Investigations of HAARP emission on super long radio paths (review)

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ABSTRACT

HAARP facility is unique research instrument, which can be used both for investigations of the interaction between high-power electromagnetic waves and ionospheric plasma and for studying of propagation effects on long-distant HF radio paths. The observation of HAARP signals at several geographically dispersed radio sites are carried out in the Institute of Radio Astronomy, National Academy of Sciences of Ukraine (IRA NASU) for about ten years. They are performed using the network of digital HF receivers developed by the IRA NASU team. It worth to note that access to the data and remote control by the acquisition systems are implemented via Internet.

1. INTRODUCTION

In this paper we will discuss results collected at the observational sites located near Kharkiv (Ukraine, 49.93^0 N, 36.95^0 E), Tromsø (Norway, 69.65^0N, 18.94^0E), at Svalbard (Norway, 78.15^0 N, 16.30^0 E) and at the Ukrainian Antarctic Station (UAS) *Akademik Vernadsky* located near Antarctic Peninsula (65.25^0 S, 64.25^0 W) during the measuring campaigns that were carried out from 2002 to 2014 years. The map of receivers is shown on Figure 1. The results of data processing show that heater signal simultaneously recorded at several spaced observation points can be used to study the "self-scattering" on ionospheric irregularities produced by the same HF pumped wave. This effect was firstly observed for EISCAT heater emissions at the sites located, near Kharkiv, St. Petersburg and at UAS [*Zalizovski et al.*, 2009]. The effect manifested itself by the fact that the variations in the scattered component signal intensity and Doppler frequency shifts (DFS) recorded at the greatly separated sites showed a high level of correlation (Fig. 2).

2. OBSERVATIONS

Results of investigating the scattering and propagation effects for the HF radiation from the HAARP heating facility (Alaska, USA) are presented. The emission from the HAARP HF heater during the measurement campaign that was conducted from February 21 through March 3, 2008 were monitored at geographically dispersed sites in the USA, Europe, and Arctic using digital Doppler receivers of the Institute of Radio Astronomy and Digisondes of the University of Massachusetts Lowell (Lowell, USA) [*Galushko et al.*, 2007]. Average relaxation times for the self-scattered signals were determined to be several tens of seconds (40-60s), while the observed rise time was much longer, up to a few minutes (Fig. 3). These numbers are characteristics of the types of the

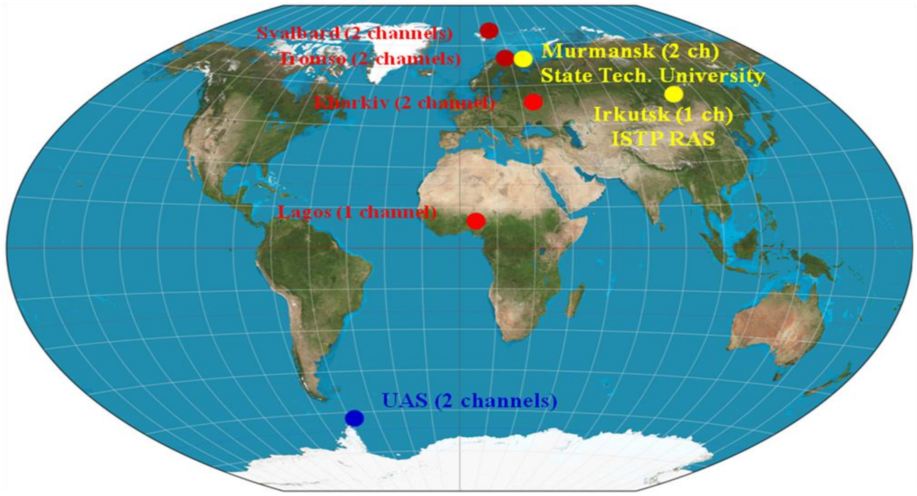


Figure 1. Map of digital HF receivers. Red – Internet-controlled, Blue – manually controlled, Yellow – Partner instruments

