Study of diatom succession in the Sea of Japan based on satellite and ship data

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Remote definition of structural groups of a phytoplankton

The diatoms dominate in the phytoplankton community of the Sea of Japan (*Mescherjakova, 1954; Konovalova, 1972; Orlova, 1990; Shuntov, 2001****). Attempts to estimate the biomass (BM) of diatoms from space by means of the NOBM Diatoms model (Oceanic biochemical model of NASA) are undertaken by experts of NASA . However, the data for the Sea of Japan are not adduced. It is caused by the applicability of the NOBM Diatoms model only for the open ocean areas at depth, which is below 200 meters. The Sea of Japan is not the open part of the World ocean.***

The resolution of this model is 1.25 0.66 (longitude and latitude, respectively). It does not allow to study in detail the diatoms distribution in the mesoscale hydrological structures, such as mesoscale eddies.

Remote definition of structural groups of a phytoplankton

Alvain et al.(2005) obtained the spectral characteristics of chlorophyll "a" (Chl) at five bands in the visible domain for a phytoplankton of different species composition to define the distinction between the dominating phytoplankton groups for Case 1 waters (*Erlov, 1980****). Thus, it was shown that the empirical relationships between the spectral characteristics and the species composition of phytoplankton are exists. However, this approach requests the large a number of various data for each investigated region.***

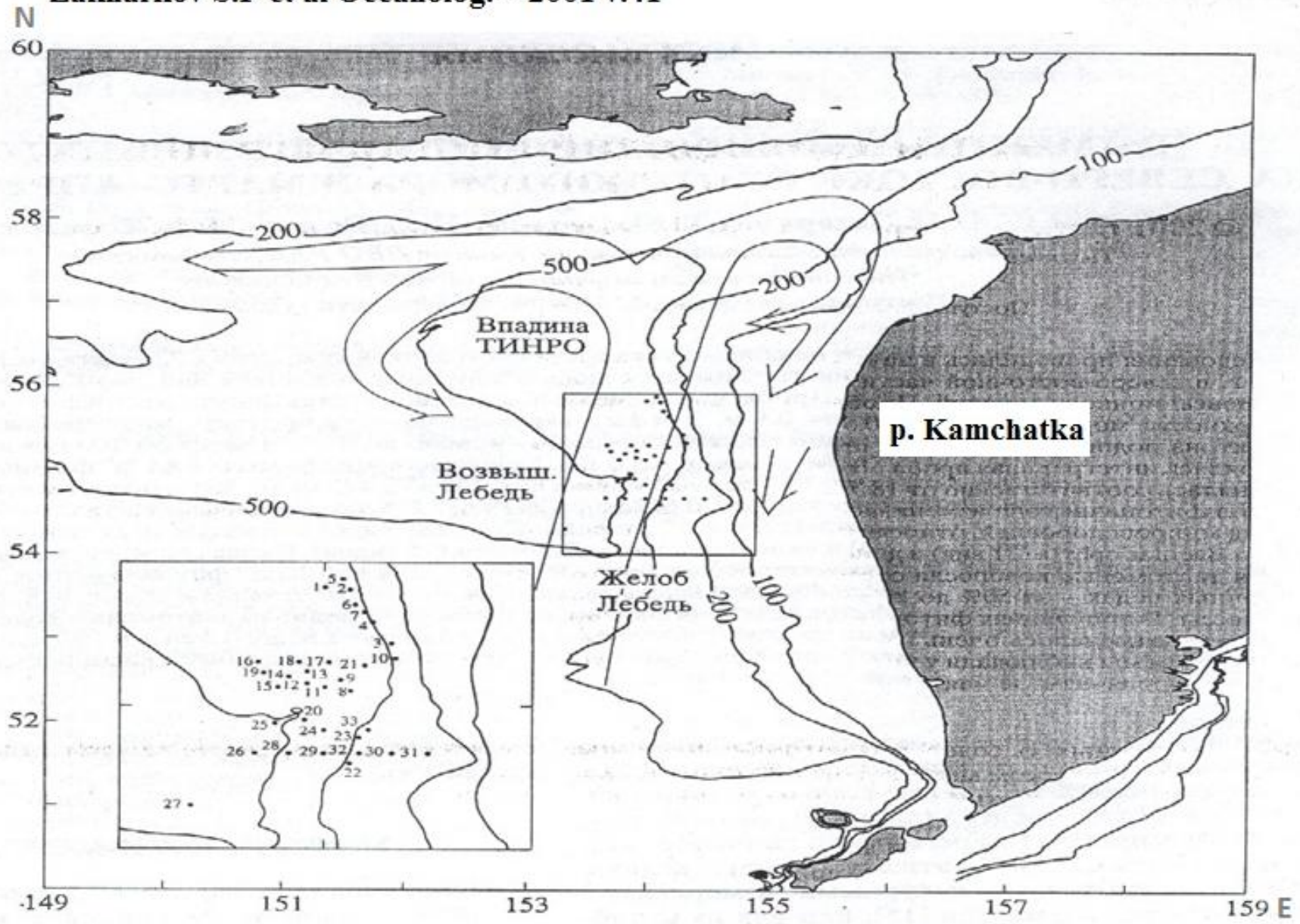
Gregg et al. (2007) used the global three-dimensional model to define the coccolithophores distribution as primary source of ocean calcium that is important for the ocean geochemistry and studying of a global carbon cycle. Reliability of applied model was shown by comparison of the modeling data on concentration of a total chlorophyll and biogenic elements on a surface with ship and satellite observations.

