This article appeared in a journal published by Elsevier. The attached copy is furnished to the author for internal non-commercial research and education use, including for instruction at the authors institution and sharing with colleagues.

Other uses, including reproduction and distribution, or selling or licensing copies, or posting to personal, institutional or third party websites are prohibited.

In most cases authors are permitted to post their version of the article (e.g. in Word or Tex form) to their personal website or institutional repository. Authors requiring further information regarding Elsevier’s archiving and manuscript policies are encouraged to visit: http://www.elsevier.com/copyright
Circulation on the West Antarctic Peninsula derived from 6 years of shipboard ADCP transects

Dana K. Savidge*, Julie A. Amft

Skidaway Institute of Oceanography, 10 Ocean Science Circle, Savannah, GA 31411, USA

A R T I C L E   I N F O

Article history:
Received 24 June 2008
Received in revised form 5 May 2009
Accepted 19 May 2009
Available online 29 May 2009

Keywords:
Antarctic Peninsula
Circulation
ADCP
Cross-shelf transport
Shelf-edge transport

A B S T R A C T

Over the past 30 years, shelf circulation on the West Antarctic Peninsula (WAP) has been derived from hydrographic data with a reasonable level of confidence. However, with the exception of a very few drifter tracks and current-meter time series from moorings, direct velocity measurements have not previously been available. In this article, shelf and shelf-edge circulation is examined using a new velocity dataset, consisting of several years of acoustic Doppler current profiler transects, routinely collected along the ship tracks of the R/V Gould and the R/V Palmer since the fall of 1997. Initial processing and quality control is performed by Dr. Teresa Chereskin and Dr. Eric Firing, who then place the data in an archive accessible by public websites, resulting in the broad availability of the data for a variety of uses. In this study, gridded Eulerian means have been calculated to examine circulation on the shelf and slope off the South Shetland Islands, in Bransfield Strait, and on the shelf and slope south of these regions, including Marguerite Bay and the adjacent shelf and shelf-edge. Shelf-edge flow is northeastward in the study area from the offshore of northern Alexander Island to Smith Island, while a southward flowing shelf-edge feature, probably the shallow component of the polar slope current, appears between Elephant Island and Livingston Island. The shallow polar slope current appears to turn shoreward to pass through Boyd Strait between Smith and Livingston Islands. In Bransfield Strait, there is cyclonic circulation. The previously identified northeastward-flowing South Shetland Island jet is strong and present in all seasons, with a large barotropic component not revealed by the hydrography-based velocities derived in the past. On the shelf seaward of Adelaide, Anvers and Brabant Islands, the strong along-shelf Antarctic Peninsula coastal current flows southwestward, with strongest velocities in winter (June–September) off Anvers and Brabant Islands, but stronger in summer (December–March) off Adelaide Island. Seaward of Marguerite Bay, there is seaward flow in the upper 400 m of the water column over the southwest bank of Marguerite Trough, strongest in summer, and shoreward flow near the northeast bank and adjacent shallower shelf areas.

© 2009 Elsevier Ltd. All rights reserved.

1. Introduction

Until quite recently, understanding of shelf circulation on the West Antarctic Peninsula (WAP) was derived almost exclusively from hydrographic data, augmented by drifter tracks and a very few current-meter time series from moorings. With the recent completion of the US Southern Ocean (SO) GLOBEC field activities and associated regional modeling of the circulation in Marguerite Bay and the adjacent shelf and slope of the WAP, understanding of the circulation system is advancing. The large SO GLOBEC effort in this area is testimony to the importance of examining circulation here, in order to understand and quantify life-cycles and importance of

* Corresponding author. Tel.: +1 912 598 3344; fax: +1 912 598 2310.
E-mail address: dana.savidge@skio.usg.edu (D.K. Savidge).
krill in the Antarctic ecosystem. Circulation not only controls the connections between sites of krill spawning, recruitment, and high chlorophyll a (chl-a) content, which presumably correlates to krill food stocks, but also contributes to or controls nutrient and heat budgets for the shelf, thus affecting ecosystems from the building block level up, as well as influencing sea–ice development, and thus both physical habitat and stratification (thus water column stability) on the shelf.

However, even with the concerted efforts of multiple PIs and institutions during SO GLOBEC, the quantity of velocity data near the WAP remains extremely limited. It is important to examine all existing data sources to their fullest extent, to make the most of the limited quantities of drifter and moored instrument data that have been obtained to date. In addition to the well-documented recent SO GLOBEC efforts, a separate NSF-sponsored analysis project has been underway since 2003 which examined WAP shelf-edge and shelf circulation using 6 years of archived shipboard acoustic Doppler current profiler (ADCP) data from the R/V Nathaniel B. Palmer and R/V Laurence M. Gould. This article describes results from this project in three regions: on the shelf and slope off the South Shetland Islands (SSI); in Bransfield Strait; and on the shelf and slope south of these regions, including Marguerite Bay and the adjacent shelf and shelf-edge. First, existing knowledge of circulation will be summarized, including SO GLOBEC results to date. Results from the ADCP archive will then be examined in depth.

2. Background

Over the past 30 years, sufficient hydrographic data have been accumulated on the continental shelf of the West Antarctic Peninsula to define the shelf circulation with a reasonable level of confidence. Early descriptions based on hydrographic cruise data from the 1890s through the 1930s have been incrementally enhanced by a series of more recent observational efforts. Typically, the primary focus of these efforts has not been the physical oceanography of the region. Circulation features defined prior to the SO GLOBEC studies were based almost exclusively on the ‘properties as tracers’ approach and estimates of geostrophic velocities from dynamic height gradients, augmented by a few drifter tracks and current-meter moorings. Hofmann et al. (1996) have summarized the understanding of the WAP shelf circulation, based on a review of past literature and analysis of the accumulated hydrographic and drifter data from cruises on the WAP to that date, to produce a schematic of the flow (their Fig. 9). In the following, primary features of the WAP shelf circulation are briefly reviewed, based on Hofmann et al. (1996) and Hofmann and Klinck (1998) unless otherwise indicated.

On the shelf off the ‘nearshore islands’ (Alexander, Adelaide, Anvers, and Brabant are the largest), cyclonic circulation predominates. The nearshore southwestward limb of this circulation is forced by predominantly downwelling-favorable winds and associated coastal setup, which is perhaps amplified by buoyancy effects of nearshore freshwater inputs. This circulation has been verified off Adelaide Island by Klinck et al. (2004) and Beardsley et al. (2004), and described more thoroughly by Moffat et al. (2008). The results described below verify this limb farther northeastward along Anvers and Brabant Islands as well. Wind-stress forcing over the WAP southward of Anvers Island is downwelling-favorable year-round, with semi-annual variability in wind strength (van Loon, 1967). Buoyancy forcing is seasonal (Stammerjohn and Smith, 1996), such that the nearshore limb of the cyclonic shelf circulation may exhibit some seasonality (verified by Moffat et al., 2008 and by the results reported herein). The shelf-edge limb is northeastward, in keeping with the energetic northeastward flow of the Antarctic circumpolar current (ACC), which abuts the shelf in this region. Circulation on the shelf between the nearshore and seaward limbs consists of at least two cyclonic gyres, whose existence and scale are probably due to bathymetric control. These two gyres imply specific pathways for cross-shelf transport along their cross-shelf limbs. Dinneman and Klinck (2004) have used a regional high-resolution model to demonstrate that cross-shelf flows (consistent with past hydrographically based circulation schemes) can result from isobath curvature at the shelf-edge.

