

## Project Summary

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### Palmer LTER Lagrangian Current Measurements

R. C. Beardsley, R. Limeburner, and H. Ducklow (VIMS)

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We propose to deploy satellite-tracked surface drifters and isobaric float during the annual austral summer Palmer Long Term Ecological Research (LTER) cruises in January 2005, 2006, and 2007 in order to investigate the near-surface and sub-pycnocline Lagrangian currents over the western Antarctic Peninsula (wAP) shelf between 63° and 68°S. The Palmer LTER investigators have focused their studies in this region since 1990, and have collected much valuable hydrographic and biological data on this ecosystem, but to date there have been very few direct measurements of currents. Satellite-tracked drifters and floats provide simple yet powerful tools to track the motion of near-surface and deeper water on time scales ranging from the tidal/inertial band to monthly and longer. The deployment of drifters and floats on LTER cruises will yield Lagrangian current data of intrinsic interest and help place the other LTER measurements in the context of the regional circulation. These new Lagrangian measurements will also complement the drifter and float measurements made in Marguerite Bay and adjacent wAP shelf south of 66°S during the 2001–2003 U.S. Southern Ocean (SO) GLOBEC program. The combined drifter data will provide the first detailed look at the near-surface flow in this important section of the wAP shelf. In particular, the LTER Lagrangian measurements should identify (a) the source region(s) of the buoyant coastal current discovered flowing southwest along the outer coast of Adelaide Island and into Marguerite Bay during SO GLOBEC and (b) if organized cross-shelf flows occur that help create a gyre-like circulation over the shelf as suggested by regional hydrography.

This proposal specifically seeks support to collect, process, and analyze the drifter and float data and collaborate with Palmer LTER investigators on the interpretation of the Lagrangian data with their studies. Raytheon Polar Services Inc (RPS) and WHOI will supply the 21 drifters and 4 isobaric floats, respectively, which will be deployed on each austral summer LTER cruise under the supervision of Ducklow as part of his LTER work. The repeated drifter and float deployments will give the first synoptic measurements of the regional near-surface and sub-pycnocline Lagrangian circulation, providing a unique data set for understanding LTER and other observations plus testing regional circulation models. The edited data, analysis results, and animations of the drifter and float data with surface weather data will be posted on the LTER website for use and viewing by scientists, students, and the public

**Intellectual Merits:** The proposed LTER drifter and float measurements together with the SO GLOBEC data will provide the first detailed look at the near-surface and deeper flow on the wAP shelf between 63°S and 69°S. This region is experiencing the highest surface air temperature increase (roughly +0.06 °C per year) in Antarctica, and LTER and other investigators have found that ecosystem responses to the rapid warming and sea ice decline are already apparent at all trophic levels from phytoplankton to penguins. Building a better understanding of the regional circulation and its variability seems an essential component to understand existing physical and biological processes and longer-term changes in this important and sensitive Antarctic ecosystem.

**Broader Impacts:** This research will allow us to work directly with LTER and other investigators working in the study region, helping them interpret their work within the context of our evolving understanding of the regional circulation. All LTER drifter and float data, animations, supporting data, and analysis results will be posted on the LTER website for general use, and results will be presented at national meetings and published in referred journals.

## **Section B. Results from Prior NSF Support**

**BEARDSLEY, LIMEBURNER, OWENS. *OPP-99-10092: “WinDSSOcK: WINTER Distribution and Success of Southern Ocean Krill: Moored Array, Drifter and Float Measurements”*** \$2,082,652 (9/15/00-8/31/04).

This component of U.S. SO GLOBEC supported the deployment of arrays of subsurface moorings to measure currents, water properties and sea ice motion, satellite-tracked drifters and isobaric floats to observe the Lagrangian near-surface and deep flow, and two Automatic Weather Stations to monitor surface weather conditions in the Marguerite Bay-WAP shelf study region. Supporting bathymetric, hydrographic (CTD/microstructure) and meteorological data were also collected to document the physical environment and surface forcing during the 2001-2003 field study.

*Scientific Findings:* The drifter and moored measurements indicate a surface circulation consisting of an open regional clockwise gyre, with a wind- and buoyancy-driven coastal current that flows southward along Adelaide Island, into and around Marguerite Bay, and westward along the northern end of Alexander Island. Drifters exiting the Bay eventually move northeastward near the shelf break. The deeper currents tend to be barotropic, weakly bottom-intensified, and strongly influenced by local topography due to small subpynocline stratification. The moored current and hydrographic data suggest a mean flow of Lower Circumpolar Deep Water into Marguerite Bay along the northern flank of Marguerite Trough, thus making this deep canyon an important cross-shelf conduit for heat and salt. The strongest currents in all seasons are near-inertial oscillations, driven by both wind and sea ice motion. These are thought to be the primary source of vertical mixing.

*Training and Development:* Two MIT/Woods Hole Oceanographic Institution (WHOI) Ph.D. students (J. Hyatt and C. Moffat) and one WHOI summer student fellow (D. Liptzin) were supported to analyze data collected by this grant. Hyatt, A. Stine (MIT/WHOI M.S.), C. Cenedese (WHOI assistant scientist), and two new WHOI mooring technicians gained valuable at-sea training on the SO GLOBEC mooring cruises.

*Outreach Activities.* There have been 12 presentations at national and international meetings, 6 cruise reports, 2 WHOI technical reports, and 3 publications and 1 submitted manuscript acknowledging this award. The WHOI tech reports describe a new high-resolution digital bathymetry data set created for the SO GLOBEC study area and the moored array study and basic data. These reports and the moored, drifter, float and AWS data sets are available online at the U.S. GLOBEC Data Management Office.

*Publications:*

Klinck, J., E. Hofmann, R. Beardsley, B. Salihoglu, and S. Howard, 2004. Water mass properties and circulation on the west Antarctic Peninsula continental shelf in austral fall and winter 2001. *Deep-Sea Res. II*, 51, 1925-46.

- Beardsley, R., R. Limeburner, and B. Owens, 2004. Drifter measurements of surface currents near Marguerite Bay on the West Antarctic Peninsula Shelf during austral summer and fall. *Deep-Sea Res. II*, 51, 1947-64.
- Howard, S., J. Hyatt, L. Padman, 2004. Mixing rates in the pycnocline of the Western Antarctic Peninsula shelf. *Deep-Sea Res. II*, 51, 1965-79.
- Hyatt, J., M. Visbeck, R. Beardsley, and W.B. Owens, Measuring sea ice coverage, velocity and draft using a moored upward-looking acoustic Doppler current profiler (ADCP). Submitted to *J. Atmos. Ocean. Tech.*

**H. W. DUCKLOW, NSF-OPP 0217282. “LTER: PALMER, ANTARCTICA LTER: Climate Change, Ecosystem Migration and Teleconnections in an Ice-Dominated Environment” 10/15/2002 – 9/30/2008. \$4.2M.**

