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Modification of the local substorm ionospheric and field-aligned currents produced by the Tromsö heating facility

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Abstract. Coordinated observations of ionospheric and magnetic pulsations in the 100–120 s range observed in the high frequency (HF) modified ionosphere during the onset of an auroral substorm activation in the area of the upward field-aligned current (FAC) on 17 February 1996 are reported. The experiment was unusual in that during the near-vertical HF pumping an overhead strong sporadic E layer was present. The Doppler shift of HF signals on the London–Tromsö–St. Petersburg path showed wave-like variations during the HF pumping. There is an association between these signals, scattered from the HF pump-induced E region irregularities, and magnetic pulsations in the east-west magnetic field component measured at Tromsö. Magnetic field oscillations from all other IMAGE magnetometers in Scandinavia have also been analyzed. The data suggested that under the initiation stage of the FAC system, HF pumping of the ionospheric E region can modify the compressional mode of the Pi2 magnetic pulsations by modulating of the field-aligned currents associated with the substorm. In particular, the mechanism which we postulate is a modulation of background field-aligned currents by HF pump-generated direct and reflected Alfvén waves.

1. Introduction

It is known that heating of the D and E region electrons by amplitude-modulated powerful high frequency (HF) radio wave pumping of the ionosphere gives rise to a corresponding modulation of the ionospheric conductivities and therefore to current disturbances in a localized region of the lower ionosphere. Changes of ionospheric conductivities and currents are produced by electron temperature disturbances as well as electron density changes. Changes of the electron temperature is more efficient at low altitudes and for short time intervals while the electron density changes are more important at somewhat higher altitudes and for longer time intervals. Modification of the D and E region ionosphere at ULF frequencies can be used to artificially generate a magnetic response of up to 10 nT [*Stubbe*, 1996,

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and references therein]. ULF waves within the Pc3–4 range observed from HF pumping experiments in the $F2$ region were reported by *Blagoveshchenskaya et al.* [1992, 1995, 1998a], *Blagoveshchenskaya and Troshichev* [1996], *Belenov et al.* [1997], and *Yeoman et al.* [1997]. It should be noted that during these experiments a continuous HF pumping rather than amplitude-modulated pumping was used. *Belenov et al.* [1997] and *Yeoman et al.* [1997] attributed the observed ULF waves to naturally occurring geophysical phenomena. Results obtained by *Blagoveshchenskaya et al.* [1998a] clearly demonstrate that there exists a relation between the HF pump power level and the magnitude of the Doppler frequency shift oscillations, appearing in the signals scattered from artificial field-aligned irregularities (AFAI). This confirms the hypothesis of an artificial origin of the observed ULF waves within the Pc3–4 range caused by powerful HF radio waves. However, the explanation for possible generation mechanisms of the ionospheric and magnetic pulsations observed during HF pumping experiments is still an open question, particularly for long-period pulsations of large amplitudes. Recent results of ULF wave activity observed in an ionospheric HF pumping experiment performed in the nocturnal auroral ionosphere at Tromsö were presented by *Blagoveshchenskaya et al.* [1998b].

Here we report in detail on coordinated observations of ionospheric and magnetic pulsations within the range 100–120 s observed in an experiment on 17 February 1996 at the Tromsö heating facility (geographical coordinates 69.6°N, 19.2°E, $L = 6.2$, magnetic dip angle $I = 78°$) during an auroral substorm in the premidnight hours. The unique features of the experiment are as follows: (1) The powerful HF radio wave interacted with an auroral sporadic E_s layer. Therefore the upper hybrid region was close to altitudes of the HF pump-enhanced conductivity level and the auroral electrojet. (2) Continuous rather than an amplitude-modulated HF pumping of the ionosphere was used. This means that the period of the pulsations observed was shorter than the duration of the pumping cycle.

Ionospheric pulsations excited by the powerful HF wave were studied with the use of the field-aligned scattering method of diagnostic HF radio waves. The observations of HF diagnostic signals scattered from artificial field-aligned irregularities (AFAI) were made by Doppler equipment. The magnetic variation data from Tromsö were obtained at the Tromsö University Auroral Observatory. Data from the Tromsö dynasonde, the IMAGE magnetometer network [*Viljanen and Häkkinen*, 1997], IMP 8, and LANL spacecrafts were also used in the analysis of our experimental results.

2. Observations and Analysis

The Tromsö heating experiment on 17 February 1996, was performed during a weak auroral substorm in the nocturnal auroral ionosphere. To analyze the geomagnetic variations during the heating, we used the IMAGE magnetometers which have 10 s time resolution. The IMAGE magnetometer chain data exhibited an abrupt decrease in the X component of the magnetic field at about 2000 UT, and

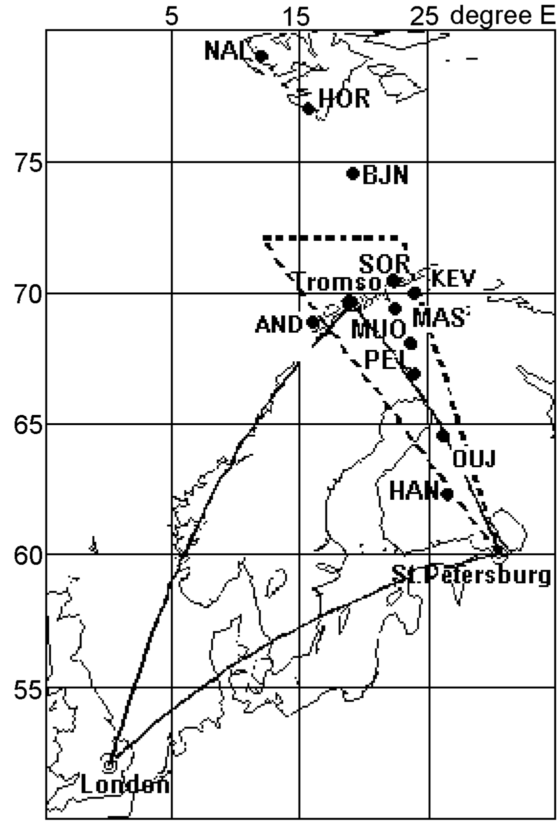

Figure 1. General view of the experiment geometry showing the position of the London–Tromsö–St. Petersburg path where the HF Doppler observations of HF signals scattered from AFAI were made and location of the IMAGE magnetometer stations used in this study.

