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SWELL PREDICTION FOR THE EAST KOREAN COAST

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ABSTRACT: Long-period abnormally high swell waves have been generated in the East Sea near Hokkaido, Japan, in winter during the atmospheric depression. These waves, named Yorimawari in Japanese, occasionally attack the coasts of both Korea and Japan. Waves significantly higher than normal years were recorded along the east Korean coast in 2006. In 2008, the swell caused considerable damages in Toyama and the Niigata coastal area of Japan and in Anmok east coast of Korea. This paper attempts to hindcast these events using unstructured grid wave model UnSwan with input of high resolution reanalysis wind data from ECMWF. Wave heights and periods are found to be fairly well reproduced comparing with the observed values in the south of the East/Japan Sea, although the long period wave with small amplitude is hardly reproduced.

Keywords: Swell, swell prediction model, ECMWF, the east Korean coast

INTRODUCTION

In recent years, abnormally high swell-like waves frequently occurred in the east Korean coast (Fig. 1) during winter seasons mainly from October to February (Oh et al. 2010). These waves caused considerable damages in both public life and property. Since 2005, the dead or missing people toll is put at 45, and the property damage exceeds on average ten billion won per year (Jeong and Oh 2009). While people can be warned of the occurrence of high waves due to typhoon or storm events, the high swell waves occurring in the good weather condition can be hardly predicted and thus cause unexpectedly fatal human and property damages in coastal regions. Therefore, it is necessary to study the characteristics of the abnormal swell wave and predict the swell wave accurately as much as possible. However, studies for these swell waves have been insufficient and the prediction system has not worked well.

In this study, we simulate the abnormal swell waves occurred in the East/Japan Sea in 2006 and 2008. It was noted that waves were in 2006 much higher than those of normal years in the east Korean coast. Also the swell wave caused great damage in Toyama and the Niigata coastal area of Japan in 2008.

We investigate the occurrence and reproduction of abnormal swell waves using SWAN with unstructured grids (known as UnSWAN). Also the enhanced wind-generated wave simulations about the coupling process in coastal ocean waters and the simulation scheme of weighting factor on the relative wavenumber were discussed.

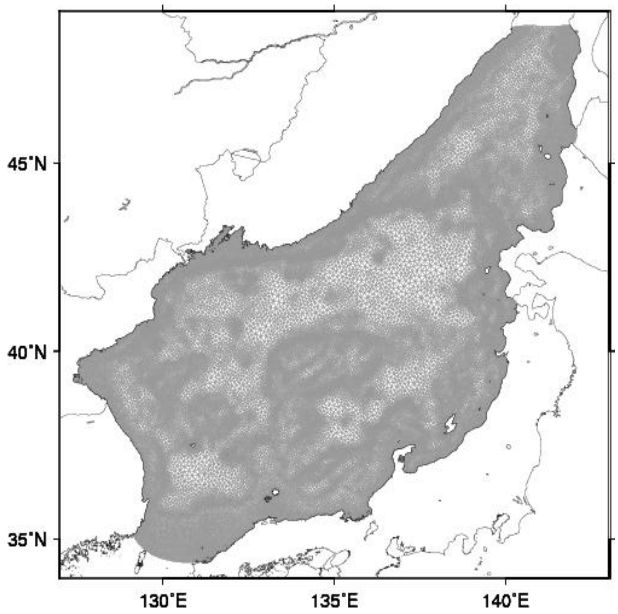

Fig. 1 Computational domains and meshes of UnSWAN.

NUMERICAL MODEL

In this study, the ECMWF wind data are used as the meteorological inputs (Fig. 2). The SWAN frequencies ranging from 0.031 to 0.548 Hz are discretized into 30 bins on a logarithmic scale ($\Delta\sigma/\sigma \approx 0.1$). The wave directions are discretized into 36 sectors, each sector representing 10°. For the shallow-water source terms, depth-induced breaking is computed with a spectral version of the model due to Battjes and Janssen (1978)

