E and F Region Electric Fields Over Dip Equator

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The horizontal east-west drift velocity V_E of ionisation irregularities in E region, and the vertical drift velocity V_F of electrons in F region over Jicamarca (dip latitude $\approx 1^\circ\text{N}$) are used to estimate the average diurnal variation of the east-west components of the electric fields in these two regions. The F region field is estimated from V_F by using the relationship derived earlier by Woodman. The E region field is estimated from V_E by using a relationship different from the one used earlier by Balsley and Woodman and is derived by using more realistic electrojet and conductivity models. The E region electric field thus obtained is found to be weaker at least by a factor of 3 than that estimated by Balsley and Woodman. A comparative study shows that the east-west electric field in the F region is, most of the time, stronger than that in the E region, and also that the ratio of the E region field to the F region field systematically increases from forenoon to afternoon hours, and from pre-midnight to post-midnight hours.

INTRODUCTION

As the geomagnetic field lines can be considered equipotential [Martyn, 1955; Richmond, 1973a], the electric fields in the equatorial F region should be closely related to the fields in the corresponding nonequatorial E region. Hence, the study of the relative strength of electric fields in the equatorial E and F regions is useful in understanding the distribution of electric field with latitude. The average horizontal drift velocity of ionization irregularities in the 95- to 110-km region and the average vertical drift velocity of electrons in the 300- to 400-km region were estimated from radar observations made from Jicamarca during the period July 1967 to March 1970 and reported by Balsley and Woodman [1971]. Seasonally and annually averaged values of these drifts were later reported by Balsley [1973]. The horizontal electric fields in the E and F regions over Jicamarca are computed from these drifts for the different seasons, and the results are presented and discussed here. Balsley and Woodman [1969] from a comparative study of the E and F region drifts find that the two parameters are very well correlated in their diurnal variation. This relationship is reviewed here, in light of more realistic electrojet and conductivity models; with an aim of finding the relationship between the east-west electric fields in the E and F regions.

While the relationship between the horizontal electric field and the vertical drift velocity of electrons in the F region, given by Woodman [1970] is straight forward, the relationship between electric field and horizontal drift velocity of irregularities in the E region given by Balsley and Woodman [1971] is model dependent and has been critically examined in this paper.

ELECTRIC FIELDS FROM DRIFT VELOCITIES

The following sign convention is adopted here:

1. Electron drift velocity is taken positive when directed westward in the E region and upward in the F region.
2. The horizontal electric field is taken positive when directed eastward.

The vertical drift velocity (V_F) of electrons in the F region (300-400 km) is related to the horizontal east-west electric field E_{yF} through the following expression given by Woodman [1970]:

$$E_{yF} = 2.5 \times 10^{-5} V_F \quad (1)$$

The expression relating V_E (the horizontal drift velocity of irregularities) and E_{yE} (the east-west electric field) in the E region is quite involved and depends on the model of the equatorial electrojet used. The expression $E_{yE} = 6 \times 10^{-6} V_E$ used by Balsley and Woodman [1971], and Balsley [1973] is based on the σ_{yy} electrojet model of Sugiura and Cain [1966] and the conductivities given by Tarpley [1969]. The rocket studies of the equatorial electrojet by Davis *et al.* [1967] showed that the latitudinal distance ' d ' over which the peak electrojet current decreases to half is about 350 km as compared with 50-80 km predicted by the σ_{yy} model. A model more realistic than the σ_{yy} model was developed by Untiedt [1967] which gives a value of $d \approx 275$ km. The value of d determined from the later model of Sugiura and Poros [1969] is in agreement with that given by Untiedt's model.

The electrojet model of Untiedt and the conductivity model of Richmond [1973a] are used here to determine the relationship between V_E and E_{yE} . The following simplifying assumptions are also made:

1. The electrojet current density over Jicamarca (dip lat. $\approx 1^\circ\text{N}$) is about 90% of that over dip equator, as given by the electrojet model of Untiedt.
2. The Hall conductivity per electron whose height profile is shown in Figure 1 is assumed to be constant within 3% of e/B_E , where e is the electronic charge and B_E is the E region geomagnetic field over Jicamarca ($\approx 2.7 \times 10^{-5}$ Tesla).
3. The phase velocity of irregularities (V_E) is related to the drift velocity of electrons (V_d) through the relation

$$V_E = \frac{V_d}{1 + \psi}$$

— where $\psi = \nu_e \nu_i / \Omega_e \Omega_i$, ν_e , and Ω_e being the usual electron and ion, collision, and gyro frequencies, respectively. This is based on the linear theories for the generation of type II irregularities [Rogister and D'Angelo, 1970; Sudan *et al.*, 1973].

4. The average eastward electrojet current density over the dip equator is given by approximate relation $J_y \approx \sigma_2^2 / \sigma_1 \cdot E_{yE}$.

