THE OFFICIAL MAGAZINE OF THE OCEANOGRAPHY SOCIETY

Oceanography

CITATION

Ducklow, H., A. Orsi, and J.S. Wellner. 2012. Introduction to the special issue on Antarctic oceanography in a changing world. *Oceanography* 25(3):14–17, http://dx.doi.org/10.5670/oceanog.2012.68.

DOI

http://dx.doi.org/10.5670/oceanog.2012.68

INTRODUCTION TO THE SPECIAL ISSUE ON ANTARCTIC OCEANOGRAPHY IN A CHANGING WORLD

BY HUGH DUCKLOW, ALEJANDRO ORSI, AND JULIA S. WELLNER

"Antarctic Oceanography in a Changing World" commemorates the twentieth anniversary of the commissioning of Research Vessel Icebreaker (RVIB) *Nathaniel B. Palmer* and the fifteenth anniversary of Antarctic Research and Supply Vessel (ARSV) *Laurence M. Gould*. The addition of these two Antarctic research vessels to the US fleet in the 1990s ushered in a new era of Antarctic oceanographic research for US scientists and their international collaborators. Although several US Coast Guard icebreakers in the Arctic and Antarctic waters conduct oceanographic research, their primary mission is icebreaking to facilitate access to land-based stations. The *Palmer* was, and remains to this day, the first and only purpose-built US research icebreaker in Antarctic service and has been serving sea-going scientists in all areas of Antarctica's seas for two decades. The *Gould* has afforded reliable year-round access to Palmer Station and has conducted oceanographic research in the Antarctic Peninsula area since 1997.

In this issue of *Oceanography*, many of the scientists who have lived and worked aboard the *Palmer* and *Gould* describe expeditions and scientific discoveries enabled by these two US Antarctic Program (USAP) vessels. A few contributions cover accomplishments of programs that examine waters around the Antarctic Continent from deployments onshore or on ice. Short articles (sidebars) on particular technical programs or areas of new research are interspersed with longer scientific review articles that cover physical, chemical, and biological oceanography, and marine geology and geophysics. This issue of *Oceanography* opens with a historical overview of Antarctic oceanography and closes with a look toward the research questions that will drive the next two decades of Antarctic oceanography.

PREDECESSORS OF THE *PALMER* AND *GOULD*

US surveying of Antarctic waters dates back to USNS *Eltanin*, initially designed and designated as an ice-strengthened (double-hulled) cargo vessel in 1957 but retrofitted and recommissioned as a research vessel in 1962. As described by Gordon in this issue, the *Eltanin* carried out systematic expeditionary oceanography (Table 1)—long hydrographic sections that defined the large-scale structure and geographical distribution of the Southern Ocean's physical properties, circulation, and some associated chemical and biological properties around the continent. The *Eltanin* also collected transects of piston cores during a series of Southern Ocean circumpolar surveys. Multidisciplinary programs continued on the *Eltanin* even after she was recommissioned as the Argentine vessel ARA *Islas Orcadas*. The Antarctic Research Facility chilled core repository at Florida State University archives the sediment cores from these early cruises, which continue to be valuable to paleoceanographers as core locations remain few and far between for most of the southern waters.

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The opening of the USAP Palmer Station on Anvers Island in 1968 saw the entry into USAP service of R/V *Hero*, the aptly named 38 m wooden ship that plied the notoriously stormy waters of Drake Passage until 1983. The *Hero* primarily supported and resupplied Palmer Station, but also carried out some basic oceanography in the peninsula region.

If we consider that modern, systematic oceanography demands sophisticated laboratory-based experimental capabilities and advanced digital data collection and on-ship processing, we can date the beginning of the modern era of US Antarctic oceanography to 1983 when R/V *Polar Duke* was launched. The *Polar Duke* was originally designed and commissioned as a research vessel by Rieber Shipping A/S (Kyrksæterøra, Norway) in 1983, and chartered by the National Science Foundation in 1984 to replace the *Hero* and serve as the first modern laboratory-equipped research vessel in the peninsula region (Karl, 1999). Rieber operated the *Polar Duke*, first under Canadian flag (1985–1989), then as a Norwegian-flagged vessel until leaving US Antarctic service in 1997 when the *Gould* replaced her.

