Creation of Drifter Technology for the Ocean and the Atmosphere Monitoring

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In the early 70s, 20th century, the tools for studying the World Ocean (besides the already existing research vessels equipped with celestial navigation) were expanded with automatic buoys and remote sensing technologies. The first idea was to create the global observing system on basis of large quantity of surface mooring buoys, equipped with hydrological and meteorological equipment. The evaluation of this suggestion revealed the fact that such tool was too expensive. It was decided to construct a network on the basis of drifting buoys which are significantly cheaper. The article shows the results of scientific and practical efforts to perform a step by step development of the drifter technology, which is the main instrument for global observation in the Ocean now.
The cycle of works executed from 1973 to 2016 provided a creation of a world-class drifter technology for solution of different scientific and practical challenges. The research results are actively used for the needs of the Russian Federation and the global drifter program. The prospect of future works is related to the national challenges on the research of the Arctic and other World Ocean regions, participation in national and international projects on calibration of satellite onboard systems for the Earth remote sensing and also to validation of numerical simulation results for refining the marine environment variability forecast.

Keywords: drifting buoys, drifters, measurements, currents, satellite communications and locations, buoyancy control, balloons.

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Introduction. In 70s of the 20th century it was supposed to monitor the ocean and near-water atmosphere by means of global network of measuring anchorage buoys. But it became clear quite quickly that the problem had no solution in such statement due to excessive financial and material costs. The stake was made on inexpensive drifting buoys (drifters). However, in this case the efforts to create communication and positioning systems, to develop reliable and stable measuring channels and to achieve a long and reliable operation of devices in the harshest meteorological conditions, were also required. Complex solution of these problems became the basis for the author's works in Marine Hydrophysical Institute (MHI).

1976. PION-2. The first meaningful research results were obtained in 1976 – 1977 when the developments in the field of digital phase meter [1] allowed one to go over to radio navigation instead celestial navigation. It was important for improving the quality of field works on POLYMODE project that had been performed by the Institute at that time. A receiver-indicator PION-2 was developed for the operation with a global very low frequency radionavigation system (RNS) "Omega". On its basis a shipboard navigational complex (which includes the mentioned receiver-indicator, specialized computational machine PKG-1 for converting of the hyperbolic coordinates into geographic ones and exact time radio equipment) was developed. External design of the complex is represented in Fig. 1.

Two such complexes provided the positioning of MHI vessels "Akademik Vernadsky" and "Mikhail Lomonosov" during the marine field works in late 70s. The author repeatedly participated in expeditions during which the features of RNS

“Omega” operation with the prospect of its use to trace the drifting buoys [2] were studied.

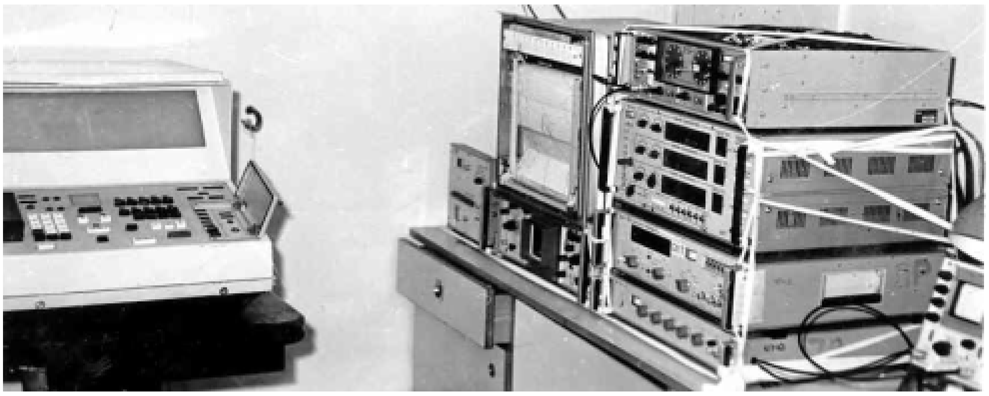

Fig. 1. Automated shipboard navigational computing complex on the basis of PION-2 receiver-indicator of “Omega” radionavigational system

It became clear that at that time the required technical level allowing one to develop an automatic receiver for tracing the drifting buoys was absent. The gap was filled by a number of inventions and that provided the solution of this difficult problem [3 – 5]. Experimental prototype of automatic buoy receiver was developed by late 70s.

1980. The first buoy. The first drifting buoy with RNS “Omega” receiver and satellite data acquisition and transmission system (SSPI-IK), developed according to the “Interkosmos” project, was designed in early 80s. The external design of MHI-9301 buoy during its tests at the test-site near Katsiveli is represented in Fig. 2. This buoy had been used in 1983 in a series of experiments that took place in the Atlantic Ocean. During these experiments important scientific and practical results which confirmed the possibility of measuring the vertical structure of shearing currents by one buoy with subsurface drogue [6, 7] were obtained. The author defended PhD thesis based on the results of these works [8].

