# THE MECHANISM OF THE HIGH WAVE "YORIMAWARI-NAMI" ON FEBRUARY 24TH 2008

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## 1. INTRODUCTION

The weather in Japan was so stormy by strong northwestern monsoons on February 24th 2008. The strong winds generated high waves in the seas around Japan. In the Toyama Bay (shown in Fig.1), high waves came from the morning of Feb. 24th, broke the breakwaters and other structures, and severe disasters occurred: 2 casualties and 4 fully damaged houses were counted, and more than 100 houses were flooded. According to NOWPHAS (Nationwide Ocean Wave information network for Ports and HArbourS) operated by the Ports and Harbours Bureau of the Ministry of Land, Infrastructure, Transport and Tourism, The maximum significant wave height of 9.92m was observed at Toyama (0700UTC) and 7.73m at Wajima (0500UTC) on February 24th, which were the highest records respectively.

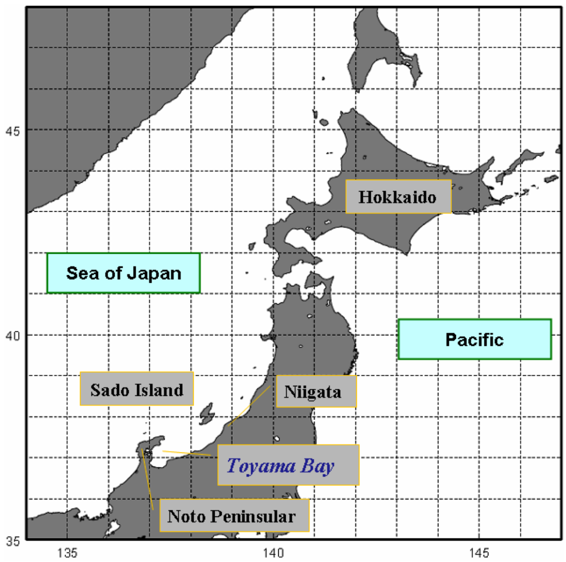



Fig. 1 The map of the northern part of Japan.

It is rather common that high waves hit the coast of the Sea of Japan in winter, since strong NW-monsoons often blow against the coast of Japan. However, the Noto Peninsula acts as a good barrier for the Toyama Bay against high windseas which usually come from northwest. Nevertheless, high waves actually hit on even the most inner beach of the Toyama Bay and sometimes caused disasters. The local residents call those curious waves as 'Yorimawari-Nami'.

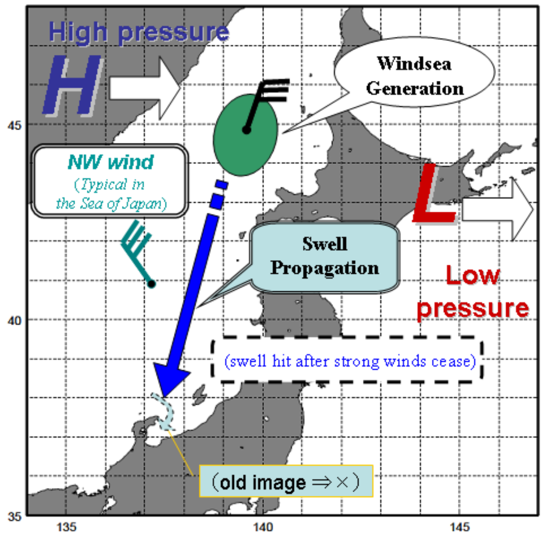



Fig. 2 The schematic image of Yorimawari- Nami.

*Yorimawari-Nami*

Yorimawari-Nami directly means 'turning-around waves' in Japanese. Old residents imagined the high waves strolled around the Noto Peninsula and turned toward inner part of the Toyama Bay (shown as the old image in Fig.2). In fact, it is one of the typical characteristics that high waves usually came after when the strong wind had ceased. In calm weather, people were released from stormy condition and felt at ease, which made the high waves unexpected attacks and sometimes led to disasters.

There are several researches about the mechanism of the Yorimawari-Nami. Kitaide (1952) firstly investigated the mechanism from a scientific point of view, and found that the Yorimawari-Nami is basically a swell which generated in the northern part of the Japan Sea and propagated toward the Toyama

Bay (Fig. 2). It needs about ten hours for swell to reach the Toyama Bay and this explained satisfactorily the delay of Yorimawari-Nami coming, from the peak time of high winds. Isozaki (1971) analyzed observed wave spectra, investigated the shallow water effects on local points of the Toyama Bay in detail, and detected their preferred wave direction.

