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A study of ionospheric absorption events at very high latitudes

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Abstract—Riometer recordings at Dumont d'Urville station (Antarctica) show very often absorption events characterized by an irregular and slowly varying absorption of about 0.2 to 1 dB.

Analysis of these data and of simultaneous ionograms allows the separation of these events into three homogenous populations, one of which is associated with *F*-lacuna, i.e. the disappearance on the ionograms of all or part of echoes from the *F*-region.

This paper describes the method of separation of these populations and describe the properties of occurrence of each of them.

INTRODUCTION

In spite of the results gained from a number of satellite experiments, the behaviour of the ionosphere at very high latitudes (transauroral regions and polar cap, above ~75° invariant latitude) is still not well understood.

This is mainly due to the great complexity and the diversity of the physical processes involved. The behaviour of the transauroral ionosphere is indeed dominated by processes of magnetospheric origin and the coupling between the ionosphere and the magnetosphere. If the mechanisms of plasma production, transport and loss present at midlatitude are still operative, other phenomena such as transport by convection electric fields and ionization by energetic particles precipitations are of major importance.

Dumont d'Urville station in Antarctica (66.6° S; 140.0° E), with a set of complementary experiments (ionospheric sounder; riometers; magnetometers; photometers; reception of telemetry from ISIS satellites) is particularly well located for studies of the transauroral ionosphere since its invariant latitude is 81°.

Ground based data, due to their temporal continuity, are the most appropriate for long term statistical studies aiming at discovering the major sources of perturbation and eventually their origin.

We present in this paper a statistical analysis of several years of simultaneous ionograms and riometer recordings from Dumont d'Urville station (1965–1968) leading to the recognition of three different groups of ionospheric events with small amplitudes, typical of transauroral regions where they are commonly observed.

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2. ANALYSIS OF RIOMETER DATA

Besides Polar cap Absorption Events (PCA), following solar flares and generally characterized by an increase of the absorption by several dB during periods of one day or more and by complete black out on ionograms, recordings from the 30.1 MHz from Dumont d'Urville show another type of events which are weaker but more frequent.

These events appear as an irregular and slowly varying absorption, of small amplitude (0.3–1 dB) lasting from a few minutes to several hours. An example is shown in Fig. 1. We have called them "type M" events due to their morphological similitude (despite a much smaller level of absorption) with type M auroral absorption events described by AKASOFU (1968).

2.1. *Data processing*

Events are identified by visual inspection of the recordings.

The extra absorption of interest is superimposed on a 'normal' absorption whose value changes from day to day and is determined by a three step procedure (VASSAL, 1971):

(1) For each month, using data digitalized at a five minutes rate, we build the quiet day curve (LAVERGNAT *et al.*, 1976) by the IQSY method. This curve gives the variation of the cosmic noise versus sidereal time taking into account the normal solar-induced absorption.

(2) We then calculate the absorption at any particular time TU by $A(TU) = 10 \log(I_0(TS)/I(TU))$ where $I_0(TS)$ is the value given by the quiet day curve at sidereal time TS corresponding to time TU.

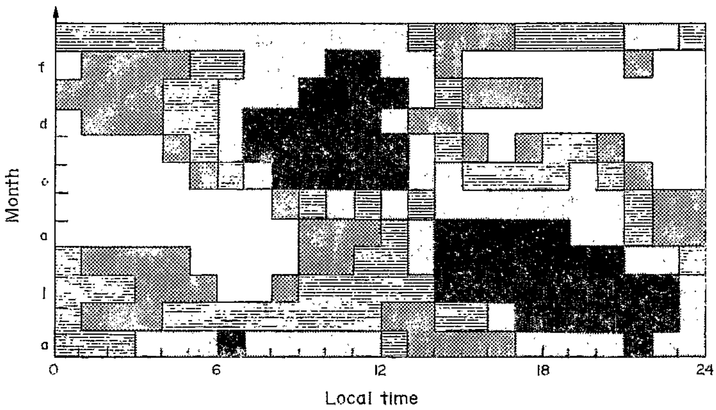


Fig. 2. Schematic representation of the occurrence of type M events at Dumont d'Urville in a month local time diagram. Five quantiles of occurrence have been represented by a grey scale.

(3) Values of this absorption before and after each of the type M events are interpolated throughout the duration of the event and thus represent the level of reference from which the true extra absorption is obtained.

This method works well for not too long events during which a linear interpolation of the reference level is valid. During events lasting several hours, the level of normal absorption may vary markedly and results are less precise.

