MOSES (*M*easuring system for the *o*bservation of *se*a *s*urfaces): Lagrangian drift experiments in the East Frisian Wadden Sea

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Keywords: Lagrangian, drifter, temperature sensor, conductivity, gelbstoff, fluorometer, trajectories, Spiekeroog

ABSTRACT: A low-cost Lagrangian drifter has been developed for the observation of coastal currents in the East Frisian Wadden Sea. It is used to support the interpretation of data taken at a time-series station which is operated in the tidal inlet between the East Frisian islands Spiekeroog and Langeoog, with the goal to analyse the input/output of dissolved and particulate matter between the back barrier tidal flats and offshore areas by tidal fluxes.

With the intention to design a drifter suitable for the near-surface water layer and to avoid any drift due to wind, the main part of the instrument floats below the sea surface and the whole construction is as small as possible. This is realised by arranging the measuring probes in three small separate cylinders. They are connected by bars to a fourth cylinder in the centre, which contains the battery and housekeeping electronics. The bars act as underwater sails. A GPS receiver acquires the position of the drifter continuously. The drifter is equipped with a temperature and conductivity sensor, from which seawater salinity and density are calculated. Moreover, it includes a miniaturized fluorometer to measure yellow substances. Its fluorometer components can be easily modified for measurements of chlorophyll a fluorescence from phytoplankton. The data are transmitted by telemetry to receivers on land or onboard a ship, and can be used to validate ocean colour data in the Wadden Sea where algorithms for deriving substance concentrations in the water are mostly not valid due to the very high amount of suspended matter.

1 INTRODUCTION

The coastline of the German Bight is characterised by a barrier of islands, which are separated by tidal inlets. Tidal flats are placed in the region landwards the islands, the backbarrier area. They originate from the exclusive geographical position between land and sea in this highly dynamical region. Tidal inlet systems strongly influence the budgets of the coast in view of sediments, nutrients and water masses. Thus, flats appear or disappear within relatively short time periods and tidal ways change their positions in the course of a few years.

The East Frisian inlet system is located between Borkum island and Wangerooge island. Our research area is close to the second island from the east, Spiekeroog island (Figure 1).

The exploration of coastal currents and the characteristics of water masses in the East Frisian Wadden Sea is more complicated than in the open North Sea: Research vessels are unable to enter the area because of the low water depth. To overcome this limitation, a time-series station has been installed between Langeoog island and Spiekeroog island (http://www.las.physik.uni-oldenburg.de/wattstation). Its data which are taken at a fixed location (Eulerian measurements) may now be supplemented by measurements along the current flow with a drifter (Lagrangian measurements).

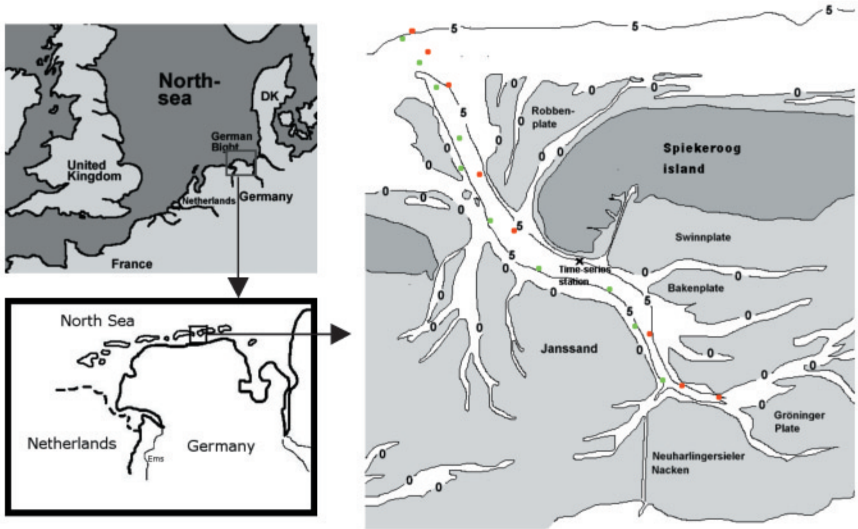

Figure 1. The area of interest. Cross in the right picture: Time-series station. Numbers in the lower map denote the water depth at low tide in meters. Red and green dots denote the waterway.

