National Science Foundation

Office of Polar Programs Advisory Committee

Report of the

Subcommittee on U.S. Antarctic Program Resupply

August 2005

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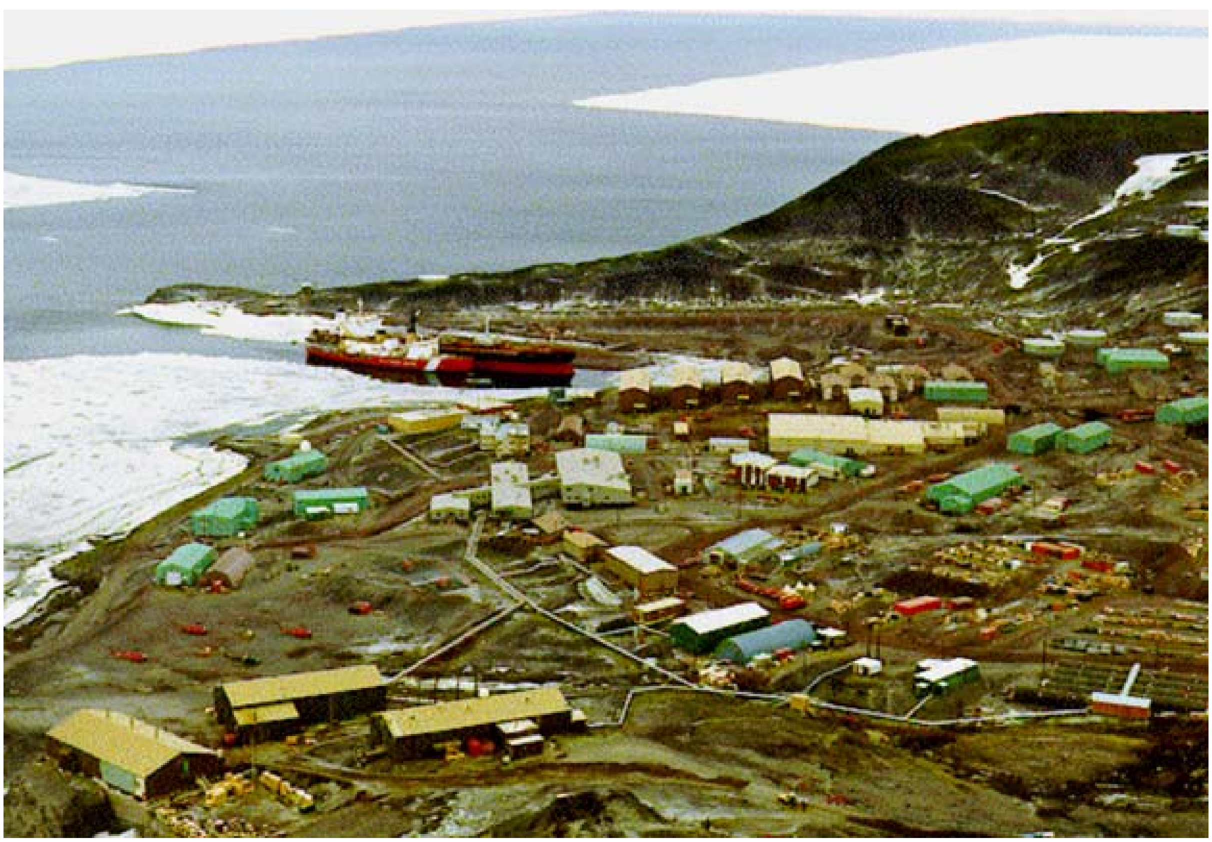

Précis - Antarctic Resupply

The United States Antarctic Program (USAP) is at a logistical crossroads. The processes and systems that have faithfully served the program are near their practical limits. That they have served so well is a testimony to the many dedicated individuals who have continually stretched available resources and assets to cope with an increasingly demanding and complex logistical mission. It is time for a paradigm shift to more effectively meet today's needs as well as to prepare for the future.

Understanding the urgency of the situation, the National Science Foundation Office of Polar Programs (OPP) initiated a study of resupply alternatives and asked the OPP external Advisory Committee (OAC) to form a subcommittee to oversee and guide the development and analysis of alternatives, resulting in recommendations to achieve effective long term resupply capabilities.

The Subcommittee examined a broad spectrum of prior studies, research, professional opinions, and practical experiences to achieve a set of recommendations that would enable the establishment of a future resupply paradigm focused on:

Assurance: The ability to continue to operate USAP science given a one-year lapse in primary resupply capability,

Efficiency: The ability to sustain additional science and science support with existing levels of resource investments,

Agility: The ability to readily adapt to changes in mission driven logistical needs and operating environmental conditions, and

Environment: The ability to conduct science and science support in Antarctica with absolute minimum impact on the natural environment.

The major recommendations of this effort include:

- *Develop a comprehensive systems approach to Antarctic icebreaking* in order to alleviate the single point of failure inherent in the current mode, and to reduce operating, maintenance, and fuel costs. In the near term this should include commercial sources, backed up by the US Coast Guard icebreakers. Ultimately a *new McMurdo-capable icebreaker may be required* to meet future logistical needs of the USAP. *Commercial business models (possibly involving the private sector) should be examined considering procurement and/or operation of that icebreaker.*
- *Construct a wheeled-aircraft capable runway at South Pole Station* to allow direct supply from off Continent and more efficient resupply from McMurdo. A companion capability would be a *blue-ice Runway on the polar plateau*.
- *Continue development of a ground traverse capability* to provide alternative resupply of South Pole Station, to support remote field site research, and to assist McMurdo resupply.
- *Lean McMurdo functions and assets* to reduce resource requirements and optimize its utility as a logistics hub and science support base. In conjunction with this it would be necessary to *move appropriate support operations off Continent.*

- *Examine commercial business models and heavy-lift capability* to augment and extend military capabilities.
- *Examine Lighter-Than-Air technologies* to provide greater heavy-lift flexibility and efficiencies in the future.

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PART I. SUMMARY

A. EXECUTIVE SUMMARY

The United States Antarctic Program has a centric resupply system whereby all materials, fuel and personnel transit by sea and air through McMurdo Station (Fig. A.1) en-route to science and support operations throughout the Continental side of Antarctica. This includes McMurdo Station, South Pole Station, and local area and remote field science camps. This centric resupply system is inherently risky due to a single point of failure condition created by a growing frailty of US Polar class icebreakers and recent severe southwestern Ross Sea ice conditions. Recognizing this situation, the National Science Foundation Office of Polar Programs (OPP) initiated an internal preliminary study last year of several resupply alternatives related primarily to the US Antarctic Program's (USAP) McMurdo and South Pole stations. The OPP Director subsequently asked the OPP external Advisory Committee (OAC) to form a resupply subcommittee to oversee and guide this analysis of alternatives and to develop its own recommendations concerning resupply options, both to assure continuity of operations and national policy of the USAP, and also to help assure that the most cost effective and reliable approaches are implemented. This Executive Summary of the Subcommittee's report highlights the principal recommendations. Many recommendations are intertwined and some were challenging to summarize succinctly. Readers of this summary are

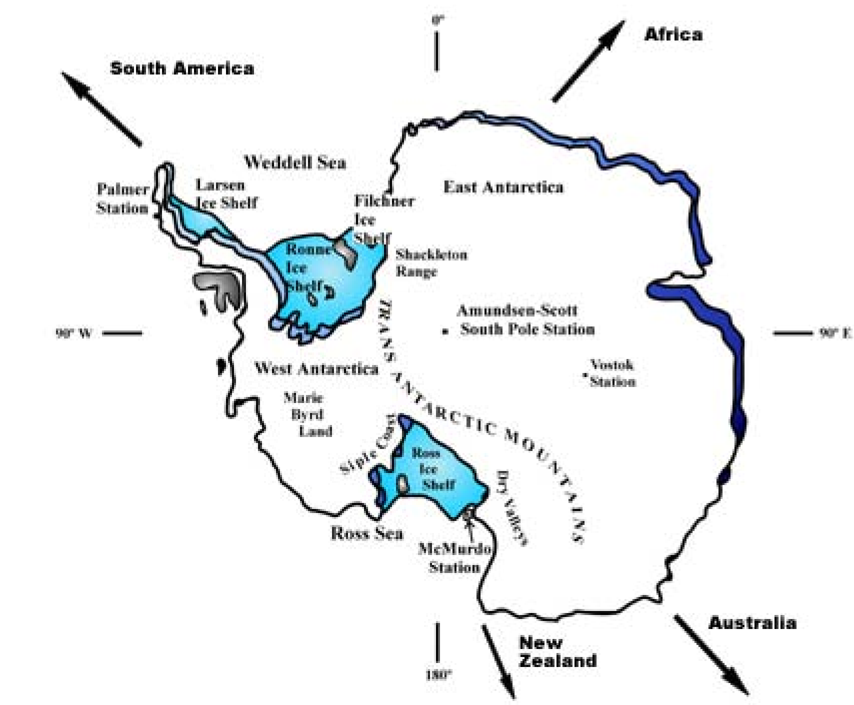

Figure A.1 General map of Antarctica.

therefore encouraged to explore the details, discussion, and supporting information available in the full report.

The Subcommittee kept in mind that today's USAP logistics system represents 50 years of refinement and optimization. There is obviously great merit and justification for the way the program has operated. Even so, the Subcommittee's review pinpointed, as had NSF's informal internal study, a single point of potential failure regarding the dependence upon annual delivery of fuel and cargo by ship to the hub at McMurdo Station. The Subcommittee also noted that there have been significant advances in technology and practice that may provide some advantages for supporting the changing needs of the USAP in the future. Today, large icebreakers - two working together in some years - open a shipping channel through the ice to McMurdo Station (Fig. A.2) which is then used by the resupply vessels. From McMurdo supplies and fuel are used directly or are flown to South Pole Station and the USAP's various remote field locations. The Subcommittee shares the community's admiration of and respect for the US Coast Guard Polar Icebreaker program, which has completed this icebreaking mission for many decades, but only with increasing difficulty in recent years. The two Coast Guard Polar

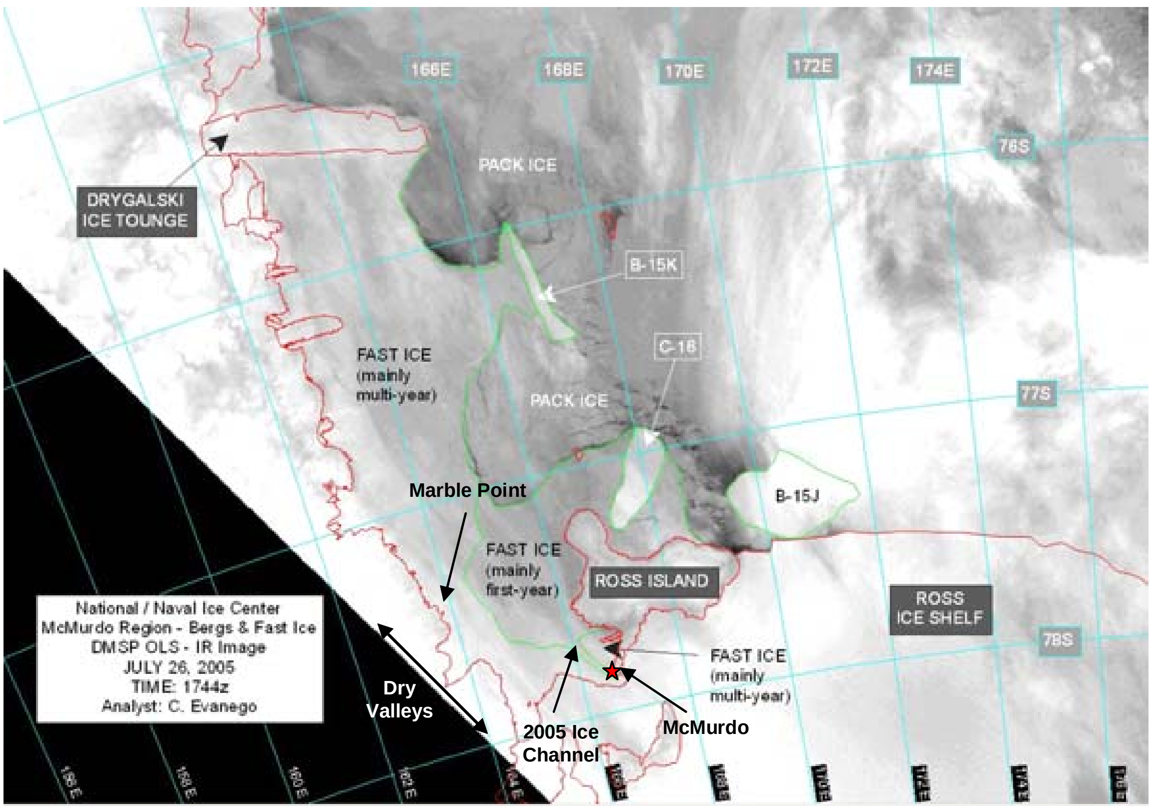

Figure A.2. Satellite photo (DMSP, IR image) of the Southwestern Ross Sea, July 26, 2005, illustrating sea ice, large icebergs, and fast ice. The principal geographic features are labeled and outlined in red. The principal sea ice features and ice channel to McMurdo Station are outlined in green. A latitude/longitude grid is shown in blue.

class icebreakers are within a very few years of their estimated 30-year lifetime and more to the point they are becoming increasingly difficult and costly to keep in service. No other US vessels have the icebreaking capacity required.

A.1 Overarching Recommendations

- The Subcommittee's first overarching recommendation is that NSF should develop the means to continue science support at and from McMurdo and South Pole stations in the event of one missed sea-borne annual resupply to McMurdo Station. This responds to the immediate risk posed by the deteriorating condition of the Polar class icebreakers, and to other identified elements of risk to seaborne resupply of McMurdo Station.

- The Subcommittee's second overarching recommendation is that NSF should consider in its evolution of USAP logistics both the immediate situation and some extrapolation of the changing future needs of the USAP as identified in long-term science planning documents and discussions. For example, the Subcommittee determined that the science community desires access to portions of the Continent that are now difficult or impossible for the USAP to support by air from McMurdo Station.

The Subcommittee was strongly of the opinion that in addressing these, NSF and the science community should not miss an opportunity to revolutionize USAP logistics, while overall seeing that risk is minimized and reliability, agility, flexibility, efficiency, and opportunity are further developed.

A.2 Specific Recommendations

The Subcommittee proposes that a paradigm shift in the South Pole Station supply chain logistics and methodology, possible over both the short and long term, will significantly reduce, if not eliminate, the single point failure risk of operating all logistics through McMurdo Station. Perhaps equally important, it allows existing resources to be used to support new expeditionary science and other program priorities.

To accomplish this, the Subcommittee recommends:

- NSF investigate construction of a hard surface processed snow runway at South Pole Station capable of receiving heavy-lift wheeled aircraft directly from New Zealand or South America. This appears to be relatively inexpensive, and may take only a few years to construct.

- NSF continue development of safe, efficient ground-based traverse capability between various key points (for example McMurdo Station, South Pole Station, and an ice shelf or sea ice edge) for support of both science and logistics missions of the USAP. Traverse capability needs to include transport of cargo and fuel, and return of waste to removal points.

An immediate ancillary benefit of these two steps would be availability for science support of a large number of valuable LC-130 aircraft flight hours, currently expended on fuel, cargo, and personnel transport flights between McMurdo and South Pole stations.

A corollary recommendation is that NSF also investigate establishing an infrastructure capability to land heavy-lift wheeled aircraft at a blue-ice runway area near South Pole, and traverse cargo and fuel from the blue-ice area to/from South Pole.

USAP heavy-lift aircraft support is now provided through the military. Longer term, the Subcommittee recommends that NSF investigate charter of commercial heavy-lift and passenger aircraft for the delivery of cargo, fuel and personnel. The Subcommittee does not, however, recommend entirely abandoning the military option of long-range air transportation, because the Department of Defense can provide unmatched capabilities to meet unforeseen – and potentially catastrophic – events, such as the need for search and rescue. On the other hand, commercial options are important if there comes a time when military aircraft are not available to the USAP, not equipped for or capable of a particular mission, or the military flight hour cost becomes prohibitive.

The Subcommittee sees substantial long-term potential in using Lighter-Than-Air (LTA) heavy-lift craft (now being developed) to transport cargo and fuel from New Zealand to South Pole Station, and/or from McMurdo Station to South Pole Station and remote research sites. NSF should now begin to work with the LTA developers, demonstrating NSF's interest, and consider providing USAP performance criteria to be considered during the design stages.

The Subcommittee recommends that McMurdo Station continue to operate in its current location as a major research and logistics hub for the USAP. NSF should, however, investigate ways to reduce and restructure the size and impact of its McMurdo-area operations. In addition to reconfiguring South Pole Station resupply, NSF should investigate (1) moving applicable support services to New Zealand, (2) using support groups whose operational mode requires minimum on-Continent personnel and limited during-season rotations, (3) keeping days on-Continent per science team member to those required for the immediate mission, and (4) providing economic incentives to contractors for saving energy and reducing impact on-Continent.

The Subcommittee recommends that NSF maintain the ability to offload shipborne fuel and cargo at McMurdo Station. The preferred mode for that shipborne logistics support is to provide tankers and cargo vessels, escorted by an icebreaker capable of opening the supply channel through the ice.

The Subcommittee recommends that fuel reserves at McMurdo Station allow for one missed annual fuel delivery. Needs following a missed year could be met from the current tank farm capacity by reducing the total fuel consumption at and through McMurdo Station, in part by: 1) reducing the number of support personnel operating out of McMurdo Station, 2) reducing or even eliminating the direct dependence of South Pole Station fuel resupply on McMurdo Station, and 3) reducing or even eliminating icebreaker refueling.

The Subcommittee recommends that NSF address both short and long term means to provide appropriate icebreaker support for the annual break-in to McMurdo Station. In the short term NSF should charter an icebreaker on the commercial market as it did in 2004-2005. However, NSF should use the US Coast Guard Polar class icebreakers, once repaired, in reserve in order that their capabilities are maintained as long as feasible. This would best satisfy NSF's present tasking to maintain these vessels' capabilities economically and at low risk. The Subcommittee's rationale is for other icebreakers to take some of the load, and wear and tear, while US national icebreaker policy is being reviewed. Examples of circumstances where a US polar icebreaker might be required during this interval include (1) failure to obtain a suitable contract with a commercial or other operator for a given USAP field season, (2) southwestern Ross Sea ice conditions requiring support from a back-up icebreaker for a commercial or other icebreaker, or (3) a mechanical casualty suffered by a commercial or other icebreaker used to support the USAP.

The Subcommittee notes that NSF's stewardship of icebreaker operation and maintenance funds may make it possible to explore polar icebreaker operation models that promote greater retention of expertise, longer field seasons, increased maintenance in the field, and other aspects of more efficient use. (Much the same may also apply to some aircraft operations in the Antarctic.) Use of USCGC *Healy* for more than the current sea days per year seems to be an obvious place for improvement. Were the *Healy* operated in a mode more nearly like that of PFS *Polarstern*, which spends only about one month each year in Germany, it might be possible to both increase its total Arctic science days and also provide the vessel for Antarctic support during years when a primary icebreaker would especially benefit from back-up and channel-grooming support.

Although there is much to admire about the remarkable hulls, fine maneuverability, and long string of missions supported by the two US Coast Guard Polar class icebreakers, in the longer term private sector construction and operation of a new icebreaker with appropriate capabilities, to NSF specifications and with NSF chartering the vessel for its needs, appears to be an attractive option which merits further and immediate study. This would offer advantages of availability to other icebreaker users, bi-polar operation, and optional use in science support at other times of the year. Icebreaker specifications for USAP logistics support should be focused squarely upon the requirements of the McMurdo Station resupply mission, with a goal of mission success *at least* approximately 9 out of every 10 years. Resupply in "missed" years would depend on reserves, alternate resupply methodologies, and other flexibility and contingency measures recommended by the Subcommittee. In addition high priority should be given to vessel reliability, ability to carry out Antarctic missions without refueling within the Antarctic (potentially making available to other USAP priorities ≈25% of the fuel annually delivered to McMurdo Station), and overall economy of operation. Support for seakeeping and habitability on long transits, including through the tropics, is also highly desirable. Other factors, such as onboard support for polar marine science, should be addressed as feasible. The Subcommittee recommends that in addressing funding of new icebreaker(s), NSF's Major Research Equipment (MRE) program should not be considered, because the cost would likely have a very large impact on all NSF program areas.

To mitigate risk in the event sea ice conditions prevent access to the McMurdo Station wharf, NSF should be prepared to deliver fuel via hoses over the sea ice to the McMurdo Station tank farm, as it did in 2003. Resupply should not depend upon unloading of a large amount of cargo onto sea ice with subsequent traverse to McMurdo Station, however, as this appears to carry high risk.

NSF should carry out further feasibility studies and develop cost/logistics models for alternative McMurdo Station fuel delivery from a tanker via ice shelf offload and traverse, noting especially the relationship of the traverse mode to other areas of USAP support, including South Pole logistics support and support for new remote, expeditionary science initiatives.

All said, the Subcommittee emphasizes that it is most important to mend the USAP's present reliance on a resupply mode which has a single point of failure, a point which has recently come worryingly close to reality. Recent iceberg calving and drift greatly challenged the McMurdo break-in, and this situation could have just as easily developed into one which made the present mode of resupply inoperable, even for 100% fit icebreakers. There is also the matter that although the US Coast Guard Polar class icebreakers are severely worn and have weak points in their mechanical systems design, the demands of heavy icebreaking can result in mechanical failure of *any* icebreaker. The responsible approach to this near-crisis situation is to provide back-up, alternative, or redundant supply systems for the USAP. Moreover, the right choices can both result in efficiencies in the present system and also enable new major science by virtue of the developed logistics *plus* net USAP energy savings which can then be applied to science. The work of the Subcommittee so far suggests that several believable alternatives exist, and that these can be addressed both immediately and in the long term.

The OAC Subcommittee recommends that the OAC advise NSF to further investigate means and costs associated with the recommended changes, for example via expert groups and consultants, and in doing so to continue to evaluate and update appraisal of their risks, benefits, reliability, environmental impact, timeliness, and impacts to science.

B. IMPETUS AND APPROACH

B.1 Synopsis of Issues

"The U. S. Antarctic Program (USAP) has three principal justifications and objectives: presence, science, and stewardship." This is quoted from the 1997 report of the U.S. Antarctic Program External Panel, *The United States in Antarctica* (also known as the Augustine Report). The report also acknowledges the role of national prestige, particularly at the South Pole. The annual resupply that enables the manifestation of these Antarctic objectives, and hence much of the USAP on-Continent research, has depended for many years on a single annual event: large icebreakers - two working together in some years - opening a shipping channel through the ice to McMurdo Station which is then used by resupply vessels to gain wharf-side access to the station (Fig. B.1). From McMurdo supplies and fuel are used directly or are flown to South Pole Station and the USAP's various remote field locations. All personnel – scientists and contractor support – are also flown to the South Pole and remote field locations.

The US Coast Guard has completed this icebreaking mission for many decades but only with increasing difficulty in recent years. Its two Polar class icebreakers are within a very few years of their estimated 30-year lifetime and more to the point are becoming increasingly difficult and costly to keep in service. In addition, Coast Guard funding has been inadequate to meet the maintenance and overhaul needs of these ships. One is presently out of service and the other requires significant maintenance to be kept in operable condition. No other US icebreaking vessels have the icebreaking capacity required for the McMurdo break-in ice conditions in recent years.

