INTRODUCTION

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CONTENTS

A previous volume in the Antarctic Research Series, *Geomagnetism and Aeronomy* [*Waynick*, 1965], was devoted to certain aspects of United States upper atmosphere research activities in the Antarctic. Since the publication of this book over a decade ago, the level and sophistication of our understanding of the upper atmosphere and space environment surrounding the earth, including the influences of solar phenomena upon the earth, have increased significantly. It is fitting therefore that this present volume describe and outline in some detail the current research activities in the Antarctic and how these activities are related to our present-day overall understanding of natural phenomena in the space around the earth. Further, it is hoped that this present book will provide some insight into future directions for antarctic research.

It is appropriate to outline briefly the upper atmosphere research activities that were being conducted in the Antarctic in the early 1960's and to place this research in the context of our understanding of the outer reaches of the earth's space environment at that time. This introduction provides such an outline as well as a brief description of certain aspects of the present-day understanding of the magnetosphere and ionosphere. Following this will be a discussion of some of the important reasons for antarctic upper atmosphere research, particularly in the context of the geomagnetic locations of the stations maintained by the United States and other nations.

1. EARTH'S OUTER ENVIRONMENT

Early ionospheric research was strongly motivated by applications in long-distance radio communication. The need for improved communication helped to accelerate the development and deployment of ionospheric sounders (ionosondes) at a large number of stations around the world for the purposes of monitoring and forecasting propagation conditions. These stations also provided valuable scientific data for regional and global studies of the ionosphere. Today ionospheric research remains as vital as ever but with some shifts in emphasis. For example, on the practical side the development of alternative communication systems has greatly reduced the dependence on high-frequency (HF, 3–30 MHz) radio, which requires a reflecting ionosphere to reach distant receivers. In the case of satellite communication systems, however, the ionosphere is still important because it now represents an obstacle between super-high-frequency (SHF, 3–30 GHz) satellite channels and ground stations. Small-scale irregularities in the ionosphere can sometimes cause serious signal fading and has become an area of intensified research.

Scientifically, regular variations in the ionosphere under the influence of solar radiation, chemical reactions, and diffusion are reasonably well understood. New challenges and opportunities lie in understanding the anomalous behavior of the ionosphere in terms of the dynamics of the upper atmosphere as a whole. The ionosphere is a weakly ionized plasma (about 1% ionized at peak electron density) and responds strongly to wind, temperature, and composition changes in the neutral atmosphere. Thus radio probing of the ionosphere can greatly aid studies of the neutral atmosphere, which is difficult to observe directly. Dynamical processes in the magnetosphere transmit their effects to the underlying ionosphere through the geomagnetic field, which guides the flow of particles and energy and serves as an efficient transmission line for electric fields. The ionosphere can be likened to a projection screen that directly or indirectly reveals signatures of complex electrodynamic processes that occur in the huge volume of distant space. In recent years, one of the main goals in upper atmosphere physics has been to relate the various ionospheric features to their counterparts in the magnetosphere.

Ground-based ionosondes can probe the ionosphere only up to the altitude of maximum electron density (typically about 300 km). With the advent of the space age it became possible to explore the topside ionosphere by using satellite-borne instruments and to measure the total ionosphere density by using satellite radio beacons. The use of satellite-based ionospheric probing techniques, combined with parallel advances in magnetospheric physics, made ionosphere-magnetosphere coupling a very important area of study.

The emphasis of much magnetospheric research in the 1960's, particularly that conducted on spacecraft, was on the characterization of the protons and electrons with energies of a few hundred to several thousand kiloelectron volts (keV) that are trapped in the earth's magnetic field (the 'radiation belt' particles that comprise the high-energy 'tail' of the magnetospheric plasma distribution). Substantial emphasis remained on radiation belt research for the next several years (see, for example, *McCormac* [1966]). The origins of some of the highest-energy electrons, and perhaps even protons, found trapped in the earth's field still remain somewhat of an enigma. Nevertheless, the thrust of magnetospheric research in the mid-1970's has been aimed at the study of electrons and protons with energies from a fraction of an electron volt (eV) to several keV (the energy interval of the magnetospheric plasma that contains the bulk of the particle energy density) and the physical effects that result from the existence of these charged particles in the magnetized space. In the mid-1960's the existence of these energetic plasma particles was only beginning to be measured, and the overall distributions were very incompletely known. Spacecraft particle detectors [*Gringauz et al.*, 1960] had revealed evidence of a plasma 'void' in the outer magnetosphere. Ground-based whistler measurements [*Carpenter*, 1962, 1963] had identified the location of the important plasma boundary, now called the plasmapause, that marks the inner edge of the void. However, little was known about the dynamical behavior of this boundary and its importance in many magnetospheric and ionospheric processes.

