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ROCKET OBSERVATION OF ION DENSITY IN THE IONOSPHERE

By

Yuichiro AONO, Kunio HIRAO and Shigeru MIYAZAKI

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ABSTRACT

In September, 1960, the first experiment of rocket observation of the ionosphere in Japan was carried out at the Michikawa Rocket Range by using a K-8 rocket and an ion detector. Day and night observations were made with success. Both rockets reached the altitude of about 180 km, and the observation of the *E* and *Es* layers and of the lower part of the *F* layer were carried out.

1. Introduction

On the 22nd and the 26th of September, 1960, two Kappa-8 rockets, K-8-3 and K-8-4, were sent up to observe the ion density in the ionosphere, one being for the daytime observation on the 22nd and the other for the nighttime observation on the 26th.

These Kappa-8's were the 2nd stage rockets measuring 420 mm in the maximum diameter and about 10 m in length. The instruments installed were an Ion density detector, a cosmic ray detector, a thermometer, a telemeter, a rader transponder, a timer, and the opening mechanism of nose cone. The total weight of the payload was about 15 kg.

The K-8-3 rocket was sent up at 15 h 32 m and reached the maximum altitude of 187 km and the K-8-4 at 20 h 25 m to the altitude of 183 km, both succeeded in the measurement of positive ion density.

The measurement of positive ion density in the ionosphere is very important to discuss ion on the physical state of ionosphere, and has already been made by USA and USSR investigators by means of Langmuir probe and Ion Trap. In Japan, the rocket-borne positive ion detector using the double-probe method has been investigated since 1956. K. Takayama, et al. investigated the electron emission from a probe by the photoelectric effect of solar radiation and concluded that the error in ion-density by photoemission could be depressed to a negligibly small amount by using the meshed probe. This is a very important point in the ion density measurement by vehicle in the ionosphere.

In 1960, the test flight of Kappa-8 rocket was carried out successfully and the Kappa-8 rocket became available for a sounding rocket. By this time, the fundamentals of rocket observation of ion density were investigated and the design and

construction of an ion detector started. In July, the first ionosphere sounding rocket was sent up. But, as the nose cone of the rocket did not open and the probe was not exposed in the ionosphere, the observation failed though the ion detector was fund to work completely by telemeter. The next experiments were made in September, 1960. The present paper is the report on these experiments.

The principle of the ion detector is that of Langmuir probe. As described previously, the meshed spherical probe was used in the daytime observation. In the nighttime observation, however, an ordinary spherical probe was used, because there was no solar radiation at night.

The ionosphere exists above the height of about 80 km and spreads to a very high altitude. The molecular density of ionosphere, therefore, changes very widely, so the analysis of ion current is not simple. Furthermore, as the rocket vehicle moves with the velccity of some Machs, the analysis becomes more complicated. T. Dote made these analyses[2], which was published in the Journal of the Physical Society of Japan.

2. Instrument Used

The measurement of ion density is made by applying variable voltage to a probe and measuring the probe current.

The measuring circuit is shown in Fig. 1. The voltage is changed continuously from +10 V to −20 V and then step by step in every 10 V from −20 V to −100 V through the potentiometer RV 1.

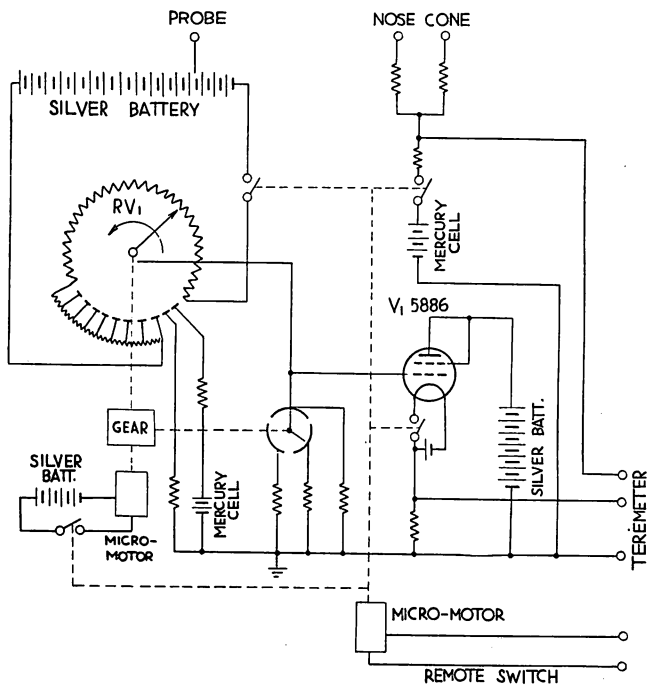


Fig 1. Measuring Circuit of Ion Detector.

