AN APPROACH FOR TOUGH NAVIGATION SEA INFORMATION

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1. INTRODUCTION

Wave information is very important for voyaging vessels and boats, and marine activities. Japan Meteorological Agency (JMA) issues several kinds of information on waves, such as wave charts, forecasts, advisories, and warnings. The main products are wave charts in which significant wave height distribution is basically indicated. However, there are some sea states which could be dangerous or at least tough for voyaging vessels regardless of significant wave height (e.g. Niclasen et al., 2011).

When multiple waves simultaneously exist or waves are modulated by currents, sea state becomes rough. Such condition will be tough for voyaging vessels. JMA is going to issue some information on such notable areas, namely "tough navigation area". Two conditions are currently considered: 1) complicated seas by existing multiple waves, and 2) seas where waves are modulated by currents.

In the first plan, wave components derived from wave spectra are checked, and the sea is regarded as rough if some waves have comparable energy (wave height). As for the second one, wave height modification is estimated by wave and current condition, and the area is supposed to be rough if wave height is much amplified than a certain criterion.

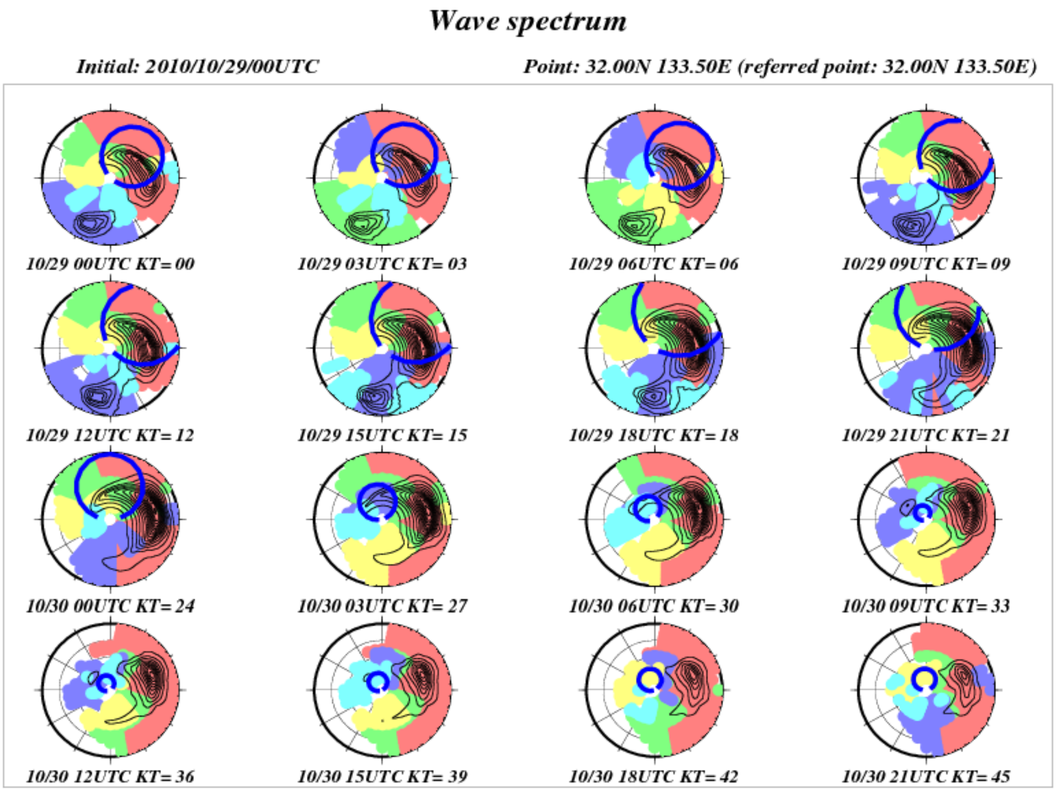

Figure1. An example of partitioned wave components.

The contours show wave energy. The colors (red, green, blue, yellow, and aqua) stand for five wave components in order. The thick blue lines indicate windsea area.

The information is considered to be qualitative and it can be easily added to operational wave charts. General images of information have been fixed and now preferable criterions for new information are mainly investigated.

In this paper, our approaches are introduced. A method of wave partitioning and the way of detecting dangerous region are explained in the next section. In section 3, the results of detected areas and their product images are introduced. Some comments and further aspects are described in section 4, and summary in end.

