The nutrient supply and mixing control the primary production seasonality in the subarctic Pacific

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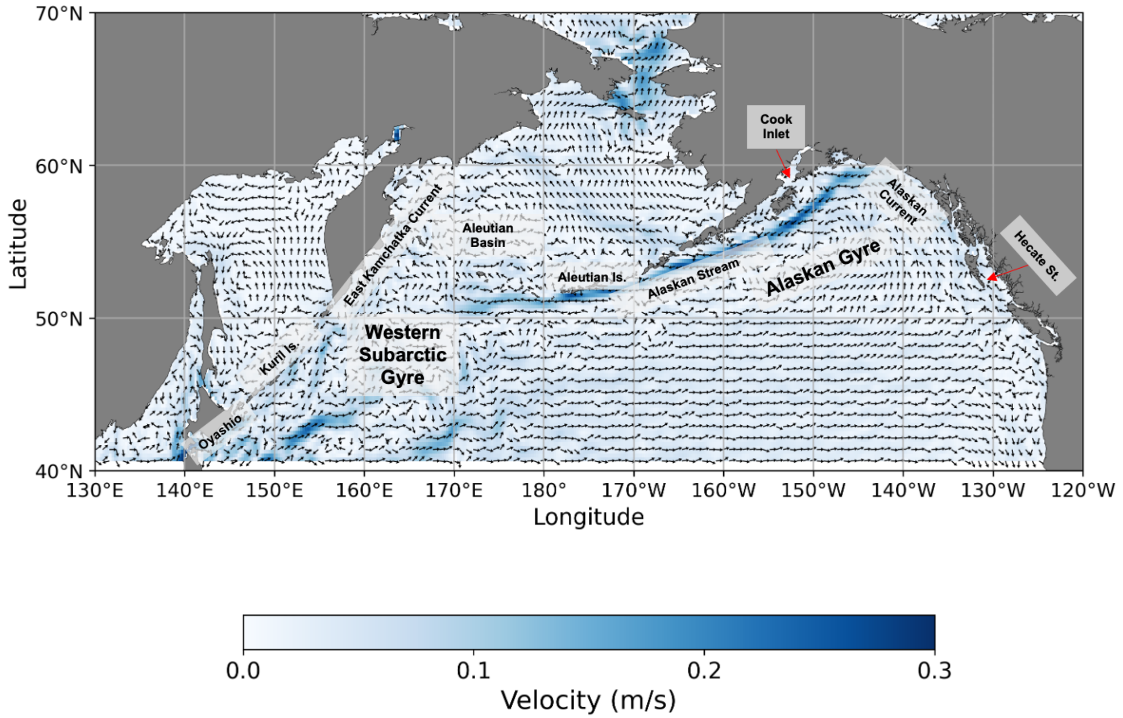
Seasonality of primary production is a reliable indicator for monitoring the state of an ecosystem and is controlled by the biogeochemical cycles of nutrients in the ocean; however, the linkage between the primary production seasonality and nutrient supply processes is not sufficiently understood.

To understand the physical and biogeochemical mechanisms controlling biological production in the subarctic North Pacific, we present a satellite-derived geographic distribution of the primary production seasonality minimizing spatial gaps and compare it to ship/buoy-based observed MLD, nutrients and dissolved iron flux data.



