

THE IMPROVEMENT OF JMA OPERATIONAL WAVE FORECASTING SYSTEM

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1. INTRODUCTION

The Japan Meteorological Agency (JMA) issues marine information including ocean wave condition. The wave information is important for the safety of voyaging vessels or fishing boats, as well as disaster prevention for coastal residents, mitigation and so on.

JMA is responsible for the North Pacific region (0 to 60N in latitude and 100 to 180E in longitude), and wave analysis charts for 00UTC (AWPN) and 24-hours wave forecast charts (FWPN) shown as Fig. 1 are produced. Wave charts (AWJP and FWJP) are also produced to provide detailed wave condition for the seas around Japan. The wave charts are disseminated once a day via radio facsimile for voyaging vessels, and also available in the JMA web site[†].

These wave charts are manually made by the JMA staffs, based on wave model prediction and referring to observations and weather conditions etc. In order to analyze wave condition automatically, an objective analyses system for wave heights has been developed. This system uses optimum interpolation (OI) scheme, and rectifies wave fields using observed data, and is going to be put in operation in this December.

JMA has been operating numerical wave models since 1977. The current wave models are the third generation wave model MRI-III, which was originally developed in Meteorological Research Institute of JMA (Ueno and Kohno, 2004), and was

put into operation on May 30th, 2007 (Tauchi et al., 2007).

JMA now operates two wave models (global wave model; GWM and coastal wave model; CWM) as listed in table 1. The JMA operational wave model was slightly modified and optimized to the JMA global weather model (GSM). They have been used in operation since July 3rd 2008, and they give good predictions.

JMA are also quasi-operating the Shallow-water Wave Model (SWM) for several bays in Japan.

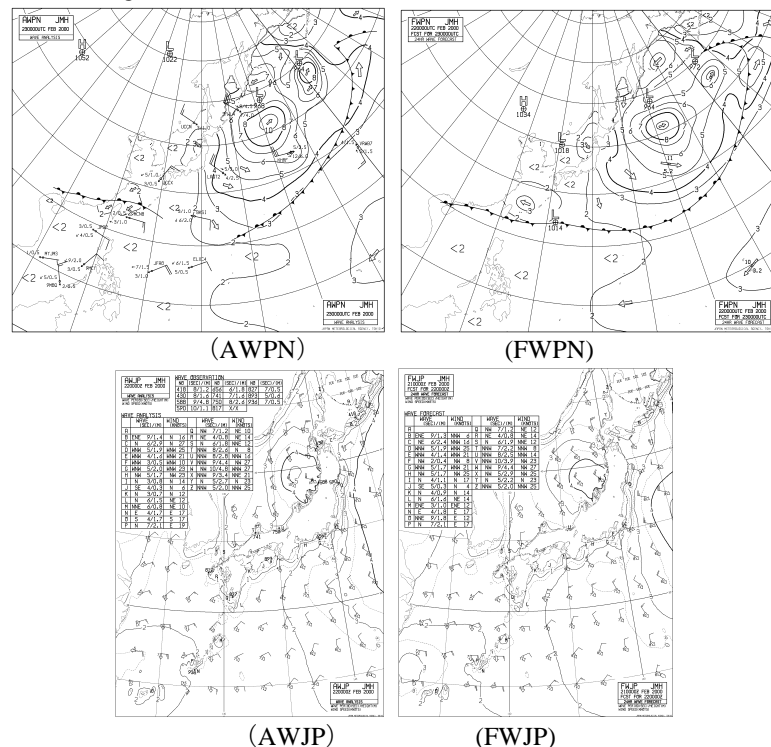


Fig. 1 Examples of ocean wave charts of JMA.

This model has high resolution of 1minute and power to simulate the detailed wave conditions. This model was developed in the National Institute for Land and Infrastructure Management, as a cooperative work between JMA and the River Bureau of Ministry of

[†] http://www.data.kishou.go.jp/kaiyou/db/wave/chart/awpn_e.html (AWPN).

Table 1. The outline of JMA operational wave model.