This is done with a concept similar to a "message in a bottle": The drifter follows the same trajectories as the surrounding water. Its position is observed over a time period of several hours with a GPS receiver. Furthermore, relevant physical and biochemical parameters are recorded. The concept of an easy-to-use and re-useable low cost drifter for applications in shallow water regions is described in the following.

For the Lagrangian analysis of marine currents various kinds of drifters have been used for years. Modern drifters are optimized for the territory where they are used. Since 1988, for instance, more than 7,500 drifters have been deployed in the surface velocity program (SVP), which is part of the world ocean circulation experiment (WOCE). They measure temperature, barometric pressure and their positions. After 9 to 24 months of operation the battery of these drifters fails and the drifters are lost. SVP-drifters often comprise an additional attached part, which follows a water column in some 10 meters beyond the uppermost surface.

Other floats like Argo floats are hydrodynamically constructed in a way that they stay in a depth of down to 2,000 meters. These floats arise to the surface at certain times and create a vertical temperature- und salinity profile on their way up.

There exist a lot of other drifters for several purposes, but it has turned out, that a drifter for research in the Wadden Sea is not available yet. A surface drifter for shallow waters should meet the following requirements:

- It should be possible to use the drifter several times. Unfortunately, the commercialization of non-returnable instruments is still common.
- Use in shallow waters requires a compact housing. Stranding on sandbanks may happen during autonomous measurements. This should happen without any damage.
- The drifter should be as cheap as possible, because the high traffic of ferries and fishery boats may be a problem in the reseach area. A collision with ships may cause loss of the drifter.

2 THE DRIFTER

The drifter has been designed to be an accurate current follower in the presence of wind and surface waves. It is not be driven by the wind directly, but the current near the surface is partly driven by the wind itself. The drifter has to be inexpensive, because as many pieces as possible have to be deployed to do extensive research in the region of interest.

2.1 *Layout*

The flow of an initially compact water volume is characterized by a spread of its parcels even after a short time lapse due to turbulent diffusion. That implies that it is not possible to realise a Lagrangian drifter that follows a fluid volume forever, since the water disperses while the float follows a single trajectory. Thus, the instrument moves with the average velocity of the current flow surrounding it. Water parcels surrounding this path are exchanged by motions on scales much smaller than the averaging volume of the drifter. The main idea of a Lagrangian drifter is, that its trajectory should approximate the motion of the water at the same location.

A drifter should be as small as possible so that its trajectory represents the smallest possible scales of a current field on the one hand, but the requirement of easy handling must be met as well. The size of its elements below the water surface must be much larger than above, so that it sails with the water flow instead of being driven by the wind. It must be considered that the current a few centimetres below the surface is strongly determined by the wind. This wind-induced shear decreases exponentially with depth.

The drifter housing was made of polyethylene (PE) for practical reasons: It is easy to work with, and tubes of this material are easily available. PE has approximately the same density as water. The average density of the drifter itself must be close to that of water, which has been achieved by balancing the heavy components (i.e. the battery) by hollow spaces (Figure 2).

