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Characterizations of the diurnal shapes of OI 630.0 nm dayglow intensity variations: inferences

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Abstract. Measurements of OI 630.0 nm thermospheric dayglow emission by means of the Dayglow Photometer (DGP) at Mt. Abu (24.6° N, 73.7° E, dip lat 19.09° N), a station under the crest of Equatorial Ionization Anomaly (EIA), reveal day-to-day changes in the shapes of the diurnal profiles of dayglow intensity variations. These shapes have been characterized using the magnetometer data from equatorial and low-latitude stations. Substantial changes have been noticed in the shapes of the dayglow intensity variations between 10:00–15:00 IST (Indian Standard Time) during the days when normal and counter electrojet events are present over the equator. It is found that the width (the time span corresponding to 0.8 times the maximum dayglow intensity) of the diurnal profile has a linear relationship with the integrated electrojet strength. Occasional deviation from this linear relationship is attributed to the presence of substantial mean meridional wind.

Key words. Ionosphere (equatorial ionosphere; ionosphere – atmosphere interactions; ionospheric disturbances)

1 Introduction

The low and equatorial thermosphere-ionosphere system (TIS) is known for multifarious geophysical processes uniquely characteristic to this particular region. Equatorial electrojet (EEJ), counter electrojet (CEJ), equatorial ionization anomaly (EIA), etc., are some of the examples of those processes, and comprehensive reviews are available in the literature regarding them (Raghavarao et al., 1988b and references cited therein). Electrodynamical and neutral dynamical coupling processes are responsible for the manifestations of the above-mentioned phenomena. Until recently, most of the experimental studies regarding the low-latitude TIS were based primarily on ground-based radio probing, magnetometer and in situ rocket and satellite borne measurements. With the advent of the Dayglow Photometer (DGP) (Narayanan et al., 1989; Sridharan et al., 1992a), it has become possible to carry out airglow observations even during daytime. DGP is operated to monitor the OI 630.0 nm dayglow emission, which emanates from the altitude region centered ~ 220 km during daytime with a typical semi-thickness of ~ 60–70 km (Hays et al., 1978; Solomon and Abreu, 1989).

Earlier results using the DGP revealed that F-region electron densities solely control the temporal variabilities (Sridharan et al., 1991) in OI 630.0 nm dayglow intensity. The electron density distribution in the low-latitude ionospheric F-region is strongly controlled by the vertical $\boldsymbol{E} \times \boldsymbol{B}$ drift of the plasma over the dip equator (Hanson and Moffett, 1966; Sterling et al., 1969; Anderson, 1973a, b), followed by diffusion of plasma along the magnetic field lines. This process is known as the "fountain effect" (Appleton, 1946) and through this, the equatorial zonal electric field modifies the electron distribution at F-region altitudes over low latitudes. The fountain effect generates two enhanced regions of ionization (crests) at $\sim \pm 20°$ in the magnetic north-south plane with depleted plasma concentrations over the dip equator (trough). Thus, the fountain effect explains the otherwise anomalous distribution of charge particles over the equator, which is termed as the Equatorial Ionization Anomaly (EIA). Meridional winds are known to cause asymmetry in the intensity (crest to trough density ratio), as well as the location of the crest (Bramley and Young, 1968; Anderson, 1973a), formed at low latitudes due to EIA. The zonal electric field (due to global scale dynamo action), which is responsible for EIA, also causes an intense band of current in the E-region of the equatorial ionosphere known as the equatorial electrojet (EEJ), which generally shows a diurnal pattern with peak amplitudes at local noon. However, even during geomagnetically "quiet" periods, for reasons still being debated (Raghavarao et al., 1980; Somayajulu et al., 1993, Stening et al., 1996), the primary zonal electric field changes its direction from eastward to westward during daytime (Gouin and Mayaud, 1967), which is known as the "Counter Electrojet" (CEJ). Earlier investigations (Raghavarao et al., 1978) revealed that the strength of the EIA has a high degree of cor-

