Impacts of climate change on wave regimes in the East Sea

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Received 20 July 2016; accepted 25 October 2016

Abstract:

The study applied the PRECIS and SWAN modelling packages to simulate wind and wave regimes under climate change in the Vietnam East Sea. The results indicated that under RCP4.5 climate change scenario, by the end of the century, there are significant changes in both wave height and wave period in summer and winter months. In the East Sea during July, wave height is expected to increase 11.5% while wave period expected to increases 3.3%. On the other hand, wave height in January is projected to decrease approximately 7% while wave period in the same month is projected to decreases 4.4%. There are no significant changes in wave direction.

Keywords: ***climate change, climate change scenario, PRECIS, SWAN.***

Classification number: ***6.2***

Introduction

Climate change causes global warming and consequently, changes meteorological, coastal, and wave conditions, ocean currents, and sea level. There is a large number of studies within the last few years assessing the impacts of climate change on sea wave regimes. The study by Seneviratne, et al. (2012), based on a large number of data sources such as data from monitoring stations, satellite image and wave hindcasting, concluded that average weight height have increased in the Pacific, and Northern Atlantic within the last 50 years and at the southern parts of global oceans in the 1980s [1]. Other studies such as Woolf, et al. (2002), Allan & Komar (2006), Adams, et al. (2008), Menendez, et al. (2008), Izaguirre, et al. (2011) also based on different data sources, determined the linkages between changes in the wave-wind regime and the changes in climate such as ENSO [2-6]. Other studies on the impacts of climate change on oceanic wave regime include Wang & Swaii (2006), Hermer, et al. (2013), Mori, et al. (2013), also showed an increase in average significant wave height, wave period and wave direction in the oceans. The region with largest change occurs in the southern part of global oceans with an increase in average significant wave height between 5 and 10% as compared to now [7-9]. Graham, et al. (2013), using several models (for the SRES A2 scenario), predicted a decrease in average significant wave height in winter in the Northern Hemisphere in the mid latitudes in the Pacific by the end of the 21st century [10]. Hemer, et al. (2012) applied various simulation models (for SRES A2 and B1 scenarios) have also projected a decrease in average significant wave height in the South Eastern coastal area of Australia by the end of the 21st Century as compared to now [11].

In the East Sea region, the wave regime is strictly governed by the monsoon wind system. Under climate change, however, the East Sea monsoon is epected to be altered in both intensity and timing [12], thus leading to changes in the wave regimes in the East Sea.

Methodology

PRECIS model

Providing Regional Climates for Impacts Studies (PRECIS) model is a PC based regional dynamical climate model developed by the Met Office Hadley Center. The model is designed to generate detailed climate change scenarios for small regions of the world. The basis of the PRECIS model is the HadRM3P model developed in 1991 to project climate change. The PRECIS model has been widely used globally to generate regional and national climate change scenarios. For a more detail description of the PRECIS model, relevant documents could be referred to [13].

SWAN model

Simulating Waves Near shore (SWAN) model is a third generation wave simulation model which simulates the 2 dimensional wave spectral through solving for the spectral action balance equation. SWAN allows the simulation of wave characteristics in the coastal zones close to land, in lakes and estuaries from input variables such as wind, bed surface and current conditions. Detailed description of the SWAN model could be referred to in relevant documents [14].

Simulation conditions

PRECIS model:

In this study, the PRECIS model was used in the bounded grid region between 95^{o}E - 135^{o}E; and 10^{o}S - 30^{o}N, with a resolution of 1/8 longitude/latitude degree, and 19 horizontal levels. Boundary and initial conditions are updated from output predictions of the third generation atmosphere-ocean coupled model HadCM3Q0 of the Hadley Center, United Kingdom. Five different runs were performed on PRECIS with a large scale boundary condition from the HadCM3Q0 global model. The five runs include: HadCM3Q0, HadCM3Q3, HadCM3Q10, HadCM3Q11 and HadCM3Q13. In which: (i) HadCM3Q0: is the base model, run under moderate emissions. The remaining HadCM3Qx scenario are dynamically and physically

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adjusted from the base scenario; (ii) HadCM3Q3: Small temperature amplitude changes calibrated; (iii) HadCM3Q10: Dry skew prediction calibrated; (iv) HadCM3Q11: Wet skew prediction calibrated; (v) HadCM3Q13: Large temperature amplitude changes calibrated.

