SYNTHETIC OBSERVATIONS OF HIGH-LATITUDE IONOSPHERE BY S-310JA-4 SOUNDING ROCKET

Masaki EJIRI, Hisao YAMAGISHI, Takeo HIRASAWA,

National Institute of Polar Research, 9-10, Kaga 1-chome, Itabashi-ku, Tokyo 173

Koichiro TSURUDA,

Institute of Space and Aeronautical Science, University of Tokyo, Komaba 4-chome, Meguro-ku, Tokyo 153

Iwane KIMURA

Department of Electrical Engineering, Kyoto University, Sakyo-ku, Kyoto 606

and

Masanori NISHINO

Research Institute of Atmospherics, Nagoya University, Honohara, Toyokawa 442

Abstract: A comprehensively instrumented S-310JA-4 sounding rocket was launched into a ray band type auroral region from Syowa Station in Antarctica at 0032 (UT) on August 18, 1978, in order to study mechanisms of high-latitude ionospheric disturbances, specifically to clarify the mechanism of ionospheric irreguralities in the aurora such as two-stream, cross-field and ion cyclotron instabilities. Payload instrumentations and ground-based observations corresponding to the mission objectives are discussed. All payloads functioned successfully and a general view of obtained data is also briefly outlined.

1. Introduction

There have been many rocket and radar observations as well as theoretical works on the plasma instabilities that occur in the equatorial *E* region and in the auroral *E* region. Several interpretations have been proposed, among which the so-called type 1 (Farley and Buneman instability: FARLEY, 1963; BUNEMAN, 1963) and type 2 (cross-field instability: SATO and OGAWA, 1976) instabilities seem to be predominent (PRAKASH *et al.*, 1970; BALSLEY and ECKLUND, 1972; BALSLEY *et al.*, 1973; PRIMDAHL *et al.*, 1974; OLESEN *et al.*, 1975; D'ANGELO, 1977). Whereas another type of instability (type 3) possibly associated with ion cyclotron instability (D'ANGELO, 1973) exists in the aurora (BALSLEY and ECKLUND, 1972).

In situ rocket observation revealed directly the plasma instability in the polar cusp region by measuring plasma density, waves, and DC electric field, and identified the Farley-Buneman instability (UNGSTRUP *et al.*, 1975). Many rocket experiments have also been carried out at Syowa Station and have found the electron density irregularities in the aurora (OGAWA *et al.*, 1976; MORI *et al.*, 1979).

In order to understand more precisely and clarify the mechanisms of ionospheric irregularities coupled with other auroral phenomena, a comprehensively instrumented S-310JA-4 sounding rocket had been designed and was launched from Syowa Station in Antarctica. The payload design with scientific objectives is discussed followed by the instrumentation of the payloads. A general view of obtained data is also briefly presented.

2. Scientific Objectives and Payload Design

2.1. Scientific objectives

In the ionospheric E region at the altitude range around 100 km where $f_{\mathrm{Hi}} < \nu_{\mathrm{in}}$ and $f_{\mathrm{He}} \gg \nu_{\mathrm{en}}$ ($\nu_{\mathrm{i(e)n}}$ being an ion (electron)—neutral collision frequency and $f_{\mathrm{Hi(e)}}$ an ion (electron) cyclotron frequency), there are at least 3 types of plasma instabilities associated with auroral activities, that is, a two-stream (Farley-Buneman) instability, a cross-field instability and an ion cyclotron instability.

A two-stream instability may occur under the condition that the velocity of electron due to the $\vec{E} \times \vec{B}$ drift exceeds the sound velocity, *i.e.*

$$\vec{k} \cdot \vec{v}_{\mathrm{E}} > k_y C_s \left[1 + (\mu_e \mu_i B^2)^{-1}\right]$$

where $\vec{v}_{\mathrm{E}} = \vec{E} \times \vec{B}/B^2$, $\vec{k}$ and k_y are excited wave propagation vector and its y-component ($x // \vec{v}_{\mathrm{E}}$, $z // \vec{B}$ and y makes the third orthgonal coordinate system), C_s an ion accoustic velocity, $\mu_{\mathrm{(e)i}}$ a mobility of electron (ion), $\vec{E}$ a dc electric field vector, and $\vec{B}$ the geomagnetic field vector.

