Onset dates of spring phytoplankton bloom in the Southern Yellow Sea during 2003-2019 based on satellite remote sensing data

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1 Purposes

Spring phytoplankton bloom (SPB) is the duration in a year when the phytoplankton productivity reaches the peak (Wei et al., 2001). The onset time is one of the important parameters of SPB, and varies both spatially and interannually (Wang et al., 2022). The Southern Yellow Sea (SYS) is an important fishing area in China, hence analyzing the spatial and interannual variations of SPB onset time in this region is valuable for predicting the changes in the marine ecological environment and the management of fishery production.

Previous studies have given the multi-year average rule of the onset time of SPB in the central SYS, indicating that spring bloom occurs from March to May in the central SYS, and the peak of chlorophyll-a (Chl-a) concentration mostly occurs in April (Zheng et al., 2012; Shi et al., 2017; Lv et al., 2022). However, the regional differences and interannual variations of the SPB onset time in this area still need further study.

2 Methods

The Chl-a concentration is an important representation of marine phytoplankton biomass. And the onset time of phytoplankton bloom can be judged according to the time when Chl-a concentration reaches a certain threshold C_{SPB}, which is called the threshold method (Thomalla et al., 2011; Racault et al., 2012). Due to weather influence, there is a lack of measurement of the daily Chl-a concentration product. Based on the data characteristics, this paper improved the traditional threshold method and adopted the following judgment method for the SPB onset time in the central SYS:

1) In this study, we used the MODIS-Aqua level 3 daily Chl-a concentration product, with a spatial resolution of 9 km (https://oceancolor.gsfc.nasa.gov/l3/order/). The time series of Chl-a concentration of each grid point deep than 50 m in the SYS was extracted from March to May each year, and the time when Chl-a concentration first exceeded the threshold C_{SPB} (followed Zhou et al.(2013), we set it as 4 mg/m^3) was recorded as t_1.

2) Mark the time of the last Chl-a concentration data before t_1 as t_2.

3) The median value of t_1 and t_2 is defined as the onset time of SPB at a single grid point, we marked it as t_3.

$$\Delta t = t_1 - t_2, \ \ \Delta t \geq 1 \tag{2-1}$$

$$t_3 = \begin{cases} t_1 - \frac{\Delta t - 1}{2} & \text{(when } \Delta t \text{ is a odd number)} \\ t_1 - \frac{\Delta t}{2} & \text{(when } \Delta t \text{ is a even number)} \end{cases} \tag{2-2}$$

If the Chl-a concentration of a single grid point does not reach 4 mg/m^3 from March to May, the SPB onset time of this grid point this year is unestimated.

4) During 2003-2019, Δt of most grid points are less than 15 days, but some points can be more than 20 days. According to formula (2-2), the larger Δt is, the larger t_3 error. After selection, we removed t_3 data where Δt greater than 10 days.

5) The central SYS (deeper than 50 m) is divided into 70 0.5°×0.5° units (**Fig. 1**), and each unit contains 36 grid points. When there are no less than 3 effective grid points in the unit, the mode of t_3 in the unit is taken as the SPB onset time of the unit in the current year. If less than 3 grid point are valid, the SPB onset time of the unit this year is unestimated.

Figure 2 shows the determination process of the SPB onset time from grid point to unit in the year of 2004 as an example.

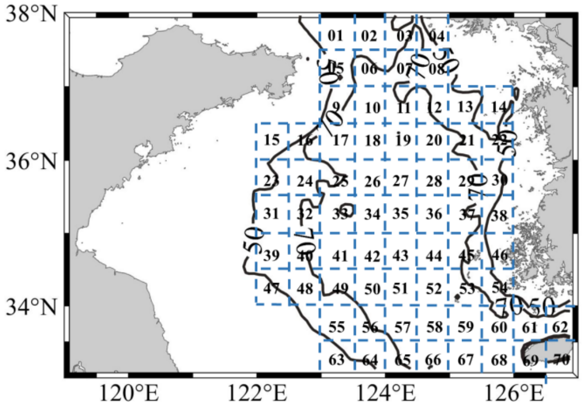

Fig.1 Distribution of 70 units in the central SYS.