This award is to continue support for the Palmer, Antarctica LTER Project (PAL) in its third 6-year funding period. For the previous 12 years the award was made to the University of California-Santa Barbara (Raymond Smith, PI). The award moved to VIMS with the impending retirement of Smith and with Ducklow's succession to lead PI. Since I am a recent addition to the program, I list below recent publications by project PI's, focusing on the project rather than exclusively on my own work. PAL seeks to understand the structure and function of the Antarctic marine and terrestrial ecosystem in the context of physical forcing by seasonal to interannual variability in atmospheric and sea ice dynamics, including forcing by long-term climate change (Dierssen et al., 2002; Goodin and Smith, 2003; Stammerjohn et al., 2003; Smith et al., 2003;). Focused on the western Antarctic Peninsula (WAP) region, the PAL LTER measurement system is explicitly designed to study changes in time and space of marine foodwebs consisting principally of diatom primary producers (Garibotti et al., 2003ab), the dominant herbivore Antarctic krill, *Euphausia superba* (Frazer et al., 2002; Haberman et al., 2002, 2003ab; Quetin et al., 2003ab), the apex predator Adélie penguin, *Pygoscelis adeliae* (Fraser and Hofmann 2003; Chapman et al., 2004) and a microbial foodweb in which planktonic *Bacteria*, *Archaea* and bacterivorous protozoa may play an important role as food for zooplankton (Church et al., 2003). In addition to foodweb ecology PAL also studies the effects of UV irradiation on the marine ecosystem (Hader et al. 2003), ocean biogeochemistry in the Antarctic (Carillo et al. 2004) and the entry and effects of persistent organic pollutants into the Antarctic marine ecosystem (Chiuchiolo et al. 2004) and ecological network information system development (Baker et al. 2003, 2004; Karasti et al., 2004). The papers mentioned here supported by this grant are denoted in the references by a cross (†).

### **Section C. Project Description**

We propose to deploy satellite-tracked near surface drifters during the annual austral summer Palmer Long Term Ecological Research (LTER) program cruises in January

2006 and 2007 in order to investigate the near-surface Lagrangian currents over the Western Antarctic Peninsula (WAP) shelf between 63° and 68° S. The LTER investigators have focused their studies in this region since 1990, and have collected much valuable hydrographic and biological data on this ecosystem, but to date there have been very few direct measurements of currents. Satellite-tracked drifters provide a simple yet powerful tool to track the motion of near-surface water on time scales ranging from the tidal/inertial band to monthly and longer. The deployment of drifters on LTER cruises will yield Lagrangian current data of great intrinsic interest and help place the other LTER measurements in the context of the regional circulation.

These drifter measurements will also complement the drifter measurements made in Marguerite Bay and adjacent WAP shelf south of 66° S during the 2001-2003 U.S. Southern Ocean Global Ocean Ecosystem Dynamics (SO GLOBEC) program. The combined drifter data will provide the first detailed look at the near-surface flow in this important section of the WAP shelf. In particular, the LTER drifter results should identify (a) the source region(s) of the buoyant coastal current discovered flowing southwest along the outer coast of Adelaide Island and into Marguerite Bay during SO GLOBEC and (b) if organized cross-shelf flows occur that help create a gyre-like circulation over the shelf as suggested by regional hydrography. These direct current measurements in combination with the extensive LTER shipboard water column physical, chemical and biological measurements will provide a significant improvement in our understanding of this atmospherically-forced ecosystem.

This proposal is organized as follows. First brief descriptions are given of the Palmer LTER program and the conceptual model of the regional circulation presented prior to the recent SO GLOBEC program. Then results of the SO GLOBEC drifter and float studies are presented. Then a more detailed description of the proposed work is given, followed by summary statements about the scientific and other merits of this work. This research effort has been designed by the following team of investigators - R. Beardsley and R. Limeburner at the Woods Hole Oceanographic Institution and H. Ducklow at the Virginia Institute of Marine Sciences - with significant input from D. Martinson at Lamont Doherty Geophysical Observatory. While not a formal component of the present Palmer LTER program, the proposed work will be conducted in close collaboration with LTER investigators, and Ducklow (lead Palmer LTER Principal Investigator) will help ensure that our results will be fully integrated with LTER results.

### **The Palmer LTER Program**

The Palmer LTER program was started in 1990 by the National Science Foundation Office of Polar Programs to investigate the marine ecosystem on the western Antarctic Peninsula (WAP) shelf and its sensitivity to climate change and sea ice variability on season to inter-annual and decadal time scales (Smith et al, 1995). Long-term air temperature measurements at the British station Faraday (65.25° S, 64.27° W) plus shorter records at the British station Rothera (Adelaide Island) and Palmer Station show that the highest warming trends in the entire Antarctic occur in the LTER study area (Smith and Stammerjohn, 2001). In particular, while there is large inter-annual

variability, these records show that the yearly mean (and especially the winter minimum) air temperatures are rising at a rate of roughly  $+0.06\text{ }^{\circ}\text{C}$  per year. Ecosystem responses to the rapid warming and sea ice decline are already apparent at all trophic levels from phytoplankton to penguins (Smith et al., 2003).

The Palmer LTER study area includes Palmer Station, where year-around studies can be readily conducted, and extends along the shelf towards the southwest to Marguerite Bay (Figure 1). The shelf bathymetry in this area is quite variable, with an average depth of order 400 m, numerous banks and deeper channels, and a shelf break at roughly 500 m. A line of islands stretching southwest from Palmer Station on Anvers Island to Adelaide Island tends to separate the shelf from the coast, forming an “inner passage” along the coast that is connected to the shelf through several straits and passages.

