6.6 Ocean Wave Models

6.6.1 Introduction

The Japan Meteorological Agency (JMA) operates two models for ocean wave prediction. One is the global wave model (GWM) and the other is the coastal wave model (CWM). Both are so-called third-generation wave models. The current GWM has been in operations since 1 Mar. 2001. CWM has been in operations since 6 Mar. 2002.

6.6.2 Structure of the ocean wave models

Both GWM and CWM are composed of prognostic differential equations of wave spectra. The specifications of the ocean wave models are summarized in Table 6.6.1, and the geographic coverage of the models is shown in Fig. 6.6.1.

The physical processes of these models were originally developed in the Meteorological Research Institute, JMA, and called MRI-III. The models are classified into the third generation Discrete Interaction (DI) model.

The time evolution of ocean waves is governed by the energy balance equation.

$$\frac{\partial F}{\partial t} + C_{\mathrm{g}} \cdot \nabla F = S_{\mathrm{net}} = S_{\mathrm{in}} + S_{\mathrm{nl}} + S_{\mathrm{ds}} \qquad (6.6.1)$$

where $F(f, \theta; \boldsymbol{x}, t)$ is the two dimensional spectrum dependent on the frequency f and the wave direction θ, $C_{\mathrm{g}}(f)$ is the group velocity, and S_{net} is the net source function which consists of three terms; S_{in}, S_{nl}, and S_{ds}. The tree terms are explained by five energy transfer processes as follows:

(i) S_{in} : the energy input from wind,

(ii) S_{nl} : the nonlinear energy transfer by resonant interaction. Because the rigorous calculation requires too much computation time, a practical scheme (Hasselmann et al., 1985) is suggested, which allows us an approximate calculation by using only one specific combination of wave spectral components among a virtually infinite number of combinations. In this model, three combinations of spectrum are introduced.

(iii) S_{ds} : wave breaking, frictional (viscous) dissipation and the effects of opposing wind. The basic assumption of wave breaking is that water mass at a crest, which is proportional to the square of the wave height, loses its wave energy.

6.6.3 Wind field

Wind fields for GWM are given by GSM, and those for CWM are given by RSM and GSM. In addition, an empirical method to estimate wind field near a tropical cyclone (TC) (Fujita, 1952) is adopted. TCs are a major contributor to produce severe wave events in the western North Pacific. Accurate wave forecasts are crucial to prevent shipwreck and coastal disasters, especially when TCs are present . Since the performance of NWP models are not enough to represent the wind fields near a TC precisely in its path and strength, a bogus TC is created with the official forecast and implanted onto the numerical model prediction, whenever a TC exists in the western North Pacific.

In the bogus TC scheme, atmospheric pressure distribution near a TC is assumed to be described by Fujita's (1952) empirical formula

$$P(r) = P_{\infty} - \frac{P_{\infty} - P_0}{\sqrt{1 + (r/r_0)^2}}, \tag{6.6.2}$$

where P_{∞} , P_0 and r_0 denote the ambient pressure, the central pressure of the TC, and the scaling factor of the radial distribution of the pressure, respectively. Surface winds near the TC are estimated from the pressure field by assuming the gradient wind balance with modifications based on the TC movement and surface friction effects.

6.6.4 Initial condition

The initial conditions for the wave models are given by the 12-hour forecast initiated 12 hours before. Wind fields for the initial conditions are given by GSM and RSM initiated12 hours before with the latest version of a bogus TC.

6.6.5 Statistical correction of wave field

The models predict ocean waves fairy well in general. However, some statistical corrections are required to alleviate the bias/tendency of the wave models and of the atmospheric forcing. In JMA, the significant wave height and period which are calculated from the prediction of wave spectra are statistically corrected in the following way.