Even though the early measurements were limited, the theoretical understanding of the plasma in the magnetosphere was nevertheless being greatly influenced at that time, as it is today, by a number of fundamental papers. These include (1) the work of *Alfvén* [1942, 1950] on the existence of a type of wave (hydromagnetic waves) that can exist in a highly conducting plasma in a magnetic field (a magnetoplasma) and the application of this concept to the earth's outer 'envelope' by *Dungey* [1954], (2) the work of *Storey* [1953] on the production by lightning of certain types of very low frequency (VLF) electromagnetic signals called 'whistlers,' (3) the discussions by *Dungey* [1961] on the possibility of the interconnection of magnetospheric magnetic field lines and interplanetary magnetic field lines, and (4) the work of *Axford and Hines* [1961] on the possible convection of magnetospheric plasma (motion of the plasma across magnetic field lines) produced through the viscous flow of the solar wind around the magnetosphere boundary.

The International Geophysical Year (IGY) in 1957–1958 provided the first opportunity for extensive continuous measurements of the upper atmosphere conditions over Antarctica. Some of the results based on the antarctic IGY data were summarized in the previous volume, *Geomagnetism and Aeronomy*. Two chapters in this volume were devoted to analyses of geomagnetic disturbance indices as derived from magnetometer data acquired at various antarctic stations [*Rourke*, 1965*a*, *b*]. The study of these indices provided extensive data that significantly supplemented the work of *Vestine and*

Snyder [1945], who had initially made estimates of the location of the southern auroral zone from much more limited sets of data. The variations in geomagnetic activity at polar stations continue to receive considerable attention today, particularly because of the discovery that these variations are apparently strongly influenced by the direction of the interplanetary magnetic field [e.g., *Mansurov*, 1969; *Svalgaard*, 1973].

Other chapters were devoted to studies of ionospheric conditions in the Antarctic, largely determined on a statistical basis. *Sato* [1965*a*] reported a detailed examination of ionospheric disturbances at altitudes of approximately 300 km (the F_2 region) during geomagnetic storms. We now know that the F_2 region is intimately involved in plasma exchange processes between the ionosphere and the magnetosphere and also supplies the plasma that escapes from the earth along magnetic field lines in the polar regions. Ionospheric storm effects continue to be areas of active research at all latitudes using both ground-based and satellite techniques.

Although small-amplitude (few parts in ten thousand) variations of the earth's magnetic field have been known to exist since the latter part of the 19th century, it is quite valid to say that the IGY enabled the investigation of this phenomenon to be placed on a much firmer footing [*Troitskaya*, 1964]. The morphology of the distribution of long-period magnetic field oscillations measured in Antarctica was discussed in a chapter of *Geomagnetism and Aeronomy* by *Sato* [1965*b*] in terms of the theory of hydromagnetic waves in the magnetosphere. This theory was just beginning to be applied to such variations [*Obayashi and Jacobs*, 1958; *Sugiura*, 1961], even though such a possibility had been proposed as early as 1954 [*Dungey*, 1954].

As was noted above, several areas of interest in antarctic upper atmospheric research in 1965 are still active and important research areas today. For example, a special issue of the *Journal of the Franklin Institute* in 1970 was devoted to topics in upper atmosphere geophysical studies in both polar cap regions. In addition to discussing several of the research areas covered in *Geomagnetism and Aeronomy* the special issue of the journal also contained articles on cosmic ray research that illustrated the unique location of the polar regions for these investigations.

In contrast to the somewhat limited geophysical view of antarctic research that existed more than a decade ago the upper atmosphere research now being conducted in the Antarctic is essentially entirely motivated by the desire to interrelate ground-based observations to the geophysical phenomena throughout the magnetosphere. The unique locations of several antarctic stations are utilized for obtaining data about the magnetosphere and interplanetary space that could not readily be obtained in any other way.

A contemporary view of the magnetosphere is shown in Figure 1.1. The earth with its magnetic field carves a huge cavity in the solar wind (an ionized gas with protons of about 1-keV energy and electrons of a few hundred electron volts energy) continually flowing radially away from the sun with an average velocity of approximately 400 km/s. The tail of the magnetosphere, produced by the solar wind interaction with the earth's field, has been observed to extend as far as 1000 earth radii (R_E) beyond the earth. The solar wind provides the driving energy source for magnetospheric processes. Solar cosmic rays, emitted during solar storm (flare) events, are measured in the polar regions and can provide information on the degree of interconnection of the interplanetary magnetic field, embedded in the solar wind, to the earth's magnetic field.

Inside the magnetospheric cavity is a complex environment of electromagnetic and electrostatic waves (covering a frequency range from a few tenths of a millihertz to many megahertz) and plasmas with particle energies ranging from a few electron volts to many MeV. Although even at this time the distributions (and especially the time dependencies) of the waves and plasmas are not completely understood, it is clear that there are several important boundaries across which the distributions of waves and particles change abruptly.

