First incoherent scatter radar observations of radio wave pumping in the ionosphere around the second electron gyroharmonic

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Abstract

We report results from a unique experiment performed at the HIPAS ionospheric modification facility in Alaska in conjunction with the Poker Flat incoherent scatter radar (PFISR). High power radio waves at 2.85 MHz, which corresponds to the second electron gyro-harmonic at ~240 km altitude, were transmitted into the nighttime ionosphere. Kodiak radar backscatter, which is a proxy for upper-hybrid resonance, shows strong production of striations without a minimum on the second gyro-harmonic. PFISR analysis shows clear evidence of electron temperature enhancements, maximizing when the pump frequency matches the second electron gyro-harmonic and when double resonance occurs, i.e. the upper-hybrid resonance frequency matches the second gyro-harmonic.

1. Introduction

High-power high-frequency (HF) radio waves beamed into the ionosphere with O-mode polarization cause plasma turbulence, which can accelerate electrons. These electrons collide with the F-layer neutrals, primarily atomic oxygen, causing artificial optical emissions identical to the natural aurora. The brightest optical emissions are $O(^1D)$ 630 nm, with a threshold of ~2 eV, and $O(^1S)$ 557.7 nm, with a threshold of ~4.2 eV. The optical emissions give direct evidence of electron acceleration by plasma turbulence, the non-Maxwellian electron energy spectrum as well as the morphology of the accelerating region with high spatial resolution. For a review of the phenomenon, see [1]. Pump-induced optical emissions are associated with large bulk plasma electron temperature increases up to ~3500 K [6, 7], which can be monitored by incoherent scatter radars, but these alone are not sufficient to explain the optical emissions. HF pumping the ionosphere can induce several turbulent plasma instabilities, such as Langmuir turbulence, upper-hybrid resonance, parametric decay instabilities, thermal parametric instability and lower hybrid waves [2-5].

Most ionospheric heating phenomena are sensitive to the pump frequency relative to an electron gyro-harmonic frequency [8]. The electron cyclotron frequency is a function of magnetic field strength and hence altitude, being ~1.35 MHz in the high-latitude F-layer ionosphere. Phenomena such as pump-induced optical emissions, electron temperature enhancements, anomalous absorption, the production of 1-10 m scale field-aligned plasma irregularities (called striations), and several stimulated electromagnetic emission spectral features all minimize on the third or higher gyro-harmonic pump frequency. This provided the first evidence that upper-hybrid resonance was important for the mechanism of artificial optical emissions [8]. In addition, there is an asymmetry about the electron gyro-harmonics [9, 10] whereby the optical emission intensity is significantly greater when the pump frequency is just above, compared to just below, the gyro-harmonics. The same asymmetry has been found in the radar backscatter data of striation intensity [8]. Furthermore, there is no minimum in optical intensity on the second electron gyro-harmonic [10] unlike all other higher gyro-harmonics. For pump frequencies below the second gyro-harmonic, parametric decay instabilities involving Langmuir and electron-Bernstein waves exist [2]. Above the second gyro-harmonic parametric decay instabilities involving Langmuir and upper-hybrid waves, as well as the thermal parametric instability of upper-hybrid waves, exist [2]. The efficiency of photon production per MW of radiated HF power is approximately an order of magnitude greater on the second gyro-harmonic than for any other pump frequency [8].

2. Results

Here we investigate the bulk plasma electron temperature enhancements due to ionospheric pumping on the second electron gyro-harmonic for the first time. This experiment was performed using the HIPAS ionospheric modification facility in Alaska in conjunction with the new Poker Flat Incoherent Scatter Radar (PFISR) in March of 2007. Figure 1 shows the pump wave reflection altitude for 2.85 MHz (solid curve) and the upper-hybrid resonance altitude (dashed curve) for the experiment run on 19 March 2007 as a function of time. Also shown are the different phases of the pump cycle, black for continuous wave (CW), grey for pulsed and white for off. The second gyro-harmonic altitude is at ~240 km for 2.85 MHz. Gyro-resonance occurs at ~05:30 UT and double resonance occurs at ~06:00 UT.

