AFCRL-72-0413
18 JULY 1972
ENVIRONMENTAL RESEARCH PAPERS, NO. 404

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

A Model of Auroral Substorm Absorption

TERENCE J. ELKINS

Approved for public release; distribution unlimited.

AIR FORCE SYSTEMS COMMAND

United States Air Force

Qualified requestors may obtain additional copies from the Defense Documentation Center. All others should apply to the National Technical Information Service.

AFCRL-72-0413
18 JULY 1972
ENVIRONMENTAL RESEARCH PAPERS, NO. 404

IONOSPHERIC PHYSICS LABORATORY PROJECT 4643

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

A Model of Auroral Substorm Absorption

TERENCE J. ELKINS

AIR FORCE SYSTEMS COMMAND
United States Air Force

Contents

Illustrations

Tables

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Cambridge Research Laboratories (LI) L. G. Hanscom Field Bedford, Massachusetts 01730	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
A MODEL OF AURORAL SUBSTORM ABSORPTION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Scientific. Interim.

5. AUTHOR(S) (First name, middle initial, last name)
Terence J. Elkins

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
18 July 1972	23	13

8a. CONTRACT OR GRANT NO. b. PROJECT, TASK, WORK UNIT NOS. 4643-01-01 c. DOD ELEMENT 62101F d. DOD SUBELEMENT 681000	9a. ORIGINATOR'S REPORT NUMBER(S) AFCRL-72-0413 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) ERP No. 404

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES TECH, OTHER	12. SPONSORING MILITARY ACTIVITY Air Force Cambridge Research Laboratories (LI) L. G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

High-frequency radio propagation at high latitudes is strongly affected by auroral absorption, which is known to occur sporadically in events known as auroral substorms. A brief discussion of the morphology of substorms is presented, followed by an analysis of auroral absorption during 60 substorms. The statistical parameters necessary to specify a predictive model are derived empirically as a function of time after substorm onset. Also presented from other evidence are relationships to model the latitude dependence, substorm duration, frequency dependence, and the seasonal and solar cycle dependence. A brief discussion of structure size in auroral absorption events is included.

DD FORM 1473 1 NOV 65

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Polar ionosphere model						
Auroral absorption						
Riometer measurements						
Aurorai substorms						

Unclassified

Security Classification

A Model of Auroral Substorm Absorption

1. INTRODUCTION

A dominant feature of the high latitude ionosphere is the auroral substorm with its accompanying ionospheric disturbance. The high latitude coverage of hf-radio propagation systems will be seriously degraded by these catastrophic events, and while it is rarely possible to compensate for such degradation, it is definitely of value to be able to predict their extent and duration. This study describes the development of a predictive model for substorm absorption, which is based on the analysis of 60 substorms, recorded by a network of Arctic riometers.

2. PHYSICAL NATURE OF SUBSTORMS

Auroral substorms may be considered to be the ionospheric manifestation of magnetospheric substorms. These in turn are generated by interplanetary "storms" in the solar wind. An interplanetary storm is initiated by some energetic outburst of solar coronal plasma, whose rapid outward expansion drives a shock in the unperturbed interplanetary plasma. The region behind the shock is highly disturbed, with plasma motions and turbulent magnetic field displaying large variances. In general, the slowly varying interplanetary magnetic field will

(Received for publication 17 July 1972)

develop either a northward or southward directed component, in a magnetospheric-based system of coordinates. If this component remains southward for a period of the order of 1 hr, there is a high probability that a magnetospheric substorm will develop. Arnoldy (1971) has determined that the correlation between southward turning interplanetary fields and auroral substorms is >0.8, with a time delay of ~1 hr between the two.

The magnetospheric substorm involves the enhancement of magnetospheric electric fields and plasma drifts, and the acceleration of trapped and pseudo-trapped charged particles. The plasma sheet in the earth's magnetic tail first thins rapidly and then thickens again, while its inner edge moves closer to the earth (reaching 6 to 7 earth radii). The complex sequence of magnetospheric events is accompanied by enhancement of the auroral electrojet current, the incidence of magnetic bays and precipitation of electrons and protons into the atmosphere. Precipitation initially takes place near the midnight meridian and is accompanied by bright, highly variable auroras, which exhibit a poleward drift motion. This phase has been called the "auroral breakup".

Following auroral breakup, the source region of precipitating particles often moves eastwards around the auroral oval under the influence of magnetic field gradient drift and the enhanced magnetospheric electric fields. The high energy tail of the auroral particle spectrum ($\gtrsim$40 keV energy) precipitates equatorwards of the visible aurora, causing intense D-region ionization and consequent radio wave absorption. Although the foregoing may be regarded as the description of a typical substorm sequence, it must be appreciated that exceptions are common, and that auroral substorms are highly erratic phenomena.

3. DATA BASE

The data on which this study is largely based were analyzed by an international study group coordinated by Professor Hultqvist of Sweden (Temporal Development of the Geophysical Distribution of Auroral Absorption for 30 Substorm Events in Each of IQSY (1964-1965) and IASY (1969), 1971). Sixty individual substorms were examined, as recorded by a network of ~36 Arctic riometers, spaced fairly uniformly in longitude. The recording network coverage was sufficiently complete to enable contours of absorption to be drawn at any instant. The report generally shows substorm development by means of such contour maps at 15-min intervals, starting at the time of substorm onset. The riometer operating frequencies were 30 to 32 MHz and the absorption contours are displayed in increments of 1 dB, with a minimum contour of 0.3 dB.