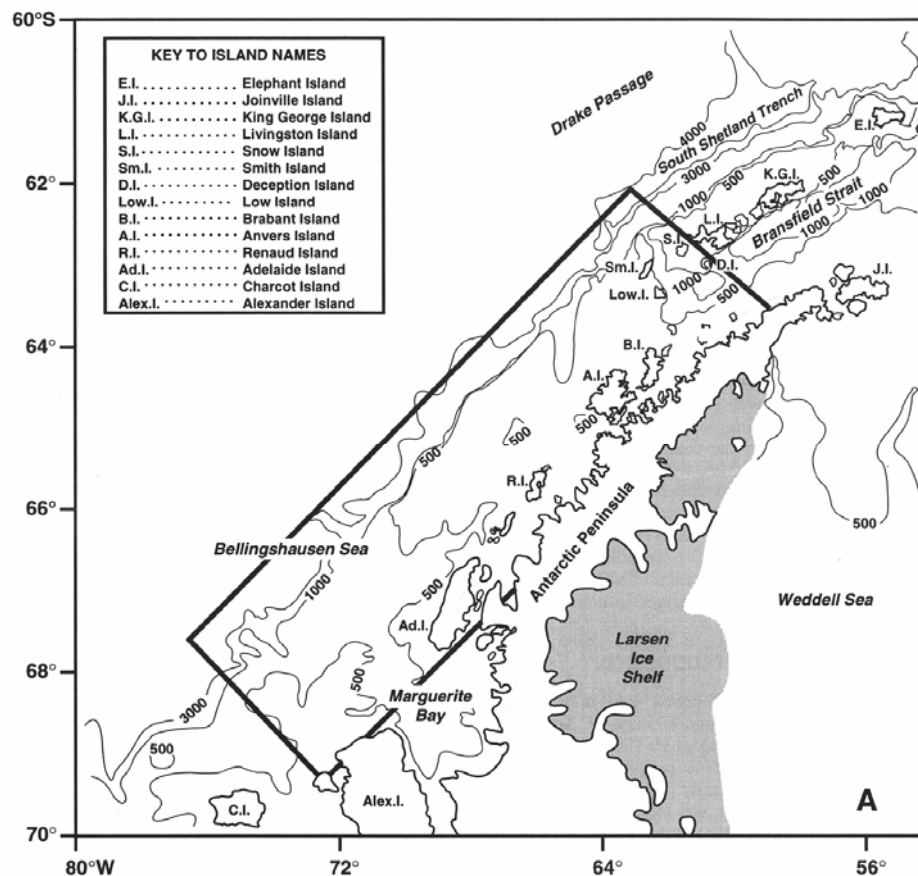


Figure 1 Map of the western Antarctic Peninsula (WAP) shelf region. The bottom contours are given in m. The rectangle shows the PAL study region. (Figure from Hofmann and Klinck, 1998)

The Palmer LTER program features a wide mix of interdisciplinary studies designed to (a) characterize the physical environment (water structure) and forcing (especially solar radiation, sea ice, and air-sea exchange), (b) investigate the WAP food web with a focus on keystone species (phytoplankton, krill, and penguins) and their linkages, (c) investigate biological processes that strongly influence community structure and carbon fluxes, and (d) develop coupled physical/chemical/biological models to synthesis the field data and examine in greater detail ecosystem response to variability in the physical

environment. Each year, PAL investigators conduct an intensive sampling cruise in austral summer (December-January) aboard the RV *L. M. Gould* to map spatial patterns in the key physical and biological fields and undertake specific process studies. The physical measurements include full water-column CTD casts, discrete water samples for DO and nutrient analysis, shipboard ADCP and surface meteorological measurements, and other more specialized measurements. Additional LTER cruises have been made in several years (e.g., Sept.-Oct. 2001) to examine seasonal changes in the physical environment and ecosystem.

Palmer LTER investigators (Hofmann et al., 1996; Hofmann and Klinck, 1998; Smith et al., 1999; Martinson et al., 2004) used LTER hydrographic data to present a clear picture of the seasonal evolution of water properties and stratification in the PAL WAP study area. An on-shelf flow of Upper Circumpolar Deep Water (UCDW) from the Antarctic Circumpolar Current (ACC) maintains a relatively warm, salty, nutrient-rich lower layer over the shelf beneath an upper layer of relatively cooler, fresher Antarctic Surface Water (AASW). The two layers are separated by a permanent pycnocline, centered between 150 m and 200 m, maintained by a mean vertical flux of heat and salt into the upper layer (Klinck, 1998; Smith and Klinck, 2002). Vertical mixing of the UCDW into the surface layer enhances diatom growth and exerts a powerful influence on nutrient biogeochemistry in the region (Prezelin et al., 2004). Over much of the shelf, net surface heating in austral spring through fall ( $\sim +80 \text{ W/m}^2$ ) warms the upper water column to depths of 50 to 100 m, while increased wind mixing, surface cooling ( $\sim -80 \text{ W/m}^2$ ), and brine rejection during ice formation in fall through winter creates a  $\sim 80$ -m deep surface mixed layer. The shelf region is typically covered with sea ice from July through December, which melts in spring to form AASW. Anomalously fresh surface water found in the “inner passage” and adjoining coastal regions is dominated by glacial melt (mainly from calving events and subsequent brash ice, which is frequently observed as a blanket over the entire local area) (Martinson et al., 2004)

In comparison, very little is actually known about currents in the Palmer LTER study area. Prior to 2001, the only direct current measurements made in this area consist of the drift of one FGGE drifter in 1979 and shipboard ADCP data (which exhibit too much variability to infer any regional “mean” current field). The FGGE drifter moved northeastward along the shelf break during austral spring, then crossed the shelf near  $65.5^\circ\text{S}$  and moved southwestward to Adelaide Island in summer (mean speed  $\sim 6 \text{ cm/s}$ ) before failing. Hofmann et al. (1996) used this drifter movement plus LTER water property and dynamic topography maps to propose the regional circulation model shown in black in Figure 2. Their schematic consists of flow to the northeast over the outer shelf, a counter flow towards the southwest over the inner shelf, and cross-shelf flows near  $65^\circ \text{ S}$ , west of Renaud Island, and near  $63^\circ \text{ S}$ , northeast of Anvers Island. The ACC runs towards the northeast roughly parallel to the WAP slope and is thought to drive the flow over the outer shelf. The inner-shelf southwest flow is thought to be a buoyant wind-driven coastal current. The cross-shelf flows near  $65^\circ \text{ S}$  form a two-gyre pattern.

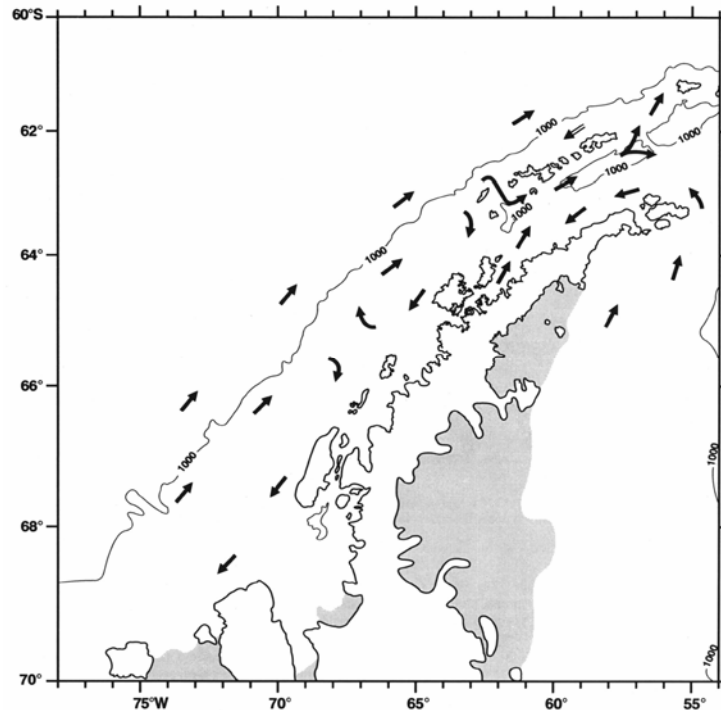


Figure 2 Schematic of circulation over the western Antarctic Peninsula shelf proposed by Hofmann et al. (1996). The 1000-m isobath is shown to demark the outer edge of the shelf.

Recent data on penguin foraging activity, ocean color observations and plankton ecology all suggest biological activity from microbes to penguins is concentrated in three localized areas, as opposed to being spread more uniformly across the region. Palmer LTER investigators hypothesize that these hotspots are characterized by unique conjunctions of topography, bathymetry and circulation, which support enhanced biological productivity and, hence, large, associated seabird colonies (Fraser and Trivelpiece, 1996). Two of these hotspots occur, respectively, at the southern end of Anvers (Palmer populations) and Adelaide (Avian populations, northern Marguerite Bay) islands. A principal aim of the proposed drifter and float study is resolving the surface and deeper currents that link UCDW intrusions and surface productivity supporting the penguin colonies.

