PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The Importance of the Antarctic in Atmospheric Sciences

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Phil. Trans. R. Soc. Lond. B 1977 **279**, 275-285
doi: 10.1098/rstb.1977.0090

Phil. Trans. R. Soc. Lond. B. **279**, 275–285 (1977) [275]
Printed in Great Britain

The importance of the Antarctic in atmospheric sciences

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A prime objective of atmospheric science research in Antarctica is to use the special conditions found there to throw new light on global problems and, in particular, to test theories of the dynamics of the environment and its reactions to solar phenomena. This involves much international collaboration in planning, data collection and analysis, which is briefly described. The British Antarctic Survey theatre of operations is geographically and magnetically unique and therefore offers exceptionally favourable conditions for such tests. The development of new instruments, in particular those carried by satellite, has made research possible in uninhabited regions and enabled problems to be studied which were previously impracticable. The objects of this paper are to draw attention to the needs and possibilities, and to show some of the ways in which the specific investigations discussed by other contributors interact.

Historical

Systematic atmospheric science research in Antarctica started with the German International Polar Year expedition to Royal Bay, South Georgia, in 1882–3, which produced systematic meteorological and magnetic field measurements. Long period meteorological observations began in 1904 at Orcadas Station (South Orkneys). The effective network of meteorological observations, during the whaling season, was very dense in the years of intensive whaling (1920–40 and 1945–65) but the main effort in atmospheric sciences as a whole really started with the International Geophysical Year, 1957–8. The plans for this were crystallized at four Antarctic conferences held under the auspices of the Special Committee for the International Geophysical Year (C.S.A.G.I.), Paris 1955, 6 and 7 Brussels 1955 (*Annals of the I.G.Y.* 1959, vols. 1, 2A, 2B). The pattern of cooperation developed in these conferences forms the basis of modern scientific cooperation in Antarctica and set the scene for the signature of the Antarctic Treaty, 1959 (S.C.A.R. Manual 1972). During 1957–8, there were 55 observatories engaged in I.G.Y. programmes in Antarctica and the subantarctic islands. The initial results of this intensive effort were discussed in three important symposia, (*a*) Symposium on Antarctic Research, Wellington, New Zealand, 1958, (*b*) The Symposium on Antarctic Meteorology, Melbourne, 1959 (*Antarctic Meteorology* 1960), (*c*) The Antarctic Symposium, Buenos Aires, 1959.

The International Council of Scientific Unions (I.C.S.U.), acting on the advice of the fourth C.S.A.G.I. Antarctic Conference, established a Special Committee on Antarctic Research, which first met in February 1958 at The Hague. The name of the Committee was changed to Scientific Committee on Antarctic Research (S.C.A.R.) in 1961 (S.C.A.R. Manual 1972). The Upper Atmosphere Physics Working Group of this committee receives specialized advice from the working groups in the International Union for Radio Science (U.R.S.I.), International Association of Geomagnetism and Aeronomy (I.A.G.A.) and the International Association of Meteorological and Atmospheric Physics (I.A.M.A.P.).

