



# Observations of astroclimate with the broad band radiometer using the atmospheric dip method



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Introduction

Method and equipment

Postprocessing algorithm

Algorithm efficiency test

Astroclimate investigation review

Conclusion

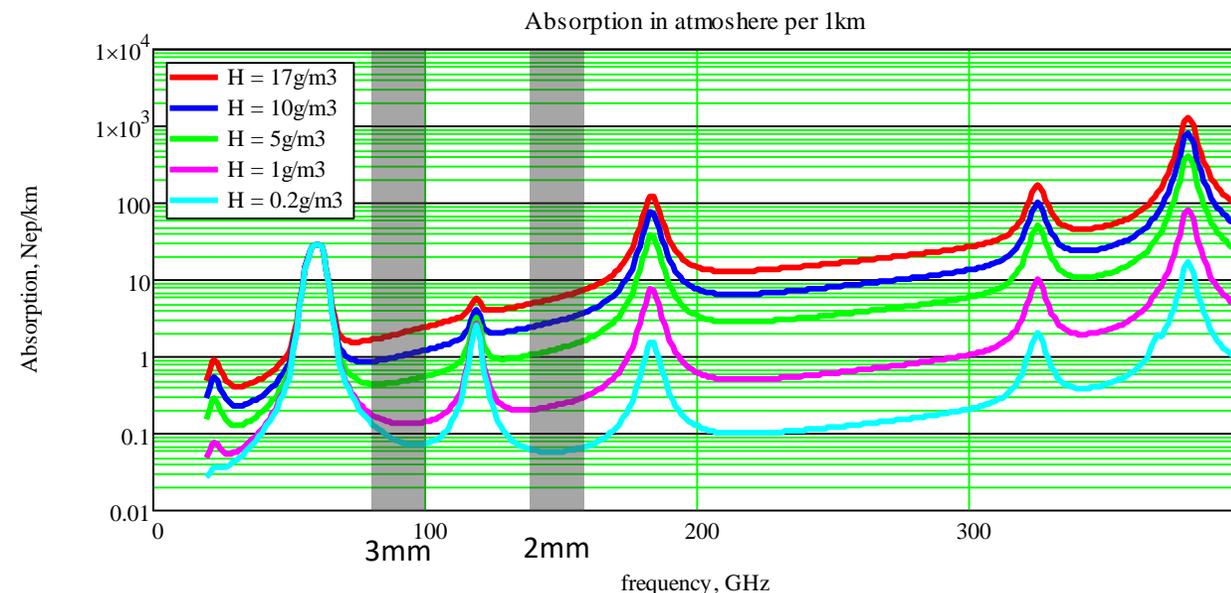
Studying astroclimate of a location is essential, when one chooses the most appropriate site for radio astronomical observations or space telecommunications. The suitability of a site is determined by a number of days per year, during which astronomical observations and space communication sessions are possible. In the millimeter range, astroclimatic conditions largely depend on the absorption of such waves by the atmospheric water vapor and oxygen. This absorption depends on the elevation of the site, local and global climatic peculiarities, and weather; as the result, it may vary greatly from season to season and from day to day.

The local climate is often responsible for how dry and wet air masses interchange over time, and, consequently, how the atmospheric absorption varies. The statistical data on the atmospheric absorption are the chief astroclimatic parameter for the purposes of radio astronomy and space communications in the millimeter wavelength.

## Pictures:

<sup>top</sup> Specific absorption spectra in atmosphere gases.

<sup>bottom</sup> ALMA observatory (5km above sea level) – possibly the best astroclimate in the world.



## Method and equipment

The radiometric system “MIAP-2” was developed in 2012 by IAP RAS (N.Novgorod) [1]. We permanently upgrade the instrumentation [2] and improve the methods [3] for investigations of atmospheric propagation in terahertz waves.

