HF PUMP-INDUCED ELECTRON HEATING AND ARTIFICIAL AIRGLOW AT HIGH LATITUDES: ASPECT ANGLE DEPENDENCE

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ABSTRACT

Large electron temperature increases (~3000 K) in the ionospheric F-region, produced by powerful HF wave injection, were measured using the EISCAT incoherent scatter radar near Tromsø, Norway, on 7 October 1999. Magnetic field-aligned measurements showed HF-initiated ion outflows reaching several hundred ms^{-1} at 580 km. When scanning the radar antenna from field-aligned (77.2º southward) to vertical, the strongest heating effects were always in the field-aligned position, irrespective of the HF beam direction which was varied. The imaged 630 nm HF-enhanced airglow also remained localized near field-aligned. Why the strongest heating effects occur for HF rays transmitted along the magnetic field is unclear.

INTRODUCTION

Electron temperature enhancements caused by powerful HF wave injection experiments have been measured by incoherent scatter radars many times since the first observations [1]. Night-time observations of electron heating at Arecibo [2] showed enhancements of some 40% (about 350 K). Experiments done at night in winter at solar minimum using an HF frequency of 3.175 MHz showed much larger enhancements of about 1000 to 2000 K [3] which were explained by the much lower cooling rates associated with the lower electron densities [4]. The only other facility where HF-induced electron heating has been directly measured using incoherent scatter is EISCAT, in the high latitude region. Most measurements were made during the daytime [5,6] when the ionosphere is most stable and similar to that at mid-latitudes. Temperature increases up to about 50% were measured and electron density changes of up to about 15% near the HF wave interaction height. The HF beam was vertical or near field-aligned, but no comparison between the results for different HF beam directions has been made.

Since the beginning of the present solar cycle maximum, experiments at Tromsø have been increasingly performed at night to investigate artificial airglow. The HF-enhanced 630 nm airglow was observed to be associated with much larger electron temperature increases than those during the daytime experiments [7,8] and furthermore, the airglow showed a pronounced southward displacement [9]. To investigate these observations further it was decided to examine the spatial variation of the electron temperature increases for varying positions of the HF beam.

EXPERIMENTAL RESULTS

The EISCAT HF facility (69.59º N, 19.23º E) near Tromsø, in northern Norway was used to create large electron temperatures in the high-latitude F-region during quiet geomagnetic conditions in the hours after sunset on 7 October 1999. The pump frequency at 4.544 MHz, O-mode was modulated with a cycle of 8 min on followed by 4 min off. All 12 transmitters were used at 80 kW each connected to an antenna array with a gain of 23.4 dBi resulting in an effective radiated power of 210 MW. The half-power width of the HF beam was 15º.

The EISCAT UHF radar was used with CP-1-K modulation which involves a basic time resolution of 5 s and best altitude resolution of 3.1 km in power profile and alternating code data. A long pulse modulation also gives 21 range gates in the F-region from 145 to 596 km with 22.5 km spacing.

