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Online Publication of Tiltmeter Data Based on the SeedLink Protocol

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Abstract—The main goal of this work is to provide real-time access to the data of the NSH tunnel tiltmeters via the Internet. Software is developed that solves this problem and also provides real-time visualization and archiving of data. The solution is based the specialized real-time protocol SeedLink, which ensures lossless data delivery with minimal transmission overhead. In order to simplify access to the device via IPv4 and to protect data from unauthorized access, a secure channel based on virtual private networks has been used. The solution was tested on two tiltmeters installed in the building of the Institute of Physics of the Earth, Russian Academy of Sciences (IPE RAS). Further device testing with an unstable power supply and communication conditions is planned. Therefore, the developed software was ported to energy-efficient ARM computers. Data transmission tests were carried out in the local IPE RAS network and in the wireless network of a mobile network operator. Real-time visualization of data from both tiltmeters and access to the archive are provided in addition to real-time access to data on the IPE RAS website.

Keywords: tiltmeter, real-time data transmission, miniSEED, SeedLink, SeisComP3

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INTRODUCTION

One of the key trends in developing systems for geodynamic monitoring of critical facilities and structures is near real-time observations (Kuzmin, 2014). Such observations make it possible to solve a number of problems in a comprehensive manner, including the study of long-term operational stability of precision equipment and methods for processing the obtained data, as well as determining the deformation resistance of the building of the Institute of Physics of the Earth as a critical facility.

In this paper, the real-time publication of data from two NSH tunnel tiltmeters installed on buried pedestals in the specially equipped basement of the Institute of Physics of the Earth, Russian Academy of Sciences (IPE RAS), is described. The tiltmeters of this series were developed at the Special Design Bureau of the Institute of Physics of the USSR Academy of Sciences and had unique characteristics at the time of their development (mid-1990s). They are described in the next section. The device has been repeatedly upgraded. In particular, digital representation of the measured signal was implemented based on the E14-440M 14-bit USB analog-to-digital converter (ADC) (L-Card..., www.lcard.ru): the analog output signal of both devices is fed to the ADC input, where it is digitized at a frequency of 1 Hz.

LGraph2 software supplied with the ADC visualized the obtained data and stored the recorded data in files with its own binary format. LGraph2 has no tools for real-time data publishing. Trivial solutions, such as placement of recorded files on an FTP server or in cloud storage, cannot be considered satisfactory, because in this case the use of data will require specific software to read and/or convert them.

In addition, the data files themselves do not contain metainformation, such as information on the number of channels, sampling frequency, etc. This information is stored in separate header files, which are also generated by LGraph2. The format of header files is limited by the time error, which is no better than 1 s. This significantly complicates analysis of the results in the LGraph2 format in the case of long observations with high requirements on time measurement accuracy.

A tiltmeter is essentially a seismometer with a wide dynamic range that detects two orthogonal components of the surface displacement gradients. Therefore, the idea naturally arises of using approaches and solutions in the field of long-term observations that are common in seismology for it. Currently, data acquisition in miniSEED format (IRIS, miniSEED, 2017) is the most widely used, and the SeedLink protocol (IRIS, SeedLin, 2017) based on it is used for real-time data transmission.

A detailed description of the format and protocol, as well as a description of their application for geophysical data transmission, are given in other works, in

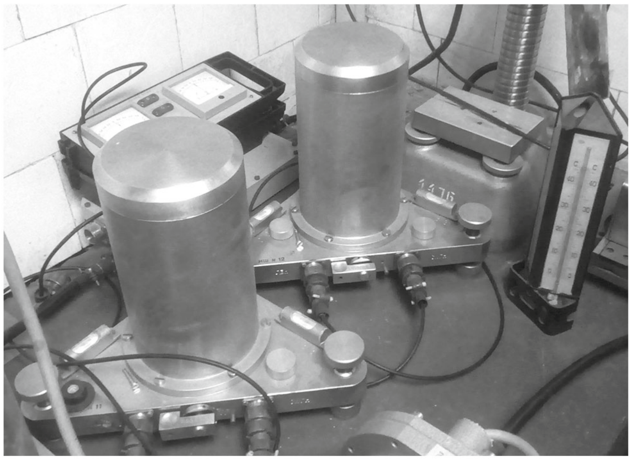

Fig. 1. Installation units of tiltmeters NSH-11 and NSH-12 on the pedestal.

particular, (Il'inskii et al., 2012; Perederin et al., 2016). The implementation of this approach for NSH tiltmeters required the development of appropriate software and a number of works on equipment harmonization, communication channel establishment, and development of data publishing mechanisms, a description of which is given below and constitutes the main content of the paper.

