

## **UV Radiation and natural fluorescence linked primary production in Antarctic waters**

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### **Abstract**

Primary productivity and chlorophyll values have been measured using an underwater profiling radiometer for the first time in the waters around Indian Antarctic Station (70°46'S & 11°44'E) in the summer of 1994. The profiles include natural fluorescence (upwelled radiance at 683 nm), scalar irradiance (photosynthetically active radiation, PAR), computed primary production (pp), diffuse attenuation coefficient, UV B (308 and 320 nm) and UV A (340 and 380 nm) radiation, and water temperature, measured as a function of depth from 21/1/94 to 6/3/94. The profiles covered measurements between 2-75 metre depth. Fifteen observations were made at an anchored station in Antarctic waters (69°53' to 70°02'S). Sub-surface chlorophyll ranged from 0.2 to 0.5 mg m<sup>-3</sup>. Range in column chlorophyll was 6.6 to 71 mg m<sup>-3</sup>. The average values for sub-surface chlorophyll *a* and pp was 0.3 mg m<sup>-3</sup> and 6.3 mgC m<sup>-3</sup> hr<sup>-1</sup> respectively. The mean value for column chlorophyll was 19.2 mg m<sup>-2</sup> and primary productivity 102.4 mgC m<sup>-2</sup> hr<sup>-1</sup>. The mean specific sub-surface productivity was 19.4 mgC m<sup>-2</sup> hr<sup>-1</sup>. Interestingly, positive correlations were observed between primary productivity, UV A and UV B in sub-surface waters. However, when the primary productivity values were normalized for PAR, a more negative effect was noticed in the sub-surface and column waters and this negative effect was significant at 1 % level (p<0.01) in column waters. This response in the photosynthetic parameters could be due to the varied effect of UV A and UV B on phytoplankton.

### **Introduction**

Depletion of stratospheric ozone, particularly in the Antarctic has stimulated concerted efforts to predict the effects of increased ultraviolet radiation on biological systems (Cullen and Neale, 1994). The subsequent negative effect on Antarctic phytoplankton is not totally unequivocal. There is as much evidence for the negative effect of UV B and UV A on phytoplankton and other living community (Roberts, 1989; Karentz, 1991) just as there are enough positive results to show photoadaptability to overcome the deleterious effects (Marchant *et al.*, 1991;

Helbling *et al.*, 1992; Mc Minn *et al.* 1994). Phytoplankton respond to this stress by shifting pigment content of cells by producing photoprotective mycosporine aminoacids (Carreto *et al.*, 1990). Thus the effects range from damage in the cellular level to physiological impairment and reduced reproduction and increased mortality. UV B penetration into the sea varies with turbidity, concentration of DOM, absorption by plants and other factors. Increased UV B during austral spring due to the ozone hole decreased primary production by 6-12% in the marginal ice zone (Smith *et al.*, 1992). In

spite of the variability of UV B attenuation in space and time, the global concern revolves around the ecological impacts upon the biologically active surface layers. The Antarctic waters are extremely transparent owing to low concentration of cells, particulate and dissolved substances, resulting in maximal UV penetration (Romankevich and Peresypkin, 1993). In the light of this divided opinion on the net effect of UV light on Antarctic primary productivity (PP), it was relevant to use an underwater profiling radiometer that not only gives the *in situ* UV penetration (308,320,340, 380 nm) but also computes values of PP in relation to depth. The present paper deals with chlorophyll (Chl *a*) and PP values of station in Antarctica (69°57'S, 11°55'E) and discusses the effect of UV light on the PP in those waters during January to March, 1994.

