MAGNETOSPHERIC AND ATMOSPHERIC PHYSICS AT THE UNIVERSITY OF NATAL

BY

A.D.M. WALKER

Department of Physics, University of Natal, Durban, 4001

Delivered on the occasion of the
50th Anniversary of the Hermanus
Magnetic Observatory, Aug 4 1982

INTRODUCTION

The modern era of understanding of the near-space environment of the earth can be regarded as having begun with the International Polar Year, one hundred years ago. The breakthrough achieved at that time was the recognition that, in order to understand global problems in geophysics, it is necessary to have collaboration between research groups using many different kinds of data, and located all over the world. International collaboration in geophysics began at that time, and has been of enormous value.

The establishment of the Hermanus Observatory coincided with the second International Polar Year fifty years ago. The Observatory is a symbol of fruitful national and international collaboration, and I am very happy to be participating in the celebration of this fiftieth anniversary. The Department of Physics of the University of Natal has been carrying out work in related fields for almost as long. This paper will give a historical outline of this work as well as a summary of some of the research programmes which are being actively pursued.

MAINLY HISTORICAL

1938 to 1959 : Lightning

As in many other institutions in South Africa, the influence of Sir Basil Schonland was of great importance in bringing to the attention of South African physicists the inherent interest of geophysical problems.
D.B. Hodges, then heading the Durban Physics Department, and W.E. Phillips, Head of the Department of Electrical Engineering, and later Vice Principal of the University, collaborated with Schonland in his classic series of papers on the nature of lightning.[1,2,3] Some of the original equipment used in this study, including a splendid Boys' Camera, is on display in the Department of Physics.

The outbreak of World War II severely curtailed research activity for a decade and it was only at the beginning of the fifties that members of the Department were able to find time to escape the demands of the recently demobilized students and again participate actively in research. It was at this time that N.D. Clarence joined the group and initially participated in the research on Lightning which continued through the decade.[4,5,6,i]

The end of the decade was marked by the next great international collaborative year - the I.G.Y. This gave the impetus for a broadening from the study of lightning to the study of radio atmospherics, particularly whistlers.

1960 - 1969 : Whistlers

During the I.G.Y. workers in the Department developed, under the leadership of Clarence with C.A. Schoute-Vanneck (afterwards head of the Department of Physics at University of Durban-Westville), a series of experiments on the nature of radio atmospherics, particularly whistlers. These were reported in a series of papers [7 - 13] which appeared throughout the decade. The group participated in the IQSY and it was a particularly fruitful period for training of students through the higher degree programme [ii - ix]. It is noteworthy that roughly the same number of students were awarded higher degrees in the sixties as in the seventies, although the group has increased dramatically in size and activity over this period. This is a reflection of falling numbers of senior students in the physical sciences, a nationwide trend.

One of the M.Sc. degrees granted at this time was to M.S. Muir, who was afterwards to make a substantial contribution in developing the programme in atmospheric electricity.

1970 - 1982 : The magnetosphere

At the beginning of the seventies the group was poised to spread its interests more widely. South African Universities were better funded, and had grown fast. Universities encouraged staff more strongly to do research. Clarence was able to make several appointments to the Department, who were able to broaden the scope of the work. These included A.D.M. Walker (now Head of Department), M.W.J. Scourfield (now Professor of Experimental Physics), and M.D. Barker. Walker brought a background of work in radio propagation theory (particularly whistler propagation), Scourfield had been involved in pioneering work in Canada, in which low light-level television systems were used to study aurora, and Barker worked with Clarence in developing a programme to study geomagnetic pulsations. The move into a wide range of magnetospheric problems had begun.

At the beginning of 1975 Prof Clarence left the Department to become firstly Vice-Principal and then Principal of the University. New appointments made during the decade included A.R.W. Hughes, who came from Sheffield with a background in VLF work, and J.P.S. Rash who had worked on ionospheric problems at Rhodes University. A permanent post of Antarctic Research Officer was filled first by A.C. Woods and later by P.A. Wakerley.

The research programmes in the seventies were dominated by the Antarctic programme. The location of the South African base made Sanae a very attractive site for studying a wide variety of experimental phenomena. Collaborative work became very important, between experimenters in the group, and with other groups in South Africa and abroad.

The nature of geophysical work demands the application of a wide variety of techniques - far wider than can be offered by a single group. The resources of a single group are its own data sets and expertise. It is with these that it can collaborate with other groups on an exchange basis. The experimental programmes of the group provide data sets which are of wide interest and which themselves bring contact with other groups, and access to other sets of data. There has been over the decade close collaboration with groups at the University of Sheffield, British Antarctic Survey, Stanford University, Max Planck Institut für Aeronomie, The Johns Hopkins University Applied Physics laboratory, Bell Telephone Laboratory and last, but not least, the Magnetic Observatory, Hermanus. Some of the results of this work are listed in the papers and theses published since 1970 [14 - 57, x - xvii]. Details of these research programmes and some current problems of interest follow.

