Ann. Geophys. Discuss.,
https://doi.org/10.5194/angeo-2019-122-AC1, 2019

Interactive comment on "Equatorial Plasma Bubbles Developing Around Sunrise Observed by an All-Sky Imager and GNSS Network during the Storm Time" *by* Kun Wu et al.

Kun Wu et al.

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Received and published: 23 December 2019

Reviewer comment:

This paper reports all-sky airglow and GNSS-TEC observations of plasma bubbles growing around sunrise terminator during a magnetic storm. This work could contribute to study of effects of magnetic storm on ionospheric disturbances. Therefore, this paper is worth publishing in this journal. However, the followings need to be addressed before its publication.

Reply: Thank you for your positive comments. All the comments from you have been

considered in the revised manuscript. And with the corrections made, we hope it's accepted for publication in Annales Geophysicae now.

Reviewer comment:

Specific comments: – "recombination": This reviewer recommends the authors to use a term "merging". "Recombination" is confusing because "recombination" is widely used to represent reaction of ions with electrons resulting in neutralization. "Merging" is used commonly compared to "recombination". See the following references:

Narayanan, V. L., S. Gurubaran, and K. Shiokawa (2016), Direct observational evidence for the merging of equatorial plasma bubbles, J. Geophys. Res. Space Physics,121, 7923–7931, doi:10.1002/2016JA022861.

Huba, J. D., T.-W. Wu, and J. J. Makela (2015), Electrostatic reconnection in the ionosphere, Geophys. Res. Lett., 42, 1626–1631, doi:10.1002/2015GL063187.

Huang, C.-S., J. M. Retterer, O. de La Beaujardiere, P. A. Roddy, D. E. Hunton, J. O. Ballenthin, and R. F. Pfaff (2012), Observations and simulations of formation of broad plasma depletions through merging process, J. Geophys. Res., 117, A02314, doi:10.1029/2011JA017084.- l.

Reply: Thanks for this suggestion. After reading above references, we used "merging" to replace "recombination" and cited those references in the revised manuscript.

Reviewer comment:

- l. 55,"and the background ionospheric/thermosphere": Describe concretely which parameter the authors mean. Does the authors mean vertical gradient of plasma density at the bottomside of the F region or ion-neutral collision frequency?

Reply: We want to address that the growth rate of Rayleigh-Taylor instability (RTI) will be influenced by the vertical gradient of plasma density at the bottomside of F region, and also the change of ion-neutral collision frequency. We have revised related texts at lines 56-57.

Reviewer comment:

- l. 96,"Hall electric field": It is better to add more detailed explanation of the Hall electric field.

Reply: In the revised manuscript, we added related explanation of "Hall electric field" at lines 96-100. "Santos et al. (2016) also showed some EPBs of zonal drifts reversal (eastward to westward) during a geomagnetic storm, and they suggested the reversal was caused by a vertical Hall electric field which induced by a zonal prompt penetration electric field (PPEF) in the presence of enhanced conductivity in the E region during night."

Santos, A. M., Abdu, M. A., Souza, J. R., Sobral, J. H. A., Batista, I. S., and Denardini, C. M.: Storm time equatorial plasma bubble zonal drift reversal due to disturbance Hall electric field over the Brazilian region, J. Geophys. Res., 121, 5594–5612, https://doi.org/10.1002/2015JA022179, 2016.

Reviewer comment:

– ll. 110-111, Figure 1: Field-of-view (FOV) is shown by a circle in Figure 1. It would be better to describe the zenith angle corresponding to the circle shown as FOV.

Reply: In Figure 1, the blue circle represents the projected regions with a radius of ~900 km [about 140° field of view (FOV)] of the all-sky imager at an altitude of 250 km. We have revised related texts at lines 113-115.

Reviewer comment:

– l. 122:Describe minimum and maximum frequency (or period) of the band-pass filter.

Reply: The minimum and maximum period of the band-pass filters we used are 2 min and 12 min, respectively. In the revised manuscript, we added related content at lines 127-128.

Reviewer comment:

– ll. 176-197: The authors describe that TEC depletion can be seen in Figures 4 and 5. However, TEC variations in these figures show positive and negative values rather than depletion. Spatial scale of the TEC variations seen in the figures is small. Therefore, the TEC variation corresponds to the plasma density irregularities existing within plasma bubbles. If the authors show ROTI (Rate of TEC change Index), structure of the plasma bubbles can be seen clearly as ROTI enhancements. See the following paper.

