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The results of atmospheric parameters measurements in the millimeter wavelength range on the radio astronomy observatory "Suffa Plateau"

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ABSTRACT
The results of measurements of atmospheric absorption and the amount of precipitated water on the Suffa Plateau for the period from January, 2015 to November, 2020, are presented. The measurements of atmospheric parameters in the 2 and 3 mm range of the radio waves spectrum were carried out using the MIAP-2 radiometer. The results of more than six years of measurements have show that on the Suffa Plateau, atmospheric parameters in the above range remain fairly stable. The median value of the atmospheric absorption and the amount of precipitated water over the entire observation period were 0.14 and 0.12 Nep and 5.91 and 9.83 mm, respectively, for the ranges of 2 and 3 mm.

Section: RESEARCH PAPER

Keywords: astroclimate; turbulence; transparency windows; atmospheric absorption; precipitated water; radio range; millimeter wave; Neper

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1. INTRODUCTION

Recently, thanks to the rapid development of microwave technology, the creation of adaptive large-aperture radio telescopes and the possibility of combining them into a system of ground-based and ground-space interferometers with very long bases, has gained considerable interest In fact, this represents a real possibility to fully realize the advantage of the millimetre range in solving fundamental problems of cosmology, as well as in solving a number of applied problems at a completely new level.

At the same time, such a rapid technological breakthrough in the development of microwave technology inevitably required the solution of new problems in a detailed study of the parameters of the medium for the propagation of mm-wave radio waves.

Significant factors, in addition to insignificant attenuation in space plasma due to scattering and absorption, affecting the propagation of mm waves from the source of radiation to terrestrial observation are distortions introduced by the terrestrial atmosphere.

In addition, the Earth's atmosphere absorbs electromagnetic radiation of most wavelengths. However, there are frequency bands (radio windows) in which the atmosphere is substantially transparent. Such a radio window in the mm region of the spectrum is a region from 1 to 15 mm, in which several absorption lines of oxygen and water vapor are located.

A large number of papers and monographs have been devoted to theoretical studies of molecular absorption of mm waves. In these papers, it is emphasized that, in theoretical absorption calculations, special attention should be paid to the feasibility of the physical approximations used and to the adequacy of the description of the corresponding processes. From this point of view, interesting results were obtained in [1], where it was possible to achieve agreement between the theory of molecular absorption in water vapor in transparency windows and experimental data by taking into account the duration of molecular collisions in the framework of the memory function method.

Figure 1. Location of the Suffa Plateau (λ = 65°26, ϕ = 39°37, h = 2500).

Noteworthy are the calculations of absorption in water vapor and in molecular oxygen [2], [3] using natural (from a balloon) and laboratory measurements [4], taking into account the influence of the Earth's magnetic field on the characteristics of the propagation of millimeter waves in the region λ = 5 mm. However, in theoretical calculations, there is still a problem of correct comparison of the theory of molecular absorption of millimeter waves with experimental and laboratory data, as well as with insufficiently studied statistical characteristics of fluctuations of atmospheric meteorological parameters.

Recently, interest has been growing in the construction of radio models of the atmosphere, with the help of which it would be possible to determine quickly (and with fair reliability) the characteristics of the propagation of millimeter waves along paths of various orientations and lengths.

In the radio model constructed in [5], the input parameters are meteorological elements (pressure, temperature, humidity), the concentration of water particles suspended in the air, and the intensity of rain. The model makes it possible to calculate the influence of the attenuating and refractive characteristics of the medium on the propagation of radio waves in various atmospheric conditions. However, the authors note the need to refine and supplement the model and, first of all, the need for a much more thorough meteorological support.

Recently, scientists have paid much attention to the study of the influence of atmospheric parameters on the characteristics of microwave radio waves both in areas that are promising for the installation of large radiometric systems, and at operating complexes. One of such radiometric complexes being created on the Plato de Chajnantor in the Central Andes (Chile) is ALMA (Atacama Large Millimeter Array) [6], [7]. Another potential site for installing mm-submm telescopes is Antarctica (South Pole), where the Dome-C Antarctic observatory is being created on a plateau at the altitude of 2835 m [8]-[10]. Detailed studies of transparency and stability of atmosphere in this range were also carried out at Mauna Kea (Hawaiian Islands, USA) [11], where submillimeter telescopes (in particular, the SMA complex - submillimeter array) are installed. Radio transparency studies for mm-submm astronomy were also carried out at the Indian Astronomical Observatory Hanle in the Himalayas in 2000-2003. [12], Pampa la Bola (8 km NE from Chajnantor) [13], Rio Frio [14].

Water in different phases and mixtures is a key element of the climate system. Long-term chemical and isotopic changes of oceanic and atmospheric water mixtures must be monitored regularly and precisely [15].