The spatial and temporal variations of absorption during substorms permits a realistic model to be constructed consisting of a convolution of a radial (latitudinal) model and an azimuthal (longitudinal) model, in the corrected geomagnetic coordinate system, when an additional time parameter (substorm time) is introduced. This part of the model is described in Sections 5, 6 and 7.

4. PARAMETERS TO BE COMPUTED

If the time of substorm onset is designated as T_o, then it is required for OHD application to estimate, as a function of time (measured from T_o) the following parameters:

(1) Probability distribution of absorption as a function of spatial coordinates.

(2) Joint probability density of absorption at spaced points.

(3) Statistics of absorption duration.

(4) Irregularity size and shape.

(5) Frequency dependence of absorption.

(6) Seasonal and solar cycle dependences.

(7) Time variation of absorption within an individual substorm.

The data in the international study report do not permit high spatial or temporal resolution. However, other studies are available which are used to supplement them where necessary.

5. LATITUDINAL DISTRIBUTION

Studies of Hartz et al (1963), Jelly (1970) and others have repeatedly shown that auroral absorption is confined to a narrow belt, centered on ~65.4° corrected geomagnetic latitude (see Figure 1). From these studies the latitudinal distribution may be represented by

$$A = A_o \exp\left[-\frac{(\theta - 65.4)^2}{32}\right] \qquad (1)$$

where

A is absorption (dB),

A_o is maximum absorption (at $\theta = 65.4^o$), and

θ is geomagnetic latitude.

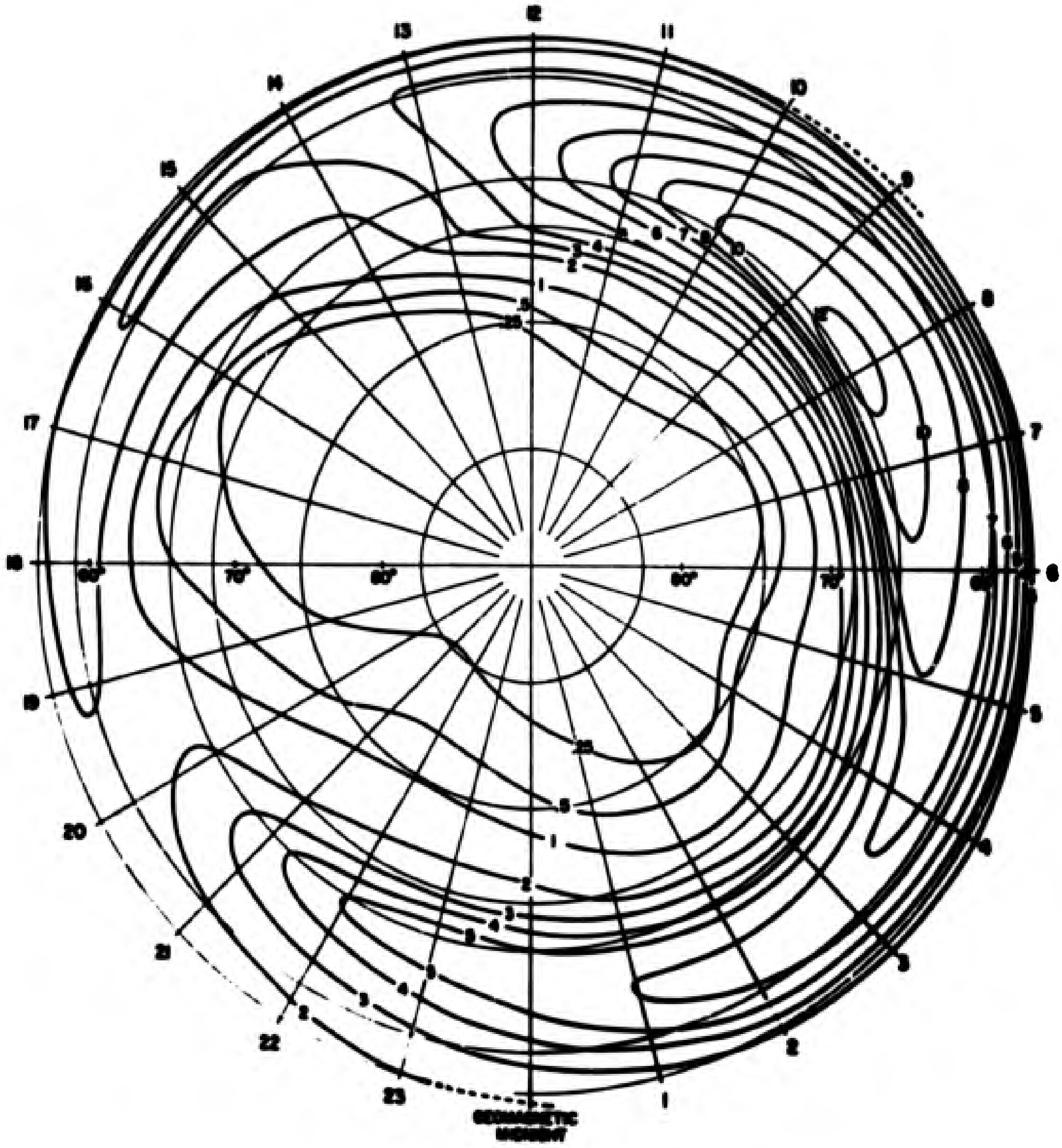

Figure 1. Probability of Occurrence of Absorption Greater Than 1 dB (Hartz et al, 1963)

6. PROBABILITY DISTRIBUTION

The contour maps in the WDS report were scaled at times (T_o + t); t = 15, 30, --- min to estimate the probability distribution at the latitude of maximum absorption (~65.4°). The longitudinal parameter used was local time, measured from the midnight meridian. Data were averaged over 3-hr intervals to achieve better stability.

