Thunderstorm investigations based on the data obtained by the URAGAN muon hodoscope and Doppler weather radar DMRL-C

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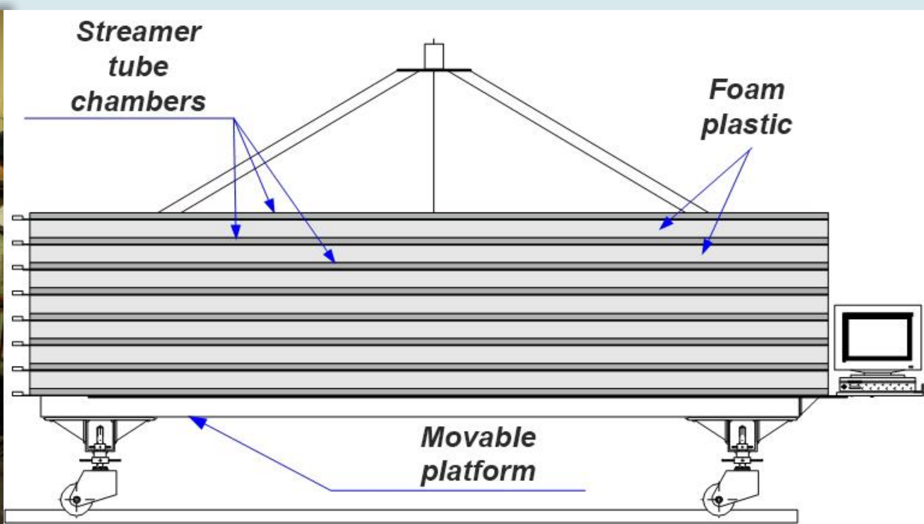
Muon hodoscope URAGAN

- provides registration of muons with a high spatial and angular resolution (about 1 cm and 0.8°, respectively) in a wide range of zenith angles (from 0° to 84°)
- track parameters are reconstructed in real time and accumulated in a two-dimensional matrix for one minute interval. Such a matrix is a "muon picture" of the upper hemisphere

characteristics reflecting the distortion of the distribution of the muon flux used in this analysis are:

- vector of local anisotropy (A) which indicates the average direction of muon arrival recorded by the detector
- vector of relative anisotropy (R) which is the difference between the local anisotropy vector in the current time and averaged over a long period anisotropy vector and its projection on the horizontal plane (R_{hor})



Doppler weather (meteorological) radar DMRL-C

- Displaying distribution of various meteorological data such as precipitation intensity and velocity and direction of movement of cloud systems
  - a view range of 250 – 300 km
  - a maximum detection height of about 20 km
  - a high spatial resolution (0.5 – 1 km)
- Detection of dangerous weather phenomena such as thunderstorms

The research

- Muon pictures (muonographs) and meteorological maps obtained every ten minutes by means of two facilities during thunderstorm periods of spring and summer of 2018 (~27 events) are compared with each other
- Wavelet analyses of obtained data are performed
- Results are illustrated by thunderstorm events occurred in Moscow on July 14, 2018 and August 30, 2018

14.07.2018

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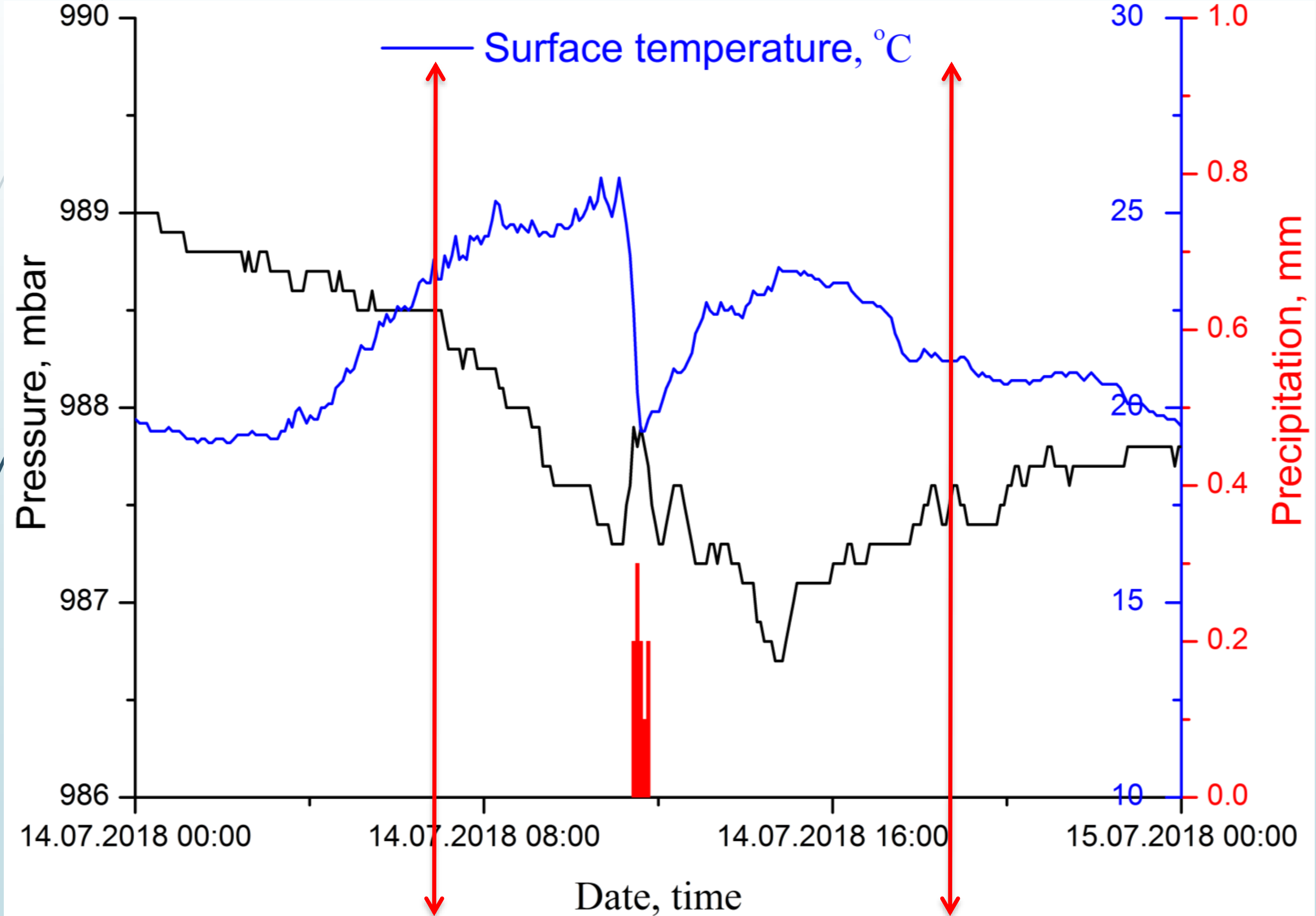
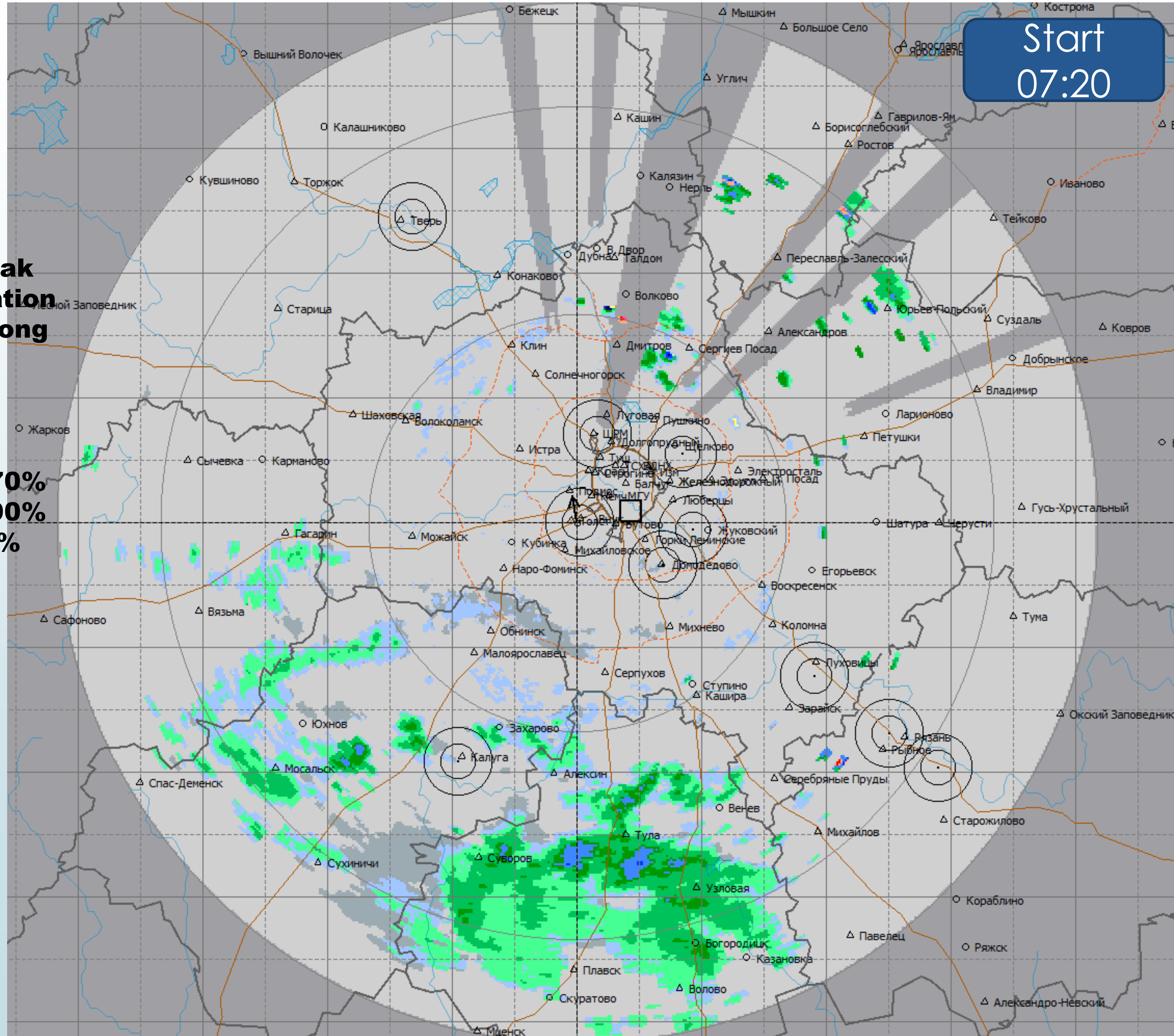
The thunderstorm was observed at the Domodedovo airport meteorological station at 14:00 (UTC time) and at the VDNKh meteorological station from 14:00 to 17:00



Meteorological maps

- Precipitation is weak
- Moderate precipitation
- Precipitation is strong
- Cumuliform clouds
- Rain is weak
- Moderate rain
- Heavy rain
- Thunderstorm 30-70%
- Thunderstorm 70-90%
- Thunderstorm> 30%



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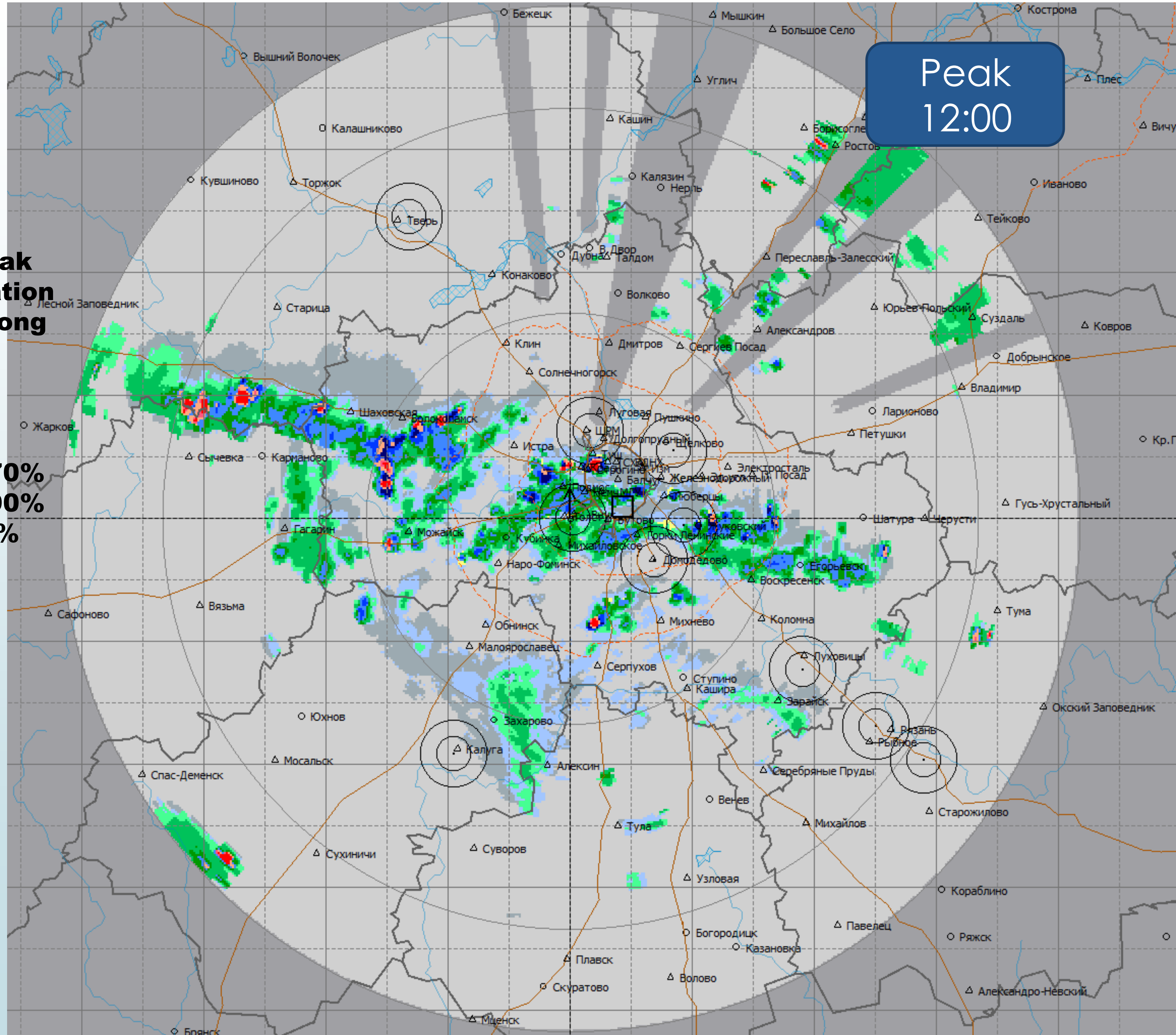

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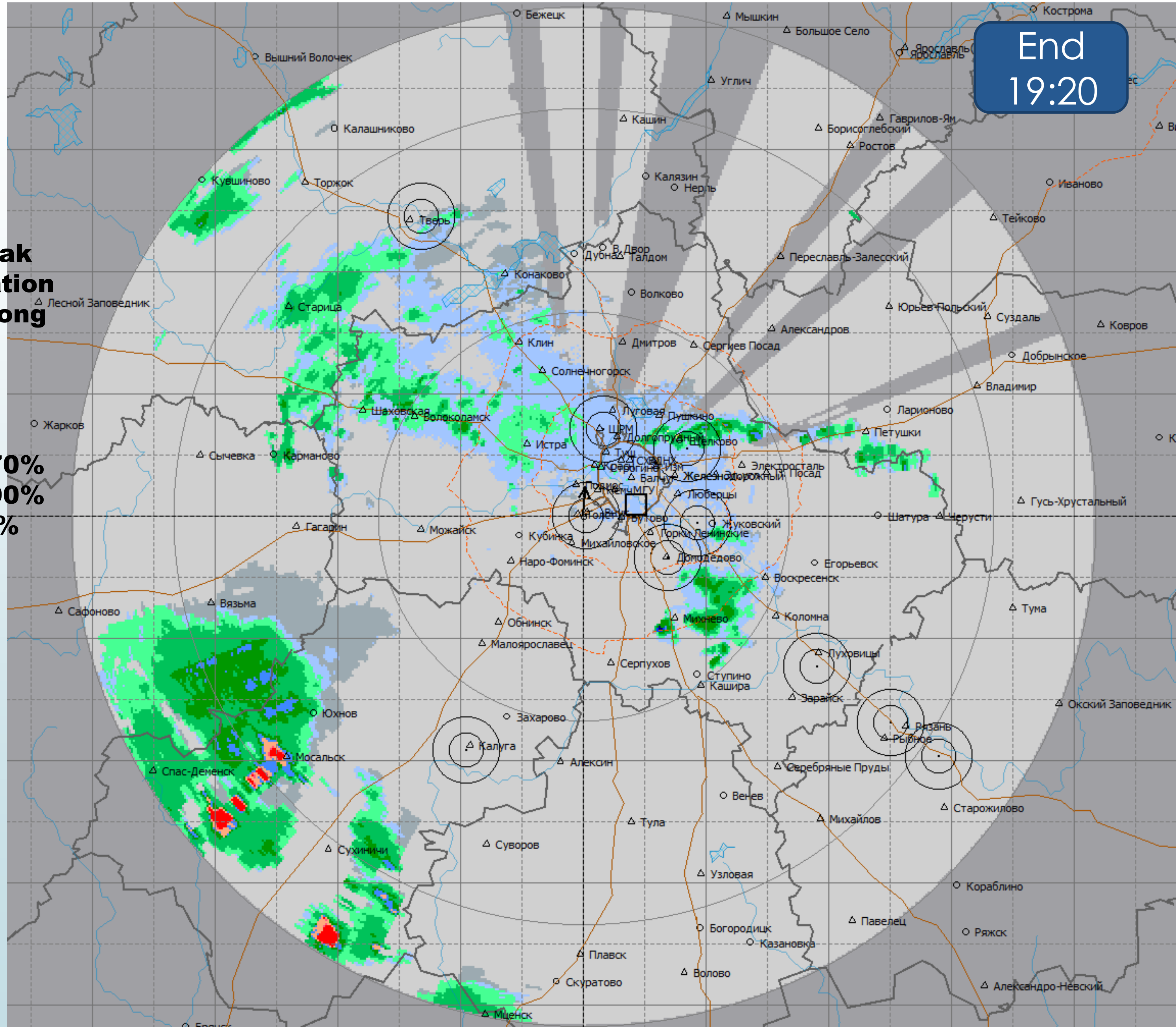
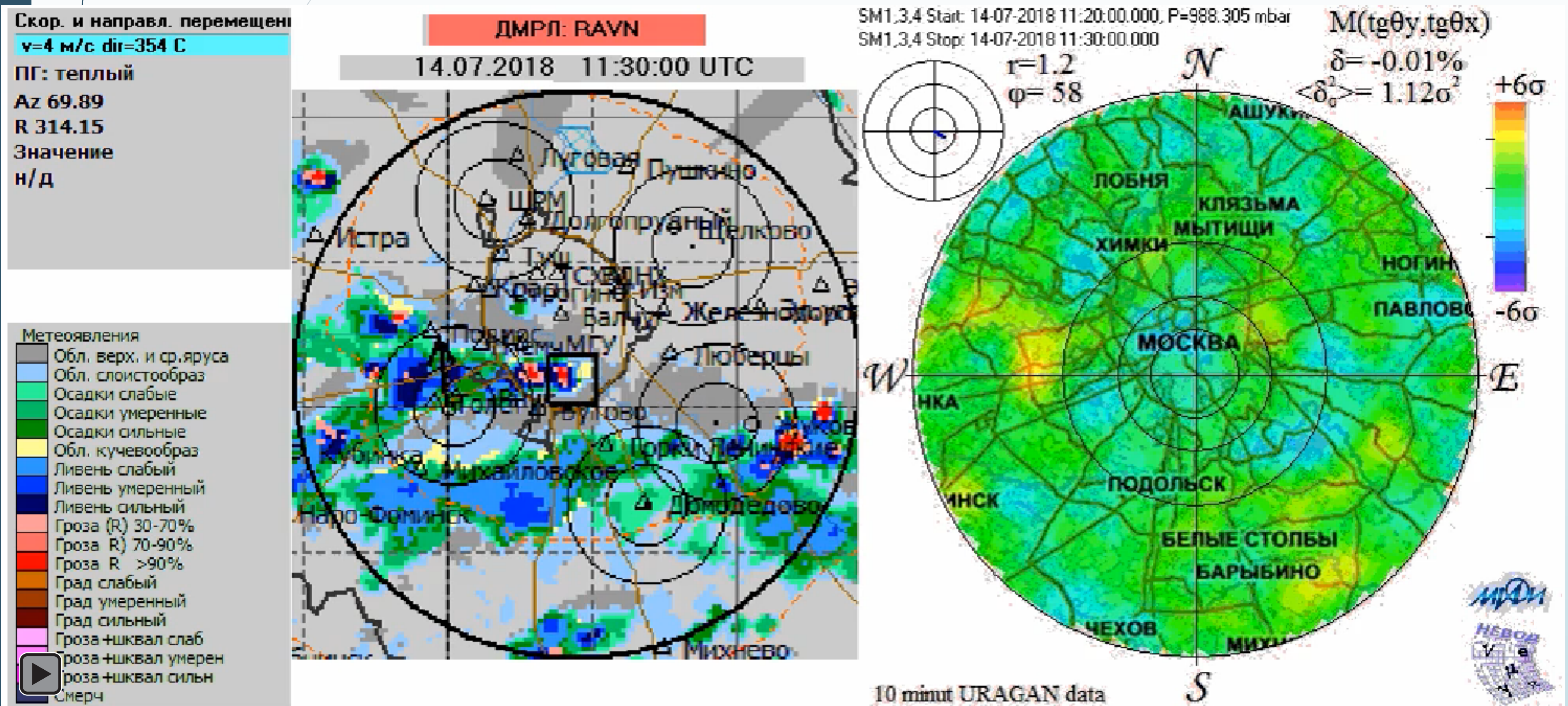
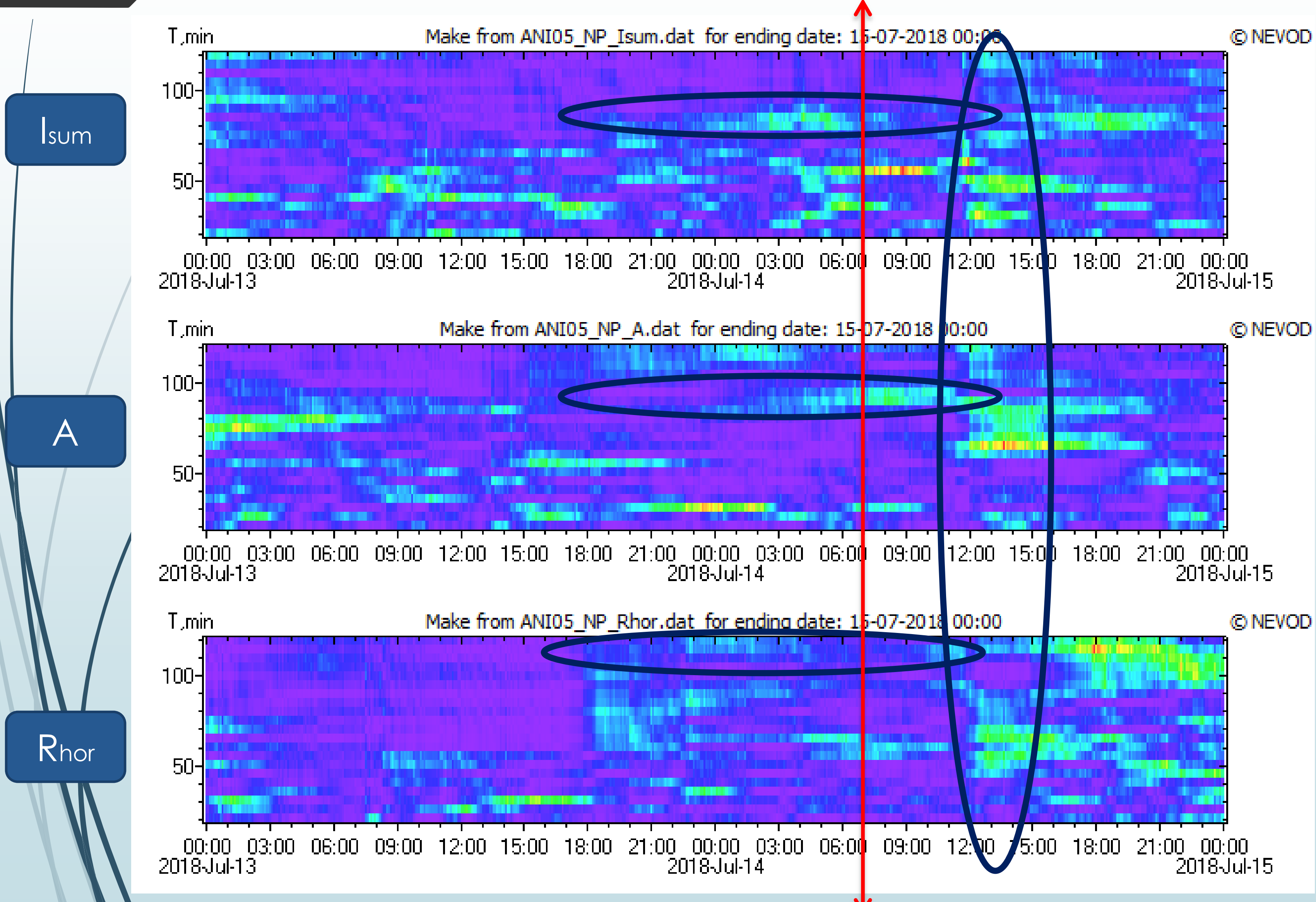


Comparison (11:30 – 13:10)



Wavelet analyses of URAGAN data



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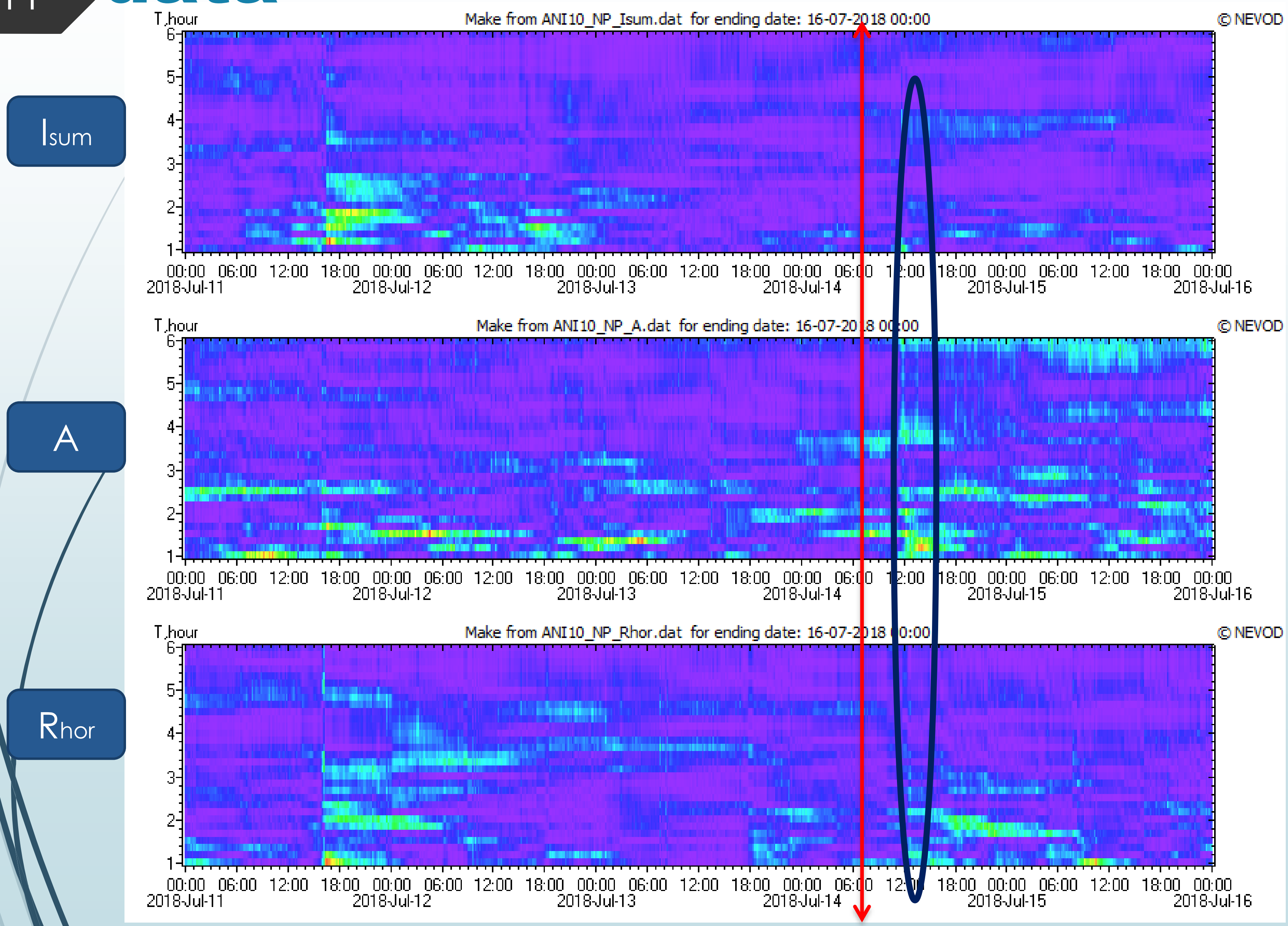
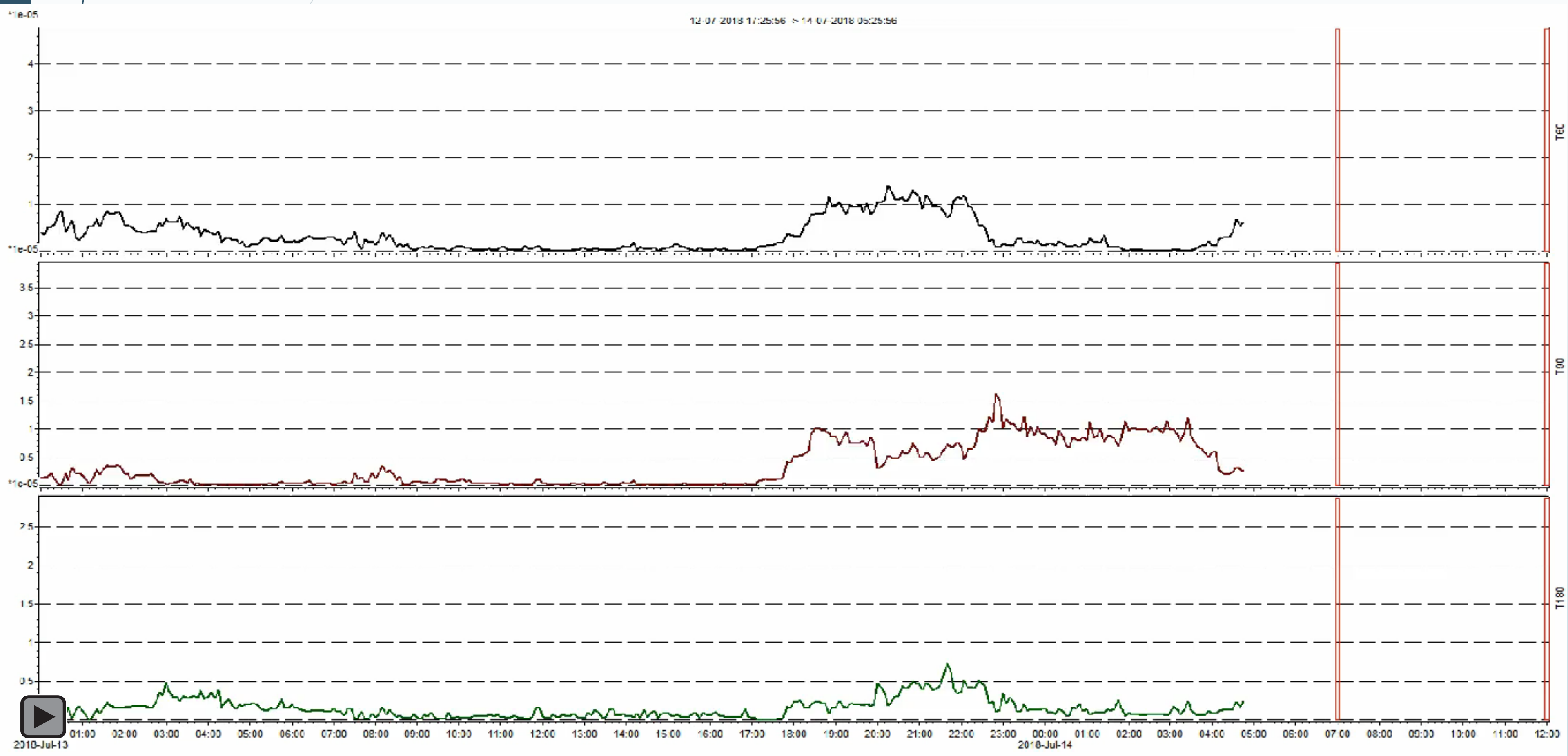
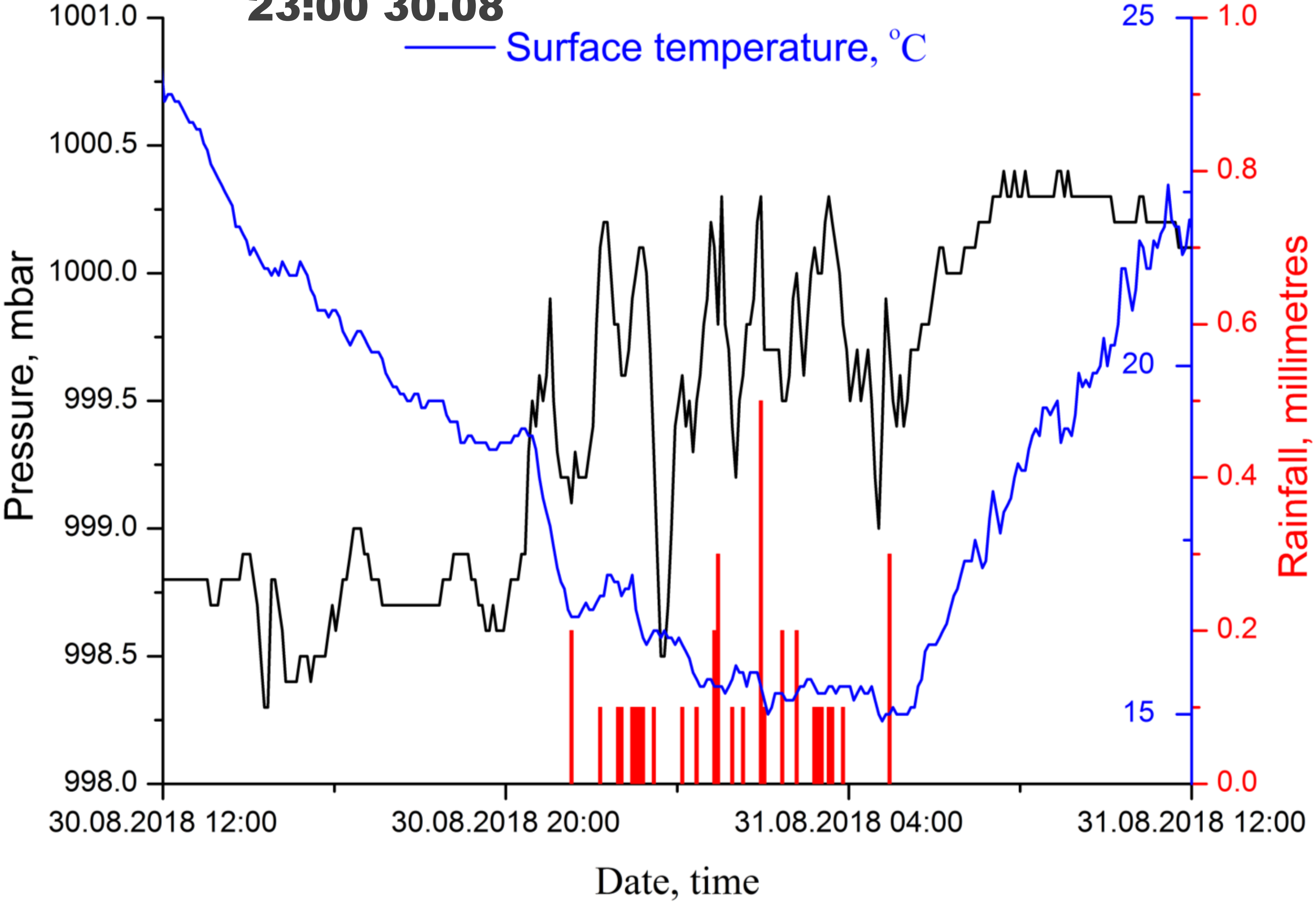


Wavelet analysis: R_{hor}



30.08.2018 – 31.08.2018

The thunderstorm was observed at the Domodedovo airport meteorological station from 21:00 30.08 to 05:00 31.08, at the Balchug meteorological station from 21:00 30.08 to 05:00 31.08 and at the VDNKh meteorological station at 23:00 30.08



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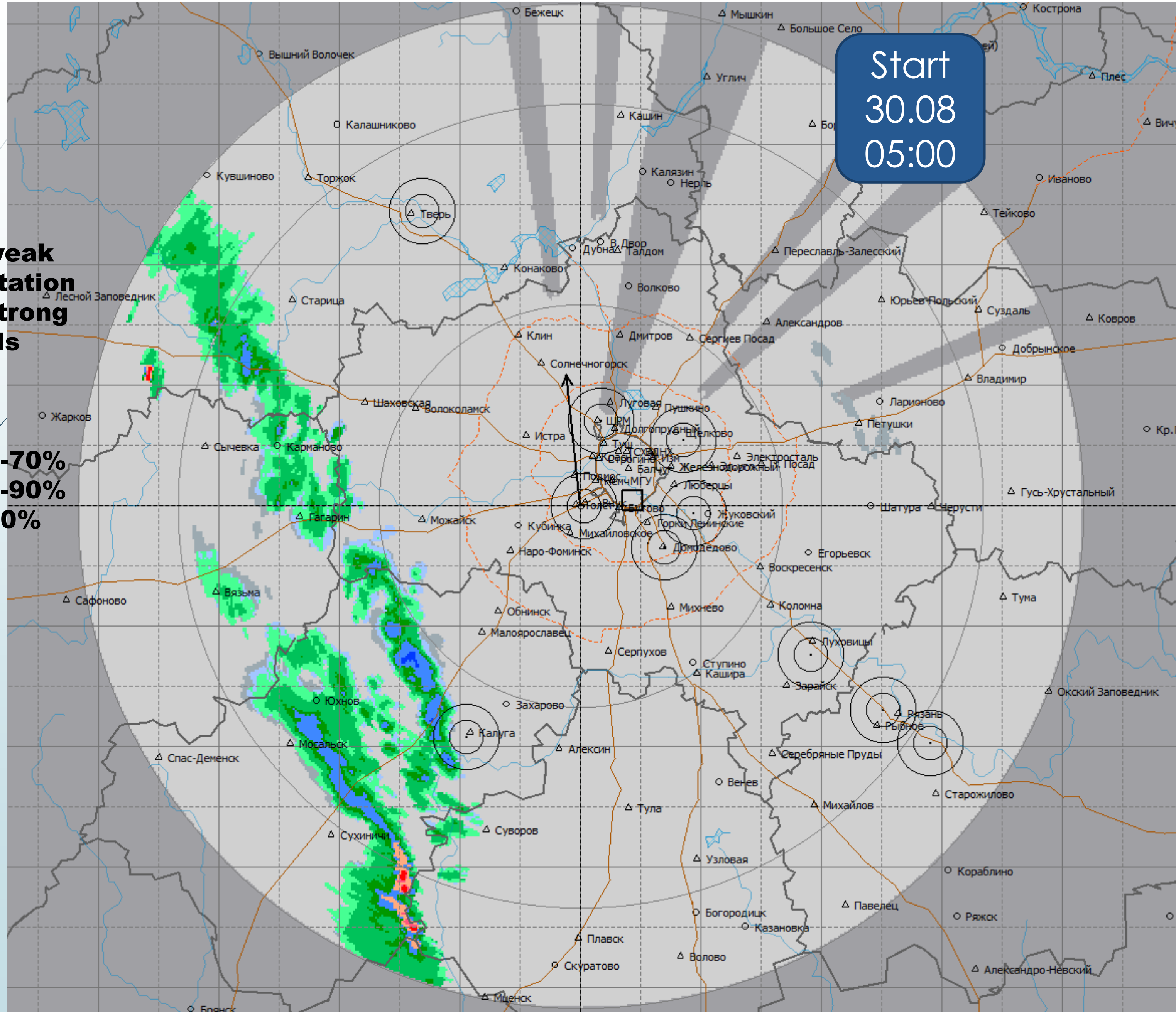

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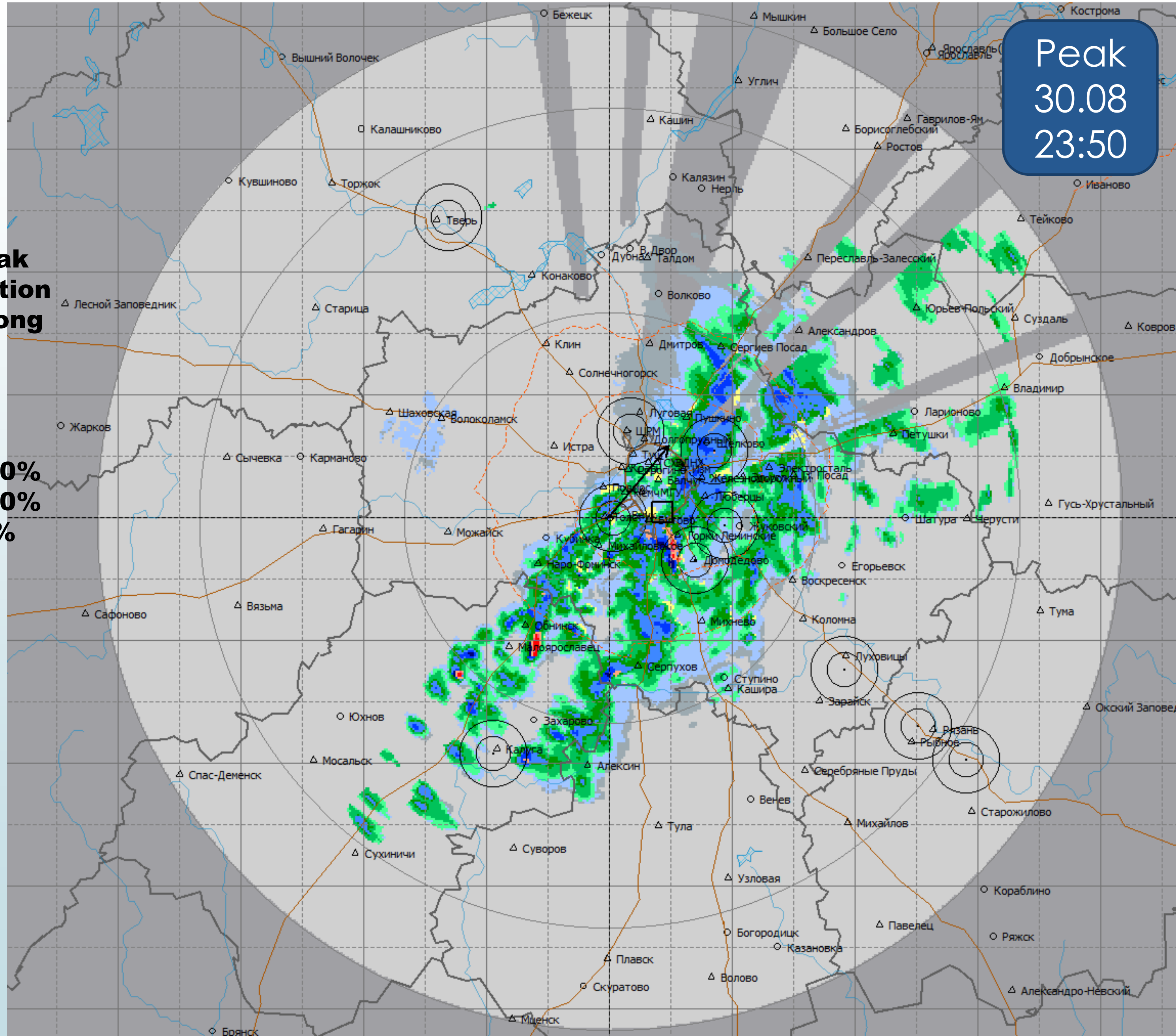

Peak
30.08
23:50

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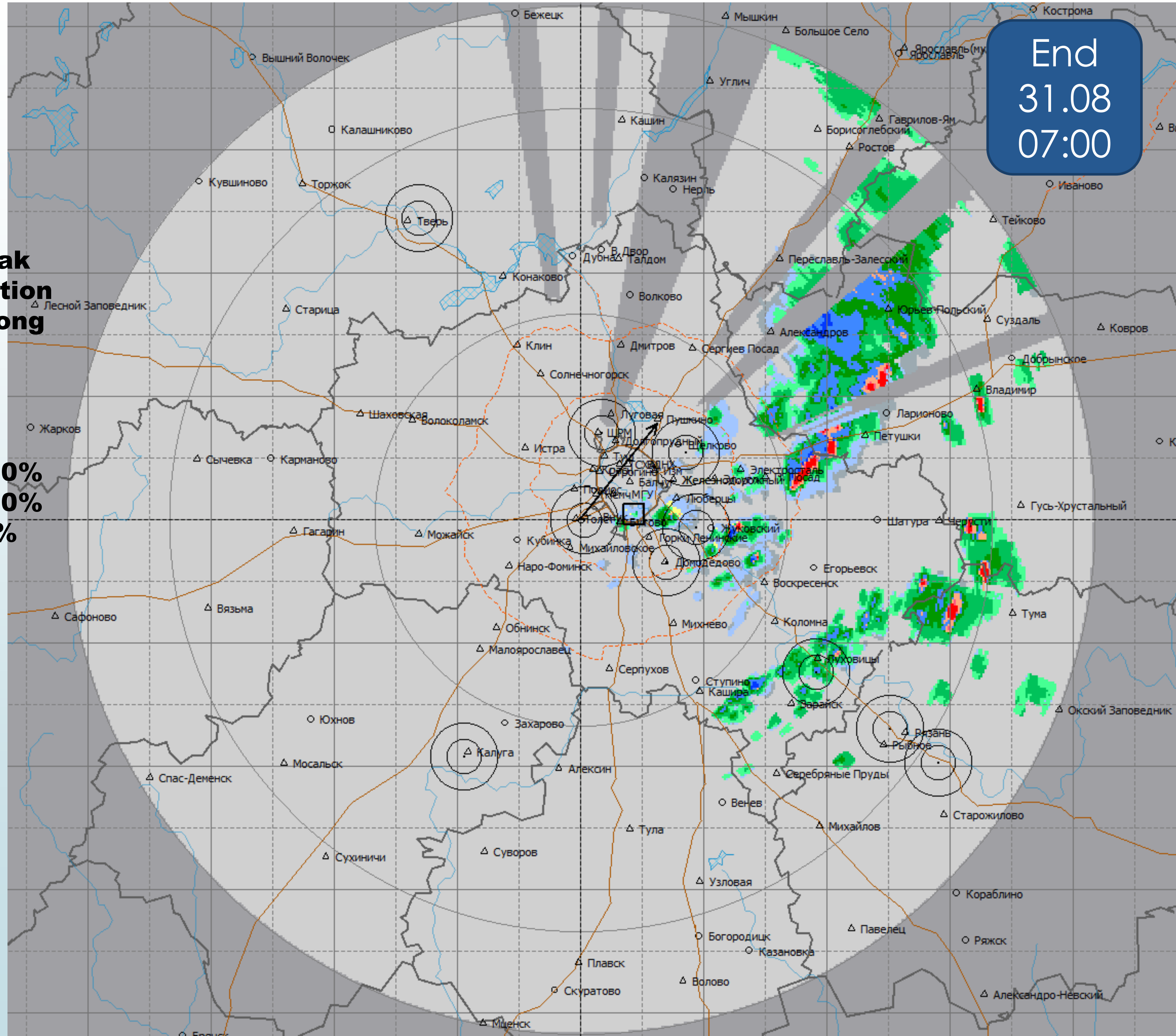
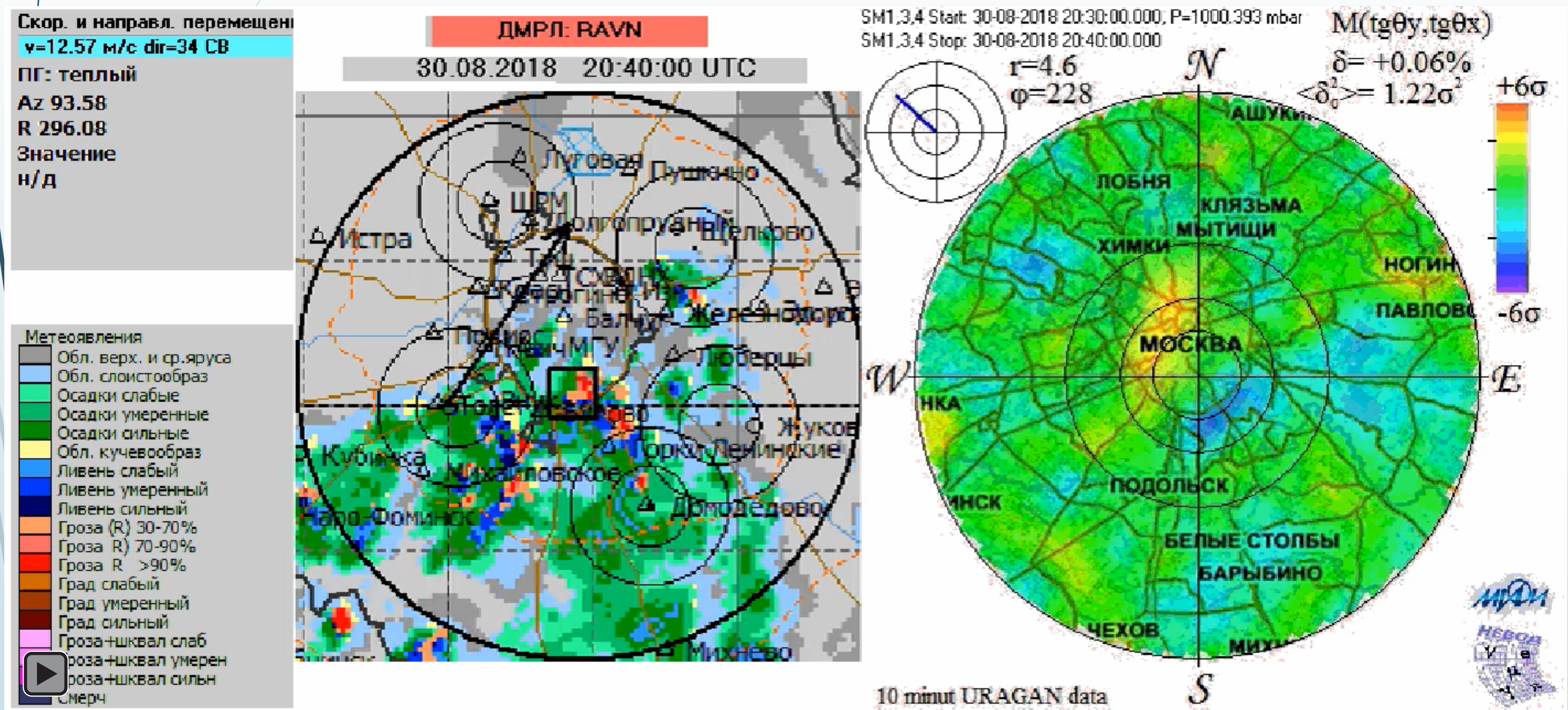


Comparison (20:30 – 05:20)

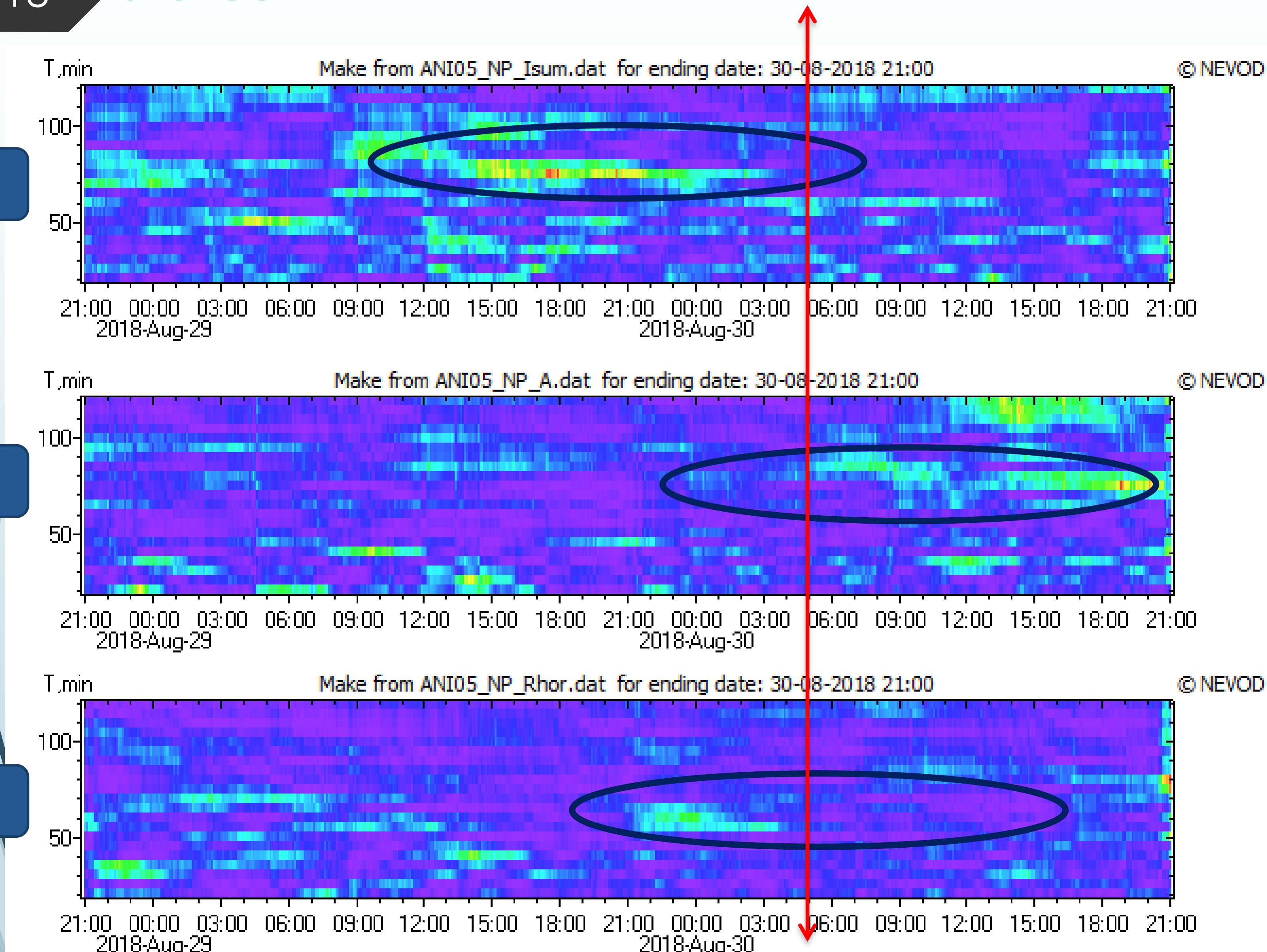


Wavelet analyses of URAGAN data

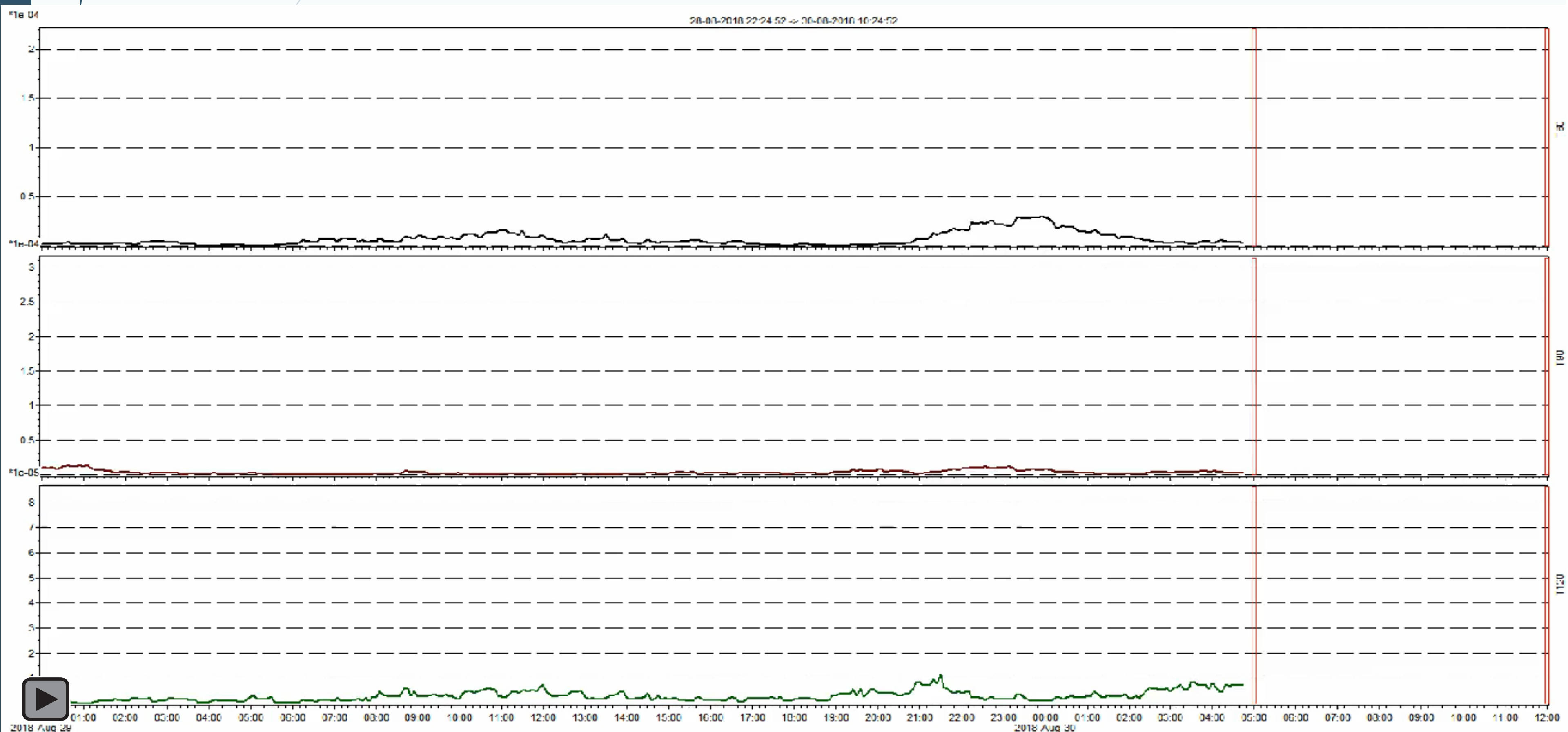
Isum

A

Rhor



Wavelet analysis: Rhor



Conclusions

- **Results obtained from the analysis of data provided by MH URAGAN are consistent with DMRL-C data**
- **Characteristics of the muon flux provide a good reaction to the passage of a thunderstorm**
- **Wavelet analysis of different time series shows that before and during the passage of a thunderstorm there are periodic disturbances in the characteristics of the muon flux. Periods of those disturbances are ranging from 60 to 180 minutes**

Thank you for your attention!