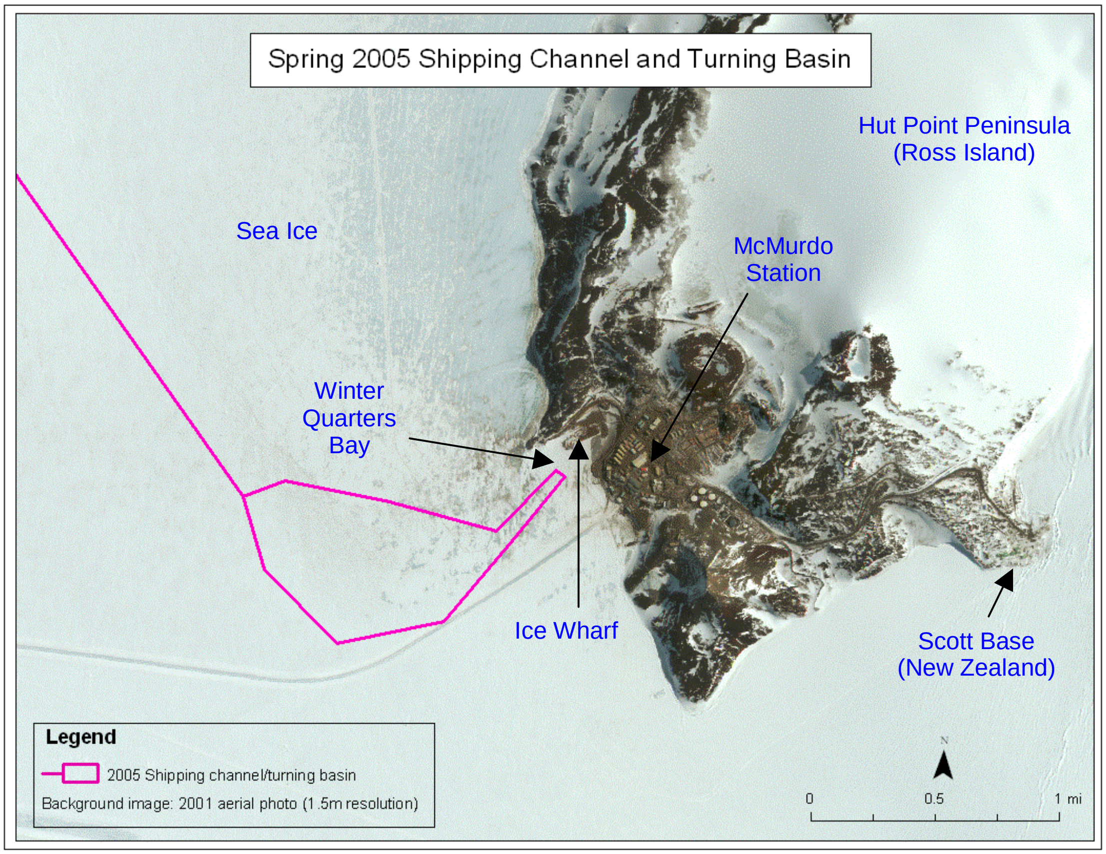

Figure B.1. Aerial photograph of the McMurdo Station region, illustrating spring 2005 shipping channel and turning basin (pink).

Simply put, the present situation regarding heavy icebreaker support can jeopardize fulfillment of the nation's Antarctic objectives, including the USAP. A thorough analysis of resupply alternatives is thus essential both to assure continuity of operations of the US Antarctic Program, and also to help assure that the most cost effective and reliable approach is implemented.

The urgency for a study of resupply alternatives was further driven by related events. In March 2000 an enormous iceberg, dubbed B-15, calved from the Ross Ice Shelf and eventually major pieces of it drifted to partially block sea access to McMurdo Station. Although a sea route remained available, it filled with sea ice, and transformed the previous approximately 35±18 kilometer annual break-in (based on more than four decades of McMurdo break-in statistics), through mostly first-year ice, to as much as 135+ kilometers, with reduced opportunity for broken ice to flush out, thus raising the specter of break-ins through tough multi-year ice. This greatly increased the icebreaking burden on the already-fragile US Coast Guard Polar class icebreakers, plus it was apparent that future iceberg movement, from B-15A or another large iceberg, could totally block sea access to McMurdo Station. There were clearly abundant reasons to explore changes to the resupply model, most importantly because the events demonstrated the risk to the USAP incurred by a resupply model with a single point of failure.

The National Science Foundation Office of Polar Programs (OPP) initiated an internal preliminary study last year of several resupply alternatives related primarily to the McMurdo and South Pole stations. The OPP Director subsequently asked the OPP external Advisory Committee (OAC) chaired by Dr. James Swift to form a resupply subcommittee to oversee and guide this analysis of alternatives and to develop its own recommendations concerning resupply alternatives. This document is the report of that Subcommittee to the OAC, and highlights the recommended changes.

The OAC Subcommittee recommends that the OAC advise NSF to further investigate means and costs associated with the recommended changes, for example via expert groups and consultants, and in doing so to continue to evaluate and update appraisal of their risks, benefits, reliability, environmental impact, timeliness, and impacts to science.

B.2 Panel Charge and Scope of Activities

The complete charge to the Subcommittee is contained in Appendix 1. In summary, the Subcommittee was tasked to:

- identify the full initial universe of options worth considering;
- assist the [OPP] working group in focusing on the most promising options in a timely fashion;
- monitor progress of the OPP working group analyzing the options; and
- prepare a short summary of the pros and cons of any options the Subcommittee deems worthy of serious further consideration by NSF.

In carrying out this work the Subcommittee was also asked to take into full consideration the potential impacts on the present and future scientific programs, both positive and negative, as well as the potential impacts on safety, environmental protection, reliability, cost, and timeliness.

Subcommittee members were:

Dr James Swift, Chair
Dr. Ed Link, co-Chair
Dr. Sridhar Anandakrishnan
Mr. Sam Feola
Dr. Berry Lyons
Dr. Olav Orheim

The formal activities of the Subcommittee included:

- teleconference on 27 April 2005,
- meeting during 15-16 May 2005,
- teleconference 02 June 2005,
- meeting 06 July 2005,
- teleconference 02 August 2005.

In addition, the Chair sent an electronic letter to the OAC outlining Subcommittee progress, which generated responses. On 29 July the Chair sent a near-final draft of the report to the OAC.

During the 02 August teleconference the Subcommittee discussed the draft report, and determined that although there remained need for small changes, the thrust and recommendations were close enough to final that the report could be formally reviewed by the OAC.

On 03 August the OAC carried out an informal teleconference to discuss the Subcommittee report. A number of small revisions were recommended.

B.3 General Approach

The approach chosen by the Subcommittee included identification and examination of a wide range of documents, conversations with experienced persons, and internal discussion by email, teleconference, and at meetings. The Subcommittee found the documents assembled and developed by OPP staff to be impressively broad, thoughtful, and complete, and NSF staff very well prepared to discuss the issues. The Subcommittee was, however, in no way bound by these.

Throughout the course of its work, the Subcommittee considered both the immediate situation and a hypothetical future USAP defined by needs identified in long-term science planning documents and discussion, rather than the present day USAP logistics structure, including how the immediate recommendations might segue into the future. Overall principles were to see that USAP resupply retained and further developed reliability, agility, flexibility, efficiency, and opportunity while minimizing risk.

There was ongoing discussion of the interplay between resupply and science. For example, how do the options examined relate to the support of science in important but non-traditional working areas on the Continent? What is the demand for access to regions that are currently hard or impossible to reach by air in the present mode? Science foci are expected, as each evolves to the fore, to temporarily shift the resources required. How do the various resupply alternatives relate to maintaining flexibility for science priorities, for changing environmental conditions, and/or for direct support of science (for example science carried out on polar icebreakers)?

In keeping with the charge, the principal report presented here provides a short summary, focusing on the principal recommendations. The Subcommittee has, however, referenced many of the documents considered during the discussion, or provided them as electronic appendices to this report.

B.4 Acknowledgements

The Subcommittee was greatly assisted in its work by its ongoing discussions with Dr. Karl A. Erb, Director, NSF Office of Polar Programs. Dr. Erb also made freely available the assistance of his staff. We note and thank in particular Elena Riestra King, Altie H. Metcalf, Brian W. Stone, and Dr. Michael L. Van Woert for their contributions. We owe special thanks to George Blaisdell, OPP's Operations Manager, for the huge amount of work on behalf of the Subcommittee he carried out with cheerful efficiency. He was a valued contributor to our team who seemed able to come up with any report or detail.

C. A STRATEGIC FRAMEWORK FOR DEVELOPING AND ASSESSING ALTERNATIVES FOR ANTARCTIC RESUPPLY

C.1 Background

The *Thomas W. Lawson* (Fig. C.1) sank in the English Channel Friday, Dec 13, 1907. The ship was designed to compete against the new steam powered vessels (introduced in mid 1800s) that were taking cargo business away from sailing ships. It was fast, 22 knots, but to gain speed (a function of hull length and sail area), the designers sacrificed maneuverability, making the vessel unstable. In fact, it capsized at anchor during a gale. Clipper ships were actually approaching their limits 50-60 years before the *Lawson* took to the seas.

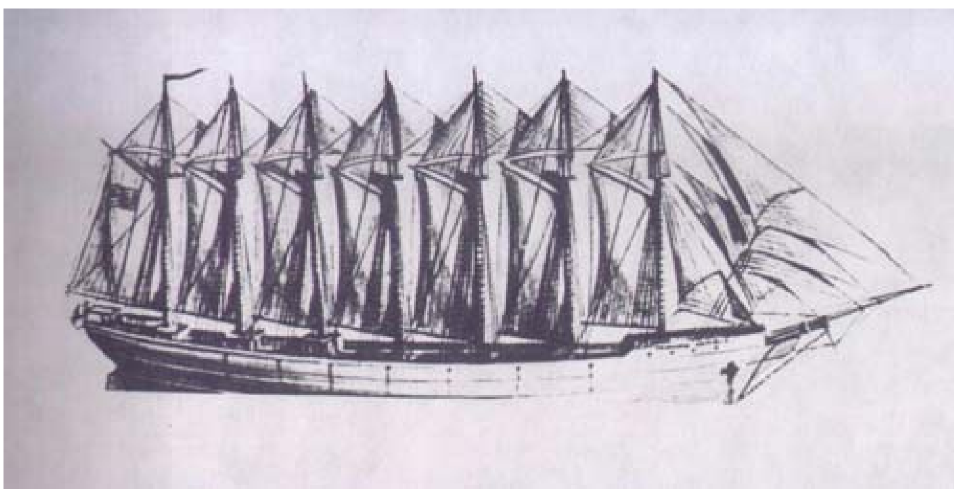

Figure C.1. The *Thomas W. Lawson*, an example of extending a capability beyond its inherent capacity to perform. Source: Angelucci and Cucari, "Ships", McGraw Hill, 1975.

In his book, “Innovation, The Attacker’s Advantage", Richard Foster used the *Lawson* as an example of a concept stretched beyond its practical limits. It is also an example of the impact of momentum, the desire to continue doing something by the tried and true or accepted approach rather than shifting to a new approach. Foster introduced the idea of “S” Curves to generalize the concept. For any process, technology or capability, the S-Curve relates the level of performance or output resulting from a level of input or effort. Early in the evolution of a capability, a significant amount of effort is needed to gain increases in output as the bugs are worked out and efficiencies are introduced. As a capability matures, one reaches the steep slope of the curve where there is an increase in output for a given input. Eventually, however, it will take increasing amounts of input to achieve increases in output. This is the time when a capability is ideally replaced by an alternative that provides a productivity advantage. In essence, this is moving from one S-Curve to another, and as illustrated in Figure C.2, may depict the situation with the current logistics capability in Antarctica. It may not be practical to extend the current resupply model to meet the changing needs of the future, but rather to change the paradigm of how logistics resupply are provided.

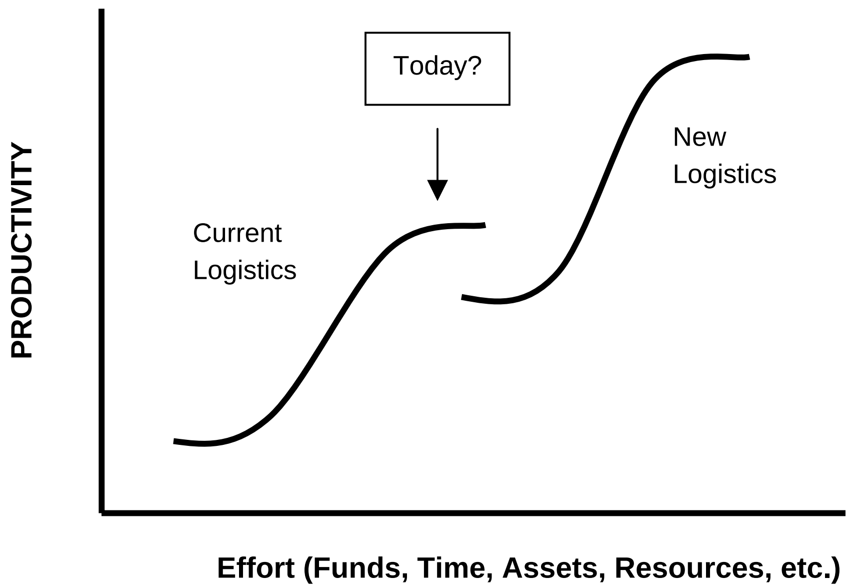

Figure C.2 The S-Curve concept in relation to Antarctic Resupply.

Examining the current logistics chain reveals why it may be characterized as being at the “top” of the S-Curve where it requires extraordinary input to gain a significant increase in output. First of all, there is very little redundancy built into the current system. It is vulnerable to a single point failure, especially with regard to the bulk supplies (materials and fuel) that are needed to sustain and support research. The path from New Zealand to Antarctica is totally reliant on ships being able to reach McMurdo Station. This in turn requires icebreaker support, the lack of which has been the primary stimulus for undertaking this Subcommittee's work. Second, the pathway to South Pole Station is similarly singular, with total logistics support reliant upon LC-130 aircraft from McMurdo Station. Additionally, while research in the Dry Valleys and East Antarctica can be served from McMurdo Station, any future endeavors in West Antarctica may be out of bounds from McMurdo, due to the limited operating range of the LC-130s. The current concept of operations has also reached some practical limits. Refueling icebreakers at McMurdo Station consumes a significant percentage (≈20%) of the fuel transported there each year and transport of fuel to South Pole Station via LC-130 is very fuel intensive (approximately 1.7 liters of fuel consumed to deliver each liter to the pole) and reduces aircraft availability to support science elsewhere. The infrastructure at McMurdo Station itself has grown significantly and requires a substantial level of support. While this may be justified, if that infrastructure were focused more on science, it may be less necessary than if the focus at McMurdo is increasingly administration and logistics.

The recent presence of the B-15A iceberg in the Ross Sea highlighted the vulnerability of the entire operation, because of the lack of redundant pathways if the current avenues are for some reason denied. Missing one year's delivery of fuel or supplies would be traumatic to the USAP, causing little to happen except survival and subsistence. While the current system has served the USAP well, it seems not to have the flexibility or capability to continue to serve it for the future, if icebreaker support and ability to bring resupply ships to the McMurdo ice wharf, are not possible.

C.2 Objective

There are four major objectives for any new strategy developed for Antarctic resupply. These are also the primary criteria by which alternatives will be judged:

- Assurance: Gain redundancy, through development of alternative means to supply materials needed to continue priority research in the event the traditional or primary means fail.
- Efficiency: Reduce cost, by providing means of resupply that will reduce cost and allow enhanced science support.
- Agility: Create a logistics capability that is agile and capable of adjusting to changes in program needs and environmental conditions.
- Environment: Develop a logistics system that reduces environmental impact.

C.3 Approach

Dealing with an issue such as Antarctic resupply requires examining the potential future operating environment as well as considering current issues and requirements. The development and assessment of new approaches to provide a more capable resupply system must consider the probable needs of the future as well as those of today. Assessing the future is tricky business. The Toffler Associates, the strategic advisory firm of internationally renowned futurists Alvin and Heidi Toffler, commonly start by defining the drivers, the primary forces that are shaping the future environment with respect to the area of interest. The drivers are used to examine the implications of different possible future conditions that might result from combinations of the drivers at their logical extremes. This examination leads to insights from which a strategy can be developed that consider the spectrum of possible futures. Drivers for future Antarctic Resupply are depicted in Figure C.3. “Modes” denotes the means for conveying supplies while “nodes” denotes the logistics hubs that serve as points of debarkation and embarkation. “Mission” relates to the primary purpose of the logistics operation (i.e., enabling science research). For each driver it is useful to describe antipodes, extremes that will stretch the thinking and current practice and provide insights for more effective strategies in the future. The antipodes are often best made simple, such as single or multiple for modes and nodes. For modes, this postulates that for any pathway, say from New Zealand to McMurdo Station, there is only one primary mode (e.g., ships) to transport bulk supplies, or multiple modes (ships, heavy aircraft, Lighter-Than-Air, etc.). For nodes, it postulates that there is a single pathway to reach a point (e.g., South Pole Station can only be supplied via McMurdo Station, and in turn, McMurdo Station can only be supplied from New Zealand). Or, there are multiple pathways to supply a location (e.g., South Pole Station supplied either through McMurdo Station, another coastal logistics base, or directly from New Zealand). Mission was considered to have antipodes of supporting science at major sites (e.g., South Pole Station) or expeditionary science (e.g. West Antarctica, remote East Antarctica). Considering how NSF would operate in future years that are defined by combinations of these antipodes provides insights into the types of alternatives that may provide a more adaptive and capable resupply system for the future.

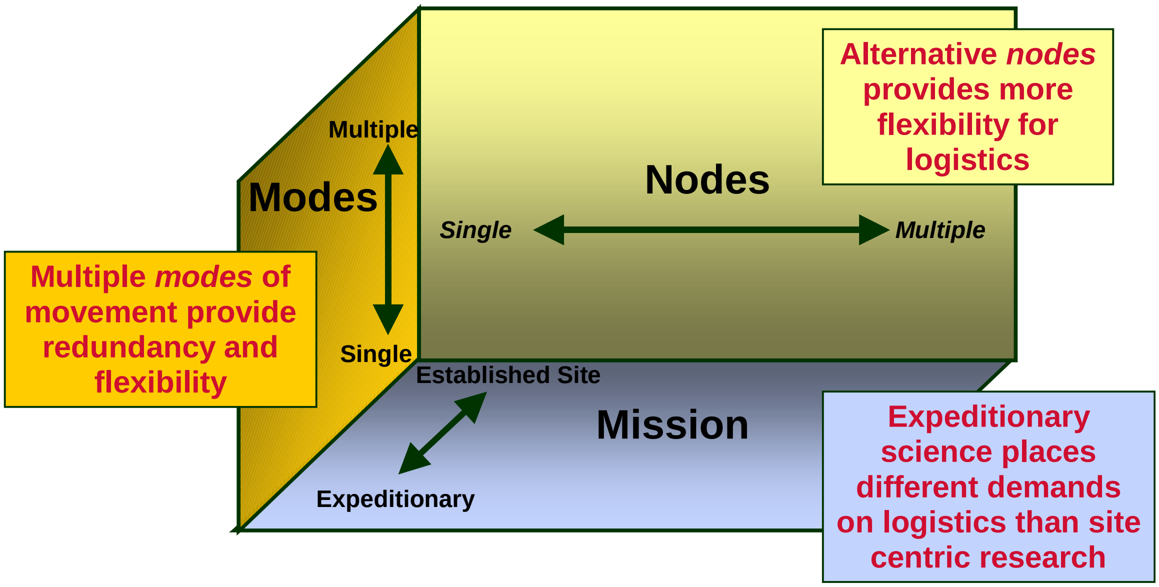

Figure C.3. Specification of major drivers of future operating environments for Antarctic Resupply. Source: Toffler Associates, Manchester, MA.

PART II. ANALYSIS, DISCUSSION, AND DETAILED RECOMMENDATIONS

D. US ANTARCTIC PROGRAM LOGISTICS/RESUPPLY INFRASTRUCTURE AND SITE CENTRIC ISSUES

D.1 Overview

The Subcommittee reviewed the current USAP logistics system, pinpointing, as had NSF's informal internal study, a single point failure modus of operation whereby the program operates all Continental logistics support through a single event: the annual delivery of fuel and cargo by ship to the hub at McMurdo Station. Thus the Subcommittee gave highest priority to logistics shifts which would provide flexibility and reduce risk to the USAP.

In general, it can be difficult to broadly visualize a move into the future by directly building from where one is today. Hence the Subcommittee began with the future, using ongoing community discussion regarding future Antarctic science as a starting point. By defining (realistic) ideal/future logistics support, the Subcommittee hoped it would be possible to determine how well any one proposition met the ideal, thereby establishing mission critical elements for future operations and logistics capabilities. Then the Subcommittee mapped backwards to today's USAP to establish feasible roadmaps.

As "Grand Challenges" are developed for the USAP by the science community (see, for example, http://www.nsf.gov/od/opp/gpra/cov_prss_2004.pdf) these will provide a vision of the future USAP (e.g., "science in the dark"). Future science goals are also part of community planning for the International Polar Year (IPY). From these the Subcommittee understands, regarding logistics needs for future science, that in addition to requiring support from the three permanent USAP stations, the science community desires access to portions of the Continent that are now difficult or impossible for USAP to support due to limited range, flexibility, and agility of current support systems. Hence the Subcommittee supplemented its discussion of logistics support for the three USAP stations by considering a conceptual generic (currently inaccessible) remote field site for an interdisciplinary, complex, multi-year science initiative. Also, the Subcommittee noted that future science foci are expected, as each evolves to the fore, to temporarily shift the resources required. Hence the Subcommittee discussed how the various resupply options related to maintaining flexibility for science priorities, and for changing environmental conditions.

Recent threats to USAP resupply logistics, the examinations of future support needs, and the interconnected nature of the USAP support system together create an opportunity to bring about change. But to minimize risk, to some extent it will be necessary to implement change via small steps. Although the Subcommittee discussed attractive, but expensive, concepts with dramatic long-range benefits, the view was that high cost and drastic change concepts at this time are not likely to reach the starting line. Nonetheless, the Subcommittee was strongly of the opinion that NSF and the community should not miss an opportunity to revolutionize USAP logistics. This is one reason the Subcommittee initially focused on an ideal future scenario rather than immediately trying to "polish the apple" (i.e., simply put a band-aid on present logistics). For example, the Subcommittee felt it would be advantageous both in the short term and long term to address de-coupling South Pole Station resupply from its present complete reliance upon McMurdo Station, rather than address only the immediate McMurdo resupply issue.

The Subcommittee focused specifically on the logistics underlying the NSF mission (science support). Other National interests, including for example missions of US polar icebreakers which are not in support of NSF science, were regarded as the purview of other bodies.

The Subcommittee parsed the issues various ways, such as temporally into the short-term and long-term, with a medium-term defined as a transition. Thanks to recent northward movement of the principal large blocking iceberg, and based on the 2004-2005 austral summer experience, the Subcommittee determined that one reasonably heavy icebreaker could likely reach McMurdo Station in the 2005-2006 austral summer. Because this closely parallels NSF's analysis of the situation, the Subcommittee did not overtly focus on the very short term, though there was extensive discussion of support several years into the future.

For the long term, the Subcommittee worked in part from community expressions of the "where we want to be" type reports from various community long-term science planning workshops, science user group meetings, and so forth. Discussion of realistic future logistics support options also reduced the constraints imposed by beginning with only the present day options and, it was hoped, set the stage for evolution of a viable long-term US strategy. USAP marine science support did not receive explicit attention, except as a science support ramification of the use of icebreaking and ice-capable vessels to support on-Continent logistics.

The Subcommittee's development of shorter-term resupply strategies was based upon providing continued support for the present-day scenario (i.e., support for the three permanent US Antarctic stations; Palmer, McMurdo, and South Pole), with the present-day balance of materials sent to each station. Because Palmer Station resupply is not in jeopardy and involves relatively small amounts of fuel and cargo, Subcommittee attention focused on McMurdo and South Pole stations, with South Pole Station being resupplied (in the short term) via McMurdo, and the other USAP activities enabled through those sites, as at present. The Subcommittee also addressed how the South Pole Station can be supported assuming the primary sea-borne resupply fails to reach McMurdo during one year in the relatively near future. Noting that South Pole Station resupply cannot be improvised at the last minute, whatever alternatives are recommended must be reliable and in place.

The Subcommittee is aware of the excellent tradition of mutual support, especially during emergencies, carried out by the Antarctic nations. And there are many instances of icebreakers coming to the aid of other nations on an occasional basis. But there is nowhere within the international Antarctic community the kind of redundancy needed to handle the much larger US logistic transport requirements. For example, were the USAP not to have alternative logistics systems ready, a massive effort would be required to maintain the USAP after a missed annual resupply of McMurdo Station, on a scale which would overwhelm any other nation's Antarctic facilities. There is also the matter that those non-US facilities are not located strategically to the benefit of maintaining the USAP.

