke, L. Hasse, and H. M. Chadwick, 1992: Sea surface wind stress and drag coefficients: The HEXOS results. *Boundary-Layer Meteorol*., 60, 109-142.
Taylor, P. K. and M. J. Yelland, 2001: The dependence of sea surface roughness on the height and steepness of the waves. *J. Phys. Oceanogr*., 31, 572-590.