NUMERICAL STUDY OF WAVE-CURRENT INTERACTION USING HIGH RESOLUTION COUPLED MODEL IN THE KUROSHIO REGION

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1. INTRODUCTION

Global and regional wave forecasts are routinely conducted nowadays thanks to advances in numerical weather prediction, satellite scatterometers and computers. The demand for further improvements in such models comes from engineering communities, as well as climate research communities. A number of researchers have suggested the possibility of wave concentration caused by the ocean current. But because of the lack of high resolution current forecast in the open ocean, most wave forecast models do not include the wave–current interaction.

There are a few examples demonstrating the significance of wave-current interactions. Janssen et al. (2005) have investigated the impact of currents on the significant wave height with a global model. The monthly mean wave height difference with and without current highlights the major current of the ocean. A more regional study was conducted for the strong western boundary currents. Tolman et al. (1994) showed that the wave height was enhanced for wave traveling against the Gulf Stream and currents had a distinct effect on the wave spectrum. Similarly, Wolf (2003) has demonstrated the impact of the meandering Kuroshio with a 1/32 degree resolution wave model coupled to the ocean model OCCAM.

WAVE-JCOPE project aims to establish a realistic high-resolution coupled current-wave prediction model in the Kuroshio region. The current field is prescribed by the Japan Coastal Ocean Predictability Experiment (JCOPE) model developed at Frontier Research Center for Global

Change (Guo et al., 2003; Miyazawa et al., 2004). In this study, we focus on the influence of ocean current upon waves around the strong jet of the Kuroshio, by using high resolution wave model and existing reanalysis products of wind and current.

2. NUMERICAL MODEL

The wave model employed in the wave-current coupling is based on the third-generation wave model WAVEWATCH-III (Tolman, 2002). The source terms of WW-III use the wind input expressed Snyder et al. (1981), the nonlinear wave–wave interaction of Hasselmann and Hasselmann (1985), the dissipation by Janssen (1991), and the bottom friction based on the JONSWAP parameterization (Hasselmann et al., 1973). The wave model is driven by 6 hourly wind stress (1/8 - 1/10 degree resolution) estimated from Japan Meteorological Agency Meso-scale Spectral Model and the 2-day mean current field from the JCOPE reanalysis linearly interpolated at every integration time steps.

JCOPE model is based on the Princeton Ocean Model (POM); a high-resolution regional model (117E to 180E and 12N to 62N, at 1/12 degree resolution) is embedded in a low-resolution basin-wide model (1/4 degree resolution) and assimilates Sea Surface Height, Argo and T & S from various sources. The model has successfully predicted the appearance of a large meander of the Kuroshio in 2004. The two-month forecasts as well as the reanalysis data are available from the web page which is updated weekly (http://www.jamstec.go.jp/frsgc/jcope/).

Figure 1 shows the computational domain of the wave model(120^o-149^o E, 23^o-46^o N). The spatial resolution is $\Delta x = \Delta y = 1/12^o$ and the model has 348×276 grid elements. The wave spectrum is discretized using 36 directions ($\Delta\theta = 10^o$) and 25 frequencies extending from 0.042 to 0.414 Hz with a logarithmic increment.

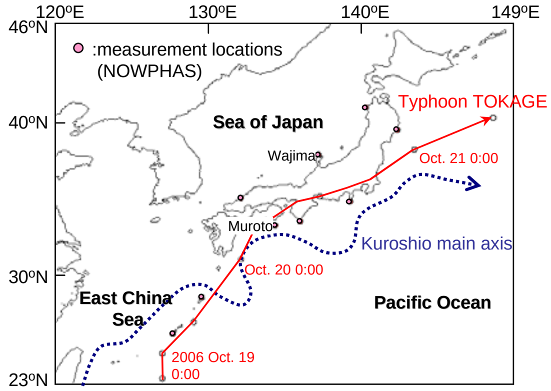


Fig. 1. Study site and the computational domain.