SWAN model:

SWAN model was applied for the entire East Sea region between 1°N-23°N and 99°E-121°E with a grid size of 1/8 longitude/latitude degree. The boundary conditions of the model are long term wave characteristics determined from global hindcasting data [15].

The topography of the study area was generated from the Gebco database with a resolution of 30 second. Fig. 1 depicts the topography of the study area that was used in the SWAN model.

Wind input data of the model is the output of the PRECIS simulation from above.

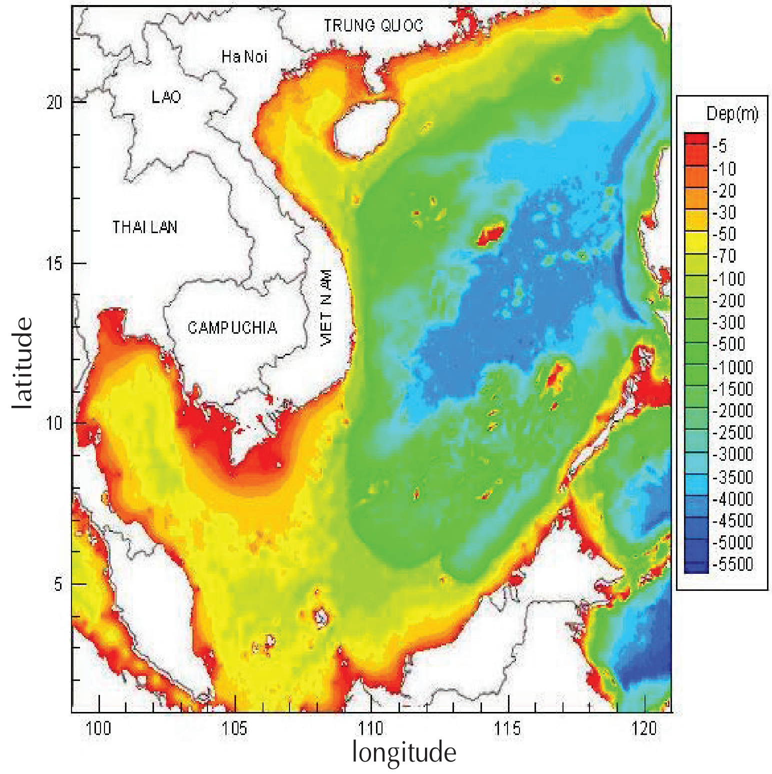
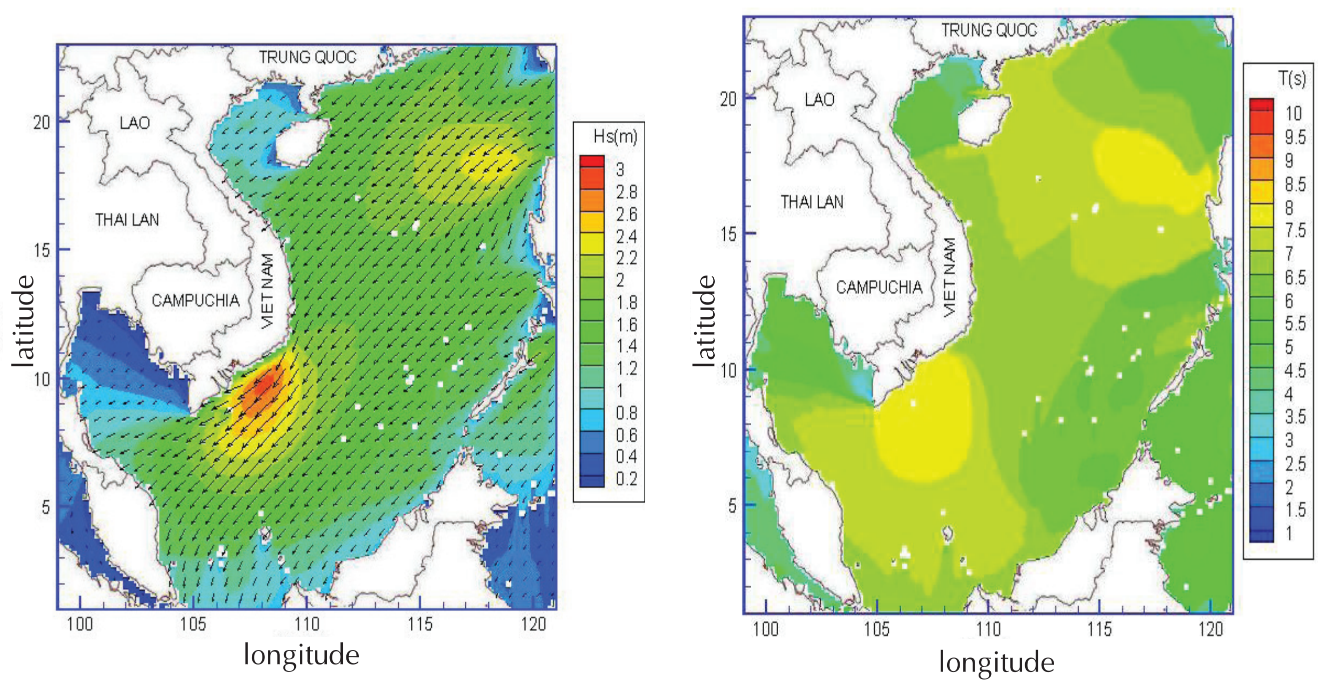


