

Flow and sediment transport in a stratified estuary

Overview

Background

- Human pressures on Rhine-Meuse Delta^[1].
- Wish to better understand long-term effects of (future) human measures and climate change.
- Need for modelling tools that incorporate relevant processes for long-term morphological development.

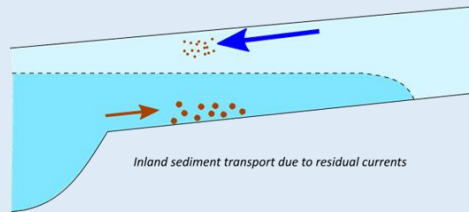


References

- [1] Vellinga, N.E., A.J.F. Hoitink, M. van der Vegt, W. Zhang and P. Hoekstra, 2014. Human impacts on tides overwhelm the effect of extreme water levels in the Rhine-Meuse Delta. Coastal Eng., 90, 40 – 50.
- [2] Cox, J.R., Y. Huismans, J.F.R.W. Leuven, N.E. Vellinga, M. Van der Vegt, A.J.F. Hoitink, and M.G. Kleinhans. "Anthropogenic effects on the Contemporary Sediment Budget of the Lower Rhine-Meuse Delta Channel Network." Manuscript submitted to Earths Future, 2020.
- [3] Nijs, Michel A. J. de, Johan C. Winterwerp, and Julie D. Pietrzak. "The Effects of the Internal Flow Structure on SPM Entrapment in the Rotterdam Waterway." Journal of Physical Oceanography 40, no. 11 (November 1, 2010): 2357–80.

Challenges

- Sediment exchange North Sea unknown^[2]
- Broad range of grain sizes
- Intensely stratified flow^[3]



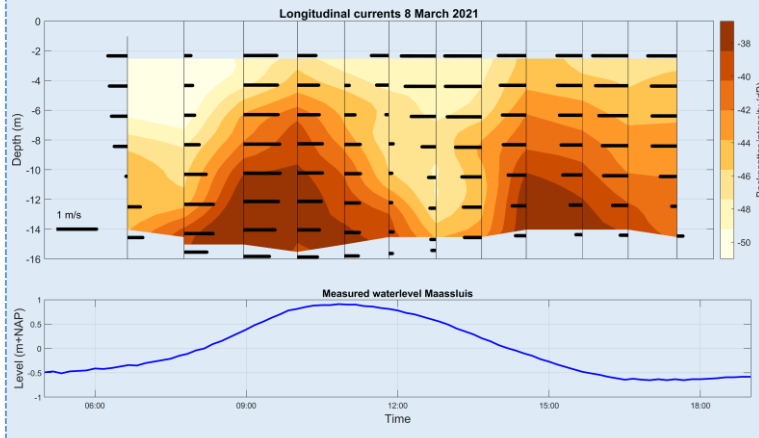
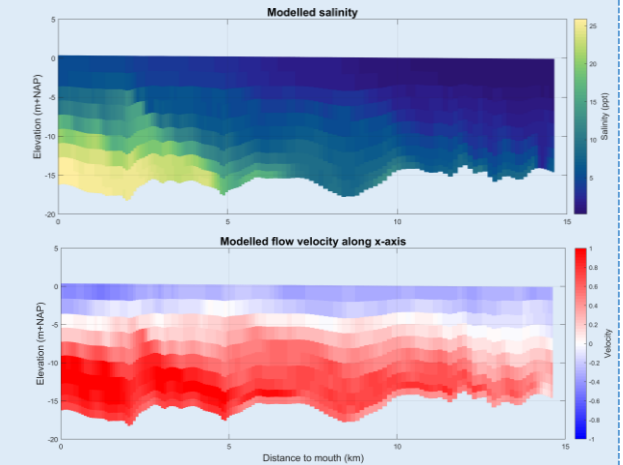
Research goals

- To improve understanding of sediment transport in mixtures.
- To improve sediment transport modelling under baroclinic conditions.

