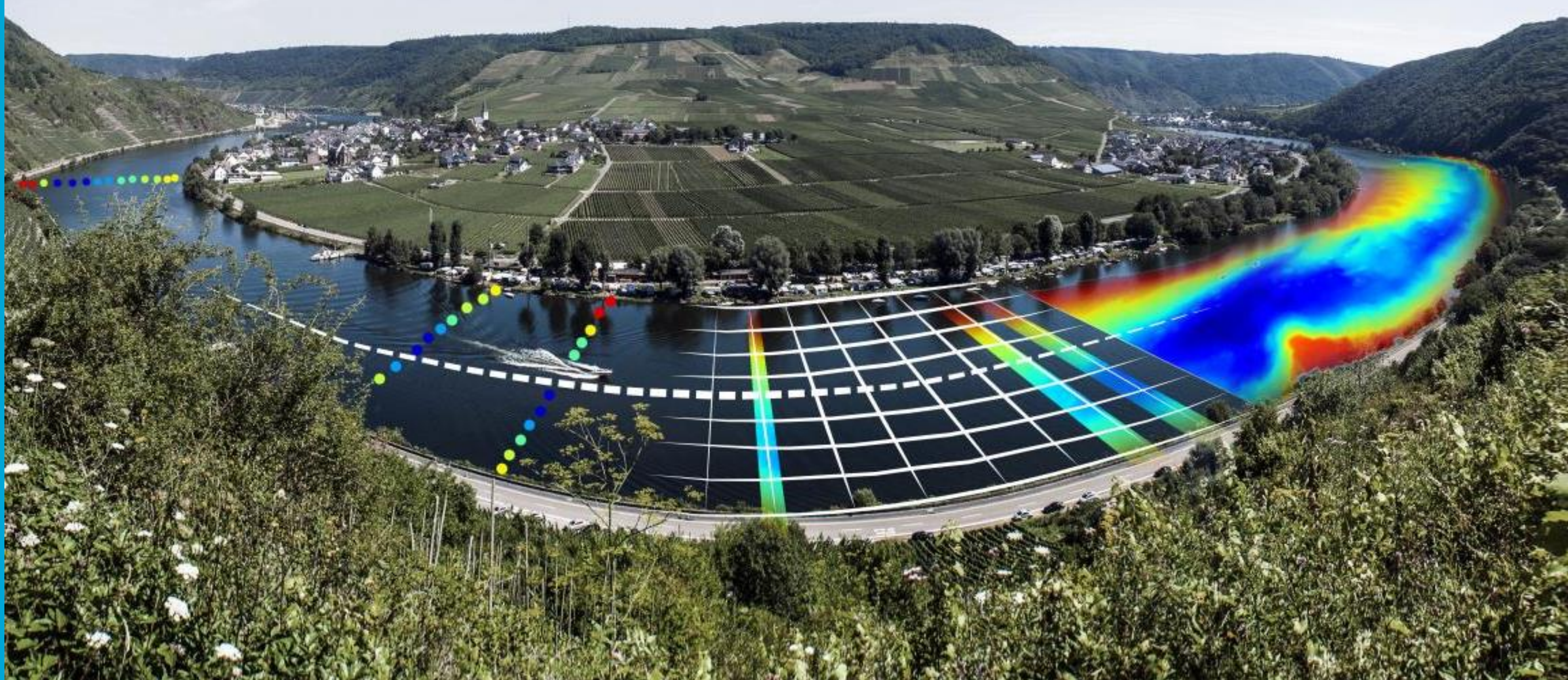
Graduation Presentation for MSc Geomatics

6 November 2015

Combining a Physics-based Model and Spatial Interpolation of Scarce Bed Topography Data in Meandering Alluvial Rivers

