Long term hydrographic conditions and climate trends in Potter Cove*

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* *This work is dedicated to the memory of Augusto "Alfa" Thibaud and Teófilo González, who lost their lives in a glacier crevasse near Jubany during the overwintering in 2005.*

Introduction

A marked warming of mean air temperature has been recorded over the last 50 years in the Western Antarctic Peninsula (WAP) (see Turner et al., 2005 and references therein). This rise in air temperature was mainly observed during the autumn-winter months (Kejna, 2003). In particular, in King George Island (25 de Mayo), South Shetlands air temperature rose on average by 1.1 ^{o}C between 1947 and 1995 (Ferron et al., 2004); if only the winter months are considered, temperature increase in the same period amounts to 1.9 ^{o}C. This trend was also apparent in the air temperature data from the meteorological station in Jubany station for the decade 1994-2004 (Schloss, 2003). Climate warming in Antarctic environments has been associated with glacier retreat and increased ice melting (Cook et al., 2005) which, in turn, change the vertical structure of the water column, especially in Antarctic shallow coastal environments in the WAP. Moreover, glacier runoff has been shown to transport high particle loads, affecting water column light climate and changing the optical conditions for phytoplankton photosynthesis. Light and salinity changes are, therefore, indirect consequences of regional air temperature increase. A direct effect on sea water temperature could also be expected. Although stable sea water temperatures have been recorded around Antarctica for a period of at least 10 million year (Peck, 2005), making it one of the most thermally stable environments on Earth there is already some evidence on surface water temperature warming (Meredith and King, 2005).

Since the beginning of the Argentinean – German cooperation at Jubany Station – Dallmann laboratory, sea water temperature and salinity, as well as chlorophyll-a and suspended particulate matter concentrations have been measured in Potter Cove, in the vicinity of the station. Several projects, using hydrographical data as central or complementary information were carried out. As a result, a 15-years series of data is available, although there are many gaps, especially in the winter months, when difficult weather conditions made sampling impossible. In the present paper, a preliminary analysis of these series is presented and discussed in the face of climatic change (warming) observed in the WAP coastal ecosystems.

Materials and methods

Air temperature data, obtained by the Servicio Meteorológico Nacional from the Argentinean Air Force at Jubany, will be presented in order to compare them with the hydrographic information. Monthly averages were calculated.

Sampling was conducted on a weekly basis during the summer season and two-weekly during the winter in the inner Potter Cove (King George Island, South Shetlands, Antarctica, 62°14'S, 58°38'W), close to Jubany Station. Average depth in the inner cove is around 30 m (maximum depth: 50 m). Water samples (4.7 l Niskin bottles) and CTD data were collected using Zodiac boats over the entire water column. However, in this paper, only surface water data (0, 5, and 10 m) will be considered. All the data were averaged over the upper 10 m of the water column. This depth was chosen based on the depth of the summer pycnocline, which is found at very shallow depths, usually around 10 m (Schloss et al., 2002).

Sea water temperature and salinity: Over the years, several instruments, calibrated to salinity standard and temperature were used to measure temperature and salinity in seawater. They are summarised in Table 1.

Table 1. Sensors and/or methods used for the sea water temperature and salinity data

Year	Temperature	Salinity
1991-1992	Inversion thermometer	Beckman RS9 induction salinometer
1993-1996	ME-ECO219 mini-CTD	ME-ECO219 mini-CTD
1997-2000	CTD - ECO PROBE ISITEC, (General Oceanics)	CTD - ECO PROBE ISITEC, (General Oceanics)
2001	FSI 3" micro CTD model MBP-S.	FSI 3" micro CTD model MBP-S.
2002-2004	Sea-Bird SBE 38 sensor	Sea-Bird SBE 37 sensor
2005	FSI 3" micro CTD model MBP-S.	FSI 3" micro CTD model MBP-S.