Remote definition of structural groups of a phytoplankton

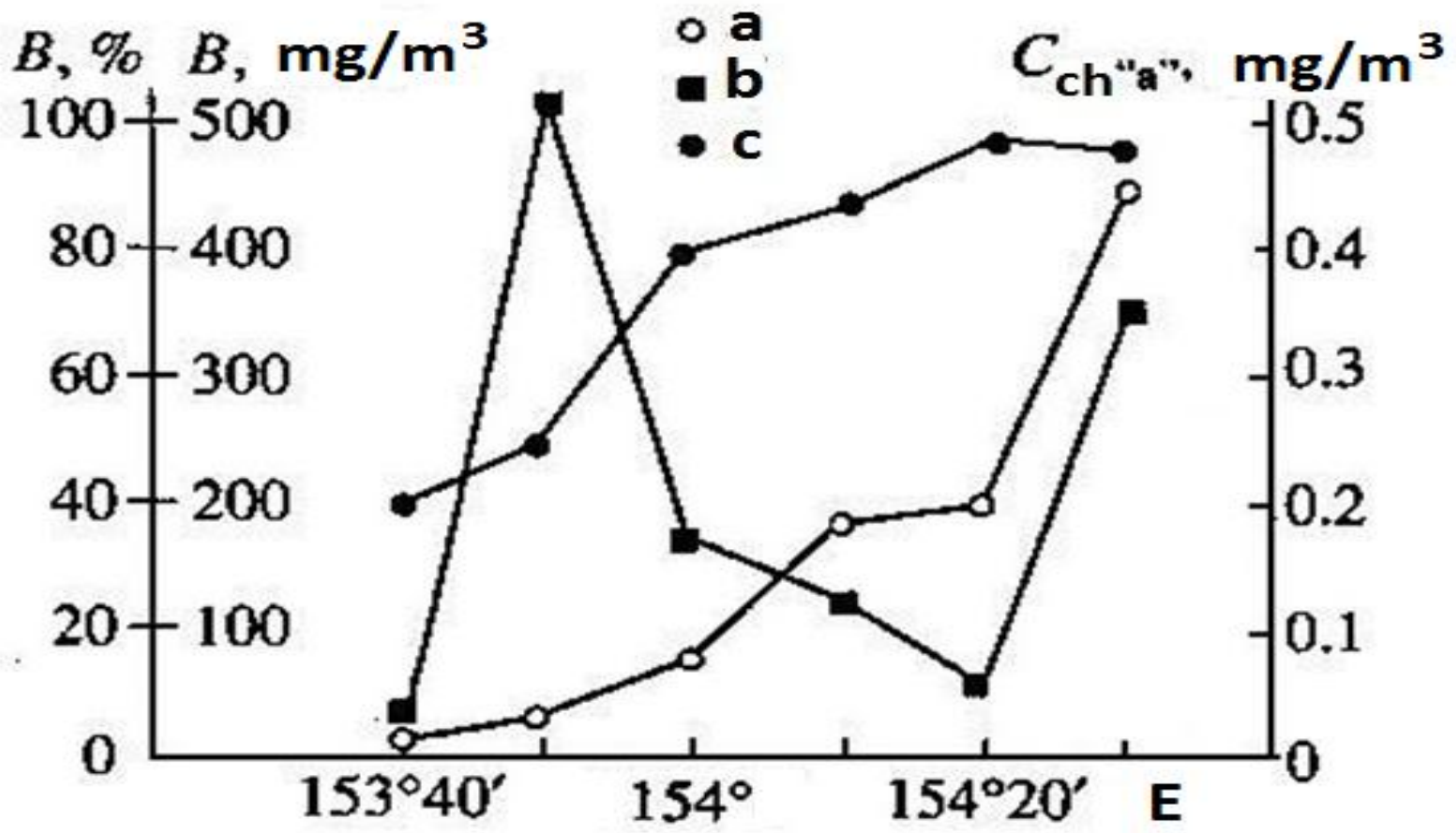
In the Sea of Japan the definition of species composition and BM of algae on a surface was implemented by A.I. Aleksanin et al. (2008). The problem solution was based on the recognition algorithms of diatoms types on the spectra of upwelling radiation. Characteristics of radiation for two diatoms species which can be used for identification of areas where these diatoms make the basic BM volume are obtained.