It is now known that photosynthesizing plants have a natural fluorescence. It is the solar stimulated fluorescence of chlorophyll in the phytoplankton community. Measurements of natural fluorescence is now an accepted optical method for assessing both gross photosynthetic rate and chlorophyll concentration within the water column and is a cost effective, rapid non-invasive technique (Chamberlin *et al.*, 1990; Chamberlin and Marra, 1992; Kiefer *et al.*, 1989). It has thus been possible to estimate this net effect on chlorophyll values and primary productivity in these waters using the under water radiometer. Mendoza and Maske (1996) have highlighted the importance of primary productivity method based on natural fluo-

rescence. It can provide significant advantage over the conventional primary productivity as it avoids the use of radioactive inorganic carbon. Besides being faster and non-invasive it is easier to calibrate. The limitation of natural fluorescence must be viewed against the methodological artifacts of  $^{14}\text{C}$  incubation method (Maske and Mendoza, 1994). Besides, there could be considerable differences in the intercalibration exercises (Richardson, 1991). Mendoza and Maske (1996) confirm that the quantum yield ratio  $f_c; f_f$  is a function of *in situ* irradiance but not of nutrient concentration or temperature as has been reported earlier in literature. It is also assumed that in nature phytoplankton physiology is forced only by a small margin of nutrients, so that the average irradiation functions of  $f_c; f_f$  is not significantly changed.

A survey of the literature published on the use of underwater profiling radiometer and connected work show that different authors have used different cut off depths to minimize contamination of the fluorescence signal from backscattered solar radiation.

Our profiles extend from 2 m to 40-75 m depth. If 10-20 m is used as the cut off (Culver and Perry, 1997) a good portion of the data would get eliminated, leaving only 20-55 m for estimation. This would lead to a gross underestimate. A comparison with  $^{14}\text{C}$  experiments is warranted. Nevertheless, Mendoza and Maske (1996) have indicated in their studies that the error of natural fluorescence must be

Location	Cut off depth	References
1. South Pacific Ocean, Sargasso Sea Weddell-Scotia Seas & North Atlantic Ocean	2 m	Chamberlin & Marra (1922)
2. Western South Pacific gyre	6	Kiefer <i>et al</i> (1989)
3.	-?	Cullen & Lewis (1955)
4. a) Oceanic water from Pacific Ocean b) Coastal water in the Atlantic maximum 20 m	> 10 m	Culver & Perry (1977)
5. Mexican Pacific waters		Gracia - Mendoza & Maske (1996)

balanced against the methodological artifacts of  $^{14}\text{C}$  incubation method for measuring primary productivity. They have also shown that when the photosynthetic rate is below  $300 \text{ nm C m}^{-3} \text{ s}^{-1}$ , natural fluorescence data are a useful proxy of primary productivity with a correlation coefficient  $r^2 = 0.85$ . We have retained 2 m as the cut off depth as recommended by the originators, (Chamberlin and Marra, 1992) for minimising the contamination from backscattering. The present work aims to assess sub-surface and column productivity from the profiles of the under water radiometer in the Antarctic waters and compares it with the values obtained from  $^{14}\text{C}$  measurement. It is assumed that the values of chlorophyll and pp vary little over decadal scale. Here we have used the under water profiling radiometer to measure pp to answer two questions a) do the values measured by the profile deviate from the values measured by  $^{14}\text{C}$  technique a decade ago? and b) do these values reflect photo adaptability or photoinhibition due to UV R in Antarctic waters.

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### Material and methods

A profiling underwater radiometer (Biospherical Instruments Inc. San Diego, CA, USA) was used to collect data on natural fluorescence (upwelled radiance at 683 nm, scalar irradiance - PAR (photosynthetically available radiation), diffuse attenuation coefficient (K), computed primary production (pp) in  $\text{ng at C m}^{-3} \text{ sec}^{-1}$  J, UVB and UV A radiation as function of depth from 21st January to 6th March 1994 (15 observations) at an anchored stations in Antarctic waters ( $60^{\circ}53'$  to

73°02'S). The instrument enables to assess the effect of sub-surface transmission of UV radiation.

The whole unit is lowered from the ship board and the data transmitted is displayed and stored in the computer. Certain precautions were taken to avoid contamination of signal by artifacts and biases. At the Antarctic station underwater profiling was timed to avoid adverse climatic conditions. Clear sunny weather was always preferred with no floating ice in the vicinity of the measuring zone. Thus more radiometric measurements were made during January than in the other months. Care was taken to clean the natural fluorescence window each time before use. The sensor was positioned in such a way that it would neither be shaded by parts of the ship nor affected by reflections from the ship's superstructure. The ship's orientation was adjusted in such a way that the optimum combination of wind and sun angle helped to avoid the shadow and to have the wind coming from the direction of the sun. Before deploying the temperature equilibration was carried out by immersing the instrument and letting it rest at the surface. The surface dark values were collected before and after the deployment.

