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MASTER

SPATIAL AND TEMPORAL EVOLUTION OF 630.0 nm AIRGLOW ENHANCEMENT DURING IONOSPHERIC HEATING EXPERIMENTS

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ABSTRACT

Images of 630.00 nm enhancements have been recorded during the January, 1986 ionospheric heating campaign at Arecibo. The artificial airglow clouds convected eastward, vanished, and then reappeared at the zenith of the HF heater. Occasionally, the airglow patches are bifurcated. The structure and motion of the airglow clouds is an indication of the dynamic behavior of the modified ionosphere.

INTRODUCTION

The transmission of high power radiowaves in the ionosphere affects the intensity of airglow from excited oxygen atoms. Natural 630.0 nm airglow in the nighttime ionosphere comes from dissociative recombination of molecular oxygen ions and electrons

$$O_2^+ + e^- \rightarrow O^* + O^* \quad \text{rate: } 2.2 \times 10^{-7} (300/T_e)^{0.7} \tag{1}$$

Ionospheric heating increases the electron temperature and consequently reduces the rate for production excited atomic oxygen by reaction (1) /1/.

If electrons are accelerated above 2 eV during ionospheric heating, collisional excitation becomes important /4/.

$$e^{-*} + O(^3P) \rightarrow e^- + O(^1D) \quad \text{cross-section: } \sigma_o = 2 \times 10^{-17} \text{ cm}^2 \tag{2}$$

Enhanced radiation occurs by transition to ground state.

$$O(^1D) \rightarrow O(^3P) + h\nu \text{ (630.0 nm, 636.4 nm)} \quad \text{rate: } A_o = 6.76 \times 10^{-3} s^{-1}$$

These airglow enhancements have been used by Carlson et al. /2/ and by Tepley et al. /5/ to infer suprathermal electron fluxes produced by parametric instabilities in the HF beam. Such measurements used photometers to determine the temporal variations of relatively weak (four Rayleighs or less) airglow enhancements.

During the January 1986 ionospheric heating campaign at Arecibo, Puerto Rico, an intensified, charge coupled device (CCD) imager was used to record the enhanced emissions at 630.0 nm. This paper presents an interpretation of the airglow images from that campaign.

EXPERIMENTAL

A computer-controlled, low-light-level imaging system was set up at the Arecibo Observatory for the ionospheric heating experiments. The airglow images were made with an interference filter centered at 630.0 nm, having a passband of 9.0 nm. The objective lens had a 50mm focal length, and a 53mm aperture. The airglow image intensity was amplified by a 40mm diameter microchannel plate (MCP) intensifier. The luminous gain of the intensifier was 5000. The output of the intensifier was focused on a 512 × 320 pixel CCD array by an 85mm focal length, f/1.0 relay lens. The quantum efficiency of the CCD array was 80%. The data from each pixel was digitized to 14 bits and stored on magnetic tape. The system was controlled by a 68000 microprocessor. All exposures were for 30 seconds. An additional 20 seconds was required for data storage.

The images in this paper were produced by subtraction of the background airglow of the unmodified atmosphere from the images obtained when the heater was on. The saturated bright spots are stars. The dark spots in the airglow clouds are a result of subtracting bright star images in the background image.

The formats for the airglow images are illustrated in Figures 1 and 2 for the 9 and 14 January, 1986 results, respectively. The HF facility was north-east of the Arecibo Observatory where optical and radar measurements were made. The HF beam has a 2 to 1 elongation in the north south direction. All images are oriented along the magnetic meridional plane.

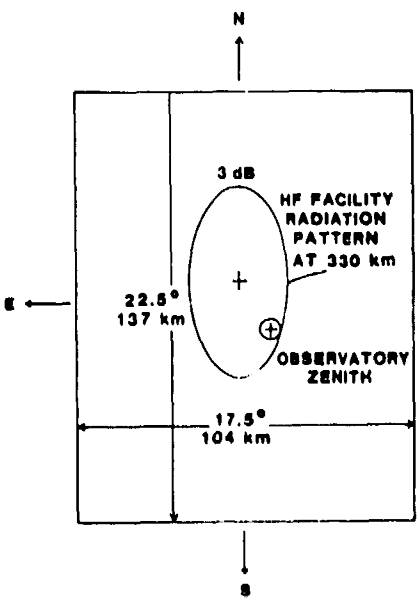


Fig. 1. Format of the January 9, 1986 airglow images.

