July 1, 2000

Simulation of the prereversalenhancement in the low latitude vertical drifts

C. G. Fesen
R. G. Noble
A. D. Richmond
G. Crowley
Bela G. Fejer, *Utah State University*

GEOPHYSICAL RESEARCH LETTERS, VOL. 27, NO. 13, PAGES 1851-1854, JULY 1, 2000

Simulation of the pre-reversal enhancement in the low latitude vertical ion drifts

C. G. Fesen, [1] G. Crowley, [2] R. G. Roble, [3]
A. D. Richmond, [3] and B. G. Fejer [4]

Abstract. Low latitude *F* region ion motions exhibit strong seasonal and solar cycle dependences. The pre-reversal enhancement (PRE) in the vertical ion drifts is a particularly well-known low latitude electrodynamic feature, exhibited as a sharp upward spike in the velocity shortly after local sunset, which remains poorly understood theoretically. The PRE has been successfully simulated for the first time by a general circulation model, the National Center for Atmospheric Research thermosphere/ionosphere/electrodynamic general circulation model (TIEGCM). The TIEGCM reproduces the zonal and vertical plasma drifts for equinox, June, and December for low, medium, and high solar activity. The crucial parameter in the model to produce the PRE is the nighttime *E* region electron densities: densities $\geq 10^4$ cm^{-3} preclude the PRE development by short-circuiting the *F* region dynamo. The *E* region semidiurnal 2,2 tidal wave largely determines the magnitude and phase of the daytime *F* region drifts.

Introduction

A unique feature of the low latitude ionosphere is the pre-reversal enhancement (PRE) [e.g., *Woodman*, 1970], a sharp upward spike in the vertical ion velocities that occurs shortly after local sunset, superimposed on the typical diurnal variation of daytime upward and nighttime downward drifts. Observations from Jicamarca Radio Observatory (JRO) (11° 57′ S, 76° 52′ W; magnetic dip 2° N) in Peru reveal a strong seasonal and solar cycle variation [e.g., *Fejer et al.*, 1989, 1991]: upward drifts are larger at solar maximum than solar minimum in all seasons and largest during equinox and smallest in southern winter.

The PRE signals an enhancement in the eastward electric field just before it reverses to westward in the early evening and is generally attributed to the *F* region dynamo [e.g., *Rishbeth*, 1971, 1981; *Farley et al.*, 1986; *Crain et al.*, 1993] in which strong *F* region winds generate polarization fields perpendicular to the magnetic field. During the day, the polarization fields are largely shorted out by the large *E* region conductivities. At sunset, however, the *E* region conductivities decrease dramatically allowing the *F* region dynamo to dominate.

[1]W. B. Hanson Center for Space Sciences, U. of Texas at Dallas, Richardson, Texas

[2]Southwest Research Institute, San Antonio, Texas

[3]High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado

[4]Center for Atmospheric and Space Sciences, Utah State University, Logan, Utah

Paper number 2000GL000061.
0094-8276/00/2000GL000061$05.00

Zonal F-region plasma drifts observed over JRO also exhibit a solar cycle variation. The daytime drifts are due to *E* region dynamo winds [*Richmond et al.*, 1976] while the nighttime drifts are attributable to the *F* region dynamo [e.g., *Rishbeth*, 1981]. *Anderson and Mendillo* [1983] suggested that, for the nighttime zonal drifts, the ratio of the field-line-integrated Pedersen conductivities in the *F* and *E* regions is a key factor. At low latitudes, where the path length through the *F* region can be very long, the field-line-integrated *F* region conductivity can overwhelm that in the *E* region [*Crain et al.*, 1993] near solar cycle maximum.

Here we describe the first successful simulation of the low latitude plasma drifts by a general circulation model, the National Center for Atmospheric Research (NCAR) thermosphere-ionosphere-electrodynamic general circulation model (TIEGCM), which reproduces the seasonal and solar cycle variation of the drifts.

