Southern Antarctic Circumpolar Current Front to the northeast of South Georgia: Horizontal advection of krill and its role in the ecosystem

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[1] During December 2000 and January 2001 we conducted a high-resolution hydrographic and bioacoustic transect (RRS James Clark Ross cruise 57) that extended across the South Georgia shelf from close to Cumberland Bay, across the shelf break and slope and into the deep waters of the Georgia Basin beyond. We observed a high biomass of zooplankton between 53.8°S and 53.4°S associated with the inshore, northwestward flow of the Southern Antarctic Circumpolar Current Front (SACCF) that occurred in around 2500 m of water close to the base of the slope. There was very little zooplankton biomass present in the more offshore, eastward flowing waters where a second manifestation of the SACCF was also present on the section. The region of enhanced zooplankton biomass was over 50 km in horizontal extent with the highest densities (>10 g m⁻³) in the area of strongest flow (>35 cm s⁻¹). The majority of the zooplankton present on the section was Antarctic krill and most of it occurred in the upper 100 m. The rate of physically mediated transport of Antarctic krill across the off-shelf sections (~10 km) of the transect showed marked variation, with highest rates (>10⁶ g s⁻¹) associated with the northwestward flow of the SACCF. Farther offshore, where the krill biomass and flow rates were much reduced, the flux of krill was very low. The integrated horizontal flux of krill across the offshore sections was large (192 × 10³ t d⁻¹) and to the northwest. A second occupation of the transect showed that the krill flux is highly variable, and we discuss the various physical and biological factors that will generate such variability. We show that horizontal flux of krill in ocean currents is a major factor in determining the abundance of krill around South Georgia.

INDEX TERMS: 4207 Oceanography; General: Arctic and Antarctic oceanography; 4815 Oceanography: Biological and Chemical: Ecosystems, structure and dynamics; 4855 Oceanography: Biological and Chemical: Plankton; 4528 Oceanography: Physical: Fronts and jets; 4899 Oceanography: Biological and Chemical: General or miscellaneous; KEYWORDS: Southern Ocean, krill, circulation, ecosystem, South Georgia, food web


1. Introduction

[2] To be able to predict the dynamics of marine ecosystems we require an understanding of the physical and biological interactions that maintain the systems. That ocean currents transport biological material was recognized in early studies of species and large-scale ecosystems [Darwin, 1884; Hardy, 1967], and transport of plankton in ocean current systems is known to be important in the development and maintenance of particular plankton populations [e.g., Bryant et al., 1998; Gurney et al., 2001]. Yet, there has been little quantification of the importance of horizontal transport in the maintenance of marine food webs, although such external input of biological material is known to be crucial to the maintenance of some regional ecosystems [Agusti et al., 2001; Anzorge et al., 1999; Pakhomov and Froneman, 1999; Perissinotto et al., 1992; Polis and Hurd, 1996; Sanchez-Pinero and Polis, 2000]. A likely consequence of climate change will be shifts in the pattern of ocean circulation [Bigg, 1996; Houghton et al., 2001] disrupting these pathways of biological transport, potentially resulting in the collapse of regional food webs.

[3] Some of the world's largest breeding colonies of seabirds and seals occur on the island of South Georgia (Figure 1) in the northeastern Scotia Sea [Croxall, 1987; Evison, 1977; Laws, 1984]. During the summer, penguins, albatrosses and fur seals rely mainly on a single species of zooplankton, Antarctic krill (Euphausia superba Dana), as their major source of food [Boy, 2002; Evison, 1977]. Antarctic krill was also the major
prey of many of the whale species that were exploited so heavily during the first half of the last century [Everson, 1977] and is the target of a commercial fishery that operates around South Georgia during the winter months [Murphy et al., 1997]. The krill around South Georgia do not form an isolated population [Marr, 1962; Murphy, 1995; Murphy et al., 1998; Watkins et al., 1999] as there is thought to be an input of individuals from the southern Scotia Sea (Figure 1), either from the west around the Antarctic Peninsula or from farther east across the South Scotia Ridge. Indeed, studies of krill populations have shown that the large interannual fluctuations in the abundance of krill at South Georgia are linked to basin-wide changes in abundance and krill population dynamics [Brierley et al., 1999a; Hofmann et al., 1998; Murphy and Reid, 2001; Murphy et al., 1998; Watkins et al., 1999], which in turn have been linked to large-scale environmental processes [Loeb et al., 1997].

Recent work has shown the importance of frontal regions in determining the distribution of Antarctic krill in the Southern Ocean [Loeb et al., 1997; Nicol et al., 2000; Tynan, 1998]. Coupled biological-physical model studies suggest that the large-scale ocean circulation, and in particular the flow in association with the Southern Antarctic Circumpolar Current Front (SACCF) [Orsi et al., 1995], may play a role in the transport of krill into the South Georgia region [Hofmann et al., 1998; Murphy et al., 1998]. A multidisciplinary biological-physical oceanographic transect was undertaken on the northern side of South Georgia to quantify krill transport rates in the ecosystem and to determine specifically whether the SACCF is important in transporting krill (Figure 1). In the associated paper [Meredith et al., 2003] we described the detailed physical oceanography of the section. Here we report on the detailed field-based estimates of vertically resolved upper water column velocities and abundance of Antarctic krill that we combine to calculate the horizontal flux of krill in association with the current systems. We consider the magnitude of the flux in relation to local predator demand for krill in the regional food web and the large-scale transport of the krill.

2. Methods

During December 2000 and January 2001, a 160 km transect on the northern side of South Georgia between
53.29°S, 34.26°W and 54.10°S, 36.27°W was undertaken by the RRS James Clark Ross [Meredith et al., 2003; Ward et al., 2002] (Figure 1). A continuous acoustic survey leg was performed during 26 December 2000 using towed and underway instrumentation [Meredith et al., 2003], followed by a return along the transect during which 17 hydrographic stations were sampled. The continuous transect was completed during daylight hours so that the acoustic survey encompassed periods when most of the krill would be expected to be deeper in the water column. The second return transect was then undertaken over a period of about 2.5 days so included day and night sampling.

[6] Full depth hydrographic data were collected using a SeaBird 911 plus conductivity-temperature-depth (CTD) instrument. CTD salinities were calibrated using discrete water sample measurements, and CTD downcasts were averaged at 2 dbar intervals for analysis. Station separation was around 10 km, close to the Rossby radius of deformation in the region [Houry et al., 1987]. Measurements of water velocity in the upper part of the water column were made using a 153.6 kHz vessel-mounted RD Instruments Acoustic Doppler Current Profiler (ADCP). Underway measurements of acoustic biomass between 10 and 500 m were made with a Simrad EK500 scientific echosounder operating through hull-mounted transducers with frequencies of 38, 120, and 200 kHz. A pulse repetition rate of 2 s was combined with a survey speed of 10 knots. Data were logged using SonarData EchoLogEK with visualization and post-data collection processing carried out using SonarData Echoview software. The echosounder was calibrated at Stornness Bay, South Georgia, on 24 December 2000 using the standard target technique [Foote et al., 1987].

[7] Acoustic biomass due to Antarctic krill was separated from biomass attributable to other scattering targets by calculating the difference between acoustic mean volume backscattering strength (Sv) measured at 120 and 38 kHz ($\delta_{120-38}$) [Madureira et al., 1993]. Inspection of $\delta_{120-38}$ resulting from a series of targeted net hauls conducted during the cruise revealed that $2 < \delta_{120-38} < 14$ was a reasonable range to include the majority of krill targets found in the study area (Woodd-Walker, personal communication, 2001). Previous studies using multifrequency acoustic techniques to delineate krill have used a variety of ranges for $\delta_{120-38}$, from 2–12 dB [e.g., Brierley et al., 1999b] to 2–16 dB [SC-CAMLR, 2000]. In an attempt to estimate magnitude of error due to possible misidentification of acoustic targets in this paper, we also estimate biomass under two additional conditions: where all acoustic targets are assumed to be krill (which produces a maximum biomass but which is likely to overestimate the biomass of krill), and where only targets with $\delta_{120-38} = 2$ to 12 dB are assumed to be krill.