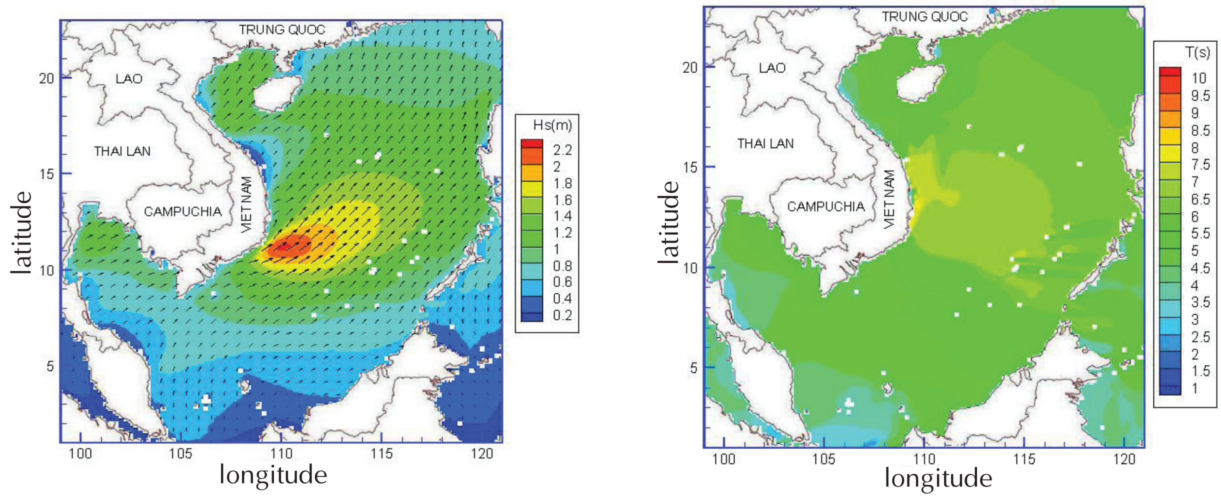
Fig. 1. Topography of the study area.



