The Physical Mechanisms for the Sunrise Enhancement of Equatorial Ionospheric Upward Vertical Drifts in June

2020 CEDAR Virtual Meeting

NCAR HAO

Junjie Chen[1,2], Wenbin Wang[2], Jiuhou Lei[1], and Tong Dang[1]

[1]CAS Key Laboratory of Geospace Environment, School of Earth and Space Sciences, University of Science and Technology of China, Hefei, China

[2]High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado, USA

Abstract

Satellite and incoherent scatter radar observations have shown frequently a strong enhancement of upward vertical E×B drifts in the equatorial ionospheric F-region near sunrise. Previous studies suggested that this enhancement is associated with the local equatorial wind dynamo, the same process used to explain the pre-reversal enhancement after sunset. However, this hypothesis has never been tested in a first-principles way. In this study, we explore the physical mechanisms responsible for the sunrise enhancement of equatorial upward vertical drifts using the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM). The model well reproduces the sunrise enhancement of upward vertical drifts observed at Jicamarca on 10 June 2004. The simulation results show that large eastward zonal electric fields occur around sunrise at all latitudes, but with a peak at middle latitudes. Further numerical experiments reveal that the equatorial sunrise enhancement is primarily driven by the E-region zonal wind dynamo at middle latitudes rather than by the local dynamo effect in the equatorial region. Specifically, the corresponding eastward electric field at sunrise is generated at middle latitudes by westward winds with longitudinal gradients.

Comparison between ISR and TIEGCM Results

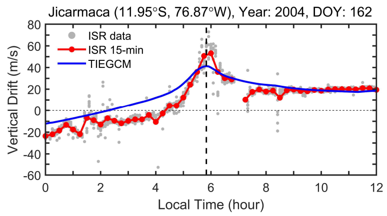


Figure 1. Temporal variations of F-region vertical **E×B** drifts at Jicamarca (GLAT = 11.95°S, GLON = 76.87°W, MLAT = 1.66°S) on 10 June 2004.

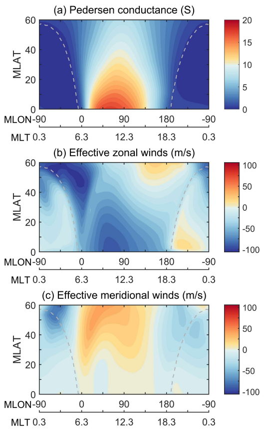
From Figure 1,

- **The observations show a prominent sunrise enhancement of the upward vertical E×B drifts.**
- **In general, the local time variations of TIEGCM simulated vertical drifts at the magnetic equator (Jicamarca) are consistent with those from the ISR observations.**

Methodology

The model used in this study is TIEGCM 2.1. The model resolution is 1.25°×1.25°×1/4 in longitude, latitude and pressure level. The high-latitude convection pattern is specified by the Heelis model.

A series of controlled simulations are conducted in this study to isolate the effects of zonal wind dynamo, meridional wind dynamo, and convection pattern on the sunrise enhancement of zonal electric fields.



To analyze the the overall effects of neutral winds, we define effective zonal winds U_1 and effective meridional winds U_2 as

$$U_1 = \frac{\int_S^N \boldsymbol{U}\times\boldsymbol{b}\cdot\boldsymbol{d}_2 ds}{\int_S^N \sigma_P ds} = \frac{\int_S^N \sigma_P U_{d1} ds}{\int_S^N \sigma_P ds},$$

$$U_2 = -\frac{\int_S^N \boldsymbol{U}\times\boldsymbol{b}\cdot\boldsymbol{d}_1 ds}{\int_S^N \sigma_P ds} = -\frac{\int_S^N \sigma_P U_{d2} ds}{\int_S^N \sigma_P ds}.$$

Figure 2. Variations of (a) height-integrated Pedersen conductance, (b) effective zonal winds (positive eastward), and (c) effective meridional winds (positive poleward/upward) as a function of MLON/MLT and MLAT at 11:00 UT.

Physical Mechanisms

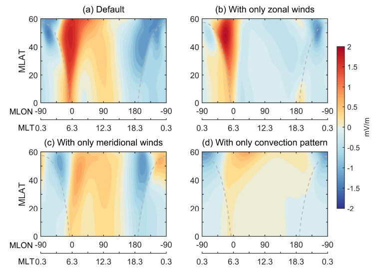


Figure 3. Magnetic zonal electric fields (positive eastward) at pressure level 2 (~295 km height) as a function of MLON/MLT and MLAT at 11:00 UT in Cases 1-4.

