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TECHNICAL NOTE

D-1043

SPORADIC-E AS OBSERVED WITH ROCKETS

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WASHINGTON

July 1961

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SUMMARY

Data obtained with rockets flown over New Mexico, U.S.A. and Manitoba, Canada have always shown the sporadic-E layer to be a thin layer with a large electron density gradient. The vertical electron density profiles and the horizontal uniformity of the sporadic-E layer are discussed herein. These layers have a strong tendency to form at preferential altitudes separated by approximately 6 km, and a striking correlation exists with wind-shears and magnetic field variations. In two cases where comparisons with ionograms were possible, the minimum frequency of the F-region echoes was found approximately equal to the plasma frequency of the sporadic-E layer reduced by half the gyrofrequency. On the other hand, the maximum frequency of the sporadic-E echoes as noted on ionograms was sometimes as much as 1 to 2 Mc greater than the plasma frequency.

CONTENTS

Summary	i
INTRODUCTION	1
GRADIENTS	2
UNIFORMITY OF THE E_s LAYER	2
HEIGHT PREFERENCE	7
GRADIENTS IN ELECTRON DENSITY	10
COMPARISON WITH THE PULSE TECHNIQUE	11
TIME VARIATION	11
References	12

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INTRODUCTION

Although sporadic-E has been intensively studied all over the world for the past two decades, it is one of the most difficult of ionospheric phenomena to explain on theoretical grounds. Beginning in 1946, the sounding rocket provided a new means of obtaining measurements. The most accurate measurements of sporadic-E to date have been made with a radio propagation technique devised by Seddon (Reference 1): Two CW harmonic frequencies (either 4.27 or 7.75 Mc and the 6th harmonic) were radiated from the rocket to ground stations nearly underneath the rocket, where the lower frequency was frequency-multiplied by a factor of 6 and mixed with the higher frequency. The result is simply a dc voltage unless the rocket traverses a medium containing free electrons, whereupon a low frequency ac voltage is obtained; the exact frequency depends upon the frequencies radiated, the rocket velocity, and the electron density. Certain assumptions are necessary, the most important of which are: (1) the angle of arrival of the signals does not change; (2) there is no time variation of electron density along the propagation path; and (3) the index of refraction of the medium in the vicinity of the rocket does not change rapidly in a distance of $\lambda/2\pi$ where λ is the vacuum wavelength. Both magneto-ionic components of the lower frequency are utilized to provide a check on the results obtained.

Except during radio blackout conditions, the ground ionograms taken during all but one of the flights in these experiments showed sporadic-E reflections. In one of the flights under blackout conditions, sporadic-E was probably present but the ionogram could not show it. Nine flights made measurements of sporadic-E, but in three of these the measurements were not detailed enough to provide much information. In two of these three flights latter signal loss occurred because the plasma frequency of the sporadic-E considerably exceeded the lower frequency used. Poor rocket attitude in the other flight made the data

discontinuous and less accurate than usual. The remaining six flights, however, provided information not attainable by other means. Of these six flights, three were made over New Mexico and the other three over Fort Churchill, Manitoba, Canada.

GRADIENTS

In all cases, over both New Mexico and Fort Churchill, it was found that the sporadic-E reflections observed on the ionograms were due to thin regions with large electron density gradients superimposed on the normal ionosphere profile. The altitudes of these layers were identical with the measured virtual heights within the reading accuracy of the ionograms. In three out of six cases, the increase in electron density in these layers above a smooth profile was approximately 10 to 20 percent; in one case, the increase was a factor of 2. The layers in the E-region varied in thickness from 500 to 2,000 m and exhibited extraordinarily large electron density gradients, generally about 10^5 to 10^6 electrons/cm³ per km. The ionograms showed constant-height reflections at frequencies up to 2 Mc greater than the plasma frequency of the thin layer. This is not unreasonable, for if it is assumed that the boundary of the layer is sharp with respect to the radio wavelength, the extraordinary ray 2 Mc higher than the plasma frequency has a reflection coefficient of about 5 percent. The highest frequency E_s echo noted during a rocket flight was 8 Mc.

UNIFORMITY OF THE E_s LAYER

One question which has remained unanswered is whether the sporadic-E layer is uniform in electron density or whether it consists of many pancake-shaped high-density clouds. The rocket data have indicated consistently that the whole sporadic-E region remains uniformly enhanced in density throughout. Examination of the ionograms taken at the same time at a station 10 to 80 km distant horizontally reveals that the minimum frequency of the F-region reflections reduced by one-half the gyrofrequency agrees fairly closely with the plasma frequency measured by the rocket in the sporadic-E region. An excellent example of this was described by Jackson and Seddon (Reference 2) for the flight of Aerobee-50. The penetration frequency was 5 Mc which agreed with the electron density at the rocket within 17 to 30 percent. The 17 percent value would apply if the penetrating ray was the Z mode, and the 30 percent value if it was the ordinary ray.

