VEANTROW BAY, SHAPINSAY, ORKNEY

Hydrodynamic Model Validation Report

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1 Summary

This report describes the appraisal of the North Orkney area hindcast hydrodynamic model against recent current meter observations that were collected outside the hindcast period to determine whether the former is suitable to use in impact assessment modelling of the proposed expansion at the Veantrow Bay fish farm.

2 Abbreviations

ATT	Admiralty TotalTide
DHI	Danish Hydraulic Institute
ECMWF	European Centre for Medium-Range Weather Forecasts
ERA	ECMWF Re-Analysis
HD	Hydrodynamic
ICAO	International Civil Aviation Organization
METAR	Meteorological Aerodrome Report
MSS	Marine Scotland Science
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 North Orkney area (Danish Hydraulic Insitute 2022). The model domain extended from the Moray Firth in the south to the Shetland Isles in the North, with the highest resolution areas focused on the Orkney Isles and in particular the focal site in Veantrow Bay (Figure 3.1, Figure 3.2).

Output from the hydrodynamic model was generated in two formats: 1) climatology simulation, based on 25 year averaged meteorological condition; and 2) “hindcast” simulation, driven using a specific time window of meteorological (ECMWF ERA5) and ocean boundary forcing, covering the period 01/06/2017-01/07/2018. 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 the proposed location in Veantrow Bay: i) a current meter deployment in 2023, and ii) a drogue study carried out at the proposed site location (Anderson Marine Surveys 2022).

The current meter record was also compared with outputs from the model driven using climatological forcing which demonstrated similar performance, however current direction was more tightly bidirectional compared to the broader range of directions seen in the hindcast and observations. Due to more favourable performance from the hindcast only these results are presented here.

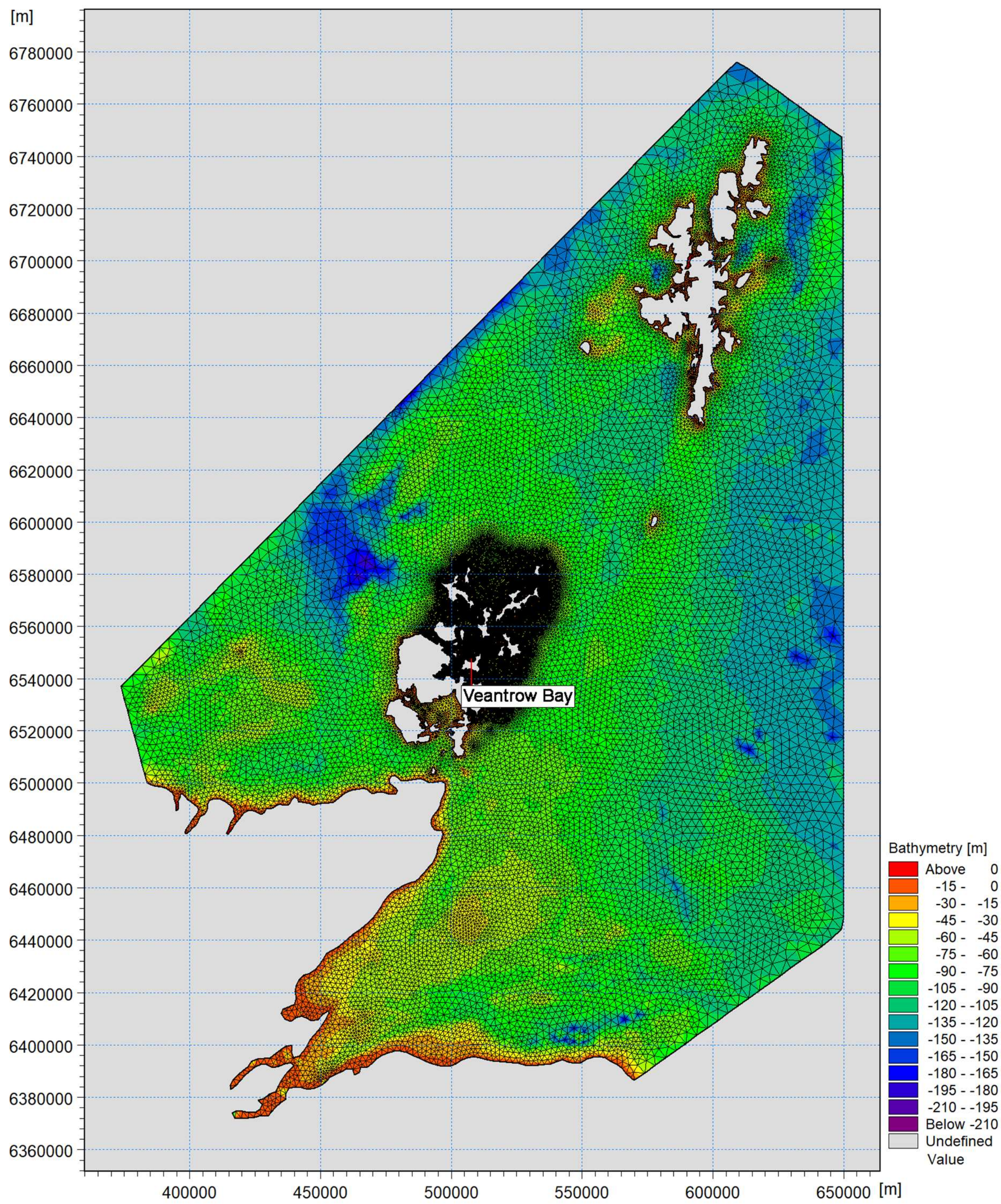

Figure 3.1: Computational mesh for the North Orkney hydrodynamic model showing the full extent of the spatial domain, which covers Orkney, Shetland, and a portion of the Scottish mainland coast. Resolution is highest around Orkney, in particular Veantrow Bay.

