Search for dependence of ionospheric parameters of meteorological local storms

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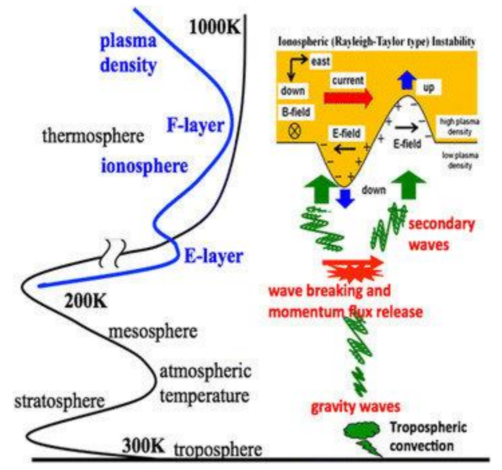

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INTRODUCTION:
During the warm months of the year (May to September), thunderstorms inside air masses occur frequently in the Central Europe. They are formed by a convection of warm and moist air inside unstable air masses. Tropospheric situations in which very moist and hot unstable air masses persist over a warmed continent for several days have become increasingly frequent in recent years. The massive temperature convection, supported by orographic convection, especially in the bordering mountainous regions of the Czech Republic, gives rise to strong storms in the form of multicells, supercells or squall lines. They persist for hours and are associated with widespread manifestations such as strong wind gusts, torrential rainfall, severe lightning activity and also large temperature fluctuations.

Summer storms inside an unstable air mass

1. Single convective storm cell (unicell storm)
- usually persist for only an hour during afternoon and dissipate rather quickly after sunset

However, our results up to now indicate that the intensity of such systems is not sufficient for generation of atmospheric waves to be noticeable in the ionosphere.

2. Severe thunderstorms (multicell, supercell, squall line)
- associated with widespread manifestations such as strong wind gusts, torrential rainfall, very frequent lightning activity and large temperature fluctuations as well
- usually persist for several hours, sometimes reforming over the same location
- develop with the support of orography in the border mountains of the Czech Republic
- Synoptic condition
  - **upper-level cyclone** (mesoscale convective system) filled with cold air relative to the surroundings causes the rapidly decreasing temperature with height, thus strongly supporting convective motions. It is often associated with:
  - **a shallow ridge or a region of low pressure with a weak horizontal gradient** filled with warm, moist air **in the lower atmosphere**
- Convective environment
  - **MUCAPE** (Most Unstable Convective Available Potential Energy) value **above 1000 J/Kg**
  - **EL** (equilibrium level - in close approximation represents the height of storm cloud tops) **close the tropopause top**.
  - **negative LI** (lifting index)
  - **θep** (pseudoequvalent potential temperature) **at 850 hPa above 50°C**
- Ground weather station measurements
  - typical pressure waves in barograph
  - the shift in wind direction before and after the storm is less than 60°
  - wind speed - light to moderate (there may be an isolated gust of wind greater than 5 m/s immediately before the storm passes)

Frontal thunderstorms
- thunderstorms associated with a moving frontal interface between two air masses differing in temperature and moisture.

DATA:
We analyse thunderstorms that occurred within 50 km radius of the Průhonice ionospheric observatory reported in SYNOP (surface synoptic observations) large enough to cover the average distance between two meteorological measurement sites, i.e. approximately 20 km, within two hours. We then select air mass thunderstorm cases from these based on measurements in the troposphere to meet the following criteria:
- the shift in wind direction before and after the storm is less than 60°
- temperature and pressure before and after the storm are not significantly different.

IONOSPHERIC OBSERVATION:
Ionosonde/Digisonde: Ionograms (and derived N(h) vertical profile)
Continuous Doppler Sounder: Doppler shift of the reflected fixed frequency signal
Detection of spreads in ionograms **using an original model** based on a convolutional neural network coded in python with the help of tensorflow library.

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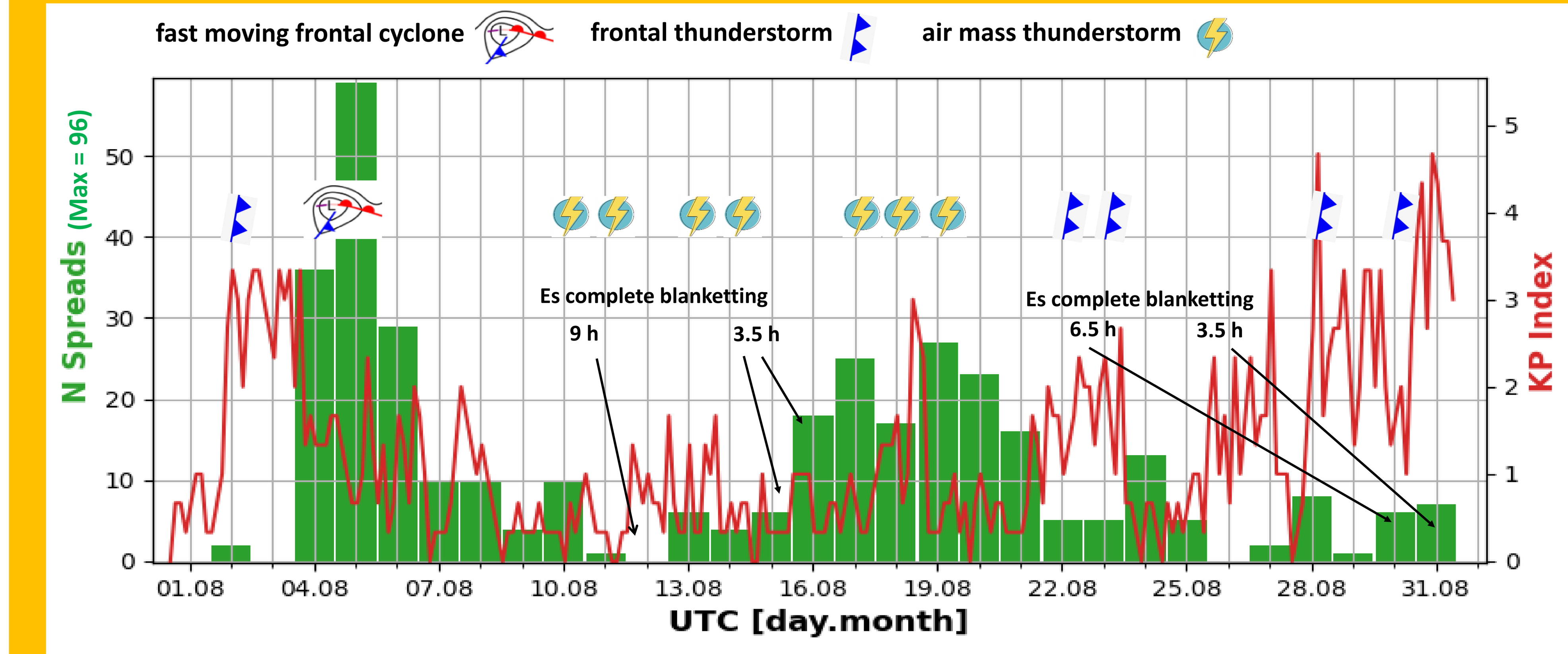
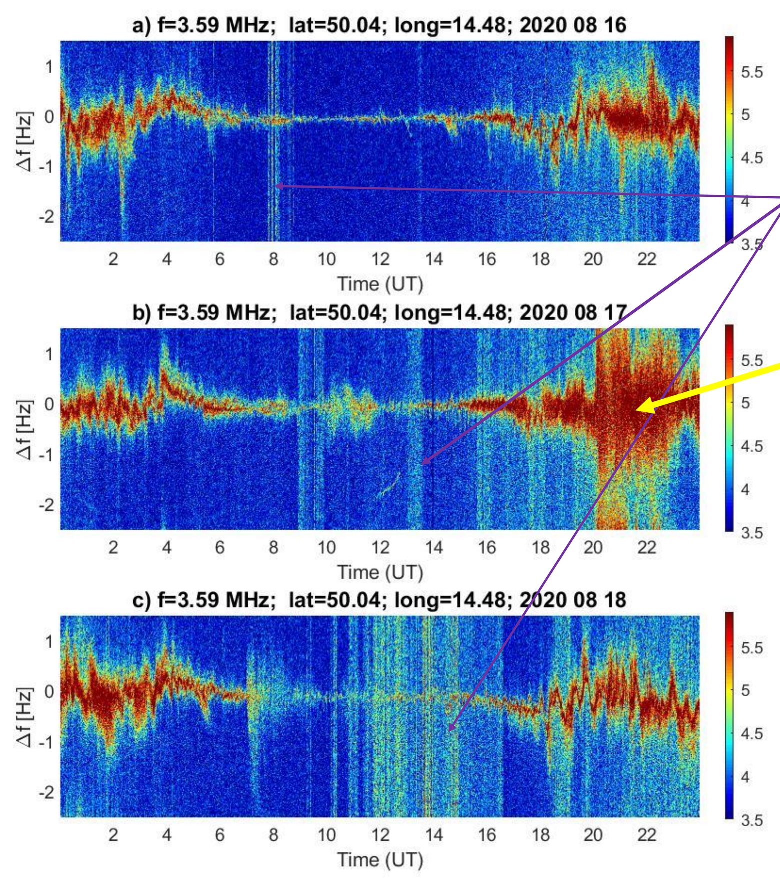
Frequency of spreads at ionograms (15-minutes schedule, 96 ionograms per day)
August 2020 - days with the occurrence of Spread F:



Squall lines thunderstorms 17 -19 August 2020

CDS spectrograms for frequency 3.59 MHz during three

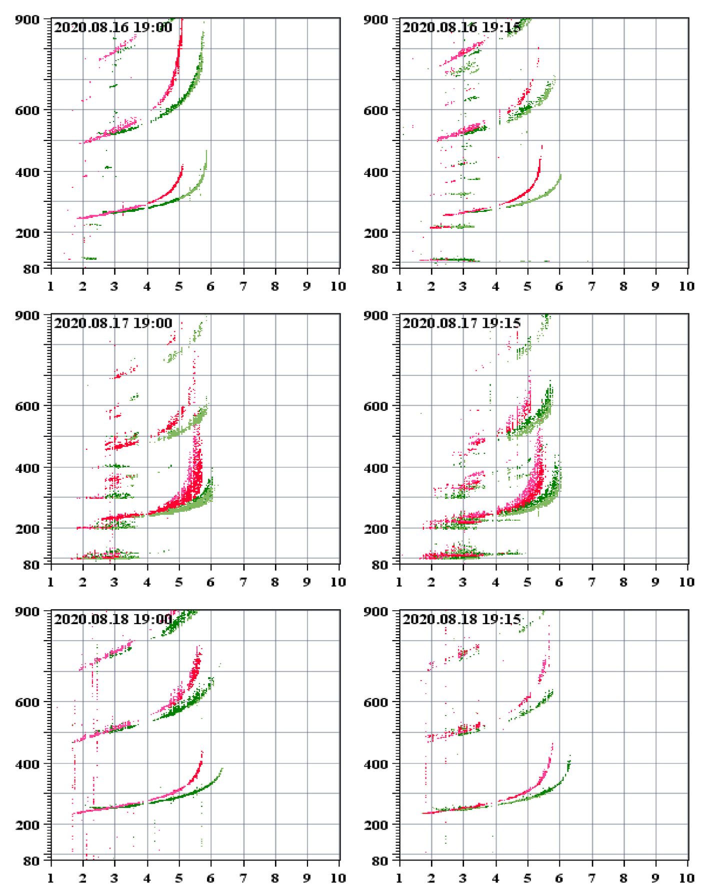


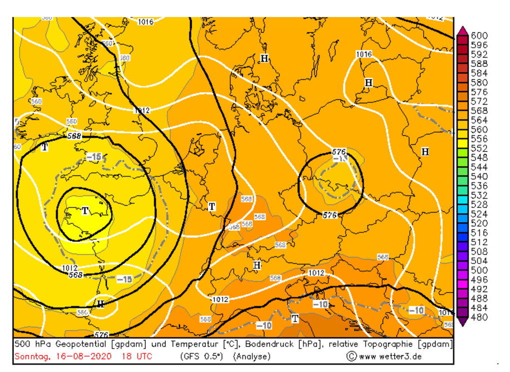
Spectrograms exhibit significant change of echo quality.

