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Diurnal variation of NmF2 associated with ExB drift at the equator during solar maxima

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RESUMEN

Se analiza la variación diurna de la densidad máxima de electrones en la ionosfera, NmF2, medida en cinco estaciones, para diferentes estaciones del año, máxima actividad solar y baja actividad magnética (Kp ≤ 3) en función de la velocidad de drift ExB en el ecuador. Las estaciones analizadas son Kodaikanal, ubicada en el ecuador magnético, Tucumán y Okinawa, en las crestas de la anomalía de ionización ecuatorial (EIA), y Yamagawa y Kokobunji fuera de ellas. Se consideró la velocidad de drift de un modelo empírico basado en mediciones del satélite AE-E y la velocidad del viento meridional en la termosfera del modelo HWM93. El apartamiento de NmF2 de una función simple del ángulo zenital se explica en la mayoría de los casos cualitativamente en función de la contribución de electrones desde el Ecuador para las estaciones en el Ecuador magnético y en las crestas de la EIA. En el caso de las estaciones fuera de las crestas, NmF2 sigue una dependencia con el ángulo zenital parecida al comportamiento del viento meridional. Hay comportamientos en NmF2 que no pueden explicarse ni en función del drift ExB ni del viento meridional.

PALABRAS CLAVE: Velocidad de drift, pico de la densidad de electrones, ionosfera.

ABSTRACT

The diurnal variation of peak electron density, NmF2, of five stations for different seasons, solar maximum conditions and quiet magnetic activity (Kp ≤ 3) is analyzed in terms of the ExB drift velocity at the equator. The stations analyzed are Kodaikanal at the magnetic equator, Tucuman and Okinawa at the crests of the equatorial ionization anomaly (EIA), and Yamagawa and Kokobunji at the outer sides of the EIA crests. The drift velocity was taken from an empirical model based on AE-E satellite measurements, and the meridional thermospheric wind from the HWM93 model. The departure of NmF2 from simple zenith angle dependence is qualitatively explained for stations at the magnetic equator and at the EIA crests based on the contribution of electrons coming from the equator. In the case of stations away from the EIA crests, NmF2 behavior follows mainly a zenith angle dependence, which is compared to the meridional wind pattern. In all cases there are features not explainable in terms of the ExB drift or the meridional neutral wind.

KEY WORDS: Drift velocity, electron density peak, ionosphere.

INTRODUCTION

The diurnal variation of the peak electron density in the ionosphere, NmF2, does not follow a simple zenith angle dependence because of plasma transport processes (Rishbeth and Garriot, 1969; Kohnlein, 1978; Schunk, 2000). In fact, around the peak height and above, the electron density depends not only on production and loss processes, but also on diffusion, electric fields and neutral wind motions.

Ionospheric electric fields play important roles on the plasma distribution and dynamics of the equatorial and low-latitude thermosphere (Fejer, 1997; Scherlies and Fejer, 1999). At equatorial latitudes, these fields develop the equatorial ionization anomaly (EIA).

Much progress in the description of the morphology of the EIA has been achieved since its discovery by Appleton (1946).

The EIA results from the daytime east-west electric field at equatorial latitudes, which gives rise to an upward ExB drift. The upward drift drives plasma across the magnetic field lines toward higher altitudes. The plasma then diffuses downwards along the magnetic field lines under the influence of gravity and pressure gradient forces, resulting the formation of a plasma "fountain" centered at the magnetic equator, which transfers plasma from the equatorial region to higher latitudes (Hanson and Moffet, 1966; Coley *et al*., 1990; Schunk, 2000). Such plasma transport depletes the F2 ionization at the equator and increases the density at locations between ± 20º geomagnetic latitude. The crest of the equatorial anomaly, where the drift contribution is maximum, is located at ± 15º (Woodman, 1970, Schunk, 2000).

The ExB drift velocity often shows a significant increase just before it reverses to its nighttime direction (Farley *et al*., 1986; Scherliess and Fejer, 1999). This feature is enhanced under solar maximum conditions.