Isozaki and Ohta (1972) summarized the statistical characteristics of Yorimawari-Nami, and partly succeeded in simulating high waves by the first generation wave model MRI. Toyama Local Observatory (1971) and Kawai (1987) statistically analyzed the characteristics of Yorimawari-Nami. According to their results, large waves tend to come when high winds are still blowing after the swell has been generated. They considered that the reason of high waves is the overlap of swell and windsea. Hatada and Yamaguchi (1998) carried out a preliminary study on the predictability of Yorimawari-Nami using a wave model including shallow water effects, although it has not been accomplished yet.

Actually, these researches mainly dealt with shallow water effects in the Toyama Bay, or qualitative interpretation about preferred conditions. Recently the wave estimation skill has nobly advanced by the invention of the third generation wave model, and development of computational power enables intense simulation. It would be significant to investigate the mechanism of the waves in the Sea of Japan on February 24th, which had extraordinary high wave heights and long wave periods.

This paper reports a simulation study of this event. The outline of simulation is described in section 2. The weather and wave conditions on February 24th 2008 are described in section 3, and the simulation results are provided in section 4. Section 5 focuses on the mechanism of large swell, mainly considering the non-linear energy transfer. We summarized our results in section 6.

## 2. NUMERICAL METHODS

### 2.1 Outline of the ocean wave model

The wave condition was simulated by the third generation wave model MRI-III, which was originally developed at the Meteorological Research Institute of JMA (Ueno and Kohno, 2004). This model is based on the energy-balance equation of ocean wave spectra $F = F(f, \theta)$.

$$\frac{\partial F(f,\theta)}{\partial t} + \nabla \cdot C_g F(f,\theta) = S_{in} + S_{nl} + S_{ds} \qquad (1)$$

here, $C_g$ is the group velocity, and the second term on the left side is an advection term that expresses swell propagation. The two-dimensional spectra consist of 900 components, which have 25 frequencies (logarithmically divided from 0.0375Hz to 0.3000Hz) and 36directions (every 10 degrees).

The terms on the right side represent source terms: (1) energy input, (2) nonlinear energy transfer, and (3) energy dissipation by wave breaking and swell decay. A modified DIA scheme is incorporated in MRI-III. This scheme can calculate the $S_{nl}$ values more accurately than the original DIA scheme used in WAM and other operational wave models. The first-order upstream method is adapted to the advection scheme. Further model numerics in detail are provided in Ueno and Kohno (2004). Actually, this model is only for deep waters and shallow-water effects such as refractions and bottom dissipation are not included. We only analyzed the mechanism of wave evolution in the Sea of Japan, the shallow water effects are not considered in this research.

### 2.2 The Calculation method

The computational area covers almost whole part of the Japan Sea, from 32.5°N to 46.5°N and from 126.0°E to 143.0°E. The horizontal grid resolution was 5 minutes, which corresponds to a physical distance of about 8km.

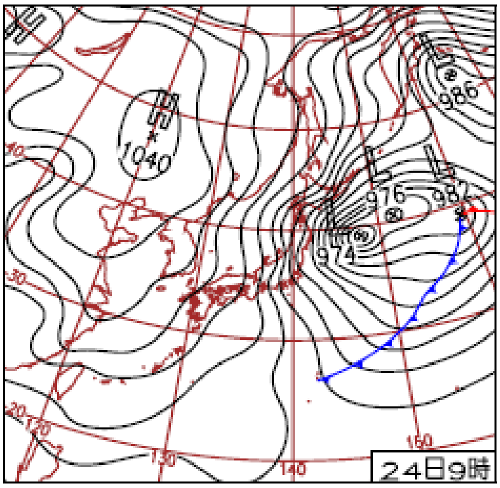
We conducted a 2-day simulation from the static initial state at 12UTC on February 22nd 2008, when the key low pressure system, which was the source of high waves, was yet to come in the Japan Sea. Therefore, we started out calculation from static initial state.

We closed the boundary of computational domain. Actually there are two open parts (Tsushima Strait and Mamiya Strait) in the Sea of Japan. However, Tsushima strait had little role on waves in the Japan Sea due to downstream location and Mamiya Strait is usually covered by thick sea ice in February, and thus it would be reasonable that we treated these part as land.

