Hydrodynamic Model Validation Report

Fish Holm, Shetland

Report to:	Scottish Environment Protection Agency
Version:	1.1
Date:	13 January 2025

Scottish Sea Farms Ltd
Barcaldine Hatchery
Barcaldine
Oban
Argyll PA37 1SE
Email: modelling@scottishseafarms.com

1 Summary

This document details the validation of hydrodynamic model output at the proposed Fish Holm 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 allow 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 and methods

Output from the DHI-SSF East Shetland model (Danish Hydraulic Institute 2023) was validated against a current meter observation collected at the Fish Holm site (SSF current meter record N008, covering period 21/04/2022-25/07/2022, included in the above report), with the objective of understanding whether this model output would be suitable for marine modelling impact assessments at the Fish Holm site. Verification of water levels and current speeds for this model against the Scottish Shelf Model has already been presented in the original project report (Danish Hydraulic Institute 2023).

Two periods of output from the model are available at the present time: i) a hindcast period, based on tide and meteorological forcing covering 16/05/2021-01/08/2022, and ii) a climatology year 01/01/1993-31/12/1993, based on 25 year average meteorological conditions. Underestimates of current speed at several locations during earlier work by DHI led to the decision for boundary velocities to be doubled in the final version of the hindcast model; this is the version reported on in the DHI report. Pre-application communication with SEPA indicated a preference not to use the hindcast output for the purposes of impact assessment, due to potential overestimates of current velocities more broadly across the domain.

The broad scale behaviour of the climatology model was verified against outputs from the Scottish Shelf Model at a number of locations around the Shetland archipelago in the original model report (Danish Hydraulic Institute 2023). This report assesses the flow statistics of the climatology model output in relation to meter data collected at the Fish Holm site.

As the model output covers a climatological year, it is not representative of any specific time window and cannot be compared point-for-point against the current meter record. Generated model outputs were therefore summarised statistically for verification against comparable metrics calculated from the current meter record. This included:

- Histograms of surface elevation, current speed and direction for sub-surface, cage-bottom and near-bed meter bin depths (based on full model year at specified location);

- Rose plots of current speed and direction for sub-surface, cage-bottom and near-bed meter bin depths (based on full model year at specified location);
- Progressive flow plots for meter and model at sub-surface, cage-bottom and near-bed meter bin depths (period of model extraction matching duration of meter record);

Scatter plots and timeseries were not generated as no direct correspondence between values is possible.

The current meter data used for the comparison presented in this report were detailed in a separate hydrographic report, previously approved by SEPA (Scottish Sea Farms Ltd 2023). The data used was deployment N008, date: 21/04/2022-25/07/2022, location: 448317E 1173770N (OSGB).

Unless otherwise stated, statistics relating to the model within this section are based upon using the full climatology year, while statistics relating the current meter relate to the time window over which the deployment was carried out. Histograms and current roses are normalised appropriately to the period covered.

Additionally, drogue movements from the site were compared against modelled drogue releases in the model. For this purpose, model releases were made at times within in the tidal cycle that corresponded with the state of the tide at actual release. As the climatology model lacks variation in meteorological conditions, wind forcing was included in the drogue simulations via direct definition of wind speeds derived from meteorological observations covering the empirical drogue release window, and tuning of the wind drag parameter.

4 Results

4.1 Surface elevation

Distribution of surface elevations observed in the meter record was matched well by the model, with only a slight tendency to a wider spread of elevations seen in the model output (Figure 4.1).

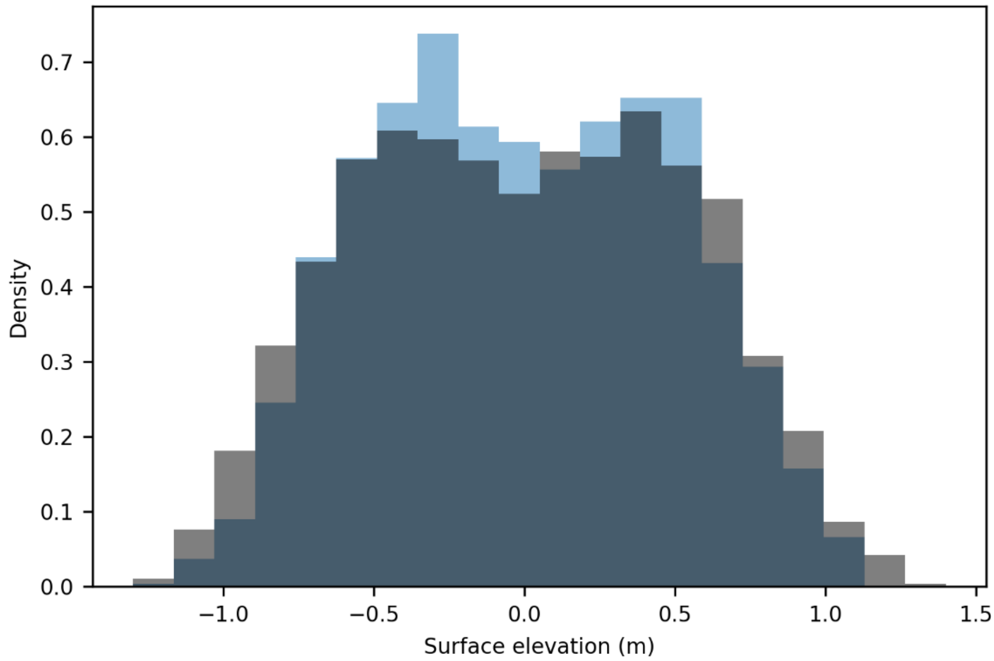

Figure 4.1 Surface elevation observed in the current meter record (blue) and in the model prediction for the same location (grey). Darker grey/blue shading indicates overlap of distribution.