Buhari, S. M., Abdullah, M., Hasbi, A. M., Otsuka, Y., Yokoyama, T., Nishioka, M., and Tsugawa, T. (2015), Continuous generation and twoâAËŸ Rdimensional structure of equatorial plasmabubbles observed by highâAËŸ Rdensity GPS receivers in Southeast Asia, J. Geophys. Res. Space Physics, 119, pages 10,569–10,580.doi:10.1002/2014JA020433.

Reply: Thanks for your advice. We calculated the ROTI variations (Figure 6) which correspond geographical area and time of each airglow imaging in the revised manuscript. In the Figure 6, we can clearly ROTI enhancement from structure of the EPBs.

Reviewer comment:

– ll. 229-232: Explain a reason why the eastern wall of EPB is unstable when the wind blows westward and equatorward. When the wind blow westward, and thus the wind-induced Pedersen current flows downward, gradient-drift instability can occur at the eastern wall of EPB, where the plasma density gradient is eastward. On the other hand, how does the equator ward wind work?

Reply: Due to Coriolis force, the enhanced equatorward wind at disturbed periods will have also a westward component, which will work on the eastward wall of EPB, causing the secondary instabilities. Similar finding of secondary instability happened at the eastward wall of EPB has been earlier reported by Makela et al. (2006), by using airglow imagers. In the revised manuscript, we added related context at lines 257-260.

Makela, J. J., Kelley, M. C., and Nicolls, M. J.: Optical observations of the development of secondary instabilities on the eastern wall of an equatorial plasma bubble J. Geophys. Res., 111, A9, https://doi.org/10.1029/2006JA011646, 2006.

Reviewer comment:

– ll. 233-247, "This is because zonal drift value of EPBs ... EPBs should be influenced by ionospheric electric field.": The authors point out that the drift velocity of EPB is smaller than the wind, and argue the reason of this difference. However, this reviewer cannot understand what the authors are describing. If the F-region dynamo process completely works, the ExB drift velocity is equal to the wind velocity. Does the authors mean that electric field generation through the F-region dynamo is not completed and thus the ExB drift is smaller than the wind velocity? Otherwise, does the authors consider another electric field, which is different from the dynamo electric filed induced by the wind?

Reply: Here, our understanding is that the zonal plasma drifts are affected by the vertical electric fields generated by the E and F region wind dynamo (Haerendel et al., 1992). The E and F region dynamo effects can be examined by using a simplified formula from Eccles et al. (1998): V_φ=$U\_\varphi\hat{}P$=ΣPFU_$\varphi\hat{}$PF+ΣPEUφPEΣP. Where V_φ is the zonal plasma drift speed, $U\_\varphi\hat{}P$ is the Pedersen conductivity-weighted neutral zonal winds, Σ is the field-line-integrated total ionospheric conductivity. E and F refer to the E and F region, respectively. P represents the Pedersen component. During nighttime, the E layer is quickly recombined and F layer dynamo plays a dominant role. So, the zonal drift value of EPBs should mainly be related to (Σ_Pˆ F U_$\varphi\hat{}$PF)/Σ_P . The simulation of Figure 7 reflect U_$\varphi\hat{}$PF. The difference between the model simulated background zonal winds and the derived zonal drifts of EPBs from airglow images is possibly due to that the model simulation provide mainly reflect a general trend of the wind, but not the exact wind velocity in reality.

Eccles., V. J.: A simple model of low-latitude electric fields, J. Geophys. Res., 103, 26699-26708, https://doi.org/10.1029/98JA02657, 1998.

Haerendel, G., Eccles, J. V., and Çakir, S.: Theory for modeling the equatorial evening ionosphere and the origin of the shear in the horizontal plasma flow, J. Geophys. Res., 97, 1209–1223, https://doi.org/10.1029/91JA02226, 1992.

Reviewer comment:

– ll. 255-256: The authors point out the EPBs kept developing after sunrise. Generally, it is considered that after sunrise, the photoionization due to the Solar EUV radiation produce the plasma in the ionosphere and fill the plasma depletion of EPB. In order to compare the time of sunrise, it would be worth showing local time variation of the absolute TEC, to compare the time of EPB existence with the time of rapid TEC increase at sunrise.

Reply: In the revised manuscript, we added it in Figure 5. The TEC depletions showed that EPBs existed after sunrise and they disappeared after 07:45 LT. These results showed that they vanished about one hour after sunrise. Their life time lasted for at least about 3 hours.

Reviewer comment:

– l. 265, "during the development phase of storm": What is the development phase of storm? Is it "main phase of magnetic storm"? Why does the DDEF appear only during the development phase of storm?

