



Investigation of muon flux variations associated with thunderstorm events according to MH URAGAN data

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The 2nd International Symposium on Cosmic Rays and Astrophysics (ISCRA-2019)

Muon telescopes, muon hodoscopes and muonography

Moscow, June 28, 2019

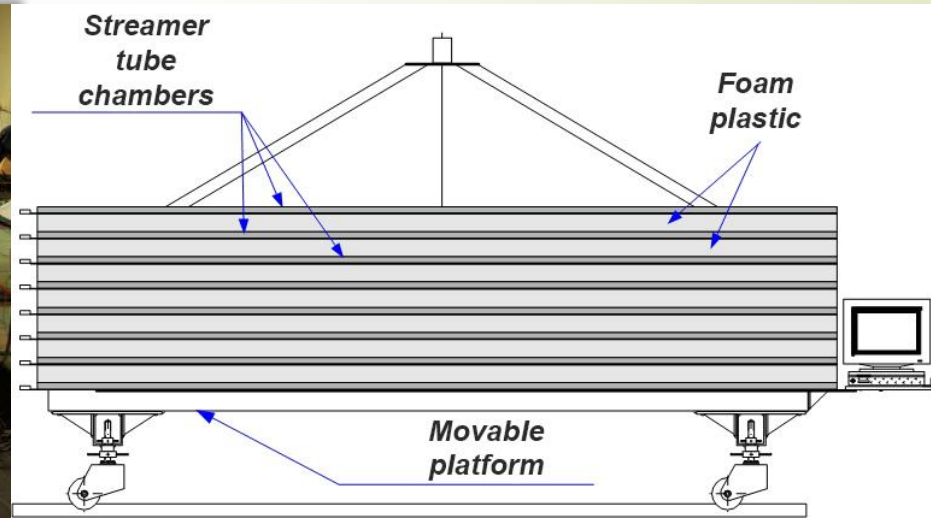
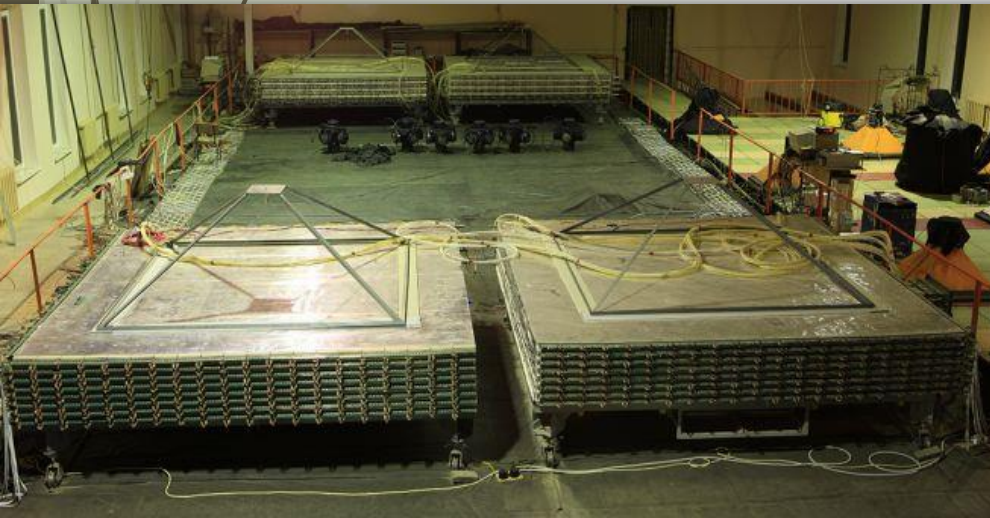
Muon hodoscope URAGAN

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- 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

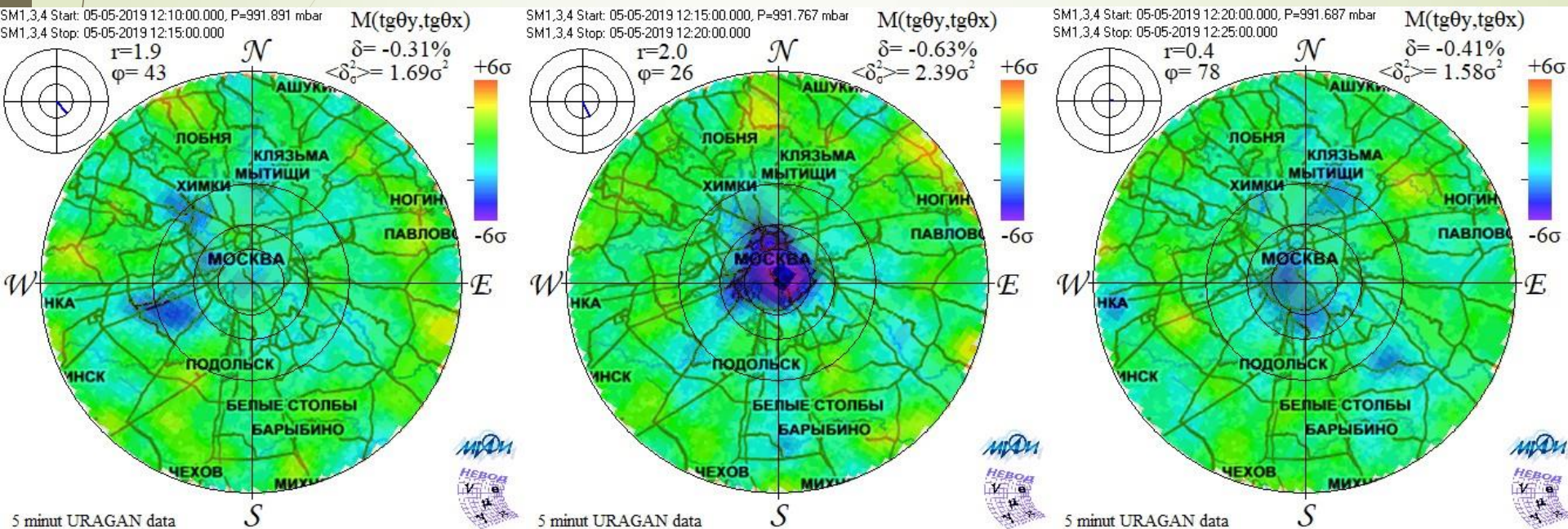
characteristics reflecting the distortion of the distribution of the muon flux used in the analysis are:

- vector of local anisotropy (**A**) that indicates the average direction of muon arrival
- vector of relative anisotropy (**r**) that is the difference between the local anisotropy vector in the current time and its value averaged over a long period. **r**'s projection on the horizontal plane (r_{hor}) is also used.



