Effect of oceanic current on typhoon-wave modeling in the East China Sea*

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(Received 10 February 2012; revised manuscript received 28 June 2012)

We use the WAVEWATCH-III model to quantify the effect of oceanic current on typhoon-wave modeling in the East-China-Sea (ECS). Typhoons Jelawat and Saomai in the autumn of 2000 are hindcasted. The oceanic currents in the ECS are mainly constituted of Kuroshio and typhoon-generated currents. The results show distinguishable differences in wave height and wave period under the typhoon conditions. The oceanic current causes the maximum differences, of up to a 0.5 m significant wave height and a 1 s mean wave period. Comparisons between typhoons Jelawat and Saomai show the dependence of the current effect on the typhoon characteristics.

Keywords: wave-current interaction, East China Sea, typhoon wave, WAVEWATCH-III

PACS: 92.10.Hm, 92.10.Fj, 92.40.Cy, 92.60.Qx **DOI:** 10.1088/1674-1056/21/10/109201

1. Introduction

Wind-generated wave modeling, especially typhoon-wave (TW) modeling, is a critical issue in oceanic forecast research.[1] The TW forecast gives essential information on ocean-based safety protection, coastal engineering, offshore developments, etc. In addition, considering the important role of the surface wave on both upper-ocean dynamics and air–sea interactions,[2−4] TW modeling is also treated as a fundamental project in physical oceanography.[5−7]

TW modeling always concerns the third-generation wave spectrum model,[1,8] which processes the wave spectrum with refined source functions. Physically speaking, a TW is mainly generated by wind forcing, and wind controls the generation and development of the TW. However, the refraction effect from the oceanic surface current and sea level has a potential impact on TW modeling. This is why WAVEWATCH-III (henceforth WW3[9]) was developed.

The East China Sea (ECS) is always intruded by a typhoon from the North West Pacific. Furthermore, the ECS is a marginal sea with complex ocean current formation. One important western boundary current named Kuroshio passes through the ECS along the shelf. Although WW3 is widely used in TW modeling of the ECS only under wind forcing,[10,11] the refraction effects of the background oceanic current on the TW modeling are still not very clear. Tamura *et al.*[12] focused their research on the current-induced modulation of the wave spectrum, and their study concentrates the source term of nonlinear transfer in WW3 but does not include the TW response to different typhoon conditions. Hence, we will address this issue, and discuss the effect of oceanic current on TW modeling in the ECS.

This paper is orgnized as follows: In Section 2, we show the data and the model configuration. Section 3 shows the results of the TW modeling with and without the background current, and Section 4 is the discussion on the TW response to different typhoon conditions. Section 5 gives the conclusions.

*Project supported by the Public Science and Technology Research Funds of Ocean (Grant No. 201105018), the Young Scientist Fund of the National Natural Science Foundation of China (Grant No. 41106019), the Natural Science Foundation of Jiangsu Province of China (Grant No. BK2012315), and the Young Scientist Fund of State Oceanic Administration, China (Grant No. 2011258).

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2. Model description

2.1. Model domain

We set the model domain as [117° E–131° E]×[24° N–41° N], which covers the East China Sea. We use the ETOPO5 data from the National Geophysical Data Center of National Oceanic and Atmospheric Administration as our water depth (data resolution is 5 min), and its bathymetry is shown in Fig. 1. The model spatial resolution is 0.17° with a longitude-latitude grid. The model runs from 2000/07/01 to 2000/10/31. At the same time, the wave buoy (B22001) from the Japan Meteorological Agency (JMA), which is located at [126.33° E, 28.17° N], supplies us with the wind and wave data.

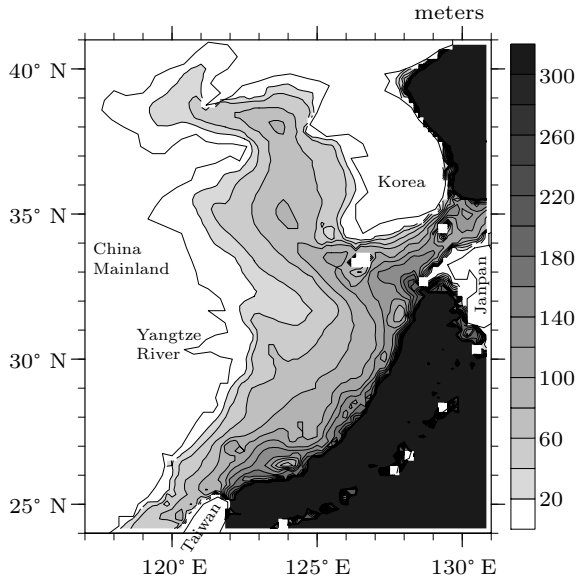


Fig. 1. Bathymetry of the East-China-Sea.

2.2. Wind input

We use the wind forcing from the Cross-Calibrated Multi-Platform (CCMP), characterized by high temporal and spatial resolution (6-hours, and 0.25° × 0.25°, http://podaac.jpl.nasa.gov). Figures 2 and 3 show the wind field during the typhoons Jelawat and Saomai, which show the best track of tropical cyclones from the China Meteorological Administration (www.typhoon.gov.cn). The grade of tropical cyclones follows the National Standards of P. R. China (GB/T 19201-2006).