	Global Wave Model (GWM)	Coastal Wave Model (CWM)
Model type	MRI-III (Third generation wave model)	
Domain	global area 75°S~75°N 180°W~0°~180°E (cyclic)	sea around japan 20°N~50°N 120°E~150°E
grids	720×301	601×601
grid interval	0.5° × 0.5°	0.05° × 0.05°
wave spectrum components	900 components (25 in frequency × 36 in direction) frequency : 0.0375~0.3Hz ; logarithmically divided direction : 10 degree interval	
forcing	Global Spectral Model GSM (20km grid) winds within typhoons are modified by ideal gradient winds (~ 72 hours)	
forecast time (12UTC) (00/06/18UTC)	216 hours 84 hours	216 hours 84 hours

	Shallow-water Wave Model (SWM)			
Model type	WAM base (Third generation wave model)			
Domain	Tokyo Bay 35.05°N~35.75°N 139.55°E~ 140.15°E	Ise Bay 34.35°N~35.05°N 136.45°E~ 137.45°E	Harima-Nada Osaka Bay 34.05°N~34.85°N 134.15°E~ 135.45°E	Ariake Sea 32.45°N~33.25°N 130.05°E~ 130.75°E
grids	37×43	61×43	79×49	43×49
grid interval	1' × 1'			
wave spectrum components	1260 components (35 in frequency × 36 in direction) frequency : : 0.0418~1.1Hz ; logarithmically divided direction : 10 degree interval			
forcing	Mesoscale Model MSM (5km grid) winds within typhoons are modified by ideal gradient winds			
forecast time (03/09/15/21UTC)	33 hours			

Land, Infrastructure, Transportation, and Tourism (MILT). The main purpose is to provide the wave run-up height information to the river control managers of MILT.

Although the JMA wave model has a good accuracy in general, there are some problems: one is the late development of windseas, which is often the case when a polar low rapidly grows in winter. Other one is the overestimation of matured waves, which occurs in the area of weak and steady winds (especially around the sub-tropical high).

In order to deal with these problems, a wave model assimilation scheme has been developed as well as a modification of the wave model. In the assimilation scheme, wave spectra are modified by the analyzed wave heights. The results showed the

wave fields were favorably modified in early forecasting time but were not significant later.

In this paper, the outline of the JMA Objective Wave Analyses System (OWAS) and an assimilation system under development are introduced in the next section. In section 3, the performances of these systems are described. The further developing plans of JMA operational wave system are briefly described in section 4.

2. NUMERICAL METHODS

2.1 Outline of the JMA Objective Wave Analyses System (OWAS)

The JMA OWAS corrects the wave model

GPVs by the observed data with the optimum interpolation (OI) scheme. The analyses are carried out in the almost whole global domain (75N – 75S in latitude and whole area in longitude), with the grid resolution of 0.5 degree.

The OWAS uses various data: significant wave heights measured by the radar altimeter of orbital satellites, in situ wave data such as moored / drifting buoys, coastal wave recorders, and wave reports by ships.

The buoy data are supposed to be the most accurate observation, but the number is limited. If the number of observation or density and average quality are considered, the most useful data will be provided by satellites. However, these data are only measured in lines, and there are some regions where observed data are not available in an analysis time. Moreover, data sometimes become entirely unavailable in JMA.

In order to compensate this problem, ship observations are also used in the OWAS. However, wave conditions are usually visually observed and wave heights are reported in 0.5m. There is some fears in the accuracy of the observed wave values. Therefore, previous to analysis, ship data are compared with the model wave heights (that is, first guess), and only the data whose wave heights are within $\pm 1.5\text{m}$ are used in analyses.

The observed data are converted to virtual observation GPVs with 0.25 degree grid resolution (what we call ‘super observation’), since original wave observations are not homogeneously distributed.

