Multi-band microwave radiometric sensing of remote rain zones

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Abstract. This work relates to the problem of forecasting dangerous weather events - heavy rains and heavy precipitation in the form of snow and hail in a certain area based on the results of passive microwave radiometric measurements. The article presents the results of research on the possibility of implementing a multi-band method for detecting and monitoring rain zones with inclined microwave radiometric sensing at small angles. The analysis of the influence of a remote rain area on the atmosphere radio brightness temperature during horizontal sounding of a multi-frequency microwave radiometric system is performed. Numerical estimates of the radio brightness temperature and its increase due to the presence of the rain zone in the direction of sounding are obtained. The atmosphere with rain thermal radiation power measurements data, made by a tri-band microwave radiometric system, show a trend for different time of the system output growth formation, when the rain area approaches to the place-based microwave radiometric system.

1. Introduction
An important task of the systems of remote sensing of the atmosphere is the formation of reliable forecasts of dangerous weather phenomena, in particular, obtaining a rapid assessment of the possibility of heavy rainfall and heavy rainfall in the form of snow and hail on a certain territory based on the results of passive microwave radiometric measurements [1-7].

Microwave radiometric systems make it possible to quickly monitor the spatial and temporal changes in the state of the atmosphere by changing the level of radio-thermal radiation it generates, so you can get operational information about the presence of precipitation zone in the monitored area of the atmosphere.

The purpose of the work is to form the prerequisites for the development of a multi-band method of detecting and monitoring rain zones at inclined microwave radiometric sounding at small angles of space.

In this article the theoretical issues of numerical estimation of the radio brightness temperature of the remote rain zone at the inclined sounding at the small angles of the antenna place are investigated, the issues of technical realization of such measurements with the use of three-range microwave radiometric system with compensation of background noise are considered, and the experimental data
on measurement of the radiothermal radiation of the atmosphere with the remote rain zones are analysed.

2. Theoretical basis for multi-band microwave radiometric sensing of remote rain zones

The complex multi-parameter dependence of the atmosphere's radio-luminance temperature on the meteorological parameters of the atmosphere, its homogeneity, the presence of precipitation and the frequency range of microwave radiometric measurements leads to the need to use regression models for estimating meteorological parameters under standard conditions in the atmosphere, or more complex statistical methods, such as the Monte Carlo method [1-3, 8, 9].

At formation of radiothermal radiation of atmosphere fixed in a certain point of space, it is possible to speak about an effective layer, basically determining the value of radio-warmth temperature of atmosphere.

The presence of a less than emitting layer in front of a highly emitting one can significantly reduce its impact on the overall radio-luminance temperature of such an inhomogeneous medium. Let us analyse in this context the conditions of microwave radiometric sensing of the rain zone, which is remote from the place of measurement of radio-luminous atmospheric temperature. We will analyse the possibility of remote detection of such a rain zone in three frequency bands with central wavelengths of 1.35 cm, 3.2 cm and 7.5 cm.

The following simplifying assumptions were introduced when simulating radio brightness temperature:
- horizontal homogeneity of the atmosphere in the area without rain and in the rain zone, characterized by a constant frequency dependent absorption coefficient;
- straightforwardness of the radio reception, which characterizes the direction of formation of radiothermal radiation of the atmosphere with the rain zone to the receiving point;
- the angle of the place, which is significantly away from the zenith, is 30º of the sensing direction, which allows neglecting the radiation of the rain cloud and taking into account only the zone of rainfall.

According to the known published data on atmospheric absorption coefficients without precipitation and rain regions were taken at calculations of radio-luminous temperature of atmosphere with the remote rain region values of attenuation coefficients, resulted in table 1.

### Table 1. Rapid atmospheric absorption coefficients.

| Wavelength, cm | No rain | Atmospheric attenuation coefficient, dB·km⁻¹ |
|---------------|---------|-----------------------------------------------|
|               |         | In rain with intensity                        |
|               |         | 1 mm/hr | 10 mm/hr | 100 mm/hr |
| 1.35          | 0.1     | 0.1     | 0.2      | 2         |
| 3.2           | 0.02    | 0.03    | 0.03     | 0.3       |
| 7.5           | 0.001   | 0.005   | 0.005    | 0.05      |

On the basis of the equation of radiation transport for heterogeneous structure and taking into account the mentioned simplifications, the model of radio brightness temperature of heterogeneous atmosphere with remote from microwave radiometric system rain area was adopted as follows:

\[
T_b = \Delta T_r + \Delta T_{nr} = \left(1 - e^{-\alpha_{lr}}\right)T_r e^{-\alpha_{nr}l_{nr}} + \int_0^{l_{nr}} T_{nr} \exp\left(-\int_0^x \alpha_{nr} dy\right) dx,
\]

where \(T_b\) - the radio brightness temperature of the atmosphere with a remote rain area; \(\Delta T_r\) and \(\Delta T_{nr}\) - the components of the radio brightness temperature of the atmosphere caused by the radio brightness radiation of the longitudinal to the rain area and the rain area respectively; \(\alpha_c\) and \(\alpha_{nr}\) - the fade coefficients of attenuation in the rain area and in the rain-free atmosphere area; \(T_r\) and \(T_{nr}\) - the thermodynamic temperatures of the rain area and without rain; \(l_r\) and \(l_{nr}\) - the longitudinal dimensions of the rain area and without rain.
The relative contribution of the remote rain zone to the measured radio brightness temperature in the three ranges was assessed using the formula:

\[
\delta T = \frac{\Delta T_r}{T_0}
\]  