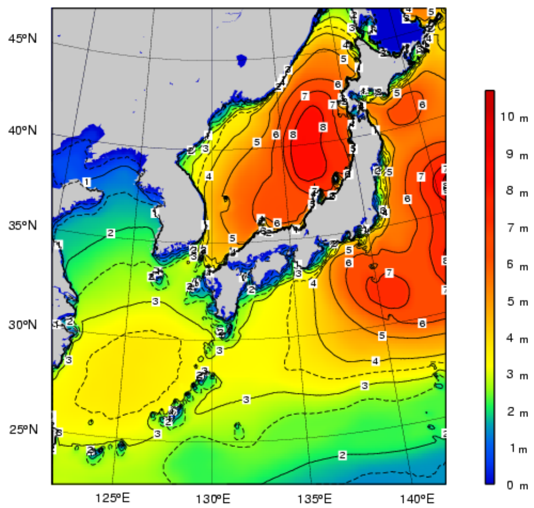
The wind data were derived from hourly wind GPVs of the operational Meso-scale Model (MSM) of JMA, which has the 5km grid resolution.

## 3. Weather and wave condition on 24th February 2008

A low pressure system in the Sea of Japan moved eastward in the morning on February 23rd and stayed in the east of Japan. The pressure gradient between the developing low and the Siberian high became large, strong NW wind blew around Japan. Figure 3 (a) is the surface weather chart on 00UTC on 24th February. The surface winds in the seas around Japan were about 20m/s.




(a) Surface analysis chart (00UTC 24th Feb.)




(b) Wave analyses chart (00UTC 24th Feb.)

Fig. 3 (a) The weather and (b) wave conditions at 00UTC on 24th February.

The strong winter monsoon generated high ocean waves of more than 6m, and the maximum wave height developed to 8m in the central Sea of Japan as shown in Fig.3 (b). In the Toyama Bay, high waves hit the beaches, from the morning on 24th and broke many coastal structures. The disasters were counted as 2 dead people, 57 broken houses, and 161 flooded houses.

High waves were observed in almost whole the coast in the Sea of Japan. Figure 4 lists the maximum values of significant wave and the observed time. Wave heights of more than 6m were observed at many stations (Fukaura, Sakata, Tanaka, Toyama, and Wajima). At Toyama quite high wave of 9.92m was observed, although at Fushiki-Toyama, which is just next to Toyama, the maximum value was only 4.22m.

It is also notable that most of wave periods were more than 10 second, which is rare in a closed and rather small sea such as the Sea of Japan. Especially long wave period of 16.2 second was observed at Toyama, which is difficult to expect in usual wave evolution.

The almost half value at Fushiki-Toyama suggests that the extraordinary high wave at Toyama would come from some local factors. Actually the large value would have been strongly influenced by the shallow water effects since the station is located in the point where the water depth is only 20m. The long wave period at Toyama also implies that shallow water effects played large role on the wave modulation, and might lead to extraordinary high wave.

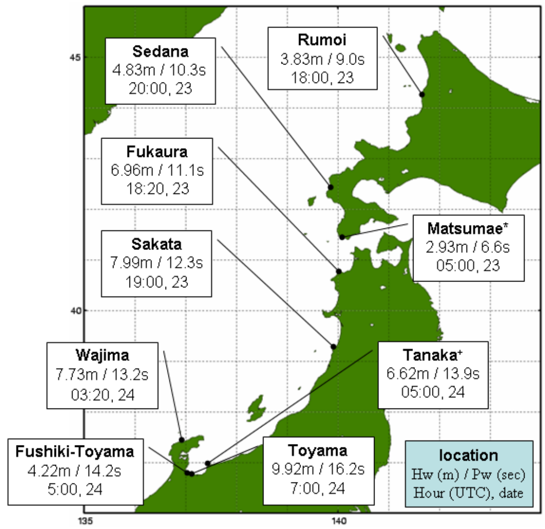



Fig. 4 Maximum Significant Waves observed. Matsumae is deployed by JMA and Tanaka is deployed by River Bureau. Other stations are deployed by Port and Harbors Bureau (NOWPHAS).

