Simulating the impact of estuarine fronts on microplastic concentrations in well-mixed estuaries

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Introduction

Due to the difficulty of *in-situ* measurements and paucity of observations, numerical modelling has substantially increased our knowledge on the distribution of marine litter and microplastic in the marine environment. Rivers are a major pathway for plastic pollution, with more than 90% of mismanaged plastic waste transported via watersheds larger than 100 km[1]. Estuaries, which connect rivers with marine environments, are therefore an important consideration when investigating the movement of microplastic along the source-pathway-sink continuum.

Microplastic transport in estuaries is often studied in the context of flow and tidal function. However, secondary flows are present and common in estuaries, proven to transport organic matter and are often associated with fronts. A type of front is an axial convergent front (ACF), occurring in well-mixed estuaries when an axial salinity gradient and a bathymetry enhancing longitudinal lateral shear leads to a cross-sectional bilateral baroclinic circulation[2]. This causes greater densities in the middle of the channel compared to near the banks. It is this density difference that produces convergence within surface waters and divergence near the bed for a short time of a few hours following high tide (Figure 1) . Despite its clear applications the ACF has not been realistically modelled nor studied in the context of plastic pollution in the literature[3].

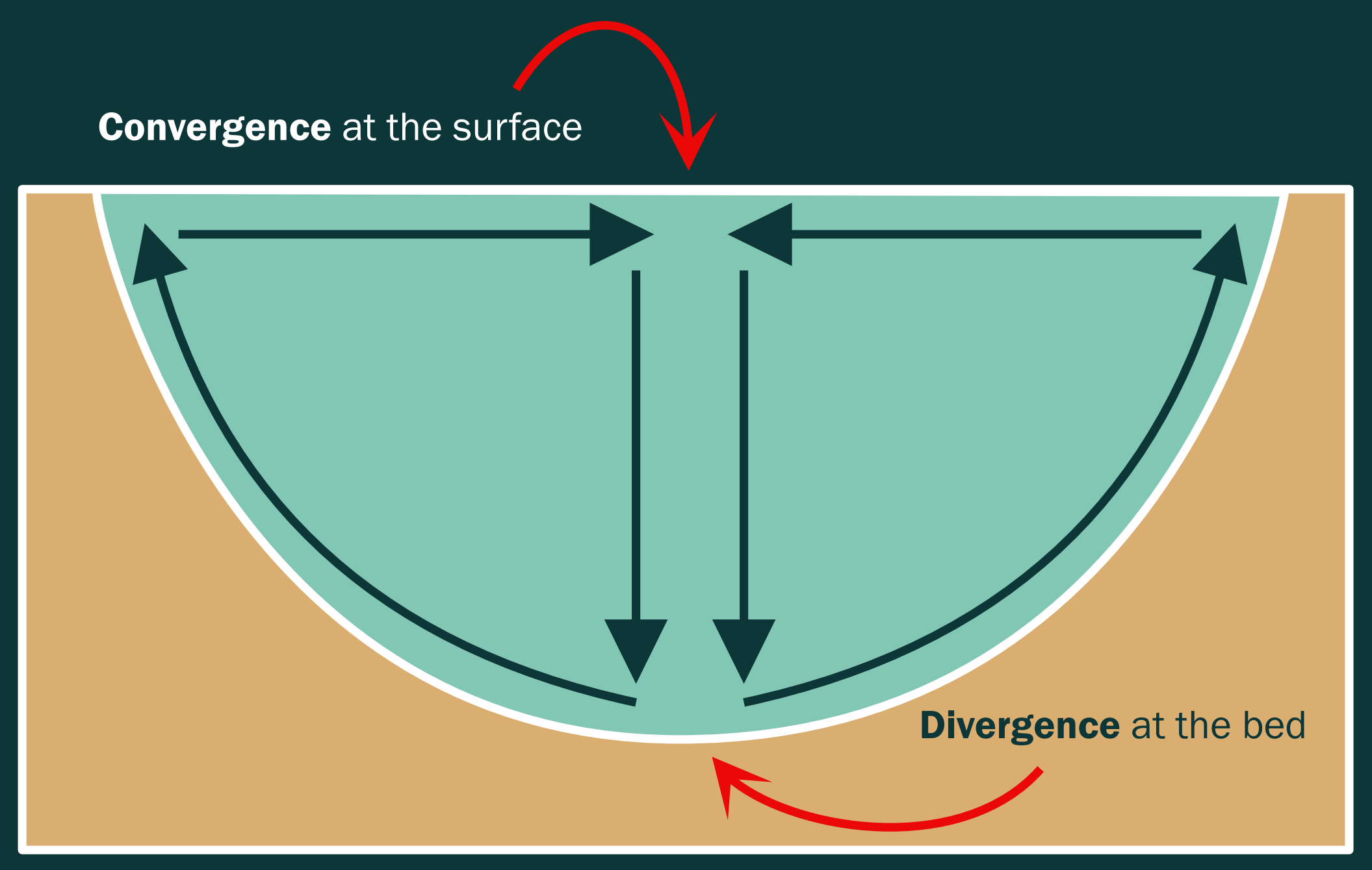
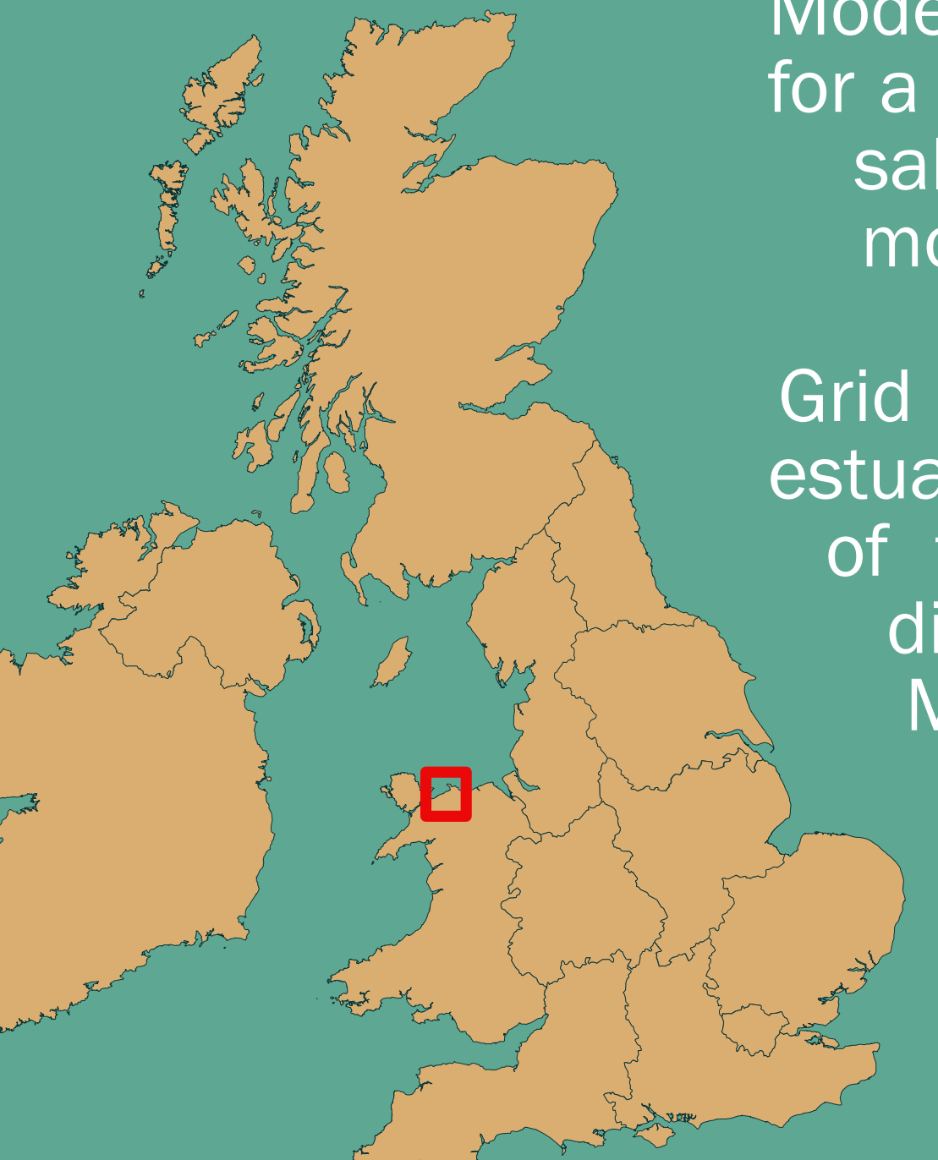


