Ann. Geophys. Discuss.,
https://doi.org/10.5194/angeo-2019-72-AC3, 2019

Annales Geophysicae Discussions

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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Received and published: 6 December 2019

Comment #01: Even though the authors had improved the English of the manuscript, there are a number of incomprehensible expressions. The referee strongly recommended the further improvement of the English of this manuscript using professional English editing services. Response #01: The manuscript has been edited for proper English language, grammar, punctuation, spelling, and overall style by one or more of the highly qualified native English speaking editor at AJE. The certificate is attached.

Comment #02: Much more detailed information of the track of the cyclone are important. The authors showed only the times of the landing on Hook Island and leaving from Brisbane. Since cyclone Debbie may affect ionospheric disturbances more than 2 days, the positions of the cyclone on shore are very informative because the enhancements of ROTI are appeared in the limited period. The information of this cyclone is available such as Bureau of Meteorology of Australia (http://www.bom.gov.au/cyclone/history/debbie17.shtml). In addition, wind speed and the centre pressure are also informative. Response #02: The more detailed information of DEBBIE cyclone have been added on page 3 line 93-98. As shown in Table 1, the maximum wind speed and minimum air pressure of Debbie cyclone centre reach 54 m/s and t 944 hPa at UT 12:00 on March 27, respectively. At the same time, the cyclone centre is about 111 km away from its landfall point. After DEBBIE cyclone landfall, the wind speed of the cyclone centre decreased rapidly. The wind speed of Debbie cyclone centre drops to 15 m/s and the air pressure increases to 1000 hPa after 24 hours. Table 1: The wind velocity and pressure of DEBBIE cyclone centre and the distance from its centre to landfall point Time Velocity (m/s) Pressure (hPa) Distance (km) 0327, 00:00 41 963 188.1 0327, 06:00 46 956 155.7 0327, 12:00 54 944 111.0 0327, 18:00 54 944 38.4 0328, 00:00 54 960 0 0328, 06:00 39 977 52.8 0328, 12:00 23 989 129.3 0328, 18:00 21 993 210.4 0329, 00:00 15 1000 267.7 The locations of the days before and after DEBBIE cyclone landfall have been added in Figure 1

Figure 1: GPS stations of ISMs (Red triangles: Willi Island), GPS stations of IGS (Pink triangles: TOW2), Ionosonde stations (Blue pentagrams: Learmonth, Townsville, Brisbane), paths of tropical cyclone DEBBIE (Red line), the tropical cyclone moving directions (arrows) and the places of cyclone centre before and after DEBBIE landfall (Blue points)

Comment #03: As shown in Figure 3, the authors used STEC data derived from PRN23, PRN01, PRN11. Why don't you use STEC data derived from the other GPS satellites? Since the authors used data derived from only 3 satellites, the variations of

ROTI in daytime were not examined. In daytime, is there no STEC data showing the variations of ROTI? ROTI data in daytime is also very useful in comparison with the ionosonde data. Response #03: The variations of ROTI (5 min) for all GPS satellites in daytime and nighttime during March 26-29 are shown in the bottom subplot of Figure 3. Compared with the other GPS satellites, the variations of ROTI observed by PRN01 and PRN11 denoted by blue and purple lines in the bottom subfigure are obviously larger at 12:00 on 27 March before DEBBIE cyclone landfall. For space limitation, only ROTI observed by PRN23 as a representative is compared with those observed by PRN01 and PRN11 in detail. The lack of ROTI derived from PRN23, PRN01 and PRN11 in daytime is due to the periodic variation of GPS satellite motion.

Figure 3: The variation of ROT for GPS PRN23, PRN01 and PRN11 and ROTI (5min) of all GPS satellites during March 26-29 over the TOW2 IGS station.