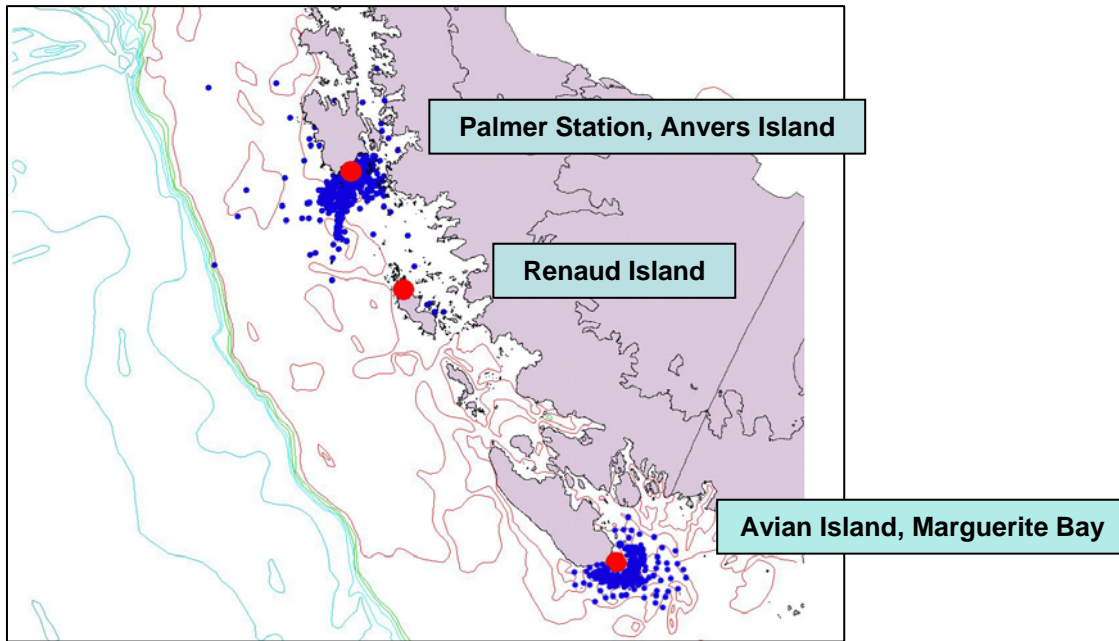


Figure 3 Adélie penguin foraging ranges reported by satellite tagged individuals during summer 2002 and 2003 at Palmer Station, Anvers Island, and Avian Island, northern Marguerite Bay (W. Fraser, unpublished data). Red dots indicate hotspots, which are among the primary sampling sites for Palmer LTER.

### The SO GLOBEC Drifter Study

As part of the SO GLOBEC program, we deployed WOCE-type satellite-tracked surface drifters during austral summer 2001 and 2002 west of Adelaide Island and Marguerite Bay (Beardsley et al, 2004). Each drifter was drogued at 15 m and provided about 20 independent position fixes per day with an rms accuracy of about 0.7 km for each fix. The drifters were launched in two sets each year, the first set during the February-March mooring cruise on the RV *L. M. Gould* and the second set during the April-May broad-scale survey cruise on the RVIB *N. B. Palmer*. The initial 2001 deployments were chosen to sample near moorings on the shelf west of Adelaide Island and in the mouth of Marguerite Bay. As these drifters began to show flow into Marguerite Bay, the second set was deployed to further explore this coastal current. A total of 14 drifters were deployed in 2001, and 10 in 2002.

The low-pass filtered drifter tracks are shown next in a sequence of monthly panels in Figs. 4 and 5 for the two field years. The tracks are color-coded to show each drifter track for days 1-10 (red), days 11-20 (green), and the remaining days (blue) during each month. Since the presence of sea ice appears to influence the surface circulation, the sea ice distribution at the beginning of each month is shown in light blue. The surface air temperature during May and June 2002 were extremely cold (the lowest May since records were started at Rothera in 1977), resulting in early and very rapid ice formation in May 2002. One interesting characteristic of the drifter tracks over the WAP shelf is that the



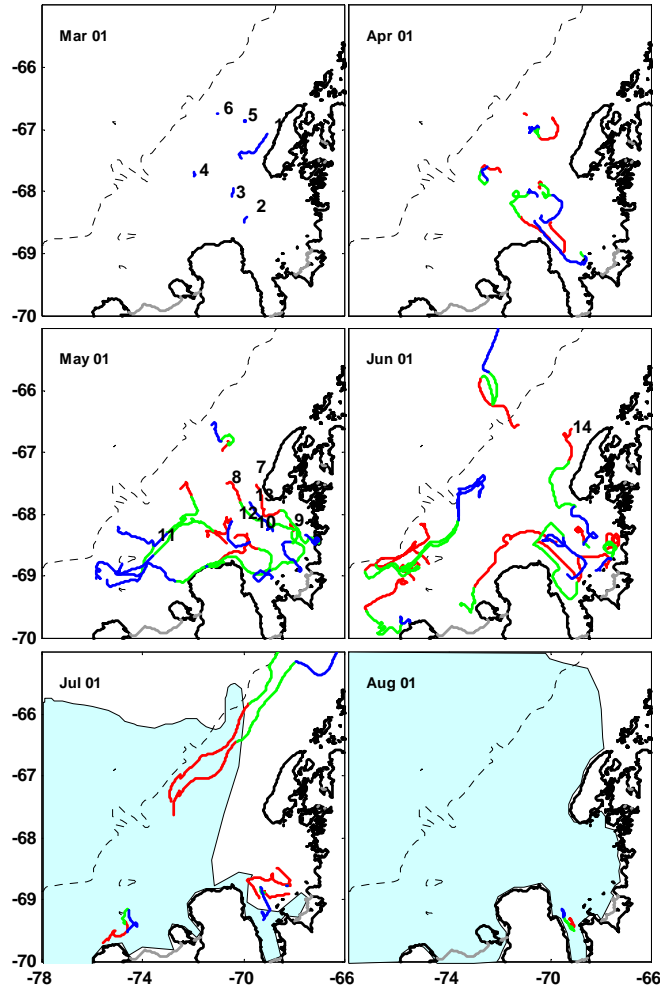


Figure 4 Low-pass drifter trajectories during March through August 2001. In each monthly panel, the drifter track(s) is drawn using the color code red for days 1-10, green for days 11-20, and blue for days > 21. The blue shading indicates sea ice cover on the first of the month for that panel.

tracks were often not coherent with each other over short 20-30 km separations. The internal Rossby deformation scale is roughly 10-15 km in Marguerite Bay and over the adjacent shelf.