## 4. SIMULATION RESULTS

The horizontal distribution of simulated ocean waves is illustrated in Fig. 5. The NW winds by the low generated windseas in the west of Hokkaido on Feb. 23rd. The generated waves propagate to the central Sea of Japan as swell, while windseas are newly generated by strong NNW monsoon (about

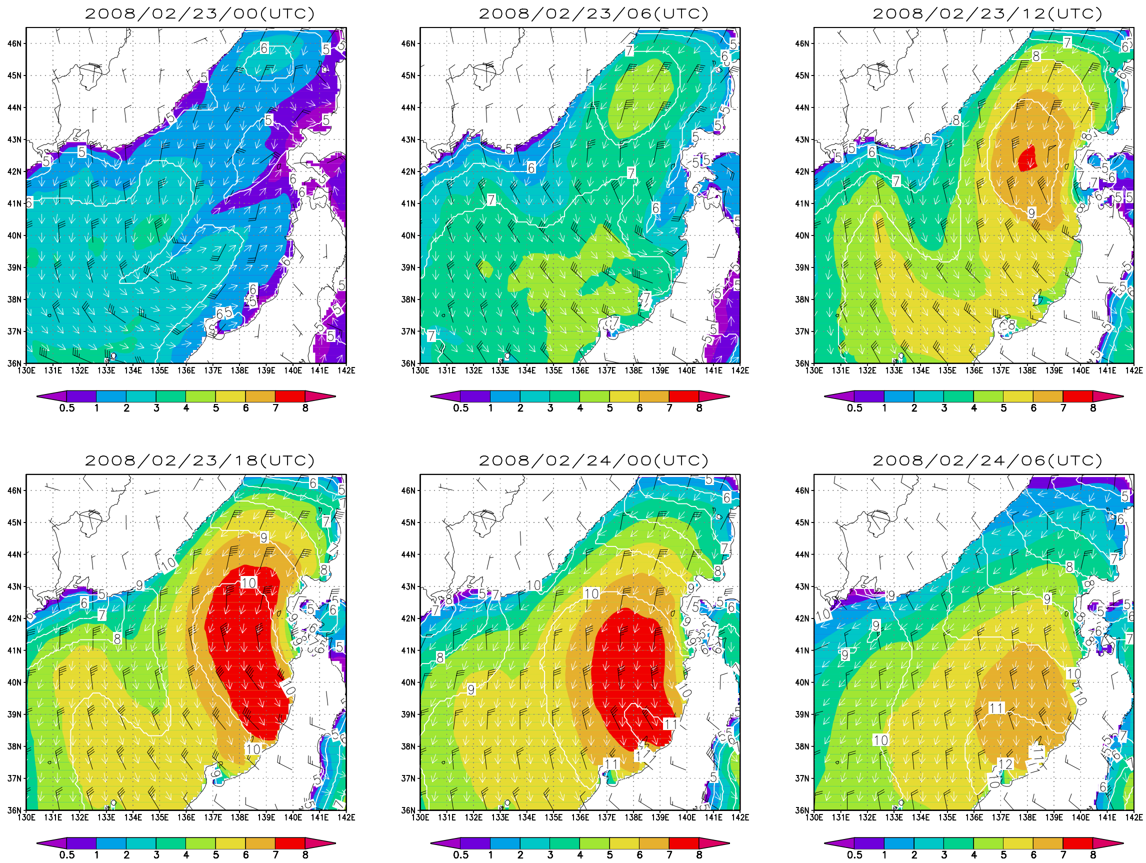



Fig. 5 Simulated wave condition in the Sea of Japan.
The shaded areas indicate simulated wave heights (m), and the contours indicate wave period (sec). The arrows indicate wave direction and the barbs indicate the surface winds (long fletching is 10kt and short is 5kt)

15m/s) there. Combined with the swell from north, the wave heights in central part become large.

These high waves mainly hit to the coast around Niigata, while some swell still propagates for the Toyama Bay. The waves of about 6m height come into the Toyama Bay, although they are smaller than the peak value in the central part. Wave periods of more than 10 seconds were simulated in many parts, and in the Toyama Bay wave periods at 0600UTC on Feb. 24th were over 12 seconds.

The simulated wave heights in the Toyama Bay are about 4m, which is much smaller than the observed value at Toyama. However it is favorably compared with the observed value at Fushiki-Toyama, and the simulated wave height of 5m at Tanaka is reasonable to observation. Since shallow water effects are not included in our model, it would be impossible to simulate the observed wave at Toyama. Therefore, we may suppose that we have fairly simulated the offshore waves except the shallow beach areas.

In order to interpret the waves, the sequences of wave spectra at several points along the path of swell are depicted in Fig. 6. In the northern Sea of Japan (P1), windseas are generated by NE winds at 0900UTC on Feb. 23rd. This is pure windsea and most wave energy is concentrated in high frequency part as an early developing wave.

In the central part (P3, P4, and P5), wave spectra gradually came to have larger energy till 21UTC. The spectra also have wide spreads since windseas were generated by strong NW wind besides the swell component. The wide spread of spectrum indicates that there are plural wave components, and it seems to be a just linear summation of swell and windsea. It is also notable that energy peaks shift towards low frequency part. It should be noted that swell periods also become long and are slightly longer than windseas.