Methods & results

Numerical modelling

- **Goal:** to test sensitivity and accuracy of modelled sediment transport with state-of-the-art formulations.
- Hydrodynamics (D3D) coupled to a 2DV offline sediment transport model.
- Varying transport formulation and sediment composition.
- Net transport validation will be based on field data.



Field data

- 2x 13-hour campaign (spring/neap), monitoring: Flow, SSC and grain size
- Data will provide insight on net sediment load and contribution of different fractions.

Acknowledgements

This study is part of the research program Rivers2Morrow, which is funded by the Dutch Ministry of Infrastructure and Water Management and its executive organization Rijkswaterstaat. We thank the Port of Rotterdam for their in-kind contribution and support with the field measurements.

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Numerical modelling

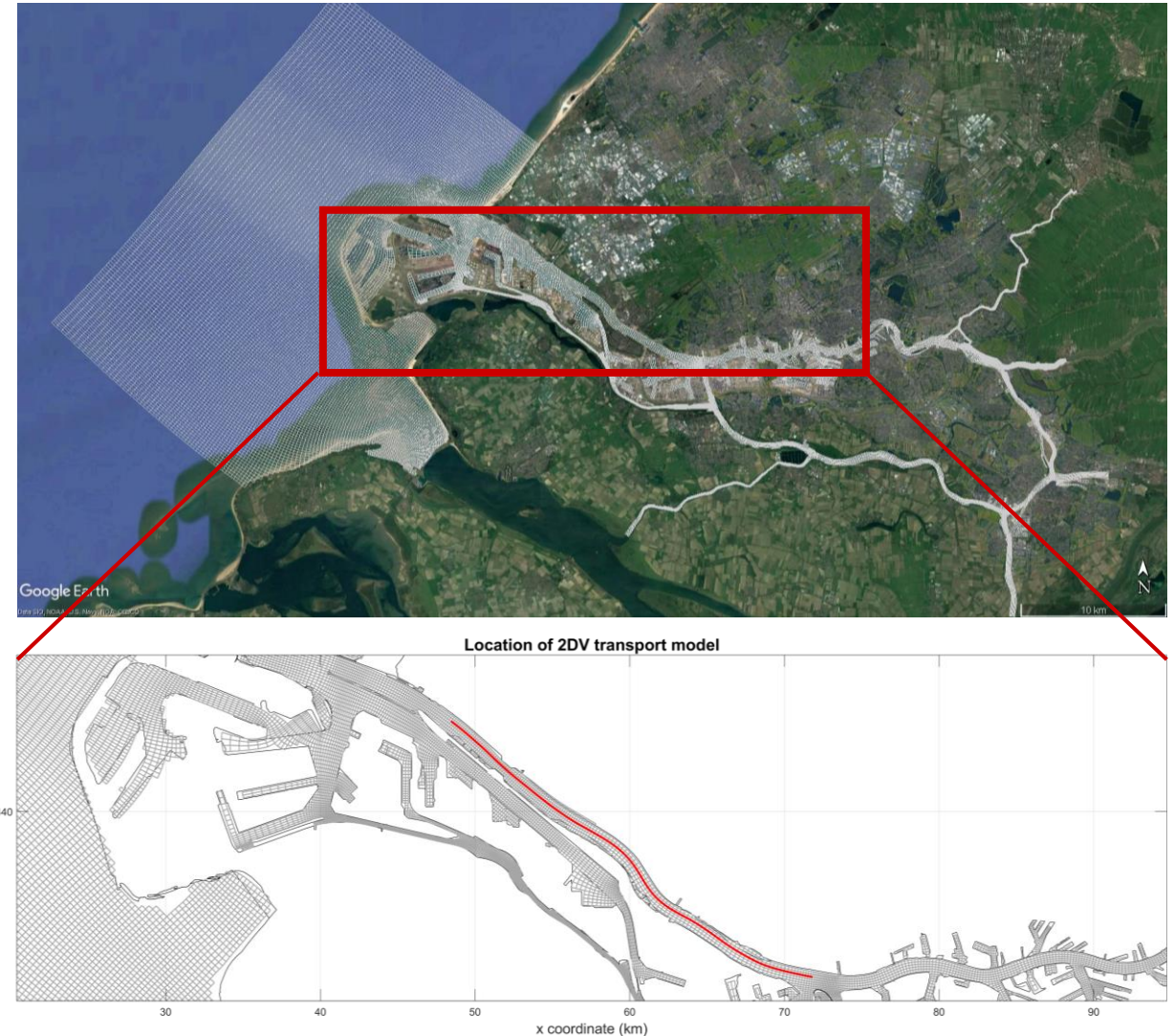
Model study overview

Research goals:

- To test the accuracy of net sediment transport computations with state-of-the-art formulations.
- To test the sensitivity of net sediment transport to different formulations for **sand-mud interaction**.
- To test the sensitivity of net sediment transport to **input sediment composition**.
- To test the sensitivity of net sediment transport to **baroclinic flow**.

Approach:

- Calculate **hydrodynamics** with a **large-domain 3D model** (Delft3D)
- Selection of historical periods with **varying degrees of stratification**
- **Validation** based on water levels, salinity and currents (where possible)
- **Offline coupling** to a sediment transport model
- **Initial bed composition** is based on a combination of datasets.
- Set of simulations which differ in terms of **interaction between different sediment fractions**.



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Numerical modelling

Figure 1: example of water level validation at two stations along the 2DV model. Upper panel: station Maeslantkering; lower panel: station Maassluis.

