IV. Investigation of the Upper Atmosphere by Rocket Sounding

-- Ken'ichi MAEDA --

1. Introduction

In July, 1960, our KAPPA rocket finally reached an altitude of 186 km and in September it flew to an altitude of 200 km through E region, and into the lower part of the F region where we succeeded in measuring ion density and cosmic ray intensity. I cannot but express my extreme pleasure in having been a member of this project since it began five years ago. In the beginning of 1955, we obtained the support of those concerned with the investigation of the upper atmosphere by rocket sounding in our country. It is five years since the Institute of Industrial Research of Tokyo University took over the research and development of a sounding rocket, and through their cooperation we have had the success that is with us today. For this reason I have the deepest respect for those who exerted their utmost efforts in overcoming economic and other restrictions.

This research promises to bring a bright future to the development of space science and technology in our country.

2. Shifts in Research and Liaison Organization

Let us look back and see how these people conducting physical research of the upper atmosphere were affiliated with the Institute of Industrial Science and how progress was made in research, leaving aside the research organization within the Institute. Already in 1955, the IGY Research Liaison Committee had been organized within the Japan Science Council with Professor Mankichi Hasegawa at its head. This committee, in conference with the Institute, formed a Rocket Research Liaison Committee within the Institute and research affiliations were begun between physicists and members of the Institute under the direction at that time of Professor Masaharu Hoshiai. Later, a sectional committee within the IGY Research Liaison Committee was formed along with the other sectional committees and since the author became a manager of this committee, by definition he also became an intermediary with the Rocket Research Liaison Committee. In 1956, a Special Committee on Rocket Sounding was established within the Science Council with Hirokuro Kaneshige as head. Within this committee people from the Institute and physicists studying the upper atmosphere as well as others were included and the Rocket Research Liaison Committee was abolished. Within the new committee, four smaller committees were set up according to the following specialities

(1) Rocket airframes, engines, propellants, (2) tracking, (3) sounding instruments, telemeters, recovery, (4) rockoon, and research liaison was promoted.

As research progressed, the stage approached for flight testing actual sounding rockets and sounding tests themselves, and a subcommittee for the materialization of observation was organized within the above committee. Later it was decided that preparations and operations for observation during the IGY were to be carried out by this committee. Recently, the Interministry Liaison Council was set up in the Ministry of Education. The Institute, by receiving their cooperation, was able to maintain contact so that rocket launching and the use of the coast of Dosen in Akita Prefecture has proceeded smoothly up to now.

After the completion of the IGY (December 1958), the above special committee continued to exist, but the actual sounding project was nominally included within the Institute, physicists were temporarily assigned to it, and sounding operations have thus been carried out up to now. The assembly for this purpose was called the Rocket Sounding Council (ROKK). Its chairman is Professor Takeo Fukuda, who is also head of the Institute. Prior to this, the importance of space research by rockets and artificial satellites as powerful means was recognized internationally and at the end of 1958, the COSPAR (Committee on Space Research) was established in UNESCO. The following year, a liaison committee on space research was established within the Science Council and the previous special committee on rocket sounding was abolished. (Since June 1960, this committee has been changed to the Special Committee on Space Research with Kankuro Kaneshige as Chairman.)

3. The Objectives of Observation

Shifts in the organization of research liaison in this country have been described above as related to the physicists involved and considered chiefly from the practical aspects of observation. It is necessary to make a separate description of the problems from the aspect of selection of objectives to be observed and other problems of a purely scientific nature related to the investigation of the upper atmosphere.

Right after the war, a General Council for the Study of the Ionosphere was organized under a grant from the Ministry of Education (last year renamed the General Council for the Study of the Upper Atmosphere) and a site established where all affiliated researchers in the country could study, with Professor Ogihara as head. This site has produced many results which have drawn attention even from abroad. Later a Liaison Committee for the Study of the Ionosphere with Professor Ogihara as chairman was established within the Science Council, and both up to the present day have continued activities in close cooperation with one another. Although these two committees formed the parent body, maintaining a high level of technology in this field within our country, many representatives from it are participating in every liaison organization for rocket observation. The selection of the first observation objectives was discussed by the IGY

Research Liaison Committee, went on to the Special Committee for Rocket Sounding and then to the Special Liaison Committee on Space Research.

