Database of the Operational Drifter Observations in the Arctic Region

T.M. Bayankina*[*], *S.R. Litvinenko, M.V. Kryl', N.Yu. Yurkevich

Marine Hydrophysical Institute, Russian Academy of Sciences, Sevastopol, Russian Federation
*e-mail: bayankina_t@mail.ru

The database (formed in MHI) for 22 drifters deployed in the Arctic region in 2012 – 2016 is represented. The most intensive drifter observations were performed in the Beaufort Sea (the Canada Basin) and in the Central Arctic.

According to the data of temperature-profiling drifters, ~ 2 million temperature profiles (including the ones acquired under the ice formations) and ~ 120.000 atmospheric pressure measurements were obtained. Total life time of drifters as at August 2016 exceeded 7000 days. General information and technical characteristics of BTC60/GPS/ice/1ps, BTC60/GPS/ice/3ps, SVP-BTC80/GPS temperature-profiling drifters are given. Features of drifter information primary preparation are enumerated and the technique of database quality assessment is shown. The studies have shown that temperature-profiling data provides the assessment of the ice thickness and its spatial-temporal variability in the region. The results of the experiments carried out in the Arctic reveal the fact that autonomous temperature-profiling "ice" drifters are an effective instrument for studying the Arctic region. According to the results of the experiments carried out in the Arctic and verification of data quality in the formed database, the drifters showed the reliability of operational characteristics. This is confirmed by failure-free operation of IMEI 245950/WMO 48541 drifter which had been performed the measurements during 1.083 days.

The obtained unique long-term series of systematic operational data can be applied for clarifying the concepts of thermal processes variability in the upper ocean layer (including the under-ice one), the dynamics of ice fields and air pressure fields in a wide range of spatial-temporal scales as well as for refining the concept of interaction processes in the Atmosphere – Ice – Ocean system.

Keywords: temperature-profiling drifter, thermo-line, water/ice temperature, temperature profile, ocean upper layer.

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Introduction. The development of polar and circumpolar regions is one of high-priority problems of modern times, therefore, in recent years the state and public interest in the problems of the Arctic region has increased. The following documents defining the purposes and objectives of the state policy in the Arctic were adopted: in 2008 – "Russian Arctic Strategy for the Period up to 2020 and for a Future Perspective" and in 2013 – "Russian Strategy of the Development of the Arctic Zone and the Provision of National Security until 2020".

The effectiveness of solving the priority problems is determined by the development level of meteorological, hydrological and ice conditions complex observation system in this region. In the world science climatic processes in the Arctic are considered as an indicator of global changes, but the current level of knowledge about the region climate system is insufficient. This is caused by an acute shortage of observational data due to a number of objective reasons: inaccessibility of the region, unfavorable meteorological conditions, limited means of remote sensing due to the presence of predominant cloudiness and ice cover, etc.

In recent decades drifter technology as a mean of operational contact monitoring has been widely developed within the framework of construction of the World Ocean and near-water atmosphere global observational network. Long-term tests of drifters in arctic conditions became the basis for developing the specialized autonomous measuring tools for the researching the water column, the Arctic ice cover and the methods of their application. Measuring-informational system on the basis of drifter technology as a mean of operational contact monitoring is one of the main segments of global observational network. Wide capabilities of drifter technologies and their economic effectiveness determine the task of creating different specialized drifting platforms adapted to the Arctic region conditions. Solution of this task is closely related to the innovative work of Marine Hydrophysical Institute (MHI) of RAS on drifter technology development [1 – 4].

UpTempO project of the University of Washington [5], aimed at investigation of temperature variation in upper- and under-ice ocean layers (measurement data is available on the website http://psc.apl.washington.edu/UpTempO/Data.php), turned out to be the most large-scale one in application of such means in the region under study.

In 2012 – 2016 hydrometeorological database was formed using the drifter measurements [6].

The structure and technical characteristics of temperature-profiling drifters. *In situ* measurements were provided by temperature-profiling drifters. Their structure is represented in Fig. 1, their technical characteristics – in Table 1.

