SEASONAL AND INTERANNUAL VARIABILITY OF CHLOROPHYLL *A* IN OKHOTSK SEA FROM SEAWIFS DATA

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ABSTRACT: Spatial distribution, seasonal and interannual variability of chlorophyll *a* concentration in Okhotsk Sea from SeaWiFS data between 2001 and 2004 were describe. An Empirical Orthogonal Function method was applied for analysis data. The ten modes described about 85% of total variance. Two maxima were defined – more intensive in spring and weaker in autumn. The first mode showed zones with chlorophyll *a* concentration during maximum bloom. The second mode specified timing of spring bloom in various regions in Okhotsk Sea. Analysis of SeaWiFS data indicated connection between highest chlorophyll *a* concentration and sea surface temperature limits during spring bloom. Similar relation was not found during fall bloom.

INTRODUCTION

Chlorophyll *a* is one of the basic parameters for calculation of sea productivity. Now we have a chance to obtain information about ocean color from satellite. Okhotsk Sea is sea with high productivity. Previously Matsumoto et al. (1998) described chl-*a* distribution in Okhotsk Sea using Binary Decision Tree classifier method. The aim of this work is description and analysis of spatial distribution, seasonal and interannual variability of chl-*a* concentration in Okhotsk Sea by means of Empirical Orthogonal Function (EOF) method.

DATA AND METHODS

The SeaWiFS images of Okhotsk Sea were obtained by the TeraScan station from SakhNIRO, Yuzhno-Sakhalinsk during April, 2001 through November, 2004. The chlorophyll *a* concentration was calculated by the OC4 algorithm (O'Reilly et al., 1998). The atmospheric parameters were downloaded from the site http://oceancolor.gsfc.nasa.gov/. Scripts with use of modules of program SeaDAS were applied to realization of algorithm (http://oceancolor.gsfc.nasa.gov/seadas/).

The Empirical Orthogonal Functions (EOF) method (Bagrov, 1959) was used for analysis of the temporal and spatial variability of chlorophyll *a*. This method was realized by TeraScan functions (TeraScan ..., 1994).

Input data is grid of chl-*a* concentration averaged by month period. Therefore, the input matrix consisted of 44 "temporary layers"; each of them was 334×341 size.

RESULTS AND DISCUSSION

The first mode explains about 45 % of the summed variance (Table 1). Amplitude of the first mode characterized the general seasonal and interannual variability of chl-*a* concentration. Fluctuations of amplitude were stable. Peaks of amplitude specified the periods of the maxima phytoplankton bloom in a spring and autumn. In May 2002 and 2004 bloom was reach (value of amplitude was equal -2.89 and -2.91). During the same period 2001 and 2003 it was less significant (-1.85 and -1.77). Weaker autumn extremum was observed in September – October. In all years its magnitude changed insignificantly – from -0.81 up to -0.88. Thus, widely known fact (Ventsel, 2000) about two periods of bloom in the sea of subarctic type has proved to be true.

Table 1

Calculated results of the EOF eigen values

Mode Number	Eigen Value	Percent Variance, %	Summed Variance, %
1	2.3805	44.538	44.538
2	0.5351	10.011	54.549
3	0.3389	6.340	60.889
4	0.2865	5.360	66.249
5	0.2489	4.656	70.906
6	0.2182	4.082	74.988
7	0.1802	3.371	78.359
8	0.1312	2.454	80.813
9	0.1053	1.969	82.783
10	0.0917	1.716	84.498

