National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No. NAS-5-9299

ST - AI - 10499

ON ONE OF THE POSSIBLE FORMATION MECHANISMS OF NARROW SPORADIC IONOSPHERE LAYERS

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(USSR)

FACILITY FORM 602

N67 13541	
(ACCESSION NUMBER)	(THRU)
7	1
(PAGES)	(CODE)
CR 80659	13
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 1.00

Microfiche (MF) .50

ff 653 July 65

7 JUNE 1966

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Geomagnetizm i Aeronomiya
Tom 6, No. 2, 397 - 399,
Izdatel'stvo "NAUKA", 1966

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SUMMARY

The difficulty in ascertaining the origin of sporadic E_s-layers by explaining the small thickness and the large electron concentration gradient is overcome by assuming the existence in the 100 — 1000 km altitude range of fluxes of trapped electrons with close pitch-angles.

* * *

The formation of the sporadic E_s-layer is one of the mysterious phenomena in the ionosphere. There are many types of E_s-layers, having different characteristics. We shall consider here the spradic E_s-layers investigated with the aid of rockets. Compiled in Table 1 are the observation data on their height $\underline{h}$, width $\underline{\Delta h}$, electron concentration n_e^* and its rise relative to n_e in neighboring heights.

The material brought out in Table 1 allows to subdivide the E_s-layers into two types: 1) layers with little excess of n_e^* over n_e (10 — 20%), of which the width is ~ 5 km; 2) narrow layers with sharp increase in the electron concentration (up to one order of magnitude), whose widths may constitute 1 — 3 km and less, while the gradient of electron concentration reaches up to $\sim 10^6 \text{ cm}^{-3} \cdot \text{km}^{-1}$. The frequency increase of E_s appearance with the rise of geomagnetic latitude and its link with the geomagnetic activity point to the fact that the sporadic type-E_s ionization may be induced by a flux of charged particles in the atmosphere.

(*) OB ODNOM IZ VOZMOZHNYKH MEKHANIZMOV OBRAZOVANIYA UZKIKH SPORADICHESKIKH SLOYEV IONOSFERY.

Comparatively wide layers may be formed by fluxes of pouring out electrons with rather low energy of 10 – 30 kev. Because of strong scattering at heights of E_s formation, the orienting action of the magnetic field of the Earth has little influence on the motion of these electrons. As is shown by calculations, even monochromatic electrons form at 100 – 110 km layers with sufficient width $\Delta h = 10 - 20$ km [17]. This is why, either monochromatic electrons, or electrons with a very steep spectrum are necessary for the explanation of sporadic layers of the first type. This mechanism does not allow to explain the formation of very narrow sporadic layers E_s with great increase of the electron concentration.

TABLE 1

DATE	h, км	Δh, км	n^*, см$^{-3}$	n^*/n_e	REF.
22.I 1948	100	8	$1{,}6\cdot10^5$	1,25	[1]
15.XII 1952	103	6,4	10^5	1,25	[2]
7.V 1954	100	2	10^5	1,1	[3]
4.VII 1957	105	5	$2\cdot10^5$	1,1	[4]
29.VI 1956	100,9	1,2	$4{,}5\cdot10^5$	2,5	[5]
4.II 1958	[illegible],5	1,4	$2{,}6\cdot10^4$	6	[5]
14.VII 1959	115	3	$1{,}6\cdot10^5$	1,25	[6]
14.VII 1959	105	4	10^5	1,25	[6]
15.XI 1961	128	8,3	$7{,}2\cdot10^4$	1,25	[7]
18.X 1962	110	8	$1{,}35\cdot10^5$	1,1	[8]
28.VI 1960	100	3,3	10^4	1,25	[9]
26.IX 1960	101	4	$8\cdot10^3$	1,25	[10]
17.VIII 1961	102	1,5	$1{,}1\cdot10^4$	6,8	[11]
27.X 1961	112	2	$6\cdot10^3$	3,1	[11]
27.X 1961	108	1,5	$6\cdot10^3$	3,1	[11]
6.XII 1961	113,5	1	$2{,}56\cdot10^5$	2	[12]
16.V 1962	108,5	5	$5{,}3\cdot10^3$	3	[13]
16.V 1962	98,5	4,5	$1{,}25\cdot10^5$	4,5	[14]
25.V 1962	102,9	3	$2{,}5\cdot10^5$	2,5	[15]
28.XI 1962	95	0,5	$1{,}7\cdot10^4$	6	[16]
28.XI 1962	116	2,1	$2{,}9\cdot10^4$	3,5	
30.XI 1962	100	1	$1{,}1\cdot10^4$	3	
30.XI 1962	114	3	$1{,}2\cdot10^4$	2	
12.VI 1963	93	2	$1{,}2\cdot10^5$	4	
12.VI 1963	95	1,5	$1{,}2\cdot10^5$	4	

As may be seen from Table 1, such layers constitute a significant fraction of the total number of sporadic layers observed with the help of rockets; however, so far no satisfactory formation mechanism has been proposed for them.

Proposed in the present communication is a mechanism of narrow E_s-layers' formation by electron fluxes of high energy $\sim 10^5$ ev, trapped by the Earth's magnetic field.

