Title：Exploring the effect of dissolved inorganic nitrogen on the seasonal variations of surface chlorophyll in the East China Sea using physical-biological coupled model and tracking module

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Aim: Using physical-biological coupled model and tracking module to analyze the effects of different sources of DIN on the temporal and spatial variations of phytoplankton (characterized by chlorophyll a, Chl) and the response relationship between DIN and Chl from various sources in the surface of the East China Sea, so as to evaluate the effects of multi-source nutrients on the surface phytoplankton over the East China Sea shelf.

2. Methods: The sub-source nutrient salt module is the same as that used in Zhang et al. (2019) and Zhang et al(2021). Four kinds of exogenous DIN in the model are labeled and tracked, they are: river runoff (R), including Huaihe River, Yangtze River, Qiantang River and Minjiang River; Atmospheric deposition (A), including dry and wet atmospheric deposition; Taiwan Strait (T) and Kuroshio (K) to the east of Taiwan.

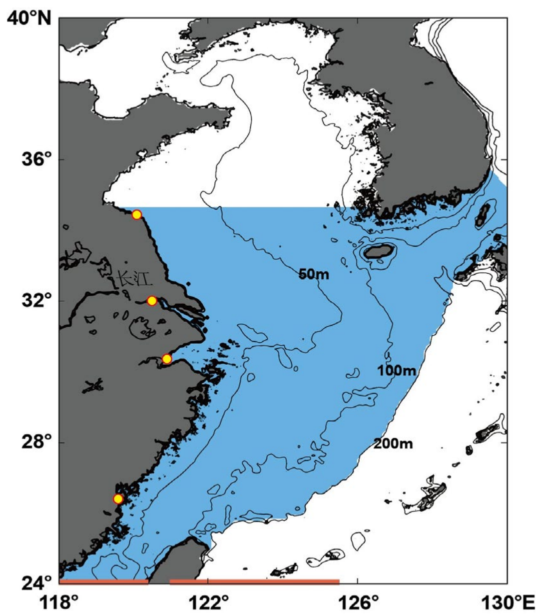

Fig.1 The topographic map of the East China Sea shelf in the physical-biological coupled model

Among them, the concentration data at the river inlet is from Zhang et al. (1996) and Liu et al. (2009), and the distribution data of atmospheric dry and wet deposition is from

Zhang et al. (2011). Nutrient, phytoplankton and debris data from Taiwan Strait are from Professor Chen Zhendong (personal communication). The data of nutrients, phytoplankton and debris from the Kuroshio source are from the average values observed by the Japan Meteorological Agency for many years. The simulation reflects the climatic conditions of the low-nutrient ecosystem in the East China Sea before 2000. The process of seafloor water-sediment interface is independent for the ecological variables from various sources, such as the sedimentation of organic matter and the mineralization of sediment, which are included in the material cycle of this source, so that the bottom layer is not used as a new source of nutrients. In the following, DIN_R, DIN_A, DIN_T and DIN_K are used to refer to the nutrient salts from these four sources, and the total nutrient salts are recorded as DIN_W. Chl supported by DIN from different sources (hereinafter referred to as Chl from different sources) also uses similar labeling methods, which are respectively expressed as Chl_R, Chl_A, Chl_T, Chl_K and total chlorophyll a concentration Chl_W.

The source and sink items caused by biological processes in the sub-source module are allocated according to the proportion of the DIN concentration of each sub-source to the total DIN concentration. The control equations of the main ecological variables DIN, DIA, FLA and DET are as follows:

$$\frac{\partial DIN_i}{\partial t} + adv(DIN_i) - diff(DIN_i) = 总呼吸_{FLA} \times \frac{FLAN_i}{FLAN} + 总呼吸_{DIA} \times \frac{DIAN_i}{DIAN} - 总生产_{DIA+FLA} \times \frac{DIN_i}{DIN} + r_{det} DETN_i ,$$

（1）

$$\frac{\partial DIAN_i}{\partial t} + adv（DIAN_i）- diff(DIAN_i) = 总生产_{DIA} \times \frac{DIN_i}{DIN} - 总呼吸_{DIA} \times \frac{DIAN_i}{DIAN} - r_{mor} DIAN_i ,$$

