THE MULTIPLE RIOMETER SYSTEM AT HALLEY, ANTARCTICA

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ABSTRACT. A group of four riometers has been operating at Halley station, Antarctica (76° S, 27° W, $L = 4.2$) since 1981. Each riometer uses a Yagi antenna with a wide beam centred at 45° elevation; the horizontal projections of the axes of the antennas are directed orthogonally in the invariant geomagnetic north, east, south and west directions. The analogue data are recorded continuously on strip charts and also digitized to magnetic tape.

Computations have been performed to relate the radio absorption measured by the riometers to the zenithal absorption in the cases of (1) a uniform absorption slab and (2) absorption in the form of a linear wedge. Examples are given of the interpretation of absorption events using these models.

INTRODUCTION

The riometer (Relative Ionospheric Opacity meter) is a stable radio receiver used for monitoring over long periods of time the intensity of the cosmic radio noise arriving at a point on the earth's surface (Little and Leinbach, 1959). If no signal is lost in the terrestrial ionosphere its intensity repeats exactly with the sidereal day, and this pattern of variation is known as a 'quiet-day curve'. Should an absorption event occur in the ionosphere, the intensity of the received signal falls below the quiet-day value for that sidereal time and thus the amount of absorption can be measured.

At high geomagnetic latitudes most radio absorption is due to an enhancement of the electron density in the lower ionosphere produced by an influx of energetic ionizing particles, which may be protons or electrons (Hargreaves, 1969). At the latitude of Halley, which is on the equatorial side of the auroral zone, it is to be expected that most absorption events will be of the auroral type due to energetic electrons. The geophysical value of riometer data is principally through this ability to monitor energetic particle precipitation from the ground, many such events being associated with substorms. An engineering interest also arises because ionospheric absorption affects HF radio circuits at high latitude, and because of the consequent need to develop prediction schemes for auroral absorption (Foppiano and Bradley, 1985).

MULTIPLE RIOMETER SYSTEMS

For reasons of convenience, expense and ease of maintenance, most riometers use a relatively small antenna, which therefore receives cosmic noise over a wide beam and creates a 'field of view' that is at least 100 km across in the ionospheric *D* region – a typical height for the absorption region in an auroral event being 90 km. A wide-beam riometer therefore cannot distinguish fine structure. While the desirability of narrow-beam riometer systems has long been appreciated, few have been built (Berkey, 1968; Nielsen, 1980). Largely, this is because of their greater cost and difficulty of construction, and the liability of large antennas to mechanical damage in a harsh environment.

To observe the spatial distribution of absorption on a wider scale, one approach is to deploy a network of riometers separated by 100–300 km. Several such networks

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are in continuous operation in the northern hemisphere. An alternative approach – and, until unmanned observatories make their appearance, the only practical approach for the remoter regions of the Earth – is to install at one site several riometers with inclined antennas, so that each 'views' a different patch of the *D* region in the vicinity of the site. This method was first used about 20 years ago (Chivers and Hargreaves, 1965) to obtain information about the spatial gradient of absorption over the station (Ecklund and Hargreaves, 1968). Such a system also allows the horizontal speed and direction of movement of some precipitation events to be determined (Hargreaves, 1970).

Riometry at Halley

A single, wide-beam, riometer with its antenna pointed to the zenith had been operated at Halley since 1972. One consequence of the discussions held in 1979 to prepare for the Advanced Ionospheric Sounder (Grubb, 1979) at Halley was a decision to develop riometry at Halley as a joint project between the BAS Atmospheric Sciences Division and the Environmental Sciences Department of the University of Lancaster. The system deployed was a group of four riometers using Yagi antennas with axes inclined at an elevation of 45°, their horizontal projections pointing in the invariant geomagnetic north, south, east and west directions. The riometer output signals were to be recorded on a multi-pen chart recorder, with digital recording at a 20-second interval to magnetic-tape cassettes. The principal equipment is as follows:

Riometers. La Jolla Sciences model, operating at 30 MHz, with bandwidth 150 kHz and output time constant 0.25 s. Four riometers are in use, with one held as spare.

Antennas. Telex 'hy-gain' type 103 BA – beamwidth between 3-dB points is 60° in *E*-plane, 90° in *H*-plane. Mounted at 45° elevation in oil drums frozen into the snow. *E*-plane is horizontal. Horizontal projection of axes directed along invariant geomagnetic north, south, east and west; the antenna pointing geomagnetically south is 17° east of geographic south.

