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F-LACUNA EVENTS IN TERRE-ADELIE AND THEIR RELATIONSHIP WITH THE STATE OF THE IONOSPHERE

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Abstract—*F*-lacuna event is a typical phenomenon of the high latitude ionosphere occurring during summer days. It consists in a disappearance of echoes from the *F*-layer on ionograms and a simultaneous extra absorption of about 0.1 to 0.4 dB on 30 MHz cosmic waves. This paper, based on data from the Dumont d'Urville station, describes the properties of this phenomenon: correlation with magnetic activity, convection electric field, interplanetary magnetic field, absorption in the lower ionosphere and electron density in the *F*-layer. A tentative model of interpretation in terms of large scale electron density irregularities in the *F*-layer is suggested.

1. INTRODUCTION

In a previous paper (Vassal *et al.*, 1976), hereafter referred to as paper I, we have shown that the weak absorption events currently observed on riometer recordings at Dumont d'Urville station (66.6°S; 140.0°E; INLAT. $\Lambda = 81°$) could be divided into three homogeneous populations with apparently different origins. In this paper, we present the results of a detailed study of one of these populations, namely *F*-lacuna events, which consist in the simultaneous observation of *F*-lacunae on ionograms and of a weak absorption event on riometer recording.

After a morphological description of the phenomenon, we analyse, mainly from a statistical point of view, its relationships with the state of the ionosphere, magnetic activity and magnetospheric phenomena. In the last part a tentative model of the ionosphere is suggested for the interpretation of the observations.

2. DESCRIPTION OF THE PHENOMENON

2.1. *Lacunae and quasi-lacunae*

The main characteristics of ionograms recorded at Dumont d'Urville have been presented by Cartron (1962) and Cartron *et al.* (1972). They show typical features due to the location of the station very near the dip pole ($I = 89.5°$).

A phenomenon very common on ionograms from summer days has been discovered by Cartron (1962), further studied by Lebeau (1965) and called *F*-lacuna by Sylvain (1972). It is defined as the disappearance of the *F*-region echoes on the ionograms whereas normal echoes from the *E*-region remain visible. The missing traces concern an entire region, either the *F*1-region, the *F*2-region or the *F*-region as a whole (Fig. 1); we have thus distinguished between three types: *F*1-lacuna, *F*2-lacuna and total lacuna. Sometimes, traces are still present but much weaker than normal echoes; we refer to these cases as quasi-lacunae and again distinguish between the same three types.

The *F*-lacuna phenomenon has been observed only at polar stations during summer days: by Olesen, in relation with slant-*E*s at Godhavn and Thule (Olesen and Rybner, 1958; Olesen, 1972); by King at Scott Base and Cape Hallett (King and Savage, 1973); by Hagg (private communication) at Resolute Bay.

Since the Warsaw 1972 General Assembly of URSI the name *F*-lacuna has been officially recognized and the presence of the phenomenon is now denoted by the descriptive letter *Y* on routine data reduction sheets (Piggott and Rawer, 1972). It must be noted, however, that before an international rule was settled, this puzzling phenomenon had been denoted, according to the observer, by the international descriptive symbols *A*, *R*, *N* or even *B*. A study using monthly tables of data or even *f*-plots is thus impossible and one needs to go back to the ionograms themselves.

2.2 *Observations of riometer data*; F-*lacuna events*

Riometer data from Dumont d'Urville show a very common type of absorption event which consists in an irregular and slowly varying absorption of 0.2 to 1.5 dB, lasting from a few minutes up to

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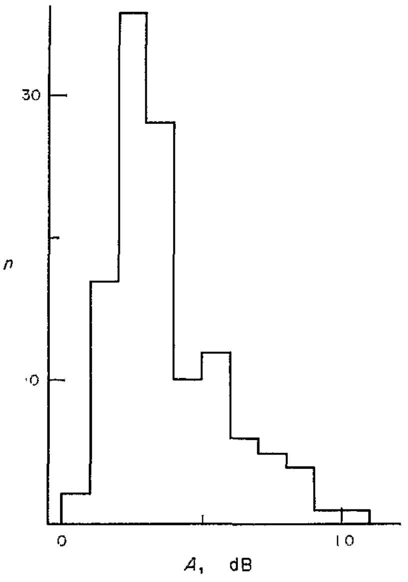


FIG. 2. HISTOGRAM OF THE *F*-LACUNA EVENTS PEAK ABSORPTION FOR THE PERIOD SEPTEMBER 1966—APRIL 1967.

several hours. We have called this phenomenon type *M* absorption event (Paper I).

F-lacunae show a remarkable simultaneity of occurrence with such events, only 1.8% of *F*-lacunae appearing without an associated absorption event. Moreover, a study of individual cases showed that total and *F*1-lacunae are closely related in time to the maxima of absorption (Paper I, Fig. 6). Neglecting the very few cases without coincidence, it seems clear that *F*-lacuna on ionograms and simultaneous type *M* absorption events are two appearances of the same physical phenomenon which we have called the *F*-lacuna event. Figure 2 gives the distribution of the values of the maximum of extra absorption on 30 MHz riometer for all *F*-lacuna events from September 1966 to April 1967. Most events show an extra absorption with a peak between 0.2 and 0.4 dB, and the number of events with higher absorption decreases rapidly.

F-lacuna events can be identified unambiguously only by observation of *F*-lacunae on ionograms. A comparison of different sampling rates has shown that 15 min soundings are sufficient to allow the identification of all events. However this sampling is still too low a rate to get a good idea of the temporal evolution.

2.3. *Influence of the characteristics of the equipment*

Three soundings at one-minute intervals, with changes in the gain of the receiver, are made routinely each hour and this enabled us to look for a possible influence of the receiver sensitivity on the appearance of *F*-lacunae. An increase of the gain by about 10 dB may lead to one of the following modifications on the ionogram:

— reappearance of all traces
— change from a total lacuna to a *F*1 or *F*2 lacuna
— change from a lacuna to a quasi-lacuna of the same type.

Change from the low gain to the high gain (25 dB above) entails disappearance of 25% of the lacunae and change of type in 30% of the cases.

Thus, the occurrence of the phenomenon depends on the characteristics of the equipment: gain, but also power at the emission and antenna directivity. As ionosondes differ from station to station, one needs to take precautions when comparing data from several stations. Nevertheless, a change of the sounder at the Dumont d'Urville station in August 1966 (change in the gain, the power at the emission and the antenna directivity) was followed by no discontinuity in occurrence curves, thus indicating that the differences among sounders do not necessarily prevent comparative studies. As a consequence, however, in all statistical studies presented below, *F*-lacunae have been determined by inspection of medium gain ionograms.

2.4. *Occurrence*

F-lacuna events occur only from September to April with a maximum in November (Fig. 3). From October to February, they occur on more than one half of the days, and are thus a typical feature of the summer ionosphere at these latitudes.