（2）

$$\frac{\partial FLAN_i}{\partial t} + adv(FLAN_i) - diff(FLN_i) = 总生产_{FLA} \times \frac{DIN_i}{DIN} - 总呼吸_{FLA} \times \frac{FLAN_i}{FLAN} - r_{mor} FLAN_i , \quad （3）$$

$$\frac{\partial DETN_i}{\partial t} + adv(DETN_i) - diff（DETN_i）= r_{mor}(FLAN_i + DIAN_i) - r_{det} DETN_i , \quad （4）$$

3. **Result:** The horizontal gradient of DIN concentration on the surface of the East China Sea shelf is large, and the range and extent of the sea area affected by DIN from different sources are different. Therefore, it is of great significance to find out the spatiotemporal distribution of Chl supported by them on the surface of the East China Sea for understanding the impact of DIN from different sources on the seasonal variation of Chl. The seasonal spatial distribution of Chl from different sources is shown in Figure 2, in which February, May, August and November represent winter, spring, summer and autumn respectively.

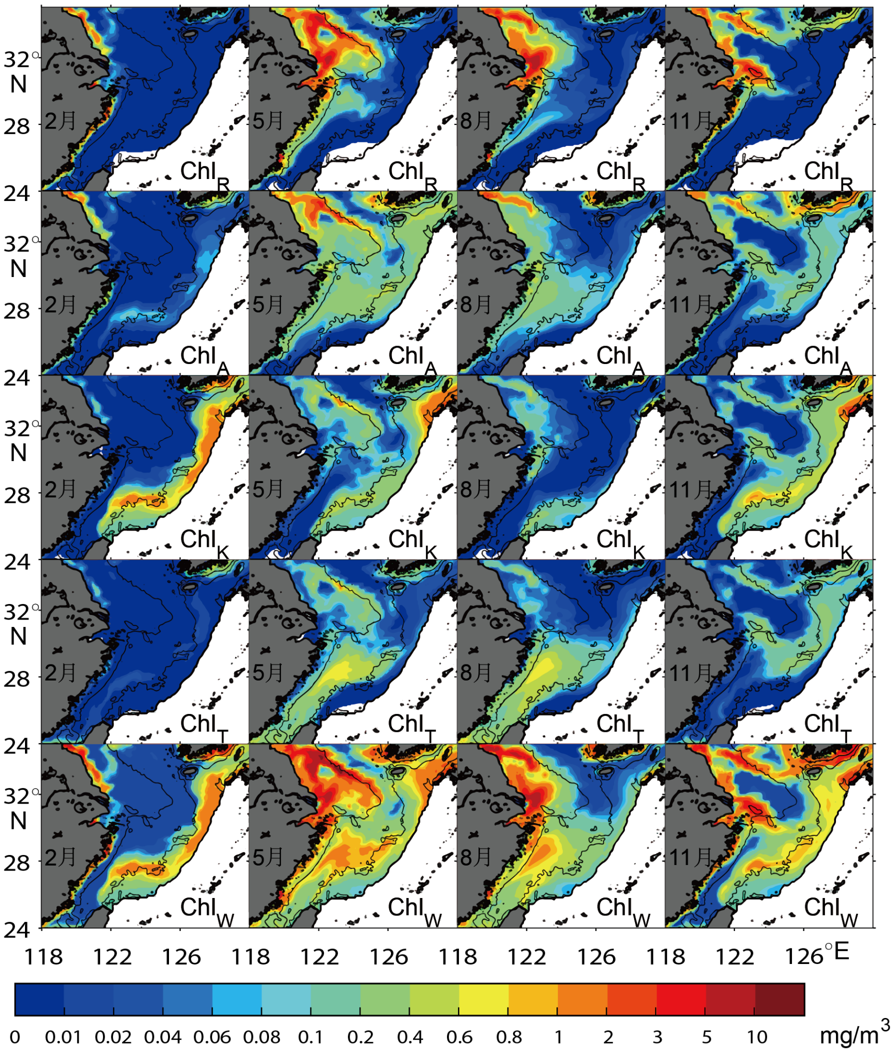

Fig.2 The spatial distributions of surface chlorophyll concentration supported by the four sources of DIN and their sum over the East China Sea in February, May, August and November (unit mg/m3)