Table 1

		meteorology				geomagnetism	
		surface	upper air	radiation	ozone	magneto-meter	micro-pulsations
Adelaide Island (U.K.)	67° 46′ S, 68° 55′ W	(×)	.	.	.	.	.
Almirante Brown (Arg.)	64° 53′ S, 62° 53′ W	×	.	(×)	.	.	.
Argentine Is. (U.K.)	65° 15′ S, 64° 16′ W	×	(×)	×	×	×	.
Arturo Prat (Chile)	62° 30′ S, 59° 41′ W	×	.	.	.	.	.
Belgrano (Arg.)	77° 48′ S, 38° 15′ W	×	(×)	(×)	.	×	.
Bellingshausen (U.S.S.R.)	62° 12′ S, 58° 58′ W	×	×	.	.	.	.
Casey (Aust.)	66° 17′ S, 110° 32′ E	×	×	×	.	×	×
Davis (Aust.)	68° 35′ S, 77° 58′ E	×	.	×	.	×	×
Dumont D'Urville (Fr.)	66° 40′ S, 140° 01′ E	×	×	×	.	×	×
Esperanza (Arg.)	63° 24′ S, 56° 59′ W	×	.	(×)	.	.	.
Gough Island (S.A.)	40° 21′ S, 9° 52′ W	×	×	×	.	.	.
Halley Bay (U.K.)	75° 31′ S, 26° 43′ W	×	(×)	×	×	×	×
Iles Crozet (Fr.)	46° 21′ S, 51° 52′ E	×	.	×	.	×	.
Iles Kerguelen (Fr.)	49° 21′ S, 70° 12′ E	×	.	×	.	×	×
Leningradskaya (U.S.S.R.)	69° 30′ S, 159° 23′ E	×	×	×	.	.	.
Macquarie (Aust.)	54° 30′ S, 158° 57′ E	×	×	×	×	×	×
Marambio (Arg.)	64° 14′ S, 56° 43′ W	×	.	(×)	.	.	.
Marion Island (S.A.)	46° 52′ S, 37° 51′ E	×	×	.	.	×	.
Mawson (Aust.)	67° 36′ S, 62° 52′ E	×	×	×	.	.	.
McMurdo (U.S.A.)	77° 51′ S, 166° 37′ E	×	(×)	.	.	×	×
Mirny (U.S.S.R.)	66° 33′ S, 93° 01′ E	×	×	×	×	×	×
Molodezhnaya (U.S.S.R.)	67° 40′ S, 45° 51′ E	×	×	×	.	×	.
Novolazarevskaya (U.S.S.R.)	70° 46′ S, 11° 50′ E	×	×	×	.	×	×
O'Higgins (Chile)	63° 19′ S, 57° 54′ W	×	.	.	.	.	.
Orcadas (Arg.)	60° 45′ S, 44° 43′ W	×	×	(×)	.	×	.
Palmer (U.S.A.)	64° 45′ S, 64° 05′ W	×	.	.	.	.	.
Petrel (Arg.)	63° 28′ S, 56° 17′ W	×	.	×	.	.	.
Port Stanley (U.K.)	51° 42′ S, 57° 51′ W	×	.	.	.	.	.
Presidente Frei (Chile)	62° 12′ S, 58° 55′ W	×	.	.	.	.	.
Sanae (S.A.)	70° 18′ S, 2° 21′ W	×	×	.	.	×	×
Scott (N.Z.)	77° 51′ S, 166° 45′ E	×	.	×	.	×	.
Signy (U.K.)	60° 43′ S, 45° 36′ W	(×)	.	.	.	.	.
Siple (U.S.A.)	75° 55′ S, 83° 55′ W	×	.	.	.	×	×
South Georgia (U.K.)	54° 17′ S, 36° 30′ W	×	.	×	×	×	×
South Pole (U.S.A.)	90° S	×	×	×	×	×	×
Syowa (Japan)	69° 00′ S, 39° 35′ E	×	.	.	.	.	×
Teniente Matienzo (Arg.)	64° 58′ S, 60° 04′ W	×	.	.	.	.	.
Vanda (N.Z.)	77° 31′ S, 161° 40′ E	×	.	×	.	.	.
Vostok (U.S.S.R.)	78° 28′ S, 106° 48′ S	×	×	×	×	×	×

It is important for all workers to know what data are available and to have easy access to them. This need is met by the annual reports from all collaborative countries to S.C.A.R. and reports of S.C.A.R. working groups. World-wide planning of the synoptic observations now forms part of the work of the Monitoring the Sun–Earth Environment (MONSEE) working group of the Special Committee on Solar Terrestrial Physics (SCOSTEP), (S.T.P. Notes 1968–75). The interchange of data is organized through the World Data Centre system under the auspices of the I.C.S.U. panel on World Data Centres or through the World Meteorological Organization. While the organization of radio communications is the responsibility of the Antarctic Treaty Organization, scientific advice has been provided by S.C.A.R. (Sheffield 1972).