From the innovation, the first guesses are corrected, considering of distances and error variances etc. In the OWAS, the observed data are referred if the distance is smaller than the criterion which is 2500km in the equator and becomes small as a cosine function of latitude. The error variance is assumed as a Gaussian which has the e-folding distance of 1650km. All observations within 3hours from the analyzing time are referred in the OWAS. However, in the real time use, the observations after the valid time are not available and only the data previous to the analysis time are actually used.

The analyses are carried out every 6 hours, that is, 4-times a day. However, in the seas around Japan, satellite data are not available in 06 and 18UTC and we have a fear in accuracy. Therefore, only the analysis results at 00 and 12UTC are going to be opened to public in the starting time of operational use.

2.2 The Assimilation scheme

A development of a wave data assimilation system is now ongoing in JMA. It makes use of the OWAS results. Actually, this development has just

started since this April, and only impact tests were carried out with a prototype.

According to the result of the inter-comparison of global wave models in the framework of JCOMM, the accuracy of wave conditions at initial (KT = 00) by the JMA model is not good. The main reason may be because wave observations are not considered in the JMA operational wave models. Actually, the problem seems to come from also the inaccuracy of surface winds of the numerical weather model (GSM).

In order to improve the accuracy at initial wave condition, the development of an assimilation system is necessary. In the data assimilation system under development, the results of the OWAS are used. The wave spectra are rectified according to the difference between the model wave heights and the analyzed ones.

The current system is a prototype, and all spectral components are simply corrected with the ratio of wave height differences. This is of course a very rough treatment. The advanced scheme, which can modify the individual spectral components of windsea and swell, are now under experiments.

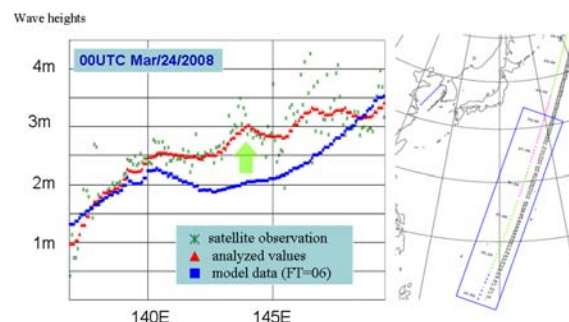


Fig. 2 An example of wave heights corrected by OI scheme.

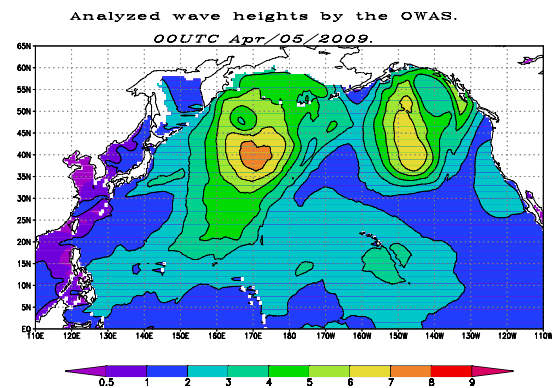
The right map shows the path of Jason-1.

3. RESULTS

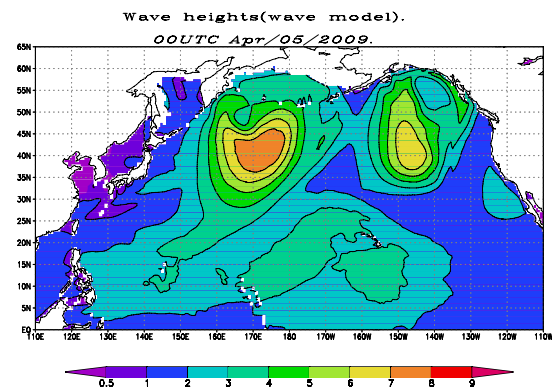
3.1 The Results of the OWAS

The performances of the Objective Wave Analyses System (OWAS) are introduced in this section. Figure 2 shows an example of corrections of wave heights by the OI scheme, based on the observations of the orbital satellite Jason-1. The satellite passed the sea south of Japan around 22UTC on March 23rd 2008, and observed higher wave heights than the model predictions (first guess) from 140E to 149E along the path. There are wave peaks over 3m in 144E (indicated by the arrow), which were not fairly predicted in the