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a) GWM

GWM tends to predict lower wave heights and shorter wave periods in the case of high waves in the mid latitudes in winter. The bias is corrected for the significant wave height and period at each grid point in the north of 20°N.

$$H_c = 50\text{cm} \times (H\text{-}150\text{cm})/H \qquad (6.6.3)$$

$$P_c = 0.3\text{sec} \times \min[1,(H\text{-}150)/150] \qquad (6.6.4)$$

where H, Hc and Pc denote the significant wave height, bias of wave height and bias of wave period.

The bias is corrected when all following conditions are satisfied.

(i) (wave height): 150cm or higher

(ii) (geography): in the North Pacific (north of 20°N)

The correction of (6.6.3) is fully applied (correction rate is 100%) in the north of 30°N.

The correction rate varies in a transition zone between 20°N and 30°N and increases linearly northward from 0% of (6.6.3) at 20°N to 100% of (6.6.3) at 30°N.

$$H_c = 50\text{cm} \times (H\text{-}150\text{cm})/H \times \max[0,(\text{latitude-}20°)/10°] \qquad (6.6.5)$$

(iii) (period): in winter (from October to March)

b) CWM

Since the prediction errors of CWM vary in time and space, correction values are calculated from the errors of CWM predictions in the latest 20 days verified against analyses which are produced by modifying CWM predictions with the latest observation and the tendency of predicted wind field.

6.6.6 Examples of wave prediction

Fig. 6.6.2 is an example of the 24-hour wave prediction by GWM. The chart contains contours of significant wave heights, predominant wave direction and representative wave periods at selected grid points.

Fig. 6.6.3 is a chart of the 24-hour prediction wave fields by CWM, which also shows wind fields.

6.6.7 Improvement and development

A set of new versions of GWM and CWM will be put into operations in the spring of 2007 to replace the current version models.

Main improvements at this version-up are:

- Improvement of wave dissipation by introducing the swell dissipation term.
- Increase of spatial resolution: 1.25 → 0.5 degrees in longitude and latitude for GWM and 0.1 → 0.05 degrees for CWM .
- Increase of wave spectral resolution: 16 → 36 azimuthal directions.
- The models will run 4 times a day, while the current models run twice a day.

These improvements are expected to contribute to producing better predictions of ocean wave field, especially in coastal regions, mainly because of better representation of small-scale variability with higher resolutions both in space and wave spectrum.

References

Fujita, T., 1952: Pressure distribution within typhoon. *Geophysical Magazine*, **23**, 437–451.

Hasselmann, S., K. Hasselmann, J.H. Allender, and T.P. Barnett, 1985: Computations and parameterizations of the nonlinear energy transfer in a gravity-wave spectrum. Part II: Parameterizations of the nonlinear energy transfer for application in wave models. *J. Phys. Oceanogr.*, **15**, 1378–1391.

Table 6.6.1 Specification of the Ocean Wave Models at JMA

Wave model	Global Wave Model	Coastal Wave Model
Version	MRI-III	
Type of wave model	spectral model (Discrete Interaction model, third generation)	
Area	global 75°N~75°S 180°W~0°~180°E	coastal sea of Japan 55°N~15°N 115°E~155°E
Grid interval	1.25°	0.1°
Grid size	288×121	400×400
Time step	30 minutes (advection and source term)	5 minutes (advection and source term)
Calculated time (00UTC) (12UTC)	90 hours 216 hours	84 hours 84 hours
Spectral component	400 components 25 frequencies from 0.0375 to 0.3 Hz (logarithmically partitioned) 16 directions	
Initial condition	hindcast	
Boundary condition		Global Wave Model
Wind field	Global Spectral Model (GSM)	Regional Spectral Model (RSM) with the supplement of GSM
	Fujita's empirical formula and a corresponding gradient wind for a typhoon	

