Chapter-III
POST SUNSET EQUATORIAL E AND F REGION
ZONAL ELECTRIC FIELDS

3.1 Introduction

Enhancement of ionospheric zonal electric fields during evening hours after sunset, especially during high solar activity period is a consistent result as revealed by the studies of F region plasma drifts and E region zonal irregularity drift velocities by various instruments and techniques (Balsley and Woodman, 1969; Balsley, 1973; Woodman, 1970; Fejer, 1981, 1993; Fejer et al., 1979, 1991), as is also revealed from the results presented in the previous chapter. Numerous studies have been made on this feature of east-west electric field to find out the actual physical mechanism behind this phenomena and resulted in many numerical models (Heelis et al., 1974; Stening, 1981; Batista et al., 1986; Walton and Bowhill, 1979; Bonelli, 1985; Haerendel and Eccles, 1992; Haerendel et al., 1992; Crain et al., 1993a, b).

Though the models considering only the E region dynamo driven by tidal winds of E region origin (Tarpley, 1970; Richmond et al., 1976; Forbes and Lindzen, 1977) predicts the Sq current system very well the F region vertical drifts are not well reproduced especially during night and evening hours. Rishbeth (1971b) pioneered the idea that the F region polarization fields set up by the F region dynamo (Rishbeth, 1971a) can cause this sunset/sunrise F region phenomena. Heelis et al. (1974) studied the effect of polarization fields of F region origin in addition to the electric fields that are mapped from the E region via the magnetic field lines. They have considered
the F region polarization field in explaining the post sunset enhancement of F region vertical drift. If the F region polarization fields are neglected then the form of the drift velocity is determined solely by the E region tidal wind. Inclusion of field aligned currents to take account of F region polarization fields have quite a dramatic effect on the vertical ion drift velocity in the F region.

Walton and Bowhill (1979) developed a model of F region electric fields during daytime and evening hours and showed that the post sunset enhancement can be reproduced even without considering the F region dynamo. Nevertheless they have considered the field aligned current resulted from the non-coincidence of geographic and geomagnetic equators and the hemispherical asymmetries in the ionospheric electrical conductivity. They argued that at least for a station like Jicamarca, where this difference is most pronounced, the F region dynamo may not be necessary to explain the post sunset enhancement.

Following the method of Heelis et al. (1974), Farley et al. (1986) developed a model of the equatorial electric fields and explained the physical mechanism behind the post sunset enhancement on the basis of the longitudinal gradient of E region conductivity (gradient is high during sunset/sunrise times), supporting the F region dynamo theory. Crain et al. (1993b) explained the mechanism of post sunset enhancement in terms of the longitudinal (local time) gradient of F region zonal wind velocity, which drives the F region dynamo.

From the foregoing discussion it is clear that the F region polarization electric fields are influenced by the E and F region dynamo and the E region conductivity. Thus simultaneous observations of the E and F region electric field would help in understanding the relative roles of the E
and F region dynamos in the post sunset period and the effects of E region fields/currents on the pre-reversal enhancement in the F region zonal electric fields. Results of such a study carried out by the author using the E and F region electric fields at Trivandrum during post sunset period from simultaneous observation of VHF backscatter radar and ionosonde are presented in the following sections.

3.2 **Experimental Techniques**

The data used in the present study consists of the E region electric fields derived using the VHF backscatter radar and F region zonal electric fields derived from the F region vertical drift obtained using the h'F data from ionograms.

The main characteristics of the VHF coherent backscatter radar at Trivandrum are given in Table 3.1. The radar antenna beam is directed westward at 60° elevation and the estimated two-way beam width is about 3.5° in the east-west plane. For each backscattered signal pulse (from electrojet irregularities) received, the phase quadrature components of the receiver output are low-pass filtered, digitized and recorded on a magnetic tape after range sampling the signal from different volume elements of the 90-115 km height region. This phase quadraure component is subjected Fast Fourier Transform (FFT) to obtain the Doppler spectrum.