The instrument measures natural fluorescence and computers the primary production from it (Kiefer *et al.*, 1989; Chamberlin, 1989). The measurements are instantaneous and are carried out with ease and rapidity without disturbing the phytoplankton community even in com-

plex environmental conditions. Though the relation between natural fluorescence and photosynthesis is complex there is generally a strong correlation between natural fluorescence and primary production. The above instrumentation is based on this relationship between these two parameters. This relationship is established based on the simultaneous measurements of natural fluorescence and  $^{14}\text{C}$  labeled inorganic carbon assimilation at stations off Tahiti and Morea in the South Pacific Ocean, stations in the N. W. Sargasso Sea and 2 protected bays. These include both short term and long term measurements of photosynthesis and instantaneous and integrated measurements of natural fluorescence (Chamberlain *et al.*, 1990).

In order to correct for the differences in the length and intensity of the day light from the stations in which the measurements were made, the productivity values were normalised by dividing all primary productivity values by the respective values for photosynthetically available radiation (PAR). Though the measurements give instantaneous values that is per second basis the data have been extrapolated to an hourly rate of carbon assimilation. Productivity values have been expressed per hour. Generally pp is calculated upto a depth of 1% penetration of incident radiation. In this study, however, the depth of penetration of incident radiation was lower and ranged from 0.6-10% (av 5.3%) in Antarctic. Average of the downward cast and upward haul have been taken for analyses.

The present study examines the measurement made by the underwater profiler and compares with the primary production estimation carried out in these waters exactly a decade ago i. e. in Jan-Feb 1984 (Pant, 1986). The study assumes that the primary production and chlorophyll values would vary in the same magnitude on a decadal scale for that location of sampling (notwithstanding the small spatial variation).

**Results and discussion**

Table 1 presents the minimum, maximum, mean and standard deviation values of chl, pp and specific productivity in Antarctic waters in Jan, Feb and beginning of March. Figure 1 shows a typical profile taken on the 3rd of February 1994 at the anchored station at Antarctic. The depth of penetration of different wave

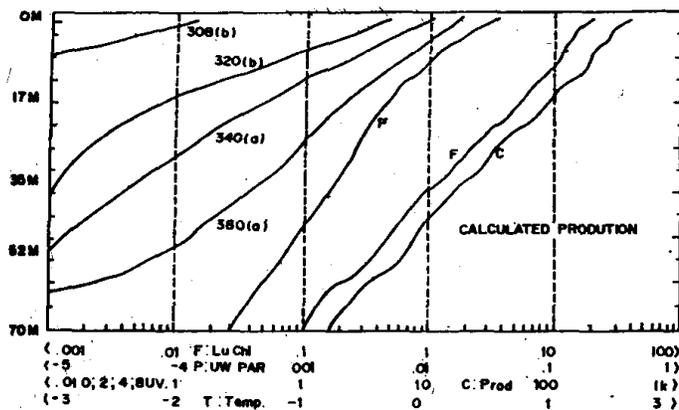


Fig. 1. Typical profile taken on 18th Feb 1994 at Antarctic waters.

- \* Irradiance at 308, 320, 340 & 380 -  $\mu\text{W}/\text{cm}^2/\text{nm}$
- \* PAR (P) -  $\mu\text{E}/\text{cm}^2/\text{sec}$
- \* Lu Chl (F) -  $\text{nE}/\text{m}^2/\text{str}/\text{sec}$
- \* C (Calculated production) -  $\text{natom C}/\text{m}^3/\text{sec}$
- \* T (Temperature) - in  $^{\circ}\text{C}$
- \* X axis (depth) - in meters

lengths is seen with UV B (308 nm) penetrating to 8.5 m and UV A (380 nm) to 62 m. Figure 2 shows the monthly variation in column chl a and computed pp at the Antarctic station. February recorded the maximum with means of  $42.1 \text{ mg m}^{-2}$  and  $155.2 \text{ mgC m}^{-2} \cdot \text{hr}^{-1}$  followed by January with means of  $12.2 \text{ mg. m}^2$  and  $79.8 \text{ mgCm}^{-2} \cdot \text{hr}^{-1}$  respectively. A column productivity  $>200 \text{ mgC m}^{-2} \cdot \text{hr}^{-1}$  was estimated from a profile taken on 28 February 1994. Earlier studies have shown that values for the coastal waters of the ice shelf zone were higher than the off shore waters. Verlencar and Parulekar (1987) have shown that a mean chl a value of  $1.7 \pm 1.0 \text{ mg m}^{-3}$  and pp  $1.3 \pm 1.0 \text{ mgC}$