At the first stage of research, the following items related to sounding were debated and accepted in the Special Committee on Rocket Sounding mentioned above. Of course, those involved maintained connections with the Council for the General Study of the Ionosphere, but the flight altitudes of the rockets were inadequate, and since there had been no experience in any point, it was impossible to take a new course of action or display any originality. However, there were reasons and objectives for each item.

(1) Ion Density of the Ionosphere

It was impossible to measure the amount of ions by emitting radio waves from the ground, and although at that time Michigan University had provided some sounding data, both the system used and the results were unreliable. It was estimated that the KAPPA rocket would reach an altitude sufficient to pierce the ionosphere, and therefore the decision was made to begin development of a method for measuring ion density accurately. It was decided that this work should be done with the cooperation of the Institute of Radio Research, and the Institute for Electric Communications Research.

The ion density of the ionosphere does not much affect the reflection of radio waves, but is a very important element that governs the electrical conductivity, and is of major importance in the dynamo theory which relates the ionosphere to variations in earth magnetism. Moreover, ion density is surmised from the theory of the origin of the ionosphere. At the present time it should be the basis on which to criticize or give support to former theories on the origin of the ionosphere through actual measurements. In this sense, the items for observation had two objectives, the development of new sounding systems, and the acquisition of new knowledge on the physics of the upper atmosphere.

(2) Air Temperature, Wind Direction, Wind Velocity

The range of observation of atmospheric temperature and wind by radiosonde is around 30 km, and wind observation above that height could only be carried out by radio waves to an altitude of about 100 km. At the beginning of our studies, a small amount of information was published on the value of observing atmospheric temperature by the sound grenade system developed in the U.S. This was effective within altitudes of 30 to 80 km. This item was adopted because it coincided with the first objective of the KAPPA at that time, and the following academic reasons. The theory of resonance vibration in the atmosphere from the ground to an altitude of 80 km based on tidal phenomena and absorption from the sun has been studied previously. In this theory the vertical distribution of atmospheric temperature is an important element, and as a result of this theory winds and their strength and structure constitute a problem. This matter is closely related to the winds within the ionosphere (especially the

E region) which is directly above. Consequently, it is an important problem connected with the structure of the winds as a source of motivation for the dynamo theory described above. Also we believe that it is of value to conduct this type of observation in Japan since the winds naturally vary from time to time and according to geographical area. It was considered expedient to adopt the observation system used in the United States and since we had access to instruments used in ground measurements, these measurements were supervised with the cooperation of the Engineering Departments of Kyoto University and Osaka Municipal University.

(3) Cosmic Rays, Solar Radiation

These two items are of value even if the rockets did not penetrate the ionosphere, since the sounding results themselves are significant. We decided to gather experience and follow these items as preliminary experiments in order to prepare for future advanced observations such as cosmic rays within a defined energy area or spectroscopic observation of short wave solar radiation with the sun follower. For the time being, we began by measuring the general amount of energy of cosmic rays. For the latter objective, we decided to conduct photographic observation of the $0.2\,\mu$ to $0.29\,\mu$ waveband. They were supervised by the Physical and Chemical Research Institute and the Tokyo Observatory of Tokyo University.

(4) Atmospheric Pressure

This chiefly served to correct the observed values for cosmic rays by measuring atmospheric pressure. The Institute supervised the above along with the development of measuring instruments.

