Investigation of the ionospheric absorption response to flare events during the solar cycle 23 as seen by European and South African ionosondes

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Ionization at the lower ionosphere (D-, E region)

- Investigation the solar flare effects on ionospheric absorption with the systematic analysis of ionograms measured at mid- and low-latitude ionosonde stations under different solar zenith angles
- Solar flare cause increased ionoization in the sunlit hemispherese
- Hard X-rays (< 1 nm) cause enhanced ionization in the D region, Soft X-ray (1-10 nm) and far UV flux (80-102.6 nm) rather enhances the ionization in the E region
- Particle ionization: solar cosmic rays, solar protons of 1–100 MeV

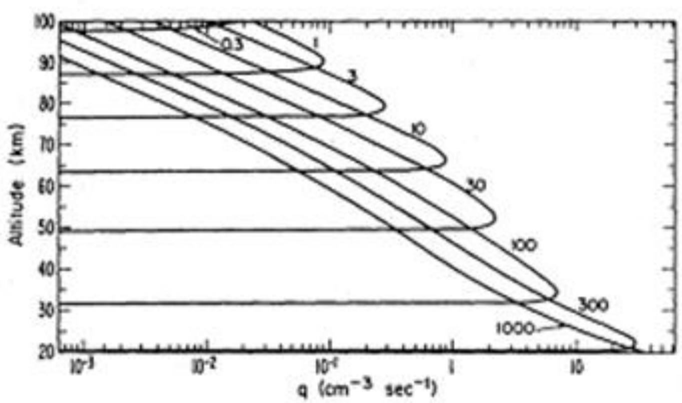


Figure 7.3. Ionization rates caused by precipitation particles: (upper panel), electrons; (lower panel), protons.

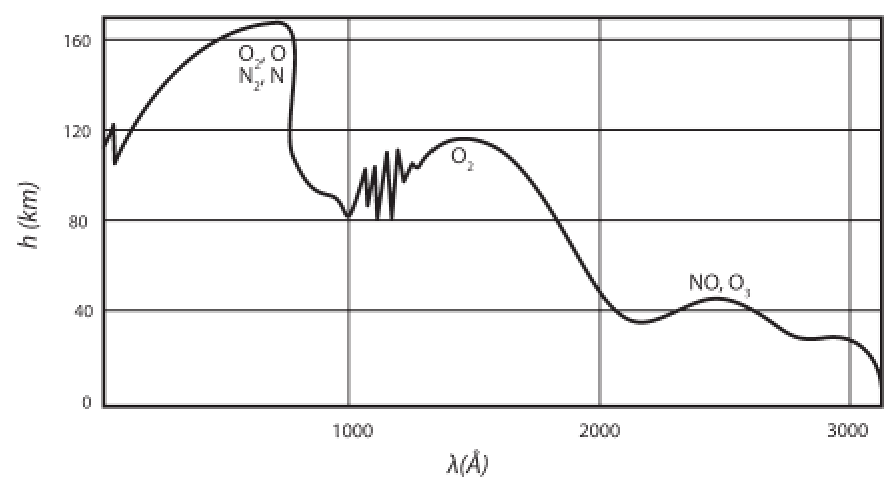


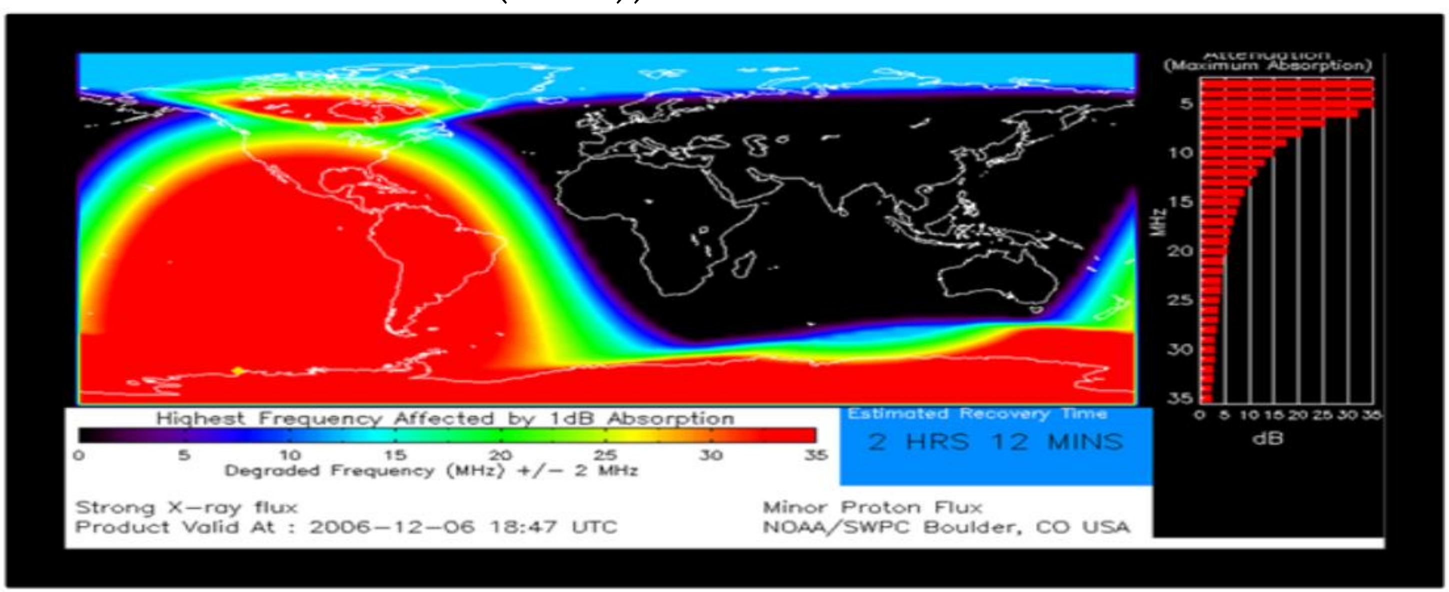
Fig. 2.24 Atmospheric absorption of solar electromagnetic radiation (from Dominici 1971)

V. Bothmer & I Daglis, Space Weather, Physics and Effects, 7.2 Chapter

B. Zolesi & L. Cander, Ionospheric Prediction and Forecasting, 2014

Ionospheric absorption

- Enhanced electron density can create increased attenuation of electromagnetic waves propagating through the ionosphere
- Ionospheric radio wave absorption: electrons accelerated by the electric field of the propagating radio waves collide with the atmospheric constituents
- D-rap model: the Space Weather Prediction Center (SWPC) has developed a model to predict the ionospheric absorption in the D-region (based on the theoretical descriptions of the ionospheric absorption by Davies (1990) and Sauer and Wilkinson (2008))