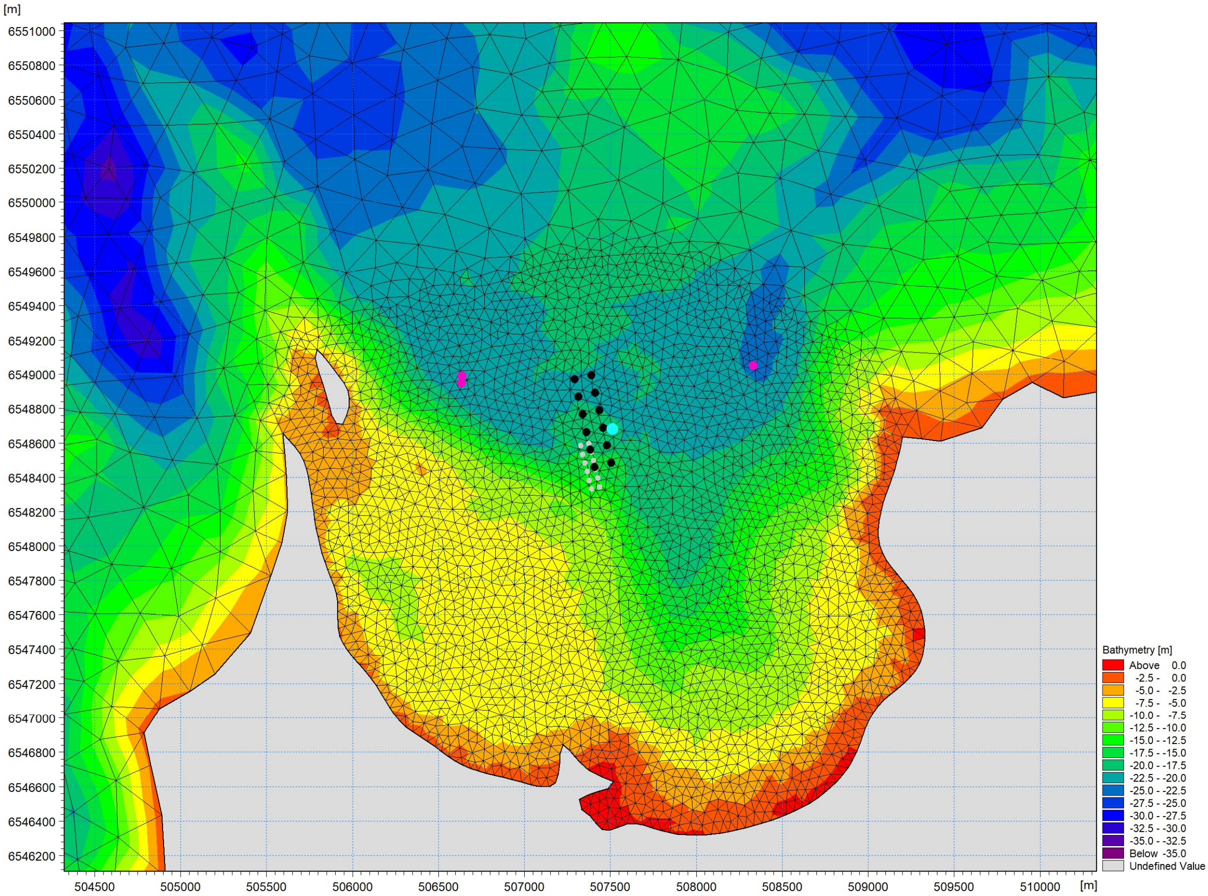

Figure 3.2: Close-up view of the computational mesh of Veantrow Bay. Existing validation current meter data sets used during the North Orkney hydrodynamic model build are indicated (magenta points), as well as the 2023 current meter deployment (cyan point), and the existing and proposed pens (grey and black points respectively).

4 Veantrow Bay current meter comparison

4.1 Meter/model temporal coverage

The current meter deployment for Veantrow Bay was made at OSGB [350293, 1021578], and covers the period 27/03/2023 - 30/06/2023 (cyan point in Figure 4.1). The model hindcast period covers the period 01/06/2017-01/07/2018. No direct comparison can be made between current meter and the model prediction. However, with a strong tidal influence apparent at this location (both modelled and observed), comparison of model output covering a period with similar surface elevation statistics to those seen during the current meter deployment will give insight into its ability to predict transport direction and speed adequately.

4.2 Identifying a suitable period

The predicted surface elevation for Egilsay from Admiralty TotalTide (ATT) software was extracted for the duration of the current meter record and for the hindcast run period. Comparison to the current meter pressure record demonstrated that the prediction for Egilsay is the closest match of the nearby secondary ports in terms of tide timing and range, as well as being the closest to Veantrow Bay. A single surface elevation was used to assess spring-neap tidal cycle patterns with respect to the timing of perigean spring tides to allow the tidal range for the candidate periods to be compared. This was then verified by comparing modelled surface elevation and observed depth.

Two candidate periods were identified during the hindcast run period with the second being the closest match (08/03/2018 11:00 +95 days, Figure 4.1, Table 4.1).

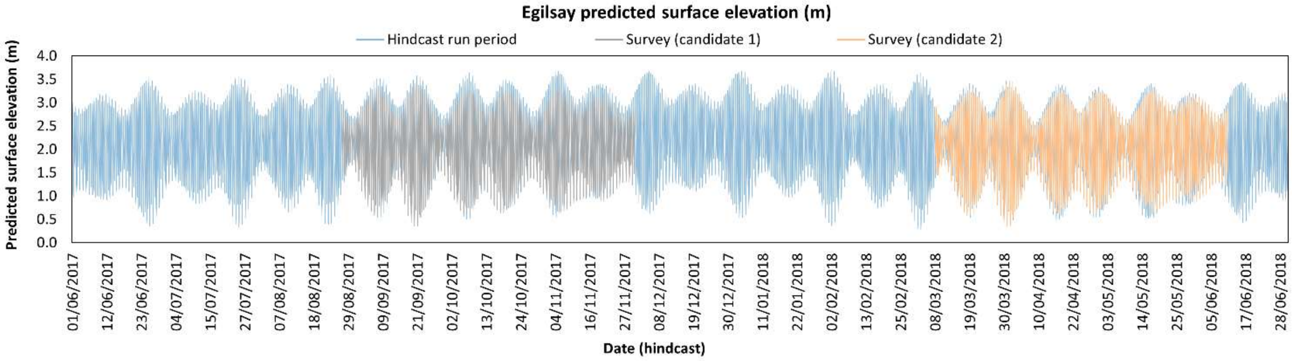

Figure 4.1: Egilsay predicted surface elevation for the hindcast model run period and the current meter deployment period (overlain) illustrating the candidate model periods for validation with the second (orange) being the closest match.

Table 4.1: Summary statistics for the 95 day predicted surface elevation at Egilsay for the current meter survey period and the most suitable equivalent candidate period from the hindcast run.

	Survey period	**Candidate hindcast period**
Start Date	27/03/2023 10:00	08/03/2018 11:00
End Date	30/06/2023 09:00	11/06/2018 10:00
Minimum (m)	0.35	0.34
Maximum (m)	3.46	3.46
Range (m)	3.11	3.12
Mean (m)	2.02	2.02

4.3 Wind statistics

The wind forcing used in the hindcast model will have some influence on current flow and direction therefore a comparison was performed between this for the model period selected on the basis of surface elevation and the weather conditions observed during the current meter deployment. Hourly wind data covering the duration of the hindcast run period, and the entirety of the Orkney 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 a speed and direction time series. Observations covering the current meter survey were sourced from archive METARs issued by Kirkwall Airport (ICAO code: EGPA) located 13.8 km south.

