NEW DEVELOPMENTS IN THE DRIFTER TECHNOLOGIES

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ABSTRACT

For a few last years the efforts were applied to progress drifter technologies according to the significant needs of the buoy observing system. The studies were carried out under the WMO and IOC Data Buoy Co-operation Panel Pilot Projects and scientific plans of the MHI NASU. The goals of studies: more controlled environment factors, better timeliness, longer lifetime, higher space-temporal resolution of measurements, even if very rough weather conditions take place during full lifetime of drifters. The following results were reached. The SVP-B automatically deployable drifters, equipped with Iridium and Argos-2/3 satellite telemetry were created. New method of GPS use on drifters, having long time submerged, was developed. The Iridium/GPS drifters with hourly samples demonstrated 4 years lifetime. It was shown that standard SVP-B drifter can keep its drogue attached longer of 450 days. The reliable barometric pressure measurements are possible now during full lifetime of new drifters. The marine and ice versions of the drifters with thermistor chains were created and evaluated in the ocean including polar areas. Micro ice markers including parachute version were developed and tested in Arctic. These results could be the reference points to keep the certainty of drifter data with necessary quality of samples and locations and without increasing of costs to support density of global drifter observations.

Introduction

The drifter segment of global buoy observing system plays main role to in-situ monitor of active layer of the Ocean and near-surface atmosphere. Drifter is free-floating data buoy to gather the environmental information with data transfer via satellite telemetry systems. Our investigations have been directed to progress the following main components of drifter segment:

- WOCE type of barometer drifters to monitor subsurface currents, air pressure and sea surface temperature;
- Temperature-profiling drifters to investigate thermodynamic activity within active layer, as well to study air pressure variability, subsurface currents and ice-flows movement;
- Micro buoys to study movement of ice-flows and surface currents in polar areas.

In spite of different technical entity of those components they have same requirements to be used in-situ. The requirements are:

- Reliable air pressure samples under rough weather conditions during full lifetime of drifter;
- Increased spatio-temporal resolution that includes study of surface and subsurface currents, sea surface temperature with high resolution, vertical and horizontal heat exchange and so on;
- Continuity of data, or in other words, all the samples, gathered with data platforms shall be delivered to users without loss. Moreover, each sample has to be connected with the point, where the measurements are carried out;
- Timeliness of data, that means that time to get data delivered to a user should be commensurable with scale of temporal resolution of the investigated process. Ideally this is that user could watch the process in real-time mode independently of reciprocal locations of both subjects: user and data platform
- Buoy has to operate as long as possible even if a buoy is equipped with new type or additional quantity of sensors, that increases power consumption. The Data Buoy Cooperation Panel (DBCP) point of view is that buoy has to have the capability to keep its perfect operation for 450 days at least.
- All the requirements listed above have to be valid under any weather conditions, which can take place when a buoy is in operation.

The problems described have three sides. One is the telemetry link, which has to transfer close to real time an increased amount of data from drifters to users if new or more sensors are used. Second is a capability to determine the points, where measurements are fulfilled. And third is the buoy, which has to collect data, gets locations and transfers both to users. All that should be combined in some optimal structure, which provides long reliable environmental measurements in ocean under any weather conditions. The article presents the results how the technical requirements were realized for three types of drifters and what are the results of this study. The final results only are presented here without interim details of studies, when many different prototypes were tested before to get final results.

WOCE type of barometer drifters [1]

This type of drifter is main tool for both communities of users: oceanographers and meteorologists to monitor open parts of the Ocean and near-surface atmosphere. The studies, the results of which are presented here, were carried out for a few last years and were directed to investigate the following items:

- Reliable air pressure (AP) samples under rough weather conditions during full lifetime of drifter;
- Increasing of duration to keep the drogue attached;
- Capabilities of Argos-2(3) and Iridium telemetry drifters to provide continuity and timeliness of samples gathered in different areas of the ocean;
- Capabilities of GPS equipped drifters to provide continuity and timeliness of GPS fixes under rough weather conditions;
- Packaging of drifter for safety deployment.

WOCE type of barometer drifters includes two prototypes: standard and mini. Standard SVP-B drifter has 41-cm hull and 92-cm Holey Sock drogue diameters. SVP-B mini has smaller diameters of float (30-35 cm) and drogue (61 cm). Design of SVP-B mini drifter was suggested by the DBCP as a decision to keep density of drifter network by means of wide use of ships of opportunity for deployments of the drifters. Both types have Drag Area Ration (DAR) near 40 that allow accepting of both types as the Lagrangian trackers.

<u>AP data from standard SVP-B drifters</u>

The Table 1 shows AP data statistics from last prototypes of mix of the standard SVP-B drifters (Argos-2 and Iridium). Some buoys came ashore after near 3 years in operation, some buoys have similar duration and continue working. The current battery voltage for operational buoys allows seeing them definitely with theoretical lifetime more than 3 years. Two buoys ID84146/WMO56939 and ID49679/WMO62505 have 3-year duration overpassed. Second buoy from this pair was the SVP-BTC temperature-profiling drifter with increased power consumption, so it got faster the battery power emptied.

It is obviously from the Table 1 that in general the buoys had mean RMS at 0.7 – 0.8 hPa level. Most interesting are two Argos-2 SVP-B drifters (WMO56939 and 62505) and 3 Iridium buoys (WMO16551, 17526 and 17572), which had more than 3 years of reliable AP data. Three buoys from this cluster demonstrated reliable AP samples longer of 1350 days, that 3 times more of the WMO requirement about minimum 450 days.

The buoys were in operation under different weather conditions from tropical to low latitudes of South Ocean. The last well known for its rough weather conditions. For example the trajectory of the buoy WMO 56939 in Indian Ocean is shown on Figure 1.

Table 1

AP data statistics from last prototypes of Argos-2 and Iridium SVP-B drifters

ID	WMO	Telemetry	Deploy-ment	Owner	Failure of buoy		AP duration, days	RMS mean, hPa
					Date	Days before stop transmitting (reason)		
84146	56939	Argos-2	25.11.08	BOM	07.09.13	1747(battery emptied)	1747	0.6
49678	62505		15.06.08	M-Fr.	18.08.11	1159 (battery emptied)	1159	0.7
84147	56943		04.01.09	BOM	19.08.11	957(ashore)	957	0.9
84152	56941		13.01.09		13.08.11	942 (ashore)	942	0.8
	16551	Iridium/ GPS	13.04.10	SAWS	07.02.14	1396 (battery emptied)	1396	0.8
	17526		15.11.09		18.04.13	1250 (battery emptied)	1250	0.8
	17572	Iridium	15.12.09		21.04.14	in operation	1588	0.8

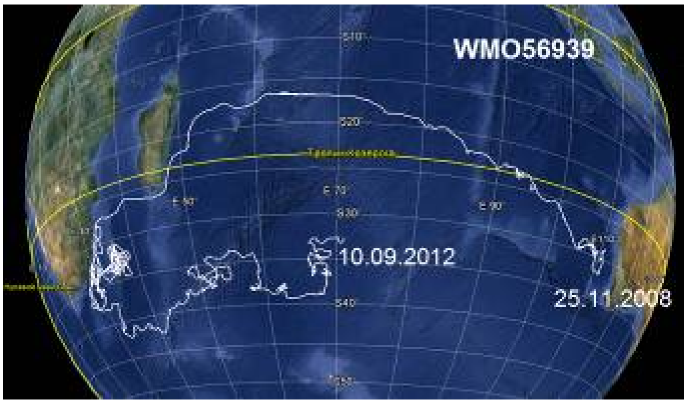

Figure 1. Full trajectory of Argos-2 SVP-B drifter (WMO56939) in the Indian Ocean

The graph on Figure 2 shows the fragment of AP data variability for this buoy from deployment to September 10, 2012. It is obviously that mean RMS was near 0.6 hPa and did not have a tendency to increase after 3 years in operation.

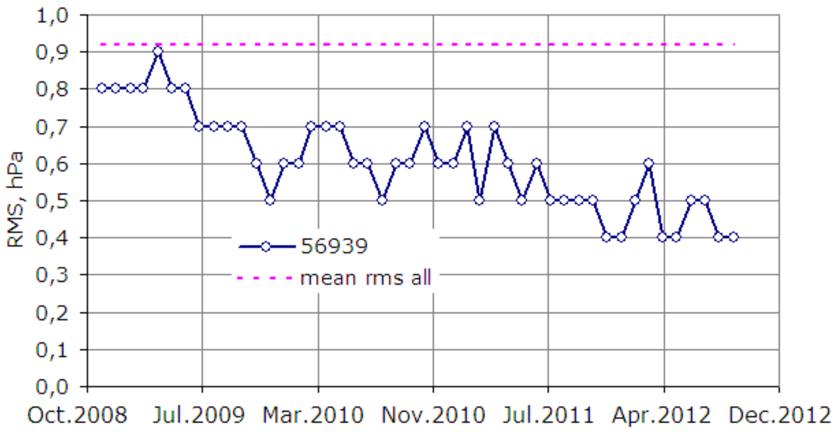

Figure 2. Mean monthly RMS for SVP-B drifter WMO56939 during its lifetime

<u>AP data from SVP-B mini drifters</u>

The Table 2 below includes data from three Argos-2 drifters. All the buoys were SVP-B mini drifters deployed approximately at the same time and continued its operation on April 21, 2014. In spite of fact that RMS for AP data from these buoys are mainly comparative with AP data from standard drifters shown at Table 1, their data have more influence from environmental parameters, as this is shown below.

The buoy ID43869/WMO13600 from this cluster had a longest lifetime. Its trajectory in low latitudes of the Atlantic Ocean is shown on the Figure 3.