Muon snapshots (muonographs) 05/05/2019

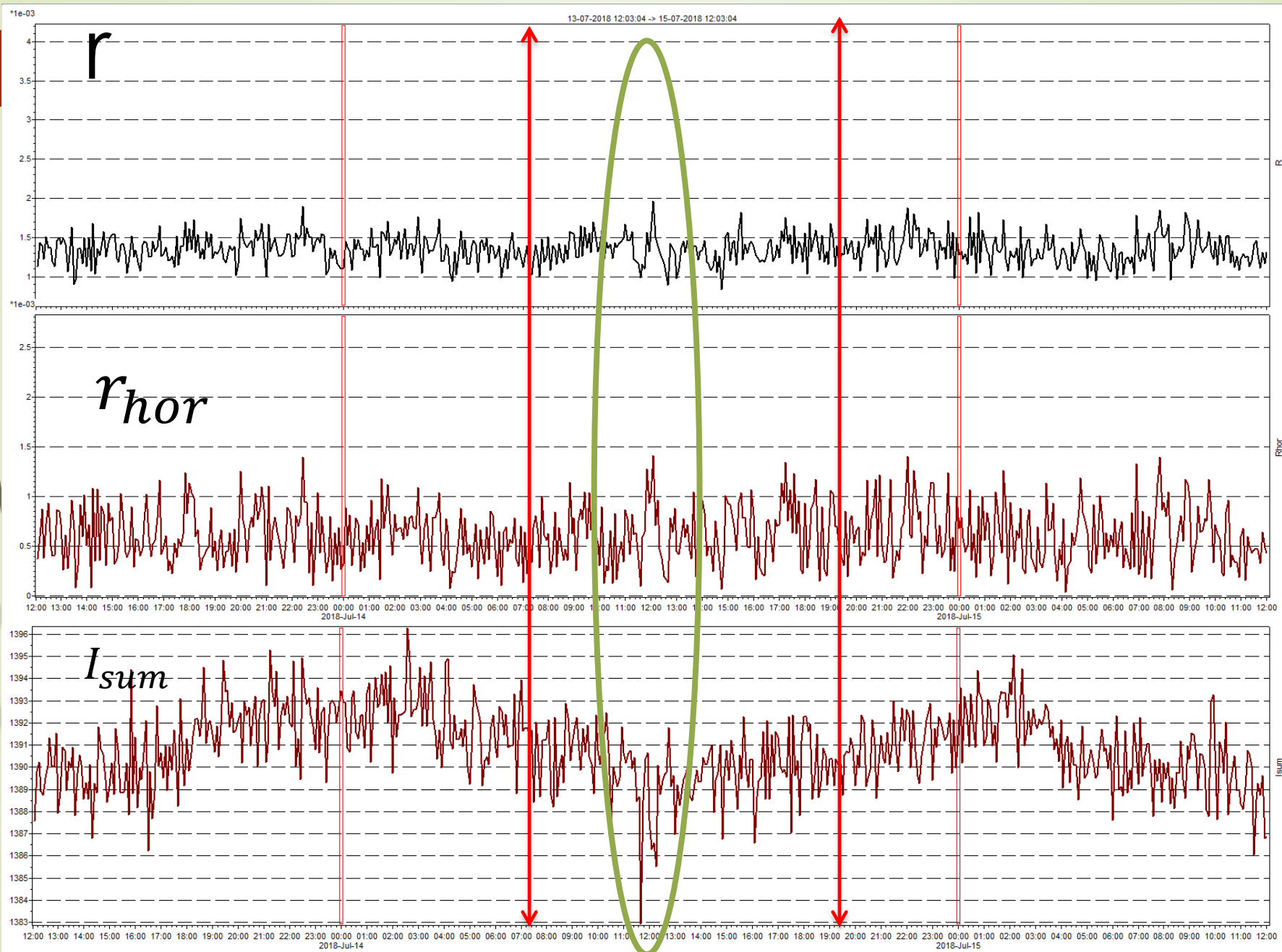
3



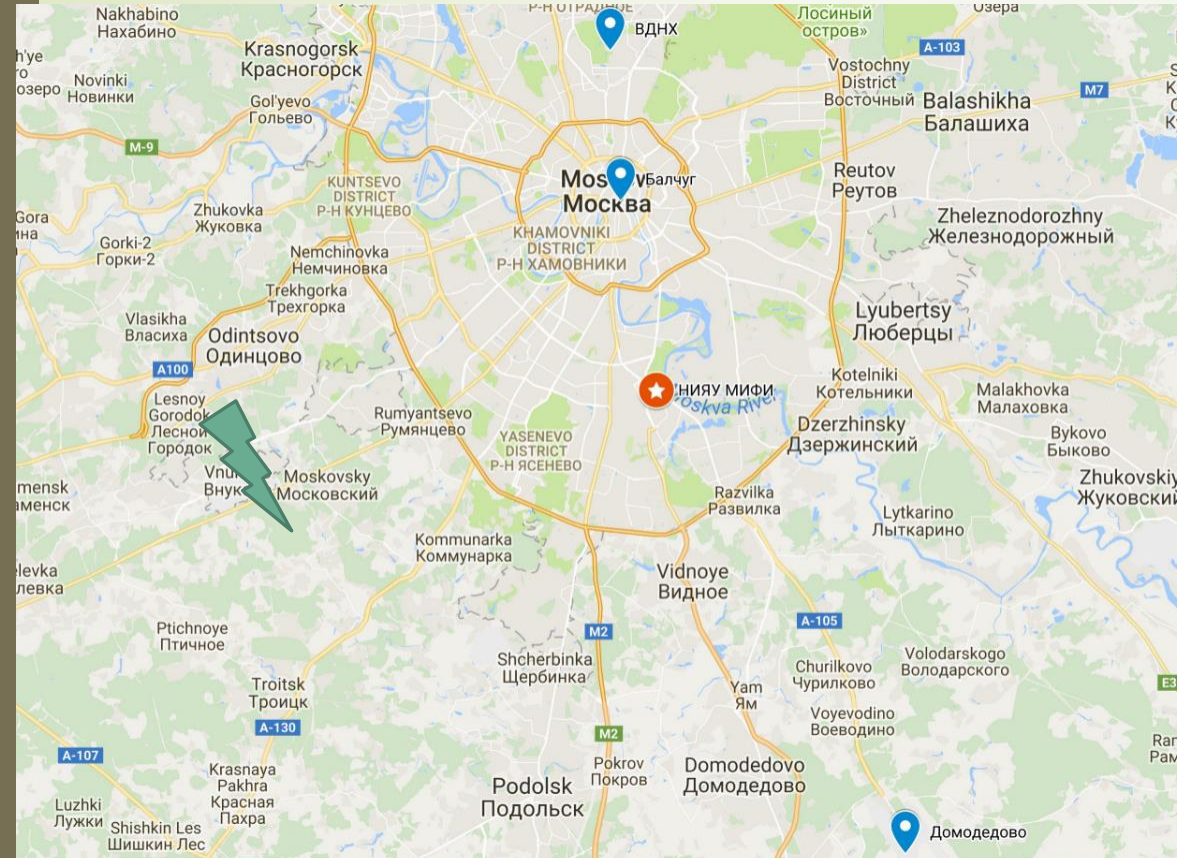
Muonograph is a graphical representation of the matrix of variations of the angular distribution of the counting rate over the last 5 minutes (current matrix) with respect to the normalization matrix the preceding 24 hours in statistical error units

Time series of characteristics during a thunderstorms

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Moscow weather stations



Doppler meteorological radar DMRL-C



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

- a view range of 250 – 300 km
- a maximum detection height of about 20 km
- a high spatial resolution (0.5 – 1 km)

Automatic event selection

