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POLAR ENVIRONMENTAL MONITORING

FINAL REPORT

SPC 392
February 1979

Robert G. Nagler
Andreas C. Schultheis

Sponsored by
NASA Advanced Ocean Mission Development Group

SYSTEM PLANNING CORPORATION
1500 Wilson Boulevard • Suite 1500 • Arlington, Virginia 22209 • (703) 841-2800

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The polar regions have engendered new interest in recent years in recognition of the presence of major untapped petroleum and fish protein resources. Scientifically, the polar regions have surfaced as major drivers in global climate, weather, and ocean processes. This dual economic/scientific resurgence has caused the governments in the polar regions to develop and expand polar services in support of exploration-and-exploitation operations scheduling, navigation and hazard avoidance, environmental forecasting, and conservation and environmental-quality management. Because of its interests in Alaska, the Great Lakes, and the Antarctic and our operation of the International Ice Patrol in the North Atlantic, the United States has both a major investment as a nation and a major responsibility due to its influential role in the polar regions.

In this study we have reviewed these present and projected benefits and have translated them, where not already officially documented, into information needs to support the array of polar activities anticipated. These needs include measurement sensitivities for polar environmental data (ice/snow, atmosphere, and ocean data for integrated support) and the processing and delivery requirements which determine the effectiveness of environmental services. An assessment was made of how well we know how to convert electromagnetic signals into polar environmental information an emphasis on the status of scientific understanding and algorithm development. The array of sensor developments in process or proposed were also evaluated as to the spectral diversity, aperture sizes, and swathing capabilities available to provide these measurements from spacecraft, aircraft, or *in situ* platforms. Global coverage and local coverage densification options were studied in terms of alternative spacecraft trajectories and aircraft flight paths. Mechanisms for centralizing all processing or dispersing a major portion of the cost to the users themselves were discussed and compared. Sample implementation schemes utilizing minor modifications to NOSS or TIROS, an optimized NOSS-based pseudo-operational polar services platform, a new NASA polar research satellite, U.S. participation in an internationally managed polar research/services satellite, and an expanded aircraft and <u>in situ</u> program were developed to help expose additional policy issues and potential problem areas.

In order to summarize the results of this effort, an attempt has been made to select out from a fairly massive array of information those policy issues of major importance at this stage in the possible evolution of a NASA polar monitoring development program. There are other issues or questions in the main text, generally of a more technical nature, but it is believed that most of these can be better stated once some initial guidelines are established for the issues developed here. The following issues were selected because of their potential effects on user relationships and funding requirements:

- Should there be a polar region focus for an environmental measurement mission?
- Are agency, industry, or science interests dominant in the polar regions?
- Can and should an ice/snow environmental measurement program be separated from one for ocean and atmospheric measurements?
- How should international interests be handled?
- How aggressively should sensors be developed specifically for polar region utilization?
- What is the best platform/trajectory combination for achieving desired polar coverage?
- If a satellite program is warranted, then what implementation mode provides the best combination in terms of low cost and user responsiveness?

It is not our intent to try to answer any of these questions, but only to lay out some of the options and as many of their implications as we were able to uncover.

Should There Be A Polar Region Focus For An Environmental Measurement Mission?

It is generally accepted that for there to be a program focus on any particular user group there should be a definable and visible user community, a fairly large and recognized potential benefit from the program, and a user community that is willing to vocally support the program in front of Congress and the various administration review bodies and to back this support with investment of their own.

There are three definable and visible user communities in the polar region: science, industry, and government. The scientific community is primarily concerned with the leading role the polar regions play in global environmental dynamics. Detailed knowledge of the growth and dynamics of ice and snow systems is needed to understand more fully the way in which they affect global climate, weather, ocean, and hydrological balance. Industry also needs to understand these same polar processes to achieve efficient operations in the exploration for and exploitation of major oil and gas and fish protein reserves. Government agencies also have a great need for polar information since, in addition to participating in polar research, they also have a social services role that is particularly important in the polar regions. Direct government support to industry and science includes polar navigation, search and rescue, and environmental forecast services.

The potential benefits from improved environmental measurements in the polar regions appear to be generally recognized by those involved with polar activities, but poorly understood by the pertinent decision-making bodies. Polar researchers and polar climate researchers comprise an enthusiastic but comparatively small group relative to those engaged in atmosphere, ocean, or land research. Recent efforts have shown that the polar regions may be the key to some of the problems in these other areas and some of these other researchers have been migrating to polar studies. Oil and gas profits could potentially be effected in the hundreds of millions of dollars category each year for each company engaged in polar activities if the environmental information were available to allow them to extend their tanker shipping season and improve scheduling of their operations. The agencies providing these environmental measurement services (NOAA/Navy/Coast Guard) understand the need for continuing and expanding their present services, but have expressed a need to further assess the user market prior to engaging in extensive and complex new development efforts. Such an activity is presently ongoing.

All of the above factors affect user community willingness to vocally support a focused program. Polar scientists are willing to express their interests, but they are a small group, relatively, and are not well represented on many of the national scientific advisory groups that guide our funding policies for NASA, NOAA, and other agency research programs. Although NSF and ONR do have a focused polar region program, again the list of participants is surprisingly small compared to other areas. Arctic oil and gas interests are willing to talk about their needs comprehensively and can show extensive investment of their own to obtain environmental information to support navigation and operations scheduling needs. However, they shy away from formally requesting government support in obtaining this information more efficiently. Their excuses for this behavior are centered around government regulatory pressures, the effect written requests of any kind have on exploration site lease acquisition, and the advantage to marginal competitors resulting from government-furnished polar information. They have, on the other hand, discussed putting up support satellites of their own. If there was any mechanism to get government permission for such a launch, they would do so for they recognize that such an action would provide a good return on investment. In the meanwhile, they are investing extensively in improved aircraft and in situ measurement support and, in many regions, have considerably more information on the environment than do the government agencies with operational environmental information responsibility. The polar region industrial experiments in SEASAT-A comprise a major portion of the total industrial experiments effort and again indicate the strength of their interests.[1]

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[1] "SEASAT-A Industry Demonstration Program (ASVT Program)," Volumes I and II, JPL, June 1, 1977.

Meanwhile, the agencies with operational responsibilities in the polar regions do not appear particularly responsive at the higher management levels to polar interests. NOAA generally provides global information services on a global scale and with coarse resolution. This is what is needed to drive environmental forecast models, and the coarse resolution scale fits present computational capacities (as always, fund limited). The polar users have data needs for finer surface resolutions, which imply major increases in computational capacity beyond any presently anticipated budget the support agencies might have. Industry, in particular, whose major benefits come in local Arctic or coastal areas, often feels that NOAA products haven't reached adequate surface resolution levels to be used extensively for the localized problems of the polar or coastal regions except in a very limited fashion. As a result, NOAA sees less customers than it might in the polar regions, and many of the polar and coastal users are disgruntled with NOAA's inadequate (to them) funding. The Navy, also, has encountered many of the same problems. Although it operates a major portion of the Joint Navy/NOAA Ice Survey Office (five of six people), and has considerable operational interest in the Arctic, the environmental measurement and forecast effort in the Arctic is not considered a main thrust activity in the Navy. The Navy recently had a broadly attended internal meeting on polar environmental information needs and appears to have concluded that Navy requirements were not sufficiently focused to warrant support to any major new thrust. The Coast Guard supplies extensive service in the Arctic regions and the Great Lakes and operates the International Ice Patrol in the North Atlantic. But they, too, do not yet appear convinced that satellites would do them any more good than outfitting their airplanes (which they have to have for other reasons) with improved environmental sensing packages. Based on their needs alone, out of context with the other needs, they may be right.

The problem, then, is that there are viable user groups with large potential benefits, but their interests are generally not given high priority, in our present fund-limited climate, by the agencies set up to support them. However, based on the many technical and cost uncertainties in implementing such a program, and the often missing or controversal documentation of benefits, the agency positions are not unreasonable. NASA appears to have a needed role in evaluating these uncertainties and developing program alternatives that meet the industry and science needs and satisfy agency concerns.

Are Agency, Industry, Or Science Interests Dominant In The Polar Regions?

Polar research is actively supported by NSF, ONR, the Army CRREL, and the USGS. Some of NASA's polar environmental research subprograms under the Oceans Program have been integrated with these external research efforts so that there is a good awareness in the polar research community of the opportunities afforded by SEASAT-A (especially the imaging radar), NIMBUS-G, and NOSS. GSFC has been the major NASA center working on scientific efforts, and their IPACS mission [Ref. 18] reflects these science interests (e.g., emphasis on new measurements and on resolutions that are not quite as fine as those of interest to operational users in order to ensure that processing demands are more consistent with expected limits in budget).

Polar industries have a tremendous need for environmental data, but tend to be reticent in asking the government to supply such information. They are actively pursuing the SEASAT-A opportunity and have made extensive investment of their own in environmental measurement facilities; much more is needed, however. Harnessing their independence is a challenge. NASA might want to undertake to place the polar mission on a firm support foundation by establishing a direct industry investment for some portion of the mission. LeRC and JPL have emphasized industry users, and their mission deliberations reflect the needs of this user group.[1,2]

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[1] P.J. Rygh, et al., "National Oceanic Satellite System Definition Phase," Final Report, Volumes 1 through 3, JPL Internal Report 624-12, June 16, 1978.

[2] Richard T. Gedney and Ronald J. Schertler, "Microwave Systems for Monitoring Sea Ice," Presented at WMO Workshop on Remote Sensing of Sea Ice, Washington, D.C., October 18, 1978.

Polar government agencies presently have a relatively low interest, but could potentially play a major role if a program were developed to support science and industry interests. As discussed earlier, the agencies involved in supplying present polar services are supportive to industry and science needs; however, three major problems limit their support. First, they are generally too small to command a significant share of their agency's support. Second, many of the unanswered technical questions limit their effectiveness in presenting the case. And third, the suborganizations with operational responsibility have to make too large a capability jump either in using space-derived data, if that is the best source, or in processing the volumes of data actually needed from whatever source is appropriate (space or aircraft or _in situ_). This capability jump implies changes in budget which are difficult to obtain in today's climate.

Extensive interaction is needed with agency personnel to document their concerns and interests if NASA wants to develop a program focus in this area. The science and industry interests appear to be there for harnessing, but agency reticence needs to be addressed. More _in situ_ and aircraft tests are needed to shed light on agency concerns with the viability of some measurement types and with the magnitude of the processing implied by the resolutions needed.

Can And Should An Ice/Snow Environmental Measurements Program Be Separated From Ones For Ocean And Atmospheric Measurements?

There are two aspects to this issue. First, many of the dynamics of the ice/snow system in polar regions are controlled, or at least strongly influenced, by conditions at the water and air boundaries. The water and atmospheric systems not only furnish water or take water from the ice/snow system, but they also move the ice/snow around due to wind, wave, current, and tidal actions. Thus, to understand the dynamics of the ice and snow system, it is necessary to understand the ocean and atmosphere interactions.

Second, many of the sensor techniques to measure ice and snow properties are the same as those to be used for these ocean and atmospheric measurements. Thus, the same sensor used to determine ocean surface and cloud temperatures can be used or adapted to measure ice/snow surface temperature. Radar images, altimetry, scatterometry, etc., measure ice but the measurement concept is essentially identical. In other cases, the horizontal resolution needs are a little bit finer, but again it is only the scale not the concept.

It would thus appear that the ice and snow disciplines are excellent candidates for an integrated environmental observation approach utilizing shared sensors flying on a limited number of common orbits. Where there is any unique requirement demanding other than a reasonable multidiscipline commonality approach, it appears very possible that aircraft would be excellent candidates for obtaining special measurements due to the limited geographical extent of the U.S. Arctic interests.

How Should International Interests Be Handled?

The Canadians and Europeans have both studied polar spacecraft missions. They have much more extensive Arctic interests than we do and have expressed interest in some form of cooperative venture to provide environmental measurement services for this region. Preliminary informal meetings have already been held at which the mutual interests and mutual advantages deriving from a cooperative effort have been identified.

There are several subissues in this area. The first evolves out of the fact that the fourth major interest in the Arctic region is Russia. This makes the military very interested in Arctic environmental measurement programs, especially when the major sensor of interest is the imaging radar. Further study needs to be made of how military interests in defending the polar regions can complement oil and fisheries interests in exploiting the polar regions.

The second subissue arises once the first one is settled. If the cooperative international program option was chosen as the proper way to go, what should be the U.S. role in this cooperative venture? A brief comparison was made of the U.S. role as a leader with Canadian and ESA participation versus a U.S. role as a participant with Canadian or ESA leadership.

Based on U.S. interests in being a leader in space, the first appears appropriate. Based on the smaller U.S. share of the polar regions and more recent interests in sharing expenses more broadly with our fellow men, the second role seems desirable. A thorough evaluation of these options, however, is beyond the scope of this report.

How Aggressively Should Sensors Be Developed Specifically For Polar Region Utilization?

At present, the investment in polar specific sensors is small. The investments projected in the near term for the NASA polar-environment subprogram[1] are limited to testing the utility of sensors developed for other purposes rather than making unique spectral changes or developing unique new concepts for polar application. Downstream,[1] there are some efforts directed towards special measurement capability for ice and snow thickness but, by and large, the funding levels are barely sufficient to maintain a viable program. If it is accepted from the discussion of the first issue that a viable user activity exists, then NASA should take a much more dynamic approach to the support of technique developments for polar research and operations. Potential areas of research are discussed in Section V. These include visible, infrared, and microwave radiometric surface mappers with more optimum channel selection and finer surface resolutions; atmospheric sounders with special channels for the ice/snow boundary as well as for the ocean boundary; new radar and LIDAR altimetry sensors with narrow beams for surface profiling, MHz frequencies for ice thickness sounding, etc.; and new wide-swath imaging radars with 100-m capability plus more narrow-swath options with 20-m resolution (as desired by Canada and ESA) or with 5-m resolution (the long-term industry desire) for navigation and iceberg identification support. In addition, a wide variety of new sensors appear on the horizon with improved frequency diversity, finer footprints, and broad application to other environmental disciplines.

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[1] "Sensor/Ice Dynamics Interaction and Modeling Subprogram Plan," NASA Lewis Research Center, May 5, 1978 Revision.

What Is The Best Platform/Trajectory Combination For Achieving Desired Polar Coverage?

For the combination of research (climate, ice dynamics, etc.), military operations, and international industrial operations, it would appear that a satellite implementation for monitoring the polar regions is the best comprehensive solution. If military interests limit the real-time accessibility of this information to industry, then an alternative airplane solution may be appropriate for the U.S. industrial community due to the limited area of particular interest to U.S. companies.

For the satellite implementation, there are three orbits of interest. The strictly polar orbit option (83- to 87-deg inclination) covers the entire pole with the fine resolution imaging radar and gives good systematic coverage of both poles if the side from which the radar looks out is switched in the northern and southern hemispheres. This is the most popular orbit for the widest range of users. The sun-synchronous orbit is only of interest for the visible spectrum sensors utilizing reflected polar energy. For the most part, these are the same sensors and spectral channels of interest to lower latitude users, so little is needed other than directing the data through processing capabilities using algorithms specifically focused on polar regions. The cloudiness of the polar regions also limits the utility of these sensors.

The third orbit of interest is the orbit creating greater time density of coverage in local polar areas. The example used in the main text is the 69-deg inclination orbit for aiding access to the north slope of Alaska. Other inclinations might be important for other local regions of interest. This local densification orbit concept may not be practical unless there are other local areas covered by the same orbit, since airplane implementations may be able to effectively compete with satellites on local coverage. A well-instrumented aircraft is required, also, to provide ground truth support, to provide increased coverage densification in local areas for operations or research, and to visually check out phenomena identified by the sensor package in real time. _In situ_ measurement packages with data relay capability also have a role in polar regions.

The question of satellite, airplane, and in situ roles and the selection of the most practical user responsive orbits need to be studied in more depth with a user advisory group having a technical rather than a policy orientation.

If A Satellite Program Is Warranted, Then What Implementation Mode Provides The Best Combination In Terms Of Low Cost And User Responsiveness?

Much of the relatively off-the-shelf sensing capability for polar regions could be accomplished with relatively minor modifications to existing designs for NOSS, TIROS-O, and DMSP-Block 6. These differences are primarily spectral channel changes or additions, but in some cases include increases in aperture sizes to achieve finer surface resolution. The problem with this solution is that these three satellites are dominated by global modeling users, and there appears to be little interest in satisfying the broad array of polar users.[1] Fine resolution images and real-time information availability have not been of particular interest to the operational-agency management and, in fact, a concern with potentially large processing costs caused removal of the imaging radar from NOSS when the imaging radar was a key sensor for polar and coastal interests.

Thus, a separate satellite system with more research and industry-support emphasis might be appropriate. This satellite might look more like that proposed for the GSFC IPACS mission, but could contain a broader array of sensors or could even be built into their more general Platforms for Applications Research (PAR) concept, which uses 84- to 87-deg and 55- to 75-deg orbits for supporting research in many disciplines while exploring industry benefits and evaluating new sensors with potential operational roles. Neither the IPACS nor PAR concepts needs be more expensive as a mode of operation than the alternatives. This depends, of course, on the complexity of payload carried, the ability to use previously proven hardware, and access to experienced personnel. The data processing system,

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[1] The coastal users have the same problem.

on the other hand, could probably be designed to be considerably more supportive to research and industry users than the NOSS and TIROS and DMSP systems. Foreign participation could also be solicited.

A final potential implementation option is to provide U.S. support to a basically international satellite implementation led by Canada or ESA, both of whom have more extensive polar interests than the U.S. Our share of this international goodwill adventure should be much less than the investments implied by the other U.S.-controlled options. The international system will probably go ahead without us, in which case we would miss the opportunity to share in the data base generated.

I. BACKGROUND AND PROBLEM

This work has been performed by System Planning Corporation (SPC) under the auspices of the Advanced Ocean Mission Development Working Group, which is composed of representatives of each NASA center involved in NASA's ocean programs. The effort is the result of an Applications Notice award and is funded through the Jet Propulsion Laboratory (JPL). The technical monitor is Dr. Edwin Sherry. The membership of the Advanced Ocean Mission Development Working Group included:

- Dr. Edwin Sherry, NASA JPL, Coordinator
- Mr. S. W. McCandless, Jr., NASA Headquarters, Chief of Ocean Programs
- Mrs. Marjorie Townsend, NASA Goddard Space Flight Center (GSFC)
- Dr. Joseph Siry, NASA Goddard Space Flight Center (GSFC)
- Mr. Wayne Darnell, NASA Langley Research Center (LaRC)
- Dr. Richard Gedney, NASA Lewis Research Center (LeRC)
- Mr. John Oberholtzer, NASA Wallops Flight Center (WFC)
- Mr. John Ivey, NASA National Space Technology Laboratories (NSTL)
- Mr. John Sherman, III, NOAA National Environmental Satellite Service (NESS)
- Dr. Vince Noble, Naval Research Laboratory (NRL).

In this year's effort, SPC was directed by JPL and the working group to focus on ice missions. The specific task included an assessment of the present user interfaces at JPL, GSFC, and LeRC; collection of a cohesive set of requirements based on the work done by JPL, GSFC, and LeRC and any documented agency positions; an assessment of the state of the art in sensor, satellite, and data systems to meet the identified requirements; and an evaluation of alternative implementation options, including the potential impact of international participation.

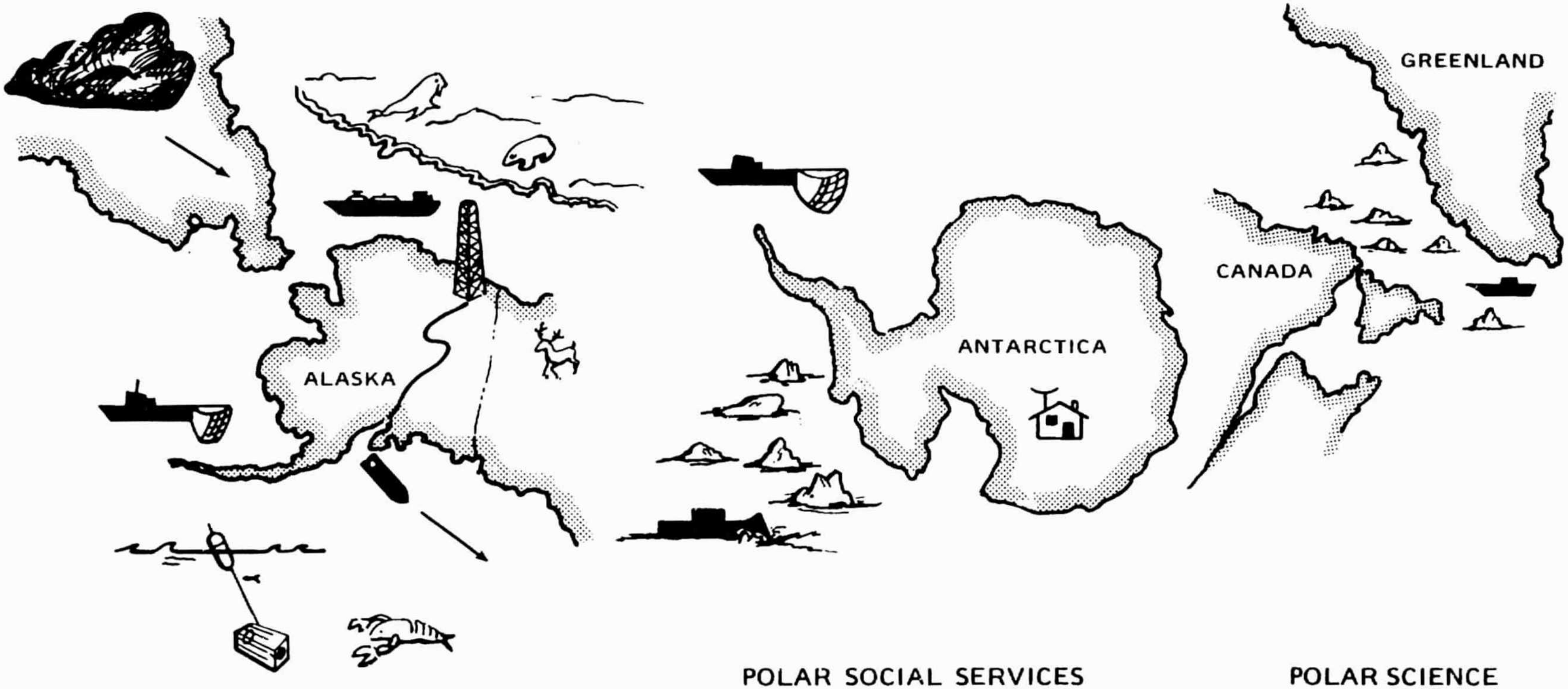
The JPL scientists consulted in this effort included Dr. Charles Elachi (ice dynamics research), Dr. Atul Jain (radar sensor options), Mr. Johnie Driver (trajectory options), and Dr. Edwin Sherry and Mr. Pat Rygh (spacecraft and implementation options). The scientists at GSFC who were consulted included Mr. Fred Flatow, Polar Satellite Study manager, Dr. J. Zwally, polar science manager, and Dr. Jerry Eckermann, microwave sensor manager. At Lewis Research Center, we consulted with Dr. Richard Gedney concerning polar research and applications programs. Dr. Gedney provided us with extensive documentation on Lewis polar activities and on the Lewis ice dynamics subprogram plan. It is important that this mission effort be tied to the ice dynamics subprogram plan. The long-range goals of this subprogram are "to determine and characterize remote sensing methods and sensor combinations capable of measuring ice properties at the necessary temporal and spatial frequencies."

