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The F_1 ledge: density, height and slope

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Abstract
Diurnal variations of the F_1 region ionization at 170 km altitude and the slope $\Gamma_{170} = dN/dh$ at this height are analyzed for mid-latitude and equatorial stations: Millstone Hill, Ramey, Puerto Madryn and Jicamarca. Both the density $N(t)$ and the slope $\Gamma(t)$ at 170 km show well defined diurnal variations with day-to-day variabilities of less than 10%. The heights of the F_1 ledge, hmF_1, are spread over ± 20 km and are therefore of limited value for modeling purposes.

Key words *ionosphere – electron density profile – ionospheric modeling*

1. Introduction

It has long been recognized that one of the limitations of the bottomside $N(h)$ profiles is the specification of the F_2 layer thickness. In July 1994, during an IRI task meeting on the F_1 region at the International Center for Theoretical Physics (ICTP) in Trieste, it was decided to establish a database for the following profile characteristics: height and slope at $f = f_0F_1$, *i.e.*, hmF_1 and $\Gamma_1 = dN/dh\,|_{f_0F_1}$, and the density and slope at a fixed height of 170 km, *i.e.*, N_{170} and Γ_{170}. Using available electron density profiles from several digisonde stations, the diurnal, seasonal and latitudinal variations of these characteristics are investigated in this paper. Sample data from four stations covering the mid-latitude and equatorial regions have been analyzed to provide a basis for comparison with ionospheric models.

2. The Database

Electron density profiles from Millstone Hill, Ramey, Puerto Madryn and Jicamarca, covering the northern and southern mid-latitude and the equatorial regions, provided the basis for the analysis. Table I lists the geographic coordinates of the four stations and the data months used for the analysis.

Ramey and Puerto Madryn are magnetically conjugate stations, and Jicamarca is an equatorial station. The ionogram rates at the stations were at least 2, generally 4, and in some cases 12 per hour. The real time electron density pro-

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Table I. Geographic coordinates of digisonde stations.

Millstone Hill, Massachusetts	42.5°N	288°E	Jan., Jul., Aug., Nov. 90
Ramey, Puerto Rico	18.5°N	293°E	Jan. 93
Jicamarca, Peru	12.0°S	283°E	Feb., Mar., May, Jun. 93
Puerto Madryn, Argentina	42.5°S	295°E	Jan. 93

files have all been edited with ADEP (Zhang, 1990), which means that the ARTIST (Reinisch and Huang, 1983) trace scalings were manually corrected where necessary, and the profiles recalculated (Huang and Reinisch, 1995).

The Huang-Reinisch (HR) profiles present each layer in the form

$$h = h_m + \sqrt{g} \sum_{i=0}^{I} A_i T_i^*(g) \qquad (2.1)$$

where *hm* is the peak height, *I* equals 4 for the *F* region and 2 for the *E* layer, T_i^* are shifted Chebyshev polynomials, and

$$g = \frac{\ln(f_N / f_m)}{\ln(f_s / f_m)}; \qquad (2.2)$$

$f_N / H_z = 9\sqrt{N / m^{-3}}$ is the plasma frequency, f_s and f_m are the starting and critical frequencies of the trace. If the ionogram scaling specifies f_0F_1, eq. (2.1) calculates the profile from f_0E to f_0F_1; if no F_1 ledge exists, the profile is calculated from f_0E to f_0F_2. In either case it is easy to invert eq. (2.1) and determine N_{170}. To facilitate the comparison with scaled f_0F_1 values, the plasma frequency $f_{N_{170}} = 9\sqrt{N_{170}}$ rather than N_{170} is plotted in the figures. An analytical expression for the gradient $\Gamma = (dh/dN)^{-1}$ can also be obtained from eq. (2.1) and used to calculate Γ_{170}. When an f_0F_1 value is given, NHPC outputs hmF_1 directly. The results of these calculations for several station months are discussed in the next section.