Analysis of these drifter tracks suggests the existence of a persistent coastal current flowing southward along the west coast of Adelaide Island and into Marguerite Bay, then flowing clockwise around the Bay and exiting near Alexander Island. This coastal current flowed along the eastern boundary of Marguerite Bay in 2001, but across the central part of the Bay in 2002 due to the early presence of ice in the southern half of the Bay. The outflow from Marguerite Bay continued along the coast of Alexander Island toward the southwest in 2001, but was directed northwestward across the shelf in 2002 because of the early ice coverage. A mean drifter current speed of about 10 cm/s was observed in the coastal current with maximum speeds of about 20 cm/s during periods of strong wind stress.

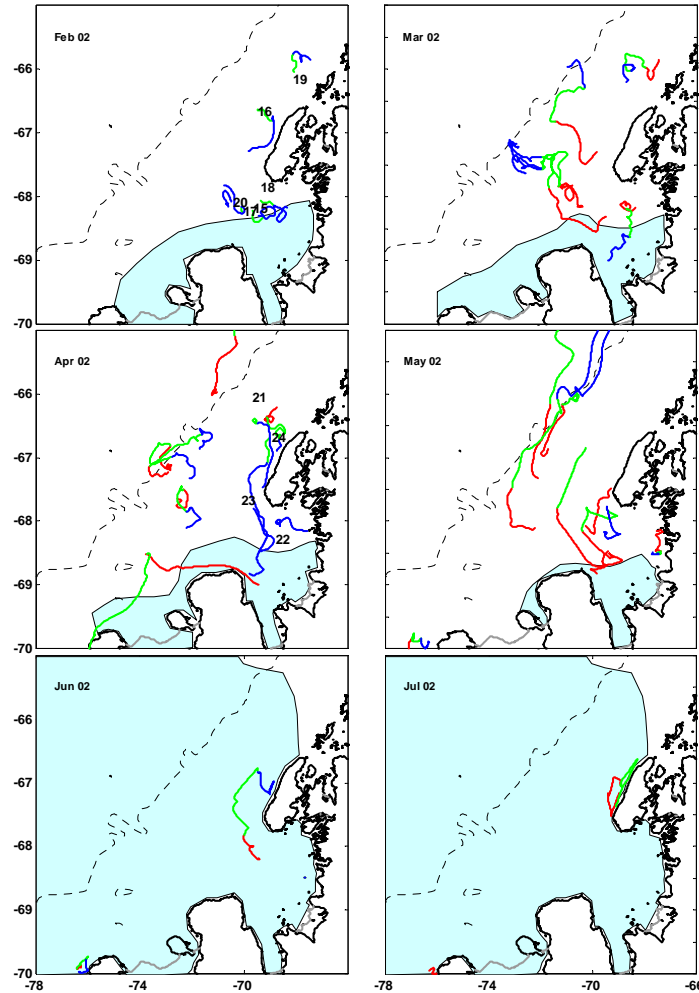


Figure 5 Low-pass drifter trajectories during February through July 2002. Same color code as used in previous figure. Note rapid increase in ice cover between the May and June panels.

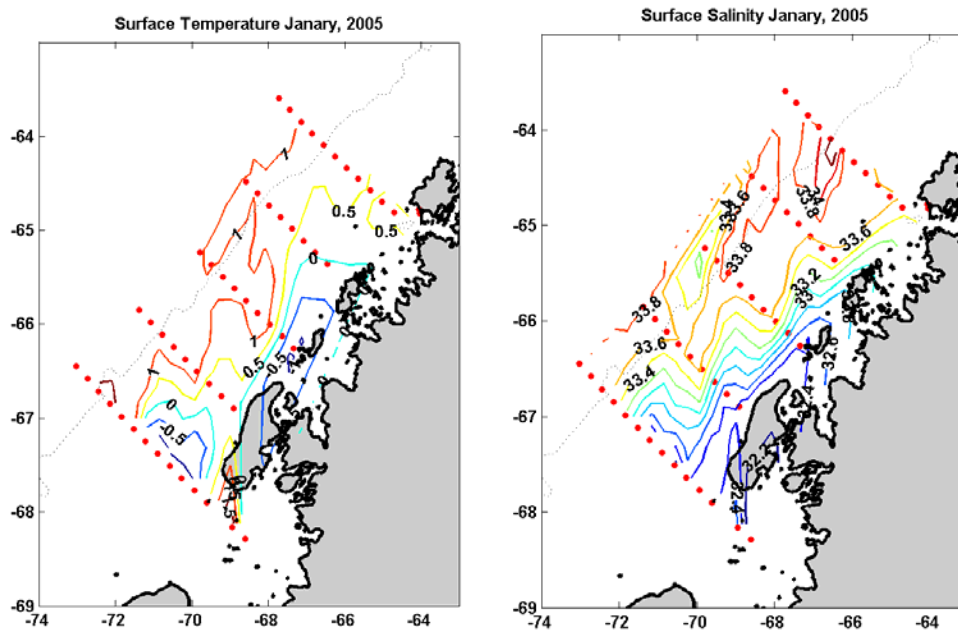
The SO GLOBEC hydrographic data show a band of fresher (lighter) water along the west coast of Adelaide Island and into Marguerite Bay during austral summer and fall (Klinck et al., 2004). This observation, combined with our drifter data and concurrent Automatic Weather Station (AWS) measurements in Marguerite Bay indicating mean southward wind stress in Marguerite Bay, suggest that the observed coastal current is surface-intensified and driven by both buoyancy and winds. The mean southward wind stress is downwelling-favorable, which helps keep the fresher surface water near the coast of Adelaide Island and the coastal current spatially coherent. The upstream source of this fresher water is thought to be Crystal Sound and the more northern inner shelf and “inner passage”.

Drifters that reached the outer shelf near Marguerite Bay generally moved towards the northeast parallel to the shelf break until eventually turning more northward and leaving the shelf. This northeastward flow over the outer shelf combines with the southward coastal current to form a regional clockwise circulation. While most of the drifters in the coastal current that exited Marguerite Bay eventually moved across the shelf and turn

northeastward, none left the outer shelf and shelf break region to re-enter the coastal flow along Adelaide Island. This suggests that the regional clockwise surface circulation is not a closed gyre, but is open at its northeast end.

### 2005 LTER Drifter Deployment

In 2004 we submitted an NSF proposal to deploy drifters and isobaric floats during the 2005-2008 LTER cruises and the proposal was declined due to the costs associated with the isobaric float component. However, 16 satellite-tracked near surface (15 m) WOCE-type drifters were supplied by Raytheon Polar Services to the LTER researchers and were deployed during the January 2005 LTER cruise. Although we were not funded by NSF to support this research, we provided the basic data processing, archiving support, and initial analysis. The objective of this 2005 LTER drifter deployment was to obtain high-quality direct Lagrangian current measurements in the LTER study region during the austral summer when the LTER survey measurements were being made and the ocean surface over the WAP shelf was mostly ice-free.