It was found that the probability distribution were generally log-normal (see Figure 2). Assuming log-normal distributions, the median, and upper and lower deciles were estimated and are tabulated in Table 1.

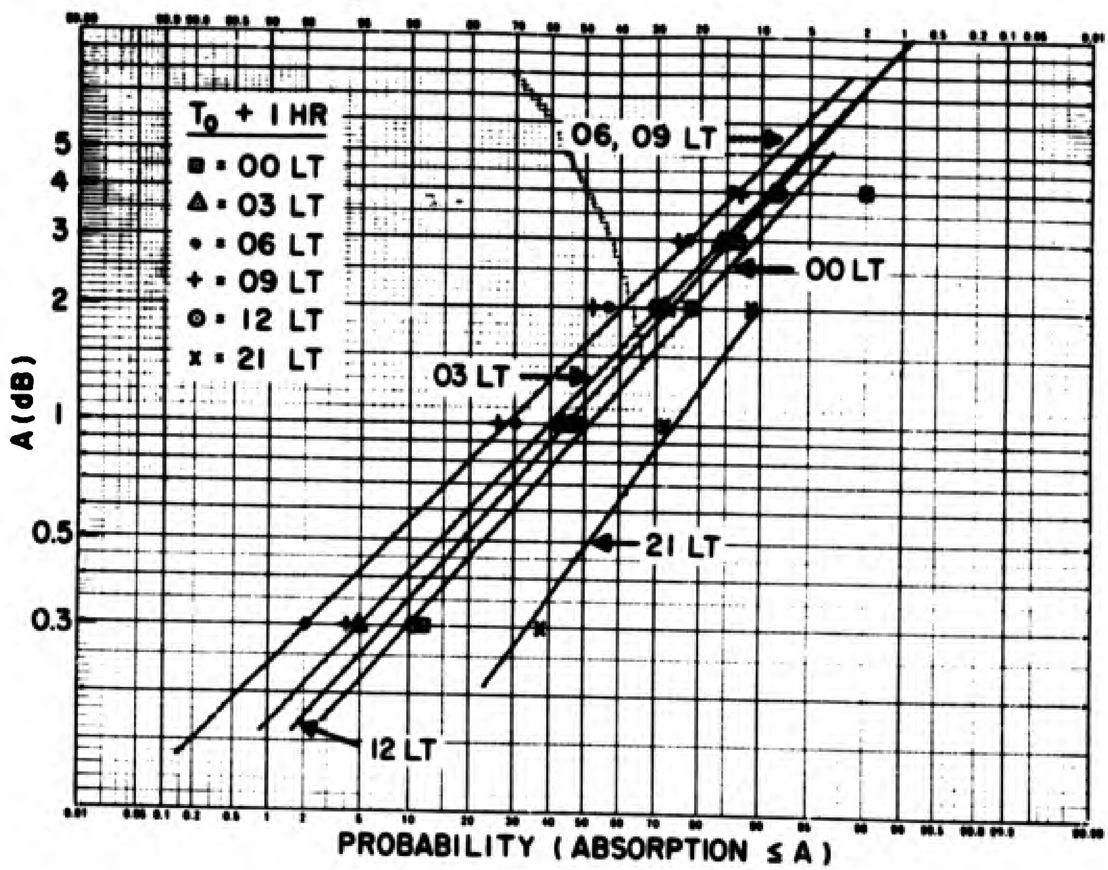

Figure 2. Probability Distribution of Auroral Substorm Absorption at Substorm Time 1 hr, as a Functior of Local Time

Table 1. Probability Distribution Parameters for Substorm Absorption

Substorm Time	Local Time	Median (dB)	Upper Decile (dB)	Lower Decile (dB)
T + 15	00	0.75	2.6	0.22
	03	0.70	2.2	0.22
	06	0.54	1.8	1.17
	09	0.28	1.25	0.066
	12	0.10	0.56	0.019
	15	(0.14)	(0.38)	(0.052)
	18	0.10	0.56	0.019
	21	0.37	1.5	0.090
T + 30	00	0.94	3.7	0.24
	03	1.1	4.0	0.32
	06	1.1	4.5	0.30
	09	0.64	2.8	0.14
	12	0.42	1.7	0.10
	15	(0.20)	(0.78)	(0.052)
	18	(0.17)	(0.58)	(0.050)
	21	0.50	1.9	0.13
T + 45	00	1.1	3.5	0.34
	03	1.3	4.0	0.43
	06	1.6	4.5	0.54
	09	1.4	6.0	0.32
	12	0.67	2.8	0.16
	15	0.28	1.3	0.064
	18	(0.20)	(0.84)	(0.049)
	21	0.44	1.8	0.11
T + 60	00	1.0	3.2	0.30
	03	1.3	3.8	0.40
	06	1.6	4.5	0.56
	09	1.6	4.5	0.56
	12	1.1	3.6	0.35
	15	0.38	1.5	0.096
	18	(0.25)	(1.0)	(0.063)
	21	0.50	2.0	0.070

Notes:

1. Parentheses ( ) indicate values with large uncertainties due to small statistical samples.

2. Time is to be interpreted as follows: Local time "00" means the hours 0000-0259 and so forth.

7. JOINT PROBABILITY DENSITY

There are a number of reasons for requiring the joint probability density of absorption amplitude at spaced points. In computing path loss, the absorption at each D-region intersection must be known. If a monitoring observatory is to be used to provide short term predictions for other longitudes than its own, the joint probability density must be known.