Model Description

The TIEGCM is described by *Richmond et al.* [1992] and references therein. The model self-consistently calculates the coupled thermosphere and ionosphere, including electric potential, fields, and currents, and ion and neutral densities, temperatures, and velocities. Latitude and longitude resolution is 5° by 5°. Altitudes extend roughly from 100 to $\geq$ 500 km with 2 grid points per scale height. The model contains a realistic geomagnetic field, IGRF 1985.0.

An important feature is the formulation of the lower boundary condition which allows simulation of effects due to upward propagating waves generated in the lower atmosphere. The model includes the diurnal 1,1 mode and the semidiurnal 2,2 through 2,6 modes which are adjustable parameters. Here, we tuned the model to reproduce winds observed near 100 km by the Upper Atmosphere Research Satellite (UARS) [e.g., *McLandress et al.*, 1996].

All the simulations here were for geomagnetically quiet conditions; total hemispheric power of precipitating auroral electrons was 16 GW and the cross–polar–cap potential was 45 kV. The model had been previously tuned against the empirical models MSIS and IRI to reproduce their global and zonal means. For the ionosphere, this necessitated imposing downward O^+ fluxes at the top boundary at all times, resulting in good to excellent reproduction of the empirical model means and ensuring a realistic background atmosphere and ionosphere. Simulations were performed for March, June, and December for solar 10.7–cm levels of 85, 150, and 200, respectively, corresponding to solar cycle minimum, medium, and maximum conditions. In the following, the model simulations are compared with JRO observations of vertical and zonal ion drifts for the same seasons and levels of solar activity [e.g., *Fejer et al.*, 1991] which were averaged over 300 to 400 km.

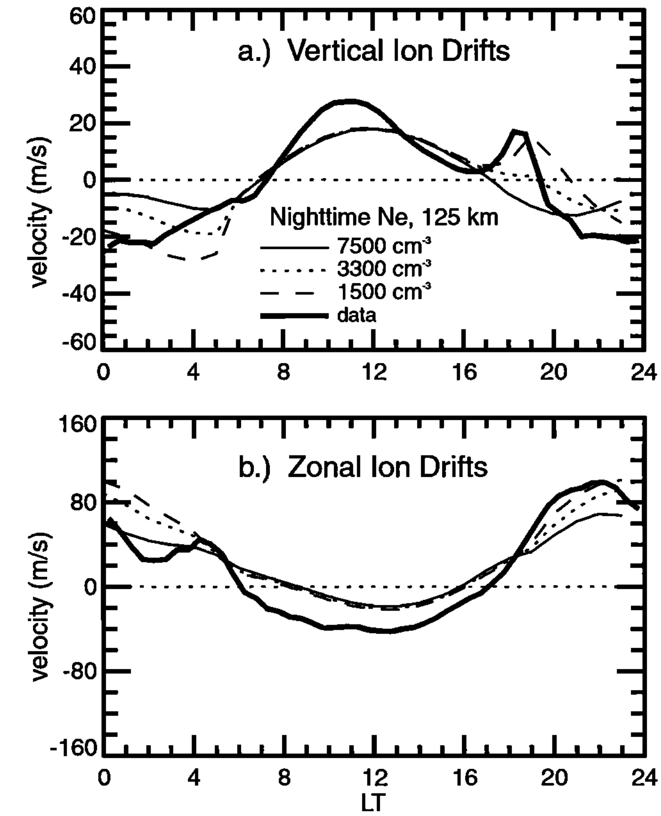

Figure 1. Ion drifts averaged over 300 to 400 km at Jicamarca. In each panel, the thick curve shows observed drifts; the thin curves show model results for different nighttime electron densities at 125 km. Top panel: vertical ion drifts; bottom panel, zonal ion drifts. See text for details.