Planning for resupply alternatives should include analysis of the impacts on science and on construction costs which might take place if scientific equipment or construction cargo scheduled to be delivered by ship were delayed. This will help to make the rationale for development of viable strategies even more compelling.

Long-term strategies were much less constrained. Again, for the most part Palmer Station was not explicitly included in the discussion, but this recognized that many of the future resupply options which apply to other USAP sites and activities would also apply to Palmer Station or similar future sites. More central to the discussion was the Subcommittee's assumption that the US would continue to operate a South Pole station with approximately today's personnel complement and annual local-use cargo and fuel requirements, but it must be emphasized that South Pole Station resupply options other than through McMurdo were considered as high priority, and achievable. One goal of the discussion was to specify means to maintain South Pole Station science - and as many other USAP science activities as possible - with occasional (ca. once per decade) lapses in direct (at the ice wharf) McMurdo annual resupply from sea. Moreover, a wide-ranging discussion took place concerning the future role and resupply of McMurdo Station. For example, how might resupply be affected if McMurdo Station annual needs were larger or smaller, if some - or even all - of the activities now at McMurdo Station were moved to one or more other sites on or off the Continent, or if environmental issues affecting annual resupply improved or deteriorated (e.g., close presence of very large icebergs)? A parallel discussion focused on the logistics methodologies themselves, covering a wide range: icebreakers and ice-strengthened vessels, aircraft of various sizes and types (including lighter-than-air), ground support from tracked vehicles and hovercraft, plus the sites used by these, including various types and locations of ship offload sites, runways, and vehicle routes.

The Subcommittee found that OPP staff were commendably well along on identifying and studying resupply alternatives. Examples include developing one or more supply chains parallel to the existing one, milling the channel to McMurdo continuously with smaller ships, disembarking cargo at a point near McMurdo where icebreaking would not be such a great challenge, increased reliance on air transport to McMurdo and/or South Pole stations, and measures to reduce the amount of fuel and supplies needed. OPP staff had also examined a broad suite and mix of air, water, and ground-based transport methodologies.

With excellent background work available, the Subcommittee focused on the principal strategic issues: What are the mission essential priorities in the supply chain? What do we have to be able to do?

The overall strategic situation of "southbound" USAP resupply is illustrated schematically in Figure D.1.1, which shows the global flow of materials to Antarctica now carried out in support of the USAP. There is also a flow of materials from Antarctica, not shown in the figure.

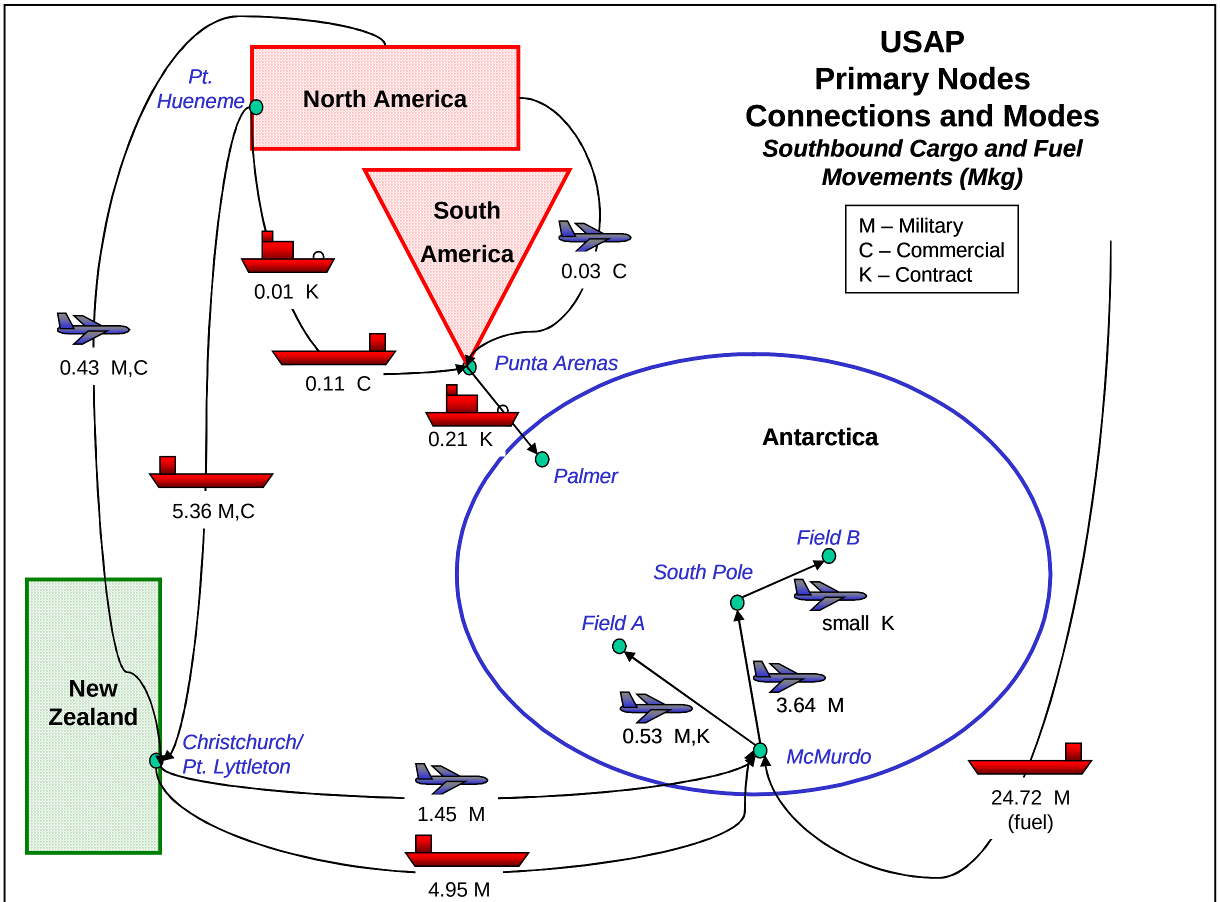

Figure D.1.1. Present-day flow of materials (in millions of kilograms) to Antarctica in support of the USAP. A parallel diagram can be created for outbound materials (not shown).

It was determined early in the Subcommittee's work that due to the large amount of fuel and cargo annually required - some 25,000,000 kilograms of fuel and 7,000,000 kilograms of cargo at present - that one way or another, ships were going to be involved. Considering the Antarctic context, at some point sea ice must be taken into account in that ship support. Furthermore, due primarily to the cost of air transport, it was decided not to pursue in depth those resupply alternatives which required in a typical field year a significantly greater number of resupply flights than now take place. Also, because Antarctica is, in the words of the Augustine report, "the coldest, driest, windiest, remotest, and highest (on average) continent," and is ringed by myriad ice shelves and tongues, seasonal and fast sea ice, and other extremely challenging features, the Subcommittee recognized that resupply alternatives which might be promising in other locations may not be suited to the Antarctic.

D.2 South Pole Station

The Subcommittee believes that a paradigm shift in the South Pole Station logistics supply chain methodology is possible, over both the short and long term. This shift will significantly reduce, if not eliminate, the single point failure risk of operating all logistics through McMurdo Station. It also acts as a redundancy to using McMurdo as a centric hub. Perhaps equally important, it allows existing resources to be used to support new expeditionary science and other program priorities.

The Subcommittee recommends that NSF investigate:

> **Construction of a hard surface processed snow runway at South Pole Station capable of receiving heavy-lift wheeled aircraft directly from New Zealand or South America;**
>
> **Establishing an infrastructure capability to land heavy-lift wheeled aircraft at a blue-ice runway area near South Pole Station, and traverse cargo and fuel from the blue-ice area to/from South Pole Station;[1]**
>
> **Continuing development of the traverse capability from various start points (e.g., McMurdo Station or an ice edge) to/from South Pole Station to transport cargo and fuel, and to return waste to McMurdo Station for removal; [1] and**
>
> **Proactively investigate the potential of using Lighter-Than-Air (LTA) transport of cargo and fuel from New Zealand to South Pole Station, and from McMurdo Station to South Pole Station and other parts of the Continent.[1]**
>
> [1] (Note: Personnel may still need to be flown via McMurdo Station.)

The principal logistics alternative is to establish direct air operations from New Zealand or South America to South Pole Station to move cargo (materials), fuel, and both science and support personnel. This would involve heavy-lift wheeled aircraft and/or lighter-than-air craft (LTA). A secondary logistics alternative is to complete the development of a traverse capability. Collectively, these would significantly increase the efficiency and timeliness of deploying science personnel and priority supplies and equipment to South Pole. It would provide direct fuel resupply without using valuable LC-130 aircraft, which could then be dedicated to direct science support.

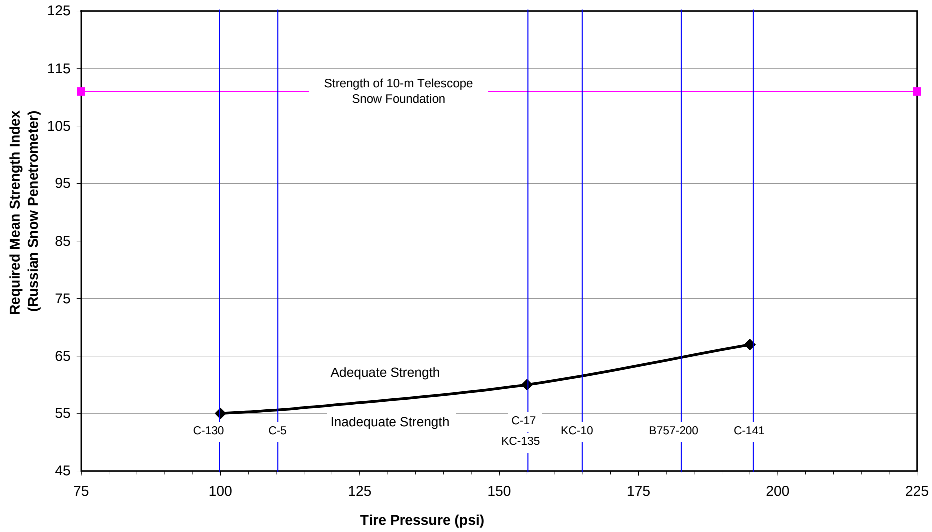

Figure D.2.1. Snow-pavement surface-strength requirements for various heavy wheeled aircraft.

NSF has made great strides in developing a traverse capability to South Pole from the Ross Sea area. This capability should be completely developed and incorporated as a logistics mode, at least until other modes of transportation render the traverse capability obsolete or uneconomical.

A key element to making South Pole Station "free and independent" from a single point centric logistics hub in McMurdo is the construction of a processed-snow hard surface runway to land heavy-lift wheeled aircraft. Recent experience by NSF to construct a thick base of processed snow for a large telescope project indicates the feasibility of building a hard surface runway at the approximate cost of $3M in 2005 funds (11 personnel, equipment and fuel). The snow index strength requirements (Russian Snow Penetrometer, RSP) indicate that the tire pressure and weight bearing of various types of aircraft that NSF would likely use to land at South Pole are well within the engineering capacities (see Fig D.2.1).

In today's resupply model, NSF uses ski-equipped LC-130s flown by the 109th New York Air National Guard (ANG) to fly all cargo, fuel, science and support personnel to South Pole via McMurdo Station. This resupply must first make its way to McMurdo Station – by air from New Zealand, and/or by cargo and fuel ships to McMurdo Station (requiring icebreaker support) - where it is off-loaded, moved to separate staging areas and flown by LC-130s to South Pole. Cargo and fuel are handled multiple times, as shown in the examples below, requiring significant contractor and ANG personnel support on the ground in McMurdo. This adds significant costs and environmental risks through the double or triple handling of the resupply, increased staffing and infrastructure in McMurdo to handle the resupply and personnel, and 6-8 days (round trip) of non-productive “wait-time” for scientists deploying and redeploying through McMurdo Station. (Note that the fuel is delivered through the existing aircraft wing tanks, whereas the cargo is generally palletized and delivered in the cargo bay. Science and support personnel are delivered via troop seats and can be transported with cargo and/or fuel.) Additionally, in the 2004-2005 USAP season, 320 of the 401 flights flown by the ANG in Antarctica were between McMurdo and South Pole stations, thus tying up high valued LC-130 time and airframes that could be used for direct support of science elsewhere on the Continent. In the Subcommittee's suggested new model, direct air operations (using large wheeled aircraft) from New Zealand or South America to South Pole would get materials and fuel, and science and support personnel to South Pole in the most timely and efficient manner, thus providing mission assurance, flexibility and economy to the program.

CARGO PIPLINE EXAMPLE
Cargo shipped through McMurdo to South Pole is unloaded from the aircraft or ship; un-palletized or unloaded from a container; moved to a staging or storage area; moved again to priority staging areas; palletized and moved to the aircraft staging area several kilometers away; loaded on the aircraft; flown to South Pole where it is unloaded, un-palletized and moved to storage or operational areas. The multiple handling allows an increase in risk associated with lost or damaged cargo. If aircraft flew directly from NZ to South Pole, cargo would be delivered to NZ by air or ship, transported to the cargo yard at the airstrip, palletized and loaded on an aircraft and flown directly to South Pole, where it would be unloaded, un-palletized and moved to storage or operational areas. The risk of damage or loss is greatly reduced via direct air flights from NZ to South Pole.
FUEL PIPLINE EXAMPLE
Fuel is discharged/pumped from the resupply tanker into a variety of storage tanks located around McMurdo Station. Fuel for delivery to South Pole is then piped to tanks at the runway of departure (either the ice runway or Williams Field), for loading into the aircraft wing tanks for delivery to South Pole. At South Pole, fuel is offloaded directly from the aircraft wing tanks into station storage tanks. A dedicated LC-130 fuel flight (all payload is fuel) delivers 14,000 liters. If flights originated in New Zealand directly to South Pole, fuel, likely in larger units of 80,000-170,000 liters, would be loaded one time and off-loaded one time, thus reducing the risk of environmental damage and reducing necessary McMurdo storage capacity.
PERSONNEL TRANSPORT EXAMPLE
Science and contractor personnel destined for South Pole Station are flown from New Zealand to McMurdo Station where they enter the infrastructure support system (berthing, food, water, work spaces) until they are manifested on a flight to take them and their personal effects, cargo and science equipment to South Pole. This could take several days depending on aircraft priorities and availability, as well as good weather for flying. It is not uncommon for grantees to be "stuck" in McMurdo for three to five days or longer before flying to South Pole. Conversely, scientists returning to New Zealand to redeploy to their home institution can be stuck in McMurdo for similar time frames. Several times a season, McMurdo infrastructure, especially berthing, can be overextended with South Pole contractor personnel and scientists. Direct flights from New Zealand to South Pole would eliminate these delays and infrastructure impact.

Another practical alternative for NSF to consider, in somewhat the same vein as using a processed-snow hard surface runway at South Pole Station, is to fly various types of heavy-lift aircraft to a blue-ice runway near South Pole Station, then traverse the cargo, fuel and possibly personnel the remaining distance to the South Pole. [The Subcommittee clearly favored the processed-snow runway option based on the information examined.] The Mt. Howe blue-ice area is located 260 kilometers from South Pole Station, and coincidentally is less than 100 kilometers from the projected traverse route from McMurdo Station. Synergies may exist for a mixed mode of resupply using this blue-ice area and long-haul traverses from the McMurdo area or other alternate start points. The Mill Glacier blue-ice area is located 500 kilometers from South Pole. The Subcommittee's brief discussion of anecdotal information about blue-ice sites produced mixed opinions, with the negative views having to do mostly with possible aviation weather issues. If NSF's investigation of this alternative showed early promise, a suggestion is that one or two leading blue-ice sites be instrumented with satellite-reporting remote weather stations.

Aircraft landing directly from New Zealand/South America (at either South Pole Station or a blue-ice area) could also return retrograde and waste for transshipment to the United States. In fact, a blue-ice area could be an alternate landing site, as well as McMurdo, New Zealand or South America for weather diverts. Additionally, the Subcommittee recommends NSF complete the development of the traverse capability from other locations, such as McMurdo or an alternative cargo landing site, and use it to deliver cargo and fuel to South Pole Station. (Personnel would be flown by aircraft, most likely LC-130, unless a hard surface wheeled capable runway is built.) A traverse could then be utilized to take retrograde equipment and waste back to McMurdo for return to the United States.

The Subcommittee looked at the probabilities of utilizing KC-10s, KC-135s, and C-17s in the near and mid term for flying cargo, fuel and personnel directly from New Zealand/South America to South Pole. This mode of operating requires a hard prepared-surface runway, which NSF believes is technically achievable in a two-year time span. Longer term, the NSF could also charter commercial heavy-lift and passenger aircraft for the delivery of cargo, fuel and personnel. The Subcommittee does not, however, recommend entirely giving up the military option of long-range air transportation, because, as noted in the 1997 Report of the U.S. Antarctic Program External Panel, "*The United States in Antarctica*," the Department of Defense can provide unmatched capabilities to meet unforeseen – and potentially catastrophic – events, such as the need for search and rescue. On the other hand, commercial options are important if there comes a time when military aircraft are not available to the USAP, not capable of a particular mission, or the military flight hour cost becomes prohibitive. For example, in April 2001, the NSF chartered a commercial Twin Otter to fly an emergency medical mission to South Pole Station, when military LC-130 aircraft could not operate at South Pole due to low outside air temperatures (maximum on-ground operating temperature is -55°F). The Twin Otter safely and successfully recovered the medical patient in less than five days, operating in temperatures of -90°F.

The Subcommittee also reviewed other alternatives to provide fuel in the event of a single point failure in McMurdo if the current New Zealand-McMurdo-South Pole resupply model continues. Examples included air-to-air refueling of LC-130s from KC-10 or KC-135 "mother ships" orbiting South Pole; or, the utilization of "near by" blue-ice runways, traversing from there to South Pole. If the station life-support demanded it, the station could also be re-supplied by airdrop of cargo/materials.

Consideration was given to building a hard surface gravel runway at Marble Point (Fig. A.2). However, aircraft payloads, using LC-130s from McMurdo to South Pole, would not increase as the LC-130s are currently operating from McMurdo Station on skis at the same maximum allowablegross weight as they would on wheels. Moreover, this alternative would require a significant cost to build, and would also require the logistics to move major cargo between McMurdoStation and the runway plus the infrastructure needed to support flight operations. Nevertheless, if a hard surface snow runway was constructed at South Pole to allow heavy-lift aircraft, it may be practical to do an economic study to determine if a gravel runway in the McMurdo area would be beneficial.

A future (long term) alternative for moving cargo, fuel and personnel from New Zealand direct to McMurdo and/or South Pole stations is Lighter-Than-Air (LTA) aircraft. This is also referred to as Hybrid Ultra Large Aircraft (HULA) in developing literature. The mode of transport is still in commercial and military development, but marketing advertisements and preliminary studies indicate significant capabilities to move large amounts of cargo and/or fuel (500-1000 tonnes) over long distances (up to 6500 kilometers).

The Subcommittee recommends that NSF investigate the development of LTA/HULA concepts, demonstrating the Government's interest, and consider providing criteria and requirements that could be added into the design stages.

Economics:

Flight hour costs utilizing military heavy airlift vary from year-to-year. Historically, heavy-lift flight hour costs for the C-5 were in the $10,000 to $12,000 range. C-17 flight hour costs are projected to be at the level of a C-5, except that extraordinary circumstances have kept the flight hour cost artificially low since the C-17 was first introduced to the Antarctic Program. Also, C-17s came with warranty programs that kept the maintenance costs relatively low in the early years of use. Today, and in the recent past, USAF flight commitments to support conflicts in the Middle East have kept the flight hour costs very low ($3,000 per hour) due to the spreading of operations and maintenance costs to the many current users. Once the flying pace decreases, operations and maintenance costs (with fewer total users and less benefit from warranty programs) will most likely drive the flight hour costs to significantly higher levels. When that occurs, NSF may wish to examine cost effective means to obtain heavy airlift via the commercial sector to see if any meet USAP mission requirements.

Today's fuel delivery requirement to South Pole is 2,660,000 liters annually. This covers the Austral Summer science season and the winter-over period. Typically, after the winter-over ends and the station opens for the Austral Summer, fuel delivery begins, and just before station closing at the end of the Austral Summer, the fuel storage capacity of 1,710,000 liters is topped off. The 2,660,000 liter requirement is approximately 10% of the fuel delivered by chartered tanker (requiring Icebreaker support), and stored at McMurdo Station.

The cost of one liter of fuel delivered to South Pole Station is about $6.58 ($25/gal), or $17,500,000 for 2,660,000 liters, using the traditional McMurdo resupply route. This considers the initial cost of the fuel, the prorated charter cost of the tanker vessel, the prorated cost of the icebreaker(s), and the prorated flight hour costs and number of LC-130 missions flown to South Pole (320 in 2004/2005 season, of which 60% of the payload moved was fuel). If a hard surface runway was built at South Pole, it would take 50 C-17 missions, at a cost of $1.32 per liter ($5 per gal), or about $3,600,000. This is a mere one-fifth of the cost of the current McMurdo resupply route, saving nearly $14,000,000. This does not factor in mobilization and demobilization costs to the NSF. Using KC-10 tanker aircraft instead of C-17s, it would take 15-16 flights at a cost of about $2,500,000, saving about $15,000,000.

To re-emphasize one of the Subcommittee's primary recommendations, the technology exists to build a hard surface processed snow runway at South Pole today. It is inexpensive. It would take a few years to construct, thus providing an immediate short term achievable goal that would literally shift the paradigm of USAP logistics resupply to positively benefit the NSF and direct support of science.

D.3 McMurdo Station

McMurdo Station is the largest US base of operations in the Antarctic. It is located in the Pacific sector at approximately 77.9 °S, 166.7 °W on the southwestern Ross Sea. As noted in the Augustine Commission Report, McMurdo Station currently serves as the logistics base for most USAP inland operations and has been critical in providing logistics support for South Pole Station. Historically, the McMurdo region has been utilized by USAP and pre-IGY researchers and explorers because it is located close by the site chosen by the 1910-1913 Scott Expedition as their base camp due to its being nearly the farthest south sea-accessible point in the Antarctic in the majority of years. McMurdo Station remains accessible by sea today, though for only a relatively short portion of the year, and even during those times the sea approaches are typically blocked to varying degrees by residual first-year sea ice, fast ice, and hard multi-year ice.

McMurdo Station is by any measure the largest scientific and logistics support facility in the Antarctic, housing approximately 1,000 persons in the summer, with an over-winter complement of approximately 200. These USAP scientific and support staff, and the Continental research they enable, currently depend upon annual delivery of 25,000,000 kilograms of fuel and 7,000,000 kilograms of cargo to McMurdo Station for immediate use there and for transshipment to South Pole Station, Scott Base, and remote field sites. Approximately 5,000,000 kilograms of scientific samples and gear, end-of-service equipment, and USAP waste (most of the total), must be removed from Antarctica each year, currently through McMurdo Station.

The annual McMurdo Station resupply cannot realistically take place via aircraft. The C-17 is now the primary USAP airlift platform. It has a maximum payload of approximately 45,500 kilograms, but if operated from Christchurch it is likely that the USAF would limit loads to approximately 34,000 kilograms so that the aircraft can carry enough fuel to have a point of safe return from overhead at McMurdo Station (without landing) and also to not require taking fuel from McMurdo Station to complete its return to Christchurch. Thus something on the order of approximately 730 flights would be required for the annual USAP fuel delivery, with another 200 for cargo. And even if that heavy flight load were feasible in the sense of aircraft and crew availability and cost, there would remain the issues that (1) the type of runways currently used in the Antarctic by wheeled aircraft can handle a maximum of only a small fraction of the total loading and wear represented by that annual use and (2) aircraft engines produce approximately 25 to 1000+ times the pollutants per kilogram of cargo delivered (depending on the specific pollutant; see table D.3.1) compared to typical modern terrestrial engines (much the same applies to marine engines), an important consideration in the US role in the stewardship of the Antarctic environment and ecosystem.

