Monitoring of the Optical Properties of Lake Baikal's Deep Waters in 2024

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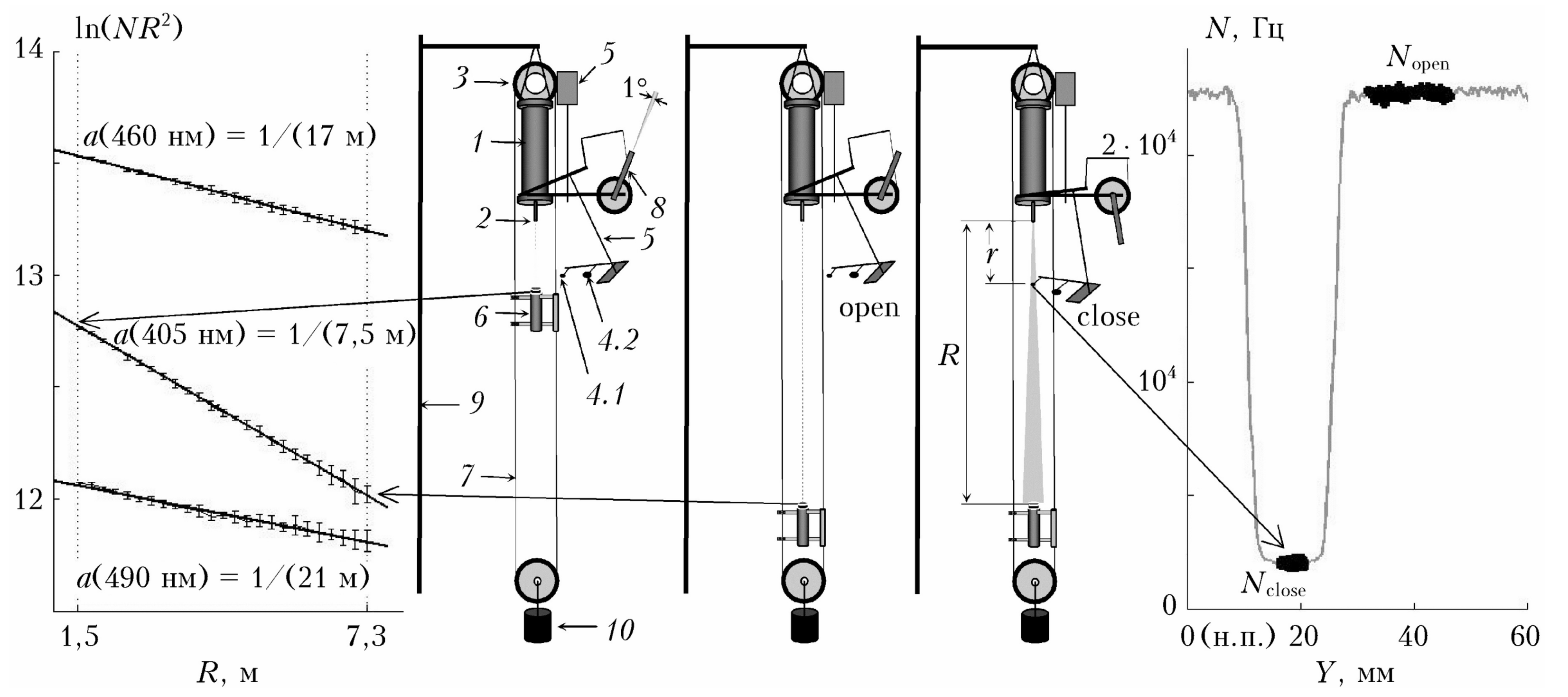
BAIKAL-GVD

Introduction

- Baikal-GVD consists of more than 4000 optical modules, located at depths 750-1270 m.
- The optical properties of deep water are essential for the analysis of the collected data.
- Regular monitoring of inherent optical properties (IOP) improves the accuracy of neutrino energy and direction reconstruction, and provides unique data for limnological studies.
- Several custom-made devices, called Baikal-5D, were developed and manufactured at API ISU in Irkutsk, Russia, and installed in Lake Baikal at different depths.
- Since 2020, in situ measurements of IOP have been carried out using Baikal-5D instruments.