In order to further clarify the impact of DIN from different sources on the seasonal variation of surface Chl in the East China Sea, the seasonal variation of Chl concentration supported by DIN from different sources is calculated in this paper as shown in Figure 3. First of all, the lowest concentration of Chl_W in January is 0.29 mg/m3. At this time, the four sources except Chl_K are at the lowest level throughout the year. With the rapid growth of the four kinds of Chl concentrations in January and April, Chl_W also began to rise rapidly to the highest value of 1.21 mg/m3 in April in spring. Chl_K began to decline sharply after April in spring, resulting in the decline of Chl_W. Chl_R, Chl_T and Chl_A also began to decline after May, resulting in the accelerated decline of ChlW. After June, the decline of Chl_W slowed down mainly because Chl_T began to rise. Until a small trough was formed in August, Chl_K and Chl_A began to grow rapidly, resulting in the rise of Chl_W. After the formation of another small peak in October of autumn, the concentrations of the other three chlorophyll a except Chl_K showed a downward trend, leading to the decline of Chl_W. In general, Chl_W presents a bimodal distribution, and the distribution from high to low is: spring, autumn, summer, and winter.

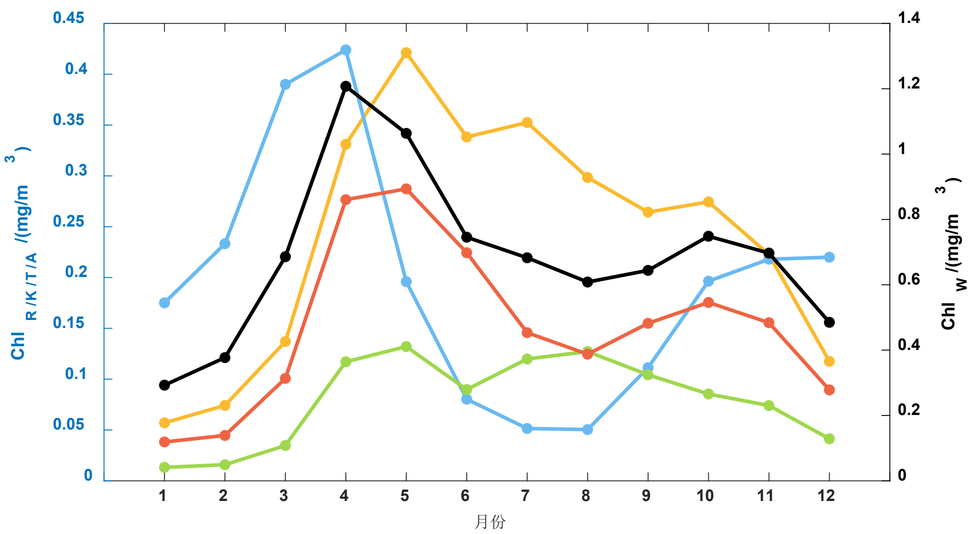

Fig.3 Seasonal variations of surface Chl concentration supported by DIN from four sources over the East China Sea

The four main rivers and atmospheric dry and wet deposition affecting the study area carry terrestrial signals from the west into the East China Sea, while the waters of the Taiwan Strait (Hu et al, 2010) and the main axis of the Kuroshio, which are composed of coastal currents, waters of the South China Sea and branches of the Kuroshio, carry oceanic signals from the south into the East China Sea. The time and space differences of the growth of phytoplankton supplied by four different sources of DIN in the East China Sea lead to different main influence areas of different sources of Chl. In this paper, the concentration of Chl in three months of each season is averaged, and the seasonal average of Chl from different sources is compared, and the dominant region of the region where the highest concentration of Chl from one source accounts for the four sources is defined. The dominant region of Chl from different sources is shown in Figure 4.