THE EXPERIMENTAL PROGRAMME

Whistlers and VLF

Since 1969 a broad band vlf receiver has been operated at Sanae and since 1976 satellite telemetry for VLF data from ISIS 1 and 2 has been operated, first from Sanae and then from Durban. The interest is no longer in the nature of whistlers, but in their use as a magnetospheric diagnostic. Figure 1 shows a typical whistler spectogram from Sanae. This originates as a broad band impulse in the opposite hemisphere which is strongly dispersed as it is propagated. The audio data have been spectrum analyzed every 10 ms and the resulting spectra plotted as a function of time. There are a number of traces, each corresponding to propagation in a different magnetic field-aligned duct. From the characteristics of each trace the magnetic shell on which the whistler has been propagated can be identified, and the equatorial electron density can also be deduced. Other types of vlf noise, particularly from above the ionosphere, can also be used for magnetospheric diagnostics (Figure 2).

Low-light level TV

The advantage of TV over an all-sky camera for studying aurora is its temporal resolution (0.04s as against 60s). This means that it is of vital importance in studying the dynamic behaviour of aurora. Over the last decade a large data set of auroral events at Sanae has been built up.

Geomagnetic pulsations

For a number of years observations of pulsation events have been made at Sanae (Figure 3). The existing magnetometers are now obsolete and will eventually be replaced by the Hermanus instruments.

Co-ordinated observations

At all times the emphasis has been on co-ordinated observations with instrumentation from all Sanae groups as well as workers at Halley and Siple making simultaneous observations. This means that the data set which has been built up is extremely valuable.

CURRENT WORK

The Magnetosphere

The magnetosphere is the region in which physical processes are dominated by the earth's magnetic field. The solar wind, impinging on the earth's magnetic field, interacts with it in such a way as to carve out a large cavity surrounding the earth. The result is to divide space into three regions: that for which the magnetic field lines have both feet on the ground, that for which they have one foot on the ground, and one for which they are not connected to the ground. The first and second regions form the magnetosphere and the third is interplanetary space. Various physical processes ensure that the plasma populations have very different properties different parts of the magnetosphere, and it can be divided into numerous regions according to these properties. During the sixties and early seventies this structure was established by numerous workers all over the world. Current interest is on dynamic processes taking place in this structure and on the energy budget of the system.

The regions which we mention in the work described below are:

(i) The plasmasphere, a region of enhanced plasma density extending to about 60° invariant latitude, in which cold plasma essentially co-rotates with the earth. It is bounded by the plasmapause.

(ii) The plasmatrough, a region in the upper ionosphere in which the plasma density drops off and which maps up along the field lines to the region just outside the plasmapause.

(iii) The plasma sheet, a large sheet of plasma in the magnetotail, which maps down to the auroral oval.

(iv) The unnamed region between the plasmapause and the magnetopause.

(v) The low latitude boundary region, just inside the magnetopause, forming a region of shear between the magnetosheath and the magnetosphere.

In the following section we highlight some recent activity of the group.

Plasma convection in the plasmasphere

The plasma in the plasmasphere does not exactly co-rotate with the earth. As conditions in the magnetosphere change it drifts inwards and outwards under the influence of an electric field which ultimately arises from the solar wind dynamo. As the solar wind flows past the magnetosphere it drags plasma and the associated magnetic field lines back into the magneto tail. Ultimately, in the steady state these "frozen-in" field lines are convected back along the tail towards the earth where their motion is affected by the earth's rotation. Other frozen-in field lines remain inside the plasmasphere but their motion is affected by the general convection patterns.

Whistlers have been used to study these motions [22,35,43].

Figure 4 shows an example of such a study at a time during which the magnetosphere was settling down to quiet conditions after a period of magnetic activities. Each set of connected points on the diagram represents successive positions in L-value (the number of earth radii at which a field line cuts the equatorial plane). The interesting double bulge will be noted. From such data the plasmaspheric east-west electric field can be deduced.

The position and motion of auroral features

Whistlers allow the determination of the position of the plasmapause. Auroral radar data allow determination of the position of auroral features. Intercomparison of data allows the relative position of these boundaries to be established [28,33]. Figure 5 shows an occasion on which the diffuse aurora lay equatorwards of the plasmapause, indicating that the ring current region has penetrated the plasmasphere.

More recently Scourfield has operated the auroral TV system in northern Scandinavia in the same region as that observed by the Stare auroral radar [55]. This has allowed the observation of the spatial and temporal structure of ionospheric electric fields to be compared with auroral structure. A detailed study of the Harang discontinuity in the electrojet currents, and its analogue, has been carried out. In addition the drift of auroral arcs has been compared with the plasma drifts observed by Stare (to be published) and found to follow them closely (Figure 6).

Geomagnetic Pulsations

Barker [31] has studied pulsations occurring at Sanae and these have been intercompared with those obtained at Siple [32] to establish their azimuthal characteristics.

More recently, in a series of experimental and theoretical papers [40,44,46,47,50,51] Walker in collaboration with co-workers in West Germany, U.S.A. and U.K. has established the nature of one class of Pc 5 pulsations using the Stare auroral radar data. Figure 7 shows an example of a theoretical prediction of the structure of the Pc 5 resonance region in the ionosphere, compared with that observed by Stare.

Another type of Pc 5 pulsation has also been studied using Stare and Geos 2 data [52,56]. The importance of the low-latitude boundary layer has been studied theoretically.