Solar zenith angle dependence of the absorption

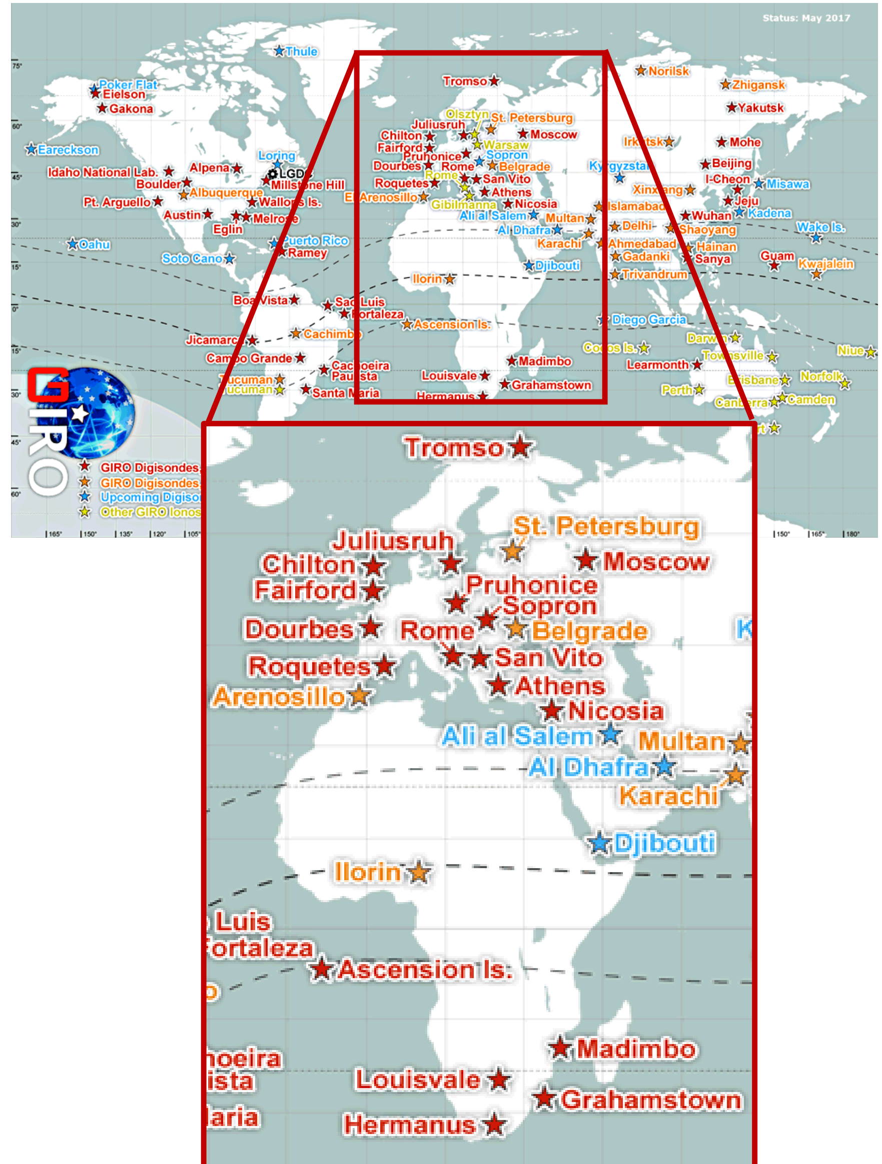
Contradictory results:

- D-rap modell: Highest Affected Frequency (HAF) is largest at the sub-solar point and it decreases with increasing solar zenith angle.
- Zhang and Xiao (2005) and Sripathi et al. (2013) have demonstrated a good correlation between the TEC enhancement caused by solar flares and the solar zenith angle
- However, Li et al. (2018) concluded that there is no strong relationship between the Ne variation of the D region (MF radar measurements) and the solar zenith angle
- Furthermore, Nogueira et al. (2015) demonstrated an abrupt increase of the TEC. The observed anomaly seemed larger and remained for a longer time in the crest region of the equatorial ionization anomaly (EIA) than at the subsolar point.

→ Goal: investigation of the solar zenith angle dependence of the ionospheric response

Data and research methodology

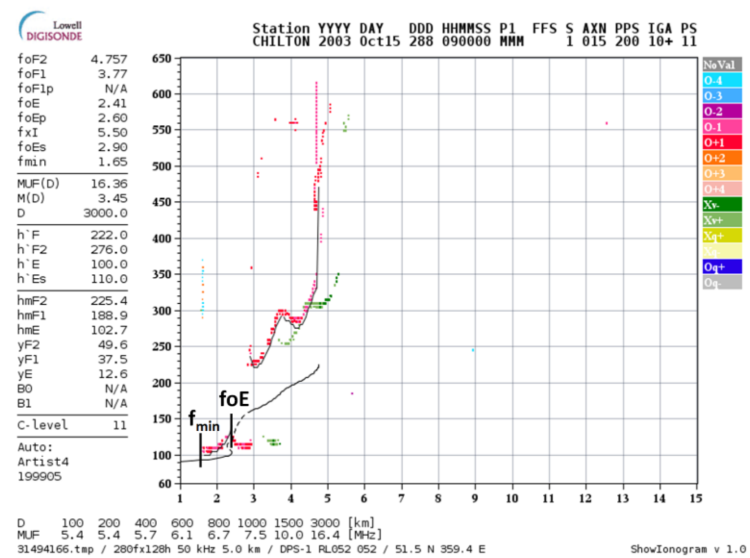
- Goal: investigate the solar flare effects on ionospheric absorption at mid- and low-latitudes during 8 X and M class flares taking into account the solar zenith angle with the systematic analysis of ionograms
- Solar data (X-ray, protons, GOES-10 and 12), ionospheric parameters from Global Ionospheric Radio Observatory (GIRO)