Wind roses and histograms of wind speed and direction are presented in Figure 4.2 and Figure 4.3 respectively. The ERA5 wind field forcing the model during the period shows similar characteristics to the winds observed during the survey with a dominance of winds from the southeast. During the current meter survey there was a greater proportion of winds from the west and fewer from the northeast than in those forcing the part of the hindcast model selected to best represent the survey. Velocities are also lower during the survey than when compared to the ERA5 wind field. However, this is also seen when METAR and ERA5 data from the same period are directly compared and likely relates to the resolution of the ERA5 data. An ERA5 grid cell represents approximately 385 km^2 at

10m above ground level and is not subject to local topographical modification by land features within that cell.

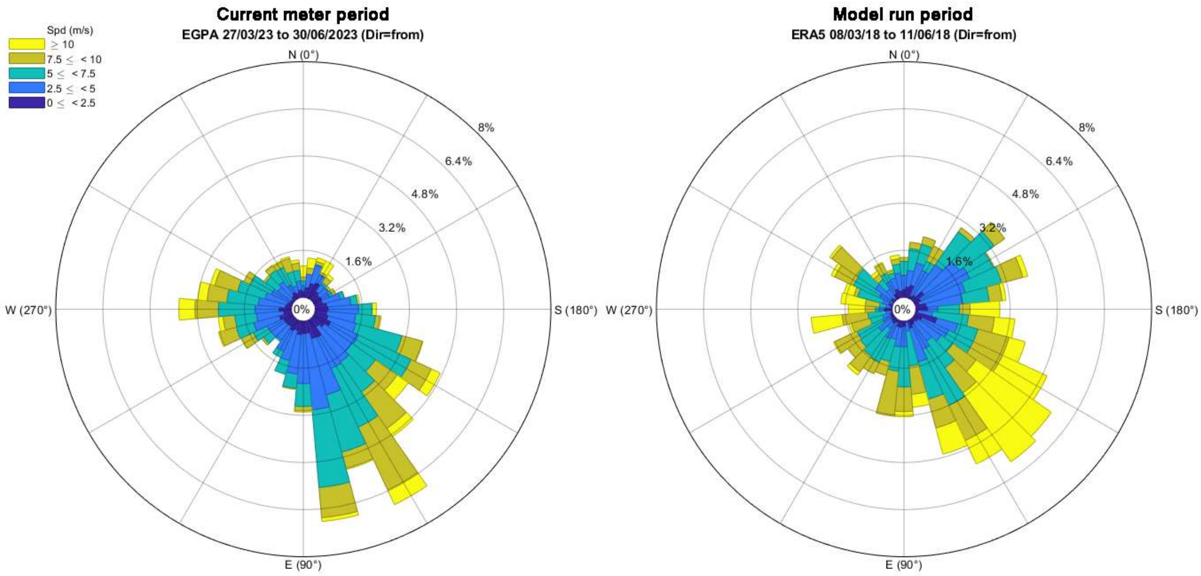

Figure 4.2: Wind roses showing speed and direction of wind observations at Kirkwall Airport (EGPA) during the current meter period (left) and the ERA5 data extracted for the selected model run period (right).

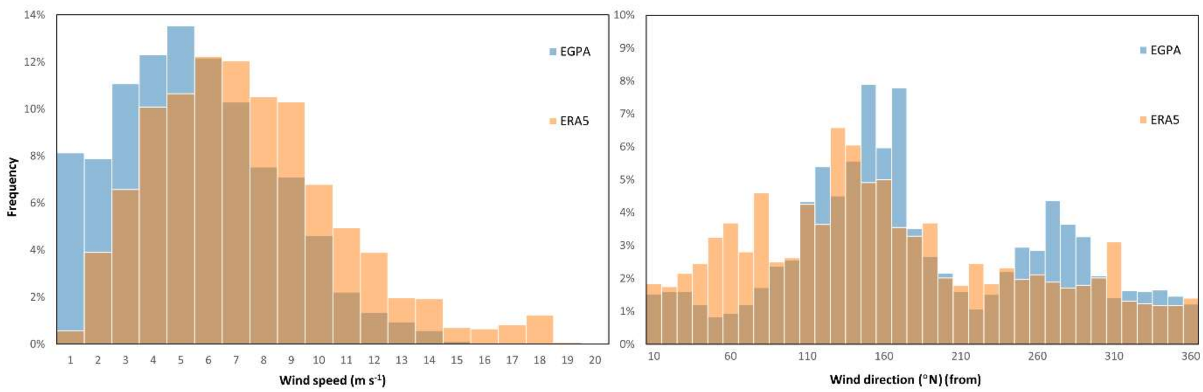

Figure 4.3: Histogram plots of wind speed (left) and direction (right) over the current meter observation period (blue, Kirkwall Airport (EGPA)) and selected model run period (orange, ERA5).

4.4 Hydrodynamic model/current meter comparison

4.4.1 Water levels

Distribution of water levels matched very well between the current meter observation and HD model extract for the location (Figure 4.4 & Figure 4.5).

