The Improvement of JMA Operational Wave Models

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1. INTRODUCTION

Wave information is crucial for ships and vessels in oceans, and various activities around coasts. Japan Meteorological Agency (JMA) is responsible for disseminating wave information with the purpose of disaster prevention and mitigation, in addition to weather information. JMA operationally analyzes the wave condition in the North Western Pacific, by making wave charts, and forecasts or warnings are issued every day.

For the sake of these activities, JMA has been operating numerical wave models for ocean wave prediction since 1977. Historically, all of JMA wave models were developed at Meteorological Research Institute of JMA (MRI). The first generation wave model MRI(-I) had been in operational from 1977 to 1986, and it was replaced with the second generation (Coupled Discrete) model MRI-II. In 1998, the third generation wave model MRI-III (hereafter we refer to this model as MRI-III_1998) had been introduced in operation (JMA, 2002). MRI-III_1998 had a good correlation between wind and wave, however it had a clear bias in swell heights. In order to reduce this bias, a statistical correction technique was provisionally introduced to modify output products in 2003 (JMA, 2007).

The MRI-III was upgraded to a new version (Ueno and Kohno, 2004), and the new version showed definitely better performance than the previous one. The new model was put into operation on 30th of May 2007, which was a major revision in operational wave models of JMA in recent years.

In this paper, we give an outline of operational wave models at JMA in the next section. The operational wave models and their performance are described in section 3. We discuss about the remained problems in section 4, and end with conclusion.

2. OPERATIONAL WAVE MODELS AT JMA

JMA is responsible for providing marine meteorological information around the Northwestern Pacific in the framework of GMDSS (Global Marine Distress and Safety System). Many kinds of marine meteorological information such as analyses, forecasts, and warnings are provided for the safety and efficiency of shipping, fisheries and offshore activities. As for ocean wave information, JMA disseminates daily wave analyses / forecast charts, and issues warning in case of severe condition. JMA also operates two ocean wave models, and their results are not only used in operational analyses in JMA, but also provided for many public organizations and private companies.

JMA has been operating two wave models: One is Global Wave Model (GWM), and the other is Coastal Wave Model (CWM). These models are driven by the wind GPVs predicted by the operational weather models of JMA.

JMA operates various weather models as listed in Table 1. GWM uses the Global Spectral Model (GSM) wind only, while CWM uses Regional Spectral Model (RSM) and GSM since the forecasting time of CWM is longer than that of RSM. Moreover, the winds around typhoons are modified by the gradient winds derived from the empirical pressure profile of Fujita (1952).

Table 1. Major weather models operated at JMA.

Model	abbreviation	Resolution		Forcast hours (Initial time)	Analysis
		Horizontal	Vertical (Top)		
Global Spectral Model	GSM	0.5625deg. (TL319)	40 (0.4hPa)	90hours (00UTC) 216hours (12UTC)	4D-Var
Regional Spectral Model	RSM	20km	40 (10hPa)	51hours (00, 12UTC)	4D-Var
Meso Scale Model (Non-Hydrostatic Model)	MSM	5km	50 (21800m)	15hours (00, 06, 12, 18UTC) 33hours (03, 09, 15, 21UTC)	4D-Var
Typoon Model	TYM	24km	25 (17.5hPa)	84hours (00, 06, 12, 18UTC)	4D-Var

2.1 Global Wave model (GWM)

The GWM covers almost whole globe except polar regions and the results are used mainly for safety and efficient shipping in oceans. The results of GWM are provided for not only domestic meteorological services but also foreign meteorological services through the server of RSMC Tokyo-Typhoon Center. The RSMC Tokyo-Typhoon Center is one of the six Regional Specialized Meteorological Centers (RSMCs) in the framework of the World Weather Watch (WWW) Programme of the World Meteorological Organization (WMO), which is responsible for analysis, tracking and forecasting of tropical cyclones.

Table 2. the model specification of the Global Wave Model.