This quantity was estimated as follows:

At four separate times, t, following T_o, the probability

$$p \{A (t, \phi_o) \; ; \; A (t, \phi_o + \bar{\phi}) \}$$

was determined where A (t, ϕ_o) is the absorption (dB) at time t and longitude ϕ_o (hours); ϕ is the longitude difference between the selected points. The bar over ϕ signifies that the probability density is averaged over 3-hr intervals in longitude (45°) for better stability.

An example of a computed joint density is shown in Figure 3, for t = 45 mins. Figure 4 shows the result of integrating over the ordinate to convert it to a

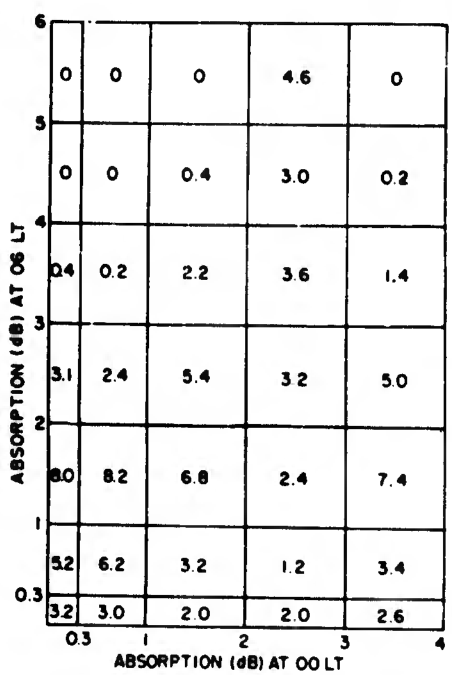

Figure 3. Example of Joint Probability Density at Substorm Time 45 Minutes. The joint probability of absorption at local midnight and 06 LT is shown in percent

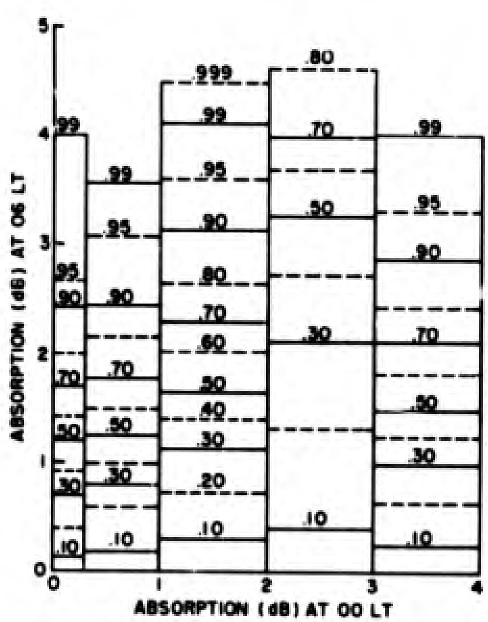

Figure 4. Joint Probability Distribution Corresponding to Figure 3

probability distribution. Thus any point in Figure 3, for example, represents the probability that the absorption at midnight lies in a certain 1 dB range, while that at 06 LT simultaneously lies in another 1 dB range. Alternatively, any point in Figure 4 represents the probability that if the absorption at midnight lies within any 1 dB range, the absorption at 06 LT will exceed some given value. Space limitations do not permit reproducing all of the joint probability density results. These are being built into a general propagation model of the polar ionosphere which will take the form of a computer program.

8. SUBSTORM DURATION

Jelly (1970) has shown, using riometer data, that the duration of substorms, observed at any fixed point, is 1 ~ 2 hrs. Cox and Davies (1954) presented the results of many years of ionosonde data from four high latitude stations, in which auroral absorption was estimated by the prevalence of blackout, or total absorption of the ionosonde pulses. Figure 5 shows the Cox and Davies data points replotted, and a least-squares best-fit exponential superimposed. The exponential probability distribution is characterized by:

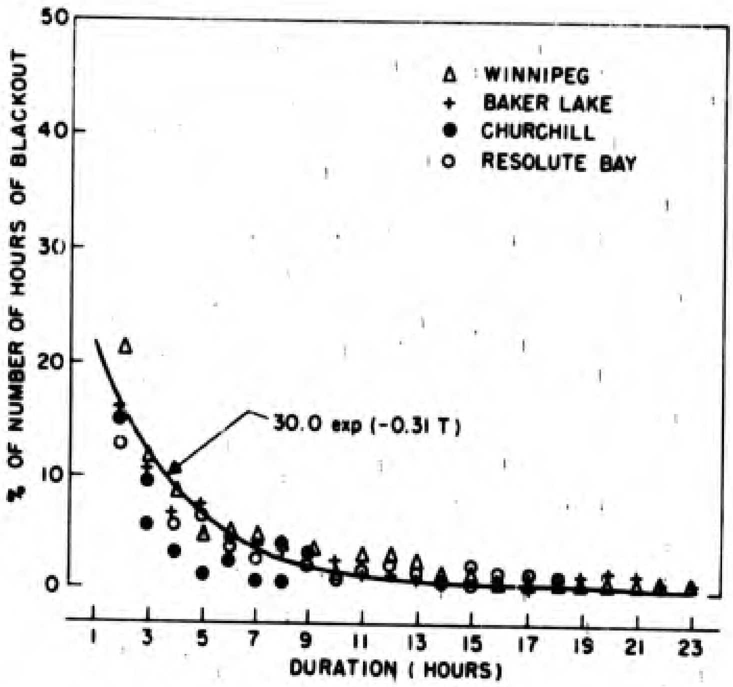

Figure 5. Probability Density of the Duration of Auroral Substorm Absorption (adapted from Cox and Davies, 1954)