At mid-latitudes, meridional winds play a more important role on NmF2 diurnal pattern. A poleward neutral wind induces a downward plasma drift, while an equatorward wind induces an upward plasma drift. For the upward plasma drift, the F layer moves to higher altitudes, where the O^+ loss rate is lower and, therefore, NmF2 increases. The reverse occurs for a downward plasma drift (Schunk, 2000; Rishbeth, 1998). In this work, the NmF2 diurnal variation in relation to the ExB drift velocity at the equator and the neutral meridional thermospheric wind, was qualitatively analyzed. NmF2 data of five ionospheric stations located one in the equator, two at the EIA crests and two at the outer sides of the crests, during equinox and solstices periods were analyzed during solar maximum conditions.

DATA ANALYSIS

Hourly foF2 data from Kodaikanal (10.2ºN, 77.5ºE, geom. lat.: 0.6ºN), Tucuman (26.9°S, 65°W, geom. lat.: 15.5ºS), Okinawa (26.3ºN, 127.8ºE, geom. lat.: 15.5ºN), Yamagawa (31.2ºN, 130.6ºE, geom. lat.: 20.6ºN), and Kokobunji (35.7ºN, 139.5ºE, geom. lat.: 25.7ºN) were used. The first station is located at the magnetic equator, the second and the third at the southern and northern crest of the EIA respectively, and the rest at the outer sides of the crests.

The vertical plasma drift velocity was taken from the empirical model based on the Atmosphere Explorer E satellite measurements (Fejer *et al.*, 1995).

The meridional wind in the thermosphere was taken from the empirical model HWM93 (retrievable from NSSDC anonymous FTP site). This model is based on wind data obtained from the AE-E and DE-2 satellites (Hedin *et al.*, 1991).

The seasonal periods considered are March 1959 for equinox, and December 1979 and June 1980 for solstices.

In Figure 1a, NmF2 measured at Kodaikanal during March 1959 is depicted. This equatorial station presents a first peak coincident with the ExB drift peak around 8 LT, not expected since a peak in ExB drift means a depletion of electrons in the equator. The second peak may result from the trough in ExB drift (less electron depletion would result in enhanced electron density in the equator). During June solstice (Figure 1b) NmF2 shows a similar pattern to that of equinox: a first peak coincident with an ExB drift peak, and a second one which can be explained in terms of a decrease in ExB drift, as in the case of equinox. During December (Figure 1c) a peak at 14-15 LT can be noticed probably associated with the trough at 15 LT in ExB drift.

NmF2 for Okinawa and Tucuman, both located at the EIA crests, clearly show two peaks during equinox (Figures 2a and 3a), matching the peaks in ExB drift, with a time delay needed for the electrons to arrive from the equator. During June (Figures 2b and 3b), Okinawa show again two

