IN-SITU MEASUREMENT OF ELECTRON DENSITY PERTURBATION IN THE IONOSPHERIC CUSP REGION DURING ICI-2 CAMPAIGN

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ABSTRACT

We present the *in-situ* measurement of the electron density and its perturbation on the sounding rocket in the ionospheric cusp region during the ICI-2 (Investigation of Cusp Irregularities-2) campaign conducted in Svalbard, Norway in late 2008. The scientific objective of ICI-2 was to investigate generation mechanism(s) of coherent HF radar backscatter targets. Strong coherent HF backscatter echoes are a well-known characteristic of the polar cusp, and are thought to result from field-aligned plasma irregularities with decameter scale length. In this paper, a result from Fixed-Bias Probe (FBP) which aimed at measuring fine-scale (~1 m) electron density perturbation is mainly described.

1. INTRODUCTION

Strong HF backscatter radar echoes are well-known characteristics in the cusp, and this is probably caused by the electron density irregularity of decameter scale length. The relationship between HF radar cusp signatures and cusp auroral dynamics has been described (e.g., [1], [2]). It was also reported that the collocation between the equatorward boundary of broad spectral width HF radar backscatter and 630 nm auroral emission probably due to precipitating electrons [3]. We have conducted ICI-2 campaign in Svalbard Island in December 2008, to investigate generation mechanism of such density irregularities. It is believed that this mechanism can only be resolved by the combination of in-situ measurement by sounding rocket and a network of radar and optical instruments on the ground. The ICI-2 rocket was launched at 10:35:10 UT from Ny-Ålesund in Svalbard on December 5, 2008.

2. SOUNDING ROCKETS FOR ICI-2 CAMPAIGN

A total of six instruments were installed on the ICI-2 rocket; 1) Fixed Bias Probe, 2) Low energy electron spectrometer, 3) High energy particle spectrometer, 4) AC&DC Electric field and Wave instrument, 5) Multi-needle Langmuir probe, and 6) Attitude detection System. Two instruments, 1) and 2), were provided from Japan while the rest of the onboard instruments were developed in Norway. The main purpose of Fixed Bias Probe is to measure the small-scale electron density perturbation with a spatial scale smaller than 1 m. This instrument has four different telemetry channels in its measurement; 1) low-gain DC, 2) high-gain DC, 3) low-gain AC, and 4) high-gain AC, with the sampling rate of 2.894 kHz for DC channels and 11.574 kHz for AC channels. The probe was installed on the top of the payload zone to avoid a possible influence of the rocket wake, and was biased by +4V with respect to the rocket body to collect ambient thermal electrons. In this paper, we mainly present the data from Fixed Bias Probe as well as data from the ground-based instruments.

3. DATA FROM FIXED BIAS PROBE OBSERVATION

Figure 1 shows Fixed Bias Probe (FBP) data during the upleg of rocket. The right panel shows a profile of the electron current incident to the FBP probe surface as a function of time from the launch, while the left panel is a dynamic spectrum of the incident current in the frequency range from ~3.16 (=$10^{0.5}$) Hz to 1 kHz. Provided that the electron temperature is constant, the incident current is supposed to be proportional to the number density of electrons. The power spectrum density is significantly enhanced during an interval of 120 - 140 sec (called Region1, hereafter) after the launch. During this time interval, no sharp peaks are found in the power spectra but the power was enhanced in a broad frequency range. In Longyearbyen, All-Sky Imager (ASI) was operated to observe the auroral emission at 557.7 nm and 630.0 nm wavelength during ICI-2 campaign. According to ASI observation in Longyearbyen, the rocket was flying in the far front of the Poleward Moving Auroral Forms (PMAF) at 10:37:31 UT, which corresponds to 141 sec after the launch (T=141 sec). However, as is explained later, the rocket might be encountering with the remaining influence of the PMAF at this time.

Figure 2 shows the same kind of data for the rocket's downleg, during which the electron density variation was relatively insignificant. However, the power spectral density was increased between 400 and 430 sec (called Region 2) after the launch. ASI data shows that the rocket was just entering into the front edge of the

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PMAF at this time. Although the increase in the power spectrum density was also found after 500 sec, this might be caused by change of the rocket attitude.

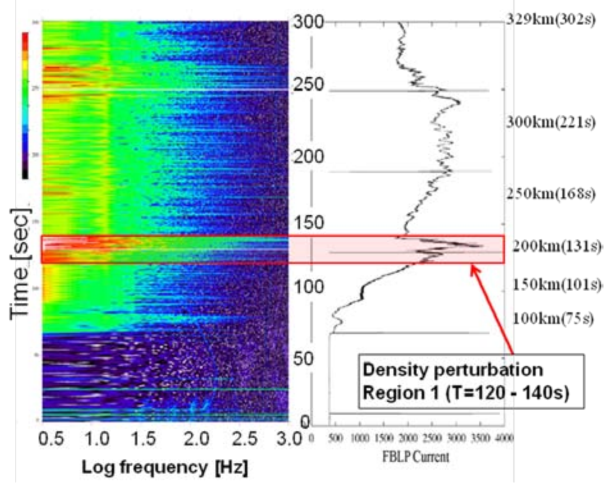

Figure 1. FBP incident current and its dynamic spectrum as a function of time for the rocket's upleg (T=0-302 sec). Numbers in the right side denote the rocket altitude at each time.

