Palmer Long-Term Ecological Research

Palmer Long-Term Ecological Research (LTER): Annual January cruise for 1996 (*PD*96-1)

MARIA VERNET *and* KAREN S. BAKER, *Marine Research Division, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, California 92122*

The Palmer Long-Term Ecological Research (LTER) annual cruises make physical and biological measurements west of the Antarctic Peninsula (Ross, Hofmann, and Quetin in press). Sampling on *PD*96-1 from 8 January to 10 February 1996 aboard the R/V *Polar Duke* included cardinal transect lines, inshore stations, and periodic visits to the nearshore Palmer grid to provide temporal continuity to the Palmer Station season sampling effort (figure 1). Standard measurements included optics; hydrography; microbial parameters; plant pigments; primary production; plant physiology; acoustic surveys; net tows for zooplankton, krill, and fish; and krill physiological condition (figure 2).

In addition, higher density observations within the foraging area of Palmer Adélie penguins link this apex predator to the environment during critical periods of its life history. Surveys of seabird abundances (figure 3) were continued using picket line (PL) transects, high-density grids (HD), and observations from zodiacs. Also, a day was spent recording Adélie penguins arriving and departing from Torgersen Island. A continuous underway carbon dioxide equilibrator system mapped variations in the air-to-sea gradients in carbon dioxide partial pressure. Two 1-day experiments were

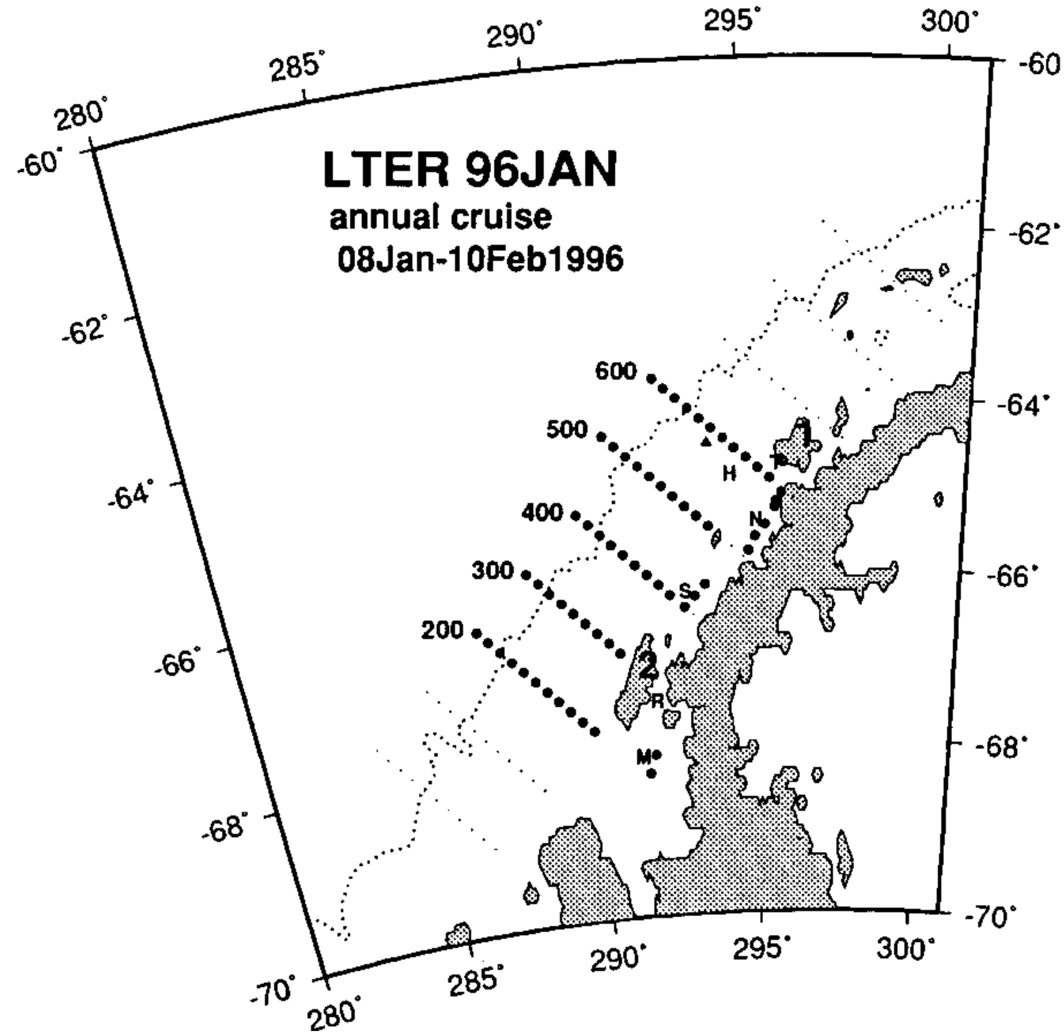
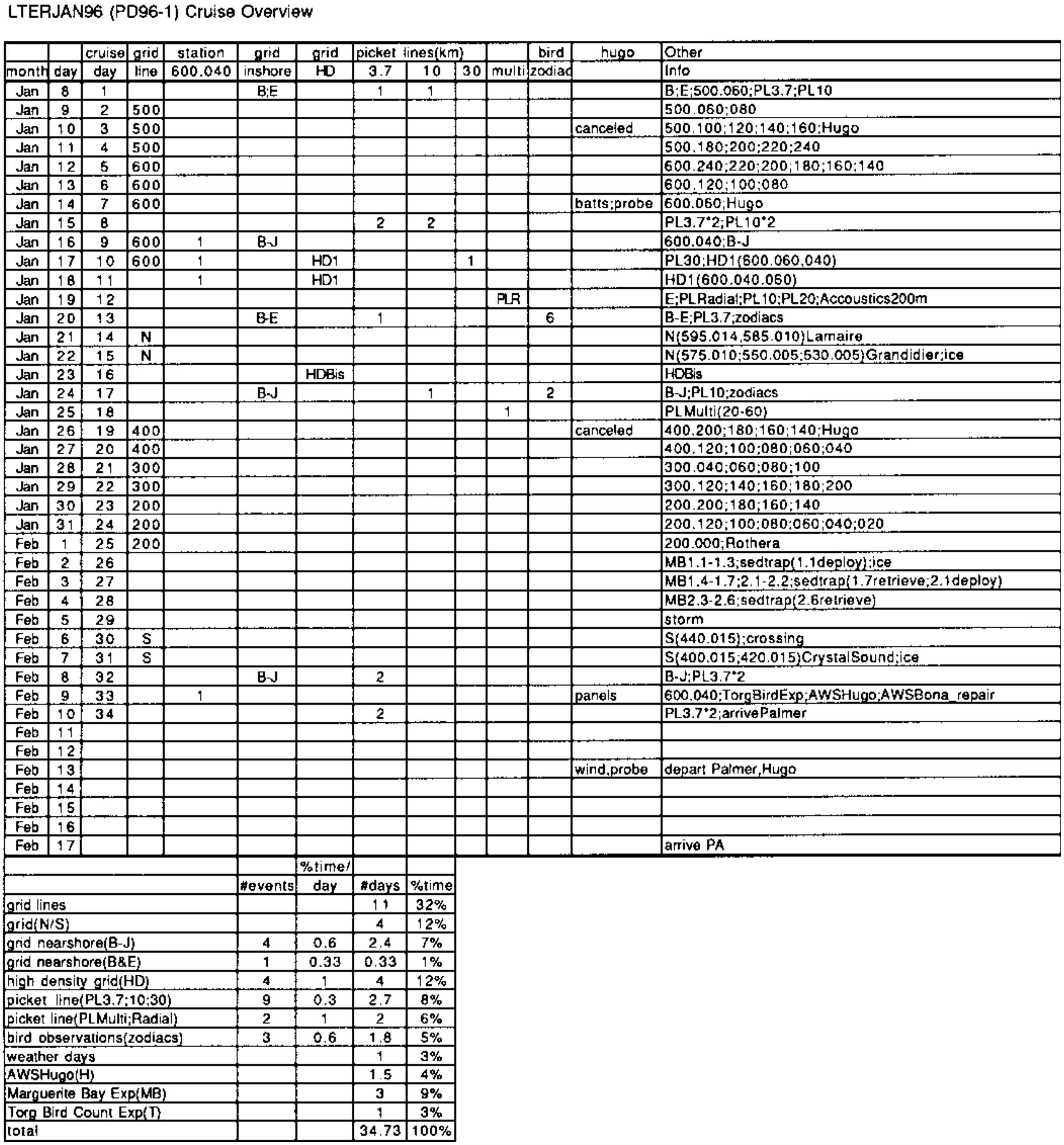


Figure 1. The cardinal stations of the Palmer LTER regional grid (dots) off the Antarctic Peninsula are overlaid with large dots to indicate stations occupied during *PD*96-1. Labeled are Anvers Island (1), Adelaide Island (2), Torgersen Island (T), Palmer Station (o), Rothera Station (R), Hugo automatic weather station (H; 64°57'S 65°41'W), northern stations (N), southern stations (S), and Marguerite Bay (M). The Hugo area sediment-trap site is marked with a filled triangle. The 1,000-meter bathymetry line (dotted) is shown.

conducted to investigate particle flux in ice-covered regions in Marguerite Bay. Stations north (N, figure 1) (Biscoe-Renaud/Lemaire/Grandidier) and south (S, figure 1) (Biscoe-Levoisier/Crystal Sound) inshore of the coastal islands are ice covered in some years, are often highly productive, and are considered nursery grounds for larval fish and antarctic krill.

High-density sampling (Quetin et al. 1995) along with coincidental measurements of terrestrial sampling on Adélie penguin foraging durations were collected. Over time, this sampling has been modified based on results from previous cruises. Originally a 70-kilometer (km) × 70-km grid near Palmer was sampled twice in January 1993. A smaller 50-km × 50-km grid



LTERJAN96 (PD96-1) Cruise Overview

		cruise	grid	station	grid	grid	picket lines(km)				bird	hugo	Other
month	day	day	line	600.040	inshore	HD	3.7	10	30	multi	zodiac		Info
Jan	8	1			B;E		1	1					B;E;500.060;PL3.7;PL10
Jan	9	2	500										500.060;080
Jan	10	3	500									canceled	500.100;120;140;160;Hugo
Jan	11	4	500										500.180;200;220;240
Jan	12	5	600										600.240;220;200;180;160;140
Jan	13	6	600										600.120;100;080
Jan	14	7	600									batts;probe	600.060;Hugo
Jan	15	8					2	2					PL3.7*2;PL10*2
Jan	16	9	600	1	B-J								600.040;B-J
Jan	17	10	600	1		HD1			1				PL30;HD1(600.060,040)
Jan	18	11		1		HD1							HD1(600.040.060)
Jan	19	12								PLR			E;PLRadial;PL10;PL20;Accoustics200m
Jan	20	13			B-E		1				6		B-E;PL3.7;zodiacs
Jan	21	14	N										N(595.014,585.010)Lamaire
Jan	22	15	N										N(575.010;550.005;530.005)Grandidier;ice
Jan	23	16				HDBis							HDBis
Jan	24	17			B-J			1			2		B-J;PL10;zodiacs
Jan	25	18								1			PLMulti(20-60)
Jan	26	19	400									canceled	400.200;180;160;140;Hugo
Jan	27	20	400										400.120;100;080;060;040
Jan	28	21	300										300.040;060;080;100
Jan	29	22	300										300.120;140;160;180;200
Jan	30	23	200										200.200;180;160;140
Jan	31	24	200										200.120;100;080;060;040;020
Feb	1	25	200										200.000;Rothera
Feb	2	26											MB1.1-1.3;sedtrap(1.1deploy);ice
Feb	3	27											MB1.4-1.7;2.1-2.2;sedtrap(1.7retrieve;2.1deploy)
Feb	4	28											MB2.3-2.6;sedtrap(2.6retrieve)
Feb	5	29											storm
Feb	6	30	S										S(440.015);crossing
Feb	7	31	S										S(400.015;420.015)CrystalSound;ice
Feb	8	32			B-J		2						B-J;PL3.7*2
Feb	9	33		1								panels	600.040;TorgBirdExp;AWSHugo;AWSBona_repair
Feb	10	34					2						PL3.7*2;arrivePalmer
Feb	11												
Feb	12												
Feb	13											wind,probe	depart Palmer,Hugo
Feb	14												
Feb	15												
Feb	16												
Feb	17												arrive PA

		%time/		
	#events	day	#days	%time
grid lines			11	32%
grid(N/S)			4	12%
grid nearshore(B-J)	4	0.6	2.4	7%
grid nearshore(B&E)	1	0.33	0.33	1%
high density grid(HD)	4	1	4	12%
picket line(PL3.7;10;30)	9	0.3	2.7	8%
picket line(PLMulti;Radial)	2	1	2	6%
bird observations(zodiacs)	3	0.6	1.8	5%
weather days			1	3%
AWSHugo(H)			1.5	4%
Marguerite Bay Exp(MB)			3	9%
Torg Bird Count Exp(T)			1	3%
total			34.73	100%

Figure 2. LTER January 1996 (*PD*96-1) cruise overview. Daily events summarized including LTER gridlines, LTER nearshore stations, high-density grid (HD), picket lines (PL), zodiac operations, and automatic weather station. Event time use during cruise is summarized at the bottom of the table.

within the previous 70-km grid was sampled once in January 1994. Based on these results, a 10-km × 20-km grid (HD1) within the 50-km × 50-km area was sampled three times in January 1995 and twice in January 1996. During January 1996, the Bismarck Strait was sampled (HDB; figure 3) in addition to acoustic transects on the south side of the Bismarck Strait and along the 200-km contour to the east of the Palmer Basin.

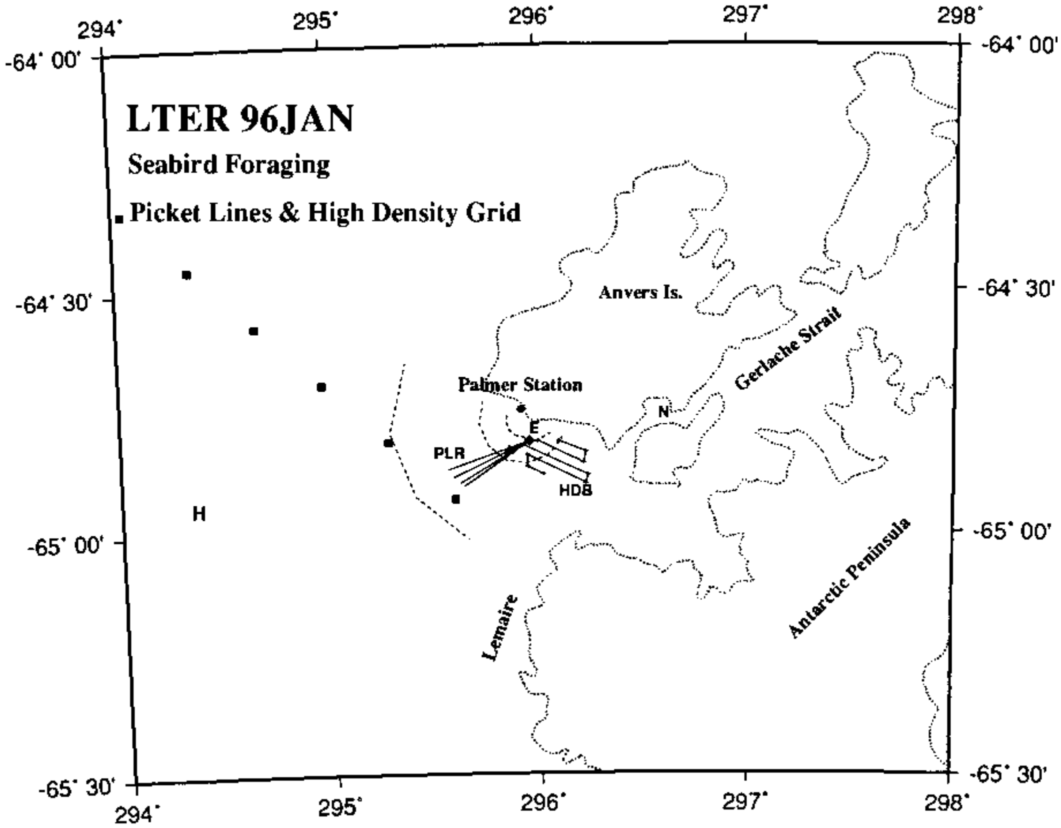


Figure 3. Sampling area near Palmer Station on Anvers Island with the Neumeyer (N) and Gerlache Strait to the east. The Hugo automatic weather station (H) location is given. The Palmer basin sediment-trap site is marked with a filled triangle. Shown are the 3.7-km, 10-km, and 30-km picket lines (dashed lines), the radial picket line sampling (PLR) grid originating at station E (triangle), and the Bismark high-density grid (HDB). The LTER regional grid 600 line stations 040, 060, 080, 100, and 120 are marked (filled squares).

