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The US Southern Ocean Global Ocean Ecosystems Dynamics Program

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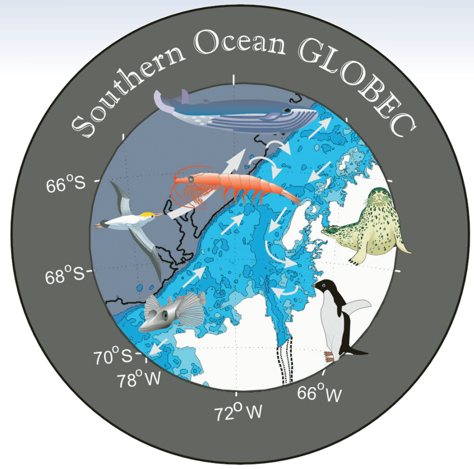

Introduction

The first scientific exploration of the Antarctic dates to the end of the seventeenth century, when Sir Edmund Halley ventured just south of the Polar Front (about 60°S). During the following century, many scientific expeditions were undertaken to explore and describe the vast oceans surrounding the Antarctic continent. One of these expeditions, aboard the Belgian vessel, *Belgica*, provided the first winter scientific observations when it became beset in sea ice and spent the winter of 1898 drifting off the west coast of the Antarctic Peninsula. About fifteen years later, Sir Ernest Shackleton and his crew overwintered on Elephant Island, at the tip of the Antarctic Peninsula, after their ship, the *Endurance*, was crushed by sea ice in the Weddell Sea. This expedition is remembered mostly for the epic rescue of the ship's crew, but it did provide important scientific results (see Shackleton, 1919 and Wordie, 1918, 1921a,b).

Since the start of the twentieth century, numerous Antarctic scientific expeditions have been undertaken, the majority of which occurred during the austral summer (Fogg, 1992; El-Sayed, 1996). These have provided the view of a diverse Antarctic marine food web that is strongly connected to its environment. Thus, understanding potential effects of climate change in the Antarctic, which has recently received attention because of the calving of large parts of the Larsen Ice Shelf along the eastern side of the Antarctic Peninsula, is of importance for managing and protecting one of the most unique environments on Earth.

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Although the Antarctic food web is diverse, it is characterized by short trophic linkages that are dominated by fewer than four to six species. These short trophic connections arise because the basic prey types available to predators are limited, with Antarctic krill (*Euphausia superba*) serving as a primary prey. As a result, predators concentrate on a single prey, such as Antarctic krill, or on a core group of species, such as other euphausiids and some fish. Thus, environmental or biological perturbations can potentially affect all components of the Antarctic marine ecosystem irrespective of their initial impact. The knowledge base on which predictions about potential trophic changes that might be expected from climate and population variations is very limited. In particular, little is known about how marine animal populations adapt to austral winter, which is a critical part of many life cycles.

It is the strong linkage to climate and close coupling between trophic levels that resulted in the choice of the Southern Ocean as one of the first study sites for the Global Ocean Ecosystems Dynamics (GLOBEC) program, which has the goal of understanding marine population variability in response to environmental change. The primary objective of the Southern Ocean GLOBEC (SO GLOBEC) program is to understand the physical and biological factors that contribute to enhanced Antarctic krill growth, reproduction, recruitment, and survivorship throughout the year. This objective also includes the predators and competitors of Antarctic krill, such as penguins, seals, cetaceans, fish and other zooplankton (Figure 1). The emphasis by SO GLOBEC on habitat and top predators, as well as Antarctic krill, is a first in international interdisciplinary Antarctic science and reflects the lessons learned from prior multidisciplinary Antarctic research programs, such as the Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS; El-Sayed, 1994), the Antarctic Marine Ecosystem Research at the Ice-Edge Zone (AMERIEZ; Smith and Garrison, 1990), and the Research on Antarctic Coastal Ecosystem Rates (RACER; Huntley et al., 1991) programs.

The initial planning for the SO GLOBEC program also benefited from the approach developed by the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), which operates under treaty mandate to manage the marine living resources of the Southern Ocean (Croxall, 1994). The CCAMLR approach is to manage species in an ecosystem context, which is unique in marine resource management. CCAMLR has established programs to monitor the status of harvested resources, such as Antarctic krill, and key species that are dependent on the harvested resources, like penguins and seals. Results from SO GLOBEC that give improved understanding of the effect of climate change on marine populations will directly feed into the design and implementation of the CCAMLR long-term monitoring programs. This will provide an avenue for the transfer of SO GLOBEC scientific program results into an ongoing effort to man-

