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Original article

Record and Assessment of Seiche Oscillation Parameters in Alekseev Bay (Popov Island) based on the Coastal Laser Strainmeter Data

V. A. Chupin ✉, G. I. Dolgikh, V. K. Fishchenko, P. S. Zimin, S. K. Shabelnikova, V. A. Shvets, S. V. Yakovenko

V. I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch of Russian Academy of Sciences, Vladivostok, Russian Federation
✉ *chupin@poi.dvo.ru*

Abstract
Purpose. The purpose of the study is to assess the potential of coastal laser strainmeters for recording and quantitatively identifying seiche oscillations in small coastal water areas using the example of Alekseev Bay (Popov Island, Peter the Great Bay).
Methods and Results. Micro-displacements of the Earth's crust were recorded by a 20-metre coastal laser strainmeter installed at a distance of approximately 20 meters from the coastline. To independently monitor sea level fluctuations, video recording of a marker object in the bay was performed, followed by metric image calibration (with a scale factor of 0.69 cm/px). Comparison of the signals required identical bandpass filtering of the time series within the range of the main seiche mode. A linear relationship between the micro-displacements of the strainmeter base and the amplitude of sea level fluctuations was revealed. The linear transformation coefficient $K = 0.66 \pm 0.03$ μm/cm at $|r| > 0.9$ was determined based on a series of synchronous observation intervals. Analysis of time series, dynamic spectrograms, and amplitude spectra made it possible to detect stable periods of approximately 10.5 min, 2.6–2.7 min, and 4.1–4.3 min, which correspond to the fundamental longitudinal seiche of the whole bay, the first eigenmode, and the localised mode of the inner sub-basin, respectively. It was shown that intensification of wind forcing results in an increase in the oscillation amplitude without changing the set of dominant periods.
Conclusions. A coastal laser strainmeter provides reliable recording of seiche oscillations in a small bay and makes it possible to quantify their amplitudes based on deformation measurements. The obtained results confirm the decisive role of the water area geometry and bathymetry in the formation of the eigenmode spectrum, as well as demonstrate the applicability of remote deformation methods to monitoring coastal hydrodynamic processes.

Keywords: laser strainmeter, seiche oscillations, micro-displacements of the Earth crust, calibration, hydrodynamics of coastal zone

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Introduction

Seiche oscillations are standing long-period fluctuations of the water level in enclosed and semi-enclosed water bodies, whose eigenperiods are determined by the basin geometry and depth and can range from several tens of seconds to hours. Classical reviews on seiches, harbour oscillations, and other low-frequency oscillations in water bodies emphasise the fundamental role of resonance and the spectral structure of eigenmodes of a specific water area, as well as the wide variety of atmospheric forcing mechanisms (wind, frontal passages, pressure jumps), including phenomena such as meteotsunamis [1].

Contemporary studies of seiche oscillations in enclosed bays and harbours are developing along several lines. First, spectral diagnostics of stable and quasi-stationary seiche regimes are being actively improved, in these regimes, the resonant response manifests itself not as a single event but as a "continuous" component of the system dynamics, modulated by external forcing [2]. Second, considerable attention is paid to the role of atmospheric disturbances of different origins (wind forcing and/or barometric impulses) and their relative contributions to the triggering and amplification of seiche regimes during the passage of storms and cyclones [3, 4]. Third, studies of various water areas demonstrate that the dominant mode and energetics of the seiche response depend not only on the "internal" resonant structure of the bay but also on the nature of external excitation, the conditions at the bay entrance, and the interaction between adjacent water areas [5–7]. Recently, studies have also been carried out in which seiches are considered in the context of coupled oscillatory processes in the atmosphere–ocean system and a broad spectrum of low-frequency hydrodynamic oscillations in the coastal zone [8].

For Peter the Great Bay, the relevance of studies of seiche oscillations is determined by the complexity of the coastline, pronounced seasonal variability of atmospheric circulation, and the frequent occurrence of cyclones. In this regard, the results obtained earlier for Vityaz Bay, located in the south-western part of the bay near the Marine Experimental Station (MES) *Cape Schultz*, are of interest. It was shown that seiche oscillations with periods of about 16–18 min were consistently observed in Vityaz Bay and were interpreted as its natural oscillations; the passage of cyclones over the Sea of Japan and the intensification of wind forcing were accompanied by an increase in the oscillation amplitude in the corresponding range [9].

Alekseev Bay, located on Popov Island in Amur Bay, is a convenient natural test site for studying resonant oscillations in small coastal water areas because of itsproximity to POI FEB RAS MES *Popov Island*. Previously, field experiments, coastal and bottom measurements of sea level and oscillations, as well as numerical modelling, were carried out in the bay. Published studies have compared numerical modelling results for Alekseev Bay with field measurement data, confirming thepresence of a pronounced modal structure and resonant frequencies in the range of interest [10, 11]. In addition, technologies for remote recording of waves and sea level oscillations using shore-based video monitoring have been developed at theMES *Popov Island*, with the possibility of recording seiche oscillations being explicitly demonstrated [12].

