HEIGHT PATTERN OF JJY 8MHZ WAVE IN THE IONOSPHERE OBSERVED BY A ROCKET

Tetsuo FUKAMI* and Isamu NAGANO**

* Ishikawa National College of Technology, Ishikawa-ken, 929-0392 Japan
E-mail: fukami@ishikawa-nct.ac.jp
** Faculty of Technology, Kanazawa University, Kanazawa-shi, 920-8667 Japan
E-mail: nagano@ec.t.kanazawa-u.ac.jp

Abstract: An HF radio wave at the distance of about 1000 km away from the transmitter was received in the daytime by a sounding rocket. Height patterns of the HF wave intensities show the step-like structures with about 10 dB damping at the both altitudes of about 170 km and 200 km in the lower ionosphere. It is found that these are caused by reflections of both one-hop and two-hop modes for an ordinary wave. And, calculated ionogram traces on an electron density profile estimated by the HF height patterns agree well with observed traces.

1. Introduction

The sounding rocket K-9M-72 was launched at the middle latitude having a receiver of the HF radio wave about 1000 km away from the transmitter. This HF receiver was loaded in order to measure the wave damping in the ionospheric D layer [1,2]. The field intensities were obtained with fading in the lower ionosphere from altitude 70 km to 230 km. Height patterns of the field intensities do not have remarkable damping in the D layer, but two stepped damping about 10 dB at both about 200 km and 170 km. We explain these step-like structures using a ray path theory and quantities of ionospheric damping. As results, it is first suggested that these step-like structures are caused by reflection points of both one-hop and two-hop modes of an ordinary wave using an electron density profile obtained by the DC probe loaded simultaneously. Next, the electron density profile is so modified that the calculated reflection heights fit well with observed ones. Calculated ionogram traces [3] on the modified electron density profile are in good agreement with ionogram traces measured at the rocket launching point.

2. Experiment

The rocket K-9M-72 was launched at 11:00 (JST) on February 13, 1982 at Kagoshima Space Center (KSC, lat.31º15'N, lon.131º04'E) of ISAS (Institute of Space and Astronautical Science), and had a trajectory shown in Fig. 1. The rocket went up to an apogee 328 km at 294 sec and reached about 382 km horizontally in a direction 30º measured anti-clockwise from the south in 580 seconds after firing. The spin frequency of the rocket was 2.5 Hz in the observation.

In order to measure absorption in the D layer, we observed an HF signal 8 MHz (2kW) transmitted from a horizontally half-wave dipole antenna (lat.36º11'N, lon.139º 51'E) in Japan. This 8 MHz signal was a standard radio wave code-named JJY announcing JST and ionospheric conditions, and was the only continuous wave in the world [4]. In Fig.1, a horizontal directivity diagram of the JJY transmitter was horizontally shown, and arrows from the JJY transmitter indicate points of the altitude range 190 km both during ascent and descent. So, the receiving points are in the nearly maximum direction, and are 984 km and 1052 km distant from the transmitter during ascent and descent, respectively.

Figure 2 shows the block diagram of the JJY receiver and the DC probe abroad the rocket. We used a bar antenna of 250mm to measure a nearly horizontal component of electric field for the JJY 8 MHz wave. The DC probe was a stick type of size 190 mm long and 3 mm diagonal, and was biased DC +5.1 (V) against the rocket body potential. The bar antenna and the DC probe were extended on the rocket at 48 second after launching (altitude 64 km).

The electric intensities profile observed during ascent are shown in Fig.3a. The wave intensities are modulated by both fast fading of about 10 dB and slow fading of about 10 dB caused by the rocket spin, the standing wave, focusing and so on. Two peaks of the electric intensities appear from 110 to 120 km. The average intensity doesn't remarkably attenuate in the ionospheric D layer. But the rapidly damping points of the intensities appear at 178 km firstly and at 208 km secondly during ascent. In Fig.3b during descent, characteristics of the intensities are similar to the ones during ascent. The damping points of the step-like structures are both 169 and 207 km high, too.