Doppler power spectra, $P(f_{d})$ of the coherently backscattered signals thus obtained correspond to 2.7 m scale size ionization irregularities in the equatorial electrojet (EEJ). For the radar geometry at Trivandrum the Doppler frequency shift, $f_{d}$ is negative/positive for a westward/eastward drift of irregularities under the action of eastward/westward electric field, $E_{x,e}$. The weighted mean Doppler frequency, $\bar{f}_{d}$, is estimated from the first moment of
Table 3.1  Characteristics of the VHF radar at Thumba, Trivandrum.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>54.95 MHz</td>
</tr>
<tr>
<td>Pulse width</td>
<td>20 µs</td>
</tr>
<tr>
<td>PRF</td>
<td>500 Hz</td>
</tr>
<tr>
<td>Peak power</td>
<td>20 kW</td>
</tr>
<tr>
<td>Receiver bandwidth</td>
<td>50 kHz</td>
</tr>
<tr>
<td>Yagi antenna array (T/R)</td>
<td>16 x 4</td>
</tr>
<tr>
<td>(magnetic EW x NS)</td>
<td></td>
</tr>
<tr>
<td>Yagi antenna</td>
<td>5 element</td>
</tr>
<tr>
<td>Spacing between Yagis</td>
<td>0.8λ in E-W</td>
</tr>
<tr>
<td></td>
<td>1.2λ in N-S</td>
</tr>
<tr>
<td>Beam axis elevation</td>
<td>60°</td>
</tr>
<tr>
<td>One-way beamwidth</td>
<td>4.5° E-W plane</td>
</tr>
<tr>
<td>(Half-power points)</td>
<td></td>
</tr>
<tr>
<td>Two-way beamwidth</td>
<td>10° N-S plane</td>
</tr>
<tr>
<td>(Half-power points)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.5° E-W plane</td>
</tr>
</tbody>
</table>
the Doppler power spectrum and is used as a measure of mean phase velocity of irregularities in the sampled volume. \( \bar{f}_D \) is computed from,

\[
\bar{f}_D = \frac{\int f_D P(f_D) \, df_D}{\int P(f_D) \, df_D}
\]  

(3.1)

with the integration done over the range -200 to 200 Hz for \( \bar{f}_D \). The error in \( \bar{f}_D \) so computed is found to be typically \( \pm 1 \) Hz, though it is variable according to the condition of signal to noise ratio (Reddy et al., 1987). \( \bar{f}_D \) values with very low signal to noise ratio are usually rejected.

The average line of sight phase velocity \( V_p^0 \) of the irregularities in the sampled volume is related to the mean Doppler frequency \( \bar{f}_D \) by the relation

\[
V_p^0 = \frac{\lambda}{2} \bar{f}_D = 2.7 \bar{f}_D
\]  

(3.2)

where \( \lambda \) is the wavelength of the transmitted wave.

VHF and HF radar observations have shown that two types of plasma irregularities namely Type-I and Type-II (i.e., two-stream and gradient drift) are commonly present in the equatorial electrojet (e.g., Fejer and Kelley, 1975). In the present study only type-II Doppler spectra are used as the type-II irregularity phase velocities are directly related to the zonal electric field. On occasions when mixed type Doppler spectra are present the type-I spectra are separated out by assuming a gaussian fit for type-I spectra and only the remaining type-II spectra are used for further analysis. The primary EEJ
eastward electric field $E_yE$ is obtained from $V_p^\theta$ from the following relation (Reddy et al., 1987) applicable to the radar geometry at Trivandrum (with antenna beam oriented at 60° elevation angle towards west)

$$E_yE = -\frac{B \ V_p^\theta \ \text{sec}\theta}{C_E}$$

where $B$ is the magnetic induction and

$$C_E = \frac{\rho_i}{(1 + \alpha)^2}$$

$$\alpha = \frac{\rho_i \ \rho_e}{\rho_i + \rho_e}$$

$$\rho_{i,e} = \frac{v_{i,e}}{\omega_{i,e}}$$

$v$ and $\omega$ are the collision and gyro frequencies respectively and subscripts $i$ and $e$ denote the quantities corresponding for ions and electrons. The collision frequencies of electrons and ions with neutrals appearing in the above equations are calculated using the expressions given by Banks and Kockarts (1973). Neutral densities ($n$) and temperatures ($T$) appearing in the expressions for collision frequencies are obtained from the neutral atmospheric model MSIS-86 (Hedin, 1987).

The E region zonal electric field $E_yE$ is calculated from $f_D$ values at 101 km, the height at which signal power is maximum, by the procedure explained above. $E_yE$ thus calculated is not sensitive to changes in $\rho_i$ and $\rho_e$. 

