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Long-distance HF propagation during natural and artificial ionospheric disturbances

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We report on the results of global diagnostics of natural and artificially stimulated ionospheric irregularities using coherent monitoring of HF signals at super long radio lines. Radio signals were radiated by high-power HF heating facilities such as HAARP (at Gakona, Alaska, USA), EISCAT (Tromsø, Norway), and Arecibo (Puerto Rico, USA) as well as by transmitters of time service in Europe (RWM, Russia) and Northern America (CHU, Canada), and detected at the Ukrainian Antarctic station *Akademik Vernadsky* (UAS) (Fig. 1).

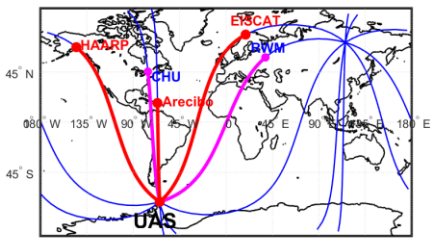

Figure 1. Map of the experiment. It is shown the direct (red for heaters and magenta for time and frequency service) and opposite (blue) radio paths. The length of direct radio paths to UAS from: HAARP – 15600 km, CHU – 12300 km, Arecibo – 9200 km, EISCAT – 16300 km, RWM – 15100 km.

Simultaneous transmissions of time and frequency service at three frequencies (4996, 9996, and 14996 kHz for RWM, and 3330, 7850, and 14670 kHz for CHU) are used as probe signals due to continuous highly stable operation. They have been recorded round-the-clock at the UAS since 2010. Time and spectral analyses of the RWM signals allowed us to reveal four different pathways: the direct and reverse paths along the great circles. Two other trajectories are formed by focusing along the solar terminator and scattering on the ionospheric irregularities of auroral ovals. The registration of the fourth spatial mode made it possible to track the position of the oval equatorial boundary and the drift velocity of plasma inhomogeneities. The impact of solar activity on the long-distance HF propagation is demonstrated by comparison of averaged spectrograms obtained in different years. The second part of this paper is devoted to the features of long-distance propagation of HF signals emitted by powerful heating facilities. Artificially excited field-aligned irregularities (FAI) scatter transmitted signals into the ionospheric waveguide formed in a valley region between the E and F ionospheric layers. Trapping and channeling of waves provide super long-range propagation from the northern to the southern hemisphere. As a result, transmitted signals are consistently recorded at the UAS. Specific features for the channeling of the HF signals occur due to the aspect scattering of radio waves by field aligned irregularities, when the scattering vector is parallel to the Earth surface. Such FAI's geometry takes place over the Arecibo heating facility where the geomagnetic field line is inclined by 43 degrees south to vertical. Since the heater antenna beam is oriented vertically, the aspect-sensitive scattered waves will be directed toward the South almost horizontally. This geometry provides a unique opportunity to channel the radio wave energy into the ionospheric waveguide and excite the whispering gallery modes. Therefore, the presentation demonstrates the novel techniques and results of global diagnostics of natural and artificially stimulated ionospheric irregularities using coherent monitoring of HF signals at super long radio lines.