As to the daily variation, we have analysed separately the properties of the three types of *F*-lacunae (Fig. 4). The shape of each histogram is typical, and independant of the year. *F*1 and total lacunae exhibit unimodal distribution with a well-defined maximum of occurrence near 10.00 L.T.; the distribution of total lacunae has a greater dispersion. The shape of the distribution of *F*2-lacunae is quite different, much more irregular and dispersed, with two main maxima of occurrence earlier and later than those of other types. It has been shown (Paper I) that monthly histograms have the same typical shapes.

We have looked for a long term variation of *F*-lacunae occurrence on data from 1958 to 1969. We observe a maximum of occurrence in 1961–62 and a minimum in 1964–65. These variations are not in agreement with the solar cycle, but quite similar to those of the percentage of ionograms for

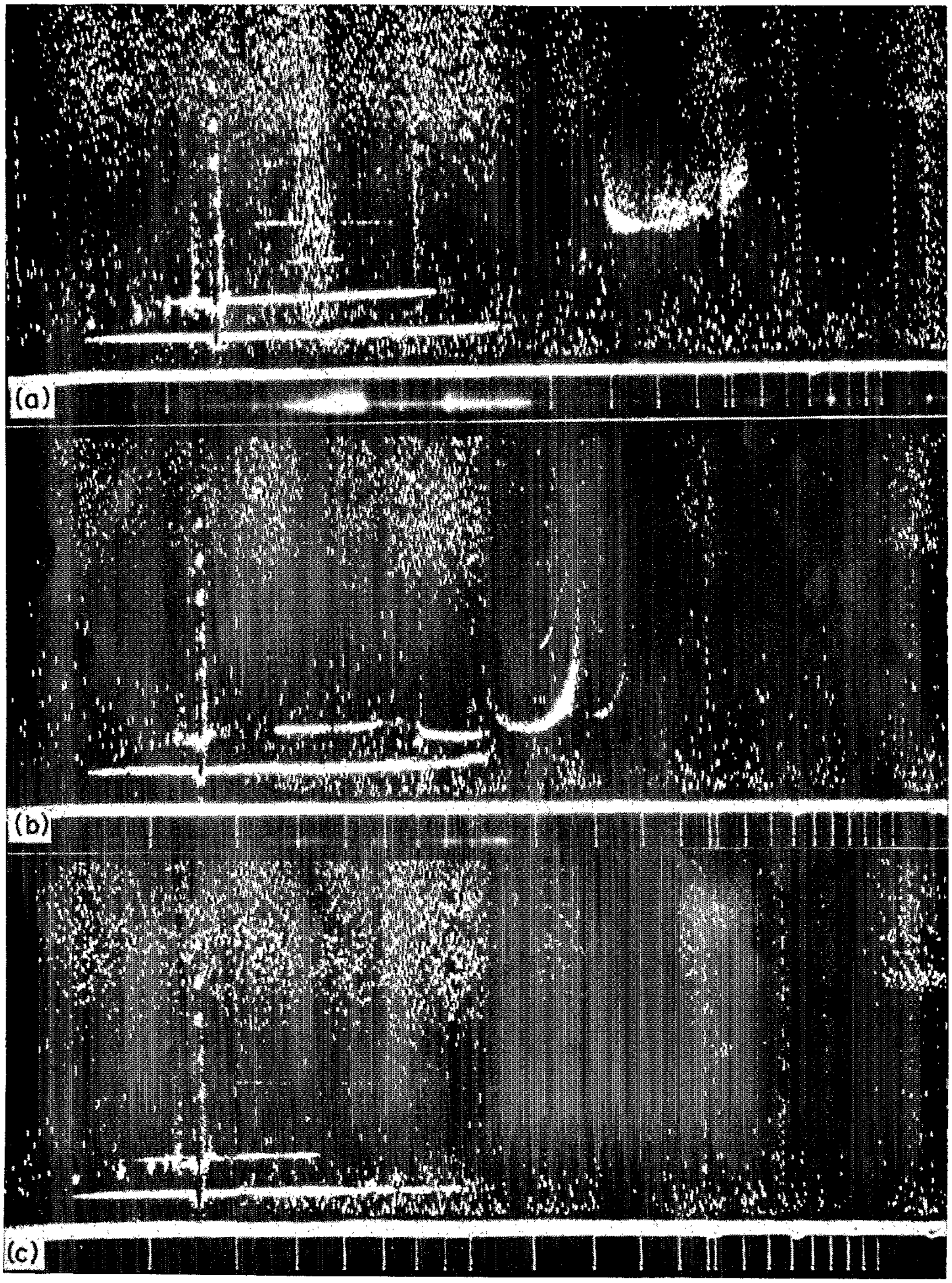


FIG. 1. TYPICAL IONOGRAMS: a) *F*1-lacuna
b) *F*2-lacuna
c) total lacuna.

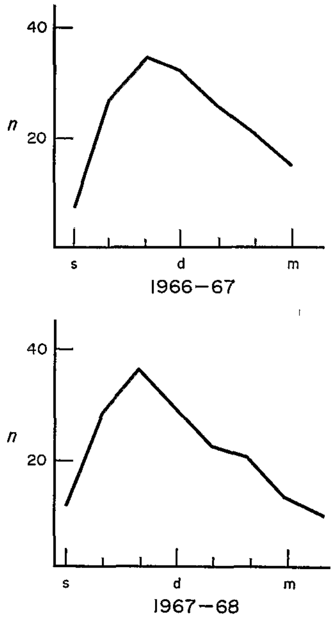


FIG. 3. HISTOGRAMS OF OCCURRENCE OF *F*-LACUNA EVENTS.

which the *f*min parameter is above the threshold.

The proportion of a given type of *F*-lacunae may vary strongly from one month to another or from one year to another. These changes, however, appear to be without any seasonal or long term regular variation.

2.5. *F-lacunae and slant* Es

Slant *Es* trace is defined (Piggott and Rawer, 1972) as a diffuse *Es* trace which rises steadily with frequency and emerges from the high frequency end of a normal or sporadic *E*-trace. It occurs, with the same morphological aspect, in equatorial, auroral and polar regions but its properties, summarized in Table 1, are not the same in these regions. Slant *ES* is a non-blanketing sporadic *E* and is sensitive to the equipment performance. It is admittedly due to obliquely propagating waves.