Let us notice that in our method, any shift in absorption absolute value, as a consequence for instance of the use of the IQSY method, is eliminated from extra absorption.

Under good conditions, extra absorption may be determined above a threshold of about 0.1 dB.

The start and end of the events are defined with an accuracy of about ±15 min.

We define also for each event its mean time H_m as:

$$H_m = \frac{\sum_{i=1}^{N} h_i \cdot A(h_i)}{\sum_{i=1}^{N} A(h_i)} \tag{1}$$

where $A(h_i)$ are the sample values of extra absorption during the event at the N times h_i.

The advantage of this parameter is to be more sensitive to the absorption maxima which characterize the peaks of the events than to the badly defined extremities of the event.

2.2. *Occurrence of type-M events*

To each hourly interval, we assign an index n_{ij} (i: day number; j: hour number) whose value is 1 if there is a type M event during part of the interval and 0 otherwise.

Properties of occurrence are studied by computing $n_j = \sum_i n_{ij}$ for two-month long periods centred on each month of the year.

Results for 1966 are shown in Fig. 2. Two maxima of occurrence appear clearly: the first one between 0900 and 1200 (LT) in summer; the second one, more spread in time, during afternoon hours between April and August.

3. ANALYSIS OF BOTTOMSIDE IONOGRAMS

Simultaneously, an independent analysis of the ionograms was pursued in an attempt to study in more details a phenomenon already discovered by CARTRON (1962) and LEBEAU (1965), and mentioned by OLESEN (1958) in relation with slant *Es* namely the disappearance of part or totality of the *F*-layer traces. We have called this perturbation *F*-lacuna, and this name has been since adopted by URSI (with a somewhat more restricted meaning) and denoted as Y on routine data reduction sheet (PIGGOTT and RAWER, 1972).

More detailed results of this study will be presented in a forthcoming publication and we will here only give the most important results connected to the study of the absorption events.

3.1. *Morphological study*

The *F*-lacuna phenomenon is defined as the disappearance of the *F*-region echoes on the ionograms whereas normal echoes from the *E*-region remain visible.

