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Millimeter-wave astroclimate investigations on Badary observatory near Baikal lake

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Abstract

This paper deals with results of long-term astroclimate investigations in millimeter-wave band in the Badary observatory near Baikal lake. The optical depths for the 3-millimeter and 2-millimeter-band windows have been determined with the atmospheric dip method. The results of measurements taken at Sayan Solar Observatory of ISTP RAS and on Badary observatory are presented. The collected statistical data yield the mean percentage of good-condition time for mm-wave radioastronomy per year. In addition, the seasonal variations of the precipitable water vapour (PWV) have been approximately calculated. Using available data on the measurements of the absorption, the PWV, height, etc., suitability of the site can be evaluated for potential stationing of a millimeter or a submillimeter wave range observatory. The other goal of the work is to calibrate the mm-wave radiometer operating in 2mm & 3mm atmospheric windows by comparing the data with Water Vapour Radiometer operating in cm-waveband.

1. Introduction

It is well known the problem about an absorption of radio-waves in atmospheric gases on the frequencies above approx. 40 GHz. In total the set of atmospheric and weather conditions affecting the quality of astronomical observations is called astroclimate. In cloudless weather conditions the total atmospheric absorption in Zenit, so called optical depth (Nep), depends on oxygen content and total amount of water vapor in column (PWV).

Astroclimate measurements near Baikal lake were started in June 2016 and are planned to be completed till June 2017. It is the part of whole cycle of astroclimate investigations begining from 2012 year in different locations. [1][2] The ultimate goal of this research is to find a suitable location for the radio astronomic observatory designed for the ground support of the future submillimeter wave VLBI space mission ("Millimetron"), as well as for the terahertz satellite telecommunication and CMB observations. [3][4]

2. Equipment

We used a dual-band radiometric "tau-meter", developed in IAP RAS (so called MIAP-2) as the most appropriate instrument for the needed astroclimate measurements in the THz band. This equipment is fully described in our publications. [5] The 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 84-99 GHz (λ ~ 3 mm) and 132-148 GHz (λ ~ 2 mm), a rotary support, and a control as well as a firmware system. The control and the firmware system are a PC and a USB-4716 interface (see Figure 1).

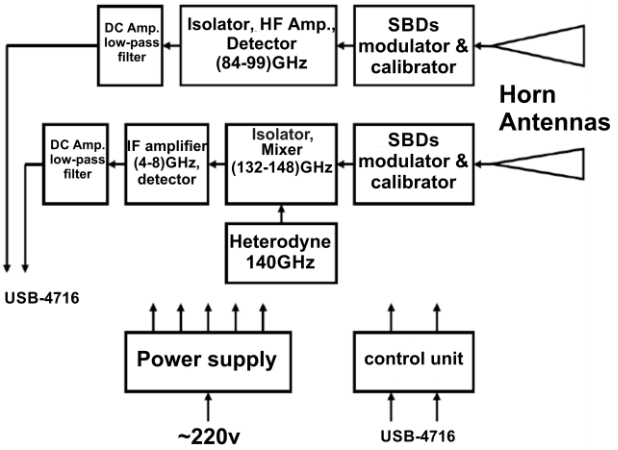

Figure 1. Block scheme: The measuring channels of the radiometer MIAP-2.

In total there were manufactured two radiometers: one is mounted stationary and provides astroclimate measurements on Suffa plateu (Uzbekistan) beginning 2014. [2] Other one is used in all our expeditins and particular in this investigations. The addition equipment presented in this work is the dual-wave Water Vapor Radiometer (WVR) established on Badary observatory. It determines the total anount of Precipitable Water Vapour (PWV) on 20.7GHz & 31.4GHz waves. [6]

3. Expedition and results

3.1 Expedition

We have organized an expedition to the Tunkinskaya valley near Baikal lake and the first place to observe was a Sayan Solar Observatory of ISTP RAS (2,100 m/6,890 ft). Measurements were taken during 3 days in clear and stabile weather. After we have relocated the MIAP-2 radiometer to Badary observatory (815m/2,670ft) as soon as possible. Further we have mounted MIAP-2 radiometer near the WVR on the roof of a building, connected it to the Internet and started a year-term measurement. On the picture below (see Figure 2) a comparison of ISTP and Badary sites is presented. We can see about 2 times lower PWV on ISTP due to height difference.

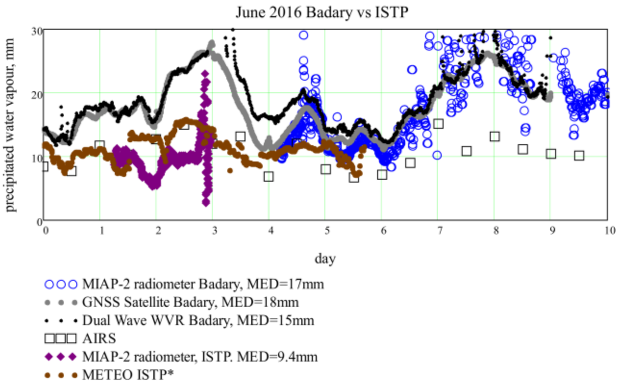

Figure 2. Comparison of PWV-altitude relationship by the data of observations on Sayan Solar Observatory of ISTP RAS (2,100 m/6,890 ft) and on the Badary observatory (815m/2,670ft). *data calculated from on-ground humidity.

3.2 Long-term observations

The MIAP-2 radiometer takes optical depth maesurements every 10 minutes around the clock. Till present time we have collected 7 months – statistic of optical depth in 2mm & 3mm atmospheric windows and the full-year statistic will be collected in June 2107. The most convenient way to present the long-term statistics is the histogramms and cumulative distributions (see Figure 3 and 4).

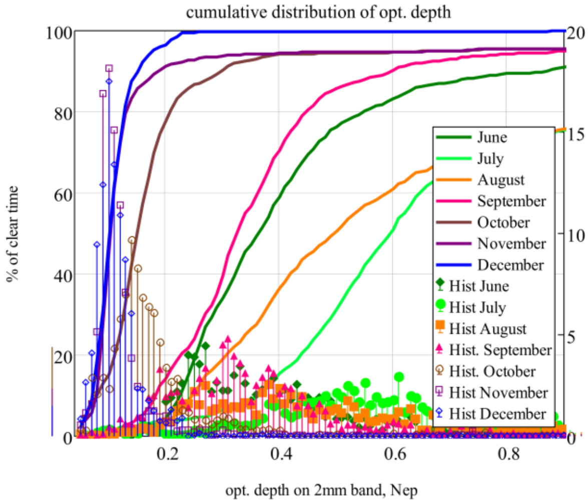

Figure 3. Histogramms and Cumulative distributions of optical depth in 2mm atmospheric window on Badary observatory.

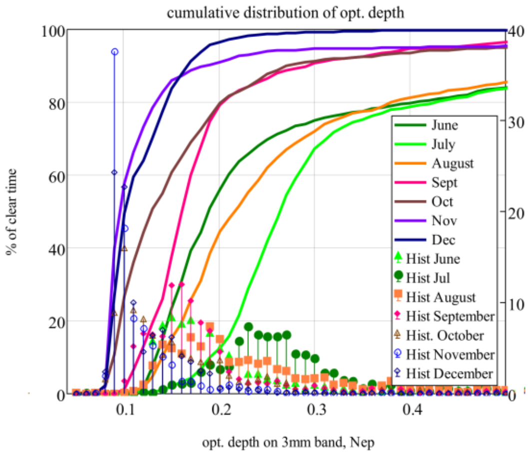

Figure 4. Histogramms and Cumulative distributions of optical depth in 3mm atmospheric window on Badary observatory.

By the end of year-term statistic these graphs will be combined by 3 seasons: Winter, Middle and Summer. In general we can see a deterioration of the weather condidtions in summer due to atmospheric moisture as well as improvement astroclimate for mm-wave observations in winter months.

4. Water vapor and calibration

4.1 PWV statistics

To have a sound analysis results, so that they could be compared to the weather observations and the absorption could be interpolated for other atmospheric windows, we need to know how different atmospheric constituents contribute to the resulting absorption (1).

$$\tau(\lambda, h, W, Q) = \alpha(\lambda)\cdot\exp\left(-\frac{h}{h_0}\right) + \beta(\lambda)\cdot PWV + \gamma(\lambda)\cdot Q \qquad (1).$$

where τ_{tot} is the observable total absorption (Neper),
h – the altitude of the point of observation (km),
h_0 – the characteristic height of the oxygen =5.3 (km),
W – PWV (mm),
Q – the cloud water content (kg/m3),
α – the absorption due to the oxygen content at sea level (Neper),
β – the specific absorption per PWV unit (Neper/mm),
γ – the specific absorption per cloud water content unit (Neper·m3/kg).

