

Studying the ionospheric absorption during large solar flare events in September 2017

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Abstract

The most intense external force affecting the ionosphere from above is related to **large solar flare events**, therefore it is of particular importance to **study their impact on the ionosphere**. During solar flares, the suddenly increased radiation causes increased ionization and **enhanced absorption of radio waves** leading to **partial or even total radio fade-out** lasting for hours in some cases (e. g., [1] [2]).

The ionospheric response to large solar flares have been investigated using the ionosonde data measured at Průhonice (PQ052, 50°, 14.6°) in September 2017, the most active solar period of Solar Cycle 24. A novel method [3] to calculate and investigate the absorption of radio waves propagating in the ionosphere is used to **determine the absorption during large solar flare events** (M and X class). Subsequently, the absorption data are compared with the indicators derived from the f_{min} method (f_{min} , the minimum frequency is considered as a qualitative proxy for the “nondeviative” radio wave absorption occurring in the D-layer). Total and partial radio fade-out and increased values (with 2-5 MHz) of the f_{min} parameter were experienced during and after the intense solar flares (> M3). The combination of these two methods may prove to be an efficient approach to monitor the ionospheric response to solar flares.

[1] Sripathi, S., Balachandran, N., Veenadhari, B., Singh, R., and Emperumal, K.: Response of the equatorial and low-latitude ionosphere to an intense X-class solar flare (X7/2B) as observed on 09 August 2011, J. Geophys. Res.-Space, 118, 2648–2659, 2013.

[2] Barta, V., Sători, G., Berényi, K. A., Kis, Á., and Williams, E. (2019). Effects of solar flares on the ionosphere as shown by the dynamics of ionograms recorded in Europe and South Africa. Annales Geophysicae, Vol. 37, No. 4, pp. 747-761

[3] Sales, G. S., 2009, HF absorption measurements using routine digisonde data, Conference material, XII. International Digisonde Forum, University of Massachusetts



Introduction

The **main objectives** of this study are:

- to use digisonde data to **determine ionospheric absorption**,
- to study the **effect of solar flares on the ionosphere** based on absorption data,
- to compare the results with the corresponding **f_{min} data**,
- and to find possible ways to **further develop the present method**.

Data

- **Digisonde data** (i.e., amplitudes, frequencies, f_{min} , etc.) from *Průhonice* (PQ052, geographic coordinates: 50°, 14.6°), Czech Republic.
- Data from **quiet** (10-27. May 2017; 08. June - 02. July 2017; and 22. October - 31. December 2017) **and disturbed periods** (06-10. September 2017).

Flares	Date	06.09.2017. 09:10	06.09.2017. 12:02	07.09.2017. 10:15	07.09.2017. 14:36	08.09.2017. 07:49	09.09.2017. 11:04	10.09.2017. 16:06
	Class	X2.2	X9.3	M7.3	X1.3	M8.1	M3.7	X8.2
	Investi- gated time period	06.09.2017. 09:10-10:15	06.09.2017. 12:00-14:00	07.09.2017. 09:54-10:30	07.09.2017. 14:36-15:00	08.09.2017. 07:48-08:00	09.09.2017. 11:00-11:45	10.09.2017. 16:00-16:30

Methodology

- Calculating the **loss term** from digisonde data according to the method presented by *Sales* (2009, [3]).
- This method involves the **calibration of the used digisonde** system at certain frequencies (i.e., at 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, and 5.5 MHz, +/-200 kHz) by using nighttime data (i.e., 20-05 LT).
- Afterwards, the **losses at the chosen frequencies can be determined**, however this approach is only eligible to detect **relative changes** in the absorption.
- The calibration was carried out based on the ***Friis transmission equation***:

$$10 \lg(L) = 10 \lg(P_t G_t G_R) + 20 \lg\left(\frac{\lambda}{4\pi 2h}\right) - 10 \lg(P_R)$$

where the unknown terms are: P_T , G_T , G_R , and $L(f)$, the power of the transmitted signal, the gain of the transmitter, the gain of the receiver, and the loss, respectively. λ is the wavelength and h is the (approximate) height of the reflection.