Table 1

Technical characteristics of temperature profiling drifters

Parameters		Drifter type		
		*SVP-BTC*80/*GPS*	*BTC*60/*GPS*/*ice*/1*ps*	*BTC*60/*GPS*/*ice*/3*ps*
Air pressure, hPa	*R*	from 850 to 1054.6		
	Δ	±2.0		
	μ	0.1		
Water temperature, °C	*R*	from minus 20 to 20.94		from minus 5 to 35.94
	Δ	±0.1		
	μ	0.04		
Depth, m	*R*	from 0 to 100		
	Δ	±0.2		
	μ	0.01		
Latitude, °	*R*	from minus 90 to 90		
	Δ	±0.0005		
	μ	0.0002		
Longitude, °	*R*	from 0 до 360		
	Δ	±0.0005		
	μ	0.0002		
Horizons of temperature measurement (nominal), m		0.2; 11; 13; 15; 20; 25; 30; 35; 40; 45; 50; 55; 60; 65; 70; 75; 80	0.2; 2.5; 5; 7.5; 10; 12.5; 15; 17.5; 20; 25; 30; 35; 40; 45; 50; 55; 60	
Horizons of hydrostatic pressure measurement (nominal), m		80	60	20; 40; 60

N o t e. *R* is a range, *Δ* is an error, μ is resolution.

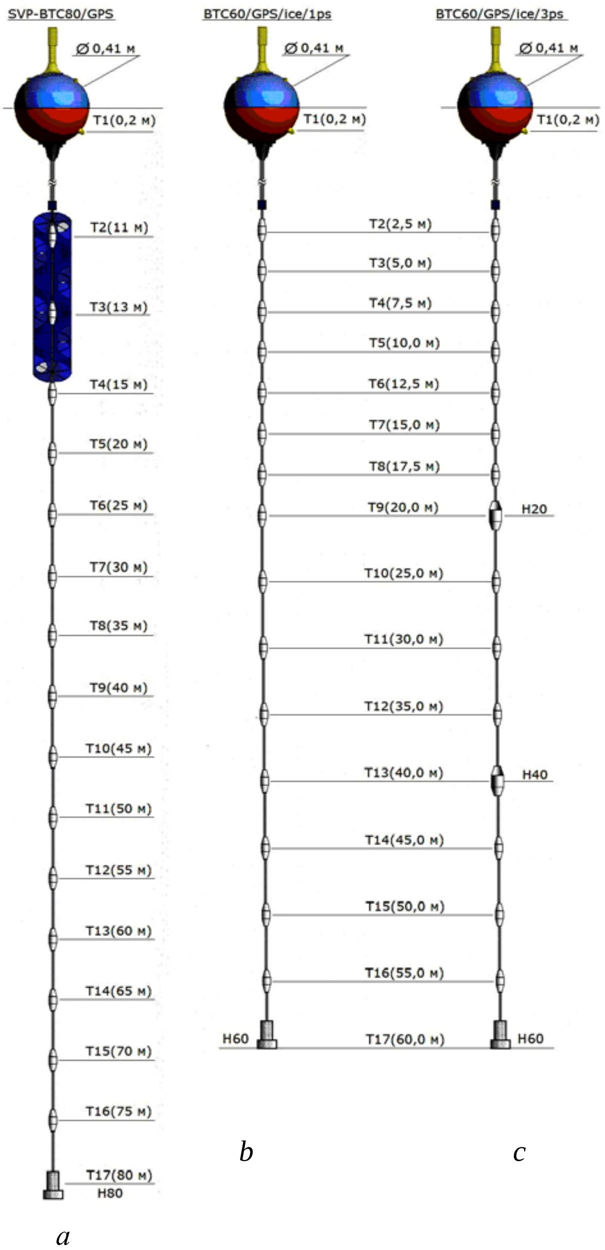


Fig. 1. The structure of MHI temperature-profiling drifters: *SVP-BTC*80*/GPS – a; BTC*60*/GPS/ice/1ps – b; BTC*60*/GPS/ice/3ps – c*

Brief description of measuring tools. *SVP-BTC*80*/GPS* drifter is a quasi-Langrangian temperature-profiling one with an underwater sail, thermoline down to 80 m and hydrostatic pressure gauge at the lower end of the temperature line (Fig. 1, *a*). *BTC*60*/GPS/ice/*1*ps* drifter is a temperature-profiling one with a thermoline down to 60 m depth and hydrostatic pressure gauge at the lower end of the line (Fig. 1, *b*). *BTC*60*/GPS/ice/*3*ps* drifter is a temperature-profiling one with a thermoline down to 60 m depth and hydrostatic pressure gauges at the lower end of the line as well as at 20 and 40 m nominal horizons (Fig. 1, *c*).