(5) Electron Density of the Ionsophere

It is not possible to measure electron density at all altitudes by radiowave observation using pulses transmitted from the ground. This must be done by direct rocket measurement in the lower E region, parts of the D region, the space between the E and F region and the upper F region. Also, it is impossible to measure accurately and sufficiently the electron density of the E region at night using conventional radiowave methods. These problems are important for explaining the structure of the ionosphere and for the practical problem of radiowave propagation. In the United States an idea by Seddon which is being pursued for measuring electron density by rocket, but we do not believe it is worth promoting at present. If a method for the direct measurement of ion density is developed, it will prove valuable and we have decided to make an effort in that field and at the same time to take into consideration the preparations for trying the Seddon method. Supervision is the same as that for the study of ion density.

(6) Earth Magnetism

At the early stages in this study an American named Singer published data on the measurement of earth magnetism in the vicinity of the magnetic equator, as far as the lower region. It was discovered that the dynamo current that is important in the dynamo theory, was clearly detectable from the lower E region. Although this coincides with earlier suppositions based on investigations, it is not sufficient for determining magnetism out of the E region or up into the F region. Since it appeared that this measurement was not under continued consideration, we decided to study a way of loading a proton magnetometer onto a rocket. The program was supervised by the Science Faculty of Tokyo University.

The above was described as a function of the KAPPA rocket program. In addition, the development of a rockoon was carried on, though on a smaller scale. Although one defect of the rockoon at first was that it was carried far away by the wind, we decided to use in observing items such as cosmic rays, atmospheric pressure, ion density, earth magnetism, etc., if such a program could be conducted reaching high altitudes at a comparatively low cost.

4. Results of measurements

I will first describe the atmospheric temperatures and winds which were measured the most.

(1) Atmospheric Temperature and Wind. Details on methods of measurement are left to other references (1-5). In general, the following system was used. In a rocket, several sound grenades were carried which were ejected and detonated one by one, beginning at an altitude of 30 km, by means of a time-programmed timer [fuze], the last grenade being detonated when the rocket reached maximum altitude. While obtaining the time and place of explosion of each grenade, by means of a rocket tracker and infrared detector, the sound waves were received by microphones at several ground sites and their times of arrival recorded. From these values, the sound velocity, wind direction and wind velocity were found by theoretical calculation and the atmospheric temperature was determined by the sound velocity. In the United States, the number of sound grenades used is about 20, and since the difference in altitude between one grenade and the next between points on the ground is extremely small, the calculation of atmospheric temperature and wind from the data is simple, since one can assume that the intermediate spaces for the air temperature and the wind are uniform. However, in our country we first used one, then two and finally five grenades and in this year's observation we are using six. Therefore, we calculated the distribution of air temperature and wind between two points of sound quadratically. For this reason we formulated the theory anew, but the calculations required a considerable amount of effort. We were proud in thinking that research on this theory originated in Japan, but later we discovered that London University had also formulated the same theory.

Altogether we conducted many experiments including two this year. The main points are given in Table 1. Our policy from the beginning was to make observations during representative seasons of the year, and we aimed at making them around noon during the middle periods of each season. At times we deviated from this rule, but in general operations went on in the above manner.

Table 1

Table of Air Temperature and Wind Observation

			K6-TW-1	K6-TW-2
1.	Overall length (m)		5.389	5.304
2.	Weight (kg)		255.45	254.95
3.	Launching Angle (Degrees)		78	75
4.	Altitude (km)		20 (appr. value)	40 (appr. value)
5.	Tracking		Radar bad	Radar bad
6.	Date and Time		6/24/58, 11:10	6/30/58, 17:12
7.	Weather	General Condition	Clear	Clear after rain
		Wind Velocity, Wind Direction	2.5m/s, 315°	3.5m/s, 270°
		Air temperature	20° C	21° C
8.	No. of Sound Grenades		1 (1 kg)	1 (1 kg)
9.	Sound Altitude		unknown	unknown
10.	No. of microphones		7	7
11.	Wind observation balloon		to 6 km	--
12.	Rawinsonde		to 30 km	to 18 km
13.	Results		Bad	Incorrect