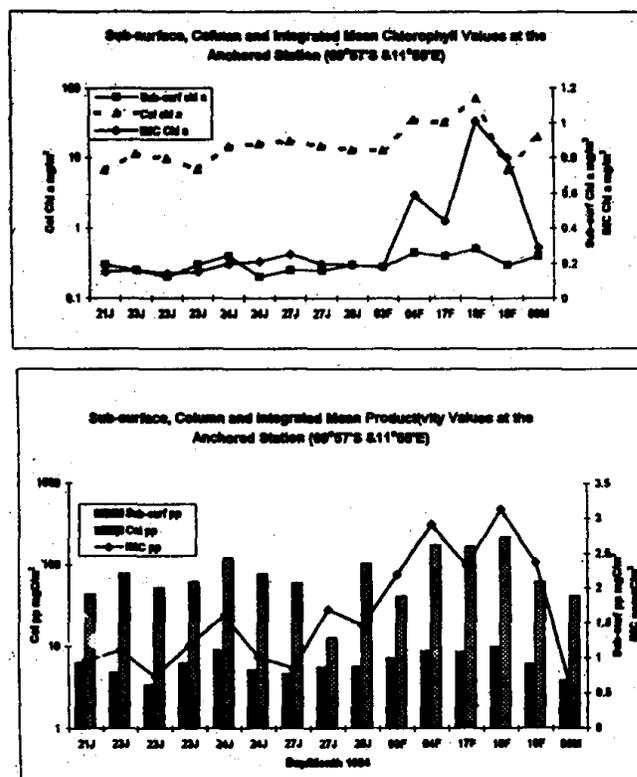


Fig. 2. Monthly variation in sub-surface, column and integrated mean chl a and computed primary productivity values of Antarctic waters.

**Table 2** Reported values of Chlorophyll and primary productivity of Antarctic waters

No	Area	Date	Chla	PP	Depth m	Method	Reference
1	Surface Antarctic waters	Jan 1982	0.28 mg/m <sup>3</sup> (0.05-15)	2.11 mgC/m <sup>3</sup> /d (0.02-9.95)	0	<sup>14</sup> C uptake. Incubation on board for 24 hrs	Matondkar & Qasim, 1983
2	70°S 11°E	Jan 1984	35.45 mg/m <sup>2</sup>	0.95 mg C/m <sup>3</sup> /hr (0.1-1.6)	0	<sup>14</sup> C uptake Incubation at full surface light intensity	Pant. 1986.
3	"	Feb 1984	26.8 mg/m <sup>2</sup>	3.2 mgC/m <sup>3</sup>	5	"	"
4	60-69 °S 12-13° E Coastal	Jan-Feb 1985	1.72±1.0 mg/m <sup>3</sup>	1.27±1.0 mgC/m <sup>3</sup> /hr	0	<sup>14</sup> C uptake. Incubation on board for 24 hrs	Verlencar & Parulekar, 1987
5	60-69 °S 12-13° E offshore	Jan-Feb 1985	0.28 ± 0.1 mg/m <sup>3</sup>	0.31±0.1 mgC/m <sup>3</sup> /hr	0	"	"
6	69-50°S	Jan-Mar 1988	0.07 mg/m <sup>3</sup> (0.02-0.15)	91 mgC/m <sup>2</sup> /d (49-156)	0	<sup>14</sup> C uptake on incubation for 24 hrs	Bhattathiri, 1988
7	70°S 11°E	Jan-Mar 1986	10-90mg/m <sup>2</sup>	50-5000 mgC/m <sup>2</sup>	-	<sup>14</sup> C uptake Incubation on board for 24hrs	Pant, 1988
8	69°S coastal ice edge	Jan-Mar 1990	2.68 mg/m <sup>3</sup> (0.75-6.64)	1.68 mgC/m <sup>3</sup> /hr	0	"	Ram, 1988, 1994
9	69°S Antarctic Ocean Region	Jan-Mar 1990	0.74 mg/m <sup>3</sup>	0.18 mgC/m <sup>3</sup> /hr	0	"	"
10	(69°57'S & 11°55'E	Jan 1994	0.27 mg m <sup>3</sup> (0.2-0.4)	5.55 mgC/m <sup>3</sup> /hr (3.39-8.79)	0	Under water Profiling Radiometer	Present study
11	"	"	12.17 mg/m <sup>2</sup> (6.63 -17.38)	79.82 mg C/m <sup>2</sup> /hr (42.9-126.6)	0-45/75	"	"
12		Feb 1994	0.41 mg/m <sup>3</sup> (0.3-0.5)	7.3 mgC/m <sup>3</sup> /hr (3.82 - 9.8)	0	"	"
13		"	29.69 mg/m <sup>2</sup> (6.75-71)	136 mg C/m <sup>2</sup> /hr (41-219)	0-60/75	"	"