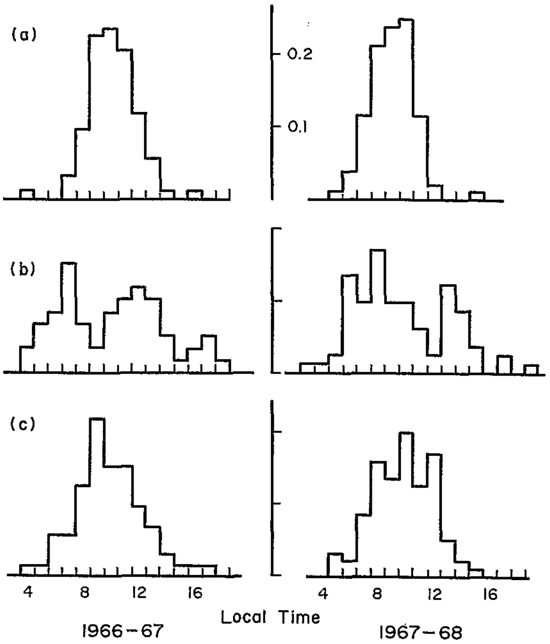


FIG. 4. NORMALIZED HISTOGRAMS OF OCCURRENCE OF *F*-LACUNAE.

(a) *F*1-lacunae; (b) *F*2-lacunae; (c) Total Lacunae.

Olesen (Olesen and Rybner, 1958; Olesen, 1972) studying the occurrence and properties of slant *Es* at high latitudes (Thule, Godhavn and Narssarssuak) noted that the phenomenon was often accompanied by others considered as secondary characteristics. This led him to the concept of slant-*E* condition (*SEC*) for which slant *Es* traces are just an identification criterion among others. The most reliable criterion of *SEC*, according to Olesen, is what he called *E–F* height gap which consists in disappearance of echoes from the upper *E* and lower *F*1 region or higher. It is clear that *F*1 and total lacunae enter this definition. But an *E-F* height gap constitutes a *F*-lacuna only if the whole *F*1-layer is affected; this is not always the case (Fig. 5). The relation between *F*-lacuna and slant *Es* has

TABLE 1. PROPERTIES OF SLANT *Es*

Region	Influence of equipment characteristics	Diurnal variation	Seasonal variation	Correlation with magnetic activity
Equatorial	strong	day event	?	correlated with magnetic bays
Auroral	strong	night event	winter maximum	correlated with magnetic bays
Polar	strong	day event	summer maximum	correlated to day activity.

also been mentioned by King and Savage (1973).

We have investigated statistically the relationship between both phenomena. Slant *Es* at Dumont d'Urville is a rare phenomenon. For the two summers 1966–67 and 1967–68 it appears on only 106, 15 min ionograms.

For a given hourly period k, let n_k (F_i) and n_k (Es) be the respective numbers of occurrence of *F*-lacunae (type i) and slant *Es*; also let N_k be the total number of ionograms for the period. If simultaneous occurrence of both phenomena were randomly distributed, their expected number of coincidences would be $\tilde{n}_k = n_k(F_i)n_k(Es)/N_k$. Comparing it with the effective number of coincidences, shows that slant *Es* and *F*2-lacunae can be considered as statistically independant but that slant *Es* on the one hand, *F*1 and total lacunae on the other hand are strongly correlated. Moreover, it appears that 94% of slant *Es'* occur during a *F*-lacuna event, 3.5% during a type *M* event (with no observation of lacuna on 15 min ionograms during it) and 2.5% only are observed without a concomitant absorption event.

These results lead us to the following conclusions:

— slant *Es* in polar regions is a signature of the ionospheric phenomenon which also produces *F*-lacunae and associated type *M* absorption events

— as indicated by correlation with *F*1 and total lacunae, but not with *F*2-lacunae, slant *Es* must be due to a perturbation in the *F*1-layer and upper part of the *E*-layer.

2.6. *Sequences of ionograms*

Ionograms taken on a routine basis are well adapted to statistical studies, but their sampling rate (generally 15 min) is not adapted to a precise study of the temporal behaviour of *F*-lacunae events. Figure 6 shows a sequence of ionograms taken at one minute intervals during part of a lacuna event (December 4, 1975 from 9 h 10 to 9 h 33 L.T.; 0 h 10 to 0 h 33 U.T.).

The following features, typical of all or most of studied cases of *F*-lacuna events, appear:

— a lacuna appears or disappears very quickly; (traces from the *F*1 layer are present at 00.20, not at 00.19 and 00.21)

— the type of lacuna changes during the event from one type to another (*F*2 lacuna at 00.20; total from 00.21 to 00.24; *F*1 lacuna from 00.25 to 00.30)

— the *F*2-layer critical frequency is well below its average value for the season and time of observation (below 5.5 MHz instead of about 6 MHz)

— both the *F*1-layer and *F*2-layer critical frequencies do not change markedly before and after a lacuna

— the *X* trace of the *F*2-layer is not present

— there are almost no double echoes from the *F*-region

— the *F*2-layer virtual height *h'F*2 sometimes increases strongly just before and after occurrence of a *F*2-lacuna (400 km at 00.11; 500 km at 00.14; *F*2-lacuna at 00.15).

The last two points are in favour of the assumption of an oblique propagation of the waves, which implies horizontal gradients in the ionosphere.

2.7. F2-*lacuna or* G *conditions*?

The *G* condition is defined as a decrease in the *F*2-layer electron density until the *F*2-layer critical frequency becomes lower than the *F*1-layer critical frequency. As observed on bottomside ionograms, it looks similar to the *F*2-lacuna as defined by us. Hence the question whether *F*2-lacuna is a different phenomenon needs to be studied in detail.

Some of the characteristics of *F*2-lacunae seem difficult to explain in terms of the *G*-condition.

When considering ionograms at different gains at one minute intervals, it often happens that a *F*2-lacuna appears at higher gain as a quasi-lacuna and it is then possible to observe that *foF*2 is still higher than *foF*1.

Additional evidence is given by examination of topside ionograms. *G*-conditions associated with proton flares have been observed on topside ionograms by Herzberg and Nelms (1969). It has also been shown that *G*-conditions occur at high latitudes even during magnetically quiet times (Herzberg, Nelms and Dyson, 1969). In all cases, the *G*-condition produces a stratification in the topside ionosphere giving typical loops at the high frequency end of the traces. Herzberg *et al.* (1969 have shown that:

— The *G*-condition is a rare phenomenon

— there is, on both sides of the region where it occurs, a spatial variation of *foF*2;

— it does not show any dependance on L.T. or U.T.

On the contrary, *F*2-lacunae, as observed on Dumont d'Urville bottomside ionograms:

— are common on summer days

— may occur without any appreciable change of *foF*2 before or after the event

— show a typical dependance on L.T.