A sufficiently narrow ionization layer may be formed near the reflection point of a charged particle moving helicoidally in the geomagnetic field, inasmuch as at approaching the reflection point, the loops of particle's trajectory thicken. Let us estimate the profile of the rate q of ion formation, induced by a continuous flux of hard electrons with reflection point at heights 100 – 110 km. The concentration of the freshly forming ions q per unit of time at the height Δh above the reflection point, will be determined by the flux density of incident electrons, which is inversely proportional to the displacement velocity of the charged particle along the magnetic line of force

$$v_{\|} = v\sqrt{1 - H/H_0}, \qquad (1)$$

where v is the total velocity of the electron ; H and H_o are respectively the intensities of the magnetic field at the considered point and at the reflection point. Near the latter $(H_o - H) \sim \Delta h$. This is why, as it gets nearer to the reflection point, the quantity q will increase according to the law

$$q \sim (\Delta h)^{-1/2}, \qquad (2)$$

provided we neglect the effect of atmosphere density variation over the distance Δh. For example, as Δh decreases from 1 km to 10 m and then to 10 cm, the quantity q increases by respectively 10 and 100 times, Thus, the assumption of the existence of a beam of electrons with close reflection points permits the explanation of the formation of quite narrow ionization layers with $\Delta h < 1$ km and $n_e^*/n_e \geqslant 2 - 3$. At the same time the energy of electrons must be sufficiently great for the scattering not to take place.

In order to conduct concrete calculations it is important to determine the maximum value q_{max} at the reflection point. Formula (2) gives $q_{\Delta h \to 0} \to \infty$, ; however, from the physical viewpoint it is evident that the quantity q is limited, inasmuch as the time of particle motion to the reflection point is finite. Taking into account (1), we may obtain that the motion time of the particle to the reflection point $\Delta t \sim \sqrt{\Delta h}$. – Assuming Δt equal to the Larmor revolution period, it is possible to estimate the thickness of the atmosphere layer, traversed by the electron at effecting a single revolution around the line of force. The mean value of q in the cylinder described around the first loop at the reflection point, gives the value

$$q_{\max} = d_0 \frac{2}{rl}, \tag{3}$$

where d_o is the linear density of ions, having formed at passage by the electron of a 1 cm path; r is the radius of the loop. The results of calculation for electrons with energy E = 100 and 30 kev for the geomagnetic latitude $\sim 45^\circ$ at 110 km altitude are compiled in Table 2.

TABLE 2

E, кэв	d_0, $см^{-1}$	r, см	l, см	$q_{\max}$, el·$см^{-3}$
100	10^{-5}	$2,2 \cdot 10^3$	0,15	$0,5 \cdot 10^{-7}$
30	$2 \cdot 10^{-5}$	$1,25 \cdot 10^3$	0,05	$0,7 \cdot 10^{-6}$

At 100 km the density of the atmosphere is five times greater and this is why q_{max} must also be 5 times greater. The choice of greater energy is determined by the fact that the mass of the atmosphere, covered by the electrons till the reflection point, must be substantially less than the path. We may start also from the condition that there be no more than one collision at the electron over the last loop, for after collision, the direction of motion of the electron in the atmosphere is somewhat disrupted and conditions can not be realized for the electron to be absorbed in the atmosphere (in this case $\bar{q}_{\max} \approx (\pi r^2 l)^{-1}$ and the estimates will be by one order higher than in the Table 2 for h = 110 km). At heights below 110 – 105 km, this condition is no longer satisfied for electrons with energy $E \lesssim 30$ kev.

Let us estimate the power of the electron flux, required for the explanation of formation in the sporadic layer of n_e^* up to $\sim 10^5$ cm^{-3}. We shall estimate that the measured n_e^* represents a stationary value (in the opposite case the estimate of q will be less hard). Assuming the effective recombination coefficient in the altitude range 100 – 110 km to be $\sim 10^{-7}$ cm^3 sec^{-1}, we shall obtain $q \approx 10^3$ cm^{-3} sec^{-1} in the layer maximum. Taking into account the value of q_{max} in Table 2, we shall obtain that for the formation of the layer at 100 km altitude by electrons with energy of 100 kev, a flux $\sim 10^{10}$ electron/cm^2 sec is required, and for layer formation at 110 km about the same flux will be necessary but with energy ~ 30 kev. Thus, the power of electrons is $\sim 10^3$ erg/cm^2 sec (this value could be decreased by one order by utilizing the second criterion for the estimate of q_{max}. According to contemporary representations, the emergence in the upper atmosphere of sporadic local fluxes of trapped electrons of such power may be admitted. Such fluxes were observed on satellites.

The works [18, 19] speak in favor of realism of the proposed mechanism; in these works it was established on the basis of the observation material diring the time of IGY and IGC that the sporadic E_s-layer appears simultaneously in magneto-conjugate points.

In connection with the fact that at passing from one hemisphere to the other every electron loses $\sim 0.1 - 0.01$ % of its energy, the latter's total amount should be sufficient for $10^3 - 10^2$ such passages. This would correspond to the observed existence time of sporadic layers of $\sim 10^2 - 10^3$ seconds.

Therefore, the assumption of the existance at 100 – 1000 km heights of fluxes of trapped electrons with close pitch-angle values allows to overcome one of the essential difficulties of explanation of sporadic layers, that is, the explanation of the small thickness and of a great electron concentration gradient. The proposed mechanism agrees well also with the representation about the floccular or cloudy structure of E_s.

***** THE END *****

Institute of Applied Geophysics

Manuscript received
on 6 August 1965.

Contract No.NAS-5-9299
Consultants and Designers, Inc
Arlington, Virginia

Translated by ANDRE L. BRICHANT
on 6 June 1966

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