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Nightglow Measurements of 630.0 nm Line from Kolhapur, India and Their Association with TEC Enhancements

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Nightglow measurements of 630.0 nm emission line by high resolution tilting photometer have been compared with simultaneous Faraday rotation measurements of the ionosphere's total electron content (TEC) from ETS-II satellite (~130°E) at a low latitude station, KOLHAPUR (Geog. lat. 16.8°N, long. 74.2°E, dip lat. 10.6°N) in India. The preliminary observational data are presented and discussed for seven nights during March, 1989 and April, 1990. The comparative study shows that in general the airglow enhancements are associated with the night time enhancement in TEC. The airglow enhancement due to downward motion of the *F* layer during pre-dawn hours does not correlate with TEC fluctuations. Further, the time rate of change of content has been used to obtain rough estimate of the nightglow intensity level at the station. On comparisons 630 nm emission intensities computed from TEC values and those predicted by MSIS-86 (Hedin, 1987) and FAIM (Anderson *et al.*, 1989) models show an accepted level of agreement. Results focus the coupling between airglow producing irregularities and TEC at low latitude ionosphere.

1. Introduction

The ground based and spacecraft measurements of the equatorial and low latitude ionosphere have established clearly that the various phenomena such as airglow enhancements, VHF scintillations, TEC variations and equatorial spread-*F* (ESF) are coupled to each other and can be explained by the generation of $\boldsymbol{g} \times \boldsymbol{B}$ plasma instability which occurs initially at the bottom of the *F* layer (Anderson, 1981; Sipler *et al.*, 1981; Zalesak *et al.*, 1982). Subsequently the irregularities move up nonlinearly by polarization $\boldsymbol{E} \times \boldsymbol{B}$ motion. Multidiagnostic experiments (both optical and radio) in the equatorial and midlatitude regions have demonstrated clearly that there exists a close association between airglow producing irregularities, VHF scintillations, range type spread-*F* and simultaneous Faraday rotation measurements (Weber *et al.*, 1978, 1980, 1982, 1983; Fejer *et al.*, 1991).

Airglow observations at the ground provide the integrated effect of the column emission along the line of sight within the field of view of the photometer which can be used to infer ionosphere thermosphere dynamics. Usually a very strong airglow signal implies more recombinations between O_2 molecules and electrons along the path and therby indicating lower *F* region height (Weber *et al.*, 1978; Mendillo *et al.*, 1992).

The night time enhancements in 630 nm airglow signal are associated with the temporal/spatial maxima of electron density. They are most intense in two zones centred at about ±15° magnetic latitude; the latitude of maximum intensity tends to move towards the equator during the night. The airglow enhancements in 630.0 nm are caused partially by changes in electron density, but largely by variations in the height of the *F*2 layer (Mendillo and Baumgardner, 1982).

Simultaneous measurements of airglow and total electron content measurements have been used earlier by Brown and Steiger (1972) to infer the number of 6300 and 6364 Å quanta produced per electron lost in the night time *F* layer of the ionosphere at Hawaii. They also found out from the recorded observations that the airglow intensity variation is more closely related to the time rate of change of content. In this report, we present the results of comparison of the first simultaneous measurements of

630.0 nm nightglow intensity and Faraday rotation (Kailiang and Jianming, 1994) measurements from a low latitude station, Kolhapur (Geog. lat. 16.8°N, long 74.2°E, dip lat 10.6°N) in India in order to provide an example of coupling in the ionosphere/thermosphere environment and to study the low latitude ionospheric irregularities. The station being located close to the crest of the equatorial ionisation anomaly (EIA) region, the results presented bear special significance.

2. Observations

Ground-based observations of the 630.0 nm nightglow presented here were made at KOLHAPUR with a tilting photometer (Mukherjee and Dyson, 1992) having a field of view of 1 degree diameter. The interference filter has a band width of 1 nm and diameter 50 cm and was rocked between two positions to give the online and background intensities, the difference between the two gave the airglow signal with respect to the background. The OH contamination has been considered to be insignificant since a narrow band filter has been used. Faraday rotation measurements of the ionosphere's total electron content (TEC), a measure of the integral of the electron density profile along a column at 136 MHz signal from the ETS-II satellite (~130°E) propagating through the ionosphere were recorded simultaneously at the same station. Figure 1 shows the location of the observing station and the subionospheric point corresponding to 400 km height. The data are presented and discussed for the nights of 18–19, 19–20, 20–21, 21–22, 22–23, 23–24 April, 1990 and 8–9 March, 1989. The airglow data were collected on clear moonless nights. During the periods of our observations the mean solar 10.7 cm flux was 240 units. The case studies include 4 quiet days and 3 disturbed days thereby allowing us to study the role played by geomagnetic activity in low latitude ionospheric irregularities.