A previous flight over New Mexico (Reference 3) showed that the rocket, immersed in an electron density whose plasma frequency exceeded the radiation frequency (but by

an amount less than half the gyrofrequency), was able to transmit the signal to the ground by way of the Z-mode. Additional evidence was provided through the presence of a reflected ray from the bottom of the sporadic-E region when the rocket was below it. These reflections occurred immediately upon penetration of the sporadic-E region on the descent, and continued during the remainder of the descent. It was calculated from the geometry that the reflection point must have moved 20 km horizontally along the bottom of the layer. During this time there was a small variation in amplitude but never any cessation of the reflected signal. Further, as a result of differential refraction, the ordinary and extraordinary rays would have a horizontal separation at the bottom of the E-region of as much as 1 km during the rocket descent. If, then, there were clouds 1 km or so in vertical thickness present in this layer, with lower electron densities between them, there would have been a substantial difference between the electron densities near the rocket computed from the two magneto-ionic components due to the different electrical path lengths. There seems to be no definite evidence that this was happening. A possible explanation, however, is that there were numerous small clouds very close together, which would tend to average out this sort of effect and so maintain the agreement between the results of the two magneto-ionic components.

Still further evidence of the approximate continuity of the ionization can be found in the V2 flight of January 22, 1948 (Reference 1). The 4.274 Mc signal abruptly disappeared at an altitude of 100 km. For the remainder of the flight, there were only five short occasions when a very weak signal could be detected. These signals were received during only a few seconds of the time the rocket was above the layer (about 4 minutes). They could have been due to a modest decrease in the electron density in the layer, which apparently had a plasma frequency slightly greater than the signal frequency. Comparison with measurements made on the ascent could not be made because the rocket record was very irregular at that time, apparently as a result of rocket out-gassing. (This situation has been considerably improved in recent rockets by using propellant shut-off valves.) However, an interesting comparison can be made with measurements made by a probe technique over Australia, as reported by Massey (Reference 4). Figure 1 shows the similarity between sporadic-E over New Mexico at mid-day with that over Australia at night. The difference in altitude is only about 1/2 kilometer.

The data obtained from a rocket flight at Fort Churchill, Canada at night, along with the corresponding ionograms, are shown in Figure 2. The grid, placed over the ionogram at the ionosphere station, is placed incorrectly, nearly 10 km too low. This could be verified from other ionograms in which multiple echoes were present. The electron density was quite low up to an altitude of about 170 km, with no trace of an E-region except for sporadic layers. The critical frequency of the lowest layer was approximately 1-1/2 Mc, but the ionogram shows sporadic echoes up to 3-1/2 Mc at this same altitude.