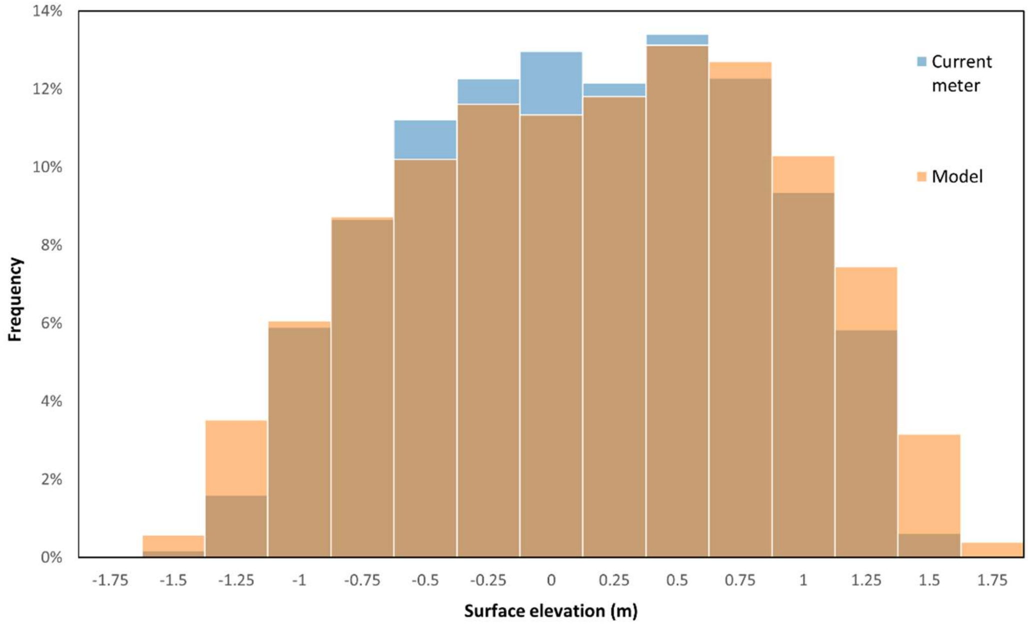

Figure 4.4: Water level comparison between current meter observation (blue) and HD model extract for the location (orange).

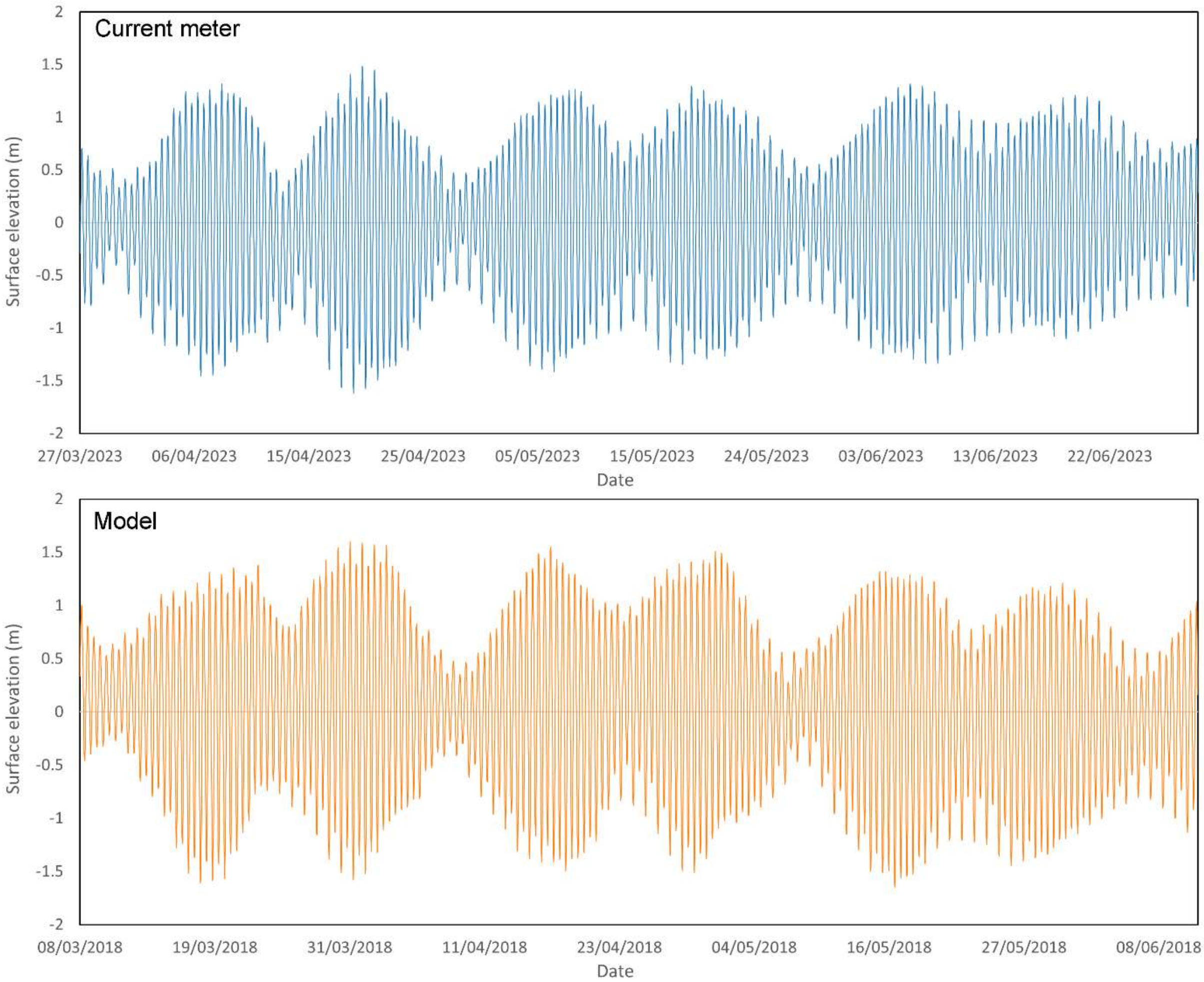

Figure 4.5: Surface elevation timeseries recorded by the current meter (blue), and for the selected model period (orange).

4.4.2 Water flow

A comparison of the current meter record (depth averaged flow) and the 2D model is shown in Figure 4.6 and Figure 4.7. Distribution of directions (right hand margin in Figure 4.7) is very similar with the observations having an axis closer to ESE than the model. The maximum speed in the meter record is around twice the maximum in the model, but such high velocities occur with very low frequency (top margin in Figure 4.7)

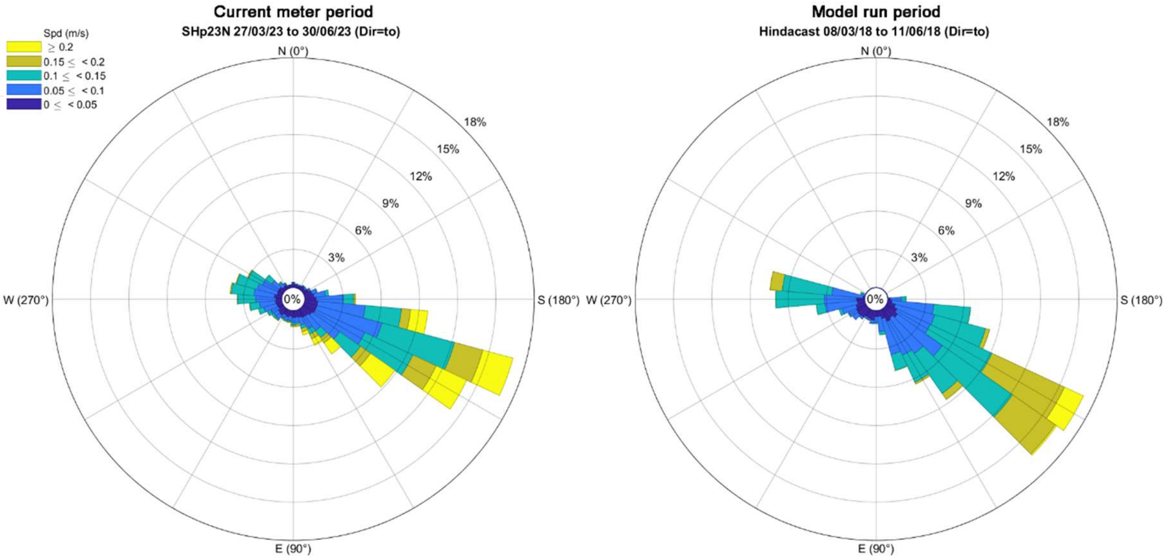

Figure 4.6: Current rose for current flows showing current meter observation (depth averaged, left) and model prediction for the selected period (right).