1985 – 1997. LOBAN buoy. In 80s new satellite communication systems with ability to determine the coordinates of objects on the Earth surface using the Doppler method have appeared. They provided an important advantage when using drifters. The advantage consisted in the fact that two tasks (data transmission and determination of the coordinates) were resolved simultaneously using the only buoy transmitter. This feature contributed to the fact that the Doppler systems rapidly (and for a long time) became a part of drifter work practice.

Surface light disposable buoy with automatic navigation (LOBAN) became the first drifter, where the Doppler system was applied. Its external design is represented in Fig. 3. Along with the surface current parameters (determined by the drifter motion) air and water temperatures had been also measured.

Fig. 2. MHI-9301 drifter with RNS “Omega” receiver and satellite transmission system SSPI-IK equipment during the tests in the area of oceanographic platform in Katsiveli

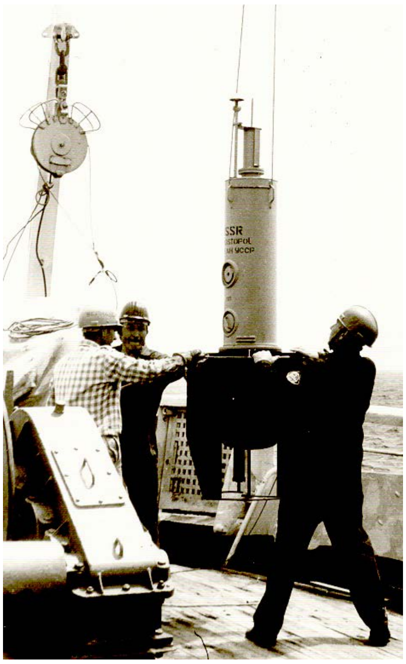

Fig. 3. External design of LOBAN drifter

The first two buoys were deployed in the Tropical Atlantic in 1985. Totally, 8 buoys of this type were used in the Atlantic in 1985 – 1988. Experiment results confirmed the possibility of Equatorial Countercurrent break-up into the large-scale eddy formations of different polarity in the Central Atlantic. The data on average seasonal heat transfer in the Equatorial Countercurrent surface layer as well as on mesoscale pulsations of water fluxes [9, 10] were obtained.

During 1987 – 1997 5 drifter experiments using 14 LOBAN type drifting buoys were carried out in the Black Sea. The experiments were of complex nature as the drifter works were carried out together with shipboard measurements at test-sites and remote observations. One of the aims of these works was to investigate the Black Sea Rim Current (BSRC) velocity fields. Also the method of radiation temperature "spots" calibration by means of water temperature gauges (which were the part of the drifters [11, 12]) was applied for the first time.

Basic physical results of the performed works consist in the fact that it became possible to provide long-term observations of the BSRC in the surface layer around the Black Sea perimeter with the detailed transfer velocity measurement and obtaining surface temperature measurement data during the periods of intensive surface layer warming and cooling. Complex monitoring methods using the buoy measurements and remote observations [13] were practiced.

1986. Underwater buoys. During the period from 1987 to 1995 a number of developments of diving and underwater drifters have taken place. Diving drifters are mainly designed for performing pop-up cycles. Underwater drifters were able to drift in the water column and to surface from time to time for data transfer via satellites.

A technique for determination of elastic and plastic deformations of underwater buoy bodies under hydrostatic pressure effect and also due to temperature expansion and compression [14] was developed.

Systematization of buoyancy control methods was performed. It was revealed which methods were applicable for diving buoys (where wide buoyancy variability range in pop-up cycle was required) as well as for underwater buoys with small buoyancy variability for keeping them at some depth and to compensate water density variability under conditions of variable temperature or salinity.

These investigations have been carried out long before the *Argo* floats were developed [15] and they have been aimed at solution of a number of applied problems. Much attention has been paid to the use of energy background sources (e.g. such as vertical gradient of water temperature or salinity profile and also unevenness of current vertical profile) to increase the autonomy of the buoys. One of the developed subsurface buoys [16], capable of keeping its position in the water depth due to displacement volume change, is represented in Fig. 4.

