Influence of Large-scaled Reclamation on the Cold Wave in Coastal Area of Jiangsu Province

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Abstract. Taking the large-scaled reclamation in Jiangsu Sea as study background, on the premise of large-scaled area (East China Sea) having a good accuracy. The cold wave of Jiangsu Sea is simulated by the nested model of SWAN, and analyzing the Hs (significant wave height) near the reclamation area extracted from the results. It is found that the cold wave field around the reclamation area is influenced remarkably by large-scaled reclamation. The large change of wave field is mainly concentrated in the southern part of central Jiangsu province, and it has a significant influence on the wave field. Due to the effect of covering, the wave height of the southern sea area of Dongsha, Gaoni and Lengjiasha reclamation area decreases greatly, and the decline can be as much as 30%. Due to the extent of reclamation is small, the change of wave field in the northern part of Jiangsu province is not obvious, and the range of change is not obvious.

1. Introduction
The coastal coastline of Jiangsu is about 954 kilometers, and the unique topography and landform of Jiangsu region has accumulated a large number of tidal mudflat resource. According to the comprehensive survey and evaluation of Jiangsu's coastal ocean in 2008 (part of Jiangsu 908 special project), the areas of unenclosed tidal mudflat is more than 7.5 million mu, accounting for about 1/4 of the national total areas [1-2]. Jiangsu province has put forward the plan of exploitation and utilization of reclamation on tidal flats in Jiangsu coastal area. Meanwhile, many problems brought by reclamation on tidal flats have been put on the research agenda. The implementation of large-scale tideland reclamation project will change the topography of coastal areas and have an impact on the coastal environment, thus leading to change the hydrodynamic environment and silting environment. And on the one hand, it will bring a large number of land and economic benefits to human beings. On the other hand, it will also have a certain impact on the natural environment [3-4]. Cold wave wind is one of the disastrous extreme weather which has great influence on the coastal water in Jiangsu province. It's a mass movement of cold air. Cold wave wind is usually accompanied by the phenomenon of sharp cooling, strong wind, big wave and so on. As the cold wave
lasts for a long time, the wind wave caused by cold wave wind grows sufficiently, which seriously threatens people's life and property safety and offshore engineering facilities in coastal areas [5]. Therefore, it is of great practical significance to research the influence of large-scale reclamation on cold wave. In this paper, SWAN wave numerical model was used to establish a wind wave model in the east China sea, to simulate the wave field before and after the coastal reclamation planning in Jiangsu under cold wave and windy weather, focusing on the variation of wave height in the coastal area before and after the reclamation project implementation, and to analyze the impact of large-scale reclamation on the wave field.

2. SWAN model

SWAN model [6] describes the random wave field with two-dimensional dynamic spectral density $N(\sigma, \theta)$, $N(\sigma, \theta)$ is related to two-dimensional energy spectral density $E(\sigma, \theta)$, and the relation between $N(\sigma, \theta)$ and $E(\sigma, \theta)$ is $N(\sigma, \theta) = E(\sigma, \theta)/\sigma$. Where $\sigma$ is frequency and $\theta$ is wave direction.

In the cartesian coordinate system, the balance equation of the motion spectrum is expressed as:

$$\frac{\partial}{\partial t} N(x,y,\sigma,\theta) + \frac{\partial}{\partial x} c_x N(x,y,\sigma,\theta) + \frac{\partial}{\partial y} c_y N(x,y,\sigma,\theta) + \frac{\partial}{\partial \sigma} c_\sigma N(x,y,\sigma,\theta) + \frac{\partial}{\partial \theta} c_\theta N(x,y,\sigma,\theta) = \frac{S_{\text{swell}}}{\sigma}$$

Where: the first item on the left represents the rate of change of $N$ over time; the second and third items represent the propagation of $N$ in the direction of $x$ and $y$; the fourth item is the change of relative frequency caused by the change of water depth and water flow; the fifth item is the refraction caused by water depth and water flow ($c_x$, $c_y$, $c_\sigma$, $c_\theta$ represent the wave propagation velocity in the direction of $x$, $y$, $\sigma$ and $\theta$ respectively); On the right side of the equation, $S_{\text{swell}}$ is the source sink term which is represented by energy spectral density. And it can reasonably simulates the complex wave field under the environment of tidal current, topography and wind field. SWAN model takes into account the wave shallower, reflection, refraction, bottom friction, crushing and non-linear wave effects, etc. It adopts the fully implicit finite difference scheme and is unconditionally stable. This model has been successfully applied to wave prediction of coastal, estuary and offshore waters [7-15]. The version used in this paper is SWAN40.91.