At the entrance to the Toyama Bay (P6), wave spectra have large energy and wider spreads, partly because the predominant winds turn to west.

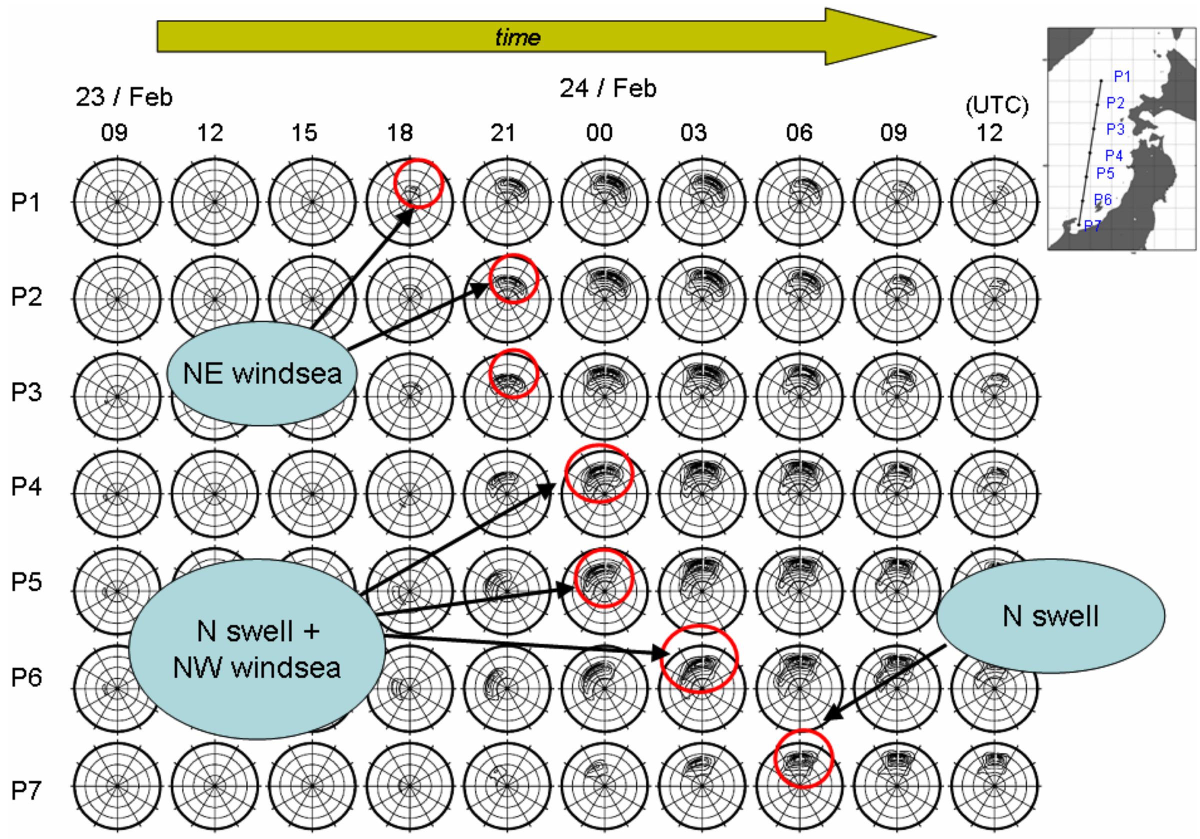



Fig. 6 Simulated wave spectrum from 09UTC 23nd to 12UTC 24th, February.
The circles are drawn in every 5 seconds of wave period from the center. The contours are drawn in the square root of energy density.

However, only swell from the north can reach the inside of the Toyama Bay since windseas from WNW are blocked by Noto Peninsula. Therefore, the spectra at P7 have energy only in north components at 03UTC on Feb. 24th. The swell energy seems to be larger than those of the upstream spectra. This suggests that the swell could be intensified in propagating through the Sea of Japan. Usually it is difficult to expect for swell to get large energy from winds. The other mechanism would be necessary for swell evolution.

## 5. DISCUSSION

In order to seek the mechanism of the change of swell spectra, wave spectrum and their non-linear energy transfer ($S_{nl}$) are depicted in Fig. 7.

In the northern part, spectrum and $S_{nl}$ express a typical windsea development. The spectrum has energy in NE components since NE winds were predominant, and energy flows into the low frequency side.