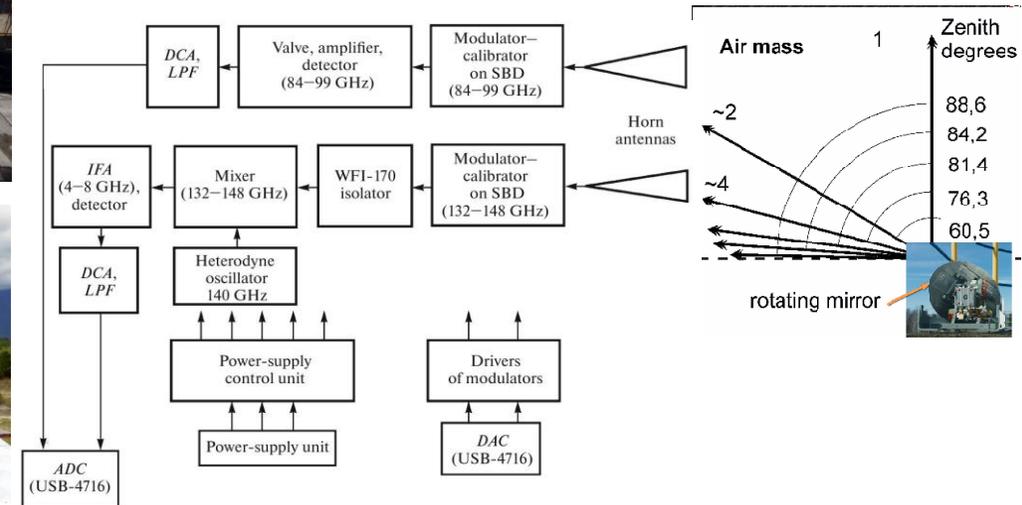
The dual-band radiometer allows us to estimate an integral absorption by using the “atmospheric dip” method. The hardware includes a radiometric system comprising of two self-contained radiometers operating in two different bands of 2mm and 3mm with a waveband of 15 GHz each. A quasi-optic system includes two horn-lens antennas and rotating mirror, which allows us to change elevation. The control and the firmware system includes ADC and Toughbook. It is also equipped with an automatic meteostation.

**Picture:** MIAP-2 radiometric system without protective shield.



## Atmospheric dip method

### “MIAP-2” radiometric system



$$T_B(\lambda, \theta) = T_{aver}(1 - e^{-\tau(\lambda) \sec \theta})$$

### References

- [1] V. I. Nosov et al., “A dual-wave atmosphere transparency radiometer of the millimeter wave range”, Instruments and Experimental Techniques, Vol. 59, Issue 3, pp 374-380, May 2016.
- [2] G. Bubnov, V. F. Vdovin, P. M. Zemlyanukha, V. S. Okunev, and V. F. Grigor’Yev, “Svalbard astroclimate research: Expedition and first results,” EPJ Web Conf., vol. 195, 2018;
- [3] Grigoriy M. Bubnov et al., “A refined method of the data processing for astroclimate measurements in mm-waves”, Proc. of 29th ISSTT, Pasadena, California, USA, March 26-28, 2018.



Grigoriy Bubnov, Vyacheslav Vdovin, Peter Zemlyanukha, and Igor Zinchenko

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Method and equipment

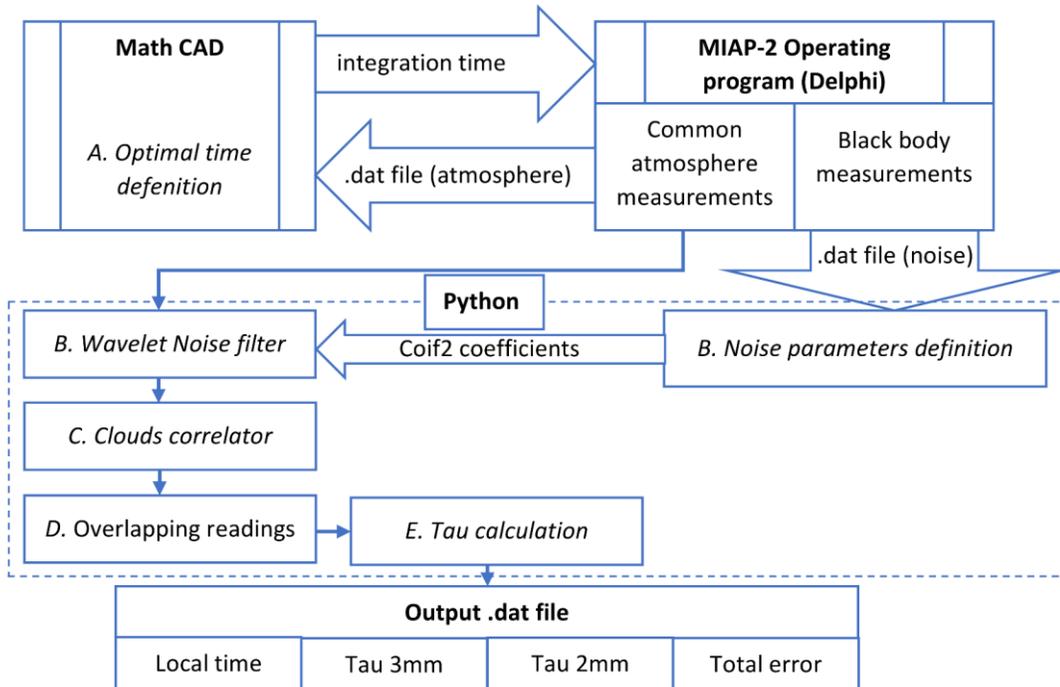
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### Post-processing algorithm

