B-7.3 Study on Variation of Inorganic Carbon with the Biological Productivity in the Ocean

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Abstract We examined the pCO2 in surface water in North Pacific off Sanriku Japan at January, May, August 1997, April 1998, March and November 1999 and the environmental factors such as water temperature(WT), nutrients(nitrate, phosphate and silicate) and carbonic system (total carbon:TC, Alkalinity:TA). The pCO2 was negative relation to WT at January and March, positive to WT at May and August, negative lower 15℃ and positive above 15℃ at November and no relation to WT at April. The pCO2 had a good relation to TC at January and August but a bad relation at May. We examined the seasonal change of the same salinity water in order to know the change of the same water. We thought that the pCO2 was decreased by the decrease of TC through diatom blooming from January to May and was more decreased than the expected value with the increase of WT because of TC decrease , the reason of the decrease was unknown. We predicted the change of pCO2 from the change of TC and TA and the error of the prediction was within 10 %.

Key Words pCO2 in Surface Seawater, Oyashio, Transition Area, Nutrients, SST, Chlorophyll, Total Carbon, Alkalinity

1.Introduction

The carbon dioxide is one of the green house effect and the estimation of its budget is very important to human being. The Western North Pacific has been taken notice of the possibility of strong absorption of carbon dioxide (Tsunogai et al(1993))[1]. At the same time, this region is one of the most productive water, so carbon dioxide could be absorbed by the photosynthesis by phytoplankton. The distribution of the pressure of carbon dioxide in surface water are in need of measure in the Western North Pacific in order to understand the role of this sea in carbon cycle in the earth.

We observed the partial pressure of carbon dioxide(pCO2) in the surface water of Oyahsio, Transition and Kuroshio area in off Sanriku and off Boso. Our purpose was the elucidation of the relation between pCO2 and environmental factors such as temperature, salinity nutrients and carbonate material. These relations could be used the estimation of pCO2 from the environmental factors.

2.Research Method

The data used in this work were obtained during the cruises of the R/V Soyo-maru belonging to the National Reserch Institute of Fisheries Science. We observed from the south(33~36° N) to the north(42° N) along 144° E in January, May and August 1997, April 1998, March and November 1999January, May and August 1997. Vertical distributions of water temperature and salinity were measured by a CTD system. Water samples were obtained by a CTD-Rossete system fitted with twenty-four 2.5L Niskin bottles at every 30 miles. Continuous measurement of pCO2 was performed using a modified compact pCO2 measurement system with membrane equilibrator and nondispersive infrared gas analyzer which was originally to measure pCO2 at coral reefs (Saito et al.,1995)[2]. Temperature, salinity and fluorescence in surface water were measured by EPCS. Sea water examined was transported from the pipe at the bottom of the vessel (below 4m from the sea surface) and the water qualities (water temperature, salinity and fluorecence) were analyzed by the EPCS system. EPCS data and pCO2 data were incorporated into computer in EPCS. The methods about another factors such as chlorophyll a, nutrients and total inorganic carbon were described in the paper (Sasaki et al., 1998)[3].

3.Result and Discussion

1) Seasonal meridional change of pCO2: The pCO2 was about 300ppm at Kuroshio (K) and about 400ppm at Oyashio(Oy) in January, about 300ppm at K and about 400ppm from Transition area(T) to Oy in March, about 330ppm at K and 220-400ppm from Oy to T in April, below 200ppm from Oy to T in May, about 350ppm at K and 300ppm at Oy in August, about 300-350 ppm in November. The pCO2 in these area was higher than the value in air (365ppm) in January and March, but lower in other season, so the area surveyed would absorb carbon dioxide since the pCO2 in air in latest data was about 365ppm.

2) Relation of pCO2 to the surface temperature: The pCO2 were decreased with the increase of WT in January and March, increased with the increase of WT in May and August, decreased below 15℃ and increased above 15℃ with the increase of WT in November, finally had no relation with the SST in April.