The current deployment of experiments involving international collaboration in atmospheric sciences is shown in table 1, in which an entry in parentheses means that the experiment is non-standard, either through use of equipment with less than normal capacity or because the programme is restricted. Siple Station is temporarily closed during 1976, but will form part of an important international collaboration. Many of the Antarctic Peninsula stations are in close

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TABLE 1 (*cont.*)

aurora		ionosphere				miscellaneous			
all-sky camera	photo-meter	absorption	v.l.f. whistlers	ionosonde	Doppler	pollu-tion	cosmic rays	rockets	seismo-logy
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×	×	×	.	.	.	×	×	.	×
.	.	×	×	×	.	.	.	(×)	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
×	×	.	.	×	.	.	.	.	.

proximity to each other, particularly in areas where conflicting national claims have existed, and add relatively little to the effectiveness of the network. In practice the availability of reliable data is appreciably less than that suggested by the table – some programmes will not be carried out successfully. Traditionally seismic observations are concentrated at Atmospheric Science Observatories and are therefore included in the list.

THE ANTARCTIC LABORATORY

The importance of Antarctica as an Atmospheric Sciences Laboratory derives primarily from the unique displacement of magnetic and geographical coordinates found in this hemisphere, and the relatively very simple topographical structure given by the antarctic continent and its surrounding oceans. In addition, the isolation of Antarctica from local sources of pollution gives special advantages for studies of global transport of pollutants. The cold conditions and lack of dust provide exceptionally favourable conditions for the measurement of ozone and radiation from the surface.

We shall attempt to illustrate some of the possibilities by short discussions of these features as applied to atmospheric science experiments. Details of some of the applications already exploited have been given elsewhere in this volume.

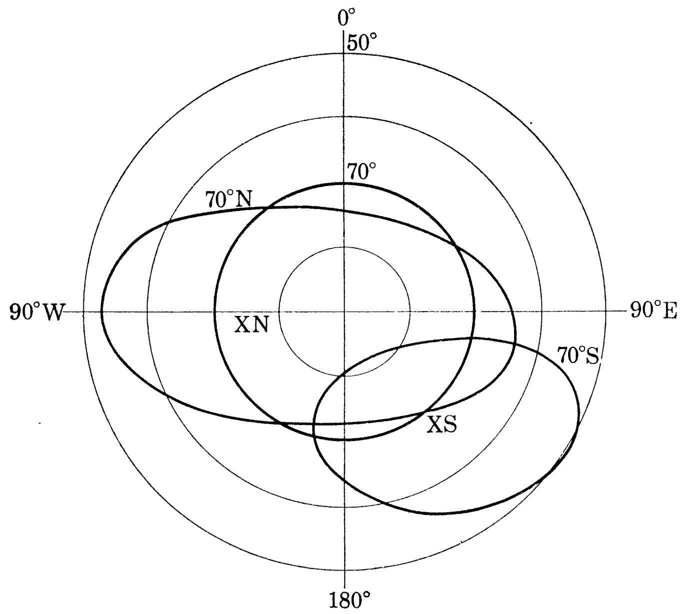

FIGURE 1. Polar projection map showing the dip poles, 70° magnetic latitudes north and south and 70° geographic latitude. The displacement of magnetic coordinates relative to geographic differs greatly in the two hemispheres.

The great advantage of the Antarctic for magnetic, auroral, ionospheric and magnetospheric research arises from the properties of the Earth's magnetic field. These are illustrated in figure 1. For our purposes the field may be approximated by a triangular magnet model offset from the centre of the Earth. The South Pole is a reasonable approximation to a point pole whereas the north is really a line pole with two widely spaced maxima in total field. As can be seen from the figure, which shows the dip poles and dip latitudes, the south magnetic pole is much further from the geographic pole than the northern magnetic pole. This difference is critical.

Atmospheric research in Antarctica is based on systematic and accurate observations from stations where the geophysical conditions are extreme. The analogue of the physicists' key experiment is then a detailed study of particular significant events. In general, particularly in ionospheric and magnetospheric studies, it is also necessary to have a simple means of classifying when and where the given phenomenon is occurring. The classical examples of this type of parameter are, of course, the magnetic K and A indices which give convenient, widely used, crude classifications of level of magnetic disturbance.