3. F_1 characteristics

One of the difficulties of using the F_1 ledge as a fix point for the electron density profile is the large scatter in hmF_1. This is illustrated in fig. 1a-c for winter and summer data (1990) from Millstone Hill. In winter, F_1 is rarely observed. In summer, the peak heights are spread almost ± 20 km around a mean value of 180 km, while the critical frequency has a reasonable narrow spread. Selecting a fixed height eliminates the height uncertainty and the point can be characterized by its density and gradient. Scatter plots of $f_{N_{170}}$ and Γ_{170} for Millstone Hill are shown in fig. 2a-c, where full circles are used if $f_{N_{170}} > f_{\min}$, and open circles if $f_{N_{170}} < f_{\min}$; $f_{\min}$ (scaled from the ionogram) is the lowest frequency for which an *F* region echo is observed. Open circles generally occur for $f_{N_{170}} < 1.7$ MHz, although this is difficult to see in fig. 2a-c because of overplotting. The trace sections with the open circles are influenced by the model assumptions contained in NHPC, since no *h*′(*f*) readings were available.

Not surprisingly, the $f_{N_{170}}$ functions during daytime (12 LT = 17 UT) have a $(\cos \chi)^x$ shape, reaching their highest average noon time values in January. The spread during daytime is about 0.5 MHz (or ± 5%). The slope Γ_{170} on the right side also shows a well defined diurnal behavior and relatively small spread. The daytime average values are larger in winter than in summer, reaching a maximum in December of about 10^4 cm^{-3}/km. The summer month has two Γ_{170} maxima, one in the morning at 7 LT (12 UT) and the other in the late afternoon at 17 LT (22 UT) with a minimum around local

