Sporadic-E ionization observed by the backscatter technique

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Summary. — The examination of the results of the ionospheric sounding by ground backscatter carried out at Torrechiaruccia (S. Marinella, Rome) since 1957, as to the occurrence of the propagation via sporadic-E ionization, is referred.

The seasonal and diurnal occurrence, as well as the azimuthal distribution of the Es echoes are discussed.

There was a good correlation between the time occurrence of Es echoes and the occurrence of Es ionization, the top frequency of which exceeds a critical value related to the frequency of the sounding radio waves. To account for a lack of correlation between the azimuthal distribution of the echoes and the azimuthal distribution of $foEs$, it is suggested that the latter one depends even on an azimuthal variation in the vertical radiation diagram of the antenna, due to some characteristics of the ground.

A statistics of Es "clouds" was performed; about 60% of the observed clouds were "moving clouds", their main movement occurring towards South-West; the mean dimension of these clouds was about 250 km.

Riassunto. — Si riferisce sui risultati dei sondaggi ionosferici per retrodiffusione dal suolo effettuati dal 1957 a Torrechiaruccia (S. Marinella, Roma), per quanto concerne la ionizzazione E sporadica.

Viene discussa l'occorrenza nel tempo e la distribuzione in direzione degli echi retrodiffusi via E sporadica. È stata trovata una buona correlazione tra l'occorrenza temporale (diurna e stagionale) di tali echi e l'occorrenza temporale di ionizzazione E sporadica la cui frequenza limite $foEs$ supera un certo valore dipendente dalla frequenza delle radioonde impiegate nel sondaggio. Per spiegare alcune discrepanze tra la distribuzione azimutale degli echi e quella di $foEs$ viene suggerito che la prima dipenda anche da variazioni con l'azimut del diagramma verticale di radiazione dell'antenna, dipendenti da particolarità del suolo.

È stata effettuata una statistica delle cosiddette « nubi » di E sporadica; circa il 60% delle nubi osservate erano animate da moti prevalentemente diretti verso Sud-Ovest; la dimensione media di tali nubi è risultata dell'ordine di 250 km.

1. Introduction.

The results of the ionospheric soundings by ground backscatter, performed since 1957 at the experimental station of Torrechiaruccia (S. Marinella, Rome; lat. 42.03° N; long. 11.83° E) belonging to the Centro Radioelettrico Sperimentale «Guglielmo Marconi», were examined as concerning to the ground backscatter via sporadic-E ionization.

We used a sounder delivering to a 4-element rotating Yagi R. F. pulses of about 1 msec on $f = 18.6$ Mc/s and on $f = 22.3$ Mc/s, at a rate of 50/3 pulses per second and with a peak power level of about 2 kW. As it is shown by the records, taken on a 35 mm film, the b.s. echoes appear to be in a system of rectangular coordinates, their equivalent b.s. distance D' (*) stretching along the one and the geographical azimuth of the antenna beam along the other axis.

An attempt was made (*a*) to determine the dependence of the occurrence of the *Es* echoes on the time and on the direction, and (*b*) to put into evidence some significant characteristics of the *Es* echoes.

2. – Statistical occurrences of *Es* echoes.

The b.s. sounding at Torrechiaruccia has been considered from the research point of view; the frequency of the radio waves, the type of the sounding (for example, fixed direction sounding instead of a variable direction one) and even the type of the antenna were frequently changed.

A series of omogeneous soundings was performed during the I.G.Y. 1957-58, exactly from August 23, 1957 to January 31, 1958 on 18.6 Mc/s and from February 1, 1958 to January 31, 1959 on 22.3 Mc/s, with one sounding per hour from 9 to 19 hours of local time (15° E Mean Time). This series has represented the base of the statistical examination, integrated by the data from other observation periods.

2.1. *Time occurrence of echoes.*

In the Fig. 1, it is shown the behaviour of the time occurrence of *Es* echoes from the four cardinal directions on 22.3 Mc/s, from February

(*) D' means the quantity $c\Delta t/2$, c being the velocity of the light in vacuo and Δt being the echo delay.

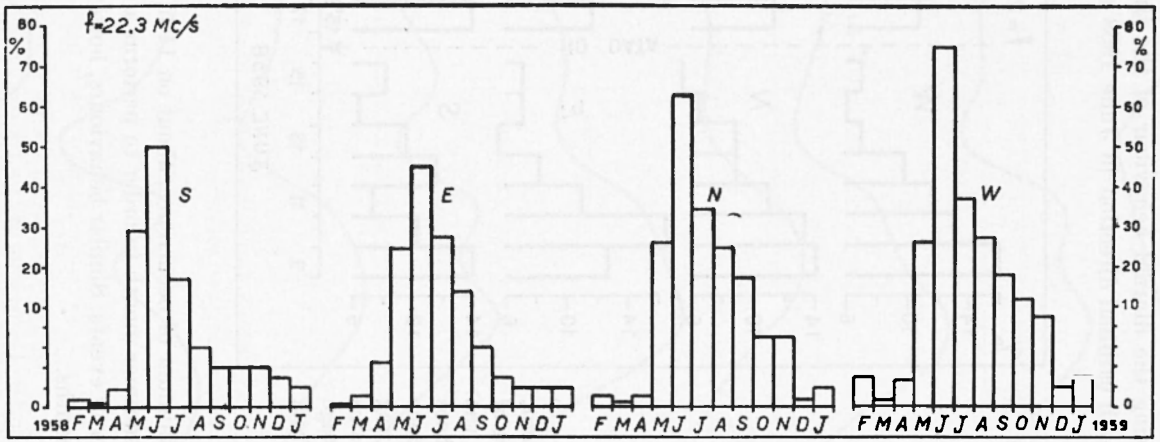

Fig. 1 – Monthly percentage of the observation time during which *Es* backscattered echoes on 22.3 Mc/s occurred from the four cardinal directions at Torrechiaruccia. The histograms concern the period from February 1958 to January 1959, when the sounding was performed every hour from 9 to 19 hours of local time. There is an expanded scale of occurrence, between 0 and 10%.