Picket line seabird censuses, adopted during *PD*95-1 (Smith et al. 1995), indicated again foraging range of Adélie penguins to be within 50 km of Palmer Station. Acoustic biomass measurements were added to the last four 3.7-km picket line surveys to quantify the temporal link between the location of penguins and acoustic (primarily krill) biomass. A new radial picket line (PLR; figure 3) was initiated to determine whether counting penguins in the direction of travel affected a survey. The direction of travel from island breeding sites was determined using penguin tracking from zodiacs.

In addition, the Hugo automatic weather station was serviced. High seas prevented small boat landings on later visits to repair the water-temperature probe. A visit to the British Antarctic Survey Station at Rothera permitted discussion of a British nearshore sampling program scheduled to begin in 1996–1997. Annual servicing of the two LTER program sediment-trap moorings (Hugo Island and Palmer Basin) was conducted on *PD*95-10 the preceeding December.

Ice-free open water was observed during most of the cruise. Ice was encountered in the southern part of Grandidier Strait (inshore North), in the southern part of Crystal Sound (inshore South), and in the southern part of Marguerite Bay. Bad weather days were used to sample nearshore, so only 1 day (5 February) was lost because of stormy weather.

The highest concentration of feeding penguins was found farther from Torgersen Island as January progressed, varying from within 3.7 km on 9 January, to within 10 km on 16 January, and to within 30 km on 25 January. Acoustic biomass was observed with higher concentrations nearshore, along the 200-meter contour line, and in Palmer Basin. During January, the pattern of krill aggregations changed from layers to more defined swarms. Phytoplankton biomass was higher than in the three previous January cruises with a strong north-south component and large biomass accumulation in Palmer Basin and Marguerite Bay. A large diatom bloom near Palmer Station extended to 600.080 and the Lemaire Channel.

Thanks are given to the Palmer LTER research team members, the Antarctic Support Associates, as well as the captain and crew of the R/V *Polar Duke*. This research was supported by National Science Foundation grant OPP 90-11927 and is Palmer LTER contribution number 106.

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Palmer LTER: Annual season October 1995 through March 1996

KAREN S. BAKER, WENDY A. KOZLOWSKI, *and* MARIA VERNET, *Marine Research Division, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, California 92093*
JANICE L. JONES, LANGDON B. QUETIN, ROBIN M. ROSS, *and* RAYMOND C. SMITH, *Institute for Computational Earth System Science* and *Marine Science Institute, University of California, Santa Barbara, California 93106*
WILLIAM R. FRASER, *Polar Oceans Research Group, Biology Department, Montana State University, Bozeman, Montana 59717*

In March 1996, the Palmer Long-Term Ecological Research (LTER) Program (Smith et al. 1995) completed a fifth season of sampling at Palmer Station. The Palmer LTER sampling strategy combines seasonal time series data from the nearshore Palmer grid and seabird observations from nesting sites near Palmer Station with annual cruises covering a regional grid along the western Antarctic Peninsula. The LTER January cruise aboard the *Polar Duke* (*PD*96-01) visited the inshore stations five times to provide continuity in the seasonal record (Vernet and Baker, *Antarctic Journal*, in this issue).

A summary of events for the 1995–1996 Palmer field season is given in figure 1. Significant dates include arrival of research teams at Palmer (7 October 1995), first bird observations (10 October 1995), first chlorophyll sample (16 November 1995), first zodiac profiling cast and acoustic transect (16 November 1995), the cruise beginning (8 January 1995), the cruise ending (10 February 1996), last profiling cast and acoustic transect (19 March 1995), departure of water-column research teams from Palmer (26 March 1996), and last bird observation (27 March 1996). In figure 1, each line summarizes one cycle of standard sampling (*see* the table in Smith et al., *Antarctic Journal*, in this issue) consisting of approximately 7 days where the initial event number, month the event began, day it began, day, and year are given in the first five columns. The sixth column summarizes the types of standard days included in this particular cycle. A summary of the 13 scuba dives to obtain krill samples for laboratory experiments, acoustic transects, hydrographic and optical profiling, phytoplankton sampling, targeted krill tows for physiological condition and instantaneous growth rate experiments, and zooplankton trawls are given in the next columns followed by general comments.

We made some changes from past seasons in the sampling program. For example, an equipment upgrade permitted us to run instruments, winch, and computers on the zodiacs on batteries rather than on a gasoline generator. Batteries have proven to be a more reliable, stable, cleaner, and quieter power source than the generator. In addition, chlorophyll

Event No.	Mo	Day		Yr	Std. Day	dive	bio-ac	ctd/prr chl/sal	par hplc nuts poc	pico net Ppi	tep Psis	Pc/ chl	krilltarg	phyconl	igr	trwl	comments
		Beg	End														
1	10	7	7	95	arrive												ARRIVE PALMER
2	10	8	31	95	ice	1-3											
26	11	1	15	95	ice			TEST									
76	11	16	19	95	1	4-7		E-B	x	x	x			DK5;DK	DK		
135	11	20	27	95	1245		x	x	x	x	x			I	I	I	brash pushed E. of Stat
270	11	28	4	95	12345	8-13	x	x;600	x;600	x	x		GH	GH/HUGO		x	near B; brash ice & wind
411	12	5	10	95	123455		x	x	x	x	x	B	JI;IH;IJ			x	brash ice edge
503	12	11	16	95	11234		x	x	x	x	x	B	B	B	B		krill at transect end;wind&rain
613	12	17	25	95	ice												iced in Arthur Harbor
637	12	26	1	95	13425		x	x	x	x	x	B	2*AH				ice moved to .8nm from D;ice out
768	1	2	7	96	1325		x	x	x	x	x	B	AH	AH	2*AH	x	
	1	8	14	96	cruise												CRUISE: lterjan96: PD96-01
844	2	15	20	96	43		x	E	x	x	x		3*LIM	LIM	LIM		targ=no catch
914	2	21	25	96	123		x	x	x	x	x		D				batteries died
1015	2	26	4	96	1223455		x	x	x	x	x		2*SPUME			x	
1110	3	5	10	96	123		x	x	x	x	x	B	IJ;3*I	I	I		targ=no&small catch; hit bottom
1230	3	11	17	96	12345		x	x	x	x	x	B	B;TOR			x	larval fish targ=no catch
1362	3	18	21	96	1323		x	x	x	x	x		3*B;4*HI	B;HI	HI		
1433	3	22	26	96	depart									HI			DEPART PALMER

Figure 1. Palmer LTER 1995–1996 season event log overview by sampling week (*see* the table in Smith et al., *Antarctic Journal,* this issue, for definition of standard sampling week). Events include acoustics (bio-ac, Biosonics 120 kilohertz), discrete sample for chlorophyll analysis (chl), conductivity-temperature-depth (ctd, Seabird), scuba krill collection (dive), high-performance liquid chromotography of phytoplankton pigments (hplc), instantaneous growth rate (igr), targeted tow for krill (krilltarg, 50 kilohertz), microscopic analysis of net plankton (net, >5μm), inorganic nutrient analysis (nuts), photosynthetically active radiation (par), physiological condition of larvae (phyconl), microscopic analysis of picoplankton (pico, 0.5–5.0μm), particulate organic carbon (poc), production photosynthesis vs irradiance (Ppi), primary production simulated-*in-situ* (Psis), profiling radiometer (prr, BSI), discrete sample for salinity analysis (sal), transparent exopolymer particles (tep), and standard zooplankton tows (trwl).

samples, routinely run using HA 0.45-micron (µm) filters, were also run separately for the fraction of phytoplankton less than 20 µm at selected depths.

This season included service to the Hugo automatic weather station. Although visits were made during the LTER annual January cruise, a later return attempt was made on 23 March to correct a temperature probe failure but high swells prevented landing.

The season was preceded by a heavy ice winter as was also true of the first Palmer LTER season 1991–1992 when Arthur Harbor did not clear of pack ice until early December (Ross and Quetin 1992). During the 1995–1996 season, the timing of the ice departure differed. Sea ice began to clear from the nearshore Palmer grid in November 1995, but a return of sea ice on 17 December prevented sampling for over a week until high winds blew the harbor clear of ice on 24–25 December.

Figure 2 shows the seasonal progression in selected parameters versus time. These preliminary data provide an overview of the season. The 1995–1996 season was a period of high biomass with an initial phytoplankton bloom of 15 milligrams per cubic meter (mg m^{-3}) in November 1995, chlorophylls greater than 10 mg m^{-3} after January, and another bloom reaching 35 mg m^{-3} in February 1996. The silicate and nitrate decreased concurrently, reaching low values of 36.5 micromolar (µ*M*) silicate and 2.24 µ*M* nitrate when chlorophyll peaked at 38.9 mg m^{-3}.

Between 20 November and 19 March, 21 acoustic transects were run from stations A to E and 15 from F to J. Net samples indicate that young-of-the-year krill dominated the zooplankton; salps were absent. Acoustic estimates of zooplankton biomass ranged from 0 to 382 grams per square meter g m^{-2}; most of the higher values found were from the third week in February to the middle of March. Some of the reproductive events associated with breeding chronology of Adélie penguins on Humble Island this season (Fraser et al. in press) are noted by arrows in figure 2*C*. The breeding success of these penguins was 1.58 chicks creched per pair, representing a small increase relative to last year.

The LTER seasonal observations of the marine environment, the lower-trophic level abundance and distributions for the area, and the seabird observations at nesting sites near Palmer were recorded from October 1995 to March 1996. The sampling event log, participant list, and other project information for the season are available online (*http://www.icess.ucsb.edu/lter*).

Acknowledgment and thanks are given to members of the Palmer LTER research team and of Antarctic Support

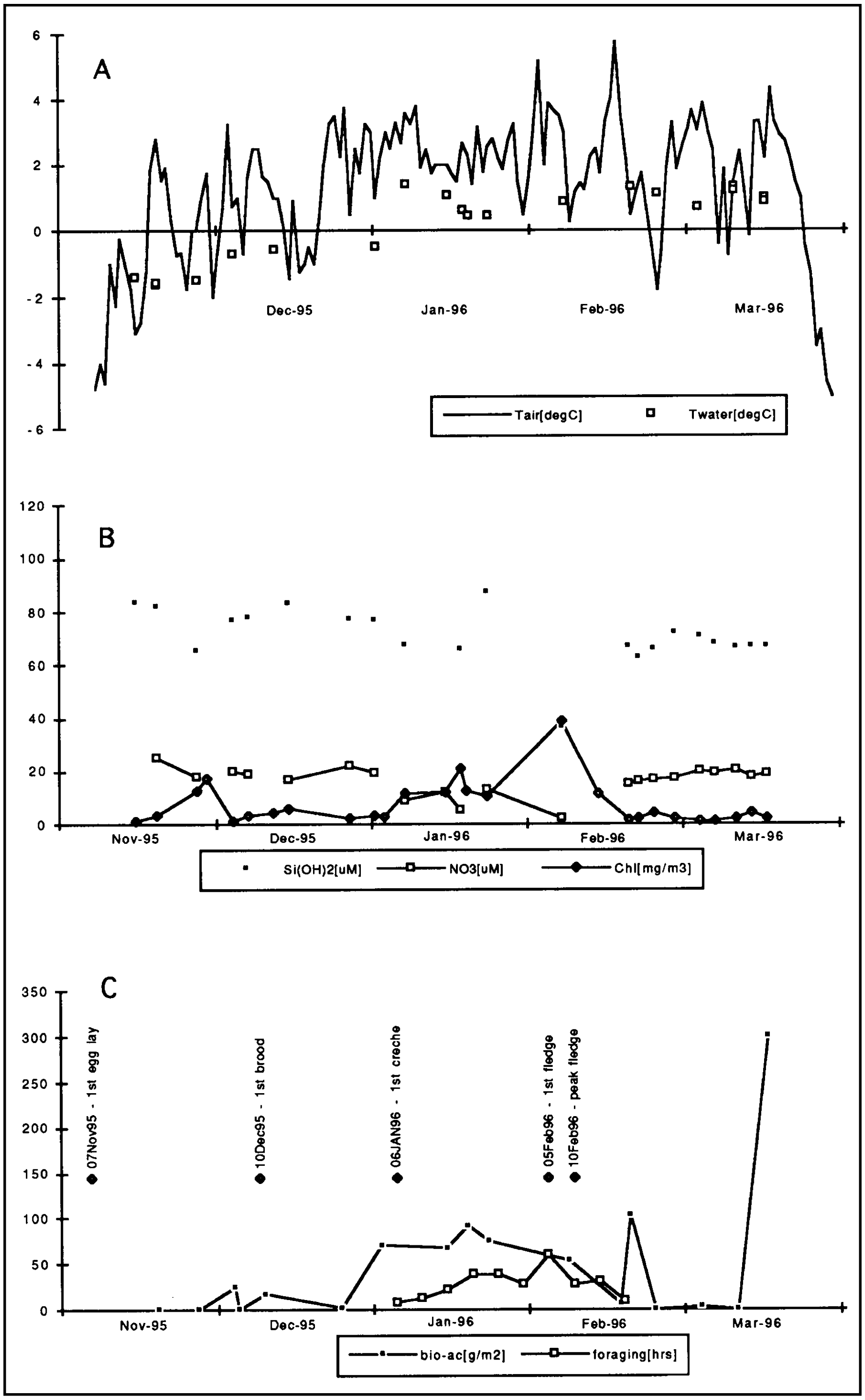

Figure 2. *A.* Air temperature (in degrees Celsius, solid line) at Palmer station and water temperature (in degrees Celsius, boxes) at station E for the 1995–1996 season. *B.* Surface chlorophyll (in mg m^{-3}, filled diamonds), nitrate (in µ*M*, open squares), and silicate (in µ*M*, filled squares) at station E for the 1995–1996 season. *C.* Krill abundance (in g m^{-2}, filled squares) from transect A to E and Adélie penguin foraging (in hours, open squares). Arrows indicating day of first egg laying, first brood, first creche, first fledging, and peak fledging at Humble Island for the 1995–1996 season.

Associates. This research was supported by National Science Foundation grant OPP 90-11927 and is Palmer LTER contribution number 104.

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Palmer LTER: Palmer Station air temperature 1974 to 1996

KAREN S. BAKER, *Marine Research Division, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, California 92093*

Climate variability is of central importance to long-term ecological studies in general and to bioclimatology in particular. As a consequence, the Palmer Long-Term Ecological Research (LTER) program has gathered historical meteorological data taken for Palmer Station as well as initiated the quality control and archiving of this data. The following is a preliminary report summarizing Palmer Station air temperature records from May 1974 to August 1996.

Meteorological measurements began after the first scientific occupation of Palmer Station in 1968. Over the years, the reporting of these data has undergone some change. Two separate records available from Palmer Station include

- monthly weather starting in 1974 and
- daily weather initiated in 1989.

Historical data in addition to the Palmer data provide the basis for this preliminary report.

Although early data is scarce, monthly measurements for Palmer Station beginning in 1974 have been published primarily in *Antarctic Journal of the United States.* Subsets have also been archived in other locations. For instance, the station holds some digital records for this early period whereas the National Climatic Data Center (NCDC) archives a subset of daily observations. A report of Palmer Station weather from 1975 to 1983 (Jacka, Christou, and Cook 1984) provides a few missing points in the *Antarctic Journal* series. Monthly maximum, minimum, and average temperatures available in *Antarctic Journal* were compared for consistency. Statistical outliers and obvious mistakes were corrected. For example, one average temperature reported was twice the reported maximum, and inspection showed that a negative sign had been dropped.

In April 1989, consistent daily weather records were begun (Oxton personal communication), and observations were made four times a day by Antarctic Support Associates personnel at Palmer Station. Daily measurements include maximum and minimum air temperature, wind speed, and wind direction. Daily mean air temperature is determined by taking the average of the daily maximum and minimum observed for that day. These daily air temperature observations were found to be well correlated with the higher frequency sampling of the automatic weather station at Bonaparte Point located roughly 750 meters west-southwest from the station (Baker and Stammerjohn 1995).

The daily temperature observations have been averaged into monthly values and combined with earlier data to create a 22-year composite record (May 1974 to August 1996) of monthly data. As a check of internal consistency for this combined data set, a subset of this series was compared with Faraday station temperature data (1974 to 1991).

As discussed elsewhere (Smith, Stammerjohn, and Baker in press), the Palmer Station air temperature data are well correlated with the Faraday data, and Faraday data can, when necessary, be used as a proxy for Palmer data. Palmer data outside two standard deviations from the Faraday regression were flagged and removed for the subsequent analysis.

The resultant monthly averages and standard deviations for Palmer Station are shown in figure 1 and summarized in table 1. A harmonic, known to describe seasonal variation (Lynn 1967; Van Loon 1967; Schwerdtfeger 1984) fit through these data, provides a simple method for calculation of the 22-year average value given julian day. Further, it provides an average against which one may view the variability of a single year's air temperature. For example, the Palmer Station 1995 daily temperature values are plotted along with the fit in figure 2.