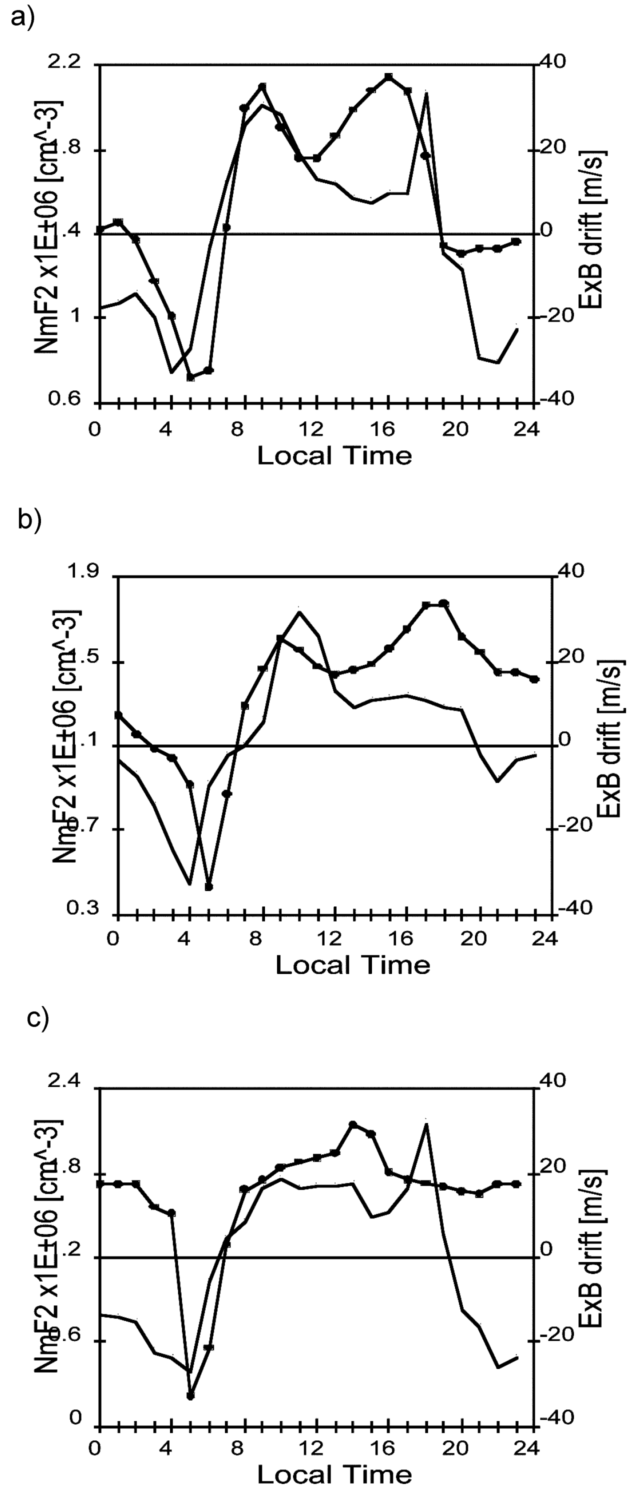

Fig. 1. Mean NmF2 measured at Kodaikanal (filled circle–solid line) and the ExB drift in the equator (solid line) for (a) March 1959, (b) June 1980 and (c) December 1979.