DESCRIPTION OF THE NSH TILTMETER

The NSH-1 tiltmeter was developed in the mid-1990s by the temporary creative team Applied Geodynamics within the ROSS cooperative, in which I.M. Vasil'ev, I.A. Shirokov, V.L. Sorokin, E.S. Grushin, N.S. Milyukova, and I.I. Suvorova participated. The device measures the tilt of the surface with respect to the local gravitational vertical in two mutually perpendicular directions along the deviation of a vertical pendulum with a capacitive transducer. The installation unit is shown in Fig. 1.

The system is supplied with power both via household ac 220 V and via dc 12 V supply. The tiltmeter delivery kit includes an installation unit, an electronics unit, a recording unit with replaceable nonvolatile memory cards, and a recording unit with electromechanical loggers. In total, 14 such kits were produced. The configuration of tiltmeters installed in the IPE RAS building has undergone a number of upgrades and includes an installation unit, an electronics unit, a USB ADC, and a personal computer as a data logger.

The current range of measured tilt is $\pm 1 \times 10^{-4}$ rad with an error of 5×10^{-10} rad (the device operates in two ranges with different accuracy). The voltage conversion factor is 5 V per angular second. The range of measured frequencies is 0–0.005 Hz. The zero drift is 2.4×10^{-6} rad/yr. The system is equipped with an integrated calibration system.

STRUCTURE OF REAL-TIME DATA TRANSMISSION SERVICE

Real-time data transmission technically means that there is a continuously functioning service that provides the user with the appropriate data stream. In our case, this is a server that provides data transmission in miniSEED format using the SeedLink real-time protocol.

The general view of the service is shown schematically in Fig. 2. The data stream from the loggers (marked 1–3 in the diagram) is converted to the miniSEED format and fed to the SeedLink service input for subsequent transmission to clients on request. Let us mention two important features of the protocol.

First, transmission is carried out in real-time: the data are available immediately after receipt from the logger. Second, the protocol guarantees lossless data delivery. Third, if necessary, the server can broadcast several channels simultaneously; i.e., one logger can be used to record and publish data from multiple devices. Finally, the output of another SeedLink server (marked with 4 in Fig. 2) can be used as an input data stream.

The latter is convenient when it is necessary to publish data from a distributed local logger network: the collected data are transmitted over the local network to a server with a stable Internet connection, and from this server the data are transmitted to the storage center. The SeedLink protocol simplifies real-time data acquisition as much as possible. For this, it is sufficient for a user to use the SeedLink client, i.e., to establish a connection to the server via the specified TCP port (usually port 18000) and select the desired channel (Fig. 3).

As in our earlier solution (Perederin et al., 2016), we used the SeedLink server implementation from the SeisComP-3 package (SeisComP..., 2017). The implementation of the client is relatively straightforward, but there is no need to write a personal program, since there are a large number of client implementations (including freely distributed ones) running on different platforms and operating systems. Strictly speaking, such clients are one of the arguments in favor of using the SeedLink protocol.

Thus, the external side of the service responsible for real-time publication of data uses standard well-developed seismology tools for transmitting and obtaining real-time tiltmeter data. However, this does not in any way apply to the part of the service that ensures acquisition of real-time input data.

In order to operate the SeedLink server, it is necessary that the input stream be in miniSEED format. In the SeisComp3 package, there is a fairly large set of various converter plugins. Some are designed to work with frequently used seismic data loggers, others to convert common file types, for example, ASCII, to miniSEED. There is also a frequently used miniSEED data input plugin via a file buffer, a named pipe, a net-