The monthly data in the Faraday temperature record (1946–1991) have shown a warming trend, particularly in winter months (Smith et al. in press). A trend analysis for each month of the Palmer Station weather record (1974–1996) is summarized in table 2, and the January results are illustrated in figure 3. In agreement with previous reports (King 1994;

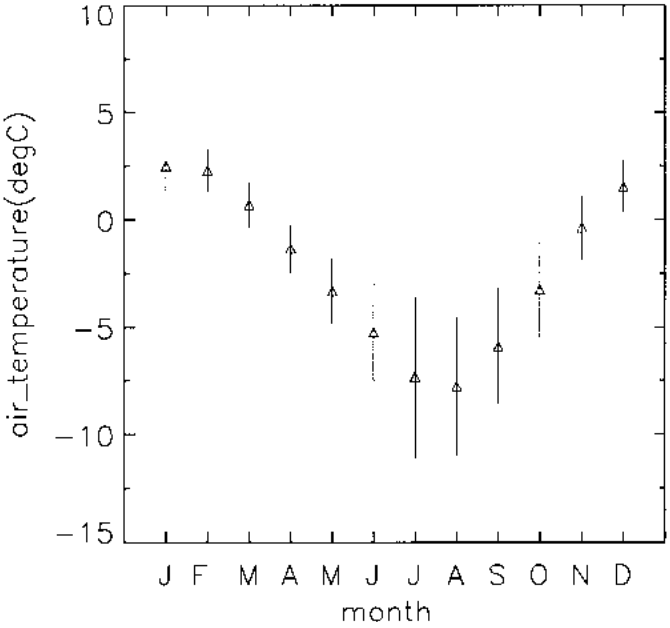

Figure 1. The Palmer Station 1974–1996 monthly average air temperatures and their standard deviations versus month.

Smith et al. in press), these data indicate a warming trend in the western Antarctic Peninsula region during the period that Palmer Station has been in operation. Although the statistical significance is less than that for the 44-year Faraday data, F-tests show the relationships are strong, and no serial correlation was indicated by Durbin-Watson tests.

Weather records are an integral component of any long-term study of an ecosystem. It is important to collect standardized, quality-assured weather measurements as well as to provide access to the data. The weather records discussed here have been placed in the Palmer LTER data system (*http://www.icess.ucsb.edu/lter*) as part of an ongoing effort to provide access to past and current meteorological data at Palmer Station.

Table 1. Palmer Station 1974–1996 monthly average air temperatures and standard deviations

Month	Average	Standard deviation
January	2.51	1.21
February	2.29	0.96
March	0.68	1.04
April	–1.33	1.08
May	–3.32	1.50
June	–5.23	2.22
July	–7.33	3.74
August	–7.76	3.21
September	–5.90	2.68
October	–3.25	2.18
November	–0.37	1.46
December	1.53	1.19

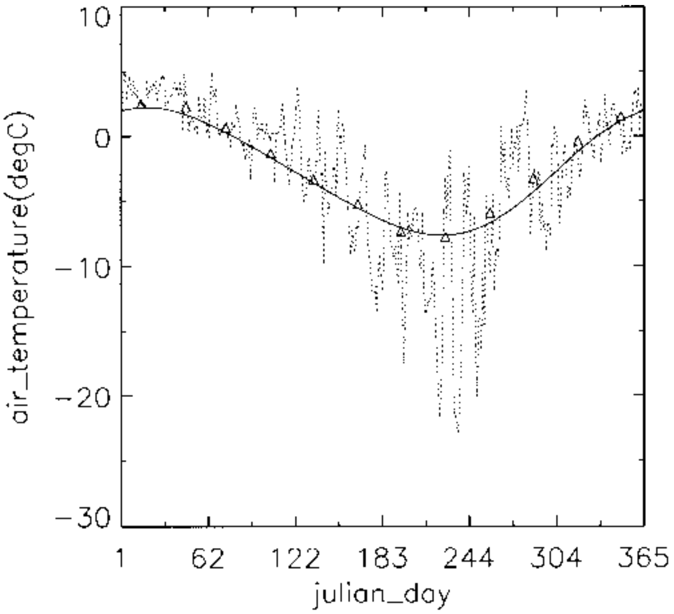

Figure 2. The Palmer Station 1995 daily air temperature (dotted line) and the 1974–1996 monthly average air temperatures (triangles) represented by a harmonic fit (solid line) versus the julian day where the harmonic fit takes the form

$$T = C + A1*\cos(\theta) + B1*\sin(\theta) + A2*\cos(2*\theta) + B2*\sin(2*\theta)$$

where the parameters are $C = -2.710$, $A1 = -4.199$, $B1 = -2.406$, $A2 = 0.464$, and $B2 = -0.245$, and θ is julian day converted to

$$\theta = (jd/365)*360^\circ - 180^\circ).$$

Acknowledgment is given to the Antarctic Support Associates science technicians, who make the weather observations, and to Al Oxton, who initiated the development of the digital weather record at Palmer Station. Thanks to both Raymond Smith and Sharon Stammerjohn, who contributed to this work. This research was supported by National Science Foundation grant OPP 90-11927 and is Palmer LTER contribution number 102.

Table 2. Palmer Station 1974–1996 monthly average air temperature trend analysis results

Month	Slope	Standard	f-test	Npoints
January	0.071	1.14	91.9	20
February	0.054	0.92	89.8	21
March	0.034	1.04	64.9	19
April	0.024	1.21	43.3	21
May	0.055	1.49	74.7	23
June	0.059	2.24	58.8	23
July	0.207	3.53	92.0	21
August	0.174	3.07	90.3	22
September	0.106	2.66	75.0	22
October	0.050	2.21	49.2	22
November	0.086	1.37	91.9	20
December	0.072	1.12	92.6	20

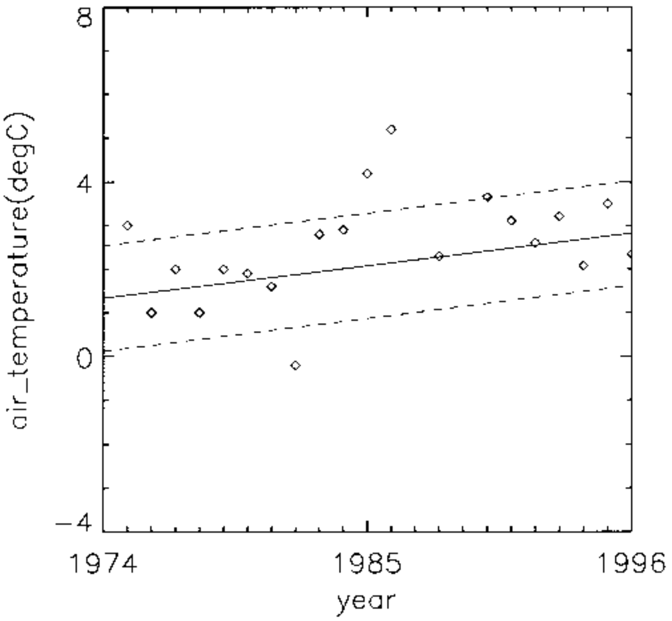

Figure 3. The Palmer Station January monthly average air temperatures versus year from 1975 to 1996 (*N*=20). The solid line is the least-squares regression line with a gradient of 0.071°C per year, and the dashed lines indicate ±1 standard deviation from this line.

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Palmer LTER: Annual season sampling on station

RAYMOND C. SMITH, JANICE L. JONES, LANGDON B. QUETIN, *and* ROBIN M. ROSS, *Institute for Computational Earth System Science* and *Marine Science Institute, University of California, Santa Barbara, California 93106*
KAREN S. BAKER, WENDY A. KOZLOWSKI, *and* MARIA VERNET, *Marine Research Division, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, California 92093*
WILLIAM R. FRASER, *Polar Oceans Research Group, Biology Department, Montana State University, Bozeman, Montana 59717*

The seasonal sampling program for the Palmer Long-Term Ecological Research (LTER) site (Smith et al. 1995) has developed over the past five seasons. Weekly observations from October through March at Palmer Station provide a time series that is enabling us

- to understand interannual variability in the seasonal timing and rates of lower trophic processes, which are reflected spatially and temporally in higher trophic levels,
- to place results from the regional scale annual cruises within a year's seasonal progression, and
- to place short-term experiments by LTER and other Palmer Station principal investigators in a seasonal/interannual context.

Observations include the seasonal progression of hydrography, nutrients, pigment biomass, and primary productivity; the near-shore abundance and distribution of antarctic krill and their larvae; and timing and success of the reproductive cycle of a major predator, Adélie penguins. The marine water column and seabird sampling schedule, summarized in the table, accommodates variability in weather.

The seasonal progression of seabird measurements follows the Adélie penguin breeding cycle. The seabird methods follow those developed and standardized by the Commission and Scientific Committee of the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR 1992). Studies typically begin on Humble Island with censuses to determine the peak arrival periods of breeding adults (October) and end with chick weights at fledging (February). Additional measurements include censuses of breeding population size and the number of chicks creched per colony. These censuses encompass all colonies on each of the five island rookeries (figure; Humble, Torgersen, Litchfield, Christine, and Cormorant). Other information obtained includes data on adult Adélie breeding chronology and success (chicks creched per pair based on monitoring 300–500 nests annually) and foraging ecology (foraging trip durations and diet composition).

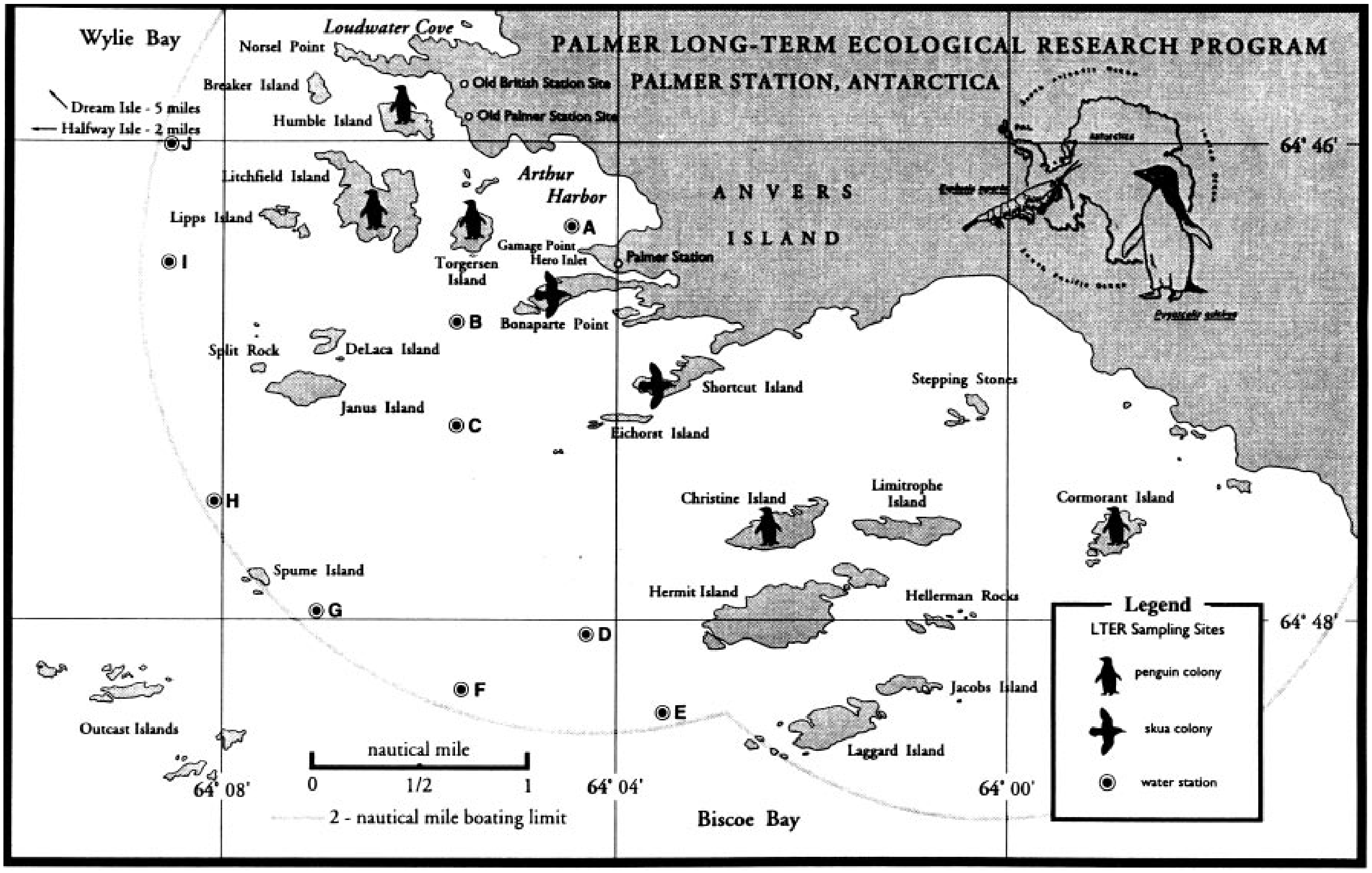
For marine water column sampling, each station activity is given a sequential event number. Transects from station A to E and from F to J (figure) each cover a few kilometers and are

Palmer LTER 1995–1996 standard sampling events

NOTE: Abbreviations used in the table are as follows: acoustics (bio-ac, Biosonics 120 kilohertz), discrete sample for chlorophyll analysis (chl), conductivity-temperature-depth (ctd, Seabird), scuba krill collection (dive), high-performance liquid chromotography of phytoplankton pigments (hplc), instantaneous growth rate (igr), targeted tow for krill (krilltarg, Furuno 50 kilohertz), microscopic analysis of net plankton (net, >5 mm), inorganic nutrient analysis (nuts), photosynthetically active radiation (par), physiological condition of larvae (phyconl), microscopic analysis of picoplankton (pico, 0.5–5.0 μm), particulate organic carbon (poc), production photosynthesis vs irradiance (Ppi), primary production simulated-in-situ (Psis), profiling radiometer (prr, BSI), discrete sample for salinity analysis (sal), transparent exopolymer particles (tep), and standard zooplankton tows (trwl).

Date	Frequency	Location	Activity
October to March	Weekly	Palmer Basin	Zodiac: water column sampling
	Day 1	Stations A to E	ROZE: bio-ac
	Day 1	Stations E to B	ROZE: profile ctd, prr, chlsurf, salsurf
	Day 1	Stations E to B	LEGEND: profile par, hplc, nuts, poc, Ppi, Psis, tep, net, pico
	Day 1	Bonaparte and Gamage Points	LEGEND: chlsurf, salsurf
	Day 2	Stations J to F	ROZE: bio-ac
	Day 2	Stations F to J	ROZE: profile ctd, prr, chlsurf, salsurf
	Day 2	Laboratory	LAB: conclude 24-hour experiments
	Day 3	Palmer Basin	RDUKE: krilltarg (50 kilohertz) for igr, phyconl
	Day 3	Laboratory	LAB: igr experiments
	Day 3	Station B	LEGEND: water for prod, c/chl experiments
	Day 4	Stations E and B	LEGEND: profile par, hplc, nuts, poc, Ppi, Psis, tep, net, pico
	Day 4	Stations D and C	LEGEND: chlsurf, salsurf
	Day 4	Bonaparte and Gamage Points	LEGEND: chlsurf, salsurf
	Day 4	Palmer Basin	RDUKE: weather and/or krilltarg
	Day 4	Laboratory	LAB: conclude 24-hour experiments
	Day 5	Stations A to J	RDUKE: trwl AB, DE, FG, JI
	Day 5	Laboratory	LAB: conclude 24-hour experiments
	Day 6	Laboratory	LAB: analysis
	Day 7	Laboratory	LAB: conclude igr experiments
1 October to 15 November	Once/2 days	Humble rookery	Arrival chronology of breeding adults
1 October to 15 March	Daily	Humble and Torgersen rookeries	Adult overwinter Age-specific survival/recruitment
1 October to 15 March	Weekly	Litchfield, Christine, and Cormorant rookeries	Adult overwinter Age-specific survival/recruitment
15 to 30 November	Once/colony	Humble, Torgersen, Litchfield, Christine and Cormorant rookeries	Breeding population size
15 November to 30 January	Daily	Humble and Torgersen rookeries	Adult breeding chronology and success (chicks creched per pair)
5 January to 25 February	Once/5 days	Torgersen rookery	Chick diet composition and meal size
5 January to 25 February	Daily	Humble rookery	Adult foraging trip duration
15 to 30 January	Once/colony	Humble, Torgersen, Litchfield, Christine, and Cormorant rookeries	Chicks creched per colony
1 to 25 February	Once/2 days	Humble rookery	Chick weights at fledging
15 February to 25 March	Weekly/colony	Humble, Torgersen, Litchfield, Christine, and Cormorant rookeries	Colony-specific breeding chronology

sampled with three specially outfitted zodiacs (Roze, Legend, and Rubber Duke). A standard water column week begins with the Roze completing an acoustic transect for water column biomass from station A to E. The Roze and Legend rendezvous at station E and sample stations E to A simultaneously. An electric winch with conducting cable aboard the Roze permits deployment of the profiling conductivity-temperature-depth (CTD) followed by the profiling radiometer (PRR). The Legend is outfitted with a winch to permit water sampling throughout the water-column. Photosynthetically available radiation (PAR) is measured, and water samples are used for determination of photosynthesis rates (simulated *in situ* and photosynthesis versus irradiance curves at the depth of 50 percent irradiance), analysis of photosynthetic pigments by high-performance liquid chromotography (HPLC), determination of major inorganic nutrients (nitrate, silicate, phosphate), and analysis of particulate organic carbon (POC) and nitrogen. At stations E and B, samples are also taken for picoplankton and netplankton analysis. At station B, samples are taken for transparent exopolymer particle analysis. Sample concentration and analysis as well as incubations for photosynthesis experiments start immediately upon return to station.