	K6-TW-3	K6-TW-4	K6-TW-5	K6-TW-6
1.	5.352	5.351	5.443	5.616
2.	259.14	259.61	263.70	270.50
3.	78	78	80	80
4.	43.5	47.0	50.5	50.5
5.	Radar bad	Radar good	Radar good	Radar, infrared good
6.	9/25/58, 12:15	9/26/58, 13:10	12/23/58, 12:23	3/18/59, 12:05
7.	Cloudy	Cloudy	Somewhat cloudy	Clear
	5m/s, 315°	4m/s, 225°	0.1m/s, 90°	5.5m/s, 0°
	24° C	26° C	9° C	5.5° C
8.	1 (1 kg)	1 (1 kg)	2 (0.5 kg x 1)	5 (0.5 kg x 4)

Table 1 (continued)

	K6-TW-3	K6-TW-4	K6-TW-5	K6-TW-6
			(1 kg x 1)	(1 kg x 1)
9.	43.5	47.0	41.1 48.5	x, 34.0, x 44.8, 50.0
10.	7	7	10	10
11.	to 5 km	to 3 km	to 5 km	to 4.5 km
12.	to 20 km	to 22 km	to 24 km	to 24 km
13.	Incorrect	Incorrect	Rather good	Good

	K6-TW-7	K6-TW-8	K6H-TW-9
1.	5.616	5.600	6.870
2.	270.50	263	330
3.	80	80	80
4.	48.6	45.5	69.5
5.	Radar good, Infrared bad (cloudy)	Radar, infrared good	Radar, infrared good
6.	3/20/59, 12:12	9/17/60	9/29/60, 11:48
7.	Cloudy 4m/s, 340° 90° C	Clear almost no wind 25° C	Clear almost no wind 21 ° C
8.	5 (0.5 kg x 4) (1 kg x 1)	6 (0.3 kg x 3) (0.6 kg x 3)	6 (0.3 kg x 3) (0.6 kg x 3)
9.	27.8, 33.1, 38.5 44.0, 48.6	--	--
10.	10	10	10
11.	--	to 3 km	to 7 km
12.	to 21 km	to 20 km	to 26 km
13.	Good	Good	Good

As can be seen from the table, we obtained no data until after the fourth observation (TW-1 to TW-4). All observations after No. 5 were of value in numerical calculations. At the present time some are still being calculated and others have been calculated but are not yet published. Therefore, I would like to take this opportunity to mention one part of them. As an example, the results of WT-5 conducted on December 23, 1958 are shown in (a) and (b) of Figure 1. (a) is atmospheric temperature and (b) is wind direction and velocity. In the graph, the results of observations by Rawin Sonde at the Akita Local Meteorological Station from the ground to an altitude of 24 km are shown, the directions and sizes of the wind are shown by vectors and the numbers next to the line indicate wind velocity in m/sec. Recently the Soviet Union published the results of observations of atmospheric temperature (not by sound grenade). Observations which took place in North America at Fort Churchill (Canada) and White Sands have been published. A topic for future research is to add Japanese data to the above and examine it. However, it is still insufficient for academic examination and it is necessary to gather more data by continuing observations according to a set policy and plan to be described later.

(2) Solar Radiation

Although this observation was conducted four times, no data was obtained. Details are given in other references (4, 5).

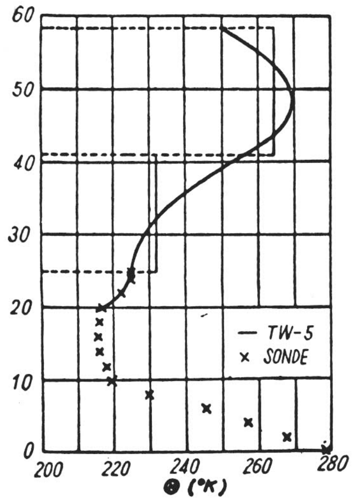
(3) Cosmic Rays (Including Atmospheric Pressure)

These observations were carried out four times (the latter two times do not include observation of atmospheric pressure) and data was obtained for each time. Since the same type of rocket was used in the third and fourth observations as in the study of ion density, data was obtained up to an altitude of 190 km. The results of the first and second observations are given in references (6, 7). Although details are left to other literature (4, 5, 8, 9) the results obtained were very similar to those in the United States, and we reached our goal satisfactorily for the preliminary research which was our first objective. This gave us confidence and hope for future investigations.