Figures 2 and 3 show that the typhoon centers from CCMP Are consistent with the best track routine. The general agreement between the CCMP and

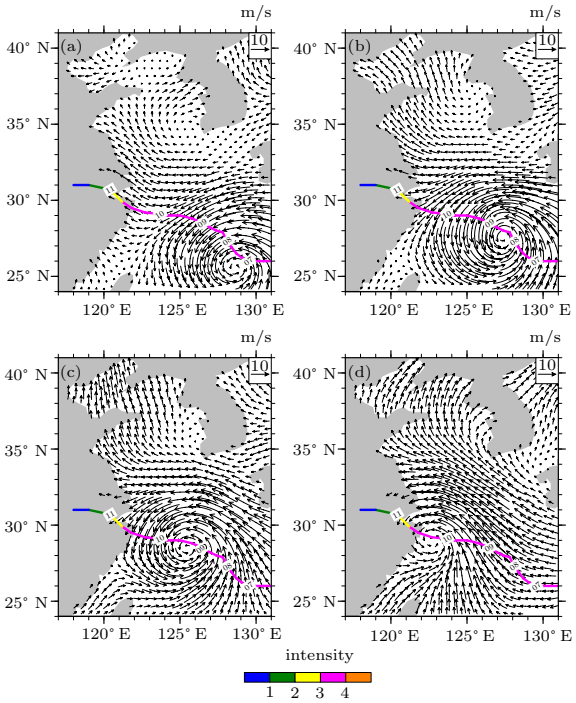


Fig. 2. (colour online) Wind field of typhoon Jelawat at (a) 2000/08/07 00:00:00, (b) 2000/08/08 00:00:00, (c) 2000/08/09 00:00:00, and (d) 2000/08/10 00:00:00. The best track of typhoon Jelawat and the date (days in August) from the China Meteorological Administration are shown, and its intensity is indicated near the bottom of the panels.

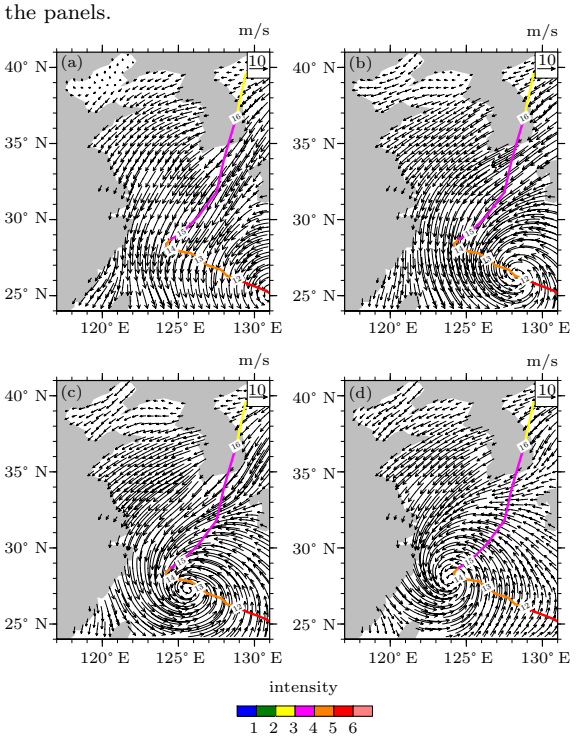


Fig. 3. (colour online) Wind field of typhoon Saomai at (a) 2000/09/11 00:00:00, (b) 2000/09/12 00:00:00, (c) 2000/09/13 00:00:00, and (d) 2000/09/14 00:00:00. The best track of typhoon Saomai and the date (days in September) from the China Meteorological Administration are shown, and its intensity is indicated near the bottom of the panels.

buoy measurement also gives us the confidence in the wind field, as shown in Figs. 4(a) and 4(b). Note that the CCMP wind underestimates the wind speed during typhoon Jelawat, which means that the typhoon center does not pass through the wave buoy, and the typhoon track given by CCMP is not realistic. Another important feature is that the wind field in the ECS just prior to typhoon Jelawat occurring is significantly weak in comparison with that of Saomai. The north–east monsoon during typhoon Saomai is supposed to generate a stronger surface current along its directions.

