Hydrodynamic Model Validation Report

Billy Baa, Scalloway, Shetland

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1 Summary

This document details the validation of hydrodynamic model output at the proposed Billy Baa site. The hydrodynamic model output covers a different time period to the current meter and drogue release observation periods, and so a procedure of matching wind forcing conditions was taken to determine an appropriate assessment window.

The model predictions of current patterns and drogue transport at the site were generally accurate, and should allow for confidence in the impact assessment studies made at the site.

2 Abbreviations

DHI	Danish Hydraulic Institute
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA	ECMWF Re-Analysis
HD	Hydrodynamic
MSS	Marine Scotland Science
SEPA	Scottish Environmental Protection Agency
SSM	Scottish Shelf Model

3 Introduction

The marine modelling impact assessment elements of this project made use of the outputs of an HD model developed for the Scalloway area (Danish Hydraulic Insitute 2021). The model covers the Scalloway area from the island of Foula in the west to the Shetland mainland (Fitful Head in the south to Wats/Braga Ness in the north). This was developed as a higher resolution subdomain of a wider scale model covering the whole of Shetland.

At the time of development, a version of the model driven using climatological (25 year averaged) meteorological condition was calibrated and validated against the MSS SSM at several locations in the waters surrounding Shetland (Danish Hydraulic Insitute 2021). An additional “hindcast” simulation driven using a specific time window of meteorological (ECMWF ERA5) and ocean boundary forcing was also carried out, covering the period 01/11/2017-01/11/2018. Due to the use of more realistic (and higher frequency) variation in boundary conditions, this model exhibits much higher variability in flow at specific locations over time.

This report therefore details the performance of the hindcast model in relation to more recently collected data at Billy Baa: i) a current meter deployment in 2022, and ii) a drogue study carried out at the proposed site location (Anderson Marine Surveys 2023).

The current meter record was also compared with outputs from other candidate models: i) DHI-SSF Scalloway climatology (mentioned above), and ii) DH-GSS Scalloway 1.04 model (developed as part of a previous application at Easter Score Holm). However, overall worse performance for this specific site and current meter record means that those results are not presented here.

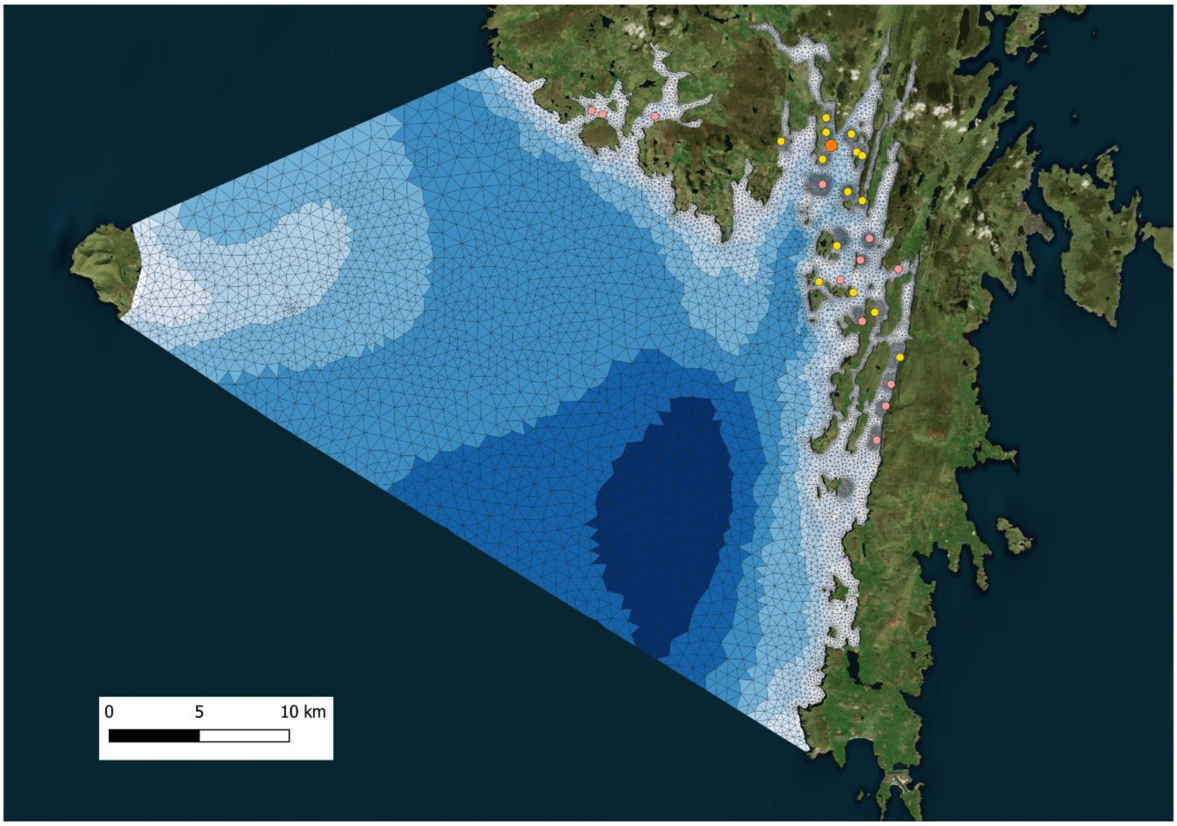

Figure 3.1: Computational mesh for the Scalloway HD model, with shading indicating bathymetry. Orange point indicates the location of the current meter record. Pink discs indicate the locations of sites which have been active in the last 3 years, and yellow discs the locations of sites which are inactive.

4 Billy Baa current meter comparison

4.1 Meter/model temporal coverage

The current meter deployment for the Billy Baa site was made at OSGB [435978, 1145767], and covers the period 31/08/2022 - 21/12/2022. The model hindcast period covers the period 01/11/2017-01/11/2018. No direct comparison can be made between current meter and the model prediction. However, comparison of model output covering a period with similar wind statistics to those seen during the current meter deployment will give insight into its ability to predict transport direction and speed adequately.

4.2 Wind statistics

Hourly wind data covering the duration of the current meter record and the hindcast run period, and the entirety of the Shetland archipelago, were extracted from the ECMWF ERA5 reanalysis data product (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview). Data were extracted as U and V components 10 m above ground level at the current meter location (nearest ERA5 grid cell), and converted to speed and direction time series.

An initial period was considered at the end of the model hindcast output with a view to obtaining dates as close to the current meter period while maintaining a continuous extraction period (12/07/18 - 01/11/18). The wind direction for this period was consistently from the south west, mismatching the wind direction during the meter record (and leading to a corresponding mismatch in hydrodynamic model flow patterns).

A second period was then considered (22/03/18 - 12/07/18). The wind direction during this period does not exactly match that seen during the current meter record but was much closer (Figure 4.1). As with the meter observation period, wind from all directions was represented, and there was a dominance of south-south-easterly wind. This model run period exhibited slightly more wind from the north than the current meter period (though velocities in this direction were lower than those from the south), and the velocities were lower overall (Figure 4.2).