2. NUMERICAL METHODS

2.1 wave partitioning

Information on each wave component is necessary for sea state evaluation. In JMA, a simple wave partitioning scheme was adopted in 2012. However this scheme only divides wave spectra to windsea and swell components, which is not sufficient for interpretation of multiple wave situations. Hanson and Phillips (2001) developed a sophisticated wave partitioning method, based on a shape of wave spectrum. Our method is almost same as the method, but slightly different in the way detecting windsea region. The way of partitioning is as follows.

1) The location (frequency and direction) of the energy peak of spectra is detected.
2) Referring each energy of spectrum around the peak, spectrum components are put to the same group till wave energy becomes zero or the sign of energy gradient changes (which means the gradient becomes positive).
3) The selected spectrum components are categorized to the first wave component W_1.
4) By repeating the procedures from 1) to 3) to the remaining spectrum components, wave components W_i (till five components) are defined.
5) From the surface wind speed U_{10}, the corresponding peak frequency of windsea f_p is determined by the following equation

$$f_p = \frac{0.13 g}{U_{10}} \quad (2.1)$$

6) The wave component whose peak frequency is nearest to f_p is set as windsea. The searched range of the spectrum is that in frequency higher than f_p and in angle to wind within 20 degree. If no suitable wave component is found in this range, we assume that windsea does not exist.
7) The other components are regarded as swell.

The reason why windsea area is not defined by the wind situation (speed and direction), although it is popular way, is to avoid overestimation. When wind speed decreases or wind direction changes, windsea cannot develop so quickly. There may be swell nearby. If we define the wind sea by wind situation such swell is sometimes regarded as windsea, and windsea tends to be overestimated and swell is underestimated. Operational forecasters in JMA often notice about underestimation of swell. Therefore, we firstly divide wave spectra to each wave component, and choose one of them as windsea. Hanson and Phillips (2001) have different opinion on this matter: All wave spectra within the windsea region are supposed to be forced by wind and thus, they are regarded as windsea.

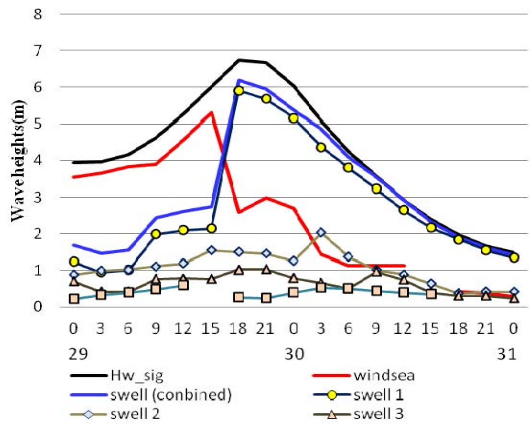

Figure 2. Time sequence of wave components.

We can define any number of components by this method. However, it turned out by many partitioning tests that four components can cover almost all wave components. In WMO Manual on Codes, only windsea and two swell are regulated in ship reports, and thus, up to three wave components seems sufficient for practical use. If wave height of calculated wave component is lower than 0.2 m, the component is neglected, following the manual.

Figure 1 shows an example of wave partitioning. Wave components are basically determined by the gradient of wave spectrum. The thick lines in the spectra indicate the area of windsea. Some wave components are determined although spectrum energy seems to be continuous and belongs to same component. The fifth component was detected in the region where there is almost no energy. The corresponding wave height is under 0.1m, and it can be omitted. In this example, four wave components could be sufficient. Basically the partitioning seems to be fairly carried out.

Figure 2 shows time sequence of wave components. The windsea fairly becomes small after 15UTC on 29 October. In that time, wind direction was shifted from NE to NNE, although wind speed did not change.

2.2 Rough sea by multiple waves

If multiple waves exist, sea state tends to become rough and complicated, which leads to irregular rolling or bitching of vessels. The situation is sometimes dangerous, possibility of ship overturn becomes high. Especially, by collision of several waves may instantaneously generate an extraordinary high wave (what we call pyramidal waves).

Conventional sea state information is based on significant wave height (energy), but it will be very useful for voyaging vessels if additional information on rough sea condition is available.