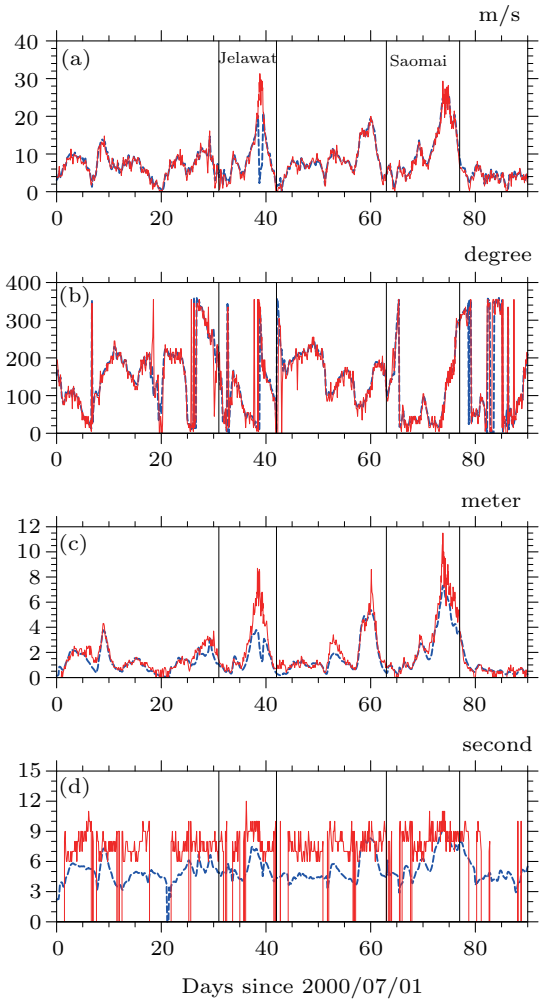


Fig. 4. (colour online) Time series of (a) wind speed, (b) wind direction, (c) significant wave height, and (d) mean wave period. The measurements in a buoy station from the JMA are denoted by red solid lines, and the model input and output are blue dashed lines.

2.3. Background surface current

We use the surface currents from a diagnostic model (SCUD)[13] as our background surface current, which is provided by the Asia Pacific Data Research Center (APDRC) and International Pacific Research Center (IPRC). SCUD is mainly based on the drifter trajectories, and also considers the local horizontal pressure gradient and the local surface wind. Although the SCUD has some uncertainty in the surface current, we believe that its daily products can give us useful information different to the re-analysis products from the numerical models, it is at least survey based.

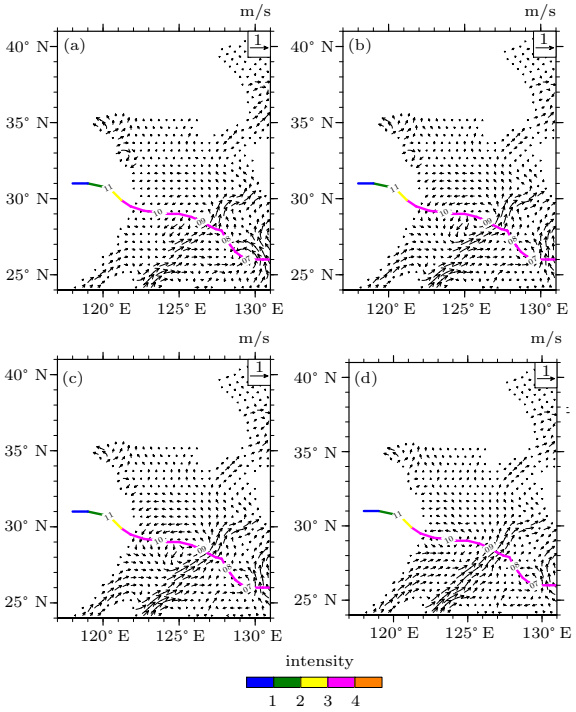


Fig. 5. (colour online) As in figure 2, but for the oceanic surface current from SCUD.

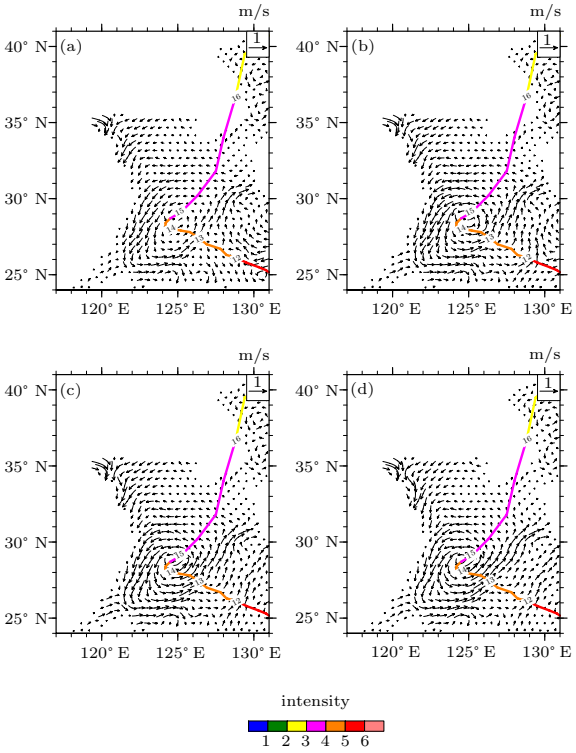


Fig. 6. (colour online) As in figure 3, but for the oceanic surface current from SCUD.

Figures 5 and 6 show the surface current during typhoons Jelawat and Saomai respectively. Kuroshio is still the main current in the ECS, and its velocity exceeds 1 m/s on its main pathway. The typhoon coherent current is nearly 0.5 m/s around its eye. The typhoon-induced current of Saomai is more significant than Jelawat, possibly due to the contribution from the current field prior to the typhoon.

3. Results

3.1. Wave height

Figure 7 gives the significant wave height during typhoon Jelawat from our WW3 simulation. It demonstrates the developing and decaying of the TW, and shows the maximum significant wave height exceeding 4 m. Figure 8 is the difference in significant wave height with and without background surface currents. Note that the significant wave height always increases (decreases) when the typhoon wind direction is along (against) the background ocean current.