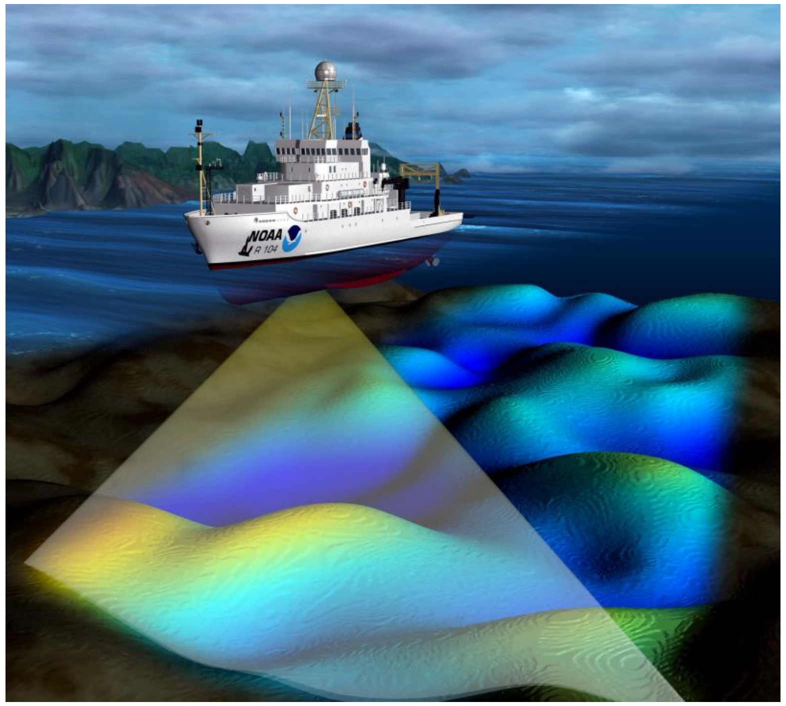
Dimitrios-Ioannis Zervakis



TU Delft

Introduction

Motivation



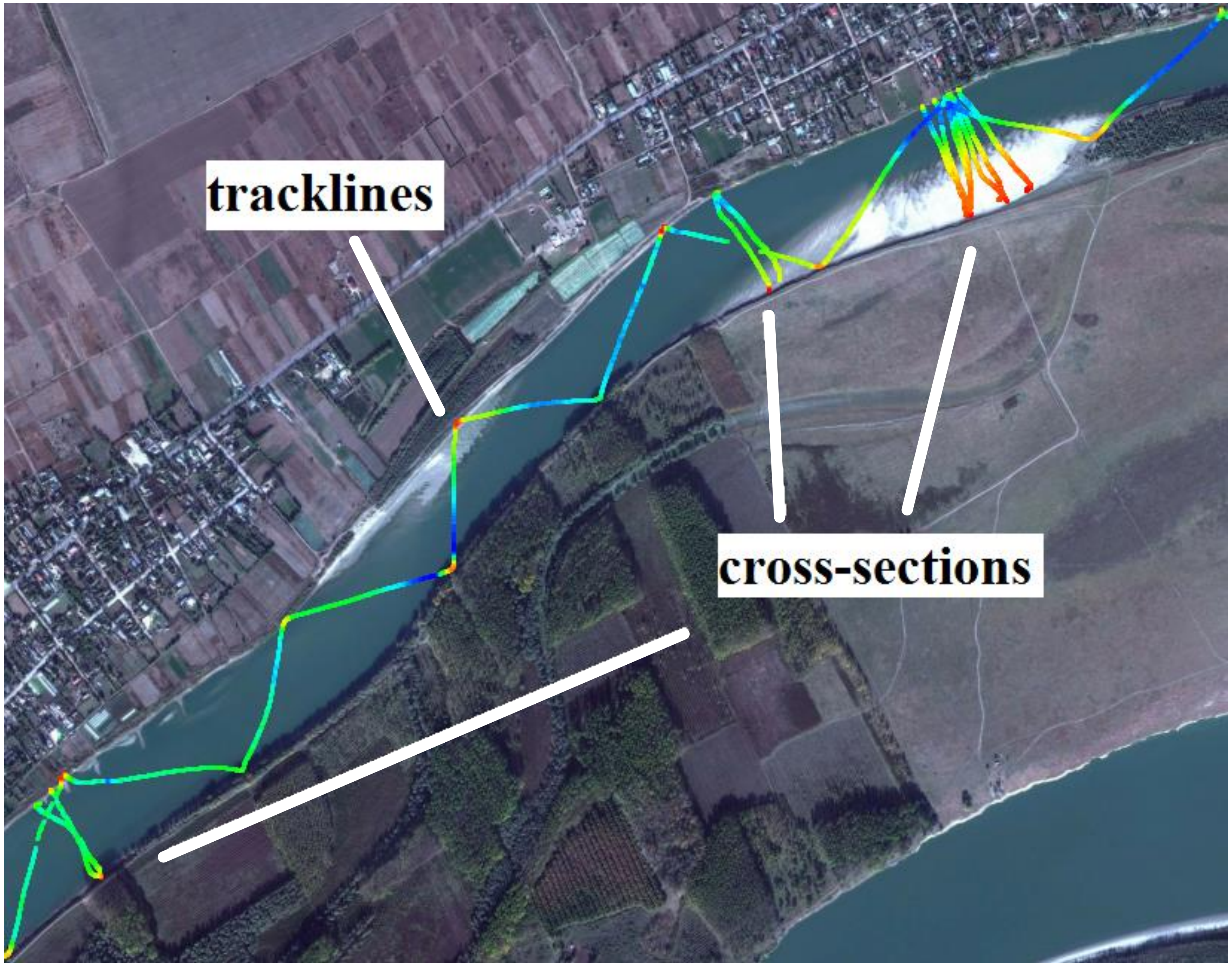
TUDelft

Problem Statement

Limited data, so called "*scarce*" data

- <u>Partial solutions:</u>
  1. Interpolation ✗
  2. Models ✗
  3. Manual Labour ✗

Combination?



TU Delft

Research Questions

How can a spatial interpolation method be coupled with river morphology physics in order to approximate better* the river bed topography when input data are scarce**?

*: numerical or qualitative form of assessing

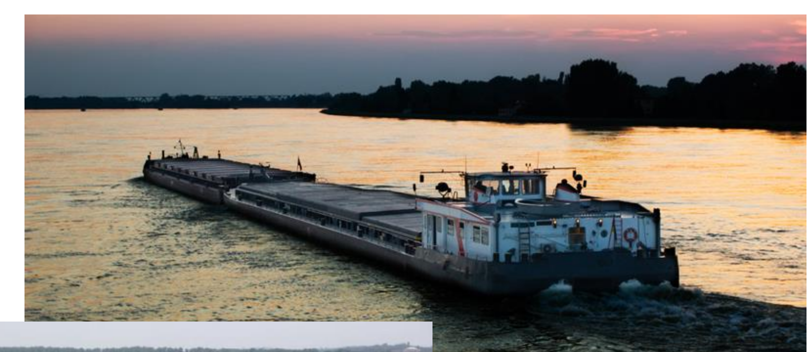
**: “trackline” data or cross-sectional data.

- *What is an objective function to measure ‘goodness-of-fit’ of the method?*