To study of diatoms succession in the Sea of Japan, we have undertaken the independent approach. The approach is based on the phenomenon revealed by us earlier in the Sea of Okhotsk (Zakharkov et al. Oceanolog. - 2001 v.41). This phenomenon is difference of ratio of Chl to BM (after this ratio was named by us the chlorophyll index) along the hydrological section.

Zakharkov S.P et al Oceanolog. – 2001 v.41



The scheme of circulation of a northeast part of sea of Okhotsk. The rectangle designates area of works. On insert are specified positions and numbers of hydrobiological stations in March-April, 1998 are resulted



Distribution along the section of 54 40' N:

a- diatoms biomass (B, mg/m3)); b- chlorophyll "a" concentration (Cch "a", mg/m3);
c- diatoms biomass in % from the total biomass of algae (B, %).

Approach proposed by us is based on the significant difference of ratio of the Chl to BM between the diatoms and other algae divisions. This ratio sometimes differs on an order and more (Darley, 1977). It is known that for the algae cultures of fresh-water reservoirs the lowest values of ratio of Chl / BM are obtained for blue-green algae (0,37-0,62 %) and diatoms (0,43-0,81 %), and the highest for green (1-2 %) (Pyrina, Yelizarova, 1971). For diatoms the low values of ratio of Chl / BM (0,1-0,3 %) were noted at the natural communities of a sea phytoplankton (Zakharkov et al., 2001; Zakharkov et al., 1997). We developed technique for the diatoms determination by satellite data using the ship data on Chl, total suspended material, biomass and phytoplankton species composition (obtained during cruises of POI FEB RAS (Pacific Oceanological Institute)in 2000-2005) and the satellite data on Chl, Total Suspended Material (tsm)_Clark (tsm_clark; Ocean Color Product, http://ocean.color.gsfc.nasa.gov). This finding have allowed us to study the diatoms succession in the Sea of Japan.

Data

Ship data

chlorophyll a concentration

biomass of phytoplankton

total suspended material (tsm)

species composition

Data were obtained during cruise of R/V "Kril'on" (March-April, 1998) and 30th , 38th cruises of R/V "Academik M.A. Lavrentiev" from February, 26th to March, 9th, 2003 and in October, 2005, respectively, stations of 30th cruise are shown on figure 1 and data are presented in table 1.

Satellite data

chlorophyll a concentration

total suspended material calculated by Clark algorithm (tsm_clark)

Satellite distributions of mentioned characteristics were obtained from IACP FEB RAS. To process these data, Glance software was used.