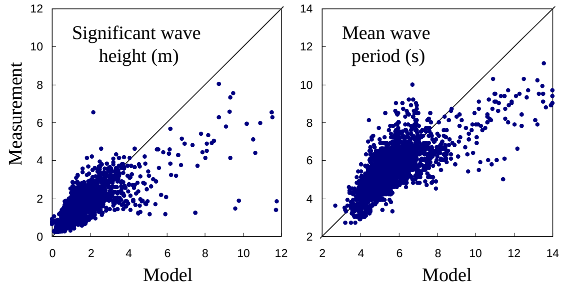


Fig. 2. Comparison between model analysis and measurement data.

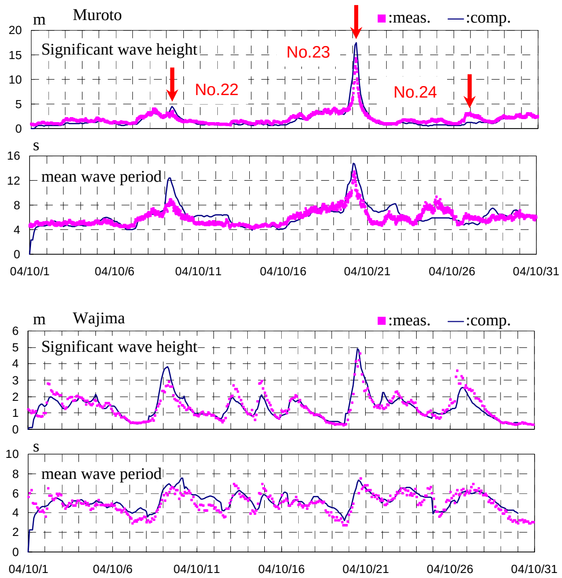
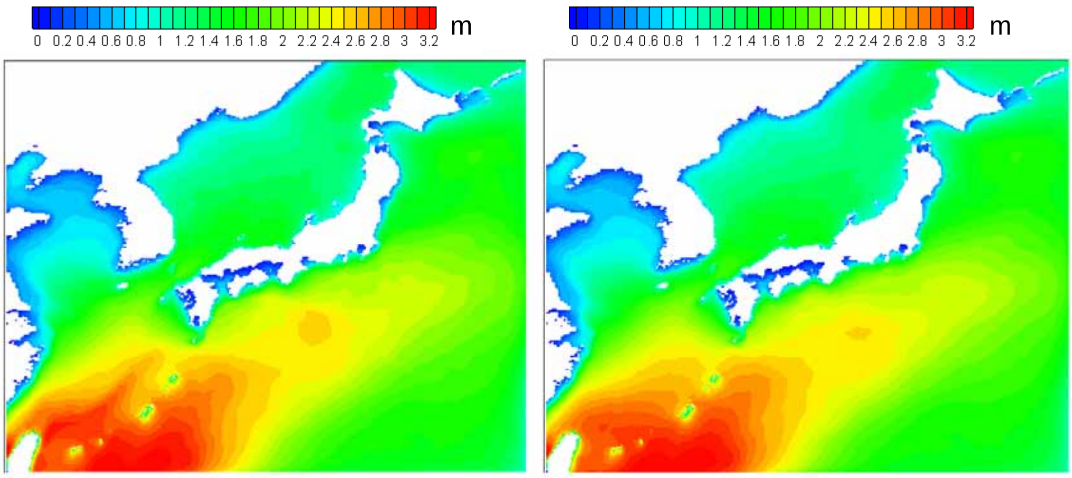


Fig. 3. Time variations of significant wave height and mean wave period compared with measurement data at two locations.

In this study, we present a case study of the October 2004 which was an unusual month with 3 consecutive typhoons (Typhoon 22, 23, 24) struck Japan. We pay special attention to the Typhoon



(a) (b)

Fig. 4. The monthly-average spatial distribution of the significant wave height (a) with and (b) without current

23, nickname TOKAGE, because one of the buoy located at Muroto (shown in Fig.1) has indicated an occurrence of an extreme wave of over 25 m wave height.

