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OCEANOLOGY

Data processing and performance testing of a low-cost surface drifter design for use in coastal waters

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Abstract. A surface drifter design suitable for deployment in the Gulf of Finland is presented. The drifters were designed for deployments lasting several weeks, and used a GPS/GPRS tracker unit to transmit drifter coordinates at a sampling frequency of 10–15 min. The drifter design was modified during the deployment period 2010–2014, which increased the lifetime and reliability of the track recording and reduced the direct wind drag impact, but did not significantly alter the current following performance of the drifter. A novel data quality control scheme was developed, where a time-varying reference speed derived from the data was used to identify data outliers. Compared with traditional quality control methods that use a constant reference speed limiter, the method presented here limits both the local maximum and local minimum drifter speed and is capable of identifying local extrema in relatively low drifter speed regimes.

Key words: Lagrangian drifter, data quality management.

1. INTRODUCTION

Surface drifters have been applied for tracking the movement of surface currents since the end of the 18th century [1], initially relying on visual tracking of drifters and later aided by radar tracking. In recent decades the use of surface drifters has been revolutionized due to the development in satellite positioning systems. Global ocean currents are now continuously monitored through the Global Drifter Program (GDP) (http://www.aoml.noaa.gov/phod/dac/gdp.html), which has a stated aim to maintain a global 5°× 5° array of 1250 satellite-tracked drifting buoys as part of NOAA's Global Ocean Observing System (GOOS). Drifters have also been applied for the study of currents in smaller sea basins and localized coastal areas, but no systematic observation programme similar to the GDP has been devised for such observations.

This paper documents the development of a drifter used in the Gulf of Finland, the Baltic Sea, taking into account specific conditions in this sea basin, and the management of data recorded by the drifter. Scientific studies of the general circulation in the Gulf of Finland date back to the late 1890s (see [2,3] for references), originally based on data collected from lightships and regular oceanographic cruises. During much of the 20th century basin-wide investigations were restricted in the Gulf of Finland, but from the 1990s onward there have been a number of studies making use of both numerical modelling tools and recent measurement techniques [2,4]. Currently, oceanographic observations from various permanent monitoring stations in the Baltic Sea are provided through the Baltic Operational Oceanographic System (BOOS) (http://www.boos.org) network. However, unlike the global GOOS programme, BOOS does not include a programme for Lagrangian drifter observations.

The recent drifter deployment programme for which the drifters described in this paper were designed, was mainly devised to support studies of current-driven transport of adverse impacts in the uppermost layer of the sea. This topic has been the focus of the recently completed BONUS project BalticWay [5], with the specific aim of quantifying the potential adverse impact to the coast of pollution originating from offshore ship traffic [6–8]. This approach addressed the inverse

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problem of connecting the impact of coastal pollution with offshore sources, thereby assessing the potential of the source locations to pose a risk to the coastal areas. The method thereby devised required statistical analysis of a large number of Lagrangian trajectories, which was primarily achieved through numerical modelling. The drifter deployment programme was therefore designed in order to obtain a large database of current recordings that could be related to transport in the uppermost surface layer in the Gulf of Finland.

The drifter design most often used for ocean studies is the Surface Velocity Program (SVP) drifting buoy [9], also called a WOCE drifter. This design consists of a surface float connected by a tether line to a holey-sock drogue centred at 15 m depth. The performance of this drifter under various conditions is well documented, and the drifter is suitable for open ocean conditions where the depth of the surface mixed layer is typically in the range 25–100 m. This type of drifter has recently been used to study current conditions in the Baltic Proper [10]. However, in the Gulf of Finland the thickness of the surface mixed layer is usually in the range 10–20 m [2] with a large variability both regionally and seasonally. Studies based on numerical simulations have suggested that flow properties may vary significantly between the uppermost, mostly wind-driven layer (0–2.5 m), and the immediate sub-surface layer (2.5–7.5 m) displaying a more persistent circulation pattern [11]. Furthermore, the Gulf of Finland is quite shallow, with an average depth of only 37 m [3], hence there is a considerable risk of grounding for drifters deployed in this sea area. Under such conditions it is difficult to determine if the motion of a SVP drifter represents the surface current motion or the sub-surface current motion. It was therefore decided to design a drifter specifically for use in shallow and coastal waters.

Several drifter designs have been applied for use in shallow or coastal waters. However, these drifters are not produced according to a single standard design specification, as is the case for the SVP drifters. Probably the most common drifter design for use in shallow water is the DAVIS drifter [12,13], also called the Coastal Ocean Dynamics Experiment (CODE) drifter, which consists of a tube equipped with four sails mounted as a cross and extending along the length of the tube. Another design used for similar purposes is the Microstar drifter [14], which consists of a buoy equipped with a shallow drogue shaped as a octahedron. The advantage of using drogues or sails is that the slippage between the drifter and current motion due to wind stress is reduced. A previous study in the Gulf of Finland used a Current Spy drifter [15], which is of a similar design as the Microstar drifter, but uses a shallow drogue consisting of four intersecting 30 cm×30 cm steel plates reaching a maximum depth of 0.7 m. These drifters were used to validate drift forecast models, primarily for use within an oil-spill management system.