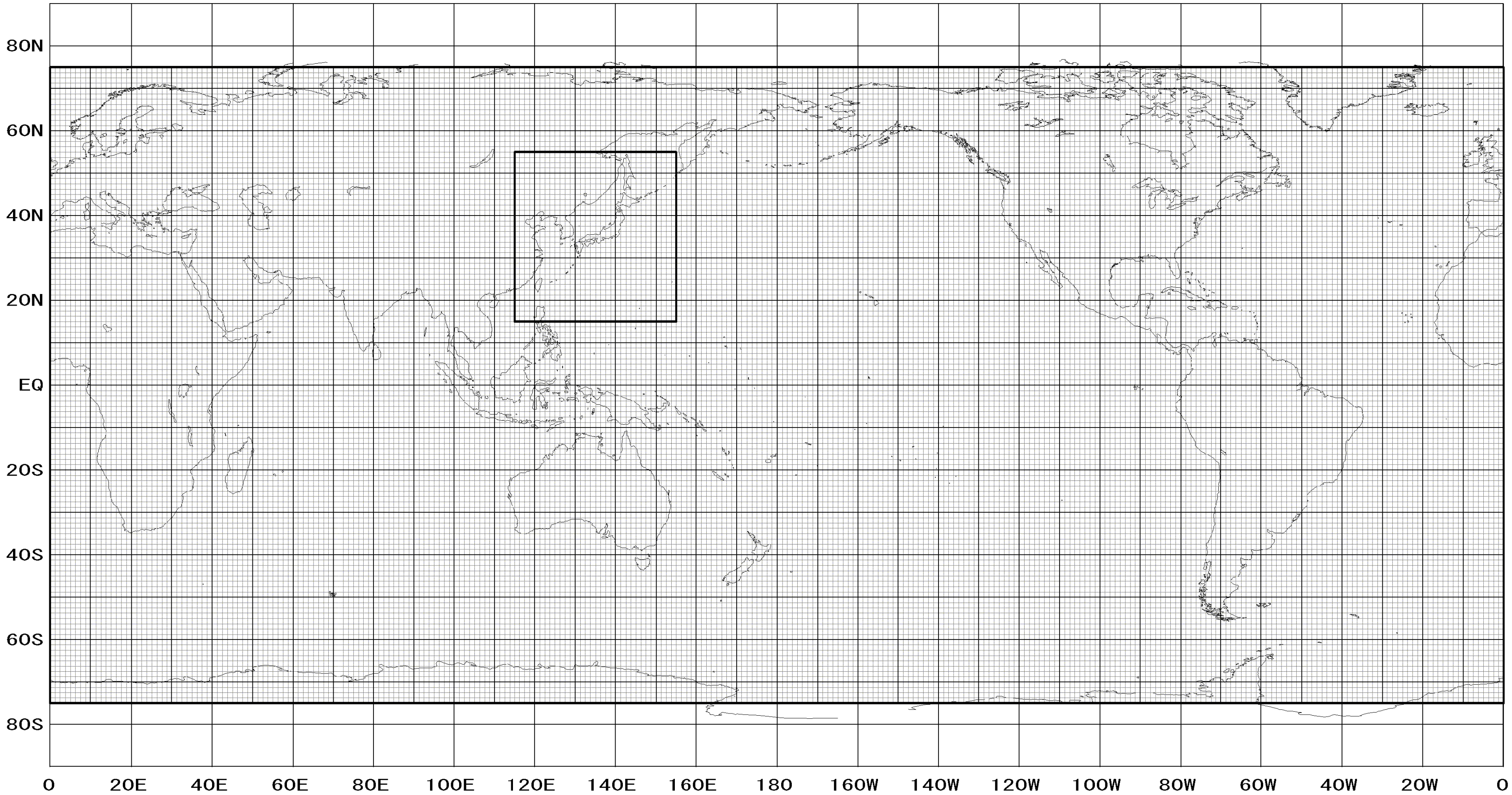

Fig. 6.6.1 The calculation area of the Global Wave Model (outer thick line) and the Coastal Wave Model (inner thick line).