Table D.3.1 Comparison of Annual Air Emissions From South Pole Resupply Alternatives

	Cargo Transported (kg)	Fuel Use (liters)	Fuel Combustion Byproducts (kg)				
			Sulfur Oxides	Nitrogen Oxides	Carbon Monoxide	Exhaust Hydro-carbons	Particulates
Traverse	800,000	750,000	51.2	27.6	10.2	1.4	2.3
LC-130	800,000	1,200,000	1,358	10,734	7,208	3,210	2,953

A portion of today's annual fuel and cargo resupply to McMurdo Station is transported onwards to the US South Pole Station. (See Table D.3.2.) Yet even were South Pole Station to receive its annual resupply independently of that for McMurdo Station, for example via direct air delivery from South America or New Zealand, a majority of the total USAP annual resupply would remain destined for McMurdo Station. Also, if a major new USAP research initiative were to require staging from a location other than one of the three present USAP stations, the most likely logistics scenarios include landing at least a substantial fraction of the needed materials at a suitable coastal site. In addition, ships also are needed to transport scientific equipment, science samples, and environmental recycling from the Continent.

The Subcommittee thus concluded that under almost any scenario NSF would need to be able to move fuel and cargo to Antarctica, including to McMurdo Station, by ship. The Subcommittee also felt strongly that McMurdo Station in its current location should be retained as a major research and logistics hub of the USAP.

<table>
<tr><td rowspan="5">USA</td><td rowspan="5">25,000,000 liters (100%)</td><td rowspan="5">McMurdo offload</td><td>11%</td><td>South Pole</td></tr>
<tr><td>12%</td><td>Field Sites</td></tr>
<tr><td>19%</td><td>Icebreakers</td></tr>
<tr><td>22%</td><td>Flights to South Pole</td></tr>
<tr><td>36%</td><td>McMurdo</td></tr>
</table>

Table D.3.2 Schematic of present-day use of fuel delivered annually to McMurdo Station

There are no realistically feasible sites to land seaborne fuel and cargo in the McMurdo Station vicinity which are free of sea ice and have suitable harbors. Hence, McMurdo Station resupply will continue to require icebreaker operations in order to retain its current and future role in the USAP. This does not mean that the *status quo* need be maintained: Managing USAP risk, for example in the icebreaker program, is essential from NSF's standpoint. The Subcommittee discussed a number of issues regarding the McMurdo Station resupply and logistical operations which would lead to more flexibility and economy in operation, as well as to a more reliable mix of logistics/resupply alternatives for the future USAP. This will ensure resupply of McMurdo Station over years when ice conditions or mechanical casualties prevent direct resupply by sea, and also greatly improve flexibility in support for USAP science missions.

McMurdo Station support for icebreaker operations: In order to help stockpile fuel for McMurdo Station and science operations, it was strongly advocated by the Subcommittee that a reduction in the refueling of icebreakers at McMurdo Station would be a significant boon to the overall program. Currently ca. 20% of the fuel delivered to McMurdo Station every year is used to refuel ships, mostly the icebreakers. This is more than half of what is used by McMurdo Station annually.

McMurdo Station support for fixed wing operations: The Subcommittee suggests that NSF examine air operations at McMurdo Station. Consolidation of air operations via reducing the number of runways, currently at three, to one or two could lead to savings (Fig. D.3.1). For example, could an improved, wheeled-runway be developed at Williams Field? There is a need for runways that accommodate both heavy wheeled and ski-equipped aircraft. Risk reduction must also be considered in this examination.

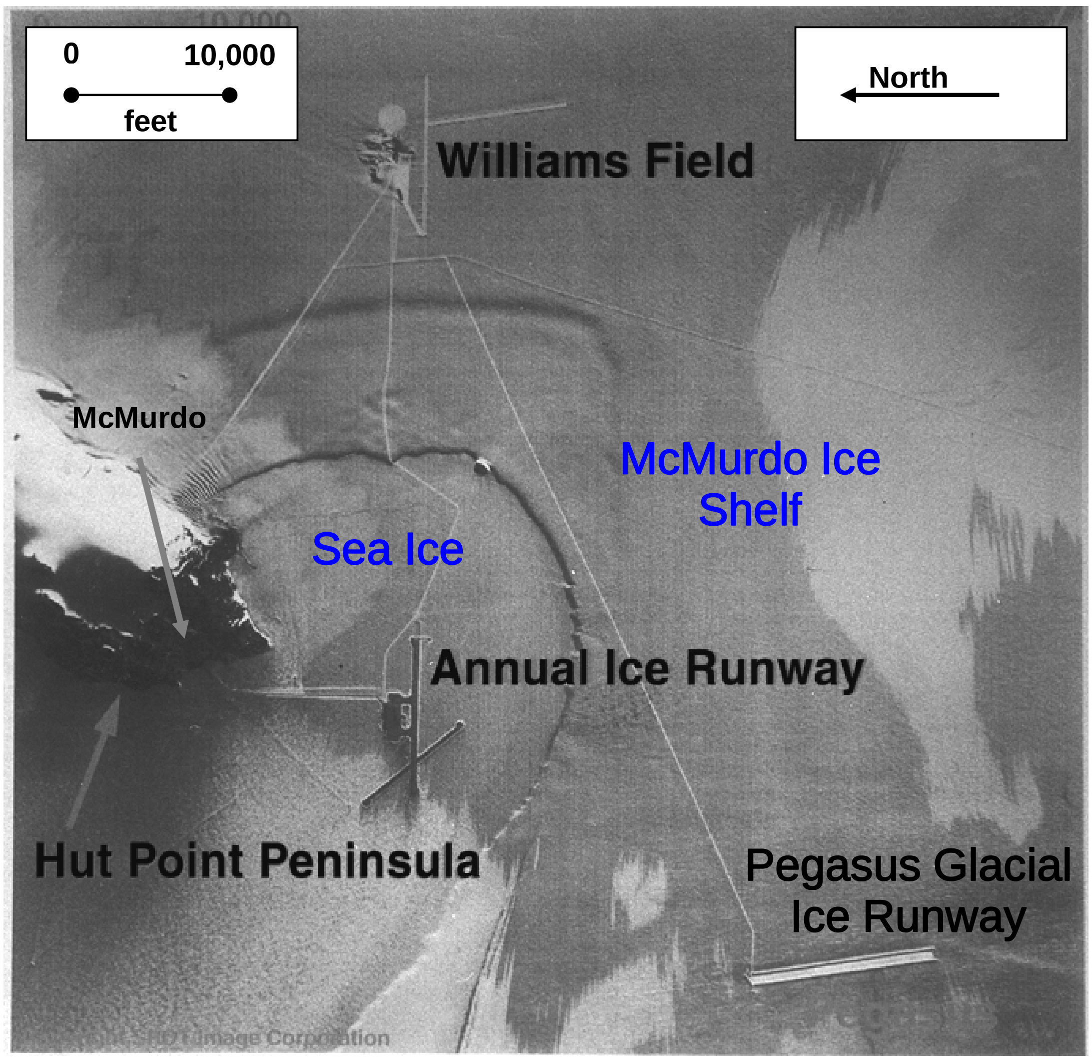

Figure D.3.1. Satellite image of McMurdo Station region showing location of airfields. (SPOT HRV image ID 30445569412011812251P © 1994 CNES, Licensed by SPOT Image Corporation, Reston, Virginia.)

McMurdo Station fuel capacity: The Subcommittee recommended that fuel capacity at McMurdo Station permit one missed annual fuel delivery. If nothing else in the overall logistics scenario were to change, a doubling of capacity of the McMurdo Station tank farm plus delivery of the extra fuel during one or more years would be required. But there are worthwhile alternatives. Specifically, needs after a missed year could be met from the current tank farm capacity by reducing the total fuel consumption at and through McMurdo Station, in part by: 1) reducing the number of support personnel operating out of McMurdo Station, 2) reducing or even eliminating the direct dependence of South Pole Station fuel resupply on McMurdo Station, and, as noted above, 3) reducing or even eliminating icebreaker refueling.

Also, currently there may at present be insufficient incentive for fuel conservation at McMurdo Station. Fuel use reduction at McMurdo could be stimulated in several ways. For instance, the logistics support contract for the Antarctic with NSF could provide appropriate incentives for reducing McMurdo Station resupply requirements as well as for minimizing the number of deployed personnel for on-Continent science support operations. NSF could continue to develop so-called "green" (generally, renewable) energy resources in the Antarctic. Also, it is possible that some science support operations/activities could be transferred to New Zealand (see below).

McMurdo Station operations style: The Subcommittee suggests that an evaluation be undertaken to establish the pros and cons of McMurdo Station being more of a "just in time" science support operation than a "we have everything right here" base. There is a need to establish what savings in logistic and science support personnel costs would be gained by this shift in philosophy. This change in philosophy should not jeopardize the science mission of USAP in any manner, but instead, for example, streamline contracted services and also transfer more science support activity from the Continent to New Zealand. Moving towards a "just in time" resupply mode would more often utilize the off-Continent air link (e.g., with New Zealand) to supply parts and equipment, as opposed to heavy dependence on maintaining warehouses at McMurdo Station resupplied using the annual cargo vessel. There would be more support flights to McMurdo Station, but this would not significantly increase the amount of fuel needed at McMurdo Station because the aircraft could fly round trip (or close to it) with fuel supplied off-Continent. Less stock on-Continent reduces the local need for warehouses, and the people and energy used on-Continent to support the warehouses. This mode of operation also works to reduce the disruption caused by missing one year's resupply by cargo vessel because the USAP would not depend so strongly upon the resupply vessel for critical items, having already committed to fly them in as needed.

It also was suggested that changes in the opening and closing dates of McMurdo Station might benefit the USAP in terms of both economics and logistics. Many other Antarctic nations have longer field seasons and take advantage of better environmental conditions in the austral Fall which benefit their resupply. Extending the USAP season into March and April could also facilitate science operations that could take advantage of these different environmental conditions. The balance between extended season fuel consumption and more dependable resupply needs to be evaluated.

D.4 Expeditionary Science and Traverses

The US Antarctic program has always been a pioneer in flight operations in the Antarctic. This has allowed the US to continuously maintain well-supported science programs in the interior of the Continent, far from the ship- and wheeled-aircraft-based coastal stations. The crown jewels of this capability are the ski-equipped LC-130 fleet, which are unique to the US Antarctic Program. These heavy-lift, long-range aircraft, with their deep-field landing capability (i.e., landing in areas without prepared skiways) have been instrumental in allowing research to be carried out virtually anywhere on the Continent.

The US was also a leader in mechanized over-snow traverses for scientific research and exploration. These traverses from the late 1950s continuing on into the 1970s were fundamental in advancing our understanding of the Antarctic. This over-snow traverse mode of operation has been de-emphasized in recent years. There were many reasons for the shift of emphasis to the air-supplied field camps from the traverse mode of operation, including a desire to do targeted research rather than broad-brush exploratory research.

The completed development of safe, efficient ground-based traverse capability will significantly benefit both science and logistics missions of USAP.

D.4.a Science

The Antarctic is increasingly recognized as extremely heterogeneous, and results obtained in one location are difficult to extrapolate beyond relatively short distances (perhaps 10s to 100s of km). The extraordinary results of recent satellite-based work and airborne geophysics all point to the variability of glaciological, geological, climatological, atmospheric, and other parameters on strikingly short distance scales. There is an increasing need for *corridors/swaths* of research to complement the airborne/satellite measurements and to link together the sites where intensive *point* measurements have been conducted (cores, high-resolution surveys, long-term data collection efforts, etc.)

In addition, research efforts in Antarctica are being undertaken at greater and greater distances from the two main aircraft bases at McMurdo and South Pole stations. In the next decade, work in central East Antarctica (e.g., the Gamburtsev Mountains, Lake Vostok, Dome Fuji), in the Amundsen Sea Embayment (e.g., Pine Island, Thwaites, and Smith Glaciers), and in the Filchner-Ronne drainage will all stretch or exceed USAP's ability to support that science solely with airborne resources.

To support the increasing geographic spread of science, and to support this different corridor-based style of science, the USAP needs to diversify its *modes of transport* to include options other than the current airborne support of field camps.

Recently, OPP initiated a proof-of-principal demonstration of overland traverse for partial resupply of South Pole Station. The 2005-2006 operating season will be the final year of this four year project and is expected to enable overland delivery of up to 2,000,000 kilograms of cargo annually to South Pole Station from McMurdo Station. The Subcommittee recommends that the benefits of this technological development be applied to enable more effective support of expeditionary science.

D.4.b Logistics

The logistics burden of most deep field operations are fuel, camp infrastructure, camp consumables, and technical/scientific instrumentation. Arguably, the lion's share of the burden is on fuel and camp infrastructure. By utilizing ground-based traverse capability to deliver these less-time-sensitive items to the deep field, the USAP would free up aircraft for supporting people and time-critical cargo. One hybrid mode of deep-field resupply that needs to be investigated is air-drops of "dumb cargo" such as building materials; retrograding the packing and parachutes could be done by the ground-traverse equipment that would otherwise return to base camp empty.

The USAP could also investigate launching traverses from ice-shelves edges where ships dock. This would allow delivery of materials directly from the ship to ice shelves near the final science location, from where the traverse could proceed. In addition, the traverse capability would allow USAP to conduct field operations into the marginal-weather conditions at the beginning and end of the austral summer.

Finally, there is an opportunity to improve camp infrastructure from the present Jamesways to well-insulated, modular structures. Currently, setting up a remote field camp involves a week or more of work by a team of specialists (carpenters, electricians, plumbers). The Jamesways are heavy to deliver to the site, and are inefficient to operate in terms of both personnel time to keep them clear of drift and also in terms of fuel. (Ironically, Jamesways are permanently illuminated by light bulbs because there are no windows. Thus more fuel must be burned to generate electricity to light the interiors!) A modular design that could be towed into place and with services pre-wired (electrical, plumbing, etc), could make significant gains in reducing fuel consumption, reducing the need for trained trades-people to raise a camp, and reduce the time to occupation of a camp and reduce the amount of maintenance.

D.4.c Recommendations

To evaluate the risks and rewards of ground traverses, the Subcommittee recommend that the USAP complete development of the McMurdo Station - South Pole Station traverse, and further study this option for use in other routes. This should continue present collaboration with international partners, such as the close relationship with the French National Antarctic Program to gain and share traverse technology expertise. To fully utilize this capability, some fundamental restructuring and retraining of personnel may be needed. Some of the investments that will need to be evaluated are:

- Acquisition of additional equipment appropriate to traverse operations (in consultation with international partners);

- Development of traversing protocols, maps, route-finding, terrain characterization, safety.;
- Development of an experienced cadre of personnel to support over snow travel; and
- Evaluation of launching of traverses from remote ice shelves where ships offload.

Some of the opportunities are:

- Access to the regions in between stations, field camps, and skiways;
- Access to regions far from McMurdo Station and South Pole Station in an efficient manner (to land LC-130s farther than 1500 km from McMurdo requires either refueling from aircraft-cached fuel depots or severely restricting the delivered payload);
- Redirecting aircraft resources to support time-sensitive missions and people; and
- Extending the field season at each end (i.e., into early November and into early February).

Example – West Antarctica science:

- Develop capability and experience to land cargo, fuel, and science teams at ice shelf edge (where suitably low), and remove equipment, personnel, and waste.
- Develop traverse capability and experience in this region.

D.5 New Zealand and Other Off-Continent USAP Support

For many years the USAP has had a science support facility in Christchurch, New Zealand. In addition to this facility acting as a primary transfer and resupply hub, it currently is the distribution center of polar clothing for grantees and contract personnel, thus acting as an important science support operation.

The Subcommittee discussed shifting locations for some science support activities in order to help minimize the number of people deployed and cargo transported to McMurdo Station. The Subcommittee suggested that where practical and feasible, science support operations could be transferred from Antarctica to Christchurch, New Zealand, or other off-Continent locations. For example, some support activities conducted in the Berg Field Center in McMurdo might be better suited to an off-Continent staging center. In addition, the construction of modular field camp buildings and other such activities could be done off-Continent, if economically advantageous.

The Subcommittee also suggested that an investigation be made of direct flights from off-Continent to South Pole Station. These might be staged from various locations, such as New Zealand or South America. This could resupply the South Pole Station without transit through McMurdo Station. The fueling of South Pole Station via C-17 or KC-10, would give important flexibility to the overall resupply strategy, and greatly aid in planning for any unexpected situation. A major consideration here is that the Subcommittee recognized that the supply chain to South Pole Station did not necessarily have to all run through McMurdo Station. Fuel savings in McMurdo by direct flights to South Pole would be substantial.

These actions may increase the total USAP-related personnel off-Continent, but because this would come with reductions in on-Continent personnel, and costs to support on-Continent personnel are very much greater than for personnel based elsewhere, substantial savings to the USAP should immediately result.

E. US ANTARCTIC PROGRAM LOGISTICS/RESUPPLY TRANSPORTATION SYSTEMS AND OPERATIONS ISSUES

E.1 Perspective

The Subcommittee kept in mind that today's USAP logistics represents 50 years of refinement and optimization. There is obviously great merit and justification for the way the program operates now. Even so, changes in science drivers, future vision, and in technology and resource availability make it logical to re-examine the logistics and resupply issues. Certainly, recognition of risk due to the present single-point failure potential makes it important to seek reliable back-up systems at a minimum.

The Subcommittee discussed the possible benefits of a relocation of assets in USAP support, noting that new Antarctic science initiatives, for example those envisioned as US contributions to the upcoming International Polar Year, must to some extent be supported within existing budget levels. User-group reports and other related information show that USAP investigators are well supported, and that this support considerably aids accomplishment of their Antarctic science missions. Still, it may be possible to retain excellence in science (and in the support of science) but gain in efficiency if the present USAP logistics system, which operates in a full-service mode, works to optimize use of very expensive on-Continent logistics and operational support. Specifically, the Subcommittee determined it likely that USAP overall science programs can grow somewhat, with little change in overall budget, if per-science-team-member days on-Continent are kept to those essential for the science missions; if some on-Continent services can be moved to New Zealand, Chile, or the US; if on-Continent support is moved toward a "just in time" model; if off-Continent direct supply to South Pole Station can reduce dependence on the McMurdo Station hub; and if in general the approach to on-Continent support focused strongly on the assets required for the direct science support.

The Subcommittee noted further that while future science initiatives will likely require USAP logistics support in areas now remote from the Palmer, McMurdo, and South Pole stations, to support these remote operations the US cannot realistically afford anything amounting to (or which could be considered to be) a fourth year-round Antarctic station. Hence, remote-area logistics must be handled via new capabilities, ideally provided without large budget increases, without adding to the total personnel complement at the three stations, yet without deflating the ability of those stations to support the type of science carried out at and from them today.

Supporting new science operations within the overall constraints will require streamlining, and the largest single element in streamlining USAP on-Continent operations lies in optimizing the number of USAP-supported personnel. Each person on-Continent requires a massive pyramid of facilities, energy, supplies, and support staff (incrementally), not to mention the direct effect of salary costs. The Subcommittee encourages the USAP to move away from on-Continent support groups whose present operational models require frequent personnel rotations and/or large support staff. This can be accomplished either by changing the operation models of the existing groups or by replacing groups with others with operational models which have the desired characteristics. It should be possible to not only bring about savings across every aspect of the relevant personnel/logistics pyramid, but also in some cases provide improved support. The Subcommittee notes as an example that large economic benefits were an immediate result of the shift from military to commercial USAP helicopter operations, a shift which also brought to the USAP an even greater level of expertise in those operations. NSF should examine every aspect of USAP logistics with an eye to maximizing the science/expertise per dollar/energy expenditure.

All this said, the Subcommittee notes that it is most important to mend the USAP's present reliance on a resupply mode which has a single point of failure, a point which has recently come worryingly close to reality. Recent iceberg calving and drift greatly challenged the McMurdo break-in, and this situation could have just as easily developed into one which made the present mode of resupply inoperable, even for 100% fit icebreakers. There is also the matter that although the US Coast Guard Polar class icebreakers are worn and have weak points in their mechanical systems design, the demands of heavy icebreaking can result in mechanical failure of *any* icebreaker. The responsible approach to this near-crisis situation is to provide back-up, alternative or redundant supply systems for the USAP. Moreover, the right choices can both result in efficiencies in the present system and also enable new major science by virtue of the developed logistics plus net USAP energy savings which can then be applied to science. The work of the Subcommittee so far suggests that several believable alternatives exist, and that these can be addressed both immediately and in the long term.

E.2 Ship Support

E.2.a McMurdo Station resupply ship support requirements

Ship support to the USAP is currently crucial to the logistics model. In fact, even with full implementation of some of the Subcommittee's air-support-related recommendations, it is clear to the Subcommittee that ship support for fuel and cargo will continue to play a significant role in USAP Continental logistics for many years to come. The Subcommittee further notes the obvious: ship support to the USAP must take ice conditions into account.

Currently, nearly all the fuel and cargo delivered to McMurdo Station are carried by an ice-strengthened naval tanker (e.g., USNS *Lawrence H. Gianella*) and a long-term chartered ice-strengthened cargo vessel (e.g., M/V *American Tern* chartered by the Military Sealift Command). Neither of these vessels is configured for the degree of icebreaking required for the McMurdo Station resupply mission, and thus heavy icebreakers - two working together in some years - open and maintain the shipping channel through the ice to McMurdo Station used by the resupply vessels. [Other vessels may also use the channel to McMurdo Station. Except for RVIB *Nathaniel B. Palmer* access to McMurdo Station, that channel use is outside the immediate scope of this report.]

The USAP marine science program is supported chiefly by the NSF-chartered ice-strengthened research and supply vessel *Laurence M. Gould* and the icebreaking research vessel *Nathaniel B. Palmer*. These vessels, especially the *Laurence M. Gould*, also provide logistics support for Palmer Station. Because these two vessels and their activities, however important, do not figure into the principal issues addressed by the Subcommittee, they will not be considered further here.

The Subcommittee determined that exotic means of vessel-based support (such as a dedicated aircraft carrier or use of tanker/cargo submarines) were not realistically viable. Thus the USAP annual vessel-based resupply needs would be most appropriately met (considering the evaluation criteria) by vessels falling into the traditional scope (i.e., tankers, cargo vessels, and/or tanker/cargo vessels), either self-sufficient in the ice, or with icebreaker support. The mix of vessels within these categories needed to support annual McMurdo Station resupply was examined by the Subcommittee. Vessel options were examined in detail, with every reasonable combination from the following:

Naval tanker and icebreaking cargo ship (as at present) supported by icebreakers:

- Service life extension (SLEP) of one or two US Coast Guard Polar class icebreakers
- One or two new US Coast Guard icebreakers (equivalent to Polar class)
- NSF-owned or commercial lease of icebreaker equivalent to Polar class icebreaker
- NSF-owned or commercial lease of icebreaker equivalent to FESCO *Krasin*
- NSF-owned or commercial lease of icebreakers suitable to support year-long grooming of channel to McMurdo Station
- NSF-owned or commercial lease of icebreakers suitable to support offload at sea ice edge or Ross Ice Shelf edge, with traverse to McMurdo Station

NSF-owned or commercial lease of self-sufficient icebreaking resupply ship(s):

The further choice of vessels depends upon the site(s) chosen to offload fuel and cargo from ships, the degree of ice capability of the cargo and tanker vessels, and the choice of icebreaking mode. With regards to the last, the selection of icebreakers further lies between US Coast Guard, commercial lease, or NSF-owned vessels. These choices are further explored below.

E.2.b Offload sites

McMurdo Station is currently served by an ice wharf extending a small distance offshore in Winter Quarters Bay (see Fig. B.1.). Within the context of this report, the ice wharf is regarded as effective and sufficient.

If access to the McMurdo Station ice wharf were not feasible — for example, due to ice conditions too severe for the icebreaker(s) in service that season to reach the ice wharf, iceberg blockage of the immediate McMurdo Station area, or mechanical failure of the icebreakers - alternative sites and methodologies must be considered. If it were possible for the tanker to get within about five kilometers of the McMurdo Station tank farm, it is currently feasible to pump fuel from the vessel to the tank farm via hoses laid over the ice, an operation which takes approximately 17 days, all told (based upon actual experience during early 2003: 6 days set-up, 4.5 days pumping, and 6 days breakdown). Cargo can in theory be landed on sea ice and driven to McMurdo, and, at distances greater than five kilometers, fuel must also be carried via vehicles. Resupply operations over long stretches of sea ice carry somewhat increased environmental risk in the case of fuel (spillage). There are also significantly increased operational delays and hazards due to the variable stability and weather response of the sea ice. Although unloading fuel and supplies on sea ice is carried out as part of some nations' Antarctic resupply, the present large size of the McMurdo Station annual resupply significantly increases the risk above that faced by these smaller operations due to the time and repeated exposure involved. To make the point clear, the Subcommittee does not support USAP use of unloading cargo onto sea ice except under special circumstances which warrant the increased risk.