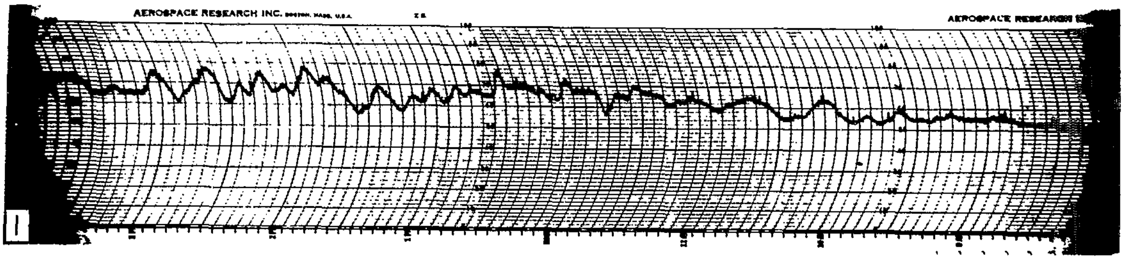
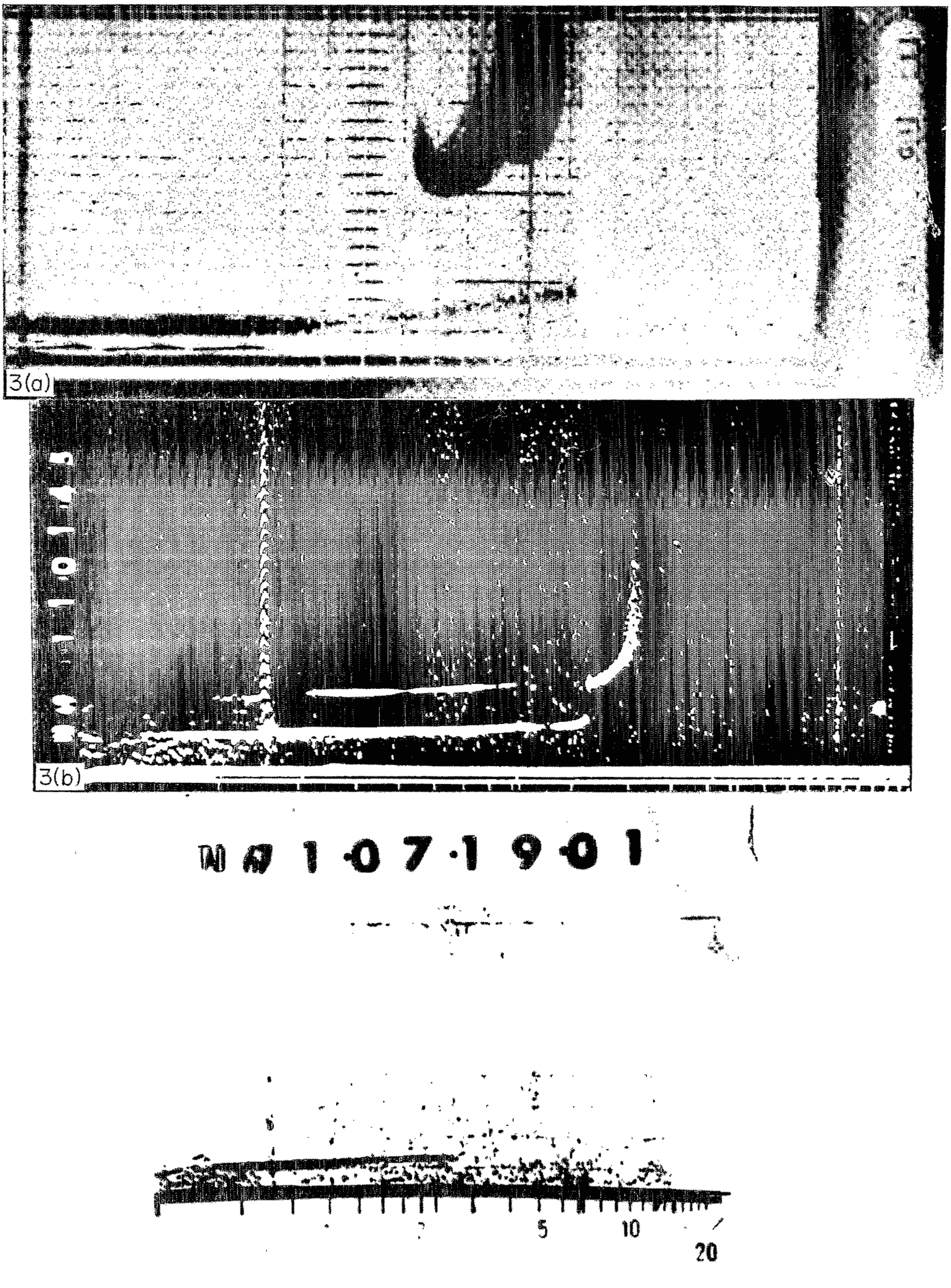


Fig. 1. Example of riometer recording exhibiting a "type M" event (30.1 MHz riometer from Dumont d'Urville station).



3(c)

Fig. 3. Typical ionograms. (a) *F1*-lacuna and slant *Es*; (b) *F2*-lacuna; (c) total lacuna.

The missing traces always concern a whole region either the $F1$-layer, or the $F2$-layer, or the F-region as a whole (Fig. 3); we thus have distinguished between three types: $F1$-lacuna, $F2$-lacuna and total lacuna.

Further analysis of $F2$-lacunae (SYLVAIN, 1972) have shown that this phenomenon, in many cases, was not to be interpreted as a G condition.

Sometimes, traces are present but obviously much weaker than normal echoes would be; we will refer to these cases as quasi-lacunae.

The phenomenon has been observed only during summer days on polar stations Dumont d'Urville (CARTRON, 1962; LEBEAU, 1965), Thule and Godhavn (OLESEN and RYBNER, 1958; OLESEN, 1972), Scott Base (KING and SAVAGE, 1973) and Resolute Bay (HAGG, private communication).

To within the temporal resolution of the sounder, lacunae appear on ionograms during periods lasting from less than 10 min to a few hours. When the phenomenon persists for a long time, the sequence of ionograms generally presents different types of lacunae or quasi-lacunae separated by ionograms of normal appearance; a summary of observations during such a sequence of ionograms is given in Table 1.

We have taken advantage of soundings at one minute interval with changes of the gain to look for

Table 1. Description of a sequence of ionograms with F-lacunae. For each layer (E, $F1$ and $F2$) are indicated the observed traces (O, X and Z). Parenthesis indicate a trace present but very weak.