Chart recorder. Rikadenki model R-16. Four pens used, offset to distinguish between channels. Paper speed 6 cm/h.

Logger. Prior to 1986: Memodyne Model 324-3 Data Logging System, recording to digital tape cassette. Each channel sampled every 20 s. Sample rate increased to 5 s for specific scientific campaigns. From 1986 onwards: BAS data logger (developed by R. I. Kressman and J. T. E. Turton) based on BAS in-house microprocessor. Each channel sampled every 1 s. Data recorded to standard 1600 bpi computer tape.

The University of Lancaster provided two riometers and the chart recorder. BAS provided three riometers, the antennas and the logger. The system was installed at Halley (75.5° S, 27.0° W) in the summer of 1980–81 and moved to the replacement base at the beginning of 1984. Table I summarizes the operation for each of the years 1981–1985. All digital data are destined for the AIS Database, from which they can be retrieved using software provided. The database is currently a G-EXEC-based system mounted on the NERC Honeywell computer at Bidston, but will be transferred to an ORACLE-based system mounted on the NERC VAX 8600 computer at Keyworth during 1986.

Interpretation of Data from the Array of Oblique Riometers

Introduction

Because of their wide beams, the riometers respond to absorption occurring within large patches of the *D* region. Fig. 1 shows the intersections of the antenna 1-dB, 2-dB and 3-dB curves with a plane at 90 km altitude (based upon polar diagrams computed by the manufacturer). How the riometer responds to an absorption event depends on the extent and location, as well as the intrinsic strength, of the patch of absorption formed, and there is no simple rule covering all cases. Interpretation can, however, be made in terms of models of the horizontal distribution of absorption, and we shall pursue this using two specific models. Measurements from a single riometer contain only one piece of information and have been interpreted under the assumption that over the intersection between the beam and the *D* region the absorption is uniform. The next simplest assumption is that the absorption is in the form of a linear wedge, and the array of four riometers should then make it possible to determine the magnitude, gradient and orientation of the wedge. Curvature could also be estimated in some cases, but that will not be considered here.

Table I. Halley riometer operations.

Year	*Strip chart*	*Digital cassette*	*Data base*
1981	From Feb. 1981	Days 178–236, with 60% coverage	Loaded
1982	All year, but poor data on north riometer	Days 152–365, with minor data gaps	Loaded
1983	All year	Partly verified	Not yet loaded*
1984	All year, but some time marks lacking	Verified	Not yet loaded*
1985	All year	Verified	Not yet loaded*

* To be loaded directly onto ORACLE/VAX system in 1986.

A linear wedge represents a reasonable first order approximation to many large-scale geophysical events; for example, auroral absorption events observed by chains of riometers often extend over 1000 km or more and their intensity varies relatively smoothly and consistently with latitude (e.g. Hargreaves and others, 1975).

Uniform slab model

If the absorption patch is spatially uniform, all practical riometers indicate too high an absorption value because some waves have passed through the region obliquely and have thereby suffered more absorption than those passing through vertically. The absorption should therefore be described by the 'zenithal absorption', defined as that value that would be measured by a riometer using an ideal pencil beam antenna directed to the zenith. The zenithal absorption, A(dB), can be related to the apparent absorption, B(dB), as measured by a practical system, if the antenna pattern and form of absorption are known. In fact such corrections are rarely applied to riometer data as published. Correction is essential in quantitative work as, for example, when relating the absorption to another geophysical measurement such as a charged particle flux. Whether it is necessary to apply a correction in other applications depends on the accuracy required. The equations relating apparent and zenithal absorption in a uniform slab model are given in Appendix I.

Fig. 2 shows the *E*- and *H*-plane patterns for the Halley antennas. The *E*-plane (plane of the antenna elements) is horizontal, and the *H*-plane is vertical with the maximum 45° from the zenith. Ground reflections have been neglected. The calculated curve for correction from apparent to zenithal absorption is given in Fig. 3 (curve O). Curve V shows the result for an antenna pointed vertically. Each curve

