Thunderstorms and Elementary Particle Acceleration
(TEPA-2019)
October 17 2019
Nor Amberd International Conference Centre of the Yerevan Physics Institute, Byurakan, Aragatsotn District, Armenia

Thundercloud imaging by means of muon hodoscope URAGAN and Doppler weather radar DMRL-C

A.P. Kachur[1], Yu.B. Pavlyukov[2], A.A. Petrukhin[1],

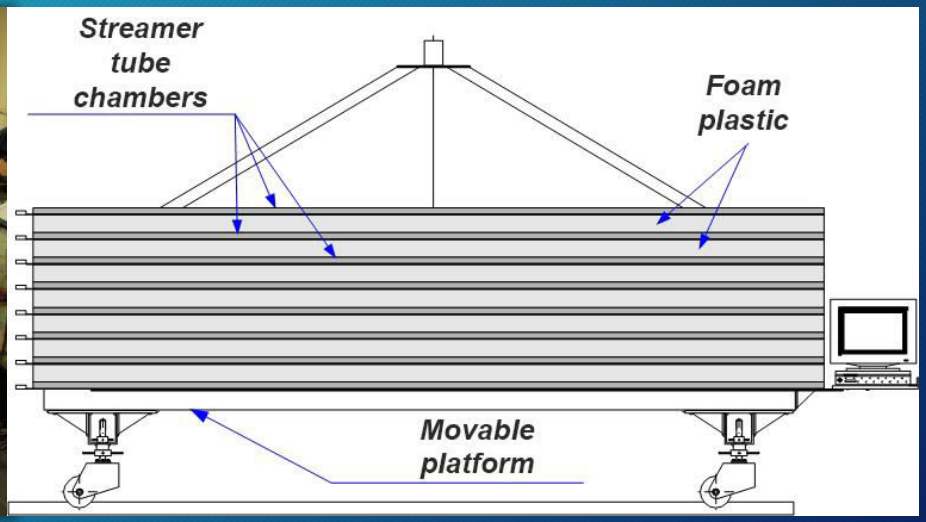
N.I. Serebryannik[2], V.V. Shutenko[1]

[1]National Research Nuclear University MEPhI

[2]Central Aerological Observatory

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 angular matrix for one minute interval. Such a matrix is a "muon picture" of the upper hemisphere



Characteristics reflecting distortions of the muon flux

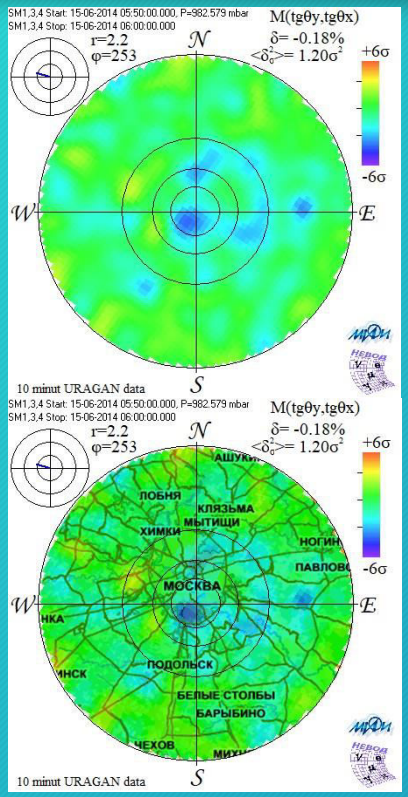
Characteristics reflecting distortions of the muon flux:

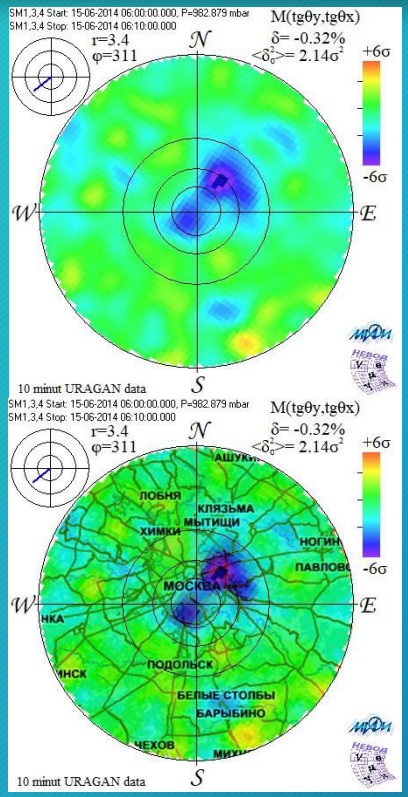
- vector of local anisotropy (**A**) which indicates the average direction of muon arrival. This value is calculated as the sum of unit vectors, each of which has a reconstructed direction of a single muon track, normalized by the total number of muons
- vector of relative anisotropy (**r**) which is the difference between the local anisotropy vector in the current time and anisotropy vector averaged over a long period
- **r**'s projection on the horizontal plane (r_{hor}) and other projections

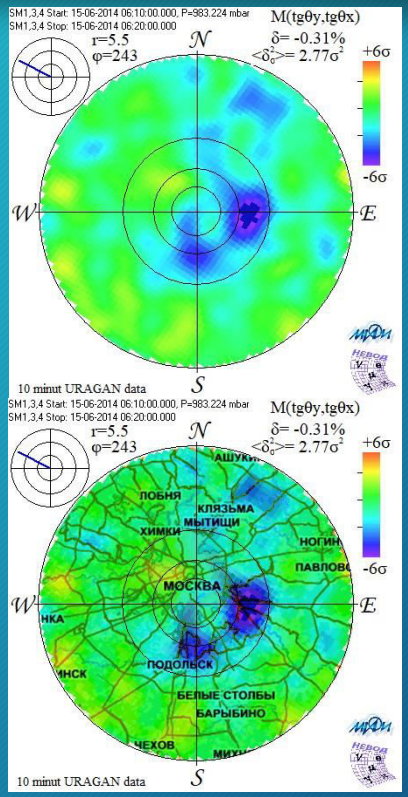
$$\vec{R} = \vec{A} - \vec{A}_N \,, \quad R_{hor} = \sqrt{R_{South}^2 + R_{East}^2}$$

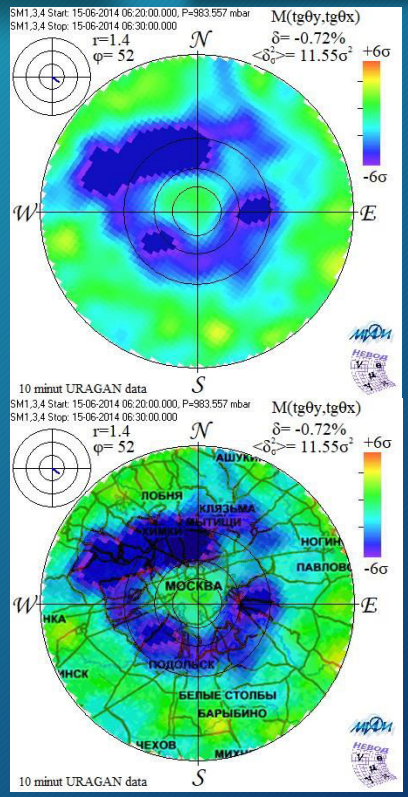
Muon pictures (muonographs) 15.06.2014 Thunderstorm event

Scientific & Educational Centre NEVOD









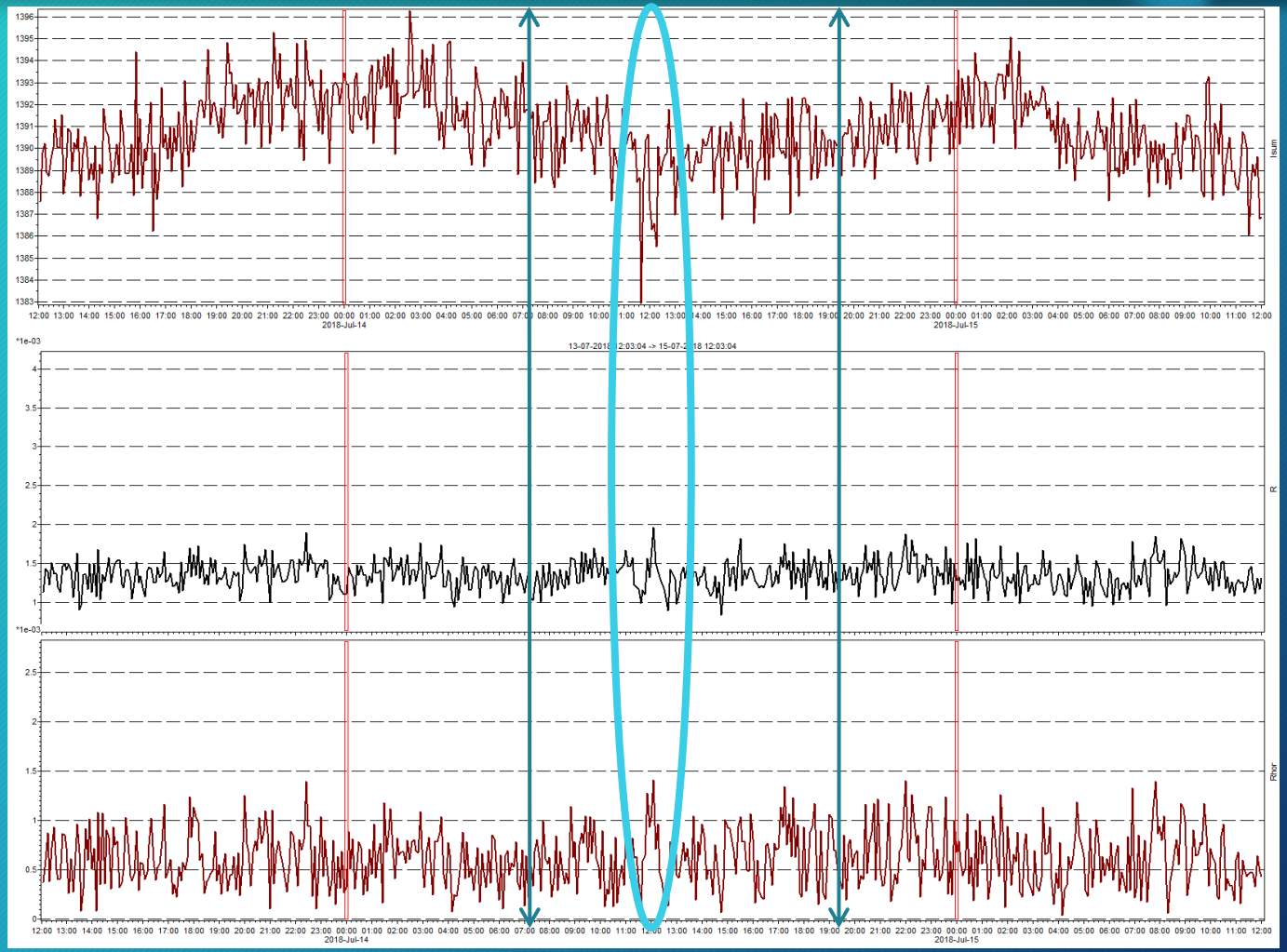
Muonograph is a graphical representation of the variations matrix of counting rate angular distribution over the last 10 minutes with respect to the normalization matrix of the preceding 24 hours in statistical error units

Muon flux characteristics during a thunderstorm (13.07.2018)