Median duration - 1.5 hr

Upper decile - 7.4 hr

Lower decile - 0.34 hr

While an exponential appears to give a reasonable fit, the reasonableness of such a distribution must be examined from a physical standpoint. If the rate of change of flux of charged particles is proportional to the number density, N, in the precipitation source

$$\frac{dN}{dt} = -kN \tag{2}$$

so that

$$N \sim e^{-kt} . \tag{3}$$

With such a model, an exponential distribution of substorm durations would be physically reasonable. A similar conclusion follows if it is assumed that the decay of an accelerating electric field is proportional to the number density of charges in its source regions.

9. TEMPORAL VARIATION OF INDIVIDUAL SUBSTORM EVENTS

Auroral substorm absorption events generally show a rapid increase in absorption as a function of time after onset, followed by a slower decrease. The statistics of substorm absorption duration which have been presented (adapted from Cox and Davies, 1954) may be considered to be averaged over all local times, although there would obviously be increased weighting for the late morning hours, where absorption is most intense. It may, however, be of interest to know the detailed time variation of absorption within a given event, and the manner in which this varies with local time of the event. These dependences should therefore be modelled.

Shumilov (1971) has studied 100 intense (~2 dB) auroral substorm absorption events at Loparskaya in 1963-1964, and summarized the results in suitable terms for this purpose. The increase and subsequent decrease of absorption during an event may be expressed analytically as

$$A(t) = A_{max} \exp \left[+ \frac{t - t_o}{\tau_{in}} \right]$$

and

$$A(t) = A_{max} \exp\left[-\frac{t - t_o}{\tau_d}\right]$$

respectively. Here:

$A(t)$ is absorption at time t,

t_o is time of maximum absorption A_{max},

τ_{in} is "rise time" (min), and

τ_d is "decay time" (min).

Shumilov presents the local time variation of the hourly average values of τ_{in} and τ_d for the 100 events studied. While there is considerable spread in the data, these variations may be represented by the following analytic expressions, where the error limits are approximate "standard" deviations, estimated by eye from Shumilov's plots:

$$\tau_{in} = 1.08 + 2.21(t') - 0.057(t')^2 \quad (\pm 5) \quad (0 < t' < 13)$$

$$\tau_d = 15.57 - 4.12(t'') + 0.99\,(t'')^2 \quad (\pm 10) \quad (0 < t'' < 14)$$

where

t' is local time measured from 22 LT, and

t'' is local time measured from 21 LT.

Thus rise and decay times of absorption are very short (< 15 minutes) near the midnight meridian, but become progressively longer with increasing local time. Near the midmorning absorption maximum, the rise time is ~20 min, and decay time ~2 hr. Figure 6 illustrates a typical synthesized absorption event.

10. FREQUENCY DEPENDENCE OF ABSORPTION

The task of converting absorption values measured by a wide beam riometer at 30 MHz to path loss at high frequency contains several pitfalls. Nonfilling of the beam must be considered as well as ionospheric (F-region) focussing of the galactic radio emission, and the altitude variation of collision frequency. It has been found experimentally (Khodzha-Alchmedov, 1965) that the frequency dependence follows a power law:

$$A(f) \sim f^{-n}$$

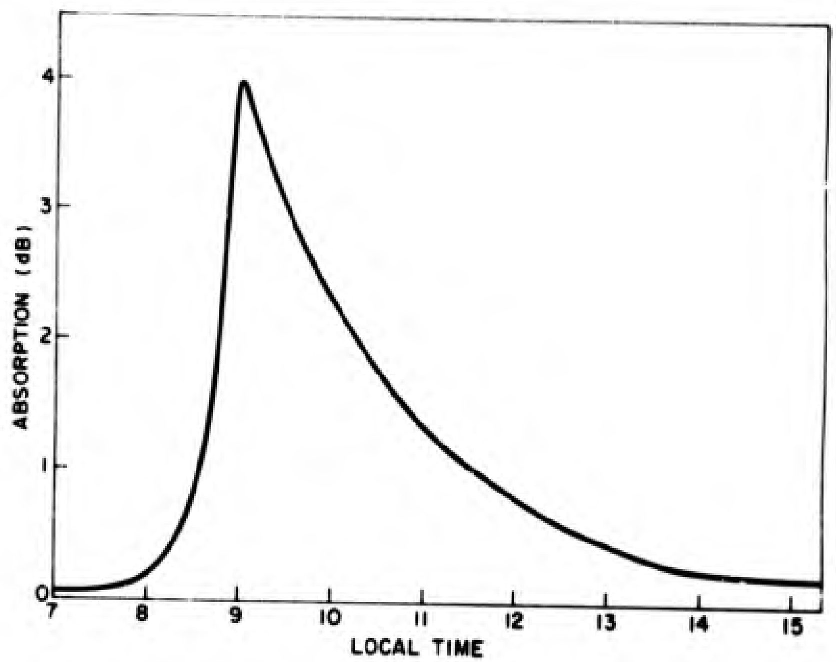

Figure 6. Local Time Dependence of a Typical Synthesized Substorm Absorption Evert

where n = 1.6 ± 0.1. Thus the 30 MHz absorption values in Figures 1 through 4 and in Table 1 may be converted to equivalent absorption values at, say, 10 MHz, by multiplying them by $3^{1.6}$ = 5.9. The largest median absorption at 10 MHz, obtained in this way, is therefore about 9.5 dB (for a one-way, vertical path through the ionosphere).

