Coupling effect of the equatorial F region irregularities on the low latitude E region instability processes

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[1] Simultaneous observations of E and F region irregularities made using the Gadanki MST radar are presented. The observations show that the E region echoes weaken or disappear during the growth phase of the topside F region irregularities. Unlike Jicamarca observations, no valley region echoes are observed during this phase. It is shown that the weakening or disappearance of E region signals are not directly coupled with the F region irregularities just overhead, but linked with the instability processes over the magnetic equator through the magnetic field lines. It is proposed that the fringe fields present in the valley region in association with the equatorial F region plasma bubbles, in the presence of appropriate background electric field conditions, are responsible candidates. It is shown that these fringe fields and the electric fields associated with the irregularities in the valley region can map to the low latitude E region and thereby inhibit the growth of the E region instability processes as revealed by the Gadanki radar observations. *INDEX TERMS:* 2415 Ionosphere: Equatorial ionosphere; 2437 Ionosphere: Ionospheric dynamics; 2439 Ionosphere: Ionospheric irregularities; 2471 Ionosphere: Plasma waves and instabilities; 5729 Planetology: Fluid Planets: Ionospheres (2459). **Citation:** Patra, A. K., S. Sripathi, and D. Tiwari (2004), Coupling effect of the equatorial F region irregularities on the low latitude E region instability processes, *Geophys. Res. Lett.*, *31*, L17803, doi:10.1029/2004GL020486.

1. Introduction

[2] Plasma irregularities observed in the Earth's ionosphere are often evaluated in terms of local parameters. Coupling between the ionospheric E and F regions, however, is known to have significant role on the redistribution of plasma and excitation of irregularities. For example, the coupling of the polarization electric field associated with unstable E region may play significant role on the generation of F region electron density irregularities both at the equatorial and middle latitudes [e.g., *Prakash*, 1999; *Kelley et al.*, 2003; *Haldoupis et al.*, 2003]. Once the F region irregularities are generated, they can have important implication on the redistribution of plasma and the irregularities in the E region. The valley region irregularities observed by the Jicamarca radar in association with the F region irregularities (commonly referred to as equatorial spread F, ESF) [e.g., *Kelley et al.*, 1981; *Woodman and Chau*, 2001] and that observed over Natal and Kwajalein (located at ~5° magnetic latitude) in the rocket experiments [*Vickrey et al.*, 1984] have been explained as due to the effect of the F region instability processes. While the Jicamarca observations are explained in terms of fringe field effects [*Zalesak and Ossakow*, 1980; *Sekar et al.*, 1997; *Kherani et al.*, 2002], the Kwajalein observations have been related to the effects of F region electric field structures through mapping [*Vickrey et al.*, 1984; *LaBelle*, 1985].

[3] While the effects of the E region processes on the generation of F region irregularities and the F region processes on the generation of the valley region irregularities have been studied, the effects of the F region irregularities on the E region are yet to be known. Since very large electric fields are generated through the F region instabilities, their mapping to the underlying E region and thereby affecting the plasma remotely could be of significant value for an overall understanding of the E region irregularities.

[4] In this paper, we present observations of E and F region field-aligned irregularities made using the Gadanki MST radar (13.5°N, 79.2°E; dip latitude 6.3°), which shows that growth of the E region irregularities are controlled in a significant way by the F region instability processes through electrostatic coupling. We present a mechanism capable of explaining the observations presented here.

2. Observations

[5] The observations on the E and F region irregularities presented here were made using the MST radar located at Gadanki [*Rao et al.*, 1995]. Studies on the F region irregularities using this radar have been reported earlier (for details, see *Patra et al.* [1997] and *Rao et al.* [1997]). The observation that is of concern here is the variability of signal strength of the E region echoes in relation to ESF.

[6] Figure 1 shows an example of intensity map representing SNR of the echoes from both E and F regions observed on 17–18 April 1998. It may be noted from Figure 1 that in the early part of the spread F, the E region echoes are weaker or missing completely. Before the event took place and at the later part of the event, however, the E region signals are very strong. In order to show that this feature is repetitive (although there exists day-to-day variability), we present the percentage occurrence of both E and F region echoes in Figure 2. To obtain the percentage occurrence, we have used 18 events of spread F observations that were made in 1998–1999. It is very clear that the occurrence probability of signal is much less during the early part of ESF development as compared to that before the onset and at the later part of the ESF manifestations. It may be mentioned that weakening of the E region echoes during same local time have not been observed on non-ESF