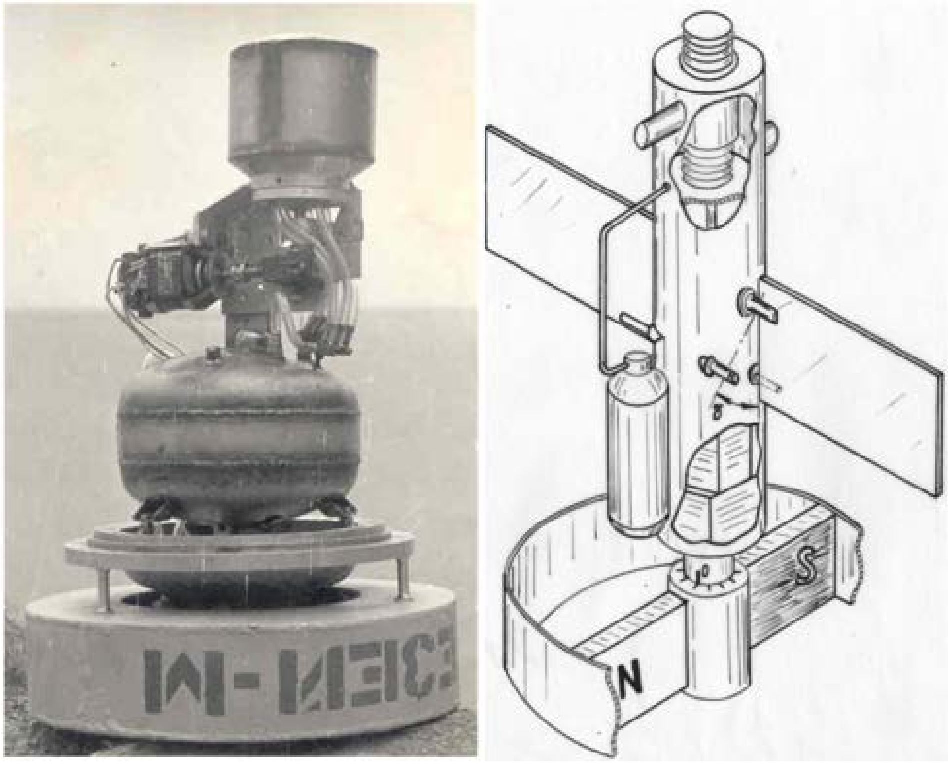

Fig. 4. External design and structure of the subsurface buoy with controlled buoyancy

Expansion of diving float measuring possibilities can be attained if they are capable to perform not only vertical profiling but also a sideways sliding motion. The developed diving buoy [17], providing long-term researches in the specified water area by ascent and descent with multidirectional sideways sliding, has such a possibility. For the present date such type of buoys is called glider. The main distinction of our developments is that the cylindrical body of the buoy has a vertical orientation, whereas the body of modern gliders is placed horizontally.

Unfortunately, the continuation of these developments, which are of great practical importance, has become impossible due to the breakup of the USSR.

1990. Balloons. The developments on drifter technologies have provided performances on air flux study in the stratosphere at 25 – 50 km heights, where the outside temperature drops down to –65°C at night. For this aim balloon satellite marker “Chirok” (Fig. 5), in which the equipment was placed in the rugged thermal protective spherical container, was developed.

A stratospheric route Kamchatka – Volga which is of interest for physicists, who study high-energy cosmic rays was mastered using “Chirok” marker. Previously this route was unavailable due to impossibility of monitoring the balloon flight with ground-based radars (as for hundreds of kilometers it ran across the regions where radar tracking points were absent).