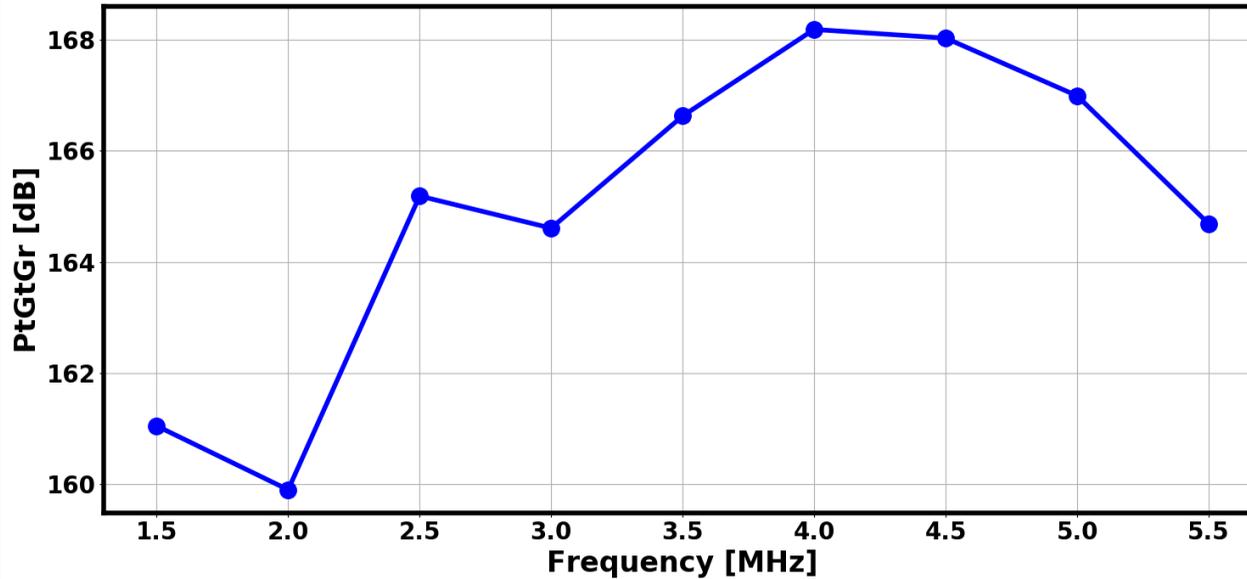
- Firstly, **we determined the $P_T G_T G_R$ product at the given frequencies (calibration)** for **nighttime data** from a **quiet period** (10-27. May 2017; 08. June -02. July 2017; and 22. October - 31. December 2017; 114 days in total).

[3]: Gary Sales: D-region absorption normal and solar flare using the digisonde; oral presentation at the XIII. International GIRO Forum, Lowell MA USA, 10-13 May 2011

