PROCEEDINGS OF SCIENCE

The optical noise monitoring systems of the Lake Baikal environment for the Baikal-GVD telescope

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We present data on the luminescence of the Baikal water medium collected with the Baikal-GVD neutrino telescope. This three-dimensional array of light sensors allows the observation of time and spatial variations of the ambient light field. We report on observation of an increase of luminescence activity in 2016 and 2018. On the contrary, we observed practically constant optical noise in 2017. An agreement has been found between two independent optical noise data sets. These are data collected with online monitoring system and the trigger system of the cluster.

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1. Introduction

Lake Baikal remains home to various unique species of plants and animals for millions of years, many of which are endemic. The vital conditions for these creatures are horizontal and vertical water exchange processes, which supply and distribute the oxygen and organic substances. The study of the hydrodynamic processes in Lake Baikal are of particular interest for earth and life sciences. Beyond limnology, it may improve our understanding of the hydrodynamics of seas and oceans.

The next generation neutrino telescope Baikal-GVD is placed in the southern basin of Lake Baikal about 3.6 km from shore at a depth of 1 366 m. The main goal of the experiment is the detection of high energy astrophysical neutrinos, whose sources remain still unknown. In particular, the aim is the registration of the Cherenkov radiation emitted when secondary charged particles, created in the reactions of neutrinos with surrounding medium, are passing through the deep water in Lake Baikal. The detector itself is a three-dimensional array of photo-sensitive components called optical modules (OMs). A fully independent unit called cluster consists of 288 OMs attached on 8 strings, 7 peripheral strings surrounding the central one with a radius of 60 m. Each string carries 36 OMs with 15 m vertical spacing. The top and the bottom OMs are located at depths of 750 m and 1 275 m, respectively. In 2016, the first cluster "Dubna" has been deployed. In the two subsequent winter expeditions of 2017 and 2018, two more clusters have been deployed. Another two clusters have been deployed during the winter expedition of 2019. In recent, the total number of the deployed clusters is five [1].

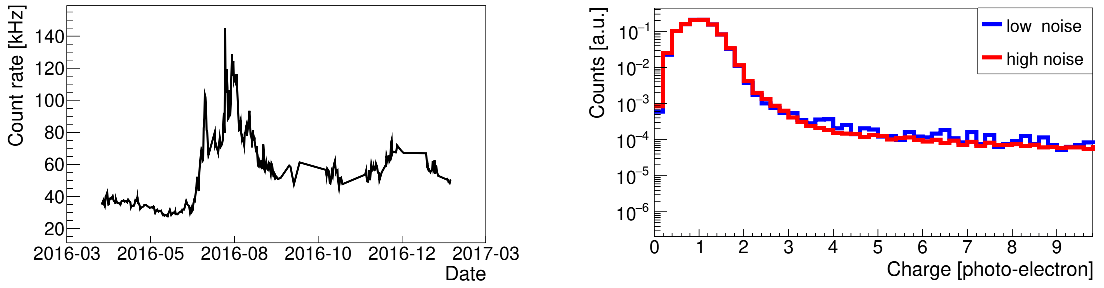
Apart of Cherenkov radiation, also the ambient background light is registered. The amount of the registered background light is derived from the photo-multiplier noise rates from each particular OM. There are two independent ways of collecting the data. The trigger system of every cluster is designed in such a way that signals from each OM in a time window of 5 μs are stored, if a trigger condition is fulfilled [2]. In this way, we obtain the data on count rates of pulses registered by OMs. Besides this way, there is an online monitoring system, which collects data from the OM controller electronics placed inside every OM. The origin of the background noise rates is mainly associated with the luminescence of the Baikal water. By means of the two independent systems, the light registration is almost continuous. In this article, we present some selected results on luminescence in Lake Baikal.

2. Optical activity of the Baikal water

Baikal-GVD is designed to detect the Cherenkov light from charged particles. In open water, light not related to relativistic particles constitutes an unavoidable background to the Cherenkov light. Therefore studies of the related light fields are of crucial importance. The photon flux from the sunlight below a depth of $\sim$ 700 m is negligible as shown in previous work [3].