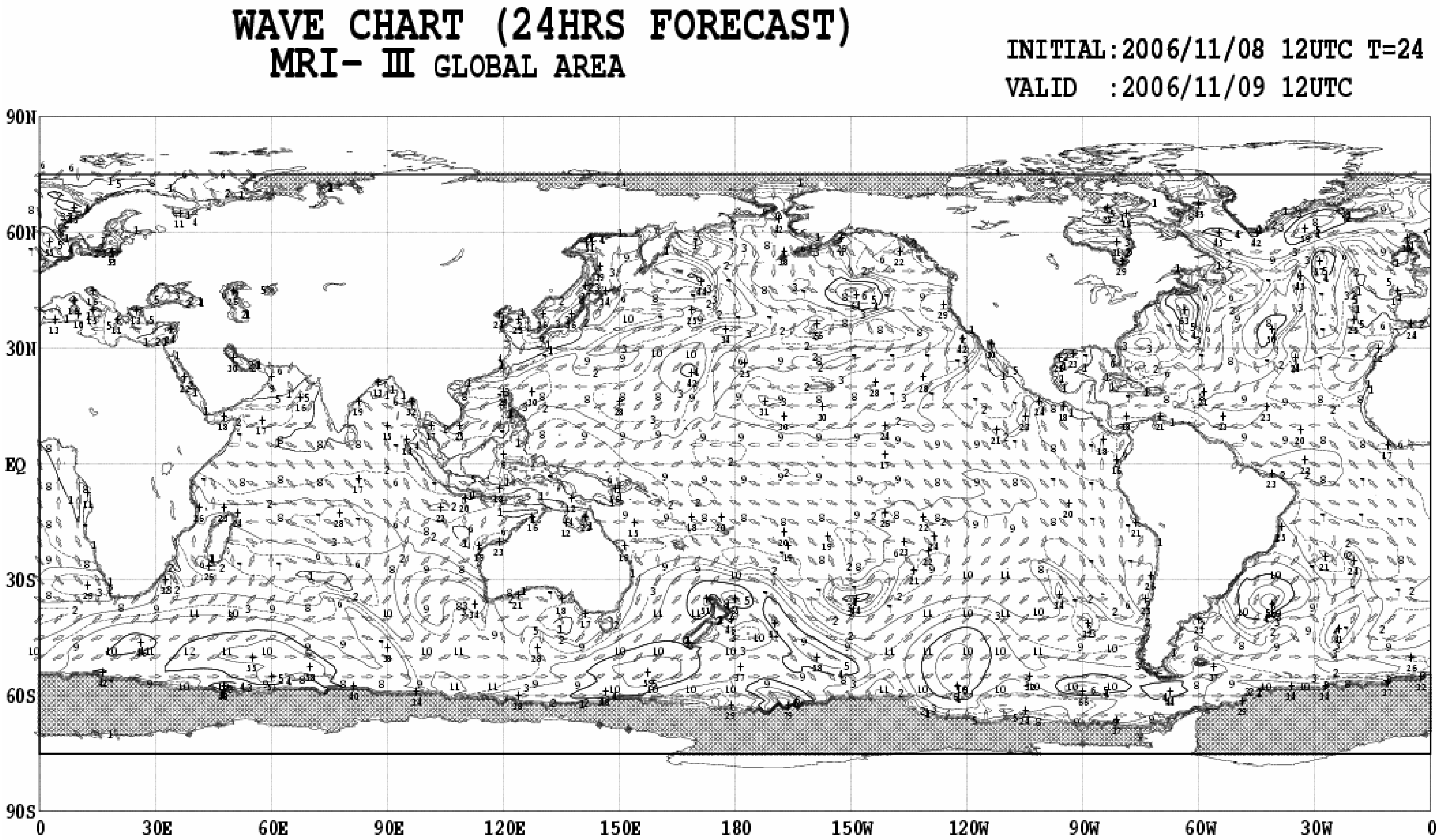

Fig. 6.6.2 An example of 24-hour prediction of ocean wave by the Global Wave Model for 8 Nov. 2006. Significant wave heights are contoured with dashed lines for half a meter, solid lines for every meter and thick solid lines for every 4 meters. Prevailing wave directions are represented by arrows with a representative wave period by a small numeral attached to the arrow for selected grid points. Local maximum wave heights are represented as numerals in 0.1m at the point of local maximum. Area of ice is shaded.