On the other hand, a cross-field instability is associated with a density gradient drift instability, its condition being expressed as

$$\nabla n_e \cdot \vec{E} > 0$$

where ∇n_e is an electron density gradient perpendicular to the geomagnetic field vector $\vec{B}$.

The third one is an ion cyclotron instability due to the large influx of energetic particles.

In order to reveal each instability condition and clarify the above-mentioned mechanisms and their non-linear developments, it is essential to measure electron density and temperature, irregularities in electron density, the fluctuations of electric field and magnetic field vectors, a wave propagation vector, a dc electric field, and an energetic particle flux. It is also required to measure a VLF wave spectrum, a HF wave spectrum, and a Poynting flux of VLF waves, together with ground-based observations by means of an all-sky camera, a sanning photometer, an auroral radar, a cosmic noise absorption, an ionosonde, a magnetogram, and a VLF receiver, in order to investigate a cross-correlation of instabilities in the aurora with the high-latitude ionospheric phenomena. Since the auroral radar is directed towards south, the S-310JA-4 was launched southwards. To translate the coordinate system fixed to the rocket into the earth-fixed coordinate system, aspect sensors must be installed and detect an attitude of the rocket with respect to the earth.

2.2. *Payload design*

(1) EMF (Electric and Magnetic Fields) instrument with four separate sphere probes (one dipole along X-axis about 6.9 m apart and another dipole along Y-axis about 3.7 m apart and two dipoles are separated by about 0.83 m in Z-axis) measures 3 components of dc electric field, (EDC1, EDC2, EDC3), and 4 ac (ELF band) electric field components (EAC1, EAC2, EAC3, EAC4) relative to the rocket body. Using three orthogonal loop antennas with a diameter of 10 cm, 3 components of ac (ELF band) magnetic field (HAC1, HAC2, HAC3) are measured. To find out the Poynting vector of the 7 kHz noise (probably hiss band), 6 components (EPV1, EPV2, EPV3, HPV1, HPV2, HPV3) of $E_\alpha B_\beta$ ($\alpha \neq \beta$ and $\alpha, \beta = x, y, z$) and one Z component (*i.e.* PZT$=E_x B_y - E_y B_x$) are computed onboard and transmitted to the ground. The wide-band signals of both E and H components (WBE, WBH) of VLF waves are transmitted via a specially designed subcarrier band of telemetry.

(2) PWH (Plasma Waves in High-frequency range), by using a whip antenna, measures a swept frequency spectrum of 200 kHz to 10 MHz waves generated by wave-particle interactions in the aurora.

(3) TEL (Temperature of Electrons) is a standard rocket-born probe to measure an electron temperature ranging from 300 K to 5000 K, together with a floating voltage of the rocket (TEL-VF).

(4) NEI (Number of Electrons by Impedance probe) is also a standard rocket-born probe to measure an absolute value of electron density every 10 s.

(5) NEL (Number of Electrons by Langmuir probe) measures a dc electric current (NEL-DC) flowing into the sphere probe with a positive biased voltage. This current gives a continuous relative electron density profile. AC (ELF band) components (ΔNE1, ΔNE2) of electron density irregularities at two sphere probes 30 cm apart and the wide-band spectrum (WNE1) are also measured. A correlation between ΔNE1 and ΔNE2 gives a wave number of the irregularities. A Faraday cup with an aperture of 10 cm in diameter is used to detect a total energetic particle influx (PAR) with energies more than 90 eV, to obtain a correlation between particle irregularities and electron density irregurarities, as well as to study a relation of an energetic particle precipitation to auroral VLF waves (hiss band) and other auroral phenomena.

(6) HOS (Horizon Sensor) is an infra-red detector which gives a boundary of the earth and the sky. To combine this data with the geomagnetic field vector

obtained by GA sensor, it is possible to determine an attitude of the rocket in the earth-fixed coordinate system.

(7) GA (Geomagnetic Aspectmeter) is a standard rocket-born instrument to measure the geomagnetic field vector, *i.e.* the Z component (GAZ) parallel to the rocket spin axis and the H component (GAH) perpendicular to the axis.

In addition to the standard telemetry system (TM1), another specially prepared telemetry system (TM2) is installed to support the required member of signals. Since

Table 1. Channel allocation of signals for both TM1 and TM2.