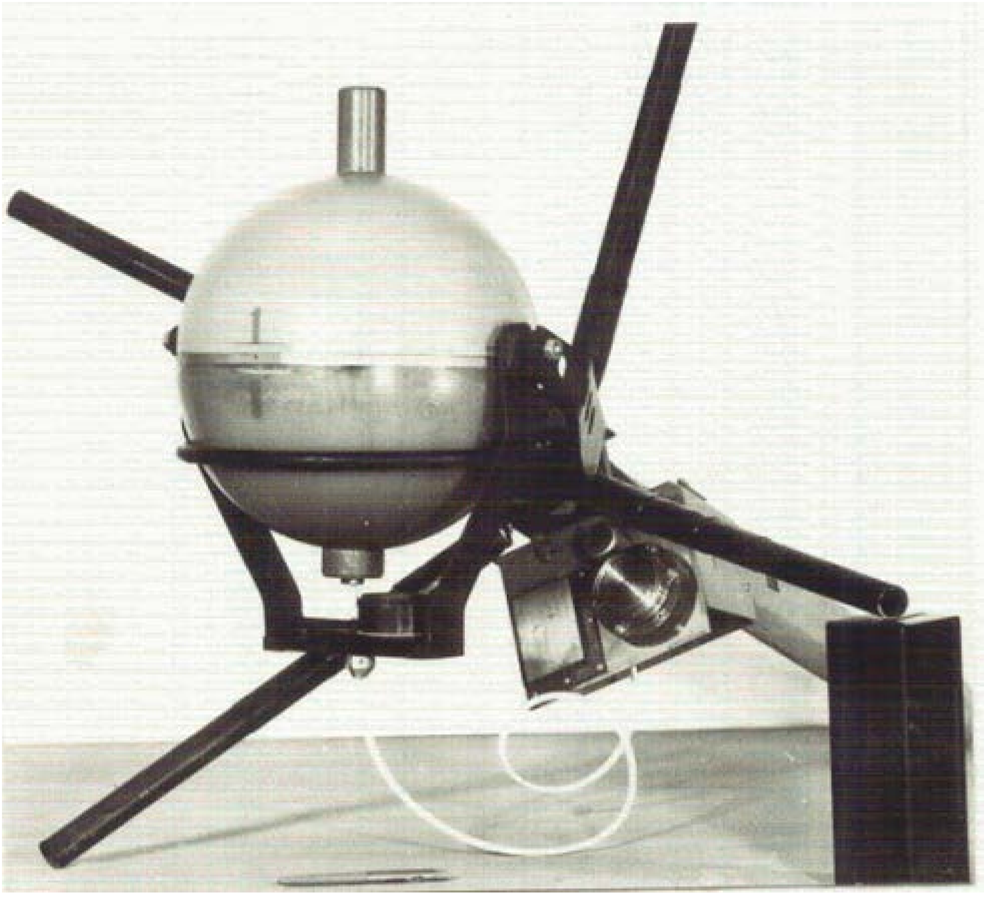

Fig. 5. Balloon satellite marker “Chirok” mounted on a gimbal suspension which is able to eject and ascent if the balloon nacelle falls into the water

1996. Marlin-Yug Ltd. MHI-9301 drifter application revealed that scientific idea, implemented in "metal" by other developers, often results in device inoperability. As a result, it was decided to establish an independent venture capital firm, and it became a firm of "Marlin-Yug» (http://marlin-yug.com). Over 20 years of existence, the company has occupied a leading position in the world in the field of the development, production and application of different buoy systems and, primarily, drifting buoys. The victory in long-term comparative tests carried out by different firms was achieved; a number of world records for the duration of drifting buoy operation were set [18]. More than a thousand of *SVP-B* drifting buoys with the drogues (Fig. 6) were manufactured for the global drifter network.

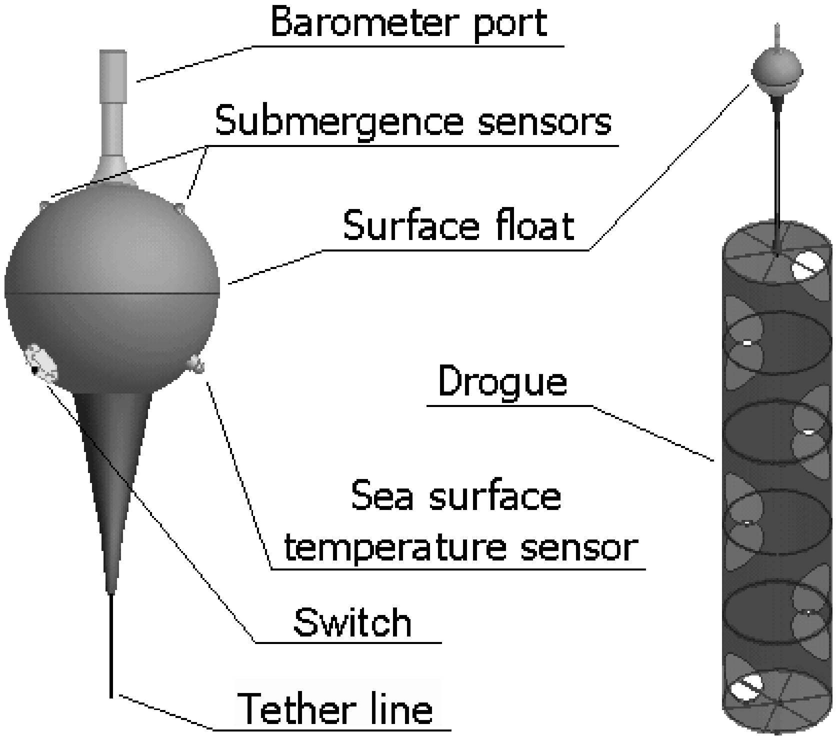

Fig. 6. The structure of *SVP-B* drifting buoy

A great variety of drifting buoy types was developed and put into production on the basis of *SVP-B* drifters. Marine and ice versions of thermo-profiling buoys with measuring string [19] should be especially pointed out. The main scientific results were obtained using Marlin-Yug Ltd. drifters during the studies of the Black and the Caspian Seas, the Southern Ocean and the Arctic region as well as during the performance of a number of targeted projects (e.g. *Storm buoy* project).

1999. The Black Sea. During the next phase of the Black Sea study (1999 – 2015) with the new generation drifters 94 buoys were deployed. Drifter "spaghetti" of the trajectories of all the drifters deployed in the sea is given in Fig. 7.

Data analysis allowed one to make a series of conclusions, although additional experiments are required to refine them [20]. Particularly, the stability of general cyclonic circulation of water in the Black Sea in the BSRC form was confirmed. At the same time, a steady presence of eastern and western gyres (sub-gyres), represented in the common Black Sea circulation schemes, was not found. It was proved that the shelf edge is not a considerable obstacle for the water exchange in the *shelf* – *open sea* system. Very high velocity of orbital motion (0.6 – 0.8 m/s, "Batumi" anticyclone) was displayed.

