HAARP HIGH POWER EXPERIMENTS

AND OBSERVATIONS OF IONOSPHERIC INTERACTIONS

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ABSTRACT

We review experiments in ionospheric modification and long distance propagation performed at the HAARP facility. Most experiments were in bistatic configuration with the WAVES receiver on the NASA/WIND satellite. Initial experiments showed scintillation-like variations in low frequency propagation through the earth's ionosphere. A HAARP-HIPAS transmission experiment set up a spatial interference pattern measured at WIND. The Kodiak SuperDARN radar scanned the modified region above HAARP and observed the growth of ionospheric irregularities. Recently, lunar echoes at 8 MHz were detected by WIND. The experiments at HAARP will extend to nonlinear regimes as power levels increase.

DISCUSSION

Over a period of several years, as the HF Active Auroral Research Program (HAARP) facility near Gakona, Alaska, has increased total power from 300 kW to 960 kW, we have conducted experiments in ionospheric modification and long distance propagation. Most of these experiments have been done in collaboration with the WAVES high frequency

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receiver experiment on board the NASA/WIND satellite. Thus, WIND has provided a space-based receiving platform beyond the earth's ionosphere for measuring the modifying and/or diagnostic signal from HAARP. This bistatic configuration allowed observation of the effects of low frequency propagation through the earth's ionosphere for various conditions.

The initial WIND-HAARP experiments were conducted to begin the study of the global distribution of large scale plasma density irregularities in the ionosphere and magnetosphere. The experiments also ascertained that a spacecraft at relatively large distance from earth would be able to receive the HAARP transmissions. HAARP transmitted at various frequencies from 4.525 to 9.075 MHz with the main beam pointed as much as possible in the direction of the WIND spacecraft. Typically, the separation distance between HAARP and WIND was greater than about 15 R_e (where R_e is in earth radii) and experiments were successfully conducted to the maximum distance of WIND, about 250 R_e, in the direction of the sun. Fig. 1 shows the first 10 minutes of the experiment on 16 November 1996, when the separation distance between HAARP and WIND was about 25 R_e, or about 160,000 km. The initial 5 minutes of ON-OFF modulation of the transmitted signal provides a signature of HAARP as the source. The fluctuating signal intensities received at WIND shows the effect of density irregularities in the intervening space plasma (mostly ionospheric). The measurements showed that relatively strong signal fluctuations occurred which indicated that density irregularities with a power law spectrum occupied the space between HAARP and WIND. The data suggest that scintillations of the radio waves occur even in low ionospheric density conditions, such as at nighttime. Signal strengths also indicate that absorption of the waves occurred. The experiments provided the first radiowave measurements made over such large ranges beyond the earth's magnetosphere.

In December of 1996, the HIPAS transmitter near Fairbanks, Alaska was included in a new experiment with HAARP and WIND to study the use of two spatially separated high power HF transmitters in interferometric mode. The combination of HAARP and HIPAS transmissions provided greater power density at scale sizes corresponding to the "fringe" size of the interference pattern resulting from the spatial separation of the two radio wave sources. The configuration is thus similar to the classic Young's two-slit experiment of optical physics. The ground separation distance between HAARP and HIPAS is about 290 km. The fringe size is a function of the frequency of transmission and would be used to modify and/or stimulate space plasma density structure at particular scale size. For this experiment, HAARP and HIPAS transmitted simultaneously at 4.525 MHz with the main beam of each site pointed to the WIND spacecraft. The wave interference pattern calculated for the position of the WIND spacecraft (at about 22.6 R_e, or 144,000 km from earth) would have fringes about 33 km apart. Fig. 2 shows that the measurements at WIND detected the characteristic fringe pattern and compared favorably with the calculated pattern. Smaller scale fluctuations are the result of ionospheric interaction. The results imply it may be possible to induce specific size density structures in space plasmas by varying the frequency and power of transmission. This experiment was the first to use two high power transmitters in an interferometric mode.

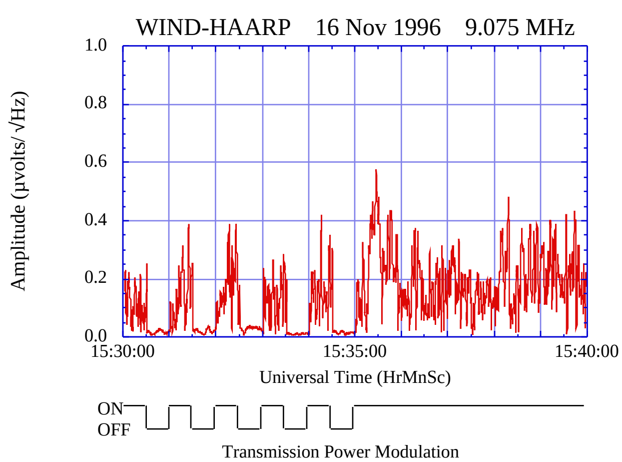

Fig. 1. HAARP transmission at 9.075 MHz received at WIND.