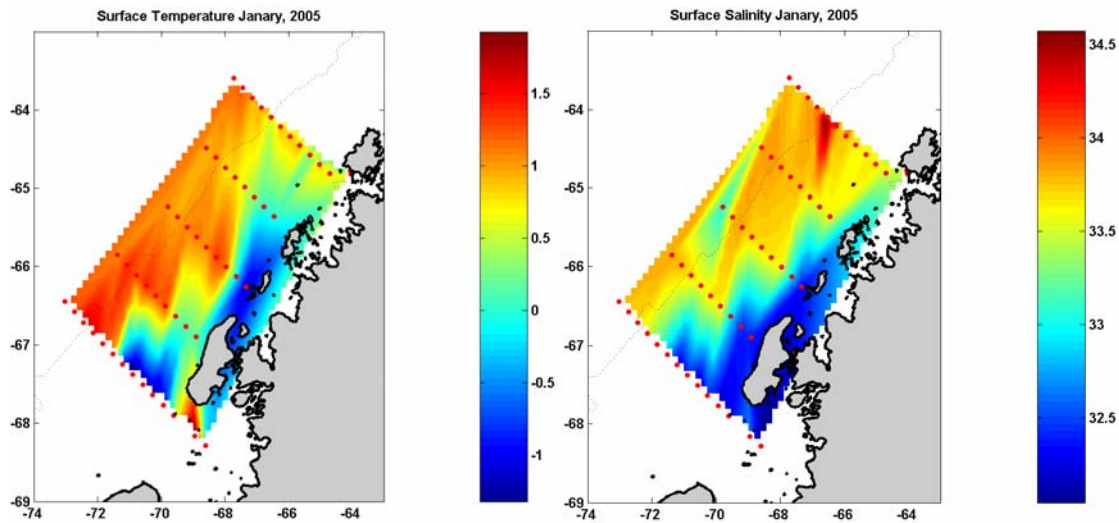


Figure x1. Surface temperature and salinity from the January 2005 LTER cruise.

Sea ice usually covers the entire region from June to December. The surface temperature and salinity distributions for the LTER region during January 2005 when the sea ice had recently melted are shown in Figure x1. Density is strongly dependant on salinity at lower temperatures so the salinity distribution in Figure x1 generally reflects the density field. The inshore survey region had low salinity ( $< 32.6$ ) and low temperature ( $< 0.5$  C) that extended into Marguerite during January 2005.

The surface drifters were deployed along the LTER cruise track. The initial (January to April) 2005 LTER drifter trajectories can be characterized by four separate circulation patterns as shown in Figure x2. The first circulation pattern can be described as an eastward flowing circumpolar current offshore of the 1000 m isobath. Four drifters were deployed seaward of the 1000 m isobath. The northern two (Figure x2a) of these four drifters remained outside the 1000 m isobath and moved at speeds up to 1.08 m/s toward the northeast in a general meandering circumpolar direction. The second circulation pattern (Figure x2b) shows drifters deployed over the inner and mid shelves in the central LTER region tend to flow southeastward toward Adelaide Island where they form into a coastal current that flows southwestward and into Marquerite Bay at speeds up to 50 cm/s. In 2001-2002 drifters deployed over the inner shelf near the numerous small islands flowed in a similar pattern to the southwest in a coastal current (Beardsley et al, 2005). This coastal current is located in the region of low salinity and temperature shown in Figure x1.

The vertical structure of the coastal current is shown in a plot of the currents measured at the 2002 A1 mooring located in Figure x3 by a solid red circle. The 8-17 cm/s southwestward along shore coastal current is found here during periods of no sea ice. Need to expand here.

The other 2 flow patterns are separated by a divergence in the flow over the mid shelf located at about 65 S. The third circulation pattern (Figure XXc) can be described as a cyclonic circulation over the inner shelf north of Adelaide Island between the coastal

current and the offshore flow. The southern two of these four drifters deployed offshore of 1000 m slowly moved inside the 1000 m isobath and toward the central part of the LTER region shelf. There a slowly varying Lagrangian flow was observed with weak mean to the southwest during January to April 2005. The fourth circulation pattern (Figure x2d) can be described as a weak flow toward the northeast over the inner shelf.

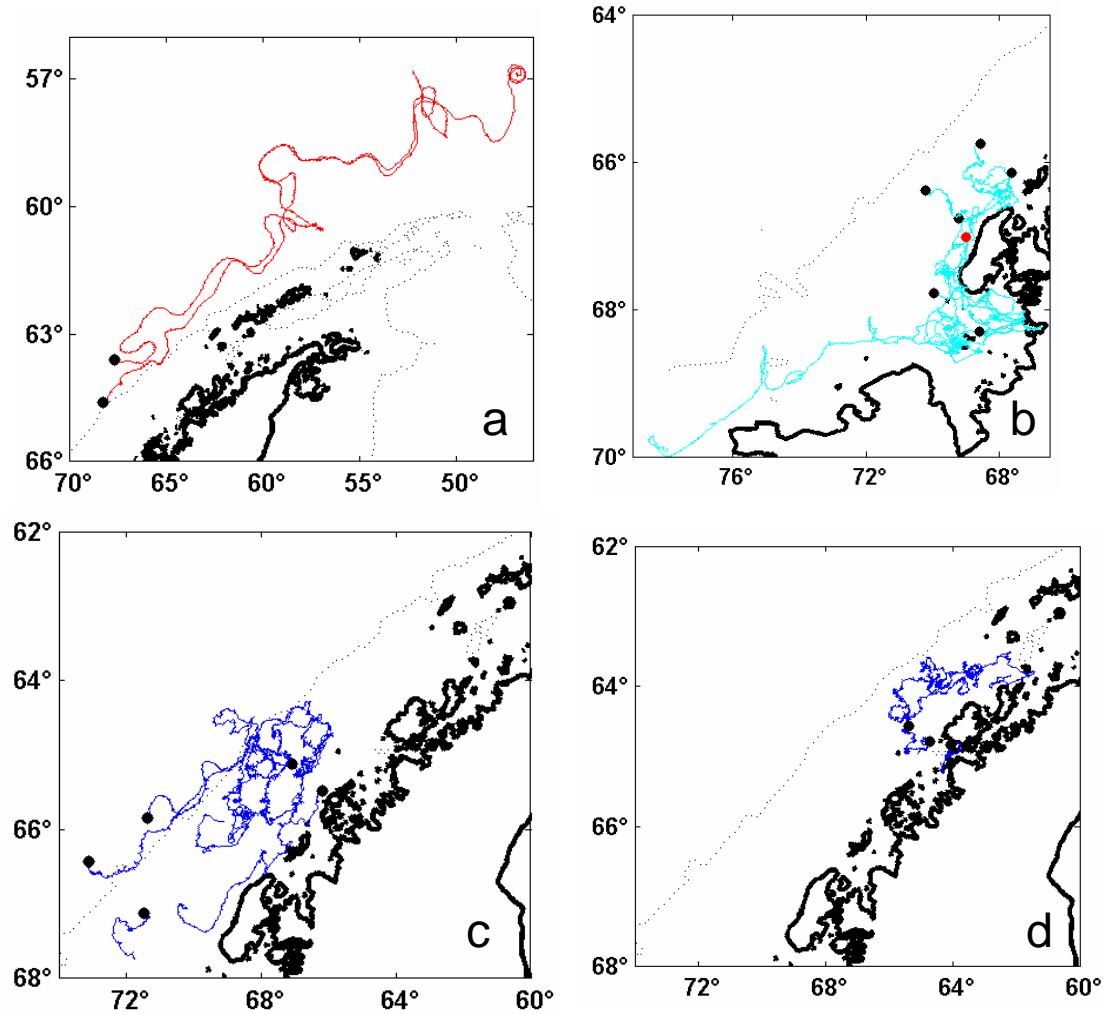


Figure x2. Tracks of near surface satellite tracked drifters over the LTER region during January-April 2005. Solid black circles indicate the location where the drifters were deployed. The solid red circle in B shows the location of the A1 mooring in 2001.