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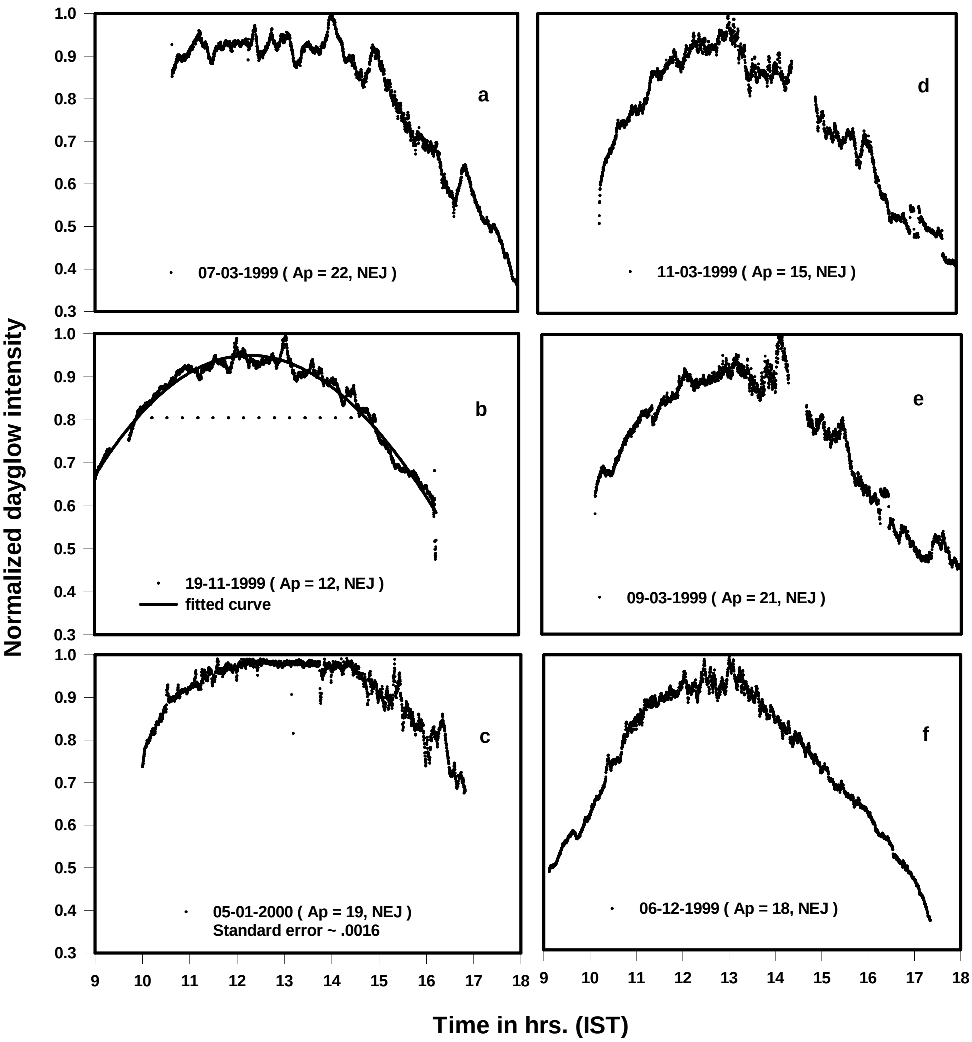

Fig. 1. **(a)**, **(b)** and **(c)**. Normalized dayglow intensity variations on 7 March 1999, 19 November 1999 and 5 January 2000, respectively. The fitted polynomial routine is represented by a solid line, while the width, which is the time interval corresponding to .8 of the maximum intensity, is denoted by the dotted lines in Fig. 1b. The representative standard error in the normalized intensities at 13:00 IST is provided for Fig. 1c. Fig. **(d)**, **(e)** and **(f)**. Normalized dayglow intensity variations on 11 March 1999, 9 March 1999 and 06 December 1999, respectively.

relation (correlation coefficient closer to unity), with the time integrated EEJ strength obtained from ground-based magnetic data. As a consequence, the electron density distribution in the F-region of the low-latitude ionosphere depends critically on the normal electrojet (NEJ) or counter electrojet (CEJ) conditions in the E-region of the equatorial ionosphere.

OI 630.0 nm dayglow intensity variabilities, which are dependent on the ambient electron concentrations, become influenced by the electrodynamical and the neutral dynamical drivers, which cause changes in the electron concentration in the emission altitude. Thus, the dayglow intensity variabilities recorded from a low-latitude station close to the EIA crest are expected to become affected by the zonal electric field and the meridional wind. However, their effects in the temporal variations of dayglow intensities are not studied in detail. In the present paper, it has been indicated that the interplay of zonal electric field and neutral meridional wind has distinct repercussions on the diurnal shape of the dayglow intensity variations recorded from a low-latitude station.