II. USER BENEFITS FROM POLAR MONITORING

The polar regions have generated considerable interest in recent years. Economically, our view of the polar regions has been changed drastically by the discovery of substantial oil reserves in the Arctic and by the reaffirmation that the Arctic and Antarctic regions have large, relatively untapped populations of marine fish for food and fertilizer. This new economic interest has spurred the government to initiate services in the areas of ice breaking, iceberg hazard avoidance, polar weather forecasting, polar fauna and flora protection, etc. The recognition of the importance of the polar regions to such factors as weather, climate, ocean dynamics, and hydrology has similarly given impetus to polar research. A summary of the economic, social, and scientific activities in the polar region is given in Figure 1. This chapter provides a brief examination of the economic, social, and scientific benefits achievable through polar monitoring. Further detailed information can be found in the references.

A. ECONOMIC (INDUSTRY) BENEFITS

The oil companies have moved into the Arctic en masse. The United States has major operations on the Alaskan north slope. The Canadians are exploring the area from Alaska to Newfoundland. The Europeans are exploring Norway and Sweden. At all of these locations, information about atmospheric and ocean conditions and ice motions is necessary for scheduling of drilling rigs, tankers, and pipelines and for ascertaining the effects of transportation choices and scheduling. In the Alaskan area, 2 weeks of additional surface transportation of oil by tanker is purported to affect a company's yearly income in the $100M category. Multiplying this by the number of companies involved and the number of other locations where good ice-edge and ice-lead navigation data can affect the length of the transportation season presents



POLAR ECONOMICS

- OIL AND GAS OPERATIONS
- TANKER OPERATIONS AND DESIGN
- SHIP NAVIGATION AND ROUTING
- MARINE FISHERIES OPERATIONS

POLAR SOCIAL SERVICES

- ICE BREAKING
- ICE FORECASTING
- ICEBERG HAZARD PROTECTION
- POLAR MAMMAL/BIRD PROTECTION
- POLAR SEARCH AND RESCUE
- WEATHER FORECASTING
- MILITARY OPERATIONS

POLAR SCIENCE

- ICE DYNAMICS
- CLIMATOLOGY
- POLAR HYDROLOGY
- POLAR BIOLOGY
- WEATHER FORECASTING
- POLAR IMPACT ON WEATHER FORECASTING
- POLAR IMPACT ON OCEAN DYNAMICS

FIGURE 1. USER BENEFITS FROM POLAR MONITORING

an awesome spectra of potential large profits. Improved data on iceberg formation in the Labrador current region could save several ships a year from damage or loss due to iceberg encounters. Better information would also allow more use of shorter routes across the Atlantic by St. Lawrence Seaway-based vessels. More extensive information on Arctic oil and gas operations and Arctic tanker and ship routing can be found in the ECON SEASAT-A Economic Benefit Study [Ref. 1] done for NASA several years ago; more detailed case studies on Arctic oil have been performed by Battelle [Ref. 2]; and tanker ship routing studies [Ref. 3] have been conducted by Ocean Routes, Inc., and JPL. In addition, several of the SEASAT-A industry experiments are directed toward validating the benefits of improved Arctic data on Arctic operations and tanker routing [Ref. 4]. Also, one of the industry experiments addresses the design criteria for tankers traversing the Arctic waters [Ref. 4].

The Arctic and Antarctic areas are growing sources of fish protein for man, animals, and agricultural fertilizer. Use of real-time information by the extensive fisheries operations in the Bering and Labrador Seas and in the North Atlantic could help to improve catch efficiency and reduce equipment losses and loss of life and fishing boats. Some estimates of these impacts are provided in the ECON report [Ref. 1] and in the Fisheries Case Study done by JPL [Ref. 5]. The king crab fisheries in Alaska have devised a SEASAT-A industry experiment to validate the benefit of better ice-edge motion data on the ability to retrieve king crab traps before the moving ice destroys the surface buoys [Ref. 4].

Lewis Research Center is the major contributor to the present work being done on industrial interactions in the polar region. The people at this center have participated extensively with shipping and oil companies in Great Lakes and Alaskan surveillance tests. LeRC has also organized ice ridging experiments, investigated ice thickness measurements, aided industry in design of SEASAT-A experiments, and has generally been available for industry consultation. Battelle Memorial Institute has also been active in Arctic industry interactions, through NASA support contracts, in the areas of economic benefit case studies and the SEASAT-A Industry

Experiment Design. JPL, too, has worked closely with industry in Arctic research, particularly with the oil companies in the area of imaging radars. It has developed a series of experiments for the fisheries and goose management industry. GSFC has also worked with industry, but has been involved primarily with scientific issues. Langley Research Center and Wallops Flight Center have participated primarily in ice and snow profiling and scatterometry research in the Arctic region to obtain roughness and thickness data.

B. SOCIAL (GOVERNMENT SERVICES) BENEFITS

The U.S. Coast Guard operates the International Ice Patrol in the North Atlantic and has extensive responsibilities for icebreaking in Alaskan waters and in the Great Lakes. Means of improving the efficiency of Coast Guard operations and the benefits to be derived from such improvements were addressed by the ECON report [Ref. 1] and several of the Arctic and iceberg-water industry experiments for SEASAT-A [Ref. 4].

The Navy and NOAA operate a joint ice monitoring office that provides navigation data for Arctic and Antarctic shipping. This effort could benefit from improved polar information. The requirements of each in the Arctic region are addressed in References 6 and 7, respectively. A recent Navy meeting has provided an upgrading for some of these requirements, but to date this report has not been released. The joint Navy/NOAA ice monitoring effort in the Antarctic appears to be the only available navigation aid for krill and Antarctic fishing and for supplying the Antarctic stations of various countries.

In the area of polar search and rescue services, benefits are possible through space surveillance systems. Such systems would benefit a wide spectrum of military and civilian agencies, in particular the Coast Guard. However, the present efforts to establish a space-based search and rescue system for general application can probably be adequately utilized in the polar regions.

There has been renewed interest in recent years in management of the limited living land resources in the Arctic and preservation of wildlife.

Particular attention has been given to land and water mammals such as polar and Kodiak bears, caribou, walruses, seals, whales, and other polar mammals, which from time to time are threatened with extinction. In addition, the understanding of the process of freeing Arctic valleys from snow at the time the Canadian goose nests provides an important input into the Bureau of Fish and Wildlife management programs that have the responsibility for establishing the bag limit for hunters each year [Ref. 4].

The polar region is also important to military operations. Extensive environmental data are needed by the services to allow proper application of strategic and tactical strategies. Survival of personnel, operation of equipment, and preserving communications are real problems in the Arctic.

Lewis Research Center has again taken the lead in working with the operational side of the agencies. Their success with Project Icewarn and other joint programs with the Coast Guard in the Great Lakes and Alaska have given them excellent credibility [Ref. 8]. JPL has worked with the Coast Guard on ice navigation in Alaska and iceberg detection off Greenland, primarily in the area of imaging radar. JPL has also worked with NOAA, USGS, and the Army Cold Regions Research and Engineering Laboratory (CRREL). GSFC also has strong ties with NOAA, USGS, and CRREL, but primarily from the research standpoint.

C. SCIENTIFIC (BASIC UNDERSTANDING) BENEFITS

The polar regions act as major end points in the dynamics of our planet, both in the long-term climate sense and in the shorter term weather and ocean circulation sense [Refs. 9 and 10]. In climate, the poles are recognized as major sinks in the total system. They act as drivers of the planetary fluid circulations and radiate much more energy into space than they take in from the sun. In addition to these longer term influences in terms of ice ages, etc., the poles make large contributions to our global weather. Understanding how a major portion of U.S. weather is generated over Siberia and then proceeds across the Bering Sea to Alaska and beyond is a critical task. Why this weather goes inland and down into the plains states or south to

Washington, Oregon, and Northern California is the subject of many studies and investigations (e.g., Ref. 11).

The area of research in ice dynamics is well covered in Reference 12. In this area, it is important to understand the deviations from local isostatic equilibrium, especially relative to ridging. The amount of open water and thin ice in the polar regions is critical to the thermal exchange process with the atmosphere. Studies of convergence and divergence processes in the icepack also are of interest.

GSFC has taken the NASA scientific lead in ice research and interacts broadly with universities and with ice research programs funded by the National Science Foundation (NSF), the Office of Naval Research (ONR), the U.S. Geological Survey (USGS), and the Army Cold Regions Research and Engineering Laboratory (CRREL). Lewis Research Center presently is the coordinator of the NASA ice dynamics research program which involves both science and application studies. GSFC, LeRC, JPL, LaRC, WFC, and NSTL have all participated in ice research efforts.

III. USER NEEDS FOR POLAR ENVIRONMENTAL INFORMATION

After conferring with a wide range of people concerning their needs for polar data and their present and planned acquisition and use of it, a list of separable polar-environment disciplines was derived (see Table 1). Industry, to achieve economic benefits, needs environmental forecasts of four scales (ice, weather, storm, and ocean), cumulative average and 100-year maximums for engineering design, and fish management and exploitation information. Government agencies, to achieve social benefits, provide the information base for environmental forecasts, provide a management and control function for the fisheries and pollution monitoring, and provide support for tactical and strategic military operations. The scale (spatial resolution and frequency of repeat) desired by industry and often used locally in their own systems is often an order of magnitude or more finer than that considered feasible by the service agencies. Real time is the key for industry. Science, in general, utilizes non-real-time analysis of real-time data and generally needs an order of magnitude more resolution than do the operational systems to identify the next level of conceptual detail for the new generation of operational models.

The difference in scales between disciplines is important to keep in mind even in the polar region since it helps in understanding the differences in payload complexity evolving out of different NASA centers and different agencies, depending on what discipline group dominates their advisory activity. The scales used in the polar region activities, as derived from later tables, are shown in Figure 2. Global weather is central in that the NOAA TIROS, Air Force DMSP,[1] and NOAA/Navy/NASA NOSS[2] scales are designed for

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[1] Defense Meteorological Satellite Program.

[2] National Oceanographic Satellite System.

TABLE 1

DISCIPLINES WITH SEPARABLE NEEDS

	Economic	Social	Scientific
Sea Ice Forecasts	*	*	
Sea Ice Research			*
Glaciology & Hydrology			*
Climate			*
Global Weather Forecasts	*	*	*
Severe Storm Warning Forecasts	*	*	
Coastal Ocean Condition Forecasts	*	*	
Physical Ocean Research			*
Ocean/Ice Engineering	*		
Living Marine Resources	*	*	
Biological Ocean Research			*
Ocean Contamination		*	
Tactical Military Operations		*	
Strategic Military Operations		*	

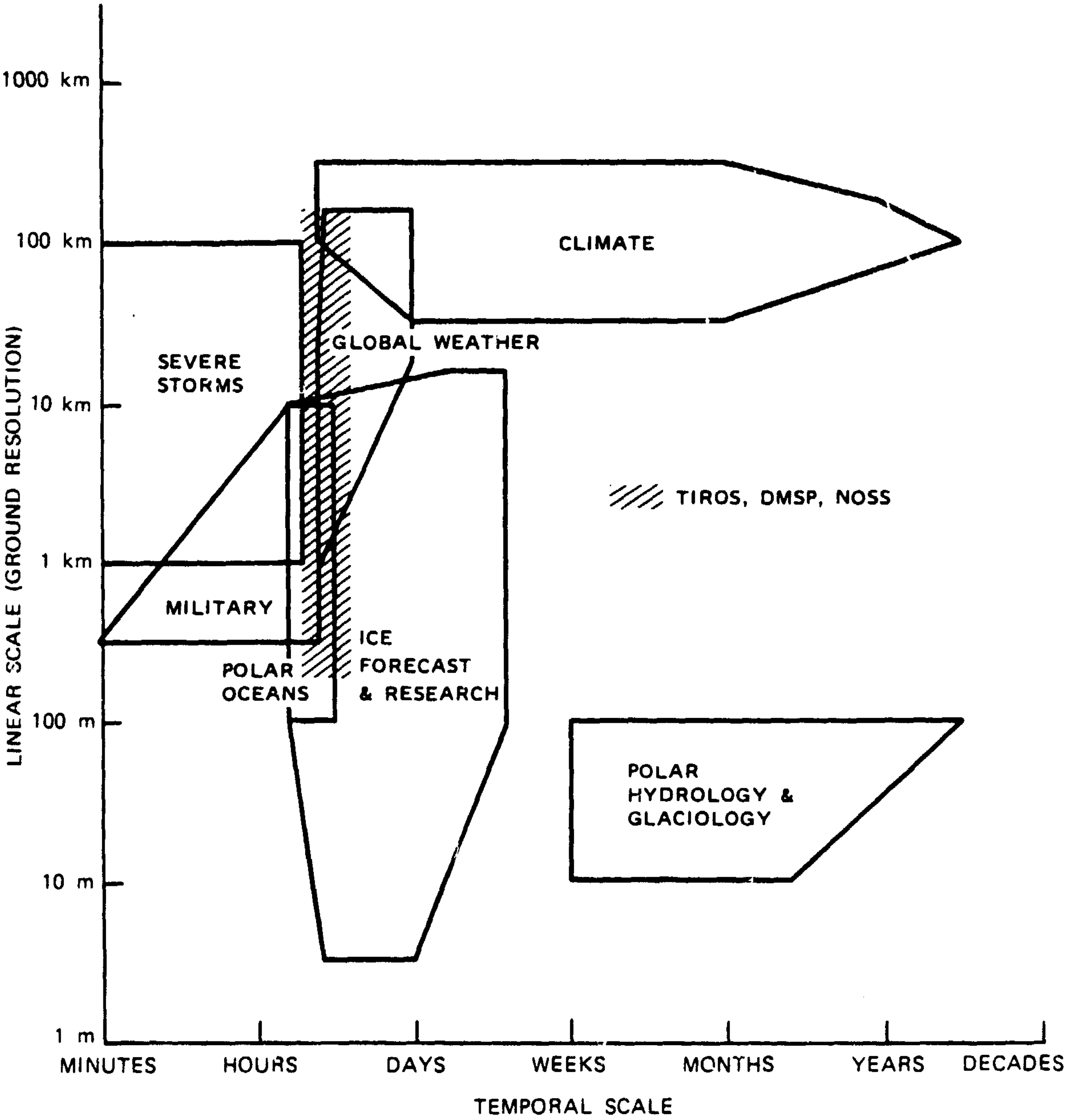

FIGURE 2. ENVIRONMENTAL SCALES FOR POLAR DISCIPLINES

global variations of weather, oceans, and ice. Polar ocean research, engineering, and biological resource management are more locally oriented in linear scale. Climatologists are satisfied with the coarser areal (linear squared) resolutions, generally, but need them averaged over long times and with sensitivities that allow differentiation between very small changes in the average values. The severe storm warning and tactical military operation areas require very quick data turnaround, a requirement that cannot be met at the present time. Ice dynamics, forecasts, and research require a wide range of scales, but tend to need finer linear resolution to differentiate deformations, drift, leads, icebergs, etc. Polar hydrology and glaciology disciplines require fine resolution that can be averaged over long times.

A. MEASUREMENT REQUIREMENTS

In order to provide the polar environmental information base for all of the disciplines evaluated, all of the measurements listed in Table 2 would have to be addressed. The list of ice measurements shows only a part of the problem. Growth and increase of the ice and snow levels depend on complex ice/air, ice/ocean, and air/sea interactions. These can only be evaluated if both sides of the interactive interface are monitored. Therefore, a list of atmospheric and ocean parameters was also developed to complete the set.

References 6, 7, 9, 10, 12, 13, 14, 15, 16, and 17 were then evaluated to extract a set of measurement requirements for the polar regions. This set of requirements for the ice, atmosphere, and ocean measurements is shown in Tables 3, 4, and 5. The measurement requirement for each discipline is given in terms of the measurement precision, the horizontal and vertical resolution, and the temporal repeat needed. Two values are given for most requirements: the most difficult value desired and the minimum useful value. The referenced source or sources are provided in the lower right-hand corner of each box. Where no reference is cited, the measurements were extrapolated by the authors based on similarities with other parameters that had referenced values. Where no values are given and the box is not crossed out, it was felt that some value should be appropriate, but that no satisfactory rationale for extrapolation came to mind. A general review

TABLE 2

MEASUREMENT TYPES OF INTEREST TO POLAR DISCIPLINES

Ice/Snow	Atmospheric	Oceans
Ice/Snow Surface Temperature	Vertical Atmospheric Temperature Profile	Sea Surface Temperature
Vertical Ice/Snow Temperature Profile	Cloud Top Temperature	Surface Wind Shear
Polar Region Albedo	Surface Air Temperature	Astronomical and Storm Tides
Ice/Snow/Glacier Extent	Regional Net Radiation	Ocean Current Amplitude/Direction
Ice/Snow Fraction	Vertical Pressure Profile	Ocean Current Location
Ice Thickness	Vertical Wind Profile	Coastal/Estuary Circulation Amplitude/Direction
Snow Depth	Vertical Humidity Profile	Coastal/Estuary Circulation Location
Ice Top/Bottom Surface Roughness	Cloud Extent	Upwelling Location/Extent
Water Equivalency of Snow	Cloud Levels and Thicknesses	Sea Surface Salinity
Ice Age and Salinity	Precipitable Water	Chlorophyl Extent/Concentration
Ice/Snow Sublimation Rate	Precipitation Extent/Amount	Dissolved Nutrient Concentration
Ice/Snow Melt Rate	Precipitation Type	Phytoplankton Type/Extent
Sea Ice Drift Rate	Precipitation Rates	Turbidity
Ice Deformation Rate	Fog/Mist Visibility	Petroleum Pollutant Thickness
Ice Lead Location/Sizing	Aerosol Extent/Concentration	Fish Oil/Biproduct Thickness
Crevasse Location/Sizing	Ozone Concentration	Fish/Mammal Identification/Sizing
Iceberg Location/Sizing	Carbon Dioxide Concentration	Ship/Search-and-Rescue Location/Identification/Sizing/Activity
Iceberg Formation Rate		

FOLDOUT FRAME

TABLE 3

POLAR REGION ENVIRONMENTAL MEASUREMENT NEEDS-ICE PROPERTIES

PRECISION
HORIZONTAL RESOLUTION
VERTICAL RESOLUTION
TEMPORAL REPEAT
(GOAL/MIN. USEFUL)
REFERENCE SOURCE

	SNOW/ICE SURFACE TEMPERATURE	VERTICAL SNOW/ICE TEMPERATURE PROFILE	POLAR REGION ALBEDOS	ICE/SNOW/GLACIER EXTENT	ICE/SNOW FRACTION	ICE THICKNESS	SNOW DEPTH	ICE TOP/BOTTOM SURFACE ROUGHNESS	WATER EQUIVALENCY
SEA ICE FORECASTS	0.1/0.5°C 5 m/25 km DAILY 12	0.1/0.5°C 5 m/25 km 10 cm/5 m DAILY	3% 1/10 km DAILY 6	5 m/1 km 5 m/1 km 4/2 PER DAY 12,27	5/20% 2/20 km 0.5/3 DAYS 6,18,27	0.1/1 m 0.5/20 km 10 cm/1 m 0.5 DAY/ WKLY 6,18,27		10 cm/2 m 1/30 m 10 cm/2 m MONTHLY 12,27	1/3 c 50 k WEEK
SEA ICE RESEARCH	0.1/3°C 5 m/50 km DAILY/MTHLY 12,18	0.1/0.5°C 5 m/25 km 10 cm/5 m WKLY/MTHLY 12	2/4% 100 m/100 km WKLY/QRTLY 6,18	5 m/50 km 5 m/50 km DAILY/WKLY 12,18	2/5% 5 m/25 km DAILY 12,18	0.1% 5 m/50 km 10 cm/5 m WKLY/YRLY 12,18		10 cm/1 m 1/10 m 10 cm/1 m YEARLY 12	1/3 c 50 k WEEK
GLACIOLOGY	0.1/0.5°C 5 m/25 km MONTHLY AVE 18	0.1/0.5°C 5 m/25 km 10 cm/5 m MONTHLY AVE 16	2/4% 1/500 km MONTHLY AVE 18	100 m 100 m 1/5 YR 18	2/5% 5 m/25 km WEEKLY	10 cm/50 m 1/100 km 10 cm/50 m 3 MO/5 YR 18			1/3 c 50 k WEEKL
CLIMATE	0.1/0.5°C 200/500 km MONTHLY AVE 10	0.1/0.5°C 200/500 km 10 cm/5 m MONTHLY AVE	2/4% 50/500 km 3 DAYS/ MTHLY 10,18	1 m/50 km 1 m/50 km DAILY/5 YR 6,18	1/5% 50/100 km DAILY/3 DAYS 6,18	10 cm/1 m 1/3 km 10 cm/1 m 3 MO/5 YR 10, 18		▨	1/3 c 50 k WEEK
LARGE-SCALE WEATHER FORECASTS	0.25/1°C 25/200 km DAILY	▨	0.2/3% 1/100 km 4 PER DAY	1 km 1 km 2 PER DAY	2/4% 100/200 km 2 PER DAY	▨	▨	▨	▨
SEVERE STORM WARNINGS & FORECASTS	0.5/1.0°C 5/100 km 10 MIN/6 HR 15	0.5/1.0°C 5/100 km 10 cm/5 m HOURLY/6 HR	0.2/1% 1/25 km HOURLY/6 HR	▨	▨	▨	▨	▨	▨
COASTAL OCEAN CONDITION FORECASTS	0.1/0.5°C 1/100 km 2 PER DAY	▨	0.2/1% 1/100 km 10/2 PER DAY			▨	▨	▨	▨
PHYSICAL OCEAN RESEARCH	▨	▨	0.2/1% 1/100 km 10/2 PER DAY		12% 2/20 km 0.5/3 DAYS 6	0.25/0.5 m 2/20 km 0.25/0.5 m 0.5/3 DAYS 6	▨	▨	▨
OCEAN ICE ENGINEERING	0.25/0.5°C 5/100 km 2 PER DAY	0.1/0.5°C 1/100 km 2 PER DAY	0.2/1% 1/100 km 2 PER DAY		▨	0.25/0.5 m 2/20 km 0.25/0.5 m 0.5/3 DAYS	▨	▨	▨
LIVING MARINE RESOURCES	▨	▨	0.2/1% 1/100 km 10/2 PER DAY	▨	12% 1 km DAILY 6	▨	▨	▨	▨
BIOLOGICAL OCEAN RESEARCH	▨	▨	0.2/1% 1/100 km 10/2 PER DAY	▨	12% 2/20 km DAILY 6	0.25/0.5 m 2/20 km 0.25/0.5 m 0.5/30 DAYS 6	▨	▨	▨
OCEAN CONTAMINATION	▨	▨	0.2/1% 1/100 km DAILY	▨	▨	▨	▨	▨	▨
TACTICAL MILITARY OPERATIONS	0.25/1°C 10 km HOURLY	0.25/1°C 10 km HOURLY	5% 10 km HOURLY 7	2 km 1 km 3 HOURS 7	10/30% 0.5/1 km 4 PER DAY	12 cm/2 m 1/50 km 12 cm/2 m 4 PER DAY 7	5 cm 10 km 5 cm 3 HOURS 7		
STRATEGIC MILITARY OPERATIONS	0.25/1°C 10 km 3 HOURS	0.25/1°C 10 km 3 HOURS 7	5% 45 km 3 HOURS 7	10 km 1 km 6 HOURS 7	10/30% 1/25 km 2 PER DAY 7	12 cm/2 m 1/50 m 12 cm/2 m 2 PER DAY 7	5 cm 45 km 5 cm 8 HOURS 7		
RANGE OF PARAMETER	2 TO 35°C				0 TO 100%	0 TO 500 m			