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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 effectiveness of automatic selection varies from 60% to 75% because of some inconsistencies in meteorological data.

Открыть файл данных

Выбрать параметр

Построить график

Сигма = 0.000141487234012697

Выбор параметра

- Isum
- Ax
- Ay
- Az
- PhiA
- ThetaA
- A
- Rx
- Ry
- Rz
- PhiR
- ThetaR
- R
- Rhor
- Asouth
- Aeast
- Rsouth
- Reast
- C
- Alpha

Выбор размера окна

1 час

6 часов

12 часов

Начало интервала

30.08.2018

Конец интервала

01.09.2018

Усреднение по

предшествующим данным

"окружающим" данным

Фоновый уровень

3 sigma

4 sigma

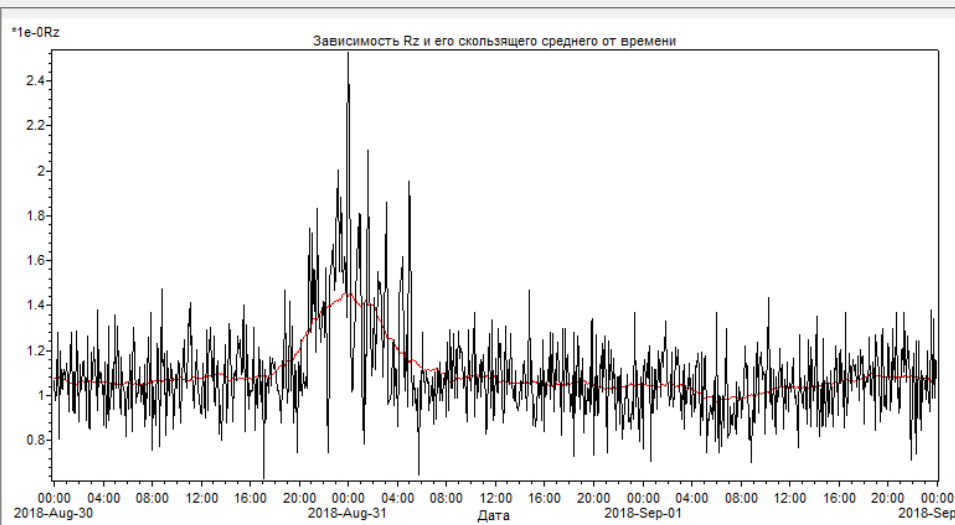
5 sigma

считать данные

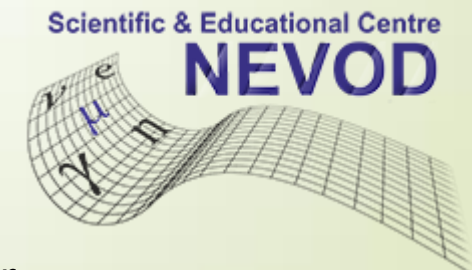
график скользящего среднего для заданного интервала