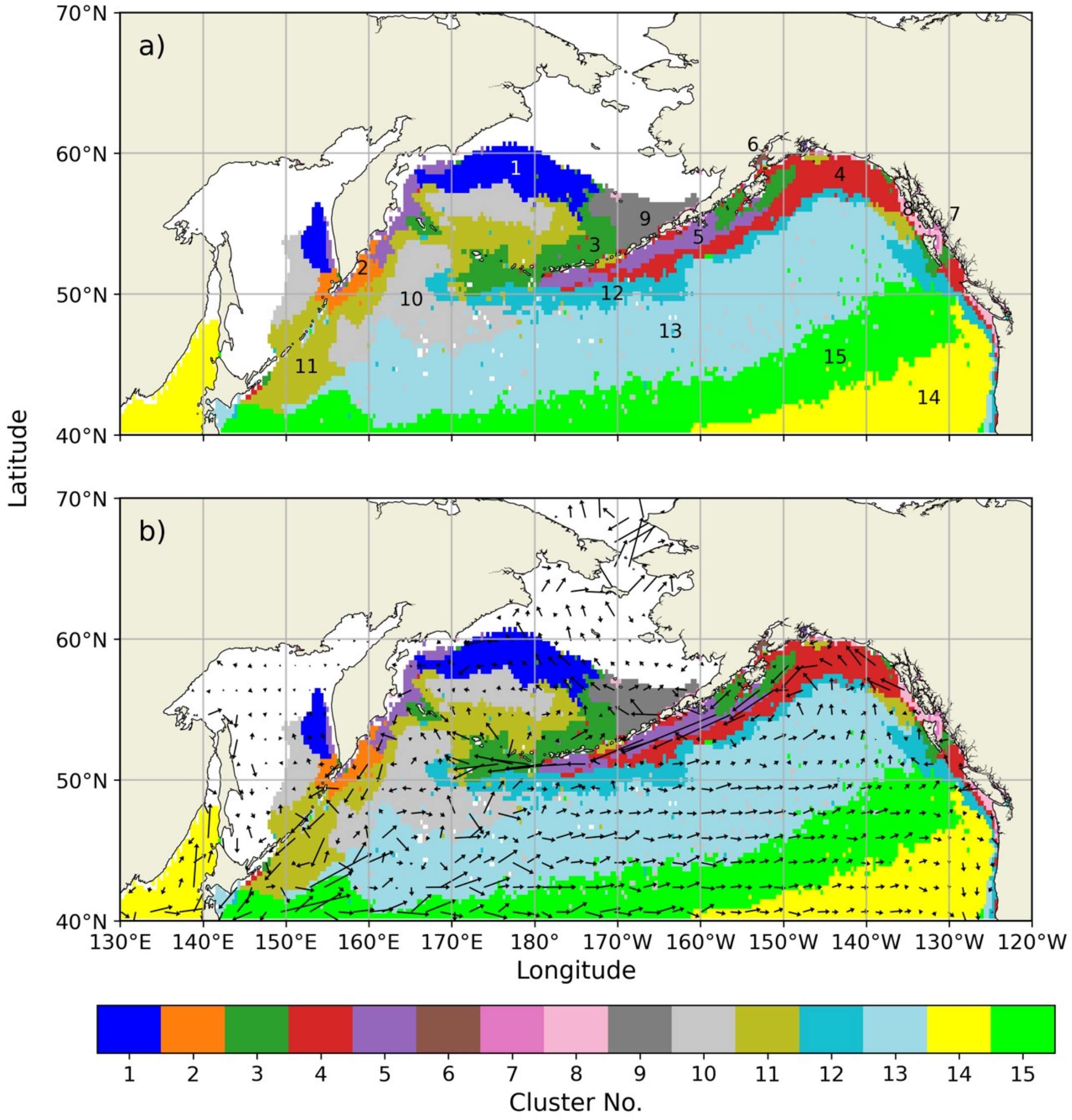
← Study area.

The Alaskan Gyre (AG) has a high nitrate concentration (8–16 μmol L^{-1}) but very low chlorophyll all year (<0.5 mg m^{-3}), with low seasonal variation in primary production (300–600 mg C m^{-2} d^{-1}) (Harrison et al, 1999). In contrast, seasonal increases in phytoplankton lead to a higher chlorophyll concentration (0.5–1.5 mg m^{-3}) in the Western Subarctic Gyre (WSG) than in the AG in April-May and finally decrease when iron is depleted (Fujiki et al., 2014.