1958 to January 1959; a maximum of occurrence, about on June, is quite evident.

The histograms showing the diurnal behaviour of the time occurrence of *Es* echoes from each cardinal direction in June 1958 are reproduced in the Fig. 2; a minimum of occurrence, about on 14 h, is clearly visible. It was chosen a summer month in order to perform a statistical analysis on a large number of events. Similar behaviours, however, occur even during the other months.

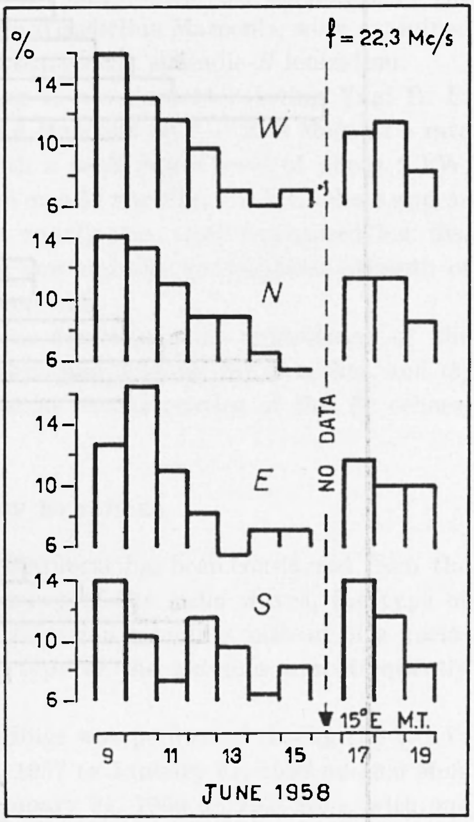

Fig. 2 – Diurnal behaviour, between 9 and 19 hours of local time, concerning the time occurrence of *Es* echoes on 22.3 Mc/s from the four cardinal directions, during June 1958. The histograms show the hourly percentage of the echoes observed from a particular direction.

2.2. *Azimuthal occurrence of echoes.*

The Fig. 1 shows a certain prevalence of the echoes coming from westerly directions. To put this phenomenon into evidence, the echo

