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Effect of IMF on the E- and F-region drifts over Patiala*

Darshan Singh, H S Gurm, H S Somal & L K Patel
Department of Astronomy & Space Sciences, Punjabi University, Patiala 147 002

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Effect of the eastward and northward components of IMF (B_y and B_z) on the daytime E-region and nighttime F-region drifts at Patiala, which is situated near the S_q focus, has been studied. Drift records pertaining to the year 1987-88 have been used. The E-region drift speed decreases with increase in B_y in winter while it increases during summer and equinoxes. It is opposite in the F-region. Significant increase of westward drift with B_z is seen in the E- and F-regions where the correlation coefficients are -0.90 and -0.70 respectively. The southward component of the E-region drift decreases significantly with increase in B_z or B_y. With increase in B_y the drift speed in the E-region decreases while it increases in the F-region. The westward components of both the E- and F-region drifts show an increase with an increase in B_y.

1 Introduction

The interplanetary magnetic field (IMF) is an active component in the study of solar wind-magnetosphere-ionosphere interaction. The most quoted schematic representation[1] of magnetospheric-ionospheric interaction (Fig. 1) was given by Heikkila[2] in 1972. The complex interaction involves electric fields, particle precipitation, field-aligned currents, heat flows, etc. A block diagram[3] representing the dynamical interaction between the magnetosphere and ionosphere through connecting space is given in Fig. 2. The boxes are interconnected and are not time independent. Recent efforts are to build semi-empirical models[4-6] for various aspects of coupling. However, to do so we need to know global distribution of various parameters, more so of the magnetosphere, for a period long enough to eliminate uncertain initial ionospheric conditions, i.e. over a few hours. Such extensive data are not available. Hence, the effort is based upon 'empirical' or statistical magnetospheric inputs and not upon instantaneous patterns[7].

The electrodynamical coupling (Fig. 1) is very strong at high latitudes where empirical models for various components have been simulated from different data sets for the southward and the northward IMF[8,9]. The former provides more consistent results than the latter, where the interpretation of results from sunward plasma convection, particle precipitation and field-aligned currents is rather controversial. Multi-cell and turbulent convection patterns have been proposed to explain these features over the polar caps[7]. The study of correlation between high latitude ionospheric convection and current system with the IMF direction and magnitude has been reviewed by Matushita[10]. In summary, most of the studies pertain to the climatology of the ionosphere-thermosphere system[7].

On the other hand, the ionosphere exhibits a variety of density structures of different scales: small scale (~1 km), medium scale (~10 km), and large scale (~100 km). The small scale structures generally exist in or around the larger scale structures. These are caused by plasma instabilities, turbulence, etc. and are called irregularities.

There is a connection between IMF and drift of irregularities which are stipulated by the neutral wind patterns and variations in the electric fields and conductivities. The motion of the neu-

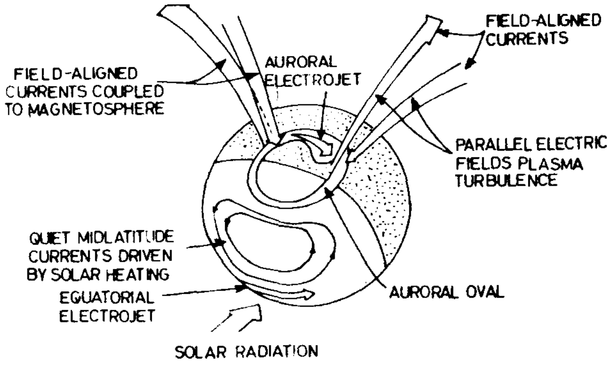

Fig. 1 – Schematic representation of electrodynamic coupling (after Heikkila[2]).

