Possibilities of atmospheric disturbance investigations in muon flux (muon diagnostics)

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1. What does mean “muon diagnostics”?
2. Muon diagnostics of heliosphere.
3. Muon diagnostics of atmosphere.
4. How to separate them?

Main idea of muon diagnostics

Cosmic ray muon flux and its variations on Earth's surface depend on both primary cosmic ray changes in the Heliosphere and secondary cosmic ray changes in the atmosphere caused by their disturbances.

Muon diagnostics is solution of the inverse task – study of dynamic processes in the atmosphere and in the Heliosphere by using cosmic ray muon variation data.

Cosmic rays in the Heliosphere

Primary cosmic rays go through the Heliosphere in any directions.

Any disturbances (in principle in any place) of the Heliosphere can be detected in cosmic ray flux near the Earth or on its surface.

Important. In cosmic rays, the Solar disturbances directed even in opposite direction from the Earth can be detected.

Secondary cosmic rays on the Earth's surface

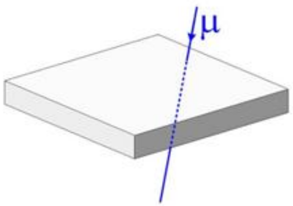
Two types of particles - neutrons and muons - are used for diagnostics of the heliosphere.

Neutron monitors detect mainly low energy neutrons which give no information about the direction of primary particles.

Muons save the directions of primary particles, and for their investigations the detectors which can measure the muon direction are required.

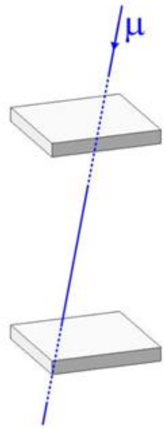
Muon detectors

Muon detector (MD)



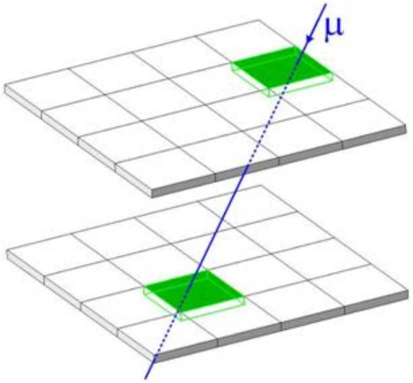
$\Delta\theta \approx 90^{o}$
$\theta \in [0; 90]^{o}$
$\Delta\varphi \approx 360^{o}$
$\varphi \in [0; 360)^{o}$

Muon telescope (MT)



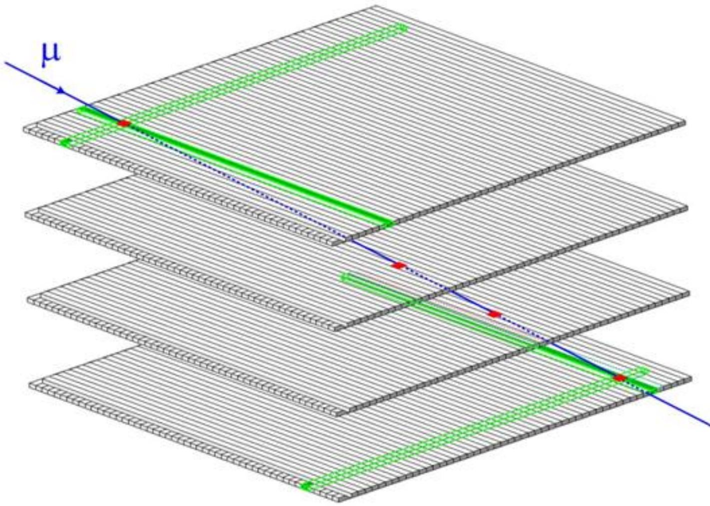
$\Delta\theta \approx 30^{o}$
$\theta \in [0; 30]^{o}$
$\Delta\varphi \approx 360^{o}$
$\varphi \in [0; 360)^{o}$

Multidirectional muon telescope (MMT)



$\Delta\theta_{min} \approx 15^{o}; \Delta\theta_{max} \approx 30^{o}$
$\theta \in [0; 65]^{o}$
$\Delta\varphi_{min} \approx 28^{o}; \Delta\varphi_{max} \approx 35^{o}$
$\varphi \in [0; 360)^{o}$

Muon hodoscope (MH)



$\Delta\theta \leq 1^{o}$
$\theta \in [0; 80]^{o}$
$\Delta\varphi \leq 1^{o}$
$\varphi \in [0; 360)^{o}$

Muon hodoscope

MH is a coordinate-tracking detector which can measure muon flux simultaneously from any direction of upper hemisphere with a good spatial and angular accuracy.

The difference between muon hodoscope (MH) and multi-directional muon telescope (MMT) is the following:

MMT collects muons in fixed zenith - azimutal cells.

MH allows to reconstruct a track of each muon in real time and to obtain practically continuous angular distributions, which can be separated in any zenith - azimutal cells.

The number of channels depends on the angular accuracy for MH – linearly, for MMT – quadratically.

Detector requirements

For muon diagnostics realization the new type of cosmic ray muon detector - muon hodoscope is necessary. Its main characteristics:

- Two coordinate data readout system.
- Large area of detector (> 10 m^2).
- High angular resolution (< 1^o).
- Possibility of simultaneous detection and on-line analysis of muon flux variations from all directions of upper hemisphere.

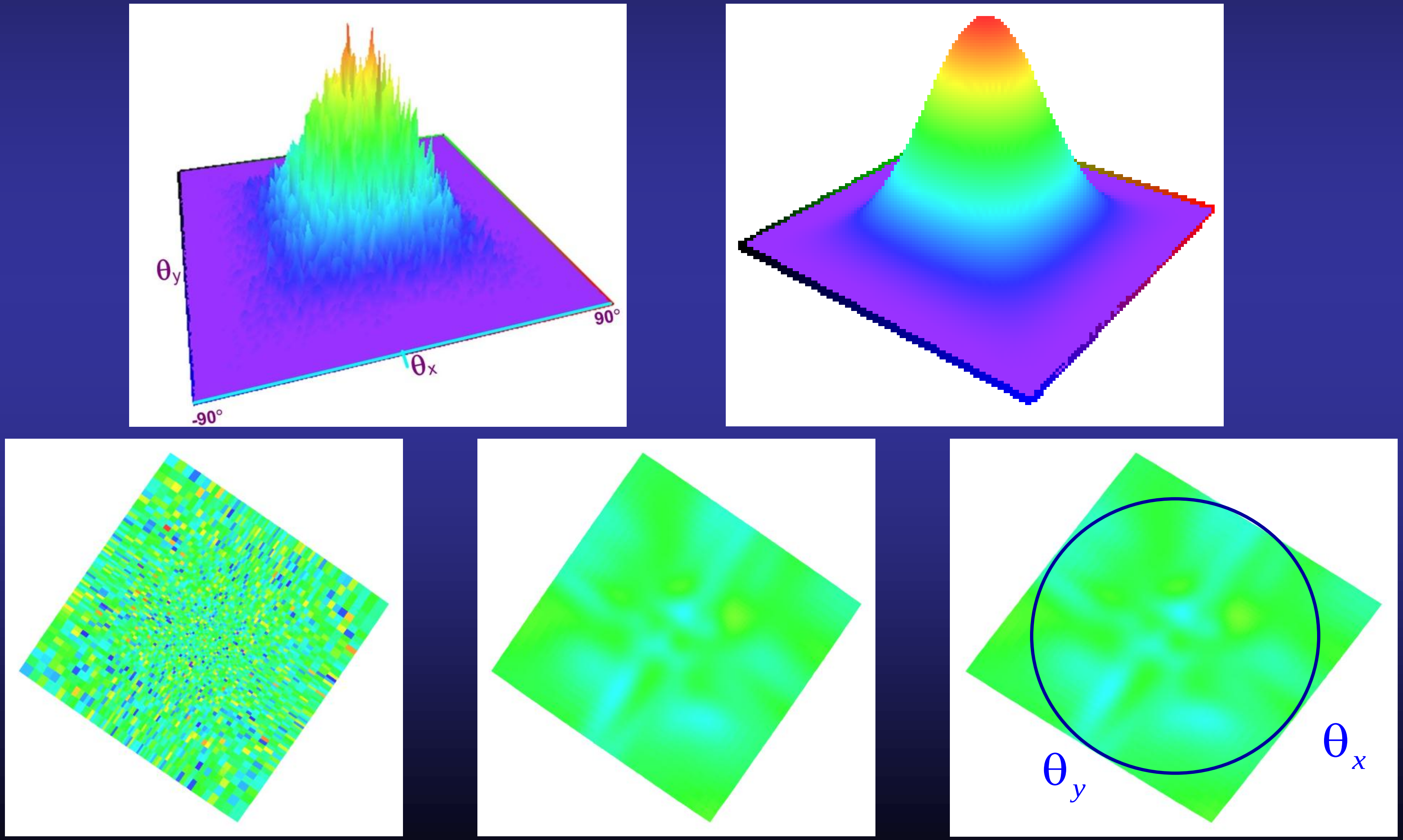
Muon Hodoscope URAGAN

Total area – 45 m^2 (~ 6000 μ / s).

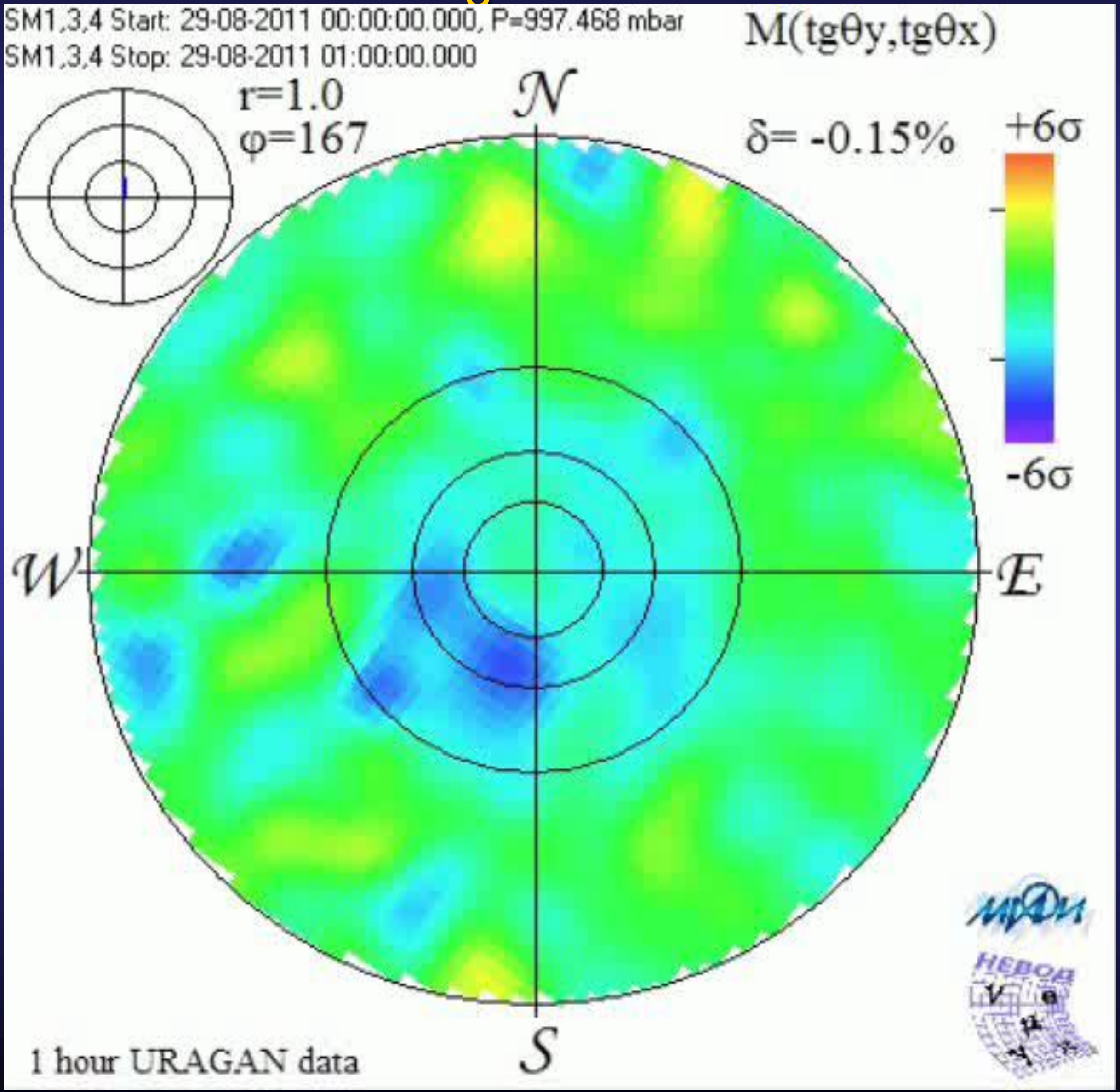
Readout system – 19456 channels (resolution: spatial – 1 cm, angular – 1º).

Muonography

Muonography is a two-dimensional angular matrix of relative variations of muon flux.

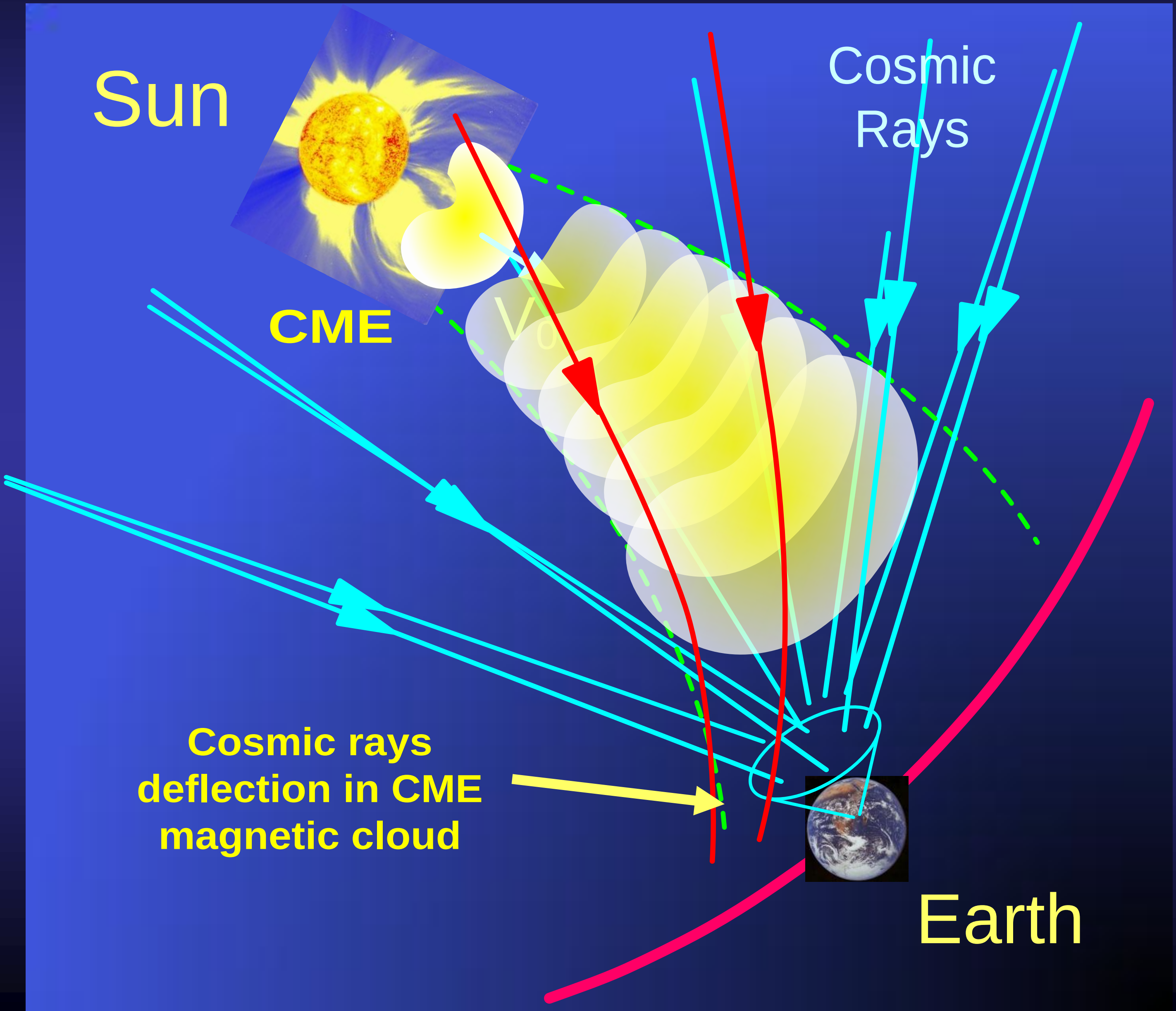


2D-dynamics of muon flux variations in quiet conditions

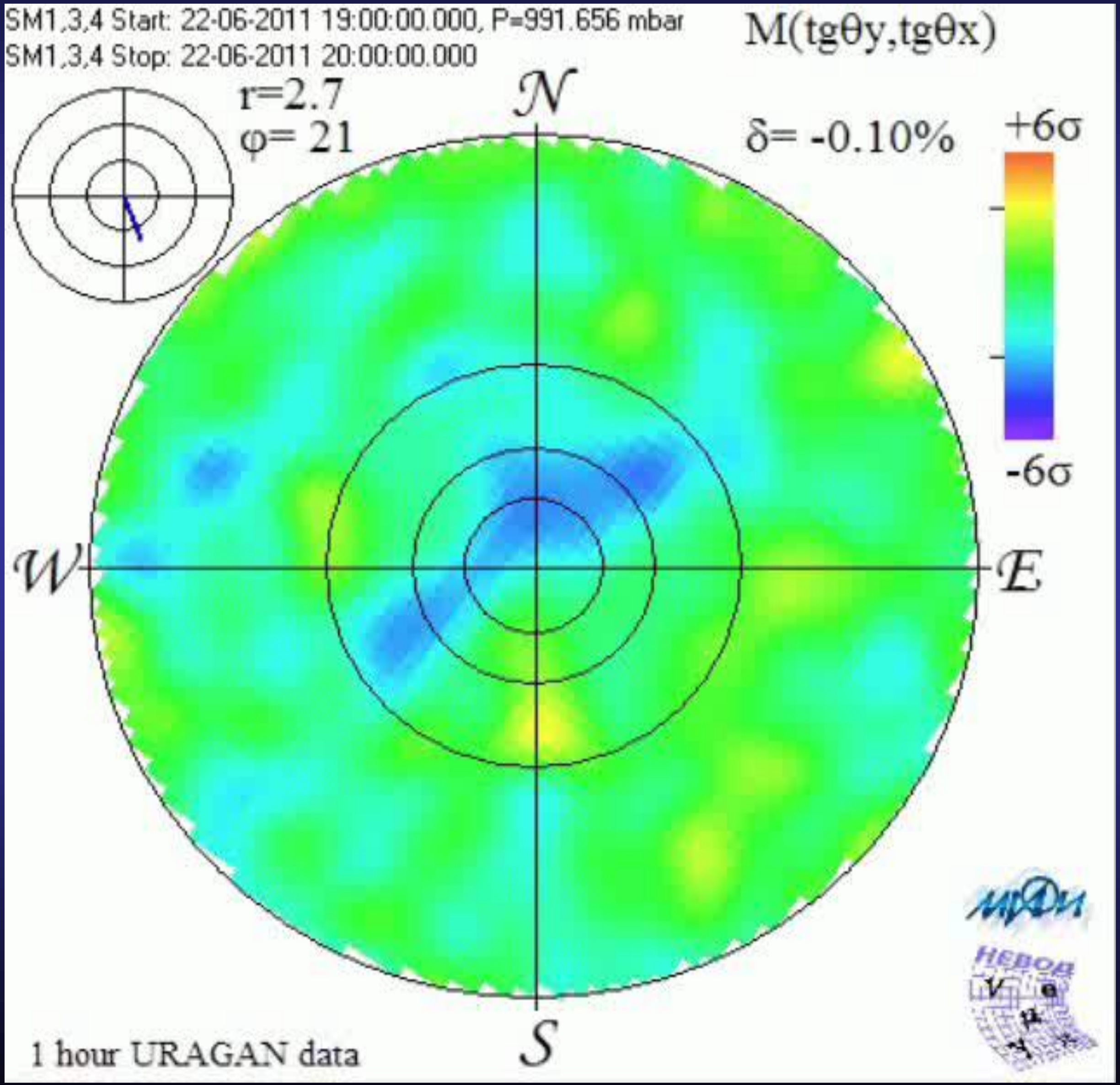


Muon diagnostics of heliospheric processes

Cosmic rays in the heliosphere



Muonography of heliospheric disturbance



How to use muonographies for heloispheric process investigations

To translate obtained muonographies to Heliosphere it is necessary to take into account asymptotic directions of primary particles.

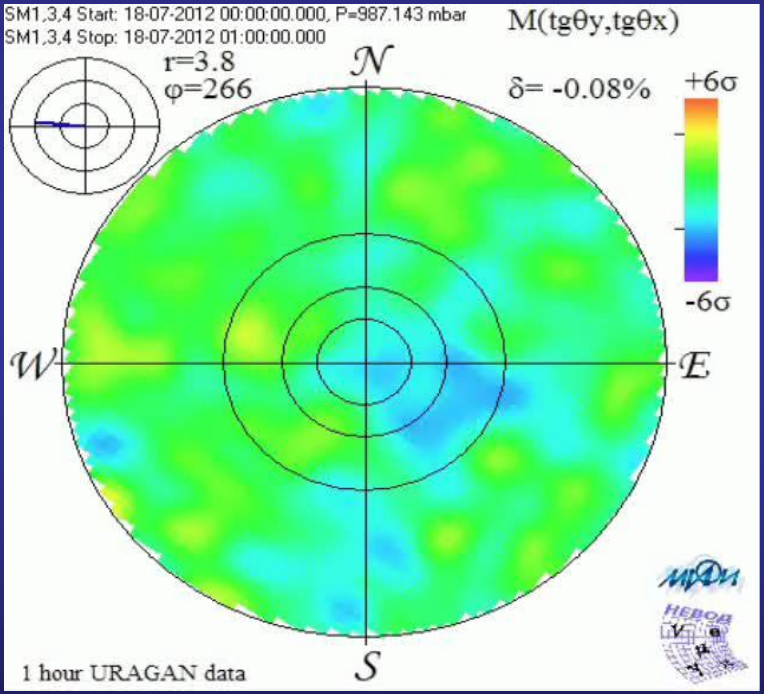
For that, inverse trajectories of particles from muon hodoscope to generation points in the atmosphere and further to the border of the magnetosphere are calculated.

