Influence of ice and wind conditions on spring phytoplankton bloom in the Bering Sea

Aleksandra Malysheva[1,2,*], **Kirill Kivva[1]**, Aleksandra Sumkina[1]

1. Russian Research Institute of Fisheries and Oceanography (Russia);
2. Lomonosov Moscow State University, Faculty of Geography, Department of Oceanology (Russia)

e-mail: malysheva@vniro.ru

The objective of this study is to assess the impact of changes in wind and ice conditions on the phenology of the spring phytoplankton bloom in the Bering Sea and surrounding waters, using satellite data.

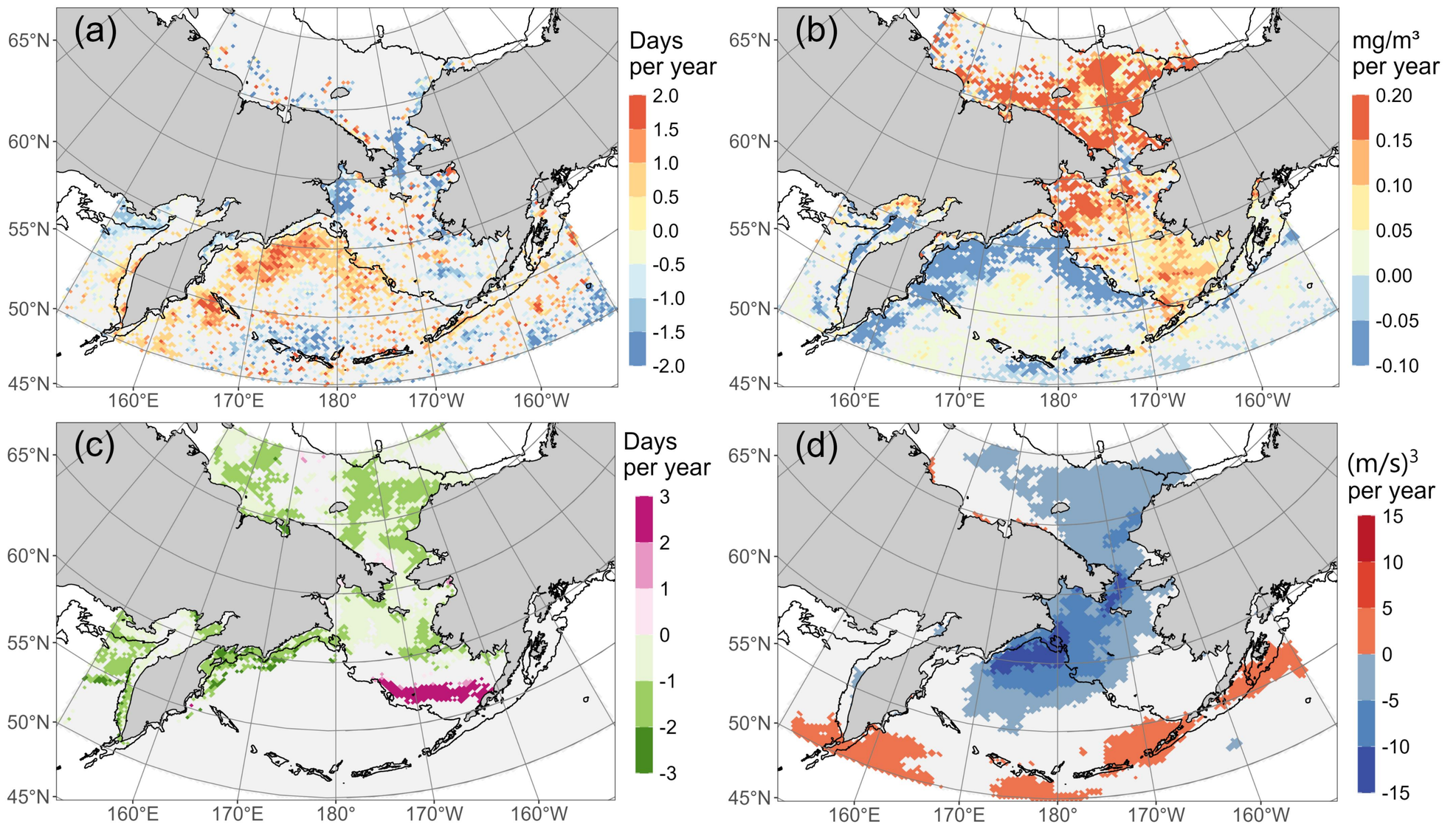

Fig. 1. Long-term trends (Theil-Sen method) in (a) onset date, and (b) intensity of spring phytoplankton bloom; (c) date of sea ice retreat (DOR), and (d) mean wind speed cubed, V^3 (January–March) in the Bering Sea and surrounding waters based on data from 1998–2024. Non-significant trends ($p > 0.05$) are shown in gray. Black line shows isobath 200 m.