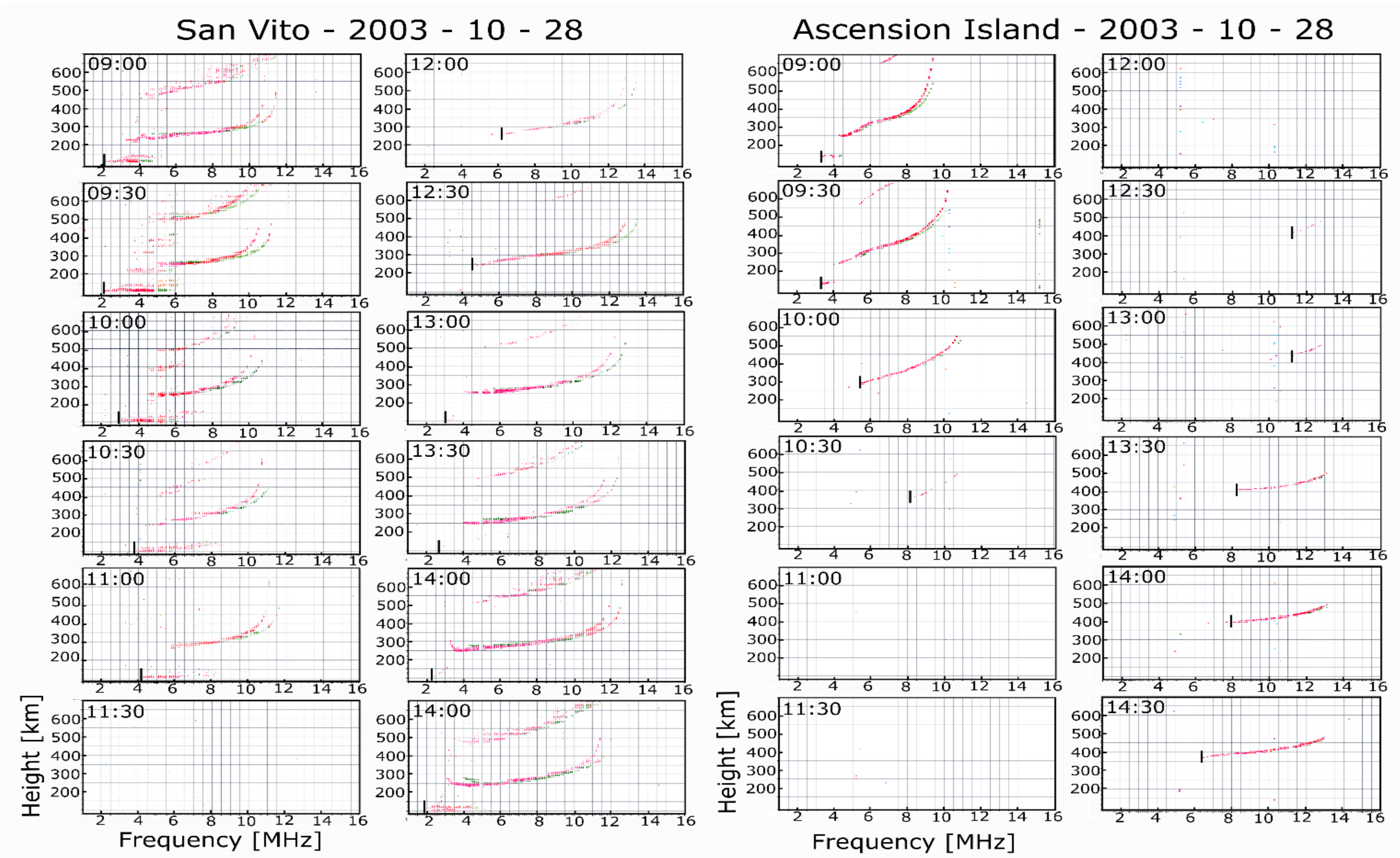
Ionospheric Station	Latitude (°)	Longitude (°)
Tromso	69.6	19.2
Juliusruh	54.6	13.4
Chilton	51.5	359.4
Pruhonice	50	14.6
Rome	41.9	12.5
San Vito	40.6	17.8
Ascension Isl.	-7.95	345.6
Madimbo	-22.39	30.88
Grahamstown	-33.3	26.5

Data and research methodology – ionosonde data

- We used ionograms measured at ionosonde stations under different solar zenith angle. The solar zenith angles of the stations at the time of the peak of the 8 flares have been determined for the analysis.
- We examined three parameters that can be determined from ionograms:
    - duration of the total radio fade-out,
    - value of the fmin parameter
    - value of the dfmin parameter
- The fmin parameter: a qualitative measure of the so called ‘‘nondeviative’’ radio wave absorption in the ionosphere [Risbeth and Gariott, 1960, Kokourov, 2006; Sharma et al, 2010; Schimmer et al, 2011].
- fmin is dependent on the radar instrumental characteristics and radio-noise level. → dfmin: difference between the value of the fmin and the mean fmin for reference days
- The analysis was repeated for ionospheric data recorded at meridionally distributed stations