3) Relation of pCO2 to WT and chlorophyll a(Chl): Chl was analyzed using the water samples obtained at every 30 miles . We examined the relation of pCO2 to WT and Chl using data of January, May, August and November and the result is shown in Table 1. The results showed that WT had a negative relation to pCO2 in January and positive one in other months and Chl had always a negative relation to pCO2. The bi-regression of pCO2 to WT and Chl is shown in Table 2 and the results shows the errors of the predicted values of pCO2 are within

10ppm except May where the prediction is difficult.

Table 1. Regression of pCO2 with water temperature(WT) or chlorophyll a(Chl)

month	WT		Chl	
	a	R	a	R
1	-5.08	0.93	-6.03	0.04
5	11.77	0.71	-35.94	0.72
8	4.45	0.92	-71.7	0.52
11	1.80	0.85	-26.59	0.58

A:regression coefficient, R:coefficient of correlation

4) Relation of pCO2 to Salinity: The patterns of the relation are the same with the relation of pCO2 with WT.

5) Relation of pCO2 to nutrients: The pCO2 is higher in higher concentration of nutrients in general. These nutrients(Y: μM) have a good correlation to WT(X:℃). In the case of nitrate, Y=-0.93*WT+19(R^2=0.96) in January, Y-0.82*X-3.1(R^2=0.86) below 9 ℃ and Y=-0.38*X+7.1 above 9℃ in May. The relations of phosphate and silicate are the same as the case of nitrate. In general, nutrient concentration is higher at lower WT except the case of May where nutrient concentration is lower at lower WT because of blooming at lower WT.

Table 2. Bi-regression of pCO2 with water temperature(WT) and chlorophyll a(Chl)

month	regression (pCO2=a*WT+b*Chl+c)	RMS	SD
1	pCO2=-5.098*WT-12.304*Chl+385.9	6.1	4.3
5	pCO2=6.458*WT-21.348*Chl+204.5	20.4	12.5
8	pCO2=4.714*WT+11.739*Chl+229.9	6.5	3.3
11	pCO2=2.759*WT+24.42*Chl+241.7	3.3	1.6

6) Relation of pCO2 to total carbon(TCO2) and alkalinity(TA): We eliminated the effect of WT and pCO2 value was shown that at 10℃ using the equation of Takahashi et al (1993), pCO2(10℃)=pCO2(t℃)*EXP(0.0423*(10-t))

The relation in January: pCO2=EXP(-102)*TCO214.1, and that in August: pCO2=EXP(-93.1)*TCO213.0, but no relation in May. The relations of TCO2 and normalized TCO2 (NTCO2 normalized to Salinity 35) to WT and NTCO2 relation to WT are found to be better than TCO2 one. The relations of NTA in May and August are found to be good, but the relation in January is not found. The relation of TCO2 to nitrate, phosphate and silicate in January is good but that in May was not good and TCO2 in August is decreased without the consumption of nutrients which are exhausted from May to August.

7) Seasonal change of pCO2 and other factors in the same salinity water: We examined the seasonal change of pCO2 and other factors such as nutrients in the same salinity water. We thought that the same salinity water was the same water, for example, the 33.0 salinity water was the same Oyashio water. If these assumptions were correct, we could estimate the seasonal change of the same water. First, we examined the relation between salinity and temperature. (Y:temperature, X:salinity): Y=9.1*X-300(January), Y=3.1X-97(May) and Y=7.2X-220 (August). The correlation was good in January and August and not good in May. We can estimate the seasonal temperature change at salinity 33.0, then estimate the pCO2 seasonal change at salinity 33.0. We can estimate also the seasonal changes of nutrients and

total carbon by the same way. The results with the waters of 33.0, 33.5 and 34.0 were shown in Table 3.

Table 3 Seasonal change of several factors about pCO2

month	Salinity	WT	pCO2	NO3	PO4	Si(OH)4	TCO2	TA	*CA
1	33.0	0.3	379	18.7	1.38	29	2108	2300	2203
	33.5	4.85	355	14.5	1.08	22	2071	2300	2187
	34.0	9.4	332	10.3	0.79	16	2035	2300	2175
5	33.0	5.3	204	1.5	0.39	1.1	2027	2224	2246
	33.5	6.9	222	2.2	0.47	3.1	2020	2219	2205
	34.0	8.4	240	2.8	0.55	5.2	2013	2214	2189

*CA was calculated from pCO2 and TCO2

(1)Seasonal change of pCO2: We estimated the seasonal change of pCO2 in the water of salinity 33.0 to be 379-204-319ppm from Jan.-May-Aug. as shown in Table 3. CA* in the left column is Carbonc Alkalinity and it was calculated from the equation after Sasai et al(2000). $CO2=(K1/K2)*(2TCO2-CA)^2/(CA-TCO2)$, K1&K2 are dissociation constant for carbonic system, TCO2 was observed and CO2 was calculated from pCO2.