There are several ship accidents whose cause could be rough sea state, not simply a high wave. In Japan, such accident occurred in 2008 (Tamura et al., 2009). A fishing boat of 135 gross tonnages overturned in the sea of wave height 3m. After the accident, many people are interested in a way to detect a dangerous sea state in Japan. In JMA, an approach to detect a dangerous region started.

Wave components, derived from the way described in 2.1, are referred, and checked whether there are several waves which have comparable energy. In a grid of wave model, let derived wave components H_{wi} (i=1,2,⋯) from the highest wave. When several components exist in a grid, each wave height is compared with the largest one. If there is a wave whose wave height is larger than 0.6 times of the maximum value H_{w_max},

$$H_{wi} \geq 0.6 \cdot H_{w\_\max} \qquad i = 2, 3 \ldots$$

then the grid point is regarded as dangerous condition. We do not check the wave energy if the angle of the two wave directions is within 30 degrees. Those waves can be regarded as coming from almost same direction and it is difficult to regard them as multiple waves.

When several waves simultaneously exist, sea state will surely be rough. However, it could not be so serious if (total) wave height is rather low. However, many grid points are regarded as rough in relatively low wave condition. This is because comparable waves become highly possible when the maximum wave height is low, and many points are easily detected as rough in this method.

To exclude such unimportant condition, only the area where significant (total) wave height is larger than 1.2 m is checked. The wave height threshold of 1.2m is definitely dependent on the type of ships. For small boats, even wave height of around 1m can be dangerous in some cases. Therefore, the threshold should be determined considering of the target users.

The detection way is entirely qualitative. It seems to be difficult to define reliable dangerous fields in quantitatively. We may develop more detailed information but it will be complicated and not suitable for operational purpose, at least now. We tried to make a simple information but practically useful.

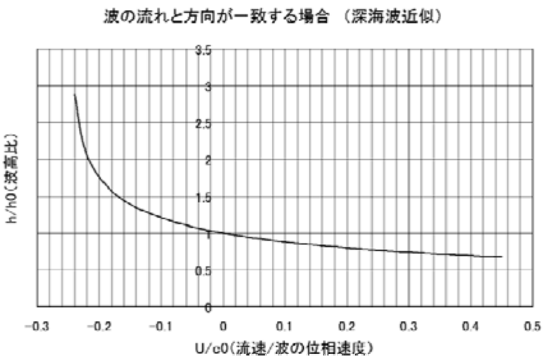

Figure 3 wave height ratio by current modification.

2.3 Waves modified by currents

Waves are modified by currents and there are many researches on this subject (e.g. Peregrine, 1976). However, current influenced wave information is not yet issued operationally. The reason could be it requires dynamically coupled-model system and very complicated, if the mechanism is sincerely considered. It is not suitable for operational prediction.

If ocean current against wave exists, wave height becomes higher, wave steepness becomes larger, and the region becomes rough. In JMA, a practical way to estimate wave modulation by currents was tested, for issuing the information operationally (Kubo and Kohno, 2010).

Assuming waves and currents are steady, modified wave height h in deep water can be estimated by the following relationship

$$\frac{h}{h_0} = \sqrt{\frac{2}{1 + \frac{4U}{C_p} + \sqrt{1 + \frac{4U}{C_p}}}} \quad (2.2)$$

where U is current speed relative to the wave direction, C_p (= $g/2\pi f$) is the phase speed of the wave, and h_0 is the original wave height. The wave height modification ratio is shown in Figure 3. If currents are against to wave, wave height becomes higher, but currents have same direction to wave, wave height become lower. Therefore, only the cases of against currents are considered.

In JMA, both wave and ocean currents are operationally analyzed and predicted. Daily surface current data of the Ocean Data Assimilation System for the Western North Pacific (MOVE-WNP) are available. [Outline of MOVE-WNP is described in JMA (2013), as well as other operational models used in JMA.] Wave modification rate is calculated from the equation (2.2), and if wave height is enhanced more than 10 %, the area is marked as rough. In fact, modified wave height can be quantitatively calculated by the equation, but the information image is same as multiple wave regions. Kubo and Kohno (2009) evaluated the modification by referring significant (total) wave heights and dominant (mean) wave directions, now wave components are available, we are going to estimate the influence of each wave components.