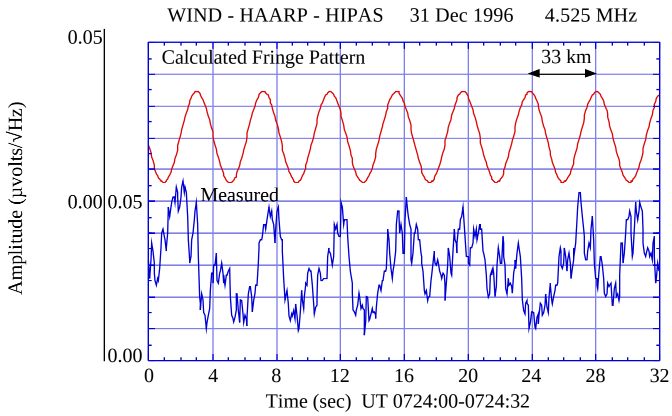

Fig. 2. Fringe pattern measured at WIND spacecraft.

During the August 1999 close flyby of the earth by the NASA/Cassini spacecraft we performed an experiment to investigate the effects of ionospheric irregularities on the determination of source directions. The first experiment window occurred when Cassini was approaching the earth from the dayside. The Cassini Radio and Plasma Waves Science (RPWS) experiment was in a mode in which 'direction-finding' of radiowave sources would be done. The data obtained can be analyzed to compare the derived source direction with the known direction. Any variations could be due to ionospheric refraction and would provide information on structure of ionospheric and space plasma structure. In the second experiment window, Cassini had passed the earth and was receding on the nightside. This experiment helped to calibrate the RPWS receiver and also provided HAARP with measurements of the effects of changes from dayside to nightside ionosphere. Our examination of the data show that HAARP is readily identified as the source of 8.025 MHz waves in the Cassini data. The transmitted and received profiles show that the ionospheric and space plasmas impose a fluctuation spectrum on the HF waves, indicating various scales sizes of plasma structure.

The SuperDARN backscatter radar located in Kodiak, Alaska is oriented to view horizontally the auroral ionospheric F-region. The fan-shaped diagnostic beam includes the F-region above HAARP. Thus, during ionospheric modification experiments at HAARP, the Kodiak radar can scan and measure the level of ionospheric density irregularities. On 3 April 2001, we conducted an experiment with Kodiak to study ionospheric heating for vertical (off-magnetic field alignment) and magnetic field-aligned orientations of the HAARP beam. Fig. 3 shows the Kodiak observations for OFF and ON phases of the HAARP heating frequency. The intensity scale shows the largest backscattered signal coming from the region of enhanced heating. The HAARP heating frequency was transmitted in 3-hour intervals about sunset and sunrise. During these periods, the foF2 passes through the heating frequency, giving heating conditions associated with underdense, critical, and overdense conditions. From this experiment, we observed that the strongest ionospheric perturbation occurred when the heating frequency was just below the foF2, and the relaxation time for the irregularities was longer that the growth time.

On September 13, 2001 the HAARP facility, transmitted radio waves to the Moon at a frequency of 8.075 MHz and the radiowave echoes from the lunar surface were detected by the WAVES radio receiver on board WIND, which was approaching the Moon in order to use lunar gravity to swing the spacecraft into a new orbit. At the time of the experiment, the WIND spacecraft was about 40,000 km from the lunar surface. HAARP illuminated the Moon with a series of 100-ms pulses at high power (960 kilowatts) for two hours. During the experiment, the HAARP transmission beam rotated to follow the Moon’s apparent motion across the sky in order to keep both WIND and the Moon within the radio beam. Thus, WIND detected both the direct HAARP pulses as they passed by the spacecraft on their way to the Moon, and the echo from the lunar surface. Fig. 4 shows a 5-s interval of data from this experiment. The timing of HAARP pulse transmissions was arranged so that the direct and echo pulses would not overlap. The echo signals are of lower intensity than the direct pulses because the lunar surface is not a 100% efficient reflector at radio frequencies. The relative intensities of the direct and echo pulses will allow us to estimate parameters such as the lunar surface scattering cross section. We believe this experiment is the lowest radio frequency that has been used in radio wave echoes from the lunar surface.