Name		new GWM	previous GWM
Area	north-south	75N-75S	
	east-west	0E-180-0.5W (periodic boundary)	0E-180-1.25W (periodic boundary)
Horizontal resolution		**0.5deg.**	1.25deg.
Number of grids		720 x 301	288 x 121
Time step	advection	**10 minutes**	30 minutes
	source term	30 minutes	30 minutes
Calculated hours (Initial time)		84 hours(00UTC) 216 hours(12UTC)	84 hours(00UTC) 216 hours(12UTC)
Spectral component		**900 components** (25 frequencies x **36 directions**)	400 components (25 frequencies x 16 directions)
Wind field		Global Spectral Model (GSM)	
		Fujita's empirical formula and corresponding gradient wind for a typhoon	

Since a long range prediction is required for shipping in oceans, the maximum forecasting time is 216 hours (12UTC initial), though other forecasting time is only up to 84 hours. JMA has been operating GWM twice a day but it is going to be changed to four times soon, with the change of GSM operation. The grid resolution of GWM becomes finer as 0.5 degrees from 1.25 degrees of the previous version. The increase of spatial resolution is expected to represent intensive wave characters.

The model specification of the new / previous GWM is summarized in Table 2.

2.2 Coastal Wave model (CWM)

The CWM covers around Japan Islands with high spatial resolution to represent wave conditions around Japan in detail. Japan consists of many islands and waves are much influenced by islands. Therefore the grid resolution is as fine as 0.05 degrees, which is also finer than 0.1 degrees of the previous model. In CWM, shallow water effect has not been included yet, since water depth around Japan is rather deep next to the coast in general, and the area where shallow water effect is predominant is quite limited. However we plan to introduce shallow water effect to CWM in a few years.

The model specification of the new / previous CWM is summarized in Table 3.

Table 3. the model specification of the Coastal Wave Mode.l

Name		new CWM	previous CWM
Area	north-south	50N-20N	55N-15N
	east-west	120E-150E	115E-155E
Horizontal resolution		**0.05deg.**	0.1deg.
Number of grids		601 x 601	400 x 400
Time step	advection	**1 minute**	5 minutes
	source term	**3 minutes**	5 minutes
Calculated hours		84 hours(00, 12UTC)	84 hours(00, 12UTC)
Spectral component		**900 components** (25 frequencies x **36 directions**)	400 components (25 frequencies x 16 directions)
Wind field		Regonal Spectal Model (RSM) with the supplement of GSM	
		Fujita's empirical formula and corresponding gradient wind for a typhoon	
Boundary		Global Wave Model (GWM)	

3. MODEL DESCPRIPTION

3.1 Model Numeric

The basic equation is the energy balance equation in deep water.

$$\frac{\partial F(f,\theta,\mathbf{x},t)}{\partial t} + C_g(f)\cdot\nabla F(f,\theta,\mathbf{x},t) = S_{in} + S_{nl} + S_{ds}$$

where $F(f, \theta; \mathbf{x}, t)$ is the two dimensional spectrum dependent on the frequency f and the wave direction θ, $C_g(f)$ is the group velocity, and the right terms are the source terms which express energy input from wind, nonlinear energy transfer and energy dissipation respectively.

The energy input S_{in} is expressed in a form of S_{in} =A+BF, where A shows a linear wave growth and BF shows an exponential growth. The linear term A is expressed as the formula of Cavaleri and Malanotte-Rizzoli (1981). The exponential term BF has a key role in wave growth. In new MRI-III, the formula type of Plant (1982) / Mitsuyasu and Honda (1982) is adopted, which is the same as the MRI-III_1998.

The integration time steps of operational models are not short enough for adequate wave evolution, especially in their early stages. In order to get sufficient wave growth, the wave spectrum is compared with the JONSWAP spectra of 5.0 m/s wind of surface wind direction, and the larger one is used as the initial wave spectrum in every step.

In MRI-III, the Extended-DIA (EDIA) scheme is used in nonlinear energy transfer term S_{nl}. This is a modification of DIA scheme (Hasselmann et al, 1985). The EDIA scheme uses the three configurations of the resonant four waves. The EDIA scheme has good accuracy in calculating nonlinear energy transfer, and gives the similar profile to the exact one. The scheme itself is the same as in the old models but coefficients in the new model have been slightly changed in order to calculate accurate S_{nl} values for the JONSWAP spectrum.

The energy dissipation term is expressed by the formula, obtained by Ueno (1998), based on the laboratory experiments and dimensional analysis.

Besides this expression, empirical swell dissipation term is also introduced in new MRI-III in order to modify over estimation of swell. This empirical term is applied to the spectrum where frequency is smaller than the half of peak frequency determined from the wind speed. Swell is supposed to decrease its energy to 71% per day.

