

TEMPORAL, SEASONAL, AND SOLAR CYCLE VARIATIONS OF THE TOPSIDE PROTON CONCENTRATION AT ARECIBO

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ABSTRACT

An estimate of the topside proton concentration can be obtained by analyzing the incoherent scatter radar autocorrelation function from that region. Our observations at Arecibo, Puerto Rico indicate that the H^+ to O^+ composition transition height often occurs as low as 450 km during winter nights, near solar minimum. In the summer, the nighttime transition height is only slightly higher, near 600 km. This height is also affected by the level of magnetic activity. Maximum concentrations of H^+ occur near 04:00 LT, with a minimum about twelve hours later. The observations of topside H^+ were acquired during the past six years as part of the Regular World Day experiments, and from studies of the low latitude hydrogen geocorona. In particular, we will emphasize the results obtained during the solstice and equinox periods of the Thermospheric Mapping Study.

INTRODUCTION

During previous times of minimum solar activity, there have been a number of studies of the behavior of the base of the protonosphere at Arecibo (e.g. /1,2,3,4,5,6,7/). Using the incoherent scatter radar technique, those measurements were used to determine the transition height at which the dominant ion changes from O^+ to H^+ . The shape of the measured backscattered spectrum is dependent upon the relative mixture of different ions, and upon the magnitudes of the electron and ion temperatures /8,9,10/. For ions of considerably different masses, such as H^+ and O^+ , the spectrum has a distinct signature that is characteristic of a superposition of a 'light' and a 'heavy' ion spectrum. As well as the measurement of ion composition and temperatures, a careful analysis of the data can also reveal separate drift velocities for the contributing ions /7/.

Regular ground-based measurements using incoherent scatter radars can provide a powerful continuous monitor of the seasonal and solar cycle patterns of the coupled ionized and neutral atmospheric system. Simultaneous observations of the upper atmosphere take place periodically at the six incoherent scatter radars and several optical facilities worldwide. These experiments are conducted on so-called 'World Days', which occur almost every month. One such coordinated experiment is the Thermospheric Mapping Study (TMS). Three TMS campaigns took place during the solstice periods of June 1984 and January 1985, and in equinox, September 1984. The basic goal of these investigations is to provide a data base from which the general morphological behavior of the ionosphere and the thermosphere can be studied globally.

Measurements of electron density, electron and ion temperatures, and O^+ composition have been made at Arecibo since 1966. Additional observations of ion drifts began in 1971, and have continued to the present time. With few data gaps, most of the results from all six radars have been archived in the newly established NCAR Incoherent Scatter Radar Data Base located at Boulder, Colorado. In this report, however, we will only present results from half of a solar cycle, starting near solar maximum in the winter of 1980-81, through to the 1985-86 winter near solar minimum. Our emphasis in this paper is on the proton structure of the topside ionosphere at Arecibo. The data obtained during the TMS campaigns will be discussed in detail.

INSTRUMENTATION

The Arecibo incoherent scatter radar (18.35° N, 66.75° W) has been described previously by Behnke and Harper /11/. Observations of temperatures, ion drifts, and composition are derived from matching the shape of the radar autocorrelation function to theory, using a

nonlinear least squares fitting technique. Measurements are made between 200 and 600 km altitude by transmitting a 300 μ s pulse and oversampling the received signal with time delays that represent 23 km height intervals. Most of the data discussed in this note were collected using a single frequency operational mode for the transmitter. Since October 1985, we have adopted a multiple frequency transmitter pulse coding for most upper atmospheric experiments. The advantages of using such a code are discussed by Sulzer /12/.

The antenna is pointed 15° from the zenith and the azimuth is continuously rotated through 360° while the data are sampled. A complete azimuth cycle requires about 16 minutes. A first order harmonic series is fit to the measurements of the line-of-sight velocity in order to estimate the vertical and horizontal velocity components. The velocity along the magnetic field line is also determined, and combined with the measured H^+ density to estimate the proton flux.

RESULTS AND DISCUSSION

A direct result of the analysis of incoherent scatter radar spectra, obtained from altitudes above about 450 km, is the ratio of the proton to electron concentration. Figure 1 shows the temporal and altitude variation of this ratio for a 28-hour period during January 1984. The illustrated error limits represent \pm one standard deviation of the mean value. The dashed line at a value of 0.5 indicates the O^+ to H^+ transition, assuming that only these ions contribute to the total ion density. This example illustrates that the transition height moves downward gradually after sunset from about 586 km at 21:30 AST to 540 km at 02:30 AST, but then rises more rapidly after local sunrise which occurs near 05:20 AST at 586 km altitude. Good measurements of $[H^+]$ can be obtained even for heights as low as 450 km. However, in the rest of this report, we will present results obtained by averaging over the top four heights of Figure 1, that is, from 516 to 586 km, with a mean altitude of 551 km. In Figure 2, we have plotted the solar cycle variation of $[H^+] / [Ne]$ for winter. The figure shows this ratio increasing as solar minimum approaches, and reaching a maximum earlier in the evening after sunset.