The impressed voltage is supplied by the silver battery which is completely floated from the case by insulator. The potentiometer RV 1 has two other contact points, one of which is the zero current calibrator and the other is the standard voltage calibrator by Mercury cells of 3 volts. As a probe current is very weak, a high load resistance is neccessary for measurement. Further, the ion density of the ionosphere is expected to vary in a very wide range during the flight of the sounding rocket. So the load resistance is determined to select three values, 2 MΩ, 10 MΩ and 50 MΩ. These three resistances are connected to a three-sectioned commutator, and the commutator is driven synchronously with RV 1. The ratio in revolution number of the RV 1 to the commutator is 1: 3. This revolving system is driven by both the gear system and the micromotor. Another micromotor is in the instrument, which controls 4 switches in the circuit. This motor is used for remote control of the start-and-stop of the instrument. As the voltage on the load resistance cannot be directly supplied to the telemeter because of the extreme high load resistance, an electrometer tube 5886 in used as a cathode follower for the impedance change. The power source of this tube is two silver batteries. Through this cathode follower, the measured value is supplied to the telemetere as a D. C. signal of 0-5 volts. In the same metal case of the instrument, there is a generator of signal, which shows the time of opening of the nose cone. From the two terminals, two short lead wires are connected to two pieces of nose cone, respectively. If the nose cone opens then the lead wire is cut by the inertia of the moving nose cone, and the current is stopped. Therefore, the telemeter signal shows a sudden life of level at the time the nose cone moves off.

The above system is enclosed in an aluminum case measuring 164 mm in diameter and 95 m in length. The maximum diameter is 200 mm. This case is sealed off from the surrounding atmosphere in order to avoid any kind of discharge in the case where it lower in pressure on account of the maximum electrical voltage of about 100 V. At the center of the front case, a spherical probe is set by means of a long supporting rod, in order to avoid any interference between the ion sheath of the probe and that of the rocket. The rod is made of duralumin and is coated with silicon resin to be insulated electrically from the environment. This rod is insulated from the case by a circular disc of ebonite which is also coated with silicon resin. The rod is 591 mm long. All the probes are 20 mm in diameter. The meshed probe is made of molybdenum wire of 0.3 mm in diameter and the cross points are fixed by spotwelding. Both the meshed and the spherical probes are gold-plated, as a work function of gold is large and gold is stainless.

The electrical insulation of all parts is kept as high as possible, because the measuring current is as weak as 2–3 μA in its maximum condition. In order to avoid the temprature raise due to heat radiation from the wall of the rocket, the side wall of the case is covered with asbestos cloth and aluminum film. Further, the conduction of heat from the rocket body is stopped by the use of a thermal insulater in the part of holding the ion detector to the rocket. The outside view of the ion detector is shown in Fig. 2 and the opening test of the nose cone in Fig. 3. The G test is made up to 100 G. The vibration test in all directions is made up to 2000 rpm in amplitude of 2 mm. The total weight of this detector