Acknowledgements

We thank A.N. Charkin for ship data on tsm

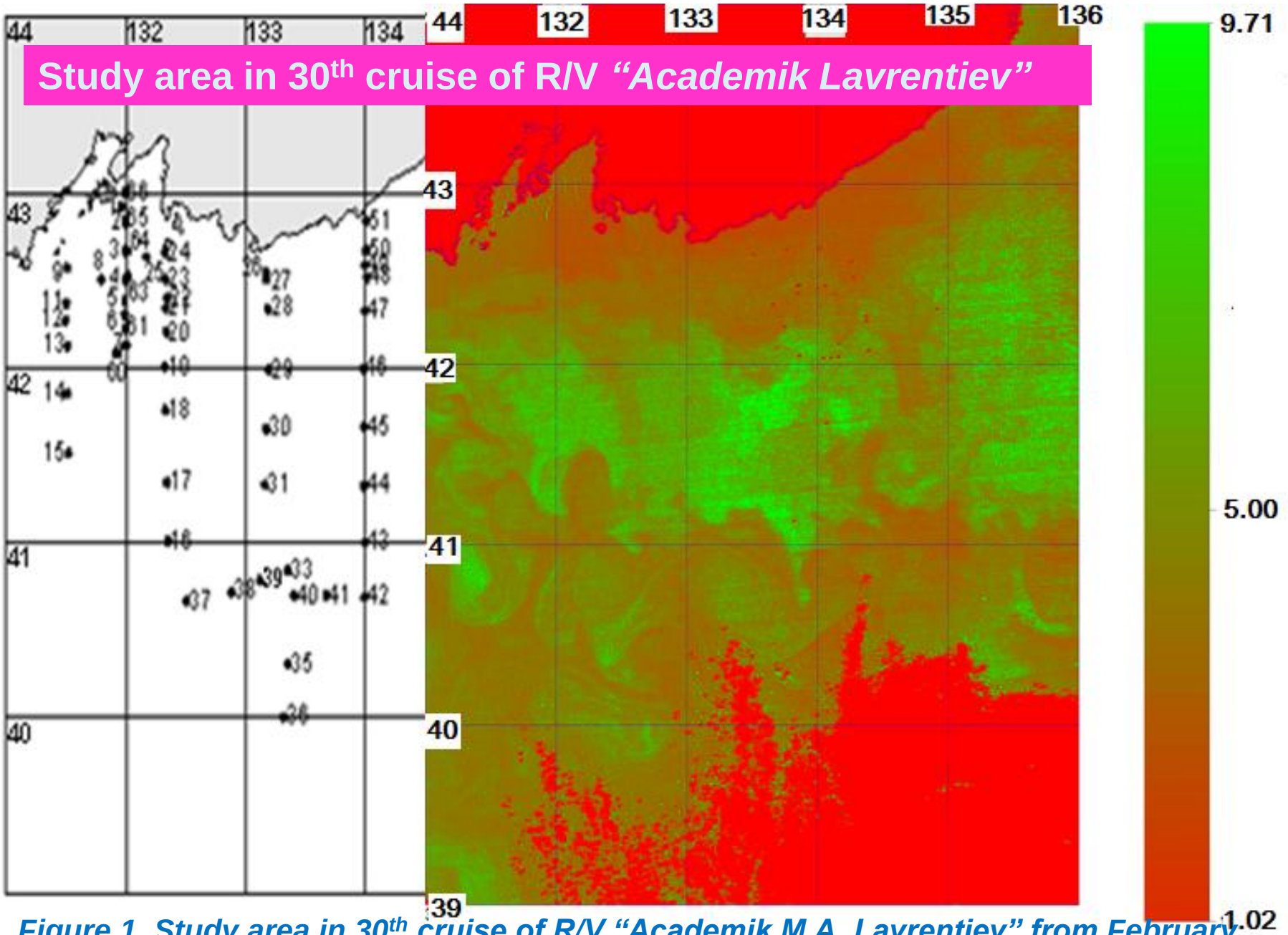


Figure 1. Study area in 30th cruise of R/V "Academik M.A. Lavrentiev" from February, 26th to March, 9th, 2003 . Location of stations (the left) and the chlorophyll Index calculated by Clark algorithm (tsm_clark) (the right).

Table. 1. Distribution of a chlorophyll a (Chl), a phytoplankton biomass (BM), the ratio of a chlorophyll a to a biomass, diatoms percent from total algae composition (defined on ship data), the total suspended material (tsm_clark) and differences between tsm_clark and BM

St	longitude (°E)	latitude (°N)	depth м	Chl mg/m^3	BM mg/m^3	Chl/BM x 1000	diatoms %	tsm clark mg/l	tsm clark-BM(mg/l)
1	131,96	42,92	58	3,6	57063	0,06	99,60	0,79	-56,27
2	132,00	42,82	72	1,56	39313,7	0,04	99,85	0,76	-38,55
3	132,00	42,66	76	0,61	15958,9	0,04	99,33	0,65	-15,31
4	132,00	42,49	97	0,62	639,5	0,97	94,74	0,41	-0,23
5	131,99	42,38	880	0,43	57,6	7,47	36,37	0,36	0,30
6	131,99	42,30	2327	0,35	16,2	21,60	33,33	0,37	0,35
7	132,01	42,12	2778	0,34	36,5	9,32	92,30	0,34	0,30
8	131,80	42,50	68	0,46	820,7	0,56	93,98	0,43	-0,39
9	131,51	42,57	75	0,88	36073,5	0,02	99,83	0,52	-35,55
11	131,50	42,37	682	0,33	407	0,81	96,68	0,37	-0,04
12	131,50	42,27	1710	0,67	2971,2	0,23	99,21	0,4	-2,57
13	131,52	42,12	2737	0,3	170,3	1,76	53,84	0,34	0,17
14	131,51	41,85	3066	0,45	421,1	1,07	88,37	0,34	-0,08
15	131,52	41,51	3252	0,58	639,3	0,91	97,66	0,34	-0,30
16	132,35	41,01	3074	0,47	138,3	3,40	86,47	0,35	0,21
17	132,35	41,34	3386	0,45	66,1	6,81	63,64	0,34	0,27
18	132,33	41,75	1620	0,3	25,8	11,63	50,00	0,3	0,27
19	132,33	42,00	2777	0,24	28,6	8,39	50,00	0,34	0,31
20	132,34	42,20	2756	0,38	145,3	2,62	50,00	0,34	0,19
21	132,34	42,34	1746	0,28	123,6	2,27	85,71	0,37	0,25
22	132,35	42,39	562	0,34	7,8	43,59	50,00	0,37	0,36