2 Database

The database for the present investigation consists of OI 630.0 nm dayglow intensity data from Mt. Abu and magnetometer data from equatorial and low-latitude stations. Based on the availability of simultaneous data spanning from January 1998 to January 2000, fifteen days of dayglow data are used for the present investigation. The dayglow counts obtained for each day are normalized with respect to the maximum count on that day. This exercise has been carried out to focus on the diurnal shapes of the dayglow intensity variations on different days and to disregard the different peak intensity levels from one day to another. To characterize

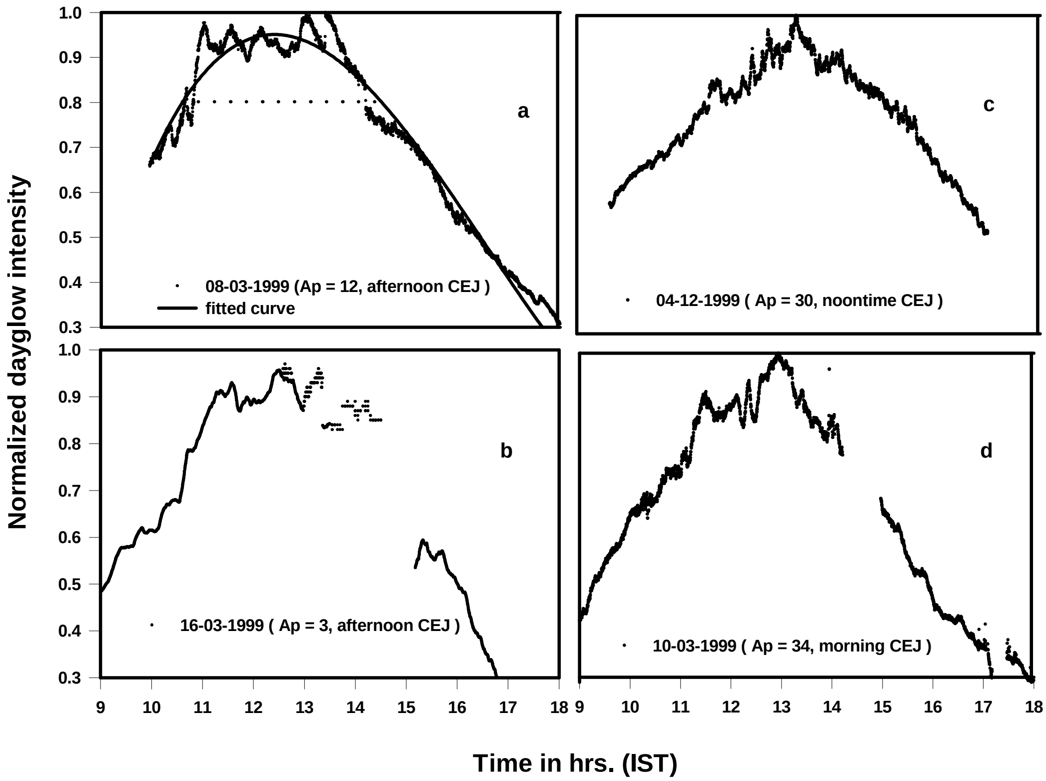

Fig. 2. (a) and **(b)**. Normalized dayglow intensity variations on 8 March 1999 and 16 March 1999. Also shown the fitted polynomial routine (solid line) and the corresponding width (dashed line) for the Fig. 2a. Fig. **(c)** and **(d)**. Normalized dayglow intensity variations on 4 December 1999 and 10 March 1999, respectively.

the diurnal shape, standard polynomial curve-fitting is carried out for all the curves, and the widths (of the diurnal profiles of the dayglow intensity variations) are then calculated as the time interval corresponding to 0.8 of the maximum intensity, falling approximately in the time between ∼10:00–15:00 IST The ground-based magnetometer data from a station close to the dip equator (TRD or Tirunelveli) and Alibag (ABG: 18.61° N, 72.83° E, dip 11.81° N), a station sufficiently away from the influence of the electrojet, have been used to decipher the changes in the equatorial electrojet strength (Rastogi and Patil, 1986) and hence, the zonal electric field that drives it. The present investigation is carried out with a database consisting of eleven normal electrojet (NEJ) days and four counter electrojet (CEJ) days.

3 Results

In the present investigation, the emphasis is given for the overall shapes of diurnal intensity variations during 10:00 to 15:00 IST and thus, the short period fluctuations are ignored. Samples of the normalized dayglow intensity variations for six NEJ days are depicted in Fig. 1. The dates and the corresponding Ap values are also given in the figure. The shapes of the curves depicted on the left panel of Fig. 1 (panel a–c) have a characteristic extended "flat" region at noontime. On the other hand, the shapes of the normalized dayglow intensity variations depicted on the right panel (d–f) have a moderate "flat" region at noontime. As a consequence, the widths of the curves on the left panel are more than those on the right panel. It is of interest to note that the overall shapes of the dayglow intensity variations for all the days depicted on the left panel are similar, whereas the shapes of the curves on the right panel resemble each other.

