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Mechanisms for *E–F* coupling and their manifestation

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ABSTRACT

E–F coupling refers to the mapping of a polarization electric field away from its source in one region of the ionosphere (e.g., *E* region), and causing an effect in a remote region (e.g., *F* region). The source may be neutral dynamic in origin, or it may be electrodynamic, in which case feedback between remote regions may be important. This work outlines the main physical mechanisms and constraints thought to be involved in midlatitude *E–F* coupling, and discusses some of the challenges to inventing an illuminating observational campaign. Mechanisms for polarizing sporadic *E* layers, effectiveness of *F* region polarization, scale sizes for neutral dynamics in the *E* and *F* regions, mechanisms for modulating the *F* layer altitude, and typical conductance ratios for the *E–F* coupled electric circuit will all be discussed. Data from a recent rocket/radar study will be used to illustrate the results.

1. Introduction

It is expected that for scale lengths longer than a few kilometers, and for time scales longer than a few tens of seconds, electric fields will map essentially unattenuated along geomagnetic field lines ($\vec{B}_0$) (Bostrom, 1974). The scale length dependent mapping of electrostatic fields is often described in terms of the Farley mapping criteria, which holds that the scale length along $\vec{B}_0$ is equal to the scale length across $\vec{B}_0$ times the Farley mapping factor $\sqrt{\sigma_0/\sigma_P}$, which exceeds 10 above 90 km, exceeds 100 above 130 km, and reaches 1000 at 300 km (Kelley, 2009). Numerical solutions have shown that the mapping of electrostatic fields along $\vec{B}_0$ is highly efficient when the scale length exceeds a few kilometers (Farley, 1959, 1960; Spreiter and Briggs, 1961; Hysell and Burcham, 2000). Considering time dependence, electric fields are transmitted along $\vec{B}_0$ by Alfven waves (Maltsev et al., 1977; Mallinckrodt and Carlson, 1978), which have phase velocity generally exceeding about 5×10^5 m/s (Lysak, 1997, 1999) (except in the lower *E* region, where it can drop to nearly 10^4 m/s, Cosgrove and Doe, 2010). From field line resonance calculations (Waters and Sciffer, 2008), the travel time between hemispheres at 48° magnetic latitude is 50 s (based on a 20 mHz fundamental resonant frequency). Restricting consideration to processes evolving on a scale of 10 min or more, we can assume that the mapping of electric fields along $\vec{B}_0$ is perfect and instantaneous. This means that polarization processes are nonlocal along $\vec{B}_0$, which is to say that the *E* and *F* regions of both hemispheres are tightly coupled. This situation is especially interesting at night, when the sheet-like geometry of a sporadic *E* (E_s) layer is easily modulated by a neutral disturbance, and facilitates interesting electrodynamical processes. For example, the driver of a dynamical process observed in the *F* region may actually reside in an E_s layer, in the conjugate hemisphere. Determining the location and nature of the driver is a difficult challenge for any nighttime observational campaign. In this work we describe the basic processes thought to contribute to polarization fields in the nighttime midlatitude ionosphere, and consider how the location and nature of the driving process can be constrained.

2. Background

The nighttime midlatitude ionosphere is known to support electric fields on the order of 10 mV/m through an internal process, that is, a process not related to the solar wind or magnetosphere. Perhaps the original evidence for this effect was given by Behnke (1979) who, using the Arecibo incoherent scatter radar, observed a sharp variation of the *F* layer altitude associated with a 400 m/s Doppler velocity, suggesting an electric field greater than 17 mV/m. Coherent echoes from the *F* region with a 250 m/s Doppler velocity were later observed by Fukao et al. (1991) using the MU radar in Japan. *E* region observations include the QP echo phenomenon, which involves distinctive coherent scatter radar echoes with mean Doppler velocity suggesting 3–5 mV/m electric fields, and wide (type II) Doppler spread suggesting larger electric fields on smaller scales (e.g., Yamamoto et al., 1991, 1992). Schlegel and Haldoupis (1994) documented *E* region coherent radar backscatter with a narrow (type I) Doppler spectrum, suggesting a 15 mV/m electric field. The SEEK and SEEK-2 rocket campaigns were coordinated with QP echoes, and made

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in situ electric field measurements up to 20 mV/m and 9 mV/m, respectively (Pfaff et al., 1998, 2005).

The *F* region observations are distinguished from the *E* region observations in that the former involve horizontal spatial scales on the order of 100 km, whereas the latter typically involve 10 km scales. While this suggests that they may not be related, both phenomena share a common orientation: they both arise as banded or wavelike structures with phase fronts preferentially aligned from northwest to southeast in the northern hemisphere (Behnke, 1979; Yamamoto et al., 1997; Tsunoda et al., 2000; Hysell et al., 2004; Larsen et al., 2007). This orientation also matches the orientation for medium scale traveling ionospheric disturbances (MSTIDs), which are 100 km-scale banded structures observed in *F* region airglow emissions (e.g., Garcia et al., 2000), and in GPS TEC measurements (Tsugawa et al., 2007). Ionosonde observations of E_s layers have also found 10 km-scale banded structures in the southern hemisphere, with an orientation that is magnetically conjugate to the northern hemisphere orientation just described. Given that it is very difficult to observe E_s layers on a 100 km horizontal scale, the shared orientation has led to speculation that some of the *F* and *E* region phenomena may be related, and may be the result of an E_s–*F* coupled phenomenon.