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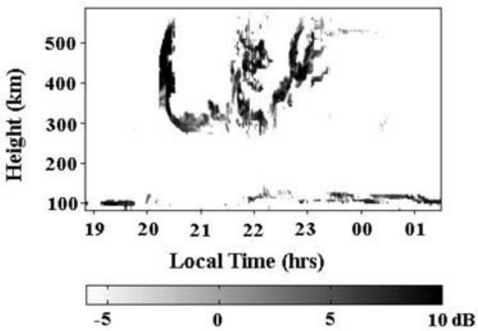

Figure 1. Height time intensity (SNR) map of backscattered signals from E and F regions observed on 17–18 April 1998. See color version of this figure in the HTML.

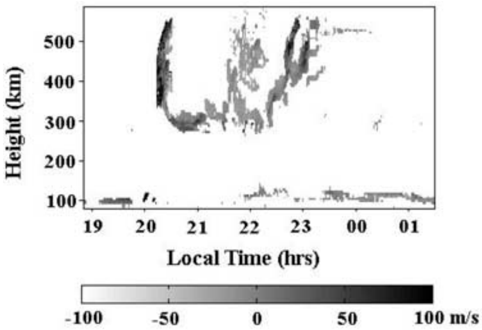

Figure 3. Height time velocity map corresponding to the event shown in Figure 1. See color version of this figure in the HTML.

events (not shown here) suggesting the role of ESF irregularities on the E region echo strength. The weakening or disappearance of the E region signals in relation to the topside spread F irregularities have been noticed earlier from Kwajalein [*Hysell et al.*, 1994] as well as from Gadanki [*Rao et al.*, 1997], but no further study has been made on this aspect.

[7] A careful investigation on this aspect suggests that the weakening/disappearance is not associated with the topside ESF irregularities alone, but it is closely associated with the development phase of ESF irregularities. In a broader sense, this can be related to the upward drift of the irregularities. To illustrate this aspect we present the Doppler velocities of the F region irregularities corresponding to Figure 1 in Figure 3. It is clear from this figure that the E region SNR has close relationship with the F region irregularity velocities. It may also be noted that there exists remarkable local time dependence of the Doppler velocities and also the E region echo strength. In the early phase of the event, the correlation is clearer than that at the later phase. Based on the 18 events, we have made a statistical analysis on the relationship of the F region velocities on the E region signal strength. We present the percentage occurrence of upward and downward velocities of the F region irregularities in Figures 4a and 4b, respectively. The occurrence of updraft at around 300 km in the initial phase of the ESF development and downdraft during the later part is very clear and these two aspects are well correlated with the strength of E region echoes. We have also found that E region signal strength decreases with increasing F region upward velocity (not presented here), while they are observed to be stronger in association with F region downward velocities.

3. Discussion

[8] The observations presented here as well as that observed earlier from Kwajalein and Gadanki [*Hysell et al.*, 1994; *Rao et al.*, 1997] clearly suggest that the E region signal strength is affected during the topside spread F conditions. Further, the observations presented here clearly suggest that the weakening/disappearance of E region echoes are associated with the upward velocities of spread F irregularities and exclusively so in the initial phase of the ESF development. The disruption of the sporadic E (E_s) layer in relation to the evening pre-reversal enhancement in the zonal electric field (PRE) has been studied by *Abdu et al.* [2003] using the ionosonde obser-

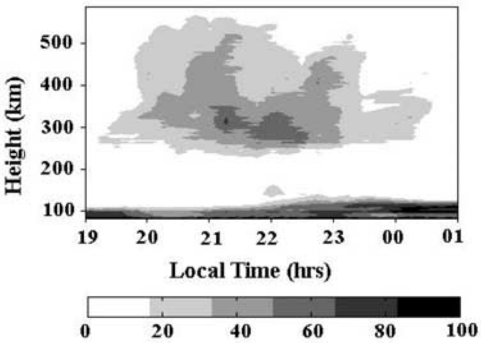

Figure 2. Percentage occurrence of E and F region echoes. See color version of this figure in the HTML.