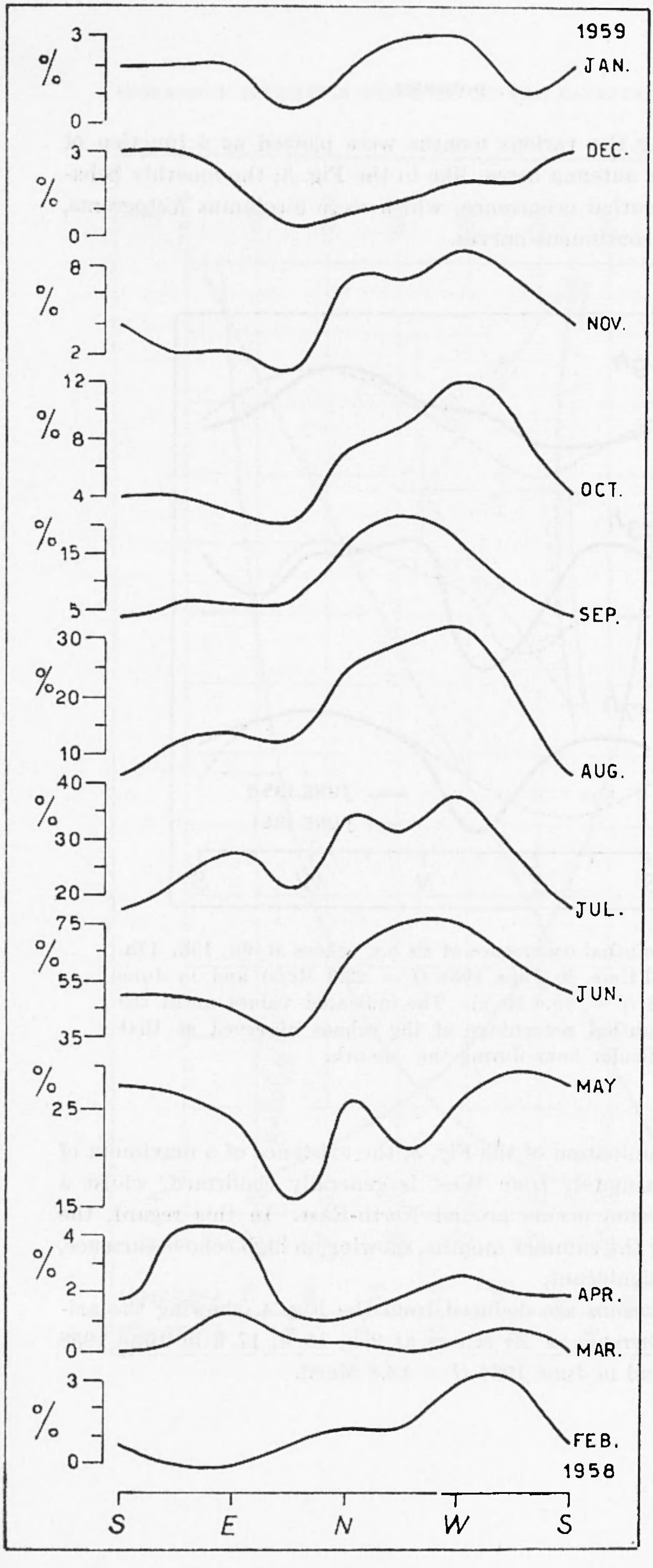

Fig. 3 – Monthly percentage of the observation time during which *Es* b. s. echoes on 22.3 Mc/s occurred from the different directions. The curves concern the months from February 1958 to January 1959.

occurrencies during the various months were plotted as a function of the azimuth of the antenna beam, like in the Fig. 3; the monthly behaviours of the azimuthal occurrence, which were 8-columns histograms, were arranged as continuous curves.

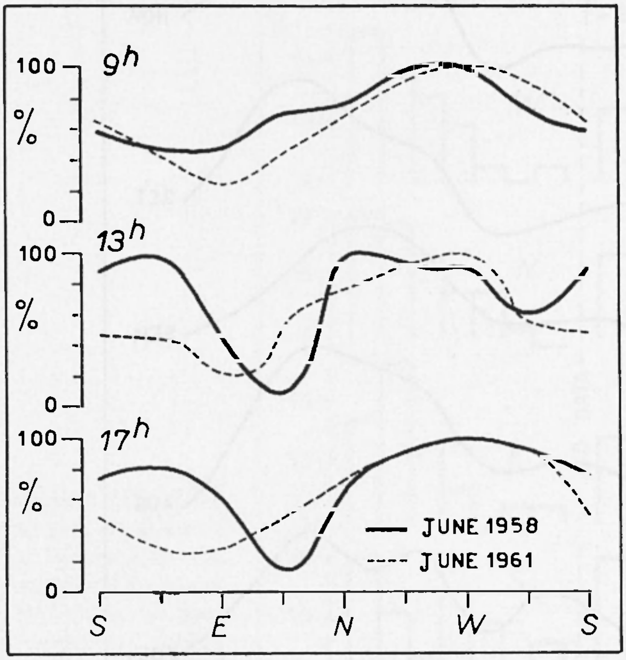

Fig. 4 – Azimuthal occurrence of *Es* b.s. echoes at 9h, 13h, 17h, local time, in June 1958 (f = 22.3 Mc/s) and in June 1961 (f = 18.6 Mc/s). The indicated values mean the azimuthal percentage of the echoes observed at that particular hour during the month.

From the examination of the Fig. 3, the existence of a maximum of occurrence approximately from West is generally confirmed, whilst a well defined minimum occurs around North-East. In this regard, the behaviours during the summer months, showing an high echo occurrence, are particularly significant.

Similar conclusions are deduced from the Fig. 4, showing the azimuthal mean occurrence of *Es* echoes at 9 h, 13 h, 17 h in June 1958 (f = 22,3 Mc/s) and in June 1961 (f = 18.6 Mc/s).

