Spatial positioning of underwater components for Baikal-GVD

A.D. Avrorin[1]*, *A.V.* Avrorin[1], *V.M.* Aynutdinov[1], *R.* Bannash[7], *I.A.* Belolaptikov[2], *V.B.* Brudanin[2], *N.M.* Budnev[3], *N.S.* Gorshkov[2], *A.A.* Doroshenko[1], *G.V.* Domogatsky[1], *R.* Dvornický[2,8], *A.N.* Dyachok[3], *Zh.-A.M.* Dzhilkibaev[1], *L.* Fajt[2,8,9], *S.V.* Fialkovsky[5], *A.R.* Gafarov[3], *K.V.* Golubkov[1], *T.I.* Gres[3], *K.G.* Kebkal[7], *O.G.* Kebkal[7], *E.V.* Khramov[2], *M.M.* Kolbin[2], *K.V.* Konischev[2], *A.V.* Korobchenko[2], *A.P.* Koshechkin[1], *V.A.* Kozhin[4], *M.V.* Kruglov[2], *M.K.* Kryukov[1], *V.F.* Kulepov[5], *D.A.* Kuleshov[1], *M.B.* Milenin[5], *R.A.* Mirgazov[3], *V.* Nazari[2], *A.I.* Panfilov[1], *D.P.* Petukhov[1], *E.N.* Pliskovsky[2], *M.I.* Rozanov[6], *E.V.* Rjabov[3], *V.D.* Rushay[2], *G.B.* Safronov[2], *F.* Šimkovic[2,8], *A.V.* Skurichin[4], *B.A.* Shaybonov[2], *A.G.* Solovjev[2], *M.N.* Sorokovikov[2], *M.D.* Shelepov[1], *O.V.* Suvorova[1], *I.* Shtekl[2,9], *V.A.* Tabolenko[3], *B.A.* Tarashansky[3], *S.A.* Yakovlev[7], *A.V.* Zagorodnikov[3]

[1]Institute for Nuclear Research, Moscow, 117312 Russia
[2]Joint Institute for Nuclear Research, Dubna, 141980 Russia
[3]Irkutsk State University, Irkutsk, 664003 Russia
[4]Institute of Nuclear Physics, Moscow State University, Moscow, 119991 Russia
[5]Nizhni Novgorod State Technical University, Nizhni Novgorod, 603950 Russia
[6]St. Petersburg State Marine Technical University, St. Petersburg, 190008 Russia
[7]EvoLogics, 13355, Berlin, Germany
[8]Comenius University, 81499, Bratislava, Slovakia
[9]Czech Technical University, 16000, Prague, Czech Republic

Abstract. Baikal-GVD is a cubic kilometer-scale neutrino telescope currently under construction in Lake Baikal. The detector's components are mobile and may drift from their initial coordinates or change their spatial orientation. This introduces a reconstruction error, particularly a timing error for PMT hits. This problem is mitigated by a combination of a hydroacoustic positioning system and per-component acceleration and orientation sensors. Under regular conditions, the average positioning accuracy for a GVD component is estimated to be less than 13 cm.

1 Introduction

Baikal-GVD [1] is a gigaton volume neutrino telescope currently under construction in Lake Baikal. At the moment, it is the largest neutrino detector in the Northern Hemisphere. It is designed to measure direction and energy of astrophysical neutrinos by observing Cerenkov radiation from secondary particles produced by neutrino interactions with Baikal water. The detector consists of a 3-dimensional array of photomultipliers housed in optical modules (OMs). OMs are mounted on flexible strings with 15 m intervals at depths between 1270 m and 745 m. The strings are stretched between an anchor and subsurface buoys and are

*Corresponding author: avrorin@inr.ru

arranged into clusters with eight strings each. A cluster consists of a central string and seven peripheral strings placed in a regular heptagon with a radius of 60 m.

Following the installation of a new cluster in spring 2018, Baikal-GVD consists of 3 clusters [2]. The baseline cluster configuration and layout for the GVD 2018 configuration are shown in Figures 1 and 2.