Comment #04: In Figure 3, in addition to the previous comment, ROT for PRN01 and PRN11 are fluctuated but that for PRN23 is not. The authors explain that “the IPP trace of GPS PRN23 over TOW2 station is far away from the cyclone.” To confirm this explanation, the traces of IPPs for PRN23 are necessary. How far the IPPs for PRN23 is from the cyclone? On the other hand, the variations of ROT determined by PRN01 and PRN11appeared around 12UT. This may be related to the distance between the cyclone and IPP for PRN01 and PRN11. In order to show how effective, the distances between the cyclone and IPPs are for the variation of ROT, the tracks and positions of IPPs for PRN01 and PRN11 are also important. Response #04: The following figure has been added on page 6 line 150. And description of Figure 4 has been added on page 7 line 160-162.As shown in Figure 4, the Ionospheric Pierce Point (IPP) traces of GPS PRN01 and PRN11 satellites over TOW2 station are above the impact area of tropical cyclone Debbie on 28 March. The variation of ROT for PRN23 is not obvious, because the IPP trace of GPS PRN23 over TOW2 station is far away from the track of Debbie cyclone centre.

Figure 4: GPS stations of ISMs (Red triangles: Willi Island), GPS stations of IGS (Pink

triangles: TOW2), paths of tropical cyclone DEBBIE (Red line), the Ionospheric Pierce Point (IPP) trajectories and orientation of PRN01 (Blue line), PRN11 (Purple line) and PRN23 (Red line) GPS satellites on 27 March

Comment #05: The comments #3 and #4 are also applicable to S4 data. How close IPPs were close to the cyclone when the scintillations occurred? Response #05: According to the suggestions of comments #3 and #4, the variations of S4 for all GPS satellites in daytime and nighttime during March 26-29 are added in the bottom subplot of Figure 5. The IPP trajectories and orientation of GPS PRN01, PRN11 and PRN23 satellites are shown in Figure 4. It is obvious that the S4 of GPS PRN01 and PRN11 is stronger than that of the other GPS satellites at about UTC 12:00 on 27 March in Figure 5.

Figure 5: The GPS ionospheric scintillation S4 variations of GPS PRN23, PRN01, PRN11 and PRN01-32 satellites during 22-29 March 2017. The dotted red line is the threshold of the strong GPS ionospheric scintillation. The magenta vertical line denotes the time point when cyclone Debbie centre was the closest to GPS station The distances from IPPs to Debbie cyclone centre are described as following. When the distance from tropical cyclone centre to Willis station is 370 km along with the wind speed of 54 m/s at 12:00 of 27 March, the number and intensity of S4>0.2 observed by GPS satellite PRN01 and PRN11 near to the tropical cyclone centre are larger and stronger than those of the other GPS satellites in Figure 5. At the same time point, the distances from DEBBIE cyclone centre to PRN01 and PRN11 are 300 km and 453 km, respectively. Comment #06: In Figure 5, the authors show a map of S4 intensity. The authors explained that “What is more that the intensity and number of the points of S4>0.2 above the area of 18âŮęS − 25âŮęE in the latitude and 150âŮęE − 155âŮęE in the longitude around tropical cyclone centre (B = 19.6âŮęS, L = 149.8âŮęE) is stronger and larger than those above the other area.” From the referee’s view, the enhancement of S4 index is also appeared in the northern area (0S-18S, 145E-150E). Is not this enhancement related to the cyclone? Even though the authors may explain

this enhancement is related to the geomagnetic storm, we cannot distinguish whether this enhancement is due to the geomagnetic storm or the cyclone because the authors do not show the time of each IPP position. Basically, the enhancement of the S4 index due to geomagnetic storms appeared in wide longitudinal area. Why does not the enhancement of S4 index appear in the other longitudinal area? More detail analysis of this data is needed. Response #06:

