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Interactive comment on "Evidence of vertical coupling: Meteorological storm Fabienne on 23 September 2018 and its related effects observed up to the ionosphere" *by* Petra Koucká Knížová et al.

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Detail answer to reviewer′s comments: General comments:

1. The authors give a very good review about the troposphere -upper atmosphere coupling in the introduction part. This very detailed summary/review could be complemented with aparagraph about the impact of the tropospheric events on the sporadic E layer because there are some very interesting papers which investigate and discuss this topic (e. g. Davis and Johnson 2005, Barta et al. 2017, Haldoupis 2018).

Text added: Tropospheric convective systems are often connected with strong lightning. Possibility of thunderstorm influence on ionosphere has been already suggested by Bhar and Syam (1937). In general, two principal mechanisms are proposed. First mechanism presumes gravity waves generated by thunderstorm to propagate up to ionospheric heights. Second mechanism involves generation of electrical discharges in the E region above the storm. Applying superposed epoch analyses, Davis and Johnson (2005) reported statistically significant intensification and decent in altitude of midlatitude sporadic E layer directly above thunderstorm. Different observational result showing decrease of critical frequency of sporadic E has been reported by Barta et al. (2017). Mechanism involved in the coupling between thunderstorm lightning and ionosphere is very complicated and not well understood yet. The limitations of generally accepted mechanisms are discussed in detail in the paper Haldoupis (2018).

2. Page 8. line 17. "Around 15 UT the warm front brought light rain associated with stratiform clouds"It is not clear the date in this case for me. Text corrected: Around 15 UT on September 23, the warm front brought light rain associated with stratiform clouds.

3. Page 9. line 31-36: Please, discuss a little bit what we see on Fig. 5. and how it is related to the other observations.

Text added: The accuracy is limited by the design of the instrument. In all the comparisons we consider this aspect. Single Doppler Wind Lidar is able to measure both Mie scattering from particles and aerosols, and Rayleigh scattering from the upper atmosphere molecules. This study uses the Rayleigh scattering measurement with random error (1σ) is 1 m.sec-1 at altitudes less than 2 km, 2 m.sec-1 between 2 and 16 km. Systematic error (1σ) is in this case smaller than 0.7 m.sec-1 (Durand et al., 2004).

In the two upper panels of Figure 5a and 5b we may see situation before the storm on 22 September. At heights above 10 km there is area where the satellite registers opposite direction of the wind compare to surrounding regions (marked by blue color).

Figure 5c represents situation of early morning of 23 September before the cyclone Fabienne has entered the area of measurement site. Calming of the windflow caused by temperature daily cycle is clearly visible. Figure 5d shows the post storm effect on 24 September. The area of opposite wind direction detected by satellite Rayleight scattering is lifted up to heighs of 15 km. The measurements at the time of Fabienne storm passage above the measurement site is not available due to satellite trajectory, however from the satellite records before and after the cyclone passage indicate extremely high speed changes within troposphere and lower stratosphere.

4. Page 12. line 6-9: "Both values agree well through the studied interval and their matching can be explained by dominant contribution of F2 layer's electron contribution to the TEC and much less contribution of Elayer's variability during studied days, even during the Fabienne event." Can you detail this explanation, please? Maybe it can be useful to show the variation of the foE parameter as well on Fig. 10.

Text added: While TEC and foF2 show significant decrease in reaction to minor geomagnetic disturbance, there is no clear change in course and shape of critical frequency of E layer foE Figure 10 (middle panel) except of very short wave-like variability on 23 September before Fabienne storm passage above the observational site. On 23 September, maximum of foE reaches same values as on preceding and following days. Most of the variability is observable within time series of TEC and foF2 and both parameters agree well through the studied interval. Their matching can be explained by dominant contribution of F2 layer's electron content contribution to the TEC and much less contribution of E layer's variability during studied days, even during the Fabienne event.

Figure 10 corrected

5. Page 12. line 16-19.: "Geomagnetic disturbance started on 21 September at 21 UT. Frequency foF2 during night falls much faster than it is typical. Then foF2 oscillates and remain below 3.5 MHZ till almost noon when rapidly increases." The second part

is related to the variation on the night 22/23 September? Please, indicate the date, because it is not clear for me.