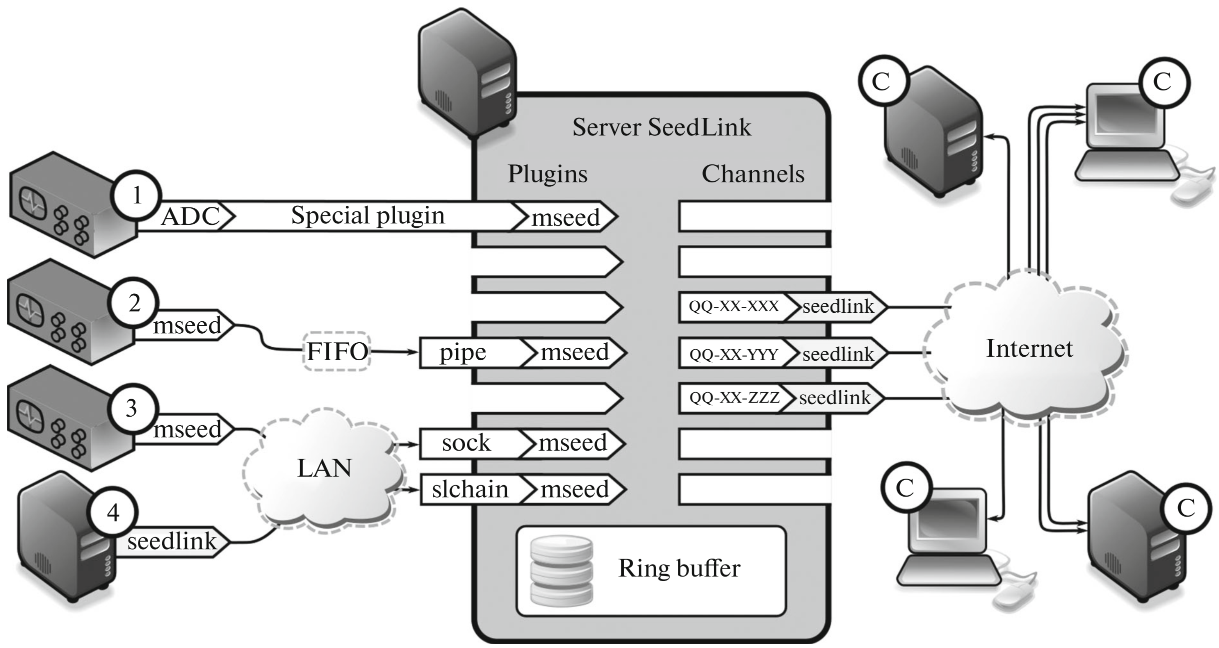

Fig. 2. General diagram of the data publishing service. The server provides access to data recorded in miniSEED format via the SeedLink protocol. In order to provide the input stream, a program (plugin) is required that converts the input data stream from the recorder to miniSEED format (1) and any miniSEED data source (2, 3) including another SeedLink server (4). Any computers with the SeedLink-client (C) installed on them can be used as the clients of the service.