In the central Sea of Japan, there are wide spread in energy spectra: developing windsea energy in NW components and swell energy around NNE components. The calculated $S_{nl}$ shows energy flow to NE low frequency part. This surely indicates that swell is developing and the wave period becomes long. The energy flow to NE components occurs in all spectra from the west of Hokkaido to the Toyama Bay. Therefore, swell from north is enlarged in propagating through the Sea of Japan, by the non-linear energy transfer.

If there was only NW windsea, it would show the pure windsea development, and no energy flew to NE components. On the contrary, it is difficult to expect the development of swell by winds, especially wind direction is different. This indicates that wave energy was firstly inputted to windseas and then injected to swell due to the non-linear energy transfer.

In order to consider this effect in detail, we carried out ideal tests. (The image of tests is drawn in Fig. 8.) We calculated the non-linear energy transfer to swell when swell and windsea exist simultaneously. We assumed that swell is expressed as a JONSWAP-type spectrum with the peak enhancement parameter

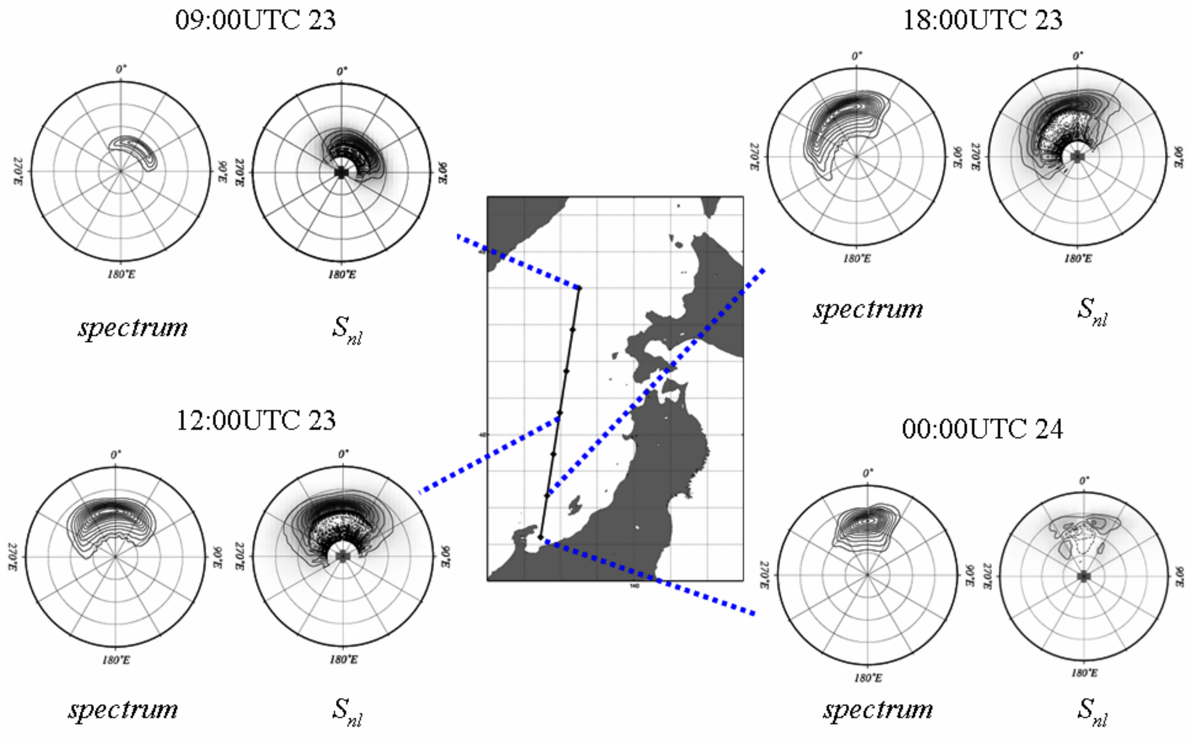



Fig.7 The wave spectra and nonlinear energy values ($S_{nl}$) along the path of swell propagation.
The contours of energy density and $S_{nl}$ values are drawn in the square root of energy density. The shaded areas in $S_{nl}$ indicate positive transfer.

γ = 5.0. The peak frequency of swell is fixed to 0.097Hz, which is lower than windsea, and swell direction is 0 degree. Windsea is expressed as a JONSWAP spectrum and is assumed to have various peak frequency (0.116, 0.137, 0.164, 0.196 Hz) and direction (relative angles are 0, 30, 60, 90 degrees). We calculated the non-linear energy transfer when a windsea is linearly overlapping swell.