ORIGINAL PAGE IS
OF POOR QUALITY

FOLDOUT FRAME 2

ICE TOP/BOTTOM SURFACE ROUGHNESS	WATER EQUIVALENCY OF SNOW	ICE AGE & SALINITY	ICE/SNOW SUBLIMATION RATE	ICE/SNOW MELT RATE	SEA ICE DRIFT RATE	ICE DEFORMATION RATE	ICE LEAD LOCATION/SIZING	CREVASSE LOCATION/SIZING	ICEBERG LOCATION/SIZING	ICEBERG FORMATION RATE
10 cm/2 m 1/30 m 10 cm/2 m MONTHLY 12,27	1/3 cm 50 km WEEKLY 18	10/20% 5 m/25 km 2 PER DAY/ MONTHLY 6,18,27	▨		0.1/1 km/DAY 20 m/5 km DAILY/ 3 DAYS 18,27	0.1/0.2% 10/100 m DAILY/ MONTHLY 18	100 m, 30/50° 100 m 10 PER DAY/ 3 DAYS 6,18,27	▨	5/100 m 5/100 m 4 PER DAY/ DAILY 18	5/100 m 4 PER DAY
10 cm/1 m 1/10 m 10 cm/1 m YEARLY 12	1/3 cm 50 km WEEKLY 18	10/20% 5 m/50 km WKLY/ YRLY 12,18,27		YES/NO 25 km 1/3 DAYS 18	0.1/1 km/DAY 50 m/25 km DAILY/ 30 DAYS 12,18,27	0.1% 10/100 m WKLY/QTRLY 12,18	5/100 m, 30/50° 5/100 m DAILY, 3 DAYS 12, 18	100 m 100 m YEARLY 12	5/100 m 5 m/1 km DAILY 12,18	5/100 m DAILY
	1/3 cm 50 km WEEKLY	10/50% 1/25 km 1/5 YR 18		YES/NO 25 km 1/3 DAYS 18	▨	0.1/0.2% 10/100 m QUARTERLY 18	▨	20/100 m 20/100 m MONTHLY	▨	100 m/1 km MONTHLY
▨	1/3 cm 50 km WEEKLY		10 W/m^2 500 km MONTHLY 10	▨	▨	1/50 m/YR 1/10 YR 9,27	▨	▨	▨	▨
▨	▨	▨		▨	▨	▨	▨	▨	▨	▨
▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
▨	▨	▨	▨	▨	100 m/DAY 20 m/1 km DAILY	▨	▨	▨	5/100 m 5/100 m 4 PER DAY	5/100 m 4 PER DAY
▨	▨	10/20% 2/20 km 0.5/3 DAYS 6,9	▨	▨	▨	▨	▨	▨	▨	▨
▨	▨	▨	▨	▨	▨	0.1/0.2% 10/100 m DAILY	▨	▨	5/100 m 5/100 m DAILY	▨
▨	▨	▨	▨		100 m/DAY 20 m/1 km DAILY	▨	▨	▨	▨	▨
▨	▨	10/20% 2/20 km 0.5/3 DAYS 6	▨		▨	▨	▨	▨	▨	▨
▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
		6/12 MONTHS 1/50 km 4 PER DAY 7	▨						15/100 m 15/100 m 4 PER DAY/ 2 DAYS 7	
		6/12 MONTHS 1/50 km 2 PER DAY 7	▨				▨		15/100 m 15/100 m 2 PER DAY/ 2 DAYS 7	
		1, 2, MULTIYEAR 0 TO 1.5 ppt								

FOLDOUT FRAME 1

TABLE 4

POLAR REGION ENVIRONMENTAL MEASUREMENT NEEDS-ATMOSPHERIC PROPERTIES

PRECISION
HORIZONTAL RESOLUTION
VERTICAL RESOLUTION
TEMPORAL REPEAT
(GOAL/MIN. USEFUL)
REFERENCE SOURCE

	VERTICAL ATMOSPHERIC TEMPERATURE PROFILE	CLOUD TOP TEMPERATURE	SURFACE AIR TEMPERATURE	REGIONAL NET RADIATION	VERTICAL PRESSURE PROFILE	VERTICAL WIND PROFILE	VERTICAL HUMIDITY PROFILE	CLOUD EXTENT	
SEA ICE FORECASTS	0.25/1°C 25 km 200 mb OR 5 km 1/2 DAYS	0.25/1°C 25 km 4/2 PER DAY	0.1/0.5°C 5/100 km DAILY 6,13	▨	▨	▨			
SEA ICE RESEARCH	0.25/1°C 25 km 200 mb OR 5 km 1/2 DAYS	0.25/1°C 25 km 4/2 PER DAY	0.1/0.5°C 10/100 km DAILY 6,18	▨	3/10 mb 25/50 km 1 km 1/3 DAYS 9,18	2/4 m/s, 10/20° 25/50 km 1/3 DAYS 18	▨	▨	▨
GLACIOLOGY	▨	▨	0.2/1°C 5 m/10 km MONTHLY AVE 18	10/20 W/cm² 1/500 km MONTHLY AVE 18	▨	▨	▨	▨	▨
CLIMATE	1/2°C 500 km 200 mb OR 5 km 1/2 DAYS 10	1/2°C 500 km DAILY 10	0.2/1°C 200 km DAILY 6	10/20 W/cm² 25/500 km MONTHLY AVE 10	1/3 mb 500 km 1 km 1/2 DAYS 10	0.5/3 m/s, 2/10° 500 km 200 mb 4 PER DAY/ 2 DAYS 10	7/30% 500 km 400 mb 1/2 DAYS 10	5/20% 100/500 km DAILY 10	▨
LARGE-SCALE WEATHER FORECASTS	0.25/1°C 25 km 1 km 4/2 PER DAY 6	0.25/1°C 25 km 4/2 PER DAY 6	0.1/1°C 100/200 km 2 PER DAY 6	1/10 W/cm² 1/100 km 4 PER DAY	1/3 mb 100/200 km 1 km 4/2 PER DAY 6	0.5/3 m/s, 5/10° 100/200 km 1 km 4/2 PER DAY 6			
SEVERE STORM WARNINGS & FORECASTS	0.1/1°C 1/100 km 1/5 km 1 MIN/3 HR 6,15	0.1/1°C 1/100 km 1 MIN/3 HR 6,15	0.1/0.5 1/100 km 1 MIN/3 HR 6,15	▨	1/3 mb 1/10 km 0.5/1 km 10/2 PER DAY 6	0.5/3 m/s, 5/10° 5/10 km 0.5/1 km 10/4 PER DAY 6	5/15% 5/100 km 2/5 km 1 MIN/3 HR 15	5/50 km 6 MIN/2 HR 15	250 1/2 250 0.5/3
COASTAL OCEAN CONDITION FORECASTS	0.1/0.5°C 1/5 km 1 km 8/2 PER DAY 6	▨	0.1/0.5°C 1/100 km 10/2 PER DAY 6	▨	1/3 mb 1/10 km 1 km 10/2 PER DAY 6	0.5/1 m/s, 2/10° 5/10 km 1 km 10/4 PER DAY 6			
PHYSICAL OCEAN RESEARCH	0.1/0.5°C 1/5 km 1 km 8/2 PER DAY 6	▨	0.25/0.5°C 10/100 km 10/2 PER DAY 6	5/20 W/cm² 100 km WEEKLY	1/3 mb 1/10 km 1 km 10/2 PER DAY 6	0.5/1 m/s, 2/10° 25/200 km 1 km 10/4 PER DAY 6			
OCEAN ICE ENGINEERING	0.25/1°C 25 km 1 km 10/2 PER DAY 6	▨	0.1/1.0°C 1/100 km 10/2 PER DAY 6	▨	1/3 mb 1/100 km 1 km 10/2 PER DAY 6	0.5/1 m/s, 2/10° 50/100 km 1 km 10/4 PER DAY 6	▨	▨	▨
LIVING MARINE RESOURCES	▨	▨	0.1/0.5°C 100 m/10 km 10/2 PER DAY 6	▨	1/3 mb 1/10 km 1 km 10/2 PER DAY	0.5/1 m/s, 2/10° 5/100 km 1 km 2 PER DAY	▨	▨	▨
BIOLOGICAL OCEAN RESEARCH	▨	▨	0.1/0.5°C 100 m/10 km 10/2 PER DAY 6	5/20 W/cm² 100 km WEEKLY	1/3 mb 1/10 km 1 km 10/2 PER DAY	0.5/1 m/s, 2/10° 5/200 km 1 km 10/4 PER DAY	▨	▨	▨
OCEAN CONTAMINATION	▨	▨	▨	▨	▨	0.5/3 m/s, 2/10° 5/10 km 1km 10/4 PER DAY	▨	▨	▨
TACTICAL MILITARY OPERATIONS	1°C 10 km 30/100 m HOURLY 7	1°C 10 km HOURLY 7	0.25/1°C 10 km HOURLY	▨		5% OR 2/4 m/s, 5/10° 10/25 km 30/600 m ON CALL/3 HR 7	1% 10 km 30/300 m HOURLY 7	0.5 km 0.5 km ON CALL 7	30/3 0.5 k 30/3 ON C
STRATEGIC MILITARY OPERATIONS	1°C 100 km 30/400 m 3 HOURS 7	1°C 10 km 3 HOURS 7	0.5/1°C 10 km 3 HOURS 7	▨		5% OR 2/4 m/s, 5/10° 10/25 km 30/600 m 8/2 PER DAY 7	1% 100 km 30/300 m 3 HOURS 7	0.5 km 0.5 km 30 MIN 7	30/3 0.5 k 30/3 30 M
RANGE OF PARAMETER			-40 TO 35°C						

FOLDOUT FRAME 2

FOLDOUT FRAME

CLOUD EXTENT	CLOUD LEVELS & THICKNESSES	PRECIPITABLE WATER	PRECIPITATION EXTENT/AMOUNTS	PRECIPITATION TYPE	PRECIPITATION RATES	FOG/MIST VISIBILITY	AEROSOL EXTENT/ CONCENTRATIONS	OZONE CONCENTRATION	CARBON DIOXIDE CONCENTRATION	SHIP SEARCH & RESCUE LOCATION/ IDENTIFICATION/SIZING ACTIVITY DETERMINATION
							▨	▨	▨	▨
▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
5/20% 100/500 km DAILY 10	▨	0.1/0.3 cm/cm^2 200/500 km DAILY 6,10	10% 500 km 2 PER DAY 6		0.5/1 cm/HR 30/50 km DAILY 6	▨	0.002/0.01 ppm 500 km 3 km MONTHLY 10	0.01/0.02 cm 250/1000 km 3 km MONTHLY AVE 10	0.5/10 ppm 250/1000 km 3 km YEARLY 10	▨
		0.1 cm/cm^2 100/200 km 2 PER DAY 6			0.5/1 cm/hr 30/50 km 2 PER DAY 6	▨	0.002/0.01 ppm 100/200 km 3 km 2 PER DAY	0.01/0.02 cm 100/200 km DAILY	0.5/10 ppm 100/200 km DAILY	▨
5/50 km 6 MIN/2 HR 15	250/500 m 1/20 km 250/500 m 0.5/30 MIN 15	0.25/0.75 cm/cm^2 5/100 km 10 MIN/3 HR 15	5/50 km 5/50 km 5/60 MIN 15	R/S/S/H 2/200 km 2 MIN/2 HR 15	50% 3/50 km 3 MIN/2 HR 15	1/10 km 150/300 m HOURLY	▨	▨	▨	▨
							▨	▨	▨	▨
					0.5/1 cm/km 30/50 km 10/2 PER DAY 6		▨	▨	▨	▨
▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	5 m/20 m 5 m/20 m
▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	5 m/20 m 5 m/20 m
0.5 km 0.5 km ON CALL 7	30/30 m 0.5 km 30/300 m ON CALL 7	0.3 mm 0.5 km 30/300 m ON CALL 7			0.3 mm/HR 1 km ON CALL 7	10 km 150/300 m HOURLY 7				
0.5 km 0.5 km 30 MIN 7	30/300 m 0.5 km 30/300 m 30 MIN 7	0.3 mm 0.5 km 30/300 m 30 MIN 7			0.3 mm/HR 5 km 3 HOURS 7	10 km 150/300 m HOURLY 7				
		0.1 TO 1.5 cm/cm^2		RAIN, SLEET, SNOW, HAIL						

TABLE 5

POLAR REGION ENVIRONMENTAL MEASUREMENT NEEDS-OCEAN PROPERTIES

PRECISION
HORIZONTAL RESOLUTION
VERTICAL RESOLUTION
TEMPORAL REPEAT ☐
(GOAL/MIN. USEFUL)
REFERENCE SOURCE

	SEA SURFACE TEMPERATURE	SURFACE WIND SHEAR	ASTRONOMICAL & STORM TIDES	OCEAN CURRENT AMPLITUDE/DIRECTION	OCEAN CURRENT LOCATION	COASTAL/ESTUARY CIRCULATIONS AMPLITUDE/DIRECTION	COASTAL/ESTUARY CIRCULATIONS LOCATION	UPWELLING LOCATION/EXTENT	SEA SURFACE
SEA ICE FORECASTS	0.25/0.5°C 25/200 km DAILY [6]	0.1/0.2 dyne/cm² 100 m/10 km 10 PER DAY	5 cm 0.5 km 10 PER DAY [6]	5 cm/s/10%, 10° 1/20 km 2/5 DAYS [6]	1/20 km 1/20 km 2/5 DAYS [6]	0.5/2 cm/s, 5° 100 m/10 km 2/5 DAYS	100 m/10 km 100 m/10 km 2/5 DAYS	100 m/10 km 100 m/10 km DAILY	▨
SEA ICE RESEARCH	0.2/1.0°C 1/25 km 1/3 DAYS [9]	0.1/0.2 dyne/cm² 100 m/10 km 10/4 PER DAY	▨	5 cm/s/10%, 10° 1/20 km 2/5 DAYS [6]	1/20 km 1/20 km 2/5 DAYS [6]	▨	▨	▨	0.1/1 1/25 1/3 DA
GLACIOLOGY	▨	▨	▨	▨	▨	▨	▨	▨	▨
CLIMATE	0.1/1°C 200/500 km 1/3 DAYS [6,10]	0.1 dyne/cm² 500 km 4 PER DAY [10]	1/2 cm 100 km 1/2 cm 4 PER DAY	2/10 cm/s 50 km DAILY/ MONTHLY [6,10]	▨	▨	▨	100 m/10 km 100 m/10 km DAILY	0.005/0 200 km DAIL
LARGE SCALE WEATHER FORECASTS	0.25/1°C 100/200 km DAILY [6]	▨	▨	2/10 cm/s 25/100 km 4 PER DAY	1/20 km 1/20 km 4 PER DAY	▨	▨	1 km/10 km 1 km/10 km 4 PER DAY	▨
SEVERE STORM WARNINGS & FORECASTS	0.1/1.0°C 5/100 km 10 MIN/6 HR [6,15]	▨	▨	▨	▨	▨	▨	▨	▨
COASTAL OCEAN CONDITION FORECASTS	0.1/0.5°C 1/100 km 10/1 PER DAY [6,13]	0.1/1 dyne/cm² 100 m/10 km 10 PER DAY [6]	2 cm 0.5 km 10 PER DAY [6]	5 cm/s/10%, 10° 1/20 km 4 PER DAY [6]	1/20 km 1/20 km 4 PER DAY [6]	0.5/2 m/s, 5° 100 m/10 km 4 PER DAY	100 m/10 km 100 m/10 km 4 PER DAY	100 m/10 km 100 m/10 km 4 PER DAY	0.005/0. 10 m/5 4 PER D
PHYSICAL OCEAN RESEARCH	0.25/0.5°C 5/100 km 10/1 PER DAY [6]	0.1/1 dyne/cm² 100 m/10 km 10 PER DAY	2 cm 0.5 km 10 PER DAY [6]	1 cm/s/10%, 10° 1/20 km 10 PER DAY	1/20 km 1/20 km 10 PER DAY [6]	0.5/2 m/s, 5° 100 m/10 km 10 PER DAY	100 m/10 km 100 m/10 km 10 PER DAY	100 m/10 km 100 m/10 km 10 PER DAY	0.005/0. 5/100 km 2 PER DA MTHLY
OCEAN ICE ENGINEERING	0.25/0.5°C 5/100 km 10/1 PER DAY [6]	0.1/1 dyne/cm² 100 m/10 km 10 PER DAY	2 cm 0.5 km 1/10 PER DAY [6]	5 cm/s/10%, 10° 1/10 km 4 PER DAY	1/20 km 1/20 km 4 PER DAY	0.5/2 m/s, 5° 100 m/10 km 4 PER DAY	100 m/10 km 100 m/10 km 4 PER DAY	100 m/10 km 100 m/10 km 4 PER DAY	0.1/1 1/100 DAILY
LIVING MARINE RESOURCES	0.1/0.5°C 5/100 km 10/1 PER DAY [6]	0.1/0.2 dyne/cm² 100 m/10 km 10 PER DAY	2 cm 0.5 km 10 PER DAY [6]	5 cm/s/10%, 10° 1/10 km 4 PER DAY [6]	1/10 km 1/10 km 4 PER DAY [6]	0.5/2 m/s, 5° 100 m/10 km 4 PER DAY	100 m/10 km 100 m/10 km 4 PER DAY	100 m/10 km 100 m/10 km 4 PER DAY	0.025/0. 1/5 km 10 PER DA
BIOLOGICAL OCEAN RESEARCH	0.25/0.5°C 5/100 km 10/1 PER DAY [6]	0.1/0.2 dyne/cm² 10 m/10 km 10 PER DAY	2 cm 0.5 km 10 PER DAY [6]	5 cm/s/10%, 10° 1/20 km 10 PER DAY [6]	1/10 km 1/10 km 10 PER DAY [6]	0.5/2 m/s, 5° 100 m/10 km 10 PER DAY	100 m/10 km 100 m/10 km 10 PER DAY	100 m/10 km 100 m/10 km 10 PER DAY	0.005/0.0 5/100 km 2 PER DAY MTHLY
OCEAN CONTAMINATION	0.1/0.2°C 200 km DAILY [6]	0.1/0.2 dyne/cm² 10 km/10 km 10 PER DAY	5 cm 0.5 km 10 PER DAY [6]	2 cm/s/10%, 10° 1/20 km 10 PER DAY [6]	1/20 km 1/20 km 10 PER DAY	0.5/2 m/s, 5° 10 m/10 km 10 PER DAY	10 m/10 km 10 m/10 km 10 PER DAY	10 m/10 km 10 m/10 km 10 PER DAY	0.005/0.0 100 m/5 DAILY
TACTICAL MILITARY OPERATIONS	0.25/0.8°C 10/25 km HRLY/3 DAYS [7]								
STRATEGIC MILITARY OPERATIONS	0.25/0.8°C 10/25 km 3 HR/3 DAYS [7]								
RANGE OF PARAMETER	-2 TO 35°C		0 TO 15 m						0 TO 40

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UPWELLING LOCATION/EXTENT	SEA SURFACE SALINITY	CHLOROPHYL EXTENT/ CONCENTRATION	DISSOLVED NUTRIENT CONCENTRATION	PHYTOPLANKTON TYPE/ EXTENT	TURBIDITY	PETROLEUM POLLUTANT TYPE/EXTENT	PETROLEUM POLLUTANT THICKNESS	FISH OIL/BIPRODUCT TYPE/EXTENT	FISH OIL THICKNESS	FISH/MAMMAL IDENTIFICATION/SIZING
100 m/10 km 100 m/10 km DAILY	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
▨	0.1/1 ppt 1/25 km 1/3 DAYS 18	▨	▨	▨	▨	▨	▨	▨	▨	▨
▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
100 m/10 km 100 m/10 km DAILY	0.005/0.01 ppt 200 km DAILY	▨	▨	▨	▨	▨	▨	▨	▨	▨
1 km/10 km 1 km/10 km PER DAY	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
100 m/10 km 100 m/10 km PER DAY	0.005/0.01 ppt 10 m/5 km 4 PER DAY	▨	▨	▨	▨	▨	▨	▨	▨	▨
100 m/10 km 100 m/10 km PER DAY	0.005/0.01 ppt 5/100 km 2 PER DAY/ MTHLY 6	▨	▨	▨	▨	▨	▨	▨	▨	▨
100 m/10 km 100 m/10 km PER DAY	0.1/1 ppt 1/100 km DAILY	▨	▨	▨	▨	▨	▨	▨	▨	▨
100 m/10 km 100 m/10 km PER DAY	0.025/0.05 ppt 1/5 km 10 PER DAY 6	0.3 μg/l/10% 400 m 2/3 DAYS 6	400 m 2 PER DAY	400 m 2 PER DAY	400 m 2 PER DAY	▨	▨	400 m DAILY	400 m DAILY	10 cm/10 m 10 cm/10 m DAILY
00 m/10 km 00 m/10 km PER DAY	0.005/0.01 ppt 5/100 km 2 PER DAY/ MTHLY 6	0.3 μg/l/10% 400 m DAILY 6	50/400 m 2 PER DAY	400 m 2 PER DAY	400 m 2 PER DAY	▨	▨	400 m DAILY	400 m DAILY	10 cm/10 m 10 cm/10 m DAILY
10 m/10 km 10 m/10 km PER DAY	0.005/0.01 ppt 100 m/5 km DAILY	0.3 μg/l/10% 400 m DAILY 6	50 m 4 PER YEAR	▨	50 m DAILY	10/40 m 1/3 MO 14	20 m 1 WK/3 MO 14	50 m DAILY	50 m DAILY	▨
								▨	▨	▨
			▨	▨		▨	▨	▨	▨	▨
	0 TO 40 ppt	0.1 TO 100 μg/l								

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of the tables shows the values to be highly inconsistent between two or more references; there are also apparent inconsistencies from parameter to parameter relative to the scale of the physical process of interest. These discrepancies are apparently due to the fact that some needs were being recommended based on a consideration of the physics of the environmental process of interest, while others were more tied to the limits in the physics of the remote measurement technique. More than enough information is provided, though, to allow an evaluation of measurement feasibilities and payload utilities.