In absence of ionospheric data from a nearby station, the ionospheric parameters $h'F$ (minimum virtual height of the $F2$ layer) and $N_{\max}$ (peak electron density computed from f_0F2 values; Moore and Weber, 1981) are presented for a near equatorial station, Kodaikanal (Geog. lat. 10°14′ N, long. 77°28′ E, dip lat.

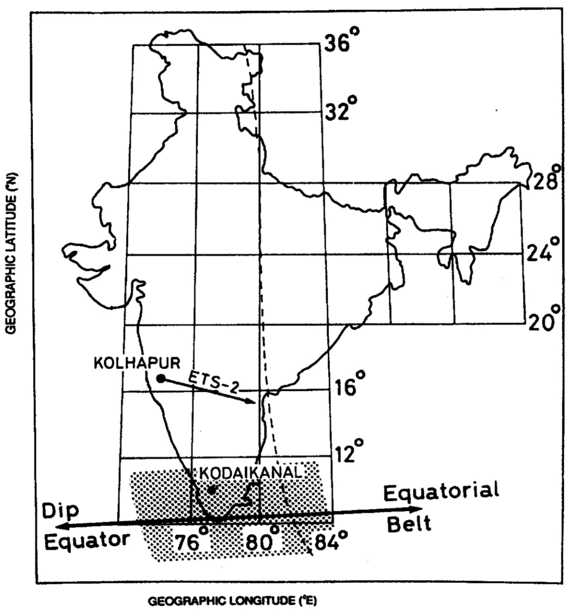

Fig. 1. This shows the respective latitude and longitude positions of corresponding ray paths to the ETS-II (130°E) satellite used to monitor Faraday rotation angle from the observing low latitude station, Kolhapur at 400 km height (subionospheric height) shown by the tip of the arrow.

2°N) in order to understand the condition of the equatorial ionosphere during the time of observations.

The time rate of change of total electron content has been used to get an estimate of the absolute night glow intensity level at the station. Finally, the intensity values are compared with the model predictions. In the following section, we shall study each case comparing the airglow observations with simultaneous TEC and Ionosonde measurements.

3. Results and Discussion

Figure 2 depicts the typical variations in 630.0 nm airglow during the night of 18–19 April 1990 in the upper panel. In the middle panel we plot the hourly values of $h'F$ and N_{max} from Kodaikanal as a

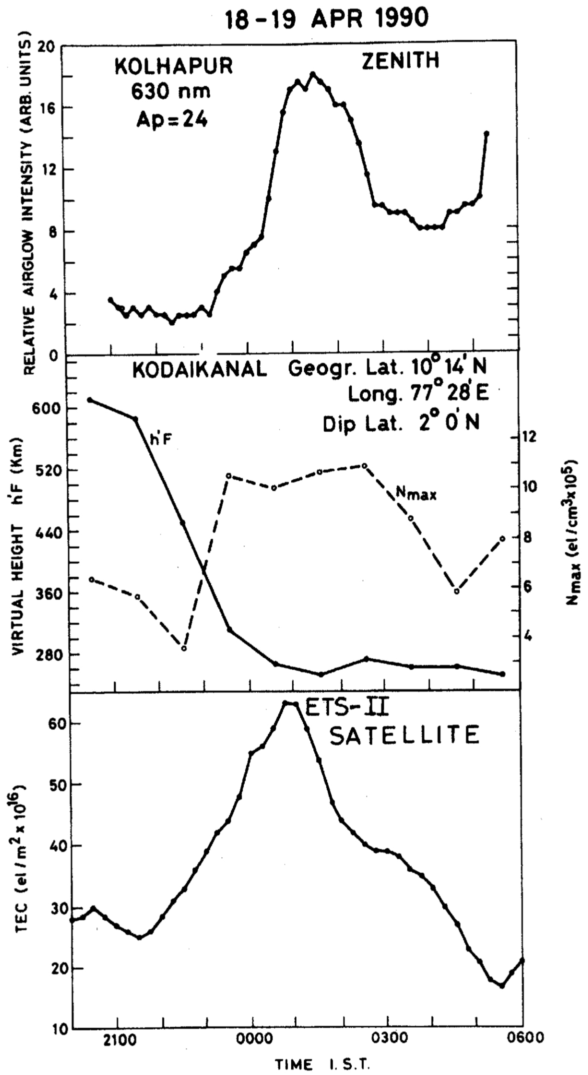

Fig. 2. This shows in the upper panel the temporal variation of intensity of 630.0 nm line during the night of 18–19 April, 1990 at Kolhapur. The lower panel shows the variation of TEC during the night at the station. Also plotted in the middle panel the hourly values of N_{max}, and $h'F$ (virtual F-layer height) from an equatorial station, Kodaikanal.