3. MODEL RESULTS

For the validation of the model, NOWPHAS (Nationwide Ocean Wave information network for Ports and HArbourS;http://nowphas.org/eng.html) data were compared, which were obtained at 9 stations (in Fig. 1) where water depth was larger than 50m. Figure 2 shows the comparison of significant wave height and mean wave period between model analysis and measurement data. It is clear that the present model can reproduce the measured results for relatively low wave height conditions.

Figure 3 shows the time series of measurement data and corresponding computational results of significant wave height and mean wave period at two locations. These are the three typhoons causing large anomalies in the record.

4. DISCUSSION

To investigate the impact of wave-current

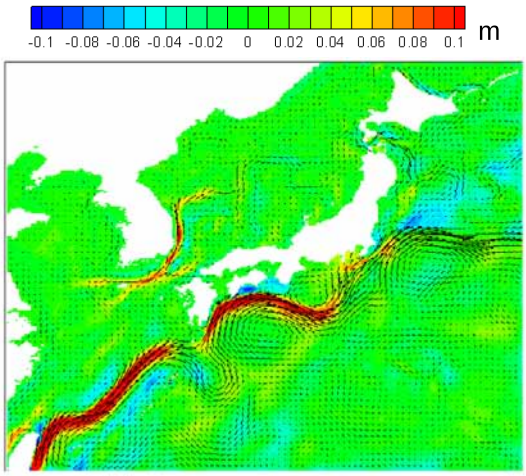


Fig. 5. The monthly-averaged current field and the difference of the significant wave height

interaction, the simulation has been performed with two numerical experiments with and without current. Figure 4 (a), (b) and 5 show the monthly-average spatial distribution of the significant wave height with and without current and the difference between them, respectively. The difference of the significant wave height over the Kuroshio is quite eminent.

To clarify the cause of such difference, we investigated the temporal evolution of the wave height difference between the cases with and without current. Figure 7 represents the wave height difference and surface wind vector when Typhoon TOKAGE passed around JAPAN.