Chlorophyll-a. Seawater (0.25 - 2 l) was filtered onto 0.45-mm Millipore (1991-1992) or Whatman GF/F filters (all other seasons). Photosynthetic pigments were extracted in 90% acetone over 24 h at 4°C in the dark . Readings were made with a Hitachi Perkin Elmer UV-VIS 139 spectrophotometer (1991 – 1999) or a Shimadzu RF-1501 (2000-2005) and chlorophyll-*a* (Chl-*a*) concentration was calculated after Strickland and Parsons (1972).

Total suspended particulate matter concentrations. Total suspended particulate matter (TPM) was measured gravimetrically after filtering 0.25 - 2 l seawater through combusted pre-weighed Whatman GF/F filters. After filtration, filters were rinsed twice with distilled water in order to remove salts, then dried for 24 h at 60℃, and weighed again.

Monthly averages for of all the data were calculated. They were then classified into winter (from April to September) and summer (from October to March). Linear regressions and the significance of the correlation with the data were calculated using Statistica (StatSoft) Software.

Results

Average annual air temperature at Jubany Station increased by 1.2° C during the 1991 – 2005 period. The augmentation calculated for the winter months only amounted to 1.66° C, whereas air temperature rose by 0.4° C if only the summer months are considered (figure 1). The slopes for the linear regressions corresponding to the whole data set (not shown) as well as for the summer and winter months separately are presented in Table 2.

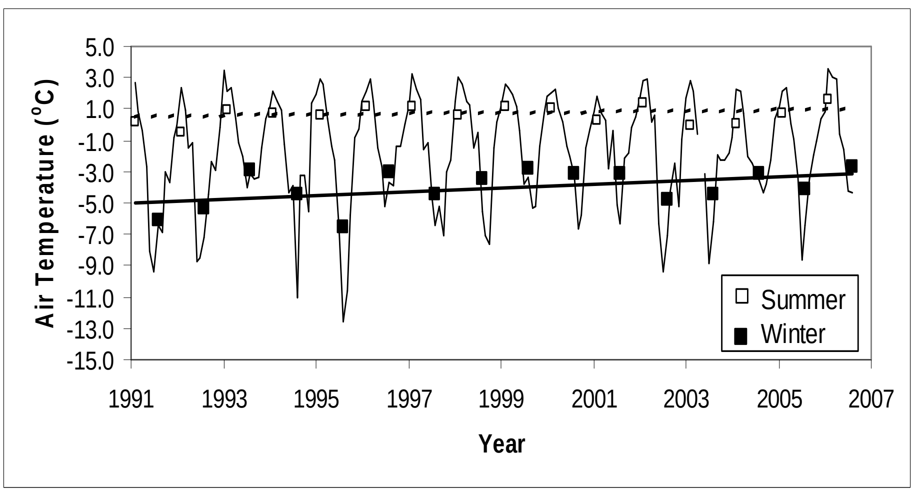

Figure 1: Monthly air temperature means, at Jubany Station (King-George Island), measured by the Servicio Meteorológico Nacional of the Argentinean Air Force. The lines show the linear regressions for summer (dashed) and winter data (solid), respectively. Slopes for the regression lines are presented in Table 2.

A significant increase was observed in sea water temperature within both seasons (figure 2). In spite of many gaps in the series, especially in the winter data from the years 2001 to 2005, water temperature increase was significant in winter data from April and June (Slope: 0.08, for April and 0.10 for June, $R = 0.76$ and $R = 0.89$, respectively, $p < 0.05$).