Dumont D'Urville Station—February 9.1976

Time (UT)	E-layer	$F1$-layer	$F2$-layer	Comments
0010	$Z-0$	$Z-0$	0	
0015	$Z-0$	$Z-0-X$	0	
0020	0	$Z-0$	(0)	
0025	$(Z)-0$	$Z-0$	$0-X$	
0030	$Z-0$	0	$0-(X)$	
0035	0	(0)	0	*Es* type *c*
0040	0		0	Oblique *F2* trace
0045	0		$0-X$	
0050	0			
0055	0		0	
0100	0		$0-(X)$	
0105	0			
0110	0		(0)	
0115	0			Oblique *F2* trace
0120	0			
0125	0	0	0	Oblique *F2* trace

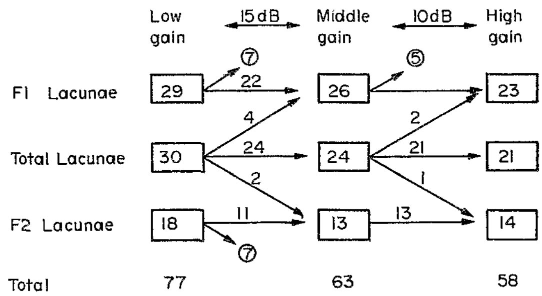


Fig. 4. Influence of the gain of the receiver. Numbers in squares are those of observations of F-lacunae. Circles indicate ionograms without appearance of lacunae. Arrows show how the appearance of the ionograms changes when increasing the gain.

a possible influence of the receiver sensitivity on the appearance of the F-lacuna.

An increase of the gain by about 10 dB may lead to the following modifications on the ionogram:

- —reappearance of all traces
- —change from a total lacuna to a $F1$ or $F2$-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 disappearing of 25% of the lacunae and change of type in 30% of the cases (Fig. 4).

3.2. *Occurrence*

Using as parameter the number of 15 min ionograms presenting lacunae, we have established the monthly histograms of occurrence for each type of lacuna during year 1966–67 (Fig. 5).

The shape of the histogram for each type is typical and independent of the month.

$F1$ and total lacunae exhibit an unimodal distribution with a well-defined peak occurrence between 0900 and 1100 (LT). The distribution of total lacunae has, however, a larger dispersion.

The shape of the $F2$-lacunae distribution is very different, with two maxima of occurrence earlier and later than those of the other types.

Seasonal variation appears clearly when comparing histograms from month to month; there are no lacunae at all from April to August (antarctic winter), and the maximum of occurrence takes place around November–December (antarctic summer).