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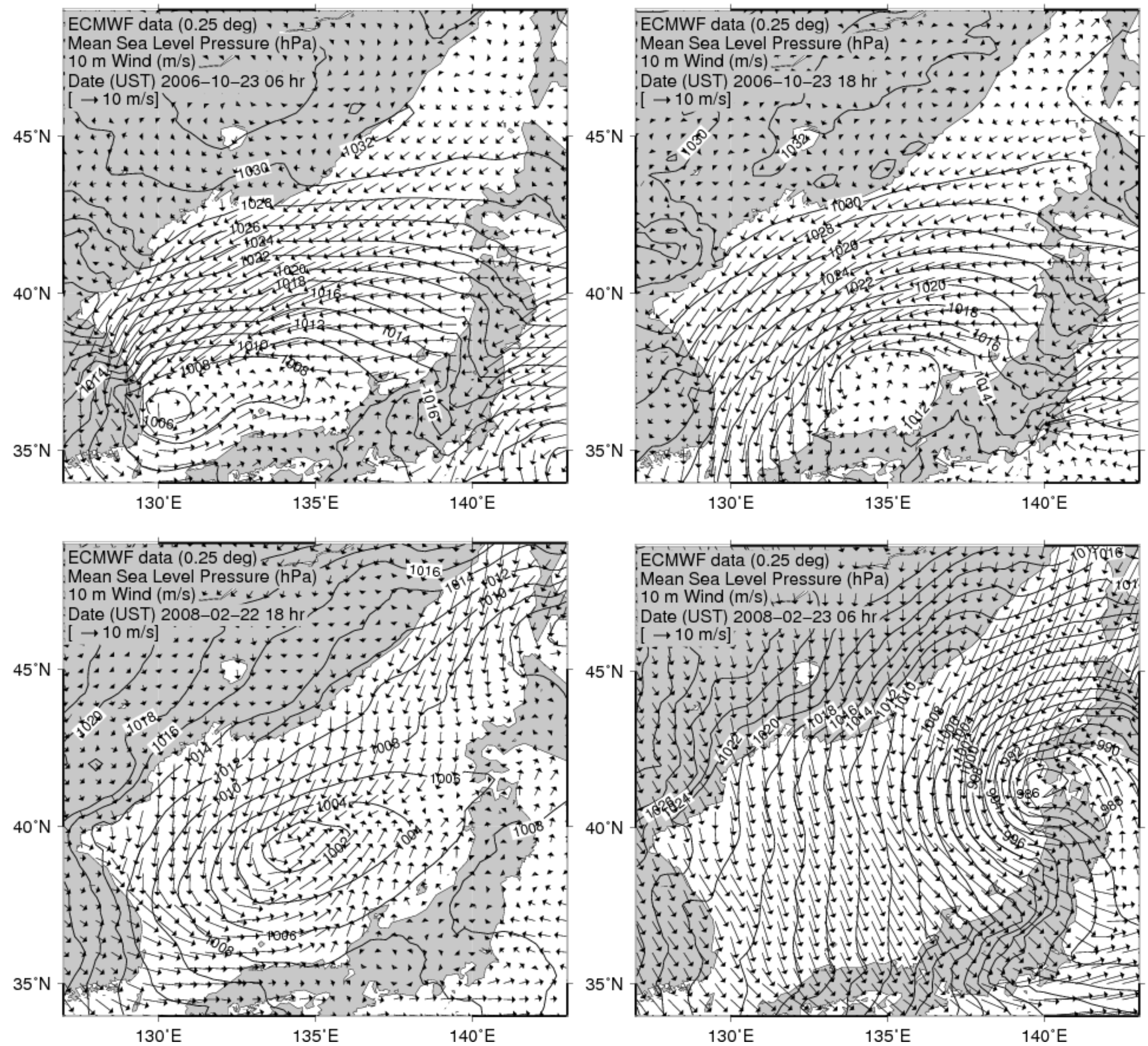


Fig. 2 Wind and pressure fields of ECMWF (top panels: 2006; bottom panels: 2008)

with the breaking index γ=0.73. Bottom friction is based on the JONSWAP formulation (Hasselmann et al. 1973) with friction coefficient C_b=0.067 m^2s^{-3}, and the triad nonlinear interactions are computed with the Lumped Triad Approximation of Eldeberky and Battjes (1996). The SWAN time step is set to 300 seconds. Noting that the relatively coarse resolution in the East/Japan Sea can create spurious wave refraction over one spatial element, though the resolution in the mesh is well-suited to simulate waves and surges along the coastlines east of Korea and north of Japan, we create the mesh using BATTRI taking into account the bottom gradient. Fig. 1 shows the created mesh and model domain. The wind drag coefficient due to Moon et al. (2007) is adopted. In the validation sections that follow, the SWAN wave quantities will be compared to the measured data.

RESULTS

Hindcast of Swell (2006)

Fig. 2 shows the wind fields of ECMWF data on 23 Oct. 2006 in UTC time. In Oct. 2006, an extratropical cyclone was formed near Huanan, China. Moving to the Yellow Sea and traversing the Korean Peninsula, the cyclone entered the East/Japan Sea. The center of the extratropical cyclone was first observed in the East/Japan Sea around 6:00 UST 23 Oct. 2006, and the extratrophical cyclone stayed about 1 day in the East/Japan Sea (Oh et al. 2010).

Abnormally high waves on the east coast of Korea were observed at five field measurement stations and three deep ocean buoys. The occurrence of the high waves might attribute to the development of the strong Donghae cyclonic winds associated with an extratropical cyclone that blew as the swell arrived on the east coast of Korea. At Sokcho, the most northern site of the five measurement stations, the maximum gust speed was 65.7 m/s, with a maximum significant wave height of 9.69 m, and a corresponding peak wave period of 12.8s. The reason for the appearance of the abnormally high waves appears that the propagation of high swells continued while the cyclonic winds blew strongly. Moreover, the fact that the wind direction was the same as the direction of the swell propagation contributes to increasing wave heights through the superposition of the swell and wind-generated waves. Fig. 3 shows the locations of wave observation stations of 2006 and 2008.