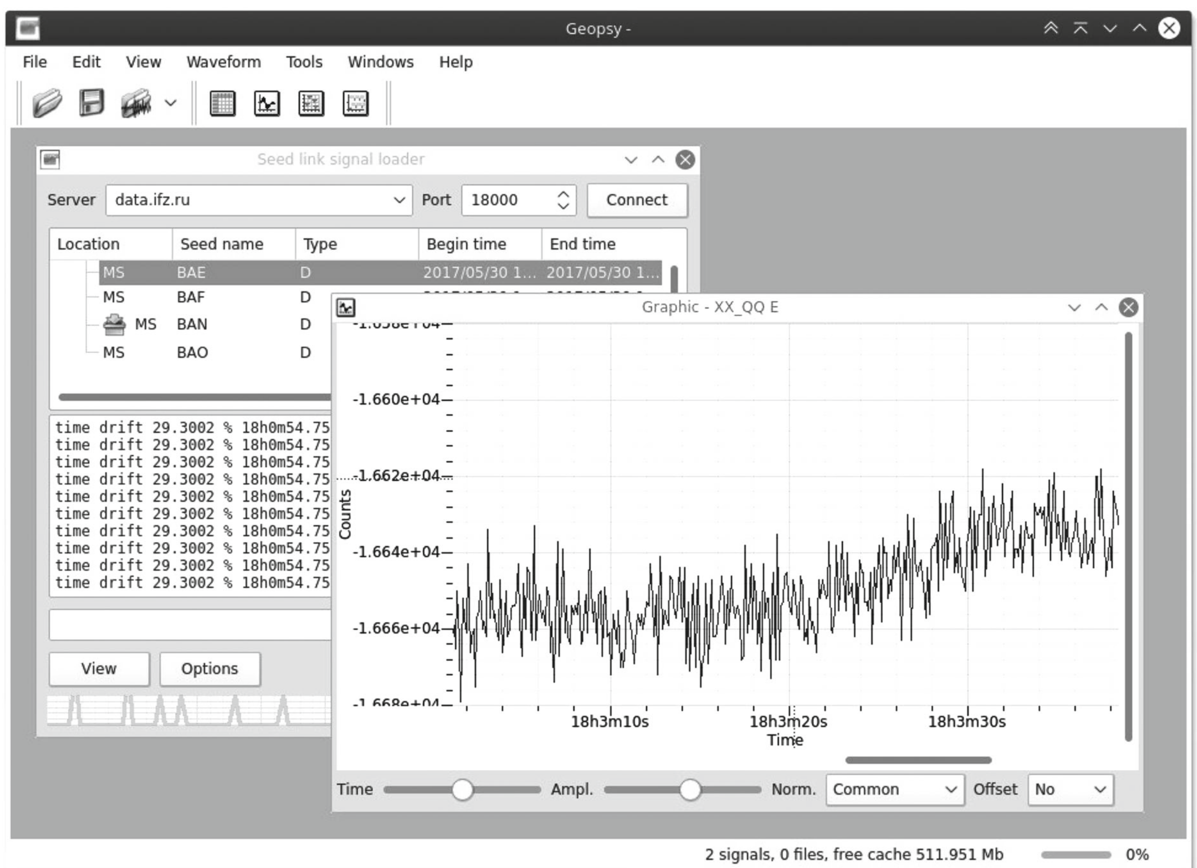

Fig. 3. Screenshot of the open source software geopsy (http://www.geopsy.org/) when receiving the time series of one of the components of the signal of the NSH-12 tiltmeter from the SeedLink server http://data.ifz.ru:18000.

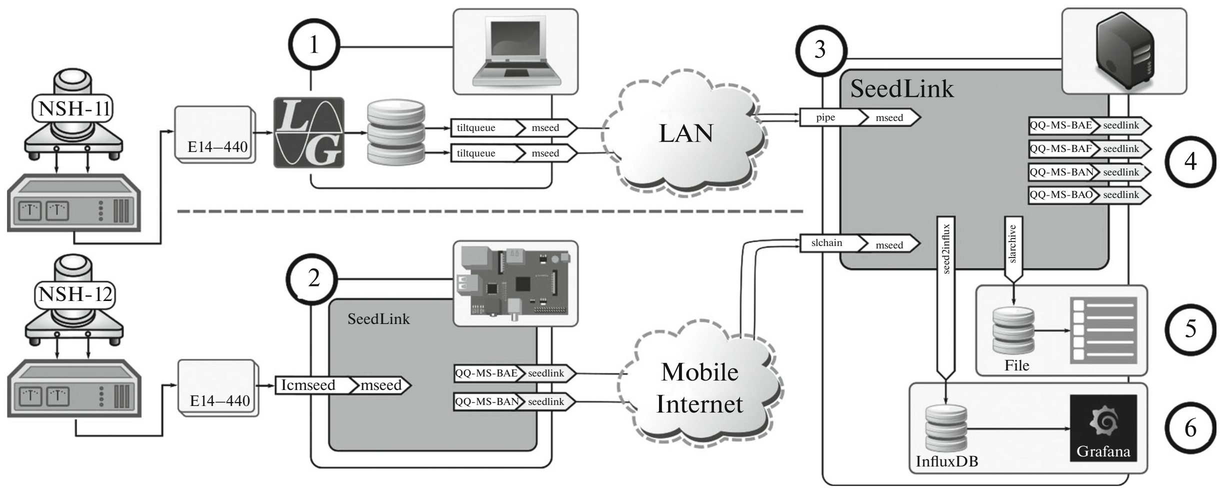

Fig. 4. Circuit diagrams of the real-time publication of NSH-11 and NSH-12 tiltmeter data. Data from NSH-11 and NSH-12 tiltmeters are converted to miniSEED format by the proprietary LGraph2 software on an Intel x86 computer (Windows operating system) (1) and the proprietary software on a single-board ARM (Arch Linux operating system) computer (2), respectively. The converted data are transferred over the local network using standard HTTP to the IPE RAS (3) data center server (NSH-11) and over the wireless channel of the mobile operator using the SeedLink protocol (NSH-12). The IPE RAS server provides real-time access to data via the SeedLink protocol (4) as well as to the daily file archive (5) and graphic display of measurement (6) via the HTTP protocol.

work socket, or a SeedLink protocol from another server.

Despite the impressive length of the list of plugins supplied with SeisComp3, there is no required component for the ADC L-Card E14-440. Therefore, the corresponding plugin was implemented by us independently using the libraries from the equipment kit as well as the libmseed library (IRIS, libmseed, 2017).

