"Year-Round Access to the McMurdo Region: Opportunities for Science and Education"

Report of a National Science Foundation Workshop

John C. Priscu, Editor

"Year-Round Access to the McMurdo Region: Opportunities for Science and Education"

Report of a National Science Foundation Workshop at the National Science Foundation, Arlington, Virginia, 8-10 September 1999

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Front Cover photograph: *Time-lapsed image of White Island field camp during the winter of 1981. The camp was the base for seal studies in the area.*

Back Cover photograph: *Late winter research at Lake Hoare, Taylor Valley, 1995.*

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EXECUTIVE SUMMARY

The highest object that human beings can set before themselves is not the pursuit of any such chimera as the annihilation of the unknown; it is simply the unwearied endeavor to remove its boundaries a little further from our little sphere of action.

HUXLEY

The McMurdo Sound region of Antarctica has provided a fertile environment for science since the time of Robert F. Scott's exploration in the early 1900's. Research in the area began in earnest with the advent of the International Geophysical Year (IGY) in the late 1950's. Most of the studies conducted as part of the IGY program were exploratory, describing the physical, chemical and biological aspects of the area. Research initiated during the IGY provided the seminal knowledge that spawned more quantitative studies over the past 40 years. From a biological perspective, it is now clear that Antarctica poses one of the most extreme environments on Earth in terms of temperature and darkness. It is a natural laboratory in which unique adaptations can be elucidated and their origin and evolution understood. We now know that most organisms are not just "surviving the extremes" but are actively feeding, growing and reproducing. Thus, it becomes an ecosystem in which we can identify and begin to understand evolutionary processes in the context of one of the most extreme environments on our planet.

We also know that winter processes play a major role in polar stratospheric ozone depletion and the geophysical properties of both pack and fast ice. Study of Antarctic ecosystems, as end-members of globally important systems, are crucial subjects in the study of global change given the polar focusing that occurs at high latitudes. In addition to science, education and outreach programs have become an integral component of the United States effort in Antarctica, particularly the McMurdo area. These educational programs focus on the culture, natural history, and the unique science of the region.

The current effort in the McMurdo area can be described as bimodal. Typically, most of the research, education and outreach in the McMurdo area occurs between late August and February when access to the area via fixed-wing aircraft and vessel is most easily accomplished. This period encompasses what has become known as "WINFLY" (late August to early October) and "MAINBODY" (early October through late February). Science support for field operations usually ends with the last fixed-wing flight to New Zealand in early March. Access to McMurdo Station from March through late August is non-existent, except for emergency search and rescue efforts. Activity at McMurdo Station during the period of inaccessibility has traditionally been relegated to station maintenance and upgrade with minimal scientific research.

Although research during the present "bimodal" science and logistics paradigm has yielded a quantum increase in our understanding of physical, chemical and biological dynamics in the McMurdo region, it has become apparent many compelling scientific questions remain that can only be addressed with year-round information. The data needed to address these opportunities cannot be deduced from studies in other habitats and ecosystems, or from the present knowledge about the summer season. Expanding the research scope beyond the current bimodal paradigm will yield new scientific discoveries and expand the educational possibilities currently present in the McMurdo area.

A workshop entitled "Year-Round Access to the McMurdo Region: Opportunities for Science and Education" was held from 7 to 9 September 1999 at the National Science Foundation's (NSF) headquarters in Arlington, Virginia to address the myriad issues surrounding a new paradigm for research in the McMurdo area. The workshop, sponsored by NSF, included 29 scientists from five countries, key members of NSF's Office of Polar Programs, a representative from the National Aeronautics and Space Administration (NASA) Exobiology Program, and representatives from the Antarctic contractor support group (Antarctic Support Associates) and Petroleum Helicopters Incorporated. The scientists represented a range of disciplines including ecology, limnology, geochemistry, microbiology, physiology, biochemistry, molecular biology, atmospheric sciences, biological, physical and chemical oceanography (both water column and sea ice), and education.

Following plenary presentations by members of NSF, NASA and selected scientists representing diverse fields, workshop participants broke up into three working groups, each tasked with addressing the following seven objectives.

1. *Identify scientific questions that can be addressed only by winter research.*
2. *Identify alternatives to winter deployment.*
3. *Define the additional logistic and scientific support that will accompany a winter program.*
4. *Describe the educational possibilities that higher-level winter deployment would offer, particularly in relation to the role of the Crary laboratory.*
5. *Describe any environmental impacts that an elevated winter effort may cause.*
6. *Define the safety issues surrounding winter research in the McMurdo region as far away as the dry valleys.*
7. *Recommend strategies for funding extended season projects.*

These objectives were to be addressed within the context of the following working definition:

Winter research is defined here as research supported by transportation between New Zealand and McMurdo Station from April through August, plus additional ground support to conduct research as far away from McMurdo Station as the dry valleys. This definition is provided to distinguish the focus of this workshop from the more traditional "overwinter" work that presently occurs.

The workshop participants discussed numerous scientific issues that can only be addressed through an extended research season. These issues included biological topics such as population dynamics of seals, penguins, benthic communities, sea ice microbes, and lake and marine plankton. Abiotic topics focused on physical/chemical oceanography, sea ice dynamics, and ozone chemistry. It was also made clear that the biological, chemical and physical studies must be integrated since biological processes are inextricably linked to physical and chemical forces. Although remote sensing and automated instrument deployment can address many of the scientific questions, experimental research associated with most of the biological needs could not be fulfilled by automation. Minimal effort would be required to support education and outreach, and artist and writers programs in concert with scientific initiatives. No obdurate impediments to extending operations in the McMurdo area through winter could be identified with respect to logistics, safety, and environmental impacts.

There was a general consensus that the Crary Laboratory is a world-class facility that is underutilized from late February to early August. Using the laboratory for science and educational opportunities throughout the year will maximize NSF's investment not only in this facility, but also in the Antarctic program. Every effort should be made to maximize international cooperation to optimize resources, and to incorporate global perspectives into the research to be conducted.

The workshop participants proposed a two season "phased approach" for attaining year-round access and conducting research in the McMurdo area. Temporal phasing would allow resources (both science funding and logistical costs) and infrastructure to be developed in a logical step-wise fashion. The proposed framework incorporates three time periods into the presently inaccessible period that exists from April through August: "FALLFLY", "WINTER A" and "WINTER B". FALLFLY would include helicopter and fixed-wing aircraft support from the end of "MAINBODY" operations until near the end of civil twilight (late April). FALLFLY would be followed by two inaccessible (i.e., no fixed-wing or vessel transportation to or from McMurdo Station) winter periods (WINTER A and WINTER B) separated by mid-June icebreaker support. The icebreaker would provide a platform for winter research addressing marine questions and allow an exchange of personnel at McMurdo Station. Traditional WINFLY operations would commence in late August. This revised operations plan will allow scientists to conduct research throughout the current period of inaccessibility without "overwintering".

The following schedule was proposed. After this two-year phase-in period, science and logistics should be reassessed to determine the future of research made possible by these year-round access opportunities.

<u>YEAR: 2001-2002</u>

- FALLFLY: Helicopter support from March to until late April (near the end of civil twilight). Deploy and redeploy personnel via fixed-wing aircraft at the end of civil twilight.
- WINTER A: Support not requested.
- WINTER B: Support not requested.
- WINFLY: Normal Operations. Additional support not requested.
- MAINBODY: Normal Operations. Additional support not requested (prepare for following year).

<u>YEAR: 2002-2003</u>

- FALLFLY: Helicopter support from March to until late April (near the end of civil twilight).
- WINTER A: Operations using ground support to surrounding areas, including the dry valleys.
- ICEBREAKER SUPPORT: Mid-June, to exchange personnel and mate-

rials. A vessel based research program should be established to study topics such as the population dynamics of seals and penguins, and water column and sea-ice processes.

- WINTER B: Operations using ground support to surrounding areas, including the dry valleys.
- WINFLY: Operations as usual. Helicopter flights during this period to support research as far away as the dry valleys.
- MAINBODY: Operations as usual.

The impacts on science and operations should be assessed following the first extended season to refine requirements for ensuing winter operations.

PREFACE

This report is derived from a workshop sponsored by NSF and held at NSF's headquarters in Arlington, Virginia. The purpose of the workshop was to bring together members of the scientific, logistic, and funding components of the Antarctic community to discuss the need and potential to extend the time frame of the research season in the McMurdo area and include year-round access to McMurdo Station. The discussions focused on important science that could be done by extending the research season, outlining the major unmet opportunities that cannot be addressed by the current McMurdo area operating paradigm. Possible logistical scenarios were presented and their feasibility in terms of safety and costs were detailed.

The workshop participants represented diverse disciplines, experiences, and nationalities, ranging from those who work in Antarctica to those who work in ecosystems with similar characteristics. The organizing committee for the workshop consisted of Sam Bowser, (Wadsworth Center, New York State Department of Health, USA), Clive Howard-Williams (National Institute for Water and Atmospheric Resources, New Zealand), John Priscu (Chair; Montana State University, USA), Donald Siniff (University of Minnesota, USA), and Warwick Vincent (Laval University, Canada).

Following a series of keynote presentations, participants of the workshop were divided into three groups, each consisting of members with diverse backgrounds. The groups addressed the same specific set of themes. Following individual working individual working group discussions, group leaders and reporters presented highlights to all workshop participants for further discussion and synthesis. Discussion groups were led by Sam Bowser, Deneb Karentz, and Martin Jeffries; Clive Howard-Williams, Warwick Vincent and Johanna Laybourn-Parry served as reporters for the respective groups. This document, which is a synthesis of the group reports, is intended to describe the unmet opportunities that can be addressed by year-round access to the McMurdo area. The document should also serve as a planning tool for scientists, operations personnel, program managers, and administrators concerned with research in the McMurdo region.

The workshop was made possible by a grant from the NSF Office of Polar Programs (OPP-9815998). I am grateful to the organizing committee and to those who provided encouragement and assistance with the workshop. In particular I thank Roberta Marinelli, Polly Penhale and Karl Erb for their encouragement. Craig Wolf, Steve Kottmeier and Marian Moyher assisted with workshop planning. Craig Wolf also produced the final "printer ready" copy of the report. Mahlon C. Kennicutt II kindly presented the ideas originating in this workshop to members of the Scientific Committee on Antarctic Research (SCAR) and the United States Polar Research Board (PRB). Finally, I wish to thank all of the participants (Appendix 12.1) and speakers for their input and ebullience throughout the workshop. Their many ideas fill the pages of this report.

John C. Priscu, Chair
Bozeman, Montana

1. INTRODUCTION

To me, and to every one who has remained here, the result of this effort is the appeal it makes to our imagination, as one of the most gallant stories in Polar History. That men should wander forth in the depth of a Polar night to face the most dismal cold and the fiercest gales in darkness is something new; that they should have persisted in this effort in spite of every adversity for five full weeks is heroic. It makes a tale for our generation, which I hope may not be lost in the telling.

SCOTT'S DIARY AT CAPE EVANS IN REFERENCE TO THE WINTER JOURNEY TO STUDY THE EMPEROR PENGUIN COLONY AT CAPE CROZIER

Antarctica in winter is one of the most extreme low temperature, aphotic, biotic environments on earth. The ecosystems in the McMurdo region are end-member systems of significant global importance. They represent a natural laboratory in which unique adaptations can be elucidated and their origin and evolution understood, because most organisms are not just "surviving the extremes" but are actively feeding, growing and reproducing. Study of Antarctic ecosystems in winter will yield new information that can be used to identify and begin to understand physiological and evolutionary processes under extreme conditions.

Most scientific activities in the McMurdo Sound region are currently limited to the sunlit period of late August to late February. This is not a significant impediment for some studies, but for others the lack of access and physical presence means that data sets are incomplete. All liquid water systems (e.g., in and beneath sea ice, lakes and brine ponds of the McMurdo Dry Valleys, subglacial lakes) in Antarctica support life. The behavioral and biogeochemical processes associated with this life occur year-round; these processes do not cease during winter darkness (Priscu 1999). Consequently, knowledge and understanding of the seasonal variability of physical and biological processes and interactions in these systems is severely limited by a lack of winter data collection, direct observation, and experimentation. Previous experience has shown that extending the traditional research season even several weeks can yield new scientific insights into natural systems. For example, by extending the early component of the research season in 1991 and 1995 to include August and September, research conducted on the dry valley lakes allowed the first assessment of the initiation of phytoplankton growth (e.g., Neale and Priscu 1995, Lizotte et al. 1996) and the first realization that the permanent ice cover provided an oasis for microbial life (Priscu et al. 1998). These findings and gaps in knowledge regarding the Antarctic demonstrate the need for increased access to Antarctica for research. To this end, McMurdo Station should remain open for research, and aircraft and boat resources should be available between the end of "MAINBODY" through "WINFLY". Information obtained during an extended season will produce a cascade of new science opportunities and allow a more complete understanding of polar processes over a time scale dictated by annual meteorological cycles.

Annual datasets are necessary for the following reasons:

- Meteorological conditions control biogeochemical rates and fluxes.
- Without coverage of the annual cycle, physical, chemical and biological balances cannot be constructed for temporal comparisons with other global systems.
- Overwintering strategies of animals and microorganisms are crucial for understanding the persistence and evolution of organisms in these climates. Their life history strategies cannot be deduced from studies in other habitats and ecosystems or from the summer season only.
- Processes that occur during winter (at any latitude) are inextricably linked to summer processes and visa-versa. NSF’s Long Term Ecological Research (LTER) initiative realized the significance of obtaining data on annual scales and stressed the importance of annual material balances for cross-site comparisons and for assessing long-term data trends.
- Annual datasets allow an assessment of immediate ecosystem response to global change and provide information to understand how biodiversity/ biocomplexity are related to climate changes.