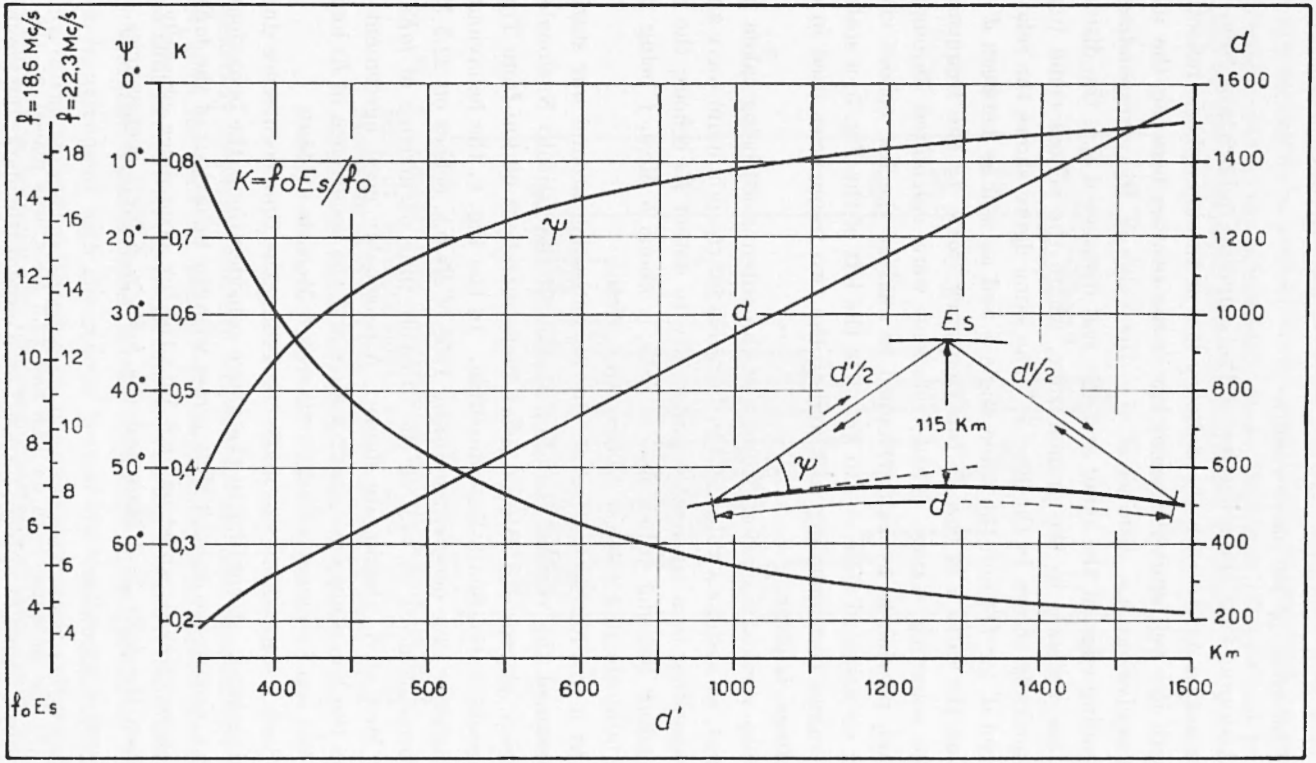

Fig. 5 – See the text.

2.3. *Discussion of the above results.*

Assuming that the reflection of the sounding radio waves from the *Es* ionization agrees with the ordinary law of the ionospheric reflection, i.e. with the well known " secant law ", the relation between the minimum equivalent b.s. distance d' (i.e. the value of D' corresponding to the leading edge of the echo) and the real distance d (i.e. the distance from the antenna to the ground zone, where the echoes come from), is graphically shown in the Fig. 5. The same figure shows the relation between d' (or D') and the wave angle ψ and as well as between d' (or D') and the ratio k of the *Es* top frequency. *foEs*, to the frequency f of the sounding waves. These relations were calculated through a method, previously by us developped to analyze the b.s. echoes via *F* layer; we assumed $h'Es = 115$ km. On the left of the Fig. 5, a scale of *foEs* values corresponding to k and to the two frequencies used in our soundings, is given.

The vertical radiation diagram of the antenna (*) being taken into account, we assume a value of 5 to 7 degrees for the minimum wave angle corresponding to a reasonable probability to detect *Es* echoes; the corresponding limiting value, f_{lim}, of *foEs*, is about 5 Mc/s, f being 22.3 Mc/s, and about 4.2 Mc/s, f being 18.6 Mc/s.

As a monitoring station on the *Es* ionization around our station, we assumed the vertical sounding station of the Istituto Nazionale di Geofisica, placed at S. Alessio, near Rome, at about 60 km from Torrechiaruccia in the South-East direction. In the Fig. 6, the behaviour of the monthly time occurrence during 1958 of *Es* b.s. echoes on 22.3 Mc/s at Torrechiaruccia as well as the monthly time occurrence of $foEs >$ 3-5-7 Mc/s at S. Alessio, are shown. A reasonably good agreement between the b.s. occurrence on 22.3 Mc/s and the occurrence of *Es* ionization the top frequency of which exceeds 5 Mc/s, is evident.

Such a comparison was made concerning the time occurrence during the day time. According to the above considerations, the behaviour of the b.s. occurrence on 22.3 Mc/s agrees with the behaviour of the $foEs \geqslant$ 5 Mc/s occurrence, whilst on 18.6 Mc/s the b.s. occurrence generally lies between the $foEs \geqslant 3$ Mc/s and the $foEs \geqslant 5$ Mc/s occurrencies.

(*) The antenna, both on 18.6 and 22.3 Mc/s, was placed at the top of a tower, about 11 m high, installed on a coastal boundary; the ground at the tower base was about 5 m above the sea surface.

The minor discrepancies between the b.s. sounding data and the vertical sounding data, both in the monthly and in the hourly behaviours, are probably due to the intrinsically large dispersion of *foEs* and to the influence of the azimuthal distribution of the echoes.

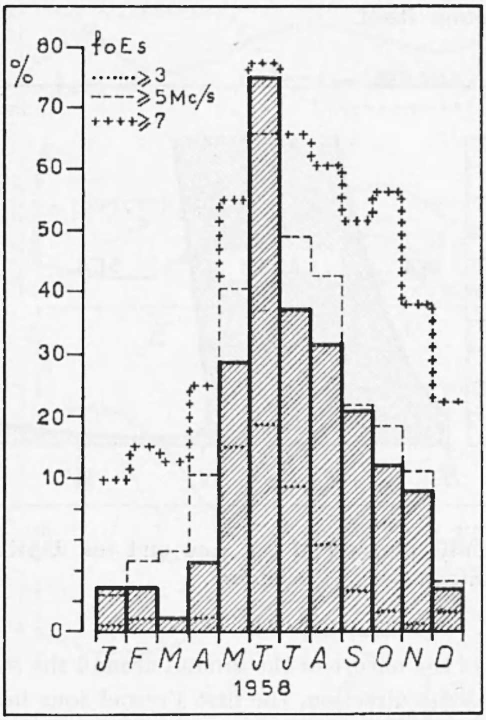

Fig. 6 – Monthly time occurrence of *Es* b.s. echoes on 22.3 Mc/s at Torrechiaruccia (solid lines) and of *foEs* exceeding 3, 5 or 7 Mc/s at S. Alessio (Rome), from January to December 1958. There is an expanded scale of occurrence between 0 and 10%.

