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PRIMARY PRODUCTION ASSESSMENT OF THE SOUTHERN INDIAN OCEAN IN CONSUMPTION OF SILICIC ACID

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Estimation of the primary productivity (PP) for the area of the Southern Indian Ocean has been made on the base of assessment of interannual variability in concentration of silicic acid in the euphotic layer. Mean for different sublatitudinal zones (subtropical, subantarctic and antarctic) summary for the vegetative period and daily PP, varied in the range 13.0-29.8 and 0.03-0.23 g C m^{-2} relatively. Kerguelen Plato was the most productivity area, where summary PP reached 165 g C m^{-2} and daily - 0.9.
Key words: primary productivity, estimation, Southern Indian Ocean

Оценка первичной продуктивности вод индоокеанского сектора Южного океана по потреблению кремнекислоты
А.Т. Кочергин
Реферат. Приводятся алгоритм и результаты расчетов первичной продукции (ПП), основанные на оценке внутригодовой изменчивости содержания кремнекислоты в эвфотическом слое антарктической, субантарктической и южной границы субтропической зоны индоокеанского сектора Южного океана. Средние для этих зон значения ПП за вегетационный период и суточные изменялись в пределах 13.0-29.8 и 0.03-0.23 г С м$^{-2}$ соответственно. Наиболее продуктивным районом являлось Плато Кергелен, где суммарная ПП достигала 165 г С м$^{-2}$ и суточная – 0.9.

Оцінювання первісної продуктивності вод індоокеанського сектора Південного океану зі споживання кремнекислоти
А.Т. Кочергін
Реферат. Наводяться алгоритм і результати розрахунків первісної продукції (ПП), засновані на оцінюванні річної змінюваності вмісту кремнекислоти в евфотичному шарі антарктичної, субантарктичної та південної межі субтропічної зони індоокеанського сектора Південного океану. Середні для цих зон значення ПП за вегетаційний період та добові змінювалися в межах 13.0-29.8 і 0.03-0.23 г С м$^{-2}$ відповідно. Найбільш продуктивним районом виявилось Плато Кергелен, де сумарна ПП досягала 165 г С м$^{-2}$ та добова – 0.9.

1. Introduction

In the Southern Ocean as a whole and its Indian Ocean sector in particular measurements of primary production (PP) are extremely rare as compared with measurements of nutrient concentrations. Besides, PP values, estimated by the radiocarbon method, as it is shown in a number of papers (Cushning, 1957; El-Sayed et al., 1981; Sapozhnikov, 1986; Sorokin, 1986) are underestimated specially for the Southern Ocean waters (Samyshev et al., 1987). Proceeding from these facts, many authors (Gusarova, 1992; Kochergin, 1992; Jennings et al., 1984; Peng Tsung-Hung et al., 1987) use the PP estimation methods taking into account assimilation of biogenic methods by phytoplankton in the euphotic zone.

2. Data and metod

This paper provides estimation of intensity of production of primary organic matter in the Indian Ocean basing on assessment of interannual variability in contents of silicic acid in the euphotic layer, i.e. reduction in their winter concentration in summer resulting from photosynthesis. According to conclusions of some researchers (Ivanenkov, 1979; Sapozhnikov, 1975) it is the bioprocesses that almost completely determine this variability. Among all the nutrient matters silicic acid was chosen as most consumed by diatomic phytoplankton in waters of the Southern Ocean.

In the subtropical (northwards to the Subtropical front - STF) and subantarctic (between STF and the Polar Front - PF) waters, where temperature conditions determine the presence of regenerative component, the part of winter concentration of silicic acid used by phytoplankton in summer under formation of primary organic matter, is calculated by the formula taking into account conclusions of Arjanova (1982, 1986) and Skopintsev (1981):

$$P = H_{eu}(C_w - C_s)\frac{1 - 0{,}n^{Kt}}{1 - 0{,}n} \qquad (1)$$

where Heu - thickness of the euphotic layer in summer; Cs, Cw - mean weighted concentration of nutrients in summer and winter; 0,n - level of mineralization of the organic matter; Kt - the coefficient of the urnover of nutrients.

In the antarctic waters (southwards to the PF), with regard for the fact that the winter resource of nutrients is used not to the full extent and to prolonged regeneration of the instable part of organic matter comes to its end below the euphotic zone we shall come to:

$$P = Heu\,(Cw - Cs) \qquad (2)$$

In case of missing of winter observations summer concentrations of silicic acid in the nuclei of the cool subsurface layer, preserving in summer winter characteristics of the layer of convention mixing, were taken as Cw. PF location, separating the subantarctic and antarctic zones, was assumed by the criterion suggested by Orsi et al. (1993), i.e. value of water temperature at the depth of 200 m and equal to 2°, and STF location between the subantarctic and subtropical zones was respectively 10°at the same depth according to conclusions of Clifford (1983).