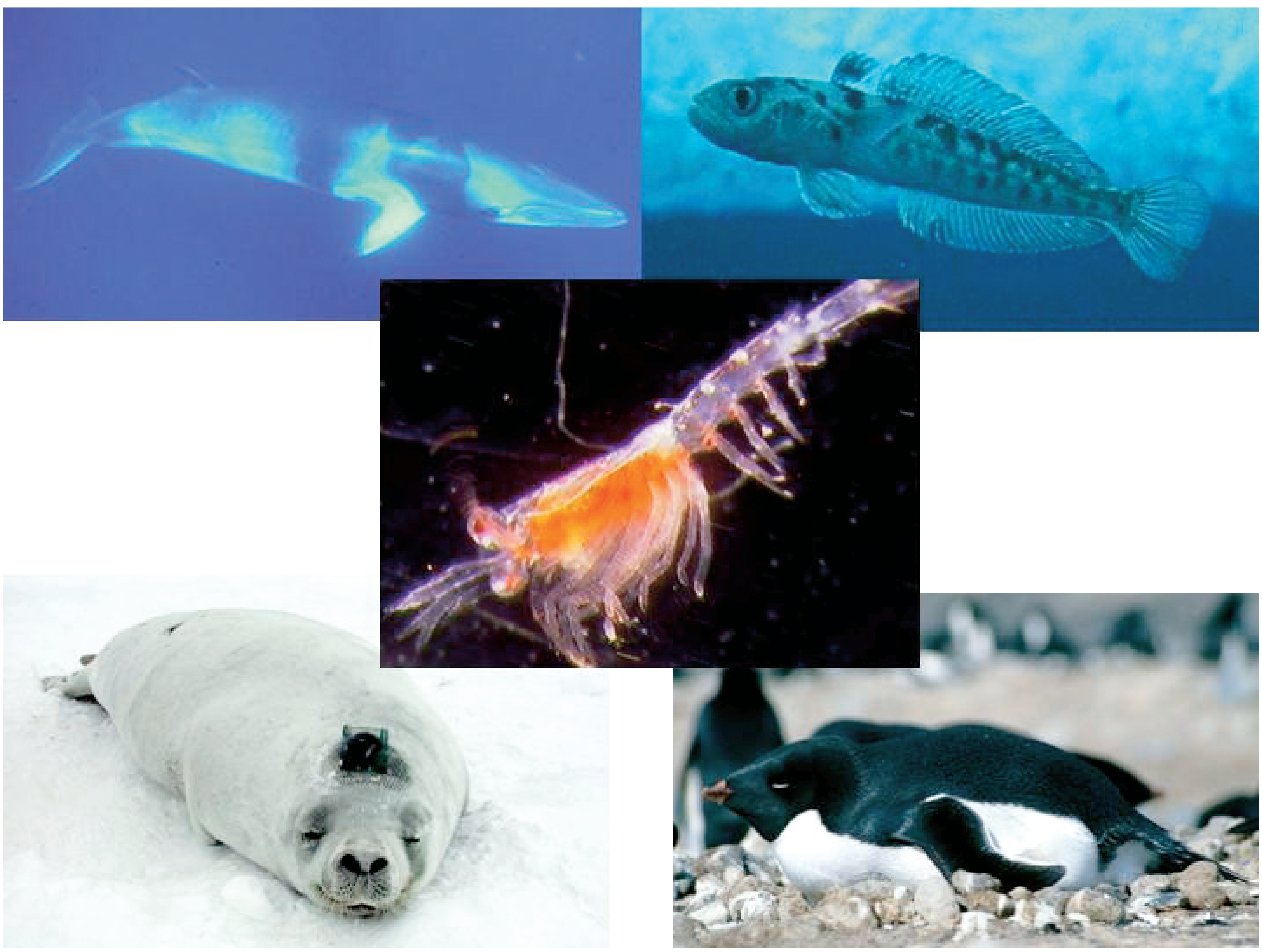


***Figure 1.** Antarctic krill (*Euphausia superba*) and its primary predators **(clockwise from top)**: minke whale (*Balaenoptera acutorostrata*), a cryopelagic Antarctic fish (*Pagothenia borchgrevinki*), Adélie penguin (*Pygoscelis adeliae*), crabeater seal (*Lobodon carcinophagus*). Photograph credits are: Dan Costa for crabeater seal, minke whale, and Adélie penguin; Randy Davis for fish; and Sue Beardsley for Antarctic krill.*

age Antarctic living resources.

The science questions developed for SO GLOBEC, as a result of four international workshops (U.S. GLOBEC, 1991; International GLOBEC, 1993, 1995, 1997), reflect a broadening in scope to take a holistic view of the Antarctic marine ecosystem (see Box 1). As a result, the SO GLOBEC science programs include studies of the habitat, prey, predators and competitors of Antarctic krill, as well as studies specifically focused on Antarctic krill biology and physiology. Moreover, the year-round focus, with an emphasis on winter processes by the U.S. SO GLOBEC program, provides a new and different thrust in international Antarctic research.

