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斯里兰卡近岸风暴潮模拟中风暴潮-潮汐相互作用特征分析:一个个例研究

摘要

利用三维普林斯顿海洋模型(POM)以及逐时水位观测数据,研究印度洋北部斯里兰卡北部海岸风暴潮-潮汐相互作用特征.选择了2008年的“Nisha”台风作为台风风暴潮个例进行研究,并进行了3个数值敏感性试验.经验证,该风暴潮模型可以很好地再现该台风期间研究区域内的潮汐和总海水水位.试验结果表明,沿斯里兰卡西北海岸的风暴潮-潮汐相互作用显著,其强度与台风的强度和轨迹相关.当TC在42 h达到较大强度时,可以得到风暴潮-潮汐相互作用导致的最大增水值TSI(0.6 m)和从印度洋外海向斯里兰卡西北部浅滩流入的最大相互作用流场.在TC强度较弱的第30小时,得到最大负TSI(-0.6 m)和向南流出西北部浅水区域的较弱的相互作用流场.在整个台风期间,强TSI都发生在斯里兰卡西北部海滩到对岸的印度洋近岸区域.

关键词

普林斯顿海洋模型(POM);潮汐-风暴潮相互作用;风暴潮;斯里兰卡

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0　导读

本文原文为英文,希望感兴趣的读者进一步关注原文.

本研究利用一个三维普林斯顿海洋模型(POM)(2002版)以及观测到的逐时水位数据研究北印度洋斯里兰卡北海岸风暴潮和潮汐模拟及其相互作用.以2008年的“Nisha”作为个例,并进行了3个数值试验来评估所选模式区域内的风暴潮-潮汐相互作用.Trincomalee站的每小时观测水位数据由斯里兰卡国家水产资源研究与发展机构(NARA)提供.使用潮汐谐波分析软件包T-TIDE获得观测海平面的潮汐升高和非潮汐残差(NTR).Nisha(2008)的最佳台风路径数据和中心压力数据来自美国海军联合台风警报中心(JTWC).

POM是一个三维的原始方程式海洋模型,被广泛用于近岸和海盆尺度的海洋过程研究中.用于本研究的海底地形数据采用欧洲的海洋一般测深图(GEBCO)的全球测深数据集,数据经过插值得到模式网格点上的地形数据.对于海表风场的数据,我们在JTWC最佳台风路径和强度数据的基础上采用经验Holland模型计算台风的10 m风速.本研究中的风暴潮模型由潮汐强迫和大气强迫驱动.为了评估风暴潮-潮汐相互作用,我们进行了3个同驱动力组合的数值试验.

结果表明,沿斯里兰卡西北海岸得到的风暴潮-潮汐相互作用非常显著.Nisha(2008)是一个中等强度的热带气旋,但仍在斯里兰卡北部海岸造成了一些显著的风暴潮灾害.该模型很好地再现了潮汐水位、总水位以及潮汐相互作用水位变化过程.数值结果表明:沿斯里兰卡西北海岸得到的最大风暴潮增水最显著(达到2 m);沿印度东南海岸得到风暴潮减水的最大值(-2 m).风暴潮-潮汐相互作用(TSI)强度与台风的强度和轨迹相关.在该台风风暴潮过程中,当TC在42 h达到较大强度时,可以得到风暴潮-潮汐相互作用导致的最大增水值TSI(0.6 m).在TC强度较弱的第30小时,得到最大负TSI(-0.6 m)和强度达到0.2 m/s的TSI流场流出斯里兰卡西北部浅水区域.在整个台风期间,强TSI都是发生在斯里兰卡西北部海滩到对岸的印度洋近岸区域,说明风暴潮-潮汐相互作用在这些区域的风暴潮研究中不能被忽略.

后续需要进一步的研究来检验和量化风暴潮-潮汐相互作用对该地区海平面的影响,并进行多个台风个例比较和统计分析.

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Characteristics of tide-surge interaction along Sri Lanka coast：a case study

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Abstract A three-dimensional Princeton Ocean Model（POM）along with the observed hourly sea level data are used in this study to investigate the characteristics of the Tide-Surge Interaction（TSI）along the north coast of Sri Lanka in north Indian Ocean.In this study，the cyclone ‘Nisha’ 2008 case was selected and three numerical experiments were performed.The model reproduces reasonably well the tides，surges and total sea water levels and TSI water levels over the study region during this cyclone.The results show that the characteristics of the TSI are significantly shown along the northwestern coast of Sri Lanka.The maximum TSI intensity is associated with the strength and track of the cyclone.In this study，the maximum positive TSI reaches 0.6 m at hour 42 when the TC was strong.At hour 30 when the TC track was relatively weak，the maximum negative TSI reaches about −0.6 m.The magnitude of the interaction current（U_{TSI}）（0.2 m/s）and the direction of the U_{TSI} were observed significantly to flow out the northwestern coast.During the whole TC cycle，strong TSI occurs in the northwestern coast of Sri Lanka and the opposite coast of India，which indicates that the tidal effect cannot be ignored in the storm surge simulation in this region.