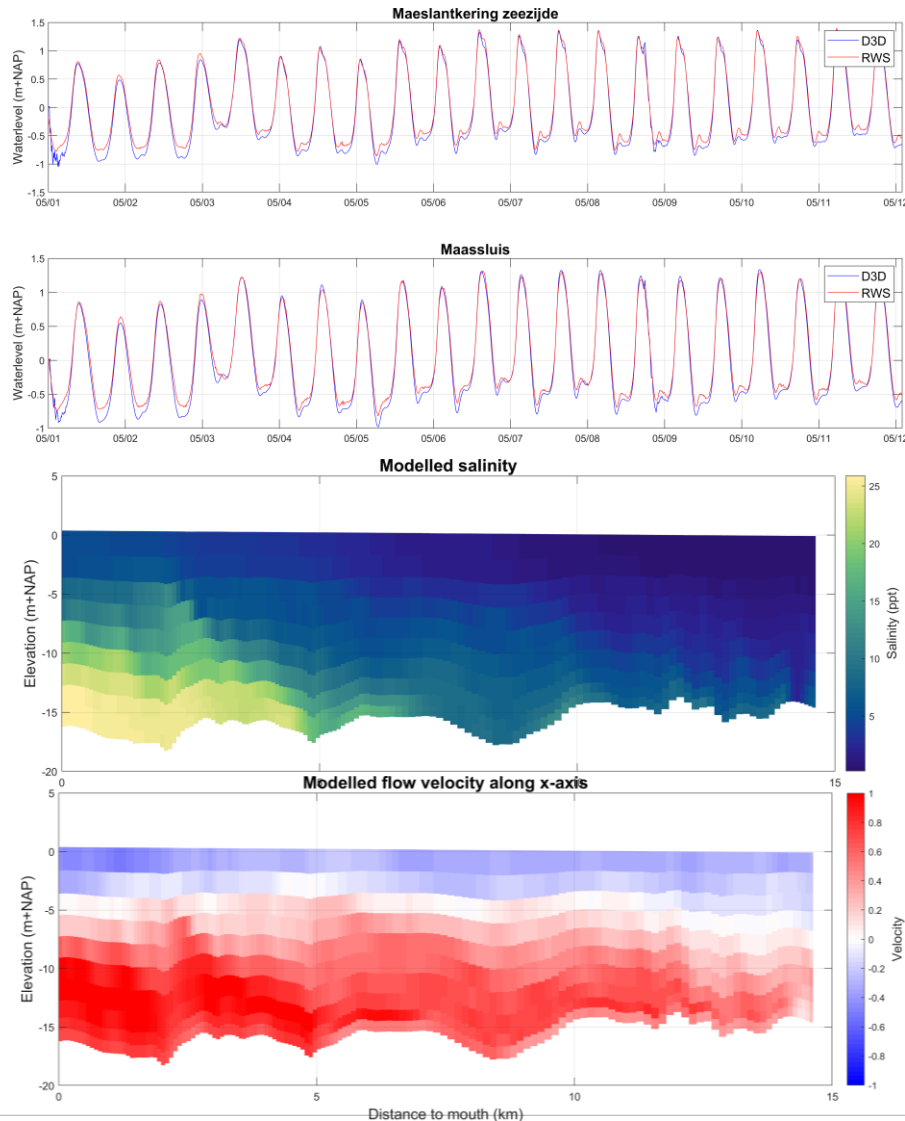


Figure 2: Modelled salinity along 2DV model after LWS

Figure 3: Modelled along-channel velocity along 2DV model after LWS. A positive velocity indicates a land inward current.

Model results

Hydrodynamic validation:

- Hydrodynamics are validated against data of **4 operational stations** (2 shown here) along the New Waterway, measuring water levels (3) and salinity (1).
- Water levels** are reproduced very well with a bias ≈ 5 cm and rmse ≈ 10 cm. **Timing of HWS and LWS** is correct within 30 minutes (figure 1).
- Timing of peak **salinity** is correct within 30 minutes, with exception of periods with high wind forcing (figure 2).