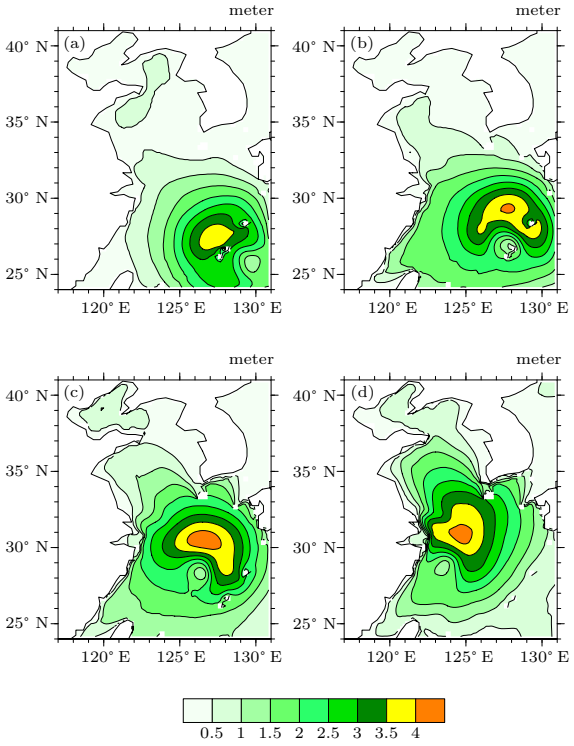


Fig. 7. (colour online) Significant wave height during typhoon Jelawat at (a) 2000/08/07 00:00:00, (b) 2000/08/08 00:00:00, (c) 2000/08/09 00:00:00, and (d) 2000/08/10 00:00:00.

As a main current, Kuroshio produces a significant difference along its axis. Wave height increases (decreases) before (after) the typhoon passes it. The maximum difference due to the influence of surface current occurred on 2000-08-09, just to the east of Taiwan, China. The maximum difference exceeding 0.5 m suggests that the effect of surface current is significant.

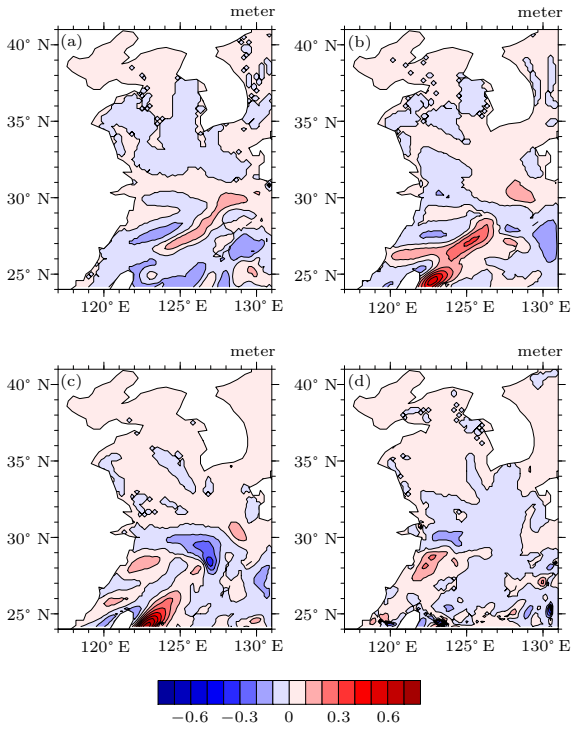


Fig. 8. (colour online) Difference in significant wave height with and without the background surface current during typhoon Jelawat at (a) 2000/08/07 00:00:00, (b) 2000/08/08 00:00:00, (c) 2000/08/09 00:00:00, and (d) 2000/08/10 00:00:00.

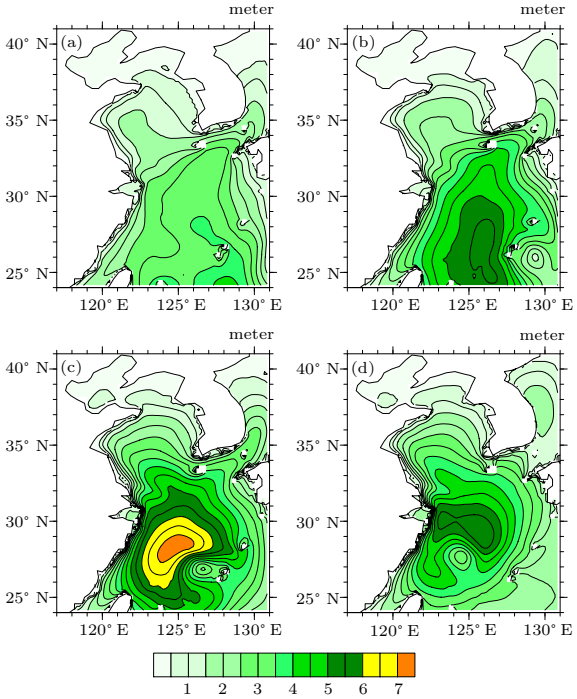


Fig. 9. (colour online) Significant wave height during typhoon Saomai at (a) 2000/09/11 00:00:00, (b) 2000/09/12 00:00:00, (c) 2000/09/13 00:00:00, and (d) 2000/09/14 00:00:00.