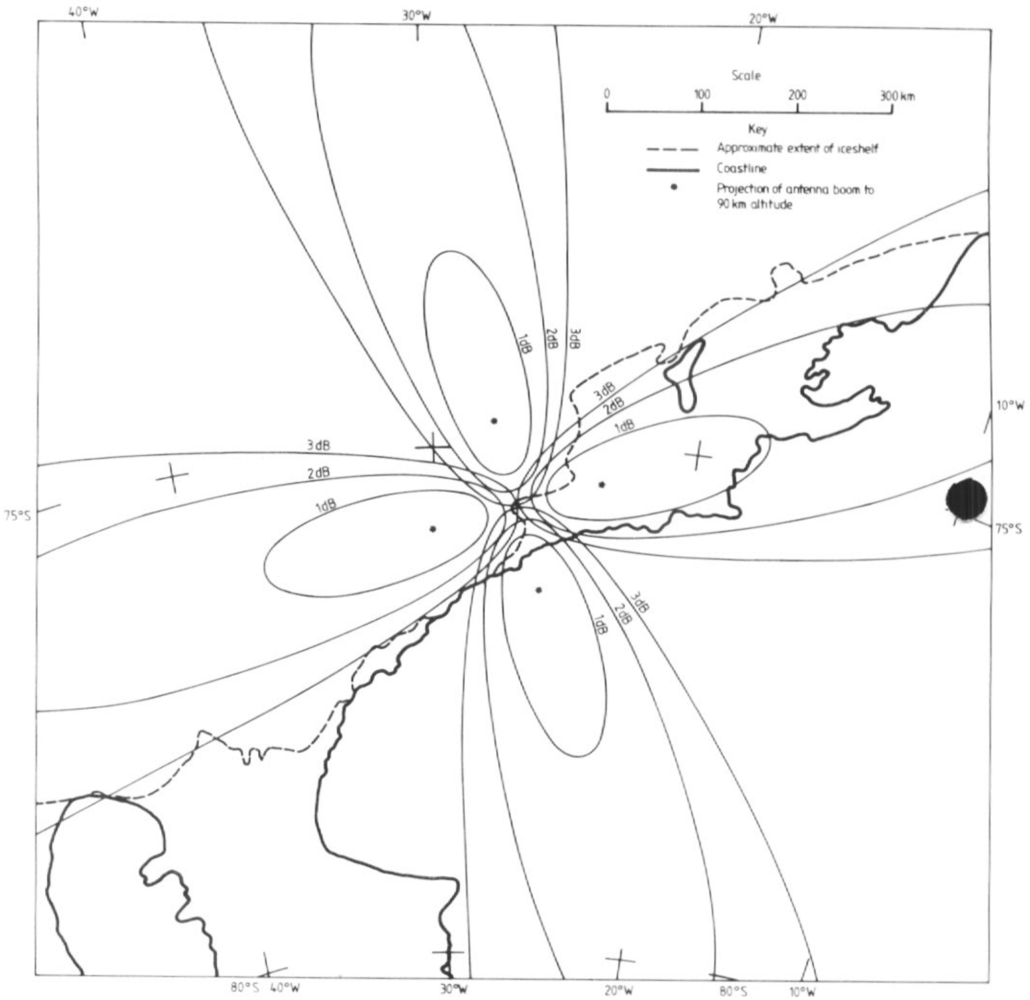


Fig. 1. Projection of Halley riometer antenna patterns to a plane at 90 km altitude.

approximates to a straight line when plotted on logarithmic axes. They may be represented by the formulae in Table II, which are regression lines fitted over the range $A = 0.03\text{–}3.0$ dB. The standard error in fitting these regression lines is also given. Since the exponents are nearly unity, the relations are almost linear. The oblique antenna is the more sensitive for detecting weak absorption provided, of course, that the event is sufficiently extended in the horizontal plane.

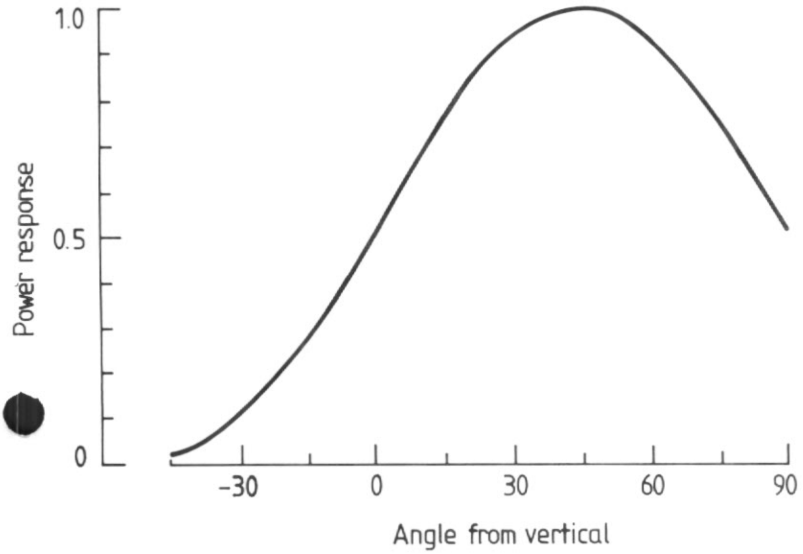
Wedge model

As the next step we assume that the zenithal absorption varies as

$$A = A_0(1 + g \cdot d/h),$$

where A_0 is the zenithal absorption directly over the station, d is the horizontal distance from the overhead point, and h is the height of the absorbing layer. The