For our experiments in the Gulf of Finland it was important to have a simple, low-cost, and robust drifter that would be easy to transport and deploy from any available vessel, ranging from small dinghies to passenger ferries. The drifter was expected to operate for several weeks, frequently within coastal areas with diverse bottom conditions, where occasional grounding could be expected. It was particularly important to ensure that the drifter performance was not altered due to mechanical failure during the deployment period. Drogues or sails attached to the drifter are particularly prone to suffer damage during grounding events, and loss of a drogue can have a considerable influence on the drifter performance [16]. Furthermore, the presence of voluminous submerged drifter extensions may enhance the impact of biofouling and drag caused by high seaweed, which can temporarily or permanently alter the drifter performance, especially in shallow sea areas. For this reason the drifter was designed as an object with a slender solid body, without any sails or drogues, instead of using the more traditional CODE or Microstar designs. As a consequence, the water following ability of the drifter was expected to be impaired to some extent when compared with drifters mentioned above, especially in strong wind conditions, which may cause increased slippage. The use of this drifter was first described in [17], and results based on this drifter data are presented in [18]. This paper provides a description of the drifter design, the data management and data quality control procedures used for the drifters, estimation of wind drag effect on the drifter, and a comparison of performance for different drifter versions.

2. DRIFTER CONSTRUCTION: DESCRIPTION OF THE PTR GROUP DRIFTER DESIGN

Drifter experiments in the Gulf of Finland have been carried out using a lightweight, autonomous surface drifter manufactured by the PTR Group (Tallinn, Estonia). The drifter design was suggested by researchers of the Institute of Cybernetics at Tallinn University of Technology (IoC, Tallinn, Estonia), and design modifications have been made in collaboration between IoC and PTR Group. The design was first used in drifter experiments in 2010, as was documented in [17], and it has been slightly modified in later experiments in order to improve drifter performance.

The basic design used in early experiments (hereafter denoted as the PTRG-v1 drifter) consisted of a polyethylene pipe, 2 m long and 50 mm in diameter, hermetically sealed with waterproof rubber lids at both ends. The drifter was positioned vertically in water, with 2/3 of the pipe submerged and 1/3 (60 cm) of the pipe above the water line (Fig. 1). The PTRG-v1 drifter was equipped with a GPS/GSM tracker (CT-24, Sanav, Taiwan), positioned at its top end, and a battery pack consisting of eight D-size standard elements (18 Ah), which enabled the drifter to work for 2–3 weeks. The battery pack and deadweight were mounted on the bottom end of the pipe to adjust the buoyancy of the

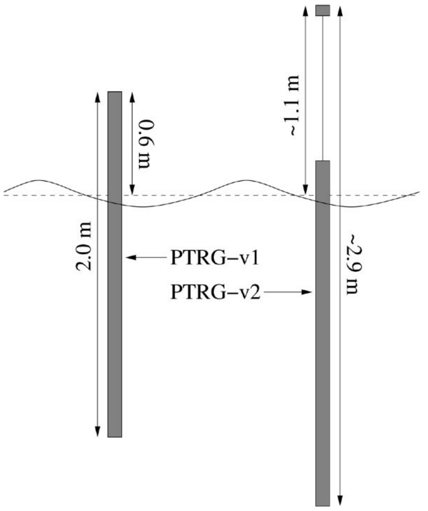

Fig. 1. Design of the PTRG-v1 and PTRG-v2 drifters.

drifter, thereby maintaining the drifter in a vertical floating position. Performance of the PTRG-v1 drifter was improved in 2011 by using an updated version of the CT-24 tracker, which included an internal memory buffer for data records. This substantially reduced the loss of data due to failure of GSM network connection.

A modified design was introduced in 2013 (hereafter denoted as the PTRG-v2 drifter), where about 9/10 of the pipe was submerged and 1/10 (20 cm) of the pipe was above water (Fig. 1). The modification was made to reduce the direct wind stress impact on the drifter, while still keeping the active tracker device well above the sea surface. This was achieved by placing the GPS tracker in a separate waterproof container, connected with the main drifter body by a narrow rod (10 mm in diameter), and located approximately 85 cm above the main drifter body. Placing the GPS tracker higher above the sea level had the added benefit of improving connectivity to the GSM network. The drifter also included a new active component – the MU-201 GPS/GPRS tracker (Sanav, Taiwan), which had a lower power consumption than the CT-24 unit, thereby extending the drifter lifetime.

Most drifters produced for ocean or coastal deployment rely on satellite communication systems for data transmission, which has a substantially higher cost of operation than data transmissions over the GSM network. In the design of drifters for coastal deployments it is therefore beneficial to make use of cellular data transmission technology, provided the drifters remain within the line-of-sight of a cellular base station during the deployment time [19]. In particular, the use of cellular data transmission is suitable for drifter deployments in the western part of the Gulf of Finland, where most of the sea area is covered by the GSM network either from the Estonian or the Finnish side of the gulf. Although the GSM network connection did not reach the central part of the Gulf of Finland, most drifters would reside within this area for only a few days before connecting to a GSM base station at the coast. However, in some cases the drifters failed to connect to the GSM network when reaching the Finnish coast, leading to loss of data.

3. DRIFTER DATA MANAGEMENT

The drifters were programmed to record their position at regular time intervals, usually 15 min intervals for drifter deployments in 2010–2011 and 10 min intervals for deployments in 2013–2014. These data were immediately transferred to a data server on land, provided the tracker was connected to the GSM network. If the tracker was disconnected from the GSM network, data were stored in the tracker memory buffer (not available for the 2010 drifters). The memory buffer sometimes filled up if the connection problem lasted several days, in which case old position records were overwritten and data were lost. The entire record would be sent once connection to the GSM network was re-established, and data that had been sent successfully were then deleted from the internal memory buffer of the GPS tracker unit.

