

# Multi-instrumental investigation of the solar flares impact on the ionosphere occurring in December 2006

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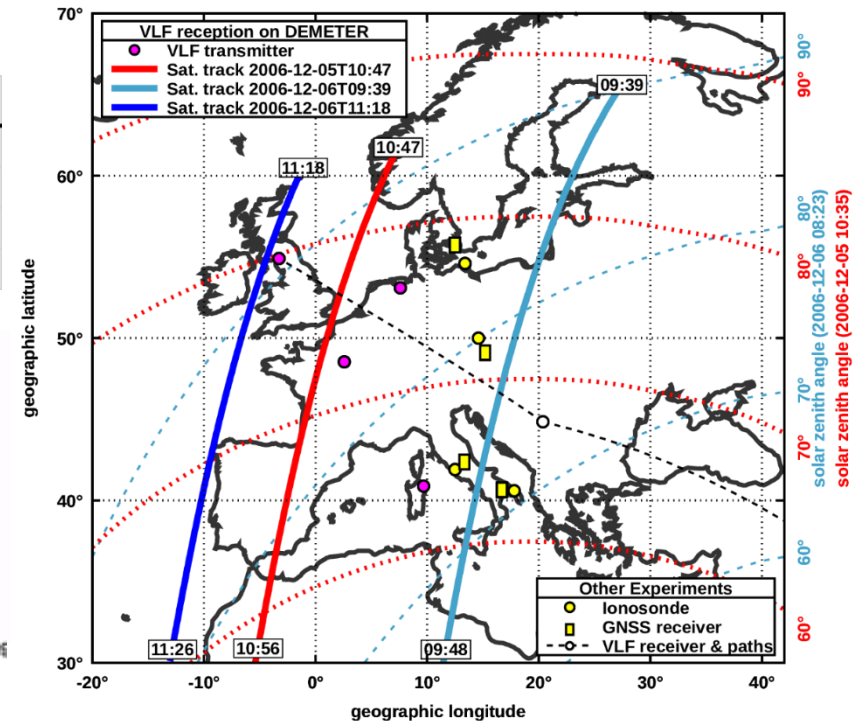
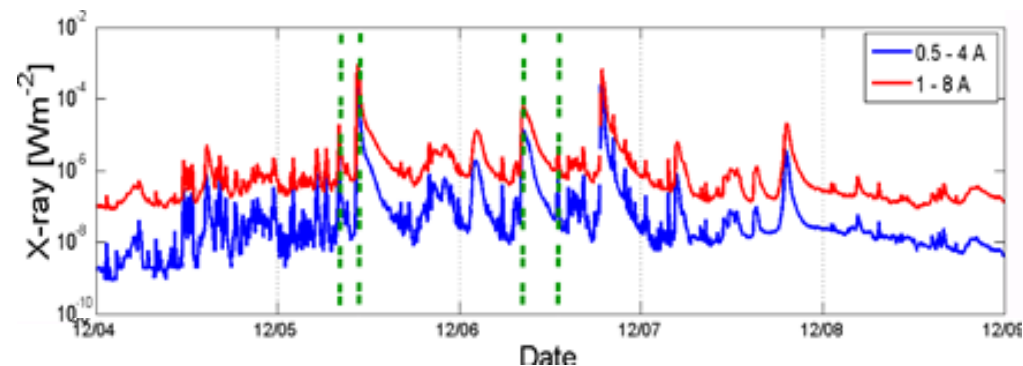
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# Purpose, method and data