Palmer station basin where the grid extent is constrained by the zodiac sampling platforms available and a 3.7-kilometer (2-nautical-mile) safe boating limit. Penguin colonies sampled are denoted by a penguin.

On the second day, the Roze completes an acoustic transect and follows the same routine as for day 1 for stations J through F. If the wind is from the northeast and greater than 5 meters per second, the sampling is done from F to J to avoid being south of Bonaparte Point in bad weather.

On day 3, the Rubber Duke is used to target tow for krill. Krill aggregation searches begin where krill were seen on the previous days followed by searches in other areas within the 3.7-kilometer boating limit. Krill are collected with a 1-meter ring net (500-micron mesh). Instantaneous growth rate (IGR) experiments are conducted over a 4-day period with the krill (Ross and Quetin 1991), and krill are analyzed for length frequency distribution and physiological condition. The Legend samples at station B for phytoplankton experiments on photosynthesis.

On day 4, the Legend samples the water-column at stations B and E for phytoplankton experiments on photosynthesis while surface samples are taken from stations C and D. Samples for chlorophyll analysis are taken at all stations. Day 4 is used on station for sample analysis and data analysis. If poor weather conditions have prevented sampling on prior days, zodiac work is resumed.

On day 5, standard tows are from Rubber Duke done with a 1-meter net from stations A to B, D to E, F to G, and I to J. In the lab, 24-hour photosynthetic rate experiments are terminated, and sample analyses from the previous day are completed.

When ice in Arthur Harbor prevents zodiac operations, water samples are taken from land at Bonaparte and Gamage Points. When possible, these stations are also sampled from the zodiac during the first day and fourth day of the sampling routine on the E to B transect. In addition, during iced periods prior to boating, scuba divers collect krill from under the ice for use in growth rate experiments and for analysis of physiological condition.

Although a season may vary, the basic structure remains in order to define the long-term measurements.

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Palmer LTER: Small boat design for water column sampling

RAYMOND C. SMITH, LANGDON B. QUETIN, JANICE L. JONES, DAVID W. MENZIES, *and* TIMOTHY A. NEWBERGER, *Institute for Computational Earth System Science* and *Marine Science Institute, University of California at Santa Barbara, Santa Barbara, California 93106*

The Palmer Long-Term Ecological Research (LTER) Program includes weekly seasonal observations of the marine environment within the foraging range of the Adélie penguin breeding sites near Palmer Station. A zodiac is equipped with two winches for hydrographic, optical, acoustic, and biological measurements within the 3.7-kilometer (km) boating limit (Smith et al., *Antarctic Journal,* in this issue). Key oceanographic equipment deployed from this zodiac, christened the ROZE (Ray's Oceanographic Zodiac Experiment), includes a conductivity-temperature-depth (CTD) system with transmissometer and fluorometer, a profiling reflectance radiometer (PRR), an above-water radiometer, a 120-kilohertz echo sounder, and global positioning system (GPS) navigation (table 1). A laptop computer system provides real-time display of CTD, optical, and acoustical data.

Table 1. Zodiac instrumentation

Function	Manufacturer	Model	Comments
CTD profiling			
CTD profiler	Sea-Bird Elec.	SEACAT SBE19	With pump SBE5-01
Transmittance	SeaTech		25-cm path transmissometer
Fluorescence	SeaTech		Chlorophyll fluorometer
Optoisolator	Sea-Bird Elec.	SBE 28	Reduce noise in data
Electric winch	Custom built		20-cm diameter, 50-cm wide aluminum drum
Winch motor	Dayton		3/4-horsepower variable speed and direction
Gear reduction	Dayton		29:1 speed reducer
Kevlar cable	Cortland Cable	4-conductor	20-gauge, 1,000-lb strength
Slip rings	IEC Corp.	IEL-BX-4	4-conductor
Optical profiling			
Light/underwater	Biospherical	PRR600	7 irradiance + 7 radiance bands
Light/deck	Biospherical	PRR611	7 irradiance bands
Hand winch	Custom built		150-m Kevlar cable
Flotation fins	Custom built		Slow freefall away from boat
Kevlar cable	Cortland Cable	4-conductor	20-gauge, 1,000-lb strength
Slip rings	IEC Corp.	IEL-BX-4	4-conductor
Acoustics			
Echo sounder	BioSonics	Model 102	120-kilohertz krill surveys
Tape interface	BioSonics	Model 171	Interface DAT to sounder
Chart recorder	BioSonics	Model 111	Thermal
Processing board	BioSonics		Mounted in docking station
Interface pod	BioSonics	ESPSCP	Interface SP board to sounder
Interface pod	BioSonics	ESPIP	Interface SP board to sounder
Deck cable	BioSonics	100-foot	Sounder to transducer
Transducer	BioSonics	120-kilohertz	
Data recorder	Sony	TCD-D3	Uses DAT format
Computer			
Computer	DEC	DEC486	Used for CTD, optics, and acoustics processing
Docking station	DEC	PCP3E-AB	
VGA color monitor	DEC	PC7XV-BA	
Power production			
DC-AC inverter	Tripp-Lite	PV1800FC	24-volt
Batteries	AC Delco	Voyager M27MF	Deep cycle 12-volt, RV
Navigation and communications			
GPS	Garmin	GPS 45	Pre-set waypoints for stations
GPS antenna	Garmin	010-10052-00	Remote mount marine
GPS mount	Garmin	010-10048-00	Tilt/swivel
Depth sounder	Furuno	LS-6000	LCD video; fish finder
VHF radio	Standard	GX2330SAB1S1	Horizon Nova
Radio antenna	Shakespeare	5202	2.4-meter very-high-frequency
Antenna mount	Shakespeare	4187	Ratchet type

The ROZE (figure 1*A*) is a standard 5.8-meter (m) inflatable zodiac (Mark V) with a soft bottom, a 45-horsepower outboard motor, and a 9.9-horsepower backup motor. This zodiac with multicompartmental flotation was chosen because of cost, safety, flexibility, strength, and low maintenance. The zodiac flooring consists of four aluminum panels and two wooden bow panels. A rear wooden pallet adds height, so the zodiac driver can see over instrument boxes mounted on a raised, 2.4-m × 1.5-m platform built across the center of the zodiac. The platform fits inside the zodiac, so pontoons function as a bumper rather than the platform edge. The platform is made from six wood beams supported 30 centimeters (cm) above the zodiac floor by two box beams running lengthwise along the zodiac pontoons and standing on a stack of 5-cm × 15-cm runners (figure 1*B*). Further structural support is provided by a beam directly under the outermost edges of the platform.

The platform, sitting 5 cm above the zodiac to prevent abrasion of the pontoons, is lashed to the zodiac. Two instrument boxes have hinged doors that close during travel for protection. Gas cans sit securely on the fourth floor panel behind the pallet. Emergency supplies include oars and an extinguisher for electrical fires. Two batteries are kept in a raised, covered wooden box under the platform.

On the platform, two winches, one electric and one hand powered, are located forward of the instrument boxes. When not in use, the CTD is secured by a bracket mounted forward and to port, and the acoustic transducer is secured to starboard. L-shaped davits with a height of 1.8 m and a reach of 1.2 m are centered on each side, extend through the platform to sit on the stack of runners, and swing both forward and aft.

A GPS antenna is mounted on the port davit. Installed on the starboard davit are a PRR deck unit and a radio antenna with a ratchet mount that folds to avoid shadowing the deck light sensor.

The starboard instrument box has three shelves:

- GPS, very-high-frequency radio, depth sounder, and a ground fault circuit interrupt for safety;
- computer monitor, PRR power box, CTD interface box, and controller for the electric winch, and
- DEC486 laptop computer with a separate color monitor and docking station.

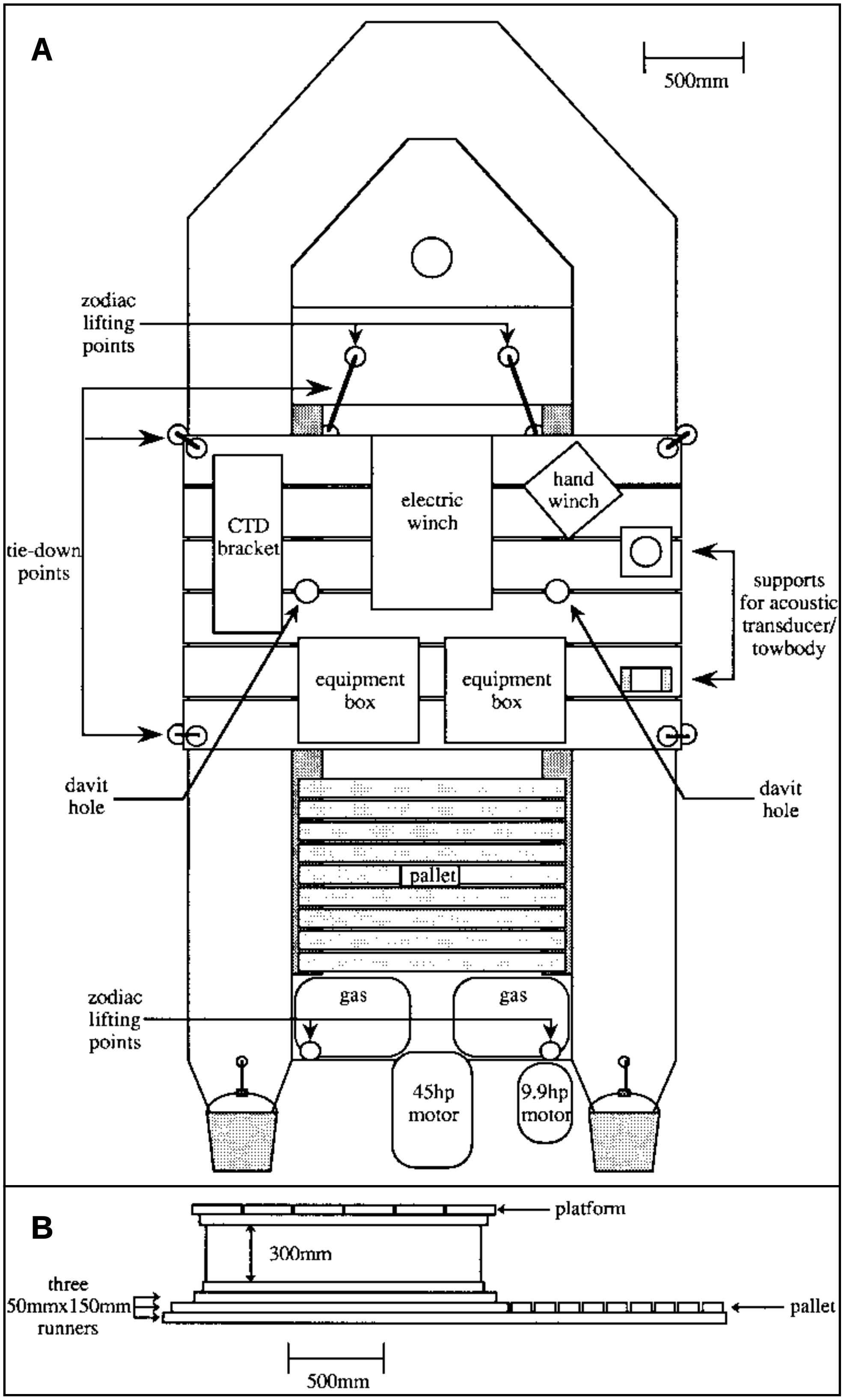

Figure 1. *A*. Overhead schematic of zodiac layout. (hp denotes horsepower.) *B*. Side schematic of zodiac platform. (mm denotes millimeter.)

Table 2. Zodiac power budget

Equipment	Watts	Amps
125-volt alternating current		
Winch motor	900	9.42
Laptop computer	55	4.58
Color monitor	85	7.08
CTD	55	4.58
Profiling radiometer	55	4.58
GPS	2	0.16
Scientific echo sounder	32	2.67
Tape interface unit	25	2.08
Thermal chart recorder	30	2.50
DAT tape recorder	15	1.25
12-volt direct current		
Furuno fishfinder	10	0.83
VHF radio	25	2.08

Figure 2. Photograph of zodiac being removed from water.

The port box contains BioSonics acoustic sounding system electronics including a scientific echo sounder, thermal chart recorder, and tape interface unit as well as a DAT tape recorder and a direct current/alternating current inverter.

The power budget (table 2) includes a maximum steady battery current load of 30 amps with the winch operating. Peaks up to 60 amps occur when the winch is starting under full load. The draw decreases to 20 amps with the acoustic gear off. Two 12-volt deep-cycle marine batteries provide 105 amp-hours, sufficient power for five stations of CTD and PRR casts to 90 m. Currently, the inverter is 24 volts with an 1,800 watt output. An optoisolator box protects instrument electronics. The radio and depth sounder have an external connection directly to the battery.

The 12-volt batteries are recharged overnight with a Voyager 20-amp charger (Deltran Corp.) modified to charge optimally at approximately 13°C rather than the standard 23°C. Six batteries include two on the zodiac, two charging, and two spares. The battery-powered inverter is a big improvement over previous gasoline-generator configurations.

A sampling party has the driver aft and one or two others forward of the platform. A GPS navigation unit locates stations accurately as well as provides safety should visibility become limited. Both winches are equipped with 150 m of Kevlar conducting cable. The electric winch is used to deploy the CTD from the port davit. The PRR is deployed using a hand winch to facilitate a free-fall release (Waters, Smith, and Lewis 1990). The acoustic transducer is towed from the starboard davit alongside the boat within 1 m of the surface. The driver maintains a zodiac event log while all in-water instruments are launched by personnel in the bow, from either side of the zodiac. A very-high-frequency radio mounted for ease of access along with its antenna have improved communications with Palmer Station during field sampling.

At the end of a day's sampling, the computer is removed for data transfer and batteries are removed for recharging. The CTD and PRR are removed from the boat for fresh-water rinsing and laboratory storage for drying. Equipment left on the zodiac is covered by tarps. By turning on the inverter in the morning, the computer and the monitor warm up the instrument boxes, quickly removing condensation.

The zodiacs remain in the water as long as ice conditions permit. If ice conditions suddenly change at Palmer Station, ROZE with all equipment aboard can be lifted free of the water within 10 minutes using eight sling arms on a lifting ring lifted by a movable crane. Experience with leopard seals indicated that tying buckets onto the conical end of pontoons would prevent bite puncture damage when ROZE is moored at the station (figure 2). In summary, the ROZE has provided a flexible, robust oceanographic sampling platform for the past five seasons.

Acknowledgment is given to the Antarctic Support Associates science technicians who helped with construction and repair. Many thanks to Deltran personnel for providing rapid field communications and postseason equipment modifications. This research was supported by National Science Foundation grant OPP 90-11927 and is Palmer LTER contribution number 105.

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Palmer LTER: Open-water profiling ultraviolet radiometer albedo measurements

KAREN W. PATTERSON, PHILIP L. HANDLEY, *and* RAYMOND C. SMITH, *Institute for Computational Earth System Science, University of California, Santa Barbara, California 93106*

It is widely documented that reduced ozone will result in increased levels of ultraviolet (UV) radiation, especially UV-B [280–320 nanometers (nm)], incident at the surface of the Earth, and increasing evidence suggests that these higher levels of UV-B may have an important impact on various forms of marine life in the upper layers of the ocean (Häder et al. 1994, pp. 174–180; Smith and Cullen 1995). Measurement and/or estimation of incident spectral irradiance, especially in the UV region, is a necessary element for a quantitative assessment of possible UV effects. In the modeling of incident irradiance, the surface spectral albedo can have a significant influence, via refluxing between surface and clouds, on the incident spectral irradiance (Gautier, Ricchiazzi, and Yang personal communication). In this article, we present preliminary measurements for the spectral albedo of open ocean water; we believe these measurements are the first such data using a narrowband instrument in a high-latitude region.