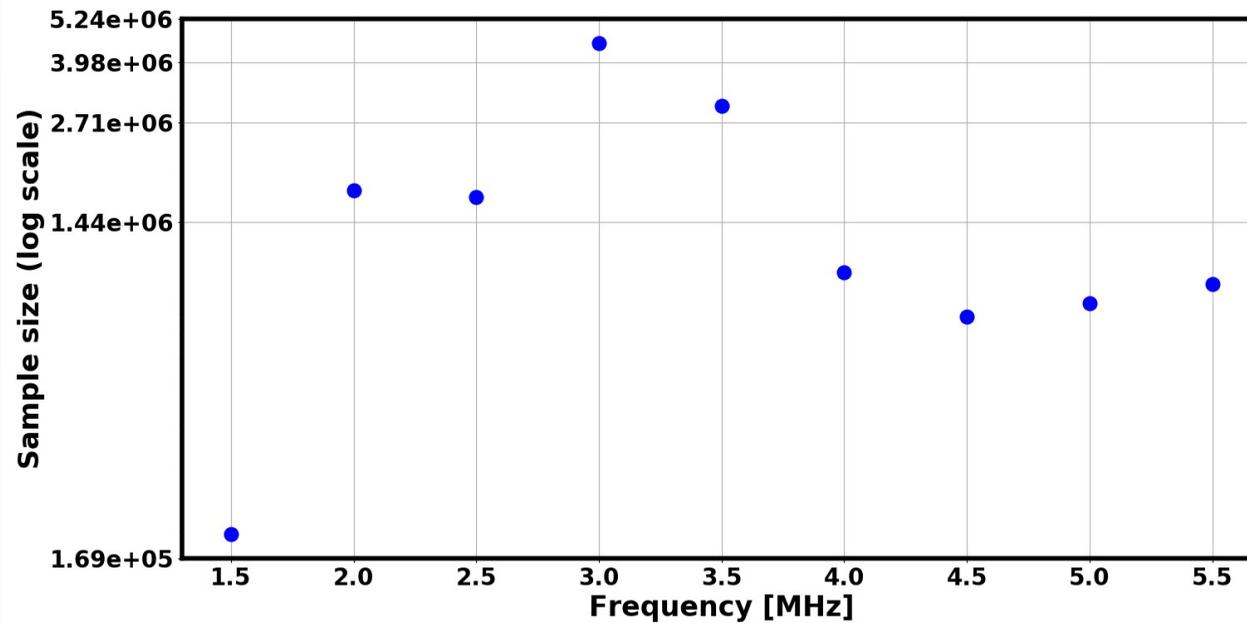


Calibration

- Calibration of the digisonde system

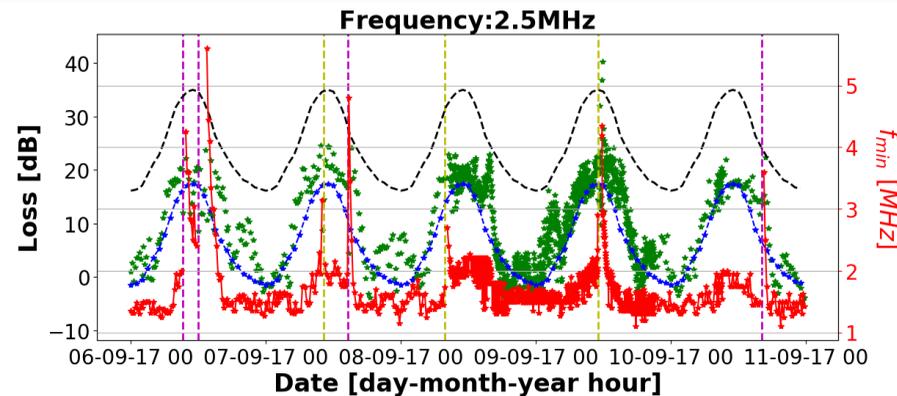
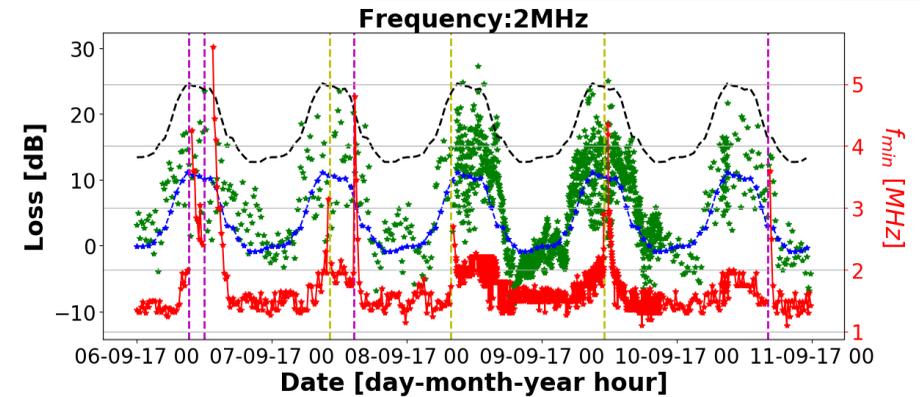
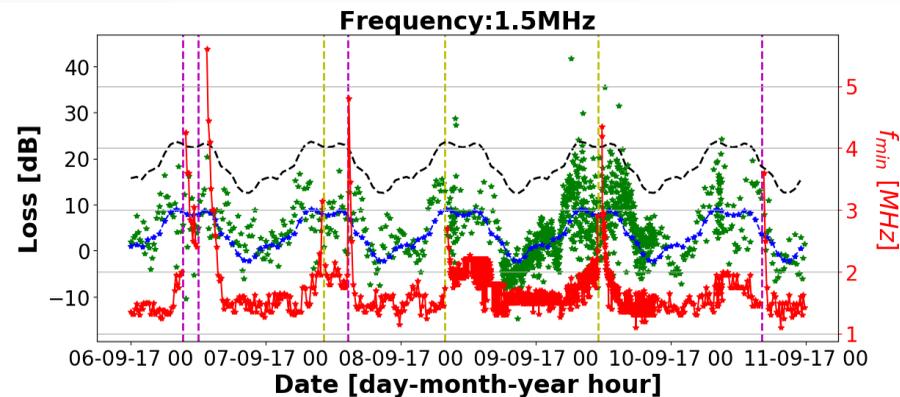


- Sample sizes of the data used in the calibration



Results – diurnal variation

- After calculating the $P_T G_T G_R$ product **we determined the loss term and compared it to the f_{min} parameter.**
- Please note that the “*Mean diurnal variation of the loss*” is the mean diurnal variation of the loss taken from data of the quiet period and the “ $2*std$ ” is two times the standard deviation of the quiet period data that was derived after the removal of the diurnal cycle.