To address the important issues concerning the constraints placed upon science under the present operating regime in the McMurdo area, NSF’s Office of Polar Programs sponsored an international workshop in September 1999 at their headquarters in Arlington, Virginia. The workshop participants strongly recommend that steps be taken as soon as possible to initiate the transition from “daylight only” to year-round access for McMurdo Station and vicinity. In addition to a myriad of new scientific and educational opportunities within the direct vicinity of McMurdo Station, year-round access will lengthen the science season at South Pole and provide additional time for logistic support of South Pole station. Longer access will also allow greater flexibility for senior scientists (many of whom have teaching commitments during the austral summer) to participate directly in field research and will encourage new participants to enter the field of polar research. The increased number of scientists should produce new insights on Antarctic ecosystems through enhanced scientific interaction and synergy of ideas.

To facilitate discussion and to distinguish the focus of this workshop from the more traditional "overwinter" work that presently occurs in the McMurdo area, workshop participants developed the following working definition for winter research:

Winter research is defined here as research supported by transportation between New Zealand and McMurdo Station from March through August, plus additional ground support to conduct research as far away from McMurdo Station as the dry valleys. This definition is provided to distinguish the focus of this workshop from the more traditional "overwinter" work that presently occurs.

Workshop discussion was further facilitated by dividing participants into three individual groups each tasked with discussing the same set of objectives. Following discussion by individual groups, participants met collectively to develop a common strategy for science, education, logistics and funding that will result from and be required to implement a year-round research program in the McMurdo area. The specific objectives addressed during the workshop were:

1. *Identify scientific questions that can be addressed only by winter research.*
2. *Identify alternatives (e.g., remote sensing, contractor support) to winter deployment.*
3. *Define the additional logistic and scientific support that will accompany a winter program.*
4. *Describe the educational possibilities that higher-level winter deployment would offer, particularly in relation to the role of the Crary laboratory.*
5. *Describe any environmental impacts that an elevated winter effort may cause.*
6. *Define the safety issues surrounding winter research in the McMurdo region as far away as the dry valleys.*
7. *Recommend strategies for funding extended season projects.*

2. SCIENTIFIC QUESTIONS

The ecosystems in the McMurdo region are end-member systems of significant global importance. For example, McMurdo is the most southerly site for inshore marine studies on viruses, protists, bacteria, algae, benthos, zooplankton, penguins and seals as well as the most southerly site suitable for year round terrestrial/fresh water investigations. The McMurdo region also provides a unique location for the collection of atmospheric data and biological responses related to stratospheric ozone depletion. Collectively, year-round data obtained from the McMurdo area address the cardinal issues of:

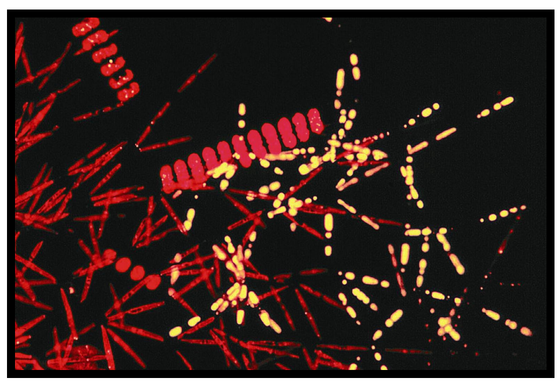
- Persistence and evolution of life in extreme environments
- Biodiversity
- Genomics
- Biocomplexity
- Global change
- Earthly analogues for extraterrestrial life

Environmental controls influence all of these ecosystem features. Year-round research will enable the environmental controls to be addressed in an interdisciplinary context, allowing physical/ chemical processes to be linked with biological dynamics over the annual cycle. The Scientific Committee on Antarctic Research (SCAR) and the United States Polar Research Board (PRB) supports the concept of extended season research in the McMurdo area. Compelling scientific questions that can be addressed only in the context of year-round access are described in this section.

2.1 Marine Environment

2.1.1 Sea ice dynamics

Large quantities of platelet ice have been reported in the water column of the Weddell Sea, Prydz Bay (East Antarctica), McMurdo Sound and elsewhere (e.g., Jeffries et al. 1994). The platelet ice has been observed to accumulate at the base of the overlying sea ice, where it can consolidate completely and become an integral part of the ice cover. As this occurs, a distinct platelet ice microbial community develops, and the ice reaches greater thickness than would occur by columnar ice growth alone. At McMurdo Sound, the thick, platelet-laden landfast sea ice is both a blessing (as a stable platform for scientific studies and a runway for large aircraft) and a curse (an obstacle to the annual sealift and resupply of McMurdo and South Pole Stations).



Sea ice diatoms from McMurdo Sound.

Platelet ice is most commonly observed close to the front of ice shelves, e.g., Filchner/Ronne, Amery, Ross/ McMurdo. Consequently, it has been hypothesized that platelet ice owes its origin to melting at the base of the ice shelves and the outflow of resultant cold, low salinity seawater to the open ocean. However, this hypothesis has not been tested and the transport of heat and mass, as manifested by platelet ice formation, is poorly understood and remains to be fully quantified.

Basic questions that need to be answered include:

- What triggers the formation of platelet ice?
- What are the rates and amounts of platelet ice formation?
- What is the spatial and temporal variability of these variables?

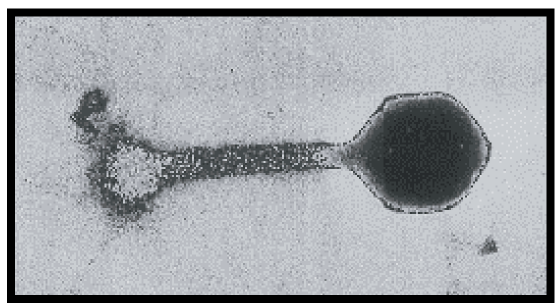
Drilling holes to measure the thickness of a first-year sea ice floe in the Ross Sea, August 1995, R.V. Nathaniel B. Palmer in the background.

McMurdo Station, where platelet ice appears to form for the first time between June and July each year, is an ideal location for the year-round interdisciplinary studies that are necessary to understand the origin of platelet ice in Antarctic coastal waters. Year-round studies would also define the role of platelet ice in sea ice formation, thickness and ecology, its relationship to sub-ice shelf circulation and ice shelf mass balance, and the role in water mass modification and transformation.

2.1.2 Sea ice biological community dynamics

The sea ice contributes significantly to primary production in McMurdo Sound (Grossi et al. 1987), but estimates of its contribution are based on austral spring and early summer investigations alone. Fall blooms have been observed in pack ice (Garrison and Buck 1989, Gleitz and Thomas 1993, Fritsen et al. 1994, Melnikov 1995), but have not been studied at the high latitude or fast ice sites in McMurdo Sound, which may be the best known sea ice system (Arrigo and Sullivan 1994). There is a critical need for fall studies of sea ice biota in McMurdo Sound. These studies should focus on biodiversity and biocomplexity, the geophysical controls on blooms, and exchanges of energy and materials (including nutrients and organisms) between the ice and the water column. There is little or no information available for the fall and winter periods when sea ice decays and is reformed. This is a period of active biological and geochemical exchange between the ice and water column that has not been studied. It is most likely an important time for exchange between the sea-ice/melt water and the atmosphere. Biological, chemical and geophysical parameters change rapidly in this highly seasonal environment and thus studies that address only a few temporal-windows cannot be extrapolated to give a picture for the entire year. These temporally restricted studies almost certainly miss quantitatively important but transient biological and geochemical exchanges between the ice, water and atmosphere. Atmospheric exchange is particularly important for geochemical budgets, including understanding the annual and seasonal contributions of sea ice to local and global organic carbon and sulfur cycles (DiTullio et al. 1998, DiTullio et al. 2000). Sea ice is a source of dimethylsulfoniopropionate (DMSP) and its hydrolytic breakdown product dimethylsulfide (DMS). DMS, a gas that photochemically transforms to methyl sulfonic acid in the atmosphere, can influence the global radiative balance (Charlson et al. 1987). Sea ice may also be a source of halogenated organic compounds that may be exchanged with the atmosphere (Sturges et al. 1993).

Sea ice, particularly the upper sea ice, is one of the most extreme environments on earth in which active growth of eukaryotic cells (algae and protozoa) regularly occurs. During the austral winter, organisms in the upper sea ice can be exposed to temperatures below -20 ^{o}C and salinities greater than four times that of seawater. In early austral spring when the ozone hole is at its maximum and sea ice is most transparent, organisms, particularly at snow free sites, may be exposed to high levels of ultraviolet radiation. Although bacteria, algae and protozoa in the upper ice are exposed to these extremes during the winter, they start growing rapidly in the austral spring while temperature and salinity are still extreme in the upper ice (< -7 ^{o}C and salinities >100 parts per thousand). Sea ice biota have not been investigated experimentally during the period in which this environment is most extreme. The physiological adaptations of upper sea ice organisms, their winter resting stages, and their reinitiation of growth under extreme conditions are unknown. Succession and changes in the biodiversity and biocomplexity of sea ice communities during the period from late January to early October have not been studied, nor have changes in the ecophysiology, including trophic biology, of the dominant species. In fact, many of the dominant species have not even been described or identified, and controls on these populations are presently unknown. Recently, viruses have been reported in Ross Sea pack ice communities during both the winter and summer (Gowing et al. 2000), but their dynamics are not yet known. Determining the role of viral control on sea ice populations will require data over an annual cycle. Viruses have been described as “punishing the dominant organism” and thus have the potential for control of some organisms during each successional stage of an annual cycle.



Virus from the water column of a dry valley lake.

2.1.3 Water column plankton community dynamics

The annual cycle of the plankton community at high latitude sites such as McMurdo Sound is poorly known. In particular, the biodiversity, biocomplexity and succession of organisms and their life history adaptations to the extreme seasonality have not been investigated except for a few groups such as krill, diatoms, and *Phaeocystis*. However, it is clear from limited observations in McMurdo Sound that there is a complex seasonal succession in the microbial plankton and a diversity of phytoflagellates, ciliates, heterotrophic dinoflagellates and bacteria. Even less is known about the succession and biodiversity of non-krill crustaceans and “jelly” plankton (e.g., salps, pteropods) that are important in McMurdo Sound and the Ross Sea (Hopkins 1987). There have been studies of the over-wintering strategies and nutritional biology of invertebrate larvae, but few investigations of the trophic ecology and over-wintering strategies of the dominant metazoan and protistan plankton. In fact, plankton succession has been studied in the austral spring and summer only; data from the end of January until early October are lacking. Fall blooms and heterotrophic stages in plankton succession may be completely missed with summer-only sampling. The role of viruses in terminating these blooms is currently unknown. Determining the dynamics of these blooms and successions is important if we are to understand McMurdo Sound and other high latitude sites, as both producers and consumers of carbon.

2.1.4 Benthic communities

Under the present support regime, most benthic community studies have been restricted to the interval from early October through late January when the McMurdo Sound sea ice becomes unsuitable for surface work (Laws 1985, Fisher et al. 1988). Researchers working under this restricted interval are aware that they are acquiring only part of the picture of the annual cycle of the marine benthic communities. Essential information from late summer, fall and winter are needed for a complete understanding of marine benthic community structure and dynamics.

One of the most striking annual events in McMurdo Sound is the high primary productivity beginning in November and the subsequent breakup of the sea ice to expose the water column. This period of productivity is the source of organic matter that fuels benthic communities for the entire year. How are species specialized to accommodate the strong seasonality in food production? Where does the organic matter accumulate? Benthic species are undoubtedly utilizing this abundant energy resource for growth, reproduction and storage for the onset of winter. The quality and quantity of productivity must control the dynamics and diversity of the benthic communities, and these must be observed and quantified before they can be effectively modeled.

Benthic community in McMurdo Sound.

The dark winter period is a critical portion of the annual ecological cycle. There is no primary production and benthic communities must survive for several months on metabolic reserves, or by feeding on organic matter accumulated in the sediment or on other species. Numerous questions and hypotheses can be formulated concerning this period: Do organisms enter hibernation or otherwise reduce metabolism and survive on stored nutrients? Do they switch from omnivory to carnivory? Does species abundance change relative to the summer productive period? One can hypothesize that like most productive situations, there are opportunistic summer species that develop significant populations only to be grazed by the dominant winter species. Clearly, the autumn transition between the productive summer and the unproductive winter states is an exceptionally important interval for understanding the dynamics of benthic communities. This period would be readily available to investigators if the proposed changes to McMurdo area operations were adopted.

2.1.5 Marine mesozooplankton dynamics

Knowledge of marine mesozooplankton in the Southern Ocean is relatively poor for organisms other than *Euphausia superba*. Other major zooplankton groups that are ecologically important (e.g., salps, copepods, pteropods, fish larvae) have also received little attention. The United States Antarctic Program's research in this area has traditionally focused on studies in the Antarctic Peninsula region, where *E. superba* dominates the mesozooplankton community. The Ross Sea region, including McMurdo Sound, has a more diverse mesozooplankton community, and thus year-round studies of zooplankton based in McMurdo Sound has the potential for greatly expanding our understanding of zooplankton for the Southern Ocean. Studies of the seasonal aspects of life cycles and ecological roles of individual species are needed. This knowledge will be critical for modeling the possible ecosystem-level effects of global change. For example, in the Antarctic Peninsula region, decreased sea ice coverage has been correlated to a population shift from krill to salps (Loeb et al. 1997). Salps feed differently and may not be consumed to the same degree by predators, thus changes in zooplankton have implications for higher and lower trophic levels.

