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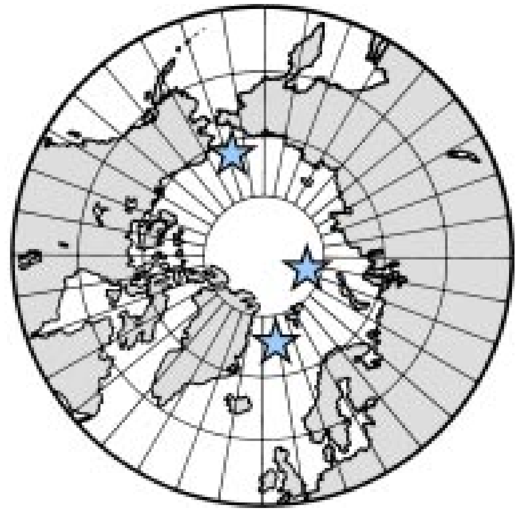
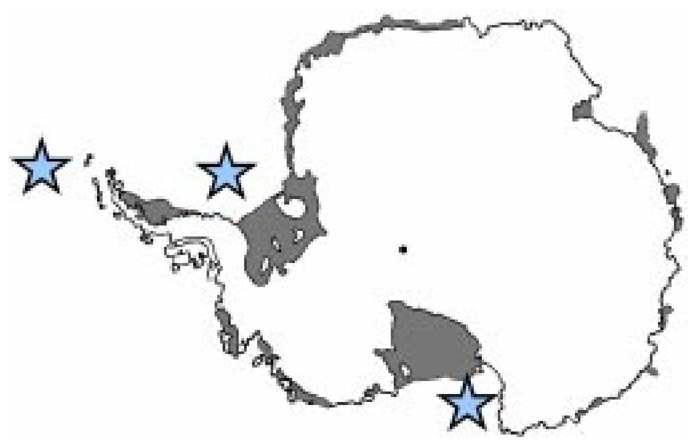
Report of the Arctic and Antarctic Undersea Workshop

15-17 April 1998



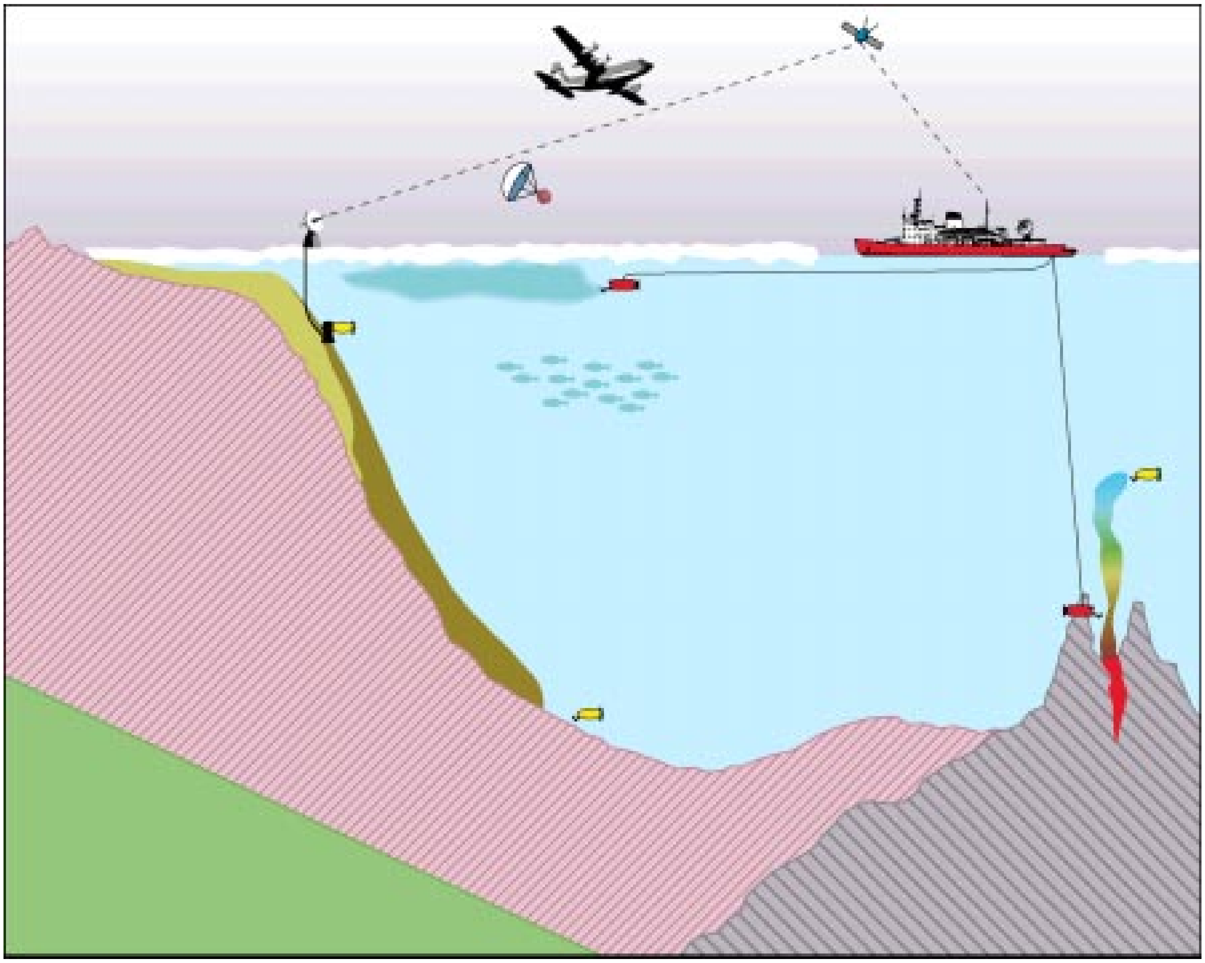
Science at the Extremes:

Improved Capabilities for Exploring Earth and Space



West Coast & Polar Regions Undersea Research Center

NOAA - NASA - USCG



Pictured is a cross-section through an Arctic Ocean coastline, extending through a mid-ocean ridge system.

On the right side of the figure, a USCG icebreaker supports science activities by deploying tethered ROVs equipped with advanced sensors and telepresent video capabilities and links. Just under the ice, one of the remotely operated vehicles (ROVs) makes measurements of water chemistry, light intensity, and physical parameters while a robotic arm equipped with a sampling device collects algal material and other plankton. Along the mid-ocean ridge, another ROV takes water measurements and samples from a hydrothermal vent, while recording information about vent biology using advanced video capabilities tied to mapping software. Information from both ROVs can be conveyed real-time through a satellite link overhead, while operators on land (connected to the satellite link via the NASA Research and Education Network) can control the ROV in near-real-time.

Autonomous Underwater Vehicles (AUVs) are also on hand to support scientific research. In this case, three AUVs are already at work. One is sampling the hydrothermal vent plume and taking water-chemistry measurements. Another is taking a core sample in the basin between the ridge and the shore. The third is connected to its power/data dock, communicating (via satellite) with investigators back on shore who are directing it to take under-ice, water column or benthic samples on the outer shelf/upper slope region, and then to return its data and obtain additional tasking, while recharging its batteries. The dock and the AUVs were delivered to this far-northern site via air-drop of a package that not only included an AUV but the power/data dock and an ice-penetration capability.

Science at the Extremes: Improved Capabilities for Exploring Earth and Space

Report of the Arctic and Antarctic Access Undersea Workshop, 15-17 April 1998

NOAA — NASA — USCG

VISION

As we prepare to enter the 21st century, significant new opportunities in the exploration of this and other planets are forthcoming. These explorations have the potential to expand our understanding of the Earth's oceans, particularly in polar regions, and to multiply our knowledge of the relict seas of Mars and the frozen ocean that may exist on Jupiter's moon Europa. Exploration and study of other planetary bodies in conjunction with the Earth's polar oceans can address numerous overlapping scientific issues and pose related technological challenges. NOAA's West Coast & Polar Regions Undersea Research Center, NASA, and the US Coast Guard have strong interests in the synergy and economy of collaborative approaches to scientific opportunities in extremely challenging locations. This workshop investigated a number of areas where interagency cooperation will provide mutual benefit to the organizations and scientists involved in the scientific study of extreme environments on Earth and elsewhere. A cooperative activity involving NOAA, NASA, and the USCG (and potentially NSF and ONR as well) is required to make the maximum use of these opportunities. Nonetheless, in a number of areas this cooperation can (and should) begin to reap benefits even before the signing of formal agreements for interagency cooperation on polar undersea research and technology development.