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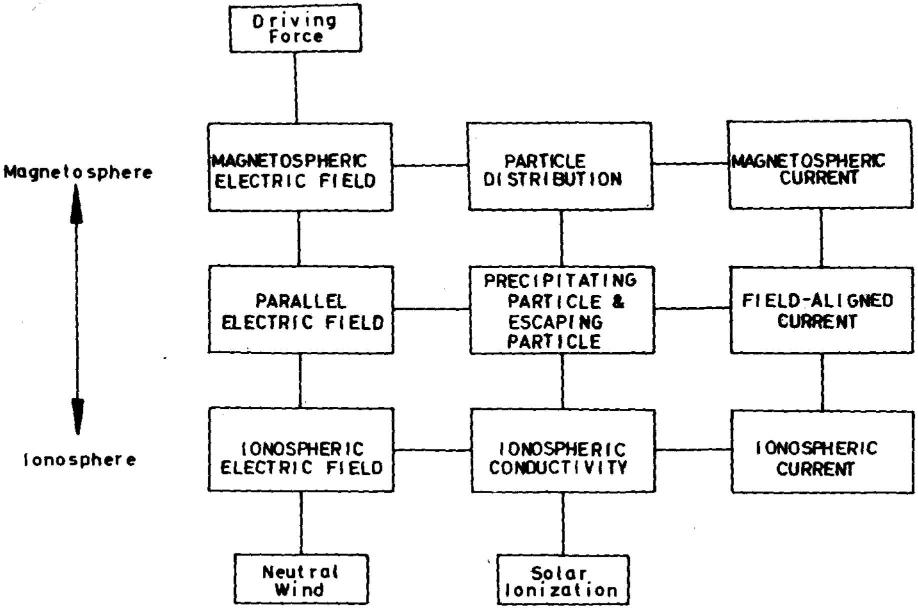

Fig. 2 – Block diagram showing electrodynamic coupling between the magnetosphere and ionosphere (after Kamide[3]).

tral air in the polar upper atmosphere is controlled primarily by ion-to-neutral gas momentum transfer[11]. The multi-cell drift patterns associated with the northward component have been observed[12] to drive a similar but weaker neutral wind system, involving a longer time of a few hours for the momentum exchange. For a large and steady northward IMF, there is a unique neutral wind pattern corresponding to the ion-convection characteristic of the northward IMF[3]. Penetration of electric field variations down to the mid- and low-latitudes is either due to direct penetration or leakage of electric fields into low latitudes or the action of ionospheric dynamo generated by the global thermospheric wind circulation[3]. The enhancement of the auroral conductivities by electron precipitation significantly increases both the characteristic time scales and the degree of penetration of the convection electric fields to the mid- and low-latitudes. Although signatures of such a penetration are seen, but one-to-one correspondence is full of complexities[13]. The latter seems to be related not only to changes in the ionospheric electrodynamics but also to changes in the solar wind and IMF.

In practice, the IMF (**B**) is represented by three components, namely, B_x, B_y and B_z in the sun-earth co-ordinate system, where subscripts x, y and z represent respectively sunward, eastward and northward components of **B**.

Matushita and Balsley[14] reported correlations among southward B_z (i.e., $-B_z$), geomagnetic fields at various latitudes, Esq disappearance at Huancayo and the E-region E-W electron drifts over Jicamarca (dip 0.5°S) during disturbed periods. Rastogi and Chandra[15], Rastogi and Patel[16] and Vyas *et al.*[17] have supported these results at Thumba and Tiruchirapalli. In extending the study to other IMF components over the low latitude stations in the Indian subcontinent, similar observations have also been made by other workers[18-20].

On the contrary, in the equatorial region, according to Fejer *et al.*[21], the average drifts show little dependence on the IMF components (B_z or B_y). However, there is a reversal in drifts associated with rapid reversal in B_z from south to north. There are also a few occasions when IMF may reverse without any effect on the drifts. They further observed that the changes in the equatorial ionospheric parameters are not directly related to IMF but result from variations in the magnetospheric convection and high latitude substorm phenomena. Both the latter causes, in turn, are probably triggered by changes in IMF. Hence, there is an indirect coupling between the equatorial ionosphere and the magnetosphere. The existing studies are mainly confined to the equatorial and low latitude stations. Hence, a need arises to conduct the studies over Patiala (dip 43.8°N), a station close to the S_q focus. The present study corresponds to the year 1987-88 as the IMF data from the World Data Centre (WDC) were available for this period only.

Table 1 – Effect of northward component of the IMF (B_z) on the E- and F-region drift speeds

Region	Cor. between	Season	Regression coeff.		Cor. coeff.	Significance level
			b	a		
E	V_a and B_z	Winter	−2.4	73.3	−0.81	5%
		Summer & equinoxes	2.9	60.0	0.89	1%
		Annual	0.4	67.5	0.44	Not significant
F		Winter	2.8	73.9	0.85	2%
		Summer & equinoxes	−4.0	74.8	−0.95	1%
		Annual	−0.4	66.0	−0.15	Not significant
E	V_w and B_z	Winter	−2.6	−46.8	−0.90	1%
F		Winter	−2.5	−43.9	−0.79	5%
E	V_e and B_z	Summer & equinoxes	1.1	46.9	0.61	Not significant
F		Summer & equinoxes	−0.8	47.1	−0.10	Not significant
E	V_s and B_z	Annual	4.7	−39.5	0.95	1%
F		Annual	0.5	−50.9	0.55	Not significant