Table. 1 (continued). Distribution of a chlorophyll a (Chl), a phytoplankton biomass (BM), the ratio of a chlorophyll a to a biomass, diatoms percent from total algae composition (defined on ship data), the total suspended material (tsm clark) and differences between tsm_clark and BM

St	longitude (°E)	latitude (°N)	depth м	Chl mg/m^3	BM mg/m^3	Chl/BM x 1000	diatoms %	tsm clark mg/l	tsm clark-BM(mg/l)
23	132,34	42,50	100	-	1064,8	0,00	98,91	0,46	-0,60
24	132,33	42,65	88	1	4096,6	0,24	98,83	0,57	-3,53
25	132,17	42,63	98	0,67	881,9	0,76	96,34	0,65	-0,23
26	133,17	42,54	622	0,35	203,3	1,72	75,00	0,38	0,18
27	133,17	42,50	1353	0,17	138,2	1,23	66,00	0,37	0,23
28	133,19	42,33	2440	0,54	28,3	19,08	43,48	0,35	0,32
29	133,20	41,98	3400	0,37	38,3	9,66	69,25	0,31	0,27
30	133,17	41,65	3444	0,33	176,4	1,87	57,89	0,3	0,12
31	133,16	41,33	3441	0,2	31,3	6,39	19,99	0,29	0,26
32	133,34	41,09	3300	0,72	60	12,00	39,53	0,35	0,29
33	133,36	40,84	3420	0,58	24,3	23,87	58,33	0,32	0,30
35	133,35	40,31	3319	1,07	51,5	20,78	31,59	0,73	0,68
36	133,32	40,00	2352	0,74	60,1	12,31	34,89	0,37	0,31
37	132,51	40,67	3366	0,48	217,8	2,20	66,67	0,35	0,13
38	132,88	40,72	3390	0,3	16,5	18,18	100,00	0,34	0,32
39	133,16	40,72	3400	0,3	358,5	0,84	73,91	0,34	-0,02
40	133,41	40,69	3416	0,24	76,9	3,12	64,27	0,32	0,24
41	133,67	40,70	3440	0,25	142,2	1,76	53,34	0,32	0,18
42	133,99	40,69	3455	0,5	62,8	7,96	84,09	0,35	0,29
43	134,00	41,00	3480	0,11	27	4,07	69,99	0,32	0,29
44	133,99	41,32	3484	0,22	33,1	6,65	69,24	0,33	0,30

Table. 1 (continued). Distribution of a chlorophyll a (Chl), a phytoplankton biomass (BM), the ratio of a chlorophyll a to a biomass, diatoms percent from total algae composition (defined on ship data), the total suspended material (tsm clark) and differences between tsm_clark and BM