Some stretches of the Antarctic glacial ice shelf can be relatively stable offload points for shipborne fuel and cargo. Such sites are used by several other nations. In general, a site where the ice shelf surface is not much higher than approximately the same as the height of the ship's deck (about 2-7 meters) above the sea is required for cargo unloading, so that the ship's crane(s) can lift cargo to the top of the ice shelf. South Africa has used a high ice shelf with an access ramp carved into it for its station's annual resupply, but persons involved report occasional problems, such as vehicles and/or cargo sliding down the ramp, and it was informally reported to the Subcommittee that South Africa may abandon this approach. It should be noted that the 7-meter maximum ice shelf height does not directly apply to fuel offloads, which could reach the tops of significantly higher ice shelves via hoses and pumps. With this in mind the Subcommittee briefly reviewed information concerning ice shelf heights in the southwestern Ross Sea region, and nearby conditions at any sites with relatively low ice shelves. No suitable ice shelf sites for cargo offload/onload were found in the southwestern Ross Sea. There may, however, be sites suitable for fuel offload, in which case a system of intermediate storage and ground traverse to McMurdo would be required. The Subcommittee suggests that NSF investigate further whether there are suitable locations along the ice shelf in the vicinity of McMurdo Station that could be used for offloading if and when circumstances require.

As noted elsewhere in this report, a developed and proven capacity to offload fuel, cargo, and personnel from ships in remote locations could enable new "expeditionary" science initiatives, and the capability to support long traverses could be important to both South Pole resupply and to new science initiatives.

It was clear to the Subcommittee that in most future years, under most environmental and economic conditions, fuel and cargo offload at the McMurdo ice wharf would be the preferred and primary shipborne logistics choice, as it is today.

The Subcommittee determined that to mitigate risk, McMurdo Station annual resupply should not depend upon unloading of a large amount the cargo onto sea ice with subsequent traverse to McMurdo Station. Fuel delivery via up to several kilometers of hoses to the McMurdo Station tank farm, over sea ice, appears to carry somewhat lower net risk, and remains worthy of consideration as a back-up methodology in unusual circumstances.

The Subcommittee recommends that NSF carry out and/or direct further feasibility studies and develop cost/logistics models for alternative McMurdo Station fuel delivery from a tanker via ice shelf offload and traverse, noting especially the relationship of the traverse mode to other areas of USAP support, including South Pole logistics support and support for new remote, expeditionary science initiatives.

E.2.c Choice of cargo/tanker vessel types

A basic vessel-related choice to carry out the task of delivering fuel and cargo to McMurdo Station lies between (1) using one or more tanker/cargo vessels which are self-sufficient in southern Ross Sea summer ice conditions (i.e., are not only ice-strengthened but can also break and maneuver through southern Ross Sea ice, reaching the McMurdo Station ice wharf), (2) a hybrid of this concept using a somewhat smaller ice-strengthened tanker/cargo vessel which operates year-round (ca. monthly), using the channel frequently, and (3) something akin to the present-day mode (i.e., using vessels - one tanker and one cargo vessel which can maneuver through light and broken ice, escorted by one or two icebreakers which are responsible for most icebreaking and channel maintenance).

The RVIB *Nathaniel B. Palmer* has twice successfully navigated winter (May and July) ice in the Ross Sea, reaching the continental shelf. The cruise plan in both instances was to go into the ice as far as possible and then return, thus there was no imperative to reach the ice shelf edge. Ice conditions were thought to have been relatively light both times. The Subcommittee suspects from discussion that some winters would present conditions where this would have not been possible, and also that an icebreaker like the *Nathaniel B. Palmer* would have a hard time breaking all the way into McMurdo Station in the summer unless the conditions were very favorable. There is also the matter that the operating costs for fuel, crew and maintenance would be considerable to maintain a year-round shipborne resupply mission. Also, the contractor would require stationing sufficient personnel in McMurdo Station year-round, including winter, to handle the fuel and cargo operations.

Regarding tanker/cargo vessels which are self-sufficient in terms of icebreaking, the experience to date includes vessels used in the Arctic "Northern Sea Route", north of Russia, and in support of commercial operations in the Canadian Arctic. (There may be others; these were the two examples examined by the Subcommittee.) Subcommittee discussion included documents such as an informal report regarding M/V *Arctic* (http://www.ri.net/tni2001/main10.29.01.htm), a concept report for a commercial cargo vessel for use in the Russian Arctic (http://www.arcop.fi/workshops/ws6day1_matyushenko.pdf), and an article by Lawson Brigham discussing the Northern Sea Route and some particulars regarding suitable vessels (http://www.fni.no/insrop/execsum.htm). Although noting that future developments in this area may be worth watching, the Subcommittee is not aware of any independently-operating icebreaking tanker and/or cargo vessels with icebreaking capability heavy enough to enable solo operations in the McMurdo Station region, including even if the resupply operations were moved somewhat later in the season. This is based in part upon published reports of both fairly heavy hull damage experienced by some of the existing vessels of this type used in the Arctic and also published reports referring to their need to be escorted by heavy icebreakers from time to time. One might conceivably construct an icebreaking cargo and/or tanker vessel appropriate for fully independent support of the McMurdo Station annual resupply. But the Subcommittee questioned whether its design and operational profile would be sufficiently versatile to enable it to effectively work in other regions at reasonable cost (such other work would be a major factor in helping to defray the cost of its construction). Also, it is thought that such a vessel would be very expensive to build.

The Subcommittee thus recommends that ship support for McMurdo station resupply be carried out using ice-capable vessels (one tanker and one cargo vessel at present, but the mix could change) supported and escorted by one or two icebreakers which are responsible for icebreaking and channel maintenance.

E.2.d Icebreaking mode

Three principal modes of icebreaking were examined by the Subcommittee: (1) the recent mode of using up to two very heavy icebreakers to break into McMurdo Station under "any" (historical) sea ice conditions and to maintain the channel over the season; (2) using one or more medium-duty icebreakers nearly year-round to maintain a groomed channel to McMurdo Station; and (3) using one heavy icebreaker, possibly with back-up from a second, somewhat lower-duty icebreaker, to break into McMurdo Station in "most" (historical) sea ice conditions and maintain the channel over the season.

Very heavy icebreakers (the recent US Coast Guard-supported mode): According to US Coast Guard statements made during a recent OPP Advisory Committee meeting, the icebreaking specifications of the two present US Polar class icebreakers were designed to meet the needs of the annual McMurdo Station break-in under any historical ice conditions, as understood at the time of design and construction. Today, knowledge of the specific conditions faced by icebreakers in the McMurdo region draws on 46 years of successful US icebreaking experience there. These icebreaking demands are generally the heaviest of any nation's Antarctic program, and it may be that during some exceptional years, for example when the approach has been partially blocked by a large iceberg, or when hard, multi-year ice must be cut, the icebreaking demands are among the heaviest handled anywhere by non-nuclear icebreakers. The recent discussions between the US Coast Guard and the community regarding improving the status of their Polar class icebreakers are aimed primarily at maintaining this mode of operation, either by a very extensive refit (Service Life Extension Program, or SLEP) of one or both Polar class icebreakers, construction of one or two replacement icebreakers of similar intended icebreaking capacity, or some combination of this nature. The Subcommittee carefully considered this mode of McMurdo Station resupply icebreaking, considering it as the "Polar class icebreaker approach". Further elaboration on the Polar class icebreakers is found elsewhere in this report.

Maintaining a groomed channel: An alternative icebreaking approach discussed by the Subcommittee was to use medium-duty icebreakers (undefined specifications at this time) to maintain a year-round channel to the McMurdo Station ice wharf. The concept is that new ice in the channel would not be allowed to mature and thicken, and so icebreakers meeting the redefined icebreaking need might be much less expensive to build and operate than very heavy icebreakers would be. At least two such icebreakers would probably be required, to permit refueling, personnel exchanges, and maintenance. This approach is used successfully on some commercial shipping routes elsewhere. It would permit nearly year-round vessel access to McMurdo Station, which could have some exciting science ramifications, and access by a larger number of vessels. The Subcommittee concluded, however, that year-round vessel access to McMurdo Station did not appear as a likely driver of the sort of new science initiatives envisioned in long-term science planning documents. Perhaps more to the immediate point, the extreme winter weather which routinely occurs in the McMurdo region could make icebreaker operation impossible over a period of time which could result in the channel breaking apart (and/or the ice thickening) to the point where the channel could not be re-created by the medium-duty icebreakers. The channel could well need to be re-made due to iceberg movements (as has occurred in recent years) or become impossible due to iceberg blockage, and that the demand to have vessels reach McMurdo Station was likely to remain much too low in numbers to justify the effort of maintaining a year-round channel. Hence this option is not elaborated further in the report.

Icebreaker capable of opening the supply channel, to succeed in almost all years: The Subcommittee was intrigued by an icebreaking approach which differs in at least one crucial aspect from the "Polar class icebreaker approach", namely, to use icebreaking capacity sufficient to assure break-in to the McMurdo Station ice wharf in almost all years, relying on reserves and on alternatives identified by the Subcommittee to carry the day in an occasional missed year. There are attractive facets to this approach. Considering that the Subcommittee determined it is wise to the point of mandatory that the USAP have in place alternatives to the present approach (which has a single-point-of-failure), then why not use those alternatives from time to time? An icebreaker which can meet the need almost all the time (for example, perhaps, a FESCO-*Krasin*-like icebreaker), is going to be significantly less expensive to build and operate than a more powerful, more exotic icebreaker, and because it will not be subjected to the extreme demands of the rare very-heavy-ice year, it will be less likely than a Polar class type icebreaker to suffer casualties requiring extraordinary (and unplanned and expensive) maintenance. It may be feasible to use the services of a single such icebreaker, if it is proven to be reliable under typical McMurdo region icebreaking service, though it may also be possible to have available or on-call the services of a reserve icebreaker, for example USCGC *Healy* or equivalent, for tasks such as channel maintenance should the heavy icebreaking use the principal icebreaker nearly 100% of its available time. Such an icebreaker might be chartered from the present world fleet, it might be constructed to specification and operated by the US Coast Guard, or it might be constructed to specification and chartered or owned by NSF. Further elaboration on this approach - the most attractive to the Subcommittee - is found elsewhere in this report.

E.2.e US Coast Guard polar-region icebreakers

The US Coast Guard currently operates three icebreakers which work in the polar regions: the two Polar class icebreakers, USCGC *Polar Star* and USCGC *Polar Sea*, commissioned in 1976 and 1978, respectively, and the science icebreaker UCSGC *Healy*, commissioned in 2000.

The two US Polar class icebreakers are large (399 feet/121 meters; 13,500 tons/12,270 tonnes), with very strong, specially shaped hulls made from a special grade of steel. It is understood that the hulls remain in excellent condition after nearly three decades of icebreaking. The Polar class icebreakers are heavily powered: their three main electric drive motors are rated at a sum of 13,400 kW (18,000 hp), and three gas turbines can be substituted individually for electric motors, yielding up to 55,950 kW (75,000 hp). (The Subcommittee learned through informal discussion that some engineers, citing power-to-mass optimization, consider the Polar class icebreakers overpowered when under full turbine power. In their view, the turbine engines were a Cold War substitution in an original-design all-diesel-electric drive, carried out to ensure the US operated the most powerful conventionally-powered icebreaker in the world.) When the turbine engines are used their fuel consumption is prodigious. Power is applied to the water through three variable-pitch props.

Serious problems have arisen throughout much of the Polar class icebreakers' drive trains, including (it is understood) maintenance of the main diesels, and maintainability and sustainability of the turbines, main electric drive motors, and the variable pitch prop hubs. Moderate to serious maintenance casualties have become the rule rather than the exception during most recent icebreaking missions. The present maintenance lay-up of USCGC *Polar Sea* arises partly from serious problems with the main electric drive motors, and it is thought from anecdotal information that USCGC *Polar Star's* drive motors may be only a little more than one year's service from the same fate.

Use of variable pitch props in heavy polar icebreaking, at the drive power of the Polar class vessels, would appear attractive on paper: this allows the massive drive shafts to continue to rotate in one direction while varying prop thrust fore and aft, a potentially valuable contribution to the backing and ramming which is essential to heavy icebreaking. But problems with one or more aspects of the variable pitch prop system have been ongoing. In simple terms, the problems may result from the fact that the hubs which vary the pitch must also handle extraordinary stress, for example when the props mill ice (a common occurrence during heavy icebreaking). Today, one or more of the hubs must often be extensively rebuilt after an icebreaking mission, a time-consuming, expensive, and, ultimately wearing operation. Informal discussion with US Coast Guard personnel included the observation that the present hubs may have endured nearly their maximum number of re-builds.

US Coast Guard briefings to the OPP Advisory Committee (e.g. http://www.nsf.gov/od/opp/opp_advisory/briefings/may05/may9/coast_guard_icebreakers.ppt), to the UNOLS Arctic Icebreaker Coordinating Committee, and to other groups have firmly established that for many reasons including and additional to those cited here, the two US Polar class icebreakers are near the end of their 30-year design service life. Nearing end of design service life is not by itself a statement that a vessel is in jeopardy of failing to carry out its missions. For example, as is widely reported, nearly every vessel in the US Coast Guard blue water fleet is today already long past its service life, with Coast Guard ships typically much older than US Navy ships. Yet for the most part the Coast Guard has been able to persevere, carrying out the primary missions of its blue-water ships, doing more, longer, with less as it were. Questions which may occur to some persons include: Why cannot the Polar class icebreakers be operated similarly; where does the near-crisis nature of the Polar class icebreakers' readiness arise; and why are they at imminent risk of no longer being able to carry out their missions? The answers arise from the nature of their mission: heavy icebreaking is extraordinarily difficult work, and concomitantly hard on the icebreaker. If the icebreaker's capabilities are weakened, for example by one or more of its three drive trains being out of service, it is much more likely that the vessel cannot do the tough icebreaking portions of its mission. Extensive documentation and presentations from the US Coast Guard unambiguously establish the present fragility of the Polar class icebreakers: Extensive maintenance is required so that they can carry out a rapidly dwindling number of future missions. The US Coast Guard Polar class icebreakers are no longer sustainable without a major investment of effort and funds.

The Coast Guard has defined the various options and needs to provide the services of the Polar class icebreakers to heavy icebreaking, such as the McMurdo Station annual break-in. In the immediate term this involves "band-aid" maintenance programs in the tens of millions of dollars, required to place USCGC *Polar Sea* back into service and keep the USCGC *Polar Star* in service. Furthermore, because these short term maintenance programs cannot address the fundamental underlying problems, it is widely accepted that, barring massive refit, if and when the two Polar class icebreakers are next used for heavy icebreaking, they will continue to suffer maintenance casualties, including those sufficiently serious that the vessels may not complete a mission.

Hence the Coast Guard has investigated, in some detail, a "Service Life Extension Program" (SLEP) for the two Polar class icebreakers. The SLEP options and costs are addressed only in rough terms in this report, but ample details are available in reference documents. A SLEP for these vessels is intended to provide a reliable, maintainable, sustainable power train, in addition to addressing many other issues attending to the age and wear of the icebreakers. (One can imagine an "ice cream scoop" approach, during which most systems of the ships except for the hulls are replaced.) SLEP costs per icebreaker are in the low hundreds of millions of dollars. It was not clear to the Subcommittee which SLEP option, if any, would be most likely to receive approval, and, importantly, whether a SLEP program, once initiated, would be fully funded and fully seen through. In any event, at least some components and systems of a Polar class icebreaker would still be 30 years old after a SLEP refit. Would these provide another 30 years of service, and remain effective and trouble free?

The Subcommittee questioned whether, even if a Polar class icebreaker's power train were fully and successfully replaced during SLEP, the resulting vessel would be ideal for the annual McMurdo break-in. For example, as noted previously in this report, the annual 25,000,000-kilogram fuel delivery to McMurdo Station is both fully utilized each year and also represents the capacity of the tanker used for the mission. Thus the annual USAP energy expenditure is currently at its maximum without a step-function increase in cost. All else staying the same, the energy needs of new remote-area USAP science initiatives must be met by energy savings elsewhere. The Subcommittee notes that the Polar class icebreakers require substantial refueling at McMurdo Station to maintain a high mass so as to increase their icebreaking efficiency (it is the Subcommittee's understanding that they cannot routinely take on seawater ballast to compensate for weight lost to fuel use). (Weight and its distribution is an important factor in icebreaking.) Refueling icebreakers has accounted for as much as 20% of the fuel delivered to McMurdo Station. Much of that fuel could be made available for other USAP purposes, such as increasing stored fuel (to help mitigate effects of a future missed fuel delivery) or supporting new science initiatives in remote regions of the Continent, if the icebreaker(s) used to support McMurdo Station did not require substantial refueling while in the Antarctic.

The Subcommittee's discussion of the Polar class icebreakers' role in supporting the USAP has been a dispassionate analysis, and the Subcommittee shares the community's admiration of and respect for the dedication, enthusiasm, skills, and many successes of the personnel of the US Coast Guard icebreaker program, including their support for the annual McMurdo Station resupply. But the Subcommittee notes, in addition to the previous discussion, that these personnel, and their operation of the three heavy icebreakers (USCGC *Polar Star*, USCGC *Polar Sea*, and USCGC *Healy*), presently require a base budget of $48,000,000 annually, plus very substantial additional funds for maintenance needed to restore the ships to operational capability. With the primary mission of the two Polar class icebreakers now reduced to support for McMurdo Station resupply, their mechanical health problematic at best, and the cost for short term lease of the Russian icebreaker used in the 2004-2005 austral summer under $5,000,000, the Subcommittee found it essential to thoroughly examine the status and options of icebreaker support for the annual break-in. [It must be noted, however, that part of the $48,000,000 annual Coast Guard icebreaker base budget, and a fraction of the maintenance funds, is involved in supporting USCGC *Healy*, which is typically involved in supporting Arctic marine science, and hence at this time decoupled operationally and fiscally from the USAP.]

E.2.f USCGC Healy in relation to the USAP

USCGC *Healy* is the largest icebreaker in the US fleet (420 feet/128 meters; 16,000 tons/14,550 tonnes), and at 22,400 kW (30,000 hp) (from twin AC drive engines) the most powerful under diesel-electric power. The ship was designed and constructed as a science icebreaker, with Arctic research support in mind. *Healy* has an icebreaking bow fitted to a somewhat conventional hull shape, unlike the rounded hulls of the two Polar class icebreakers. This, or perhaps other factors such as maneuverability, appear to play a role in *Healy's* somewhat lower all-around icebreaking capabilities (though good) than those of the two Polar class icebreakers. For example, when the *Healy* assisted the *Polar Sea* in the 2002-2003 McMurdo Station break-in, US Coast Guard personnel reported informally that the *Healy* could not turn as effectively as required in the tight quarters near McMurdo Station (e.g., see the "Deep-Freeze '30" entries at http://www.uscg.mil/pacarea/healy/). Whether or not additional experience with USCGC *Healy* in the annual McMurdo break-in would produce more favorable results, there is also the matter that the vessel was constructed as a science icebreaker, is heavily used in support of top-priority US Arctic marine science, and in every way seems to be headed towards a distinguished career in that regard.

The Subcommittee notes there are means to lessen the impact upon NSF Arctic marine science were there a future redeployment of the *Healy* to the Antarctic. These focus on the changing operational mode, or "op tempo", of the vessel, and are discussed in more detail elsewhere in this report. We repeat here from that discussion that, were the *Healy* operated in a mode more nearly like that of PFS *Polarstern*, which spends only about one month each year in Germany, it might be possible to both increase its total Arctic science days and also provide the vessel for Antarctic support during years when a primary heavy icebreaker (as discussed elsewhere in this report) would especially benefit from back-up and channel grooming support.

E.2.g Military icebreaker support versus civilian icebreaker support

Organizations have unique needs, methods and procedures which are expressed in their operations, including staffing for those operations. Classic military staffing of a vessel (e.g. US Navy) provides personnel to operate and (to some extent) maintain the vessel, personnel being trained to operate the vessel, personnel to train and test trainees, personnel who focus on high-level emergency and wartime matters, plus sufficient extra personnel to accommodate casualties without loss of primary function of the vessel. US Coast Guard staffing of the polar icebreakers follows much of the military model, with the exception that there is no need for a wartime reserve plus other reductions as feasible within the organizational model. This has enabled a US Coast Guard complement of 141 on each of the two US Polar class icebreakers, as opposed to 262 Navy personnel which were assigned to the now-decommissioned USS *Glacier* (later USCGC *Glacier*), a capable but smaller (310 feet/95 meter; 8,650 ton/7,860 tonnes) icebreaker. In the case of USCGC *Healy*, a Coast Guard complement of 85 was made possible, within the non-war military operational model, by a combination of use of semi-automated systems and shifting maintenance to dockside periods. Coast Guard personnel are continually rotated, promoted, and reassigned as a matter of policy and routine practice. It is thus common at the start of an icebreaking mission to find a significant proportion of the complement, including officers as high ranking sometimes as the Captain, with no prior icebreaking experience. Within the context of both the McMurdo Station resupply and also recent US Coast Guard support for Arctic science missions, it must be made clear, however, that the officers and crews have generally succeeded with their missions.

Heavy icebreakers are national assets, dedicated foremost to support of their nation's icebreaking missions. But it is not required that the icebreakers be operated directly by the nation, for example through the military or civil service. Many large conventionally powered icebreakers world-wide are operated by non-military officers and crew, for example various large Russian icebreakers including FESCO *Krasin*, Icebreaker *Oden* (Sweden), MS *Fennica* and MS *Nordica* (Finland), and PFS *Polarstern* (Germany). The United States operates RVIB *Nathaniel B. Palmer*, an icebreaking research ship, with a civilian crew, as is the case for the entire non-ice-strengthened US research fleet coordinated by the University National Oceanographic Laboratories System (UNOLS).

> PFS *Polarstern* (387 feet/118 meter; 17,300 tons/15,730 tonnes) and RVIB *Nathaniel B. Palmer* (308 feet/94 meter; 6,640 tons/6,040 tonnes) are well-known examples of icebreakers which are operated effectively and efficiently with commercial crews, which brings about an operational style which differs distinctly from that of a military organization. Their operational personnel complements (i.e., not including their science parties) are 44 (maximum) and 22 respectively. By any measure these are clean, well-maintained polar vessels which suffer very little "down" time. PFS *Polarstern* in particular is known for its intense operations tempo, annually supporting both Arctic and Antarctic marine science as well as Antarctic resupply, with dedicated dockside maintenance as low as 30 days per year.

Moreover, because both *Polarstern* and *Palmer* officers and crew are carefully selected and retained, their knowledge and experience are substantial assets to the success of their missions.

FESCO *Krasin* (442 feet/135 meter; 19,920 tons/18,190 tonnes) provides an example of a heavy escort icebreaker (no science support), run by a non-military complement (65 officers and crew). This is a heavy icebreaker optimized for icebreaking and vessel escort. The *Krasin* successfully supported the 2004-2005 break-in to McMurdo Station at a small fraction of the cost of the US Coast Guard icebreaker also used that season, plus its fuel draw from McMurdo Station was much smaller than that of the Polar class icebreaker. Regarding the ship's personnel complement, which is higher than in some other commercially-operated icebreakers, Al Sutherland (OPP Ship Operations Manager), in his report to NSF, stated "This [would be] a very high crew number for a U.S. ship and I can only attribute it to the fact that the resupply of [worn] equipment is not done on Russian ships. Almost everything is remanufactured aboard."

The Subcommittee discussed the unique nature of military staffing and operation of support services when applied to polar icebreaking. Community experts noted anecdotally that the efficacy of icebreaking can be attributed "half to the quality of the ship and half to the quality of the crew." The military operation model makes it certain that new personnel make up a significant fraction of the US Coast Guard icebreaker personnel at sea. Moreover, organizationally there are no means for the Coast Guard to shift to a mode of operations which promotes career-length retention of experienced, successful personnel, and which minimizes icebreaker group and on-vessel staffing to operational optimums more like those in the UNOLS and commercial arenas, despite promise of extremely valuable payoffs. For these and other reasons the number and proficiency of military staffing will always appear unattractive from the standpoint of economical support to the USAP.