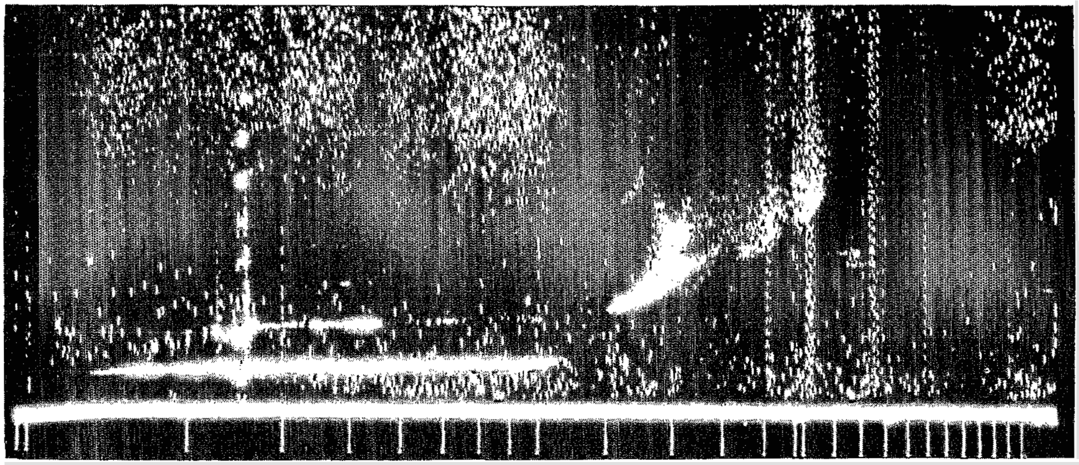
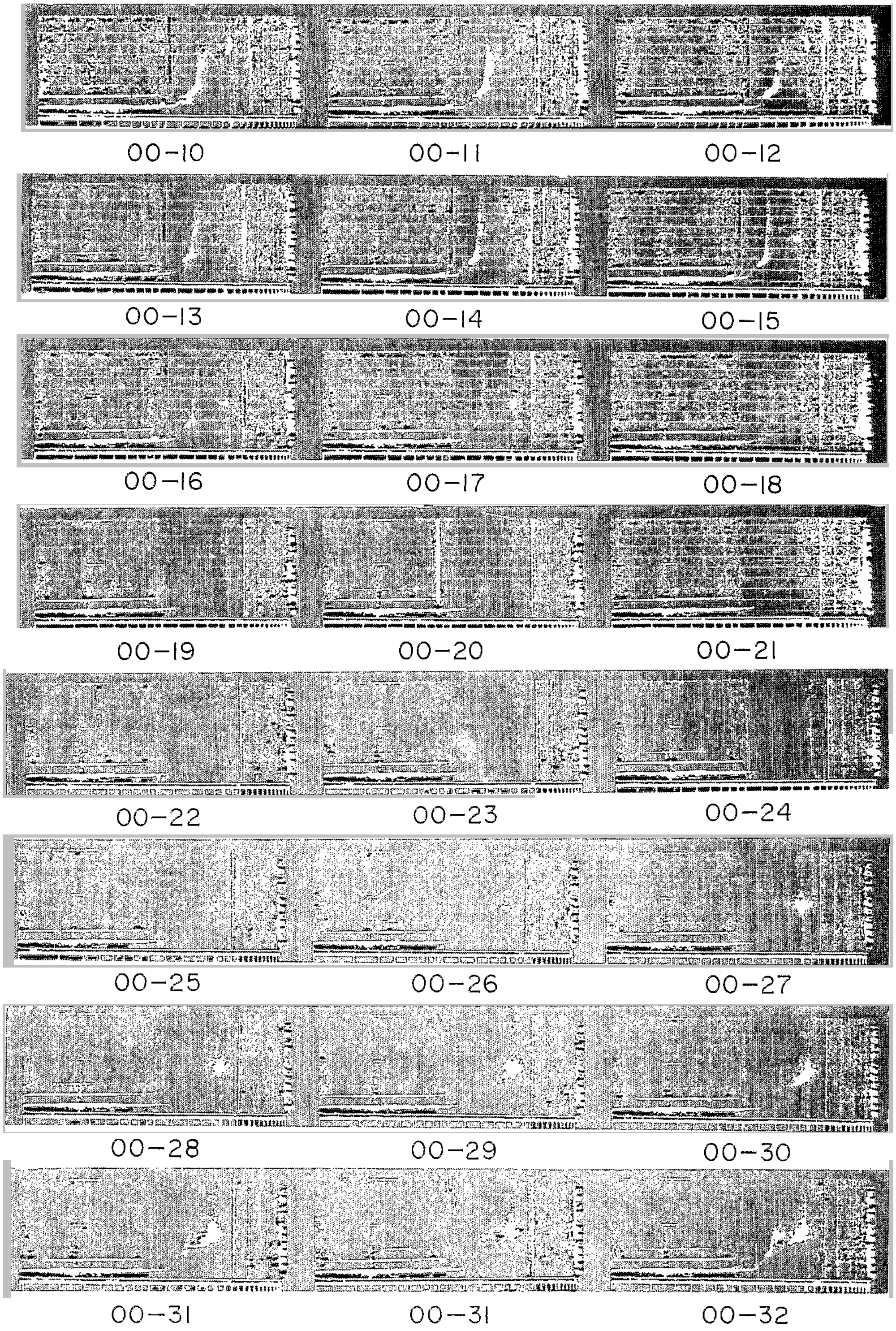


FIG. 5. IONOGRAM SHOWING A SEC (SLANT-*E* CONDITION) NOT CORRESPONDING TO A *F*-LACUNA (2/9/73 21 h 15).



00-10 00-11 00-12

00-13 00-14 00-15

00-16 00-17 00-18

00-19 00-20 00-21

00-22 00-23 00-24

00-25 00-26 00-27

00-28 00-29 00-30

00-31 00-31 00-32

FIG. 6. SEQUENCE OF ONE-MIN IONOGRAMS DURING PART OF A *F*-LACUNA EVENT.
(Times are indicated in U.T.).

Preliminary observations of ISIS 2 passes near Dumont d'Urville at times of *F*2-lacunae have not revealed the presence of *G*-conditions. Therefore, it seems justified that we consider the *F*2-lacuna as different from a *G*-condition.

In any case, we have shown that disappearance of *F*2-layer traces on ionograms of Dumont d'Urville are one of the manifestations of the *F*-lacuna type *M* events. Even if it were only a *G*-condition, i.e. a decrease of *foF*2 below *foF*1, it should be explained as a part of the complete phenomenon and it is therefore convenient to call it *F*2-lacuna.

3. STATISTICAL STUDY

3.1. *Correlation with magnetic activity*

Occurrence of *F*-lacunae at Dumont d'Urville shows the same diurnal and estival characters as local magnetic activity (Lebeau, 1965), with a maximum between local noon and magnetic noon.