the substorm ended at about 2140 UT. Locations of IMAGE magnetometer stations used in this study are shown in Figure 1. The IMAGE X and Z component features show that a maximum westward electrojet appeared to the north from Tromsö between BJN and SOR stations (the reversal of the Z component sign from positive at BJN to negative values at SOR, as well as the maximum amplitude in X component). It should be pointed out that the decrease of the X component was accompanied by a positive bay in the Y component as measured by the IMAGE magnetometers and produced by the southward portion of the ionospheric Hall currents in the substorm surge. *Inhester et al.* [1981] identified an upward field-aligned current in the head of a surge. A few minutes before the onset of magnetic disturbance in Scandinavia the appearance of an enhanced flow of the energetic electrons (50–75 keV) in the near-Earth midnight plasma sheet was observed from LANL spacecraft data (Figure 2).

The heating facility at Tromsö was operated at the frequency 4040 kHz, O mode polarization with heating cycles 4 min on/6 min off beginning at 2000 UT. The HF pumping was directed nearly along the geomagnetic field by tilting the antenna beam 6° to the south. The HF effective radiated power (ERP) was about 150 MW.

Doppler measurements of HF diagnostic signals were

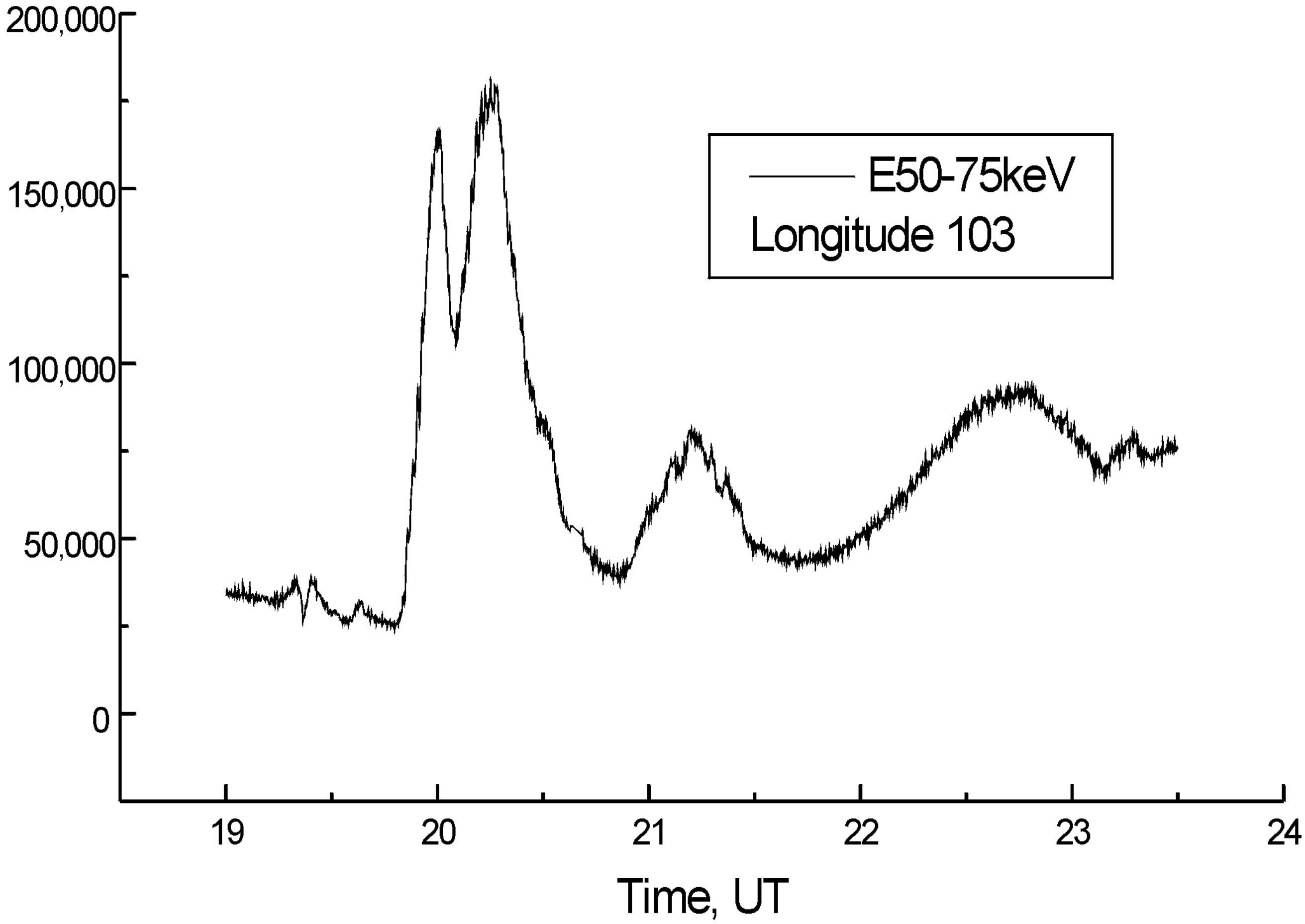

Figure 2. Variations of the electron flux from LANL spacecraft measurements on 17 February 1996 at longitude 70°E. Differential fluxes F are plotted in units of particles cm^{-2} s^{-1} sr^{-1} keV^{-1}.