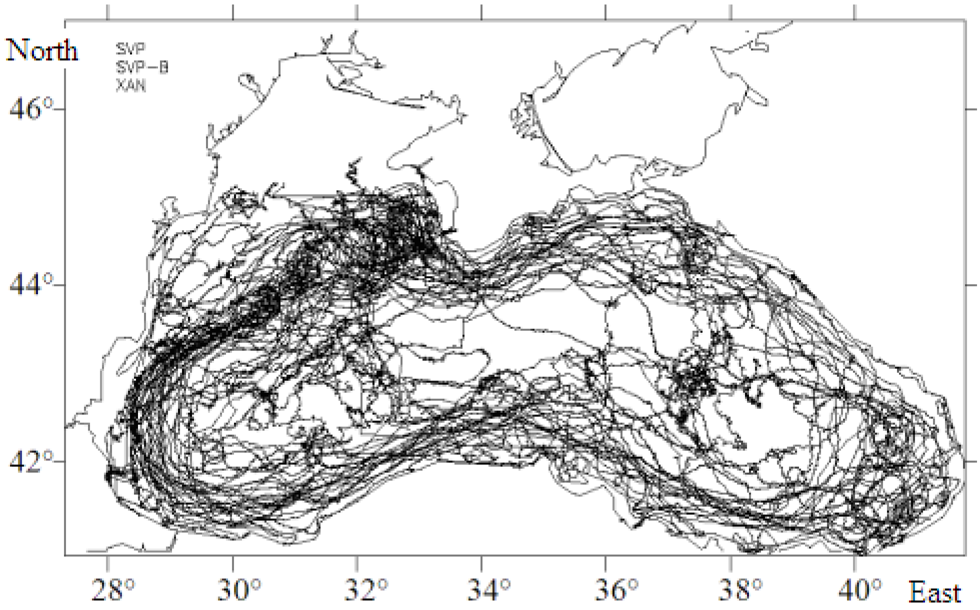

Fig. 7. Drifter “spaghetti” constructed on the basis of the data from 94 drifter deployments in 1999 – 2014

Great contribution to the Black Sea thermal activity study was made on the basis of temperature-profiling drifters [21]. The results of the sea upper active layer cooling (August – December) and warming (January – April) in 2007 – 2008 obtained by the buoys with the temperature string are given in Fig. 8 as an example.

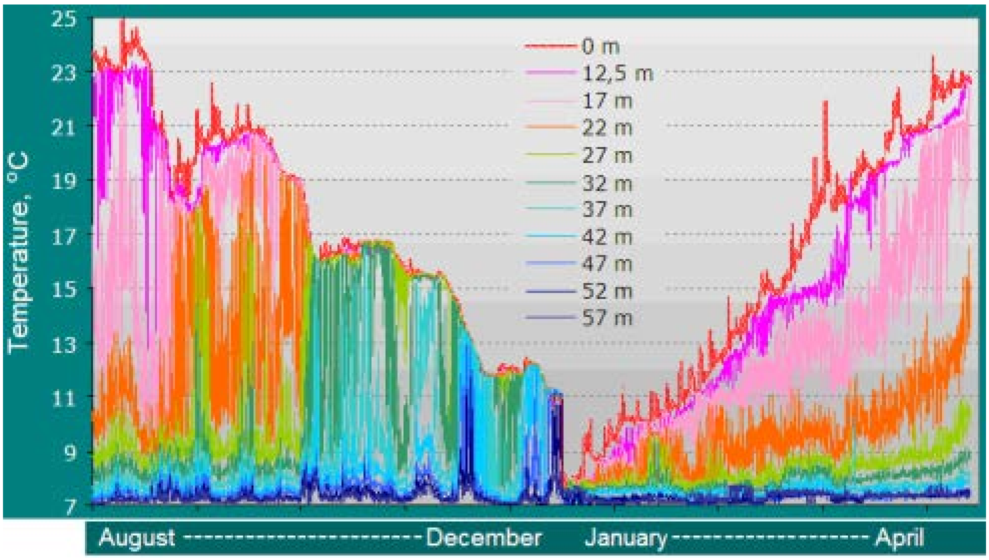

Fig. 8. The results of the Black Sea upper active layer cooling (August – December) and warming (January – April) in 2007 – 2008

At the same time, the results of studies contain a lot of data which has not been required for physical analysis yet (for instance, seasonal and inter-seasonal features of Cold Intermediate Layer formation, heat transfer in different seasons, atmospheric pressure effect on the circulation of different scales and much more). A database of drifter research in the sea [22] was created in order to systematize the results of the performed experiments and, in its turn, to facilitate further analysis. In 1999 the author defended the doctoral thesis [23] based on the results of these experiments.