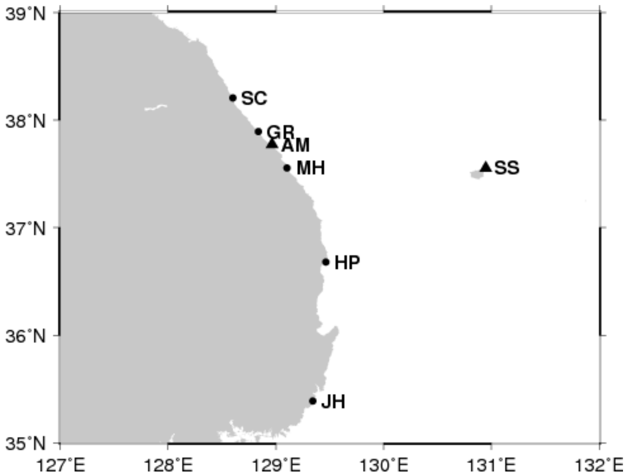


Fig. 3 Location of wave observation stations. Stations marked with circles (2006) and triangles (2008). SC: Sokcho, GR: Ganreung, MH: Mukho, HP: Hupo, JH: Jinha, AM: Anmok, SS: Ssangjeoungcho

Fig. 4 shows the comparison of measured and simulated significant wave heights at five wave observation stations. Although the simulated highest significant wave heights were lower by 1~3 m than observations at Sokcho, Mukho and Jinha, the simulation results were fairly well agreed with observations throughout five stations in terms of time-varying patterns. Especially, the comparisons at Gangreung and Hupo show good results.

Fig. 5 shows the comparisons of measured $T_{1/3}$ and computed peak wave period. All computed wave periods and significant wave heights are shown to be agreeable with observations except for Jinha. It can be seen that at Jinha very small amplitude of waves are observed and computed on 23th. However long wave period over 10 sec is observed while the wave period below 4 sec is calculated. That is, the long period wave with small amplitude south of the East/Japan Sea is not reproduced. Nevertheless our study shows better agreement than the previous study for abnormal swells in the East Coast of Korea in 2006 with FDM-based SWAN by Kim and Lee (2008). It is noted that, although the comparison was made at different stations and hence results are not directly comparable with each othe, the significant wave heights simulated in the previous study was apparently disagreed with observations.