Generally speaking, we may affirm that the time occurrence of *Es* echoes, both for seasonal and for day time variations, occurs according to the time occurrence of *Es* ionization, the top frequency of which exceeds a critical value related to the frequency of the sounding radio waves, in agreement with the general laws of the ionospheric reflection.

As to the azimuthal distribution of the echoes, trials performed to find a correlation between the observed distribution (Fig. 3 and Fig. 4) and the *foEs* distribution around our station, were not successful, expecially when we tried to explain the systematically occurring minima in the East direction and the maxima in the West direction.

According to the recent finding by I. Ranzi [1], we think that a remarkable influence is exerted by the variation of the vertical radiation diagrams of the antenna, depending on the topographical characteristics around the antenna itself.

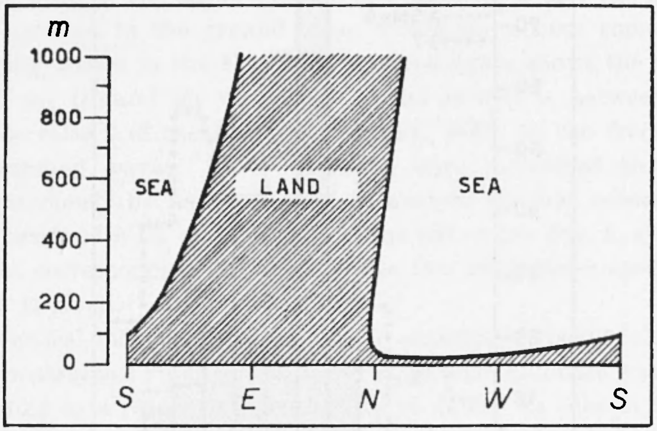

Fig. 7 – Schematic diagram of the land and sea distribution around the antenna of the sounder.

The change of the nature of the ground around the antenna is shown in the Fig. 7; in some direction, the first Fresnel zone lies on the sea, in other ones on the land, the vertical antenna patterns being quite different in the two cases. We must even consider that, owing to the different values of the reflection coefficient and to the irregularities of the land, the sharpness of maxima and minima in the vertical radiation pattern of the antenna is lower when the ground reflection occurs over a land surface.

The theoretical radiation diagram of the 22.3 Mc/s antenna shows a maximum at about $\psi = 13^o$ towards West and at about $\psi = 18^o$ towards East; the previously introduced limit value of *foEs*, f_{lim}, changes with the antenna azimuth, according to the behaviour shown in the Fig. 8. In this figure, the upper curve indicated as "*foEs*", shows the behaviour of the median values of *foEs*, at a distance of 500 km from Torrechiaruccia, during June 1958 at 9 hours. If we assume that the "expected" percentage of time occurrence of *Es* echoes is proportional to *foEs*, a maximum of occurrence should be observed towards South. However, if we assume that the " expected " occurrence is linearly proportional to the difference ($foEs$–f_{lim}), a maximum should be observed

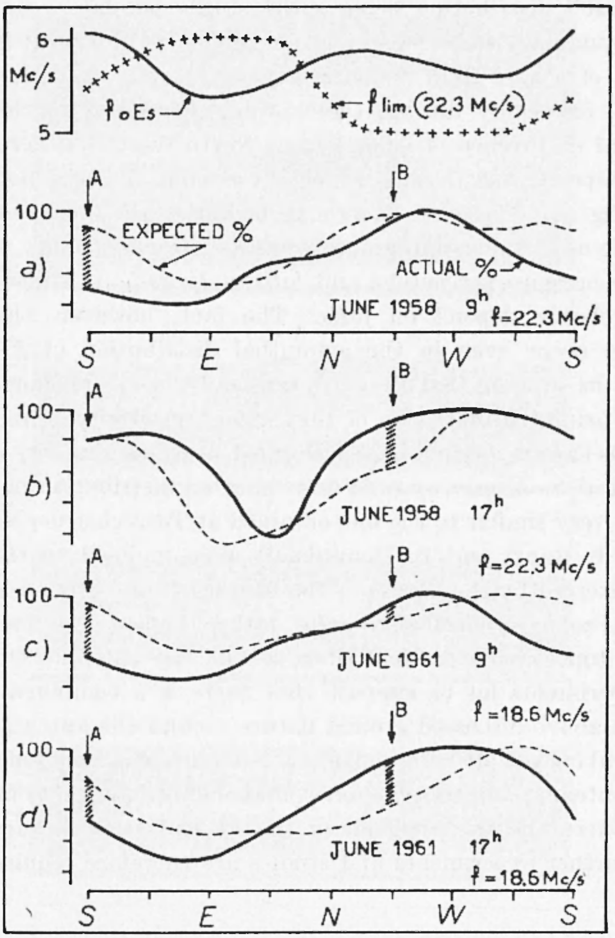

Fig. 8 – See the text.

towards West, as it really occurs (curves " Expected % " and " Actual % " in *a*, Fig. 8). Some other results obtained by this way are shown in *b*, *c*, *d* of the Fig. 8.

Owing to the very uncertain basic data (i.e. *foEs* and f_{lim}) and to the approximation of the adopted method, the comparison between the experimental data and what we call the " expected " azimuthal distribution of echoes, cannot have a well defined physical meaning. However, as to the influence of the antenna characteristics on the experimental data, the comparison is quite significant, the behaviours of the " expected" and " actual " distribution being satisfactorily similar.