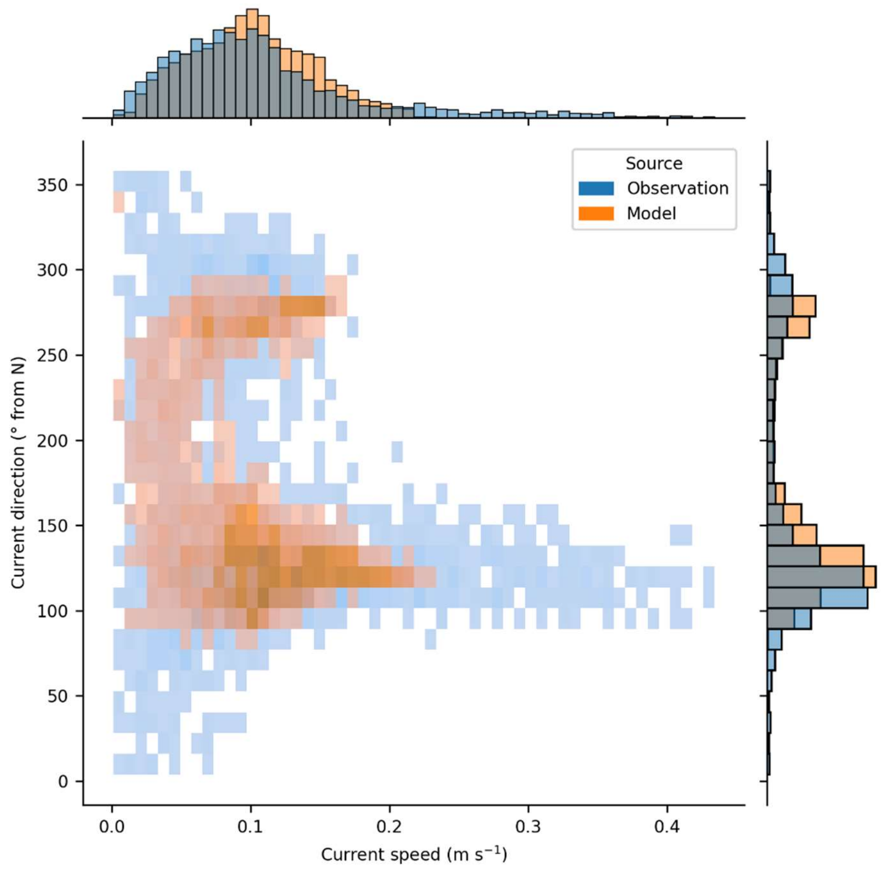

Figure 4.7: Histogram of speed versus direction for current meter observation (depth averaged, blue) and model prediction for the selected period (orange).

4.4.3 Progressive flow

Progressive flow vectors generated from the meter record and model extract are shown in Figure 4.8. The overall transport distance observed in the current meter record is very closely matched by the model. Both illustrate transport along a comparable vector with the model exhibiting a tendency closer to southward transport than the observation.

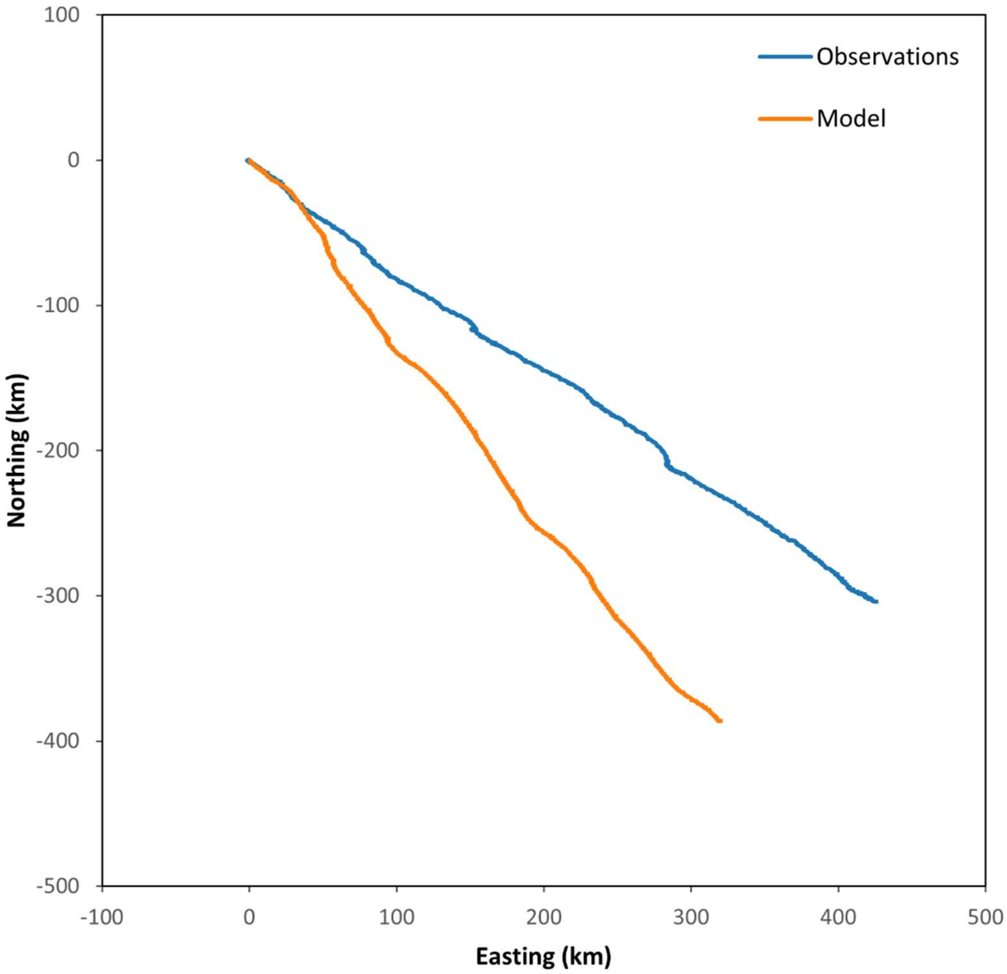

Figure 4.8: Progressive flow plot showing vectors generated from the current meter record (blue), and those from the model output (orange, lines matching direction from point (0,0) would indicate a good match).