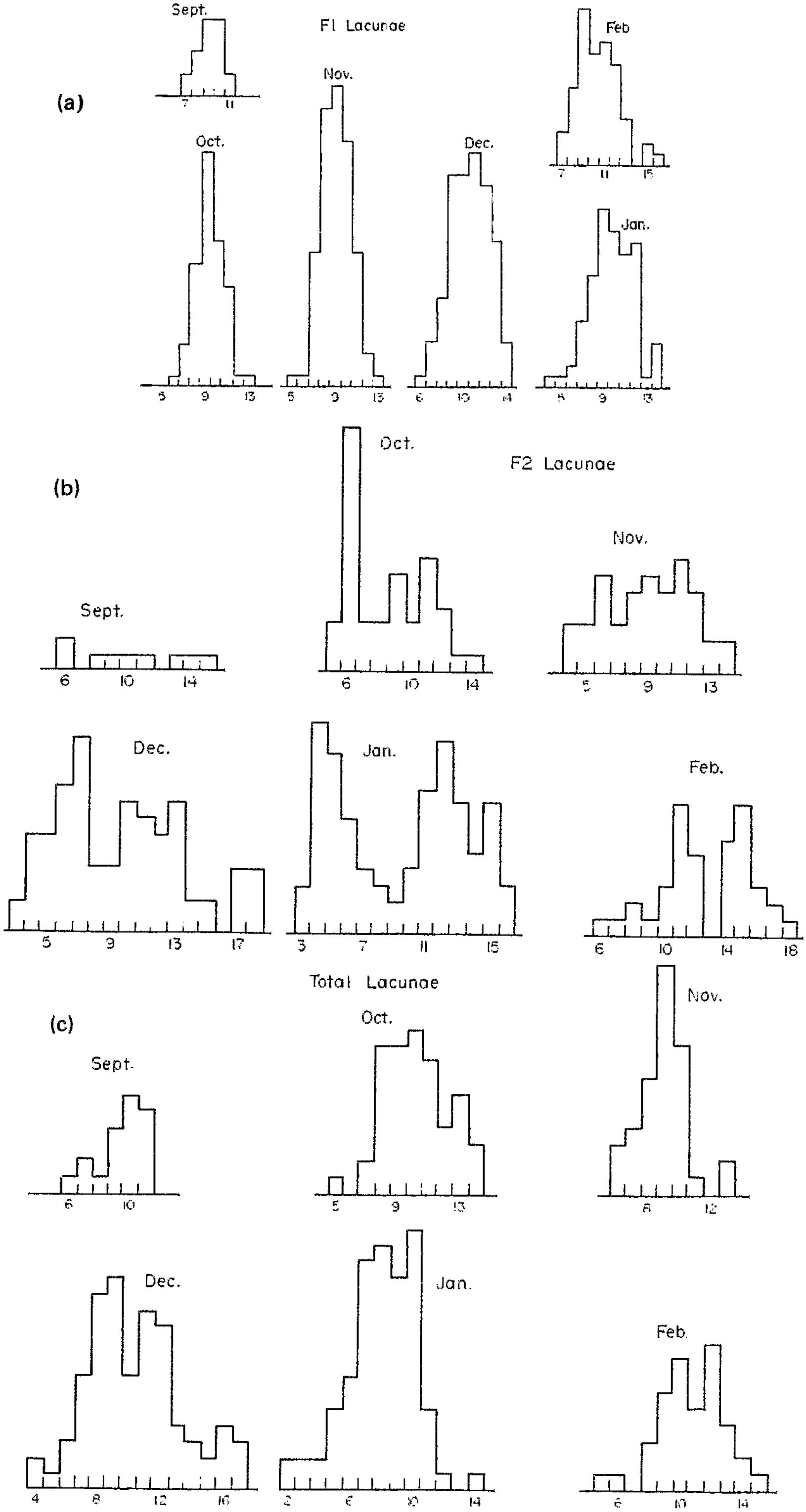


Fig. 5. Monthly histograms of occurrence of the various types of F-lacunae (Dumont d'Urville—1966–67). Local time is given in hours. (a) $F1$-lacunae; (b) $F2$-lacunae; (c) Total lacunae.

4. CLASSIFICATION OF TYPE-M EVENTS

4.1. *Events associated with F-lacunae*

The close temporal correspondance between the observed maximum of occurrence of summer type-M events and that of *F*-lacunae led us to undertake a more precise comparison.

4.1.1. *Comparison between F-lacunae and type-M events.* Starting from a table of *F*-lacunae observed on 15 min ionograms from September to December 1966, we have checked for each of them if it occurred during a type-M event or not.

As the times of start and end of type M events can not be precisely determined, we have considered as dubious, and counted separately, lacunae occurring outside an event but less than an hour apart.

Results (Table 2) exhibit a remarkable simultaneity, still enforced by cases of coincidence between isolated *F*-lacunae with type-M events of less than five minute duration.

Figure 6 is typical of more detailed studies of individual cases. The following conclusions may be drawn:

—total lacunae appear during maxima of absorption
—*F1*-lacunae appear during maxima of absorption, or on its flanks, then encompassing a total lacuna.
—there is no apparent relationship between *F2*-lacunae and extra-absorption.

Above-mentioned results demonstrate that *F*-lacunae and simultaneous type-M absorption events are two appearances of the same physical phenomenon which we will identify as *F*-lacuna event.

As a consequence, simultaneous use of riometer and sounder allows a classification of type M events into two populations: *F*-lacunae events on the one hand, all other type M events on the other hand.

Table 2. Analysis of coincidence between *F*-lacunae and type M absorption events.

Dumont D'Urville—September–December 1966	Number	Percentage
F-lacuna (all types)	445	100
F-lacuna coincident with a type-M event	387	87
Dubious coincidence between a *F*-lacuna and a type-M event	50	11.2
No coincidence	8	1.8

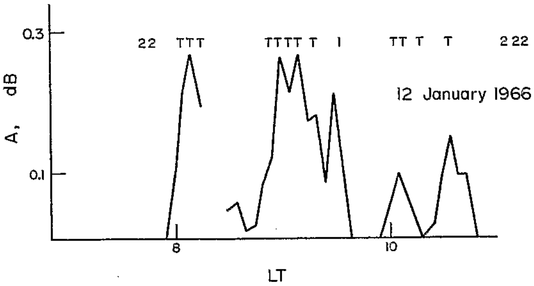


Fig. 6. Extra absorption of a type M event and simultaneous observations of lacunae on ionograms.

This classification does not change when the temporal separation between ionograms is less than fifteen minutes.