BACKGROUND

The Arctic and Antarctic Access (AAA) Undersea Workshop was held from 15-17 April 1998, convened by NOAA's West Coast & Polar Regions Undersea Research Center (WC&PR) and NASA, in collaboration with the US Coast Guard (USCG). The purpose of the workshop was to examine requirements and capabilities for the conduct of science in some of the most extreme environments on Earth (polar regions, deep sea) and to explore areas of commonality with the technologies that NASA, and in particular NASA-Ames Research Center, have developed to explore Mars and other bodies in the solar system. Included in the discussions were an examination of opportunities to employ existing NASA shallow-water ROV's for oceanographic research of the sort sponsored by NOAA's National Undersea Research Program (NURP) and the potential development of specially equipped deep-water robotic vehicles to conduct scientific research at sites of opportunity in the Arctic and Antarctic and selected sites elsewhere within the Pacific Basin. The use of such vehicles could greatly enhance the capabilities of the WC&PR Center and others (such as the National Science Foundation's [NSF's] Office of Polar Programs) to conduct oceanographic science in these demanding environments. Conversely, through the use of telescience techniques for data transfer and remote operation of robotic vehicles, NASA can hone its ability to conduct science on other worlds while supporting significant, related research opportunities on Earth. The Coast Guard is interested in increased use of ice breakers as research platforms, especially when the newest icebreaker, the *Healy,* comes on line.

One objective of the workshop was to bring together agency representatives and scientists in disciplines which could make use of opportunities for improved access and teleaccess to shallow-water sites, particularly through use of NASA-owned telepresent ROV's deployed on Coast Guard-operated support ships. Because of the significant overlaps among NASA's astrobiology, ecology, and Earth-science research objectives and those of NOAA/NURP and NSF's Polar Programs and Ocean Sciences, especially in the area of biology, the workshop also focused attention on deep-water research questions for the polar regions and the technologies required to forward such research.

Specific technology implementations were discussed in the context of the research questions of workshop participants. The nature of arrangements for interagency cooperation to enable cooperative advances were also the focus of workshop discussions. These discussions progressed beyond the initial objective to employ extant NASA underwater equipment to support polar science on Coast Guard vessels, and framed potential areas where interagency interests with respect to space and ocean exploration, astrobiology, and technology were broadly overlapping. The workshop promoted a dialog between two communities that are united by the requirement to operate in extreme environments to undertake the study of basic chemical, geological, geophysical, and biological processes. Ocean scientists reviewed research priorities in polar latitudes while space scientists defined the scope and scale of their interests in Europan and Martian ecosystems. At the end of the meeting it was clear that a formal interaction among the discussant agencies would serve the scientific and technical goals of all. In addition, the provision of tele-operated robotic capabilities (a fundamental technology for NASA's exploration of space) could greatly simplify certain logistical challenges faced by NOAA, NSF and the USCG in conducting ocean sciences on Earth.

DISCUSSION

During the course of the workshop, scientific questions across the spectrum of chemistry, geology, geophysics and biology were addressed by the participants. The workshop was both multi- and interdisciplinary in focus with respect to the science considered. For ease of discussion below, polar marine sites of interest to the various disciplines represented at the workshop will be referred to as 'ecosystems' (in deference to Earth as a living planet), and unless specifically stated otherwise, measurement objectives referred to in this report are attributed to the broad scope of multidisciplinary research needed to further our understanding of the polar regions of the Earth.