The study of the atmospheric absorption at the Radio Astronomy Observatory "Suffa Plateau" (Uzbekistan) has been carried out from 2015 to 2020 in atmospheric transparency windows of 2 and 3 mm using the MIAP-2 measuring complex. A detailed description of the radiometer, its functional diagram, basic principles of measurements and calculations, estimates of permissible errors are given in [16].

2. CHARACTERISTICS OF THE MEASURING COMPLEX

The MIAP-2 measuring complex is a radiometric system that includes two radiometers for frequencies of 84-99 GHz (λ_{av} = 3 mm) and 132-148 GHz (λ_{av} = 2 mm), a turntable and a control, acquisition and processing system based on a personal computer.

The receiver in the range (84-99) GHz is made according to the direct amplification scheme with detection at the fundamental frequency. The modulator at the input of the receiver is made on the basis of chains of series-parallel connected diodes with a Schottky barrier (SBB) installed in the waveguide of the main section. The modulator control and synchronous data acquisition are carried out using a PC via the USB-4716 module. The modulation frequency is about 36 Hz. The noise temperature of the receiver is 1300 K.

The solid-state receiver of the radiometer in the range (132-148) GHz is made according to the super heterodyne circuit and includes a local oscillator based on the Gunn diode, a balanced mixer on the DBSH and an IF in the range (4-8) GHz. The modulator is similar to the one described above, it is also controlled and data is collected via the USB-4716 module. The modulation frequency is also about 36 Hz. The noise temperature of the receiver is 6300 K.

The turntable consists of a support frame for mounting the radiometer module, a swivel mirror, and a mirror drive system based on a stepper motor. The weather protection housing is made of stainless steel and has a radio-transparent PTFE window. The limits of change of the angle of observation are 0º-90º. The drive is controlled according to a given program via the USB-4716 module.

The control, data collection and processing system ensure fully automatic operation of the complex in the mode of cyclic observations at a given time.

Both radiometers are equipped with lens antennas with a conical feed. The lenses are made of Teflon and are limited on one side by a hyperbolic surface and flat on the other. Each of the boundary surfaces has an enlightenment, which is made in the form of periodic circular concentric grooves ("corrugations"), providing a reflection coefficient in the entire operating range of each of the radiometers no more than 0.5 %. The irradiators are in the form of circular cones with a break. The antenna beam width at half power level in both bands is about 2.5º.

Atmospheric absorption measurements of radio waves in the millimetres range carried out by the method of vertical cuts were described in [17]. The method is based on measuring the intrinsic thermal radiation of the atmosphere, while comparing the brightness temperature increments of two parts of the atmosphere at different zenith angles relative to the known temperature of a certain reference region.

In spite of all its advantages, this method is limited by the choice of one or another model of the structure of the atmosphere. In

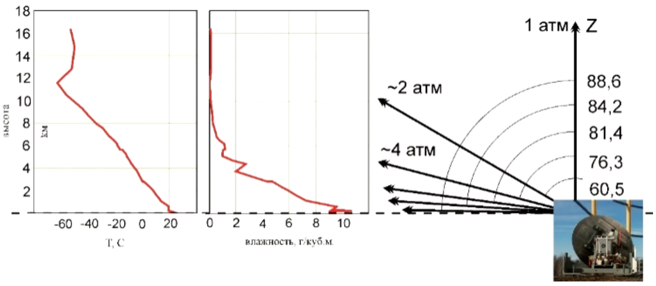

Figure 2. The principle of measurement by the method of vertical cuts. The left side shows a typical temperature distribution in the troposphere with respect to height (the so-called temperature profile). In the middle - a typical distribution of humidity in height. These profiles are subject to significant seasonal and daily changes, in fact, from them it is possible to calculate the amount of precipitated water and extrapolate it to absorption. On the right are the zenith angles (that is, the number of atmospheres) by which the radiometer approximates the brightness temperature profile [16].

particular, it is assumed that the Earth's atmosphere is isothermal in horizontal coordinates, which can lead to errors associated with drifting temperature in homogeneities of the surface layers of the atmosphere.

The measurement principle is illustrated in Figure 2. The left side shows a typical temperature distribution in the troposphere with respect to height (the so-called temperature profile). In the middle - a typical distribution of humidity in height. These profiles are subject to significant seasonal and daily changes, in fact, from them it is possible to calculate the amount of deposited water and extrapolate it to absorption. On the right are the zenith angles (that is, the number of atmospheres) by which the radiometer approximates the brightness temperature profile.

Before starting, the device is set to a strictly horizontal position according to the hydraulic level. The measurement cycle begins with the rotation of the mirror along the photo sensor exactly in the "zenith" direction. Next, the mirror is moved using a stepper motor (the “step” value is 0.72 degrees) to a certain angle, the brightness temperature of the “spot” of the sky in the direction of observation is measured, the mirror moves to the next angle, the next measurement is made, etc. The signal averaging time can be changed from 1 s (with a “calm” atmosphere) to tens of seconds.

