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Seasonal characteristics on the wave-induced sediment resuspension potential off the Mekong River Delta, Vietnam

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Abstract

Monthly-mean climatology on wave heights and bottom stress intensities around the Mekong River Delta were estimated by conducting a wave simulation for the period from 1993 to 2006 to obtain fundamental information on the wave-induced sediment resuspension off the deltaic coast which is considered to have played a key role on the evolution of the delta morphology. It was found that the occurrence of large waves and strong bottom stresses were influenced primarily by the Southeast Asian monsoon climate and the shape of the delta. The seasonal occurrence of the high waves and intense stresses differed between western and eastern side of the delta. They were observed mainly during the southwest monsoon season in the western side, whereas took place quite frequently during the northeast monsoon season in the western side. Intense bottom stresses were observed mostly in coastal areas shallower than 20 m, though they were also found in some locations as deep as 50 m depth when waves having a long fetch approached to the area. These features agreed well with water-color distribution in satellite images.

Key words : *Sediment resuspension, Southeast Asian Monsoon, Wave climate, Numerical model*

1. Introduction

The Mekong River is the largest river in Southeast Asia, which is 4800 km long and drains an area of 795,000 km^2 in six countries[1)]. In the last 7000 years, the river has discharged an enormous amount of sediments into the South China Sea to form a lowland called the Mekong River Delta[2-3)]. The area of the delta is about 55,000 km^2 at present and is still changing[4)]. A large number of beach ridges aligned parallel to the deltaic coast indicate the contribution of wave actions on the evolution of the delta.

Recent studies suggest the occurrence of active sediment deposition and resuspension along and off the deltaic coasts under the influence of the Southeast Asian monsoon climate[5)]. However, climatology on wave-induced sedimentary processes over the area has not yet studied in detail, partly because the number of observation has been limited until recent years.

This study aims to compile monthly statistics on the occurrence of sediment resuspension due to wave actions by conducting a long-term wave simulation of the South China Sea, in order to understand the role of waves on sediment dynamics around the Mekong River Delta.

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2. Methods

In the current study, bottom stresses caused by wave actions were used as a measure to estimate the occurrence of sediment resuspension due to the wave action. The stresses were estimated from a near-bottom orbital velocity of wind waves by using the method of Soulsby (1997)[6)], and the orbital velocity was derived from an output of the third generation wave model called WAVEWATCH-III (version 3.14)[7)]. Detailed description on the method to calculate the wave-induced bottom stress are found in Uehara (2012)[8)].

The wave model was first applied to a global domain covering latitudes from 77°S to 80°N with the spatial resolution of 1.25° (zonal) and 1.00° (meridional), and was further nested to a finer grid covering the South China Sea, ranging latitudes from 9°S to 23°N and longitudes from 99°E to 125°E with the spacing of 0.25° in both zonal and meridional directions. The waves were forced by NOAA/GFS4 reanalysis winds which were supplied in an hourly basis with the spatial resolution of 0.3125°.

The wave simulation was conducted for periods from October 1992 to December 2009 and hourly outputs of wave parameters during 1993-2009 were used for analyses. Using these results, probabilities of significant wave heights and bottom stresses exceeding specific threshold values were calculated for each month.

3. Results

3.1 Significant wave height

Figure 1 denotes the occurrence probability of significant wave heights larger than 1 m in the South China Sea at July and December 2008, which was compiled from the wave-simulation results. A probability of 0.5, for example, corresponds to the situation that wave heights were larger than 1 m at half of that month. In Fig. 1, monthly-mean wave heights and directions are also indicated by vectors.

The wave characteristics were found to show a distinct seasonal change, following the pattern of the Southeast Asian monsoon climate: At around the Mekong River Delta, southwesterly monsoon winds prevail from May to October (SW monsoon) whereas northeasterly winds are dominant from October to May (NE monsoon). Wave directions at each season were similar to the direction of monsoon winds.

During the SW monsoon season (Fig. 1a), waves larger than 1m were observed more frequently along the west coast of the Mekong River Delta than along the east coast, because the Camau Peninsula (the southern tip of the Indo-China Peninsula) hindered developed waves approached from the southwest to propagate toward the east coast of the delta. In the South China Sea, the occurrence probability increased in northeastward direction as the wave was developed by the prevailing southwesterly winds. A high probability value found off the southeastern Vietnam (around 11°N, 110°E) is associated with the constriction of monsoon winds under the presence of high mountains north of about 10.5°N.

The situation was quite different during the NE monsoon season (Fig. 1b). High waves were found quite frequently at a large portion of the South China Sea as a result of strong northeasterly monsoon winds blown over the sea. In this season, high waves emerged more frequently at the eastern side of the delta than at the western side.

3.2 Bottom stress

The occurrence probability of bottom stresses larger than 1 N/m^2 in the western South China Sea are shown for August 2006 and January 2007, the periods correspond to SW and NE monsoon seasons, respectively (Fig. 2). In this study, the bottom stress was used as a measure to infer the occurrence of resuspension of bottom sediments. Under the definition adopted in this study, the bottom stress becomes larger if the wave height is larger, the wave period (i.e., the wave length) is longer, or the water depth is shallower.

Comparison between Figs. 1 and 2 shows that regions where large wave heights occur frequently do not necessarily coincide with areas where frequent high bottom-stress events are expected, because the impact of the wave action cannot reach bottom if the water depth relative to the wave length is too large. Therefore, areas showing high stress values were limited mostly to coastal regions shallower than 20 m. Exceptions are the area off the southern Chinese coast east of 110°E during the SW monsoon season (Fig. 2a) and the area southeast of the Mekong River Delta during the NE monsoon season (Fig. 2b). In these regions, long fetches are expected during the corresponding seasons and the probability higher than 0.1 were observed at places as deep as 50 m.

Similar to the case of the wave heights, high bottom stresses were observed more frequently along the west coast of the Mekong River Delta than along the east coast during the SW monsoon season, indicating that the sediment resuspension occurred more actively at the western side of the delta (Fig.2a). In the Gulf of Thailand west of 105°E, high stress values were observed most frequently at the delta west coast around 10°N, whereas high waves occurred most frequently off the southeastern Thai coast around 11.5°N. This discrepancy indicates the importance of considering factors other than wave heights when estimating the occurrence of resuspension.

During the NE monsoon season, high stress values were observed more frequently off the east coast of the delta than off the west coast (Fig. 2b). The probability was especially high along the western deltaic coasts and around Con Son Island situated to the south of the delta (8.5°N, 106.5°E).

3.3 Bottom stress field along deltaic coasts

To investigate seasonal characteristics of the sediment resuspension around the Mekong River Delta more in detail, monthly statistics on the occurrence probability of intense bottom stresses were drawn for ten stations along the coast of the Mekong River Delta (Fig. 3). The probabilities were calculated from the output of the wave simulations obtained for 1993-2009.

The seasonal pattern of the occurrence probability was different between the eastern and western side of the delta. Along the east coast, the probability was generally higher than 0.7 in December and January and lower than 0.15 from June to October, except at stations 4 and 6 where the peak probability in January was only about 0.3.

Along the west coast, in contrast, the probability peaked at July and August and the peak values were lower than those along the east coast. At the southern tip of the Camau Peninsula (station 7) between the east and west deltaic coasts, the probability indicated maximum values at two periods, December-January and July-August, showing characteristics observed at both sides of the delta. These results suggest that the occurrence of the wave-induced resuspension is linked closely with the monsoon climate and the geometry of the deltaic coasts.

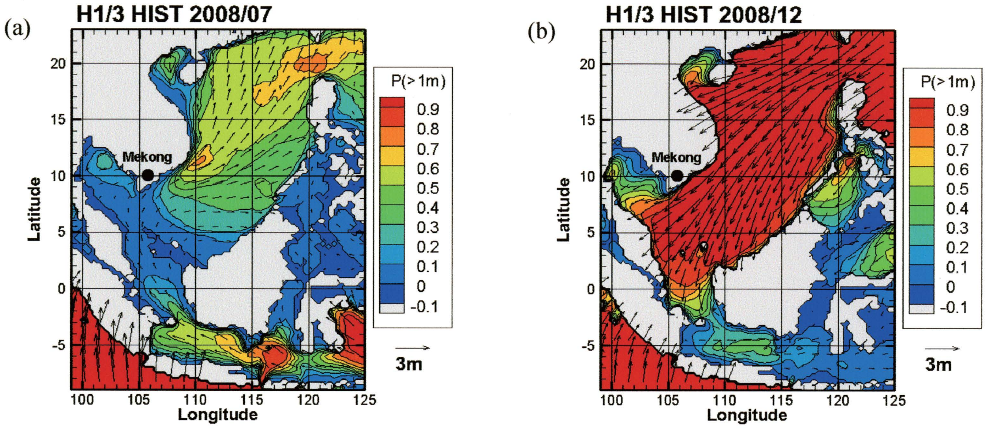

Fig. 1. Occurrence probability of significant wave height larger than 1m in (a) July and (b) December 1993, in the South China Sea. Vectors denote monthly-mean significant wave height and direction, and a filled circle shows the location of the Mekong River Delta.