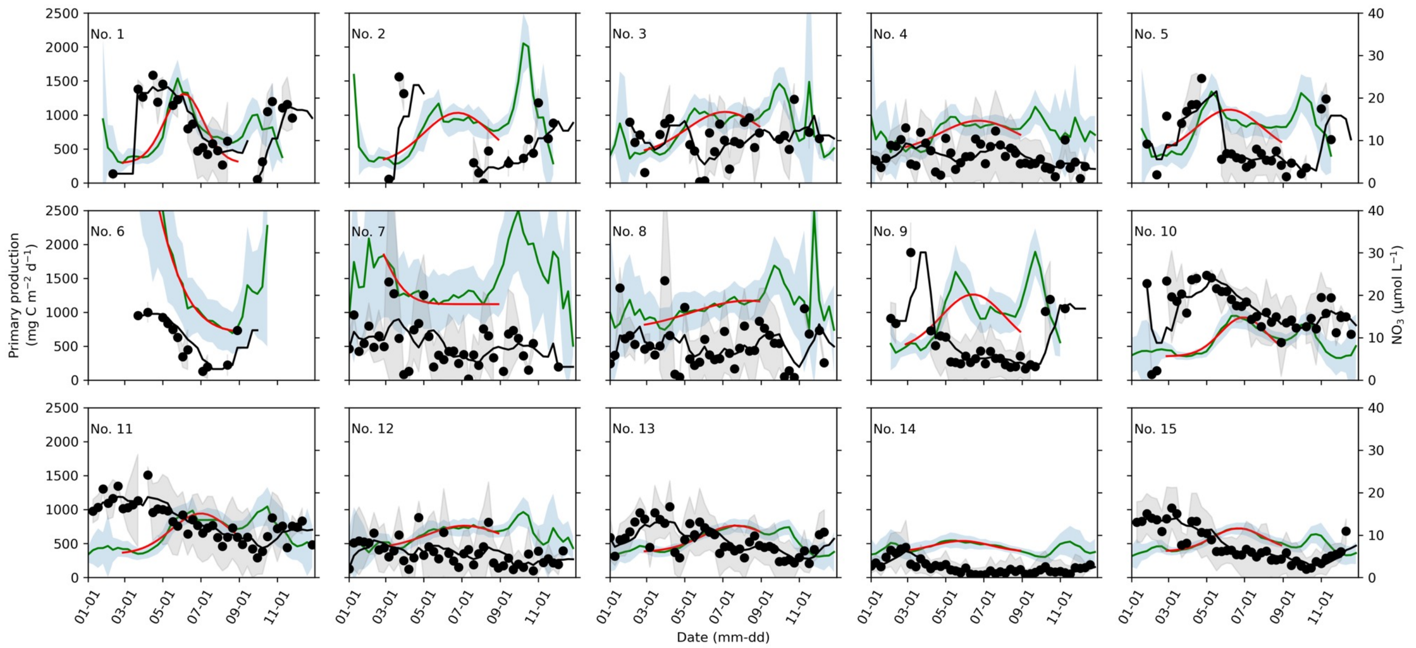
Question:
How do the ocean mixing and nutrients supply link to the geographical distribution of of primary production and its seasonality?