- Additional validation** based on the field campaign of March 2021 is planned, with an additional focus on currents (figure 3).

Sediment transport approach:

- Suspended sediment transport using advection-diffusion.
- Different formulations for near-bed sand-mud interaction.
- Extended model domain to avoid boundary effects.
- Validation based on field data (SSC).

Expected output:

- Better insight in relevant processes for net sediment transport.
- Better insight in performance of existing sediment transport formulations.

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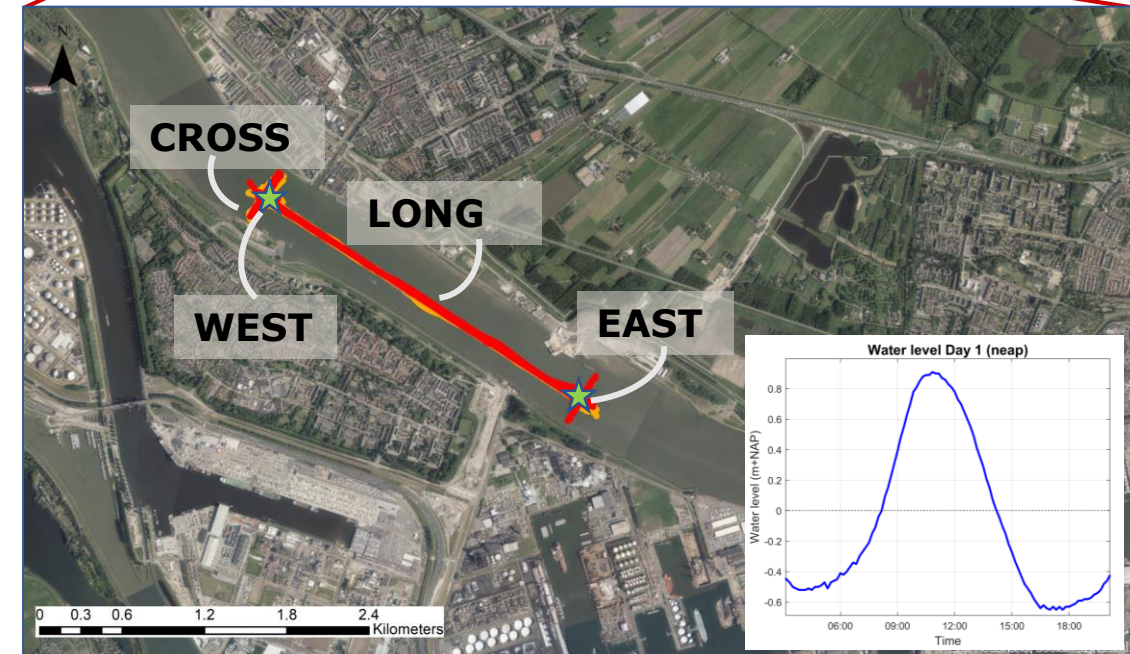
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Field measurements - overview