Reply: We are sorry for the misleading description in our previous manuscript. Once DDEF established, the DDEF could be last from hours to couple of days (Richmond et al., 2003). So, we rewrote the sentence in the revised manuscript. It is modified for "The DDEF caused by storm will drive plasma drift to move upward during nighttime (Blanc and Richmond, 1980)".

Blanc, M., and Richmond, A. D.: The ionospheric disturbance dynamo, J. Geophys.

Res., 85, A4, https://doi.org/10.1029/JA085iA04p01669, 1980.

Richmond, A. D., Peymirat, C., and Roble, R. G.: LongâĂŘlasting disturbances in the equatorial ionospheric electric field simulated with a coupled magnetosphereâĂŘionosphereâĂŘthermosphere model, J. Geophys. Res., 108, A3, https://doi.org/10.1029/2002JA009758, 2003.

Reviewer comment:

Minor comments:

-l. 127: "Digisond" –> "Digisonde" l. 308: "rise" may be "sunrise". Figure 6: Legend of vertical axis in Figures 6c and 6e is "W-S distance". It should be "W-E distance". Furthermore, describe positive eastward.

Reply: Thank you for these detailed suggestions. We used "Digisonde" to replace "Digisond" and used "sunrise" to replace "rise". The previous Figure 6 has been updated as Figure 7 in the revision.

Please also note the supplement to this comment:
https://www.ann-geophys-discuss.net/angeo-2019-122/angeo-2019-122-AC1-supplement.pdf

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Interactive comment on Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2019-122, 2019.

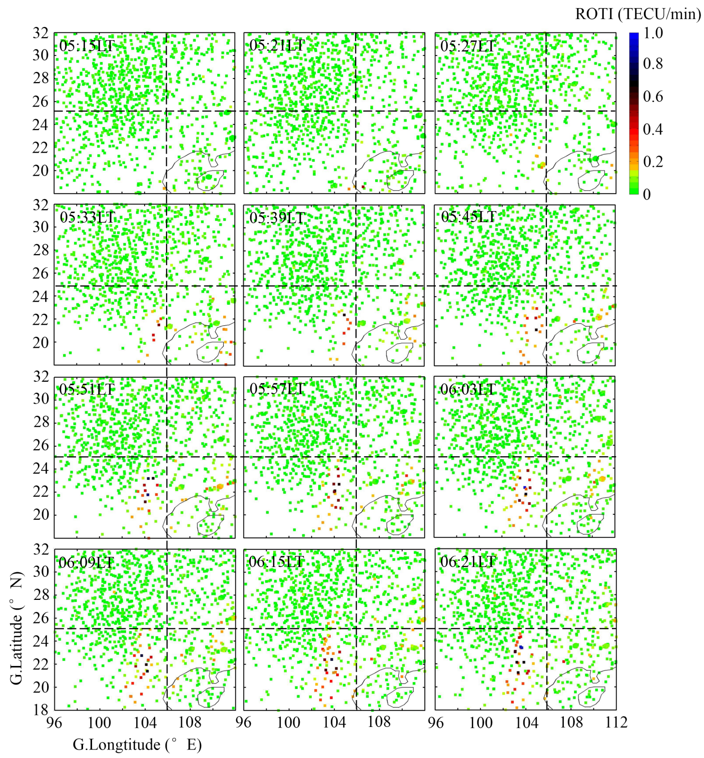

Fig. 1. Fig6.Two-dimensional map of rate of TEC index (ROTI) correspond to each image of Figure 3. The black horizontal line is a reference line of 25° N. The black vertical line is a reference line of 106° E

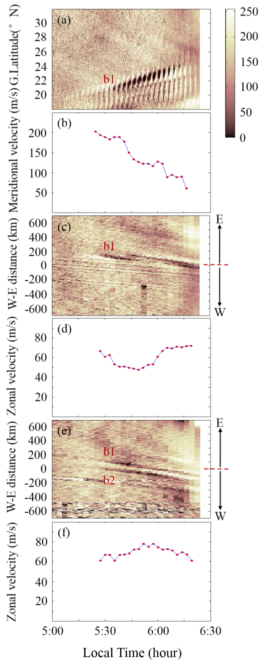

Fig.7.(a) N-S cross sections (between 104° E and 105° E) of the airglow images on 08 November 2015.
(c) W-E cross sections (between 21.5° N and 22° N) of the airglow images.
(e) W-E cross sections (between 18.5° N and 19° N) of the airglow images.
(b) The variations of the meridian velocities of "b1" with local time.
(d) and (f) The variations of the zonal velocities of "b1" at ~ 22° N and ~19° N geographical latitudes, respectively.

Fig. 2.