Use of VLF data in measuring plasma properties

Hughes has been concerned with the use of VLF data, particularly satellite data [26,48]. A recent interesting study [57] makes use of lower hybrid resonance noise (Figure 8) observed by the ISIS satellites. From this the plasma density at the satellite can be established. The whistler technique can be used to find the equatorial plasma density. This latter technique involves a plasma distribution model with temperature as a parameter. The whistler data, with assumed temperature, is used to predict the density at the satellite altitude. Comparison of this prediction with observation allows a better temperature estimate to be made. By successive approximations the value of equatorial plasma density is refined and the temperature established.

Atmospheric electricity

An important series of investigations has been carried out by Muir and co-workers (14,15,21,27,34,38,41-43,49,53) on the nature of atmospheric electricity. Results include the relating of a sunrise effect in the potential gradient near the ground to ionospheric processes suggesting that the ionosphere may be important in closing the global circuit. This work was also involved in the field of sun-weather relationships and a mechanism has been proposed which may help us to understand the link.

Substorm studies

A most encouraging development in the study of magnetospheric physics in South Africa has been the series of workshops which has brought together observations of all the groups to provide a coherent and extensive case study of a magnetospheric substorm. This work has not yet been published, but when it is, it will be an outstanding example of intergroup scientific collaboration.

CONCLUSION

The study of the magnetosphere is a field in which national and international co-operation is of vital importance. Although South Africa has relatively small resources, it can play an important part in this study. There are two major reasons for this. One is that it is important to have ground observations from a global network of stations of which Sanae and South African stations form an important part. The other is the resource of expert workers in the field which has been built up. The level of activity in the country is sufficient to maintain an interested and able community of scientists who can interact with each other and make an important contribution to international science.

Acknowledgements

I should like to thank all the co-workers who over the years have contributed to the work of the group. In addition, individuals in CSIR and

Department of Transport, too numerous to list by name, have contributed friendly help, while the Institutions named have provided all-important finance. One individual who must be singled out is Dr F J Hewitt who presided over SANCGASS at the time when the Durban group was growing most rapidly, and whose influence in encouraging work in magnetospheric physics has been so great.

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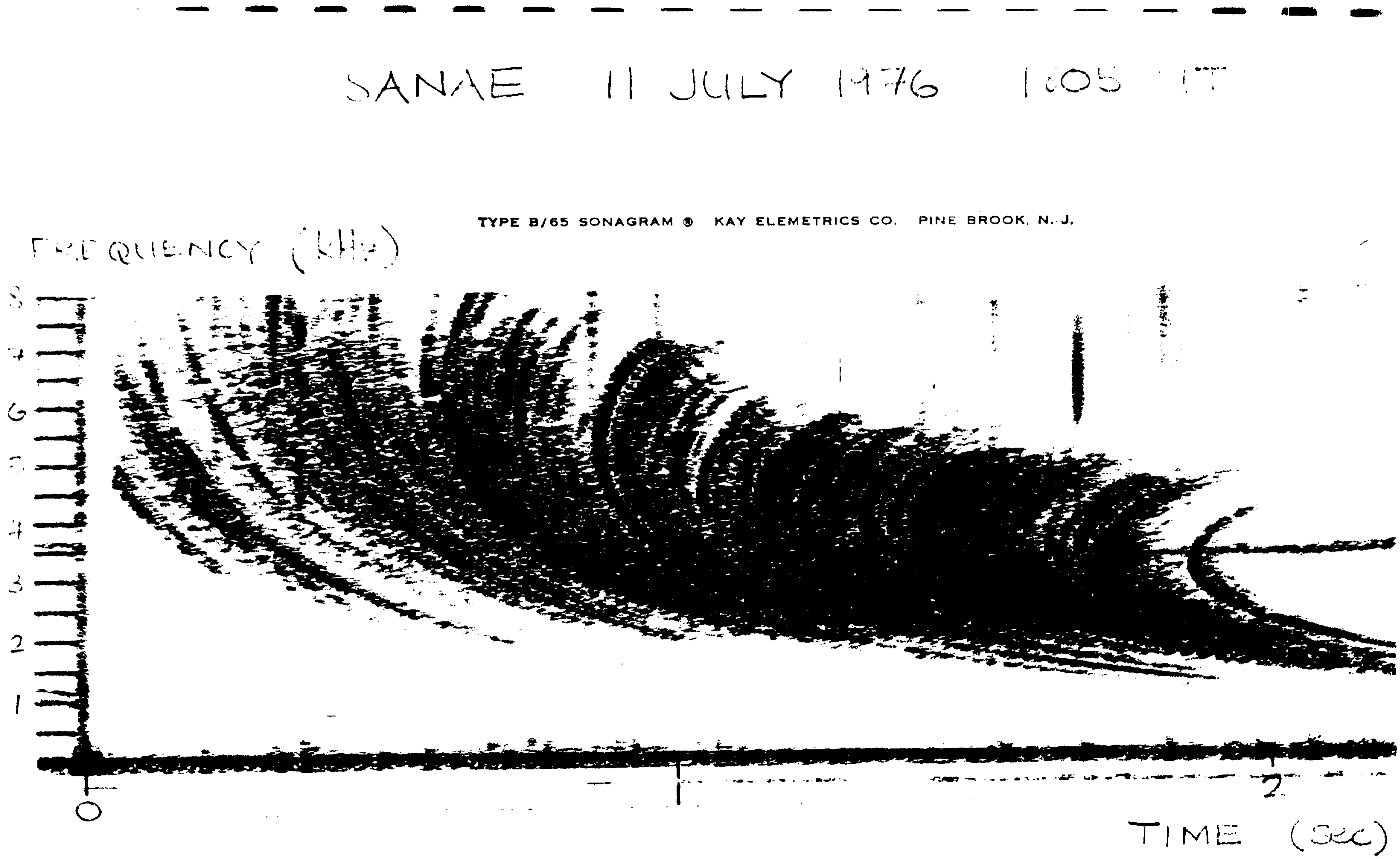