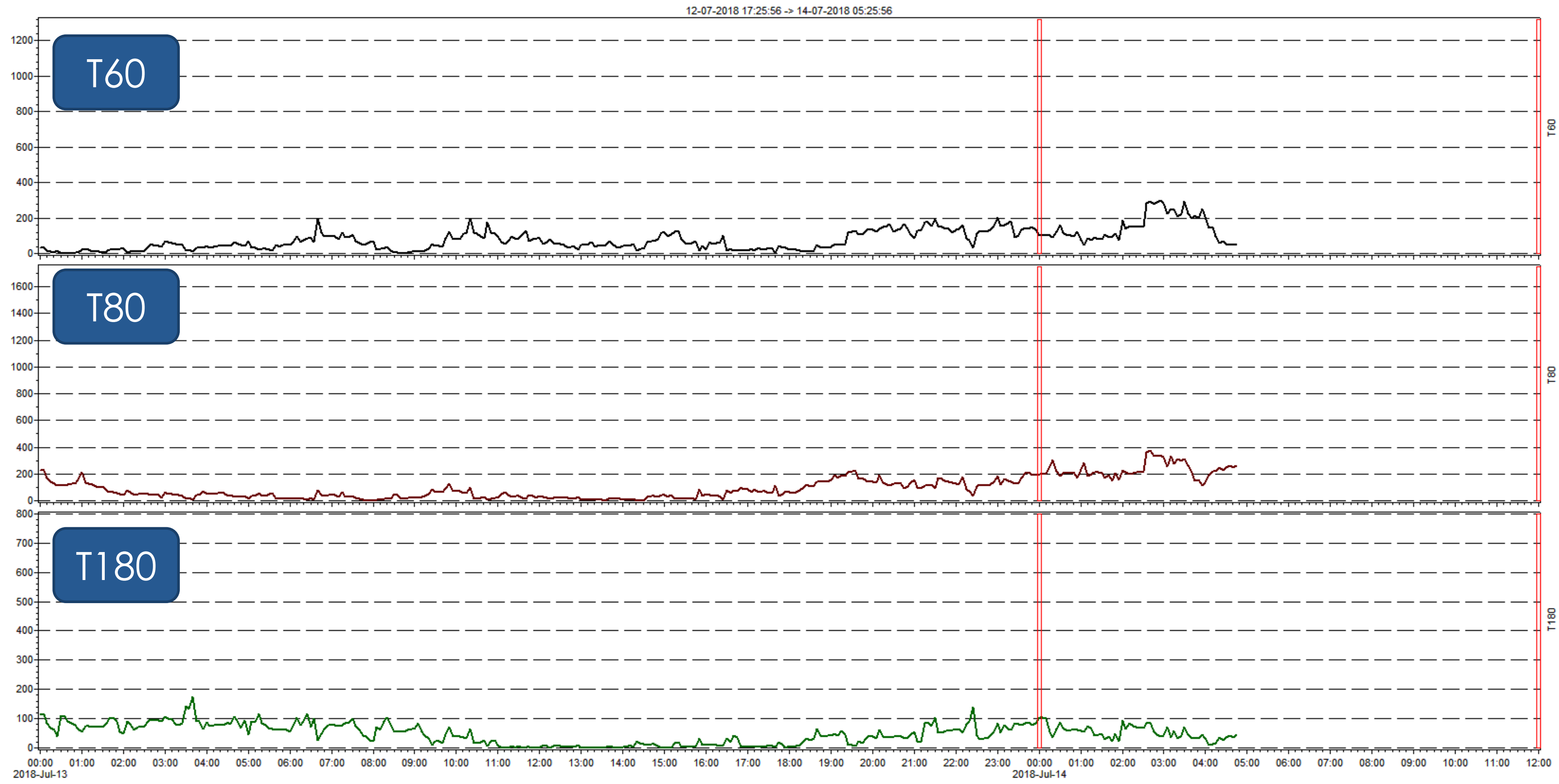
Characteristics reflecting the distortion of the distribution of the muon flux

- Vector of local anisotropy (**A**) indicates the average direction of muon arrival recorded by the detector. This value is calculated as the sum of unit vectors, each of which has a reconstructed direction of a single muon track, normalized by the total number of muons.
- The vector of relative anisotropy (**r**) is the difference between the local anisotropy vector in the current time and averaged over a long period anisotropy vector

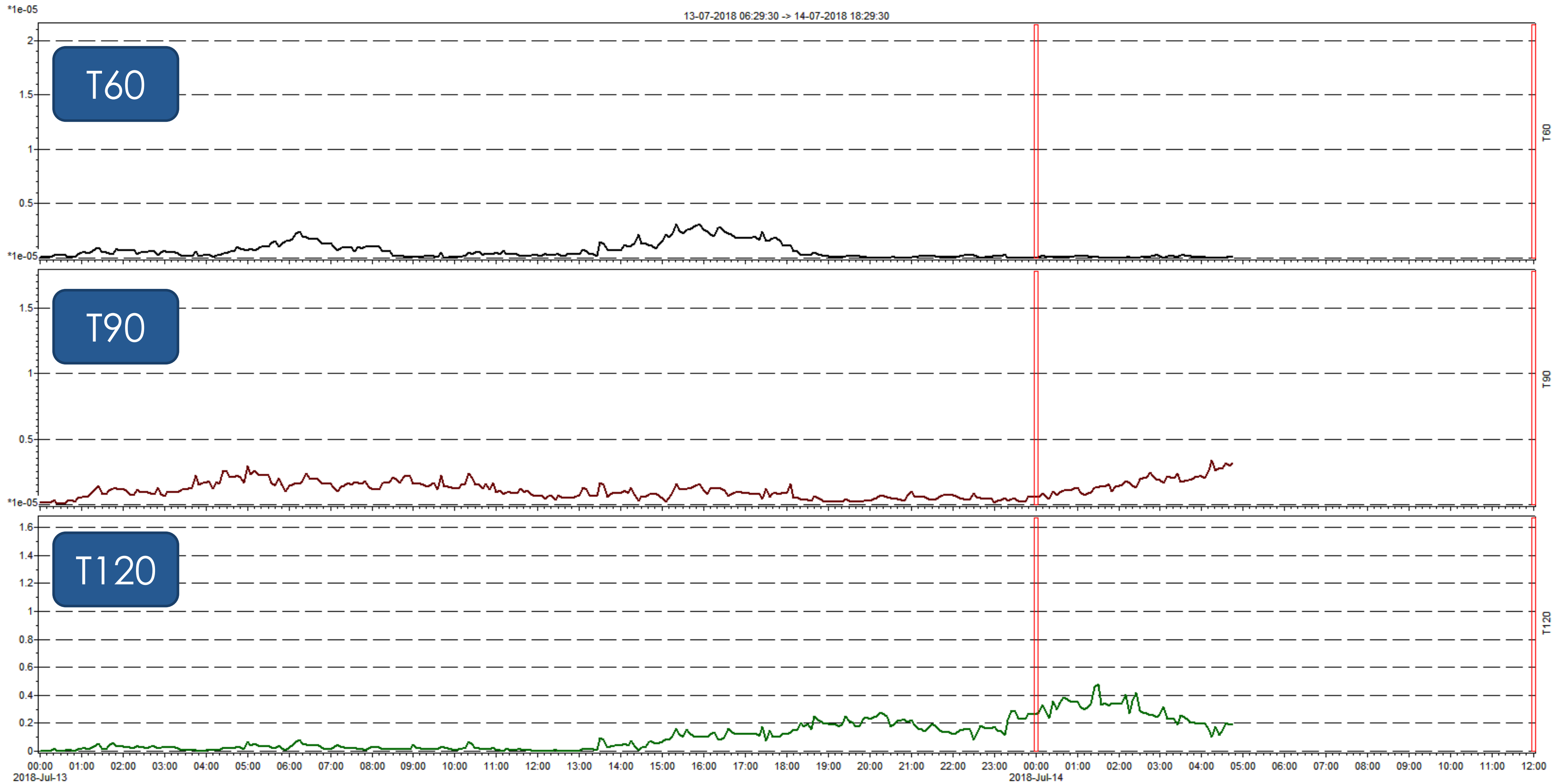
$$\vec{R} = \vec{A} - \vec{A}_N \ , \quad R_{hor} = \sqrt{R_{South}^2 + R_{East}^2}$$

- In this analysis, the value of the vector **r** module and its projection on the horizontal plane (r_{hor}), the projections onto the horizontal axis South (r_{south}) and East (r_{east}), as well as the projection on the vertical axis (r_z) are used
- Registration of muon flux variations at the Earth's surface from different directions allows to obtain a picture of the conditions in the upper atmosphere, to trace the dynamics of their changes and to identify disturbed regions