2005. Hurricane Katrina. In 2004 – 2006 a pilot project called *Storm Buoy* had been carried out in the western part of the Atlantic tropical zone together with the colleagues from the United States. The project concept consisted in the investigation of the cases of tropical hurricane generation. For this aim, a version of barometric *SVP-B*-drifter with two operating modes (standard and storm) was developed. In the standard mode the measurements were carried out every hour, as is usual for drifter networks. In the storm mode the buoy independently switched to 15 minutes measuring interval. A special test site where the buoys were placed by the airplane deployment before the beginning of hurricane season has been established for carrying out the works in the western part of the Tropical Atlantic.

One of the most interesting results was obtained during the Hurricane Katrina passage over our buoy at the end of August 2005 (Fig. 9). Atmospheric pressure variability before, during and after the passage of the hurricane is denoted by the red line. Semi-diurnal pressure cyclicity which is typical for the tropical convergence zone is traced. Blue line corresponds to the water temperature variability in the surface layer.

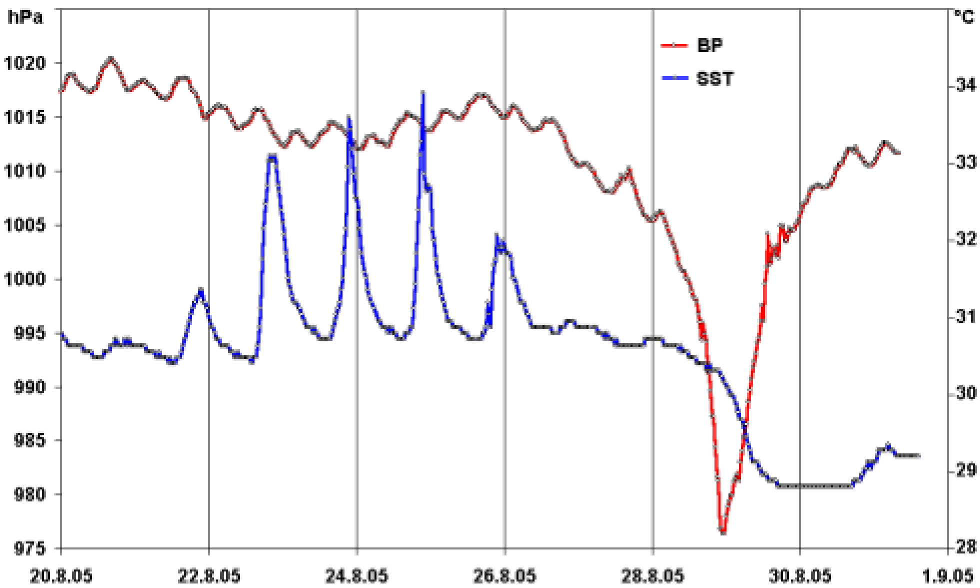

Fig. 9. The record of surface temperature variability (blue line) and atmospheric pressure (red line) during the tropical Hurricane Katrina passage

Significant diurnal temperature spikes were, apparently, related to the characteristic smooth state of the ocean at a time preceding the coming of the hurricane when poorly pronounced turbulent exchange in the upper layer takes place and, accordingly, an intensive water warming exists. Using the obtained data, special indices were developed in Massachusetts Institute of Technology (USA) on the basis of such temperature variation characteristics as amplitude and slope. These indices allow one to assess possible force of a coming hurricane. These work resulted in a development of a new technology for tropical hurricane warning. The processes of their generation and evolution were studied [24].

2006. The Caspian Sea. The first Caspian drifter experiment with the use of *SVP-B*-drifters equipped with an additional temperature sensor placed at 12 m depth was carried out in 2006 – 2008 [25]. The experiment was performed in two stages. At the first one (October 2006) three drifters were deployed, at the second stage (July 2008) – three more drifters. Buoy drift trajectories are given in Fig. 10.