The decade of workshops and planning that resulted in the International SO GLOBEC field programs occurred during a time when much was being learned about the importance of winter processes in determining the structure, function, and productivity of Antarctic coastal waters. The atmospheric phenomena, the Antarctic Circumpolar Wave (Murphy et al., 1995; White and Peterson, 1996), was identified as being critical in determining the timing of the advance and retreat and the extent of maximum winter sea ice cover, which varies with a frequency of 4 to 6 years. The role of subsurface intrusions of Upper Circumpolar Deep Water onto the Antarctic continental shelf in modulating heat and salt budgets of coastal waters was described (Smith et al., 1999) and its potential effect on primary production and higher trophic levels was suggested (Prézelin et al., 2000). The effects of winter sea ice extent on survival of Antarctic krill (Daly, 1990; Siegel and Loeb, 1995) and on Adélie penguin (*Pygoscelis adeliae*) population dynamics (Fraser et al., 1992) were identified. Physiological studies (Nicol et al., 1992; Hopkins et al., 1993; Torres et al., 1994; Huntley et al., 1994; Hagen et al., 1996) suggested a range of processes that contribute to overwintering success of Antarctic krill. The importance of the southern boundary of the Antarctic Circumpolar Current to top predators, such as cetaceans (Tynan, 1998), was identified. This new information places SO GLOBEC in a position to actually test hypotheses about interactions between the environment, Antarctic krill, and predators. This is a unique aspect of SO GLOBEC and one that will provide a benchmark for future multidisciplinary Antarctic research programs.

Related International Programs

The SO GLOBEC research programs (described below) complement programs that are being undertaken by the International Whaling Commission (IWC). In 1992, the Scientific Committee of the IWC established a Standing Working Group on Environmental Concerns with the long-term objective of ''defining how spatial and temporal variability in the physical and biological environment influence cetacean species in order to determine those processes in the marine ecosystem which best predict long-term changes in cetacean distribution, abundance, stock structure, extent, and timing of migrations and fitness.'' Three specific objectives were further defined under the framework of the overall objective: 1) characterize foraging behavior and movements of individual baleen whales in relation to prey characteristics and physical environment; 2) relate distribution, abundance, and biomass of baleen whale species to the same for Antarctic krill in a single season; and 3) monitor interannual variability in whale distribution and abundance in relation to physical environment and prey characteristics.

To address these objectives, the IWC is participating in the SO GLOBEC cruises to provide studies of linkages between particular baleen whale species, such as minke (*Balaenoptera acutorostrata*) and humpback (*Megaptera novaeangliae*) whales, and Antarctic krill populations. The IWC observers are undertaking line transect sightings surveys during daylight hours, photographic and video recordings of individuals and groups for species identification, group size verification, observations of feeding and other behavior, sea ice and oceanographic habitat use, and animal fitness (via biopsies of individuals). The cetacean observations are concurrent with observations of the physical environment, prey distribution and abundance, and many other environmental parameters. The combination of the many data sets will provide a unique view of baleen whale biology and ecology in Antarctic coastal waters.

U.S. SO GLOBEC Field Studies

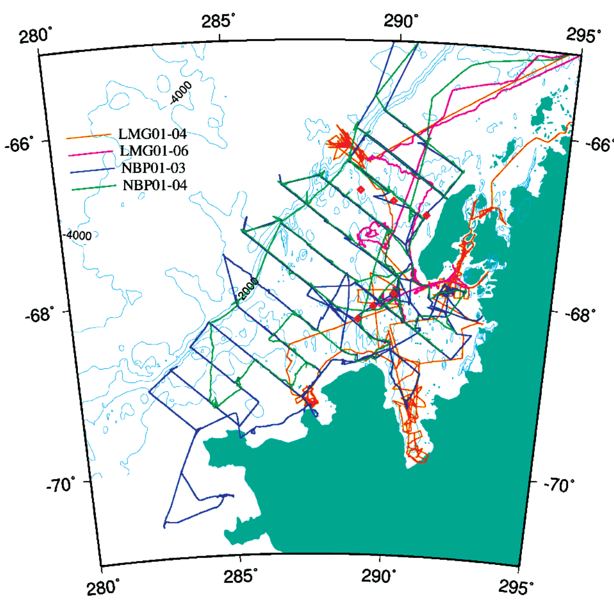
The SO GLOBEC field program consists of multidisciplinary oceanographic research programs that are focused near 70°E, in the southeastern Weddell Sea, and along the western Antarctic Peninsula (Figure 2). The SO GLOBEC studies in the first two regions are part of the Australian and German Antarctic programs. The SO GLOBEC field programs in the western Antarctic Peninsula (WAP) region are being undertaken by Germany, the United States, and the United Kingdom. The cruises that have occurred and are planned are shown in Table 1.

The U.S. SO GLOBEC field studies are focused on Marguerite Bay and environs (Figure 2) for several reasons. This portion of the WAP is biologically-rich and is known to support a persistent and large standing stock of Antarctic krill (Marr, 1962; Lascara et al., 1999). Also found in this region are large populations of top predators (Fraser and Trivelpiece, 1996; Costa and Crocker, 1996) that depend entirely or to a large extent on Antarctic krill as a food source. The Marguerite Bay region is consistently covered by sea ice in winter (Comiso et al., 1990; Jacobs and Comiso, 1993; Stammerjohn and Smith, 1996; Jacobs and Comiso, 1997) and circulation over the shelf is thought to consist of one or more gyres (Stein, 1992; Smith et al., 1999). The latter effect may provide a retention mechanism for Antarctic krill.