The magnetopause (the outer boundary of the

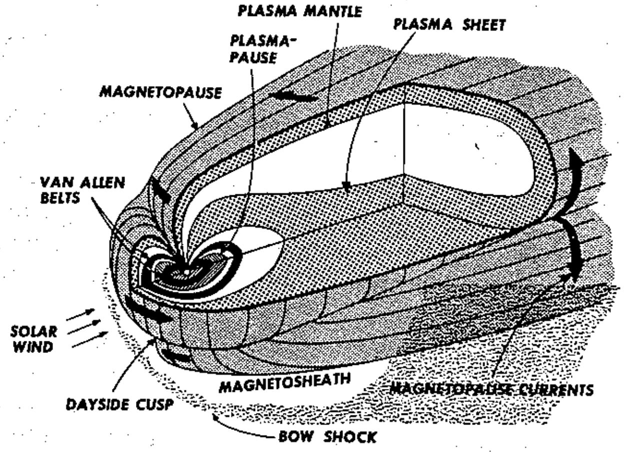

Fig. 1.1. The earth's magnetosphere.

magnetosphere) and the collisionless shock wave, standing upstream from the magnetopause, are locales for energy transfer from the solar wind into the magnetosphere. Other boundaries associated with the solar wind interaction are the high-latitude cusp regions on the dayside of the magnetosphere and the plasma mantle, a region of plasma flow located near the boundary of the magnetotail. Other important boundaries of the magnetosphere include the plasma sheet in the center of the magnetotail region separating the oppositely directed geomagnetic field lines and the more or less well defined inner and outer radiation belts deep within the magnetosphere. Perhaps one of the most important boundaries in the inner magnetosphere is the plasmapause, where the low-energy plasma density drops abruptly from typical values of ~100 electrons/cm^3 to a few electrons per cubic centimeter in radial distances small in comparison to 1 R_E.

The plasma boundaries in the magnetosphere have received considerable attention because such spatial boundaries are regions where plasma instabilities can be expected to occur. Physical processes associated with several of these boundaries (such as the cusp region and the plasmapause) can be monitored by ground-based instruments for extended periods of time. The inner edge of the plasma sheet appears to map into a region of 'diffuse' auroral emissions on the low-latitude side of the nighttime auroral oval. (The auroral oval is the instantaneous global location of auroral activity, whereas the auroral zone is the locus of the midnight position of auroral activity and corresponds approximately to a circle at 67° geomagnetic latitude.) Photographs of the aurora taken by optical scanning instruments on satellites appear to show that the nightside auroral oval merges continuously into the dayside aurora, the location of which is determined by the cusp.

2. ANTARCTIC RESEARCH LOCATIONS

A principal rationale for much of the present upper atmosphere research in Antarctica can be related to the mapping of several of the magnetospheric boundaries shown in Figure 1.1 to the ionosphere and to the ground along geomagnetic field lines. These boundaries are quite dynamic, and ground measurements play an extremely important role in the study of their spatial and temporal behavior. The passage through a boundary region by a single spacecraft (or even dual spacecraft as are planned for the International Sun-Earth Explorer missions in late 1977) is insufficient to distinguish completely between temporal and spatial changes in the physical phenomena connected with the boundary. In situ measurements in the magnetosphere and sophisticated ground-based measurements are complementary to one another. Each type of measurement requires the other in order to best elucidate and unravel the spatial and temporal changes in the complex magnetospheric plasma environment.

Figure 2.1 shows the locations of major year-round stations in Antarctica that have contributed significantly to upper atmosphere research during the past decade or so. The observational programs at these stations are summarized in Table 2.1. The map in Figure 2.1 shows that most of these stations are located on the antarctic coast. This largely arises from logistical considerations; the inland stations must be resupplied by air (in the case of U.S. stations) or by air and overland traverses (in the case of the USSR station at Vostok).

In addition to the stations listed in Table 2.1, Campbell Island (New Zealand), Macquarie Island (Australia), and Ile Kerguelen (France) in the antarctic waters have made significant research contributions through numerous ground-based, balloon, and rocket programs (see Table 2.1 and Figure 2.1*a* of Chapter 8 for the locations of these stations). More detailed information about international activities in Antarctica can be found in the Scientific Committee on Antarctic Research Bulletin published by the Scott Polar Research Institute in Cambridge, England, and by the Instituto Antarctico Argentino in Buenos Aires, Argentina.

The central importance of many antarctic upper atmosphere research stations can be illustrated by mapping the auroral oval and plasmapause regions to the ground, as illustrated in Figure 2.2. In this figure, selected antarctic stations are shown relative to these regions at four different universal times. The location of the auroral oval over Antarctica shows clearly that not only can nightside aurora be studied by properly sited stations such as Syowa and Byrd, but also dayside aurora can be investigated on an essentially continuous basis at the Amundsen-Scott South Pole station. In fact, nowhere else in the world is it possible to monitor dayside auroral phenomena through many months of continuous darkness (see Chapter 7).