B. PROCESSING AND DELIVERY REQUIREMENTS

Most of the processing and delivery requirements of industry and government services are for real-time or near-real-time information. In 1 to 3 hours, the atmosphere, the ocean, and sea ice can change drastically, either preventing or delaying operations, navigation, lobster pot retrieval, etc. This means that nowcasts and forecasts are needed on short turnaround times, preferably in less than 1 hour; but delivery in less than 3 hours is acceptable under some conditions. Government control functions such as fish management and pollution control also benefit from near-real-time information, but daily sources are adequate as a rule. In order to maintain efficient control, however, violators must be identified and contacted. This implies that too much time cannot be allowed to elapse between the measurement and the analysis and display. Military operations require extremely short processing and delivery times for both strategic and tactical purposes.

Scientific analysis is often conducted based on hindcasts and does not usually require real-time data delivery. The major interest of the scientist is to have all of the archives easily accessible to him at a price affordable from NSF, ONR, or other grants. Climate, glaciology, hydrology, and ocean/ice engineering disciplines, in addition, require information that is averaged over long periods of time. Thus, some archiving capability that averages the data taken over several different time cycles to preserve an understanding of the seasonal, diurnal, and other temporal cycles could be of great benefit to ongoing research in these areas. The distributions of deviations about these averages are also important.

IV. POLAR MEASUREMENT STATUS

The array of measurement requirements presented in Tables 3, 4, and 5 are imposing and illustrate how difficult it is to assess the ability to make each measurement, to place priorities on the measurement based on their apparent utility, and to assign the sensors derived to satellite orbits or aircraft flight paths depending on the coverage required and sensor feasibilities. Tables 6, 7, and 8 match the present satellite remote sensor capability to these requirements in terms of polar ice, atmosphere, and ocean properties, respectively. Required capability is taken by summing the columns in Tables 3, 4, and 5. No attempt has been made to prioritize the different levels of required capability since it is difficult from our perspective to assign relative importance to disciplines. The present capability was derived from the listed capabilities for each of the sensors on existing flight systems or soon to be launched sensors [see Ref. 19]. The acronyms for the spacecraft sensor systems are defined in Table 9.

The proposed capability is a combination of that proposed by GSFC [Ref. 18], JPL [Ref. 20], LeRC [Ref. 21], Canada [Ref. 22], and ESA [Ref. 23]. In general, the capabilities proposed do not represent high-risk developments. Many are but adaptations of existing sensors, while others, though new to the satellite, are well demonstrated from aircraft flights. In order to evaluate the proposed capability, it is useful to discuss the measurements in terms of groupings of physics problems. As noted in Reference 19, measurement optimization tends to differ depending on whether the process being measured is thermal, convective, water cycle, chemical/biological, texture, or special feature oriented.

TABLE 6

POLAR ICE MEASUREMENT CAPABILITIES COMPARISON

Measurement	Required Capability				Proposed Capability				Present Capability				Spacecraft Sensor Acronym or Development Status
	Precision	Resolution		Temporal Repeat	Precision	Resolution		Temporal Repeat	Precision	Resolution		Temporal Repeat	
		Horizontal	Vertical			Horizontal	Vertical			Horizontal	Vertical		
Ice/Snow Surface Temperature	0.1°C/3°C	5m/100km	-	3hr/Monthly	0.25°C/0.5°C	10km/25km	-	6 hr	0.25°C/1°C	10km/12km	-	1 Day/2 Days	AVHRR/SMMR
Vertical Ice/Snow Temp. Profile	0.1°C/1°C	5m/25km	10cm/5m	Weekly/Monthly	-	-	-	-	-	-	-	-	-
Polar Region Albedo	0.2%/3%	100m/500km	-	Daily/Monthly	2%	25km	-	Daily	<10%		-	Daily	ERBI
Ice/Snow/Glacier Extent	1m/50km	1m/50km	-	3hr/Yearly	20m/5km	20m/5km	-	Daily	25m/21km	25m/21km	-	Weekly/3 Days	SAR/SMMR
Ice/Snow Fraction	1%/30%	1km/100km	-	6hr/Weekly	2%	100%/25%	-	Daily	TBD/5%	25m/50km	-	Weekly/3 Days	SAR/SMMR
Ice Thickness	10cm/50m	100m/50km	10cm/50m	12hr/Monthly	TBD	1km	1m	Monthly	-	-	-	-	<u>Aircraft</u>
Snow Depth	5cm/1m	10km/50km	5cm/1m	Daily	TBD	1km	1m	Monthly	-	-	-	-	<u>Aircraft</u>
Ice Top/Bottom Surface Roughness	10cm/1m	1m/10m	10cm/1m	Monthly/Yearly	TBD	1km	1m	Monthly	-	-	-	-	<u>Aircraft</u>
Water Equivalency of Snow	1cm/3cm	1km/50km	-	Weekly	TBD	25km	-	Weekly	-	-	-	-	-
Ice Age and Salinity	10%/20%	1km/500km	-	Daily/Yearly	TBD	25km	-	Daily	TBD	75km/121km	-	3 Days	SMMR
Ice/Snow Sublimation Rate	10W/m^2	20m/500km	-	Daily/Monthly	-	-	-	-	-	-	-	-	-
Ice/Snow Melt Rate	Yes/No	1km/25km	-	1 Day/3 Days	Yes/NO	25km	-	Daily	-	-	-	-	-
Sea Ice Drift Rate	100m/day	50m/10km	-	3hr/3 Days	TBD	20m/100m	-	Daily	TBD	25m	-	Weekly	SAR
Ice Deformation Rate	0.1%	10m/100m	-	Weekly/Yearly	TBD	20m/100m	-	Daily	TBD	25m	-	Weekly	SAR
Ice Pattern Identification	10m/100m	10m/100m	-	Weekly/Yearly	TBD	20m/100m	-	Daily	TBD	25m	-	Weekly	SAR
Ice Lead Location/Sizing	5m/100m	5m/100m	-	Hourly/3 Days	TBD	20m/100m	-	Daily	TBD	25m	-	Weekly	SAR
Crevasse Location/Sizing	5m/100m	5m/100m	-	Yearly	TBD	20m/100m	-	Daily	TBD	25m	-	Weekly	SAR
Iceberg Location/Sizing	5m/100m	5m/100m	-	6hr/Daily	TBD	20m/100m	-	Daily	TBD	25m	-	Weekly	SAR
Iceberg Formation Rate	TBD	5m/100m	-	Daily/Weekly	TBD	20m/100m	-	Daily	TBD	25m	-	Weekly	SAR

(Most Difficult Capability Desired/
Minimum Useful Capability)

(First Sensor Type/Second Sensor Type from Last Column)

TABLE 7

POLAR ATMOSPHERIC MEASUREMENT CAPABILITIES COMPARISON

Measurement	Required Capability				Proposed Capability				Present Capability				Spacecraft Sensor Acronym or Development Status
	Precision	Resolution		Temporal Repeat	Precision	Resolution		Temporal Repeat	Precision	Resolution		Temporal Repeat	
		Horizontal	Vertical			Horizontal	Vertical			Horizontal	Vertical		
Vertical Atmospheric Temp. Profile	0.1°C/2°C	1km/500km	30m/5km	Min/Days	0.2°C/0.5°C	25km	2km	12hr	0.5°C/1°C	25km/150km	2/5km	Daily	HIRS, MSU
Cloud Top Temperature	0.1°C/2°C	1km/500km	-	3hr/Daily	0.2°C/0.5°C	1km	-	12hr	0.5°C/1°C	1km/121km	-	1 Day/2 Days	AVHRR, SMMR
Surface Air Temperature	0.1°C/1°C	100m/200km	-	Hourly/Days	TBD	25km	-	12hr	-	-	-	-	-
Regional Net Radiation	2W/25W/m^2	100km/500km	-	Daily/Monthly	5W/m^2	100km	-	Daily	10W/m^2	-	-	Daily	ERBI
Vertical Pressure Profile	1mb/10mb	1km/500km	1km/5km	3hr/Days	3mb	25km	3km	12hr		4x2km	Column	Daily	PMR
Vertical Wind Profile Ampl/Dir	1m/4m/s,2/20°	5km/50km	0.5km/5km	Min/Days	2m/s,5°	25km	3km	12hr		1km		Hourly	VISSR
Vertical Humidity Profile	1%/30%	5km/500km	30m/5km	Min/Days	5%	25km	2km	12hr	20%	25km	2km	Daily	HIRS
Cloud Extent	1%/20%	0.5km/500km	-	Min/Daily	1km	1km	-	12hr	1km	1km	-	Hourly	VISSR
Cloud Levels and Thicknesses	0.5m/1km	5km/500km	0.5m/1km	3hr/12hr	2km	25km	2km	12hr	2km	25km	2km	Daily	HIRS
Precipitable Water	0.1m/1m/m^2	0.5km/500km	30m/300m	Min/Daily	TBD	25km	-	12hr	TBD	121km	-	3 Days	SMMR
Precipitation Extent/Amount	10%	5km/500km	-	Min/12hr	TBD	1km	1km	Daily	-	-	-	-	-
Precipitation Type	Rain/Snow	2km/200km	-	Min/Daily	TBD	1km	1km	Daily	-	-	-	-	-
Precipitation Rates	0.5cm/2cm/hr	3km/200km	-	Min/Daily	TBD	1km	1km	Daily	-	-	-	-	-
Fog/Mist Visibility	10/4 levels	1km/200km	-	1hr/12hr	TBD	25km	2km	12hr	-	-	0.5km	-	-
Aerosol Extent/Concentration	5%/25%	10km/500km	0.5km/5km	Daily	TBD	50km	0.5km	12hr	TBD	190km	Column	Daily	SAGE
Ozone Concentration	2%/20%	50km/500km	0.5km/10km	Daily	TBD	50km	3km	12hr		40km		Daily	BUVS
Carbon Dioxide Concentration	2%/20%	10km/500km	0.5km/3km	Daily	TBD	50km	3km	12hr					ATMOS

(Most Difficult Capability Desired/
Minimum Useful Capability)

(First Sensor Type/Second Sensor Type from Last Column)

TABLE 8

POLAR OCEAN MEASUREMENT CAPABILITIES COMPARISON

Measurement	Required Capability				Proposed Capability				Present Capability				Spacecraft Sensor Acronym or Development Status
	Precision	Resolution		Temporal Repeat	Precision	Resolution		Temporal Repeat	Precision	Resolution		Temporal Repeat	
		Horizontal	Vertical			Horizontal	Vertical			Horizontal	Vertical		
Sea Surface Temperature	0.1 C/1 C	1km/500km	-	Hourly/Daily	0.25/0.5°C	10km/25km	-	12hr	0.25°C/0.5°C	10km/120km	-	1 Day/3 Days	AVHRR,SMMR
Surface Wind Shear	0.1 dyne/1 dyne/cm^2	50m/500km	-	6 hr/Daily	0.2 dyne/cm^2	25km	-	12hr	0.2 dyne/cm^2	50km	-	Daily	SASS
Astronomical and Storm Tides	1cm/10cm	0.5km/100km	1/10cm	Hourly/Daily	<10cm	1 to 10km	40km	2½ Months	<10cm	2 to 12km	<10cm	5 Months	ALT
Ocean Current Amplitude/Direction	1cm/5cm/s,5°/10°	1km/100km	-	Hourly/Daily	TBD		-		TBD	2 to 12km	<10cm	Daily	ALT
Ocean Current Location	1km/100km	1km/100km	-	Hourly/Daily	100m/30m	100m/30m	-	Daily/Weekly	25m/80m	25m/80m	-	Weekly	SAR,MSS
Coastal/Estuary Circulation Ampl/Dir	0.1m/50m/s,2/10°	10m/10km	-	Hourly/Daily			-		-	-	-	-	-
Coastal/Estuary Circulation Location	10m/10km	10m/10km	-	Hourly/Daily	100m/30m	100m/30m	-	Daily/Weekly	25m/80m	25m/80m	-	Weekly	SAR,MSS
Upwelling Location/Extent	10m/10km	10m/10km	-	Hourly/Daily	100m/30m	100m/30m	-	Daily/Weekly	25m/80m	25m/80m	-	Weekly	SAR,MSS
Sea Surface Salinity	0.005ppt/0.05ppt	50m/200km	-	Hourly/Yearly	TBD	25km	-	Daily	-	-	-	-	-
Chlorophyll Extent/Concentration	0.3μg/ℓ/10%	50m/5km	-	Daily/Weekly	TBD	400m	-	12hr	TBD	800m	-	Daily	CZCS
Dissolved Nutrient Ext/Concentration		50m/5km	-	Daily/Weekly	TBD	400m	-	12hr	TBD	800m	-	Daily	CZCS
Phytoplankton Type/Extent		50m/5km	-	Daily/Weekly	TBD	400m	-	12hr	TBD	800m	-	Daily	CZCS
Turbidity	0.01/ppm	50m/1km	-	Daily/Weekly	TBD	400m	-	12hr	TBD	800m	-	Daily	CZCS
Petroleum Pollutant Type/Extent		10m/1km	-	Daily/Weekly	100m/400m	100m/400m	-	Daily	25m/400m	25m/800m	-	Weekly/Daily	SAR,CZCS
Petroleum Pollutant Thickness		10m/50km	-	Daily			-						Aircraft
Fish Oil/By-product Type/Extent		10m/1km	-	Daily	100m/400m	100m/400m	-	Daily	25m/800m	25m/800m	-	Weekly/Daily	SAR,CZCS
Fish Oil/By-Product Type/Extent		10m/50m	-	Hourly/Daily			-						Aircraft
Fish Oil/By-Product Thickness	100cm/10m	10m/10m	-	Hourly/Daily	-	-	-	-	-	-	-	-	-
Ship Location/Ident/Sizing/Activity	1m/100m	1m/10m	-	Hourly/Daily	100m	100m	-	Daily	25m	25m	-	Weekly	SAR
Search and Rescue	1m/100m	1m/100m	-			-	-	-	-	-	-	-	-

(Most Difficult Capability Desired/
Minimum Useful Capability)

(First Sensor Type/Second Sensor Type from last Column)

TABLE 9

SENSOR ACRONYM DEFINITIONS

ABLS	Advanced Boundary Layer Sounder
ALT	Altimeter
ATMOS	Atmospheric Trace Molecules Observed by Spectroscopy
AVHRR	Advanced Very High Resolution Radiometer
BSU	Basic Sounding Unit
BUVS	Backscatter Ultraviolet Spectrometer
CPR	Cloud Physics Radiometer
CZCS	Coastal Zone Color Scanner
ERBI	Earth Radiation Budget Instrument
HIRS	High Resolution Infrared Radiation Sounder
HRMI	High Resolution Microwave Imager
LIMS	Limb Infrared Monitoring of the Stratosphere
MSS	Multispectral Scanner
MSU	Microwave Sounding
PMR	Pressure Modulated Radiometer
RBV	Return Beam Vidicon
SAGE	Stratospheric Aerosol Gas Experiment
SAR	Synthetic Aperture Radar
SASS	SEASAT-A Scatterometric Sensor
SMMR	Scanning Multichannel Microwave Radiometer
SPR	Surface Pressure Radar
TM	Thematic Mapper
VAS	VISSR Atmospheric Sounder
VISSR	Visible/Infrared Spin Scan Radiometer
WSIR	Wide Swath Imaging Radar

A. THERMAL AND STATE MEASUREMENTS

Thermal measurement physics generally can be grouped into three categories: surface emission, atmospheric emission, and subsurface emission. For emission, the problem is one of isolating a local temperature from the effects of surface and subsurface emittance and of absorptance through the intervening material, whether in the infrared or microwave region. For atmospheric emission, then, it is important to separate out the effects of variable composition, aerosols, and water content and to use variable sensitivity on the absorption bands of some major atmospheric constituent like oxygen to develop a series of absorption extinctions in depth, in order to determine vertical profile. For selected frequencies, emitted energy below a certain altitude will be reabsorbed by this higher atmosphere and will not be received at the satellite sensor. The trend is thus towards narrower bandwidths to get these sensitivities. In the infrared, wave numbers ($\Delta\lambda/\lambda$) of the order of 0.01 are appropriate if the surface air temperatures at the 6-m altitude reference level are desired. Present sensors have wave numbers of about 1, and the proposed capability in Table 7 is for a sensor (currently being developed at JPL) with a wave number of about 0.1. Resolutions of 25 km are consistent with presently available optics sizes and these narrow bandwidths. Pressure profiles can be similarly developed by utilizing pressure-sensitive frequency bands in this same absorption extinction fashion or by using reflected laser energy on and off absorption bands with differing pressure sensitivities.

Surface emission measurements similarly have to deal with atmospheric losses and with surface emittance effects due to roughness and, occasionally, composition. Four to six infrared or microwave channels, if well chosen, can usually be used to make these separations. Four are presently suggested by GSFC for improved sea surface temperatures; one or more additional channels would be useful to better account for ice and snow roughness effects plus the tendency of ice and snow to absorb and emit in depth rather than at the surface. Since wider bandwidths are allowed for these measurements, finer surface resolution can be obtained for the same detector sensitivity limits. Infrared sea and ice surface temperatures can thus be measured to resolutions on the order of a kilometer or less, but suffer from too large an error in cloudy skies. The present microwave surface mapping sensor systems with five channels, similarly, would need additional channels to account for ice/snow emittance differences. The microwave is desirable from the point of view of better sensitivity to atmospheric water, but suffers from lack of availability of channels. Channels must be selected from those available by international agreement or suffer from periodic saturation when passing by communications channels in that frequency regime. In fact, some of the channels in the existing microwave surface mapper are not up for approval in next year's international meeting to establish bandwidth allocation. Subsurface ice temperatures are not presently feasible from space. Some success with ocean vertical profiles has been acquired using laser spectral extinction techniques. The ability of ice and snow to emit in depth can provide some separable information on temperature profile, but present research is not sufficiently advanced to provide useful correlations.

B. CONVECTIVE PROCESS MEASUREMENTS

Motions are primarily derived from time series images or from doppler shifts in the signals from active sensors. Time series images are used to record slow moving ice motions and their drifts and deformations. Small changes require fine resolution and, since cloud cover is typical in the polar reflections, synthetic aperture radar images are needed to see through clouds. Canadian and ESA studies [Refs. 22 and 23] show resolutions of 20 m to be necessary. NASA studies show resolutions as low as 5 m to be important for some uses, but suggest a 100-m compromise in order to allow a wide swath from a single sensor and "reasonable" data rates. This compromise is driven by science interests and agency cost concerns rather than industry interests, which tend to favor Canadian and ESA recommendations. Time series images of cloud motions are used similarly to infer wind motions. Because the motions are more rapid, the scale can be compromised and resolutions of 1 km (similar to the infrared thermal mapping) are adequate.

Doppler techniques for determining surface velocities are under study. Ship and plane motions appear on radar images and suitable analysis could provide velocity. The use of doppler techniques to study water motions is also of interest, but these do not offer suitable sensitivities at present.

Laser and radar sounding of the atmosphere also provides some doppler data due to aerosol and cloud motions. This is under study also, and a test of the concept could be made if an experimental atmospheric laser or atmospheric radar sensor is included in the payload.

Several more indirect measures of velocity are also utilized. North/south currents cause localized bulges in the ocean surface due to Coriolis effects. Altimetric techniques can determine the height of these bulges, and mass velocities can be derived. Similarly, wind-shear-caused surface roughness on the water can be measured with scatterometers or with microwave radiometers. This roughness measure can be interpreted upward to indicate surface wind velocity and downward to indicate surface layer transport.

C. WATER CYCLE MEASUREMENTS

Humidity is just another major atmospheric constituent, and appropriate development of the IR/μw atmospheric thermal and pressure sounder mentioned earlier will also provide a humidity profile. Precipitation is somewhat more difficult. Microwave radiometric techniques have been successfully used to identify areas of rain and have been used with mixed success to quantify the rain. Radar systems are sensitive to precipitation and conceptually could determine all of the precipitation parameters noted in Table 7. These rain radars, under development at GSFC and LeRC, are limited, however, by the availability of suitable frequencies. An experimental sensor needs to be flown in space.

Fog or mist visibility may be derivable from the 0.01 wave number sounder, but is also detectable with suitable laser wavelengths. Lasers suffer from the difficulty of their space implementation. The utility of a laser for this use alone would not justify it unless the frequency of interest had a wide range of other uses. An experimental laser was suggested by GSFC, but more work is needed before the wavelengths are chosen.

The extent and thickness or depth of sea ice, sheet ice, and snow cover are important to global weather, navigation, climatology, polar hydrology, and glaciology. Extent and fraction cover are easily grossly determined by passive microwave mapping to resolutions of about 1 km. Finer detail can be derived from the imaging radar.

Thickness of sea ice and depth of sheet ice on glaciers are more difficult to determine. Single layers of freshwater ice have been measured with S- and L-band altimetry. As the layering becomes more complex and the contained debris increases, sensitivities drop off. Similarly, variable salinity in saltwater ice makes interpretation difficult if not impossible. It may be possible to determine sea ice even with salinity to thicknesses up to 1 m with S-band or L-band systems, but much more experimental work is needed. Studies such as Reference 24 imply that megahertz frequencies (10 to 300 MHz) may provide adequate sensitivity, but more experimental verification is needed. Megahertz active radars in space require <u>very</u> large antennas if ground resolutions are to be "reasonable." Some experiments measuring sheet ice thickness using a swept frequency microwave radiometry have been made, but success was limited by the same layering complexity effect.

D. CHEMICAL AND BIOLOGICAL MEASUREMENTS

Ice is of little interest in obtaining chemical or biological measurements, except perhaps in the determination of sea ice age from salinity content. Microwave radiometers have been successfully used to measure this to adequate sensitivities.

Ocean chemistry and biology do affect the interaction between the two systems and the viability of the fish resources in the polar regions. Colorimetry (multispectral, narrow bandwidth radiometry in the visible and infrared regions) has been broadly used from aircraft to measure chlorophyll, nutrients, phytoplankton, turbidity, etc., and a space demonstration of this capability is planned for NIMBUS-G. The specific frequencies of interest to the polar regions are only partially the same as those of the NIMBUS sensor. Sea surface salinity has been measured from L-band (∿1.4 GHz) radiometry and from sea glitter using visible channels. Salinity does not appear important enough in polar regions to warrant a separate L-band radiometer development, but the colorimeter could be used in a glitter mode with relatively minor modifications to the scanning optics.