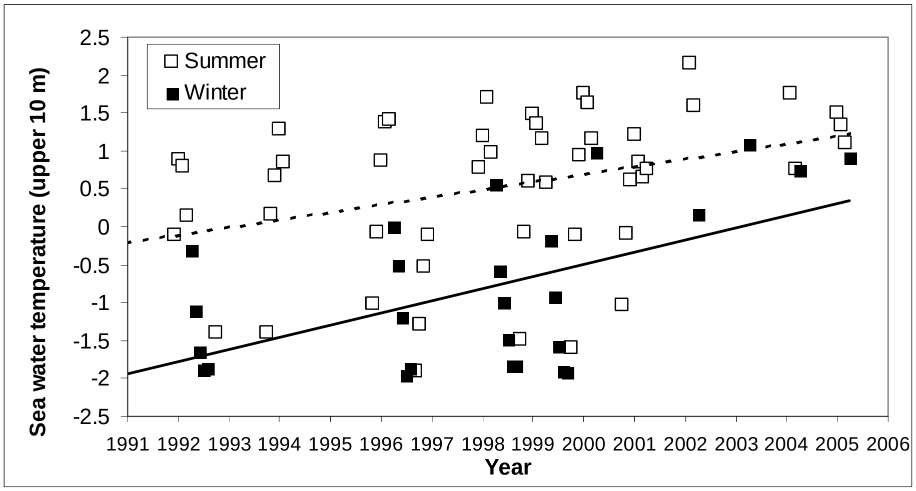

Figure 2: Monthly sea water temperature in the inner Potter Cove (averaged over the upper 10 m). The lines show the linear regressions for summer (dashed) data and winter (solid), respectively. Slopes for the regression lines are presented in Table 2.

Average annual surface water salinity in the upper 10 m water column (figure 3) decreased significantly ($R = 0.26$; $p < 0.05$) over the years, although this was not significant for the summer and winter data, if separately analyzed ($p = 0.20$ for winter and $p = 0.13$ for summer data). A significant negative decrease was found for the months of July ($R = 0.88$; $p < 0.05$) over the years, whereas not enough data were available for May, June and September.

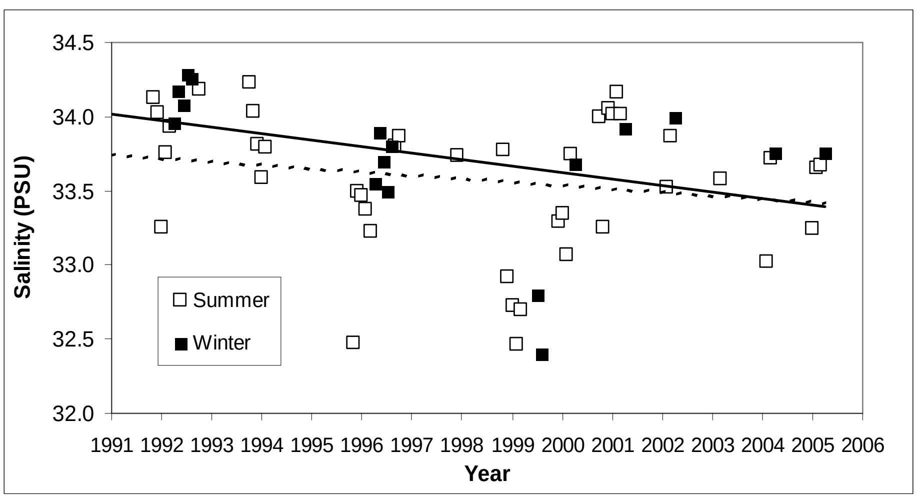

Figure 3: Monthly salinity data in the inner Potter Cove (averaged over the upper 10 m). The lines show the linear regressions for summer (dashed) data and winter (solid), respectively. Slopes for the regression lines are presented in Table 2.

No significant change of water column Chl-*a* concentrations was observed for any single month throughout the studied years (figure 4). However, a significant decrease became evident within the winter values (solid line, in figure 4, $R = 0.46$; $p < 0.05$; see slopes in Table 2). Monthly averages were consistently low (< 2 mg m^{-3}), with the maximum values corresponding to either November or late March.