(a) H- plane



(b) E- plane

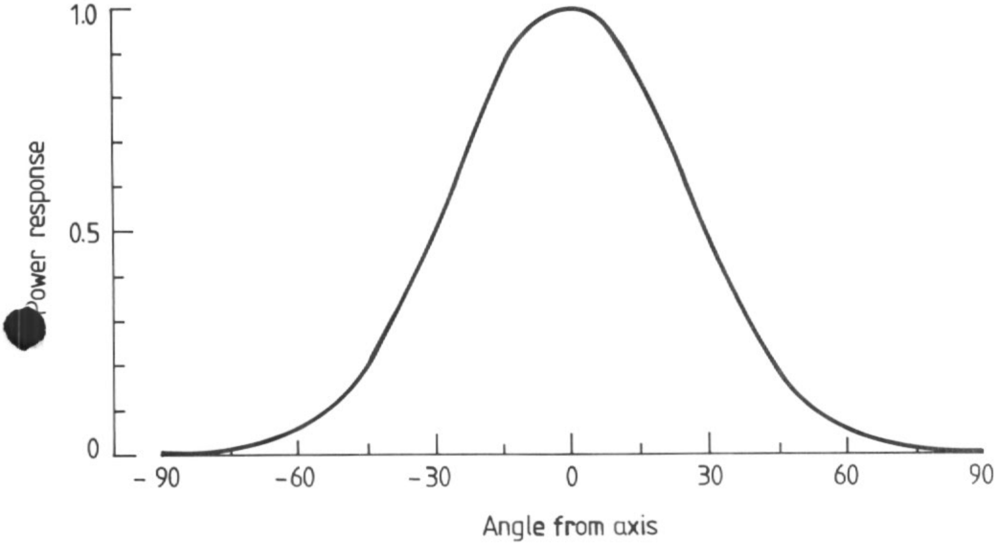


Fig. 2. *H*-plane and *E*-plane patterns for Yagi antennas at Halley, plotted on a linear scale of power. Each antenna is directed 45° from the zenith with the *H*-plane vertical.