Figure 4 shows the electron density profile obtained by the DC probe current above the altitude 84 km during ascent. We first assume that the current is proportional to the electron density. And the electron density profile has been normalized by foE 3.7 (MHz) of ionogram traces at KSC shown in Fig.5. Below 84 km, the electron density profile is estimated by a full wave method with VLF wave intensities observed by the same K-9M-72 rocket [1].

3. Numerical simulation and discussion

On estimating of the wave electric intensity, we use the CCIR recommendation [5]. That is, the electric intensity E (dB(μV/m)) for one wave is as follows;

$$E = 107.2 + Gt - Ld - Li \quad (1),$$

where Gt is transmitting antenna gain (dB), Ld is loss $20\log_{10} D$ caused by slant range distance D km and Li is loss caused by ionospheric absorption. Gt is obtained from the direction pattern [4]. Ld is obtained from ray tracing, which has applied both the Snell's law including a spherical surface effect and the Booker's quadratic equation into the Hase1grove's differential equations. And we obtain Li using the phase integral method for a direct mode, one-hop mode and two-hop mode.

To investigate the rapidly damping points, a ray trajectory is first calculated for an arbitrary incident angle by using the electron profile of the DC probe. Fig.6 shows the ray trajectories from the JJY transmitter to the observation point during ascent. The wave traveled from the transmitter is separated into an ordinary wave and an extraordinary wave in the ionosphere. In Fig.6, a height reflected for the extraordinary wave is lower than the one reflected for the ordinary wave. The observed damping heights are shown by dot-and-dash line in Fig.6. Only for the ray trajectories, it would seem that the first and second damping points of 177 and 208 km are, respectively, the reflecting heights the extraordinary and ordinary wave of the one hop mode. Next, we estimated electric intensities from equation (1), as shown in Table-1. It is unfortunately suggested that the intensity of the extraordinary wave is 6.2 [dB] less than the ordinary wave for the same hop mode. Therefore, the step-like structures are not caused by both the ordinary and the extraordinary waves as the electric intensity of the extraordinary wave is covered with the ordinary wave. Furthermore, though apparent heights of ordinary waves are calculated with the DC probe profile using our calculation method [3], the ones in the F layer are clearly different from the observed trace as shown in Fig.5

By the way, the loss of the ordinary wave for the two-hop mode is nearly 10 dB greater than the one for the one-hop mode in ascent. Therefore, it will be inferred from this that the one-hop and two-hop modes for the ordinary wave cause the damping points though the reflected points are higher than the observed ones.

In order to fit the calculated reflection points with the observed ones, we modify the electron density profile. For the E-layer cap region between 85 km and 130 km, it is given by both of the DC current profile and foE of the ionogram in Fig.5. Therefore, we modify the electron density profile of the lower F-layer above 130 km. In Fig.4, we show the final modified electron density profile. Both Fig.7 and Table 2 show results calculated with the modified profile during ascent. It is clear during ascent that the observed reflection heights of 178 km and 208 km are nearly equal to calculated heights of 177.7 km and 208.5 km, respectively. For the electric field strengths, a estimated value 28.0 dB(μV/m) of the two hop mode is in good agreement with the observation. But a estimated value 34.8 dB(μV/m) of the one hop mode is several dB smaller than the observation values. For this estimation, we didn't consider the effects of polarizations, focusing and so on, but this wave intensity must be the one hop mode of the ordinary wave. During descent as shown in Table 2, calculated reflection heights are nearly equal to the observed ones, too. There is moreover suggestive evidence that apparent heights estimated with the modified profile agree well with the observed values as shown in Fig.5.

4. Conclusion

Height patterns of the JJY 8 MHz wave intensities have two stepped damping about 10 dB of both about 200 km and 170 km. We first suggest that the reflection points of both the one-hop and two-hop modes of the ordinary wave cause these damping. Next, we modify the electron density profile by using the reflection heights. Theoretical ionogram traces for the modified electron density profile are in good agreement with actual ionogram traces measured at the rocket launching point.