During the I.G.Y., efforts were made to obtain observations in Antarctica in all fields of Atmospheric Sciences. After the I.G.Y., however, the degree of interest varied considerably from field to field. In ionospherics for example, the advantages of the theatre were recognized and it was found possible to exploit these with relatively few stations. In contrast, in meteorology the network was really too thin to justify serious research and most of the National Meteorological Offices involved had little interest in Southern Hemisphere synoptic meteorology. Thus the effort dwindled to that needed for relatively local requirements or political needs. Recent developments in satellite techniques and in the production of unmanned stations appear to have transformed this situation and make it worth while to reconsider the prospects of research based on Antarctic data. This paper draws attention to the need for such a reappraisal.

Magnetospheric studies

Brief descriptions of the magnetosphere, its boundaries, and some methods of measuring it, have already been given by Kaiser, Orr & Smith (1977, Figures 1–3), and Helliwell (1977), in this volume. The magnetosphere can be studied either by satellites or by ground-based observations, the two techniques being in general complementary. A satellite cannot distinguish between a change in time and a change in space, and movements of magnetospheric boundaries associated with changes in the solar wind demand the presence of at least two satellites – even then only occasional measurements are possible. Thus it is desirable to develop methods of monitoring the positions of magnetospheric boundaries from the Earth.

The Antarctic region offers special advantages for this type of study. The large displacement of the magnetic pole causes the auroral oval and plasmapause projection surface to traverse a remarkably large range of geographic latitude as the Earth rotates relative to the Sun. Thus the rotation of the Earth carries these boundaries across many antarctic observatories, giving characteristic changes in the ionosphere when they cross the zenith. In particular, changes in the diameter of the oval give abnormally large changes in the local time at which it crosses a given station, a monitoring possibility which has not, as yet, been exploited.

The Weddell Sea–peninsula zone, in particular, offer special advantages for studying the position of the plasmapause in winter by using whistler techniques (Kaiser *et al.* 1977), the number of one-hop whistlers available for study being exceptionally large in this sector. The associated movements of the plasmapause trough can also be monitored in the late night period by ionospheric means. The skew in the axis of the magnetic field should have important implications in magnetospheric studies since the angle between the magnetic polar axis and the solar wind makes much greater diurnal and seasonal excursions in the south than in the north. The importance of this angle was stressed by Dr Mayaud at the meeting.

Ionospheric phenomena

In addition to ionospheric phenomena associated with changes in the magnetosphere, mentioned above, extreme conditions suitable for testing theories of normal ionospheric changes occur over and near Antarctica. Remarkable changes in the ratio of atomic oxygen to molecular nitrogen with position have been observed over the Antarctic (Hedin & Reber 1972) which are not yet fully explained. The theatre offers exceptional opportunities for studying dynamic effects due to horizontal thermospheric winds or to electric fields in the F region, particularly in the zone where the magnetic dip latitude is low compared with geographic latitude.

The h.f. Doppler project (Dudeney, Jones, Kressman & Spracklen 1977, this volume) forms part of an experiment planned to evaluate the links between the troposphere and ionosphere in a zone where the effects should be particularly easy to observe and unravel.

Observations in this theatre have played an important part in the development of F region wind theory (King, Eccles & Kohl 1971; Rishbeth 1972) and the magnetic field geometry may be expected to be equally important for studies of electric field phenomena in the F region.

The long winter nights associated with high geographic latitudes greatly help the study of relations between auroral and ionospheric phenomena and enable mid-latitude red arcs to be observed from suitably placed stations within the Antarctic Circle throughout the 24 h.

Solar activity relations with climate and weather

Interest in possible solar cycle perturbations of climate and weather has increased considerably recently. A valuable reference document has been issued by the SCOSTEP Secretariat (Shapley, Kroehl & Allen 1975), listing both papers and books on the subject and names and addresses of recent authors. In particular it contains two contemporary review articles which summarize much of the recent evidence both for such phenomena and for interactions between climate and weather and the magnetic field of the Earth. Many of the figures collected in this document by J. W. King (pp. 109–125) illustrate the types of problems whose solution may well be best found by using Antarctic data. Summarizing, he notes a correlation between meteorological factors and the normal 11 years period sunspot activity cycle at the higher latitudes. Such variations could be associated with changes in the variable ultraviolet and X-radiation from the sun or with changes in the solar wind, or both. At low latitudes the solar terrestrial relations appear to show a 22-year cycle. If true, this implies that the solar wind must be the immediate agent involved since the significant difference between successive 11-year solar cycles is a reversal in the magnetic fields seen on the sun. Solar magnetic field information is carried to the Earth's orbit by the solar wind. As mentioned above, magnetic field characteristics in the Southern Hemisphere offer exceptional opportunities to study possible causes of such phenomena.