sig и скользящее среднее в заданном интервале

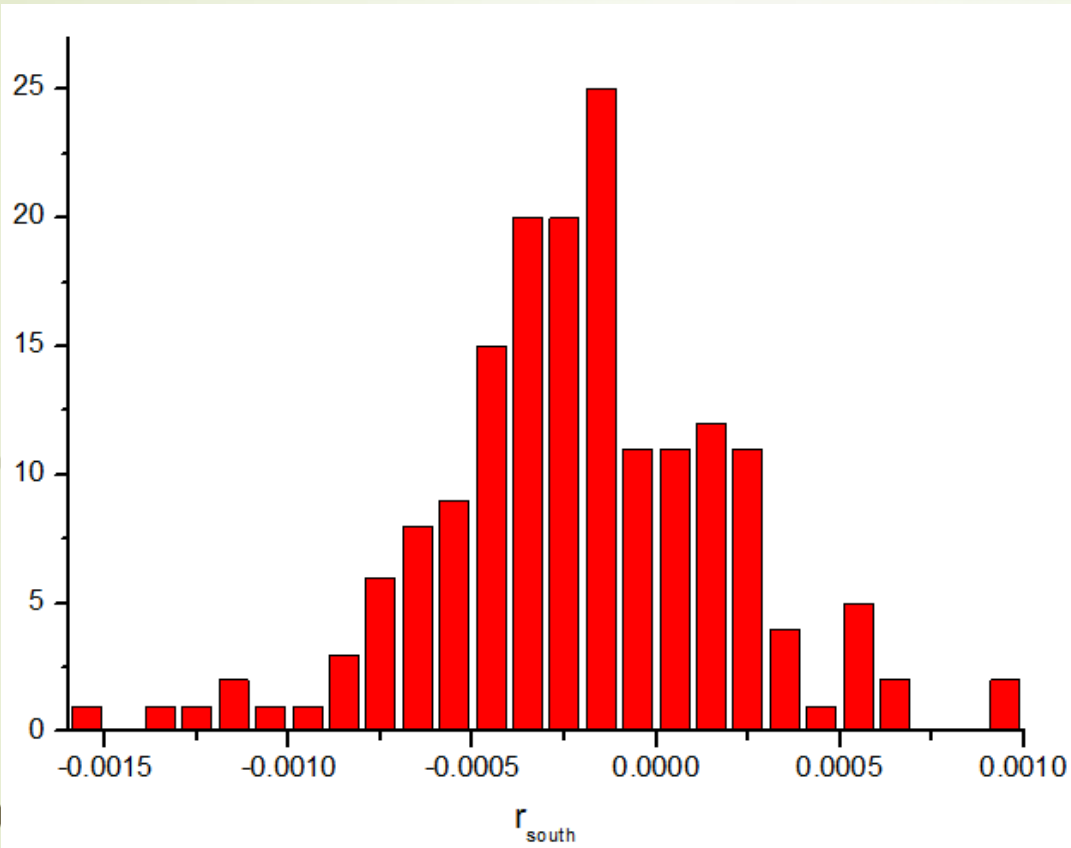
выбросы больше выбранного уровня в заданном интервале



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



Selection of the most «powerful» events



- 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

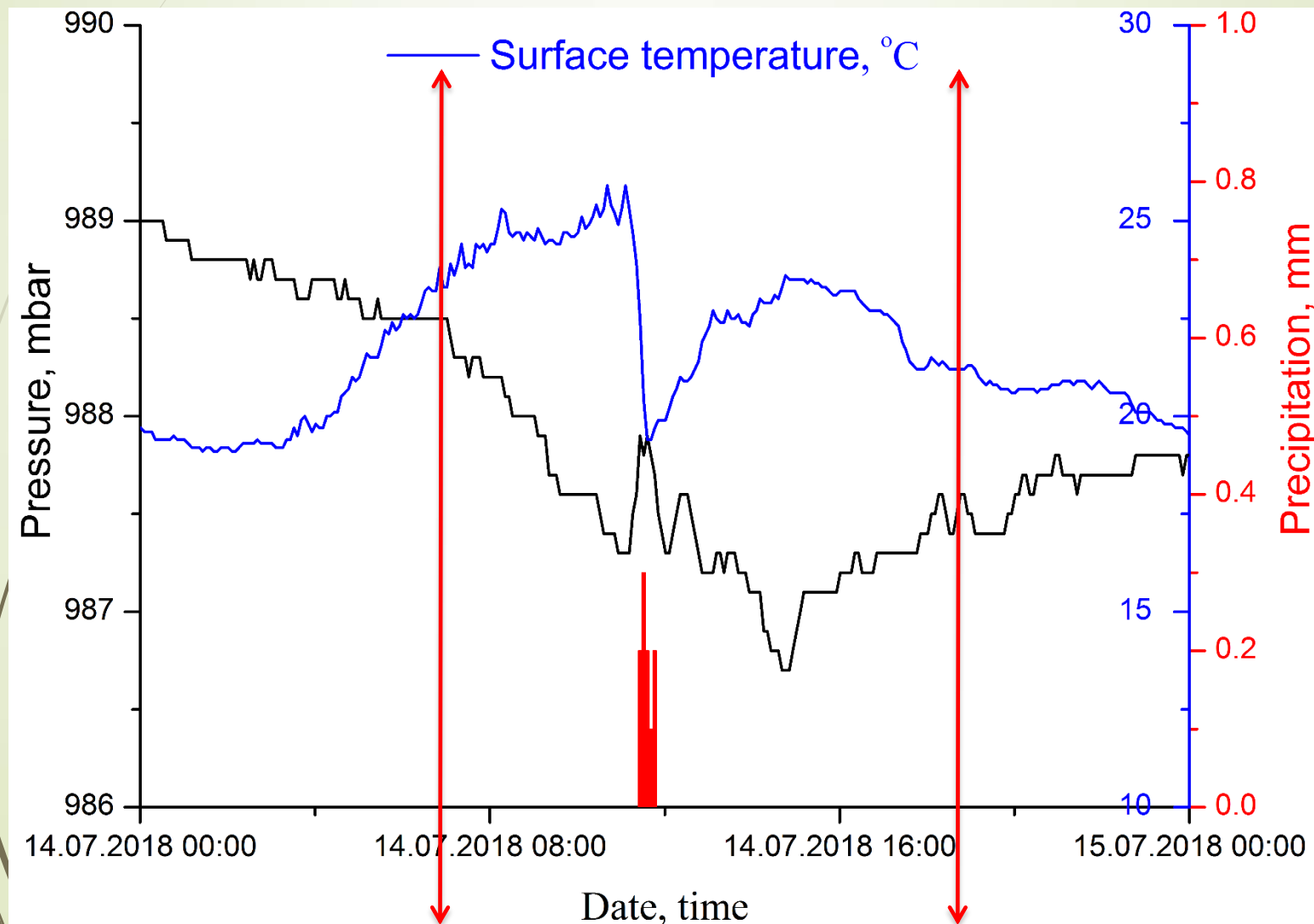
Of the 561 thunderstorm events, 23 events were classified as “powerful” (4.1%); of 173 thunderstorm events selected by the thunderstorm event search program based on MH URAGAN data 17 events (10%) were classified as “powerful”.