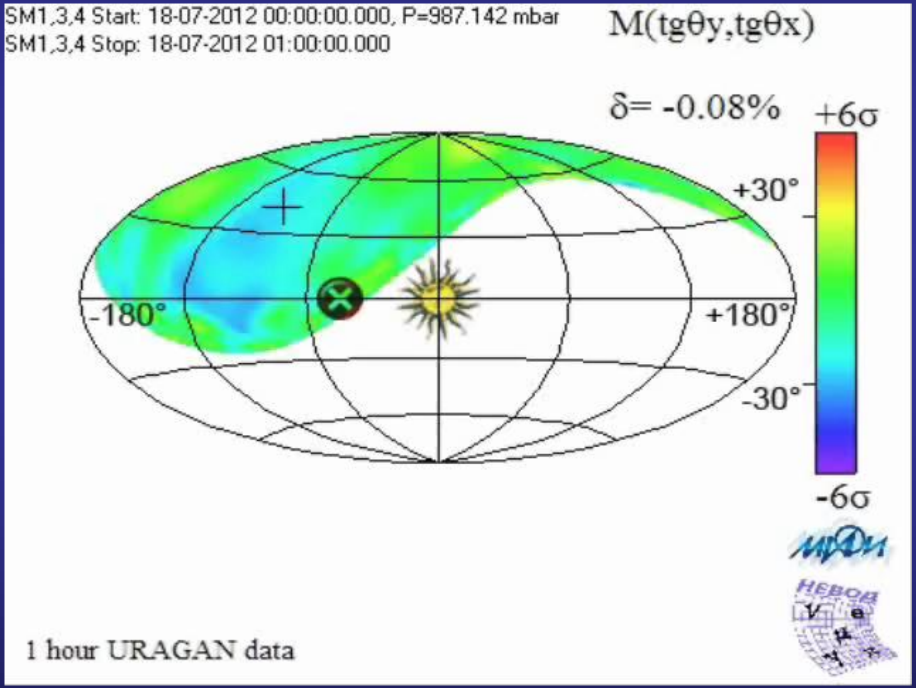
At that, well-known models of the atmosphere and the magnetosphere are used.

Muonographies of Solar event in July 2012

Solar flare M1 17.07 18:00

CME → Forbush Decrease

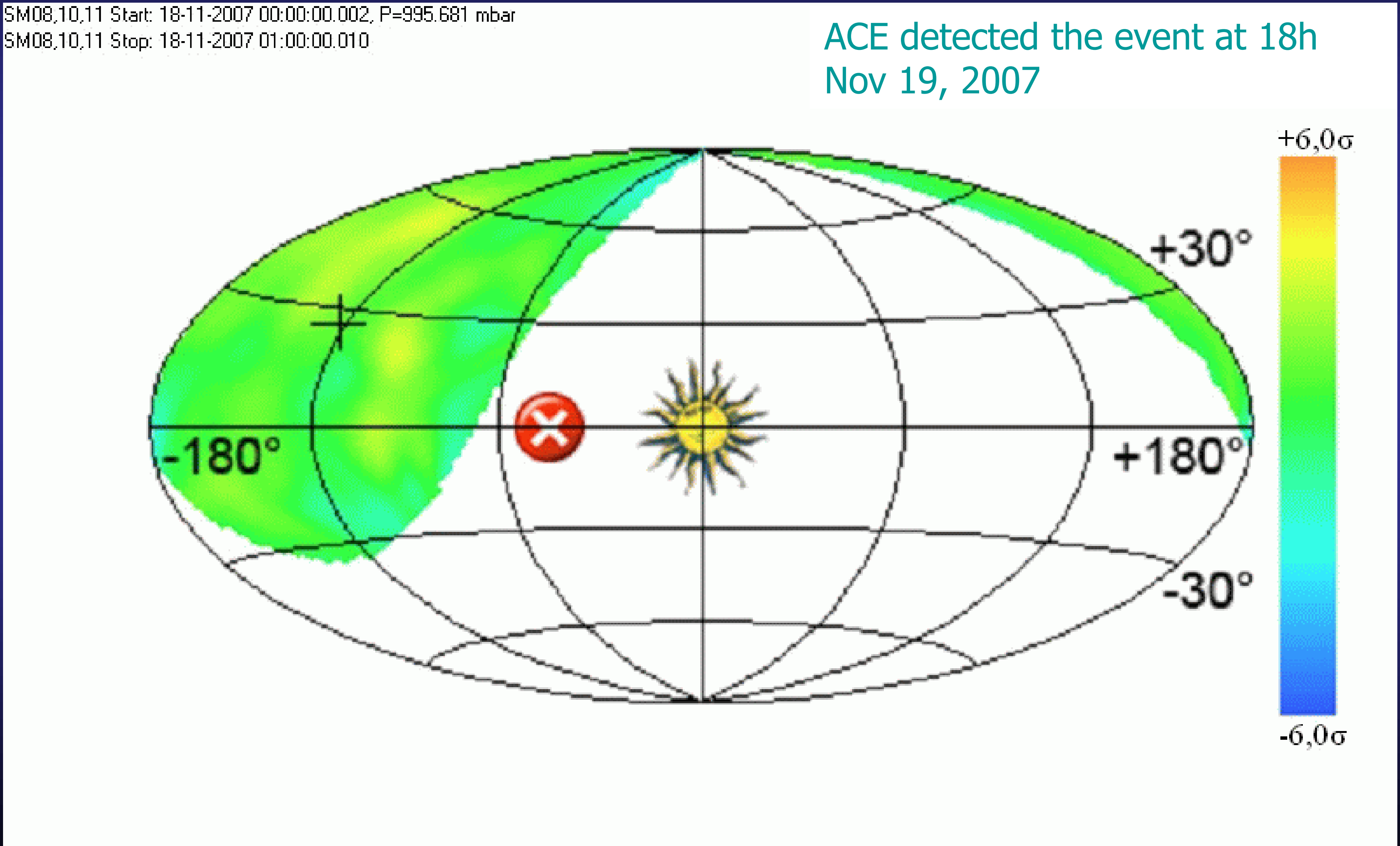




In local coordinate system

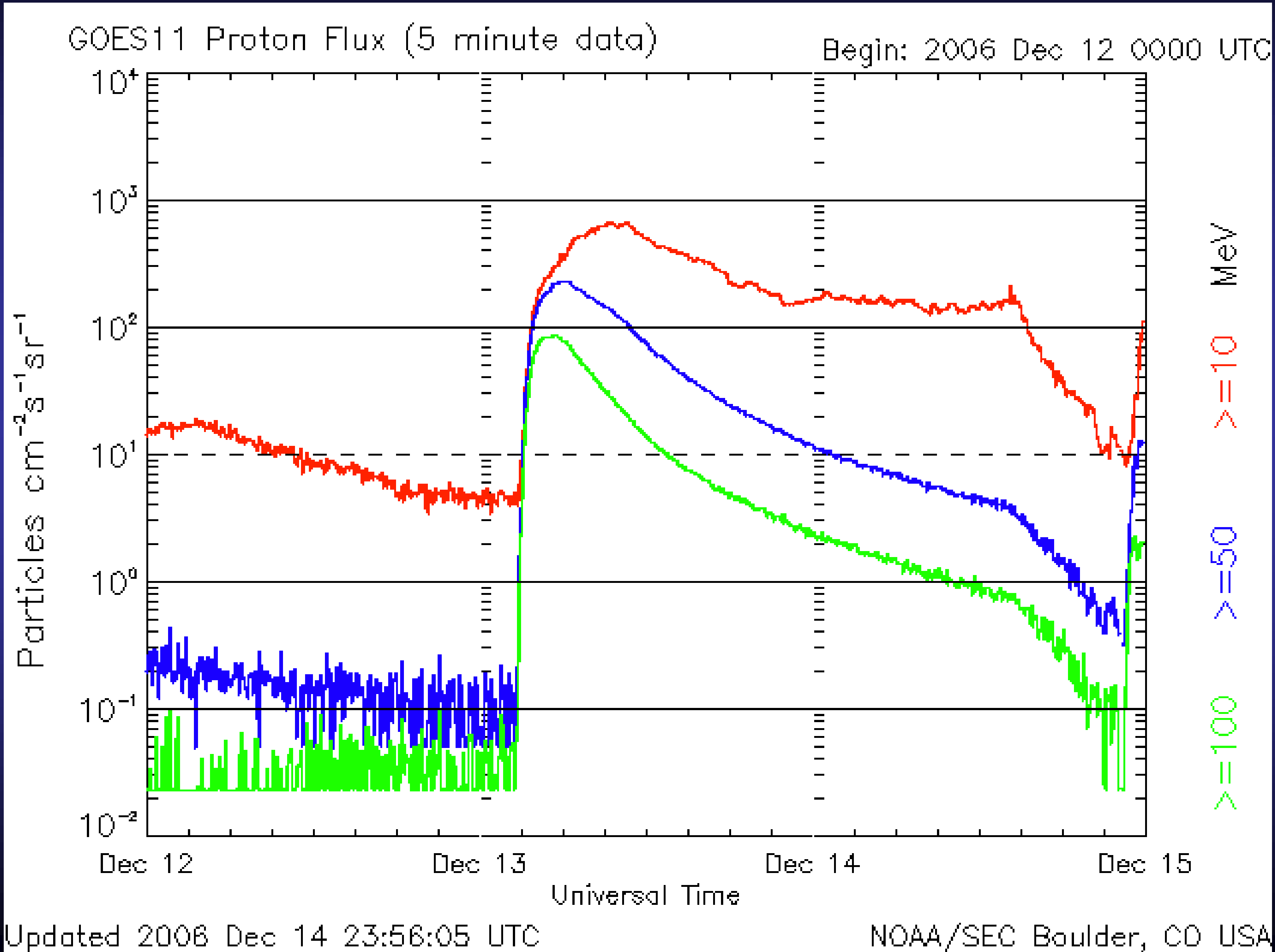
In GSE system

Muon scanning of the sky in GSE system

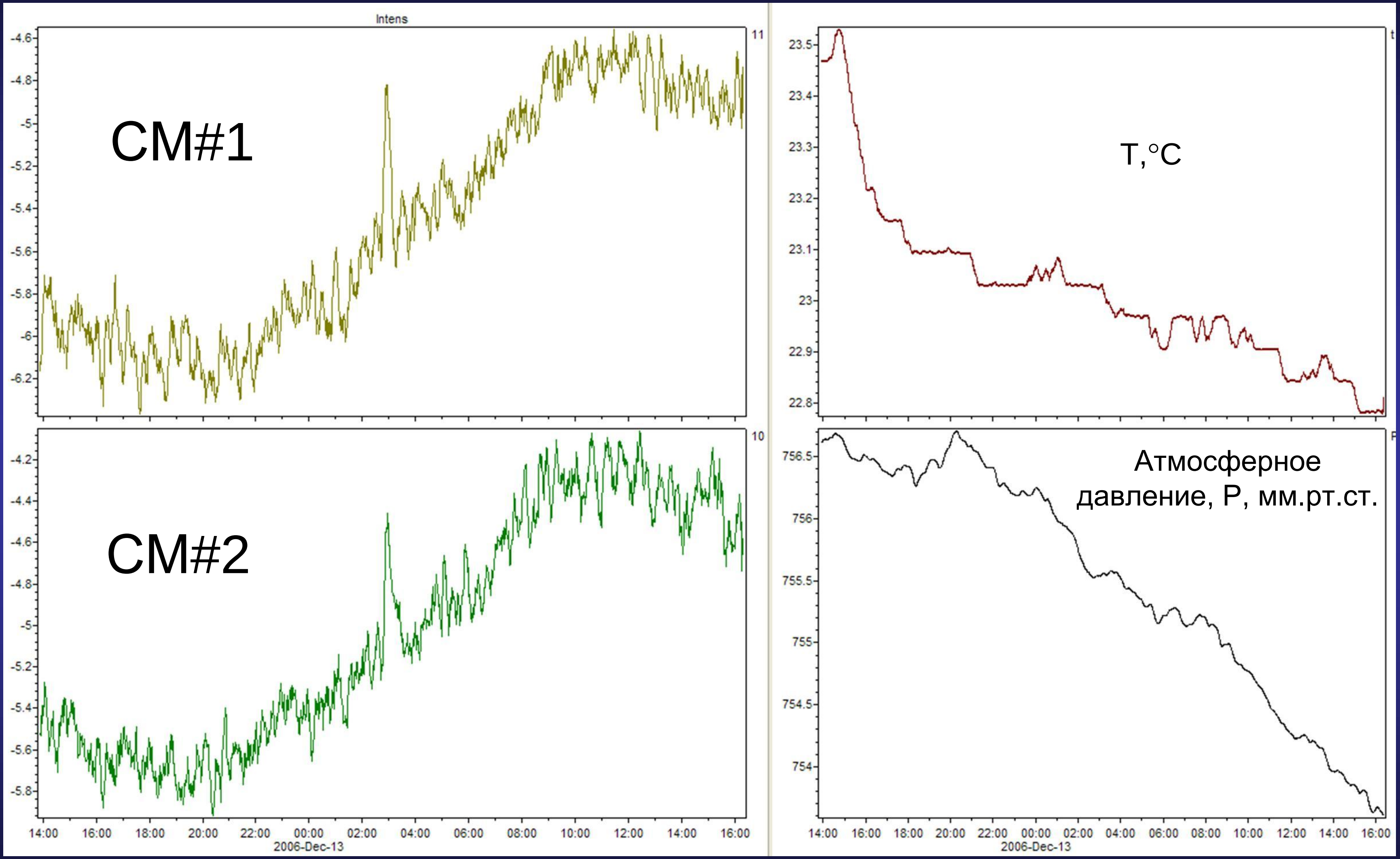


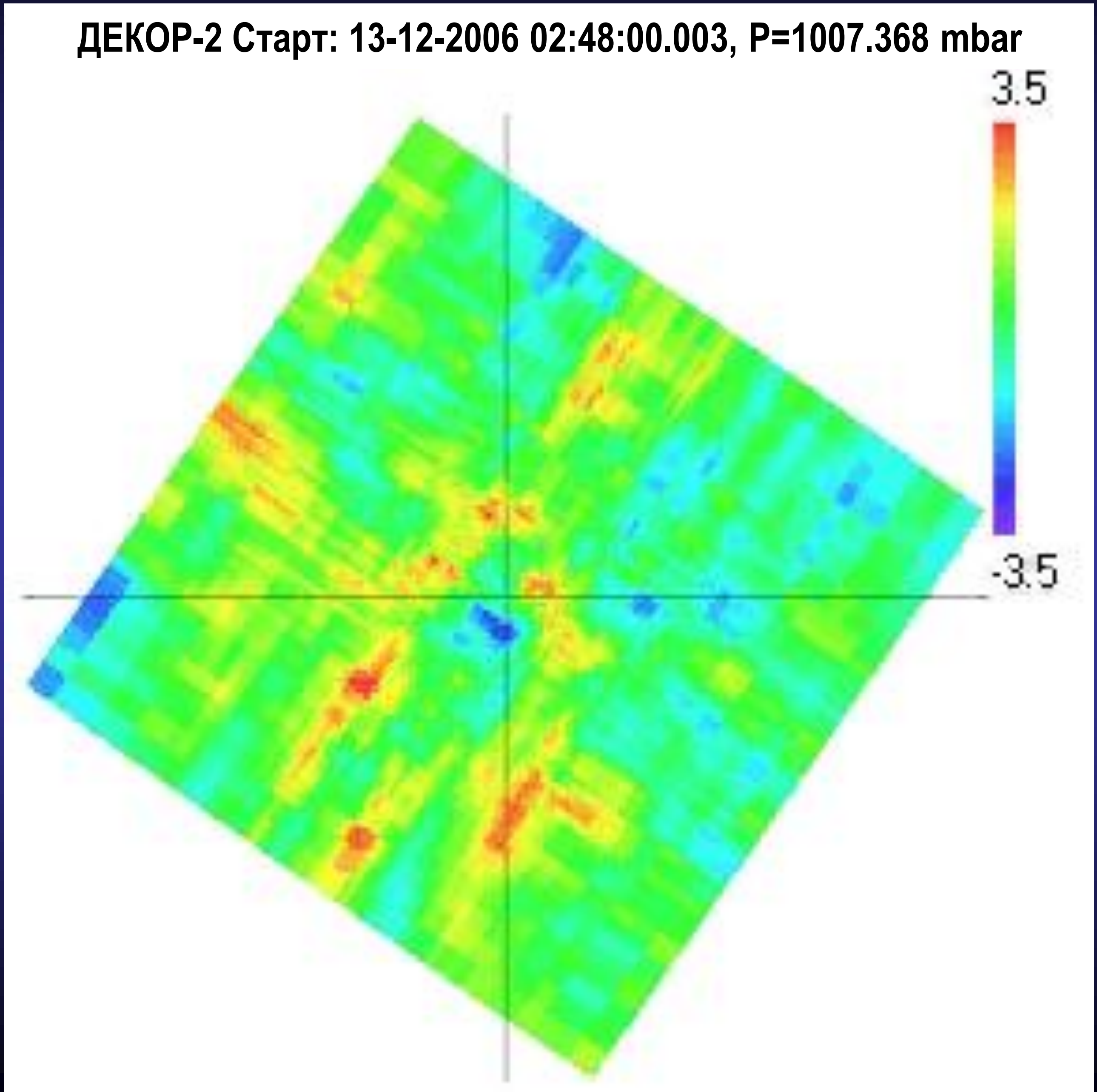
Muon hodoscope's data analysis during solar proton event of December 13, 2006