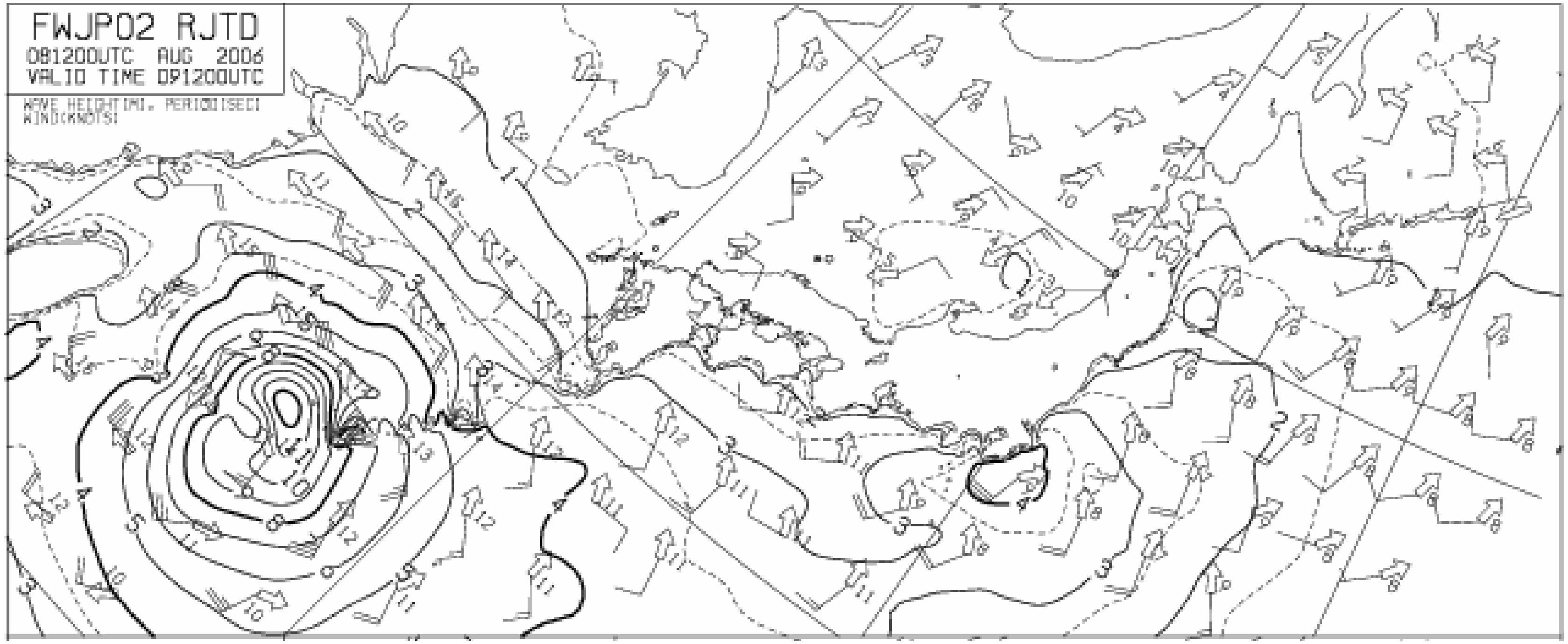

Fig. 6.6.3 An example of 24-hour prediction around Japan by the Coastal Wave Model for 8 Aug. 2006. Notations are the same as in Fig. 6.6.2 except that winds are also plotted.