There is a large displacement of the magnetic dip pole (where the magnetic field is perpendicular to the earth's surface) relative to the geographic pole in the southern hemisphere, the dip pole lying near the Hobbs Coast. This fact has been especially important for antarctic ionosphere research and for

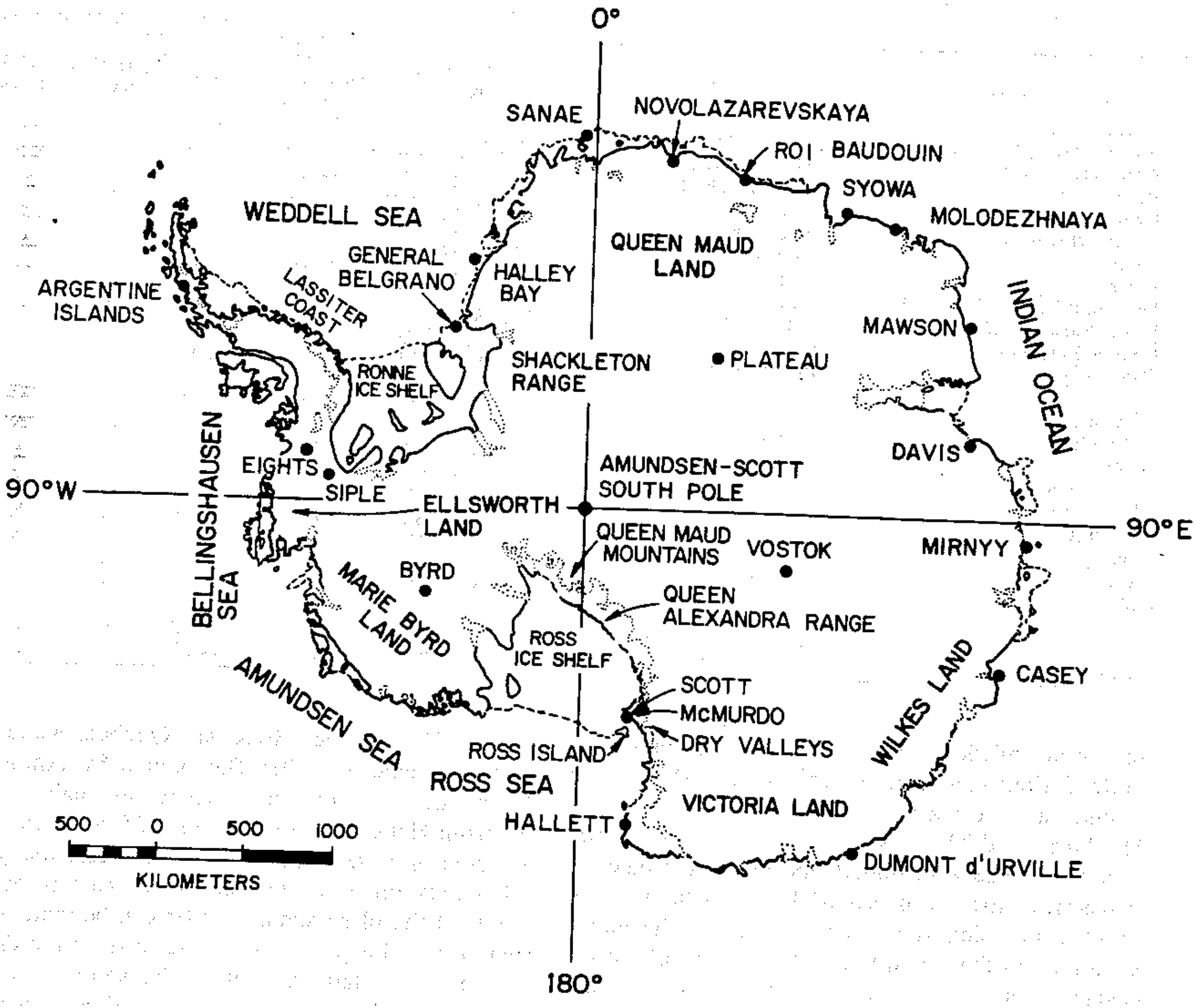

Fig. 2.1. The antarctic continent with locations of major stations involved in upper atmosphere research activities.

the study of high-altitude (150–300 km) winds (see Chapter 8).

Another important aspect of antarctic upper atmosphere research is the location of the plasmapause region, extending from the coast west of Siple Station through Halley Bay and Sanae (Figure 2.2). The combination of high whistler rates and low electromagnetic noise levels in this area allows detailed studies of the plasmapause dynamics not possible anywhere else in the world. The thick, relatively stable ice sheet in the Siple area provides a unique platform for a long (21 km) horizontal dipole antenna. This antenna permits the efficient transmission of VLF signals into the magnetosphere for controlled wave-particle interaction experiments (see Chapter 5).

