



## **Catalogue of x-ray solar flare induced variations in sub-ionospheric very low frequency (VLF) waveguides**

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In this study we present a catalogue of solar flare induced very low frequency (VLF) variations along sub-ionospheric paths between several transmitters and the Graz seismo-electromagnetic UltraMSK receiving station. These measurements of non-seismic disturbances are important in order to carefully characterise the Earth-ionosphere VLF waveguide and disentangle possible earthquake related phenomena from natural and man-made ambient VLF amplitude and phase modifications.

The period of investigation is from Jan. 2010 to April 2016, i.e. largely covers the sunspot cycle 24. In total we've 373 VLF amplitude and phase fluctuations related with C/M/X-class solar flare events (the data are from NOAA GOES x-ray flux measurements). We obtain the statistics (dependence on VLF signal vs. x-ray flux variations) for high signal-to-noise ratio VLF links under consideration of the zenith angle.

We conclude, that with the mid-latitude Graz VLF knot, a part of the European receiver network, a reliable service for solar flare induced variations of the VLF waveguide can be established. In addition to complementary region-wide network multi-parameter observations this could be a crucial step towards a full characterisation of the behaviour of sub-ionospheric VLF paths including modifications related to seismic activity.