Seaward of the South Shetland Islands (Smith, Livingston, King George and Elephant, for the purposes of discussion herein), an along-shelf southwestward-flowing current exists. An outer shelf and shelf-edge component and a deep slope near-bottom component extending to 2700 m exist, both apparently termed the polar slope current by Nowlin and Zenk (1988). The deep component exists as a topographic flow resulting from subducting cold water masses, and may be continuous with the Antarctic slope current (ASC). The ASC is believed to exist virtually everywhere along the slope around Antarctica, except off the WAP south of the South Shetland Islands. Heywood et al. (2004) discussed a variety of criteria to define the ASC location as a frontal feature, and trace it from the Weddell Sea as far as the sharp turn from the Weddell Sea to north of the SSI. The shallower component, cited as existing between 400 and 600 m depth on the outer shelf and upper slope by Hofmann et al. (1996), may exist due to east-wind drift near the continent (Whitworth et al., 1982). Nowlin and Zenk (1988) considered this shelf and upper slope component to be kinematically distinct from the deep slope component, based on current-meter mooring records. Capella et al. (1992) found that the shallow component does not extend as far south as Smith Island, and found no evidence in the temperature fields of this component of the shelf flow turning through Boyd Strait.

However, Hofmann et al. (1996) mentioned two cross-shelf transport pathways between the outer shelf and the Bransfield Strait. One pathway extends from the outer shelf through Boyd Strait between Smith and Livingston Islands, the southernmost South Shetland Islands. Northeastward currents between King George and Elephant Islands represent a cross-shelf conduit from Bransfield Strait to the outer shelf. Both the cross-shelf limbs on the shelf off the SSI and the southward extent of the shallow polar
Fig. 1. Bathymetric details in northern (panel a) and southern (panel b) portions of the study area. Depth contours shown (in m) are the 0, 100, 250 through 1500 by 250 m increments, and 2000–5000 by 1000 m increments. Marked features mentioned in the text include SM: Smith Island, BY: Boyd Strait, SN: Snow Island, LV: Livingston Island, KG: King George Island, JN: Joinville Island, AS: Antarctic Strait, GR: Gerlache Strait, BT: Brabant Island, AV: Anvers Island, AD: Adelaide Island, AX: Alexander Island, CH: Charcot Island, Mg Bay: Marguerite Bay, Mg Tr: Marguerite Trough. The South Shetland Islands, Bransfield Strait, and the Antarctic Peninsula (Ant. Pen.) are also indicated. Bathymetry is Smith and Sandwell (1997) with modifications as defined in Hofmann et al. (2004) and Bolmer (2008), which has been smoothed in some figures.
slope current are consistent with mean structures from the ADCP archive discussed herein.

In Bransfield Strait, there is cyclonic circulation, with strong flow to the east-northeast along the southern margin of the SSI and a less intense southwestward flow in the near-Peninsula part of the Strait. The western portion of the near-SSI jet is referred to as the Bransfield jet in Garcia et al. (2002), while the overall east-north-eastward feature has been referred to in this document and elsewhere as the SSI jet. Subtidal velocities have been estimated from hydrography and current meters near the Boyd Strait and south of Livingston Island as between 10 and 30 cm/s in the upper 300 m (Niiler et al., 1991; Lopez et al., 1994) with strong tidal velocities of 30–40 cm/s (Lopez et al., 1994). Drifter estimates of near-surface flow are higher still, in excess of 50 cm/s (Hofmann et al., 1996). At the northeastermmost end of the jet between King George and Elephant Islands, flow out of Bransfield Strait and northward onto the shelf seaward of the SSI is probable. There are several identified inflows to Bransfield Strait, listed here in counter-clockwise order starting from the inflow through Boyd Strait mentioned above. Just south of the SSI at the shelf-edge, along-shelf north-eastward flow along the shelf-edge (part of the ACC) may divert cross-shore, perhaps entering Bransfield Strait across the shallower shelf south of Smith Island. Flow into Bransfield Strait is likely through Gerlache Strait. Heywood et al. (2004) have identified the inflow of the Antarctic coastal current at the northeast tip of the Peninsula, off Joinville Island (Fig. 1).

3. Data and methods

Since 1997 and 1999, respectively, the R/V Nathaniel Palmer and the R/V Laurence M. Gould have used ship-mounted ADCP systems (RD Instruments narrowband VM–150 ADCP with Ashtech ADU–2 GPS attitude sensors) to routinely collect underway velocity profiles along ship tracks. Data acquisition and initial processing are accomplished by Drs. Eric Firing (University of Hawaii) and Teresa Chereskin (Scripps Institution of Oceanography) under separate NSF funding, and the processed 5 min tracks. Data acquisition and initial processing are accomplished by Drs. Eric Firing (University of Hawaii) and Teresa Chereskin (Scripps Institution of Oceanography) under separate NSF funding, and the processed 5 min averaged transect data have been made available through the Joint Archive for Shipboard ADCP (JASADCP) webpage, http://ilikai.soest.hawaii.edu/sadcp/index.html. Additional processing details can be found in the recent article by Lenn et al. (2007). The effort to date has resulted in a large number of ADCP transects across the southern edge of the ACC, over the slope and shelf-break of the WAP, and onto the shelf itself. In the region of the WAP at 54–78 W, 59–72 S, data from 52 R/V Gould cruises and 19 R/V Palmer cruises were available for the present analysis (Fig. 2, panel a), affording a temporal coverage for the Gould from September 1999–December 2003, and for the Palmer from August 1997–September 2002 (though the archive extended through March 2005, there were no cruises in the study area past September 2002).

Much of what is known about the circulation on the WAP has been elucidated in the past based on geostrophic velocity estimates from dynamic height gradients, so many named features in the literature refer to density fronts, as opposed to the associated geostrophic velocities. Accordingly, available CTD data from SO GLOBEC and the Palmer Long Term Ecosystem Research (PAL LTER) have been examined to enhance the analysis. SO GLOBEC data from 2001–2002 were downloaded from the SO GLOBEC archive at http://globec.whoi.edu/jg/dir/globecc/globecog/ (Klinck, 2008; Groman, 2008). PAL LTER data were derived from two sources: the archive from 1991–1997 was generously supplied by Drs. Hoffman and Klinck of Old Dominion University, while the 2003–2005 period was accessed from the PAL LTER website http://pal.lternet.edu/data/ (Martinson, 2008). The PAL LTER and SO GLOBEC data were plentiful on the WAP shelf and shelf-edge, especially south of the SSI (Fig. 2, panel b). Data processing details for the PAL LTER data are discussed in Martinson et al. (2008), and for the SO GLOBEC data in Klinck et al. (2004).