(a)

(b)

(c)



(d)

(e)

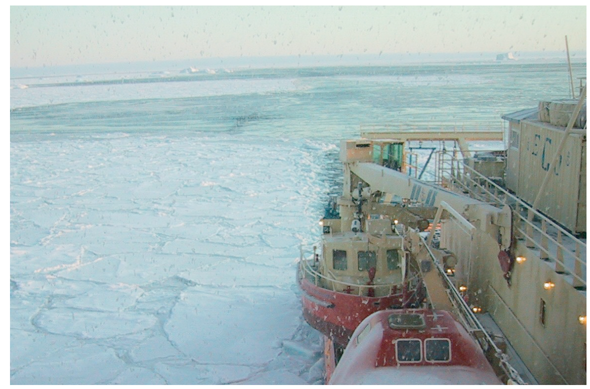


Figure 2. *Tracks followed by the U.S. SO GLOBEC cruises in 2001* ***(shown in panel c)****. The process cruises in April to June and July to September are designated by LMG01-04 and LMG01-06, respectively. The survey cruises for the same time periods are designated by NBP01-03 and NBP01-04, respectively. The red squares show the locations of the current meter moorings that were deployed in March 2001. Bottom bathymetry contours are given in meters. Marguerite Bay is the indentation in the coastline of the Antarctic Peninsula. Adelaide Island and Alexander Island are located to the north and south of Marguerite Bay, respectively. The surrounding figures show* ***a)*** *Adelaide Island,* ***b)*** *Lazarev Bay on the coast of Alexander Island,* ***d)*** *an iceberg near Marguerite Bay, and* ***e)*** *the RVIB* Nathaniel B. Palmer *working in sea ice off Adelaide Island. Photographs by John Klinck, Eileen Hofmann, and Baris Salihoglu.*

Mooring Deployments

The U.S. SO GLOBEC field activities began in early 2001 with the deployment of an array of current meter moorings from the R/V *Laurence M. Gould* (Table 1) and details of the mooring cruise are given in U.S. SO GLOBEC (2001a). The current meter moorings were placed along a line extending off Adelaide Island and along a line across the opening of Marguerite Bay (Figure 2). This mooring array remained in place for one year. A second cruise in early 2002 retrieved the first array and redeployed a second current meter array that consisted of three moorings aligned across the opening to Marguerite Bay. The current meter arrays deployed as part of the U.S. SO GLOBEC program provide the first long-term measurements of the current structure on the WAP continental shelf.

Other activities on the mooring cruises consisted of deploying arrays of passive acoustic moorings to obtain information on cetacean distribution and deploying surface velocity drifters. The IWC observers aboard the R/V *Laurence M. Gould* also completed cetacean surveys that established a baseline for cetacean abundance along the Antarctic Peninsula at the start of the austral fall. The cetacean surveys provide observations from regions and seasons that have not been previously sampled and, as such, are important information for the IWC, which has responsibility for management of cetacean resources in this region of the Southern Ocean.

Process and Survey Cruises

The U.S. SO GLOBEC field program consists of joint survey and process cruises on board the RVIB *Nathaniel B. Palmer* and R/V *Laurence M. Gould*, respectively. The region covered by the U.S. cruises (Figure 2) overlaps with the region covered by the German SO GLOBEC cruise and that proposed for the United Kingdom SO GLOBEC cruise. The U.S. SO GLOBEC cruises provide information from mid to late austral fall and during the austral winter for two years (Table 1). The German program sampled during late summer to early fall and the United Kingdom program plans to sample during spring and early summer. Thus, the sequence of cruises in the WAP region will provide essentially year-round coverage.

Studies on the RVIB *Nathaniel B. Palmer* survey cruises are based upon data collected from conductivity-temperature-depth (CTD) casts, an Acoustic Doppler Current Profiler (ADCP), a Multiple Opening/Closing Net and Environmental Sampling Sensing System (MOCNESS) with nine 1-m^2 nets, and a Bio-Optical Multifrequency Acoustical and Physical Environmental Recorder (BIOMAPER-II) (Figure 3). These data sets provide repeated realizations of hydrographic structure, upper water column currents, nutrients, phytoplankton, micro-zooplankton and mesozooplankton, and Antarctic krill distributions. Seabird and cetacean surveys are done during the relatively short daylight periods and buoys are deployed for listening to cetacean sounds. Other activities consisted of Remotely Operated Vehicle (ROV) operations and deployment of surface drifters. The first survey cruise also deployed two Automatic Weather Stations on the Kirkland Islands and the Faure Islands inside of Marguerite Bay. These stations are now providing the first continuous meteorological observations from this region of the Antarctic. Detailed accounts of the 2001 survey cruises and some preliminary results are given in U.S. SO GLOBEC (2001b, 2001c).