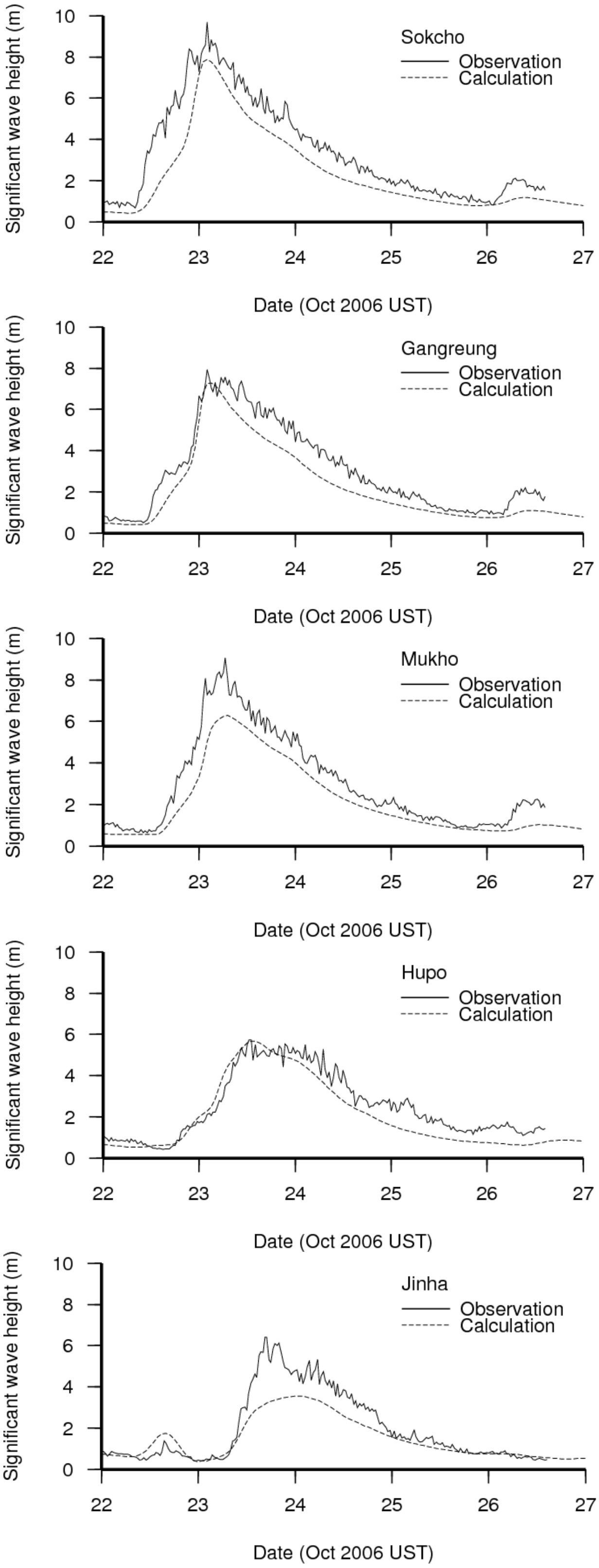


Fig. 4 Comparison of observed and simulated significant wave heights

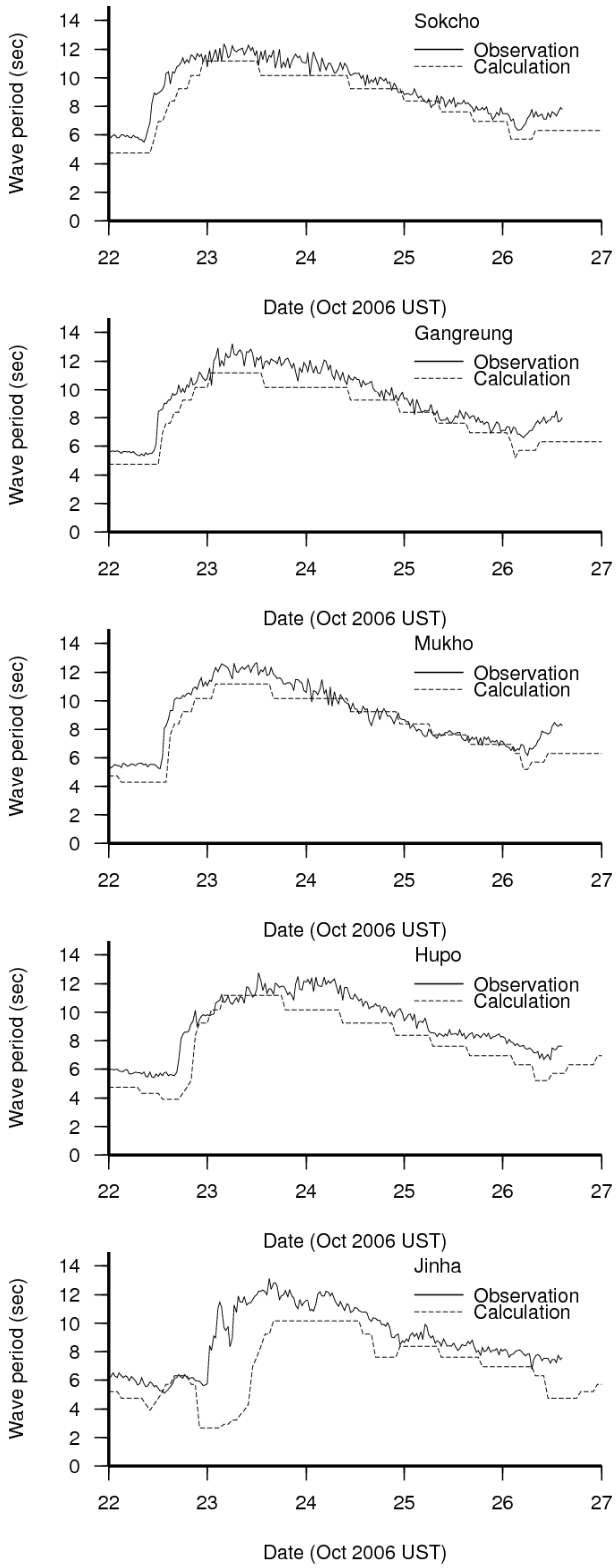


Fig. 5 Comparison of $T_{1/3}$ (observation) and peak wave period (calculation)

Fig. 6 shows the computed 2D variance density spectrum of direction and frequency at Sokcho at the interval of 1 day from 00:00 UST 23 to 26 Oct. 2006.