GOES11 proton flux intensity on December 13, 2006



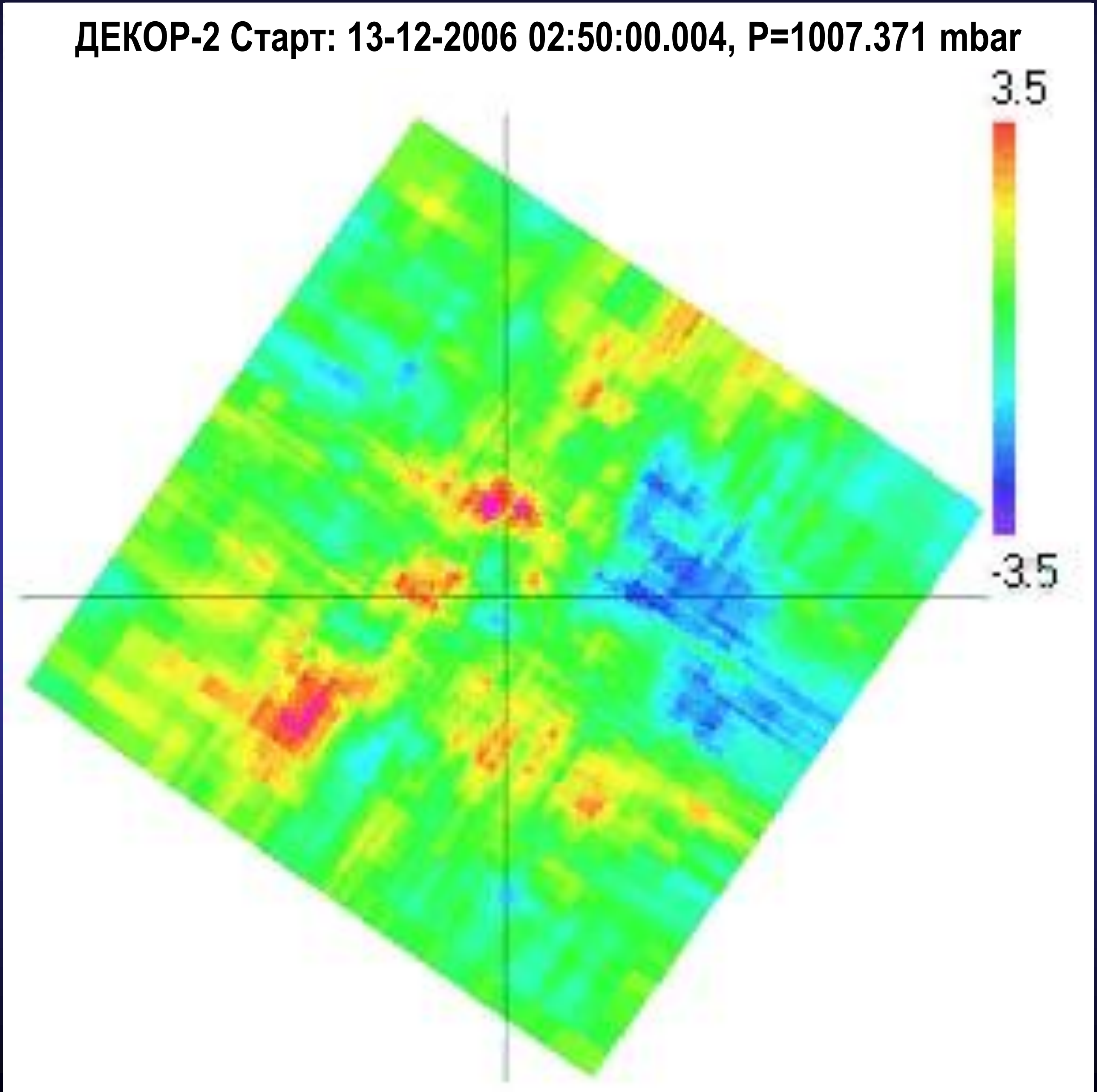
Detection of GLE 13.12.2006





December 13, 2006

02:48 UT



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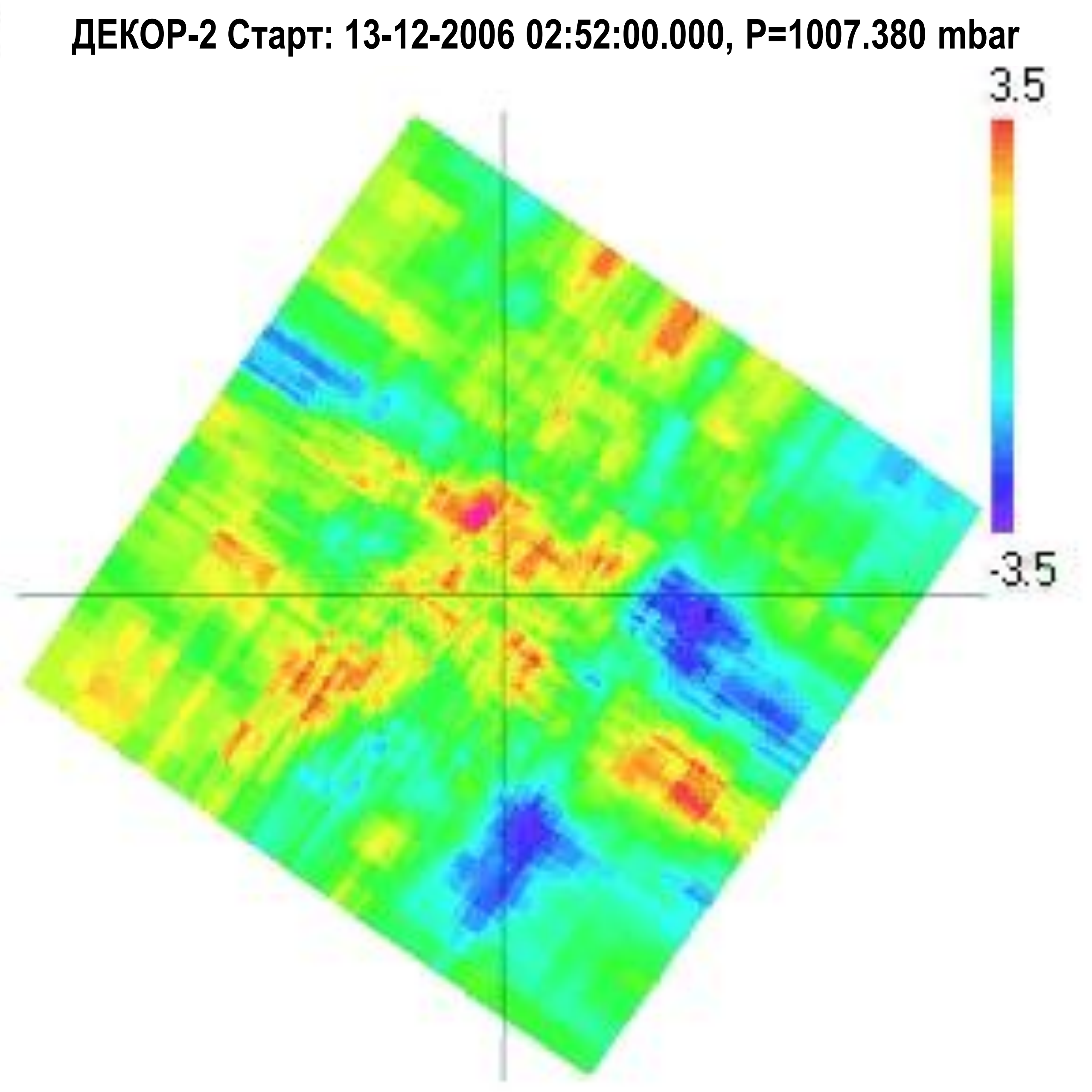

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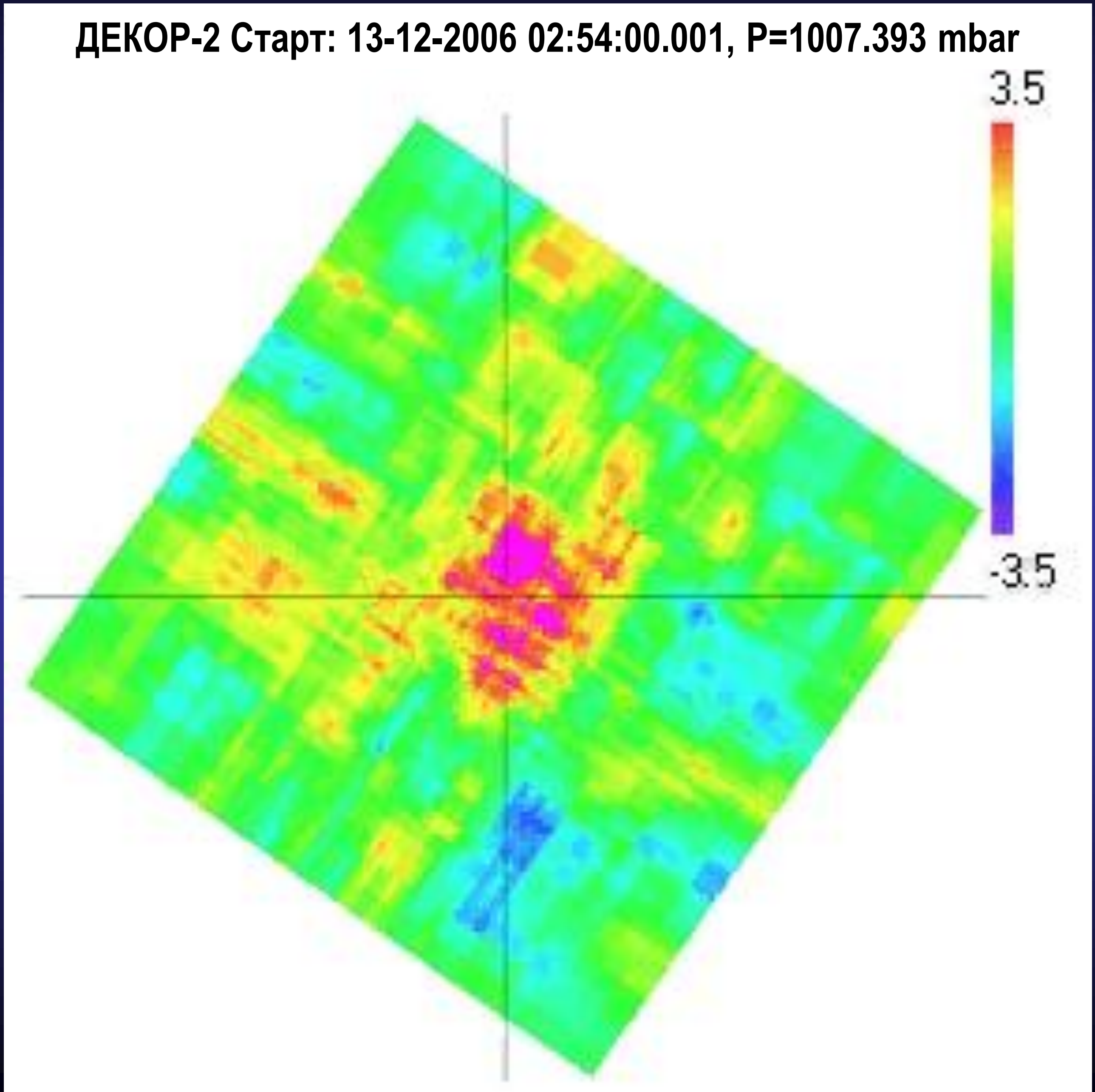

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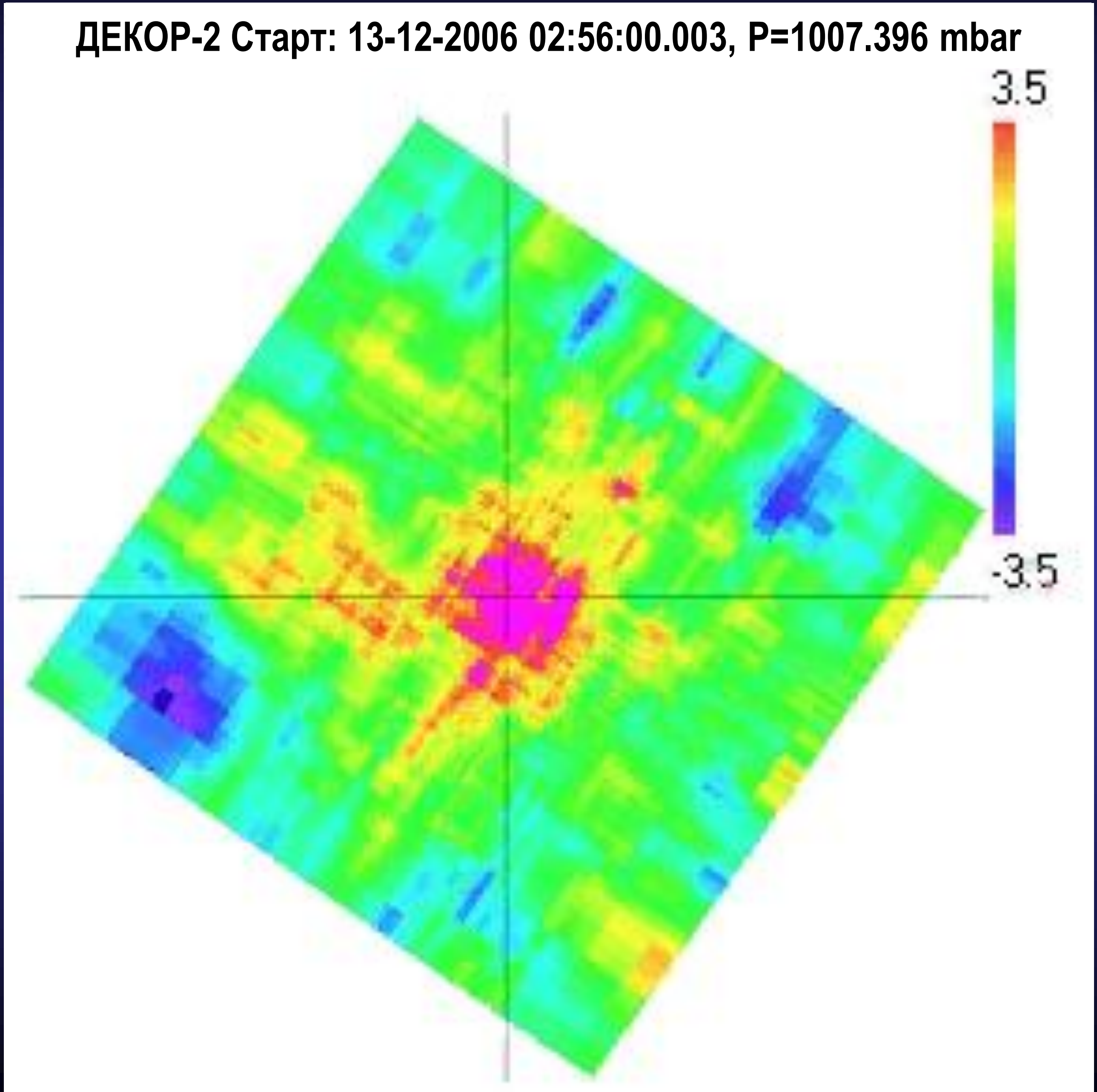

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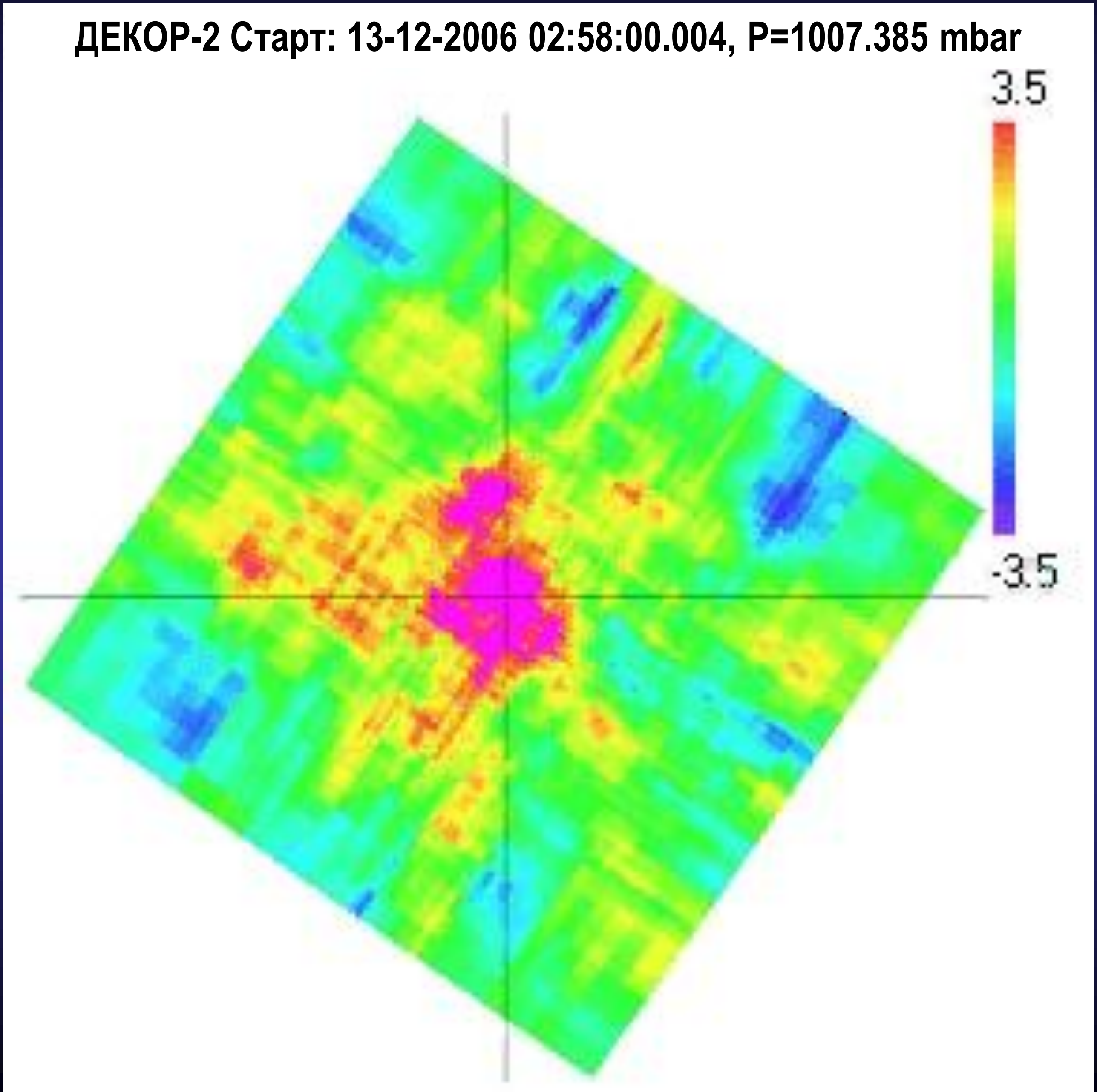

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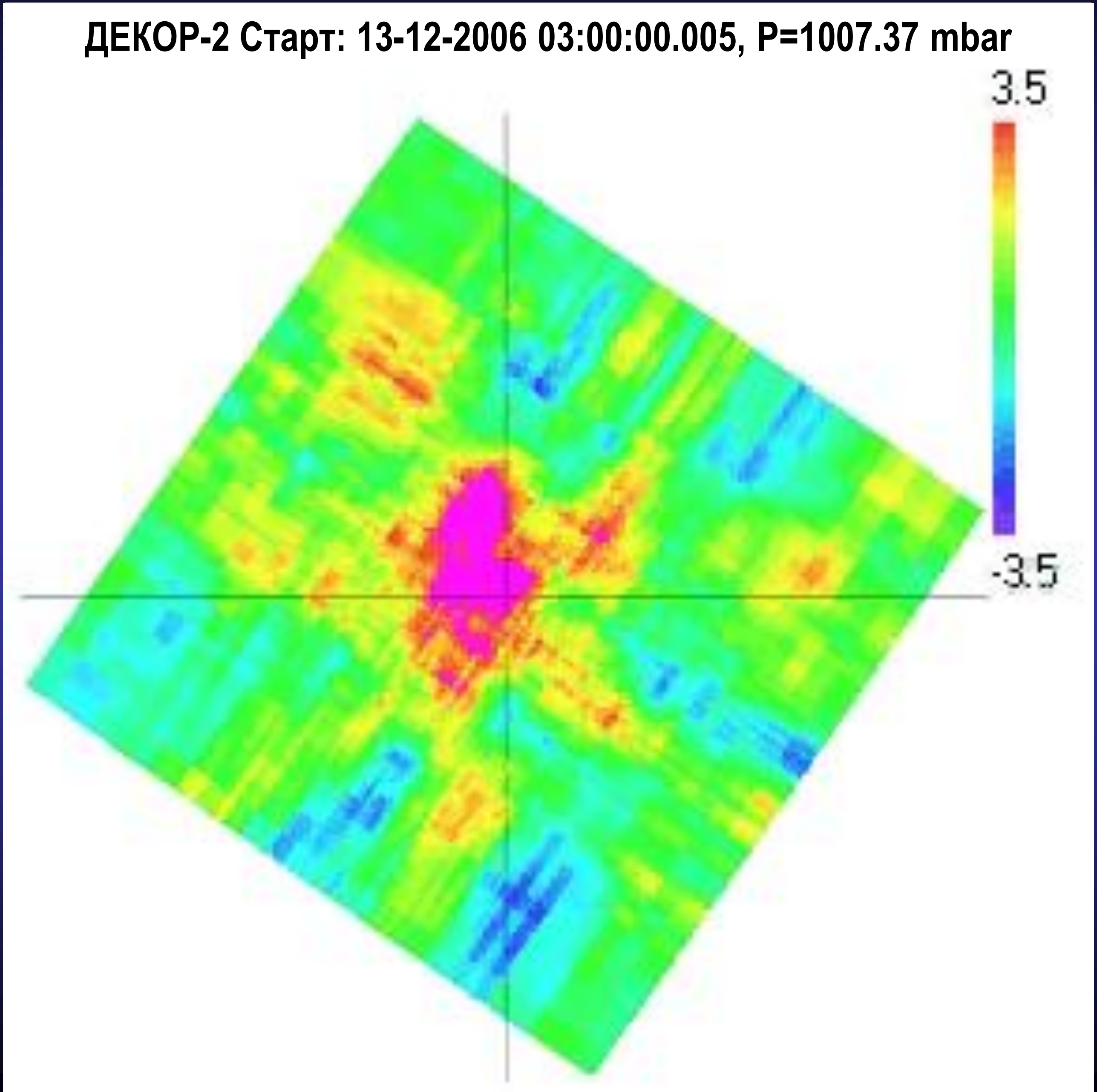
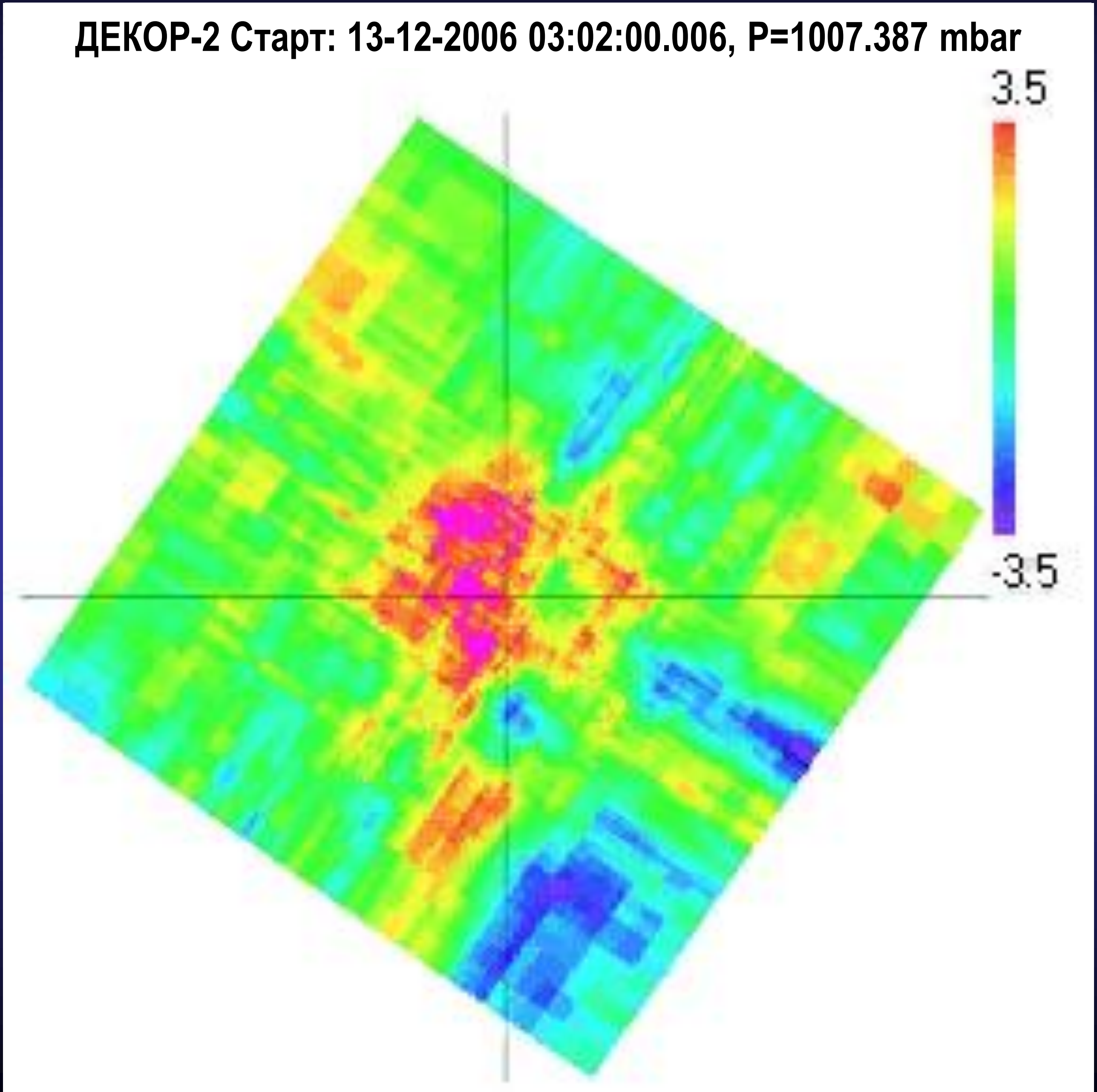