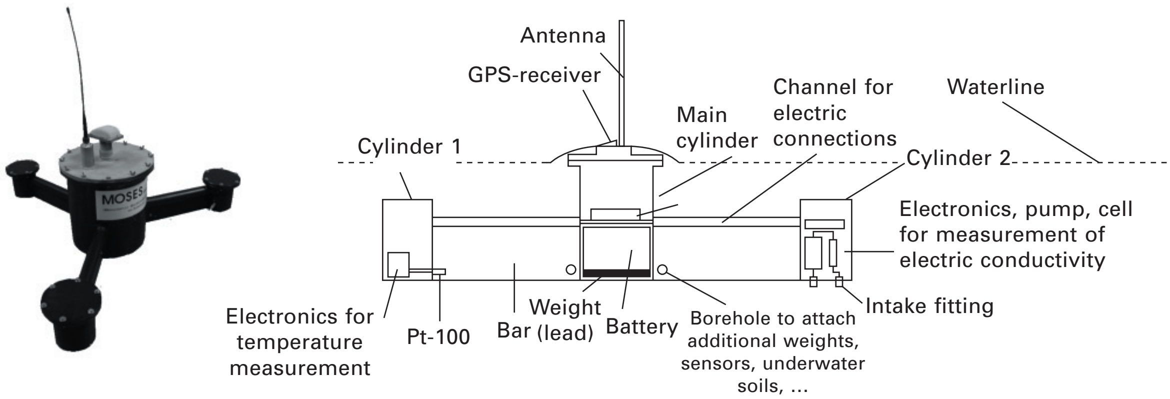

Figure 2. Photo (upper picture) and side-view schematic of the drifter (lower picture). The third cylinder contains a gelbstoff fluorometer.

This drifter consists of three small separate cylinders equipped with measuring probes and a fourth cylinder in the centre for the battery (the position of this part influences the centre of mass more than all other components) and housekeeping electronics, which are connected by bars. The dimensions of the drifter are approximately $80 \times 80 \times 30$ cm^3. The upper 3 cm remain above the surface. These three submerged arms act as underwater sails: with an assumed wind speed of 7 m/s and current velocity of 2 m/s the wind driving force is calculated to be more than 700 times below that of the water. A similar concept of sails attached on a main drifting body was mentioned in Davis (1985).

A GPS receiver has been mounted on top of the central cylinder to detect the drifter position with an accuracy of approximately two metres. The antenna must be above the waterline, since GPS uses the 5 GHz frequency band which is not transmitted in seawater. Thus, the mounting for the GPS receiver and the receiver itself are the main reasons, why a part of the instrument can be subject to some wind drift. The GPS and sensor data are stored in eight electrically erasable programmable read-only memory (EEPROM) with a total size of 64 kilobytes, which should be sufficient for a 24-hour continuous operation at a sampling frequency of 1 per minute. Moreover, the data are sent through a telemetry device to land stations within a range of up to 5 km. For this,

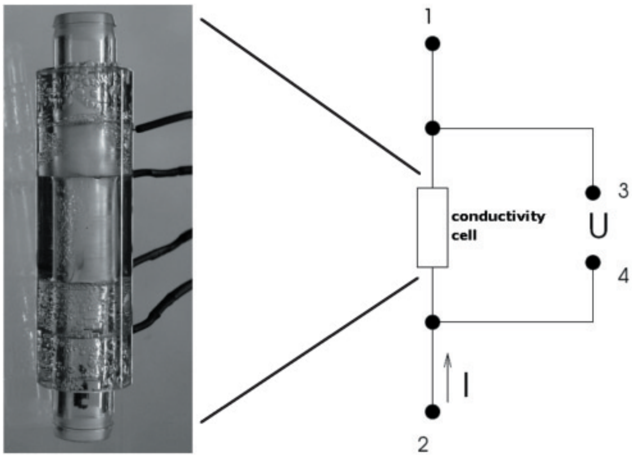

Figure 3. Schematic and photography of the conductivity cell.

the data are encoded to packed radio format by a special radio modem and transmitted by professional mobile radio.

2.2 *Sensors*

Seawater temperature measurements are done with a PT-100 sensor between 0 and 25°C with 0.007°C resolution. The electric conductivity is measured with a four-point conductivity cell. The water is pumped through a plastic tube which contains four platinum rings inside. The outer pair of rings is connected to an alternating 200 Hz current source. The decrease of voltage in the water sample is measured by the inner pair of rings. The electrodes are made of platinum because of its high thermal stability. The surface of the electrodes has to be as large as possible to achieve a high sensitivity. This has been reached by electrolytic platinising (Metrohm). With this method microscopic platinum crystals grow on the surface of the electrodes which lead to a fluffy surface structure and hence to an increase of the area in contact with the seawater. Conductivity can be measured in the range between 0 and 35 mS/cm with 0.13 mS/cm resolution. However, the accuracy of the sensor is still not sufficient for open ocean conditions, but useful to show general trends in the Wadden Sea where larger gradients are present.