Figures 9 and 10 show the significant wave height and the changes due to current during typhoon Saomai. The strong typhoon generates extremely large waves whose significant wave height exceeds 7 m. We obtain a large difference caused by oceanic current, up to 0.6 m on 2000-09-14, to the north–east of Taiwan, China.

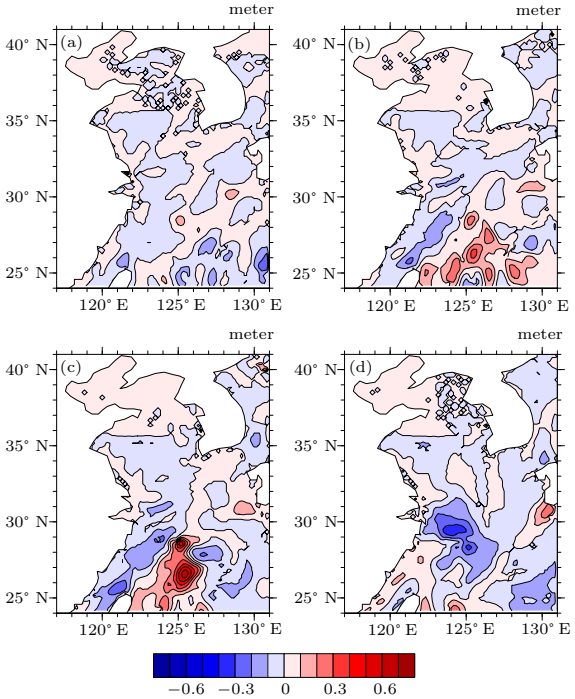


Fig. 10. (colour online) Difference in significant wave height with and without the background surface current during typhoon Saomai at (a) 2000/09/11 00:00:00, (b) 2000/09/12 00:00:00, (c) 2000/09/13 00:00:00, and (d) 2000/09/14 00:00:00.

Figure 4(c) shows comparisons between the WW3 and wave buoy on the significant wave height, where the oceanic current is considered in the WW3 modeling. It is observed that WW3 captures the variance of the significant wave height well. The result of the case without current is not shown, because the difference between them is not distinguishable.

3.2. Wave period

First, we compare the wave period between WW3 and buoy measurement in Fig. 4(d), and it is observed that the wave period of WW3 is significantly less than the measured one. This less than satisfactory performance is mainly caused by swell from the north-west Pacific, which is not involved in the present model. Nesting grid and data assimilation are believed to improve the wave period modeling but are beyond the main topic, and we would like to study this in future work. The difference in wave period with and without the current effect is still not evident on this buoy location (not shown here).

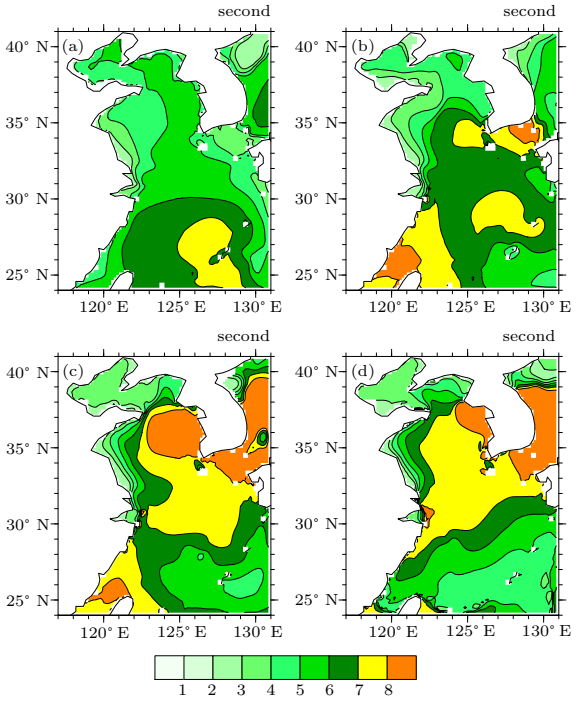


Fig. 11. (colour online) As in figure 7, but for the mean wave period.

Second, we analyze the current effect on the wave period from the WW3 output. The mean wave period of typhoon Jelawat is shown in Fig. 11, and its difference caused by the surface current is shown in Fig. 12. Note that the patterns of significant wave height and mean wave period are different, and the mean wave period shows less dependence on the local wind forcing. The maximum difference of the mean wave period is about 1 s. The significant difference occurs mainly near the boundary, where the developing wave is.

During typhoon Saomai, the mean wave period and its difference due to surface current is shown in Figs. 13 and 14 respectively. The maximum wave period exceeds 10 s, but the difference due to the surface current is less significant than typhoon Jelawat in the ECS. It supports the theory that the impact of surface current on the wave not only depends on the magnitude of current, but also the wave parameter like wave age.