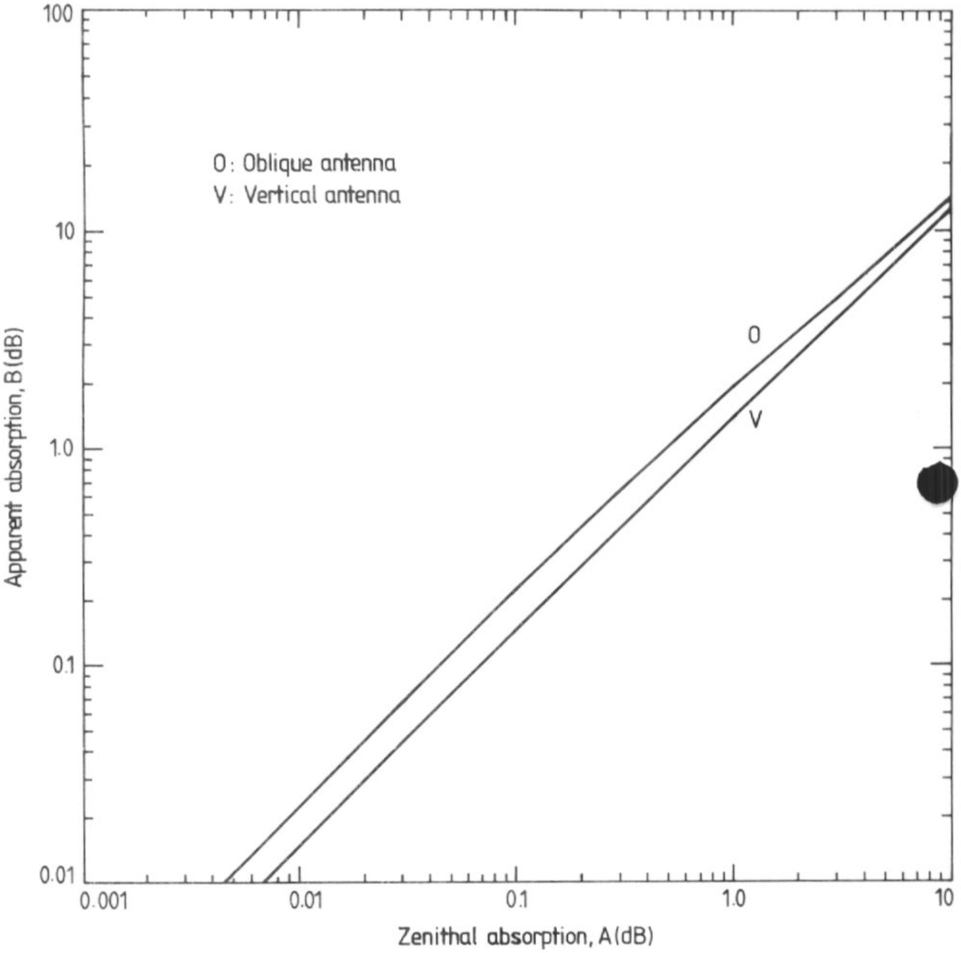


Fig. 3. Relation between apparent and zenithal absorption for Halley riometer antenna; (O) if pointed 45° from the zenith, and (V) if pointed to the zenith. A uniform slab of absorption is assumed. The best fitting regression equations are given in Table II.

Table II. Equations relating zenithal (A) and apparent (B) absorptions, in dB, for a uniform slab mo[illegible]

Antenna	*Formulae**	*Standard error*
Oblique	$B = 1.87\ A^{0.929}$	4%
	$A = 0.50\ B^{1.075}$	4%
Vertical	$B = 1.40\ A^{0.980}$	1%
	$A = 0.709\ B^{1.020}$	1%

* Valid for zenithal absorption in the range 0.3–3.0 dB.

relative gradient $(h/A_0 \cdot \delta A/\delta d)$ is g. Thus $A = A_0(1 \pm g)$ at zenithal angle 45° along the line of maximum gradient. Values of $A < 0$ will be set equal to zero.

A series of computations has been made over a range of A_0 and g, taking the line of maximum gradient at various azimuths, θ, east of north. It is a simple matter to compute the apparent absorption, B, for each of the riometers (N, E, S, W) given an