The removal of the tidal signal from the ADCP currents is necessary for the studies of subtidal circulation processes. Tides are mixed on the WAP, and of relatively low magnitude, amounting to total tidal velocities $c(10 \text{ cm s}^{-1})$ (Klinck, personal communication, and Klinck, 1995). However, predicted tidal velocities are somewhat larger at the shelf-edge and near the SSI in the Bransfield Strait, as illustrated in Fig. 3, which shows tidal ellipses for M2 and K1 tidal constituents predicted by the Padman et al. (2002) Antarctic Peninsula forward model. Three methods were used to estimate tides in this study, including the empirical approach of Dunn (2002), harmonic analysis of data along short sections of data using the routines of Pawlowicz et al. (2002), and the use of tidal velocity estimates from the model of Padman et al. (2002). Results from the Dunn (2002) approach were unfortunately indeterminant, presumably because of quite inhomogeneous data coverage in space and time. For harmonic analysis, short sections of ship-track were sequentially extracted for fitting with a minimal set of harmonic constituents. Typically, 6–12 h intervals passed during the ship’s crossing of the shelf-edge, providing a bare minimum sample for fitting of the tide. In places where the tide is mixed or primarily diurnal, the time-frames are even less satisfactory. An assumption that tidal phase lags are negligible across the shelf and shelf-edge was necessary, which can be locally dubious. However, the harmonic analysis and model predictions produced somewhat consistent results, with similar values of RMS difference between measured velocities and estimated tides, providing a measure of confidence in the model predictions. For these reasons, the model predictions were taken as the best estimate of tidal magnitude and phase to remove from the data. Ultimately, the results turn out to be rather insensitive to the method used to eliminate the tidal signal, as all mean or seasonal mean circulation features discussed below appear using either detided or undetided data.

After detiding, data from these tracks were binned into grids oriented along and across the shelf and shelf-edge. Regions examined are (1) the shelf and slope off the nearshore islands, (2) the region northwest and seaward of the SSI, and (3) the Bransfield Strait. Latitudes and
longitudes were first converted to a local coordinate system oriented approximately parallel to the average trend of shelf-edge isobaths for each subregion. Bins are long and narrow, with much higher horizontal resolution in the cross-shelf direction (≈3–13 km, depending on the subregion) than in the along-shelf direction (≈20–165 km). Autospectra of the 5 min average along-track cruise-by-cruise ADCP data indicated a fairly robust 4–5 h decorrelation scale, which is some combination of a space and time decorrelation, as gridded means and along-track inspection of ship speeds indicate typical motion at 5–10 knots. The data were consequently binned and averaged by day (a conservative interval, as the autospectra would support subdividing the data down to

![Data coverage for the study period. Panel a: cruise tracks from the R/V Gould in green/gray and from the R/V Palmer in blue/black, in color/grayscale figures. Panel b: locations of available CTD casts from early PAL LTER (upward triangles), SO GLOBEC (x), and 2003–2005 PAL LTER (downward triangles) studies. Red/gray bars indicate the approximate locations of the southern parts of the three cross-Drake Passage XBT lines discussed by Sprintall (2003), for reference.](image)
quarter-days), then averaged by bin over all days. Bin centers for 'standard' gridding schemes are shown in Fig. 4 which represents days of observations available in each bin, with dots at bin centerpoints. Additionally, data in Bransfield Strait and the region off Marguerite Bay and the nearshore islands have been binned in more than one way to address specific features. The Eulerian means calculated are somewhat dependent upon the binning scheme selected, of course, but the major features examined below are all robust to this variability. Examples of the data included along two grid lines (Fig. 5, with line locations indicated by gray bars in Fig. 6) provide confidence that the means are representative. In the following, mapviews of layer mean velocities are plotted with the arrow originating at bin centers. Details of the various binning schemes are presented in Table 1.

Errors are estimated as the standard errors of the means, using the values in Fig. 4 for numbers of observations. They are consistent with independent estimates from averaging and bootstrapping the 5 min along-track average data to define confidence intervals on the calculated means as in Press et al. (1992), using the Matlab software package of Zoubir and Iskander (1998). In the following, only vectors whose magnitudes exceeded the error estimate magnitudes are plotted and discussed. Bias in the data itself could still be present. However, this worry is reduced due to the work of Lenn et al. (2007). In an examination of upper ocean transport through Drake Passage utilizing this same ADCP dataset (though perhaps a different subset of cruises) they found no significant differences in cross-line transports calculated from either all poleward or all equatorward transits of the passage. This suggests that heading error, the largest source of systematic error in the data (Chereskin, personal communication), is small.

4. Results

Several important features have been defined in the examination of these data. Results are listed briefly below and shown in Fig. 6, which depicts circulation averaged over the upper 40–200 m. Results are then elaborated upon in the following subsections. Three regions are defined: (1) the shelf and shelf-edge over the northern WAP around the SSI, (2) Bransfield Strait, and (3) the more southern shelf and shelf-edge of the WAP, from the SSI south to Alexander Island south of Marguerite Bay. Much of the following is consistent with the present understanding of WAP circulation based on hydrography, though with a few interesting details emerging. Circulation features of interest include the following:

- Seaward of the shelf-edge from offshore of northern Alexander Island to Smith Island, flow is northeastward in the study area (Fig. 6, panel b). Northeastward flow along this stretch of the shelf-edge has been identified before, and is likely part of the open ocean ACC flow.
associated with the southern ACC front (SACCF). This study indicates that this flow resides over the lower slope, moving slightly seaward off the SSI.

- A southwestward flowing shelf-edge feature appears in ADCP velocity data between Elephant Island and Livingston Island, tentatively identified here as the shallow component of the polar slope current (Fig. 6, panel a). This feature does not appear farther southward in the study region. It resides over the upper slope and outer shelf, and is stronger in winter than in summer. This current appears to turn shoreward to pass through Boyd Strait between Smith and Livingston Islands (Fig. 6, panel a). The through-flow is present in year-round, winter and summer means. Upon leaving Boyd Strait and entering Bransfield Strait, the direction of the smaller along-shelf component changes with season, turning slightly clockwise from shoreward in summer, slightly counterclockwise from shoreward in winter.

- In Bransfield Strait, there is a cyclonic circulation. The previously identified northeastward-flowing limb
nearest the South Shetland Islands is the South Shetland Island jet, strong and present in all seasons (Fig. 6, panel a). The new insight is that this jet has a large barotropic component not revealed by the hydrography-based velocities derived in the past.

- South of the northeastward-flowing SSI jet, the flow is southwestward (Fig. 6, panel a). This flow is quite strong in summer (Fig. 11, top panels), but the subregion is almost completely unsampled in winter. There is evidence of flow north of the Antarctic Sound, between the northeast tip of the Antarctic Peninsula and Joinville Island farther east.

- On the shelf south of the SSI, seaward of Adelaide, Anvers and Brabant Islands, there is an along-shelf coastal current. This current was previously suggested by Hofmann et al. (1996), and has since been observed off Adelaide Island in wintertime shipboard and moored current-meter data collected as part of the SO GLOBEC project, and described as the Antarctic Peninsula coastal current (APCC) (Klinck et al., 2004; Beardsley et al., 2004; Moffat et al., 2008). The 6-year archive of shipboard ADCP data also confirms the APCC off Adelaide Island in both winter and summer, as well as demonstrating its existence in both summer and winter farther northeast off Anvers and Brabant Islands (Fig. 6, both panels). There is a strong seasonal variability, with strongest velocities in winter (June–September) off Anvers and Brabant Islands, but stronger in summer (December–March) off Adelaide Island. In the Gerlache Strait on the Peninsula side of Anvers and Brabant Islands, currents flow the opposite direction along-shelf, toward Bransfield Strait.