The horizontal scale of this effect is not so large. Because the breadth of currents is not large, modified region will be too narrow to indicate in a wide range map. Therefore, this information is planned to be added only to the large scale wave chart (for the sea around Japan, not for NW Pacific).

3. RESULTS

3.1 Multiple waves

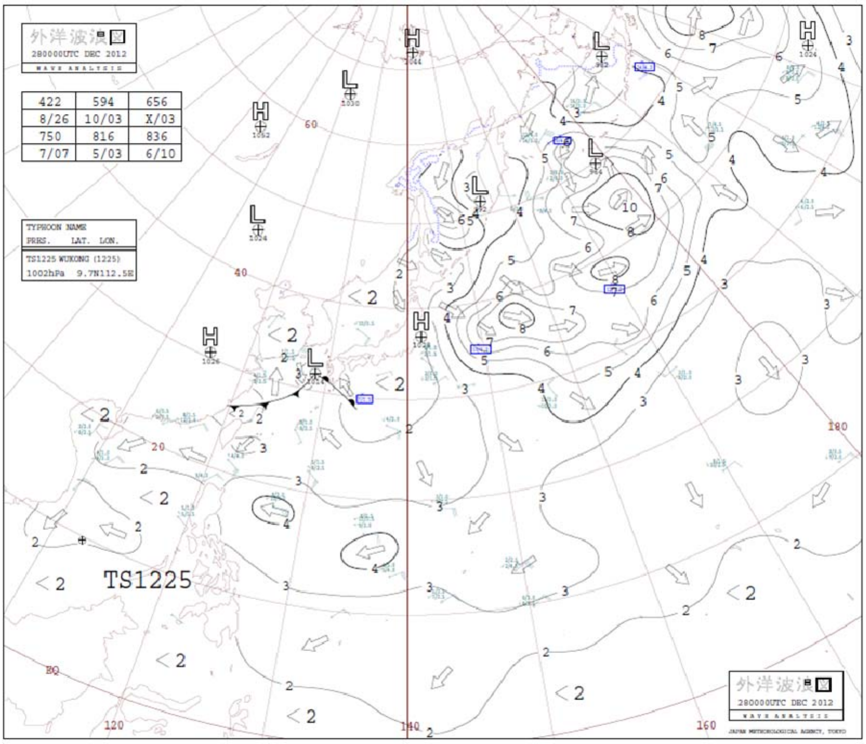

Figure 4. Wave chart at 00UTC on 28 Dec. 2012. (00UTC on 28 Dec. 2012)

Figure 4 is the wave chart at 00UTC on 28 Dec. 2012. There is an occluded low pressure system in the sea around date line and very high waves above 10 m exist in this region. Along with the passage of this low, high swell region extends to sub-tropical area. There is another low pressure system in the Kamchatka Peninsula, and the low newly generates windsea in the sea around the peninsula, as well as the Sea of Okhotsk. High wave area of 8 m is located in the sea east of Japan, which might be newly generated by an implicit low. In the NW Pacific, both swell generated by the former low and windsea by the new low exist and there are some regions where multiple waves exist. In the East China Sea, a low pressure system with front is moving eastward and multiple waves generated around the front.

The wave spectra at the same time, calculated by the operational global wave model, are shown in Figure 5. The spectrum patterns indicate that the wave in the sea east of Japan is basically windsea only, but multiple wave components are predominant