Figure 1. Sonagraph of multiple whistler trace from Sanae Antarctica.

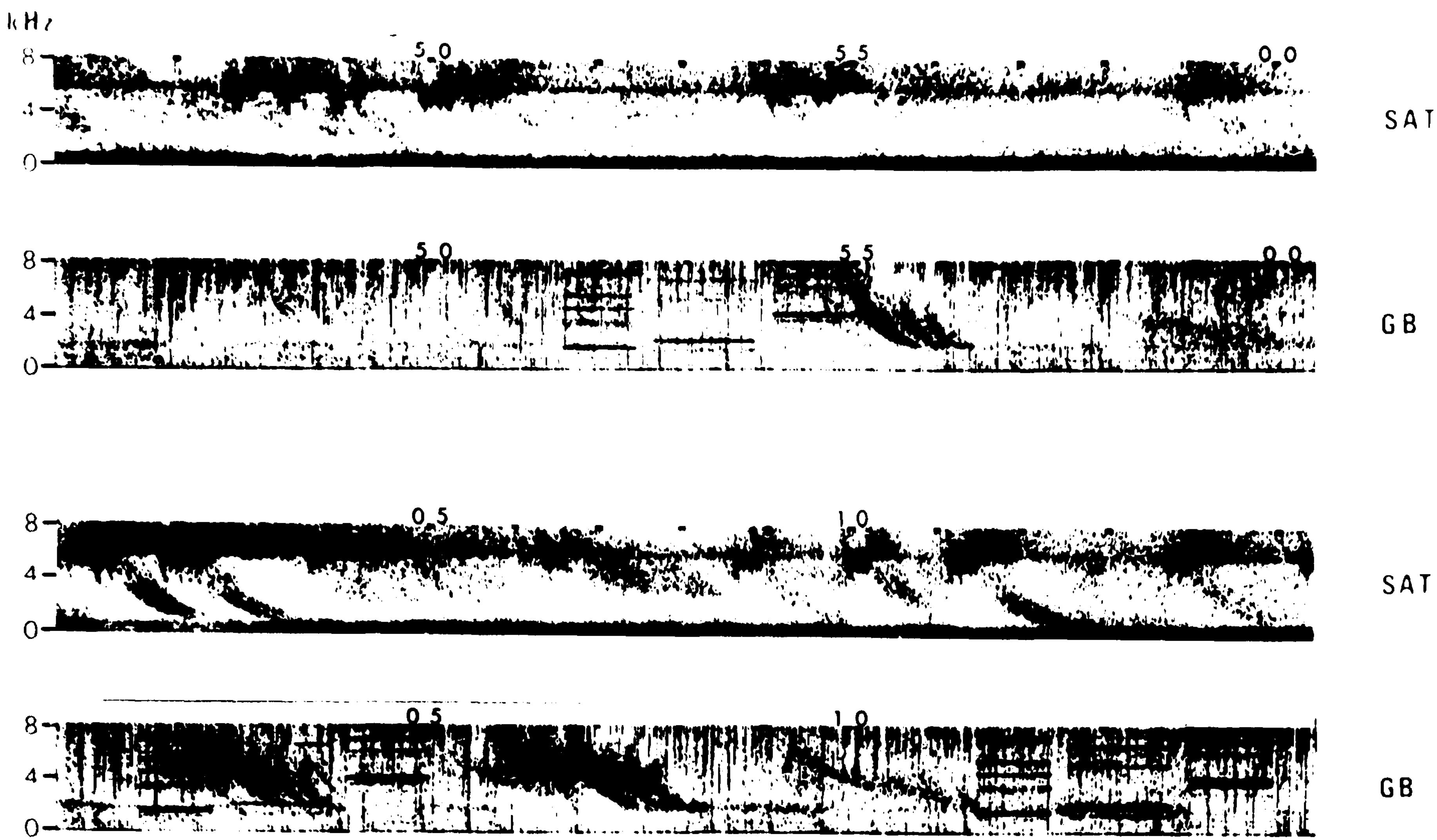


Figure 2. Comparison of ISIS and ground-based vlf data. The satellite data shows lower hybrid noise and whistlers.