Table 2

AP data statistics from last prototypes of Argos-2 and Argos-3 SVP-B mini drifters

ID	WMO	Telemetry	Deployment	Owner	Failure of buoy		AP duration, days	RMS mean, hPa
					Date	Days		
43869	13600	Argos-2	19.08.10	NOAA		in operation	1341	0.7
43877	55614		23.08.10				1337	0.9
43878	15501		26.08.10				1334	0.9

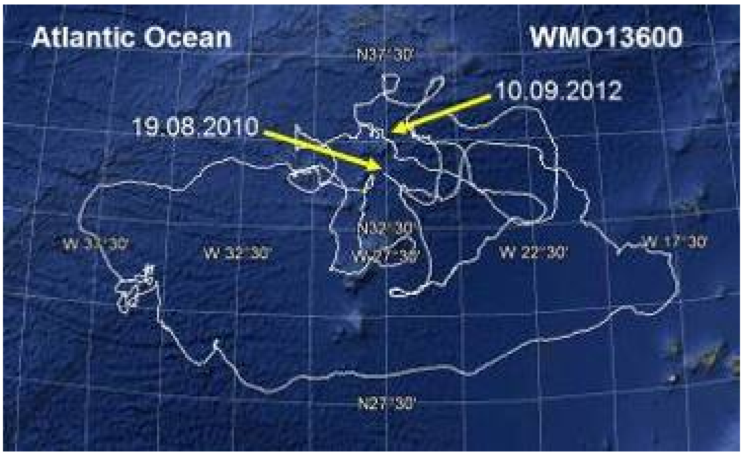

Figure 3. Full trajectory of SVP-B mini drifter ID43869/WMO13600 in the Atlantic Ocean

The graph on Figure 4 shows the fragment of AP data variability for the buoy WMO13600 from deployment to September 10, 2012. It is obviously that mean RMS was near 0.7 hPa.

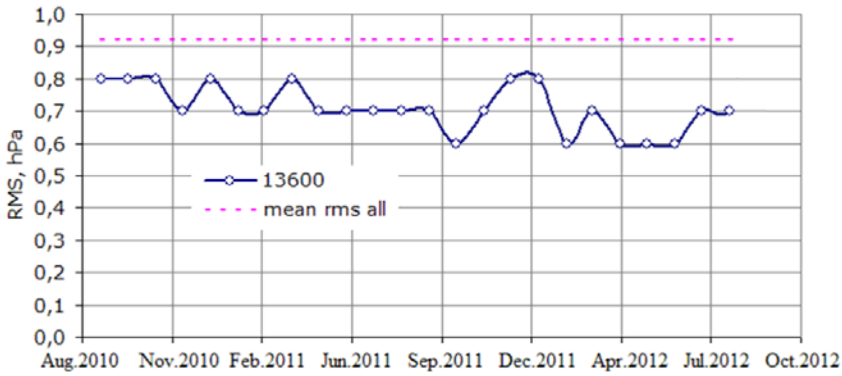

Figure 4. Mean monthly RMS for SVP-B mini drifter ID43869/WMO13600 during its lifetime

Another feature of AP variability had Argos-3 SVP-B mini drifter WMO55644, deployed in the Tasman Sea. This buoy did not have problems with AP while it had its drogue attached. After the drogue was lost, the buoy had sometime too scattered data as it is shown on the Figure5.

It is visible from Figure 5 that AP spikes had positive value, i.e. abnormal AP samples were larger in contrast with nominal air pressure. We guess that main reason for those positive spikes was difference to swim at sea surface for floats from standard and mini drifters after they got its drogues lost. The matter of this point of view is explained on Figure 6.

The float swimming at sea surface has two main characteristics, which determine vertical orientation of the float and stability of this orientation. The characteristics are: B – center of water displacement volume and W – center of gravity. If positions of B and W are determined from lower point of the float, the difference B – W has to have positive sign. In this case the float has vertical orientation independently of drogue presence or absence as well as environmental wind-wave conditions. The difference B – W is named as metacentric height. The more this parameter is, the more vertical stability the float has.

It is obviously also that float with larger outside diameter can have larger B – W value and correspondingly it keeps better vertical orientation, when wind pressure is applied to barometric port. Because the ports have same outside sizes for both drifters, the heeling pressure is same for both floats. Different diameters of floats provide small input, because of float's streamline and possible submergence.

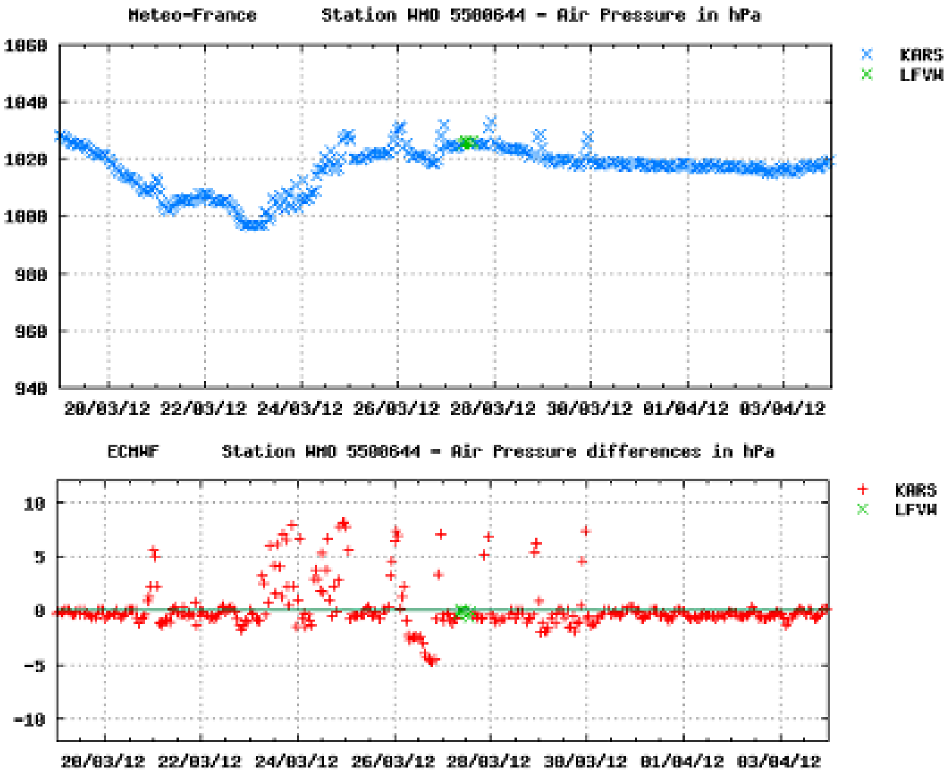

Figure 5. Too scattered AP data, which took place sometimes for Argos-3 SVP-B mini drifter ID42961/WMO55644, deployed in the Tasman Sea

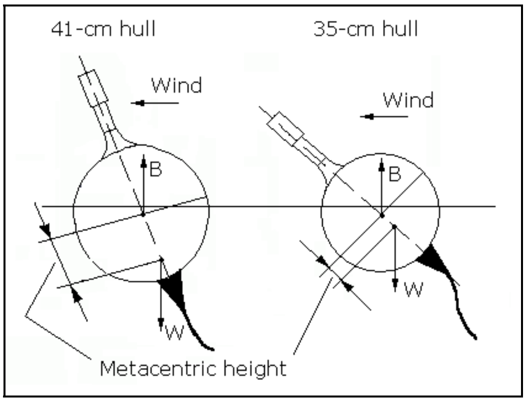

Figure 6. Different conditions to swim at sea surface for floats from standard and mini SVP-B drifters

Thus, the float of SVP-B mini drifter has larger dependence on wind pressure and its inclination from vertical is more in contrast with float of standard SVP-B drifter if same wind is applied to both buoys. Larger inclination of SVP-B mini drifter provides getting the port's inlet opened for wind pressure and its influence on AP sensor. As a result the AP samples have wrongly increased reading.

This effect is clear visible for buoys, deployed in the Tasman Sea and might be the wind-wave conditions, specific for this sea, make to get inclinations larger here.

Currently we suggest the following. The long-living drifters with 41-cm hulls and reliable AP measurements under any weather conditions should be used in difficult of access South Ocean and may be in North high latitudes, while the mini drifters with smaller diameter of float and shorter lifetime could be used in low latitudes, where there is large probability to get a buoy lost because of getting ashore or vandalism, but there is good probability to support density of drifter network by means of ships of opportunity.

Increasing of duration to keep the drogue attached

One of the problems which has large influence on quality of AP data is presence or absence of drogue. This item has two important things: keeping of the drogue attached as long as possible and confirmation of the fact that drogue has been really lost. Our point of view, which is confirmed with all the Marlin drifters, is that submergence sensor is a reliable tool to determine loss of drogue. Correct design of this sensor provides very clear signal, which fixes the moment, when drogue was lost. SVP-B as well as SVP-B mini drifters have same output from this sensor as it is shown on the Figure 7. After the drogue was lost, the buoy keeps zero submergence data during full remainder of its lifetime.

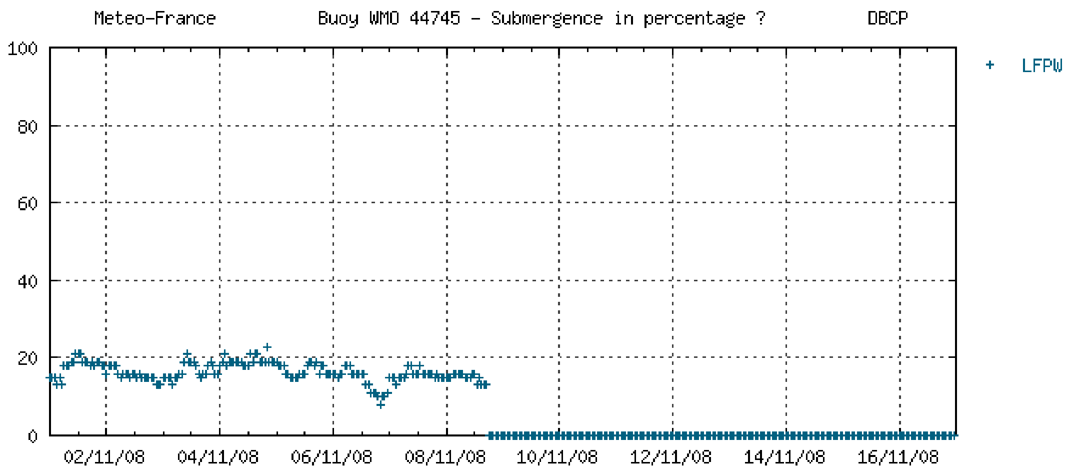

Figure 7. Determination of the time, when drogue was lost

Below are the comments about our understanding why the drogues are lost. It seems “wire” technology of tether connection with drogue is a reliable method. As well the drogue, built from firm synthetic fabric under technology, described in DBCP #4 document, has good strength to operate under rough wave conditions. We studied a few Marlin buoys beached in the Black Sea and other regions after near one year in operation and they had good quality of drogue and “wire” connection. Figure 8 below shows the main view of SVP-BTC temperature-profiling drifter, which was recovered by Meteo-France after one year operation in the Bay of Biscay.