Besides temperature and salinity, gelbstoff is – especially in coastal zones – a characteristic property of seawater. Gelbstoff is defined by its light absorption properties, but it can also be measured due to its fluorescence as well. Scattering particles, which are present in tidal flats at high concentrations, affect fluorescence much less than absorption measurements. Therefore, a miniaturised fluorometer has been realised by use of UV-emitting LEDs with a peak wavelength at 365 nm and pn photodiodes as the detector in a 90° configuration (Figure 4). A Schott UG11 colour glass filter between the light emitting diodes and the sample volume cuts the red part of the spectrum, which is emitted by almost all LEDs. Fluorescence emission is detected at wavelengths above 480 nm by using a Schott KV480 plastic compound filter with low self-fluorescence. Following final tests and revisions the device will be installed in one of the peripheral sensor cylinders, which allows also for a good shielding against daylight. Water samples are continuously fed to the sample volume using a small bilge water pump. The measured photocurrent in Wadden Sea waters is in the range of some picoampères. The data agree well with those found with a laboratory spectrofluorometer.

3 TESTS AND FIRST APPLICATIONS

The behaviour of the drifter has been tested in a tank. It has been shown that the drifter is able to set up automatically, when it is turned upside down with respect to its centre of gravity close to the bottom of the central cylinder. The freeboard is approximately two to three centimetres, so that

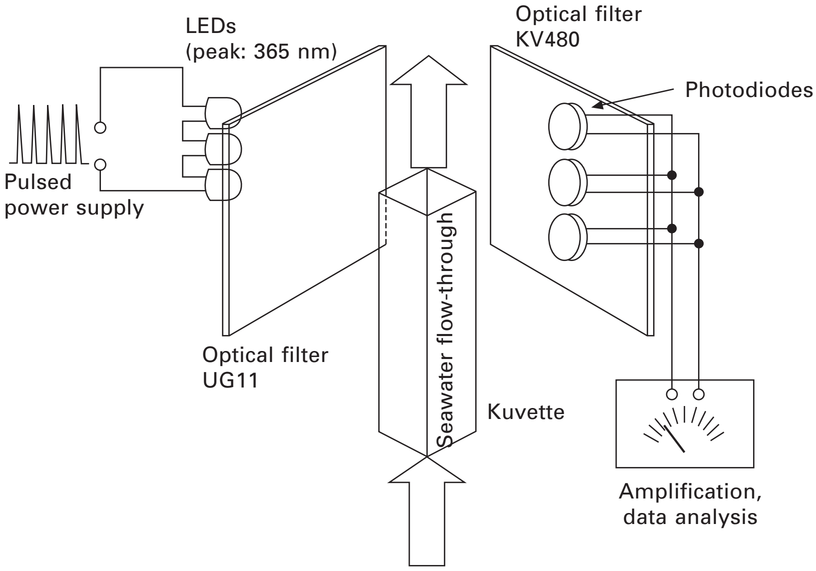

Figure 4. Schematic of the gelbstoff fluorometer. The approximate size of this part is 10 × 10 × 15 cm (water pump not included).