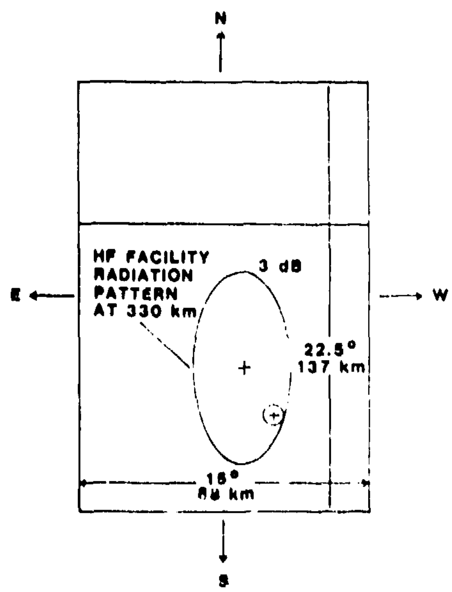


Fig. 2. Format of the January 14, 1986 airglow images.

JANUARY 9, 1986 RESULTS

The F-region profile is substantially modified by the HF heater. Figure 3 illustrates the reduction of the bottomside electron density three minutes after the heater is turned on. Density cavities such as described by Duncan et al. /3/ are formed.

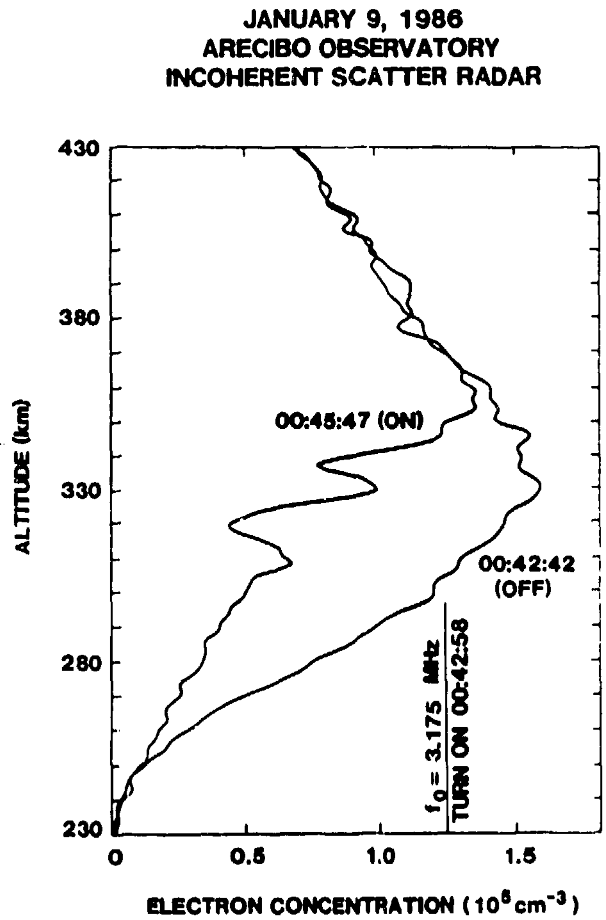


Fig. 3. F-region density profile change as a result of ionospheric heating.

The HF heater produces an enhancement in airglow which evolves dynamically. The series of images in Figure 4 show the turn on and the north-eastward convection of the airglow cloud. By the last frame of Figure 4, the airglow cloud has snapped back to the zenith position.

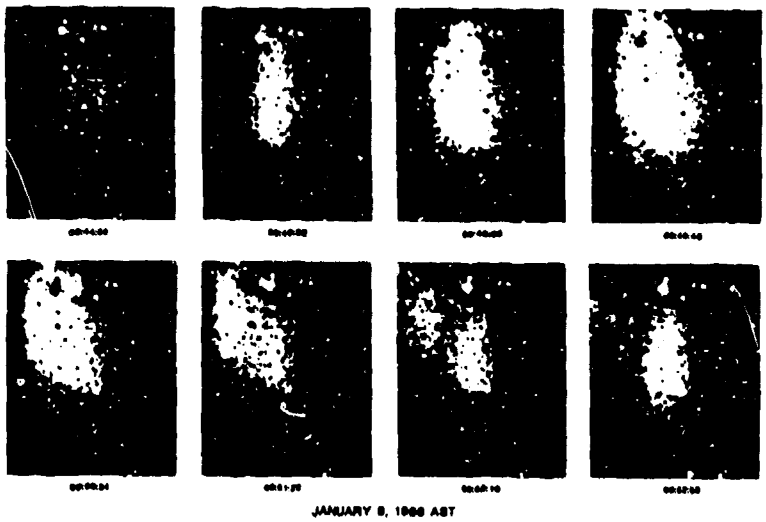


Fig. 4. Initiation and convection of the 630.0 nm airglow cloud above the HF heater.

This motion is schematically shown in Figure 5. When the HF transmitter is first turned on, the wave interacts directly overhead, triggering parametric instability, heating the plasma, and generating enhanced airglow. After 90 seconds, the enhanced plasma pressure forms a plasma depletion which begins to be convected eastward under the influence of polarization electric fields and neutral winds. The convecting depletion carries the HF ray paths along, bending them to the east. The airglow patch continues moving until the depletion can no longer refract the heater rays. The heater beam returns to the vertical and the process repeats.