Figure 8. Main view of the SVP-BTC temperature-profiling drifter, which was recovered after one year operation in the Bay of Biscay

The buoy has much more load applied to the “wire” connections and drogue as a whole. This is because temperature chain is connected with buoy via lower “wire” connection, which has same design with upper ring, so drogue is under influence of two oppositely directed forces: float’s positive buoyancy, directed upward and gravity force of the chain directed down. In spite of this twice effect, the connections and drogue did not have damages after one year in operation, as that is obviously from the Figure 9, which shows the view of drogue after it was cleared from biology fouling.

Figure 9. The view of SVP-BTC drifter’s drogue after it was cleared from one-year biology fouling

The breaking load for 4-6 mm rope, used as a tether for SVP-B and SVP-B mini drifters, is much more in contrast with static and dynamic load applied to tether of buoy in operation. We guess that there are two possible variants to get a drogue lost. The first event could take place within 3 months after deployment. For second variant the loss could be on some day during 300-450 days interval. The matter of these variants is presented on the Figure 10.

The first event could be a consequence of "weak place" creation on tether during deployment of drifter, when bad weather conditions. The "weak place" means that small loop could be formed at some point of tether during submergence of drogue. Because float can "jump" under wave influence, this loop can be shrunk with creation of fissure on tether. The rupture of tether in this place can be within 3 months.

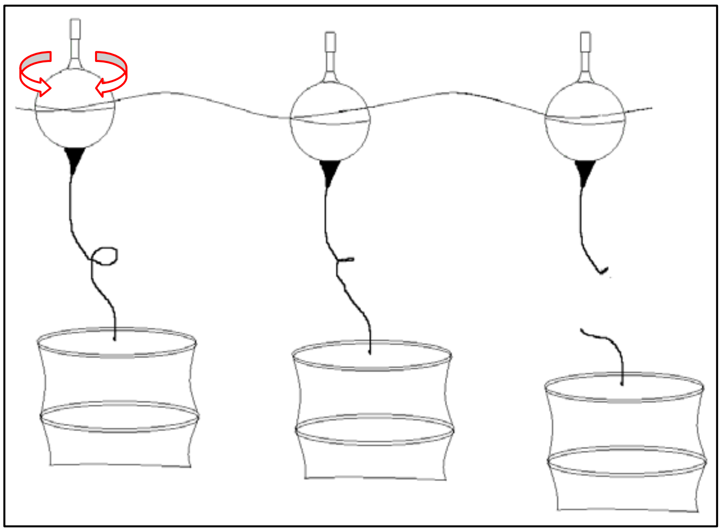

Figure 10. Creation of loops on tether and bidirectional rotation of float, which are the main reasons to get the drogue lost

We study a few buoys beached in the Black Sea and it became visible that more often the "weak place" can be closer to drogue (lower part of tether).

If deployment takes place without creation of the "weak place" on tether, the buoy could keep its drogue attached during much longer time. Of course, the situation during strong storm could be unexpected and "weak place" can appear under storm influence. Nevertheless, we guess that probability of "weak place" under storm influence is smaller in contrast with situation during deployment.

To avoid appearance of those two events for temperature-profiling drifters the 6-mm outside diameter tether between float and upper ring of tether is inserted now in hydraulic hose with 14-mm outside diameter. Creation of loops for this tether is unlikely and influence of bidirectional rotation become smaller. The buoy, shown on the Figures 9 and 10, was the device, built on basis of this design, and it demonstrated one-year reliable operation in rough Bay of Biscay.

This variant can be used only for quasi Lagrangian SVP-BTC drifter and it is inapplicable variant for Lagrangian buoys, because the DAR (Drag Area Ratio) for SVP-B drifter decreases up to DAR = 20-25. Thus, another technical solution should be found for SVP-B and SVP-B mini drifters.

To decrease a probability of first variant appearance to get the drogue lost, we started using for last years the spiral packaging of tether in the clips, attached to radials of upper ring, and swivel, inserted in tether. The view of tether's spiral packaging is shown on Figure 11.

The packaging is used since 2010 and a few SVP-B mini buoys with 4-mm OD rope got its drogues attached longer than 400 days. On the other hand in isolated instances the buoys lost their drogue within 100 days and approximately 50% within 200-350 days. Thus, the spiral packaging is not a perfect decision of this problem.

Since 2012 we started application of swivels inserted into tether below float. We think that swivel should prevent the influence of float's bidirectional rotation on tether. And second positive thing here could be to prevent or additionally decrease a probability of "weak place" creation on tether. The view of swivel, inserted in tether, is shown on Figure 11 too.

Figure 11. Spiral packaging of tether line in the clips, fixed to radials of “wire connection” and swivel, inserted in tether below float, to decrease probability of loops creation on tether during submergence of drogue after drop of buoy to water and influence of float’s bidirectional rotation on tether

Tracking capabilities of Argos-2 SVP-B standard drifter

The capabilities of this type of drifter to study ocean currents can be demonstrated via results of the buoy ID67381/WMO56631. The buoy has 64 alkaline D-cells and continuous mode in operation. It was deployed by BOM Australia on May 11, 2006 and has continued to be in operation 2902 days (near 8 years) till April 21, 2014 (the day, when preparation of this article was ended). The view of buoy’s trajectory is shown on the Figure 13. This information demonstrates the adequate power budget of Argos-2 standard drifters.

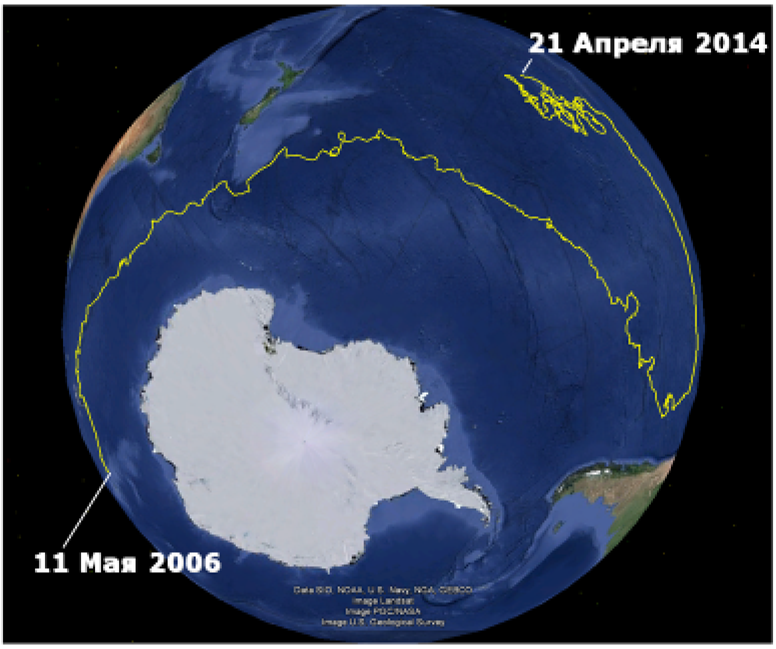

Figure 13. The near 8-year trajectory of SVP-B drifter (ID67381/WMO56531) deployed by May 11, 2006 in South Indian Ocean

Tracking capabilities of Argos-2 SVP-B mini drifter

In spite of smaller number of batteries the SVP-B mini drifters have large enough duration to keep tracking capabilities. The capabilities of this type of drifter are shown in the Table 2. The buoys, deployed in 2010, demonstrate that lifetime of this type of buoys is close to 4 years.

Continuity of samples and GPS fixes

SVP-B type of drifters has small float and large enough drogue. If water surface is calm, the float can support drogue, keeping own position at surface. But if water surface is not calm, the float cannot follow the surface profile, covered with waves. This is because the Holey-Sock drogue has large hydrodynamical resistance, while positive buoyancy of float is small. Thus, the float and buoy as a whole has submergence and the more amplitude of waves, the more depth of submergence and longer the time, when buoy is covered with water.

The water, especially salted water, has good screening effect, which is a reason to lose radio contact between buoy and both satellite constellations: telemetry and GPS. Continuity of data and locations can be lost in this case. GPS receiver, if it has continuous power supply, can support getting of locations even if some time the receiver does not have contacts with GPS satellites. But power consumption is too large in this case, even if energy-conserving GPS chip is used.

The obvious suggestion is that discontinuous duty cycle mode could be used to support GPS in operation. Yes, this variant works, when duration of the cycle to keep GPS switched on is limited and water surface is calm. In general the ocean does not have calm surface and loss of link between buoy and GPS satellites depends on two reasons: discontinuous duty cycle mode and submergence. Thus, it should be found some compromise between those both reasons.

And finally. The continuity of data sent through telemetry link has to be better or equal at least to the continuity of GPS fixes. This is because if GPS operates perfect and provides continuity of fixes, but telemetry link cannot transfer parameters of those fixes, there are holes in data as well as in GPS fixes and there is not capability to estimate how the GPS works.

Argos-2 SVP-B/RTC/GPS drifters

First use of GPS for Marlin drifters took place in 2006 in the Black Sea. Because we did not have any experience to use GPS on drifters, when the last had periodical submergence, as well as taking into account the possible bad conditions for reception of the signals from satellites, when buoy's antenna had small height above sea surface, the decision was accepted to use continuous mode for GPS to be switched on. The decision was not optimal, because increased power consumption, became a reason for shortened lifetime of buoy as a whole. Two experimental Argos-2 SVP-B mini drifters with GPS were deployed in 2006 in west part of the Black Sea. It became visible, that regular GPS locations took place while level of submergence was below of 12%. Both drifters had lifetimes near two months.

Next step was in 2006-2007, when discontinuous duty cycle mode for GPS receiver was used to decrease power consumption. To get hourly locations, the GPS was activated for 3 minutes and next 57 minutes it had "sleeping mode". Thus, it was used the pulse method to control GPS to get hourly locations, when duty factor was 0.05 (3min/60min).

15 drifters, built under the idea above, were deployed in 2006-2007 in different areas of the Ocean. Lifetimes of those buoys were more of one year. One of the buoys demonstrated 438 days in operation, that was five times more in contrast with lifetime of previous prototype and became a confirmation on performance of the used algorithm to control GPS receiver. However, it should be noticed that the buoys had large number of holes in locations (near 40%) and GPS could not produce locations, when reaching only 10% level of submergence.