carried out on the London–Tromsö–St. Petersburg radio path (Figure 1). As diagnostic signals we used the carriers of broadcasting transmitters located near London (geographical coordinates 52°N, 0°E) at frequencies 9410 and 12,095 kHz. The reception of the diagnostic waves scattered from artificial field-aligned irregularities was made by a Doppler spectral method in St. Petersburg (59.6°N, 30.4°E) at a distance of about 1200 km from the Tromsö heater. The receiving antenna was directed toward Tromsö. Spectral processing of the HF diagnostic signals was made by the fast Fourier transform (FFT) method. The frequency analysis band was 33 Hz and the 512 coefficients used in the FFT allowed a frequency resolution of 0.064 Hz.

Figure 3 displays the dynamic Doppler spectra (sonograms) of the HF diagnostic signals at 12,095 kHz on the London–Tromsö–St. Petersburg path. The scattered signals appear after the HF pump turn-on and disappear after turn-off. They were recorded as additional tracks on the negative part of the Doppler sonograms, displaced in Doppler frequency from that of the direct signal propagating from the transmitter to the receiver along a great circle path. The Doppler frequency of the direct HF signal corresponds to 0 Hz. The intervals when the Tromsö heating facility was operating are marked on the time axis in Figure 3.

An analysis of Tromsö dynasonde ionograms as well as EISCAT UHF radar data during the HF pumping experiment on 17 February 1996 shows the presence of an intense sporadic E_s layer at the altitudes between 100 and 130 km, with a maximum plasma frequency $4.1 \leq f_oE_s \leq 4.5$ MHz. The detailed examination of Tromsö dynasonde ionograms as well as the simulation of the geometry of the diagnostic HF signals scattered from AFAI in the E region were performed by *Blagoveshchenskaya et al.* [1999]. One can conclude that the E_s region of the auroral ionosphere was actually the region where the powerful HF radio waves were reflected. This leads to a generation of intense artificial field-aligned irregularities in the ionospheric E region responsible for the scattering of the diagnostic HF signals on the London–Tromsö–St. Petersburg path. The HF radar measurements (12,095 and 9410 kHz) were sensitive to AFAI having a wavelength of 12 and 15 m across the geomagnetic field lines. Note that AFAI scale lengths from 1 to 7 m were observed in the auroral E region by *Djuth et al.* [1985] and *Noble et al.* [1987]. The thermal resonance instability occurring at the upper hybrid level is believed to be the most likely candidate for the excitation of AFAI in the E region.

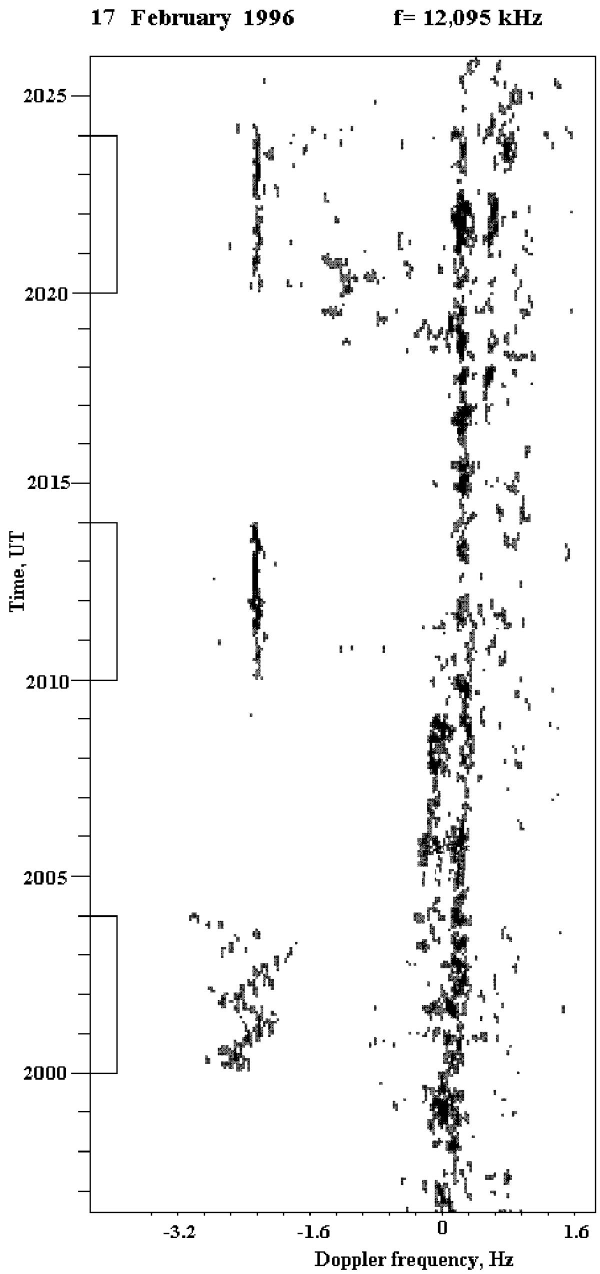

Figure 3. Dynamic Doppler spectra of HF diagnostic signals on the London–Tromsö–St. Petersburg path at $f = 12,095$ kHz from 1957 to 2026 UT during heating experiment on 17 February 1996. The direct signal lies in the vicinity of the zero Doppler frequency.

The generation of AFAI should be limited to a region about the size of the heater beam in the ionosphere. Nonetheless, the real size of the heated region in the auroral E layer is significantly larger than the area determined from the heater beam. From 46.9 MHz radar observations it was found that the heated spot averaged between 80 and 90 km at the altitude of about 100 km during Tromsö HF pumping experiment in the nightside auroral E region [*Djuth et al.*, 1985].