At the same time, the question of the extent to which remote deformation measurements conducted onshore can serve as a reliable and informative tool for diagnosing seiche oscillations in a specific small bay (including variations in the dominant frequency and amplitude during the passage of cyclones and changes in wind direction) remains insufficiently explored. The recording of seiche oscillations in Vityaz Bay is possible only during periods of their maximum excitation, owing to the significant distance between the strainmeter from the bay's coastline (approximately 373 m). Previous studies have reported cases in which seiche oscillations were recorded using seismic data [13].

This paper presents the results of recording seiche oscillations in Alekseev Bay (Popov Island) using a coastal laser strainmeter commissioned in 2025 [14]. The main purpose of the study is to assess the potential of coastal deformation measurements for recording and diagnosing the parameters of seiche oscillations in a small bay, including stable periods and their amplitude modulation under atmospheric forcing.

Measurement methods and data calibration

Coastal laser strainmeter. Micro-displacements of the Earth's crust in the area of Alekseev Bay (Popov Island) were recorded using a coastal laser strainmeter commissioned for continuous operation in 2025. The development of this instrument followed a phased approach: in 2024, a mobile version of the laser strainmeter was installed on a trial basis at the MES *Popov Island*, and the first experimental records were obtained. These data confirmed the possibility of high-precision recording of micro-deformations of the Earth's crust over a wide frequency range and served as the basis for creating a stationary continuous monitoring system [14].

Based on the results of preliminary tests [14], the preparation of a specialised underground room was completed in 2025. The room provides stable temperature conditions and protects the measuring equipment from external influences. As a result, the instrument was put into continuous operation. Fig. 1 shows the layout of the coastal laser strainmeter. It is located in an underground room on a natural elevation along the shore of Alekseev Bay, at a distance of approximately 20 m from the coastline. This location proved to be effective for achieving the objectives of this study. In contrast to strainmeters located further from the shore, such as the strainmeter at Cape Schultz, this location provides direct sensitivity to deformation processes generated by changes in the hydrodynamic conditions in the bay. The short distance from the coastline makes it possible to record the elastic response of the Earth's crust to the redistribution of water mass during seiche oscillations, including sea level variations and the associated changes in crustal loading.

The laser strainmeter is configured as an unequal-arm Michelson interferometer with a sealed measurement arm 20 m long, which ensures stability and protection of the laser beam from external influences. High measurement accuracy (down to picometres) makes it possible to record micro-displacements of the Earth's crust caused by hydrodynamic processes in the coastal zone.

Micro-displacements are recorded by the strainmeter at a sampling rate of 1000 Hz, which enables the analysis of processes over a wide frequency range. When studying long-period oscillations, including seiche oscillations, preprocessing is performed to optimise the primary data and isolate the frequency range of interest. During data processing, low-pass filtering is first applied using a Hamming window of 1500 samples and a cut-off frequency of 1 Hz, which makes it possible to suppress high-frequency signal components. Then, to eliminate the influence of ultra-low-frequency components, a high-pass filter with a window length of 15 000 samples and a cut-off frequency of 0.001 Hz is additionally used. Subsequent decimation produces time series optimised in terms of data volume and spectral composition, thereby reducing computational requirements.

F i g. 1. Location of the coastal laser strainmeter on Popov Island. Geometric dimensions and bathymetry of Alekseev Bay. *1* – sea level video recording site

Video recording of sea level oscillations. One of the aims of the study was to compare strainmeter signals with independent measurements of sea level oscillations. For this purpose, simultaneous observations were conducted in autumn 2025 using a laser strainmeter and an above-water video camera monitoring the oscillations of marker objects on the sea surface.

The above-water video camera recorded the position of special markers placed in the bay. The most effective marker object proved to be an inflatable life raft placed on the aft section of a floating barge subjected to vertical oscillations under wave action. The white container of the raft provided high contrast and was clearly visible both during the day and at night. Fig. 2 shows an example of the video recording of marker objects by a stationary camera, as well as the arrangement of the markers and the above-water video camera used during observations at the head of Alekseev Bay.

To convert the vertical displacements of the marker object from the pixels to metric units, image calibration was performed. The structural elements and equipment of the barge indicated in Fig. 2, whose geometric dimensions had been measured in advance, were used as reference objects. Comparison of their actual dimensions with the corresponding dimensions in the video frames made it possible to determine the scale factors (cm/px) for each element and to estimate the spread of the obtained values.