All elements of amplitude and vector of the first mode had negative value (Figure 1). Using spatial distribution of the first mode it was possible to allocate zones with high phytoplankton abundance. In figure 2 it is visible, that in the central part of Okhotsk Sea values of a vector are less then 1, that means practically full absence of photosynthetic activity without dependence from a season. High concentration chlorophyll-*a* occurred along coast of Kamchatka Peninsula. The significant chl-*a* concentration characterized northern part of Okhotsk Sea from northwest shelf to Shelikhov Bay. Small parts of increased pigment concentrations are located near mouth parts of large rivers: Uda Bay, Tugur Bay and Tauyskaya Guba, water area near Marekan Cape (a place with mouth of several rivers), Zabiyaka Bay, Babushkin Bay and Terpeniya Bay. Here carrying out of nutrients is observed. The highest photosynthetic activity indicated at mouth part of Amur River, namely, in the Amur Liman and Sakhalin Bay. The increased chl-*a* concentration were shown in shelf region near the northeast coast of Sakhalin. Here nutrients were carried out by means of upwelling, Amur waters directed along coast and a flow from lagoons. On Kuriles the local zone of bloom is plased between a southwest end of Iturup Island and Shikotan Island. Usually it is connected with region of high producing along east coast Hokkaido and the Small Kuril Islands.

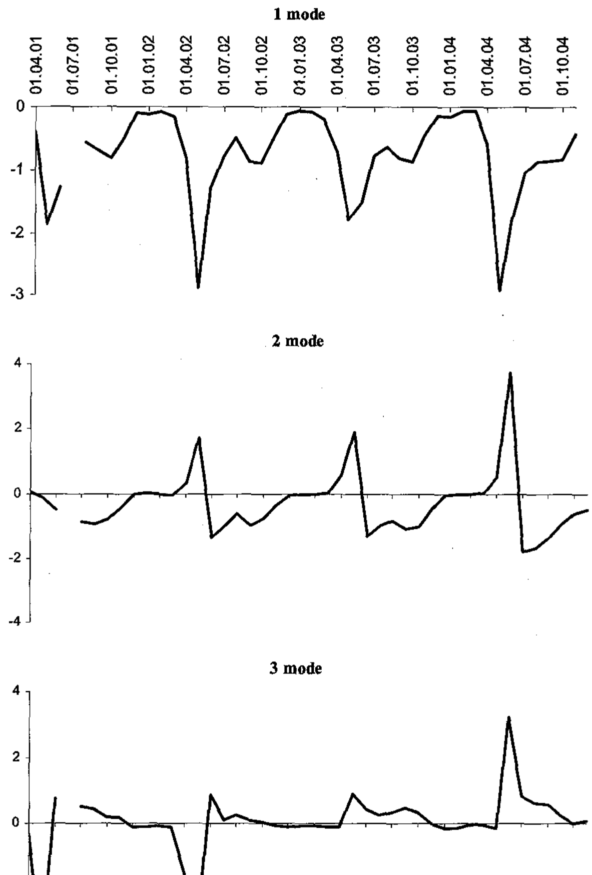

Figure 1. Amplitudes of the first, second and third EOF modes.

A second mode was enough informative. Its temporal variability had seasonal character. Magnitude of spatial vector accepted negative and positive values. The amplitude had positive values in April – May, and negative – from June till November, (exception – May, 2001), i.e. during ice-free period. The maximum positive value in May was replaced extreme negative in June.

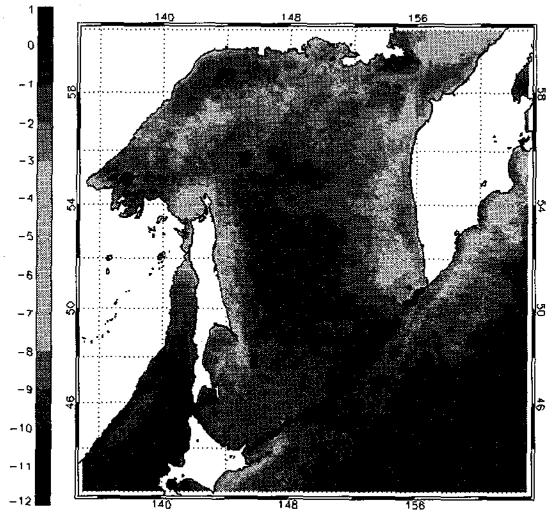

Figure 2. Spatial distribution of the first EOF mode.