2.1 Background light - features

In Fig.1a, we present data on count rates for a selected OM for April 2016 – February 2017. There are two periods of relatively stable optical background noise, which are intermitted by increased optical activity. The charge distribution of the noise pulses is displayed in Fig.1b. We



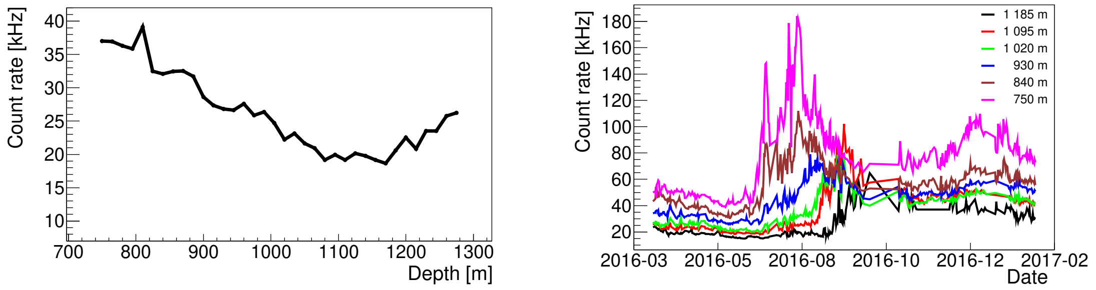
(a) (b)

Figure 1: a) Count rates of a selected OM versus time (April 2016 - February 2017). b) Charge distribution of the registered pulses in units of photo-electrons.

stress that the charge distribution remains unchanged in different periods of the optical activity. Our measurements are performed with a threshold of half a single photo-electron charge. In this way, the dark noise of the photo-multiplier is significantly suppressed. We note that by setting the threshold to one photo-electron the background count rate is reduced by a factor of two. The one photo-electron background is well correlated with the half photo-electron background. The count rates in both cases exhibit the same modulation of the relative amplitude. We clearly see that the major contribution comes from single photo-electron pulses.

2.2 Background light - time variations

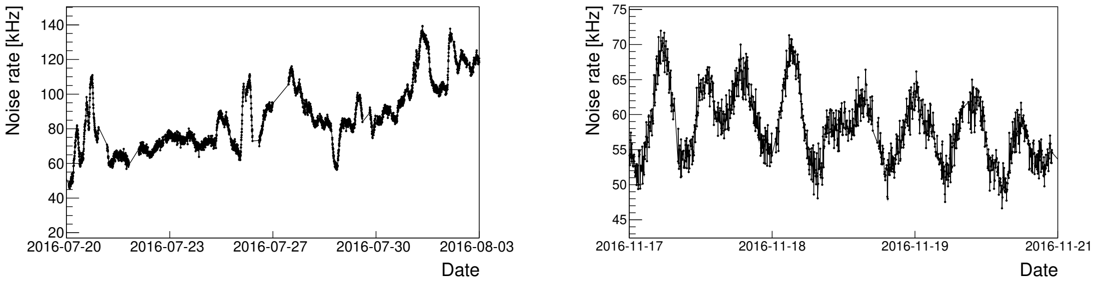
The depth dependence of the ambient light field is the same for all eight strings of a cluster. By averaging the count rates over the OMs at the same horizon, we obtain the depth dependence of the background light noise. The average count rates versus the depth are presented in Fig.2a. The analysed data are from June of 2016. This is the period of the lowest optical activity. We note that the pattern remains the same for other periods of stable noise activity.



(a) (b)

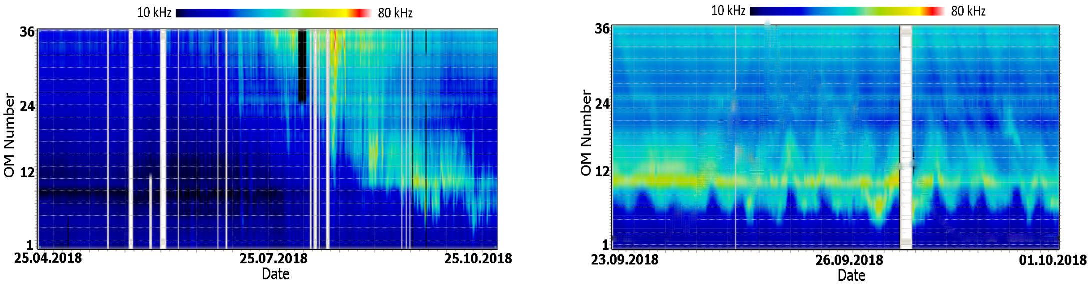
Figure 2: a) Count rates as a function of depth, averaging for each depth over the OMs from different strings. The lake bed is at 1 366 m depth. Data from June 2016. b) Count rates for the OMs at the same string at different depths. For the sake of simplicity, we show only six of 36 OMs, placed at depths of 750, 840, 930, 1 020, 1 095, and 1 185 meters.

