Numerical studies of sporadic E layer dynamics at geomagnetic mid-latitudes

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Abstract

This dissertation investigates sporadic E layer (EsL) dynamics at geomagnetic mid-latitudes and attempts to advance our understanding of them using a newly developed ionospheric numerical model.

Chapter 1 provides a general introduction to EsL dynamics and morphology at geomagnetic mid-latitudes. The objectives of this dissertation are also stated in this chapter.

Chapter 2 presents numerical model descriptions and variable definitions in this dissertation. This chapter details a numerical algorithm, physical and chemical processes of ions, and input data obtained from a variety of empirical models.

Chapter 3 examines mechanisms of day-to-day EsL variations at geographic mid-latitudes, in Japan. For the first time, my numerical model succeeds in reproducing observed day-to-day EsL variations at geographic mid-latitudes. These day-to-day EsL variations are driven mainly by those semi-diurnal tides. In addition, the results assert that vertical winds affect day-to-day EsL variations especially lower than 100 km altitude at geographic mid-latitudes, where diurnal tides are weak.

Chapter 4 investigates mechanisms of day-to-day EsL variations at geographic low-latitudes, Arecibo. It is known that diurnal tides prevail more dominantly in the low-latitude ionosphere than in the mid-latitude ionosphere. Thus, EsLs formed by semi-diurnal and diurnal tides coexists in the low-latitude ionosphere. In this chapter, I succeeded in reproducing observed day-to-day EsL variations at geographic low latitudes, driven by both diurnal and semi-diurnal tides, for the first time. At geographic low latitudes, semi-diurnal tides contribute day-to-day EsL variations more significantly than diurnal tides as with the case at geographic mid-latitudes.

Chapters 3 and 4 focus on wind-driven day-to-day EsL variations at Japan and Arecibo, which are located at geomagnetic mid-latitudes, and indicate that the day-to-day EsL variations can be explained primarily by winds. Chapter 5 further examines day-to-day EsL variations including electric field (E-field) and wind effects at the geomagnetic mid-latitudes. EsL simulations in chapter 5 exhibit that E-fields are not negligible for the day-to-day EsL variations, although wind effects are dominant for the variations. E-fields change vertical ion motions and distributions and affect geomagnetic mid-latitude EsL dynamics.

Chapter 6 provides fundamental 3D EsL dynamics driven by winds. The temporal evolution of EsLs can be classified into 4 phases depending on the ratio of ion-neutral collision frequency (ν_{in}) to ion gyro-frequency (Ω_i). The most remarkable finding of their temporal evolution is that EsLs can deviate from the zonal wind shear nodes and be modified by the horizontal winds below ~110 km. Effects of wind shears and horizontal wind transport on EsL dynamics differ in altitudes. The “sporadicity" of EsLs observed by 1D observations such as ionosondes can be ascribed to the 3D spatial EsL variations. The present result exhibits that 3D EsL dynamics are not fully explained by the wind shear theory.

Further EsL simulations are conducted in chapter 7 to investigate relationships between horizontal EsL movements and horizontal winds of tides. I found that, above ~110 km, the vertical

Lorentz force is effective to control EsL dynamics, and EsLs appear in the strong vertical ion convergence (VIC) regions. Thus, horizontal Es movements result from spatiotemporal variations of VIC regions. Below ~110 km, EsLs are transported horizontally by the horizontal winds because Ω_i becomes much smaller than ν_{in} below ~110 km. Hence, vertical ion motions driven by the Lorentz force are inhibited by the frequent ion-neutral collisions, and horizontal wind transport of EsLs becomes not negligible to vertical compression/transport.

In chapter 8, my model investigates long-period Es variations, and intra-seasonal EsL intensity enhancement in the wintertime. In general, vertical ion convergence is weak in winter, and intense EsLs are seldom formed. However, temporary intensity enhancement of EsLs sometimes occurs even in the wintertime for several tens days. In this chapter, wintertime EsL (WiEsL) simulations for 2009--2011 are conducted to elucidate mechanisms of temporary WiEsL intensification. It is revealed that VIC at the altitudes of 100–120 km amplifies between 4 and 8 LT and especially after 15 LT. The VIC intensification is attributed to the amplified semi-diurnal and diurnal tides, and causes the temporary WiEsL intensity enhancement. The VIC intensification, that is, vertical wind shear intensification may be driven by lower atmospheric variations such as sudden stratospheric warmings.

Chapter 9 summarizes the results obtained in this dissertation. The summarized results advance our knowledge in ionospheric physics and lay the foundation of 3D ionospheric models for EsLs in the future. The future perspective of numerical EsL studies is also presented in this chapter.