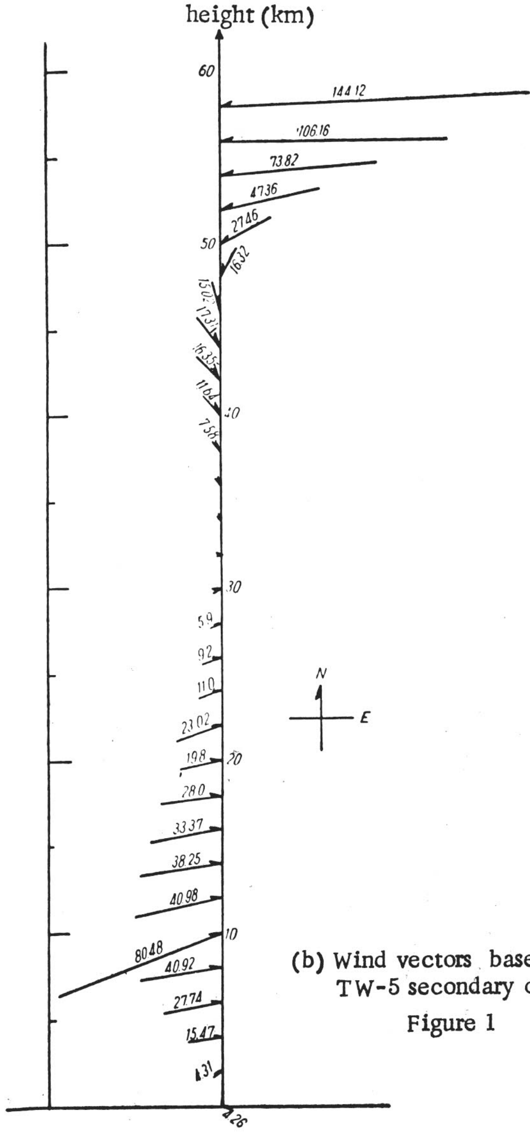
(4) Ion Density

Details on an instrument for measuring ion density is of great significance due to the fact that the Japanese were first to develop it. They are given in other literature (10). This measuring device is an improvement of the probe system used in experimental research on electric discharges. Special care was taken to construct a probe spherical in shape, of mesh plated with gold in order to restrain and reduce to a minimum the photoemissions due to photoionization occurring as a result of solar radiation from the probe.

Two observations were made, one on September 22, and the other September 26, 1960. In both cases an altitude of 190 km was reached. The first was performed in the daytime and the second at night. According to the data obtained, we learned that the influence of photoemission from the probe, which had first been a cause of apprehension, was negligible. Details of results are published in the name of those involved. According to a preliminary report made last September 30, the results of



(a) Distribution of Temperature, Based on TW-5



(b) Wind vectors based on TW-5 secondary curves

Figure 1

the observation are thought to be fully satisfactory. This was the first time that it was possible to investigate ion density at an altitude of 190 km during the day and at night by this type of observation. It is believed that this would be valuable as data for further academic investigation to accompany continuation of observation.

(5) Please refer to separate article on matters concerning the rockoon.

5. Plans for Further Research

COSPAR, the international committee on space science which we described in the beginning, has already held three general meetings, and last January an International Symposium on Outer Space was held in Nice, France. This is evidence of rapid scientific progress in this field. Even in our country there is an Inquiry Council on the Exploration of Space, within the Cabinet. It studies from all points of view how Japan should advance in science and technology in this field, the nature of her cooperation with the rest of the world, and a report given on the policy to be followed at present.