Figure 9 depicts the results of several cases. The energy flow to low frequency side and 0-direction (swell) by the non-linear energy transfer becomes the largest when swell and windsea almost coincide. The energy flow to swell is detectable when the relative angle is small. As relative angle becomes large, the energy flow to low frequency side becomes small and has wide spread.

When the difference of peak frequency becomes large, the non-linear transfer occurs separately in swell and windsea, and thus, the energy flow to the swell becomes also small. Since we define windsea as a JONSWAP spectrum, the total wave energy becomes small as the peak frequency becomes high, and amount of energy flow also becomes small. This would be also the reason why the energy flow to swell becomes small if the difference of peak frequency becomes large.

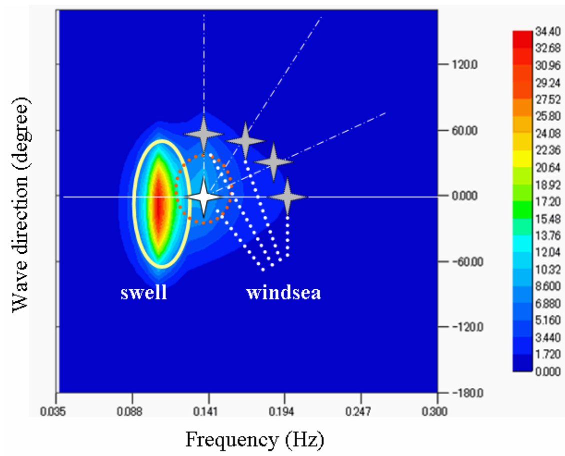



Fig. 8 The image of test calculation.
The swell is fixed and the stars indicate various windsea cases (peak frequency and direction).

It should be note that we just calculated the non-linear energy transfer when swell and windsea are linearly combined and other factors are not considered. For example, wave breaking tends to occur if swell and windsea coincide, since wave steepness becomes large. However, it seems plausible