Key words Princeton Ocean Model（POM）；Tide-Surge Interaction（TSI）；storm surge；Sri Lanka

1 Introduction

The global warming has caused the increase in the intensity of Tropical Cyclones（TCs）which severely affect the TC-induced storm surges on coastal regions with dense population and large economic community[1].Most of the largest cities in the world are located on the coast and most of the world's population lives within 150 km of the ocean.Coastal regions are often low lying and susceptible to an increase in sea surface elevation[2].

During the past half century，enormous progress has been made in numerical prediction of storm surge[3-4].Storm surge is a phenomenon related to abnormal rise in near shore water levels above the regular astronomical tides.Forcing mechanisms for storm surge are maximum sustained wind speed，waves，and reduced atmospheric pressure[5].

A meteorologically forced（strong wind stress and atmospheric pressure depression）long wave motion，and the extremely sustained storm surge increases the water surface elevations above the astronomical tide，causing inundation in low-lying coastal areas[6].

Storm surges are an extremely serious hazard along the east coast of India，Bangladesh，Myanmar，and Sri Lanka.Although Sri Lanka is affected only occasionally by the storm surge，tropical cyclones of November 1964 and November 1978，and cyclone of November 1992 have caused extensive loss of lives and property damage in the region[7].

Sri Lanka，an island nation located off the southern tip of India，is vulnerable to cyclones generated mostly in southern part of Bay of Bengal，and to a lesser extent，those in southeast of Arabian Sea[8].However，unfortunately very rare analysis and assessment of the storm surge hazard has been carried out for the coastline of Sri Lanka[9].Therefore，the real-time monitoring and warning of storm surges is of great interest.

A three-dimensional Princeton Ocean Model along with the observed hourly sea level data are used in this study to investigate the characteristics of the TSI around Sri Lanka in north Indian Ocean.

The selected tropical cyclone case of Cyclone Nisha hit northern Sri Lanka on November 25, 2008, causing heavy rains and flooding that reportedly displaced 70 000 people in Vanni and 20 000 people in Jaffna district.Jaffna recorded the highest weekly cumulative rainfall since 1918.

Many previous studies were made to improve the storm surge forecasting skills.These studies have identified that the accuracy of storm surge forecasting can be improved by investigating the TSI[10] and by optimizing the wind drag coefficient[1,11].

Most of the previous studies have analyzed the mechanism of TSI using various approaches. Along the UK coastline[12] this is well studied and a spatial sea level trend estimate was obtained for all UK coastlines including the South and West. Along the North Sea coastline around UK[13] it shows that the mode of peak residual occurrence can be found everywhere 3 to 5 hours before the nearest high water.

The non-linear interaction between tides and surges has been studied in many other regions such as, off the east coast of Canada, northeastern United States[14], north Queensland coast of Australia[15], and Taiwan Strait[16].

Extreme sea levels associated with storm surges and tides over the northwest Pacific are investigated[17] and it is showed that the model well reproduces tides and storm surges over the study region and the extreme total sea levels are mainly determined by tides and tropical cyclones.

The effects of TSI on storm surge elevations along the coast of Bohai Sea, Yellow Sea, and East China Sea[18] have been identified to be very significant.

In the north Indian Ocean around Bay of Bengal the TSI studies were started by Johns & Ali[19] with numerical modelling experiments. They used a non-linear model to determine the interaction between tides and surges.

By using numerical modeling studies in the Meghna estuary, As-Salek & Yasuda[20] found that the cyclone which makes landfall before the arrival of the tidal peak produces a higher and shorter-duration surge than the cyclone that makes landfall after the tidal peak.

Nearly thirty years of hourly tide-gauge data were analyzed from four stations of east coast of India and in the head of the Bay of Bengal and showed that the tide-surge interaction characteristics observed are identical to those reported in extra tropical regions, such as the North Sea[21].

The tide-surge interaction along the east coast of the Leizhou Peninsula, South China Sea[10] was identified as significant in recent study, and it is showed that the nonlinear bottom friction is the main contributor to tide-surge interaction, while the contribution of the nonlinear advective effect can be neglected.

There is no research has been published about the tide-surge interactions along the Sri Lankan coastal region to the best of our knowledge. Accordingly, this study is based on the Princeton Ocean Model and the characteristics of tide-surge interaction around Sri Lanka in northern Indian Ocean during the selected tropical cyclone 2008 case occurred within the selected model domain.The purpose of this work is to investigate the characteristics of tide-surge interaction and to improve the forecasting skills of storm surges by identifying the tide-surge interaction.

The rest of this paper is organized as follows. In section 2 the data, the POM used in this study and model setup and forcing and the experimental set up are briefly introduced. Section 3 presents the results and corresponding analysis. Discussion and conclusion are given in section 4, section 5 respectively.

2 Methods

2.1 Data

The oceanographic data used to analyze the TSI in this study are 2008 November month hourly observed sea levels from Trincomalee station of Sri Lanka. The observational data of Colombo station and Trincomalee station were provided by Oceanography and Hydrography unit of National Aquatic Resources Research and Development Agency (NARA), Sri Lanka.

The tidal elevations and non-tidal residuals (NTR) of the observed sea levels were obtained using a harmonic analysis package, T-TIDE[22]. The resultant tidal elevations and NTR of the observed sea levels were used to analyze the tide-surge interaction and assess the model performances[10].

2.2 The Princeton Ocean Model setup and forcing

The Princeton Ocean Model (POM) 2002 version (referred to as pom2k) is used for the forward prediction model in this study. The POM is a three-dimensional, primitive equation ocean model[23-24].