New GPS receivers on basis of SiRFstarIII chipset had been used in 2008-2009. The chipset had better sensitivity and performance. To estimate the performance of the chipset, when the last had submergence, a few laboratory experiments were carried out with simulation of submergence. The result was that after a number of submergence with 15-sec duration, the chipset could get first location on 3-4 second after appearance at surface. Previous chipset could get first location on 8-12 second, that meant 3 times better performance. The results were confirmed in-situ in 2008-2009, when 15 Argos-2/GPS drifters were deployed in the Ocean. For example, the trajectories of 3 Argos-2 SVP/RTC/GPS drifters are shown on Figure 14. The deployments were fulfilled in the Baltic Sea with goal to study a splitting of subsurface currents.

However, later a few Argos-2 buoys got failures of GPS receivers especially under level of submergence between 15 and 20%. The GPS receivers with high sensitivity were used for those buoys and it seems that separate devices were incompatible with high enough power, emitting by Argos-2 PTT.

Our supposition was that, when buoy has intensive submergence, the Argos-2 antenna does not have optimal matching. As a result, electrical current for Argos-2 PTT is changed. This was a reason that voltage with amplitude higher of permissible level can be applied to power supply circuits of GPS and GPS preamplifier. These voltage jumps were the reason to get failure of GPS. Depending on the level of those jumps the failure could be with keeping of capability to produce GPS fixes or not. The issue of failure with producing GPS fixes was an increased power consumption. It is clear now why the GPS continued operation for buoys swimming in calm water or for ice buoys. No submergence, antenna keeps good matching and no voltage jumps.

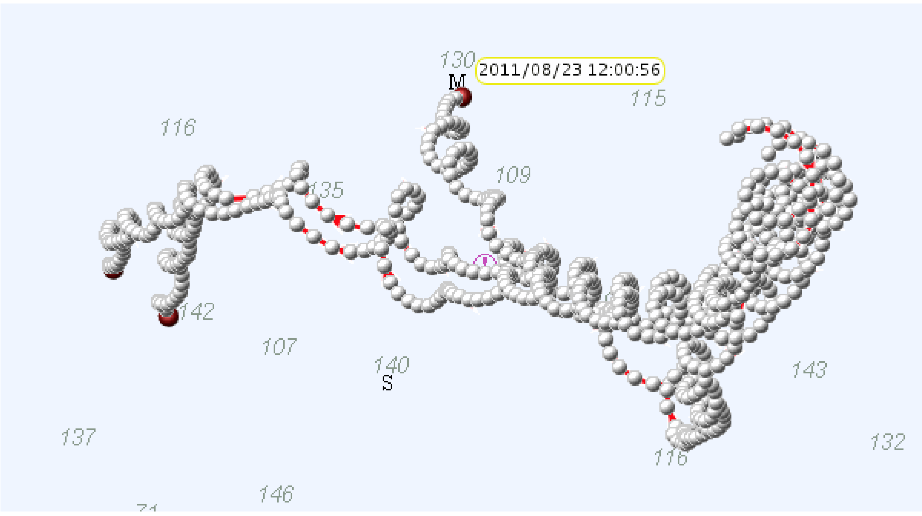

Figure 14. Splitting of subsurface currents in the Baltic Sea by means of study, when using the Argos-2 SVP/RTC/GPS mini drifters, deployed in one point

Next approach to get a decision of this issue was when we used new GPS receiver on basis of MTK MT3329 chipset with built-in antenna (so called “smart GPS antenna”). However, in spite of the re-design of electronics and different complex tests in laboratory, which confirmed a reliability of those chipsets, the deployments in-situ of new prototypes of Argos-2 SVP-B mini drifters with GPS were not successful. The problem took place again, when buoy got intensive and long submergences.

Against this background the following study was our reaction on the problem with goal to understand the reasons of GPS failures for some Argos-2 SVP-B mini buoys and eliminate them for further prototypes of GPS drifters. This analysis became a result of estimation of 5 Argos-2 SVP-B/RTC/GPS mini drifters, built for JAMSTEC, Japan, in 2012. The data from those buoys were chosen because they are typical to estimate quality of GPS operation on this type of drifters. All five drifters were in operation, when they had similar same situation with increasing submergence, however three buoys (IDs 120542, 120543, 120544) got failures of GPS, while two other (IDs 120540, 120541) kept their functionality.

First of all look on those two buoys. As an example, variability of data from drifter ID120541 is presented below on Figure15. Variability of three parameters: SubM – submergence, GPS(Lat) – latitude from GPS receiver and Ub – Battery Voltage are shown on the same temporary scale. Presence of GPS latitude means that there is a GPS location.

After deployment the buoy had GPS operational and battery voltage had usual falling of amplitude. But level of submergence started to become larger, may be as a result of biology fouling of Holey Sock drogue. The higher was value of submergence, the smaller number of fixes the GPS receiver could produce. It is visible that if SubM<15%, the GPS had stable operation. On the other hand, if SubM>15%, there were not stable GPS locations. This result was the expected one, when buoy was in operation under pulse mode to get hourly location with 0.05 temporal duty factor.

This experiment demonstrated the limited capabilities of Argos/GPS mini drifters, when they are used in areas with high level of biology fouling. The float of mini drifter with smaller positive buoyancy in contrast with standard buoy cannot provide for the buoy stable position at sea surface very soon after deployment. The critical value of submergence takes place on near 4-th month. After that GPS cannot produce locations because of too large time interval the buoy spend been submerged, when there is not radio contact between GPS receiver and satellites.

As for other three buoys where GPS got failure, the reason was electrical incompatibility of emitting transmitter and GPS receiver both having power supply from single battery as it is described above.

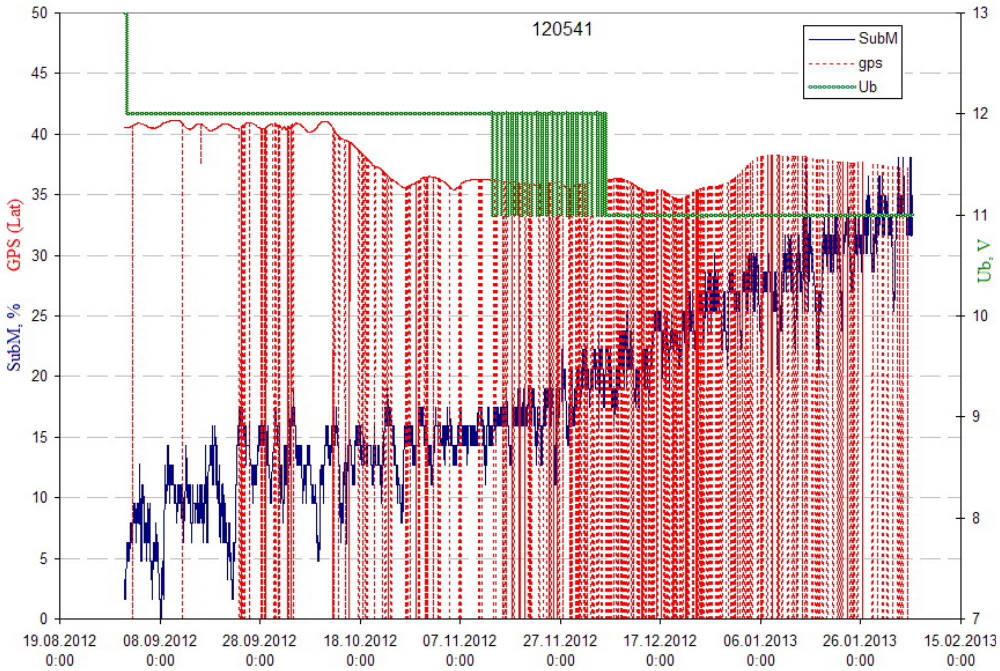

Figure 15. Variability of SubM, Ub and GPS fixes for drifter ID120541

To avoid the problem with Argos-2 transmitter and GPS receiver radio and electrical incompatibility, the buoy's electronics was updated. The special precautions were realized to protect preamplifier and electrical circuits of GPS receiver. Since the end of 2012 all the buoys has been manufactured with new electronics. More than 50 Argos-2 buoys with new electronics were deployed and there were not electrical failures on new buoys.

The dependence between stable operation of GPS, when it kept continuity of locations, and submergence became the matter to determine capability of new algorithm to control GPS, when variable duty factor was used. This algorithm was developed to be used on the drifters, equipped with Iridium telemetry.

Iridium SVP-B/RTC/GPS drifters

This type of drifter is a thing, where large efforts have been applied to create perfect tool for study of ocean circulation with high spatial-temporal resolution under any weather conditions.

First prototype of Iridium SVP-B/RTC/GPS drifters was developed within the DBCP Iridium Pilot Project. A few buoys were produced and deployed. The results of their evaluation became a basis for further step by step updating after evaluation of new and new clusters of drifters in situ.

The results of Iridium drifters evaluation in-situ showed that main technical advantages of this telemetry system in comparison with Argos-2 are that Iridium modems can transfer data under large level of submergence as well as the compact Iridium and GPS patch-antennas allow optimal placing of both inside buoy's float

The first prototype of Iridium SVP-B/RTC/GPS drifters had discontinuous duty cycle mode with 3-min duration for GPS receiver to be switched on after round hour, that is same with used on Argos-2 buoys. Additionally once a day at 00:00 the receiver had 30-min interval to be activated. Two Iridium SVP-B/RTC/GPS drifters of this prototype were deployed by South Africa Weather Service as the input in the DBCP Iridium Pilot Project. These buoys having WMO16551 and 17526 are presented in the Table 1.

Both buoys had hourly GPS locations. The buoy WMO16551 had 1396 days in operation and buoy WMO17526 stopped operation after 1250 days. The reason to stop transfer for both was that they got their batteries emptied. Figure 16 shows 1250-day track of drifter WMO17526 in South Ocean. The figure shows full track and detailed fragment built on basis of hourly GPS locations.