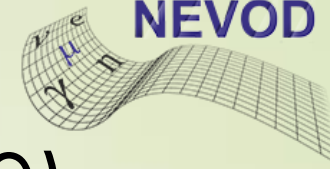
Condition of selection: deviation from the average by more than 3σ by at least one of the characteristics considered.

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





Comparison (11:30 – 13:10)

Скор. и направл. перемещени

$v=4.06$ м/с dir=0 С

ПГ: теплый

Az 69.89

R 314.15

Значение

н/д

ДМРЛ: RAVN

14.07.2018 12:10:00 UTC

SM1,3,4 Start: 14-07-2018 12:00:00.000, P=987.825 mbar

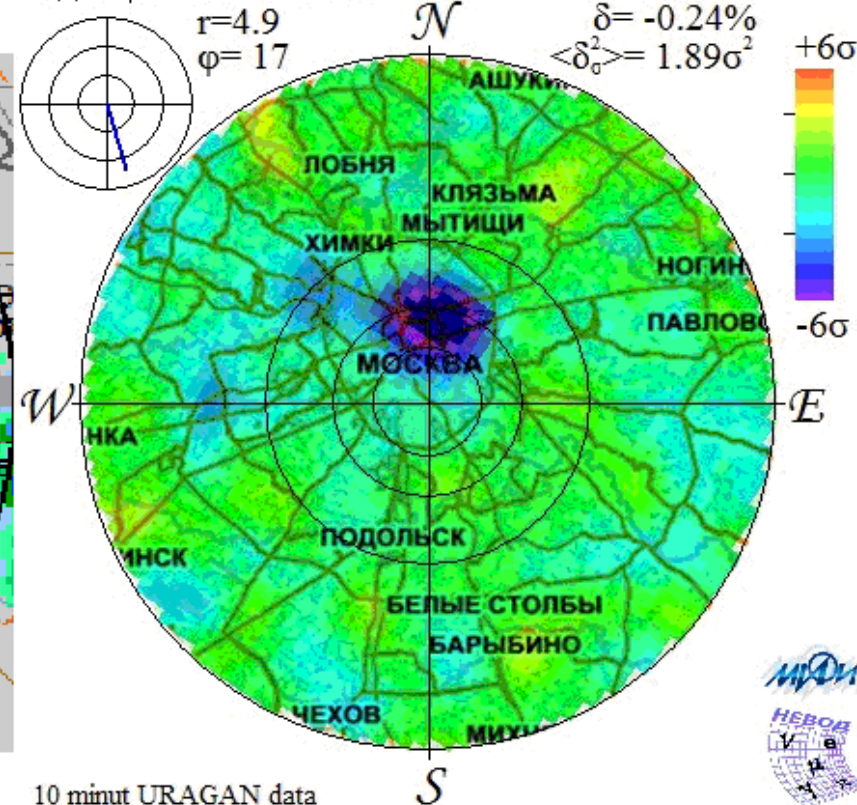
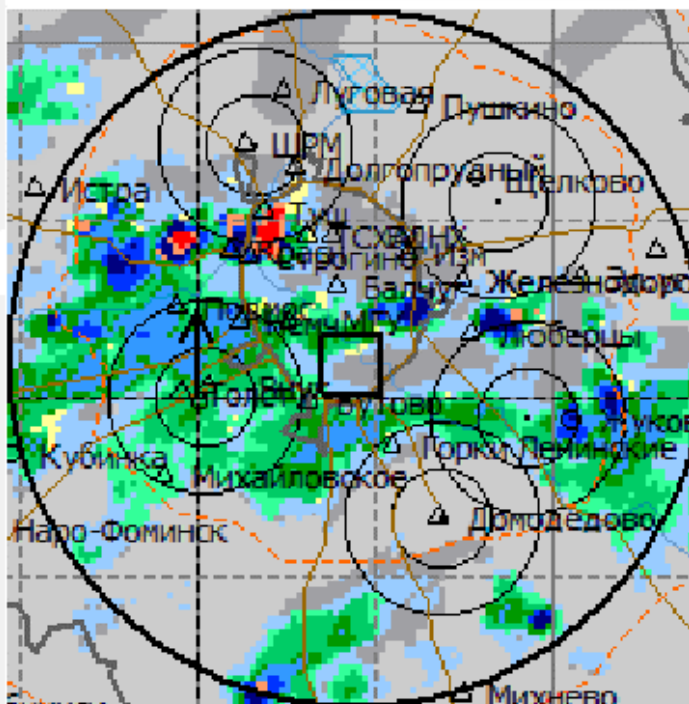
SM1,3,4 Stop: 14-07-2018 12:10:00.000