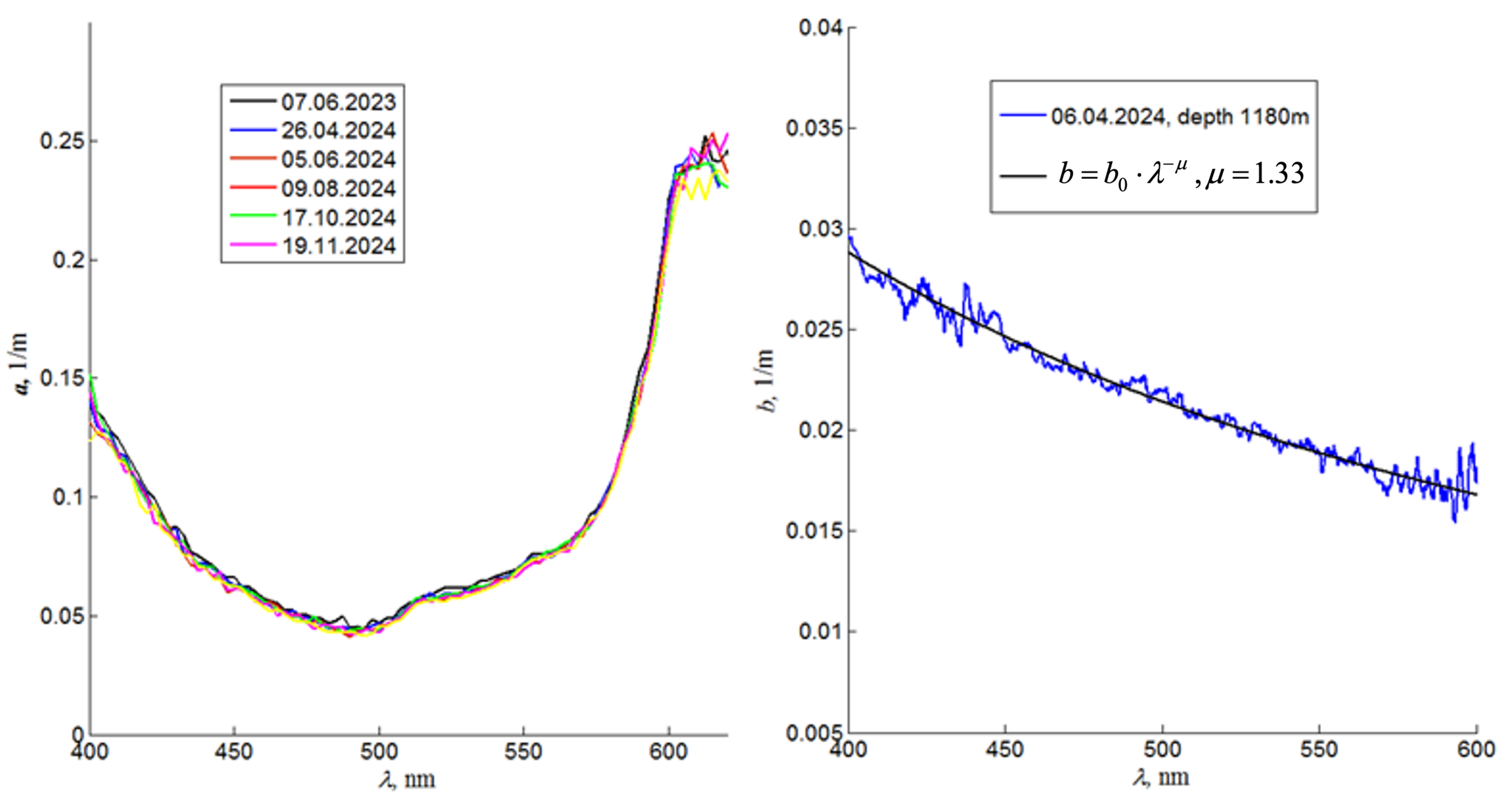
1. The BAIKAL-5D instrument

- Absorption and scattering spectra measurements at wavelengths 400-620 nm,
- Registration of the small-angle dependence of the scattering indicatrix.
- New corrections are applied to account for the incomplete collection of scattered light in the optical scheme of the instrument.
- Long-term operation (one year or more) without maintenance or adjustment.



2. Absorption and scattering spectra

- The absorption spectrum (depth 1180 m) has a stable shape throughout the entire 2021–2024 observation period.
- The absorption minimum (La=24-28 m) corresponds to the spectral range 485–495 nm.
- The changes in the absorption spectrum (within ±9% during 2024) can be characterized as a vertical shift without a change in shape.
- The observable fluctuations in the absorption and scattering spectra lie within the measurement error.



Conclusion

- In 2024–2025, weekly monitoring of the IOP of the deep water continued at the Baikal-GVD site.
- BAIKAL-5D instruments of our own design have demonstrated the ability to long-term operation.
- Stable absorption spectrum was recorded with an absorption minimum corresponding to L_a=24÷28 m.
- Scattering length varied in the range 30–48 m.
- Asymmetry coefficient of the scattering indicatrix is on the order of 10.