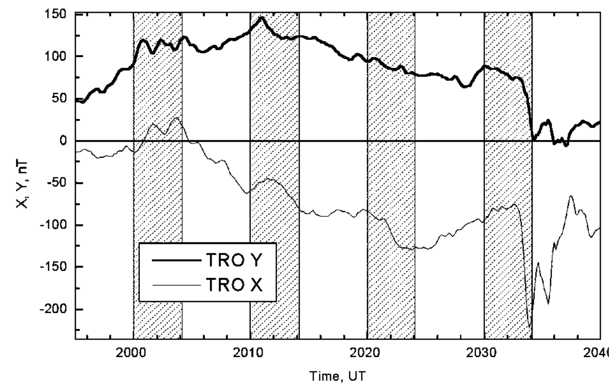

Figure 4. X (north–south) and Y (east–west) components of magnetic field variations at Tromsö from 1950 to 2040 UT during the heating experiment on 17 February 1996.

The most interesting peculiarity of the field-aligned scattered HF signals is the appearance of the oscillatory variations in the Doppler shift, f_d, with periods about 115 s during the first heating cycle from 2000 to 2004 UT. The amplitude of this wave-like process was determined as the maximum fluctuation of f_d during the heating cycle ($f_{d\,\max} - f_{d\,\min}$), and was about 1.1 Hz. The periods in f_d of the wave-like processes mentioned fall within the range of Pi2 geomagnetic pulsations. In the subsequent HF pumping cycles, no variations of f_d were observed in the scattered signals. The direct HF signal from London to St. Petersburg does not exhibit any such variations during the whole interval analyzed.

It is of interest to compare the observed ionospheric small-scale wave process with magnetic variation data. To do so, we have used the 10 s resolution geomagnetic field variation data obtained from the Auroral Observatory in Tromsö. Magnetograms of the X (north-south) and Y (east-west) components at Tromsö during the HF pumping experiment on 17 February (from 1955 to 2030 UT) are shown in Figure 4. There is evidence for the appearance of well-defined magnetic oscillations in the Y and X components of the geomagnetic field during the first HF pumping cycle (2000–2004 UT). A comparison of Figures 3 and 4 clearly exhibits the correlation between the ionospheric f_d and magnetic Y component pulsations during the HF pumping of the E_s layer. This corresponds to a correlation between the north-south component of the electric field E_x and the east-west component of the magnetic field B_y. The maximum peak-to-peak amplitude observed in the Y component of the Tromsö magnetic field during the first HF pumping cycle was 15 nT. Wave-like variations of the Doppler shifts were detected not only at $f = 12,095$ kHz but also at 9410 kHz. One may speculate that observed f_d and magnetic wave-like oscillations are indicative of Alfvén waves. These waves are identified with electric to magnetic field relations of the order of the Alfvén velocity. It is possible to make the rough estimation of E_x/B_y rations on the basis of experimental data obtained. On the assumption that electron drift is a pure $\mathbf{E} \times \mathbf{B}$ drift, from Doppler measurement data