- There is some indication of a cyclonic circulation along the boundary within Marguerite Bay in the record-long means, consisting primarily of intensified nearshore flow into the Bay just southwest of Adelaide Island, and a similar intensification in an outflowing limb immediately north of Alexander Island (Fig. 6, panel a). Both are surface-intensified, and do not appear in the 200–300 m layer maps.

- There are numerous aspects of the mean circulation plots that suggest cross-shelf transport; for example, in the region off Adelaide Island and Marguerite Bay, and seaward of the bay regions between Adelaide and...
Anvers Islands. Specific cross-shelf transport pathways may be associated with bathymetric features on the shelf. One feature of interest is a seaward flow in the upper 400 m of the water column over the southwest bank of Marguerite Trough, strongest in summer, and shoreward flow near the northeast bank and adjacent

---

**Fig. 6.** Record long means (red) and standard errors (blue) from detided, binned shipboard ADCP velocities between 40 and 200 m depth. Note the blue arrows are all oriented to the northeast, as the standard errors in the north and east directions are expressed as positive values. Panel a: region near SSI; panel b: region south of SSI. Long gray bars indicate lines shown in Fig. 5.
shallower shelf areas. Shoreward flow in the Marguerite Trough at deeper levels has been surmised, based on property distributions and the presence of LCDW within the Trough (Klinck et al., 2004).

These results illustrate the utility of the data and the feasibility of the use of this substantial and growing resource for the broader community. In the following, these features are examined more closely, in some cases by regridding more finely or coarsely cross-shelf or along-shelf. Vertical variability is examined more closely through taking gridded averages by level, instead of over the 40–200 or 200–300 m depth averaged layers. Seasonal contrasts are also examined, defining 4 month periods in summer (December–March) and winter (June–September) over which to take gridded level or layer averages. Transport is roughly assessed for a number of features from the gridded level averages, and potential pathways between associated or adjacent features are suggested.

### 4.1. Northeastward shelf-edge jet

A northeastward flow immediately seaward of the shelf-edge is evident in the study area south of Boyd Strait, from Alexander to Smith Island (Sections Nr1–Nr4 and Sh1 in Fig. 7; ‘Nr’ for sections off the nearshore islands, ‘Sh’ for sections off the SSI), especially in summer (Fig. 8). The jet exists over the outer slope along sections Nr1–Nr4, and shifts slightly offshore along section Sh1 in the vicinity of Livingston Island.

A reasonable first hypothesis is that this jet is part of the circumpolar trough at deeper levels, associated in this southern instance with perhaps the SACCF, which is known from hydrography to encroach on the shelf-edge along the WAP (Orsi et al., 1995). To investigate whether the jet is sufficiently removed from the appropriate hydrographic signatures to invalidate this presumption, the available archive of CTD data was examined. Orsi et al. (1995, p. 650) pointed out that along the 1027.6 kg m\(^{-3}\) density surface (the 27.6 \(\sigma_\theta\) surface), strong salinity, potential temperature, and dissolved oxygen gradients exist in the SACCF, with salinity ranges from 34.5 to 34.4, potential temperature from 1 to \(-1\) °C, and dissolved oxygen from 5–7 ml/l (217.3–304.2 \(\mu\)mol/kg), with salinity and potential temperature decreasing poleward across the SACCF, and dissolved oxygen increasing. CTD data on the 27.6 \(\sigma_\theta\) surface were therefore extracted and averaged into 26 \(\times\) 100 km along-shelf-oriented bins. Bins centers are nominally but not exactly placed along ITER repeat station lines. The gridded Eulerian mean approach here seems appropriate, since locations of the front and the jet may not correspond well on a snapshot basis, based on the recent results of Lenn et al. (2007) and Sprintall (2003). However, the overall gridded Eulerian mean hydrographic structure should indicate the presence of the SACCF, if the jet structure in the same region is geostrophically associated with it. Resulting record-long average salinity and potential temperature fields along this density surface near the shelf-edge clearly indicate the presence of strong gradients near the shelf-edge south of the SSI and off Smith Island, with salinities between 34.48 and 34.4, and potential temperature between 1.4 and 0.4, both in the ranges defined by Orsi et al. (1995), both decreasing poleward (Fig. 7, panels b and c). Available shelf-edge dissolved oxygen data are more sparse, but gridded mean values of 160–220 \(\mu\)mol/kg are present (not shown), which approaches the lower limit of the range expected. Together with the salinity and potential temperature data, there appears to be insufficient evidence to define the layer average northeastward jet just off the shelf-edge here as distinct from the southernmost component of the ACC. While this does not prove the converse, that the jet is therefore a part of the ACC associated circulation, this presumption appears reasonable.

In the following, the jet will be referred to as the ‘SACCF jet’, in keeping with the presence of SACCF-consistent hydrography in the jet’s vicinity. As discussed by Orsi et al. (1995) and references therein, the density structure and associated geostrophic velocities of the fronts and jets of the ACC are complex. They are not nearly so easily related as the simpler and robust cross-frontal structure of, for example, the Gulf Stream, whose name applies equally well to either velocity jet or thermocline slope. Indeed, Gulf Stream position proxies include both velocity-related and temperature structure definitions. For the ACC, definitions of the fronts themselves vary considerably, with resulting positions diverging somewhat according to definition (Orsi et al., 1995; Sprintall, 2003). Dynamical constraints require density gradients, velocity shear, and sea-surface slope to be consistent with one another. However, efforts to establish jet locations associated with the front locations based on summary definitions of either often suggest some disparity between the locations of the strongest elements of the jets relative to the strongest property or density gradients, both vertically and horizontally. For example, Lenn et al. (2007) found better correspondence between the sub-Antarctic and polar fronts and jets of the ACC than between the SACCF and the near-WAP jet(s) of the ACC in Drake Passage.

Sections of velocity averages by 8 m bin depth levels of the northeastward flow over the slope (Fig. 9) indicate that the jet is slightly depth-intensified, with northeastward flow extending from over the slope-rise to the shelf break in some cases. Peak velocities at this grid-spacing coincide with about the 2500–3000 m isobaths.
The banded nature of the northeastward flow is also evident, consistent with the Drake Passage investigation of Lenn et al. (2007). Order of magnitude transports within the summer SACCF jet were estimated from cross-line velocities rotated into (large) along-shelf and (small) cross-shelf components, with signs taken from the along-shelf component (positive is northeastward). Vertical column sums were normalized to constant depth (40–375 m) for all vertical columns containing data (termed ‘fill’). That is, if only half of the upper water column has data, the transport value for that portion is scaled up to represent the remainder of the water column.