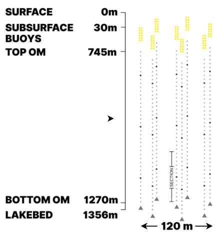

Figure 1: GVD cluster

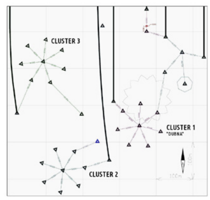

Figure 2: GVD 2018 layout

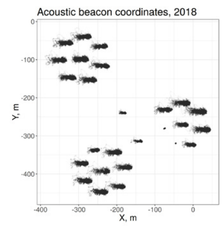

Figure 3: AM coordinates, 2018

Because of the currents in Lake Baikal, the string geometry changes with time and individual OMs can drift tens of meters from their initial coordinates. An OM positioning error is equivalent to an error in time calibration, so correctly positioning OMs is crucial for event reconstruction and causality-based hit selection. To address this problems, a spatial positioning system has been developed [3, 4].

2 Hydroacoustic positioning

The hydroacoustic positioning system (APS) is an array of EvoLogics S2C R42/65 acoustic modems mounted along the strings as shown on Figure 4, with a minimum of 4 modems per string in 2018 configuration. The modems communicate with each other using the D-MAC protocol [5]. The modems installed along the optical modules are called beacons and are directed downwards. Some strings have modems installed near the anchor (nodes).

The node coordinates are determined shortly after string installation and are assumed constant. During cluster operation the beacons are regularly polled from the shore for acoustic distances to the lake floor acoustic antenna formed by the nodes. This data is used to trilaterate beacon coordinates with an accuracy of several centimeters. OM coordinates are then interpolated from beacon positions assuming a piece-wise linear model of the string. The coordinates for the calibration light sources like lasers and LED matrices are acquired the same way.

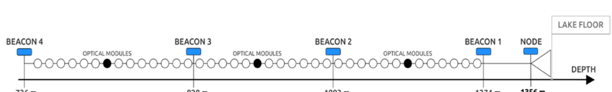

Figure 4: Layout of acoustic modems on a Baikal-GVD string

Trilaterated coordinates for beacons on one string are provided on Figures 5 and 6. An ‘active’ period in autumn 2017 is characterised by unusually high drift and speed of beacons and was displayed separately. This period includes a week in September (September 11th to September 18th) and a total of 9 days in October. Similar periods are present in 2016 and 2018 data. As can be seen on Figures 5 and 6, the drift mainly occurs in the XY plane.

Season-long depth variations are within 0.5 m (except in the ‘active’ period, when they can reach up to several meters). Coordinate variation decreases with depth from about 25 m at the top of the cluster to about 2.5 m below the bottom OM (about 50 m to about 5 m for active period). A collection of beacon coordinates for season 2018 is shown in Figure 3.

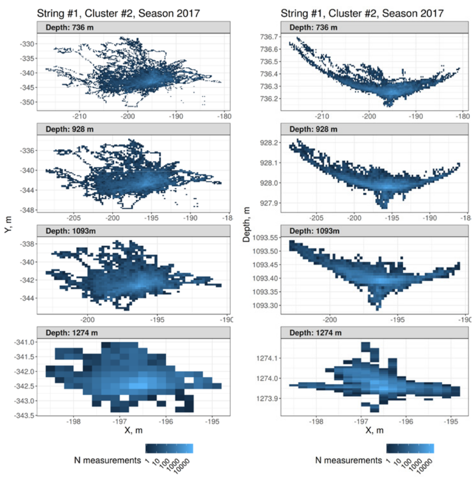

Figure 5: Beacon drift in a regular period

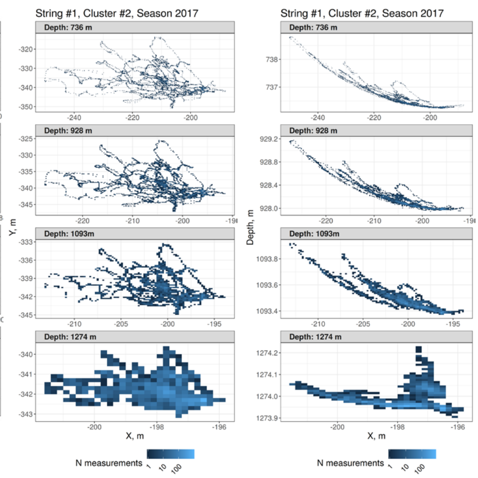

Figure 6: Beacon drift in an ‘active’ period

The acoustic data acquired in 2017 can be used to observe the dynamics of GVD. The maximum speed of the most shallow and, therefore, the most mobile, beacon is estimated to be below 3 cm/s (Figure 7). The mean speed for the most shallow beacons is about 0.5 cm/s. As with coordinate range, the speed falls with depth. The distance travelled by the AM between polls may reach several meters during the ‘active’ period (Figure 8). The average distance a beacon travels between subsequent measurements at the depth of 736 m is about 0.5 m.