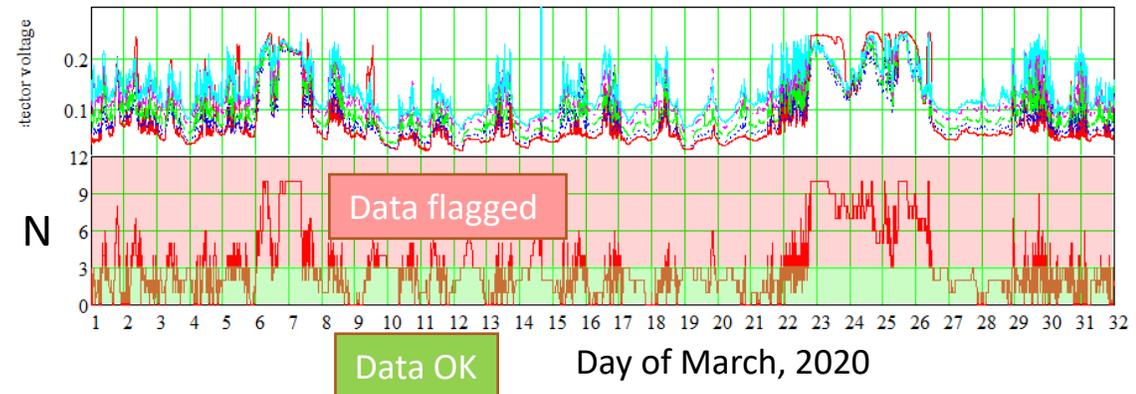


The algorithm includes a calibration process, internal noise parameters definition as well as atmosphere data post-processing. It allows to separate the data obtained in clouds. This this data is difficult to process, due to inconsistency with the real atmosphere to the flat-layered model applied in the method.

### Record flagging

The algorithm allows flagging of corrupted data whereas observation conditions are significantly different from flat-layer model. The algorithm includes wavelet-smoothing based on typical time-periods in data, flagging the data corresponding to broken or stratus clouds and exclusion of the angles with an opaque atmosphere. Based on physical parameters of the atmosphere and the hardware, the algorithm helps to save the data which otherwise are not suitable for processing.

**Pictures:** <sup>top</sup> The record of detector voltage on different elevation angles.   
<sub>bottom</sub> Number of excluded angles. N>3 testifies cloudy weather. 44% was rejected because of clouds, this time is unsuitable for radio astronomical observations.



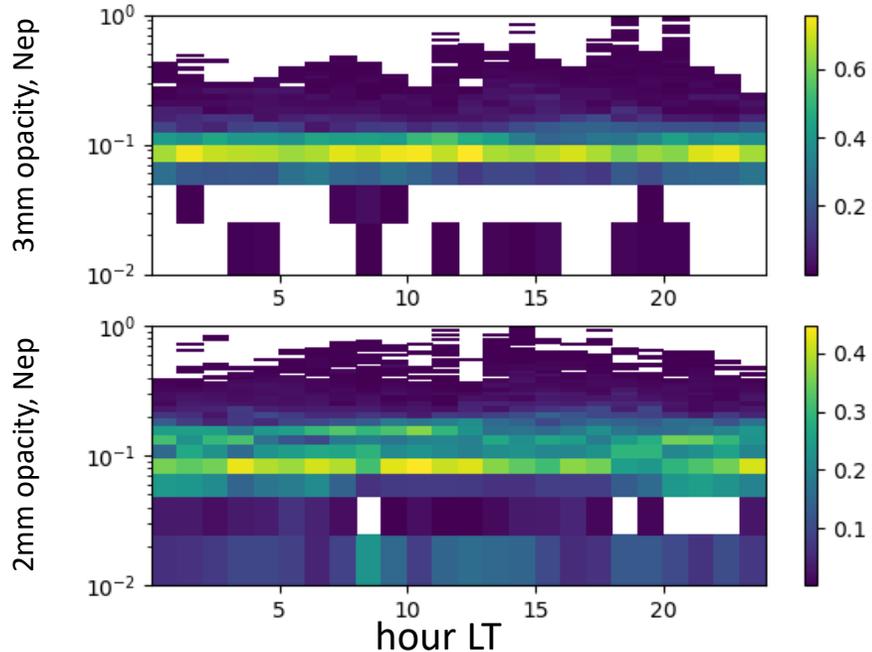
We have developed the algorithm in 2018, tested it on real investigations in 2019-2020 and now we have to check the effectivity.