The Subcommittee agrees that NSF should pursue economics- and performance-based arguments for its icebreaking/resupply needs. If ongoing US national polar icebreaker policy discussions result in recommendations to retain the Coast Guard's polar icebreakers (it is regarded as very likely that the *Healy* will be retained in service, for example), there are advantages to achieving efficiencies in operation for these icebreakers such as those common to most other large icebreakers. Benchmarking of polar icebreaking and ship-based science support could assist in establishing best business practices. The Subcommittee notes that the UNOLS office may have non-icebreaker benchmarks in hand. Regarding icebreakers which support science, perhaps the operators of Icebreaker *Oden*, PFS *Polarstern*, and the RVIB *Nathaniel B. Palmer* could provide benchmarks. Benchmarks from the operators of large commercial escort icebreakers should also prove useful, if they can be obtained.

It is clear to the Subcommittee that a non-military model of operation for polar icebreakers can potentially provide substantial benefits in terms of economy of operation and retention of experienced personnel as compared to a military model. (Much the same may also apply to some aircraft operations in the Antarctic.) Considering that the National Science Foundation has been directed to explore economies in its vessel support for the USAP, the Subcommittee recommends further investigation of this option for present and future US

polar icebreaking support. Use of the *Healy* for more than the current sea days per year seems to be an obvious place for improvement.

E.2.h Long-term issues and recommendations

Heavy icebreakers are expensive to build and operate, the stresses of their missions occasionally take a toll in mechanical casualties requiring substantial maintenance funds and down-time beyond the routine, and most nations' heavy icebreaker missions, however essential, take place during relatively brief times of the year. [Exceptions might be Canada and Russia, both of which provide nearly year-round icebreaker support in various waters in their EEZs as warranted by seasonal ice conditions and mission.] There is very little, if any, spare icebreaker capacity in the Antarctic during the primary resupply operations window.

In general, longer annual operating windows help to lower daily costs to individual users and missions by spreading fixed costs over a greater period of time and greater number of users. Bi-polar operation can provide additional annual operating days for an icebreaker, but this must be balanced by the costs of long, unproductive transits, the need for the additional cooling systems required for operations in warm environments, and the sometimes heavy off-season maintenance needs of the vessels. Perhaps this helps to explain why relatively few icebreakers are today routinely used in both the Antarctic and Arctic.

There is also the matter of the mission which underlies the design of a given icebreaker. An icebreaker designed primarily to lead (escort) one or more non-icebreaking vessels through pack ice may have quite different characteristics from one designed to back-and-ram through pressure ridges, each in turn perhaps differing from ones designed primarily for research support and for resupply. In some cases icebreakers have been successful with more than one primary mission profile.

> The Swedish icebreaker *Oden* was designed with a huge bow uniquely constructed to slice Baltic ice, push it under adjacent ice, and leave a relatively clear channel for escorted vessels. *Oden* has immense fuel capacity, a unique capability to carry containers, and superb maneuverability, so has been successfully used in its summer "off" season to support Arctic research. By all accounts, however, *Oden* rides open seas poorly, so is not an ideal candidate for long transits.
>
> The German polar research and supply vessel *Polarstern* was designed to annually resupply the German Antarctic program, plus to carry out polar marine research in both the Arctic and Antarctic. An icebreaking bow is fitted to a fairly conventional hull, providing sufficient icebreaking capacity for its Antarctic missions, though the vessel must be escorted in central Arctic operations. The hull form, active "wings", and anti-roll systems provide good characteristics for long transits and for open-water oceanographic work.

The Subcommittee was directed to study the USAP resupply needs - and not asked to specifically address polar marine science support - but there is overlap. Long-term science planning documents and reports from science user groups make it clear that the marine scientific community strongly desires future missions in both polar regions requiring heavy icebreaker support and substantial on-board research facilities. The Subcommittee thus acknowledges temptation to recommend a multi-purpose heavy icebreaker built to address support both for Antarctic resupply and also for polar marine research. And it may be that an examination of US national icebreaking needs will reach such a conclusion. [It is well known to the Subcommittee that soon after this report is due, the National Research Council's Committee on the Assessment of the U.S. Coast Guard Polar Icebreakers Roles and Future Needs will begin its work.] But the Subcommittee notes that design for marine science and design for heavy icebreaking and escort do not necessarily overlap in vessel characteristics. Certainly laboratory and accommodation support for a substantial on-board science complement (and the additional vessel complement to deal with them) would add to vessel size, and with icebreakers, greater size tends to scale upwards more rapidly than with blue water vessels. Greater size increases operating costs, of course. More to the point, perhaps, is that changes made to better support marine science operations may work against icebreaking capability, for example via changes in hull shape. PFS *Polarstern*, though an excellent science platform, is not a heavy icebreaker. USCGC *Healy* is a big, powerful icebreaker, with fine science support, but has proven to be somewhat less effective than the Polar class icebreakers in terms of heaviest icebreaking and maneuverability. The Swedish icebreaker *Oden* appears to have few compromises to its icebreaking and maneuverability, but most science is supported with container vans, and the ship has poor seakeeping and on-station capability in open water.

The Subcommittee recognizes that national interests and priorities, beyond those of the USAP, may play a role in icebreaker selection and operation, and in possible construction of a new heavy icebreaker. The Subcommittee emphasizes, however, that if the US were to seek or construct a new heavy icebreaker destined to be the primary icebreaking and escort vessel for the annual break-in to McMurdo Station, the icebreaker specifications should be focused squarely upon that mission. For example, breaking into McMurdo Station for a specified number of days, arriving no later than a specified date, and under ice conditions typical of 9 out of 10 years, rather than thinking in terms of an icebreaker which can break a specified ice thickness at a specified rate. Icebreaker engineers and specialists can determine the primary icebreaker and escort specifications. The Subcommittee notes that high priority should also be given to vessel reliability, ability to carry out Antarctic missions without refueling within the Antarctic, and overall economy of operation. Support for seakeeping and habitability on long transits, including through the tropics, are also highly desirable. The Subcommittee recommends that other factors, such as onboard support for polar marine science, be considered later as feasible.

Considering the present favor provided to commercial operation of national support needs in both the military and non-military governmental sectors, the Subcommittee notes that a reasonable scenario for providing a new US icebreaker to support McMurdo Station annual resupply might be something on the order of a commercial construction to NSF specification, with NSF chartering the icebreaker for its needs, and the vessel owners being free to market their services at the times NSF does not require use of the vessel. The Subcommittee suggests that USAP tasking may represent approximately one-third of the full-time use of an icebreaker and that this might be considered by a potential commercial supplier as sufficient "guaranteed baseline" in making a business case. The Subcommittee expressed optimism that if the US makes clear its interest in long-term icebreaking support aimed at the annual McMurdo Station resupply mission, a number of commercial companies would respond. It should not be difficult for a charter operation to staff an icebreaker. For example many retired US Coast Guard icebreaker group personnel have the type of experience required.

The Subcommittee recommends that in addressing funding of new icebreaker(s), purchase through NSF's Major Research Equipment (MRE) program should probably not be considered, because the cost would likely have a very large impact on all NSF program areas. Leasing appears to be a cost effective option.

One of the options the Subcommittee discussed involved utilizing one or more foreign ships, whether re-flagged or not. NSF has used a Russian icebreaker when the US Coast Guard could not provide the two icebreakers judged necessary to meet McMurdo region ice conditions expected during that year. A careful analysis of costs, benefits and downsides would be needed to set the stage for serious consideration of use of foreign ships as a long-term option. Also, consideration of using the private sector for icebreaking brought up (a) the legal requirements for a US flagged and/or US staffed ship, and (b) the ability of NSF to compete for icebreaking assets given budding international oil and gas exploration in Arctic waters.

The Subcommittee has determined that the long-term ship-based resupply option which best meets USAP objectives is to provide a heavy icebreaker to annually break and maintain a channel to the McMurdo ice wharf and escort tankers and cargo vessels in the channel. Construction and operation of that icebreaker via the private sector would be significantly more efficient and cost effective than military operation, and would offer further advantages of availability to other icebreaker users, bi-polar operation, and optional use in science support at other times of the year. The Subcommittee recommends that in its design and construction, and projected operating costs, the icebreaking and escort capabilities of that icebreaker take priority over its direct use as a science platform. Such an icebreaker could, however, provide escort services to icebreaking and/or ice-strengthened research vessels. The Subcommittee further recommends that the icebreaking capability of that icebreaker be matched to historical McMurdo region ice conditions and the specifics of the McMurdo break-in mission, with a goal of mission success at least 9 out of every 10 years. Resupply in "missed" years would depend on reserves, alternate resupply methodologies, and other flexibility and contingency measures discussed in this report.

E.2.i. Short- to medium-term issues

At some point US national polar icebreaking policy will be reviewed, ongoing or subsequent Congressional actions may resolve US icebreaker actions and funding, and such actions (e.g., a Polar class SLEP program, construction and/or charter of a new icebreaker, etc.) may be completed. But overall these will take time - at least one year for policy recommendations, decision, and actions, and at least several years to complete vessel refurbishments or replacements. During this interval, which has already begun, US polar icebreaking capabilities will remain at their most fragile.

The Subcommittee was informed that NSF has been tasked to maintain a National icebreaking capability until policymakers determine what degree of capability is needed for the future. This is interpreted to include repairing damage to USCGC *Polar Star* from its 2004-2005 Antarctic service, so that the vessel is ready to go to sea, if needed, during the 2005-2006 austral summer; returning USCGC *Polar Sea* to an operable state, with timing dictated partly by budget realities; and continuing operation and maintenance of USCGC *Healy*.

The Subcommittee finds USCGC *Healy* is fully occupied with the Arctic scientific research for which the vessel was designed, plus recent experience in southwestern Ross Sea with the *Healy* suggests that the vessel is not suitable as a lead icebreaker for the present mode of USAP resupply.

The Subcommittee discussed the short-term status of the two Polar class icebreakers, considering the directives to NSF, today's very tight budgets, the many unknowns regarding cost and timing of the major repairs to USCGC *Polar Sea*, and fears that USCGC *Polar Star* is likely to suffer further maintenance casualties when next used in heavy icebreaking, not to mention what is widely felt to be imminent decertification of one or more of the *Polar Star's* main drive motors (due to the same type of problems which resulted in *Polar Sea's* main motors being decertified).

The Subcommittee concluded that the most economical and nearly certain means to include the two Polar class icebreakers with respect to NSF's tasking to "maintain a National icebreaking capability" would be to repair them, and then keep them in stand-by mode, meanwhile using other icebreakers for the annual break-in to McMurdo Station.

The Subcommittee's rationale is more or less along the lines of letting other icebreakers take some of the load while US national icebreaker policy is being reviewed, in order to assure that the US Coast Guard's heavy polar icebreaking capacity is ready when required. Examples of circumstances where a US polar icebreaker might be required during this interval include (1) failure to obtain a suitable contract with a commercial or other operator for a given USAP field season, (2) a return to southwestern Ross Sea ice conditions requiring support from a back-up icebreaker for a commercial or other icebreaker, or (3) a mechanical casualty suffered by a commercial or other icebreaker used to support the USAP.

The Subcommittee notes that NSF's stewardship of icebreaker operation and maintenance funds may make it possible in the short-to-medium term to explore polar icebreaker operation models that promote greater retention of expertise, longer field seasons, increased maintenance in the field, and other aspects of more efficient use. For example, the Coast Guard continues to maintain two complete full-time Polar class icebreaker crews, despite existing and potential future extended port-bound periods. Perhaps NSF and the Coast Guard can determine if the Polar class icebreaker officers and crew can provide some form of rotation for USCGC *Healy* personnel. This would not only provide sea time and icebreaking experience for the officers and crews of the Polar class icebreakers, but might also be used to increase USCGC *Healy*'s annual total days at sea in the near term. NSF and the Coast Guard might also examine the possibility of replacing some of the Coast Guard complement at the base and at sea with appropriately-qualified contractors. This would reduce the massive annual loss of expertise and concomitant annual training load. The large pool of retired (or otherwise separated) US Coast Guard icebreaker group personnel may be thought of as a cadre of experienced icebreaker support personnel, some of whom may wish to participate as contractors.

It must be made completely clear, however, that for the Polar class icebreakers, efficiency-promoting measures are at best a last stand - the vessels will clearly become unsupportable, and are alarmingly close to that point as this is being written. At nearly any moment during a mission, these vessels are on the cusp of becoming non-operable. For that reason, we suggest that for the short-to-medium term the Polar class icebreakers be tasked as the back-up, rather than primary, icebreaker.

E.3 Aircraft

E.3.a. Aircraft types and mix

Today's aircraft types supporting the USAP mission in Antarctica consist of a combination of military (heavy fixed-wing) and commercial (small fixed-wing and rotary-wing) aircraft. Prior to mid-1990, nearly all logistics support to the U.S. Antarctic program was from the military. The US Navy (VXE-6) flew the ski-equipped LC-130 fixed-wing aircraft for both logistics (materials and fuel) and science support missions. In the latter 1990's they were augmented by the 109th New York Air National Guard (NYANG). They flew wheeled and ski-landing missions between New Zealand and McMurdo Station, as well as ski-landing operations between McMurdo Station and South Pole, and various field stations and field camps. In addition, the Navy flew UH-1N helicopters to support science missions in local and remote field camp areas. The US Air Force flew heavy-lift wheeled aircraft to support only materials logistics and mass personnel movement to/from New Zealand and McMurdo Station to hard surface runways (Annual Sea Ice Runway and Pegasus) with C-141's, C-5's and C-17's. They did not transport fuel, which has always been delivered to McMurdo by MSC chartered fuel tanker ships, then flown to South Pole by LC-130's. In mid 1990 the Navy decided to withdraw from the Antarctic mission support role. The NSF opted to commercialize the rotary wing science support operations from VXE-6 in 1996, followed by the selection of the New York Air National Guard to assume the Navy's mission flying LC-130's in 1999. The commercialization of the helicopters (rotary wing), flying a mix of Bell 212's and Aerospatiale A-Stars, was a resounding success in supplying safe, reliable, consistent and economical flight operations to the science community. Additionally, the costs associated with the commercialization of the helicopter support were reduced by 50% without a reduction in capability and flight hours, and the support personnel required at McMurdo Station reduced by 77%, thus making a noteworthy decrease in the impact on the Station's infrastructure, as well.

E.3.b. Commercialization of LC-130 operations

A commercial model for operating the LC-130's may be desirable and more cost effective because a commercial operation does not have the military training mission and non-mission essential overhead of a military organization that comes with the total cost to the program. As the world economy becomes more globally integrated, methodologies of support to government and corporate programs become more intertwined. Witness the extensive use of civilian contractors in war zones, providing all manner of goods and services. Additionally, since the end of the Cold War it has become more acceptable to utilize other government or other nation's corporate entities to provide support as required. Last year, for example, NSF chartered a Russian icebreaker after one of the US Coast Guard icebreaker had a material failure. Since the inception of the US Antarctic Program NSF has utilized the military for air support, until the commercialization of the helicopter operations noted above. Military support service brings a significant overhead not necessarily benefiting the NSF directly. For example, the 109th NYANG is contracted for 249 military personnel, many who never deploy to Antarctica, at a cost of $26M annually, to fly ten active-service LC-130 aircraft. (Four older model LC-130's are mothballed.) Since the 109th is principally a Ready Reserve squadron as part of the total US Air Force, the NYANG provides operationally-ready combat and combat support units and qualified personnel for active duty in the Air Force to fulfill Air Force war and contingency commitments. NYANG units are assigned to Air Force major commands during peacetime to accomplish this mission. In addition they have a role serving the Governor of New York in civil disasters and other State activities. The NSF must pay for all the support personnel including extensive training programs which a military organization must sustain to be combat ready. Moreover, the NSF contracts for a Chaplain, Command and Control functions from the USAF Transportation Command, Department of Defense Liaison Officers, a US Armed Forces Post Office, contract services for aircraft repairs and washes in New Zealand, and the costs of berthing, feeding and providing infrastructure support to approximately 100 personnel in McMurdo during the Austral Summer season. In total, the costs to obtain the 109th's support to fly ten active service LC-130 aircraft approaches $35M annually. In addition to these costs, the 109th flies two round-trip flights per week for 20 weeks from McMurdo to New Zealand to rotate nearly 500 flight crews and other support personnel. This consumes high cost fuel from the McMurdo storage tanks, as well as per diem and hotel costs in New Zealand to the tune of more than $3M.

E.3.c. Airlift support

In the past 35 years, until early 2005, the USAF flew the C-141, C-5 and C-17 heavy-lift aircraft to support the USAP. In early 2005, the last C-141 was flown to McMurdo, and this aircraft will be retired from Antarctic operations. As well, the C-5 has become outdated and has been replaced by the C-17. As mentioned above, the NSF contracts for commercial helicopter support of science, and also contracts a commercial company to fly ski-equipped Twin Otters for deep field remote camp science support.

The Past (to the end of the 2004/05 field season):

<u>Military</u>
C-141 – Retired from Antarctic service early 2005
C-5 – No longer flying to Antarctica due to nearing end of service life
C-17 – Replaces C-141 and C-5 for heavy-lift logistics
UH-1N – Last mission flown in 1996. Replaced by commercial charter.

LC-130 – Workhorse for Intercontinental and Intracontinental logistics operations and science support
C-130 – Available, but not used in the past 4 years due to poor economics

Commercial – all direct science support
Bell 212 helicopter
Aerospatiale A-Star helicopter
Twin Otters, ski-equipped

The Present (start 2005/06 season forward):

Military
C-17 – Heavy lift logistics. 18 pallets (68,200 kg) cargo to Antarctica
LC-130 – Logistics and science support. 11,800 kg of cargo or fuel (3700 gal) from McMurdo to South Pole + deep field camps

Commercial – all direct science support
Bell 212
Aerospatiale A-Stars
Twin Otter, ski-equipped

A Potential Future:

Military heavy-lift
C-17 – 18 pallets (68,200 kg) cargo to Antarctica
KC-10 – 40-45,000 gal fuel or 27 pallets (136,300 kg) cargo to Antarctica
KC-135 – 19,000 gal fuel, or 34,100 kg of cargo to Antarctica
LC-130 – Logistics and increased science support, including expeditionary
LTA – “future future” once developed – potential for 450,000 – 1,000,000 kg of cargo/fuel

Commercial close Support - science
Twin Otter – or suitable replacement
CASA 212
Bell 212 – or next generation replacement
Aerospatiale A-Stars – or next generation replacement

Commercial heavy-lift
Boeing type heavy-lift cargo, fuel and passenger aircraft
Antonov type heavy-lift cargo, fuel and passenger aircraft
LTA/HULA - future future once developed – heavy-lift cargo and fuel

E.4 Ground vehicles

Initial exploration of Antarctica was done entirely via ship-landed parties who then set out on the surface to probe the Continent’s coastal and inland regions. In pioneering the first mechanized traverse to South Pole in 1957, Sir Edmund Hillary traveled with light-weight agricultural tractors, towing only his essential gear including just enough fuel to reach South Pole. Light aircraft based out of Scott Base were used to resupply the traverse along the way, within the range of the single engine airplane.

Ironically, a thriving station already existed at South Pole when Hillary arrived, established by the US entirely by aircraft support (airdrop and heavy ski-equipped aircraft).

The early days of the USAP extensively utilized traversing. Heavy tractors and sledges were used for inland logistics purposes and light tracked vehicles were the foundation of numerous scientific explorations. With the advent of large ski-equipped aircraft starting in 1956 and culminating in the introduction of the LC-130 in 1961, traversing disappeared as a means of moving materials anything more than short distances within the USAP.

In the mid to late 1990's the USAP began reviving traverse technology. A "light" science traverse (ITASE) has been active in various seasons and earnest development of a "heavy" South Pole resupply traverse has now nearly completed its proof of concept. Several other Antarctic Nations have remained active in traversing from their inception. Some (e.g., Great Britain, South Africa, Germany) use this mechanism to move resupply materials from their cargo ship between 10 and 100 km inland to their stations. Others (e.g., France, Russia) traverse many hundreds of kilometers inland to construct and/or resupply stations.

A wide range of traverse vehicles is in use in Antarctica. Virtually all over-snow traverse vehicles are tracked, since wheeled vehicles suffer from higher ground pressures (greater sinkage) and smaller contact areas (less traction production). Further, the most efficient are designed to maximize their towing power, rather than to attempt to carry a load on their back. In general, these prime movers can be divided into light (e.g., Kassbohrer Pisten Bully's, Haaglunds vehicles, Tucker SnoCat's) and heavy categories. Heavy hauling traverse vehicles can further be divided into the slower and heavier (greater towing capability) steel-tracked tractors (e.g., Caterpillar D8) and the faster and slightly lighter rubber-tracked tractors (e.g., AGCO Challenger MT series, Case STX series).

Towed units currently in use in Antarctica are less varied and can be divided into tracked trailers and sledges (heavy ski-equipped trailers). The French Antarctic Program has experimented with a number of designs of both types, and combination track-ski units. Terrain conditions, including snow strength and roughness, and slopes, dictate which type of towed unit can move the greatest mass with the least towing resistance.

In other parts of the world, off-road movement of heavy loads over low strength terrain is also done utilizing air cushion technology. Both hover-barges and hovercraft are used. The former suspends its payload on an air cushion (leading to very low towing resistance per unit of mass moved) and uses conventional prime movers to tow the load (e.g., tractors, helicopters). Hovercraft suspend their load on an air cushion as well, but use onboard aircraft-style propulsion (propeller and rudder). As such, they are more complex and consume more fuel per unit of payload moved than a hover-barge towed by a tractor.

USAP resupply volumes and masses are large enough to dictate that heavy prime movers will be required for any of the resupply scenarios involving traversing that are considered in this report.

Determination of the best type of prime mover, and the towed payload-carrying units will be driven by the duration, distance, surface type and features, and the time of year in which traversing will be required. For example, moving resupply cargo from a ship moored at the Ross Ice Shelf edge slightly to the east of Cape Crozier to McMurdo could be done with a few steel-tracked tractors over the course of a month or more. This limits capital outlay and operating costs, but requires that either (a) the ship remained at the ice edge for an extended period of time or (b) cargo from the ship be cached at the ice shelf edge. More tractors, faster tractors, lower towing resistance trailers, all change this equation, as does the round trip distance between the two points being connected by traverse.

F. APPLICATION OF THE STRATEGIC FRAMEWORK TO THE ANALYSIS

The Subcommittee recommends that NSF apply a strategic framework to its ongoing and developing analysis of resupply issues and alternatives. The Subcommittee carried out an example version, presented below, to suggest a useful approach. It must be stressed, however, that NSF's subsequent examination of the issues and alternatives may result in revised - perhaps even heavily revised - outcomes than those reached by the Subcommittee in this example. Specifically to readers: Please do not place undue emphasis on the placement of a particular alternative in a specific quadrant of these example figures.

F.1 Issues and Alternatives

The principal Antarctic resupply issues were derived from a systematic examination of the drivers and their implications to the success of the USAP. Figures F.1a and F.1b are examples of the framework for summarizing the issues identified by the Subcommittee, who used a wealth of reports and separate data obtained through the Office of Polar Programs and other open sources, as well as in-depth discussions.

	Site Centric	Expeditionary
Multiple Nodes	• Need to develop alternative logistics hub to McMurdo • Ice-free port would be desirable • Need alternative hub for South Pole resupply • Blue-ice runway near South Pole	• Alternative means to support East & West Antarctic science initiatives • Alternative to supply South Pole • Blue-ice runway(s) for expeditionary science
Single Node	• McMurdo is single entry point for supplies & single supplier of South Pole • Icebreaking is essential for ships • South Pole requires ski-equipped aircraft • Fuel storage provides no buffer	• McMurdo can not support West Antarctica • South Pole can not support expeditionary science initiatives

Figure F.1a Example of parsing **nodes** of USAP resupply logistics into site centric and expeditionary categories.

	Site Centric	Expeditionary
Multiple Modes	• Traverse capability to South Pole • Alternative to ships for bulk supplies to McMurdo • Direct support to South Pole from New Zealand • Support to South Pole by larger aircraft	• Traverse for expeditionary science support • Direct support to expeditionary science initiatives
Single Mode	• Ability to send larger aircraft to South Pole • Less fuel demand for icebreaking • Streamlined logistics at McMurdo • Reduced fuel demand from McMurdo	• Greater aircraft range to support expeditionary science sites

Figure F.1b Example of parsing **modes** of USAP resupply logistics into site centric and expeditionary categories.

