Southern Ocean Optical Drifter Experiment.

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During the austral summer of 1994-1995, and as part of the SANTA CLAµS research cruise (PD94-12; Karl, this volume) of the Palmer LTER project, we deployed two WOCE/OCM (Ocean Color Monitor, METOCEAN Data Systems) drifters, one in the Gerlache Strait (64°11'S, 61°20'W) and the other in the south of the Drake Passage (62°00'S, 62°16'W, Fig. 1A). The aim of these deployments was to monitor temporal variations in the optical properties of water masses, to interpret these variations in terms of phytoplankton biomass changes, and to study the variability of chlorophyll (chl) natural fluorescence when normalized to chl concentrations. Each drifter was equipped with a seven-channel upwelling radiance sensor (412, 443,490, 510, 555, 670, and 683 nm) located just below the sea-surface, a one channel downwelling irradiance sensor (490 nm), and temperature and pressure probes. A drogue, located at 15 m depth, allowed the buoy to drift with the near surface water current. Measurements were made automatically every 90 seconds and relayed via the ARGOS satellite system as hourly average and standard deviation values.

The concentration of chlorophyll plus phaeopigments (chl + phaeo) surrounding the drifters was estimated using the ratio between upwelling radiance at 443 and 555 nm (Gordon et al., 1983). The calibration of this ratio was performed by comparing shipboard measurements of upwelling radiance obtained using a Tethered SpectroRadiometer Buoy (TSRB, Satlantic Inc.), which had the same optical channel characteristics as those of the drifters, to sea-surface concentration of chl + phaeo measured by fluorometry (Strickland and Parsons, 1972). Chlorophyll natural fluorescence was measured at 683 nm and corrected for backscatter by subtracting the upwelling radiance at 670 nm.

Sea-surface chl a concentrations measured during the cruise in conjunction with TSRB deployments ranged from less than 1 $\mu g\ l^{-1}$ to 13.2 $\mu g\ l^{-1}$. Chlorophyll plus phaeopigment values ranged between 0.7 and 15.1 μg l-1 (Fig. 2). The phytoplankton crop was dominated in all sampled stations by cryptophytes. These organisms contain phycoerythrin, a water soluble pigment that absorbs light at 555 nm (O'h Eocha, 1965). For this reason we expected our pigment algorithm to differ from those previously reported for the Southern Ocean (Mitchell and Holm-Hansen, 1991). However, the relationship between chl + phaeo and the upwelling radiance ratio (Lu443/Lu555) using Model II linear regression was found to be:

$$\log_{10}(\text{chl} + \text{phaeo}) = 0.55 + \log_{10}(\text{Lu443/Lu555})^{-1.83}, \quad (r = 0.88, n = 15)$$

with 95% confidence interval of $\pm$ 0.44 for the intercept and $\pm$ 0.50 for the slope. These results are similar to those calculated by Mitchell and Holm-Hansen (1991), suggesting that the presence of phycoerythrin containing organisms in surface waters has a negligible effect in the estimation of chl + phaeo by the standard radiance ratio method.

While the drifter released in the Gerlache Straight ran aground after 3 weeks, the drifter released in the Drake Passage on Christmas Day transmitted data for 18 weeks. During that period, this drifter moved initially northward before becoming trapped in a cyclonic eddy for forty days (between day 8 and day 48, Fig. 1B). Sea-surface temperature measured by this drifter varied between 0.5 and 4°C, with the highest temperature recorded at the time when the drifter was leaving the eddy. The SST increased during the first 30 days following the deployment. However, chl + phaeo concentration appeared to decrease from 1 to 0.7 $\mu g\ l^{-1}$. During the following three weeks a constant increase in pigment concentration was observed while SST remained constant (Fig. 3).

When comparing the SST and chl + phaeo concentration relative to the drifter's position we observe that during the initial days of the drifter in the gyre (days 8 through 27) there was no apparent effect of the cyclonic circulation on SST or pigment concentration. However, following day 27, SST stopped increasing and pigment concentration increased. This change in trends coincided with a shift in the direction of the eddy displacement from northeast to southwest. A small increase in SST was also observed at the time when the drifter started to move away from the eddy. Natural fluorescence normalized to chl + phaeo concentration and downwelling irradiance tended to increase between days 65 and 82 (Fig. 3).