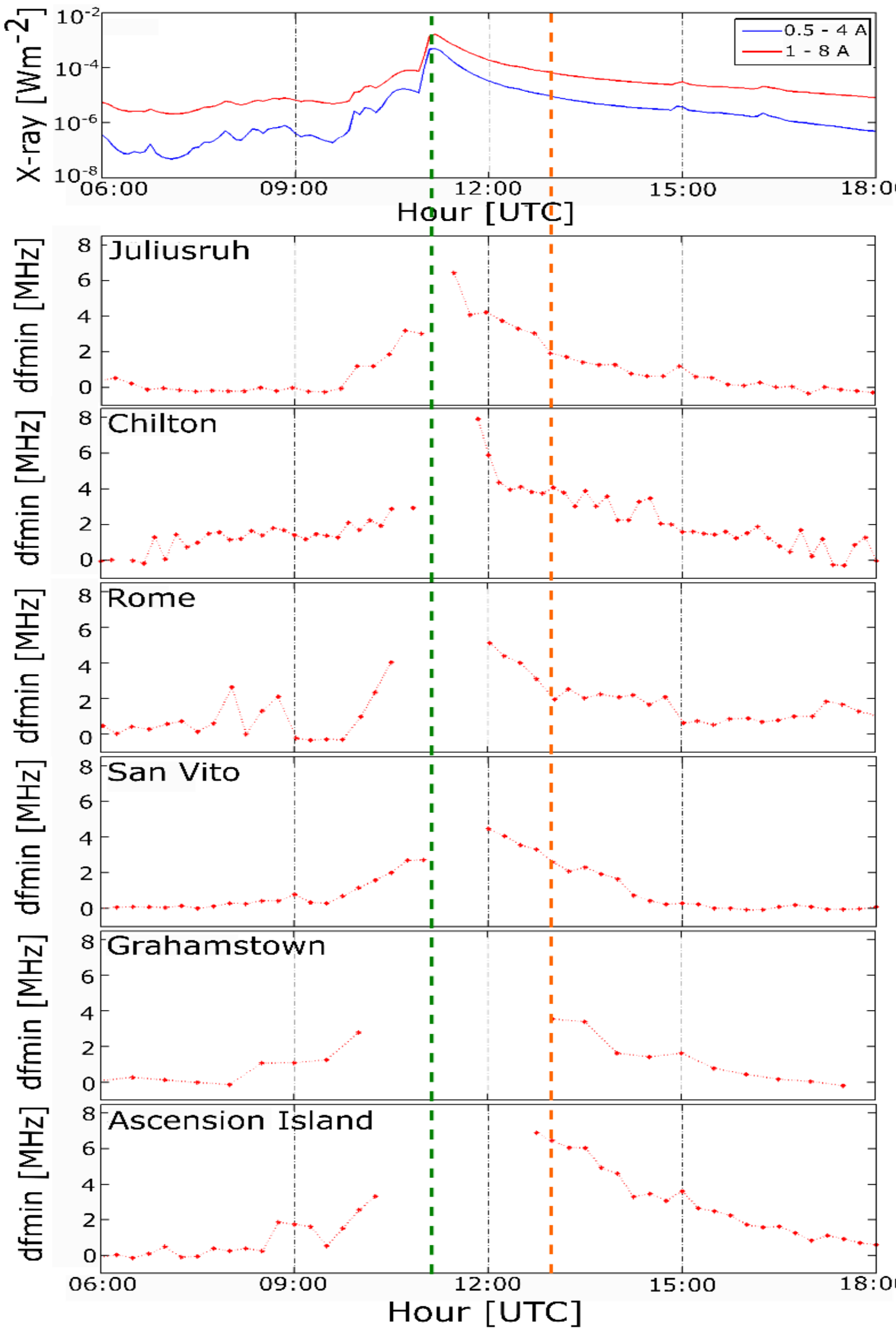
Results – ionosonde



Results – 28 October 2003

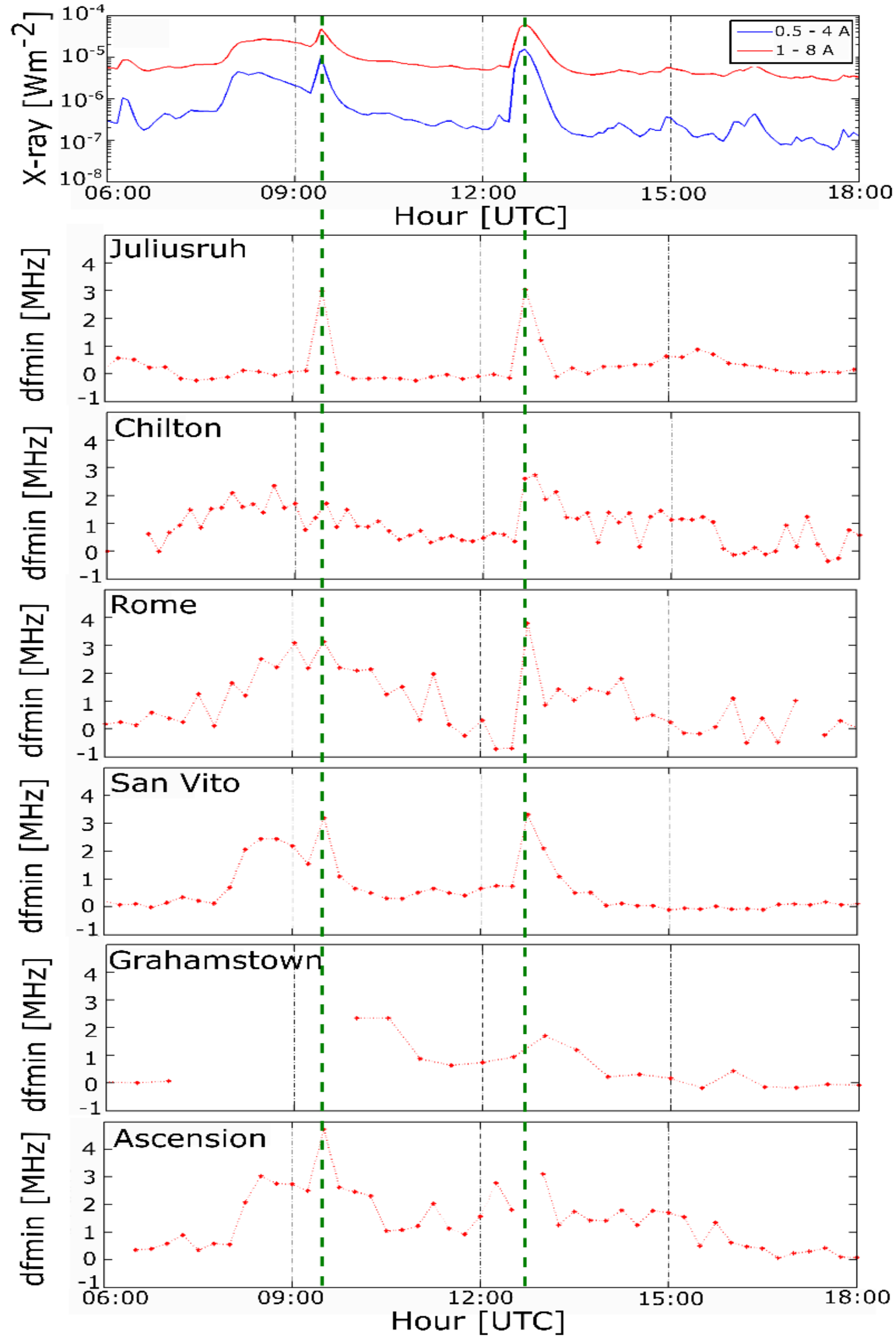
- X17-class flare
  - Total radio fade-out
  - dfmin parameter

X-ray class and time of the solar flare [UTC]				
Station name	Solar zenith angle [°]	Duration of fade-out [min]	fmin [MHz]	dfmin [MHz]
X17, 2003-10-28, 11:24				
Juliusruh	67.77	15	8.5	6.7
Chilton	65.15	50	10.4	7.8
Rome	55.07	75	8.5	5.8
San Vito	54.06	30	7.4	4.8
Grahamstown	26.09	150	6.7	4.2
Ascension Isl.	22.9	135	10.1	7