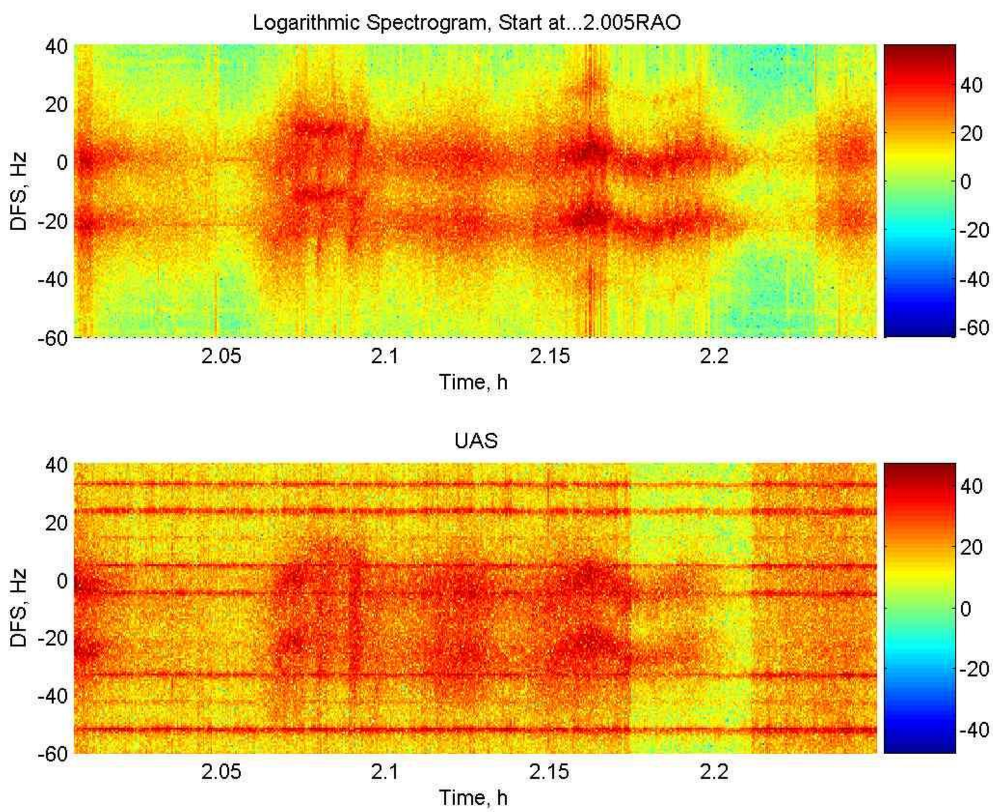
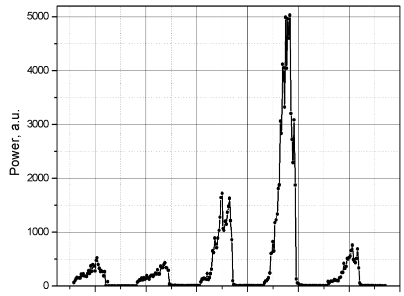
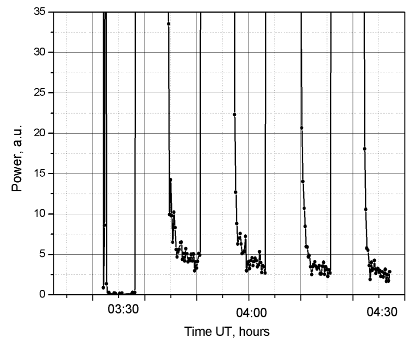


Figure 2. Spectrograms of EISCAT heater signal received on October 29, 2002 at 02:00:30-02:15:00 UT at RAO (top panel), and at UAS (bottom panel). The transmission frequencies were 4.040,717 and 4.040,695 MHz



a)

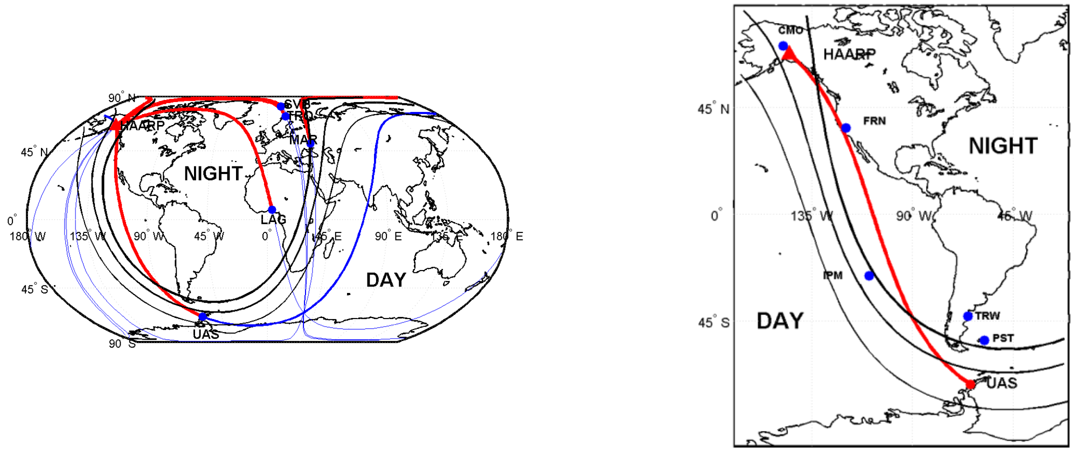


b)