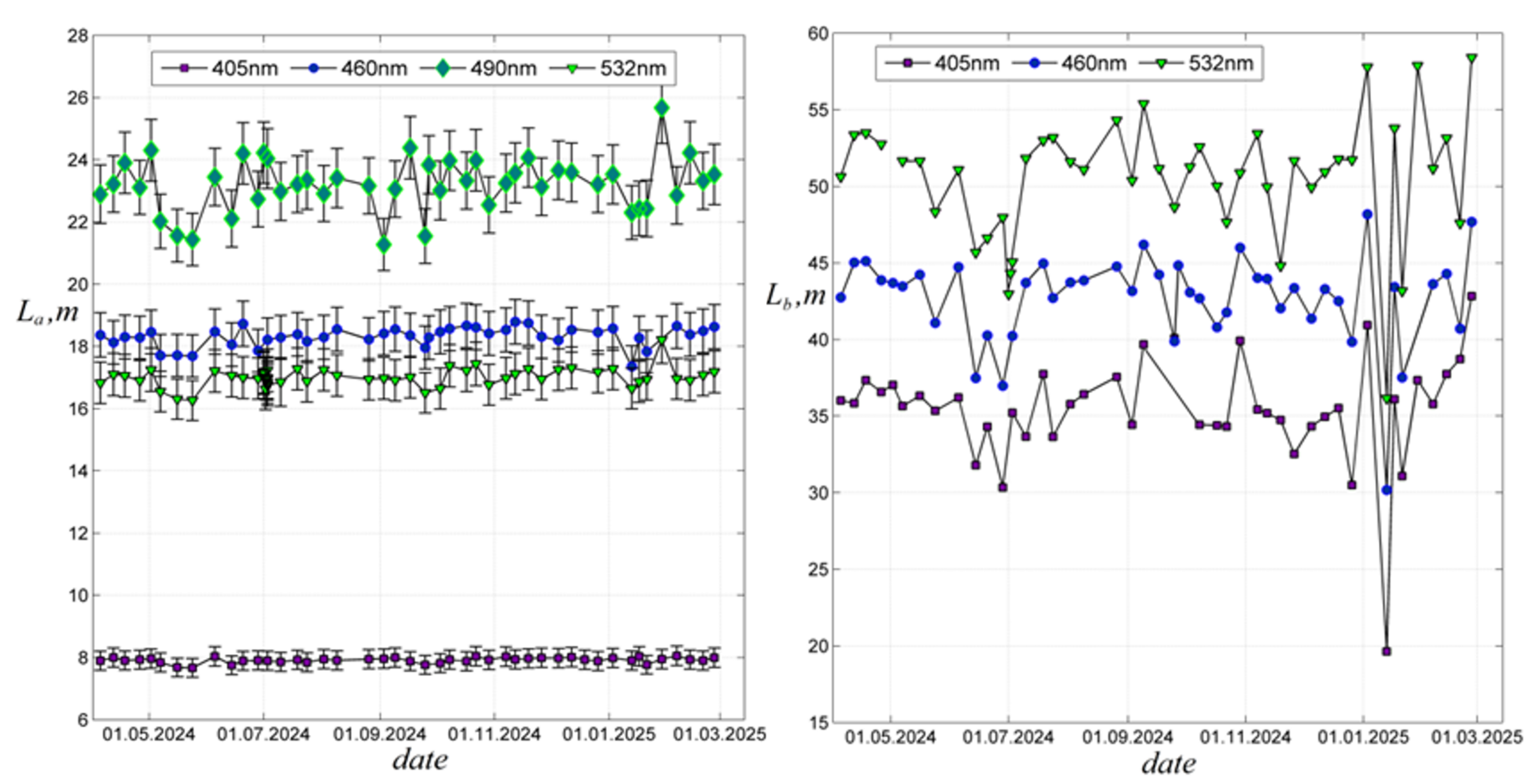
3. Depth dependence of IOP

- Presence of a weak minimum in absorption and scattering in 1000-1175 m.
- Variation in the absorption coefficient is about 9 %, and about 19 % in the scattering coefficient.
- Indicatrix asymmetry coefficient K is close to the minimum values measured in the ocean and is 2–10 times smaller than the values obtained for depths of 0-150 m.

Dept h, m	L_a(450nm), m	L_b(450nm), m	K(468 nm)	K(521nm)
700	15,7±0,5	37,2±2,0	8,9±0,5	13,1±0,9
800	16,3±0,6	35,0±1,7	9,5±0,6	13,0±0,7
900	16,5±0,5	36,8±1,5	9,5±0,5	12,9±0,8
1000	16,7±0,5	40,4±1,6	8,7±0,4	12,4±0,9
1100	16,9±0,6	41,4±1,7	8,5±0,5	12,5±1,0
1175	17,1±0,7	42,6±1,8	8,3±0,7	11,6±0,9
1250	15,8±0,7	37,8±1,8	9,2±0,6	13,0±1,1

4. Time dependence of absorption and scattering lengths

- Uninterrupted series of IOP measurements at depth of 1180 m over 4 years
- From March 2024 to March 2025, weekly monitoring of the IOP was conducted at the Baikal-GVD site.
- A relatively stable absorption spectrum was recorded, with minimal absorption L_a = 24-28 m in the wavelength range 485-495 nm.
- The scattering length at λ=460 nm varied in the range of 30–48 m. A short-term scattering maximum was recorded on January 13, 2025.
- $\sigma(L_a) \approx 4\%$, $\sigma(L_b) \approx 10\%$.
- Maximum L_a deviation from the average is about 16 %, strong correlation of blue and yellow-green parts is observed.
- L_b deviation is about 35 %.
- Connection between changes in absorption and scattering exists, but it is weak and only intermittently evident.
- The asymmetry coefficient of the scattering indicatrix is about 10 in the transparency window of the deep water.



5. Scattering indicatrix at small angles

- Estimate of the slope of the indicatrix in the small-angle region $\gamma < 30°$
- Approximation function: $a_0 \cdot \exp(-s \cdot \gamma)$, where s=27-35 rad^{-1} for λ=470 nm with the uncertainty of about 20 %.