The polar locale is crucial for cosmic ray measurements. The magnetic field of the earth defines the directions (the asymptotic cone of acceptance) from which cosmic rays can arrive at the magnetosphere in order to be counted at a ground station. The asymptotic cone of acceptance for cosmic rays observed at McMurdo station is approximately perpendicular to the ecliptic plane (~70°S for a particle of rigidity ~5 GV). Thus data from McMurdo, when they are combined with data obtained in the northern hemisphere at Thule, Greenland, provide valuable information on the north-south asymmetry of the galactic cosmic ray fluxes. In fact, the correlative data from McMurdo and Thule are essentially the only means presently available for examining the gradient of cosmic rays perpendicular to the ecliptic and thus learning about interplanetary conditions outside the ecliptic plane. Even though possible

TABLE 2.1. Antarctic Upper

Station	Country	Geographic Coordinates	Geo-magnetic Latitude	*L* Value	Magne-tometer	Magnetic Pulsation
Amundsen-Scott South Pole	United States	90.0°S	78.5°S	13.48	X	X
Argentine Islands	United Kingdom	65.2°S, 64.3°W	53.7°S	2.35	X	
Roi Baudouin	Belgium/Netherlands	70.4°S, 23.3°E	68.0°S	5.20	X	
Byrd (closed 1971)	United States	80.0°S, 120.0°W	70.6°S	7.05	X	X
Hallett (closed 1964)	United States/New Zealand	72.3°S, 170.2°E	74.7°S	21.23	X	
Casey	Australia	66.2°S, 110.3°E	77.7°S	37.88		X
Davis	Australia	68.6°S, 78.0°E	76.8°S	13.87	X	X
Dumont d'Urville (Terre Adélie)	France	66.6°S, 140.0°E	75.7°S	36.85	X	X
Eights (closed 1965)	United States	75.2°S, 77.2°W	63.8°S	3.88	X	X
General Belgrano	Argentina	77.9°S, 38.6°W	67.2°S	4.58	X	
Halley Bay	United Kingdom	75.5°S, 26.6°W	65.8°S	4.19	X	X
Mawson	Australia	67.6°S, 62.9°E	73.1°S	8.67	X	
McMurdo	United States	77.9°S, 166.7°E	79.0°S	32.74	X	X
Mirnyy	Soviet Union	66.5°S, 93.0°E	77.0°S	19.81	X	
Molodezhnaya	Soviet Union	67.7°S, 45.9°E	69.8°S	6.31	X	X
Movolazarevskaya	Soviet Union	70.8°S, 11.8°E	66.2°S	4.63	X	
Plateau (closed 1969)	United States	79.3°S, 40.5°E	77.2°S	9.93	X	X
Sanae	South Africa	70.3°S, 2.4°E	63.6°S	3.95	X	X
Scott	New Zealand	77.9°S, 166.8°E	79.1°S	32.60	X	
Siple	United States	75.6°S, 83.6°W	64.7°S	4.10	X	X
Syowa	Japan	69.0°S, 39.6°E	69.7°S	6.09	X	X
Vostok	Soviet Union	78.5°S, 106.9°E	89.2°S	74.27	X	X

spacecraft missions out of the ecliptic plane are under serious consideration for the mid-1980's, the cosmic ray information obtained on the ground at McMurdo and Thule will remain important in the future as we seek to understand better the electromagnetic control by the sun of the three-dimensional space comprising the solar system. Furthermore, even though the asymptotic cone of acceptance for cosmic rays observed at the south pole is only approximately 40°S, the altitude of the south pole (2800 m above mean sea level) combined with its geographic latitude means that the cosmic rays measured at this station are the lowest energy that can be observed on the surface of the earth.

Besides the intrinsic importance of the location of Antarctica with respect to significant magnetospheric boundaries the locations of many antarctic stations are also very important in terms of studying conjugate phenomena in the magnetosphere. The study of the conjugacy of ionospheric and magnetospheric phenomena can provide information on the similarities and differences of geophysical conditions in opposite hemispheres. Furthermore, the use of conjugate stations together with spacecraft measurements provides an extra 'dimension' for the spatial study of magnetospheric and ionospheric phenomena. Conjugate studies on land (as opposed to sea) of the magnetospheric boundary regions are possible only in limited areas of the world. The area conjugate to Siple is near Roberval, Quebec, while the area conjugate to Halley Bay is near St. Anthony, Newfoundland. Thus the plasmapause region ranging from Halley Bay to just west of Siple maps into a region in eastern Canada. There is essentially no other location on earth where conjugate measurements of the plasmapause region can be made over such a wide longitude range. Because of the distribution of the land masses in the southern hemisphere it is also difficult to find conjugate regions for auroral studies other than those stretching across northern Canada and the Antarctic.