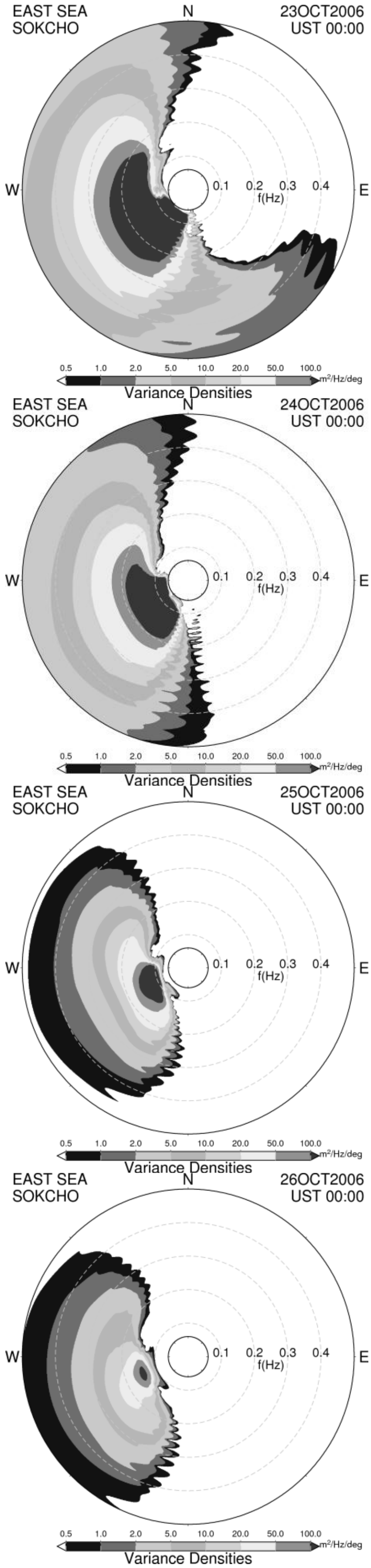


Fig. 6 Computed 2D wave spectrum at Sokcho

In 23th Oct., the strongest wave energy over 100 m2/Hz/Deg are found to be located near the 7~10 hour of clock direction and 0.1~0.2 Hz.

Wave height and period dramatically increase after 12:00 22th and then slowly decrease after 23th when the peak significant wave height of 10 meters was recorded at Sokcho. We note that the decrease of wave height is relatively faster than that of wave period. It appears that far moving low pressure contributes to the development of the steady easterly wind, and thereby the generation of the wave with long period.

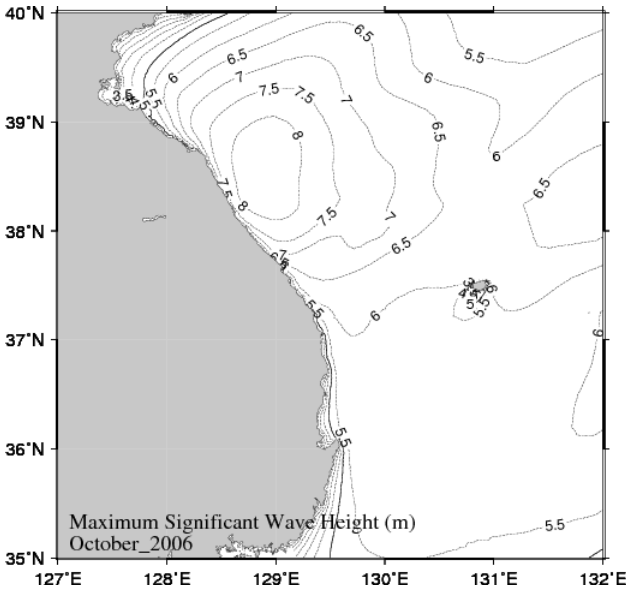


Fig. 7 Distribution of maximum significant wave height in the east coast of Korea in Oct. 2006

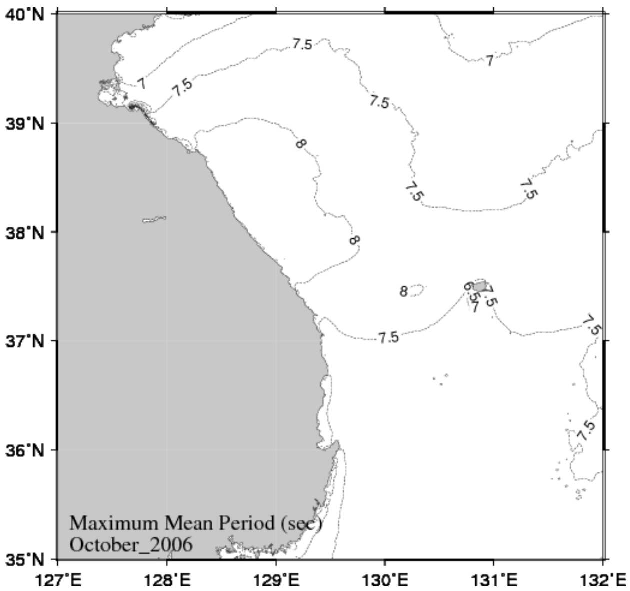


Fig. 8 Distribution of maximum mean period in the east coast of Korea in Oct. 2006

Fig. 7 shows the distribution of computed maximum significant wave heights in the east coast of Korea in October, 2006. It is noted that the highest value over 8 m is found near Sokcho. Fig. 8 presents the distribution of computed maximum mean periods. We have to notice that the mean period can be represented the generalized frequency (period) of whole waves and the peak period showing the frequency band with the highest wave energy. The peak period is better to explain the swell component. The maximum mean period ranges about 4 ~ 9 sec and 7 ~ 9 sec in the East/Japan Sea and the eastern coast of Korea, respectively.

On the east Korean coast, the outbreak of this type of storm wave is very probable during winter; therefore, the establishment of counter measures for minimizing possible damage caused by storm waves has been requested.

Hindcast of Swell (2008)

The wind fields of ECMWF data from 22 to 23 Feb. 2008 UTC are shown in the bottom of Fig. 2. The atmospheric low pressure moved through the East/Japan Sea on 22 Feb and moved out on 24 Feb 2008. Along the Korea coasts, more variable wind patterns are shown than 2006. The northwesterly winds blew strongly at the eastern coast of Korea on 23 Feb. and the winds were observed in the Gangneung meteorological station near Anmok, Korea (Jeong et al. 2007). On 24th Feb. 2008, a high swell wave was generated at the northeastern part of the East/Japan Sea near to Russia and Hokkaido, Japan, which continued for 12 hours due to the passage of the low air pressure through the East/Japan Sea.