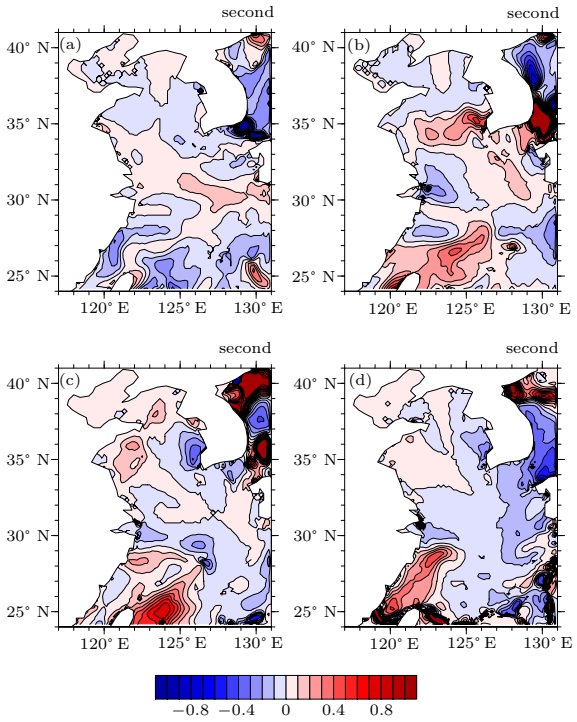


Fig. 12. (colour online) As in figure 8, but for the mean wave period.

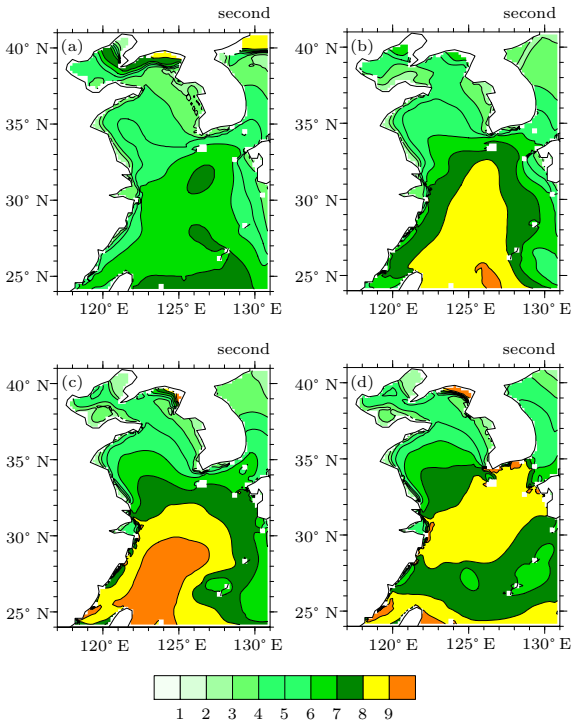


Fig. 13. (colour online) As in figure 9, but for the mean wave period.

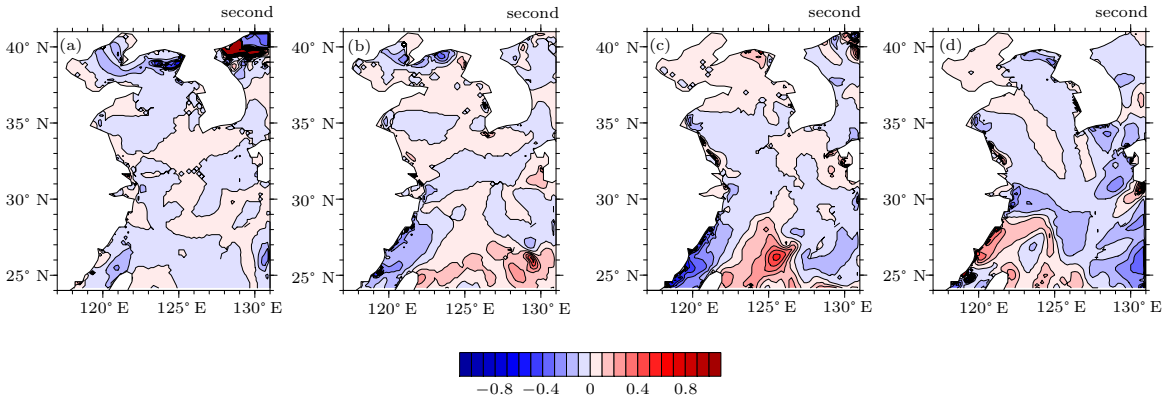


Fig. 14. (colour online) As in figure 10, but for the mean wave period.

3.3. Wave direction

Figure 15 shows the wave direction under typhoon Jelawat. We observe that the wave direction has a vortical feature like the typhoon wind. Thus, the TW is mainly constituted by the wind-waves but not the swell. Figure 16 shows the difference of wave direction due to the surface current. Ocean current changes the wave direction within 15° in most of the ECS before and after the typhoon. When typhoon Jelawet just passes the Kuroshio (2000-08-09, 00:00:00), the oceanic current produces positive and negative changes before and after the eye of typhoon along the Kuroshio axis from south to north. After the typhoon Jelawat reaches land (2000-08-10, 00:00:00), a big difference up to 30° is observed just north of Taiwan, China.