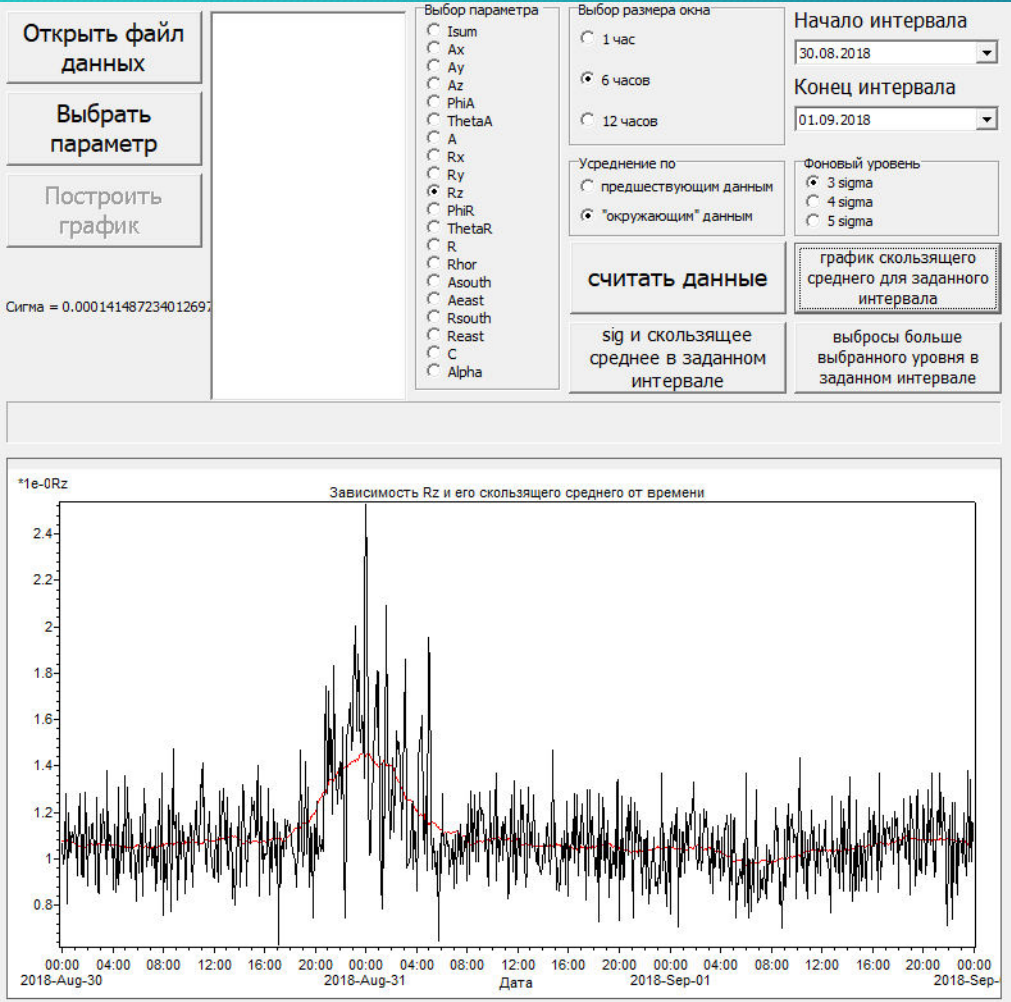
I_{sum}

r

r_{hor}



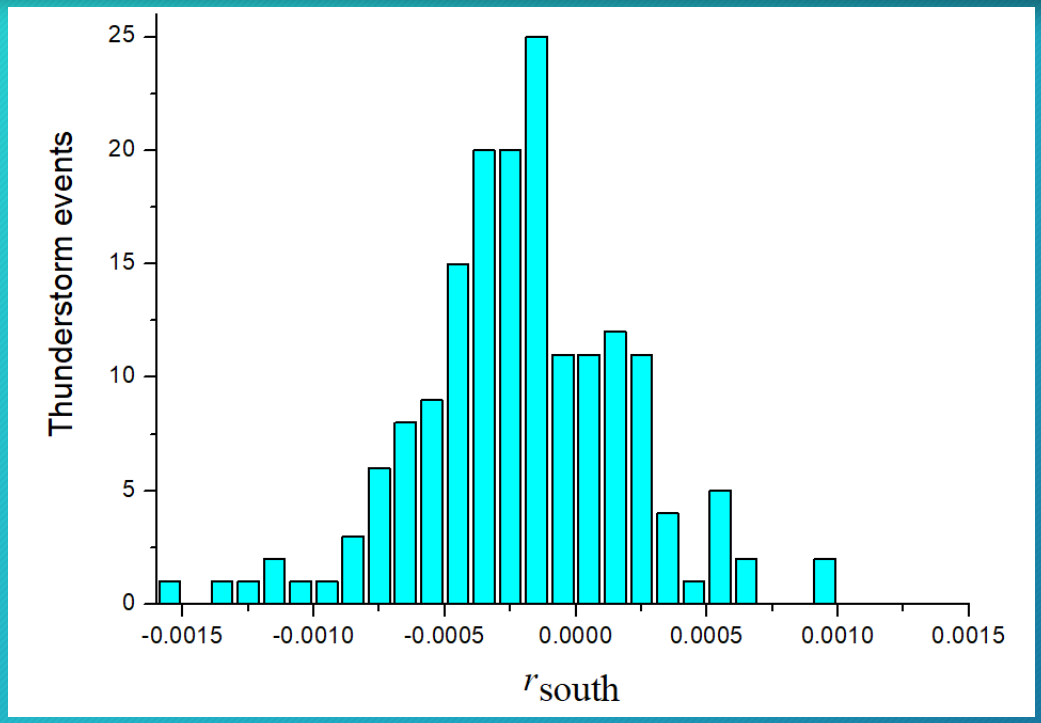
Search for thunderstorm-caused disturbances of the muon flux registered by the MH URAGAN



After analyzing the data for the spring-summer periods of 2014 - 2018, 173 thunderstorm events were found. It is 102 thunderstorm days vs. 135 (75%) thunderstorm days registered by 3 Moscow meteorological stations

The percentage of detection without any weather registered by weather stations: 5% (8 of 173)

Thunderstorm events that caused most significant response in the muon flux characteristics



1	07.06.2014 20:00
2	07.06.2014 21:30
3	09.06.2014 11:30
4	15.06.2014 06:30
5	15.06.2014 11:00
6	13.09.2014 05:00
7	23.04.2015 06:00
8	27.06.2015 00:00
9	27.06.2015 01:00
10	27.06.2015 02:00
11	27.06.2015 03:00
12	13.07.2015 13:00
13	02.03.2016 15:30
14	17.09.2016 02:30
15	29.03.2017 00:30
16	14.08.2017 21:00
17	21.09.2018 04:00

From 173 thunderstorm events selected by the thunderstorm event search program based on MH URAGAN data 17 events caused most significant response in the muon flux characteristics (10%)

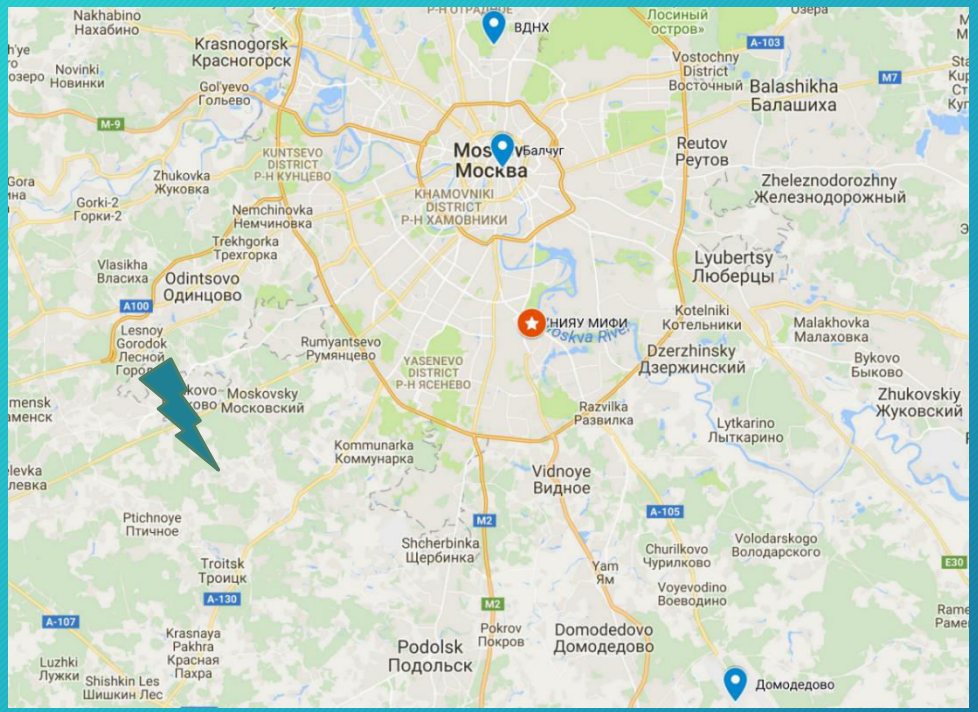
Condition of selection: deviation from the average by more than 3σ by at least one of the characteristics considered.

Sources of meteorological information

Scientific & Educational Centre NEVOD

8

Moscow weather stations

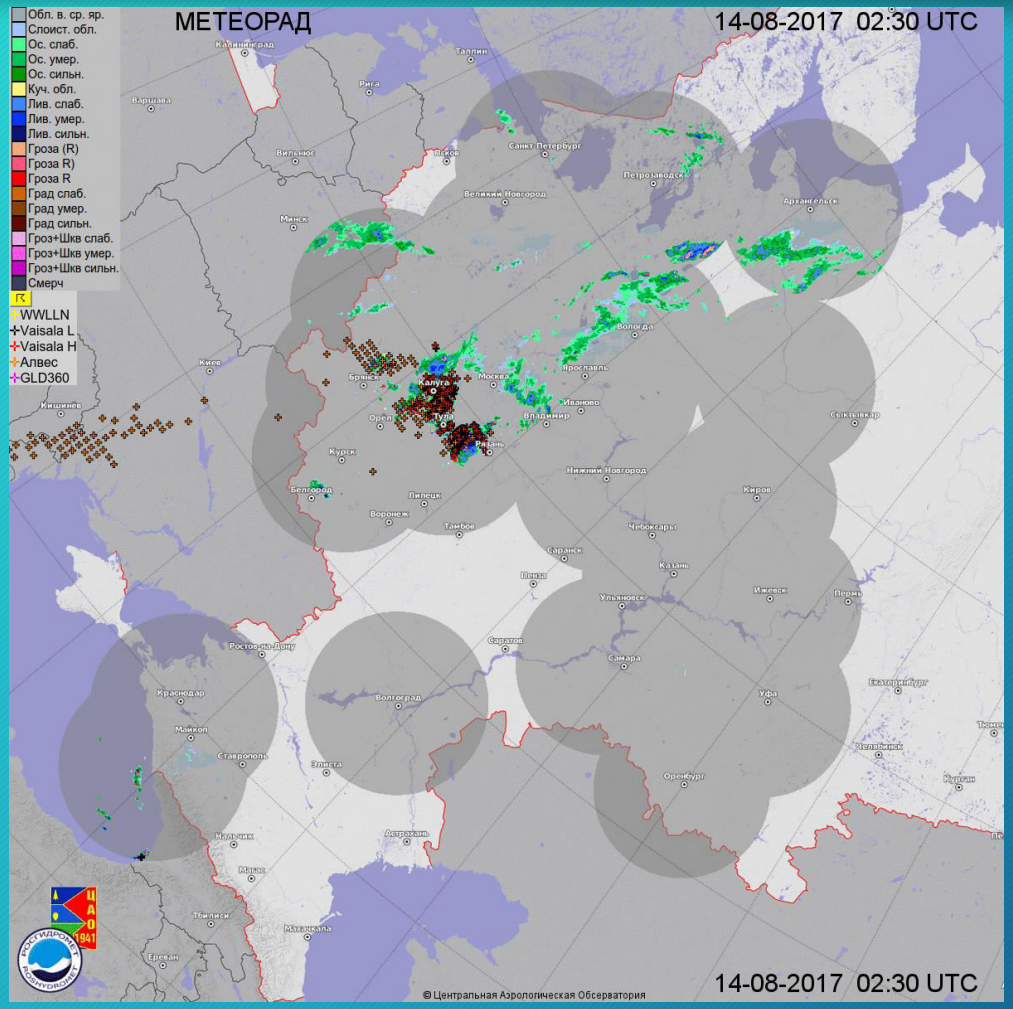


- Weather are archives available
- The most significant weather events are noted

Doppler meteorological radar DMRL-C

- a view range of 250 km
- a maximum detection height of about 20 km
- a high spatial resolution (0.5 – 1 km)