The signal through the amplitude-to-digital converter (ADC) enters the computer. Next, a system of two (measurement at two angles) and five (measurement at five angles) equations is solved. The calculated value of atmospheric absorption is displayed on the graph. The cycle lasts about a minute, then the mirror is brought to its original position, the calculated transparency value is entered into the database and marked on the graph, after which the device is ready for the next measurement cycle. The time interval between cycles also varies widely, depending on the task set by the observer.

With the help of the control program of the complex, it is possible to select any observation angles in the range from 0° (zenith) to 90° (horizon). However, this choice should take into account both the sensitivity of the device (it is necessary that the "neighbouring" corners have a difference in brightness temperatures distinguishable by the device), and some features of its design. The point is that the error introduced into the measurements and associated with the finite width of the radiation pattern and a fairly wide bandwidth has a complex dependence on the observation angle. An appropriate selection of angles can minimize this error. When processing the results from two angles, these angles are 60.5° and 76.3° (corresponding to approximately two and four atmospheric thicknesses overcome by the signal). When processing five corners, the most rational choice is: 60.5°, 76.3°, 81.4°, 84.2°, 88.6°. The last corner is as close as possible to the horizon.

Close absorption values obtained by processing the results of measurements at 2 and 5 angles indicate both the normal operation of the device and the absence of interference in the form of clouds or ground objects (at the “lowest” angle) in the direction of observation, as well as “calm state of the atmosphere.

After processing each cycle of measurements, we directly obtain the value of atmospheric absorption at the zenith, expressed in Neper (1 Nep = 8.686 dB), i.e. the so-called optical thickness of the atmosphere. This value is subject to significant seasonal and daily changes, which is primarily due to changes in the total content of water vapor in the atmosphere.

At the end of the observation session, we obtain a chronology of absorption changes in two bands during the observation time. Any observation period can be chosen. The possibility of round-the-clock monitoring of radio transparency is provided.

The total absorption of radio waves of the specified range includes absorption by oxygen molecules, water vapor contained in the atmosphere, and absorption in clouds. In clear time, the third component naturally vanishes. Oxygen absorption varies little for a particular observation site over time due to its relatively constant content in the atmosphere. It is almost constant and depends only on the height of the observation site. Thus, the change in radio transparency is mainly due to a change in the amount of water vapor in the atmosphere, or, in other words, a change in the amount of precipitated water.

3. OBSERVATIONAL STATISTICS

The significant array of measurements of atmospheric absorption in the mm spectral range has been accumulated on the Suffa plateau for the period from January 2015 to November 2020.

As an example, the full time series of atmospheric absorption obtained on the Suffa plateau for the above period are shown in the 2 mm radio wave band is shown in Figure 3. Some gaps of data in observations is due to technical reasons. As can be seen from the figure, the value of atmospheric absorption over the entire observation period remains stable. A similar trend is also observed in the values of atmospheric absorption and the amount of atmospheric deposited water in the 2 and 3 mm ranges. It should be noted that equipment malfunctions appeared

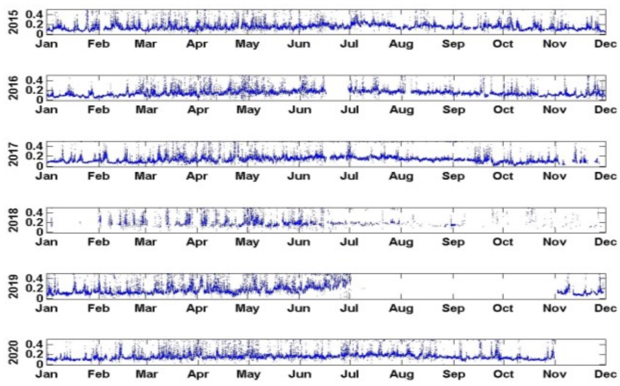

Figure 3. The atmospheric absorption time series obtained from January 2015 to November 2020 on the Suffa plateau during the entire period in the 2 mm range