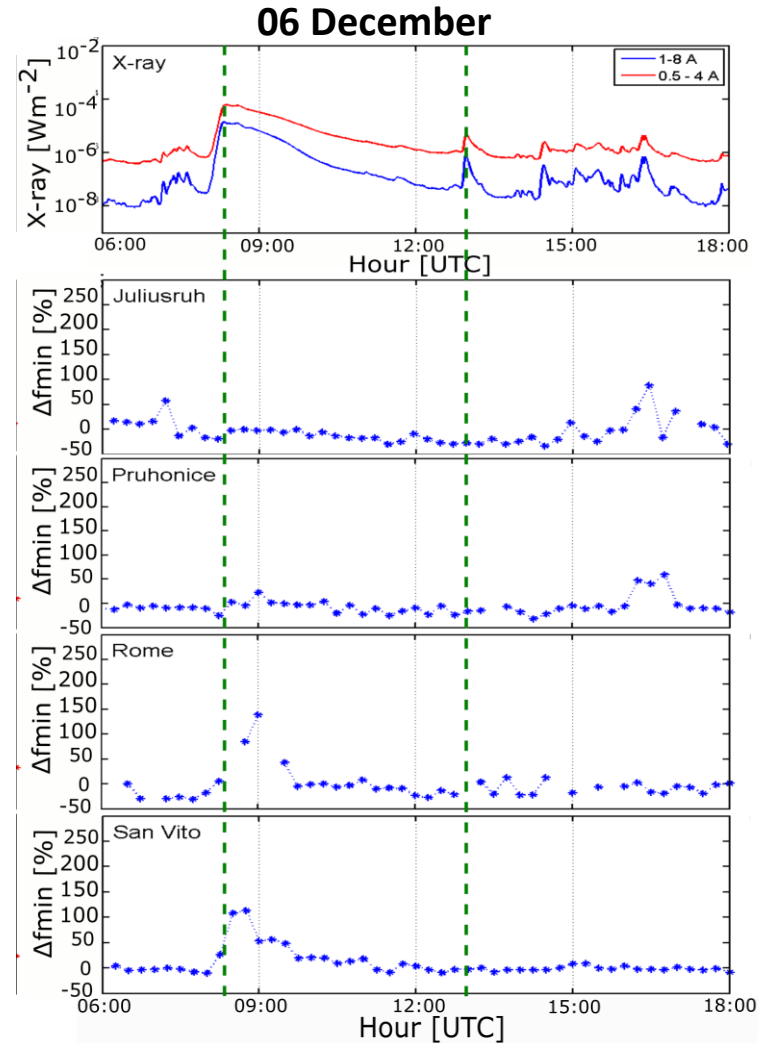
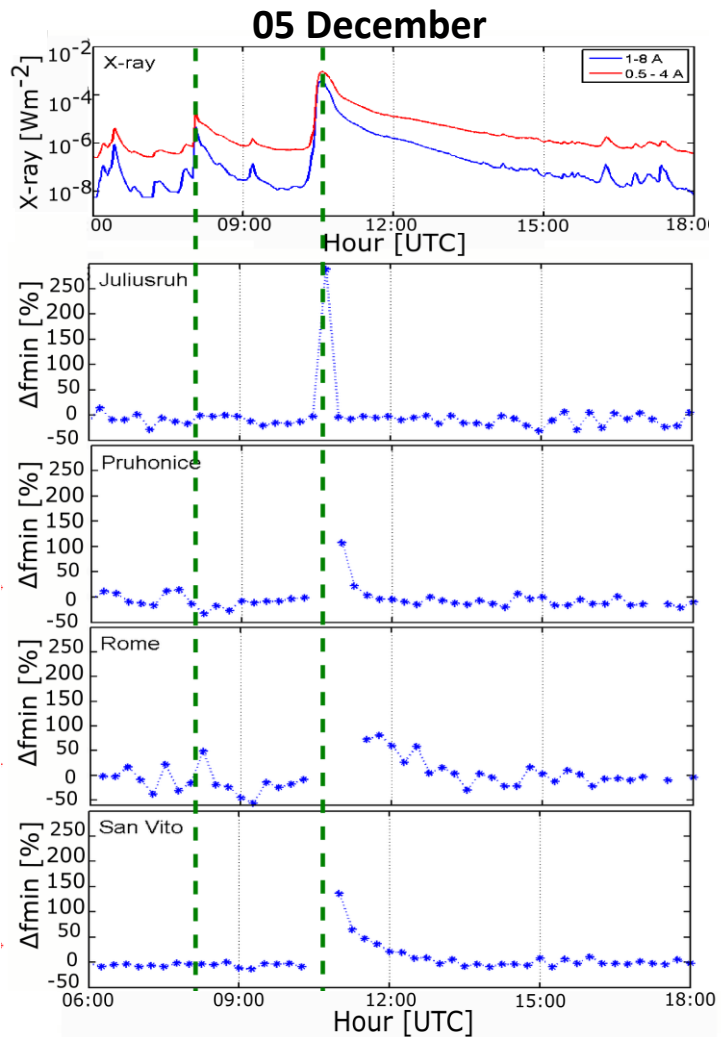
- Investigate the solar flare effects on the ionosphere above the European region (mid-latitude) on 05 and 06 December 2006.
- Ionosonde data, ground-based VLF measurements, and GNSS-derived VTEC (Vertical Total Electron Content) were used
- Comprehensive analysis of the ionospheric response to solar flares measured by the different methods. → We studied sensitivity differences between the different observational techniques.