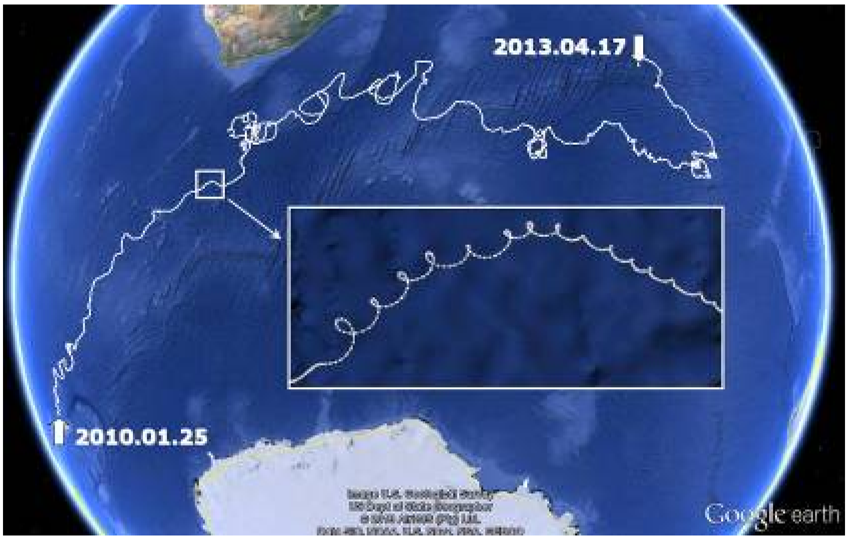

Figure 16. 1250-day track of the Iridium SVP-B/RTC/GPS drifter in the South Ocean

The buoy WMO17526 had additional pseudo Argos ID 486510 to get standard procedure of data processing in Argos receiving center. The buoy was in operation under wide variety of weather conditions. It had its drogue lost on 562 day after deployment. Continuity of hourly samples and GPS locations is shown on the Figure 17. Three graphs are on this figure.

Upper graph shows number of samples and GPS fixes in percents to theoretically possible during the time, when buoy had its drogue attached. It is visible that 99% of samples and 96.7% of GPS fixes were sent via GTS with hourly interval. Very small number of samples and fixes were sent with 2, 3 and 4-hour intervals.

The middle graph shows same data accepted under the situation, when weather conditions was most rough. The data have been extracted from 1250-day set of data, when submergence was higher of 20%. The results for samples are same with upper graph, while for GPS fixes the result is on 10% smaller.

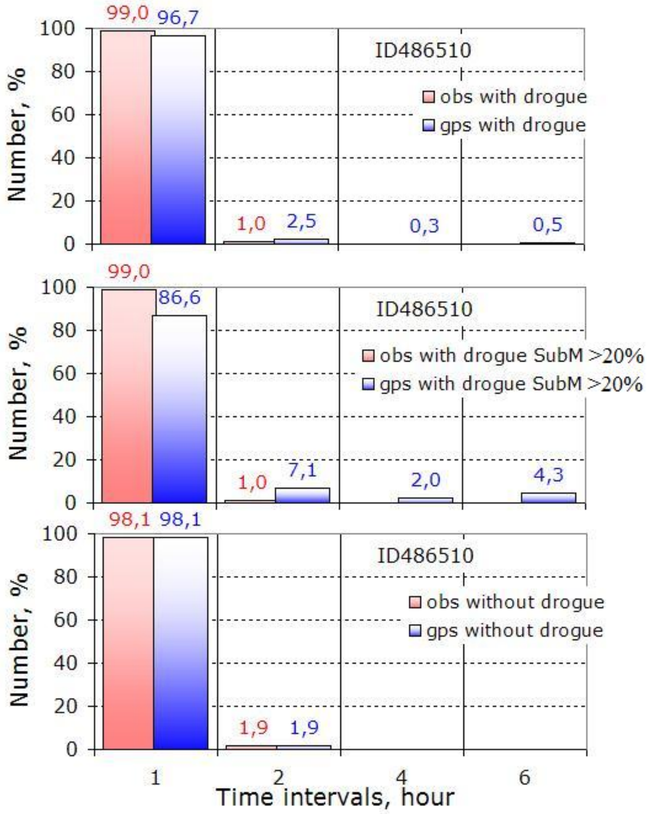

Figure 17. Continuity of hourly samples and GPS locations for Iridium SVP-B/RTC/GPS drifter during 1250-day movement in the South Ocean

Lower graph demonstrates the continuity of samples and GPS fixes after the drogue was lost. It is visible that continuity for both parameters has same value. Small decreasing of samples values in contrast with upper graphs could be explained with larger amplitudes of buoy inclinations from vertical axis after the buoy got its drogue lost. The larger amplitude and velocity of inclinations can be a reason for small worsening of quality of telemetry link. But ±1% is within statistical uncertainty, that allows to state perfect capabilities of Iridium link under any weather conditions.

Simultaneously, and this fact is very important, it should be noted, that standard Iridium SVP-B/RTC drifters, equipped with GPS receiver having discontinuous duty cycle mode with 3-min duration for GPS receiver to be switched on, demonstrated high quality to keep continuity of hourly GPS fixes under any weather conditions.

Packaging of a drifter for safety deployment

The problem to build drifter to be safety deployed is close to the item above about drifter with drogue attached for long time as well as to get drifter ready for automatic self-deploying capability after drop to water from 20-m height and velocity of deploying ship is up to 25 knots.

The 2012 prototype of SVP-B mini drifter, which has design shown on Figure 18, is next approach for decision of this the DBCP requirements.

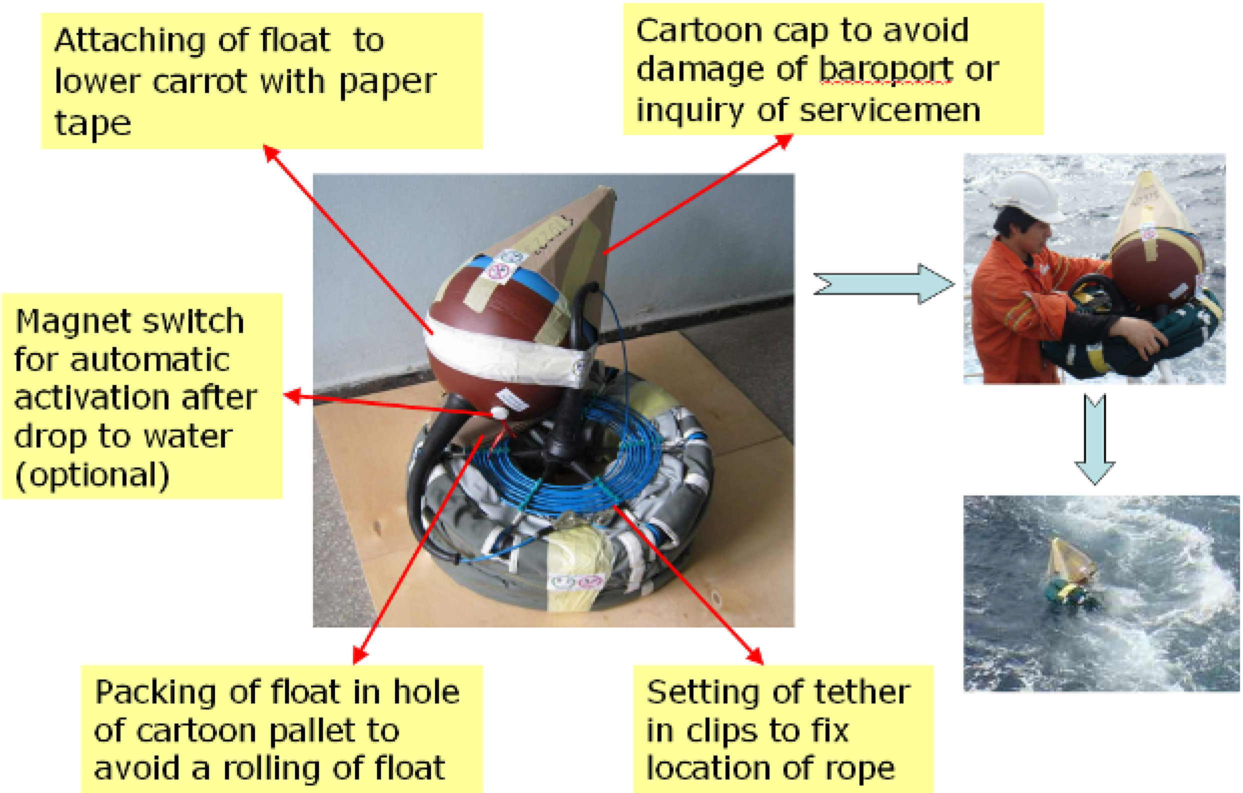

Figure 18. Packaging of the SVP-B mini drifter for safety deployment (2012 prototype)

The buoy has the setting of tether in clips to fix location of rope and prevent possible catch of deploying person's hand during drop of buoy. The float is laid in the hole of cartoon pallet to avoid a rolling of the float on ship's deck, which could be a reason to damage float or injure servicing person. Additional fixing of float to keep its location during drop is made with paper tape, which attach float to drogue's carrot. The cartoon cap is used to avoid damage of barometric port, when blow of water, and to inquiry of servicemen. At last, according to a user's request the buoy can be equipped with magnetic switch for automatic activation after drop to water. The SVP-B mini drifter of this prototype can be safety deployed by one person.

More than 30 SVP-B mini were successfully deployed under following conditions: Vship~20 Knots, Hdrop~20 m. After their evaluation in-situ our conclusion is that SVP-B mini drifters with shortened lifetime can be mainly used in central areas of the Ocean, where there is a larger probability to get failure of buoy because of beaching or sea vandalism, but on the other hand there is capability to support density of drifter network by means deployment form ships of opportunity.

Since 2012 the standard 41-cm SVP-B drifter has similar packaging. This prototype of buoy is shown on the Figure 19.

Safety deployment of this type of the drifter has to be carried out by two servicemen as it is shown on the Figure 20.

Three buoys of this prototype were successfully deployed by New Zealand MetService in the Tasman Sea in June-August 2012. The drops were carried out under following conditions: Vship = 8 Knots, Hdrop = 5 m, Vwind = 44 knots, Hwave = 6-7 m.

Figure 19. Main view of standard SVP-B drifter with 41-cm float and 92-cm drogue, prepared to be ready for self-deployment after drop to water

Figure 20. Deployment of the standard SVP-B drifter by means of drop to water

Temperature-profiling drifters to investigate thermodynamic activity within active layer

Obvious success in development of the barometer SVP-B drifting buoy became a basis for further efforts to create new tool for study of thermodynamic activity within active layer. The goal was to create temperature-profiling drifters intended for real-time study of temperature variability in active layer of the Ocean.

First prototype of the drifter was developed on basis of standard SVP-B buoy, that allows getting the Lagrangian tracker and temperature-profiling capabilities on basis low-cost drifter. First versions of these buoys had Argos-2 telemetry link, which worked in general satisfactorily. The problem was that much more passing capability needs to transfer large volume of data from this kind of drifter. If full 256 bits capacity of one message was used, this volume was not enough to send full information. 2-page format was developed and tested. However, the capabilities of 2-page format were also small.