4.1.2. *Relation with slant Es. Es* type slant consists of a diffuse *Es* trace which rises steadily with frequency and emerges from the high frequency end of a normal or sporadic-*E* trace (Fig. 3a).

This phenomenon occurs with the same characteristic aspect but different properties near the equator and in auroral and polar regions (Thomas and Smith, 1959; Olesen and Rybner, 1958).

Olesen and Rybner (1958), Olesen (1972) and King and Savage (1973), in studies of slant *Es* at high latitudes mentioned the disappearance of echoes from the *F*-region as an occasional secondary phenomenon and called it frequency gap or *E–F* height gap.

We investigated statistically the relationship between both phenomena on Dumont d'Urville data.

At Dumont d'Urville slant-*Es* is a phenomenon less frequent than *F*-lacuna. On the 15 min ionograms from 1966–67 and 1967–68 summers, it appears only in 106 cases, with maximum occurrence between 0800 and 1000 hr LT.

Assuming that *F*-lacunae and slant *Es* are independently distributed, their expected number of coincidences would be:

$$\hat{n}_k = \frac{n_{Fi}(k) \cdot n_{Es}(k)}{N_k}$$

where:

k is the time index
N_k the total number of soundings during the period in time interval k
$n_{Fi}(k)$ the number of *F*-lacunae (type i) observed on these ionograms
$n_{Es}(k)$ the number of slant *Es* observed on these ionograms.

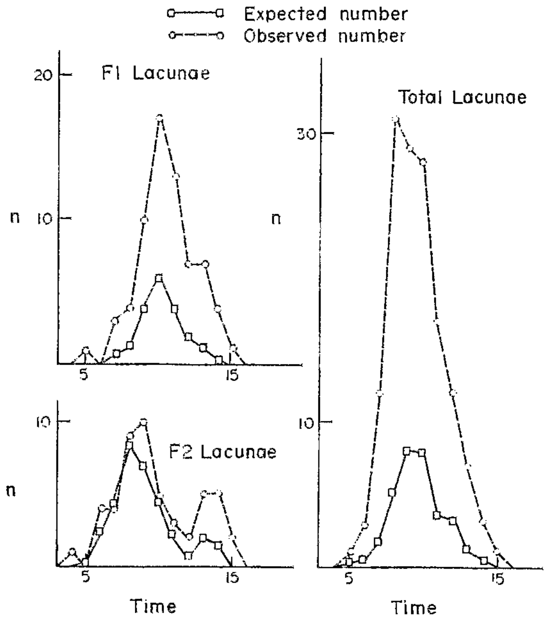


Fig. 7. Comparison of the observed coincidences $\tilde{n}_k$ between F-lacunae and slant Es and their expected value $\hat{n}_k$.

Figure 7 shows the comparison between this expected value $\hat{n}_k$ and the observed number of coincidences $\tilde{n}_k$.

If slant Es and $F2$ lacunae can be considered as statistically independent, occurrence of slant Es on the one hand, $F1$ or total-lacunae on the other hand appear to be strongly correlated.

We have then compared occurrences of slant Es and type M events in a manner similar to what we did for F-lacunae (Table 3).

Table 3. Analysis of coincidences between slant Es and type M absorption events.

Dumont D'Urville—1966–67 and 1967–68 summers		
Type of event	Number	Percentage
Slant Es	105	100
Slant Es coincident with a F-lacuna event	79	75.4
Dubious coincidence of a slant Es with a F-lacuna event	19	18.2
Slant Es coincident with a type-M event not associated with F-lacuna	3	2.6
Slant Es not coinciding with a type-M event	4	3.8
Comparision impossible	1	

These results led to think that polar type slant Es is another appearance on ionograms of F-lacunae events.

4.2. *Type-M events not associated with F-lacunae*

Let us now concentrate our attention to those type M-events which are not associated with F-lacunae. Study of their occurrence with help of the n_j parameter defined in Section 2.2 above, often shows dissymetrical distributions and sometimes even two maxima.

A new analysis has been carried out by considering, for periods of two months centred on each month of the year, the number N_j of events whose mean time H_m belongs to the hourly time interval j.

Two groups of events appear clearly from August to January. The n_j distributions of these two groups can then easily be fitted by normal distributions.

We assumed that such a splitting into two populations should be possible throughout the year and proceeded by the following method (illustrated on Fig. 8).

Let $[H_a, H_b]$ be the interval of mean times of the events. Let us consider the distribution of the mean times H_m of the events and let $\hat{H}_m$ be its centred value.