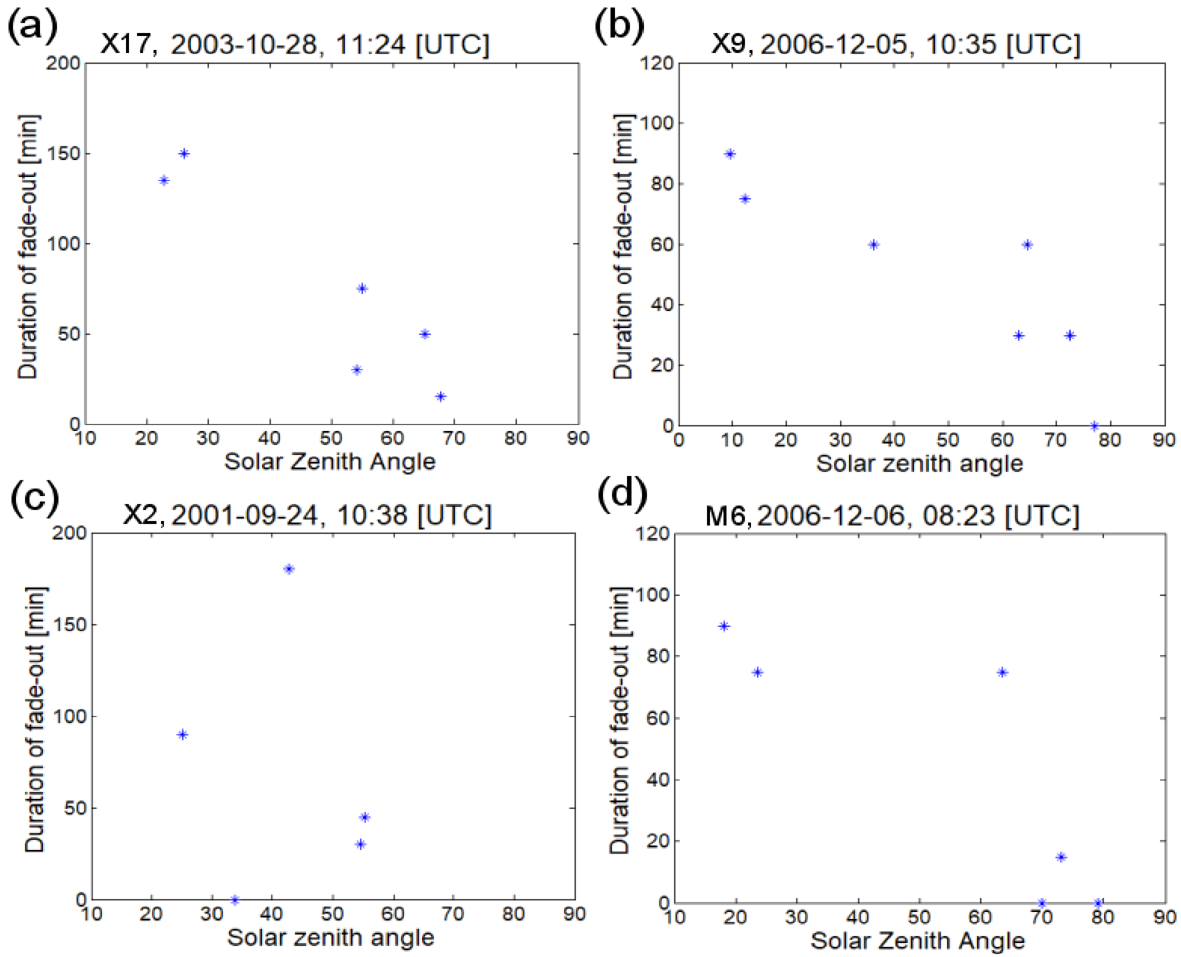


Results – 27 October 2003

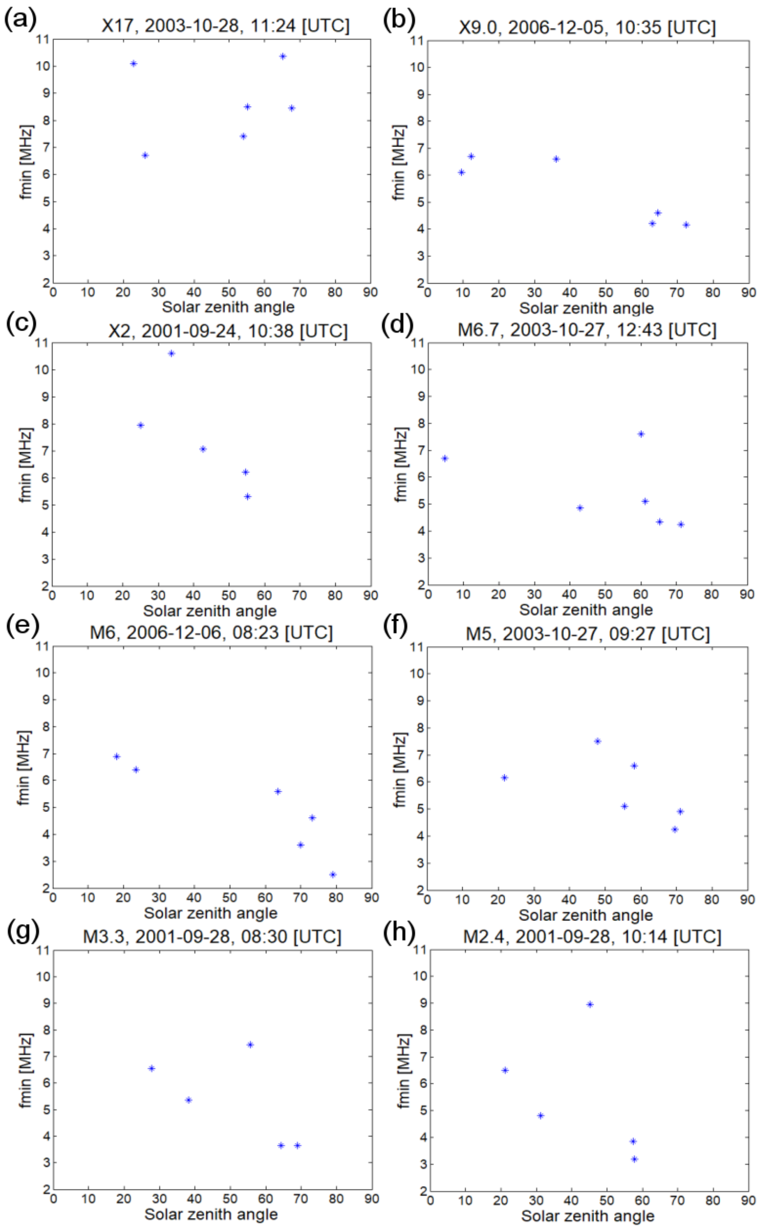
X-ray class and time of the solar flare [UTC]				
Station name	Solar zenith angle [°]	Duration of fade-out [min]	fmin [MHz]	dfmin [MHz]
M5.0, 2003-10-27, 09:27				
Juliusruh	69.56	0	4.3	3.1
Chilton	71.22	0	3.9	2.3
Rome	58.13	0	6.6	3.2
San Vito	55.41	0	5.1	3.3
Grahamstown	21.77	150	6.2	2.4
Ascension Isl.	47.96	0	7.5	4.8
M6.7, 2003-10-27, 12:43				
Juliusruh	71.41	0	4.3	3.2
Chilton	65.34	0	4.9	2.8
Rome	60.11	0	7.6	4
San Vito	61.34	0	5.1	3.4
Grahamstown	42.8	0	4.9	1.9
Ascension Isl.	4.82	15	6.7	3.1