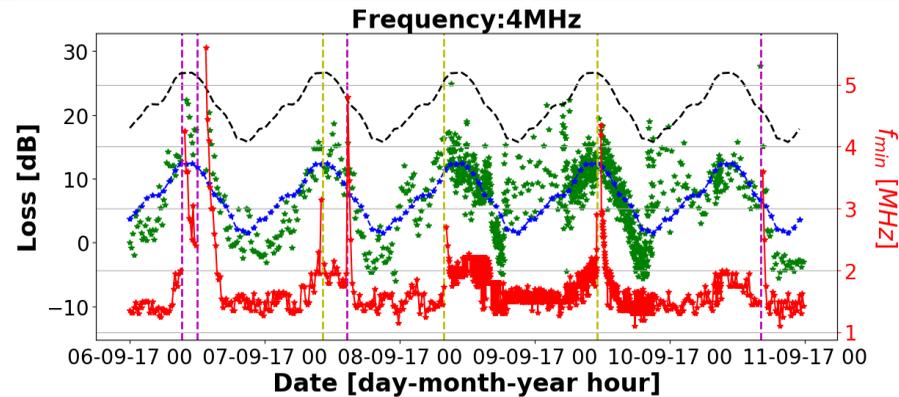
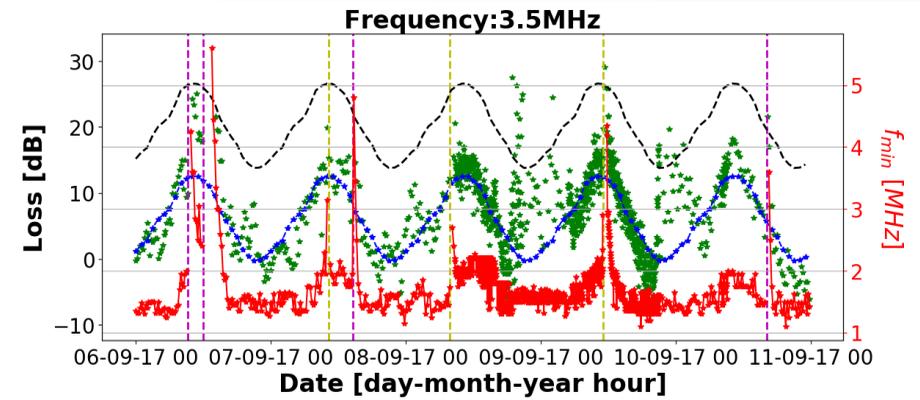
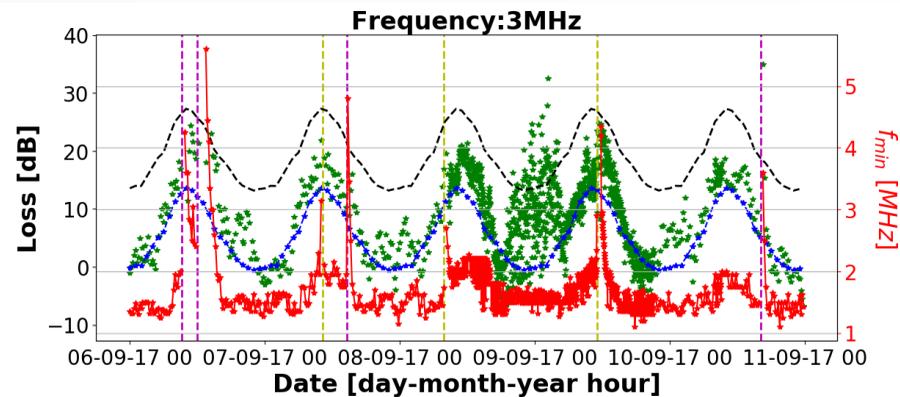
—• f_{min} - - - Mean diurnal variation of the loss, quiet period - - - M-class flares
• Loss, disturbed period - - - X-class flares - - - Quiet period median + 2*std