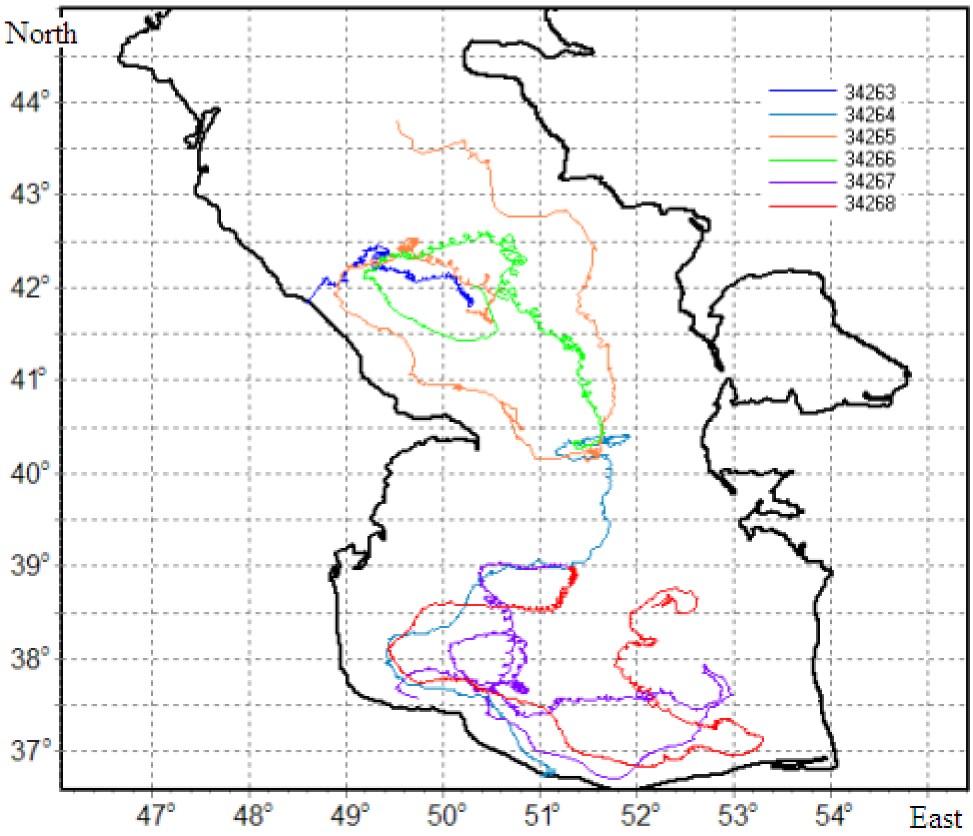

Fig. 10. *SVP-BT* buoys drift trajectories. Deployment points are denoted by large markers

An analysis of the trajectories of drifters deployed in the southern part of the Caspian Sea suggests that a relatively stable cyclonic circulation of surface waters exists there. In addition to the parameters of currents, long-term data series (with 1 h interval) of atmospheric pressure, sea surface temperature and the one at 12 m depth were obtained.

2007. The Southern Ocean. Approximately in 2004 – 2005 it became clear that the possibilities of the Doppler satellite communication system *Argos*-2 were close to their limiting operation capabilities on such parameters: passing ability, data continuity in any meteorological conditions and timeliness of measurement result delivery to the users. Therefore, a pilot project on development and test of the buoys adapted for the data transmission via *Iridium* satellite communication system was carried out.

Deployments of the buoys developed by us were performed in 2009 – 2010 in the Southern Ocean known for its harsh weather conditions. It was found out that the operation time of the buoys equipped with *Iridium* terminals and *GPS*-receivers reaches 1250 days. This exceeds the equivalent results of buoys of other developers more than by 50% [26]. Trajectory of *Iridium*/*GPS* buoy deployed in the Southern Ocean is represented in Fig. 11. A detailed fragment of drift based on *GPS*-data is given in the insert.

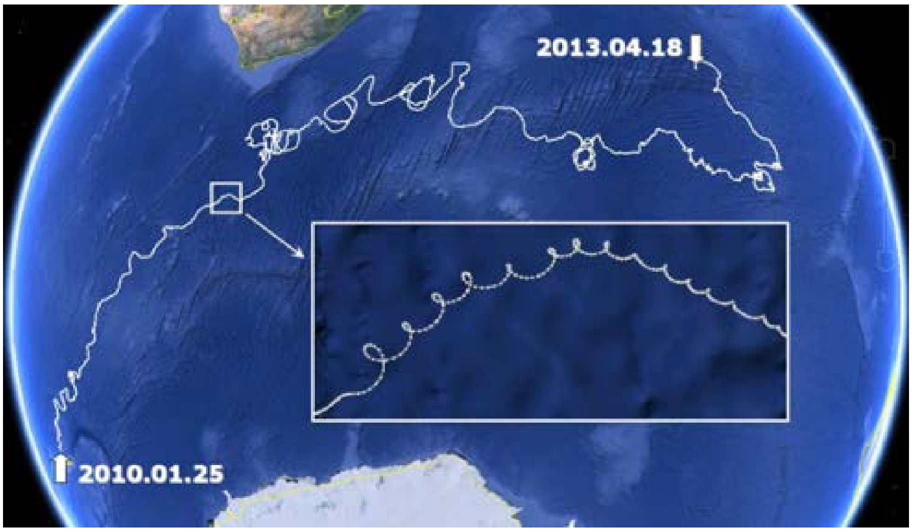

Fig. 11. *Iridium*/*GPS* buoy trajectory in the Southern Ocean for 1250 days

New tools and methods for data transmission and positioning in the conditions when the buoy was underwater for a significant time period due to continuous storms were developed. It was confirmed that air pressure measuring error did not exceed ±1 hPa at a wave heights up to 14 m. Under such operation conditions the buoy was able to transmit to the shore at least 98% of hour measurements and 96% of *GPS*-observations. This completely meets the requirements of operational observations within the framework of global drifter network.

