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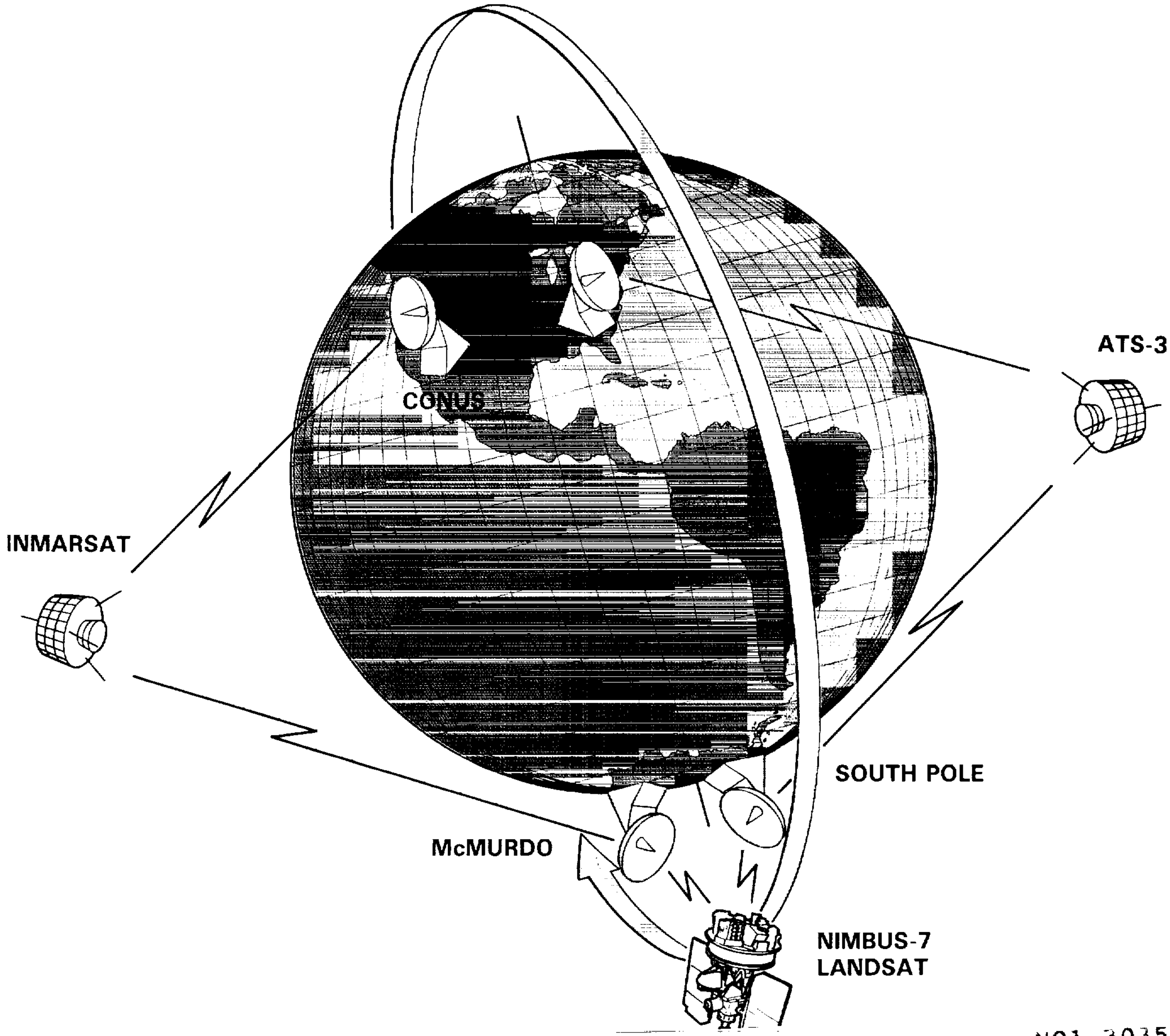
POLAR COMMUNICATIONS: STATUS AND RECOMMENDATIONS

Report of the Science Working Group



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Cover: *Schematic of current polar satellite communication links depicting data transfer within Antarctica to the continental United States (CONUS).*

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Report of the Science Working Group

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Foreword

In order to assess the communication requirements of the polar research community in the United States, NASA convened a Science Working Group (SWG) comprised of representatives of the principal scientific and operational disciplines currently active in polar work. A two-day workshop was held at NASA Headquarters starting on August 27, 1986. The members of the SWG were:

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Abstract

This report summarizes the capabilities of existing communication links within the polar regions, as well as between the polar regions and the continental United States. The report goes on to place these capabilities in the context of the objectives of principal scientific disciplines active in polar research and, in particular, of how discipline scientists both utilize and are limited by present technologies. Based on an assessment of the scientific objectives potentially achievable with improved communication capabilities, the report concludes with a list of requirements on and recommendations for communication capabilities necessary to support polar science over the next ten years.

Executive Summary

To meet the communications needs of the research and operational communities active in the polar regions, the National Aeronautics and Space Administration (NASA), National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), and Department of Defense (DOD) are investigating new concepts in satellite communications technology. New systems with increased capacity and reliability are being sought to respond to escalating communications demands imposed by the increasing awareness on the part of the science community of the importance of the polar regions in global processes and by the strategic and economic emphasis placed on the polar regions by the commercial and military sectors.

In order to gauge the needs of the user community, a two-day workshop was held at NASA Headquarters in August 1986. Participants representing a sampling of the major disciplines currently active in polar research as well as communications engineers and agency representatives were in attendance. The thrusts of the meeting were first, to evaluate the capability of existing communications systems to meet the demand of the user community over the next five years, and, second, to compile a list of user requirements that could be the focus for the design and implementation of improved systems.

This report is a summary of the proceedings of that workshop. Based on a compilation of users' scientific and operational objectives and consequent requirements, an evaluation of existing systems, and a consideration of new technologies with potential for successful development, the working group has assembled a list of recommendations. These recommendations detail the elements essential to a practical communications system that the working group believes the federal agencies could initiate in order to prepare for communications demands likely to be realized during the next ten years.

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I. Introduction

An increasing awareness of the important role the Earth's polar regions play in global dynamics is prompting vigorous scientific, commercial and military inquiry into the land, ocean and atmosphere of the polar regions. In turn, the questions spawned by these initial investigations have led to expanding requirements to send people and supplies to the Arctic and Antarctic in order to carry out the long-term programs identified as essential to understanding polar processes. To more effectively use the resources available for these projects and to maximize the efficiency of workers in the field, the technologies for managing and conducting large-scale programs at the poles are coming under careful scrutiny. In particular, the communications systems presently operational for polar work are being re-evaluated under the pressure of practical considerations such as facilitating message traffic between an investigator and his home institution, as well as the trend towards telemetry of data from remote and/or unmanned stations. Of special interest are new methods that speed data flow, increase the probability of success for an experiment and reduce the level of risk to the experimenter, provide for interactive experiments and ultimately deploy remotely controlled instruments.

For most of the past twenty years, the polar research community has been adequately served by conventional communications systems - essentially high-frequency radio links that relied on ionospheric bounce to enable communications both within the polar regions and beyond them. But more recently, the increasing costs in maintaining manned and unmanned facilities at the poles, increasing field party activity well apart from main installations, and the desire to implement a more interactive environment between workers at the poles and scientists in other parts of the world are prompting federal agencies in the United States as well as agencies in Canada and Europe to seek new, more reliable and higher capacity systems (Interagency Arctic Research Policy Committee, 1987).

In order to assess the communications requirements of the polar research community in the United States, NASA assembled a team of investigators representing a sampling of the principal scientific and operational disciplines currently active in polar work. The primary objective of the team was to compile a list of communications requirements that, if implemented, would facilitate meeting their disciplines' present and future scientific objectives. The task was bounded first by inviting communications engineers able to argue the feasibility of implementing proposed concepts, and further by imposing two constraints: (1) projects were restricted to those outside the limit of geostationary satellite coverage (see Figure 1), and (2) projects were restricted to those polar programs that are within view of geostationary satellites but have requirements that exceed the capabilities of the present geostationary satellite network.

Within this framework, the working group first set out to evaluate the present communications networks, including both voice circuits utilizing HF radio and data links such as System ARGOS. From there, concepts under development and test also were discussed. They included the systems currently operated by NSF to access the geostationary and polar-orbiting satellites for high-volume data links from South Pole Station to McMurdo Station and from McMurdo Station to the continental United States.

A consequence of the discussion led to the formulation of a list of communications requirements emphasizing the need for voice and high-volume data channels and communications capability both within the polar regions and away from the polar regions. This list, combined with the activities envisioned by the group as highly probable over the next ten years, forms the basis for the recommendations that this science working group is posing to the agencies.

Figure 1. Geostationary satellite usage typically extends from 60°N to 60°S latitude. Although the satellites are visible to latitudes as high as 81°, they appear on the local horizon and are easily masked by ground reflections and natural obstructions. Figure 1a shows that while the Arctic regions fall outside the optimal geostationary satellite coverage area, populated land masses extend well north of 60°, resulting in the proliferation of various communication links. Antarctica (Figure 1b) also falls outside the zone of optimal geostationary coverage, but isolation of the continent precludes use of technologies other than HF radio or satellite-linked transmissions. Data transmissions within Antarctica have been augmented over conventional HF transmissions through the use of transponders aboard low-altitude polar-orbiting satellites. Access to the satellites is currently via S-band links operated at South Pole Station and McMurdo Station. The heavy circle drawn around South Pole Station indicates that the station can reach an area bounded by 22.5° of latitude. Similar coverage from McMurdo is shown by the heavy oval. All of the current polar-orbiting satellites pass over Antarctica on a line tangent to the dashed circle (about 81°); the tangent path rotates daily. Overlapping areas bounded by the heavy circle and the oval contain all of the satellite passes for which communication between South Pole Station and McMurdo Station is possible.