F i g. 2. Frame from continuous video recording of marker objects in Alekseev Bay, showing the elements used for metric image calibration: *1* – diameter of the inflatable life raft (ILR); *2* – edge of the deckhouse structure; *3* – the left vertical post

Table 1 shows the actual dimensions of the selected elements, their dimensions in the video frames (in pixels), the calculated scale factors, and the labels corresponding to the elements in Fig. 2.

T a b l e 1

Determination of the scale factor of video recording based on the geometric dimensions of structural elements

Number of element	Actual size, cm	Size in video frame, px	Scale factor, cm/px
1	70	100	0.7
2	183	263	0.696
3	204	297	0.687

The spread of estimates does not exceed 2 %, which indicates that perspective distortion has little influence within the selected area of the frame. The mean value was adopted as the working scale factor:

$$K = 0.69\ \text{cm/px}.$$

Thus, the time series of vertical displacements of the marker object, obtained in pixels using QAVIS software [15], was converted to physical units (centimetres), which enabled a quantitative comparison with independent instrumental measurements.

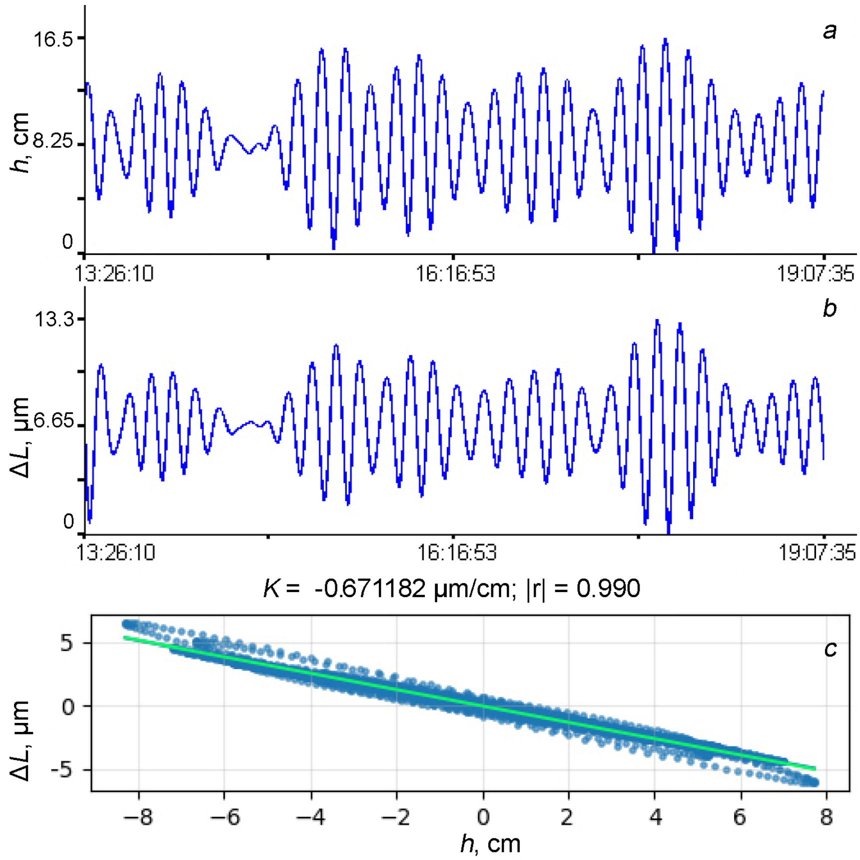
Calibration of the laser strainmeter using video observation data. To convert displacement measurements into equivalent amplitudes of sea level oscillations, the laser strainmeter data were compared with synchronous video recordings of the marker object. The vertical displacements of the marker expressed in centimetres (see above) were used as the video-derived parameter, whereas the micro-displacements of the base of the measurement arm of the laser strainmeter (µm) were used as the strainmeter parameter.

The original video-recording and strainmeter time series contain low-frequency variations (meteorological and quasi-static components) and high-frequency fluctuations unrelated to the fundamental seiche mode. To isolate the signal corresponding to the fundamental seiche mode, the signals were preprocessed and then filtered within the same frequency band. Bandpass filtering within the frequency range of 0.0013–0.0020 Hz suppressed slow trends and high-frequency components, allowing the signals to be compared based on their dominant component, with a period of 10.5 min.

The signals were then compared over synchronous time intervals. For each interval, the agreement between the oscillations was assessed using the correlation coefficient, after which the linear transformation coefficient relating the video signal $h(t)$ (cm) to the strainmeter signal $\Delta L(t)$ (μm) was calculated using the following relationship:

$$\Delta L(t) = Kh(t),$$

where K is the transformation coefficient (μm/cm) characterising the deformation response of the shore to seiche-induced sea level oscillations. An example of the comparison between the signals over an interval with an increased amplitude of seiche oscillations is shown in Fig. 3.