function of local time. Time is expressed in Indian Standard Time (IST) in hours which is ahead of UT by five and half hours. It is clear from the figure that the airglow intensity maximizes around 0100 hrs LT, at the same time, TEC also peaks. N_{max} at the equatorial station shows broad maximum during the time 2330 to 0230 hrs. The $h'F$ values fall sharply between 2130 hrs to 2330 hrs and attain its lowest values around the time of airglow maximum.

Note also from Fig. 3 that there is a sharp positive gradient in airglow intensity level as well as in total electron content between 2200 hrs to 0100 hrs LT, simultaneously the equatorial layer ($h'F$) drops from 600 km to 280 km level. There is a close similarity in the variation of airglow intensity level and TEC upto 0300 hrs. The time of maximum of airglow intensity matches well with the time of TEC enhancement.

The airglow enhancement during the night of 20–21 April, 1990 (Fig. 4) takes place around 0200 hrs. TEC enhancement occurs earlier with a small peak around the time of airglow maximum. Due to loss of

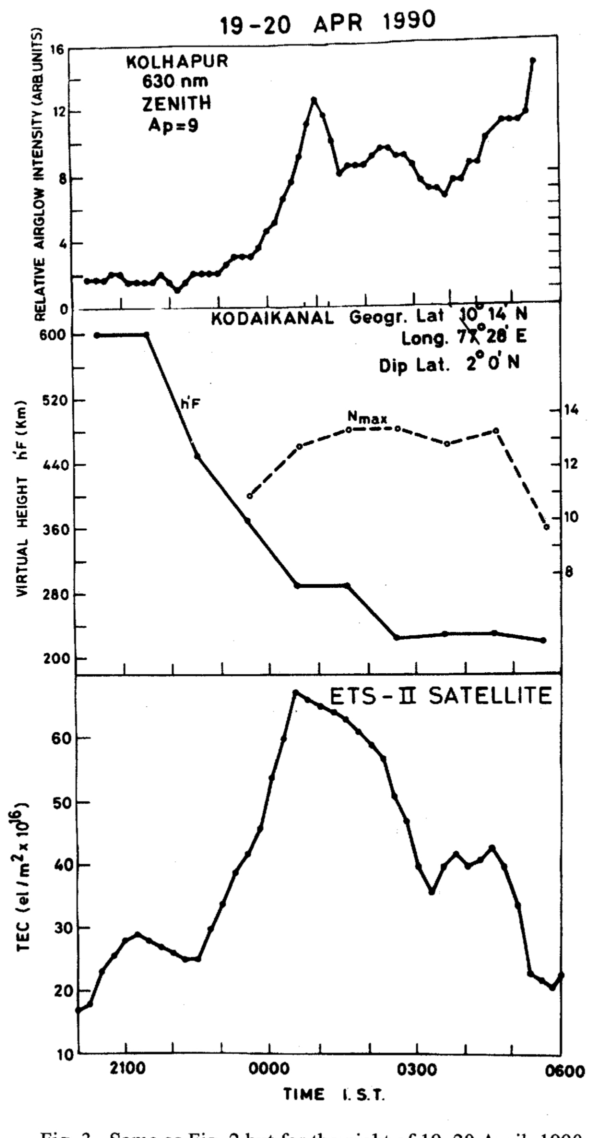

Fig. 3. Same as Fig. 2 but for the night of 19–20 April, 1990.

ionospheric data, no plot is shown for $h'F$ and f_oF2 variations during the night.

On the night of 21–22 April, 1990 (Fig. 5), F-layer height at Kodaikanal shows its prereversal peak value around 2130 hrs. It is to be noted that the layer starts falling down sharply throughout the night. Accompanying the decrease in the layer height from 320 km to 240 km at the equatorial station, a sharp rise in airglow intensity commencing at 0030 hrs was observed at Kolhapur. The lowest F layer height was attained in the early morning hours around 0530 hrs. The airglow intensity attained its maximum value around this time when the equatorial F layer height reached its minimum value. The sharp rise in N_{max} and TEC airglow intensity could be due to sudden lowering of height. The TEC variation shows two peaks during the night. The primary peak in TEC occurring at 0300 hrs is larger in intensity than the secondary peak occurring at midnight by about 20%. The time of occurrence of TEC peaks matches well with the time of maxima of N_{max}. A small dip in airglow intensity around 0215 hour is manifested in N_{max} and also in TEC, though there appears to be some phase difference between N_{max} and TEC enhancement. The airglow enhancement during pre-dawn hours due to lowering of F-layer height does not match well with TEC variation.