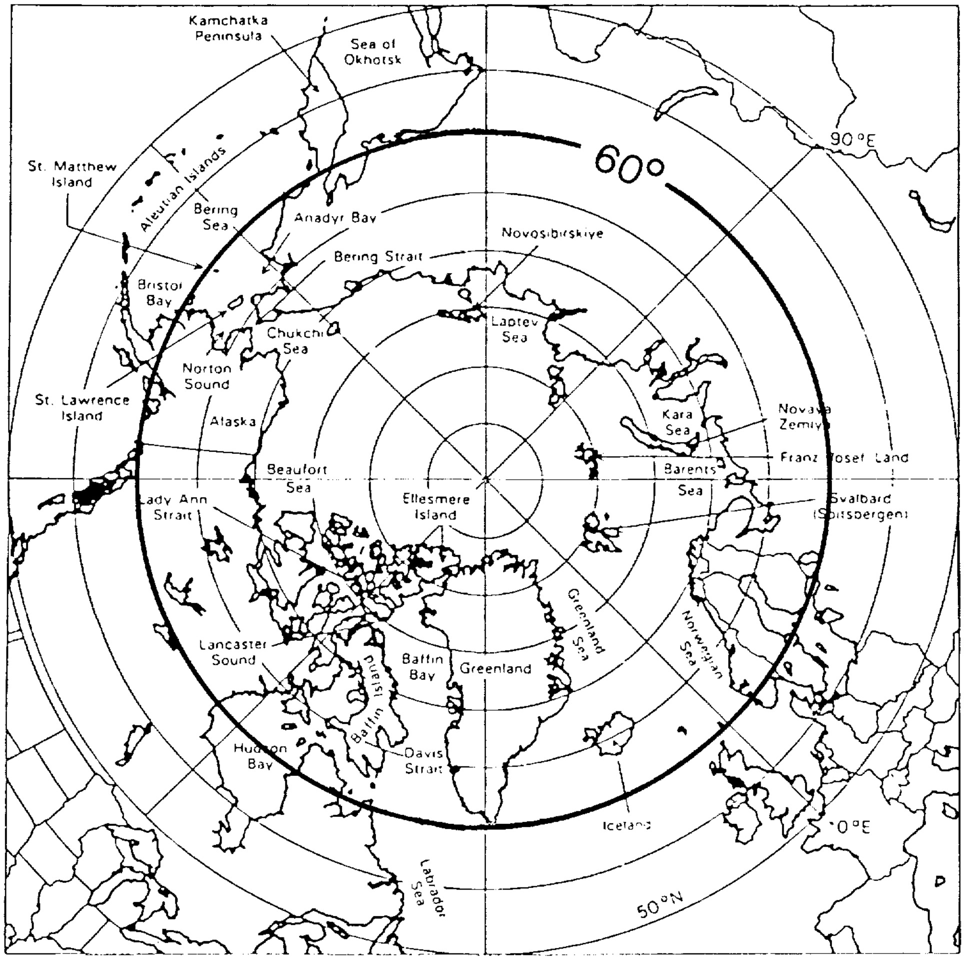

Figure 1A

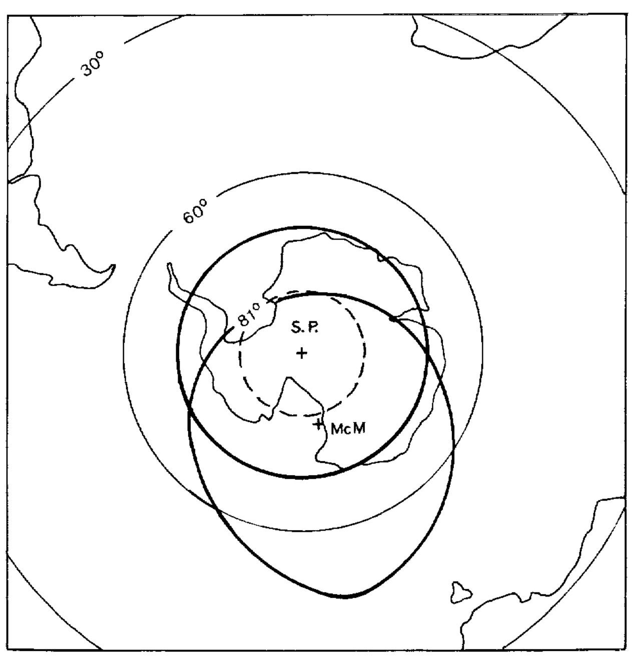

Figure 1B

II. Background on Communication Systems

A. HF Radio

Two generic types of communications networks can be identified for the polar regions. These are networks that relay information within the polar regions and those that connect the poles with the rest of the world. Until recently, the same kind of high-frequency (HF) radio technology (3 to 30 MHz) was used to construct both networks. HF radio has proved to be a usable but not entirely satisfactory solution for monitoring activities of field parties and for dispatching very limited amounts of data and regular message traffic from the poles to, for example, the continental United States. With increasing numbers of investigators in the field (the total participating in the United States Antarctic Research Program in 1960 was 130; in 1986 the number was 350), and with commensurate strains on support schedules for those investigators, the limitations of HF radio are being reached. The dilemma with HF radio communications is a fundamental one associated with variable propagation characteristics and unpredictable bounce paths. Indeed it is not uncommon for an investigator, working in the vicinity of Ross Island, Antarctica, to be unable to contact McMurdo Station directly, instead having to relay messages through either South Pole Station or, if possible, ships at sea. Furthermore, data transmission rates are low, only about 55 bits per second. While it is clear that HF radio operation will remain a fundamental element in polar communications, reliance on HF radio as the sole technique for voice and data traffic is directly impacting the size, scope, and efficiency of the kinds of scientific activities that investigators and agency sponsors are now calling for.

B. System ARGOS

Relaying small amounts of data a few times per day from unmanned instrumented platforms using the ARGOS system onboard NOAA spacecraft has proved to be a viable option for many investigators, particularly in the Arctic. Polar oceanographers have made good use of ARGOS to relay data from drifting buoys deployed in the polar ice pack (Figure 2), and polar meteorologists have adapted the technique for use with sensor packages left on the Antarctic Plateau. ARGOS itself is a French instrument integrated into a NOAA satellite, with a complementary suite of United States and French ground stations and computer centers under the responsibility of the French Space Agency. Data downlinked from ARGOS is received at one of three receiving sites, processed and then distributed over conventional communications networks. Data are typically delivered with delays of several hours from the time of reception.

Figure 2. Several drifting sea ice buoys awaiting later deployment in the Weddell Sea. Buoys record temperature and pressure. Data are telemetered from the buoy via the Nimbus-7 Random Access Measurement System. (Photo courtesy of S.F. Ackley.)

A key advantage of ARGOS is its ability to determine the geographical position of the transmitting platform. ARGOS accomplishes this by processing the Doppler frequency shift in the transmitted signal. Message lengths are up to 256 bits and may be transmitted several times a day. The principal limitation of ARGOS is the low data rate (about 0.1 bit per second). The ARGOS equipment capacity is described in Table 1.

C. Advanced Satellite Systems

The current use of satellites for Antarctic communications is one that has evolved over the last five years, utilizing available commercial and government-operated geosynchronous and polar-orbiting satellites to facilitate the United States Antarctic Program's administrative, science, and personnel communications requirements. The development was spurred on by the rapid increases in both the volume of data and the value inherent in obtaining the data in near real time over the course of an entire year. Prior to the integration of satellite transmission capabilities into Antarctic programs, data analysis would lag behind data collection by about one year as a result of the limited access to the continent imposed by climatic conditions.

TABLE 1. ARGOS EQUIPMENT CAPACITY

		Satellite		
		NOAA 10 NOAA D	NOAA H NOAA I NOAA J	NOAA K NOAA L NOAA M
Transmission Interval	Message Length		Number of Platforms	
Data Collection Platforms:				
100 sec	256 bits	225	270	1020
200 sec	256 bits	450	540	2045
200 sec	32 bits	1152	1382	5240
Location Platforms:				
50 sec	256 bits	110	132	500
60 sec	256 bits	135	162	600
60 sec	32 bits	346	415	1630

The following is a summary of the satellites employed for Antarctic communications, with a description of their capability, uses, and expected viability.

International Maritime Satellite (INMARSAT): INMARSAT provides telecommunication services to the shipping and offshore industries. In addition to Marecs A and B2, INMARSAT leases maritime communication subsystems on four INTELSAT V geostationary spacecraft. INMARSAT is now evaluating proposals for its next generation of up to nine satellites to be available from 1988, providing increased capacity (125 simultaneous telephone calls compared with 50 for Marecs). INMARSAT is being used by several Antarctic programs to meet telecommunication requirements from the continent. The United States Antarctic Program (USAP) has installed three systems, two at McMurdo Station (77°52'S, 166°40'E) and one at Palmer Station (64°46'S, 64°03'W).

The system is used for the transmission of satellite tracking data, data from upper atmosphere physics experiments, and data collected from the NOAA Geophysical Monitoring for Climate Change (GMCC) Program. Additionally, INMARSAT provides the voice link from Antarctic coastal stations back to the United States for administrative traffic, and is used to access the various electronic mail services in the United States. INMARSAT serves as the relay mode for data collected at South Pole Station and transmitted by the South Pole Satellite Data Link (SPSDL, as described later).

The system typically operates at 1200-2400 bps. Maximum transmit capability is 56 Kbps. INMARSAT is likely to continue as the primary satellite telecommunications link from Antarctic coastal stations. As usage increases with subsequent increase in overall cost, coupled with possible increases in data requirements, consideration for installation of more capable systems will be analyzed.

INMARSAT use in the high latitudes has the same limitation as all geostationary satellites, low elevation angle. At McMurdo Antarctica, the typical viewing angle for INMARSAT is less than 7° and can easily be blocked by local topographic features.

This has happened at McMurdo Station when the position of the active satellite was changed, forcing a relocation of the ground station and considerably complicating operations.

Satellites in geostationary orbits that have intentional nonzero inclinations, or that drift into a slightly inclined orbit, have viewing angles that vary over a few degrees (see items 2 and 3 below). This allows a higher viewing angle at some times of the day and a lower angle (often below the horizon) at others. Typically, the time of day at which the maximum viewing angle occurs precesses, moving one whole day per year. This can have a significant impact on data communications that have a fixed daily schedule.