The bathymetry data, which were interpolated onto the model grid (Fig.1) were obtained from the General Bathymetric Chart of the Oceans (GEBCO) 1 arc-minute global bathymetric dataset. (http://www.gebco.net/data_and_products/gridded_bathymetry_data/).

The model is driven by tidal forcing and atmospheric forcing. In this study, the empirical Holland model[25] is used to calculate the wind speed for the surface wind stress. The tangential wind speed from the empirical Holland model, which is based on the balance between the pressure gradient and centrifugal forces, can be expressed as,

$$V_c = [AB(P_n - P_c)\exp(-A/r^B)/\rho_a r^B]^{1/2}, \quad (1)$$

$$A = R_{mw}^B. \quad (2)$$

Where A and B are the scaling parameters, P_n is the ambient pressure, P_c is the atmospheric pressure at the storm center, ρ_a is the air density (1.15 kg/m^3), r the distance from the storm center, and R_{mw} is the radius (in km) at which the maximum wind speed occurs. Empirically, B lies between 1 and 2.5.

Three numerical experiments with different combinations of external forcing are conducted (Table 1) in order to assess the model performance and also to determine the main physical processes of tide-surge interaction over this selected region.

Table 1 External forcing for three numerical experiments, with checkmarks for the external forcing used in each numerical experiments

Forcing	exp-OW	exp-TW	exp-OT
Tidal		✓	✓
Wind	✓	✓	

1) Only Wind Run (exp-OW): The model in this experiment is driven by wind forcing and atmospheric pressure fields, and the insertion of a vortex associated with a cyclone based on Holland's hurricane model.

2) With Tide and Wind Run (exp-TW): Both forcing functions including Tidal forcing and Wind forcing are included in this experiment.

3) Only Tide Run (exp-OT): Only the Tidal forcing is included in this experiment.

The POM was implemented in the above three experiments for the selected 2008 case study. These model results were used in the discussion section.

2.3 Experimental setup

In this study the model domain (Fig.1) is set to cover an area of 2-15°N, 75-93°E with a horizontal resolution of 1/60°×1/60° and four vertical levels.

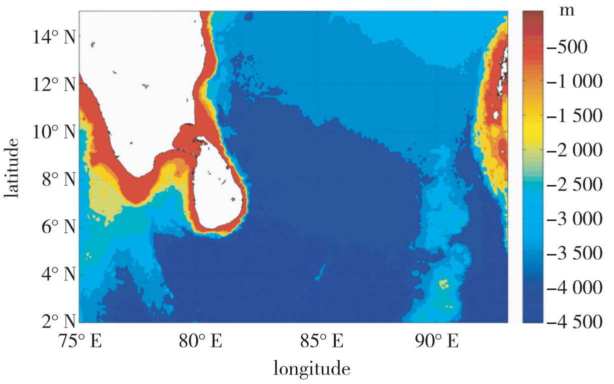

Fig. 1 Topography of selected model domain with the bathymetry values in meters in the Indian Ocean

The cyclonic storm Nisha (2008) was chosen for the numerical experiments in this study (Figs.2a,b). This cyclonic storm (IMD designation: BOB 07, JTWC designation: 06B) was the ninth tropical cyclone of the 2008 north Indian Ocean cyclone season, and the seventh tropical cyclone in the Bay of Bengal 2008 year.

Nisha (2008) is formed as a deep depression over Sri Lanka in southwest Bay of Bengal at 0006 UTC 24 Nov 2008. And then this deep depression is intensified into a cyclonic storm at 0000 UTC 26 Nov 2008. The India Meteorological Department named it as Nisha which moved northwest towards India. This cyclonic storm was weakened into a depression at 0000 UTC 28 Nov 2008.

The north Indian Ocean best track data and central pressure data of Nisha (2008) case were obtained from

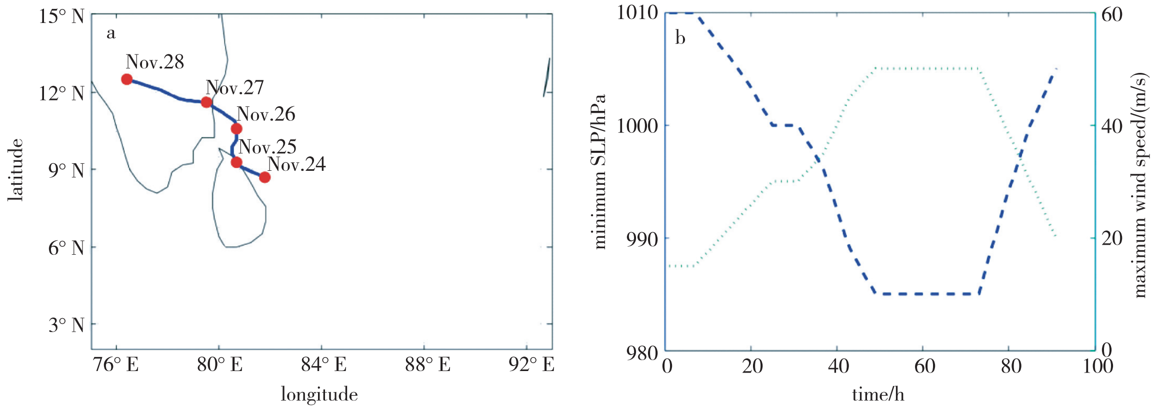

Fig. 2 (a) The best track,(b) the minimum SLP (hPa) and maximum sustained wind speed (m/s) of cyclone Nisha (2008) during 24th-27th November (91 h) obtained from the Joint Typhoon Warning Center (JTWC)

Joint Typhoon Warning Centre (JTWC) of US Navy (http://www.usno.navy.mil/NOOC/nmfcph/RSS/jtwc/best_tracks/ioindex.php).