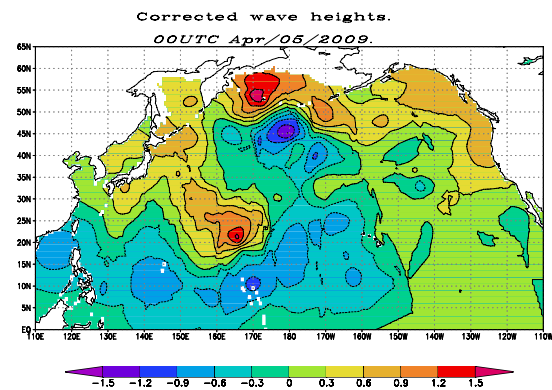
wave model although slight tendency is detectable.



(a) analysis



(b) first guess (model product)



(c) the corrected values

Fig. 3 An example of the result of the OWAS.

The wave model predicted wave heights of 2m which was 1m lower than the observed values. However, wave heights were satisfactorily corrected by the OWAS and their tendency becomes similar to the observation. Therefore, The

OWAS has good ability to rectify the wave heights predicted by wave model.

Next, an example of the actual product at 00UTC on April 5th 2009 by the OWAS is shown in Fig. 3. In Fig. 3 the model product at the same valid time and the corrected values in objective analysis are also shown.

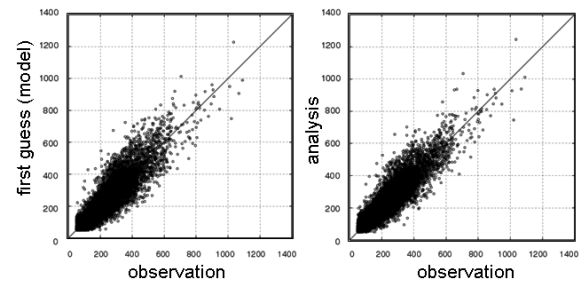


Fig. 4 The scatter plots of wave heights
The observed values are satellites data which were not used in the OWAS.

Table 2 statistical results

	First guess (model)	Analyses (OWAS)
number of data	25513	26165
RMSE(m)	0.47675	0.41638
bias(m)	0.02758	0.05446
correlation	0.897	0.920

In this period, a low pressure system was developing in the Pacific and moving eastward from April 2nd to 4th. The Northwestern Pacific was covered by high waves. The swell is rectified to have larger wave height by the OWAS. In the area around 20N, 170E, about 1.5m wave heights are added to the model products. On the contrary, in the subtropical area wave heights are decreased in general. This decrease is likely to be due to the wrong tendency of the wave model to overestimate the mature swell, and thus, the correction seems to be reasonable.

There is also large correction in the sea around 50N, 170E. The corrected values have a dipole type distribution. This indicates that the predicted position of the low pressure is slightly different from the real one, and high wave area shifts northward by the correction.

The statistical accuracy of the OWAS that were run in the quasi-operational schedule was investigated. The wave data measured by satellites but were not used in the OWAS were assumed to be true, and compared with product GPVs. The observed data in the Northwestern Pacific at 00UTC from October 1st 2008 to March 31st 2009 were used for comparison.

Figure 4 depicts the scatter plots wave heights

the first guess (model products) and the OWAS products to satellite observations. The statistical values are listed in table 2. The results showed that the OWAS products have better accuracy in RSME and correlation than first guess, although the bias becomes slightly worse.

3.2 Some results of data assimilation tests

The results by a prototype of the assimilation system are introduced. The test case is the same one of the OWAS, shown in the previous sub-section.

We carried out a 72-hours prediction, from the initial of 00UTC on Apr. 5th. For the spin-up, the initial conditions (wave spectrum) were corrected every 6 hours by results of the OWAS from 00UTC on Apr. 2nd.