4.2 Current speed and direction

4.2.1 Sub-surface

In the sub-surface, both meter and model indicate a dominance of flow to the northwest, out of the enclosed waterbody and into the more dynamic environment of Yell Sound.

The most frequently occurring current speed is almost identical in the observation and the model output. However the model overpredicts occurrence of lower current speeds, and underpredicts occurrence of high current speed in relation to the observation (Figure 4.2 a).

The climatology model generally provides a good representation of current direction, with the same dominant direction, and similar spread across the other directions (slight underrepresentation of currents towards the east; Figure 4.2 b and Figure 4.3).

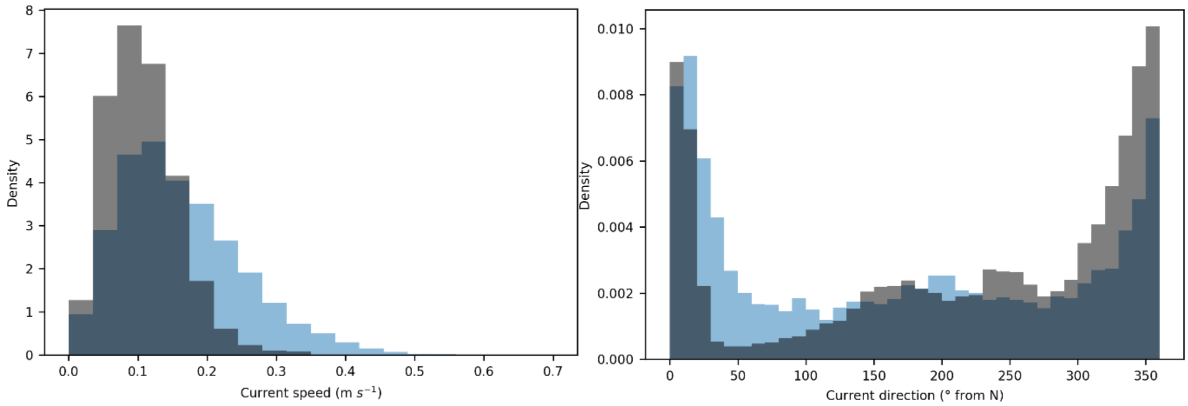

Figure 4.2 Sub-surface current (a) speed and (b) direction. Observation: blue, model: grey. Overlap indicated by darker region.

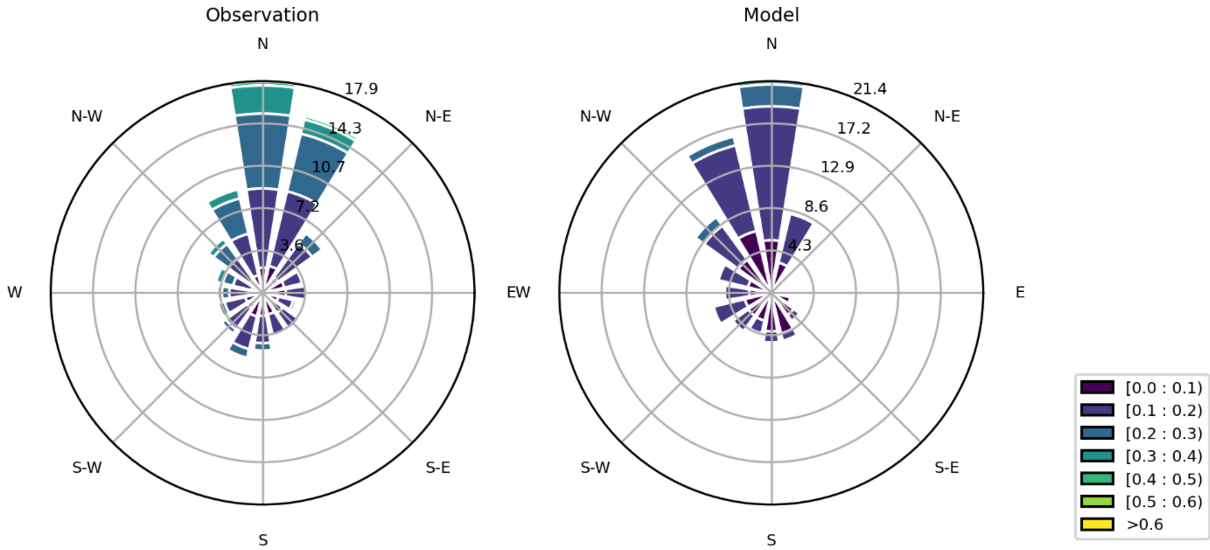

Figure 4.3 Sub-surface current roses, indicating the speed and direction of flow at this location in the observation (left) and model (right).