International cooperation has always been an important part of upper atmosphere research because of the global nature of the discipline. Nowhere is such cooperation more necessary than in Antarctica, where the harsh environment and logistic difficulties provide a powerful inducement for all participating nations to coordinate their activities for mutual benefit. Many scientific programs have benefited from exchanges of scientists, equipment, and data. Further, the Antarctic Treaty effectively eliminated national jurisdictions, so that ground stations are easier to establish and balloon flights can be more readily planned and carried out.

3. UNITED STATES RESEARCH STATIONS

As was noted above, the IGY marked the beginning of a new era in antarctic research activities, 35

Atmosphere Research Stations

Riometer	Ionosonde	VLF Receiver	All-Sky Camera	Photometer	Auroral TV	Cosmic Ray Detector	Balloons	Rockets	Satellite Tracking	Other
X	X	X	X	X	X	X				VHF forward scatter
	X	X		X						HF Doppler
	X									
X	X	X	X	X			X	X	X	VHF forward scatter
X	X	X	X	X		X				
X	X		X			X				
X		X	X							
X	X	X	X	X		X	X	X	X	
X	X	X	X							
X	X	X	X	X		X				
X	X	X	X							ionospheric drift, pulse echo absorption
X	X		X	X		X				auroral radar
X				X		X	X		X	VHF forward scatter
X	X		X			X				pulse echo absorption
X	X		X	X						
X			X							
		X	X							
X	X	X	X	X	X	X				
	X	X	X	X						
X		X	X	X	X		X			VLF transmitter, auroral radar
X	X	X	X	X	X	X	X	X	X	auroral radar
X	X	X	X			X				VHF forward scatter

stations being established by 12 countries. These stations formed a part of the global monitoring network for upper atmosphere physics, meteorology, seismology, glaciology, and other fields of geoscience. The establishment of these stations brought a quantum jump in the level of scientific and support activities; the logistic and scientific challenges often had to be met with more sheer determination and ingenuity than expertise.

The United States participation in the IGY antarctic program consisted of seven stations: Little America V, McMurdo, South Pole (named Amundsen-Scott South Pole station in 1961), Byrd, Ellsworth, Hallett, and Wilkes. The task of establishing and supplying these stations was assigned to the Navy under the able command of Admiral George Dufek, who later told his story in the book *Operation Deepfreeze* [*Dufek*, 1957]. The two inland stations, South Pole (90°S) and Byrd (80°S, 120°W), naturally offered the greatest logistical challenge. The station at South Pole, completed to receive the first winter-over crew in December 1956, was supported by airplanes from McMurdo, while Byrd station was established and resupplied by tractor trains from Little America V on the Ross Ice Shelf.

It is not difficult to imagine the enormous task of moving building materials and supplies through uncharted and often heavily crevassed areas to Byrd station. During the first austral summer (1955–1956) an advance party got as far as 80°S and 134°W, but this route had to be abandoned, and a new trail party started out the following summer in search of a different route. This time a joint Army-Navy team reached their geographical goal (80°S, 120°W) in December 1956, marking a 1000-km route that was later designated the Army-Navy Trail. A flurry of construction activity followed, and the station was finished in good time for the beginning of the IGY on July 1, 1957. When the IGY ended on December 31, 1958, most of the participating nations were sufficiently impressed by the success of the program to continue their support. The United States decided to retain four permanent stations (South Pole, Byrd, McMurdo, and Hallett) beyond the IGY period and to close or transfer to other nations the remaining three.

The original IGY station at South Pole was in continuous service until 1974, when it finally retired under 15 m of snow and ice. A new station was dedicated to take its place on January 9, 1975. At Byrd, where the snow accumulates much faster than at the south pole, the original station had to be abandoned in 1962. Its successor served from 1962 through 1971. Hallett was operated jointly by the United States and New Zealand until it was claimed by fire in 1964. McMurdo still serves as the base of U.S. antarctic support activities. The United States later established three new upper atmosphere re-