The beacon coordinates are correlated. As shown in Figure 9, the distance between beacons installed at similar depths within one cluster is consistent even at the most shallow depths. A similar dynamic is present within one string and even between clusters.

The spatial orientation of OMs is determined from accelerometer and compass data provided by intra-OM sensors polled independently from APS. As of 2018, the system is fully deployed.

3 Positioning precision

The error in OM positioning using the above described procedure varies with speed of the OM and its distance to the nearest beacon. To gauge the OM positioning error for the APS an additional beacon has been installed on the central string of cluster 3, between beacons 3 and 4. Its coordinates have then been reconstructed as if it was an OM and compared to the coordinates acquired via acoustic trilateration. The beacon placement ensures that its positioning error provides an upper bound for the OM coordinates on the string.

The analysis used data acquired from April 30th to October 1st 2018. The period between September 20th and September 29th 2018 is characterised by an unusually high drift and speed, and has thus been processed separately. As can be seen in Figure 10, the mean positioning error is 13 ± 3 cm for the regular period, and 21 ± 10 cm for the ‘active’ period. Note, that the photocathode diameter is 25 cm.

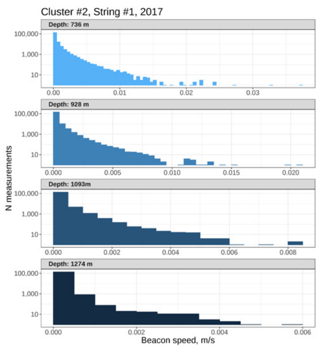

Figure 7: Beacon speed at various depths, 2017

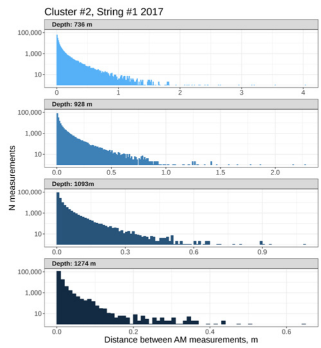

Figure 8: Distance between measurements, 2017

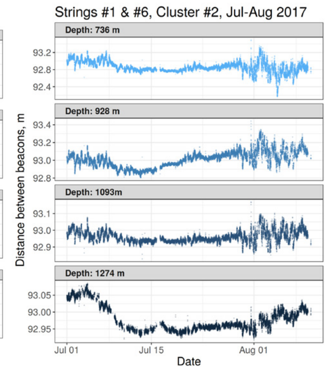

Figure 9: Distance between same-depth AMs, 2017

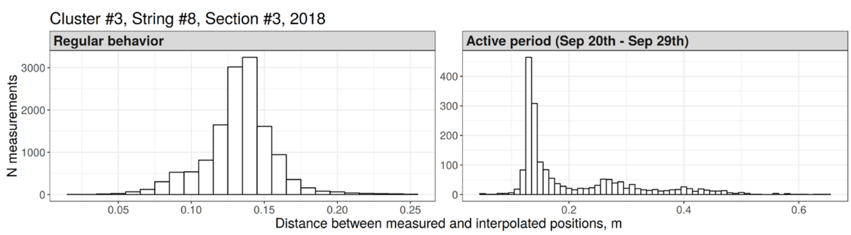

Figure 10: Error of the OM position measured with the APS positioning procedure

4 Conclusion

A system for spatial positioning of underwater components has been developed for Baikal-GVD. As estimated from 2018 data, it allows positioning OMs with an average position precision of 13 ± 3 cm for most of the season. During short-term periods of high hydrodynamic activity the positioning precision falls to 20 ± 10 cm. Acoustic measurements show that the most mobile OMs move with an average speed of about 0.5 cm/s with a maximum speed of 3 cm/s. Coordinates of acoustic modems are highly correlated within one string, and on same depths at the strings of a cluster and between clusters.

Acknowledgements

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