Text corrected: Geomagnetic disturbance started on 21 September at 21 UT. Frequency foF2 during night falls much faster than it is typical. Then during night 22-23 September, critical frequency foF2 falls even faster, oscillates and remains below 3.5 MHz till almost noon when rapidly increases.

6. Page. 13. line 40-41: "The spectral content changed withtime and was different during the strong storm event compare to preceding and following day. " We can't see similar effect at 4.65 MHz. Can you give an explanation for that?

Text enlarged: The spectral content changed with time and was different during the strong storm event compared to preceding and following day. During afternoon hours on 22 September, CDS registers clear sharp echo with wave-like fluctuations. On 23 September on both frequencies we have observed sudden increase of noise at 18 UT that could indicate arrival of acoustic wave packet from the frontal border. After that, stronger and blurred echo compared to 22 September is registered on both frequencies. Wave-like fluctuations are not detected within the signal on 3.59 MHz and 4.65 MHz. On both frequencies (better pronounced on 4.65 MHz on Figure 15 b), there are apparent coincidental drops in frequency at 18 UT. Blurred strong echo was observed until around 4 UT on 24 September. In the afternoon hours on 24 September, recorded CDS echo remains slightly blurred but it is significantly weaker. The occurrence of stronger echo on CDS sounding on 3.59 MHz in the interval 18 UT (23 September) till 4 UT (22 September) corresponds to the increased wave activity on directograms and detection of plasma flow on both North and East plasma drift components. The trace of 4.65 MHz is limited due to diurnal course of foF2. Hence the changes of in the CDS signal can be discussed only till 20 UT. Signal detected on 23 September is significantly stronger with respect to preceding and following days, especially in the part that corresponds to the frequency drop at 18 UT.

7. Page 14. line 30-32. "According to the evolution of Kp index and ionospheric plasma parameters (TEC and foF2) ionosphere was already in the recovery phase of the geomagnetic storm. Nevertheless, the observed disturbances are induced both by geomagnetic storm and convective activity in the lower laying atmosphere." Can you discuss in more details the convective activity effect on the TEC and/or foF2 and how it appears on Fig. 10.? I can not distinguish its impact from the geomagnetic storm in the case of these two parameters. Text added:

In the introduction part: Model study (Pedatella, 2018) demonstrated variability of the response of the atmosphere and ionosphere system to one particular storm when the internal variability characterized by the ensemble standard deviation is introduced. The study shows that implementation of arbitrary internal atmospheric variability leads to the geomagnetic storm occurring under a different, though climatically similar, atmospheric state for each ensemble member. The study has found that variability leads to uncertainty typically 20%–40% with locallized regions exceeding 100%. It clearly shows that large-scale features of the storm are reproduced well and while small-scale characteristics of the response are dependent on lower atmosphere variability. Hence neglecting of the lower atmosphere may lead to significant complication in the geomagnetic storm interpretation.

In the Discussion part: The observed variability of the parameters TEC, foF2 and foE on Figure 10 is caused jointly by the minor geomagnetic disturbance and atmospheric waves associated with Fabienne storm. It is practically impossible to distinguish what part of the variability belongs to the particular forcing. Ionospheric vertical sounding has, unfortunately, limitations and provides integral information about resulting behavior of the atmosphere. However, in addition to the time of flight of the electromagnetic wave the DPS 4D equipment recorded additional parameters of the reflected wave from ionosphere. Variability of critical frequency foF2 must be interpreted together with complete ionogram record. As it is demonstrated in the Figure 8, there is well seen change of the ionogram pattern through experiment. Ionograms recorded on 22

September (type on panel a) are usually recorded when the reflection plane is practically flat while ionograms recorded on 23 September (type on panel b) are measured when reflection planes are significantly undulated. Such situations occur in association with atmospheric wave activity. Hence, this additional information can be used to slightly untangle effects of the geomagnetic disturbance and convective activity. Taking into account the course of foF2 and TEC together with change of ionogram reflection patterns, we suppose, that dominant effect of the geomagnetic disturbance is pronounced as decrease of foF2 and TEC, while short term wave-like variability around mean course associated with spread echo occurrence on ionograms can be attributed to the convective activity in the lower atmosphere.