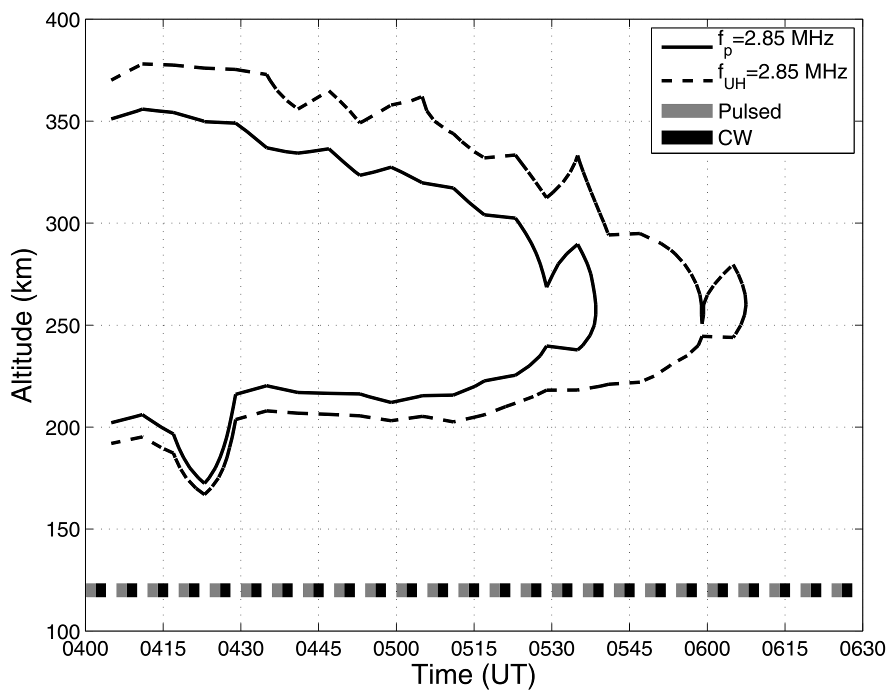

Figure 1. The altitude of the pump wave reflection and upper-hybrid wave resonance altitudes. The different phases of the pump cycle are shown.

Figure 2 shows the pump-induced electron temperature enhancements as observed by the PFISR for three different altitudes where the radar beam intersected the heater beam as a function of time. The different phases of the pump cycle are also shown. Gaps in the data are due to the ion-line overshoot phenomenon, caused by Langmuir turbulence when the pump wave is initially turned on, which prevents proper analysis of the radar spectra. Electron temperature enhancements of 200-400 K occur when pumping the ionosphere at 2.85 MHz. However, at ~05:30 UT, when gyro-resonance occurs, the electron temperature enhancement is about 500 K. Likewise, at ~06:00 UT, when double resonance occurs, the electron temperature enhancement is also about 500 K. Hence, just when these resonances occur, the electron temperature enhancement maximizes. In addition, the maximum enhancement appears to occur for pump frequencies just above each resonance condition.

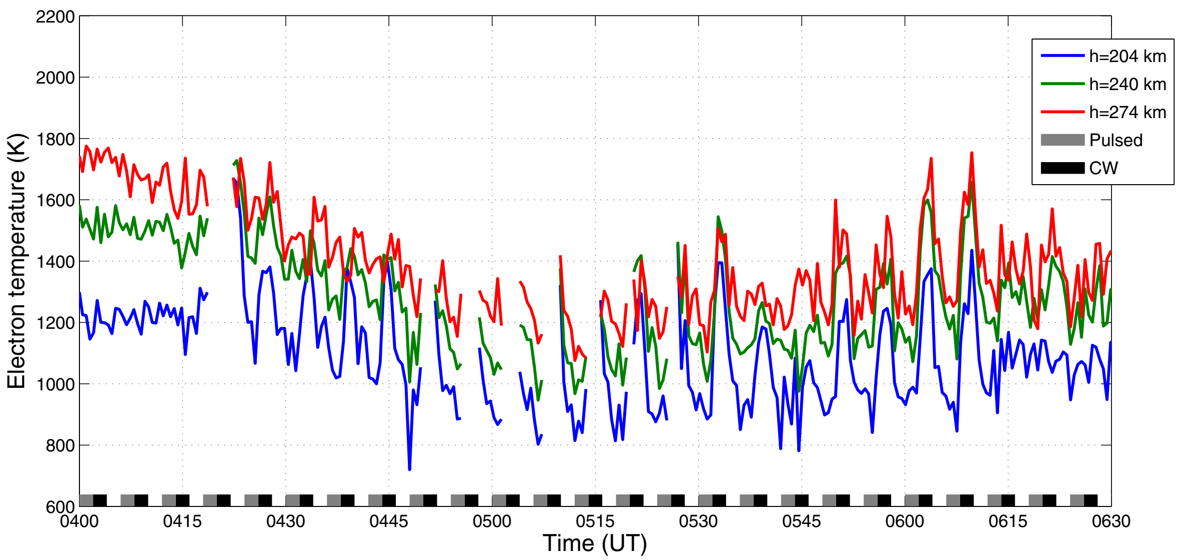

Figure 2. Pump-induced electron temperature enhancements for different altitudes. The different phases of the pump cycle are shown.

For the entire experiment of 19 March 2007, the Kodiak SuperDARN radar observed artificial backscatter, indicating the presence of pump-induced striations and upper-hybrid waves. As with the electron temperature enhancements shown in figure 2, as well as artificial optical emissions (not shown), the backscatter from pump-induced striations showed no minimum when the pump frequency passed through the second gyro-harmonic or double resonance condition.

3. Conclusions

For the first time, we have shown that the ionospheric bulk electron temperature has greater enhancements when the HF pump frequency corresponds to the second electron gyro-harmonic, and when the pump frequency corresponds to the double resonance condition on the second electron gyro-harmonic. For the latter, this is when the pump frequency corresponds to the electron gyro-harmonic whilst at the upper-hybrid resonance altitude. These results are consistent with previous optical observations.

4. Acknowledgements

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5. References

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