Class of flare	Intensity [ $\text{Wm}^{-2}$ ]	Start	Peak	End	Date
M1.8	1.84E-05	7:45	8:03	8:06	2006-12-05
X9	9.06E-04	10:18	10:35	10:45	2006-12-05
M6	6.08E-05	8:02	8:23	9:03	2006-12-06
C4.8	4.82E-06	12:53	12:58	13:03	2006-12-06



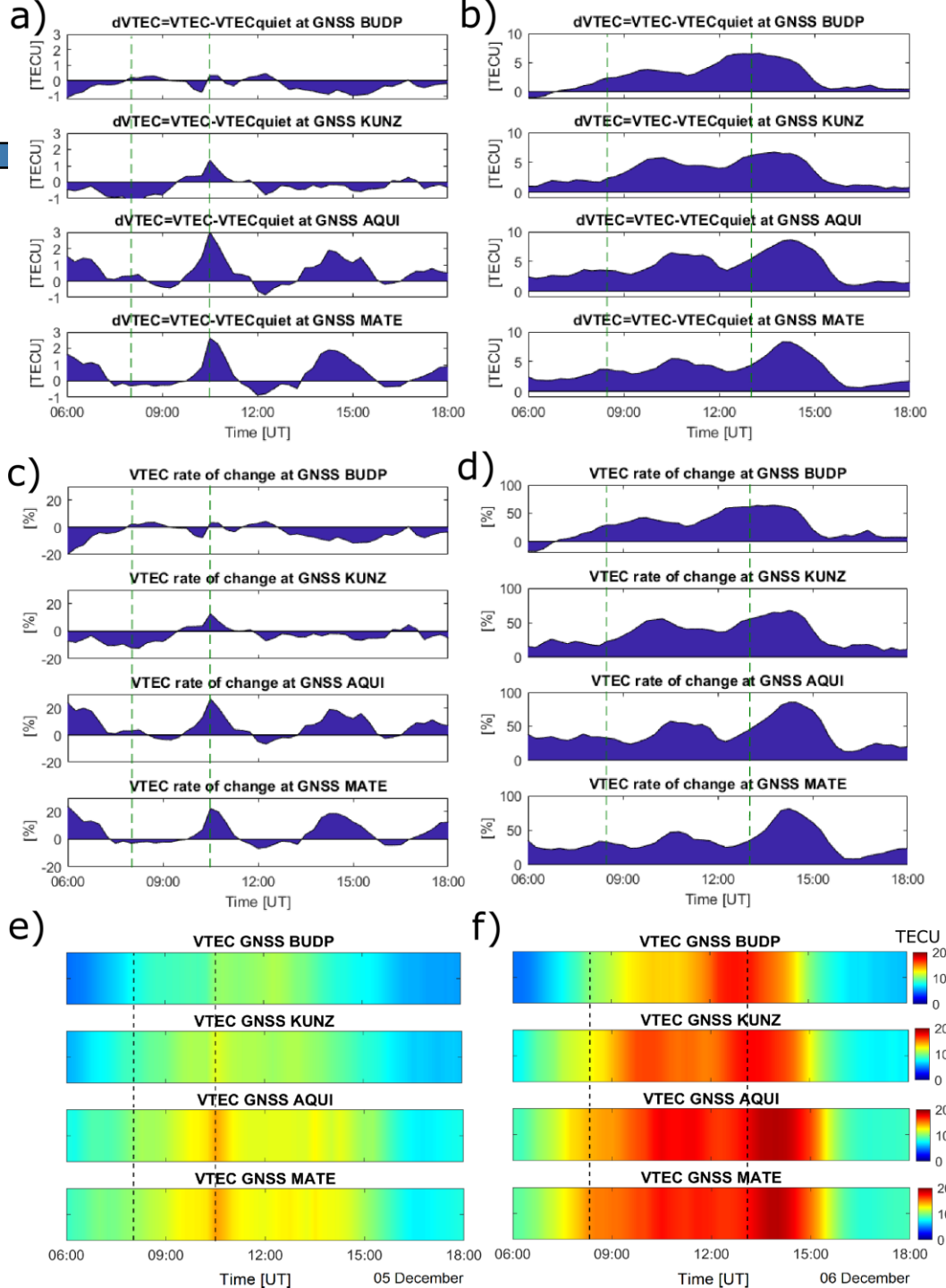
# Results – Ionosonde data

- Total fade-out during the X9 flare, duration: 30 – 60 min