The *Polar Duke* was ice-strengthened but not an icebreaker, and first commissioned to support Palmer Station and conduct oceanographic research in the summer, ice-free season, much as the *Hero* had done previously. But, before the end of her first year in service, the *Duke* conducted a mission in winter (August to September 1985) under the leadership of Langdon Quetin (Parfit, 1986). The objectives of the cruise were to demonstrate the ship's ability to resupply Palmer Station in winter and to investigate marine ecological processes under winter conditions along the peninsula (Kottmeier and Sullivan, 1987). With this historic cruise, the *Duke* showed a year-round scientific capability in the region and defined year-round operations as the default expectation of this vessel and, later, the *Gould*. Until this time, Palmer Station had a true winter-over contingent like the other two US bases, as annual photographs of the (all male) winter-over teams attest.

Scientists aboard the *Duke* carried out research on the penetration of ultraviolet radiation into the water column beneath the newly discovered ozone hole, and its impacts on phytoplankton and other microbes during cruises in the late 1980s and early 1990s (e.g., Holm-Hansen et al., 1989). In a series of multiple-cruise programs like AMERIEZ (Antarctic Marine Ecosystem Research at the Ice-Edge Zone) and RACER (Research on Antarctic Coastal Ecosystem Rates), oceanographers aboard the *Polar Duke* laid much of the foundation for modern research on Antarctic foodwebs and biogeochemical dynamics, as discussed by Steinberg et al. Likewise, *Polar Duke* sediment cores became the foundation for understanding glacial and marine deposits around Antarctica, particularly in the peninsula region (cf. Anderson, 1999). Karl (1999) reviews the *Polar Duke*'s extensive achievements.

RVIB *NATHANIEL B. PALMER*

Despite the scientific advances made throughout the 1980s, scientists still lacked regular use of a true icebreaker to give them access to Antarctic waters in the winter or reliable access to areas covered by sea ice in other seasons (Maksym et al.). In 1992, Edison Chouest Offshore Inc. of Galliano, Louisiana, completed the *Palmer*, capable of breaking one meter of ice at three knots and conducting 75-day missions.

Immediately after entering the Southern Ocean on her maiden voyage, the *Palmer* conducted a series of cruises in the Weddell Sea during May to September 1992, making a statement about the new US capability. (See back cover of this issue for cruise track maps of the *Palmer* and of *Gould*.) In

Table 1. US Antarctic Research Vessels, 1962–2012

Vessel	Years of Operation	Length (meters)	Displacement (long ton)	Science Berths	Principal Areas of Operation
USNS *Eltanin*	1962–1975	81	1,850	??	Weddell Sea, Circum-Antarctica
R/V *Hero*	1968	38	300	6	Peninsula/Palmer Station
R/V *Polar Duke*	1985–1997	67	1,600	??	Peninsula/Palmer Station
RVIB *Nathaniel B. Palmer*	1992–	94	6,800	39	Ross Sea, Circum-Antarctica
ARSV *Laurence M. Gould*	1997–	71	3,400	28	Peninsula/Palmer Station

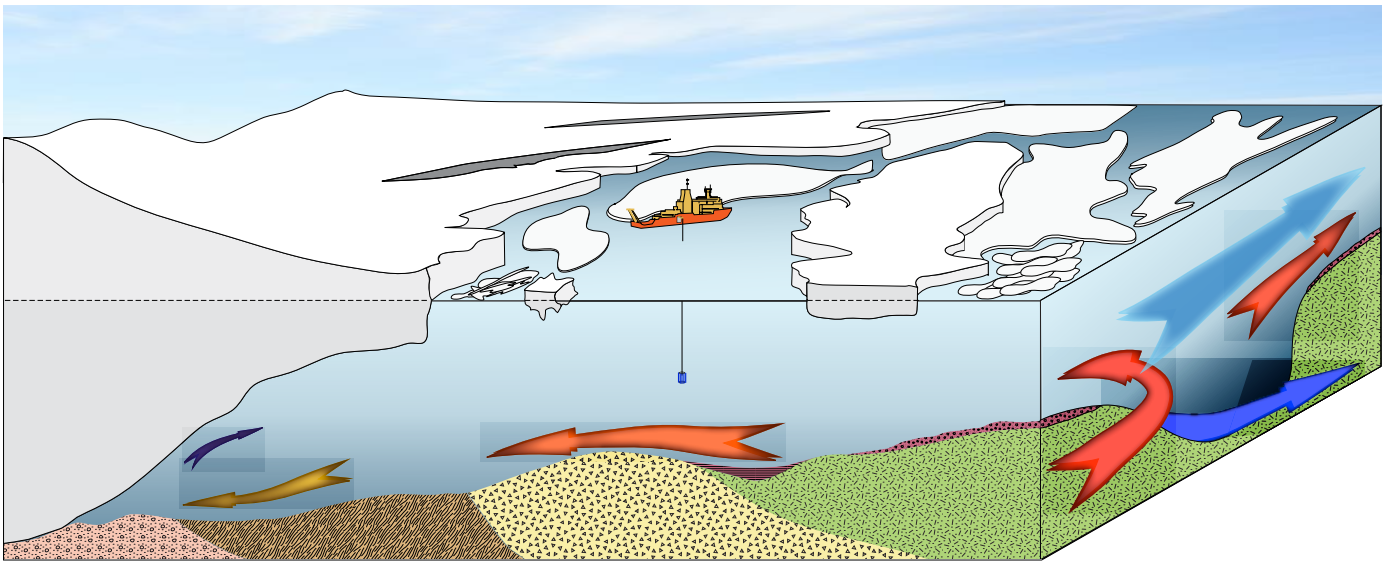
this issue, Gordon describes scientific observations conducted on Ice Station Weddell, a drifting ice floe whose track closely matched that of Shackleton's party after the loss of the *Endurance* in 1915. The *Palmer* supported Ice Station Weddell by ferrying scientists and support personnel to and from the ice floe from April to May. The ship stayed in the region throughout the winter, conducting research on sea ice and marine biogeochemical processes.

In her first two years of operation, the *Palmer* worked out of Punta Arenas, Chile, mostly in the Antarctic Peninsula region and Weddell Sea, before calling at McMurdo Station in December 1993 for two geology projects. The *Palmer* first sailed from Port Lyttelton, New Zealand, in November 1994, bound for the Ross Sea Polynya. Her entry into the polynya was the most southerly penetration of the ice pack by a US research vessel, and it initiated a long series of investigations of the Ross Sea—"the last pristine marine ecosystem on Earth" (W. Smith et al.).

In 1994, the *Palmer* also successfully surveyed the Amundsen Sea to reveal its regional water mass structure and circulation for the first time, and in more recent years to elucidate ocean-ice interactions now believed to uniquely influence West Antarctic Ice Sheet stability (Jacobs et al.). Reaching out to latitudes left behind by other vessels, the *Palmer* completed a few oceanographic sections to near the shelf break. Since then, the *Palmer* has worked almost ceaselessly around the continent. In 1996, the *Palmer* ventured across the Indian Ocean on its 62-day winter cruise as a US contribution to the S04I WOCE (World Ocean Circulation Experiment) line (Key and McNichol), a feat repeated across the Pacific Ocean in 2011 during the S04P cruise as a US contribution to CLIVAR (Climate Variability and Predictability; Swift and Orsi), revealing dramatic ongoing changes in regional deepwater properties (Takahasi and Chipman).

From the beginning years of operation, the *Palmer* pioneered the US underway measurement of currents in the Southern Ocean's upper layer by means of routine hull-mounted acoustic Doppler current profilers (ADCPs; Firing et al.). Some of the most obvious products to represent the areas that have been surveyed by the *Palmer* are the multibeam swath bathymetry maps described by Nitsche et al. The *Palmer* was one of the first ships to have multibeam capability in Antarctic waters; the system was installed in 1994, forever changing how we imagine the formerly glaciated seafloor.