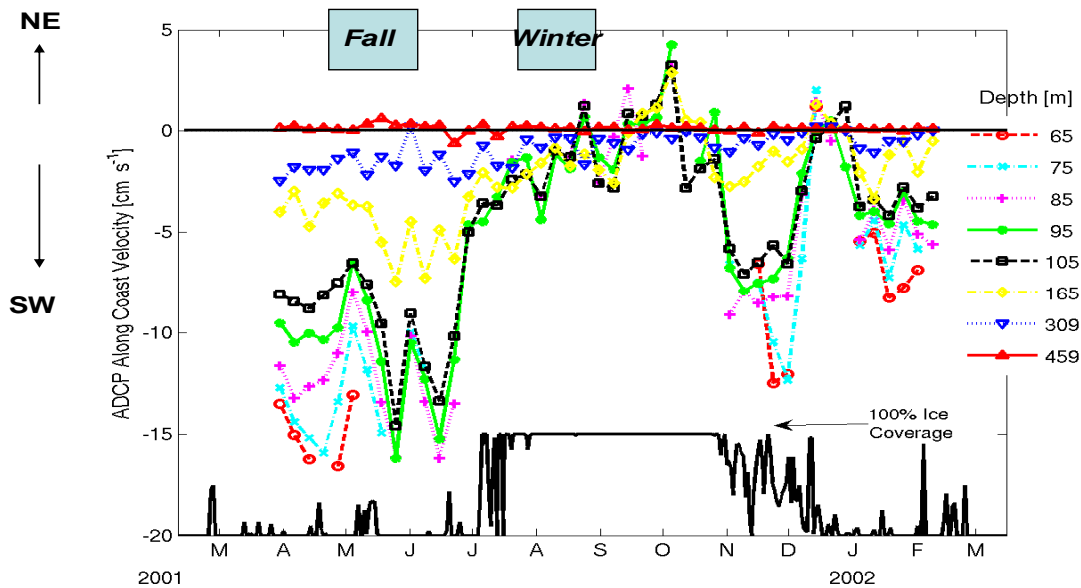


Figure x3 Time series of (a) along-coast current at depths from 65 m to 459 m measured at the SO GLOBEC A1 mooring site (upper) and (b) percent ice cover west of Adelaide Island near A1 (lower). Note that the strong down-coast flow above 105 m during ice-free conditions in austral summer/fall 2001 that decays rapidly in winter (July/August) with the arrival of ice.

## Proposed Research

We propose to deploy a total of 21 surface drifters during each Palmer LTER austral summer cruise during 2006 and 2007. The immediate objective of these deployments is to obtain high-quality direct Lagrangian current measurements in the LTER study region during the austral summer when the LTER survey measurements are being made and the

ocean surface over the WAP shelf is mostly ice-free. The drifters and floats should continue to collect good current data through the austral fall until the drifters and floats become stuck in new sea ice over the shelf or leave the study area. We anticipate a few drifters will continue to work in the sea ice and provide detailed data on local sea ice drift through the austral winter.

The drifter deployment pattern (Figure 8) consists of 16 drifters deployed in the standard LTER grid over the shelf to test the two-gyre paradigm suggested in Figures 2 and 8, 4 drifters deployed in the main passes between the “inner passage” and the inner shelf to track any buoyancy-driven coastal flow, and 2 drifters deployed north of Anvers Island to look at cross-shelf flow there. While this deployment pattern may need to be modified to fit the existing sea ice distribution at the start of the LTER summer cruise and the ship’s operating parameters, the resulting deployment pattern will feature the same three-component focus.

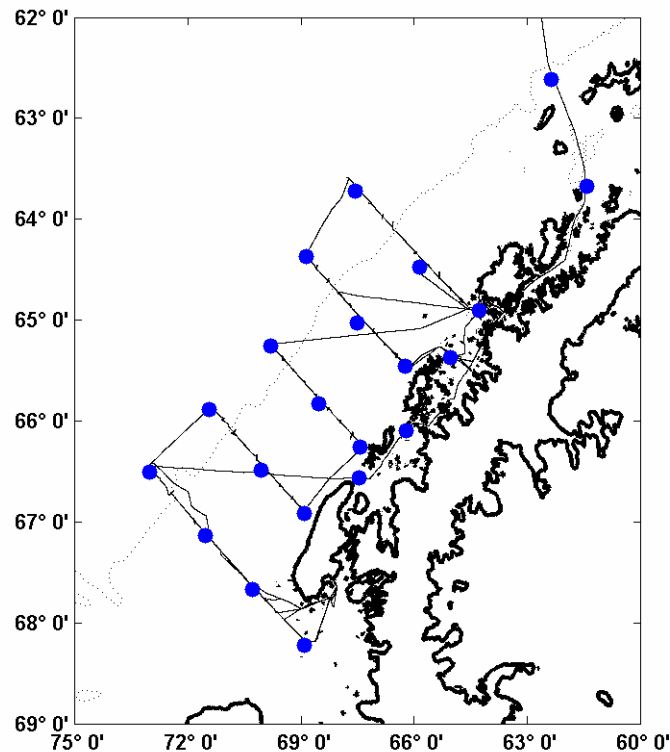


Figure 8 Cruise track of LMG03-01 showing approximate deployment positions for the satellite-tracked drifters (red dots) during the PAL austral summer cruises in 2005, 2006, and 2007. We plan to use WOCE-type surface drifters modified for this cold and icy environment (similar to those used in SO GLOBEC). Each drifter features a holey sock drogue centered at a depth of 15 m, and transmits identification and other information every 90

sec. These transmissions are picked up by satellite and processed in near-real time by Service ARGOS, providing about 20 position fixes per day for each drifter in the study area. The position and other data are sent daily to WHOI, where the data are archived and processed for scientific analysis. During each LTER cruise, the drifter position data will be analyzed daily at WHOI and plots of drifter tracks sent to Ducklow on the RV *L. M. Gould* each day to help guide cruise planning and the deployment of the remaining drifters and floats. This approach worked well in our SO GLOBEC drifter study, and we expect an excellent return of high quality data.

The primary goal of these drifter deployments is to develop a better understanding of the regional circulation in the LTER WAP study area through direct Lagrangian current measurements. In particular, we hope to (a) test the present two-gyre paradigm shown in Figure 8 and (b) examine the upstream continuity of and identify the source(s) of the southwestward coastal current found off Adelaide Island. As seen in SO GLOBEC, the WAP shelf can experience large year-to-year variability in surface forcing and sea ice conditions, so that repeating the LTER drifter deployments each year will allow comparison of the flow field between years as well as detailed descriptions each year. This time series will be important in the identification and separation of those parts of the regional circulation that persist each year from those parts that are more ephemeral.