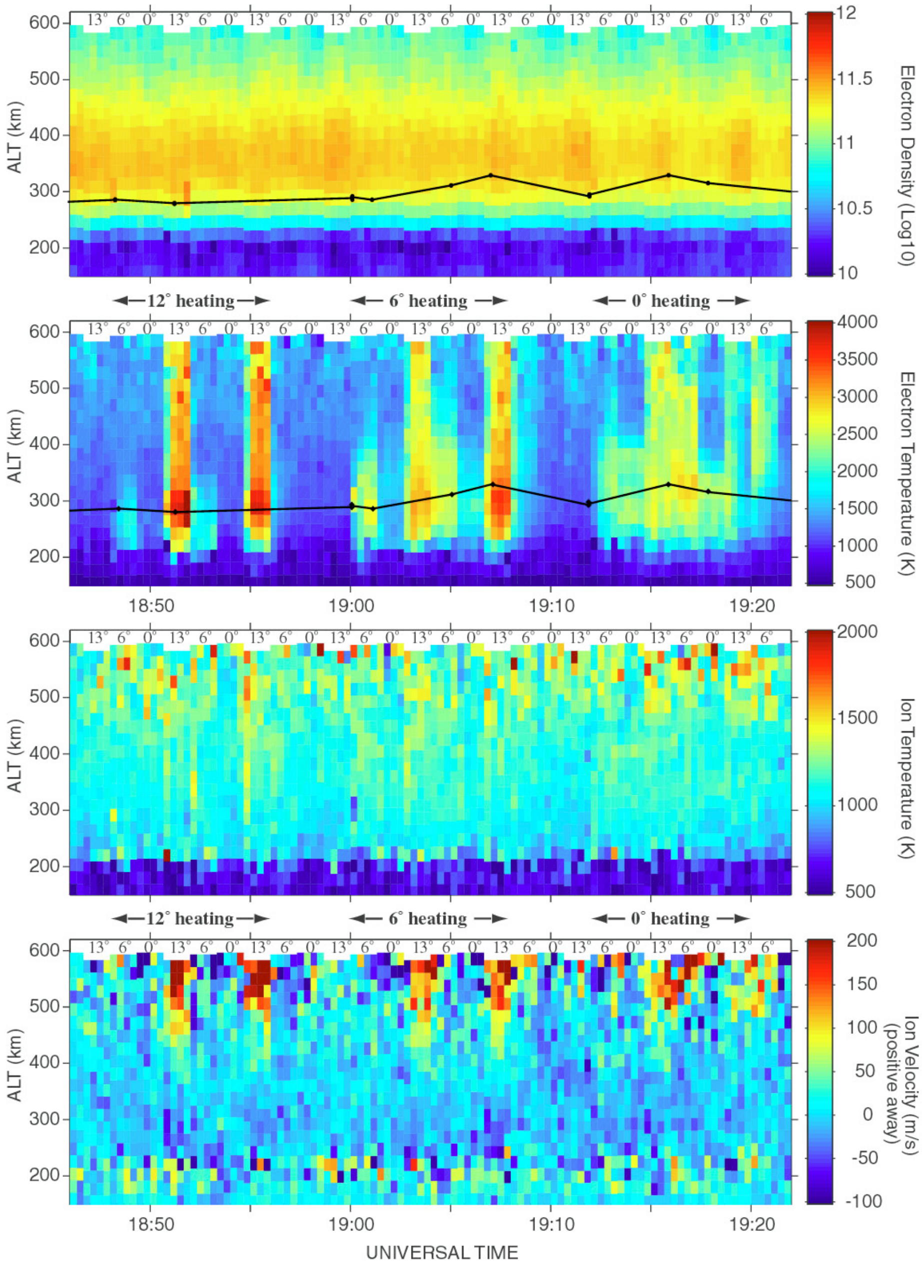

Fig. 1: Data from the EISCAT UHF radar at Tromsø on 7 October 1999, obtained using the long-pulse and analysed with 20s integration time, showing the effects of HF pumping. The HF was cycled 8 min on, 4 min off, with the beam directed at southward zenith angles shown by the numbers and arrows between the top and bottom two panels. The UHF antenna was scanned between almost the same positions (6º, 0º, 12.8º zenith angles) in a 4-min cycle, as indicated by the numbers near the top of each panel. The solid line in the upper two panels connects points indicating the HF-enhanced ion line height which should be close to but below the HF reflection height.

An interval of EISCAT data where the HF beam was tilted to three positions between field-aligned and vertical is shown in Fig. 1. The electron temperature increases are clearly seen for all positions of the HF beam. The modulation in electron density as a function of antenna position is caused by a north-south electron density gradient. The magnetic field-aligned measurements in Fig. 1 showed electron temperature enhancements up to about 3000 K, some ion heating of a few hundred degrees and ion outflows above the source region of the heated volume reaching several hundred m/s at the highest measured altitude of about 600 km. The electron density was affected very little by the heating. Some of these results are similar to those from another experiment conducted on 16 February 1999 [7,8].

One striking new result of these measurements was that when the radar antenna was scanned over three positions between field-aligned (77.2º elevation southward) and vertical, the strongest heating effects were always obtained in the field-aligned position. Also the HF pump beam was scanned between the same three positions, but at a slower rate such that the radar made a full scan for each position of the HF beam. Irrespective of where the HF beam was tilted, the measured temperature enhancement was always strongest near the field-aligned position, even though more HF energy was radiated in other directions. Fig. 2 shows, using data from several HF beam scans, how the heating effect is much larger for HF waves directed along the magnetic field than for two other positions 6º and 12º away.

At the same time HF-induced optical emissions at 630 nm from O^1D, were recorded by a low-light-level camera in Skibotn, 50 km south and east of the HF facility. In Fig. 3 are images of the 630 nm line in the airglow showing that the enhancement caused by the HF waves also remained localized near the field-aligned position. This result is consistent with that found on 21 February 1999 [9], when the artificial aurora appeared in the field-aligned position even though the HF beam was pointed vertically.

HF pump-enhanced decameter-scale field-aligned irregularities (striations) also formed, as observed with the CUTLASS HF radars in Hankasalmi, Finland and Pykkvibær, Iceland both operating at 10 MHz. Bistatic scatter measurements of 12.095 MHz diagnostic HF signals on the London-Tromsø-St. Petersburg path showed stronger backscatter and increased spectral width for the field-aligned HF position at 19:24 UT.

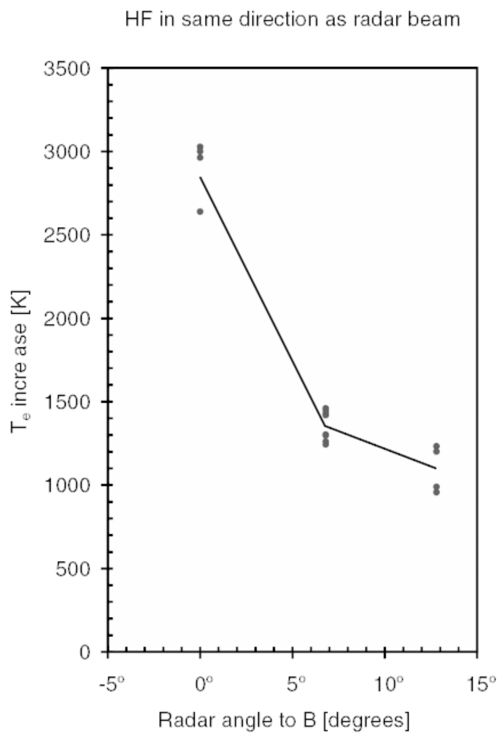

Fig. 2. Electron temperature increase as a function of radar and HF angle to the Earth's magnetic field.