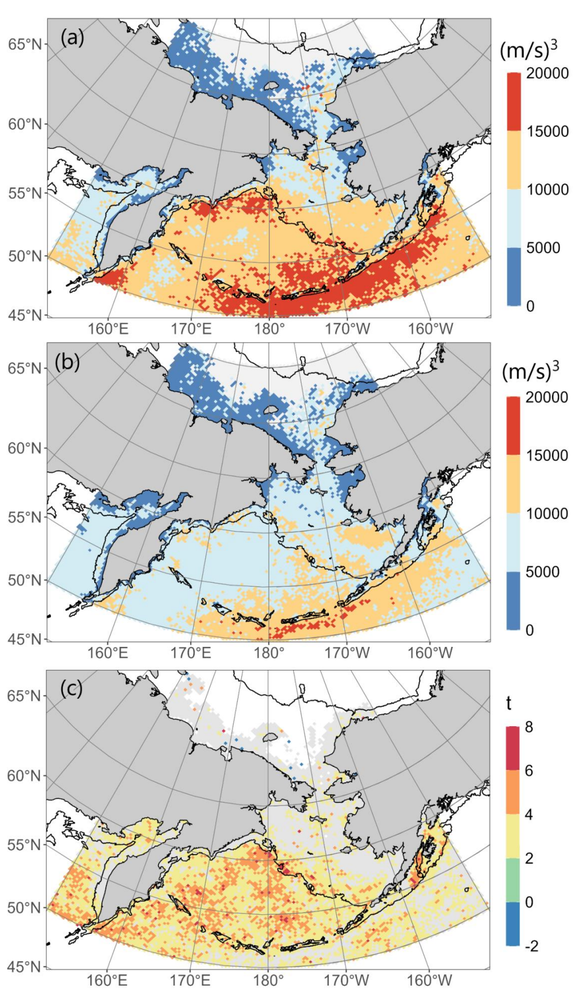

Fig. 2. Median wind speed cubed integrated over the 30 days (a) before and (b) after spring bloom onset during 1998–2024; (c) paired t-test results showing significant differences in wind speed between the two periods.

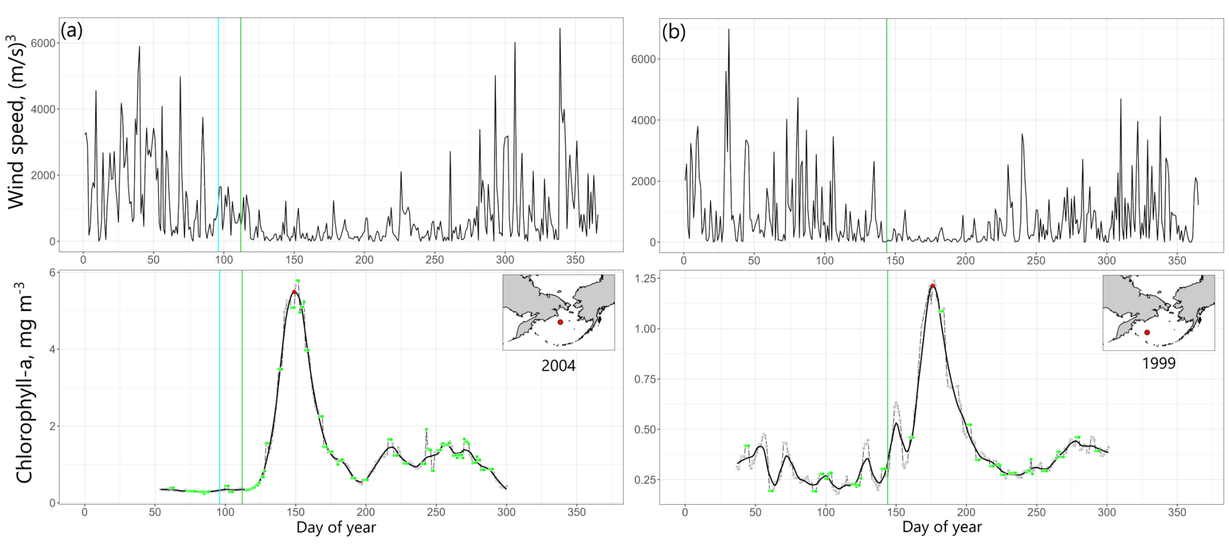

Fig. 3. Examples of the annual cycles of wind speed cubed (top) and chlorophyll-a concentration (bottom) in (a) the shelf and (b) the 'oceanic' domain of the sea. The DOR is indicated by the blue line, and spring bloom onset by the green line.