- $f_{min}$  parameter: first echo on the ionogram – rough measure of the nondeviative absorption
- $\Delta f_{min}$ : 80 – 280 % during the X9, 20 – 130 % during the M6 flare



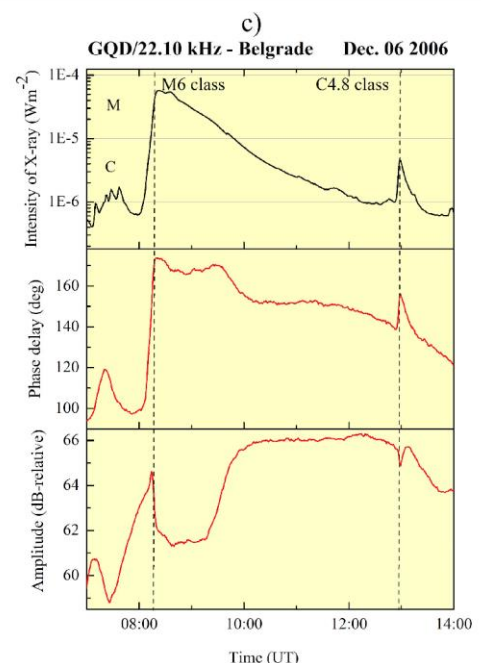
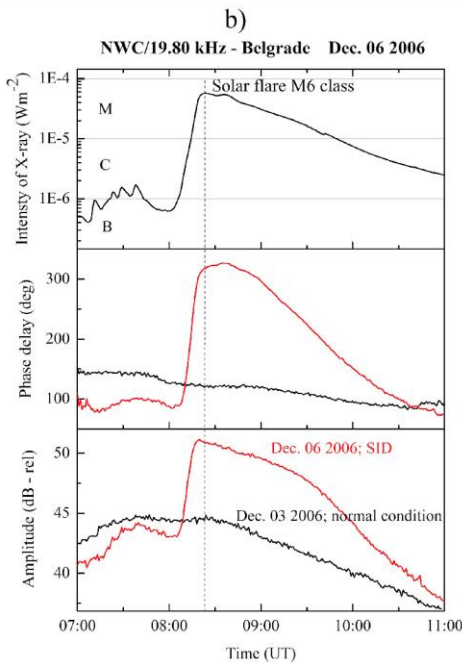
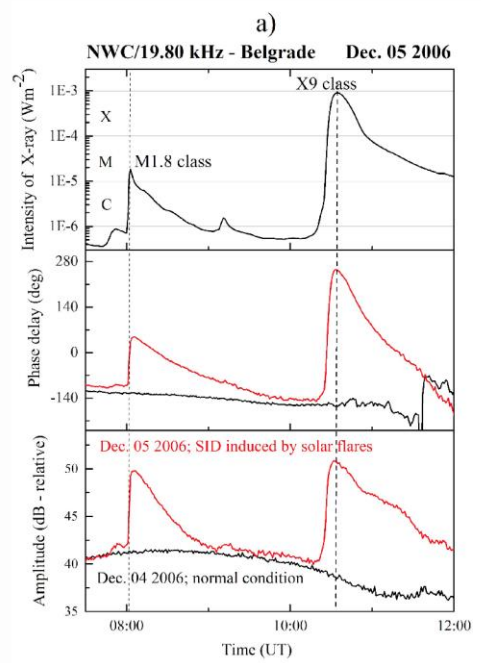
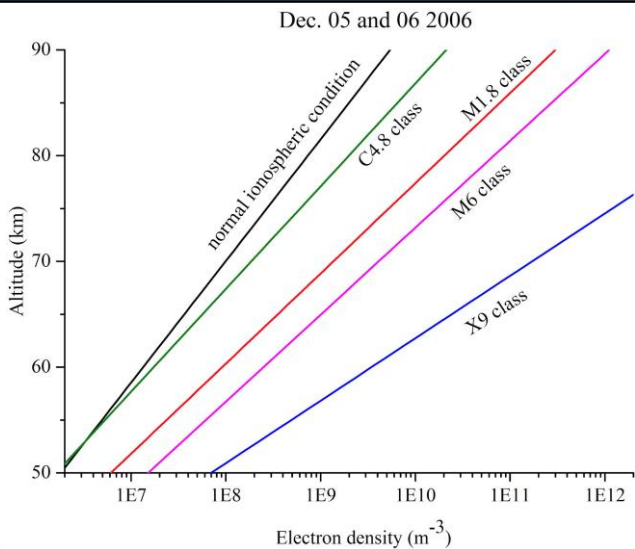
# Results – VTEC