2.1.6 Emperor penguin biology

Wintering and breeding behavior by Emperor penguins is unique among Antarctic birds. At the most southern colony on Cape Crozier it is as if there is a Martian in our midst, and the colony is in McMurdo Station's backyard. Of the 9,600 species of bird, only the Emperor has adapted to remaining year-round at such high latitude. Adaptations allowing this are complex, and only a few of the physiological ones are known. The behavioral adaptations have never been studied because of the imposing conditions of the colony environment. Fall and winter ac-

Emperor penguin.

cess to McMurdo Station offers the opportunity to obtain a greater understanding of this bird. Beginning in March, when the birds start to arrive at the colony, the 64 km journey from McMurdo Station to Cape Crozier can be made overland by tracked vehicle or helicopter to establish a small camp. The camp will be used periodically until August when the females return from their two month journey to unknown parts of Antarctica. They will have just returned from the longest continuous night experienced by any foraging bird. Where and how they have survived and prepared for relieving the male of his incubation duties could be determined by the continuous monitoring of their travels in real time with satellite transmitters. Archival recorders attached to the females would log several variables during the entire journey. The August arrival of the penguins and the retrieval of the recorders back at the colony would allow the collection of one of the most important data sets that could be obtained for a higher vertebrate.

2.1.7 Seal Biology

The Weddell seal population in the McMurdo Sound area has been studied almost exclusively during the austral summer period, particularly from the beginning of pupping (mid-October) to late December. We know that some seals are present during the winter but the number in residence, their sex, and their age composition are unknown. Further, their foraging behavior and movement patterns during the winter have not been studied. The role of vocalizations in their behavior during the winter also needs to be documented. Logistical support and access to McMurdo Station during the winter would allow these topics to be investigated.

Of particular interest is the role of vocalizations and habitat conditions in the establishment of colonies. During the early explorations in the McMurdo area seals were killed to feed dog teams. This harvest seems to have contributed to the demise of seal colonies close to McMurdo Station and Scott Base. Colonization of these areas has not occurred to any degree over the years, thus experimentation to recolonize these areas seems appropriate. It has been hypothesized that the vocalizations of territorial male seals early in the pupping season attract other seals and facilitate the establishment of the seal colonies. Winter experiments could be conducted by playback of vocalizations and the manipulation of ice conditions to determine what would attract seals and facilitate the reestablishment of historic seal colonies.

Other studies that should be conducted include censuses, similar to the current summer census, to learn which segments of the population are present during the winter and how many seals actually winter there. Winter work on foraging behavior, prey selection, and diving physiology would also greatly increase our knowledge of this species and allow decisions about future environmental impacts that might influence the dynamics of the seals in the McMurdo Sound area.

Weddell seals during pupping season in McMurdo Sound.

2.1.8 Transient events

Identifying transient events in the annual cycle and over longer time scales is important for understanding ecosystems and for modeling them. These unpredictable events of short duration can have a large impact on an ecosystem. For example, a swarm of salps moves through a water mass, consuming a large number of micro- and nanoplankton and depositing a significant amount of carbon on the seafloor via fecal pellets. Such events are often serendipitously observed or recorded, and the chances of documenting one are increased if data are obtained routinely over annual time scales. No data (terrestrial or aquatic) exists on the type and magnitude of transient events in the McMurdo Sound area during winter.

2.1.9 Sediment biogeochemistry

We are hampered in understanding the global carbon cycle by a paucity of data on the fate of materials sedimenting from the surface layer of the ocean. Sedimentation of carbonaceous materials in the ocean is one of the few means by which carbon is sequestered from the atmosphere for long periods. Research projects on the ocean carbon cycle have not provided adequate understanding of the sediment processes that decompose, transform or bury carbon in the ocean. Such studies must include the annual cycle to be meaningful. The Southern Ocean is important in the global carbon cycle (e.g., Arrigo et al., 1999; DiTullio et al., 2000), and there are good reasons why extrapolations from other regions will not be valid. For example, the continental shelf of Antarctica is much deeper than other continents and the biogenic sediments of the Southern Ocean are rich in siliceous material with respect to other marine systems.

2.2 Terrestrial and Lake Processes

2.2.1 Terrestrial and shallow aquatic systems

Terrestrial and shallow aquatic systems are among the most extreme habitats within the McMurdo region. Organisms in these habitats may be exposed to a range of temperatures exceeding 70 °C over an annual cycle and to frequent wet/dry and freeze/thaw cycles. It is important that we understand the behavioral, physiological and life history mechanisms employed to tolerate these environmental conditions. Knowledge of the forcing effects that extreme physical conditions have on organism performance, and community structure and function is essential to understanding the biodiversity/biocomplexity of communities and their sensitivity to any man-made or natural change. Liquid water, ambient temperature, and light are known to be important constraints on growth and reproduction in these communities. Most studies to date have focused on the early portion of the summer period, when all of these variables are in their most benign states. Summer represents the "growth-compatible" phase. The winter period when light and liquid water are absent and temperatures are lowest is the period incompatible with growth, i.e., physical stress is at its highest. Several investigations of spring thaw have been in

Collecting microbial samples from highly saline Don Juan Pond, Wright Valley.

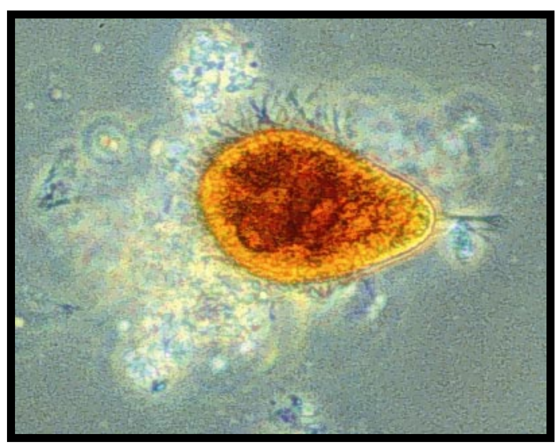
streams and terrestrial communities, but to date there are no data covering two important periods, the autumnal freeze-up and the winter-frozen period. In addition, the transition from winter freeze to summer is poorly understood.

The period normally available for research does not cover the full extent of the "growth-compatible" period for most of these habitats. Increasing the duration of fieldwork into March and April will encompass this period and allow a more complete understanding of annual growth to be developed. In addition, there are many unanswered questions regarding the transitions from summer to winter and the consequences to organisms. It is likely that this transition is fundamental to survival. Physiological adjustments are required to survive freezing. For example, nematodes must enter a freeze-tolerant state, involving accumulation of compatible solutes, voiding of gut contents and ultimately entering anhydrobiosis. The cues and molecular basis for these preparative changes are not yet known. Protists too must prepare for low temperatures and osmotic stresses by accumulating appropriate osmoprotectants, but again there is a dearth of data on the transition.

Physical conditions within the late summer/early winter period have been partially described in some habitats using data-logging arrays. For example, in the shallow ponds of the McMurdo Ice Shelf it is known that ice-cover is complete by mid-late February and that the ice front descends through the water column progressively, reaching the deepest parts by June. An increase in solute concentration accompanies the final stages of freezing (Hawes et al. 1999). Of potential significance is the observation that shallow parts of the ponds freeze before the onset of darkness, while deeper parts freeze after prolonged darkness. The consequences of this difference to biogeochemical processes may be profound both for pond chemistry and biology because reduction/oxidation conditions may change dramatically during darkness. Understanding such issues requires an experimental approach that is not currently amenable to remote instrumentation.

2.2.2 The McMurdo Dry Valley LTER-Taylor Valley

A number of important questions in the McMurdo Dry Valleys can only be addressed by physical access across an annual cycle. Documenting full annual input of stream flow is the only way to elucidate the hydrology of these systems. Photosynthetic and heterotrophic processes continue throughout the year, and presumably involve significant trophic switching. Trophic switching, a reversal of the ratio of autotrophic to heterotrophic processes, has been observed in alpine lakes under winter ice cover and should be a dominant factor influencing the composition and recovery of plankton communities in the dry valley lakes.

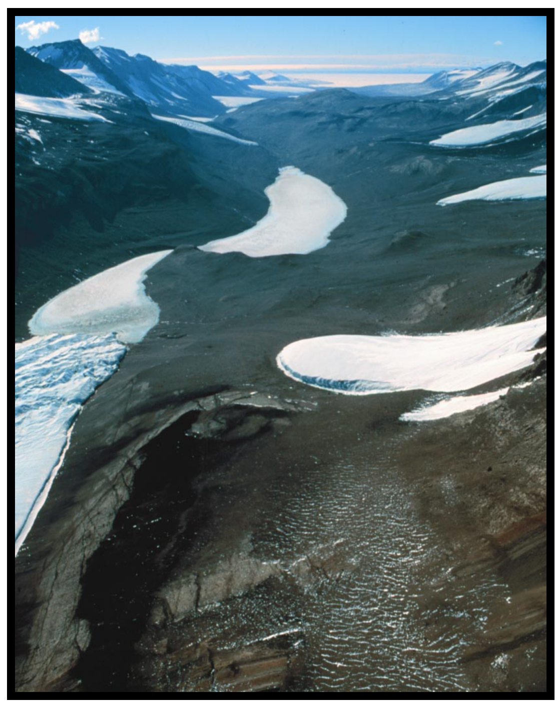


Chlamydomonas sp., a common phytoplankter in dry valley lakes. Note the bacteria attached to the outer surface of the cell.

There are important geochemical questions, e.g., the changing nature of the dissolved organic carbon (DOC) pool, that require continuous seasonal monitoring. The biological impacts on biogeochemical cycles in soils, streams and lakes cannot be determined without annual "hands-on" investigation.

Preliminary evidence from the water column of the Taylor Valley lakes points to significant interannual variation in species composition and biomass (Spaulding et al.1994, Lizotte and Priscu 1998). Detailed information on species succession and its driving forces is necessary if we are to fully understand these unique ecosystems. The temporal extent and fate of organic matter produced by phytoplankton photosynthesis has been modeled (Fritsen and Priscu 1999, Priscu et al.1999a, Moorhead et al. 1999) but never verified. Model results reveal that photosynthesis to respiration ratios are less than one for Lake Bonney indicating that the biological system oxidizes organic carbon faster than it is produced. If modeled predictions are true, eventually the dominance of heterotrophic processes could yield a biologically "dead" system. Data during the FALLFLY and winter periods are required to corroborate model results and allow dry valley lake data sets to be compared accurately to similar data being collected at other latitudes as part of the NSF LTER program.

Benthic microbial mats are a ubiquitous component of lake ecosystems. Process-related research on these mats has begun only recently and lags behind research on lake plankton. However, enough data now exist to show that benthic mats may contribute a higher biomass and productivity than plankton. Evaluating the importance of these communities to biogeochemical cycling of materials requires construction of budgets for carbon and nutrients, including the extent to which these are sequestered as organic or inorganic material or are returned to the overlying water column. Current models are based on data obtained from a two-month summer period only. During this summer period, growth conditions are optimal, and net organic matter accumulation is observed. During winter darkness, however, photoautotrophic growth is impossible and heterotrophic processes dominate. This is the likely period when organic matter is released from the benthos to the water column. It is essential to understand this period to produce realistic models of the contribution of benthic organisms to lake budgets. In addition, understanding the mechanisms employed to survive the winter period and the degree of stress that darkness imposes will provide insights into the controls on community structure, functioning and biodiversity.



Lake Bonney and the Taylor Valley, with the Taylor and Calkin Glaciers in the foreground.

Lake ice sediment/microbial aggregates in a frozen state during late winter.

Benthic mat communities in dry valley lakes represent end-members in the phototrophic spectrum. These communities are dominated by phototrophs, yet experience one of the lowest annual light doses known. This may reflect the virtual absence of biotic and abiotic loss processes that allows them to reach the maximum extent of their physiological niche. Models based on summer-only data suggest that further acclimation is required to enable mats to survive over winter, and laboratory experiments suggest that this involves a reduction of respiration during low light conditions. Understanding how they acclimate to the lowered light in autumn and the prolonged period of darkness in winter will provide insight into low light adaptation and the limits to photosynthetic life on earth.

Benthic mats are perhaps the only inland biological system in the Ross Sea sector to offer the possibility of short-term (up to 100 years) hind casting of growth conditions. These mats are laminated on a fine scale, and recent research has provided circumstantial evidence to suggest that these laminations may be annual growth layers. Confirmation of this result will require further research. Current data suggest that the laminations are due to highly seasonal growth accompanied by a pulse of sedimentation of fine suspensoids some time during late summer or winter. If this proves to be true, interpretation of the features of laminations, in terms of conditions at the time of formation, will require winter access to enable that part of the lamination cycle to be described.

2.3 Atmospheric and Meteorological Processes

2.3.1 Linking meteorological events to processes in the McMurdo Dry Valleys

The transport of organic matter in desert environments is important to the biogeographical distribution and survival of organisms. The McMurdo Dry Valley environment is considered a polar desert (Priscu 1998) characterized by low fluvial transport of materials. Consequently, the geomorphic landscape is extraordinarily stable on a long temporal scale (Denton et al. 1993, Prentice et al. 1998, Lyons et al. 2000). Owing to the low fluvial transport, aeolian transport becomes a relatively important process controlling the distribution of particulate organic matter (Fountain et al., 1999, Moorhead and Priscu 1998). The most intense winds occur during the winter months (Clow et al. 1988) and coincide with catabatic flows from the Polar Plateau. Fritsen et al. (2000) have shown that most of the organic matter in the Taylor Valley occurs in its eastern extent, which may be partially related to aeolian deposition. The current research emphasis of the McMurdo LTER program is the role of past climatological events on contemporary ecosystem structure and function. Clearly, the present distribution of organisms and organic matter are inextricably linked to both their sites of active growth and to their physical movement by the extreme winds in the area (Wall and Virginia 1998, Fountain et al. 1999). To date, no research has been conducted to determine the temporal scales for aeolian flux of organic matter in the dry valleys, particularly in the winter. Winter field deployment, in concert with automated instrumentation, are required to determine the flux of organic matter in this oligotrophic desert ecosystem.

Nacreous clouds above McMurdo Station in August.