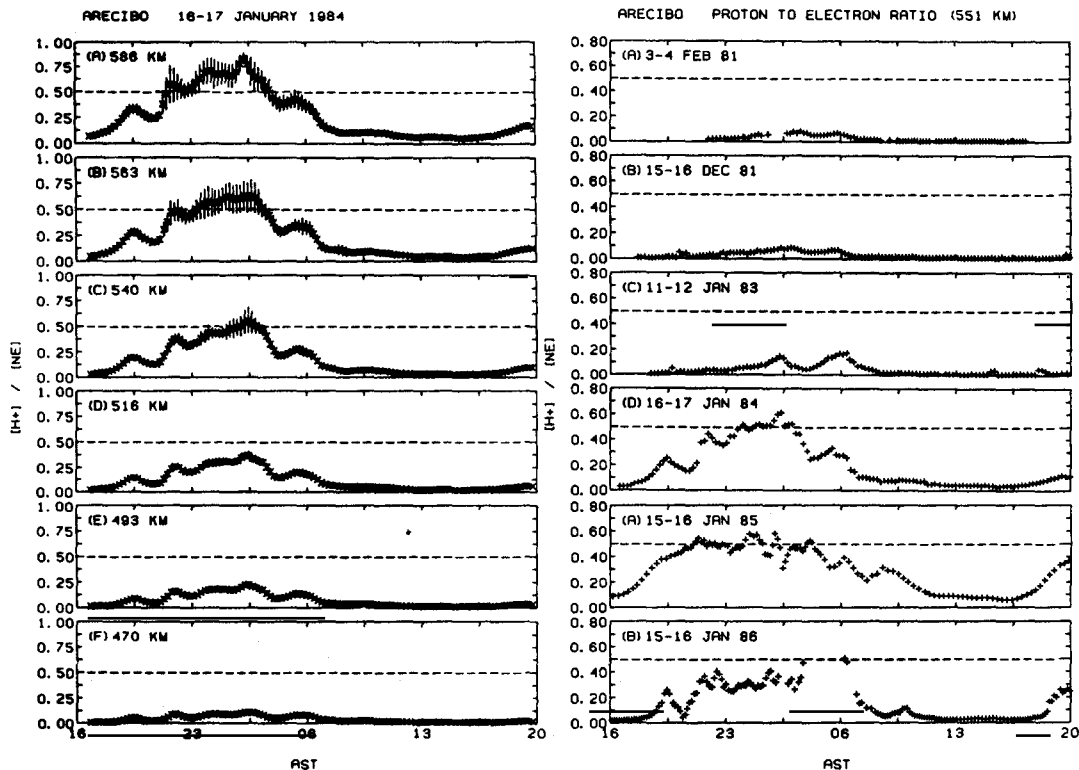


Fig. 1. The variation of the proton to electron concentration ratio with altitude for 16-17 January 1984. The dashed line represents the O^+ to H^+ transition height.

Fig. 2. The wintertime solar cycle variation of $[H^+] / [Ne]$ for an altitude average between 516 and 586 km.

Figures 3, 4, and 5 show the diurnal behavior of the electron and proton concentration of the topside ionosphere for June and September 1984, and January 1985, respectively. The magnetic dip angle for the L=1.4 flux tube at Arecibo is 50° . Positive fluxes are upward and equatorward. These figures show a significant difference between summer and winter concentrations of both $[H^+]$ and $[Ne]$, as well as for the percentage of $[H^+]$ of the total ion density, and for the magnitude of the flux. Generally, the component of $[H^+]$ flux along the field line is near zero during the day, and downward at night as H^+ diffuses from the protonosphere to maintain the nighttime ionosphere through charge exchange with atomic oxygen /6/.

On 19 September 1984, a large magnetic storm took place starting at about 10:00 UT (06:00 AST). Three-hour tabulations of the Kp index showed a jump from 2 to 6 during this time. The effect of this storm was observed immediately at Arecibo where the H^+ flux turned positive (Figure 4d). Positive fluxes of this magnitude are rare at these latitudes and represent a southward flow of ionization toward Arecibo from higher L-shells. An unusual daytime enhancement in the $[H^+]$ concentration at 551 km was also observed, peaking at about 11:30 AST, 5.5 hours after the storm commencement, and then decaying away to more steady state levels. This was coincident with an enhancement in $[Ne]$. $O + H^+$ charge exchange must have been responsible for the enhanced electron density since the ratio of $[H^+]$ to $[O^+]$ shows no increase even though there is an excess of $[H^+]$.

Kp values fluctuated between 4 and 6 for the rest of the day on 19 September 1984, but no further enhancements in $[H^+]$ were observed. Some of the excess H^+ was probably consumed through the charge exchange mentioned previously. H^+ should be replenished at night through the inverse reaction of $H + O^+$. However, $H + H^+$ charge exchange reactions also takes place leaving the resultant neutral hydrogen with enough excess energy to escape the exosphere /13,14/. The depressed amounts of $[H^+]$ for the two days following 19 September are consistent with a depleted flux tube, which is in the process of refilling after the storm /15/.