5 Drogue comparison

5.1 Methods

5.1.1 Drogue release

Six drogue releases were made, each consisting of 4 drogues. The location of release was close to the focal site. Mean coordinates of all drogues released: x=350036, y=1021689 (OSGB 1936).

Table 5.1: Drogue releases made at the existing site location. Easting and Northing are the mean values for the 4 drogues used in each release. Range x and y indicate the distance (in m) on each axis between the extremes of the drogue release points.

#	Date	Start	End	Easting	Northing	Range x	Range y
1	05/07/2022	10:09:11	11:53:11	349956	1021694	42.56	59.75
2	05/07/2022	12:35:20	14:25:20	350017.8	1021709	71.26	61.54
3	05/07/2022	14:43:30	16:05:30	350020.4	1021693	25.03	33.75
4	05/07/2022	16:12:30	17:46:30	349976.9	1021732	19.05	46.54
5	07/07/2022	07:19:26	10:31:26	350131.2	1021655	51.36	20.4
6	07/07/2022	10:56:35	12:46:35	350116.3	1021655	122.37	10.95

5.1.2 Model simulations

An additional hydrodynamic model simulation was carried out for the period 30/06/2022-19/07/2022 (excluding initial run-up/burn-in period), which covers all drogue releases listed in Table 5.1. All hydrodynamic model parameters, and the source for initial conditions and boundary conditions, matched those of the hindcast model used for the main hydrodynamic model calibration/validation (Danish Hydraulic Insitute 2022).

To mimic the drogue releases, particles were released within the hydrodynamic model current field. For each drogue release, 10,000 model particles were released with a random start location within a 200 m side square centred on the mean drogue release location. Particle starting depth was 2 m below the surface. Hydrodynamic model current fields are 2D, negating any impact of changes in particle depth. The particle tracking model was run using a 30 second time interval, with the baseline release time being the nearest 30 second increment to the actual release time.

Simulations were made using the actual release time, in addition to 15 minute increments up to 1 hour before and after the actual release time, to check for possible offsets in tidal phase. Initial simulations were made omitting direct effects of wind. Additional simulations were carried out including wind, with a weighting (proportional contribution to particle transport velocity) of 0.1 (MIKE default), 0.02 and 0.01.

5.2 Results

As suggested by the current meter record and the hydrodynamic model outputs, the existing site location has relatively low tidal flow. Several of the drogue releases did not travel far from their start location. The observed drogue movements and associated model predictions are summarised in Table 5.2.

Models omitting wind

Particles in models omitting wind travelled further than the observed drogues in some cases (R1, R3, R4) and a shorter distance than the drogues in other cases (R2, R5). Direction was well represented in those trajectories where significant drogue transport was observed (R2, R5, R6) (Figure 5.1, Figure 5.2)

Observed drogue movements were best matched using an offset in model particle release time, with +/-45 minute releases matching observed patterns best in different cases (-45 minute being the best overall). The effect of an offset was particularly noticeable in the models without wind forcing. Shifting the model release to an earlier time (45 minutes earlier, as in the best fitting simulation for the proposed site) yields an improved representation of the drogue tracks in releases R3 and R6. Directional representation for R2 and R6 is maintained, with a reduction in magnitude/distance match for R6. R1 and R4 remained poorly represented (not shown).

Shifting the model release to a later time (45 minutes after the actual drogue release) yielded an improvement in magnitude/distance of transport for R5, the strongest moving drogue release. Match of R2 was lost for this simulation. Direction of R1 match was better than the other models, but distance travelled was too high. R4 was better represented here than for the other models, but distance travelled was still too high. R3 remained poorly represented, and match to R6 was similar to the baseline simulation (not shown).

Models including wind

Models including wind with the default weighting resulted in particles moving further than the actual drogues in most cases (not shown). However, they improved the representation of travel direction overall, although there was a tendency to transport to be offset slightly anti-clockwise in comparison with the observed tracks (most notable in R2, R5 and R6). The models including the effect of wind with a reduced weighting (0.01 of overall velocity derived from wind vectors) generally matched the drogue movements best, with an offset of -45 minutes again offering a slight improvement over particle releases at the exact moment of the drogue release (Figure 5.3, Figure 5.4).

Table 5.2: **Summary of drogue releases and model comparisons.**

Release	Drogue movement	Model no wind	Model wind (weighting 0.01)
R1	Weak SE	All models go too far south.	Direction correct, distance grater in model.
R2	Fairly strong ESE	Direction good. No models go as far as drogues. -45min is closest to magnitude of distance.	Direction closer to E. Distance approximately correct (best with 0min).
R3	Weak E	Only the -45min model release gets close to the drogues, otherwise model tracks are in the opposite direction.	Approximately correct direction (with -45min) and distance.
R4	Limited	Models go too far NE. +45min is closest to the drogues.	Direction correct, distance greater in model.
R5	Strong E	No models go far enough. +30/45min are closest.	Direction slightly N of drogue, distance correct with -45min.
R6	SE	Model distance OK, direction is too far south, get closer as shift earlier in time. -45min closest.	Direction initially good, distance in model greater.