Figure 1: *Diagrammatic representation of the axial convergent front, forming in a well-mixed estuary channel following high water.*

Hydrodynamic Model (Delft 3D Flexible Mesh)

Set Up

Delft 3D Flexible Mesh (Delft 3D FM), a finite volume model, is the hydrodynamic model used for this study. Its flexible, irregular grid, allows for the development of a single domain of the complex geometry of the North Wales Coast and Conwy Estuary at relatively low computational cost. Modelling in three-dimensional space allows for a realistic simulation of temperature and salinity dynamics which are intergral to the modelling of microplastic.



Grid resolution ranges from 30 m within the estuary channel up to 4 km at the boundaries of the domain and vertical structure is discretized using ten vertical σ layers. Model bathymetry is dervied from multibeam datasets and interpolated onto the grid. Two model boundaries were imposed (fluvial and tidal) using the TPXO tidal model and 15-minute river flow data.

Validation

Simulated tidal elevations were validated using observed tidal elevations from Llandudno Tide Gauge, the closest tide gauge to the area of interest: Conwy Estuary and the surrounding area. The model showed high accuracy and skill (RMSE = 0.27, NRMSE = 3%, R^2 = 0.984) capturing the tidal cycle effectively (Figure 2).

Modelled current speeds and salinities were also validated against observations from CTD and ADCP instruments showing realistic results. The modelled estuary does have a shorter saline intrusion, however this a known limitation in D-Flow and steps have been taken to lengthen the saline intrusion including increasing the number of vertical layers and using a σ vertical-coordinate system.