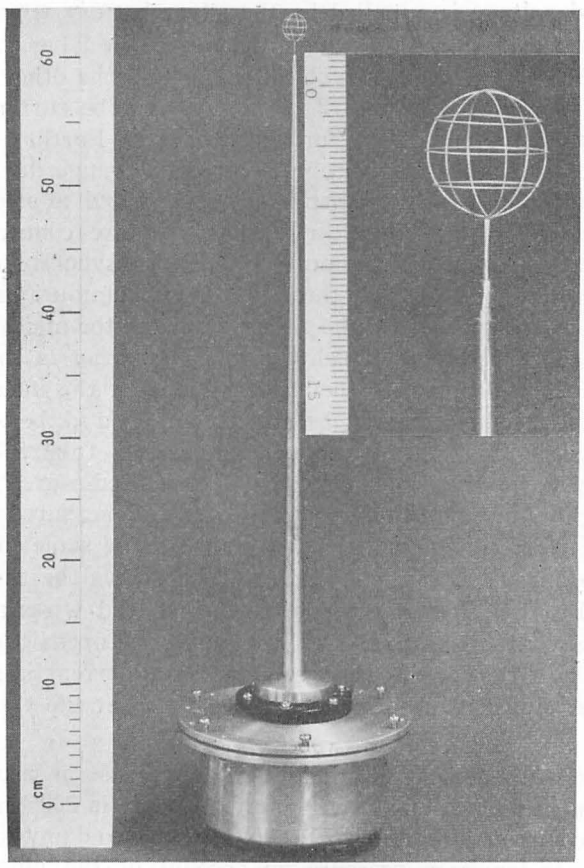


Fig. 2. View of Ion Ditector

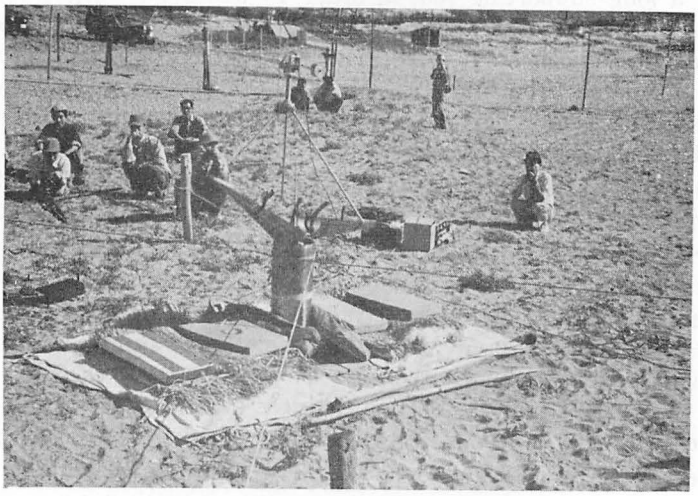


Fig. 3. Field Test of Opening of Nose Cone.

is 2.75 kg. The final design and construction were made by T. Sugiyama and T. Muraoka of the Yokogawa Electric Works.

3. Observation and Results

The site of the rocket is at Michikawa, Akita Prefecture, in the northern part of Japan.

The daytime observation was made by the K-8-3 rocket which was sent up at 15 h 32 m on the 22 nd September, 1960. It reached the altitude of 187 km. The nose cone opened at an altitude of about 60 km and then the probe was exposed in the atmosphere. The ion current flowed almost just after tne opening of the cone. The probe current increased as the rocket ascended, and attained to the maximum of about 2.5 μA at the top of trajectory, and then decreased with the descent of the rocket and became almost zero at an altitude of 60 km. But, when the rocket descended to an altitude of about 30–40 km, the probe current increased again. It is considered to have been caused by a thermal emission from the probe which became hot by friction between the surface of the probe and the surrounding air. The thermal emission became larger and larger and at last the current stopped to zero, then the probe was considered to be destroyed completely.

The night observation was made by the K-8-4 rocket sent up at 20 h 25 m on the 26 th of September, 1960. It reached the maximum altitude of 183 km. The nose cone opened at an altitude of about 60 km. The probe current began to flow above the height of 70 km and also increased with the height to the maximum of about 1 μA. During this flight the probe current showed an abrupt increase at a height of about 110 km in both ascent and descent measuments. These increases correspond to the sporadic E layer as shown later on. In this flight also, the thermal emission current existed at the time of reentry into the atmosphere. The profile of ion current at the probe potential of -100 V is shown in Fig. 4.

The ion density profiles were calculated by T. Dote. The elements necessary for analysis, such as temperature, density and molecular number, were determind from Yonezawa's model atmosphere.[8]. The calculated ion density profiles are shown in Figs. 5 and 6. In these figures, the ordinate is for the height in km and abscissa for the logarithmic expression of the ion number in cm^3.