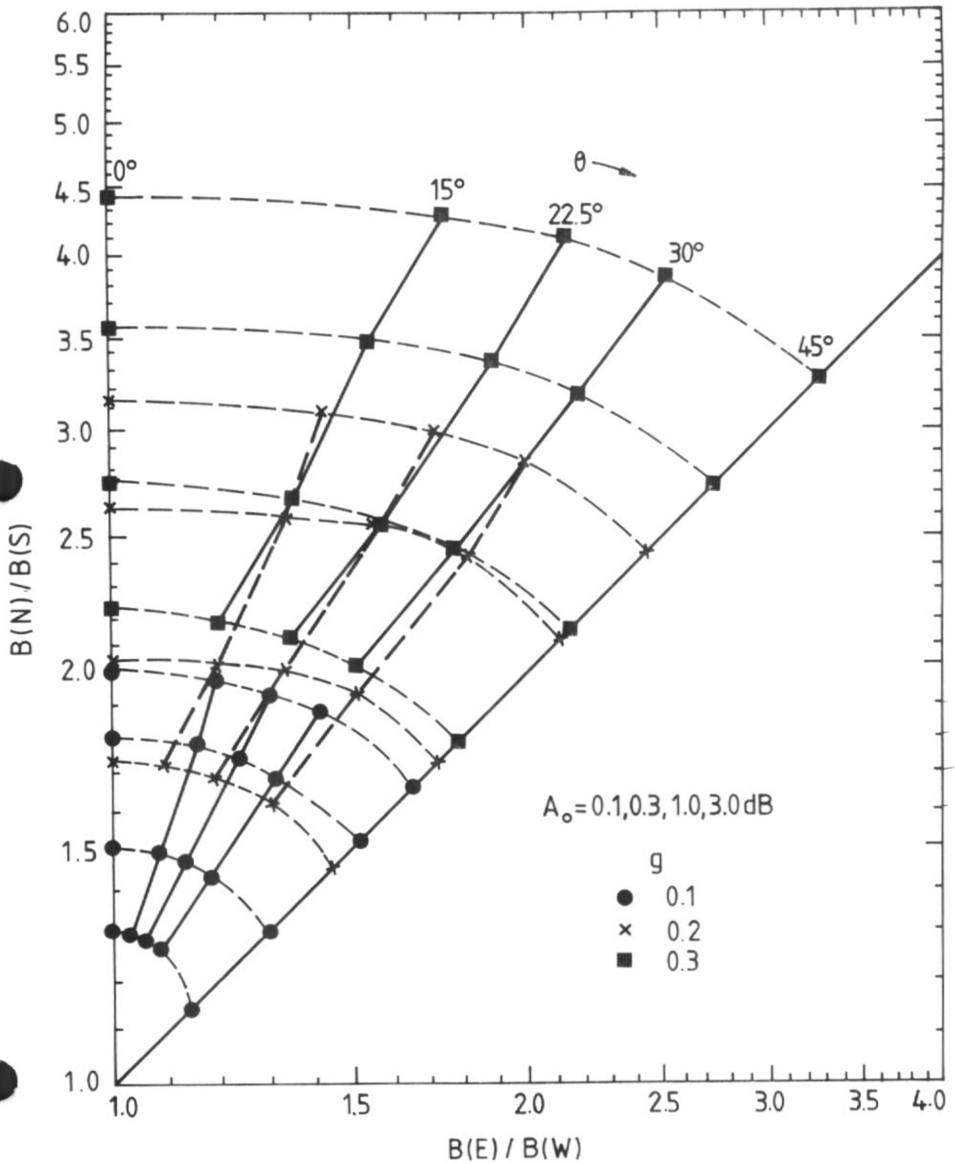


Fig. 4. Apparent north–south and east–west ratios for various wedge models with maximum absorption gradient oriented $\theta°$ east of north. From the formula $A = A_0(1+g \cdot d/h)$ values are plotted for $g = 0.1$, 0.2 and 0.3, and $A_0 = 0.1$, 0.3, 1.0 and 3.0 dB. The ratios decrease as A_0 increases.

absorption wedge defined by A_0, g and θ, but more difficult to present the results to aid the interpretation of observed B(N), B(E), B(S) and B(W) in terms of the wedge parameters A_0, g and θ. In Fig. 4, corresponding values of B(N)/B(S) and B(E)/B(W) have been plotted for $\theta = 0°$, 15°, 22.5°, 30° and 45°, $A_0 = 0.1$, 0.3, 1.0 and 3.0 dB and $g = 0.1$, 0.2 and 0.3. Since values with the same θ tend to be along the same curve whatever A_0 and g, this diagram can be used to estimate θ from observed north–south and east–west absorption ratios. It appears that another family of curves connects values with the same A_0 and g; by moving along one of these the wedge can be