F i g. 3. Comparison of video-derived record and deformation signal during the period of increased amplitude of seiche oscillations on November 16, 2025: *a* – sea level fluctuations based on video observation data; *b* – micro-displacements recorded by a laser strainmeter; *c* – scatterplot of instantaneous values of displacements and sea level, and linear approximation (green line) $\Delta L = Kh$

To check the stability of the estimates, the coefficient K was determined for a series of intervals, including periods of both relatively weak excitation and increased amplitudes of seiche oscillations. Table 2 shows the maximum amplitudes of sea level oscillations derived from video recording data, h_{max}, and the corresponding micro-displacements of the strainmeter base, ΔL_{max}, for synchronous observation intervals. The absolute value of the correlation coefficient between the video-derived sea level signal and the strainmeter signal, |r|, is also presented.

T a b l e 2

Determination of the linear transformation coefficient *K* based on synchronous intervals of video recordings and deformation measurements in November 2025

Observation interval	h_{max}, cm	ΔL_{max}, μm/cm	K, μm/cm	|r|
November 2 12:00–23:00	4.83	2.72	0.649	0.918
November 5 09:00–16:00	9.75	5.91	0.632	0.994
November 7, 19:00 – November 8, 07:00	13.12	8.51	0.685	0.968
14:00–22:00	5.92	3.99	0.633	0.979
November 14, 17:00 – November 15, 05:00	8.18	5.28	0.696	0.929
15:00–18:00	16.52	13.29	0.671	0.99

The transformation coefficient was determined from a series of synchronous observation intervals with varying seiche amplitudes (Table 2). For all the intervals considered, strong agreement was observed between the video-derived sea level and strainmeter signals ($|r| = 0.918 - 0.994$), indicating that both signals reflect the same fundamental-mode oscillation with a period of about 10.5 min. The obtained values of the coefficient K clustered in the range of 0.63–0.70 μm/cm for most intervals. In intervals with weak excitation ($h_{max} \approx$ 3–4 cm), greater variability in the estimates of K was observed, which was attributed to the limited accuracy of video measurements over a small dynamic range and a lower signal-to-noise ratio. Therefore, to calculate the final estimate of the transformation coefficient, it is advisable to use intervals in which the amplitude of the video-derived sea level signal exceeds 4 cm.

Estimates of the transformation coefficient K show little dependence on the amplitude within the range considered and cluster around $K \approx 0.66$ μm/cm. According to Table 2, the mean value of the transformation coefficient is

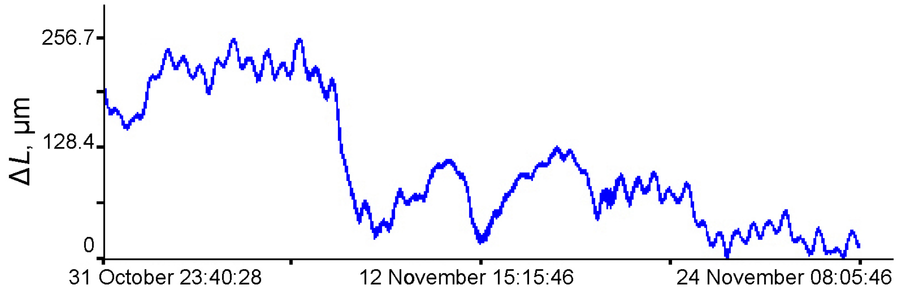
$$K = 0.66 \pm 0.03 \text{ μm/cm},$$

where the indicated spread reflects the variation among the estimates obtained for individual intervals. The obtained coefficient enables the micro-displacement data recorded by the laser strainmeter on Popov Island to be converted into equivalent estimates of seiche-induced sea level amplitude using the relation $h(t) = \Delta L(t)/K$, which can subsequently be used to analyse changes in the seiche activity of Alekseev Bay.

General dynamics and spectral structure of seiche oscillations in Alekseev Bay

Before proceeding to a detailed analysis of the spectral characteristics of seiche oscillations, we first consider the general dynamics of the strainmeter signals recorded by the coastal laser strainmeter in Alekseev Bay.