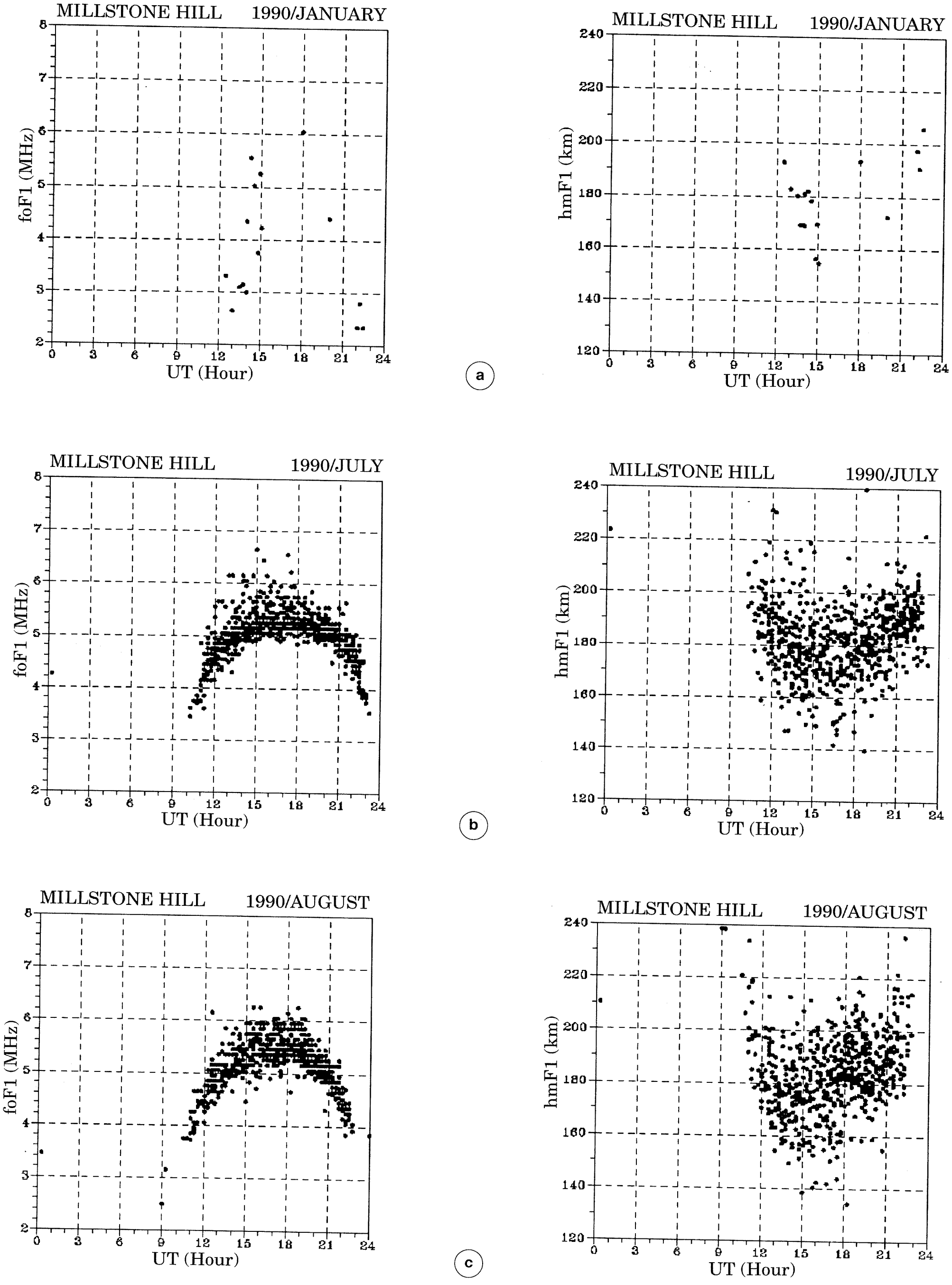

Fig. 1a-c. Scatter plots for f_0F_1 and hmF_1 *vs.* time for Millstone Hill in 1990: a) January; b) July; c) August.