In the conclusion part: Regarding results of model study (Pedatella, 2018) we attribute general decrease in foF2 and TEC to the geomagnetic forcing (longer-term, negative storm scenario) and significant increase in wave-like activity (short-term, wave-like activity) to the convective system forcing. General comments to the Figures: Unfortunately, it is very difficult to see the following figures (especially in print version):Fig. 3, Fig 6. and 7., Fig. 8, Fig. 14. Please, indicate the letters a, b, c etc. on the subplots where it is necessary.In some cases, when you show sequence of pictures it could help if you indicated the dates (in row e.g. on Fig 6 and 7) and the time (above the columns e.g. on Fig. 6 and 7) Figures corrected

Minor comments: 1. Sometimes the line spacing change in the manuscript: e.g. page 3. line ...7-8 / 9-10....; page 7. line ... 30-31 / 32-33 corrected 2. Page 3. line 16.The effects of gravity waves on in the ionosphere: in should be deleted corrected 3. Page 4. line 1. On the longer term-termscale: one term should be deleted corrected 4. Page 6. line 25. Kouba et al. (2008) corrected

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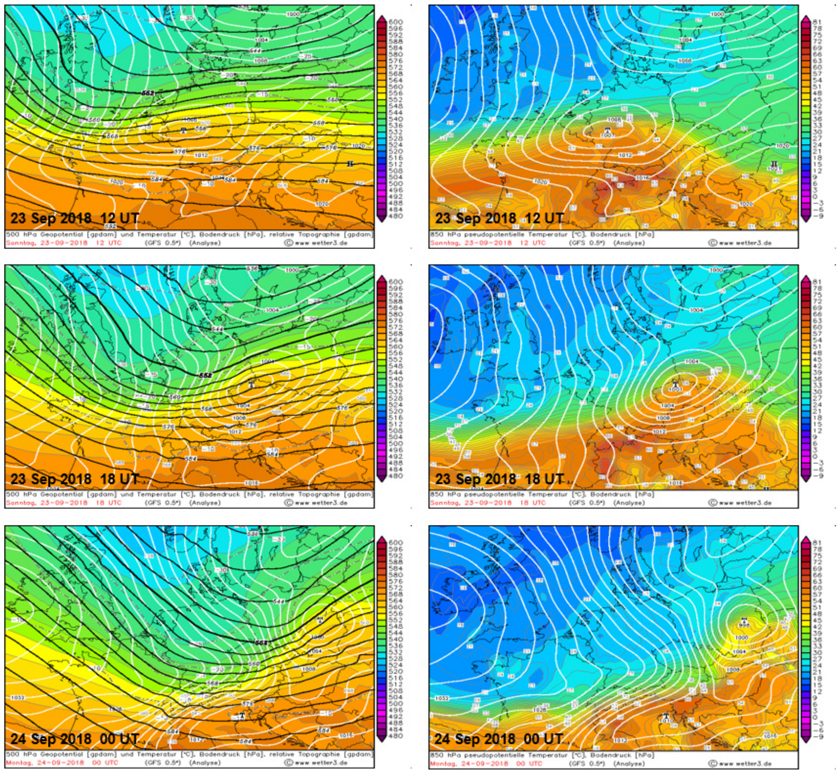