IRIG Band No.	Response	TM1 (295 MHz)	TM2 (400 MHz)
B	7.25 kHz	WBE	WHB/WNE1
14	300 Hz	ΔNE1	ΔNE2/PAR
13	220	EAC1//EPV1	EAC3//EPV3
12	160	EAC2//EPV2	EAC4
11	110	HAC1//HPV1	HAC2//HPV2
10	81	HOS	HAC3//HPV3
9	59	PWH///NEI	PAR/ΔNE2
8	45	TEL	NEL-AGC
7	35	PZT	EDC2
6	25	EDC1+PG	EDC3
5	20	PWH///NEI	NEL-DC
4	14	GAH	TEL-VF
3	11	GAZ	HOS-MON
2	(f_0=560 Hz)	PWH-R	(NA)

Note: A/B A to B at X+230 s (X: Launching time)
A//B A to B at X+102 s
B to A at X+360 s
A///B A ↔ B at every 2 s///8 s
PG Monitor of pantagraph extension

Table 2. Summary of sensors used in the S-310JA-4 rocket experiment.

Sensors	
4	Spheres (30 mmϕ) for $\vec{E}_{DC}$ and $\vec{E}_\omega$ (EMF)
3	Orthogonal loops (100 mmϕ) for $\vec{H}_\omega$ (EMF)
2	Spheres (30 mmϕ) for NEL
1	Whip (1.2 m) for NEI-PWH
1	TEL disc (100 mmϕ) probe (TEL)
1	Faraday cup (100 mmϕ) (NEL)
1	Horizon sensor (HOS)
2	Axis flux-gate magnetometer (GA)

there is only one rocket-telemetry receiver at Syowa Station, the TM2 with a carrier frequency of 400 MHz is designed to adapt it for a satellite telemetry receiver, though a ground telemetry receiving antenna must be operated manually according to the pre-calculated rocket trajectory and adjustment must be made by the off-line radar tracking data.

All telemetry signals discussed above are listed in Table 1. Table 2 is a summary of sensors used in this rocket experiment. In order to separate two dipole antennas in Z direction, a pantagraph is used between them and expanded after the rocket nose-cone jettison.

3. Experiment Performance

The S-310JA-4 was successfully launched southwards from Syowa Station at 0032 (UT) on August 18, 1978, into the ray band type auroral region. The timer, which determines a time sequence of the events as scheduled in Table 3, was correctly operated, and all payloads performed the observations accordingly. The final spin frequency of the rocket after all antennas were deployed was 0.71 Hz. The apex of the rocket trajectory was 199 km at 224 s after the launch, and the flight time was about 420 s.

Table 3. Time sequence of S-310JA-4.

X	:	Life-off
X+ 50 s	:	Despin by Yo-Yo despiner
X+ 55 s	:	Nose-cone jettison
X+ 56 s	:	Pantagraph raise
X+ 57 s	:	NEI-PWH whip antenna extension, internal calibration for 1 s
X+ 61 s	:	Two dipoles extension, TEL sensor and NEL probes deployment
X+ 62 s	:	Loop antennas deployment
X+102 s	:	TM channel exchange 1, internal calibration for 1 s
X+230 s	:	TM channel exchange 2, internal calibration for 1 s
X+360 s	:	TM channel exchange 3, internal calibration for 1 s

The experiment was carried out just after the small substorm onset was recognized by the ground magnetogram. Detailed interpretation of the ground-based observational data during the rocket flight is given in the paper by YAMAGISHI *et al.* (1981).

4. Experimental Results and Discussion

Brief discussion on the experimental results is given in this section. More detailed data are presented and interpreted in the paper by YAMAGISHI *et al.* (1981)