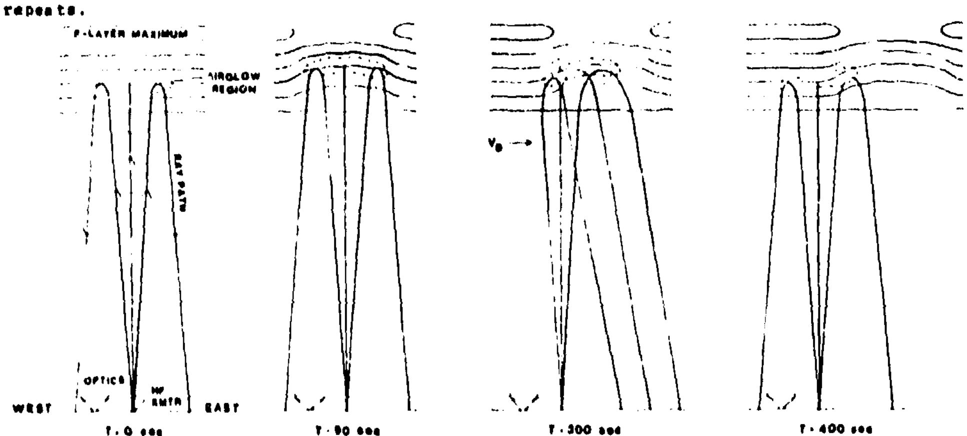


Fig. 5. Schematic illustration of ray bending by convecting depletions.

When the beam is bent to the east it looses efficiency for producing energetic electrons. Consequently, the 630.0 nm airglow intensity pulsates as the beam moves back and forth. The periodic enhancement and depression of the heater airglow continues until the heater is turned off at 02:01:35 AST. After turnoff, the long lived $O(^1D)$ species diffuses outward. The 148 second lifetime of $O(^1D)$ limits the response time of the airglow to fluctuations in the energetic electron fluxes.

JANUARY 13, 1986 RESULTS

The experiment was conducted again on 13 January 1986. A narrow band photometer with 5 degree field of view recorded the 630.0 nm intensity in response to the HF heater (Figure 6). The images show that the temporal fluctuations in the photometer signal which can be traced to movement of the airglow cloud.

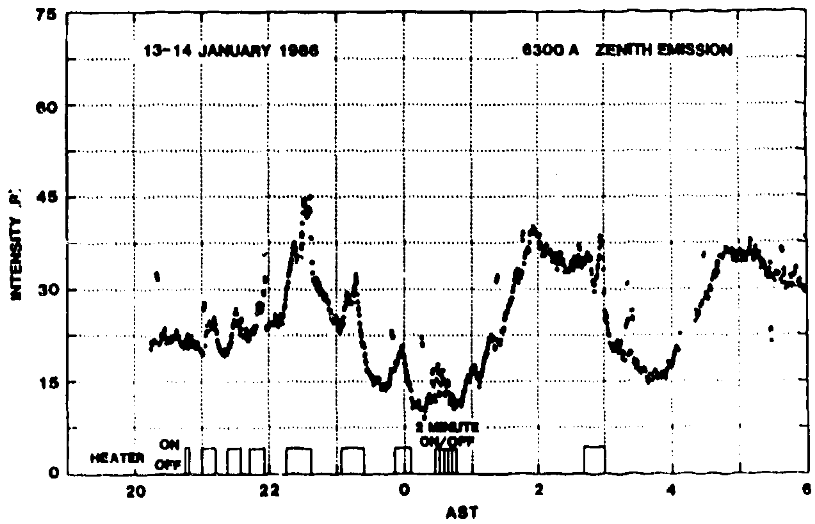


Fig. 6. Photometer record of January 13-14, 1986 HF experiments.

The heater turn on at 23:05:16 showed a brightening to the east of the heater. Ambient density gradients refracted the HF rays eastward. This turn on sequence is shown in frames 1-A through 1-E of Figure 7. The cloud to the east of the heater disappears as one is formed at the zenith (frames 2-A through 2-E of Figure 7). This patch then drifts eastward until the heater is turned off at 23:29:00 (just after frame 5-C of Figure 7). This drift speed is approximately the same as for January 9, 1986.