Fig. 1. Figure3

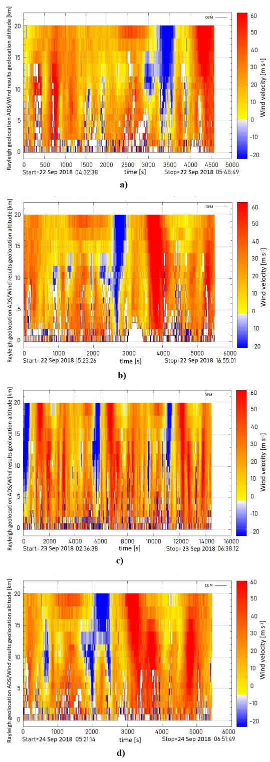

Fig. 2. Figure5

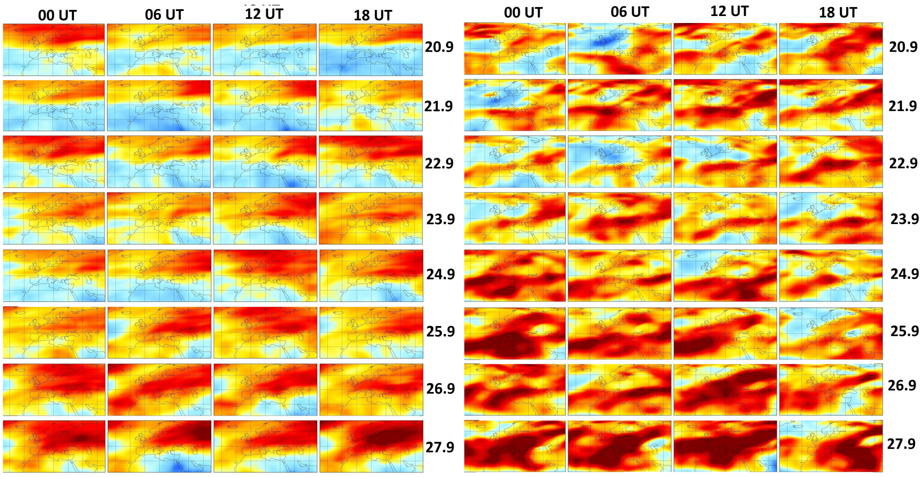

Fig. 3. Figure6

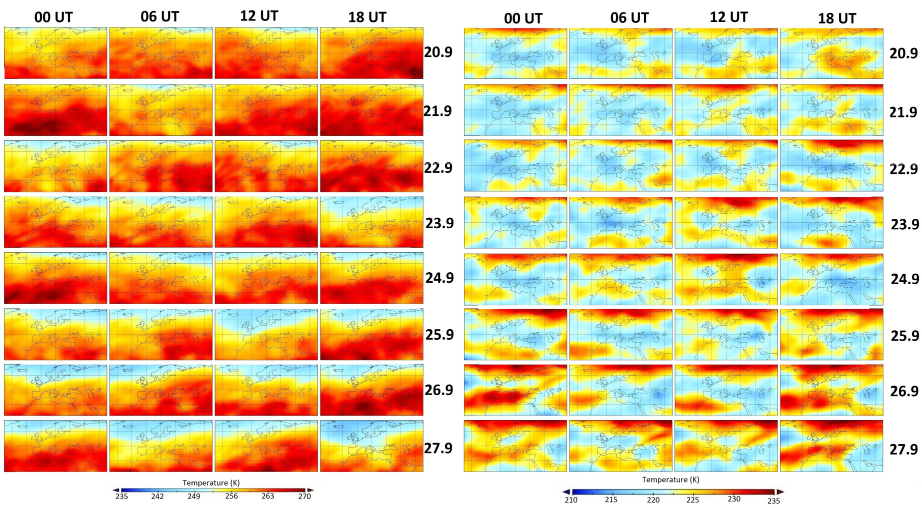