St	longitude (°E)	latitude (°N)	depth м	Chl mg/m^3	BM mg/m^3	Chl/BM x 1000	diatoms %	tsm clark mg/l	tsm clark-BM(mg/l)
45	133,99	41,66	3488	0,22	57,8	3,81	62,54	0,29	0,23
46	133,98	41,99	3326	0,33	15	22,00	0,00	0,31	0,30
47	133,99	42,32	3314	0,38	41,2	9,22	31,57	0,32	0,28
48	134,01	42,51	1821	0,3	58,8	5,10	64,10	0,34	0,28
49	133,99	42,58	1136	0,38	50,7	7,50	73,59	0,35	0,30
50	134,00	42,67	284	0,2	37,5	5,33	71,18	0,37	0,33
51	134,00	42,83	125	0,5	293,1	1,71	93,58	0,42	0,13
52	135,10	43,39	103	0,34	31,7	10,73	94,78	0,37	0,34
53	135,22	43,30	455	0,52	200	2,60	81,91	0,34	0,14
54	135,28	43,25	1312	0,36	37,8	9,52	44,46	0,35	0,31
55	135,38	43,20	3339	0,8	152,5	5,25	63,90	0,34	0,19
56	135,69	42,96	3460	0,3	80,1	3,75	33,99	0,32	0,24
57	135,99	42,75	3365	0,22	145,3	1,51	36,20	0,32	0,17
58	136,28	42,61	1415	0,19	22,7	8,37	77,28	-	-0,02
59	135,33	42,17	3590	0,22	23,8	9,24	30,00	0,29	0,27
60	131,92	42,08	1496	0,26	23,7	10,97	76,96	0,34	0,32
61	132,00	42,22	2675	0,38	14,3	26,57	24,98	0,34	0,33
63	132,00	42,50	98	2,04	14339,2	0,14	98,60	0,41	-13,93
64	132,00	42,67	70	0,4	28138	0,01	99,47	0,73	-27,41
65	132,00	42,84	71	0,57	27414,7	0,02	98,90	0,76	-26,65
66	132,00	43,00	40	0,73	14864	0,05	97,82	0,76	-14,10

Technique of diatoms determination

To study the diatom distribution by satellite data, we used the chlorophyll index (I chl). This (I chl) was calculated as the ratio of the Chl to BM. BM was determined using estimates on tsm_clark with corrections for the Inorganic Suspended Materials and Organic Materials. Analysis of data presented in table 1 is shown that the difference between the ship estimates on tsm and phytoplankton BM is about 0,25 mg/l. Therefore, (I chl) was calculated as:

I chl = chl_OC3 / (tsm_clark – 0,25),

where chl_OC3 is the satellite Chl estimate calculated by OC3 algorithm, tsm_clark is the satellite estimate on tsm calculated by Clark algorithm, http://ocean.color.gsfc.nasa.gov. However, the estimate of tsm can vary depending on a dust from atmospheric aerosol (Mishukov et al., 2004; Kopelevich et al., 2005; Bukin et al., 2007), that it is necessary to take into account for more exact estimates.

According to the chlorophyll index and chlorophyll concentration the total biomass of phytoplankton may be calculated. It is important for estimates of trophic conditions of area.

Applicability of proposed technique

In most cases the tsm_clark estimate on depths up to 100 meters was lower than the ship BM. Probably, the reason of the underestimated tsm_clark estimates is stream of total suspension from a bottom. Therefore, the applicability of proposed technique for the diatoms determination on surface is for depths of below 100 meters. In table 1 these cases, where the tsm_clark estimate is underestimated, are shown by red color.

Relationship between the ship and satellite tsm estimates

The correlation coefficient of 0.479 (46 measurements) was significant for the significance level of 0.999 **(**Johnson, Lyons, 1980**)*. It confirms applicability of Clark algorithm for the Sea of Japan. The ratio between average estimates of ship on tsm and satellite on tsm_clark was 0.67.***

Relationship between the diatoms percent from total algae composition and chlorophyll index (Chl / BM)

According to the diatom distribution researches implemented by data of cruises of R/V " Kril'on" (in the Sea of Okhotsk, March-April, 1998) and "Academik Lavrentiev" (in the Sea of Japan, late February – early March 2003) (Zakharkov et al., in the press) the inverse relationship between the diatoms percent and chlorophyll index was observed. Correlation coefficient between the diatoms percent and chlorophyll index by data of R/V "Academik Lavrentiev" in the Sea of Japan (2003) was significant for the significance level of 0.999 ((-0,42) for 50 measurements) (Johnson, Lyons, 1980).

Study of diatoms succession in the Sea of Japan

To study the diatoms succession we selected the most contrast areas of the Sea of Japan with coordinates:

1) 41 23.4' - 41 49.2'N and 133 10.8' - 133 36.6'E ,

2) 39 25.8 ' - 39 52.8' N and 131 03.6 ' - 131 30.6 'E,

3) 42 00.6 ' - 42 26.2'N and 135 06.2' - 135 32.2 'E,

4) the eddy area with the center near by 40 7'N and 133 5' E.

Images of 200x200 pixels were considered at study of the succession. Area 4 was divided into subareas: the center and periphery (together 50x50 pixels). During study of diatoms succession the coordinates of areas 1,2,3 were not shifted, while the eddy coordinates were shifted depending on its migration and development.