Two systematic discrepancies are nevertheless observed: (*i*) the real occurrence of echoes from South is generally lower than the expected occurrence, expecially during, the morning (points A in the Fig. 8), (*ii*) the real occurrence of echoes from North-West is generally larger than the expected occurrence, expecially during the afternoon (points B in the Fig. 8). These two facts may be due to the method employed, for example as to the assumption of constant proportionality coefficients between occurrence percentage and *foEs* or ($foEs$-f_{lim}), whilst the coefficients probably depend on *foEs*. The fact, however, that similar phenomena occur even in the azimuthal distribution of *F*-layer b.s. echoes, let us suppose that they are caused by some phenomenon producing an azimuthal variation of the sounder sensitivity or/and affecting the b.s. mechanism. Soundings performed in other localities (at S. Marinella and at S. Alessio) showed an azimuthal distribution of *F* echoes, which was very similar to the one obtained at Torrechiaruccia: as to the *F* echoes, I. Ranzi and P. Dominici (2) were inclined to think to an influence exerted by the nature of the backscattering ground zone (open sea, coastal zones or continental area), rather than to an influence exerted by the topographic particularities around the antenna. Other, more recent experiments let us suppose that there is a combined influence, due to the above discussed ground nature around the antenna, to some geographical factors (distribution of sea and land some hundreds km apart from the antenna) and to some ionospheric factors (higher complexity of the ionosphere and in particular of the *Es* ionization towards North-West). Further experiments and studies are therefore required on this matter.

3. Characteristics of individual echoes.

Several considerable difficulties were met as to the analytic examination of our data, owing to the fact that the frequency of the soundings was no higher than one sounding every ten minutes. This is the reason why we were not able to perform a satisfactory statistics on the speeds of the moving echoes.

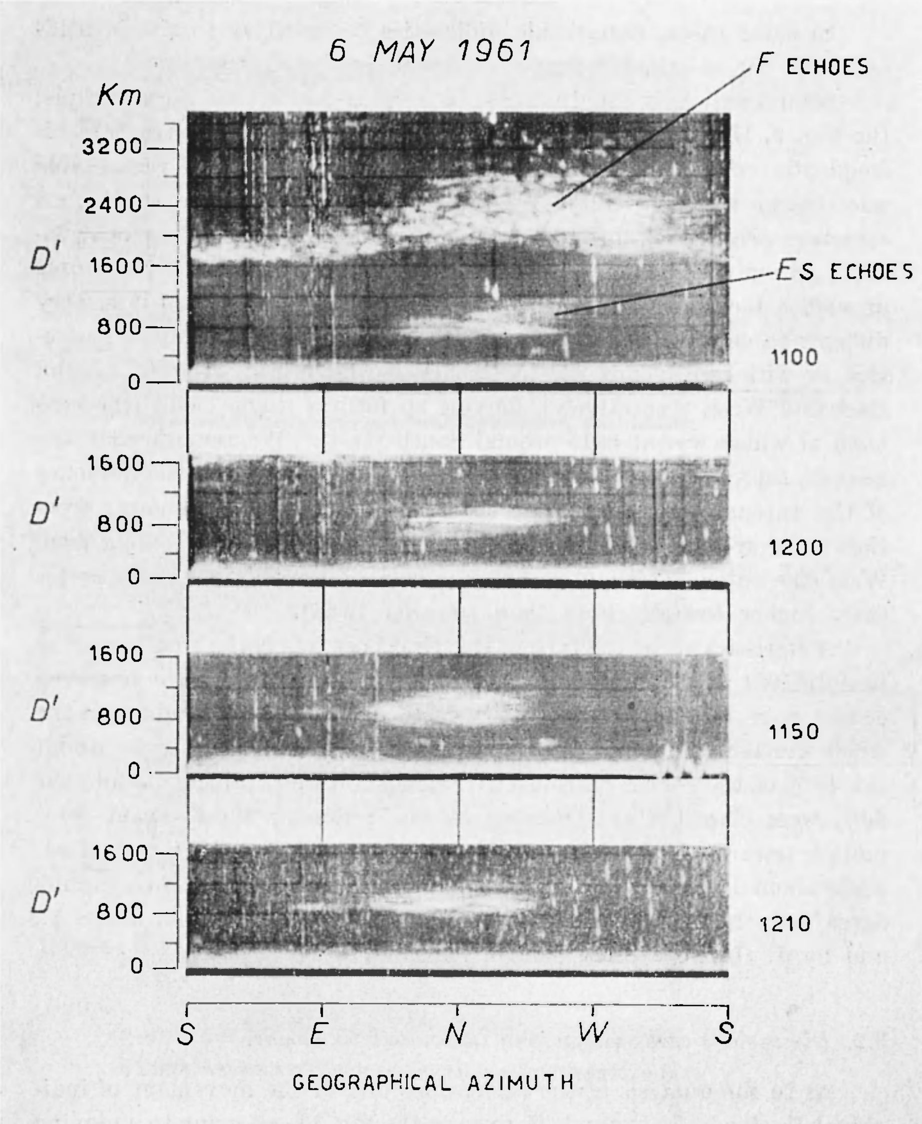

Fig. 9 – Records taken on May 6, 1961, between 1100 and 1210, local time. The whole distance range is about 4500 km, the distance marks being every 400 km. There is an example of an *Es* cloud.