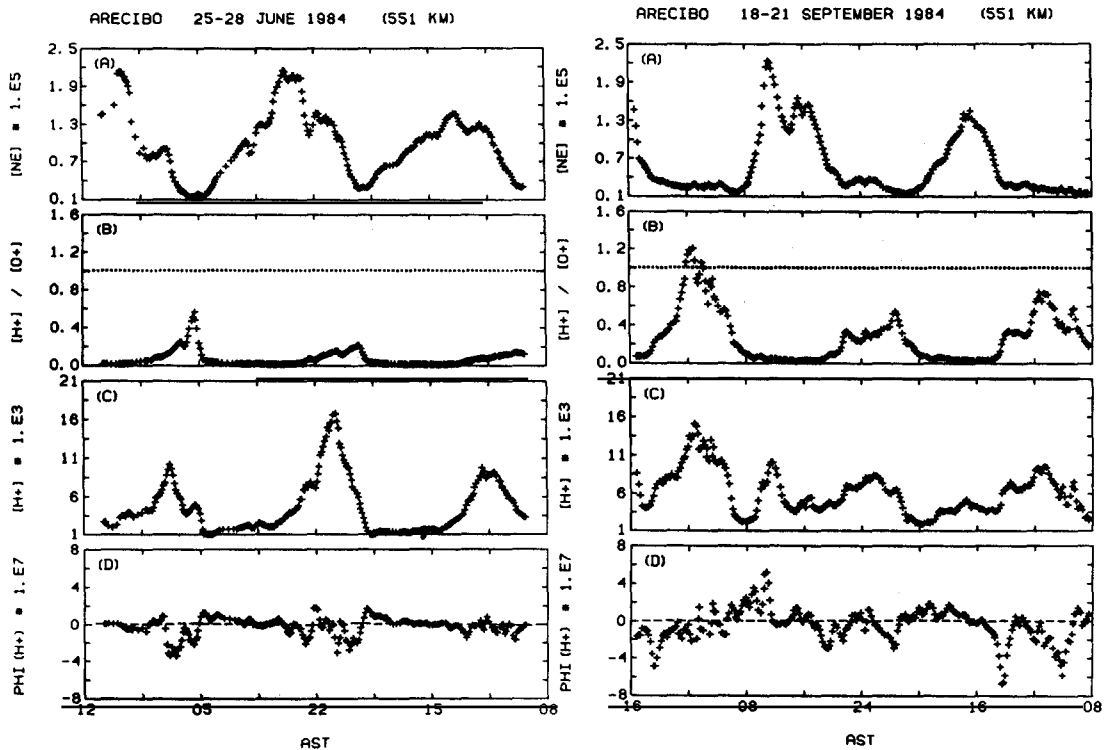


Fig. 3. Diurnal variations of the electron and proton densities (cm^{-3}), the ratio of $[H^+]$ to $[O^+]$, and the field aligned proton flux ($cm^{-2} s^{-1}$) for 25-28 June 1984.

Fig. 4. Same as Figure 3, but for 18-21 September 1984.

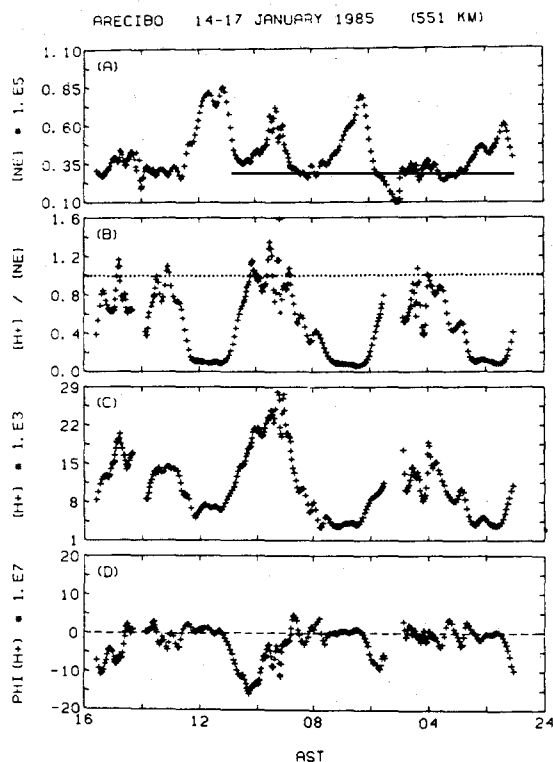


Fig. 5. Same as Figure 3, but for 14-17 January 1985.

We have shown that incoherent scatter radar measurements of the proton content of the topside ionosphere can be achieved routinely. Similar observations using other radars could assess the latitudinal and local time variations of $[H^+]$ and the proton flux.

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