V_a, apparent drift speed; V_w, westward drift speed; V_e eastward drift speed; V_s, southward drift speed; b, slope; and a, intercept

2 Method of analysis

In the hourly mean values of the IMF data (NSSD centre of WDC-A for rockets and satellites), northward (eastward) component B_z (B_y) is taken as positive and southward (westward) as negative. Observed values of apparent drift speeds and their E-W and N-S components are grouped together for midday (10-14 hrs LMT) in case of the E-region and for midnight (22-02 hrs LMT) in case of the F-region. Their average value is taken to represent drift for comparison with the mid-values of B_z/B_y for the intervals $+9\gamma$ to $+7\gamma$, $+7\gamma$ to $+5\gamma$, ..., $+1\gamma$ to -1γ, ..., -5γ to -7γ, -7γ to -9γ. Hence, B_z/B_y is represented as 8γ, 6γ, ..., 0γ, ..., -6γ, -8γ. As the drift parameters over Patiala[22] show diurnal variations only, the midday and midnight values are taken for comparison with the IMF components. Since the E- and F-region drifts are mostly westward during winter and eastward during summer and equinoxes, the analysis for grouping the drift speeds has been limited to the study of the westward drifts during winter and of the eastward drifts during summer and equinoxes. As the E- and F-region drifts are mainly southward during different seasons, only annual averaged variations of southward component with IMF have been studied. The average value of the drift parameters and the mid-values of the IMF components form ordered sets for the following study.

3 Results

The results of correlation study between apparent drift speed (V_a) and its components with IMF components, B_z and B_y, are presented in Tables 1 and 2 respectively. The variations of the E- and F-region drift speeds with northward component of the IMF (B_z) are shown in Figs 3 and 4 respectively. The lines drawn through the various points represent the lines of best fit obtained by the least square method.

Although no significant correlation is seen between V_a and B_z in the E- and F-regions over the years, but significant correlation is seen during different seasons. In the E-region, during winter, the drift speed decreases by 2.4 ms^{-1} per γ increase in the northward component, B_z. During summer and equinoxes, the drift speed increases by 2.9 ms^{-1} per γ increase in B_z. In the F-region, during winter, the drift speed increases with B_z while it decreases during summer and equinoxes.

There is a significant increase of 2.6 ms^{-1} per γ of the westward drift speed in the daytime E-region and of 2.5 ms^{-1} per γ in the nighttime F-region with an increase in B_z [Fig. 5(a) and (c)]. The eastward component of the drift does not show any significant variations with B_z in both the regions (Table 1).

The southward component of the E-region drift decreases significantly with increase in B_z towards north [Fig. 5(b)]. Though F-region southward

Table 2 – Effect of eastward component of the IMF (B_y) on the E- and F-region drift speeds

Region	Cor. between	Season	Regression coeff.		Cor. coeff.	Significance level
			b	*a*		
E	V_a and B_y	Annual	−1.3	64.4	−0.67	5%
F		Annual	1.9	76.0	0.71	5%
E	V_w and B_y	Winter	−2.4	−54.0	−0.88	1%
F		Winter	−2.7	52.6	−0.90	1%
E	V_e and B_y	Summer & equinoxes	−1.1	57.3	−0.59	10%
F		Summer & equinoxes	−0.65	44.0	0.43	Not significant
E	V_s and B_y	Annual	−1.1	−38.0	0.43	Not significant
F		Annual	−1.9	−58.7	−0.81	5%

Note: V_a, V_w, V_e, V_s, *b* and *a* are defined in Table 1.

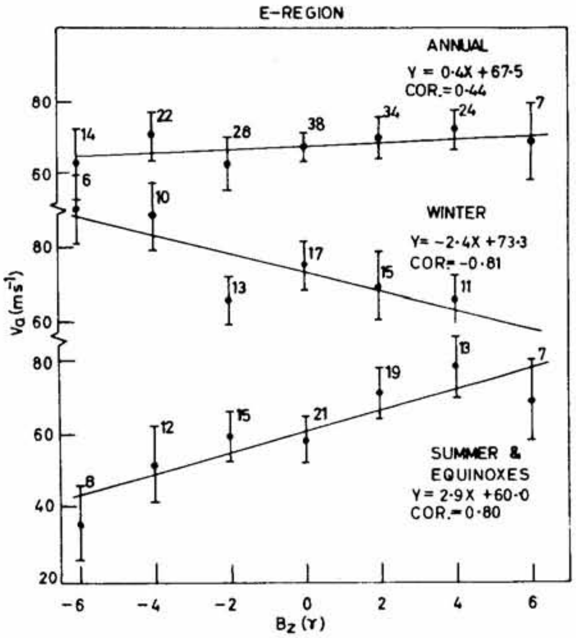

Fig. 3 – Seasonal and annual mean variations of midday E-region drift velocity with B_z.