- *What coordinate system allows for better predictions on riverbed topography?*
- *How much of the full data can be thinned out and still have a successful outcome?*

Relevance

- Proposed by *Deltares* independent institute for applied research.
- The research is related to the *Rapid Assessment Tool for Inland Navigation* (RAT-IN, under development).
- A fast accurate representation of riverbed topography is useful in various applications.

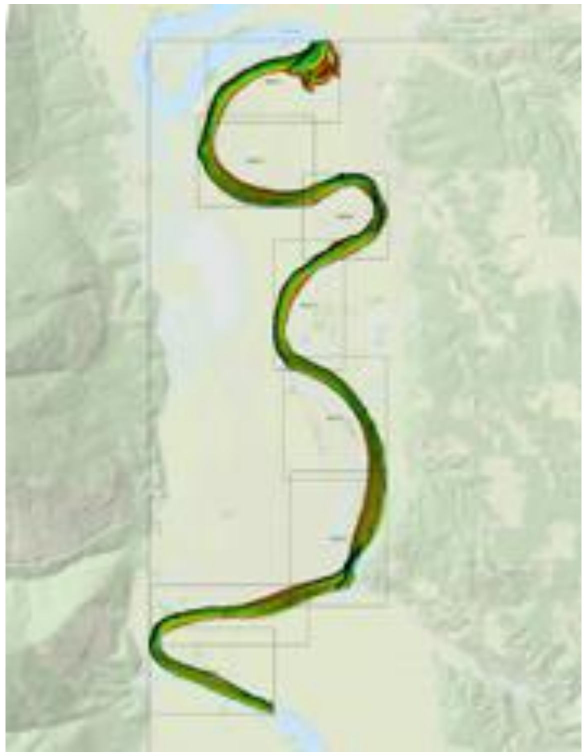
RAT-IN: "To rapidly assess a river's suitability for inland navigation based on state-of-the-art scientific knowledge and freely available data sources"