II. SUBSTORM PRECURSORS

It is clearly desirable that some observable precursor be identified with substorm initiation, in order that warning may be provided. Although it has been shown in many studies (for example Arnoldy, 1971) that the southward turning component of the interplanetary magnetic field is a suitable precursor, this is not really a practical solution to the problem, due to the limited satellite coverage. The only ground based technique for anticipating substorms which is presently known to the author involves impulsive type geomagnetic micropulsations (Pi2) (Rostoker, 1968). These are apparently caused by the interaction of the interplanetary shock wave with the magnetosheath, and may be observed over the entire earth's surface. The delay between onsets of Pi2 and substorms is approximately log-normally distributed, with a median value of 15 min.

12. SEASONAL AND SOLAR CYCLE DEPENDENCES

Driatskiy (1965) showed that the percentage occurrence of 30 MHz absorption ≥ 1 dB exhibited a seasonal variation with values of 6, 7, and 11 percent for summer, winter and equinox respectively. These values refer to the absorption maximum in the late morning sector, and, of course, are averaged over all substorm times. It is not yet well established whether this seasonal variation is due to a variation in the frequency of substorms or in their intensity or both, although present indications are that the first alternative is the most likely. If this is true, then the distributions in Table 1 can be used to estimate the seasonal variation in substorm occurrence frequency. Note that, on the average, substorm absorption is observed roughly 30 percent of all time.

The solar cycle dependence may be estimated from the work of Hook (1968), who analyzed Alaskan riometer data for 1958 (sunspot number 177) and 1964 (sunspot number 13). The results showed a variation of absorption by roughly a factor of 2. One may assume a linear interpolation, with a factor of 2 in mean absorption corresponding to a change in sunspot number of 164. Further inferences on the solar cycle dependence of auroral absorption can be made on the basis of magnetic data, as illustrated in Section 14.

13. STRUCTURE SIZE

The gross dimensions of the substorm absorption region may be determined from Eq. (1) and from the longitudinal distribution of occurrence probability. Figure 7 illustrates the local time variation of mean absorption as a function of time after substorm onset. From these considerations, it may be seen, for example, that the average dimensions of the absorbing region are ~5.5 deg in latitude and ~240 deg in longitude, 1 hr after substorm commencement. The longitudinal extent increases with substorm time as indicated in Figure 8. The rate of expansion of the precipitation region is seen to be approximately 3 deg/min, averaged over an interval of 1 hr. This figure may be compared to one of 3.8 deg/min, obtained by Wilson (1970), using data of Hargreaves (1968), for the eastward expansion velocity of substorms. Wilson also deduced a westward velocity of expansion, from the midnight sector, of 2 deg/min, and northward and southward velocities of 0.22 and 0.31 deg/min respectively.

The absorbing region also displays instantaneous structure on a smaller scale, as shown by Ecklund and Hargreaves (1968). A typical longitudinal correlation distance is ~750 km at night and about half that amount in daytime. Latitudinal correlation distances of 155 to 465 km were also observed.

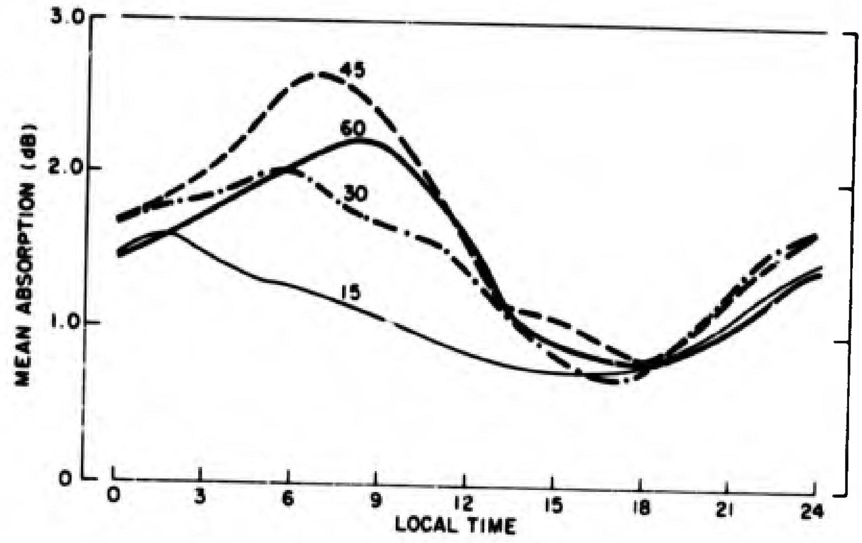

Figure 7. Local Time Dependence of Mean Absorption at Substorm Times Indicated (in minutes after substorm onset)

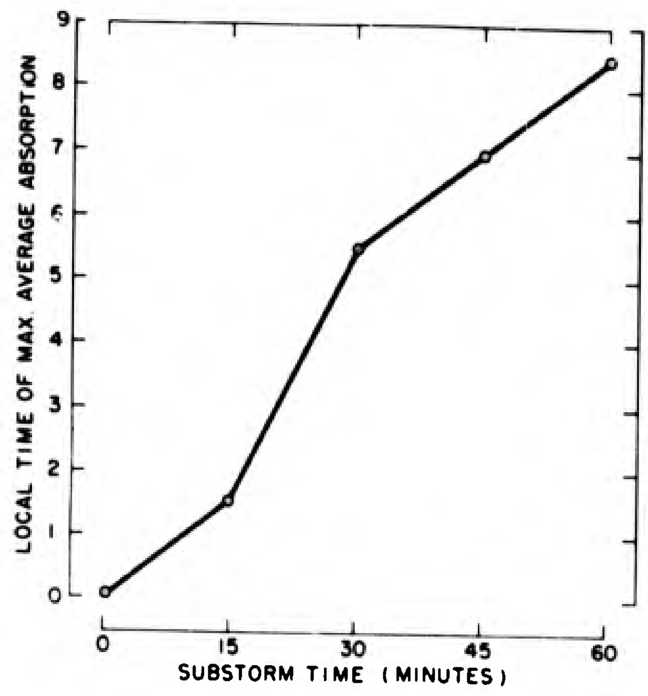

Figure 8. Local Time of Maximum Average Absorption as a Function of Substorm Time, Indicating Eastward Expansion of the Absorbing Region

14. RELATIONSHIP BETWEEN AURORAL ABSORPTION AND AE INDEX

Owing to the limited amount of data concerning the instantaneous spatial distribution of auroral absorption over the entire auroral oval, little can be inferred about the long term statistics of auroral absorption from this source alone. In order to establish some statistical occurrence relationships, it is convenient to use the auroral electrojet index (AE), which is known to be a good measure of substorm occurrence and intensity. The AE index is a measure of the non-rotationally symmetric component of the magnetic disturbance field.

The long term statistics of AE, over a 10.5 year interval, have been evaluated in terms of the probability distribution expressed as a function of solar activity, season and UT and are summarized in a separate report. In order to provide a quantitative relationship between auroral absorption and AE, a further analysis was undertaken. The data from the WDC report were again used, and the maximum absorption occurring during each individual substorm was plotted against the maximum hourly value of the AE index during the same period (usually 2 to 3 hr). A moderately good correlation was observed, with the following relation between the parameters being satisfied approximately:

$$(\text{Absorption})_{max} \sim (\text{AE})_{max} \times 0.008$$

where Absorption is measured in dB at 30 MHz, and AE is measured in gammas.

Since it might be expected that the total amount of energetic electron deposition would be a better measure of the substorm intensity, a crude parameter (AD) was devised, defined by

$$\text{AD} = (\text{Absorption})_{max} \times (\text{substorm duration}).$$

The substorm duration was taken to be that determined by the authors of the WDC report (Temporal Development of the Geophysical Distribution of Auroral Absorption for 30 Substorm Events in Each of IQSY (1964-1965) and IASY (1969), 1971). The parameter AD was then correlated against $(\text{AE})_{max}$, and a significant improvement in correlation was observed. Unfortunately, AE data for 1969 is not available, so that only 30 of the 60 substorms considered in the WDC report could be used in this particular study.

The results of the correlation study are illustrated in Figure 9, together with the least-mean-squared-fitted straight line, and the computed standard deviation. Note that the point indicated by a cross was omitted in the computations. The relationship between AD and $(\text{AE})_{max}$ was found to be

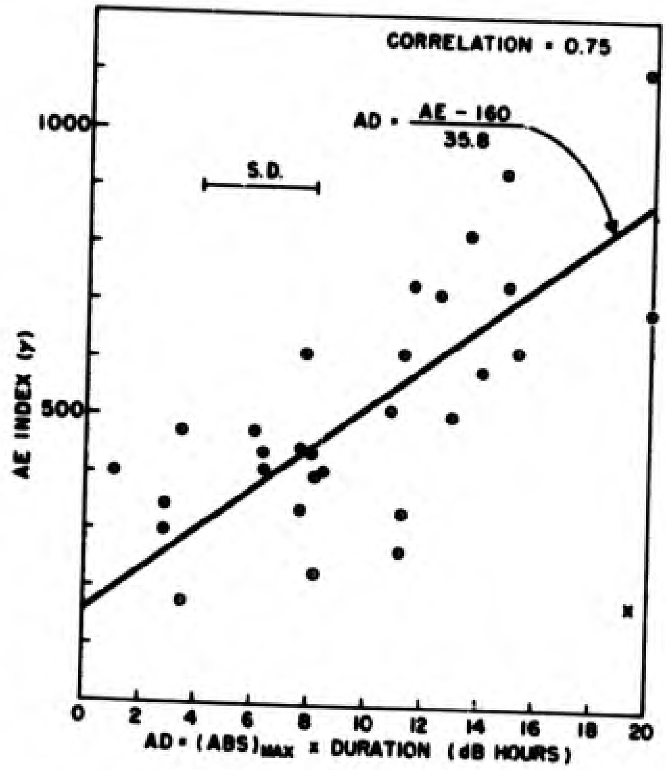

Figure 9. Substorm Absorption × Substorm Duration, Plotted Against Maximum Hourly AE Value During the Substorm