The coordinates of drifters are measured by built-in *GPS* receivers. Measurements of all parameters are carried out at the beginning of each hour. The measurement results are transmitted in messages via *Iridium* satellite communication system. The delay of message delivery to the user does not exceed 10 min [7 – 10]. It should be pointed out that drifter design allows them to be deployed both on the ice and in the open water with further freezing of their body and a part of temperature line into the ice.

Due to design features of temperature-profiling drifters, only upper horizons are fixed in depth. Actual depths of temperature sensors placed below depend on drift conditions and may differ from the nominal depths (Table 1). One may refine temperature measurement horizons by making adjustments according to thermoline geometry reconstruction algorithm with the known hydrodynamic parameters by the results of hydrostatic pressure measuring with the sensors installed in the thermoline:

$$H = P_H 100/g\rho,$$

where H is a depth; P_H is a hydrostatic pressure; g is the free fall acceleration; ρ is a density of liquid. Thermoline geometry can be reconstructed using, for instance, the method based on the known results of solving the problem of a homogeneous inextensible thread behavior in a steady flow [11].

Information on the drifters and measurement areas in the Arctic. In 2012 – 2016 period the most intensive drifter observations were carried out in the Beaufort Sea (Canadian Basin) and in the Central Arctic. The trajectories of buoy drifts and general information on them are given in Fig. 2 and Table 2, respectively.

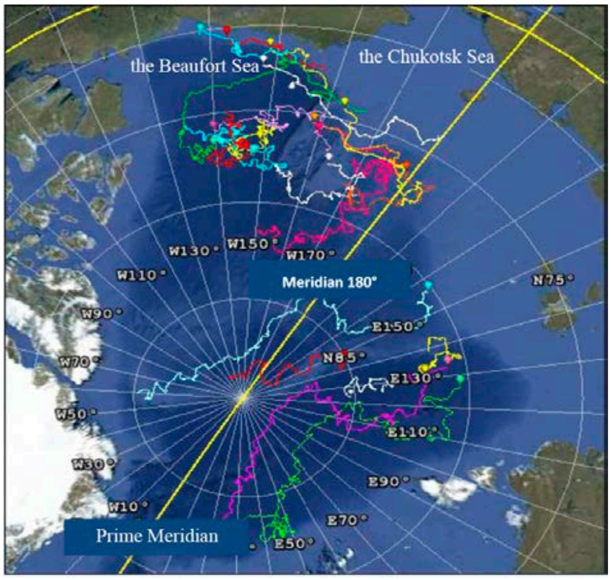


Fig. 2. Trajectories of “ice” temperature-profiling drifters deployed in the Arctic in 2012 – 2016

Total life time of drifters as at August 2016 exceeded 7000 days. According to the data of temperature-profiling drifters, ~2 million temperature profiles (including the ones acquired under the ice formations) and ~120.000 atmospheric pressure measurements were obtained. Within the framework of *UpTempO* project operational systematic monitoring of hydrometeorological parameters was performed using *BTC*60*/GPS/ice/*1*ps*, *BTC*60*/GPS/ice/*3*ps* and *SVP-BTC*80*/GPS*-type drifters measurement results of which indicate the possibilities for the ocean upper layer temperature profiling.

Temperature profiling data provides an assessment of temperature vertical distribution in the ocean upper layer near the North Pole, ice thickness and its spatial-temporal variability.