The 12-hour predictions of wave heights, by the operational model (the control run) and by the assimilated calculation are depicted in Fig. 5. Comparing wave heights with the analysis by the OWAS, the assimilated calculation shows better accuracy: The swell heights the sub-tropical Pacific

was fairly modified in the OWAS, and the impact is detectable in 12 hours calculation. The wave heights in the sea around Mariana Islands were decreased, which had been overestimated by the wave model. The windseas in the Bering Sea, which were generated by the east winds of the low pressure, become larger.

On the other hand, there is no significant change in the high waves in the central part of the low pressure. This may be because these waves were basically determined by the (strong) winds and predicted winds determine the changes of waves, not the initial wave condition.

Figure 6 depicts the differences of wave heights between the control run and the assimilated one. The impacts of initial correlation are detectable till 24 hours prediction, but there is almost no difference between the two calculations after the prediction hours become larger than 24.

Figure 7 depicts the Scatter Index of these calculations. The results indicate that the assimilated calculation has better accuracy, the improvement is not large and the difference becomes small in the later

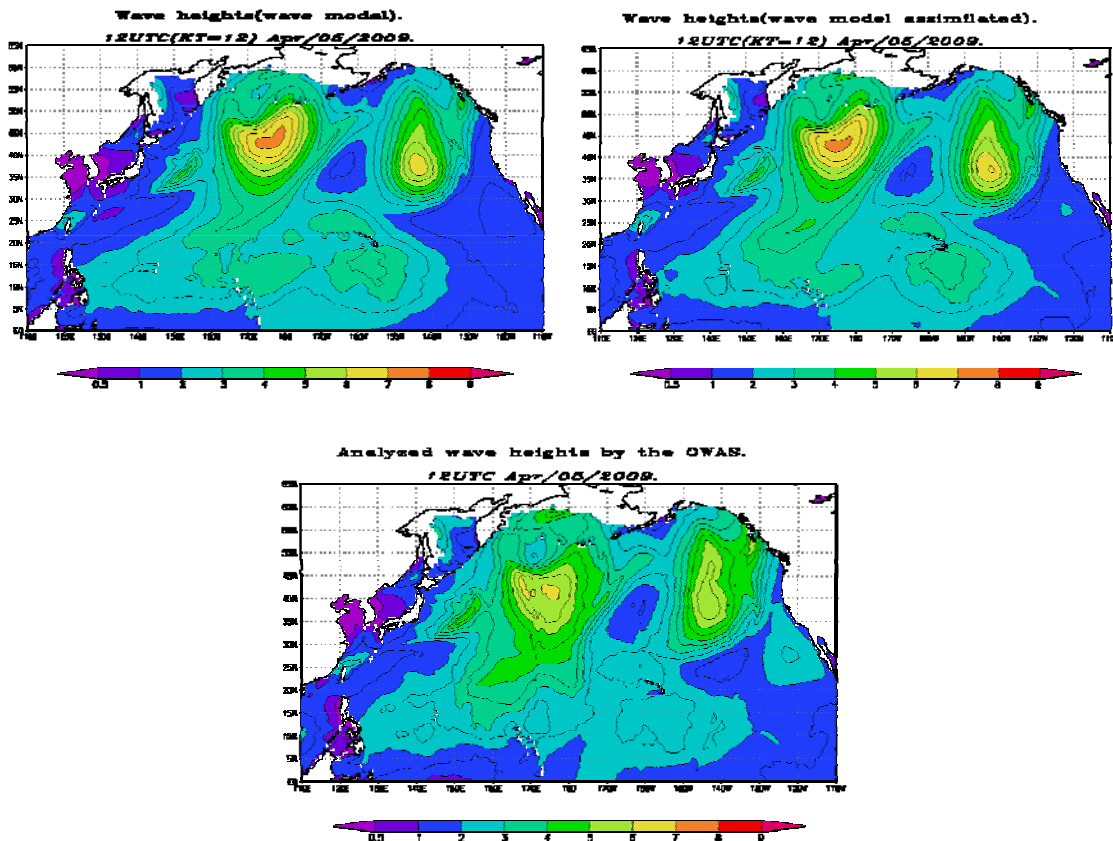


Fig. 5 The 12-hour forecast of wave heights, by the operational model (upper left) and the assimilated model (upper right). The lower map depicts the analyzed wave heights by the OWAS.