As shown in Fig. 6 airglow intensity portrays two enhancements occurring at 0130 hrs and 0430 hrs on 22–23 April, 1990. The second peak is larger in intensity compared to first peak by 30%. The change of equatorial F layer height takes place in two stages around such time, at each downward movement of the layer brings more ionisation to lower altitudes. The time of maximum of TEC (0115 hrs) occurs around the time of maximum of the first airglow peak (0130 hrs). N_{max} at Kodaikanal shows highest value around the time of enhancement of TEC. The airglow enhancement around 0430 hrs may be due to lowering of F layer height further to 225 km which does not correlate with TEC variations.

It is important to notice from all the case studies that the nightglow enhancements (0000–0200 hrs) are generally associated with electron content increases when the F-layer height is low. Frequently there

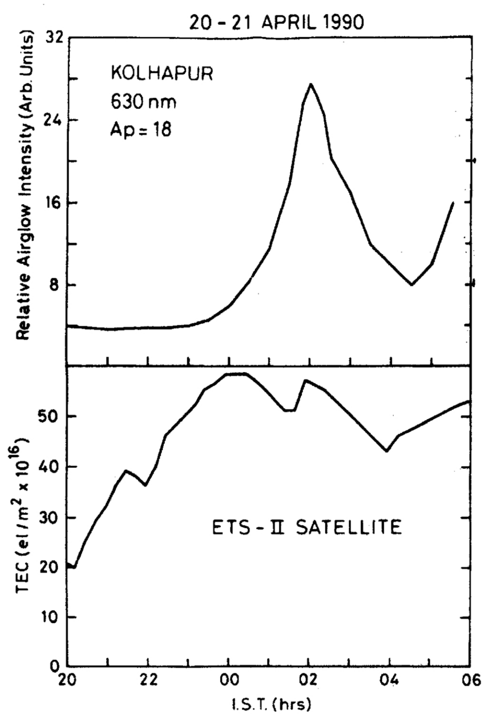

Fig. 4. This shows airglow intensity and TEC variations during the night of 20–21 April, 1990.

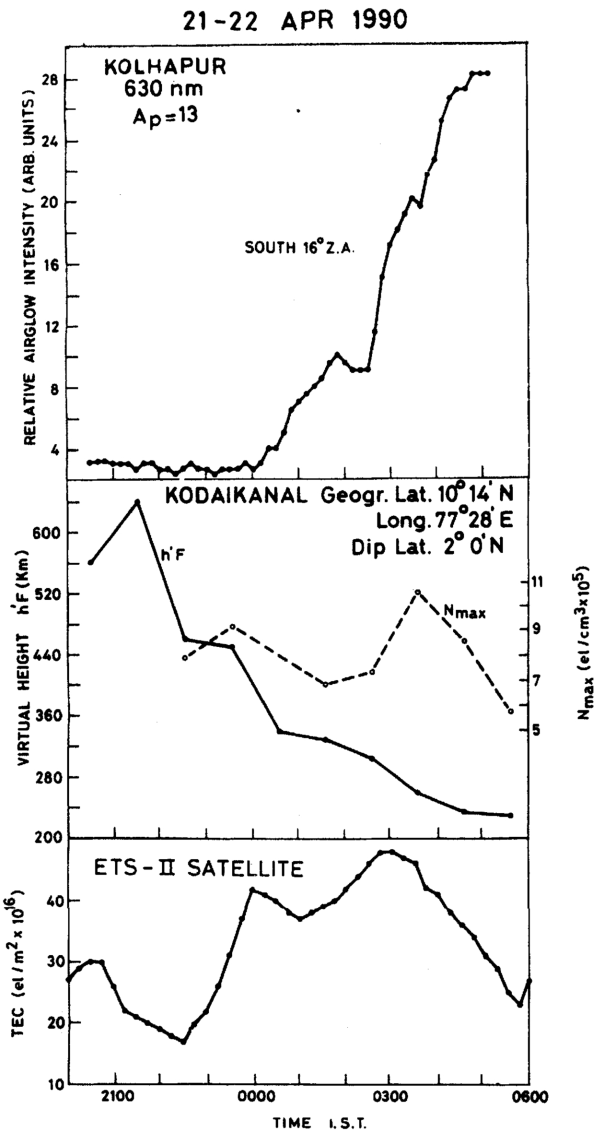

Fig. 5. Same as Fig. 2 but for the night of 21–22 April, 1990.

is a small time delay between the two enhancements. This may be caused due to spatial separation in the viewing geometry as well as the possible difference in the ionization sources of the two measurements. We next bring out some characteristic features of airglow intensity and TEC variation on magnetically disturbed nights.