Research Priorities

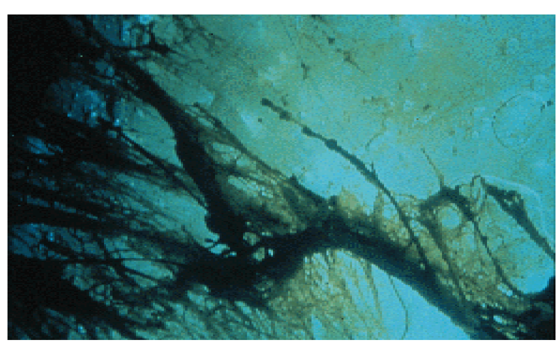
Research priorities in polar marine ecosystems have been considered by a variety of groups involving private, academic and government scientists with varied emphases on shallow- and deep-water environments. Rather than reiterate details of each theme, workshop participants cited documents generated by an international set of working groups that encompass an intellectually rich suite of issues related to functioning of polar ecosystems and planetary-scale processes (e.g., US Arctic Research Plan (1997); InterRidge Arctic Ridges: Results and Planning (1997); Western Arctic Shelf-Basin Interactions Science Plan (1998); Report of the U.S. Antarctic External Panel (1997); and in appropriate sections of the NSF APROPOS, FOCUS, FUMAGES, and OEUVRE Reports (1997-98)). Examples of these consensus priorities are used below to illustrate themes particularly relevant to joint WC&PR Center, NASA and Coast Guard interests.

Extreme Environments as Analogs and Relicts

Participants discussed the overlap of NASA's Astrobiology and Gravitational Biology and Ecology Programs and a growing interest in the theme of life in extreme environments (e.g., NSF's LExEn Program) as analogs and relicts of conditions on early Earth and on planetary bodies elsewhere in the solar system. In high latitude oceans, the environments of interest include hydrothermal vent systems and methane clathrate deposits, often under ice or at significant depths. Extreme conditions in high latitude oceans also include high salinities (due to brine rejection events) and low temperatures (<0°C). Low-temperature extremes also occur in freshwater lakes in polar regions. Both marine and freshwater ice-covered areas may be analogs for the ocean environment on Jupiter's moon Europa. Shared interests of ocean and space scientists include the origin and evolution of ecosystems, and the faunas and processes involved in biospheric functioning or that illustrate patterns in planetary biogeography. Global warming and biotic (including human) influences on the biosphere are topics of interest to marine scientists working in polar environments, where such effects may be most pronounced, as well as to astrobiologists tracking the continuing evolution of Earth.

Ice Science and Climate Change

Much remains to be learned about water, heat, and salt fluxes during sea ice formation, maturation, break-up, and melting. These processes are difficult to study from ships, while ROV or AUV studies could greatly improve our knowledge of ice dynamics and associated heat fluxes believed significant in climate change. Sea ice dynamics can also be difficult to monitor during any single research cruise, while the potential for an ROV or AUV to remain in the field and conduct extended studies could enormously improve our knowledge of these processes. Such deployments could greatly reduce the costs and human risks associated with ice camps or overwintering ships. Studies of ice chemistry, dynamics, and environments will also be required if NASA should pursue a suite of missions that will result in a landing on the surface of Europa and an eventual penetration through the ice of that satellite. While the conditions of surface vacuum, intense radiation, and a lower surface gravity will complicate the Europan deployment, polar regions of the Earth can provide an initial analog to Europan conditions.



Important near-surface uses of ROVs and AUVs exist in the study of the Earth's cryosphere. Extensive NASA studies recently concluded—by default—that the retreat of Greenland's glaciers must be due to subsurface melting where the ice tongues extend into the sea. To date, however, no direct measurements have been possible to support this hypothesis, or to monitor glacial subsurface melting by the ocean, despite the importance of glaciers as indicators of climate change. ROVs or AUVs deployed in shallow-water mapping surveys of glacial ice tongue submarine surfaces are the only way to effectively obtain this critical data.

Biotic Processes

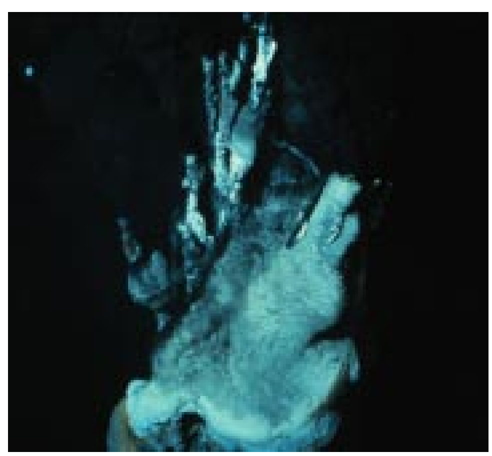
The need exists for both short- (weeks) and long-term (multiple month) studies of under-ice and benthic processes (biotic and sediment). An immediate use for ROVs in high latitude environments would be to obtain better data on under-ice biotic communities, allowing better spatial integration over more extensive areas than is now possible. Data from areal ROV surveys could be used to improve calibration of satellites in the NASA Earth Observing System network, and better data for models of global carbon and pollutant-flux dynamics. Where the successful SeaWiFs mission and other platforms can provide remotely sensed information that allow monitoring of the surface of the Earth's oceans, there are many questions left to be resolved with respect to the processes that remotely sensed data represent. In particular, the interactions of biological, chemical and physical processes in the polar seas are complex and variable throughout a year or a decade, and their effects on the biology and climate of the planet are only beginning to be appreciated. *In situ* studies have much to uncover in our understanding of these dynamic environments.

In addition to near-surface studies, ROVs and AUVs can make significant contributions to studies of the broad and productive continental shelves that dominate the Arctic Ocean. An important component of Arctic climate studies involves measurement of carbon flux from these shelves to deep ocean sediments, in association with the seasonal retreat of the ice cover. ROVs and AUVs could be used to monitor not only under-ice productivity, but also the deposition, respiration, and removal of its products from continental shelves. Studies already underway could be expanded to investigate regional scales of shallow-seafloor processes and, with telescience capabilities, to incorporate interactive studies of the temporal dynamics of oceanographic processes.

As with surface studies, the potential for a long-term deployment near a continental shelf break would greatly simplify the problem of timing ship schedules to coincide with ice retreat, and would improve monitoring of both particulate fluxes and the release of carbon dioxide, methane, and other gases into the atmosphere. The NSF Surface Heat Budget of the Arctic Ocean (SHEBA) program is increasing our knowledge of Arctic climate sensitivity and the underlying atmospheric and surficial oceanic processes in the deep basins of the Arctic Ocean. Dynamic ice environments preclude complementary studies in nearshore regions, but establishment of a polar underwater observatory with a fleet of rapid response AUV's deployed from aircraft could be staged to study events such as opening of transient leads and polynyas. With the availability of appropriate sensors, such rapid response vehicles can be used to address questions from biological, chemical, physical, and geological oceanography. Shelf-edge ROV studies can also document the dynamics of methane hydrate formation and its release from sediments. These processes are widely recognized as important to climate studies, but are still poorly understood.

Deep-Ocean Science

ROVs, and particularly AUVs, can open a new window on the deep seafloor in Polar Regions. Of all the worlds' oceans, the Arctic deep ocean is the least well studied. The same technologies that have permitted remote operation of a Mars rover will need to be improved and extended for future NASA planetary missions to Mars and on to Europa, and those same technologies can be tested and applied in deep ocean work. Sensor development is one particular area relevant to both planetary and deep sea missions. Remote data transmission and interactive AUV control are additional areas of similar developmental synergy. AUV and ROV studies of high latitude, deep ocean environments represent a field of research most likely to produce exciting science and likewise requires the development of technological capabilities and the most complete test of systems intended for planetary exploration.



The inaccessibility of ice-covered oceanic basins at high latitudes has resulted in our knowing less about this portion of the Earth's surface than we know about the surfaces of other planets such as Mars. Our studies of these parts of the Earth will require a series of baseline measurements and maps to provide a context into which later experiments can be placed. Some examples of what needs to be accomplished include 1) detailed characterization of major topographic features such as ridges and their intersections with the large expanse of continental shelves, and 2) identification of sites of enhanced energy flow, such as cold seeps and hot vents, which often provide habitats with enhanced productivity. Macro and micro-faunal diversity and distribution within these habitats are unknown but of extreme importance in understanding the ecology, biogeography and evolutionary issues associated with these communities and ridge systems in general. Moreover, this unknown diversity may form the basis for the discovery of unique biomolecules important in biotechnology and biomedical applications.