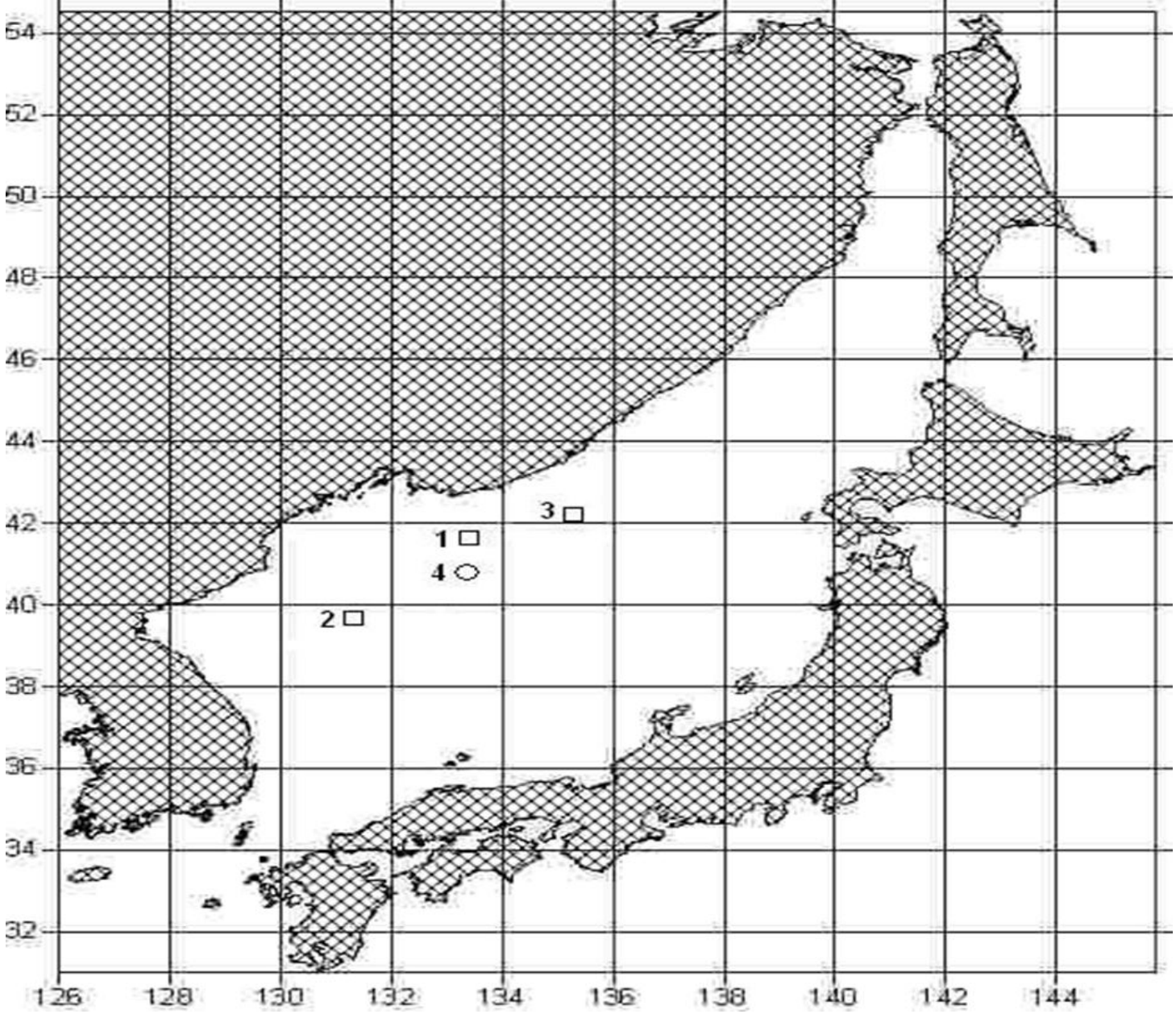
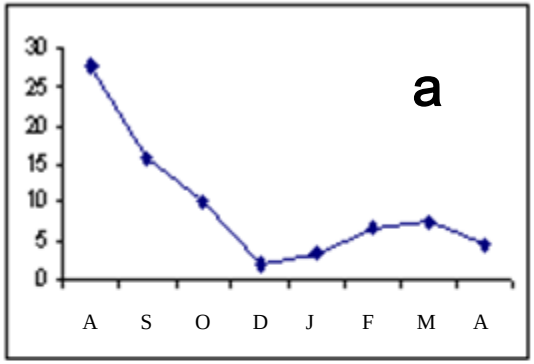
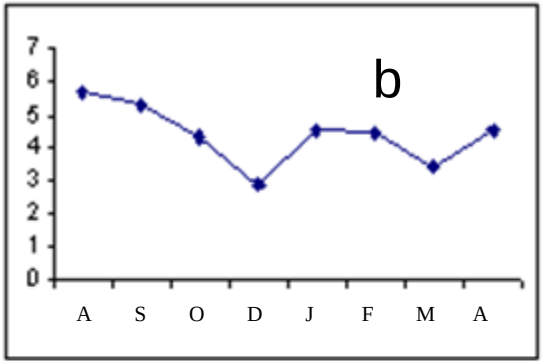