Figure 3. Variations of the scattered signal power after the heater was switched to radiate the full power (a) and relaxations of probe signal as observed at RAO positions on February 26, 2008 at the HAARP transmission frequency of 2.755,056 MHz

irregularities responsible for the scattering of the heater signal. A time constant of 50-60 sec is usually associated with the relaxation time of small-scale irregularities with the spatial scale-size from a few to tens meters [*Hysell et al.*, 1996].

Another effect, which is discussed here, is enhancement of HAARP signal detected at UAS located 15.6 Mm from the heater. The possible explanation of this effect is propagation of the HAARP signal in the ionospheric interlayer waveguide. In order to experimentally test the hypothesis of exiting of the interlayer ionospheric waveguide, the signals of HAARP heating facility were recorded in spatially separated sites located in Antarctica, Arctic, Europe, and Africa during the measurement campaign performed in November 2012 (Fig. 4). The time interval for the measurements was chosen such that the sunset solar terminator passes simultaneously through HAARP and UAS. Such conditions for the given radio link are realized in the middle of November near 3:00 UT. For this reason, let us consider the measuring session for 2:30–3:15 UT on 13 November, 2012. During this session the HAARP radiated in 5 min ON/5 min OFF mode at the carrier frequency 6.9 MHz. During the OFF intervals the heater transmitted a reduced power about 100 kW at the same frequency. Signal-to-noise ratio for the Antarctic site was the greatest. Further data processing consisted in comparison of the Doppler frequency shift (DFS) variations recorded in Antarctica with magnetic field fluctuations in the vicinity of the HAARP heater and at several points along the radio path. It was found that the amount of correlation between variations of the DFS in Antarctica and H component of the magnetic field was small (less than 0.5 for all stations along the radio path). Bigger values of correlation were observed between variations of the DFS and D components of the magnetic field. The variations of the D magnetic field components along the radio



a) b)

Figure 4. Layout of the experiment in different scales and the solar terminator boundary at the Earth's surface and at the heights of 100 and 300 km

path are shown in Figure 5. The greatest amount of correlation between the DFS and magnetic field variations (correlation coefficient -0.89) was registered in the close vicinity of the HAARP heater (at CMO observatory). Magnitudes of the magnetic field variations at the closest points to UAS (Southern hemisphere) were smaller than at CMO.

These experimental facts could be considered as indirect evidence in support of the hypothesis of waveguide propagation of the HAARP signal to Antarctica. Indeed, the signal could be scattered by field-aligned plasma irregularities which drifted in the crossed fields over HAARP, thus producing the observed DFS, and then propagate via the interlayer waveguide with small losses and without additional spectral distortion. Excitation of the interlayer waveguide by pump wave is possible due to aspect-sensitive scattering mechanism which should be considered for the conditions of the experiment and measurement geometry with account of the wave refraction [*Galushko et al.*, 2013]. The scheme illustrating this mechanism is shown in Figure 6. The pump wave reaches the height of the upper hybrid resonance (UHR) where the wave-plasma interaction leads to stimulating of field-aligned plasma irregularities. It is evident that scattering in the horizontal direction is most favorable for the wave to be captured in the ionospheric duct. Due to refraction (Snell's law), the incident field wave vector changes its orientation along the propagation trajectory with respect to the geomagnetic field lines. As a result, the apex angle of the aspect-scattering cone is changed with height as well and under certain conditions the scattering might occur close to the horizontal direction. The excitation of the waveguide may be produced by wave scattering on artificial or natural ionospheric plasma irregularities. In both cases, area of the ionosphere over the heating facility will produce the dominant contribution to the variations of spectra parameters recorded at UAS, because propagation in the interlayer waveguide occurs with small losses and minimal spectral distortions. This effect was confirmed by good correlation between variations of Doppler frequency shift observed at UAS and D component of magnetic field measured close to HAARP.