The ionospheric observation station is in Akita city 18 km to the north of Michikawa. The simulataneous observations of both rocket sounding and vertical-incidence sounding from the ground were made at the Akita Radio Wave Observatory. As the rockets were sent up almost westwards with the launching angle of about 80°, the points of observation by rocket were about 100 km and 250 km apart from the Akita Radio Wave Observatory in the case of ascent and descent observation, respectively.

4. Consideration of the Results

Figs. 5 and 6 show very zigzag features. In order to smooth the distribution, the running average values of three successive values are computed and smoothed in distributions as shown in Figs. 7 and 8 corresponding to the day and night

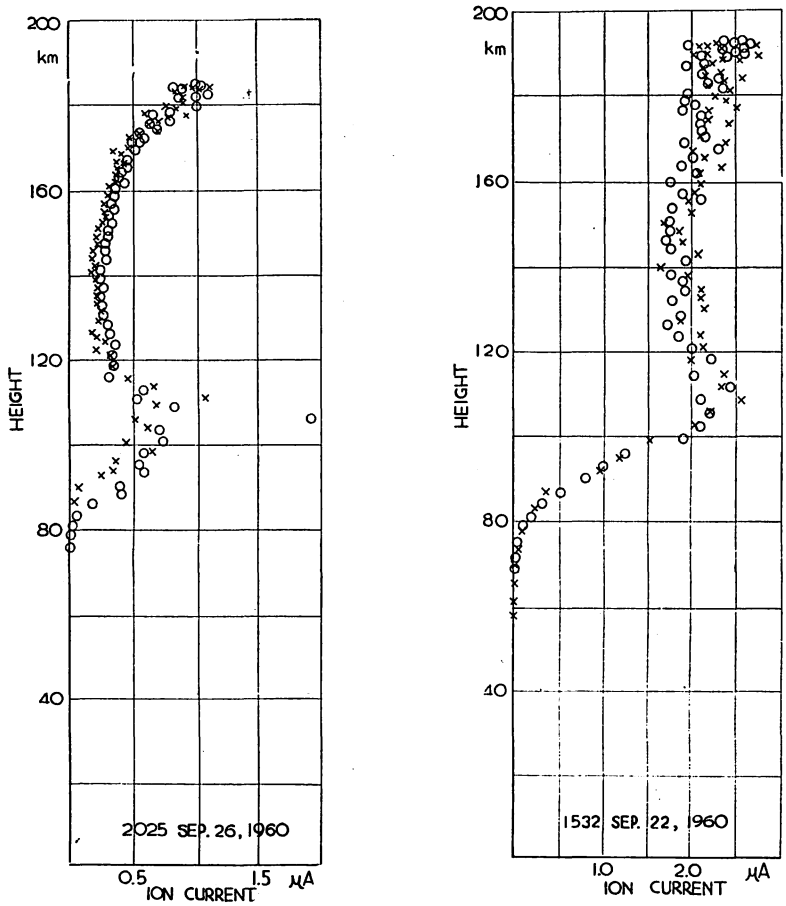


Fig. 4. Vertical Distribution of Ion Current. ○: Ascent, ×: Descent

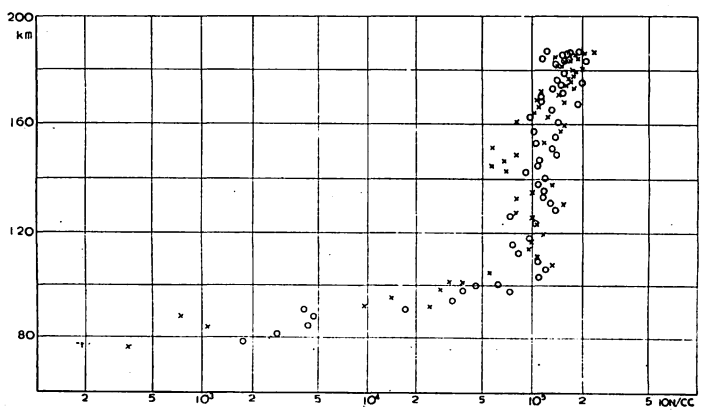


Fig. 5. Ion Density Observed on September 22, 1956 (Daytime).
○: Ascent, ×: Descent

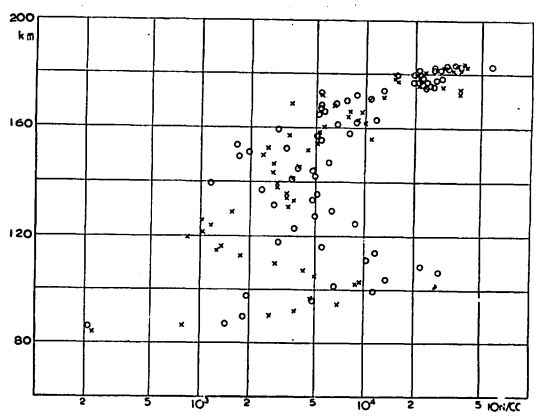


Fig. 6. Ion Density Observed on September 26, 1960 (Nighttime).
○: Ascent, ×: Descent

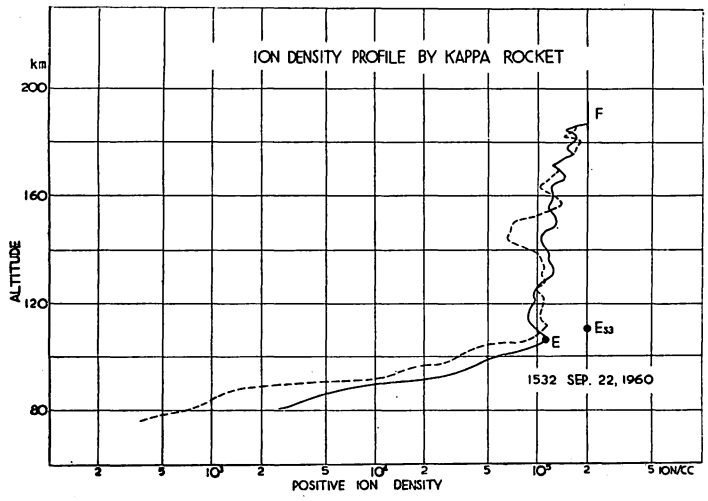


Fig. 7. Smoothed Ion Density Profile on September 22, 1960 (Daytime).
—— Ascent, - - - Descent

observations, respectively. The autocorrelation analysis is made of the difference between original and averaged values. The results of analyses show no predominant periodicity and this fact shows that the observed ion density was not affected by a spin motion of rocket.

In Fig. 7 a black point E shows the real height of the E-layer observed by the vertical incidence sounding at the Akita Radio Wave Observatory, Es shows that of the Sporadic E layer, and the vertical real line named F shows that of the f_{min} F. The calculation of retardation of radio wave was made on the assumption that the electron density distribution was the same as the ion density distribution observed by rocket. Though the sporadic E layer does not correspond

between rocket and ground data, both the E layer and the point of f_{min} F correspond very well. The discrepancy of the sporadic E layer is considered to be caused by the difference of points of observation, and it gives some suggestion about the structure of the sporadic E layer.

It is noticeable that the E layer continues to the F layer gradually and a valley does not exist between these two layers. It is true also in the later observations as shown in Fig. 9.

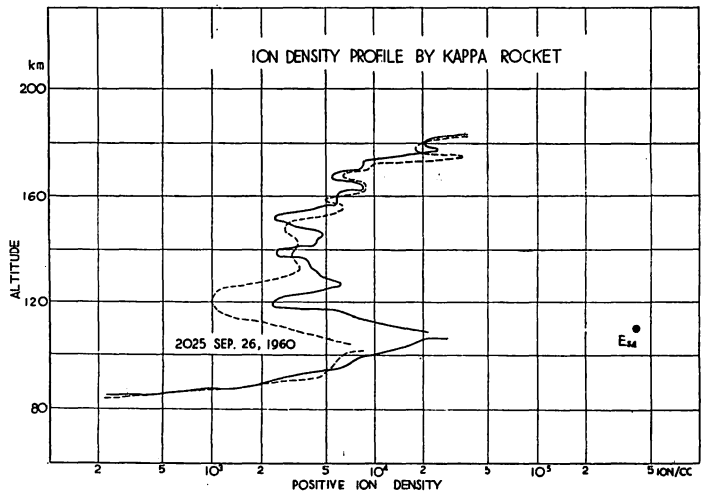
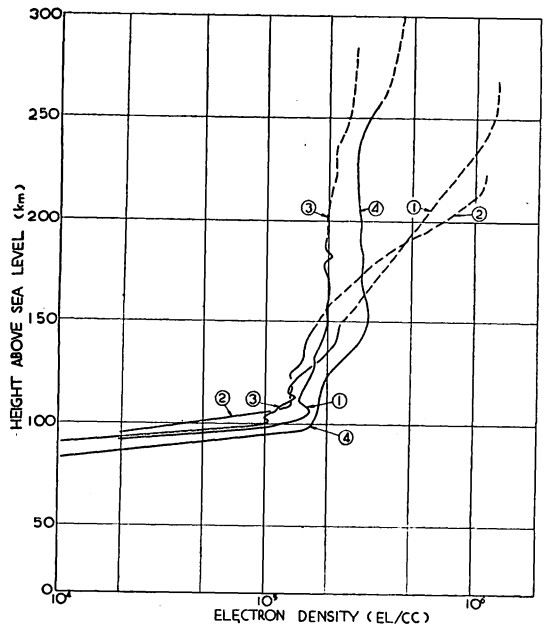


Fig. 8. Smoothed Ion Density Profile on September 26, 1960 (Nighttime).
—— Ascent, - - - Descent

In Fig. 8, a black point Es shows the real height of the sporadic E layer observed by the vertical sounding incidence at the Akita Observatory. As previously described, the measurement of ion density by rocket was made intermittently. The analyses were made of the probe current corresponding to the probe voltage of -20 V and of the characteristic curve obtained by the load resistance in series of 2 MΩ. The data of observation in Fig. 8, therefore, cannot completely express the distribution. The rocket data of the height of the sporadic E layer agreed well with the ground data, but the correspondence in density of both data remains unknown. The sporadic E layer was observed during both ascent and descent flights. Two points of observation are about 170 km apart. These three points of observation being considered, the sporadic E layer on this night has a lateral dimension greater than 200 km. And the thickness of the observed sporadic E layer is about 2–3 km.

The E layer in this observation has an ion density of about 10^4 or less. N. Wakai[4] has shown that the non-deviative absorption of short waves at night can be explained well by the same electron density as this ion density in the E-layer. The valley between the E and F layers at night is rather deeper than in the daytime.



① 1000 MST SEPT. 29, 1949, WSPG N. M.
② 1018 MST NOV. 21, 1950 WSPG N. M.
③ 1000 MST MAY 7, 1954, WSPG N. M.
④ 1209 MST JUNE 29, 1956, WSPG N. M.
SOLID CURVES-ROCKET DATA
DASHED CURVES-EXTRAPOLATION, USING P'-F RECORDS

Fig. 9. U. S. Naval Research Laboratory Rocket Measurements of the Ionosphere. (After Newell H. E.)

At the top of the trajectroy, the rocket flew horizontally. So the ion density fluctuation shows horizontal irregularities of ion density in the ionosphere. Here, the ion density data during the horizontal flight of the rocket within the height difference of 1 km were adopted as shown in Fig. 10. The intensity of irregularity or the ratio of the RMS value of the density fluctuation to its mean value is almost 20%. The statistical scale of irregularity cannot be obtained exactly for lack of data available for calculation of the statistical scale. Fig. 10 shows, however, that such a scale is more or less 10 km. Finally, a comparison of the rocket data with the grounded *h'-f* curve is made. Using the Shinn and Whale's[5] group refractive index expression, and assuming that the ion density profile is equal to an electron density profile, an *h'-f* curve expected from the rocket data is calculated as shown in Fig. 11. In this figure are shown the *h'-f* curve obtained by the vertical incidence sounding, the *h'-f* curve expected from the ion density distribution, and the *h-f* curve of ion density. The hatched area is the error area. This figure shows that the two *h'-f* curves agree generally well with each other, except below the height of 140 km in the *h'-f* curve. This discrepancy corresponds to the height below 110 km in the real distribution and suggests the existence of negative ion.