Magnetic phenomena

Although it has long been recognized that magnetic perturbations in the south can differ considerably from those found at corresponding magnetic latitudes in the north, these differences have not been studied properly, largely because of the wide spacing of magnetic stations. The real need is for chains of closely spaced magnetic observatories so that the position of current systems can be evaluated. This has now become possible with the development of unmanned magnetic observatories, discussed below. S.C.A.R. plans for the International Magnetospheric Survey stress this point and it appears likely that a number of such chains will be established within the next few years.

The configuration of the magnetic field in the south offers special advantages for distinguishing between the effects of currents generated by tidal action in the ionosphere and those due to currents flowing mainly in the magnetosphere. The driving forces for the former are determined by geographical position, for the latter by magnetic position. The Weddell Sea–peninsula area also offers special advantages for the study of current systems in quiet conditions since perturbations due to auroral type disturbances are exceptionally small in this theatre.

Meteorology

In the past it has not been easy to exploit the meteorological advantages of the Southern Hemisphere because the observing network is inadequate – in some sectors it was possible for a weather system not to be detected from the ground. However, the development of satellite methods (Barnett 1977) of measuring temperature and cloud cover transforms this problem. The main difficulty now is to concentrate attention on the advantages and possibilities of such research.

Geographically, Antarctica forms a great dome centred nearly at the geographic pole, which is almost entirely surrounded by oceans, a remarkably simple geophysical situation, very different to that found in the Northern Hemisphere. There is really only one obstruction to zonal circulation – the Andes and peninsula mountain ranges. Even here the gap between the mountain ranges is wider than the diameter of average weather systems, most of which pass through it. Thus the weather systems can grow and decay with little interference from topographical features (Newton 1972; Stretan & Troup 1973). It also offers special advantages for studying the interaction between the oceans and atmosphere, a major objective of the Global Atmospheric Research Programme (G.A.R.P.) and the influence of the extensive sea-ice present

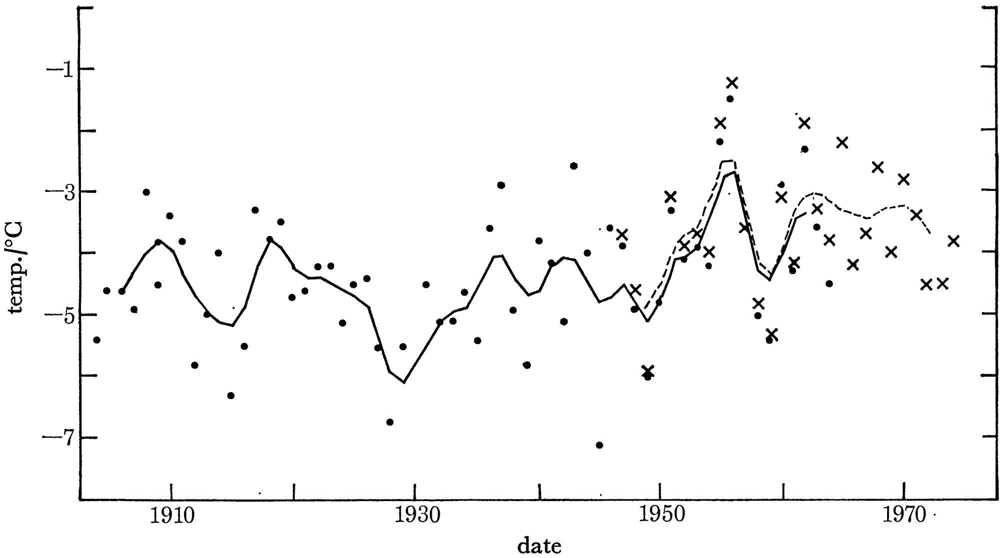

FIGURE 2. Five-year weighted running means of annual air temperature in the South Orkneys, showing large long-term trends. ●, Laurie Island; ×, Signy Island.