Our result are consistent with divergence occurring within the cyclonic eddy (Pond and Pickard, 1983). The constancy of SST between days 28 and 48 implies a heat balance between upwelling within the gyre and solar heating. If our interpretation is correct, the increase in pigment concentrations during this period was caused by active phytoplankton growth fueled by nutrient input into the sea-surface water from below the euphotic zone. The increase in natural fluorescence normalized to chl + phaeo between days 65 and 82 (Fig. 3) could indicate a change in the phytoplankton assemblage. However, this ratio is a function of species composition, temperature, light history and nutrient availability (Kolber et al., 1990). Furthermore, natural fluorescence is a pathway of deexcitation of chl a when all active centers are closed (Demmig et al., 1987). Hence, the relative increase in natural fluorescence may also reflect phytoplankton nutrient stress once the nutrients injected in the euphotic zone as a result of the upwelling have been depleted.

We thank the officers and crew R/V Polar Duke, as well as J.Christian, D. Jones, T. Houlihan, L. Fujieki, and R. Scharek, for their contribution to the collection of our field data, and B. Barksdale for the retrieval of the drifter data. This research was supported by NASA grants NAS5-31360 and NAGW-2454 to Mark R. Abbott and NSF grant # OPP-9118439 to David M. Karl. SOEST Contribution #0000.

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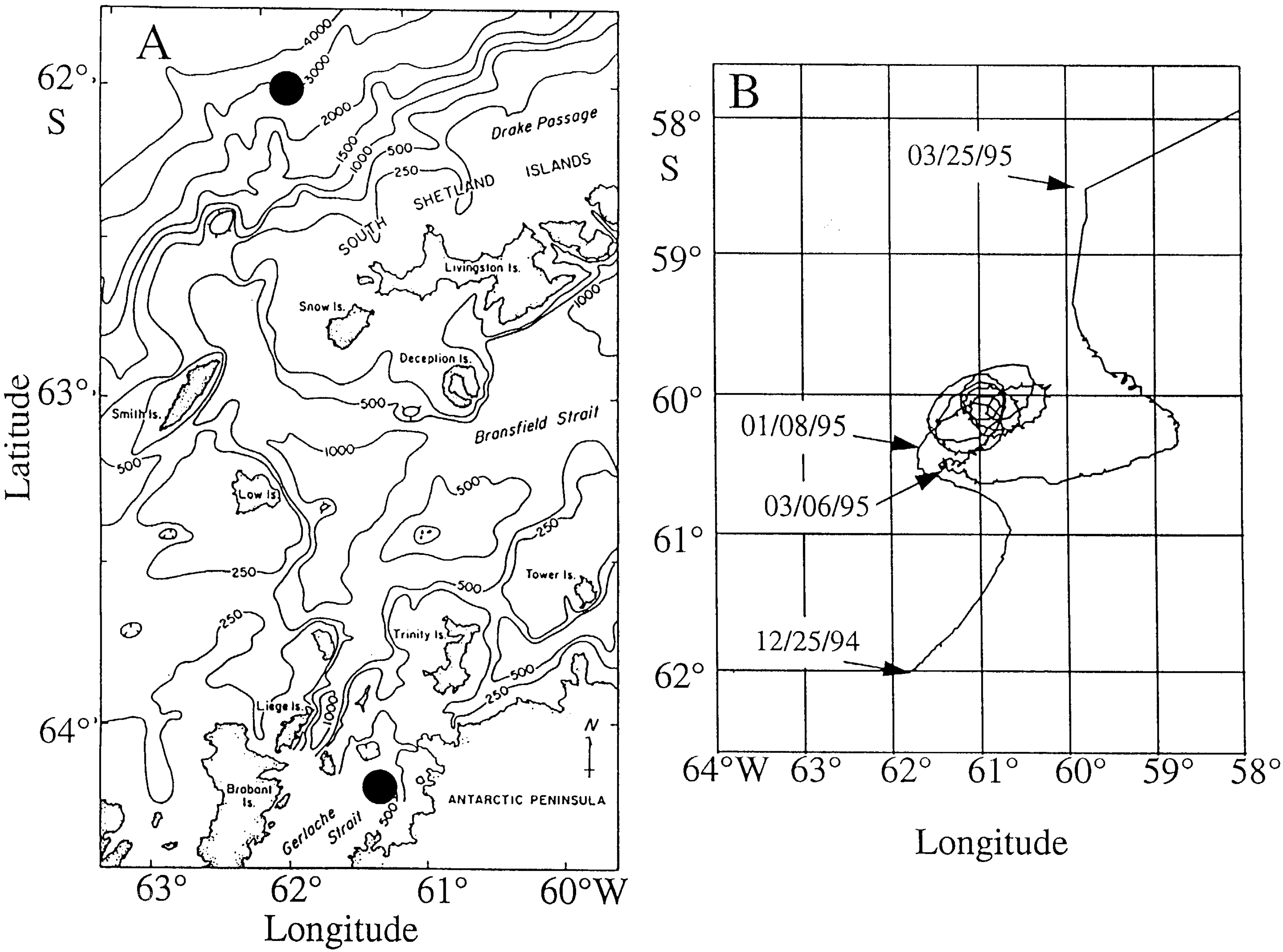
Figure captions:

Figure 1: (A) Position of deployment of WOCE/OCM drifters during PD94-12, and (B) track of WOCE/OCM drifter #22623 in the Drake Passage between 12/25/94 and 03/27/95.