Petroleum and fish oil extent appears well in synthetic aperture radar images and often in colorimetry. These materials change the surface roughness which affects the amount of reflected energy seen by the radar or the colorimetry and, in the case of the colorimeter, compositional variations change the fraction absorbed by the surface in different wavelengths. Typing and thickness measurements have been made from aircraft using laser systems. Choice of frequency appears to be important since absorption or fluorescence effects are often specific to layers from different sources (oilfields or fish). Again, some experimental effort is needed, but a program has been initiated at LeRC to explore this problem [Ref. 25]. This problem is not unique to the polar region; neither are any of the chemistry and biological measurements.

The final chemistry measurements are in the atmosphere. Ozone and carbon dioxide have a major effect on radiation balance in the polar regions, and this needs to be determined at high latitudes. NIMBUS-G and UARS[1] have addressed this atmospheric constituent problem for these and for a wide variety of natural and man-induced trace constituents thought to be important to the chemistry involved with atmospheric radiation balance. Downward looking absorption techniques have had some success for these major constituents, but there is a longer range trend towards continuous-wave (CW) and pulsed laser systems. Use of matched line pairs on and off an absorption line provide very sensitive measures of constituent concentrations in the upper atmosphere using CW lasers. Pulsed lasers are needed to extend the technique deeper into the troposphere through application of similar concepts. The UARS [Ref. 26] and Shuttle LIDAR [Ref. 27] reports provide good detail on these techniques. Again, the problem is not peculiar to the polar region; therefore, inclusion of pulsed lasers on a polar satellite may be questionable unless there are physics reasons that indicate a need for a shared orbit.

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[1] UARS - Upper Atmosphere Research Satellite.

E. SURFACE AND IN-DEPTH TEXTURE MEASUREMENTS

Surface texture in ice relates to both top and bottom roughness due to ridging, dislocations, and storm erosion. Ocean roughness in terms of waves and tides also affect edge erosion and dislocations. Radar and laser altimetry provide the best measure of surface roughness. Ocean wave roughness and other surface height oscillations have been measured with radar on GEOS-3 and SEASAT-A. These are essentially pulse-limited techniques in terms of the surface resolution being related to the wave height. For ice, the roughness is so much greater that pulse-limited resolution becomes too large for the scale of interest. This means either that very large antennas and higher frequencies (if beam limited techniques are to be undertaken with radar) are necessary or that switching to laser implementations is needed to get better beam control. The laser implementation suffers from loss of measurement capability due to cloud absorption. The larger altimeter antennas suggested in the more ambitious NOSS report [Ref. 20] thus help the ocean surface roughness determination, but do little for ice since the footprint is still pulse limited. Because many of the users require only monthly coverage broadly or daily coverage in local areas, this technique may prove more advantageous for aircraft implementations. In addition, since roughness has been shown to respond best to radar wavelengths of the same relative magnitude as the roughness, it may be that L-band or megahertz (10-to 300-MHz) altimetry implementations will prove more beneficial than the existing X-band (spacecraft) and S-band (aircraft) sensors presently under evaluation.

F. SPECIAL FEATURES

Special features primarily involve location and identification of point, line, or areal features. In polar regions, ship locations, leads, thin ice, ice edges, and icebergs all have to be choreographed for efficient navigation. The synthetic aperture radar appears to do a good job in this area, providing accurate locations, observation through clouds, and small feature detection. Ships, icebergs, and leads are sufficiently different in reflectivity from the surrounding material that they are usually easily detectable in resolution cells much larger than their size.

Top feeding fish, seals, walruses, and whales have been observed to modulate the surface of the water when they feed or travel near the top surface. Systematic studies to quantify the effect of this modulation and distinguish it from background noise have not been undertaken and indeed may prove infeasible or impractical from space. There are similar problems associated with identifying polar mammals from space. In the management of these animals, it is sometimes adequate to identify environmental conditions conducive to their proliferation in order to infer population pressures. Thus, caribou need thin snow to stomp up the foods they need from the land underneath, and Canadian geese need certain valleys to be free from snow at the proper time in order to lay their eggs and hatch their eggs in time for the fall migration south. These types of problems are not strong enough by themselves to warrant special sensor developments for ice missions, but relevant data could be obtained peripherally using sensors that are designed for other purposes; e.g., a goose management experiment was planned utilizing SEASAT-A radar images [Ref. 4].

V. SENSOR STATUS

Many of the sensors needed for polar monitoring are available today and, with slight modifications in the spectral bands, could be optimized for ice properties rather than for atmosphere, ocean, or land use. Most of the new sensor concepts are centered in the active sensors, whether they be laser or radar based. In this section, we will look at passive and then active sensors, starting with microwave and working towards the ultraviolet. For each sensor type, a comparison will be made between existing systems and those proposed by GSFC, JPL, and LeRC in their studies. Other possibilities that need consideration will be suggested where appropriate. A key connecting the requested measurements with generic sensor types is provided in Table 10.

A. MICROWAVE AND MILLIMETER WAVE RADIOMETERS

Microwave radiometers have the advantage of being able to make surface measurements in the presence of reasonably heavy cloud cover. A comparison of existing and proposed microwave surface mappers is provided in Table 11. These appear useful for measuring ice/snow/glacier extent and coverage fraction, ice age and salinity, gross sea ice drift rates, ice/snow/water surface temperature, surface wind stress, and rain and cloud water content. The 6.6-, 10.69-, 18-, 21-, and 37-GHz channels represent current satellite flight experience. Inclusion of an L-band channel ($\sim$1.4 GHz) has some potential for surface soil moisture, and inclusion of several frequencies about the oxygen band at 55 GHz provides an important adjunct to the improved infrared atmospheric sounder. The addition of the 94-GHz channel provides finer surface resolution for determining ice extent and coverage fraction and some improvement in atmospheric water determinations. The 6.6- or 4.25-GHz channels represent the breadth of the best water window.

TABLE 10

SENSOR CONCEPTS APPLICABLE TO POLAR MISSIONS

	Spacecraft Sensor Acronym or Development Status	BUVS	ERBI	HIRS	ATMOS/LIMS	AVHRR	CZCS	MSS/TM	Aircraft		Aircraft	Laboratory	Laboratory	SMMR	Aircraft	MSU	Laboratory	Aircraft	Aircraft	Aircraft	Laboratory	Aircraft	SAR	Aircraft	Aircraft		ALT	SASS	Aircraft	Laboratory	
	Sensors	Atmospheric Composition Mapper	Radiation Budget Mapper	Atmospheric Sounder	Atmospheric Composition Mapper*	Thermal/Cloud Mapper	Surface Composition Mapper*	Surface Feature Mapper*	Stereo Surface Mapper*	Pointable Imager*	Glitter/Polarization Mapper*	Surface Mapper	Atmospheric Sounder	Surface Mapper	Swept Frequency Mapper	Atmospheric Sounder	CW Atmospheric LIDAR	Pulsed Atmospheric LIDAR	Surface Composition LIDAR	Laser Altimeter	Laser Scatterometer	Doppler Laser	Synthetic Aperture Radar	MHz Real Aperture Radar	Precipitation Radar	Swept Frequency Radar	Radar Altimeter	Radar Scatterometer	Doppler Radar	Pressure Radar	Unknown
	Measurement	UV	VSIR									MMW		μW			VSIR						μW								
ICE	Ice/Snow/Glacier Extent							x		x		x											x								
	Ice/Snow Fraction							x		x		x											x								
	Ice Thickness														x									x		x	x				
	Snow Depth														x									x		x	x				
	Ice Top/Bottom Surface Roughness								x		x									x	x			x		x	x	x			
	Water Equivalency of Snow																														x
	Ice Age and Salinity										x			x														x			
	Ice/Snow Sublimation Rate																														x
	Ice/Snow Melt Rate																														x
	Sea Ice Drift Rate							x		x		x											x								
	Ice Deformation Rate							x	x	x													x								
	Ice Lead Location/Sizing							x		x													x								
	Crevasse Location/Sizing							x		x													x								
	Iceberg Location/Sizing							x		x													x						x		
	Iceberg Formation Rate							x		x													x								
	Snow/Ice Surface Temperature					x								x																	
	Vertical Snow/Ice Temperature Profile																														x
	Polar Region Albedos		x			x																									
	Net Regional Radiation		x			x																									
ATMOSPHERIC	Ozone Concentration	x			x												x	x													
	Carbon Dioxide Concentration				x								x			x	x	x													
	Vertical Atmospheric Temperature Profile			x									x			x		x													
	Cloud Top Temperature			x									x																		
	Surface Air Temperature (6 m)			x																											
	Vertical Pressure Profile			x														x												x	
	Vertical Wind Profile					x		x														x							x		
	Vertical Humidity Profile			x									x	x		x	x	x													
	Cloud Extent					x		x																							
	Cloud Levels and Thicknesses			x																											
	Precipitable Water												x			x									x						
	Precipitation Extent/Amount												x			x									x						
	Precipitation Type																								x						
	Precipitation Rates																							x	x						
	Fog/Mist Visibility			x																											
	Aerosol Extent/Concentrations				x												x	x				x							x		
OCEANS	Sea Surface Temperature					x				x				x																	
	Sea Surface Salinity						x			x	x			x					x												
	Chlorophyll Extent/Concentration						x			x									x												
	Dissolved Nutrient Concentration						x			x									x												
	Phytoplankton Type/Extent						x			x									x												
	Turbidity						x			x									x												
	Fish Oil By-Product Type/Extent						x			x	x	x							x				x								
	Fish Oil Thickness																		x				x								
	Fish/Mammal Identification/Sizing																						x								
	Surface Wind Shear													x														x			
	Astronomical and Storm Tides																			x							x				
	Ocean Current Amplitude/Direction																			x		x	x				x		x		
	Ocean Current Location							x		x													x								
	Coastal/Estuary Circulations Amplitude/Direction																					x	x						x		
	Coastal/Estuary Circulations Location							x		x													x								
	Upwelling Location/Extent					x	x	x		x									x				x								
	Petroleum Pollutant Type/Extent						x			x		x							x												
	Petroleum Pollutant Thickness																		x												
	Ship/Search and Rescue Location/Identification/Size/Activity							x		x													x								

*Requires specific sun lighting

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TABLE 11

POLAR MICROWAVE AND MILLIMETER WAVE SENSOR COMPARISONS

	Frequencies	Precision	Antenna Size	Effective Resolution		Scan Angle	Effective Swath	View Angle
				H	V			
Microwave Surface Mappers								
Existing: SMMR (SEASAT-A/NIMBUS-G)	6.6, 10.69, 18, 21, 37 GHz	0.3°C to 1.1°C	0.8m	121km to 21km	-	±25°	638km	42°
NOSS (Ref. 20)	6.6, 10.69, 18, 21, 37, 94 GHz	0.3°C to 1.2°C	4m	21km to 7 km	-	360°	1325km	42°
IPACS (Ref. 18): HRMI	1.4, 4.25, 10.7, 18, 21, 37, 94 GHz		3m	185km to 3km	-	360°	2000km	45°
PMS (Ref. 28)		0.5°C	10m	10km	-		1000km	Cross-Track
Microwave Atmospheric Sounders								
Existing: MSU (TIROS-N)	50.30, 53.74, 54.96, 57.95 GHz	0.3°C	0.2m	323km to 109km		±47.4°	2320km	Cross-Track
NOSS (Ref. 20): ABLS (Optional)	54, 55 GHz				±3km	±30°		
IPACS (Ref. 18): HRMI	52.8, 53.8, 55.4 GHz			5km		360°	2000km	45°

There is a trend toward larger apertures. In fact, a Navy study indicates 10 m to be an appropriate size. The 4-m choice of NOSS apparently addresses a combined NOAA/Navy requirement that established 25 km as the largest useful resolution cell for temperature in the next development phase. The 3-m aperture shown was chosen to meet science and climate requirements where temperatures with 50- to 100-km resolutions are adequate.

There are two problems with the sensors suggested that we feel require further investigation. First, the 10.69- and 18-GHz channels, with bandwidths of interest, are not being proposed in next year's international WARC meeting as radiometer channels for operational systems. Either the proposed allocation needs to be changed or alternative channels need to be developed. In the process of looking for alternative channels, a second problem arises. The 6.6- through 37-GHz channels were selected to optimize on sea surface temperature, sea surface roughness, and atmospheric water content within the limits of channels that could be used for experimental radiometry. For ice optimization, the atmospheric water window (4.25 or 6.6 GHz) and atmospheric water (18 and 21 GHz) channels appear to be similar. The channels for measuring water surface roughness (10.69 and 37 GHz, nominally) may not be the same as those needed to deal with ice and snow roughness and with the fact that both ice and snow tend to emit and reflect extensively in depth rather than at the surface. Optimizing for an ice surface temperature is thus a much more complex problem, and research is needed to show which channels aid interpretation more than the present array.

The microwave atmospheric sounders are also shown in Table 11. These sounders provide atmospheric temperature and humidity profiles plus an indication of the amount of precipitable water in the clouds. Recent studies [Ref. 26] have shown that good matching with radiosonde data can be achieved when the 0.1 wave number infrared sounder is combined with a few microwave channels. The microwave channels remove a major uncertainty when they are viewing the atmosphere at relatively correspondent times with the infrared signals. What channels are needed and in what quantity are still not adequately established.

Swept frequency microwave radiometers have been flown on aircraft with a limited number of frequencies. LaRC presently has one for aircraft use. One of the interesting applications has utilized the variable emittance over ice and snow with frequency. This has been related to ice and snow depth. As with other ice and snow thickness-measuring concepts, to be discussed later, this technique turns out to be very sensitive to layering, salinity in the ice, and surface roughness. Unique interpretation has not been demonstrated under these conditions. For this reason, the swept frequency radiometer has not been recommended for present satellite payloads.

B. VISIBLE AND INFRARED RADIOMETERS

A wide range of visible and infrared radiometers has been shown to be useful for ice and snow measurements as well as for atmospheric and ocean measurements. These applications are summarized in Table 10. A summary of an appropriate sample of the available sensor design concepts in the visible and infrared radiometer regime are provided in Table 12. Polar region albedos and net radiation balance can be measured with wide band radiometers similar to those used for the earth radiation budget sensors. Active cavity and other radiometers with improvements in radiation sensitivity are under development and are to be included in later versions as their improved capability is demonstrated on the ground and in Shuttle flights.

Infrared atmospheric sounders have received recent attention. Present infrared atmospheric sounders have wave numbers about two orders of magnitude above those needed to make good vertical profiling, especially near the surface. A sounder with one order of magnitude improvement has been proposed by JPL and was included as a desirable demonstration option by JPL and GSFC proposals for early Shuttle flights. The need for this sensor is only incidentally related to polar measurements.

A thermal and cloud mapper is flown on TIROS-N. This AVHRR-I becomes AVHRR-II on about the third or fourth flight. The AVHRR-II has a third infrared channel, which improves the surface temperature measurement.

TABLE 12

POLAR VISIBLE AND INFRARED SENSOR COMPARISONS

Sensor	Wavelengths or Wave Numbers	Precision	Aperture Size	Effective Resolution		Scan Angle	Effective Swath	View Angle	Remarks
				H	V				
Radiation Budget Mapper ERBI	0.2 to 50 µm (12)	1%					Horizons		
Atmospheric Sounder HIRS-II	669, 680, 690, 703, 716, 733, 749, 900, 1030, 1225, 1365, 1488, 2190, 2210, 2240, 2270, 2360, 2515, 2660, 14,500 cm^{-1}		15.5 cm		5 km	±49.5°			
NOSS (Ref. 20): ABLS	588, 627.5, 635.8, 646.65, 652.75, 666.0, 667.0, 667.5, 668.7, 1203.0, 1772.0, 1784.5, 1789.5, 1809.5, 1839.4, 1850.9, 1881.7, 2012.5, 2381.5, 2383.75, 2386.1, 2388.2, 2390.2, 2392.35, 2424, 2498, 2616 cm^{-1}				<3 km	±30°			
IPACS (Ref. 18)	15(10), 8(2), 5.5(7), 4.2(6), 3.9(3) cm^{-1}	1.0°C		40 km	3-4 km	±50°	2100 km		Cooler
Thermal/Cloud Mapper AVHRR-II	3.74, 10.8, 12.0 µm	0.5/0.25°C	20 cm	1/10 km		±40°	1500 km	Cross-track	
IPACS (Ref. 18): CPR	0.7, 0.7, 1.1, 1.6, 11.0 µm			2km					
NOSS (Ref. 20): AVHRR-II+	3.74, 8.5, 10.8, 12.0 µm	0.25/0.1°C	20 cm	1/5 km		±40°	1500 km	Cross-track	
Atmospheric Composition Mapper IPACS (Ref. 18): LIMS	6.2, 6.3, 9.6, 11.3, 15.0, 15.0 µm	0.4 ppm H_2O		200 km	4 km		1800 km		Cooler
Surface Composition Mapper CZCS	0.443, 0.52, 0.55, 0.75, 0.67, 11.5 µm		17.73 cm	825 m		±40°	1500 km	Cross-track	
NOSS (Ref. 20): CZCS Extension	0.443, 0.463, 0.52, 0.55, 0.575, 0.60, 0.67, 0.75 µm		17.78 cm	825 m		±40°	1500 km	Cross-track	Glitter also
CCD Version	Same		30 cm	400 m		±40°	1500 km	Pushbroom	
Surface Feature Mapper MSS	0.45 to 1.0 µm (4)		20 cm	80 m			185 km		
RBV	0.45 to 0.7 µm (3)			40 m			185 km		
TM	0.45 to 2.35 µm (5)			30 m			185 km		
Stereo Surface Mapper									
Glitter/Polarization Mapper Same as CZCS extension									

( ) refers to the number of channels in that wavelength regime.

In NOSS, a third version was suggested by GSFC, adding a channel in the 8.5-μm region to again improve surface temperature. The fourth infrared channel is easily added within the existing sensor design [Ref. 20]. The two numbers for precision and surface resolution given represent the precision at the resolving limit of the system, 1 km, and the improved precision if many of these small resolution cells are averaged. The Cloud Physics Radiometer (CPR) suggested in the GSFC study was inserted more for addressing climate needs, but provides improved determination of cloud water. Neither sensor is probably adequate for the full spectrum of polar measurement needs. Some combination is probably appropriate to handle both cloud properties and surface temperatures. For surface temperatures, some additional channels might also be appropriate to separate out the effects of emittance in depth from snow if small surface indications of melting, etc., are to be adequately identified as they begin happening. Studies in this area need to be made or applied to this problem if already accomplished.

The only atmospheric composition mapper shown in Table 12 is a limb sounder (LIMS). A better sensor might be the spectrometer of ATMOS, but its size and complexity make it more suitable for Shuttle implementation. A number of other implementations have been flown on NIMBUS or are proposed for ERBSS-A. These are either earth looking or sun occultation pointing, but for a limited selection of trace species. LIMS was also flown on NIMBUS, but the suggested addition of an active cooler would make the sensor much more effective. LIMS is again climate oriented in the IPACS-suggested design and provides important input for stratospheric dynamics, both in the climate scale and in the scale for shorter term stratospheric pollution effects. LIMS appears to be an inadequate mechanism for obtaining ozone and carbon dioxide information at the poles. Sun occultation measurements are too infrequent at the poles using the orbits of interest to build up measurement statistics of use to but a relatively small user group. If only ozone and carbon dioxide were of interest, then more limited earth-looking sensors would be more appropriate; with cooling, these could also be designed to attain the necessary sensitivities. Laser heterodyning technologies have also advanced far enough to allow for their reasonable implementation, providing the number of species to be evaluated is limited to those of critical interest in the polar region. Active LIDAR sensors may replace these passive composition mappers later due to their potential for improved sensitivities. A simple demonstration of a limited version of that system might be even more desirable, but the polar mission aspect is incidental.

Surface composition mappers like the coastal zone color scanner are also useful for fishing and pollution management in the polar regions. The 825-m resolutions of the present coastal zone scanner need to be dropped to a 400-m resolution just to satisfy the NOAA/Navy longer range interests, but could equally well benefit from a drop to the 100-m resolutions of interest to the fisheries industry in polar waters. The NOSS version is probably adequate for this time period, especially if the frequencies were adjusted slightly to address specific polar fishing environments and pollution species. For polar mission purposes, it would probably be more effective if flown in a LANDSAT-type orbit with near-noon Equator crossings in a sun-synchronous orbit.

The major features and capability of the glitter/polarization mapper are identical to those of the surface composition mapper. Its added capability would primarily be a secondary mirror system that allows tracking along a sun glitter angle on several wavelengths, which may or may not be wavelengths in common with the choices without glitter. In this development, though, it would be better to implement the sensor on a NOSS orbit so that a variety of sun angles could be investigated to allow determination of the best orbit for the measurement. The existing optics system designed to help avoid glitter could be used to effectively maximize it over some portions of the trajectory.

The surface feature mappers and stereo feature mappers are not described here. LANDSAT and STEROSAT developments appear adequate for this use. It is probable that there might be a better set of wavelengths for polar measurements, but their value is limited compared to the synthetic aperture radar, which does not have the same cloud cover limitations.

C. ULTRAVIOLET RADIOMETERS

Ultraviolet radiometers are used to determine stratospheric ozone concentrations. The BUVS sensor initially flown on NIMBUS and adapted for TIROS-N provides adequate data for most needs, and an improved version is now in development. The present flight schedule for this series of sensors appears adequate for ice needs without specific emphasis.

D. RADAR

Active microwave sensors play an important role in the polar regions, where cloud formations are typical. The synthetic aperture radar (SAR), in particular, is probably the most important sensor for polar region research. Its fine resolution images provide ice and snow dynamics from time series data. Extent changes, melting rates, drift rates, deformation rates, ice patterns, ice leads, crevasses, and icebergs are all best detected and located with SAR. In addition, SAR ocean images provide wave and current information and locate special features like ships, oil spills, etc. A second class of important radar is the radar altimeter. This sensor has the potential for measuring ice/snow thickness and roughness for sea ice, sheet ice, snow cover, and glaciers. The altimeter also can provide supportive ocean data in terms of wave height spectra, tidal variations, and current structure. Radar scatterometers have recently been tested in the Arctic and have shown promise for measuring surface roughness and ridging when used in conjunction with altimeters. Rain and pressure radars are also important in the polar regions, but are not peculiar in their needs relative to the designs for more general usage. Doppler and swept frequency capability can be developed into almost any of the above designs, but more experimental data are needed to assess their utility for the polar regions. Doppler measurements are normally good for sensitive motion measurements while the swept frequency method can conceptually produce better measures of surface roughness and ice/snow thickness. A comparison of existing and proposed sensors is provided in Table 13.