The 6-hour interval data was interpolated into hourly data. These interpolated hourly Minimum Sea Level Pressure (MSLP) data with longitudes and latitudes data were used with POM for analysis.

Before perform the three numerical experiments, a 6 h spin-up of POM started at 0600 UTC 24 December 2008 was carried out. A 48 h forward model run starting at 1200 UTC 24 December 2008 was performed.

3 Results

The spatial distribution of water level variations during Nisha (2008) cyclone for the three numerical experiments exp-OW (Fig. 3), exp-TW, exp-OT were done for 48 h forward model which runs starting at 1200 UTC 24 December 2008 case.

Figure 3 shows the spatial distribution of sea water level variations of exp-OW obtained for 48 hours. This experiment includes only the wind forcing. As shown in Figure 3, the maximum storm surge is 1.64 m (2 m) along the northwest coast of Sri Lanka and the minimum is around −2.3 m (−2 m) along the southeast coast of India.

Figure 4 shows the spatial distribution of resultant surge variations from the difference between exp-TW and exp-OT ($\eta_{sg} = \eta_{TW} - \eta_{OT}$) obtained for 48 hours and it can be seen that the high storm surge occurs along the storm track. This experiment includes the difference between the all forcing and only tide forcing which gives the surge variation. In this figure the maximum surge is about 2 m and the minimum surge is about −2 m. Similar to the result of exp-OW, the maximum surge can be observed significantly along the northwest coast of Sri Lanka, while the minimum surge can be observed along the southeast coast of India.

The model outputs are also used to quantify the tide-surge interaction for the cyclone event as follows:

$$\eta_{TSI} = \eta_{TW} - \eta_{OT} - \eta_{OW} . \tag{3}$$

Where η_{TSI} is the intensity of tide-surge interaction (Fig.5), and η_{TW}, η_{OW} and η_{OW} are hourly sea level results from exp-TW, exp-OT and exp-OW, respectively.

According to Figure 5, the spatial distribution of tide-surge interaction can be seen within the selected region. If η_{TSI} equals to zero, tide-surge interaction does not occur and if η_{TSI} is greater than zero, tide-surge interaction makes surges produced by exp-TW larger than surges produced by exp-OW, and vice versa[10]. In this figure the maximum positive TSI (0.6 m) can be observed at hour 42 around the north coast (9.5°N, 80.5°E). And the minimum negative TSI (maximum absolute value) (−0.6 m) can be observed at hour 30 along northwest coast (9.2°N, 80.2°E).

At the maximum positive TSI of 0.6 m, the TC track (Fig.2a) is located at 0600 UTC 26th November 2008 around 10.6°N, 80.7°E with 50 m/s maximum sustained wind speed (Fig.2b) and 985 hPa minimum SLP. At the maximum negative TSI of −0.6 m, the TC track is located (Fig.2a) at 1800 UTC 25th November