The spectral albedo is also essential for some remote-sensing applications. For example, with the recent launches of two total ozone mapping spectrometer (TOMS) satellite instruments and the upcoming launch of a sea-viewing wide field-of-view sensor (SeaWiFS), new opportunities are emerging for the study of the impact of UV radiation on marine organisms. Global total ozone maps will once again be available from TOMS data for modeling surface UV spectra. Surface UV reflectance must be accounted for to calculate accurate total column ozone. In addition, estimates of gelbstoffe and suspended sediments from SeaWiFS ocean color data will allow first-order estimates of the rate at which UV radiation is attenuated within the surface waters on a regional and global scale. Surface UV reflectance is an essential component both for remote sensing and for the calculation of UV penetration through the surface waters.

Measurements were taken with a profiling ultraviolet radiometer (PUV-500) during the August to September Long-Term Ecological Research (LTER) cruise aboard the *Polar Duke* (*PD*93-7) off the west coast of the Antarctic Peninsula to obtain initial estimates of the UV reflectivity of ocean waters in this region. The PUV-500 consists of two units, a surface unit and an in-water unit. Each unit measures downwelling irradiance in four UV channels and a broadband photosynthetically active radiation (PAR) channel. Each of the UV channels has an effective bandwidth of about 10 nm. The centers of the four UV channels are at approximately 305, 320, 340, and 380 nm. To measure irradiance upwelled from the ocean's surface, the in-water unit was turned upside down and secured to a boom extended away from the side of the ship as far as possible (figure 1). The unit was maintained at approximately 5 meters above the ocean's surface. The sur-

Figure 1. The PUV instrument suspended above antarctic waters.

face unit was attached to a laboratory van on the helicopter deck and collected downwelling irradiance at the same time. For intercalibration of the two units, downwelling irradiance values and dark readings were collected following the sampling period while the units sat side-by-side on the deck of the ship.

Upwelling irradiance measurements were made over a variety of mixtures of ice and open water during the sampling period. At 17:52–17:54 Greenwich mean time (GMT) on 23 September, the ship passed through an area of open water that had some whitecapping and a few small ice flows. The skies were totally overcast during this period. The ratio of the upwelling irradiance to the downwelling irradiance is plotted for each of the PUV channels (figure 2). The mean albedo for all PUV channels was about 7.5 percent, and numbers ranged from a minimum of 7.0 percent at 320 nm to a maximum of 8.3 percent at 305 nm (table). This is 2 percent higher than the broadband albedo value of 5–6 percent commonly used for wind-roughened ocean surfaces under overcast skies (e.g., Burt 1954; Saunders 1967; Payne 1972; Preisendorfer 1976; Lubin 1989). The smallest albedo measured during our sampling period was approximately 5.5 percent (figure 2), and the variability observed in the data is most likely due to slight differences in the timing of the up- and downwelling instruments. The average higher albedo measured here is most likely due to high solar zenith angle (67°). Measurements taken at a solar zenith angle of 67° are representative of typical Sun angle conditions in this region since solar zenith angles remain fairly high even at solar noon in polar regions.

The mean albedo and standard deviation for each of the PUV channels

Channel	Albedo (%)	Standard (%)
305	8.31	0.55
320	7.01	0.74
340	7.08	0.67
380	7.54	0.82
PAR	7.30	0.82

Acknowledgment is given to the Antarctic Support Associates personnel, to the Palmer LTER research team, and to Elizabeth Bruce in particular, who helped with the data collection. This research was supported by National Science Foundation grant OPP 90-11927 and National Aeronautics and Space Administration grant NAGW290 and is Palmer LTER contribution number 107.

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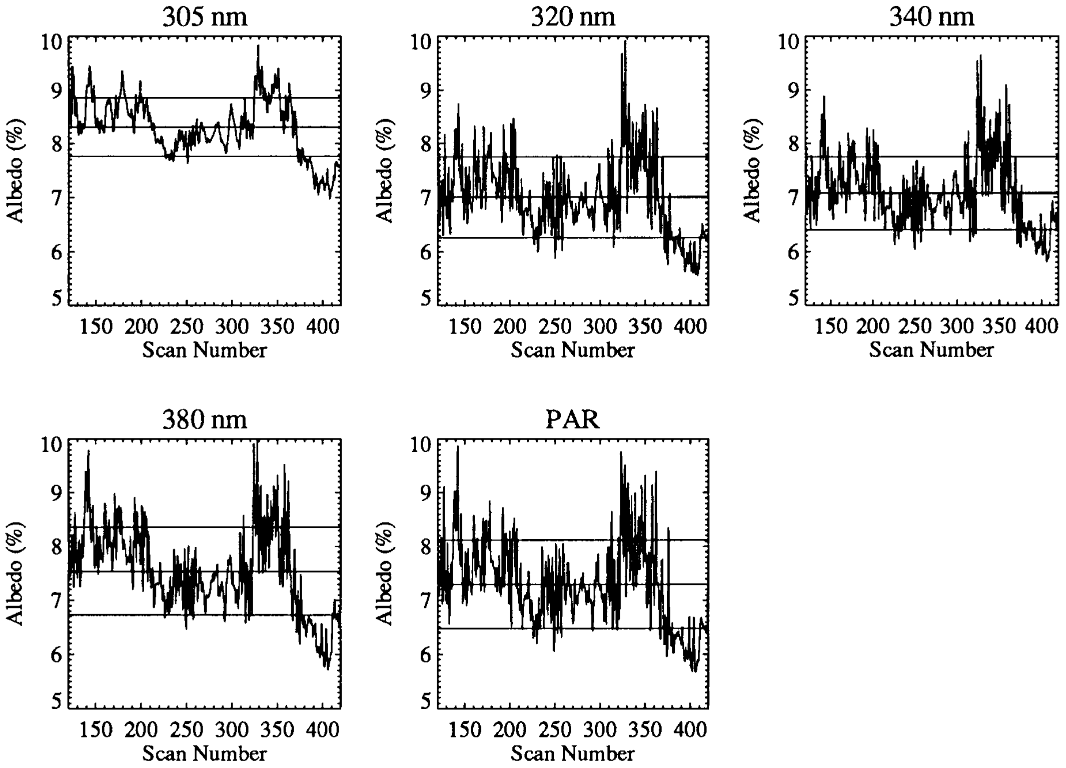

Figure 2. Upwelling irradiance divided by downwelling irradiance for each of the PUV channels. Values have been multiplied by 100 to convert them to percentages. The horizontal lines plotted are the mean albedo, the mean albedo plus 1 standard deviation, and the mean albedo minus 1 standard deviation for each channel.

Palmer LTER: Seasonal comparison of spatially averaged estimates of krill abundance

CATHY M. LASCARA, *Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, Virginia 23529*

As part of the Palmer Long-Term Ecological Research (LTER) program (Smith et al. 1995), acoustical measurements of krill biomass have been collected since 1991 during multidisciplinary cruises conducted within the waters of the west Antarctic Peninsula continental shelf system. The observations from the first four of these cruises (austral spring 1991 and summer, fall, and winter 1993) represent a unique antarctic data set because full seasonal coverage was provided over a defined region and three seasons were sampled consecutively in a single year. This article describes the observed seasonal changes in spatially averaged estimates of krill abundance and compares the acoustically derived krill biomass values with similar measurements from other programs.

Portions of the Palmer LTER study region (grid defined in Waters and Smith 1992) were surveyed during research cruises conducted in spring (7–21 November 1991), summer (8 January to 7 February 1993), fall (25 March to 15 May 1993), and winter (23 August to 30 September 1993). The locations at which acoustic observations were made during each cruise are shown in figure 1. The sampling intensity and region occupied differed between cruises; however, sampling for each of the 1993 surveys included transect lines 200 through 600. A full description of acoustic sampling methods and postprocessing analysis is available in Lascara (1996).

Spatially averaged estimates of krill biomass increased three-fold from spring to summer [34 to 110 grams per square meter (g m^{-2})] and then decreased an order of magnitude to the low values (<10 g m^{-2}) observed during fall and winter (table). The number of aggregations detected per unit sampling effort followed a similar seasonal pattern (table) with maximum and minimum values observed in summer [12.1 aggregations per kilometer (km^{-1})] and winter (0.4 aggregations km^{-1}), respectively. Total aggregation area [in square meters per kilometer (m^2 km^{-1})], followed the seasonal trend of krill biomass with the exception that total area increased from fall to winter (table). This increase in total aggregation area between fall and winter was accompanied by a decrease in number of aggregations and a decrease in mean vertically integrated krill biomass suggesting a seasonal change in the character of aggregations; this change is further described in Lascara (1996).

Quantitative acoustic observations that can be used for direct comparison with the spatially averaged, vertically integrated estimates of krill biomass obtained during this study are available for only a few surveys conducted primarily in the region encompassing the Bransfield Strait, South Shetland Islands, and Elephant Island (figure 2). The magnitude of krill biomass observed in spring 1991 and summer 1993 are consistent with the limited measurements available for direct comparison. Interannual variability is apparent in the combined summer observations, and the summer 1993 krill biomass value (110 g m^{-2}) was higher than all other summer estimates (17–90 g m^{-2}) with the exception of the 1993 estimate obtained by the U.S. Antarctic Marine Living Resources (AMLR) program (135 g m^{-2}, Hewitt and Demer 1993b).

The Palmer LTER observations represent the only quantitative acoustic estimates of krill abundance available for the west Antarctic Peninsula shelf region from the fall through late winter. The reduction in acoustically derived estimates of krill biomass by an order of magnitude during the fall and winter compared to summer 1993 in this study, however, is consistent with the seasonal pattern described from analysis of net-derived krill density estimates from Bransfield Strait and around the South Shetland Islands (Stepnik 1982; Siegel 1988, pp. 219–230; Siegel 1992). These combined data sets suggest that the seasonal change observed in this study is a recurrent annual pattern at least for the broad region from Adelaide Island to Elephant Island. Moreover, the variation in spatially integrated krill biomass is higher between seasons than between years for waters west of the Antarctic Peninsula. Long-term programs, such as the Palmer LTER, which are focused on the characterization of interannual ecosystem variability in this region, need to interpret their observations with an understanding of the magnitude of seasonally induced variability in krill biomass.

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Spatially averaged estimates of krill abundance by season. Aggregation number and total area provided per unit of sampling effort (km).

Parameter	Spring	Summer	Fall	Winter
Vertically integrated krill biomass (g m^{-2})	34	110	10	7
Number of aggregations (km^{-1})	4.8	12.1	0.9	0.4
Total area of aggregations (m^2 km^{-1})	1,770	3,345	450	1,715

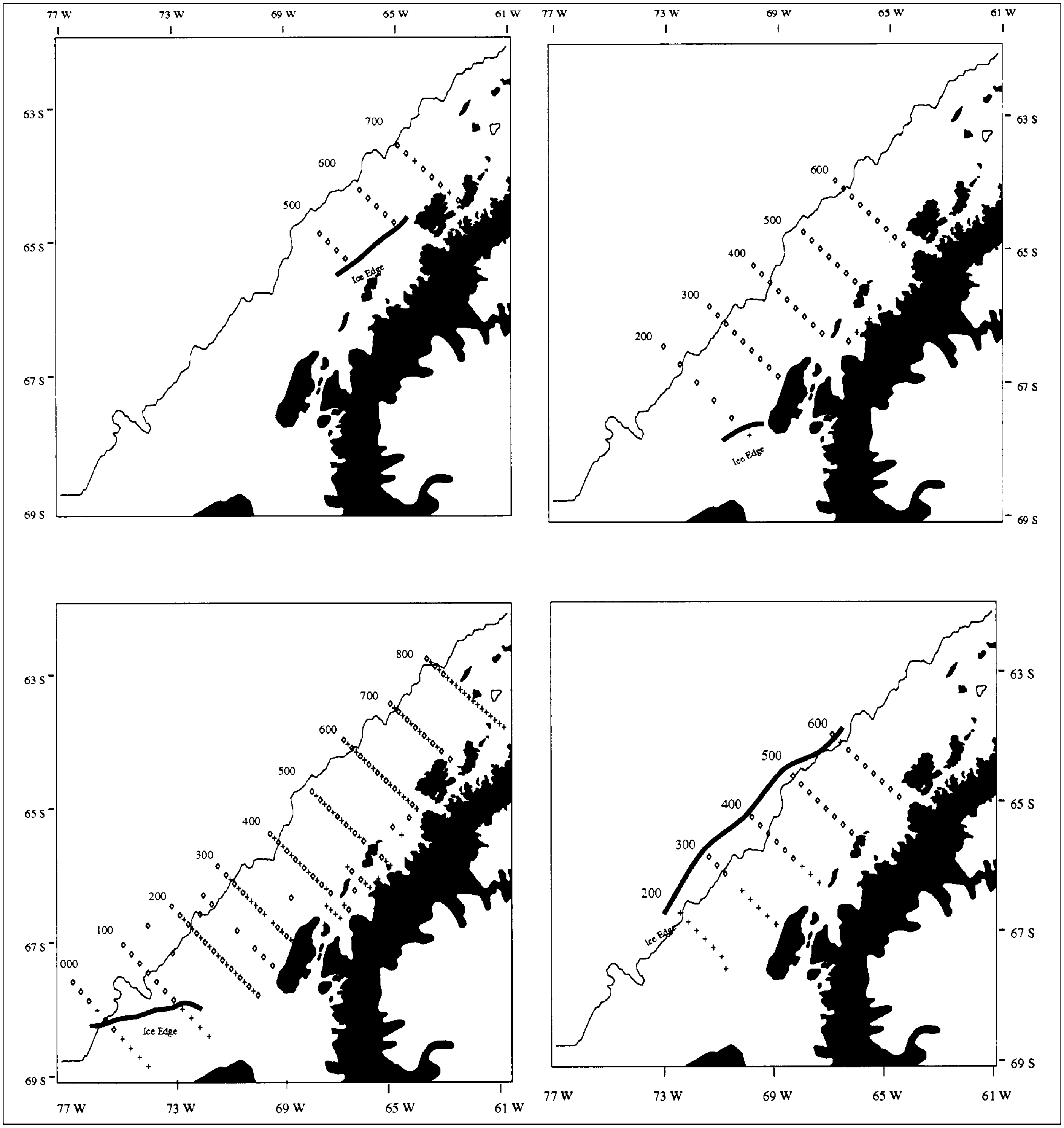

Figure 1. Locations sampled during (*A*) spring: 7–21 November 1991; (*B*) summer: 8 January to 7 February 1993; (*C*) fall: 25 March to 15 May 1993; (*D*) winter: 23 August to 30 September 1993. The ◇ indicates stations where environmental and acoustic measurements were collected; the X indicates environmental measurements only. The 1,000-m isobath is denoted by the solid line and the ice edge by the heavy line.

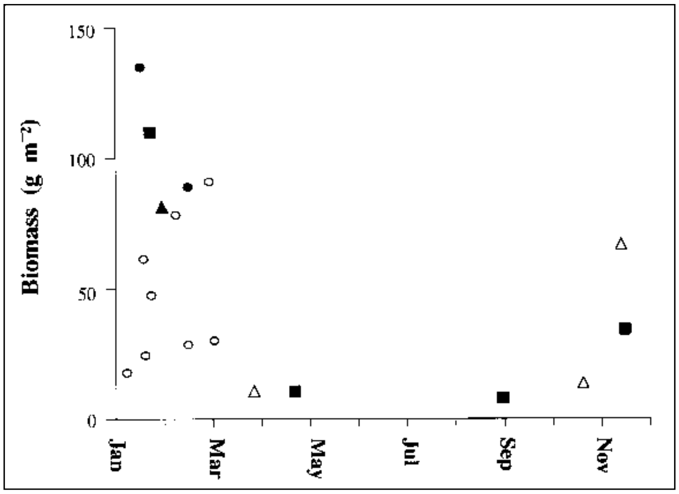

Figure 2. Comparison of acoustically derived, spatially averaged estimates of krill biomass by month. Datasets are denoted as the following: filled box—this study; open circle—AMLR study region near Elephant Island (1190–1992) (Hewitt and Demer 1993a): filled circle—AMLR study region in 1993 (Hewitt and Demer 1993b); open triangle—Elephant Island (Klindt 1986 as adjusted by Hewitt and Demer 1993a); and filled triangle—southwest Atlantic Survey region during FIBEX (Trathan et al. 1995). (FIBEX is the First International BIOMASS Experiment. BIOMASS is Biological Investigations of Marine Antarctic Systems and Stock.)

Old Dominion University. Thanks are extended to the many individuals involved in field collection and the crews of the R/V *Polar Duke* and R/V *Nathaniel B. Palmer*.

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Palmer LTER: Interannual variability in near-surface hydrography

EILEEN E. HOFMANN, CATHY M. LASCARA, JOHN M. KLINCK, *and* DAVID A. SMITH, *Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, Virginia 23529*

As part of the annual January cruise undertaken by the Palmer Long-Term Ecological Research (LTER) program, hydrographic surveys are made of the offshore waters west of the Antarctic Peninsula. To date, January cruises have been made in 1993, 1994, 1995, and 1996. This report focuses on the interannual differences observed in the horizontal distributions of the near-surface temperature and salinity fields in January 1993 and January 1994.

