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Short Communication

Significant coastline changes in China during 1991–2015 tracked by Landsat data

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In China, following national economic reform and the open-door policy in 1978, there has been a rapid industrialization and urbanization of coastal regions which has dramatically changed the environment and ecosystems in these areas [1]. Regions with rapidly growing economies, such as Shanghai and Shenzhen, face the double pressure of limited land area and population growth, and many land reclamation projects have been implemented to create new land from ocean [2,3]. Sea level rise and delta subsidence can also increase the vulnerability of coastal zones [4]. Despite the importance of coastal areas, a comprehensive knowledge of the changes of China's coastline is rare at national scale. Hou et al. [5] recently carried out a coastline change assessment over mainland China using topographic maps of the 1940s and 1960s and Landsat images circa 1990, 2000, 2010 and 2014. They found substantial coastline changes in China. Because topographic maps are made over a long duration of time and are generalized during map compilation, such data is temporally inconsistent and will contain many uncertainties. More frequent observational data and an automatic approach are necessary to continuously track coastline changes with more temporal details [6,7].

To better monitor China's coastline changes, we collected a total of 19,041 scenes of Landsat imagery (Thematic Mapper (TM): 10,900 scenes and Enhanced Thematic Mapper Plus (ETM+): 8,141 scenes) at L1T level from the USGS (United States Geological Survey) Earth Explorer website. The annual mean waterline, established by averaging many observed waterlines, was used to represent the annual coastline position [8,9], which can minimize the impact of short-term coastal variability associated with sea level variations, the length of wave run-up, sedimentary seasonal variations in the beach profile, and coastal storms. A modification of the normalized difference water index (MNDWI) [10] was used for land-water classification because it was assessed to be the best water index for coastline mapping based on its performance and threshold replicability [11]. A zero threshold was used to generate the land-water map, which was the optimal threshold of MNDWI for land-water classification [12]. Then, all the land-water binary maps for one year were stacked together at a pixel level to generate an annual land frequency map. The frequency of observed land at each pixel location was divided by the total effective observation number (i.e. observed as land or water) at the location to produce a ratio of land. Pixels with a ratio greater than 0.5 are defined as the annual land area and an annual land-water map can thus be produced. Annual land-ocean maps can be generated after infilling inland water bodies using the MATLAB function "*imfill*". Manual checking based on Google Earth historic maps was conducted to ensure the quality of the mapping results. A coastal mask representing the spatial extent of coastline variation between 1991 and 2015 was established by combining 5-km coastal grids with the proportion of land area for any year between 0 and 1 during 1991–2015. For each coastal grid, the change rate of the land area estimated by linear regression was calculated to characterize the coastline change rate. It should be noted that the significance of the linear regression was obtained at the 0.05 level. Furthermore, the coastline change rate, average coastline change rate and percentage of coastline expansion for each province were calculated. The coastline change rate was calculated as the change rate of the annual land area within the coastal mask for each province. The average coastline change rate was defined as the ratio between the coastline change rate and the number of grids of the coastal mask within each province. The percentage of coastline expansion was computed as the proportion of grids exhibiting a coastline expansion within the coastal mask for each province.

Fig. 1 shows the spatial distribution of coastline change in China during 1991–2015. 77.93% of the coastline in China expanded to the ocean (55.19% significantly) while 22.07% retreated to the land (7.89% significantly) during 1991–2015 (Fig. 1d). 63.08% of the coastline changes are statistically significant, while 36.92% are