T a b l e 2

General information on the drifters deployed in the Arctic Basin

Buoy identification number	Drifter type	Thermo-line length, m	The number of hori-zons	De-ploy-ment date	Last date of meas-urements
240990	*BTC*60/*GPS/ice*/1*ps*	60	17	05.09.12	24.08.13
244780				31.08.13	11.11.13
IMEI 242970/*WMO* 48540				17.08.13	12.01.15
IMEI 242840/*WMO* 48539				22.08.13	14.09.14
IMEI 245960/*WMO* 48542				27.08.13	06.02.15
244950				29.08.13	23.02.14
IMEI 245950/*WMO* 48541				30.08.13	16.08.16
IMEI 246740/*WMO* 25584	*BTC*60/*GPS/ice*/3*ps*			30.08.13	14.10.14
IMEI 246950/*WMO* 25585				03.09.13	15.12.14
IMEI 247800/*WMO* 25586				07.09.13	23.01.15
IMEI 235160/*WMO* 48649				25.03.14	14.09.14
IMEI 233190/*WMO* 48648				01.04.14	09.09.14
IMEI 238150/*WMO* 48681				13.08.14	04.05.15
IMEI 239180/*WMO* 48682				15.08.14	17.03.15
IMEI 233150/*WMO* 48679				02.09.14	29.07.15
IMEI 236150/*WMO* 48678				06.09.14	04.05.15
IMEI 235320/WMO 48677				14.09.14	06.10.14
IMEI 237170/*WMO* 48676				14.09.14	16.10.14
IMEI 233160/*WMO* 48680				02.10.14	04.05.15
243770	*SVP-BTC*80/*GPS*	80		03.09.13	12.10.13
246990				05.09.12	10.12.12
243950				09.09.12	13.10.12

N o t e. *International Mobile Equipment Identity – IMEI; World Meteorological Organization – WMO.*

The results of arctic experiments reveal the fact that autonomous temperature-profiling "ice" drifters are an effective instrument for the Arctic region study. The obtained unique long-term series of systematic operational data allow expanding and refining the understanding of the interaction processes in the atmosphere – ice – ocean system [12].

Features of initial drifter data preparation for a database formation. Drifter information acquired via *GPS* global telemetry system sometimes contains failures of different types which may lead to erroneous results. In this regard, in order to create a reliable database interactive programs for identifying and eliminating faulty situations were developed [13].

Filtering by diving measurement results. Initial data on coordinates and sea surface temperature acquired by *SVP-BTC*80*/GPS*-type drifters is subjected to the filtering by the diving. As a result of filtering, only the data from drifting buoys with connected underwater sail was selected. Information on mean duration of drifter float submerged state acquired by the dive measurement channel is the criterion for the underwater sail presence. Continuous zero readings by this channel indicate the breakage of underwater sail. Further movement of the buoy can not be considered as Langrangian particle drift, and its trajectory is mainly determined by the wind effect.

Filtering of rough failures according to the temperature and air pressure measurement results. To filter the failures in data on the surface temperature and its profiles, the program by which the acquired information is processed has been developed. The program allows one interactively detect the failed measurement and delete it. The rejection of water temperature measurement results is carried out on the basis of two consistently applied criteria. The range of physically significant temperatures of the sea upper layer in the drift region is taken as the first criterion, and as the second one the threshold value of the temperature gradient specified by the operator is taken. The samples where temperature values exceed the threshold one are considered to be faulty.

The procedure for filtering the faults in air pressure data is similar to the technique for temperature data filtering. The readings in which the values of pressure gradients exceed 1 hPa/h are classified as doubtful ones. The solution for such realizations is made by analyzing the monotonicity of the pressure values in subsequent readings or by using the data acquired from other sources in a compatible spatial-temporal scale. After carrying out the abovementioned procedures of primary data filtering and processing at rough failures, the entire drifter measurement array was systematized and composed into a database by the following structure.

The structure of drifter database. Drifter database includes the measurements obtained by 22 drifters (Table 2). For each drifter there is a separate text file with *".txt"* extension and the name in *ASCII* encoding corresponding to the identification number of the drifter. The database is systematized by the types of drifters and consists of *"Archive_Arctic"* top-level directory within which there are three catalogs: *"SVP-BTC80_GPS"*, *"BTC60_GPS_ice_1ps"* and *"BTC60_GPS_ice_3ps"*. Within each of these directories the text files with the data of drifters of appropriate type are placed. For instance, the path "*Archive_Arctic/SVP-BTC*60*_GPS_ice_*1*ps/*240990*.txt*" corresponds to *BTC*60/*GPS/ice/*1*ps* type drifter with 240990 identification number.