(A) Height and direction

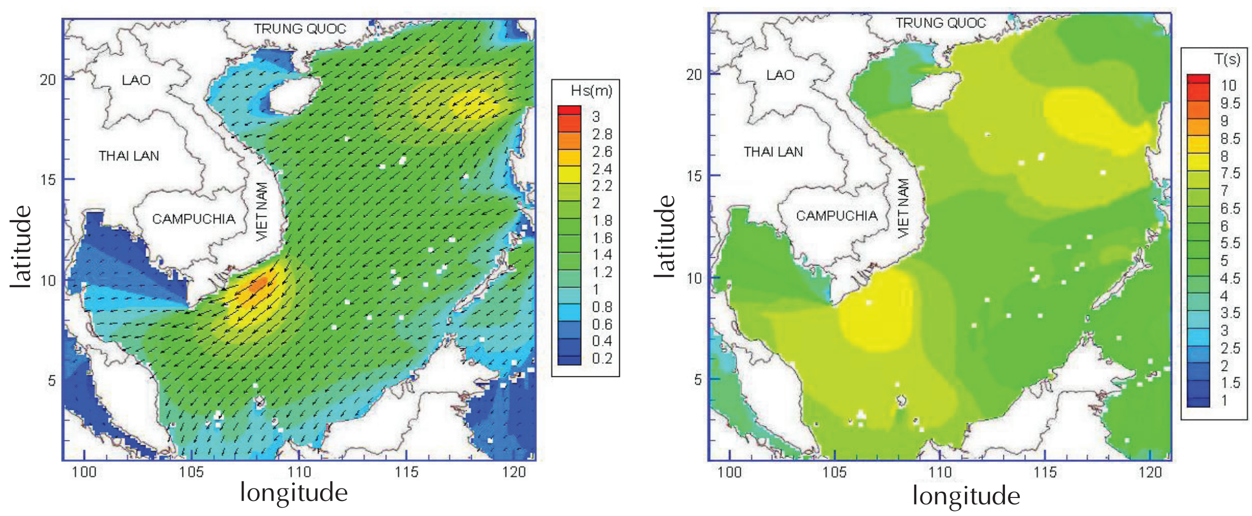
(B) Period

Fig. 2. Average wave characteristics for January in the East Sea based on average wind data for the period of 1980-2000.



(A) Height and direction **(B)** Period

Fig. 3. Average wave characteristics for July in the East Sea based on average wind data for the period of 1980-2000.



(A) Height and direction **(B)** Period

Fig. 4. Average wave characteristics for January in the East Sea based on average wind data for the period of 2080-2099.

Simulation results

Scenarios and assumptions

To determine the impacts of climate change on wave regimes in the East Seas, 2 wind system scenarios were used: (i) a status quo scenario (wind values were determined from hindcasting in the period between 1980-2000; (ii) a climate change scenario (wind was determined from PRECIS under RCP4.5 scenario for the period of 2080-2099).

Results and discussion

The simulated results showed that under the status quo scenario, in winter months, wave direction in the East Sea is predominantly North-East. Largest wave height occurs in the middle of the East Sea, along the North East-South West axis from the Bashi Chanel region to the Mekong River estuary region with an average weight height of 2-3 m.

In the coastal zone of Vietnam, the largest wave height occurs offshore South Eastern Vietnam with average wave height between 3-3.5 m, wave in the Northern coastal zone is less in height and lies between 0.5 to 1 m while wave heights in the Central coastal area is around 1.5 to 2 m. Common wave period is in between 5 to 7.5 seconds; with a maximum reaching up to 8s in the North Eastern part of the East Sea near the Philippines and offshore South Eastern Vietnam (Fig. 2). In the summer months, wave direction in the East Sea is predominantly South-West, with largest wave height up to 2-2.5 m, occurring in the middle of the East Sea. For the coastal zone of Vietnam, largest wave height occurs offshore South Central Vietnam with height above 2 m. In the sea of the northern part of Vietnam, wave heights are between 1.2 to 1.5 m, while in the south, wave only reaches 1m in height. Wave period in the East Sea fluctuates between 4 to 7 seconds, reaching a maximum of 7.5 seconds in the seas of the South Central Vietnam between Binh Dinh and Ninh Thuan provinces (Fig. 3). The results agree well with studies from Nguyen Manh Hung (2005) [15].

Under climate change scenario RCP4.5,

wave simulation shows that in comparison to the 1980-2000 period (baseline), in the 2080-2099 period, spatial distribution of wave height and period changes significantly, while wave direction remains mostly unchanged.

In winter months, wave height and wave period mostly decrease in the East Sea, leading to a reduced regional spatial distribution of wave height (Fig. 2A and 3A) and wave period (Fig. 2B and 3B) compared to the baseline scenario.

The changes in wave regimes under climate change is further assessed at 8 locations through comparing the simulated wave height and period at 8 representative points in the East Sea (refer to Table 1).

Table 1. Data point location.