Model Results

The initial simulation of plasma drifts, shown in Figure 1 by the thin solid curves, was done for equinox solar cycle minimum conditions. The observations are also shown by thick solid curves. There is gross agreement in the diurnal variations but obvious and substantial discrepancies: the model seriously underestimates both the zonal and vertical drifts. Most importantly there is no hint of a PRE.

For this simulation, the nighttime E region electron density n_e was on the order of $\sim$ 7.5 – 10 x 10^3 cm^{-3} from 100 to 125 km. Figure 1 shows results from two simulations which reduced the 100– to 125–km n_e to about 3.3 and 1.5 x 10^3 cm^{-3}, respectively, consistent with an empirical model of low altitude n_e [*Freidrich and Torkar*, 1992] and with Arecibo measurements [*Zhou et al.*, 1999]. The figure shows that as the nighttime E region n_e decreases, the PRE develops and strengthens; the critical value appears to be about 4 x 10^3 cm^{-3}, above which the PRE does not appear. This is consistent with a short-circuit of the F region dynamo as occurs during the daytime [*Farley et al.*, 1986]. In the TIEGCM, the magnitude of the nighttime E region n_e was found to be the single biggest driver of the PRE. Reduction of the nighttime E region n_e yields much improved agreement with JRO zonal drift observations in the evening (Figure 1*b*) before midnight. However, the model daytime drifts remain too small in both the zonal and vertical components.

The daytime drifts are attributed to the dynamo action of E region neutral winds which have large semidiurnal components [e.g., *Bernard*, 1974]. Figure 2 shows results of numerical experiments which varied the tides at the model lower boundary; the runs included (1) no tidal waves from the lower atmosphere; (2) "nominal" semidiurnal tides consistent with climatology for March [*Forbes and Vial*, 1989]; and (3) an increase in the "climatological" 2,2 mode amplitude by a factor of 3.3. The latter improves agreement with UARS-observed winds near 100 km [e.g., *McLandress et al.*, 1996] and produced daytime F region plasma drifts in good agreement with both the vertical and zonal drift observations. These runs confirm that the tidal waves at the model lower boundary largely determine the daytime drifts, but have little influence on the vertical drifts after 20 LT. The slight phase discrepancy between the modeled and observed vertical drifts could be ameliorated by adjustment of the 2,2 phase.

Using the above results for the E region n_e and tides, simulations were performed for equinox solar cycle medium and maximum conditions (F10.7 = 150 and 200, respectively). Then the day number, lower boundary tidal forcing, and F10.7 index were varied appropriately to simulate June and December for the same three levels of solar activity. The results are shown in Figure 3 along with the JRO observations for the same levels of solar activity. The modeled seasonal and solar cycle behavior is in good to excellent agreement