On a moderately disturbed night ($Ap = 37$) on 23–24 April (Fig. 7), the dynamical variations of the F-layer is large and the F-layer remains at a higher altitude (500 km) upto 0100 hrs compared to earlier quiet nights, thereafter sudden lowering of the F-layer is associated with steep rise in airglow intensity. The airglow variation shows wavy disturbances during 0130 to 0500 hrs local time. As the airglow enhancement during post midnight hours does not show a clear peak, TEC also portrays a broad maximum during 0245 to 0330 hrs. N_{max} and TEC values are considerably reduced on the night compared to their

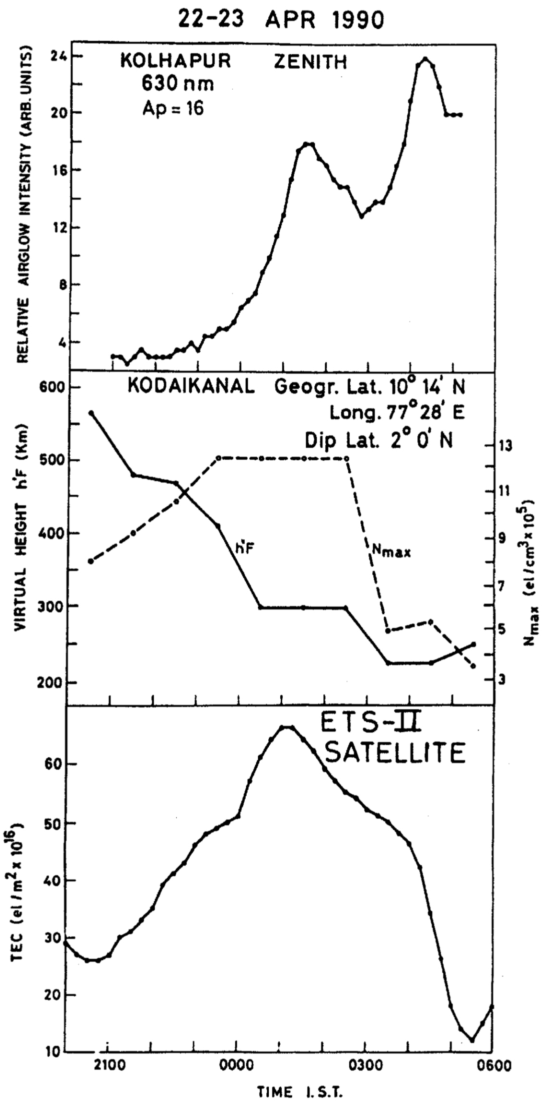

Fig. 6. Same as Fig. 2 but for the night of 22–23 April, 1990.

values during earlier quiet night (Ap = 16) on 22–23 April.

Figure 8 reveals the close resemblance between the airglow intensity variation and TEC fluctuations on March 8–9, 1989 at KOLHAPUR. A magnetic storm with SSC at 2327 hrs LT was in progress. The lower panel of Fig. 8 displays the horizontal (H) component variation from a nearby magnetic station, Alibag (Geog. lat. 18.4°N, long. 72.5°E). It is interesting to note that the rate of enhancement and decay are almost same for 630.0 nm intensity variation and TEC fluctuation during the night.

The top curve in Fig. 9(a) shows the variation of negative derivative of total electron content with respect to time ($-dN_T/dt$) as a function of local time during the night of 18–19 April 1990. For comparison with airglow intensity level we also portray the airglow intensity variation during the corresponding night on the same figure. It is interesting to note that negative time rate of change of the content is more closely correlated to the corresponding airglow intensity variation during the night. The airglow and the rate of