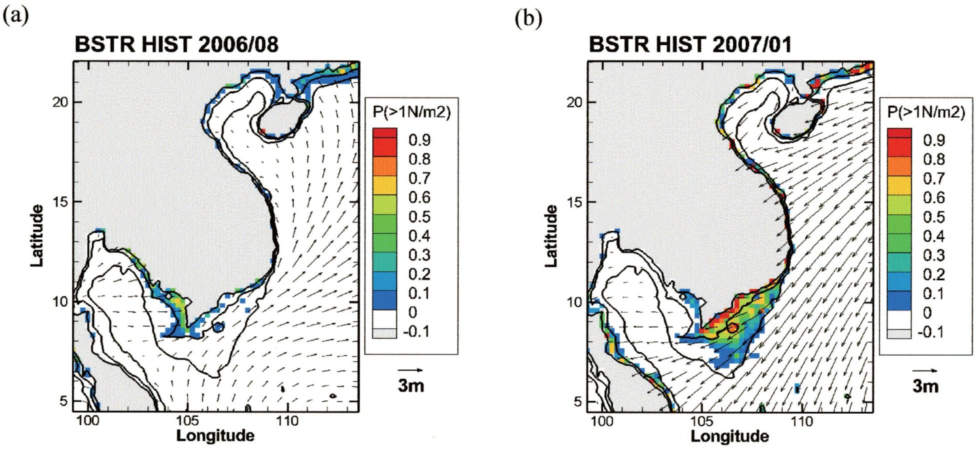

Fig. 2. Occurrence probability of bottom stress larger than 1.0N/m^2, a measure for the frequency of sediment-resuspension occurrence, in (a) August 2006 and (b) January 2007. Vectors denote monthly-mean wave height and direction. Isobath contour for 20 m and 50 m depths are also drawn in solid lines.

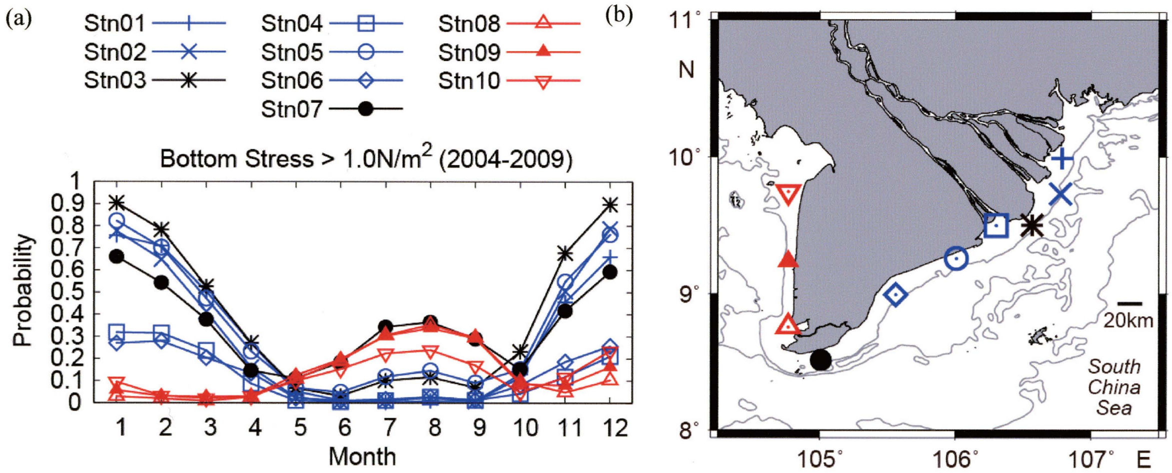

Fig. 3. (a) Monthly statistics on the occurrence probability of bottom stress larger than 2.0N/m^2 at 10 stations along the Mekong River Delta. The probability for each month uses model results obtained for periods from 1993 to 2009. (b) Location of the station.

Fig. 4. True color satellite images of MODIS/Aqua around the Mekong River estuary taken at (a) 13:10 (local time) on Feb. 2, 2006 and at (b) 13:30 on Aug. 19, 2006. The data coverage is 9°N-10.5°N, 105.25°E-107.25°E.