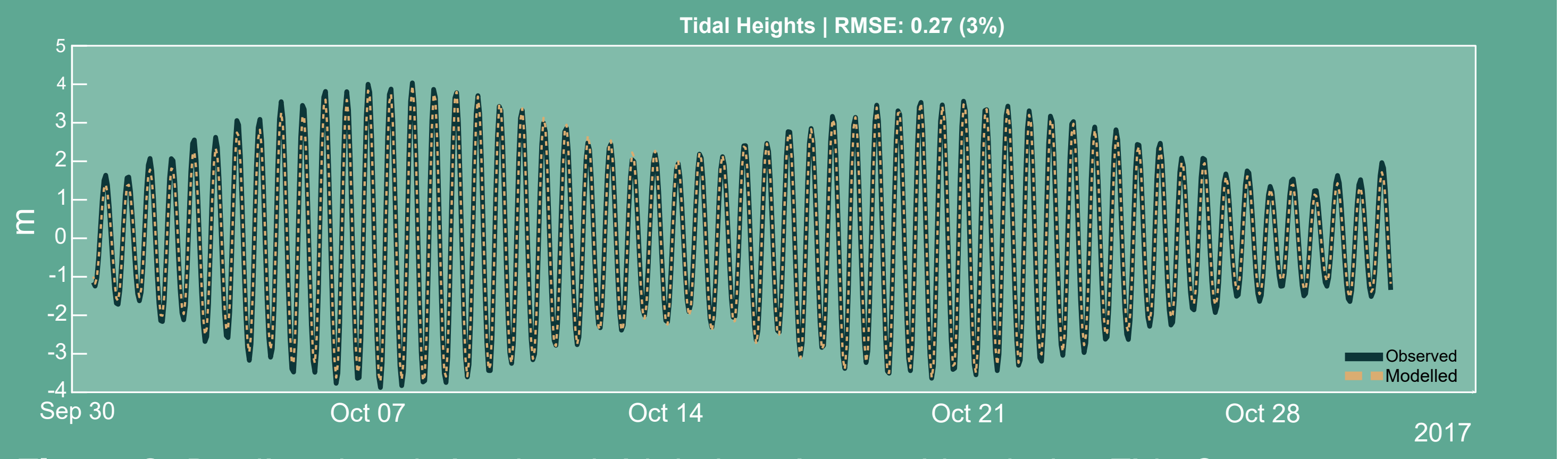


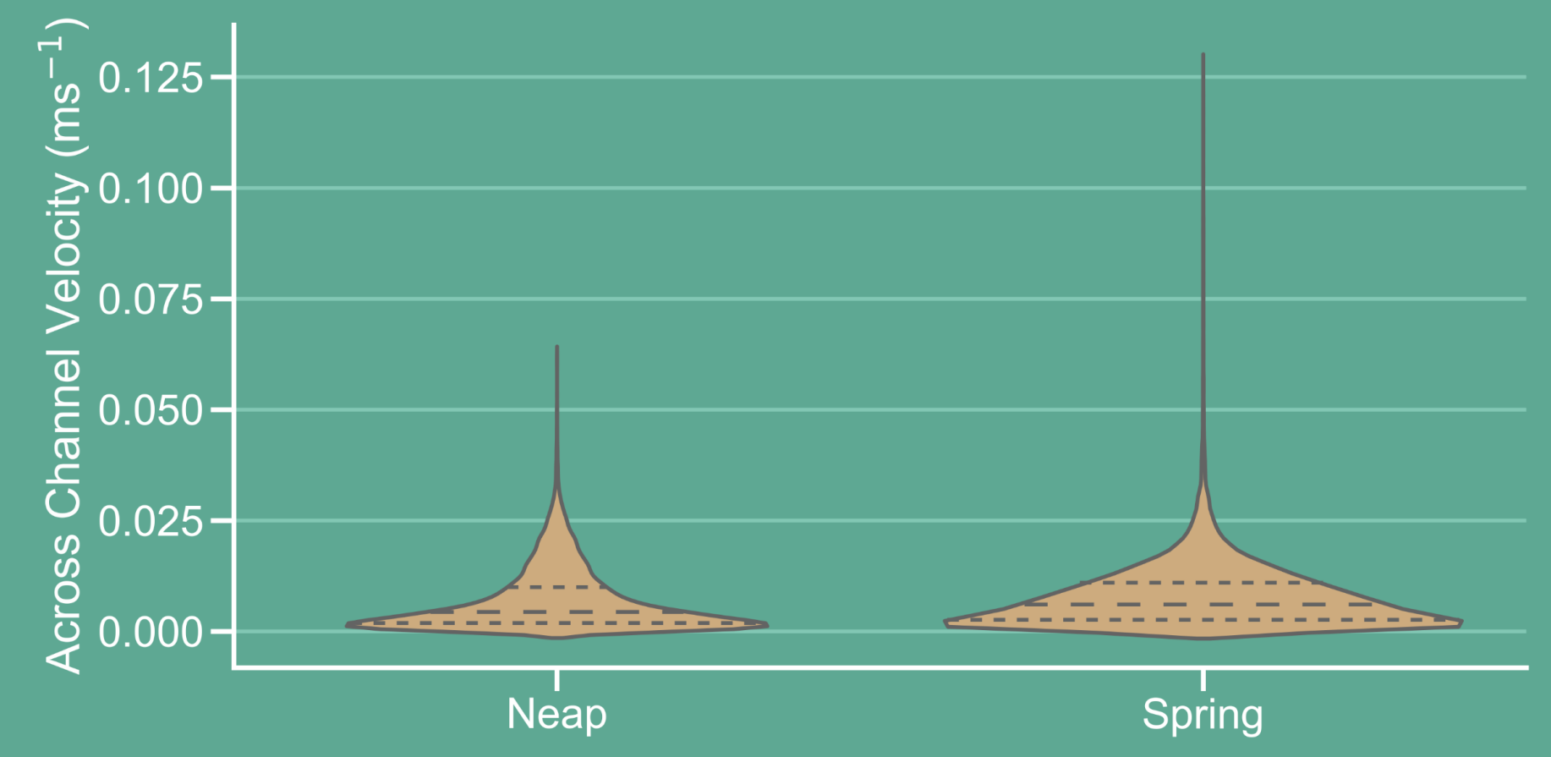
Figure 2: *Predicted and simulated tidal elevations at Llandudno Tide Gauge*