The content of text files is ordered by lines and columns. "Space" symbol is used as a separating sign. Each line of text file contains the result of one drifter measurement cycle, except for the first line where the names of columns are given.

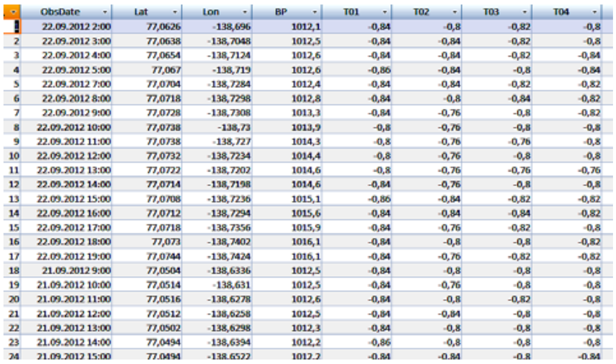
The number of columns may vary from 23 to 25 depending on the number of hydrostatic pressure sensors (Table 3).

T a b l e 3

An example of the fragment with 243770.*txt* file data for -*BTC*80/*GPS*-type drifter

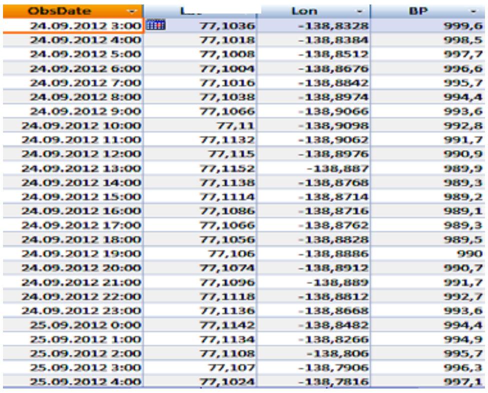
ObsDate	*ObsTime*	*Lat*	*Lon*	*BP*	*T*01	*T*…	*T*17	*H*80
03.09.2013	10:00	71.4	-148.9	1007.5	2.96	...	-1.28	79
03.09.2013	11:00	71.4	-148.9	1006.6	2.88	…	-1.28	81
03.09.2013	12:00	71.4	-148.9	1005.7	2.84	…	-1.20	81
03.09.2013	13:00	71.4	-148.9	1005.5	2.8	…	- 1.32	83

The columns of Table 3 contain the following information: *ObsDate* is a measurement date; *ObsTime* is a measurement time; *Lat* is latitude; *Lon* is a longitude; *BP* is an air pressure; *T*01 … *T*17 is water (ice) temperature calculated at the nominal depths (Table 1); *H*80 is a depth calculated by the readings of hydrostatic pressure sensor placed at 80 m nominal horizon (Fig. 1, *a*).



	ObsDate	Lat	Lon	BP	T01	T02	T03	T04
1	22.09.2012 2:00	77,0626	-138,696	1012,1	-0,84	-0,8	-0,82	-0,8
2	22.09.2012 3:00	77,0638	-138,7048	1012,5	-0,84	-0,84	-0,82	-0,8
3	22.09.2012 4:00	77,0654	-138,7124	1012,6	-0,84	-0,84	-0,82	-0,84
4	22.09.2012 5:00	77,067	-138,719	1012,6	-0,86	-0,84	-0,8	-0,84
5	22.09.2012 7:00	77,0704	-138,7284	1012,4	-0,84	-0,84	-0,82	-0,82
6	22.09.2012 8:00	77,0718	-138,7298	1012,8	-0,84	-0,8	-0,84	-0,82
7	22.09.2012 9:00	77,0728	-138,7308	1013,3	-0,84	-0,76	-0,8	-0,82
8	22.09.2012 10:00	77,0738	-138,73	1013,9	-0,8	-0,76	-0,8	-0,8
9	22.09.2012 11:00	77,0738	-138,727	1014,3	-0,8	-0,76	-0,76	-0,8
10	22.09.2012 12:00	77,0732	-138,7234	1014,4	-0,8	-0,76	-0,8	-0,8
11	22.09.2012 13:00	77,0722	-138,7202	1014,6	-0,8	-0,76	-0,76	-0,76
12	22.09.2012 14:00	77,0714	-138,7198	1014,6	-0,84	-0,76	-0,8	-0,8
13	22.09.2012 15:00	77,0708	-138,7236	1015,1	-0,86	-0,84	-0,82	-0,82
14	22.09.2012 16:00	77,0712	-138,7294	1015,6	-0,84	-0,84	-0,84	-0,82
15	22.09.2012 17:00	77,0718	-138,7356	1015,9	-0,84	-0,76	-0,82	-0,8
16	22.09.2012 18:00	77,073	-138,7402	1016,1	-0,84	-0,8	-0,8	-0,82
17	22.09.2012 19:00	77,0744	-138,7424	1016,1	-0,84	-0,76	-0,82	-0,82
18	21.09.2012 9:00	77,0504	-138,6336	1012,5	-0,84	-0,8	-0,8	-0,8
19	21.09.2012 10:00	77,0514	-138,631	1012,5	-0,84	-0,76	-0,8	-0,8
20	21.09.2012 11:00	77,0516	-138,6278	1012,6	-0,84	-0,8	-0,82	-0,8
21	21.09.2012 12:00	77,0512	-138,6258	1012,5	-0,84	-0,84	-0,8	-0,8
22	21.09.2012 13:00	77,0502	-138,6298	1012,3	-0,84	-0,8	-0,8	-0,8
23	21.09.2012 14:00	77,0494	-138,6394	1012,2	-0,86	-0,8	-0,8	-0,8
24	21.09.2012 15:00	77,0494	-138,6522	1012,2	-0,84	-0,84	-0,8	-0,84