The process cruises are based on focused studies of several days duration at specific sites in and around the

Table 1. *Summary of SO GLOBEC cruises that have occurred and are planned. Western Antarctic Peninsula is abbreviated as WAP.*

COUNTRY	AREA	CRUISE DATES
Australia	70°E	January 2001
U.S. mooring cruise 1	WAP	March – April 2001
Germany	WAP	April – May 2001
U.S. survey cruise 1	WAP	April – June 2001
U.S. process cruise 1	WAP	April – June 2001
U.S. survey cruise 2	WAP	July – September 2001
U.S. process cruise 2	WAP	July – September 2001
U.S. mooring cruise 2	WAP	February – March 2002
U.S. survey cruise 3	WAP	April – May 2002
U.S. process cruise 3	WAP	April – May 2002
U.S. survey cruise 4	WAP	July – September 2002
U.S. process cruise 4	WAP	July – September 2002
United Kingdom	WAP	October – November 2002
Australia	70°E	January – February 2003
United Kingdom	Scotia Sea	January – February 2003
U.S. mooring cruise 3	WAP	February – March 2003
Germany	Lazarev Sea	February – March 2004 October – November 2004 August – September 2005

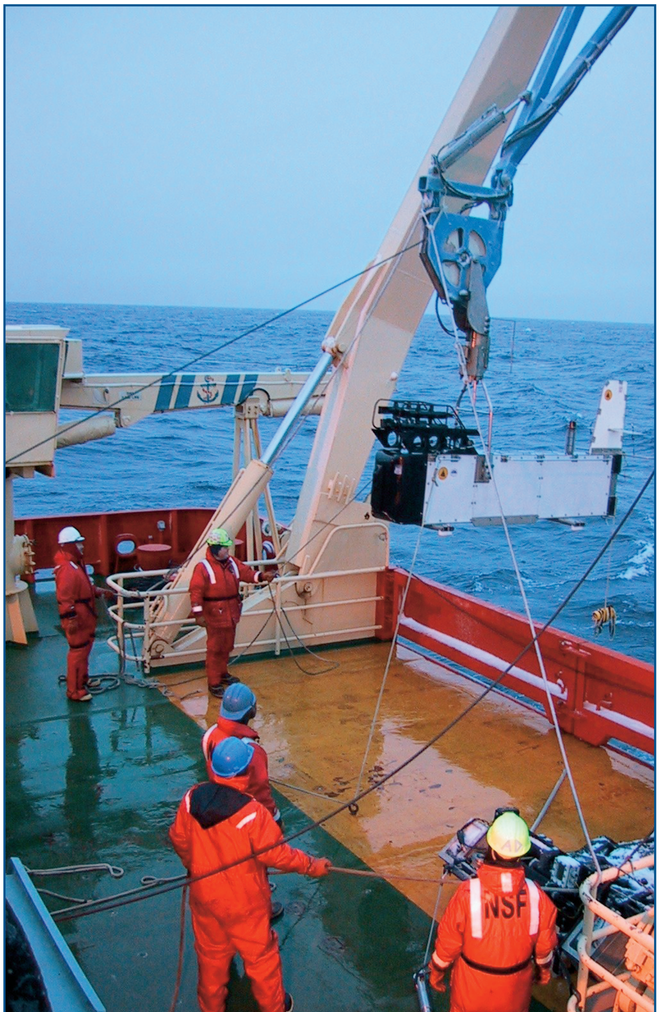


Figure 3. *The Bio-Optical Multifrequency Acoustical and Physical Environmental Recorder (BIOMAPER-II) being brought back on board the RVIB* Nathaniel B. Palmer *during the first U.S. SO GLOBEC survey cruise, 17 April to 5 June 2001. Photograph by Eileen Hofmann.*

Marguerite Bay region. The objectives of the process studies were understanding the factors that govern Antarctic krill survivorship, overwintering strategies, and availability to higher trophic levels. Studies on the process cruises consisted of ship-based laboratory experiments of zooplankton and Antarctic krill physiology; under-ice diving to characterize the sea ice habitat, sea ice biota, and to collect animals for experiments; and focused 1 m^2 and 10 m^2 MOCNESS net tows to characterize community assemblages in the water column. In addition ADCP and hydroacoustic measurements were made to complement observations on the survey vessel. Detailed accounts of the 2001 process cruises and some preliminary results are given in U.S. SO GLOBEC (2001a, 2001c).

