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Monitoring mangrove forest change in China from 1990 to 2015 using Landsat-derived spectral-temporal variability metrics

Luojia Hu[a], Wenyu Li[b], Bing Xu[a,b,*]

[a] State Key Laboratory of Remote Sensing Science, College of Global Change and Earth System Science, Beijing Normal University, Beijing, 100875, China
[b] Department of Earth System Science, Tsinghua University, Beijing, 100084, China

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ABSTRACT

Reliable information of national-level mangrove forest change in China is urgently needed for Chinese government to make appropriate policies of mangrove forest conservation. Yet, employing traditional methods (all based on single-date remotely sensed imagery) to accurately map mangrove forest in China is relatively difficult, given the influence of tide variability on the spectrum of a large proportion of mangrove forest and the spectral similarity between mangrove forest, cropland, and natural terrestrial vegetation. However, the temporal profile of spectrum for mangrove forest is likely to be distinctive, due to the influence of tide variability on mangrove forest spectrum. Therefore, in this study, we investigated the potential of using some robust spectral-temporal variability metrics (quantiles), capturing characteristics of temporal profiles for different land cover types, to reliably separate mangrove forest. We also mapped mangrove forest in China for 6 periods (1986–1992, 1993–1997, 1998–2002, 2003–2007, 2008–2012, and 2013–2017) and analyzed mangrove forest change over past decades using all available Landsat imagery. Producer's and user's accuracies of the land cover type "mangrove forest" for all periods are high (> 90%), indicating the effectiveness of our method. We found that mangrove forest in China has significantly increased, from 10774 ha in the period 1986–1992 to 19220 ha in the period 2013–2017. There is also a potential for employing our method to map global mangrove forest around 2015.

1. Introduction

Mangrove forest, located in intertidal zone of tropics and subtropics, is critically important for mitigating climate change and shielding coasts from storm surges (Arkema et al., 2013; Duarte et al., 2013). Yet, mangrove forest has been seriously threatened by rising sea level, declining precipitation, accelerating subsidence, as well as increasing agriculture, aquaculture, and urbanization (Cavanaugh et al., 2014; Kirwan and Megonigal, 2013; Lovelock et al., 2015; Osland et al., 2016; Richards and Friess, 2016; Webb et al., 2013). To make appropriate policies of mangrove forest conservation, accurate information of mangrove forest change over past decades is required.

To date, with the support of remote sensing, which has the ability of effectively observing earth surface at a variety of spatial and temporal scales (Heumann, 2011; Li and Gong, 2016; Yang et al., 2013), the extent change of mangrove forest for most of areas around the world has been well investigated. Yet, for China, reliable information of national-level mangrove forest change is still lacking. Specifically, there are only two relevant studies, and their results are obviously deficient. By synthesizing two remotely sensed products (the Mangrove Forests of the World product and the Global Forest Cover product) and the Terrestrial Ecoregions of the World product, Hamilton and Casey (2016) developed a dataset of global mangrove forest change (Hamilton and Casey, 2016). However, that dataset merely delineated about 14% of mangrove forest in China and overlooked increases in mangrove forest (Chen et al., 2017). Through visually interpreting Landsat imagery, Wu et al. (2013) mapped mangrove forest in China for 3 periods (around 1990, 2000, and 2010) and further measured the change (Wu et al., 2013). However, in their study, the extent of mangrove forest is overestimated. For example, a total area of 24578 ha was reported for the period around 2010, much higher than a reliable result of 20303 ha (Chen et al., 2017).

To derive reliable information of mangrove forest change, high-accuracy mangrove forest map is essential. Yet, employing traditional methods (all based on single-date remotely sensed imagery) to accurately map mangrove forest in China is relatively difficult (Chen et al., 2017; Younes Cárdenas et al., 2017). Firstly, for a large proportion of mangrove forest in China, the branch or even the canopy is periodically submerged given tide variability. Therefore, the spectrum of a large proportion of mangrove forest is similar to that of water when water

* Corresponding authors at: College of Global Change and Earth System Science, Beijing Normal University, No. 19 Xinjiekouwai Street, Haidian District, Beijing, 100875, China.
E-mail address: bingxu@tsinghua.edu.cn (B. Xu).

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level is relatively high. Secondly, the spectrum of some mangrove forest is nearly same to that of nearby cropland or natural terrestrial vegetation at some time.

Although the spectrum of mangrove forest is easy to be confused with that of other land cover types, the temporal profile of spectrum for mangrove forest is likely to be distinctive, due to the influence of tide variability on the spectrum of mangrove forest. Hence, we hypothesized that employing some robust indicators (e.g. percentiles) calculated from available observations of multi-date remotely sensed imagery, which represent characteristics of temporal profiles of spectrum for different land cover types, is able to reliably distinguish mangrove forest.

The main objectives of this study are to: 1) investigate the potential of using those indicators (hereafter referred to as "spectral-temporal variability metrics") to map mangrove forest. 2) use spectral-temporal variability metrics derived from Landsat time series to map mangrove forest in China for 6 periods: 1986–1992, 1993–1997, 1998–2002, 2003–2007, 2008–2012, and 2013–2017 (hereafter referred to as "around 1990", "around 1995", "around 2000", "around 2005", "around 2010", and "around 2015", respectively), and 3) analyze mangrove forest change in China over past decades.