[8] Biomass of krill (g m$^{-3}$) was derived from acoustic mean volume backscattering strength ($S_v$) in decibels (dB) using the procedures described by SC-CAMLR [1991, 2000]. The calculations use the length-weighted mean target strength ($TS_{120}$) and the mean krill mass ($\bar{W}$) calculated from the length-frequency distribution sampled from the local krill population. Biomass (g m$^{-3}$) is given by

$$\text{Biomass} = W \times 10^{(S_v-TS_{120})/10},$$

where $TS_{120}$ (dB) is related to length (L) in millimeters by the relationship:

$$TS_{120} = -127.45 + 34.85 \log(L),$$

with length converted to mass (g) using the allometric relationship:

$$W = 2.236 \times 10^6 L^{1.314}.$$
For the food web calculations regional krill stock estimates are based on a 35 g m\(^{-2}\) mean krill density estimate for the northwest shelf region from January 2001 [Brierley et al., 2002]. The biomass was calculated over an arc of 270° centred on the western tip of South Georgia, the location of the most dense predator colonies. Biomass values were calculated for an area with a 75 km radius with values for a 50 and 100 km radius to give a range. Mass increases due to growth were calculated for values of 2 and 5% increases in biomass per day [Atkinson et al., 2001]. A range for the regional increases in biomass is calculated by applying these figures for the proportional increases in biomass per day to the range of the biomass estimates. The estimate (and range) of the consumption rate of krill by the major krill predators at South Georgia during summer was based on seasonal energy-based calculations for fur seal and macaroni penguin populations [Boyd, 2002].

3. Results and Discussion

3.1. Krill Biomass Associated With the SACCF

Detailed analyses of the physical oceanography are given in an associated paper [Meredith et al., 2003]. Here we present a brief description of the key points required to interpret the biological data and calculate the fluxes. The SACCF was found close to the base of the slope on the north side of South Georgia (Figure 1). The location of the front was marked by strong horizontal gradients in temperature, salinity and density [Meredith et al., 2003], and was close to the position of the 1.8°C isotherm at 500 m depth [Orsi et al., 1995]. At the front a strong northwestward flow rate reached a maximum of approx. 40 cm s\(^{-1}\) with enhanced flow rates in a narrow band approximately 40 km wide. Further offshore there was a weaker southeastward flow (maximum 15 to 20 cm s\(^{-1}\)) associated with an isolated ring that had spun off the SACCF retroflexion [Meredith et al., 2003].

Associated with the strong northwestward flowing jet of the SACCF was an enhanced biomass of zooplankton (Figure 2). The region of enhanced biomass extended over about a 40–50 km region, from inshore of the center of the front, around 53.8°S, out across the front to about 53.4°S. Detailed analyses of the upper water column showed that flow rates >25 cm s\(^{-1}\) to the northwest were associated with the SACCF, with flows of ≥20 cm s\(^{-1}\) occurring over a 30–40 km region across the front (Figure 3a). In the more offshore region where there was a generally weak eastward flow there was some vertical structure, with water deeper than 40 m flowing eastward at ≤15 cm s\(^{-1}\) while there was a very weak northwest flow (<5 cm s\(^{-1}\)) in the upper 40 m. On the basis of the net sampling and acoustic analyses the majority of the zooplankton echoes were attributed to krill [Ward et al., 2002] so the echo-based identification of krill accounts for the majority of the biomass in the region. The highest densities of krill occurred in an approximately 10 km section centered on the front at 53.8°S to 53.7°S (Figure 3b). The majority of the krill occurred in the upper 100 m of the water column. The krill were present in the higher densities in the area with the strongest flow rates to the northwest. In the most offshore 40–50 km section there were few krill present anywhere. What krill were present in the most offshore region occurred in the upper 40 m of the water column associated with the very weak northwest flow. The krill

![Figure 2. The distribution of acoustically detected zooplankton (g m\(^{-3}\)) in the upper 200 m of the transect shown in Figure 1.](image-url)
were almost absent in the depth range between about 40 and 250 m in the most offshore regions where the water was flowing to the southeast.