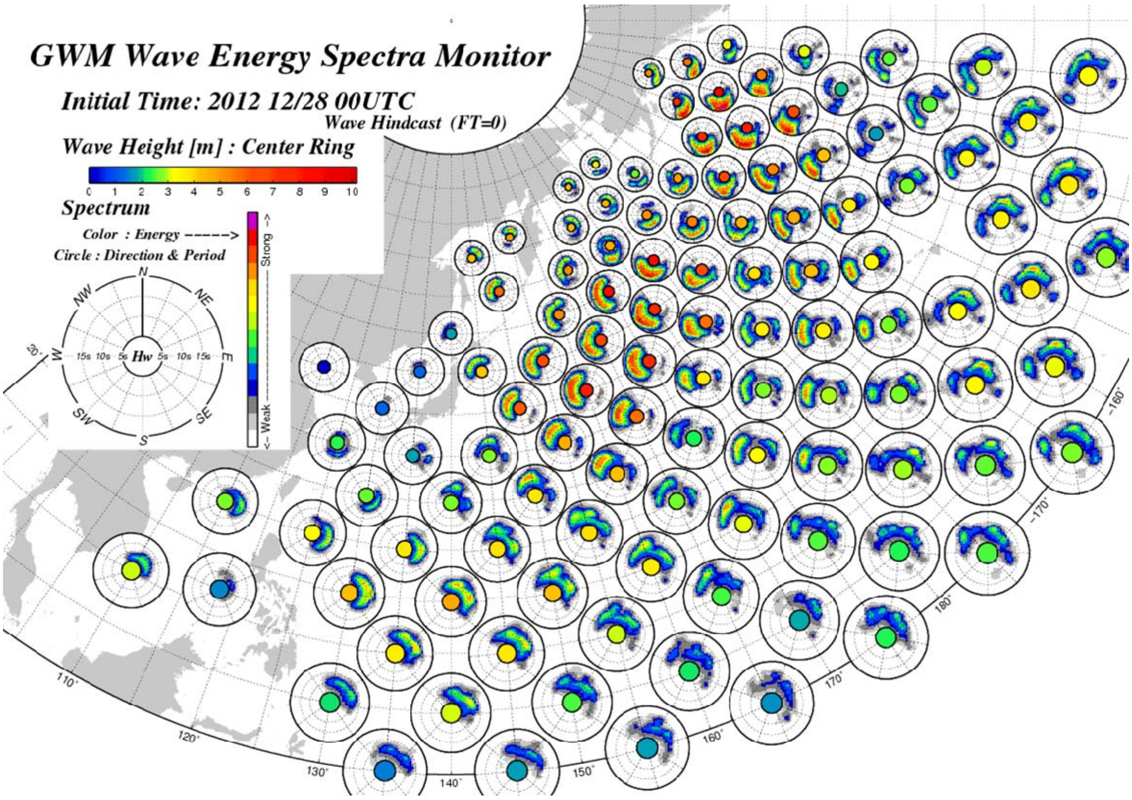

Figure 5 Wave spectra of Global Wave Model GWM.
(00UTC on 28 Dec. 2012)

in sub-tropical zone. Also, multiple waves can be detected in seas around the Kamchatka Peninsula and son.

Figure 6 depicts the wave chart image in which multiple wave regions are marked. Comparing with the spectra in Fig. 5, the regions where multiple waves exist seems to be reasonably detected. Wide region of sub-tropical area was detected, but in the equatorial area was excluded because wave height was not so high. The region in the East China Sea is also marked, although this region is not wide and not so predominant because

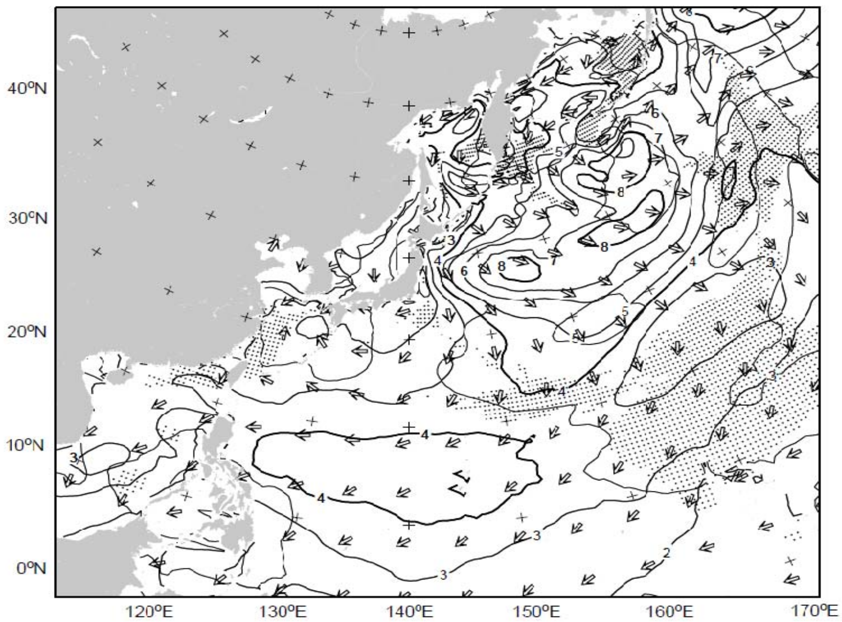

Figure 6. Wave chart with complex sea state mark

multiple waves come from the passing low and front

Actually, the image is very simple. These wave charts are supposed to be disseminated via radio facsimile (JMH). It is desirable that map image is visually simple and understandable even if map image is not clearly received. This example is rather extreme case and wide regions are marked. However, marked area will be usually much smaller, and it is not so difficult to find the marked area.