Next prototype SVP-BTC80/RTc/GPS drifter was developed in 2009. The buoy had 80-m thermistor chain and was equipped with GPS receiver and Iridium modem for data transfer close to real time mode. Main view of drifter is shown on Figure 21 The parameters of buoy are in the Table 3. Many buoys of this prototype were applied in different international and regional projects.

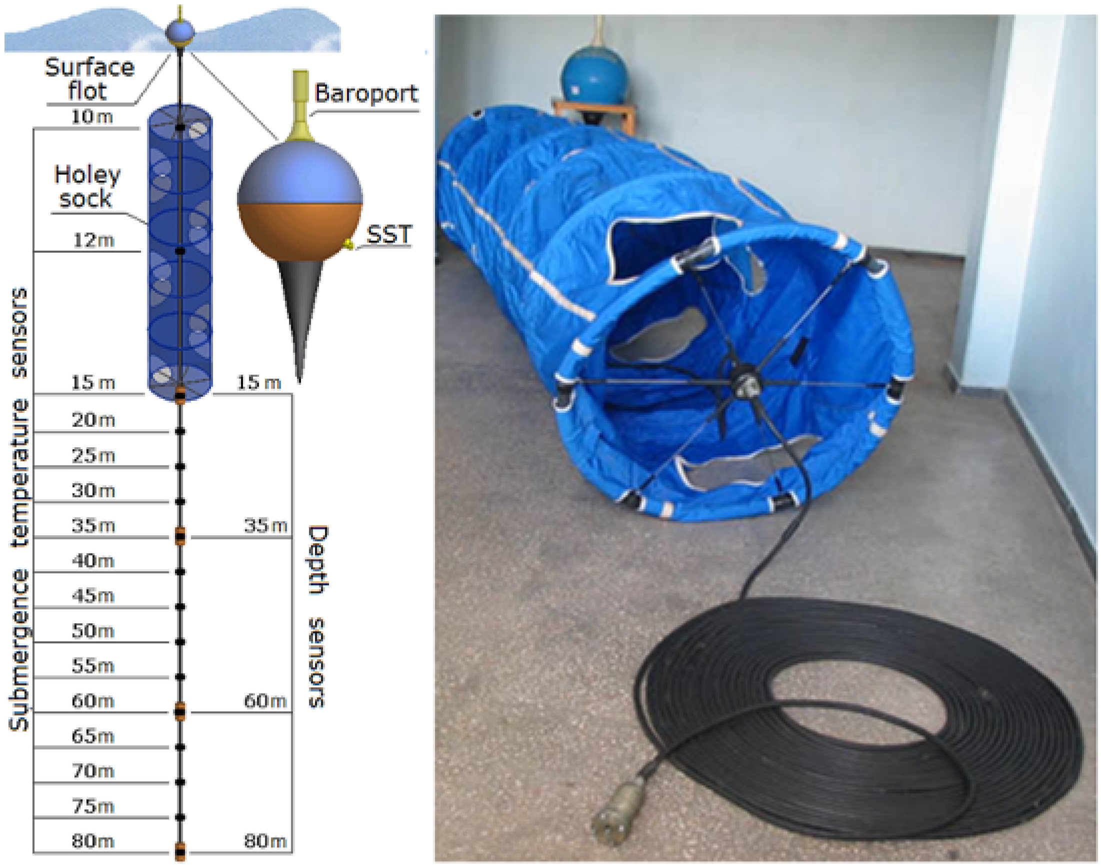

Figure 21. Structure (on the left) and main view (on the right) of the Iridium SVP-BTC80/RTC/GPS drifter Main

Table 3

Main parameters of the Iridium SVP-BTC80/RTC/GPS drifter

Air pressure гПа		Water temperature °C		Nominal depths of water temperature sensors M	Accuracy of locations m	
|Δ|	μ	|Δ|	μ		GPS receiver	Iridium Doppler method
≤ 1,0	0,1	≤ 0,1	0,04	0,2; 10; 12,5; 15; 20; 25; 30; 35; 40; 45; 50; 55; 60; 65; 70; 75; 80	≤ 100	Longitude: ≤ 10000 м Latitude: ≤ 1000 м

Notes to the Table: |Δ| – accuracy of measurements; μ – resolution of measurements

The buoy with thermistor chain is more loaded in water in contrast with standard barometer drifter. As a result it has more level of submergence. On the other hand it is important to provide for this type of buoy high spatial-temporal resolution to study the vertical and horizontal heat transfer and heat exchange on the level of mesoscale variability.

The first prototype of Iridium SVP-BTC80/RTC/GPS drifters had same discontinuous duty cycle mode as used on Iridium SVP-B/RTC/GPS drifters. As the example, it is shown on Figure 21 the results in operation of Iridium SVP-BTC80/RTC/GPS temperature-profiling drifter WMO62510, which Meteo-France deployed in the Bay of Biscay in 2010. The graph, shown on Figure 22, was built by Pierre Blouch from Meteo-France.

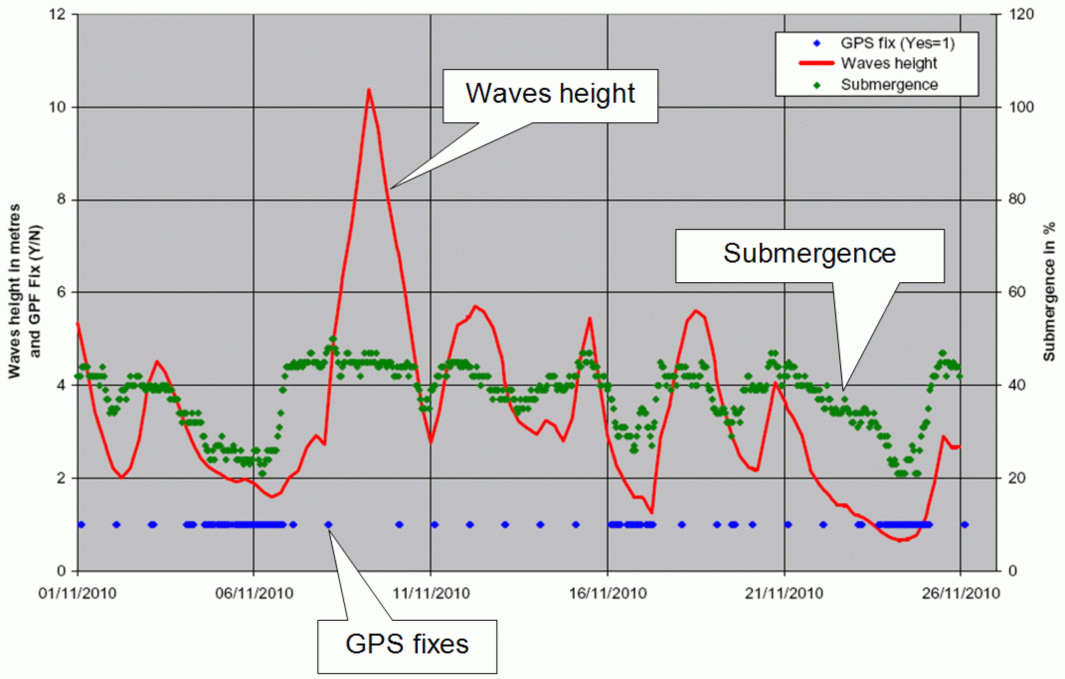

Figure 22. Operation of the GPS receiver on Iridium SVP-BTC80/RTC/GPS temperature-profiling drifter IMEI300034012487510/WMO62510 under influence of waves (the graph was accepted from Pierre Blouch, Meteo-France)

Figure 22 shows three parameters: model wave's heights (red line), submergence (green) and presence of GPS fixes (blue). It is visible that continuity of GPS fixes took place when level of submergence was down to 30% with surface waves height near 3 meters. If both parameters were higher of those values, GPS could produce fixes only once a day at midnight, when it had 30-min interval to be activated. This interval was added to algorithm to decrease probability to lose GPS almanac because of high level of submergence. However, if wave amplitude reached 10-11 meters, GPS could not produce fixes, even if GPS had 30-min interval to be switched on.

Figure 23 shows another presentation of the dependence between capabilities of the buoy's GPS to produce locations and submergence values.

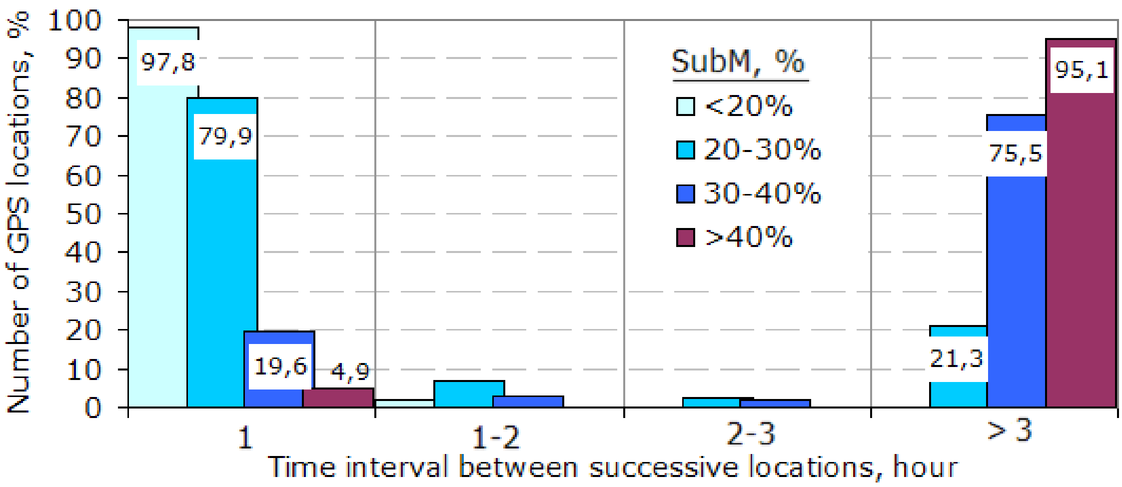

Figure 23. Distribution of time intervals between successive GPS locations depending on the Submergence (SubM) for Iridium SVP-BTC80/RTC/GPS drifter WMO62510 with thermistor chain from May 2010 to December 2010 in the Bay of Biscay

It is visible on Figure 23 that if submergence was smaller of 20%, 97.8% of locations were received with 1-hour interval. Correspondingly 79.9% of locations were received with 1-hour interval if submergence was from 20 to 30%; but if SubM was higher of 30%, the situation with continuity of location became catastrophically smaller: only 19.6% of locations were received with 1-hour interval if submergence was from 30 to 40% and only 4.9% - when level of submergence was more of 40%.