For the model validation, the simulated significant wave heights were compared with the observations at Ssangjeongcho and Anmok. The bouy of Ssangjeongcho is located in the open ocean near Ullengdo, the island in the East/Japan Sea far-off from mainland of Korea. The high waves of 9 m in Ssangjeongcho and the 4 m in Anmok show the peak wave period of 14 sec. Except for the high wave with the long period over 10 sec on earlier 24th, the computations are generally well agreeable with the observation (Fig. 9 and 10).

The direction of wind in Anmok was rotated south to north in clockwise direction on 24th, but the direction of wave remained south-west continuously. This means that the swell wave component was not generated by the local wind but propagated from the northeast.

Fig. 12 shows the computed energy density spectrum in 1 day interval from 00:00 UST on 23 February 2008, and indicates that the swell-like wave directed to the southwest mainly came from the northeast. The short period waves to south direction with the frequency of 0.2~0.25 Hz are generated by local wind on 26th.

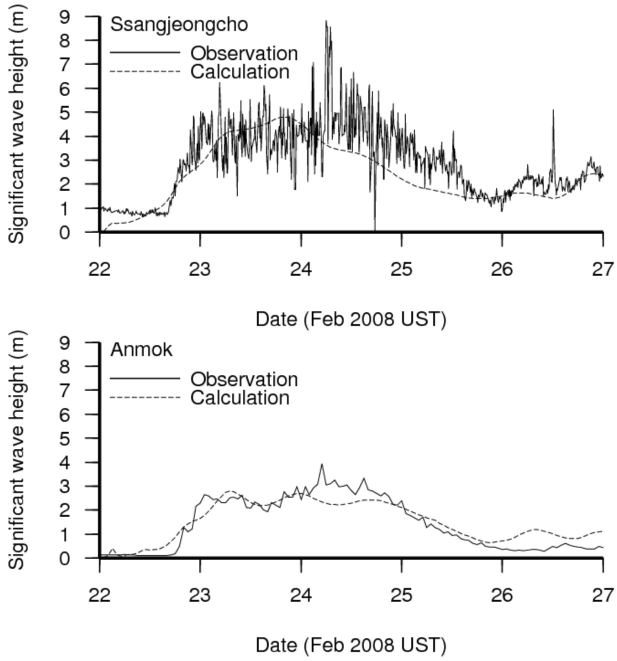


Fig. 9 Comparison of observed and simulated significant wave height

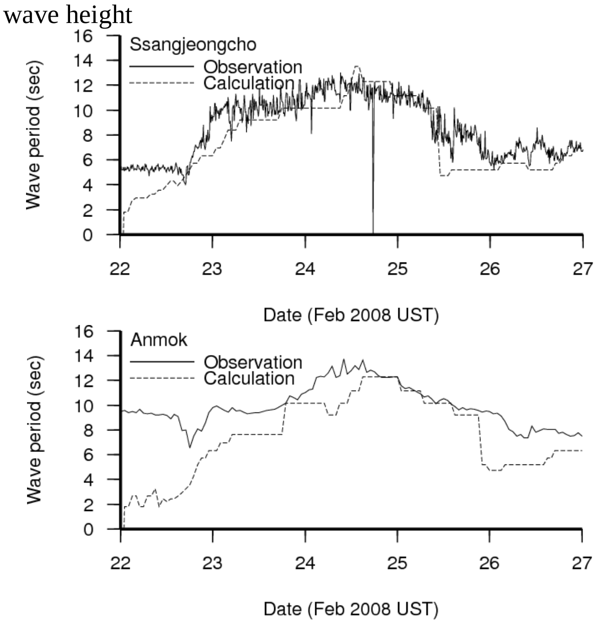


Fig. 10 Comparison of $T_{1/3}$ (observation) and peak wave period (calculation)

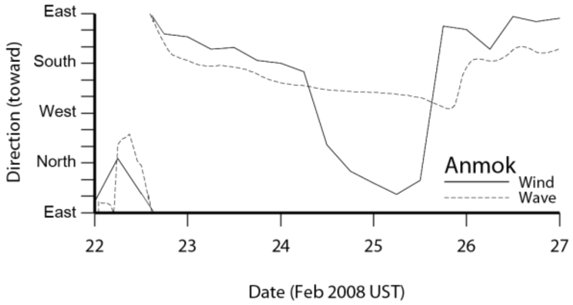
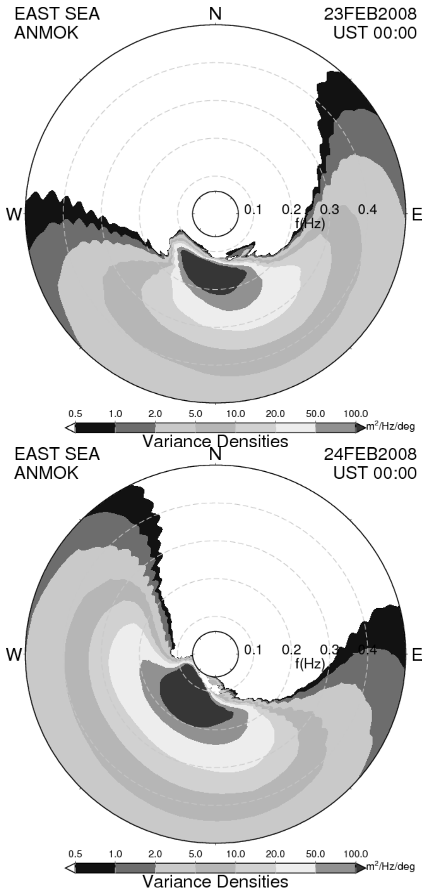