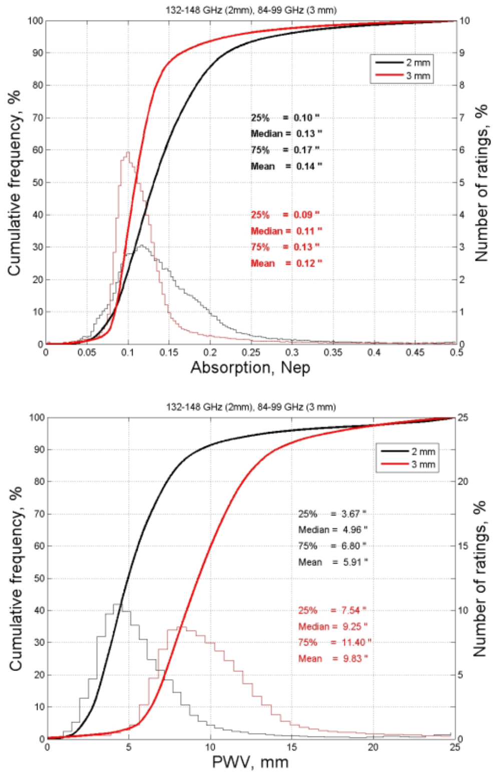

Figure 4. Statistical distribution of atmospheric absorption (on top) and amount of deposited water (below) on the Suffa plateau, calculated for the radio wave bands of 2 and 3 mm, from January 2015 to November 2020. The y-axis of the histogram is on the right, the cumulative distribution is on the left.

in 2018, and the data obtained were very different from the previous values of atmospheric parameters. Therefore, when calculating atmospheric parameters, the data of 2018 were discarded.

The statistical distribution of atmospheric absorption and the amount of precipitated water is shown in Figure 4. The median value of atmospheric absorption over the entire observation period was 0.13 and 0.11 Nep for the 2 mm and 3 mm radio range, respectively. The median value of the atmospheric amount of precipitable water for the entire period of observations in the 2 mm radio band was 4.96 mm, and for the 3 mm band, 9.25 mm.

Table 1. Monthly average values of atmospheric absorption and integral amount of deposited water from January 2015 to December 2020.

Months	Absorption 3 mm	Absorption 2 mm	PWV 3 mm	PWV 2 mm
January	0,11	0,11	8,81	4,84
February	0,12	0,14	10,44	5,05
March	0,12	0,15	11,42	5,89
April	0,13	0,16	12,22	6,22
May	0,14	0,18	12,82	7,21
June	0,14	0,19	13,26	7,27
July	0,14	0,17	13,38	7,40
August	0,14	0,16	13,25	7,28
September	0,14	0,14	12,57	7,09
October	0,13	0,14	12,05	6,62
November	0,12	0,12	11,11	5,56
December	0,12	0,11	9,25	4,69
Mean	**0,12**	**0,14**	**11,30**	**5,91**

The sesonal trends are shown in Table 1, which reports the average monthly values of atmospheric absorption (Abs) and the amount of precipitable water vapor (PWV) computed after merging different years. As can be seen from the data, in the 2015-2020 period, the average monthly values of atmospheric absorption and the amount of deposited water on the Suffa plateau remain fairly stable. The main range of changes in atmospheric absorption and the amount of deposited water lies within 0.11-0.19 Nep and 4.84-7.40 mm for the 2 mm range of the radio wave spectrum, and for the 3 mm range – 0.11-0.14 Nep and 8.81 -13.38 mm, respectively.

For a visual representation of the statistics of atmospheric parameters and its trend of change, the seasons were chosen according to the principle of weather conditions: November, December, January and February belong to the winter season; the transitional season includes March, April, September and October, the summer season - May, June, July and August. In the winter season, the average value of atmospheric absorption is less than 0.10 Nep, in the transitional season it is less than 0.12 Nep, and in the summer season it is more than 0.12 to 0.15 Nep, for the 3 mm range. For the 2 mm range in the winter season, the average value of atmospheric absorption is less than 0.12 Nep, in the transitional season it is less than 0.14 Nep, and in the summer season it is more than 0.14 to 0.15 Nep.

The temporal dynamics of precipitated water in January and July are characteristic of extreme climate conditions. The average value of deposited water in January is about 4.84 mm for the 2 mm range, 10.0 mm for the 3 mm range, and in July 7.40 and 13.38 mm for the 2 and 3 mm ranges, respectively.

The diurnal variations of the deposited water in the summer period are more significant than in winter. On some nights in December and January, the amount of precipitated water drops to a minimum of about 2 mm, in summer it rises to 12 mm.

4. CONCLUSIONS

Based on this study, it can be concluded that over a six-year period of time, the atmospheric parameters on the Suffa plateau remain fairly stable. The values of atmospheric absorption and deposited water presented here correspond to the values of the entire thickness of the atmosphere at the zenith. Measurements of atmospheric parameters on the Suffa Plateau showed that the value of atmospheric absorption at the zenith at a wavelength of 3 mm, sometimes for several is was within 0.06–0.08 Nep, and at a wavelength of 2 mm - within 0.08-0.10 Nep. At shorter time intervals, for several hours, the absorption of the 3 mm wave sometimes drops to 0.06–0.08 Nep, and at a wavelength of 2 mm to 0.05–0.06 Nep. Such cases occur in the winter. The amount of precipitated water for several days is in the range of 1.6-2.0 mm.

They can be reduced to parameters at any angle, as well as extrapolated to any height, taking into account the standard atmosphere model.

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