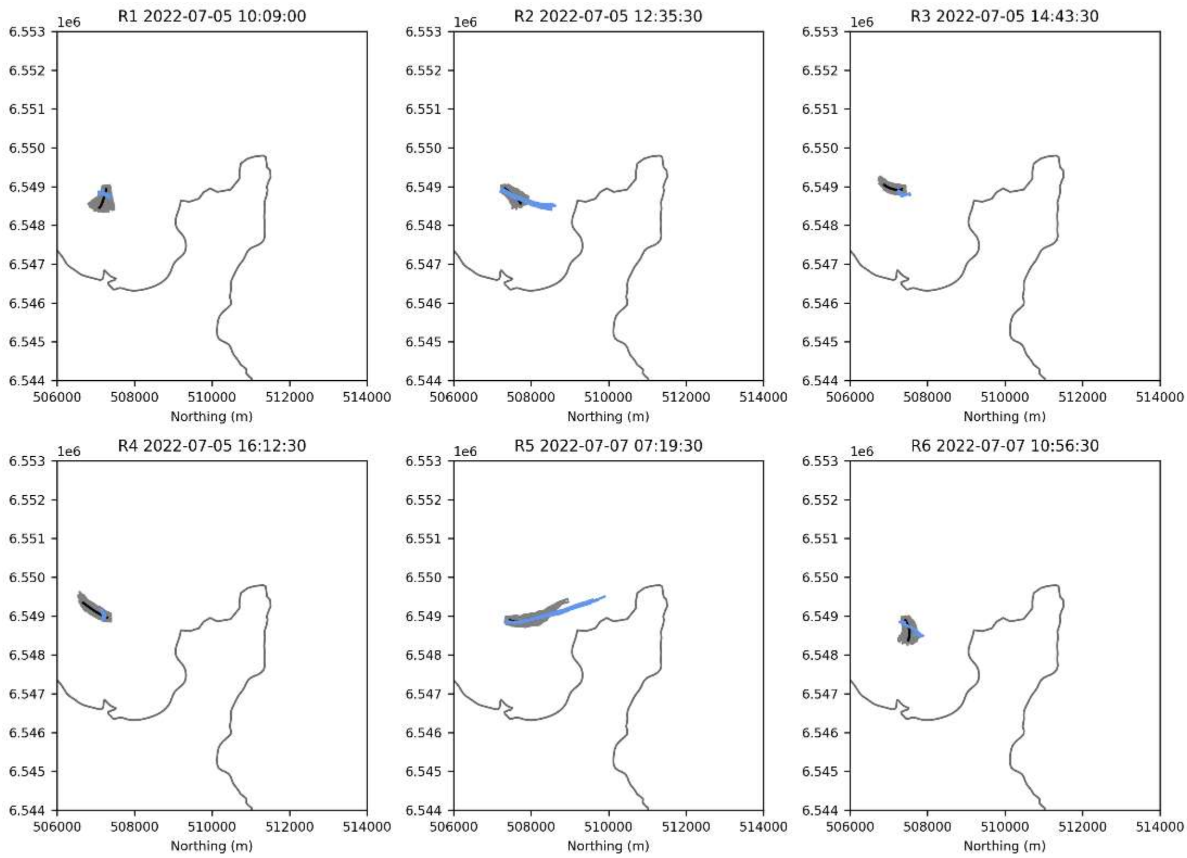

Figure 5.1: No wind, no time offset. Drogue tracks (blue) overlaid on a sample of 100 model particle tracks (grey), and the mean of all model tracks for that release (black).

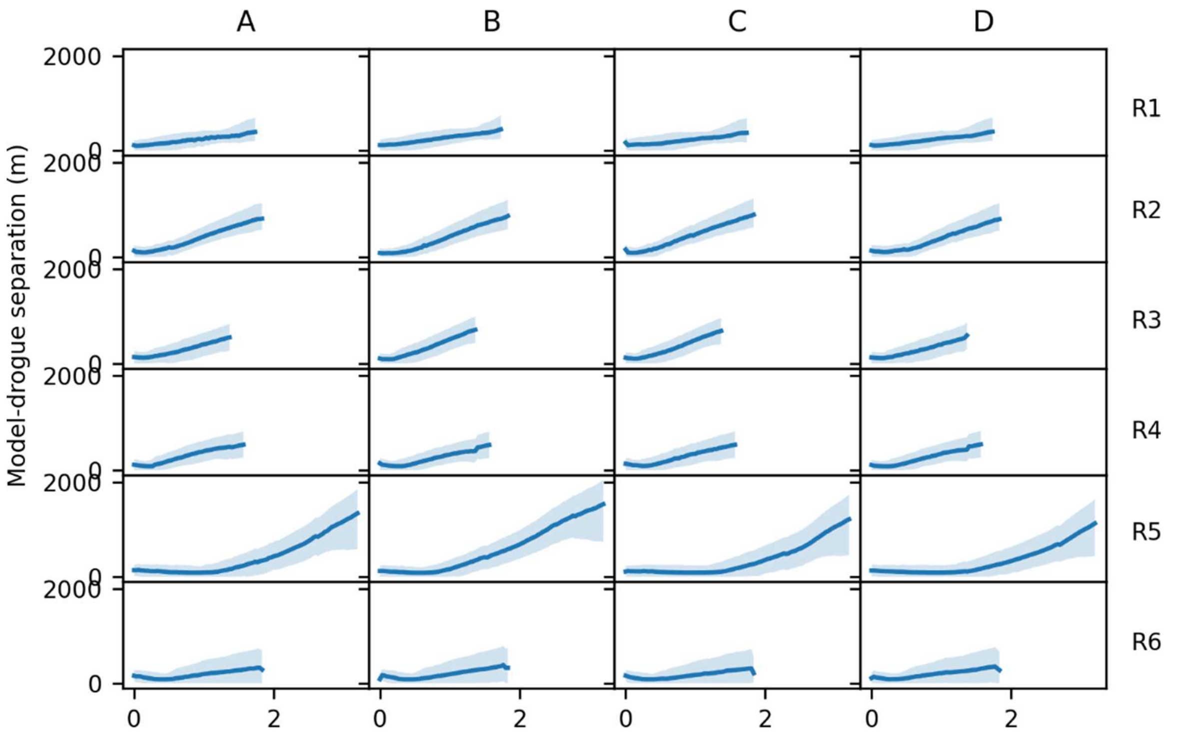

Figure 5.2: No wind, no time offset. Distance between model particles and each drogue (columns A-D) within each release (rows R1-6). Dark blue line indicates the median particle distance to the specific drogue, light blue shading indicates minimum and maximum distance.