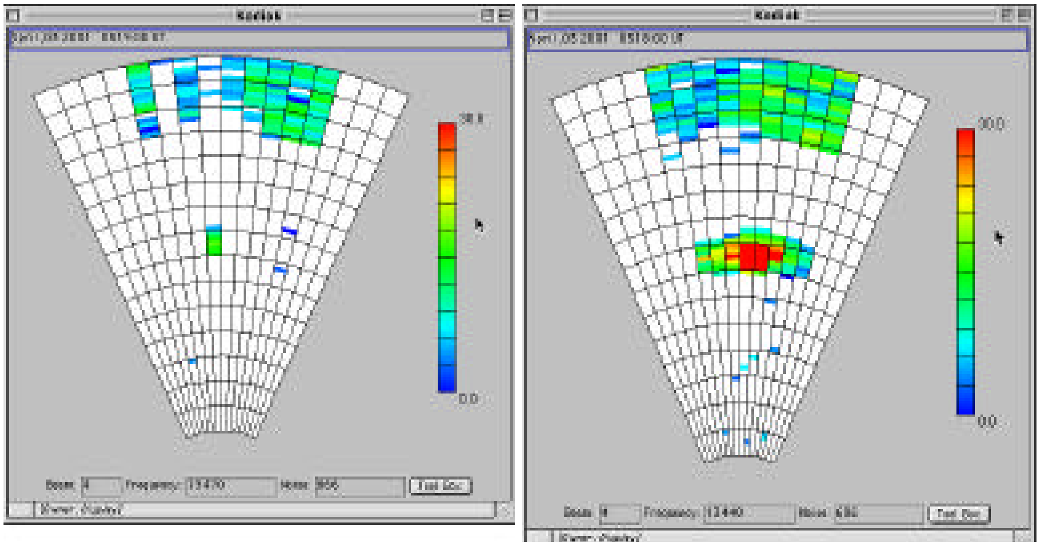

Fig. 3. Kodiak backscattered power for HAARP OFF and ON phases

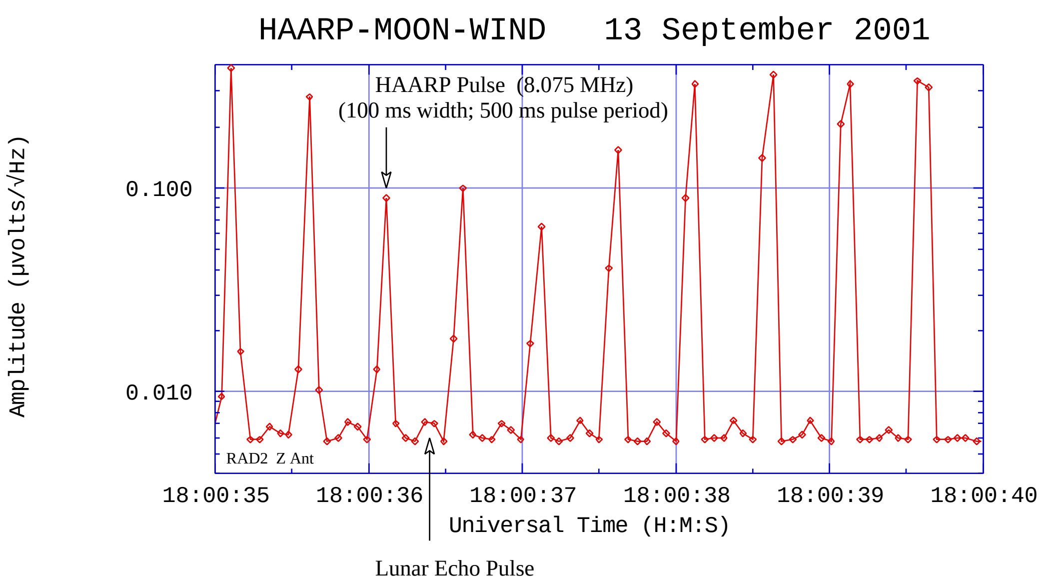

Fig. 4. The measurements of the HAARP direct lunar and echo pulses received on WIND.

SUMMARY

Generally, both daytime and nighttime experiments are done at frequencies above and below the ionospheric cutoff. The increasing power levels of HAARP have provided access to more distant regions, including the recent lunar echo experiment. We have also begun to use the SuperDARN radar at Kodiak, Alaska to image the overhead modified region and measure the time scales of enhanced ionospheric irregularities. These experiments demonstrate the great versatility of HAARP to address a wide range of scientific problems associated with high power transmissions, especially in conjunction with satellite diagnostic systems. With increasing power levels at HAARP, we expect to extend the study of ionospheric interactions to wider nonlinear regimes.

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