3.2 Current influenced waves

Figure 7 is a wave chart at 00UTC on 29 October 2010. Typhoon Chaba (1014) is located in the sea south of Japan, and associated high wave are generated in this area. In the sea off Shikoku, wave heights are higher than 9 m. It is notable that easterly wind is predominant in the south of Japan and most waves come from east. In the Japan Sea, NE winds and waves are basically predominant, although waves are not so high. These wind and wave fields can be regarded as a part of counter-clockwise wind field of a typhoon in the Northern Hemisphere in general.

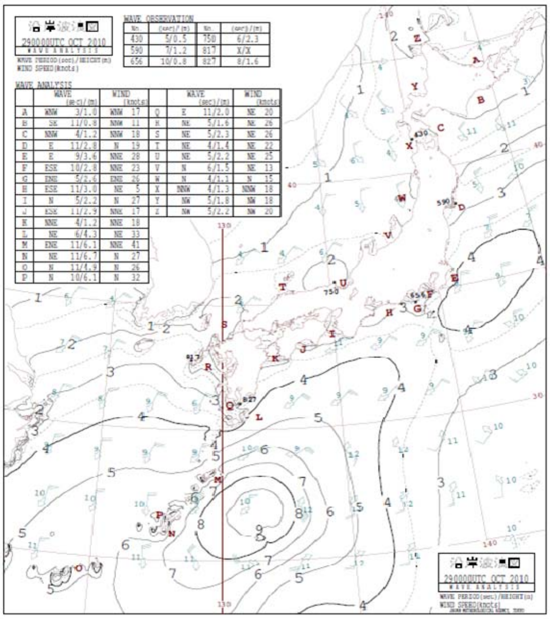

Figure 7. Wave chart at 00UTC on 29 Oct. 2010.

The surface current fields of MOVE-WNP on 29 Oct. are shown in Figure 8. Strong current Kuroshio is predominant, especially in the south of Japan and the west of Okinawa Islands (in the East China Sea). There are some meandered currents in the Japan Sea, which is corresponding to the Tsushima Current.

In Figure 9, a chart image, in which waves become higher than 10 % by current effects are marked, is shown. Basically, the areas where strong currents exist and waves come from the opposite to currents are marked: the region in the south of Japan and the west of Okinawa Islands are caused by Kuroshio. There are several small marked areas in the Japan Sea, which is caused by the Tsushima Current.

4. DISCUSSIONS

Our approach is under development. The detailed ways and thresholds etc have not been fixed yet, although product images become concrete. In this section, some comments on the validity of these kinds of information are described. Some aspects on further development are also discussed.

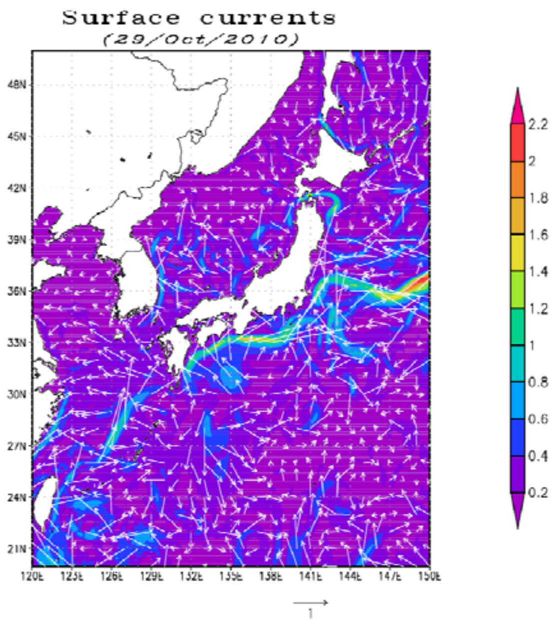

Figure 8. Surface currents on 29 Oct. 2010.
The shaded colors indicated current speeds.