every winter. This is reflected in the dynamic behaviour of the stratosphere, which appears to be much more stable in the south than in the north (Farman 1977, this volume). This fact is important for studies of stratospheric and ionospheric interaction. The B.A.S. zone has special advantages for such studies since the auroral oval is at uniquely high geographic latitudes in this sector. In the Northern Hemisphere, it is often difficult to distinguish between phenomena in the ionosphere which may be associated with stratwarm phenomena and similar phenomena due to the aftermath of ionospheric and magnetic storms. The latter phenomena show increasing delay and decreasing intensity as the distance from the auroral zone increases, but are very evident in the main stratwarm zones over Europe and North America. In the Weddell Sea sector it is very exceptional for such phenomena to reach the main area in which ionospheric stratwarm phenomena can be observed, i.e. the area north of the Antarctic Circle. This is a promising field for future research in this sector of Antarctica.

Climatic studies

Changes in the climate of the Antarctic are important not only in themselves but because of the potential effects in other parts of the world. The accumulation of snow and ice in Antarctica is so great that a relatively small change in its climate can cause significant changes in the sea level all over the world. There is therefore much interest in studies of Antarctic climatology.

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For most of Antarctica, instrumented sequences of observations cover only a short period, the longest being that for the South Orkney Islands, shown in figure 2 (Limbert 1974). Similar changes have been seen throughout the peninsula. The long-term rise in mean annual temperature is surprisingly large, about 2 °C. The summer rainfall at South Georgia also shows an upward trend since 1910, figure 3 (Limbert, private communication). Such large changes may have important repercussions in biological and glaciological fields.

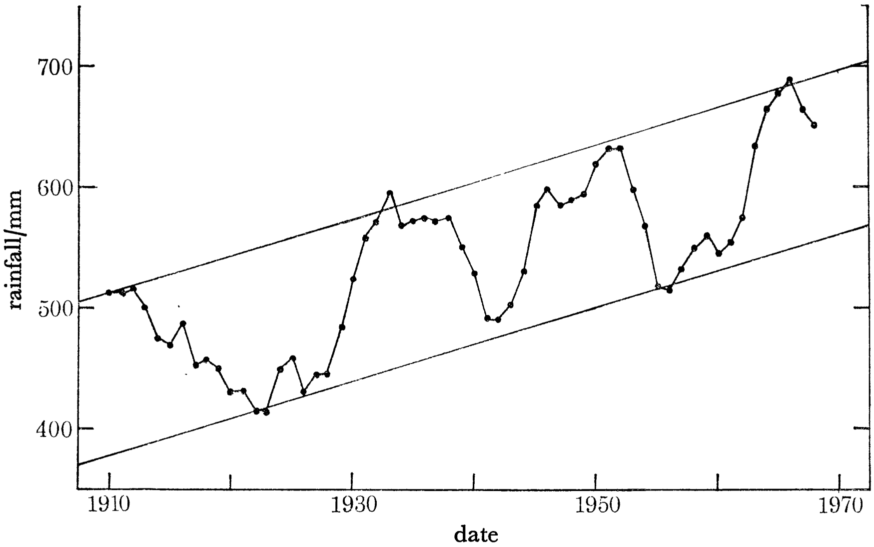

FIGURE 3. Ten-year running means of summer rainfall (November–March) at South Georgia, showing 33% increase since 1910.

There is much interest in carrying the climatic sequences back to earlier dates by using oxygen and hydrogen isotope methods (Swithinbank 1977). This could be expected to be more reliable in Antarctica than in the north since the original water vapour passes over great distances of sea or, in winter, sea-ice, and thus should have a relatively stable initial composition.

The extremely wide areas in and near Antarctica over which the albedo is remarkably constant provides good possibilities for testing the effect of albedo on meteorological conditions. The albedo is either remarkably high when snow is present or very low over the sea. This also generates dramatic changes in the apparent brightness of clouds, commonly known to mariners as water sky and ice blink, which have long been used in high latitude navigation.

Ozone

The distribution of ozone with latitude and time shows very different behaviour in the two hemispheres, for example the winter maxima are not separated by 6 months but more nearly 9 months (Farman & Hamilton 1975).