(2) Factors determining the seasonal change of pCO2…Table 4 shows the changes of pCO2 and nitrate concentration from January to May and ΔpCO2/ΔNO3 was 8.6 at 33.0, 10.2 at 33.5 and 10.3 at 34.0, so pCO2 was thought to be decreased by about 10 ppm with the decrease of 1 μM nitrate through blooming. The pCO2 was increased from May to August and the increase was about 100 ppm. The calculated increase with the increase of temperature (equation was shown in the under Table 4) was higher than the observed one. The reason why the observed value was smaller than the calculated was thought to be due to the decrease of total carbon from May to August.

We examined the ratio of the decrease of nitrate, phosphate, silicate and total carbon. We calculated the change of total carbon by the equation :$\Delta C=\Delta TCO2-0.5*\Delta CA$ because one change of CA equal to 0.5 total carbon in equation: $Ca^{2+}+2HCO_3^-=CaCO_3+CO_2(g)+H_2O$ $\Delta C/\Delta N$ is about 4.9 from January to May and it is smaller than Redfield ratio, so nitrate decrease was thought to be more than that of Redfield ratio. These ratios indicated that total carbon was decreased with nitrogen, phosphate and silicate by diatom blooming from January to May. Since $\Delta C/\Delta N$ from May to August is about 28 and $\Delta C/\Delta P$ is more than that of January to May, carbon was more decreased than nitrogen and phosphorus compared with Redfield ratio. The reason why so much carbon was decreased was unknown and the theme solved.

(3) Total carbon and alkalinity determining the seasonal change of pCO2: pCO2 is determined by WT, Salinity, TC (Total Carbon) and Alkalinity. Here, we examined the same salinity water, so we need not think about salinity. We used the equations of the relation of pCO2 to WT, TC and TA after Takahashi et al (1993).The relation of pCO2 to WT was already shown. About TC, Ln(pCO2(2)/(pCO2(1))=12*Ln(TC(2)/TC(1)),

about TA, Ln(pCO2(2)/(pCO2(1))=-9.4*Ln(TA(2)/TA(1)). Table 5 shows the comparisons between the predicted values of pCO2 from the change of TC and TA and the observed values.

Table 4 Relation of pCO2 change to nitrate and water temperature

months	factor	33.0(psu)	33.5(psu)	34.0(psu)
Jan→May	△pCO2	-153.0	-131.0	-81.0
	△NO3	-17.7	-12.8	-7.9
	△pCO2/△NO3	8.6	10.2	10.3
May→Aug	△pCO2	109	106	100
	△WT	12.3	14.4	16.4
	Cal△pCO2	145	188	248

CalpCO2(t2)=pCO2(t1)*EXP(0.0423*(t2-t1))

Table 5 Estimation for the variation of pCO2 from January to August through May

month	Salinity	WTpCO2	TCpCO2	CApCO2	TC/CApCO2	Real pCO2	Difference	Error(%)
Jan-May	33.0	468	270	390	193	204	-11	-5
	33.5	387	272	358	243	222	22	10
	34.0	318	274	300	255	240	15	6
May-Aug	33.0	342	205	444	306	319	-13	-4
	33.5	407	232	528	352	335	17	5
	34.0	481	260	571	351	352	-1	0

In this table, WTpCO2 indicates the change of pCO2 only due to WT change, TCpCO2 does the change of WTpCO2 only due to TC change, TApCO2 only due to TA change and TC/TApCO2 due to both change of TC and TA. The results shown in Table 6 indicate the errors are within 10 %, so the pCO2 change was thought to be due to TC and TA. If we could estimate the change of TC and TA, we would estimate the change of pCO2.

5.References

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