Lincoln Experimental Satellite 9 (LES-9): LES-9 was placed into service in May 1978. It was established as a network used for government communications between fixed and mobile earth stations. LES-9 has a diurnal motion swinging north and south about 18° from the 0° latitude at a nominal longitude of 105° W. Satellite location and orbital inclination permit about six hours of visibility from McMurdo and South Pole Stations. At present, the network is operated in the UHF band at half-duplex for voice communications. It is planned to include data transmission limited to 1200 bps in the near future. Use for Antarctic/Arctic communications, however, can be preempted without warning for high-priority military requirements.

Applications Technology Satellite 3 (ATS-3): ATS-3 (shown in Figure 3) was placed into service in 1967. The satellite is located at 105° west longitude. As of January 1985, the orbit inclination of ATS-3 is 10.6°. The inclination of the orbit plane is currently increasing at approximately 0.5° per year. The control center for the ATS network is operated under a project office contract with the University of Miami and is split-funded between NSF and NASA. The satellite services a wide range of users. Recently service has expanded to the Antarctic research community as the satellite becomes visible to the polar stations due to its changing orbital inclination.

ATS-3 services Palmer, South Pole, McMurdo, and Siple Stations in Antarctica, and provides voice communications and data transmission capabilities (1200 bps) to the continental United States (CONUS). The service time window varies between stations according to location in Antarctica to a minimum of about four hours at South Pole Station. The continued use of ATS-3 is attractive for several reasons.

It is (1) user friendly, requiring only simple antennas and basic computer hardware and software to operate the system; (2) a system with a centralized CONUS data distribution network established which facilitates usage and encourages new applications; and (3) inexpensive to the user and to the funding agencies. With any new systems, the operating model of ATS-3 should be considered in further planning and development.

South Pole Satellite Data Link (SPSDL): This system was established in 1984 to demonstrate how polar-orbiting satellites could be used routinely to send high volumes of scientific data across Antarctica at low error rates (cover). The system was designed to handle relatively high-speed digital transfer of data (9.6 Kbps) from the Amundsen-Scott South Pole Station (90°S) to McMurdo Station, Antarctica (77°52'S), for transmission back to the continental United States via commercial geosynchronous satellites.

To effect this transfer, two ground-based tracking antennas are used, one located at South Pole Station and the other at McMurdo Station. The space segment system

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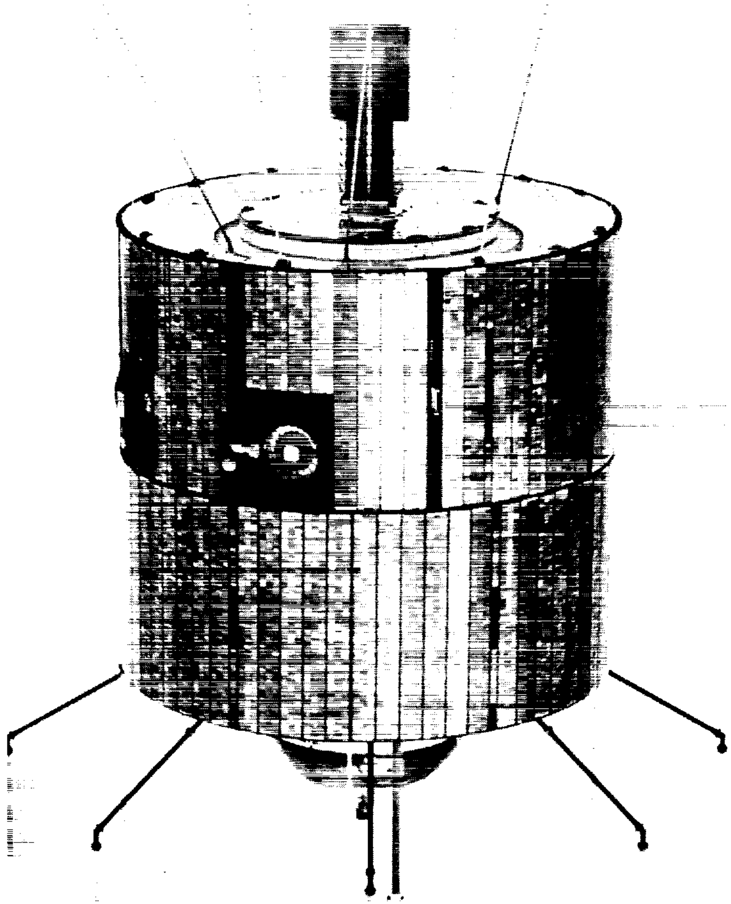

Figure 3. Applications Technology Satellite 3 (ATS-3), showing VHF antenna arrays at top of spacecraft. (Courtesy of P.A. Eden.)

includes polar-orbiting satellites carrying S-band ranging transponders that are employed to relay the signal from one tracking antenna to the other. Currently, NIMBUS 7, LANDSAT 4, and LANDSAT 5 carry the primary relay responsibilities. Data are relayed during the periods of covisibility between the orbiting satellites and the established ground stations (generally on the order of 10-15 minutes). When received at McMurdo Station, the data are transferred to INMARSAT for direct delivery to the user.

At present, the system is operated by two science projects, one at McMurdo and the other at South Pole. The McMurdo operations will be taken over by NSF in 1987-88. SPSDL has become the primary large-volume data transmitting system from the interior of the continent. Currently, the simplex data rate is 19.2 Kbps in either direction. It is anticipated that with various upgrades in computer hardware and antenna configuration (3-meter dishes instead of 2-meter), the potential data transmission rate could approach 43 Kbps (Comberiate, *et al.*, 1986).

In summary, as Table 2 shows, the current Antarctic telecommunications capability is a mix of systems employing existing satellite and surface capabilities. The federal government has taken the lead by making these systems available and the scientific community has responded, in some cases, by designing and installing the hardware necessary to employ these new capabilities and quickly adapting their experiments to take advantage of near real time receipt of data.

Unfortunately, these systems are vulnerable to unannounced disruptions or failure in service. With the exception of the INMARSAT system, the satellites being employed have exceeded or soon will exceed their design lifetimes. In some cases (LES-9, SPSDL), use is "piggybacked" on satellites with other primary missions, which further aggravates the concern about service disruptions. Because existing systems have been employed to meet the immediate polar communication demands, and hence are limited to the original design criteria of those particular satellites, it is unlikely that the existing systems can be significantly expanded to accommodate future demands in polar telecommunications.

In addition to the systems described above, several other novel technologies, such as meteorburst and HF packet radio, are under study. These technologies are described in the report on ocean data telemetry prepared by M. Briscoe for the Office of Naval Research (Briscoe, 1986). It seems unlikely at this time that any one of these approaches alone will fulfill the future needs of the polar community.

TABLE 2. ANTARCTICA DATA LINKS

SYSTEM	SERVICES	ACCESS	DATA RATE (BITS/SECOND)	CAPABILITY (BYTES/DAY)	BIT ERROR RATE	LIMITATIONS	PRACTICAL IMPROVEMENTS
High Frequency (HF) Radio	Voice, Messages, Limited Data	24 hrs/day	75	800K	$3x10^{-3}$	Long periods of non-usability (48-72 hrs). Strongly affected by solar cycle. Operator intensive.	
ATS-3 (VHF) Geosynchronous Inclined Orbit	Voice, Messages, Data	4 hrs/day	1200	1.7M	$1x10^{-3}$*	May need to share window with other users. Spacecraft is beyond its life expectancy and cannot be considered a long-term asset.	Upgrade systems to provide simultaneous voice and data service.
ARGOS (UHF) Polar Orbit	Data, Location	11 passes/ day	256-1000 bits per pass	3.5K/ pass	$1x10^{-4}$	Low data throughput	Increase equipment capacity.
LES-9 (UHF) Geosynchronous Inclined Orbit	Voice, Messages	6hr/day	2400	5.1M	$1x10^{-4}$	Currently available data transmission equipment is high cost and labor operator intensive. May need to share window with other users. Spacecraft is beyond its life expectancy and cannot be considered a long-term asset.	Develop low-cost ground station equipment similar to ATS-3 equipment. Use full-duplex data link and same software as ATS-3 for data transfers and error correcting.

*Data Errors corrected to zero by software handshaking.

TABLE 2. ANTARCTICA DATA LINKS *(continued)*

SYSTEM	SERVICES	ACCESS	DATA RATE (BITS/SECOND)	CAPABILITY (BYTES/DAY)	BIT ERROR RATE	LIMITATIONS	PRACTICAL IMPROVEMENTS
South Pole Satellite Data Link (SPSDL) (S-Band) Polar Orbit	Data Transfer	4-12 min/pass	19,200	34M	$1x10^{-6}$	NOAA and NASA can preempt service. Operator intensive. Old ground equipment. Service usable only within continent.	Update equipment to fully automate. Replace 2-meter dishes with 3-meter to increase data rate to 43Kbps.
INMARSAT (L-Band) Geostationary	Voice, Messages, Data	Continuous	1200-2400	20M	$1x10^{-6}$	$10/min. user fee. Not usable from South Pole	Test one-way 56Kbps capability and implement if feasible.
Future INTELSAT (C-Band) Geostationary	Voice, Messages, Data	Continuous	120,000	1296M	$1x10^{-6}$	Cost considerations will constrain and limit data rates.	

III. Impact of Communications Technology on Polar Science

The scope and intensity of scientific inquiry in the polar regions is directly coupled to the ability to communicate within and away from the high latitudes. In this section we present a brief summary of the primary scientific questions currently being addressed utilizing existing communications systems, and suggest scientific questions that could be addressed given the assumption of enhanced communications capabilities maturing over the next ten years. Current use of voice and data transmission and anticipated future requirements are summarized by discipline in Table 3.

A. Upper Atmosphere Physics

The focus of research is on the transport of energy from the solar wind into the magnetosphere and the eventual dissipation of a portion of this energy into the upper atmosphere. Energy is dissipated through the loss of trapped energetic particles, which leads to enhanced ionization of the upper atmosphere, and by the Joule heating from ionospheric currents driven by magnetospheric electric fields. Understanding the physical processes (e.g., plasma instabilities, wave-particle interactions) that control the transport, energization, and loss of particles is one of the fundamental scientific objectives of this research. Equally important are the practical applications of this work in such areas as radio communication at ELF to HF frequencies.