$\text{m}^{-3} \text{hr}^{-1}$  in the ice shelf zone to be more productive than the offshore waters where the corresponding mean values were  $0.28 \pm .1 \text{ mg m}^{-3}$  and  $0.31 \pm 0.01 \text{ mgC m}^{-3} \text{hr}^{-1}$  (Table 2). The mean column chlorophyll *a* content of  $35 \text{ mg m}^{-2}$  at a polynya station at  $70^\circ \text{S}$  and  $11^\circ \text{E}$  in the euphotic zone for the period 1st Jan to 29th Feb 1984 of  $35 \text{ mg m}^{-2}$  is much higher than the offshore value of  $9.6 \text{ mg m}^{-2}$ . In the ice edge a value of  $40 \text{ m}^{-2}$  had been recorded during January (mean chl  $69 \pm 17$ ). Primary productivity values measured with water samples from various depths at full surface intensity showed a high of 1.1 and  $2.3 \text{ GMC m}^{-3} \text{hr}^{-1}$  in January and February at 0 m depth and 2.1 and 3.2 in these months at 5 m depth (Pant 1986). Matondkar and Qasim (1983) have reported primary productivity values ranging from  $0.021\text{-}9.95 \text{ mgC m}^{-3} \text{d}^{-1}$  in the same Antarctic waters. They measured  $\text{CO}_2$  fixation under simulated *in situ* conditions for 24 hr. Primary productivity estimates based on summer nitrate and phosphate deficits over 90 days varying

from 1.96-2.02 &  $0.39\text{-}1.02 \text{ gC m}^{-2} \text{d}^{-1}$  respectively have been reported for McMurdo Sound (Barry, 1988). The values obtained with the underwater radiometer near the ice edge fall close to these values. As the amount of pp in the present study indicated is only upto the depths where there was 0.6-10% of the incident radiation there could be an underestimate in the Antarctic waters as productivity is normally calculated for depths upto 1% of incident radiation.

Analysis of variance (ANOVA) on monthly variation in chl *a* and pp revealed highly significant differences in pp ( $P < 0.001$ ;  $f 17.45 \text{ d.f } 2,12$ ) and in Chl *a* ( $P < 0.01$ ;  $f 7.59 \text{ d.f } 2,12$ ) between January, February and first week of March values.

Depthwise variation in productivity was found significant at 0.1% level ( $p < 0.001 \text{ f } 29.47 \text{ d.f } 6,92$ ). Maximum production was recorded for the 0-10m depth interval (av.  $44.4 \text{ mgC m}^{-2} \text{hr}^{-1}$ ).