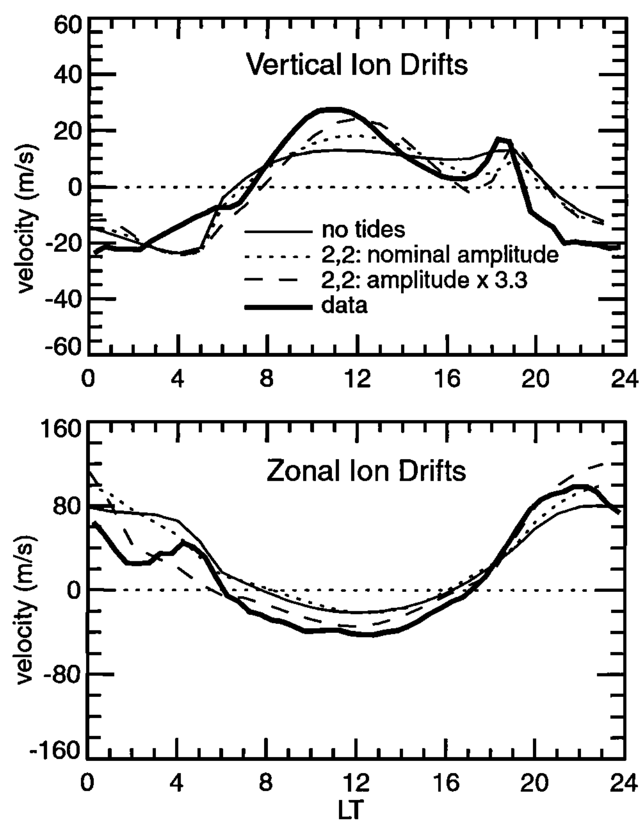

Figure 2. Ion drifts averaged over 300 to 400 km at Jicamarca. In each panel, the thick curve shows observed drifts; the thin curves show model results for different tidal waves imposed at the model lower boundary (see text for more details). Top panel: vertical ion drifts; bottom panel, zonal ion drifts.