Fig. 4. Figure7

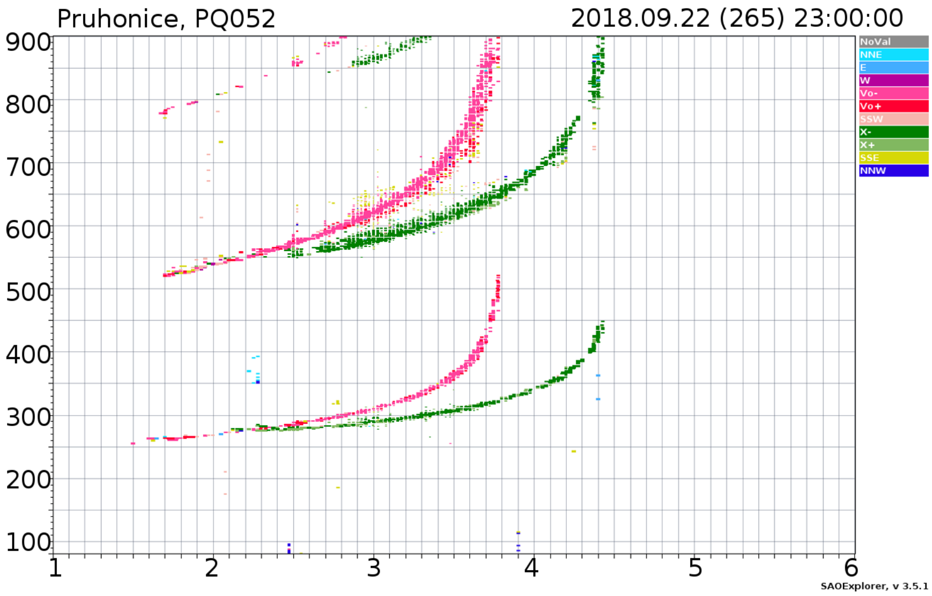

Fig. 5. Figure8a

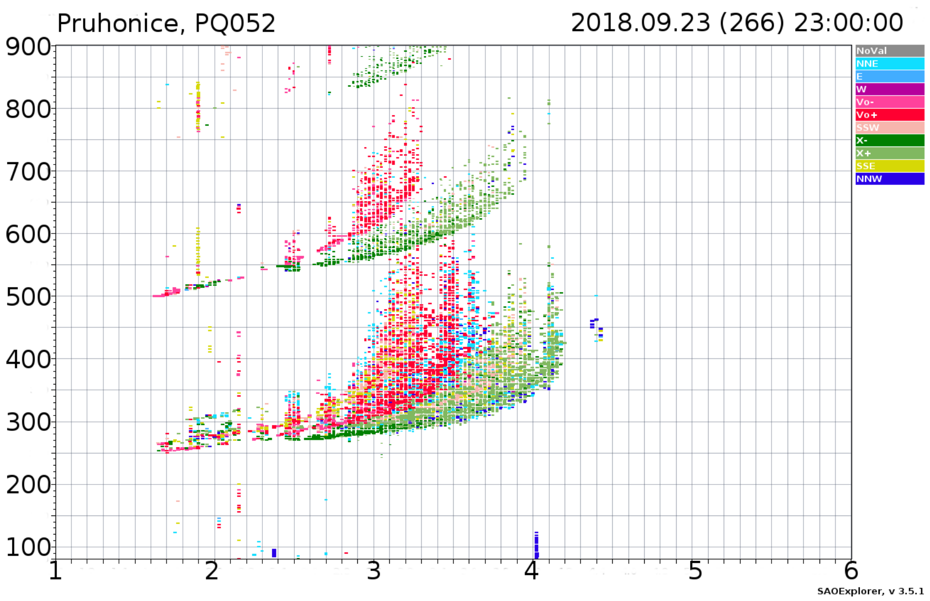

Fig. 6. Figure8b

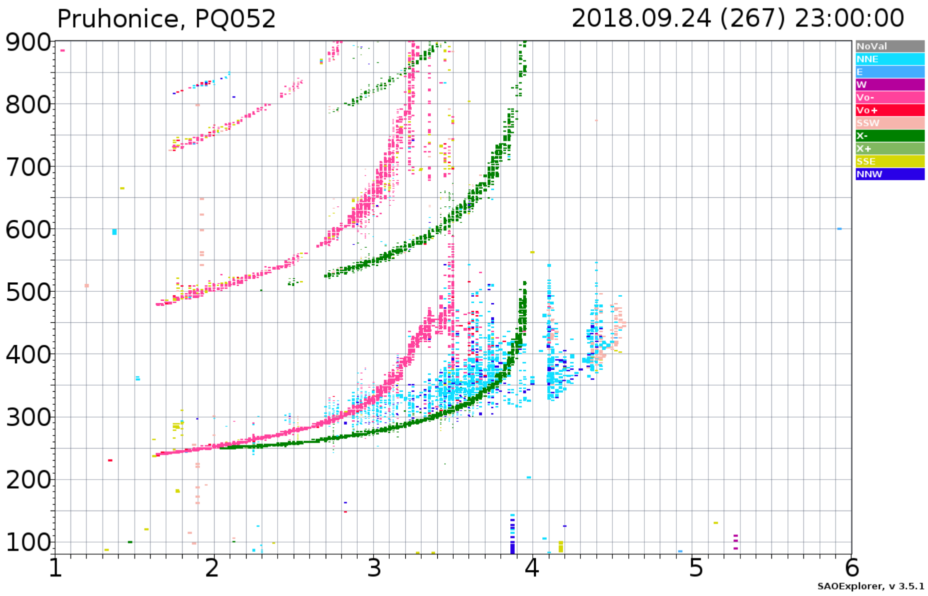