A clear correlation of the signal intensity recorded at UAS with amplitude of downshifted maximum (DM) and anticorrelation with strength of broad upshifted maximum (BUM) of SEE observed near HAARP were detected during the BRIOCHE heating campaign performed in June 2014 [*Milikh et al.*, 2014]. Figure 7 shows amplitudes of PSDs obtained from the SEE spectrum combined with the intensity of the HAARP signal measured at UAS taken from the Doppler spectra versus the heating frequency. The red and blue lines in Fig 7 show the amplitude of the BUM and DM respectively,

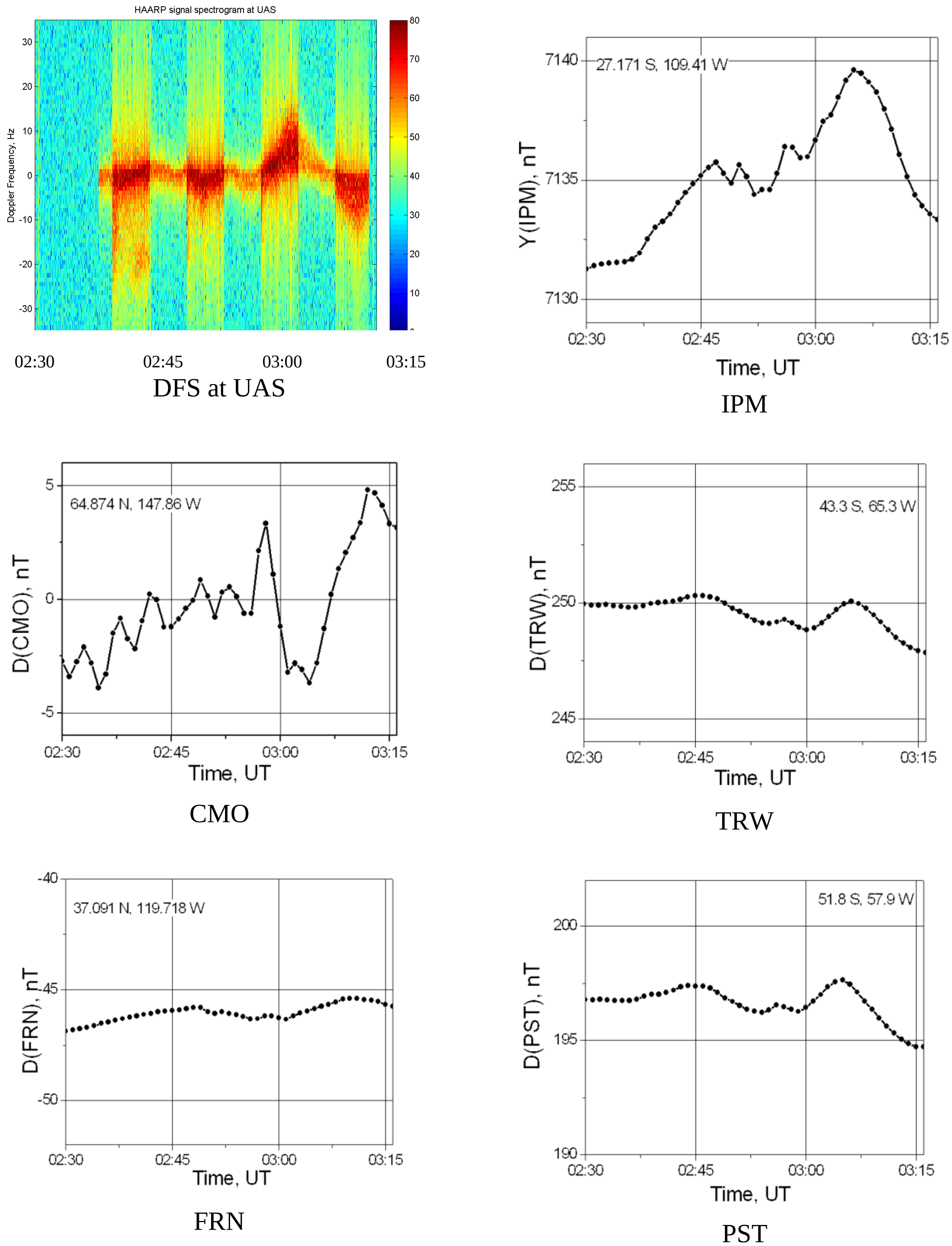


Figure 5. Variations of DFS of HAARP signal and the magnetic field D or Y component near the HAARP position (CMO observatory) and along the HAARP-UAS radio path at the observatories of the INTERMAGNET network