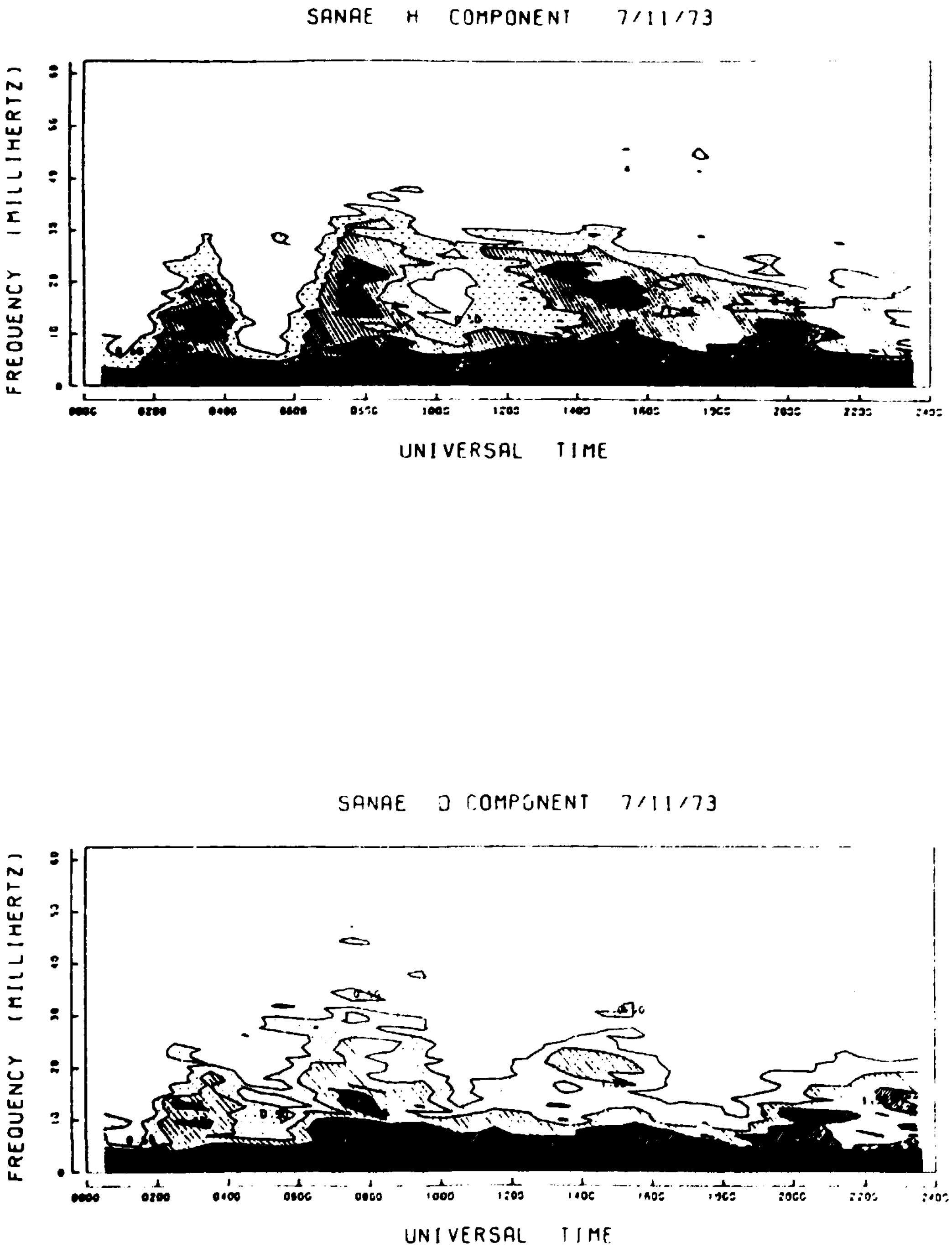
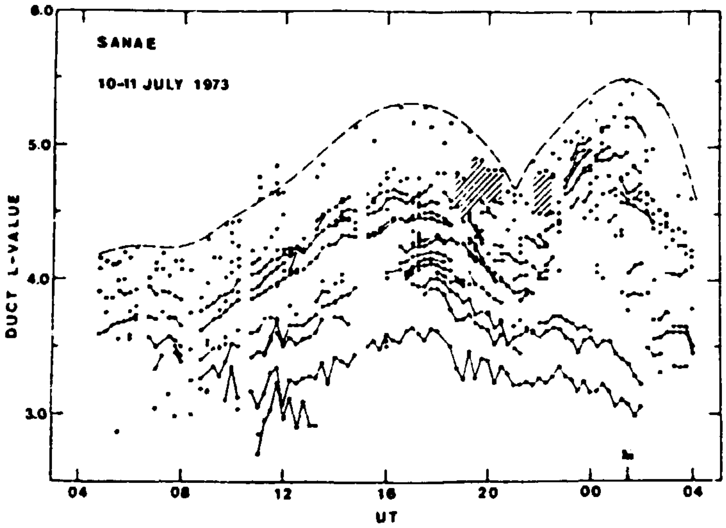