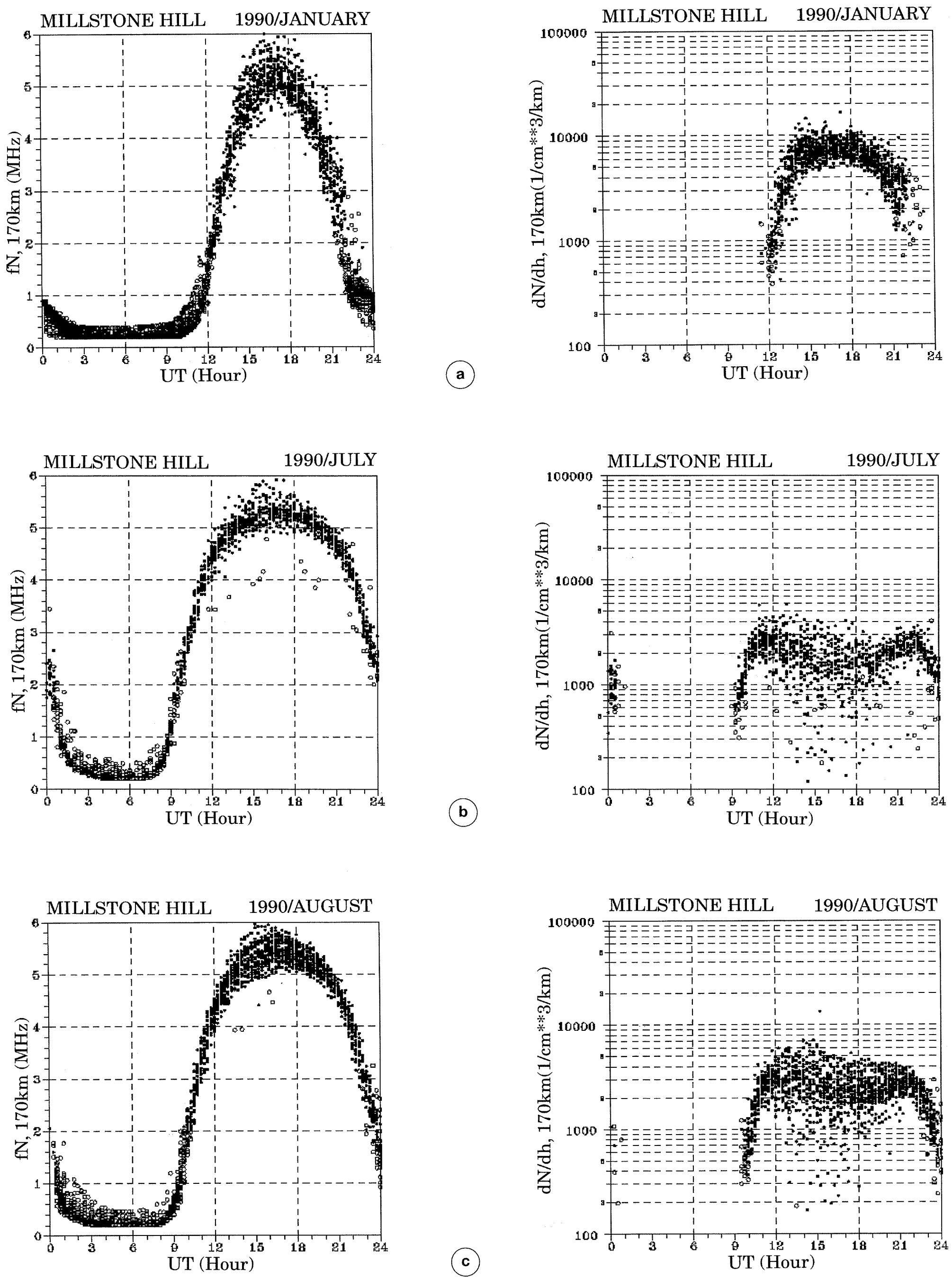

Fig. 2a-c. Scatter plots of $f_{N_{170}}$ and Γ_{170} *vs.* time for Millstone Hill in 1990: a) January; b) July; c) August.

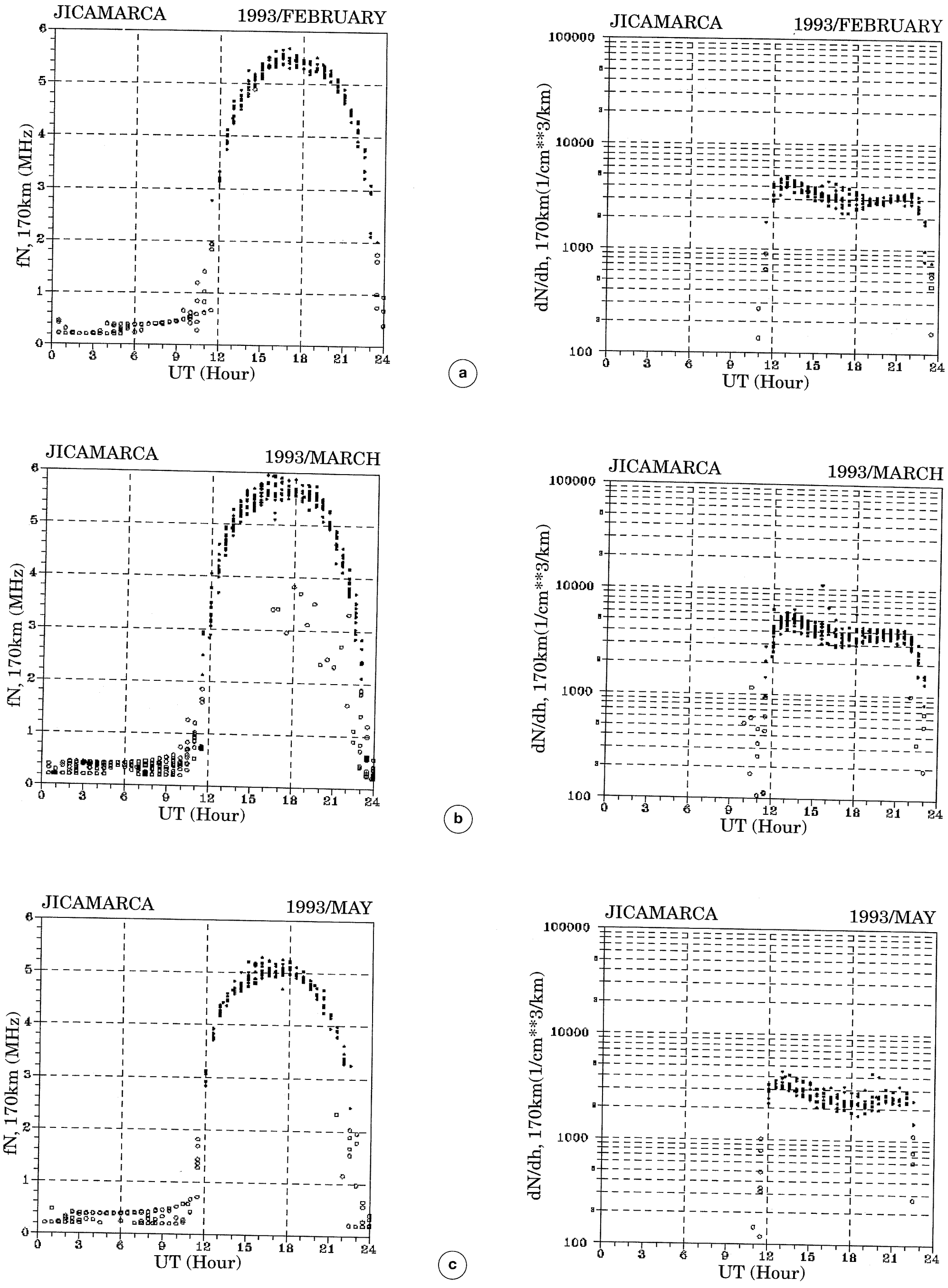

Fig. 3a-c. Scatter plots for $f_{N_{170}}$ and Γ_{170} *vs.* time for Jicamarca, Peru, in 1993: a) February; b) March; c) May.