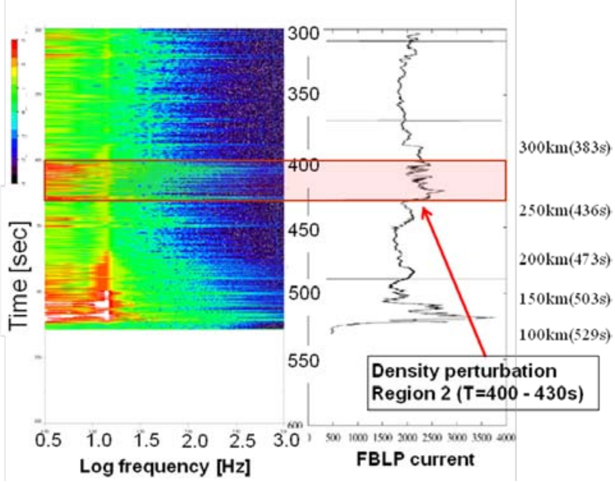

Figure 2. The same as Fig. 1 but for the rocket's downleg (T=302-529 sec).

Figure 3 represents a special kind of keogram which shows the geometrical relationship between 630 nm auroral emission region and the rocket position. In this plot, the vertical axis is taken by a flight time after the rocket launch, and the black solid line denotes the rocket trajectory on this keogram. Note that ICI-2 rocket was launched into the south-west direction, and therefore the top of this figure corresponds to the north direction. The temporal variation of auroral intensity along the rocket trajectory is expressed by the color code shown in the right end. The red region elongated from bottom-left toward top-right is likely the Poleward Moving Auroral Forms (PMAF) because it was moving toward the polar cap. If we extrapolate the PMAF trajectory toward the north direction, it encounters with the rocket nearly at 10:37 UT. This is almost consistent with FBP observations that Region 1 was identified on the rocket at 10:37:31. This keogram implies that the rocket encountered with another auroral emission region at 10:42-10:43. However, this is unlikely the PMAF but remained in the same latitude. It is noticeable that Region 2 observed by the FBP at 10:41:50-10:42:30 UT corresponds to the poleward edge of 630 nm auroral emission region in the keogram.

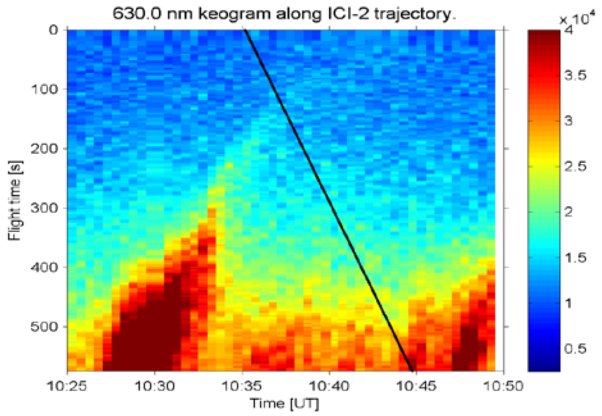

Figure 3. 630 nm auroral emission keogram. Vertical axis is taken by a flight time of the rocket launch.

Next, 630 nm auroral emission intensity at the rocket position was estimated from the keogram, and was compared with amplitude of the electron density perturbation. The bottom panel of Fig. 4a shows amplitude of the perturbation with spatial scale of 10-30, 30-60, and 60-100 m, while the top panel is for the emission intensity at the rocket position. No correlation was found between these parameters during this time interval. This suggests a possibility that the auroral emission disappears but the electron density perturbation remains in this region.

Figure 4b is the same kind of figure but for the rocket's downleg. In Region 2, the increase of the power spectrum with a spatial scale of about 10 meters is identified between 400 and 420 seconds. In the upper panel, the corresponding increase of 630 nm emission particularly is found at the beginning of the disturbed region. This is a good example of collocation of auroral emission and electron density perturbation.

4. DISCUSSION

Next, the rising of the spectral power for different spatial scales was noted, and the power spectrum density variation for 1-3, 3-6, 6-10, …, 60-100 m spatial scale before T=120 sec was examined. As already explained, the spectral power of about 10 m scale was intensified between 120 and 140 seconds. In addition, it is obvious that a tendency of the power increase can be seen much long before T=120 sec. Moreover, the spectral power tends to rise earlier for longer spatial scale, i.e., the power for 60-100 m increases first, the power for 30-60 m scale does second, and that for smallest scale does last.