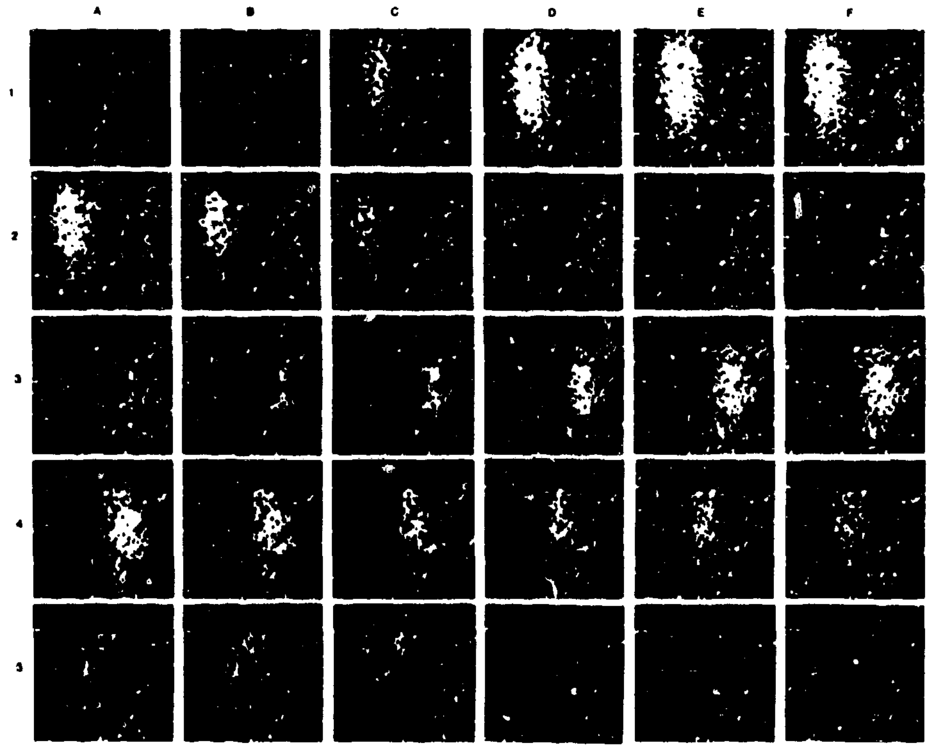


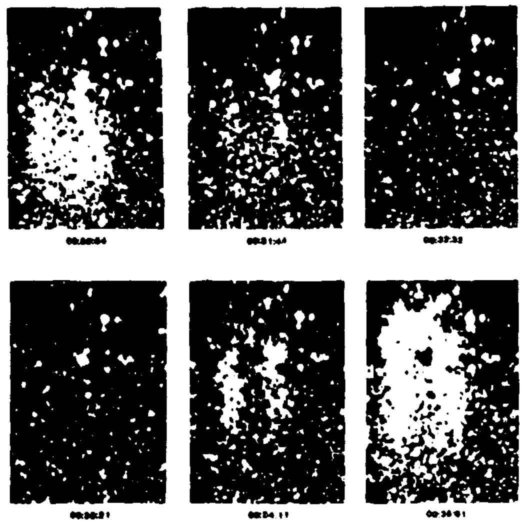
Fig. 7. Formation and convection of artificial 630.0 nm airglow cloud. The images are separated by 30 seconds.

The HF heater was pulsed with a 2 minute on and a 2 minute off sequence. Figure 8 illustrates reproducibility in the airglow images indicating that the plasma structures remain after the heater is turned off.

The post midnight collapse in the F-layer produced enhancement of the natural 630.0 nm airglow (Figure 8), reaching a maximum at 0200 AST. The HF transmitter was turned on at 02:40:00 but no artificial airglow enhancement was recorded until 02:53:48 when a patch spontaneously materialised. This cloud lasted until the heater power was reduced by 3 dB at 02:58:00. No airglow was observed at half power. We therefore conclude that the full power HF signal barely exceeded the threshold for airglow excitation.

CONCLUSIONS

The energization of electrons with excite airglow occured in a constantly convecting region. The cavities which were produced by HF heating bent the HF ray paths. As the cavities



JANUARY 14, 1986 AST

Fig. 8. Pulsation of bifurcated airglow cloud when the HF heater is turned on for two minutes and off for two minutes.

drifted under the influence of external electric fields or neutral winds, the HF rays were convected eastward. Only eastward drifts of the airglow clouds was recorded. On occasion, the HF beam was split in two.

The cavity gradients diffuse the HF beam, yielding a reduction in HF power. The electric field strength may fall below the threshold for cavity and airglow production. In these cases, the HF beam only becomes effective after the cavity has been transported away from the zenith of the heater.

The coincidence between enhanced airglow and caviton formation is reserved for future study. Preliminary data analysis indicates that the airglow patches only occurred when cavitons were formed. This may be because both phenomena have similar energetic electron requirements.

Future imaging studies should use other airglow lines. For instance, the 557.7 nm line from $O(^1S)$ requires 4.19 eV or greater excitation energy. The shorter (0.75 sec) lifetime of this state would provide better temporal and spatial resolution for the airglow images.

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