The issues became the stimulus for development of alternative approaches to providing resupply capabilities. The alternatives considered are a spectrum of approaches from changes in fundamental mode and node configurations (e.g., directly supporting South Pole Station using Lighter-Than-Air craft rather than ships to McMurdo Station and aircraft to South Pole Station) to less dramatic consideration of the philosophy or concept of operation for using an existing mode/node configuration (e.g., changing approach to icebreaking to reduce costs, or changing aircraft crew cycling requirements to reduce sorties). It was of interest to consider a broad range of alternatives and then to evaluate which individual alternatives and which combinations had the most promise for achieving the major objectives of the resupply effort as documented above. Figures F.2a and F.2b provide examples of the Subcommittee's work to summarize the types of alternatives identified during its deliberations.

	Short Term	Long Term
McMurdo Station	Reduced fuel requirement Ice edge modal transfer Local traverse capability	Resize of facilities and support staffing based on mission essential task analysis
South Pole Station	Wheel landing capability Blue-ice runway (Howe) Traverse capability	Direct KC-10/C-17 fuel, cargo, & personnel to South Pole LTA service to South Pole Mt Howe blue-ice runway Marble Point hard runway
New Zealand & Other	Move administrative function to New Zealand Just-in-time logistics vs. station stockpiling East & West Antarctic camp support	Direct support to South Pole via heavy aircraft or LTA Marble Point logistics portal Marble Point hard runway Ice-free logistics portal

Figure F.2a. Example summary of **nodal** alternatives for Antarctic resupply.

	Short Term	Long Term
Ships	Means of acquiring ice breaking Reduce refueling at McMurdo Polar class/*Healy* as backup to contract ice breakers "*Polarstern*" schedule ethic	Reducing need for icebreaking Offload on ice shelf for research
Air	Wheel landing at South Pole ANG crew rotation reduction Larger aircraft to South Pole	Direct KC-10/C-17 fuel, cargo, & personnel to South Pole Mt Howe blue-ice runway & traverse LTA service to McMurdo & South Pole Marble Point hard runway Commercialize fixed wing operations
Ground	Local traverse	South Pole traverse

Figure F.2b. Example summary of **modal** alternatives for Antarctic resupply.

F.2 Analysis of Alternatives

Alternatives were evaluated by using a two stage process. First, as depicted in Figure F.3, alternatives were examined with regard to their fundamental level of technical feasibility and the level of potential impact they might have on the USAP. The alternatives that made it through this screening were subjected to a more detailed evaluation with respect to their conformance with the overall objectives of the resupply study. This is depicted in Figure F.4.

<table>
<tr><td colspan="2"></td><th colspan="2">Technical Feasibility</th></tr>
<tr><td colspan="2"></td><th>Needs New Capabilities</th><th>Accomplished With Current Knowledge/Resources</th></tr>
<tr><th rowspan="2">Impact</th><th>Significantly Contributes to Meeting Logistics Objectives</th><td>• Blue-ice runway at Mt. Howe
• Lighter-Than-Air ships
• Wheeled runway at South Pole
• Direct South Pole air resupply from New Zealand
• Locate ice-free port</td><td>• Ground traverse to South Pole
• Contract icebreaker support
• Reduce McMurdo fuel demand
• Reduce number of McMurdo airfields.</td></tr>
<tr><th>Not a Major Factor in Contributing to Solution</th><td>• Open field landings
• Marble Point wheeled runway
• Ice shelf offload of supplies for McMurdo</td><td>• Rebuild Polar-class icebreakers
• Ice shelf offload for fuel and science support
• Move many functions to New Zealand
• Private sector model for air and icebreaker operations
• Deploy select science projects directly from New Zealand</td></tr>
</table>

Figure F.3. An evaluation scheme for screening primary alternatives with regard to relative technical feasibility and impact. This is an example only, showing how an analysis of this type would proceed.

Alternative	Efficiency	Agility	Assurance	Environment
Wheeled Runway at South Pole	+	?	+	+
Blue-Ice Runway	?	?	+	?
Directly Support South Pole	+	+	+	+
Fuel Unload Over Ice Shelf	-	?	?	-
Customized Icebreaker	+	?	+	?
Systems Approach to Icebreaking	+	+	?	?
Lighter-Than-Air	+	+	?	+
Ground Traverse	?	+	?	?
Lean McMurdo Operations	+	+	+	+
Move Support Off Continent	+	?	?	+
Commercial Air Model	+	+	?	?

Figure F.4. Evaluation scheme for primary alternatives with respect to Antarctic resupply objectives. [+, -, ? refer to positive benefit compared to present, negative benefit compared to present, and benefit about the same as at present, respectively.]

F.3 Summary

The results of this process are a short list of Antarctic resupply alternatives that are recommended by the Subcommittee to the USAP for further consideration and development. These emphasize a combination of initiatives that are highly feasible (potentially implemented in the near term) and some that will need more development and are therefore more likely for implementation over a longer time frame. More specific details are provided in the main text on their character and consequences with respect to the stated objectives. The framework for analysis illustrated above, applied with more in-depth evaluation of specific alternatives and approaches, is recommended to provide a more rigorous assessment of their individual and integrated suitability for the future USAP resupply mission.

APPENDIX 1. CHARGE TO THE SUBCOMMITTEE

OAC SUBCOMMITTEE ON U.S. ANTARCTIC PROGRAM RESUPPLY

Background (provided by OPP staff)

The annual resupply that enables much of the U.S. Antarctic Program's on-Continent research has depended in recent years on two Polar class icebreakers working together to open a shipping channel through the ice to McMurdo Station. From McMurdo supplies then are flown to South Pole Station and our various remote field stations.

The U.S. Coast Guard completed this icebreaking mission for many decades but only with increasing difficulty in recent years. Its two Polar class vessels are within a very few years of their estimated 30-year lifetime and are becoming increasingly difficult and costly to keep in service. In addition, Congressional appropriations to the Coast Guard had been inadequate to meet the maintenance needs of the ships. Thus, two years ago NSF had to divert the *Healy* from the Arctic to provide assistance to the only US Coast Guard Polar class vessel operational at that time. This year NSF had to charter a heavy icebreaker from the Russian Company FESCO to assist the USCGC *Polar Star* as USCGC *Polar Sea* was not in operable condition. The *Polar Sea* will not be back in service until at least 2007, and then only if adequate funds can be found for her repair. It is hoped that last season's damage to the *Polar Star* can be repaired in time for the 2005-2006 season and that a foreign icebreaker can be again chartered to assist her.

The Coast Guard has estimated that it would cost approximately $600 million to refit (SLEP) its two Polar class vessels to the extent that they could provide reliable continued service beyond the next few years. In the meantime the Coast Guard estimates that some $20-25 million will be needed annually for maintenance of the *Polar Star*, *Polar Sea* and *Healy* over and above the $48 million currently in the Coast Guard budget for operations and maintenance. Moreover, the President's budget for FY-06 proposes to transfer funding responsibility for the ships to NSF beginning in FY-06, along with $48 million from the Coast Guard. No matter which Agency ends up with the responsibility it will be extremely difficult to secure Congressional appropriations adequate to fund the deferred maintenance needs and then the $600 million SLEP. It's worth noting that the latter would be by far the largest single expenditure for equipment in NSF's history, and also that there is already a multi-year list of pending projects waiting in queue in the Agency's MREFC program.

Given the above state of affairs a thorough analysis of resupply options is essential both to assure continuity of operations of the U.S. Antarctic Program, and also to assure that the most cost effective and reliable option is implemented.

The Office of Polar Programs initiated a preliminary study of several options last fall. Examples of options identified then or over the ensuing months for study by OPP include:

- Unloading fuel and supplies on the ice shelf rather than at McMurdo Station and transporting them overland to the Station, in order to greatly reduce the icebreaking challenge;
- Continuously milling the channel through the austral winter months using relatively light and much less costly icebreakers;
- Moving the resupply base from McMurdo to a new Station;.
- Establishing one or more additional supply chains as a hedge against "bad-ice" years;
- Airlifting all supplies to McMurdo;
- Direct resupply of South Pole Station by air from New Zealand or elsewhere;
- Establishing a multi-year store of fuel and non-perishable supplies at McMurdo during years of light sea ice combined with some of the above;
- Either purchasing or contracting for a build-to-lease icebreaker tailored to the needs of the USAP;
- Partnering with another country, sharing access to USAP infrastructure in exchange for icebreaking support.

Several of these options have been analyzed in some detail by OPP staff; most have not, and there may well be additional promising options that should be considered.

Charge To The Subcommittee

The Advisory Committee to the NSF Office of Polar Programs is responding to this situation by forming a subcommittee to oversee and guide the analysis of options for the resupply of McMurdo and South Pole Stations.

As a steering committee the Subcommittee is tasked to:

- identify the full initial universe of options worth considering;
- assist the working group in focusing on the most promising options in a timely fashion
- monitor progress of the OPP working group analyzing the options; and
- prepare a short summary of the pros and cons of any options the Subcommittee deems worthy of serious further consideration by NSF.

In carrying out this work the Subcommittee should take into full consideration the potential impacts on the present and future scientific programs, both positive and negative, as well as the potential impacts on safety, environmental protection, reliability, cost, and timeliness.

An OPP staff member selected by the OPP Director and the Subcommittee Chair will serve as the OPP Point of Contact for the Steering Committee and will have full authority to task OPP staff and contractors for the purposes of this study.

The Steering Committee is asked to provide its report to the OPP Advisory Committee by June 30, 2005, for discussion and adoption by the Advisory Committee in July.

The membership of the Subcommittee is:

Dr James Swift, Chair
Dr. Ed Link, co-chair
Dr. Sridhar Anandakrishnan
Mr. Sam Feola
Dr. Berry Lyons
Dr. Olav Orheim

APPENDIX 2. LIST OF DOCUMENTS AVAILABLE TO THE SUBCOMMITTEE

Many documents were accessed by the Subcommittee in the course of this study. Most were unpublished notes and data reports. The following is a list of published materials used by the Subcommittee.

Aircraft and Runways

"USN, DARPA See Blimps & HULAs Rising" 2005 *Defense Industry Daily*, 26 April.

"Application of Fuel Cell Technology at South Pole Station." 2000. Brier, F. and J. Rand. In *Proc. Workshop on Increasing LC-130 Availability in the USAP*, Washington, DC, 14-15 June.

"Consideration of Renewable Energy Sources for South Pole Station." 2000. Rand, J. In *Proc. Workshop on Increasing LC-130 Availability in the USAP*, Washington, DC, 14-15 June.

"Analysis of Commercial Contractor Operations and Maintenance of NSF-Owned LC-130 Aircraft." 2000. Scheuermann, M. and D. Fisher. In *Proc. Workshop on Increasing LC-130 Availability in the USAP*, Washington, DC, 14-15 June.

"Annex B to: Airfield Construction Feasibility Study, Marble Point, Antarctica." 1958. Construction Battalion Reconnaissance Unit, Metcalf and Eddy Engineers. 15 May.

"U.S. Antarctic Research Program: Scientific Support Study: Marble Point Station" C. Arnold. 1972. Bechtel Inc. March.

"Long Range Development Plan, Volume III, Marble Point." 1979. Holmes & Narver, Inc. 25 April.

Icebreaker Information

"Adequacy of emergency capacity during winter." 2003. Ice Expert Working Group (Finnish contribution), Helinski Commission, Helinski, Finland, 16 June.

"Adequacy of emergency capacity during winter." 2003. Ice Expert Working Group (Swedish contribution), Helinski Commission, Helinski, Finland, 17 June.

Northern Sea Route

"Arctic Marine Transport Workshop." 2004. Institute of the North, U.S. Arctic Research Commission, and International Arctic Science Committee, 28-30 Sept.

"The Northern Sea Route: Its Development and Evolving State of Operations in the 1990s." 1996. Mulherin, N. CRREL Report 96-3, April.

"Development and Results of a Northern Sea Route Transit Model." 1996. Mulherin, N., D. Eppier, T. Proshutinsky, A. Proshutinsky, L. Farmer, and O. Smith.. CRREL Report 96-5, May.

Strategic Planning

"Grim Forecast for a Fading Fleet." Malakoff, D. 2005. *Science* (www.sciencemag.org),Vol. 307, 21 Jan.

"Shift in Icebreaking Fleet Could Crunch NSF Budget." Mervis, J. 2005. *Science* (www.sciencemag.org), Vol. 307, 4 March.

Traverse

"Science advantages of an oversnow traverse to resupply S. Pole." 2001. Prepared by the McMurdo Area Users Committee, 1 July.

USCG-related Documents

"USCGC *Polar Star* Deep Freeze 2002 Cruise Report." 2002. US Coast Guard, May.

"USCGC *Polar Sea* Cruise Report: Deep Freeze 2003." 2004. US Coast Guard, Jan.

APPENDIX 3. CURRICULUM VITAE FOR SUBCOMMITTEE MEMBERS

Dr. James Swift – Chairperson
Ed Link - Co-Chairperson
Dr. Sridhar Anandakrishnan
Sam Feola
Dr. W. Berry Lyons
Dr. Olav Orheim

JAMES H. SWIFT

a. Professional Preparation

Undergraduate Institution:	Case Western Reserve University	Physics	B.S	1970
Graduate Institution:	University of Washington	Physical Oceanography	M.S.	1975
	University of Washington	Physical Oceanography	Ph.D.	1980
Postdoctoral Institution:	UCSD/SIO	Physical Oceanography		1980-1981

b. Appointments

1998-present	Research Oceanographer	UCSD/Scripps Institution of Oceanography
1987-1998	Associate Research Oceanographer	UCSD/Scripps Institution of Oceanography
1986-present	Academic Administrator (ODF)	UCSD/Scripps Institution of Oceanography
1988-1990	Affiliate Associate Professor	School of Oceanography, Univ. of Washington
1985-1988	Research Associate Professor	School of Oceanography, Univ. of Washington
1981-1985	Assistant Research Oceanographer	UCSD/Scripps Institution of Oceanography
1980-1981	Postdoctoral Research Oceanographer	UCSD/Scripps Institution of Oceanography
1972-1979	Research/Teaching Assistant	School of Oceanography, Univ. of Washington

c. Publications

i. Five publications most closely related to the proposed project:

Swift, J.H., K. Aagaard, L. Timokhov and Ev.G. Nikiforov. "Long-Term Variability of Arctic Ocean Waters: Evidence From a Reanalysis of the EWG Data Set." *J. Geophys. Res.*, Submitted, 2004. [May be obtained from ftp://odf.ucsd.edu/pub/jswift/2004JC002312.pdf.]

Carmack, E.C., K. Aagaard, J.H. Swift, R.W. Macdonald, F.A. McLaughlin, E.P. Jones, R.G. Perkin, J.N. Smith, K.M. Ellis and L.R. Kilius. "Changes in Temperature and Tracer Distributions Within the Arctic Ocean: Results from the 1994 Arctic Ocean Section." *Deep-Sea Res.*, 44(8), 1487-1502, 1997.

Swift, J.H., E.P. Jones, K. Aagaard, E.C. Carmack, M. Hingston, R.W. Macdonald, F.A. McLaughlin, and R.G. Perkin. "Waters of the Makarov and Canada Basins." *Deep-Sea Res.*, 44(8), 1503-1529, 1997.

Jones, E.P., L.G. Anderson, and J.H. Swift. "Distribution of Atlantic and Pacific waters in the upper Arctic Ocean: Implications for circulation." *Geophys. Res. Let.*, 25(6), 765-768, 1998.

E.P. Jones, J.H. Swift, L.G. Anderson, G. Civitarese, K.K. Falkner, G. Kattner, M. Lipizer, F. McLaughlin, and J. Olafsson. "Tracing Pacific Water in the North Atlantic Ocean." *J. Geophys. Res.*, 108 (C4), 3116, 2003.

ii. Five other significant publications:

R. Dickson, J. Lazier, J. Meincke, P. Rhines, and J. Swift. "Long-Term Coordinated Changes in the Convective Activity of the North Atlantic." *Prog. Oceanog.*, 38(3), 241-295, 1996.

Aagaard, K., J.H. Swift and E.C. Carmack. "Thermohaline circulation in the Arctic Mediterranean Seas." *J. Geophys. Res.*, 90, 4833-4846, 1985.

L.G. Anderson, L.G., G. Bjork, O. Holby, E.P. Jones, G. Kattner, K.P. Koltermann, B. Lijeblad, B. Rudels, and J.H. Swift. "Water Masses and Circulation in the Eurasian Basin: Results from the Oden 91 North Pole Expedition." *J. Geophys. Res.*, 99, 3273-3283, 1994.

U. Schauer, B. Rudels, E. P. Jones, L. G. Anderson, R. D. Muench, G. Björk, J. H. Swift, V. Ivanov, A.-M. Larsson. 2002, "Confluence and redistribution of Atlantic water in the Nansen, Amundsen and Makarov basins." *Annales Geophysicae*, 20(2), 257-273, 2002.

L.G. Anderson, E. P. Jones, and J. H. Swift. "Export production in the Arctic Ocean evaluated from phosphate deficits." *J. Geophys. Res.*, 108(C6), 3199, 2003.

d. Synergistic Activities

i. With John Osborne developed Java OceanAtlas (JOA), an oceanographic section/profile data exploration application for Windows (9X/NT), MacOS (9 and X), and Unix/Linux. JOA imports common data types such as spreadsheets, WOCE, NODC SD2, and netCDF and provides common oceanographic plots, all linked, plus powerful data browsing, coloring, and filtering options. Tutorials and a User Guide are available. This free application is widely used in education and research.

ii. Developed the Atlas of Ocean Sections V.2, a free CD-ROM containing more than 2000 oceanographic sections assembled from Joe Reid's collection of high quality oceanographic data, assembled WOCE One-Time Survey sections, subsets and sections extracted from the Levitus WOA98, a collection of Arctic and Nordic Seas data, and the complete Java OceanAtlas application and documentation suite. See http://podaac.jpl.nasa.gov/order/order_displaytools.html.

iii. As Scientific Advisor to the UCSD/SIO Oceanographic Data Facility (ODF) have worked to bring about improvements in data reliability and quality control, improvements in rosette bottles, testing of improved CTD profiling methodologies, development and institution of improved equipment and methods for salinity, oxygen, and nutrient measurements and CTD pressure and temperature calibration, and improved efficiency and lowered costs for production and documentation of reference-quality measurements in seawater. All innovations have been made available to the community.

iv. As Director of the WOCE Hydrographic Program Office have led the effort to gather and assemble the WHP data (≈500 cruises) and documentation, repair the data files for deficiencies, improve adherence to standard format specifications (including creating two new file formats, WHP-Exchange and WOCE netCDF, which greatly simplify user import of WHP data, make the data widely and freely available, and provide all data and documentation to the WOCE Archive.

v. As Chair of the UNOLS Arctic Icebreaker Coordinating Committee, 1996-2000, provided scientific oversight of Arctic marine science support on US vessels, with primary focus on USCGC Polar Star, USCGC Polar Sea, and the new USCGC Healy. The AICC provides Arctic marine science projects with planning and scheduling assistance, facilitates communications between scientists, science funders and facility providers, and provides oversight and advice to the Coast Guard for the purpose of enhancing facilities and science aboard their icebreaker fleet. Also served *ex officio* on the UNOLS Council.

e. Collaborators & Other Affiliations

i. Collaborators on projects, books, articles, reports, abstracts or papers within last 48 months

Knut Aagaard, Leif Anderson, John Bullister, Lou Codispoti, Scott Doney, Bill Emery, Kelly Falkner, Dick Feely, Rana Fine, Eric Firing, Chas Flagg, Niki Gruber, John Gunn, Greg Johnson, Peter Jones, Terry Joyce, Bob Key, Bob Knox, Rob Macdonald, Fiona McLaughlin, Robin Muench, Andreas Muenchow, Jon Olafsson, Alex Orsi, Laurie Padman, Bob Pickart, Paul Robbins, Ursula Schauer, Peter Schlosser, Bill Smethie, Dean Stockwell, Lynne Talley, Leonid Timokhov, Martin Visbeck, Rik Wanninkhof, Terry Whitledge, and Rebecca Woodgate.

ii. Graduate and Post Doctoral Advisors

Graduate Advisor:	Knut Aagaard
Postdoctoral Advisor:	Joseph L. Reid

iii. Thesis Advisor and Postgraduate-Scholar Sponsor

Ilse M. Hamann	(Ph.D., 1990; University of Washington)
Michael Alfultis	(M.S., 1987; University of Washington)
Diana Lewis	(M.S., 1996; UCSD Scripps Institution of Oceanography)

LEWIS E. LINK, PH.D.

Dr. Lewis E. (Ed) Link is a Senior Fellow on the faculty of the R. H. Smith School of Business and the Burns Academy of Leadership, School of Public Policy, University of Maryland. He is also a Senior Consultant to Toffler Associates where he has been engaged in futures studies involving technology, infrastructure and innovation in government and industry. As a senior executive, he served as the Director of Research and Development and Principal Scientific Advisor to the Chief of Engineers, and Commander, U.S. Army Corps of Engineers, from 1996 to 2002. During this period he led a diverse R&D program exceeding $550M annually, and created and served as the Acting Director of the U.S. Army Engineer R&D Center. He previously served as the Technical Director and Director, U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH, from 1986 to 1996. Dr. Link has a broad knowledge of environmental and infrastructure technologies and has pioneered innovative approaches to Army sustainment and logistics, exploitation of environmental dynamics and transformation of military practices to meet constantly changing future needs.

After receiving a BS degree with High Honors in Geological Engineering from North Carolina State University in 1968, Dr. Link earned an MS Degree in Civil Engineering from Mississippi State University in 1973 and a Ph.D. in Civil Engineering from Pennsylvania State University in 1976. He served as an Adjunct Professor of the Graduate School, Mississippi State University and graduated from the Federal Executive Institute in 1985. While at N.C. State he was selected to the National Collegiate All-American Soccer Team, the Tau Beta Pi National Engineering Honor Association and the Phi Kappa Phi National Honor Society.

Dr. Link has served as the chair or member of technical and advisory committees for the American Society of Photogrammetry and Remote Sensing, the American Institute of Hydrology, the American Society of Civil Engineers, the Transportation Research Board, the American Society of Mechanical Engineers, the Society of American Military Engineers, the U. S. Navy, the National Aeronautics and Space Administration, the International Permafrost Association, and the NATO Special Group of Experts on Camouflage, Concealment and Deception. He was a member of the U. S. Antarctic Program External Panel for the National Science Foundation. Dr. Link chaired the Department of Defense Joint Engineers Management Panel and led a number of major studies to create more effective collaboration in engineering and environmental R&D among the military services and across government and industry. He was a member of the senior executive panels overseeing all Army research and development and modeling and simulation activities. He has published more than 80 technical papers and reports.

During his tenure with the Corps of Engineers, Dr. Link received the Department of Army's highest award for research and development achievement in 1982 and 1985. He received the Department of Army Meritorious Civilian Service Award in 1981, 1990 and 1996 and its highest award, the Exceptional Civilian Service Award in 2002. He was honored by the President of the United States as a Meritorious Executive in the Senior Executive Service in 1990 and 1995 and a Distinguished Executive in 1992 and 1999. The Society of American Military Engineers awarded him the Wheeler Medal in 2001. The Army Engineer Association awarded him the

DeFleury Medal, Silver Order, in May 2002, for exceptional contributions to the Army Engineer Regiment.

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Professional Preparation:

Electrical Engineering. Columbia University. Graduated Tau Beta Pi (Engg. Honor Soc.) and Eta Kappa Nu (EE Honor Soc.) 1982 B. S.

Electrical Engineering. Columbia University, 1983 M. S. Geophysics. University of Wisconsin—Madison (1990). Thesis title: *Microearthquakes as indicators of ice stream basal conditions.* 1990 Ph. D.

Appointments:

2002-to present	Associate Professor, Pennsylvania State University
1999-2002	Assistant Professor, University of Alabama
1992-1999	Research Associate, Pennsylvania State University
1991-1992	Senior Researcher, Mobil Oil

Research Funding

Anandakrishnan, S., D. A. Wiens, A. Nyblade. NSF–OPP 02–265338 and 99–14567. A Broadband Seismic Investigation of Deep Continental Structure across the EastWest Antarctic boundary. 8/1/00–7/31/04 ($250,000).