The drifter record consisted of a list of events, each event represented by a single line of ASCII data, consisting of the date and time (UTC) of the record, geographical coordinates, GPS status, and nature of the record event. In most cases the record event would be the automatic waypoint recording, but also events such as low power or GSM network connection problems would trigger an event record. In each case the tracker would also record if the GPS coordinate was fixed at the record time, but would not provide information about the accuracy of the GPS recorded position if a fixed position had been obtained. Automatic waypoint records would be made even if the GPS position was not fixed. The first step of the data processing was therefore to extract only the automatic waypoint records for which the GPS position was fixed to form the drifter track record (hereafter denoted the DTR). Thereafter the DTR was sorted in chronological order of the record events. This was necessary because the chronology in the drifter record was altered when some of the data had been temporarily stored in the tracker memory buffer.

The DTR should be restricted to the time period when the drifter was floating freely in the surface layer of the water column. In some cases the drifter remained in off-shore conditions throughout the duration of its lifetime, and therefore the termination of the DTR would coincide with the loss of connection with the drifter. However, in most cases the drifter entered a shallow coastal area at some time after deployment. The DTR was terminated when the track showed signs of stagnation, but in many instances there was a gradual deceleration of the drifter before a point of stagnation was reached. It is likely that some of this deceleration was due to the drifter being restrained by bottom topography, and therefore the average DTR near the coast shows slower movement than the actual current speed in these areas. In some cases the grounding of the drifter was only temporary, and the drifter would return to open waters after a while, in which case the track was recorded as a new DTR.

Analysis of drifter tracks was performed with the aid of the QGIS software in combination with the GSHHS shoreline data. This analysis also revealed gaps and noise in data records. Most tracks contained short gaps due to failure of obtaining GPS fixed positions. A likely path of the drifter could usually be determined even for data gaps of several hours, provided the drifter followed a steady trajectory before and after the gap. Some tracks also contained longer time gaps due to loss of GSM network connection. For long time gaps (usually more than 24 h), the DTR was terminated at the start of the gap and a new DTR was defined from the time that the drifter re-connected to the GSM network. Due to temporary groundings and large time gaps, the number of DTRs was larger than the number of drifter deployments. In the following, drifter deployments have individual labels of the form 'F<YY>-<DD>', where '<YY>' indicates the deployment year, and '<DD>' an incremental drifter number for that year.

4. ACCURACY OF GPS POSITION

The GPS/GSM tracker units used in the experiments were compact units originally designed for asset tracking. These units were equipped with internal GSM and active GPS patch antennas and a receiver for C/A Code on the L1 frequency (20 channels for the CT-24 unit, 50 channels for the MU-201 unit). The tracker records did not provide information about the accuracy of the GPS position, but the analysis of DTRs indicated differences in performance between individual tracker units. This can be illustrated by studying the start of drifter tracks when two or more drifters were in close proximity to each other (Fig. 2). Drifter F13-8 reported its position at regular intervals and followed a steady path, whereas F13-7 had significant gaps in the record and also single waypoints that deviated from the expected path line. If regarded in isolation, the slightly perturbed path of F13-7 could be interpreted as influence by small-scale turbulent noise, but this is an unlikely cause because the effect is only seen for one of the two drifters. However, this example illustrates that it is difficult to distinguish between small-scale turbulent noise and noise due to inaccuracy of the GPS coordinate when analysing the drifter tracks.

The GPS/GSM tracker units are generally quite reliable when tested from a fixed position on land, but this does not necessarily reflect how the tracker units perform during deployment at sea. In order to examine the accuracy of the GPS position under field conditions, we studied records of positions for drifters after they grounded at the coast. Table 1 shows statistics of GPS accuracy for three drifters (F14-12, F14-14, and F14-15), measured as the deviation from the mean GPS position of the record. Drifters F14-14 and F14-15 appear to be quite reliable, with mean drifter deviation of less than 3 m, whereas the mean deviation for F14-12 is about 12 m. The maximum deviation for the F14-12 drifter was more than 50 m, and even the presumably more reliable F14-15 drifter contained a maximum deviation of more than 20 m. This is particularly important when calculating instantaneous drifter speed, as a deviation of 50 m over a 10-min sampling interval results in an erroneous drifter speed component of 8 cm/s.

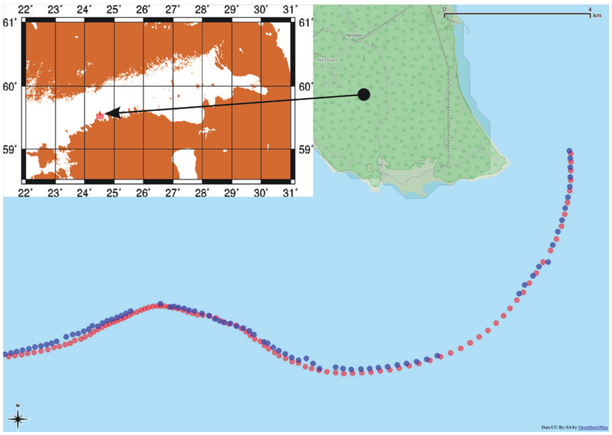

Fig. 2. Start of drifter tracks for deployment on 19 May 2013, illustrating the problem of gaps and noise in drifter track records. The two drifters can be assumed to follow the same path within the segment shown. Drifter F13-7 blue, F13-8 red.