Modelling the Axial Convergent Front

Results confirm we have modelled an axial convergent front within a realistic estuary simulation for the first time. A regular frontogensis and frontolysis of the ACF can be seen following high tide with converging surface currents and diverging bed currents appearing throught the lower and middle estuary (Figure 3).

The strength of the across channel velocities within the front during tidally-dominant conditions are generally similar however velocities can increase by an order of magnitude during the spring tide (Figure 4). Analysis is ongoing to analyse the response of the ACF to different hydrological conditions in the historical record.

Figure 4: *The absolute values of the across channel velocities in the spring and neap phases of the tide. Dashed line is the median and dotted lines represent the first and third quartiles.*



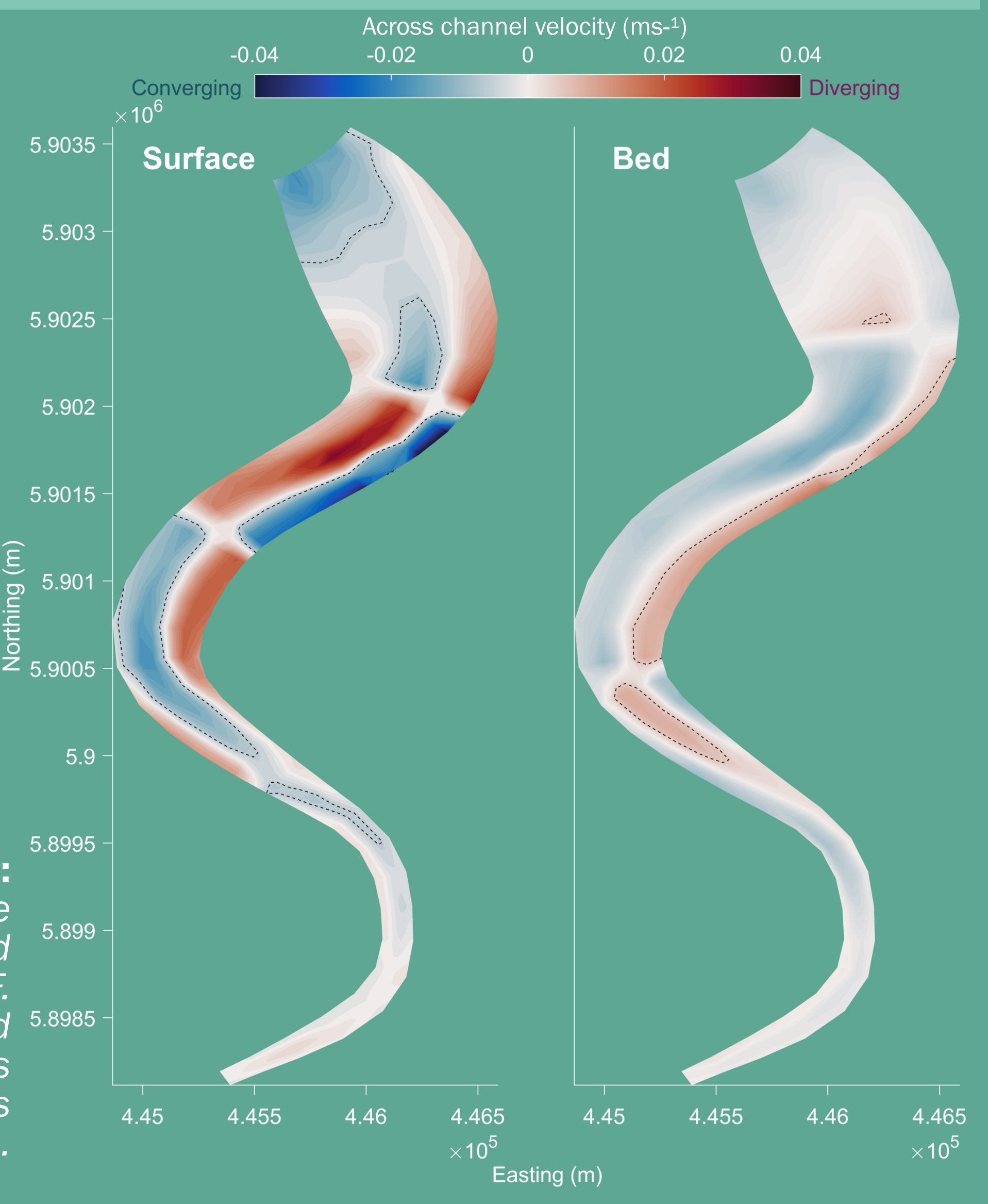


Figure 3: *Across channel velocities of the surface and bed of the simulated Conwy Estuary during an ACF. Concurrent surface convergence and bed divergence indicates an ACF is present. Dashed lines represent areas of velocity greater than 0.5cms-¹.*

Particle Tracking Model

Development

At the time of development, there was no available particle tracking model coupled with Delft 3D FM, able to use the same irregular, curvilinear grid. This coupled approach to particle tracking eases the computational cost of having to regularly interpolate results and maintains the benefits of an irregular grid where resolution varies according to areas of interest.

The model (developed in Python 3.8.1) is able to take results from the Delft 3D FM model, seed plastic particles throughout the grid and account for the advection and diffusion of particles across the time series in both two- and three-dimensions.