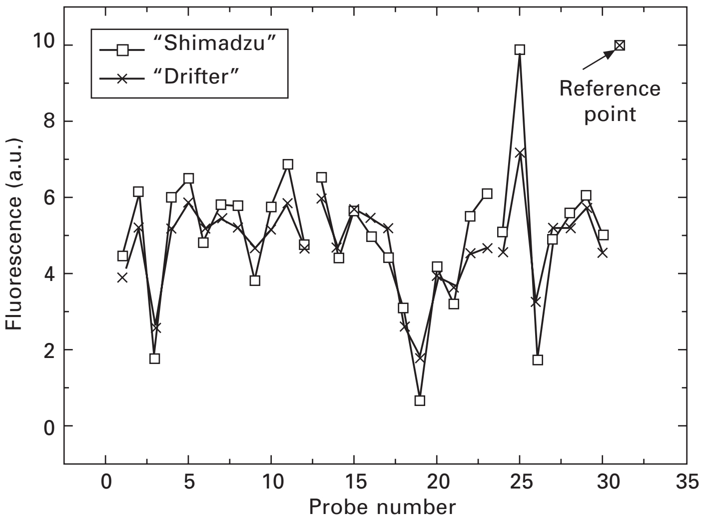

Figure 5. Comparison of gelbstoff data from the fluorometer onboard the drifter with data from a Shimadzu model RF-1501 spectrofluorometer with 365 nm excitation wavelength. Emission is integrated over wavelengths from 480 nm to 700 nm. The data are normalised to the "reference point" sampled. The number of probes is in an accidental sequence and the lines between measuring points are just for your orientation.

small waves swashing over the top cannot prevent the GPS from operating. A sloping position of the drifter has not been observed.

In the following we report on first results of drift experiments which were done to test the performance of the instrument. The region of interest is shown in Figures 1 and 6. The experiments were done in the relatively deep water (up to 20 m) of the main tideway. The water is pressed through this tideway two times per day due to the tides. The highest dynamics are expected at the narrow section between Spiekeroog and Langeoog island.

Drifter deployments were done during November and December 2004 in periods of moderate winds from southern or eastern directions. Therefore, the experiments were not affected by strong

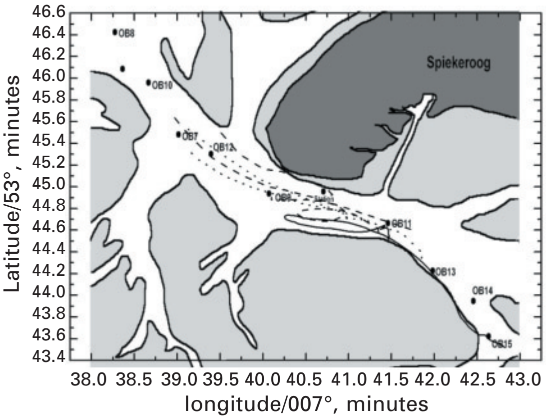

Figure 6. Trajectories of the first three drift experiments (line: Nov, 9th; dashed: Nov, 10th; dotted: Nov, 11th 2004. All experiments started at high tide at the southern end of the lines.

waves. Each experiment started at high tide at the southern end of the main tideway. The drifter was escorted by a boat for survey purposes, which also allowed water samples to be taken and additional *in situ* measurements to be performed to validate the drifter data. The boat operated at a distance of some 10 m to prevent any disturbances around the drifter. Due to the variations over small spatial scales in that region the drifter and shipboard data are not necessarily identical.

The first experiment on 9 Nov 2004 started more southward than those on 10 and 11 November (Figure 6). Flow velocities are relatively small in this region, since the cross-section of the tidal channel is much larger there when compared to the tidal inlet northwards between the islands. The turning point to southern direction was reached already two hours before low water. The reason may be the tidal flat westwards the trajectory, which induces an eddy if the water level is low enough. The flow direction in the middle of the tidal channel is still northwards at the same time. All following experiments started more northwards, closer to the islands, because the position of the time-series station (which was planned to be used as reference station) was rarely reached on the first day.

The data of the first experiments are shown in Figure 7. Salinity values are calculated from temperature and electrical conductivity. The current velocity has been derived from geographical position and local time measured with GPS.

When the drifter had stopped to change its drift direction on 9 Nov, (and, not shown, on November 10th as well) the water temperature decreased, while salinity increased, which was also confirmed by measurements done onboard the escorting boat. This may be a consequence of the fact that backbarrier tidal water mixes with inflowing saline water at high tide, which is often observed at the time-series station and in ship cruises as well.