Overview

Overall set up:

- 2x 13-hour campaign (spring cycle + neap cycle)
- 2 measuring locations (EAST + WEST) in the New Waterway, with a distance of 3 km in between.
- Measuring frame collecting hourly data at both locations at 3 depths.
- Water samples are taken to determine SSC (hourly) and PSD (3-hourly)
- Continuous flow monitoring using 2 ADCP's
 - Sailing additional cross section at WEST every hour
 - 1 ADCP measuring at 600 kHz; 1 ADCP measuring at 1200 kHz



Device	Measured quantity	Location	Frequency	Depths
ADCP-600 kHz	Current + ABS	LONG + CROSS	Continuously	Profile
ADCP-1200 kHz	Current + ABS	LONG + CROSS	Continuously	Profile
LISST-100x	PSD in suspension	E + W	2 locations per hour	3
Niskin bottle	Water sampling	E + W	2 locations per hour	3
Seaport CTD	Salinity + depth	E + W	2 locations per hour	3



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Field measurements - results

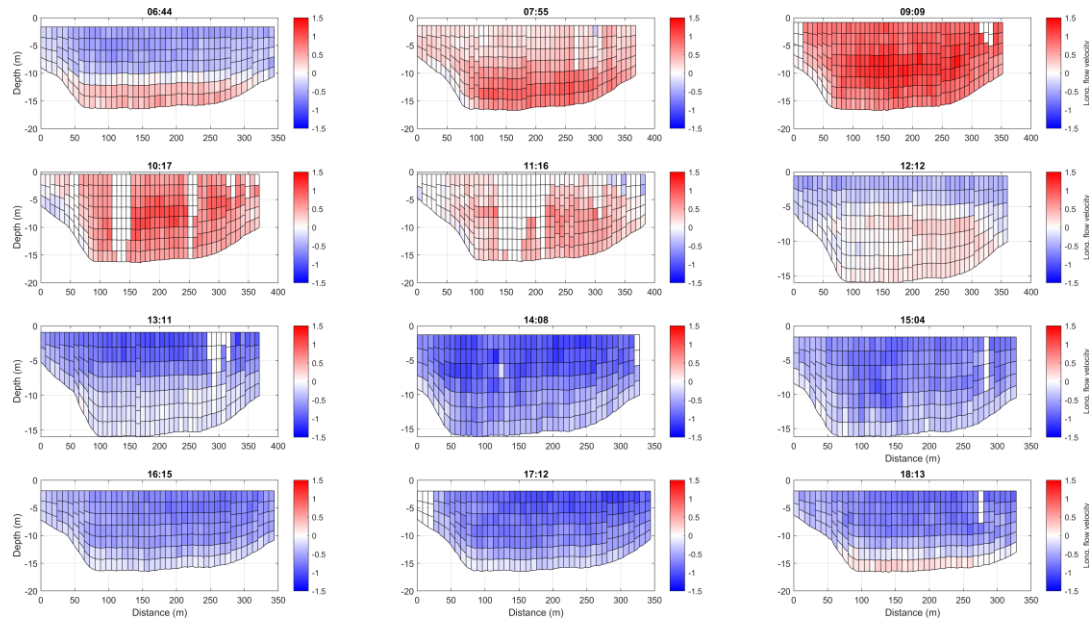


Figure 1: Measured along-channel current at location CROSS during neap tidal cycle. A positive flow velocity indicates a land inward current.