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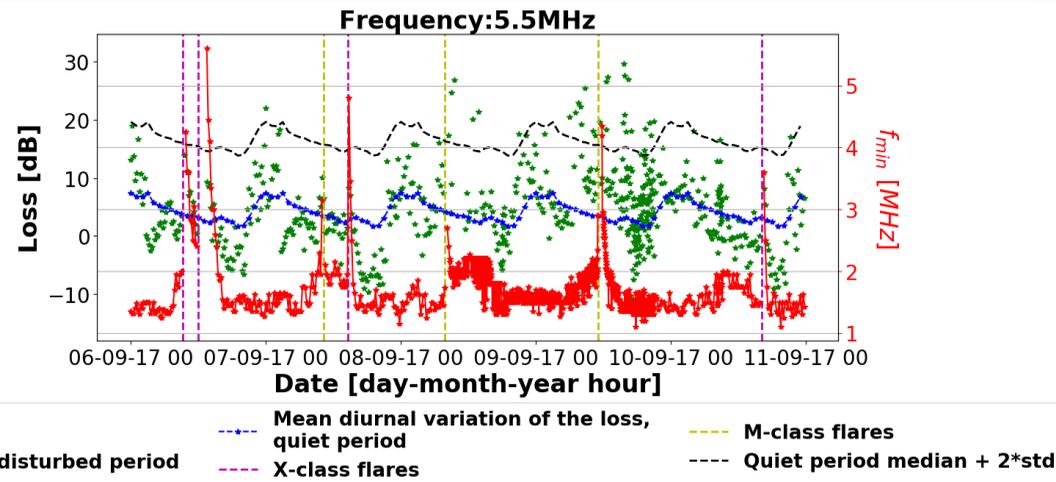
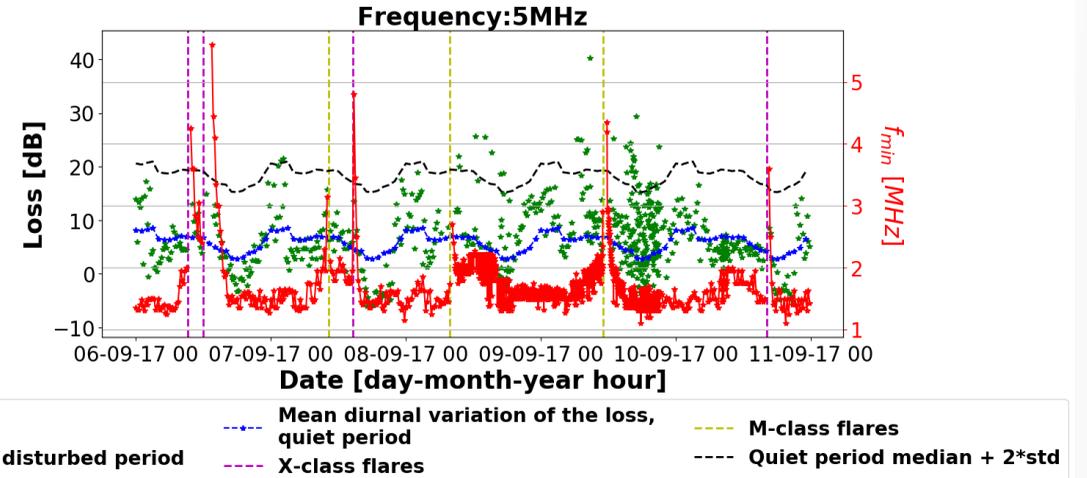
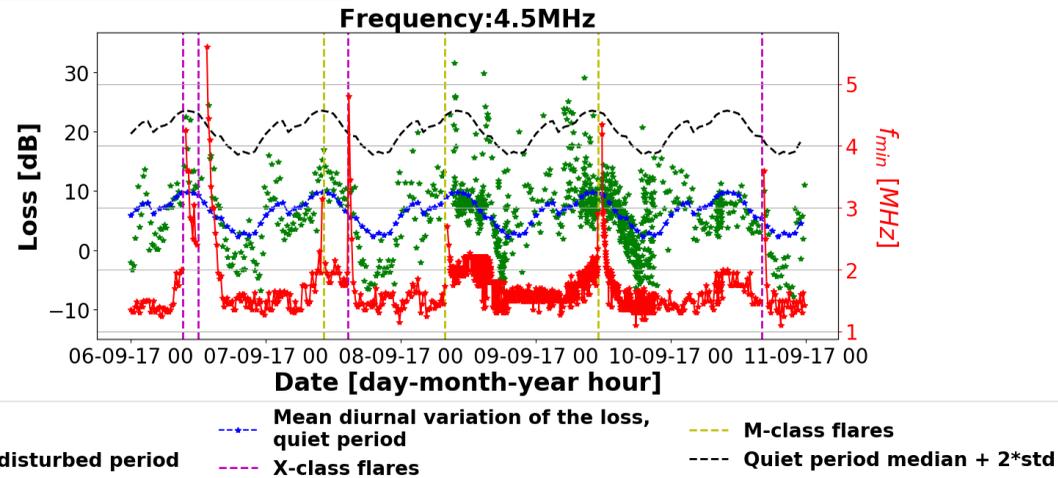