$M(tg\theta_y, tg\theta_x)$

$\delta = -0.24\%$

$\langle \delta_{\sigma}^2 \rangle = 1.89\sigma^2$

$r=4.9$
 $\phi=17$



10 minut URAGAN data



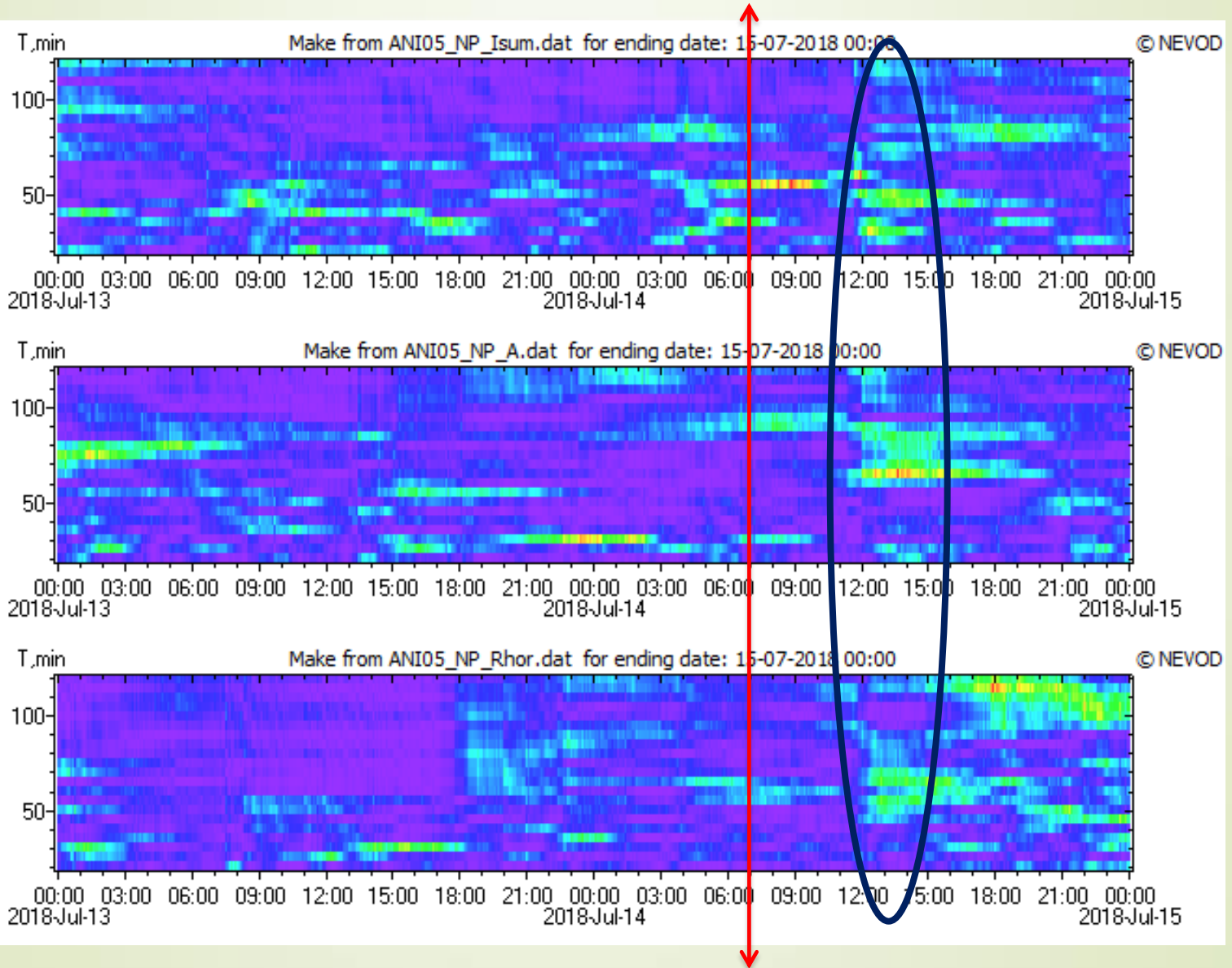
Wavelet analyses of URAGAN data

10

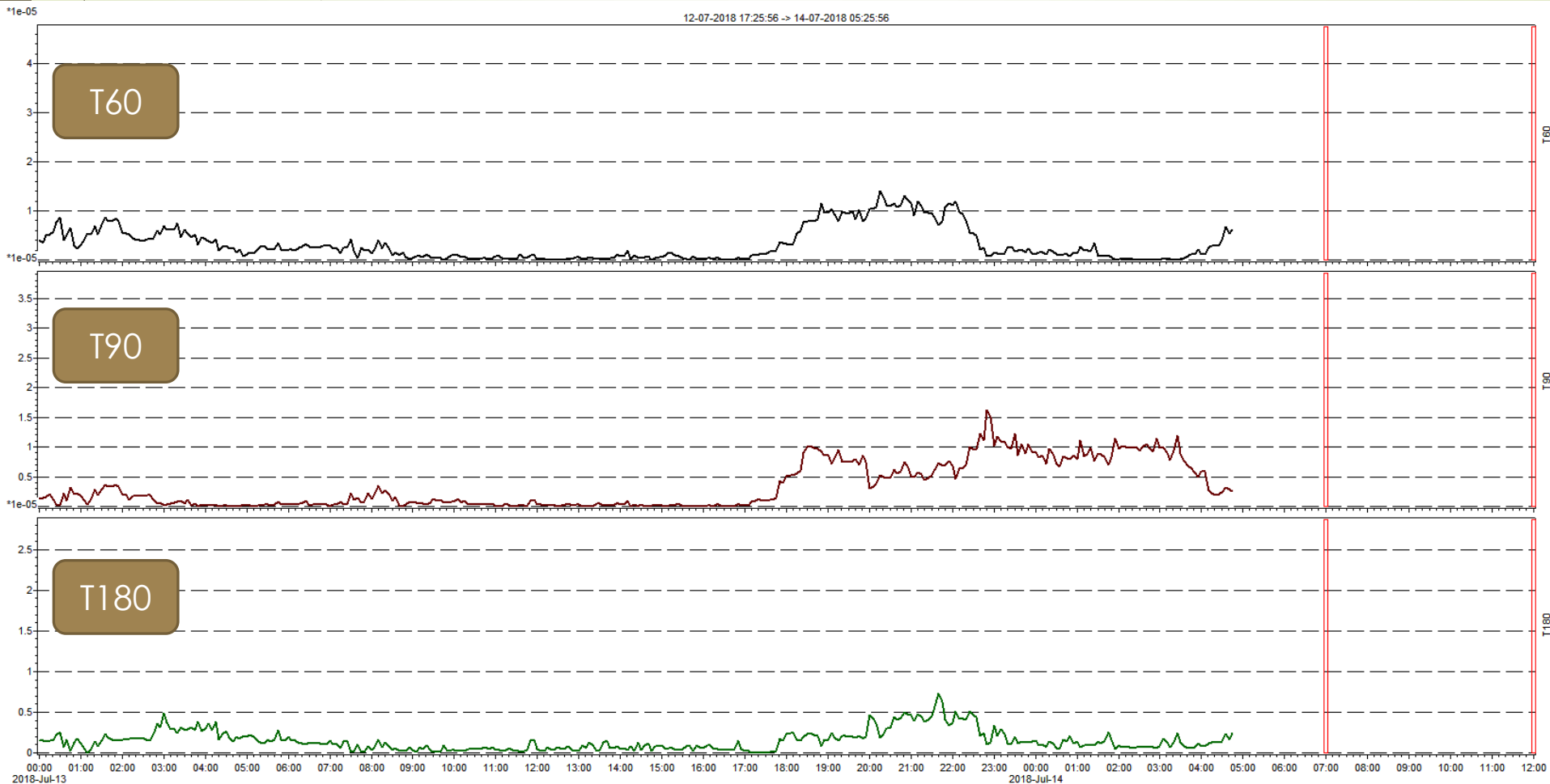
I_{sum}

A

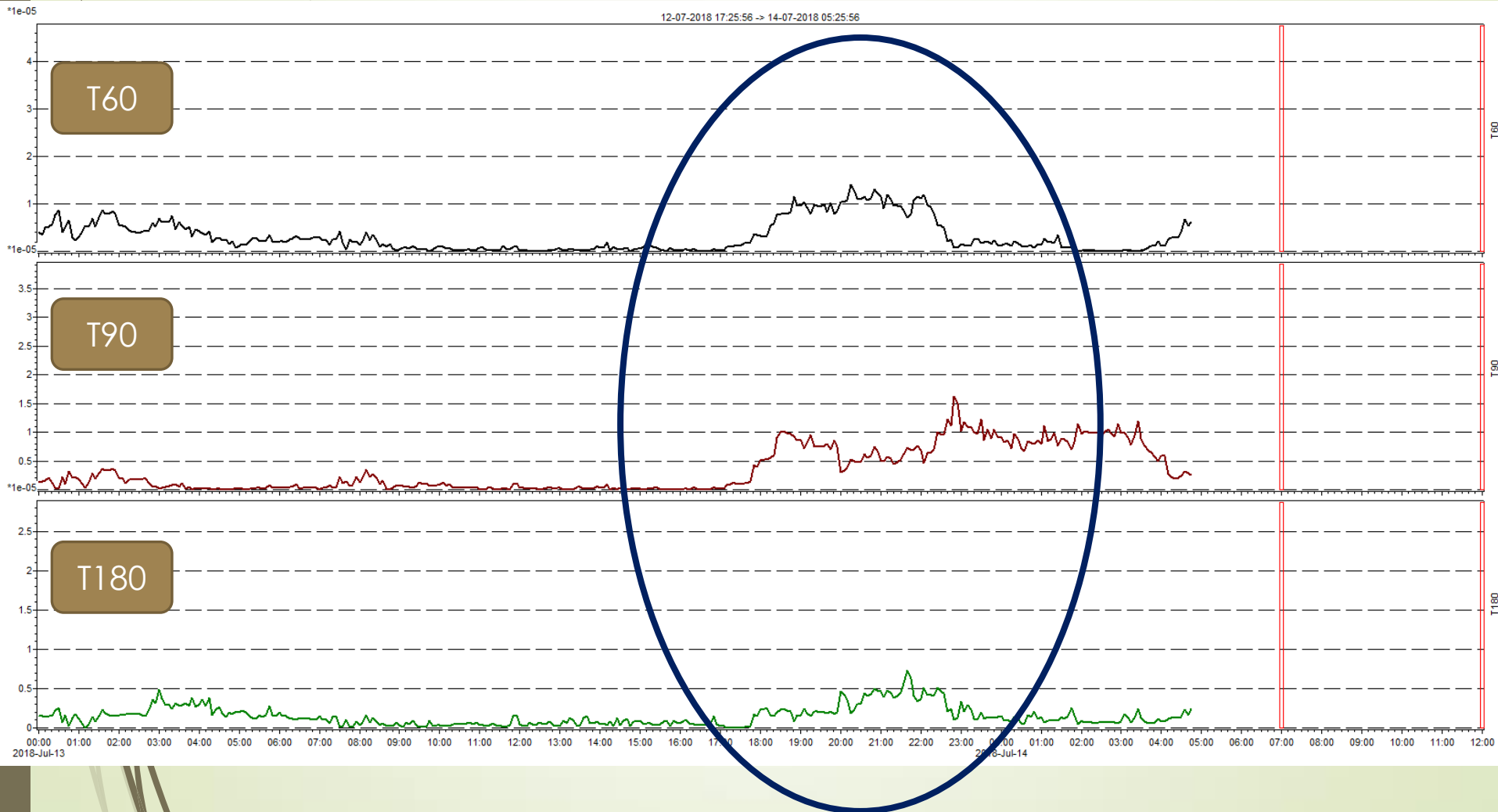
r_{hor}



Wavelet analysis: r_{hor}

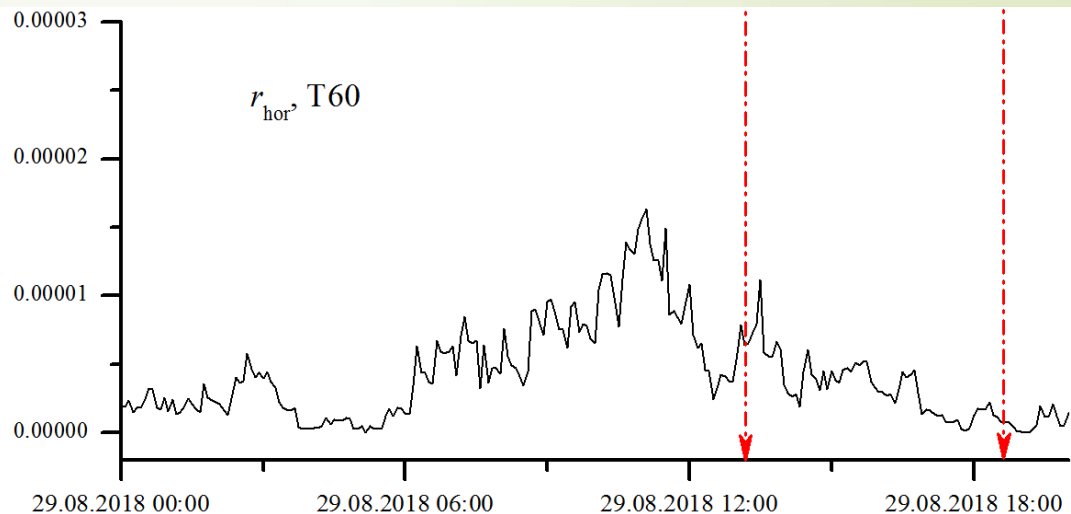
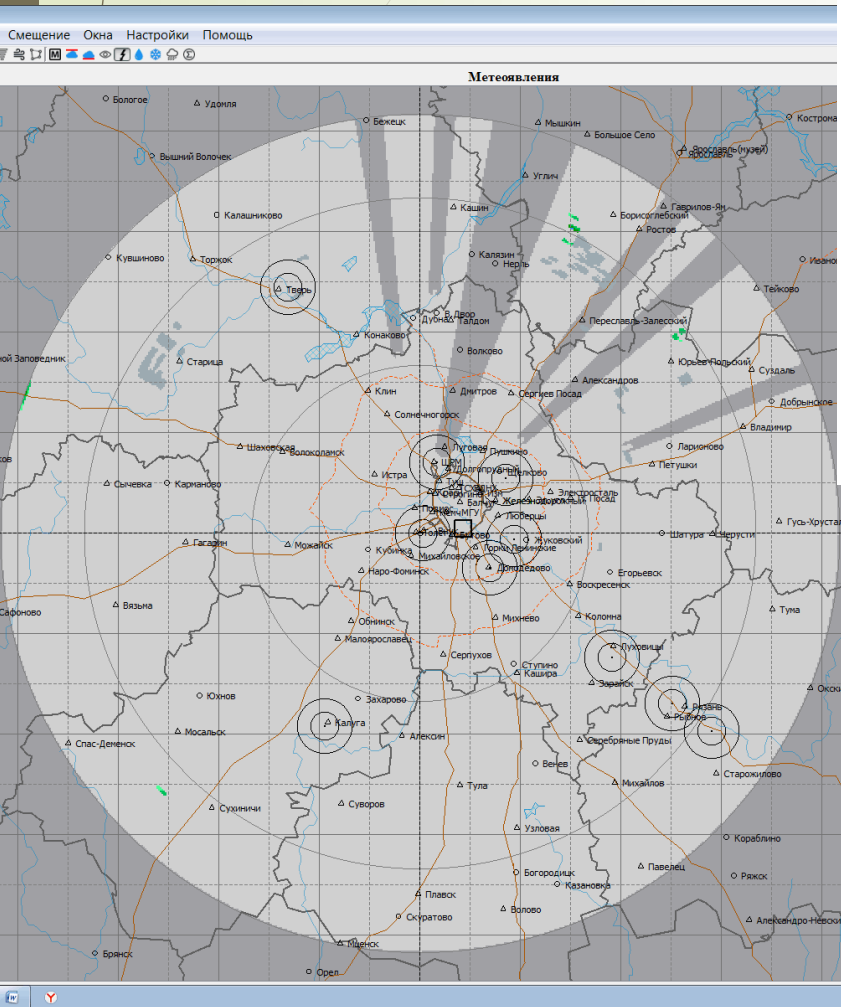


Wavelet analysis: r_{hor}



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

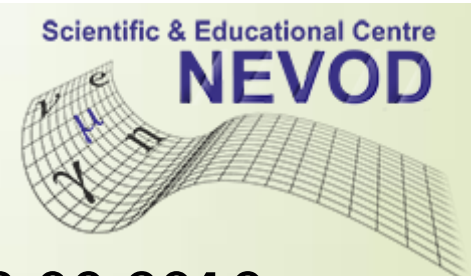
13



| |
|-----------------------|
| 20180829_082000_L.inr |
| 20180829_083000_L.inr |
| 20180829_084000_L.inr |
| 20180829_085000_L.inr |