Fig. 7. Panel a: record long means (red) and standard errors (blue) from detided, binned shipboard ADCP velocities between 40 and 200 m depth along the shelf-edge. Note the blue arrows are all oriented to the northeast, as the standard errors in the north and east directions are expressed as positive values. Panel b: potential temperature along the $\sigma_0 = 27.6$ surface from archived CTD data. Contour interval is 0.2 °C. Panel c: salinity along the $\sigma_0 = 27.6$ surface from archived CTD data. Contour interval is 0.02 psu. Numbers of CTD observations in each bin are represented as dots in panels b and c. Light gray lines in all panels are the locations of the SACCF and the southern boundary of the ACC as determined by Orsi et al. (1995).
between 40 and 375 m, assuming depth uniformity of net transport. Areal weighting along the Nr1-4 and the Sh1 lines was determined by ADCP bin depth (8 m) and gridpoint spacing (~12 km for the Nr lines, ~6.7 km for the Sh line). Only positive velocities were summed over the portion of the vertical section encompassing the SACCF jet. The SACCF jet transport ranges roughly from 1 to 2 Sv from lines Nr1 to Nr4 and line Sh1 in summer. These values are intended only as order of magnitude estimates, as approximately 0–15% is vertical fill, with an error of approximately 20% of the remainder estimated from the error bars. The apparent changes in along-shelf flow from line to line probably do not represent a real along-shelf changes in ACC-related transport, but rather a cross-shelf shift in where the transport is carried in the banded velocity structure. Lenn et al. (2007) showed that, despite along-shelf changes in the details of near-shelf-edge velocities in the southern Drake Passage, net transport across the entire ACC system does not change appreciably with along-shelf position (see their Fig. 4). Additionally, the means for particular lines may be taken over dramatically different timeframes than the other lines, such that synopticity of the sections is unlikely.
4.2. Southwestward shelf-edge jet

Farther north along the WAP, a southwestward flowing current is evident at the shelf-edge from north of King George Island to Livingston Island (Sections Sh2–Sh3 in Fig. 7). This current is slightly depth-intensified in winter and resides over the upper slope shoreward of the 1800 m isobath (Fig. 9). In summer, there is some indication of a similar slightly surface-intensified flow in sections Sh2 and Sh3 (Fig. 9). For a southern hemisphere current flowing with the shore on its left, looking downstream, depth intensification requires the isopycnals to slope up in the shoreward direction, while surface intensification requires a downward slope shoreward. Seasonal heating and cooling of the shelf waters would be consistent with this effect, as would seasonal nearshore salinity changes from ice melt. Unfortunately, the SO GLOBEC and LTER CTD archives do not include shelf stations near this shelf current.

Two recent studies are especially relevant to this feature. In the southernmost portions of the eastern Drake Passage transect examined by Lenn et al. (2007), a small southwestward mean velocity on the shelf is observed (see their Figs. 4 and 5), using the same ADCP archive used herein (though the exact set of cruises used may be somewhat different). Additionally, Sprintall (2003) used repeat XBT (and limited XCTD) transects along these same cross-passage lines to examine upper ocean (to 800 m) hydrographic structure. At the southern end of many of their eastern and middle sections, the continental water boundary (CWB) is present, accompanied by westward transport poleward of this front. Sprintall (2003) identified this transport as the same upper ocean flow identified by Nowlin and Zenk (1988) and Whitworth et al. (1982).

A short digression on the name of this feature is appropriate. While Nowlin and Zenk (1988) and Whitworth et al. (1982) termed this feature (both deep and shallow components) the polar slope current, Sprintall (2003) chose the term Antarctic slope current, whereas Heywood et al. (2004) used this term to signify a deeper topographically controlled flow which appears in many locations around the Antarctic continent. Nowlin and Zenk (1988) considered the deeper component of the polar slope current in this location to be a topographically controlled feature also. However, they considered the shallower limb to be ‘kinematically distinct’ from the deeper limb, perhaps associated with the west wind drift. Hofmann et al. (1996) also referred to the 400–600 m depth feature as the polar slope current. Without concurrent CTD or wind information, identification of the southwestward flow on the outer shelf observed here is problematic. However, in keeping with the correspondence in Sprintall (2003) between the CWB and the westward flow, but in recognition of the distinction between the shallower and the deeper components, and their apparently different characters, as well as the history of nomenclature, the southwestward outer shelf current observed seaward of the SSI herein is referred to as the shallow polar slope current (ShPSC). The reader should consider this a convenient shorthand until the community settles on the proper distinction. Whitworth et al. (1998) provided a thorough description of the history and definition of the Antarctic slope front along all sectors of the Antarctic continent.

Transport in the ShPSC has been roughly estimated from cross-line velocity magnitudes, as above, with areal weighting from ADCP bin depth (8 m) and along-line gridpoint spacing (~6.7 km). Only the negative transport values over the upper slope (shoreward of the 1800 m...
isobath but deeper than the shelf break) have been included. Total estimated ShPSC transport in winter is of order $\frac{1}{2}$ to 1 Sv southwestward across lines Sh2 and Sh3. As with the SACCF associated shelf-edge current, these values are intended only as order of magnitude estimates. Here, only 1% is vertical fill, with an error of 40–75% of the remainder estimated from the error bars.

A shelf-edge convergence is weakly implied between the ShPSC north of the Smith Island and the SACCF jet south of Smith Island. However, the two currents occupy different positions of the slope, and different depth ranges in the water column, such that the convergence only exists in integrating across the entire slope. Furthermore, near Smith and Livingston Islands, both currents apparently veer to their left looking in the direction of flow. The northeastward shelf-edge current turns offshore, as mentioned above, and the planview maps also clearly suggest that the ShPSC transport turns shoreward and passes through Boyd Strait into Bransfield Strait. This strong shoreward cross-shelf flow through the passage between Smith and Snow/Livingston Islands is present in year-round, winter and summer means. This contrasts with the indication from temperature fields in Capella et al. (1992) that no ShPSC turns through Boyd Strait. Hydrographic evidence has not been examined herein to determine whether ShPSC is the source for water carried through Boyd Strait.

It would be of value to estimate transport carried by the ADCP average currents through Boyd Strait, though with very little cross-channel distribution of track lines within the channel, and consequently only one line of gridpoints oriented north to south through the channel, it is not possible to define the structure of any through-channel jet. However, cross-shelf (along-line) velocities along the line through the channel can be areally weighted in the same way as the along-shelf (cross-line) velocities were, to estimate transport across a column of water a unit length wide, taken here to be 10 km wide for concreteness. Along the line, such transport varies somewhat, but is $-0.2$ Sv or above wherever it is calculated along the line through the channel (0–3% fill, 20–40% error in remainder). If such transports applied over adjacent 10 km wide columns, the estimated magnitude of the ShPSC transport could be accommodated through Boyd Strait. The channel itself appears to be $\sim 50$ km wide, and it is fairly deep (500–750 m).

The transport through Boyd Strait flows directly into Bransfield Strait shoredaw of the SSI. The cross-Boyd Strait component of the along-Boyd Strait inflow changes with season at the south end of Boyd Strait, turning slightly to the southwest, or clockwise in summer, turning slightly southeasterward, or counter-clockwise in winter. In such a constrained geometry, these seasonal means may represent a sampling artifact of some sort. For example, ships transiting the passage may favor one bank more than the other during specific seasons, which may bias the measured currents in one season relative to another. This does not appear to be the case, as neither an examination of individual ship-tracks, nor the average locations of the binned data indicate that tracks vary appreciably by season.

4.3. Bransfield Strait

In Bransfield Strait, there is cyclonic circulation, with strong flow to the east-northeast along the southern margin of the SSI, and weaker, wider flow to the southwest along the boundary with the Antarctic Peninsula itself. The western portion of the northeastward jet south of Smith Island is referred to as the Bransfield jet in Garcia et al. (2002), while the overall feature has been referred to in this document and elsewhere as the SSI jet.