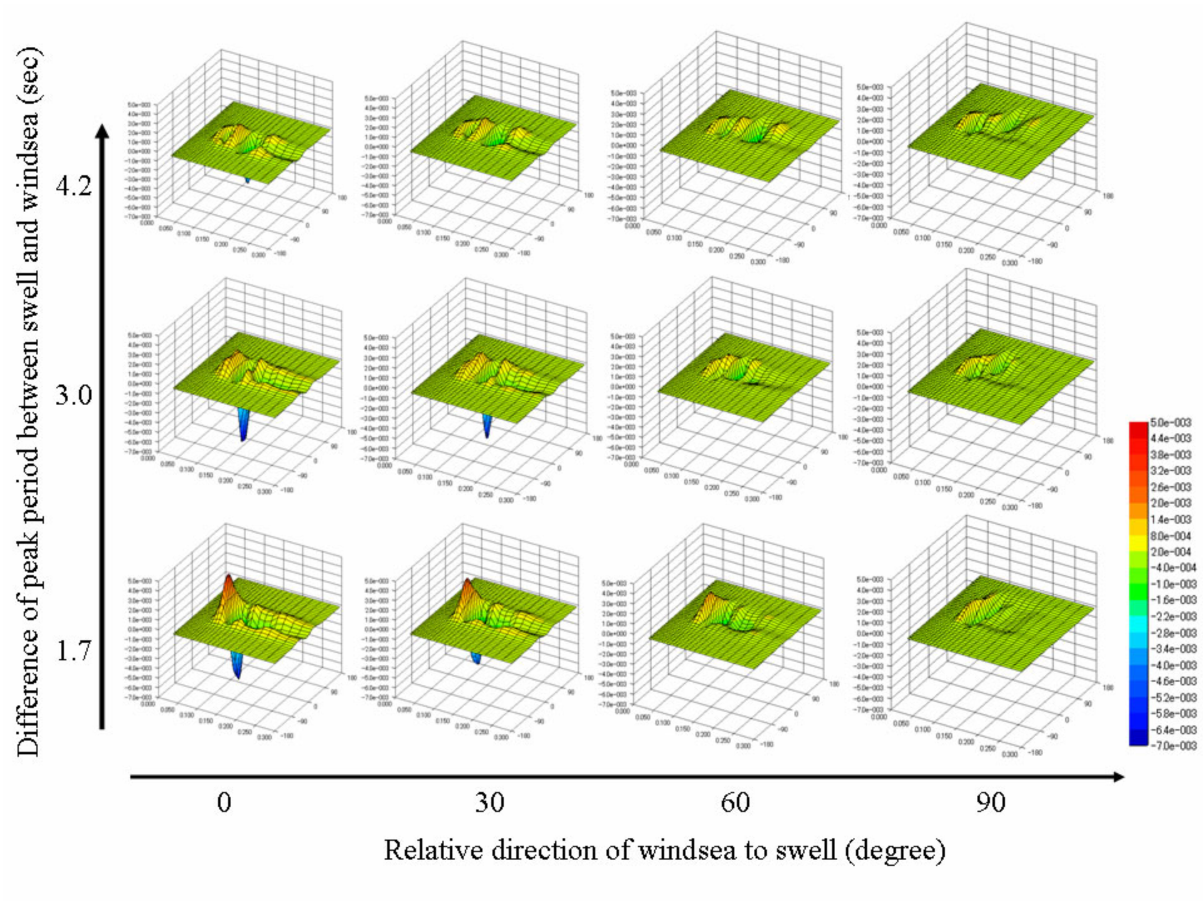



Fig. 9 Calculated non-linear energy transfer when a swell and a windsea exist.
The x-axis indicates the relative angle from swell to windsea direction. The y-axis indicates the difference of the peak periods between swell and windsea.

that windsea energy will be flown to swell due to the non-linear effect, and the energy flow becomes large if swell and windsea have comparable energy and nearly same direction.

When swell and windsea have similar wave period, the energy transfer to low frequency side (swell) becomes large. Moreover, transferred energy tends to concentrate to the direction of lower spectrum (swell), if relative angle is small.

In the central Sea of Japan, strong wind generated large windseas, which had almost same wave periods as the swell from the north. Moreover, the windsea direction of NNW was similar to the swell direction (N or NNE).

Therefore it would be a preferred condition for swell to get energy from windsea, and thus large swell was generated.

## 6. SUMMARY

The mechanism of the Yorimawari-Nami (large swell in the Toyama Bay) on 24th February 2008 was numerically investigated. The results are follows:

1. The high waves were generated by a low pressure system passing through the northern part of the Sea of Japan. These waves propagated southward as swell, while strong NW monsoon winds still blew and large windseas were also generated. The main reason of high waves in the central Sea of Japan was the overlap of these waves.
2. Simulation results showed that large energy was transferred to swell from windseas which led to extraordinary large swell.
3. That is the reason why extraordinary large wave of over 9m height and 16sec period was observed at Toyama. However, this value is supposed to have been influenced by the shallow water effects which we did not consider.
4. The nonlinear effect would be crucial

mechanism for development of swell. It is difficult to interpret in qualitative arguments, and quantitative evaluation is necessary.

The simulation results indicated the importance of the non-linear energy transfer. It has been satisfactorily estimated by invention of the third generation wave model. This means that operational prediction of Yorimawari-Nami will be available by making use of a fine-grid third generation wave model. One of our objects is to develop such a system in near future. In that system, the shallow water effects should be also included.

We would like to further investigate the role of non-linear energy transfer on swell evolution in detail, since it seems to contain general topics, not only the Yorimawari-Nami.

## REFERENCES


Hatada, Y. and M. Yamaguchi (1998): Preliminary Study on Prediction Method of Large Swell-Like Waves in Toyama Bay 'Yorimawari-Nami'. *Memories of the Facility of Engineering, Ehime Univ.*, **17**, 261-271. (*in Japanese*)

Isozaki, I. (1971): On the Characteristics of Coastal Waves on the Coast of Toyama Bay (Report I). *Notes of Cooperative Research for Disaster Prevention*, **25**, 3-15. (*in Japanese*)

Isozaki, I. and Y. Ohta (1972): On the Characteristics of Coastal Waves on the Coast of Toyama Bay (Report II). *Notes of Cooperative Research for Disaster Prevention*, **28**, 3-17. (*in Japanese*)

Kitaide, M (1952): On the mechanism of and Forecasting of the so-called "Yorumawari" Wave. *The Oceanographical report of the Japan Meteorological Agency*, **2**, 125-151. (*in Japanese*)

Toyama Local Observatory (1971): Synoptic analyses of the ocean waves in Toyama Bay. Toyama Local Observatory, Toyama. pp55. (*in Japanese*)

Ueno, K. and N. Kohno (2004): The development of the third generation wave model MRI-III for operational use. *Proc. 8th Int. Workshop on Wave Hindcasting and Forecasting*, **G2**, 1-7.