Vertical profiles of temperature and salinity were obtained at 52 stations during January 1993 (figure 1*A*) and at 49 stations during January 1994 (figure 1*B*) with a Sea-Bird conductivity-temperature-depth (CTD) system. On all casts, observations were made to within a few meters of the bottom or to 500 meters (m) at deep locations. In both years, the horizontal spacing between hydrographic stations was about 20 kilometers (km). In January 1994, the southernmost transect was not occupied; otherwise, the sampling regime was similar in both years.

The CTD measurements for both cruises were processed as described in Lascara et al. (1993). The near-surface temperature and salinity were obtained by averaging the CTD measurements over the upper 40 m of the water column. This part of the water column is Antarctic Surface Water (Hofmann et al. 1993; Hofmann et al. in press) and is strongly influenced by surface heating and cooling and by buoyancy fluxes. During the austral summer, this region is typically stratified, and the use of an average value was considered to be more representative of the mesoscale hydrographic conditions than observations from a specific depth.

The near-surface temperature in January 1993 (figure 1*A*) shows an onshore-offshore gradient; the inner shelf waters are cooler. Temperatures over the shelf are everywhere positive, and maximum temperatures of 1.5°C occurred at the outer edge of the sampling region. Along the northernmost transect, a lens of water warmer than 0.5°C occurred near Anvers Island and extended southward along the inner shelf. Water warmer than 0.5°C was found throughout the inner shelf in the southern portion of the sampling region. Also, water warmer than 1°C was found over the outer shelf in the southern portion of the sampling region.

In January 1994, the inner and middle shelf near-surface waters were generally warmer than observed in 1993 particularly in the southern portion of the study region and near Anvers Island (figure 1*B*), where temperatures exceeded 1°C. In contrast, the outer shelf waters in 1994 were cooler than observed in 1993 and were generally less than 0.75°C.

The near-surface salinity distribution in January 1993 (figure 2*A*) shows an offshore-onshore gradient with lower salinities present on the inner shelf. An across-shelf salinity gradient occurred along the inner shelf region; however, most of the shelf stations showed salinity values ranging from 33.6 to 33.8. In January 1994 (figure 2*B*), lower salinity water was present in the inner shelf, and water less than 33.7 extended

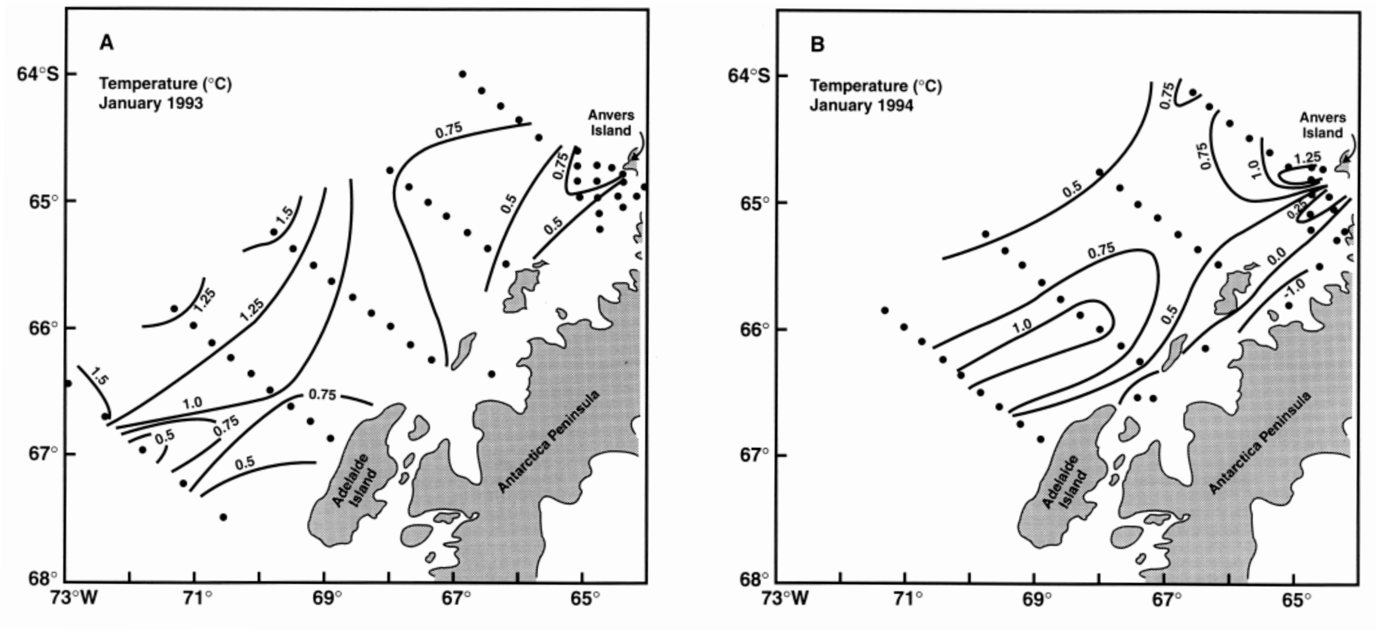

Figure 1. Surface temperature distribution observed in (*A*) January 1993 and (*B*) January 1994. Contour interval is 0.25°C. The hydrographic station distribution is indicated by the dots.

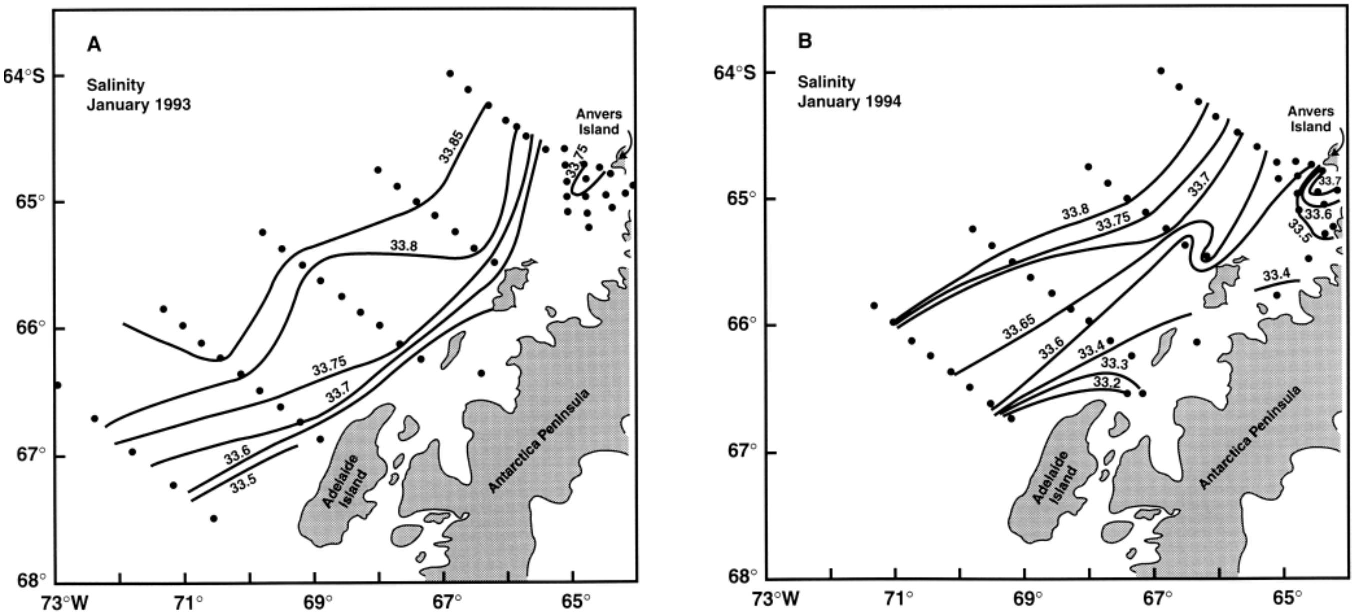

Figure 2. Surface salinity distribution observed in (*A*) January 1993 and (*B*) January 1994. Contour interval is variable. The hydrographic station distribution is indicated by the dots.

farther offshore than in 1993. As a result, the 33.7 and 33.8 isohalines were farther offshore (20–50 km) in 1994. The strongest salinity gradients occurred along the inner shelf region in 1993 and in the region near Anvers Island in 1994. In both years, a region of higher salinity water was found near Anvers Island but was more pronounced in 1994.

The decreased offshore temperature and decreased salinity in 1994 suggest that this year may have been characterized by a larger influx of fresh water from the regions to south or inner shelf or by increased local ice melt. For example, it is possible that the wind patterns and inner shelf circulation in 1994 were such that more of the fresh water near the coast was allowed to spread out onto the shelf. The LTER data, however, are not adequate to evaluate the influx of fresh water from the south or inner shelf. The contribution from local ice melt may be estimated by considering the duration and extent of the ice cover in the preceding austral winter. During the 1992 austral winter, the sea-ice duration around Palmer Station was about 18 weeks and the maximum sea-ice extent in September was to 60°50'S. These values compare to a sea-ice duration around Palmer Station of 15 weeks and a maximum September extent of 62°20'S during austral winter 1993. Thus, in 1993, the sea ice was of greater extent and disappeared faster than in 1992. It may be that more rapid melting of more sea ice in 1993–1994 introduced fresh water faster than it was mixed or advected away.

The source of the high-salinity water around Anvers Island is unknown, but this water may derive from outflow from the Bransfield Strait through the Gerlache Strait. It is, however, more likely that this may be a region of upwelling of the saltier and warmer Circumpolar Deep Water that is found throughout the continental shelf west of the Antarctic Peninsula (Hofmann et al. in press; Smith et al. 1995), which would then mix with the Antarctic Surface Water. Irrespective of the source of this water, however, the near-surface temperature and salinity distributions indicate that the region near Anvers Island differs from the rest of the west Antarctic Peninsula shelf region.

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Palmer LTER: Temporal variability in the location of the Antarctic Circumpolar Current along the west Antarctic Peninsula continental shelf

JOHN M. KLINCK, *Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, Virginia 23529*

As part of the Palmer Long-Term Ecological Research (LTER) program, a series of cruises was completed during which physical and biological properties of the continental shelf west of the Antarctic Peninsula were measured. In particular, between January 1993 and January 1994, four cruises, covering the same region, provide observations adequate to describe seasonal variability of hydrographic properties. These cruises occurred in January 1993 (Lascara et al. 1993), March to May 1993 (Hofmann et al. 1993), August to September 1993 (Klinck, Smith, and Smith 1995), and January 1994 (Hofmann et al. 1996).

The Antarctic Circumpolar Current (ACC) flows northeastward through Drake Passage; its southern boundary is near the continental shelf break west of the Antarctic Peninsula (Orsi, Whitworth, and Nowlin 1995). Associated with the southern boundary of the ACC is a distinctive water mass, Upper Circumpolar Deep Water (UCDW), which is characterized by relatively warm temperatures (above 1.5°C) and high salinity (34.7) (Orsi et al. 1995). Because of the elevated temperatures, the location of the ACC is easy to identify along this shelf. Thus, the objective of this article is to use the Palmer LTER hydrographic observations to describe changes in hydrography that occurred between January 1993 and January 1994 at the outer continental shelf.

The area covered by the four LTER cruises is shown in figure 1, where locations are determined by the LTER grid system (Waters and Smith 1992). This system is based on distances in kilometers along the shelf and across the shelf from a base point on the peninsula far to the southwest (on Alexander Island).

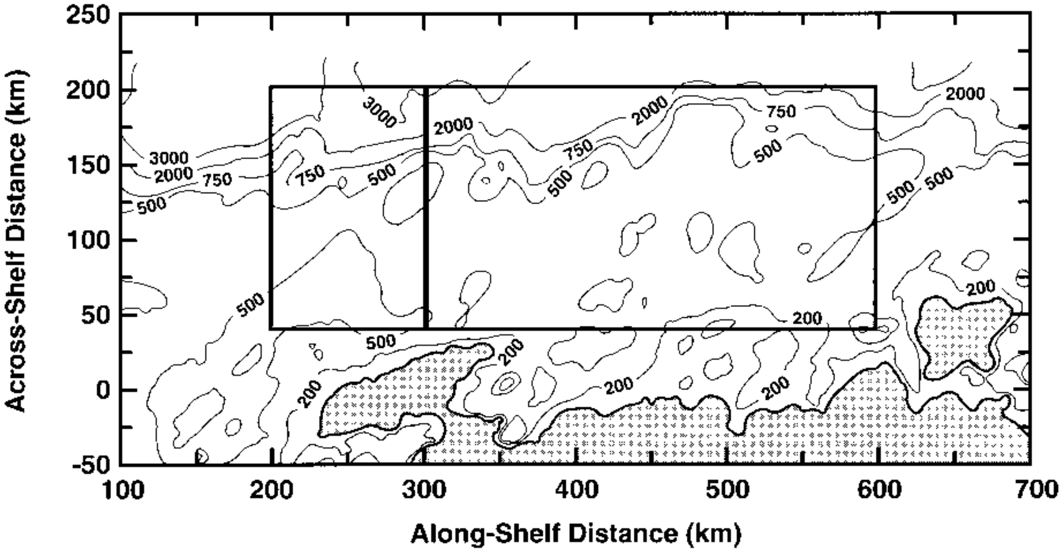

Figure 1. Bathymetry of the Palmer LTER study region. Locations are in distance (km) alongshore and across shore from a base point southwest of the study area (Waters and Smith 1992). The area of LTER sampling is enclosed in the heavy box. A heavy dashed line shows the location of the transects in figure 2. Shaded areas are land. Solid lines are isobaths at depths of 200, 500, 750, 2,000, and 3,000 m. The shelf break typically occurs near the 500-m isobath.

The repeated hydrographic measurements near the shelf break, coupled with the easily identified core of the southern ACC, allow a determination of the time variability in its position. The location of the 1.8°C isotherm at a depth of 300 meters relative to the LTER baseline (figure 1) was determined for each transect on each cruise (table). Two points are clear immediately. First, the 1.8°C isotherm is never observed in the middle portion of the sampling region because the sampling did not extend far enough offshore to capture the southern boundary of the ACC. Second, the location of the ACC is variable everywhere except at the north and south ends of the sampling region.

No clear pattern is evident to the location of the 1.8°C isotherm along the shelf break. In particular, the ACC location at one section does not indicate the location at any other section, which means that the across-shelf movement of this current does not occur as a large-scale shift in position but rather as local meanders with scales smaller than the resolution of the hydrographic observations [100 kilometers (km)]. Dynamical considerations indicate that the meander length scale should be 30 to 50 km.

The nature of the shelf break variability is illustrated by the vertical temperature distribution from the four cruises from a transect in the southern portion of the sampling region (figure 2). The pool of water just cooler than 1.8°C, seen in January 1993 (figure 2*A*), indicates a recent intrusion of UCDW. This temperature structure is reminiscent of that seen at the outer edge of the southeastern U.S. shelf where the Gulf Stream meanders are associated with exchange of water across the shelf break (Lee and Atkinson 1983). Two months later, the ACC is firmly against the shelf break (figure 2*B*). Five months later, the warm core of the ACC has retreated more than 20 km offshore (figure 2*C*). A pool of water with temperatures above 1.6°C remains on the middle shelf and the 1.4°C isotherm has moved closer to the coast. After an additional 4 months, the warmest waters are still offshore and the 1.4°C isotherm on the shelf has lifted offshore almost to the shelf break (figure 2*D*).

The implication of these measurements is that the oceanic flow along the outer shelf break west of the Antarctic Peninsula is dynamically active, likely due to baroclinic instability and the interaction of this current with the rugged topography of the shelf break. The time and space scales of this variability are typical of other meandering coastal currents (timescales of 1–2 months and space scales of 30–50 km). This variability is smaller and faster than can be measured by the current sampling scheme, leaving the possibility that changes between cruises will be a mixture of real interannual variability and higher frequency changes. It appears that this variability is largely confined to the outer half of the continental shelf, but these details remain to be determined.

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Location of the 1.8°C isotherm at a depth of 300 m at the outer edge of five across-shelf transects occupied during four cruises between January 1993 and January 1994

Location	93a	93b	93c	94a	Shelf break
200	150	150	160	NO	140
300	OFF	160	180	185	160
400	180	OFF	OFF	180	160
500	OFF	OFF	OFF	OFF	190
600	190	190	OFF	195	170

NOTE: Each section is identified by its distance alongshore from a base point (Waters and Smith, 1992). The location of the isotherm is in kilometers offshore of a base line along the Antarctic Peninsula. The location of the shelf break along each of these lines is included. The absence of observations along a transect is indicated by NO. The notation OFF indicates that the isotherm was not observed.