During the period of increased activity, the depth dependence is displayed in Fig.2b. The appearance of the outbreak maximum depends on time, starting with the top modules. Indeed, we observe a layer of highly luminescent water moving from the top to the bottom of the lake. By comparing the maximum for different depths, we obtain a velocity profile of the flows. In the beginning of August, the estimated speed reached its maximal value of ∼45 m/day, while it remained almost constant (∼8 m/day) till the end of September, i.e. when the activity asymptotically reached the background plateau. The observed pattern is similar to previous investigations with NT200 detector (see [4]).



(a) (b)

Figure 3: a) Count rates for a particular OM during the optically high active period (July – September 2016) are shown. We see sudden outburst of the rates. b) An example of the regular modulation of the noise rates is displayed. Data are from the period of stable plateau (October 2016 – February 2017).



(a) (b)

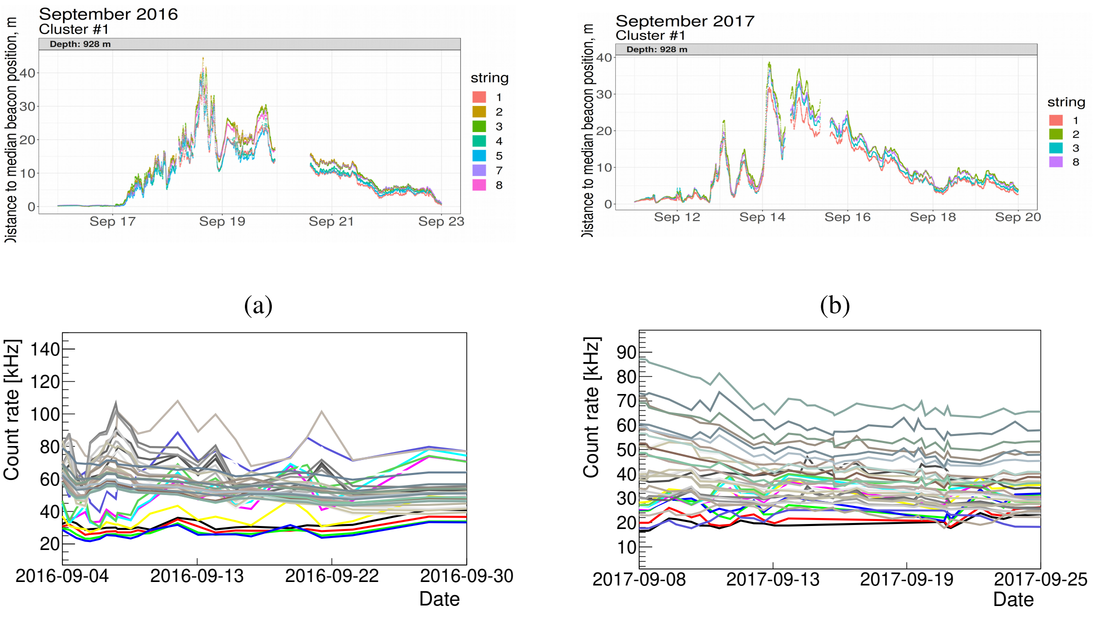
Figure 4: a) Count rates for 36 OMs on the same string are shown. The bottom and the top OM, respectively, are labeled as No.1 and No.36. Collected data are from the year 2018. Red color stands for high noise rates while blue color for low rates. b) Same as for a) with a particularly selected time window, when the effect of regular modulation is manifasted clearly.

The time evolution of the count rates, as shown in Fig.(2b), exhibits sharp changes on top of relatively continuous smooth optical background. The effect is more visible in particularly selected time window displayed in Fig.(3a). The amplitude of these sudden changes reached almost 50 kHz. The duration of such variations which distort the smooth background ranges typically from several hours up to a few days. We note that effect is present in July – September 2016, i.e. the period of increased luminescent activity. However, the period of relatively stable plateau (October 2016 – February 2017) shows (see Fig.(3b)) regular modulation of noise rates. The period of these modulations is quite stable and varies from 10-12 hours. We stress that these waves are probably the manifestation of the internal waves in the lake. The end of these modulations cannot be determined as far as the measurement during the year is interupted by the winter expedition (For further details see [1]). On the other hand, we observed a practically constant background noise without a period of high luminescence activity in 2017.