TABLE 13

POLAR RADAR SENSOR COMPARISONS

Sensor	Frequencies	Precision	Antenna Size	Effective Resolution		Angle Scan	Effective Swath	View Angle	Remarks
				H	V				
Synthetic Aperture Radar									
SEASAT-A	1.275 GHz		10 x 2 m	25 m		Fixed	100 km	20 deg	4 looks
NOSS (Ref. 20)	1.275 GHz		13 x 2 m	25 m		Fixed	100 km	20 deg	4 looks
IPACS (Ref. 18): WSIR	13 GHz		6 x 4 m	100 m		Fixed	360 km	25 deg	2 looks
Radar Altimeter									
SEASAT-A	13.9 GHz	7 cm	0.8 m	12 to 2 km	50 cm	Nadir fixed	12 to 2 km	Nadir	
NOSS (Ref. 20)	13.5 GHz	10 cm	4 m or 1.8 m(3)	12 to 2 km	30 cm	Nadir fixed	50 km	Nadir	5 beam option
IPACS (Ref. 18)	13.5 GHz	10 cm	3 m	2 km	50 cm	Nadir fixed	2 km	Nadir	
NOSS (Ref. 20)	150 to 300 MHz								1 or 2 frequencies
Comet sounder	20 to 180 MHz	7 to 15 m							A/C test
APOLLO 17	5, 15 MHz			60 km	50 m				
Radar Scatterometer									
SASS	14.6 GHz		3 m (4)	50 km		45°, 135°	1000 km		
NOSS (Ref. 20)	14.6 GHz		3 m (6)	50 km		45°, 90°, 135°	1000 km		
IPACS (Ref. 8): HRMI+	16, 37 GHz			15 x 9, 7 x 4 km			2000 km		4 beams
Precipitation Radar									
LaRC GSFC Ongoing developments (Ref. 20)	3.0, 13.9, 35.0 GHz		15 to 2 m	1 to 10 km	1 to 3 km		1500 km		
Pressure Radar									
NOSS (Ref. 20): SPR	27.9, 35.3, 44.76, 52.76 67.84, 73.24 GHz	±3 mb	1 m (2)	2 km		Nadir fixed	2 km	Nadir	

( ) refers to the number of antennas of that size.

The synthetic aperture radar was fairly well demonstrated in SEASAT-A. A similar system was proposed for NOSS (see Table 13), but is not presently in the baseline NOSS design. NOAA, NESS, tends to be more interested in global resolution than in regional or local resolution and does not appear to accept that the expense of processing such high resolution data is appropriate in their data processing budget. The Navy, in contrast, appears to want the SAR in a more restricted satellite situation. This lack of a civilian SAR to service ice, coastal, geological, and agricultural users is a serious gap in the civilian space program. A number of Arctic users would be willing to pay for their own SAR system if they could obtain military approval. Much of the impetus from the international interests to be discussed later comes from industry backing (primarily oil companies). The various NOSS reports [e.g., Ref. 20] also proposed alternative SAR implementations with higher frequencies, wider swaths, coarser resolution multiple beams for wide swath sampling, digital chirp, and nadir altimetry. The GSFC IPACS study proposed a wide swath implementation using electronically stepped beam shifting to allow wider swaths and much higher frequencies (see Table 13). Some kind of SAR is needed for ice, but it does not appear that any systematic analyses or tests have been conducted to determine optimum frequencies for polar region uses. The 1.275- and 13-GHz bands proposed are the areas at which most existing experience is centered. Resolutions of 100 m are adequate for most users, but international studies by Canada and ESA have identified 20-m resolutions as a practical requirement. A number of users have a real requirement for resolution as low as 5 m. For polar regions, 100-km swaths are marginal, while 400- to 500-km swaths appear to be more realistic in terms of operational needs. At 500-km swath and 100-m resolution, the high data rate is still in the 20-Mbps range for four looks and 5-bit digitization. Real-time data processing capabilities are under development, though, and if some of the weighted CCDs presently under development become feasible, then low cost processors may become practical.

Several problems are associated with the use of radar altimeters in the polar regions. If they are only to be used to measure ocean processes like wave heights, tidal variations, and current bulges, then the design proposed for NOSS (see Table 13) with a larger antenna is probably adequate. This antenna size is still not large enough to make the signal beam-limited rather than pulse-limited, so the footprint is still variable between 1 and 10 km for wave heights from flat to about 40 m. With the greater roughness and irregularity of ice, the effective footprint becomes even more variable and difficult to interpret. Larger antennas and higher frequencies are needed to provide fine surface resolution, and for these systems the technology is costly at best. Microwave altimetry from satellites may thus offer limited application to ice from satellites, but may be extremely cost efficient from airplanes.

Microwave altimeters are also used for ice and snow thickness measurements. An L-band Apollo 17 radar was used to sound Greenland ice sheets, and S-band altimeters have been flown from aircraft in the Great Lakes and Alaska. Both give valid data in some freshwater ice or snow situations, but do not operate well if significant layering or debris is present of if the sea ice is new enough to be saline. Megahertz wavelengths appear to be less susceptible to these layering efforts and may provide an important improvement. NOSS [Ref. 20] proposed an experimental option in the 20- to 180-MHz range with perhaps two frequencies similar to the Apollo 17 experience. In addition, there is a megahertz sounder being developed to probe cometary ice, which may have application to this situation. Again a word of caution, though, in that lower frequencies imply larger footprints unless very large antennas are provided. These turn out to be in the hundreds of meters range if beam-limited footprints of appropriate size are required. Synthetic aperture approaches alleviate some of this antenna size problem but introduce other questions. Again, aircraft implementations or reliance on laser altimetry may be more desirable.

Radar scatterometers have recently been tested in Alaska and then backscatter coefficients appear to be related to ridging and other ice dynamics phenomena. More ice ridge dynamics studies are proposed. The NOSS scatterometer radar will be tested for these effects, but generally no systematic effort has been undertaken to determine pseudo-optimum[1] wavelengths for ice scatterometry. A polar satellite, therefore, does not appear to need a scatterometer until basic research on ice/snow scatterometry is more complete.

Atmospheric radars that make precipitation, pressure, or doppler measurements (see Table 10) are under development for nonpolar uses. The precipitation radar and pressure radar concepts were proposed in NOSS as possible use of experimental sensor capacity. GSFC and LeRC have activities on rain radar, and JPL and GSFC have activities on pressure radars. Both developments are just entering the aircraft test stage, and early demonstrations are needed. However, it may be premature to consider them for a NOSS-type mission. The next environmental research mission with any reasonable orbit could be a good candidate for either or both sensors. The doppler radar concept could be built into the precipitation radar without major effort. The swept frequency radar concept, or any radar with frequency diversity, is popular at present, but little has been done with hardware, and limits on frequency allocations constrain feasibility. Although ice frequency sweeping may provide a better measure of roughness, ice type, and ice/snow porosity than normal scatterometry and radiometry, research is needed to validate these suppositions.

E. LIDAR

LIDAR has great potential for a wide variety of measurements, but it has not been tested thoroughly on present aircraft, and progress towards space implementations is hindered by projections of bulky, power-hungry configurations with short useful lifetimes. In general, a good review of LIDAR systems for space and of present aircraft test experience was put together under the Shuttle LIDAR activity [Ref. 30].

For specific ice measurements, the laser altimeter and laser scatterometer have very beneficial application. Spot sizes of 200 m appear feasible, which allows much better surface profiling than the best of the

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[1] Pseudo-optimum refers to the fact that the available wavelengths are restricted.

large-antenna microwave implementations. Scanning capability provides a good chance for surface slope measurements plus a reasonable swath for surface scatterometry. Laser scatterometric measurements could provide improved determination of surface type and a measure of ice/snow/porosity. GSFC has proposed a combination laser altimeter and pulsed atmospheric LIDAR [Ref. 18] with a 2-km effective altimetry surface resolution and less than 10-cm vertical resolution. The frequency they have chosen at present is 0.532 μm, but this could be flexible with further research. The laser scatterometric and doppler LIDAR functions could be accommodated with this system. For the pulsed atmospheric LIDAR aspect of the system, the effective surface resolution proposed is 300 m, and the effective swath with beam scanning is 900 km. This is an experimental concept and not much detail is presently available for this system. It appears to be a natural evolution of the concepts proposed for the Shuttle LIDAR [Ref. 30]. Power requirements of 750 to 1500 W on board the spacecraft are anticipated.

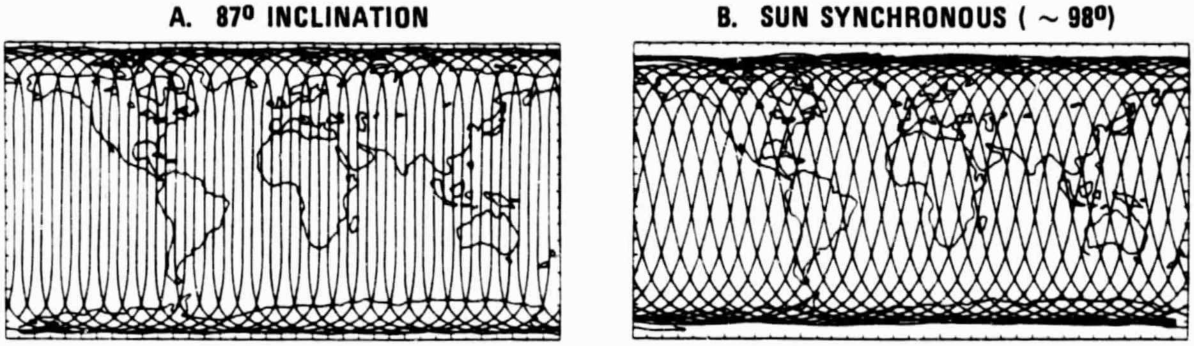
The surface composition LIDAR is of interest to fishing and pollution control activities, but is not unique to polar regions. Although aircraft tests have shown good sensitivities, the power required is in excess of that proposed for the pulsed atmospheric LIDAR. This system is probably immature right now, but development will proceed with or without polar user pressures.

The continuous wave (CW) atmospheric LIDAR has been shown to have particularly sensitive capability for detecting trace constituents in the stratosphere and can be implemented with powers on the order of watts or tens of watts per pair of spectral lines utilized. The sensor is under development by NASA for Shuttle demonstration, but similarly will proceed without polar user pressures. CW and pulsed lasers for atmospheric composition measurements are also under extensive development by the military.

VI. TRAJECTORY TRADEOFFS

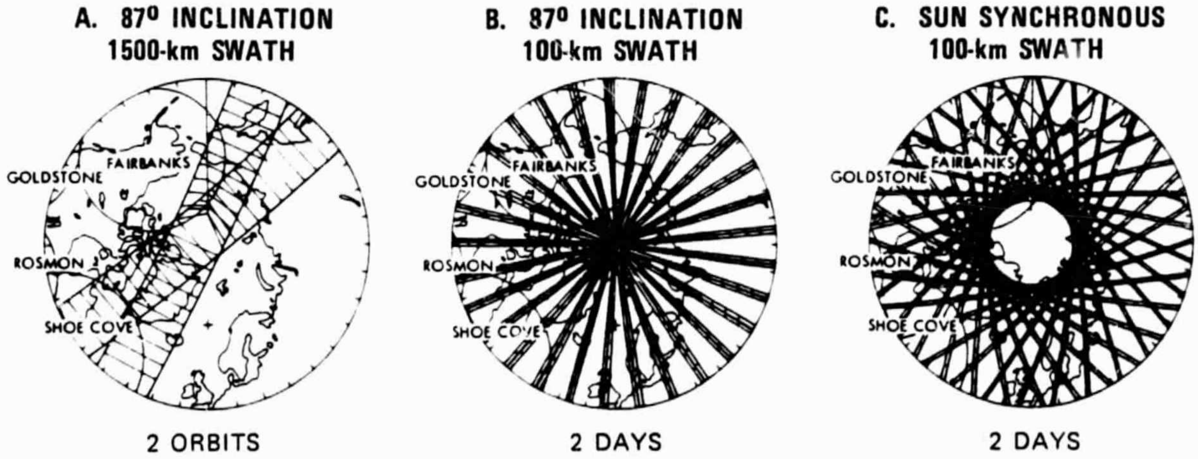
There are a number of orbit options that make sense in the polar regions. Mr. Johnie Driver at JPL has made an excellent study of most of these alternatives. Many of the displays in this section are from his study. In attempting to optimize ice coverage patterns, there are several conflicting needs. Some polar environmental information users need broad coverage with the most rapid total fill-in possible, consistent with the scale of the change process being monitored. Other users benefit from rapid repeat in a single location over consecutive passes to monitor specific events like sea ice edge motions, sea ice thickness variations, lead patterns, etc. Initially, their information needs could be satisfied by special orbits with rapid repeat for several days followed by a large time gap before the next repeat cycle.

The best satellite ground track for providing rapid total coverage of the polar regions appears to be in the orbits between 84 to 87 deg in inclination. These orbits provide coverage of the pole, assuming the outer limit of the side-looking radar image with swaths between 100 and 400 km wide. The 87-deg orbit provides almost parallel patterning in a longitudinal sense (see Figure 3a) compared to the crossing patterns of the lower inclination or sun-synchronous orbit (e.g., Figure 3b). The wide swath sensors in the 87-deg orbit give the efficient fill-in pattern shown in Figure 4a, with rapid synoptic coverage of about 50-deg latitude and considerable repeat coverage very near the pole. The narrow swath sensors like the SEASAT imaging radar provide a wheel-spoke effect (see Figure 4b), with a wide variety of options as to whether consecutive passes have just-touching swaths at some prechosen latitude or whether a more complex fill-in is desired. The lower inclination or sun-synchronous orbits provide considerably different patterns for narrow swath sensors (illustrated in Figure 4c), where an "ice-hole" is left unimaged at the pole, but considerable densification of coverage takes place at some lower latitude.


A. 87° INCLINATION

B. SUN SYNCHRONOUS (~ 98°)

FIGURE 3. INCLINATION EFFECTS ON SWATHING PATTERNS


A. 87° INCLINATION 1500-km SWATH

B. 87° INCLINATION 100-km SWATH

C. SUN SYNCHRONOUS 100-km SWATH

2 ORBITS

2 DAYS

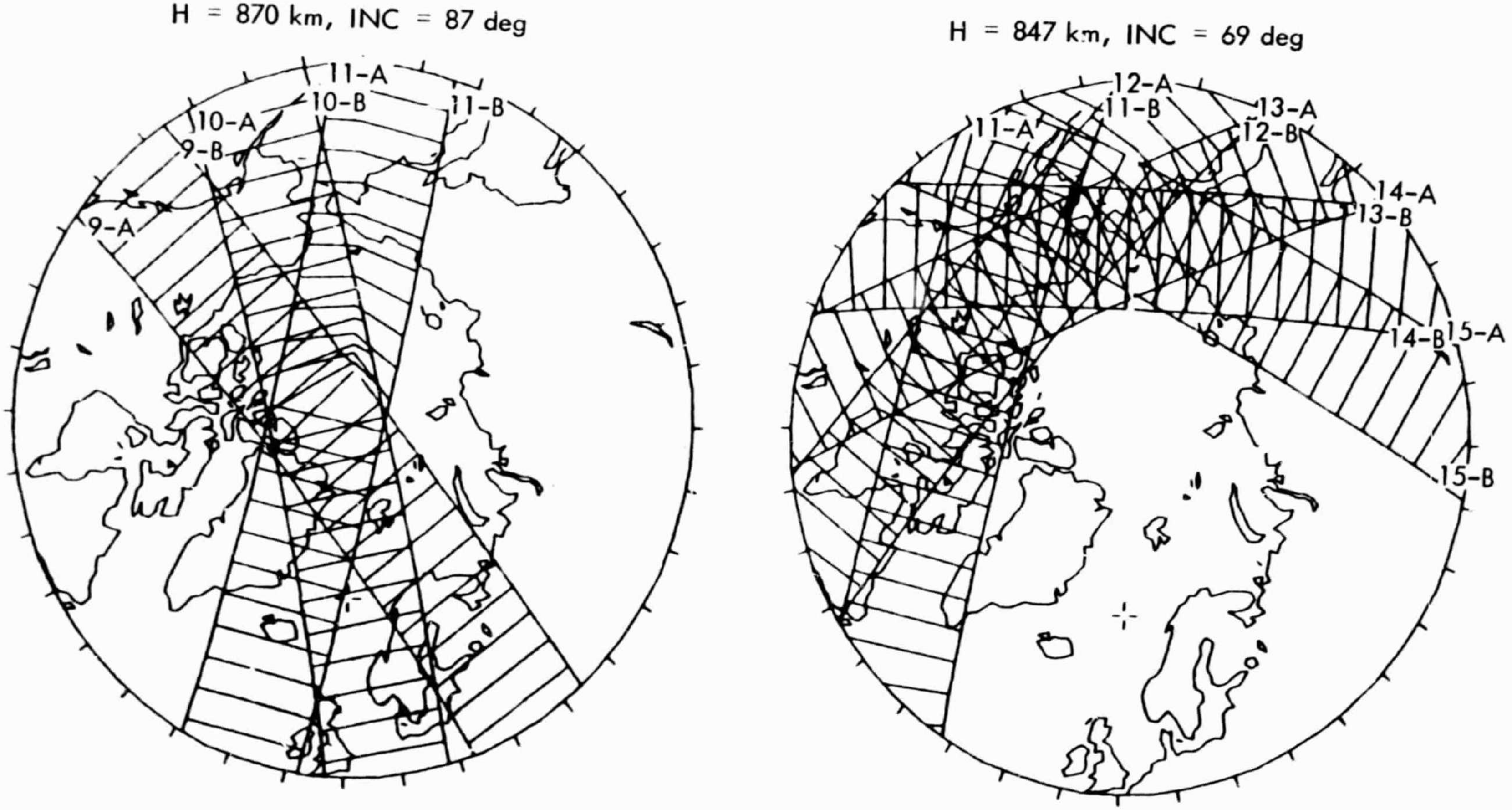
2 DAYS

FIGURE 4. SWATH WIDTH EFFECTS ON POLAR COVERAGE

The two major coverage alternatives have some contrasting advantages that merit further study. In Figure 5, a comparison is made for wide swath coverage between 87- and 69-deg inclination orbits. In the 87-deg orbit, the highest density of coverage is above 75-deg latitude. At latitudes around the north slope of Alaska, any ground site is covered once or twice consecutively at one time of day; this sweep is repeated once or twice 12 hours later when the satellite is coming around the other way. In the 69-deg orbit, a similar ground site in Alaska is seen on three to five consecutive orbits, but is then not seen again until the next day. This increase in consecutive coverage has some advantage for some kinds of navigation support and for some kinds of research.

For narrow swath sensors, some further optimization can be accomplished by investigating what inclination provides the best densification for some particular area of interest. Figure 6 shows some gross variation in an attempt to find the best densification in the region just above the north slope of Alaska. Something about 70 deg looks appropriate. By varying this swath, as shown in Figure 7, it can be seen that a swath around 400 km wide provides a good coverage for the navigation support proposed. A 400- to 500-km swath appears to also be the maximum swath practical in the present state of the art for a synthetic aperture radar imager with 100-m resolution. It is interesting to note that this high coverage density orbit for the north slope is at approximately the same inclination as the coastal processes orbit that best follows (in a compromise sense) the eastern and western U.S. coastlines. Payloads for polar and coastal missions are also quite similar in that they are generally not interested in a finer areal resolution scale, but more localized coverage than that addressed by NOSS and System 85 (where the main customers are concerned primarily with global ocean and weather processes).

In order to provide some insight into other prospects, Mr. Driver has looked at several other kinds of swathing and other orbital types. A multibeam SAR swathing pattern is shown in Figure 8. In this concept 15 separate 10-km swaths are produced, separated by 100 km each. Each beam is treated as a SAR and samples the wide swath coverage, allowing improved