We have two tiltmeters (NSH-11 and NSH-12). This has made it possible to simultaneously test two real-time data transmission circuits (Fig. 4). When connecting the NSH-11 tiltmeter, we proceeded from ease of implementation and maximum use of existing equipment and supplied software. NSH-11 records data using a personal computer (x86 processor architecture) running the Microsoft Windows XP operating system.

The measurements are displayed in the graphics window of the LGraph2 software supplied with the ADC L-Card and are simultaneously stored in pairs of binary files of the specified format described in the attached documentation. The first is an array of 16-bit values of ADC codes received from the device. The second is a header file that contains metainformation including, in particular, the count and numbers of active ADC channels, the sampling rate, the date and time of completion of data entry, the amount of input data, and the bias and scale factors that make it possible to obtain specific values of the measured voltage from the ADC codes. The length and saving frequency of the files are determined by the LGraph2 settings. We wrote a program that controls the appearance of new files in the LGraph2 output folder.

As new files appear, the latter are converted to miniSEED format and transferred via an intermediate agent via HTTP to a remote server that transmits them in real time. On the remote server, the received files arrive at the input of the hosted SeedLink server by the named pipe (using the appropriate plugin). The software is implemented in Python (Python..., 2017) using the libmseed library. Note that, technically, miniSEED volumes could be delivered to the data center using a local SeedLink server; however, although it is possible to launch such a server in the Microsoft Windows XP operating system, it requires significant effort because the developers of MinGW have terminated support for this operating system (MinGW, 2017).

The NSH-12 tiltmeter is used to solve the problem directly. Its circuit diagram is shown in the lower part of Fig. 4. In this case, we focused on the possibility of conducting measurements under rather difficult conditions including unstable power supply and the lack of a stable broadband communication channel.

The solution is based on a single-board computer with an ARM processor, which has made it possible to significantly reduce power consumption. In the used RaspberryPi (Raspberry..., 2017) (Fig. 5), this parameter is 3 W instead of about 15–20 W for low-power x86 computers.

RaspberryPi has an integrated Ethernet controller and several USB ports, which fully meets our communication needs. In order to simulate field work with wireless data transfer, one of the ports was connected to a Huawei E171 GPRS/3G modem.

Another USB port was used to connect the ADC. An 8 GB SD card was used as a local nonvolatile memory device. The operating system Arch Linux (Arch... www.archlinux.org) was installed on it. The same card was used to store a local data archive.

Porting of standard tools necessary for the SeedLink server operation (the libmseed libraries and the software components from the SeisComp-3 package) to ARM computers does not cause any difficulties (see, for example, (Il'inskii et al., 2012)). Next, the ADC L-Card comes with a driver for the GNU/Linux operating systems. After a minor change in the source code, it was possible to use it in our device. As a result, it became possible to use the library for C lcomp, which is also supplied with the ADC, for interaction with the ADC.

Thus, all the necessary components for the development of a plugin to input our data into SeedLink were obtained; it was implemented in the C++ programming language. The software receives data from the driver using methods from lcomp, then functions from the libmseed library packages them in mini-SEED format. Packaged data are transferred to the input of the local SeedLink server using the pipe plugin.

This procedure actually solves the task, since the output of the SeedLink server can either directly transmit data to the Internet, or via the chain plugin, be the data source for a dedicated server that performs real-time data transmission, as shown at position *4* in the diagram in Fig. 2. In practice, both the local IPE RAS network and the wireless network of one of the mobile operators to connect SeedLink-servers were used with NSH-12. In order to avoid problems related to difficulties in obtaining real IPv4 addresses, we used a virtual private network (VPN) as described in (Aleshin et al., 2015) instead of a dynamic domain name system (see, for example, (Il'inskii et al., 2012)).

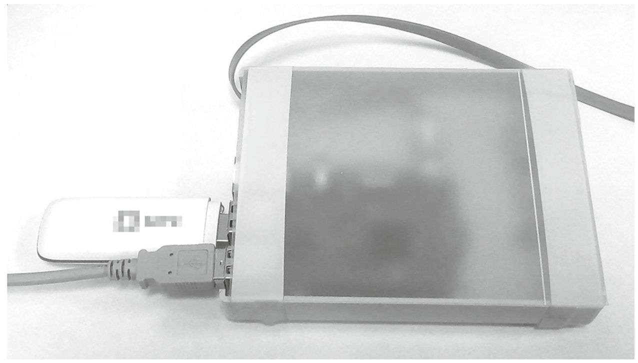

Fig. 5. RaspberryPi single-board computer in the case. The computer is powered up. The USB cable from the ADC and a 3G/GPRS modem are connected.