4.2.2 Cage-bottom

Currents at the cage-bottom tell a similar story to those at sub-surface: most frequent (modal) speed is the same in the observation and model, but fast speeds are underrepresented in the model (Figure 4.4 a).

The model predicts a similar dominant direction to the observation, but is more focussed on flow in the north-west direction than the observation, again with an underrepresentation of flows in an easterly direction (Figure 4.4 b and Figure 4.5).

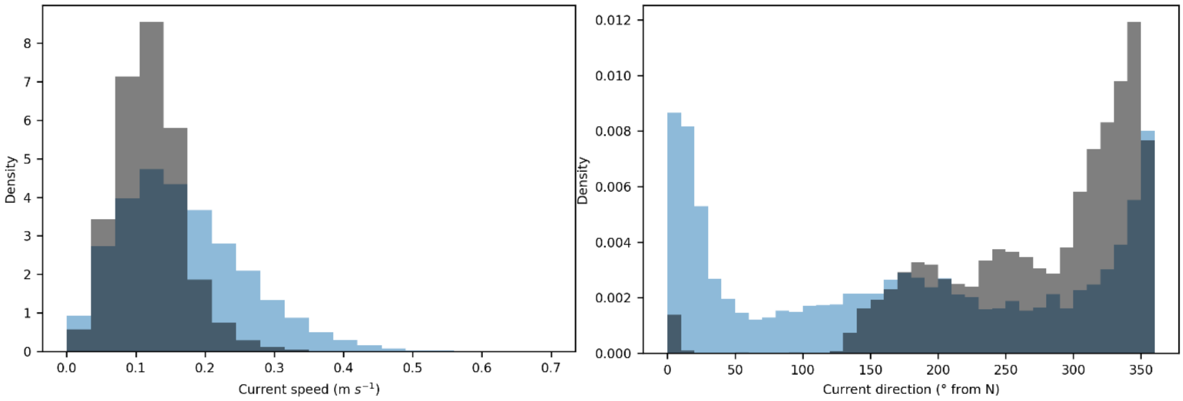

Figure 4.4 Cage-bottom current (a) speed and (b) direction. Observation: blue, model: grey. Overlap indicated by darker region.

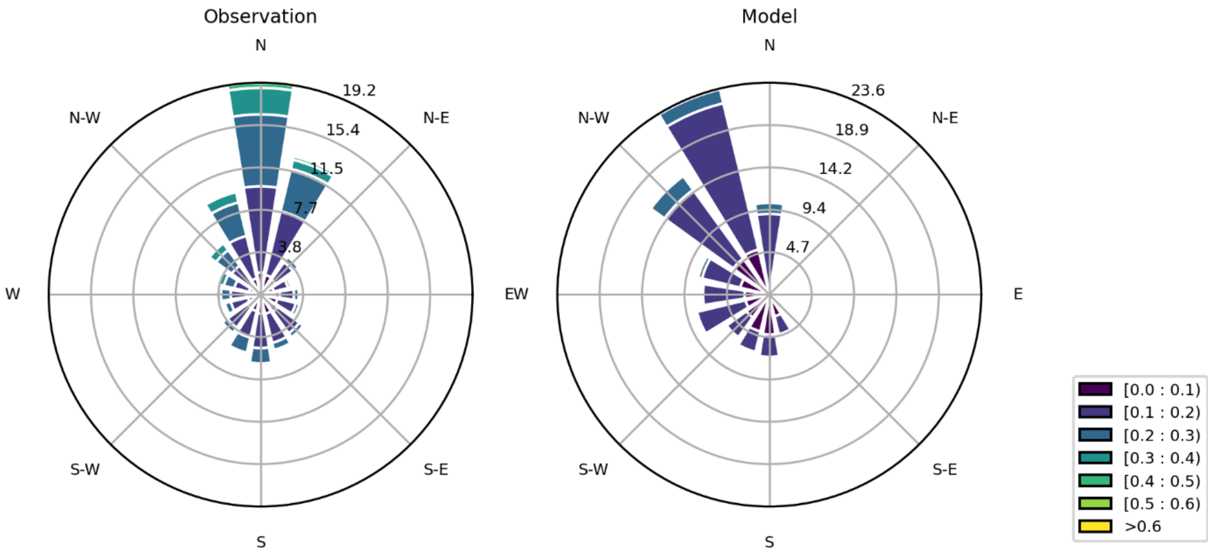

Figure 4.5 Cage-bottom current roses, indicating the speed and direction of flow at this location in the observation (left) and model (right).

4.2.3 Near-bed

Model currents at the near-bed are more closely matched to the observation than at other depths: most frequent (modal) speed is the same in the observation and model, and fast speeds are underrepresented to a smaller degree (Figure 4.6 a).

Current direction in the observation is more uniformly spread at the bed than at the other depths, although flows to the north-west still dominate. This model direction is matched by the model, but the full spread of current directions (particularly to the east) is not fully represented (Figure 4.6 b and Figure 4.7).