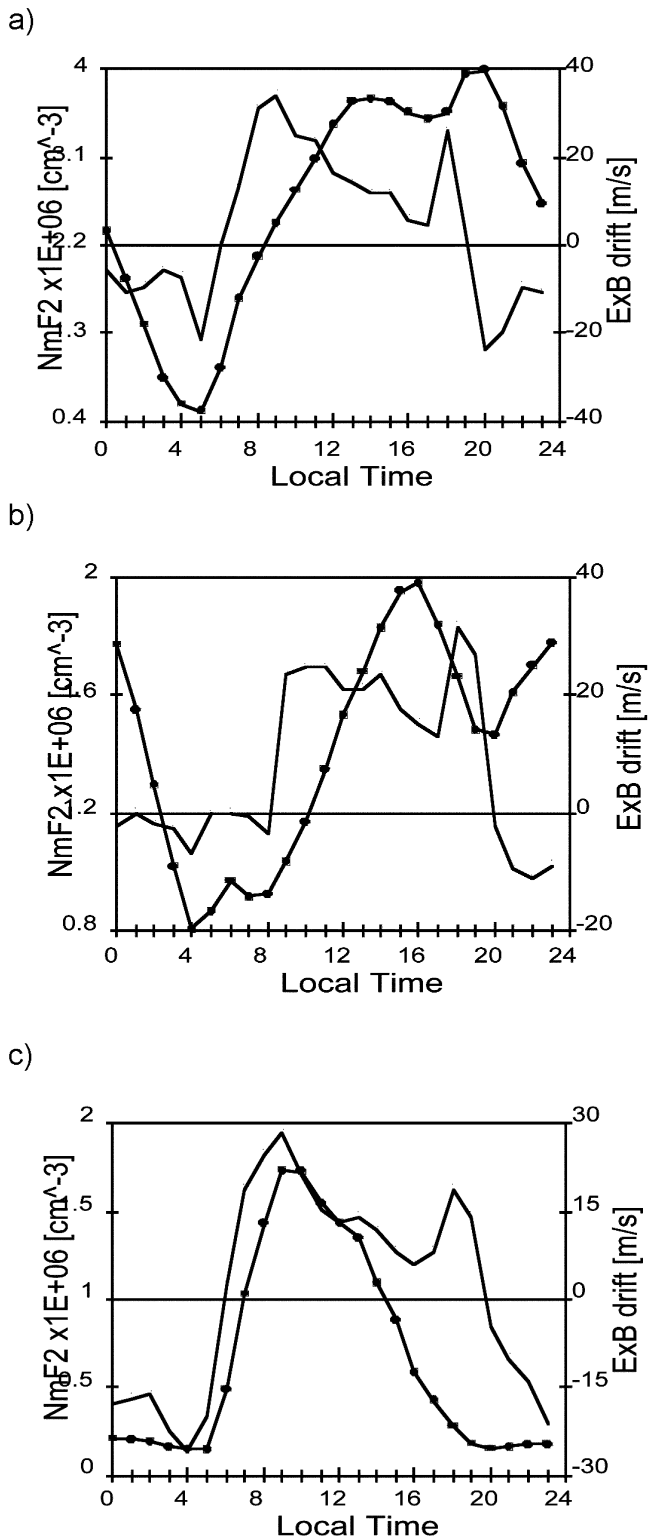

Fig. 2. Mean NmF2 measured at Okinawa (filled circle–solid line) and the ExB drift in the equator (solid line) for (a) March 1959, (b) June 1980 and (c) December 1979.

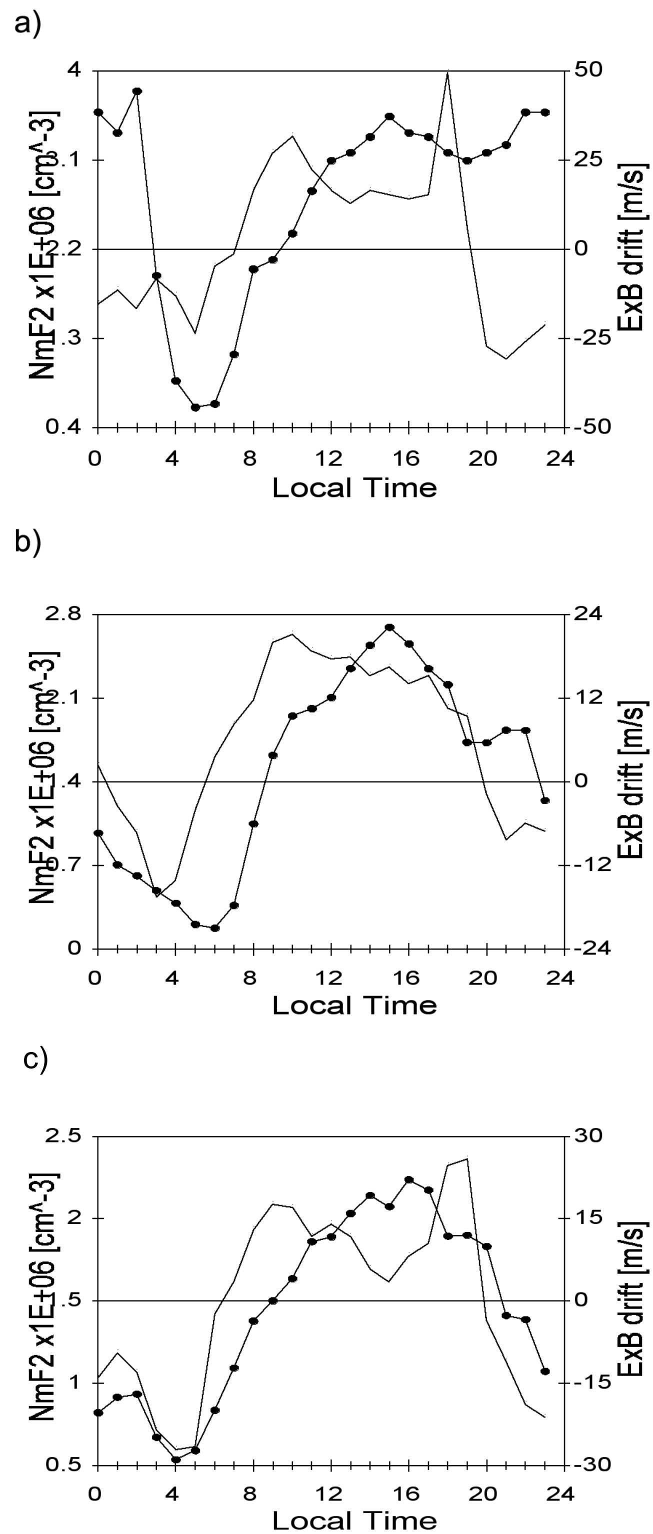

Fig. 3. Mean NmF2 measured at Tucuman (filled circle–solid line) and the ExB drift in the equator (solid line) for (a) March 1959, (b) June 1980 and (c) December 1979.

peaks in coincidence with peaks in the ExB drift. Tucuman also present two peaks, but the ExB drift velocity does not present pre-reversal enhancement in this case. In December (Figures 2c and 3c), Okinawa and Tucuman follow a zenith angle dependence, except that Tucuman presents the maximum at 16 LT, and although the ExB drift velocity do present pre-reversal enhancement in both cases.