Figure 6: Ionospheric pierce point traces and S4 intensity of GPS ionospheric scintillation observed by PRN01, PRN11 and PRN23 satellites through cyclone Debbie on March 27. The red line indicates the path of cyclone Debbie centre. The colourful solid circles are GPS ionospheric scintillations and their intensity According to your suggestions, the S4 values of PRN01, PRN11 near Debbie centre and PRN23 far from Debbie centre on 27 March are compared. The IPP traces and S4 intensity of GPS ionospheric scintillation observed by PRN01, PRN11 and PRN23 satellites on 27 March has been redrawn and shown in Figure 6. The colourful solid circles represent the IPPs of GPS ionospheric scintillations and their intensity. It is obvious that the intensity of GPS ionospheric scintillation for PRN01 and PRN11 with the path of the Debbie cyclone centre is significantly stronger than that of RPN23 further away from Debbie. The IPPs with stronger GPS ionospheric scintillations are mainly distributed around the outer edge of Debbie. Under the same geomagnetic conditions, the intensity of the GPS ionospheric scintillations for all GPS satellites should be approximately identical. Therefore, the difference in the intensity of GPS ionospheric scintillation for PRN01, PRN11 and PRN23 further verifies that Debbie might have enhanced the intensity of ionospheric scintillation.

Comment #07: In Figure 6, fo'E in Brisbane during 26th to 29th March was somewhat fluctuated as compared to Learmonth and Townsville. Is this fluctuation not related to the cyclone? Response #07: The f0E observed by Learmonth and Townsville Ionosonde are all approximately equal. In Figure 7, f0E in Brisbane during 26th to 29th March is somewhat fluctuated as compared to Learmonth and Townsville. But the

ionosonde instrument at Townsville closer to DEBBIE cyclone centre did not observe similar small disturbances. Hence, the small fluctuation of f0E in Brisbane during the period from 26th to 29th March could not be disturbed by cyclone Debbie. The reason is that the distances from Brisbane station to DEBBIE cyclone centre are more far on those days.

Comment #08: Page 9 line 225: The authors explained that "the periodic anomaly of foF1 in those day might be due to Ionosonde noise." The small fluctuations of fo'E is also noise? How about ionograms in this period ? Response #08: The ionograms at UT06:00 from 25 to 30 March above Brisbane station are shown in the following Figure. The disturbances in the ionograms on 27 March should be attributed to the geomagnetic storm shown in Figure 2, because the Debbie cyclone centre is still more far away from Brisbane station during the same period. The ionograms in F1 layer on these days are also anomalous and agreed with the fluctuations of f0F1. The source of ionospheric disturbance is complex. Therefore, the periodic anomaly of f0F1 and small fluctuations of f0E should be not directly ascribed to Ionosonde noise.

Comment #09: Page 9 line 239: What does "vertical gravity wave" mean? Basically, gravity waves cannot propagate vertical direction. Response #09: Inertio-gravity waves (IGWs) caused by typhoon can spread in vertical direction. IGWs in the stratosphere generated by Rusa have a vertical wavelength of 3–11 km (Kim, el al., 2005). Gravity wave can affect the atmospheric layer with high altitudes because of their relatively large vertical wavelengths and about 50 m/s vertical velocity (Kong, el al., 2017). [1] Kim, S. Y., et al. (2005). "A numerical study of gravity waves induced by convection associated with Typhoon Rusa." Geophysical Research Letters 32(24). [2] Kong, J., et al. (2017). "A clear link connecting the troposphere and ionosphere: ionospheric responses to the 2015 Typhoon Dujuan." Journal of Geodesy 91(9): 1087-1097.

Comment #10: Page 10 line 255: The authors described "some neutral molecules (N2, O2) in E layer will be taken into the ionospheric F1 and F2 layer. "Most of the neutral molecules, such as N2, O2, distribute around the altitude of 150 km. It is possible that these molecules might be transferred to F1 region by some turbulences. However, are these molecules transferred to F2 region by any turbulences? Response #10: The neutral molecules in E layer is difficult to be taken into F2 layer. The neutral molecules in E layer are mainly taken into F1 layer and change the structure of F1 layer. Furthermore, the electric ions of F1 layer will be taken into F2 layer.