Data point	Coordinates	
	Longitude	*Latitude*
Bach Long Vi	107.750	20.125
Con Co	107.375	17.125
Cu Lao Cham	108.500	16.000
Hoang Sa	111.625	16.500
Phu Quy	109.000	10.500
Truong Sa	111.875	8.625
Con Dao	106.625	8.625
Gulf of Thailand	101.875	9.750

Results comparison for January - representing winter (Table 2), indicated that on average, wave height and wave period in the East Sea decreases approximately 7% and 4.4% respectively. Wave height reduction in the Bach Long Vi Island in the Northern Gulf (aka Gulf of Tonkin) is 13.1% and 15.4% respectively. In Con Co Island, lowest wave height reduction is at 5.6%, while lowest wave period reduction is 0.4% at Con Dao Island. At Cu Lao Cham, Hoang Sa, Phu Quy, and Truong Sa Islands, wave height decreases between 7.7% and 8.9% while wave period decreases between 1.3% and 3.9%. On the contrary, wave height in the Gulf of Thailand increases 1.9% while wave period decreases 1.7%.

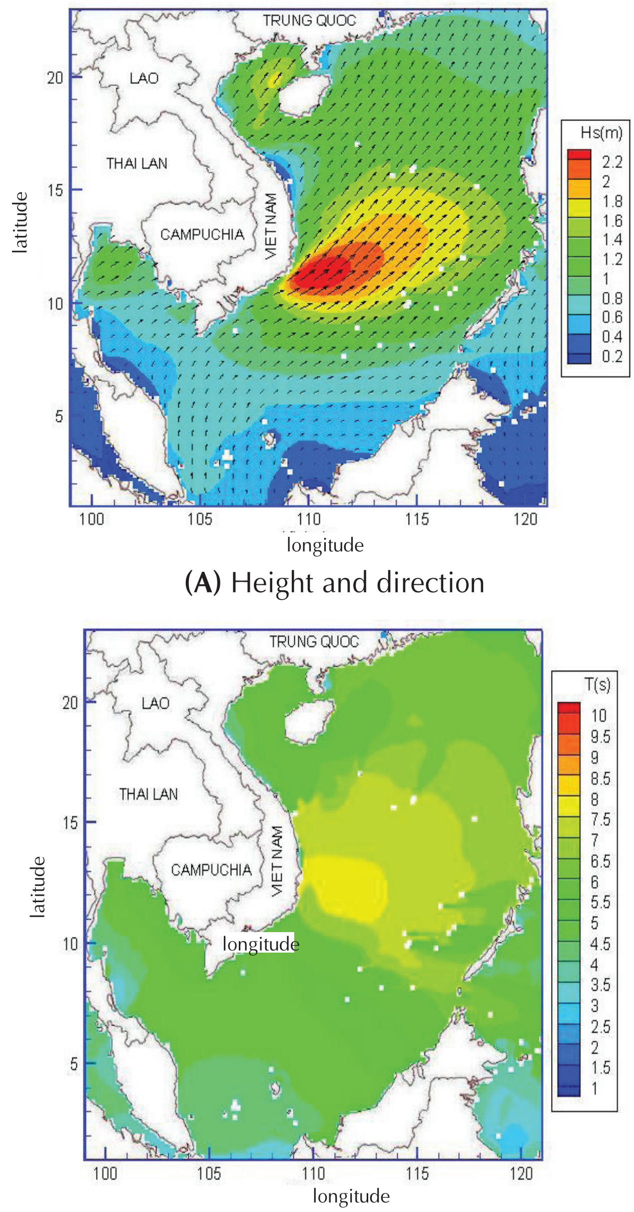
It can therefore be seen that changes in wave height and period in the East Sea is spatially variable. More specifically the changing trend of wave height in the middle of the Gulf of Thailand is in contradiction with the changes in other regions.

In contrast to winter months, wave height and wave period in summer mostly increase in the East Sea, leading to an increase in spatial distribution of wave height (Fig. 4A and 5A) and wave period (Fig. 4B and 5B) as

Table 2. Wave height and period in January comparison for selected locations in the East Sea for the baseline period and under climate change scenario.

Location	Wave height (m)		Change (%)	Wave period (s)		Change (%)
	Baseline	*CC*		*Baseline*	*CC*	
Bach Long Vi	0.99	0.86	-13.1	5	4.23	-15.4
Con Co	1.08	1.02	-5.6	6.89	6.62	-3.9
Cu Lao Cham	1.26	1.16	-7.9	6.82	6.68	-2.1
Hoang Sa	1.68	1.55	-7.7	7.15	7.06	-1.3
Phu Quy	2.54	2.34	-7.9	7.08	6.83	-3.5
Truong Sa	1.68	1.53	-8.9	6.59	6.13	-7.0
Con Dao	1.97	1.84	-6.6	7.72	7.69	-0.4
Gulf of Thailand	0.54	0.55	1.9	5.97	5.87	-1.7

Note: the "-" sign indicates a reduction in either wave height or wave period.