-61-
and represents fairly well the E region eastward electric field (Reddy, et al., 1987).

The F region zonal electric field, $E_{yF}$ is calculated from the vertical drift of the bottom of the F layer obtained from Trivandrum ionograms as explained in Chapter-II. Ionograms recorded at 5 minutes interval using KEL Digital ionosonde are scaled to obtain $h'F$ values at 2.5 MHz for the present study. From this $h'F$ data, $\Delta h'F/\Delta t$ is calculated and the apparent drift velocity $\beta H$ due to chemical loss is subtracted from it to obtain the true vertical (purely electrodynamic) drift velocity, $V_d$ (as described in Chapter-II). The attachment coefficient, $\beta$ is calculated using MSIS-86 for appropriate geophysical conditions as explained in Chapter-II and $H$, the ionization scale height parameter, is taken as 10 km (see Chapter-II for details). From this the F region zonal electric field is calculated as $E_{yF} = V_d B$ at the magnetic equator. For Trivandrum, $B = 3.3 \times 10^{-5}$ Tesla at F region altitudes.

### 3.3 Results

Only on some of the days on which $E_{yF}$ data are available, the VHF backscatter data could be obtained in the evening hours as, in general, the backscatter signals disappear (which depends upon the sensitivity of the radar) around 1700 hrs in the evening. So the availability of the simultaneous data of $E_{yE}$ and $E_{yF}$ is rather limited. The results of the simultaneous observations of $E_{yE}$, $E_{yF}$ and $h'F$ are shown in Figures 3.1 to 3.16. Figures 3.1 to 3.11 show the plots for equinox days and Figures 3.12 to 3.16 show those for solstice days. In these figures time variation of $E_{yE}$ at 101 km along with that of $E_{yF}$ are shown in the bottom panel. The top panel shows the variation of $h'F$ during this period. Corresponding to the altitude of the base of the F region ($h'F$) at the magnetic equator, the geomagnetic latitude of E region which is linked to this altitude through magnetic field lines is marked on the
Fig. 3.1 Temporal variation of $E_yE$ and $E_yF$ and $h'F$ for February 13 and 15, 1991.
Fig. 3.2 Same as Figure (3.1) but for February 18 and 20, 1991.
Fig. 3.3  Same as Figure (3.1) but for February 21 and March 15, 1991.
Fig. 3.4  Same as Figure (3.1) but for March 16 and 17, 1991.
Fig. 3.5  Same as Figure (3.1) but for March 18 and 19, 1991.
Fig. 3.6 Same as Figure (3.1) but for March 21 and 22, 1991.
Fig. 3.7  Same as Figure (3.1) but for March 23 and 25, 1991.
Fig. 3.8  Same as Figure (3.1) but for March 26 and 27, 1991.
Fig.3.9  Same as Figure (3.1) but for April 03 and 04, 1991.
Fig. 3.10  Same as Figure (3.1) but for April 05 and 09, 1991.
Fig. 3.11 Same as Figure (3.1) but for October 03 and 04, 1991.
Fig. 3.12 Same as Figure (3.1) but for November 22, 1990 and January 14, 1991.
Fig. 3.13 Same as Figure (3.1) but for January 15, 1991 and December 18, 1991.
Fig. 3.14 Same as Figure (3.1) but for December 19 and 20, 1991.
Fig. 3.15 Same as Figure (3.1) but for December 23, 1991 and January 21, 1992.
Fig. 3.16 Same as Figure (3.1) but for June 18, 1992.
right hand side of the top panel (see section 2.5.1 for details). It may be noted here that the correction for chemical loss is applied to the F region vertical drift velocity throughout the period of observation, irrespective of the fact that the production of ionization due to solar radiation in the early evening periods (prior to ~1730 hrs LMT) can partly compensate for the recombination loss. This makes the estimated $E_{yF}$ prior to ~1730 hrs LMT somewhat erroneous.