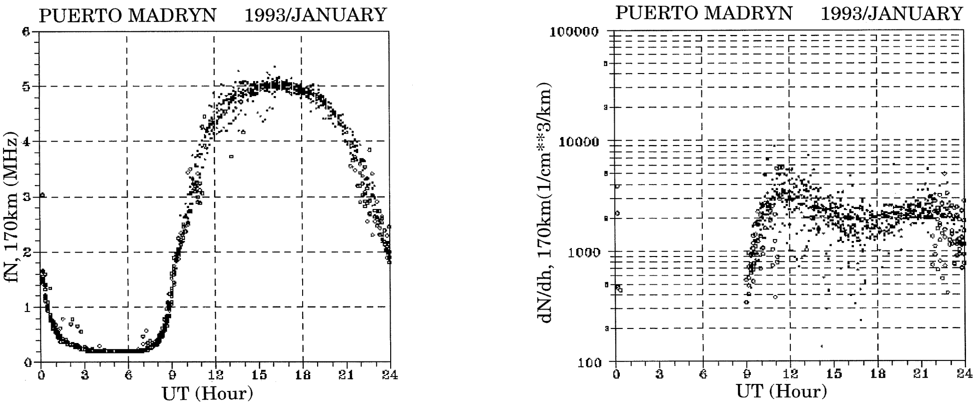

Fig. 4. Scatter plots for $f_{N_{170}}$ and Γ_{170} *vs.* time for Puerto Madryn, Argentina, January 1993.

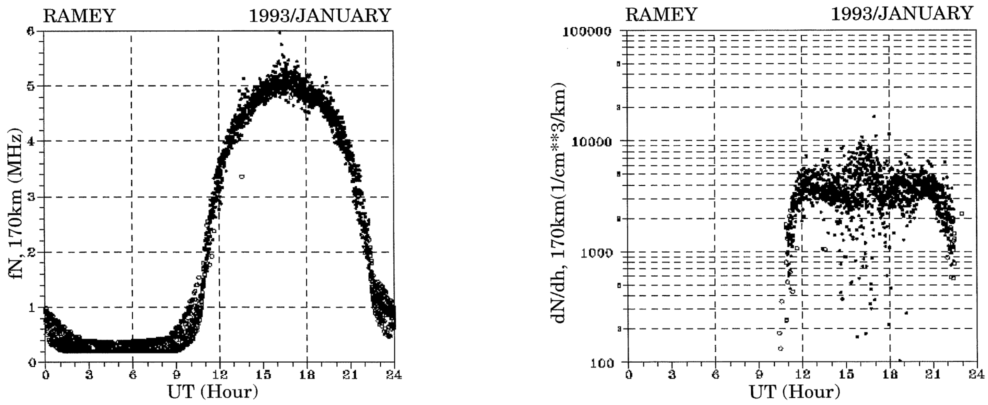

Fig. 5. Scatter plots of $f_{N_{170}}$ and Γ_{170} *vs.* time for Ramey, January 1993.

noon. These double peaks are also seen for Puerto Madryn (fig. 4) in January (summer), and for Jicamarca in February, March and May (fig. 3a-c), but not at Ramey in January (fig. 5).

The regular solar zenith angle dependence of both $f_{N_{170}}$ and Γ_{170} and the moderate day-to-day spread suggest the use of these characteristics as fix points for ionospheric models instead of the previously used F_1 ledge point (f_0F_1, hmF_1).

4. Conclusions

Analysis of F_1 region profiles for four different latitudes reveals a very predictable behavior of the electron density N and its gradient at 170 km altitude. Analytical functions $f_{N_{170}}$ and Γ_{170} as function of solar zenith angle, season and sunspot number could be determined statistically using available profile data.

These fixed height characteristics appear to be more useful for ionospheric modeling than the previously used F_1 ledge (f_0F_1, hmF_1).

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