HF Propagation Characteristics of Artificial Ionospheric Layers

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Abstract

Artificial ionospheric layers descending from the background F-region ionosphere can be produced by high-power HF transmissions with effective radiated powers of 10^5->10^6 W, especially near harmonics of the electron gyrofrequency. Multiple high-speed DPS-4D ionosondes were utilized to obtain direct and oblique ionospheric soundings from a large number of artificial layers during an experimental campaign at the High Frequency Active Auroral Research Program (HAARP) facility in November 2009. Initial analysis of this data shows remote oblique echoes to be qualitatively similar to direct echoes received at the transmitter site. This pattern holds when the artificial layers are created in different locations including vertical, magnetic zenith, and midway between the two ionosonde sites. Artificial layers can have higher critical frequencies and maximum useable frequencies (MUF) than the background ionosphere when the background is decaying after sunset, and echo amplitudes can be significantly stronger, even when the shorter path lengths are taken into account.

1. Introduction

Descent of enhanced VHF/UHF radar echoes and indications of density enhancements have been observed in a number of high-power HF heating experiments [1-4]. At the High Frequency Active Auroral Research Program (HAARP) facility in Alaska (62.4° N 145° W, magnetic inclination 74°) these artificially induced density enhancements develop further and appear as distinct traces in HF ionograms at altitudes as low as 140 km, or >100 km below the natural F region [5]. Combined evidence from ionosondes, VHF radar, and optical measurements indicates that these are localized plasmas dense enough to support resonance with and absorb power from the high-power transmitter beam [6]. Local ionization of neutrals within the artificial layer has been proposed to explain the dynamic and characteristic descent at rates of hundreds of m/s and disappearance of the features after reaching the minimum altitude [5,7]. It remains unclear to what degree transport of electrons or plasma from higher altitudes or reduction of recombination due to temperature or chemical effects is involved, as simulations lacking ionization mechanisms have thus far failed to reproduce the extreme changes in plasma density and altitude observed. Optical measurements suggest the density enhancements can range from localized km-scale rod-like bright spots to relatively thin and homogenous layers extending up to 50 km across, sometimes with complicated three-dimensional structure giving multiple ionosonde traces. Regardless of the specific production mechanisms, the propagation characteristics of these artificial ionospheric plasmas are of scientific and practical interest, and motivated establishment of a temporary oblique ionospheric sounding link to measure HF propagation characteristics during layer generation experiments conducted at the HAARP facility in November 2009.

2. Experiment Setup and Geometry

An actively transmitting DPS-4D ionosonde [8] was located at the HAARP facility (62.4° N 145.15°W) and attached to the existing ionosonde transmit and receive antennas at the site. This provided a means of transmitting HF pulses over a wide range of frequencies from < 1 MHz to approximately 30 MHz, although as employed in November 2009 only the lower part of this range was utilized. A second DPS-4D and receive antenna array were temporarily installed for the experiment along the Richardson Highway near Kenny Lake, Alaska at a ground distance of 82 km along a bearing of 181° geographic from the HAARP site. The site (61.66°N 145.18°W) was selected as the closest available location to the point a wave transmitted parallel to the HAARP field line (inclination 76° declination 22° W)

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would return to the ground after specular reflection from a layer at 150 km altitude. The calculated optimal receiver location for this scenario was at 61.79°N 145.67°W, which is located in a remote glaciated mountainous region far from any transportation, power, or communications infrastructure. Figure 1 shows a map view of the experiment geometry, and a raytrace simulation of waves transmitted from the HAARP site propagating back down to the remote site after reflection off an artificial layer.