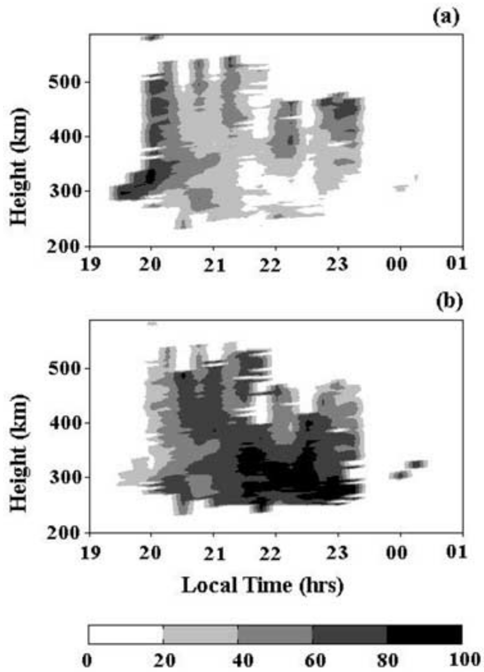

Figure 4. Percentage occurrence of (a) upward velocity and (b) downward velocity as a function of height and time. See color version of this figure in the HTML.

vations made from Fortaleza (dip latitude ~4°S). They have shown that the larger PRE amplitudes are associated with disruption of E_s layer, whereas for smaller PRE amplitudes such disruption does not occur. It may be mentioned that this PRE that causes the evening uplift of the F layer is a pre-requisite condition for the ESF generation.

[9] In the observations presented here, it is also important to note that during the time of growth phase, when the E region echoes weaken/disappear, there is no occurrence of valley region echoes over Gadanki. During this phase, however, on several occasions, Jicamarca radar observed the valley region echoes [*Kelley et al.*, 1981; *Woodman and Chau*, 2001]. It may be mentioned that Gadanki radar is capable of detecting the valley region echoes and in fact it detected the valley region echoes but at the later part of the ESF events [*Patra et al.*, 1997]. Accordingly, as far as the occurrence of the valley region echoes, especially during the growth phase of the ESF, are concerned, the Gadanki observations are in contrast to that observed at the equator with the Jicamarca radar. The observations hence seem to suggest that the F region irregularities in its growth phase over Gadanki do not have influence in the generation of irregularities in the valley region just below in the same way as it does at the magnetic equator. Hence any effect on the E region process over Gadanki needs to be viewed as not due to the vertical coupling of the F region irregularities occurring just above. Accordingly, the source, if any, has to be non-local in nature and is likely to function through the highly conducting magnetic field lines. It may be mentioned that the field lines of the E region over Gadanki connect 180 km over the equator. And it is also known that at this height region there is no strong instability process that can have important effects on the E region along the magnetic fields. But the observations of the F region irregularities at and around 300 km show clear relationship with the E region echo strength.

[10] The height of 300 km over Gadanki is connected to 400 km over the equator through the magnetic field lines. It may be mentioned that during the development of the Rayleigh-Taylor (RT) instability, responsible for the plasma bubbles, the entire flux tube gets depleted and rises to the topside resulting in generation of irregularities of various scale sizes. If the observed upward velocities at Gadanki are taken as indicator of the growth of the ESF at the equator, which is a reasonable assumption, it is more logical to link the effects on the E region echoes by the equatorial F region irregularity processes. Still we will be left with the problem raised earlier that the F region field lines do not connect directly with that of the E region over Gadanki. The footprint of the equatorial F region field lines at the E region would be at around 10° dip latitude. Hence question arises how does the E region over Gadanki is affected by the F region irregularities? We suggest that the answer lies in the pre-reversal enhancement of electric field and associated RT instability process, which develop large depleted region in plasma density, polarization electric field within the depleted region and fringe fields down below in the valley region. We show in the following that these fringe fields are responsible for the weakening of the E region signals over Gadanki.

[11] *Zalesak and Ossakow* [1980] showed that the vertically oriented plasma structures behave like capacitor plates and the fringe fields associated with it can penetrate to the lower altitudes. Later *Sekar et al.* [1997] showed that these fringe fields can generate irregularities down below. In a more recent study *Kherani et al.* [2002] have shown that these fringe fields are the ones that are responsible for the valley region irregularities in association with ESF observed by the Jicamarca radar. The depth of penetration of the fringe fields from F region altitudes depends on the strength of the polarization field and the wavelength of the initial perturbation. They have clearly shown that the penetration depth of the fringe fields increases with increase in the perturbation wavelength. Using realistic value of perturbation wavelength they have shown in their simulation study that the effect is significant at altitudes as low as 180 km and their results are consistent with the Jicamarca observations. These fringe fields and the perturbation electric fields associated with the irregularities in the valley region at the equator could then map along the magnetic field lines to the E region over Gadanki and affect the irregularity processes.