Figures 17 and 18 are the mean wave direction and its difference under typhoon Saomai. We observe the curl of wave direction again, and also the positive (negative) feedback before (after) the typhoon eye hits, along the Kuroshio axis from south to north.

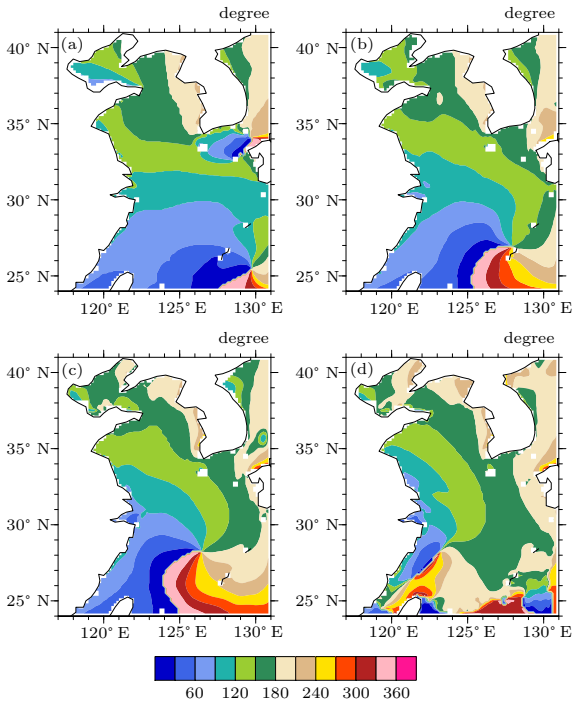


Fig. 15. (colour online) As in figure 7, but for the wave direction.

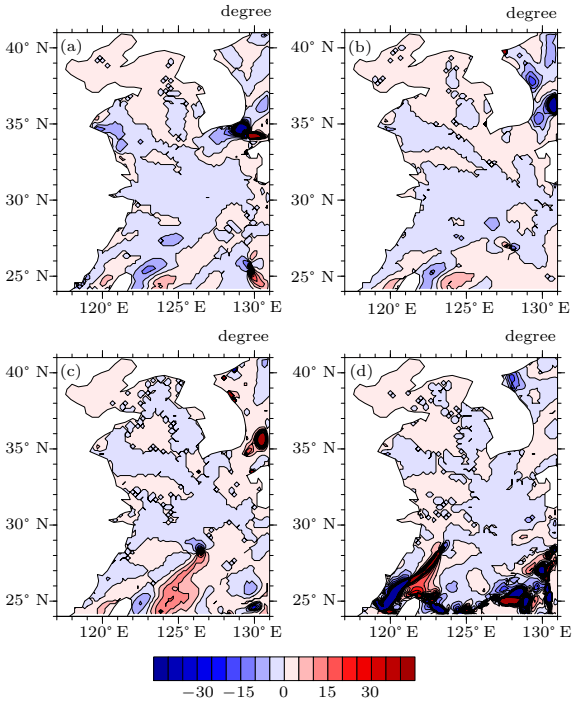


Fig. 16. (colour online) As in figure 8, but for the wave direction.

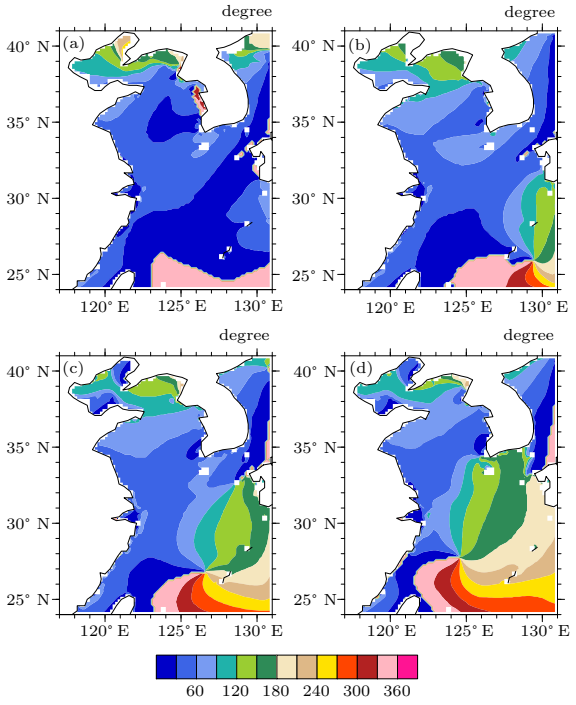


Fig. 17. (colour online) As in figure 9, but for the wave direction.