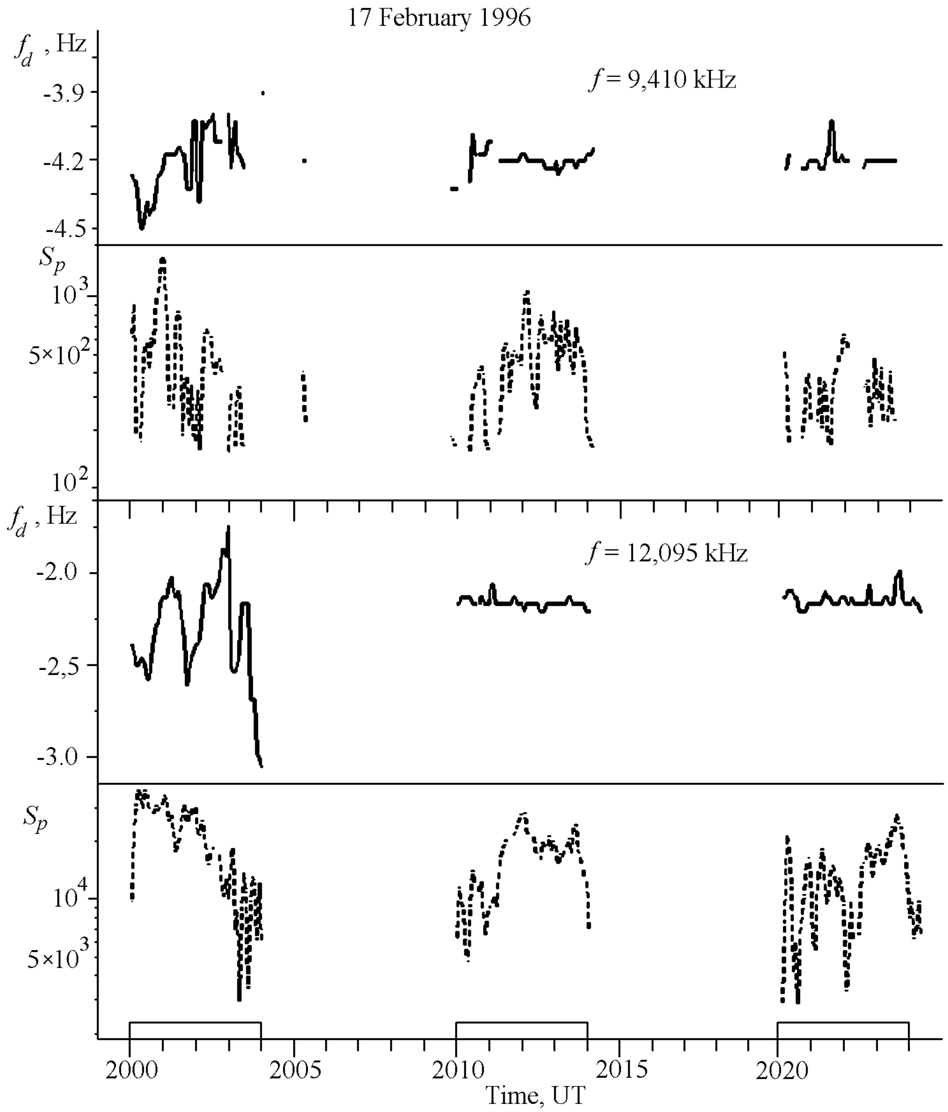

Figure 5. Temporal variations of median values of Doppler frequency shift, f_d, and spectral power, S_p, of diagnostic signals scattered from AFAI during three heating cycles from 1958 to 2026 UT on 17 February 1996, at operational frequencies of 9410 kHz (the first and second panels from the top) and 12,095 kHz (the third and fourth panels).

($f_{d\,\max} = 1,1$ Hz, $f = 12,095$ kHz) the electric field ranges up to about 4 mV m^{-1}. Therefore E_X/B_Y ratio is of the order of 300 km s^{-1}, which is in agreement with the Alfvén velocity at the altitude of the electron density maximum of the ionosphere.

Temporal variations of the median values of f_d and the spectral power S_p of the scattered HF signals at operational frequencies of 12,095 and 9410 kHz during the first, second, and third pumping cycles are presented in Figure 5. At both operational frequencies the behavior of f_d and S_p shows the following: (1) A similar ULF wave activity with periods of 115 s in f_d can be seen only during the first pumping cycle simultaneously at both operational frequencies. The maximum amplitude ($f_{d\,\max} - f_{d\,\min}$) of the wave processes were about 0.5 and 1.1 Hz at frequencies of 9410 and 12,095 kHz, respectively. (2) Irregular wave variations of the spectral power occurred at both operational frequencies throughout the whole time interval analyzed. Even though the S_p values at 9410 kHz were significantly lower compared to 12,095 kHz, there is some evidence of a similarity between the wave-like changes of S_p at both operational frequencies. (3) There is no correlation between the variations of f_d and S_p at neither operational frequency. This is indicative of their different origin.

The most likely explanation for the wave-like behavior of f_d (electric field) is Alfvén waves, while the spectral power variations S_p (intensity of back-scattered signals) are due to the fast mode MHD waves as shown by *Yeoman et al.*

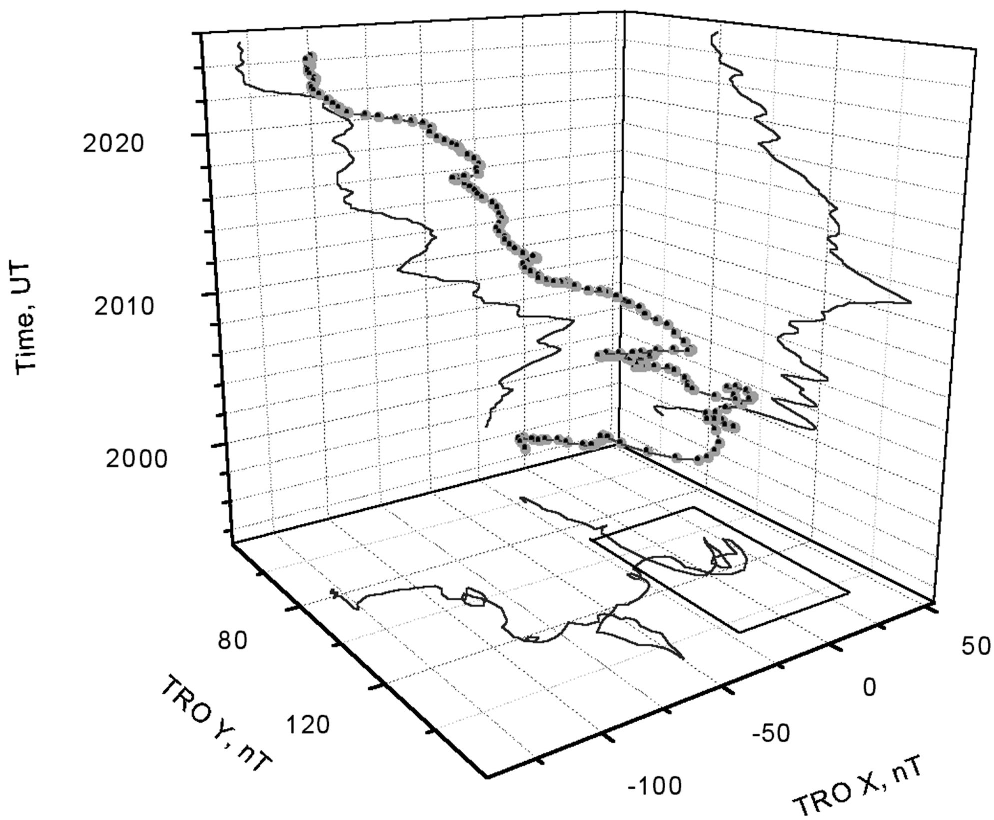

Figure 6. A 3-D view of magnetic field variation vector at Tromsö from 1950 to 2030 UT on 17 February 1996. The rectangle on the polarization surface (XY plane) marks the behavior of the magnetic field hodograph during time interval from 1957 to 2006 UT containing the first heating cycle (2000–2004 UT).