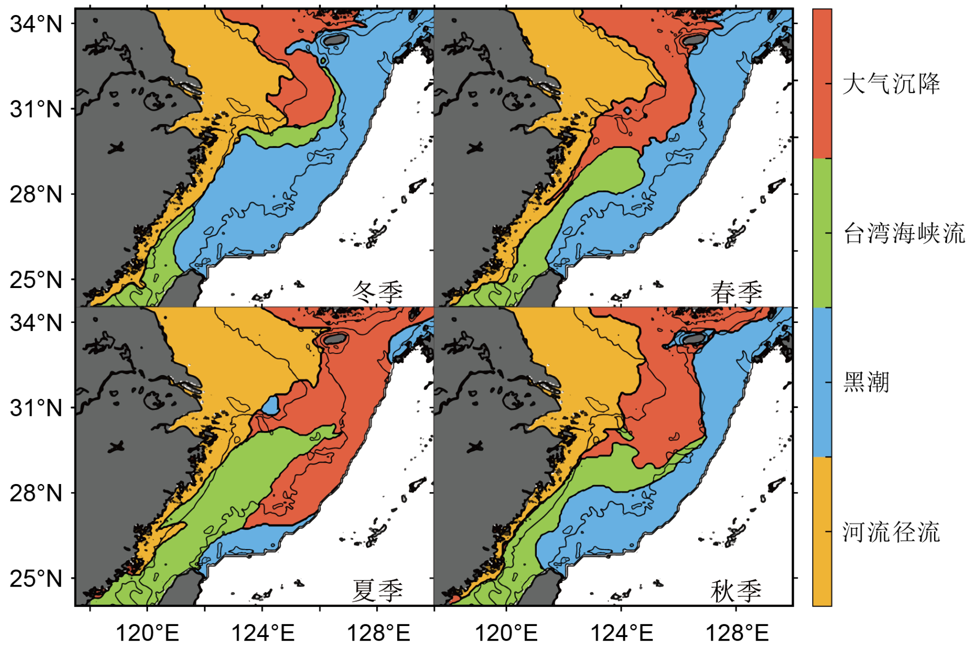

Fig.4 The distributions of Chl-dominated areas from different sources in the East China Sea in winter, spring, summer and autumn

The leading region defined in this paper can intuitively show the change of the centralized distribution of different sources of Chl in space, but limited to the calculation method, it is not known whether the leading source factors in the leading region can occupy the absolute contribution position and how much other non-leading sources can contribute, so it is necessary to quantitatively evaluate the contribution of various sources in different leading regions. Table 1 shows the proportion of Chl concentrations from different sources in different dominant areas in four seasons.

Tab.1 The Proportion of Chl concentrations from four sources in the four dominated regions in the East China Sea

月份	不同源 Chl / 主导区域	Chl_R	Chl_K	Chl_T	Chl_A
冬季	Chl_R 主导区域	70%	4%	4%	22%
	Chl_K 主导区域	2%	82%	6%	10%
	Chl_T 主导区域	8%	16%	62%	15%
	Chl_A 主导区域	22%	16%	10%	52%
春季	Chl_R 主导区域	65%	5%	6%	24%
	Chl_K 主导区域	<1%	77%	7%	15%
	Chl_T 主导区域	11%	13%	55%	21%
	Chl_A 主导区域	19%	17%	15%	49%
夏季	Chl_R 主导区域	71%	5%	6%	18%
	Chl_K 主导区域	3%	65%	9%	23%
	Chl_T 主导区域	11%	4%	58%	28%
	Chl_A 主导区域	10%	16%	20%	54%
秋季	Chl_R 主导区域	69%	7%	6%	29%
	Chl_K 主导区域	2%	64%	16%	18%
	Chl_T 主导区域	2%	20%	49%	29%
	Chl_A 主导区域	18%	20%	16%	46%

4. Conclusion:(1) Chl_K and Chl_R successively occupy the dominant position in the four sources of Chl concentration on the surface of the East China Sea.(2)The spatial distribution of Chl from different sources varies in different seasons, mainly due to the changes in the supply of surface phytoplankton by DIN from different sources.(3)Chl from all sources has a dominant region, and the size and scope of the dominant region also shows seasonal variation characteristics.(4)The seasonal variation of surface Chl from different sources is mainly affected by DIN, and the response time and degree between Chl from different sources and DIN are quite different.

5 Perspectives in future: In the future, we will continue to use this model to study the interannual changes of chlorophyll in the East China Sea.