The *Palmer* is an ideal platform for interdisciplinary research, with sampling and laboratory equipment available for



RVIB *Nathaniel B. Palmer* performs oceanographic research in ice-covered waters around Antarctica. As ice shelves warm from the atmosphere above creating surface melt ponds (dark gray), and from the ocean (yellow arrow) below sustaining basal melt (dark blue arrow), field programs proximal to the ice front are critical for determining how ocean waters interact with the ice in a changing climate; a CTD cast is shown, to capture a relatively warm bottom inflow (orange arrow) along the shelf trough, of oceanic deep water (red arrow) near the sill that crossed below the strong westward-flowing Antarctic Slope Current (light blue arrow), and in some places above outflowing denser and colder Antarctic Bottom Water (blue arrow). Geologic sampling from an icebreaker reveals the sedimentary record of both recent and ancient ocean-ice interactions; recent marine sediment shown in pink layers, glacial sediment from a recent ice advance shown in irregular pink layer on outer shelf; older sedimentary rocks eroded by grounded ice are shown dipping offshore on a fore-deepened shelf.

use in a wide range of scientific endeavors. In this issue we include as much of this scope as possible, with articles focusing on topics from long-term geologic records of paleoceanography, glacial history, and climate change (Anderson and Wellner; Bart and De Santis; Rack et al.; Shevenell and Bohaty), to modern sedimentary processes (Miller et al.) and ice calving (Pettit et al.), to trace metal distributions (Measures et al.). In 2010, the *Palmer* joined the Swedish icebreaker *Oden* in a multidisciplinary study of the Amundsen Sea Polynya (Yager et al.).

ARSV LAURENCE M. GOULD

The *Gould* entered Antarctic service in January 1998 for the sixth annual midsummer cruise of the Palmer Antarctica Long Term Ecological Research (LTER) project, one of 26 sites in the US LTER Network (Ross et al., 1996; Robertson et al., 2012). Palmer LTER operations started aboard the *Polar Duke* in 1993, and continue aboard the *Gould* today—having completed the twentieth LTER cruise in January 2012. Although smaller and with limited ice capabilities, the *Gould* is capable of completing a range of tasks: coring; subbottom profiling; underway shipboard ADCP; surface conductivity-temperature-depth (CTD); CTD/LADCP profiling; planktonic tows; nutrient, upper ocean, and surface atmospheric CO_2 measurements (Takahashi et al.); and mooring deployments and recoveries. In addition, the *Gould* is able to support small field parties from Zodiacs. As such, she has serviced a host of research groups in the peninsula region over the last 15 years. The articles and sidebars by Chereskin et al., Detrich et al., Oliver et al., C. Smith et al., Sprintall et al., and Vernet et al. highlight some of these programs.

NEXT STEPS

One year ago, a special issue of *Oceanography* focused on the scientific work conducted in the Arctic as part of the International Polar Year (Ortiz et al., 2011). Since then, several national and international reports have appeared that focus on the globally and societally important science that can—and must—be done in the Antarctic region in future years (NRC, 2011; Rintoul), as well as on the logistical and infrastructure needs that could allow such science to be accomplished (Augustine et al., 2012). Many of the science drivers identified in these reports require advanced research laboratories aboard a capable icebreaker. For example, how are warm oceanic waters reaching the margin of grounded ice (Jenkins et al.), and how is the ice responding? How has ice behaved during past warm periods? These questions cannot be answered using only satellite data or by taking ships to the mid-latitudes. They are scientific questions that require long time-series ocean observations and long geologic records, both in positions proximal to the great ice sheets.

Our goal with this issue of *Oceanography* is to highlight the marine science that has been accomplished from the *Palmer*, *Gould*, and related programs over the last two decades and the ongoing successes of these platforms. But, we are also looking to the future of Antarctic science. The final article in this issue by Dunbar et al. summarizes the report *US Polar Research Vessel Science Missions and Requirements* completed in February of this year (see http://www.unols.org/committees/fic/smr/PRV/PRV_SMR_FinalReport_Feb2012.pdf). The article and report detail the critical need for the United States to begin construction of the next polar research vessel—one that has scientific and icebreaking capabilities beyond those of the *Palmer*. Delivery of a new vessel will take about eight years and the realistic lifespan of vessels is no more than about 30 years. As this is the twentieth anniversary of the *Palmer*, now is the time for action.

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