Coordination of much of the upper atmospheric physics activities at South Pole, Siple, and McMurdo Stations is handled by the University of Maryland, because it has provided the primary digital data acquisition systems for recording the multi-sensor groundbased data (e.g., riometers, magnetometers, photometers, ELF-VLF receivers).

Current applications of satellite transmission technology employ the VHF transponder on the ATS-3 satellite for the purpose of: (1) transmitting the multi-sensor data from Antarctica, (2) transferring specialized analysis software to Antarctica, and (3) conducting interactive problem solving.

TABLE 3. VOICE AND DATA TRANSMISSION REQUIREMENTS

ITEM	UPPER ATMOSPHERE PHYSICS	ASTRONOMY & ASTROPHYSICS	SOLID EARTH GEOPHYSICS	GEODESY	OCEANOGRAPHY	GLACIOLOGY	METEOROLOGY
Voice (Current)							
Contacts/Day	2	1/wk	2	0	10	10	1
Hours/Day	1	2	0.5	0	2	2	0.2
Voice (Future)							
Contacts/Day	150*	3/wk	2	1/mo	10	10	1
Hours/Day	11	3	0.5	.25/mo	2	2	1
Data (Current)							
Bits/Day, Avg.	.1M	0.15M/wk	1.2M	1.5M	0.2M	0	0.25M
Bits/Day, Peak	.1M	0.15M/wk	2.4M	3M	0.2M	0	0.25M
Data (Future)							
Bits/Day, Avg.	700M	8M	600M	2M	26M	15M	25M
Bits/Day, Peak	700M	8M	600M	4M	26M	50M	25M

*Includes transmission of analog broadband signals via a voice channel.

The transmitted data are used to produce low-resolution survey plots for verification of data quality and performance of instrumentation, for enabling identification of periods of special interest (for which requests can then be made to transmit data at higher time resolution), and for responding and contributing to special coordinated study campaigns. Current transmission rates for this purpose average 10 Kbytes per day.

The transfer of specialized analysis software is currently at the rate of 100 Kbytes per year. Computer systems management and software installation can be performed remotely in the case of the Siple station facility via an interactive full-duplex data link.

Interactive problem solving is carried out mainly via the 15 KHz bandwidth voice channel on ATS-3. This has been particularly helpful when equipment problems arise that the field operator cannot readily diagnose and fix. Another valuable use of the voice link is program coordination between Siple and Mistassini (the magnetic conjugate point in Canada) for interactive wave experiments with the Siple VLF transmitter.

The need for coordinated simultaneous observations of the upper atmosphere from multiple groundbased sites with an increased spatial resolution has resulted in the development of unmanned Automatic Geophysical Stations (AGS) for use in Antarctica (see Figure 4). An AGS provides shelter, power, heat, and data acquisition for several experiments and is designed to operate for a year at a time without servicing. Plans to establish as many as six AGS sites in Antarctica over the next five years are currently being explored by the National Science Foundation Division of Polar Programs. Interest has also been expressed for deploying AGS facilities for research in Arctic regions.

The nature of potential parameters sensed by AGS experiments requires a data volume that far exceeds the capabilities of currently available systems such as ARGOS or HF communication paths. Most of the planned unmanned stations will be located at high latitudes from which line-of-sight telemetry to geostationary satellites is precluded. Terrestrial communications links are not practical from any of the Antarctic AGS sites. As a result, the AGS facilities are forced to record a full year of data at each remote site. This places a limitation on the volume of data generated by each instrument and also has the disadvantage that the data are inaccessible until the site is revisited at the end of the year. Installation and visitation require significant expenditure of logistic resources that can be ultimately conserved by the development of fully automated expendable systems that can telemeter all data to a relay base.

AGS data communications require that no steerable antenna be used at the remote sites and that the integrated power usage be low. A UHF communication channel using an omnidirectional antenna is recommended. It is envisioned that the UHF data would be relayed over the horizon by the satellite to a manned station where local review, recording and forwarding out of Antarctica by S-band telemetry could occur. It will be necessary for the satellite to command a remote site to initiate a data transfer. In addition, the unmanned stations could be commanded through the satellites to alter the operating modes and allow interactive control of experiments whereby operating decisions could be based on a review of data either in real-time or on subsequent satellite passes.

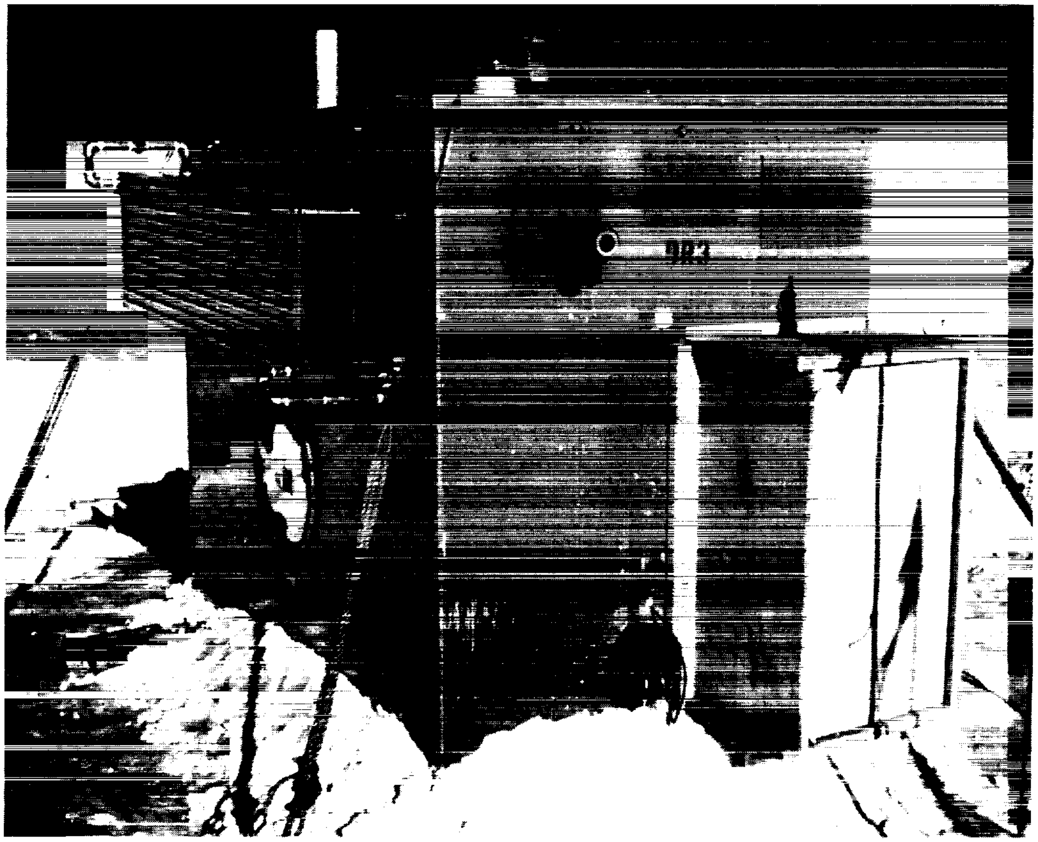

Figure 4. Prototype Automatic Geophysical Observatory operated at South Pole Station. Auroral photometers look out through dome at the top.

The current requirements for data acquisition using the AGS result in a total daily data acquisition of about 30 Mbits per station. A modest expansion of the data acquisition rates to accommodate additional and higher rate experiments could bring the daily data volume up to 100 Mbits per station. Such an increase would provide the means for greater time resolution studies of geophysical phenomena and would permit bringing out higher spatial resolution images of the optical aurora from groundbased instruments.

Manned stations in Antarctica routinely record broadband VLF radio noise with a bandwidth of many kilohertz. Because of the huge volume of data that results, it is not now practical to observe this important geophysical parameter in this format at the unmanned sites. However, a channel in the voice band of a polar orbiting satellite would give a means for relaying such broadband data from an AGS. Voice band data could be stored by audio recorders for playback during satellite passes. A two-minute contact with each station on each satellite pass would be sufficient to relay about one minute of VLF data for each hour. Future needs could increase the voice band data volume by a factor of four with contacts occurring twice as frequently using a second polar-orbiting satellite.

Regarding future applications, the possibility of circumpolar balloon flights also must be considered (Figure 5). These would be launches of instrumented payloads