At the present stage, considering the high level of scientific circles in our country, whose scientists have accumulated much in the field of research in the upper atmosphere, and the fact that we have made rapid progress in rocket engineering, we believe that all scientists throughout the country should now aim at scientific research and development of space technology. In accordance with such conditions, the Special Committee on Outer Space Research and the General Research Committee on the Upper Atmosphere together held a symposium on future plans in astrophysics. The symposium lasted for two days from September 30, to October 1, and discussions and announcements were made concerning the research being carried out by the scientists who assembled there from all parts of the country. We can make a general survey of plans for research based on the KAPPA rocket which holds our greatest interest at present, by the contents of the discussion. The plans for research on rocket sounding compiled by the author after various discussions held at the end of the symposium are as follows:

(1) The Nature and Structure of the Upper Atmosphere

1) Composition of the Atmosphere

Research will be done on the ozone layer and the problem of water vapor at relatively lower regions and in the upper regions research will be done on the composition of the atmosphere. A sonde will be dropped from a rocket or a mass spectrometer will be carried on the rocket. The altitudes will be from approximately 30 km to the ionosphere.

2) Atmospheric Temperature and Wind

In addition to continuing former methods, the Chuff method and the supersonic method will be developed for 80 to 110 km. The method based on the vaporization of sodium will be developed by those experienced in spectrum observation. It has been considered to propose this to each affiliated country through COSPAR.

3) The Physical Nature of the Ionosphere and Exosphere

In addition to measuring ion density by former methods electron density will be measured by the recently developed resonance probe method. Also a method will be developed for measuring together electrons and ions by materializing the concept of a universal probe. These methods will not only be usable in the ionosphere but in the exosphere above it (above 300 km).

(2) Field Intensity and Structure

1) Electric Fields

This is a method for measuring the electric fields in the ionosphere and the exosphere. At the present time, however, no confident method has been proposed. However, a method of some value does exist as a result of some deliberations and this will be studied. The problem of electric fields in the upper atmosphere is an unexplored area, and if a reliable method is devised, it will be a great scientific contribution.

2) Magnetic Fields

Although this is a development of previous methods for measuring the magnetic fields of the ionosphere and exosphere, its objective also includes the new objectives of electric currents in the ionosphere, the shielding effect in the ionosphere and magnetic vibration. Also, a magnetic aspectmeter will be developed since it is expected that it will be possible to know the aspect of a rocket by using magnetometer techniques.

(3) Radiation and Emanation

1) Radiation of Electromagnetic Wave Area

Since electromagnetic wave radiation should occur automatically within the exosphere, it will be determined by suitable frequency bands. This will be determined in the exosphere through the ionosphere. In this problem there are questions of the rocket attitude and antenna, etc. The electromagnetic waves which penetrate the atmosphere from outer space will be received and their intensity and polarized waves determined. Measurements will be made in the exosphere.

2) Light

Observations will be made of the brilliance of the sky, the color index of the stellar field, infrared radiation during noctilucence, ultraviolet rays from the sun, and soft X-rays. For this purpose, a sun-follower and aspectmeter are necessary, and basic research is required on the measuring instruments themselves. The observation of infrared during noctilucence, however, is relatively close to realization. Although it is important to measure ultraviolet (1000-1500 A°) and infrared (28μ) from outside the solar system, technical difficulties are great at present.

3) Emanation

In addition to continuing observation of cosmic rays, observation of the so-called subcosmic rays -- the radiation of energy lower than ordinary cosmic rays, will be conducted. Although basic research has been done on measuring instruments for this purpose, research should be further stimulated.

Of course in the above items are included various stages of possibilities that can be carried out, but I cannot say that all these are included within the plans for investigation in our country. We have anticipated promotion through research grants (though meager) of a general research council for the above research grants from the Institute through the ROKK.

From here on, it is necessary to consider receipt of research grants for new plans, and the nature of the affiliation of the Institute with the ROKK. Several anticipated technical questions are arising. In answering the demands of those engaged in rocket engineering, it is hoped that a joint meeting can be held between rocket research personnel (including rocket electronics engineers) and researchers on the upper atmosphere in the near future, and I hope to promote plans for this purpose.

(October 28, 1960)

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