3.1.1. *Worldwide activity*. The three-hour long intervals of the period September 1966–February 1967 have been arranged into five classes according to their magnetic activity defined by using the $3\,K_m$ index (Mayaud, 1968) ($3\,K_m = (0,1)$; $(2,3)$; $(4,5)$; $(6–8)$; $(\geqslant 9)$). For each type of *F*-lacuna, and each class of activity, we have calculated the number of three-hour intervals during which at least one 15 min ionogram exhibits a lacuna of the considered type. Each class of activity is thus characterized by the ratio ρ of the number of these intervals to its total number of intervals. This analysis (Fig. 7) shows that *F*2 and total lacunae are postively correlated to worldwide magnetic activity. Concerning *F*1-lacunae, there appears to be an optimum level of the intensity of the magnetic activity with a positive correlation at lower activities and a negative correlation at higher level.

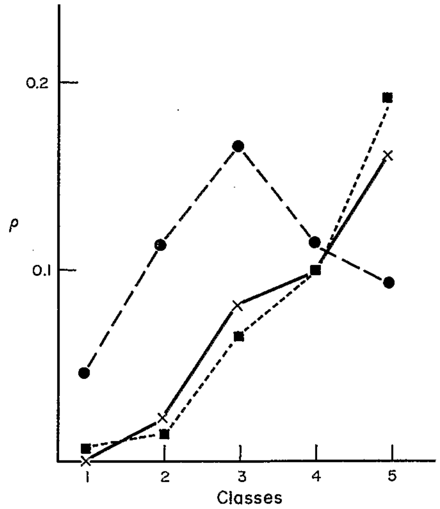


FIG. 7. CORRELATION OF *F*-LACUNAE WITH WORLD MAGNETIC ACTIVITY, *F*1-LACUNAE (FULL CORCLES AND DASHED LINE): *F*2-LACUNAE (FULL SQUARES AND DOTTED LINES): TOTAL LACUNAE (ASTERISKS AND FULL LINES). (See text for description of the method.)

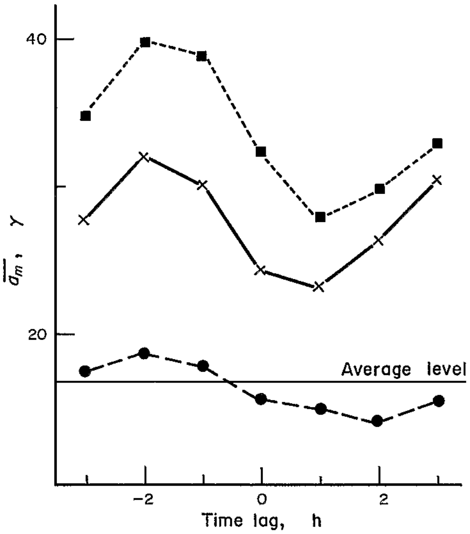


FIG. 8. APPLICATION OF CHREE'S METHOD. (Same notation as Fig. 7.)

To look more precisely for a possible temporal correlation, we have applied Chree's method as follows to the period October–December 1966. Let $\{S_i;\ i=1,\ N\}$ be the set of the three-hour long intervals of the period. To study *F*-lacunae of the type $j (j=1,3)$ we consider the function $A_j(S_i)$ defined as:

$$A_j(S_i)=\begin{cases}1 & \text{if a lacuna of type } j \text{ occurs on at least} \\ & \text{one of the 15 min ionograms of } S_i \\ 0 & \text{otherwise.}\end{cases}$$

Each interval is also characterized by the value of the a_m magnetic activity index (Mayaud, 1968). We then compute:

$$I_j(p)=\frac{1}{N}\sum_{i=1}^{N} a_m(S_{i+p})A_j(S_i)$$

$$p=0, \pm 1, \pm 2, \ldots$$

Results are plotted on Fig. 8. The fluctuations are smaller than the standard deviation of a_m during the period, showing no significant temporal correlation. Nevertheless, curves related to *F*2 and total lacunae are well above the average level of a_m, confirming that these types of lacunae occur

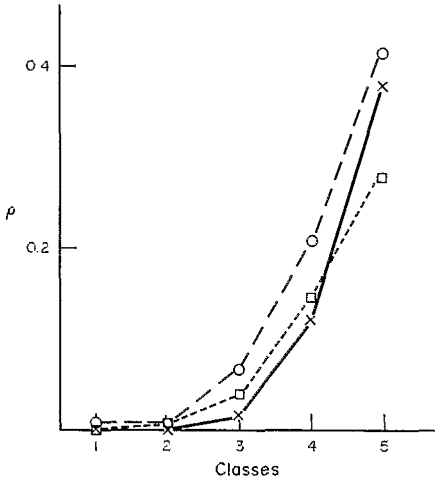


Fig. 9. Correlation of F-lacunae with local magnetic activity.
(Same notations as Fig. 7.)

preferentially during periods of relatively high activity. The opposite behaviour of $F1$-lacunae is quite clear.

3.1.2. *Local activity*. The same analysis has been made with indices of local magnetic activity. Analysis by classes of increasing magnetic activity, with K index (Fig. 9) shows that the three types of F-lacunae have a strong positive correlation with local magnetic activity. This result is confirmed by Chree's method (Fig. 10): all types of F-lacunae are accompanied by a maximum of local magnetic activity with no time lag.

3.1.3. *Auroral activity*. The same analysis was performed, using the hourly averages of the AE index (Davis and Sugiura, 1966) and showed no significant correlation between F-lacuna events and auroral activity. Let us mention, however, that an AE index is mainly influenced by the situation on the night sector whereas F-lacuna is a daytime phenomenon, and that this index is computed from data of stations in the northern hemisphere.

3.2. *Correlations with ionospheric parameters*

In order to determine the physical mechanisms involved in the F-lacuna phenomenon, we have looked for simultaneous modifications of the ionosphere.

The main difficulty is due to the fact that occurrence of F-lacunae makes it impossible to determine from the ionograms most of the characteristic parameters of the ionosphere such as $foF2$ or $h'F$. The best we can expect is to find, relative to an average behaviour, a change in the evolution of these parameters in the hours preceding or following the events. As the level of all these parameters can vary markedly from one day to another, such a study can be made only statistically.

To get significant results, the period of study must be as long as possible. But it has also to be short enough to avoid the inconvenience of too strong seasonal variations. A three-month long period appears to be a reasonable compromise.

All the days of the period under consideration (November 1966–January 1967) have been classified into several groups; all days without occurrence of F-lacunae composed the reference population; another population is made up of days during which only $F1$-lacunae occur; days presenting $F2$-lacunae and total lacunae constitute the two other populations but unfortunately have many days in common.