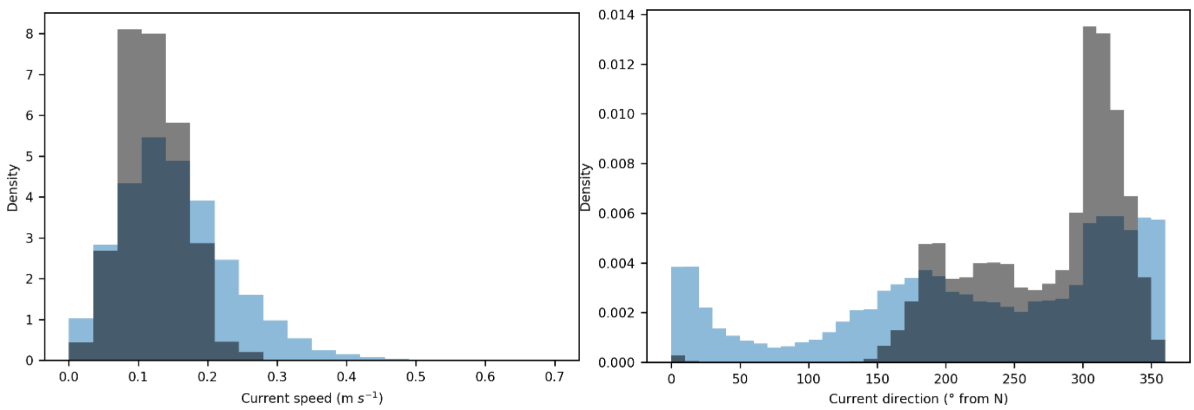

Figure 4.6 Near-bed current (a) speed and (b) direction. Observation: blue, model: grey. Overlap indicated by darker region.

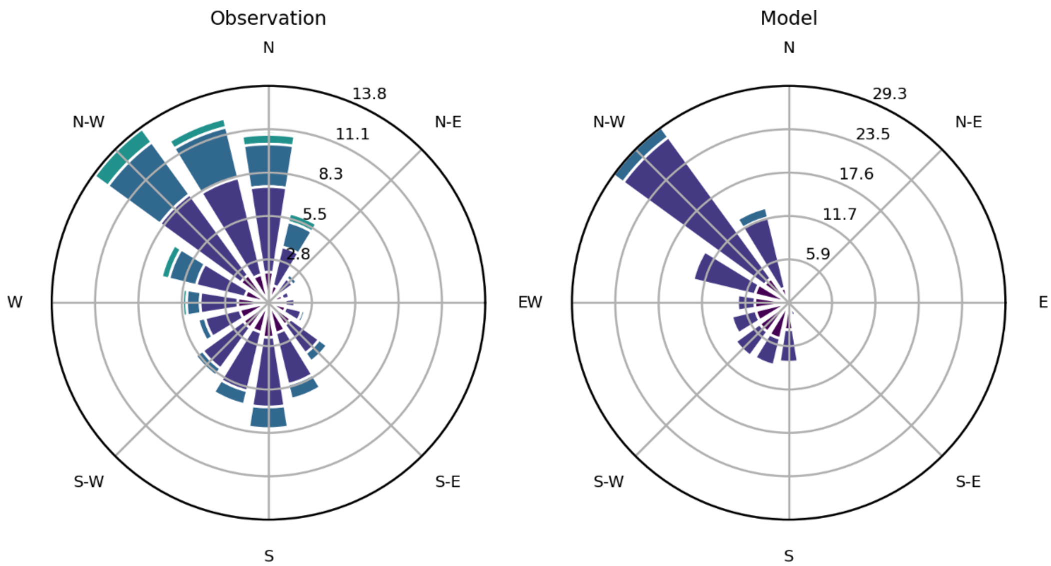

Figure 4.7 Near-bed current roses, indicating the speed and direction of flow at this location in the observation (left) and model (right).

4.3 Progressive flow (all depths)

Progressive flow vectors indicate the cumulative effect of the current speed and direction values presented in the previous plots.

Although the model underrepresented the highest flow speeds, the overall cumulative vectors are of comparable lengths in the model and the observation. The observed vectors are oriented in a northerly direction for the sub-surface and cage-bottom records, and to the north-west for the near-bed record. The model has a tendency to predict vectors in a more westerly direction than the observation, although the broad direction is quite similar at near-bed (Figure 4.8).