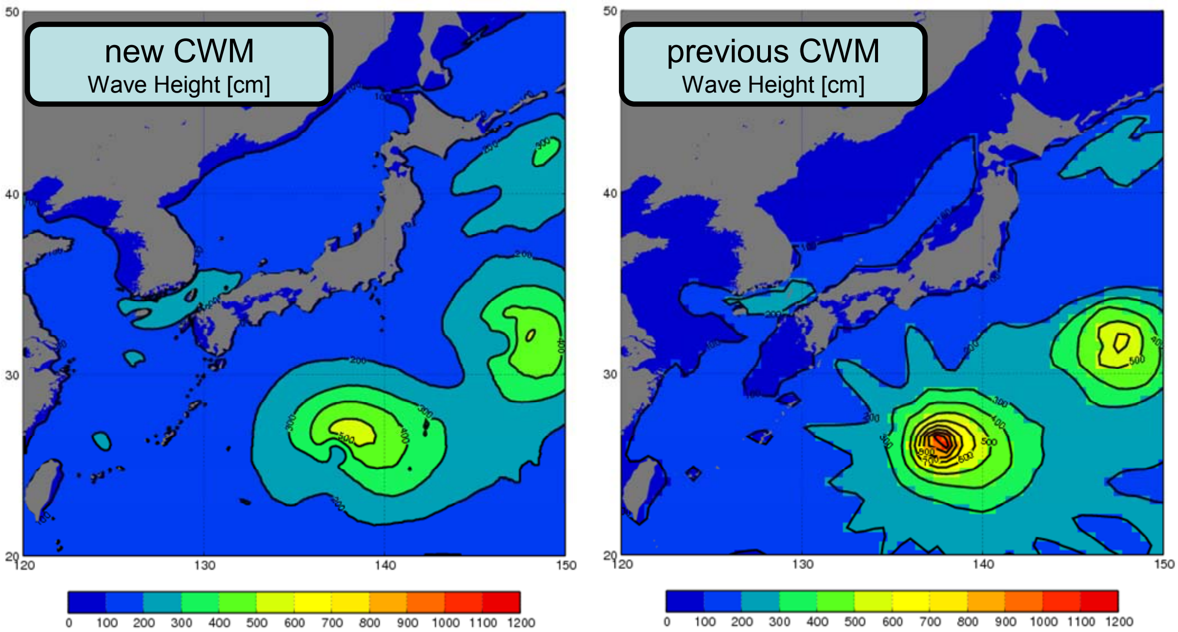


Figure 1. An example of swell from a typhoon calculated by CWM.

There are other changes in models. The directional component of wave spectrum became fine as 36 directions, which can express isotropic and smooth spreading than the previous model (which has 16 directions). Figure 1 shows an example of swell calculated by CWM. The previous CWM calculated un-isotropic spreading of swell, but new CWM is able to calculate reasonable spreading, which comes from the increase of directional resolution.

About the new MRI-III in detail has already been presented at the 8th Wave Workshop (Ueno and Kohno, 2004).

3.2 Performance

We made a comparison between the results of new MRI-III and MRI-III_1998, from March 2007 to the end of May 2007. The models were executed cyclically every 12 hours.

Table 4 shows the statistical results of wave height in March 2007. This is a comparison between GWM 12 hours forecast and JASON-1 radar altimeter. The satellite data, whose observing time was within one hour difference from the model valid time, were used for comparison. The data near to land grids were excluded. Data distribution is shown in Figure 2.

The bias is reduced especially in Southern Hemisphere, and result of the root mean square error (RMSE) shows neutral or slightly improved.

new GWM			
Region	data num.	bias [m]	RMSE [m]
Global	25637	−0.130	0.750
N.H.(75−20N)	6328	−0.408	0.786
Tropics(20N−20S)	6458	−0.212	0.401
S.H. (75−20S)	12851	−0.044	0.857

previous GWM (MRI−III_1998)			
Region	data num.	bias [m]	RMSE [m]
Global	25557	−0.463	0.777
N.H.(75−20N)	6093	−0.468	0.787
Tropics(20N−20S)	6414	−0.082	0.408
S.H. (75−20S)	13050	−0.647	0.901

Table 4. Statistics of 12 hours forecast wave height errors against JAOSN-1 radar altimeter in March 2007.

