2nd URSI AT-RASC, Gran Canaria, 28 May – 1 June 2018

Recent Advances in Active Ionospheric Modulation by High-Power HF Radio-waves and Sideband Detections

Alireza Mahmoudian*(1), Brett Isham(1), Paul Bernhardt(2), Eliana Nossa(3), and Stan Briczinski(2)
(1) Inter American University of Puerto Rico, Bayamon Campus, Puerto Rico, USA
(2) Plasma Physics Division, Naval Research Laboratory, Washington D.C., USA
(3) Arecibo Observatory, Arecibo, Puerto Rico, USA

Abstract

This paper presents our recent break through in the remote sensing of the near Earth space environment using high-power high-frequency (HF) radio waves transmitted from the ground and detection of the backscattered signal using HF receivers, GPS receiver, radars, and all-sky imagers.

1. Introduction

Use of high-frequency (HF) heating experiments has been extended in recent years as a useful methodology for plasma physicists wishing to remotely study the properties and behavior of the ionosphere as well as nonlinear plasma processes [1]. The high-power transmitters used for these experiments are sometimes called HF facilities or HF heater, since the electric field in the transmitted radio-wave can reach over 1 V/m, more than strong enough to energize the ionospheric electrons within the beam of the transmitter, which then collide with the ions, randomizing and thermalizing their energy and increasing the electron and ion temperatures. High power electromagnetic waves transmitted from the ground interact with the local plasma in the ionosphere and can produce Stimulated Electromagnetic Emissions (SEEs) through the parametric decay instability (PDI). The classical SEE features known as wideband SEE (WSEE) with frequency offset of 1 kHz up to 100 kHz have been observed and studied in detail in the 1980s and 1990s [2]. Sideband emissions of unprecedented strength have been reported during recent campaigns at HAARP (High Frequency Active Auroral Research Program), reaching up to 10 dB relative to the reflected pump wave which are by far the strongest spectral features of secondary radiation that have been reported [3-7]. These emissions known as narrowband SEE (NSEE) are shifted by only up to a few tens of Hertz from radio-waves.

2. High-latitude observations

Electron temperature assessment: The Magnetized Stimulated Brillouin Scatter (MSBS) is a strong NSEE mode involving a direct parametric decay of the pump wave into an ES and a secondary EM wave that sometimes could be stronger than the HF pump [3] The excited ES waves through MSBS process could be either Ion Acoustic (IA) or Electrostatic Ion Cyclotron (EIC). Our recent work has shown that IA line can be used for the assessment of electron temperature and artificial aurora due to electron acceleration during radio-wave heating of the ionosphere.

Ion mass spectrometry: The primary ion constituent in the main F layer is O^+. Previous observations have shown the association between sporadic ion and sporadic neutral sodium and other metal layers. Typically, the sporadic-E layer is believed to be composed of metallic ions (with dominant abundance by Na^+, Mg^+, and Fe^+). The first observation of MSBS EIC line produced by a minor ion species (Na^+) in the presence of sporadic E layer for pump frequency stepping near $3f_{ce}$ is presented in Figure 1. The observations show the importance of tuning the pump frequency to distinguish one ion line from the other, demonstrating a potentially powerful remote sensing diagnostic utilizing MSBS lines as ion mass spectrometer to determine the minor species in the lower ionosphere.

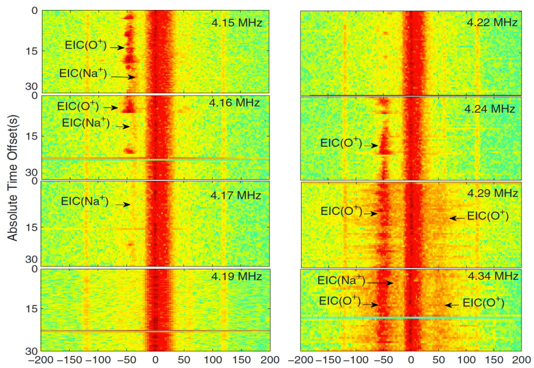

Figure 1. Time evolution of narrowband SEE spectra showing MSBS spectral lines with pump frequency stepping near $3f_{ce}$ and associated with minor ionospheric constituents.

Artificial GPS scintillation: We have reported the first modulation of GPS phase signal during radio-wave heating of the ionosphere at HAARP. The excited artificial GPS phase scintillation has been studied using a theoretical model of 4-wave decay instability involving the decay of the HF pump wave to plasma waves at the interaction altitude responsible for small scale plasma density fluctuations and Bragg scattering of the GPS signal. We have also investigated the possibility of decameter scale irregularities in Fresnel zone in the scintillation of GPS signal using the simultaneous SEE observations on the ground.