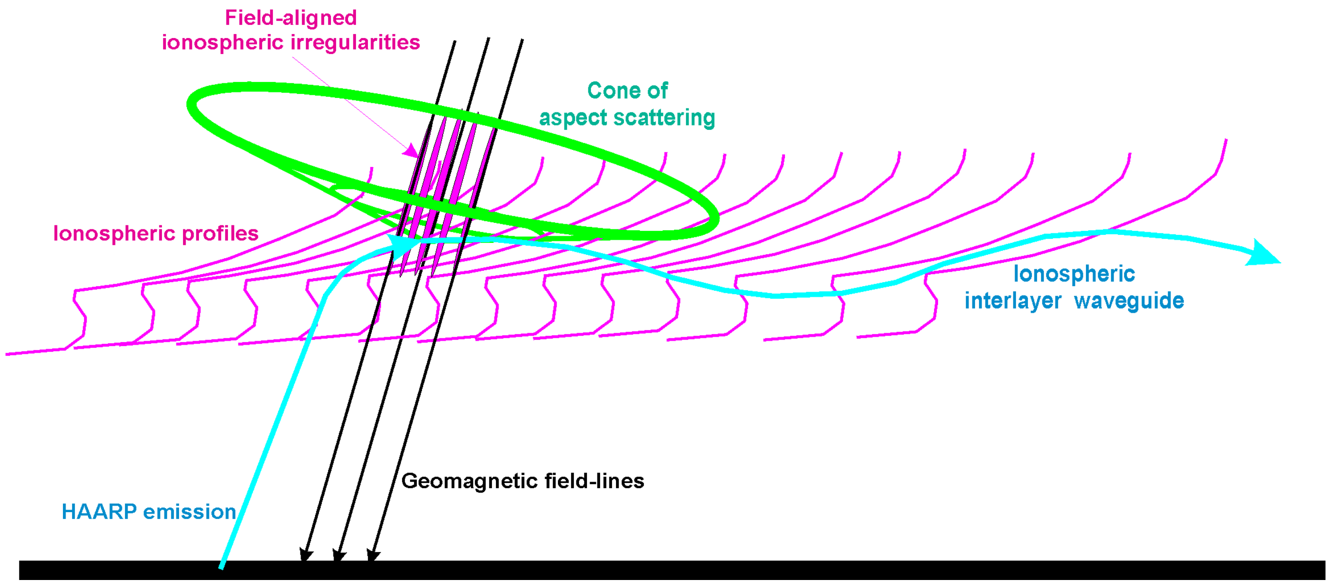


Figure 6. Excitation of the interlayer waveguide due to aspect-sensitive scattering of the pump wave.

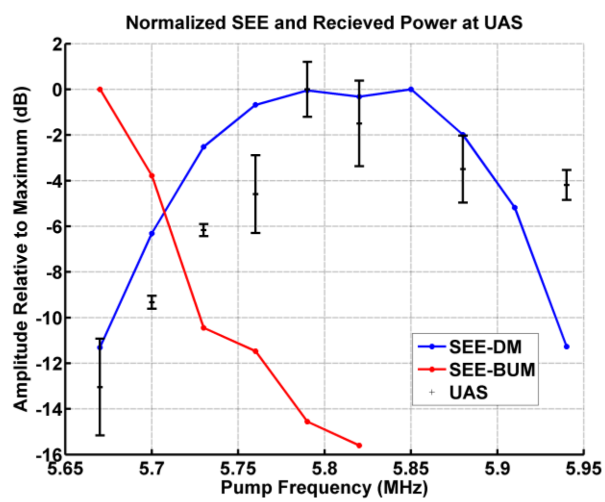


Figure 7. Amplitudes of DM, BUM, and received power at UAS relative to maximum values, as a function of heating frequency. *SEE signals were measured by the Naval Research Lab. Detector 15 km away from HAARP*.

both normalized by their peak values. The black line shows the intensity of the HAARP signal measured at UAS smoothed first by moving average and then normalized by its peak value.
Furthermore, it is known that the BUM is associated with the pumping of 10 cm transverse scale striations, often called super small striations (SSS), while the DM is associated with the 7-30 m scale striations [*Norin et al., 2008*]. Since SSS inefficiently scatter the HF waves compared to the decameter striations related to the DM, this implies that the HAARP signal detected at UAS could be due to the scattering of the HF radiation having the half wavelength of 25 m by the decameter size artificial striations into the ionospheric channel.