Fig. 11 The head direction of wind and mean wave in Anmok



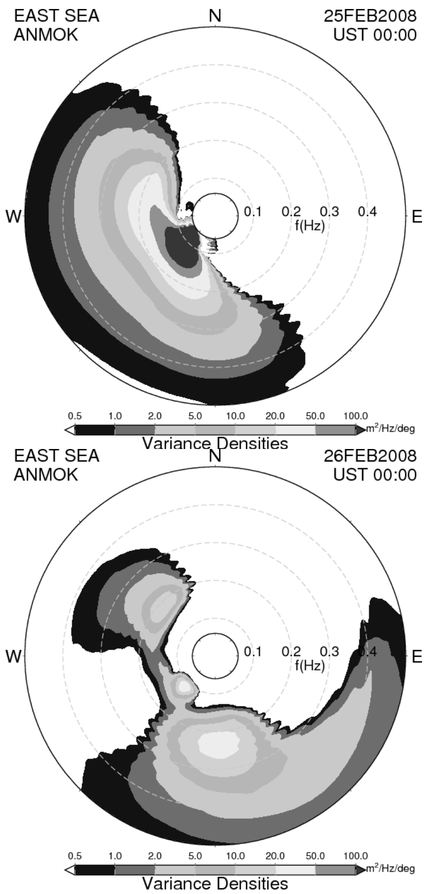


Fig. 12 Computed 2D wave spectrum at Anmok

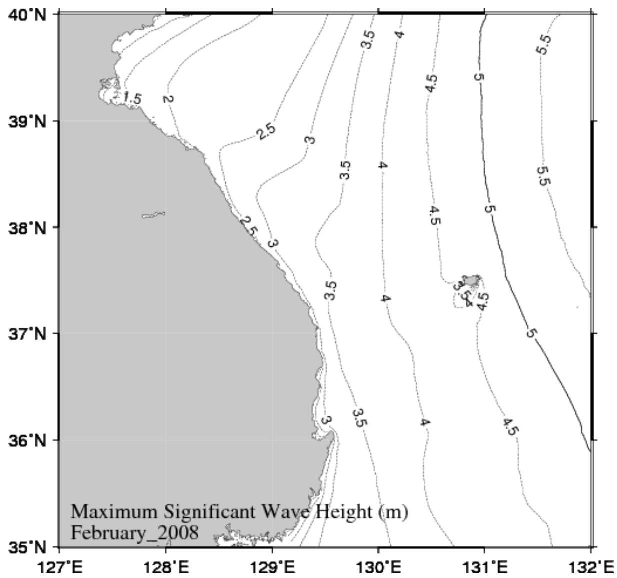


Fig. 13 Distribution of maximum significant wave height in the east coast of Korea in Feb. 2008

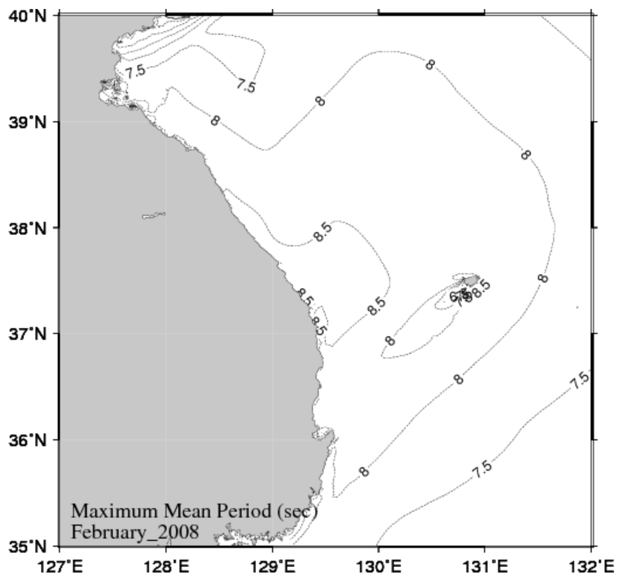


Fig. 14 Distribution of maximum mean period in the east coast of Korea in Feb. 2008

Fig. 13 and Fig.14 show the distribution of computed maximum significant wave heights and computed maximum wave periods in Feb. 2008, respectively. We can see that results are comparable with observations. The maxima of about 3 m and 8 sec are observed in the east coast of Korea.