Figure 2 depicts the normalized dayglow intensity variations for all four CEJ days. The panel on the left-hand side of Fig. 2 consists of the normalized dayglow intensity variations on 8 March 1999 (a) and 16 March 1999 (b), when the CEJ events took place over the equator in the afternoon hours (∼12:30–16:00 IST on 8 March and 13:30–16:00 IST on 16 March). The shapes of the diurnal intensity variations of dayglow on these days have a somewhat steeper (for example, in Fig. 2a, the time intervals between the $I_{\max}$ and the .8 $I_{\max}$ are ∼2 h, whereas in Fig. 1b, the same intervals are ∼2.5 h) rise and fall in comparison with the curves in Fig. 1. The counts started to fall at an earlier instant of time in the afternoon CEJ days in comparison to the NEJ days (especially Fig. 1a–c). The "flat-topped" features noticed in Fig. 2a and b, to some extent, are similar to those noticed in Fig.1a–c, but are present for a shorter duration of time. The panel on the right-hand side of Fig. 2 consists of the normalized dayglow intensity variations on 4 December 1999 (c)

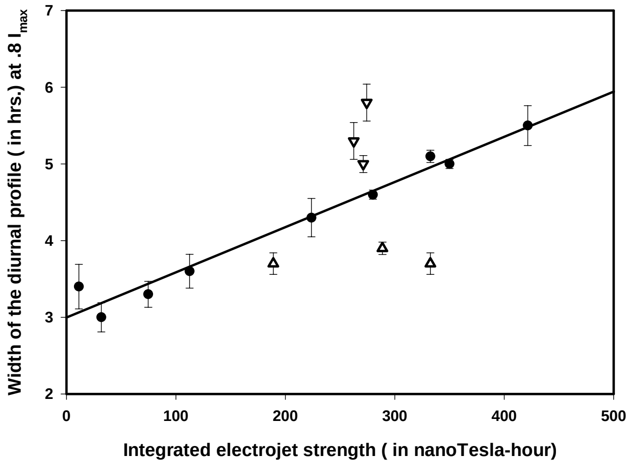

Fig. 3. Relationship between the width of the diurnal dayglow profile with the integrated electrojet strength. The points which are sufficiently scattered on the positive and negative sides are denoted by the symbols "∇" and "Δ", respectively. The errors involved in calculating the widths are also shown in the figure.

and 10 March 1999 (d), the days when one notices events of the noontime CEJ (∼ 12:30–13:45 IST) and morning CEJ (∼ 10:15–11:45 IST), respectively, over the equator. The diurnal shapes of the dayglow intensity variations on these two days are "triangular" with not much of a flat region during noontime. The widths are consequently less on these days.

Figure 3 depicts the widths of the dayglow intensity profiles for all 15 days plotted against the time-integrated (between 08:00–15:00 IST) electrojet strength on those days (Fig. 3). A linear relationship is seen with some scattered points having substantial (more than the standard errors involved in calculating the width) positive (denoted by the symbol "∇") and negative (denoted by the symbol "Δ") deviations. The significance of this linear relationship and the possible reasons for the substantial deviations of some points will be discussed in the following section.

4 Discussion

There are three main processes that are responsible for OI 630.0 nm dayglow emission. Among them, the two dominant processes, namely the photoelectron excitation (PE) of O and the photodissociation (PD) of O_2 by the Schumann-Runge continuum (125–175 nm) account for nearly 70% of the 630.0 nm dayglow intensity. These two processes are dependent on solar zenith angle. However, their contributions integrated over the emission altitude region hardly vary with time during 09:00–16:00 IST over low-latitude regions (Sridharan et al., 1992b). The above-mentioned two processes have considerable effects on the mean intensity levels during noontime on a given day and significant effects in the variations in the intensities during dawn and dusk hours. On the basis of the above discussion, it can be inferred that the shapes of the normalized dayglow intensity variations during ∼ 10:00–15:00 IST do not change much with the contributions from the PE and PD channels. The other process, namely the dissociative recombination (DR) of O_2^+ with the ambient ionospheric electrons, dictates the variabilities between 09:00–16:00 IST (Sridharan et al., 1991, 1992b). So the variations in the dayglow intensities during this period of a given day depend on how the electron distribution changes with time in the region of emission altitude.