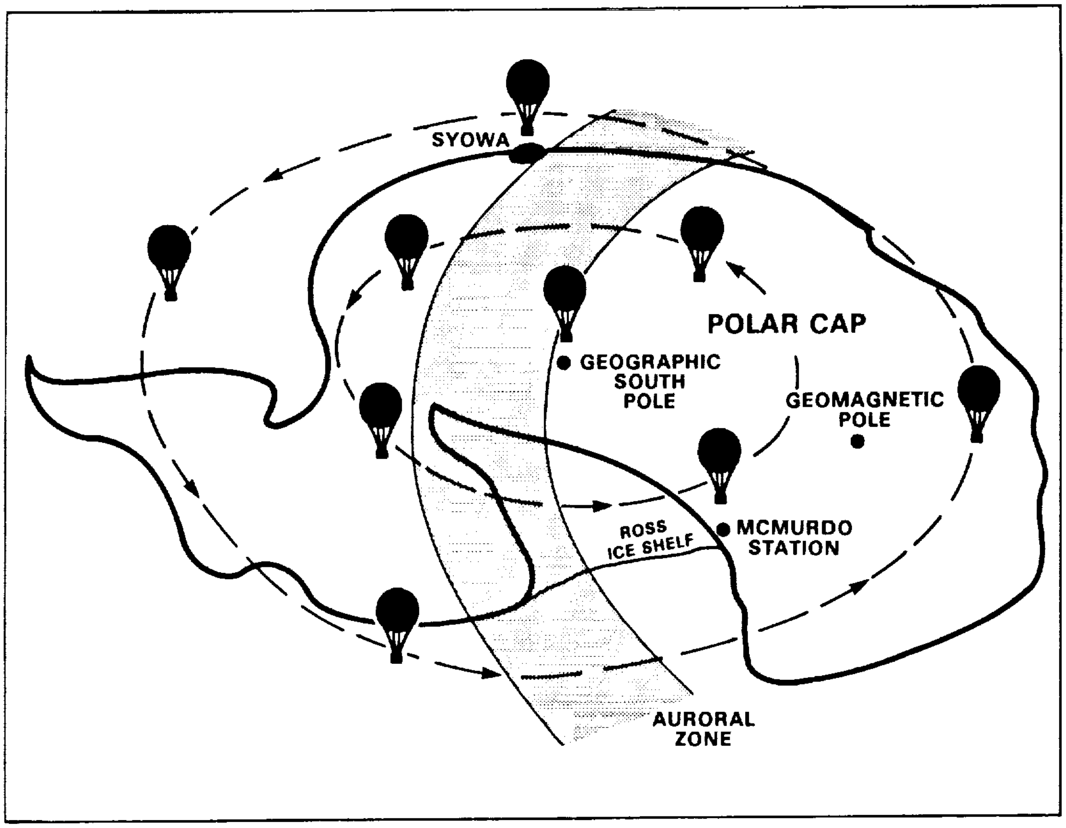

Figure 5. Conceptual drawing of a proposed high-altitude balloon experiment over Antarctica. Balloons would be equipped for studies of polar meteorology and upper atmosphere physics research. Data potentially could be telemetered back via satellite to a main base in Antarctica for subsequent retransmission to the U.S.

that would stay aloft simultaneously measuring a variety of upper atmosphere and meteorological parameters. Although there could be occasional data transmission from the balloons to some groundbased receiving sites in Antarctica, relay transmission via polar or geosynchronous satellite would be necessary in order to obtain complete polar coverage. Estimated data rates of 1-10 Kbps would be required, depending on the type of measurement and the use of onboard data processing. The Japanese Antarctic Research Program is planning to test fly a circumpolar balloon launched from Syowa Station in the near future.

B. Astronomy and Astrophysics

In view of the fact that the geographic South Pole is a remarkable site for conducting certain types of astronomical observations, this discussion is devoted almost exclusively to South Pole Station. In particular, the circumpolarity of the sky provides a uniqueness that cannot be duplicated elsewhere on earth.

Thus far, all astrophysical experiments have been conducted in the campaign mode during the austral summer. Consequently, since the senior investigators are all on site, there has been no impact on communications. Studies of the solar interior by observations of global solar oscillations have been and will continue to be the major area of concentration (Figure 6). Conflicting results have been obtained concerning possible frequency shifts during the solar activity cycle. If the changes are real, the nature of the time variations of modes that probe different depths in the solar interior remains to be determined.

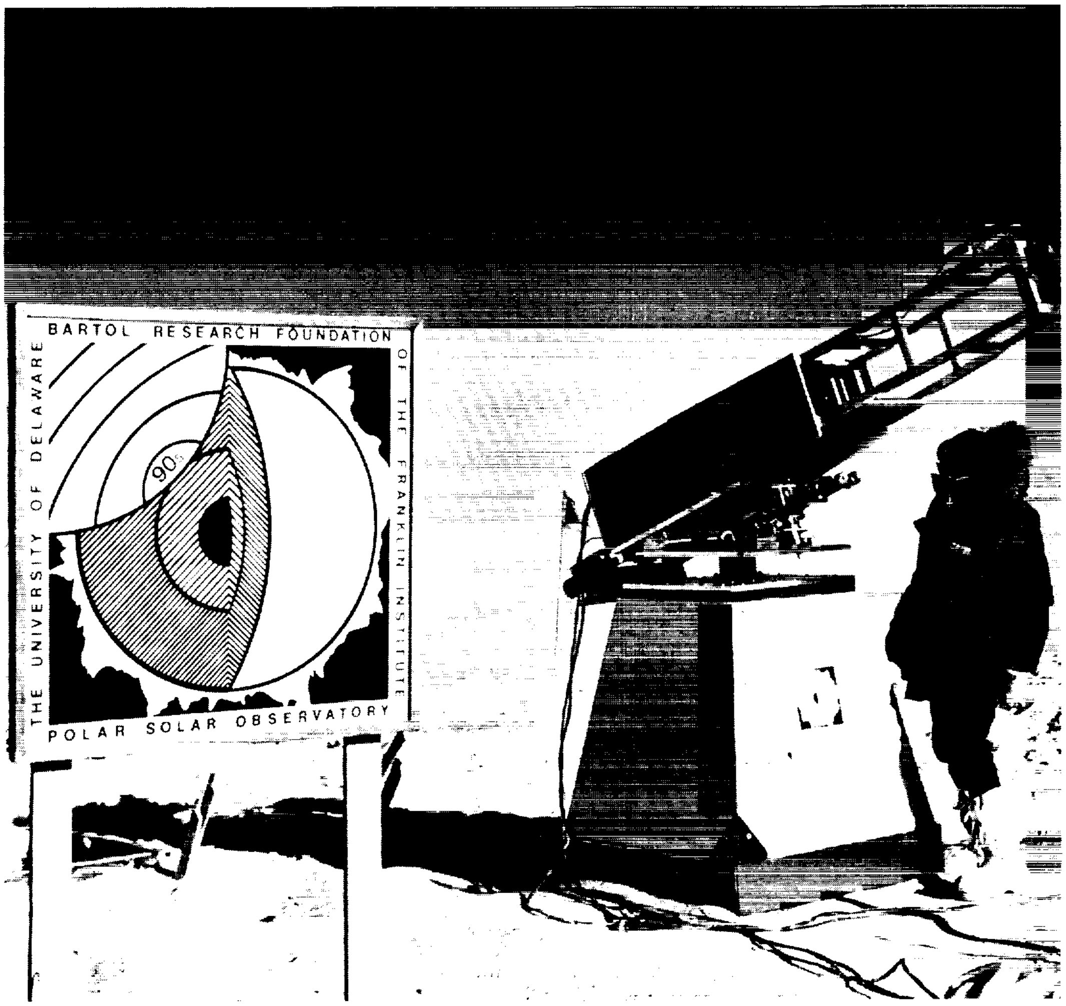

Figure 6. Solar telescope for helioseismology studies operating at the South Pole.

It also has been established that South Pole is the best site in the world for far infrared and microwave radio astronomy. If work that was started during the 1986-87 austral summer succeeds in detecting structure in the early universe, an explosion of interest in obtaining measurements covering a variety of angular separations and directions can be expected. Although the precipitable water vapor content and its fluctuations are significantly lower than at the best infrared observatory in the world even in the summer, conditions in the winter are even better. A consequence of winter operations would be a requirement for remote control of instrumentation at the South Pole. It is not clear how this can best be accomplished, or what the data transmission loads might be. In any case, a significant increase in the amount of voice and data communications would be expected.

These same considerations apply to observations of stellar oscillations, which require a large telescope (~30") capable of operating in the winter. Here, we can envisage instrumentation similar to that designed for operation in space. The application of the revolutionary new techniques for studying the solar interior to a wide variety of stellar objects can be expected to foster the need for a remotely controlled telescope at the South Pole.

The field of ultra-high-energy gamma ray astronomy also probably will flourish in the years ahead, if, as expected, the first such experiment, which will become operational at the beginning of 1988, detects interesting cosmic ray sources in the southern skies. In this case, the communications requirements are rather well defined, since real-time control and transmission are not required.

For the sake of completeness, we include a brief comment about the cosmic ray observations that have been conducted since 1959 to yield a unique data base for studies of the large-scale structure of the heliosphere. The data transmission and communications requirements of this program are modest indeed and have no impact on long-range planning of Antarctic communications.

C. Solid Earth Geophysics

The South Pole is a unique place at which to observe seismic events. It is seismically quiet, making it useful to observe events located elsewhere in the world without having local noise interfere with data acquisition. In addition, seismic energy from elsewhere in the world is focused toward the South Pole by rift lines running longitudinally on the earth. The relatively small number of other seismic stations in the southern hemisphere makes the South Pole particularly critical for analyzing observed events in the southern hemisphere. Indeed, geophysical programs rely on data from the South Pole to such an extent that it affects the determination of every epicenter in the southern hemisphere; it is certainly one of the most important stations in the world. To take advantage of this unique location for some studies, a continuous digital recording is required. For most purposes, however, data limited to immediate events would be of great benefit.

A broadband vertical (BBZ) component seismometer yields 17 Mbits per day (20 bits per sample, 20 samples per second). With some data compression, this could be cut to about 8 Mbits per day. Two long-period horizontal (LPH) components at 1 sample per second would add 3.5 Mbits per day, or perhaps 2 Mbits per day with compression. Record readers at the South Pole could select seismic events to be transmitted each day. (Tractor noise would limit the usefulness of an automatic event detector.) Because there is no local seismicity, we would expect the real seismic events to occupy less than 5% of the record each day. Thus, a BBZ and two LPH channels would reduce to (17M + 2 x 3.5M) x 5% = 1.2 Mbits per day, which could be sent at any time during the day following recording of the events. If the communication system has a 9.6 Kbps capability, this would require about two minutes.

In addition to South Pole Station, there are three stations in the Arctic that would be logical candidates for a similar data transmission system: Alert (82.5°N) and Mould Bay (76.2°N) in Canada, and Kingsbay, Spitzbergen (78.9°N). At present, voice-grade communications are intermittent with Kingsbay; the capability for data-grade quality is unknown. Further investigation is needed to determine whether improvements are possible with geosynchronous satellites. The primary importance of these stations is for monitoring seismicity on the northern segment of the mid-

Atlantic ridge and its Arctic extension. Unlike Antarctica, the north polar region is seismically active.

Near real-time digital data from these four remote stations would be a significant advance in operational capability, as well as an important contribution to the worldwide seismic data base. In fact, the USGS has already successfully tested sending seismic data via the ATS-3 link from the South Pole to Malabar, Florida. The ATS-3 serves as an alternative backup route for the data that are currently being sent by the South Pole Satellite Data Link. Unfortunately, both systems are not permanent and rely on satellites that are not dedicated solely to the use of the polar scientific community. This can have adverse effects, as has occurred in the past with timing and availability of transponder use.