3. Parameter selection and calculation conditions

In this chapter, the numerical simulation of cold wave and wind wave during December 20-22, 2008 was performed by SWAN model. The frigid wind field datum is obtained from CCMP satellite remote sensing of sea surface wind field datum. The offshore calculated domain is 20.4° N to 41.9° N and 117.1° E to 131.4° E in China. The model uses the unstructured triangular mesh with 70147 elements and 35814 nodes, direction is divided into 36 sections, resolution is 10°. The simulation time is from 0 o'clock on December 17, 2008 to 18 o'clock on December 26, 2008, and the simulation time step is 600s. The simulation results were verified by Jason-1 track datum. The calculation area of large-scale wave mathematical model is shown in figure 1. During cold wave wind, the satellite was in the cycle 256, and orbits T127, T138, and T153 passed over the simulated area at about 21:00 on 22nd, 8:00 on 23rd and 13:00 on 23rd respectively (as shown in Figure2).
In order to further verify the accuracy of the simulation results, the simulated wave height is verified with the measured data of the wave station in the cold wave model. The Xiangshui wave station is located near the waste Yellow River estuary along the coast of Jiangsu province. The depth of the buoy is about 8m. The data is collected every hour. The buoy records the wave element process near the measured wave point during cold wave wind. The simulation results during the occurrence of cold wave wind and the measured effective wave height of the Xiangshui station were compared and analyzed. The results are shown in Figure 4. It can be seen from the verification results in Figure 3 and Figure 4 that the effective wave height calculated by SWAN model has a good accuracy, that is, the large-range mathematical model which has been established can reflect the wave field distribution in the east China sea during the period of cold wave wind, which can provide reliable spectral boundary for the simulation of large cold wave in a small range.
4. Impact of coastal beach reclamation planning in Jiangsu on cold wave and wind wave field

In order to study the effect of large-scale reclamation on offshore wave field in cold wave and windy weather, on the background of large-scale beach reclamation planning project in Jiangsu sea, on the basis of accurate simulation of large cold wave in east China sea, the SWAN model was used to self-nest to calculate the wave field before and after the large-scale reclamation in Jiangsu coastal area. The small scale research area is a little larger than the Jiangsu coastal area (The range is from 29.5 ° N to 35.8 ° N and 119.1 ° E to 124.3 ° E), the model adopted unstructured triangular mesh which is in accordance with the coastline of high degree. The grid node number is 48172, grid cell number is 94814, grid spacing decreases from the coast to the nearshore. In order to better depict the reclamation area and conduct grid encryption for the Jiangsu coastal area, the minimum grid spacing is 500m, which not only saves the calculation time, but also can fully improve the simulation accuracy of coastal areas of Jiangsu. The grid section diagram of the simulated area is shown in Figure5.

In order to fully research scale reclamation planning engineering impact on wind wave characteristics in Jiangsu sea a series of characteristic points have been selected in Jiangsu coastal area surrounding the enclose tideland(as shown in Figure6).And the feature points and reclamation area were positively associated with the degree of distribution density, the larger reclamation area is, the more intensive the feature points layout are, and the smaller the reclamation area is, the sparser feature points are. According to the distance between the feature points and the reclamation area, the feature points were divided into three layers. The first layer, A1~A25, was mainly distributed in the nearshore sea area near the reclamation area. B1~B19 are the second layer, slightly farther from the reclamation area than the first layer. C1~C15 are the third layer, which is distributed in the outermost sea area.

In order to fully depict the impact of large-scale reclamation on the cold wave, three typical moments are selected from the simulation results as the analysis objects. The typical moment includes the moment when the cold wave and the wind start to affect the study area, the moment when the influence is greatest and the moment when the influence will disappear. Figure7 shows the wave field distribution of cold wave wind at each typical moment. According to the wave field of cold wave wind at each typical moment, the cold wave wind had the biggest impact on the whole reclamation area of Jiangsu at around at 22 o’clock on the 21st.In order to further analyze the impact of coastal beach reclamation on wind and waves in Jiangsu province, the wave height data of the pre-reclamation and post-reclamation wave feature stations were extracted respectively at 22 o’clock on the 21st according to the model calculation results, and the statistical analysis was conducted, as shown in table 1.
Figure 6. The distribution of feature points of surrounding sea area after reclamation

Figure 7a. The distribution of Hs and direction at 13:00 on day 21.