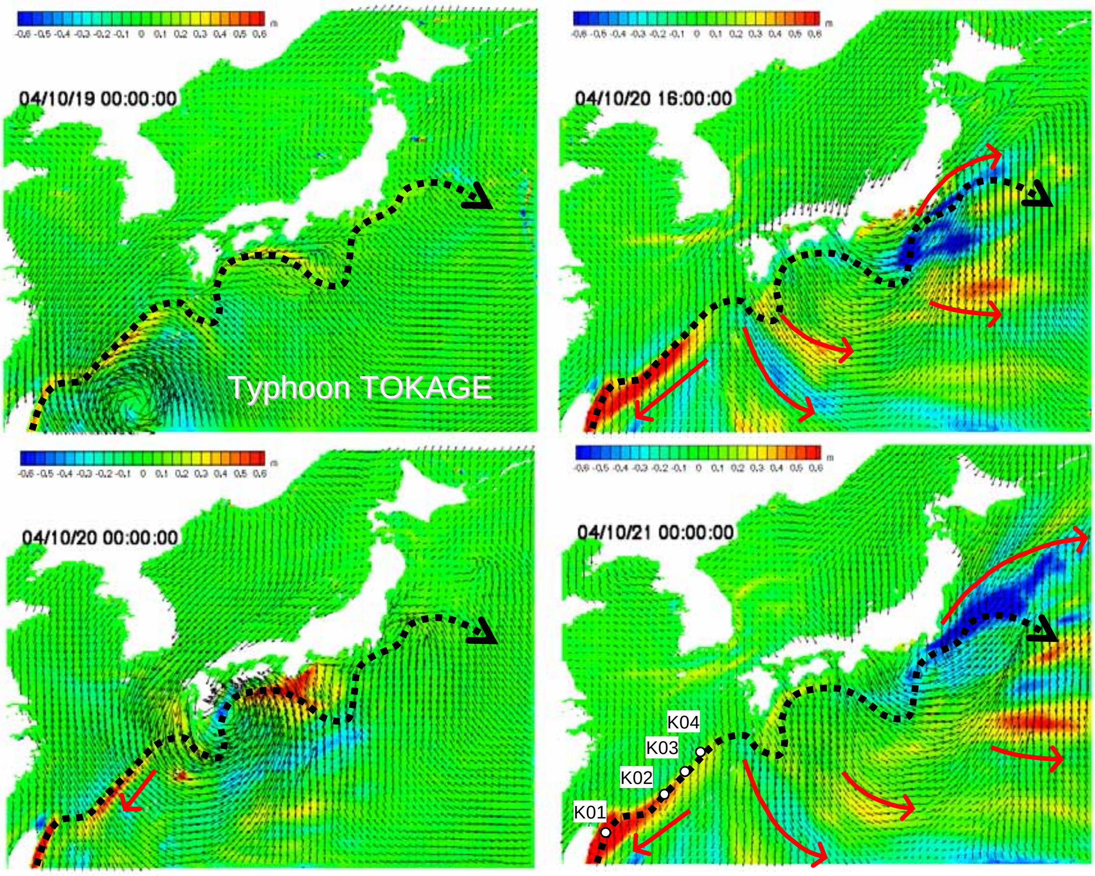


Fig. 6. The temporal evolution of the wave height difference between the cases with and without current.

Associated with the changes of both the surface wind and the current, the wave-current interactions seem rather complicated. During the early stage, Typhoon TOKAGE passed south part of Kuroshio main axis. In contrast, during the late stage, it passed north part. Corresponding to these relative positions between Typhoon path and Kuroshio main axis, the convergence of wave propagation in the countercurrent region and wave divergence in the following current region are recognized.

Moreover, these differences are extending for quite a distance away from the Kuroshio downwind. This indicates that the effect of the wave-current interaction is not limited locally but extends further away from where the interactions actually occur. As demonstrated here, the effect of wave-current interaction is highly sensitive to the small current structure, and therefore the realistic representation of the current field is very important for high-resolution wave forecast.

Figure 7 represents the time series of the wave height difference at 4 locations indicated in Fig 6. The difference of the significant wave height increases along the Kuroshio main axis and reaches 1.4m (This value is about 30% of the significant wave height) at K01. Figure 8 (a) and (b) indicate the directional wave spectra calculated with and without wave–current interactions at K01 (Oct. 21 0:00). One obvious effect is that wave energy to south-southwestward direction is added to the south-westward spectrum for Fig.8 (a) and it creates a second peak in the spectrum, increasing the directional spreading. This component may be considered as the trapped wave by Kuroshio. Another effect is the veering of the wave by the current. The wave corresponding to the main peak of the spectral is directed clockwise by the Kuroshio. The difference of the significant wave height and the

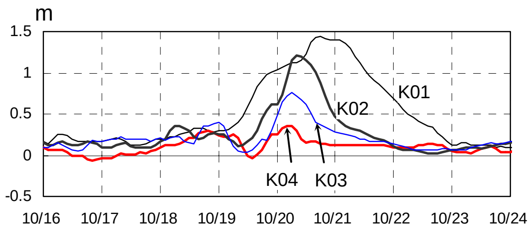


Fig. 7. Time series of the wave height difference at 4 locations

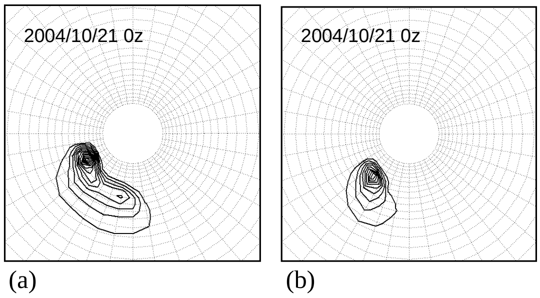


Fig. 8. Directional wave spectra calculated (a) with and (b) without wave–current interactions at K01.