2. Study area

Our study area is located in the south and southeast of China (18° N to 30° N, 105° E to 125° E), covering all potential areas where mangrove forest occurs (Fig. 1). The study area comprises coasts of Hong Kong, Macao, Taiwan, the Guangxi Zhuang Autonomous Region (hereafter referred to as "Guangxi"), and the provinces of Hainan, Guangdong, Fujian, and Zhejiang. Mangrove forest is only distributed in intertidal zone. Other land cover types in coasts include cropland, natural terrestrial vegetation, salt marsh, impervious surface, water, tidal flat, and bare land. Dominant species of mangrove forest in China include *Kandelia obovta*, *Bruguiera gymnorrhiza*, *Acrostichum aureum*, *Acanthus ilicifolius*, *Aegiceras corniculatum*, and *Avicennia marina* (Liao and Zhang, 2014).

3. Data

3.1. Landsat imagery

All available high-quality Landsat surface reflectance data with a spatial resolution of 30 m from 1986 to 2017 (a total of 11597 scenes), generated from Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM +), and Operational Land Imager (OLI) Collection 1 Level-1 products, were downloaded from the United States Geological Survey Center for Earth Resources Observation and Science (USGS/EROS). High-quality data were selected based on the following criteria: land cloud cover < 80%, scene cloud cover < 80%, and Collection category is Tier 1 (Landsat Collection 1 Level-1 data with highest geometric and radiometric quality are placed into Tier 1). Clouds, cloud shadows, and Scan Line Corrector (SLC)-off gaps in Landsat ETM+ imagery were screened by employing pixel quality assurance bands included in Landsat surface reflectance products. The mean number of clear observations per pixel per period is 25.

3 spectral indices (Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Modified Normalized Difference Water Index (MNDWI)) (Gao, 1996; Tucker, 1979; Xu, 2006), which are able to capture spectral properties of vegetation and

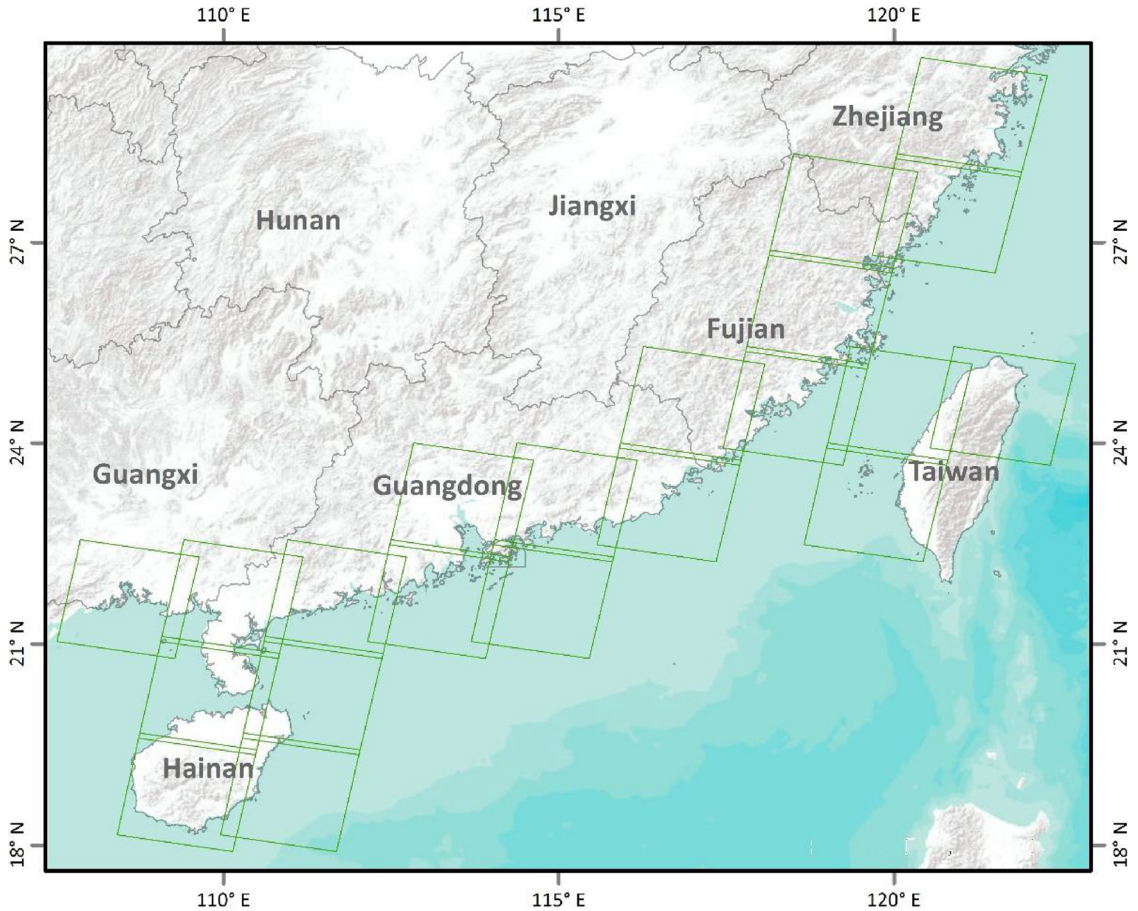

Fig. 1. Location of our study area. Green boxes represent the coverage of Landsat WRS2 (Worldwide Reference System2) tiles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)