Comment #11: Fig. 5.: Page 10 line 260: The authors described the generation mechanism of equatorial plasma bubbles, which cause scintillations of GPS signals. As for the source of the bubbles, the ionospheric perturbations are important. On the other hand, as for the growth rate of Rayleigh-Taylor instability, not the electric field perturbation but the eastward electric field is important. The referee wonder if perturbations always generate the eastward electric field? In the present case, the growth rate happens to be larger? This explanation cannot be applied to all the cases for ionospheric disturbances by cyclones. Response #11: The production of the plasma bubbles initiated by gravity waves takes a much shorter time than that resulting from two-dimensional initial density perturbations. The Rayleigh-Taylor instability initiated by gravity waves can also produce a steep gradient on the west wall, which provides a favorable condition for excitation of smaller-scale secondary instabilities. Although the viewpoint proposed in this paper cannot be applied to the all cases for ionospheric disturbances by cyclones, it can provide a new idea for the uncertain mechanism of ionospheric disturbance caused by cyclones. The following description has been added on page 12 line 275-279. The production of the plasma bubbles initiated by gravity waves takes a much shorter time than that resulting from two-dimensional initial density perturbations. The Rayleigh-Taylor instability initiated by gravity waves can also produce a steep gradient on the west wall, which provides a favorable condition for excitation of smaller-scale secondary instabilities. When the hole arrives at the topside of F layer, the bubble is produced.

Minor comments: M1. Caption of Figure 1: The locations the ionosonde are shown by Blue pentagrams not Blue triangles. Response to M1: The mistake has been modified

on page 3 line 84

M2. Page 3 line 92: What is “ellipsoidal distance”? Response to M2: The distance between two points on the surface of the ellipsoid.

M3. Equation (1) : The definitions of ROT and ROTI were originally submitted by Pi et al. (1997). Response to M3: It has been modified on page 4 line 119 and page 13 line 356.

M4. Page 6 line 168: “midnight of 27 March” is 0UT or 24UT on 27 March? Response to M4: It has been modified on page 8 line 178.

M5. The location (latitude and longitude) of the cyclone centre is shown by (B, L), e.g.page 7 line 181, page 10 line 277. This expression is not familiar with those related to Aeronomy field. Response to M5: This has been modified on page 8 line 191 and page 12 line 294.

M6. Page 9 line 239: Shao et al. (2013) is not listed in Reference. Response to M6: The reference is added in the revised manuscript and as following. Shao, X. M., Lay, E. H., Jacobson, A. R.: Reduction of electron density in the night-time lower ionosphere in response to a thunderstorm, nature geoscience, 6, 29-33, doi: 10.1038/NGEO1668, 2013.

Please also note the supplement to this comment:
https://www.ann-geophys-discuss.net/angeo-2019-72/angeo-2019-72-AC3-supplement.zip

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Interactive comment on Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2019-72, 2019.