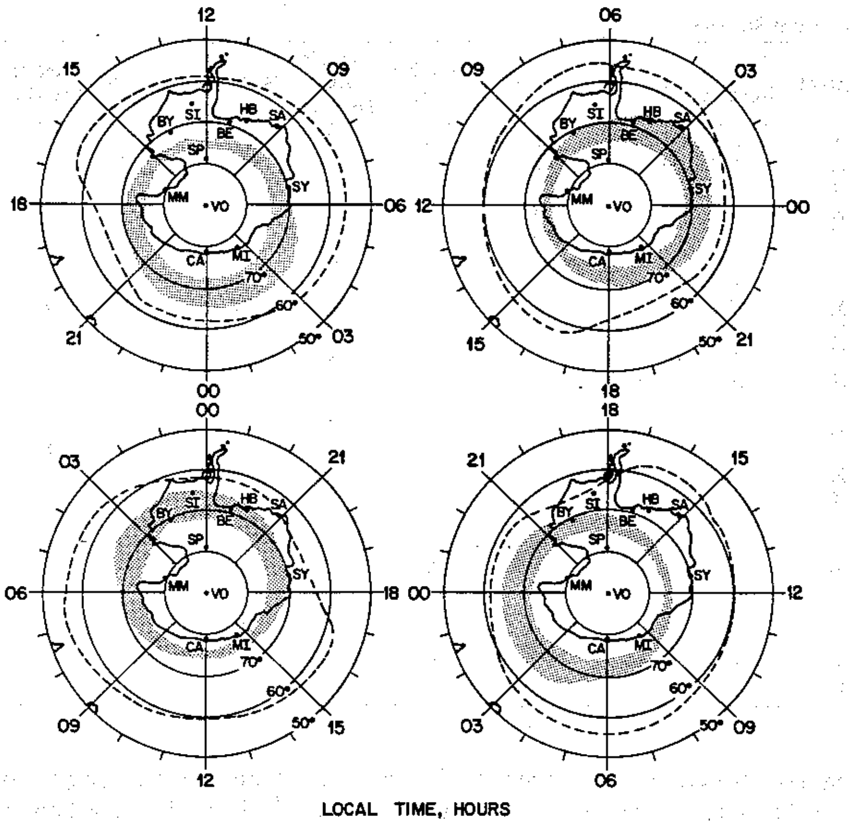

Fig. 2.2. The antarctic continent at four different magnetic local times showing the mapping of the auroral oval and plasmapause to the earth's surface along magnetic field lines. The universal times corresponding to the four maps, from upper left in clockwise order, are ~1700, ~1100, ~2300, and ~0500. The locations of several stations are also shown.

search stations: Eights in 1963, Plateau in 1965, and Siple for summer only activity in 1969. Eights and Plateau were closed in 1965 and 1969, respectively, but Siple, which began winter-over activity in 1973, maintains strong programs today along with South Pole and McMurdo.

Scientific programs at the earlier stations led to many important discoveries as will be discussed in the chapters that follow. The scientific knowledge and experience gained at these stations were invaluable in developing later programs, and therefore these research results and station operations must be appreciated in a broad context. For example, early VLF (100 Hz to 100 kHZ) whistler studies at Eights provided the main motivation and rationale for establishing Siple station in the same general area in order to continue the studies of the plasmapause region. The VLF transmitters and the 21-km dipole antenna that were operated at Byrd provided important design data for the present transmitting facility at Siple. The expertise in basic station construction and operation that developed over the years have been important factors in the success of later programs.

4. FUTURE OF UPPER ATMOSPHERE RESEARCH IN ANTARCTICA

In the early days of upper atmosphere research it was useful and convenient to subdivide space into various 'spheres,' i.e., the magnetosphere, ionosphere, thermosphere, etc. Such a division allowed specialists to make rapid progress in their own subdisciplines. However, it is now clear that these subdisciplines cannot make substantial further progress independent of one another. The entire space around the earth works as one complex coupled system that must be understood as a whole. The task in the future is to understand the internal workings of this vast and complex plasma system and to understand how this system interacts both with the interplanetary medium and with the 'lower' atmosphere below.

It has been known for a long while that geomagnetic storms and substorms can cause serious disruptions in radio and cable communications and in power distribution systems [*Davidson,* 1940; *Slothower and Albertson,* 1967; *Williams,* 1977]. With extensive data available for analysis an outage of the continental telephone cable powering systems was attributed to a large compression of the magnetosphere and the resulting intensification of magnetopause currents [*Anderson et al.*, 1974]. As technological advances produce increasingly sophisticated and sensitive communications and power systems, their susceptibility to geophysical disturbances becomes an even more important consideration.

Another equally important aspect is man's impact on the upper atmosphere. For example, it was discovered only very recently that VLF (below ~10 kHz) radiation from large power lines in North America leaks into the magnetosphere and significantly affects the wave environment and energetic particle populations there (see Chapters 4 and 5). Although these effects at present appear to be 'harmless,' an important lesson to be learned from this discovery is that man is already capable of significantly affecting, intentionally or inadvertently, even the remotest regions of the earth's atmosphere.

An important and challenging area of research that awaits much further attention is the interaction between the 'upper' atmosphere (above ~60 km) and the stratosphere and troposphere below. The altitude range between about 20 and 80 km is a difficult region to probe experimentally, and consequently it remains poorly understood. This situation in turn has had the unfortunate effect of creating a barrier between scientists working on the lower and the upper sides of this intermediate 'no-man's-land.' Yet evidence is gradually accumulating for important coupling effects that must be investigated more vigorously. For example, there seems to be increasing evidence that the sun affects our weather and climate through the solar wind interactions with the magnetosphere [e.g., *King*, 1975; *Roberts and Olson*, 1973; *Wilcox*, 1976] as well as through the more obvious direct heating of the troposphere. This question has generated a great deal of controversy over a long period, both because of the statistical approaches to the problem and because it is difficult to explain such effects by any known physical mechanism(s). It appears from energy arguments that if such effects are real, they may likely involve 'trigger mechanisms' or some subtle control exerted through minor atmospheric constituents such as ozone or condensation nuclei.