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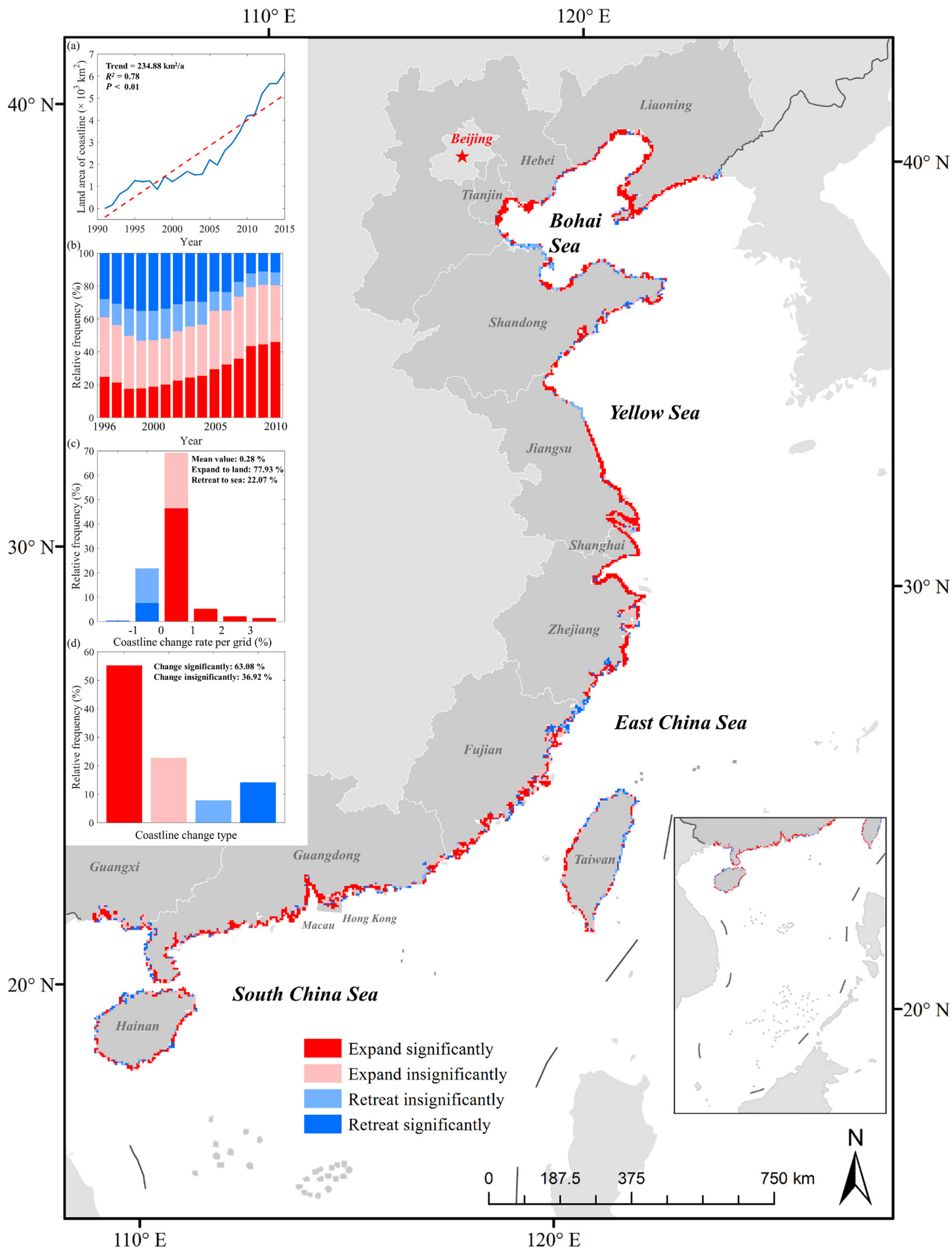

Fig. 1. Coastline change in China over the period 1991–2015. Red represents areas with a significant ($P < 0.05$) expansion of coastline into the ocean and light red represents areas with insignificant ($P \geq 0.05$) expansion. Blue represents areas with a significant ($P < 0.05$) retreat of coastline towards land and light blue represents areas with insignificant ($P \geq 0.05$) coastline retreat. (a) Observed land area of coastline between 1991 and 2015 across China. (b) Temporal variation of coastline change types during the period. (c) Frequency distribution of coastline change rate per grid. (d) Frequency distribution of coastline change in four classes: expand significantly, expand insignificantly, retreat insignificantly and retreat significantly (at 0.05 significance level).

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