December 13, 2006

03:00 UT



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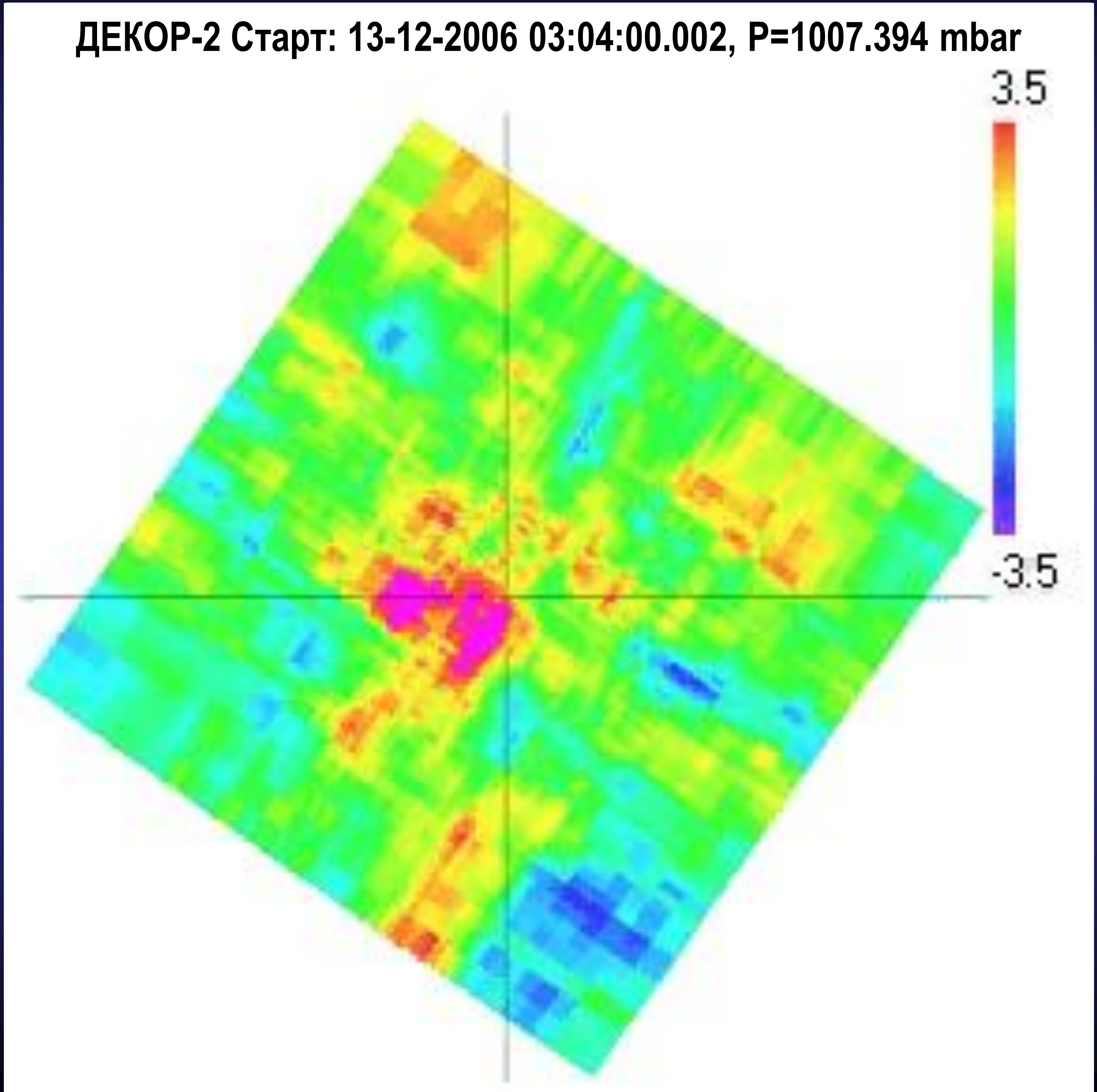

December 13, 2006

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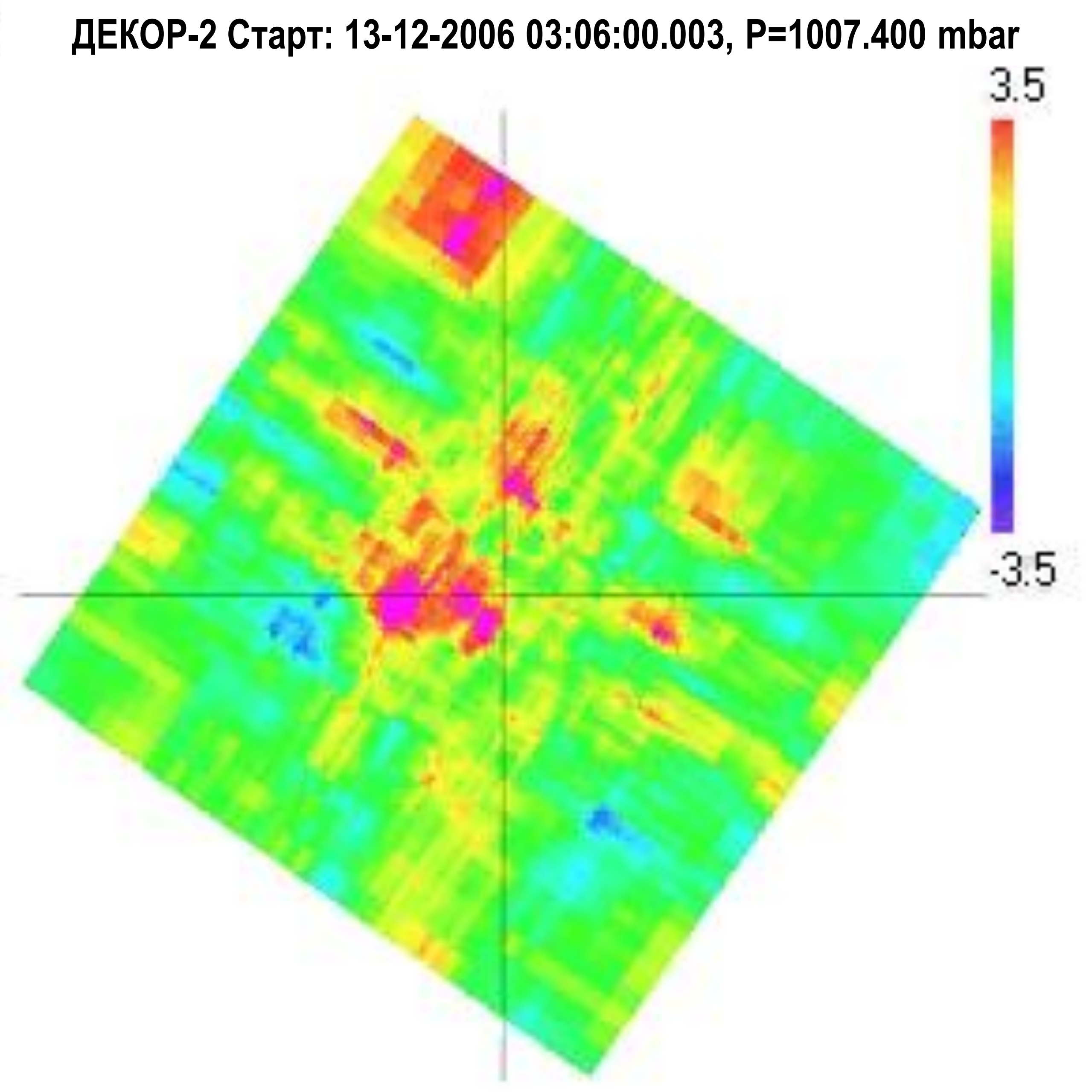

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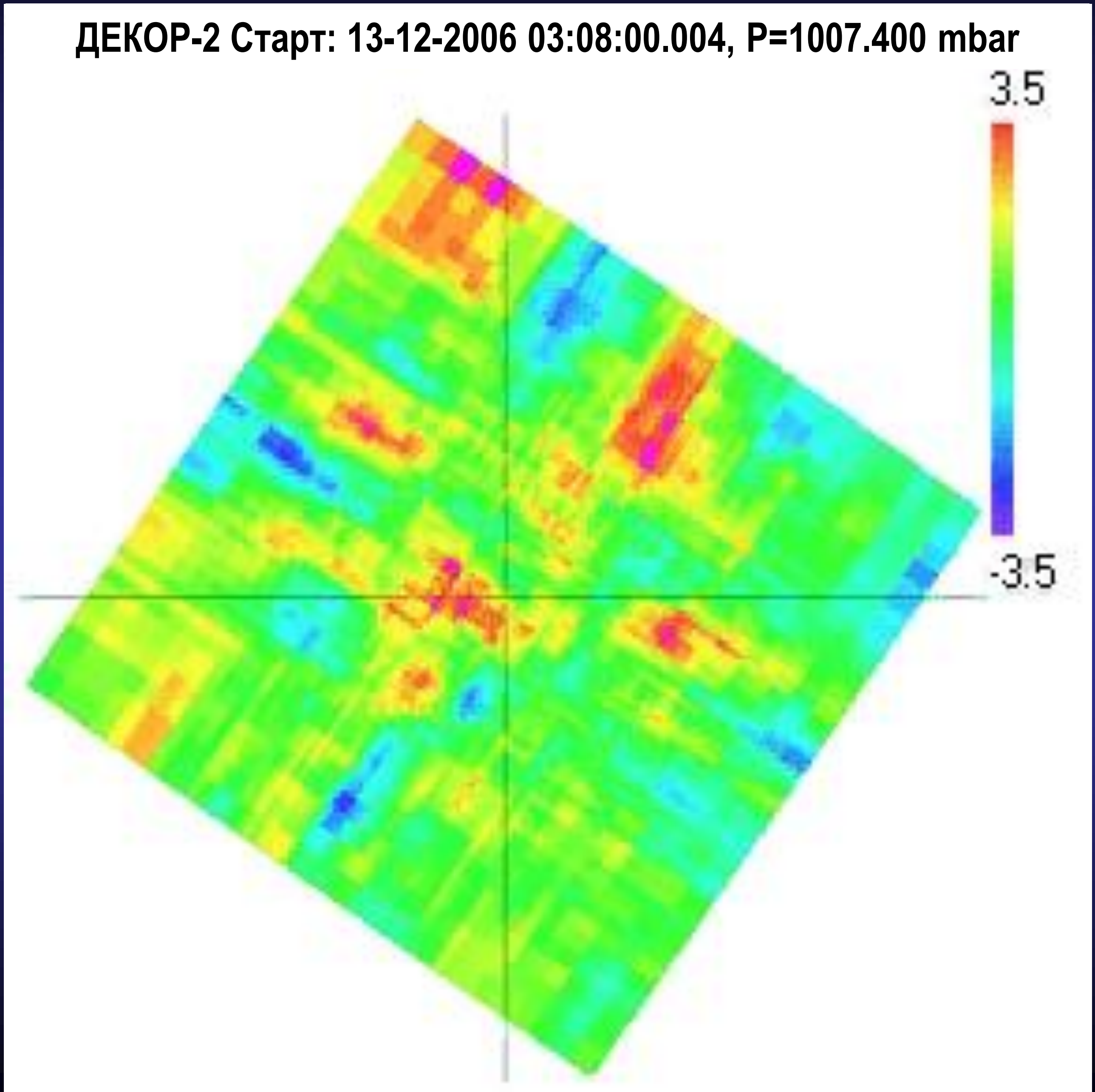

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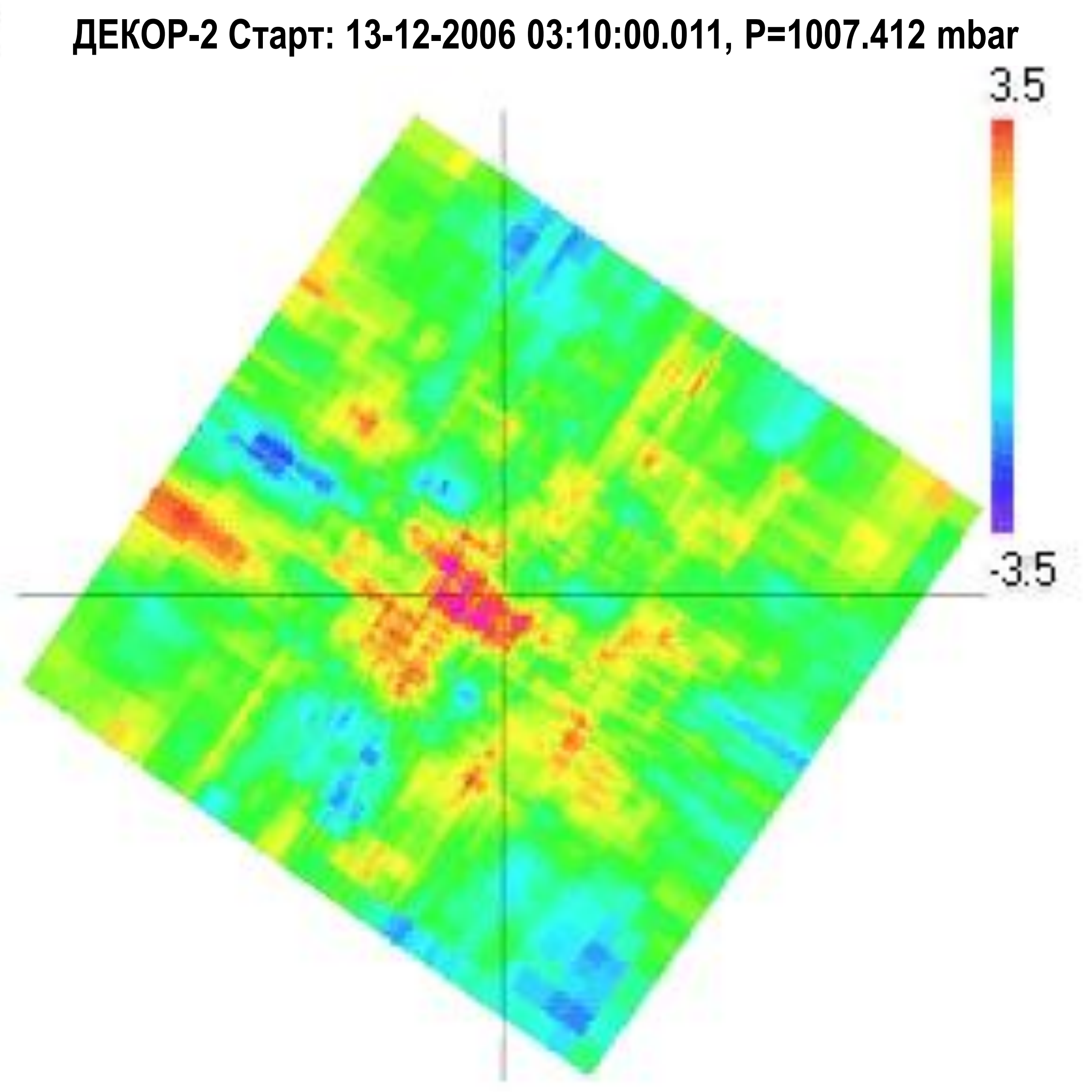

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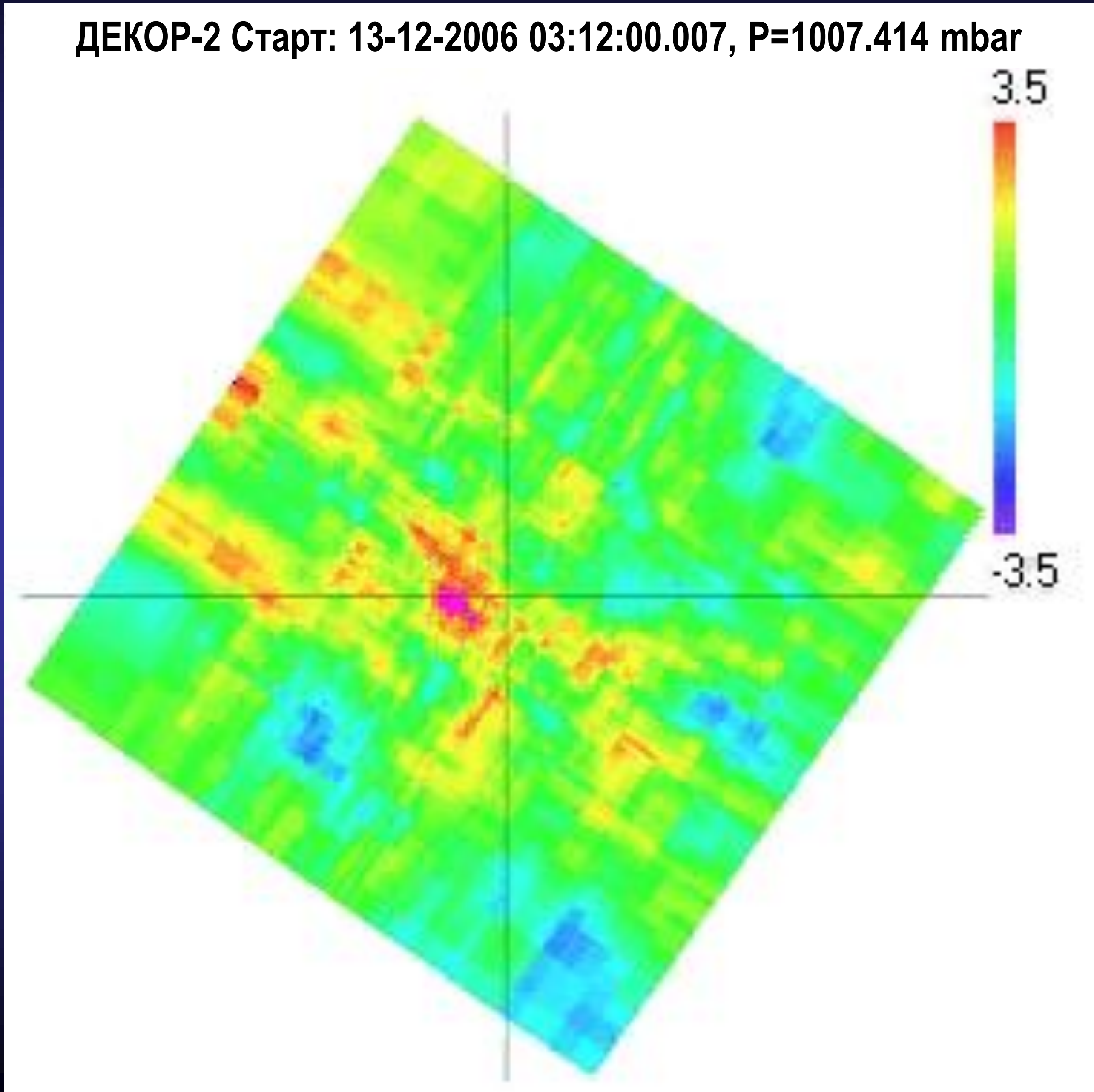