Fig. 7. Figure8c

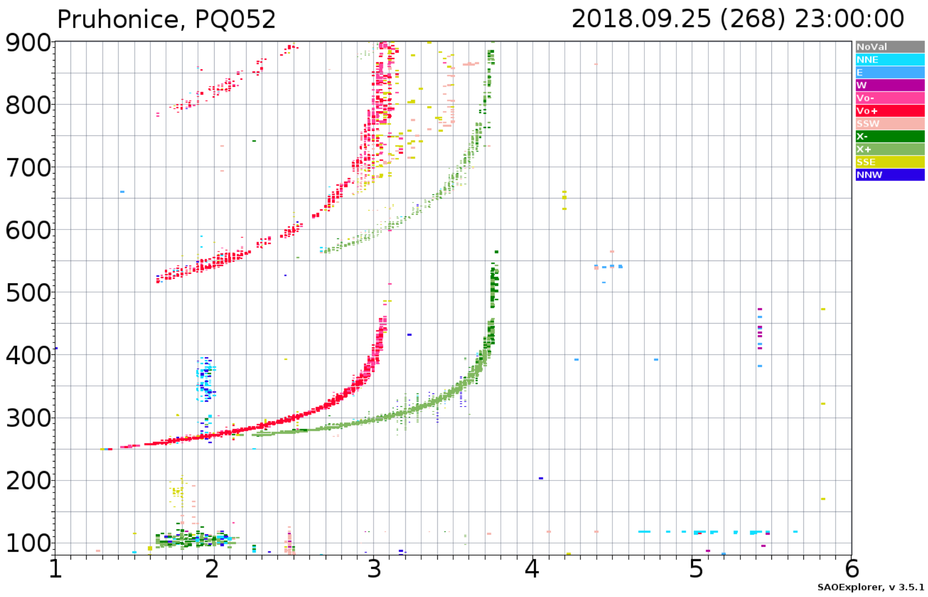

Fig. 8. Figure8d

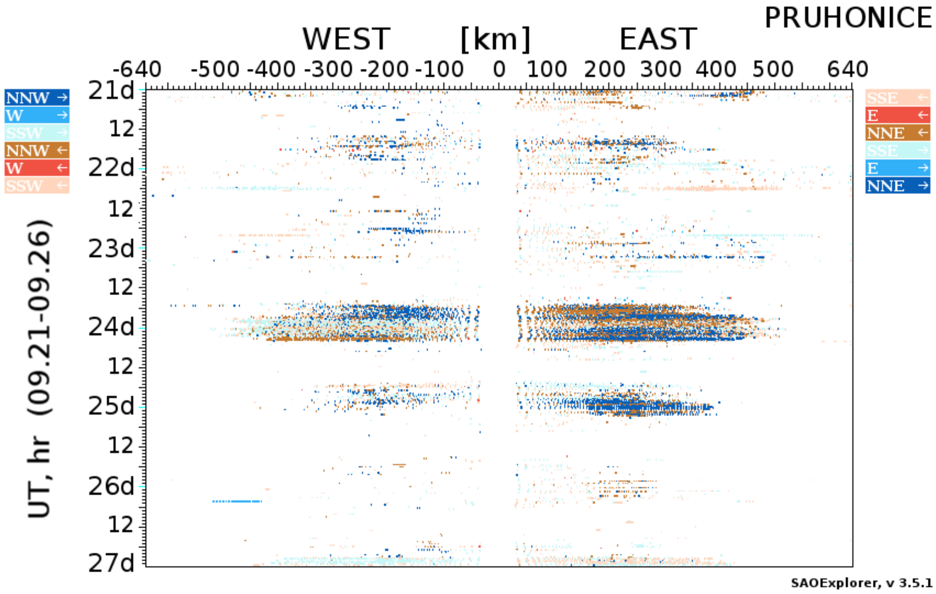

Fig. 9. Figure9

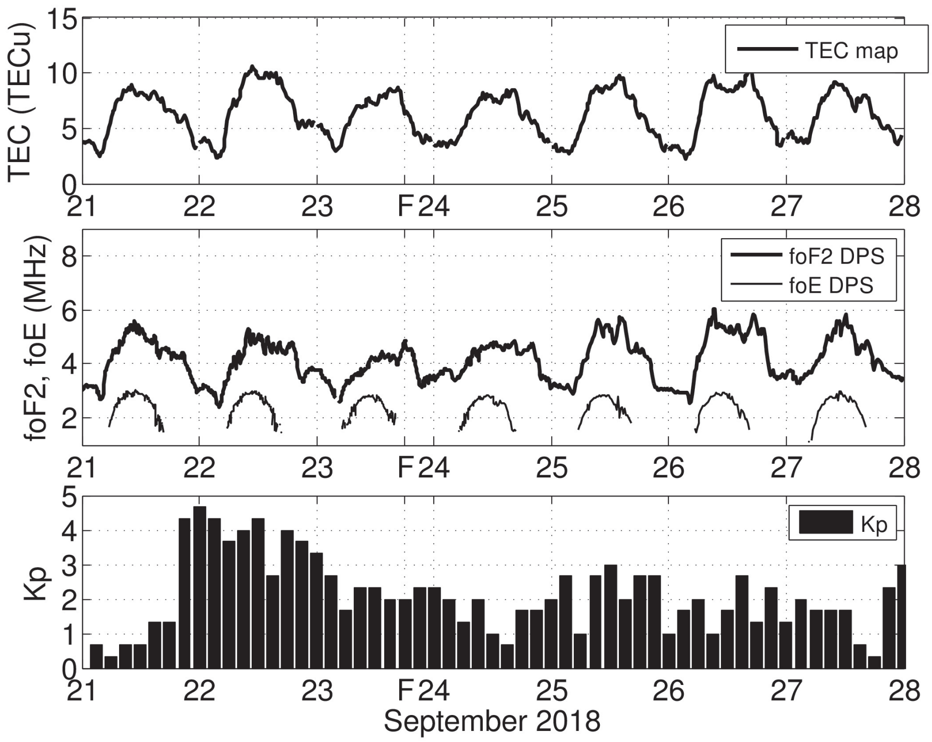