The majority of the krill biomass on the transect was therefore associated with the strong northwestward flowing jet of the SACCF. We consider that these krill associated with the SACCF will subsequently have been physically advected to the northwest of the transect section. Krill are not just passive tracers and horizontal and vertical movements will modify their position in the water column [Nicol, 2000]. In the present situation however it is difficult to conceive of any way in which the krill would not be transported with the current flow observed. Horizontal swimming speeds of 10 to 20 cm s⁻¹ have been suggested for krill [Miller and Hampton, 1989], but to have a marked effect on the large-scale transport, krill would have to maintain such speeds in a particular direction for a long period; this is unlikely. Krill are known to be able to diurnally vertically migrate [Godlewska, 1993; Tarling et al., 1998], and although this is far from a universal

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**Figure 3.** Data combined for flux calculations: (a) vertically resolved data on the current flow (negative values represent northwestward flow) and (b) the abundance and distribution of krill in the water column. The bioacoustic data have been integrated to the same resolution as the current flow data: 2 m vertical and approximately 10 km horizontal. The figures show the data for the upper 150 m and for the 12 most offshore stations.
observation in Antarctic krill, such behavior can in theory affect their horizontal distribution in regions of vertical current shear. Hardy [1967] discussed how vertical migration of krill around South Georgia could modify their distribution. However, in the present study there was no marked vertical shear structure that would be required to allow the horizontal distribution to be modified greatly. With no strong vertical structure in the current field for krill to exploit by migrating vertically, horizontal physical advection will have dominated the movement of krill.

3.2. Krill Flux in the South Georgia Ecosystem

Vertically resolved estimates of water transport and biomass were combined (Figure 3) to calculate the physical advective transport of krill in the region. High krill biomass associated with the strong northwestward flow resulted in a high krill flux in the southern arm of the SACCF (Figure 4). Low krill densities combined with relatively weak southeastward flow rates resulted in little flow of krill to the east. These field observations of high krill flux associated with the SACCF confirm model-based suggestions that this front is important in the Scotia Sea ecosystem [Hofmann et al., 1998]. The instantaneous gross northwestward flux was \( \sim 211 \times 10^3 \) tonnes per day, with a net northwestward flux of krill of \( \sim 192 \times 10^3 \) tonnes per day integrated across the whole section. The classification of acoustic targets as krill is based on the backscatter signal at 2 frequencies and depending on the classification method used, the estimate of the net flux varied in the range of \( \sim 154 \) to \( 200 \times 10^3 \) tonnes per day.

The above study cannot reveal the level of variation in the current flow or in the biomass of krill being transported. We have effectively sampled a single point in a continuous flux series and variability of krill flux into the region must be expected so our measurements of krill flux are unlikely to be representative of a longer-term average. This was emphasized by calculating a second flux estimate based on the biomass of krill surveyed between stations over the 2.5 day period of the CTD transect [Ward et al., 2002]; this produced a much lower estimate of krill flux \( (35.3 \times 10^3 \) t d\(^{-1}\)). Some of the sections on this repeat survey were sampled during the night when krill migrate into the surface layers outside of the range of detection of the acoustic system, so the estimate of krill biomass would be expected to be lower. However, for those sections undertaken during daylight hours in the vicinity of the SACCF there was a reduced biomass of krill compared to the biomass on the first survey. Such variability may be generated in a variety of ways: physically through fluctuations in ocean currents or frontal positions [Thorpe et al., 2002] affecting the amount and the pathways of krill transport, or biologically through variations in the input of krill into the current flow as a result of population or behavioral effects further upstream [Murphy et al., 1998]. Whatever the basis for the variability, the study has shown that advection of krill by ocean currents is an important process, and needs to be considered in studies of regional ecosystems in the Southern Ocean.

We have observed an enhanced abundance of krill in an offshore region toward the eastern end of the island while much of the predator demand for prey occurs at the western end of the island both offshore [Boyd et al., 2002] and also on the shelf [Trathan et al., 1998a]. Simple views of the circulation in the region indicate that the westward route along the north coast of South 

Figure 4. The ocean current data and acoustically derived biomass data were combined to estimate the potential transport flux of krill orthogonal to each section of the transect in the upper 250 m. The water volume transport between each station pair is shown by the red arrows (Sv), and the blue arrows show the associated krill flux \( (10^6 \) g s\(^{-1}\)).
Georgia is likely to be the major pathway of input of krill into the western region [Murphy et al., 1998]. However, the surface circulation of the region shows complex interactions with the local bathymetry [Meredith et al., 2003]. Eddy shedding in the area of the retroflexion of the SACCf may be important in moving krill out of the SACCf and toward the west rather than returning to the east in the offshore flow of the SACCf. Cross-shelf transfer processes associated with the complex bathymetry are also likely to be important in krill movement onto the shelf [Brandon et al., 1999]. Where significant cross-shelf exchange occurs is presently not clear; however, krill on the shelf in the west may have been entrained onto the shelf on the eastern and southern side of the island before being advected west. Understanding the mechanisms for such transfers will be crucial for understanding the links between the offshore ocean systems and the more inshore high predation regions.