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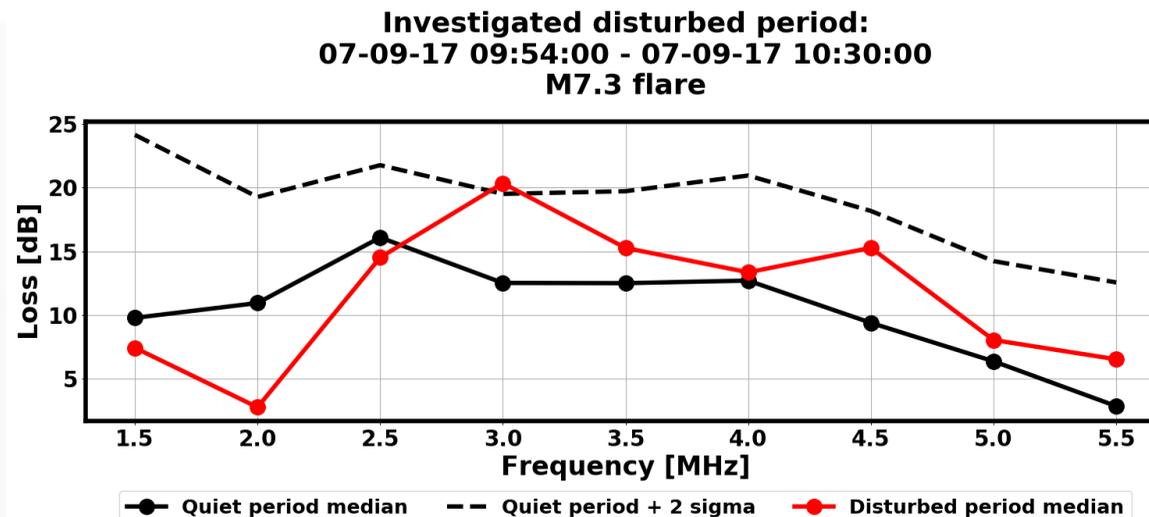
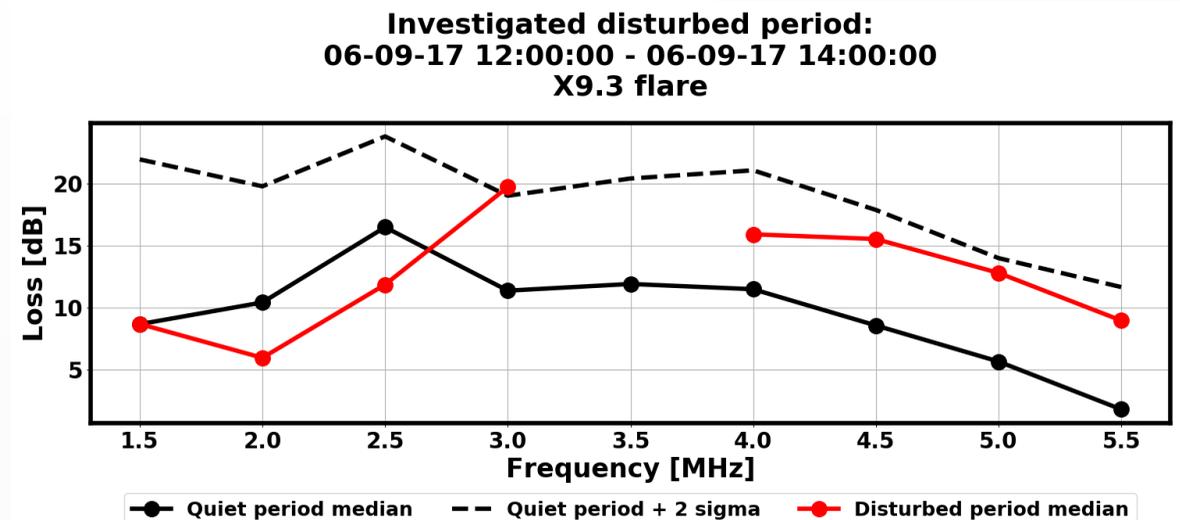
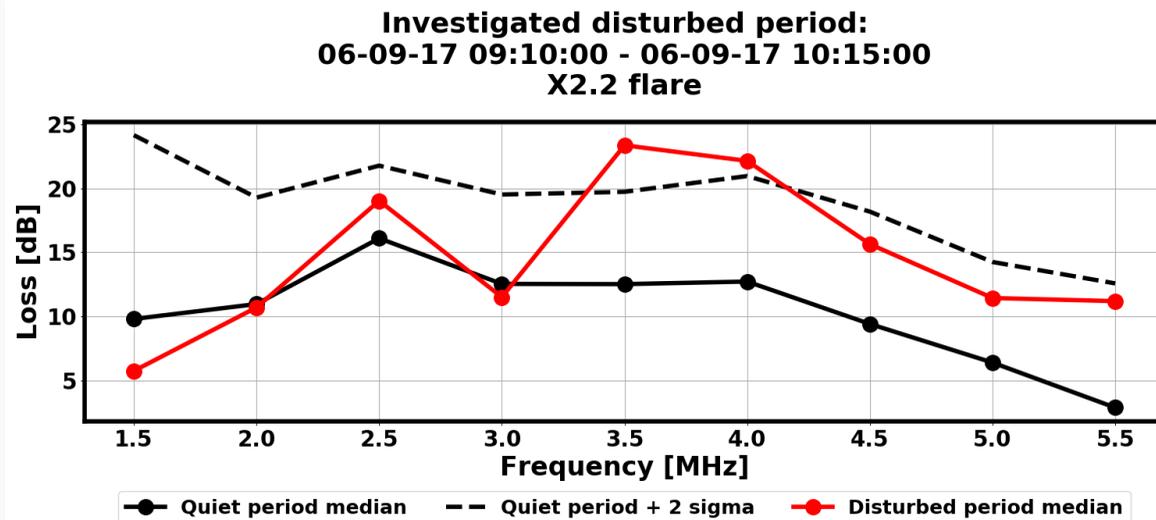