Exploration of deep-sea polar environments poses special challenges, including sub-ice detection and sampling (both problems important to NASA's future exploration of Europa) and extreme weather conditions. While some baseline studies can be done with current technologies and tools—providing the context for more detailed studies—substantial progress toward exploring these last frontiers on our planet will require enhanced technological developments. Exceptionally capable ROVs, a new generation of AUVs designed for sub-ice maneuvers, and enhanced moorings are likely to be important components of this future mix of tools. Enhanced sensors and robotics will be needed from all of these types of platforms. Enhanced acoustic modems, robust all-weather satellite communications, and other reliable means of transferring data streams from these remote regions also require continuing development.

Initial deep-ocean studies will be largely exploratory and primarily 'discovery-based' science. As information and capabilities mature, research efforts will likely require manipulative and time-series studies to identify controlling processes and their temporal and spatial scales. Immediate tasks involving current technology include mapping at a variety of scales from basin-wide, to kilometer and sub-meter scales. Some of this mapping will require video imaging as well as sonar-based systems focusing on bathymetric features from 100s of meters to centimeter scales. Acoustic measurements will provide information from both below the seafloor as well as in defining features within the oceanic water column.

Technology Development and Transfer

One focus of discussion concerned the generic issue of technology development and transfer between space and ocean sciences to accomplish polar research objectives, and the consideration of practical examples of shared benefits drawn from the existing research agendas. Space and ocean scientists share a requirement for a suite of capabilities ranging from tethered or teleoperated vehicles through autonomous vehicles capable of working on other planets, sub-ice under harsh conditions, with precision navigation and sampling capabilities and the potential for remote telescience control (e.g., NREN Workshop Report 1998). The ability to place the intellectual and operative capabilities of a human scientist in a position to study, sample, and manipulate extreme environments is a common thread, as logistical and cost issues are an omnipresent reality for all such science. Robotics may be the most effective way to accomplish this end. In addition, sensor development is clearly a shared objective, with detection capabilities ranging from those needed to identify specific chemical species to the use of molecular microchips to study *in situ* microbial physiology and diversity.

Placing human scientific capabilities into extreme environments requires some separation of the frail human body from the environment itself. Whether separated from the sub-zero temperatures of the polar regions, the high pressure of the deep sea, or the radiation and vacuum of space, work in extreme environments involves placing sensors, effectors and visual aids between observer and environment. With human space travel and submersible operations, the effectors are usually constructed of aluminum or titanium, and the window is glass or plexiglass. The use of telerobotic or telepresence techniques make it possible to exchange the glass window for an electronic one, and the material separating the human from the extreme environment may be a combination of air, water, and space that may be from meters to millions of kilometers thick. Improvements in the electronic connection can keep the virtual thickness of the window to a minimum, or may even seem to make the window disappear completely.

Coast Guard Icebreakers

A particular feature of access to polar environments on the surface is the need to "break ice" from time to time to assure an ability to reach certain locations and to leave them again on-schedule. Within the US scientific establishment, US Coast Guard icebreakers, including a new vessel, the *Healy*, provide access to Arctic and Antarctic environments otherwise inaccessible. Significant strides have been taken by the Coast Guard in recent years to provide improved scientific support aboard these vessels. During icebreaker cruises, ROVs and AUVs can be deployed or serviced for improved near-surface and under-ice measurements, studies of continental shelves, and investigations of deeper seafloor environments. With upgrades to communications capabilities, the support of telescience by investigators not on the ship will become possible. Such telescience/telepresence capabilities would greatly contribute to the flexible and full use of Coast Guard icebreakers in the support of scientific studies of the polar regions.

ACTION ITEMS FOR CONVENORS

1. NOAA/NURP through the West Coast and Polar Regions Undersea Center should pursue an interagency cooperative activity with NASA and other partners (including the USCG, NSF, and perhaps ONR) to coordinate and focus the funding of undersea technology development aimed at providing better capabilities for scientific research in polar regions. This cooperative activity should be reflected in a document outlining the means to facilitate interagency cooperation and to seek Administration support and Congressional funding of undersea science and technology development for polar regions.

2. Studies/workshops/development projects to define specific study sites, sensors, and the capabilities of new and existing robotic systems to implement science programs should be supported-particularly where interagency cooperative activities can make new science opportunities available.

3. As more formal activities are being defined and developed, close communications among NOAA, NASA, and US Coast Guard program officials should be maintained to take advantage of existing science and technology opportunities that may be pursued through the use of extant resources within existing agency programs.

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