Gelbstoff was measured in the laboratory with the fluorometer, which is described above, with samples taken from the escorting boat. This instrument was not installed on the drifter during the time of the experiments reported here. The fluorometer was calibrated with a prepared solution of 10 mg/l humic acid (Aldrich) in distilled water. The fluorescence emission of this solution was set to a value of 10, thus the values shown in Figure 8 correspond numerically to the emission of milligrams of humic acid per litre. The data are in a realistic range but do not show any trend similar to temperature and salinity.

The trajectories observed on 24 and 25 Nov are shown in Figure 9. On 25 Nov the drifter was transferred to a westward position, since the day before it had drifted towards a flat too shallow for the escorting boat. The drifter passed the smallest cross section of the tidal outlet west of Spiekeroog island, but there was no possibility to measure to the north of the given positions. Strong currents and high waves may not be a problem for the drifter, but operation of the boat would not be safe under these conditions. Therefore, no full tidal cycle was observed.

Figure 10 shows the results of measurements of the physical parameters. Temperature and salinity are almost constant on both days and one can see increasing current velocities with decreasing

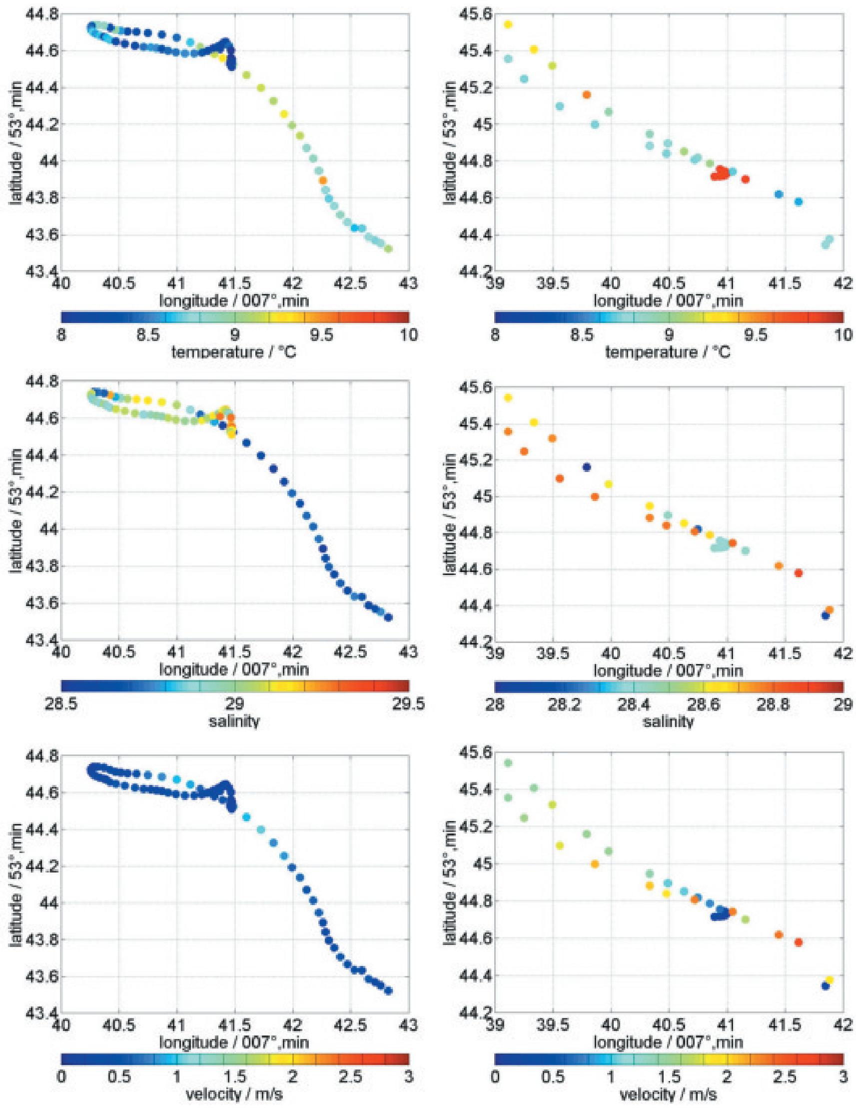

Figure 7. Temperature, salinity and current velocity data from 9 (left column) and 11 (right column) November 2004.