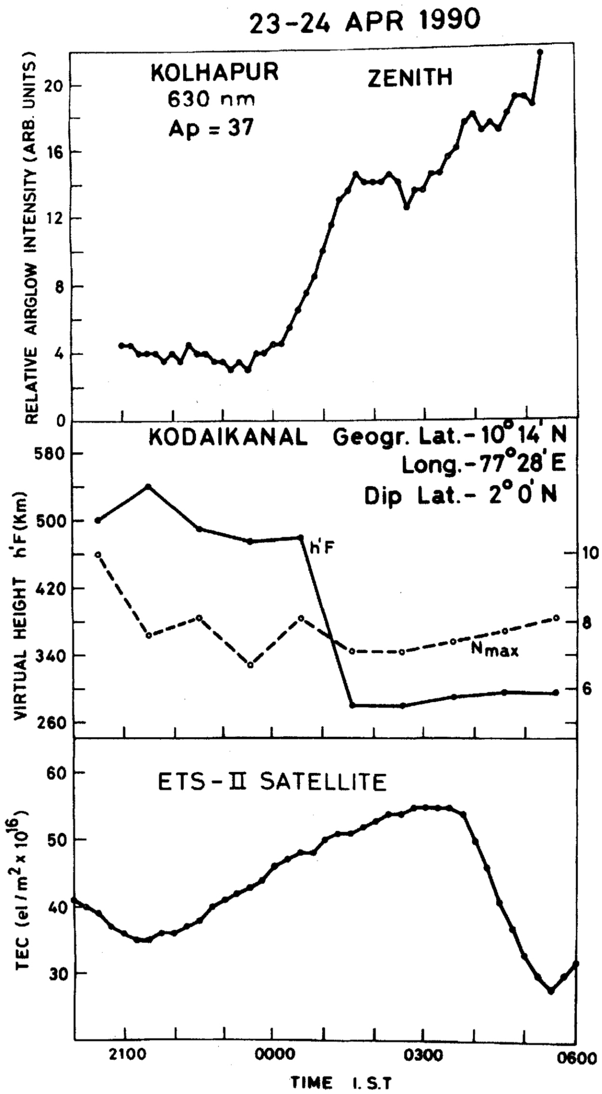

Fig. 7. Same as Fig. 2 but for the night of 23–24 April, 1990.

change of content do not peak at exactly the same time which could be due to longitudinal difference in the ionisation source of the two enhancements. After airglow enhancements the two curves are straight and parallel indicating exponential decay of the form $e^{-\beta t}$ where $\beta = 12.21 \times 10^{-4}\ \mathrm{sec}^{-1}$. Assuming negative derivative of total electron content with respect to time being proportional to airglow enhancement (Brown and Steiger, 1972) we plot in Fig. 10 the airglow intensity values as a function of $-dN_T/dt$ for the corresponding nights during the time of enhancement of airglow intensity. We also plot a best fit line through the data points. Figure 10 shows a significant linear relationship between airglow intensity level >12 units thereby confirming the dominant loss process in the ionosphere as the dissociative recombination near the peak of airglow intensity variation where the F layer height ($h'F$) is found to be low. In the next section, we also compare the column intensity calculated from TEC observation with the model prediction for a typical night condition.

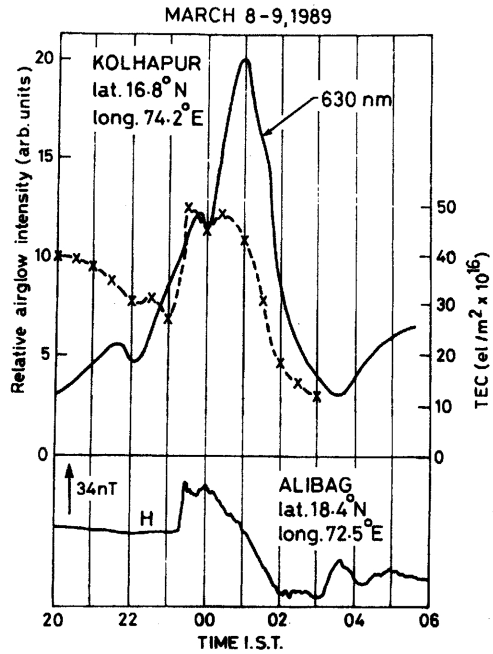

Fig. 8. This shows airglow and TEC variations during the night of 8–9 March, 1989. The lower panel displays that a magnetic storm is in progress.