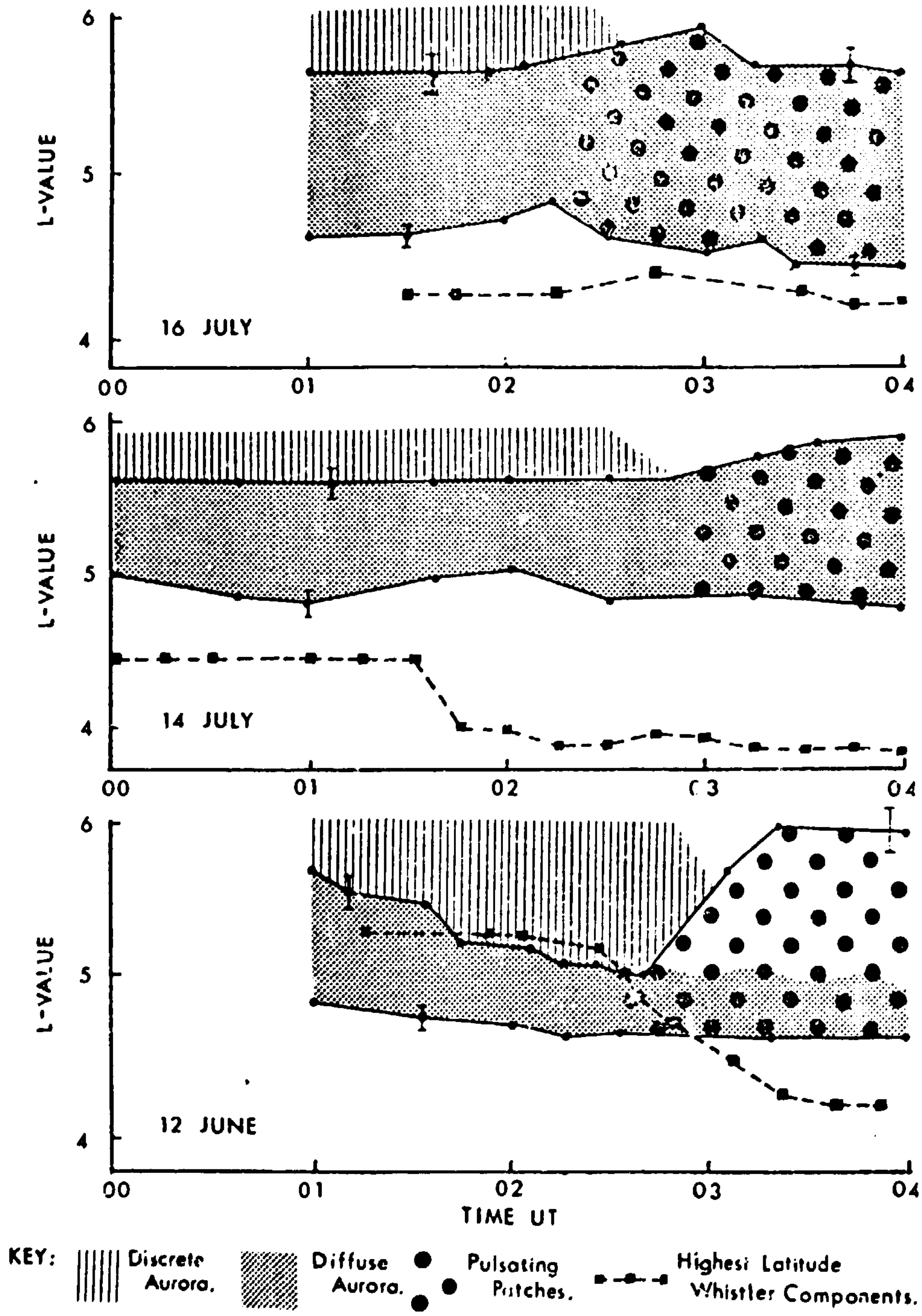