The National Science Foundation Continental Lithosphere Program recently sponsored a new initiative for a 100-station permanent global seismographic network, and a 1000-station portable seismographic network, to support research in global and lithospheric seismology. The major tasks under the program include, in addition to the development and deployment of the permanent and portable data acquisition systems, the concurrent development of the facilities necessary to collect, process and distribute the seismic data to research organizations throughout the world. The facilities established through this NSF-sponsored initiative will significantly improve the seismic data base for research and are expected to serve as the principal source of teleseismic earthquake data for the next 25 years or more.

Initially, the data will be recorded on magnetic media and shipped back to a data collection center in the U.S. However, the final plans call for the data to be transmitted back to the data collection center via satellite. This new network will replace the existing obsolete global analog network with modern, high quality digital instrumentation. Each station will record continuous broadband (0-5 Hz) three-component seismic data, with a dynamic range of 140 dB.

The initial plan for establishing a global network divides the surface of the Earth into 128 blocks of roughly equal area. Of these 128 blocks, 115 contain land masses suitable for placement of seismograph stations. Twenty-five of the blocks will be occupied by existing or planned networks. This leaves 90 blocks still to be occupied in order to achieve the desired station density. Most of these already have operating seismograph stations, so that the principal task will be to upgrade existing stations with new sensors and digital electronics. This will probably take about ten years to complete.

Six stations of the global network will definitely be above 72° latitude. There may be up to 20 additional stations at latitudes that preclude reliable communications with standard communications satellites. These stations, along with some of the stations located on islands in the middle of ocean basins, may require special types of communications links not available with current commercial satellites.

The data rates for a station are relatively modest. Depending upon the type of station, the rates can vary from 160 Mbits to 800 Mbits per day for each station. Because of the worldwide distribution of station locations and the need to get all of the data to a central facility, it may be necessary to utilize several different communications systems.

Development of the global network is being implemented by the Incorporated Research Institution for Seismology (IRIS), which operates a number of seismic stations in the polar regions: Alert, Canada; College, Alaska; Kevo, Finland; and South Pole, Antarctica. Alert and South Pole are gravimeter sites for measuring the Earth's free oscillations. Alaska and Finland are sites of three-component very broadband (VBB) seismometers. None of these stations currently possesses telemetry capabilities. The digital data are recorded on magnetic tape and routinely - or in the case of South Pole, expediently - mailed to the data collection facilities in the United States.

Within the next five years, IRIS will have VBB seismic stations operating in Spitzbergen and Greenland, and the South Pole and Alert sites will be upgraded to VBB response. These stations produce three data rate channels for each of the three components of ground motion: broadband - 20 samples per second (sps), long-period - 1 sps, very-long-period - 0.1 sps. Additionally, the IRIS stations have six optional channels for 100 sps very-short-period and log-gain data plus 12 auxiliary channels for environmental, state-of-health, and other geophysical data.

The data rates vary depending upon the configuration and instrumentation, but they range from about 1000 Kbps to about 6000 Kbps continuous (data compression has been taken into account). Thus, uplink telemetry for polar-orbiting satellites needs to be of the order of 1 Mbps.

The science that these seismic stations contribute to Arctic and Antarctic research is multifold and includes: (1) the transition from oceanic to continental regimes in Northeast Asia, (2) continental margin seismicity and the effects of glaciation, (3) the evolution of northern Alaska, and (4) detection of seismicity in the deep Arctic basin and Antarctica. On a global scale, all of these stations are important to the overall coverage of the Earth's seismicity. Further, the South Pole station plays a unique role in the study of the Earth's free oscillations, as it is the only place (other than the North Pole) where mode-splitting due to the Earth's rotation does not occur (Figure 7).

D. Geodesy

Geodetic research, conducted by the Applied Research Laboratories of the University of Texas and the U.S. Geological Survey, is an on-going activity at McMurdo and South Pole Stations. The principal work of the University of Texas centers around the collection of data derived from Doppler beacon transmitters onboard polar-orbiting navigational and geodetic research spacecraft. Subsequent reduction of the collected data provides continual monitoring of the position of these orbiting spacecraft, with an accuracy in the meter range.

Utilization of the positional information extends into a diverse field of applications. Navigational beacons provide point positioning for both maritime navigation and terrestrial surveying. Use of very accurate point positioning has played a key role in the study of plate tectonics, ice flow dynamics, and other similar disciplines. Detailed knowledge of geodetic research spacecraft position is significant in the interpretation of data collected by these spacecraft for the investigation of ionospheric and earth magnetic field effects. Fine-scale mapping of the Earth's gravitational field, derived from accurate determination of spacecraft position, has been instrumental in the development of earth gravity models.

Collection, and subsequent transmission, of data to the United States for reduction is a continuous process based on a 24-hour cyclic loop, repeated seven days per week, 365 days per year. Data collected during a 24-hour UT day must be transmitted for

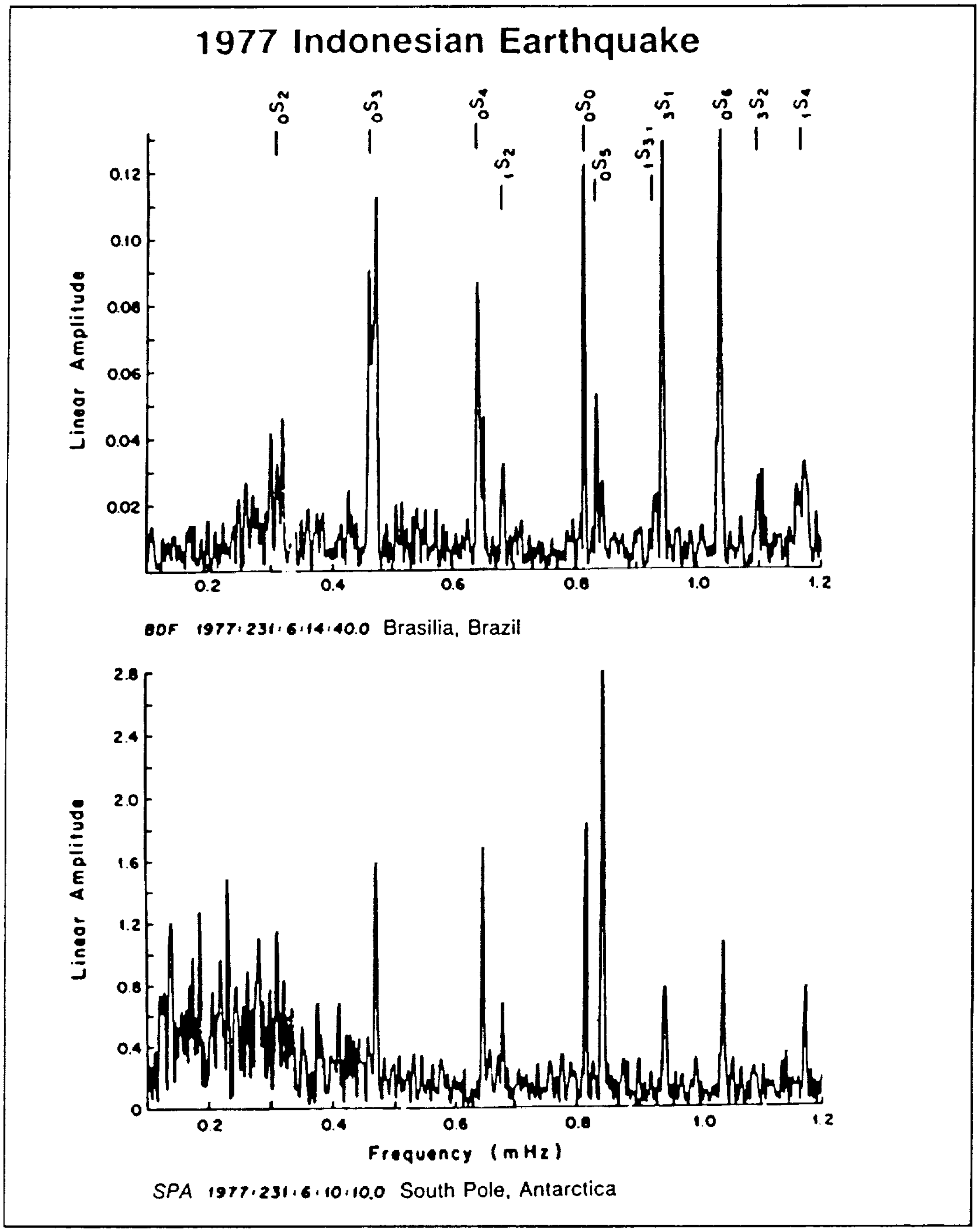

Figure 7. Amplitude spectrum of the Earth's free oscillations, showing mode splitting effects (e.g., OS3) observed in Brazil as compared to its absence at the South Pole for the 1977 Indonesian earthquake. (Courtesy of G. Masters.)

reduction within 12 hours after the end of the UT day of collection. Data arriving after the 1200 UT cutoff is not usable. Reliable, timely transmission of data is therefore as vital to project operations as is the primary data collection. Quality of the data is directly affected by the bit error rate (BER) of the communication system. The maximum tolerable BER is on the order of 10^{-5}. Typical daily data blocks transmitted by geodetic research are on the order of 150-200 Kbytes. Future requirements could increase this to 300 Kbytes per day with peaks of as much as 650 Kbytes per day.

In summary, geodetic research requires a high reliability data communication system usable in the 0000 UT to 1200 UT timeframe with a BER better than 10^{-5}. Any enhancement of the Antarctic data communications capabilities that improves reliability, usability, or BER is of direct benefit to this research and will aid in accomplishing project goals.

E. Oceanography

The unique focus of Arctic oceanography is to understand the growth, motion and decay of sea ice, and how sea ice modulates the interaction between the relatively warm polar ocean and the cold atmosphere. Such research is pertinent to issues such as the production of deep ocean water as related to global ocean circulation, and the need to operate in an economically and strategically important part of the globe.