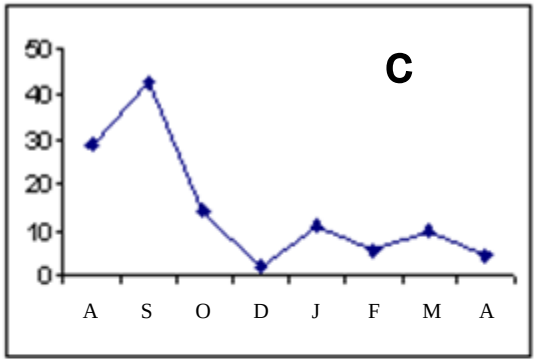
Figure 2. Locations of areas where study of diatoms succession was fulfilled.

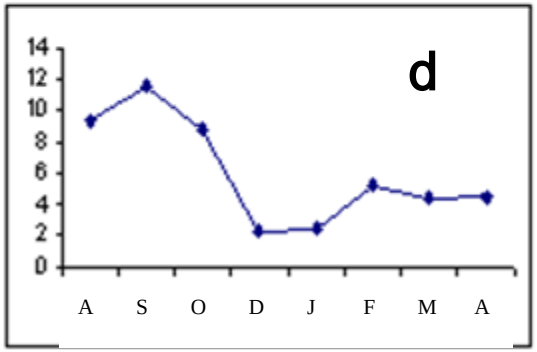
For each area of study of diatoms succession the monthly chlorophyll index was calculated and the diagrams of its variability from August to April (except November), 2003 were constructed.

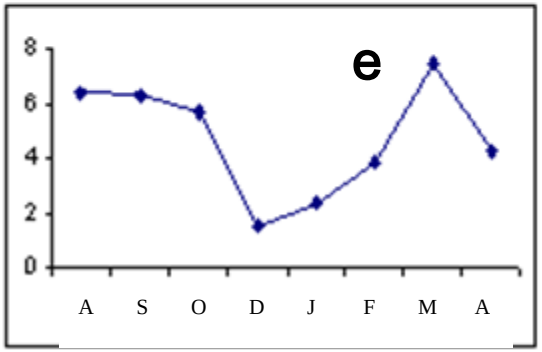
Monthly Chlorophyll Index (Chl/BM x 5000) (a- area 1, b- area 2, c- area 3, d, e – the center and periphery of anticyclonic eddy)











In August the chlorophyll index had high values relative to other months in all areas. It means that the diatoms percent from total algae composition is lowered. It is known, that the phytoplankton species composition in the Sea of Japan (except for coastal areas) is controlled by seasonal variations of stratification and light exposure. J.I. Zuenko (2008) notices, that during the summer period in Peter the Great Bay the diatoms replace on flagellates. From August-September to October-December the index went down. Autumn bloom is caused by destruction of stratification and is favorable for development of any algae, especially for diatoms. It is established, that at abundance of nutrients and light they will dominate, suppressing the development of other kinds (Gregg at al., 2007).

From August to December depending on an area the change of summer structure of a phytoplankton occurs. Probably, dinoflagellates (according to Zuenko, 2008) replace on diatoms.

Spring bloom begins in March - April when the water column becomes thermally stratified. Concentration of a pigment in all areas is high in the spring and in the autumn, and is low in the summer. Accordingly, on all presented diagrams the lowest indicators of chlorophyll index, and, hence, high diatoms concentration, are observed during autumn and spring blooms of a phytoplankton.

Thus, application of chlorophyll index allows to track the change of a condition of a phytoplankton in any area of the sea and during different seasons of year. At that the diatoms make basic part of species composition of phytoplankton.

Thank you for attention