Meteorological radar network



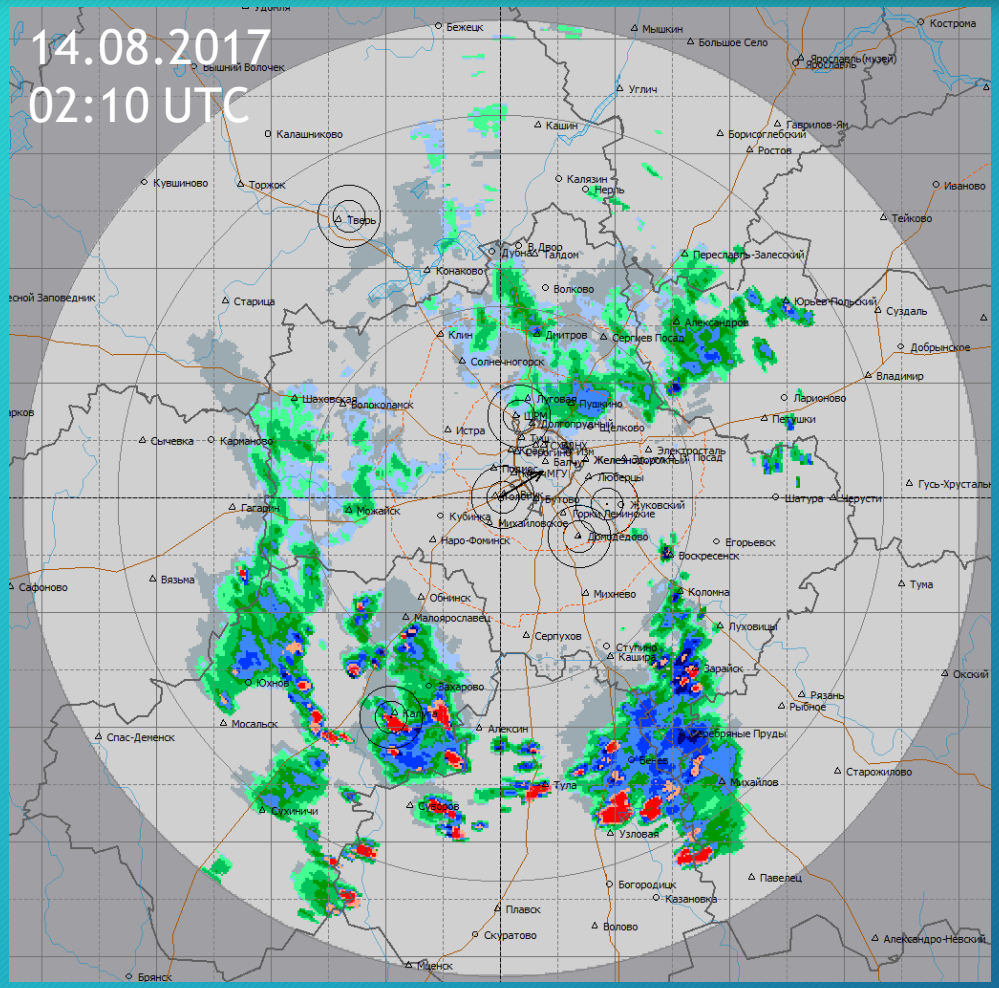
- Precipitation is weak
- Moderate precipitation
- Precipitation is strong
- Cumuliform clouds
- Rain is weak
- Moderate rain
- Heavy rain
- Thunderstorm 30-70%
- Thunderstorm 70-90%
- Thunderstorm > 90%

Displays distribution of various meteorological data such as precipitation intensity and velocity and direction of movement of cloud systems

Detects dangerous weather phenomena such as thunderstorms

Data from DMRL-C located in Vnukovo airport is used

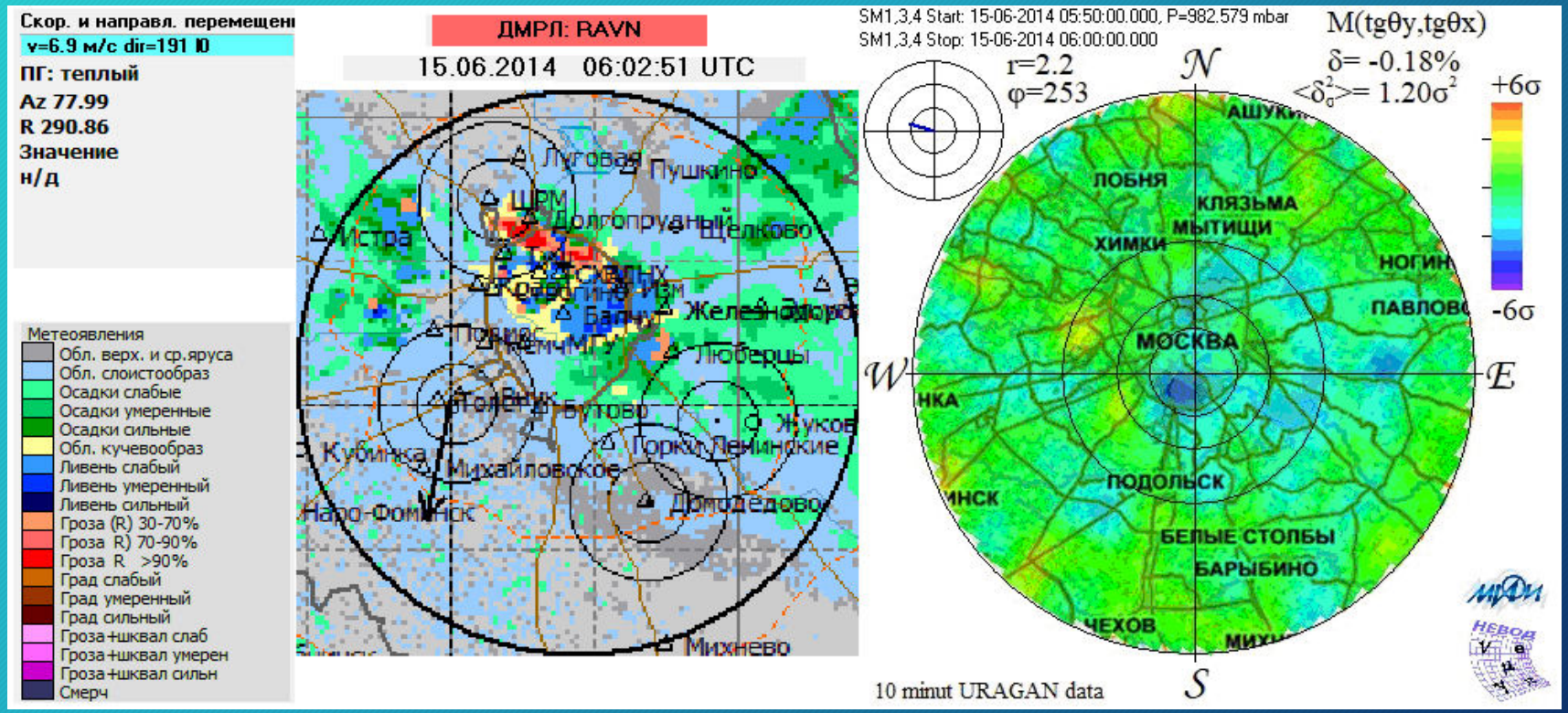
DMRL-C (Vnukovo airport)



DMRL provides cyclic monitoring at 10 minutes intervals and obtains data with a high spatial resolution (1 km × 1 km).
Radar operates by conducting a survey sequence of circular azimuthal scans of the upper celestial hemisphere at several different angles. By doing so it collects data on cloudiness and precipitation on several conical sections of the atmosphere.

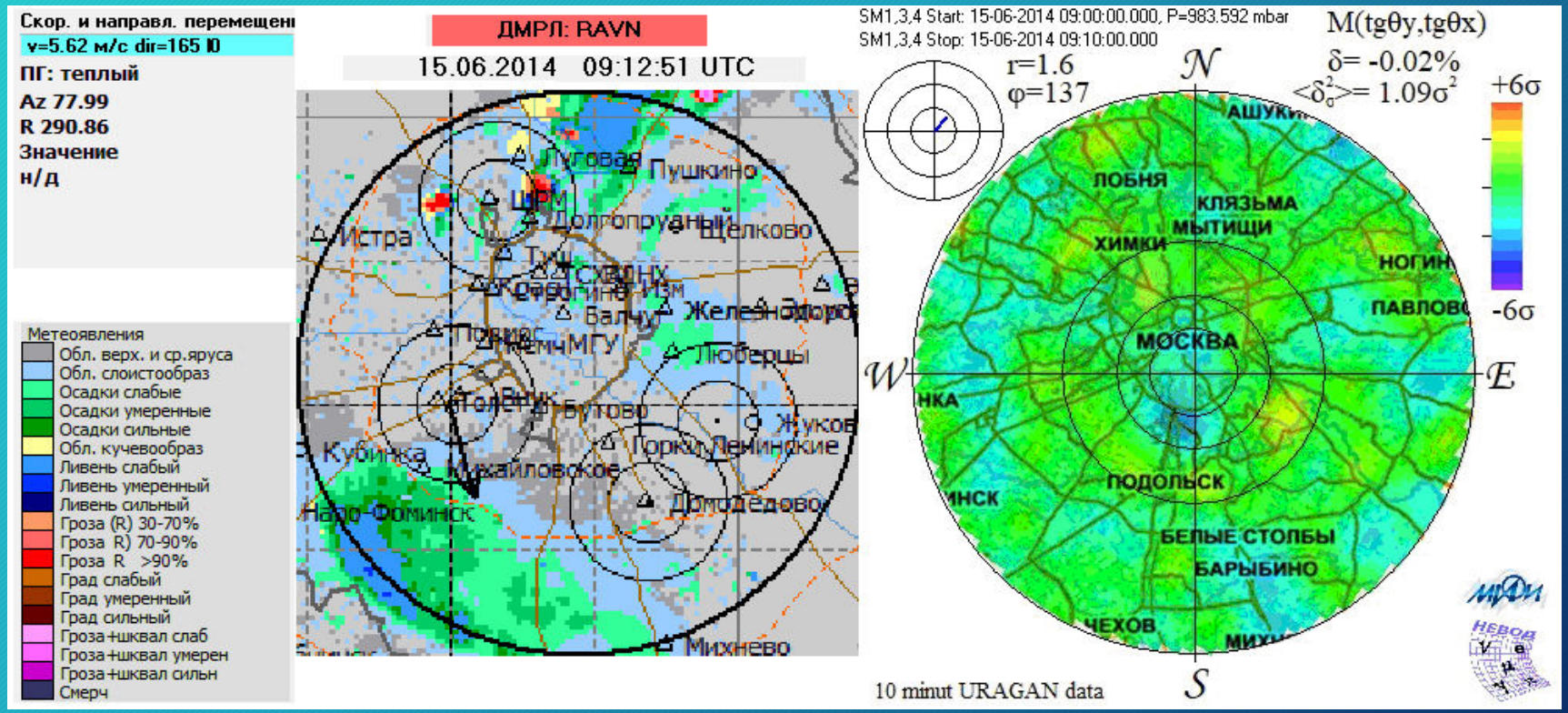
Visual comparison of muonographs and meteorological maps