A large quantity of data is available from Bransfield Strait. Finer resolution gridding along the length of the Strait illustrates the structure more completely (Fig. 10). Immediately southward of the Boyd Strait inflow is the northeastward flowing SSI jet, situated just south of the South Shetland Islands. This northward limb of the overall cyclonic circulation filling Bransfield Strait appears to be continuous from Livingston Island eastward, wrapping counter-clockwise to the north past King George Island as it nears Elephant Island.

Continuity between the Boyd Strait inflow and the SSI jet is of interest. In winter, flow through Boyd Strait turns eastward, apparently feeding directly into the SSI jet (Fig. 10). The summertime SSI jet in line A, southward of Boyd Strait, is absent along that line in winter. In summer, the inflow through Boyd Strait turns slightly westward, perhaps not feeding directly into the SSI jet. The western end of the SSI jet in line A may be fed in summertime from farther west, south of Low Island (the small island south of Smith Island).

The summertime SSI jet in the vicinity of Boyd Strait is weaker and much more surface trapped than it becomes farther east in the Strait (Fig. 11, line A, top left panel). South of Livingston Island (line B), the jet deepens and transport increases, conceivably fed from the south by the inflowing (westward) weaker velocities south of the jet. The jet becomes strong and deep eastward of Livingston Island (Figs. 10 and 11, lines B and C). Velocities in the jet reach 0.50 m/s in the 8 m depth bin averages, and exceed 0.35 m/s in the averaged layer between 40 and 200 m depth. Velocity falls off somewhat with depth, but is still quite strong at the depths to which the ADCP data extend. Velocities are stronger at those levels (Gomis et al., 2002), the jet likely extends deeper still.

The known tidal velocities are quite strong in Bransfield Strait (Lopez et al., 1994), so it is worthwhile to eliminate tidal biasing of the shipboard ADCP data as a problem in this case, since the model has not been validated there. To establish faith in the tidal predictions, the tidal parameters are estimated from the model (Padman et al., 2002) at the current-meter locations of Lopez et al. (1994). These instruments were in place for an approximately two month period in 1992–1993, and have not been assimilated nor used in prior validation of this model (Padman, personal communication, 2008). In fact predicted tidal magnitudes (Table 2) are of nearly the same magnitudes as the mooring estimates at the 200 m depths for all the components listed in Tables 2 and 3 of Lopez et al. (1994) (also shown in Table 2 herein). Predicted inclinations at the southern site were nearly exact, within a few degrees in the semi-diurnal and
Fig. 10. (Panel a) summer and (panel b) winter means (red) and standard errors (blue) from detided, binned shipboard ADCP velocities between 40 and 200 m depth. Note the blue arrows are all oriented to the northeast, as the standard errors in the north and east directions are expressed as positive values. Lines indicate locations of sections shown in Fig. 11.
Diurnal components listed. Predicted inclinations at the central site were less exact, but were within 25–30°. (No relative phases were reported for the moorings in Lopez et al., 1994.) This correspondence in magnitude and inclination indicates that the model predicts tides reasonably well at the western end of the Bransfield Strait. To examine further, phase bias was investigated by ascertaining the relative phase distributions for the binned data at several along-jet locations. If all phases are evenly represented in the data from which means are calculated, presumably any tidal component not properly removed by subtracting the model predictions will be averaged out by other phases of the tide, as with low-pass filtering. In the east near line C, the phase distribution across the data used is fairly evenly distributed in both M2 and K1 phases. Farther west, data are less evenly distributed. However, phase distributions near line B do not show gaps at the same relative phases as the gaps near line A, suggesting that resulting bias should be different from one line to the next. However, strong velocities are consistent across the lines from west to east, suggesting that if they are from bias, they are similarly biased. Taken together, the evenly distributed phases in semi- and diurnal tides at the east end, the validation of the model at the west end, and the differing gaps between two nearly adjacent locations in the west with similar resulting mean velocities in the jet, suggest that the strong jet velocities do not result from tidal bias in the averages.

Lopez et al. (1994) found that after removing tides at their mooring stations south of Boyd Strait, their measured upper ocean velocities matched prior geostrophic estimates from hydrography fairly well. Across line A, the strength of the jet from ADCP bin averages calculated...
herein also matches prior estimates from hydrography in magnitude. But farther east, the ADCP averages are much larger than prior estimates from hydrography, matching near surface drifter speeds more closely. Dynamic height-based velocity estimates render only the part of the current that is sheared in the vertical (the baroclinic part) but will miss any component that is constant with depth. The low vertical shear evident in the archive ADCP means vertical sections across line B and especially C is consistent with this discrepancy. For quantitative assessment, the barotropic portion of vertical profiles of velocity is here defined as the part that does not vary with depth (as in, e.g. Fofonoff, 1962). This is taken as equal to the velocity at 300 m depth, where presumably the baroclinic (sheared) part falls to zero, as the geostrophic velocities referenced to 500 m of Gomis et al. (2002) indicated (their Fig. 5). The barotropic part is then subtracted at every level from the total velocity (Fig. 11, top panels) to estimate the baroclinic part of the measured ADCP means. Across lines A and B, this baroclinic component of the ADCP-based velocity is very similar in magnitude to that derived from the density field by Gomis et al. (2002) (Fig. 11)—these two sections are near Gomis’s section S2). Farther east across line C, the baroclinic component approximately doubles. However, the barotropic component is larger still, and must be due to some additional externally forced sea-surface height gradient across the jet, in the sense that sea surface falls from northwest to southeast, driving a geostrophic current to the northeast. Sea level setup due to wind forcing is a possible forcing mechanism.

Transport across each cross-strait section between 40 and 375 m depth has been roughly estimated from the available mean cross-section velocities by areal weighting from ADCP bin depth (8 m) and cross-Strait gridpoint spacing (~3.4 km), normalized to constant depth for all vertical columns containing data, as discussed for the transport estimates above. These estimates suggest that the transport in the SSI jet approximately doubles from 1–5 Sv in the vicinity of Boyd Strait to 2–5 Sv east of Livingston Island, remaining large eastward from there. As above, transports are intended only as order of magnitude estimates. Here, 10–20% is vertical fill, with an error in the remainder of 40% in the western end, and 15–30% in the east, based on error bars.

It appears that the increase may come from south of the jet, where the flow is generally westward, forming the southwestward limb of the cyclonic circulation within Bransfield Strait (Fig. 10). Especially strong westward velocities are found along the southern rim of the deep basin south of Elephant and King George Islands, flowing along the 250–1000 m isobaths. Generally weaker westward inflow is also apparent through most of the region south of the SSI jet. Westward transport in the western part of Bransfield Strait is of lower magnitude than farther east (Fig. 10), suggesting some loss during westward transit, perhaps through contributions to the SSI jet, which increases eastward. However, the southern extent of many of these lines is poorly sampled, so this spatial pattern in the westward inflow may be illusory. Farther east, the westward inflow meets or exceeds SSI jet transport by as much as 30–50%, though here too large gaps exist. Strong velocities also exist in summer north of the Antarctic sound, the passage through to the southeast backside of the Peninsula, between the 100 and 500 m isobaths (Fig. 10). This may be the Antarctic coastal