References

[1] Nagano,I., M.Mambo., T.Fukami and S.Morita, Analysis of the collision frequency in the lower ionosphere from simultaneous measurements of VLF signal and Langmuir probe current by a rocket., Proc. of ISAP 1985, 242-6,pp.1015-1018, 1985.
[2] Nagano,I., M.Mambo, T.Fukami and M.Tomura, Estimation of collision frequency in the lower ionosphere by means of K-9M-72 Rocket, Special report on space research of ISAS, 27, pp.1-14, 1985 (in Japanese).
[3] Fukami,T., I.Nagano and J.MacDougall, A new method obtaining the ionograms from the electron density and the collision frequency profiles in the lower ionosphere, Proc. of ISAP 1996,pp.685-688, 1996.
[4] Tanaka,M., Kikuchi,M. and Honma,S., Supply by HF standard waves (JJY), Rep. Radio Res. Lab., 29, 149, pp.263-278, 1983.
[5] CCIR, Estimating sky-wave field strength and transmission loss at frequencies greater than 2 MHz, Rec.533-1, 1986.

Table 1 Calculated results with the DC probe profile.

During ascent	Ordinary wave				
	Refl.	Field intensity			
	Height [km]	Gt [dB]	Ld [dB]	Li [dB]	E [dBμ]
Direct	90.4	-11.0	60.0	8.8	27.4
One-hop	214.2	+4.9	61.7	14.1	36.3
Two-hop	236.1	+2.6	64.0	18.0	27.8
	Extraordinary wave				
Direct	90.3	-11.0	59.9	10.9	25.4
One-hop	199.0	+5.0	61.6	20.5	30.1
Two-hop	227.5	+2.9	63.8	26.5	19.8

Table 2 Calculated results with the modified electron density profile.

	Ordinary wave during ascent				
	Refl.	Field intensity			
	Height [km]	Gt [dB]	Ld [dB]	Li [dB]	E [dBμ]
One-hop	177.7	+5.5	61.3	16.7	34.7
Two-hop	208.5	+3.2	63.4	19.0	28.0
	Ordinary wave during descent				
One-hop	170.2	+5.8	61.6	17.9	33.5
Two-hop	206.6	+3.6	63.7	19.9	27.2

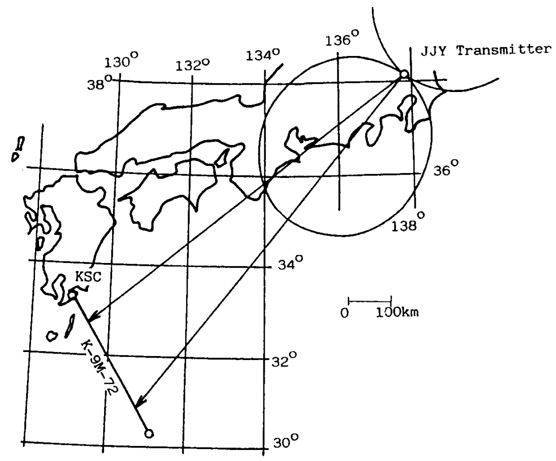

Fig. 1 The K-9M-72 sounding rocket trajectory.

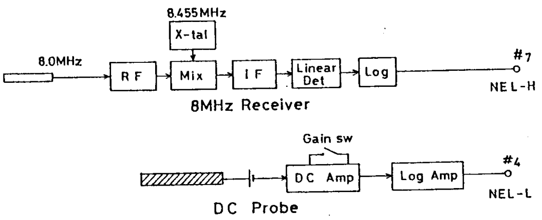

Fig. 2 Block-diagram of the JJY 8MHz receiver and DC probe.