3.1. *Statistics of Es clouds.*

In some cases, remarkable difficulties occurred as to the identification of the so-called " clouds " of sporadic-E ionization.

Sometimes, this identification was quite clear; see, for example, the Fig. 9. However, during the summer months the echo structure his frequently continuous on the whole horizon (Fig. 10 A); a remarkable uncertainty may be caused by the fragmentation of this continuous structure (Fig. 10 B), due to the above discussed apparent lack of sensitivity, when the sounder works towards East. An interesting example of such a fact is shown in the Fig. 10 C-D-E. In this case it is very difficult to decide if it dealts with a " fragmented " continuous ionization or with two clouds (the centroids of which lead at 0845 around East and West, respectively), moving to form a single cloud (the centroid of which was at 0915 around South-West). We remark that the records, reproduced in the Figures 9 and 10, evidently show the influence of the antenna diagram on the echo pattern; the echoes coming from East have systematically smaller distancies than the ones coming from West (the antenna's height is lower and the antenna's lobe is consequently higher towards East than towards West).

A statistics about the type of the *Es* echoes was performed from May to July 1961 and from June to August 1962. The 30% of the observed echoes were of the " continuous " type, i.e. the one spreading on the whole horizon; the doubtful cases were classified under this type. About the 40% of the echoes classified as "clouds" were stationary, while the 60% were classified as " moving clouds "; among these, about 30% moved towards North-East, about 60% moved towards Sourth-West, while about 10% showed a rather complicated movement. These results agree with the ones obtained by A. M. Peterson (3), at Stanford, U.S.A., and by J. Harwood (4) at Slough, England.

3.2. *Dimensions and movement of individual Es clouds.*

As to the analysis of the dimensions and of the movement of individual *Es* clouds, an example is given in the Fig. 11, referring to a moving cloud, observed on May 12, 1961, during the morning.

The b.s. equivalent distancies D' of the echoes and the azimuths of clouds's centroid, are given on the left of this figure. It seems that there is a cloud, moving from North to North-West and then from North-West to North, the dimensions of which decrease until, between 1200 and 1215,

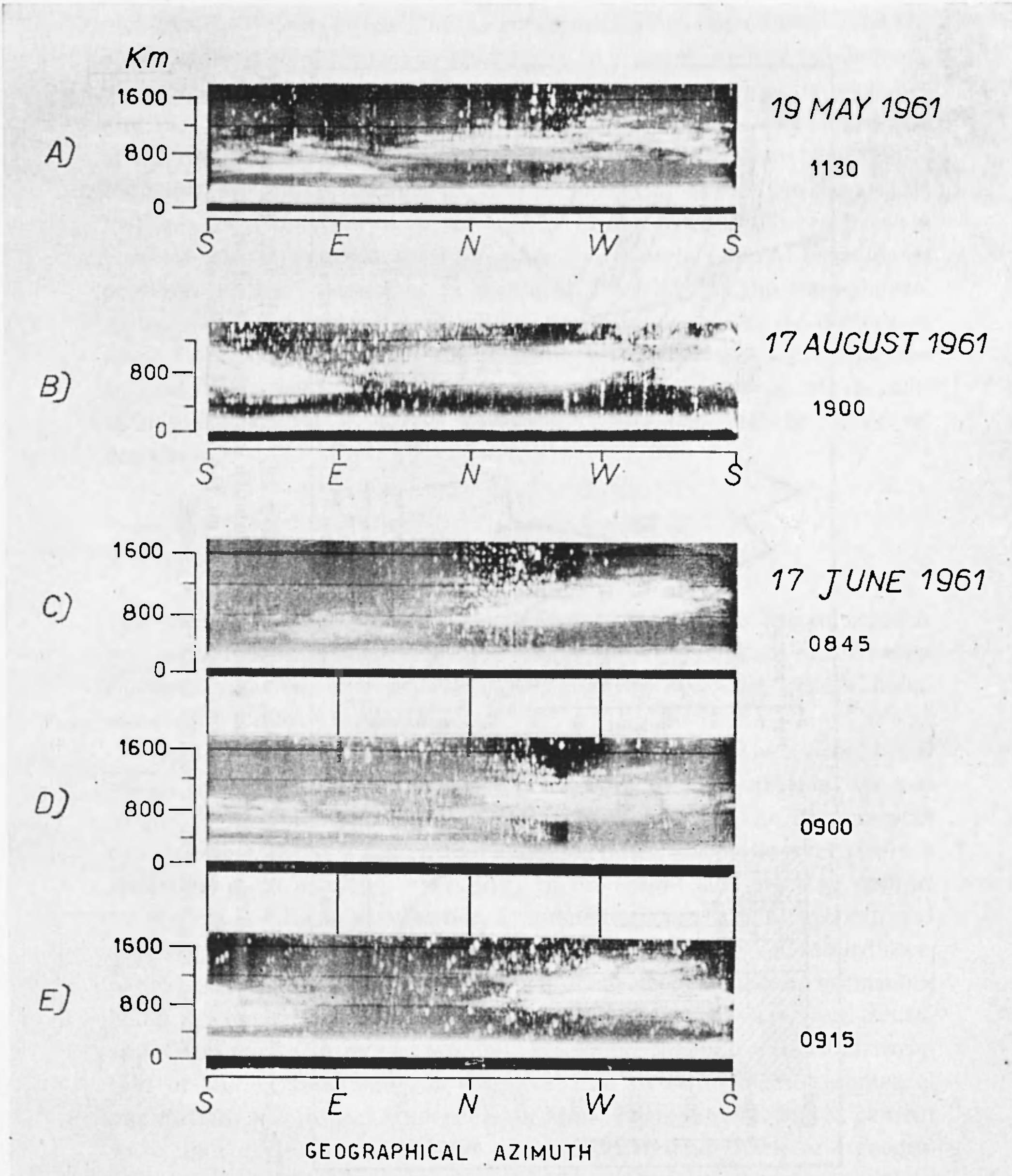

Fig. 10 – Some examples of *Es* echo patterns: « continuous » pattern in A, « fragmented » pattern in B; as to C, D, E, see the text.