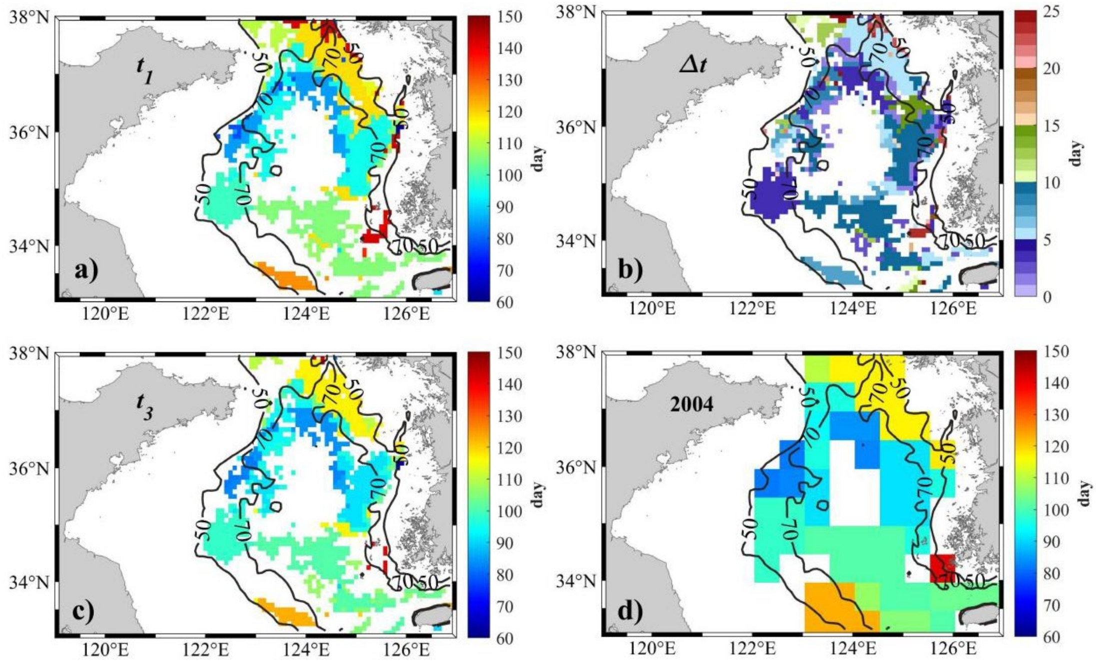

Fig.2 The determination process of SPB onset time in 2004. a) The time when the Chl-a concentration at each grid point exceeded the threshold for the first time b) The difference between t_1 and t_2 at each grid point c) SPB onset time at each grid point after removal d) SPB onset time of each unit.

3 Results

Using the threshold method to determine the onset time of SPB in the central SYS from 2003 to 2019 (**Fig. 3**). The general rule is that the bloom on the west coast of the Korean Peninsula is significantly later in most years than the central Yellow Sea. We further divided the central SYS into five sub-regions: west, central, east, north and south (**Fig.4a**). The muti-year averaged result of the SPB onset time shows that the SPB gradually delays from northwest to southeast, with a time span about 40 days. It begins in the western area at about late March, and finally occurs off the west coast of the Korean Peninsula and near the boundary between the Yellow Sea and the East China Sea in early May (**Fig.4a**).

This sequence of SPB occurrence is basically consistent with the results of Zheng et al. (2012).