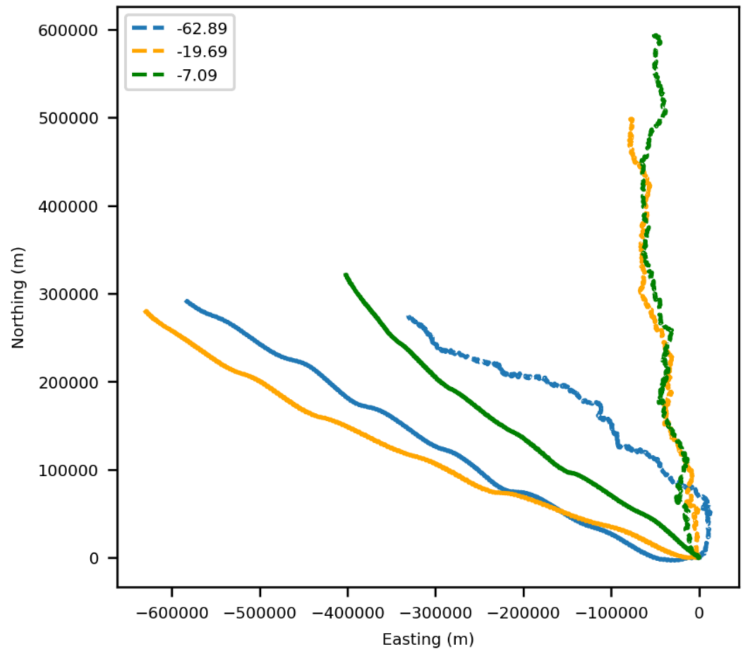

Figure 4.8 Progressive flow vector plot, indicating the cumulative effect of flows at this location in the observation (dashed lines) and model (solid lines).

5 Drogue assessment

5.1 Drogue release

A drogue release study was conducted at the proposed site location from 22-24 April 2024 by Anderson Marine Surveys. This is described in detail in a separate report (Anderson 2024).

5.2 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. An extract was made from the ERA5 weather model hindcast covering the period of the drogue study and the area of interest. Wind statistics were derived from the nearest grid cell within the downloaded data file.

The conditions likely to have been present at the time of the actual drogue releases in April 2024 are indicated in Figure 5.1 (wind) and Figure 5.2 (surface elevation). The conditions at the time of the drogue deployments were of fairly strong northerly winds, between 8-10 m s^{-1}.

Tidal phase during the drogue releases was replicated by choosing a matching date (albeit with a nominal year of 1993) from the climatology output, and shifting releases by +1 hr from their actual times (Figure 5.3).

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 (Stokes drift, using default MIKE parameters, and the approximate observed wind speed/direction during the drogue releases;
3. As 2., but reducing the “wind weight” parameter to 0.05 (50% of its default value).

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

Wind conditions for simulation sets 2 and 3 were implemented as a constant speed and direction for each drogue simulation, set within the MIKE PT module using the “surface wind acceleration” drift profile. A summary of the release times and wind forcing conditions used is given in Table 5.1.

Table 5.1 Summary of drogue study and model drogue releases, in addition to wind conditions applied for each simulation.

Release	Release time (actual)	Release time (model)	Wind speed (m s^{-1})	Wind direction (FROM °)
1	13:35 22/04/2024	14:35 22/04/1993	9	13
2	14:55 22/04/2024	15:55 22/04/1993	9.25	13
3	07:04 23/04/2024	08:04 23/04/1993	9.8	357
4	08:23 23/04/2024	09:23 23/04/1993	9.8	359
5	09:48 23/04/2024	09:48 23/04/1993	9.2	359
6	11:36 23/04/2024	12:36 23/04/1993	10	355
7	05:39 24/04/2024	06:39 24/04/1993	8.3	354