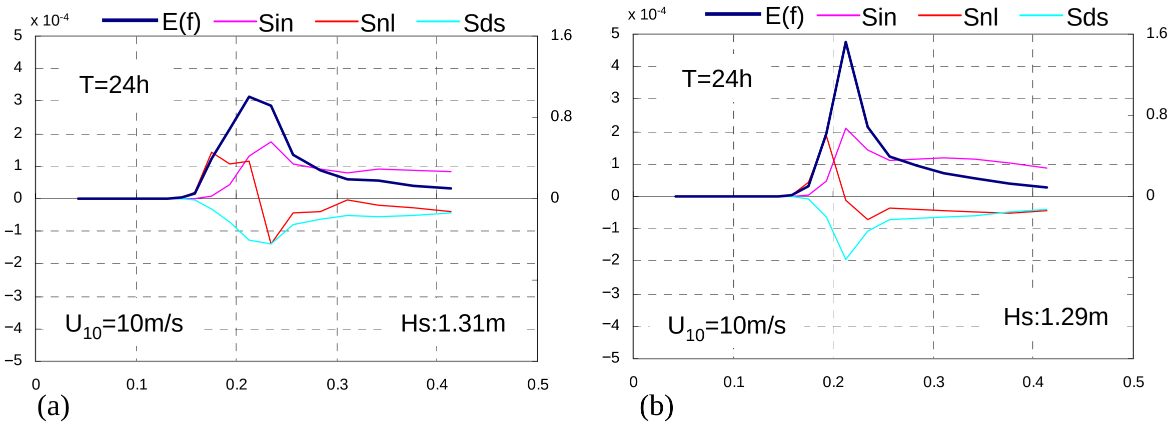


Fig. 9. One-dimensional frequency spectrum and the energy source terms calculated by (a) DIA and (b) SRIAM as the non-linear interactions.

profile of the wave spectral over the Kuroshio are quite eminent and are in accord with the earlier work of Holthuijsen & Tolman (1991).

5. CONCLUSION AND DISCUSSION

In this study, we have presented the hindcast results as the preliminary results of WAVE-JCOPE project. Comparing the monthly-averages with and without current, the difference of the spatial distribution of the significant wave height, over the Kuroshio is quite eminent. Moreover, instantaneous differences extend for quite a distance away from the Kuroshio downwind suggesting that the effect of the wave-current interaction is not limited locally to where the interactions actually occur. The shapes of the directional wave spectra calculated with and without wave–current interactions are also quite different.

In the presentation, we will discuss the balance of the energy source terms with and without current, and apply different numerical schemes such as RIAM (Komatsu and Masuda, 1996) for calculating the accurate nonlinear energy transfer, to improve the estimation of the wave-current interaction.

The following methods for computing the nonlinear source terms were compared; DIA, WRT, RIAM and S-RIAM. While DIA and WRT are standard modules of WWIII, both RIAM and S-RIAM were implemented in this study as new modules for the WWIII. We conclude the discussion by showing one result from the case of fetch-limited wave. Figure 9 indicates the one-dimensional frequency spectrum and the energy source terms calculated by (a) DIA and (b) SRIAM as the non-linear interactions. The CPU time of SRIAM is about 15 times longer than DIA. It is emphasized that energy spectral level for peak frequencies and frequency bandwidths are completely different for two cases. In addition to the effect of wave-current interactions for spectral shape, these differences results in the modification of the average steepness and the frequency bandwidth that are the two important parameters considered to alter the wave statistics from the Rayleigh distribution. The parameter often used these days is called the Benjamin-Feir Index and this is in the interest of identifying seas with high chances of extreme event.

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