CONCLUSIONS AND DISCUSSION

This paper showed the results of the high swell wave simulation occurred in the East/Japan Sea in 2006 and 2008. In 2006, the hindcast of the wave heights and periods were well reproduced comparing with the observed values. The simulation also quite well reproduced the event of 2008 which involved combined occurrence of a locally generated wind wave and swell propagated over a long distance, but more enhancements are needed. In the case of swell propagation over very long distances, low diffusive higher order schemes for the geographical propagation terms are required. Another issue concern with the swell propagation was dissipation term, especially the whitecapping term related to the wave period in spectral energy equation. There is a tendency of under-predicting periods when the default SWAN model is used.

In combined swell-sea situations, Donelan (1987) suggested that the presence of low-frequency waves may actually reduce the growth of the wind-sea part of the spectrum, while the swell energy is not dissipated. Also many modifications to the whitecapping expression have been proposed in the literature to improve the simulation results of wave numerical models.

In combined swell-sea situations. Holthuijsen and Booij (2000) suggest that the dependence of wind-sea dissipation on swell in the Komen et al. (1984)

expression be removed by making the dissipation at a particular frequency a function of the mean wavenumber and steepness of only the frequencies higher than itself. This method succeeds in removing the dependence of wind-sea dissipation on swell, but does not appear to be based on any physical considerations. Furthermore, this method retains the problem of enhanced dissipation of swell in the presence of wind-sea. Hurdle and Van Vledder (2004) propose an opposite approach (the so-called Cumulative Steepness Method, CSM), and demonstrate that their dissipation source term successfully decouples the growth of wind-sea from the presence of low-energy swell, but their model variant does not reproduce fetch-limited growth curves for pure wind-sea very well. Rogers et al. (2003) propose to disallow the dissipation of swell energy, so that the dissipation of swell in combined swell-sea conditions is prevented. Kim et al. (2011) showed the efficiency of computed wave period on the weighting factors but not enough to verify the other parameters. There is always room to improve numerical schemes; thus, the advanced spectral wind wave model is needed to understand the swell of the East Sea.

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REFERENCES

Battjes, J.A. and Janssen, J.P.F.M. (1978). Energy loss and set-up due to breaking of random waves. Proc. 16th Int. Conf. Coastal Engineering, ASCE:569-587.

Donelan, M.A. (1987). The effect of swell on the growth of wind waves. Johns Hopkins APL Technical Digest, 8(1):18-23.

Eldeberky, Y. and Battjes, J.A. (1996). Spectral modelling of wave breaking: Application to Boussinesq equations. J. Geophys. Res., 101(C1):1253-1264.

Hasselmann, K. et al. (1973). Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP), Dtsch. Hydrogr. Z. Suppl., 12(A8):1-95.

Holthuijsen, L.H. and Booij, N. (2000). Oceanic and nearshore whitecapping effects in SWAN. Proc. 6th Int. Conf. on Wave Hindcasting and Forecasting, 362-368.

Hurdle, D.P. and van Vledder, G.Ph. (2004). Proc. 23rd Int. Conf. on Offshore Mech. and Arctic. Eng.

Jeong, W.-M., Oh, S.-H. and Lee, D.Y. (2007). Abnormally high waves on the East Coast (in Korean with English abstract). J. Korean Society of Coastal and Ocean Engineers, 19:295-302.

Jeong, W.-M., Oh, S.-H. (2009). Abnormal swells occurred in the east coast of Korea in recent years. Proceeding of the Korean Association on Ocean Science and Technology Societies, 2119-2122 (in Korean).

Kim, K.O., Lee, H.S., Min, B.I. and Choi, B.H. (2011). Hindcasting of High swell waves off the eastern Korean coast on 24 February 2008 using structured and unstructured wave models. J. Coastal Research, SI64:1073-1077.

Kim, T.-R. and Lee, K.-H. (2008). Examinations on the wave hindcasting of the abnormal swells in the East Coast (in Korean with English abstract). J. Korean Society of Ocean Engineers, 22:13-19.

Komen, G. J., Hasselmann, S. and Hasselmann, K., (1984). On the existence of a fully developed wind-sea spectrum. J. Phys. Oceanogr., 14: 1271- 1285.

Moon, I. J., Ginis, I., Hara, T. and Thomas, B., (2007). A Physics-based parameterization of air-sea momentum flux at high wind speeds and its impact on hurricane intensity predictions. Monthly Weather Review, 135:2869-2878.

Oh, S.-H., Jeong, W.-M., Lee, D.Y., Kim, S.I. (2010). Analysis of the reason for occurrence of large-height swell-like waves in the east coast of Korea. Journal of Korean Society of Coastal and Ocean Engineers 22(2):101-111 (in Korean with English abstract).

Rogers, W.E., Hwang, P.A. and Wang, D.W. (2003). Investigating of wave growth and decay in the SWAN model: three regional-scale applications. J. Phys. Oceanogr. 33:366-389.