Data and Methods

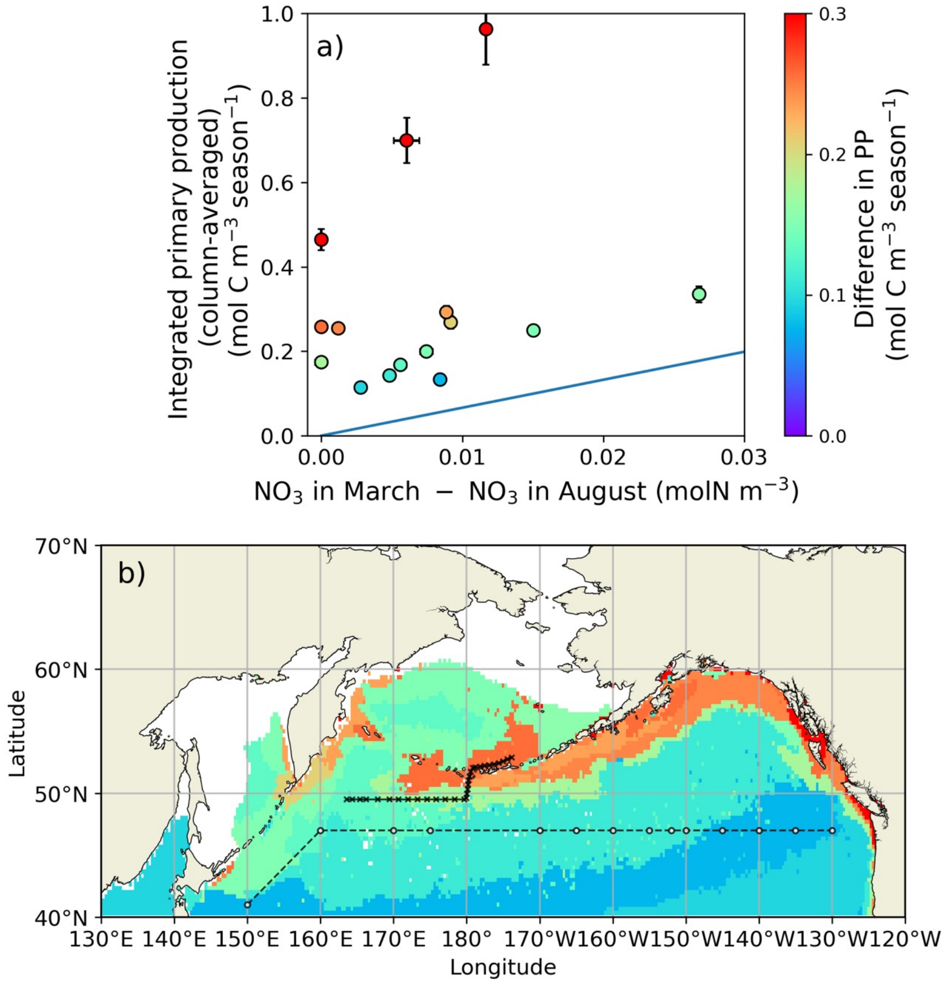
- GlobColour, Rrs, PAR, Zeu, 8-days, 1998-2020 → Primary production (PPeu)
- SSMI/SSMIS, Sea ice concentration
- WOD2018, GLODAP, GO-SHIP, Nutrients, 1929-2018
- Argo, temp. & sal., 1998-2020 → Mixed Layer Depth (MLD)
- Dissolved iron (DFe) and nutrients (Nishioka et al, 2020)
- Vertical diffusivity (Goto et al, 2016, 2018, 2021; Yasuda et al, 2021)
- All satellite data were gridded to 32 km resolution and calculated PPeu
- 20-years climatological value of PPeu for each 8-day was calculated
- Hierarchical clustering (the Ward variance minimization algorithm) was performed on the climatological PPeu data.
- Extract nutrients and MLD data for each cluster



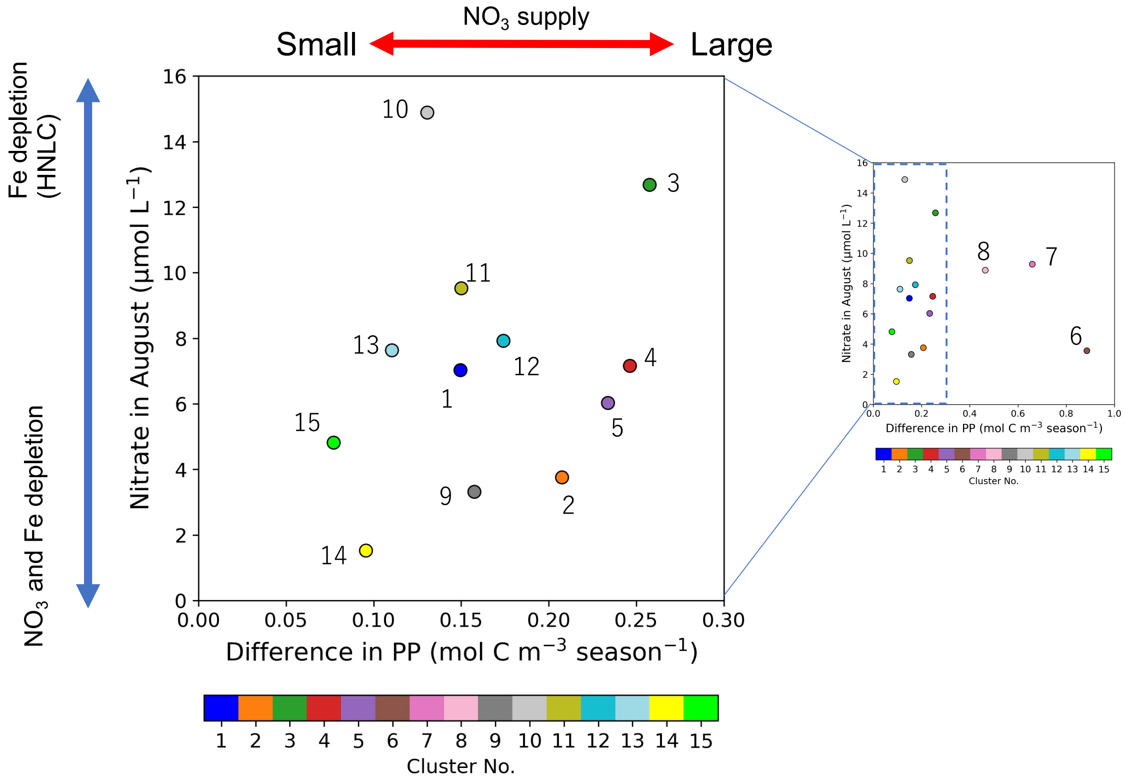
(a) Distribution of clusters based on the seasonality of primary production. Colors express the cluster number shown in the colored bar. The number is annotated on the distribution map as well. (b) Geostrophic currents calculated from topographic data were overlaid on the map of the cluster distribution. Several clusters (nos. 13–15) illustrate latitudinal gradation but not along either parallel or east-west symmetric gradients. These clusters are inclined northward in the eastern part of the study area. The blank pixels show had missing data by cloud mask, sea ice cover, or irregular value.