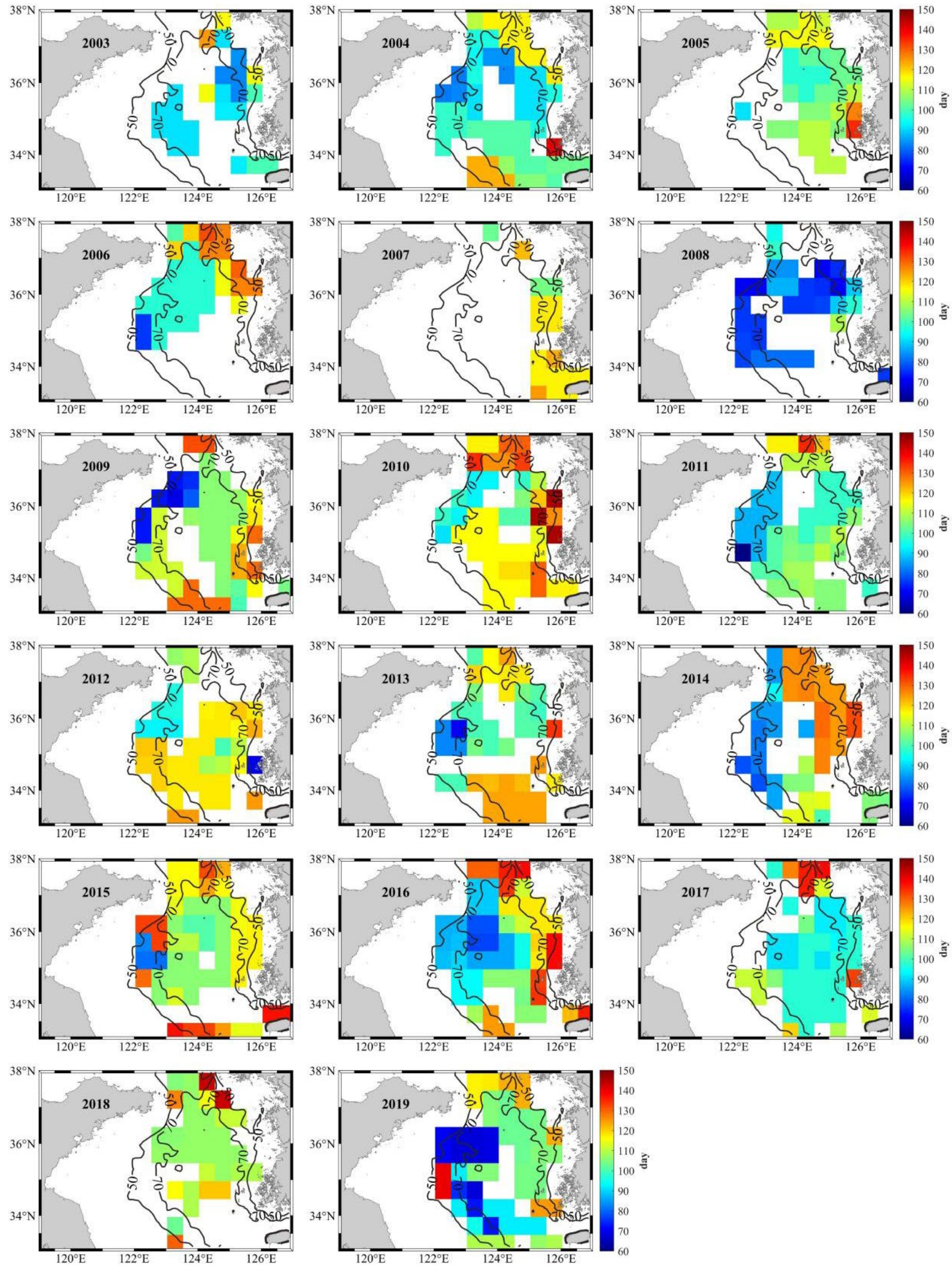

Fig. 3 Distribution of SPB onset time of the central SYS from 2003 to 2019.

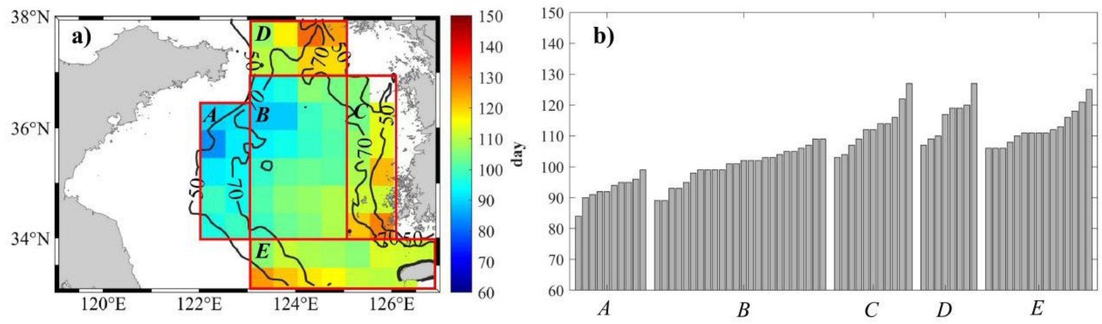

Fig.4 a) Spatial distribution of the muti-year averaged SPB time in the southern Yellow Sea; b) Muti-year averaged SPB time in 5 sub-regions.

The range of the SPB onset time of each unit in each sub-region was extracted from the multi-year average results (**Fig. 4b**). Taking January 1st as the first day of each year, the average SPB onset time of the west sub-region is the 84-99th day of the year, about from late March to early April. The time range of the central sub-region is the 89-109th day, 5-10 days later than the west sub-region, about early to mid April. The onset of SPB often occurs on the 104-127th, 107-129th and 106-125th day in the east, north and south sub-regions, respectively. It happens from mid or late April to early May, about 15-20 days later than the central sub-region.