(2)

The results of calculation of the relative contribution of radiothermal radiation of the remote rain region to the radio brightness temperature of the atmosphere are shown in figure 1.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Radiocarbon atmosphere temperature with a remote rainfall area with intensities of 1 mm/hr (a) and 10 mm/hr (b) at wavelengths of 1.35 cm (1), 3.2 cm (2), 7.5 cm (3).}
\end{figure}

The results of the numerical evaluation of the radio brightness temperature of the atmosphere with the remote rainfall region showed that the general trend of the dependence of the change in magnitude from the distance to the rainfall region coincides. As the distance increases, it decreases for all three wavelengths, but according to Figure 2, the contribution to atmosphere-damped radiothermal radiation of the remote rainfall region depends on the wavelength, rain intensity and distance from the point of observation: as the rain intensity increases, the increase in observed radio brightness temperature due to the influence of the remote rainfall region increases and the greater the wavelength.

The results of the analysis of the radio brightness temperature of the atmosphere with the remote rainfall region suggest that there may be a time difference in the observation of the increase in the output signal in different frequency channels of the microwave radiometric system when a rain zone appears in the remote area.

3. Technical issues of experimental research

In order to check the assumption of different time formation of the increase in the radio brightness temperature of the atmosphere with the remote rain zone in different frequency bands, inclined measurements of the radiothermal radiation power of the horizontally heterogeneous atmosphere in different frequency bands were made.

For these studies, a three-channel microwave radiometric system with central wavelengths of 1.35 cm, 3.2 cm, 7.5 cm was used with the reception of radiation on the general aperture of the mirror antenna with the formation of additional signals to compensate the influence of background noise in the central wavelengths of 3.2 cm and 7.5 cm [10, 11].

Measurements were made to direct the antenna of the corresponding angle of 30° at the base of microwave radiometric system in Murom district of Vladimir region. Technical specifications of the system for the three frequency bands are given in table 2.

Estimates of the radio brightness temperature growth of the atmosphere at approximation of the rain region to the basing point of the microwave radiometric system were obtained in the assumption of zero width of the antenna pattern, i.e. for the case of linear horizontal direction in the atmosphere.
The difference between the real conditions of the microwave radiometric sounding of the atmosphere and those mentioned earlier is in the reception of radiothermal radiation of the atmosphere by an antenna with a nonzero width of the antenna pattern, which leads to the influence of changes in the state of the entire space surrounding the antenna on the measurement results. This has determined the need for experimental validation of theoretical calculations on the differences in the radio-waves temperature gain for multi-frequency studies and evaluation of their manifestation in the temperature antenna gains and, accordingly, the output signals.

Table 2. Specifications of the three band microwave radiometric system.

| Parameters                               | Values    |
|------------------------------------------|-----------|
| 1. Wavelength, cm.                       | 7.5       |
| 2. Radiometric sensitivity, °K.          | 0.03      |
| 3. Bandwidth, MHz.                       | 800       |
| 4. Receiver noise temperature, °K.       | 13        |
| 5. Receiver gain, dB.                    | 60        |
| 6. Antenna pattern width, at (D = 1000 mm, F = 320 mm) - mobile version, °. | 5.07      |
| 7. Antenna gain, dB.                     | 31        |
| 8. Antenna pattern width, at (D = 2400 mm, F = 900 mm) - stationary version, °. | 2.13      |
| 9. Antenna gain, dB.                     | 39        |

4. Results of multi-band microwave radiometric measurements of remote rain zones

To solve the problem of preliminary estimation of the system reaction time differences on the remote rain area in different frequency bands, measurements of the atmospheric radiothermal radiation power were made for inclined sounding at a small angle of 30°.

The significant difference between the expected results of sounding and those obtained by numerical calculations of the radio-luminous temperature of the atmosphere with a remote rainfall area may be due to the non-zero width of the antenna pattern.

The results of long-term (daily) measurements of the radiothermal radiation power of the atmosphere in the presence of remote rain zones by a three-range microwave radiometric system are shown in figures 2-4.

![Figure 2](image-url) The dependence of the output signal of the three band microwave radiometric system at an angle of 30° from 18.04.2020.
Figure 3. The dependence of the output signal of the three band microwave radiometric system at an angle of 30º from 16.04.2020.

Figure 4. The dependence of the output signal of the three band microwave radiometric system at an angle of 30º from 16.04.2020.

In figures 2-4, vertical lines specify moments of time for maximum increase in output signals in three frequency bands. All figures 2-4 show the trend of earlier time observation of output signal growth at 7.5 cm wavelength than at 3.2 cm and 1.35 cm wavelengths. Figure 4 shows the different time observations of maximum gain at all three wavelengths of 7.5 cm, 3.2 cm and 1.35 cm.

Conclusion
Theoretical analysis of the remote rain zone influence on the atmosphere radio brightness temperature in three frequency bands allowed to draw a conclusion about nonlinear dependence of changes in the increase of radio brightness temperature, which depends both on the distance to the rain zone and on the frequency at which the radio-warmth radiation of the atmosphere is measured. The full-scale measurements of the atmosphere radio-thermal radiation under the conditions of the rain zones presence showed the relative shift of time variations of the output signals.
Thus, the presence of a complex time dependence of the radio brightness temperature for atmosphere with a remote rain area, observed from its intensity and distance to the rain area in three frequency bands, allows us to conclude that it is possible to form operational forecasts of the approaching rain area with its rapid tracking on the data of multi-frequency microwave radiometric measurements.

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