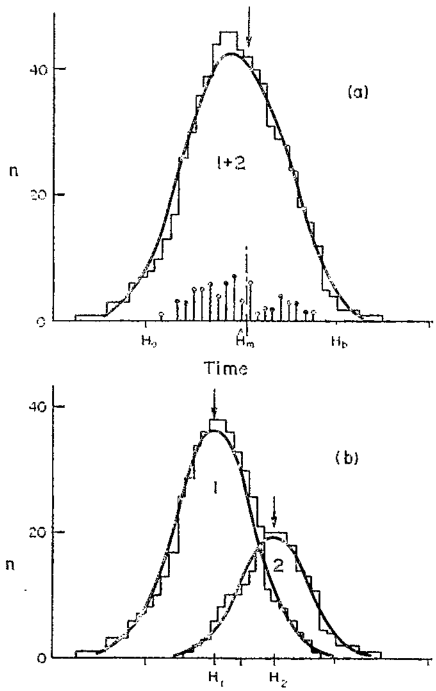


Fig. 8. Statistical separation of type M events non associated to F-lacunae into two populations. (a) Global histogram and distribution of mean times. (b) Histograms of separated populations.

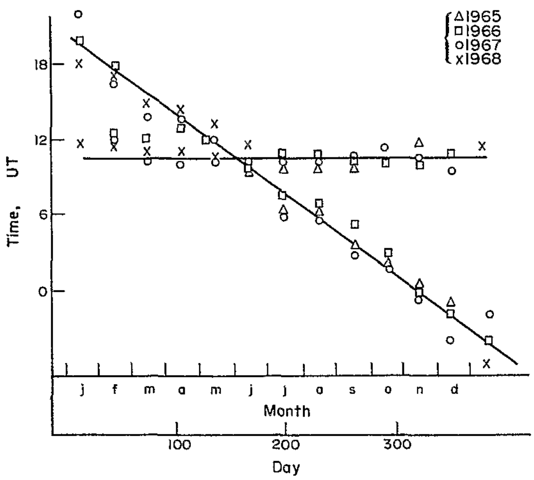


Fig. 9. Times of maximum occurrence of type-M events non associated to F-lacunae.

We then consider the n_j distributions of the two populations of events whose mean times are respectively in intervals $[H_a, \hat{H}_m]$ and $[\hat{H}_m, H_b]$. Using only the external flanks, we fit two normal distributions to these. Let H_1, σ_1 and H_2, σ_2 be the means and standard deviations of these two normal distributions.

We admit that the separation is justified if:

$$|H_1 - H_2| \geqslant \frac{\sigma_1 + \sigma_2}{2}$$

Moreover, we check the normality of the experimental distributions by a χ^2 test.

Results of this analysis are the times of maximum occurrence H_1 and H_2 versus the month (Fig. 9). The existence of two populations appears clearly, thus giving an *a posteriori* justification to the assumption made in splitting the distribution.

The first one has its maximum of occurrence at a rather constant local time (1900–2100 h). We will call them evening type-M events.

The second population has a time of maximum occurrence which varies throughout the year and is given in UT by:

$$H_n = -2 \cdot N + 22$$

where N is the number of the month (1 for January).

This corresponds to a fixed sidereal time.

We will call these events itinerant type-M events.

Seasonal variation of occurrence, given by the n_j parameter of fitted distributions is given on Fig. 10.

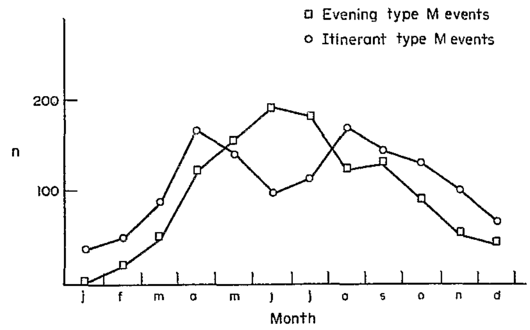


Fig. 10. Seasonal variation of the occurrence of evening and itinerant type-M events.

Evening type-M events have their maximum of occurrence in winter; itinerant type-M events show two maxima in April and August.

5. COMPARISON WITH OTHER STATIONS

Our study has been essentially based on results obtained at Dumont d'Urville station for which we had several years of uniformly processed data.

However, F-lacunae have been observed at a sufficient number of locations (see above) to be sure they are not a local peculiarity.