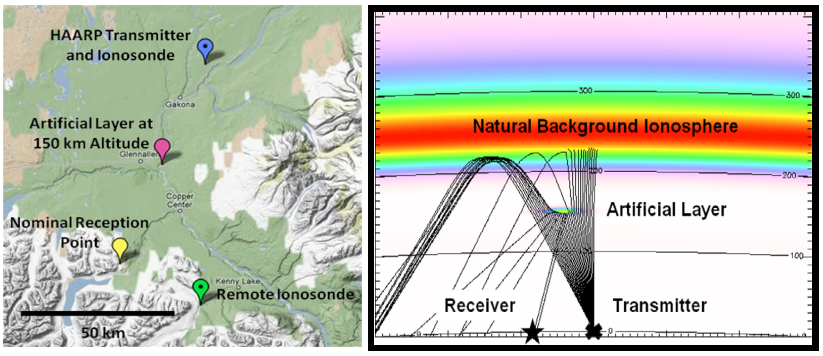

Figure 1. Left: Experiment geometry showing the positions of the HAARP transmitter and active ionosonde just NE of Gakona (blue marker with dot), the sub-ionosphere location of an assumed artificial layer at 150 km altitude along the magnetic field direction near Glennallen (pink marker), the optimal reception point for specular reflection from the layer (yellow marker in remote area SW of Copper Center), and the actual receive ionosonde location along the Richardson Highway west of Kenny Lake (green marker). Right: Raytrace for propagation at 2.85 MHz between the ionosondes via an artificial layer at 150 km altitude along the magnetic field line.

The passive remote ionosonde was synchronized to the active ionosonde at HAARP using GPS timing. By running identical data acquisition programs on both ionosondes, the remote ionosonde was able to record echoes from the active ionosonde transmitter to produce oblique ionograms. Due to the relatively short distance between the ionosondes, and the location of the artificial layers partway between the two sites, the oblique ionogram echoes look very similar to the ionograms from the HAARP site. If the artificial layers have propagation characteristics similar to the natural ionosphere, those echoes are also expected to be similar, the main differences being the angle of arrival and reduced interference from the main HAARP transmitter.

3. Propagation via Artificial Layers in Different Positions

The HAARP transmitter array is able to direct its beam anywhere within 30 deg. of vertical. During the experiments, attempts to produce artificial layers were carried out in a number of beam positions, including magnetic zenith (202° az, 16° zen), vertical, geographic south (az 180 zen 15—along the direct line to the receive ionosonde), magnetic west, and magnetic north. Artificial layers detectable by both ionosondes were observed in at least the first three positions mentioned. Figure 2 shows ionograms from both the remote site (top row) and HAARP site (bottom) for artificial layers produced by the HAARP array pointed vertically (left column), parallel to the magnetic field (center), and toward the remote ionosonde (right). Conditions for each of these experiments were somewhat different, and provide an overview of the various relative configurations between the natural background ionosphere and the artificial layers. In the left column of Fig. 2, a clear artificial layer at ~170 km altitude is apparent at 01:57 UT on Nov. 15, 2009. The trace is light blue in the remote data (top row) indicating the echoes are from the general direction of north-northeast, while the trace from the ionosonde at HAARP (bottom row) is red, indicating the echoes are from overhead, consistent with the layer being created directly over HAARP. Note that the background ionosphere extends beyond 4 MHz while the artificial layer reaches ~3.0 MHz. The center column shows an artificial layer created in the magnetic zenith position at 02:42 UT on Nov. 16, 2009. In this case, the local background F region (red) is mostly below 2.5 MHz, while the artificial layer extends to almost 3 MHz at an altitude of about 180 km. Echoes from sporadic E are apparent between 100 and 140 km. The dark blue in the remote trace indicates echoes coming from the NNW, consistent with the artificial layer being in the magnetic zenith as seen from HAARP, which puts it slightly west of north relative to the remote site. The right column show an artificial layer created when the HAARP beam was directed toward the remote site at 02:52 UT on Nov. 12, 2009. The ionogram from HAARP shows a large gap in both artificial and natural echoes due to local interference from the HAARP transmitter. This difficulty was reduced later in the experiments by synchronizing the ionogram sweep with a short blanked period of the transmitter. In this particular case, the echoes are

relatively weak and are not observed above 2.5 MHz. The interference makes it difficult to determine the true critical frequency in either the artificial or natural layers. It is also likely that artificial layers produced in this position are less pronounced than those in the magnetic zenith or vertical orientations, which are known to be effective geometries for layer production.