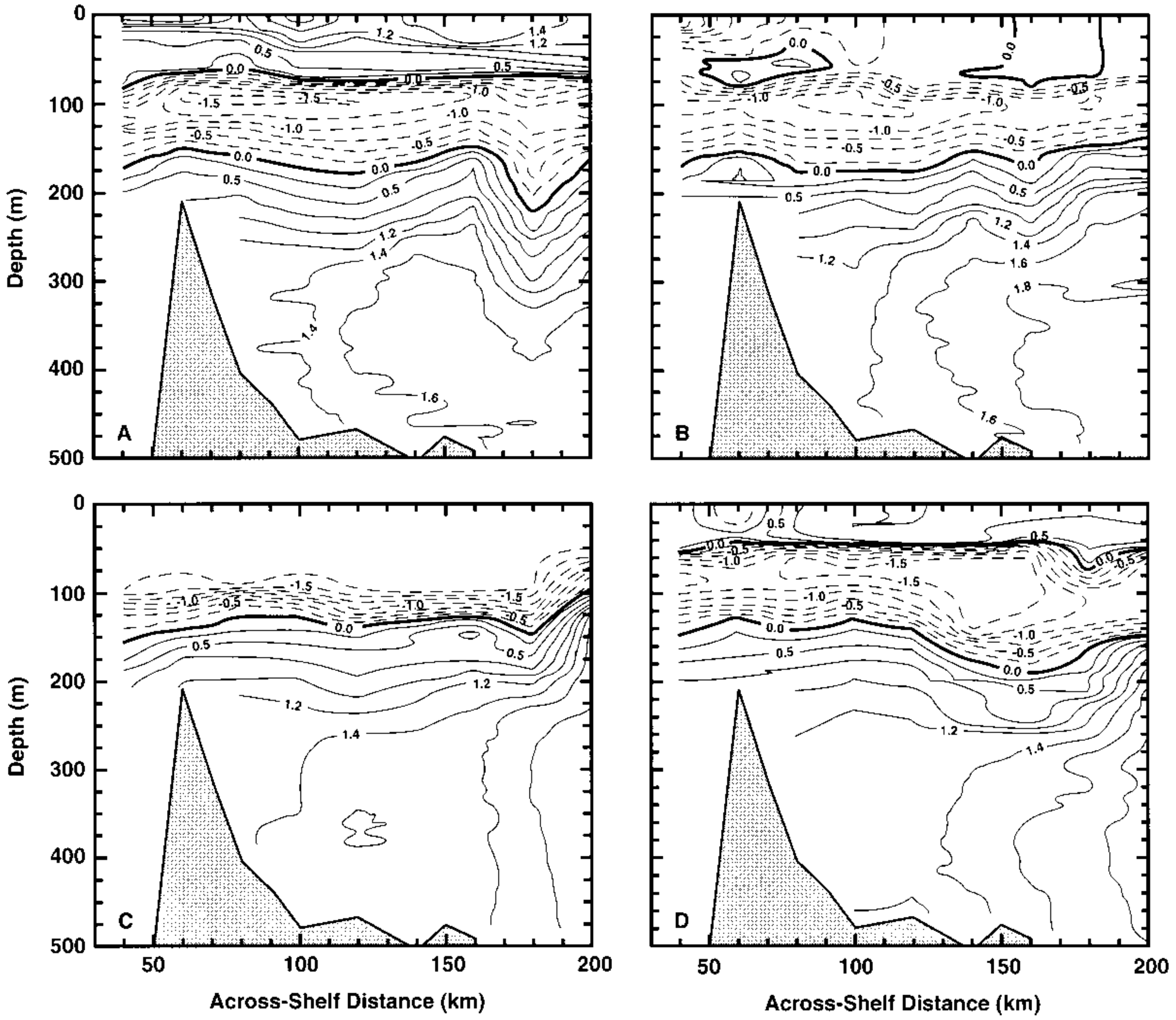

Figure 2. *In situ* temperature from across-shelf transects from four cruises in the southern part of the sampling region (figure 1). Dashed contours indicate temperatures below 0°C. The contour interval is 0.25°C from –2.0 to 1.0°C. The contour interval above 1.0°C is 0.2°C. The ocean bottom, determined by soundings during the March to May cruise, is indicated by shading. (*A*) January and February 1993 cruise. (*B*) March to May 1993 cruise. (*C*) August to September 1993 cruise. (*D*) January and February 1994 cruise.

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Palmer LTER: Comparison of meteorological observations from R/V *Nathaniel B. Palmer* to those at Palmer Station

JOHN M. KLINCK *and* DAVID A. SMITH, *Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, Virginia 23529*

The Palmer Long-Term Ecological Research (LTER) program is focused on understanding the structure and function of the marine ecosystem on the western side of the Antarctic Peninsula. The major emphasis of the research is on the documented interannual changes in the ice cover in this region and the effect that these changes have on the physical, chemical, and biological processes that are important to the ecosystem.

A part of the LTER program considers hydrographic properties and circulation of the continental shelf. Exchanges between the surface ocean and the lower atmosphere have important effects on the processes that control the hydrography and circulation. These exchanges are based on air temperature, humidity, and wind speed as well as other factors, and control formation and melting of ice and heat exchange between the atmosphere and ocean as well as circulation of the ocean.

Estimating the atmospheric conditions over the ocean in antarctic coastal areas can be particularly challenging because of the small number of coastal meteorological stations and, more important, because of the strong effects from the continent on meteorological observations at coastal stations (Schwerdtfeger and Amaturo 1979). Two effects are topographic steering caused by mountain ranges and gaps and katabatic winds, which occur by dense air draining from the antarctic plateau or being pushed over a mountain range. The distance over which land influences meteorological conditions ranges from a few kilometers to perhaps 10 or more kilometers (Schwerdtfeger and Amaturo 1979).

The purpose of this study is to compare atmospheric conditions measured at Palmer Station with simultaneous measurements made on the R/V *Nathaniel B. Palmer* during a cruise in March through May 1993. Correspondence between the two measurements allows a predictive relationship to be developed.

The meteorological observations available from Palmer Station are the daily average temperature, surface barometric pressure, and wind speed and direction, all of which are the World Meteorological Organization (WMO) 6-hour observations. The data used in this study cover yeardays 102 to 132 (11 April to 11 May 1993), the time that the ship was sampling in the coastal waters west and south of Palmer Station (figure 1).

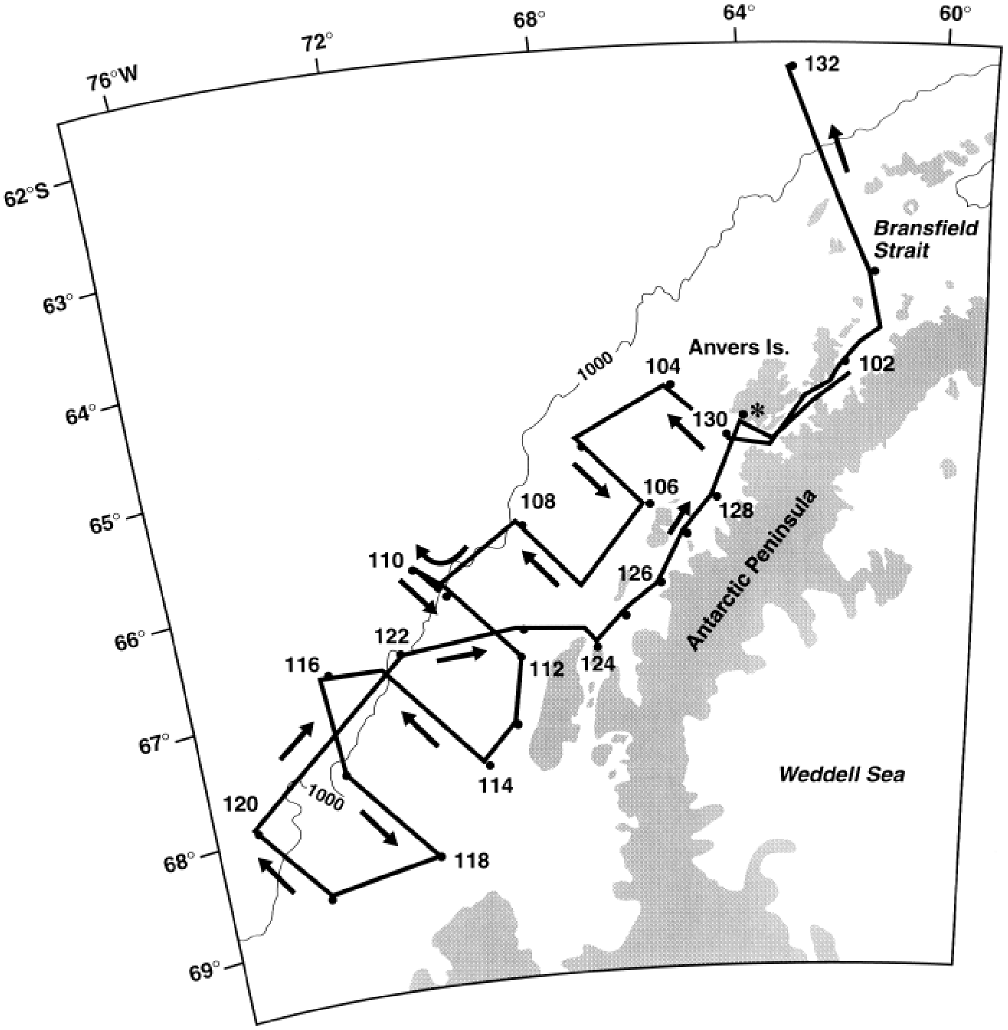

Figure 1. Cruise track for LTER cruise that occurred March to May 1993. The heavy line is the smoothed ship track (from daily values) with a solid dot every day. The numbers are the yearday for the indicated location. Shaded area is land. The line labeled 1,000 is the 1,000 m isobath, which approximately coincides with the edge of the continental shelf.

Meteorological conditions during the cruise were sampled every 6 seconds and averaged over 1 minute for logging (for details, *see* Smith et al. 1993). No corrections were applied to the temperature or surface pressure records. The wind readings were corrected for ship heading and motion, both of which were also included in the real-time logging system. All wind measurements are relative to magnetic north and indicate the direction toward which the wind is blowing (oceanographic convention). For the purpose of this study, ship observations were averaged to daily values to match the time interval of the station observations. Measurements were compared at yeardays 103 and 130 when the ship was near Palmer Station to give confidence that the various corrections were applied properly.

The comparison of the conditions on the ship and at the station is based on 30 daily measurements of surface pressure (figure 2*A*), air temperature (figure 2*B*), and the east-west (figure 2*C*) and north-south (figure 2*D*) wind components. A linear relationship (the simplest assumption) is assumed to exist between the station and the ship observations and a linear least-square technique was used to obtain the slope and intercept of the linear model for each pair of time series (table). The predicted meteorological conditions at the ship obtained from the station observations using the linear regression model are shown in figure 2.

The predicted surface pressure has the best correspondence with offshore observations: 92 percent of the variance is explained (figure 2*A*). The predicted values match well except between days 113 (ship near Adelaide Island) and 123 (ship returned to Adelaide Island). This fit is not surprising because of the large length scales (100s of kilometers) associated with atmospheric pressure variations.

The predicted air temperature has poorer agreement between conditions at the station and the ship; however, the linear relationship explains two-thirds of variance. At the beginning of the time interval (until day 110), the air is consistently warmer (2–3°C) over the shelf relative to the station. After day 115, the temperature is consistently colder on the ship, which has to do with the ship being south of the station, near Marguerite Bay. The predicted values are within 3°C of the ship values, but the predicted temperatures miss the warmer conditions over the shelf off Palmer Station (days 103–112). The model also underestimates peak values through the rest of the cruise. The slope parameter shows that the temperature variations over the shelf are about 60 percent of those observed at the station.

The predicted winds have a different character for each component. The station east-west wind is almost always weaker than winds over the shelf. At times, the east-west wind strengths at the station and offshore agree, but differences as large as 7 meters per second (m s^{-1}) occur. The agreement of the two wind time series does not seem to depend on separation distance. Although the two time series look different, the linear regression model produces a reasonable prediction.

The north-south component of the winds matches more closely, except when the ship is far to the south and offshore (days 120 to 125). The offshore winds are consistently stronger than the station winds but not by as much as the

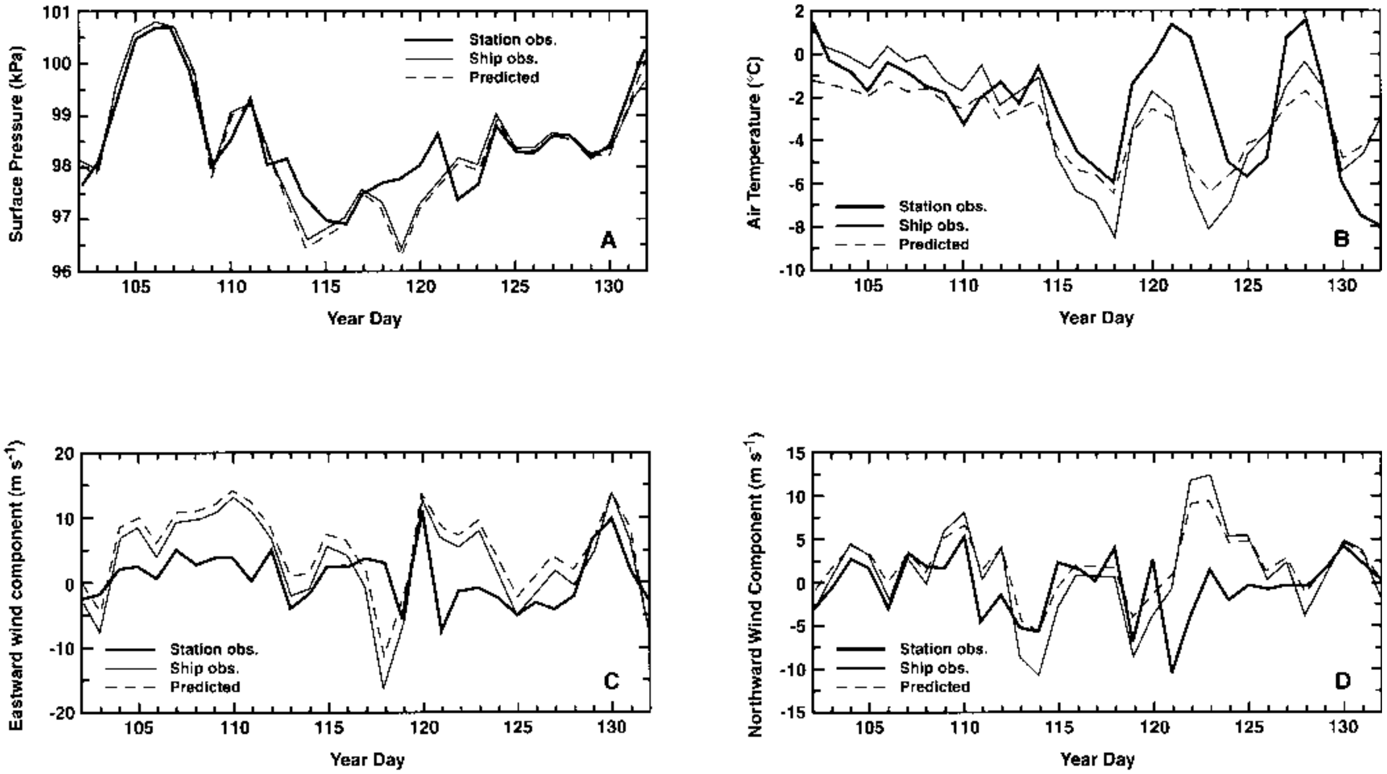

Figure 2. Daily values of four meteorological observations from Palmer station (heavy line) and from the R/V *Nathaniel B. Palmer* (thin line). The dashed line is the predicted values at the ship from the linear relationship. (*A*) Surface barometric pressure. (kPa denotes kilopascals) (*B*) Air temperature. (*C*) East component of surface winds. (*D*) North component of surface winds.

Parameters obtained for the linear model derived to predict offshore atmospheric conditions from those measured at Palmer Station

Parameter	Units	Intercept	Slope	r^2
Temperature	°C	–1.51	0.594	0.636
Surface pressure	Kilopascals	–3.15	1.030	0.918
North-south wind speed	Meters per second	1.28	0.653	0.446
East-west wind speed	Meters per second	2.53	0.880	0.520

east-west winds. Once again, the linear model produces a reasonable prediction of the observed ship winds, but it underestimates the amplitude of some of the peaks.

Overall, the offshore winds are well represented by the linear model. The largest misfit is in the range of 1.3 $m\ s^{-1}$, which is not small but is within acceptable limits for many studies. This study demonstrates that it is possible to use station observations of atmospheric conditions to estimate conditions over the ocean. The values predicted from the station observations have similar amplitude and time variation as the values measured on the ship over a wide area of the shelf. The relationship must be used with caution because it would be valid only over the austral fall and may not apply to all years without additional testing. This work could be extended with longer data records and more sophisticated models. It would also be useful to have independent observation to test the quality of the prediction formulas.