Figure 3. Spectrograms of pulsation activity at Sanae.



DUCT L-VALUE VS TIME OF OCCURRENCE (MAGNETIC MIDNIGHT IS SHOWN AT 0128 UT). Solid circles represent ducts subjected to 15 min averaging and open circles represent ducts not averaged (see text). Crosses represent knee components. Joined ducts indicate duct identification during successive 15 min intervals. The dashed line is the estimated plasmapause position.

Figure 4.



Plots of the L-values of auroral forms and highest latitude whistler components vs Universal Time on the 16 July, 14 July and 12 June, 1975.

Figure 5.

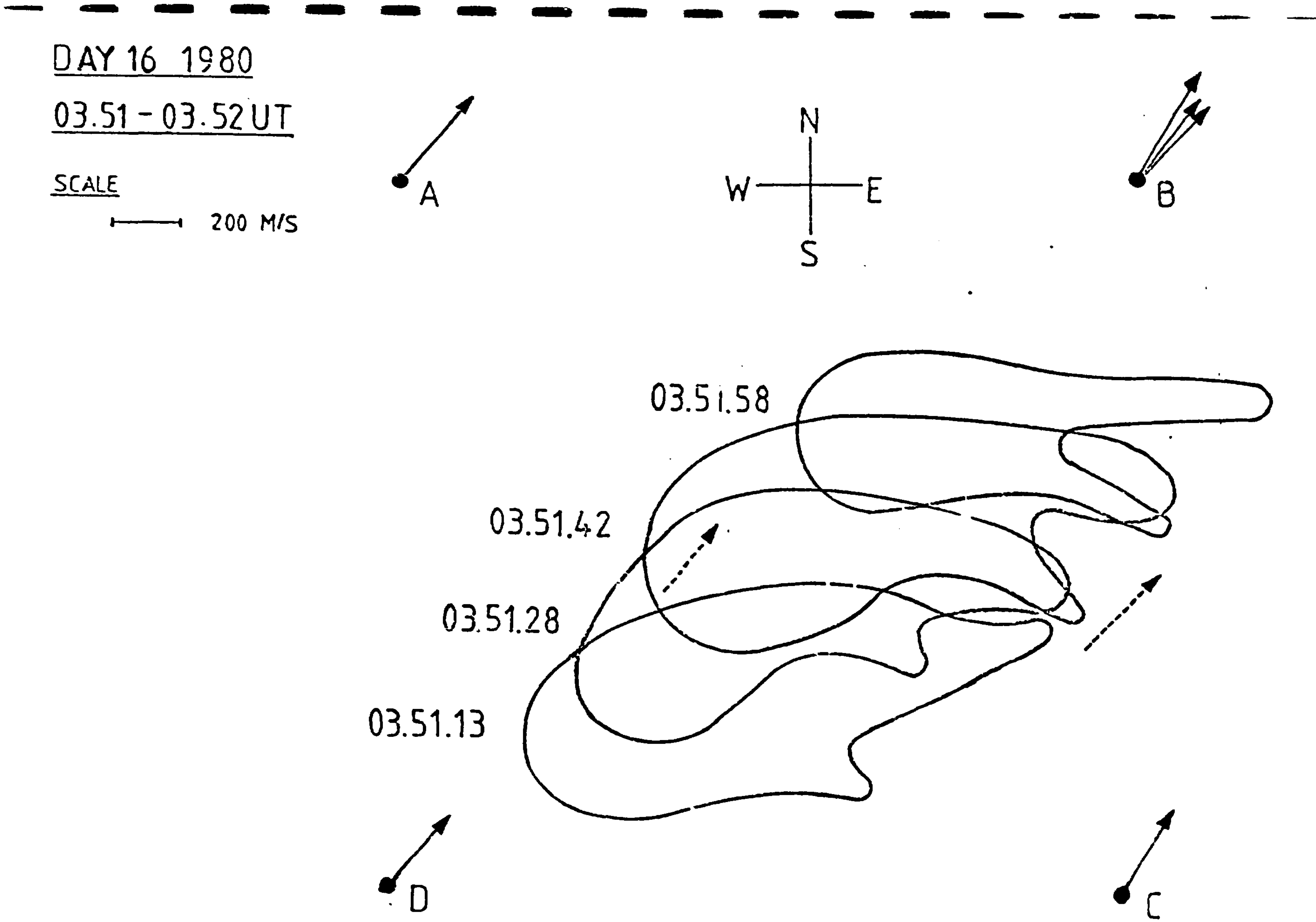


Figure 6. Drift velocity of an auroral form at successive time compared with the Stare drift velocity at four grid points (A, B, C, D).