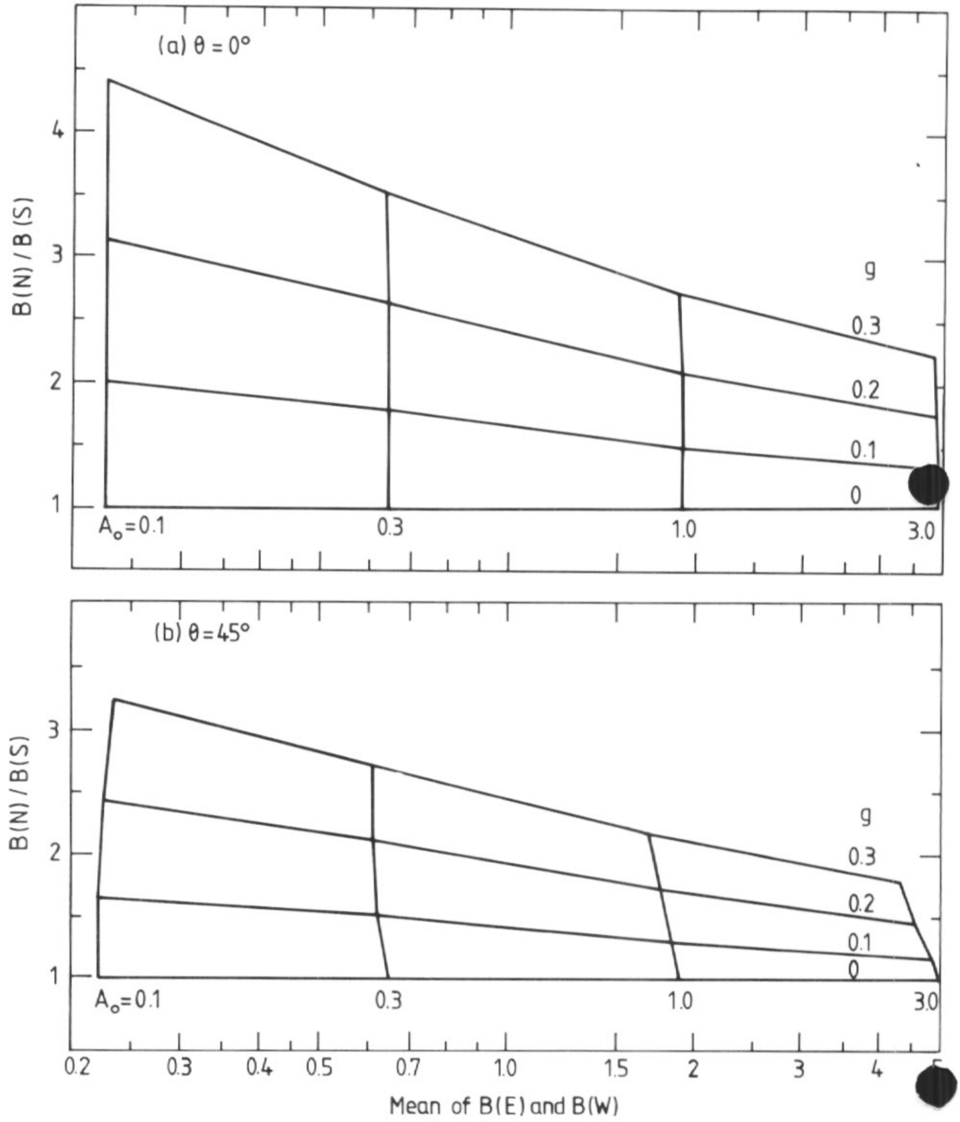


Fig. 5. Variation of north–south ratio and east–west mean absorption for wedge models when (a) the gradient is to the north ($\theta = 0°$) and (b) the gradient is to the northeast ($\theta = 45°$). Parameters g and A_0 are as in Fig. 4.

'rotated' into the north–south direction, when reference to Fig. 5(a), showing $B(\mathrm{N})/B(\mathrm{S})$ against the mean of $B(\mathrm{E})$ and $B(\mathrm{W})$, enables A_0 and g to be determined. For values of θ close to 45° it is more convenient to rotate to 45° and then use Fig. 5(b).

EXAMPLES OF ABSORPTION EVENTS

To demonstrate the application of this interpretive method to real data, two examples are given below of absorption events recorded at Halley, together with the time varying characteristics of the absorption wedge which would produce such signatures.

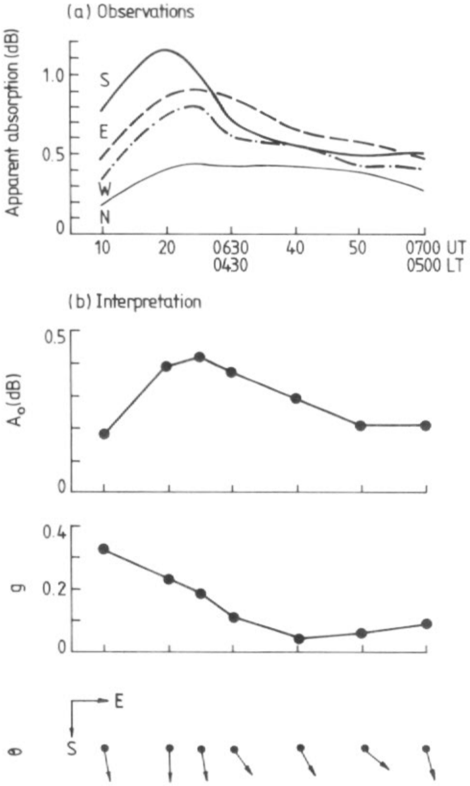


Fig. 6. (a) Absorption observed during a trough precipitation event, on 17 June 1982. (b) Interpretation as an absorption wedge described by A_0, g and θ.

