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Interactive comment on "Combinatorial observation ionospheric characteristics during tropical cyclone Debbie passing eastern Australia in 2017 using GPS and ion sounder" *by* Fuyang Ke et al.

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Comment #01: The authors called in different strange names the ionosondes: e.g. "The stronger enhancement of f0F1 and f0F2 was observed by High Frequency at" and "ion sounder" in the title, abstract and in the whole text. I suggest to use the further expressions to name this instrument: High Frequency radio sounder or ionosonde. Response #01: All High Frequency and ion sounder in this paper have been replaced by ionosonde.

Comment #02: The English of the whole text have to be improved. Please, use the same, past or present tense during the whole manuscript. Take care of the word order of the sentences, check singular/plural, furthermore the prepositions. Avoid the repetition of a word. Response #02: The English of the manuscript has been improved. The same tense has been used in the whole manuscript. The word of the sentences, singular/plural, and the prepositions have been checked and revised. The repetition of a word has been avoided. The details are shown in the revised manuscript.

Comment #03: Introduction: In the discussion part the author counts the different coupling mechanisms but they didn't detail them in the introduction. Please, write 1-2 paragraphs about the different mechanisms what you listed in the discussion with more reference. Response #03: The following description has been added in the fourth paragraph on page 2 lines 67-75. Additionally, there are also some controversies about the coupling mechanism between tropical cyclones and ionospheric disturbance. Hung et al. (1978) of NASA in the United States have found the existence of gravity waves and mesoscale disturbances in the F layer of the ionosphere during the tornado eruption using ionosonde, and considered that the gravity wave may be the main source of ionospheric disturbance. It is suggested (Shen, 1982; Liu, et al. 2006; Wang, et al. 2005) that the turbopause motion is a possible mechanism for the interaction between the lower layers of the atmosphere and ionosphere. It is considered that the electric field disturbance in typhoon or hurricane is activated by the ionospheric disturbance caused by the current perturbation from the charged water droplets and aerosols transmitted upward (Isaev 2002, 2010). So, the study on tropical cyclone Debbie is also valuable to realize the coupling mechanism between ionospheric disturbances and tropical cyclones.

Comment #04: Page 2 line 50: I miss a reference in connection with the hurricanes in Czech republic: "the results of statistical analysis showed that ionospheric disturbance percentage of 24 strong typhoons in China (Xiao et al., 2007), 41 tropical cyclones in the Atlantic Ocean (Nina et al., 2017), and 25 hurricanes in western and central part of the 50 Czech Republic were 92%, 88% and 8%, respectively" Response #04: "…and 25 hurricanes in western and central part of the 50 Czech Republic (Šindelářová et al., 2009) were 92%, 88% and 8%, respectively." The reference in connection with the hurricanes in Czech Republic has been added on page 2 line 50. The referee: Šindelářová T., Burešová D., Chum J.: Observations of acoustic-gravity waves in the ionosphere generated by severe tropospheric weather, Studia Geophysica et Geodaetica, 53(3): 403-418, 2009.

Comment #05: Page 3 Fig. 1 and its caption: Why do you indicate the same type of symbol more times on the Figure? Caption: I only see blue stars and one arrow and one red pentagram on the Figure. Please, correct the caption. Response #05: The legend and caption in Fig. 1 have been corrected as the following figure.

Comment #06: Page 3 line 80 and more times after that: "the wind speed of 105m/s" Are you sure in this data? 105 m/s = 378 km/h! Response #06: Cyclone Debbie landed on Hook Island of Queensland at UT00:00 on 28 Mar 2017 at the wind speed of 105 knots, about 54 m/s. Corrections have been made in the paper.

Comment #07: Page 4 line 89-91: This sentence is a little bit confusing: "The shortest distances from the tropical cyclone center to these stations above were 160 km at UT00:00 of 24 March 2017, 230 km at UT00:00 of 28 March 2017, 167 km at UT12:00 of 29 March 2017, 230 km at UT00:00 of 28 90 March 2017 and 925 km at UT12:00 of 30 March 2017, respectively." It would be better the define the distance station by station. Response #07: The sentence has been adjusted to the sentence of "When tropical cyclone Debbie landed on Hook Island of Queensland, the ellipsoidal distances between the tropical cyclone center and the observation stations of Willis, Townsville and Brisbane were 460 km, 230 km and 925 km, respectively."