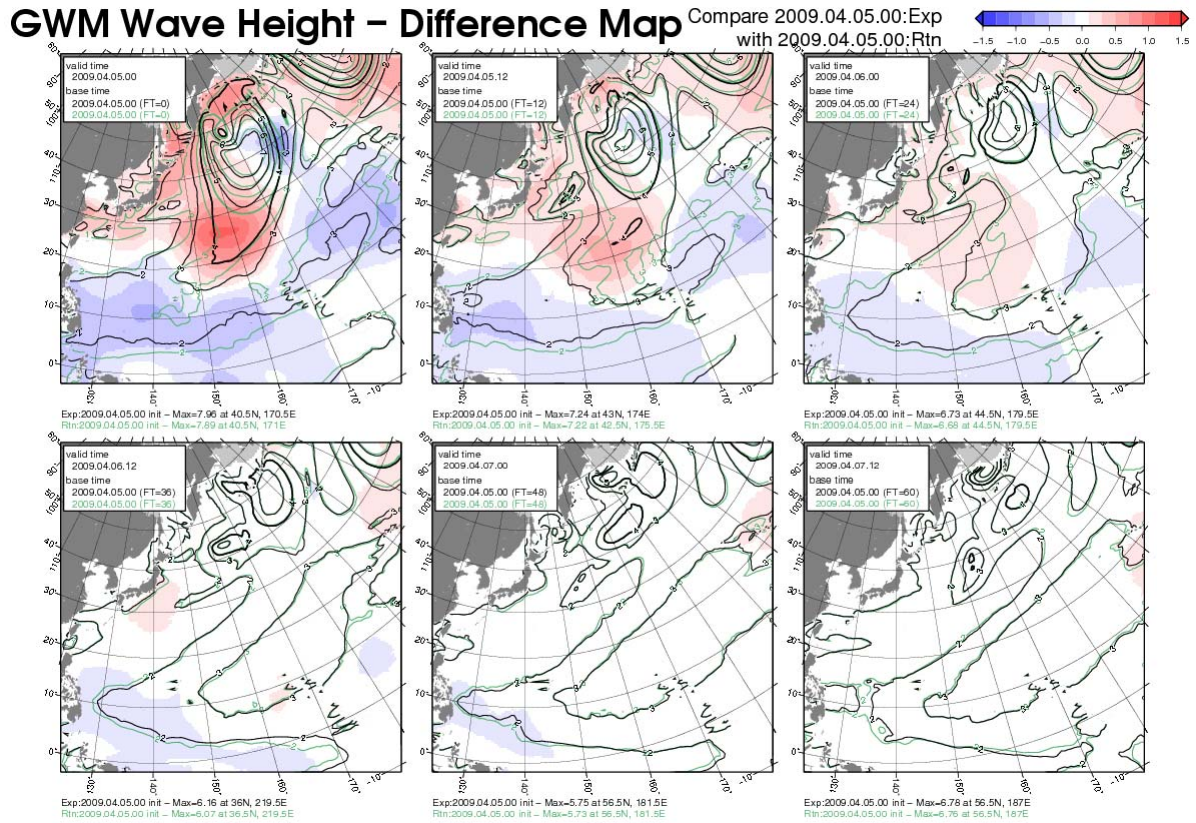


Fig. 6 The wave height differences between the assimilated model and the operational model. The wave height differences are shaded. The black and red contours indicate the wave heights by the assimilated calculation and the operational calculation respectively.

forecast time.

In general, since the change of ocean waves is small compared with winds, the impact of the assimilation on the propagating swell had been expected to be large. However, ocean waves are quickly modulated to winds, and the impact is likely not to be so large except on high swell. The swell whose height is a few meter is comparable to windsea generated by local winds, and thus, it is difficult to expect large improvement in prediction accuracy only by data assimilation. In fact, the accuracy of predicted surface winds is the key factor for the accuracy of long range prediction.