From Figures 3a,

- **Zonal electric fields at low and even middle MLATs also have a prominent eastward enhancement at 5:50 MLT near sunrise**
- **The eastward electric fields at 5:50 MLT peak at midlatitudes**
- **The peak of electric fields at 5:50 MLT in the off-equatorial latitudes occurs after local sunrise**

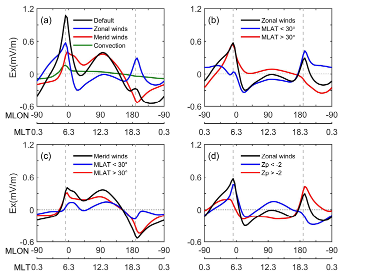


Figure 4. MLON/MLT variations of magnetic zonal electric fields at the magnetic equator at pressure level 2 from different control simulations at 11:00 UT.

From Figures 3 and 4a,

- **Zonal wind dynamo plays a significant role in the sunrise enhancement,**
- **the meridional wind dynamo has a secondary effect**
- **PPEFs from the high-latitude convection pattern contribute further but minor**

From Figures 4b-4d,

- **The wind dynamo (both zonal and meridional) above 30° MLATs plays a dominant role, whereas the effects of low-latitude one are much weaker.**
- **The eastward sunrise enhancement is primarily caused by the E-region wind dynamo rather than the F-region dynamo**

From Figures 5 and 6, after sunrise and at middle latitudes,

- **The E-region westward winds drive an equatorward Pedersen dynamo current $\sigma_P(U\times B)_y$ and a westward Hall dynamo current $\sigma_H b\times(U\times B)_y$**
- **Then, poleward E_y occurs and it produces poleward Pedersen currents $\sigma_P E_y$ and eastward Hall currents $\sigma_H b\times E_y$ to balance the wind-driven currents**
- **Additional eastward electric fields associated with eastward Pedersen and equatorward Hall currents are established to close the currents**

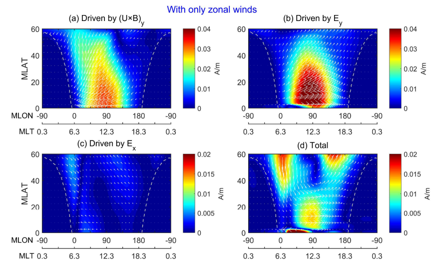
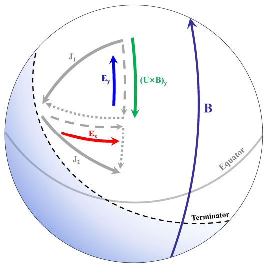


Figure 5. MLON/MLT and MLAT variations of height-integral horizontal current densities (a) driven by zonal-wind dynamo electric fields **$(U\times B)_y$**, (b) meridional electric fields (**E_y**), (c) zonal electric fields (**E_x**), and (d) total electric fields in the control simulation with magnetic zonal winds only at 11:00 UT

Figure 6. A schematic diagram of the physical mechanism of the eastward enhancement of zonal electric fields caused by the zonal wind dynamo at middle latitudes near sunrise. The westward-wind-driven dynamo electric fields **$(U\times B)_y$** and poleward polarization electric fields **E_y** cause equatorial net Pedersen currents (grey dashed in the topside) and westward net Hall currents (grey dotted in the topside), whose combined currents **J_1** are westward/equatorward. To satisfy current continuity (∇·J=0), eastward polarization electric fields **E_x** are established and they generate eastward Pedersen currents (grey dashed in the bottemside) and equatorward Hall currents (grey dotted in the bottemside), whose combined currents **J_2** are eastward/equatorward.



Conclusions

1. **TIEGCM simulations reproduce the sunrise enhancement of upward vertical E×B drifts observed by the Jicamarca ISR.**
2. **The model results show that the sunrise enhancement of zonal electric fields occurs from low to high latitudes and it peaks at middle latitudes.**
3. **The sunrise enhancement is mainly associated with the zonal wind dynamo at middle and high latitudes rather than a local dynamo effect in the equatorial region.**

Contact Me

Junjie Chen

Major: Space Physics in USTC

Email: cjjvince@mail.ustc.edu.cn WeChat: