Spatial distribution of surface velocities on the ebb tidal delta near Ameland

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Contents

Abstract:

Drifters equipped with GPS-trackers have been widely used to investigate surface velocities in a wide range of coastal and oceanic settings. A detailed description of a new, cell-phone based, budget drifter system is given, along with an overview of the potential error sources and the magnitude of these sources. Drag related "windage" errors were found to be significant.

As a part of the SEAWAD research project, the surface velocities on the ebb tidal delta of the Amelander Zeegat (the Netherlands) are measured over a period of two weeks. The drifters performed well in the field (no drifter losses) but the results showed relatively frequent data gaps and filtering resulted in significant data loss. The signal quality in the area appeared to significantly influence the data loss.

The velocities on the ebb tidal delta vary around 0.7 [m/s], depending on location, depth, tidal phase and wind. The spatial structure of the velocities shows generally a uniform flow structure. Different wind conditions caused the most significant changes in the spatial distribution of the velocities, followed by the effect of the tidal range. Waves were found to have an insignificant effect on the flow velocities.

A number different deployment configurations were investigated in order to shorten the measurement interval as much as possible. Due to the absence of spatial structure, spatial "resolution" can be exchanged for a shortened measurement interval by deploying the drifters in two or more groups across the research area. Methods for measurement verification using nearby ADCP- equipped measurement points are presented but not performed.

Overall, the described drifter measurement method provides a cheap way of measuring the spatial distribution of velocity in an area. However, the accuracy of the measurement has not been verified. Until then, the accuracy of the results is uncertain.

Keywords:
Surface drifter, SEAWAD, Ameland, spatial distribution, budget, ADCP, GPS-trackers

Chapter 1

Introduction

Spydell et al (2015) define tidal inlets as important transitional regions between estuaries, bays, lagoons, marshes, and the coastal ocean. They are ubiquitous features of barrier island geography. Tidal inlets are important economically as navigation routes, and ecologically as conduits through which material flows from estuaries to the ocean.

The Waddensea is the largest tidal basin in the Netherlands and therefore it plays an important role in the sediment budget of the Dutch coast. Recently, rising sea levels and several closures in the tidal lagoon have caused the Waddensea to start importing sediment from the Holland coast and the barrier islands in the Waddensea, leading to erosion problems. To maintain the current dutch coastline, the Dutch government initiated a nourishment program in 1990.

1.1 The Dutch nourishment program

In 1990 it was determined that the coastline needed to be maintained in its current location to ensure the ensure the safety and preserve the functions of the dunes. Structural losses of sediment were compensated by nourishments. In 2001 it was decided that not only the coast line position would be maintained, but also the location of the 20 meter depth contour. This ensures the total amount of sediment in the 'coastal foundation' remains constant.

Currently, the Dutch governments policy towards the Waddensea aims to preserve the buffer function of the Wadden-islands, the outer delta's and the intertidal areas. Measures to ensure the sediment balance, as well as measures to ensure flood protection are designed together with many partners. A number of project consider innovative dyke design and dyke reinforcements on the Wadden-islands as well as on the dutch mainland. The Kustgenese 2 program was started in 2015 to investigate the sediment fluxes between the 'coastal foundation', tidal inlets and tidal basins. This knowledge is essential for making well-informed decisions on future nourishment policy.

As part of the Kustgenese program, research is being conducted to determine whether or not giant nourishments, such as the 'Sand Engine' can be used in a tidal system. This project is titled SEAWAD.

In a joint study of Rijkswaterstaat and the universities of Delft, Utrecht and Twente, researchers are investigating among others the sediment fluxes, bed forms, bed topography, benthos and the hydrodynamics around the ebb tidal delta between Terschelling and Ameland.

This investigation into the surface velocities is part of research into the intrawave modelling of sediment transport. Waves are strongly influenced by the surface currents, which illustrates the importance of knowledge about the spatial variability of the currents. (L. Holthuijsen, 2007)

1.2 Research topics

In this thesis the spatial and temporal variability of the currents on the ebb tidal delta of the Amelander Zeegat is investigated. This work looks to answer two key questions. Firstly, how are the currents distributed over the ebb tidal delta of the Amelander Zeegat? Secondly, how do other factors influence the spatial distribution. Factors like the spring-neap tidal cycle, windage and wave influence will be investigated using measurements from a budget drifter method. Additionally, some attention will be paid to the verification of the drifter measurements using ADCP measurements in the research area, along with possible improvements to the measurements method.

Relevant literature will be briefly summarized in chapter two. The SEAWAD measurement campaign will be described in chapter three, while the processing of the acquired data will be treated in chapter four. Finally the discussion of the results and any conclusions will be treated in chapter five, six and seven.

Chapter 2

Literature Review

2.1 Tidal lagoons

The Waddensea can be classified as a tidal lagoon, because of the presence of barrier islands enclosing the tidal basin. Due to the presence of the barrier islands, the penetration of waves is limited. Where the basin itself is tide-dominated, the inlets to the basin and the ebb tidal delta are exposed to both wave and tidal influence. Finer sediment tends to be found in the more sheltered areas away from the inlet and fresh water runoff is typically limited.

In a situation with a complex bottom topography, computing the wave-induced currents requires in principle a 3D model. A general pattern is a net flow in the direction of the waves over shoals, turning seawards again via the channels between the shoals. Wave-driven currents around shoals on the outer delta can be so strong that they dominate tidal residual currents, which has strong implications for sediment bypassing mechanics.

An often forgotten type of currents in tidal inlets are the wind-driven currents, either directly, via the wind-induced shear stress on the water surface in the inlet, or indirectly, via the set-up of the water level against the coast. This effect can be included by including a wind shear stress component in the momentum balance equations.

Due to large variations in water depth, which are inherent to a tidal inlet, the wind-driven current field will strongly vary in space. The wind forcing also affects the vertical structure of the flow. The primary flow profile (logarithmic) is disturbed by a secondary wind current that follows the wind direction in the top part of the water column and goes against the wind direction in the lower part. Since fresh water runoff is limited in the tidal basin of the Waddensea, complex 3D stratification effects are not occuring. (Bosboom & Stive, 2015)

2.2 Wave-current interactions

The tidal and wave-driven current pattern on the outer delta is largely concentrated in the deeper channels. Consequently, there can be strong currents which affect the wave propagation via current refraction. This may even go as far as wave blocking. One often observes a sharp distinction between areas with waves and areas with a flat water surface. (Bosboom & Stive, 2015)

During the measurement campaign these abrupt changes in wave conditions were observed. Because of the important contribution of waves to sediment transport in general, accurate modelling of the interaction between waves and currents is needed.

Currents may change the amplitude, frequency and direction of an incoming wave. Changes in amplitude may be caused by energy bunching, current induced refraction and transfer of energy between wave and current. The change in frequency is closely related to the Doppler effect and is caused by refraction due to current induced changes in propagation speed. This is essentially similar to depth induced refraction, as the wave turns towards an area with a lower propagation speed.

Interaction of the current and the waves by exchanging energy implies that wave energy is not a preserved property as the wave propagate through the current fields. Rather, action is preserved. Wave models that account for wave-current interaction are based on an action energy balance rather than an energy balance equation. (Holthuijsen, 2007)

This form of interaction makes it particularly difficult to predict the wave field on the outer delta. Such a prediction should be based on a carefully calibrated, combined wave and current model. In order to further our understanding of the effects of wave-current interaction on morphology, a detailed picture of the currents is required. (Holthuijsen, 2007)

2.3 Drifter error sources

The concept or measuring current velocities with drifters is based on the assumption that the drifters will move along with the water with the same velocity. By measuring the location location of the drifter, the velocity can be determined. In practice however, a number of other factors play a role.

Schmidt et al. (2003) summarize these effects. They can be identified as a slip error, a GPS accuracy error and a windage error. The slip error, the difference between the velocity of the drifter and the surrounding water. Emery and Thomson (2001) estimate this error to be in the order of 1-3 cm/s and is neglected in this study.

Schmidt et al. (2003) indicates that the absolute error in the GPS measurements is in the order of 2 meters, the error is assumed to be varying slowly in time and therefore does not lead to very large velocity fluctuations.

Schmidt et al. (2003) also discus the errors stemming from the heaving and rolling motions of the drifter. However, the observed behaviour of the drifters, most notably the absence of big rolling and heaving motions, as well as the compact design means that these errors will be neglected in this study.

Lastly the effect of wind on the drifters affects the velocity. Emery, Thomson (2001) estimate the resulting velocity difference to be

$$U_{wind} = k\sqrt{\frac{A}{B}}U_{10} \tag{1}$$

Where U-wind is the contribution to the velocity due to wind friction. A and B are, respectively, the surface area of the object above and below the water line, and k = 0.025 is a constant. For an object with an equal surface area above and below the water line drifts at 2.5% of the wind speed relative to the surface velocity.

2.4 ADCP measurements

ADCP's function based on the Doppler effect. High frequency sound waves are emitted into the water. This wave will reflect off of particles suspended in the water. Based on the frequency difference between the ingoing and outgoing signal, a velocity can be calculated. By looking at the return period of the returning waves, the velocity at different depths can be calculated. The velocity measurements in the water layers close to the surface can be used to compare to the velocity obtained by drifter measurements. The velocities measured by the ADCP are measured with respect to an Eulerian frame of reference and therefore have to be adjusted for Stokes' drift. According to Longuet-Higgins (1953), the Stokes' drift velocity can be estimated using:

$$U_s = \frac{a^2\omega k \, cosh \, 2k(z-h)}{2\sinh^2 kh} \tag{2}$$

Spydell et al. (2013) compared similar ADCP and drifter data and found a strong correlation between the two.

Chapter 3

Measurement Campaign

On the 28th of August 2017, the SEAWAD measurement campaign was kicked off with the placement of five steel measurement frames on various locations of the tidal inlet and the ebb tidal delta between Ameland and Terschelling. These frames were were equipped with devices that measure the flow and the concentration of sediment in the water. The frames performed these measurements until October 3rd. Between the 28th of

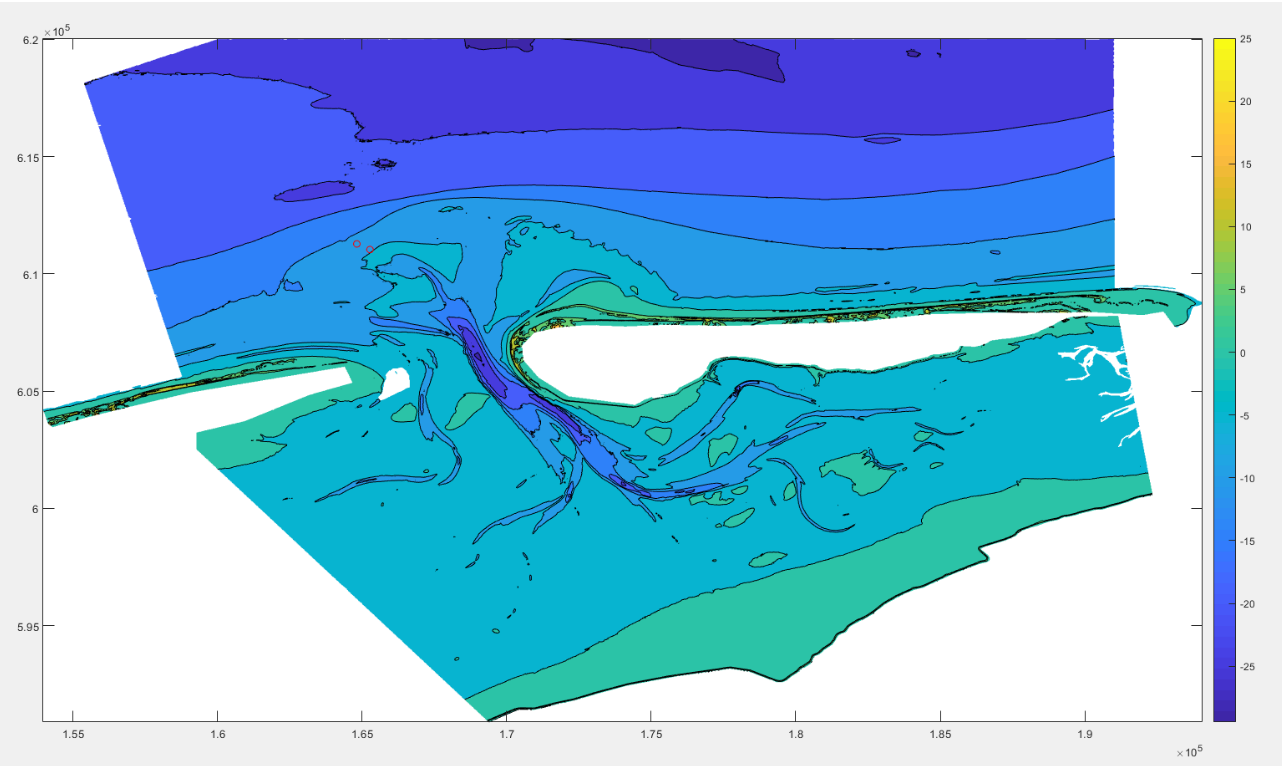


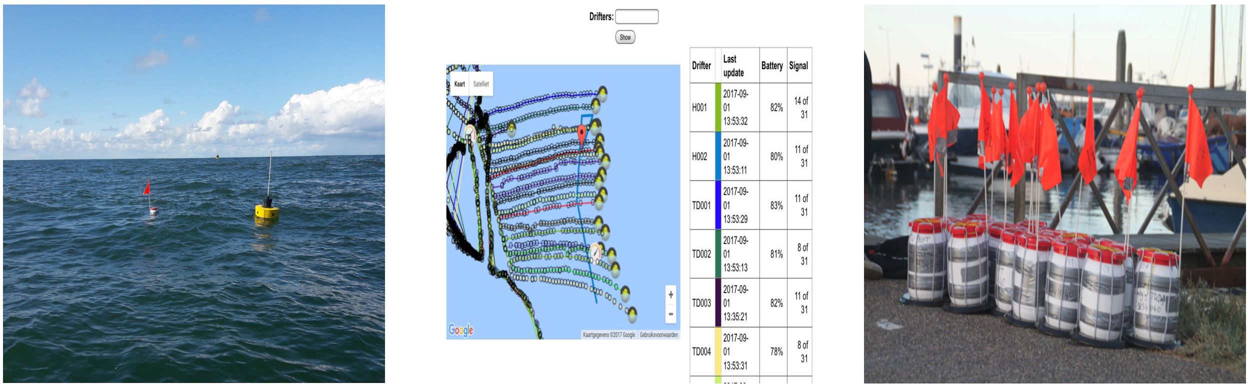
Figure 3.1: Area overview of the ebb-tidal delta near Ameland

August and the 10th of September, various other aspects of the ebb tidal delta were measured. Among these measurements were bathymetry measurements, sediment composition measurements and tracers studies. Also various lifeforms in the sediment were investigated by means of grab and box core samples. To obtain this information, a number of ADCP's and pressure sensors were deployed on the ebb tidal delta. In addition to that, a large number of bathymetry surveys and bottom samples were taken. For this report, the focus will be placed on a research area where two ADCP's and seven pressure sensors will be placed.

3.1 Measurement location

The ebb tidal delta between Ameland and Terschelling consists a number of alternating tidal channels and shallow areas. These channels show cyclic behaviour in their migration eastward. To ensure navigation depth for ships, dredging and nourishments are performed to maintain the Westgat and to prevent the Borndiep from migrating towards Ameland. The measurement site is located approximately 2 kilometers from the easters edge of Terschelling and approximately 4.5 kilometers from the western edge of Ameland. In this measurement location seven pressure sensors and two measurement frames were placed. Figure 3.1 shows the location of the measurement frames equipped with ADCP's (red circles). A number of surface drifters was released into the area to measure the flow velocity in the area. To limit the disturbance caused by shipping traffic, only research vessels were allowed into the research area.

3.2 Drifter design



(a) Deployed drifters (b) Interface of the tracking app (c) Tracking drifter

Figure 3.2: Equipment used for measuring velocities

In many drifter studies, few expensive drifters with large subsurface 'sails' are used to measure velocities over a long period of time. For this study a less sophisticated and expensive method is used to obtain the measurements. The most important part of the drifter is the watertight container which contains the GPS tracker. To enhance the performance of the drifter, it was weighed down using five kilograms of concrete in order to minimize the emerged drifter surface. This reduced emerged surface reduces the effect of wind related drag on the results. The resulting emerged area of the drifter is around 20% of the total area.

Additionally a plate was attached to the bottom of the drifter to dampen the vertical motions of the drifter. Lastly the drifters were equipped a flag for localization at sea, a phone number in case of a lost drifter and a number for identification. As part of this 'budget' drifter, a cheap mobile phone was used as a GPS tracker. The phone was attached to the lid of the watertight compartment, encased in a watertight bag.

3.3 Drifter deployment

The velocity at the water surface will be determined from position measurements from GPS trackers in the drifters. The use of multiple drifters allows the creation of a spatial velocity distribution.

Between August 28th and September 10th 2017 a number of deployments were performed. Drifters were deployed in such a way that the current would transport them across the research area. A total of 30 drifters were available for use. A typical deployment comprised of around 10 to 15 drifters and lasted between 30 and 60 minutes, depending on tidal velocities.

3.4 Measurement times / tidal conditions

During the measurement campaign, a number of deployments were performed during both rising and falling tide and during a number of different stages of the spring-neap tidal cycle. Figure 3.3 shows an overview of the conditions during the deployments. The wind data was obtained from a nearby measurement point (Terschelling) and provided by the KNMI (Dutch meteorology institute). The wave data obtained from one of the measurement frames placed in the research area (equipped with pressure sensors) and the water level data was obtained from a nearby measurement facility and provided by Rijkswaterstaat.

As can be seen in the overview, drifters were deployed under a range of different wind, wave and tidal range conditions. The shaded area in the overview denotes the moments measurements were performed. From the 6th until the 8th of September, the conditions were deemed too dangerous to deploy drifters.

In order to maximize the number of deployment that could be performed during a flood or ebb period, a staggered deployment strategy was used. This means that around half of the drifter were in the process of being transported across the research area while the other half was being picked up and re-deployed. The intended result of this strategy was that a larger part of the research area could be covered during a set interval. The velocities on the tidal delta are both a function of time and space. Ideally, the spatial distribution of velocities should be measured at the same moment in time. Since this is not possible, the delay between the first and last measurement should be a short as possible. This allows one to assume the conditions during the deployments are constant over time.

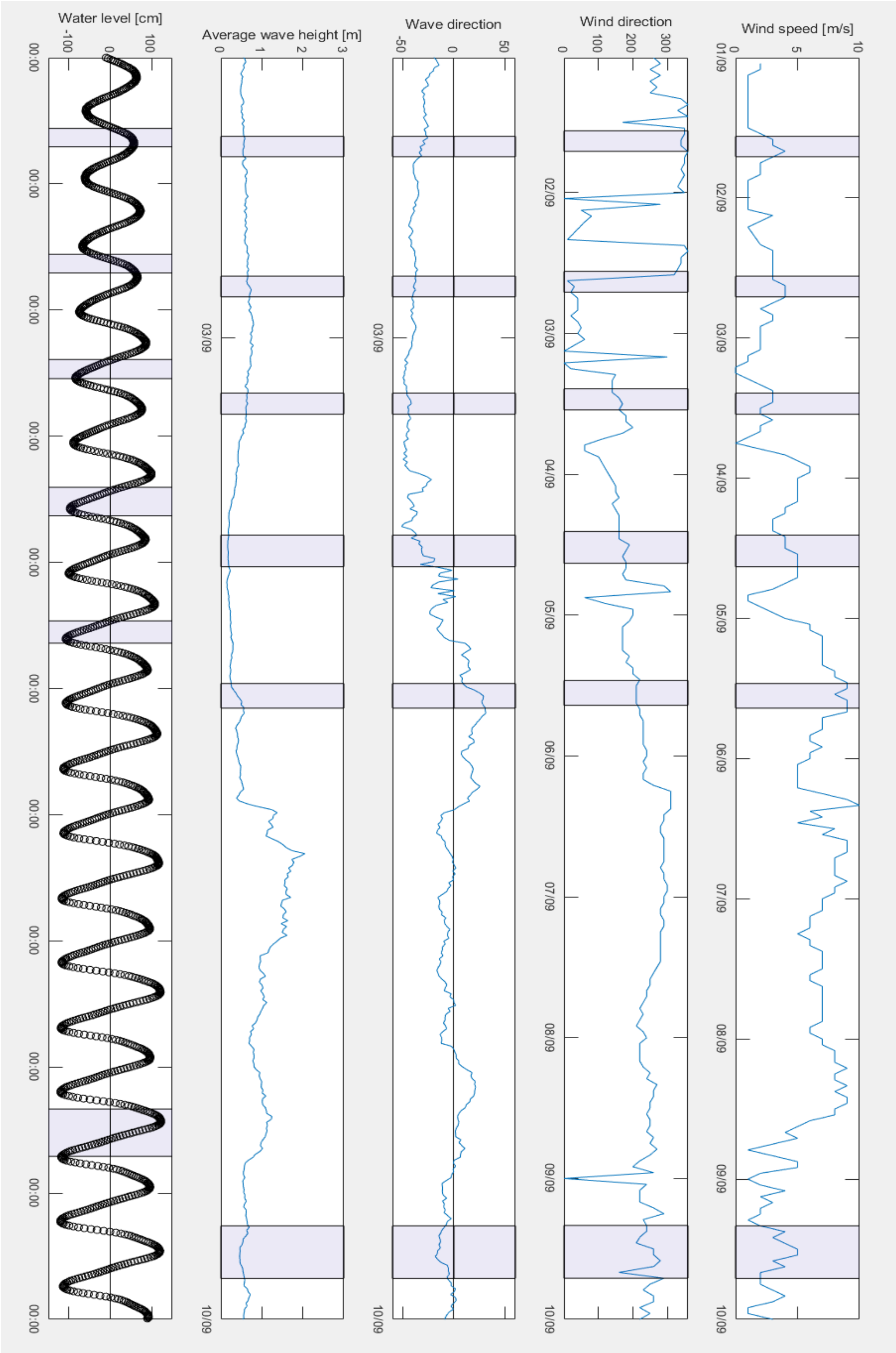


Figure 3.3: Conditions during the drifter campaign (Shaded areas denote measurement times)

Chapter 4

Data Processing

4.1 Filtering

The raw GPS tracker data, measured with a frequency of 1Hz, is put through a number of filters meant to exclude faulty measurements. The tracking devices were switched on and off only at the start and end of each measurement day. Consquently the raw data has to be filtered to include only data from when the drifters were deployed in the water. After this first filter the data is put through a number of other filters with the goal to improve the data quality.Measurements where the satellite time-stamp has not changed are removed. This is indicative of a lack of satellite signal. Lastly the measurements where the position of the GPS tracker has not changed are removed. Because of the assumed constant motion (due to waves and/or currents) these measurements were assumed to be faulty.

As a result of these filters, the number of data points measured per deployment (and therefore also the sampling rate) was reduced by around 60% to 90%. The reduction rate varied substantially over the measurement days.

4.2 Velocity calculations

A very basic method for calculating a velocity field is based on dividing the measurement data into several time 'bins' of equal size. The velocities are determined using

$$v = ds/dt$$

The downside of this method is the fact that it ignores a large part of the data, as well as the fact that an 'bad' location measurement can be used to determine the velocity. In order to improve the interpolation, velocity measurements above a certain threshold value are ignored. A more advanced method for filtering noisy signals in the low pass filter. This method determines the frequency and phase of the harmonic waves that make up the signal and filters out higher frequency oscillations. The cut-off frequency is taken to be 1/600 [1/s] since only the velocity patterns on the timescales of the tidal cycle are of interest.

4.3 Interpolation

In order to fill in the gaps between measurements, the values of the measured velocities need to be interpolated over a grid. Due to the seemingly even distribution of velocities across the area of interest and the lack of distinct spatial structures, the inverse distance interpolation method is used. This method is based on the principle that the velocity at a interpolation location is determined primarily by the closest measurements. The interpolated value is calculated using

$$u_i = \frac{\sum_{j=1}^{N} u_j * w_s}{\sum_{j=1}^{N} w_s} \tag{2}$$

where the distance function is taken to be

$$w_s = \frac{1}{D_j^2} \tag{3}$$

with

$$D_j$$

the distance between the considered interpolation point and the j-th data point.

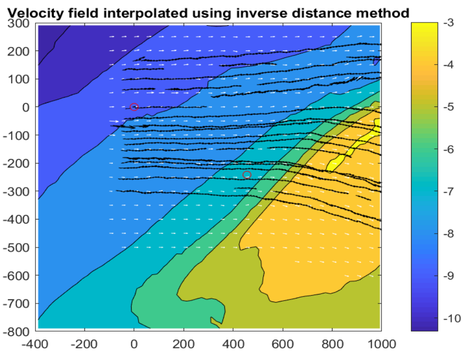
The measurements clearly show a flow pattern without any significant flow structures. Therefore it was deemed that a simple interpolation technique is sufficient for this research.

Chapter 5

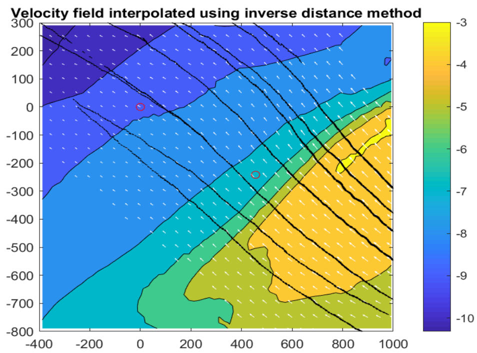
Results

5.1 Typical flow structure

Figure 5.1a shows a typical result of a deployment in the research area. The black lines denote the measured drifter velocities after filtering for GPS errors and passing through a low-pass filter. The white arrows are the interpolated velocities calculated on a grid. The red circles denote the location of the two measurement frames. The origin of the coordinate system is chosen to be the most seaward measurement frame. In figure 5.1a we can observe the general behaviour of the tidal flow through the research area.



(a) Typical flood flow pattern



(b) Typical ebb flow pattern

From these pictures it can be observed that the flow is enters the ebb-tidal delta from the west and leaves the delta again towards the north-west. This matches the observed migration of the ebb-tidal channels in the past.

5.2 Influence of wind

The conditions during September 4th and September 5th were very similar in terms of wave height and direction and tidal range. However, on the 5th of September the wind speed was substantially higher (9 m/s compared to 5 m/s) compared to September 4th. It can be clearly seen that both the velocities as functions of time and depth are very similar. Nonetheless, a clear difference in the flow direction can be observed (Figure 5.2, top left and figure 5.3, top left). From figure 3.3 it can be seen that the only substantial difference in the conditions during both deployments is the wind velocity. This increased velocity causes the drifters to be diverted more towards the north. This makes sense since the wind blows in a north-easterly direction during this particular deployment. This behaviour reoccurred during later deployments on the same days as well. Due to the difficulties in measuring velocities across the same area during each deployment, a meaningful parameter that can describe this change in direction hard to define. For now, a qualitative description of the flow direction must suffice.

5.3 Influence of waves

Based on the estimate provided by equation (2), found in chapter 3, the contribution of Stokes' drift to the velocity is negligible. When considering the observed waves (amplitude = 40 cm, depth = 6.5m, period = 5s) the magnitude of the drift is in the order of mm/s. Although the choice of deployments was made such that factors other than wave height were very much alike, we can see some slight differences in direction and velocity in figures 5.4 and 5.5. The changes should be attributed to other factors affecting the surface velocity.

5.4 Influence of an increased tidal range

The changes caused by the increased tidal range should be the most obvious. Common sense would indicate that when more water has to enter and leave a lagoon the flow velocities should increase accordingly. Surprisingly, there are pairs of measurements with the same tidal phase that would support this idea, while the another set of measurements performed slightly later in the tidal cycle would contradict that claim. As can be seen in figure 5.6 and 5.7, the velocities on September 9th are clearly higher than on September 1st. This is contradicted by the deployments performed around 30 minutes later on the respective days. In figure 5.8 and 5.9 the differences in the velocities between the two deployment is less distinct.

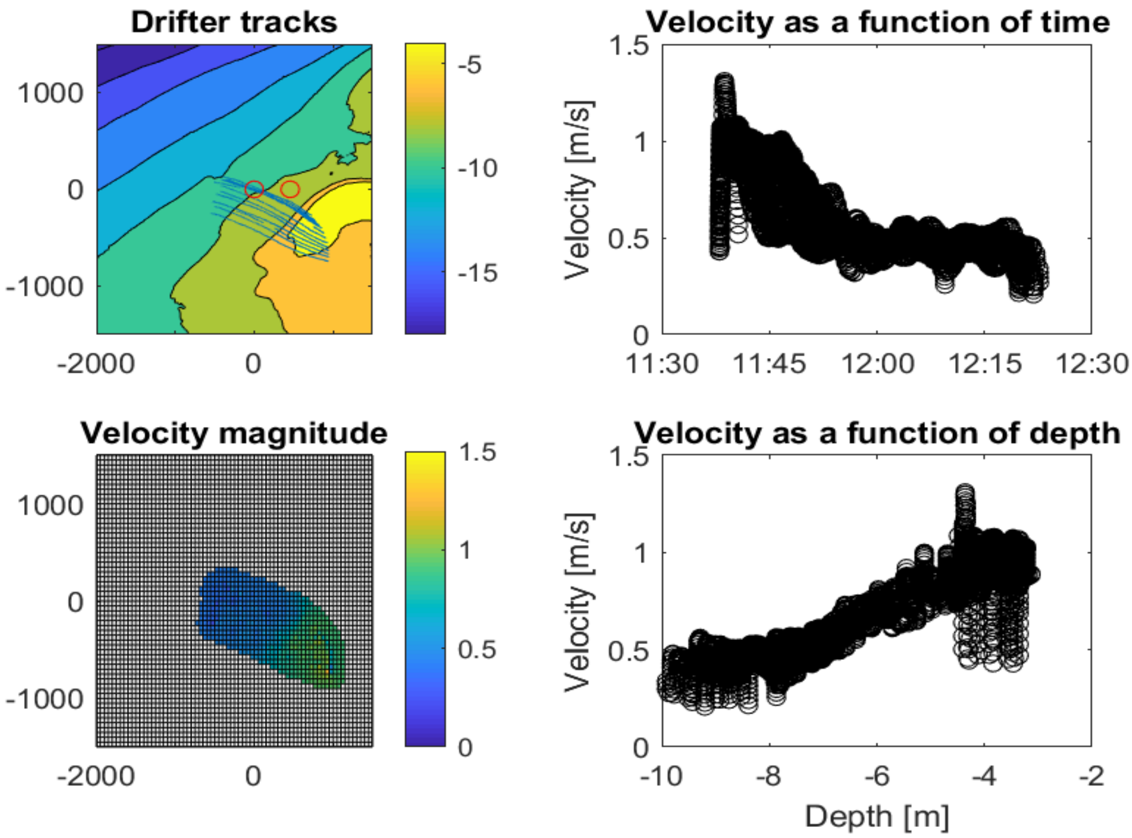


Figure 5.2: Deployment with little wind (v = 5 m/s) (September 4th - HW + 4 hrs)

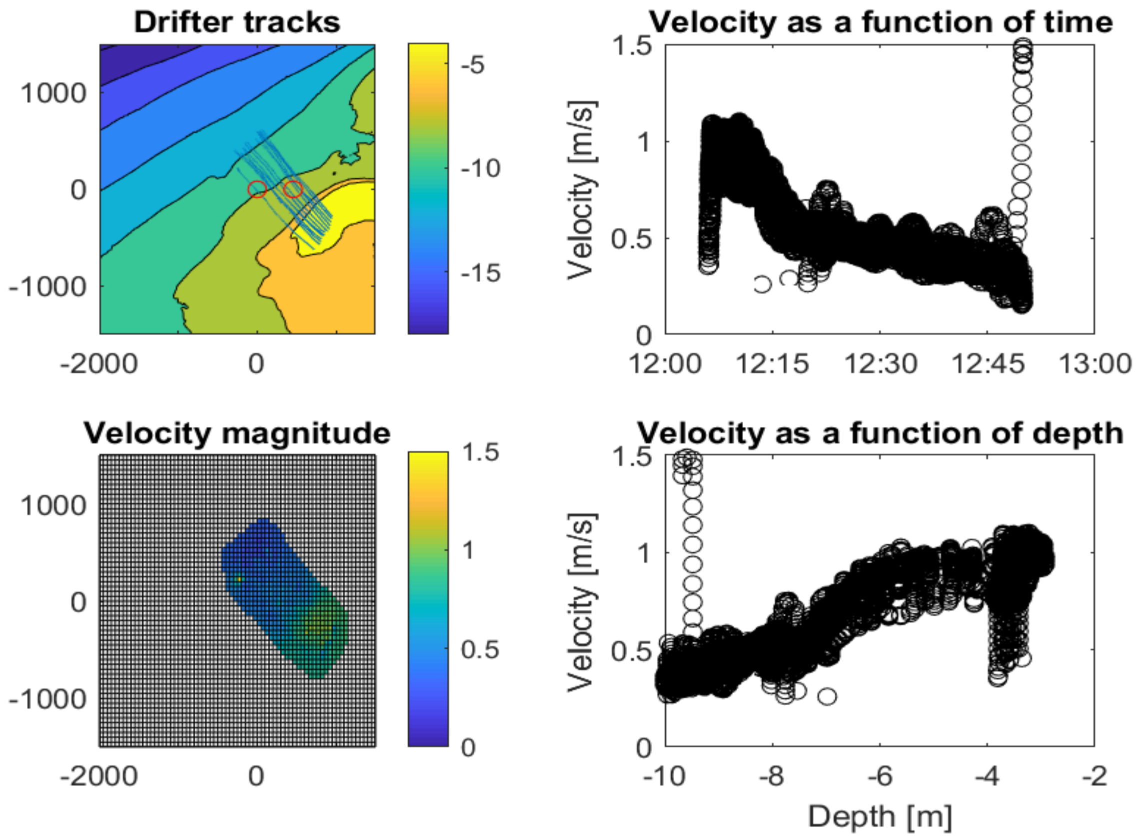


Figure 5.3: Deployment on a windy day (v = 9 m/s) (September 5th - HW + 4 hrs)

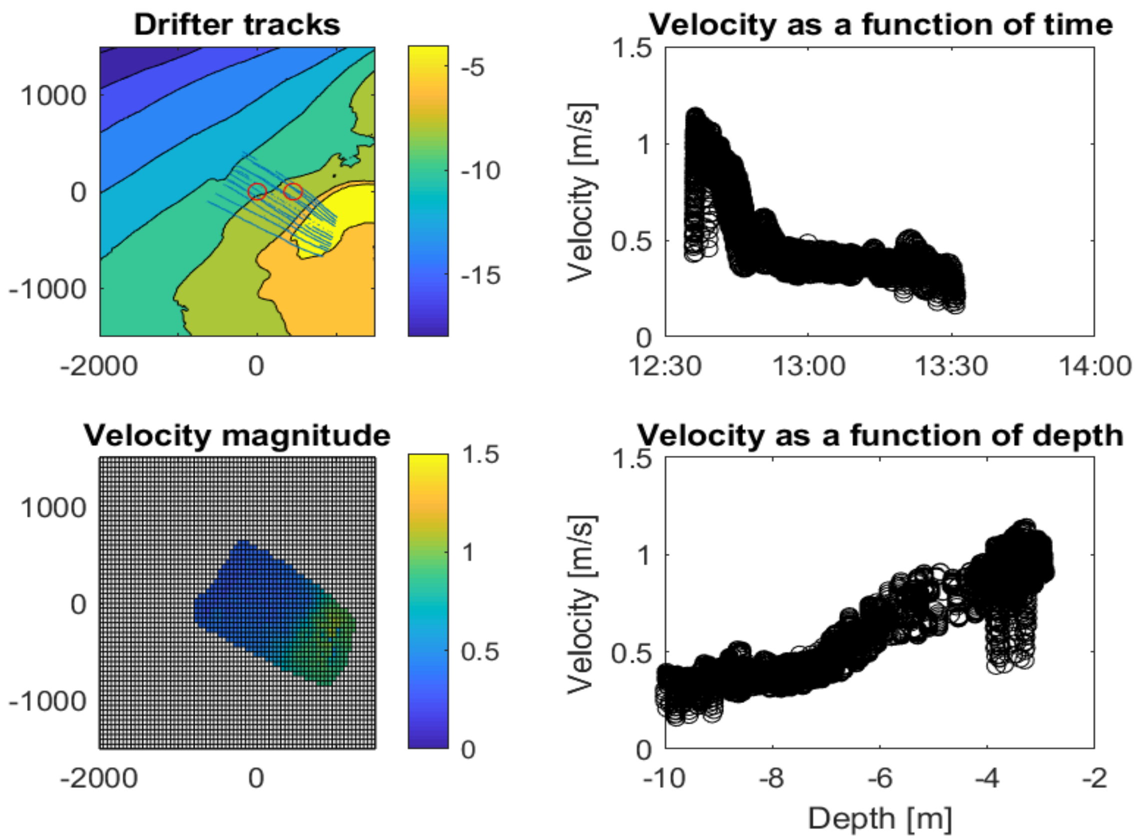


Figure 5.4: Deployment with small waves (September 4th - HW + 4 hrs 45m)

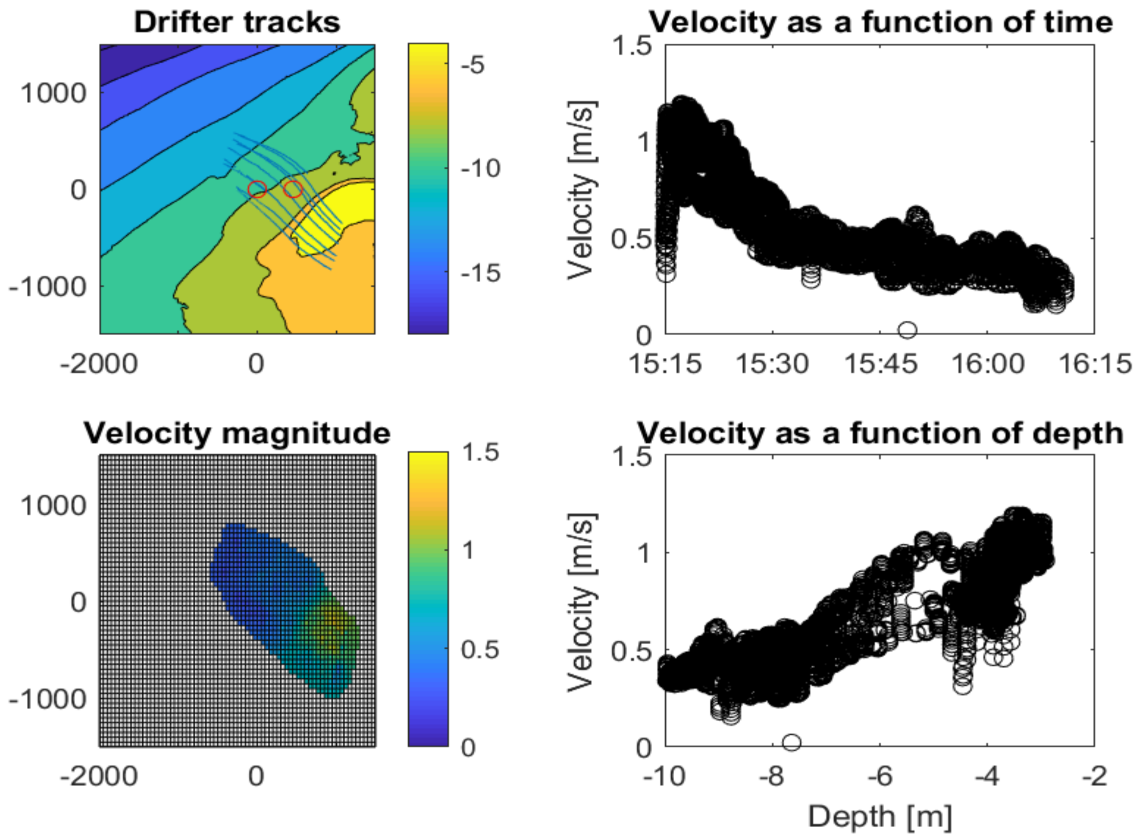


Figure 5.5: Deployment with higher waves (September 9th - HW + 5 hrs)

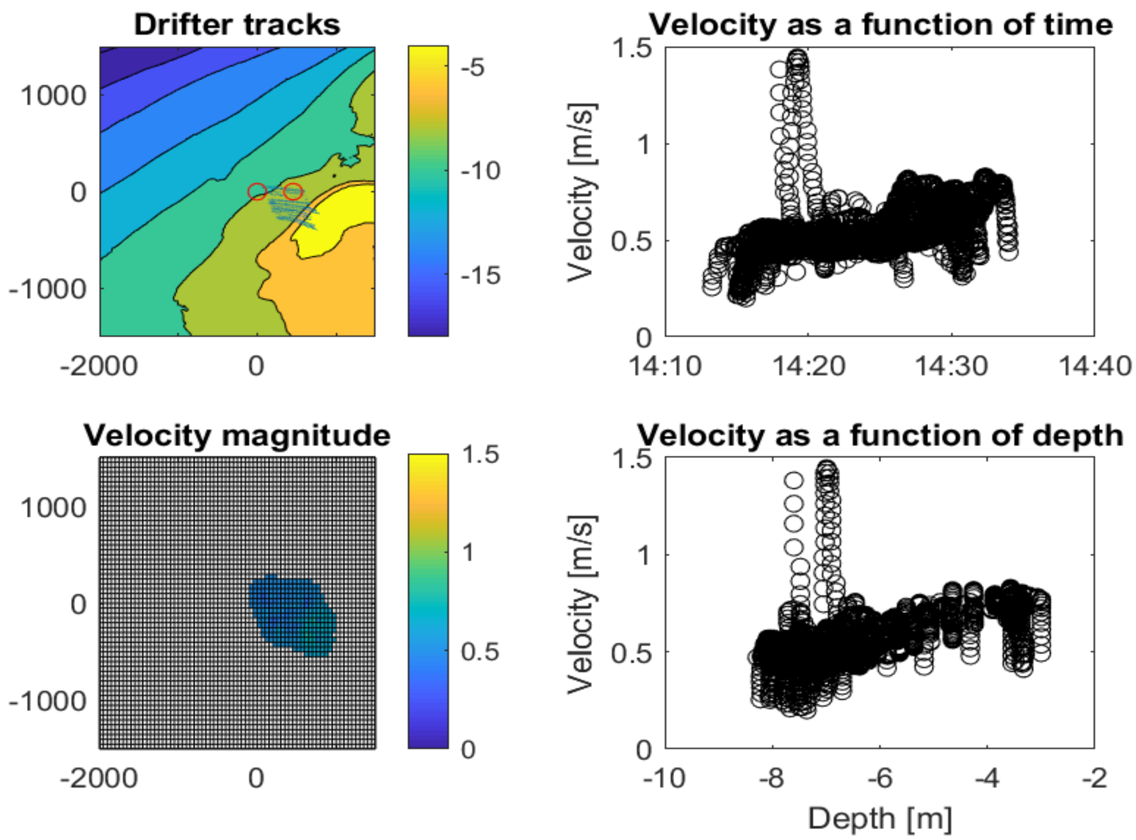


Figure 5.6: Deployment on a day with a small tidal range (September 1st - LW + 4 hrs)

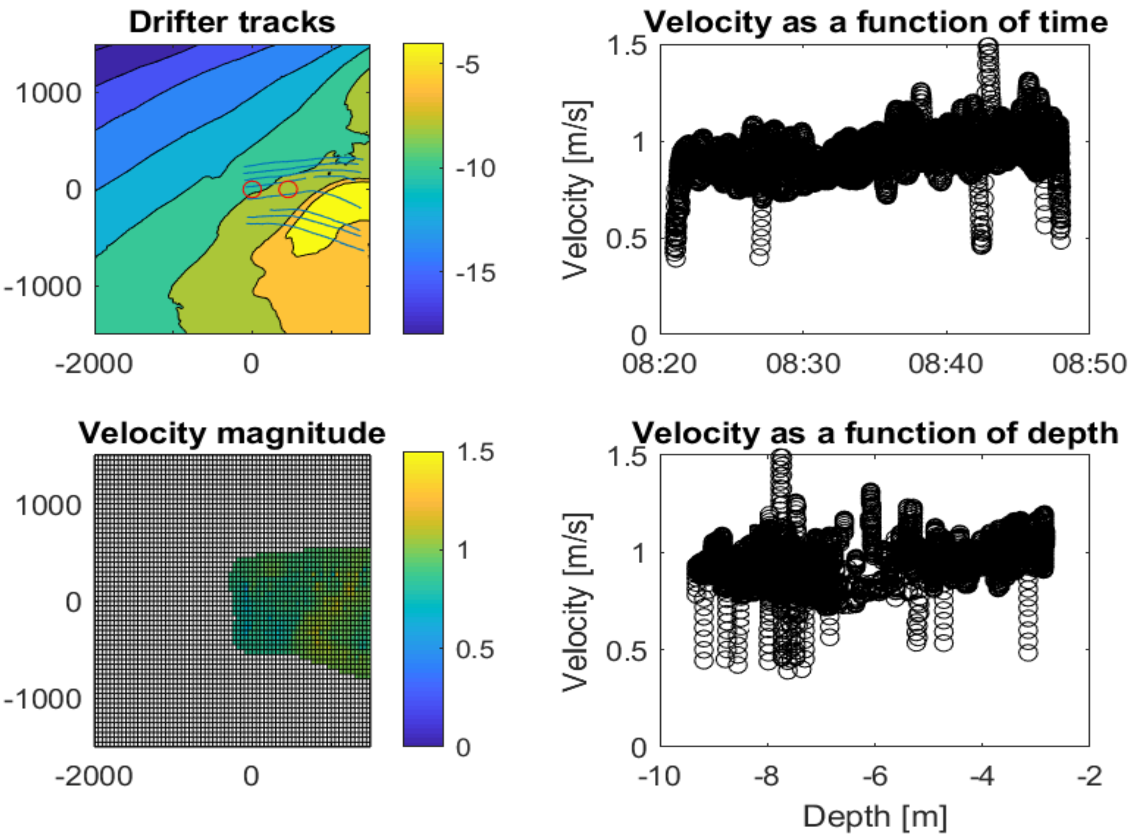


Figure 5.7: Deployment on a day with a large tidal range (September 9th - LW + 4 hrs)

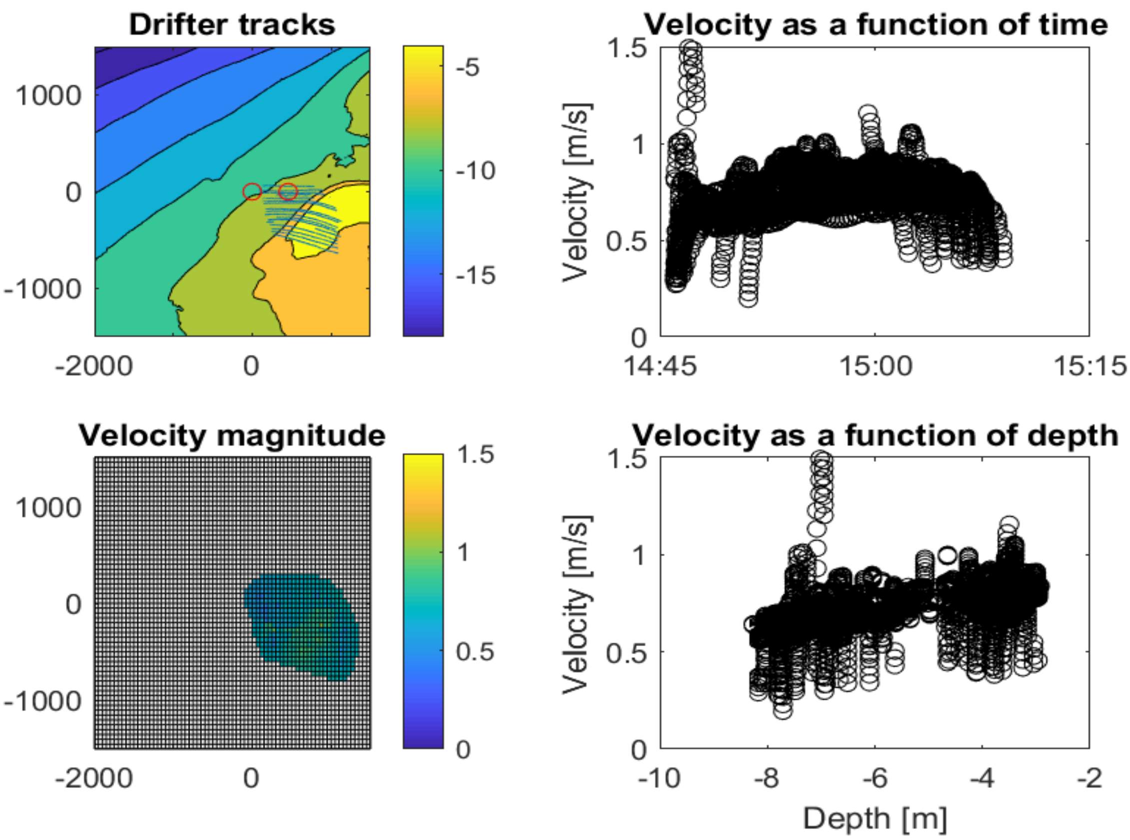


Figure 5.8: Deployment on a day with a small tidal range (September 1st - LW + 4 hrs 30m)

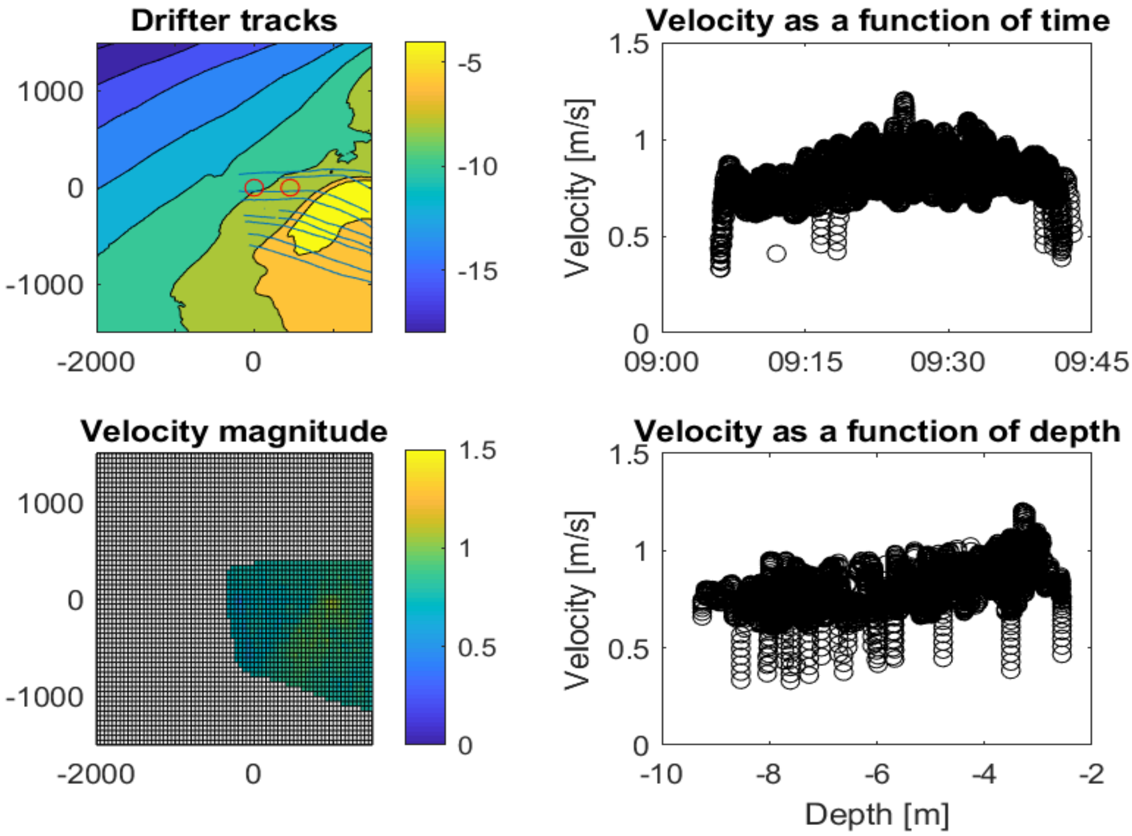


Figure 5.9: Deployment on a day with a large tidal range (September 9th - LW + 4 hrs 30m)

Chapter 6

Discussion

6.1 Effects of wind, waves and tidal range

Surface velocities are affected by a shear force caused by friction between the air and water. In addition to this, drifters measuring the velocity on the water surface are also affected by wind drag. The drift of the drifters caused by the wind relative to the water can be estimated using (1) and amounts to approximately 0.24% of the wind speed. Under the conditions that occurred during the deployment (5 m/s), this amounts to roughly 10 cm/s. It can be concluded that this is a significant contribution to the measured velocity.

When a estimate is made of the change in direction that can be attributed to windage of the drifter, it can also be concluded that the shift in direction cannot be solely be attributed to windage effects on the drifter. Using an average flow velocity of 70 cm/s and a windage velocity of 10 cm/s and assuming that the wind blows perpendicular to the surface velocity, the shift in flow direction would only be around 8 degrees. From figure 5.2 and 5.3 it can be clearly seen that the shift in direction is greater than the 8 degrees that can be attributed to windage. This is in agreement with the theory on the effect of wind drag on surface velocities. Of course, in a more general situation the direction of the wind with respect to the surface velocity plays an important role.

In cases where the only significant difference between the deployment conditions were the wave conditions, the results were not as expected. Generally the Stokes' drift velocity is negligible for very small waves (order of mm/s). Despite this, there are some remarkable differences between the mean direction of the two velocity plots. These changes in direction cannot be explained from wave effects only and can much more likely be attributed to the effects of other variables (like for example the wind or residual currents from vessels).

The influence of a larger tidal range on the flow velocity clear from the results of the experiment. This agrees well with already established theory on tidal inlet stability The velocity on the ebb tidal delta is closely related to the velocity in the tidal inlet. The amplitude of the tidal velocity is related to the tidal prism according to

$$\hat{u}_e = \frac{\pi P}{A_e T} \qquad (4)$$

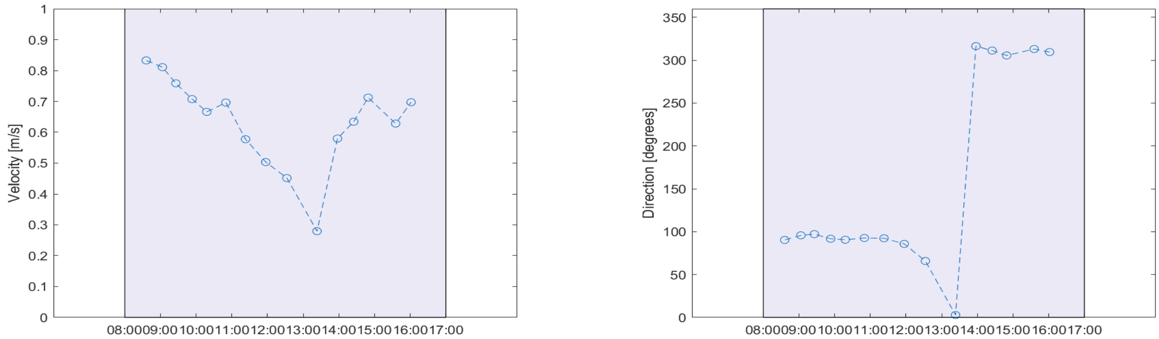
The tidal prism is in turn related to the tidal range.