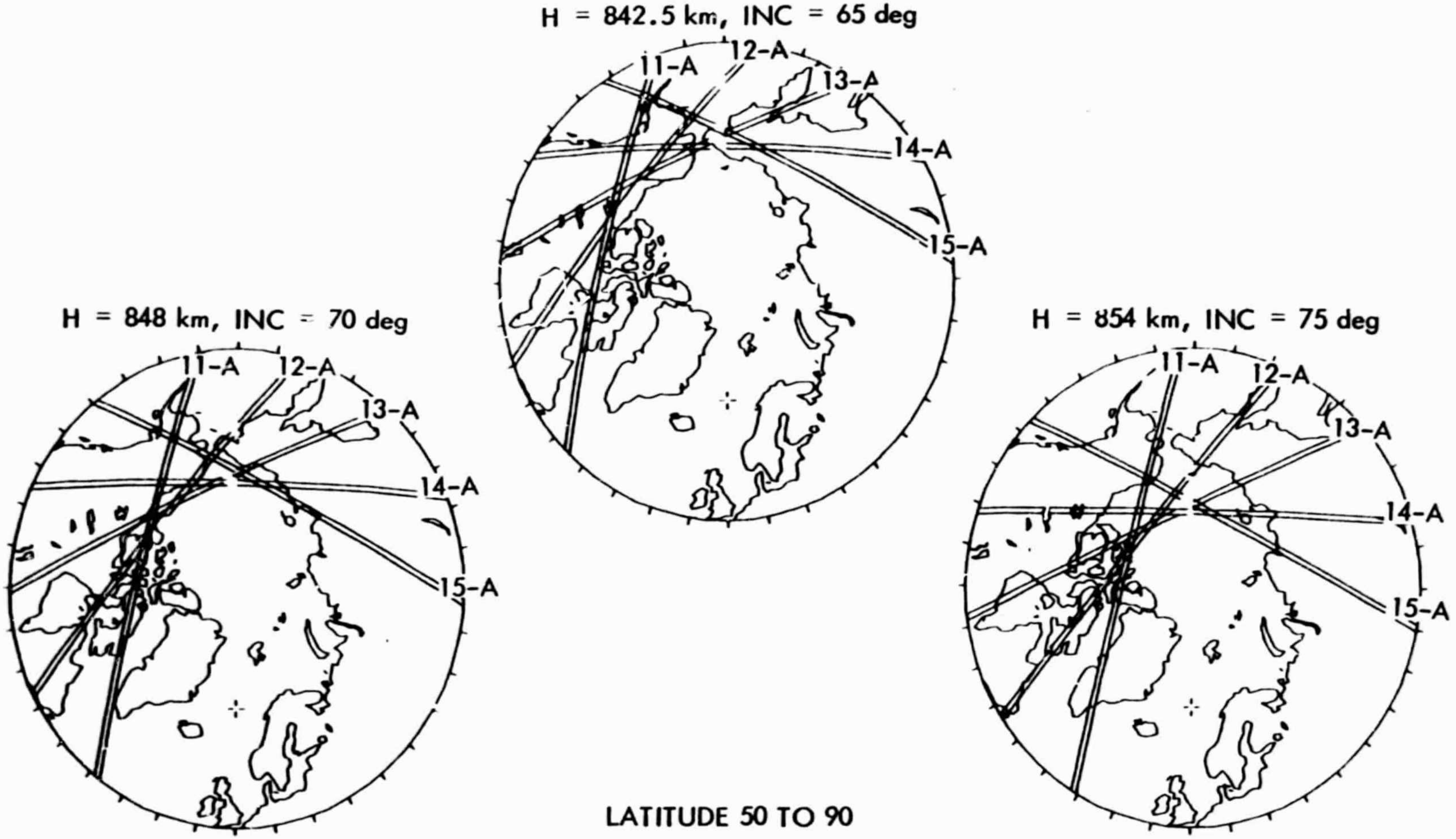


H = 870 km, INC = 87 deg

H = 847 km, INC = 69 deg

LATITUDE 50 TO 90

FIGURE 5. NORTHBANK COVERAGE, WIDE SWATH INSTRUMENT



H = 842.5 km, INC = 65 deg

H = 848 km, INC = 70 deg

H = 854 km, INC = 75 deg

LATITUDE 50 TO 90

FIGURE 6. NORTHBANK COVERAGE, DEPENDENCE ON INCLINATION

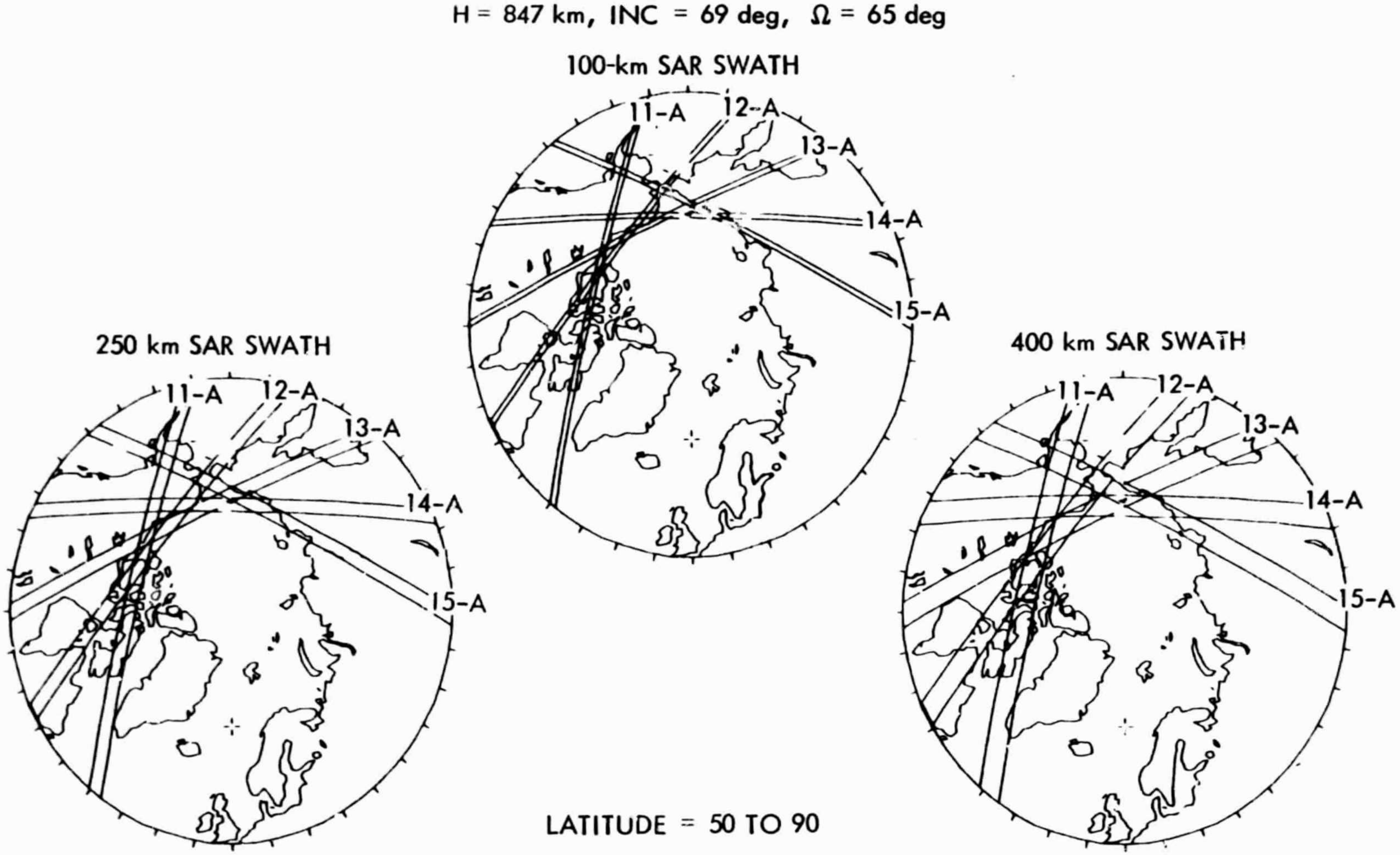


FIGURE 7. NORTHBANK COVERAGE, SWATH WIDTH DEPENDENCE

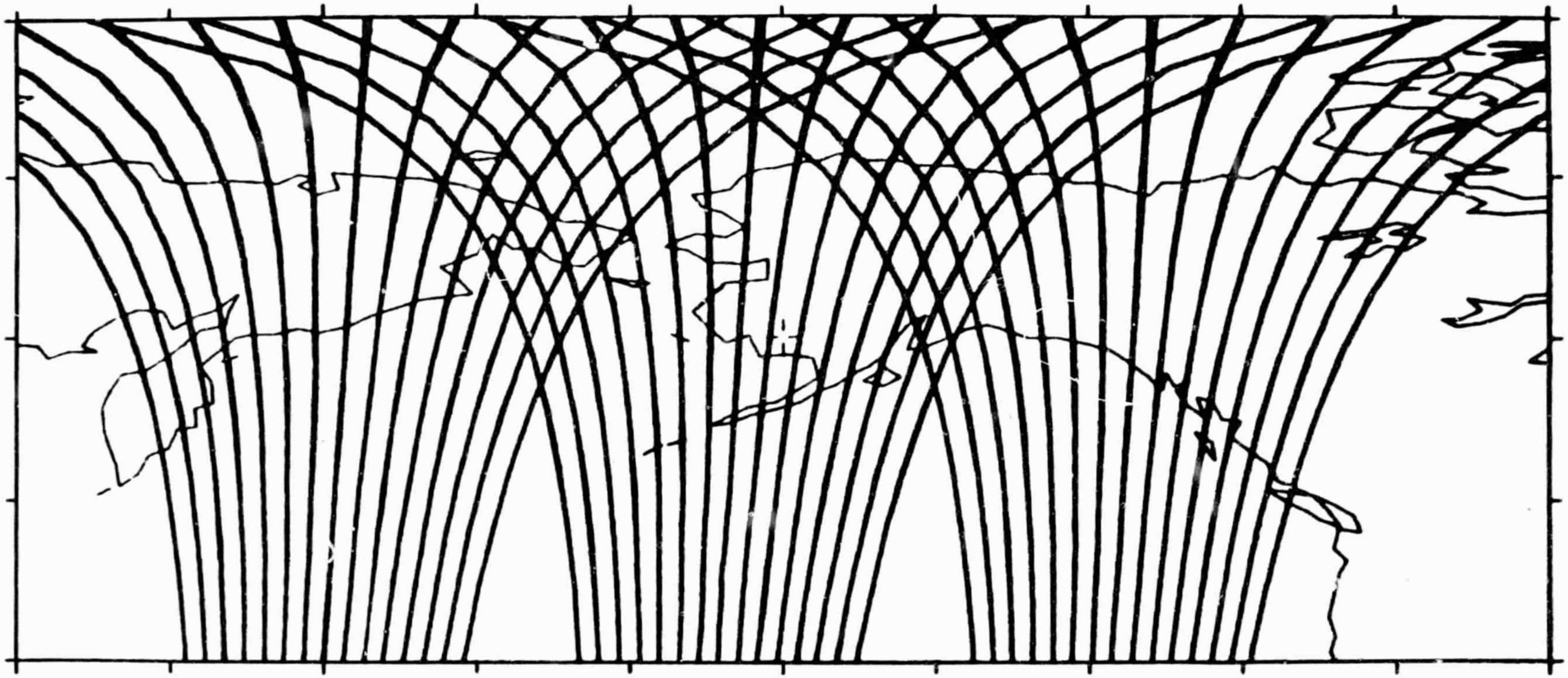


FIGURE 8. NORTHBANK COVERAGE, MULTIPLE-BEAM SAR

determination of ice edge positions on a broader scale. It also provides a better coverage for fishing and pollution control activities since it is more difficult for ships to avoid this pattern than for any of the slow fill-in options. On the other hand, it makes some types of research more difficult and certainly complicates processing and interpretation.

For continuous monitoring, geostationary orbits are often desirable. Equator-located geostationary orbits do not provide good coverage at latitudes above 50 or 60 deg. Providing inclination at geostationary orbits creates a figure-8 orbit that can loop along the southern Alaskan coast up along Juneau and back down the Aleutians or can be made to peak along the north slope. Because these orbits provide only once-a-day coverage per satellite rather than the continuous coverage desired, their value is questionable. A brief look was also taken at a "Polesitter," which uses solar electric or nuclear electric propulsion to hold a spacecraft over the pole against the earth/moon gravity field and in an unstable orbit passing in and out of the earth's orbit while holding above the plane of the ecliptic [see Ref. 29]. Mr. Driver found that, though the concept is feasible, the equilibrium altitude, using today's electric propulsion technology and near-term projections of it, are several lunar distances away from the earth. This was not considered practical for today's needs.

This leaves us with three major orbits of interest to polar monitoring. The sun-synchronous orbit is still necessary for those sensors requiring fixed sun angles. These sensors are generally identical with sensors of equal or greater interest for application in temperate and tropical areas. Polar region interests could, thus, utilize this capability without separate developments. The 84- to 87-deg and 67- to 70-deg inclination orbits are both still possibilities depending on the interests of other nonsolar disciplines in these orbits. Introduction of an 84- to 87-deg orbit mission is presently being considered for next year's budget. A decision as to whether NOSS should be used to obtain a greater portion of these polar requirements or whether separate research satellites should be developed for new sensor demonstrations at either 84- to 87-deg or

67- to 70-deg inclinations will need further study by a user group representing each of the research and industry factions with interest in the polar regions.

VII. DATA PROCESSING AND DELIVERY ALTERNATIVES

Most of the economic benefit and social service benefit in the polar regions come from the near-real-time[1] availability of environmental information. Thus, it is important to both deliver measurements in near real time and to convert the measurements into environmental information within that same time span. Some of the alternative data/information delivery systems that furnish near-real-time polar environmental information are shown in Figure 9. The same system options are typical for other regional needs also.

Options 1 and 2 assume that all information is channeled through a central processing site where all or a major portion of the processing is done. Options 3, 4, and 5 are dispersed processing options; i.e., it is assumed that processing is done on the platform by the real-time user or at a number of regional processing and redissemination centers or by some combination of these processing options as determined by economic efficiency.

A. CENTRALIZED OPTIONS

Option 1 in Figure 9 is quite similar to the expected data/information delivery system proposed in the early 1980s for both NOSS [Ref. 20] and TIROS-O. The system operation is as follows: data from the measurement platform are transferred in real time through the Tracking and Data Relay Satellite (TDRS) to White Sands, where NOAA and, in the case of NOSS, the Navy have a data preprocessing facility. The preprocessed data are then passed on to a central information processing facility through a commercial domestic satellite (DOMSAT) link. Probable information processing facilities are the National

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[1] Near real time is generally considered to be a time span of less than 3 hours, maximum, but there are some users who require the information in less than 1 hour.

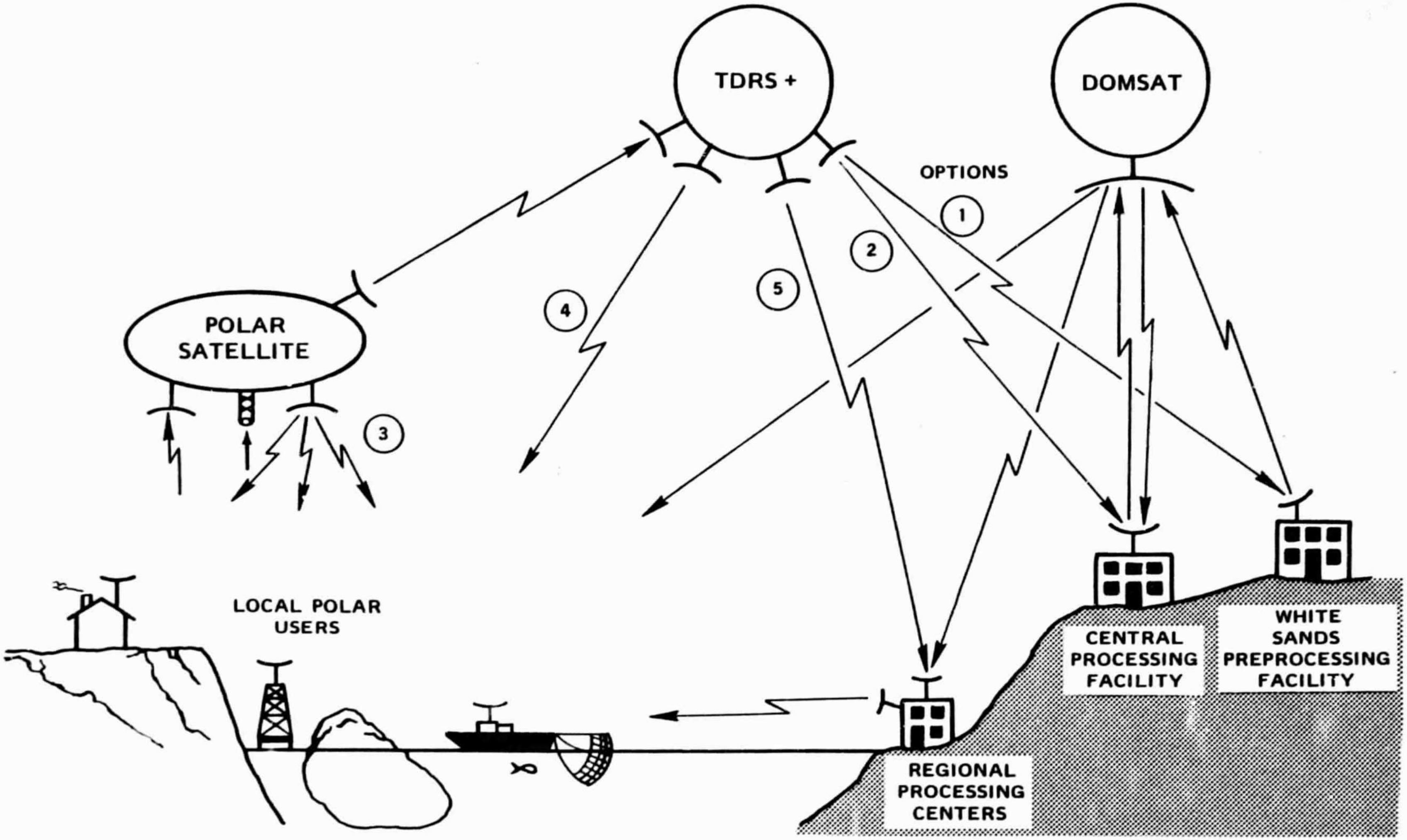

FIGURE 9. POLAR DATA DELIVERY OPTIONS

Weather Service facility in Suitland, Maryland, and the Fleet Numerical Weather Center in Monterey, California. The central facility for ice data processing would probably be the joint Navy/NOAA Ice Survey Office located in Suitland, Maryland. From there, the data are sent directly to users or to regional centers for further processing. Option 2 is similar to Option 1 except that White Sands is bypassed and a new-generation TDRS allows transfer directly to the central processing site or sites. Option 2 is not presently planned, but has potential cost savings.

In these centralized processing options, it is still possible to place part of the processing burden at the satellite, part at the central site, part at the regional dissemination centers, and part at the real-time user facilities. As far as most users are concerned, the system could be relatively transparent; i.e., they could be getting data or information in less than 1 to 3 hours without knowing the complexity of the communications channels between them and the measurement platform.

The major advantage of a centralized system is that access to the data can be easily controlled and, in fact, doctored, if it is in the national interest that military operations be protected. It is also conceptually one of the least costly options to the total economy, since processing is done centrally and duplication is minimized. Practically, it has some problems that relate to real-time polar navigation and operations scheduling. Real time in this case is less than 1 hour and some feel this would be impractical to implement in a centralized processing system. Also, because it is so central, its cost of operation is extremely visible, and since it is conceptually set up to be the most efficient system to do everything, it is also a single and visible large cost item rather than dispersed as a budget item amongst many different organizations. The centralized processing concept cannot deal with all of the formats each of the users require. Therefore, in the past, these central agencies have tended to make the data or information available only when the data has been processed beyond the point where the user community diverges in opinion as to how the processing should be done. If many of the new concepts NOAA and the Navy have proposed for NOSS are funded, then some of these types of problems with centralized systems could be alleviated.

B. DISPERSED OPTIONS

Option 3 in Figure 9 assumes that much of the data processing is done in real time on board the measurement platform so that the present environmental information can be sent in real time to users as the platform passes over user facilities. Few of the real-time users are interested in information outside the view of satellite platforms as they pass within line of sight of the user location (normally a circle with a radius of about 2000 km). Users requiring more precision in the processing or the integration of other data not available from the satellite or forecast information would have to get data from one of the centralized options.

Option 4 is like Option 3 except that it is assumed that data from any location can be sent to any user in real time through a new generation of TDRS. Option 5 assumes that all data of interest to any regional users is automatically sent to regional sites directly from the data relay satellite. Such data can be easily coded so that while all data is sent to the regional center, only that which is needed is accepted for storage and processing.

The major advantage of the dispersed processing options is that it forces the user community to accept a larger portion of the processing costs. If the institutional agencies, whether research oriented like NASA or operational oriented like NOAA, design their systems for maximum inheritability by the user, then the user can add special features at low enough cost so that he can afford to do most of the processing himself or through consortiums of people with similar needs (referred to in this report as regional centers).

For a polar satellite, the dispersed option is of particular interest. The oil and gas industry could set up regional processing sites in Northern Alaska, Northern Canada, Newfoundland, Iceland, and Norway. Arctic shipping could use the same sites and additional sites established in the Antarctic.

Polar fisheries could have similar stations, but in the Aleutians, in Nova Scotia, and in Antarctica. Polar research stations for a wide variety of disciplines could also be established at Alaskan universities, on Greenland, on Antarctica, or at other appropriate locations. These research sites would collect data for weather or climate or for polar ocean currents with later redissemination in the form of forecasts. Many regional centers in the meteorological sector, like the National Weather Service Redwood City facility in California, already put their own torque on products forwarded from the central forecasting facility in Maryland.

The key advantage of the centralized options is control; the key advantage of the dispersed options is a natural forcing of a greater portion of the cost of processing on the user rather than on the operational agency. Conceptually, both systems could be made to look identical to the user; in practice, it is difficult, given national budget constraints, for the centralized options to provide broad service. Further discussion on the decentralized options can be found in Reference 31.

VIII. PLATFORM (PAYLOAD) ALTERNATIVES

Several key questions are reexamined briefly in this section. Are there unique ice coverage orbits? Are sensor requirements for the polar region significantly different from those for atmospheric, ocean, and land measurements? Is there a separate role for a dedicated aircraft or an *in situ* measurement program? A summary of the sensor and orbital coverage evaluations is provided in Table 14.

A. SATELLITES

Based on physics considerations, there are four kinds of easily identifiable low earth orbits from which a satellite can practically provide unique measurement data capabilities for polar research and operations. The weather orbit of the TIROS or DMSP type satellite is sun synchronous, has 3:30 and 7:30 equator crossings, and helps separate out diurnal and seasonal effects. As shown in Table 14, the payload of importance is similar to present System 85 and Block 6 designs and probably does not have to be adjusted significantly for polar needs. At most, the atmospheric sounders[1] and thermal/cloud mappers[1] would require only the addition of one or two frequencies to better quantify surface temperatures on ice and snow.

The near-noon orbit of LANDSAT and NIMBUS-G maximizes the reflected solar energy to the sensor. At an 11:30 equator crossing, this orbit would also provide the final 4-hour step in sun-synchronous equator crossings for operational weather inputs. Generally, due to the pervasiveness of cloud cover in the polar regions, the visible-and-infrared surface-feature and surface-composition mappers have limited application, and it is probably

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[1] Visible, infrared, and microwave combined.

TABLE 14

SELECTING PAYLOADS FOR POLAR MISSIONS

Sensor Type		Former Acronym	TIROS-O/DMSP-B6 7:30 & 3:30 Sun-Synchronous Orbits	NIMBUS-G/LANDSAT-C 10:30 or 12:30 Sun-Synchronous Orbits	NOSS		Aircraft	New or Additional Frequencies Needed	New Capability Needed		Premature	Ice Satellites		
					84°-90° Incl. Polar Orbit	65°-70° Incl. Arctic Densification Orbit			Full	Partial		JPL	GSFC	LeRC
Ultraviolet Atmospheric Composition Mapper		BUVS	•	• 🄽				•	•					
Visible & Infrared:	Radiation Budget Mapper	ERBI	•					•	•					
	Atmospheric Sounder	HIRS	•	(•)	(•)	•	•	•		•		•	•	
	Atmospheric Composition Mapper	ATMOS/LIMS		• 🄽		•					•		•	
	Thermal/Cloud Mapper	AVHRR	•	(•)	•	•	•	•	•			•	•	
	Surface Composition Mapper	CZCS		• 🄽		•	•	•	•					
	Surface Feature Mapper	MSS/JM		• 🄻			•	•	•					
	Glittering/Polarization Mapper				•	•	•				•			
Millimeter Wave:	Surface Mapper				•	•	•	•				•	•	
	Atmospheric Sounder										•			
Microwave:	Surface Mapper	SMMR	•	• 🄽	•	•	•	•			•	•	•	•
	Swept Frequency Mapper						•				•			
	Atmospheric Sounder	MSU	•	•	(•)	•			•			•	•	
Visible & Infrared:	CW Atmospheric LIDAR										•			
	Surface Composition LIDAR										•			
	Pulsed Atmospheric				┌(•)	┌(•)	┌•			•				
	Laser Altimeter				├(•)	├(•)	├•			•			•	
	Laser Scatterometer				├(•)	├(•)	├•			•				
	Doppler Laser				└(•)	└(•)	└•			•				
Microwave:	Synthetic Aperture Radar				(•)	•	•	•	•			•	•	•
	Precipitation Radar				┌(•)	•	┌•			•			•	
	Swept Frequency Radar				│		├•				•			
	Radar Altimeter				├┌•	•	├•	•		•		•	•	•
	Radar Scatterometer				├└•	•	├•	•	•			•	•	•
	Doppler Radar				└(•)	•	└•			•			•	
	Pressure Radar				(•)	•	•		•				•	

Legend: ( ) designates sensors not presently included or considered optional.

[designates sensor designs with combined functions.