Operationally, in antarctic research (as well as in upper atmosphere research generally) there is a strong shift away from exploration by individual investigators toward coordinated experiments involving many scientists who bring different techniques and expertise to bear on common scientific objectives. In ground-based research there is increasing emphasis on the use of spaced stations in order to separate spatial and temporal effects. This requires careful planning and close collaboration among all participants. A study of antarctic research, made recently by the *Committee on Polar Research* [1974*a*] of the National Research Council at the request of the U.S. National Science Foundation, discusses in detail the development and future of the program.

The increasing emphasis on the spaced station approach on one hand and on budgetary constraints on the other has led to the consideration of an automatic station, or Unmanned Geophysical Observatory (UGO), for antarctic research. An ad hoc working group, appointed by the Committee on Polar Research of the National Research Council, studied the automatic station concept and published a report [*Committee on Polar Research*, 1974*b*] which discussed the establishment of large-scale UGO networks deployed around key manned antarctic stations. A prototype of an UGO was successfully tested at McMurdo and Byrd stations. In principle, such a station, with multiple sensors and power and telemetry systems, could be flown to any place in Antarctica, set up in a matter of a few days, and be expected to operate unattended for up to a year, the data being telemetered to a nearby manned station or directly to home laboratories via satellite link. Such automatic stations would offer great flexibility in the choice of the location and duration of observation as well as significant savings in cost compared to manned station operation.

Balloon platforms offer a relatively inexpensive means of acquiring continuous data at altitudes up to about 40 km. A number of successful balloon experiments have already been conducted in the antarctic interior as well as at coastal stations (see Chapter 3). Rapid advances in balloon technology now make it feasible to launch large (30,000 m^3) superpressure balloons on circumpolar flights lasting for more than a year. Tracking and data transmission can be handled with existing technology by using satellite systems such as the Random Access Measuring System on Nimbus satellites. Antarctica offers two important advantages for balloon experiments compared to the Arctic. First, as was noted above, the political boundaries that severely restrict scientific balloon activities in the Arctic are absent in the Antarctic. Second, balloon launches in the Antarctic do not present significant hazards to air traffic.

The altitude gap in measurement capabilities between balloons and satellites can only be filled by sounding rockets. Facilities will need to be developed at certain antarctic stations for the launching of large rockets that can reach altitudes of several hundred kilometers or more. The total absence of human habitation in Antarctica, except for the few scientific stations, makes rocket launching relatively safe. An inherent disadvantage of rocket experiments, at any location, is the brief observing period. It is therefore important to use judiciously deployed ground-based sensors to determine optimal launch times and directions. In certain experiments the observing time can be significantly extended by parachute dropping all or parts of the payload.

In the future, continued consideration and emphasis should be given to active experiments in which certain ionospheric or magnetospheric parameters are artificially perturbed in a controlled manner. For many such experiments the required technology is already available. At Siple a VLF transmitter has been used for controlled wave injection experiments since 1973 for the purpose of studying the physical mechanisms involved in wave-particle and wave-wave interactions in the magnetosphere (see Chapter 5). Plans are now being made to extend this work by using a more versatile transmitting system. When launching facilities for large rockets become available, opportunities will exist for certain other types of active experiments using energetic particle beams and tracer or chemically active gases injected into the ionosphere.

Rapid and reliable communication is essential for the coordination and successful execution of multitechnique, multiplatform experiments. Real-time communication channels linking antarctic stations with home laboratories, conjugate stations, and satellite control centers can bring dramatic improvements to many experiments. As experiments become more sophisticated and costly, scientific as well as economic considerations strongly indicate a need for instant feedback in order to achieve optimal experimental configuration for a given set of measurements at a given time. The benefits of such an interactive experimental approach have been demonstrated by the new satellite communication link between Siple and its conjugate station at Roberval, Quebec.

The harsh physical environment that makes Antarctica unfit for large settlements or commercial exploitation has been a blessing for science. Antarctica remains relatively unpolluted in comparison to other parts of the world, and scientists can go anywhere to do their work, unhindered by national boundries. Through the Antarctic Treaty (adopted in 1961) a working model for international cooperation and for the conservation of the natural environment has been created, quite unique in history. This treaty will expire in 1991. In the face of worldwide pressure for new supplies of natural resources it is crucial that the existing cooperative environment be preserved through a renewed treaty. We hope that the Antarctic cooperation will form a model for international research in the future on the earth, the moon, and ultimately the planets.

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