Table 1. GPS accuracy for stationary drifters, measured as deviation from the mean GPS position recorded for a grounded drifter

Drifter	Deviation from mean GPS position, m				
	Mean	RMS	Min	Median	Max
F14-12	11.79	13.38	0.43	9.69	55.77
F14-14	2.79	3.36	0.34	2.55	8.54
F14-15	2.94	4.48	0.04	1.99	22.18

5. DATA QUALITY CONTROL

In order to improve the reliability of the DTRs, the track data were processed through a quality control program to remove data points that cause erroneous trajectory behaviour. The procedure follows multiple steps, starting with the removal of the most obvious data points and thereafter handling the less obvious cases. The first step in the procedure was to remove duplicate position records caused by the tracker re-sending the same record multiple times. In these cases only the first recorded instance was kept and all subsequent identical records were deleted.

The following steps relied on restrictions of the drifter speed, which were computed between each drifter position with a standard one-step finite difference method. The standard method applied for SVP drifters eliminates position records that violate a pre-set maximum speed limit [20]. The finite difference speed is computed in both a forward and a backward sweep through all trajectory points, and the selection is made to eliminate the minimum number of points that restrict the drifter speed within the allowed upper limit. The problem with this method is finding a suitable speed limit, especially for a region such as the Gulf of Finland where the flow field is highly intermittent [11]. The speed limit of 1.0 m/s applied to the DTRs recorded in the Gulf of Finland did not result in the elimination of any data points, whereas halving this limit to 0.5 m/s would have eliminated some clearly valid peak values. The standard procedure [20] was devised for drifter data that recorded with a sampling interval of several hours, and would frequently contain gaps of several days. In such a scenario the quality control procedure would only be able to eliminate drifter coordinate records responsible for quite large deviations in drifter behaviour. However, the procedure is less appropriate for the elimination of outlier drifter records when positions are recorded at a much higher frequency and with fewer gaps.

Inspection of drifter speed plots (Fig. 3, upper panel) would often reveal occasional outlier values. In many cases the outliers were not associated with the maximum speed value for the entire record, but represented local maxima and minima that clearly deviated from the local average speed. A running average speed $\overline{S_{MA}}$ was therefore calculated, in this case over 12 position points. The running average was computed over drifter points as long as the gaps did not exceed 3.5 times the sampling rate. A quality control requirement was devised by limiting the deviation of the drifter speed relative to the running average, here called the speed error S_{err},

$$S_{\text{err}}(t) = |S(t) - \overline{S_{MA}}(t)| < S_\alpha, \qquad (1)$$

where S_α was a selected threshold for acceptable speed error values. The speed error was tested in two sweeps, first with a value of $S_\alpha = 0.1$ m/s, and a second time with $S_\alpha = 0.05$ m/s. The two drifter coordinates (points) associated with a speed error that exceeded the prescribed limit were flagged as potential errors, but not automatically removed. The flagged points were then examined individually to identify erroneous drifter coordinates. Speed errors flagged with $S_\alpha = 0.1$ m/s would usually result in one or more points being deleted, whereas flags raised at $S_\alpha = 0.05$ m/s would cause points to be eliminated only if they were associated with obvious deviations in the drifter tracks.

Evaluation of flagged points was made by examining both the drifter track and drifter speed for each individual case (Fig. 4). A new drifter speed value was calculated from the previous and following points relative to the point under evaluation and was used in the speed analysis to visualize the impact of point removal. The most obvious candidates for removal occurred when a single

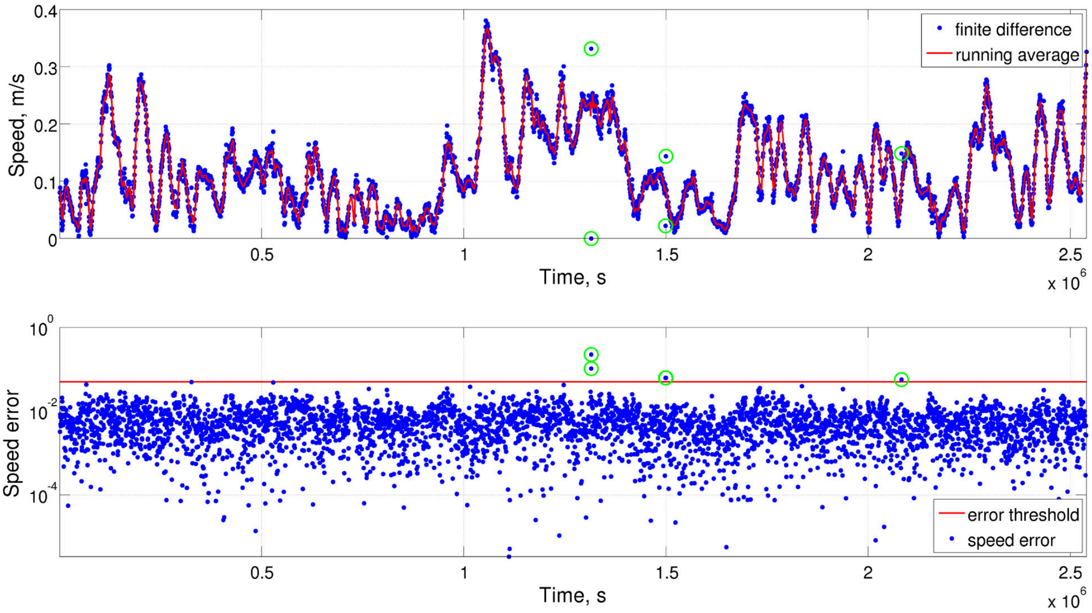

Fig. 3. Quality control of drifter coordinates for drifter F13-2, based on analysis of drifter speed. Upper panel: drifter speed as function of drift time, calculated by finite difference between consecutive drifter coordinates (blue dots) and the running average of drifter speed (red line). Lower panel: drifter speed error S_{err} (blue dots) and error tolerance level (red line). Outlier values are marked with green circles in both panels.

point deviated from an otherwise smooth trajectory (Fig. 4), causing a distinct 'kink' in the drifter path. Such points were removed if the $S_\alpha = 0.05$ m/s flag was raised.