Arctic oceanographic data are currently collected by manned camps, buoys, ships, aircraft, and satellites (Figure 8). Because high costs preclude the development of many continuously manned sites for acquisition of synoptic data, much effort goes either to servicing simple data collection buoys or to occupying many remote sites in time sequence with aircraft. An alternative approach is near real-time data collection from semi-autonomous expendable buoys and other instrumentation systems that allow monitoring of the data quality. This solution to Arctic data acquisition problems could be implemented by satellite telemetry systems. Three possible Arctic programs that would use a proposed satellite telemetry system are discussed below.

ARAMP. (Arctic Remote Autonomous Measurement Platform). The Marginal Ice Zone Experiment (MIZEX) is a study of the air/sea/ice interaction at the boundary between the ice-covered regions of the central Arctic and the North Atlantic. A major problem addressed by the MIZEX program is the generation of mesoscale eddies and internal waves and their influence on acoustic sound propagation, generation of ambient acoustic noise, and ice kinematics. This effort involves understanding and modeling the environmental data and relating it to acoustic data. Because the acoustic signals propagate from a large region to the measurement point, non-local effects require synoptic measurements of the environment and the acoustics. Therefore, the MIZEX program is sponsoring the development of the ARAMP buoys to reduce the need for manned ships and ice camps. These data could be more completely and efficiently collected by semi-autonomous buoys, but the data storage requirements are immense. The Arctic is especially difficult, because not only are geosynchronous satellites not available, but high-density data storage systems do not perform well in the cold. The need for increased data telemetry in the Arctic is very apparent for this application.

A total of 50 buoys is proposed, yielding 23 KBytes/day/buoy (an equivalent continuous data rate of less than 3 baud). This would require 23 seconds of satellite time per day per platform to dump at a 10 kbaud rate. This is well beyond the capabilities of ARGOS. The expanded capability could require as much as 2 Mbytes/day, or an equivalent data rate of 230 baud. This would require 33 minutes of satellite time per day per platform.

ARCTIC SOFAR DRIFTER PROGRAM. The purpose of the SOFAR Drifter Program is to track ocean currents at depth in the Fram Strait, which is essential to

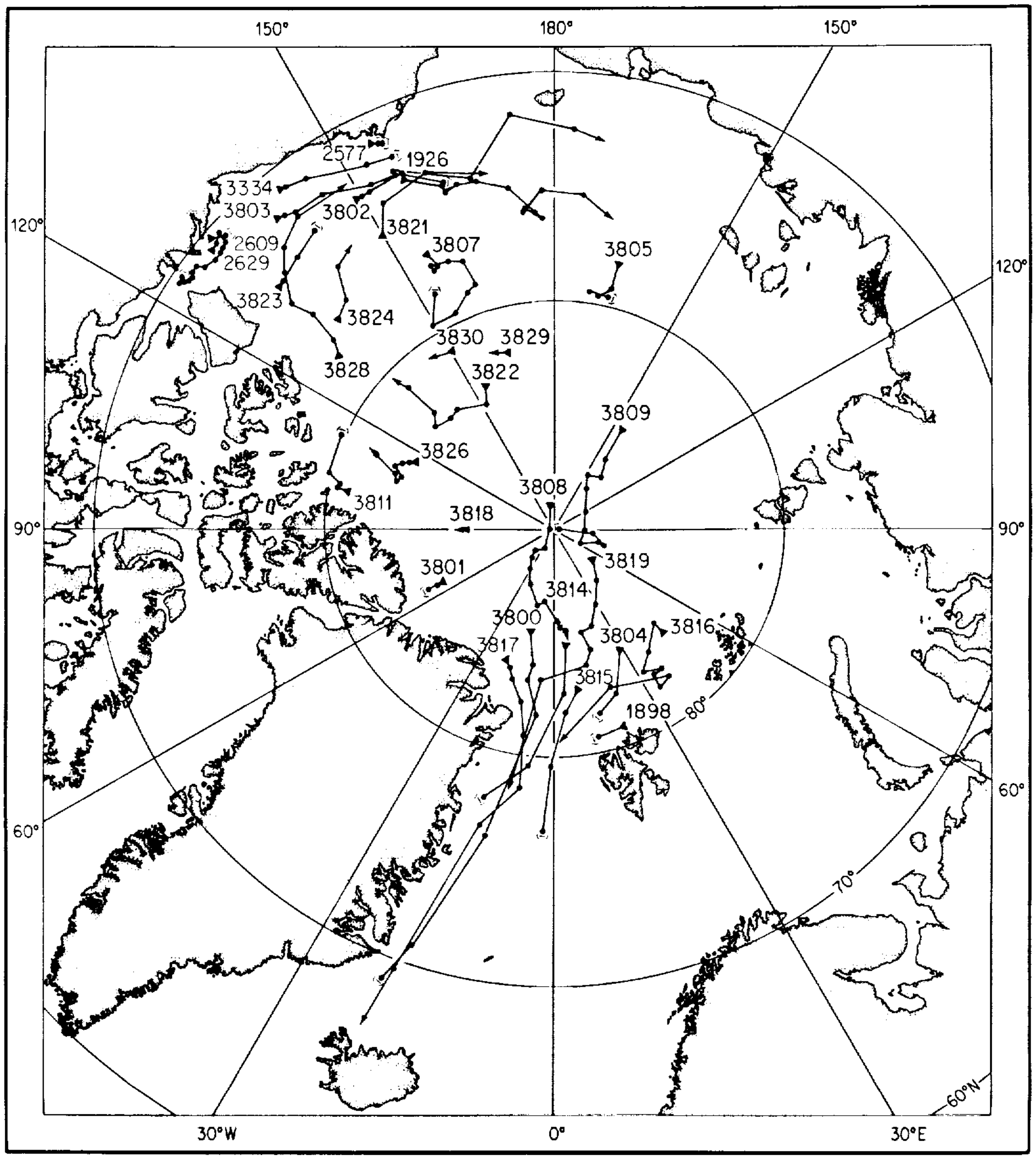

Figure 8. Trajectories of ARGOS buoys within the Arctic ice pack for the year 1982. (Courtesy of R. Colony.)

understanding the heat and mass flux between the Arctic and temperate oceans, and ice dynamics along the east coast of Greenland. This program has been scaled down so that it can be carried out using the ARGOS system to relay data on the underwater drifters. A more ambitious program could be in place if greater data capacity were available on the satellite telemetry link. Given the current crowding in this ARGOS footprint, expansion of the program may be difficult without new telemetry capabilities.

The current requirements for this program are five surface buoys at two ARGOS ID's/buoy/constellation; 40 sub-surface drifters/constellation/1.5 bytes/day; six bytes/day/drifter supplying two locations/day and one measurement of temperature or depth per day. This totals 1500 bytes/day/surface buoy/40 drifter constellation.

This can be handled by two ARGOS ID's per surface buoy, with one new message/hour. Increased capacity would allow additional groups of 40 drifters to be tracked and would relay back more environmental data.

ARCTIC ACOUSTIC TOMOGRAPHY. This program uses acoustic transmissions between underwater transceivers to measure travel-time anomalies. These anomalies are then interpreted by inversion methods to yield information about the three-dimensional underwater sound-speed structure. Tomography uses wave phenomena to penetrate the ocean rather than a large collection of research vessels or physically autonomous buoys. By measuring the integrated effects of the ocean over a large number of paths, tomographic reconstruction methods can allow calculation of sound speed maps, temperature structure maps, fluctuation (kinetic energy) structure maps of large-scale currents in three dimensions, and surface wave energy maps in two dimensions.

Currently, all of the data are recorded on-site by the tomography transceivers. This is not desirable because of the (up to one year) delay in data retrieval. In addition, if tomographic systems are to be used in an operational sense, then near real-time acquisition is necessary.

Arctic tomography is very difficult, because the procedure typically requires large and stable bottom-mounted moorings. Because of the ice cover, there are two possible solutions: (1) bottom-mounted moorings that communicate with satellites having lasers located in the blue-green wavelength window passed by seawater, and (2) drifting transceivers that locate themselves accurately using the Global Positioning System (GPS). Direct communication with the satellite from a bottom-mounted mooring may have to be done with a surface drifting intermediary, as is done in the SOFAR program, but details for acquisition still must be developed. The drifting transceiver method places additional volume demands on the data collection system, because coherent averaging for signal enhancement must be done with knowledge of the relative drift between the source and the receiver. This disallows a great deal of the internal processing typically carried out in the buoy itself in temperate bottom-moored experiments.

F. Glaciology

The polar ice sheets are one of the least explained and most poorly understood components of the global climate system. As well as reacting to changes in global climate by accumulating or releasing reservoirs of fresh water, the ice sheets are hypothesized to play active roles in affecting climate. Indeed, instabilities in the flow of the West Antarctic Ice Streams are conjectured to be of fundamental importance to the state of the entire ice sheet, potentially determining whether the ice sheet grows or shrinks.

Since much of the research currently conducted on the ice sheet is done during the summer via surface parties, communication needs are slightly different from those of other disciplines.

Three separate communication needs can be identified. In terms of their importance, they are (1) signaling an emergency, (2) communications required by the scientists for the efficient conduct of field research, and (3) communications for the linking of Antarctica to the rest of the world. Antarctica is a harsh and sometimes dangerous environment. Clearly, the safety of all field parties must be a prime concern. Field parties are not safe if they cannot contact rescue forces at a base station at any time. This requirement is filled by the SARSAT/COSPAS system, a network of satellites that continuously monitor the earth's surface for transmissions from personal locator beacons (PLB). The PLB is activated with the flip of a switch, and the alert signal, along with the beacon location, can be automatically forwarded to the main U.S. station in McMurdo to begin the rescue. If this system passes testing in the McMurdo area, scheduled for January 1987, it should be adopted for any future Antarctic field party.