Bowman (1960) was perhaps the first to suggest that an E_s–*F* coupled effect might be important. Much later, Tsunoda and Cosgrove (2001) suggested that there could be positive feedback between E_s and *F* region polarization processes. Haldoupis et al. (2003) described an effect of polarized E_s structures on the *F* region. Cosgrove and Tsunoda (2002a) discovered that E_s layers are electrodynamically unstable, through a mechanism related to the Perkins instability (Perkins, 1973; Tsunoda et al., 2004). The Perkins instability is a relatively slow-growing, 100 km scale instability of the *F* layer altitude. Later works described a coupled effect involving the E_s layer instability coupled to the Perkins instability (Cosgrove and Tsunoda, 2004; Cosgrove et al., 2004; Tsunoda, 2006; Cosgrove, 2007a; Yokoyama et al., 2009).

Another form of E_s–*F* coupling arises when neutral wind perturbations forcibly modulate an E_s layer, producing polarization fields that map to the *F* region, and beyond. This mechanism should also cause perturbations remote from the source, although without feedback. Examples of neutral perturbations include

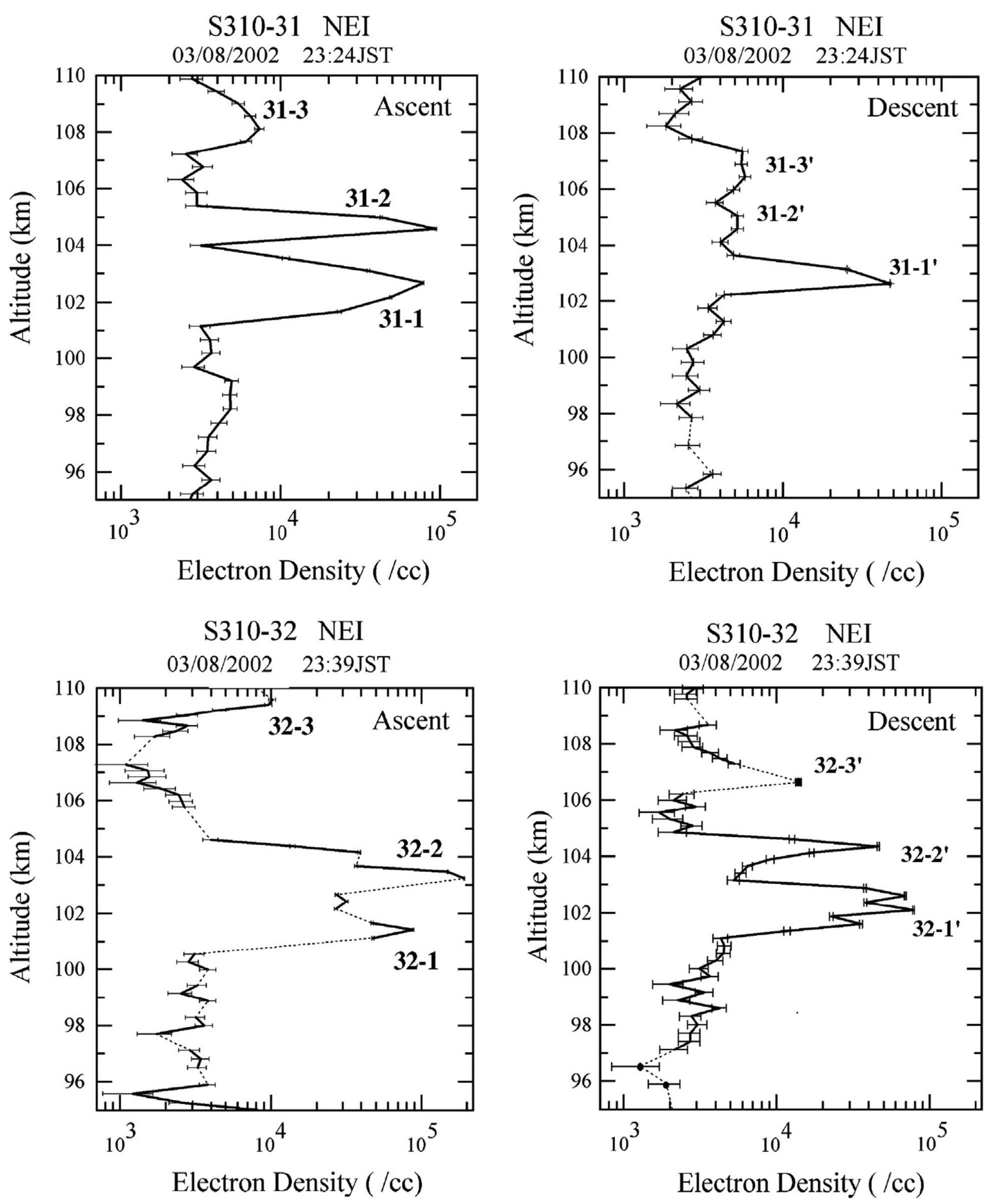

Fig. 1. Examples of E_s layer density measurements from Wakabayashi and Ono (2005).