Electromagnetic noise on spectrograms is partly caused by the lightning close to the receiver.

Strong spread echo on 17 August:CDS registers large values of Doppler shifts of the signal when the reflection plane significantly moves upward or downward. Packet of large both positive and negative Doppler shifted signal indicate simultaneous reception of multiple rays reflecting from different regions of the ionosphere (moving with different radial velocities) due to the presence of ionospheric irregularities at different scales.

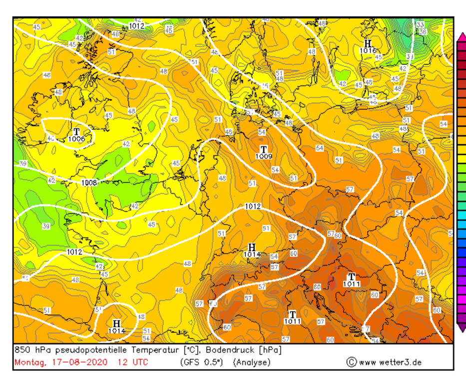
Ionograms recorded by Digisonde with Spread F echo





Both the upper-level cyclone enclosing the local temperature minimum at **500 hPa** (black lines, grey dashed line - isotherm - 13 °C) and the shallow ridge of high air pressure near the ground (white lines) accelerate the temperature decrease with altitude and thus increase the local instability of the troposphere. This strong convective environment is a precondition for the development of strong storms in the following days.
(Color scale of **relative topography** represents the vertical distance between the 1000 and 500 hPa, which is directly related to the **mean temperature and moisture of the middle troposphere**.)

Pseudoequivalent potential temperature (θep) at the **850 hPa** pressure level (color scale) and **sea-level pressure** (white lines).



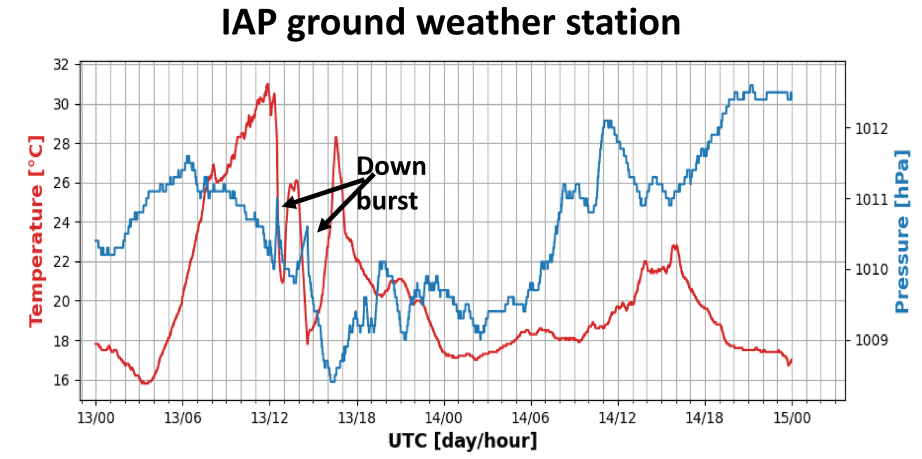
The temperature that an air sample would have if it were expanded to zero pressure by a pseudo-adiabatic process and then compressed to a reference pressure of 850 hPa by a dry adiabatic process. All the water content would have condensed, falling out in the form of precipitation. The generated condensation heat would heat the dried air. Thus the pseudoequivalent potential temperature field synthetically represents both temperature and moisture characteristics in the lower part of the troposphere.

High θep values at 850 hPa indicate tropospheric instability. In the Czech Republic, θep values above 60 °C at 850 hPa are rarely reached (only on a few summer days per year).