However, the noise rates in 2018 exhibit similar pattern to the one already described above for the year 2016. In Fig.(4a) we evidently see a luminescent layer moving from the top to the bottom of the lake. We observed the regular modulation of the noise rates again, as shown in Fig.(4b). Firstly, the modulations appeared on top OMs in June 2018 and persisted till the end of October 2018. The maximal amplitude reached 70 kHz.

3. Torrent currents in Lake Baikal

Due to the currents in Lake Baikal, the string geometry deviates from its vertical direction. To take these deviations into account, an acoustic positioning system for Baikal-GVD has been developed (For more details see the contribution to this conference [5]). Our observations show two periods of extreme deviations of the strings, in September of 2016 and of 2017. Torrent flows in the lake may produce a remarkable tilt of the string from its vertical position, two examples of which are displayed in Figs.5a and 5b. For the same period, we present the data on count rates in Figs.5c and 5d. We do not find a correlation between the torrent flows of the deep water and the luminescence activity of the lake.



(a) (b)

(c) (d)

Figure 5: a) Deviations of the beacons from their median positions at different strings. Shown are data from autumn 2016, when the deviations of the strings from their median positions were extremal. b) Same as for a), with data from 2017. c) Count rates of 36 OMs at the same string. Data shown have been taken in the period, when the deviations of the string from the median position were extremal. d) Same as for c), with data from 2017.

4. Noise monitoring system

The online monitoring system of the telescope is designed for the continuos registration of the measurement conditions for each OM. For more details see [6]. Here, we put emphasis on the photo-multiplier noise rate only, which is the subject of our interest. A counter of nanosecond pulses is built in the OM electronics. In this way, the count rates are interrogated in regular time windows almost continuosly. It is worth to mention that the noise rates obtained from monitoring system are, unlike the data acquired from the trigger system of the cluster, completely independent of the trigger system settings and parameters. However, the count rates data are collected with different thresholds of registered pulses in these two ways. Therefore, one needs to rescale the noise rates when comparing the data obtained from monitoring system versus the data acquired by the trigger system of the cluster. In Fig.(6), we present a comparison between the noise rates obtained in these two different ways. We see that both data sets agree well with each other.

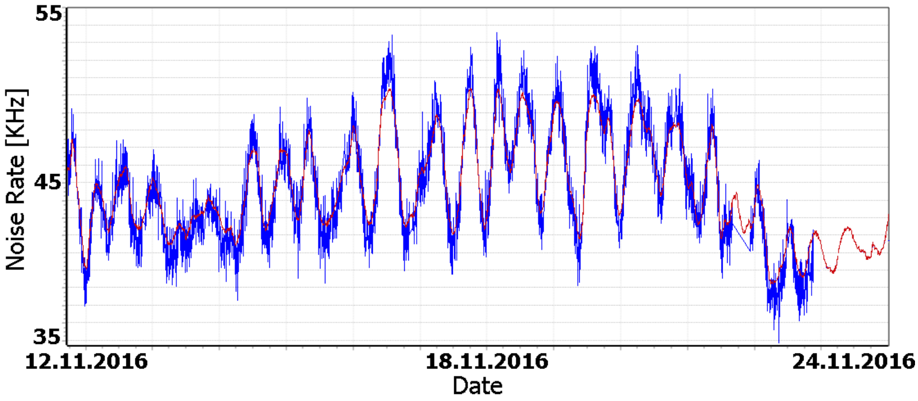


Figure 6: Noise rates acquired with online monitoring system and the cluster trigger system are shown. Due to different pulse thresholds in each of the systems data are properly scaled. The picture exhibits an agreement between the two datasets.

5. Conclusions

We have presented data on the luminescence in Lake Baikal which have been collected by the Baikal-GVD neutrino telescope. We found an increase of the luminescence activity intermitting periods of relatively stable optical background in 2016 and 2018. On the contrary, we observed practically constant background noise without a period of high luminescence activity in 2017. Moreover, we find that the maximum of the optical activity observed in 2016 propagated from top to bottom, with a maximum speed of 45 m/day. We did not find a correlation between the torrent flows and the increase of the luminescence activity. An agreement between the noise rates datasets obtained from cluster trigger system and the online monitoring system has been found.

6. Acknowledgements

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