The electron distribution over low latitudes depends critically on the strength of the primary east-west electric field in the equatorial E-region, because the strength of the zonal electric field, apart from driving the electrojet current, determines the amount of ionization to be drifted vertically over the dip equator. The greater the strength of the electric field, the greater the $\boldsymbol{E} \times \boldsymbol{B}$ drift of the plasma will be. The plasma which becomes vertically drifted over the dip equator eventually diffuses along the geomagnetic field lines to reach low latitudes. However, since plasma diffusion is a slower process, it cannot account for the faster temporal variations of electron densities at low altitudes in the low-latitude F-region. Due to this reason, the strength of the EIA is well-correlated with the integrated electrojet strength (Raghavarao et al., 1978). However, meridional winds can cause the F-region ionosphere at low latitudes to respond at a faster rate (Abdu, 1997). Thus, meridional winds, depending upon its polarity, can cause deviations from the correlation between the strength of EIA and the integrated electrojet strength.

On NEJ days, when the zonal electric field strength is more, one expects more supply of plasma over low latitudes. The extended "flat-topped" diurnal shapes of the dayglow intensity variations depicted in Fig. 1a–c adduces the supply of electrons at the dayglow emitting altitude region at a grossly uniform rate by the "fountain effect" for a considerable period of time, ably supported by poleward meridional wind. However, even on NEJ days, one sometimes encounters diurnal profiles like those shown in Fig. 1d–f, when a moderate "flat" region is seen at noontime. This is possibly due to the presence of a equatorward mean meridional wind component. The presence of an equatorward mean meridional wind circulation during 10:00–15:00 IST is not unlikely, since one notices that those days lie well within the recovery phases of moderate geomagnetic storms.

On the afternoon CEJ days, like those in Fig. 2a and b, the zonal electric field strength began weakening from ∼ 12:30–13:30 IST onwards. As a result, the rate of supply of electrons over the low latitudes by the "fountain effect" became reduced from noontime itself. Due to this reason, the dayglow counts on those days started to fall from the maxima at an earlier instant of time in comparison with the curves depicted in Fig. 1a–c. As a consequence, one obtains moderately "flat-topped" profiles on those days, with the "flat" region spanning a shorter duration of time. On the other hand, if the weakening of the strength of the zonal electric field occurs from the morning or pre-noontime, like the days in Fig. 2c and d, the "fountain effect" becomes weakened at the development hours itself, changing the rate of supply of plasma over the low latitudes. As a result, the shapes of the curves shown in Fig. 2c and d are almost "triangular" with not much of a "flat" region at noontime.

Figure 3 elicits the linear relationship of the width of the diurnal dayglow profile with the time integrated electrojet strength. The width represents the time interval during which the dissociative recombination process is active, giving rise the 630.0 nm emission in the low latitudes. The plot implies that the shape of the overall diurnal intensity variations of the OI 630.0 nm dayglow, especially during noontime, responds linearly with the strength of the zonal electric field over the equator. This is due to the fact that the ambient electron concentrations at the dayglow emitting altitude over Mt. Abu become sufficiently modulated by the "fountain effect", the process which is initiated by the zonal electric field over the dip equator. However, as mentioned earlier, the direction and the magnitude of the mean meridional wind during 10:00–15:00 IST are also expected to play a crucial role in the electron density distribution over low latitudes. Thus, the points which constitute the linear curve are considered to be on the days when the mean meridional wind is negligible as far as their effects on the dayglow emission is concerned and as a result, the zonal electric field solely governs the shape of the diurnal dayglow profile. However, points which are sufficiently deviated on either side of the linear curve are attributed to the additional effect of the mean meridional wind flow on the dayglow emission process. The comparatively larger widths on 7 March 1999 (Fig. 1a) and 5 January 2000 (Fig. 1c), for example, are considered to be due to the presence of a poleward mean meridional wind, whereas comparatively smaller widths on 9 March 1999 (Fig. 1e) and 6 December 1999 Fig. 1f) are considered to be due to the presence of an equatorward mean meridional wind. Simultaneous meridional wind measurements are needed to further strengthen these aspects.

5 Conclusions

The present investigation reveals the possible characteristic roles played by the zonal electric field and the meridional wind in the shapes of the diurnal intensity variations of OI 630.0 nm dayglow over a low-latitude station. It has been shown that the zonal electric field critically controls the diurnal shapes of OI 630.0 nm dayglow over the EIA crest region. It is suggested that the meridional wind has an additional role to play in modifying the diurnal shapes of dayglow intensity variations over the low-latitude region.

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