Comment #08: Page 6 line 148 and Fig. 3.: What was the exact time when Debbie landed on Hook Island? I can see more increase on 27 Mach also in ROT for PRN01 and PRN11. Response #08: Cyclone Debbie landed on Hook Island of Queensland at

UT00:00 on 28 Mar 2017. The increment of ROT for PRN01 and PRN11 on 27 March might be caused by the small geomagnetic storm.

Comment #9: About the 4.1 and 4.2 subsections and Fig 3 and 4.: It would be nice to see a measurement of a reference satellite for away from the cyclone. Response #9: The measurement of PRN23 far away from the cyclone is selected as the reference in Fig 3 and 4.

Comment #10: Fig. 5.: I can see more red point north from the red circle but at the same longitude. Can you detail the reason of those red dots/anomalies? Response #10: The north from the red circle belongs the low geomagnetic latitude, where the ionsopheric scintillations are highly frequent. Therefore, the ionospheric scintillations are caused by the ionospheric irregularities near the equator.

Comment #11: In connection with subsection 4.3: Why don't you use the monthly median or an average of reference days (geomagnetically quiet days) as reference and compare it with ionospheric parameters (foE, foF2, foF1) observed during the investigated period? If you use: "best fits for their mean value from 24 to 31 March… as their normal values" you use the parameters observed during geomagnetically disturbed period as reference. Thus, I suggest to repeat the analysis using the monthly median of the parameters or detected during geomagnetically calm periods. Response #11: This paper uses the monthly median as a reference, but the expression is inappropriate. The expressions have been corrected.

Comment #12: Fig. 8. What does the pink rectangular good for? Please, detail it in the caption of the figure. Response #12: The pink rectangular is just to emphasize on the tropical cyclone Debbie landfall day.

Comment #13: Page 10. line 217:" The electron density is linear related to f0F1 and f0F2." It is not true. Look at the eq. (4) at the manuscript. Response #13: The sentence has been changed to "The electron density is positively related to f0F1 and f0F2".

Comment #14: Page 10. line 220: “Therefore, the stronger f0F1 and f0F2 enhancement of Townsville station on 28 March should be attributed to tropical cyclone Debbie”. I can see strong foF1 variation also at Brisbane. How can you explain it? Response #14: Although the f0F1 in F1 layer observed by Brisbane station is also increased on 28 March in Figure 7, the periodic anomaly of f0F1 in those days might be due to Ionosonde noise. And the explanation has been added on page 8 lines 224-226.

Comment #15: Discussion: The discussion is very short. In the first paragraph the authors count the different coupling mechanisms. But they didn’t discuss them and didn’t compare them with their findings. They say that the morphological characteristic of the ionospheric variations what they found agree only one mechanism of them (turbulent top movement) but they didn’t explain why. Please, discuss you results more carefully and compare them with the findings of previous studies in the literature. Especially detail please the last 4 lines of the discussion, the mechanism in connection with the generation of the plasma bubbles. Response #15: Compared with our findings in the study, the different coupling mechanism has been discussed. Compared our results and the previous findings, the ionospheric disturbance and scintillation are explained. The detail discussion is as following. The results reveal that the ionospheric irregularity and disturbance could be likely related to tropical cyclone Debbie. Even it can further produce GPS ionospheric scintillations. However, the coupling mechanism between tropical cyclone and ionospheric disturbances is still indefinite and controversial. The previous studies considered that the source of ionospheric disturbance might be from gravity waves generated by tropical cyclone (Xiao, et al. 2007), an atmosphere divergence/convergence model and dynamic coupling (Shen, 1982), a disturbed electric field caused by tropical cyclone (Isaev, et al. 2002), turbulent top layer movement of tropical cyclone (Shen, 1982; Liu, et al. 2006; Wang, et al. 2005) and lighting discharge from clouds of tropical cyclone (Shao, et al. 2013). Nevertheless, the vertical gravity waves could not disturb the more than 100 km height ionosphere in effective range due to its dozens of kilometres wavelength. Especially, it is much difficult to explain why f0F2 in more than 300 km height F2 ionospheric layer