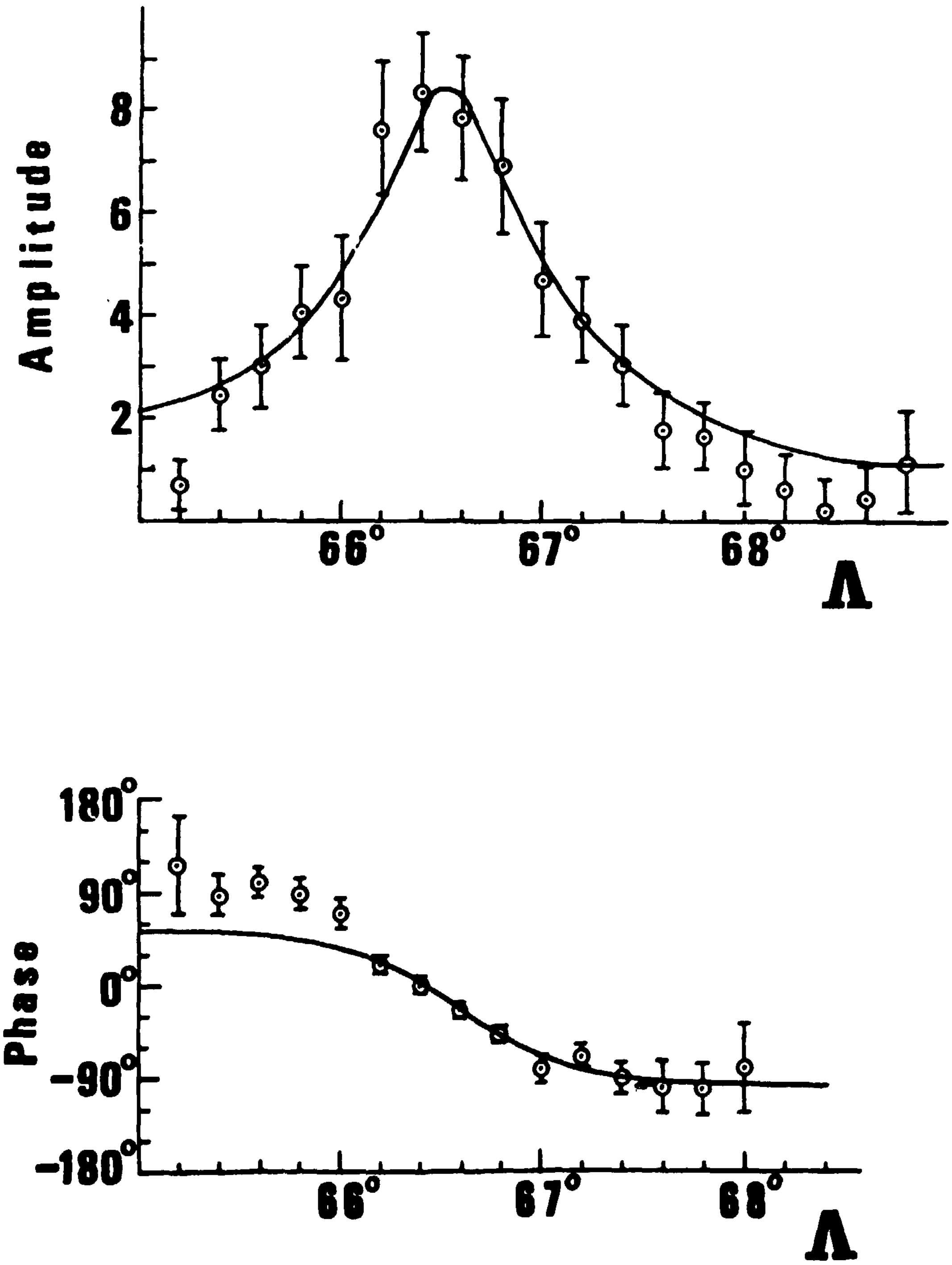


Figure 7. Latitude dependence of amplitude and phase of the drift velocity observed by Stare during a Pc5 pulsation.

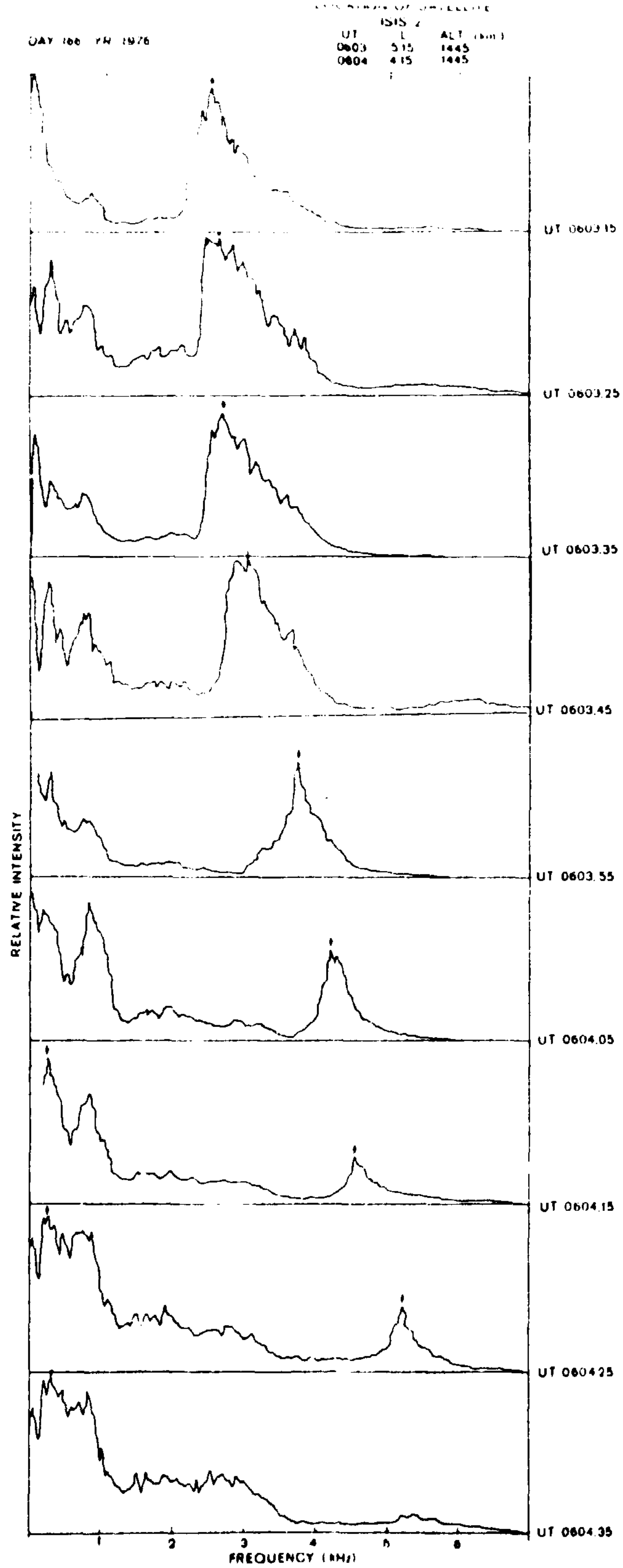


Figure 8. Spectra of vlf lower hybrid noise at various latitudes