Riometer data from Wilkes (66.3° S; 110.5° E; $\wedge = 79.7°$) and from Long Year Byen (78° N; 15° E; $\wedge = 74.7°$) allowed us to build histograms of occurrence of type-M events, without separating F-lacunae events (Fig. 11).

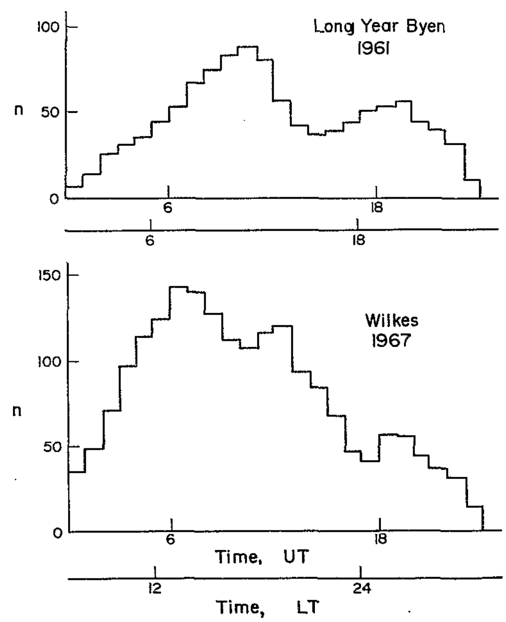


Fig. 11. Occurrence of type M events at Long Year Byen and Wilkes.

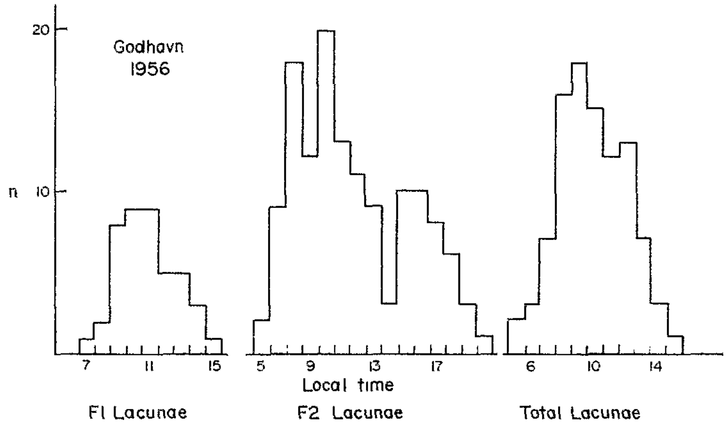


Fig. 12. *F*-lacunae occurrence at Godhavn.

As in the case of data from Dumont d'Urville, we observe a maximum around noon and a second more spread maximum in the late evening.

Comparison of results at the three stations indicates that the noon maximum is probably related to magnetic noon (LEBEAU, 1965) rather than local solar noon; as magnetic noon, it occurs earlier than local noon at Dumont d'Urville and Long Year Byen, later at Wilkes.

Figure 12 shows histograms of occurrence of *F*-lacunae for year 1956 at Godhavn station (69.2° N; 53.5° W; $\Lambda = 77°$).

Many similarities may be noted with Dumont d'Urville results:

Unimodal distribution of *F1* and total lacunae with maximum occurrence between 0900 and 1200 LT

Bimodal distribution of *F2*-lacunae, the maxima of occurrence being around 0700 and 1500 LT.

Moreover, in this northern hemisphere station, *F*-lacunae are observed only from April to August (local spring and summer).

Although preliminary, these results show the great interest there would be to study in a systematic way the latitudinal extension and variations of these phenomena.

6. SUMMARY AND CONCLUSIONS

Simultaneous analysis of riometer and sounder data had led us to a classification of type M absorption events, very commonly observed at Dumont d'Urville station, into three homogeneous populations:

F-lacunae events, associated with observation on ionograms of *F*-lacunae and/or slant *Es*, which are a summer phenomenon with maximum occurrence between magnetic and local noon.

Evening type-M events, occurring throughout the year around 1900 LT, with a winter maximum.

Itinerant type-M events, whose time of maximum occurrence is at a fixed sidereal type, and maxima in April and August.

We should notice that ionograms allow an individual identification of *F*-lacunae events.

On the contrary, evening and itinerant type-M events have been distinguished on a statistical basis and individual identification is not always possible (particularly in May and June).

Nevertheless, the separation between these families of events was a preliminary to their precise study. Properties of the three types of events and a tentative physical interpretation will be presented in a forthcoming publication.

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