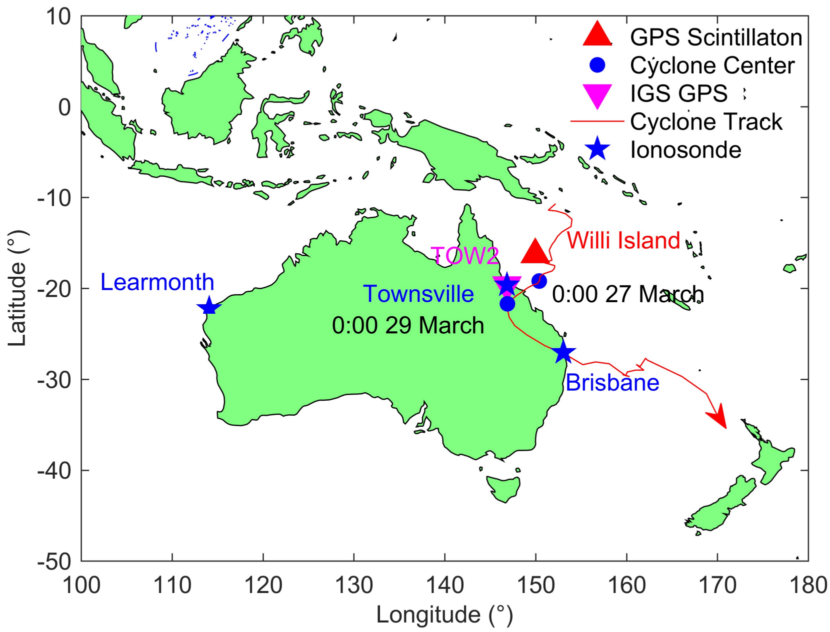

Fig. 1. Figure1

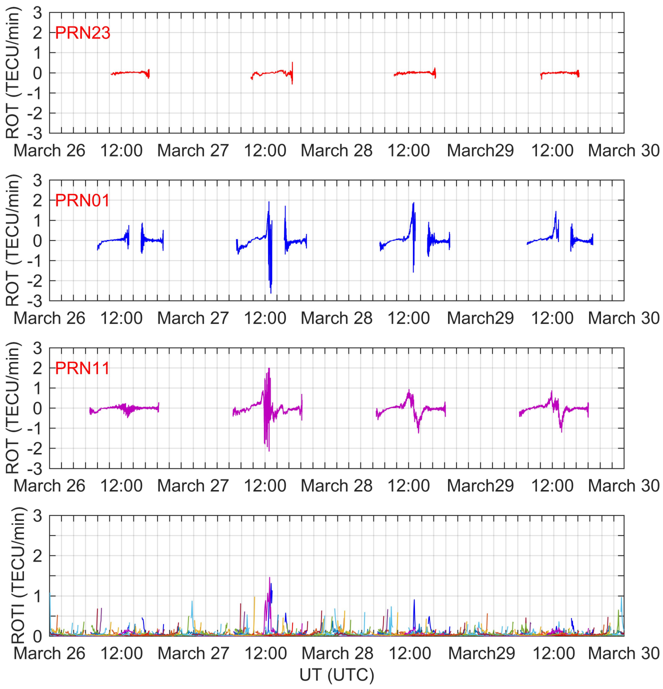

Fig. 2. Figure3

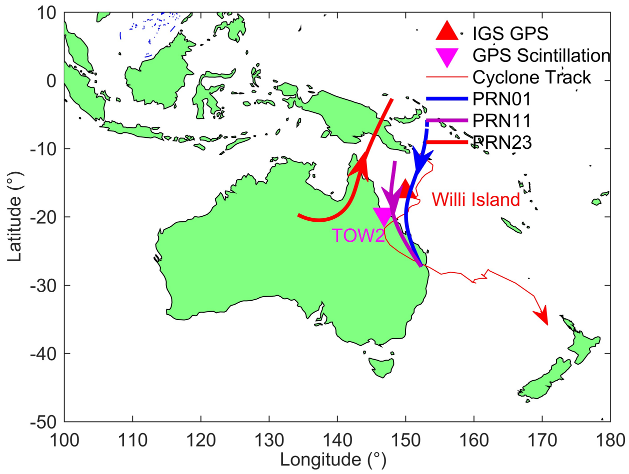

Fig. 3. Figure4