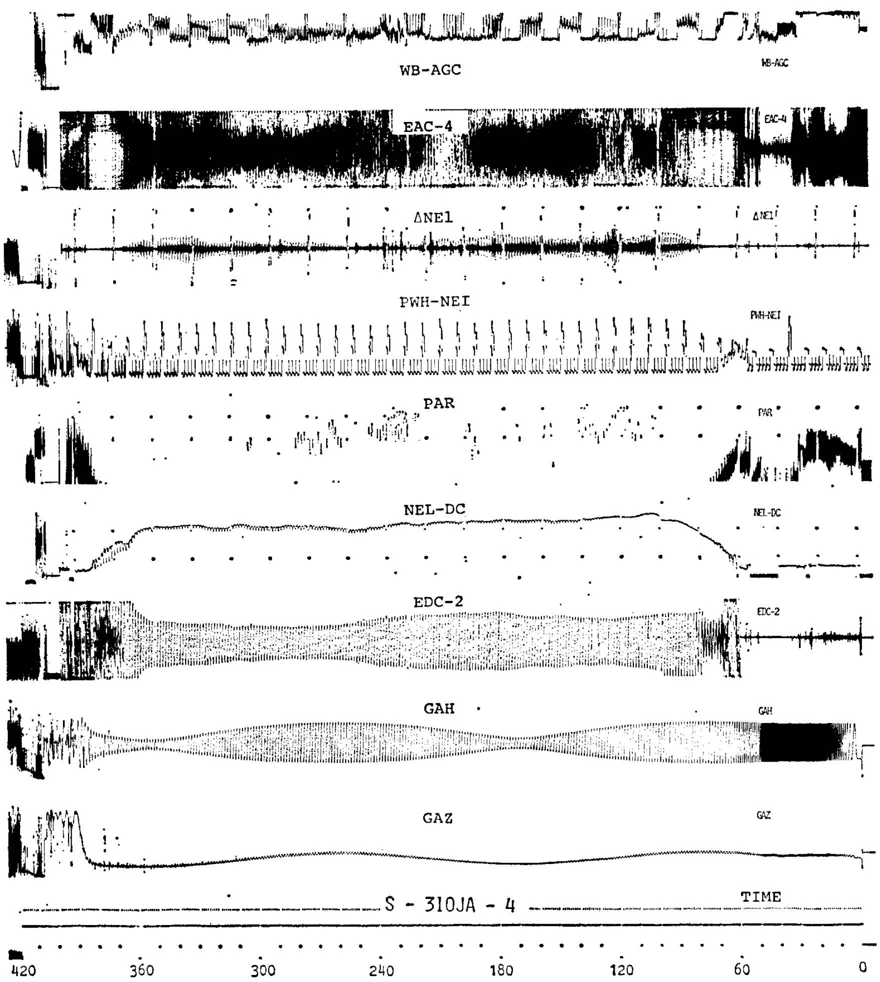

Fig. 1. Typical data set of S-310JA-4. WB-AGC is an automatic gain control level of the wide-band data of TM1 and TM2 changing at every 9 s and 11 s. Other abbreviations of signal names are explained in the text (Section 2).

in this issue. Fig. 1 illustrates the typical data set representing overall individual payload performance.

As for the electron density (N_e) and temperature (T_e) profiles, large-scale structures of N_e and T_e enhancements are observed and they show anti-correlation, that is, the density increases where the temperature decreases, and *vice versa*. HIRAO (1967) showed the same kind of structure of electron temperature. This is interpreted that there are different ionization and heating across the different geomagnetic field lines along which high energy particles vary in time and space with different energy spectra precipitating in the auroral region. The anti-correlation suggests a local pressure balance of an ionized gas. It is required to make simultaneous observations of energetic particles with high energy resolution and high sensitivity, in order to understand this phenomenon.

The ELF fluctuations of electron density and wave electric field were observed. Especially a frequency spectrum of detected electric field shows a peak power around 7 Hz and its harmonics which are very close to the Schumann resonance frequency and its harmonics.

There was a fairly large dc electric field up to about 50 mV/m and its direction was changing during the flight. The S-310JA-7 also experienced the same order (a factor of 1.5 to 2) of electric field intensity. The variations of intensity and direction seem to correlate with an auroral electro-jet and high energy particle precipitation.

The hiss band noises were intermittently observed in the wave electric field channel during the flight, and sometimes they have a relation with locally precipitating particles. There are hiss-like noises around 200 kHz and diffuse noises around 1 MHz, observed by the PWH instrument. Details of these mechanisms remain for future study.

Though the large dc electric fields are observed during the flight, there are no obvious density fluctuations in the ray band type aurora, caused by the two-stream instability or the cross-field instability. In the case of S-310JA-7 which traversed through much stronger auroral arcs than this case, several instabilities are identified. Most of the fluctuations observed in this experiment have been identified as a disturbance produced by the rocket vehicle itself. But, it is obvious from this experiment that there are wave-particle interactions which generate the waves in the wide frequency ranges from ELF of HF bands. The instrumentation techniques developed in this rocket experiment have been proved to give us useful means of the *in situ* observations in the high-latitude ionosphere.