Studies of Voronina (1977) and Semina (1977) in moderate and high latitudes have shown that thickness of euphotic layer is close there to that of the layer of summer warming, i.e. from the surface to the seasonal picnicking characterized by the maximum vertical gradient of density:

$$Heu = Zmax\,\frac{\partial\rho}{\partial z} \qquad (3)$$

It should be noted, as the layer of maximum vertical gradients is often characterized by increased phytoplankton biomass and high PP values, under conditions of calculation it is included completely into the euphotic zone. In accordance with conclusions of Bikbulatov et al. (1978), Maximova (1972), the level of mineralization of the organic matter is supposed to be 92% in subtropical waters and 75% in the subantarctic and antarctic zones. The turnover coefficient was calculated depending on duration of the vegetative period (τ_v) and the time of regeneration of nutrients (τ_r) within 24 hours:

$$K_t = \frac{\tau_v}{\tau_r} \qquad (4)$$

Maksimova's (1972) equation determines the time regeneration with me simplification suggested by Gusarova (1992):

$$\tau_r = \tau\, 10^{\,0.0342(t-tw)} \qquad (5)$$

where tw - the mean weighted water temperature in the euphotic layer, τ - duration of regeneration of nutrients in experimental conditions at the given water temperature t. In practice of estimation (Arjanova, 1982; Sergeev, 1979) it is customary to accept $\tau = 28$ at $t=11^o$ for silicic acid.

The vegetative period was estimated in conformity with Maximova's (1976) and Eskin's (1969) research data with their certain detailing and formalizing by the following formulas:

$\tau_v = 240-6(\varphi°-40)$ - for the band of latitudes 40-60°S (6)

$\tau_v = 105-9(\varphi°-60)$ - for the band of latitudes 61-70°S and longitudes 20-80°E (7)

$\tau_v = 105-11(\varphi°-60)$ - for the band of latitudes 61-70°S and longitudes 81-120°E (8)

A part of winter stock of silicic acid assimilated by phytoplankton during the summer vegetative period was converted into the quantity of carbon by the following stoichiometric correlations: Si:C = 3 for temperate latitudes (Arjanova, 1986) and C:Si = 2.5 for high ones (Copin-Montegut C., Copin-Montegut G., 1978).

A huge massif of oceanographic data collected by YugNIRO (Kerch, Ukraine) and NODC (Silver Spring, USA) for the last thirty years and above given algorithm made possible to estimate thickness of the euphotic layer, summary (new + regenerated) primary production, averaged for centers of trapeziums with sides of 2° by the meridian and by 5° by the parallel in the Indian sector of the Southern Ocean (40-70°S, 25-115° E). Availability of oceanographic data (including silicic acid) is given in Tab. 1.

Table 1

The amount of oceanographic observations, which include biogenic substances

	λ°																		
φ°	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
40	9	10	6	7	25	28	14	17	6	2	5	1	1	4	5	6	8	12	1
42	10	12	11	10	47	19	19	17	4	3	6	2	1	6	3	5	8	7	2
44	9	11	2	3	16	5	7	16	2	5	6	1	1	6	2	5	7	10	4
46	4	11	0	10	12	109	8	13	2	28	7	1	0	3	1	5	3	2	6
48	5	13	1	0	13	8	0	5	34	260	8	0	0	3	0	0	0	2	3
50	8	16	3	1	8	8	0	12	107	355	19	0	1	4	2	0	0	0	1
52	5	20	1	390	198	6	0	7	5	80	200	4	1	3	0	0	0	0	0
54	3	8	7	14	169	5	0	5	1	4	13	3	2	3	0	2	0	0	0
56	4	5	1	1	6	2	0	3	2	6	5	4	1	2	0	0	1	0	0
58	1	6	0	1	5	0	0	2	2	4	7	2	3	2	0	0	0	1	0
60	0	8	13	7	10	6	12	38	27	22	28	17	11	11	2	2	3	0	0
62	0	20	14	14	18	10	13	44	31	40	33	27	16	16	4	4	4	2	0
64	0	8	12	13	16	13	27	67	55	40	50	40	15	12	15	11	7	3	0
66	1	12	31	27	71	116	63	179	201	57	79	35	13	6	0	0	4	5	4
68	3	29	62	128	199	1	0	7	10	25	88	2	0	0	0	0	0	0	0

Results of estimations are at Figs. 1-3. Unfortunately, the absence of oceanographic observations in several squares in the eastern part of the sector imparts some interpolation smoothed character to the fields of the estimated values in this area. Within the area under study STF was located between 41-45°S, PF - 49-53°, on the extreme west and in the center of the area closeness of the fronts was observed.