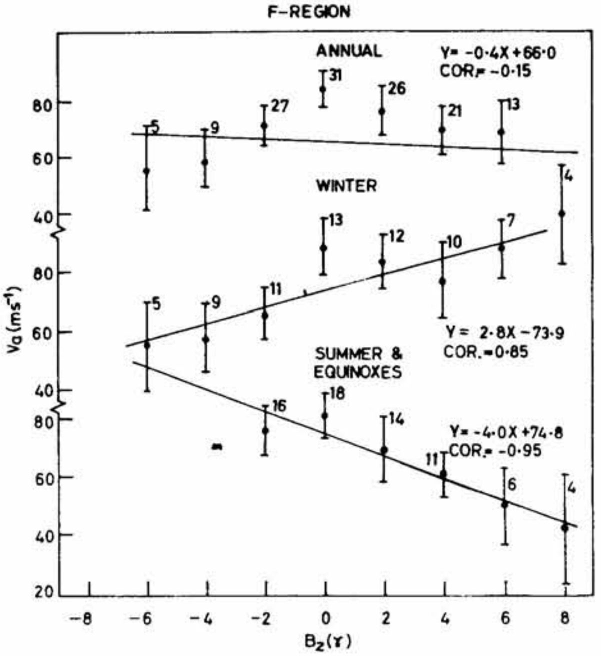

Fig. 4 – Seasonal and annual mean variations of midnight F-region drift velocity with B_z.

component of drift shows similar trend but the correlation coefficient is not statistically significant.

The eastward component of IMF (B_y) shows significant correlation with the E- and F-region drifts over Patiala [Fig. 6(a), (b) and (c)]. The daytime E-region drift speed decreases with increase in B_y towards east but the opposite is true for the nighttime F-region [Fig. 6(a)].

The westward components of the E- and F-region drift speeds show similar variations and show significant increase with increase in B_y. The eastward component of the E-region drift decreases with increasing B_y [Fig. 6(b)]. No significant variation of nighttime F-region eastward drift with B_y is seen (Table 2). The daytime E-region southward drift speed does not show significant variations but the nighttime F-region drift speed increases with increasing B_y towards east [Fig. 6(c)].

4 Discussion

On the whole, the results over Patiala (Table 1) are in accord with some of the earlier observations[17-20]. In the E- and F-regions, the westward component of drift increases significantly with an increase in B_z. This may be attributed to the introduction of westward electric field into the mag-

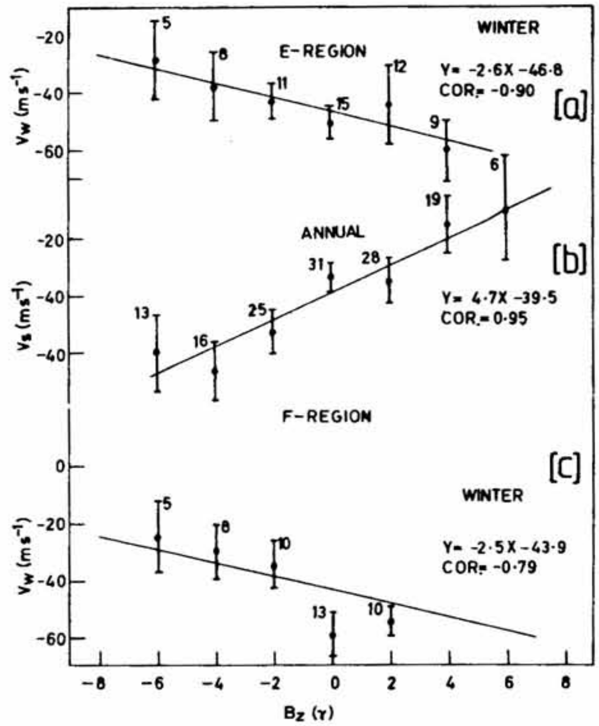

Fig. 5 – Annual variations of (a) mean midday E-region westward component of drift with B_z, (b) mean midday E-region southward component of drift with B_z, and (c) mean midnight F-region westward component of drift with B_z.

netosphere in conjunction with northward turning of IMF[23]. The field is mapped on to high latitude ionosphere. This field penetrates down to low- and mid-latitudes and tends to increase the westward-oriented electric field existing over these regions[24]. This increases the westward component of the drift speed.