In the area of field communications, the most important requirement is reliable voice communication between a remote field party and either another remote field party or an aircraft or major base. Efficient use of field time and logistics depends on reliable communications. Often, the determination of a daily operations plan can require the collected inputs of a number of isolated field parties whose only means of communication is the radio. Poor communication can tie down field parties or waste logistic effort, both of which are very costly factors in Antarctica and hinder the efficient conduct of science. The current complement of aging HF radios does not provide a reliable voice link and invites a variety of problems.

The final area in which improved communication would benefit Antarctic research is the transmission of data either to an Antarctic station or back to the United States. Data collection, storage, and transmission have become extremely commonplace. The availability of synoptic data from automatic weather stations spaced around the Antarctic continent for planning aircraft operations has obvious advantages. Transmission of these and other data (such as subsurface temperatures or water pressures in ice streams) from remote, instrumented sites year-round would greatly aid the scientist by providing data that were hitherto unavailable. While some of these data may be collected by on-site storage devices, their transmission back to the scientist not only provides a more certain means of collecting high-investment data, but also may obviate the need to return to the instrument site as often or at all, thus easing the logistic burden of Antarctic science.

G. Polar Meteorology

Routine meteorological observations in the polar regions support both operational and scientific activities. To accommodate requirements for timely observations at an increasing number of locations, instruments are being adapted to telemeter data back to central receiving sites. A description of three such programs, one using System ARGOS to transmit data from automatic weather stations, one using the ATS-3 link at South Pole, and a proposed program, follows.

ARGOS. Automatic weather stations (AWS) measure surface pressure, air temperature, wind speed, and wind direction and transmit the data to satellites for interrogation by ground stations. The data are used to study the barrier wind along the Transantarctic Mountains, vertical motion and sensible and latent heat flux from the Ross Ice Shelf, katabatic flow, and propagating weather systems at the South Pole. The weather stations also provide meteorological support for aircraft operations at McMurdo Station, as well as for remote field sites. Data transmission is via system ARGOS at 200-second intervals updated every ten minutes (Figure 9).

ATS-3. The Geophysical Monitoring for Climate Change (GMCC) Division of NOAA has established an experiment at the South Pole to monitor and analyze the buildup of trace greenhouse gases and aerosols in the atmosphere that can impact global

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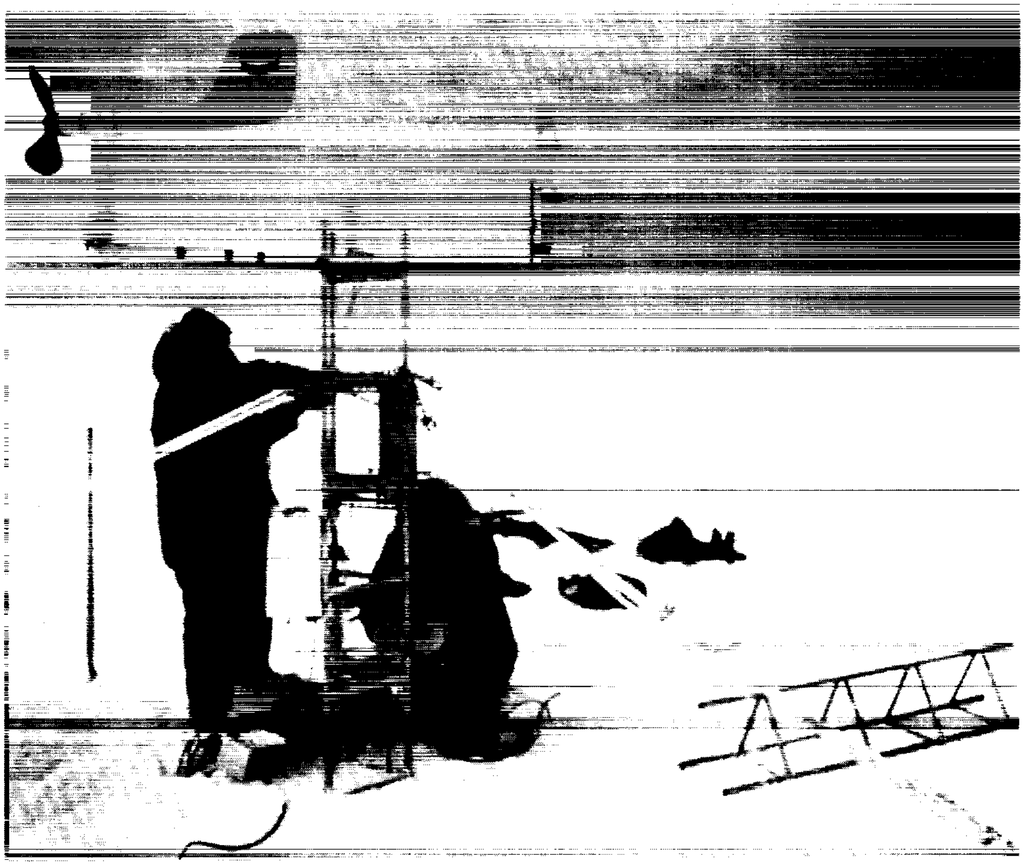

Figure 9. Automatic Weather Station being deployed on the Ross Ice Shelf. Wind speed and direction, surface pressure, and air temperature are recorded and telemetered back to the U.S. via polar-orbiting satellites equipped with the ARGOS system.

climate. The South Pole station is one of four baseline observatories operated by NOAA to provide data to ascertain whether a long-term change in the composition of the atmosphere is occurring.

The GMCC program at present measures and analyzes more than twenty individual time series of data at each of the GMCC observatories. Data are collected in varied formats, ranging from high-density continuous recordings on magnetic data tapes to handwritten entries on data forms. It is necessary that all of these data be received in a timely manner in Boulder, Colorado, where individual principal investigators process and analyze the data and disseminate the results. Because of the long period of time during which the South Pole Station is closed to air traffic, data transmission by satellite communication is critical for timely analysis, checks, and quality control of the continuous measurements being made by the GMCC Division at the South Pole. Timely review of the data is necessary to detect onsets of atmospheric phenomena that define changes, seasonalities, and sources or sinks of trace constituents in the atmosphere.

The GMCC Division uses the ATS-3 and the ATS VAX system at Malabar, Florida, to transmit data and English text communication from the South Pole to Boulder, Colorado. Both data and messages are forwarded automatically to the computer center in Boulder. The transmissions are downloaded from the computer center to an IBM PC in the GMCC Division, where they are logged and distributed to the individual project investigators.

Currently, about 20 percent of the total GMCC traffic is in text communications that are used for measurement instructions, changes, trouble shooting and timely evaluation of data and measurement protocol. At present, the GMCC Division's data transmission volume amounts to about 1 Mbyte per month.

The current ATS-3 window at 1200 baud has been adequate for these purposes, but is not sufficient for transmission of the entire data set collected at the South Pole (approximately 10 Mbytes). In order to transmit more data from the GMCC program to Boulder, either a higher baud rate or a longer window would be necessary. Additionally, the GMCC Division's research effort could be improved significantly to the extent that voice communications could be upgraded and expanded. Because of the remoteness of the station from Boulder and the harshness of the environment at the South Pole, the measurement instruments and measurement protocol require constant attention and interaction between the GMCC South Pole staff and the principal investigators in Boulder. Voice communications have proven to be the best and quickest way to do this.

IMAGE DATA. To the extent that meteorological data collected on the continent can be summarized and processed in near-real time and sent to a central location for global dissemination, a more meaningful interpretation of the GMCC data could be made on a more timely basis. Such information also could be used by investigators in Antarctica to steer and initiate measurement protocols dictated by anticipated changes or onsets in atmospheric phenomena. To that end, a future requirement might be the retransmission of image data acquired over the Antarctic by polar-orbiting satellites.

Each of the NOAA polar-orbiting satellites passes over some part of Antarctica about every 102 minutes, making slightly more than 14 passes per day for each satellite in orbit. Two satellites usually are operational at any one time. Onboard sensors include the Tiros Operational Vertical Sounder, consisting of a High Resolution Infrared Radiation Sounder, the Stratospheric Sounding Unit, and the Microwave Sounding Unit. In addition, there are an Advanced Very High Resolution Radiometer and an ARGOS-based Data Collection System. Each of the five onboard tape recorders can store one full orbit of global area coverage data at reduced resolution, 10 minutes of local area coverage data, and 250 minutes of low bit rate instrument data. The satellites can be received at McMurdo, Antarctica, for about 13 minutes out of each orbit when the satellite is within 5700 kilometers of the station. Of the more than 14 orbits per day over Antarctica, 11 or 12 can be received at McMurdo. The satellite scans 1100 kilometers on each side of the suborbital point perpendicular to the direction of travel. Given maximum practical coverage, nearly the entire Antarctic continent will be in view once every 24 hours.

At present, McMurdo Station acquires data available for forecasting at full resolution (1.1 kilometers) and at a rate of about 7.3 Gbits per day. (Limited low-resolution data collected by onboard tape recorders are already available in the U.S. from the National Climate Center.) Should a greater demand materialize for rapid dissemination of these full-resolution data, then data selection will be required to limit retransmission volumes out of McMurdo to practical levels.

IV. Recommendations

Based on the science objectives and commensurate communications requirements discussed in the preceding sections, the Science Working Group has compiled the following list of specifications that it deems critical to meeting the polar research community's communications needs for the next ten years. These items are a synthesis of the tables presented in the preceding section and are judged both as being the most essential elements of a next-generation communications system as well as being practical, given present and projected technologies. It is worth noting that, given appropriate communications hardware initiatives, flights of opportunity, such as the NOAA K, L, M series or NASA's component of the International Solar Terrestrial Program, could be considered as candidate platforms for communication devices over the next five years. Development of small commercial satellite programs may provide additional opportunities.

(1) System data capacities of 50 Mbits/day will satisfy most individual discipline requirements; a few disciplines will require on the order of 500 Mbits/day.

(2) Both voice and data links should be implemented.

(3) Coverage should extend within the polar regions and from the polar regions to the continental United States. Particular attention needs to be focused on the voice and data transmission requirements of remote field parties.

(4) Following the model of current ATS-3 satellite usage, any new system should be user friendly (simple antennas and basic hardware and software), operate through a centralized data distribution network, and be inexpensive to the user.

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