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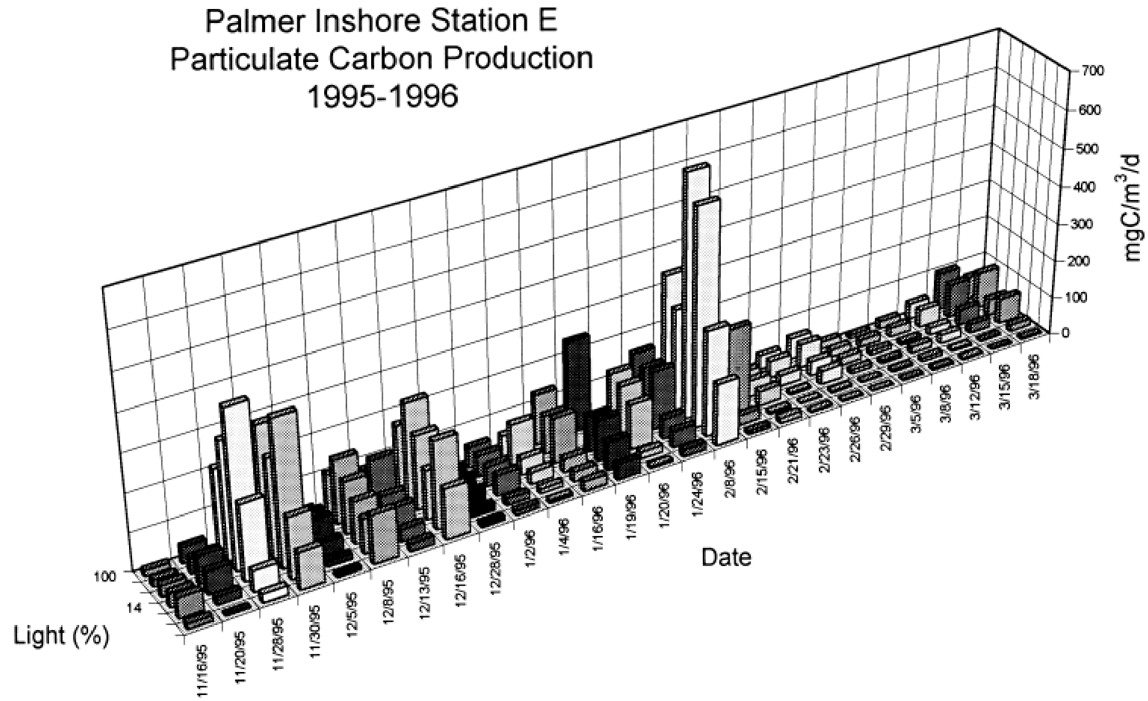
Palmer LTER: Temporal variability in primary production in Arthur Harbor during the 1995–1996 growth season

Maria Vernet, Wendy Kozlowski, Jonah Rosenfield, *and* Andrew Greaves, *Marine Research Division, Scripps Institution of Oceanography, La Jolla, California 92093-0218*

An understanding of spatial and temporal variability in primary production and its relationship to physical and biological factors is necessary to model carbon cycling in the antarctic ecosystem. The Palmer Long-Term Ecological Research (LTER) program is testing the hypothesis that the magnitude and distribution in carbon uptake by phytoplankton are linked to the extent of ice cover during the preceding winter months. This temporal variability is studied at a coastal station near Arthur Harbor on Anvers Island for 5 months to show the extent and timing of productivity in the area. The sampling represents the growth season in coastal waters of the Antarctic Peninsula, which on the average, extends from November to March in this region (Tokarczyk 1986; Smith, Dierssen, and Vernet in press).

Water samples were obtained biweekly from two stations (stations B and E in Palmer LTER inshore grid): one off Bonaparte Point, Anvers Island, and the other offshore and to the south (64°48.9'S 64°02.4'W) (Waters and Smith 1992). Samples were taken with a Go-Flo bottle at the surface and depths corresponding to 50 percent, 24 percent, 14 percent, 4 percent, and 2 percent of incident radiation. Depths were established by measuring photosynthetically available radiation with a LICOR 193-SA Quantum Sensor. Water was stored in a cooler and transported back to the station. Duplicate samples were inoculated with 5 microcuries of carbon-14–bicarbonate and incubated outside the station. Neutral nickel screens were used to simulate the corresponding light levels. Running sea water through the incubator kept the samples at *in situ* temperature. After 24 hours, samples were filtered onto a Whatman GF/F filter, acidified with 0.4 milliliters of 15 percent glacial acetic acid, and counted after addition of Universol ES. Production rates are expressed as milligrams carbon per cubic meter per day.

The major pulses in primary production in this area occur in late spring (December and January) as well as later in the summer (February and March) (Prézelin et al. 1992). The first event is generally larger and can last for a few weeks whereas the second pulse is of secondary magnitude. The 1995–1996 season blooms followed this general pattern, though the first pulse in productivity in late November and early December was slightly smaller than the second, which occurred in early February (figure). Maximum rates were observed below the surface layer (24



Primary production estimates at 64°48.9'S 64°02.4'W, based on simulated *in situ* incubations done during the 1995–1996 growth season, in units of milligrams carbon per cubic meter per day. Samples were taken at six depths corresponding to 100 percent, 50 percent, 24 percent, 14 percent, 4 percent, and 2 percent of the incident irradiance.

percent of the incident radiation corresponding to depths from 3.5 to 15.5 meters). Integrated primary production rates during these events were high: 4.41 and 6.24 grams carbon per square meter per day for 28 November and 8 February, respectively. Yearly production at this station, based on the 26 sampling dates in a growth season from 16 November to 18 March, was estimated at 279.9 grams carbon per square meter per year. Similar to the 1994–1995 season, these pulses of productivity lasted approximately 1 to 2 weeks; however, the yearly production was estimated to be 2.4 times higher and to have a deeper average depth of maximum production (24 percent of incident light in 1995–1996 vs. 50 percent in the 1994–1995 season).

Similar to 1994, the winter preceding the 1995–1996 growth season was characterized by heavy ice in the region of the western coast of the Antarctic Peninsula. This heavy ice shows in the area every 5 to 6 years (Smith and Stammerjohn in press). The high production rates observed in 1994–1995 and 1995–1996 further support the hypothesis that high primary production is associated with the ice extent.

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Palmer LTER: Paleohistory of the Palmer LTER region: Palmer Deep sedimentary record

MATTHEW LOPICCOLO *and* EUGENE DOMACK, *Department of Geology, Hamilton College, Clinton, New York 13323*

In 1992, the R/V *Polar Duke* cruise *PD*92-1 collected several piston cores from the Palmer Deep Basin, south of Anvers Island (figure 1). Analysis of core *PD*92-30, retrieved at 64°51.720'S 64°12.506'W from Basin I, found that core 30 is an excellent indicator of paleoclimatic fluctuations as shown by magnetic susceptibility and total organic carbon (TOC) content (Leventer et al. 1996). Magnetic susceptibility and TOC both experience high-resolution cyclical fluctuations on a 200–300 year timescale, which correlates with studies by LoPiccolo (1996) and Mashiotta (1992) on core 22 collected from the central basin of Andvord Bay in 1988. The importance of *PD*92-30 as a climate indicator lies in the fact that it was collected along the polar/subpolar boundary. Domack and McClennen (1996) claim that this region experiences subtle changes in sea-ice extent that affect productivity, unlike areas to the north and south where sea ice is a less or more permanent feature.

Unfortunately, piston core operations often lose approximately the top meter of sediment. This missing top of the core is crucial for the complete determination of Holocene climate change. Thus, three short gravity cores were collected from Basin I during R/V *Polar Duke* cruise 1995-10 in an attempt to obtain the sediment water interface (LoPiccolo, unpublished report) and the youngest sediments in the basin. Correlation of magnetic susceptibility, TOC content, grain size data, and carbon-14 (^{14}C) dates from *PD*92-PC30 and *PD*95-GC 1, 2, and 3 will determine how much sediment was lost from *PD*92-PC30, establish a detailed stratigraphic sequence of Basin I, and give more precise corrections for radiocarbon dates. This combined information will provide a more accurate picture of Holocene climate change in the Antarctic Peninsula region, and that information will help determine modern climate trends and possible anthropogenic influences on climate.

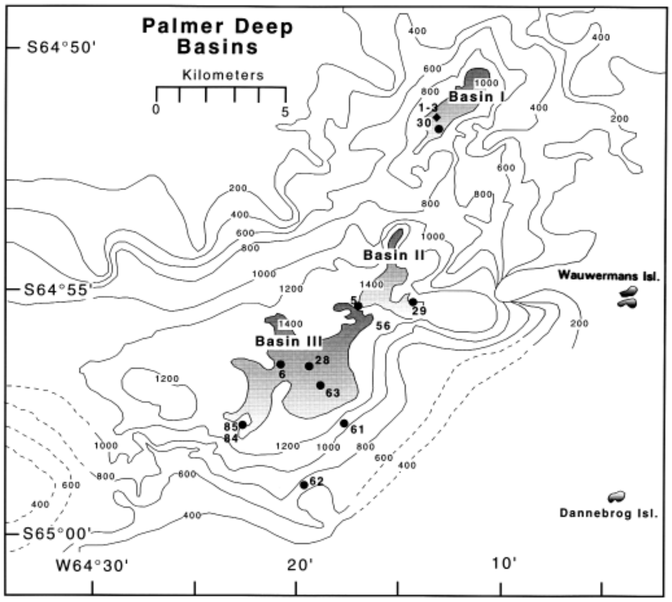

Figure 1. Region of the Palmer Deep showing locations of all sediment samples collected from the basin by the U.S. Antarctic Program. Cores *PD*95-10 (1–3) are located in Basin I (♦), close to the site of core *PD*92-30 (•). Cores *PD*92-5, -6, -28, -29 are located in the other basins of the Palmer Deep. Cores DF85-61, -62, and -63 are in Basin III. Box core DF86-85 and piston cores -84 and -56 are also located in Basin III.

Three 8-centimeter (cm) diameter gravity cores of various lengths (188 cm, 261 cm, and 264 cm) were collected in Basin I of the Palmer Deep, Antarctica, during R/V *Polar Duke* cruise 95-10. The objective of this coring operation was to obtain a sediment core of the first meter of sediment in the Palmer Deep; at approximately 64°51.720'S 64°12.506'W, the site of PC 30, retrieved during *PD*92-2 (table 1). The cores were processed for magnetic susceptibility aboard the R/V *Polar Duke* using a Bartington magnetic susceptibility recorder, model MS-2C. Measurements were taken every 5 cm. Cores 1, 2, and 3 were split, photographed, described, and x-ray radiographed, at the Antarctic Marine Geology Research Facility at Florida State University where all three cores are curated. Cores 2 and 3 were subsampled every 5 cm for further analysis at Hamilton College, Clinton, New York. The x-ray radiographs were examined to determine lithologic structures and used to conduct a gravel concentration analysis.

Core 3 subsamples were analyzed for grain size, TOC, and radiocarbon dates. The grain size analysis was conducted using a Malvern Master Sizer E. Fifty-three samples were analyzed at the 0.1–80 micron range. The TOC content was determined by combustion in a LECO induction furnace. Samples were prepared by first soaking in a 2 normal hydrochloric acid solution followed by series of decants using distilled water. Several organic-rich samples required the use of a centrifuge to separate the water from the suspended sediment sample. Six sediment samples were collected from GC 3 for ^{14}C analysis. Samples were taken at the sediment water interface, and at depths 25 cm, 50 cm, 115 cm, 200 cm, and 230 cm while on

Table 1. Core locations

Core	Water depth (in meters)	Latitude	Longitude
1	1,016	64°51.57'S	64°12.29'W
2	1,015	64°51.17'S	64°12.43'W
3	1,020	64°51.09'S	64°11.47'W

board the R/V *Polar Duke* and transferred chilled to Hamilton College where they were dried and acified in the 2 normal hydrochloric acid solution. ^{14}C dates were determined at the University of Arizona by accelerator mass-spectrometry and are reported in table 2. Core 2 subsamples were weighed for the determination of sample water content.

Our preliminary stratigraphic correlations are illustrated in figure 2 where we compare the magnetic susceptibility and radiocarbon data from the four cores collected in Basin I of the Palmer Deep. In summary, we believe that stratigraphic correlation is good between the sites below the uppermost meter because both radiocarbon and magnetic susceptibility signatures indicate normal stratigraphic succession. Above this depth, however, the stratigraphy is less clear, and evidence indicates significant reworking of organic particulates because radiocarbon ages are inversed and are older than ages from lower strata. Although our sedimentologic study of these cores is far from complete, at this early stage, it is clear that sediment gravity flows are an important component of the most recent record in Basin I of the Palmer Deep. This presence contrasts dramatically with the last 4,000 years of deposition, which is marked by pelagic and hemipelagic sedimentation (Leventer et al. 1996). The cause for this change in sediment regime will be the focus of continued research in the Palmer Deep system.

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Table 2. Uncorrected radiocarbon ages from core PD95-10, GC3

NOTE: All samples based on acid insoluble organic matter and processed according to procedures outlined in Domack and McClennen (in press).

Laboratory number	Depth (in centimeters)	Uncorrected age	$\delta^{13}C$
CAMS 25571	0–2	4,680±60	–25[a]
AA-20070	25–26	1,955±50	–25.7
AA-20071	50–51	4,040±55	–25.8
AA-20072	115–116	2,925±55	–25.2
AA-20073	200–201	3,000±55	–26.1
AA-20074	230–231	3,550±80	–25.8

[a] Sample was too small to measure $\delta^{13}C$; this figure is an estimate.

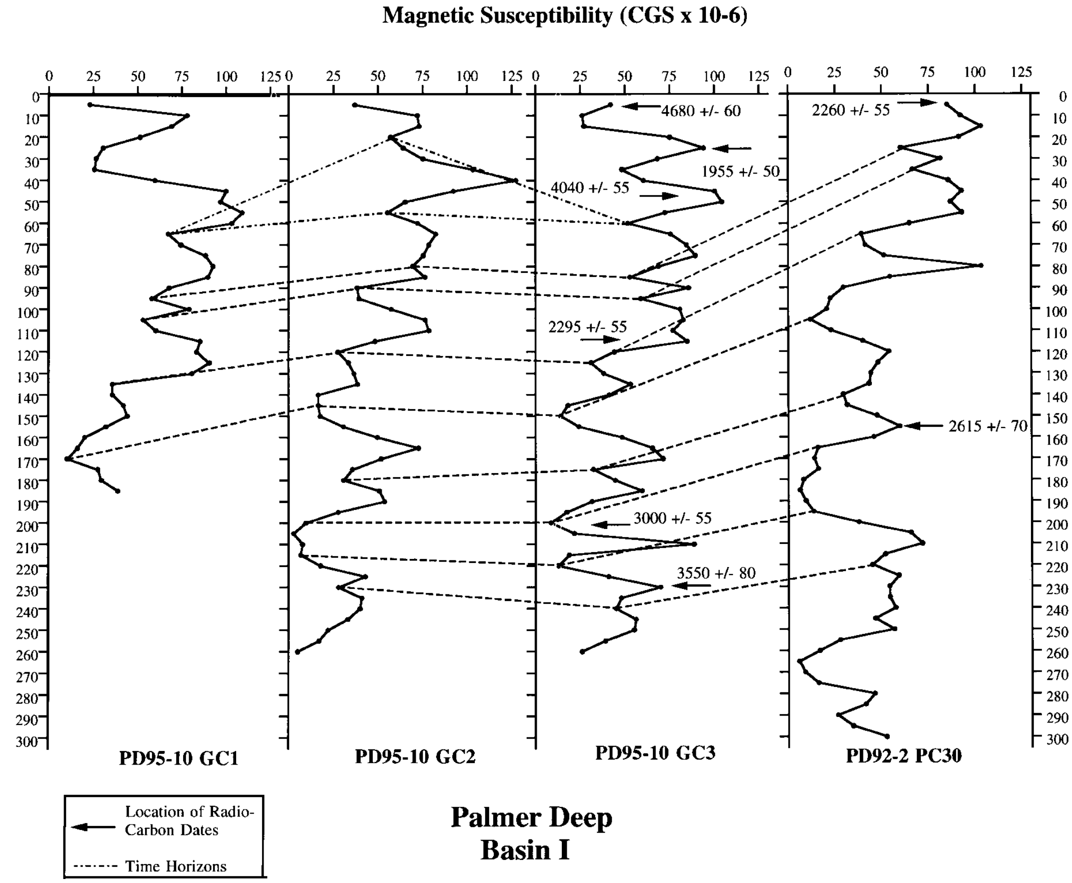

Figure 2. Magnetic susceptibility versus core depth for gravity cores 1–3 (*PD*95-10) and piston core (*PD*92-30). Locations of radiocarbon dates (uncorrected) and ages are also given for cores 30 and 3. Stratigraphic time lines are shown by dashed lines between cores. Note missing section from the top of core 30. (CGS denotes centimeter-gram-second.)

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