15.06.2014 06:00 UTC – 09:00 UTC



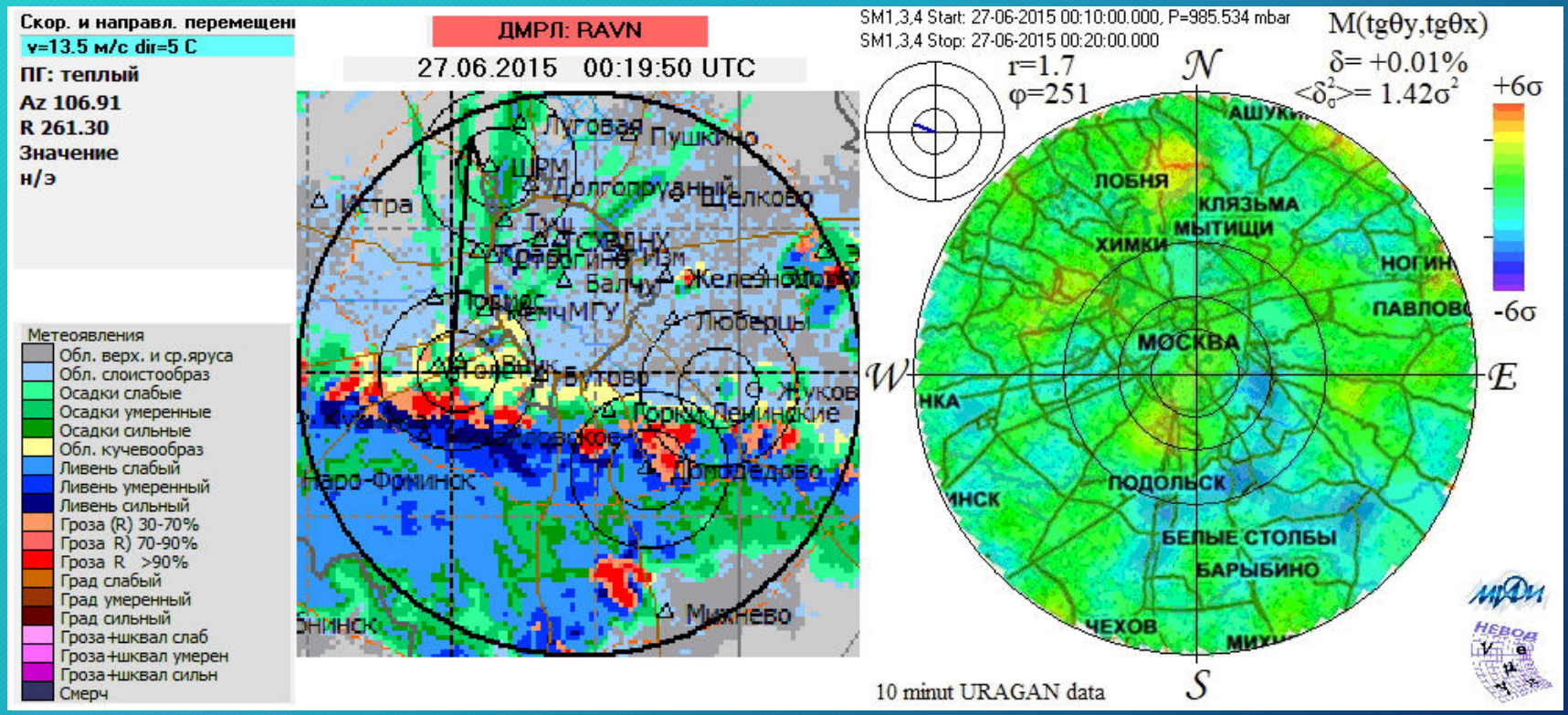
Visual comparison of muonographs and meteorological maps

15.06.2014 09:00 UTC – 13:00 UTC



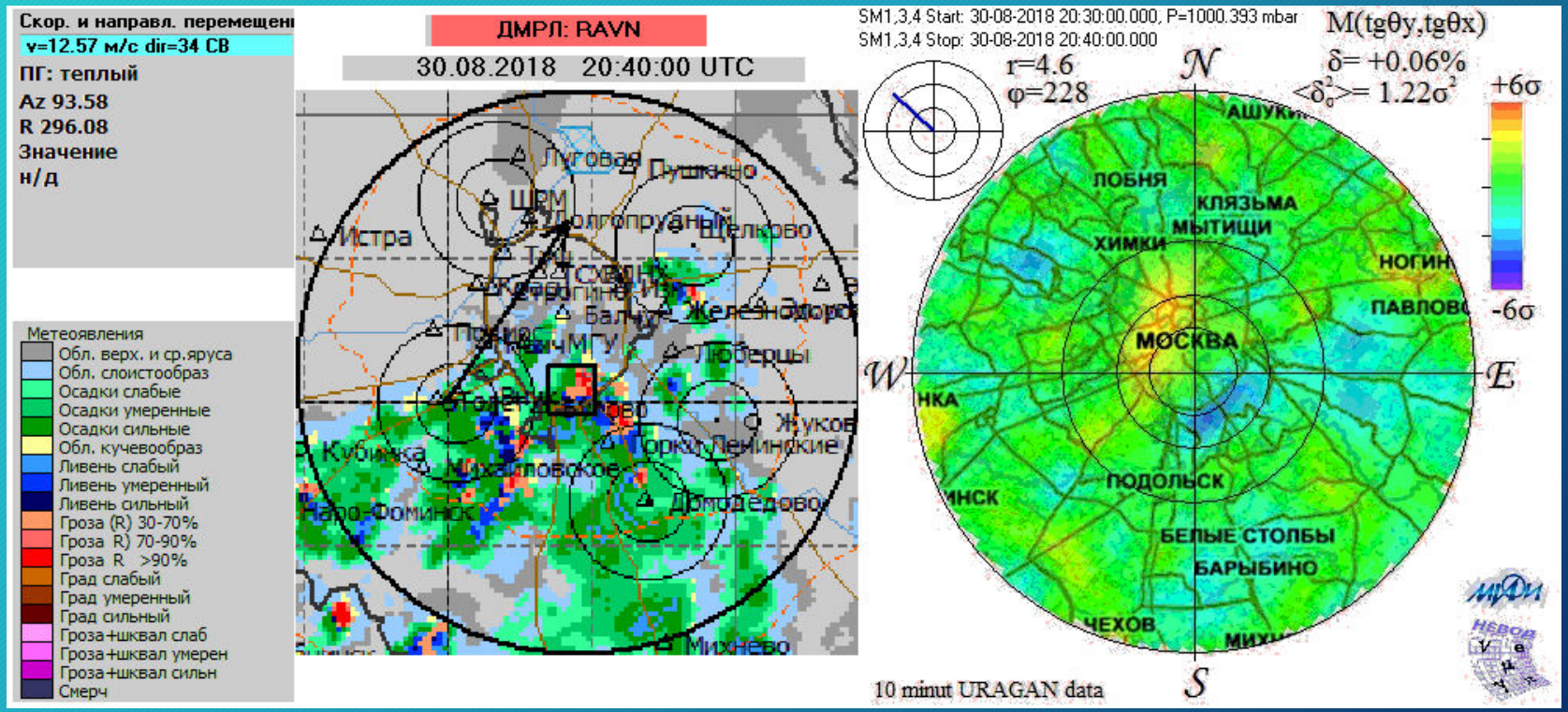
Visual comparison of muonographs and meteorological maps

27.06.2015 00:20 UTC – 07:00 UTC



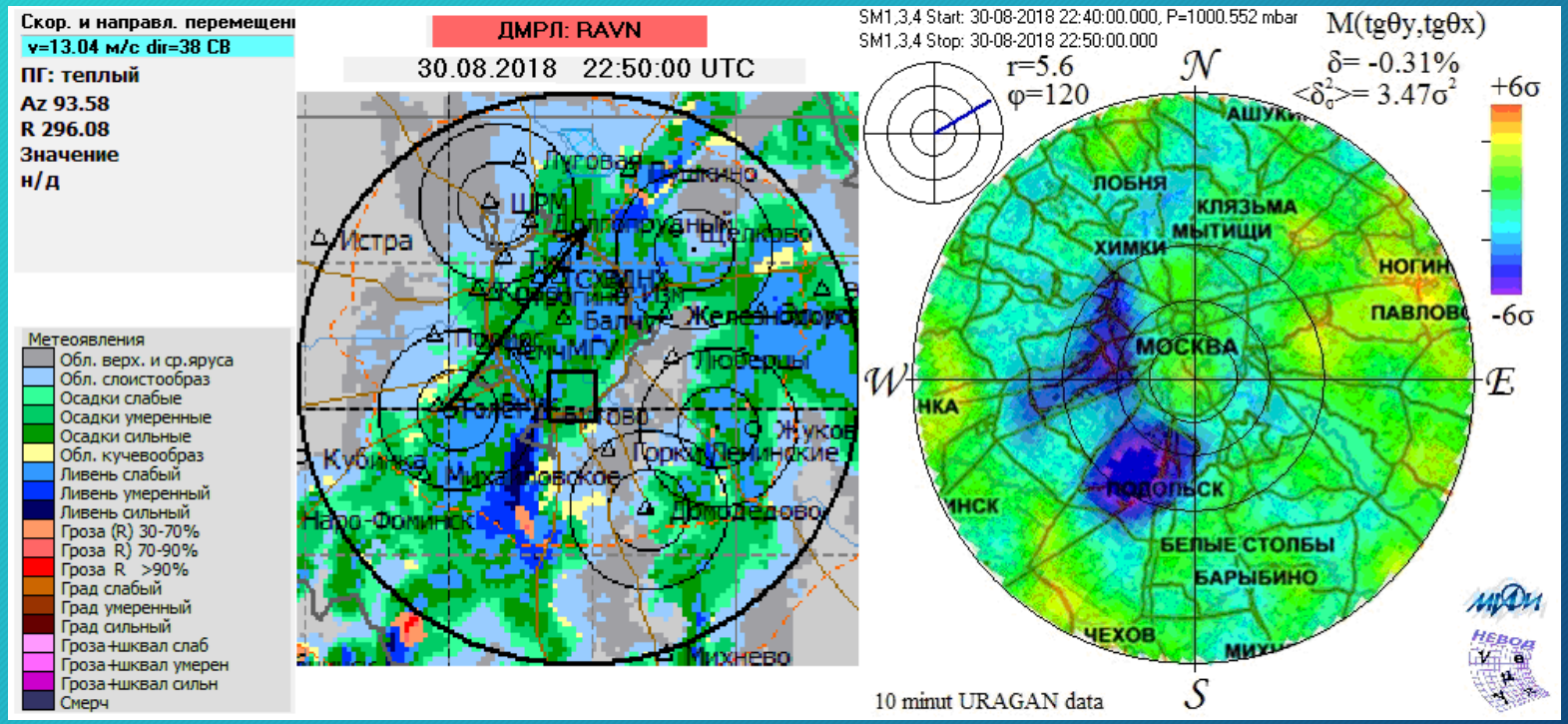
Visual comparison of muonographs and meteorological maps

