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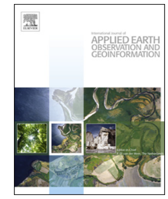

An early forecasting method for the drift path of green tides: A case study in the Yellow Sea, China

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A R T I C L E I N F O

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A B S T R A C T

Since 2007, green tides caused by massive blooms of *Enteromorpha prolifera* have occurred in the Yellow Sea during April and September every year. Generally, the macroalgae first gathered around the Jiangsu coastline and then moved northeastward toward the Shandong Peninsula, but the paths and distribution of green tides have featured obvious inter-annual variation. Here, we describe a new method to forecasting the drift path of green tides with some climate indices such as Nino3.4. This method may help policy makers to develop a strategy to prevent green tide disasters and mitigate the consequence more effectively.

Initially, we ran a numerical ocean model to simulate the movement of hypothetical green tides for last 20 years. The model was driven by remote sensing data of sea surface winds, surface temperatures, and tracers representing macroalgae that were created on certain dates so that drift paths could be traced. Ocean color remote sensing data were employed to determine the drift parameters. Next, the relationship between the displacement of tracers, including directions and distances of movement during certain periods were then analyzed along with the corresponding values of a set of six climate indices. A forecasting algorithm based on an artificial neural network was then established and trained with these data. Using this algorithm, the drift path of green tides could be predicted from the values of certain climate indices of the previous year. The model assessment with satellite ocean color remote sensing images indicated the effectiveness and practicability of this method.

1. Introduction

A new type of marine ecological disaster caused by the excessive and large-scale proliferation of marine green algae is known as a “green tide.” Green tides represent a widespread phenomenon in estuaries, lagoons, inner bays, and other waters worldwide. Since the 1970s, the frequency and regions affected by green tides have shown an increasing trend. Green tide disasters had been reported in the United States and Canada, while the worst disaster occurred on the coast of Brittany in France (Charlier et al. 2007; Teichberg et al. 2010). Since 2008, large-scale green tides have occurred in the Yellow Sea for eight consecutive years (Keesing et al. 2011; Liu et al. 2013a), while greatly affected aquaculture, coastal tourism, maritime transport, maritime events, and other related industries. Green tides also caused major economic losses and social effects on coastal cities in Jiangsu and Shandong provinces (Ye et al., 2011). Therefore, research on the sources of green tides, characteristics of the variation in the distribution, and the mechanism involved in their occurrence in the Yellow Sea is of great importance in disaster prevention, environmental protection, and economic development.

Many studies have been conducted on green tides in the Yellow Sea, but the location of green tide generation remains controversial. It is widely believed that South Yellow Sea serves as the source of green tides (Pang et al., 2010). Satellite imagery and model results have shown that green tides formed in the offshore region of Jiangsu Province and drifted into the North Yellow Sea under the influence of monsoons and ocean currents (Feng et al. 2010; Keesing et al. 2011; Cui et al. 2012; Qiao et al. 2009; Ho et al., 2011). Recent research studies have suggested that the laver culture in Rudong County, Jiangsu Province, provided the most direct and sufficient initial biomass for green tides, and also was the primary cause of the continuous blooming of green tides in the South Yellow Sea since 2007 (Li et al., 2014; Wang et al., 2015). During April and June, many algal colonies are often blown into the sea and grew rapidly in a suitable environment, and finally formed the green tides.

Based on remote sensing monitoring, many scientists have discussed the spatial distribution of green tides and their paths as they drift into the Yellow Sea on an interannual timescale (Wu et al., 2013; Huang

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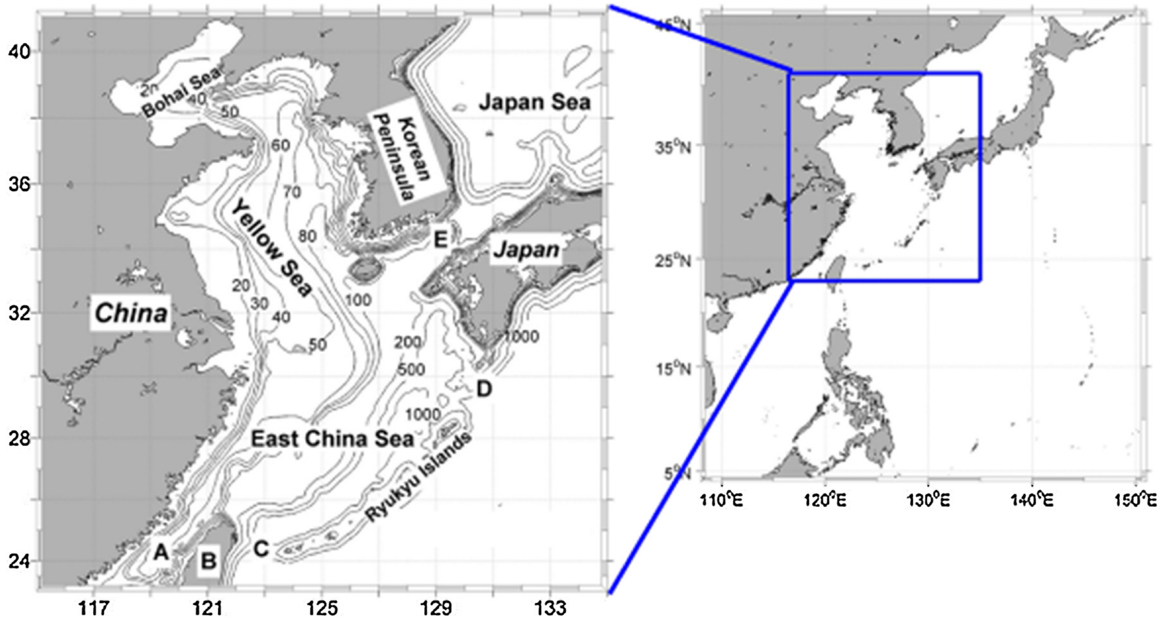