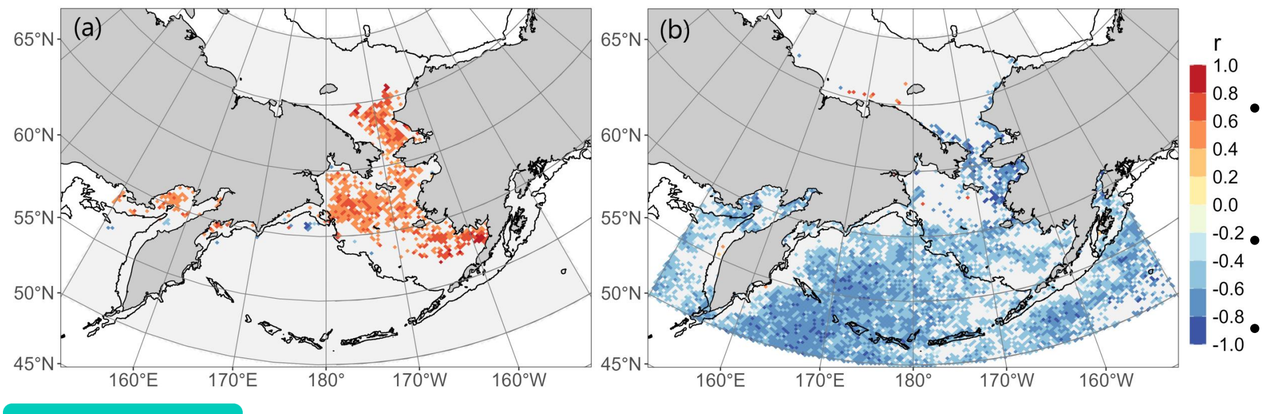

Fig. 4. Spatial distribution of Spearman correlation coefficients between (a) spring bloom peak date and DOR, and (b) spring bloom onset date and wind speed cubed during the 30 days preceding bloom onset. Only correlations with $p < 0.05$ are shown.

Materials and methods

Data	Source	Spatial resolution	Time resolution
Chlorophyll-a concentration (Chl-a, mg m^{-3})	Ocean Colour Climate Change Initiative (OCCCI) v6	4 x 4 km ↓ 25 x 25 km	daily
Sea ice concentration	Climate Data Record (CDR) NOAA/NSIDC	25 x 25 km	daily
u, v wind speed component (m s^{-1})	ERA5	0.25° x 0.25°	daily

- To reduce missing values in the chlorophyll-a (Chl-a) data, the Data Interpolating Empirical Orthogonal Functions (**DINEOF**) method was applied, followed by temporal smoothing using locally estimated polynomial regression (**LOESS**).
- **Spring phytoplankton bloom (SPB) onset** was defined as the date when Chl-a concentration exceeded **a threshold** calculated as the median Chl-a concentration from the beginning of the annual time series to the bloom peak.
- Dates of sea ice retreat (**DOR**) were determined using a threshold method, with an ice concentration threshold of 0.15.
- **Wind speed cubed (V^3)** was analyzed for the 30-day periods before and after spring bloom onset.

Conclusions

- In the northern part of the sea, SPBs are short and intense following sea ice retreat, whereas in the 'oceanic' domain, blooms may last **1.5–2 months** at low Chl-a concentrations (**< 1 mg m^{-3}**).
- Wind speeds were higher before SPB onset, with particularly pronounced significant differences in the 'oceanic' domain (Fig. 2).
- SPB onset date and DOR had a significant positive correlation (r = 0.5–0.8, $p < 0.05$): **the earlier the ice melts, the earlier the SPB begins**. The negative correlation with V^3 indicates that **stronger wind-driven mixing is associated with earlier SPB onset** (Fig. 4).
- In the northern Bering Sea, SPB phenology is more strongly associated with DOR, whereas wind-driven mixing plays a substantial role in the 'oceanic' domain (Figs. 1 and 4).

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