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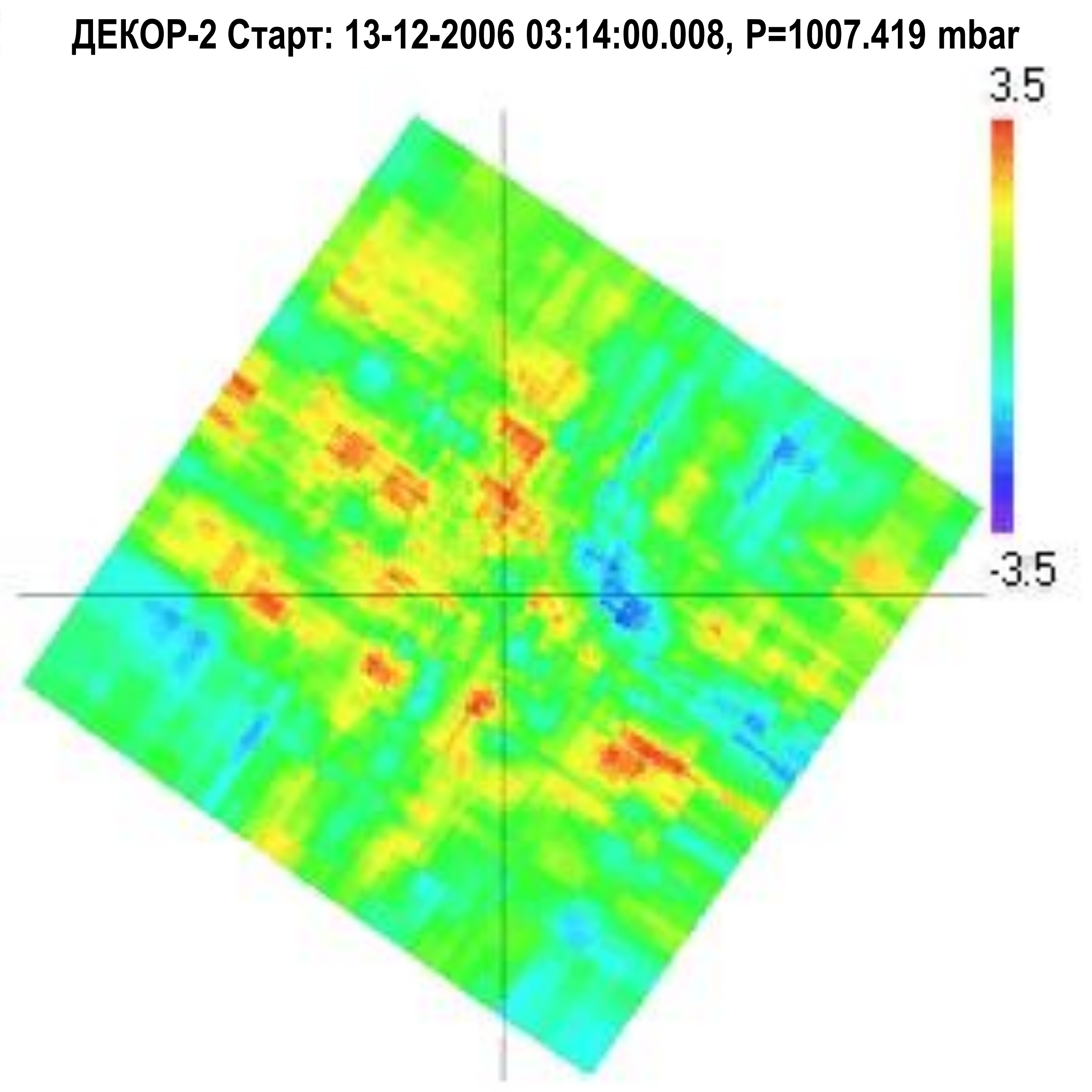
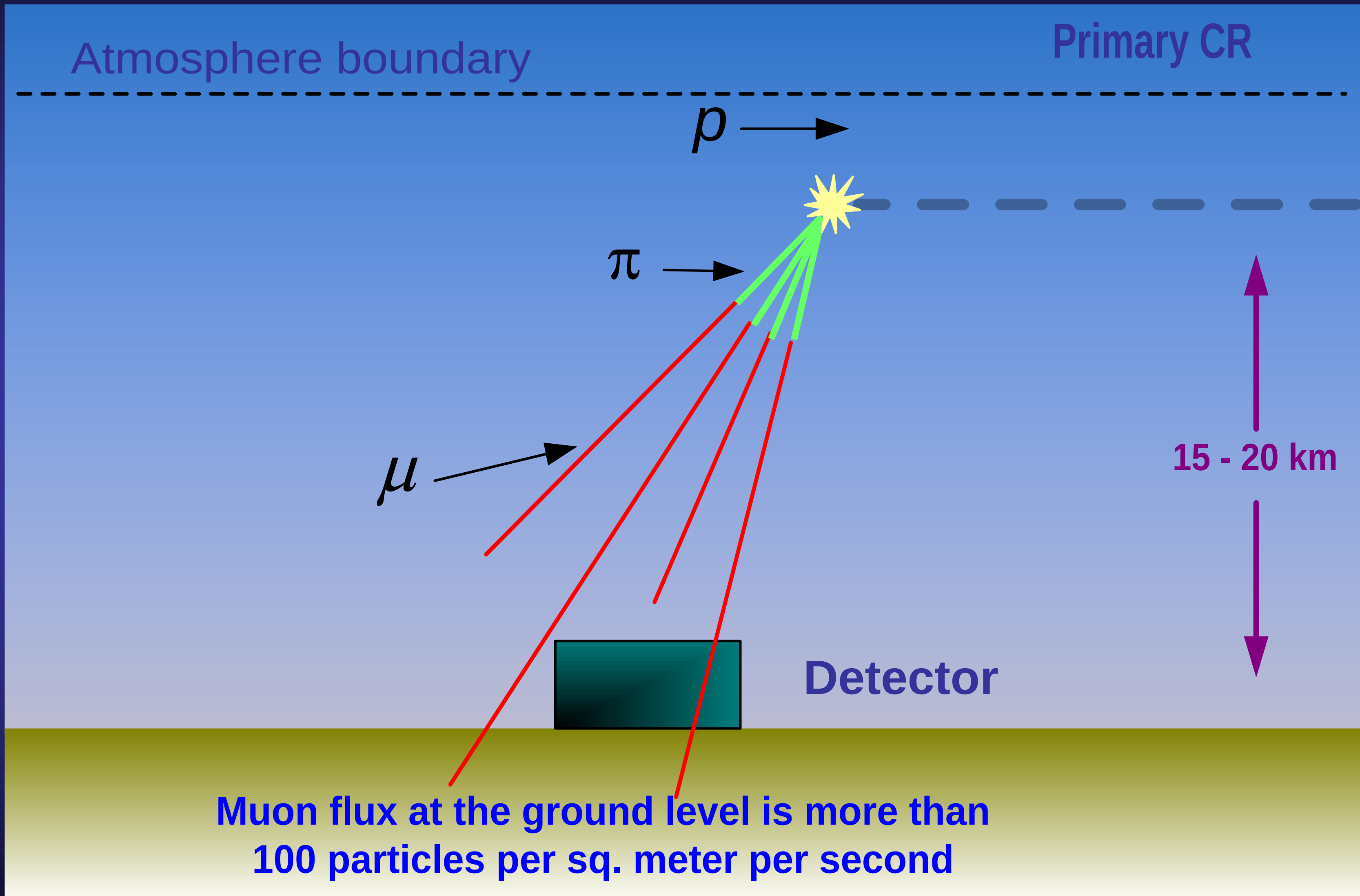


December 13, 2006

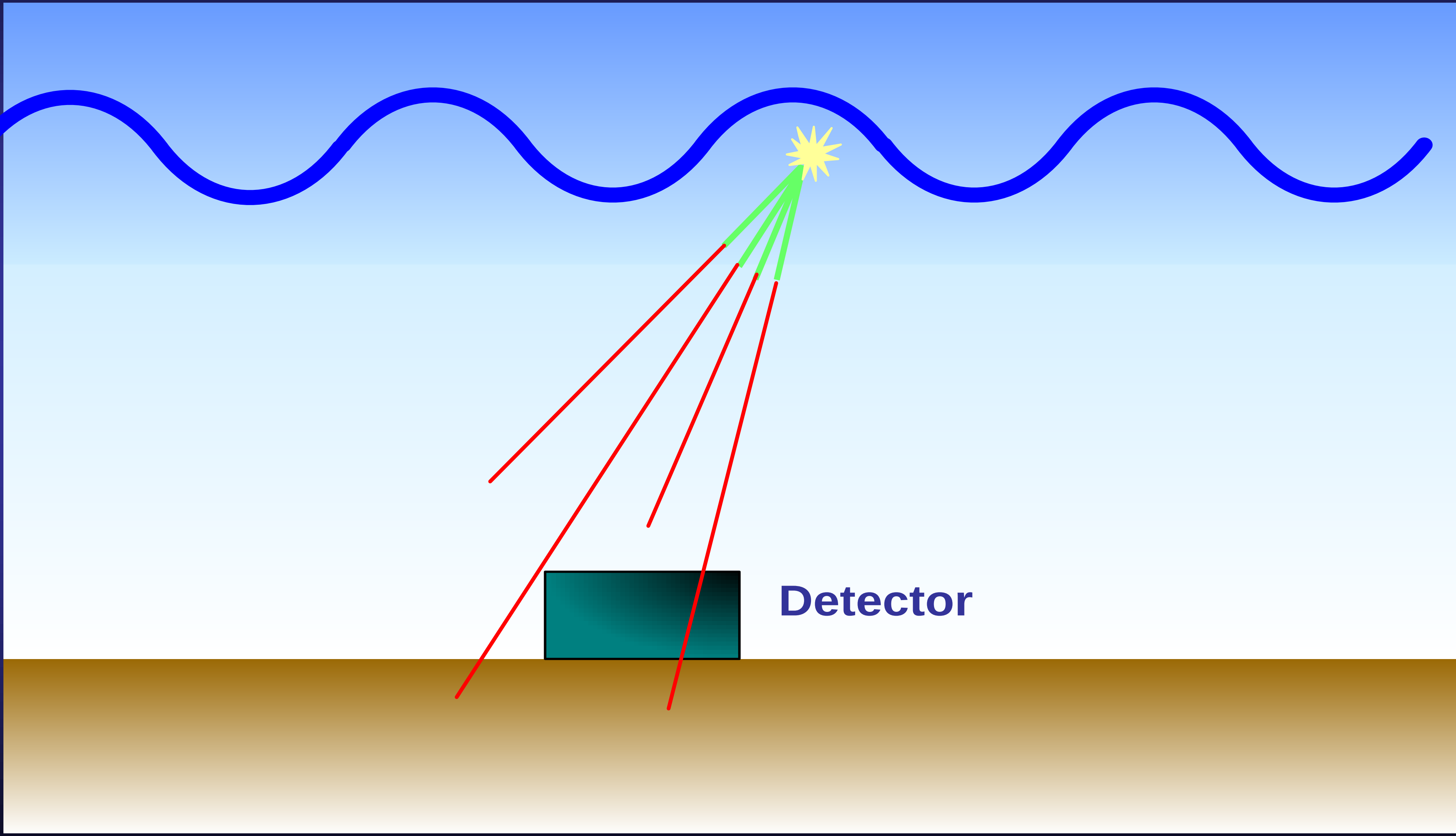
03:14 UT

Muon diagnostics of atmospheric processes

Cosmic rays in the atmosphere



Variations of detected muon flux during wave process

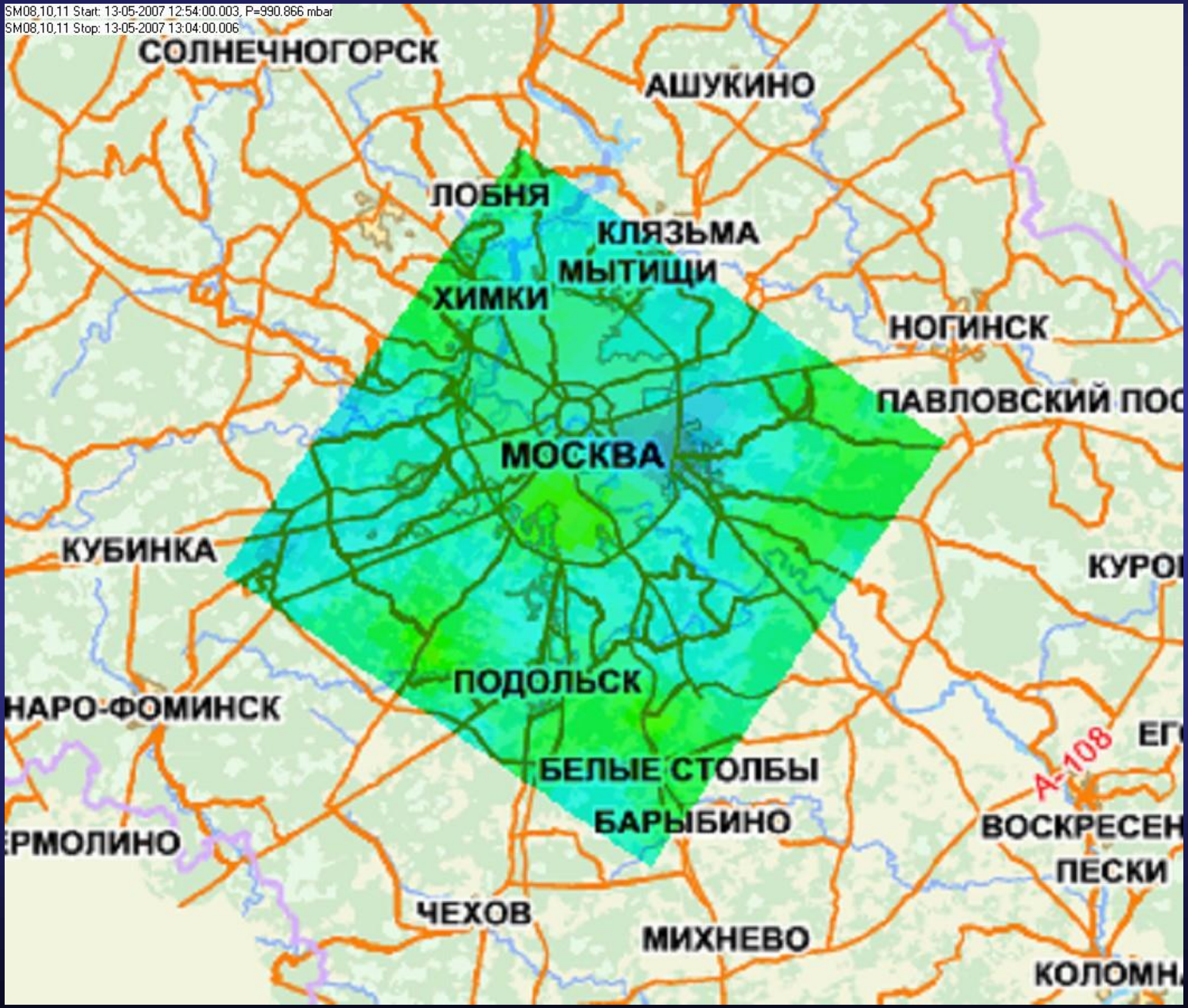


Thunderstorm in Moscow

Muon monitoring of atmosphere above Moscow during thunderstorm May 13, 2007

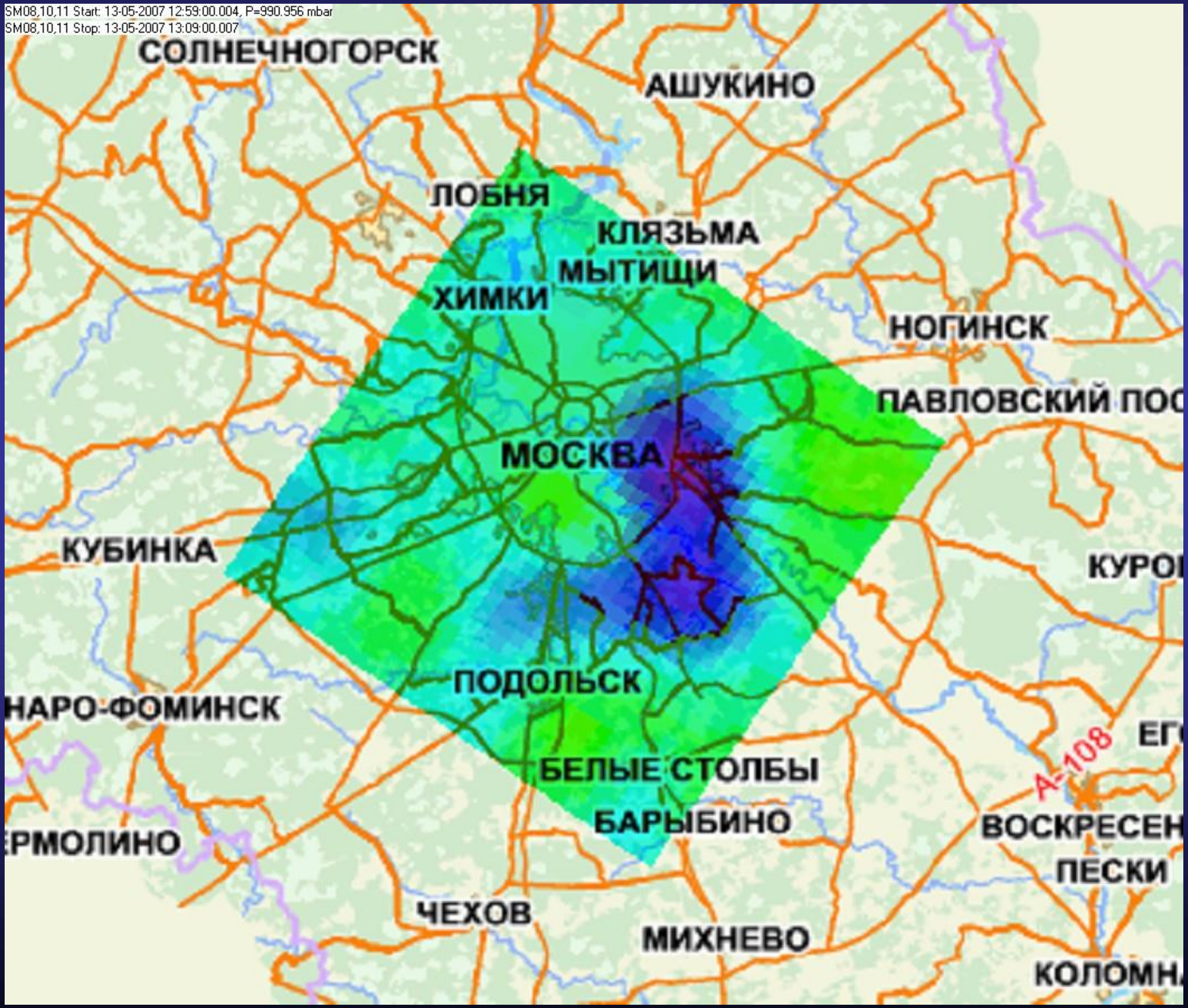
12:59

Muon monitoring of atmosphere above Moscow during thunderstorm May 13, 2007



13:04

Muon monitoring of atmosphere above Moscow during thunderstorm May 13, 2007



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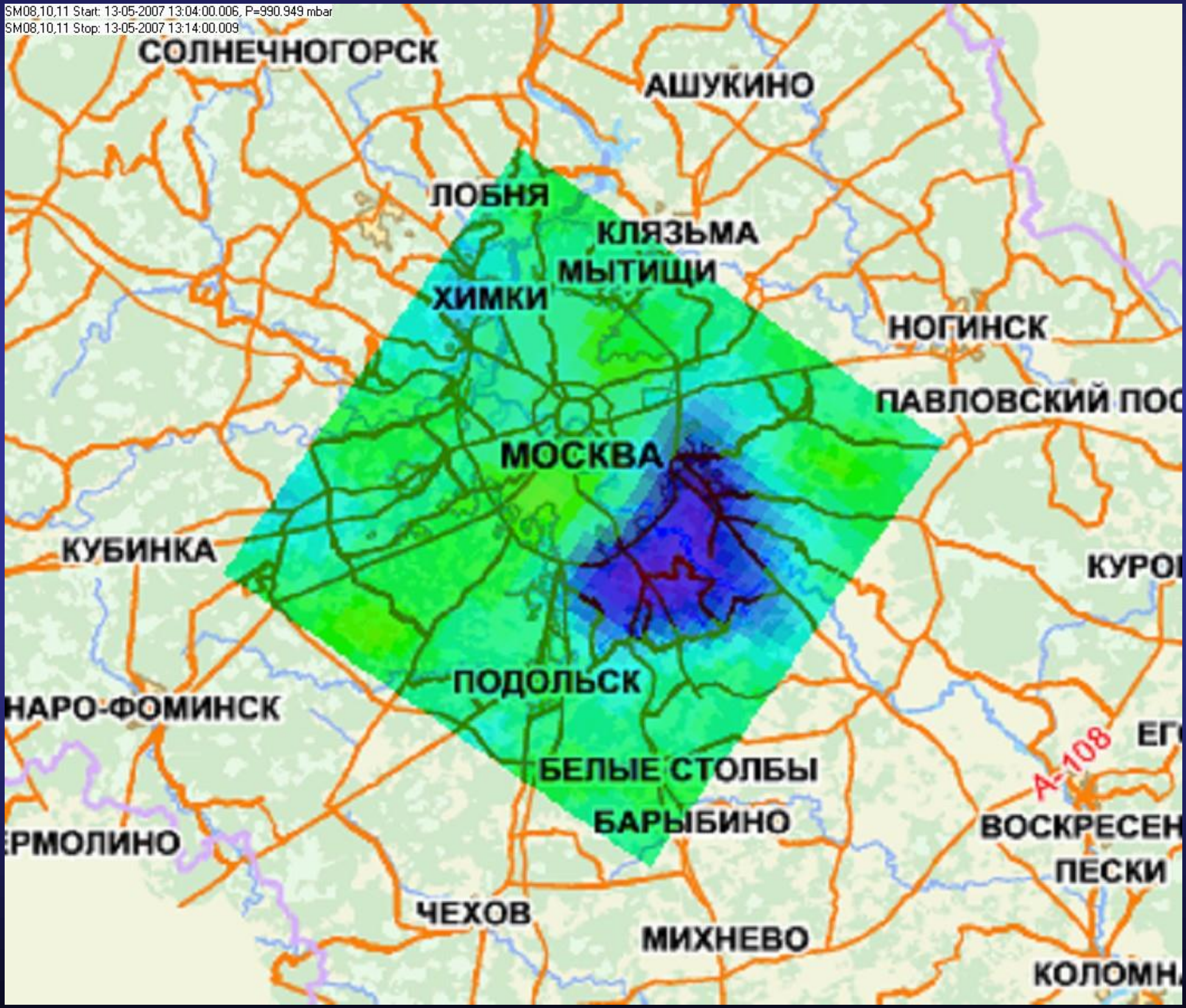
Muon monitoring of atmosphere above Moscow during thunderstorm May 13, 2007