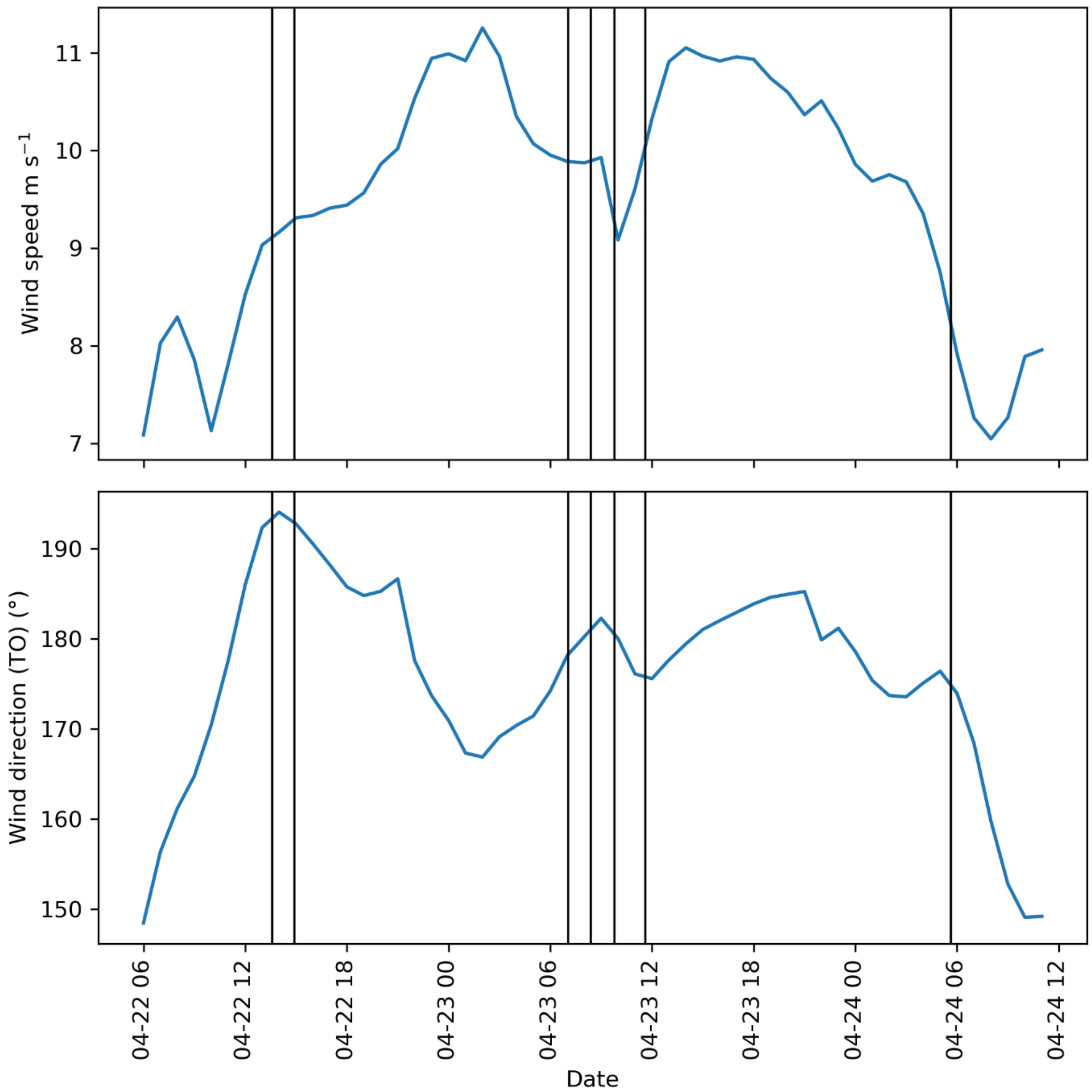

Figure 5.1: Wind speed and direction during the period of the drogue releases at Fish Holm in April 2024. Vertical lines indicate the times of the drogue releases.

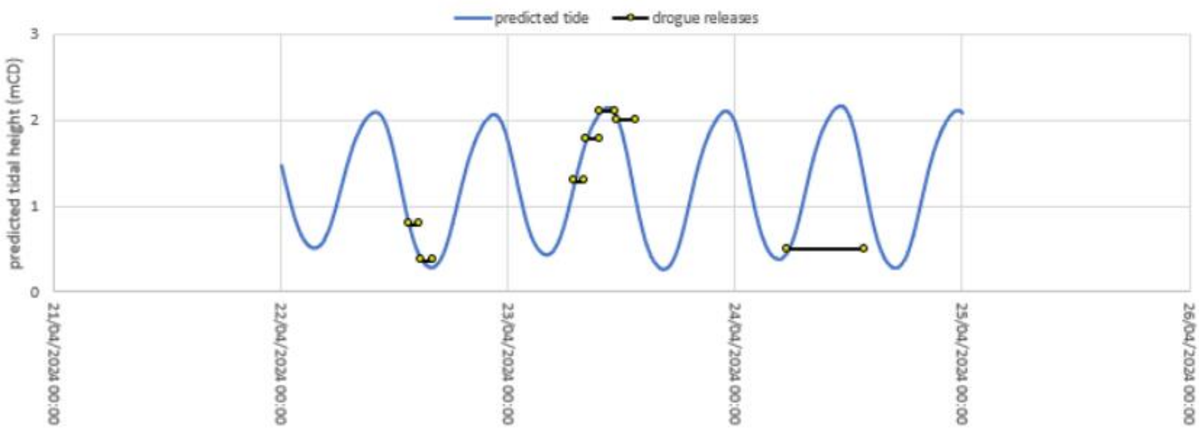

Figure 5.2: Tidal phase during the period over which drogues were released by Anderson Marine. Horizontal bars indicate the duration of drogue releases (duplicated from Anderson Marine report). Surace elevation in this plot is given relative to Chart Datum.