We offer a variety of statistical information about astroclimate conditions.

**Pictures:**

Monthly-averaged day statistics of opacity on Caucasian Mount observatory near Kislovodsk city in January - March 2016. (given as an example)

top 3mm opacity, Nep; bottom 2mm opacity, Nep

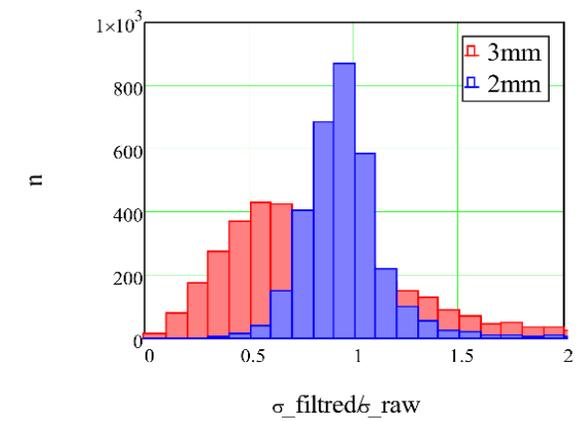
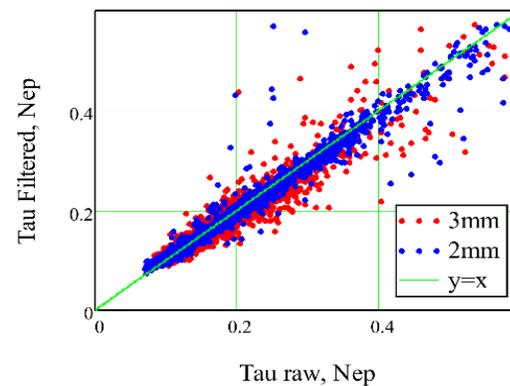


We analyzed the efficiency of the three-step algorithm based on the representative selection of the data obtained in Svalbard under different weather conditions in February 2018. We postprocessed the data with two methods, the old one, where the exponent was drawn over the points without filtering out the noise, and the new one, where we eliminated the noise first.

**Pictures:**

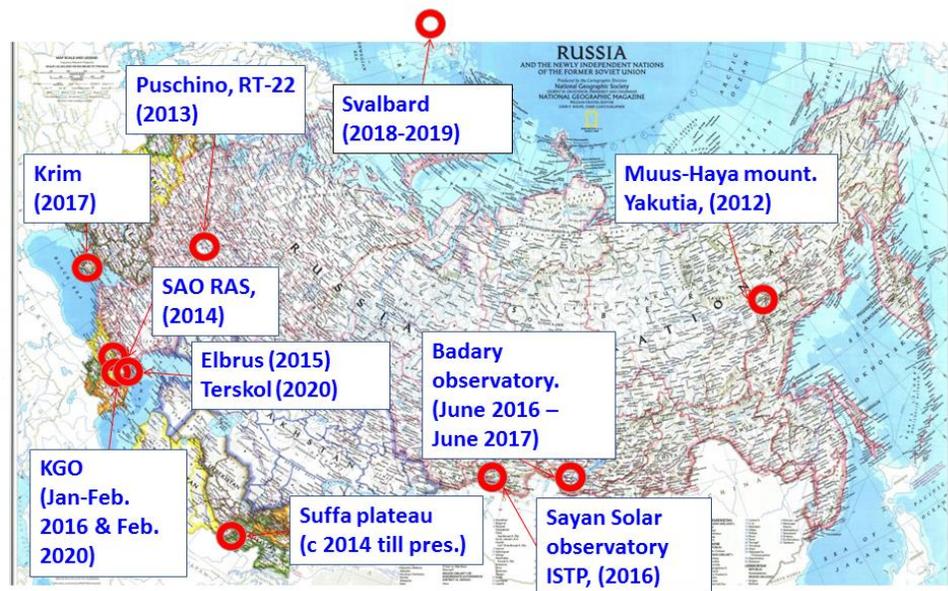
Regression between New and Old algorithm testifies to the absence of a systemic uncertainties.