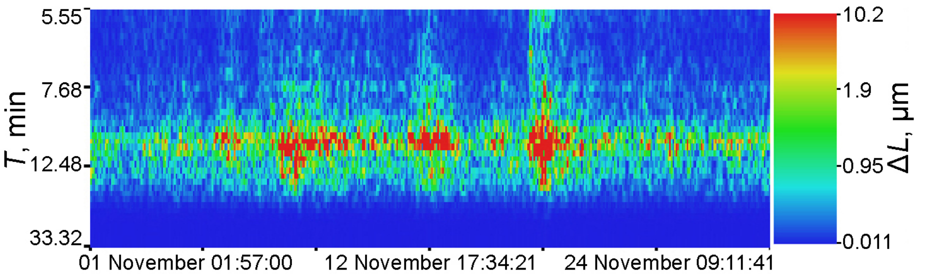
A 25-day fragment of the continuous strainmeter record (from 31 October to 24 November 2025), reflecting the characteristic features of signal variations over timescales ranging from hours to several weeks, is shown in Fig. 4. Over such an extended time interval, the dominant components of the record are the diurnal and semidiurnal tidal components, as well as slower variations caused by changes in atmospheric pressure and synoptic processes, with timescales of up to several days.



F i g. 4. Section of coastal laser strainmeter data record for 31 October–24 November 2025

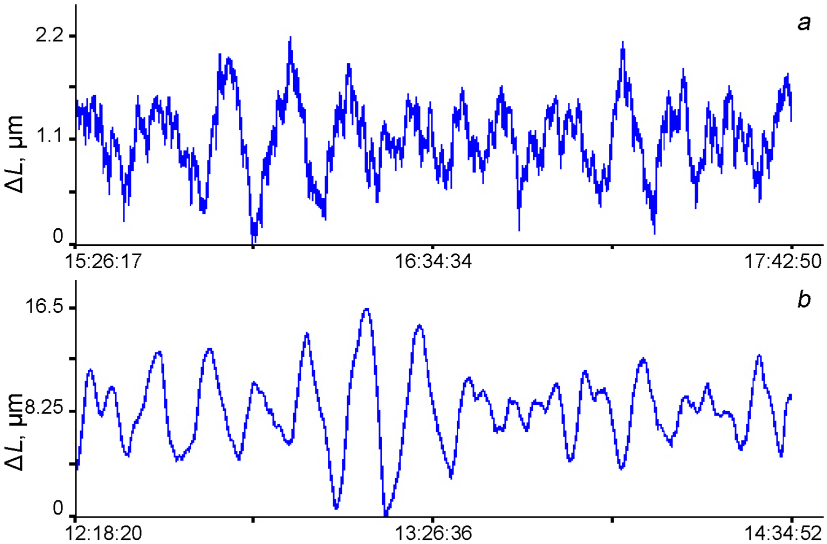
Intervals in which the record trace appears visually thicker are readily identifiable against these slowly varying components. Such intervals correspond to substantial increases in the amplitude of seiche oscillations in Alekseev Bay. Although the contribution of seiches to the total strainmeter signal over long timescales is relatively small, episodic increases in their amplitude are clearly visible even without preliminary filtering and indicate the episodic excitation of the bay's eigenmodes.

For a more detailed analysis of the temporal evolution of seiche oscillations, Fig. 5 shows a dynamic spectrogram of a record fragment, constructed over the range of periods corresponding to the natural oscillations of Alekseev Bay. The use of a dynamic spectrogram makes it possible to trace not only the presence of individual seiche modes but also changes in their amplitude over time. Stable energy bands corresponding to the main periods of seiche oscillations in the bay are clearly distinguished in the spectrogram. At the same time, the modulation of the intensity of these bands is clearly visible, reflecting the alternation between periods of weak and strong seiche excitation.



F i g. 5. Dynamic spectrogram of a fragment of the laser strainmeter record from 1 to 24 November 2025

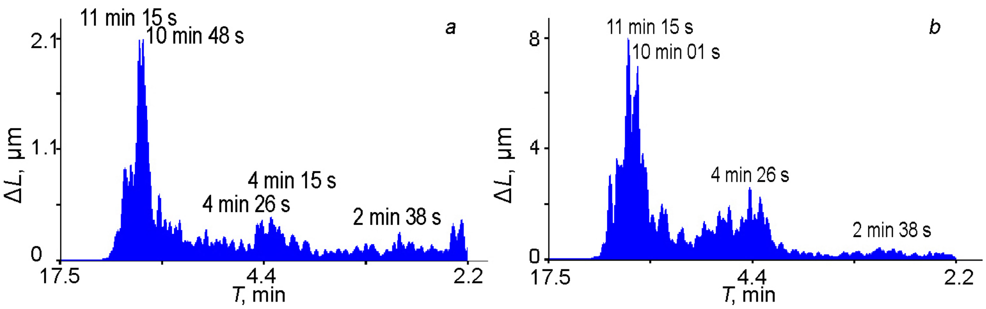
To illustrate the variability in the amplitude of seiche oscillations, Fig. 6 presents two fragments of the strainmeter record corresponding to different hydrodynamic conditions in Alekseev Bay. The upper panel shows an example of relatively calm conditions in the bay, with minimal seiche amplitude, whereas the lower panel presents a record fragment obtained after the intensification of wind forcing, which was accompanied by a marked increase in seiche amplitude.