Thus, the buoy with thermistor chain had more holes in set of hourly GPS fixes under same weather conditions in contrast with standard Iridium SVP-B/RTC/GPS drifter. This was because the buoy with chain had more intensive submergence because of additional sinking load applied to float. The threshold of submergence, after the GPS could not produce regular locations, was near 30%. However, if GPS was switched on for 30 minutes instead 3 minutes, the GPS had stable locations. This fact allows supposing that if it would be possible to control (by means of software) with time to keep GPS switched on, it would be possible to increase the threshold, when GPS has stable operation.

Since 2012 new flexible schedule to keep GPS receiver activated was developed and introduced. The time can be now varied from 3 minutes to 15 minutes for each hourly fix. If water is calm, the obligatory 3-min interval is enough to get hourly fix. If there is not a fix during 3 minutes, one extra minute is added to keep GPS receiver activated. This procedure is repeated step by step up to 15 minute. If the first fix is accepted within temporary interval from 3 to 15 minutes, the GPS receiver is switched off and this location is sent as the location, connected with current hour.

This algorithm allows realizing of flexible pulse mode of GPS in operation to produce hourly locations, when duration to keep GPS switched on has variable duty factor from 0.05 to 0.25 depending on intensity of submergence.

If there is not GPS fix during 15 minutes, the previous location is sent with notification that this fix was accepted one hour ago. Similar way is used to notify a user that last location was accepted 2, 3 or more hours ago.

As the example of new algorithm effectiveness, the results in operation of Iridium SVP-BTC80/RTC/GPS drifter, equipped with new software is presented below. This buoy was chosen because it had long time in operation under very hard weather conditions.

The buoy with thermistor chain (WMO72803) was deployed on March 26, 2013 by University of Washington, USA in South Ocean near Antarctic. Weather conditions were very rough during full time of the drifter in operation. Sometimes amplitude of waves could reach 8-m height and more.

Figure 24 shows capability of the buoy's GPS to produce locations, when buoy was under different values of SubM.

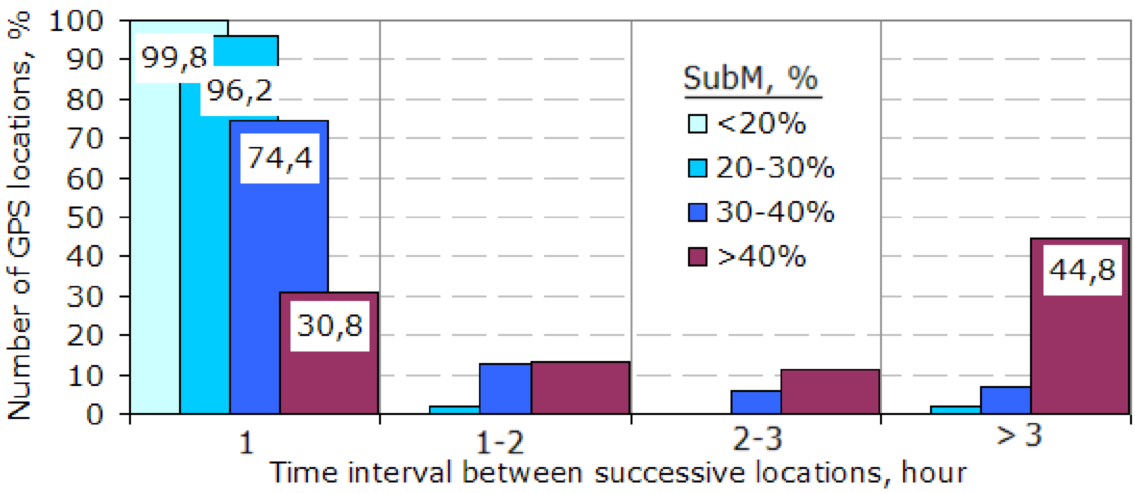

Figure 24. Distribution of time intervals between successive GPS locations depending on the Submergence (SubM) for Iridium SVP-BTC80/RTC/GPS drifter WMO72803 with thermistor chain from March 2013 to May 2013 in the South Ocean

If submergence was smaller of 20%, 99.8% of locations were received with 1-hour interval. Correspondingly 96.2% of locations were received with 1-hour interval if submergence was from 20 to 30%; 74.4% of locations were received with 1-hour interval if submergence was from 30 to 40%; and 30.8% - when level of submergence was more of 40%.

Thus, if compare the results presented on Figure 23 and Figure 24, it is visible that new algorithm to control GPS allowed accentually increasing continuity of hourly locations under high level of submergence. For example, if level of submergence was from 30 to 40%, continuity got near 4 times increasing (from 19.6% to 74.4%). If submergence was more of 40%, the continuity got near 6 times increasing (from 4.9% to 30.8%). Moreover, this algorithm provides power economy for buoy’s battery because duration to keep the GPS switched on has direct dependence on the level of submergence (waves amplitude): the smaller buoy gets submergence, the smaller power consumption is.

New step in development of temperature-profiling drifters was carried out in 2012-2014. The ice temperature-profiling drifter was developed. The structure of this buoy is shown on Figure 25.

The design of ice version of temperature profiling drifter has following differences in contrast with its marine prototype:

- The buoy does not have drogue;
- The float is connected with temperature chain via carrying cable inserted in the piece of reinforced hose. The length of hose depends on the possible maximum thickness of ice. First prototype of ice temperature-profiling drifter had 3-m length;
- The reinforced hose is connected with temperature chain via docking unit, which provides mechanical and electrical connection of the electronics inside float with chain.

Upper temperature sensor can be fixed close to docking unit and other sensors can be located at depths according to a user’s requests.

This decision became possible because ice buoy should operate under conditions, when surface float is placed on ice and there are not vertical fluctuations applied to the chain. Even if the buoy is in water, e.g. when ice melted, the level of surface waves has small amplitude in polar area.

The buoy has set of sensors and main technical parameters same with marine SVP-BTC/RTC/GPS drifter. First ice SVP-BTC60/RTC/GPS drifter was deployed in the Arctic Ocean on Sep. 4, 2012.

Figure 26 shows the fragment of the buoy’s trajectory from 4 Sep to 15 Sep 2012. The trajectory was built on basis of hourly GPS fixes. The figure has also the vertical temperature profiles for 3 points: at the beginning, in the middle and close to the end of trajectory.

The view of temperature variability from temperature sensors, fixed at the depths shown on right side, is presented on Figure 27.

This buoy was the first prototype of ice temperature-profiling drifters and further design of this tool depends on the result of long its study in situ.