30.08.2018 20:10 UTC – 31.08.2019 05:10 UTC



Detailed visual comparison

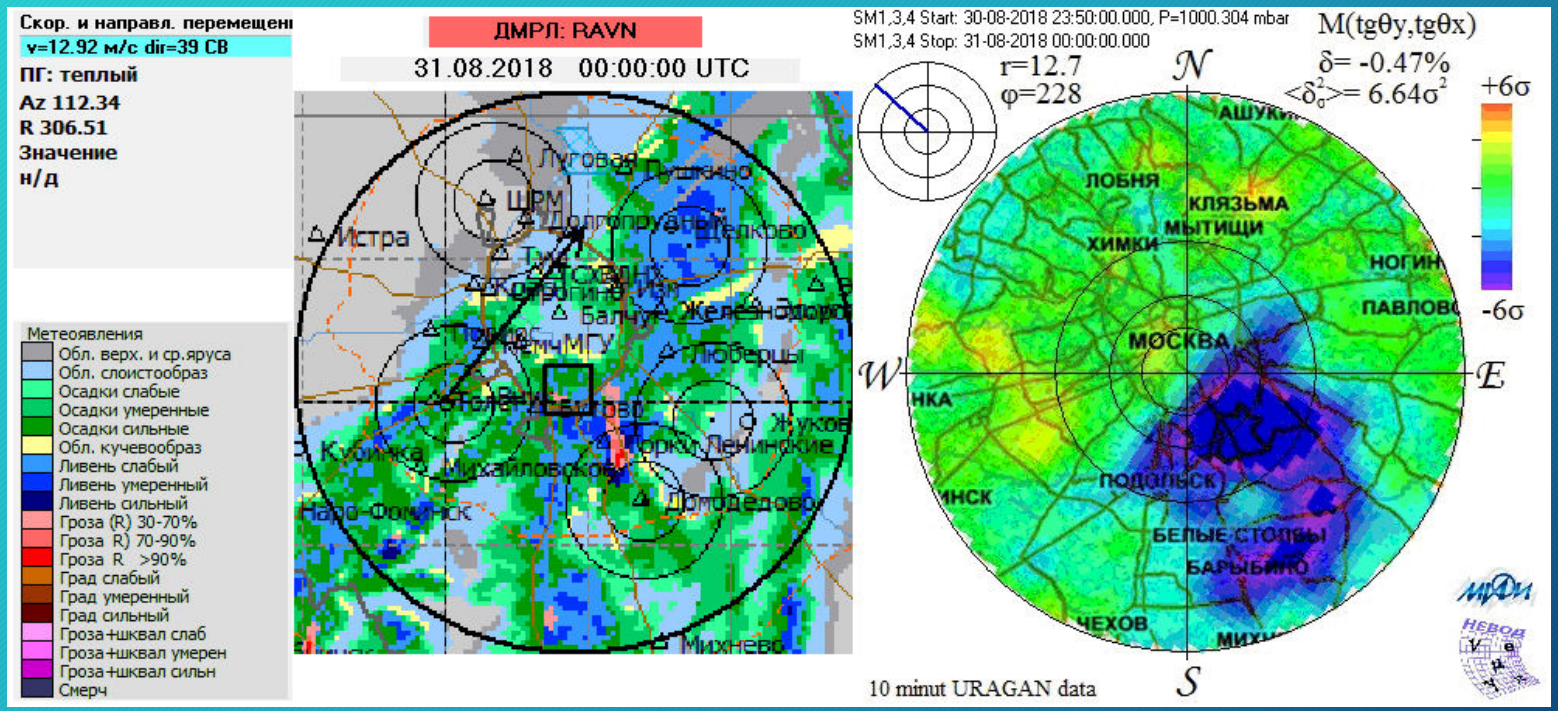
30.08.2018 22:50



It can be noted that shape and position of the shaded areas are similar to each other.

Detailed visual comparison

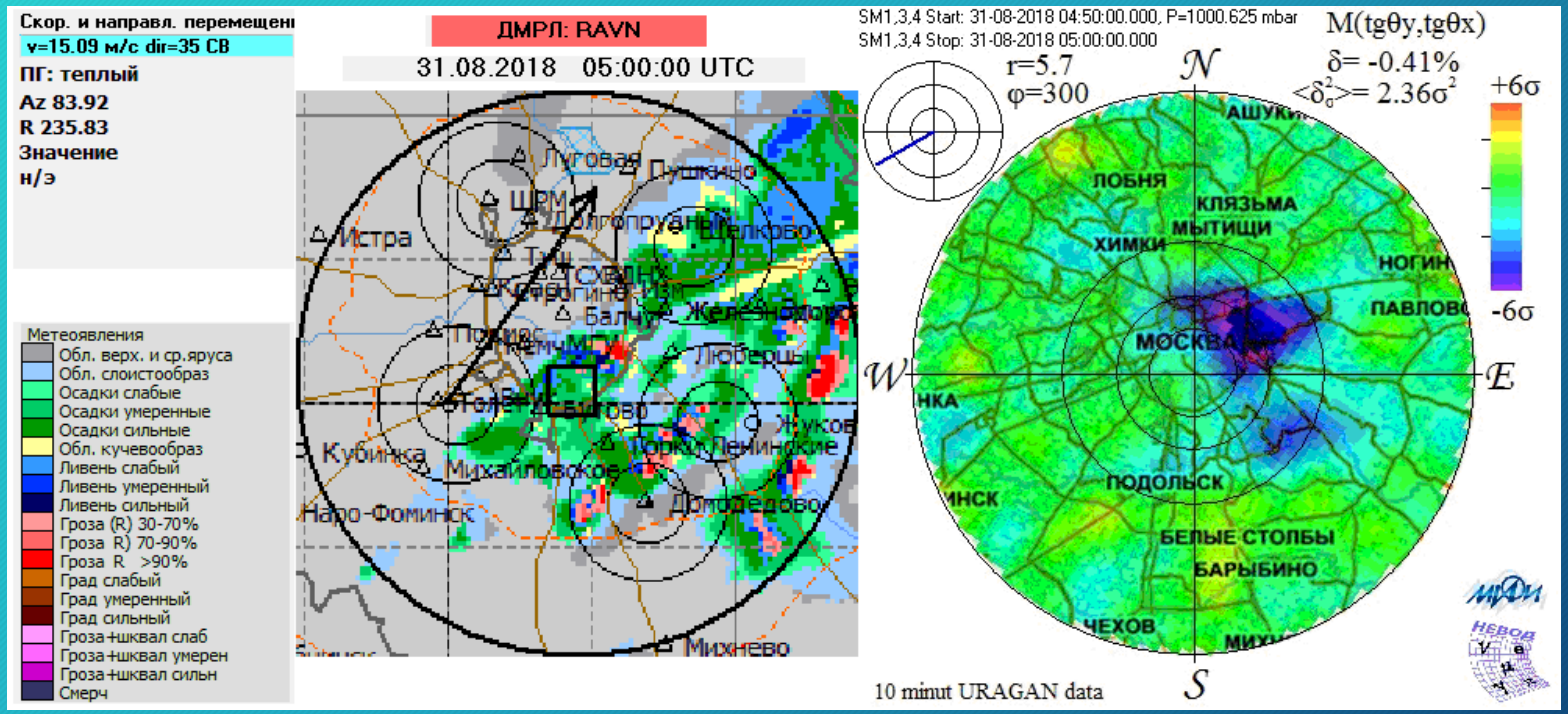
31.08.2018 00:00



It can be noted that shape and position of the shaded areas are similar to each other.