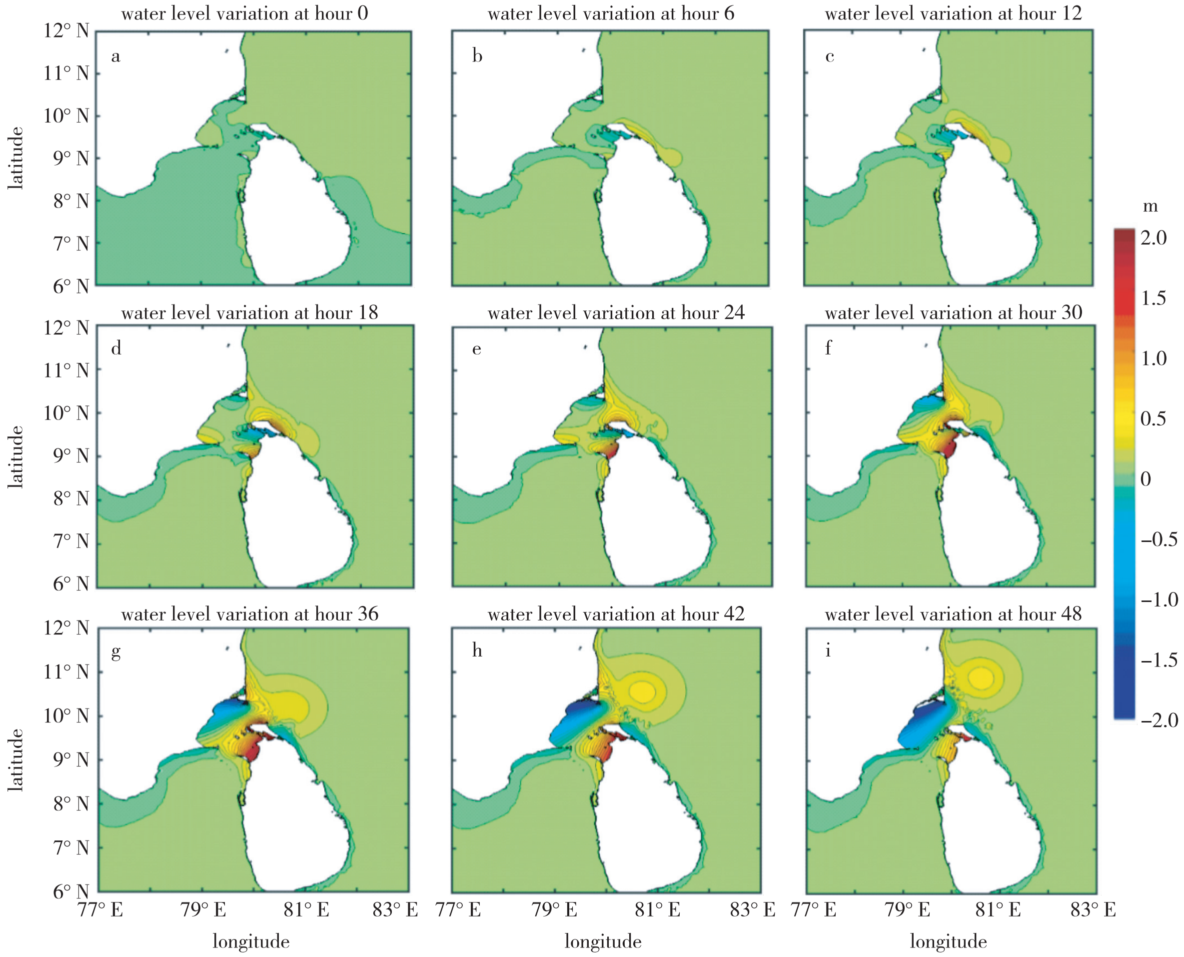

Fig. 3 Spatial distribution of storm surge variations (unit:m) of exp-OW

2008 around (9.9°N,80.5°E) with 35 m/s maximum sustained wind speed (Fig. 2b) and 996 hPa minimum SLP.

Time series representation (Fig.6) of the selected Northeast Trincomalee station for each of the three experiments water levels η_{TW}, η_{OT} and η_{OW} with tide-surge interaction water level η_{TSI} results for 12 hours show that tide-surge interaction increases in intensity as the storm surge develops. The maximum η_{TSI} value is 0.04 m at Trincomalee station during cyclone Nisha 2008 case. The minimum η_{TSI} at this station is about −0.05 m during this cyclone (Fig.6).

During the passage of Nisha (2008) the observed and modeled surge comparisons for the Trincomalee station are also shown in Figure 6. It can be found that the negative and positive surges lie between −0.1 m and 0.1 m. When comparing the observed and modeled surge values, similar variations can be seen with small discrepancies. Maximum modeled surge value is 0.09 m and at the same time η_{TSI} value is 0.04 m. Maximum observed surge value is 0.09 m and at the same time the tide-surge interaction η_{TSI} value is 0.03 m. It means that the surge induced by the surge-tide interaction is around half of the total surge when the total surge is relatively small.

In order to further examine the impact of tide-surge interaction on maximum surge region, time series of surge water levels variation (Fig. 7) at the selected northwest point were presented for surge with tidal effect and surge variations for exp-OW and surge induced by TSI for 48 hours. This figure shows that at around hour 30 the surge reduced and then at around hour 42 the surge increased, similar to the results shown in Figure 4 in this northwest region. According to Figure 5 the TSI reaches the maximum positive TSI at hour 42 and gets the maximum negative TSI at hour 30 at this