We plan to use WHOI Solo isobaric floats similar to those used in the 2003 SO GLOBEC study. These feature SeaBird temperature, conductivity, and pressure sensors, and will be programmed to drift for 5 days at 250 m, then profile from 300 m to the surface and transmit data via Iridium back to WHOI before repeating the cycle. The 4 floats will be deployed in a line along the inner shelf during the first year (Figure 8) to investigate the sub-pycnocline flow and determine if there is cross-shelf flow near 65.5° S as suggested in Figure 8. We saw no evidence of this cross-shelf flow in the SO GLOBEC drifter data, however, the sub-pycnocline flow is strongly influenced by bathymetry, and on-shelf flow of UCDW must occur somewhere in the LTER WAP study area from heat, salt and nutrient flux considerations. The initial float and drifter current data will help construct accurate dynamic topography maps for the cruise time period.

An important secondary goal of these drifter deployments is to investigate the spatial and temporal structure of semi-diurnal/inertial (SD/I) band motion over the WAP shelf. The relatively high number of ARGOS fixes per day (~ 20) allows detailed analysis of drifter motion in the 11-15 hr band. Most of the SO GLOBEC drifters exhibited intermittent predominately counterclockwise (CCW) rotary motion in this band with a spectral peak near the local inertial period (13.04 hrs at 68° S). Peak CCW SD/I-band velocities reached 20-30 cm/s for several days over the shelf and in the mouth of Marguerite Bay, greatly exceeding the local barotropic tidal currents predicted by Padman et al (2002) and generally exceeding the local subtidal current. The rms high-frequency velocity (computed over 15-day segments) ranged from 10-12 cm/s, and the rms CCW I/SD-band velocity varied from 5-10 cm/s (Fig. 6). The few drifters that penetrated deep into Marguerite Bay exhibited less high-frequency variability, with rms velocities generally less than 6 cm/s and CCW I/SD-band velocities less than 3 cm/s.



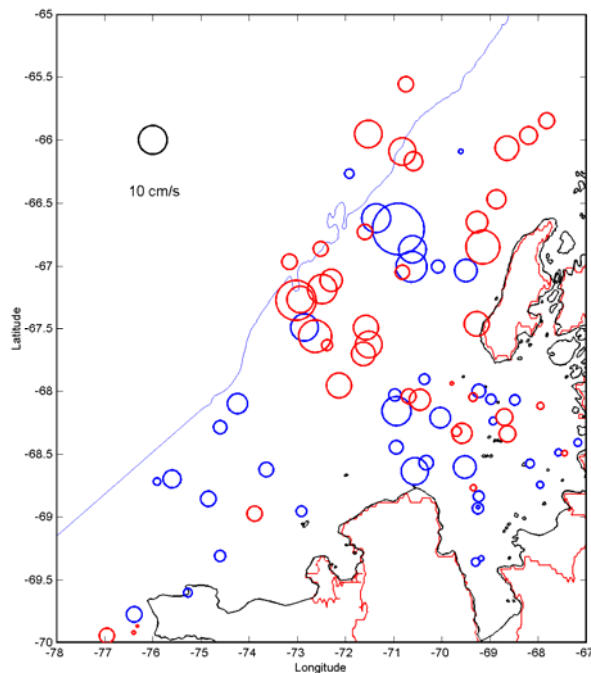


Figure 9 Map of CCW SD/I-band rms speed computed in 15-day non-overlapping segments along each drifter's track in 2001 (blue) and 2002 (red). The 1000-m isobath is shown by the thin line.

Klinck (1998) suggested from model results that the vertical fluxes of heat and salt over the WAP shelf were dominated by double-diffusive processes. Preliminary analysis of SO GLOBEC data by Howard et al (2004) shows the intermittent existence of downward propagating near-inertial internal waves in the upper water column, and Howard et al argue that shear-driven vertical mixing is the dominant process. We believe these waves are generated by surface forcing, and one clue to their generation is the presence of near-inertial motion exhibited by the surface drifters. The proposed PAL drifter deployments should provide a detailed picture of near-surface semi-diurnal/inertial band motion over the WAP study area. In addition to examining the spatial and temporal structure of this high-frequency motion, we will be able to investigate in more detail the hypothesis that these motions are forced by the surface wind (as measured on the ship during the cruise). While of intrinsic interest, the high-frequency drifter current data will also provide critical information to test and refine regional circulation models driven by realistic surface winds and offshore tidal forcing. Ultimately these models will help understand the relative roles of different advection/mixing processes (e.g., double diffusion versus inertial wave-induced shear mixing) over the shelf.

## Summary and Significance

This proposal seeks support to collect, process, and analyze surface drifter and isobaric float data to be collected on the western Antarctic Peninsula (WAP) shelf as part of the ongoing Palmer LTER program. Ducklow (lead LTER PI and co-PI in this proposed work) has requested that Raytheon Polar Services (RPS) purchase and deploy a total of 21 satellite-tracked WOCE-type surface drifters on each austral summer LTER cruise in

the next three years (starting in January 2005). Our initial main task is to help guide these drifter deployments, acquire the data from Service ARGOS, and use this drifter data plus other LTER physical oceanographic and meteorological data to describe the regional near-surface Lagrangian circulation during the summer/fall ice-free period each year.

Our second main task is to purchase and guide the deployment of 4 WHOI Solo isobaric floats on each cruise. The initial data from these floats will be obtained and sent to the ship during the cruise; however, the 5-day repeat drift cycle of these floats will minimize their impact on science planning during the cruise. Ducklow will oversee the deployment of the drifters and floats on each cruise as part of his LTER research.

Our third primary task is to work with LTER investigators to help place their observations and models within the context of the directly-observed 15-m and 250-m Lagrangian circulation and physical environment. In particular, we look forward to working with D. Martinson (lead LTER physical oceanographer) merging our direct measurements with his hydrographic observations and investigating further the structure, timing and source(s) of the coastal buoyancy- and wind-driven current (see supporting letter). As part of this effort, we plan to post the edited drifter and float data, analysis results, and animations of the drifter and float paths with surface weather data on the LTER website for use and viewing by LTER investigators, other scientists and students, and the public, and participate in the annual Palmer LTER investigator workshops.

These new drifter and float measurements will complement those made in Marguerite Bay and the adjacent WAP shelf south of 66° S during the 2001-2003 SO GLOBEC program. The combined drifter data will provide the first detailed look at the near-surface flow in this important section of the WAP shelf. The ocean temperature record to date is too sparse and short to detect any response by the ocean to rapid atmospheric warming; hence the connections between the observed surface air warming and the ecosystem are not clear. We want to contribute to the overall study of this fascinating WAP ecosystem by starting a program to directly measure the Lagrangian currents with drifters and floats and describe the circulation and its inner-annual variability, a necessary first step in understanding how this marine ecosystem responds to decadal changes in surface forcing.