Detailed visual comparison

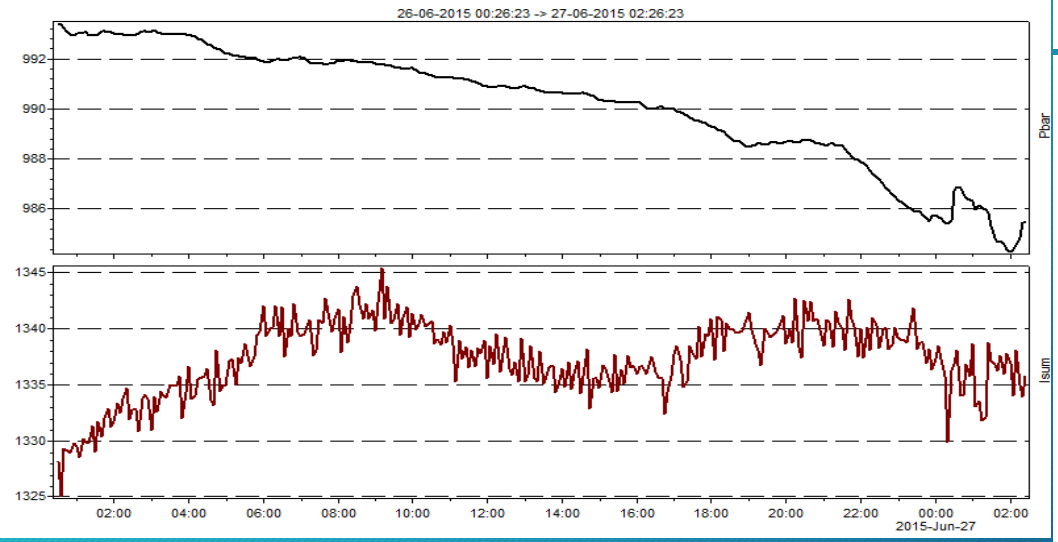
31.08.2018 05:00

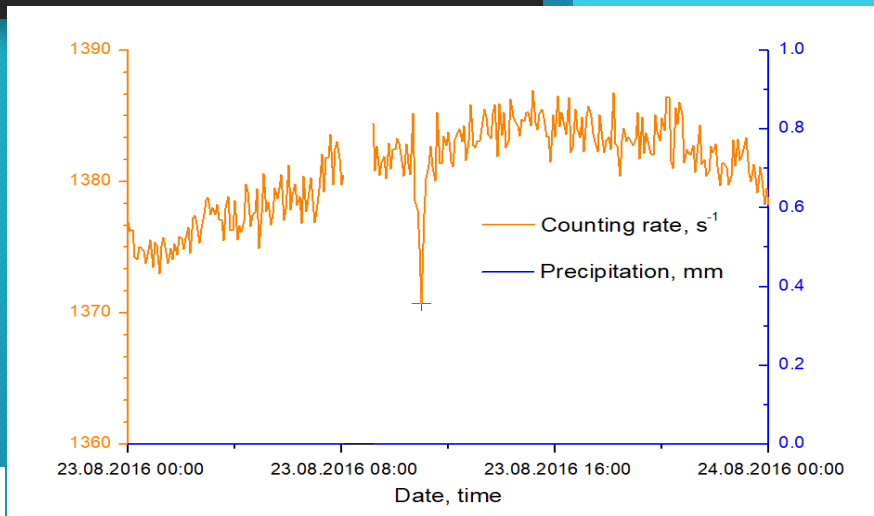


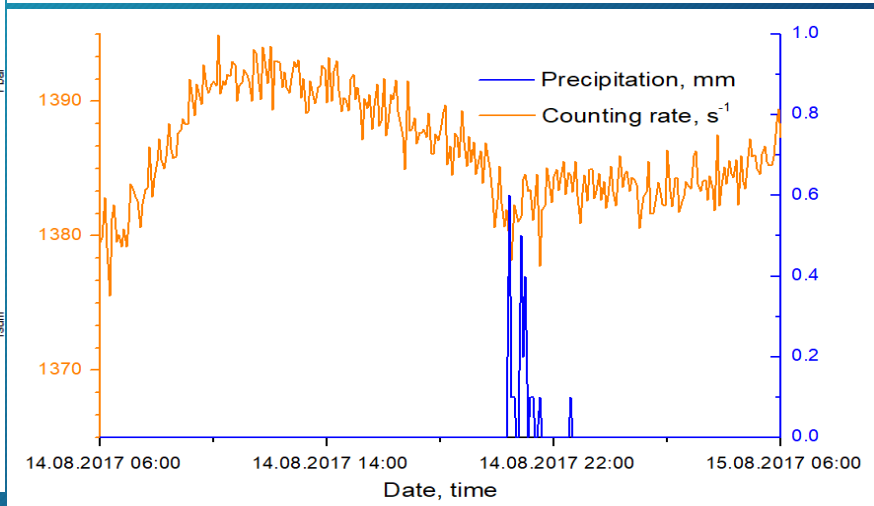
It can be noted that shape and position of the shaded areas are similar to each other.

Possible explanations of the effect

- pressure effect
- presence of a huge water mass in non-stationary state
- influence of the thundercloud electric field







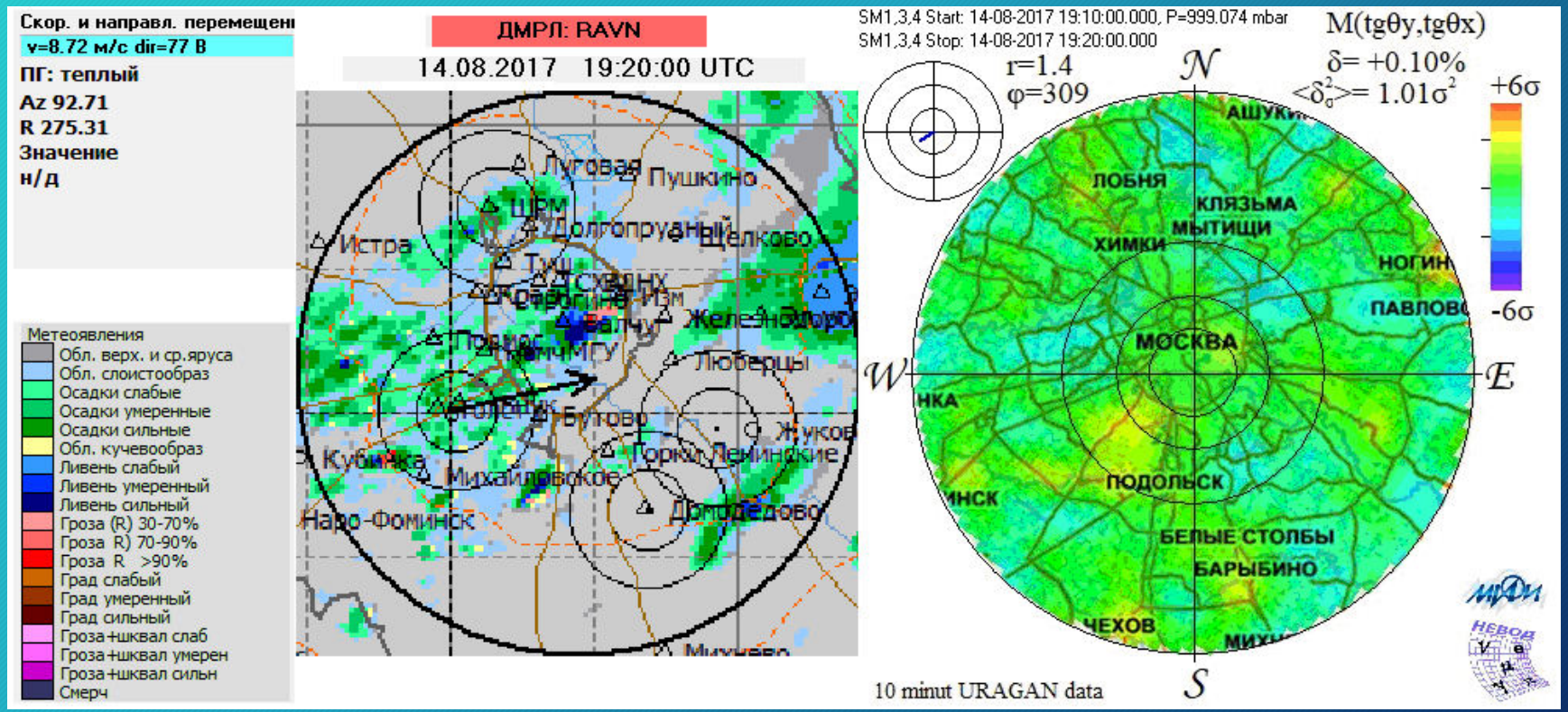
- Results obtained from the analysis of data provided by MH URAGAN are consistent with DMRL-C data
- Characteristics of the muon flux provide a good reaction to the passage of a thunderstorm
- MH URAGAN can be used as thundercloud imaging tool
- Possible explanations for the sharp decrease of the muon flux in thunderstorm activity areas are pressure effect, presence of a huge water mass in non-stationary state and influence of the thundercloud electric field

Conclusions

Thank you for your attention!