CURRENT RESULTS

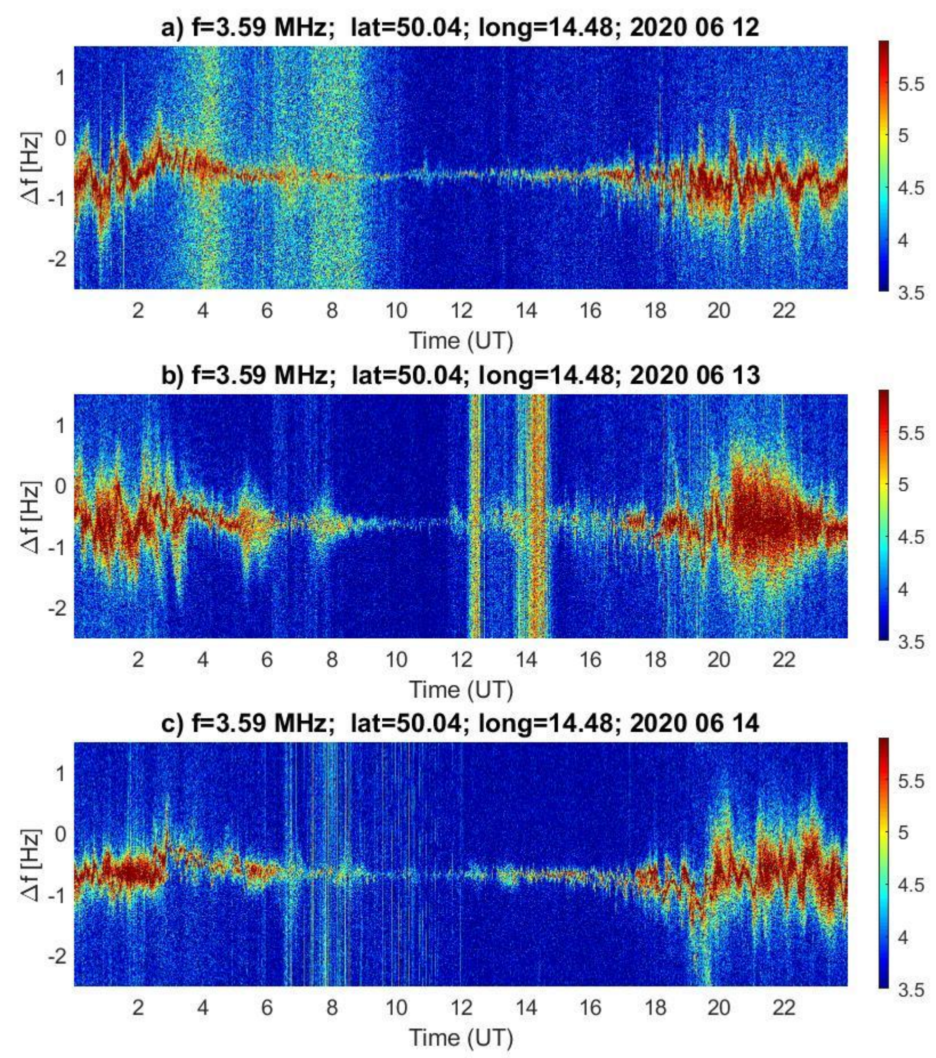
Air mass Thunderstorms 13 -16 June 2020

IAP ground weather station

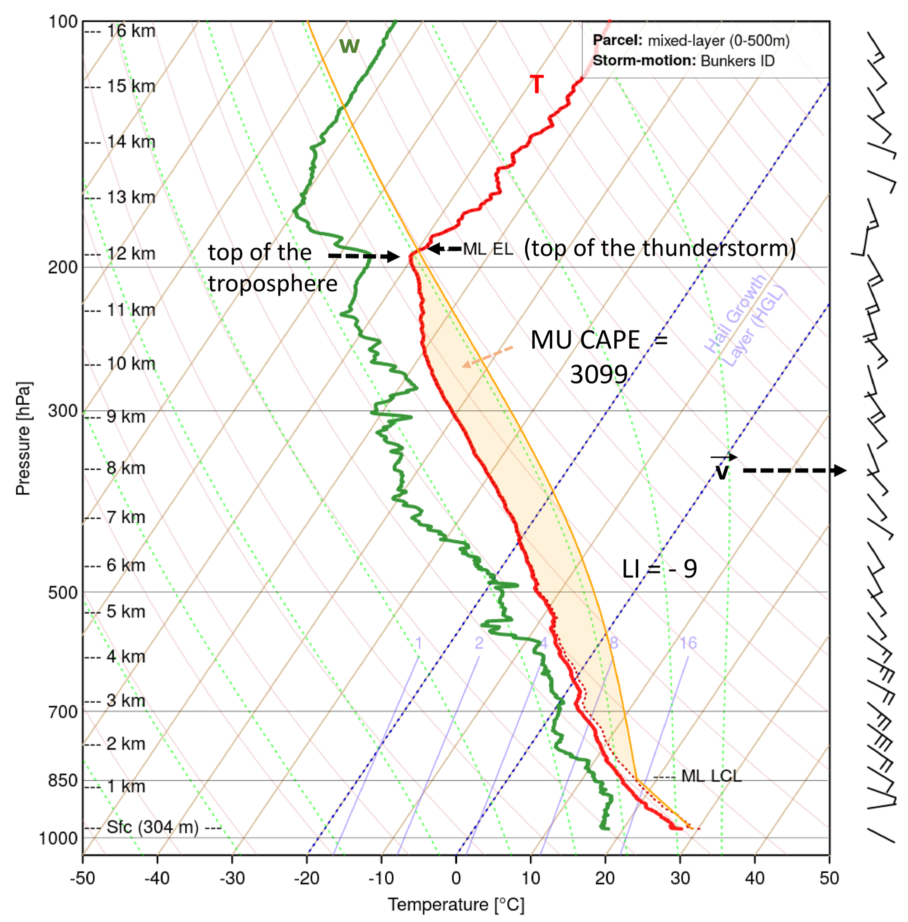


12 June, there were suitable initiation conditions for the storm formation – strong humidity, advection of warm air from the northeast. In the morning of 13 June storms formed in a thermally unstable air mass associated with orographically amplified convection. On June 13 and 14, warm advection continued and initiated a cascading secondary initiation of severe thunderstorms over the Czech Republic.

Thunderstorm, heavy rain: 13 June 12:30 - 15:00 UTC and 14-15 June 20:00 - 00:00 UTC.
Downburst: a local rise in pressure followed by a drop in temperature is caused by a downburst - cold air and precipitation that quickly drops out of the storm and spills over land.



Prague(Libuš) 11520 14.45 E 50.00 N
13 Jun 2020 (Saturday) 12:00 UTC



Skew-T diagram showing the path of an air parcel rising along the dry adiabat to the lifting condensation level (LCL) and then along the moist adiabat to the equilibrium level (EL), relative to the surrounding air mass at temperature **T**, moisture **w** and wind speed $\vec{v}$.
Most unstable convective available potential energy (MU CAPE) is a measure of instability in the troposphere. LI is calculated as the difference between **T** at 500 hPa and the temperature of the air parcel adiabatically lifted to 500 hPa. CAPE > 2000 J kg^{-1} and LI > - 6 indicate very unstable troposphere and potential for development of severe thunderstorms.

CONCLUSION and OUTLOOK:
Since 2014 till the end of 2021, approximately 80 cases of summer thunderstorms have been recorded at ground stations in Prague, which we classified as thunderstorms within the air mass. For our analysis, we excluded periods of increased geomagnetic activity from these cases. The number of cases was further reduced due to strong Es layer blanketing that prevent detail profile analyses and gaps in observation cased by lack of sounding (meteorological and/or ionospheric).
We demonstrate type of tropospheric mesoscale events in central Europe with the potential to produce oscillatory effects detectable up to the ionosphere.
In our ongoing research, we are working to enlarge the thunderstorm database with events potentially detectable at the ionospheric observatory in Sopron, so that it is robust enough to search for correlations between the convective environment in the troposphere and the types of oscillations in the ionosphere.