2.3.2 Particle composition and phase in polar stratospheric clouds during the winter

The Antarctic stratosphere during July and August is ideal for particle composition and phase measurements of polar stratospheric clouds (PSC's) because temperatures above McMurdo are conducive to PSC production. Thus PSC's are assured to be present for reasonably long periods of time. PSC’s are critical for ozone depletion since they provide the surface on which chlorine is converted from a benign to an active form. Measurements such as these are not yet available, and are important because the composition and phase of PSC’s determines their formation temperature and the rate at which they process chlorine. The formation temperature determines the threshold temperature at which heterogeneous processing begins. The reaction rates determine the amount of chlorine processed over the lifetime of a cloud. There is a critical need to make detailed seasonal measurements of the composition and phase of PSC’s through simultaneous measurements of particle size distribution, aerosol scattering and depolarization, aerosol composition, and gas phase concentrations of water vapor.

2.3.3 Stratospheric ClO/BrO before and during formation of the polar vortex

There is a need to determine the extent of ClO/BrO available in the Antarctic winter stratosphere. The important periods for data collection include: April/May before the formation of the polar vortex; May/June as the vortex is established; July/August during the coldest period and before light returns to the stratosphere; August/September during the ozone loss period. Data collected during these times are important for accurate models of the rates at which chlorine is processed in the stratosphere. This full set of measurements will require winter access over a three to four year period owing to insufficient instrumentation to do all the measurements in one year.

2.3.4 Surface halogens during late fall and late winter light transitions

BrO is effective at destroying surface ozone when it is present. Measurements have been made of surface ozone destruction at McMurdo, but the cause of the ozone loss can currently only be speculated upon. There are no measurements of surface halogens, which may attack ozone. There is a need to determine sources and sinks of reactive surface halogens and relate these dynamics to sunlight transitions and the presence of open water. Such research requires on-site work during austral fall and late winter.

Launching a radiosonde off the helicopter deck of the R.V. Nathaniel B. Palmer, Ross Sea, August 1995.

2.4 Modeling

Models, both conceptual and numerical, have been proposed for biological and physical processes in Antarctic lakes (Priscu et al.1999, Fritsen and Priscu 1999, Vincent et al. 1997), seas (Baines and Condie 1998, Arrigo et al. 1998), sea ice (Arrigo and Sullivan 1994, Arrigo et al. 1997, Fritsen et al. 1998, Arrigo et al. 1998) and animal populations (Boveng and Bengston 1997). Despite the seminal role these models have in our understanding of climatological and ecological processes in the Antarctic environment, they lack verification for key parts of the annual cycle. For example, Baines and Condie (1998) found that “smoking gun” observations from summer programs imply that downslope flow of seawater around Antarctica (an important driver for global ocean circulation) might occur during the off season via several mechanisms that can be modeled but not verified. Priscu et al. (1999) proposed a conceptual model to define food web dynamics in Lake Bonney, a permanently ice-covered lake within the Taylor Valley. Priscu et al.’s heuristic model revealed that without knowledge of winter trophic transformations, the organic carbon budget will never be understood. A numerical model based on summer phytoplankton production data in Lake Bonney (Fritsen and Priscu 1999) predicted that primary productivity should increase significantly in March due to increased ice transparency, and that nutrient deficiency should begin to exert a major control on production rates. Again, without verification, the accuracy of this prediction will not be known. It is important to note that the biological and related biogeochemical processes in permanently liquid water environments such as McMurdo Sound and the dry valley lakes continue throughout the year. Seasonal kinetics of these processes represent a temporal continuum that can produce oscillations or other dynamic changes in response to environmental forcing. Annual data collection is needed before we can understand the biological dynamics of these systems and their role in the global ecosystem.

2.5 Astrobiology

Terrestrial life, thought to have evolved from a common ancestor, is the only form of life currently known. Recent data from Mars and Europa, two other worlds in our solar system, strongly suggest that liquid water is (or was) present. On Mars, there is evidence for stable flowing water early in that planet's history and recent groundwater flow. Data from Europa indicates that a chaotic ice cover several kilometers thick covers a relatively deep ocean of liquid water. These exciting discoveries have initiated intensive research on life in extreme environments on Earth to provide important background information on evolution and physiology that can be applied to the extraterrestrial search for life. The closest Earthly analog to Mars and Europa lies in Antarctica, particularly in areas such as the McMurdo Dry Valleys (McKay et al. 1992, Wharton et al. 1993) and subglacial lakes like Lake Vostok (Seigert et al. 1996, Priscu et al.1999b, Karl et al. 1999). Microbial life in the permanently ice-covered lakes in the dry valleys and presumably in Lake Vostok persists throughout the year. It is important to obtain annual data sets from these systems if we are to use them as models for other worldly bodies. Year-round research in Antarctica may also identify additional sites of biological potential in our solar system. Issues central to NASA's search for extraterrestrial life and their interest in year-round research in Antarctica follow:

Central Issues and Related Goals

How does life begin and evolve?

Goals

- How life arose on the Earth.
- Organization of matter into living systems.
- How life evolves.
- Co-evolution of biosphere and Earth.
- Microbial ecology.
- Sources of organics on Earth.
- Origin of life's cellular components.
- Models for life.
- Genomic clues to evolution.
- Linking planetary and biological evolution.

Is there life elsewhere in the universe?

Goals

- Limits for life.
- Character and frequency of habitable planets.
- Signatures of life on other worlds.
- Past or present life in the solar system.

What is life's future on Earth and beyond?

Goals

- Environmental change on Earth.
- Terrestrial life beyond Earth.

NASA's Interest in Winter Data From Antarctica

Research in Extreme Environments

- Limits for life.
- Microbial ecology.
- Seasonal cycles of extreme environments.
- Limits of detection.
- Overwinter physiological adaptations.
- Human stresses of extreme environments and close quarters.

Exploration of Planetary Analogs

- Instrument development.
- Research directed robotic / human exploration.
- Sampling and Power technology.
- Autonomous operations.
- Reduction of environmental impacts through recycling and energy usage.
- Safety.

3. ALTERNATIVES TO WINTER DEPLOYMENT

The alternatives to year-round deployment of principal investigator (PI) level scientists to the McMurdo Sound area fall into three categories:

- Highly trained winterover technical personnel
- Use of automated instrumentation
- Home laboratory-based research

Each of these approaches serves a specific purpose and can often be used to study winter activities, but they are limited in application. It is important to understand that these are not alternatives to "hands-on" science, but are a means of complementing and extending many programs.

The use of technicians has been part of many winter research programs for years. Most of these studies have a set list of measurements that are taken by the technicians and then analyzed by researchers remotely back at their institutions. The limit of this type of research is a function of the technician's training and the complexity of the investigations. Relatively few principal investigators have participated in traditional overwinter research programs because their institutional positions do not allow them to be off-campus for an extended period. Antarctic science will be advanced at a faster rate if experienced personnel are present in the field to both conduct research and guide graduate students and technicians.

There are a number of automated instruments that measure physical conditions year-round. Examples include meteorological stations, UV monitoring stations, tide gauges, stratospheric constituent instruments, and solar, stellar and interstellar instrumentation. Most of these instruments are very expensive or have limited information output. Also under this category are satellite instruments, which are used as auxiliary data for many studies but are seldom used alone. Many satellites only have limited coverage during the polar night, particularly those measuring parameters related to atmospheric processes. For example, the very low spatial and vertical resolution of this type of satellite data is a strong limiting factor in the remote study of polar stratospheric cloud phenomena. Satellite observations can be complementary to *in situ* observation but not substitutive.

Samples have been taken back to home research facilities for studies since the beginning of research in Antarctica. Many isolated studies can be accomplished this way. In fact, controlled environments are often needed to reduce the number of dynamic variables. However, controlling the conditions often compromises the science. Also of concern are transportation artifacts, particularly of living organisms. There is no substitute to conducting "on-site" manipulations when entire ecosystems are being studied.

While alternatives to PI deployment does allow the collection of useful information, they are no substitute for the presence of a PI. The work of technicians is always subject to the interpretation of the PI. Automated instrumentation and "state-side" analysis does not allow for flexibility in the face of novel observations. PI's and advanced graduate students are the most capable individuals to make novel observations and synthesize information in real-time. Field research often needs "on the fly" decisions and interpretation while the research is being done.

Research that can only be done with scientific personnel directly involved in the research includes:

- Behavioral studies
- Experiments (complex manipulations)
- Tagging of fish, birds and seals
- Process measurements (e.g., primary productivity, trophic interactions)
- Environmentally-sensitive experiments
- Time-sensitive samples and analyses (e.g., tissues, photochemical transients, some taxonomy)
- Serendipitous observation of a unique phenomenon that requires immediate modification of a research plan

4. EDUCATIONAL POSSIBILITES

Increased access to the McMurdo area would allow for an extension of the current educational opportunities already in place. Due to scheduling conflicts associated with the academic calendar, an extended schedule would better facilitate participants in the Teachers Experiencing Antarctica (TEA) and Research Education for Undergraduates (REU) programs. More complex, formal educational activities could be phased in once the logistics associated with the science have been established.

4.1 Advantages

- Currently coordinated education efforts occur from September to late February; year-round science offers the opportunity for year-round coordinated educational efforts.
- May through August science operations coincide with school breaks for many Northern Hemisphere faculty, graduate students, undergraduates, and teachers, thus allowing access by on-site research team members previously excluded from participation.
- The Crary Laboratory is a world-class research facility that is underutilized from late February to early August, yet the existing investment in facilities, technology, and supplies occurs across the year. Using the laboratory for science and educational opportunities throughout the year maximizes NSF's investment in this facility.
- Interacting with scientists in winter showcases the extremes of Antarctica:
  - Social aspects of how individuals deal with the cold and darkness.
  - Illustrating the extreme environment itself.
  - Showing how marine and terrestrial organisms deal with extremes.
  - Highlighting processes that occur only during winter (e.g., stratospheric cloud formation and influence on ozone levels).

4.2 Challenges

- Incentives for participation. Educational efforts require a time investment by research teams, often when time is at a premium. Consider:
  - Making funding available for an educational liaison (e.g., graduate students; thus introducing graduate students to educational issues).
  - An increase in proposal ranking for projects that include strongly integrated educational projects.
- The K-12 school year currently extends from August to May/June; winter research projects would occur during summer break for elementary and secondary school students. However the opportunity exists to connect with this segment of the audience through home schooling, museum programs, Internet programs (e.g., Discovery Online), schools with year-round schedules, and school summer programs.

4.3 Recommendations

- Winter (year-round) educational programs should be designed to:
  - Integrate with all aspects of research.
  - Integrate with existing educational programs (including international efforts) where possible.

- Be multi-level (elementary, secondary, general public).
- Utilize existing technological and human resources where possible.
- Coordinate with science projects to leverage new technology.

Graduate students and journalists assist with sediment trap deployment in a dry valley lake.

4.3.1 K-12 Programs

- TEA: Expand program to year-round, taking advantage of period when teachers are not in school. Teachers can accompany research projects as members of research teams and serve as educational liaisons.
- Teacher Professional Development: Create online courses for teachers that investigate topics aligned with research projects. Exploit video-teleconferencing connections with researchers in the field when possible.
- Curriculum Development: Integrate with ongoing curriculum efforts such as GLACIER, LTER School yard projects, and ASPIRE.

4.3.2 K-12 and General Public

- Investigate ongoing efforts of Antarctic staff and researchers who are communicating with classrooms and developing Web pages.
- Develop concise Web sites for research projects targeting the general public. The site should offer information about the science, the people involved, why the science is important and a weekly update and images from the field.
- Live video links in the field in association with research needs sending real-time video to research Web sites.

4.3.3 Undergraduate/Graduate

- Incorporate Research Experiences for Undergraduates into winter research efforts; winter timeframe coincides with student break. Consider having an REU participant meeting at the close of each research phase in which students present their research results.
- Create a winter field course using Crary Laboratory, analogous to the existing course. Consider expanding to include/encompass:
  - An undergraduate version.
  - Different topics (e.g., physics and chemistry of sea ice, winter adaptations).
  - Online/distance-learning component.
- Develop weekly/monthly distance-education sessions in which research staff present their science and interests and respond to questions. Consider:
  - broad topics (e.g., adaptations of polar organisms, polar marine biology, Antarctic geology, history of exploration, international cooperation, politics).
  - different courses for undergraduates, graduate students, general public.

5. ADDITIONAL LOGISTIC AND SCIENTIFIC SUPPORT

5.1 Transportation

Enhanced year-round access to McMurdo Station and vicinity will require additional transportation to and from the continent as well as within local areas. The extent of these operations will depend upon the level of science activities.

Helicopter operations will be needed to support field activities at many remote sites. Helicopter operations must include full pilot and mechanical backup, modified search and rescue (SAR) capability, and knowledgeable weather interpretation staff. It was strongly suggested that two of the existing Astar's be replaced with Bell 212's. Helicopter operations during "unconventional" periods can safely be conducted by using certain restraints and establishing some new procedures as outlined below:

- Make inter-continental support available.
- Establish a more comprehensive SAR plan for immediate response.
- Increase heli-pad size at certain locations.
- Light heli-pads for periods of darkness.
- Enhance the storage hangar space at McMurdo.Require stricter communication and route controls.

These logistic constraints and approaches to overcoming them vary with specific and definable periods of time. For purposes of discussion, and as a means to evaluate options to overcome these constraints, specific logistic periods are defined as follows:

1) Logistic Period I (FALLFLY): From historical station closure in early March to the end of civil twilight (late April) (see Appendices 12.2, 12.3 and 12.4 for description of civil twilight, sunset, and related flight times).
2) Logistic Period II (WINTER A and B): From the end of civil twilight to the return of civil twilight (~13 August).
3) Logistic Period III: The short time from the return of civil twilight to the beginning of traditional WINFLY.