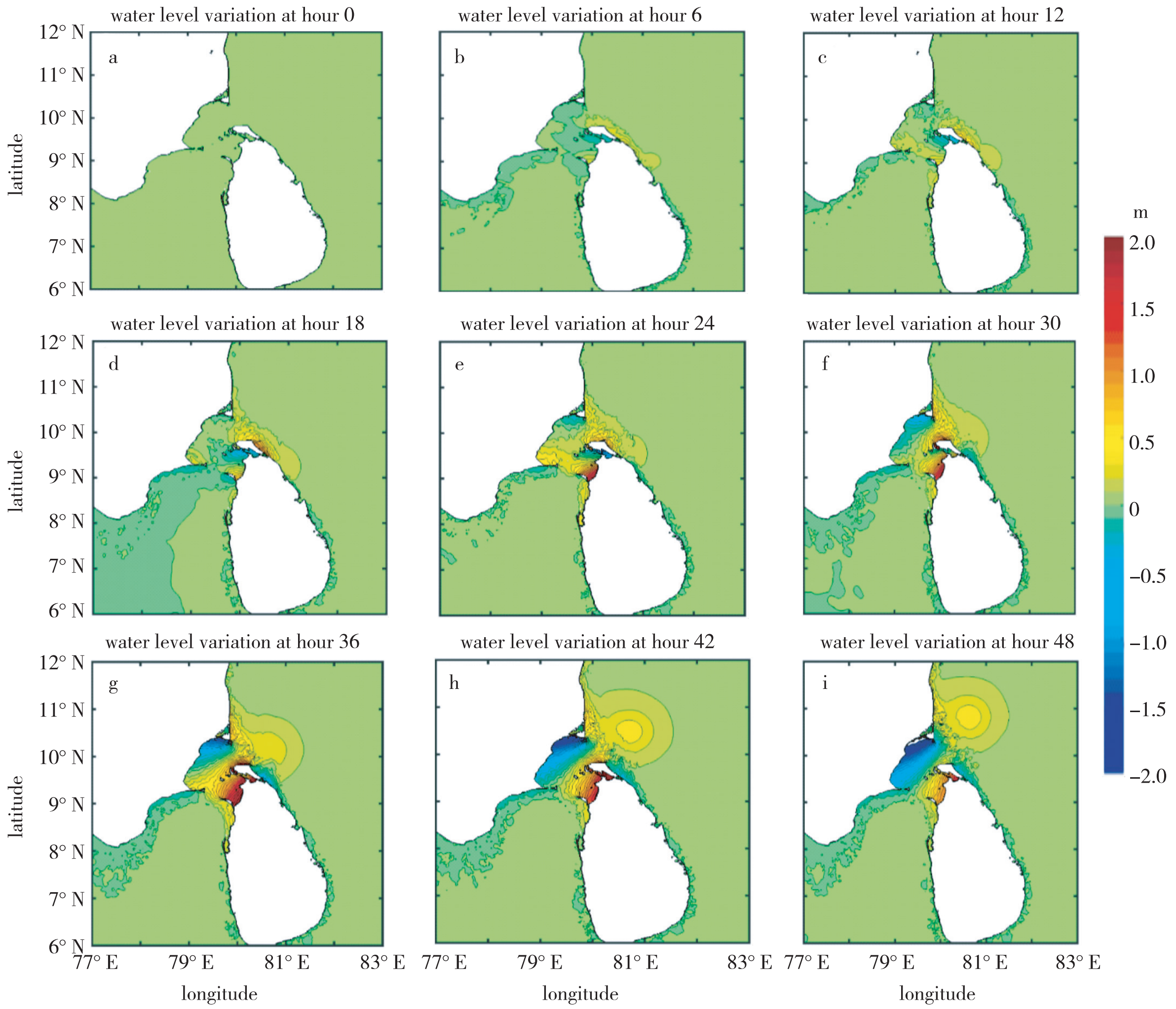

Fig. 4　Spatial distribution of storm surge variations (unit: m) with tidal effect in the model (the water level differences between exp-TW and exp-OT($\eta_{sg} = \eta_{TW} - \eta_{OT}$))

selected location of northwest region. In addition, the TSI has a similar period to the semi-diurnal tide but the amplitude is varying along with the total surge.

The magnitudes and directions of surge-tide interaction on current (U_{TSI}) at hour 30 are shown in Figure 8. At hour 30 the maximum magnitude of U_{TSI} about 0.2 m/s can be observed and the direction of U_{TSI} represented with red arrows in Figure 8 indicates that the water currents flow out off the northwestern coast of Sri Lanka, resulting in the maximum negative surge-tide interaction. Moreover, the pattern of the U_{TSI} magnitudes shows that the energy of U_{TSI} propagates in the form of tidal wave. During the whole TC cycle, strong surge-tide interaction occurs in the northwestern coast of Sri Lanka and the opposite coast of India, which indicates that the tidal effect cannot be ignored in this region.

4　Discussion

In this study the characteristics of tide-surge interaction along the north coast of Sri Lanka during the selected tropical cyclone case of Nisha (2008) was examined based on the POM. Model performance was assessed by comparing the simulated and observed hourly sea water levels. It is found that the model reproduces reasonably well the tides, surges and total sea water levels over the study region, with some discrepancy due to model grid resolution, inaccurate topography data and simplified cyclone structure.

The difference between the three numerical experiments (exp-TW), (exp-OT) and (exp-OW) during cyclone Nisha (2008) produced by the model were used to study the tide-surge interaction in this selected