Regression analysis of chlorophyll *a* and pp at the sub-surface and in the column

**Table 1.** Sub-Surface, column and integrated mean values of chlorophyll, productivity and specific productivity in Antarctic waters during the present observation

	Sub-surface			Column			Integrated Mean Values		
	Min	Max	Mean SD $\pm$	Min	Max	Mean SD $\pm$	Min	Max	Mean SD $\pm$
Chl	0.2	0.5	0.3 0.1	6.6	71.0	19.2 16.7	0.1	1.0	0.3 0.3
PP	3.4	9.8	6.3 1.9	41	219.2	102.4 58.3	0.6	3.1	1.6 0.8
Specific productivity	9.5	25.4	19.4 3.4	2.1	24.6	6.9 5.4	2.0	12.2	5.9 2.7

with their respective integrated mean concentration indicated significant relationship only between sub-surface chl, pp and their Integrated Mean values ( $r=0.78$   $P < 0.001$ , for Chl & IMC) and  $r = 0.85$ ,  $P < 0.001$ , for pp and IMC). These relationships suggest that 1) production of chlorophyll and primary production are coupled 2) photoadaptability in this strata as compared to subsurface column chlorophyll 3) minimal mixing of waters i.e. stratified condition.

Table 3 presents some of the regression values obtained between the UV light (UV B- 308 and 320 nm; UV A - 340 and 380 nm) and productivity in these waters. Though not significant a positive relationship was observed between pp and PAR, UV A and UV B in sub surface and column (2-40 m) Antarctic waters. However, when the pp values were normalised for

**Table 3.** Relationship between pp, UV A & UV B before and after normalisation with PAR at Antarctic sub-surface and column (2-40 m)

	Sub-surface	
	PP	PP/PAR
UV A (1)	0.542 0.495	-0.347 -0.388
UVB(2)	0.594 0.702	0.175 0.303
PAR	0.321	-
Column (2-40 m)		
UVA(1)	0.170 0.183	0.047 0.063
UVB(2)	0.041 0.147	0.468*
PAR	0.075	-

\*  $P < 0.01$  ; \*\*  $P < 0.001$

1 - 340, 380 nm; 2 - 308, 320 nm

PAR, the relationships between PP/PAR, UV A and UV B were found to be negative at both subsurface and column waters with more negative impact between PP/PAR and UV B in column waters ( $P < 0.01$ ) perhaps indicating that the phytoplankton are not totally adapted to the UV radiation. But they are not totally inhibited, and the negative relationship is not significant. While variability of photosynthesis in the sea could be due to many parameters like biomass, nutrients and water movements, this work presents only the net effect of the above to primary productivity in relation to UV measured by the radiometer. It is now known that environmental UV inhibit the growth of many phytoplankton species (Marchant *et al.*, 1991)

Assuming that the primary productivity and chlorophyll values do not show significant difference on annual scale, statistical analysis (Anova) was done on column chlorophyll and productivity values recorded in the present study and the values measured earlier (Pant, 1986) for the same area to verify whether the values are significantly different or similar. The 'F' value (f 2.3 (pp) and f 3.96 (Chl) d.f. 1, 28) indicate that the difference was not significant even at 5% level perhaps indicating that 1) there might not be difference in these values on decadal time scale and 2) underwater profiles could be used for such measurement in these waters.

This suggests that UV radiometer measurements could be supplementary to actual chlorophyll and pp measurements

in Antarctic waters. However, the observation of high correlation (0.95) between primary productivity and the optical determinants like irradiance, phytoplankton absorption, chlorophyll, quantum yield and *in situ* carbon assimilation by Marra *et al.*, 1993 supports the approach to predict primary production. Nevertheless, simultaneous incubation measurements for estimating primary productivity could further strengthen the approach notwithstanding considerable differences in the intercalibration exercises (Richardson, 1991).

It is inferred that intense UV light tends to reduce chlorophyll synthesis at the surface. Secondly though the UV light gets attenuated at the surface, light penetration is more in these clearer waters. Therefore column pp is higher. It has been pointed out by Bhattathiri, (1988) that in a 24 hour observation in one of the stations in the polynya the surface value of

chlorophyll and productivity was almost equal to the coastal waters of the continent. It was further observed that despite the abundant nutrient and sufficient light energy the population was patchy and the density as low as perhaps the oligotrophic waters. Smith *et al.*, (1992) showed that UVB can be transmitted to a depth of 10m and that biological effects could be detected up to 20-30 m. In our studies the profiles showed that UV B can penetrate up to 35 m and UVA up to 62 m. A column productivity of greater than 200 mgC m<sup>2</sup> hr<sup>-1</sup> has been noticed in this study in the profile taken on 28 February. Primary productivity estimates for Mc Murdo Sound based on summer nitrates and phosphates deficits over 90 days have been reported as 1.96 - 2.02 and 0.39 - 1.02 gC /m<sup>2</sup>/d respectively (Culver and Perry, 1997). Our values fall within this range. However, use of different biological weighting functions like the effect of