### Table 2

Model tidal ellipse parameters for the Lopez et al. (1994) mooring locations and times.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Major (error)</th>
<th>Minor (error)</th>
<th>Inc (error)</th>
<th>Phase (error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1 0.03873</td>
<td>7.454 (0.169)</td>
<td>1.745 (0.13)</td>
<td>29.21 (1.11)</td>
<td>258.10 (1.42)</td>
</tr>
<tr>
<td>K1 0.04178</td>
<td>8.315 (0.170)</td>
<td>1.854 (0.13)</td>
<td>27.65 (0.96)</td>
<td>267.34 (1.26)</td>
</tr>
<tr>
<td>M2 0.08051</td>
<td>7.838 (0.177)</td>
<td>1.019 (0.09)</td>
<td>19.42 (0.70)</td>
<td>186.56 (1.31)</td>
</tr>
<tr>
<td>S2 0.08333</td>
<td>5.725 (0.177)</td>
<td>0.665 (0.09)</td>
<td>19.68 (0.96)</td>
<td>222.00 (1.80)</td>
</tr>
</tbody>
</table>

Lopez et al. (1994) 200 m central mooring near 63.20°S, 60.45°W

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Major (error)</th>
<th>Minor (error)</th>
<th>Inc (error)</th>
<th>Phase (error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1 0.03873</td>
<td>6.9050</td>
<td>2.3580</td>
<td>54.5000</td>
<td></td>
</tr>
<tr>
<td>K1 0.04178</td>
<td>4.9490</td>
<td>1.7350</td>
<td>51.9000</td>
<td></td>
</tr>
<tr>
<td>M2 0.08051</td>
<td>8.2340</td>
<td>1.9020</td>
<td>36.8000</td>
<td></td>
</tr>
<tr>
<td>S2 0.08333</td>
<td>6.3350</td>
<td>1.4310</td>
<td>22.0000</td>
<td></td>
</tr>
</tbody>
</table>

Lopez et al. (1994) 200 m southern mooring near 63.38°S, 60.35°W

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Major (error)</th>
<th>Minor (error)</th>
<th>Inc (error)</th>
<th>Phase (error)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1 0.03873</td>
<td>4.1580</td>
<td>1.4070</td>
<td>34.7000</td>
<td></td>
</tr>
<tr>
<td>K1 0.04178</td>
<td>3.6390</td>
<td>0.6660</td>
<td>36.9000</td>
<td></td>
</tr>
<tr>
<td>M2 0.08051</td>
<td>6.0840</td>
<td>1.9020</td>
<td>36.8000</td>
<td></td>
</tr>
<tr>
<td>S2 0.08333</td>
<td>6.3350</td>
<td>1.4310</td>
<td>22.0000</td>
<td></td>
</tr>
</tbody>
</table>

Mooring locations were estimated from Lopez et al.’s (1994) Fig. 1.
current, known to turn into the Bransfield Strait farther east, seaward of Joinville Island (Heywood et al., 2004).

4.4. Within Marguerite Bay

Turning to the region south of the SSI and Bransfield Strait, several interesting circulation features are evident. Here they are discussed, moving from nearshore (Marguerite Bay) seaward.

An apparent cyclonic circulation within Marguerite Bay in the record-long means is seen clearly in higher resolution gridding (denser along-shelf spacing) of the data (Fig. 12). The regridding indicates that this pattern consists primarily of intensified nearshore flow into the bay just southwest of Adelaide Island, and a similar intensification in an outflowing limb immediately north of Alexander Island. Both are surface-intensified, and appear only marginally in the 200–300 m layer maps. The inflowing limb also appears in the summer (December–March) and winter (June–September) plots (Figs. 12 and 13), but outflow is not well sampled enough for the means to exceed the uncertainties in winter.

The inflow along Adelaide Island and the outflow to the south along Alexander Island have been observed before. Klinck et al. (2004) used hydrography and shipboard ADCP from a pair of SO GLOBEC cruises in fall and winter of 2001 to show flow into Marguerite Bay along Adelaide Island and out of the bay along Alexander Island. The inflow appears to be a continuation of the coastal current observed just seaward of Adelaide Island. Both hydrographic and ADCP velocity estimates suggest stronger inflow and outflow limbs during the fall cruise. Drifters deployed in fall 2001 and summer–fall 2002 also show cyclonic circulation in Marguerite Bay (Beardsley et al., 2004). Both the two cruise-ADCP data (averaged over the 183–423 m layer) and the drifter data (drogued at 15 m) suggest velocity magnitudes near 0.1 m/s in the nearshore inflow and outflow limbs, of similar order as the overall means calculated from the archived ADCP data. Moffat et al. (2008) discussed the outflowing limb from a single ADCP section in fall 2001, and showed that it is quite surface-intensified.

4.5. Antarctic Peninsula coastal current

Moffat et al. (2008) also extensively discussed the Antarctic Peninsula coastal current immediately seaward of Adelaide Island and upstream from the inflowing limb in Marguerite Bay, and off Alexander Island downstream from the outflowing limb. The coastal current clearly appears in the 40–200 m layer averages from the 6 year ADCP archive also, not only off Alexander and Adelaide Islands (Fig. 6, panel b), but farther north off Anvers and Brabant Islands as well (Fig. 6, panel a). Note also the eastward transport in Gerlache Strait between the Antarctic Peninsula and Anvers and Brabant Islands, which suggests that the westward current seaward of those Islands may be part of a topographically controlled round-islands circulation, not a continuation of the APCC. In the following, the flow seaward of Anvers Island is contrasted with the APCC off Adelaide Island, recognizing that continuity between the two circulation features has not been established.

The seasonal signal in the coastal current is of particular interest. Off Adelaide Island, the jet is strongest in summer, where peak velocity magnitudes exceed 0.20 m/s (Figs. 12 and 14). The southwestward velocities inhabit a 300–400 m depth column of water ~60 km wide. The jet transports ~1 Sv of nearshore water to the southwest in summer. In winter, the velocities are much weaker off Adelaide Island, and transport is also lower. By contrast, winter is the season of slightly stronger velocities in the coastal current off Anvers Island (Figs. 12 and 14), with transport exceeding ½ Sv. In summer, southward velocities off Anvers Island are weaker, and transport is smaller (Fig. 14, upper right panel). Fill for these estimate constitutes only 1–3% of the total over either line, either season, with an estimated possible error of 50% across either line in winter or summer.

The summer contrast between the strength of the coastal current in the two locations suggests that the supply of water from the northeast or from the outer shelf may vary with season. Some apparent seasonal variation in the 40–200 m depth mean velocity maps upstream from the coastal current just southwest of Bransfield Strait is consistent with that possibility. The shoreward flow on the eastern flank of Marguerite Trough (discussed in Section 4.6) is another potential supply conduit, though its transport seasonality is still undefined.

A coastal current to the southwest on the WAP was suggested by Hofmann et al. (1996), through examination of drifter tracks and by analogy to buoyancy-driven flow observed on the wide shelf south of Alaska. Smith et al. (1999) used additional hydrographic data to suggest quite weak southward flow along the nearshore Islands, with geostrophic velocities of 2–3 cm/s estimated from dynamic heights at 200 m relative to 400 m. The APCC observed in the ADCP dataset herein can be slightly stronger at 200 m, and is significantly more energetic in the upper water column between 40 and 200 m. Surface drifter speeds reported by Klinck et al. (2004) and Beardsley et al. (2004) are more consistent with the seasonal ADCP averages reported here. Moffat et al. (2008) described the APCC off Adelaide and Alexander Islands in detail from a variety of SO GLOBEC data sources, and defined a surface-trapped jet in fall, with maximum speeds near 0.4 m/s, extending to 80 m depth, and also of narrower horizontal scale (~5 km) than illustrated here. However, the most intense surface-intensified velocity core of the summertime Adelaide section in Fig. 14 is consistent with the observations of Moffat et al. (2008).