Seasonal changes in the daily net primary production (green line) and nitrate concentration (black circle) in all clusters. The red solid line shows the fitted Gaussian curve for the parameterization of phenology. The black solid line shows the running mean nitrate concentration. Blue and gray shades indicate the standard deviations of primary production and nitrate, respectively.

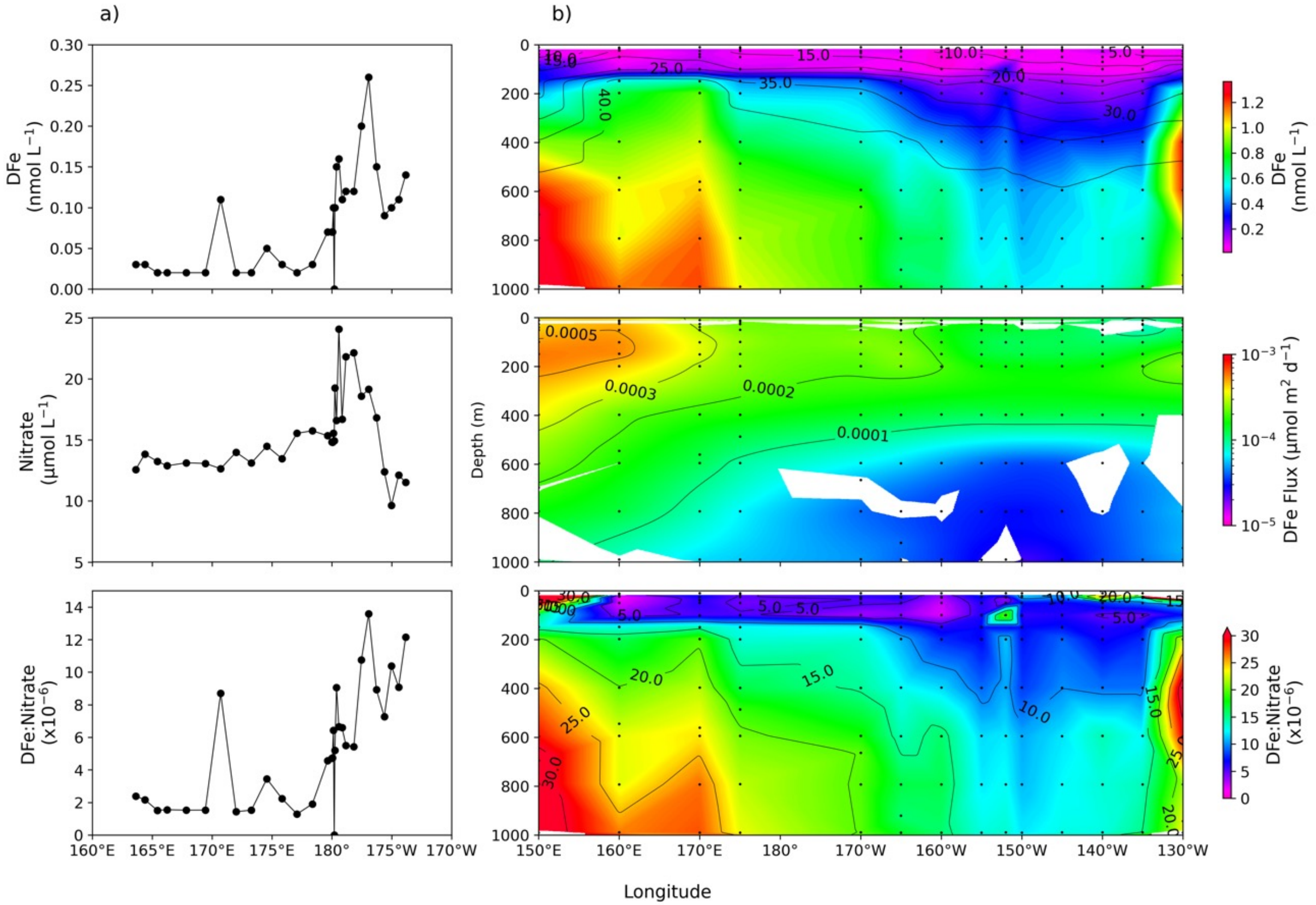


(a) Relationship between nitrate change from March to August and column (euphotic zone)-averaged primary production during spring-summer in each cluster. Blue line shows expected primary production based on the nitrate decrease (consumption) and the Redfield ratio. For the cluster with small increase (negative consumption) in nitrate, the consumption was set to 0. Colors of the solid circle indicate difference between the observed and expected primary production (dPP). Error bar shows the standard deviation of the nitrate change and the integrated primary production. (b) Map showing the distribution of the dPP in each cluster calculated in (a). Colors are the same as in (a). Crosses and circles denote stations for in situ measurements of the iron and nitrate concentrations, respectively

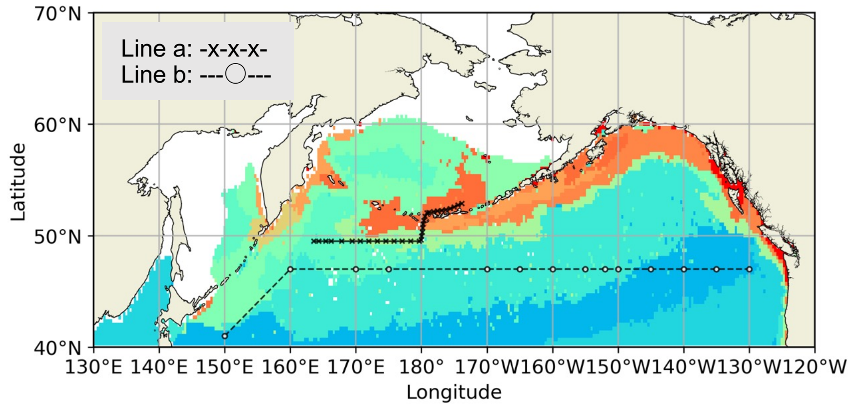


Relationship between dPP calculated in Fig. 2(a) and remained nitrate concentration in August for each cluster. Colors of the solid circle indicate cluster number shown in colored bar. Clusters outside of dotted line (right panel) distributed in coastal region (nos. 6, 7 and 8) and those inside of the line are in open ocean (enlarged to the left panel).

The difference in the primary productions between observed and that predicted from the nitrate consumption (March–August) in each cluster clearly distinguished the area containing HNLC waters from the areas with continuous supplies of nutrients and iron that persist even after the spring bloom.



(a) Longitudinal distribution of the dissolved iron (DFe) and nitrate concentrations and the ratio of DFe to nitrate in surface water along the track crossing the Amchitka pass. (b) Longitudinal vertical section of the DFe concentration upward DFe flux and ratio of DFe to nitrate over the water column along 47° N and east of the Kuril Islands. Black contour lines on the vertical section of the DFe show nitrate concentration. White parts in the vertical section of the DFe flux indicate a downward flux.



Combining the patterns with existing ship-based observational data indicates that the iron and nutrient supplied from intermediate water by ocean mixing possibly helps sustain biological production and causes east-west gradient in seasonality of primary production in the subarctic North Pacific.

Knowledge gaps and priorities for next steps

- More frequent satellite observations to fill cloudy pixels
- Interannual variation in distribution of primary production seasonality
- Quantitative evaluation of impact of aeolian dust on primary production
- Separation between new and reproductive productions from satellite
- Relationship among changes in primary production, phytoplankton community structure and nutrients