A second candidate for removal was points that were nearly overlapping (Fig. 5). Such errors often occurred before larger gaps in the record, and were therefore more

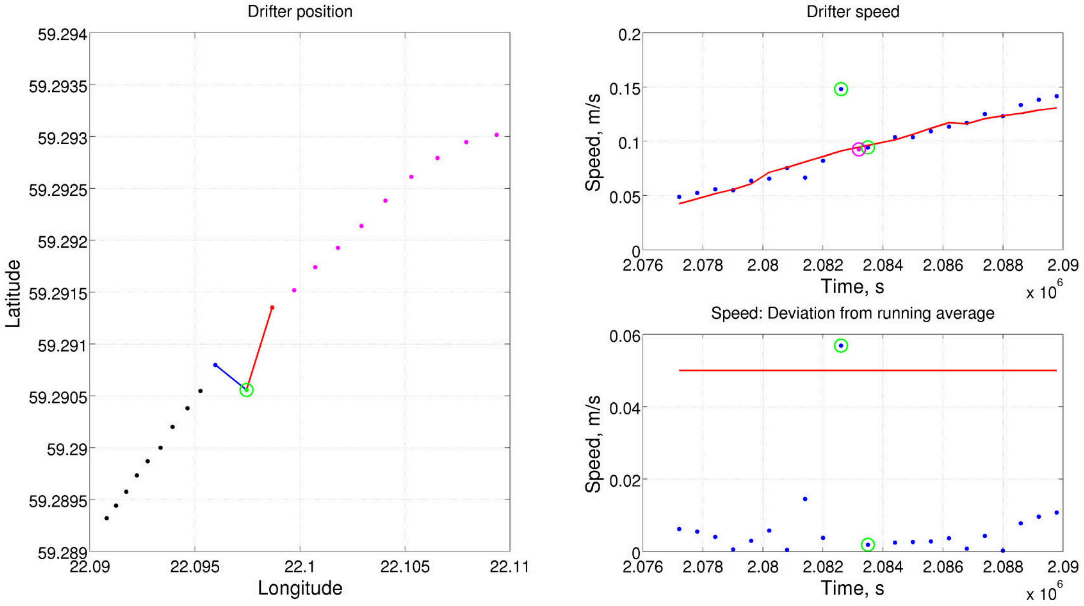

Fig. 4. Example of 'kink' removal for drifter F13-2. Left panel: drifter coordinate points near the flagged value; point under evaluation is marked with a green circle; line segments show previous point (blue) and following point (red); earlier points (black); later points (magenta). Right upper panel: drifter speed; point values (blue); running average (red); values marked with green circles will be replaced by magenta circled value if point under evaluation is removed. Right lower panel: drifter speed error S_{err} (blue); error tolerance level (red); green circles indicate S_{err} values associated with point under evaluation.

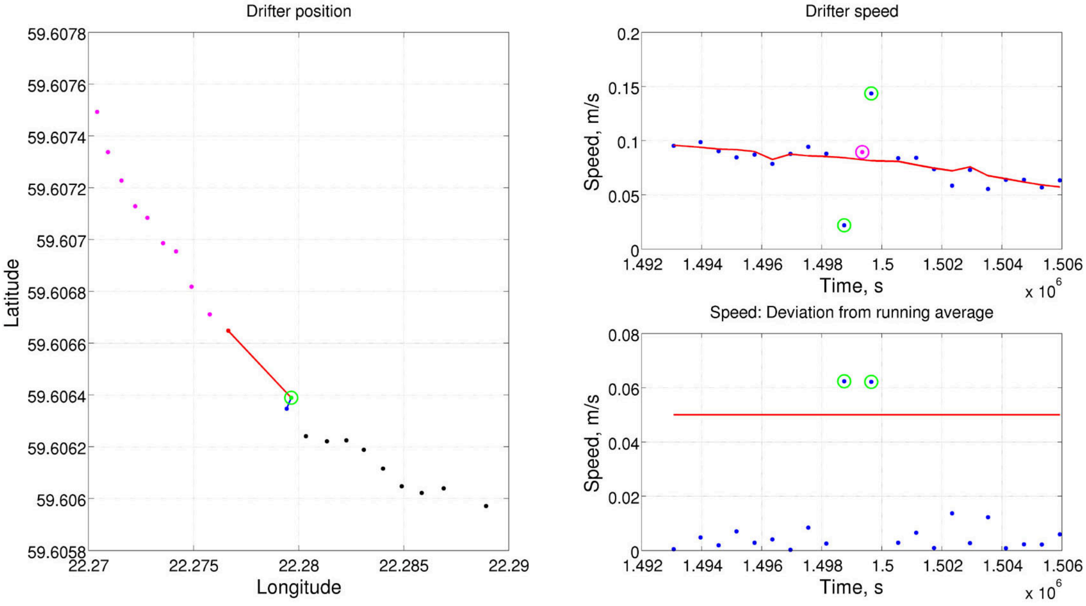

Fig. 5. Example of an 'overlapping data point' removal for drifter F13-2. (See Fig. 4 for legend).

difficult to assess than the ‘kink’ cases. The error could be associated with a ‘kink’ event where the point had been displaced along the general trajectory, but could also be ascribed to natural variability in drifter speed along the trajectory. These points were removed if the $S_\alpha = 0.1$ m/s flag was raised. If encountered due to violation of the $S_\alpha = 0.05$ m/s limit, the point would only be removed if it was also associated with a clear outlier in the drifter acceleration plot.