Figure 7b. The distribution of Hs and wave direction at 22:00 od day 21

Figure 7c. The distribution of Hs and wave direction at 21:00 od day 22.
### Table 1. The variation of Hs of feature points stations before and after reclamation at 22:00 on day 21

| Stations | Pre-reclamation Hs (m) | Variations | Rate of change | Post-reclamation Hs (m) | Variations | Rate of change |
|----------|------------------------|------------|----------------|------------------------|------------|----------------|
| A1       | 1.03                   | -0.09      | -8.72%         | B6                     | 1.57       | 0.01           | 0.45%         |
| A2       | 0.93                   | 0.01       | 91.9%          | B7                     | 1.14       | -0.22          | -19.5%        |
| A3       | 1.15                   | -0.05      | -4.57%         | B8                     | 1.04       | 0.02           | 1.77%         |
| A4       | 1.16                   | -0.38      | -32.9%         | B9                     | 2.01       | -0.05          | -2.64%        |
| A5       | 2.19                   | -0.04      | -2.00%         | B10                    | 2.24       | -0.04          | -1.98%        |
| A6       | 2.10                   | 0.06       | 2.99%          | B11                    | 2.09       | 0.02           | 1.15%         |
| A7       | 1.51                   | -0.02      | -1.18%         | B12                    | 2.18       | 0.00           | 0.20%         |
| A8       | 1.14                   | -0.12      | -10.9%         | B13                    | 2.18       | -0.03          | -1.57%        |
| A9       | 0.92                   | -0.21      | -22.7%         | B14                    | 2.20       | -0.01          | -0.48%        |
| A10      | 1.15                   | -0.11      | -9.34%         | B15                    | 1.82       | 0.04           | 1.97%         |
| A11      | 1.42                   | 0.07       | 4.88%          | B16                    | 1.77       | 0.02           | 1.35%         |
| A12      | 1.18                   | 0.00       | 0.07%          | B17                    | 1.39       | 0.04           | 2.55%         |
| A13      | 1.01                   | -0.03      | -2.55%         | B18                    | 1.38       | 0.00           | 0.23%         |
| A14      | 1.64                   | 0.07       | 4.23%          | B19                    | 1.30       | -0.01          | -0.46%        |
| A15      | 1.73                   | -0.01      | -0.59%         | C1                     | 1.65       | -0.01          | -0.48%        |
| A16      | 1.63                   | -0.08      | -4.96%         | C2                     | 2.33       | -0.02          | -0.78%        |
| A17      | 1.78                   | -0.03      | -1.86%         | C3                     | 2.50       | 0.00           | 0.07%         |
| A18      | 1.97                   | -0.02      | -1.05%         | C4                     | 3.18       | 0.00           | -0.06%        |
| A19      | 1.49                   | 0.05       | 3.15%          | C5                     | 2.83       | 0.02           | 0.58%         |
| A20      | 1.18                   | 0.10       | 8.30%          | C6                     | 2.12       | -0.01          | -0.41%        |
| A21      | 1.21                   | 0.07       | 5.58%          | C7                     | 1.58       | -0.01          | -0.61%        |
| A22      | 0.89                   | -0.01      | -0.84%         | C8                     | 2.43       | 0.00           | 0.07%         |
| A23      | 0.96                   | -0.03      | -3.53%         | C9                     | 2.69       | 0.02           | 0.70%         |
| A24      | 0.83                   | -0.02      | -0.96%         | C10                    | 2.58       | 0.01           | 0.50%         |
| A25      | 0.58                   | 0.01       | 1.74%          | C11                    | 2.49       | -0.01          | -0.60%        |
| B1       | 1.09                   | -0.06      | 5.43%          | C12                    | 2.70       | -0.04          | -1.37%        |
| B2       | 1.44                   | 0.06       | 3.92%          | C13                    | 2.39       | 0.02           | 0.74%         |
| B3       | 1.63                   | -0.17      | -10.2%         | C14                    | 1.90       | 0.00           | 0.26%         |
| B4       | 2.63                   | 0.02       | 8.1%           | C15                    | 1.85       | -0.01          | -0.42%        |
| B5       | 2.11                   | 0.02       | 1.09%          |                         |            |                |

It can be seen from Figure 7 that with the development of time, the wave direction near the coast of Jiangsu did not change much except for Haizhou bay during the occurrence of cold wave and high wind, which the direction was almost NNE. The wave direction in Haizhou bay has significant changes over time. At 7 o’clock on the 22nd, the direction was NNE. It is nearly vertical to the northern coast of Haizhou bay and has a great influence on the sea area. The wave height has a certain degree of increase, but owing to the water depth of Haizhou bay is shallow, and the area of beach reclamation is small, the wave height increment is finite (such as A19 - A21 and B15 to B17). The reclamation area in the southern part of central Jiangsu province, especially in Lengjiasha, Dongsha
and Gaoni, had a great influence on the propagation of wind and wave. The wave height in the southern reclamation area was generally reduced, and the sea area closer to the reclamation area was covered by the reclamation area significantly. The height of wave decreased, with a decrease of -32.98% in the characteristic point A4 and -22.69% in the characteristic point A9. Waves are not blocked, it can propagate directly into the bay formed in the reclamation area. Reflection occurred in the bay, and the wave height of the characteristic point A13 increased.