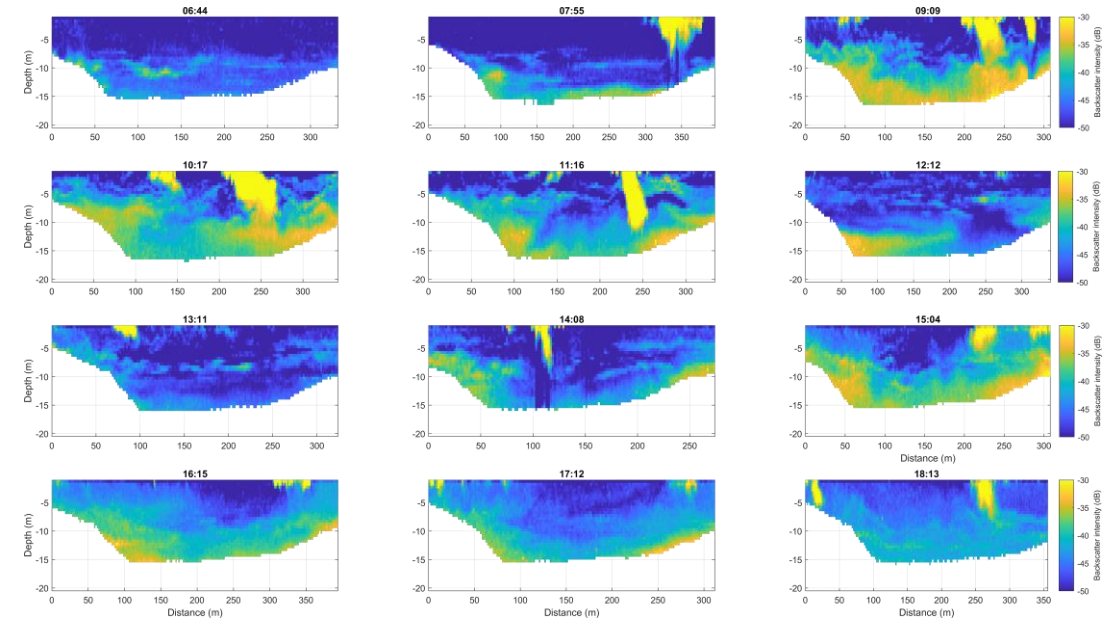


Figure 2: Measured backscatter intensity with the 600 kHz-ADCP at location CROSS during neap tidal cycle. Shown data is unfiltered.

Field data: hydrodynamics

Preliminary results:

- Clear baroclinic flow structure
- Flow in upper layer changes direction directly after HW (figure 1)
- Jet-like flow structure during flood phase halfway water column, corresponding to observations from [3].

Field data: sediment properties

- Overall increasing sediment concentration with depth.
- Backscatter intensity in lower water column increases during flooding and ebbing (figure 2); this happens simultaneously over the full trajectory measured in LONG (next slide).
- LISST-data indicate increase of sand fraction with depth (not shown here)



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Field measurements - results

To continue...

- Use field data to validate hydrodynamic and sediment transport models: how accurate are **existing formulations** in terms of net tidal transport? How sensitive is net transport to changes in **sediment composition** and **stratification**?
- Convert backscatter intensity to SSC: what is the **net transport of sediment**?
- LISST-data and sample analysis yield PSD over depth and time: how does the net transport differ for **different sediment fractions**? Is there a difference in **transport height** and effect of baroclinicity?
- How can we improve existing modelling tools to accurately predict sediment fluxes under changing conditions?