Mid-latitude thermospheric wind measurements during southward turning of IMF show an enhancement over the other days and the equatorward (southward) wind increases significantly[25]. Thus the southward component of the drift of irregularities must increase during the period of southward IMF and the Patiala observations conform to it.

Like other low latitude stations[18-20], there is a significant increase in the westward drift speed with an increase in B_y during daytime over Patiala. Galperin *et al.*[26] also demonstrated the effect of B_y on the plasma drift using the data of direct measurements of plasma convection velocity and total ion density made from the Cosmos 184 satellite. A decrease in the mean equatorial ion density accompanied by enhancement of upward and eastward components of the plasma drift during late evening hours were observed after reversals of B_y, from negative to positive. The observations further support interaction between the polar and equatorial regions, where variations in the electric field in the polar ionosphere or outer magnetosphere are propagated down to the equatorial latitudes. These variations are induced mainly by reversals of B_y.

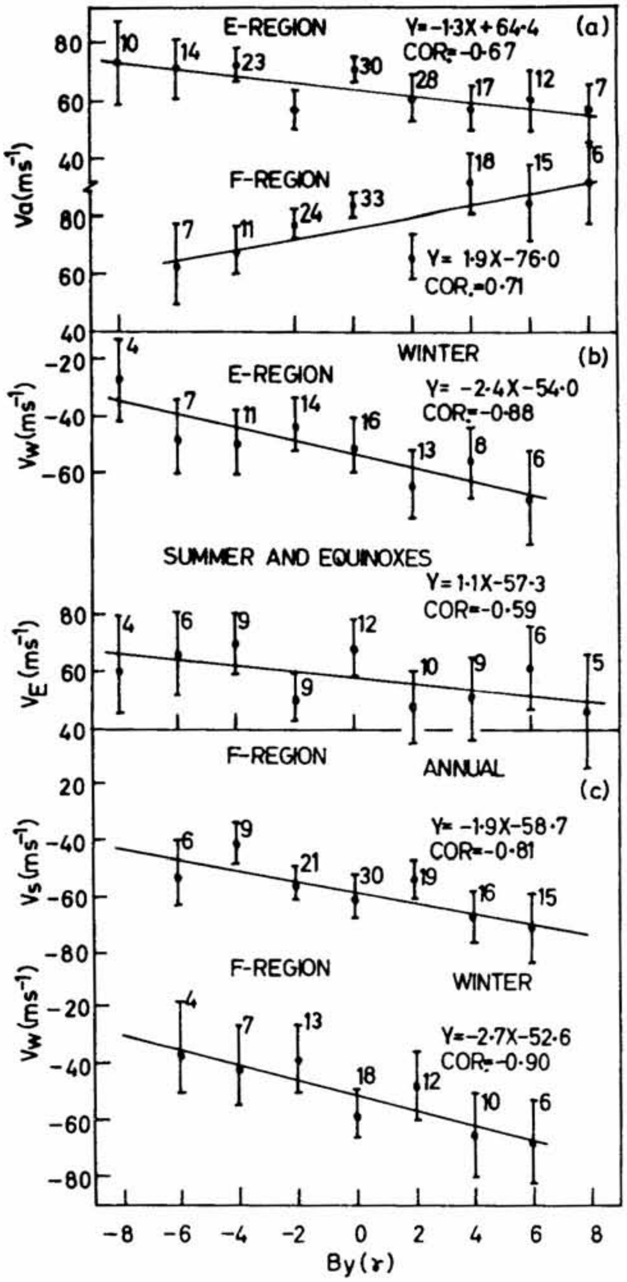

Fig. 6 – Annual variations of (a) mean midday E-region and midnight F-region drift speeds with B_y, (b) mean midday E-region westward and eastward components of drift speed with B_y, and (c) mean F-region westward and southward components of drift speed with B_y.

At Patiala, we observe significant seasonal changes in the behaviour of drifts with the IMF orientations. This may be attributed to the seasonal changes in the position of the S_q current focus with the IMF orientations[10]. Extending over a few years, further studies may lead to some conclusions regarding the seasonal behaviour of the drifts. Such studies may be further supported by other simultaneous observations, viz. the electric fields, the vertical drifts, etc. spread over different latitudes.

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