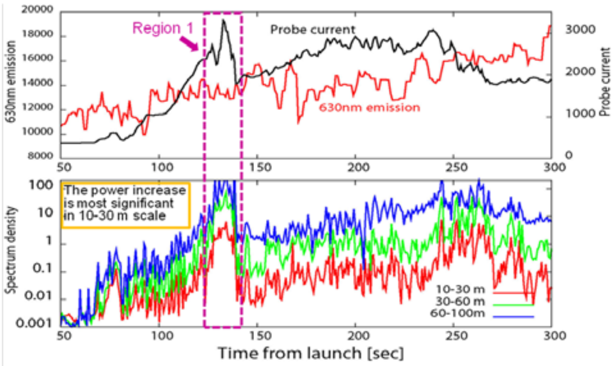

Figure 4a. Amplitude of the density perturbation with spatial scale of 10-30, 30-60, and 60-100 m together with the 630 nm auroral emission intensity for the rocket's upleg.

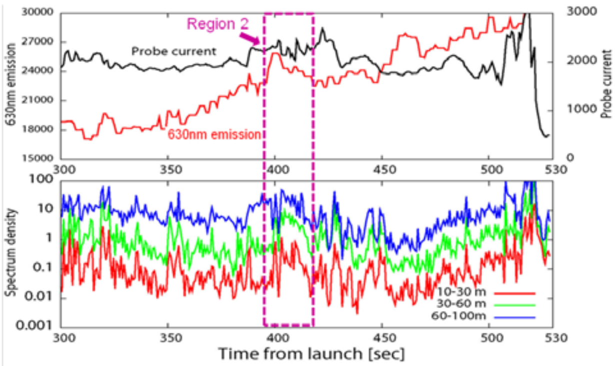

Figure 4b. The same as Fig. 4a but for the rocket's downleg.

Thus, the spectral power increase was observed earlier for longer spatial scale than for shorter scale. When we consider that the rocket was flying into southward and PMAF was moving northwardly, the power spectral variation indicates that the large-scale turbulence can reach higher latitude region than small-scale turbulence. It is suggested that this relation may be attributed to difference in decay rate according to the spatial scale of the turbulence, because Carlson et al. (2007) indicated that small-scale density structures are presumed to decay much faster than larger-density structures as they drift down-stream away from the sun and cusp. Therefore, these data are considered consistent with an idea that these density perturbations are related to the plasma irregularity.

Next, we discuss about an expected generation process of the electron density irregularity. According to a theory dealing with the growth rate of the gradient drift instability, it is not possible to explain the expected amplitude of density perturbation from the possible density gradient, because the growth rate is too small on the expected condition. Then, an explainable process consists of two steps; 1) shear driven instability rapidly structure the entering plasma, and 2) gradient drift instability build on these large seed irregularities. In any cases, growth rate of the gradient drift instability is a key parameter.

According to Tsunoda [1988], gradient scale length of the plasma irregularity is expressed by the following equation:

$$L = \left[\frac{1}{N_0} \frac{\Delta N}{\Delta x} \right]^{-1}$$

where N_o and $\Delta N/\Delta x$ are the background electron density and the horizontal gradient, respectively. The linear growth rate, γ_0, of the gradient drift instability is given by V_0 /L, where V_0 is the plasma drift velocity relative to the neutral gas.

For calculating the growth rate, we have looked into the temporal variation of the FBP current in Region 1. In fact, we are able to identify several periodic density perturbation with a spatial scale of ~10 m. For each region, N_0, and the horizontal gradient, $\Delta N/\Delta x$, were estimated. V_0 is assumed to be 500-700 m/s from meridian scanning photometer data. Finally, γ_0 is calculated and found to be larger than unity in most cases.

5. SUMMARY

ICI-2 rocket made in-situ measurement of the electron density irregularity in the ionospheric cusp region.

1) Fixed-biased probe made direct measurements of poleward moving electron density perturbation in Region 1, in which the perturbation with a spatial scale of ~10 m was identified. Corresponding variation in 630nm emission rate was insignificant.

2) Also in Region 2, the density perturbation with ~10 m scale was found to exist. Its collocation with 630 nm emission was confirmed.

3) For Region 1, a growth rate of gradient drift instability was estimated. The result suggests that the drift velocity (V_0) is larger than the scale length (L) in most cases.

4) The power spectrum analysis of the FBP current indicates that amplitude of the density perturbation increased in the region where electron density gradient is large (*i.e.*, edge of perturbation region).

5) For the PMAF event, the density perturbation with larger spatial scale reaches higher

latitudes, suggesting the dominance of plasma irregularity.

6. REFERENCES

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