Results – diurnal variation



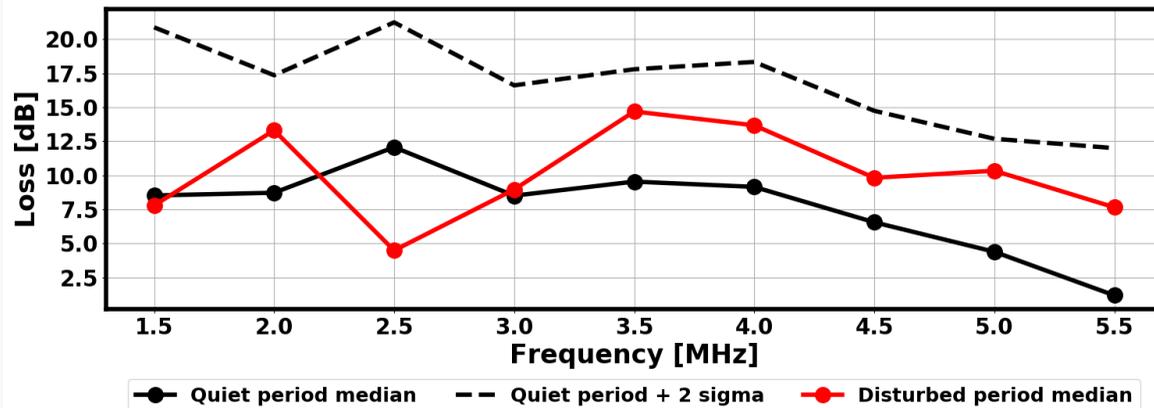
Results – impact of the flares

- Subsequently, **we analyzed the impact of the selected solar flare events** based on the determined loss.
- Please note, that the “*Quiet period median*” and “*Quiet period + 2 sigma*” (2*standard deviation) were taken from data from the quiet period in the same part of the day as in the flare effect was studied. The “*Disturbed period median*” denotes the median of the data from the time period indicated in the title of each figure.