Logistic Period I—characterized as the period most readily supportable with existing intra- and inter-continental assets. Helicopters can continue to operate with few changes to summer operations procedures and minimal infrastructure enhancements. Fixed-wing operations into and out of McMurdo are most feasible after existing infrastructure deficiencies are remedied. Additionally, essential support functions to both rotary and fixed-wing operations are already positioned for Period I. Period I is the most favorable period for proof-of-concept.

Logistic Period II—most infrastructure and procedural changes would be required; greatest impediment to fixed-wing operations with current assets; most favorable for vessel support. Helicopter support would be limited to established camps if at all.

Logistic Period III—Poses similar constraints for resumption of helicopter support as Period I with possible higher

"No-Go" rate due to low temperatures and other weather limitations.

Intercontinental fixed-wing flights would need to be extended into the autumn period to allow autumn access. Such access would necessitate:

- Enhanced local (New Zealand) emergency flight capability.
- More comprehensive SAR plan to allow for immediate response.
- Increased medical expertise and fire fighting support.

September Helicopter put-in at Lake Vida. Note contrail behind helicopter.

The R.V. Nathaniel B. Palmer or equivalent may be used in certain conditions as a helicopter support unit (from April to June) and could facilitate the transport of personnel and materials to and from Antarctica.

Small boats will be required for winter work in marine systems. Safety issues will need reanalysis but problems are surmountable. Regulations and restrictions in force at Palmer Station should be adopted for the McMurdo area.

5.2 Crary Laboratory

The Crary Laboratory is already staffed during winter and science logistics for field camp research programs could be accommodated with few extra resources. No new or unusual laboratory support functions in the Crary Laboratory are anticipated. The Crary Laboratory would be staffed at a reduced level compared to the austral summer, although additional personnel such as an analytical chemist and a research diving support specialist would be needed.

5.3 Communications

Improved winter communications for field, flight and science operations will be needed. Ideally, science operations require reliable communications within at least a 300 km radius of McMurdo Station. The system should be minimally configured as follows (adapted from "The Dry Valleys Communications Project" currently being implemented by NSF). Specific system parameters are listed in Appendix 12.5.

5.3.1 Services Provided

- Extension of the McMurdo local area network throughout the dry valleys region.
- Connectivity to the continental United States and the global Internet.
- Standard TCP/IP services (i.e., FTP, Telnet).
- Remote data collection.
- E-mail.
- PSTN voice communications linked through McMurdo Telco.
- Voice Mail.
- Fax service.
- Extension of VHF/HF voice communications.

5.4 Field Logistics

Two primary types of levels of field activities were identified: (i) McMurdo based day trips and (ii) permanent or semi-permanent field camps. Day trips are by science groups based at McMurdo Station making excursions of less than 24 hours into the field for work. The infrastructure capable of supporting this level of field activity during the winter currently exists. Additional logistics for the support of these activities is not anticipated to increase substantially. Field camps occupied for periods longer than 24 hours will require additional resources and logistics support.

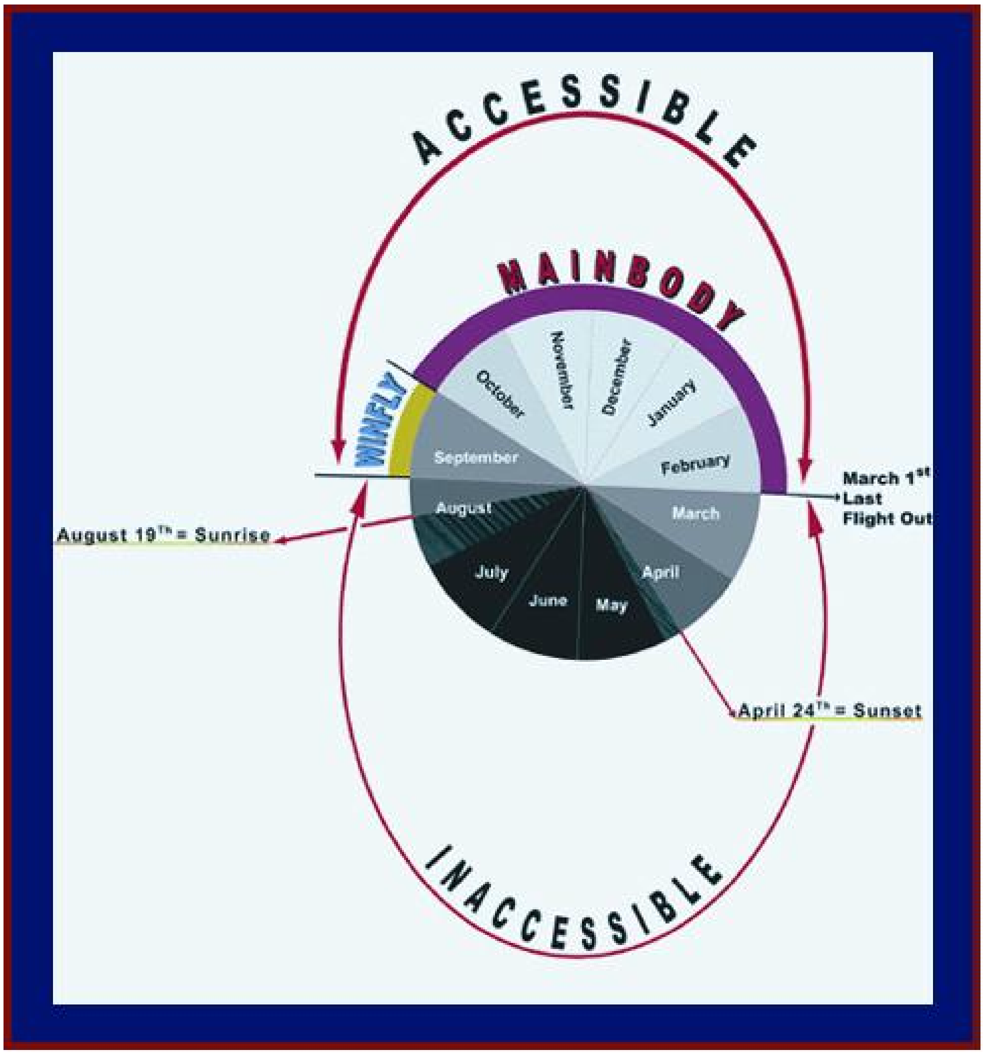
It is anticipated that the logistics in support of both mobile camps and occupancy of permanent structures (e.g., dry valley camps) will require standard resources already used to support these camps during the normal field operations. Additional requirements for support of field camps during enhanced year round activities of longer duration without resupply or transport to McMurdo Station include:

- Increased Fuel storage.
- Increased Food storage.
- Modification of camps for sleeping.
- Field camp survival caches will need to be enhanced and placed at key locations. These caches should be outfitted with extreme cold-weather clothing, sleeping bags, tents, fuel and food sufficient to support the entire remote camp populace (including transients) for at least two times the nominal expected SAR response time in view of weather variation.
- Increased storage of waste materials.
- Provision of alternative power sources.
- Provision of redundant/back-up for key instrumentation and machinery.
- Enhanced mechanical, medical and search and rescue training and supplies for field teams.
- Expanded codes of conduct for safe field operations to include winter activities.

Helicopter with contrail departing Lake Bonney Camp in late August 1995. Ambient air temperature -50°.

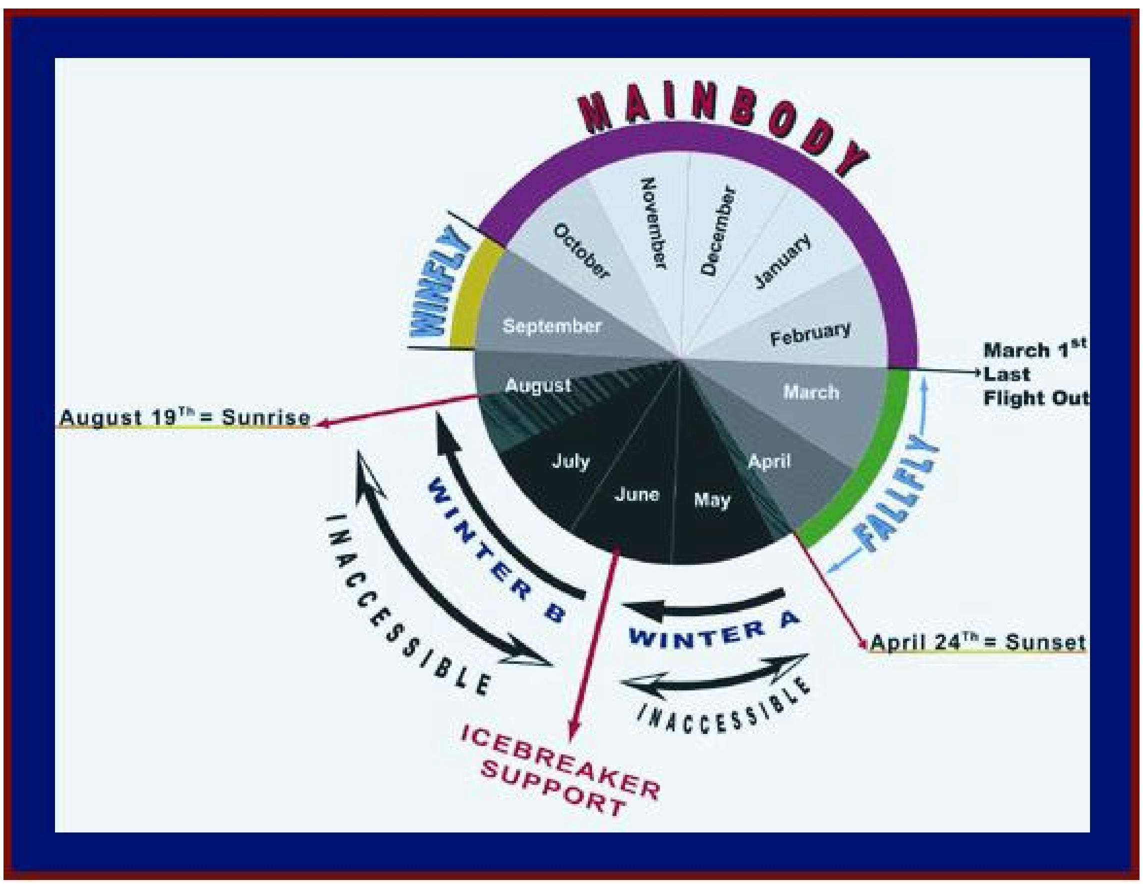
6. PROPOSED OPERATIONS PLAN

The current effort in the McMurdo area can be described as bimodal. Typically, most of the research, education and outreach in the McMurdo area occur between late August and late February when accessibility to the area via fixed-wing aircraft and/or vessel are optimal. This period encompasses what has become known as "WINFLY" and "MAINBODY". Although flight support at McMurdo Station can occur until the end of civil twilight, science support for field operations usually ends with the last fixed-wing flight north in late February. Access to McMurdo Station from early March to the beginning of WINFLY is non-existent, except for emergency search and rescue efforts.



Current operating paradigm in the McMurdo area.

The workshop participants proposed that the expansion of the McMurdo Station scientific season could take place in two distinct phases in consecutive years. Phase-in would allow resources (both science funding and logistical costs) and infrastructure to be expanded in a logical fashion. This framework incorporates three time periods into the presently inaccessible period that exists from April through August: “FALLFLY”, “WINTER A” and “WINTER B”. FALLFLY includes local helicopter operations and fixed-wing aircraft support (between New Zealand and McMurdo Station) from the end of “MAINBODY” operations until the end of civil twilight. Current helicopter regulations confine flights in the McMurdo region to periods of sufficient illumination bounded by civil twilight while still allowing adequate flight time to complete a particular mission. For example, if six hours are allowed for helicopter support on any particular day, then helicopter operations at McMurdo Station can occur as early as 13 August and as late as 29 April (Appendix 12.2). These dates are for a smooth spherical Earth under clear skies; they do not account for topographical conditions that will be encountered in mountainous areas like the dry valleys. Two inaccessible (i.e., no fixed-wing or vessel transportation to or from McMurdo Station) winter periods (WINTER A and WINTER B) separated by mid-June icebreaker support will follow FALLFLY.



Proposed operating paradigm for the McMurdo area

The icebreaker will provide a platform for winter research addressing marine-based questions and allow an exchange of personnel at McMurdo Station. Traditional WINFLY operations, with the addition of helicopter support, will commence as usual in late August. This revised operations plan will allow scientists to conduct research throughout the current period of inaccessibility, without “overwintering”.

The following phase-in approach was proposed. After this two-year phase-in period, science and logistics should be reassessed to determine the future of extended season research.

YEAR: 2001-2002

- FALLFLY: Helicopter support until the end of civil twilight. Deploy and redeploy personnel via fixed-wing aircraft at the end of civil twilight.
- WINTER A: Support not requested.
- WINTER B: Support not requested.
- WINFLY: Normal operations. Additional support not requested.
- MAINBODY: Normal operations. Additional support not requested (prepare for following year).

YEAR: 2002-2003

- FALLFLY: Operations with helicopter support until the end of civil twilight.
- WINTER A: Operations using ground support to surrounding areas, including the dry valleys.
- ICEBREAKER SUPPORT: Mid-June, to exchange personnel and materials. A vessel based research program should be established to study the population dynamics of seals and penguins, and water column and sea-ice processes.
- WINTER B: Operations using ground support to surrounding areas, including the dry valleys.
- WINFLY: Operations as usual. Helicopter flights during this period to support research as far away as the dry valleys.
- MAINBODY: Operations as usual.

The impacts on science and operations should be assessed following the first extended season to refine requirements for ensuing winter operations.

Late February icebreaker support near McMurdo Station.