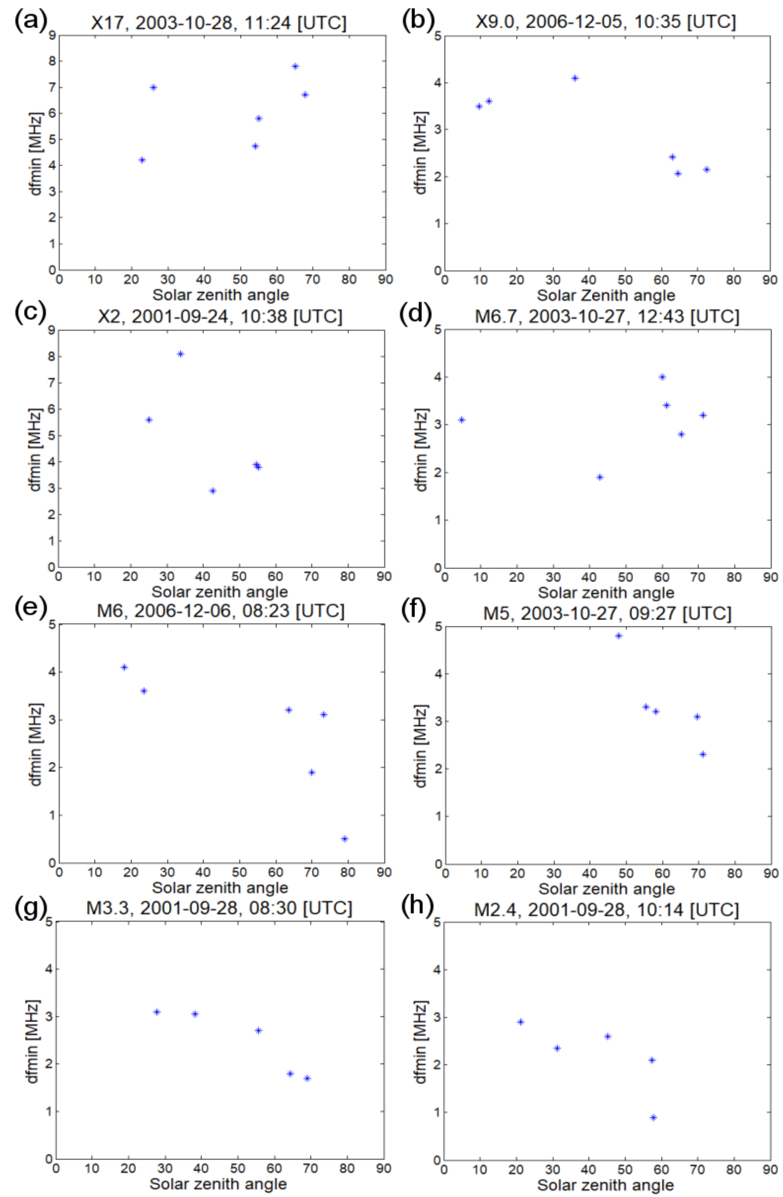


Results – ionosonde: Total radio fade-out



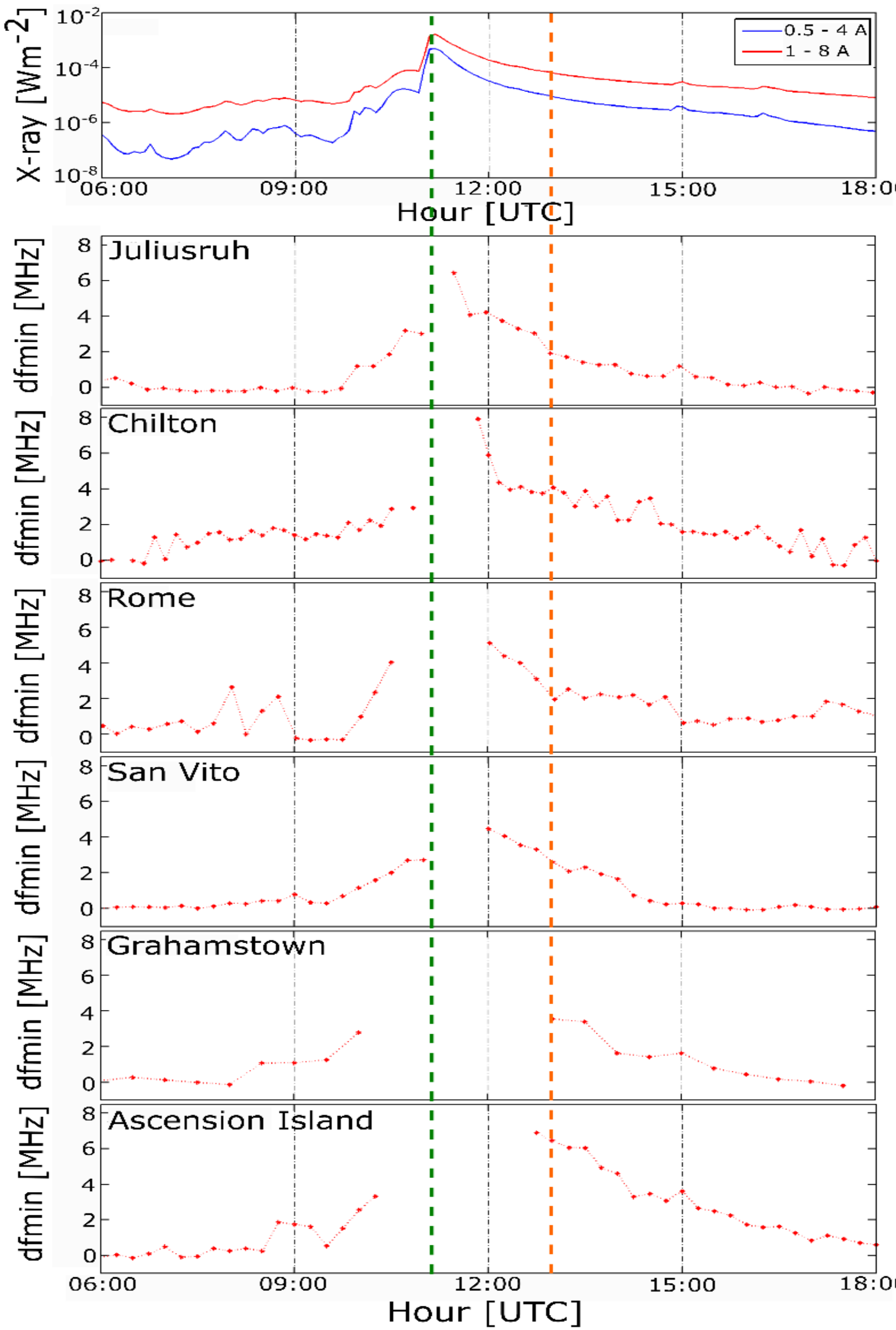
Results – ionosonde: fmin, dfmin directly after fade-out





