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IONOSPHERIC HEATING ANALYSIS
HF Plasma Line Enhancements at Arecibo

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13. ABSTRACT

The non-linear enhancement of the plasma line was observed in January 1971 by Carlson, Gordon and Showen (JGR 1972). The enhancement spectrum includes: a strong narrow line displaced below the HF (5.62 MHz) by the frequency of the ion acoustic waves f_i in the plasma (about 4 kHz); a broader line (about 30 kc width) and other weak lines near the HF; a line near f_i. Enhancements above thermal levels range above a factor of 10^4 and may be taken as verification of the HF excitation of parametric instabilities in the ionosphere. Significant time variations over scales of tens of μsec through hours were seen. Upshifted and downshifted enhanced plasma lines display asymmetries in intensity, width, power dependence, and decay rates (of the order of msec). The O-mode (but not the X-mode) excitation of these enhancements is of significance to heating experiments.

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HF Plasma Line Enhancements at Arecibo

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FOREWORD

Portions of the work described in this report were performed in collaboration with the staff of the Arecibo Observatory operated by Cornell University at Arecibo, Puerto Rico, and their support is gratefully acknowledged. The report was prepared by the principal investigator, but also includes the contribution of the project scientists H. C. Carlson and Robert Showen, and graduate students Vincent Wickwar, Robert Harper and Luiz Dias.

This technical report has been reviewed and is approved.

RADC Project Engineer

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RADC Contract Engineer

IONOSPHERIC HEATING ANALYSIS

HF Plasma Line Enhancements at Arecibo

SUMMARY

The first experiment on heating of the ionosphere at Arecibo was begun in 1967 by Showen (JGR 1972) using a 40 MHz transmitter with 100 kilowatts. He succeeded in changing the electron temperature of the ionospheric D region by several tens of percent and produced profiles of the changes in electron temperatures which he related to absorption theory.

The experiments in heating the ionospheric F region over Arecibo were begun in October 1970 by Gordon, Carlson and Showen (1971) who produced maps of electron temperature change in the meridian plane and time constants of the heating and cooling using a high frequency transmitter manufactured at the Department of Commerce in Boulder and a single frequency crossed-dipole feed for the 1000-foot dish made by L. M. LaLonde at Cornell.

A series of experiments at Arecibo followed in January, May, July and December of 1971 and are planned in March and May of 1972. The experiments have been upgraded to include a feed made by TCI to cover the range 4 to 12 MHz, the use of a Barry Research Chirpsounder, an autocorrelator designed and built by D. T. Farley and his students at Cornell, the participation of M. Biondi of the University of Pittsburgh in the photometer observations, and the cooperation of V. B. Wickwar of Yale and R. Behnke of Case Western Reserve. H. C. Carlson at Arecibo is a collaborator and the experiments are run with the full support of the Observatory staff.

The non-linear enhancement of the plasma line was observed in January 1971 by Carlson, Gordon and Showen (JGR 1972). The enhancement spectrum includes: a strong narrow line displaced below the HF (5.62 MHz) by the frequency of the ion acoustic waves f_i in the plasma (about 4 kHz); a broader line (about 30 kc width) and other weak lines near the HF; a line near f_i. Enhancements above thermal levels range above a factor of 10^4 and may be taken as verification of the HF excitation of parametric instabilities in the ionosphere. Significant time variations over scales of tens of μsec through hours were seen. Upshifted and downshifted enhanced plasma lines display asymmetries in intensity, width, power dependence, and decay rates (of the order of msec). The O-mode (but not the X-mode) excitation of these enhancements is of significance to heating experiments.

The facilities at Arecibo (latitude: 30°W magnetic, 18°N geographic; longitude: 66°W geographic; magnetic dip angle: 50°) include the following:

1. 430 MHz radar with a 1000-foot dish using the incoherent scatter technique which measures the plasma parameters, temperatures, densities and drifts, down to a scale of the order of a kilometer in the height interval 200-800 kilometers, in a vertical cone of half angle 20°.
2. Heating transmitter 4-12 MHz, power to 160 kilowatts in a 1000-foot dish, O and X modes.
3. Photometers, ionosondes.