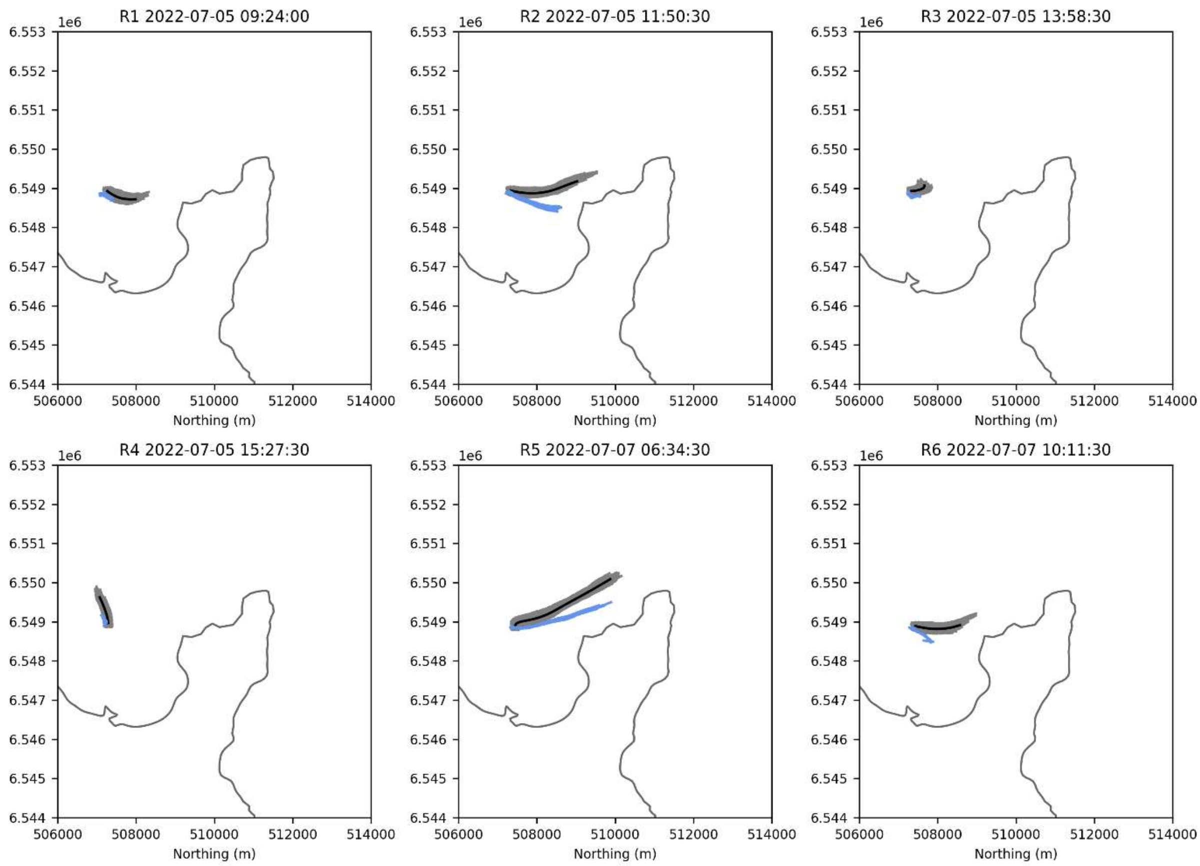

Figure 5.3: Wind (weighting 0.01), simulation release 45 minutes earlier. Drogue tracks (blue) overlaid on a sample of 100 model particle tracks (grey), and the mean of all model tracks for that release (black).

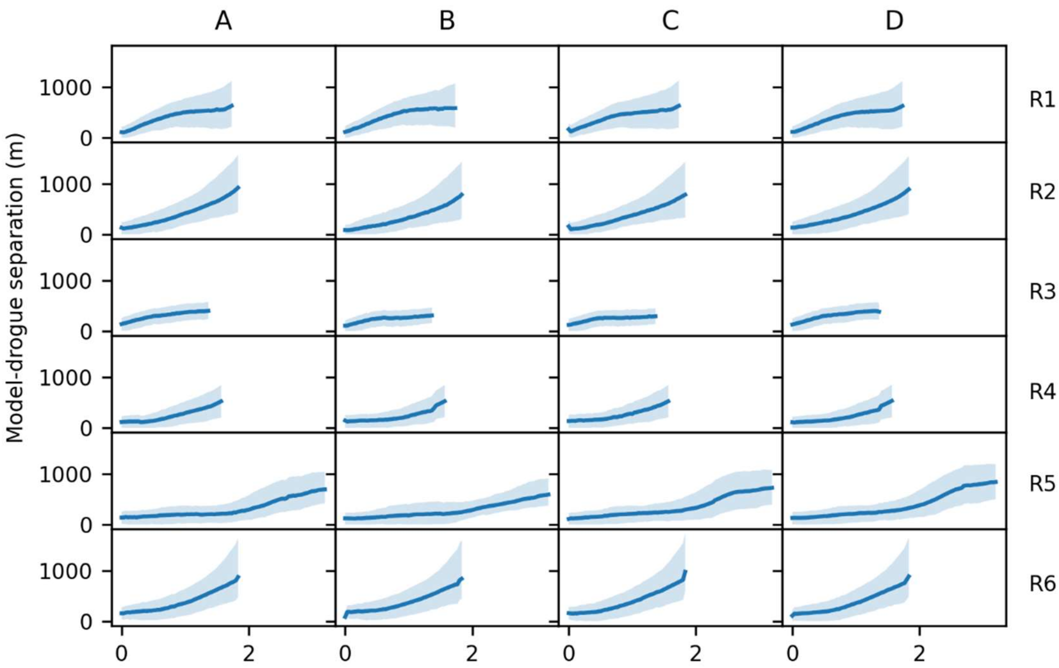

Figure 5.4: Wind (weighting 0.01), simulation release 45 minutes later. Distance between model particles and each drogue (columns A-D) within each release (rows R1-6). Dark blue line indicates the median particle distance to the specific drogue, light blue shading indicates minimum and maximum distance.

6 Summary

A hydrodynamic model developed for the focal site was tested for its ability to match current meter and drogue observations. As the period covered by the hydrodynamic model did not match that of the current meter record, a process of selecting a time window with comparable tidal forcing and wind was carried out, following which validation of model currents against the current meter was made.

The model provided a good representation of the water movements observed in the current meter record, with a comparable spread of current speed and direction. The model did not capture the highest velocities seen in the current meter record, but these occur with a very low frequency, and this therefore did not have an impact on predicted transport distance when measured using progressive vectors, which matched very closely in magnitude between model and observation.

A particle tracking model omitting wind and using default settings obtained a reasonable match to the drogue track directions in those cases where significant tidal transport was observed, but underestimated transport distance. Including the effect of wind (with a low weighting) broadly improved the presentation of both transport distance and direction, though some differences between model and observation remained, particularly in the cases of low drogue transport.

Another drogue release was made at a different location in the bay (several hundred metres to the north-east) at which much stronger tidal currents are found. In this case the particle tracking model matched the movement pathways of the drogue observations very well (not shown).

7 References

Anderson Marine Surveys (2022) Shapinsay, Orkney - Dye dispersion study.

Danish Hydraulic Insitute (2022) North Orkney Aquaculture Modelling: Hydrodynamic Climatology and Hindcast Model.