F i g. 6. Examples of recording seiche oscillations by a coastal laser strainmeter in Alekseev Bay in 2025. Sections of the records showing weak exciting of seiche oscillations on November 2 (*a*) and at increased wind forcing on November 16 (*b*) are shown

Despite the significant difference in oscillation amplitudes, the characteristic signal periods in the two record fragments appear to coincide, suggesting that the eigenfrequencies of the bay remain unchanged under different excitation conditions.

To quantitatively compare the spectral characteristics of the signals under weak and strong seiche excitation, Fig. 7 shows the amplitude spectra of the strainmeter signals, calculated from daily time series containing the corresponding intervals shown in Fig. 6. The spectra show the dominant periods corresponding to the eigenmodes of Alekseev Bay.



F i g. 7. Amplitude spectra of the strainmeter signals calculated from daily records: *a* – during the periods of weak exciting of seiches; *b* – during the wind-induced intensified exciting of seiches

Comparison of the spectra reveals that the intensification of external forcing leads mainly to an increase in the amplitude of seiche oscillations, while the dominant periods remain virtually unchanged. This supports the interpretation that the observed oscillations correspond to the eigenmodes of the bay, whose frequencies are determined by its geometry and bathymetry, rather than by the nature of the external forcing.

Relationship between seiche oscillations in Alekseev Bay and its geometry and bathymetry

Classical seiche theory has been generalised to real bays and harbours of complex shape [1]. In the long-wave approximation, in which the wavelength significantly exceeds the water depth, the phase velocity of gravity waves is given by

$$c = \sqrt{gH}, \tag{1}$$

where g is the gravitational acceleration, and H is the effective depth, which depends on the spatial distribution of the energy associated with a given oscillation mode.

Fundamental longitudinal seiche in a semi-enclosed bay. A semi-enclosed bay with an open entrance is often treated as a quarter-wave resonator, with a node of sea level oscillations located near the entrance but displaced beyond the bay. In this case, the quarter-wave form of Merian's formula is used for the fundamental mode [1]:

$$T_0 = \frac{4L_{\text{eff}}}{\sqrt{gH_{\text{eff}}}}, \tag{2}$$

where L_{eff} is the effective length of the bay, which exceeds its geometric length due to the so-called entrance correction; H_{eff} is the effective depth for this mode [1]. According to historical observation data [11] and laser strainmeter data, a period $T_0 \approx 10.5$ min (630 s) is consistently observed in Alekseev Bay. It corresponds to the maximum spectral amplitude and is therefore interpreted as the fundamental seiche.

The geometric longitudinal scale of the bay, determined from its shoreline and cross-sections, is $L \approx 1.3$–1.5 km. Owing to the open entrance, L_{eff} is expected to exceed the geometric length of the bay. Substituting the corresponding values into the expression for the period gives an estimate of the effective depth:

$$H_{\text{eff}} = \frac{1}{g}\left(\frac{4L_{\text{eff}}}{T_0}\right)^2. \tag{3}$$

This estimate (≈ 8–10 m) is in good agreement with the bathymetry of the bay: depths of 15–16 m occur in the central part of the bay, while the nearshore areas and the southern part of the bay are characterised by shallower depths. Thus, the period of 10.5 min can reasonably be interpreted as the fundamental longitudinal seiche of Alekseev Bay as a whole, consistent with the results previously obtained for bays of comparable size [11].

First eigenmode of the bay. A persistent spectral peak at a period $T \approx 2$ min 38 s (158 s) is observed in the laser strainmeter signal; this period does not correspond to a harmonic of the fundamental longitudinal mode. In a one-dimensional approximation, such oscillations could be interpreted as a transverse seiche, but for bays of complex shape and non-uniform bathymetry, this classification would be an oversimplification.

According to the theory of natural oscillations of coastal basins developed by A.B. Rabinovich, real bays should be considered two-dimensional resonators, in which the periods of seiche oscillations are determined by the combined influence of longitudinal and transverse scales, as well as the spatial distribution of depths [1].

In this case, the eigenfrequencies ω_j are obtained by solving the boundary-value problem for the shallow-water equations and cannot be expressed using simple one-dimensional relationships such as Merian's formula.

In a first approximation, the angular eigenfrequencies of long waves can be estimated as

$$\omega_j^2 \sim gH_{\text{eff}}\left(k_{x,j}^2 + k_{y,j}^2\right), \tag{4}$$

where H_{eff} is the effective depth, depending on the spatial localisation of the energy of a given mode, and $k_{x,j}$ and $k_{y,j}$ are the effective wavenumbers determined by the bay geometry and boundary conditions.