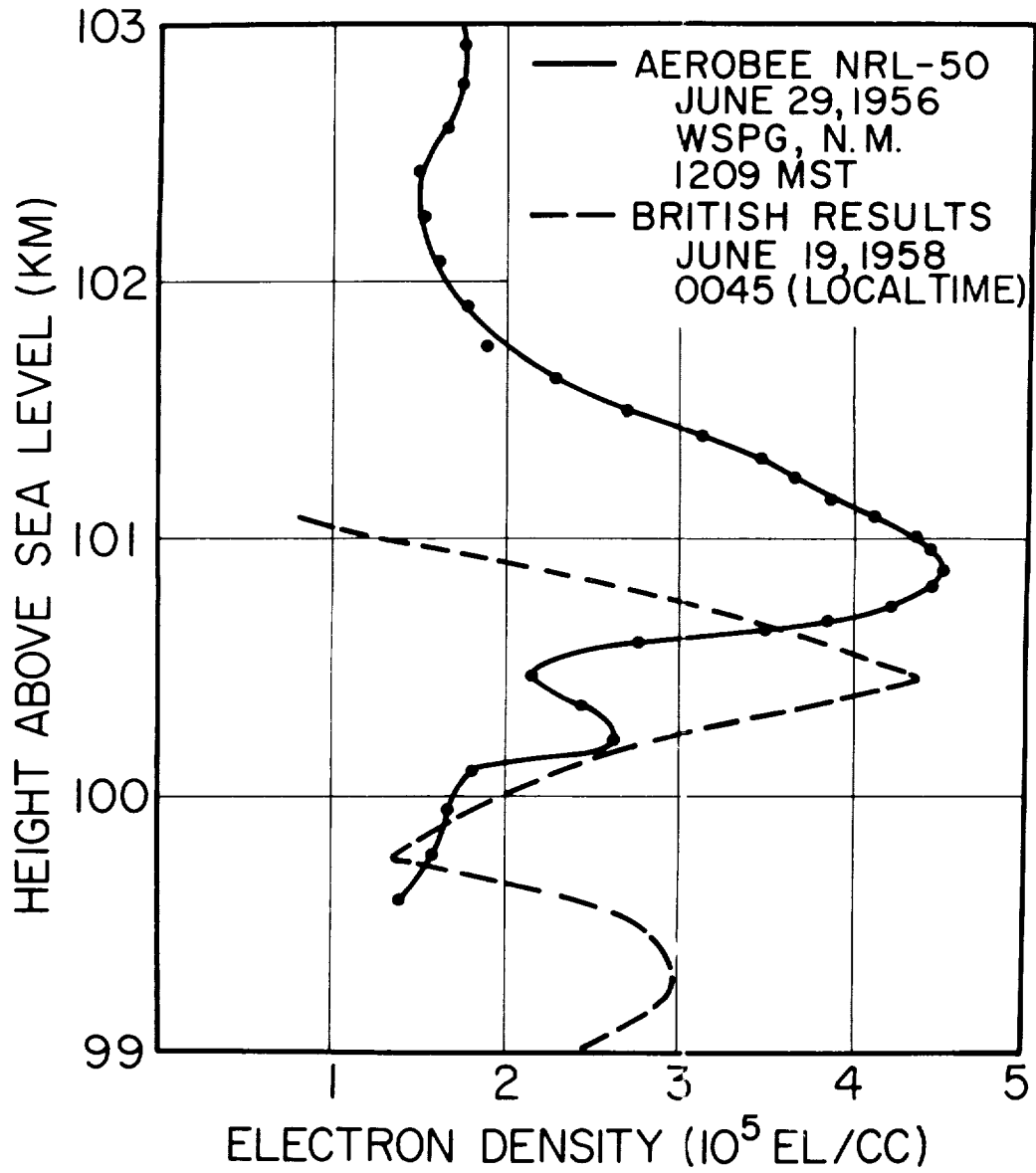
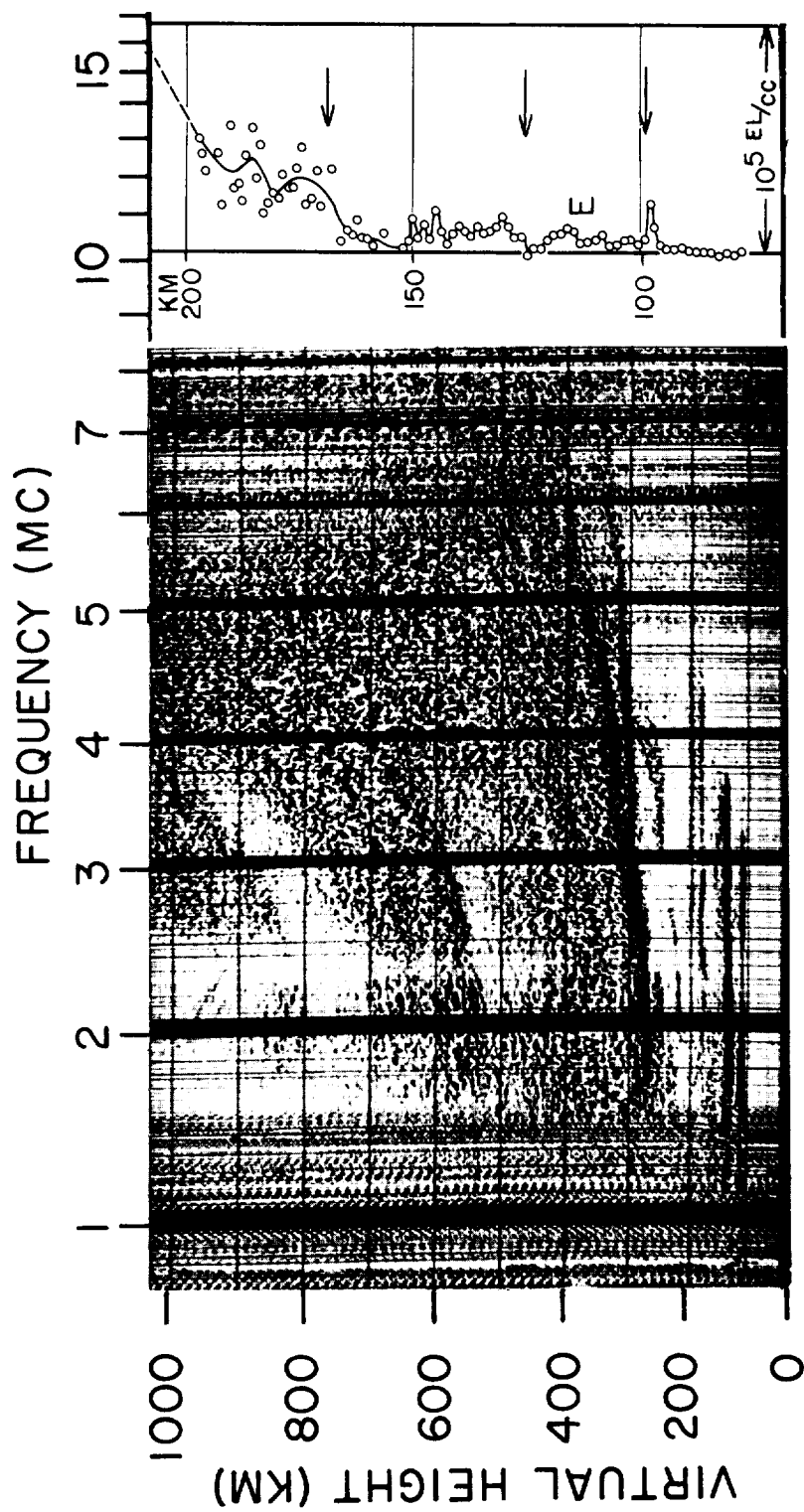


Figure 1 - Comparison of sporadic-E at noon over New Mexico, U.S.A. with that over Woomera, Australia at midnight



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FORT CHURCHILL, MANITOBA, CANADA

Figure 2 - Ionogram and electron density profile for a night flight over Fort Churchill, Manitoba, Canada

Table 1
Altitudes of High Electron Density Gradients

Rocket	Date	Launch Time (hrs-LMT)	Place	Altitudes (km)				
V2 No. 34	Jan. 22, '48	1314	White Sands	100				
Viking 5	Nov. 21, '50	1018	White Sands			109		
Viking 10	May 7, '54	1000	White Sands	100	105	112		129
Aerobee-Hi NRL-50	June 29, '56	1209	White Sands	101			117	
Aerobee-Hi IGY NN3.08F	July 4, '57	1216	Fort Churchill		105			
Aerobee-Hi IGY NN3.10F	Feb. 3, '58	1202	Fort Churchill			110		
Aerobee-Hi IGY NN3.11F	Feb. 4, '58	0017	Fort Churchill	98				129

(Reference 13) shows large wind-shears at altitudes of 92, 100, 107, 110, 115 and 130 km. Thus there are grounds for strong suspicion that the high electron density gradients are associated with wind-shear. This condition has been examined theoretically by Whitehead (Reference 14).

Accurate but unpublished measurements of the earth's magnetic field with a proton precessional magnetometer over Fort Churchill (by Meredith et al., Reference 15) show a number of maxima between 70 and 140 km. The average separation between these maxima is approximately 6.5 km. The altitudes at which the magnetic field was a minimum correspond to the altitudes of sporadic-E.

Temperature measurements are difficult in the E-region, but the pitot-static measurements of Ainsworth, Fox and Lagow (Reference 16) show definite minima at 73 and 92 km. At lower levels, between 30 and 70 km, there are small variations in the temperature profile with approximately 6 km separation between the peaks except for one case of 13 km separation. Ainsworth (Reference 17) found that the vector wind gradient $|\vec{dv}/dh|$ had

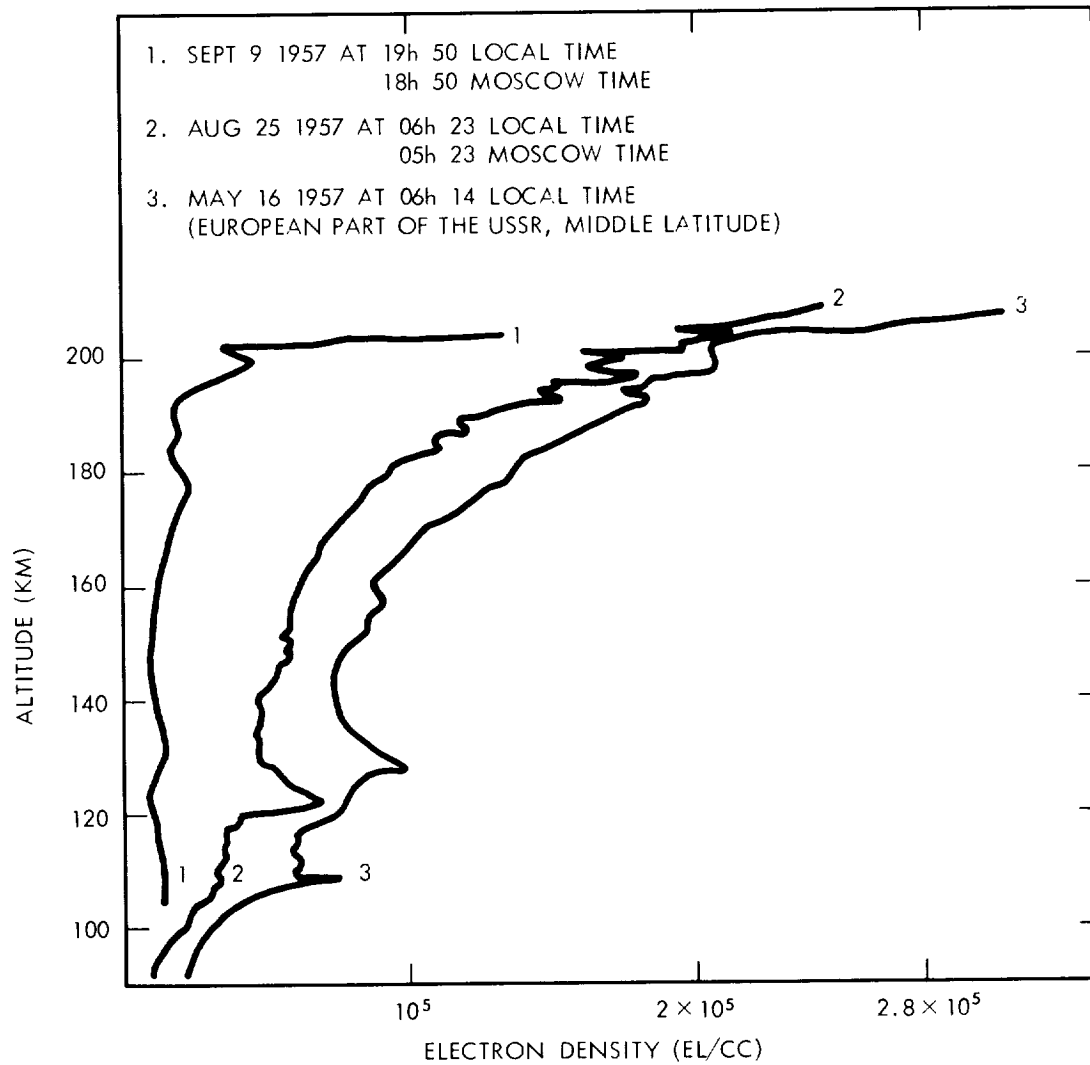


Figure 4 – Russian results using a CW technique (from Doklady Akad. Nauk S.S.S.R., and Proc. IRE, February 1959)

below the rocket, or because of inhomogeneities in the ionosphere in a horizontal direction which result in changes in the electron content along the propagation path with horizontal motion of the rocket. Some error can indeed be introduced by these mechanisms. However, two stations 10 kilometers apart give data that agree within about 5 percent. Moreover the ordinary and extraordinary components at each station are in similar agreement with each other. Still further, the computation of the virtual height at various frequencies shows good agreement with the ionograms taken at the same time. In order to account for the high electron densities in the sporadic-E layer measured during the flight of Aerobee-50 where large electron densities were observed, we might consider the error introduced by having all the ionization between 75 and 100 km double in value in a period of 1-1/2 seconds, the transit time of the rocket through the layer. This extremely improbable situation is still a factor of about 5 below that needed to account for the observed results. In addition, it can be pointed out that even when these thin, high gradient layers do not increase greatly in electron density, sporadic echoes are invariably found on the ionograms at these exact heights. The rocket results obtained thus far on sporadic-E by the CW propagation technique simply cannot be explained either by time variation of electron density or by interception of irregularities through the horizontal motion of the rocket.

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