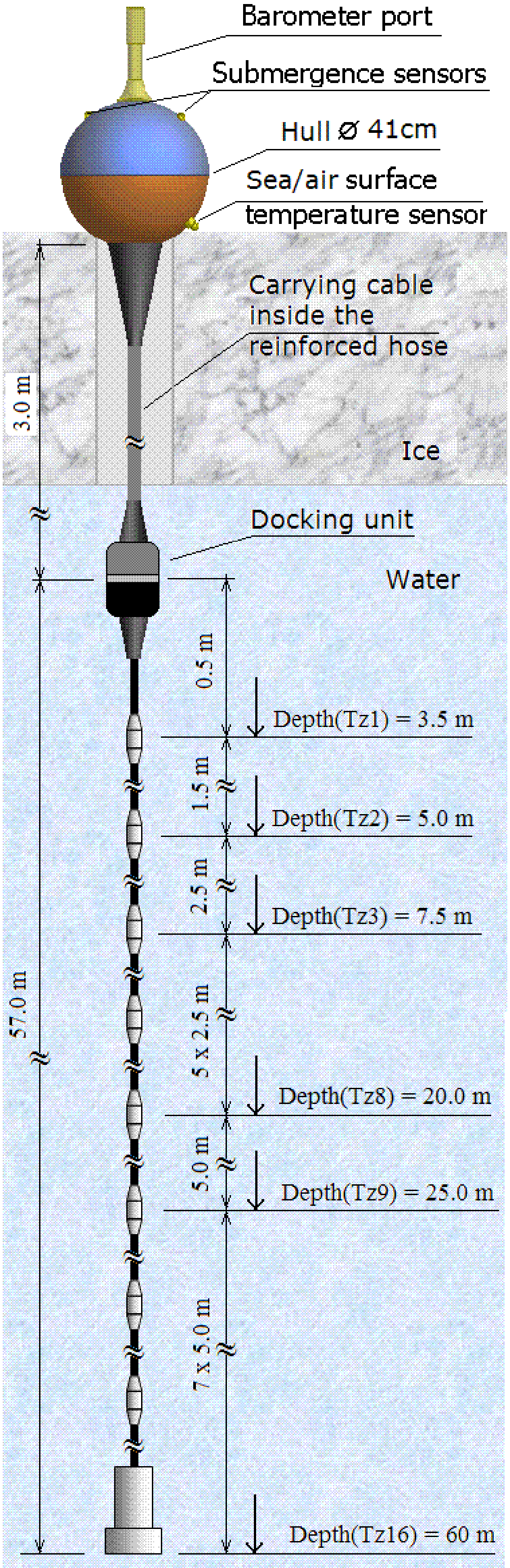

Figure 25. View of the ice temperature-profiling buoy structure

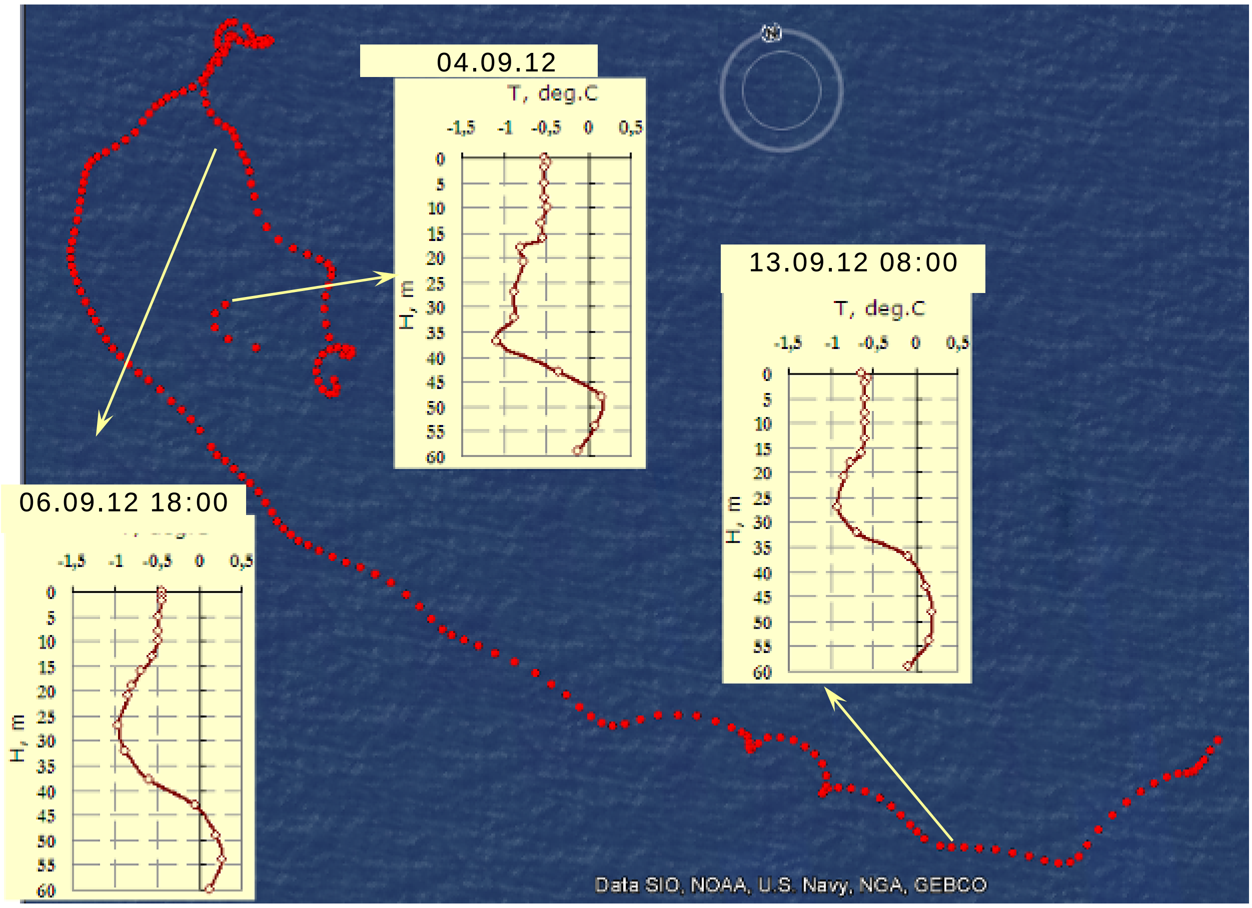

Figure 26. Fragment of the buoy's trajectory from 4 Sep to 15 Sep 2012, built on basis of hourly GPS fixes, and 3 vertical temperature profiles

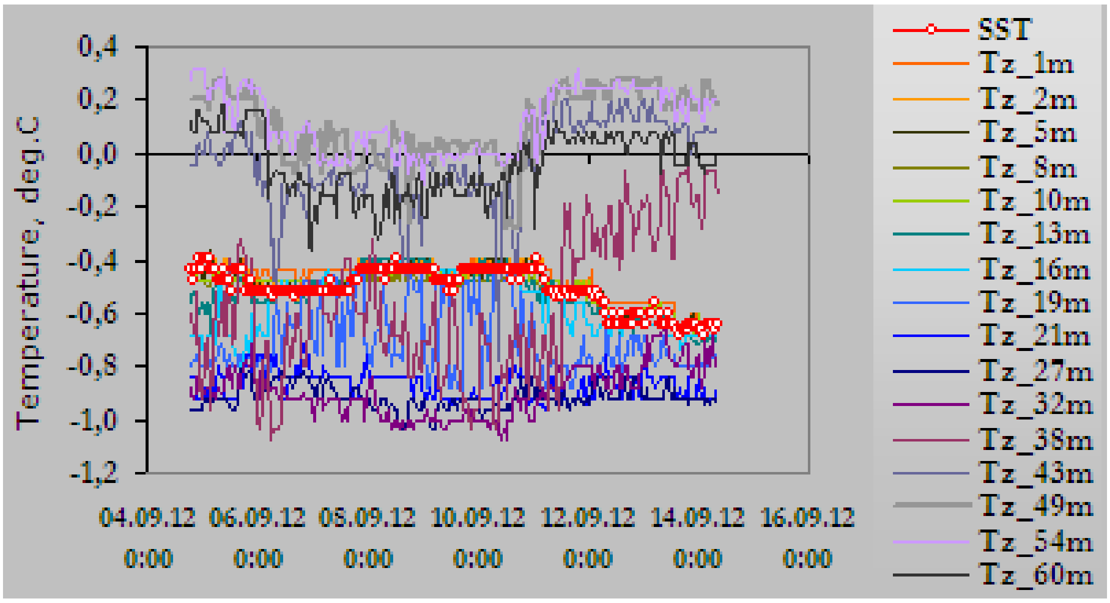

Figure 27. Temperature variability measured by temperature sensors of the chain from 4 Sep to 15 Sep 2012.

Micro buoys to study movement of ice-flows and surface currents in polar areas

New development got the “micro” drifter (ice marker) with 20-cm float. The view of this marker is shown on the Figure 28.

Figure 28. View of micro ice marker, equipped with parachute system to be deployed on ice or snow

The buoy got the parachute system to be ready for air drops on ice or snow. The parachute is connected with platform, which supports buoy. The connection of platform with parachute is via tip-up spring-supported rods. After contact with ice the rods become free to turn and be aflat fixed. Simultaneously the parachute’s container with parachute attached becomes free. As a result of this the buoy stays at platform, while parachute can be carried with wind or stay near buoy.

In spite of the fact that main application of this buoy is a tracking of ice-floes, the buoy has necessary capacity of positive buoyancy as well as static and dynamic stability of vertical orientation to be used as marine buoy swimming under wave influence. To drop the buoy in water, another prototype of parachute was developed. The parachute is connected with buoy via eyebolt in bottom of buoy as it is shown on Figure 29. Parachute keeps permanent connection with buoy and plays a role of drogue in water. The buoy can be used for tracking of oil patches.

Figure 29. Micro buoy for parachute deployment in water for oceanographic and other applications, e.g. tracking of oil patches

The test drops on ice and snow of buoy equipped with parachute were carried out from aircraft as well as from helicopter at late 2011-early 2012. Both experiments were successful. Figure 30 shows the opening of parachute after drop from aircraft. Figure 31 shows the buoy with parachute fully opened. Figure 32 shows buoy after landing. The land played role of ice.

Figure 30. Opening of parachute after drop from aircraft

Figure 31. The parachute fully opened before landing

Figure 32. The buoy after landing. The land played role of ice

The drop of buoy from helicopter is shown on Figure 33 (opening of parachute) and Figure 34 (buoy after fall in snow). There were two doubts before test drops. The first was that air flow from helicopter directed down could close the parachute's canopy. The second was that platform could not be opened because of small resistance of snow. Nevertheless, all was perfect. If helicopter velocity was 200 km/hour at least the canopy was completely opened. Similar was with fall to snow.

Figure 33. Opening of parachute after drop from helicopter

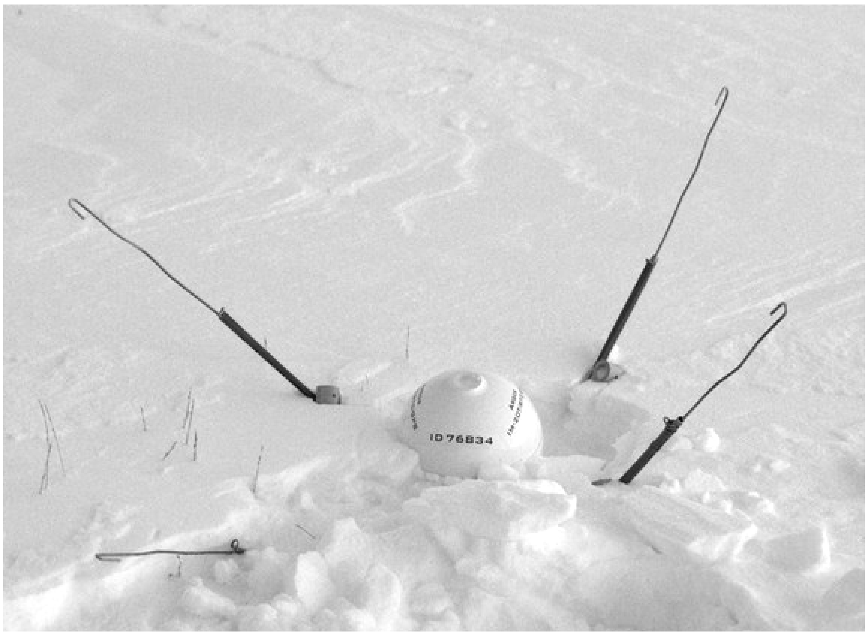

Figure 34. The buoy after fall to snow

We hope that this device could be used for different applications as oceanographic as well as other orientation. In particular, these buoys were used for study of marine animal life.

Conclusion

1. Argos-2 drifters can provide more than 7-year tracking of its movement.

2. SVP-B drifters have RMS of air pressure reports less than 0.7 hPa typically under any continuously rough weather conditions of South Ocean during overall lifetime (4 years at least).

3. SVP-B mini drifters have RMS of air pressure reports less than 0.9 hPa typically and lifetime 3 years at least.

4. Long-living SVP-B drifters can be used in difficult of access South Ocean, while SVP-B mini drifters with shorter lifetime – in low latitudes by means of deployments from ships of opportunity.

5. "Wire connection" of tether and drogue as whole are reliable parts of drifter. The problem of fast loss of drogue is wire tether. Fix of tether in clips and use of swivel below float could keep drogue attached longer.

6. Iridium SVP-B drifters with hourly GPS have 1250 days lifetime at least. Continuity of hourly samples and GPS fixes are near 99% and 90% correspondingly under any weather conditions.

7. Iridium SVP-B buoys without GPS have continuity of hourly samples near 99% under any weather conditions and should provide 3.5 years operation at least.

8. Iridium ice prototype of SVP-BTC/RTC/GPS drifter became the main tool to study thermodynamic variability in Arctic area. The buoy can be used as marine drifter or to study temperature variability below ice.

9. The drifter with 20-cm outside diameter hull, equipped with parachute, was developed and successfully tested from aircraft and helicopter.

References

1. Sybrandy A. WOCE Surface Velocity Programme Barometer Drifter Construction Manual / A. Sybrandy, P. Niiler, C. Martin, W. Scuba, E. Charpentier, D. Meldrum // DBCP Technical Document No. 4 — 2009. — 47 p.