Figure 6 illustrates why it is difficult to automate the evaluation process for the removal of drifter coordinate points. In this case a flag is raised due to a sudden change in drifter speed and heading. The change occurs within less than one hour. Points recorded during the changing conditions have a similar appearance as the ‘kink’ or ‘overlapping data point’ conditions illustrated in Figs 4 and 5. However, in this case it would clearly be unjustified to remove any of the points.

A final check of the procedure was performed by examining the acceleration of the drifter along the track (Fig. 7a). If obvious outliers still remained (Fig. 7b), the speed test procedure was repeated with a smaller value of S_α. However, the points were retained in all cases where there was a remote possibility that the outlier could be caused by natural variability of the system.

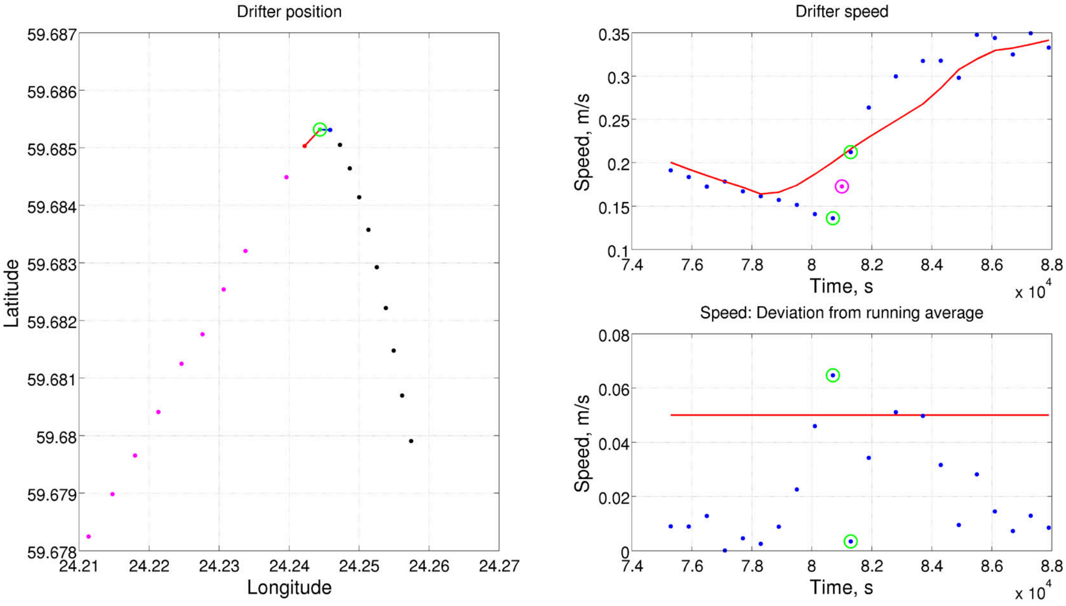

Fig. 6. Flag raised for drifter F13-20 due to sudden change in drifter speed and heading. See Fig. 4 for legend.

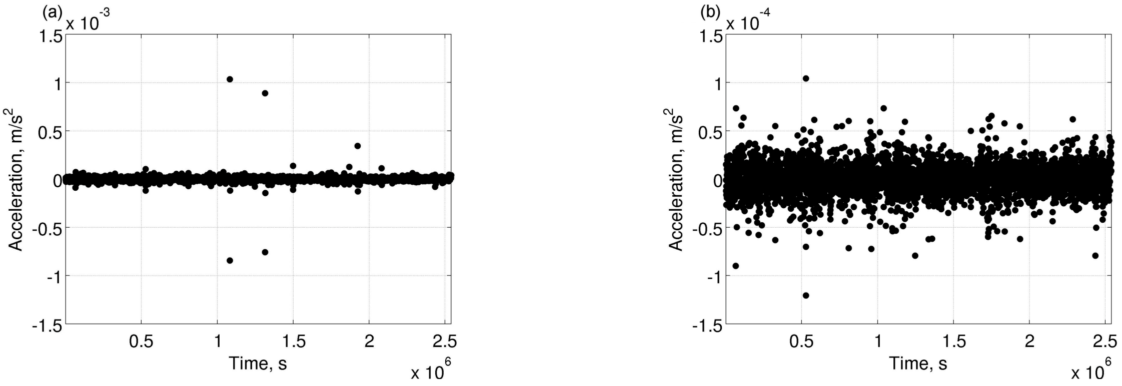

Fig. 7. Analysis of drifter acceleration before (a) and after (b) quality control.