Results

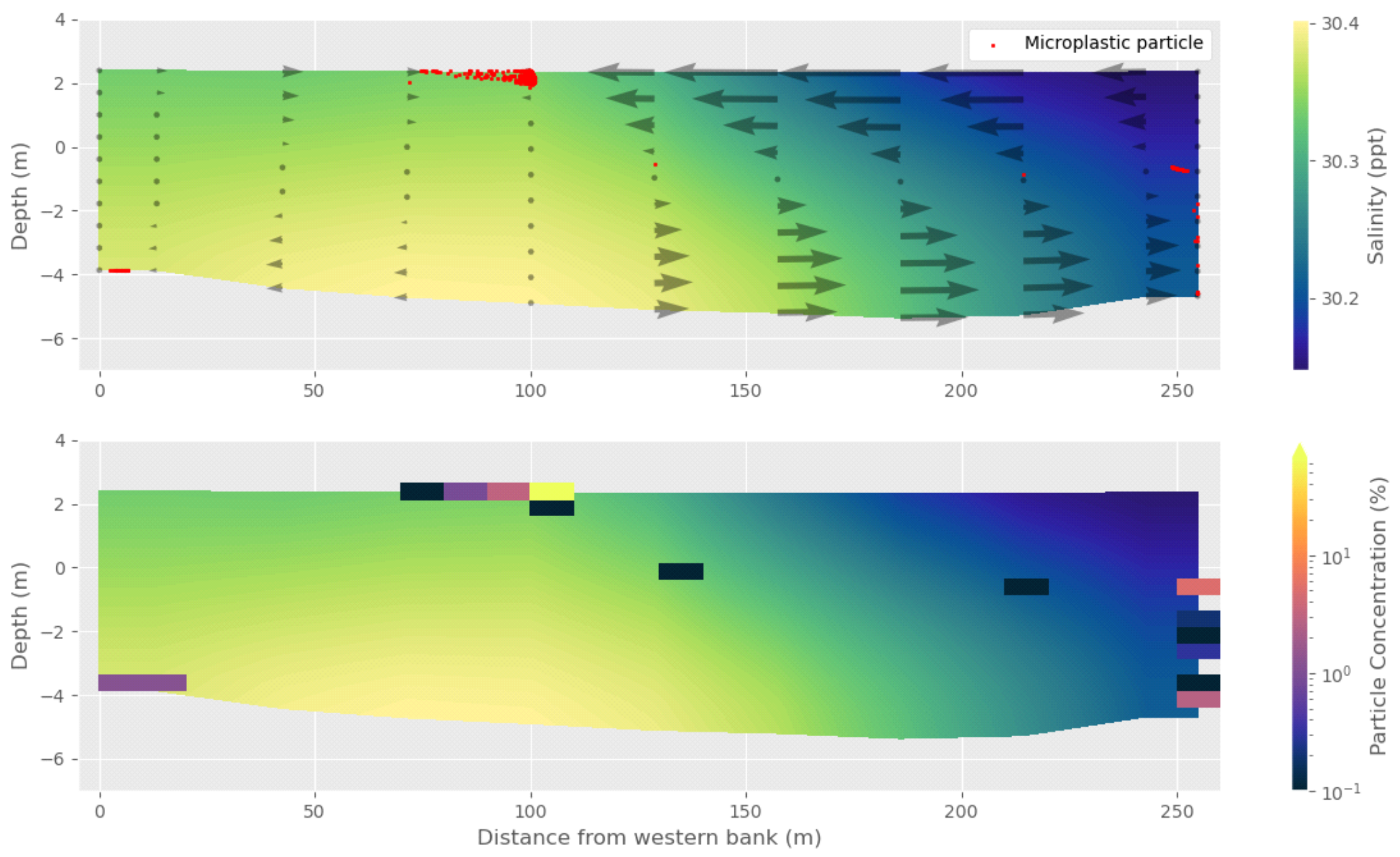


Figure 5: (a) *Individual microplastic particles being concentrated during the height of an ACF and (b) their relative concentrations across two-dimensions.*

To analyse the impact of the ACF in isolation, microplastic particles were modelled within two dimensional cross-sections of the ACF. 1000 neutrally buoyant particles were advected every half a second over three hours during an ACF within a representative cross-section in the estuary.

During this time microplastic particles concentrated in the mid-channel suface waters after being transported from deeper in the channel and near the banks. ~60% of released particles were found in the middle of the channel at the height of the ACF. Analysis is ongoing to investigate whether the front could be a mechanism for resuspension of microplastic during low-energy time periods.

Conclusion & Further Work

Latitudinal variability in microplastic concentrations caused by frontal systems such as the ACF could notably impact *in-situ* estuarine microplastic measurements and thus global budget estimations of microplastic concentrations. It is therefore important for studies measuring *in-situ* concentrations in estuaries to note the tidal conditions and ideally take microplastic concentrations across the entire channel to avoid over- or under-estimating microplastic concentrations. Further work is now ongoing to model microplastic concentrations within the three-dimensional estuary system, and measure the impact of different polymer types on distribution.

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References

(1) Lebreton, L. and Andrady, A., 2019. Future scenarios of global plastic waste generation and disposal. Palgrave Communications, 5(1), pp.1-11.
(2) Nunes, R.A. and Simpson, J.H., 1985. Axial convergence in a well-mixed estuary. Estuarine, Coastal and Shelf Science, 20(5), pp.637-649.
(3) Robins, P.E., Neill, S.P. and Giménez, L., 2012. A numerical study of marine larval dispersal in the presence of an axial convergent front. Estuarine, Coastal and Shelf Science, 100, pp.172-185.