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Additional Field Activities

The dedicated SO GLOBEC cruises already completed or planned for the next two years (Table 1) are not the only activities underway. SO GLOBEC-related studies are being undertaken by scientists from other nations (e.g. Korea) as part of their annual austral summer cruises in the Bransfield Strait and South Shetland Island region. Also, research activities on the U.S. Antarctic Marine Living Resources (AMLR) cruises, which take place in austral summer in the Bransfield Strait and Elephant Island regions, are relevant to SO GLOBEC science questions (e.g. Hewitt and Demer, 2000). The AMLR cruises are the U.S. contribution to CCAMLR and coordination with this program has been a priority since the start of the U.S. SO GLOBEC program. Further to the east, at South Georgia (54°S, 43°W), the British Antarctic Survey (BAS) is investigating interactions among the environment, Antarctic krill, and predators as part of an extensive program designed to understand variability in Antarctic krill stocks in this region (e.g. Brierly et al., 1997). The AMLR and BAS studies provide important linkages between what is ongoing in Marguerite Bay, along the WAP, and extending across the Scotia Sea to South Georgia.

Scientific Highlights From the 2001 Field Studies

During April to June 2001, little sea ice was encountered in and around Marguerite Bay. In fact, the survey area had to be expanded to south of Alexander Island where the ice edge was located to complete ROV and dive studies of under-ice distribution of Antarctic krill (Figure 2). The hydrographic distributions showed significant subsurface intrusions of Upper Circumpolar Deep Water at sites along the outer continental shelf. Larval krill were abundant over the entire study region, whereas immature adult krill were found primarily mid-depth in fjords and inner coastal waters. Areas of abundant Antarctic krill were also areas were minke whales, humpback whales, seals, penguins, and sea birds were found. The occurrence of these 'hot spots' was unexpected, and they have been targeted for more detailed studies in year two of the U.S. SO GLOBEC field program.

In contrast, the 2001 July to September cruises encountered extensive sea ice cover, which limited the area sampled during the survey cruise (Figure 2) and made for difficult working conditions, especially for net and BIOMAPER-II tows. However, the sea ice provided the opportunity to obtain considerable information about under-ice conditions from ROV and diving operations which will be used to assess behavior and overwintering strategies for Antarctic krill. Subsurface intrusions of Upper Circumpolar Deep Water were still present, with one extending into Marguerite Bay. Few cetaceans were spotted during the winter cruise, although seals, Adélie penguins, and seabirds were plentiful. Antarctic krill were mostly observed in the northern portion of the study region and in the inner coastal waters. Larval krill were frequently observed on the undersurface of ice floes, but they also occurred deeper in the water column.

The contrast in conditions between the two seasons is already providing insight into how Antarctic krill interact with its environment and predators. Because sea ice formed late during austral fall, concentrations of sea ice biota were relatively low on the undersurface of ice floes during winter and, therefore, was not an abundant food resource for Antarctic krill. Both larval and adult krill continued to feed during winter but had reduced metabolic, growth, and developmental rates. Antarctic krill also must avoid predation in order to survive during the winter. While predators of large krill are well-known (e.g. seals and penguins) little is known about predators of larval krill. During the 2001 U.S. SO GLOBEC studies, the ctenophore, *Callianira antarctica*, was relatively abundant under sea ice and ingested larval krill, and thus may be a primary predator on overwintering larvae (Figure 4).

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Acoustic Mapping of Antarctic Krill Distribution

One of the goals of the U.S. SO GLOBEC survey cruises is to determine the abundance and distribution of Antarctic krill in the Marguerite Bay study region. Hydroacoustic surveys with the BIOMAPER-II system together with MOCNESS sampling provide the primary means for obtaining this distribution. This system consists of a multi-frequency sonar, with center frequencies of 43 kHz, 120 kHz, 200 kHz, 420 kHz, and 1 MHz; a video plankton recorder and an environmental sensor package consisting of a CTD, fluorometer, and transmissometer. During the SO GLOBEC survey cruises, BIOMAPER-II is towyoed along the track lines (cf. Figure 2). The BIOMAPER-II is capable of operating to 300 m at tow speeds of 4 to 6 knots. The use of BIOMAPER-II as a primary data gathering instrument marks the first time that this type of multi-frequency environmental sampling system has been used in the Antarctic.

The acoustic observations from the individual track-lines are then combined to provide three-dimensional renderings of the scattering record (Figure 5). The acoustic scattering at specific frequencies, when combined with taxonomic information from MOCNESS samples and appropriate zooplankton scattering models, is indicative of particular species, such as

Figure 4. *The ctenophore,* Callianira antarctica, *filled with furcilia of Antarctic krill. Photograph by Kendra Daly.*