a



ObsDate	L…	Lon	BP
24.09.2012 3:00	77,1036	-138,8328	999,6
24.09.2012 4:00	77,1018	-138,8384	998,5
24.09.2012 5:00	77,1008	-138,8512	997,7
24.09.2012 6:00	77,1004	-138,8676	996,6
24.09.2012 7:00	77,1016	-138,8842	995,7
24.09.2012 8:00	77,1038	-138,8974	994,4
24.09.2012 9:00	77,1066	-138,9066	993,6
24.09.2012 10:00	77,11	-138,9098	992,8
24.09.2012 11:00	77,1132	-138,9062	991,7
24.09.2012 12:00	77,115	-138,8976	990,9
24.09.2012 13:00	77,1152	-138,887	989,9
24.09.2012 14:00	77,1138	-138,8768	989,3
24.09.2012 15:00	77,1114	-138,8714	989,2
24.09.2012 16:00	77,1086	-138,8716	989,1
24.09.2012 17:00	77,1066	-138,8762	989,3
24.09.2012 18:00	77,1056	-138,8828	989,5
24.09.2012 19:00	77,106	-138,8886	990
24.09.2012 20:00	77,1074	-138,8912	990,7
24.09.2012 21:00	77,1096	-138,889	991,7
24.09.2012 22:00	77,1118	-138,8812	992,7
24.09.2012 23:00	77,1136	-138,8668	993,6
25.09.2012 0:00	77,1142	-138,8482	994,4
25.09.2012 1:00	77,1134	-138,8266	994,9
25.09.2012 2:00	77,1108	-138,806	995,7
25.09.2012 3:00	77,107	-138,7906	996,3
25.09.2012 4:00	77,1024	-138,7816	997,1

b

Fig. 3. An example of access to the database of operational drifter observations using *Microsoft Office Access* 2007 DBMS: *a* – a fragment of database; *b* – a result of execution of a query on air pressure below 1000 hPa for 240990 drifter by the date for all the years

For the convenience of the Arctic region database use an automated DBMS (Database managing system) *Microsoft office Access* 2007 which provides an access to the data of operational drifter observations (Fig. 3, *a*) and allows one automatically select data on demand and find relation between it (Fig. 3, *b*) was developed [14, 15].

The assessment of the drifter database quality was performed in two stages. At the first stage rough failures were excluded from the data arrays according to criteria of drifter diving measurement, the data of air pressure and water temperature using the programmatic method.