In the case of our study, the sample size is highly variable from one hour to another and, due to the

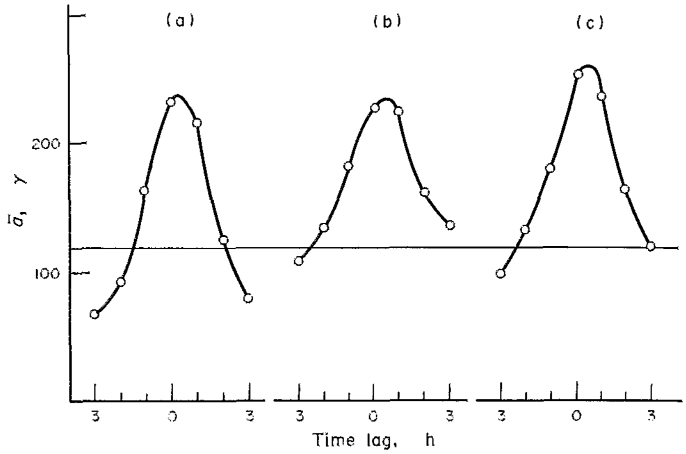


Fig. 10. Cree's method applied to local activity. (a) $F1$-lacunae; (b) $F2$-lacunae; (c) Total lacunae.

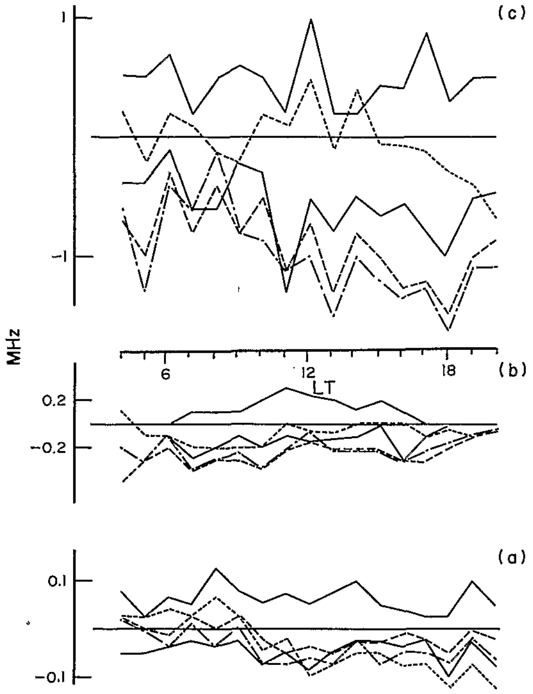


FIG. 11. RELATION OF *F*-LACUNAE WITH (a) *foE*; (b) *foF*1; (c) *foF*2.

Median of the reference population is taken as axis. Full lines delimit the interquartile range. Median of Population 1 (days with only *F*1-lacunae) is given by dotted line. Median of Population 2 (days with *F*2-lacunae) is given by dashed line. Median of Population 3 (days with total lacunae) is given by dots and dashes.

great variability of the ionosphere, some values of a parameter may be far from the average, and able to bias it in the case of a small size sample; for some parameters it is useful, in order to increase the size of the sample, to take advantage of ordinal information such as *f*min < (threshold) or *foF*2 > (maximum used frequency). For these reasons we describe the average behaviour of a parameter by its sample median and its variability by the interquartile range.

What we have to do is to compare the daily variations of ionospheric parameters in the reference population to that of the other populations. In fact, the interesting point is not the difference of behaviour at a particular time but the overall difference observed on all local times of occurrence of the events. But, data coming from different times of the same day are correlated in an unknown way; it is thus practically impossible to aggregate the results in a single test. This is why we consider the behaviour of a studied population, relative to a given parameter, as significantly different from that of the reference population if the daily median of this parameter is almost consistantly outside the reference population interquartile range. Individual tests at each time may help to support the observed differences.

3.2.1. *Electron density*. The method described in the previous paragraph has been applied to the three critical frequencies *foE*, *foF*1 and *foF*2 and gives the following results (Fig. 11):

—with the precision inherent to ionograms, the behaviour of the *E*-layer critical frequency is not statistically different during days with *F*-lacunae

—days during which *F*2 or total lacunae occur have a statistically lower value of *foF*2 (by 1 MHz) and *foF*1 (≃0.2 MHz)

—days during which only *F*1-lacunae occur present an unaffected *foF*2 and a lower *foF*1 during morning hours, i.e. mainly before lacunae occurrence.

3.2.2. *Virtual heights* (Fig. 12). The virtual height of the *E*-layer is always between 95 and 105 km. With the precision of 5 km on the data, we cannot expect significant differences. We have thus restricted our analysis to *h'F* and *h'F*2. No particular behaviour is apparent on curves relative to *h'F*. For

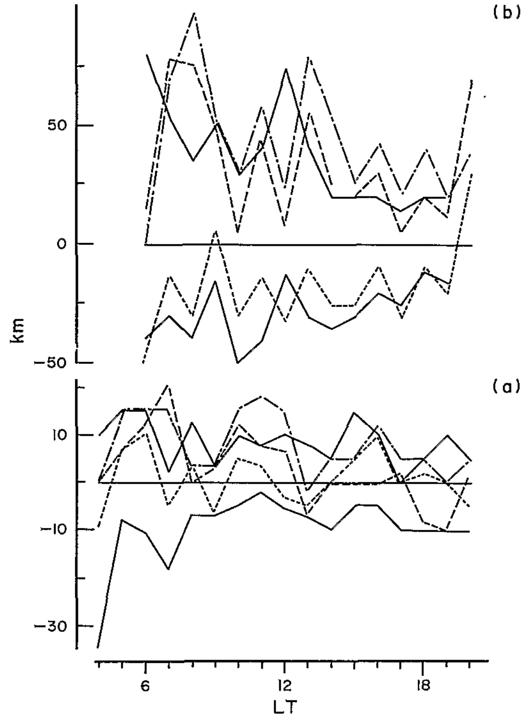


FIG. 12. RELATION OF *F*-LACUNAE WITH (a) *h'F*; (b) *h'F*2. (Same notations as Fig. 11.)

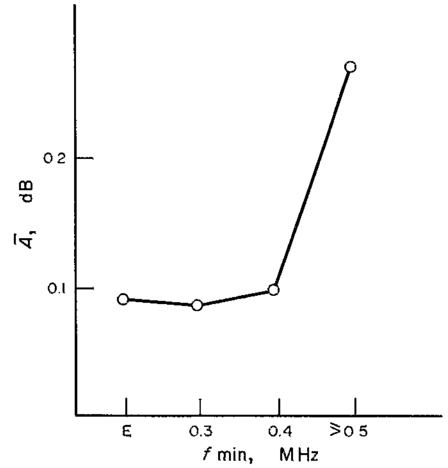


Fig. 13. Average value of extra absorption for classes of increasing $f$min.

$h'F2$, the median is higher and the dispersion greater on days with $F2$ or total lacunae. The lower value on days with $F1$-lacunae does not appear to be statistically significant.

3.2.3. *Relation with absorption in the lower ionosphere.* To look for a possible relation between occurrence of F-lacuna events and absorption in the lower ionosphere, as indicated by $f$min, we have grouped the hourly intervals for the period November 1966—January 1967 between 0800 and 1400 L.T. into four classes according to increasing values of $f$min, and computed for each class the ratio of the number of intervals belonging to an F-lacuna event to the total number of intervals in the class (Table 2).