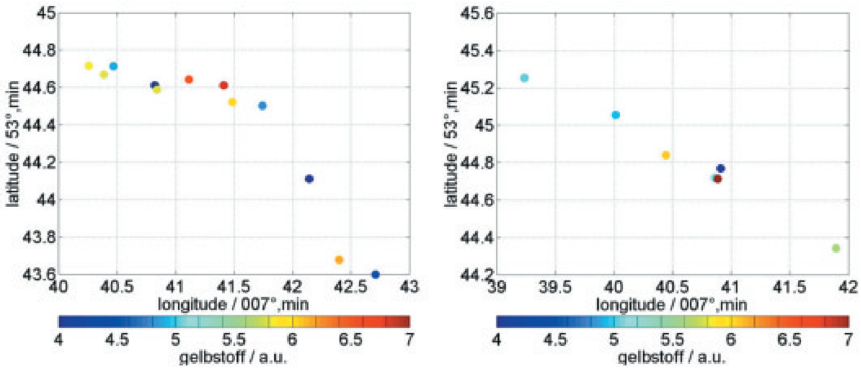

Figure 8. Gelbstoff data from 9th (left) and 11th (right) of November.

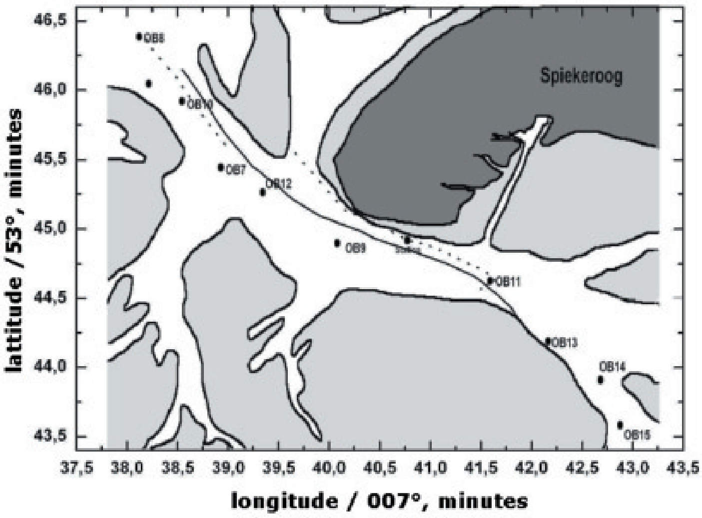

Figure 9. Trajectories of the drift experiments on 24 (full line) and 25 (dotted line) November.

cross section of the tidal channel with a maximum close to the smallest location. In all experiments the data of temperature and salinity are highly linearly correlated. Gelbstoff values are in a realistic order of magnitude, but data are too rare to show any trend or correlation to other parameters.

4 CONCLUSIONS

A prototype of a low-cost Lagrangian drifter with an easy-to-handle and low-cost design has been developed. Due to the modular concept of exchangeable components it is a flexible instrument for analysing of the water surface not only in coastal regions, but perspectively also in shallow waters of lakes and rivers. The underwater sail seems to attach the drifter to the current flow much better than to the wind field at moderate wind speeds. Capillary and short gravity waves apparently do not have an effect on the position of the drifter, and larger waves do not cause instability.

Besides data of the drifter position the integrated measuring system delivers temperature and conductivity data with a resolution of 0.007°C and 0.13 mS/cm, respectively, which is sufficient for the Wadden Sea but needs to be improved for other regions. Comparisons of these data with those from commercial instruments have shown a good agreement. The new gelbstoff fluorometer has been tested in the laboratory and will be integrated into the drifter.

As an intermediate result, comparison of the available data shows that physical parameters can change within distances of some ten metres in this region. Due to this, the results of only a few drift experiments with just one drifter are not sufficient to derive an understanding of the whole system.