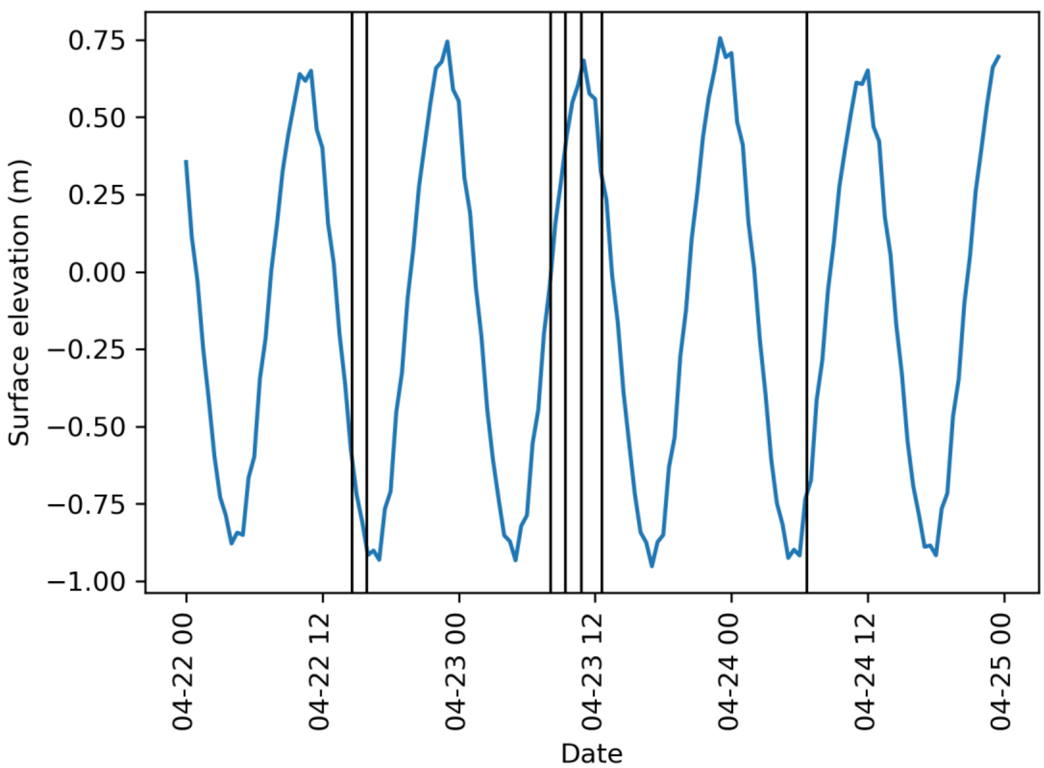

Figure 5.3: Period of the climatology hydrodynamic model run used to match conditions of drogue releases 1-5 as closely as possible. The vertical black lines indicate the release times used in the simulation (1-7 in order left-right), which used the same dates (but with a nominal year of 1993) and times as the actual releases, with an offset of +1 hr to match tidal phase on the previous plot. Surface elevation in this plot is given relative to Mean Sea Level.

5.3 Track comparison

Particle tracks generated using the information contained in the hydrodynamic fields alone captured the patterns demonstrated by drogue tracks to varying degrees.

Broadly speaking, transport distances were well matched between drogue observations and model predictions. For the first two releases, transport was in roughly the correct direction (SW), but the model transport was closer to W than the observation. For releases 3-5, the model's prediction of transport was close to the observation, particularly for 3 and 4. For release 5, initial transport was correct but over time the model diverged completely from the observation. For releases 6 and 7, observed transport was to the south, but the model prediction was towards the north (Figure 5.4).

Particle movement patterns predicted by the model were fairly insensitive to adjustments in particle release time. In particular, changing release time did not improve the representation of those tracks where there was an unpredicted southerly transport.

Incorporating a wind forcing component into the model yielded predicted drogue trajectories that were generally oriented towards the south or southwest, even for the cases where observed trajectories did not move in this direction (Figure 5.5). Reducing weighting did not improve the match in transport direction. This suggests that obtaining a better match for this specific drogue release may not be possible using the climatological flow patterns, and would require the use of a specific hindcast simulation incorporating a more precise representation of the interaction between winds and tide.

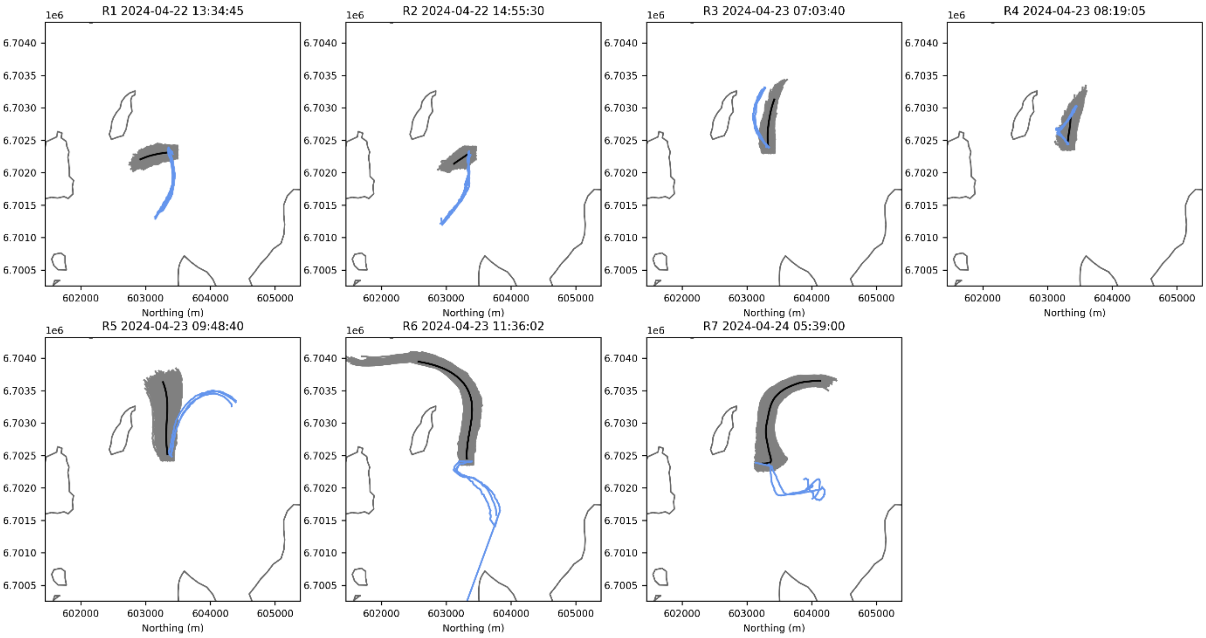

Figure 5.4: Observed drogue tracks (blue) plotted over model particle tracks (grey; mean track = black line), generated using hydrodynamic flow fields alone.