Anandakrishnan, S., D. D. Blankenship, and R. B. Alley. NSF–OPP 02–26535 and 98–14774. Characterizing the Onset of ice stream flow: a Ground Geophysical Field Program. 04/01/00–03/31/04. ($370,000).

Anandakrishnan, S. NSF–OPP 98–14797. Archiving of West Antarctic Geophysical Data. 03/01/99–02/28/00. $81,000.

Anandakrishnan, S. and R. B. Alley. NSF–OPP 97–25708. Forward and Inverse Modeling of West Antarctic ice streams. 04/01/98 – 03/31/00. ($220,000).

Anandakrishnan, S. NSF–OPP 02–96200 and 96–15147. Antarctic Network of Unattended Broadband Seismometers (ANUBIS). 04/01/97 – 03/31/02. ($495,000).

Anandakrishnan, S. NSF–OPP 96–12536. Antalith Seismic Reflection Program at Central West Antarctica Camp (CWA). 06/01/96–05/31/97. ($32,000)

Anandakrishnan, S. NSF–OPP 96–33601. Workshop on Aerogeophysical Research in Antarctica. 06/01/96– 05/31/97. ($15,000)

Anandakrishnan, S. NSF–OPP 93–18121. Microearthquake Monitoring of Ice Stream C. 04/01/94–03/31/97. ($330,000)

Dalziel, I. W. D., P. A. Stoffa, D. D. Blankenship, and **S. Anandakrishnan**. NSF–OPP 92–22121. Seismic Traverse of the Byrd Subglacial Basin—Field Test. 04/01/94–03/31/96. ($200,000)

Peer-reviewed publications:

S. Anandakrishnan. Dilatant till layer near the onset of streaming flow of ice stream C, determined by AVO (Amplitude vs. Offset) analysis. *Ann. Glaciol.*, in press.

D. E. Voigt, R. B. Alley, **S. Anandakrishnan**, and M. K. Spencer. Ice core insights into the flow and shutdown of ice stream C. *Ann. Glaciol.*, in press.

B. R. Parizek, R. B. Alley, **S. Anandakrishnan**, and H. Conway. Subcatchment melt and long-term stability of ice stream D, West Antarctica. *Geophys. Res. Lett.*, 29(8):doi:10.1029/2001GL014239, 2002.

R. B. Alley, E. J. Brook, and **S. Anandakrishnan**. A northern lead in the orbital band: North-south phasing of IceAge events. *Quat. Sci. Rev.*, 21:431–441, 2002.

R. B. Alley, **S. Anandakrishnan**, and P. Jung. Stochastic resonance in the North Atlantic. *Paleooceanography*, 16(2):190–198, 2001a.

R. B. Alley, **S. Anandakrishnan**, P. Jung, and A. Clough. Stochastic resonance in the North Atlantic: Further insights. In D. Seidov, B. J. Haupt, and M. Maslin, editors, *The Oceans and Rapid Climate Change: Past, Present and Future*, Geophysical Monograph 126, pages 57–68. AGU, 2001b.

S. Anandakrishnan, R. B. Alley, R. W. Jacobel, and H. Conway. The flow regime of ice stream C and hypotheses concerning its recent stagnation. In R. B. Alley and R. A. Bindschadler, editors, *The West Antarctic Ice Sheet: Behavior and Environment*, Antarctic Research Series, pages 283–296. AGU, 2001.

R. A. Bindschadler, J. L. Bamber, and **S. Anandakrishnan**. Onset of streaming flow in the Siple Coast region, West Antarctica. In R. B. Alley and R. A. Bindschadler editors, *The West Antarctic Ice Sheet: Behavior and Environment*, Antarctic Research Series, pages 123–136. AGU, 2001.

S. Anandakrishnan, D. E. Voigt, P. Burkett, Bruce Long, and R. C. Henry. Deployment of a broadband seismic network in West Antarctica. *Geophys. Res. Lett.*, 27(14):2053–2056, 2000.

S. Anandakrishnan. Penguins everywhere: GNU/Linux in Antarctica. *IEEE Software*, 16(6):90–98, 1999.

S. Anandakrishnan, D. D. Blankenship, R. B. Alley, and P. L. Stoffa. Influence of subglacial geology on the position of a West Antarctica ice stream from seismic measurements. *Nature*, 394:62–65, 1998.

V. Sen, P. L. Stoffa, I. W. D. Dalziel, D. D. Blankenship, A. M. **Smith, and S. Anandakrishnan**. Seismic surveys in central West Antarctica: Data and processing examples from the ANTALITH field tests (1994– 1995). *Terra Antarctica*, 5(4):761–772, 1998.

S. Anandakrishnan and R. B. Alley. Stagnation of ice stream C, West Antarctica by water piracy. *Geophys. Res. Lett.*, 24(3):265–268, 1997a.

S. Anandakrishnan and R. B. Alley. Tidal forcing of basal seismicity of ice stream C, West Antarctica, observed far inland. *J. Geophys. Res.*, 102(B7):15183–15196, 1997b.

S. Anandakrishnan, S. R. Taylor, and B. W. Stump. Quantification and characterization of regional seismic signals from cast blasting in mines: A linear elastic model. *Geophys. J. Int.*, 131:45–60, 1997.

A. J. Gow, D. A. Meese, R. B. Alley, J. J. Fitzpatrick, **S. Anandakrishnan**, G. A. Woods, and B. C. Elder. Physical and structural properties of the GISP2 ice cores. *J. Geophys. Res.*, 102(C12):26559–26576, 1997.

R. B. Alley and **S. Anandakrishnan**. Variations in meltlayer frequency in the GISP2 ice core: implications for Holocene summer temperatures in central Greenland. *Ann. Glaciol.*, 40(135):341–349, 1995.

R. B. Alley, R. C. Finkel, K. Nishiizumi, **S. Anandakrishnan**, C. A. Shuman, G. Mershon, G. A. Zielinski, and P. A. Mayewski. Changes in continental and seasalt atmospheric loadings in central Greenland during the most recent deglaciation: modelbased estimates. *J. Glaciol.*, 41(139):503–514, 1995.

S. Anandakrishnan, V. Sen, A. M. Smith, P. A. Stoffa, Ian W. D. Dalziel, and D. D. Blankenship. A multifold high resolution seismic profile in central West Antarctica. In *The Antarctic Region: Geological Evolution and Processes*, Siena, Italy, 10–15 September 1995. Universita di Siena.

W. R. Kapsner, R. B. Alley, C. A. Shuman, and **S. Anandakrishnan**. Dominant control of atmospheric circulation on snow accumulation in central Greenland. *Nature*, 373:52–54, 1995.

C. A. Shuman, R. B. Alley, **S. Anandakrishnan**, James W. C. White, P. M. Grootes, and C. R. Stearns. Temperature and accumulation at the Greenland Summit: Comparison of high-resolution isotope profiles and satellite passive microwave brightness temperature trends. *J. Geophys. Res.*, 100(D5):9165–9177, May 1995a.

C. A. Shuman, R. B. Alley, **S. Anandakrishnan**, and C. R. Stearns. An empirical technique for estimating nearsurface air temperatures in central Greenland from SSM/I brightness temperatures. *Remote Sensing of the Environment*, 51:245–252, 1995b.

R. B. Alley, **S. Anandakrishnan**, C. R. Bentley, and N. Lord. A waterpiracy hypothesis for the stagnation of ice stream C, Antarctica. *Ann. Glaciol.*, 20:187–194, 1994.

S. Anandakrishnan and R. B. Alley. Ice stream C, Antarctica, stickyspots detected by microearthquake monitoring. *Ann. Glaciol.*, 20:183–186, 1994a.

S. Anandakrishnan, J. J. Fitzpatrick, R. B. Alley, A. J. Gow, and D. A. Meese. Shearwave detection of asymmetric *c*axis fabrics in the GISP2 ice core. *J. Glaciol.*, 40(136):491–496, 1994.

K. M. Cuffey, R. B. Alley, P. M. Grootes, J. F. Bolzan, and **S. Anandakrishnan**. Calibration of the δ^{18}o isotopic paleothermometer for central Greenland, using borehole temperatures: Results and sensitivity. *J. Glaciol.*, 40(135):341–349, 1994.

S. Anandakrishnan, R. B. Alley, and E. D. Waddington. Sensitivity of icedivide position in Greenland to climate change. *Geophys. Res. Lett.*, 21(6):441–444, 1993.

S. Anandakrishnan and C. R. Bentley. Microearthquakes beneath ice streams B & C, West Antarctica: Observations and implication. *J. Glaciol.*, 39:455–462, 1993.

C. A. Shuman, R. B. Alley, and **S. Anandakrishnan**. Characterization of a hoardevelopment episode using SSM/I brightness temperatures in the vicinity of the GISP2 site, Greenland. *Ann. Glaciol.*, 17:183–188, 1993.

K. M. Cuffey, R. B. Alley, P. M. Grootes, and **S. Anandakrishnan**. Toward using borehole temperatures to calibrate an isotopic paleothermometer in central Greenland. *Global and Planetary Change*, 98:265–268, 1992.

S. Anandakrishnan. *Microearthquakes as Indicators of Ice Stream Basal Conditions*. PhD thesis, University of Wisconsin—Madison, 1990.

S. Anandakrishnan, D. D. Blankenship, R. B. Alley, and C. R. Bentley. Densitydepth profile determined by seismicrefraction studies: Ice stream B, West Antarctica. *Ann. Glaciol.*, 11:198, 1988a.

S. Anandakrishnan, D. D. Blankenship, and C. R. Bentley. Microearthquake source locations and mechanisms: Ice stream B, West Antarctica. *Ann. Glaciol.*, 11:198, 1988b.

C. R. Bentley, S. Shabtaie, D. D. Blankenship, S. T. Rooney, D. G. Schultz, **S. Anandakrishnan**, and R. B. Alley. Remote sensing of the Ross ice streams and the adjacent Ross Ice Shelf. *Ann. Glaciol.*, 9:20–29, 1987.

D. D. Blankenship, **S. Anandakrishnan**, J. Kempf, and C. R. Bentley. Microearthquakes under and alongside ice stream B, detected by a new passive seismic array. *Ann. Glaciol.*, 9:30–34, 1987.

Other Publications

C. A. Finn, **S. Anandakrishnan**, J. Goodge, J. Panter, C. Siddoway, and T. Wilson, Remote views and exploration of the Antarctic lithosphere, Eos, in press.

Science and Implementation plan for the Amundsen Sea Embayment Project. Multiple authors, but main authors are R. Bindschadler, **S. Anandakrishnan**, and D. D. Blankenship. http://www.igloo.gsfc.gov/wais/ASEPfinal.pdf

S. Anandakrishnan. Oversnow traverse capability for longterm Antarctic research support, report to NSF panel on Antarctic logistics.

S. Anandakrishnan, S. R. Taylor, and B. W. Stump. Quantification and characterization of regional seismic signals from cast blasting in mines: A linear elastic model. Technical Report LAUR–96–3747, Los Alamos National Laboratory, Los Alamos, NM 87545, 1996.

Synergistic Activities:

(a) Remote/Autonomous seismic instrumentation development (Anubis and Tamseis seismic projects); Autonomous instruments workshop; Advisor to the Dartmouth Autonomous Geophysical Observatory.

(b) Scholarly service: reviews of NSF, NERC, and Italian Antarctic Program proposals; reviews of journal mss.; council member of IGS.

(c) Community service:Chair NSF OPP Office Advis. Cmte; Cmte of Visitors; McMurdo Area Users' Cmte. Education: Taught graduate classes in Seismology, Glaciology; undergrad classes in Intro Geology.

(d) Outreach: talks to local schools, community groups; numerous contacts with press; White House OSTP.

Collaborators:

R. B. Alley (PSU), R. Bindschadler (NASA), D. D. Blankenship (UT Austin), H. Conway (U. Washington), C. Holland (PSU), R. Jacobel (St. Olaf's), I Joughin (NASA), E. C. King (BAS), M. A. King (NCL), C. J. Marone (PSU), D. L. Morse (UT Austin), A. Nyblade (PSU), B. Parizek (PSU), A. M. Smith (BAS), D.A. Wiens (Washington U. St. Louis).

Advisors:

M. C. Teich (Columbia Univ), C. R. Bentley(UW Madison)

Students:

M. S.: Seung Yoo, 1998, Peter Burkett, 2000, Paul Winberry, 2003, Leo Peters, expected 2004, Satyakee Sen, 2004, Ph. D.: Jerry Bowling, expected 2004, T.J. Cho, expected 2005

Postdoc advisee:

A Huerta.

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SENIOR OPERATIONS PROFESSIONAL

Results-driven professional executive with significant commercial and military experience on domestic and international projects, including:

Project Management	Profitable turnarounds
Global Logistics	Change Management
Global Operations	Multi-tasking
Marketing and Business Development	International Company and Project Startups

Employment History

SDF Solutions, LLC 2005-Present
Principal and Consultant
Consultant to PAE Government Services, Inc., and SNC-Lavalin ProFac as Subject Matter Expert for corporate bids and proposals.

snc-lavalin pae inc.
A PAE Government Services Inc and SNC-Lavalin ProFac joint-venture 2003-2005
General Manager
General Manager of an American-Canadian joint venture Company to support Canadian Forces deployed overseas. Responsible for executive management of the start-up and sustainment operations of construction and base-maintenance projects in Bosnia and Afghanistan, and project management in Canada.

- Took one employee and zero revenue to 850 employees and $260MM revenue in two years.
- Awarded unprecedented 100% Performance Incentive Fee on a validation exercise resulting in $500MM awards of the Bosnia and Afghanistan contracts.
- Hired to manage transition and operation of incumbent contract; ended up successfully starting up the JV company and 2 separate projects simultaneously, totaling $130MM and 850 employees in a 3-month time span while building a supporting infrastructure.
- Managed the successful construction of a $65MM 2500-man Camp Julien, Afghanistan, from a “green field” to award-winning NATO/ISAF military support camp, on-time and under budget.
- Accomplished transition from hostile incumbent contractor in Bosnia, achieving 96% award fee.
- Given 7.5% profit margin target by Board of Directors– achieved 9.5%.
- Repaid a $25MM loan, reducing interest costs from 10% to 3% through a factoring facility.

- Achieved greater health benefits plan for Expats, at less cost, increasing employee retention.
- Managed war zone turnover to 17%, saving the client $1.2MM in hiring and deployment costs.
- Improved the performance evaluation process and results by 40%, from process-based to service-based output, to more realistically reward efforts through the performance incentive fee.
- Contributed volunteer labor and corporate materials and funding to support local community activities in Bosnia, Afghanistan, and charity events in Canada.

DISH Network Service Corporation (Echostar) 2001-2003
Manager, Business Systems and Operations Reporting
Responsible for developing and managing a nation-wide support provider operations team to manage digital satellite TV hardware fulfillment reimbursement; credit program analysis and administration; operations support; and database tools and trending to monitor and report performance metrics and forecast future activity.

- Developed first ever executive management reports and trending analyzes of subcontractors' jobs, inventory accounts, credit limits, and labor and commissions payments, using Oracle databases.
- Successfully transitioned, with zero defaults, 24 subcontractors performing satellite TV systems installations from 1-year promissory notes to net 30-day terms, paying off $7MM in booked accruals.
- Managed $11MM in weekly credit of 24 subcontractors with fast turn-around reimbursements, increasing installations capacity by 30%.
- Developed and managed hardware replenishment inventory program and audit team to track payments and charge backs, resulting in a 40% increase in reimbursement cash-flow.
- Improved efficiency performance of weakest 20% of subcontractors through faster cash flow and credit management of inventory, increasing bottom line customer base by 18%.
- Served as the advocate between subcontractors and corporate executives and corporate business processes, resulting in better business practices, relationships and goodwill.

Holmes & Narver Services, Inc. 1978-2000
An international service company specializing in operations and maintenance (O&M), logistics support services, engineering, and construction.

Director, Logistics, Denver, CO On Loan 1990-2000 to Antarctic Support Associates Joint Venture
Directed contractor planning, management and operations of logistic and operational support requirements for the National Science Foundation's U.S. Antarctic Program.

- Led 280 civilian full-time, contract, and military personnel in the planning and execution of Antarctic logistics operations in support of 11 internal customer divisions; 4 external customers - a total client base of more than 3,700 customers annually.
- Consolidated and managed passenger, air and ship cargo, logistics, and supply operations for U.S., South America, New Zealand; McMurdo, South Pole and Palmer stations, and two research vessels, saving the U.S. Government more than $30MM annually.
- Project manager for four military functional transitions, adding $90M to the contract baseline.
- Received the company's highest award-fee scores in the 25-year history of the contract.
- Recovered $650K in General Sales Taxes from New Zealand Revenue Department.
- Developed and managed annual $28MM Division budget successfully under budget.
- Started up and operated a separate limited liability company formed in New Zealand to support the U.S. Antarctic Program activities in New Zealand. Replaced a military command of 360 personnel with 75 contractors providing New Zealand operations, facilities, and terminal operations for contractor, scientists and military personnel transiting NZ for Antarctica. Resulting outsourced operations saved the U.S. Government over $10 million annually.

Holmes & Narver Services, Inc. **Other Positions**

1978 to 1989

Proposal Manager, Orange, CA
Regional Project Manager, Istanbul, Turkey
Traffic Manager, Izmir, Turkey
Special Operations Manager, Honolulu, Hawaii
Port Hueneme Operations Manager, U.S. Antarctic Research Program

Military Service 1967-1978

Officer and Aviator, U.S. Navy, Honorable Discharge

Education

- Bachelor of Science, Business Administration
  West Virginia Wesleyan College

- Masters equivalent in Aviation (Designated Naval Aviator)
  Naval Aviation Schools Command

W. B. LYONS
Byrd Polar Research Center and Dept of Geological Sciences
The Ohio State University, Columbus Ohio

Professional Preparation

Brown University	Geology	A.B., 1969
University of Connecticut	Chemical Oceanography	M.S., 1972
University of Connecticut	Chemical Oceanography	Ph.D., 1979

Professional Appointments

1999-present	Director, Byrd Polar Research Center, and Professor, Geo. Sci., Ohio State University
1993-1999	Professor, Department of Geology, University of Alabama
1990-1993	Professor & Director of Hydrologic Sciences Program, University of Nevada, Reno
1986-1990	Associate Professor, Department of Earth Sciences, University of New Hampshire
1980-1986	Assistant Professor, Department of Earth Sciences, University of New Hampshire
1976-1980	Post-doctoral Fellow and Research Scientist, University of New Hampshire

Relevant Publications

Lyons, W.B., and K.A. Welch. 1997, Lithium in waters of the Polar Desert. *Geochim. Cosmochim. Acta* **61**: 4309-4319.

Lyons, W.B., K.A. Welch, A. Fountain, G. Dana, B.Vaughn and D.M. McKnight. 2003. Surface glaciochemistry of Taylor Valley, Southern Victoria Land, Antarctica and its relationship to stream chemistry. *Hydrological Processes* **17**: 115-130.

Lyons, W.B., K.A. Welch, K. Neumann, D. Moorhead and D.M. McKnight. 1998., Geochemical linkages among glaciers, streams and lakes within the Taylor Valley, Antarctic. *In: Ecosystem Dynamics in a Polar Desert: The McMurdo Dry Valleys* (ed. J. Priscu), *Antarctica Research Series*, AGU, 77-92.

Lyons, W.B., K.A. Welch and P. Sharma. 1998. Chlorine-36 in the waters of the McMurdo Dry Valley lakes, Southern Victoria Land, Antarctica: Revisited. *Geochim. Cosmochim. Acta*

62: 185-192. Welch, K.A., W.B. **Lyons**, D.M. McKnight, M. Gooseff, C. Jaros, A. Fountain, T. Nylen and

P.T. Doran. 2003. Climate and hydrologic variations and implications for lake and stream ecological response in the McMurdo Dry Valleys, Antarctica. In Greenland, D., D.G. Goodin and R.C. Smith (eds.), *Climate Variability and Ecosystem Response at Long Term Ecological Research Sites,* Oxford University Press, 174-195.

Synergistic Activities

- Associate Editor of three journals: Ground Water, Applied Geochemistry, Chemical Geology
- Member, National Academy of Science Polar Research Board, 2003-2005
- Fellow, American Geophysical Union
- Fellow, American Association for the Advancement of Science

Graduate and Postdoctoral Advisors	W.F. Fitzgerald, Ph.D., University of Connecticut. H.E. Gaudette and D. Chasteen, Postdoctoral Advisors, University of New Hampshire.

Students Advised and Postdocs Sponsored:
Ph.D.'s: K. Simmons, R. Lent, B. Ojiambo, K. Johannesson, J. Thomas, K. Neumann (29 total graduate students);
Postdoctoral: M. Hines, M.J. Spencer, J. Hayward-Fee, D. Wayne, J-C. Bonzongo, K. Neumann, Z. Yang, K. Conners, C. Dowling

OLAV ORHEIM

Born 1942. Norwegian national.

Education and employment

1989-2005	Adj. Prof., University of Bergen.
From 1993	Managing Director at NPI.
1972-93	Head, Antarctic Section/Head of research, Norwegian Polar Institute
1972	Ph. D, Ohio State University, USA, on glaciers and interhemispheric climate change.
1968	Cand. real, University of Bergen, Norway

My scientific work has been in the Arctic and the Antarctic, studying a) glacier mass balance and climatic variations, b) ice dynamics and flow, c) ice bergs and interaction between ice and ocean and d) remote sensing and snow surface properties, with a total of around 30 field seasons. In recent years I have also been concerned with climate policy. My approx. 100 publications include 20 articles in refereed international journals where I am sole, or senior, author. I have been a speaker at more than 100 international conferences.

International positions:

2003-04	member ICSU/WMO's Planning Group for the International Polar Year (IPY).
1998-2002	Chair, Committee on Environmental Protection under the Antarctic Treaty,
	Executive Member/Chair of various bodies including European Polar Board, Forum Arctic Operators, Nordic Polar Committee and International Arctic Science Committee.
1992-96	Vice President SCAR
1986-89	Vice President International Glaciological Society
1985-1990,	Chair, SCAR Working Group on glaciology,

I have been on review panels for polar/Antarctic activities of several countries including Australia, and led the review of the South African Antarctic Programme. I have chaired seven large international confeences, and been involved in the planning and content of numerous other such meetings. In August 2004 I was responsible for the programme and contents of a 36-hour briefing on Arctic climate issues for senators McCain, Clinton, Collins, Graham and Sununu at Svalbard (Spitsbergen).

National positions:

I have held and hold a large variety of national positions, and is presently chairman of the board of two foundations. In 2003 I was chair of the Norwegian government's expert committee on Northern affairs that produced the analysis document for the government's White Paper to the parliament on Norwegian Arctic foreign policy.

Further details on antarctic competence:

a) Antarctic Treaty relations

I have been a member of the Norwegian delegations to almost every Antarctic Treaty Consultative Meeting and Special ATCM from 1979 to the present, in recent years as Deputy Head of delegation. I have repeatedly been involved in bringing issues forward to solution within ATCMs, for example:

- Chair of CRAMRA subgroup that negotiated the issue of confidentiality.
- Part of the Norwegian team that developed the text for the Environmental Protocol
- Chairman of TEWG (Transitional Environmental Working Group) at ATCM XXI.
- Was elected as the first Chair of the Committee on Environmental Protection in 1998 and re-elected in 2000.

b) Experience within Antarctica.

Altogether seventeen expeditions to Antarctica, mainly studying the ice masses and climate. I worked three seasons at the Antarctic Plateau as visiting scientist with US Antarctic Program, and six seasons in the Antarctic Peninsula area with Argentinean, British, Russian and US colleagues. I was in charge of developing Norway's new Antarctic programme, and from 1976 I have led a number of national expeditions to the Dronning Maud Land/Weddell Sea region, including the establishment of Troll Station.

c) Experience with other Antarctic organisations

I have been Norway's representative on COMNAP from 1993-present. At present I chair COMNAP's sub-group on Tourism and non-governmental expeditions (TANGO).
I have been Norwegian delegate to SCAR at most meetings from 1980 to present.