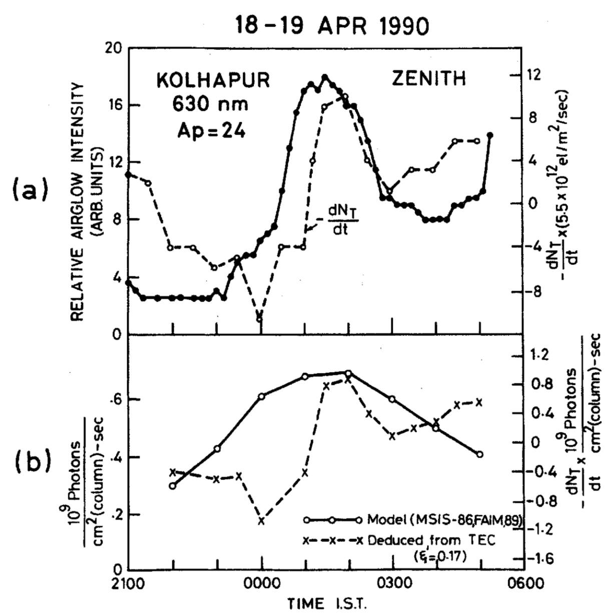

Fig. 9. (a) The upper panel shows the variation of airglow emission and rate of change of total electron content (TEC) during the night of 18–19 April, 1990. (b) The lower panel depicts the comparison between airglow intensities computed from models and those derived from TEC values for the same night.

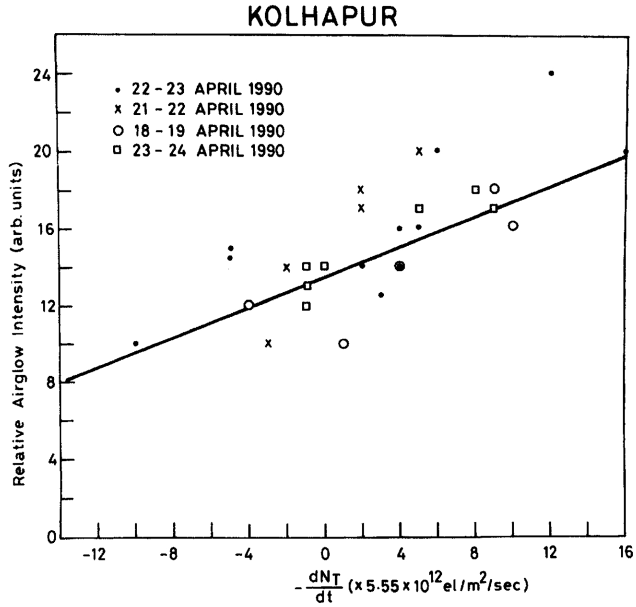

Fig. 10. This shows the variation between airglow intensity and negative rate of charge of content for a few nights.

4. Model Calculation

The neutral atmosphere used in the present calculation is adopted from the MSIS-86 (Hedin, 1987). The emperical model is the recent accurate atmospheric model developed using mass spectrometer data from seven satellites and various rocket measurements as well as data from five ground based incoherent scatter radar stations. The neutral atmospheric composition (O_2, N_2, O) and temperature (T) are calculated for the geographic location, 16°.8N, 74°.2E (Kolhapur station), the day of the year, 108, $F_{10.7}$ solar flux, 243×10^{-22} W/m^2 Hz which corresponds to solar activity level and for few local time hours with Ap, magnetic index as 24. For the computation of altitude profile of electron density, we use the FAIM model developed by Anderson *et al.* (1989). The model is more realistic than CHIU empirical model (Chiu, 1975) and is an improved version of the semi empirical low-latitude ionospheric model (SLIM) developed by Anderson *et al.* (1987). These models are based on the solution of the time-dependent continuity equation which considers only the dominant O^+ ions and take into account $\boldsymbol{E} \times \boldsymbol{B}$ drifts and thermospheric winds. The theory of OI 630.00 nm emission has been discussed in detail by Cogger *et al.* (1980). A photo-chemical equilibrium model is assumed to determine the night airglow rates (Link and Cogger, 1988) and using the same formalism the volume emission rate is computed by

$$I_{630} = \int_{100\ \mathrm{km}}^{600\ \mathrm{km}} \frac{0.76\beta_1 K_1 [O^+][O_2]dh}{1 + (K_3 N_2 + K_4[O_2] + K_5[e]) / A_{1_D}} \tag{1}$$

where β_1 is the production efficiency of O(1_D) atoms and A_{1_D} is the transition coefficient, K_i's are the rate coefficients as given by Link and Cogger (1988, Table 1).

The concentration of O_2, N_2 and O and the values of the neutral temperature (T_n) are generated from MSIS model (Hedin, 1987) at height ranging from 100 km to 600 km at an interval of 10 km and are used as input to Eq. (1). Similarly, the altitude profile of the electron concentration [e] were obtained from

FAIM model. Finally, Eq. (1) was integrated numerically throughout the altitude range with height increment (dh) of 10 km to obtain the column airglow intensity for the night (18–19 April, 1990) of observation.