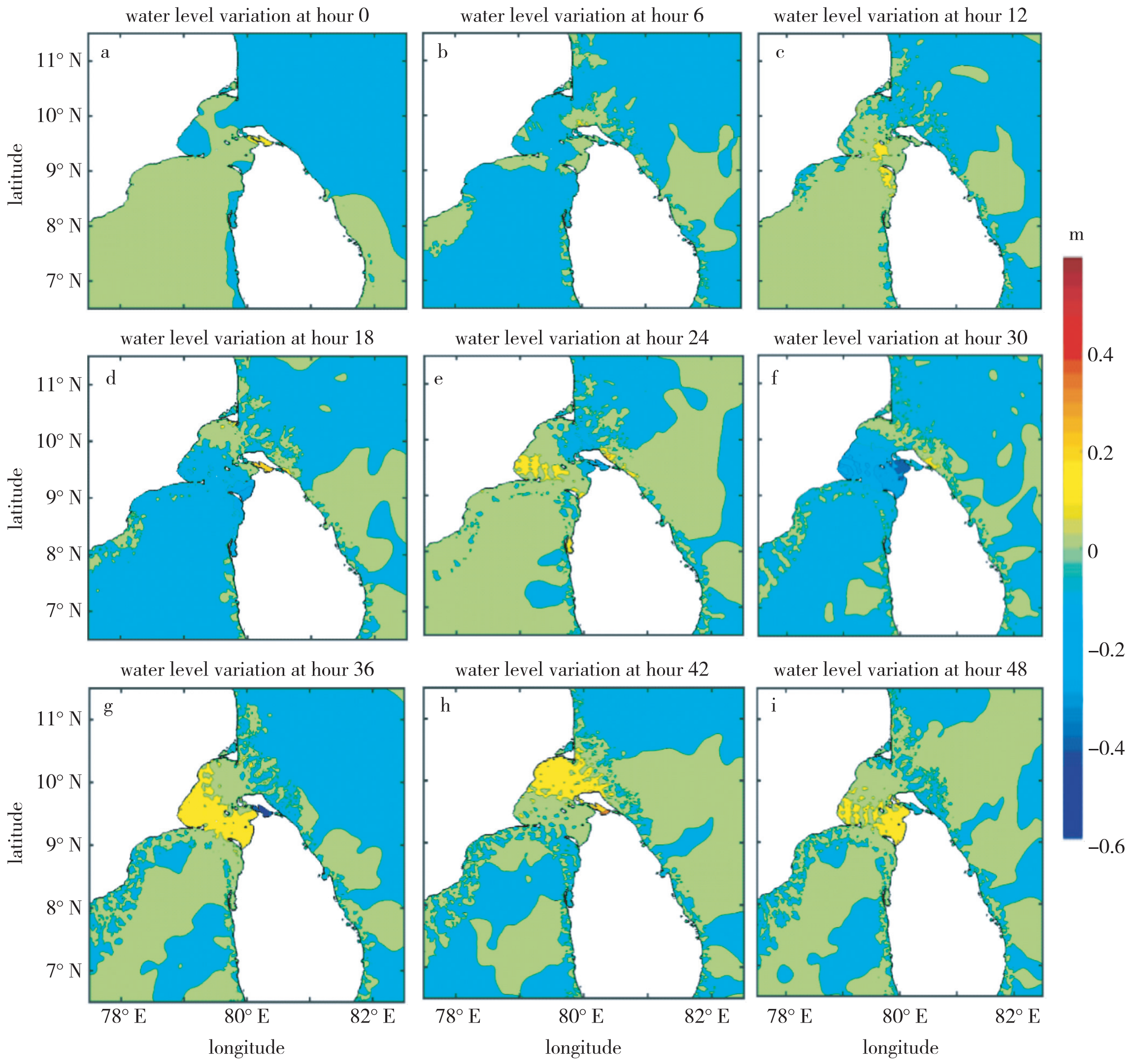

Fig. 5 Spatial distribution of($\eta_{\mathrm{TSI}} = \eta_{\mathrm{TW}} - \eta_{\mathrm{OT}} - \eta_{\mathrm{OW}}$) magnitude of tide-surge interaction(η_{TSI}) water level (unit:m)

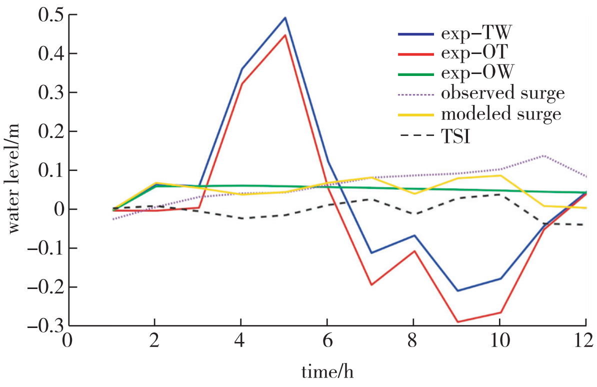

Fig. 6 Time series of water levels η_{TW}, η_{OT} and η_{OW} with tide-surge interaction η_{TSI} water level for 12 hours started at 1200 UTC 24th Dec 2008 and comparison between observed surge at Trincomalee station and modeled surge water levels for cyclone Nisha (2008)

region. The tide-surge interaction is a function of storm strength, storm track and topography[10]. Although this Nisha (2008) was a fairly weak tropical cyclone, it still caused some notable damage in the north coast of Sri Lanka. The most significant tide-surge interaction was observed in the northwest coast of Sri Lanka, which reaches around 0.6 m.

For the maximum of tide-surge interaction intensity (maximum absolute value of η_{TSI} during the cyclone event), the differences are shown to be associated with the strength and track of the cyclone. The impact of tide-surge interaction on the surge maximum can be investigated by focusing on the η_{TSI} when the surge reaches its maximum values.