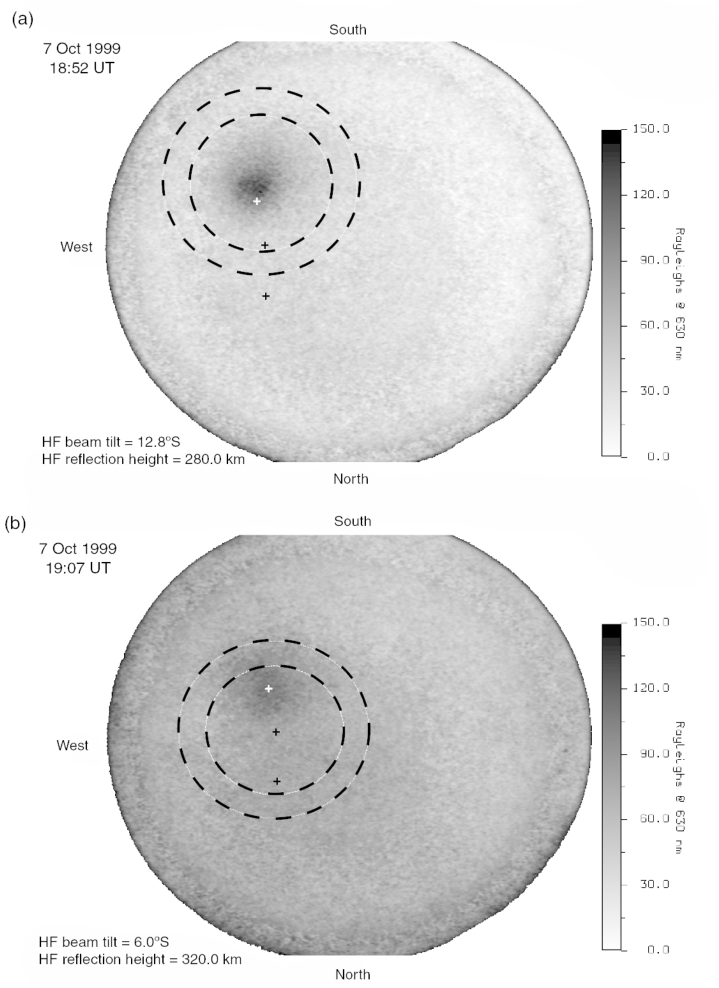

Fig. 3. Images of 630 nm red light taken by a digital camera near Skibotn, for two intervals of HF-induced aurora. The dashed circles indicate the -3 dB (inner circle) and -6 dB (outer circle) contours of the HF beam mapped onto the reflection height assuming free space propagation. The white cross marks the intersection of the magnetic field line from the HF transmitter with the reflection height. The black cross in the middle marks the 6º south (Spitze) position, while the lower black cross is the position overhead the HF facility. (a) 1848 to 1856 UT, HF beam tilted along the magnetic-field direction, reflection height 280 km. (b) 1900 to 1908 UT, HF beam tilted 6º south (Spitze), reflection height 320 km.

DISCUSSION and CONCLUSIONS

Electron temperature enhancements of up to 3000 K induced by powerful HF-pumping at night in the quiet high latitude ionosphere have been measured. They spread along the field line up to the highest measured altitude of nearly 600 km. Associated with them are field-aligned ion outflows of up to several hundred meters per second. The electron temperature enhancements show a strong dependence on the angle of the pump HF waves to the geomagnetic field. The strongest effects are for rays propagating near parallel to the magnetic field. This is consistent with observations of HF-induced airglow seen in the 630 nm (O^1D) line which is also preferentially excited by HF rays in the same direction and may be related to observations of Langmuir turbulence features also favouring the field-aligned direction [10]. There are indications from independent HF backscatter radars that decameter-scale field-aligned irregularities also produce stronger backscatter when pumping in the magnetic field-aligned direction (data not shown).

The correlation of the position of largest temperature enhancement with the position of the artificial airglow suggests that there is a common mechanism producing the airglow and the heating. Perhaps the heated electrons produce the airglow as in the thermal mechanism proposed by several authors [2,11] to explain the 630 nm airglow. It is known that the upper hybrid turbulence gives striations and heats electrons, through thermal non-linearities driven by the upper-hybrid oscillations [11]. Upper hybrid waves are excited by the pump wave electric field component perpendicular to the geomagnetic field. This geometry is met over the whole range of HF and radar antenna positions, so it is unclear why there is such a strong aspect angle dependence as that observed.

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