In bays such as Alekseev Bay, which have variable width and abrupt depth changes near the entrance, the nodal lines of eigenmodes are often diagonally oriented, and the amplitude distribution does not exhibit simple longitudinal or transverse symmetry. According to [1], higher eigenmodes in such basins are often mixed modes formed by the interaction of longitudinal and transverse standing waves.

This structure of the first eigenmode, with an estimated period of about 2.7 min, was identified in Alekseev Bay through field measurements and numerical modeling [11]. The modeling results showed that this mode has one nodal line oriented diagonally across the bay (east-northeast – west-southwest) and two antinodes, with the main antinode localised in the innermost part of the bay, near the steep southern shore.

Thus, the period $\mathrm{T}_1 \approx 2$ min 38 s should be attributed to the first eigenmode of Alekseev Bay. This mode has a two-dimensional spatial structure and cannot be described as a purely longitudinal or transverse seiche using one-dimensional theory. The significant concentration of the modal amplitude in the inner part of the bay explains why the mode is effectively recorded by the coastal laser strainmeter installed near the main antinode. Its amplitude is also strongly modulated when wind forcing intensifies.

Localised eigenmode of the inner sub-basin. In the spectrum of the strainmeter signal, a persistent peak at a period of approximately $T \approx 4.1 - 4.3$ min is observed, in addition to the fundamental seiche with a period of about 10.5 min and the first eigenmode with a period of about 2.6–2.7 min. This peak does not correspond to a harmonic of the fundamental mode and indicates the presence of an additional resonant scale within Alekseev Bay.

Analysis of the coastline indicates that the southern (inner) part of the bay forms a sub-basin bounded by prominent capes, with a characteristic longitudinal extent of about 1.0 km. At typical effective depths in this area ($H_{\text{eff}} \sim 9$–11 m), the characteristic period of natural oscillations is about 4 min, consistent with the observed spectral peak.

It should also be emphasised that, in accordance with the general theory of seiche oscillations in basins with complex geometries, the eigenmodes are defined as solutions to a two-dimensional boundary-value problem for the shallow-water equations, and their frequencies scale according to the following relationship:

$$\omega_j^2 = gH_{\text{eff}}\lambda_j, \tag{5}$$

where λ_j are the eigenvalues depending on the basin geometry and boundary conditions [1]. Accordingly, the period of about 4.2 min should be interpreted not as a purely one-dimensional longitudinal seiche, but as a localised eigenmode of the inner sub-basin, whose spatial structure is determined by the configuration of the southern part of the bay.

The localisation of the modal amplitude in the inner part of the bay enables its consistent detection by the coastal laser strainmeter and emphasises the role of the internal geometric heterogeneity of the bay in the formation of the seiche spectrum.

Conclusion

This study presents the results of the recording and analysis of seiche oscillations in Alekseev Bay (Popov Island). The study is based on data from a coastal laser strainmeter installed close to the shore. The results demonstrate that measurements of micro-displacements of the Earth's crust adjacent to the bay enable its natural oscillations to be reliably recorded under different hydrodynamic conditions, including both weak and intense atmospheric forcing.

Comparison of video-derived sea level data with strainmeter measurements revealed that seiche oscillations in the bay contribute appreciably to the long-period strainmeter signal, confirming the hydrodynamic origin of the recorded oscillations.

The strainmeter measurements were calibrated against independent video-derived data on sea level oscillations. It was found that the amplitude of the strainmeter signal was linearly proportional to the amplitude of sea level oscillations within the frequency band of the fundamental seiche mode. A transformation coefficient $K = 0.66 \pm 0.03\ \mu\text{m/cm}$ was obtained and can be used to estimate the amplitude of seiche-induced sea level oscillations from strainmeter data. The high absolute values of the correlation coefficient ($|r| > 0.9$) support the physical validity of the relationship.

Analysis of the time series and their spectrograms revealed that the intensification of wind forcing in the bay results in increased seiche amplitudes, whereas the dominant periods remain nearly unchanged. This supports the conclusion that the observed oscillations correspond to the eigenmodes of the bay, whose frequencies depend on its geometry and bathymetry, not on the nature of the external forcing.

Three main periods are clearly distinguished in the spectrum of the strainmeter signal. The period of approximately 10.5 min corresponds to the fundamental longitudinal seiche of Alekseev Bay as a whole, which behaves as a semi-enclosed basin with an open entrance. The effective-depth estimate derived using Merian's formula is in good agreement with the actual bathymetry and previously published data.