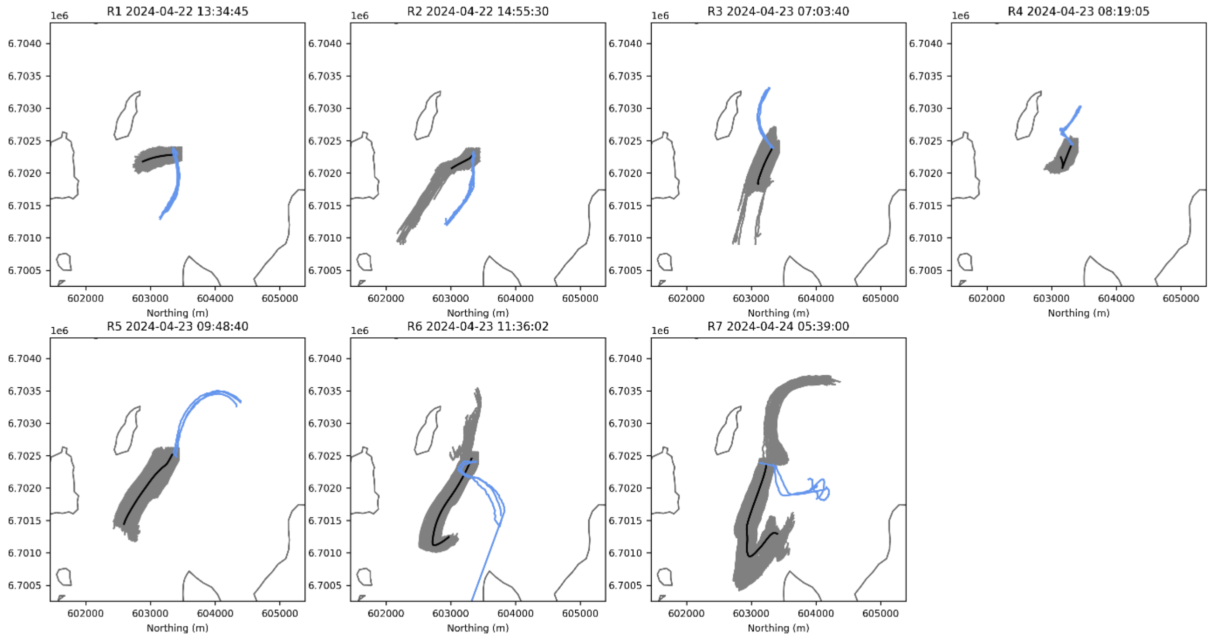

Figure 5.5: Observed drogue tracks (blue) plotted over model particle tracks (grey; mean track = black line), generated using hydrodynamic flow fields in conjunction with wind acceleration.

6 Summary and conclusions

The model is found to reflect the observed current speeds and directions at the Fish Holm quite well. In particular, the model current directions are well matched to the current meter observation in the near-surface bins. Current speeds are underestimated by the model to a certain degree: the modal speed is the same in both meter and model record, but the model underrepresents the occurrence of higher current speeds.

Despite the under-representation of high current speeds, the progressive flow plot generated indicate that net transport in the model is likely to be of approximately the correct magnitude in relation to the observed currents, albeit with more of a tendency to the northwest than the meter observation. Progressive flow vectors calculated from both the current meter observation and the hydrodynamic model predict movement away from the enclosed water body and into Yell Sound.

The empirical drogue study yielded trajectories which were approximately equally split between those moving into and out of the enclosed water body. This study was carried out during a period of consistent northerly winds, which are likely to have influenced water movements and resulting drogue movement patterns. This effect was not captured effectively either by model tracks forced only by hydrodynamic climatology model, or by including direct wind forcing on drogue trajectories within the same model. Wind interacts with tide to generate variability in current patterns that is not represented in the climatology model, and to expect a close match in all cases is therefore perhaps unrealistic.

Such effects are likely to affect drogues with a surface expression more than they do material sinking through the water column, particularly in a tidal environment such as this. It is therefore reasonable to believe that the information collected in the current meter record and from the model prediction at the same point will provide an adequate representation of the transport of material from the site.

7 References

Anderson S (2024) Fish Holm dye and drogue dispersion study.

Danish Hydraulic Institute (2023) East of Shetland Aquaculture Modelling: Hydrodynamic Climatology and Hindcast Models.

Scottish Sea Farms Ltd (2023) Hydrographic Report: Fish Holm. Barcaldine, UK.