Fig. 10. Figure10

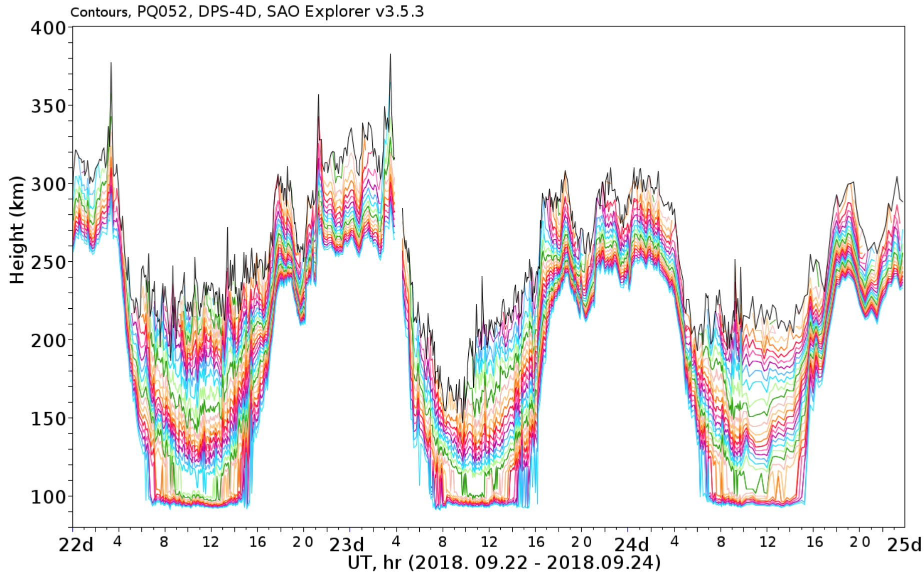

Fig. 11. Figure11

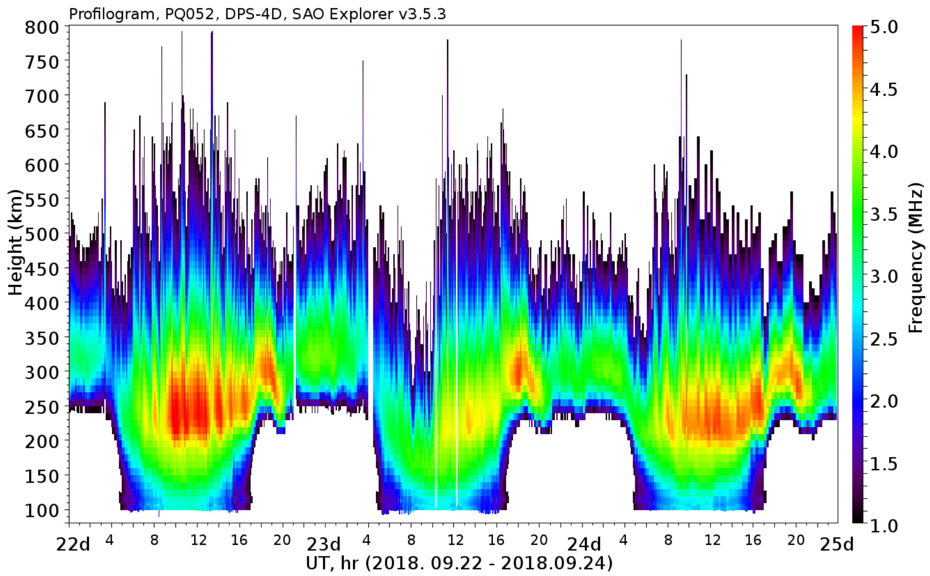

Fig. 12. Figure12

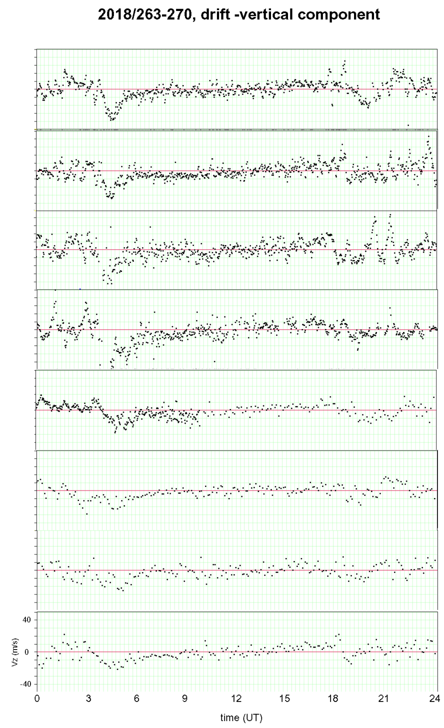