(A) Height and direction

(B) Period

Fig. 5. Average wave characteristics for July in the East Sea, results based on average wind data for the period of 2080-2099.

Table 3. Wave height and wave period in July comparison in selected locations in the East Sea for the baseline period and under climate change scenario.

Location	Wave height (m)		Change (%)	Wave period (s)		Change (%)
	Baseline	*CC*		*Baseline*	*CC*	
Bach Long Vy	1.22	1.48	21.3	5.92	5.94	0.3
Con Co	0.91	1.1	20.9	4.06	4.08	0.5
Cu Lao Cham	0.21	0.26	23.8	5.54	5.73	3.4
Hoang Sa	1.03	1.16	12.6	6.46	6.69	3.6
Phu Quy	1.73	1.86	7.5	5.97	6.01	0.7
Truong Sa	1.12	1.24	10.7	5.73	5.89	2.8
Con Dao	0.77	0.79	2.6	4.93	4.94	0.2
Gulf of Thailand	0.79	0.73	-7.6	4.34	4.97	14.5

Note: the "-" sign indicates a reduction in either wave height or wave period.

compared to the baseline period.

Results comparison for July - representing summer and results in the baseline period is depicted in Fig. 5. The results showed that average wave height increases 11.5% while average wave period increases 3.3%. The region with the largest and smallest increase in wave height as compared to the baseline is Cu Lao Cham Island and Con Dao Island with a 23.8% and 2.6% increase respectively. Wave height in Bach Long Vi and Con Co Islands increase significantly as compared to the baseline period with an increase of 21.3% and 20.9% respectively. Wave period increases most significantly in the middle of the Gulf of Thailand at roughly 14.5%. Increase in wave period in Bach Long Vi, Con Co, Phu Quy, and Con Dao Island is slightly lower, with values of 0.3%, 0.5%, 0.7%, 0.2% respectively.

Similar to the North-East monsoon months, wave height during the South-East monsoon period in the middle of the Gulf of Thailand exhibit a decreasing trend, contrasting the trend in the remaining areas in the East Sea. Wave height decrease in the area is approximately 7.6% (Table 3).

Overall, changes in wave height and period in July in the East Sea is highly variable yet the absolute change in wave height in July (summer) is greater than in January (winter) while the contrary is true for wave period, i.e. the absolute change in wave period in July is less than January.

There is also a degree of uncertainty in the assessment of changes in wave regimes in the East Sea under climate change. The uncertainties in the study is closely related to uncertainties in climate change scenarios and of climate change simulation models and wave simulation models.

Conclusion

Under RCP4.5 scenario, climate change significantly affects the wave regime in the East Sea, the impact is highly variable depending on the region and the season assessed.

In January, wave height in the East Sea decreases on average 7% while wave period in the East Sea decreases on average 4.4%. Wave height and wave period decreases the most at Bach Long Vi Island with predicted values of 13.1% and 15.4% respectively.

In the middle of the Gulf of Thailand, the trend of wave height change is reversed with the trend in other regions, with an increase of 1.9% while wave period follows the similar trend in other regions with corresponding value of 1.7%.

In July, wave height increases on average 11.5%, wave period increase on average 3.3%. The region with the highest increase in wave height as compared to the baseline period is Cu Lao Cham Island at approaximately 23.8%. The lowest increase in wave height projected is in Con Dao Island at approximately 2.6%. Wave period increases most significantly in the middle of the Gulf of Thailand, at approximately 14.5%, and least significantly at Con Dao Island at 0.2%. Wave height in the middle of the Gulf of Thailand decreases 7.6%, contradicting the general trend in the East Sea.

Average absolute changes of wave height in July in the East Sea is greater than that in January. On the contrary, average absolute changees of wave period in July is less than that in January.

The study provides the assessment of climate change impacts on wave regimes in the East Sea for January and July, the two time period representing winter and summer in the region. There is a degree of uncertainty related to the study, this mainly spurs from the uncertainties in climate change scenario and simulation models. Further detailed assessment of climate change impacts on wave regimes in the East Sea in the future is needed.

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