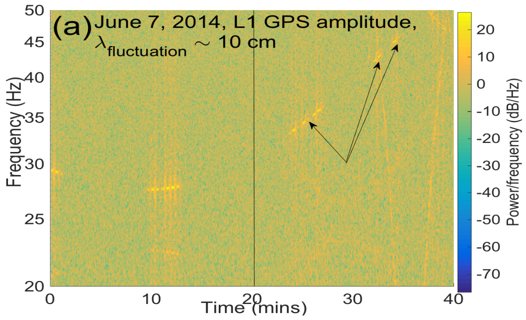

Figure 2. Spectrogram of GPS amplitude of L1 signal using high sampling rate of 100 Hz. The experiment carried out on June 7th with heating cycles for 10 HF pump frequencies. The HF pump heating at each frequency lasted 100 s and each 10 s the power was stepped up. Clear modulation of GPS phase and amplitude by the HF pump wave can be seen.

3. First Mid-latitude NSEE observations

The Arecibo Observatory has operated high-power HF transmitters, for the purposes of ionospheric radio-wave modification experiments, since the first such experiments were carried out in 1970, by scientists from the National Bureau of Standards at Platteville, Colorado. The new HF facility became operational in 2015 and has two principle frequencies, 5.1 MHz and 8.175 MHz, with a transmitter power of 600 kW. The first observations of mid-latitude NSEE feature (MSBS) are presented in Figure 3. We are currently investigating the difference between the characteristics of the MSBS lines observed at HAARP and Arecibo and possible ionospheric diagnostic information.

4. Conclusion

A new era of ionospheric remote sensing techniques was begun after the recent update of the HF transmitter at HAARP facility. Increasing the maximum transmitter power up to 3.6 MW (ERP~1 GW) has made studying some of the parametric decay instabilities responsible for SEE, which was not possible a few short years ago. Sideband emissions of unprecedented strength have been reported during recent campaigns at the HAARP facility, reaching up to 10 dB relative to the reflected pump wave, which are by far the strongest spectral features of secondary radiation that have been reported. Our recent discoveries using NSEE feature observations has resulted in the assessment active geomagnetic conditions, determination of minor ion species and their densities, ion mass spectrometry and measurements of the electron temperatures in the heated ionosphere, artificial GPS scintillation and formation small scale structures as well as a deeper understanding of physical processes associated with electron acceleration and formation of field-aligned irregularities. The first NSEE observations using the new mid-latitude heating facility at Arecibo Observatory are presented.

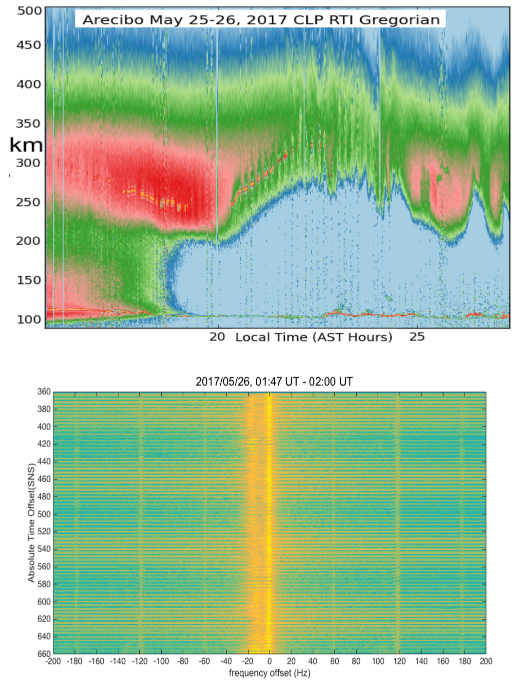

Figure 3. a) Incorent Scatter Radar (ISR) range-time ion line plot associated with b) the first mid-latitude observation of NSEE feature. The NSEE observation is promising as a compelement to ISR measurment.

5. References

1. Pedersen, T., et al., “Creation of artificial ionospheric layers using high-power HF waves,” Geophys. Res. Lett., **37**, L02106, doi:10.1029/2009GL041895.
2. Leyser, T. B., “Stimulated Electromagnetic Emissions By High-Frequency Electromagnetic Pumping of The Ionospheric Plasma,” Space Sci. Rev., **98**, 223-328, https://doi.org/10.1023/A:1013875603938.
3. Bernhardt, P.A., et al., “Stimulated Brillouin Scatter in a Magnetized Ionospheric Plasma,” Phy. Rev. Lett., **104**, DOI: 10.1103/PhysRevLett.104.165004.
4. Mahmoudian, A., et al., “Electron gyroharmonic effects on ionospheric stimulated Brillouin scatter,” Geophys. Res. Let, **41**, doi:10.1002/2014GL061050.
5. Mahmoudian, A., et al., “Ion gyro-harmonic structuring in the stimulated radiation spectrum and optical emissions during electron gyro-harmonic heating,” J. Geophys. Res. Space Phys., **118**, doi:10.1002/jgra.50167.
6. Mahmoudian, A. et al., “Investigation of ionospheric stimulated Brillouin scatter generated at pump frequencies near electron gyro-harmonics,” Radio Sci., **48**, doi:10.1002/2013RS005189.
7. Mahmoudian, A., et al., “Investigation of third gyro-harmonic heating at HAARP using stimulated radio emissions and the MUIR and Kodiak radars,” Advances in Space Research, Vol **59**, Issue 1, Pages 337-350.