Figure 2: Chlorophyll plus phaeopigment (chl + phaeo) concentrations estimated by fluorometry plotted against chl + phaeo concentrations estimated based on the blue/green ratio of upwelling radiances recorded by the Tethered SpectroRadiometer Buoy (TSRB).

Figure 3: Temporal variability of physical and biological properties derived from the WOCE/OCM drifter #22623 broadcasted data. Upper panel: sea-surface temperature. Center panel: chl + phaeo concentration estimated based on the blue/green ratio of upwelling radiances. Lower panel: Natural fluorescence estimated from upwelling radiance at 683 nm, normalized to chl + phaeo concentration and downwelling irradiance measured at 490 nm.


A
B
Drake Passage
SOUTH SHETLAND ISLANDS
Livingston Is.
Snow Is.
Deception Is.
Smith Is.
Bransfield Strait
Low Is.
Tower Is.
Trinity Is.
Liege Is.
Brabant Is.
Gerlache Strait
ANTARCTIC PENINSULA
4000
3000
2000
1500
1000
500
250
62° S
63°
64°
63°
62°
61°
60°W
Latitude
Longitude
03/25/95
01/08/95
03/06/95
12/25/94
58° S
59°
60°
61°
62°
64°W
63°
62°
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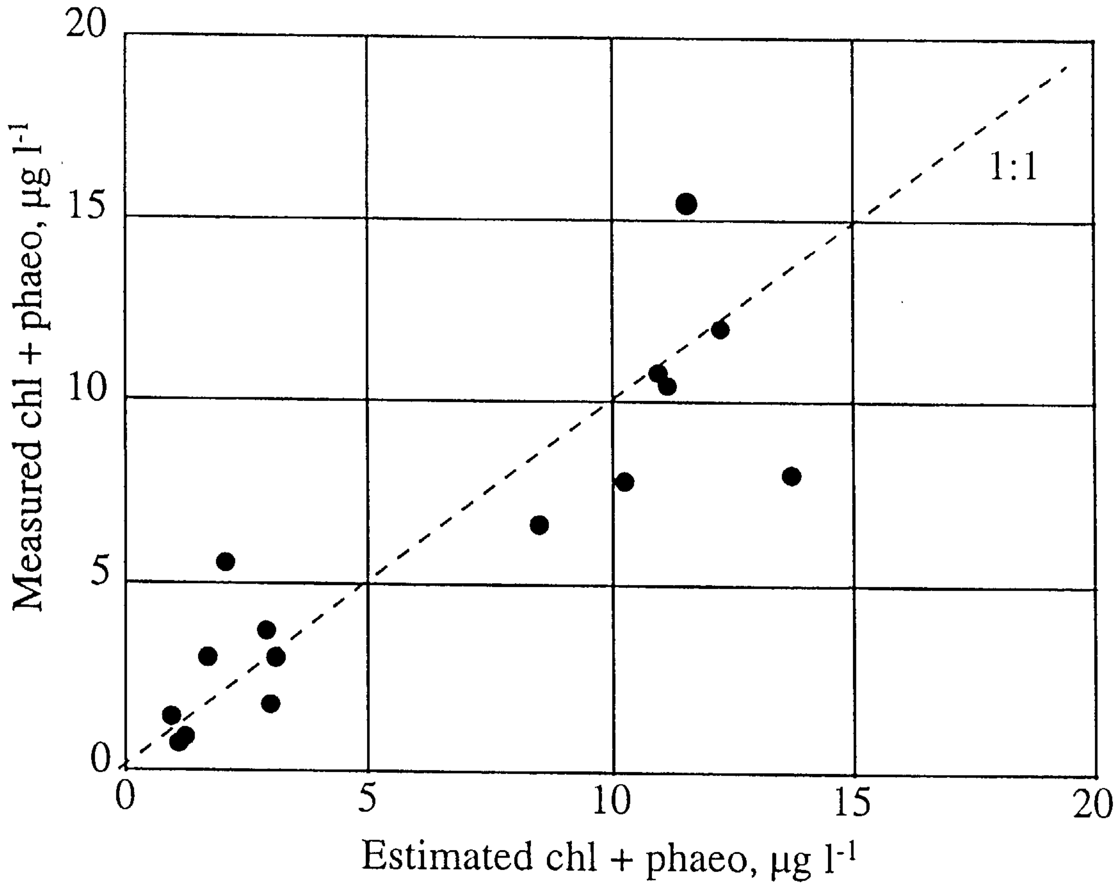
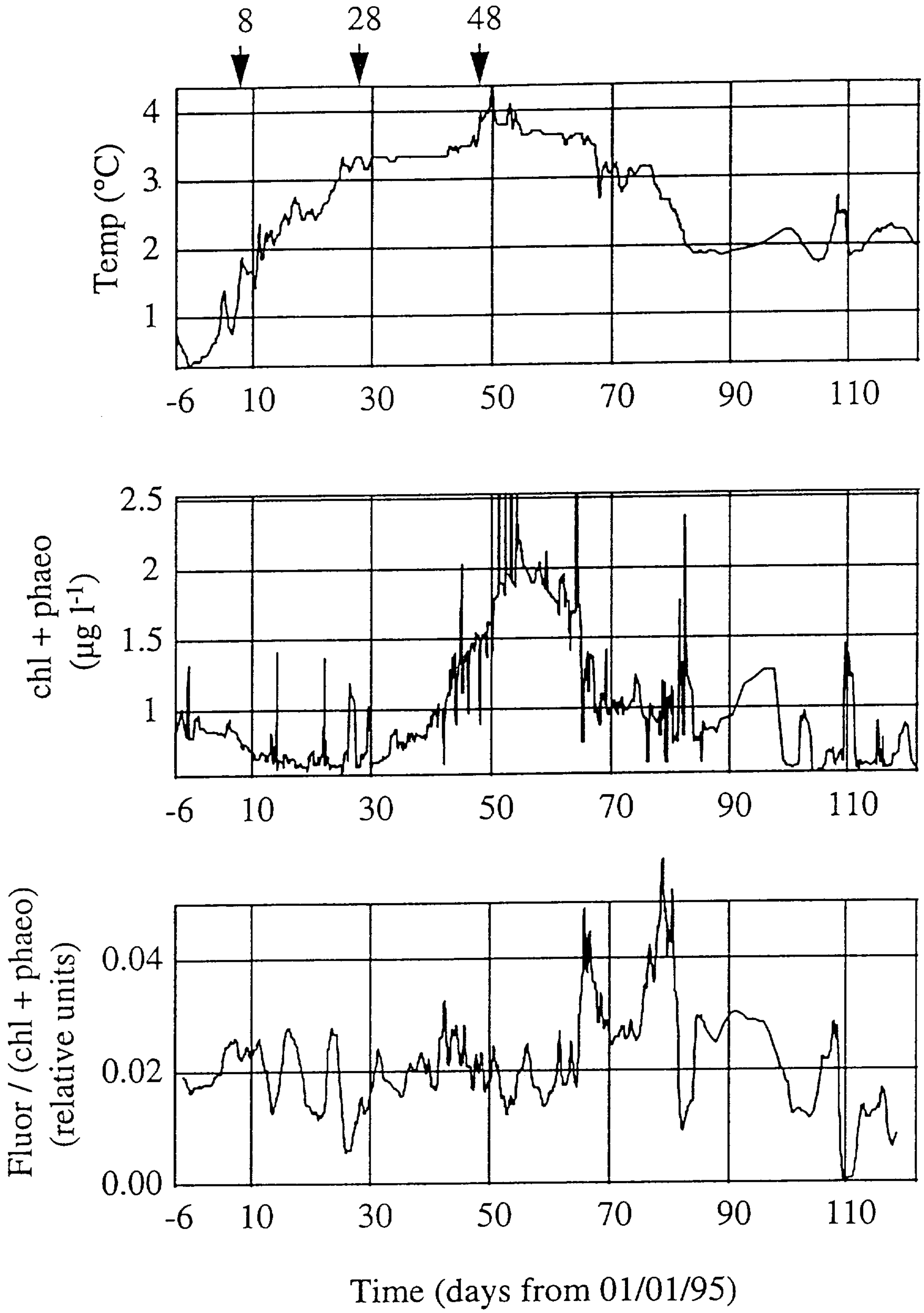
59°
58°
Longitude


20
15
10
5
0
Measured chl + phaeo, μg l-1
1:1
0
5
10
15
20
Estimated chl + phaeo, μg l-1


8
28
48
Temp (°C)
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3
2
1
-6
10
30
50
70
90
110
chl + phaeo
(µg l-1)
2.5
2
1.5
1
Fluor / (chl + phaeo)
(relative units)
0.04
0.02
0.00
Time (days from 01/01/95)