Yamagawa and Kokobunji present a zenith angle dependence during equinox as can be seen in Figure 4a and 5a. The neutral meridional wind present a similar pattern to that of NmF2 in both cases. During June (Figures 4b and 5b) NmF2 present two peaks which would correspond to the peaks in the ExB drift, but delayed a few hours necessary for the electrons to arrive form the equator. There is a third peak in NmF2, which in the case of Yamagawa could be due to a trough in the meridional wind. In December (Figures 4c and 5c) NmF2 behavior of Yamagawa and Kokobunji, again follows a zenith angle dependence, similar to the meridional wind pattern.

DISCUSSION AND CONCLUSION

The diurnal variation of NmF2 is determined by production, loss and transport processes. In the low latitude ionosphere the transport of electrons due to ExB drift determines a particular shape of the diurnal pattern of NmF2.

In the case of the stations located between the equatorial anomaly crests, some features of the diurnal pattern can be explained in terms of the ExB drift velocity variation.

For the stations located at the outer side of the EIA, the diurnal variation follows mainly a solar zenith angle dependence, except for June solstice (summer for Yamagawa and Kokobunji). Although the meridional wind in these cases would play a more significant role, in general we could not find any clear connection between wind and NmF2, taking into account that a poleward wind would produce a decrease in NmF2 and an equatorward wind, a NmF2 increase.