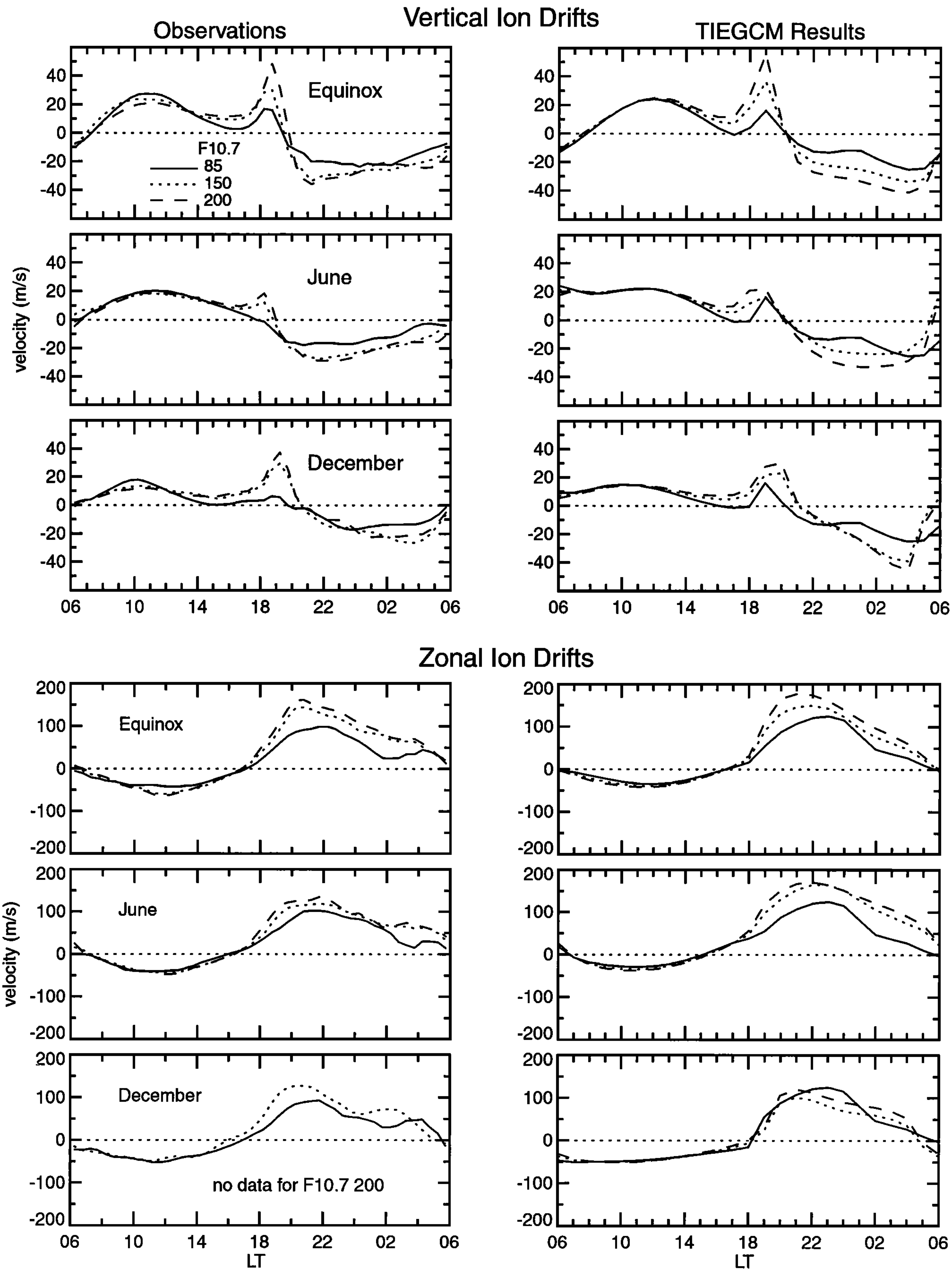

Figure 3. Ion drifts at Jicamarca averaged over heights from 300 to 400 km as a function of season and solar activity. Left side, observations; right side, TIEGCM simulations. Top three panels, vertical ion drifts; bottom three panels, zonal ion drifts. Within each panel, the different curves illustrate results for different levels of solar activity corresponding to F10.7 indices of 85, 150, and 200.

with the data. The main discrepancies now are in the nighttime drifts, particularly for the vertical velocities.

Discussion and Summary

The NCAR TIEGCM is the first general circulation model to simulate successfully the observed low latitude plasma drifts, in particular the seasonal and solar cycle variations. For the model ionosphere, the crucial parameter to produce the PRE in the vertical ion velocities is the nighttime E region electron densities: densities $\geq 10^4$ cm^{-3} preclude its development by short-circuiting the F region dynamo. The E region semidiurnal 2,2 tidal wave is important in determining the magnitude and phase of the daytime F region vertical and zonal drifts. Note, however, that the model upper boundary is relatively low in altitude and that the O^+ flux specified there is rather artificial. The F region conductivities may be underestimated for some flux tubes which obviously affects the ratio of the E region to the F region conductivities and the subsequent development of the PRE.

A detailed examination of the physics of the PRE, including the seasonal and solar cycle behavior, is beyond the scope of this paper. We investigated the cause of the PRE by selecting results from three model runs, all for equinox: one, at solar minimum, did not simulate the PRE; one, also at solar minimum, did simulate the PRE; and one simulated the PRE for solar maximum. The key difference between the runs which reproduced and did not reproduce the PRE was the behavior of the E region conductivity after sunset: it decreased more dramatically near 18 LT in the two cases with the PRE. Conversely, there was no difference in the F region conductivity or in the F region winds until an hour later. In fact, the F regin wind was nearly zero at 18 LT, close to the time of maximum PRE development. At solar cycle maximum, the rapid drop in the E region conductivity near sunset was accompanied by a marked gradient in the F region wind which turned eastward well before sunset, a scenario similar to that described by *Farley et al.* [1986]. The model supports the identification of the F region dynamo as the primary driver of the pre-reversal enhancement, in agreement with *Eccles* [1998]. Exactly how the enhanced vertical plasma drifts occur, including how they affect the zonal plasma drifts and vice versa, is still being investigated, along with the effects of the model upper boundary.

Acknowledgments. This work was supported by NASA grant 5-3598 and NSF grant ATM-9796036 to CGF and by NSF grant ATM-9505423 to GC. RGR and ADR acknowledge support from the NASA Sun-Earth Connection Theory Program through NASA grant S-13753-G. The National Center for Atmospheric Research provided computing time and assistance; NCAR is sponsored by the National Science Foundation.

The Editor would like to thank the reviewer of this manuscript.

References

Anderson, D. N., and M. Mendillo, Ionospheric conditions affecting the evolution of equatorial plasma depletions, *Geophys. Res. Lett.*, *10*, 541-544, 1983.