As the conductivity parallel to magnetic field lines is high compared to the Pedersen conductivity, the E region electric field ($E_{yE}'$) at the magnetically linked latitude will be nearly equal to $E_{yF}$. Thus any difference between $E_{yE}$ and $E_{yF}$ indicates the latitudinal gradient in the eastward electric field existing between the magnetic equator and the E region of magnetically linked latitude. The main features of $E_{yE}$ and $E_{yF}$ in the equinoxes and solstices as revealed from the present study are the following:

**Equinoxes**

i) $E_{yE}$ and $E_{yF}$ both show, in general, almost the same magnitude prior to ~1800 hrs LMT.

ii) After ~1800 hrs LMT $E_{yE}$ remains nearly constant or decreases while $E_{yF}$ shows the familiar post sunset enhancement.

iii) On the days considered, the maximum value of $E_{yF}$ varied between ~0.8 mV/m to ~2.4 mV/m after 1800 hrs LMT, whereas $E_{yE}$ is generally in the range 0.2 mV/m to 0.4 mV/m.
Solstices

i) Except on November 22, 1990, variations of $E_{yE}$ and $E_{yF}$ do not show any significant departures from each other (even after 1800 hrs). On November 22, 1990, the post sunset peak of $E_{yF}$ was quite high (~1.8 mV/m) compared to the other solstice days.

ii) It is interesting to note that on June 18, 1992, when $E_{yE}$ data is available from 1815 hrs to 1945 hrs the mean level of $E_{yE}$ is about the same as that of $E_{yF}$.

The same magnitudes of $E_{yE}$ and $E_{yF}$ observed before 1800 hrs LMT suggests that the E region zonal electric field is virtually independent of latitude between 0° and 10° geomagnetic latitudes. During this period as the E region would be sufficiently conducting that it may not be able to sustain latitudinal gradients in the electric field. Moreover, during this period the Pedersen conductivity of E region would be sufficient to short circuit the vertical polarization fields generated by the F region dynamo. As time progresses the E region conductivity decreases helping the F region vertical polarization fields to develop. This polarization fields caused by the F region dynamo are mapped into the E region where it produces zonal polarization electric fields (Heelis et al., 1974, Farley et al., 1986, Crain et al., 1993b). This enhanced zonal electric field is then mapped back into the F region where it results in upward electrodynamic plasma drifts as seen from the increase of $h'F$ (or enhancement of $E_{yF}$) as described earlier. Also it is seen from the figure for equinox days that $E_{yF}$ (or $E_{yE}$) differs largely from and is much greater than $E_{yE}$ after about 1800 hrs. This implies that there exists a large latitudinal gradient of the eastward electric field in the E region after ~ 1800 hrs. The maximum value of this gradient is estimated to be approximately 2.2 mV/m per 10° geomagnetic latitude during equinoxes. This indicates that there is a
sharp decrease in the E region conductivity after 1800 hrs to support the large observed latitudinal gradient. Such departures between $E_{yE}$ and $E_{yF}$ are not observed during the solstice days in the post sunset period except on one of the days. This indicates that, in general, the F region dynamo effect is much weaker in solstices in the post sunset period. This could be due to different sunset times at the conjugate E regions (magnetic field-line-linked) in solstices in addition to the factors like the thermospheric wind gradient as noted in the Chapter-II. The observed departure of $E_{yE}$ from $E_{yF}$ on one of the days (November 22, 1990) indicates the day-to-day variability in the thermospheric winds/wind gradients.

The large departure of $E_{yF}$ (or $E_{yE}'$) from $E_{yE}$ (in equinoxes) and the observed latitudinal gradient of $E_{yE}$ indicates that $E_{yF}$ (or $E_{yE}'$) is largely of F region origin. Thus the observed large increase in $E_{yF}$ (after 1830 hrs) can be taken as evidence for F region dynamo generated electric fields. Such large electric fields can also be expected in the E region situated at latitudes greater than those linked to h'F level, as these are linked to higher levels (than h'F) of F region of magnetic (dip) equator, where the dynamo (F region) effect is active. However, it should be noted that these large electric fields in the E region at latitudes linked to equatorial F region would not cause any appreciable currents because of very low conductivities and hence no noticeable changes in the ground magnetograms can be observed.

Balsley (1973) compared the E region east-west drifts and F region vertical drifts (both due to the east-west electric field) at Jicamarca and reported them to be quite matching with each other. But a close examination of the data presented (Figure 10 of Balsley, 1973) reveals that the E region east-west drifts do not show the pronounced post sunset enhancement as the F region vertical drifts. Some of the differences between E region east-west
drifts and F region vertical drifts were attributed by Balsley (1973) to latitudinal gradient of E region electric fields and the action of neutral winds.