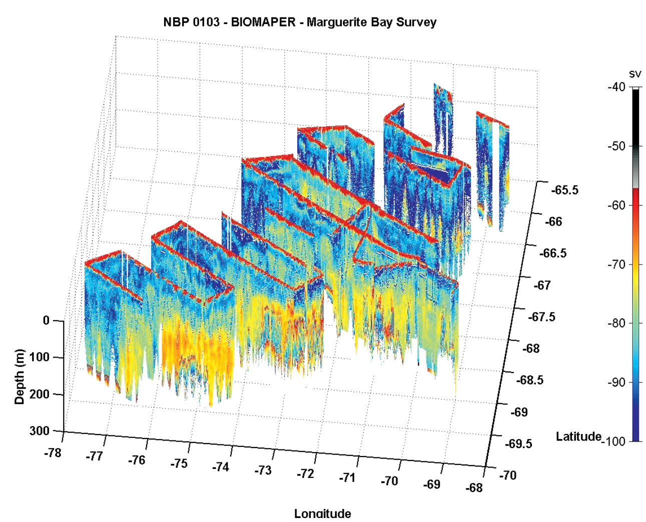

Figure 5. *Preliminary three-dimensional rendering of the 120 kHz volume backscattering data collected on the first U.S. SO GLOBEC survey cruise in April–May 2001. Data provided by and used with permission of Dr. Peter Wiebe, Woods Hole Oceanographic Institution.*

Antarctic krill at 120 kHz. Thus, the acoustic backscatter patterns can be used to determine Antarctic krill distribution and variability. Moreover, the video plankton recorder that is mounted on BIOMAPER-II allows identification of the organisms that are providing the acoustic scattering. This in turn is leading to refinements in understanding of zooplankton community structure and composition in WAP continental shelf waters, as well as refinements in using hydroacoustic observations to estimate Antarctic krill biomass and abundance.

Preliminary results from the first BIOMAPER-II surveys are already modifying ideas about how Antarctic krill are distributed along the WAP continental shelf. The three-dimensional image from the April to June 2001 cruise (Figure 5) shows that nearshore scattering is stronger than offshore scattering. This suggests that patches of adult Antarctic krill were observed primarily in the nearshore areas, especially in areas characterized by variable topography, such as near the northern part of Alexander Island. Also high concentrations of adults were found in the inner regions of Marguerite Bay. Larval krill, in contrast, were found in the upper water column offshore and over the continental shelf. This provides the first mesoscale view of Antarctic krill distribution for the austral fall from any region of the Antarctic.

Penguin and Crabeater Seal Tracking

The process cruises did their own version of drifter deployments by instrumenting Adélie penguins (Figure 6) and crabeater seals (*Lobodon carcinophagus*) (Figure 7) with satellite transmitters. Additional satellite transmitters were placed on Adélie penguins in the colonies near Palmer Station on Anvers Island (64°46′S, 64°04′W) in the early austral fall preceding the cruises. The animal tagging provides insight to where predators go during austral winter, which is still largely unknown. Also, the combination of the tagging studies with the *in situ* and survey data provides a unique opportunity to better understand the foraging strategies used by marine predators in the face of meso- and fine-scale ecological variability.

Figure 7. *Crabeater seal with satellite transmitter tag that was attached during the second U.S. SO GLOBEC process cruise. The* R/V Laurence M. Gould *is shown in the background. Photograph by Dan Costa.*

Figure 6. *Adélie penguin with satellite transmitter tag that was applied during the first U.S. SO GLOBEC process cruise. Photograph by Joel Bellucci.*

Sixteen crabeater seals were tagged with satellite transmitters that relay information on animal position and dive behavior. Crabeater seals exhibit fundamentally different behaviors than reported during summer months. In Marguerite Bay during the winter, seals dove deeper and longer than previously reported. Mean dive depth was 140 m with a maximum of 540 m and dive durations were 7.5 minutes with a maximum of 23.5 minutes. Dives were deepest in May and shallowest in September. All seals remained on the continental shelf and foraged in areas of abrupt bathymetric change (Figure 8). There was considerable variation in individual movement patterns with some seals remaining near the area of capture while others moved far to north (Anvers Island) or south (south of Alexander Island). Crabeater seal dive behavior and physiological capacity are consistent with foraging on krill in the water column; however, other prey species cannot be ruled out. Diet samples, stable isotopes, and fatty acid signatures will be used to resolve this issue. These findings emphasize the need to understand the year-round behaviors of seals when modeling trophic interactions and ecosystem dynamics. Further details of the crabeater seal tagging program and updates on the seal trajec-

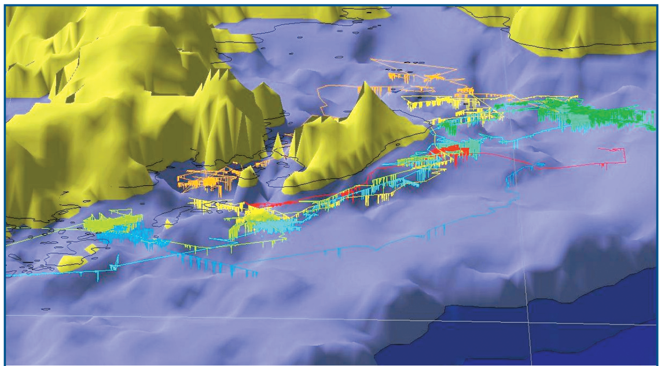

Figure 8. *The dive tracks of crabeater seals tagged during the first U.S. SO GLOBEC 2001 process cruise presented as a pseudo three-dimensional image. Each color represents the track of an individual seal. The surface track incorporates the animals' diving pattern where data are available. These data are placed in the context of the ocean bathymetry for Marguerite Bay and around Adelaide Island. The black lines show the world vector shoreline data, which do not merge well with the bathymetric data available for the U.S. SO GLOBEC study area. Image provided by Mike Fedak and Phil Lovell of the Sea Mammal Research Unit, St. Andrews, Scotland.*

tories can be found at: http://cwolf.uaa.alaska.edu/~afjmb4/GLOBEC/Crab.htm.