A trough precipitation event

Howarth and others (private communication) have identified a type of absorption event associated with the mid-latitude ionospheric trough when crossing Halley in the early morning. Fig. 6(a) shows an example of such an event. Interpretation as an absorption wedge (Fig. 6(b)) shows the overhead absorption peaking at 0425 LT, the relative gradient decreasing during the event, and the line of maximum gradient swinging from almost due south to approximately south-east after the peak. It appears that Halley was on the edge of a precipitation region that remained centred to the south of the station, moved from west to east, and was spatially sharper in the leading than in the trailing edge.

A slowly varying event

Auroral absorption events in the local morning hours often vary slowly with time, and auroral-zone measurements (Hargreaves and Berry, 1976) have indicated predominantly eastward movement of this type of event. Although such events have not been thoroughly investigated at Halley, that shown in Fig. 7(a) appears to be an example. Interpreting the observations in terms of an absorption wedge shows the zenithal absorption over Halley peaking at 0615 LT and the relative gradient (g) declining throughout most of the final bay of the event. As in the previous case, the

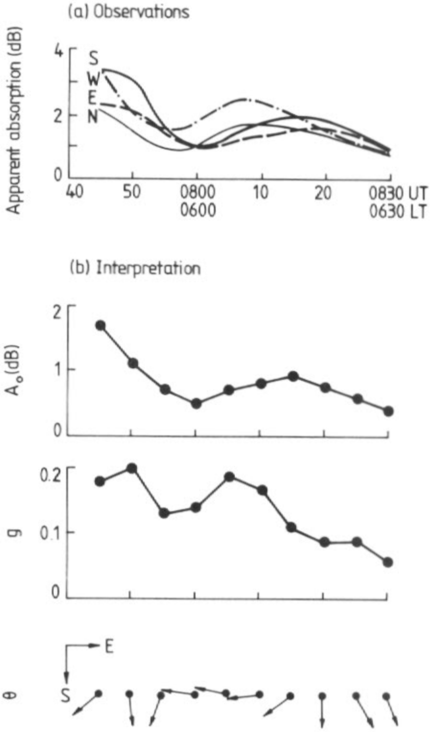


Fig. 7. (a) Absorption observed during a slowly varying event, on 14 July 1982. (b) Interpretation as an absorption wedge.

event did not pass directly overhead (or g would have fallen to zero as A_0 passed through its maximum), but was more to the south. However, the maximum gradient was almost due west as the bay commenced, moved to the south shortly after the peak and took an eastward component at the end of the bay. The pattern indicates a dominant west to east motion with some north to south component. The interpretation provides a more accurate representation of the progress of the absorption event than could be read directly from the original data in Fig. 7(a).

CONCLUSIONS

The riometer continues to be a convenient device for indirectly monitoring the penetration of energetic charged particles into the lower ionosphere. Halley is situated on the equatorward side of the main absorption zone; the riometer system operated there over the past few years is able to determine the spatial gradient of an absorption patch as well as its true magnitude. Model computations make it possible to derive a more accurate description of the absorption within several hundred kilometers of the station, which should be useful in more detailed studies of the form and dynamics of auroral absorption at $L = 4$.

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Appendix I: Response of a Wide-beam Riometer

The apparent absorption, B decibels (dB), measured with a riometer, is given by $B = 10\log_{10}(P_0/P)$ when P_0 and P are the total powers received respectively without and with an absorbing layer present. If the antenna has power polar diagrams $D(\alpha)$ and $D(\beta)$, when α and β are measured from the centre of the beam in orthogonal planes, then

$$P_0 = S_0 \int D(\alpha)\, D(\beta)\, \mathrm{d}\omega,$$

and

$$P = S_0 \int 10^{-(A \sec \xi/10)}\, D(\alpha)\, D(\beta)\, \mathrm{d}\omega.$$

$\mathrm{d}\omega$ is an element of solid angle at the intersection of planes α and β, and is given by

$$\mathrm{d}\omega = (1-\sin^2\alpha \cdot \sin^2\beta)^{-\frac{1}{2}}\, \mathrm{d}\alpha\, \mathrm{d}\beta.$$

ξ is the zenith distance of the element; if the α-plane is vertical and the beam is centred at α_0 from the zenith, then

$$\cos\xi = \cos(\alpha+\alpha_0)\cdot\cos\beta\cdot(1-\sin^2\alpha\cdot\sin^2\beta)^{-\frac{1}{2}}.$$

The zenithal absorption is A decibels (dB), encountered in the direction (α, β). In the computations α and β were taken at 5° intervals between 0° and 85°. S_0, the cosmic noise flux above the ionosphere, was taken as unity, thus neglecting variations of sky temperature within the beam.