| 20180829_090000_L.inr |
| 20180829_091000_L.inr |
| 20180829_103000_L.inr |
| 20180829_105000_L.inr |
| 20180829_110000_L.inr |
| 20180829_113000_L.inr |
| 20180829_114000_L.inr |
| 20180829_120000_L.inr |
| 20180829_121000_L.inr |
| 20180829_123000_L.inr |
| 20180829_124000_L.inr |
| 20180829_125000_L.inr |
| 20180829_130000_L.inr |
| 20180829_131000_L.inr |
| 20180829_132000_L.inr |
| 20180829_133000_L.inr |

Метеоявления

- Обл. верх. и ср.яруса
- Обл. слоистообраз
- Осадки слабые
- Осадки умеренные
- Осадки обильные
- Обл. кучевообраз
- Ливень слабый
- Ливень умеренный
- Ливень сильный
- гроза R) 30-70%
- гроза R) 70-90%
- гроза R) >90%
- Гроза слабая
- Гроза умеренная
- Гроза сильная
- гроза началась слаб
- гроза началась умерен
- гроза началась сильно
- Смерч



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.

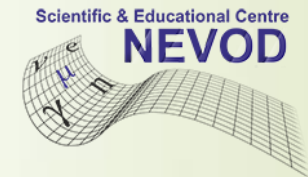
r_{hor} : 100-115 minutes.

Simultaneously with distant thunderstorms, the following periods of wave processes most often appear:

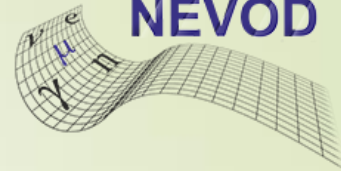
I_{sum} : 115-120 and 170 minutes;

A: 160 and 310 minutes;

r_{hor} : 115 minutes.



- 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 up to 320 minutes



Conclusions

- 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.

Thank you for your
attention!

Muon diagnostics

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

- 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