Testing showed that even using EDGE (modern version of the protocol for 2G mobile networks, backward-compatible with GPRS) with a minimal bandwidth, our solution ensures both stable data transfer of both tiltmeter channels and remote connection to the device via the SSH protocol.

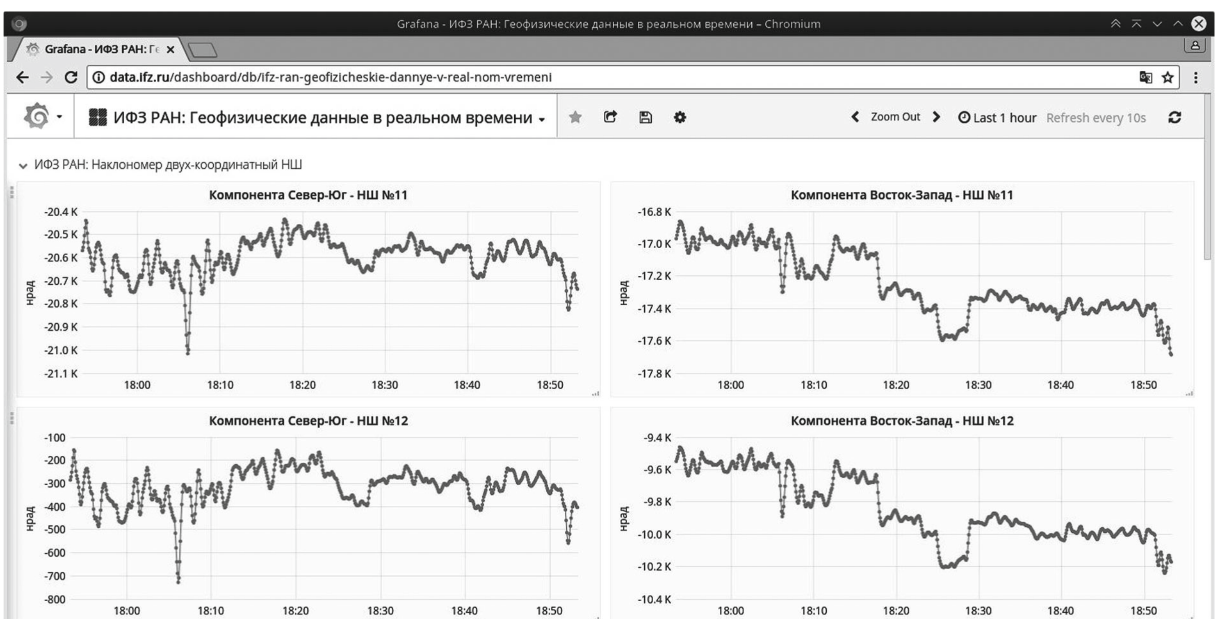

Fig. 6. Interface of the Grafana web interface displaying the real-time data from tiltmeters NSH-11 (top panels) and NSH-12 (bottom panels).

Real-time data are accessed via the SeedLink protocol in the form of corresponding streams from the IPE RAS server (http://data.ifz.ru, port 18000). In addition to general real-time access to the tiltmeter data, the developed system can be used for other purposes. Thus, we arranged a graphics display of bias components using the Grafana web interface (Grafana..., www.grafana.org) and the specialized InfluxDB database (InfluxData..., , 2017) (Fig. 6).

At present, data of both tiltmeters installed on one pedestal are transmitted, which, in particular, makes it possible to compare the stability of the devices (see Fig. 6). The web interface can be accessed via the Internet at (http://data.ifz.ru) and makes it possible to view both current data (with an adjustable update interval) and archive data at (http://dataarchive.ifz.ru/). The archive is created using the slarchive utility from the SeisComp3 toolkit in the form of daily miniSEED files.

CONCLUSIONS

The described solutions for real-time transmission of NSH tiltmeter data are original and task-oriented. At the same time, they can be used for data transmission for a sufficiently wide range of devices. This is because, on the one hand, the solutions presented in this paper are based on standard tools that have proven themselves in geophysical observations, and on the other hand, in developing the software, special attention was paid to code portability for cross-platform applications.

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