7. ENVIRONMENTAL ISSUES

7.1 Benefits

While there are important issues to be considered when extending Antarctic research to year-round activities there are also important positive benefits that will be derived from these activities. Year-round access provides an opportunity to test and showcase how humans can both live and carry out important activities under extreme conditions while at the same time minimizing impacts on this relatively pristine environment. For example, winter work in the dry valleys could make use of, and provide a strenuous test of, alternative energy sources (e.g., combined solar, wind and cold temperature storage batteries) for human habitation in remote areas.

Another important plus for year-round research is the opportunity to carry out environmental monitoring throughout the full seasonal cycle, thus providing a baseline for the full range of environmental variability. At present, station specific monitoring programs are primarily limited to the summer. It is crucial to develop a better understanding of the range of natural variability within the system to unambiguously recognize human-induced perturbations. Wintertime processes may be important in understanding the distribution, intensity, and persistence of human impacts. Important processes may include redistribution of contaminants, sequestration of contaminants, and decline or cessation of natural redemptive processes (i.e., microbial degradation). As in many other locations, natural variability may be closely linked to seasonal or annual cycles. Physical/chemical processes active during the winter that may not be readily recognized based on summer only observations can identify variations in overall system attributes. For example, change initiated by climatic events during the winter may set the stage for community responses expressed during the summer season.

Late February "small boat" based research near Tent Island, McMurdo Sound. USCG Polar Sea in the background.

7.2 Specific Issues for Concern

The environmental aspects of winter research in the McMurdo region will require early attention during the planning phase to identify potential impacts and to develop protocols and approaches to avoid or minimize such effects. The environmental impacts identified were:

- The potential for increased person-days, which will increase human impact; e.g., increased use of fuel, larger storage caches, added winter safety-related logistics. The key issue here may not be year-round activity but rather the number and duration of person-days activity.
- Severity of winter weather combined with darkness may increase the risk of

accident and subsequent environmental damage.

- Additional required logistics and/or construction (e.g., ice breaker disturbance of fast ice, need for larger helicopter landing pads, additional safety huts) might have attendant environmental impacts.
- Year-around access holds the potential for increased tourist activity with the attendant potential adverse impacts.
- Increased research activities in the dry valleys may increase the level of disturbance to soils, particularly in the vicinity of the field camps. However, the hard, frozen characteristics of the soils at this time of year suggest that they may be relatively resistant to these physical effects.
- Winter activities will increase the release of materials to the environment, for example by the emission of exhaust gases from aircraft and from field camps.
- Existing field camps will need to be modified for winter conditions. However, there is no apparent need for additional camps or expanding the size of the current laboratories and accommodations.
- Special attention will need to be given to landing sites (helicopter and fixed-wing) for civil twilight and possibly winter operations. This will entail substantial modification of existing structures or the possibility of using the lake ice in the dry valleys as a landing site. The latter will require additional environmental protection such as the use of a protective surface layer. Concern was expressed that landing lights installed on the lake might have effects on the biota.
- The ecological consequences of unseasonable disruption of the sea ice by icebreaker movement should be assessed. For example, this will increase the opportunity for seal migration along the icebreaker channels. The potential effects of noise disturbance on marine mammals should also be considered.
- Docking, fueling and hauling-out facilities will be required for marine science boats. Hovercrafts should be considered as an alternative to boats.

7.3 Cumulative Impacts

International concern has been expressed about the long-term cumulative effects of science activities in the McMurdo Dry Valleys (e.g., Vincent 1996, Wharton and Doran 1999). Winter research in this region will increase access. That in turn may result in an increased number of person-days and accelerated rates of long-term degradation. A fundamental issue in assessing such effects is the total person-day carrying capacity at specific locations in the dry valleys, and in the overall system. This and other environmental issues will be best addressed by developing an integrated, system-wide management plan for the entire McMurdo Dry Valleys. The foundation of such a plan has now been laid by two NSF funded workshops that have brought together specialists from a broad range of disciplines and from many Scientific Committee on Antarctic Research (SCAR) member nations (Vincent 1996, Wharton and Doran 1999). The winter research initiative has now heightened the need and urgency for further development and completion of the management plan. A similar approach should also be taken for the McMurdo Sound region.

7.4 Environmental Emergencies

The combination of darkness, wind, and cold temperatures in winter could increase the risk of environmental accidents as well as exacerbate the difficulty of responding to such accidents in a timely and effective manner. Contingency plans, as well as appropriate training, are required for a variety of environmental scenarios.

In summary, a year-round research effort in the McMurdo area will have many potential benefits. There are also significant concerns about the effect of the projected increased activities. These benefits and effects must be considered in the planning stage. A carefully planned and executed extended season will minimize or mitigate the impacts of increase occupation, although it is unlikely to eliminate them entirely.

8. SAFETY ISSUES

As with logistical and environmental concerns, extending the season to support active research in the McMurdo area poses increased safety concerns for field parties, air support operations, and McMurdo-based operations. All safety concerns could be addressed if the following safety guidelines are considered:

8.1 Medical/Physical Qualifying Process

- It is recommended that NSF research the need to modify current medical standards, considering that increased access to the continent would occur should year-round operations be supported.
  - ➢ While it is acknowledged that the medical qualifying process is more stringent for winter personnel, could there be a relaxation of current winter criteria because of increased access?
  - ➢ Could FALLFLY participants be qualified under current summer standards because of regular access? Participants working during the winter periods of inaccessibility should have a more rigid medical qualifying process.

8.2 Field Safety Training

- Modifications to current field safety training will have to occur to cover additional risks of extreme cold and darkness.

8.3 Field Safety

- Modifications of existing safety procedures and evacuation protocols are recommended.
  - ➢ The size of the field safety caches should be increased commensurate with rescue/relief scenarios. The distance of caches from camps should be increased to provide additional safety in the event of fire.
  - ➢ Current inventory of equipment should be reviewed to ensure that adequate spares and back-up materials/equipment are available in the event of an emergency (e.g., amount and variety of food, number of generators, radios, heaters, batteries).
  - ➢ Clothing issue may need to be enhanced, particularly during winter and WINFLY.
  - ➢ Current evacuation protocols should be revised to accommodate the extreme conditions that occur during winter and WINFLY periods.
  - ➢ Experienced mountaineers with medical response capabilities should be included at field camps.
  - ➢ Field camps should include personnel versed in radio communications and basic electronics. These personnel should have a working knowledge of the McMurdo communications system.

8.4 Search and Rescue Capabilities

- To support increased year-round activity, it is recommended that the existing winter-over search and rescue (SAR) capability be enhanced.
  - ➢ Staffing one or more existing winter-over staff positions with personnel who have a strong SAR background may mitigate the impact of increasing the size of the SAR team.

- Some proposed research locations (e.g., sea-ice camps within a few kilometers of McMurdo) will have essentially unlimited access to McMurdo Station and would not pose significantly higher safety risks during the winter than the summer. However, sea ice conditions must be regularly monitored to ensure that its stability is appropriate for surface transport.
- Other proposed field projects locations, such as the dry valleys, would require additional safety measures during winter owing to restricted helicopter and sea ice traverse access. These additional safety measures would include, for example, staffing the camp with an emergency medical technician with mountaineering skills, limiting high-risk activities such as SCUBA diving, and including more stringent radio operations.

8.5 Helicopter Operations

NSF should work closely with the helicopter contractor and support staff to develop a safety program that ensures safe helicopter operations. Items that should be considered when developing this program include:

- Increase communications in the McMurdo area, particularly the dry valleys.
- Establish flight routes accessible by ground support vehicles.
- Implement more frequent radio check-in points.
- Establish/Maintain emergency and general support facilities at Marble Point and Explorer's Cove.
- Provide improved landing facilities at established field camps with lighting (30m x 30m heliports).
- Make real-time weather data accessible from the automated stations maintained by the McMurdo LTER project in the dry valleys.

8.6 Fixed-Wing Operations

Limitations to fixed-wing aircraft operations arise with darkness and inclement weather, particularly low temperatures and blowing snow. To a large extent improved runway lighting, weather forecasting, and air traffic control can address these limitations. A New Zealand based search and rescue capability must be firmly in place. Fuel considerations should include the capability to extend the point of safe return, allowing aircraft to safely return to New Zealand should a flight be aborted due to weather. Additional landing areas should be identified in case of emergency situations or bad weather.

8.7 McMurdo-Based Support Operations

McMurdo-based operations face some increased risk attributable to possible increased vehicular activity, involvement in SAR missions, and by mere increase in the number of people. These risks can be managed through development and adherence to winter-specific procedures that include an increased awareness of the risks involved by extended season research support.

9. STRATEGIES FOR FUNDING

For extended season research the increased costs for both science and logistics must be addressed. While logistics are derived from the science, scientists must also realize the limitations of logistics and available funding. There is a need for NSF to reconsider their present *modus operandi* for research supported out of the McMurdo area. Research over the past 40 years in the vicinity of McMurdo Station has reached a point where scientific results now play a key role elucidating how Earth's and possible extraterrestrial ecosystems function. For example, the McMurdo LTER program and various programs in aeronomy and atmospheric chemistry can be considered as "canaries" of global change given the polar focusing that occurs at high latitudes. The time has now come to reevaluate the present operating paradigm for research supported from McMurdo Station to include year-round access. Though logistically intensive, new scientific discoveries will result. The information gained from the expanded season research will enhance the current state of knowledge regarding natural processes. In addition to the new science that will result, extended season research can also lead to an overall more efficient operating program. Year-round access may have the following selling points:

- More efficient use of contract labor allowing workers to deploy and redeploy as needed.
- An upgrade of the Pegasus landing site for year round access may be a one-off cost that would have the following benefits:
  - Enhance accessibility to South Pole and other remote camps.

Late February LC-130 operations.

  - Allow construction projects to proceed more efficiently.
  - Decrease the "heroic" efforts in mid-winter emergencies.
  - Provide more efficient flight scheduling to decrease fixed-wing aircraft turnaround problems.
- A higher level of international collaboration for both science and educational initiatives.

Funds to support extended season research can be made available through a "leveling" concept where existing funds are reallocated to include the unmet opportunities afforded by winter research. Alternatives to reallocating current funds would be a "line-item" request for increased funding to NSF, or through the development of interagency (e.g., NASA) and international collaborations. Ideally, a combination of elevated funding to NSF and enhanced collaboration should be pursued. The phased-in approach to extended season research would have the smallest impact on funding and allow funding agencies to reassess scientific and financial commitments over time.

10. CONCLUSIONS AND RECOMMENDATIONS

1. Ecosystems in the McMurdo area provide sentinels for environmentally driven change on our planet. Year-round research will allow the issues of environmental processes to be addressed in an interdisciplinary context, enabling scientists to link physical/chemical processes to biological processes in the annual cycle. This document clearly defines the need for year-round data on the ecosystems in the McMurdo area to address the cardinal issues of:

- Persistence and evolution of life in extreme environments
- Biodiversity and genomics
- Biocomplexity
- Global change
- Potential habitats for extraterrestrial life

2. The alternatives to year-round deployment of scientists to the McMurdo Sound area fall into three categories:

- Highly-trained technical personnel wintering over
- Use of automated instrumentation
- Home laboratory-based research

Each of these approaches serves a specific purpose and can often be used to study winter activities, but they are often limited in scope. A number of research questions cannot be answered by these techniques. Furthermore, these are not alternatives to hands-on science, but are a means of complementing and extending many programs; they are not substitutive.

Research that can only be done with scientific personnel directly involved in the research (e.g., PI's and graduate students) at McMurdo includes:

- Behavioral studies
- Experiments (complex manipulations)
- Tagging of fish, birds and seals
- Process measurements (e.g., primary productivity, trophic interactions)
- Environmentally-sensitive experiments
- Time-sensitive samples and analyses (e.g., tissues, photochemical transients, some taxonomy)
- Serendipitous observation of a unique phenomenon that requires immediate modification of a research plan

3. Increased access to the McMurdo area would allow for an extension of the current educational opportunities already in place. Many of these activities currently go unrecognized and would be better served through a coordinated effort to disseminate this information to the public. Numerous incentives, advantages and challenges were identified by the implementation of educational programs throughout the year in the McMurdo area. It is important that year-round educational programs be designed to integrate with all aspects of research, integrate with existing educational programs (including international efforts) where possible, be multilevel (elementary, secondary, general public), utilize existing technological and human resources where possible, and coordinate with science projects to leverage new technology. These programs should include K-12 (e.g., TEA, teacher professional development programs), the general public, and undergraduate/graduate components.

4. Logistic and scientific support will have to be enhanced in the areas of transportation (intercontinental fixed-wing, helicopter, ground), Crary Laboratory staffing, communications, and field logistics. These enhancements should be viewed as an upgrade in the overall operating procedures in the McMurdo area that will provide a more efficient environment for science and education.

5. A phased-in approach to extended season research is proposed. This approach will extend the typical research season and helicopter support until civil twilight in late April during year one. The following year will support winter research with an exchange of scientists and supplies in June via icebreaker. Scientists on the vessel should have a scientific agenda including studies on birds, mammals, sea ice and biological/physical oceanography. Helicopter support would begin again at civil twilight in August extending and enhancing research during the WINFLY season. Typical operations would occur during the summer season. Scientific and logistical aspects of extended season scenario should be reviewed after this two-year period to determine the future of such operations.