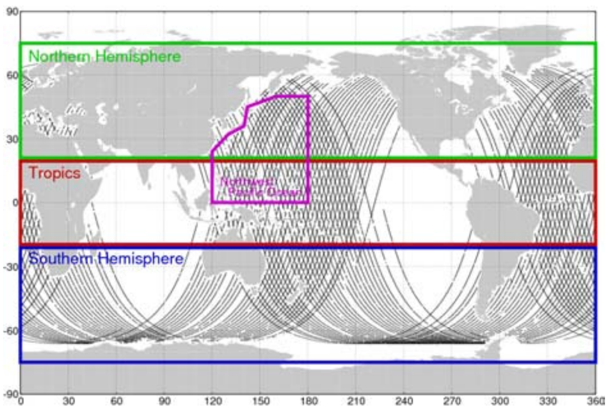


Figure 2. Data distribution of JASON-1 match-up data set in March 2007.

Figure 3 shows the scatter plot of wave height between JASON-1 radar altimeter and GWM 12 hours forecasts, in the Northwestern Pacific (0-75N, 100E-180E-140W; surrounded by purple lines) during March 2007. This shows remarkable improvement in the model – satellite correlation: In the new model, strong linear relation definitely appeared and under estimation of high waves in the previous model has been clearly removed.

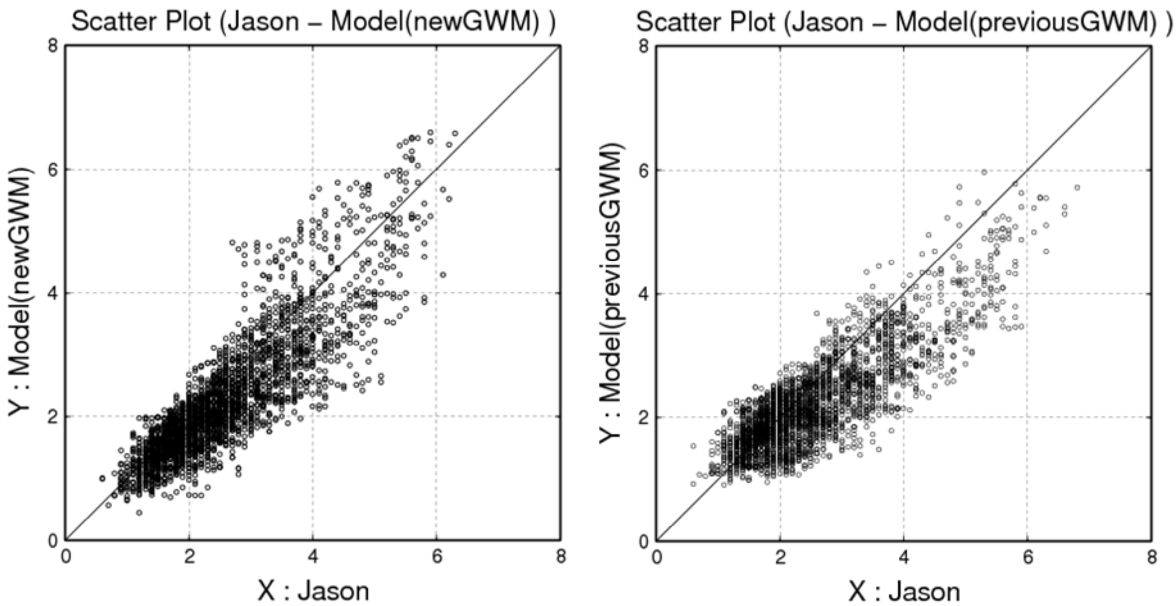
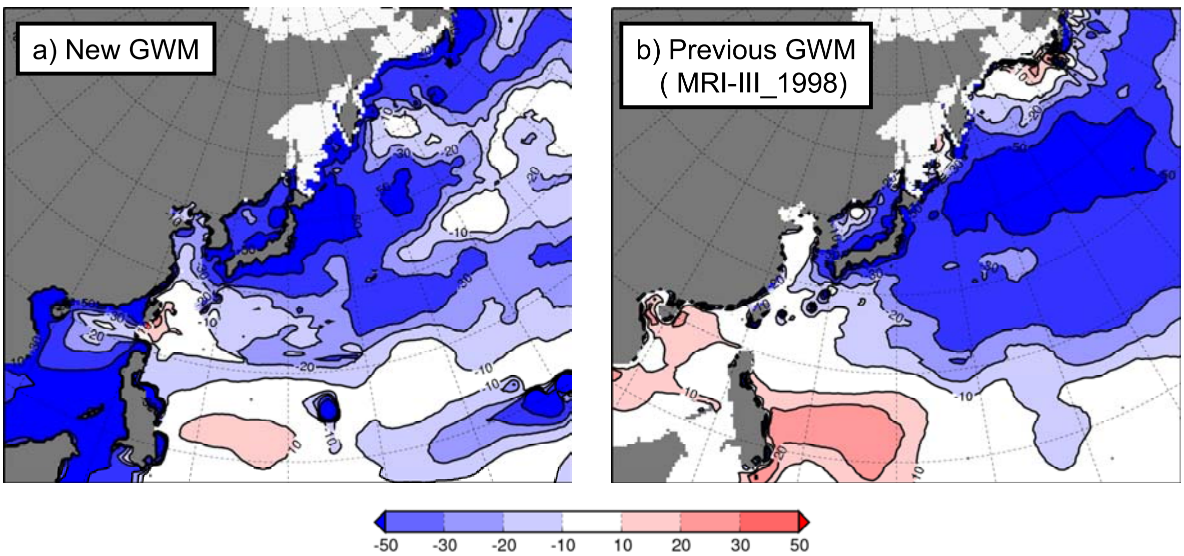