Tide-surge interaction makes destructive/construc-

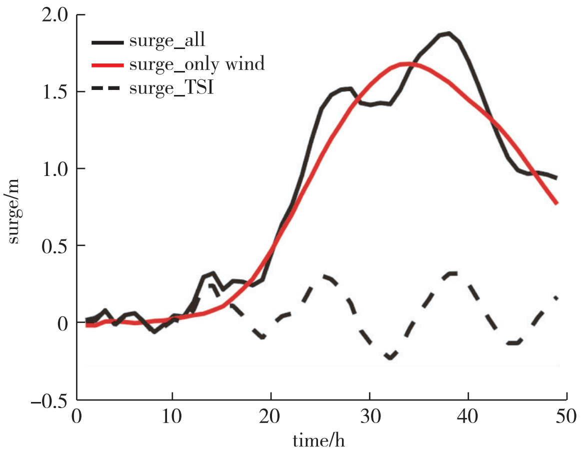

Fig. 7　Time series of surge water levels at the northwest point for 48 hours, representing surge with tidal effect (Surge_all), surge for exp-OW (Surge_only wind), and surge induced by TSI (Surge_TSI)

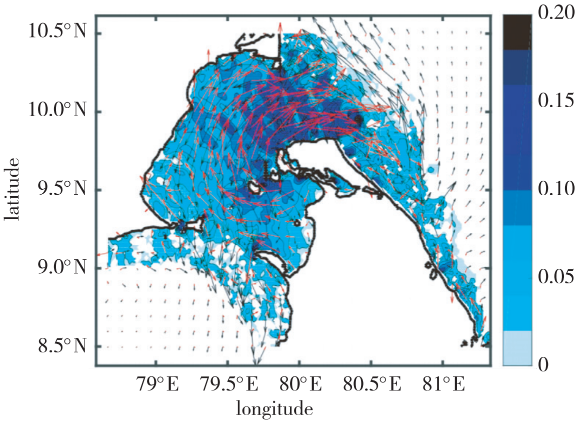

Fig. 8　The magnitudes and directions of interaction current (U_{TSI}) variations (units: m/s) at hour 30

tive contribution to the maximum surge depending on the tidal phase (high tide/low tide) during the cyclone. In addition, the tide-surge interaction increases the duration of storm surge event while reduces the maximum surge, and vice versa[10].

According to our results the maximum surge (2 m) was observed along the northwest coast of Sri Lanka and the minimum surge (−2 m) was observed along the southeast coast of India. In addition, the maximum positive TSI and negative TSI both occurred (about 0.6 m and −0.6 m) within this northwest region of Sri Lanka. Maximum positive TSI occurred at hour 42 (0600 UTC 26th November 2008) and at the same time the TC track tended towards the northwest of India.

At hour 42 when the maximum positive TSI occurred, the TC track strength increased with 50 m/s maximum sustained wind speed (Fig.2b) and 985 hPa minimum SLP. The TC track tended towards northwest direction (Fig.2a). At hour 30 when the maximum negative TSI occurred, the maximum sustained wind speed was 35 m/s (Fig.2b) and minimum SLP was 996 hPa which showed the TC track was weakened. Maximum negative TSI occurred at hour 30 which represents the 1800 UTC 25th November 2008. At this hour the TC track tended towards northeast direction (Fig.2a). The magnitude of U_{TSI} (Fig.8) about 0.2 m/s and the direction of interaction current were observed significantly pointed out along the northwestern coast. In addition, the energy of U_{TSI} propagates in the form of tidal wave and has similar period to the semi-diurnal tide in this region.

All these results identified that the maximum of tide-surge interaction intensity is associated with the strength and track of the cyclone, and mainly occurs in the northwestern coast of Sri Lanka and the opposite coast of India.

More work is needed to improve the accuracy of simulated storm surge, storm tide and tide-surge interaction in this region. Studies are needed to analyze different cyclone events to get a comparative examination of tide-surge interaction characteristics.

The only national agency which provides observed sea level data for Sri Lanka is National Aquatic Resources Research and Development Agency (NARA). But it only provides observed sea level data for two stations (Colombo and Trincomalee) and these data are limited to 2007 to present time. The main reason for the lack of observed data in northern Sri Lanka could be the ethnic war period of Sri Lanka.

The observed data are of limited quality, both in terms of time period and spatial coverage. It would be favorable if more data would be made accessible for scientific analysis in future by increasing tide gauge stations around Sri Lanka. And also it is showed in this study that the most significant tide-surge interaction was observed in the northwest coast of Sri Lanka. So it is important to locate a tide gauge station to observe sea level in northwest coast of Sri Lanka.

The observed sea level data are needed to be analyzed further with statistical approach to find the significance of tide surge interaction and to validate the model results. This is successfully done in North Sea[13], the English Channel[26], the Bay of Bengal[21] and the China Sea[10,27].

In addition, further investigations are needed to be done on the impacts of the nonlinear advective and the nonlinear bottom friction on the temporal variation of tide-surge interaction. To better understand the response of tide-surge interaction to different storm strengths and tracks, more case studies should be carried out for different number of specific cyclone events within this region in further analysis.

5 Conclusion

The present study shows that the observed characteristics of tide-surge interactions are significant along the northwest coast of Sri Lanka. The model reproduces reasonably well the tides, surges and total sea water levels. The maximum of the tide-surge interaction (TSI) intensity is associated with the strength and track of the cyclone. In this study the maximum positive TSI (0.6 m) was observed at hour 42 when the TC track was strengthened. The maximum negative TSI (−0.6 m) was observed at hour 30 when the TC track was weakened. The magnitude of interaction current (U_{TSI}) (0.2 m/s) and the direction of red arrows were observed significantly pointed along the northwestern coast. This positive and negative maximum TSI intensified water levels were observed along the northwest coast of Sri Lanka. Further studies are needed to examine and quantify the impact of tide-surge interaction on sea levels in this selected region, and to carry out a comparative analysis it is needed to study on different cyclones.

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