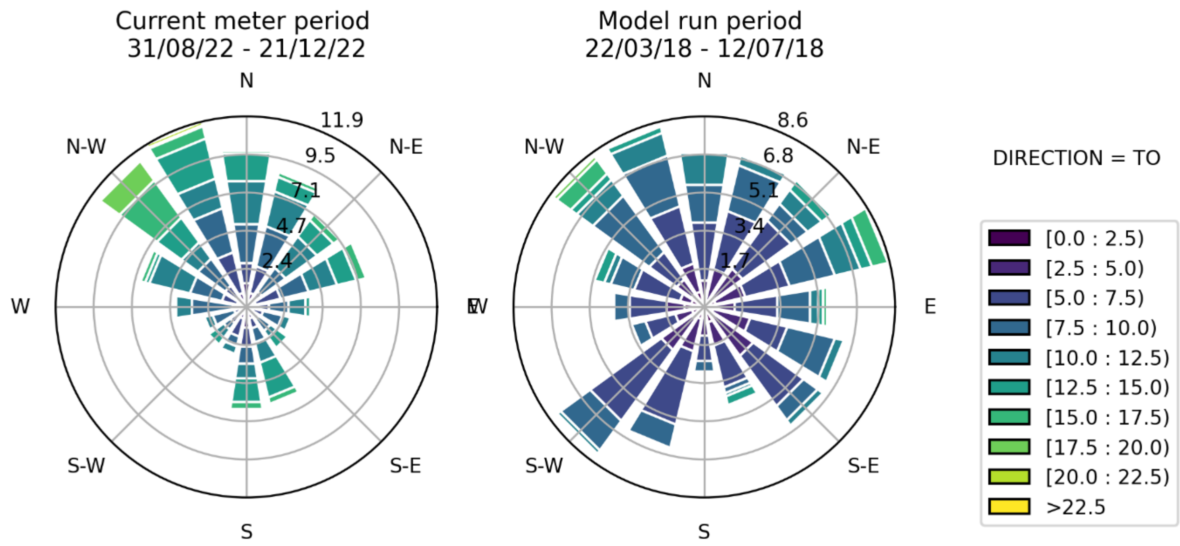

Figure 4.1: Wind roses showing speed and direction of wind extracted from ERA5 over the current meter observation period (left) and selected model run period (right).

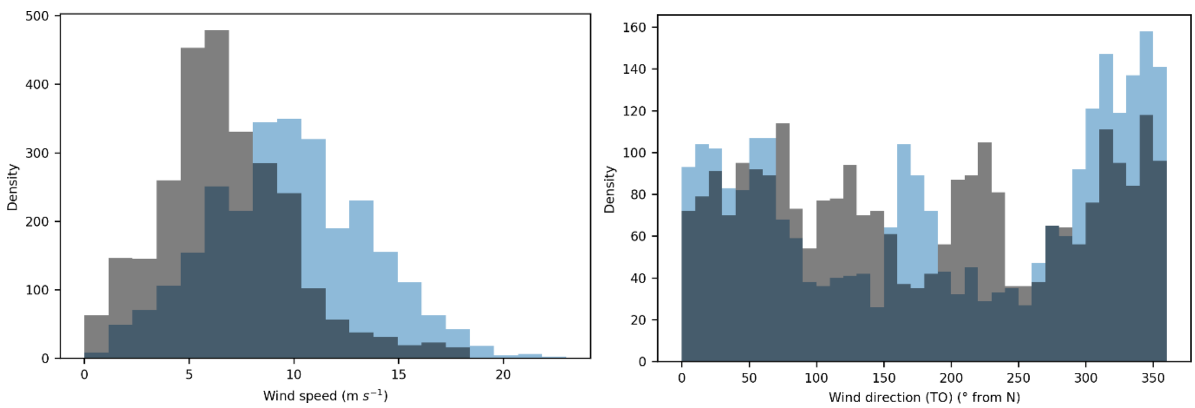

Figure 4.2: Histogram plots of wind speed (left) and direction (right) extracted from ERA5 over the current meter observation period (blue) and selected model run period (black).

4.3 Hydrodynamic model/current meter comparison

4.3.1 Water levels

Distribution of water levels matched very well between the current meter observation and HD model extract for the location (Figure 4.3).

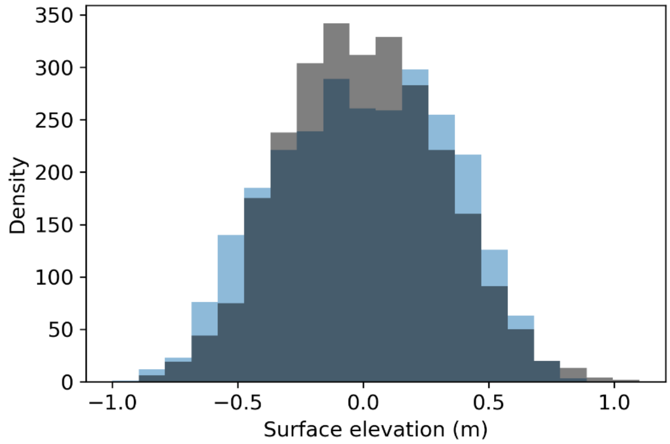

Figure 4.3: Water level comparison between current meter observation (blue) and HD model extract for the location (grey).

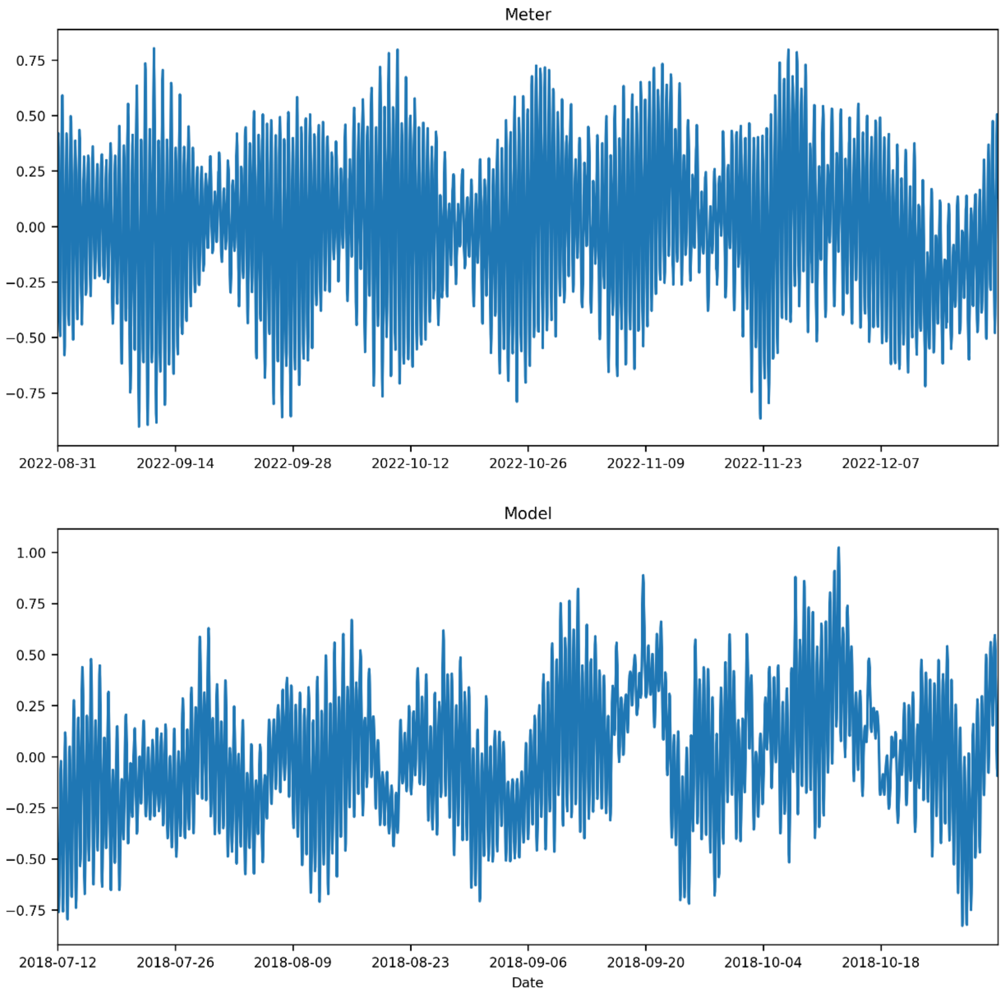

Figure 4.4: Surface elevation timeseries recorded by the current meter, and for the selected model period.

4.3.2 Near-surface flow (-6.09 m)

A comparison of the current meter record and the model, close to the surface, is shown in Figure 4.5 and Figure 4.6. Distribution of directions (right hand margin in Figure 4.6) is very similar between current meter and model, but the model exhibits somewhat slower speeds than the current meter (top margin in Figure 4.6).

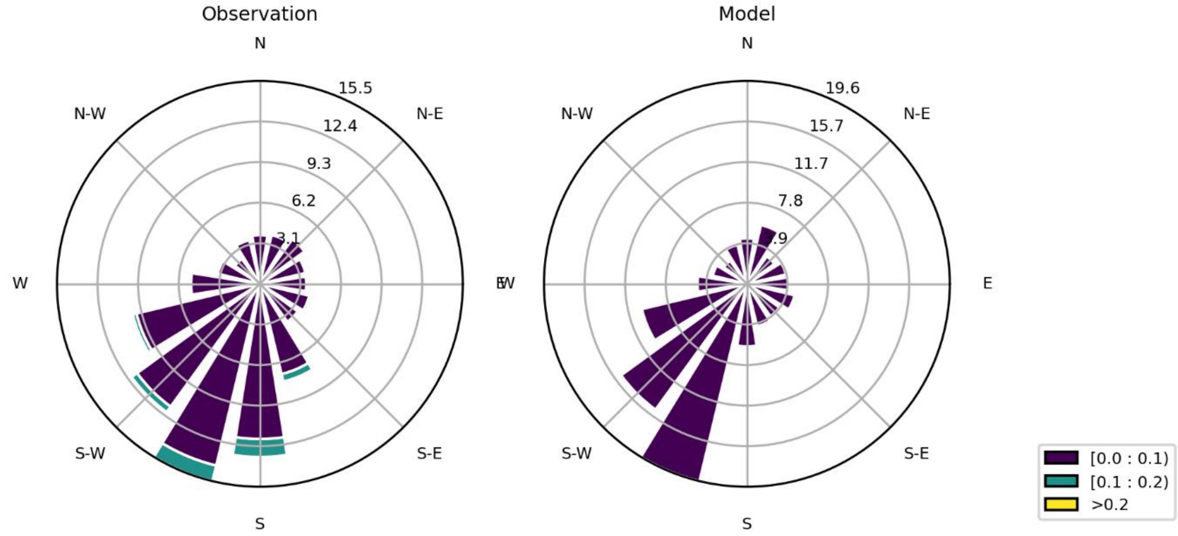

Figure 4.5: Current rose for near surface flows (-6.09 m), showing current meter observation (left) and model prediction for the selected period (right).

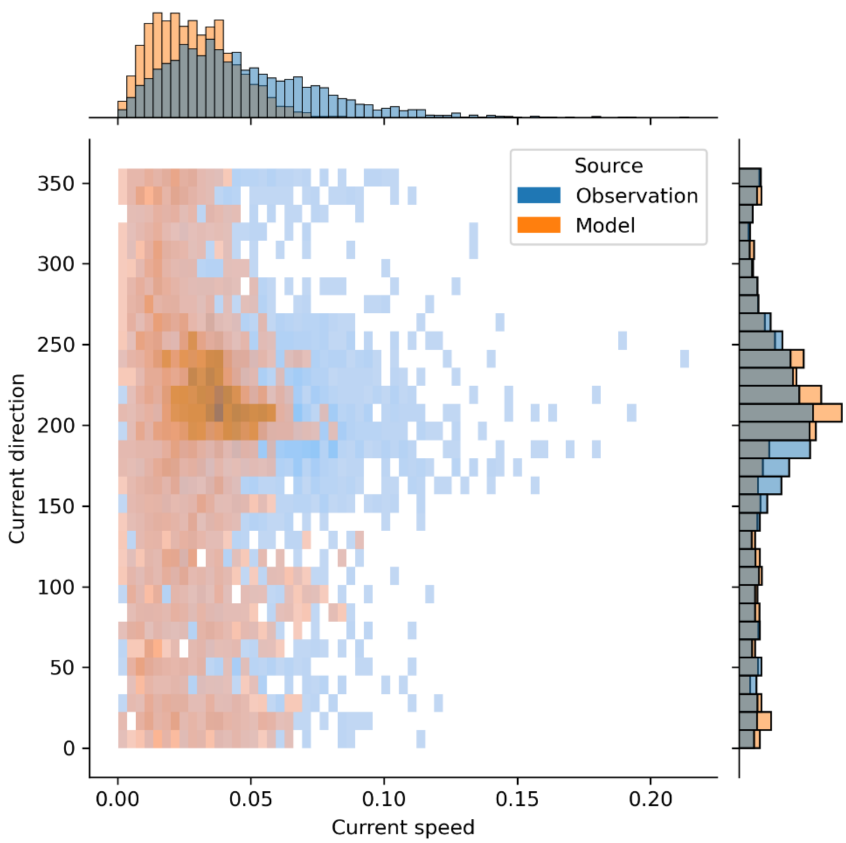

Figure 4.6: Histogram of speed versus direction for near surface flows (-6.09 m).

4.3.3 Mid-depth flow (-15.09)

A comparison of the current meter record and the model, at mid-depth, is shown in Figure 4.7 and Figure 4.8. Distribution of directions (right hand margin in Figure 4.8) is slightly more focussed on SW flows in the model, and again the model exhibits slower speeds than the current meter (though there is less difference than observed for surface flows; top margin in Figure 4.8).

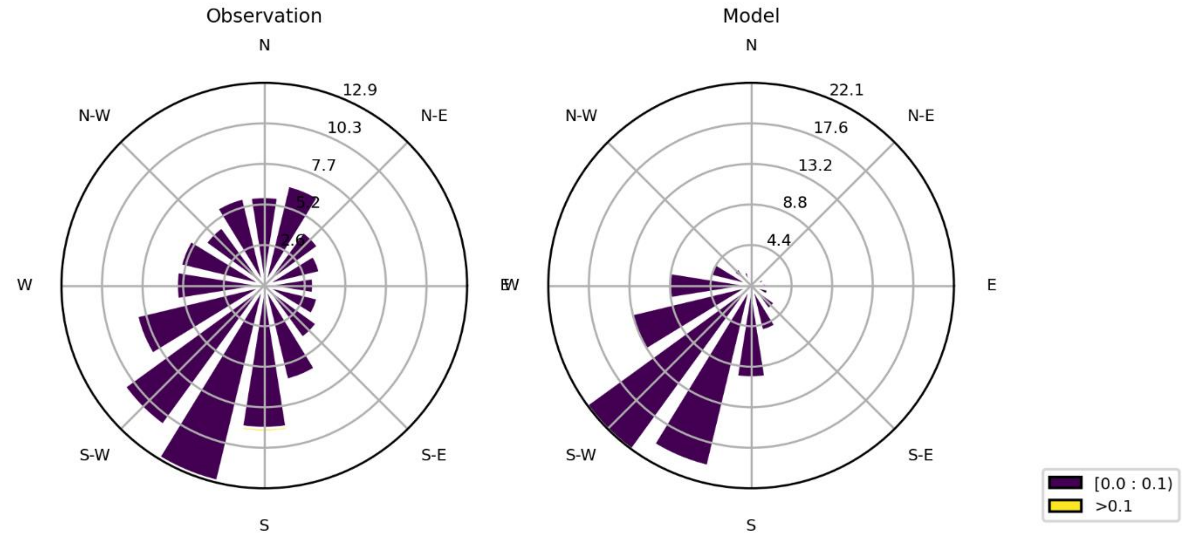

Figure 4.7: Current rose for mid-depth flows (-15.09 m), showing current meter observation (left) and model prediction for the selected period (right).

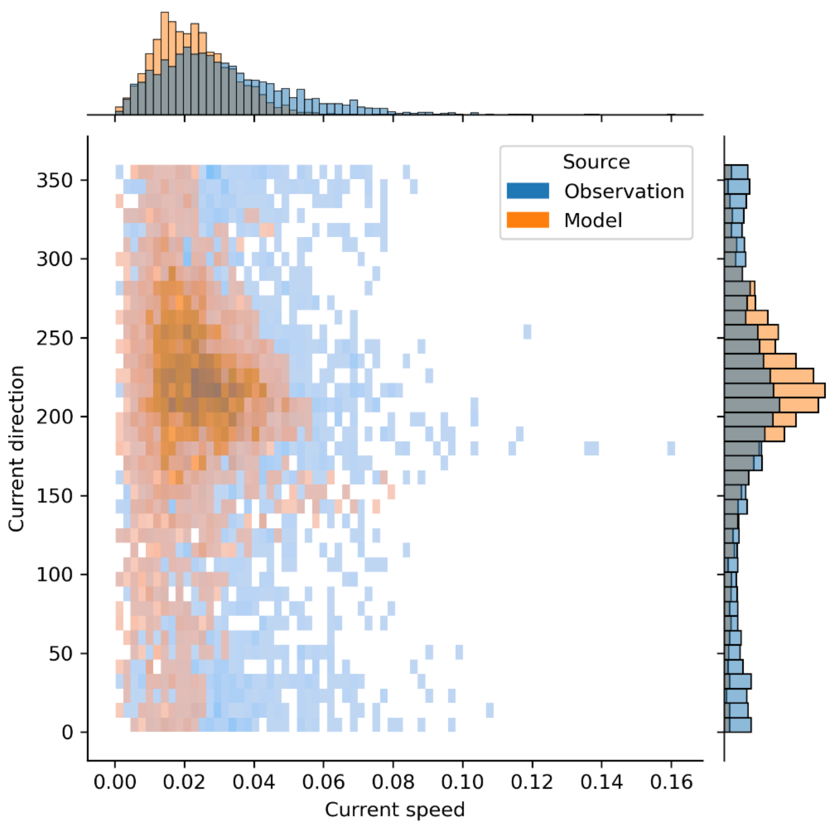

Figure 4.8: Histogram of speed versus direction for mid-depth flows (-15.09 m).

4.3.4 Near-bed flow (-42.09 m)

Close to the seabed, the distribution of flow speeds is very similar in the current meter and the model (top margin in Figure 4.10), but the distribution of directions is somewhat different. The model exhibits a greater focus on SW flows, and the current meter a greater focus on NE flows (right margin in Figure 4.10).

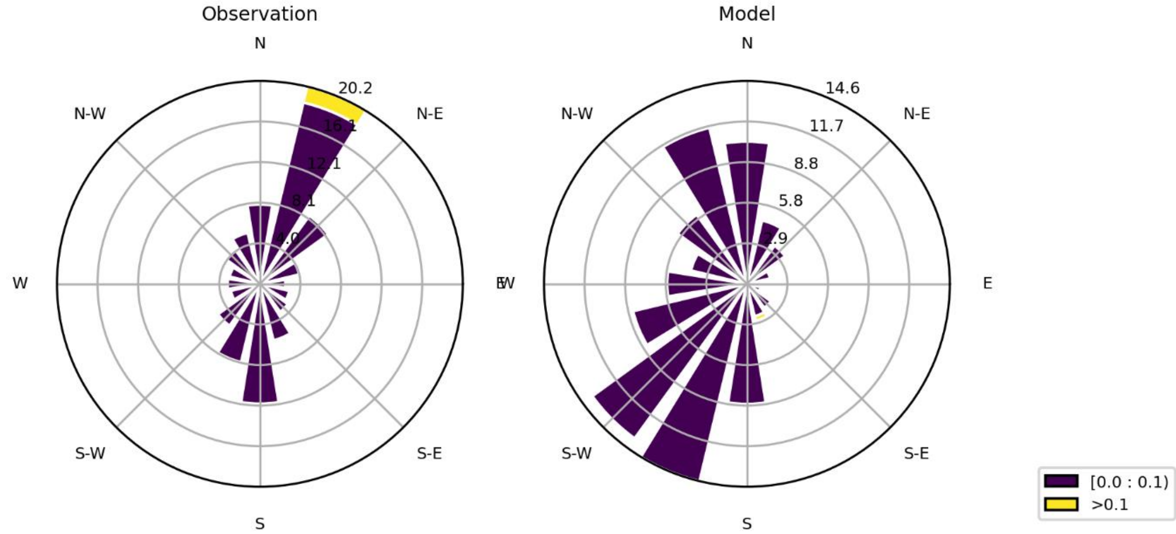

Figure 4.9: Current rose for near-bed flows (-42.09 m), showing current meter observation (left) and model prediction for the selected period (right).

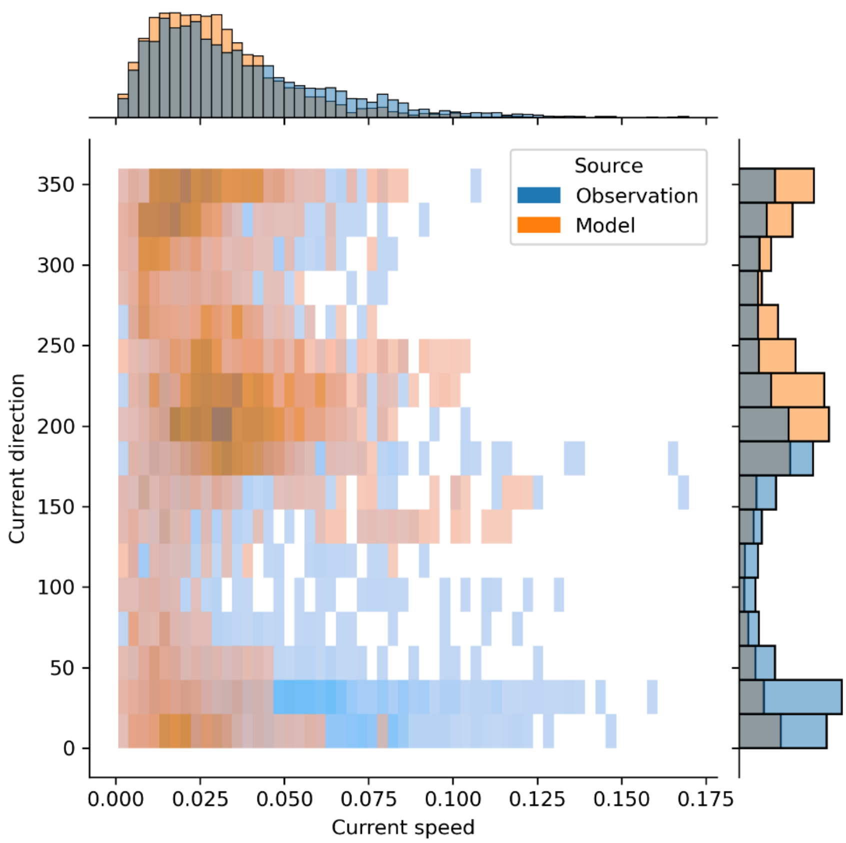

Figure 4.10: Histogram of speed versus direction for near-bed flows (-42.09 m).

4.3.5 Progressive flow (all depths)

Progressive flow vectors generated from the meter record and model extract are shown in Figure 4.11. The direction of the near-surface and mid-depth progressive flow observed in the current meter record is very closely matched by the model. For the near-surface flow, the model slightly under-predicts the transport distance. At mid-depth, the model over-predicts transport distance, due to a lower variation in current direction.

For the near-bed flow, the progressive vectors are in opposing directions.

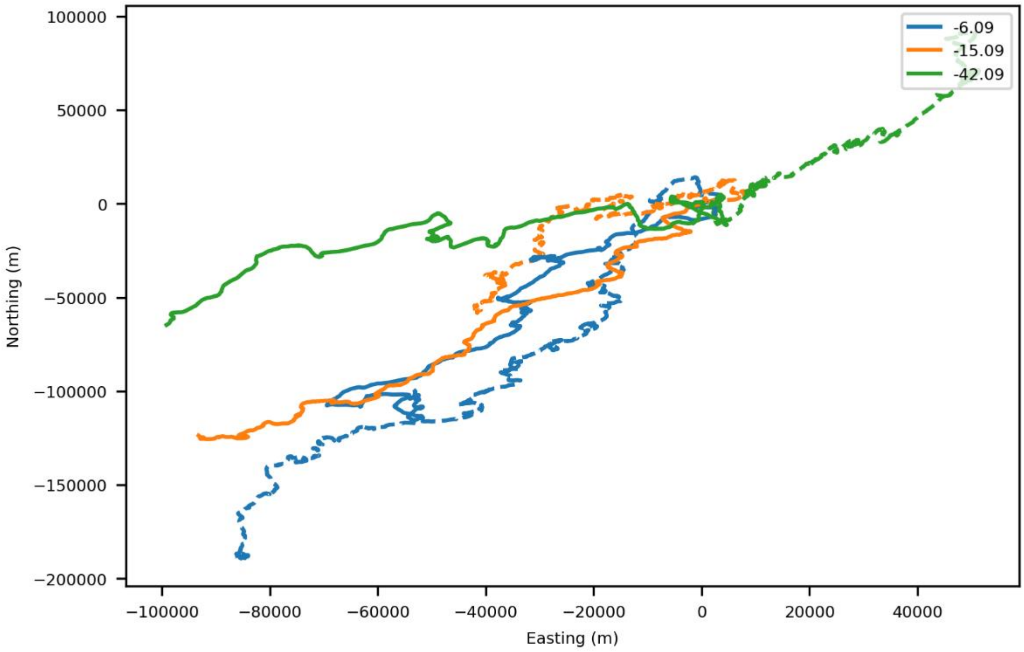

Figure 4.11: Progressive flow plot showing vectors at all depths. Vectors with dashed lines are generated from the current meter record, and those with solid lines are generated from the model output (lines matching direction from point (0,0) would indicate a good match).

5 Drogue study comparison

5.1 Billy Baa release

5.1.1 Drogue release

A drogue release study was conducted at the proposed site location from 4-6 July 2023 by Anderson Marine Surveys. This is described in detail in a separate report (Anderson Marine Surveys 2023).

5.1.2 Wind direction and tide phase

In order to carry out a comparison of predicted versus actual drogue transport, again a period of matching wind and tidal characteristics had to be selected. In this case, it was the conditions at the specific release times that were of interest, as opposed to long term statistics.

The conditions present at the time of the actual drogue releases in July 2023 are indicated in Figure 5.1 and Figure 5.2. Releases 1-5 were carried out during a period of wind to the ESE, with wind speed declining from around 6 m s^{-1} to almost zero at the time of release 5. Release 6 was carried out during a period wind towards the NW with a speed of around 3 m s^{-1}. Wind in this direction occurs a smaller proportion of the time at this location, and appears to generally be associated with higher wind speeds (as indicated by ERA5 hindcast).

Suitable model release times for drogues 1-5, allowing a fairly close replication of wind and tidal conditions, were found within a 24 hour period from 12-13 June 2018 (Figure 5.3). This was followed by a period of NW wind, but the wind speed appeared to be far too high at this time to allow useful comparison with drogue 6. An alternate period was chosen from 24 May 2018; wind speeds were still too high, but were much closer to those during the actual deployment (Figure 5.4).

Three sets of simulations were carried out, using:

1. particle movements based on hydrodynamic fields only;
2. particle movements additionally incorporating acceleration due to wind velocity, using default MIKE parameters, and the approximate observed wind speed/direction during the drogue releases; and
3. particle movements incorporating acceleration due to wind velocity, reducing the MIKE “wind weight” parameter by 50% to 0.05.

For item 1., releases at 15 minute increments up to 10 hour before and after the selected release time were also tested (to capture possible offsets in water movements relative to tide phase).

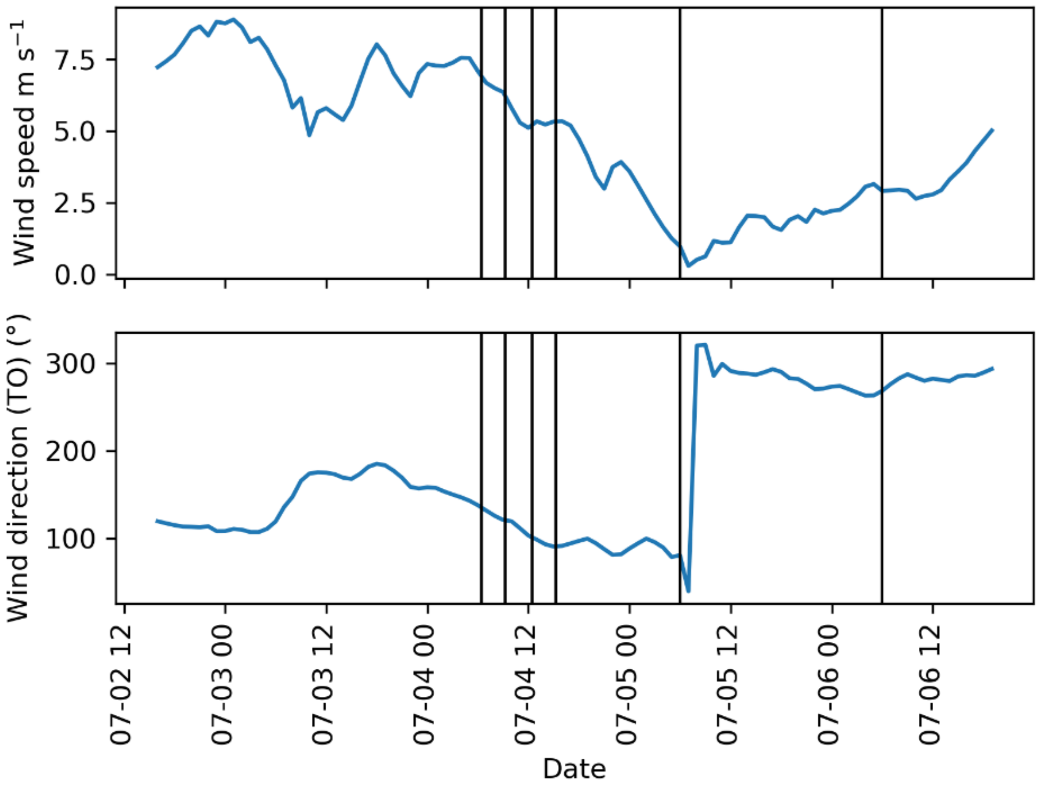

Figure 5.1: Wind speed and direction during the period of the drogue releases at Billy Baa in July 2023. Vertical lines indicate the times of the drogue releases.

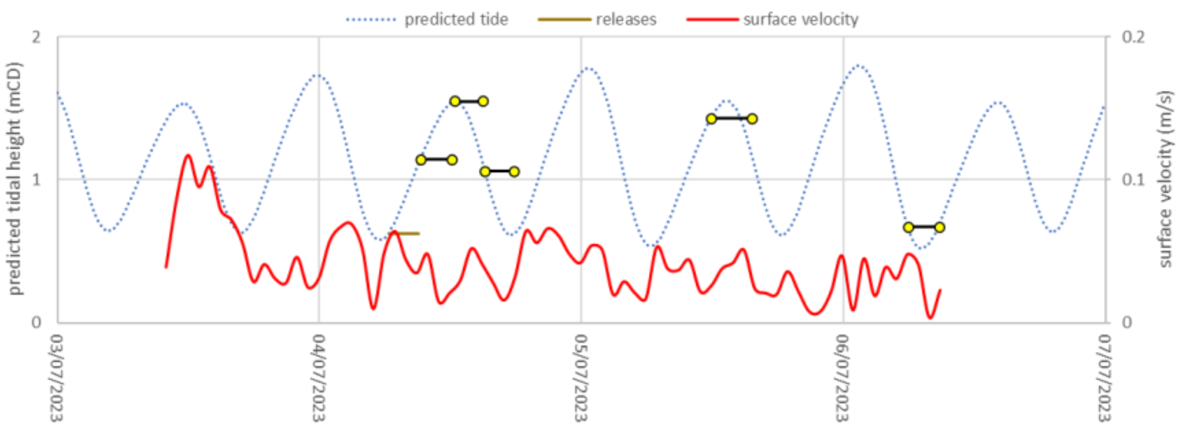

Figure 5.2: Tidal phase during the period over which drogues were released by Anderson Marine. Horizontal bars indicate the duration of dye releases (approximately concurrent with drogue releases, except release 5 where the drogues were released several hours earlier; Figure duplicated from Anderson Marine report).

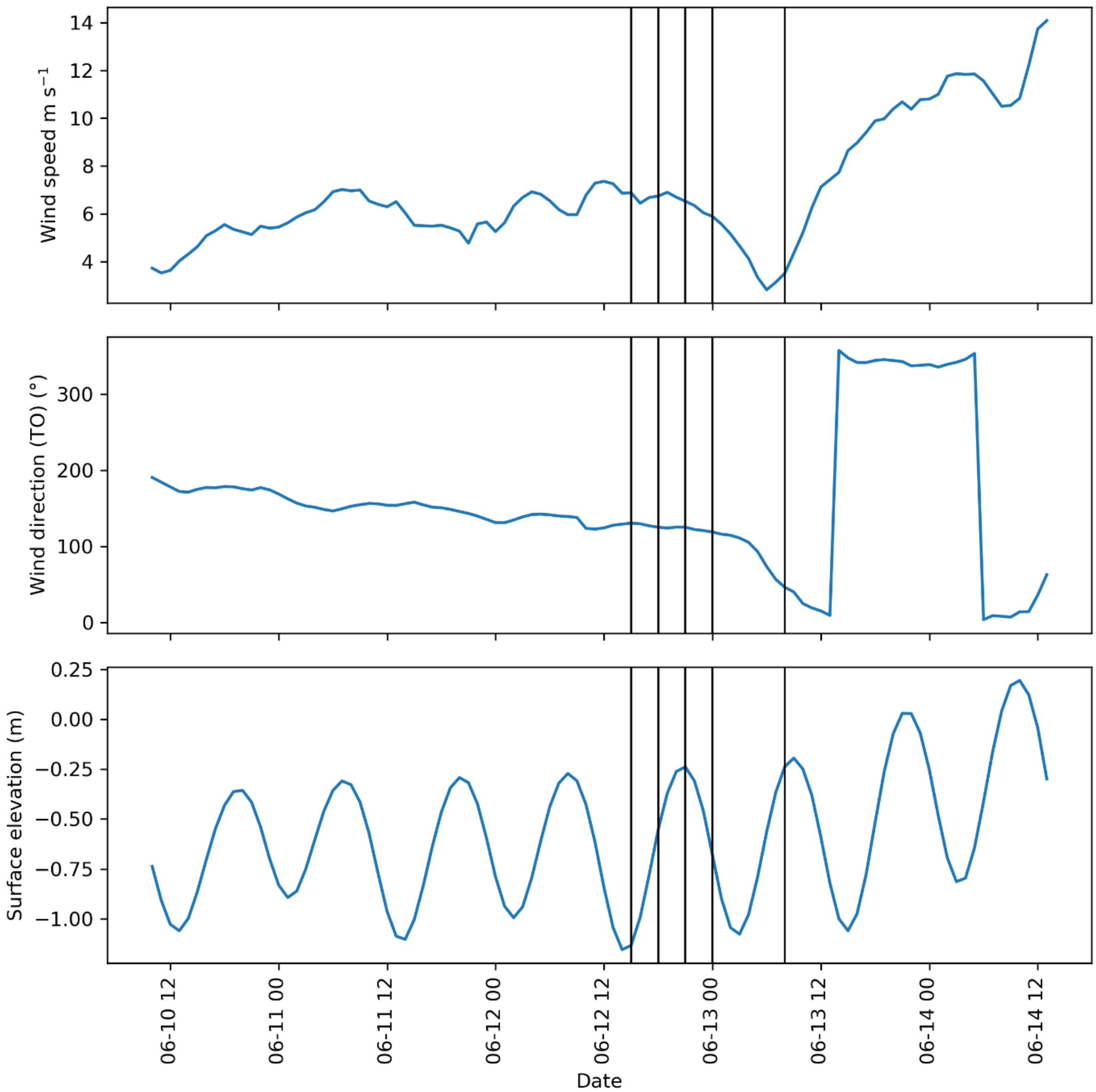

Figure 5.3: Period of the 2018 hindcast hydrodynamic model run used to match conditions of drogue releases 1-5 as closely as possible. The vertical black lines indicate the release times used in the simulation (1-5 in order left-right).

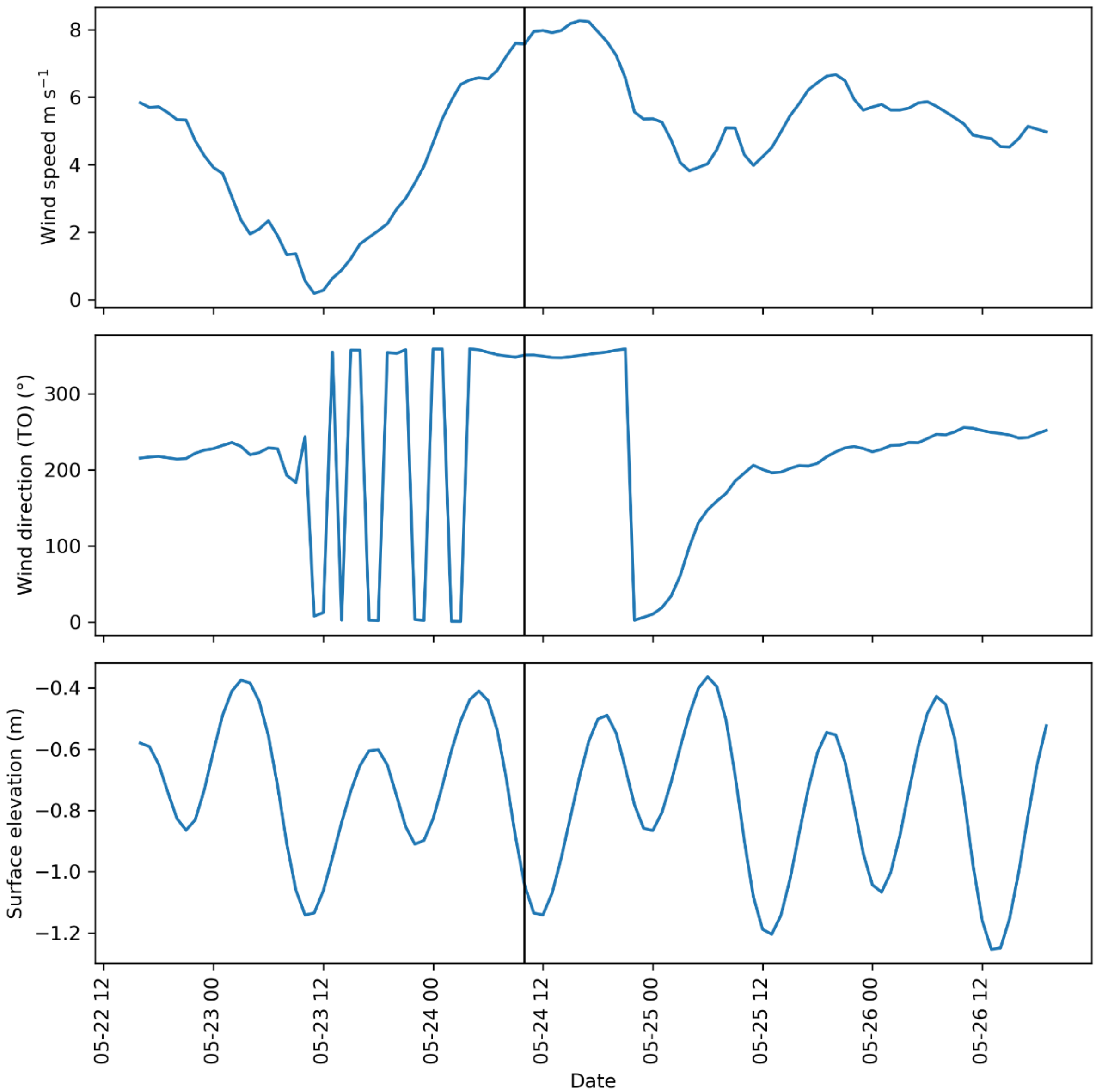

Figure 5.4: Period of the 2018 hindcast hydrodynamic model run used to match conditions of drogue release 6 as closely as possible. The vertical black line indicates the release time used in the simulation.

5.1.3 Track comparison

Particle tracks generated using the information contained in the hydrodynamic fields alone did not accurately capture the patterns demonstrated by drogue tracks (Figure 5.5), being generally characterised by insufficient movement and incorrect transport direction. The release in which movement was captured relatively best was R5, during which winds were light and drogue movement was fairly short range.

Particle movement patterns predicted by the model were insensitive to adjustments in particle release time (up to one hour before and after the selected release time; not shown).

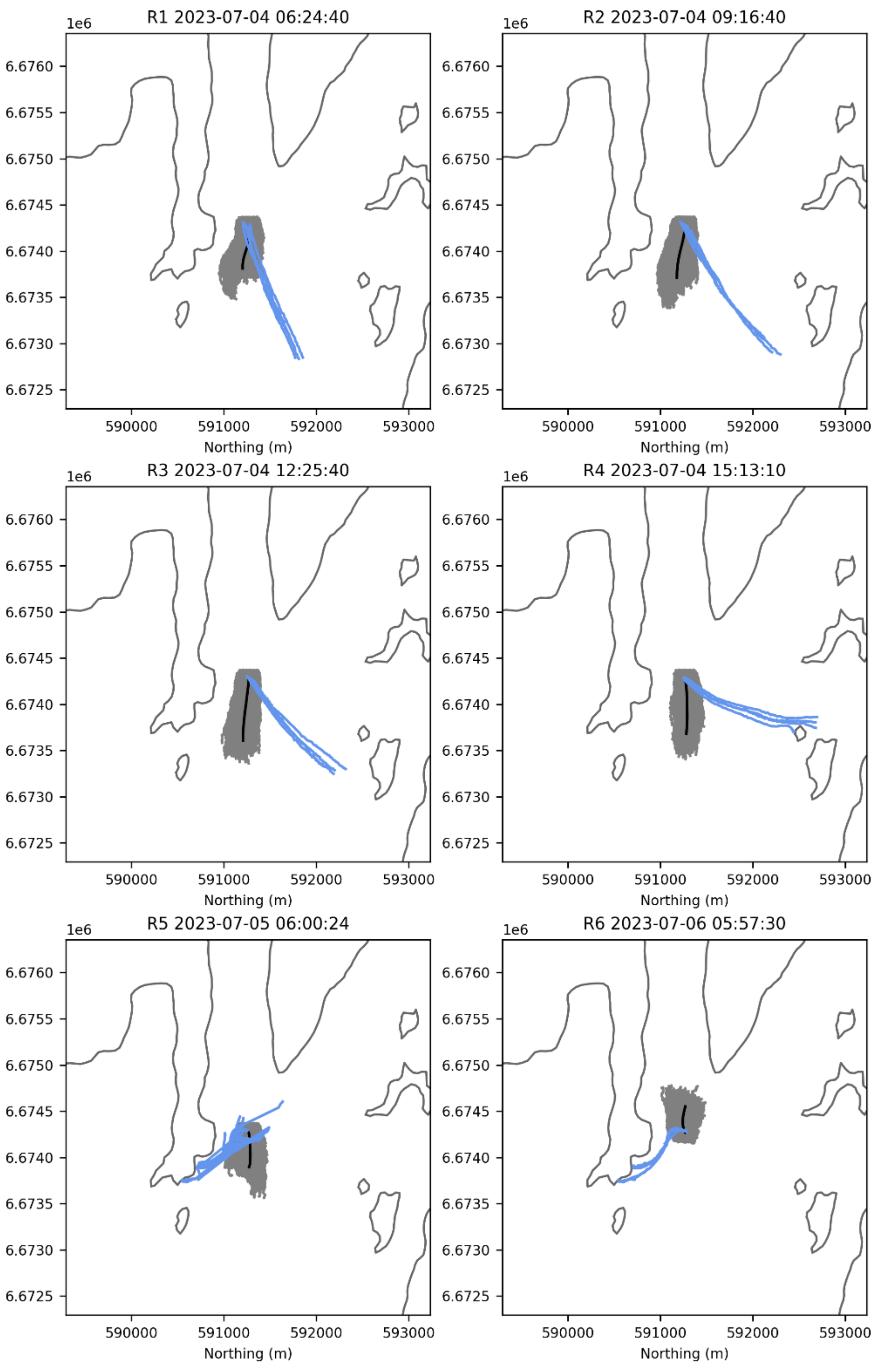

Figure 5.5: Observed drogue tracks (blue) plotted over model particle tracks (grey; mean track = black line), generated using hydrodynamic flow fields alone.

Incorporating acceleration due to wind forcing yields a much improved movement trajectory for most of the releases. Releases implementing the default MIKE parameters produced acceptable results, with the exception of releases R5 and R6. Reducing the "wind weight" parameter (i.e. the extent to which wind governs overall particle velocity) by 50% yielded further improved results, though R5 and R6 remained imperfectly fitted. In other cases, both the transport distance and direction were well matched (Figure 5.6) with separation distances remaining relatively low (Figure 5.7). For R5, transport distance was correct, but direction was incorrect. For R6, transport distance was again correct, but after a short initial period in which movement direction was correct, towards the coastline, particle and drogue movement directions diverged in opposite directions along the coastline.

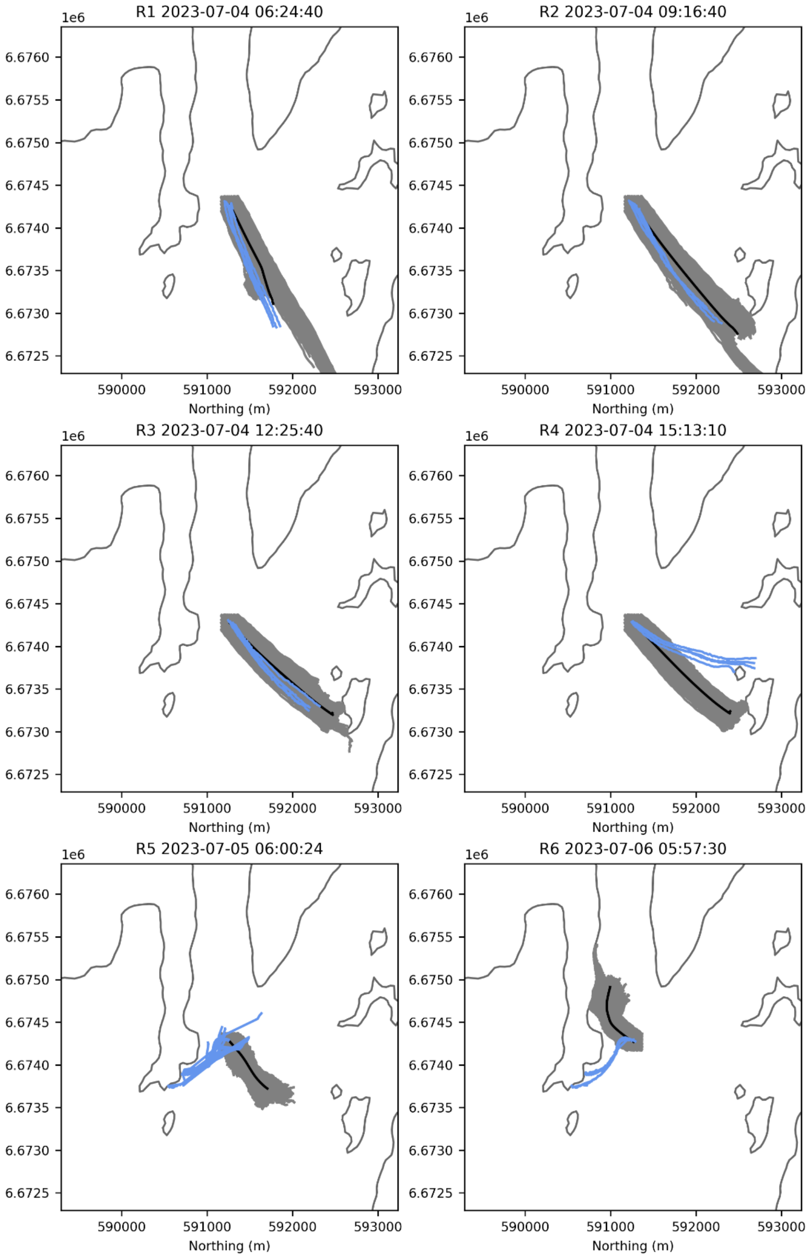

Figure 5.6: Observed drogue tracks (blue) plotted over model particle tracks (grey; mean track = black line), generated using hydrodynamic flow fields in conjunction with wind acceleration (reduced weighting).

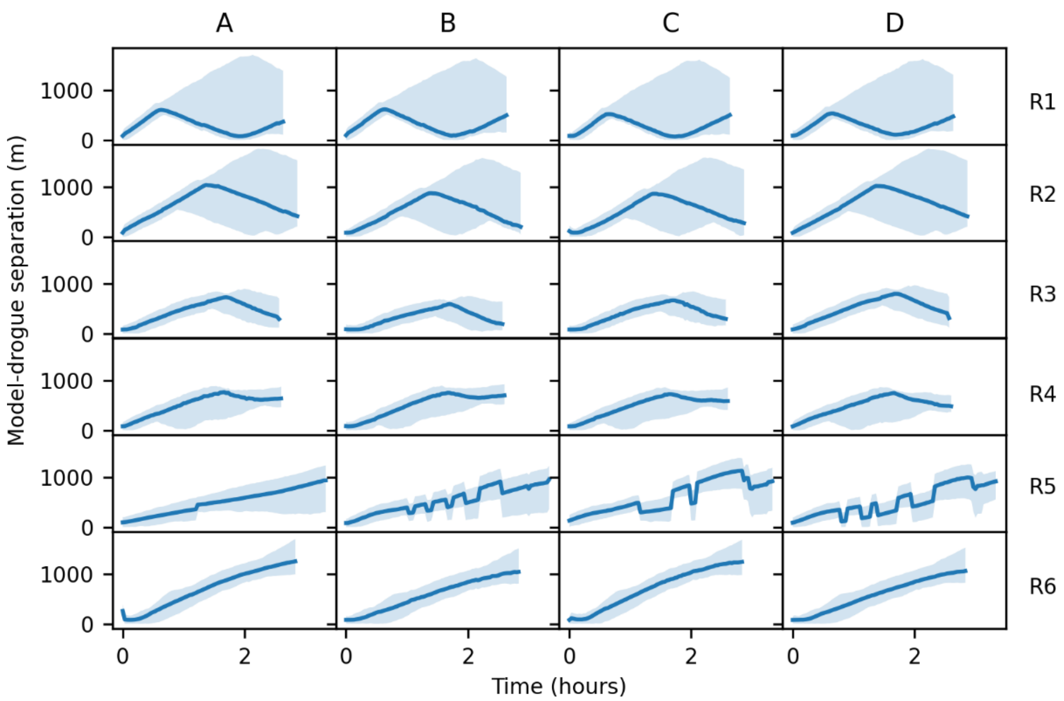

Figure 5.7: Separation between drogue position and particle trajectories, for each individual drogue (columns) within each release (rows), for the simulations including wind forcing with reduced weighting. The dark blue line indicates the median distance between model particles and the drogue, and the light blue shading indicates [5,95%] interval of distances.

6 Conclusions

It has been demonstrated that, given comparable wind forcing, model can represent flows observed in the current meter record quite well. The wind forcing was not identical for the model run periods and the current meter observation period, so it is unreasonable to expect a perfect match.

Match is good for near-surface and mid-depth flows, where most of the transport of released material will occur (baths: near-surface, deposition: during settling phase). There was a match in current speed at bed but mismatch in direction. Limited resuspension is expected due to current speeds in the locality, so this is not anticipated to affect HD PT deposition results unduly.

Comparison of model predictions against observed drogue tracks yielded generally good results, once wind forcing was incorporated into the particle model. It is notable that all observed drogue tracks moved outward from the bay (i.e. towards open water), even in cases where the model prediction was for inward movement. This should mean that predictions generated using the model are conservative with respect to dispersion within the bay.

7 References

Anderson Marine Surveys (2023) Billy Baa - Dye dispersion study.

Danish Hydraulic Insitute (2021) Shetland Aquaculture Modelling: Hydrodynamic Climatology Model.