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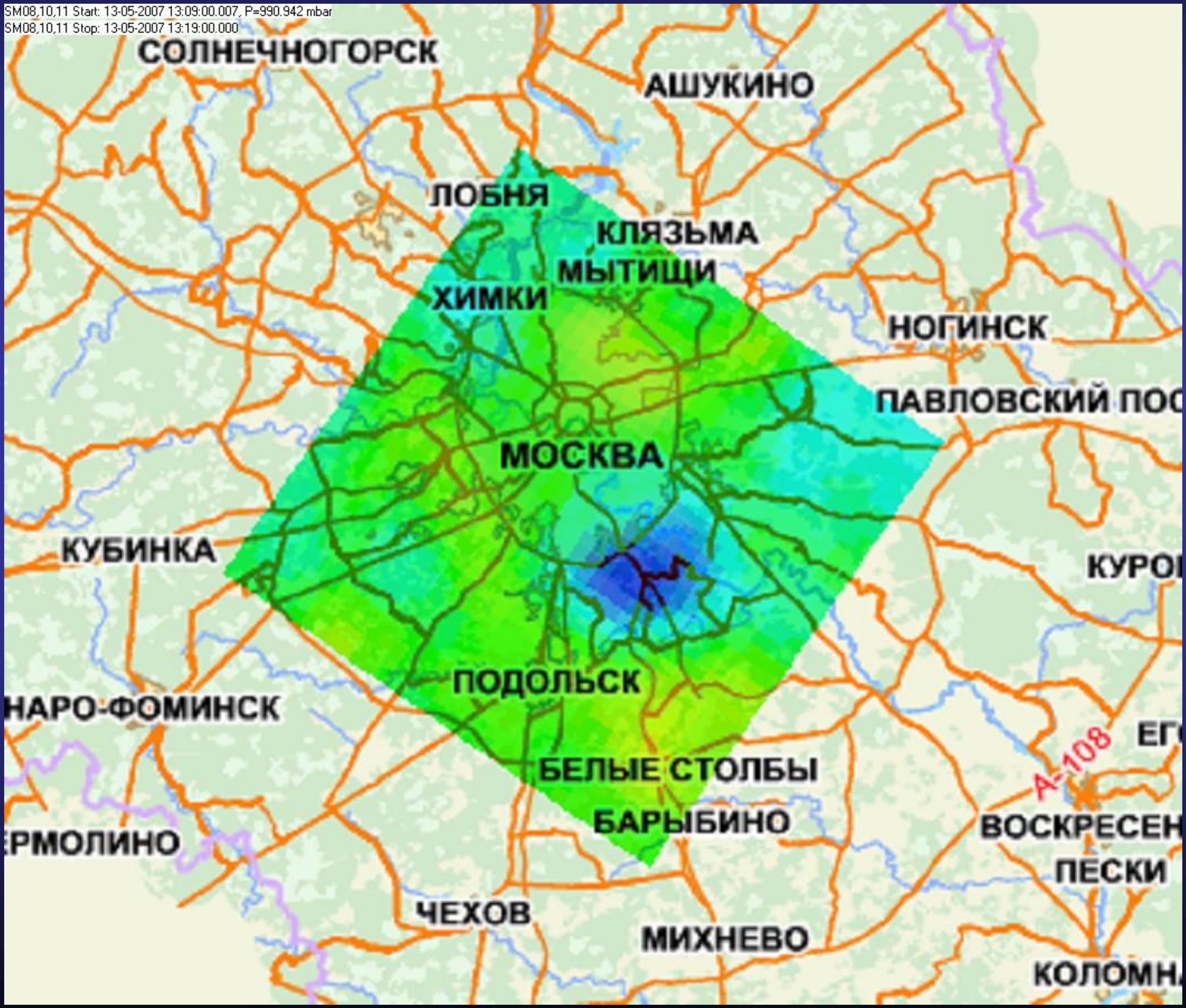
Muon monitoring of atmosphere above Moscow during thunderstorm May 13, 2007



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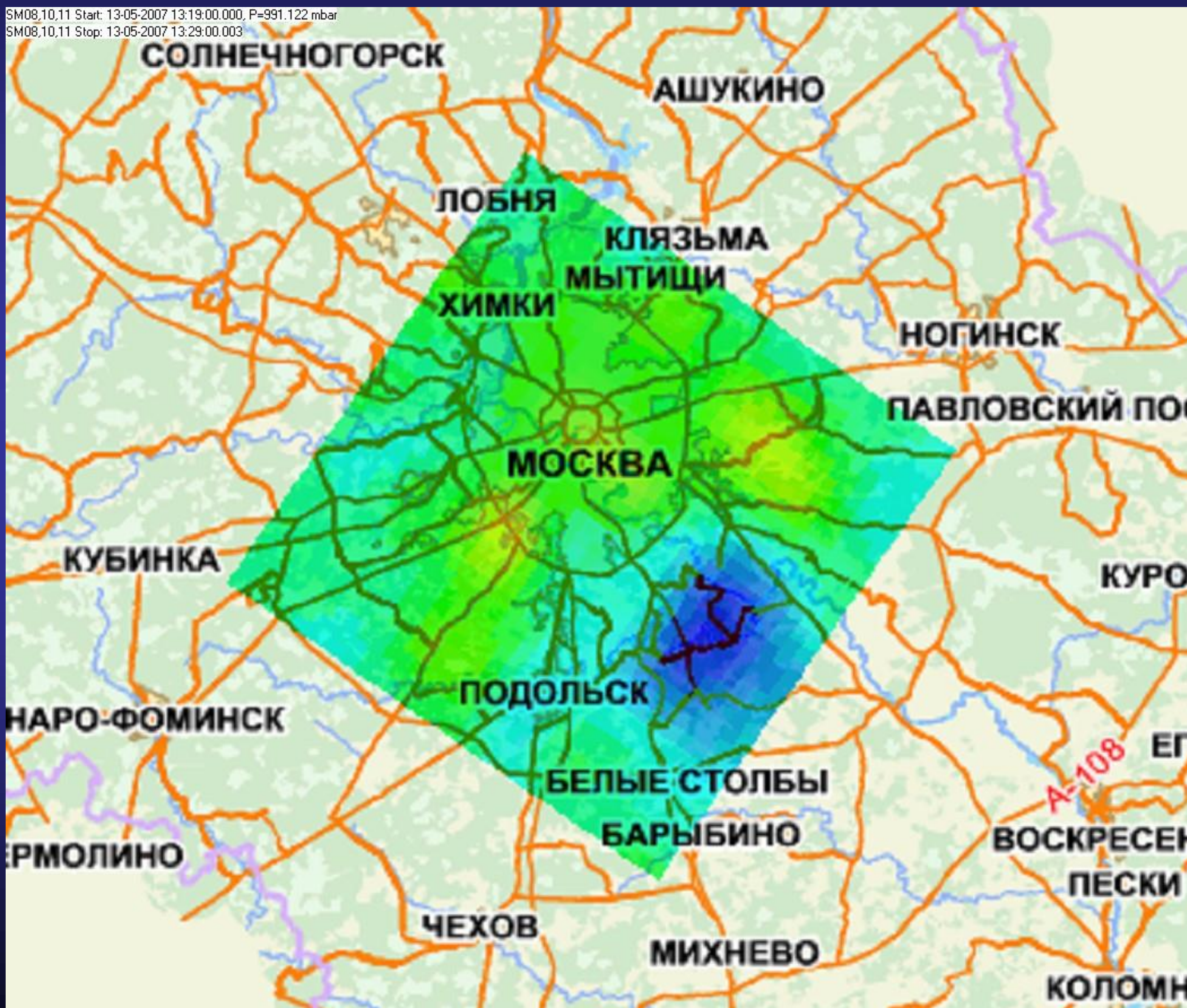
Muon monitoring of atmosphere above Moscow during thunderstorm May 13, 2007



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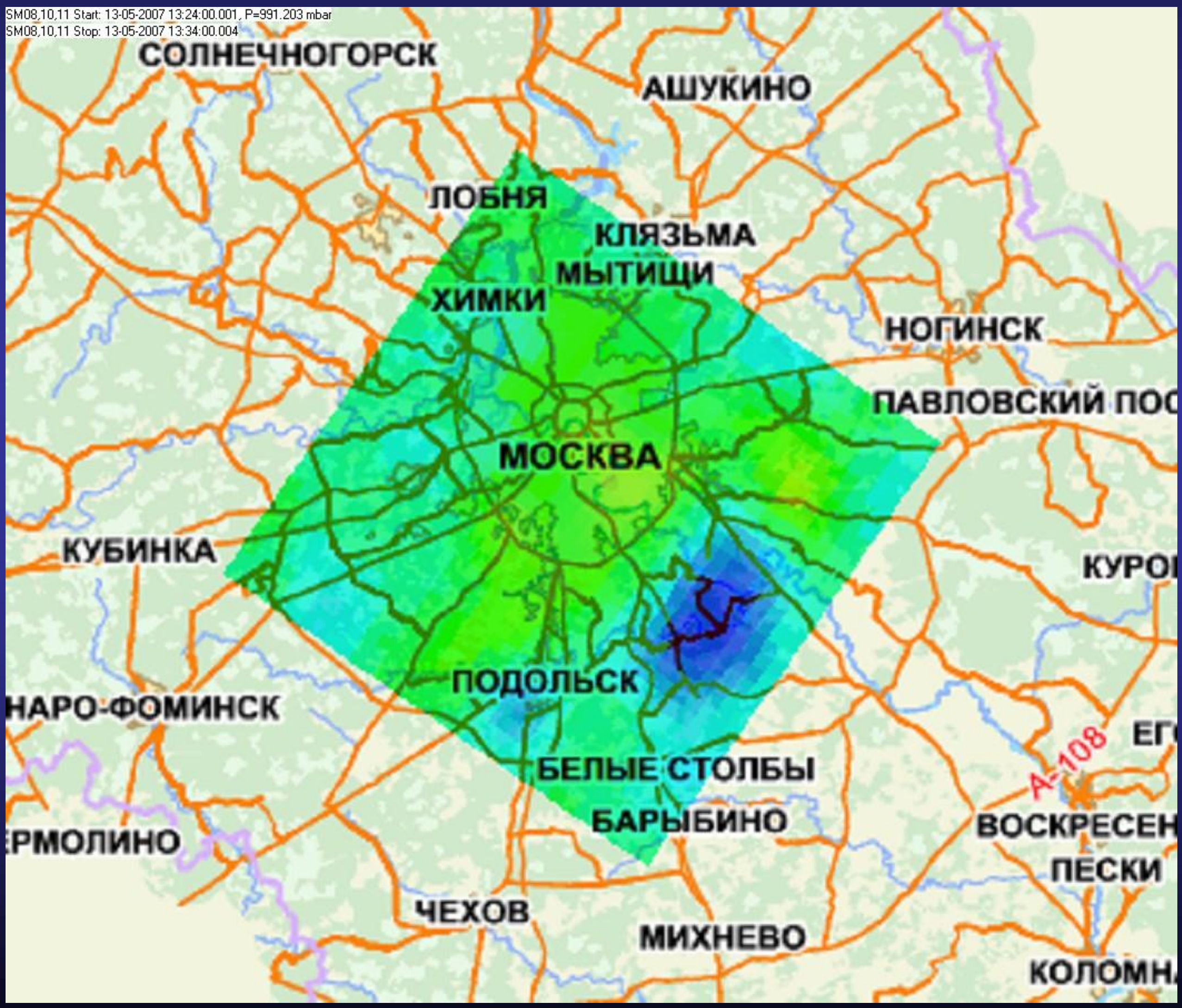
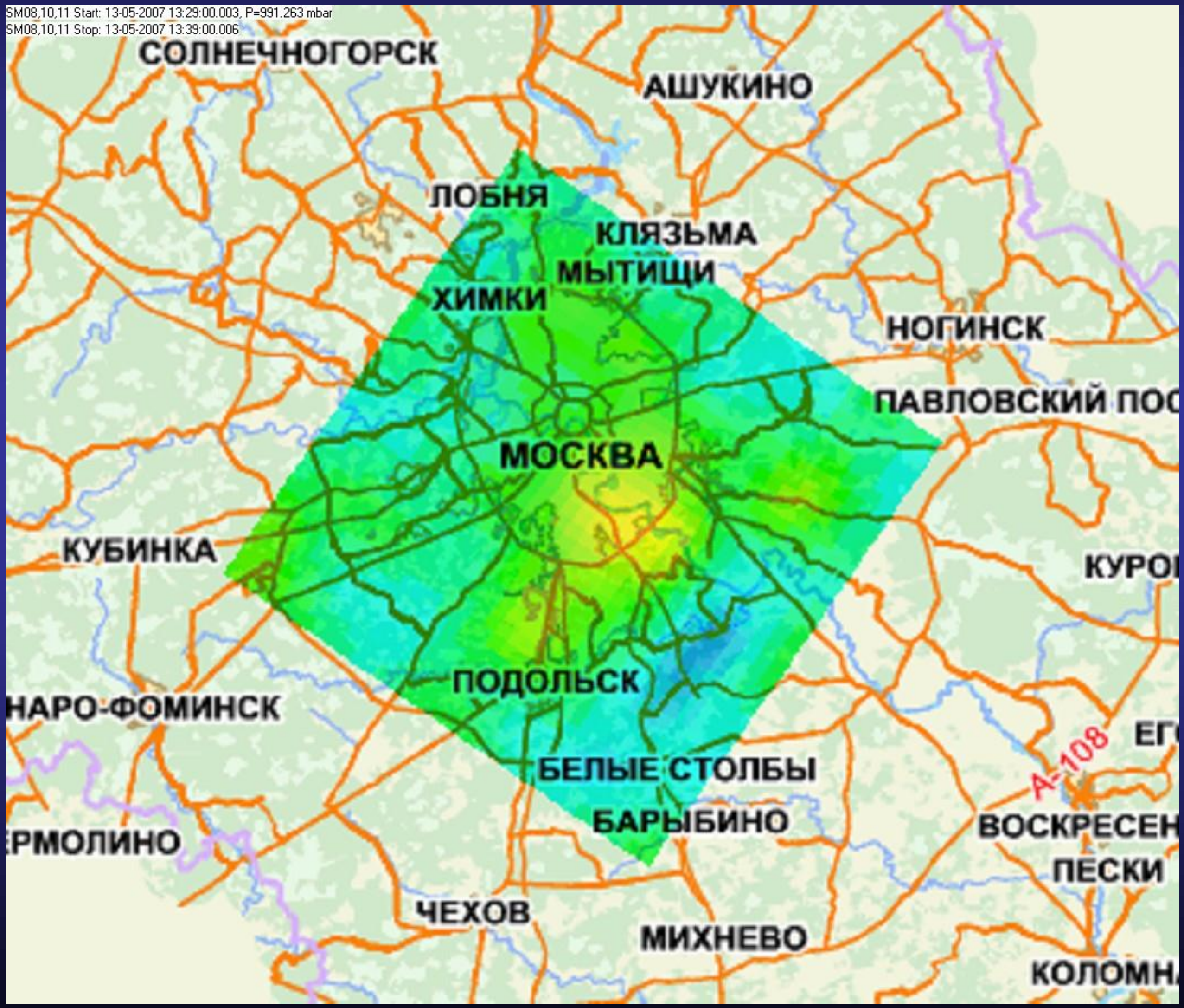
Muon monitoring of atmosphere above Moscow during thunderstorm May 13, 2007



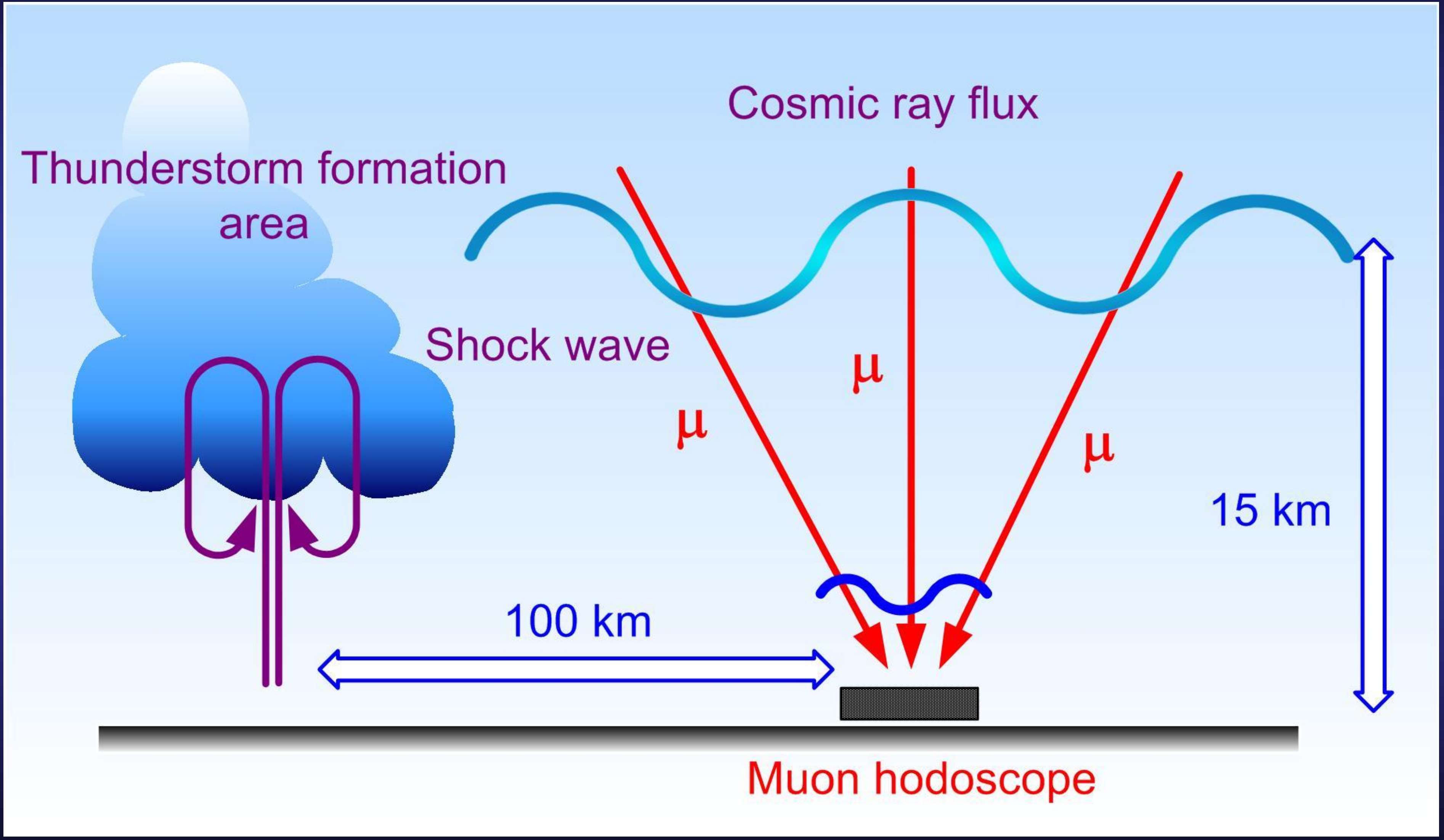
13:29

Muon monitoring of atmosphere above Moscow during thunderstorm



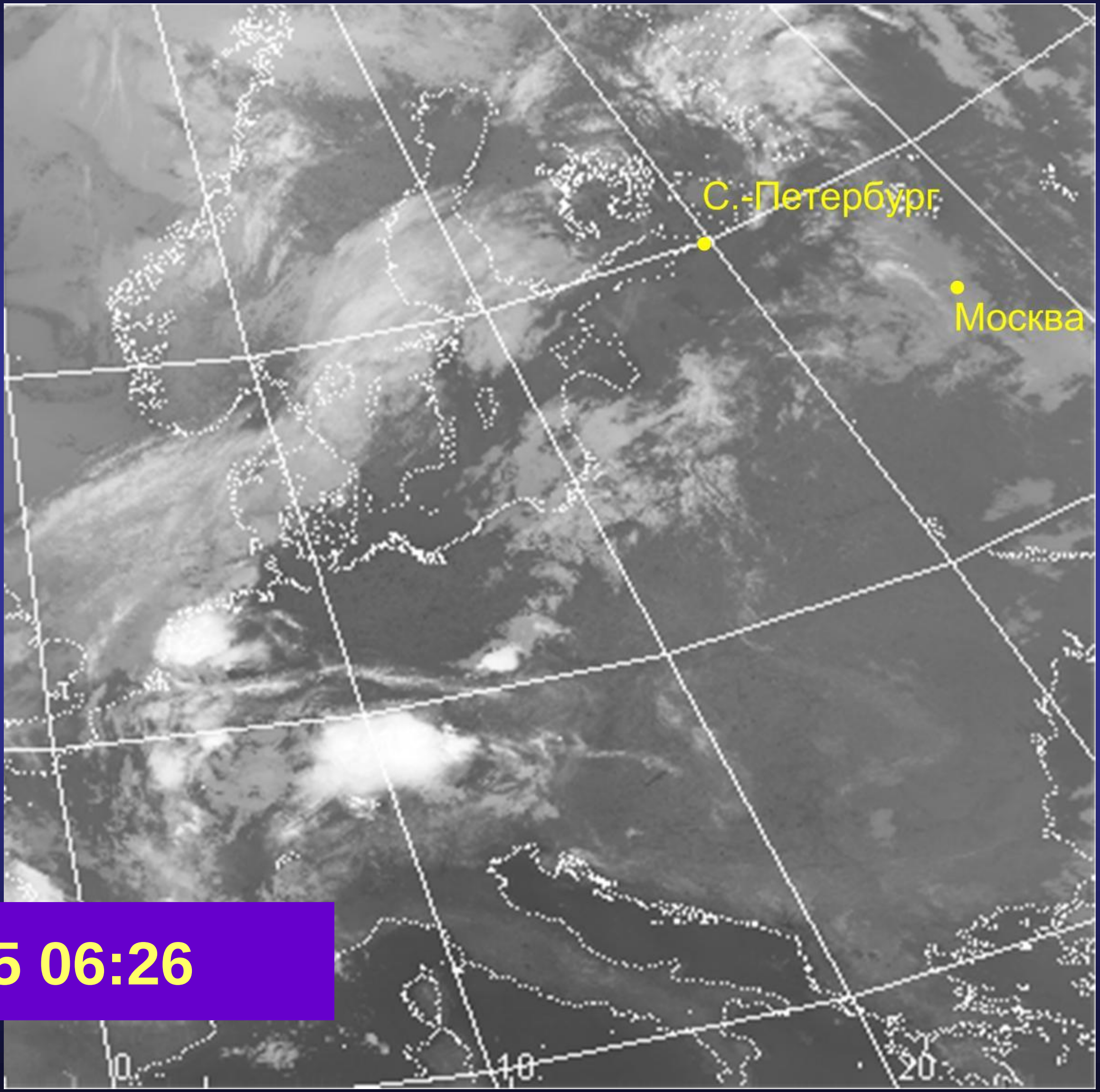
13:34

Thunderstorms and wave processes



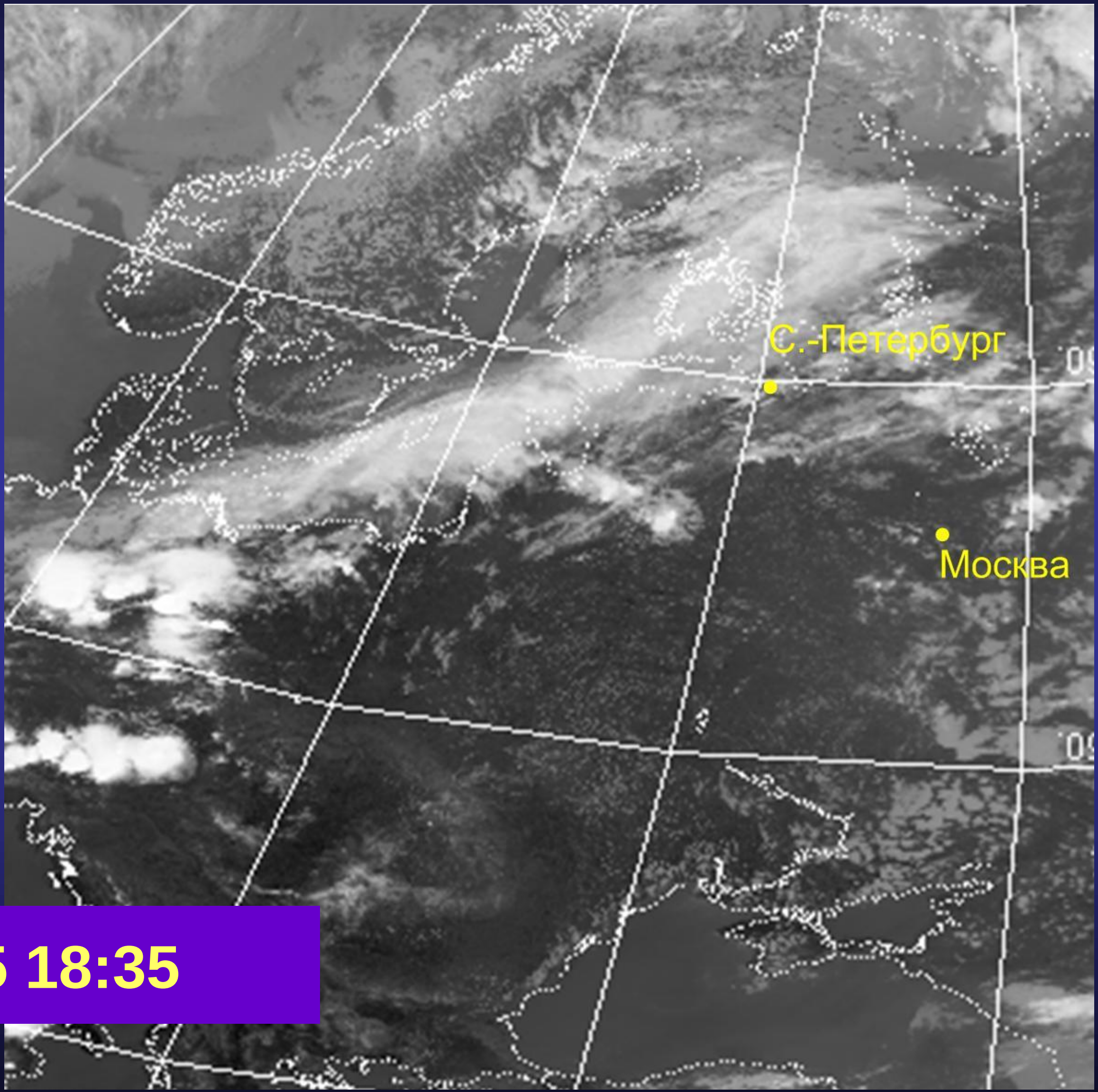
Muon hodoscope’s data analysis during atmospheric perturbations on June 26, 2005