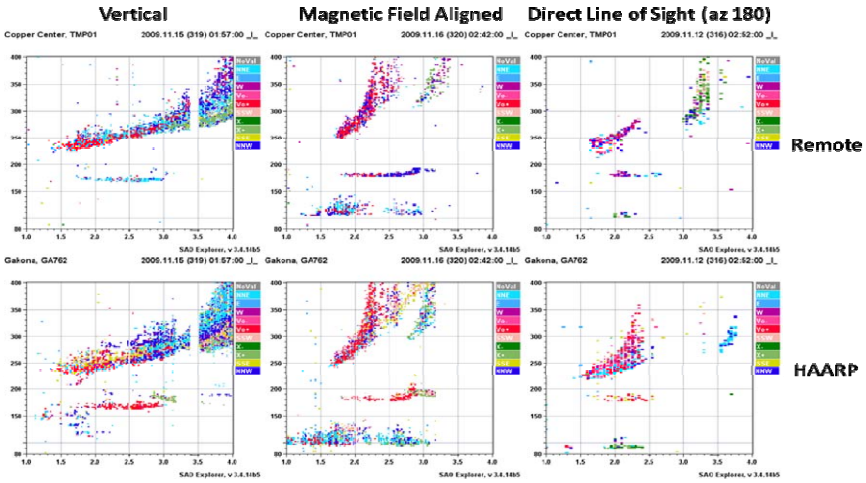

Figure 2. Comparison of remote oblique (top row) and direct (bottom row) ionograms for artificial layers created in the vertical over HAARP (left column), the magnetic zenith (center), and at 15° from vertical along the azimuth of the remote ionosonde (right).

4. Echo Amplitude Measurements

Although a calibration between the two ionosondes was not performed to allow measurement of possible aspect angle effects on the strength of echoes from the artificial layers, it is possible to compare the strength of signals received via the artificial layers with those propagating via the natural ionosphere. Figure 3 shows an oblique measurement corresponding to decay of the natural F region after sunset. A high-resolution ionogram spanning 1 MHz between 2.5 and 3.5 MHz was acquired during a short interval when the HAARP transmitter was blanked. Natural echoes are near 300 km apparent range and show significant scatter in range and intensity. The artificial echoes near 180 km range form a well-defined trace extending to 3.1 MHz. Echo amplitudes in the artificial layer were up to 27 dB, while the strongest echoes from the natural ionosphere were only 15-18 dB. Propagation distance alone would account for only ~3 dB difference in signal strength along this one-way path instead of the ~10 dB difference actually measured, indicating that propagation via the artificial layer was actually enhanced, presumably due to the layer being more homogenous and higher in density than the irregular and decaying background. In other similar cases, such as the center column of Fig. 2 above, the density in the artificial layer exceeded that of the background ionosphere and propagation via the artificial layer was recorded even when no link was available via the natural ionosphere at those frequencies.

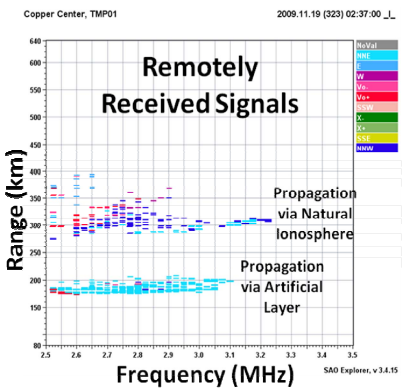

Figure 3. Remotely received echoes from the natural F region (~300 km apparent range) and an artificial layer (~180 km apparent range).

5. Conclusions

Comparison of ionosonde echoes from an ionosonde located at the HAARP facility and received by a remote system ~80 km to the south demonstrate that oblique HF propagation via reflection from artificial ionospheric layers is possible and even advantageous, sometimes providing higher frequencies or larger signal amplitudes. Remote propagation was recorded for artificial layers in several different locations in the sky. Rough indications of signal source direction are consistent with the nominal position of the artificial structures. The overall characteristics of the propagation are similar to those of the natural ionosphere, suggesting that the reflecting structures are indeed regions of enhanced plasma density reflecting the ionosonde waves and not merely irregularities or other partial backscatter from index of refraction changes.

6. Acknowledgments

HAARP is a Department of Defense facility operated jointly by the U.S. Air Force and U. S. Navy. We thank the HAARP program, operators, and site crew for their support. Work at AFRL was performed under the sponsorship of the Space Vehicles Directorate Innovation Fund and the Air Force Office of Scientific Research.

7. References

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