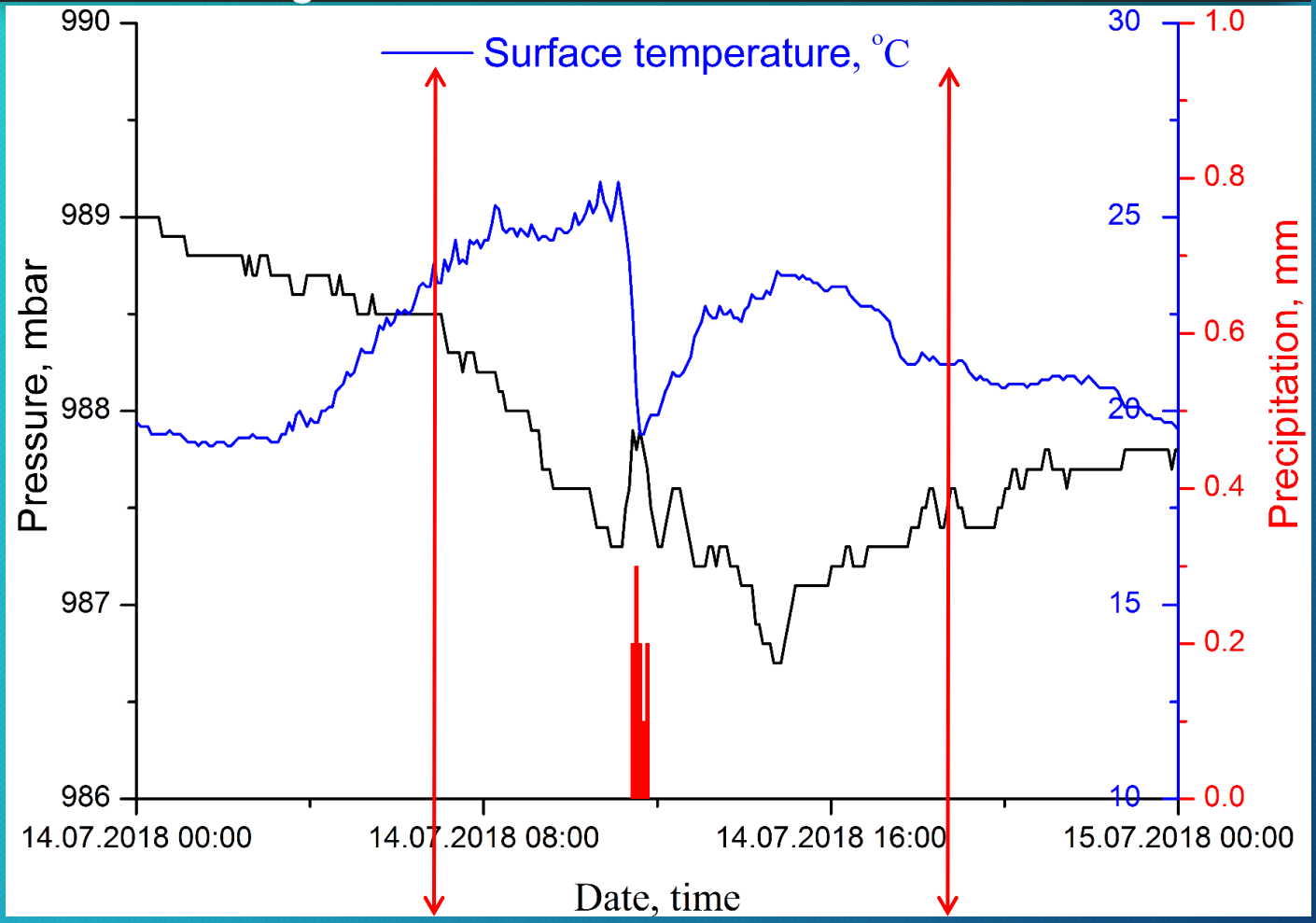
Other examples

14.08.2017 19:10 UTC – 23:50 UTC

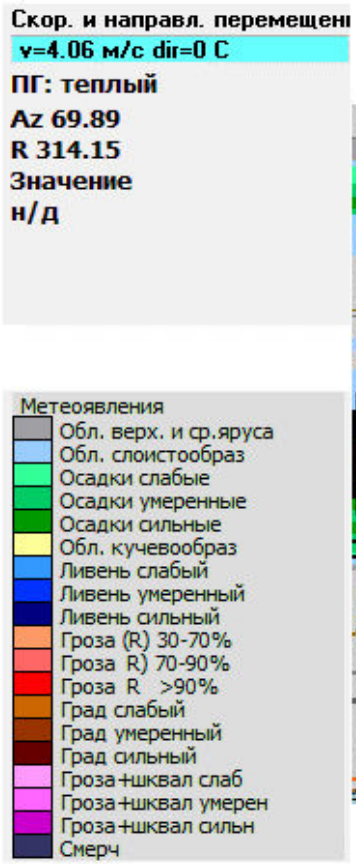


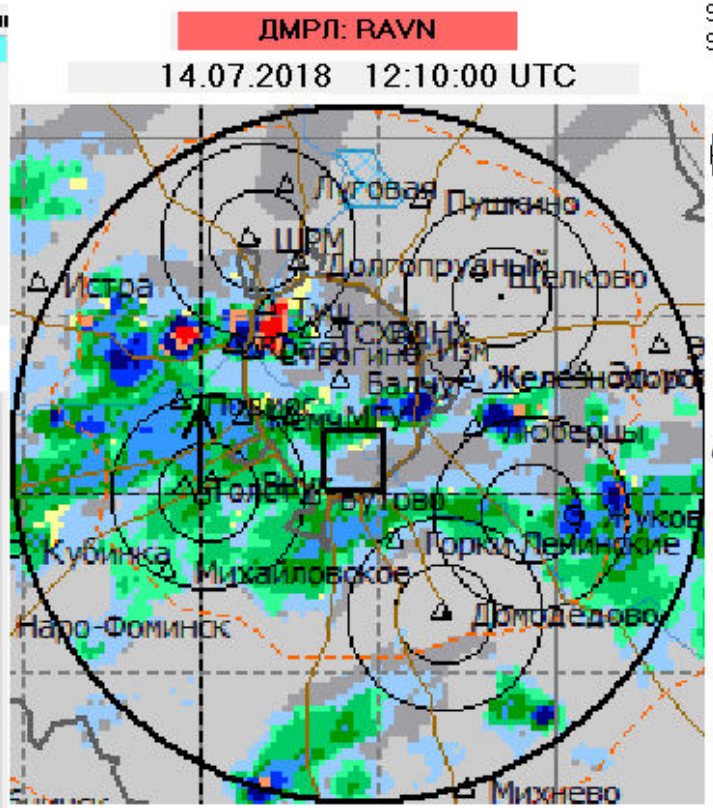
14.07.2018

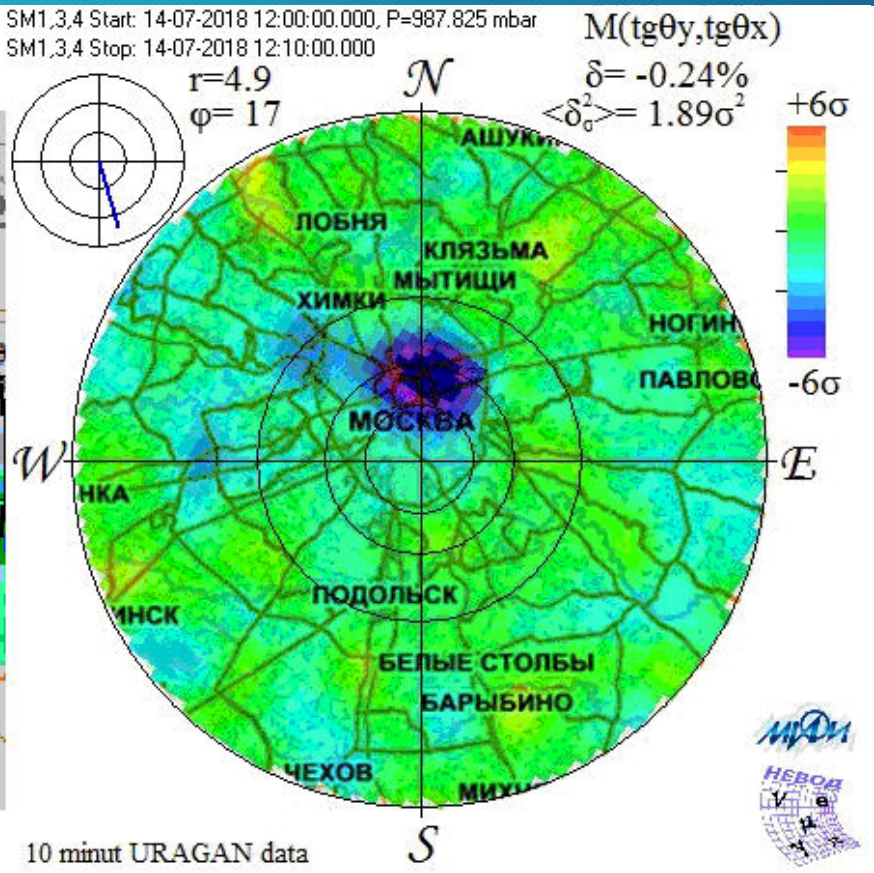
The thunderstorm was observed at the Domodedovo airport meteorological station at 14:00 (UTC time) and at the VDNKh meteorological station from 14:00 to 17:00



Comparison (11:30 – 13:10)