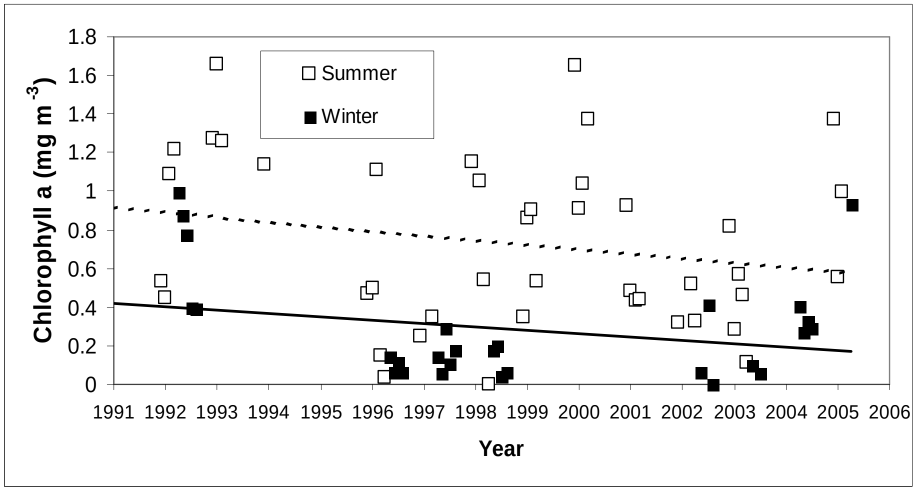

Figure 4: Monthly chlorophyll-*a* concentrations in the inner Potter Cove (averaged over the upper 10 m). The lines show the linear regressions for summer (dashed) data and winter (solid), respectively. Slopes for the regression lines are presented in Table 2.

The concentrations of TPM (figure 5) showed a significant increase over the years ($R = 0.29$; $p < 0.05$). Whereas there was no change during the summer months ($p = 0.12$), a significant increase was found in winter (dashed line in figure 5; $R = 0.46$; $p < 0.05$). Slopes are presented in Table 2.

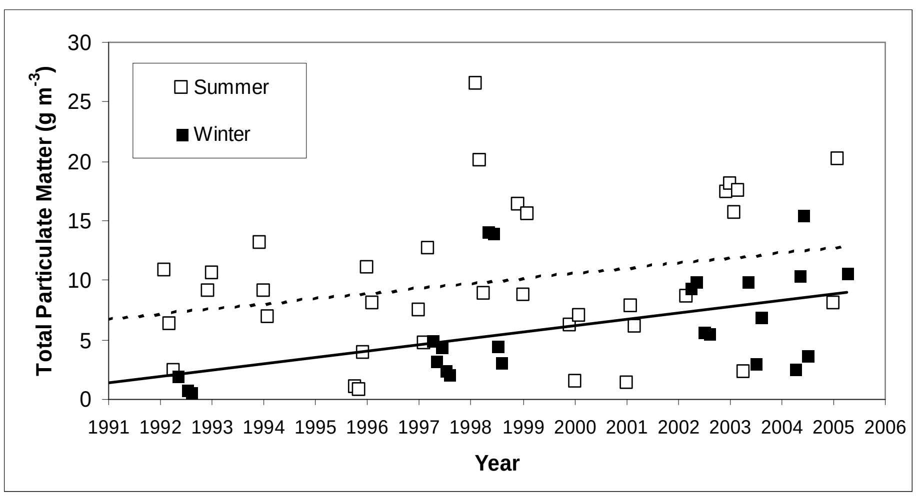

Figure 5: Monthly average total particulate matter concentrations in the inner Potter Cove (upper 10 m). The lines show the linear regressions for summer (dashed) data and winter (solid), respectively. Slopes for the regression lines are presented in Table 2.

For the complete data set, there is a significant inverse correlation between salinity and the amount of particles in the water column ($R = 0.5$; $p < 0.01$) and a significant positive correlation between particles and sea water temperature ($R = 0.49$; $p < 0.01$). Also, we found a significant correlation between temperature and salinity for the complete data set ($R = 0.25$; $p < 0.05$), within the summer ($R = 0.35$; $p < 0.05$) but not in winter months ($p = 0.62$), indicating that warm, fresh water with high particle load is entering the cove. This is probably melt water from land ice masses which is flowing over the ice free areas into the cove, whereby warming up.

Chl-*a* was positively and significantly correlated with water temperature ($R = 0.42$; $p < 0.01$), but not with salinity ($p = 0.55$). Finally, no significant correlation was found between Chl-*a* content and TPM concentration ($p = 0.06$).