A χ^2 test shows that there is no relation between $f$min and the occurrence of F-lacuna events as long as we limit ourselves to values of $f$min less than 0.5 MHz.

On Fig. 13 is plotted the average value $\bar{A}$ of extra absorption from 30 MHz riometer versus $f$min. Again there is no relation for $f$min below 0.5 MHz. In fact, values of $f$min above 0.5 MHz are very rare, representing less than 8% of the cases, and are not of any help to the understanding of the phenomenon. It can thus be concluded that F-lacuna events are not produced by an increase of the absorption in the lower ionosphere. But, when such an event occurs, its appearance as a F-lacuna on the ionograms is favoured by an increase of the absorption in the lower ionosphere.

3.2.4. F-*lacunae and spread*-F. We have looked for a possible correlation between F-lacunae and spread F, this latter phenomenon indicating the presence of small-scale irregularities of the electron density.

In a two month period (January–February 1967) we have graded the days into two groups: those presenting F-lacuna events and the others. We have taken the effect of spread F on $h'F$ as representative of irregularities in the lower part of the F-layer, its effect on $foF2$ as representative of irregularities in the $F2$-layer. In both cases, we consider that spread F is significant when it causes an uncertainty of more than ±2% (parameter qualified by U or without being given any numerical value (Piggott and Rawer, 1972). We compute, as a function of local time, the ratio of the number of ionograms with spread F conditions to the total number. We find that days without lacunae present a higher ratio on 16 occasions (and one case of equality) among 24 relative to $h'F$ and on 18 occasions among 24 relative to $foF2$. A Sign Test (Van der Waerden, 1967) indicates that these differences are significant with a test size of respectively 2.5% ($h'F$) and 1% ($foF2$). We can thus conclude that F-lacunae and spread F are either statistically independant or perhaps only slightly anticorrelated.

3.3. *Relation with the convection electric field*

Using results from a compaign of electric field measurements on balloons made in Terre Adelie in

Table 2. Relation between F-lacunae and absorption in the lower ionosphere as deduced from $f$min.

$F_{\min}$ MHz	Nb of intervals with F-lacunae events K_i	Other intervals $N_i - K_i$	Total Nb of intervals N_i	ρ_i	χ_i^2
≤0.25	41	86	127	0.32	2.38
0.3	32	46	78	0.41	1.30
0.4	110	178	288	0.38	0.05
≥0.5	21	10	31	0.68	10.6

$$\rho_i = \frac{K_1}{N_i} \quad {\chi_i}^2 = \frac{(K_i - N_i P)^2}{N_i p(1-p)} = \frac{N_i(\rho_i - p)^2}{p(1-p)} \; p = \frac{\sum k_i}{\sum N_i}$$

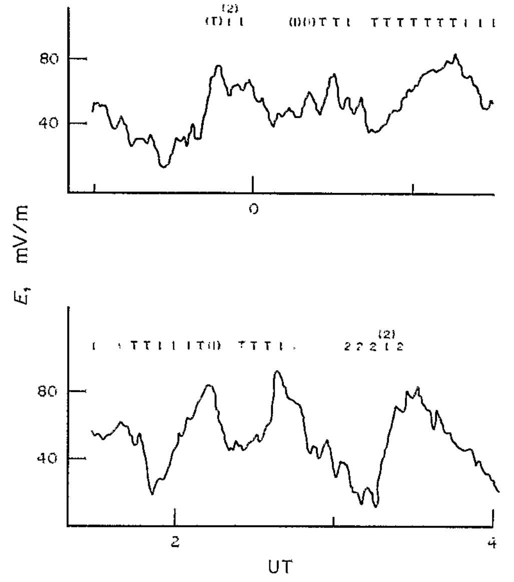


FIG. 14. MEASURED IONOSPHERIC HORIZONTAL ELECTRIC FIELD AND OCCURRENCE OF LACUNAE OBSERVED ON FIVE MINUTES IONOGRAMS.

January 28 1973 23.00 U.T.—January 29 1973 04.00 U.T.

January 1973, we have made a preliminary analysis of the relation between *F*-lacunae occurrence and electric field. One observes that *F*-lacunae generally occur during periods of relatively strong electric field (Fig. 14). But there is no threshold effect: it is possible to observe lacunae with a low electric field, as well as very strong electric field not accompanied by lacunae. Clearly, these investigations need to be further developed.

3.4. *Relation with the interplanetary magnetic field*

It is now well known that the interplanetary magnetic field is a key-parameter for the behaviour of polar ionosphere (Friss-Christensen *et al.*, 1972; Berthelier and Guerin, 1973; Pike *et al.*, 1974).

Using data for the period October 1966–February 1967, we have studied the effect of each component of the IMF on both the occurrence and the time of occurrence of each type of *F*-lacunae. Significance of results has been assessed by the use of the χ^2 test. Results are as follows:

— the B_X component does not have any perceptible effect

—occurrence of lacunae is favoured by high values of the east–west B_Y component, *F*1-lacunae by high westward component, *F*2-lacunae by high eastward component and total lacunae by high values of either eastward or westward component.

— the major effect of the north–south component Bz is on *F*2-lacunae. The peak occurrence in the morning is favoured by a southward IMF, the peak occurrence in the afternoon by a northward IMF (Fig. 15).

4. DISCUSSION

After a detailed description of the properties of *F*-lacuna events, we shall briefly discuss some of the hypothesis which can be made to interpret this phenomenon. Any complete interpretation must provide an answer to the two following questions: firstly, what are the perturbations of the ionosphere which can explain the effects observed on ionograms and riometer; and secondly, what physical processes cause these perturbations, and how do they relate to the behaviour of the high latitude ionosphere? These problems are discussed separately in the following subsections.

4.1. *Model ionosphere*

F-lacunae appear to be due to a decrease, in a broad frequency range, of *H.F.* waves coming back to the sounder, such that the signal is below the threshold of the equipment. Since a 25 dB increase of the receiver gain lessens the number of *F*-lacunae by only 25%, we may assess the necessary weakening of the waves to at least about 30 dB for frequencies of the order of 4 MHz. This effect could be attributed to absorption through collisions in the medium, strong diffusion or deviation of the waves from their normal path.