3. Analysis of the results

In the course of large-scale analysis of the field of thickness of the euphotic layer(Heu), three zones are marked: northern, central and southern. The northern one (northwards to 48-50°S) where there is a rather complex disposition of subtropical and subantarctic waters, has a wide range of variability of Heu (15-100 m) and cellular structure of its field. The central zone with the axis approximately along 52-54°S is characterized by the maximum (down to 125 m) depth of the lower boundary of Heu and is associated with the southern periphery of the Antarctic convergence. The southern one (southwards to 55-60°S), in the antarctic waters, has a quasi-zonal reduction in thickness of this layer from 50-75 m in the northern part to 15-50 m in the southern part (Fig. 1). In the south-eastern part of the area (the Mowson Sea) deepening of the lower border of the euphotic layer was observed down to 50-75 m. Between two fronts, in sublatitudinal band of the Subantarctic divergence assumed by Ivanov (1961), local areas with relatively small thickness of Heu (less than 25-50 m) were marked.

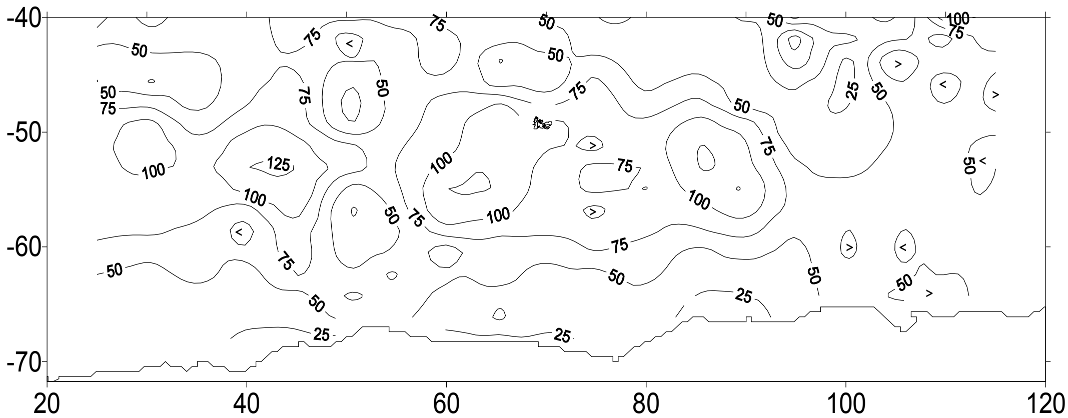

Fig. 1. Thickness of the euphotic layer (in meters).

The PP summary for the vegetative period and estimated by consumption of silicic acid northwards STF in the oligotrophic water did not exceed 50 g C m^{-2} being mainly 10-25 g C m^{-2}. PP reached its maximum values (165 g C m^{-2}) in the central part of the area, in the zone of closeness of STF and PF where the influence of the Kerguelen Plato results in forming of numerous topographic vortices concentrating plankton, and with upwelling processes in the eastern part of the Plato, as Plancke (1977) thinks. According to the assumption of Lutjeharms and Baker (1980) the Kerguelen Islands area is one of the most changeable in the Southern Ocean, so PP fluctuations are large there - from 25 to 165 g C m^{-2}.

In the periphery part of the area these values were less than 90 g C m^{-2} (Fig. 2).

PP did not exceed 40 g C m^{-2} southwards to 60° S reducing to southwards and reaching values less 10 on the Antarctic shelf. If in the oligotrophic subtropical waters PP is limited mainly by lack of nutrient matters in the Antarctic waters PP is limited by short cycle vegetative period and local deficit of silicium during summer flash of phytoplankton blooming, when its concentration is reduced from 100 to 60% as compared with winter one, for instance, in the Weddell's Sea - Jennings et al. (1984) and up to 10 - in some areas of the Prydz's Bay region.

The lowest values of the daily PP (generally less than 100-200 mg C m^{-2} day^{-1} in the western part of the area and 50-100 - in the eastern part) are for subtropical zone pertaining to the southern periphery of the oligotrophic area of the Southern subtropical anticyclone (Fig. 3).

The subantarctic and antarctic waters, adjacent to PF, were notable for high intensity of producing primary organic matters. The daily PP, determined by assimilation of silicic acid, was extremely high (908 mg C m^{-2} day^{-1}) in the zone of PF in the area of the Kerguelen Plato and eastwards to it. Beyond the Kerguelen Plato the values of the daily PP in the Antarctic were lower, mainly 100-400 mg C m^{-2} day^{-1}, increasing up to 400-600 - on the extreme south-west of the area and reducing to 50-100 in the north-eastern part of the Prydz's Bay region.