[12] It may be mentioned that during the growth phase of the ESF development, the electric field is basically eastward. In the depleted regions, the electric fields are several times larger than the background field depending upon the degree of depletion. Hence very large eastward electric field is expected to be associated with the depleted region. In fact it is this electric field that is responsible for large updraft of the plasma within the depleted region and also responsible for the updraft of the F region irregularities often observed as large Doppler velocity in radar experiments. These electric fields remain eastward for quite sometime even though the background electric field becomes westward because these eastward electric fields are related to F region instabilities and are several times larger than the background fields. While the presence of large eastward electric field in the valley region through the penetration of fringe fields is quite plausible, we need to examine the efficiency of their mapping to the E region and then their effect on the E region instability processes.

[13] We turn now to the aspect of electric field mapping. The first quantitative study on the mapping of electrostatic field was carried out by *Farley* [1959]. He examined the mapping efficiency of the E region source to the F region. Later, *Vickrey et al.* [1984] and *LaBelle* [1985] showed that the polarization electric field associated with equatorial F region irregularities can map for long distances along the magnetic field and thereby influence the low altitude plasma. The mapping efficiency of an electric field structure is given by the local reduced height $dz = (\sigma_o/\sigma_p)^{1/2}\ dz'$ [*Farley*, 1959], where σ_p is the Pedersen conductivity, σ_o is the parallel conductivity, dz is the distance along the magnetic field and dz' is the zonal dimension of the electric field structure. *LaBelle* [1985] showed that 10 km structure maps very efficiently from the F region to the underlying E region, while 1 km structure is significantly attenuated at 120 km. Since the mapping efficiency depends on the path length along the magnetic field, the efficiency will be better if the source height is low. The problem that is relevant here is the mapping of the electric fields from about 200 km to underlying E region. The values of $(\sigma_o/\sigma_p)^{1/2}$ are about 700 and 100 at 200 km and 100 km respectively [*Farley*, 1959]. Hence mapping efficiency of electric field structures of scale sizes 1–6 km is expected to be very significant. Such

scale sizes often exist in association with the ESF. It may be interesting to study the effects of the F region scale sizes on the E region instability process, a subject beyond the scope of the present study.

[14] Once the valley region electric fields map to the E region, they can have significant role on deciding the growth rate of the plasma instabilities. As far as the low latitude E region instabilities are concerned it is mainly the gradient drift instability. During nighttime, when the background electric field is westward and downward, it is the negative gradients of the electron density that become unstable. The eastward electric fields associated with the growth phase of the F region instabilities when superposed on the background westward electric field in the E region, will reduce the westward electric field or even reverse the direction, which would inhibit the growth of the gradient drift instability process. *Abdu et al.* [2003] studied the effects of the larger vertical and zonal electric field enhancements associated with the sunset electrodynamical processes on the disruption of the E_s layers. If the E_s activities are reduced at that time, as shown by *Abdu et al.* [2003], the growth of the E region irregularities would be further reduced.

[15] In the context of the present observations, it is important to mention the observations reported by *Chau et al.* [2002] based on simultaneous observations made using the Jicamarca radar and Piura VHF radar (located at $\sim 7°$ dip latitude). They reported that the likelihood of observing topside ESF irregularities is less (more) over Jicamarca when the E region irregularities are present (absent) over Piura. These observations are broadly consistent with that reported here and we believe that the mechanism proposed here is responsible as well for the E region observations from Piura reported by *Chau et al.* [2002].

4. Concluding Remarks

[16] We have shown that the E region echo strength over Gadanki during the equatorial spread F is closely related to the growth phase of the topside spread F at the equator. We monitored the growth phase of the topside irregularities through the observations of spread F irregularities over Gadanki assuming that same might be happening along the same flux tube and hence at the equator. An ideal way to study this aspect would, however, require powerful radar from the magnetic equator capable of detecting the valley region echoes in association with the topside spread F. We have proposed that, in the presence of appropriate background electric field conditions, the fringe fields associated with the plasma bubble when penetrate to altitude of about 200 km at the equator could generate irregularities. The associated valley region electric fields then could map along the field line to the E region over Gadanki and control the growth of the irregularities, which is capable of explaining the weakening/disappearance of the E region echoes during the growth phase of the F region irregularities.

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