Lower probabilities found at stations 4 and 6 compared to other stations along the east coast during the NE monsoon season may have caused because the stations were situated in the corner points of the coarse model grid. In addition, the lower occurrence of the intense bottom stress at station 6 might be associated with the concave shape of the coastline which may reduce the wave height in the nearshore area.

During the SW monsoon season, the probabilities at stations 3 and 5 were larger than 0.1 even though those at other east-coast stations were substantially zero. As stations 3 and 5 were located near the head of convex-shaped shorelines, developed waves from the southwest may have reached the area more frequently than other east-coast regions. For stations 1-6 near the Mekong River estuary, the impact of waves during the SW monsoon season seems to become less effective in the northeast direction.

Along the west coast of the delta, the occurrence probability of sediment resuspension take lower values at station 10 compared to stations 8 and 9 (Fig. 3), which might be associated with the existence of islands off station 10.

It is to be noted that Fig. 2 shows a monthly probability of a certain year, whereas Fig. 3 was obtained from multi-year statistics. Though there were inter-annual variabilities among the monthly statistics, the range of seasonal changes in the probability distribution was larger than the standard deviation of the monthly values.

3.4 Comparison with satellite images

The seasonal characteristics around the Mekong River deltaic coasts derived from the wave model results were consistent with satellite images. Figure 4 shows MODIS satellite images around the Mekong River estuary at the NE and SW monsoon seasons in year 2006, which are a part of the images taken daily or twice daily and distributed at EOSDIS (NASA's Earth Observing System Data and Information System) website (https://lance-modis.eosdis.nasa.gov).

From December to January each year, when the predicted occurrence probability of the intense bottom stress takes high values, a band of turbid water attached to the coast was observed in the satellite image almost every day, indicating the frequent occurrence of resuspension at the inner shelf region adjacent to the deltaic coast (Fig. 4a).

During the SW monsoon season, in contrast, the water color in the images indicates that the coastal water generally contains less sediments than during the NE monsoon season and the sediment-laden water seems to be originated mainly from the river mouths (Fig. 4b). Because the flow rate of the Mekong River is much larger during the SW monsoon season than during the NE monsoon season, the turbid water observed during this season probably have caused by sediment discharge from rivers. The river plumes in the SW monsoon season tend to flow northeastward following the direction of monsoon winds. Occurrence of sediment resuspension at the southwestern side of the river mouth (e.g., Station 5 in Fig. 3, or lower-center portion of Fig. 4b) may also have contributed to the formation of the sediment-laden water.

Though the results shown above indicates the close match between the resuspension probability estimated from the wave model and the distribution of sediment-laden waters found in satellite images, a care must be taken when interpreting the satellite image. The image does not necessarily reflect the condition of seafloor where the resuspension takes place, even though the water depth of the coastal area where sediment-laden water was observed is generally less than 6 m, and also because the tidal level around the Mekong River estuary tends to be higher than average during the SW monsoon season at the time when the

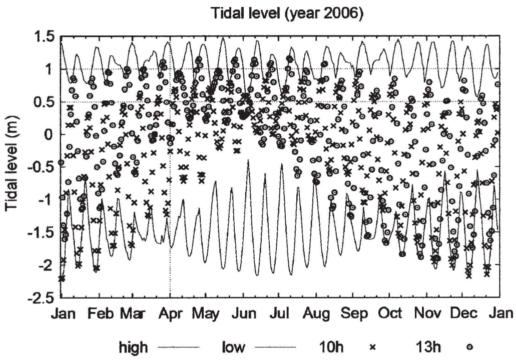

Fig. 5. Tidal levels off the Mekong River estuary in year 2006 estimated by a tidal model: (solid lines) maximum and minimum sea level of each day, (crosses and circles) sea level at 10:00 and 13:00 on each day, the times between which the most of the MODIS images are taken.

images were taken (generally around 10:00—14:00 in local time), so that the presence of sediment-laden waters may be underestimated during the season (Fig. 5). Further studies including those using observed results would be necessary to investigate the resuspension processes more in detail.

5. Conclusion

Monthly statistics on the probability of high bottom stress indicated that the occurrence of sediment resuspension around the Mekong River Delta is influenced primarily by the SE Asian monsoon climate and its seasonal pattern differs between eastern and western side of the delta. The geometry of the coastline also may have affected the occurrence.

Acknowledgement

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