Figure 3. Scatter plots of wave height between JASON-1 radar altimeter and 12 hours forecast by new GWM (left) and the previous GWM (right).

Figure 4 shows the difference of wave height between manual analysis and 12 hours forecast of each model at the Northwestern Pacific in March 2007. The result shows that under estimation of swell was obviously improved at open ocean.

On the other hand, negative bias became increase around Japan. This may come from insufficient adjustment about initial wave evolution.



a) b)

Figure 4. Bias distribution of a) new GWM and b) previous GWM (MRI-III_1998) at the Northwest Pacific Ocean in March 2007. Value indicates the difference of average wave height [cm] between manual analysis and 12 hours forecast.

One of the typical high waves to Japan is the high waves against Japan Sea coast by winter monsoons. A hindcast experiment of this case was carried out in order to check the performance of CWM especially in coastal areas.

Figure 5 shows time sequence of wave height at Sakata which located in the downstream of waves generated by the winter monsoon. The new CWM showed better correspondence with observations, especially in their peak events, though improvement is not so remarkable. However, further adjustment seems to be necessary for simulating peak values of wave height adequately. This problem may be connected with the detailed expression of wind fields, and thus we have a plan to modify wind field for wave calculation.

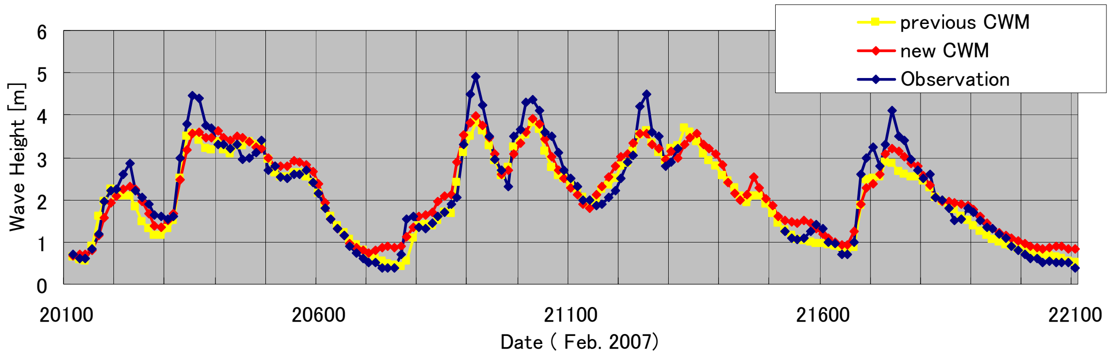


Figure 5. Comparison of wave height between model results and observations of wave recorder at Sakata.

4. DISCUSSION

Although MRI-III has better ability than MRI-III_1998 and the performances of operational models have been much improved, a few problems have been detected through the operational use.