The calculated krill flux through the transect section is at least 4 times larger than the estimated krill consumption by the main seal and penguin predators of krill in the region at the same time of year (between 22.5 and 42 $\times 10^3$ t d$^{-1}$) [Boyd, 2002]. Meeting the predator demand will be the result of a combination of the influx of secondary production (allochthonous) in the form of krill and local production (autochthonous) due to growth of individual krill. A comparison of the flux estimates with the best available estimates of predator consumption [Boyd, 2002] and krill growth [Atkinson et al., 2001] indicates that the measured influx was much larger than the krill consumption and growth flows in the food web (Figure 5). The estimates also suggest there will be a very high rate of turnover of the regional krill stock [Murphy, 1995], although efflux rates are unknown. Obtaining robust estimates of all the various flux rates in the budget requires targeted studies of the various rate processes, but the calculations further emphasize that allochthonous production will be vital in supplying the predator demand in the region.

### 3.3. Large-Scale Connections in the Scotia Sea Ecosystem

[20] A key question in analyzing the dynamics of krill populations at South Georgia is what are the source regions for the krill that occur around the island? Analyses of tracks of giant icebergs, drifters and model trajectories all indicate that krill within the SACCf that we observed in this study are likely to have been transported around the eastern end of the island from the southern central Scotia Sea [Hofmann et al., 1998; Ichii et al., 1998; Murphy et al., 1998; Ward et al., 2002]. Timescales of drifters, iceberg tracks and particle tracking using output from the Ocean Circulation and Climate Advanced Model suggest that particles could have been transported across the Scotia Sea in only 2 or 3 months [Ward et al., 2002]. Sea ice covered the southern Scotia Sea region during November 2000, suggesting that krill seen in the offshore region at South Georgia during summer may have been under the ice in the southern central Scotia Sea during spring. This view is consistent with model analyses of the overwintering and transport of krill in the region [Fach et al., 2002]. This interaction with the winter sea ice emphasizes the uncertainty in attempting to consider the longer-term, largescale transport trajectories of krill. The central southern Scotia Sea is a dynamic and variable region, with sea ice advancing and retreating over water masses originating in the Bellinghausen Sea, the Antarctic Peninsula and the Weddell Sea [Murphy et al., 1998]. This means that until we better understand the under-ice movement and transport processes of krill, both passive and active, the ice-ocean interaction processes and genetic differences between krill populations from different regions, it is unrealistic to consider whether krill at South Georgia have originated either from west of the Antarctic Peninsula or from the Weddell Sea; rather we can only consider where krill may have come from within a season. The results reported in this study and the companion paper by Ward et al. [2002] give the first description of an association between the influx of krill into the South Georgia region during summer and the ecosystem of the southern Scotia Sea during the spring, and indicate that overwintering processes in sea ice-covered regions directly affect the South Georgia ecosystem 500 to 1000 km further north during the following summer.

[21] The large flux of krill through the South Georgia area observed in this study emphasizes the dynamic large-scale nature of the population dynamics of krill [Murphy and Reid, 2001]. The distribution of krill biomass will be a function of horizontal movements and local production. The degree to which local spawning and egg production occurs at South Georgia remains unclear and the assumption is that the majority (or all) the post-larval individuals are ultimately generated outside the region. However, it is possible that spawning and egg production are occurring in areas around South Georgia but that high flow rates, and potentially high growth rates, mean that the effects are difficult to observe. The large input of krill into the region observed in this study also raises the possibility that there is a large outflow of krill from the South Georgia area. As we have seen in the calculations of flux relative to predator demand,
much of the krill in offshore regions may not be available to predators and may flow through the region and be transported north and then east in the main direction of flow of the Antarctic Circumpolar Current. Such an outflow provides a potential mechanism for the return of krill back into spawning regions of the krill population further south and east such as the Lazarev Sea and the eastern Weddell Gyre [Hardy, 1967; Spiridonov, 1996]. Any such return flow could generate feedbacks that would affect the longer-term population dynamics across the Scotia Sea region [Murphy, 1995].