In order to show the influence of tideland reclamation on the cold wave more intuitively, the wave height changes at the feature points of pre-reclamation and post-reclamation were taken, and the feature stations were numbered from A1 to C15 in order of 1 to 59, and Figure 8 was drawn.

![Figure 8. The variation of Hs of feature points station before and after reclamation.](image)

5. Conclusion
While reclamation brings social and economic benefits, it will also lead to a series of irreversible negative effects. The changes of Marine environment caused by coastal beach reclamation are of great significance to the economic and social development of coastal areas. In this paper, based on the planning of the large-scale tidal mudflat reclamation in Jiangsu province, the variation of the cold wave and wind wave field caused by the large-scale tidal mudflat reclamation was analyzed by means of numerical simulation. The large change of wave field is mainly concentrated in the southern part of central Jiangsu province, which is because the area of reclamation area in this area is large, and it has a significant influence on the wave field. Due to the effect of covering, the wave height of the southern sea area of Dongsha, Gaoni and Lengjiaha reclamation area decreases greatly, and the decline can be as much as 30%. Due to the extent of reclamation is small, the change of wave field in the northern part of Jiangsu province is not obvious, and the range of change is not obvious.

6. References
[1] Wang Jian, Xu Min, et al. Coastal mudflats in Jiangsu Province and their utilization potential[M]. Beijing: Ocean Press, 2012.
[2] Xu Min, Li Peiying, et al. Study on the suitable scale of the surrounding fill for the long tidal flat of silt – taking Jiangsu Province as an example[M]. Beijing: Ocean Press, 2012.
[3] Wang Yigang, Wang Chao, et al. Effects of Tieji Bay reclamation on deep water channel in Sansha Bay, Fujian Province[J]. Journal of Hohai University: Natural Science, 2002, 30(6): 99-103.
[4] Chen Daoxin, Chen Muyong, et al. Effects of reclamation projects on hydrodynamic performance of coastal and estuary of Wenzhou[J]. Journal of Hohai University: Natural Science, 2009, 37(4): 457-463.
[5] Zhang Jinfeng, Shi Zhichao, et al. Numerical calculation of ship stalling during cold wave[J]. Journal of Dalian Maritime University. 2014, 40(2): 1-4.
[6] Xu F, Zhang C, Tao J. Mechanism and application of a third generation wave model SWAN for shallow water[J]. Advances in Water Science, 2004, 15(4): 538-542.
[7] Li Shaowu, Liang Chao, et al. The application of SWAN growth model in wave element calculation of offshore design[J]. Port Industry Technology, 2012, 49(2): 1-7.
[8] Wang Daolong. Application of SWAN near-shore wave model in Liaodong Bay [J]. Advances in Marine Science, 2010, 28(3): 1-6.

[9] Zhang Hongwei. Application of SWAN wave model in Yellow River delta area [J]. Water Transportation Engineering, 2008(12): 1-5.

[10] Gorman R M, Neilson C G. Modeling shallow water wave generation and transformation in an intertidal estuary[J]. Coastal Engineering, 1999, 36: 197-217.

[11] Padilla-Hernandez R, Monbaliu J. Energy balance of wind waves as a function of the bottom friction formulation [J]. Coastal Engineering, 2001, 43: 131-148.

[12] Wornom S F, Welsh D J S, et al. On coupling the SWAN and WAM wave models for accurate nearshore wave predictions[J]. Coastal Engineering Journal, 2001, 43(3): 161-201.

[13] Wornom S F, Allard R, et al. An MPI quasi time-accurate approach for nearshore wave prediction using the SWAN code Part I: Applications to Wave Hindcasts [J]. Coastal Engineering Journal, 2002, 44(3): 257-280.

[14] Rogers W E, Kaihatu J M, et al. Diffusion reduction in an arbitrary scale third generation wind wave model[J]. Ocean Engineering, 2002, 29: 1357-1390.

[15] Lin W Q, Sanford L P, et al. Wave measurement and modeling in Chesapeake Bay [J]. Continental Shelf Research, 2002, 22: 2673-268.

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