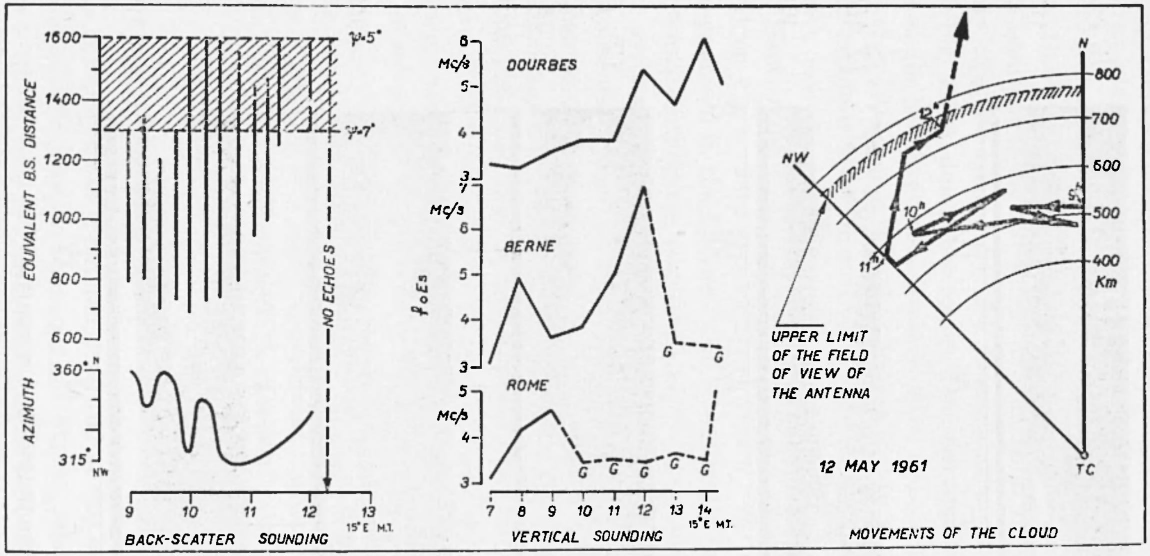

Fig. 11 – Analysis of a moving *Es* cloud, observed on May 12, 1961. On the left, the values of the b.s. equivalent distance and of centroid's azimuth are given: the behaviours of *foEs* at three vertical sounding stations appear to be on the center, while on the right the schematic movement of cloud's centroid is shown.

the cloud disappears. However, it is necessary to take into account the fact that the " field of view " of the antenna does not exceed 1300-1600 km of b.s. equivalent distance, corresponding to a wave angle of 7-5 degrees. So we have to do with a cloud, the disappearance of which is probably due to a drift out of the beam of the antenna rather than to a decay of the dimensions or of the electronic density: such an interpretation is confirmed by the behaviours of *foEs* at Rome, at Berne (Swiss) and at Dourbes (Belgium) shown in the middle of the figure. The real movement of cloud's centroid, with reference to a system of polar coordinates centered on Torrechiaruccia, is shown on the right of the same figure. When the cloud laid entirely within the antenna beam, its dimension along the line of sight from the antenna was about 250 km. This one is even the mean value deduced from the analysis of other individual clouds, and it agrees with the results obtained by other researchers (4).

4. Concluding remarks.

Though the b.s. sounding performed since 1957 at Torrechiaruccia was not specifically devoted to the study of the *Es* ionization, nevertheless the data collected were satisfactorily significant as to the general behaviour of the above ionization.

As to the occurrence of *Es* echoes, the seasonal and the diurnal behaviours took place according to the occurrence of *Es* ionization, the top frequency of which exceeds a critical value related to the frequency of the sounding radio waves. Therefore we must conclude that, from a statistical point of view, the validity of the secant law, relating oblique to vertical incidence propagation frequencies, was reasonably confirmed as to the propagation via *Es* ionization. However we observed some discrepancies as to the azimuthal distribution of the echoes, the echo occurrence being systematically larger from West or North-West than from South, as for the normal *foEs* distribution. We found that an azimuthal variation of the vertical antenna diagram, due to some characteristics of our station, was in part responsible of these discrepancies; but at present we cannot exclude the influence of some other ionospheric and geographical factors. Further experiments and studies are therefore required on this matter.

A statistics of *Es* " clouds " was performed, where from it was deduced that about 60% of the observed clouds were " moving ", their main movement occurring towards South-West; the mean dimension of these clouds was about 250 km.

The remarkable utility of the ionospheric sounding by ground backscatter, both to survey large ionospheric structures and to study the formation and the decay of particular " clouds " of ionization, is quite evidently confirmed.

5. Aknowledgements.

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