The period of about 2.6–2.7 min corresponds to the first eigenmode of the bay. Unlike the fundamental mode, it has a complex two-dimensional spatial structure and cannot be described simply as a longitudinal or transverse seiche. According to the theory of seiche oscillations in basins of complex shape, this mode is a solution to a two-dimensional boundary-value problem for the shallow-water equations. The main antinode is located in the inner part of the bay, which apparently facilitates the detection of these oscillations and their amplitude modulation during the intensification of wind forcing.

In addition, a localised eigenmode of the inner sub-basin with a period of about 4.1–4.3 min is present in the spectrum. This period is determined by the geometry and bathymetry of the southern part of the bay and does not correspond to a harmonic of the fundamental longitudinal seiche. The presence of such a mode emphasises the important role of the internal geometric heterogeneity of the bay in the formation of its resonant response.

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About the authors:
Vladimir A. Chupin, Head of the Laboratory of Physics of the Geospheres, V.I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch of the Russian Academy of Sciences (43 Baltiyskaya Str., Vladivostok, 690043, Russian Federation), DSc. (Phys.-Math.), **ORCID ID: 0000-0001-5103-8138**, **ResearcherID: G-8803-2016**, **Scopus Author ID: 7004931608**, **SPIN-code: 3093-7705**, chupin@poi.dvo.ru

Grigory I. Dolgikh, Chief Researcher, Laboratory of Physics of the Geospheres, V.I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch of the Russian Academy of Sciences (43 Baltiyskaya Str., Vladivostok, 690043, Russian Federation), DSc. (Phys.-Math.), Academician of RAS, **ORCID ID: 0000-0002-2806-3834**, **ResearcherID: A-7685-2014**, **Scopus Author ID: 7003888822**, **SPIN-code: 5241-3375**, dolgikh@poi.dvo.ru

Vitaly K. Fishchenko, Head of the Sector of Oceanological Information Analysis, V.I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch of the Russian Academy of Sciences (43 Baltiyskaya Str., Vladivostok, 690043, Russian Federation), CSc. (Tech.), **ORCID ID: 0000-0002-5744-8207**, **Researcher ID: ABF-7810-2021**, **Scopus Author ID: 6506814798, SPIN-code: 4349-8370**, fischenko@poi.dvo.ru

Petr S. Zimin, Senior Researcher, Laboratory of Geophysical Fields, V.I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch of the Russian Academy of Sciences (43 Baltiyskaya Str., Vladivostok, 690043, Russian Federation), CSc. (Geol.-Mineral.), **Scopus Author ID: 6602169956**, **SPIN-code: 9932-6299**, zimin@poi.dvo.ru

Sofia K. Shabelnikova, Senior Engineer, Laboratory of Physics of the Geospheres, V.I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch of the Russian Academy of Sciences (43 Baltiyskaya Str., Vladivostok, 690043, Russian Federation), **Scopus Author ID: 60636396200, SPIN-code:** shabelnikova.sk@poi.dvo.ru

Vyacheslav A. Shvets, Senior Researcher, Laboratory of Physics of the Geospheres, V.I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch of the Russian Academy of Sciences (43 Baltiyskaya Str., Vladivostok, 690043, Russian Federation), CSc. (Tech.), **ORCID ID: 0000-0002-4752-6865**, **Scopus Author ID: 14058856800**, **SPIN-code: 3267-9037**, vshv@poi.dvo.ru

Sergey V. Yakovenko, Leading Researcher, Laboratory of Physics of the Geospheres, V.I. Il'ichev Pacific Oceanological Institute, Far Eastern Branch of the Russian Academy of Sciences (43 Baltiyskaya Str., Vladivostok, 690043, Russian Federation), CSc. (Tech.), **ORCID ID: 0000-0003-3784-9449**, **Scopus Author ID: 7005827431**, **SPIN-code: 8671-8234**, ser_mail@poi.dvo.ru

Contribution of the co-authors:
Vladimir A. Chupin – conceptualization, methodology, software development, data processing and analysis, visualization, and writing of the original draft

Grigory I. Dolgikh – scientific supervision, interpretation of the results, critical review of the manuscript, and development of the approach for comparing video-derived sea-level variations with laser strainmeter measurements

Vitaly K. Fishchenko – processing and analysis of video observations, spatial calibration of video images, and preparation of the corresponding graphical materials

Petr S. Zimin – organization of field video observations, installation and operation of the video recording system, and data acquisition

Sofia K. Shabelnikova – participation in the field installation and adjustment of the laser strainmeter, preparation and preliminary processing of strainmeter data

Vyacheslav A. Shvets – development of the strainmeter data acquisition system, participation in the construction and commissioning of the laser strainmeter, and technical support of long-term measurements

Sergey V. Yakovenko – construction, installation, adjustment, and maintenance of the laser strainmeter, including adjustment of the interferometric system and technical support of field measurement

The authors have read and approved the final manuscript.
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