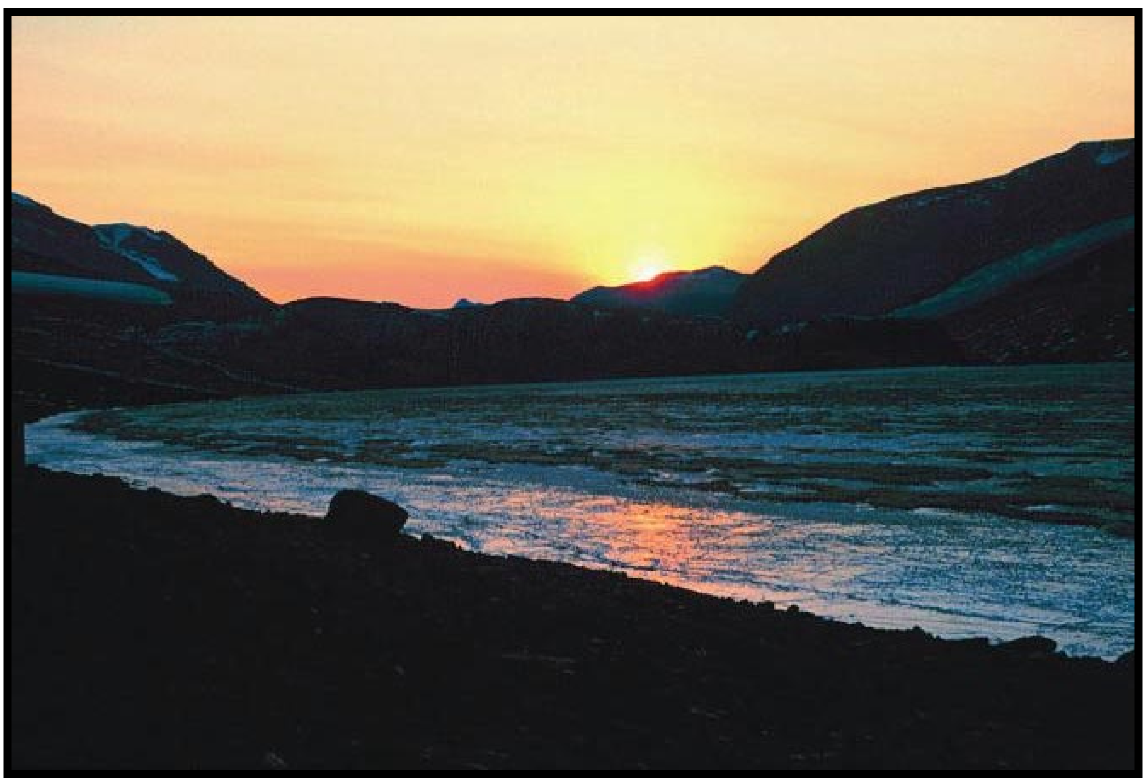
6. The expansion of the science effort in the McMurdo area into other seasons will have an impact on the environment. The number of person-days will increase and this may potentially cause a cascade of effects due to increased routine emissions, waste and disturbance. The probability of accidents may increase during the winter period and the response to such accidents may be more difficult. While these important environmental issues must be considered when extending Antarctic research to include year-round activities, there are also important positive benefits from these activities. Year-round access provides an opportunity to test and showcase how humans can both live and carry out important activities under extreme conditions while at the same time minimizing impacts on this relatively pristine environment. Environmental monitoring throughout the year will also provide a baseline for the full range of environmental variability that occurs in the area. A better understanding of the range of natural variability within the system is crucial for unambiguous recognition of human-induced perturbations. The cumulative impacts of increased presence on the environment should be addressed within the context of long-term degradation. A carefully planned and executed extended season will minimize or attempt to mitigate the effects of increased occupation, however it is unlikely to eliminate these effects entirely.

7. Extending the season to support research in the McMurdo area poses increased safety concerns for field parties, air support operations and McMurdo-based operations. All safety concerns can be addressed with modifications to the medical/physical qualifying process, field safety training, search and rescue capabilities, and helicopter and fixed-wing aircraft operations. A carefully planned year-

Tracked vehicle working near White Island during winter.

round safety program will provide an overall positive benefit to the current safety program now implemented in the McMurdo area.

8. When considering funding to support extended season research, the increased costs for both science and logistics must be addressed. Within this funding scenario, it is imperative to maintain the idea that **logistics are derived from the science**. There is a need for NSF to reconsider their present science strategy for funding research in the McMurdo area. Forty years of research in the area has brought many scientific disciplines to the point where year-round access to the area is the only avenue to address many compelling scientific issues. Although logistically intensive, new scientific discoveries and initiatives will result. In addition to new science, extended season research can also lead to an overall more efficient operating program. Funds to support extended season research could be made available through a reallocation of existing funds, a line-item request for increased funding for the unmet opportunities afforded by extended season Antarctic research, or through development of interagency and international collaborations. Ideally, a combination of elevated funding to NSF and enhanced collaboration should be pursued.



Sunset over Lake Bonney, Taylor Valley, August 1991.

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Scientists traversing between McMurdo Station and White Island during winter.

12. APPENDICES

Appendix 12.1. Participant List

Participants: Back row left to right (standing): Steve Kottmeier, Mahlon Kennicutt II, Donald Siniff, Arthur DeVries, Polly Penhale, Chad Marshall, Bill Haals, Stephanie Shipp, Roland Psenner, Diane Stocker, Sam Bowser, Marcia Gowing, William Baker, Johanna Laybourn-Parry, Martin Jeffries, Berry Lyons, Ian Hawes, Max Tilzer. Middle row: Jill Ferris, Marian Moyher, Jack Hawkins, Alberto Adriani, William Stockton, Eric Juergens, Terry Deschler, Raymond Smith, Chris Sheperd, Randall Davis, Dean Peterson, Mike Lizotte. Front row: Warwick Vincent, John Priscu, Clive Howard-Williams, Deneb Karentz, Christine Foreman, Gerald Kooyman, Christian Fritsen.

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Appendix 12.2. Times of civil twilight for ideal horizon and meteorological conditions at McMurdo Station (Latitude = 77 52 S; Longitude = 166 58 E) for year 2000. Times listed are for daylight savings time (i.e., austral summer or 13 hours east of Greenwich. + Sun above the horizon all day; - Sun below the horizon all day. See appendix 12.4 for definition of civil twilight. Source, U.S. Naval Observatory. Note: subtract 1 h for standard time.

DAY	January		February		March		April		May		June	
	RISE	SET	RISE	SET	RISE	SET	RISE	SET	RISE	SET	RISE	SET
1	+	+	+	+	+	+	0726	2025	1100	1638	-	-
2	+	+	+	+	+	+	0733	2018	1108	1629	-	-
3	+	+	+	+	+	+	0740	2010	1118	1620	-	-
4	+	+	+	+	+	+	0747	2003	1127	1610	-	-
5	+	+	+	+	0234	0133	0754	1955	1137	1600	-	-
6	+	+	+	+	0309	0157	0801	1948	1147	1550	-	-
7	+	+	+	+	0331	0135	0807	1941	1159	1538	-	-
8	+	+	+	+	0349	0117	0814	1933	1211	1526	-	-
9	+	+	+	+	0404	0101	0821	1926	1225	1512	-	-
10	+	+	+	+	0418	2347	0827	1919	1241	1456	-	-
11	+	+	+	+	0430	2334	0834	1912	1302	1435	-	-
12	+	+	+	+	0442	2322	0841	1904	-	-	-	-
13	+	+	+	+	0453	2310	0848	1857	-	-	-	-
14	+	+	+	+	0503	2259	0854	1850	-	-	-	-
15	+	+	+	+	0513	2249	0901	1843	-	-	-	-
16	+	+	+	+	0522	2239	0908	1835	-	-	-	-
17	+	+	+	+	0531	2229	0915	1828	-	-	-	-
18	+	+	+	+	0540	2220	0922	1821	-	-	-	-
19	+	+	+	+	0549	2211	0929	1813	-	-	-	-
20	+	+	+	+	0557	2202	0936	1806	-	-	-	-
21	+	+	+	+	0605	2153	0943	1758	-	-	-	-
22	+	+	+	+	0613	2144	0950	1751	-	-	-	-
23	+	+	+	+	0621	2136	0957	1743	-	-	-	-
24	+	+	+	+	0629	2128	1004	1736	-	-	-	-
25	+	+	+	+	0636	2119	1012	1728	-	-	-	-
26	+	+	+	+	0644	2111	1019	1720	-	-	-	-
27	+	+	+	+	0651	2104	1027	1712	-	-	-	-
28	+	+	+	+	0658	2056	1035	1704	-	-	-	-
29	+	+	+	+	0705	2048	1043	1655	-	-	-	-
30	+	+			0712	2040	1051	1647	-	-	-	-
31	+	+			0719	2033			-	-		

Appendix 12.2, continued. Times of civil twilight for ideal horizon and meteorological conditions at McMurdo Station (Latitude = 77 52 S; Longitude = 166 58 E) for year 2000. Times listed are for daylight savings time (i.e., austral summer or 13 hours east of Greenwich. + Sun above the horizon all day; - Sun below the horizon all day. See appendix 12.4 for definition of civil twilight. Source, U.S. Naval Observatory. Note: subtract 1 h for standard time.

Day	July		August		September		October		November		December	
	RISE	SET	RISE	SET	RISE	SET	RISE	SET	RISE	SET	RISE	SET
1	-	-	1323	1433	0832	1912	0424	2259	+	+	+	+
2	-	-	1259	1458	0824	1919	0412	2310	+	+	+	+
3	-	-	1241	1515	0817	1925	0400	2322	+	+	+	+
4	-	-	1226	1529	0810	1932	0346	2335	+	+	+	+
5	-	-	1213	1542	0803	1938	0331	2350	+	+	+	+
6	-	-	1202	1554	0755	1945	0314	0006	+	+	+	+
7	-	-	1151	1604	0748	1952	0253	0026	+	+	+	+
8	-	-	1141	1614	0741	1958	0224	0055	+	+	+	+
9	-	-	1131	1624	0734	2005	+	+	+	+	+	+
10	-	-	1121	1633	0726	2012	+	+	+	+	+	+
11	-	-	1112	1642	0719	2018	+	+	+	+	+	+
12	-	-	1104	1650	0711	2025	+	+	+	+	+	+
13	-	-	1055	1658	0704	2032	+	+	+	+	+	+
14	-	-	1047	1706	0656	2039	+	+	+	+	+	+
15	-	-	1038	1714	0648	2046	+	+	+	+	+	+
16	-	-	1030	1722	0641	2053	+	+	+	+	+	+
17	-	-	1023	1729	0633	2100	+	+	+	+	+	+
18	-	-	1015	1737	0625	2107	+	+	+	+	+	+
19	-	-	1007	1744	0617	2115	+	+	+	+	+	+
20	-	-	0959	1751	0608	2122	+	+	+	+	+	+
21	-	-	0952	1758	0600	2130	+	+	+	+	+	+
22	-	-	0944	1805	0552	2138	+	+	+	+	+	+
23	-	-	0937	1812	0543	2146	+	+	+	+	+	+
24	-	-	0930	1819	0534	2154	+	+	+	+	+	+
25	-	-	0922	1826	0525	2202	+	+	+	+	+	+
26	-	-	0915	1832	0516	2211	+	+	+	+	+	+
27	-	-	0908	1839	0506	2220	+	+	+	+	+	+
28	-	-	0900	1846	0456	2229	+	+	+	+	+	+
29	-	-	0853	1852	0446	2238	+	+	+	+	+	+
30	-	-	0846	1859	0435	2248	+	+	+	+	+	+
31	-	-	0839	1906			+	+			+	+

Appendix 12.3. Times of sunrise and sunset for ideal horizon and meteorological conditions at McMurdo Station (Latitude = 77 52 S; Longitude = 166 58 E) for year 2000. Times listed are for daylight savings time (i.e., austral summer or 13 hours east of Greenwich). + Sun above the horizon all day; - Sun below the horizon all day. See Appendix 12.4 for definition of sunrise and sunset. Source, U.S. Naval Observatory. Note: subtract 1 h for standard time.

DAY	January		February		March		April		May		June	
	RISE	SET	RISE	SET	RISE	SET	RISE	SET	RISE	SET	RISE	SET
1	+	+	+	+	0508	2254	0905	1844	-	-	-	-
2	+	+	+	+	0518	2244	0913	1836	-	-	-	-
3	+	+	+	+	0527	2235	0920	1828	-	-	-	-
4	+	+	+	+	0536	2225	0928	1820	-	-	-	-
5	+	+	+	+	0545	2216	0935	1812	-	-	-	-
6	+	+	+	+	0553	2208	0943	1803	-	-	-	-
7	+	+	+	+	0602	2159	0951	1755	-	-	-	-
8	+	+	+	+	0610	2151	0959	1747	-	-	-	-
9	+	+	+	+	0618	2142	1007	1738	-	-	-	-
10	+	+	+	+	0626	2134	1015	1729	-	-	-	-
11	+	+	+	+	0634	2126	1024	1720	-	-	-	-
12	+	+	+	+	0641	2118	1032	1711	-	-	-	-
13	+	+	+	+	0649	2110	1041	1702	-	-	-	-
14	+	+	+	+	0656	2102	1051	1652	-	-	-	-
15	+	+	+	+	0704	2054	1100	1642	-	-	-	-
16	+	+	+	+	0711	2046	1110	1631	-	-	-	-
17	+	+	+	+	0718	2039	1121	1620	-	-	-	-
18	+	+	+	+	0726	2031	1132	1609	-	-	-	-
19	+	+	+	+	0733	2023	1144	1556	-	-	-	-
20	+	+	+	+	0740	2015	1157	1543	-	-	-	-
21	+	+	0254	0120	0747	2008	1212	1528	-	-	-	-
22	+	+	0321	0053	0754	2000	1229	1510	-	-	-	-
23	+	+	0340	0033	0801	1953	1250	1448	-	-	-	-
24	+	+	0356	0017	0808	1945	1327	1412	-	-	-	-
25	+	+	0411	0002	0815	1938	-	-	-	-	-	-
26	+	+	0424	2337	0822	1930	-	-	-	-	-	-
27	+	+	0436	2325	0829	1922	-	-	-	-	-	-
28	+	+	0447	2314	0837	1915	-	-	-	-	-	-
29	+	+	0458	2304	0844	1907	-	-	-	-	-	-
30	+	+			0851	1859	-	-	-	-	-	-
31	+	+			0858	1851	-	-	-	-		

Appendix 12.3, continued. Times of sunrise and sunset for ideal horizon and meteorological conditions at McMurdo Station (Latitude = 77 52 S; Longitude = 166 58 E) for year 2000. Times listed are for daylight savings time (i.e., austral summer or 13 hours east of Greenwich). + Sun above the horizon all day; - Sun below the horizon all day. See Appendix 12.4 for definition of sunrise and sunset. Source, U.S. Naval Observatory. Note: subtract 1 h for standard time.