[1991] from coherent HF radar data. Recall that the nonlinear interaction between the ionospheric plasma and powerful HF radio waves leads to the modification of the ionospheric conductivities, and therefore current distribution, due to changes of the electron temperature as well as electron density. In view of the fact that electron density changes have a comparatively long time constant (of the order of a minute), significant electron density changes are possible only for a long heater-on period. However, in this case the conductivity disturbance is much stronger, than that of temperature changes, due to all conductivity elements (Hall and Pedersen conductivities) are modified [*Stubbe,* 1996]. Results of calculations for long-period heating cycles have shown that the heater-induced conductivity perturbations are of the order $\Delta\Sigma \approx 2S$ [*Lyatsky et al.*, 1996]. A disturbed ionospheric current distribution implies a magnetic field disturbance. Therefore the study of the polarization of the magnetic field variations in the X and Y components provides a way of getting the information about disturbances of ionospheric currents.

To demonstrate the possible modification of ionospheric currents produced by HF pump waves reflected from the auroral E region, we have analyzed the temporal evolution of the polarization from the Tromsö magnetic field variation data. Figure 6 presents a 3-D view of the magnetic field variation vector at Tromsö during the HF pumping experiment on 17 February 1996, from 1955 to 2028 UT. It is clearly seen from Figure 6 that the appearance of well-defined loops in the polarization surfaces is closely connected in time with heater-on periods of 2000–2004 and 2010–2014 UT. The polarization changes are determined by the geometry of the heated region, the direction of the external electric field, and the ratio of the height-integrated Hall and Pedersen conductivities $\sum\sigma_H/\sum\sigma_P$. Note that when the $\sum\sigma_H/\sum\sigma_P$ ratio changes during the heater-on period, a rotation of the polarization vector occurs. If this ratio is kept constant, the polarization is linear [*Lyatsky et al.*, 1996]. Therefore the appearance of the loops in the polarization surfaces are indicative for a strong $\sum\sigma_H/\sum\sigma_P$ ratio changes and consequently the ionospheric currents. The most strong changes were observed during the first heating cycle (2000–2004 UT), when a composite loop occurred. In the second heater-on period the more simple loop was observed in the polarization surfaces. Also, at last, in the third heater-on period (2020–2024 UT) a small loop took place only in beginning of the pumping cycle. Hence, the results obtained are experimental evidences for a local modification, by powerful HF radio waves, of the auroral ionospheric currents.

3. Discussion

Coordinated observations of ULF wave activity in the 110–120 s range from HF bistatic Doppler measurements on the London–Tromsö–St. Petersburg path and IMAGE magnetometer network were performed in an HF modified ionosphere on 17 February 1996. The experiment was unusual in that a strong auroral E_s layer was pumped during the initiation stage of the background upward field-aligned currents (FAC) of the substorm current system. The analysis of the HF Doppler data shows that there is a clear evidence of the excitation of intense artificial field-aligned irregularities (AFAI) in the E_s layer (see Figure 3). On the other hand, one can notice a strong modification of the ionospheric currents by powerful HF radio waves in the Tromsö magnetic field variation data (see Figure 6). Moreover, the upper hybrid resonance level where the heater-induced irregularities are excited is near the altitudes of the heater-enhanced conductivity region.

It is well known [*Kamide and Baumjohann*, 1993; *Raspopov*, 1968; *Raspopov and Troitskaya*, 1974; *Yeoman et al.*, 1991] that a substorm intensification can be accompanied by the generation of Pi2 magnetic pulsations in the range 90–150 s. Pi2 pulsations consist of an auroral zone Alfvén wave and a lower latitude compressional mode, possibly due to a cavity mode wave source. The auroral zone Pi2 polarization pattern exhibits clockwise (CW) polarization that undergoes a reversal to become anticlockwise (ACW) at lower latitudes [*Yeoman et al.*, 1991]. In our case, the ionospheric and magnetic pulsations observed during the first heating cycle could be the signatures of Pi2 pulsations. To study this point, the magnetic field variations in the X and Y components were considered from all of the magnetometers in the IMAGE network, as shown in Figure 1. The examination of the unfiltered and filtered (between 120 and 80 s) X and Y component variation data presented by *Blagoveshchenskaya et al.* [1998b] shows a 180° phase change of the X component in latitude between BJN and SOR stations located to the north from TRO station. Moreover, this phase change started 1 min before the Tromsö HF heating facility was turned on.

During the first heater-on period the magnetic pulsations exhibit the unusual behavior. It is clearly seen from the polarization changes of the magnetic pulsations. Let us also examine the polarization changes of the magnetic pulsations from the IMAGE magnetometer measurements. A detailed information about magnetic pulsations can be obtained from hodographs displaying the temporal evolution of XY polarization at different stations. Figure 7 shows the hodographs of the magnetic field X and Y components for the time interval containing the first heating cycle (2000–2004 UT) at different IMAGE magnetometer stations. Note that the time interval analyzed is marked in Figure 6 by a rectangle where the 3-D view of the magnetic field variation vector is shown. One can see from Figure 7 that during 1 min before and ~1 min after the Tromsö heating facility was turned on, the polarization of the initial wave packet was CW at the BJN station and ACW at the lower latitude stations that is in a good agreement with typical polarization signatures of the natural Pi2 pulsations. The unusual peculiarity in the polarization behavior during the first HF pumping cycle is a reversal of the polarization pattern from ACW to CW observed in the longitudinally limited area near the TRO latitude. Note that this reversal took place not immediately but ~1 min after HF heater turning on. The observed delay closely corresponds to the time when conductivity perturbation peaks due to the heater-induced electron density changes. One can see in Figure 7 the appearance of a sharp loop at the TRO station and smoother loops at the SOR and MAS magnetic stations during the first heating cycle. Taking into account the size of the heater-modified region in the auroral E_s layer, which is equal at least to 90 km at the altitudes of 110–130 km, one can conclude that the modified region occupies the area between SOR and MAS magnetic stations separated by about 1° in latitude. The interesting behavior of the hodograph is observed for the AND station, located to the west from TRO, and outside of the area of the upward field-aligned currents. There is no loop on the polarization surface at this station. Therefore, in our HF pumping experiment, the heater-induced ionospheric conductivity irregularity may be responsible for localization of the most intense magnetosphere–ionosphere coupling in the vicinity of Tromsö.