The second stage of verification consisted in identification of single ejection in the arrays of hydrometeorological data at all nominal horizons. For each drifter, The maps of trajectories, graphs for atmospheric pressure and surface temperature of water/ice were plotted at all horizons for each drifter. If single outliers in the data were within the array or there were acceptable ranges (*R*) by hydrometeorological parameters (Table 1), then these data were considered erroneous and (according to WMO requirements) were replaced by 999 which means no data. As an example, in Fig. 4 time series of water temperature at 7.5 m nominal horizon according to *T*04 sensor of *IMEI*242840 drifter is shown in blue. It can be seen that on May 19 and 28, 2014 the water temperature outliers up to −20 °C (circled) are observed. Time series of data after excluding faulty samples are given below in red.

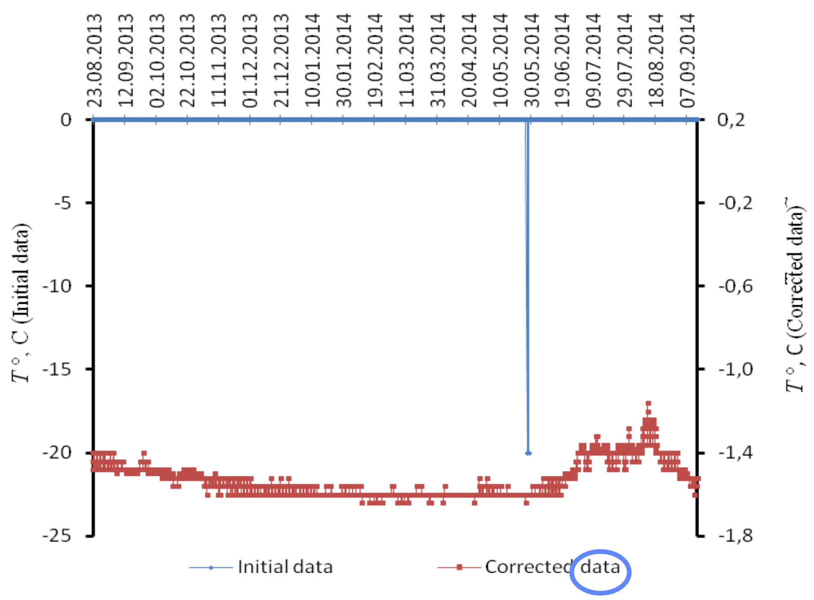


Fig. 4. An example of verification of water temperature measurement (performed by *IMEI*242840/*WMO* 48539 drifter) results

According to the results carried out in the Arctic and verification of data quality in the formed database, the drifters developed in MHI proved the reliability of their operational characteristics. This is confirmed, for instance, by long-term operation of *IMEI*245950/*WMO*48541 drifter which had been performed the measurements for almost three years (1082 days). The trajectory of this drifter that was placed on August 30, 2013 in the Arctic Ocean – *1*, and on August 16, 2016 stopped transmitting the data – *2* is shown in Fig. 5. A long period of operation of the mentioned drifter in the Arctic region provides reliable assessment of thermal processes dynamics in the Arctic Ocean under-ice layer in a wide range of spatial-temporal scales [5].

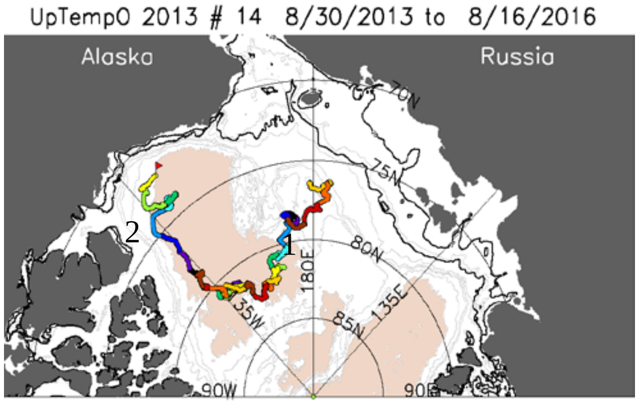


Fig. 5. The studies of the Arctic region performed by *IMEI245950/WMO*48541 drifter during 30.08.2013 – 16.08.2016 period. The drifter trajectory is given according to the data [5]

Conclusions. The database for operational drifter monitoring of thermal processes in the upper (including under-ice) layer, dynamics of ice and air pressure field in the Arctic region has been formed. The results of the experiments can be the basis for the creation of a reliable and economical observation system using temperature-profiling drifters.

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