Fig. 13. Figure14a

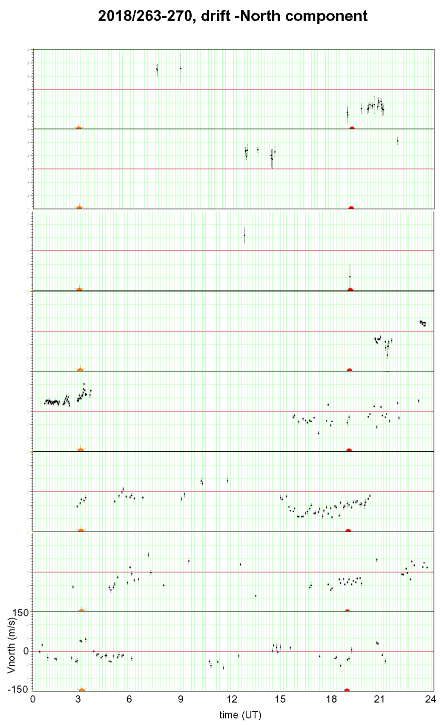

Fig. 14. Figure14b

2018/263-270, drift -East component

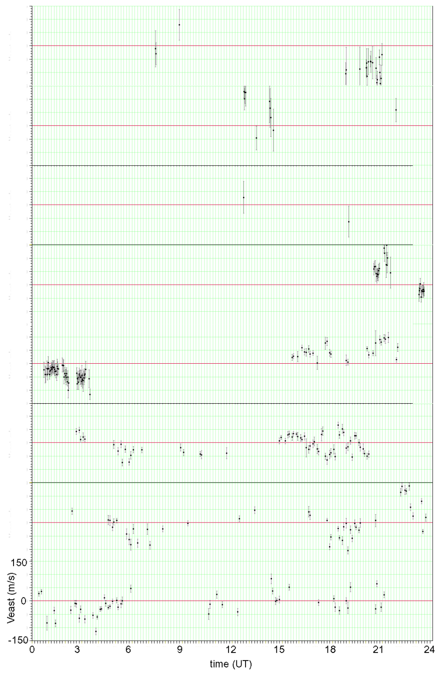

Fig. 15. Figure14c