2011. The Arctic. The developments of the tools adapted for application under polar conditions has begun in 2011. Their successful tests were carried out in the Arctic in 2012 – 2016 [27]. It was proved that the buoys successfully operate under the harshest meteorological conditions (extreme storms, hurricanes, low temperatures, strong wind etc.). From 2011 to date about 400 buoys (aimed at investigation of the motion of icebergs, ice floes, glaciers, habitat conditions of marine animals, ice thickness variability, etc.) were manufactured and deployed.

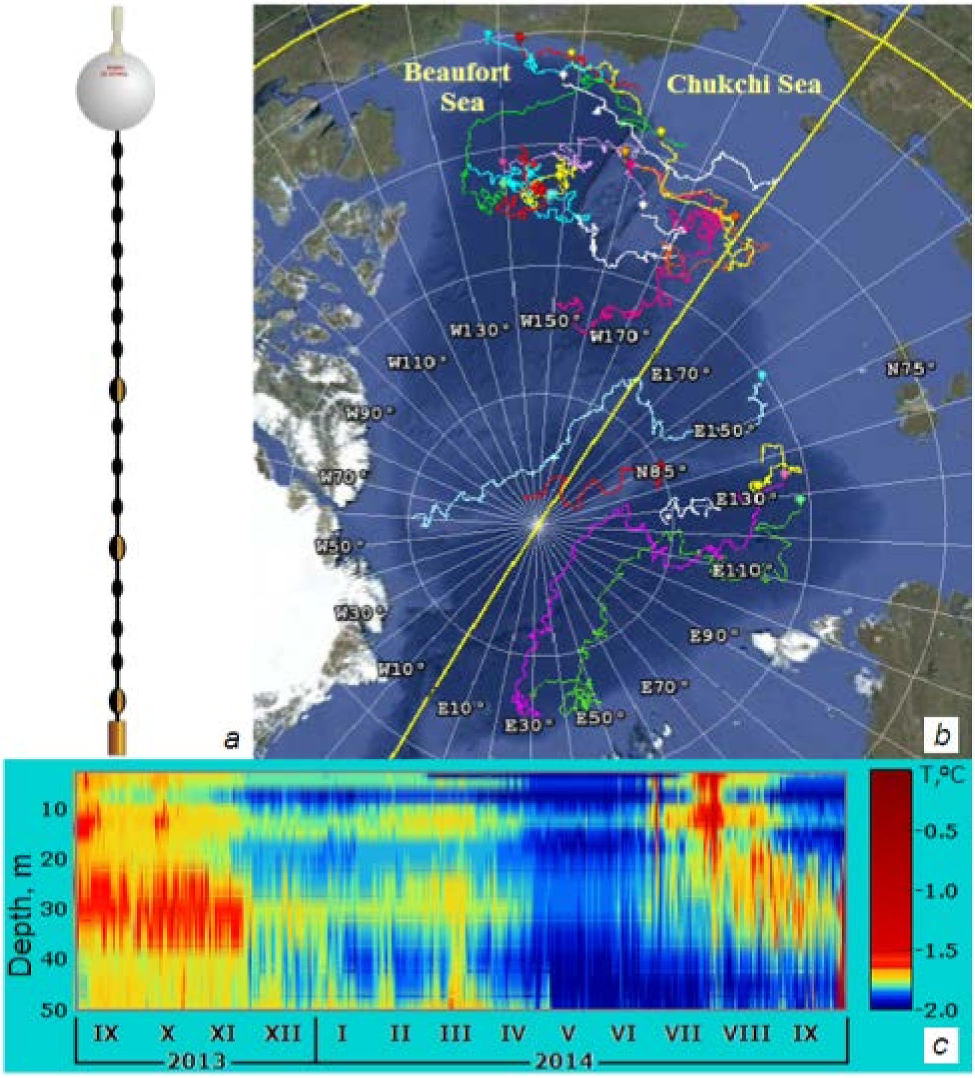

Fig. 12. The structure of "ice" temperature-profiling drifter of *SVP-BTC*60/*GPS*/*ice* type (*a*); trajectories of "ice" MHI temperature-profiling drifters deployed in the Arctic region in 2012 – 2016 (*b*); thermal structure of under-ice layer of the ocean at the North Pole region according to the data of the drifter no. 246740 (*c*)

The unique floats with temperature string designed for thermal measurements in the water column under the ice appeared to be the most demanded ones. Overall, there were deployed 30 buoys of such type. The buoy structure, drifter "spaghetti" of 30 buoys placed on the ice and a fragment of temperature temporal variability by depth are given in Fig. 12. Data bank about the Arctic studies [28] was created on the basis of these experiments and aimed at the further physical analysis.

Conclusions. The cycle of works executed during the period from 1973 to 2016 provided a creation of a world-class drifter technology for solution of different scientific and practical challenges. The research results are actively used for the needs of the Russian Federation and the global drifter program. The prospect of future works is related to the national challenges on the research of the Arctic and other World Ocean regions, participation in national and international projects on calibration of satellite onboard systems for the Earth remote sensing and also to validation of numerical simulation results for refining the marine environment variability forecast.

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