Discussion

Both, air and surface sea water temperature in Potter Cove (King George Island) increased significantly over the past 15 years. Although for the water column the time series is not complete, the records of monthly means from April and June suggest an effect of climate warming on sea water temperature in the WAP coastal environment.

Decreasing salinity was mainly observed in spring: October and November series showed lower salinity values at the end of the 1990's than in the beginning, indicating the melting process to start earlier in the spring season in the last years. This trend was not observed during either December or January, summer months in which melt waters occur on a regular basis. Although the series is not complete, very low surface salinity values (around 32 PSU) have been recorded in August, especially in 1999 (the end of the warmest decade of the last millennium, IPCC, 2001), a month typically characterised by the largest monthly sea ice cover and low air temperatures in the South Shetlands region (Ferron et al., 2004). Cold temperatures would prevent glaciers from melting. If the observed trend continues, the addition of melt water starting earlier in the season could have important effects on water column stabilization and, consequently, affect phytoplankton dynamics. This could have induced changes in species composition. Moline et al. (2004) found that salinity favoured the dominance of Cryptomonads in the phytoplankton community, a finding which is still under debate (Garibotti et al., 2005). The effects of salinity on phytoplankton and thereby on the whole Potter Cove food web are therefore subject to future studies.

TPM and Chl-*a* are negatively correlated in the area during the spring-summer season (Schloss et al., 2002). This was mainly due to the optical effect of particles in the water column, which limited light needed for photosynthesis. A high particle load in an environment as shallow as Potter Cove could be also indicative of re-suspension processes, which further contribute to light limitation of pelagic and benthic primary production. These processes respond to the observed heavy wind driven water column mixing (Schloss et al., 2002). In the long term, the lack of a consistent inverse correlation between TPM and Chl-*a* could be due to the low values of both variables that characterise the early winter situation, when glacier melting has ceased and photosynthesis is constrained by the reduced winter light climate.

The observed positive correlation between Chl-*a* and temperature could be an artifact, related to the higher summer irradiances that are accompanied by higher sea water temperatures. No phytoplankton increase was observed along the studied years. However, in the long term an increase in water temperature could be beneficial for phytoplankton photosynthesis. Although photochemical reactions are not directly related to temperature (Jacques, 1983), biochemical reactions are (Cloern, 1979), and could benefit from temperatures somewhat higher than those of the polar environments, as shown among others by Smayda (1969) for Arctic diatom species. More studies are needed in order to understand the effect of water temperature increase on phytoplankton. For instance, for benthic diatom species it has been shown that tolerance varies among species (Longhi et al., 2003). Although correlations were not significant, our results show a negative trend along the studied years with regards to phytoplankton biomass (as Chl *a*; figure 4), indicating that environmental conditions were negatively affecting phytoplankton growth. Here we hypothesise that the earlier water column stabilization might be uncoupled with the adequate light environment, which would lead conditions for phytoplankton growth to become unfavourable.

Table 2: Slopes of the linear regressions for the different parameters analysed, considering the whole data set and Winter and Summer seasons separately. Significance is indicated: *: p <0.05; **: p < 0.01; N.S: not significant.

Variable	**Slope**	**p**
Air Temperature	0.02	N.S
Winter	0.13	**
Summer	0.06	N.S
Sea water Temperature	0.13	**
Winter	0.16	**
Summer	0.1	*
Salinity	-0.03	**
Winter	-0.04	N.S
Summer	-0.02	0.20
Chlorophyll-a	-0.02	N.S
Winter	-0.03	*
Summer	-0.02	N.S
TPM	0.45	*
Winter	0.51	*
Summer	0.43	N.S

The amount of particulate matter in the water column has augmented during the studied period (figure 5). If this is a consequence of increased glacial melting which is accompanied by the entrance of land-originated particles early in the spring summer season, light could be critically limiting photosynthesis. This will certainly affect not only shallow coastal environments like Potter Cove, but other coastal environments in the WAP, where warming is most evident (Turner et al., 2005). The balance between the physiologically better temperature and worse irradiance conditions will finally determine the impact of global change processes on phytoplankton in shallow coastal Antarctic areas.

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