The sites at which Adélie penguins and seals were tagged during the 2001 U.S. SO GLOBEC process cruises ranged from Adelaide Island to the northern part of Alexander Island. As a result, a range of habitats is included in the animal tagging studies. The returned trajectories show that, like crabeater seals, penguins are moving over large areas and are suggestive that the animals are concentrating in areas that are characterized by fronts where availability of Antarctic krill may be greatest. Therefore, the information on penguin and seal movement will contribute to understanding how these animals select their foraging locations and prey, and how alterations in environmental conditions and Antarctic krill abundance may impact top predator populations.

SO GLOBEC Modeling Activities

Modeling has been an integral part of the SO GLOBEC program from the beginning of the planning process. To foster this component of the SO GLOBEC program, modeling studies were formally started in 1995 through a special announcement issued jointly by the U.S. National Science Foundation Office of Polar Programs and Division of Ocean Sciences for the Southern Ocean GLOBEC and Joint Global Ocean Flux Study (JGOFS) programs. The modeling studies sup-

Box 1 - SO GLOBEC Science Questions

The science questions that provide a framework for the SO GLOBEC field activities are focused on understanding zooplankton and top predator population dynamics and linkages of these to environmental variability.

Zooplankton Science Questions

1. *What key factors affect the successful reproduction of krill between seasons?*
2. *What key physical processes influence krill larval survival and subsequent recruitment to the adult population between seasons?*
3. *What are krill's seasonal food requirements in respect to energetic needs and distribution and type of food?*
4. *What are the geographical variations in krill distribution in relation to the between and within season variability in the physical environment?*

Top Predators Science Questions

1. *How does winter distribution/foraging ecology relate to characteristics of physical environment and prey?*
2. *How does breeding season foraging ecology relate to abundance/dispersion and characteristics of krill?*
3. *How does year-to-year variation in population size and breeding success relate to distribution, extent and nature of sea ice and krill availability and cohort strength?*

ported by this initiative were intended to provide guidance for the design and implementation of the field programs, both by addressing issues of sampling strategy and by highlighting key processes and measurements necessary to understand the coupling among physical and biogeochemical processes.

Additional modeling efforts are now ongoing as part of the current U.S. SO GLOBEC program. Effort has been focused on the development of physical and biological models, which will be coupled as part of this program. Current efforts on physical models consist of the development and implementation of ocean circulation models and a tidal model for the WAP shelf-ocean region. One circulation model has been coupled with a simple nutrient uptake model, which is being used to investigate nutrient removal and replenishment dynamics in Antarctic coastal waters. The circulation-nutrient model is now being expanded to include sea ice processes, more realistic primary production, and higher trophic levels.

More complex biological interactions, which include optical variations, several nutrients, different primary producers, zooplankton and larvae of several sizes, Antarctic krill, and top predators are being analyzed in a spatially simplified (vertical only) version of the circulation model. This modeling effort will be used to develop parameterizations for the transfer of biological complexity into the larger three-dimensional circulation-ecosystem model. Energetics models are available for Antarctic krill (Hofmann and Lascara, 2000), penguins (Salihoglu et al., 2001), and similar energetics models are being developed for other predators. Additional models are being developed to simulate physical and biological processes associated with sea ice. The intent is to eventually couple these many and varied models to each other to investigate ecosystem interactions in the WAP region.

The SO GLOBEC modeling studies will provide a framework to reveal the important physical and biological processes of the Antarctic system and for relating this study to other U.S. GLOBEC studies in the Northeast Pacific and on Georges Bank, as well as to SO GLOBEC studies in other parts of the Antarctic.

SO GLOBEC Outreach

One of the participants on the first U.S. SO GLOBEC survey cruise, Mark Christmas, is a reporter from *National Geographic*, who provided dispatches describing the cruise activities to the National Geographic Society web site (http://www.nationalgeographic.com/sealab/antarctica). Additional stories about science and daily activities aboard the RVIB *Nathaniel B. Palmer* were provided by National Science Foundation science writers, Aparna Sreenivasan and Kristin Cobb, for the 2001 and 2002 survey cruises, respectively. Their dispatches and additional information about the SO GLOBEC program, daily and weekly cruise reports, and program activities can be found at http://www.usglobec.org.

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