The analysis shows that origin of the signal detected at Verdanasky is scattering of the HAARP's HF radiation by artificially pumped striations into the ionospheric waveguide. In this process, mirror reflection does not appear to play an important role, as indicated by the low amplitude of received signal at 5.67 and 5.70 MHz. Since the amplitude of the signal varied nonlinearly with the HF power at 5.76, 5.79 and 5.82 MHz, the signal cannot be induced by sidelobe radiation which is known to be linear in the radiated power.

3. CONCLUSIONS

Self-scattering effects were observed simultaneously at greatly dispersed receive sites for several intervals of heating during the HAARP campaign of February, 2008. The similar behavior of the signals received at sites located in the USA, Europe, and Arctic following the changes in the power of the heater can be regarded as direct evidence that the pump wave is scattered by ionospheric irregularities produced by the same wave. Signal analysis has allowed estimating the relaxation and rise times of the HAARP-stimulated ionospheric inhomogeneities which are responsible for the self-scattering. The observed relaxation time was equal to several tens of seconds, while the rise time extended to a few minutes.

During the measurement campaign of November 2012 the highest signal-to-noise ratio was observed for the HAARP-UAS propagation path. The signal level in the Antarctic showed essential increase when the sunset solar terminator passed simultaneously over the receiving and transmitting sites. A high amount of correlation was observed between Doppler frequency shift variations at the UAS and D-component of geomagnetic field fluctuations measured close to the HAARP heater (the correlation coefficient was about -0.89) that can be considered as indirect evidence of ionospheric waveguide propagation of pump emission.

According to the results of the measurement campaign of June 2014 it was shown that the intensity of the signal received at UAS strongly depends on the heating frequency and on the intensity of the pumping wave. Thus the HAARP signals detected at UAS originated by the HF-pumping of the artificial striations which in turn scatters HF radiation into the ionospheric channel. The usual multi-hop propagation mode of the HAARP side lobe parasite radiation does not play an important role.

ACKNOWLEDGEMENTS

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REFERENCES

Galushko V.G., Koloskov A.V., Paznukhov V.V, Reinisch B.W., Sales G.S., Yampolski Y.M., & Zalizovsky A.V. (2008). Self-Scattering of HF Heater Emission Observed at Geographically dispersed Receiving Sites. IEEE Antennas and Propagation Magazine, 50 (6), 155-161.

Galushko V.G., Bezrodny V.G., Koloskov A.V., Paznukhov V.V., & Reinisch B.W (2013). HF wave scattering by field-aligned plasma irregularities considering refraction in the ionosphere. *Radio Science*, 48, 180–189, doi:10.1029/2012RS005072.

Hysell D.L., Kelley M.S., Yampolski Y.M., Beley V.S., Koloskov A.V., Ponomarenko P.V., & Tyrnov O.F. (1996), HF Radar observations of decaying artificial field-aligned irregularities. Journal of Geophysical Research, 101(A12), 26981-26993.

Milikh G., Najmi A., Mahmoudian A., Bernhardt P., Briczinski S., Siefring C., Koloskov A.V., Yampolski Y.M.,. Sopin A.A, Zalizovski A.V., Chiang K., Psiaki M., & Papadopoulos K. (2014), Studies of the Ionospheric Turbulence Excited by the Fourth Gyroharmonic at HAARP.

AGU Fall Meeting, San Francisco, 15-19 December, 2014. (https://agu.confex.com/agu/fm14/meetingapp.cgi#Paper/16268).

Norin, L., Grach S.M., Leyser T.B., Thide B., Sergeev E.N., & Berlin M. (2008). Ionospheric plasma density irregularities measured by stimulated electromagnetic emission. J. Geophys. Res., 113 (A09314), doi:10.1029/2008JA013338.

Zalizovski A.V., Kashcheyev S.B., Yampolski Y.M., Galushko V.G., Belyey V., Isham B., Rietveld M.T., La Hoz C., Brekke A., Blagoveshchenskaya N.F., & Kornienko V.A. (2009). Self-scattering of a powerful HF radio wave on stimulated ionospheric turbulence. Radio Science, 44 (RS3010), DOI:10.1029/2008RS00411.