Bernard, R., Tides in the E-region observed by incoherent scatter over Saint-Santin, *J. Geophys. Res.*, *36*, 1105-1120, 1974.

Crain, D. J., R. A. Heelis, G. J. Bailey, and A. D. Richmond, Low-latitude equatorial ionospheric plasma motions: When is the F region a dominant driver in the low-latitude dynamo?, *J. Geophys. Res.*, *98*, 6033-6037, 1993.

Eccles, J. V., Modeling investigation of the evening prereversal enhancement of the zonal electric field in the equatorial ionosphere, *J. Geophys. Res.*, *103*, 26,709-26,719, 1998.

Farley, D. T., E. Bonelli, B. G. Fejer, and M. F. Larsen, The prereversal enhancement of the zonal electric field in the equatorial ionosphere, *J. Geophys. Res.*, *91*, 13,723-13,728, 1986.

Fejer, B. G., E. R. de Paula, I. S. Batista, and R. F. Woodman, Equatorial F region vertical plasma drifts during solar maxima, *J. Geophys. Res.*, *94*, 12,049-12,054, 1989.

Fejer, B. G., E. R. de Paula, S. A. Gonzalez, and R. F. Woodman, Average vertical and zonal F region plasma drifts over Jicamarca, *J. Geophys. Res.*, *96*, 13,901-13,906, 1991.

Forbes, J. M., and F. Vial, Monthly simulations of the solar semidiurnal tide in the mesosphere and lower thermosphere, *J. Atmos. Terr. Phys.*, *51*, 649-661, 1989.

Freidrich, M. and K. M. Torkar, An empirical model of the nonauroral D region, *Radio Sci.*, *27*, 945-953, 1992.

McLandress, C., G. G. Shepherd, B. H. Solheim, M. D. Burrage, P. B. Hays, and W. R. Skinner, Combined mesosphere/thermosphere winds using WINDII and HRDI data from the Upper Atmosphere Research Satellite, *J. Geophys. Res.*, *101*, 10,441-10,453, 1996.

Richmond, A. D., S. Matsushita, and J. D. Tarpley, On the mechanism of electric currents and fields in the ionosphere, *J. Geophys. Res.*, *81*, 547-555, 1976.

Richmond, A. D., E. C. Ridley, and R. G. Roble, A thermosphere/ionosphere general circulation model with coupled electrodynamics, *Geophys. Res. Lett.*, *19*, 601-604, 1992.

Rishbeth, H., Polarization fields produced by winds in the equatorial F-region, *Planet. Space Sci.*, *19*, 357-369, 1971.

Rishbeth, H., The F-region dynamo, *J. Atmos. Terr. Phys.*, *41*, 387-392, 1981.

Woodman, R. F., Vertical drift velocities and east-west electric fields at the magnetic equator, *J. Geophys. Res.*, *75*, 6249-6259, 1970.

Zhou, Q. H., J. D. Mathews, and Q. N. Zhou, Incoherent scatter radar study of the impact of the meteoric influx on nocturnal E-region ionization, *Geophys. Res. Lett.*, *26*, 1833-1836, 1999.

C. G. Fesen, W. B. Hanson Center for Space Sciences, POB 830688, MS FO22, U. of Texas at Dallas, Richardson, TX 75083-0688. (e-mail: fesen@tides.utdallas.edu)

G. Crowley, Southwest Research Institute, Building 178, 6220 Culebra Road, San Antonio, TX 78238–5166. (email: crowley@pemrac.space.swri.edu)

R. G. Roble and A. D. Richmond, High Altitude Observatory, National Center for Atmospheric Research, PO Box 3000, Boulder, CO 80307. (email: roble@hao.ucar.edu; richmond@hao.ucar.edu)

B. G. Fejer, Utah State University, Center for Atmospheric and Space Sciences, UMC 4405, Logan, UT 84322–4405. (email: bfejer@cc.usu.edu)

(Received March 16, 2000, accepted April 25, 2000)