The onset of atmospheric front forming above Northern Europe



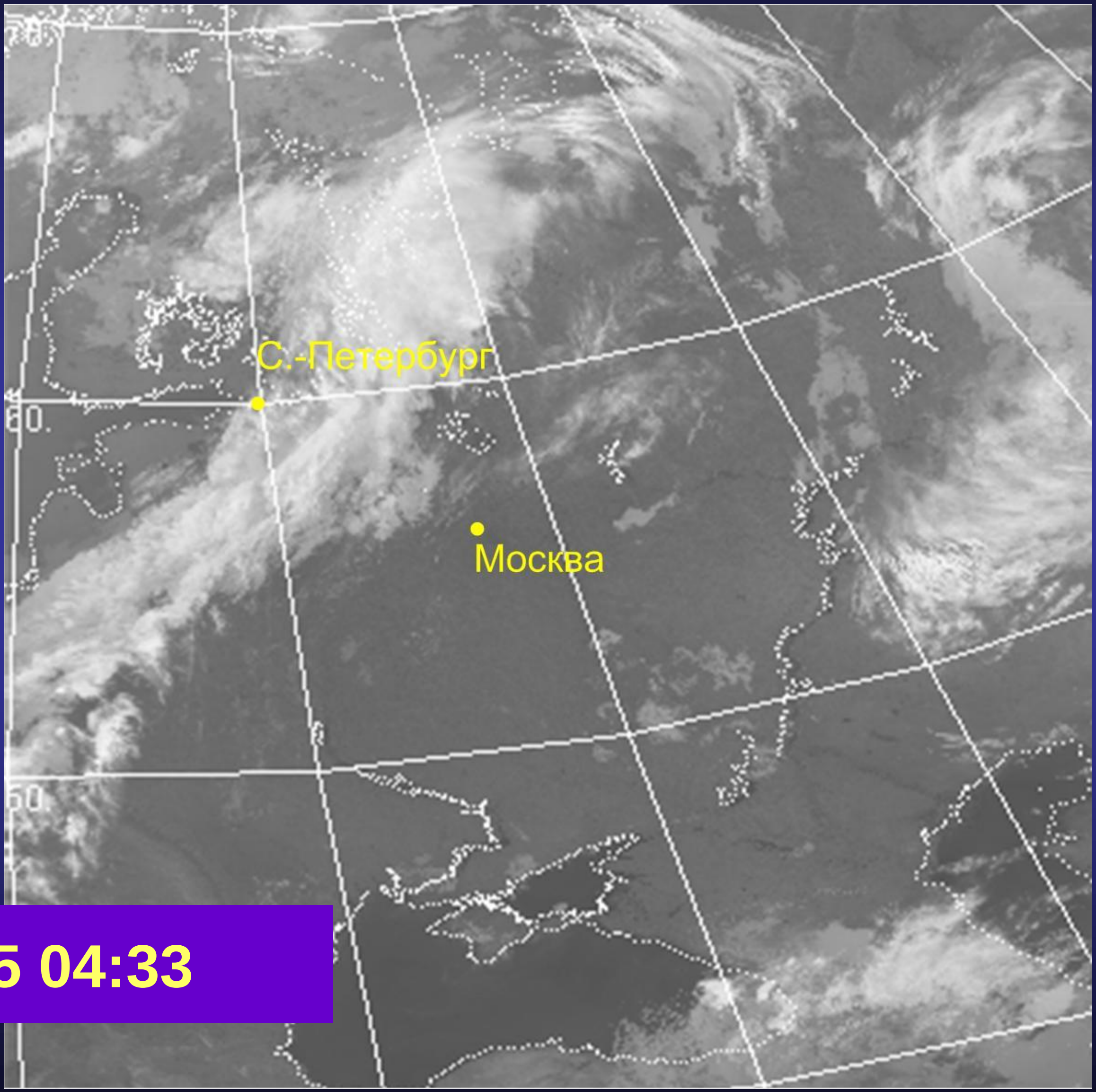
25/06/05 06:26

After 12 hours the atmospheric front arrived to north-west of Russia



25/06/05 18:35

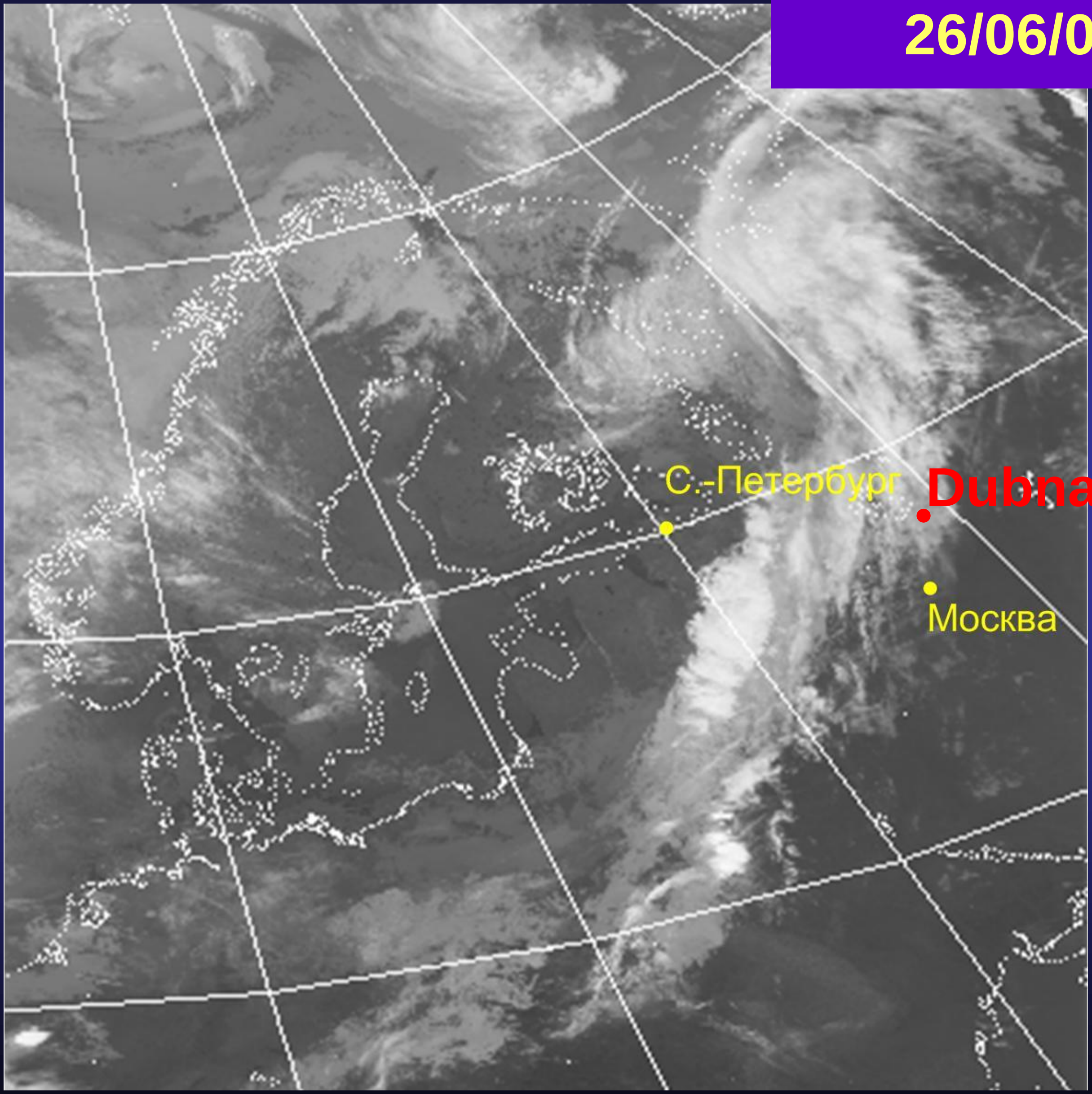
The atmospheric front is coming to Moscow



26/06/05 04:33

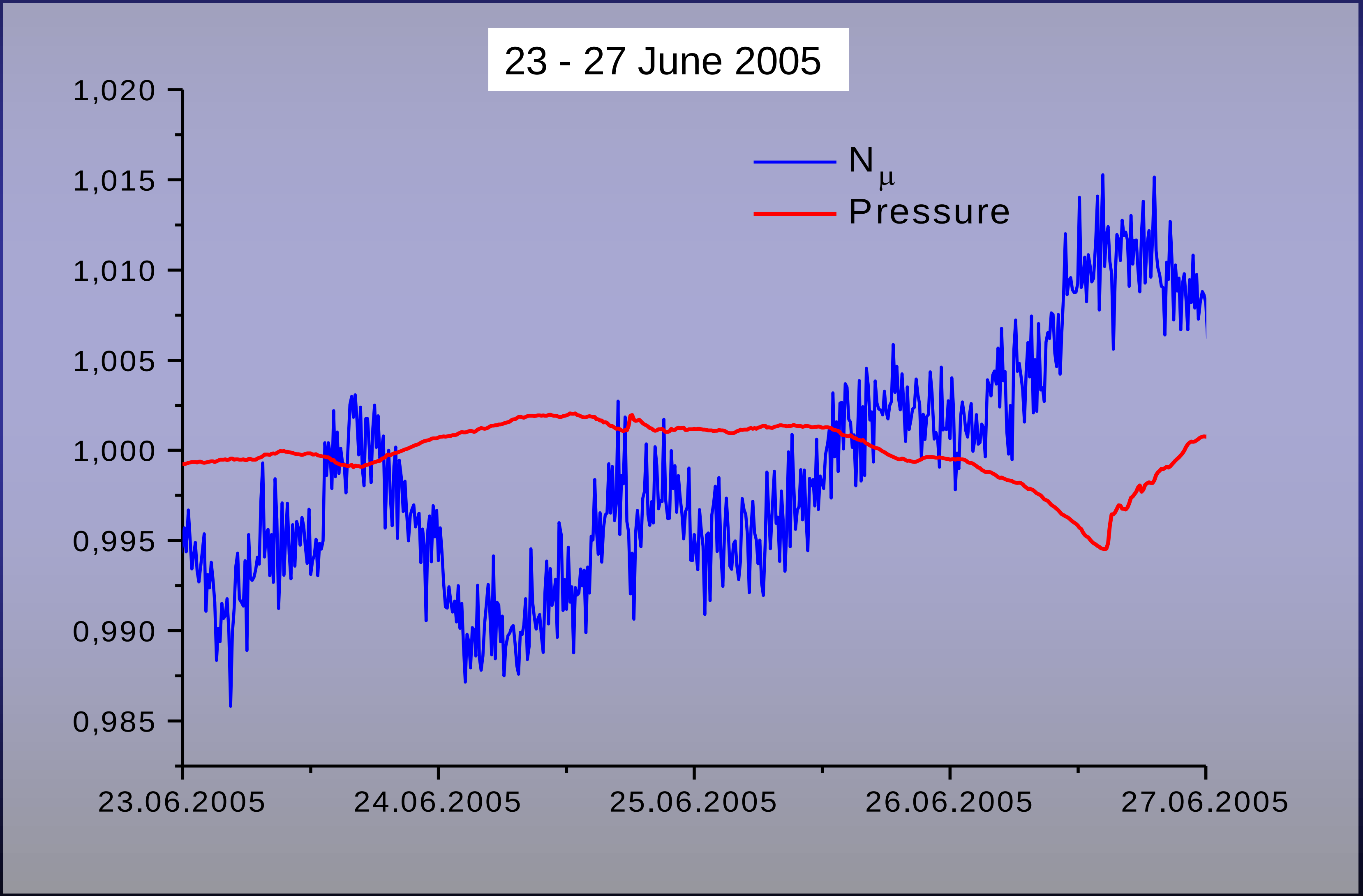
Atmospheric front reached the Moscow region

26/06/05 08:00

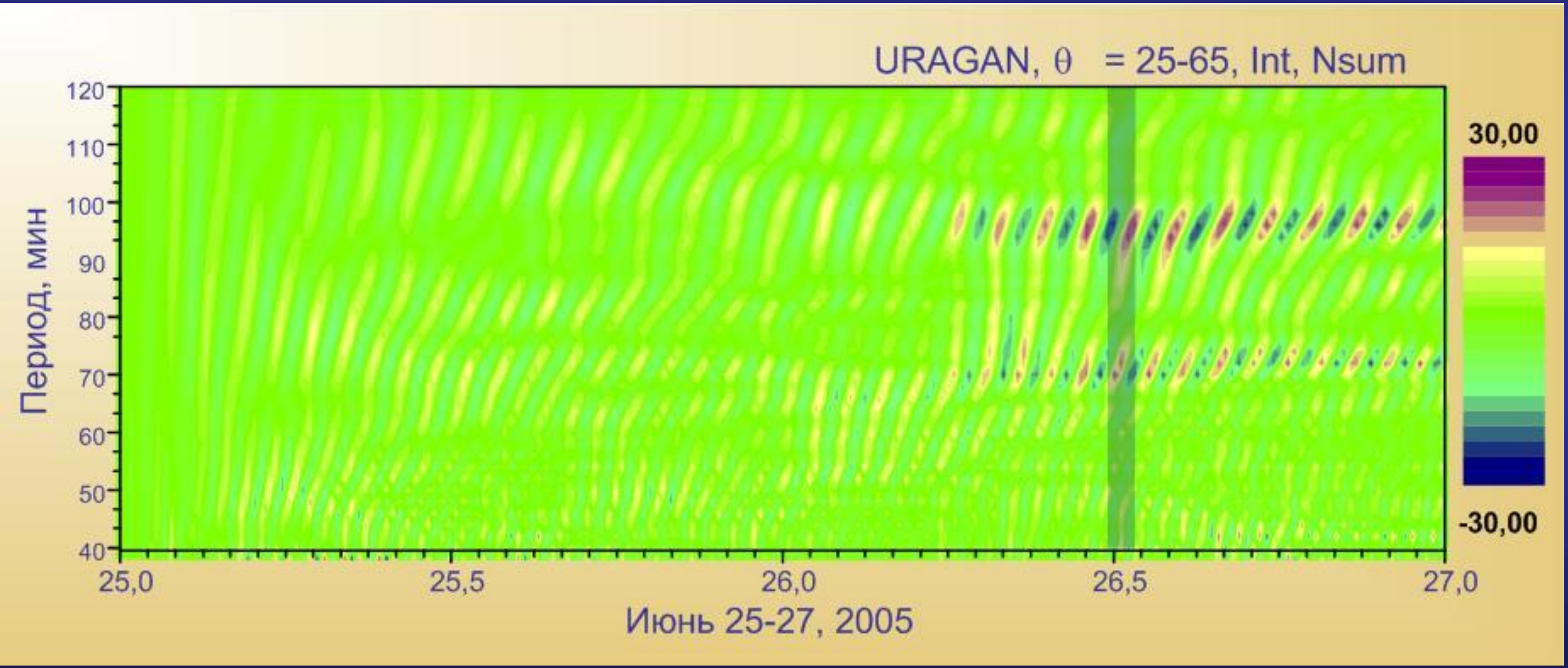


26/06/05 12:00

Muon flux variations



Wave process from hurricane in Dubna 26 June 2005 appeares in the muon flux 2 hours before



Distance from Dubna to MEPHI ~ 140 km, however:

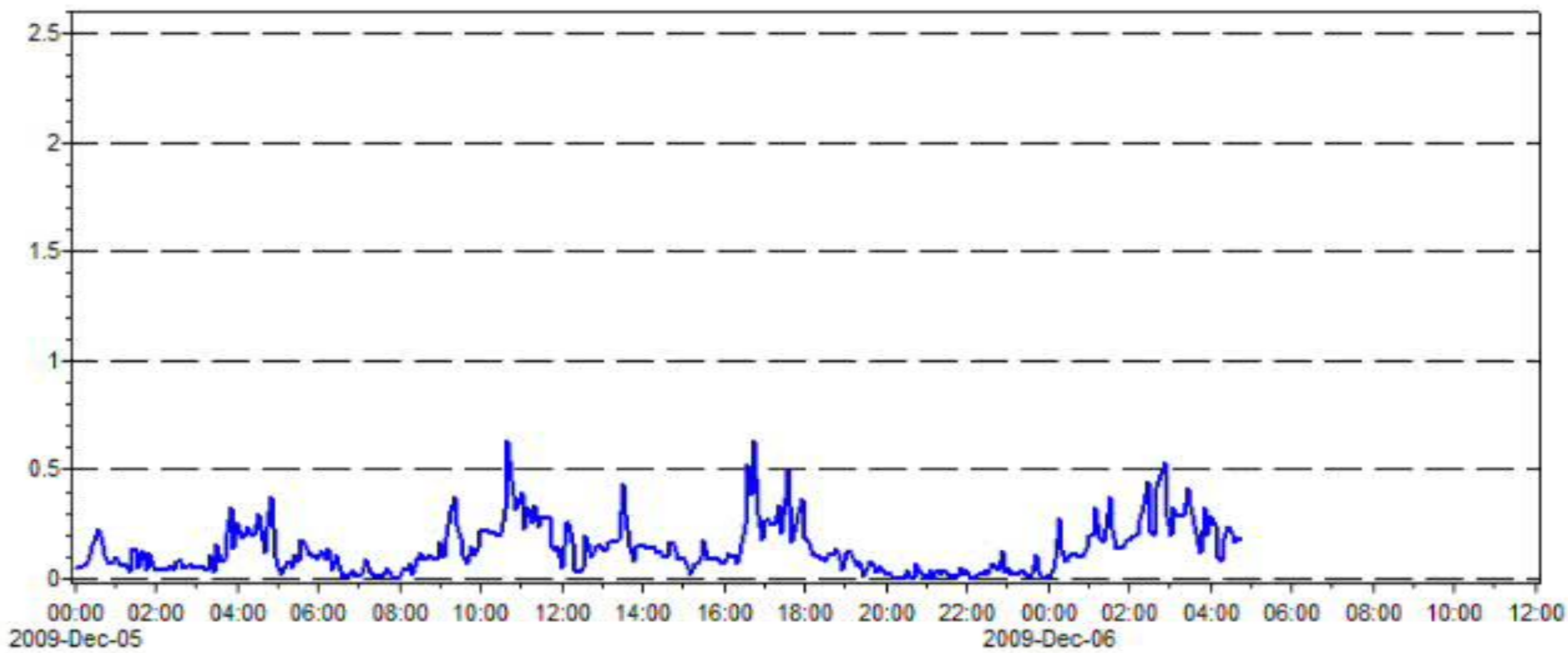
1. *Muon hodoscope registered azimuthally asymmetry of muon flux in the direction of hurricane.*

2. Wavelet analysis revealed wave process in the atmosphere, which began before the hurricane in Dubna.

Snowfall in Moscow on 7 December 2009

This snowfall was not predicted Meteorological Agencies

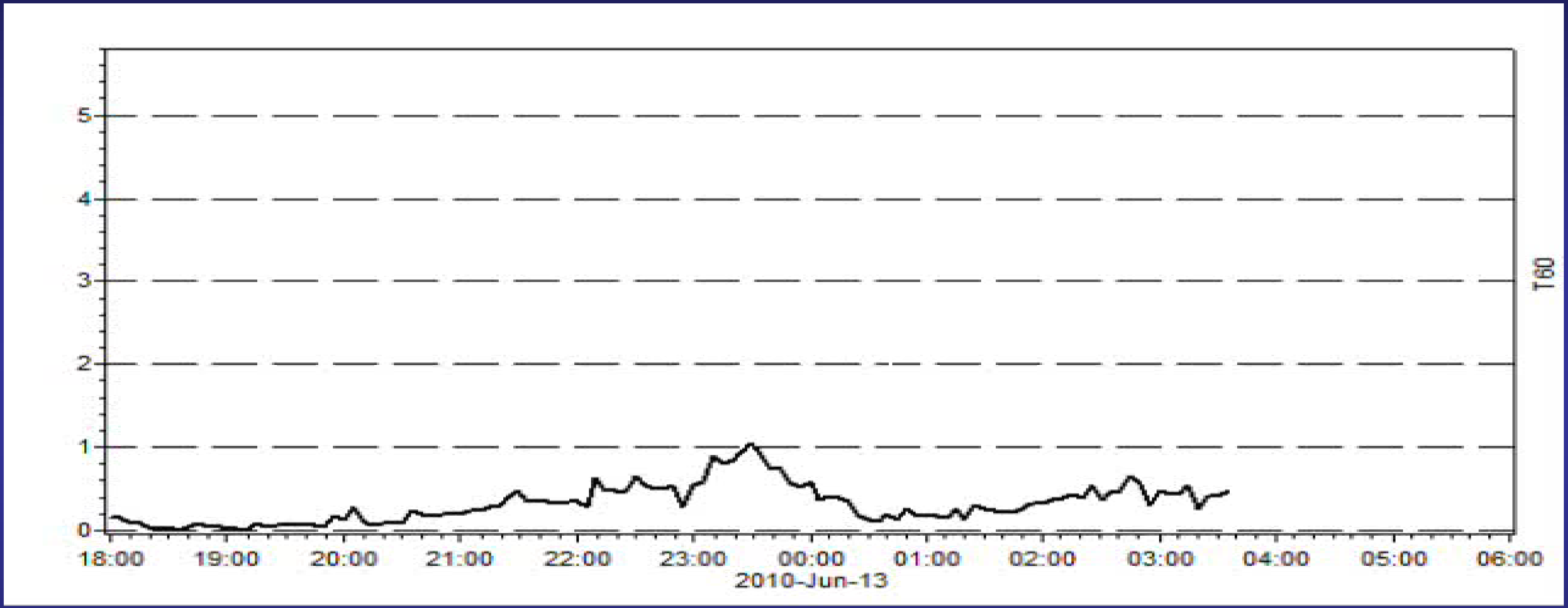
Results of wavelet analysis of muon flux



The beginning of wave process was observed about 20 h before snowfall.