A histogram of the ratio of the filtered data exponent fitting uncertainties to the raw data exponent fitting uncertainties  $\sigma_{\text{filtered}}/\sigma_{\text{raw}}$ .

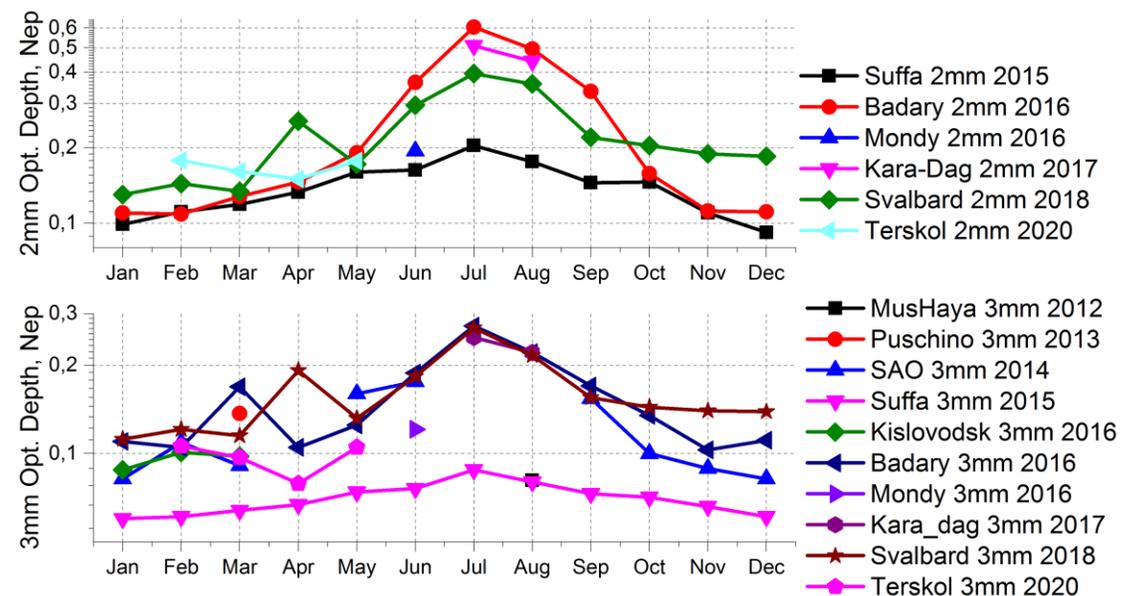


## Geography of astroclimate research 2012-2020

Since 2012 we have gone on 11 expeditions and explored atmospheric absorption at over 20 sites. Our goal is to find the most appropriate place for a radio telescope operating in the millimeter and submillimeter wavelength in Eastern hemisphere.



A month-averaged median values of opacity in 2mm and 3mm – wavelength atmospheric windows at all sites we have explored since 2012. Depending on the infrastructure and conditions at the site, we carried out short-term (hours, days) or long-term (a few months, year) studies of the astroclimate.



### References

[4] “Astroclimate investigations review for coming radio astronomy projects” Proc. of 30th IEEE International Symposium on Space Terahertz Technology, Gothenburg, Sweden, Apr 15-17, 2019 p.96.



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1. The radiometric system “MIAP-2” operating by atmospheric dip method in combination with post-processing algorithms have proven themselves from the best side.
2. Our postprocessing algorithm evaluates the optical depth with an uncertainties smaller than that involving no data filtering, especially under rough conditions. For the case of the clear sky, both filtered and raw data look similar.
3. A wide geography of investigations allows us a unique opportunity to compare different places measured using the same equipment.

We have listed some peculiarities of the equipment, methods, and setup of the millimeter-wavelength astroclimate research for space telecommunication and radio astronomy. The atmospheric dip method has proved itself to be reliable over the eight years of the use of our radiometric apparatus. An overview of the efficiency of the suggested postprocessing algorithm is presented; as an example, some results of astroclimate research are analyzed.

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