Making use of these assumptions, one can get

$$E_{yE} = 3 \times 10^{-5} V_E (1 + \psi) \frac{\sigma_1}{\sigma_2} \quad (2)$$

To compute E_{yE} from V_E by using (2), one has to first estimate the value of $\sigma_2 / [\sigma_1 (1 + \psi)]$. The fact that V_E is the weighted

Fig. 1. Height profiles of σ_2/σ_1 , $\sigma_2/[\sigma_1(1+\psi)]$ and σ_2' (Hall conductivity per electron)—After Richmond [1973a].

average of the drift velocities in the height range of 95–110 km and the height profiles of the radar echo amplitudes differ considerably between day and night, necessitates the use of different values for $\sigma_2/[\sigma_1(1+\psi)]$ during day and night. During daytime, the oblique radar echoes are received from a narrow height region with the echo peak around 105 km. [Fe-

jer *et al.*, 1975a]. The vertically directed radar observes the peak echo region around 103 km. (refer to Figure 1, Fejer *et al.* [1975b]). Rocket observations from Thumba, India, indicate that the maximum drift velocity in the electrojet region over Thumba occurs around 105 km. [Prakash *et al.*, 1971]. Richmond [1973b] also obtained similar results from rocket measurements off the coast of Peru. During night times, the echoes are spread over a wider height range of 95–115 km. Sometimes they extend to altitudes even above 115 km, though less frequently.

Thus while the radar echoes are confined to a narrow height range of 105 ± 2 km during the daytime, the nighttime echoes are confined to an altitude range of about 105 ± 10 km. Therefore, though the drift velocities are average values for the altitude range of 95 to 110 km during daytime the power contributed by irregularities outside the range of 105 ± 2 km is negligible. The average of $\sigma_2/[\sigma_1(1+\psi)]$ in the height range of 105 ± 2 km. can, hence, be used for computing the daytime electric fields. But for nighttime, since the echoes are spread over a wider height range, with comparable amplitudes, the average value of $\sigma_2/[\sigma_1(1+\psi)]$ for the whole height range of 95–110 km is to be used in the electric field computation.

The height profiles of σ_2/σ_1 and $\sigma_2/[\sigma_1(1+\psi)]$ estimated from Richmond [1973a] are shown in Figure 1. σ_2/σ_1 is a measure of the drift velocity of electrons. As can be seen from (2), for a primary electric field constant with height the drift velocity $V_E(1+\psi)$ of electrons should peak at the same altitude as σ_2/σ_1 . Fejer *et al.* [1975b] report the radar observations of the peak phase velocity around 107 km. This implies an electron drift velocity maximum around 105 km. As has already been

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Fig. 2. Seasonal and annual averages of the diurnal variation of horizontal drift velocity of ionisation irregularities in the E region (95–110 km) and vertical drift velocity of electrons in the F region (300–400 km). The diurnal variation of the east-west electric fields estimated from the electron drift velocities is also shown in the figure.

pointed out earlier, the results of Prakash *et al.* [1971] and Richmond [1973a], also indicate a peak drift velocity around 105 km. But the numerical computations made by using existing atmospheric models, and by using approximate collision frequency formulae, give a peak value of drift velocity below 100 km, as can be seen from Figure 1. Although this height discrepancy of more than 5 km has been well established, it is yet to be given satisfactory explanation.

This being the situation, the estimation of average values for $\sigma_2/[\sigma_1(1 + \psi)]$ for the electric field computations will be involved and cannot be done unambiguously. If the existing height profile of $\sigma_2/[\sigma_1(1 + \psi)]$, as given in Figure 1 is used in the computation, the average value of this parameter in the height range of 105 ± 2 km, to be used during daytime is about 20. The corresponding value for the nighttime is about 16. Substituting these values in equation (2) one can get

$$E_{yE} = 1.5 \times 10^{-6} V_E \quad (3)$$

during daytime and

$$E_{yE} = 1.9 \times 10^{-6} V_E \quad (4)$$

during nighttime.

But when one takes care of the existing height discrepancy of more than 5 km that exists in the observed drift and computed conductivity profiles and lifts the conductivity profile upward by an altitude of about 5 km, the average values of $\sigma_2/[\sigma_1(1 + \psi)]$ to be used in (2) can be expected to change. From Figure 1 when one estimates the new average values of $\sigma_2/[\sigma_1(1 + \psi)]$ one can get a value of about 25 during daytime and 16 during nighttime. Thus while (4) remains unaltered by such a height shift in the conductivity profile, (3) gets modified to

$$E_{yE} = 1.2 \times 10^{-6} V_E \quad (5)$$

RESULTS AND DISCUSSION

The average daily variation of V_E and V_F estimated for different seasons, and the annual average variation taken from Balsley [1973] are shown in Figure 2. The horizontal electric fields in the E and F regions are also computed from these drifts by using (1), (3), and (4) for the existing conductivity profiles. The value of these fields can be read by using the scale given along the 18 hour line in Figure 2. The solid curve represents both V_F and E_{yF} . The dashed curve represents V_E and also daytime E_{yE} as given by (3). The nighttime values of E_{yE} are represented by the dotted curve. The dotted curve seen during the daytime indicates the field values, computed by using (5) for the height lifted conductivity profile.