4.6. Marguerite Trough

On the WAP shelf between the nearshore islands and the shelf-edge, the ADCP archive mean velocities suggest the presence of numerous cross-shelf oriented pathways (Figs. 6 and 12). This is unusual for a coastal setting, where means and the most energetic subtidal variabilities are usually oriented along-shelf. Between Anvers Island and
the shelf-edge, the mean vectors indicate fairly complicated flow patterns, of relatively low magnitude in the layer averages.

Farther to the southwest, off Adelaide Island and Marguerite Bay, cross-shelf velocities are much stronger, approximately 0.10 m/s in some cases, and more organized. Of particular interest is a shoreward flow between the shelf-edge and eastern end of Adelaide Island. This feature apparently flows along the northeastern flank of Marguerite Trough, with velocity magnitudes exceeding...
0.05 m/s (peak ≥ 0.15 m/s) concentrated in a jet ~50–60 km wide, ~200 m depth (Fig. 15).

Equally interesting is a seaward-directed current along the southwest flank of the Marguerite Trough (Fig. 12).

Offshore velocities exceeding 5 cm/s (peak ≥ 15 cm/s) extend to 400 m depth, in a jet ~50–60 km wide near the surface, ~200 m depth (Fig. 15). This seaward flow in the upper layer sampled by the shipboard ADCPs is in contrast
to evidence presented by Klinck et al. (2004) for shoreward cross-shelf transport in the deeper layers in Marguerite Trough, including the presence of lower circumpolar deep water in the lower water column in the trough. Upper water column transport is not specifically discussed by Klinck et al. (2004) with regard to the trough, but along-trough property sections (their Fig. 6) are not inconsistent with nearshore water moving seaward in the upper 400 m.

Seasonality in either limb of the Marguerite Trough-associated circulation is difficult to ascribe, as the winter coverage is much poorer than in summer. However, the winter vertical profiles suggest a more vertically layered structure (not shown), while the less layered summer features are more strongly associated with the two flanks of the Marguerite Trough.

Cross-shelf oriented circulation features are of interest for a variety of reasons; for determining pathways of circumpolar deep water onto the shelf, or to supply conduits for the seasonally varying APCC, among other examples. The advection of CDW onto the shelf is relevant to heat and salinity budgets on the shelf, and possible contributions to nutrient budgets, including silica (Serебренникова and Fanning, 2004). Shoreward pathways for upper CDW (UCDW) intrusions onto the shelf have been examined and are believed to be primarily associated with topographic irregularities or isobath curvature along the shelf-edge of the WAP (Dinneman and Klinck, 2004). Lower CDW (LCDW) occurs on the WAP shelf only in deep depressions or swails at the shelf-edge, such as within the Marguerite Trough (Klinck et al., 2004), making circulation near this topographic feature of particular importance.

5. Implications

By evaluating overall and seasonal mean velocities in this region, several suspected circulation features have been validated or more fully described. This provides important information for understanding communication between separate regions of the study area, both in the cross-shore direction and between along-shelf regimes. The reasons for examining such connectivity are manifold,
including the importance of tracking pathways for nutrients and heat from the deep water across the shelf, supporting phytoplankton growth and influencing ice cycles, tracking connectivity between high chla regions and known spawning and recruitment regions for krill, and for understanding how the high krill spawning and recruitment on the WAP relates to high abundances of adult krill in the Scotia Sea. High spatial and interannual variability is evident in all these components supporting higher trophic levels, and greater understanding of their interdependence continues to depend on discovering details of the circulation fields.

Marrari et al. (2008) have examined chla and krill distributions on the WAP using SeaWIFS and in situ sampling, and found high chla values in the surface waters just off the shelf, along the shelf-edge, and on the shelf south of Marguerite Bay, as well as in Marguerite Bay itself. In contrast to prior studies emphasizing blooms in the northern WAP, the summer blooms near Marguerite Bay and adjacent shelf, slope and nearslope Bellingshausen Sea routinely show higher more prolonged concentrations than the northern WAP. The position of the strongest signal varies with season, with significant interannual variability. Further, bloom strength appears to correlate, at least during the limited times covered by in situ biological sampling, to recruitment success of krill.

From a circulation standpoint, the interesting feature is that the Marrari et al. (2008) analyses suggest connectivity between the blooms in the Bellingshausen Sea (along the shelf-edge and just off the shelf) and the Marguerite Bay blooms. The results of the ADCP archive study support the possibility of both northward and cross-shelf transport from the shelf-edge southward of Marguerite Trough into the bay itself, and export of high chla waters from Marguerite Bay southward along the inner shelf off Alexander Island. Such export is also consistent with surface outflux observed by Beardsley et al. (2004) and Moffat et al. (2008).

Marrari et al. (2008) also showed that the northern shelf Spring blooms do not appear to be associated with the retreat of the ice edge, as previously thought. They hypothesized instead that the blooms may depend on shelf-edge upwelling associated with ACC variability, and progress shoreward with the later advection of that upwelled water. Their SeaWIFS climatologies strongly evoke advection shoreward and into the Bransfield Strait. Yet in a careful estimation of the three-dimensional circulation from hydrography in the Western Bransfield Strait, Comis et al. (2002) showed very little transport into the Strait from the west, instead concluding there is strong recirculation of Weddell Sea water within the Bransfield Strait. Their scheme was not able to represent the Gerlache Strait, however, and was based on two short term sampling programs in December 1995 and January 1996. The ADCP archive results, based on data spanning 6 years, indicate flow into Bransfield Strait through both Gerlache and Boyd Straits. Whether flow into Bransfield Strait exists between Smith and Brabant Islands is not discernable with the present gridding scheme. Further, while the SSI jet was a previously known feature, the strength of the jet had not been accurately determined previously. The cyclonic circulation in the Strait, the westward limb of which may substantially contribute to the large volumes transported in the SSI jet is also of interest. Both aspects suggest that residence times in the Strait may not be well understood.

Though it took some time before the accumulation of pre-processed data resulted in a substantial dataset to work with, the processing of these data by Firing and Chereskin and their groups, with NSF funding, constitutes a substantial and growing resource for the community. These results from the ADCP archive project serve not only to elaborate circulation features in ways that have not been possible before, but also as a demonstration of the utility of the data and the feasibility of their use in a relatively high traffic region of the Antarctic coastal ocean.

Acknowledgments

Support for this study came from NSF Grant OPP-0404533. Processing for the ADCP data was performed by E. Firing (Palmer) and T. Chereskin (Gould) under separate funding. Patrick Caldwell of NOAA/NESDIS/NODC extracted and provided the ADCP data from the data-base. L. Padman provided generous guidance on the characteristics and use of the available tidal models. Thanks to
E. Hofmann and J. Klinck for their guidance and for access to the early LTER CTD data, and to M. Dinneman who offered very helpful reality checks and provided updated bathymetry. A. Orsi provided the traces of the circumpolar fronts defined in his 1995 paper for plotting purposes. Thanks also to D. DeMaster, who got this project rolling by contributing his Palmer ADCP cruise data to DKS initially. A. Boyette improved the figures.

References