If we suppose collisional absorption, with a f^{-2} dependance, 30 dB extra absorption at 4 MHz would correspond to 0.8 dB at 30 MHz, an absorption significantly stronger than that observed on riometer data (0.2 to 0.4 dB). Moreover, such an

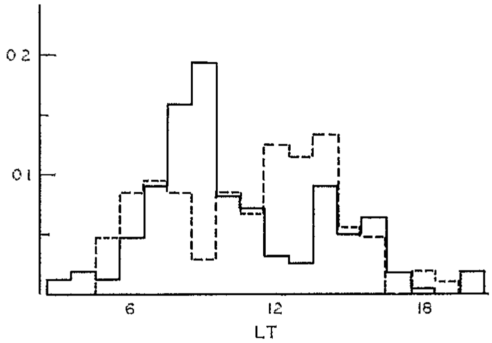


FIG. 15. NORMALIZED HISTOGRAMS OF OCCURRENCE OF *F*2-LACUNAE (1966–67 SUMMER) FOR NEGATIVE (SOUTHWARD) INTERPLANETARY MAGNETIC FIELD (FULL LINE) AND POSITIVE (NORTHWARD) INTERPLANETARY MAGNETIC FIELD (DASHED LINE).

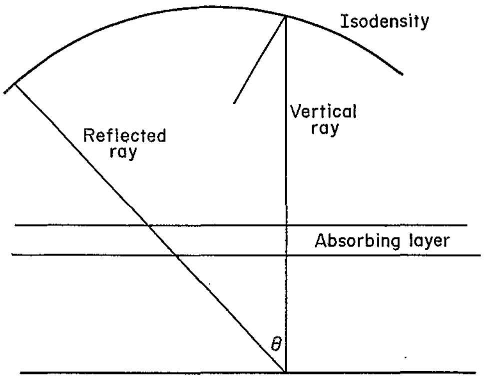


FIG. 16. SCHEMATIC MODEL OF THE PERTURBED IONOSPHERE EXPLAINING *F*-LACUNA EVENT.

absorption cannot be caused in the lower ionosphere, where it would be accompanied by an increase of *f*min which is not observed, nor in the *E* and *F*1-layer where absorption varies as the square of the electron density, a quantity which has statistically been shown to decrease the days of lacuna occurrence. It appears therefore that *F*-lacunae do not originate from an increase of collisional absorption in the lower ionosphere.

In several recent papers (Olesen, 1972; Primdhal *et al.*, 1974; Olesen *et al.*, 1975; Primdhal *et al.*, 1975) the authors have associated slant-*Es* and *F*1-lacuna events and have based their interpretation on diffusion by small scale field-aligned irregularities due to the two-stream instability of the Farley–Büneman type. It seems to us that this explanation for the generation of *F*1-lacunae is in disagreement with the two observations reported above, namely, the statistical tendency towards an anticorrelation of spread-*F* and lacunae, and the absence of any threshold on the ionospheric electric field as obtained by balloon measurements. According to Olesen (private communication) *F*2-lacunae would be simply the result of a *G*-condition. Owing to the close correlation between *F*1 and *F*2-lacunae and considering all the arguments cited in section 2.7, we cannot agree with this hypothesis. Thus, the diffusion by small scale irregularities does not offer a satisfactory explanation for the origin of *F*-lacuna events.

A tentative interpretation of *F*-lacuna events by a model of large scale irregularities of the electron density in the *F*-layer has been presented by Sylvain (1972). In such a model, lacunae and quasi-lacunae result from the fact that waves coming back to the sounder do not propagate vertically but at an angle θ (Fig. 16). Let Av be the attenuation of waves for vertical propagation. For an angle θ, it becomes $A(\theta)=(Av/\cos\theta)-20\log G(\theta)$ where $G(\theta)$ represents the directivity of the antenna, similar at the emission and the reception. For delta type antenna, and θ greater than 30°, $-20\log G(\theta)$ may be of the order of 10 dB (Cones *et al.*, 1950). With a typical value of $Av=30$ dB (Rawer and Suchy, 1967), the required attenuation of 30 dB is obtained when $\theta \geqslant 53°$. Since the ionogram depends on the level of the energy which is received, compared to the threshold of the receiver, it is clear that the observed phenomenon must be sensitive to all parameters affecting one or both of these quantites: we interpret in this way the influence of the characteristics of the equipment as well as that of the absorption in the lower ionosphere. When the pattern of irregularities is moving relative to the observing point, the level of the wave energy received is modulated, thus accounting for the succession during *F*-lacuna events of ionograms of various types. Moreover, in this model, most traces during the event are due to obliquely propagating waves, which is in agreement with the absence of multiple echoes and the behaviour of $h'F2$ before and after occurrence of *F*2-lacunae. Finally, large scale irregularities have a diverging lens effect on 30 MHz radio waves, and ray tracing calculations performed on a simplified model allow an extra absorption of 0.1 dB, which is in rather good quantitative agreement with observations.

4.2. *Origin of the perturbations*

If we accept the model of large scale irregularities, the next step concerns their origin and evolution. At high latitudes the most plausible origin for large scale irregularities is the effect of energetic particle precipitations (gravity waves are ineffective due to nearly vertical magnetic field). Among known precipitations, those from the magnetospheric cleft (Heikkila and Winningham, 1971; Franck, 1971) have many characteristics in agreement with properties of *F*-lacunae: same local time of occurrence; sensitivity to the world magnetic activity and interplanetary magnetic field; position in latitude, a few degrees below stations where the phenomenon is observed; range of altitude where they deposit most energy, between 120 and 400 km (Olson, 1972), which is similar to that of the apparently perturbed region. A problem remains, concerning the seasonal variation of occurrence of *F*-lacuna events; precipitations occur in winter, not the events; the answer could be in a variation of the flux of precipitations with season (which is not yet known) or in the difference of the normal ionospheric absorption which modulates the effect observed on ionograms and riometer.

Once irregularities have been created, they may drift towards the inside of the polar cap under the influence of the convection electric field. The stronger the electric field, the further the irregularity pattern may be observed before it is damped by recombination; this interprets the positive effect of a strong electric field. Nevertheless, it is known that conditions in the interplanetary medium affect simultaneously the position of the precipitations, their flux and energy spectrum, and the intensity and orientation of the convection electric field; it is therefore hopeless to find a simple cause–effect relationship. Let us mention, however, that characteristic times of recombination are of the order of 10 min in the *F*1-layer and of two hours in the *F*2-layer; it could explain the particular correlation between *F*1-layer and world magnetic activity: for values of 3 K_m greater than 5, the negative effect of the source distance would prevail over the positive effect of its greater intensity; but it is difficult to introduce total lacunae in this scheme.

Finally, the theoretical results of Schunk *et al.* (1975) allow us to relate the favourable effect of a strong electric field with the statistical decrease of *foF*1 and *foF*2.

CONCLUSION

We have presented a very simple model of perturbed ionosphere which is in good agreement with most morphological aspects of an *F*-lacuna event. Moreover we have discussed some possible assumptions concerning the origin of this phenomenon.

Clearly, it is impossible to go any further with existing routine data alone. One has now to plan particular experiments to allow a more refined ionosphere model, and to deepen the study of its origin, which would probably proceed better with more understanding of the dynamical behaviour of the polar ionosphere.

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