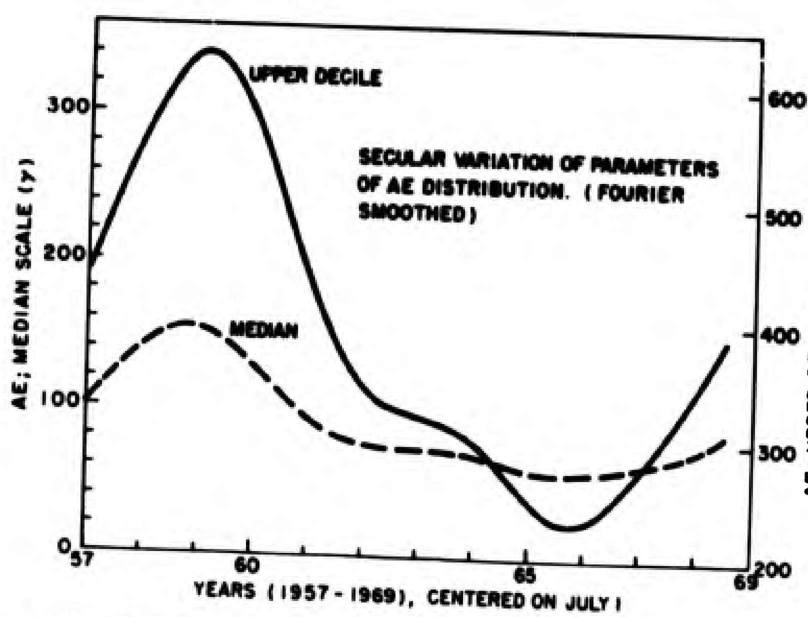

Figure 10. Median and Upper Deciles of Yearly AE Distributions (note different scales)

$$AD = \frac{(AE)_{max} - 160}{35.8} \pm 4.1$$

with units

AD (dB hours), and

AE (gammas) .

The correlation coefficient was 0.75. By this means, and making use of the statistical distributions of AE index during a substorm, it is possible to infer the long-term occurrence statistics of the maximum absorption during a substorm. Further, by making use of the statistical pattern of absorption during individual substorms, it is possible to translate the resultant information about the maximum absorption into the complete absorption sequence during a substorm, to within a moderate degree of accuracy. A more thorough treatment must await more complete data of the kind contained in the WDC report.

Having established the above relationship between the AE index and auroral absorption, it is of interest to make some semi-quantitative deductions about the long term behavior of the latter. Figure 10 shows the median and upper decile of the yearly AE distributions, plotted as a function of year. The curves have been smoothed by the application of a special numerical filter which has narrow response pass bands at the first three harmonics of the 11.5-year solar cycle Fourier expansion of the data. It is assumed that this figure represents approximately the secular variation of auroral substorm absorption. Note particularly the phase lag of about 1.5 years between these curves and a similar one for sunspot number, which minimizes in 1964.

15. CONCLUSIONS

From the analysis described herein, it is concluded that despite the apparent great variability in auroral absorption events, it is possible to model them in a manner which illuminates several notably regular features. Chief among these are the longitudinal motion displayed when substorm time is introduced as a parameter and the temporal variation in intensity with the phase of an individual substorm. Statistical relationships have been presented which reproduce these characteristics in a quantitative manner suitable for application to specific radio propagation problems. The use of the Auroral Electrojet index has been explored and found to be valuable in estimating features, such as long term trends, which cannot presently be accurately determined from riometer data. Work along these lines is continuing and will appear in further reports of this kind.

References

Arnoldy, R. L. (1971) Signature in the interplanetary medium for substorms J. Geophys. Res. 76:5189.

Cox, J.W. and Davies, K. (1954) Statistical studies of polar radio blackouts, Can. J. Phys. 32:743.

Driatsky, V. M. (1965) Study of the space and time distribution of auroral absorption according to observations of the riometer network in the arctic, Geomagnetism and Aeronomy 5:828.

Ecklund, W. L. and Hargreaves, J. K. (1968) Some measurements of auroral absorption structure over distances of about 300 km and of absorption correlation between conjugate regions, J. Atmos. Terr. Phys. 30:265.

Hargreaves, J.K. (1968) J. Atmos. Terr. Phys. 30:1461.

Hartz, T.R., Montbriand, L.E., and Vogan, E.L. (1963) A study of auroral absorption at 30 MHz, Can. J. Phys. 41:581.

Hook, J. L. (1968) Morphology of auroral zone radiowave absorption in the Alaska sector, J. Atmos. Terr. Phys. 30:1341.

Jelly, D.H. (1970) On the morphology of auroral absorption during substorms, Can. J. Phys. 48:335.

Khodzha-Alchmedov, Ch. L. (1965) Frequency dependence of ionospheric absorption at high latitudes, Geomagnetism and Aeronomy 5:58.

Rostoker, G. (1968) Macrostructure of geomagnetic bays, J. Geophys. Res. 73: 4217.

Shumilov, O.I. (1971) in Auroras, Collection of Articles No. 17, S.I. Isaye and Ya. I. Feldstein, Eds., Nauka, Moscow (1968), NASA Tech. Trans. (NASA TTF-637) (June 1971).

Temporal Development of the Geophysical Distribution of Auroral Absorption for 30 Substorm Events in Each of IQSY (1964-1965) and IASY (1969) (1971) Report UAG-16, World Data Center A, Boulder, Colorado.

Wilson, C.R. (1970) Auroral infrasonic and ionospheric absorption substorms, J. Atmos. Terr. Phys. 32:293.

Printed by
United States Air Force
L. G. Hanscom Field
Bedford, Massachusetts