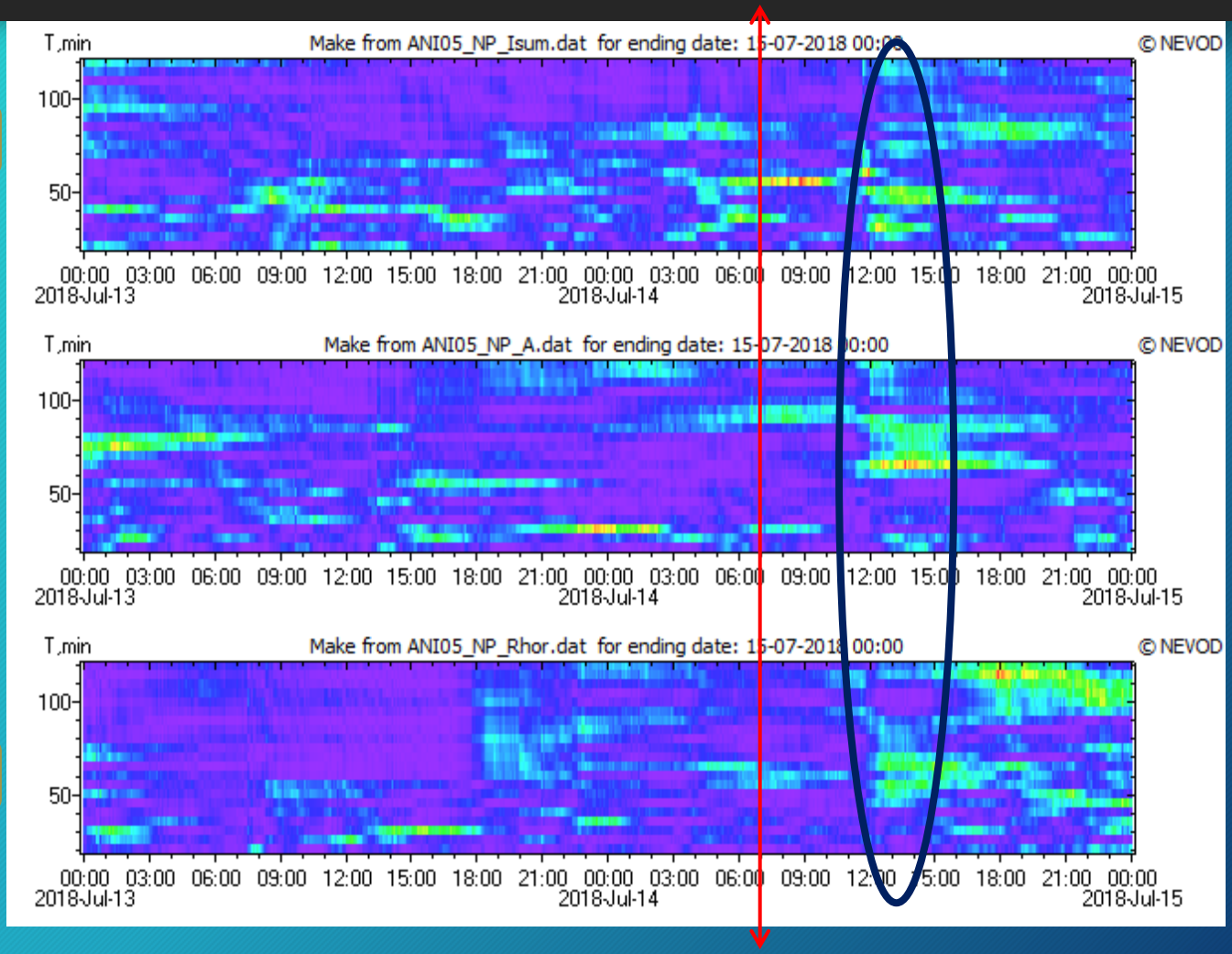


Wavelet analyses of URAGAN data

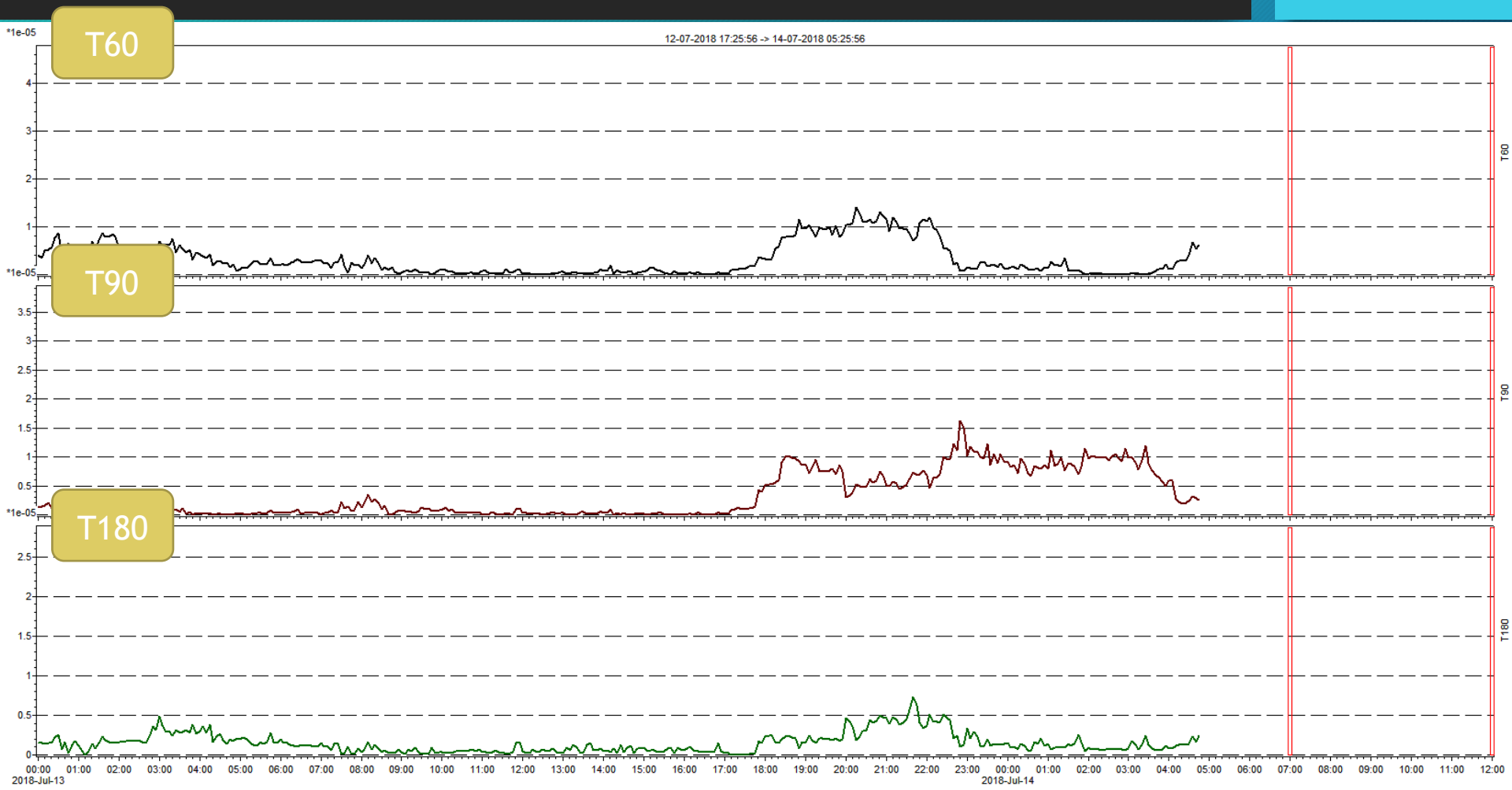
I_{sum}

A

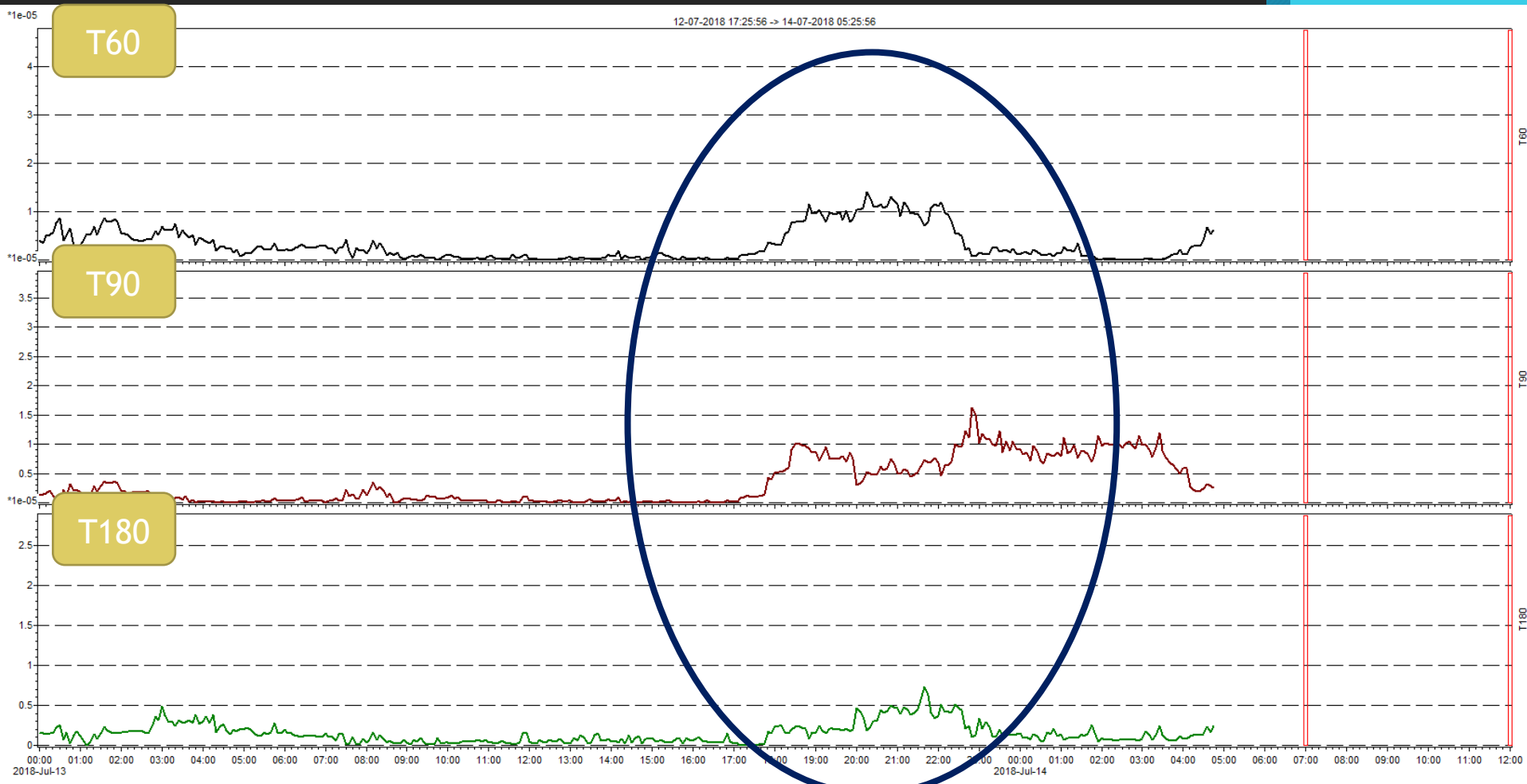
r_{hor}



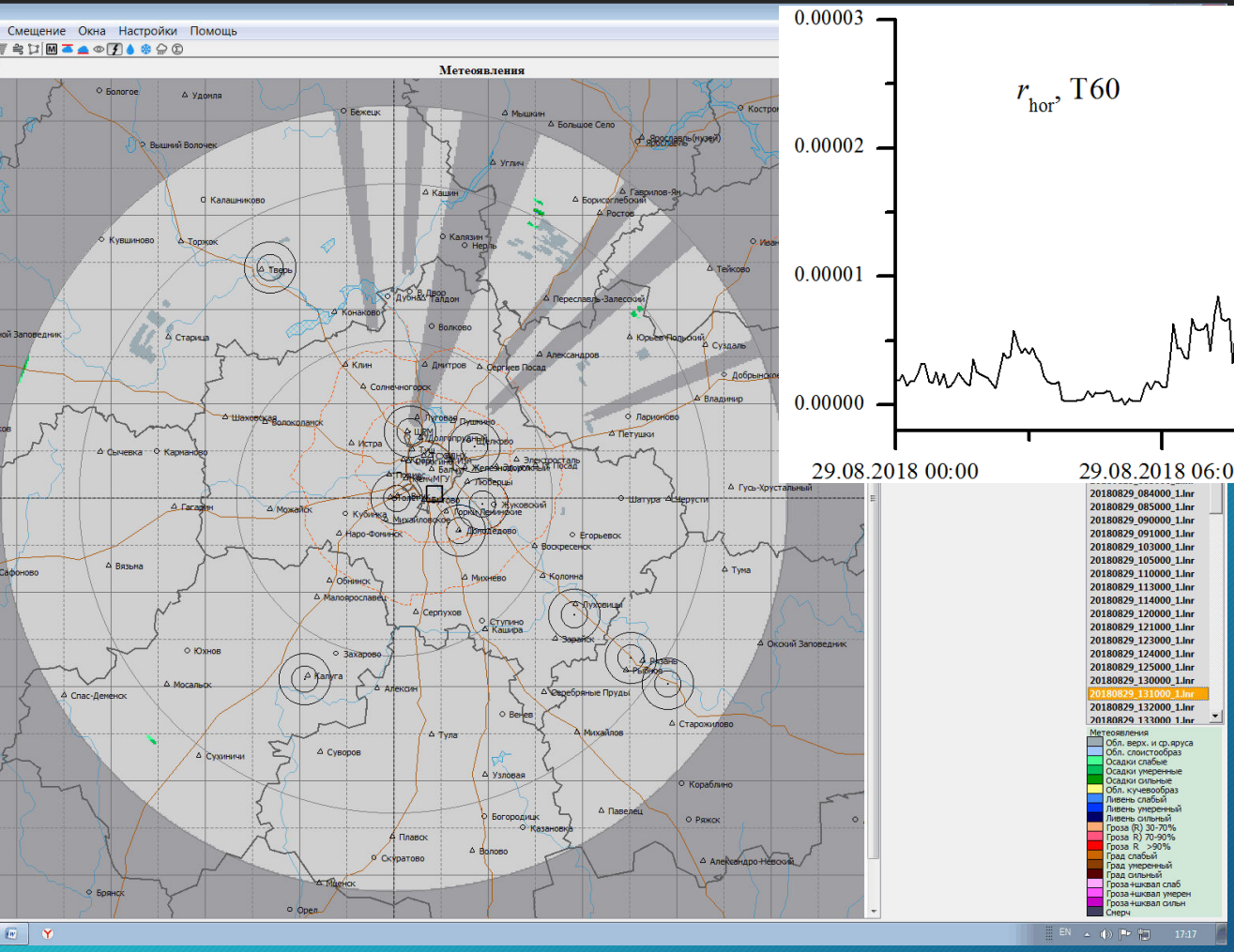
Wavelet analysis: r_{hor}

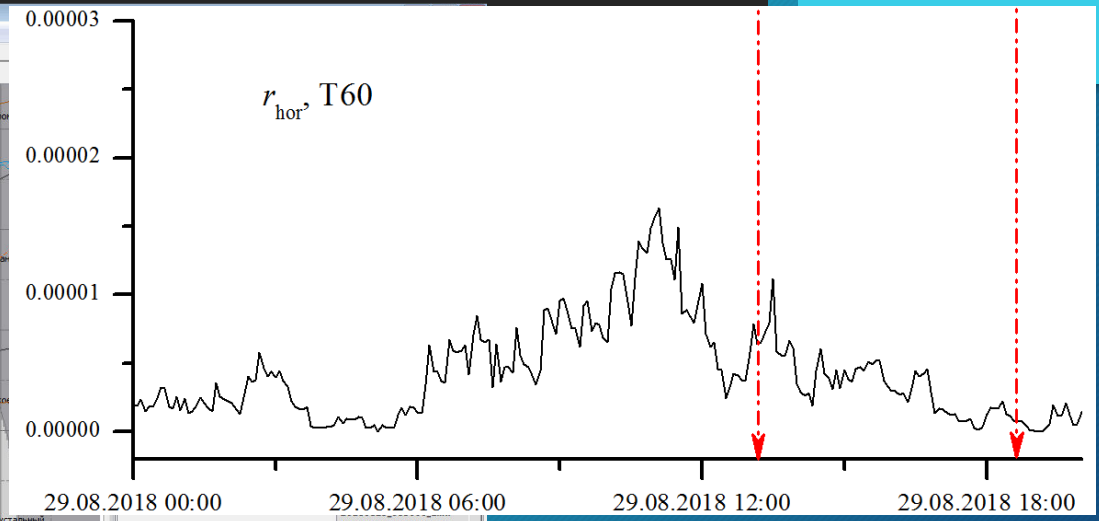


Wavelet analysis: r_{hor}



Thunderstorm activity outside the Moscow region, which is preceded by an increase in the power of the wavelet coefficient





29.08.2018
13:10 - 18:40

Distant thunderstorms are most often preceded by the following periods of wave disturbances:
I_{sum}: 110-120 and 210 minutes.
A: 115, 150, 280, 290, 310 and 320 minutes.
r_{hor}: 100-115 minutes.

Simultaneously with distant thunderstorms, the following periods of wave processes most often appear:
I_{sum}: 115-120 and 170 minutes;
A: 160 and 310 minutes;
r_{hor}: 115 minutes.

- 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 up to 320 minutes

- Obtained data demonstrate the possibility of using wavelet analysis of time series of muon flux characteristics as a tool for detecting or predicting thunderstorms.

- Those results can be used as a basis for the development of methods for the early detection of thunderstorm events by methods of muon diagnostics; they can also be used to exclude atmospheric effects in the study of outer space, the state of the magnetosphere and the heliosphere.

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.

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

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)