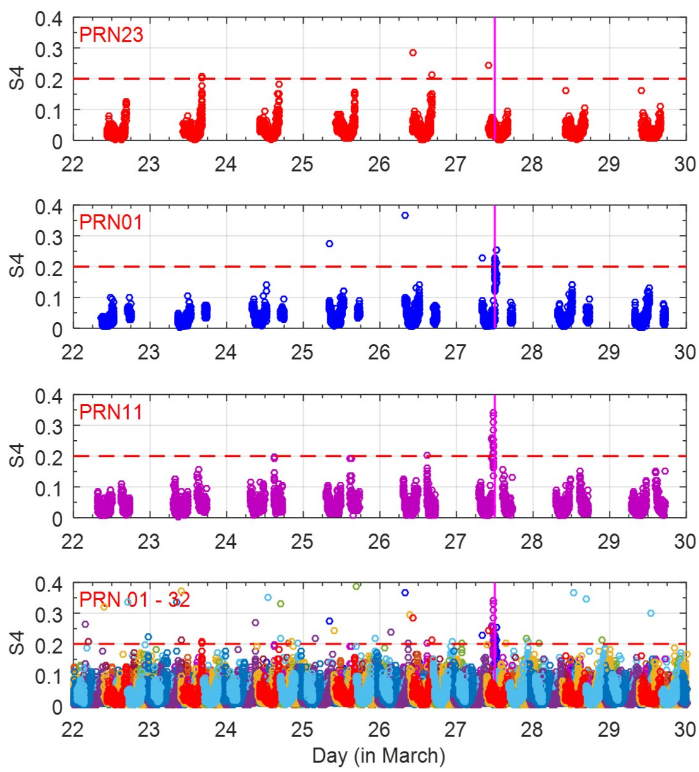

Fig. 4. Figure5

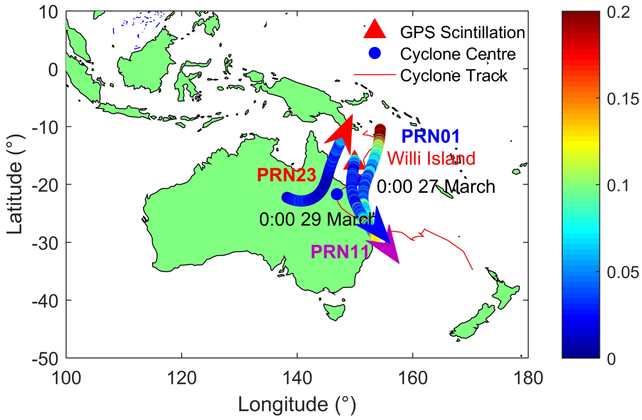

Fig. 5. Figure6

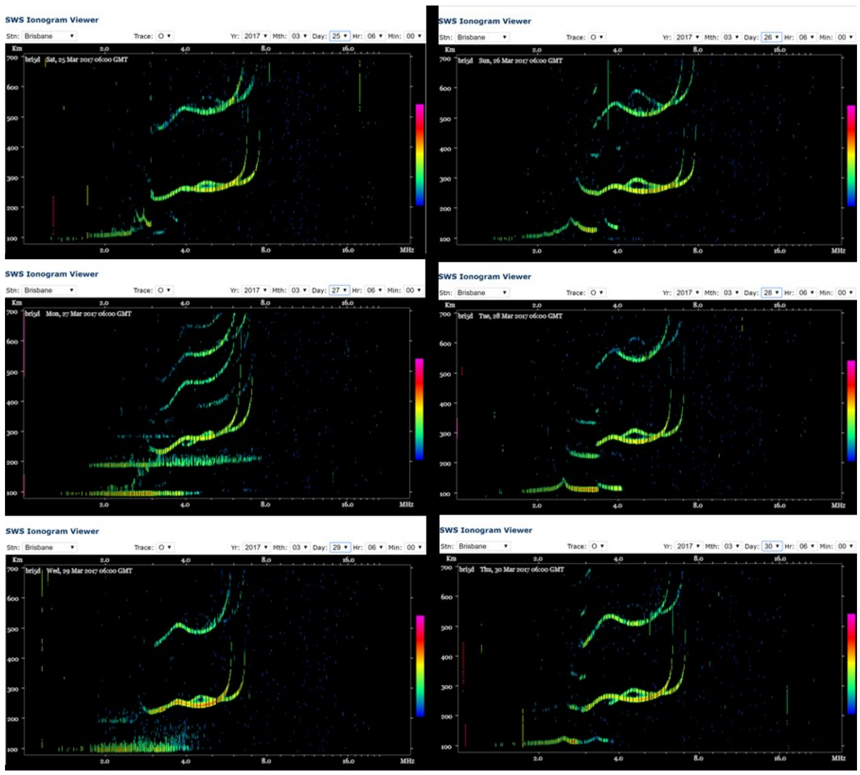

Fig. 6. Ionogram