The vector of the second mode (Figure 3) also had positive both negative values. Positive values occurred in northern part of sea of Okhotsk, at coast of Kamchatka Peninsula and south-east Sakhalin Island. Negative sizes characterized already described coastal sides – a place of the large river flows. These are bays near Shantar Islands, Tauyskaya Guba, Zabiyaka Bay and Babushkin Bay, located in the northern part of sea of Okhotsk, a mouth of Poronay River in Terpeniya Bay. The maximal negative values are observed not only in the Amur Liman, but also in east part of Sakhalin Bay, in Nevelsk Strait and northern part of Tatar Strait, i.e. there where the flow of the largest river of the Far East is directed. Insignificant negative sizes of a vector of the second mode are marked in the Amur River waters flow – at north-east coast of Sakhalin and Kashevarov Bank.

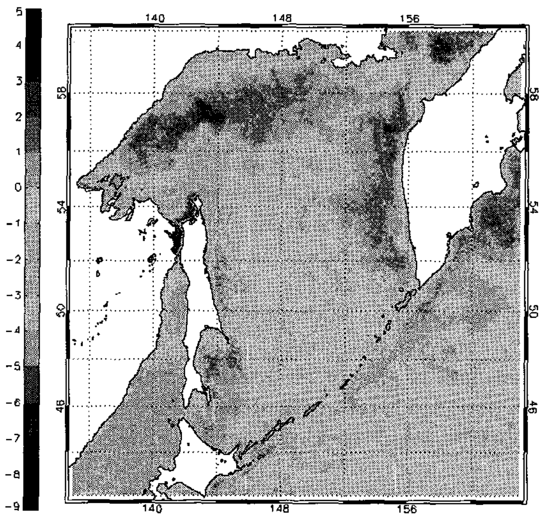

Figure 3. Spatial distribution of the second EOF mode.

Having compared values of amplitude and a vector of the second mode, we can conclude about beginning, intensity, dynamics and reasons of phytoplankton bloom in various parts of Okhotsk Sea. On the one hand, the spring peak of microalgae development in northern part of Okhotsk Sea, Shelikhov Bay, at coast of Kamchatka Peninsula and south-east Sakhalin Island comes in May. There is time of development for cryophilic diatoms with the favorable temperatures and nutrients on an edge of melting ice (Shuntov, 2001). On the other hand, the peak of bloom is displaced for June in the Amur Liman and adjoining water area. High index of chromaticity are found during summer and autumn. The reason of intensive photosynthetic activity is the continental runoff of nutrient. Active bloom is provided not only diatoms, but also other species of microalgae (e.g. Cyanophyta) (Kiselev, 1931). In contrast to the standard opinion, bloom at Kashevarov Bank most likely is supplied with the Amur River flow of nutrients.

First two modes have described the common pattern of chl-*a* concentration in Okhotsk Sea and adjoining water areas. The next modes characterized features of phytoplankton development in various time intervals and spaces. For example, the third mode indicates volume of bloom at south-west and south-east coast of Kamchatka Peninsula. In May 2001 and 2002 it was stronger, than in 2003 and 2004 (Figure 4). At the same time intensity of bloom in the Amur River and Sakhalin Bay in June is practically constant.

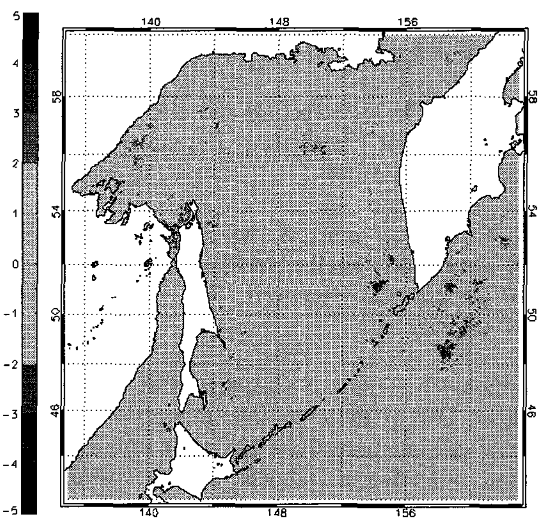

Figure 4. Spatial distribution of the third EOF mode.

Apparently, the major factors influencing phytoplankton bloom on the surface water is ice retreat, temperature of water and nutrient providing with prevalence of a continental runoff. From the above listed factors only first two are accessible to remote sensing.

Bloom on ice-edge. Some authors has noted, that increase of concentration chl-*a* is determined by ice retreat in the spring (Shuntov, 2001). Therefore sea ice cover on water areas of Okhotsk Sea are the important factor influencing development of phytoplankton in the spring. At the given stage of researches we cannot quantitatively determine dependence of bloom intensity on activity of ice retreat. However the given dependence is demonstrated by illustrative material clearly. Dynamics of two processes is reflected on figure 5. During the period from April, 16 to May, 10, 2004 concentration chlorophyll *a* steadily raised on an edge of ice cover, remaining constant on adjoining water area.

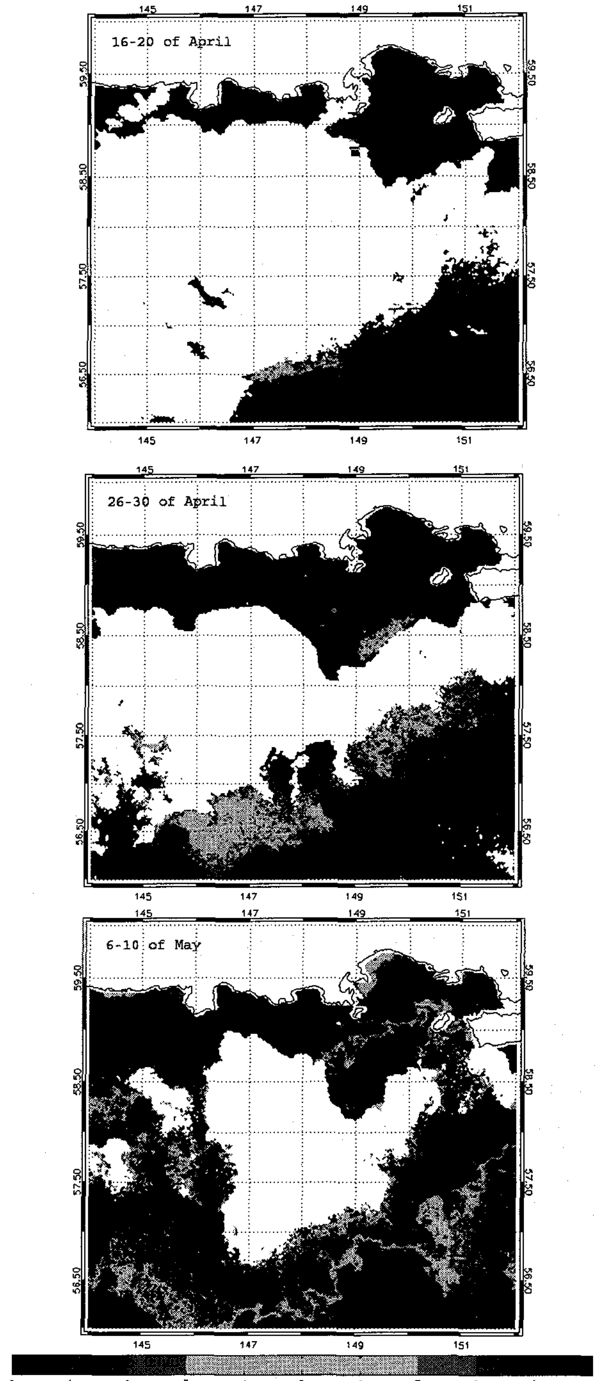

Figure 5. Development of chl-*a* concentration (mg/m^3) on ice-edge in the nothern part of Okhotsk Sea.

Sea Surface Temperature. For the analysis of influence of the given factor we preliminary have broken water area of Okhotsk Sea on 6 regions according to abiotic conditions: northern, central and south-western parts of Okhotsk Sea, water area, near the western coast Kamchatka Peninsula, a shelf at north-east Sakhalin, a influence zone of Amur River flow (Amur Liman and Sakhalin Bay). In each region the decade temperature of water and chl-*a* concentration were calculated from database of TeraScan system. The received chl-*a* concentrations were normalized to an annual maximum for each region. Dependence of the chl-*a* concentration from sea surface temperature (SST) is drawn on figure 6. This dependence is the same in all regions (except for the Amur Liman and Sakhalin Bay). In the spring chl-*a* concentration increases and reaches a maximum with SST from 2 up to 4°C. Further the chl-*a* concentration is reduced, and its variations do not depend on temperature of water. Therefore dependence of bloom from SST is clearly shown only in the spring. The given dependence is not determined by ice melting. It is shown in region where there is no ice cover (the central part of Okhotsk Sea). Probably, such dependence is peculiar only diatoms which dominate in phytoplankton structure during this time period. In the autumn pigment increase in water does not depend from SST. Most likely, it is caused by nutrient splash during destruction of the summer vertical stratification.

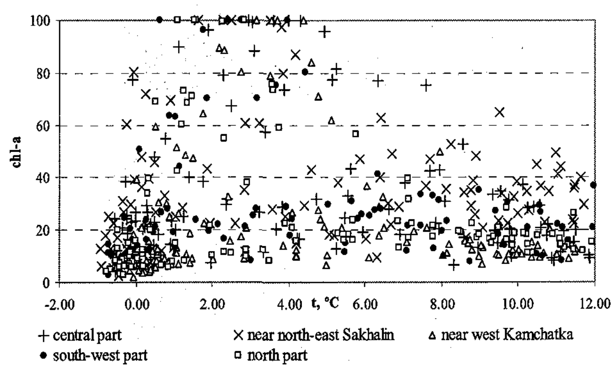

Figure 6. Dependence of normalized chl-*a* concentration (%) from SST in various regions of Okhotsk Sea.

Similar dependence it is not revealed in a zone of influence of the Amur River flow (Figure 7). The reason of it is abundance of nutrient which limit phytoplankton development in Okhotsk Sea. To similar conclusions came Matsumoto and al. (1998). They have calculated dependence between chl-*a* concentration and discharge of the Amur River in the Amur Liman.

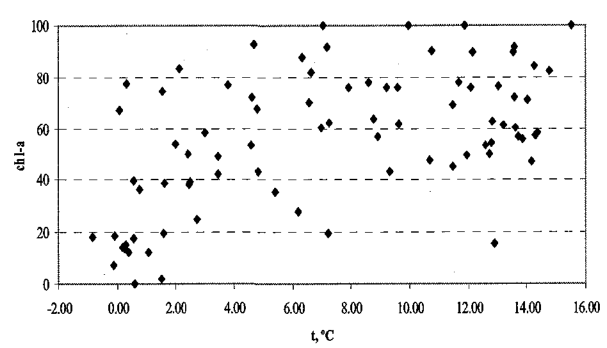

Figure 7. Dependence of normalized chl-*a* concentration (%) from SST in Amur Bay and Sakhalin Bay.

THE CONCLUSION

Using analysis of SeaWiFS images by EOF method, the most important laws of temporal and spatial variability of chl-*a* concentration in Okhotsk Sea are determined.

In amplitude of first, basic mode there are two maxima – spring and fall. The spring maximum is intensive; the fall maximum is weaker, but stable.

High chl-*a* concentration are observed in northern part of sea of Okhotsk and along coast Kamchatka Peninsula. Zones with increased pigment are located at mouth part of the large rivers Okhotsk Sea basin. The low chl-*a* concentration occurred in the central part of Okhotsk Sea.

Spring bloom in shelf regions is connected to ice melting and increase SST. This is due to the fact that diatoms development depends on water temperature. Fall bloom is defined by splash during destruction of the summer vertical stratification.

Bloom at mouth parts of the rivers is provided by only nutrient flow. In fact bloom in described before some upwelling is caused by nutrients of a river flow.

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