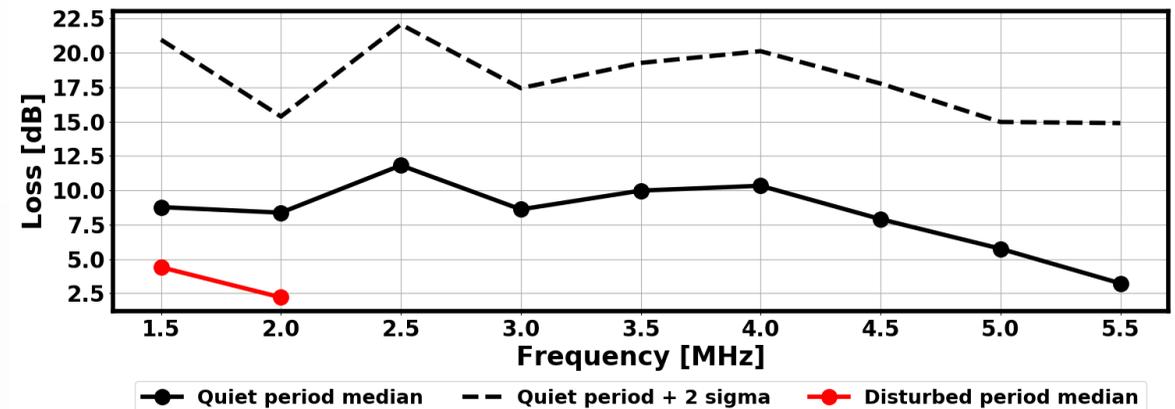


Results – impact of the flares

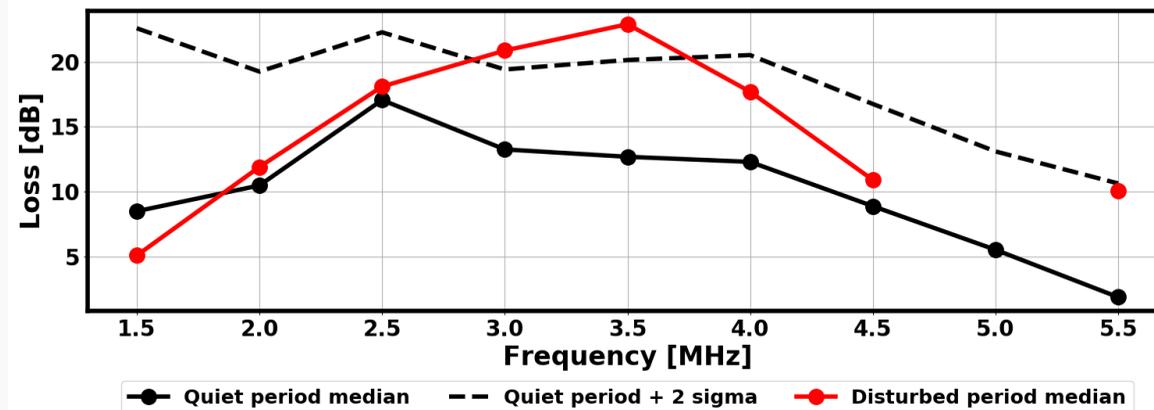
Investigated disturbed period:
07-09-17 14:36:00 - 07-09-17 15:00:00
X1.3 flare



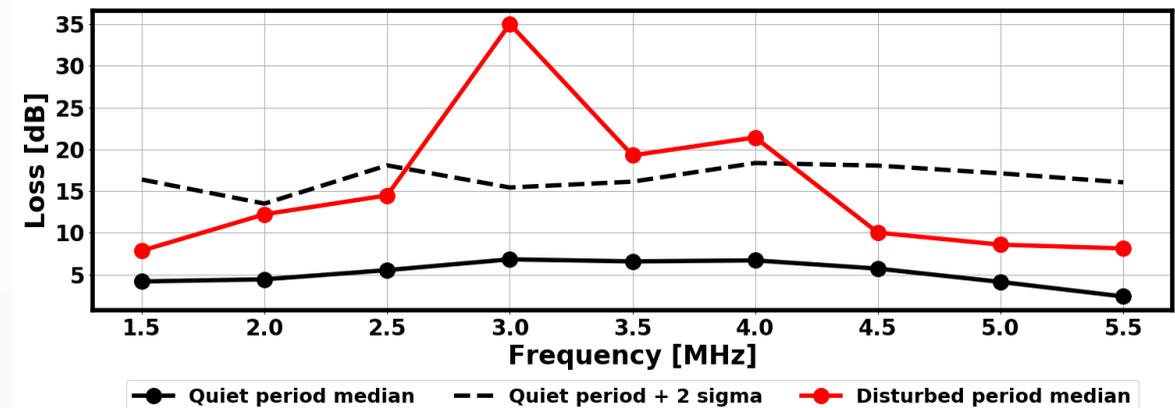
Investigated disturbed period:
08-09-17 07:48:00 - 08-09-17 08:00:00
M8.1 flare



Investigated disturbed period:
09-09-17 11:00:00 - 09-09-17 11:45:00
M3.7 flare



Investigated disturbed period:
10-09-17 16:00:00 - 10-09-17 16:30:00
X8.2 flare



Conclusions

- With the method proposed by *Sales* [3] **we were able to determine the relative ionospheric loss of HF radio waves based on digisonde data.**
- In some cases, the ionospheric loss **increased significantly during** larger (M- and X-class) **solar flares**. However, based on the data and methods used in the present study, **this behaviour is not unambiguous**. In some cases, there were not data for given frequencies probably because of partial or total radio fade-outs. In these periods the loss term becomes virtually infinite.
- Furthermore, in the present study the calculated loss **was not corrected** for effects that might have an important role in determining the true variation of the loss (e.g., focusing-defocusing). This might lead to the fact, that the calculated loss was not significant even in cases of large flares.
- **The calculated ionospheric loss and the f_{min} parameter shows similar behaviour**, with increased values during daytime than nighttime and an enhancement during the flare events.
- **At higher frequencies** (i.e., ≥ 4 MHz) **the diurnal variation of the loss** during undisturbed periods **is not so well characterized** as it is at lower frequencies. One of the possible explanation for this is that at higher frequencies the noise and the number of random reflection points might increase. One solution for this would be to apply height selection criteria on the data (i.e., analyzing different layers of the ionosphere).
- **Ultimately, this method could be a useful addition to studying the ionospheric response during solar flares but other corrections and selection criteria should be introduced in future research.**

Future plans

- **Extend the analysis** spatially and temporally.
- Study **differenet layers** of the ionosphere.
- Perform **corrections** on the absorption data suggested by *Sales* [3].
- **Compare** the absorption **with X-ray, EUV, and riometer data**.

Thank you very much for your attention!

Acknowledgements:

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