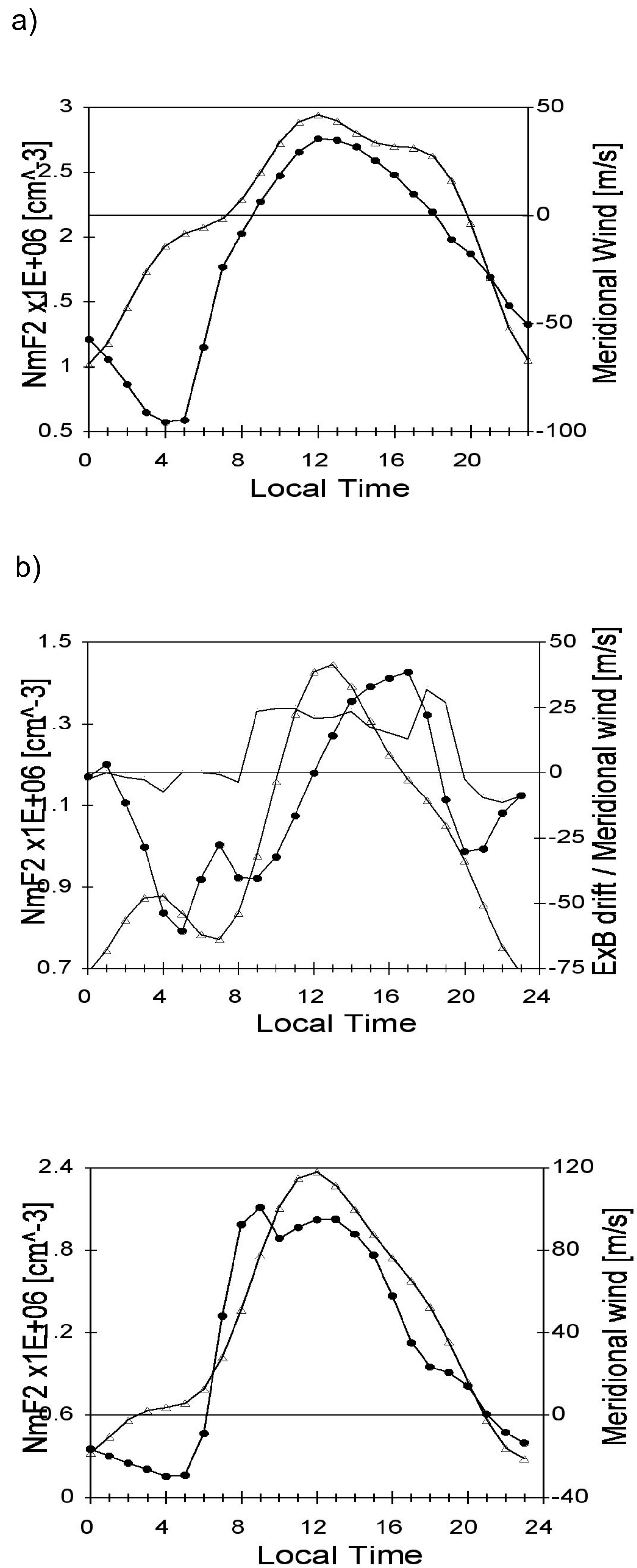

Fig. 4. Mean NmF2 measured at Yamagawa (filled circle–solid line) and the meridional neutral wind (empty triangle–solid line) for (a) March 1959, (b) June 1980 together with the ExB drift in the equator (solid line) and (c) December 1979.

a)

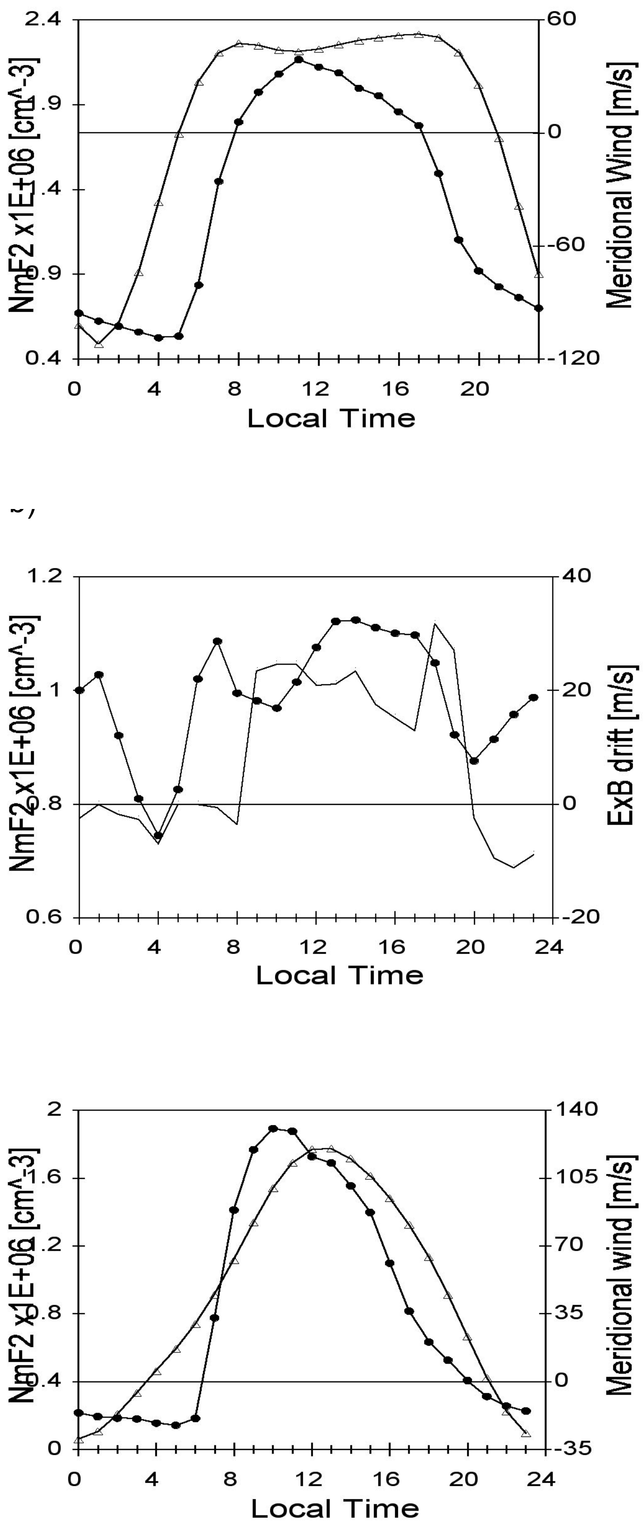

Fig. 5. Mean NmF2 measured at Kokobunji (filled circle–solid line) and the meridional neutral wind (empty triangle–solid line) for (a) March 1959 and (c) December 1979. (b) June 1980 together with the ExB drift in the equator (solid line).

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