6. INFLUENCE OF WIND DRAG

Surface drifters should under ideal conditions follow a 'tagged' parcel of fluid. Since a part of the surface drifter extends above the sea level, the drifter track will be subject to slippage due to wind drag. Assuming both air and water friction is dominated by turbulent drag, the net force on the drifter is determined by

$$F = F_\mathrm{a} - F_\mathrm{w}\,, \quad \text{where} \quad F_* = \frac{1}{2} k_* A_* \rho_* v_*^2\,,$$

F_a represents the drag force in air and F_w is the drag force in water. The relative speeds of the drifter with respect to water and air are denoted as v_w and v_a, respectively; A_* is the surface area of the drifter subject to water or air drag; k_* represent the ratio of the cross-section areas of the turbulent tail and the drifter; and ρ_* are the densities of water and air. The two forces compensate for each other in the stationary case, so that

$$\frac{1}{2} k_\mathrm{a} A_\mathrm{a} \rho_\mathrm{a} v_\mathrm{a}^2 = \frac{1}{2} k_\mathrm{w} A_\mathrm{w} \rho_\mathrm{w} v_\mathrm{w}^2\,.$$

Assuming that the ratio of the cross-section areas of the turbulent tail and the drifter are equal in water and air, i.e. $k_\mathrm{a} = k_\mathrm{w}$, and the difference in water and air density is given by $\rho_\mathrm{w} = 820\rho_\mathrm{a}$, we find that the steady wind-induced drifter speed is determined by

$$v_\mathrm{w} = \sqrt{\frac{A_\mathrm{a}}{820 A_\mathrm{w}}}\, v_\mathrm{a}.$$

The PTRG-v1 drifters were designed so that $A_\mathrm{w} = 2A_\mathrm{a}$, in which case $v_\mathrm{w}^{(v1)} \approx 0.025 v_\mathrm{a}$. The PTRG-v2 drifters had $A_\mathrm{w} \approx 10A_\mathrm{a}$, hence $v_\mathrm{w}^{(v2)} \approx 0.011 v_\mathrm{a}$. As an example, downwind slip in 10 m/s winds would be 25 cm/s for PTRG-v1 drifters and 11 cm/s for PTRG-v2 drifters. For comparison, a standard FGGE-type drifter had a drag area ratio of 10–12 and a downwind slip of 8 cm/s in 10 m/s winds [21,22]. Surface drifters with drogues will usually have drag area ratios (drogue/float) that are larger than 40, in which case the observed drifter slip is roughly 0.1% of the wind speed [19]. In practice, typical SVP drifters have drag area ratios in the range from 37.5 to 45.9, depending on the number of additional components attached to the device [9].

7. COMPARISON BETWEEN DIFFERENT DRIFTER VERSIONS

Figure 8 shows the duration of drifter tracks for drifters deployed in the Gulf of Finland during 2010–2014. About half of the tracks had a duration of 1 week or less, usually due either to drifters grounding at the shore or technical problems causing the drifter to be lost at sea. It is also apparent that the introduction of the PTRG-v2 drifter extended the lifetime of the drifters. The longest track duration was 1130.9 h, whereas the shortest track included in the data set lasted only 1.3 h.

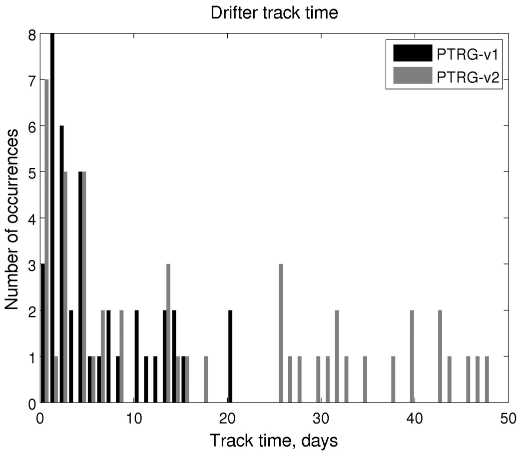

Fig. 8. Duration of drifter tracks (days) for 78 surface drifters deployed in the Gulf of Finland, 2010–2014.

Comparison of the drifter designs PTRG-v1 and PTRG-v2 shows that none of the PTRG-v1 drifters had tracks lasting longer than 20 days, whereas the PTRG-v2 drifters had tracks lasting up to 47 days (Fig. 8). Looking only at the drifters that did not reach land, we find that the average lifetime for PTRG-v1 and PTRG-v2 drifters lost at sea was 9.6 days and 19.9 days, respectively. Some of these cases were caused by loss of connection due to drifters moving too far from land or depletion of battery lifetime, while others were probably caused by technical faults. If we assume a minimum expected lifetime of 1 week for a drifter, six PTRG-v1 and eight PTRG-v2 drifters could be considered as 'failed'. Looking at the ratio between the 'failed' and 'successful' drifters, excluding drifters that reached land within 1 week of deployment, we get a ratio of 6/20 (30%) for PTRG-v1 drifters and 8/29 (27.6%) for PTRG-v2 drifters. Hence the designs appear to be equally reliable with respect to technical faults.

In an attempt to obtain a direct comparison between the performance of PTRG-v1 and PTRG-v2 drifters, both types of drifters were deployed west of Naissaar Island on 14 September 2013 (Fig. 9). Due to technical problems all drifters lost connection soon after deployment, but DTRs could be determined from three drifters (F13-20, F13-21, F13-23) that grounded in Finland and one drifter (F13-18) that later returned to the Estonian coast. Note that F13-18 was deployed east of Naissaar on the same day. Drifters F13-20 and F13-21 were of PTRG-v1 design, and F13-18 and F13-23 were of PTRG-v2 design. Although there is a large gap in the F13-23 record, it is apparent from the end point of this DTR that it must have followed a similar path as the F13-21 drifter. Drifter F13-18 did not ground at the Finnish coast, but reached before returning to sea nearly the same coastal sections as F13-21 and F13-23.