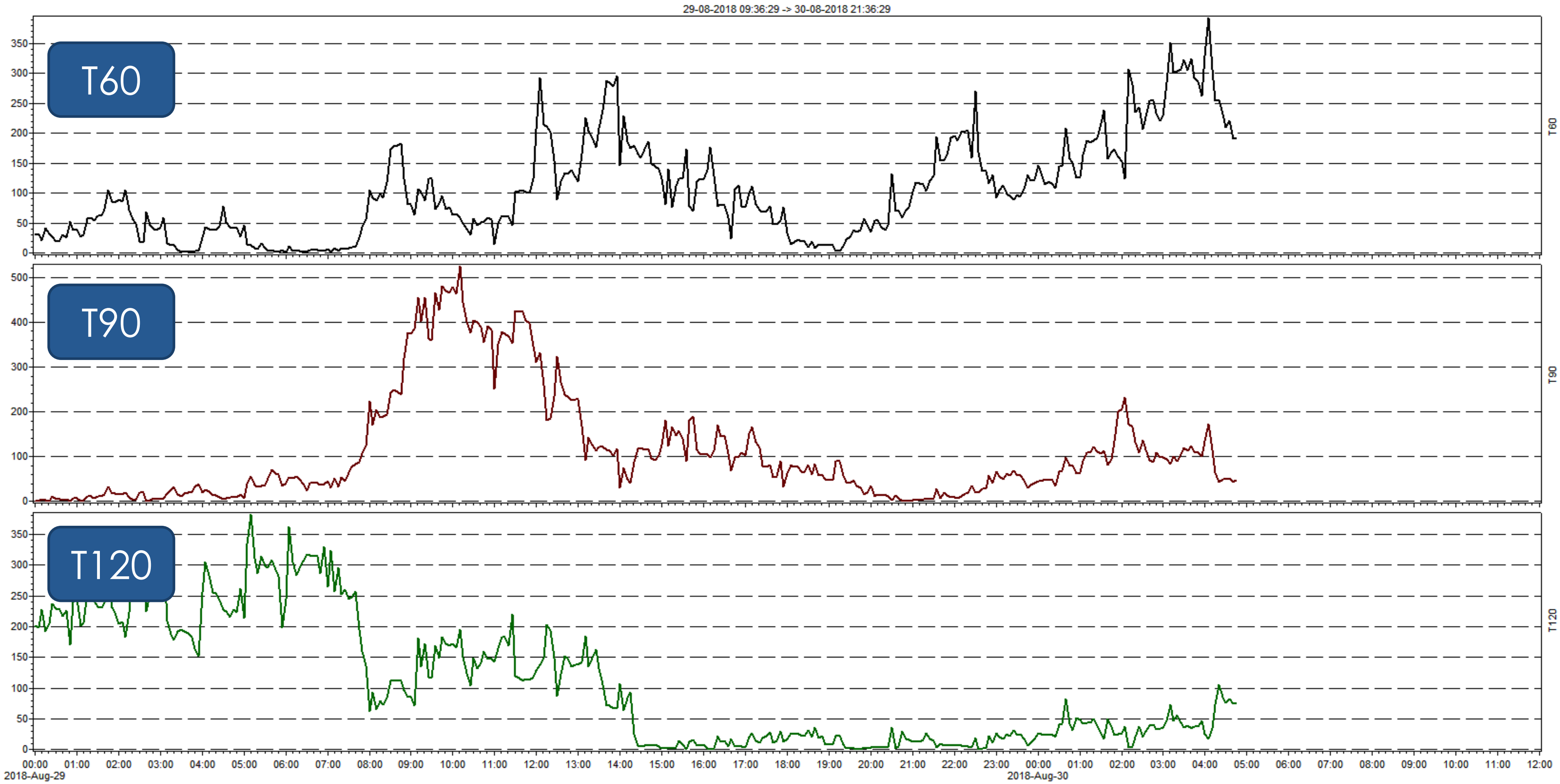
14.07 Wavelet analysis: Isum



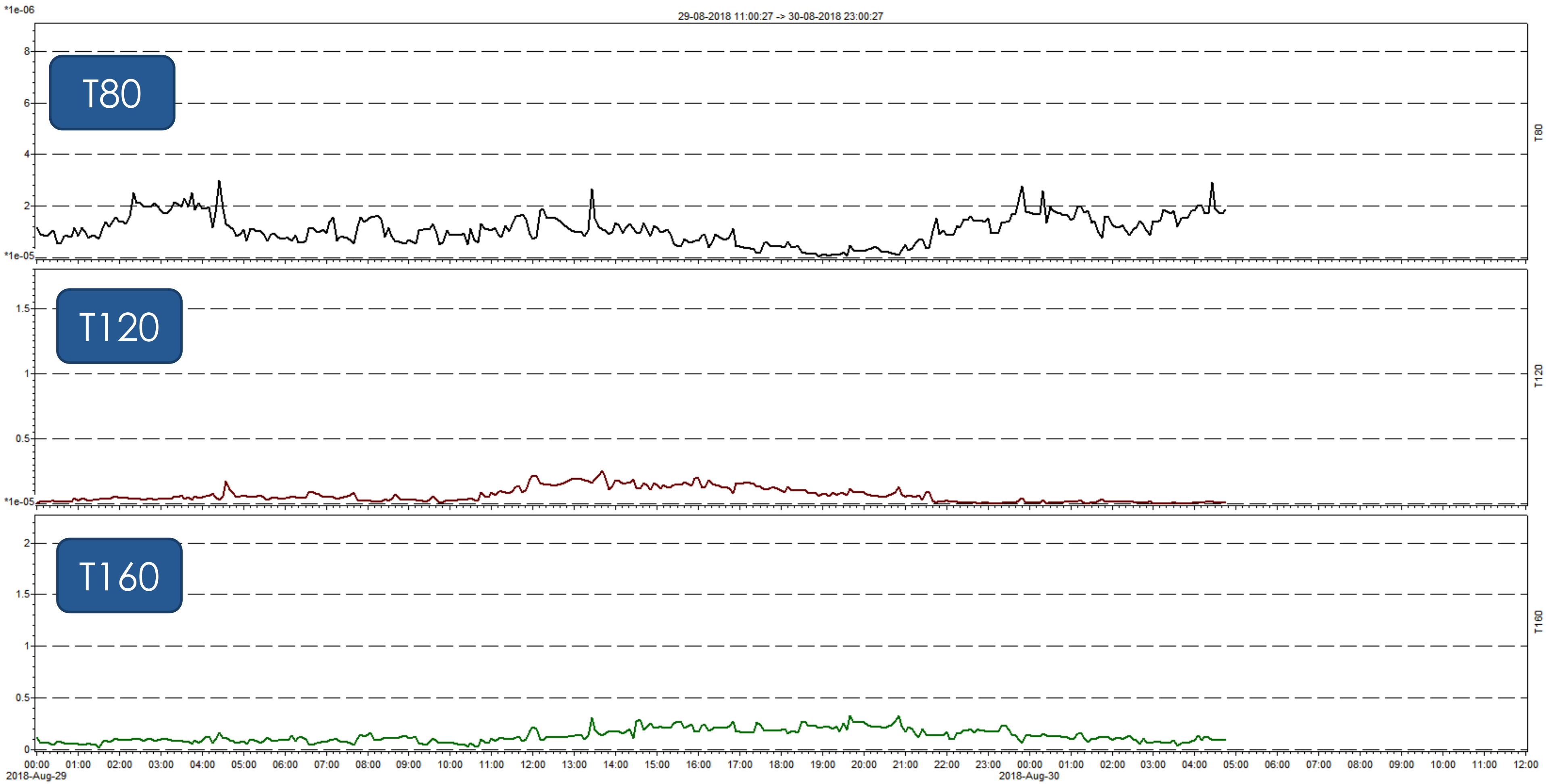
14.07 Wavelet analysis: A



30.08 Wavelet analysis: Isum



30.08 Wavelet analysis: A



Muon diagnostics

- **Formation of the muon flux: in the atmosphere at an altitude of 10 - 20 km**
- **The top of a typical thunderstorm cell: at a height of 8 - 12 km**

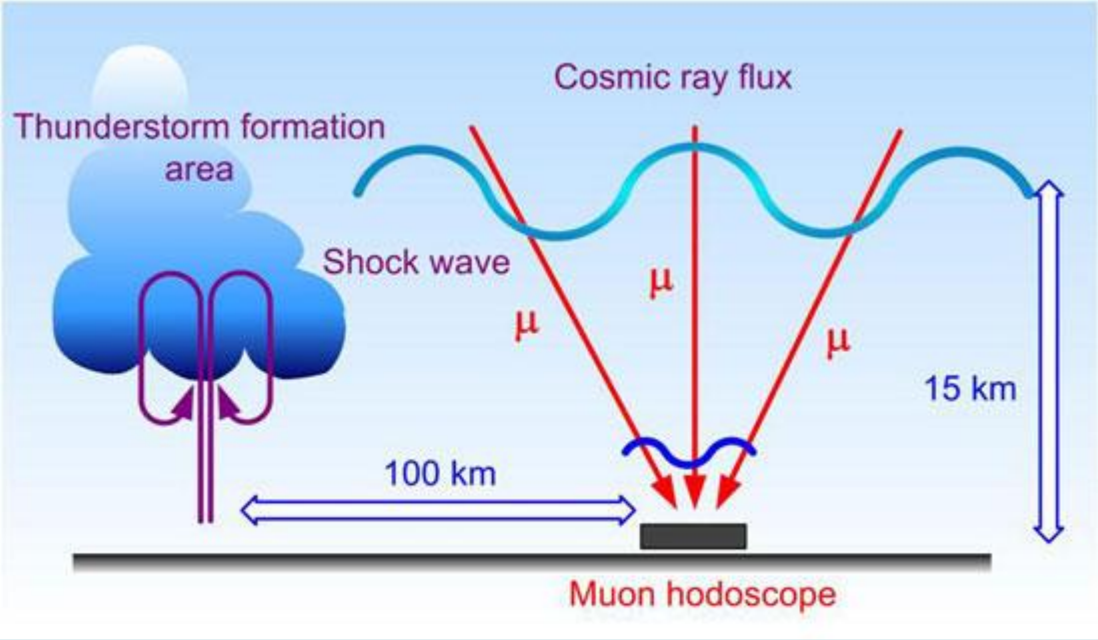
The muon flux is modulated by changes in the basic thermodynamic parameters of the atmosphere.

$$\frac{\Delta N_\mu}{N_\mu} = \beta_p \Delta p + \beta_T \Delta T$$

The higher the temperature, the:

- **higher pion generation point**
- **longer geometric path of the muon to the surface of the Earth**
- **higher probability of decay**

The greater the pressure, the greater muons absorption (due to an increase the amount of substance)



Wavelet analyses of URAGAN data