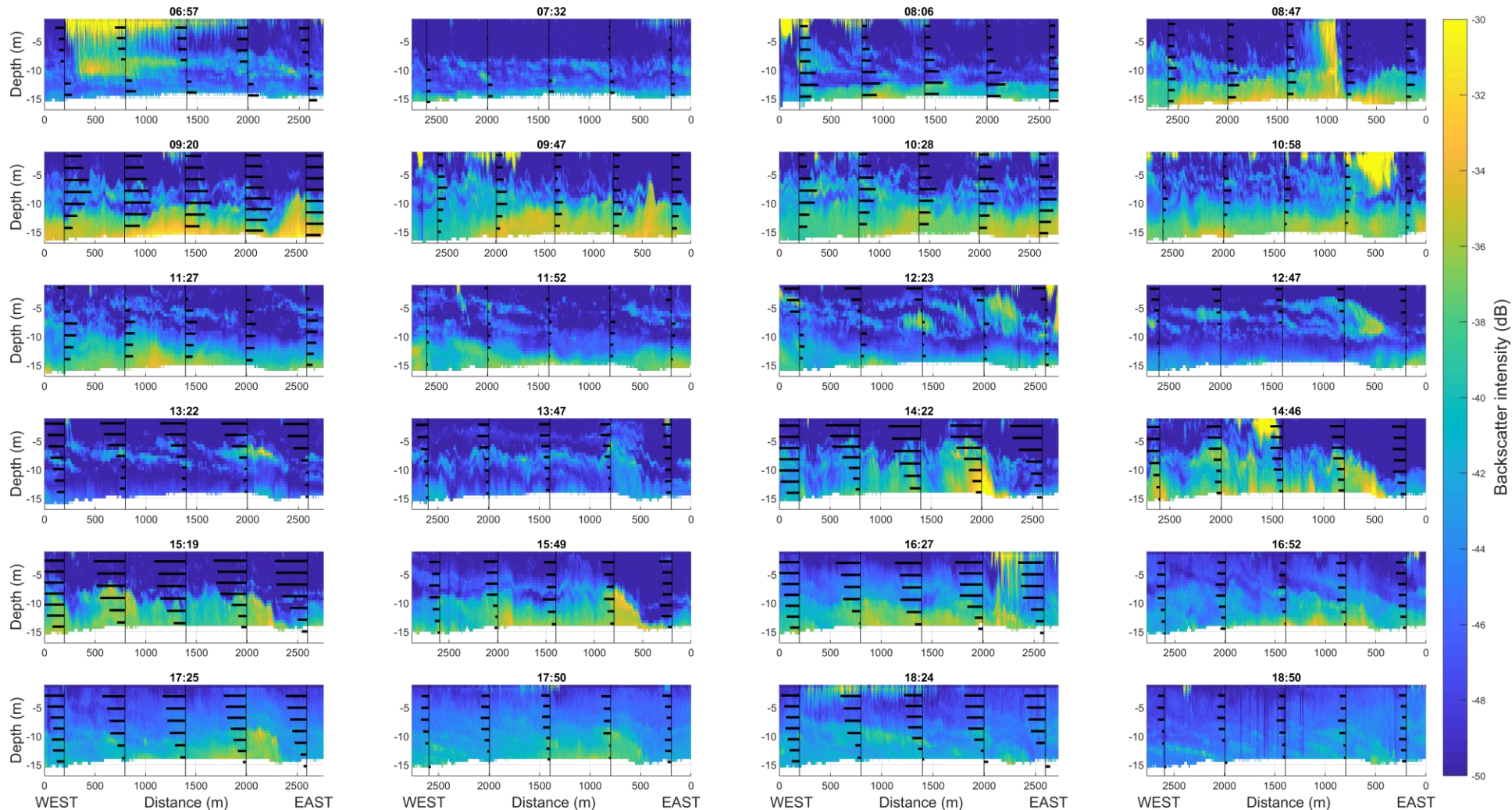


Figure 1: Measured backscatter intensity (colors) and along-channel flow velocity at location LONG during a neap tidal cycle. All panels show the trajectory from seaward side on the left to landward side on the right. Backscatter data are unfiltered.

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