The presently available version is to be understand as a prototype and test version and will be further developed. Additional components such as a compass for the examination of eddies from spinning movements of the drifter, a chlorophyll fluorometer, optical radiometers for daylight irradiance and reflectance measurements, an acoustic Doppler profiler for measuring the current depth profile, a water sampler and other devices might be included to further extend the range of applications.

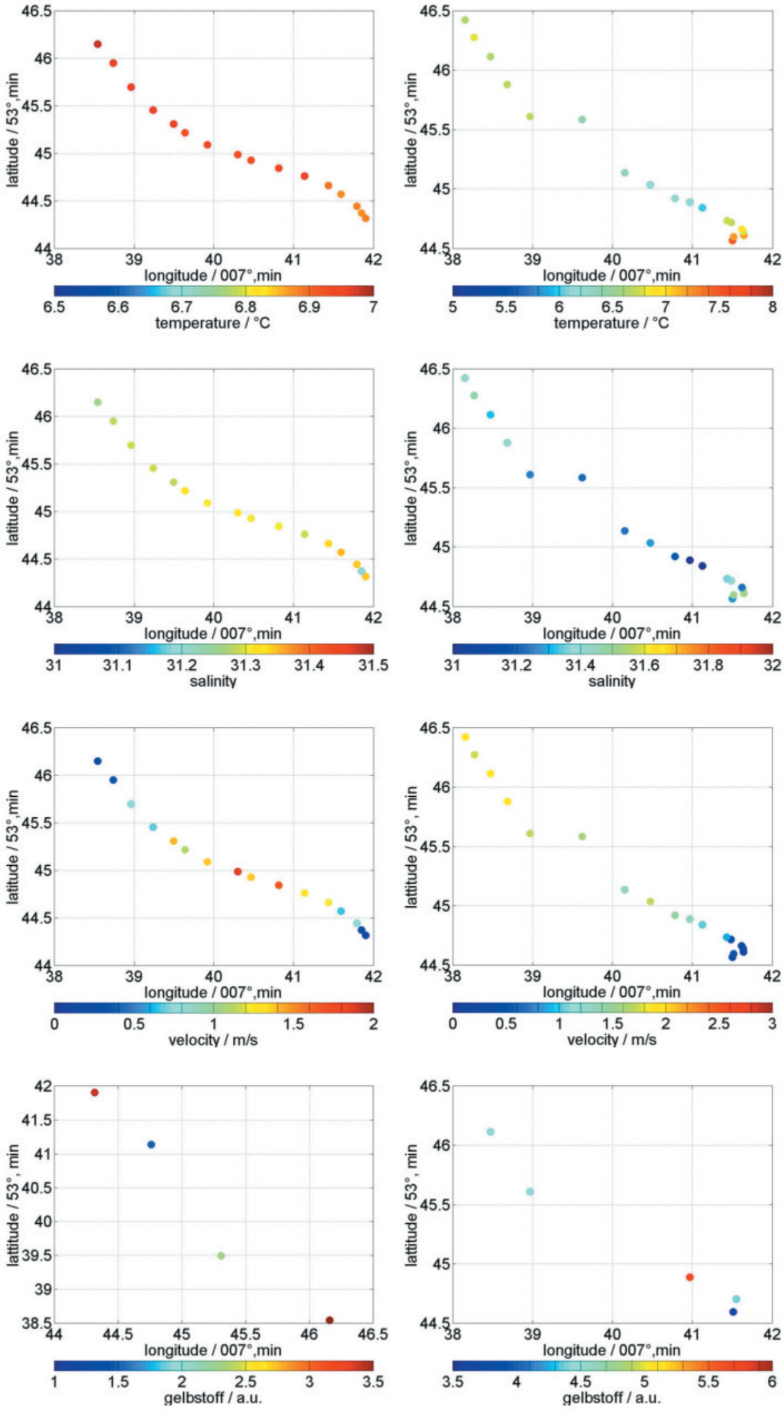

Figure 10. Drifter data taken on 24 (left column) and 25 Nov (right column).

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Evtl. noch Referenzen zu WOCE und SVP ? → MO.