[22] There has been little emphasis on the role of such horizontal transfer of biotic or indeed abiotic material for the maintenance of oceanic island ecosystems [Pakhomov and Froneman, 1999; Polis and Hurd, 1996], yet such large-scale transport of biological material is a fundamental aspect of many marine food webs. Large-scale flows are an important aspect in the maintenance of regional ecosystems throughout the oceans, such as in the eastern north Pacific, the eastern north Atlantic [Agusti et al., 2001; Springer et al., 1999] and the Georges Bank region [Manning et al., 2001; Shore et al., 2000]. Many of these shelf dominated regions support economically and socially important fisheries, yet the productivity of these regions will be in part dependent upon the horizontal flux of biological material, which could include recruiting individuals that maintain populations. In this regard, the recorded flux of krill will be particularly important in attempts now being made to develop localized ecosystem-based principles for the sustainable management of harvesting in the Southern Ocean under the international Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) [Constable et al., 2000]. Understanding the flux processes will require dedicated oceanographic field effort with year-round monitoring of the rates of throughput of krill.

[23] Such allochthonous inputs are known to generate fundamentally different ecological responses to variation and change because of nonlinearities in the interactions [Jeffries, 2000; Sanchez-Pinero and Polis, 2000]. Biological fluxes associated with the current flows will therefore be crucial in determining the dynamics of the planktonic system and of the dependent predators in the South Georgia region. As the biological flux can be such a significant component of the supply of energy in the regional food web, variations in the flux will be a major factor generating interannual variability and longer term variation in the South Georgia ecosystem [Croxall et al., 1988; Murphy et al., 1998; Fridle et al., 1988]. Fluctuation in the input of biological material into local ecosystems such as South Georgia, either as a result of physical variation in the ocean currents, changes in frontal positions or biological changes upstream, also make these systems sensitive indicators of larger-scale environmental change. Quantifying the horizontal flux of biological material in ocean food webs and associated levels of variability will be a key requirement in understanding the major controls on the operation of ocean ecosystems and their response to change.

4. Summary

[24] We have observed that physical advection associated with the SACCf on the northern side of South Georgia will have a number of important effects on the regional ecosystem. A large biomass of krill was associated with the southern manifestation of the SACCf close to the northern slope in about 2500 m of water. The enhanced biomass of krill was associated with the strong northwestern flow of the current in the vicinity of the SACCf. We observed that the strength of the flow and the depth penetration of the enhanced flow rates mean that physical advection will have dominated the movement of krill in this region. We were thus able to show that the SACCf has a profound role in transporting krill in the South Georgia ecosystem.

[25] We have compared the instantaneous flux of krill in the South Georgia ecosystem with the estimated demand for krill by predators and shown that the measured flux will have been much greater than the demand by the major land-based krill predators during the breeding season. The current best estimates of the growth of krill in the region are less than the predator demand for krill, although suggestions of a higher growth rate of krill in the region compared to areas further south [Murphy and Reid, 2001] may mean that growth could maintain most of the demand. However, the available evidence is that the krill in the region are not a self-sustaining population, since eggs and the early stages of krill are not found in the area. This evidence emphasizes that at least for some periods of the year krill will be brought into the region to maintain the regional stock. The present study indicates that very large amounts of krill can be flowing through the region at any one time but also that the flow is likely to be highly variable. The extent to which the krill flowing through the region is available to local predators and how much of the krill in the ocean flow becomes entrained in the island region is unclear and the interaction of the SACCf with the regional bathymetry will be crucial in these processes [Meredith et al., 2003].

[26] Given the large-scale nature of the SACCf in the Scotia Sea the study supports suggestions that the front will have a major role in the transport of krill across the Scotia Sea and in the large-scale population dynamics [Hofmann et al., 1998; Murphy et al., 1998; Ward et al., 2002]. The spatial transfer of secondary production from one area to another will have a major impact on the operation of such ecosystems and will be a crucial element of their response to change [Murphy, 1995]. Such processes will also be a key element of other ocean ecosystems affecting their regional biogeochemical cycling, the plankton population and community dynamics as well as determining the maintenance and development of higher trophic level species, including commercial exploited fish species. Quantification of such horizontal advection will be important in developing sustainable management procedures for regional ocean ecosystems.

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