Results – 28 October 2003

- X17-class flare
  - Total radio fade-out
  - dfmin parameter



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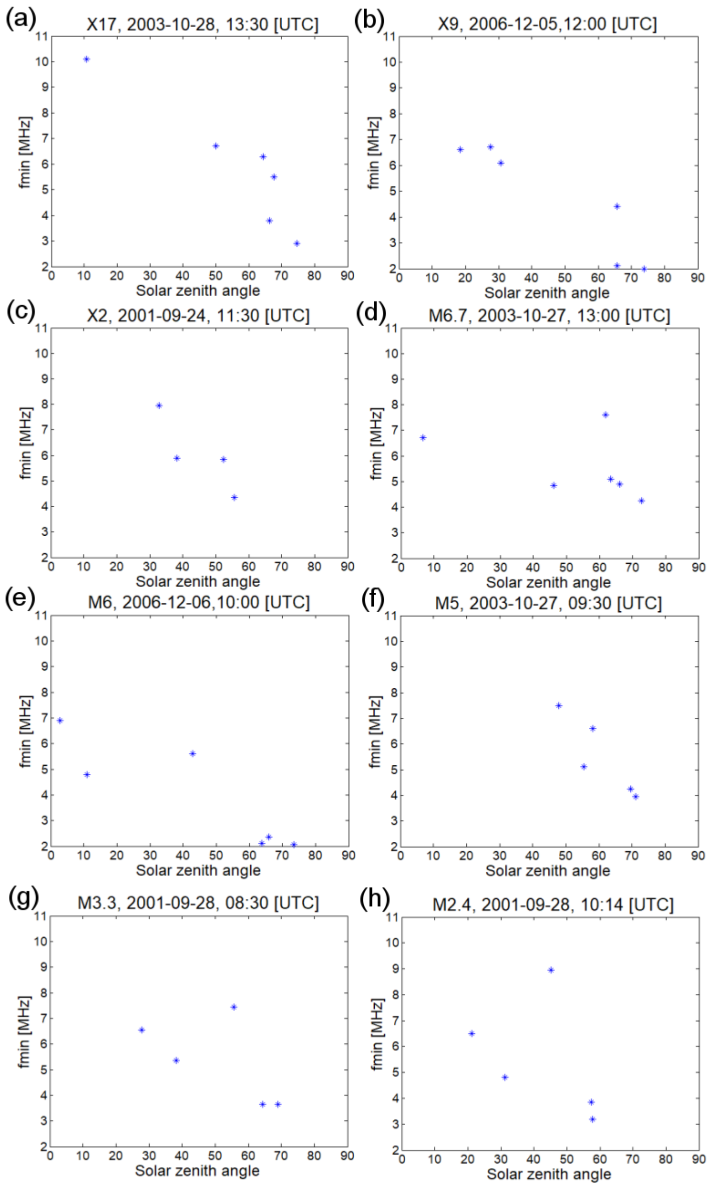
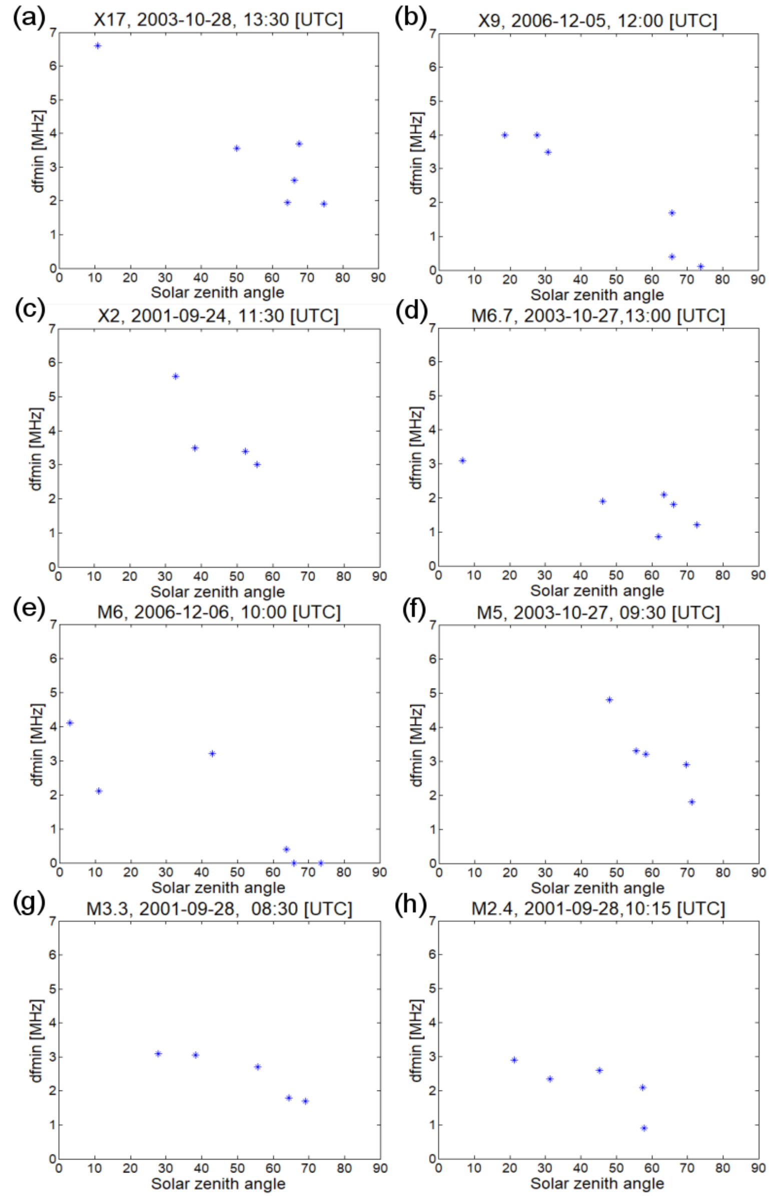
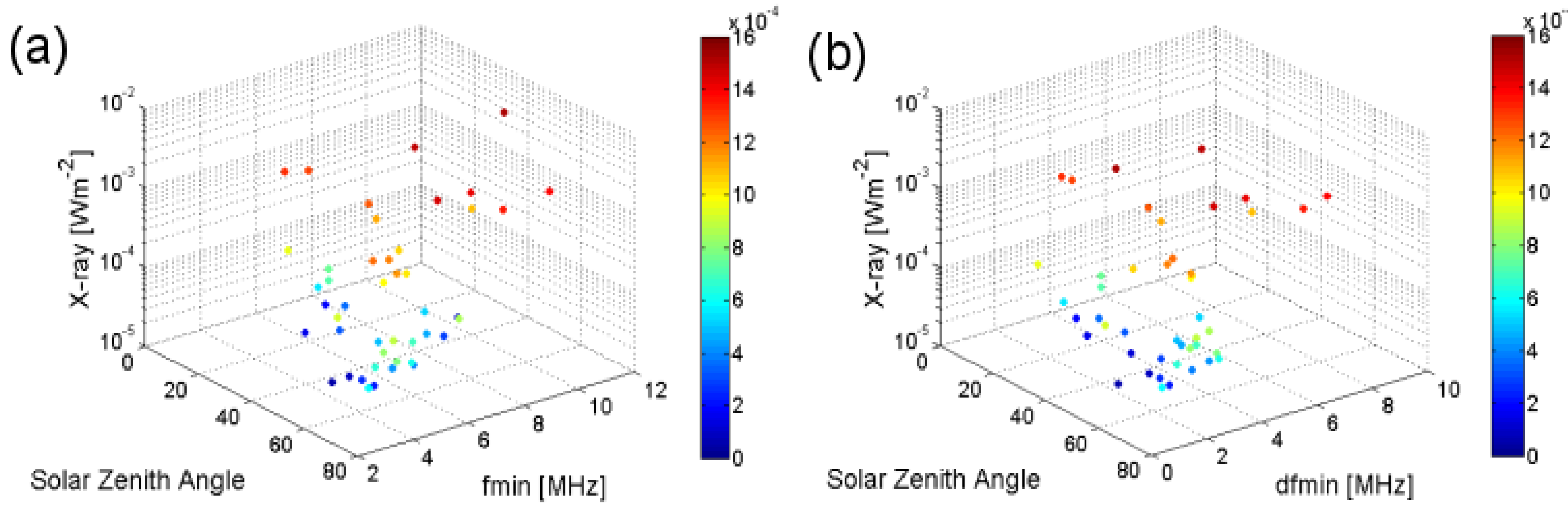
Results – ionosonde: fmin, dfmin at a later time