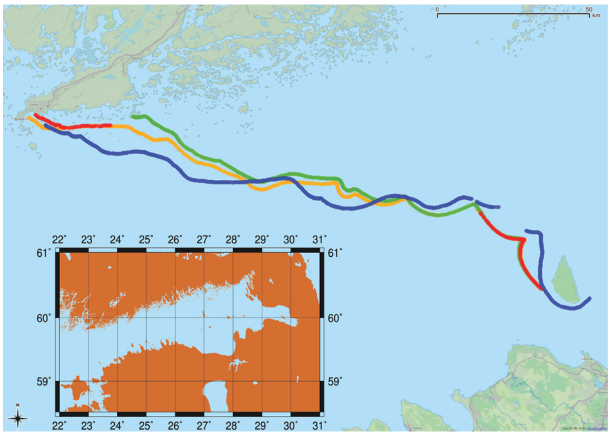

Fig. 9. Comparison of drifter tracks for two PTRG-v1 drifters (F13-20: green; F13-21: yellow) and two PTRG-v2 drifters (F13-18: blue; F13-23: red) deployed near Naissaar on 14 September 2013. The gaps in track records are due to loss of GSM network connection.

Table 2. Comparison of PTRG-v1 and PTRG-v2 drifters

Track	Duration, s	Bulk transport		Net transport	
		Dist, m	Speed, m/s	Dist, m	Speed, m/s
F13-20	407 400	83 675	0.2054	73 756	0.1810
F13-21	500 401	101 143	0.2021	89 900	0.1797
F13-18	531 661	108 953	0.2049	95 152	0.1790
F13-23	505 691			89 066	0.1761

The bulk transport (track integrated) and net transport (distance between start and end points) for the DTRs are shown in Table 2. Due to the large gap in the DTR, no bulk transport was calculated for F13-23. The average net transport speed of F13-23 is slightly lower (98%) than the net transport speed of F13-21, and the bulk and net transport speeds for F13-18 are similar to the transport speeds obtained by the PTRG-v1 drifters. Although this comparison is based on limited data from a single deployment, it indicates that the difference in drifter performance was not very large and possibly that the estimated difference in Section 6 due to wind drag could be exaggerated.

8. CONCLUSIONS

The paper documents the development of a lightweight surface drifter that specifically follows the motion in the uppermost layer of the sea used for deployments in the Gulf of Finland in 2010–2014. The drifter design evolved during the experiment period, and therefore two different designs, PTRG-v1 and PTRG-v2, were used. The lifetime of the drifters was extended, mostly due to the installation of the GPS/GPRS tracker unit in the PTRG-v2 drifter. The drifter design has proven to be robust and reliable, even if being temporarily grounded at the coast. As a result, the DTRs could be analysed without having to take into account that damage to the drifter could alter the drifter performance at any time.

Although the PTRG-v2 drifter was designed to be less influenced by wind stress than the PTRG-v1 drifter, a comparative study showed little difference in the actual drifter performance. Both drifter designs probably experience slippage due to wind stress in excess of 1% of the wind speed, which is relatively high compared to drogued drifters that are expected to experience a slippage of 0.1% of the wind speed. The wind slippage can therefore be a significant factor with respect to bulk and net transport values. However, the wind impact is likely to be very small when other properties, such as drifter spreading, are studied. This is confirmed by the comparative study of the performance of the two drifter designs. However, in order to determine the actual water-following ability of the drifters, a similar comparative study should be carried out using a fundamentally different drifter design, such as the CODE or Microstar models.

A specific data management procedure that takes into account local deviations in drifter speed with respect to the running average value was developed to ensure a high quality of the final drifter track record. This procedure is based on a standard data quality control method [20], but allows limitation of both the local maximum and local minimum drifter speed. This is particularly useful for identification of drifter coordinate outliers when the drifter is moving at relatively low speed. However, the method does not distinguish between erroneous data outliers and sudden changes in drifter speed caused by naturally occurring variability, therefore the final deletion of drifter coordinate points was performed manually after inspection of each flagged point.

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Autonoomse ujuvpoi andmetöötlus ja kasutamine rannikuvetes

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On esitatud sobilik autonoomse ujuvpoi ehitus Soome lahes kasutamiseks. Autonoomne ujuvpoi on konstrueeritud mitmenädalaseks kasutamiseks, seejuures rakendatakse GPS/GPRS-seadmepõhist asukoha määramist, mille signaal edastatakse 10–15-minutilise sagedusega. Ujuvpoi ehitust muudeti selle kasutuse jooksul aastail 2010–2014. Muudatused suurendasid seadme eluiga ja andmete salvestamise usaldusväärsust ning vähendasid tuule otsest mõju, kuid ei muutnud hoovuse jälgimise lahendust. Andmete kvaliteedi kontrollimiseks arendati välja uus skeem, kus andmetest tuletatud ajas muutuvat referentskiirust kasutati võõrväärtuste identifitseerimiseks. Võrreldes traditsioonilise kvaliteedikontrolli meetoditega, kus kasutatakse muutumatut referentskiirust, piirab artiklis esitatud skeem nii kohalikku maksimum- kui ka miinimumkiirust ja selle abil saab kindlaks teha lokaalsed ekstreemumid suhteliselt madalatel ujuvpoi kiirustel.