Acknowledgments

The authors wish to express their thanks to the members of the 19th Japanese Antarctic Research Expedition, especially to Messrs. M. Kanemitsu and O. Watanabe, for their laborious efforts in the S-310JA-4 rocket launching and operation, which was supported by the National Institute of Polar Research in Japan. Thanks are also due to the colleagues at the Institute of Space and Aeronautical Science, University of Tokyo, Tohoku University, University of Electro-Communications, the Radio Research Laboratories, Tokai University, and Kobe University, especially to Drs. M. Toyoda, I. Aoyama, H. Oya, M. Ishido, K. Oyama, T. Ogawa, F. Tohyama, and Messrs. S. Miyakake, H. Mori, and T. Takahashi, for their contributions to this project. The payload instrumentation of this rocket was made possible with the cooperation of Mr. H. Yamaki and others of Meisei Denki Co. Ltd.

References

BALSLEY, B. B. and ECKLUND, W. L. (1972): VHF power spectra of the radar aurora. J. Geophys. Res., **77**, 4746–4760.

BALSLEY, B. B., ECKLUND, W. L. and GREENWALD, R. A. (1973): VHF doppler spectra of radar echoes associated with a visual auroral form: Observation and implications. J. Geophys. Res., **78**, 1681–1687.

BUNEMAN, O. (1963): Excitation of field aligned sound waves by electron streams. Phys. Rev. Letters, **10**, 285–287.

D'ANGELO, N. (1973): Type III spectra of the radar aurora. J. Geophys. Res., **78**, 3987–3990.

D'ANGELO, N. (1977): Plasma waves and instabilities in the polar cusp: A review. Rev. Geophys. Space Phys., **15**, 299–307.

FARLEY, D.T., JR. (1963): A plasma instability resulting in field-aligned irregularities in the ionosphere. J. Geophys. Res., **68**, 6085–6097.

HIRAO, K. (1967): Electron temperature in aurora. J. Geomagn. Geoelectr., **19**, 247–251.

MORI, H., OGAWA, T. and MIYAZAKI, S. (1979): Roketto ni yoru kyokuiki-denrisô-purazuma no jôran no kansoku (Rocket observations of plasma irregularities in the auroral ionosphere). Nankyoku Shiryô (Antarct. Rec.), **65**, 36–44.

OGAWA, T., MORI, H. and MIYAZAKI, S. (1976): Rocket observations of electron density irregularities in the Antarctic auroral *E* region. J. Geophys. Res., **81**, 4013–4015.

OLESEN, J. K., PRIMDAHL, F., SPANGSLEV, F. and D'ANGELO, N. (1975): On the Farley instability in the polar cap *E* region. J. Geophys. Res., **80**, 696–698.

PRAKASH, S., GUPTA, S. P. and SUBBARAYA, B. H. (1970): A study of the irregularities in the night time equatorial *E*-region using a Langmuir probe and plasma noise probe. Planet. Space Sci., **18**, 1307–1318.

PRIMADAHL, F., OLESEN, J. K. and SPANGSLEV, F. (1974): Backscatter from a postulated plasma instability in the polar cap ionosphere and the direct measurement of a horizontal *E* region current. J. Geophys. Res., **79**, 4262–4268.

SATO, T. and OGAWA, T. (1976): Self-consistent studies of two-dimensional large-scale ($\sim$100 m) electrojet irregularities. J. Geophys. Res., **81**, 3248–3256.

UNGSTRUP, E., BAHNSEN, A., OLESEN, J. K., PRIMDAHL, F., SPANGSLEV, F., HEIKKILA, W. J., KLUMPER, D. M., WINNINGHAM, J. D., FAHLESON, U. and FALTHAMMAR, C. G. (1975): Rocket-borne particle, field, and plasma observations in the cleft region. J. Geophys. Res. Lett., **2**, 345–348.

YAMAGISHI, H., EJIRI, M., HIRASAWA, T., TSURUDA, K., KIMURA, I. and NISHINO, M. (1981): The results of auroral sounding with S-310JA-4 rocket: Electric field, particle and waves. Mem. Natl Inst. Polar Res., Spec. Issue, **18**, 335–354.

(Received August 25, 1980)