Then, the multi-year average earliest and latest SPB onset time of each sub-region can be got (real and virtual lines in **Fig.5**). The average SPB onset time of each rub-region was calculated by year (bold black line plus box in **Fig.5**), and the dispersion of SPB onset time of different units in the sub-region was obtained (shadow in **Fig.5**). In general, **Figure 5** shows the interannual variations of the SPB onset time of each sub-region in the SYS. If the average time of the sub-region in a year is 5 days or more earlier than the earliest time, or 5 days or more later than the latest time, it is considered that the SPB in the sub-region occurred too early or too late in this year.

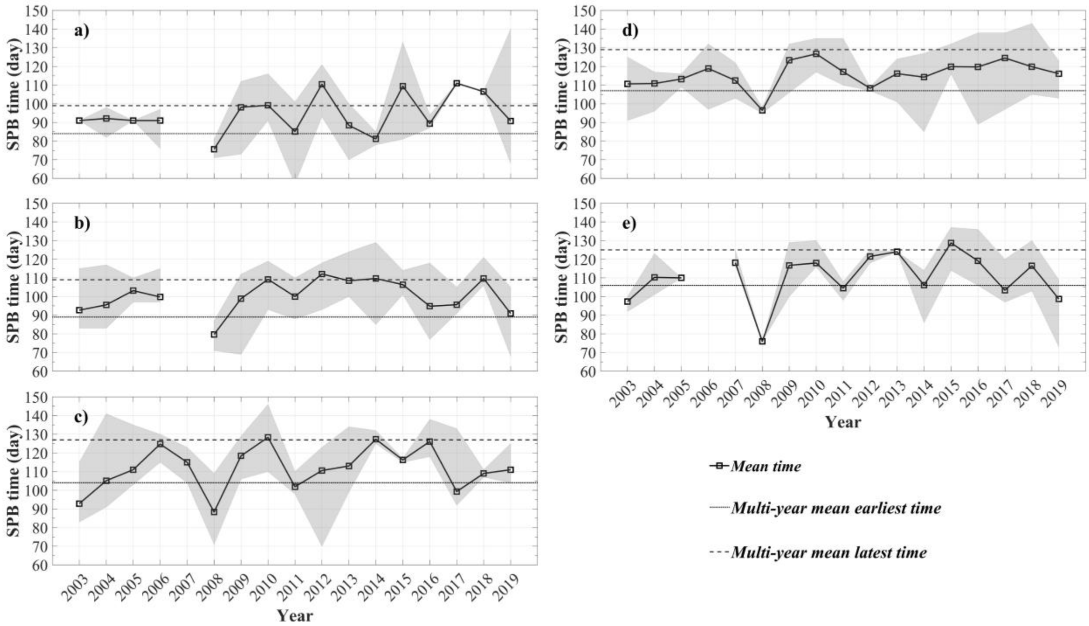

Fig.5 Interannual variation of the SPB onset time in five sub-regions of the SYS.

The central and north sub-regions shows the smallest interannual variations. The former is maintained in mid or early April (**Fig.5b**), while the latter is maintained in late April (**Fig.5d**), and advanced SPB of the two sub-regions only occurred in 2008 (about 10 days earlier) during 2003-2019. The interannual variations of SPB onset time of the east and south sub-regions are relatively obvious (**Fig.5c, e**). Both of the SPB of the east and south sub-regions occurred prematurely in 2003 and 2008, and also of the east sub-region in 2017 and of the south sub-region in 2019. The interannual variation was the most significant in the west sub-region. It occurred about 10 days earlier in 2008, but delayed to late April in 2012, 2015, 2017 and 2018, about 10 days later than the multi-year average result (**Fig. 5a**).

4 Future challenges

Previous studies have shown that the growth of marine phytoplankton is closely related to environmental factors such as solar radiation, water temperature, nutrient supply and vertical mixing of the upper layer. Therefore, the onset time of the SPB should also be affected by the above environmental factors. Previous studies mainly described these environmental background of the SYS qualitatively. To further study the dynamic factors affecting the SPB onset time of the SYS, it is necessary to conduct a comprehensive and quantitative analysis of the dynamic environmental background of the SYS in spring.

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