The monthly averaged value of PWV shows inferior conditions in comparison with Suffa plateau (2040m/6700ft., Uzbekistan), see Figure 5.

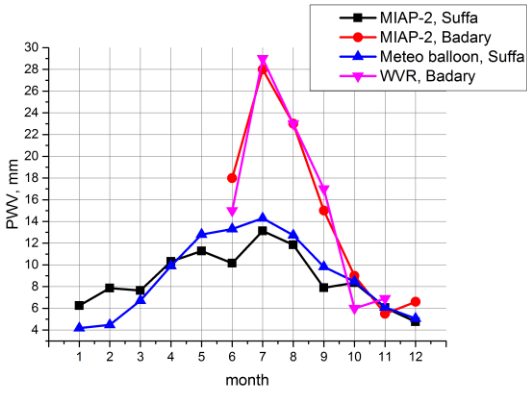

Figure 5. The monthly averaged PWV on Suffa plateau and Badary.

It is suitable to compare different locations in terms of PWV, thus we present a cumulative distribution of PWV on Badary averaged by months (see Figure 6) as well as comparison of Badary with other radioastronomic locations (see Figure 7).

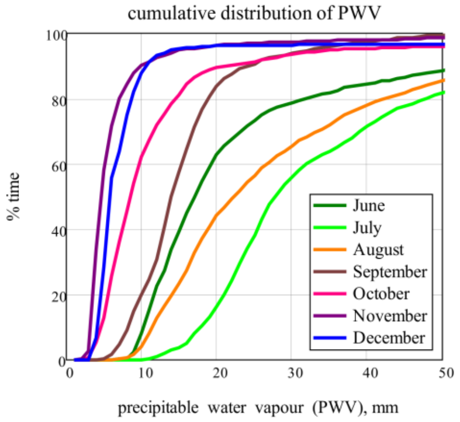

Figure 6. Cumulative distribution of PWV on Badary observatory by month.

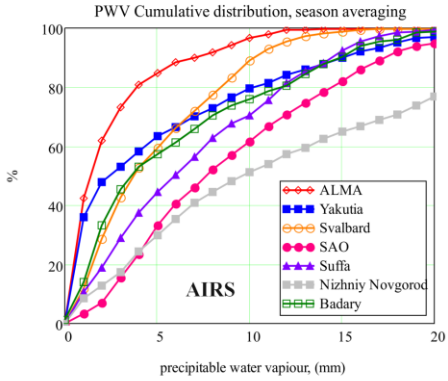

Figure 7. Cumulative distribution of PWV calculated by AIRS satellite data [7] on different sites for compare.

4.1 PWV calibration

In every work, we use the common α and β coefficients, for the first time calculated in mm and submm bands in 1980 [8], clarified in our works [1][5] by using MPM Liebe software [9] and now we are ready to present calibration of α and β coefficients in real atmospheric conditions. In principal, we compare a data sets recorded in cloudless conditions (assuming Q=0) from the MIAP-2 and WVR radiometers and calculate the regression line (see Figure 8).

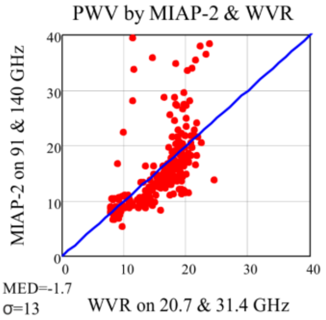

Figure 8. The template of regression line for PWV clculated by MIAP-2 & WVR for December 2016.

The first template calculated for December shows the principal opportunity of this method, however a wide scatter of data (due to clouds) introduces an error. We estimate a better condition for January.

5. Conclusion

We have made a comprehensive assessment of astroclimate on Tunkinskaya valley near Baikal lake and on Badary observatory in particular. Strictly speaking the collected optical depth data, this place cannot be called suitable for radioastronomy astroclimate conditions. However, in winter month we can observe a stabile dry weather. This conditions can be extrapolated on the height of ISTP observatory and it seems promisingly for radioastronomy and space telecommunication. On the other hand, we successfully clarified α and β coefficients in real atmospheric conditions and made the calibration of MIAP-2 radiometer.

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7. References

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