The distribution of electrons in the ionosphere is governed by the equation of continuity

$$\delta N_e / \delta t = P - I_{630} / \xi' - \vec{v} \cdot \nabla N_e - N_e \nabla \cdot \vec{v} \tag{2}$$

where N_e is the electron density, $\vec{v}$ is the plasma velocity, t is the time, P is the ionization source term, I_{630} the airglow intensity, ξ' is the quantum efficiency of recombination mechanism so that I_{630}/ξ' denotes the electron loss rate in the ionosphere. The last two terms on the right hand side of (2) fully accounts for plasma transport or diffusion, which is significantly important in the F layer at great heights (Pal and Kulkarni, 1968; Alex *et al.*, 1988). As the vertical and horizontal gradients in vertical ion velocity (v_z) are small and horizontal gradients in N_e are often negligible at lower F region heights (Burnside *et al.*, 1985), diffusion terms have been ignored. We assume only dissociative recombination between O_2^+ and electrons as dominant loss process with practically no production ($P = 0$) in the nighttime F-region ionosphere and rewrite Eq. (2) after substituting N_T for N_e in the following way:

$$\mathrm{d}N_T / \mathrm{d}t = -I_{630} / \xi' . \tag{3}$$

Equation (3) has been used to obtain 630 nm column airglow emission from the observed variation of $\mathrm{d}N_T/\mathrm{d}t$. We have used the value of ξ' as 0.17 on the basis of observations (Brown and Steiger, 1972) in the numerical computation of night airglow.

5. Model Results

Figure 9(b) compares between OI 630 nm airglow emission predicted by FAIM and MSIS models and observed OI 630 nm emission deduced from TEC measurements on the night of 18–19 April, 1990 at Kolhapur. In general, the local time variation of the column intensities computed from the models and from the observed rate of variation of total electron content show similar patterns and are fairly in good agreement. The calculated intensities predicted by the models and observations peak at the same time during the post midnight hours. Such a behaviour between observed night airglow emission (630 nm) and calculated intensities using SLIM model (Anderson *et al.*, 1987) for 12°S dip latitude under solar maximum condition has also been reported by Sahai *et al.* (1990). It should be pointed out that the calculated column emission depends on various factors, such as (1) the method of calculation, (2) the values of rate coefficients, and (3) the model of the neutral atmosphere and the electron density. The local time variation of the OI 630.0 nm emission during the night time F-region is strongly dependent on the local time behavior of the $\boldsymbol{E} \times \boldsymbol{B}$ ionospheric plasma drifts, especially around sunset time (Bittencourt and Sahai, 1979). It is understood that the peaks in airglow intensity are the result of equatorward movement of F-region equatorial ionisation anomaly (EIA) during the night which registers its signature by maximizing in airglow intensity. However, a small change in vertical distribution of F-region plasma capable of being induced by thermospheric winds can modify 630 nm morphology without changing TEC structure.

6. Summary and Conclusions

The preliminary observational evidences have been presented to illustrate the coupling between airglow producing structures and TEC from a low latitude station, KOLHAPUR in India situated at a longitude zone near equatorial anomaly region from where no such case studies have been made. The results are reported for the first time from this region. Airglow enhancements during the nights are generally found to be associated with the TEC enhancements. A comparison has also been made between the night airglow variation and the negative rate of change of the content as was done by Brown and Steiger (1972). The variation in airglow intensity seems to correlate better with rate of change of content. We have also performed model calculations to find the relationship between 630 nm intensity and TEC variations during the night. There seems to be better agreement between the 630 nm intensities calculated using models and observed dN_T/dt variations near the peak of airglow intensity when the F layer height is sufficiently low. However, there are smaller differences noticed between the computed values and observations at other times during the night. This leads us to believe additional mechanism of loss process other than dissociative recombination may be operative in the nighttime ionosphere at the time of observations. One such effect could be produced due to geomagnetic disturbances causing variations in meridional component of thermospheric neutral wind field which can affect the transport terms in the continuity equation. In summary, the study indicates the need to include the diffusion process due to the term $\nabla\cdot(N_e\vec{v})$ in the calculation to account for the discrepancies between 630 nm intensity and dN_T/dt variations. A closer look at these diffusion terms separately would help better understanding of the relationship between 630 nm intensity and TEC variation at low latitude ionosphere during the night.

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