🄽 NIMBUS

🄻 LANDSAT

not necessary to alter these from existing or projected designs. It would, however, be useful to add the surface-composition mapper to the future LANDSAT platforms. The other sensors are weather and atmosphere oriented and provide the final inputs into the operational sun-synchronous constellation.

The polar orbit of the early NOSS type was chosen to ensure full polar coverage. At 87 deg, the SAR outer swath for a SEASAT-like implementation just touches one pole, but misses the other unless it is made to look out the other side after it passes the equator. If the SAR is not flown, as present NOSS thinking goes, then the 84-deg orbit will still cover the pole with wide swath sensors and provide better diurnal variation. The NOSS would carry an upgraded thermal/cloud mapper, a surface composition mapper, a microwave radiometer, radar altimeter, and radar scatterometer plus an allowance for 25-percent extra support service capability for use with experimental sensors. The synthetic aperture radar, a precipitation/doppler radar, a pressure radar, and a new-generation atmospheric sounder have all been considered as part of the experimental portion of the payload [Ref. 20]. Based on the GSFC study [Ref. 18], an experimental LIDAR experiment might also be appropriate. In Table 14, the surface composition mapper was not included in the recommended payload because in an optimization sense it better fits the near-noon sun-synchronous orbit. The atmospheric composition mapper could similarly benefit from the near-noon sun-synchronous orbit and has already been flown in this orbit.

The 65- to 75-deg orbit was chosen to provide additional density of coverage in the Alaskan latitudes and relatively more rapid diurnal change in consecutive passes. It also happens to provide a good compromise orbit for relatively efficient coverage of the U.S. 200-mile limit on all coastlines. This relatively experimental trajectory would then carry the full complement of sensors with reasonable development history (see later columns of Table 14). It is important to note that additional new frequencies and/or additional new sensitivity or areal resolution are required in nearly all of the sensors (whatever their orbit) if a more optimum polar viewing is to be achieved.

In the next set of columns in Table 14, the JPL, GSFC, and LeRC recommendations for polar trajectory missions are provided for comparison. The JPL version is NOSS oriented; the GSFC effort adds additional climate-oriented atmospheric sensors not being considered by NOAA in the System 85 effort; and LeRC, although not specifically recommending a payload, has emphasized study of the four sensors designated in all of the ice research and development planning [Ref. 27].

In general, all of these payload options are technically feasible, but selection of a particular payload for implementation is beyond the scope of this effort. Instead, we have delineated the array of options feasible for consideration by a user group supporting the assessment of new-start options.

B. AIRCRAFT

Table 14 shows a sample payload for a dedicated polar airplane. It is proposed, by grouping several measurement functions into one aircraft sensor and eliminating stratospheric sensors, a set containing 10 sensors can be generated which would provide an extremely effective airplane payload. This airplane would be particularly suitable for demonstrating new concepts, for validating measurement capability, for supporting scientific research, and for providing short-term increased local densification of coverage for specific operational needs.

There is a need for NASA to use its high-technology capability to develop an airplane-payload prototype. Hardware and software components could then be purchased from specifications by operational agency or industry interests to provide focused support for individual needs. Like the Great Lakes, the north slope of Alaska or the International Ice Patrol region are relatively limited areas compared to the synoptic scales of satellite coverage. It is our opinion that a case could be made to show that, if an aircraft prototype were specifically designed to hold a coordinated polar payload, use of this aircraft might produce much of the added ice region support needed by industry and the operational agencies without adversely impacting present planning for other satellite systems. This high-technology prototype development job seems ideally suited to the National Aeronautics and Space Administration rather than to each of the operational agencies and industries, with their highly overlapping needs and, for the most part, relatively lower-technology experience.

C. IN SITU ENVIRONMENTAL TESTING

Polar-oriented in situ environmental sensing packages have not received the same depth of consideration as the remote sensing payloads. Because of this, the ground truth used to calibrate remote sensors is often less accurate than the remote sensor sensitivity, and comparative capabilities assessments often show superiority in the remote sensing system. There does not appear to be an agency with the responsibility or the budget to explore better high technology for in situ environmental measurement packages for polar or other regions. NASA programs would benefit if NASA took a lead in this area.

In addition, there are a number of polar environmental parameters in Table 10 that either do not have techniques identified for remote measurement or do not have a sensor identified with enough laboratory and field experience to validate utility for a spaceborne implementation. A network of in situ sensing packages with inexpensive relay link terminals for data collection via satellite could satisfy many of the identified needs. Again, this option has not been extensively evaluated.

IX. SAMPLE IMPLEMENTATION ALTERNATIVES FOR POLAR RESEARCH

A number of different platforms could be used to carry polar research payloads. Several platform options have been studied to various degrees of depth at JPL, GSFC, and LeRC. Adding our own assessment, we have rearranged their efforts into the following five illustrative categories:

- Minor modifications to NOSS and TIROS-O
- NOSS-based satellite with optimized payload
- New NASA satellite with foreign participation
- New international satellite with U.S. participation
- Aircraft and _in situ_ supplement to existing satellites.

Each of these alternatives has distinctive characteristics and a differing potential impact on service projected (see Figure 10) and funding required. A brief description of each alternative and a preliminary assessment of its advantages are described in the following sections.

A. MINOR MODIFICATIONS TO NOSS AND TIROS-O/DMSP-BLOCK-6

In this alternative (Option 1 in Figure 10), experimental sensor developments are separated from sensors considered ready for operational deployment. Thus, the major NOSS and TIROS-O/DMSP-Block-6 payloads are considered fixed relative to sensor types and surface resolutions, but may be adjustable in terms of spectral band selection without major cost impact. All the more experimental concepts like pressure radar, rain radar, doppler radar, megahertz and laser altimeters, atmospheric sounding, surface composition LIDAR, and so on, are relegated to demonstration on separate research systems, either free flier or Shuttle based, or by inclusion in the 25 percent overcapacity presently designed into the NOSS and TIROS-O systems through a NOAA decision.

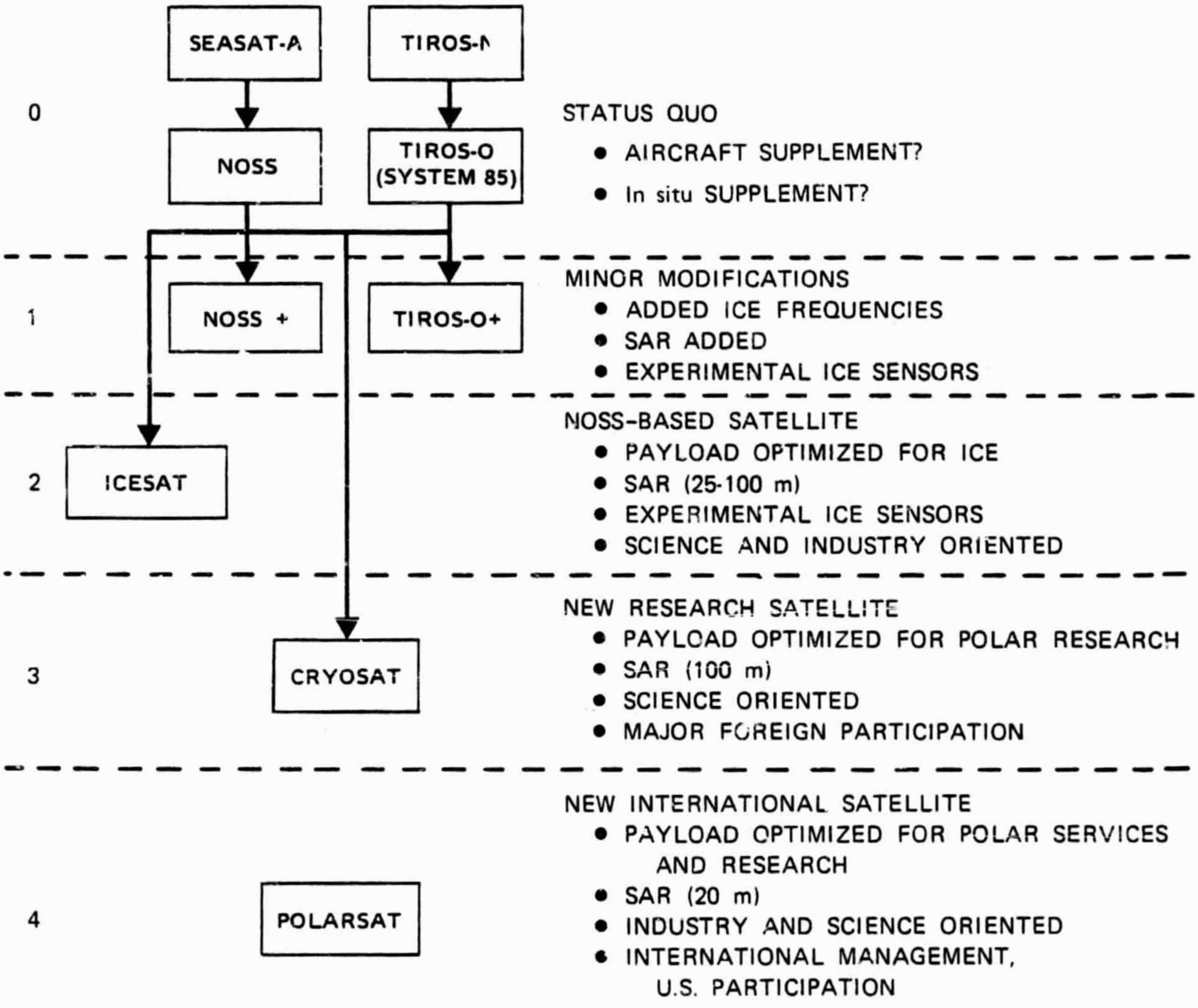

FIGURE 10. POLAR MISSION OPTIONS

The kinds of changes that might be appropriate in the present NOSS and TIROS-O/DMSP-Block-6 designs are summarized in Table 15. It should be noted that neither NOSS nor TIROS-O/DMSP-Block-6 is far enough along in the funding cycle to consider the present designs or spectral channel selections to be fixed. The V&IR and μw sounders are more and more being considered as a matched pair that require near simultaneous viewing of scenes to be most effective. Potential modifications for ice are primarily involved with the selection of extra channels to deal with ice surface temperature contributions to the atmospheric temperature profile problem. Whereas the high land variability is difficult to remove, the ice temperature/emittance variability is much less and might be handled by the addition of a few more surface oriented channels. To our knowledge, the research to direct selection of these channels has not been done, but could be done in a timely manner if this improvement was considered important. The selection of channels for these sounders is further confused by the somewhat different spectral channel selection concepts being considered at JPL, GSFC, and NOAA for the sounder system. NASA has suggested flying a JPL/GSFC joint design on NOSS as part of the experimental payload in order to give more emphasis to near-ocean and near-ice altitudes than is presently being considered in the NOAA-dominated TIROS-O concepts.

The visible and infrared Thermal Cloud Mapper and the microwave Surface Mapper provide measurements of cloud and ice extent, atmospheric humidity and precipitable water, surface roughness, and surface water temperature. In the polar region, some of these measurements are further complicated by the fact that ice and snow tend to emit and reflect in depth rather than at a fixed surface. As with the sounders, additional channels to separate out this effect would be appropriate. In fact, it would probably be adequate or sufficient to change only the NOSS version. The TIROS-O version might also be changed, but the present NOSS version might be an adequate improvement for the TIROS-O orbit.

The colorimeter design may not require modification since biological-growth and pollution-oriented species identification are for the most part similar, regardless of latitude. There are a number of effects, though,

TABLE 15

ADJUSTING NOSS AND TIROS-O TO IMPROVE POLAR REGION MEASUREMENTS

	Existing Payloads		Suggested Changes	
	NOSS	TIROS-O/DMSP Block 6	As Proposed	Adjusted Selection of Spectral Bands
UV Composition Mapper		*	*	
V&IR Sounder		*		*[a]
μw Sounder		*		*[a]
V&IR Thermal/Cloud Mapper	*	*		*[b]
Surface Mapper	*	*		*
V&IR Colorimeter	*			*
Radar Altimeter	*		*	
Radar Scatterometer	*		*	
Synthetic Aperture Radar	*[c]			*[c]

[a] JPL, GSFC and NOAA/NESS opinions on spectral bands are each different without considering an ice surface.

[b] TIROS-O should probably utilize the NOSS design, while NOSS adjusts its bands for better ice surface temperatures.

[c] Not in baseline payload but addressed for use of experimental capability.

where the relative importance of species shifts with latitude due to differences in sunlight, ocean current temperatures, or industrial makeup. Since only a limited number of spectral channels will be flown on the colorimeter, careful consideration should be given to polar-peculiar problems prior to development of selection criteria.

Few modifications need to be made to the radar altimeter and radar scatterometer. Although lower frequency choices for the altimeter (e.g., S- or L-band) might give some advantage in terms of indicating the presence of thin ice, tests show that exact thicknesses are probably not derivable from these channels. Megahertz altimetry, rain and doppler radar, pressure radar, laser altimetry, atmospheric LIDAR, and surface composition LIDAR, which were suggested for possible inclusion earlier, would all be relegated to candidacy for the 25-percent extra payload capacity presently allowed in the satellite designs. For polar regions, the synthetic aperture radar from SEASAT would have extremely high priority for utilizing the extra capacity on NOSS. It has been evaluated by JPL [Ref. 20] for inclusion, but was dropped from the NCSS payload at the suggestion of both NOAA and the Navy. It was thought to be too expensive a data processing job for NOAA budgets, not significantly important to global weather modelers, and redundant to classified surveillance systems presently in the budget for implementation. All three of these assertions appear easily challengeable, but are not addressed here.

In summary, NOSS could easily be modified to be more responsive to polar region needs. What is needed in addition, however, is demonstration of all the new radar and laser/LIDAR techniques that could provide extremely critical parameters for polar research and polar environmental forecasting. Most of these sensors are not far enough along to be considered in the present NOSS program, even as part of the 25-percent experimental payload, but projected benefits from these sensors indicate that some development activity is warranted.

B. NOSS-BASED SATELLITE WITH OPTIMIZED PAYLOAD

A related option to the first alternative would be to leave the basic NOSS design alone, but design a polar-region-optimized payload for inclusion on the spare NOSS spacecraft, or on a fourth NOSS spacecraft purchased early enough to take advantage of the cost savings in multiple buys (Option 2 in Figure 10). The spare would be utilized if the first two NOSS are successfully injected into orbit and their performance verified. The polar-region-modified NOSS payload suggested in Table 15, including the synthetic aperture radar, would be supplemented by a rain/doppler/pressure radar experimental sensor and an atmospheric/altimetric LIDAR experimental sensor (see Table 16). The surface composition LIDAR is also of interest, but its more extreme power requirements warrant leaving it to the Shuttle radar demonstration. The experimental radar concepts were considered by JPL in early NOSS designs [Ref. 20], and the experimental LIDAR was considered by GSFC [Ref. 18]. Inclusion of both may exceed projected growth capability in the present NOSS spacecraft design, but this needs more in-depth consideration before such a conclusion can be made.

The advantages of this alternative are that (1) the NOSS operational concept is not disrupted, (2) use of the spare NOSS spacecraft or a relatively inexpensive extra spacecraft keeps costs down, (3) all the highly important parameters only addressed by the experimental radar and LIDAR sensors could be investigated, (4) the polar science and operational users would have a focus in their own system, and (5) the data system could be tailored for service to polar users.

The disadvantages of this alternative are that (1) it entails system proliferation, (2) some of the changes needed are the same as those needed by coastal and other more temperate or tropical users, and (3) the U.S. polar region interests are relatively small compared to international interests. On the other hand, there appears to be enough profit involved for the U.S. oil companies in the polar region that they might be willing to launch their own imaging radar satellite, just to aid navigation above the north slope, if they could get the government to allow them to make such a launch. As we will discuss in the later options, the non-U.S. oil interests may do this anyway.

TABLE 16

POLAR SATELLITE PAYLOAD FOR ALTERNATIVES 2 and 3

Candidate Sensor Type	Derivative	Alternatives
V&IR Thermal/Cloud Mapper	AVHRR	2 and 3
μw Surface Mapper	SMMR	2 and 3
V&IR Sounder	HIRS	on TIROS-O
μw Sounder	MSU	on TIROS-O
V&IR Colorimeter	CFCS	on NOSS
V&IR Limb Sounder	LIMS	3 only
Microwave Radar Altimeter	ALT	2 and 3
Megahertz Radar Altimeter	New	2 and 3
Laser Altimeter	New	2 and 3
Atmospheric Radar	New	2 and 3
Surface Pressure Radar	New	2 and 3
Atmospheric LIDAR	New	2 and 3

C. NEW NASA SATELLITE WITH FOREIGN PARTICIPATION

This alternative is very similar to the IPACS concept developed by GSFC [Ref. 18]. It is designed to serve the research community and its emphasis is on climate and ice dynamics. In this system, the U.S. remains dominant, furnishes the launch vehicle and satellite, but invites international participation in the areas of sensor and data processing elements to reduce total investment (Option 3 in Figure 10).

The same payload suggested in Table 16 is assumed plus the inclusion of the limb sounder suggested by GSFC. The V&IR Thermal/Cloud Mapper could be the cloud physics sensor suggested by GSFC, the AVHRR derivative suggested earlier, or some combination of both. The new Surface Mapper is the one discussed in Section V. The atmospheric sounders and the colorimeter were assumed to be included on other satellites, but with channels appropriate for polar requirements. The three altimeters provide water surface profiling, ice and snow thickness, and ice/snow surface profiling, respectively. Experience may show that the first altimeter is not necessary, but for now it is the link to present space experience. The atmospheric and surface pressure radars and the atmospheric LIDAR are experimental sensors based on the NOSS [Ref. 20] and IPACS [Ref. 18] suggestions. This payload is a bit more ambitious than that suggested by GSFC in its IPACS study [Ref. 18], but is considered appropriate at this stage in the mission development to make sure that all sensing options are exposed. A user group, rather than NASA, should select which sensor options to delete.

The advantage of this option is that it focuses on the extremely experimental nature of the polar region investigations and does not tie the mission to a potential operational commitment like the NOSS derivative mission might. In this way, operational and scientific requirements are kept separate. It's important to expand slightly on this. In order to model at the scale desired for operational forecasts, it is important for the scientists developing the algorithms used in the forecast to understand the dynamics of the system to a scale with at least one more level of detail than that modeled. Thus, while the operational system limits its scale to that consistent with operational processing budgets, the scientist must understand to one additional level of depth. The danger of providing the scientific scale when there is no existing operational option is that user pressures will try to force utilization of that scientific payload operationally, when the scale is well beyond their operational needs. The non-real-time, selected-for-interesting-event processing choices of the scientific mission can thus be consumed by an operational number-crunching problem.

This alternative attempts to avoid this problem by setting up a separate research satellite that works in conjunction with operational systems in terms of data sharing, but which is not committed to extensive operational data processing. On the other hand, this is not just a testbed for selected NASA sensor developments, but is designed as a real coordinated scientific mission to explore regional or local problems comprehensively. Thus, it may duplicate some sensors on operational systems when this duplication aids interpretation. This approach is not unique to polar region interests and is embodied, in part, in the Platforms for Applications Research (PAR) concept presently being proposed by GSFC.

The disadvantages of this concept are that it does require fully new design (though use of the Multimission Modular Spacecraft [MMS] or other existing designs reduce these cost implications some) and that it is an ambitious mission in terms of funding requirements for one not claiming to provide the interested industry or government agency operations with any projected benefits. Thus, it could potentially (though it need not) split the user community into opposing factions, weakening the funding position of both the operational and research systems.

D. NEW INTERNATIONAL SATELLITES WITH U.S. PARTICIPATION

Both Canada and ESA have performed studies of polar satellite missions [Refs. 22 and 23]. Both have expressed interest in joint funding, and some initial informal meetings have taken place between Canada and the U.S. and Canada and ESA. Canada has been seeking more formal commitments through official channels, but in a low-key fashion. The Canadian and ESA interest is not surprising, since they have considerably more blocs of the polar region under their influence than does the U.S. Both governments are also responsive to Arctic oil-industry interests. For both Canada and ESA, the SAR is the sensor of greatest importance for polar environmental service missions, and how many other sensors are added is just a matter of funding availability and the acceptability of proposals.

This alternative (Option 4 of Figure 10) has some interesting implications for the U.S. The oil interests in Canada and Europe are sufficiently powerful, due to the extreme inadequacy of supply, that Canada and ESA will probably go forward with at least a "SARSAT" or "SURSAT" mission, with or without the participation of the U.S. This 20-m resolution imaging radar would then be available to their economic (and military) units and perhaps not to ours. The U.S. could join them now and work towards implementing a more dynamic capability than that presently available through individual efforts. Once the decision for joint activity is made, the next question is the magnitude of the U.S. participation. If the need to retain U.S. leadership dominates, then alternative 3 is most appropriate for it includes international participation in a basically U.S. mission. In the polar regions, due to the fact that the U.S. has less area, less industry investment, and less population than the Canadian and ESA interests, it may be appropriate to let Canada or ESA take the lead in polar space activities, with the U.S. only providing a sensor or two, some data processing, and perhaps portions of the spacecraft. Launching satellites using the French launch systems might even be more economical in this situation. Under this concept, the U.S. gets the same polar services for much less cost and costs are distributed according to international need.

E. AIRCRAFT AND IN SITU SUPPLEMENT TO EXISTING SATELLITES

For the U.S., the major polar interests are in Alaska and in the Labrador Current area for the International Ice Patrol Services. Because each of these regions are relatively limited in the areas actually requiring monitoring, an aircraft implementation may be more cost effective than a dedicated satellite. Preliminary aircraft tradeoff studies for the coastal regions by LeRC [Ref. 32] and Battelle [Ref. 33] expose the viability of such a concept when limited areas are involved.

As shown in Table 14, a constellation of about 10 sensors on a single airplane could provide a near complete environmental monitoring payload for polar regions. Less than 12 planes, even with 1 out of 3 always in repair could probably cover either area given reasonably high-altitude capability and payloads utilizing the full array of sensors of interest (interpolated from Ref. 33). The Coast Guard has requested the budget to buy airplanes of this same general type to patrol much of the coastal ocean area in the U.S. 200-mile limit. It would be up to NASA to design and demonstrate a prototype payload and data analysis system for Coast Guard operational use. Past comparisons have generally put most sensors on different airplanes and have considered much larger areas for coverage. Satellites have seemed a good alternative in these comparisons. In this case, the area is much more limited and suitable airplanes will also be available and will be working the polar regions in question. A stronger look needs to be taken at just what could be accomplished by this airplane alternative, the cost involved, and how this would affect satellite payload decisions.

A network of in situ polar sensor packages with relay data links to the central or regional processing centers might also be a practical supplement to existing satellite planning, with or without dedicated airplane payloads. Whether Option 0 in Figure 10 would be best as truly status quo or should be status quo only in the satellite rather than in the aircraft and in situ portions needs study.

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LIST OF FIGURES

LIST OF TABLES