CURRENT TASKS

Relation of the Heating Experiments at Arecibo to Plasma Physics

1. The Normal Ionospheric Plasma

a. The absorption of high frequency radio energy by the electrons is indicated by increased electron temperatures and the subsequent transfer of this energy is observed to be to the ions by collisions and transport by electron and ion drift under the influence of the magnetic field to heights other than those where the energy is deposited.

b. Changes in the photo-chemistry are observed optically.

2. The Ionospheric Plasma Excited by the High Frequency Waves

a. The anomalous absorption of high frequency radio waves and the excitation of parametric instabilities of the decaying and growing modes occur in a thin (less than 1 kilometer) layer where the frequency selection rules are obeyed. The absorption as indicated by the intensities of the excited lines of the decaying mode exceeds the normal absorption by several orders of magnitude. The growing mode is only weakly excited. The decaying mode excitations appear at $\pm f_i$, and at the frequencies $\pm(f_o - f_i)$ where f_i is the ion-acoustic frequency and f_o is the pump frequency (the high frequency radio wave).

b. Search for other enhancements. The spectra of the signal returned from the excited plasma show line structure near the pump frequency that has not been identified. A search for additional enhancements in the spectrum over the full range $\pm f_o$ to $- f_o$ is in progress, in particular, to look for the lower root, a second solution of the dispersion relation, the first solution being the upper root or plasma line regularly observed when enhanced by photoelectrons.

c. To date all of the observed excitations occur where the high frequency radiation is in the ordinary magnetoionic mode; however, additional tests with extra-ordinary mode are required before any conclusion can be drawn experimentally.

d. Since the power in the exciting wave can be changed, a threshold (predicted by plasma theory) can be sought experimentally. Since the frequency of the exciting wave can be changed, the height at which the anomalous absorption occurs can be adjusted.

Relation of the Heating Experiments at Arecibo to Scattering Models

1. The Normal Ionospheric Plasma

a. Profiles in height and time of the changes in electron temperature and electron density produced by the normal absorption and the rates at which the changes are induced and relax provide a sound basis for calculating the modifications of the medium that are needed in scattering models as they vary with time.

b. Three dimensional maps of the changes in electron temperature and electron density produced by normal absorption provide the geometric basis for the modification of the medium that is needed in scattering models.

2. The Ionospheric Plasma Excited by High Frequency Radio Waves

Maps of the excited volumes produced by the anomalous absorption will provide the observational data on which to base a scattering model. To date the layer is known to be thin (less than one kilometer thick) but has not been resolved in height; the lateral extent of the enhancement can be mapped and is expected to have dimensions of 100 kilometers or less.

FUTURE TASKS

The analysis of the experiments is continuing and results will be reported as they become available. The outline below presents the experiments that we expect to include in the March and May 1972 series at Arecibo.

1. Mapping of the ionosphere as modified by the normal absorption for the ordinary and the extra-ordinary modes varying the heater frequency in steps around the critical frequency of the F_2 layer.

a. Time constants of the increase and the decrease of electron temperature at various heights around the height where the local plasma frequency matches the heater frequency.

b. Meridian plane maps of the electron temperature and electron density through the heated volume.

c. Three dimensional maps of the electron temperature through the heated volume.

d. Height profiles of the line-of-sight component of the ion drift through the heated volume.

2. Spectra of the scatter signal anomalously enhanced by the high frequency source.

a. Features of the enhanced plasma line (the line near the pump, the high frequency but separated from it by the ion acoustic frequency) including the intensity of elements of the spectra and their variations with time and with transmitter power (incident power).

b. Features in the spectra near the plasma line.

c. Search for features in the spectra over the range ± pump frequency.

d. Search for enhancements at twice the pump frequency.

e. The thickness of the enhanced layer, the horizontal extent of the enhancement.

f. The time constants of the enhancements, the threshold of the enhancements, the variation of spectral intensities with HF power.

g. The enhancements have only been observed with O-Mode transmission; try short search using X-Mode.