The magnetic field configuration greatly displaces the zone of cosmic ray activity relative to the geographical pole and thus offers the possibility of testing whether normal or solar cosmic rays have a significant influence on the ozone equilibrium at high latitudes. At present the limited number of stations making such observations is not adequate for a critical test using existing data. An intriguing possibility which needs further investigation is the apparent concentration of total ozone content over the regions of highest magnetic field in both hemispheres (London & Kelley 1974).

Both ground-based and ozone sonde data suggest that the vertical distribution of ozone is usually very different at high southern latitudes from that found in the Northern Hemisphere, in particular, there appears to be usually relatively little ozone below the tropopause. There is a need to revise the standard reference distributions used in calculating the vertical distribution of ozone from the Umkehr measurements for this theatre. When this is done, ground-based distributions should be exceptionally reliable in this theatre, though limited by the need for clear days. As with radiation measurements, the value of the data is greatly increased when upper air observations are also available (Farman 1977).

Balloons and rockets

The lack of population in Antarctica and the surrounding oceans enable high flying balloon and rocket programmes to be mounted without interference to commercial air traffic. This has already been exploited in the Eole programme (Morel & Bandeen 1973; Angell 1975), involving many hundreds of constant pressure level balloons. The wind systems and magnetic field geometry are also favourable for high flying super-pressure balloon platforms to study X-radiation from particle activity and other magnetospheric phenomena. In both cases the data obtained complement and increase the value of the ground-based observations and, at the same time, need the latter to separate time and spacial changes.

New techniques

The high cost of maintaining bases in the hostile antarctic environment suggests that unmanned stations could provide an economical method of extending antarctic networks. Several nations have studied these problems and prototype unmanned stations have already been tested successfully in the field. These extend from the large and expensive stations with real-time satellite links to the home country favoured by the U.S.A. scientists (Jenny, Lapson & Smith 1969; Sites 1972, 1973), to relatively cheap, very low power stations developed, in particular, by Australia (Bird & Humphreys 1971; Bird & Sulzberger 1975).

In practice, widespread deployment of experiments is critically dependent on their cost and it should be remembered that, with modern transport, it is economical to visit isolated equipments once or twice a year. Thus the central problem appears to be to develop unmanned stations which can operate for 6 or 12 months without attention and produce accurate information. Modern solid state electronics as developed for satellite and rocket use, can provide remarkable facilities with low power consumption. There are two central problems in this type of development, (*a*) the provision of a reliable low cost power source which can be easily deployed in the field and (*b*) the design of sensors which will give the required information accurately and also be economical in the use of power. In particular, sensors affected by drifting snow, hoar frost or erosion due to snow blasting effects are not suitable for unmanned operation. However, new sensors are under development. The Australian observatory running with an average power consumption of 0.75 W, near Casey, provides for the operation of an all-sky camera, three-component fluxgate magnetometer, riometer, meteorological sensors to measure wind speeds, wind direction, air temperature and pressure with a digital data logger and crystal controlled chronometer (Bird & Sulzberger 1975). This observatory is powered by secondary cells charged by a 3 W wind generator and solar panels giving a maximum of 4 W in summer. A micropulsation magnetometer can now be built with similar low power requirements.

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If it proves possible to operate medium power wind generators (order 100 W, max. output) reliably for long periods in antarctic conditions, this could transform antarctic surface meteorology by enabling unmanned stations to be placed in highly exposed sites with telemetered data links to manned bases. Magnetic observatories could also be placed on more suitable sites.

The first B.A.S. unmanned observatory experiment, in collaboration with Sheffield University (Kaiser *et al.* 1977), involves deploying an unmanned v.l.f. goniometer station with some secondary meteorological observations next season some 100 to 150 km from Halley Bay. The data obtained will be telemetered in real time back to Halley Bay by u.h.f. link. This is intermediate between the two extremes mentioned above and uses a wind power generator in conjunction with secondary batteries.

Conclusion

The special magnetic and geographic features of the Southern Hemisphere provide special advantages for atmospheric science research. Limitations due to the small number of occupied stations can now be largely overcome with the aid of satellite observations and unmanned ground observatories so that it is now possible to exploit the geophysical advantages of the theatre. The remarkably rapid changes in climate in the peninsula and South Orkney area are likely to influence biological and glaciological phenomena significantly.

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