Thunderstorm in Moscow on 13 June 2010

Thunderstorm in Moscow June 13, 2010



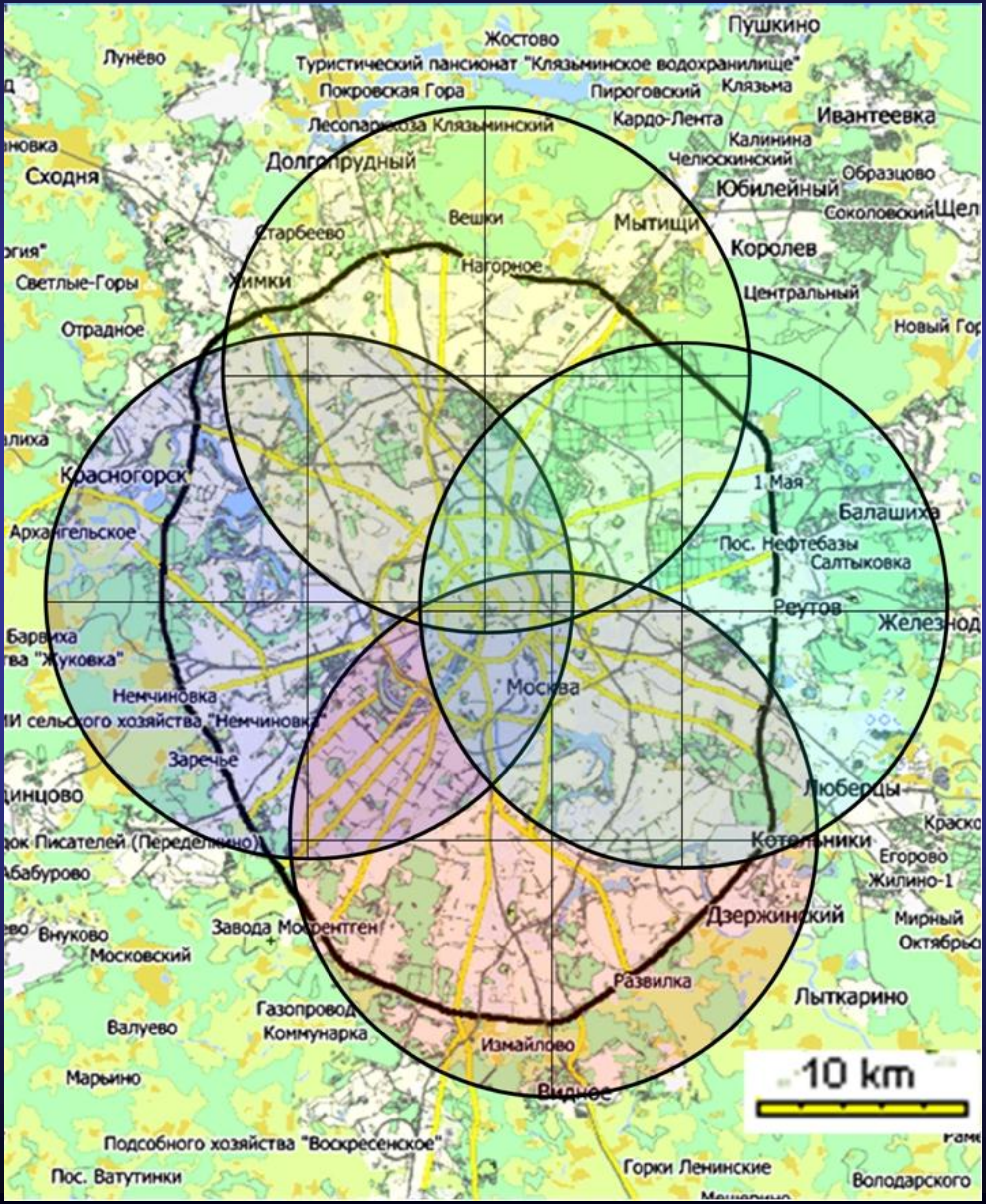
The beginning of wave process was observed about 3 h before thunderstorm.

Possible applications

Potential customers of muon hodoscopes can be:

- big cities;
- airports;
- various potentially dangerous objects.

But not all is so simple.



Drawbacks of muonography

The main drawback of muonography is the dependence of muon flux on conditions as in the Heliosphere so in the Magnetosphere and in the Atmosphere.

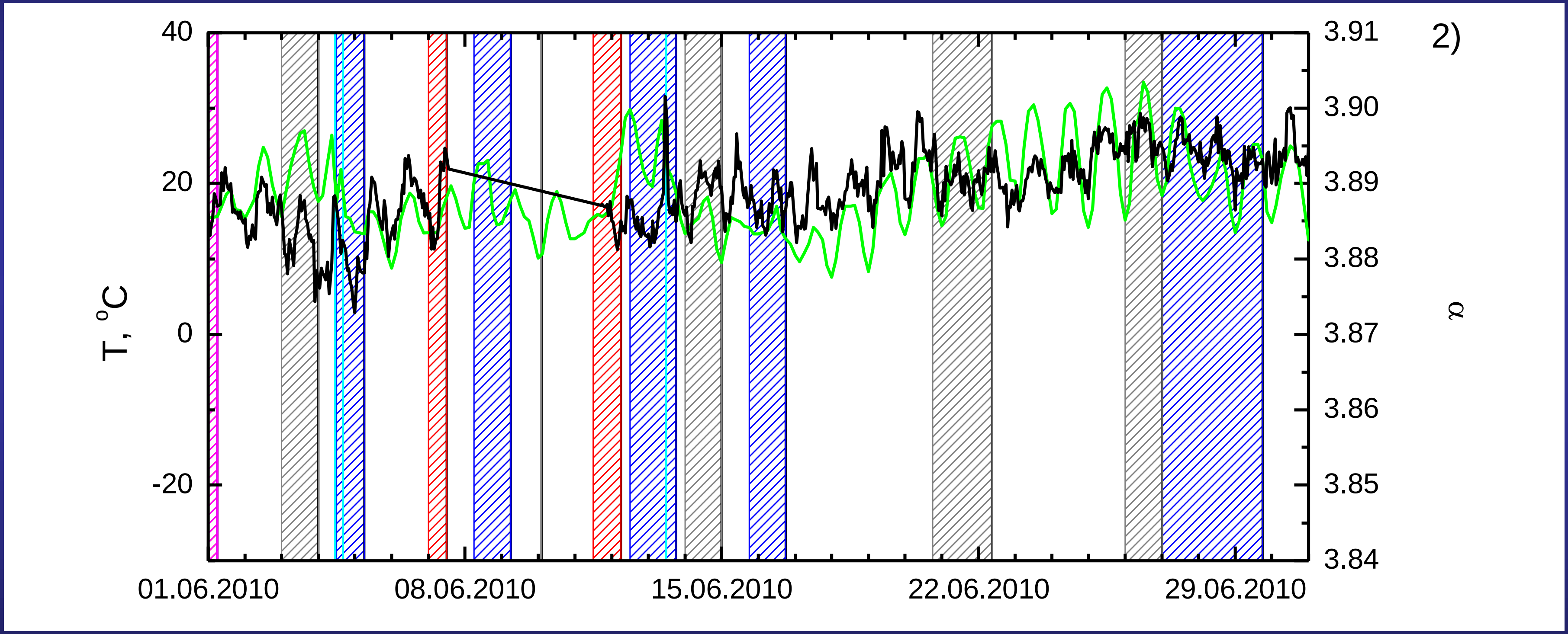
If heliospheric disturbances coincide with atmospheric ones, the problem of their separation occurs.

Possible methods of its solution:

Temporal – durations of atmospheric and heliospheric disturbances are different – hours and days correspondingly.

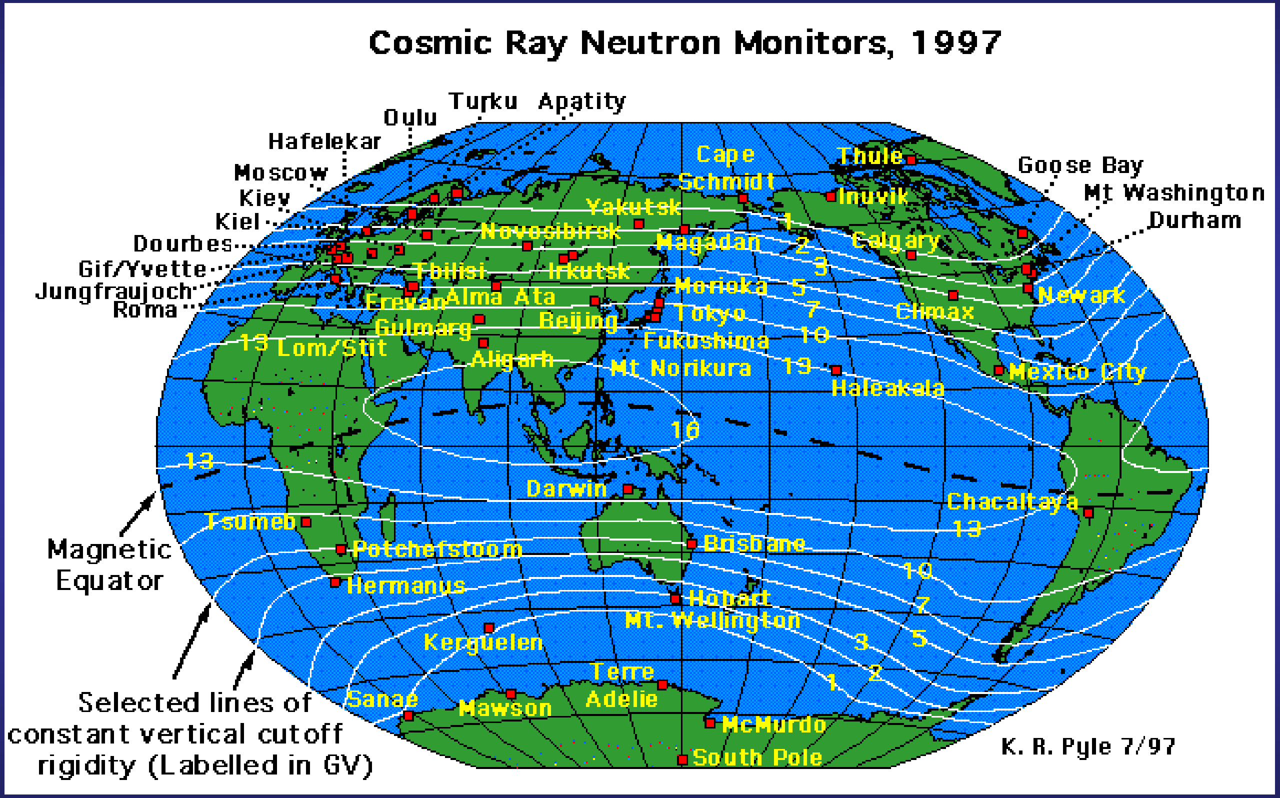
Spatial – scales of atmospheric and heliospheric disturbances are different – tens, hundreds kilometers and the whole Earth's size correspondingly.

Combination of heliospheric and atmospheric processes



Further way of muonography development

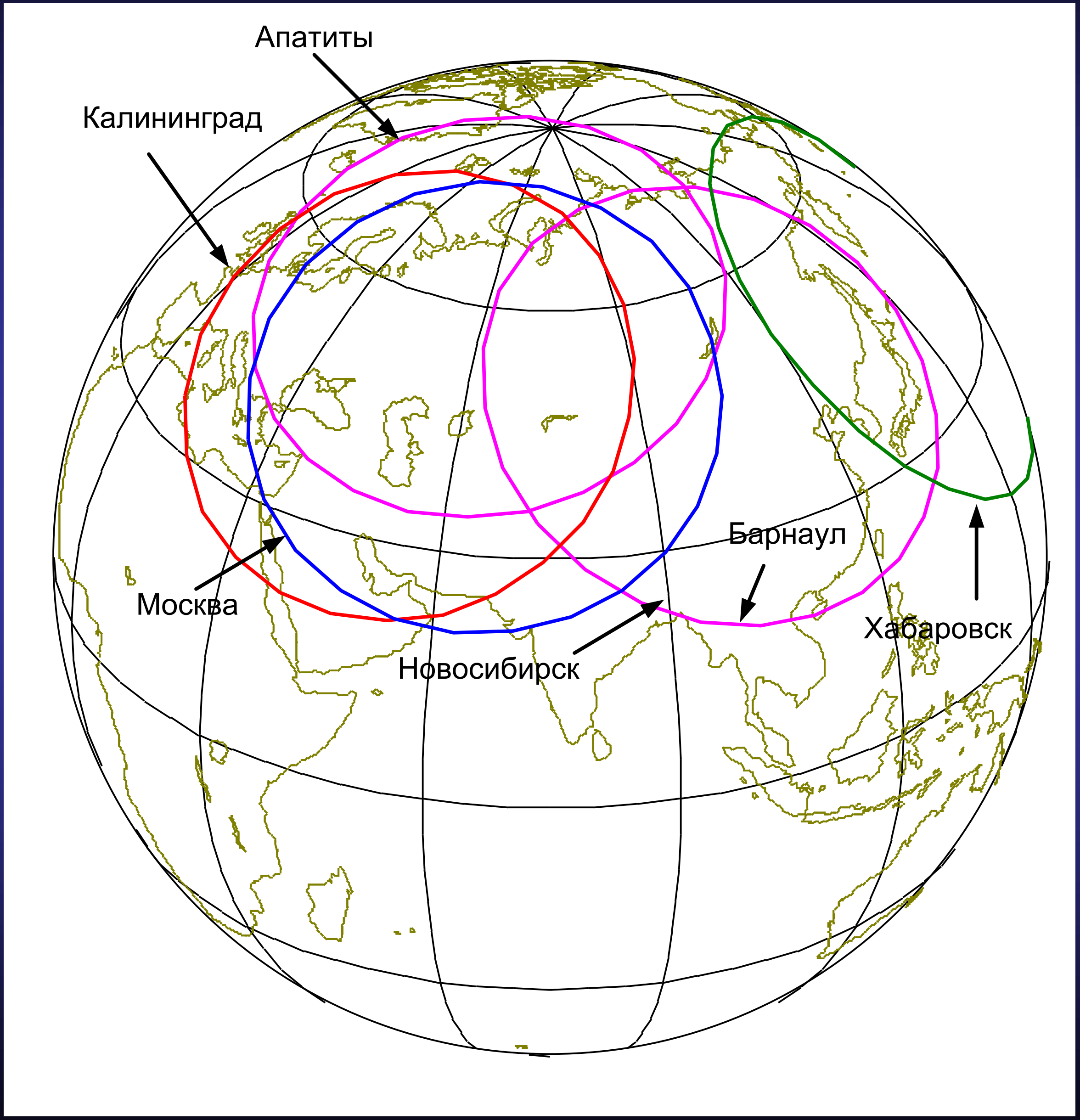
To improve the reliability of this method and its prognostic possibilities, it is necessary to construct the set of muon hodoscopes like the set of neutron monitors.



Taking into account more wide possibilities of muon hodoscopes compared to neutron monitors, total number of required muon hodoscopes will be several times less than total number of neutron monitors.

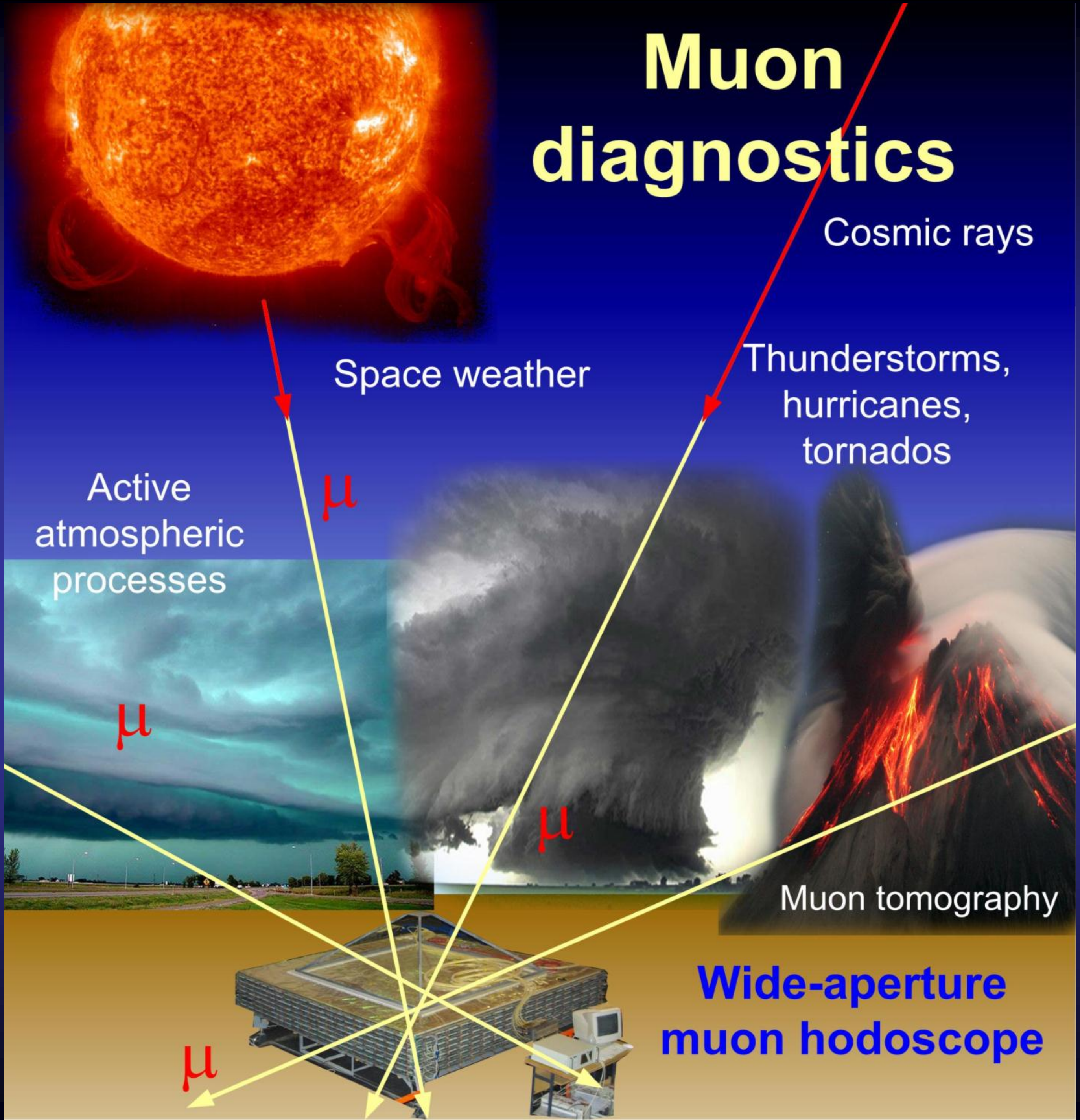
Map of muon hodoscope set

Regions of asymptotic directions



Short conclusion

Muon diagnostics (muonography) of atmospheric disturbances is a promising method of the early observation potentially dangerous phenomena in the atmosphere, but not only this…..


Muon diagnostics
Cosmic rays
Space weather
Thunderstorms, hurricanes, tornados
Active atmospheric processes
μ
μ
μ
μ
Muon tomography
Wide-aperture muon hodoscope

Thank you for the attention!