The other unexpected feature of the observed magnetic pulsations is a different period of pulsations in the X and Y components (see Figure 4). It is also clearly seen in Figure 8 obtained from Fourier power spectral analysis for the Tromsö magnetometer data presented in Figure 4. Figure 8 exhibits that the dominant frequency in the X component is about of 7 mHz (145 s) and in the Y component is of 8.7 mHz (115 s).

What is the nature of the observed ULF wave activity during the first heating cycle? In our opinion the most plausible candidate for the generation mechanism of the ionospheric and magnetic pulsations of the Pi2 type is the following: The powerful HF radio wave in the lower ionosphere locally modifies the ionospheric conductivity [*Lyatsky et al.*, 1996; *Stubbe*, 1996]. It was shown by *Lyatsky and Maltsev* [1983], *Kan and Sun* [1985], *Lysak* [1990], and *Borisov et al.* [1996] that the region of enhanced ionospheric conductivity will be polarized by the background electric field and the polarization electric field propagates into the magnetosphere along the magnetic field lines in the form of an outgoing Alfvén wave. The problem of the Alfvén wave generation over a circular inhomogeneity of the disturbed conductivity in the background field-aligned current region has been considered by *Kozlovsky and Lyatsky* [1997]. Recall that calculated conductivity perturbations range up to about $\Delta\Sigma \approx 2S$ for long-period heating cycles.

It was shown that over the region of the enhanced ionospheric conductivity, an additional field-aligned current of the outgoing Alfvén wave is directed in the same sense as the background FAC. When the outgoing Alfvén wave reaches the magnetosphere, it will be reflected. Multiple bounces of the wave can provide an electromagnetic coupling between the ionosphere and magnetosphere and lead to magnetic and electric field oscillations. The other possible mechanism for the Alfvén wave generation is a field-aligned current-driven instability which starts earlier over a patch of the heater-