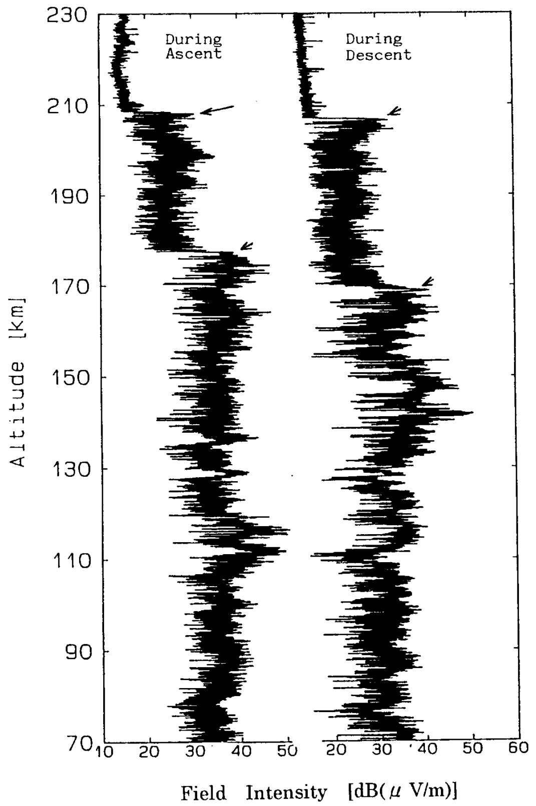

Fig. 3 Height pattern of the JJY 8 MHz wave intensities.

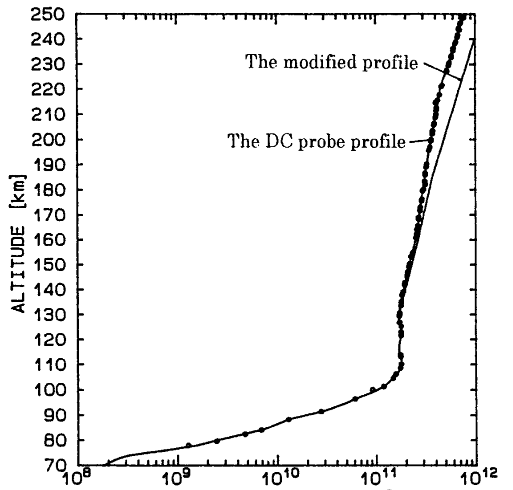

Fig. 4 Electron density profile.

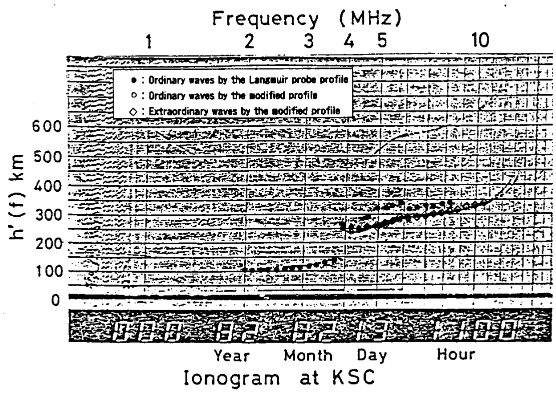

Fig. 5 Ionogram at KSC

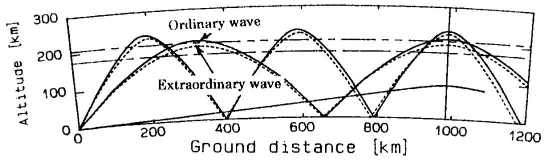

Fig. 6 Ray trajectories with the DC probe profile during ascent.

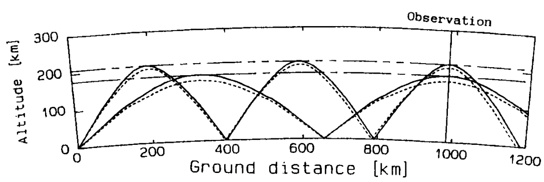

Fig. 7 Ray trajectories with the modified profile during ascent.