Fig. 1. Regional diagram for the model: A, the Taiwan Strait; B, the Taiwan Island; C, the East Taiwan Channel; D, the Tokara Strait; E, the Tsushima Strait.

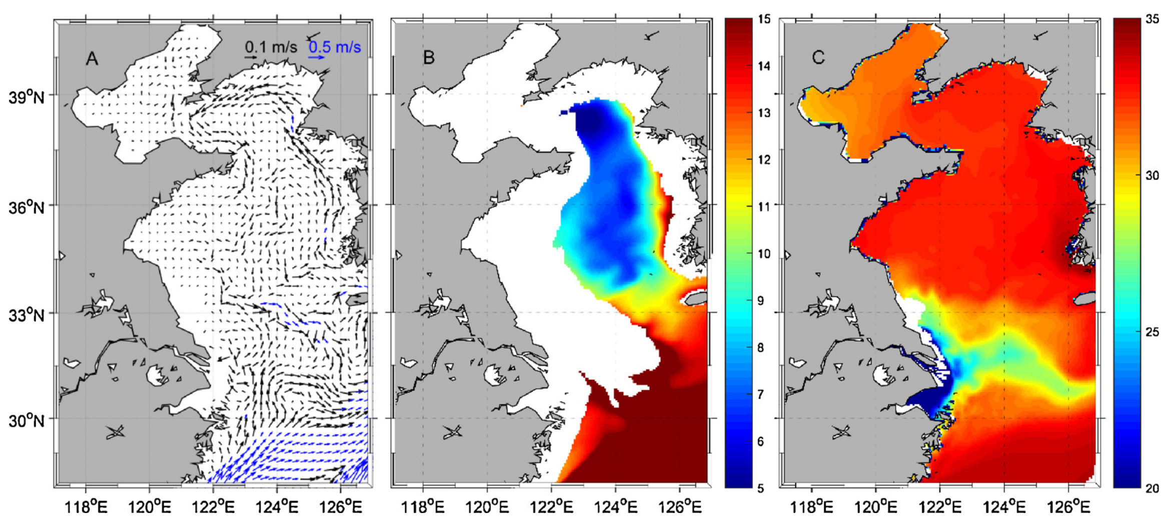

Fig. 2. Representative model results: A, 10 m depth current field; B, 50 m depth temperature; C, 5 m depth salinity.

et al., 2014). During the blooming and duration of green tides, satellite data can be used to estimate the distribution and cover area of green tides accurately. Since the usefulness of remote sensing inversion is limited on the ocean surface, most green tides have been in a striped distribution and started to gather and grow quickly soon after they were first discovered. However, no or only a little algae floats on the surface during the early growth stage of a green tide, so remote sensing inversion cannot capture the drift path of a green tide. Huang et al. (2014) and Guo et al. (2016) documented the distribution of green tides when they were first discovered with satellite remote sensing during 2008–2013 and 2008–2015, respectively. These studies showed that the initial discovery of green tides mainly occurred in mid- or late-May or in early June; the locations were mainly in the offshore regions in Yancheng city and Rudong County of Jiangsu Province. Significant interannual variation occurred in the timing and location of green tides.

The above studies mainly analyzed the features of the variation in green tide drift paths from the blooming to the extinction periods. Few studies have analyzed the early drift path of green tides from mid-April to mid- and late-May. Predictive studies on early drift path play an essential role in preventing and controlling green tide disasters. Therefore, this paper focused on predicting the early drift paths of green tides before they gathered and floated on the sea surface. We thought wind could not drag an underwater green tide directly, so we believed the early drift paths of green tides were mainly controlled by oceanic circulation. Because the local wind has the strongest effect on the summer circulation in the South Yellow Sea, this study was based on numerical simulation and artificial neural network algorithm methods. We used a climate variability index as the prediction factor and the interannual variation of the local wind field as the intermediary factor; then we established a prediction method for the early drift paths of green tides.

2. Methods and data

This study mainly consisted of two parts. First, numerical experiments were used to determine the most important dynamic factors that control the early drift path of green tides and their interannual variation. Second, based on an artificial neural network algorithm, the early drift paths of green tides were predicted with the climate variability indicators.