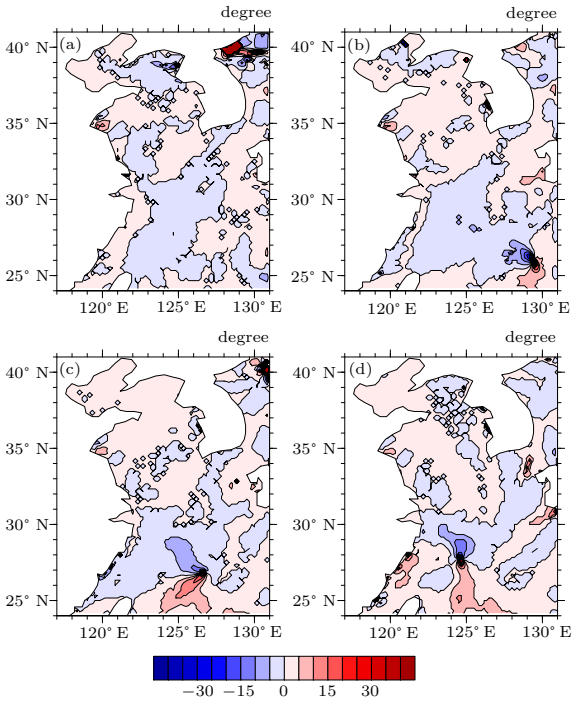


Fig. 18. (colour online) As in figure 10, but for the wave direction.

4. Discussion

The current effect is distinguishable on wave height, wave period, and wave direction. The wave buoy in the present study did not capture the current effect, possibly for at least three reasons including imperfect wind, inconsistency between the wind and current, and incorrect buoy position. The current

effect is also not supported by the Topex/Poseidon altimeter (not shown here), because the precision error of the satellite product on the significant wave height is 0.3 m,[14] not small enough to distinguish the current effect. In addition, the wave period in the present model is less satisfactory than the wave height in comparison with the buoy measurements, because the computation domain is not large enough to involve the swell from the North–West Pacific. Further improvement by nesting grid and data assimilation are proposed.

Our numerical tests show that, although typhoon Saomai has a stronger wind than typhoon Jelawat, the current effect during Saomai is less significant than Jelawat. This is because Typhoon Jelawat stays longer than Saomai in the ECS, and leaves more current information. Furthermore, the direction of the background wind field during typhoon Jelawat is less stable than the north–east monsoon during Saomai, and the current effect is extremely significant near the computation boundary. This gives us the evidence that the current effect is more important for the developing wave than the saturated wave.

Note that the wave damage is generally related to the wave energy, which is square on the wave height. Therefore, the 0.5 m difference in the significant wave height and 1 s difference in the wave period are no doubt important especially for the TW forecast. However, in some situations with a coarse demanding on wave simulation, i.e., the underdeveloping wave-current interaction study (the wave effect on current is still not clear), the current effect on the wave model can be omitted sometimes. In addition, the difference of wave direction is mainly less than 15° in the ECS, except for some large values restricted on a small region. This suggests that the wave direction does not significantly change even under typhoon forcing.

5. Conclusions

We used a survey-based ocean current product to investigate the oceanic current effect on typhoon-wave modeling. In the autumn of 2000, the oceanic current caused a 0.5 m difference in significant wave height, a 1 s difference in wave period and a 30° difference in wave direction for typhoon wave modeling in the East China Sea. Hence, the oceanic current effect is significant in the hindcast of the typhoon wave.

Typhoon Jelawat is weaker than Saomai, but the effect of oceanic current on Jelawat is more significant than on Saomai. The current effect on the wave height and wave period depends on the track and moving speed of the typhoon in the ECS, because these two factors are related to the local wave saturations. On the other hand, the background wind field may have some influence on the current effect. The current effect is more evident for the developing wave than the saturated wave.

In the wave–current interaction study, where the partition mechanism of momentum and energy from wave to current is still not very clear, it is not surprising that the current effect is excluded in the wave modeling, because the impact of the oceanic current on the wave modeling is not large enough to change the pattern of the wind-wave field.

Acknowledgments

The authors thank the support of SOED HPCC. Comments and suggestions provided by the anonymous reviewers are greatly appreciated.

References

[1] WAMDI Group 1988 *J. Phys. Oceanogr.* **18** 1775
[2] Sullivan P P, McWilliams J C and Melville W K 2007 *J. Fluid Mech.* **593** 405
[3] Bolanos R, Osuna P, Wolf J, Monbaliu J and Sanchez-Arcilla A 2011 *Ocean Modelling* **36** 102
[4] He H L and Chen D K 2011 *Geophys. Res. Lett.* **38** L07604
[5] Song J B 2006 *Chin. Phys.* **15** 2796
[6] Chen X G, Guo Z P and Song J B 2008 *Chin. Phys.* B **17** 3387
[7] Cui H, Zhang S W and Wang Q Y 2009 *Acta Phys. Sin.* **58** 6609 (in Chinese)
[8] Janssen P A E M 2008 *J. Comput. Phys.* **227** 3572
[9] Tolman H L 1991 *J. Phys. Oceanogr.* **21** 782
[10] Li M K and Hou Y J 2005 *Mar. Sci.* **29** 9 (in Chinese)
[11] Guo Y, Hou Y J, Yang Y Z and Han L L 2006 *High Technol. Lett.* **16** 1092 (in Chinese)
[12] Tamura H, Waseda T, Miyazawa Y and Komatsu K 2008 *J. Phys. Oceanogr.* **38** 2662
[13] Maximenko N and Hafner J 2010 *IPRC Technical Note* No. 5 February, **16** p. 17
[14] Cheng Y C, Xu Q, Liu Y G, Li C Y and Gu Y Z 2008 *J. Geodesy Geodyn.* **28** 117 (in Chinese)