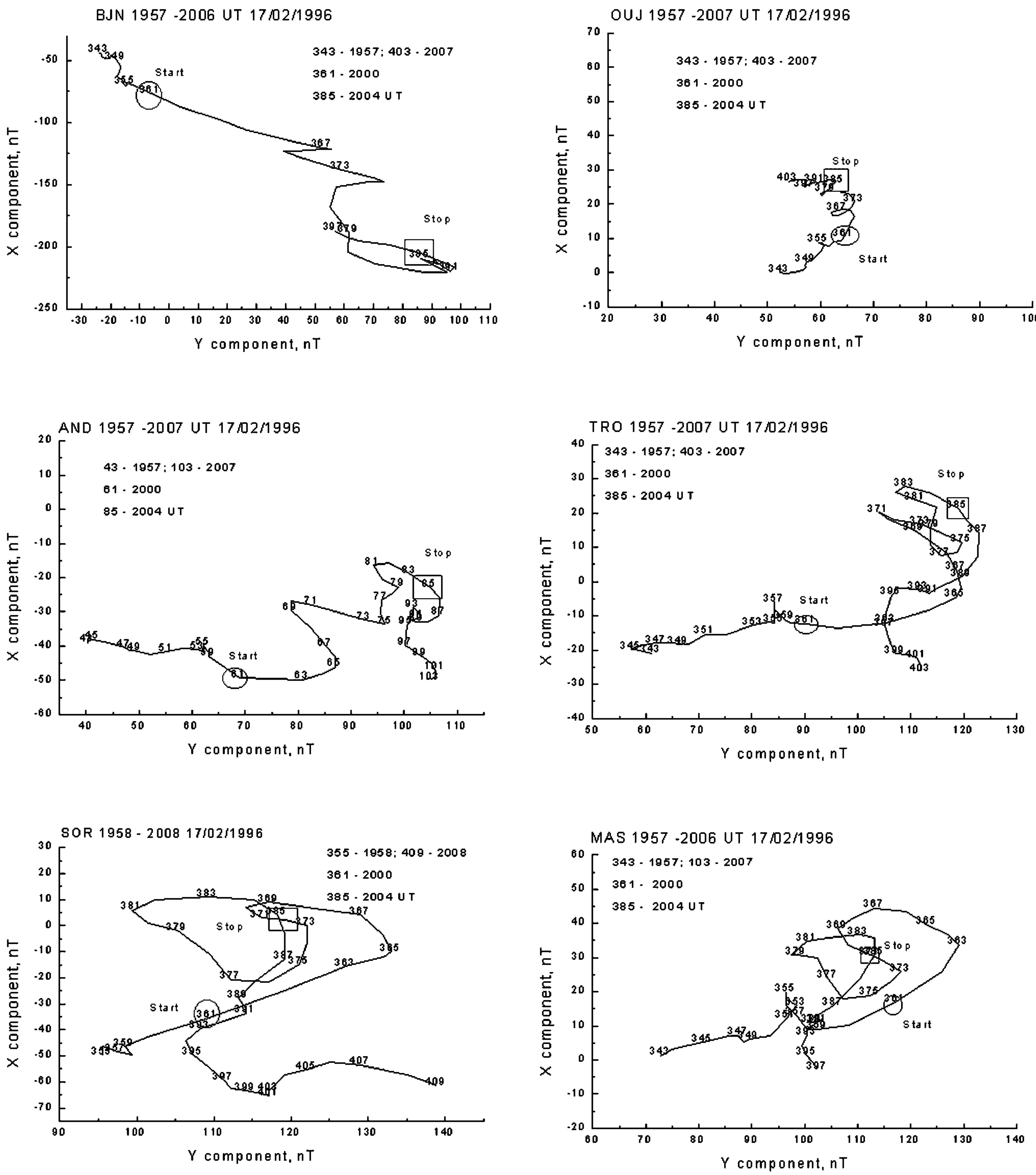

Figure 7. Hodographs of magnetic field presenting the temporal evolution of the XY polarization at magnetic stations located in the area of the upward field-aligned currents (TRO, SOR, and MAS) and outside from this area (BJN, AND, and OUL) on 17 February 1996, from 1957 to 2006 UT containing the first heating cycle (2000–2004 UT). Note that BJN, AND, and OUL magnetometers are located to the north, west, and south from Tromsö correspondingly. The Tromsö heater switchings on and off are marked by ovals and rectangles correspondingly. Digits near curves are separated by 20 s.

enhanced conductivity [*Zhulin et al.,* 1978]. This leads to the positive feedback in the magnetosphere-ionosphere system and the further growth of the upward background field-aligned currents during the initiation stage of the substorm current system. The mechanism mentioned above for the Alfvén wave excitation can be realized in the E region during the initiation stage of the FAC system. That is the reason that the substorm onset controls the occurrence of the heater-induced Alfvén wave and therefore the strong modification of the Y component of magnetic field variations. Taking into account that the Alfvén wave travel time between the ionosphere and magnetosphere for the Tromsö L shell is ~60 s, the magnetic and electric field oscillations must have a period of 120 s, which is close to our observed results. Note that the amplitude of the Y component of the magnetic field variations at Tromsö was not damped during the first heating cycle and the pulsations disappeared 1 min after the heater was turned off (see Figure 4). This corresponds to the travel time of the reflected heater-induced Alfvén wave from the magnetosphere to the ionosphere after the heater was turned off.

We therefore suggest that the outgoing Alfvén wave is generated from a heater-induced inhomogeneity of enhanced conductivity. The field-aligned current of this wave is directed so that there is a slight increase in the upward directed field-aligned current. When the Alfvén wave reflects from the magnetosphere, its downward direction acts to decrease the background current. Therefore the wave-associated currents can modulate the upward background field-aligned currents produced by the substorm surge form. The period of these pulsations is determined by the Alfvén wave travel time between the ionosphere and magnetosphere. It should be noted that less pronounced magnetic pulsations were observed at the SOR, MAS and KEV stations. These observations strongly suggest that the above mentioned stations were located in the area of the upward field-aligned current.

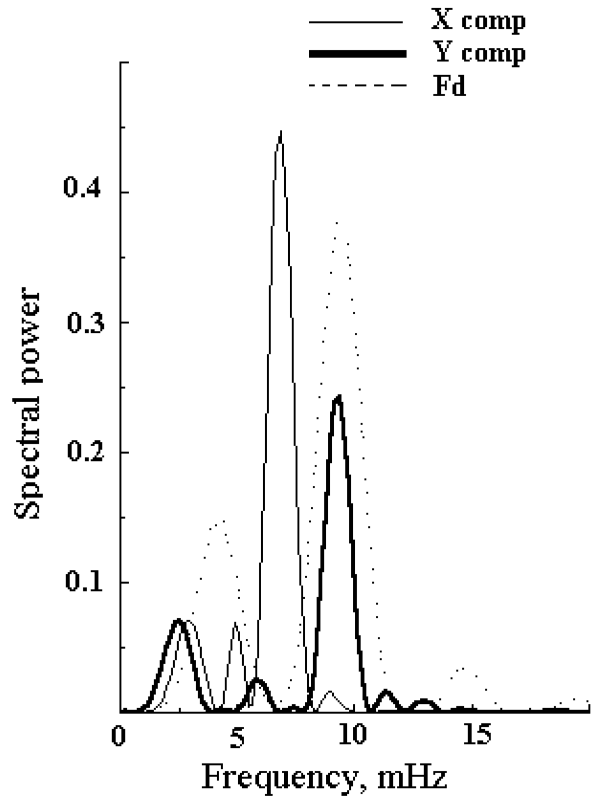

Figure 8. Fourier power spectra analysis (linear arbitrary units) for the Tromsö magnetometer data, obtained from 1959 to 2006 UT, and Doppler frequency shift from 2000 to 2004 UT on 17 February 1996.

4. Summary

We conclude that under initiation stage of the FAC system, HF pumping can modify the compressional mode of Pi2 magnetic pulsations by modulating substorm-produced field-aligned currents. The mechanism is the perturbation of those currents by heater-induced primary and reflected Alfvén waves. The excitation of the Alfvén wave, possibly due to the field-aligned current-driven instability, over a region of the heater-enhanced conductivity in the E region is in a good agreement with estimation of the E_X/B_Y ratio which is of the order of the Alfvén velocity at the altitude of the electron density maximum in the ionosphere.

The strong modification of magnetic pulsations confirmed as follows: (1) a reversal of the polarization pattern from anticlockwise (ACW) to clockwise (CW) polarization one minute after the HF heater was turned on, observed in the longitudinally limited area near TRO latitude; (2) different periods in the X and Y magnetic components; and (3) the close correlation between Doppler frequency shifts and Y magnetic component but not X component as it is usually observed for the natural compressional mode of Pi2 magnetic pulsations. We emphasize that the geophysical conditions (the onset of the substorm activation, the initiation phase of the background upward field-aligned currents, the presence of the E_s layer) during HF pumping experiment control significantly the occurrence of the heater-induced Alfvén wave.

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