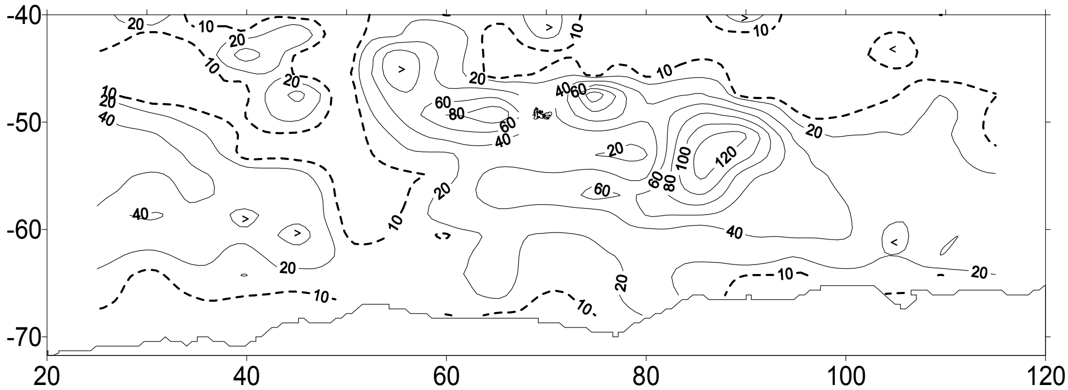

Fig. 2. Summary for the vegetative period primary productivity in g C m^{-2}.

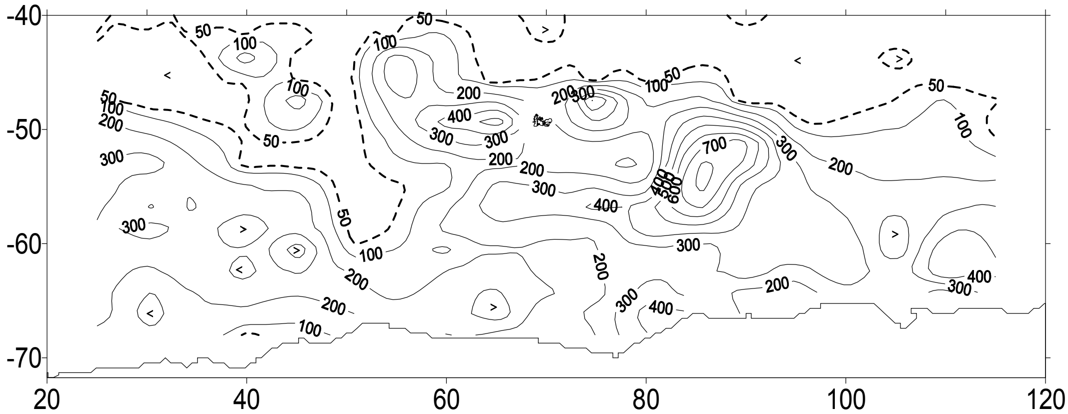

Fig. 3. Daily primary productivity in mg C m^{-2} day^{-1}.

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In the given below Tab. 2 the values of summary for all the vegetative period and daily PP which are mean for different zones for the whole area. Double increase of the mean summary PP southwards from the subtropical zone to the subantarctic and antarctic as well as approximate (within 20%) equality of intensity of producing in two latter zones should be taken into account. The daily PP increased gradually southwards at transition from the subtropical to the subantarctic (fivefold) and further to the antarctic (additionally 1.5 times) zones. The high productive ability of the antarctic zone was determined mainly owing to the antarctic waters adjacent to PF. Mean for all the area values of summary PP (24.9 g C m^{-2}) agrees rather well with assessments of annual PP in the Southern Ocean made by different authors: Burkholder P., Buckholder L. (1967) - 29-32; Green (1978) - 25; Kobelents-Mishke (1977) - 46. However, Voronina (1984), analyzing interrelations of different links in the trophic chain, gave the higher figure - 70 g C m^{-2}. Mean for the whole area the daily PP (0.18 g C m^{-2}) was close to the data of Jennings et al. (1984), Mitchel-Innes (1965), El-Sayed, Jitts (1973), but less than Sorokin's (1973) data.

Table 2

Mean values of PP (g/m^2) in different latitudinal zones

Zone	Per vegetative period период	Per day
Subtropical	13.0	0.03
Subantarctic	29.8	0.16
Antarctic	25.9	0.23
Whole area	24.9	0.18

4. Conclusion

The algorithm is developed for estimation of primary productivity of the waters of the Southern Indian Ocean; this algorithm is based on interannual variability in concentration of silicic acid in the euphotic layer.

According to the developed algorithm, calculations of the primary production for different sublatitudinal zones (antarctic, subantarctic zones and the southern border of the subtropical zone) were performed; the spatial analysis of its variability and comparative evaluation with the data of other authors are presented.

The calculation results appeared to be close to the average assessments of estimated primary production for the Antarctic waters.

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