SUBCONTRACTS

Technology for Communications, International

An HF feed was designed and constructed by TCI. The compatibility with the existing structure was assured by the participation of L. M. LaLonde, Arecibo projects engineer at Cornell. The feed was assembled in the field, and is mounted on the feed structure for each series of experiments by the Arecibo engineers and supporting staff. The feed covers the frequency range 4-12 MHz, handles 200 kilowatts, radiates left or right circular polarization, and has a VSWR better than 2 to 1 and at most frequencies better than 1.4 to 1.

The feed consists of crossed curtains, each a log-periodic structure. The physical size, essentially a half wavelength at 4 MHz maximum, is such as to interfere with the normal operation of the carriage houses on which are mounted all of the other feeds. The interference amounts to excluding zenith angles less than about three degrees.

University of Pittsburgh

The work under this subcontract involved the modification and operation of the University of Pittsburgh spacial scanning filter photometers and Fabry-Perot interferometers in support of the heating experiments during the February, May and July 1971 experiments. The data from these measurements is essential for the interpretation of the heating observations. This work was under the direction of Prof. M. A. Biondi.

Cornell University

The purpose of the work accomplished under this subcontract was to develop special purpose digital hardware to more efficiently process the signal data. This equipment consists of an auto-correlator and a Barker decoder. The auto-correlator, by permitting the processing of all available data from the return signal, circumvents the computer limitation of the conventional system and reduces the statistical fluctuations in the observations by an order of magnitude for a typical measurement and integration time.

The decoder permits the utilization of compressed pulses and therefore makes possible measurements with an altitude resolution of less than one kilometer in the E and F region.

This equipment was developed and assembled under the direction of Prof. Donald T. Farley and is presently functioning satisfactorily at the Arecibo Observatory.

Barry Research

ARPA has arranged to have available for each of the experimental series a Barry Chirpsounder which produces high quality ionograms. The Chirpsounder works dependably and yields permanent paper records in real time.

REFERENCES

Carlson, H. C., W. E. Gordon and R. L. Showen, High frequency induced enhancements of the incoherent scatter spectrum at Arecibo, J. Geophys. Res., 77, March 1972.

Gordon, W. E., H. C. Carlson, and R. L. Showen, Ionospheric heating at Arecibo: First tests, J. Geophys. Res., 76, 7808, November 1, 1971.

Showen, R. L., Artificial heating of the lower ionosphere, J. Geophys. Res., 1972 (accepted for publication).

BIBLIOGRAPHY

Behnke, Richard A., Vector Measurements of the Ion Transport Velocity with Applications to F-Region Dynamics, Ph.D. Dissertation, Rice University, December 1970.*

Carlson, H. C., W. E. Gordon and R. L. Showen, High Frequency Induced Enhancements of the Incoherent Scatter Spectrum at Arecibo, Journal of Geophysical Research, 77, 1242-1250, March 1972.

Carlson, H. C., W. E. Gordon and R. L. Showen, Ionospheric Heating Analysis - HF Plasma Line Enhancements at Arecibo, Interim Report, Contract F30602-71-C-0155, June 1971, RADC-TR-71-190, DDC Nr. AD-732-884.

Dias, Luiz A.V., High Frequency Radio Heating of the Ionosphere, Master of Science Dissertation, Rice University, April 1971.*

Gordon, W. E., R. L. Showen and H. C. Carlson, Ionospheric Heating at Arecibo: First Tests, Journal of Geophysical Research, 76, 7808-7813, November 1971.

Harper, Robert M., Dynamics of the Neutral Atmosphere in the 200-500 km Height Region at Low Latitudes, Ph.D. Dissertation, Rice University, September 1971.*

Harper, R. M., Observation of a Large Nighttime Gravity Wave at Arecibo, Journal of Geophysical Research, 77, 1311-1315, March 1972.

Wickwar, Vincent B., Photoelectrons from the Magnetic Conjugate Point Studied by Means of the 6300 Predawn Enhancement and the Plasma Line Enhancement, Ph.D. Dissertation, Rice University, April 1971.*

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