	Antarctic	Temperate
1. Contribution to pp from 2-5m column estimate from under water profiler (this study)	25%	22%
2. PP as calculated from <sup>14</sup> C incubation experiments from 0-5m Maximum (Unpublished data, Bhattathiri)	15% (40% in Polynea)	(15%)
3. Net overestimate	10%	7%
4. Underestimate due to calculation of pp upto 3-5% light penetration instead of 1%	-0.1%	0.1%
5. Variance in pp method (Garcia Mendoza & Maske, 1996)	15%	
6. Contribution to above by C. V of pp method	9.2%	
7. Net deviation from <sup>14</sup> C incubation method	1-19 (10 ± 9.2%)	2-16 (7 ± 9.2%)

the action spectrum or even examination photo-inhibition by UV B and photorecovery by UV A *per se* could give varied insight of the influence of UV radiation on column productivity.

Thus underwater radiometer could be used for routine and *in situ* experimental studies to complement or even supplement pp and chlorophyll measurements provided one is aware of its limitations. The signal could get contaminated by detrital chlorophyll such as phaeopigments. Blue green algae give an anomalously high photosynthesis to fluorescence ratio caused by severe nutrient depletion. Only gross photosynthetic rates are measured and the carbon loss due to respiration are not related to fluorescence signal. Also, the instrument could be affected by reflection from shallow bottom or high scattering within the upper few metres (Chamberlin and Marra, 1992) Chamberlin and Marra (1992) state that though a moderately-sized database suggest strong correlation between photosynthesis and natural fluorescence in oceanic and coastal waters there is evidence that light and temperature alter the ratio of their quantum yields. They find a reduction of this ratio as light increases and temperature decreases. Nevertheless, the use of the instrument provides detailed temporal and spatial variation in photosynthesis and hence could be used for making gross photosynthetic measurements routinely.

A comparison of  $^{14}\text{C}$  incubation experiments with estimates from profiling radi-

ometer shows that the net deviation of the latter from the former could range from 1-19%.

The above analyses of the profiles and comparison with the limited data available from previous study of the area clearly indicate that this underwater radiometer could complement or even supplement primary productivity measurements depending upon the sampling area in question. One could also be aware of the margin of deviation that would be obtained as compared to the  $^{14}\text{C}$  method. However, more measurements with the instrument accompanied by simultaneous  $^{14}\text{C}$  uptake measurements could further refine the technique for critical measurements. Damage due to UV A could be greater than that caused by UV B in the Antarctic sub-surface waters. Analysis of an experimental system in which phytoplankton exposed to a broad range of irradiance treatments by Cullen *et al* (1992) predicts that UV A significantly inhibits photosynthesis of a marine diatom and dianoflagellates and the effect of UV B are even more severe. Goes and Devassy (1983) state that diatoms were represented by 27 species belonging to 20 genera and were distinctly the abundant forms near the ice edge. UV A dominates and produces about 40 to 50% inhibition of photosynthesis relative to that under  $\text{E}_{\text{PAR}}$ . This effect is also seen in the surface waters of the temperate region. Though the shorter wave length UV B (280 to 320 nm) is of higher energy and is absorbed faster and could be more damaging, the longer UV A (320 to 400

nm) could be still more deleterious, if not by its energy at least by its extensive reach i.e. its greater flux (Cullen and Neale, 1994). The greater productivity in these waters could be due to higher quantum of light received. However, when this is normalised for PAR, the negative influence of UV is discernible. It is possible that 1) the variation in pp and chlorophyll in this station of study at Antarctica is about the same on a decadal scale and 2) photoadaptability *ie.* photoacclimation and photoinhibition is a fine physiological continuum on a temporal and spatial scale as it appears that the surface dwelling phytoplankton are more photoadaptable than their counterparts in deeper waters as deduced from the relationship with the UV B & UV A.

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