Day	July		August		September		October		November		December	
	RISE	SET	RISE	SET	RISE	SET	RISE	SET	RISE	SET	RISE	SET
1	-	-	-	-	1022	1725	0627	2102	+	+	+	+
2	-	-	-	-	1013	1733	0619	2109	+	+	+	+
3	-	-	-	-	1005	1741	0611	2117	+	+	+	+
4	-	-	-	-	0956	1749	0603	2124	+	+	+	+
5	-	-	-	-	0948	1757	0554	2132	+	+	+	+
6	-	-	-	-	0939	1804	0546	2140	+	+	+	+
7	-	-	-	-	0931	1812	0537	2148	+	+	+	+
8	-	-	-	-	0923	1819	0529	2157	+	+	+	+
9	-	-	-	-	0915	1826	0520	2205	+	+	+	+
10	-	-	-	-	0907	1834	0511	2214	+	+	+	+
11	-	-	-	-	0900	1841	0501	2223	+	+	+	+
12	-	-	-	-	0852	1848	0452	2233	+	+	+	+
13	-	-	-	-	0844	1855	0442	2242	+	+	+	+
14	-	-	-	-	0837	1902	0432	2253	+	+	+	+
15	-	-	-	-	0829	1909	0421	2304	+	+	+	+
16	-	-	-	-	0821	1916	0410	2315	+	+	+	+
17	-	-	-	-	0814	1923	0358	2328	+	+	+	+
18	-	-	-	-	0806	1930	0345	2341	+	+	+	+
19	-	-	1312	1442	0759	1937	0331	2356	+	+	+	+
20	-	-	1246	1507	0751	1944	0315	0000	+	+	+	+
21	-	-	1227	1526	0744	1951	0257	0014	+	+	+	+
22	-	-	1211	1541	0736	1957	0234	0037	+	+	+	+
23	-	-	1157	1555	0728	2004	+	+	+	+	+	+
24	-	-	1144	1607	0721	2011	+	+	+	+	+	+
25	-	-	1132	1619	0713	2018	+	+	+	+	+	+
26	-	-	1121	1630	0706	2025	+	+	+	+	+	+
27	-	-	1110	1640	0658	2033	+	+	+	+	+	+
28	-	-	1100	1649	0650	2040	+	+	+	+	+	+
29	-	-	1050	1659	0642	2047	+	+	+	+	+	+
30	-	-	1040	1708	0635	2054	+	+	+	+	+	+
31	-	-	1030	1716							+	+

Appendix 12.4. Rise, Set, and Twilight Definitions. Source, U.S. Naval Observatory

General Definitions

Horizon: Wherever one is located on or near the Earth's surface, the Earth is perceived as essentially flat and, therefore, as a plane. The sky resembles one-half of a sphere or dome centered at the observer. If there are no visual obstructions, the apparent intersection of the sky with the Earth's (plane) surface is the horizon, which appears as a circle centered at the observer. For rise/set computations, the observer's eye is considered to be on the surface of the Earth, so that the horizon is geometrically exactly 90 degrees from the local vertical direction.

Rise, Set: During the course of a day the Earth rotates once on its axis causing the phenomena of rising and setting. All celestial bodies, stars and planets included, seem to appear in the sky at the horizon to the East of any particular place, then to cross the sky and again disappear at the horizon to the West. The most noticeable of these events, and the most significant in regard to ordinary affairs, are the rising and setting of the Sun and Moon. Because the Sun and Moon appear as circular disks and not as points of light, a definition of rise or set must be very specific, for not all of either body is seen to rise or set at once.

> **Sunrise and sunset** conventionally refer to the times when the upper edge of the disk of the Sun is on the horizon, considered unobstructed relative to the location of interest. Atmospheric conditions are assumed to be average, and the location is in a level region on the Earth's surface.
>
> **Moonrise and moonset** times are computed for exactly the same circumstances as for sunrise and sunset. However, moonrise and moonset may occur at any time during a 24 hour period and, consequently, it is often possible for the Moon to be seen during daylight, and to have moonless nights. It is also possible that a moonrise or moonset does not occur relative to a specific place on a given date.

Transit: The transit time of a celestial body refers to the instant that its center crosses an imaginary line in the sky - the observer's meridian - running from north to south. For observers in low to middle latitudes, transit is *approximately* midway between rise and set, and represents the time at which the body is highest in the sky on any given day. At high latitudes, neither of these statements may be true - for example, there may be several transits between rise and set. The transit of the Sun is local solar (sundial) noon. The difference between the transit times of the Sun and Moon is closely related to the Moon's phase. The New Moon transits at about the same time as the Sun; the First Quarter Moon transits about 6 hours after the Sun; the Full Moon transits about 12 hours after/before the Sun; and the Last Quarter Moon transits about 6 hours before the Sun.

Twilight: Before sunrise and again after sunset there are intervals of time, twilight, during which there is natural light provided by the upper atmosphere, which does receive direct sunlight and reflects part of it toward the Earth's surface. Some outdoor activities may be conducted without artificial illumination during these intervals, and it is useful to have some means to set limits beyond which a certain activity should be assisted by artificial lighting. The major determinants of the amount of natural light during twilight are the state of the atmosphere generally and local weather conditions in particular. Atmospheric conditions are best determined at the actual time and place of events. Nevertheless, it is possible to establish useful, though necessarily approximate, limits applicable to large classes of activities by considering only the position of the Sun below the local horizon. Reasonable and convenient definitions have evolved.

Civil twilight is defined to begin in the morning, and to end in the evening when the center of the Sun is geometrically 6 degrees below the horizon. This is the limit at which twilight illumination is sufficient, under good weather conditions, for terrestrial objects to be clearly distinguished; at the beginning of morning civil twilight, or end of evening civil twilight, the horizon is clearly defined and the brightest stars are visible under good atmospheric conditions in the absence of moonlight or other illumination. In the morning before the beginning of civil twilight and in the evening after the end of civil twilight, artificial illumination is normally required to carry on ordinary outdoor activities. Complete darkness, however, ends sometime prior to the beginning of morning civil twilight and begins sometime after the end of evening civil twilight.

Nautical twilight is defined to begin in the morning, and to end in the evening, when the center of the sun is geometrically 12 degrees below the horizon. At the beginning or end of nautical twilight, under good atmospheric conditions and in the absence of other illumination, general outlines of ground objects may be distinguishable, but detailed outdoor operations are not possible, and the horizon is indistinct.

Astronomical twilight is defined to begin in the morning, and to end in the evening when the center of the Sun is geometrically 18 degrees below the horizon. Before the beginning of astronomical twilight in the morning and after the end of astronomical twilight in the evening the Sun does not contribute to sky illumination; for a considerable interval after the beginning of morning twilight and before the end of evening twilight, sky illumination is so faint that it is practically imperceptible.

Technical Definitions and Computational Details

Sunrise and sunset. For computational purposes, sunrise or sunset is defined to occur when the geometric zenith distance of center of the Sun is 90.8333 degrees. That is, the center of the Sun is geometrically 50 arcminutes below a horizontal plane. For an observer at sea level with a level, unobstructed horizon, under average atmospheric conditions, the upper limb of the Sun will then appear to be tangent to the horizon. The 50-arcminute geometric depression of the Sun's center used for the computations is obtained by adding the average apparent radius of the Sun (16 arcminutes) to the average amount of atmospheric refraction at the horizon (34 arcminutes).

Moonrise and moonset. Moonrise and moonset are defined similarly, but the situation is computationally more complex because of the nearness of the Moon and the eccentricity of its orbit. If the computations are carried out using coordinates of the Moon with respect to the Earth's center (the usual method), then moonrise or moonset is defined to occur when the geometric zenith distance of the center of the Moon is:

90.5666 degrees + Moon's apparent angular radius - Moon's horizontal parallax

Under normal atmospheric conditions at sea level, the upper limb of the Moon will then appear to be tangent with a level, unobstructed horizon. No account is taken of the Moon's phase; that is, the Moon is always regarded as a disk in the sky and the upper limb might be dark. Here again, a constant of 34 arcminutes (0.5666 degree) is used to account for atmospheric refraction. The Moon's apparent radius varies from 15 to 17 arcminutes and its horizontal parallax varies from 54 to 61 arcminutes. Adding all the terms above together, the center of the Moon at rise or set is geometrically 5 to 10 arcminutes above the observer's "geocentric horizon" - the horizontal plane that passes through the Earth's center, orthogonal to the observer's local vertical.

Accuracy of rise/set computations. The times of rise and set phenomena cannot be precisely computed, because, in practice, the actual times depend on unpredictable atmospheric conditions that affect the amount of refraction at the horizon. Thus, even under ideal conditions (e.g., a clear sky at sea) the times computed for rise or set may be in error by a minute or more. Local topography (e.g., mountains on the horizon) and the height of the observer can affect the times of rise or set even more. It is not practical to attempt to include such effects in routine rise/set computations.

The accuracy of rise and set computations decreases at high latitudes. There, small variations in atmospheric refraction can change the time of rise or set by many minutes, since the Sun and Moon intersect the horizon at a very shallow angle. For the same reason, at high latitudes, the effects of observer height and local topography are magnified and can substantially change the times of the phenomena actually observed, or even whether the phenomena are observed to occur at all.

Twilight. There are three kinds of twilight defined: civil twilight, nautical twilight, and astronomical twilight. For computational purposes, civil twilight begins before sunrise and ends after sunset when the geometric zenith distance of the center of the Sun is 96 degrees - 6 degrees below a horizontal plane. The corresponding solar zenith distances for nautical and astronomical twilight are 102 and 108 degrees, respectively. That is, at the dark limit of nautical twilight, the center of the Sun is geometrically 12 degrees below a horizontal plane; and at the dark limit of astronomical twilight, the center of the Sun is geometrically 18 degrees below a horizontal plane.

Appendix 12.5. Specific Communication System Parameters

- System Requirements
  - The communications system shall provide wireless data communications zone coverage to field camps established in the dry valleys, Cape Roberts, and Marble Point
  - The system shall provide wireless VHF and HF telecommunications services to the greater McMurdo region
- Functional Requirements
  - The system shall provide high speed LAN connectivity in the field camps in the McMurdo region
  - The system shall provide high speed connectivity from the camps to the McMurdo Station LAN and CONUS WANs
  - The system shall provide reliable service connections at the camps.
  - The system shall provide communications services for transferring data from remote sites
  - The system shall provide communications services for telephone and voice mail services
  - The system shall provide communications services for receiving pages
  - The system shall provide communications services for teleconferencing sessions
  - The system shall provide communications services for send and receive fax capability from the camps
  - The system shall provide communications services for year-round remote monitoring and collection of data utilizing TCP/IP protocols
  - The system shall provide wide-area transmission of differential GPS data
  - The system shall provide wide area transmission of VHF and HF communications
- Operational Requirements
  - The system shall provide a network infrastructure with a minimum lifespan of 10 years
  - The system shall provide expansion capability for other remote sites to be connected as required
  - The system shall provide an architecture that can be duplicated and is transportable
  - The system shall provide redundancy such that any single failure of equipment and/or software would only affect individual work areas
  - The system shall support access to enterprise resource planning tools (ERP) and logistical support

- The system shall support the use of standard network management tools for routine operations support
- The system shall utilize open standards protocols in the design, implementation, and operation of the network such that the continued operation of the network is not dependent on a single or small consortium of vendors
- The system shall support all current USAP clients as well as possible future clients
- The system shall provide support for TCP/IP standards such as IPv6, RSVP, Multicast, Voice-over-IP, and Mobile IP
- The system shall provide for frequency spectrum issues
- The system shall provide a growth path for future requirements

- Performance Requirements
  - The system trunk shall have a minimum data transfer capability of 2 Mbps
  - The system shall transfer data from the McMurdo Station LAN to the field camp LANs with an average BER of 10-8 in any 5 minute period at 2 Mbps
  - The system shall transfer data from the field camps to McMurdo Station with a data latency equal to real-time
  - The system shall transfer data from the field camps to CONUS with a data latency equal to typical satellite systems
- Interface Requirements
  - The system shall interface to the McMurdo Station LAN for data communications
  - The system shall interface to the McMurdo Station telephony system for telecommunications
  - The system shall interface to the VHF and HF radio communications systems for disseminated radio communications
- Environmental Requirements
  - All equipment located inside the communications structures shall operate under the following environmental conditions:
    - Ambient temperature: -20°C to +30°C
    - Relative humidity: 0 to 100% with condensation
  - All equipment located outside shelters and radomes shall operate under the following environmental conditions:
    - Wind survival up to 300 km/hour (185 mph)
    - Wind survival up to 265 km/hour (165 mph) with 1" radial icing
    - Ambient temperature: -55°C to 0°C
    - Relative humidity: 0 to 100% with precipitation
    - Precipitation: variable

- ❖ Solar radiation: zero to full sunlight

- Power Requirements
  - ➢ Solar powered microwave repeaters will have to include alternative power supplies such as diesel and wind generation
- Reliability Requirements
  - ➢ System equipment shall have no single points of failure
  - ➢ System equipment will be automated for nominal operations
  - ➢ System equipment shall have the capability for remote cold start from the operators position at the McMurdo Station Network Operations Center
  - ➢ System equipment shall have the capability to be remotely switched to redundant equipment from the operators position at the McMurdo Station Network Operations Center
  - ➢ The system shall have a reliability of 99.95%