observed by Townsville Ionosonde station is larger than the monthly median value as tropical cyclone Debbie was landing on 28 March in Figure 8. Assuming that gravity waves can cause ionospheric disturbances, the f0E in ionospheric E layer should be also anomalous. On the contrary, the f0E is approximately equal to the monthly median value in Figure 6. It is also difficult to explain the phenomenon only using the turbulent top layer movement of tropical cyclone and the disturbed electric field above the tropical cyclone. Because the tropical cyclone belongs to airflow system in troposphere with a height of 20 km or less and might not directly affect the ionosphere with a height of 50 km or more in the left of Figure 9. Furthermore, the short-term lightning could not explain the long-term ionospheric disturbances for about 2 hours in Figure 8. Therefore, it is supposed that the ionospheric disturbance in response to tropical cyclone Debbie is interacted by multi-source of turbulent top layer movement, electric field and electron photochemical reactions. The strong tropical cyclone airflows can lead to the structure change of stratosphere and mesosphere. Among them, the upward airflow will continue to develop upward due to the temperature structure of the middle layer and elevate the turbulence layer with about 100km height (Shen, 1982). By contrary, the airflow direction of the tropopause above tropical cyclone centre is downward. According to atmospheric turbulence layer movement theory (Liu, et al. 2006), the airflows from the tropical cyclone will make the turbulent diffusion coefficient increase and the molecular diffusion coefficient decrease. As a result, some neutral molecules (N2, O2) in E layer will be taken into the ionospheric F1 and F2 layer. X-rays and extreme ultraviolet rays from the sun can make these neutral molecules to ionize and produce free electrons and ions leading to the increment of electron density in F1 and F2 layer (Liu, et al. 2011). Therefore, it can be explained the phenomenon that the f0F1 and f0F2 on Townsville station are significantly enhanced as tropical cyclone Debbie is above Townsville station in Figure 7 and Figure 8. Along with the increment of electrons, the balance of electric field is destroyed. The growth of Rayleigh–Taylor instability from the electric field perturbations can lead to some ionospheric irregularities in the F layer (Prakash 1999), which may have velocity shear mixing within the hole gradients (Kelley 1985). When the hole arrives at the topside of F layer, the bubble is produced. As it happens that GPS signal encounters the bubble, ionospheric scintillation will occur. Therefore, it can explain why there are just some ionospheric scintillations of PRN01 and PRN11 above tropical cyclone Debbie, whose values of S4 are more than 0.2 in Figure 5. Moreover, the S4 of ionospheric scintillations of PRN01 and PRN11 observed by Townsville station is more than 0.2 on the midday of 27 March 2017 in Figure 4. Meanwhile, the f0F2 in ionospheric F2 layer is enlarged at the same time in Figure 8. Thus it can be supposed that the ionospheric scintillation is produced by the ionospheric irregularities in F2 layer due to tropical cyclone Debbie.

Please also note the supplement to this comment:
https://www.ann-geophys-discuss.net/angeo-2019-72/angeo-2019-72-AC1-supplement.pdf

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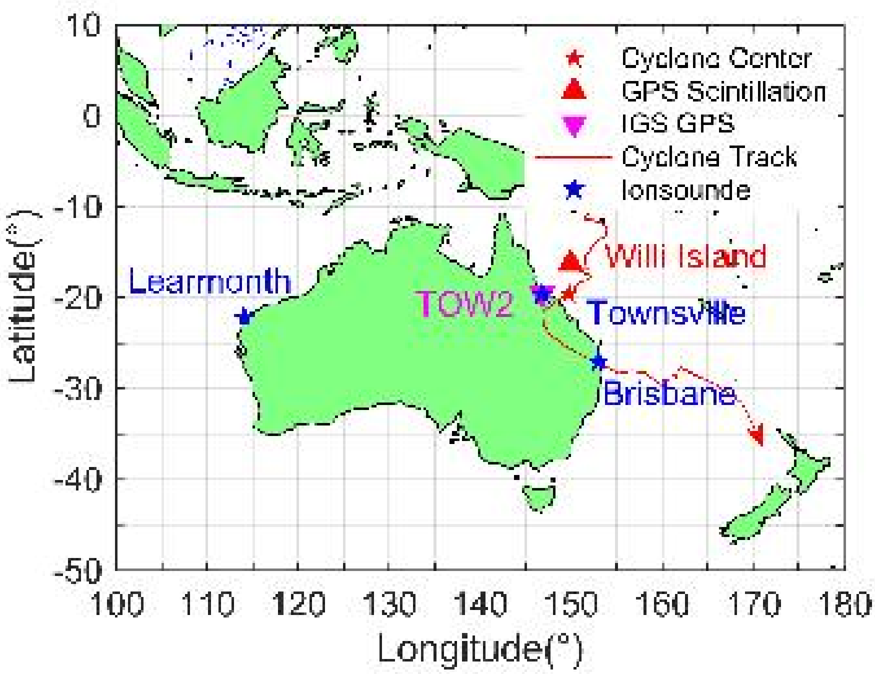

Fig. 1. Figure1