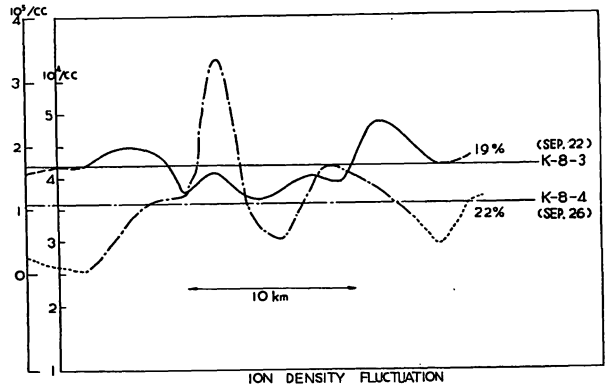


Fig. 10. Ion Density Fluctuation at the Top of the Trajectory of the Rocket.

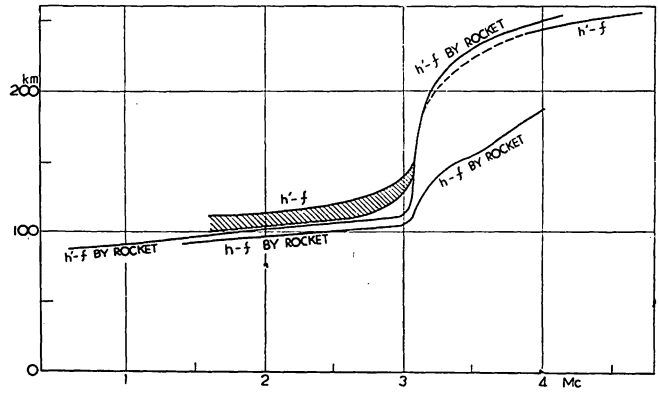


Fig. 11. Comparison between Observed h'–f Curve and Calculated h'–f Curve.
h'–f: Observed at the Akita Radio Wave Observatory;
h'–f by Rocket: Calculated from the rocket data, Assuming the electron density to be equal to the ion density;
h–f by Rocket: True distribution.

5. Conclusions

The authors are led to the following conclusions:

1) The ion density in the ionosphere can be measured by means of the Langmuir probe methode with a meshed spherical probe in the daytime without any interference of photoemission.

2) The ion density distribution obtained by the rocket measurement agrees fairly well with the electron density distribution obtained by the grounded radio observation.

3) The sporadic E layers observed at night are very thin and dense.

4) The E layer at night has an ion density of about 10^4 numbers per cc.

5) The valley between the E and F layers is not so deep in the daytime, while it is rather remarkable at night.

6) The horizontal irregularity of ion density has an intensity of about 20% and a scale of about 10 km at an altitude of 180 km.

7) Below the E layer, some negative ions may exist.

Though the rocket observations were successful, there are some problems in the analysis of probe current, especially of moving electrode. Such problems will be cleared up by theoretical and experimental investigations in the near future. The instrument will also be improved before the next experiment so as to remove the effect of large stray capacity of the probe rod.

6. Acknowlegments

In this experiment, the theoretical treatment and analysis of probe measurements were made mainly by Mr. T. Takayama and Mr. T. Dote of the Telecommunication Laboratory of the Nippon Telegraph and Telephone Public Corporation. The authors express their sincere thanks for the kind collaboration received. The authors extend their grateful thanks also to Mr. T. Sugiyama and Mr. T. Muraoka of the Yokogawa Electric Works for the elaborate work on the design and construction of the instrument and for the cooperation given in the observation at Michikawa.

The installation of the instrument and the rocket firing were made by members of the Institute of Industrial Science of Tokyo University and many members of the Japanese rocket team, to whom the authors' sincere thanks are presented.

Prof. K. Maeda of Kyoto University and Dr. H. Uyeda, Director of the Radio Research Laboratories, gave much kind instruction and encouragement, for which the authors wish to express many thanks.

At the Akita Radio Wave Observatory were made the simultaneous observations of the ionosphere by the vertical incidence sounding. Also, here was made the final adjustment of the rocket-borne ionospheric sounding instrument. The authors would like to record their hearty thanks to members of the Observatory for the special help and cooperation given.

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