- We analyzed VTEC changes during and after the flare events with respect to the mean VTEC values of reference quiet days
- 2-3 TECU and 5-20 % changes during the X9 flare on 05 December
- On 06 December, „positive” ionospheric storm (5-10 TECU) caused by the geomagnetic storm
- No additional peak in VTEC related to the M6 flare
- foF2 parameter measured by the European ionosondes show similar changes (not shown here).



# Results – Ground-based VLF measurements

- **Modified amplitude and phase on NWC/19.80 kHz and GQD/22.10 kHz radio signal are results of increased electron density and lowered reflection height caused by the flares.**
- **The size of amplitude and phase perturbations on VLF radio signals is in correlation with the intensity of X-ray flux.**
- **Altitude profiles of electron densities for the different investigated solar flares were calculated from VLF measurements (top figure). The different classes of solar flares drastically change (few orders of magnitude) the Ne of the ionosphere.**



# Conclusions

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**Comprehensive analysis** of the **ionospheric response** to four **solar flares** in the European region on 05 and 06 December, 2006.

The **used observational techniques** (TEC, ionosonde data, ground-based VLF method) **are sensitive to the changes occurring at different heights**, thus regions of the ionosphere.

- **Total and partial radio fade-out** were experienced **at every ionosonde station** during and after the X9 class flare. Its **duration seems to show a solar zenith angle dependence**. **The values of the  $\Delta f_{min}$**  (17-280% compared to the quiet period) parameter measured after the flares/blackouts **also increased with the solar altitude**, but it **depended on the X-ray flux**, too.
- The **VTEC rate of change increased by 5-20 %** with decreasing latitude during the **X9 flare**. On 06 December, the VTEC changes (5-10 TECU) showed a **„positive” ionospheric storm** caused by the minor geomagnetic storm, **no additional peak related to the M6 flare** was observed.
- **Modified amplitude and phase** were detected on NWC/19.80 kHz and GQD/22.10 kHz radio signals during every investigated event as a consequence of additional electron density in the D region. **The size of the observed perturbations** on VLF radio signals was **in correlation with the intensity of X-ray flux**. **The different classes of solar flares drastically changed** (even more orders of magnitude) **the electron density of the ionosphere**, as it can be seen in the altitude profiles calculated from the VLF measurements. Based on our results the ground-based VLF measurement technique is the most sensitive to the fine electron density changes of the lower ionosphere caused by the less intense solar flares.