However, we have only changed the amount of the wave energy, referring to the wave height differences. The change of wave period accompanied by the wave heights change was not considered. The impacts of assimilation on the extended prediction will become better if we could modify the wave spectrum more appropriately.

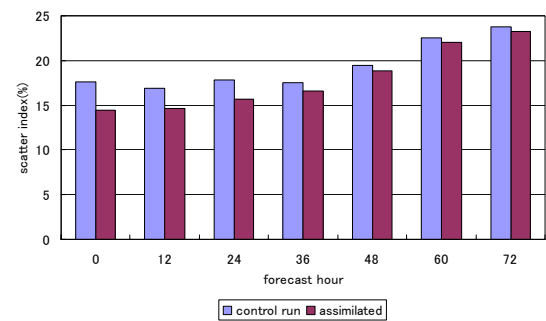


Fig. 7 The scatter plots

4. FURTHER DEVELOPMENT PLANS

The wave information is needed in many fields. Moreover, there are various requirements on wave information. Therefore, JMA is always considering the development of wave information services to cover the variety of requirements. We briefly list up some development plans.

- a) Extension the areas of Shallow-water Wave Model (SWM).

The SWM is now operated in only five areas because of the limitation of computer resources. We are going to extend the areas gradually. We will adapt two more seas till the end of 2010 fiscal year. After 2013, when the JMA computer system will be replaced, the operational areas are to be gradually increased to 11 seas.

- b) Development of MRI-III including shallow water effects.

The shallow water effects are not yet included in the JMA operational wave model MRI-III. This is because the shallow water areas are only limited to the beach zones in the seas around Japan, and it is not likely to be useful without a very fine mesh wave model which resolves the detailed sea topography.

We have started to include the shallow water effect to the MRI-III. The new model will be replaced to the SWM in future.

- c) Modification of energy input. of MRI-III

The operational wave models tend to underestimate waves. This is mainly because of the underestimation of surface winds by the global weather model (GSM), especially in the cold air part of a low pressure system in winter. In the wave model, the friction velocity calculated in GSM is simply used because the effect of lower air stability is supposed to be included.

However, wave model results show the strong underestimation tendency of surface winds in cold air. Therefore we have a plan to modify the energy input term to be able to get proper wave evolutions, although it is slightly artificial.

5. SUMMARY

In JMA, the wave forecasting system is continuously improved in order to provide the advanced wave information. The major points now ongoing are as follows:

- 1) The Objective Wave Analyses System (OWAS) has been developed using the optimum interpolation technique. This system utilizes the observed wave data, and is expected to analyze wave condition more objectively and speedily.
- 2) The OWAS is going to be put into operation in December 2009. By introducing OWAS, JMA will disseminate the wave analyses charts (AWPN and AWJP) twice (UTC and 12UTC) a day, which is now once a day. We have a further

plan to disseminate the analysis charts 4 times a day in future.

- 3) The wave assimilation system is now in development. This system utilizes the results of the OWAS, and test case showed good impacts on the initial condition, although the assimilation impact is hardly detected after 24-hours.
- 4) JMA has also a plan to improve the wave model numeric, especially the energy input term, to improve the underestimation of wave by low pressures in winter.

Since we have just started to develop an assimilation system, there are several problems to be solved. Especially, to develop the more efficient scheme to modify the wave spectrum by the analyzed wave heights is now ongoing. We have also a plan to utilize the 3D-Var scheme instead of OI scheme in future.

In addition, the wave prediction accuracy strongly depends on that of surface winds, it would be crucial to utilize the surface winds data observed by satellites such as QuickSCAT.

However, the most important thing is to improve the numerical weather model of JMA, to get good accuracy of surface winds. Therefore, we are now discussing with staffs of Numerical Prediction Division, to develop the sea surface process in NWP. It seems to be effective to consider the sea state dependency on surface drags, and a plan to couple the wave model with the weather model is now considered.

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