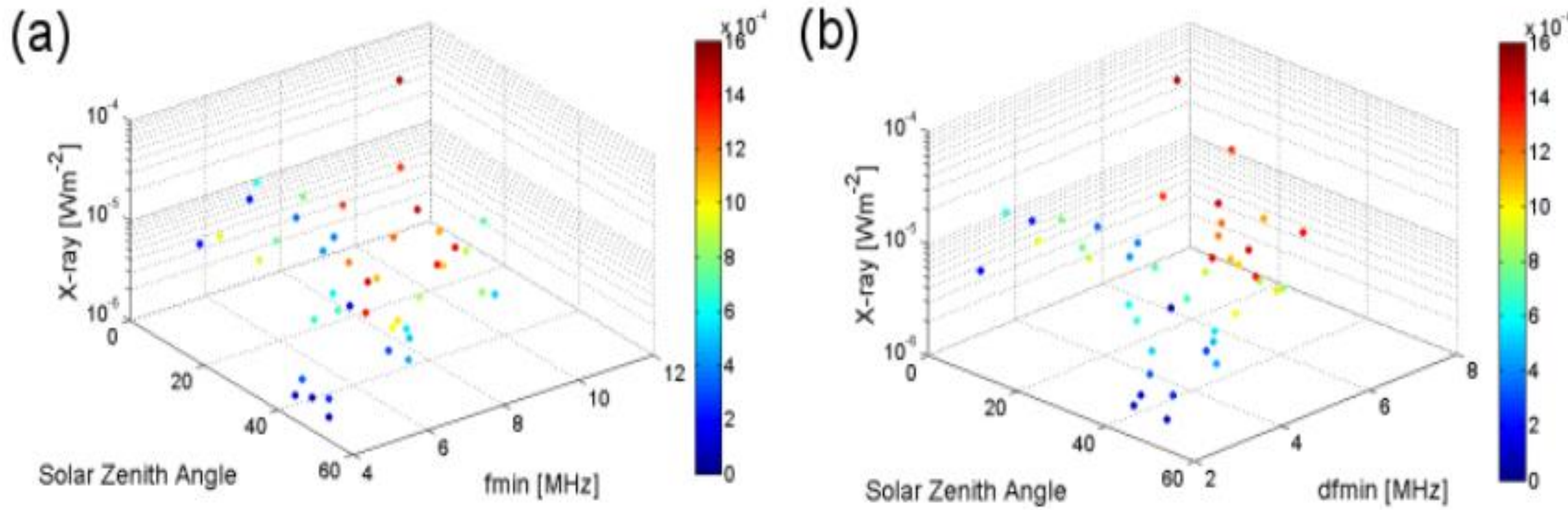


Results – intensity (fmin, dfmin just after the fade-out)



- The largest fmin (> 7 MHz) and dfmin (> 5MHz) values have been detected during the X-class solar flares (X-ray radiation > 2.61E-04 Wm^{-2}) and at the stations with low (< 40 °) solar zenith angle.

Results – intensity (fmin, dfmin measured later)



- Larger dfmin values (> 4.5 MHz) are related to the measurements when the X-ray radiation exceeded 3.4E-05 Wm^{-2}.
- The lowest fmin and dfmin values were when the X-ray radiation was weaker (< 1.33E-05 Wm-2) and the solar zenith angle was above 35 °

Summary

- A solar zenith angle dependent increase of the radio absorption was observed at the European and South-African region during 8 X and M class solar flares using ionograms measured at meridionally distributed ionosonde stations.
- Total and partial radio fade-out was experienced at every ionospheric stations during intense solar flares (> M6). The duration of the total radio fade-out varied between 15 and 150 min and was highly dependent on the solar zenith angle of the ionospheric stations.
- A solar zenith angle-dependent enhancement of the fmin (2-9 MHz) and dfmin (1-8 MHz) parameters was observed at almost every stations at the time of the flare events.
- The observed values of the fmin and dfmin parameters show an increasing trend with the enhancement of the X-ray flux.
- Our observations confirm the results of Zhang and Xiao (2005), Sripathi et al. (2013) and the D-RAP model that the solar zenith angle plays an important role in the ionospheric response to solar flares.

Barta et al. 2019, ANGEO (under review, https://www.ann-geophys-discuss.net/angeo-2019-14/)

Thank you!

Acknowledgement

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