4.1 Thresholds and targets

The approach we proposed is to detect regions where sea state is supposed to be rough by a) crossing multiple waves or b) current influences. The information style we are planning is qualitative, just indicating rough sea, not quantitative. For determination of such regions, several thresholds are used. The validity of thresholds should be discussed.

A region where multiple waves exist is searched in the sea where wave height is above 1.2 m. This criterion is small because wave heights of 2.5 – 4m are classified to “rough” in the WMO Sea State code (WMO Code 3700). In Japan, advisory is usually issued if significant wave height is feared to be more than 3m.

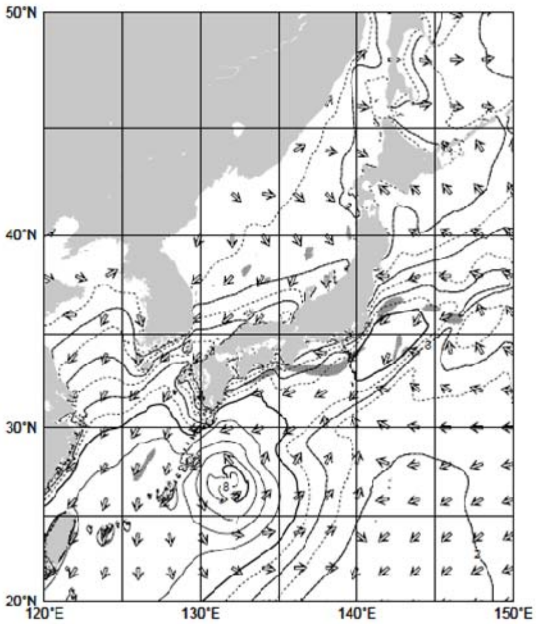

Figure 9. Wave chart with complex sea state mark (00UTC on 29 Oct. 2010)
The regions of multiple waves are shaded.
Contours indicate wave heights.

However, if multiple waves exist, the sea state becomes complicated: ships often get irregularly rolling or pitching. Even though the condition is not dangerous for the ships, it will be surely tough for voyaging. Irregularly repeated waves are very dangerous because a ship continuously receives deforming force before returning to neutral position. There are many ship overturn accidents whose main cause is considered to be this mechanism. Therefore sea state information where multiple waves exist should be issued even if wave height is not so high. Anyway, this information will be added to the wave charts, in which wave height distribution is shown. The rough sea information can be less constraint from wave heights. The detection range of wave height more than 1.2 m could be practical.

Wave information is referred by various ships, from huge vessels small boats, and thus the criterion of dangerous condition is entirely different among them. We need to define the target ship. Now we are considering the ships in off shore, which means we do not include small pleasure boats as information users. We would like to develop some information for such boats in future.

As for current effects, we can estimate modified wave heights by equation (2.2). It would be one way that modified wave heights are directly drawn in wave charts. User can directly know the wave heights, which will be simpler. If waves are influenced by currents, not only wave height but other factor such as wave steepness will change too. Ships will receive irregular forces in such conditions. It will be difficult to understand the sea getting influence by currents from only modified wave height fields. Therefore we decided to show the current effected area by explicit mark, to alert the region.

4.2 further developments

We are now planning to issue complex wave area in North Western Pacific, and current influenced wave area in the seas around Japan. The horizontal scale of phenomena is different between the two fields. It seems to be difficult to deal with them equally. Also it will become confusing if both of the information is combined. Expert Team on Wind Waves and Coastal Hazards (ETWCH) of JCOMM is now reviewing on “dangerous sea-state” information. It is expectable that an authorized definition on such state will be fixed in near future. If some comprehensive but simple way to alert such dangerous sea state is devised, it is surely useful.

5. SUMMARY

JMA has a plan of issuing information on the area where it is supposed to be tough or dangerous for voyaging. Two situations are considered: one is area where multiple waves exist and their wave heights are comparable, sea state is supposed to be rough. The other is area where ocean current against wave exists and wave height is enhanced by the current, sea state becomes rough.

The information is simple and qualitative, but can be easily added to current products. The detected regions will be marked in wave charts. The concrete image has been fixed but some criterions should be further revised. The new wave charts with the additional information will be issued in a few years.

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