6.2 Measurement reliability and verification

The velocities that have been measurement using the drifters should be verified using ADCP data measured at two location in the measurement area. Spydell et al (2015) compare the average velocities of the drifter when it makes a 'close pass' near a ADCP measurement point. The average velocity of the drifters is compared to the average velocity of the ADCP during the close pass interval. The results show a strong correlation between the two measurements, as may be expected. It was also shown that the radius for which a drifter is considered to be 'close' to a measurement location does not strongly affect the results. The same verification of the measurements should be performed on the drifter data acquired during the Ameland campaign.

6.3 Temporal evolution

When there are a sufficient number of subsequent deployments during a tidal cycle, the interpolated velocity fields can be used to gain an understanding of the temporal evolution of flow velocities and magnitudes. AS can be seen in figure 6.1a and 6.1b, taking the average flow velocities and directions over an area near one of the ADCP's of a series of deployments on September 9th results in a very plausible temporal evolution. Data from ADCP measurements can again be used to verify these results.



(a) Evolution of flow velocity

(b) Evolution of flow direction

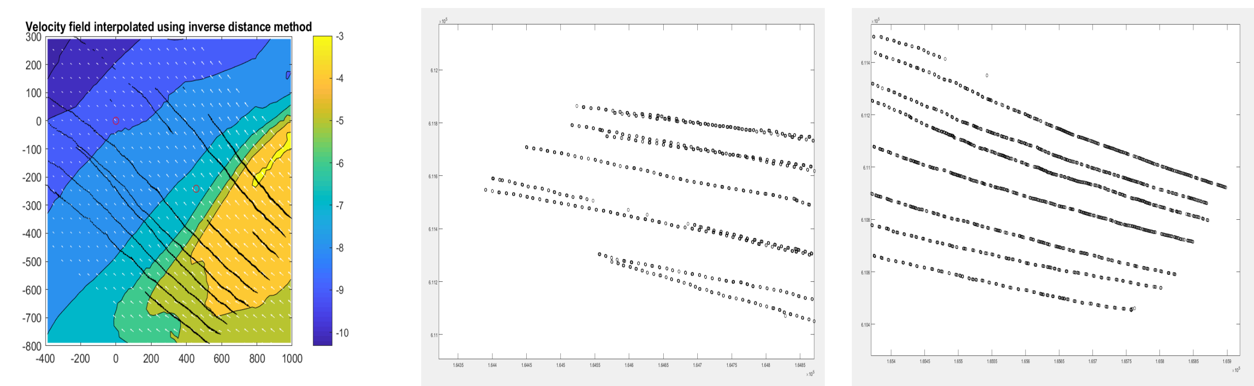
Figure 6.1: Temporal evolution

6.4 Application of measurements

Velocity measurements have a number of further applications. The velocity fields that can be constructed from the drifter tracks can be used to calibrate and validate model performances. (See Reniers et al 2010, Spydell et al. 2015) Additionally more long term deployments can be used to validate and calibrate hydrodynamic models used in particle tracking models.

6.5 Measurement improvements

In the research area the flow patterns were not very complicated. In fact, no significant flow structures were observed during any of the measurements. This means that the drifters can be deployed over a wider area, since the lack of 'resolution' will still enable the recreation of the velocity fields. The deployment over a larger area perhaps allows the observation of some large scale flow structures. Unfortunately, this will most likely result in the loss of some drifters. Because of the use of 'budget' drifters this loss is not very severe. The measurement campaign could have been improved in a number of ways in order to obtain more, more accurate or more useful results. The used 'budget drifters' resulted in frequent gaps in the measurements. An interesting observation from the GPS measurements is that the quality of the data appeared to be related to the coverage of the cell-phone network. The limits of the area with good coverage could be discerned from the measurements. It appeared that trackers that were within the area with a higher quality coverage would update their position more often. If a GPS tracker was outside of this area, it would only update its position after a certain interval.



(a) Gaps in the measurement results

(b) Poor measurement quality

(c) Good measurement quality

Figure 6.2: Measurement quality characteristics

In figures 6.2c and 6.2b you can see the difference in measurement quality within a single deployment. The closer the drifters were to the islands, the more likely they were to record better quality data. Overall, the used GPS-trackers yielded data with frequent gaps and mostly measurements with sizable intervals. In order to improve the measurement qualities, the availability of other GPS-trackers that solve these issues should be investigated. Attention should be paid to any potential limitations in its application due to the reliance of the method on cell phone coverage.

Additionally, due to logistical challenges as well as a storm preventing deployments, the number of ebb deployments is greater than the number of flood deployments. This complicates constructing a clear picture of the conditions during flood.

The use of the staggered deployments resulted in the interval during which the velocities in the area are measured. This measurement practice is highly encouraged to continue. Moreover, because of the rather simple flow pattern on the ebb-delta, more effort can be invested in creating a velocity field while shortening the deployment interval as much as possible. The use of multiple staggered deployment ('triple deployments' or perhaps 'quadruple deployments') should be investigated further.

Chapter 7

Conclusion

In this report, a methodology for budget surface velocity measurement is presented. Preliminary results indicate the measurement equipment is reliable, as no drifters were lost during the deployments. This includes a long term deployment (8 hours). However, a clear dependence on satellite connectivity was observed, where the higher quality connection yielded higher sampling rates. Overall, connectivity issues did not affect the measurements in a significant way. The simplistic nature of the flow in the research area may have alleviated problems caused by measurement gaps. In flows with more distinct structures this may present a bigger problem.

Additionally, a methodology has been presented to obtain visualizations of the velocity distribution in an area as well as visualizations for the temporal evolution of the velocity magnitude and direction.

Potential improvements to the drifter system have been suggested. These include a change in the measurement spacing between individual drifters and the use of multiple sets of drifters to limit the measurement interval.

The measurements have not been verified using ADCP data from measurement points in the same region. The comparison will verify the reliability of this measurement method.

From the measurements themselves, it can be concluded that wind and differences in tidal ranges significantly affect the velocity distribution on the ebb tidal delta. For differences in the wind conditions especially, the relative importance of drag on the drifters themselves has been quantified and shown to be a contributing factor in differences in the velocity distribution.

7.1 References

Bosboom, J., & Stive, M. J. (2016). Coastal Dynamics I: Lectures Notes CIE4305. VSSD.

Herman, P., Meijer-Holzhauer, H., Vergouwen, S., Wijsman, J., Baptist, M., 2016. Ecologische effecten van kustsuppleties; Systeembeschrijving (deel A), onderzoeksprioriteiten (deel B) en ontwerp uitvoeringsplan.

Holthuijsen, L. H. (2010). Waves in oceanic and coastal waters. Cambridge university press.

Longuet-Higgins, M. S. (1953). Mass transport in water waves. Phil. Trans. R. Soc. Lond. A, 245(903), 535-581.

Reniers, A. J., MacMahan, J. H., Beron-Vera, F. J., & Olascoaga, M. J. (2010). Rip-current pulses tied to Lagrangian coherent structures. Geophysical Research Letters, 37(5).

Spydell, M. S., Feddersen, F., Olabarrieta, M., Chen, J., Guza, R. T., Raubenheimer, B., & Elgar, S. (2015). Observed and modeled drifters at a tidal inlet. Journal of Geophysical Research: Oceans, 120(7), 4825-4844.