One is over estimation of wave heights which has long fetch and duration, especially when wind speed is rather moderate. Figure 6 shows an example of the over estimation. There was high wave area in the Sea around Aleutian Islands. Figure 7 shows the time sequence of observation at Buoy 46036 which is located at the downstream. The observed wind speeds were around 10m/s and not so large, while the calculated wind speeds were comparable though these were slightly larger and over estimation is apparent in later days. However calculated wave heights were 6-7m, which were much lager than the observed heights (5m or so). It is also notable that the calculated wave heights gradually became large, though wave period seems to be favorably compared. This may indicate that further adjustment of balance between S_{in} and S_{ds} is necessary.

JMA has a plan to replace the GSM in this November, which means that adjustments of wave model coefficients to the new GSM should be required. As a matter of fact, we have not sufficiently optimized the coefficients to atmospheric models yet, and thus optimization may contribute to solve this problem in a certain level.

The other problem is weak wave evolution in early stage. We expect that this problem will be also cleared by adjusting the model coefficients in some degree. We also have a plan to introduce data assimilation in our model cycle, which is expected as an effective way for getting proper wave evolution in early stage.

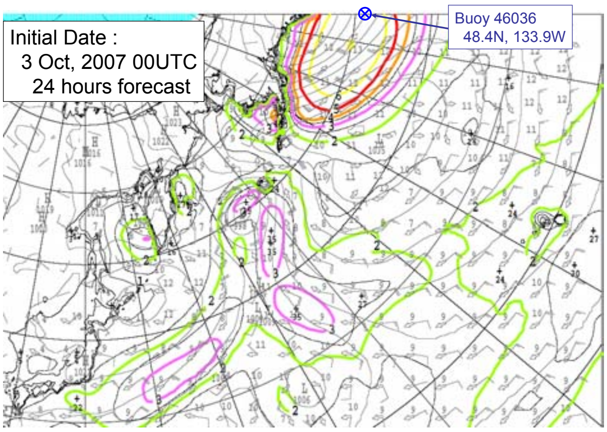


Figure 6 (Upper). An example of over estimation (4th Oct 2007). Colored lines show wave height of 24 hours forecast. The location of Buoy 46036 is also shown.

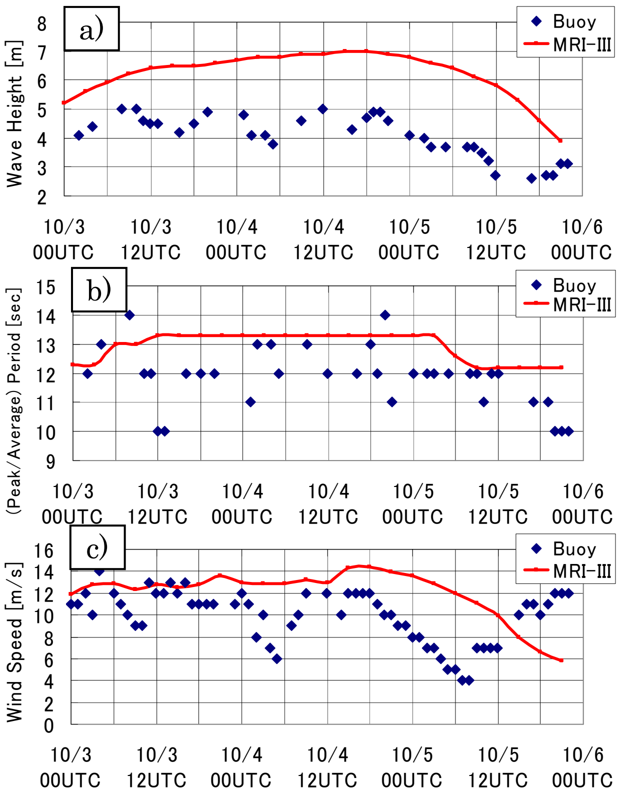


Figure 7 (Right). Time sequence of a) wave height [m], b) peak/average period [s] and c) wind speed [m/s] at the point of Buoy 46036. The dots show the observed values, and lines are the predicted values by the GWM.

5. CONCLUSION

The new version of MRI-III has been introduced in operation since the end of May 2007. It shows better performance especially for swell estimation. This upgrade could contribute to provide more accurate wave information

Though the new model shows good correspondence with observations in most cases, a few issues were found by investigations of operational use. One of the problems is the over estimation of wave height in some cases. Further research to detect the best balance of each source term is also considered.

We have also a plan to introduce data assimilation to wave models, which may also improve the model accuracy.

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