It can be seen from the figure that the electric field in the F region is usually stronger than the E region field. The difference between the fields is enhanced when the conductivity profile is height lifted. The fields are nearly equal during afternoon hours and post-midnight hours. The maximum average value of E_{yF} can be seen to be about 0.7 mV/m for local summer during evening hours, and 0.8 mV/m for equinox during pre-midnight hours. E_{yE} is maximum during night and has a maximum value of about 0.6 mV/m. This value of E_{yE} is less than the theoretically predicted value of Matsushita [1969] by a factor of two.

It can be seen from Figure 2 that in general, the electric fields in E and F regions do not reverse at the same time. The delay in reversal varies from season to season. F region fields reverse earlier than the E region fields. A delay of as much as

Fig. 3. Seasonal and annual averages of the diurnal variation of the ratio of horizontal drift velocity of ionization irregularities in the E region (95-110 km) and vertical drift velocity of electrons in the F region (300-400 km).

one hour can be seen for the local winter during the evening reversal. The annual average curve shows a delay of about 45 min during evening reversals. Gagnepain *et al.* [1976] from model estimates predict a 24 min advance reversal for the F region field, over the E region field. This model neglects the effects of winds and conductivity gradients. If the neutral wind pattern is such that the field reversals at two nonequatorial latitudes are at two different times, a time difference in the field reversals in E and F region can be observed. Further studies are to be carried out, before making any conclusive remark regarding this aspect.

Another important result that has come out of the present studies is shown in Figure 3, which gives the time variations of the ratio of V_E to V_F for different seasons. The average annual variation is also shown in the figure. As the time of reversal in the E and F regions are seen to differ by as much as an hour, the ratios during reversal periods do not have any physical significance and, hence, negative values which are very few in number are marked by crosses on the time axis. Positive values of the ratio larger than 30 occur close to the reversals, are

also not meaningful and are plotted as 30. The periods one hour before and one hour after the reversal are indicated by arrows.

From (1) and (2) it can be seen that for a given value of $\sigma_2/\sigma_1(1 + \psi)$ the value E_{yE}/E_{yF} is directly proportional to the value of V_E/V_F . So the relative variations in the field strength can be estimated from the variations in V_E/V_F . V_E/V_F shows a gradual increase from pre-midnight hours to post-midnight hours. A similar increase with time can be seen during daytime also, though less dramatically. This gradual increase in the ratio can be very clearly seen in the curve for local winter, where the ratio at 0800 hours is about 7 and it increases to a value of 22 at 1700 hours. For other curves also, there is a definite trend for the ratios to increase, but the variations are not as smooth as that for local winter. Since V_E/V_F is directly proportional to E_{yE}/E_{yF} a corresponding feature can be expected in the E and F region electric fields also.

The accuracy of the quantitative estimate of electric fields presented here is subject to the following limitations:

1. The present results are strongly dependent on the value of ψ . Though linear theory predicts a relationship of the form $V_E = V_F/(1 + \psi)$, the actual relationship may differ from this. A decrease in the value of ψ will increase the difference between E and F region fields and vice versa.

2. The approximate relation $J_y = \sigma_2^2/\sigma_1 \cdot E_{yE}$ used here, in fact, results in an overestimate of the electric fields. Calculations show that the daytime electric fields are overestimated by about 19% and nighttime electric fields by about 5%. The difference in the overestimates between daytimes and night-times is because of the difference in the averaging height ranges used.

3. The collision frequencies used in the Richmond's model are in error, as was noted by Gagnepain *et al.* [1977]. As can be seen from a comparison of (3) and (5), any attempt to bring the conductivity profiles closer to what is expected from the electrojet current profile will result in increasing the difference between E and F region electric fields.

The implications of the present results are far reaching. A change in the vertical distribution of electric fields is sure to reflect in its latitudinal variation, which has not yet been understood clearly. Such an understanding is essential in establishing the Sq and electrojet relationships and the actual flow paths of currents from nonequatorial latitudes to equatorial latitudes.

CONCLUSIONS

The important results of the present studies can be summarized as follows:

1. The horizontal electric field in the F region most of the time is stronger than the E region field over the dip equator.
2. The ratio of the E region field to the F region field shows a gradual and considerable increase from forenoon hours to afternoon hours and from pre-midnight hours to post-midnight hours. This feature has a seasonal variation and is most dominant during the winter solstice.
3. The relationship between the horizontal drift velocity of electrons and the east-west electric field in the E region is strongly dependent on the electrojet and conductivity models used. The relationship of Balsley and Woodman [1971] namely

$$E_{yE} = 6.0 \times 10^{-6} V_E$$

which is based on the electrojet model of Sugiura and Cain [1966], seems to be far from realistic, mainly owing to the unrealistic electrojet model used.

A better understanding of the conductivity profiles is essential for establishing the present results. The dependence of the phase velocity of irregularities on the drift velocity of electrons is another factor that can change the present results quantitatively, though not qualitatively.

Acknowledgements. The authors gratefully acknowledge many useful suggestions made by the referees for the improvement of this paper.

REFERENCES

- Balsley, B. B., Electric fields in the equatorial ionosphere: A review of techniques and measurements, *J. Atmos. Terr. Phys.*, **35**, 1035-1044, 1973.
- Balsley, B. B., and R. F. Woodman, On the control of the F region drift velocity of the E-region electric field: Experimental evidence, *J. Atmos. Terr. Phys.*, **31**, 865-867, 1969.
- Balsley, B. B., and R. F. Woodman, Ionospheric drift velocity measurements at Jicamarca, Peru, (July 1967-March 1970), *Rep. AUAG 17*, pp. 1-44, World Data Center, Boulder, Colo., 1971.
- Davis, T. N., K. Burrows, and J. D. Stolarik, A latitude survey of the equatorial electrojet with rocket-borne magnetometers, *J. Geophys. Res.*, **72**, 1845-1861, 1967.
- Fejer, B. G., D. T. Farley, B. B. Balsley, and R. F. Woodman, Vertical structure of the VHF back-scattering region in the equatorial electrojet and the gradient drift instability, *J. Geophys. Res.*, **80**, 1313-1324, 1975a.
- Fejer, B. G., D. T. Farley, B. B. Balsley, and R. F. Woodman, Oblique VHF radar spectral studies of the equatorial electrojet, *J. Geophys. Res.*, **80**, 1307-1312, 1975b.
- Gagnepain, J., M. Crochet, and A. D. Richmond, Theory of longitudinal gradients in the equatorial electrojet, *J. Atmos. Terr. Phys.*, **38**, 279-286, 1976.
- Gagnepain, J., M. Crochet, and A. D. Richmond, Comparison of equatorial electrojet models, *J. Atmos. Terr. Phys.*, **39**, 1119-1124, 1977.
- Martyn, D. F., Interpretation of observed F2 'winds' as ionisation drifts associated with magnetic variations, in *The Physics of the Ionosphere*, pp. 161-165, Physical Society, London, 1955.
- Matsushita, S., Dynamo currents, winds, and electric fields, *Radio Sci.*, **4**, 771-780, 1969.
- Prakash, S., S. P. Gupta, B. H. Subbaraya, and C. L. Jain, Electrostatic plasma instabilities in the equatorial electrojet, *Nature*, **233**, 56-58, 1971.
- Richmond, A. D., Equatorial electrojet, 1, Development of a model including winds and instabilities, *J. Atmos. Terr. Phys.*, **35**, 1083-1103, 1973a.
- Richmond, A. D., Equatorial Electrojet, 2, Use of a model to study the equatorial ionosphere, *J. Atmos. Terr. Phys.*, **35**, 1105-1118, 1973b.
- Rogister, A., and N. D'Angelo, Type 2 irregularities in the equatorial electrojet, *J. Geophys. Res.*, **75**, 3879-3887, 1970.
- Sudan, R. N., J. Akinrimisi, and D. T. Farley, Generation of small scale irregularities in the equatorial electrojet, *J. Geophys. Res.*, **78**, 240-248, 1973.
- Sugiura, M., and J. C. Cain, A model equatorial electrojet, *J. Geophys. Res.*, **71**, 1869-1877, 1966.
- Sugiura, M., and D. J. Poros, An improved model equatorial electrojet with a meridional current system, *J. Geophys. Res.*, **74**, 4025-4034, 1969.
- Tarpley, J. D., Ionospheric wind dynamo, Ph.D. thesis, Univ. of Colorado, Boulder, 1969.
- Untiedt, J., A model of the equatorial electrojet involving meridional currents, *J. Geophys. Res.*, **72**, 5799-5810, 1967.
- Woodman, R. F., Vertical drift velocities and east-west electric fields at the magnetic equator, *J. Geophys. Res.*, **75**, 6249-6259, 1970.

(Received July 13, 1978;
revised April 2, 1979;
accepted April 17, 1979.)