Data

Study Cases

- IJssel (Netherlands):
  - Good multibeam (1x1 m)



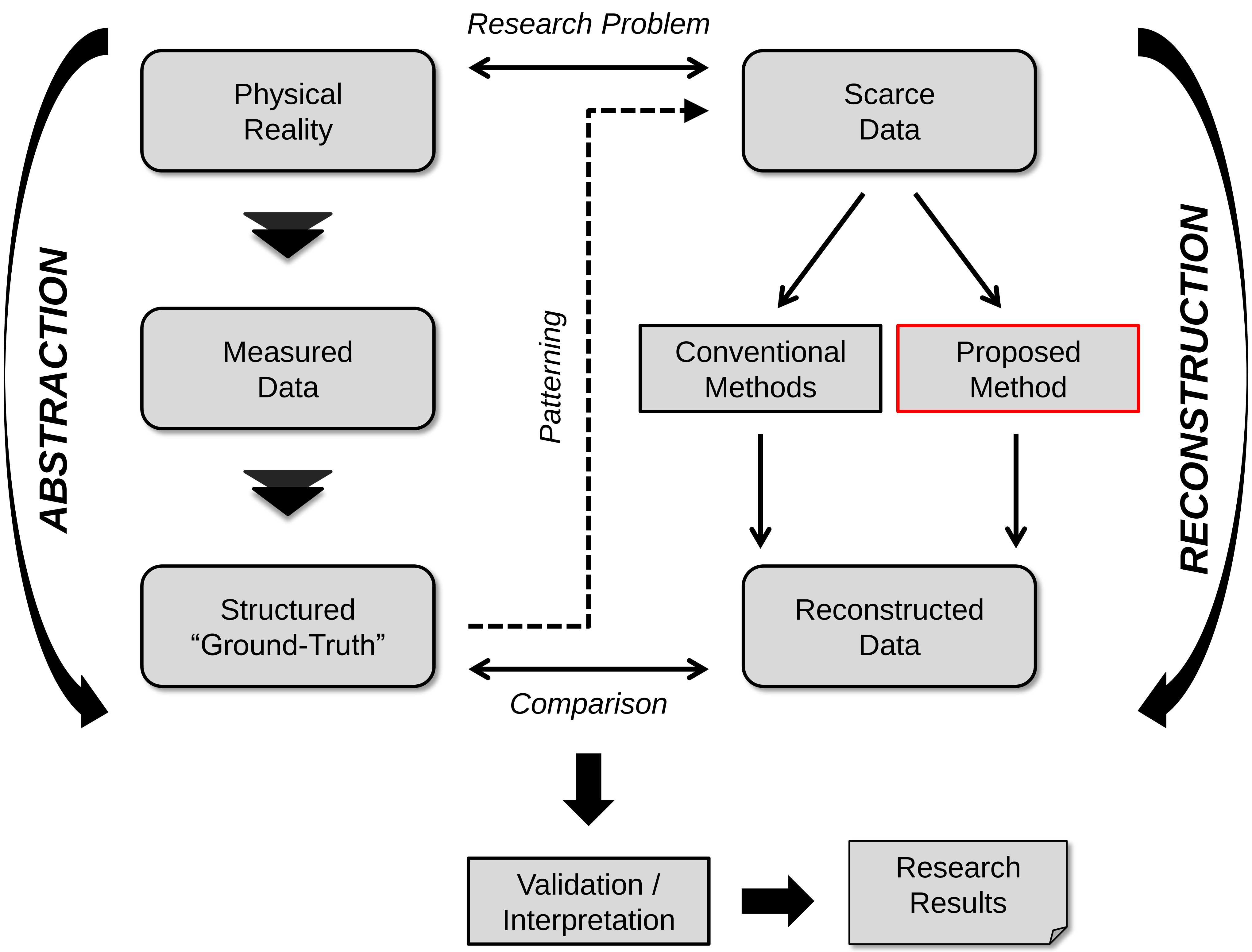
- Kootenai (Idaho, US):
  - Very dense multibeam (random samples, unstructured)

- Danube (Romania):
  - Relatively dense singlebeam, with scarce areas

TU Delft

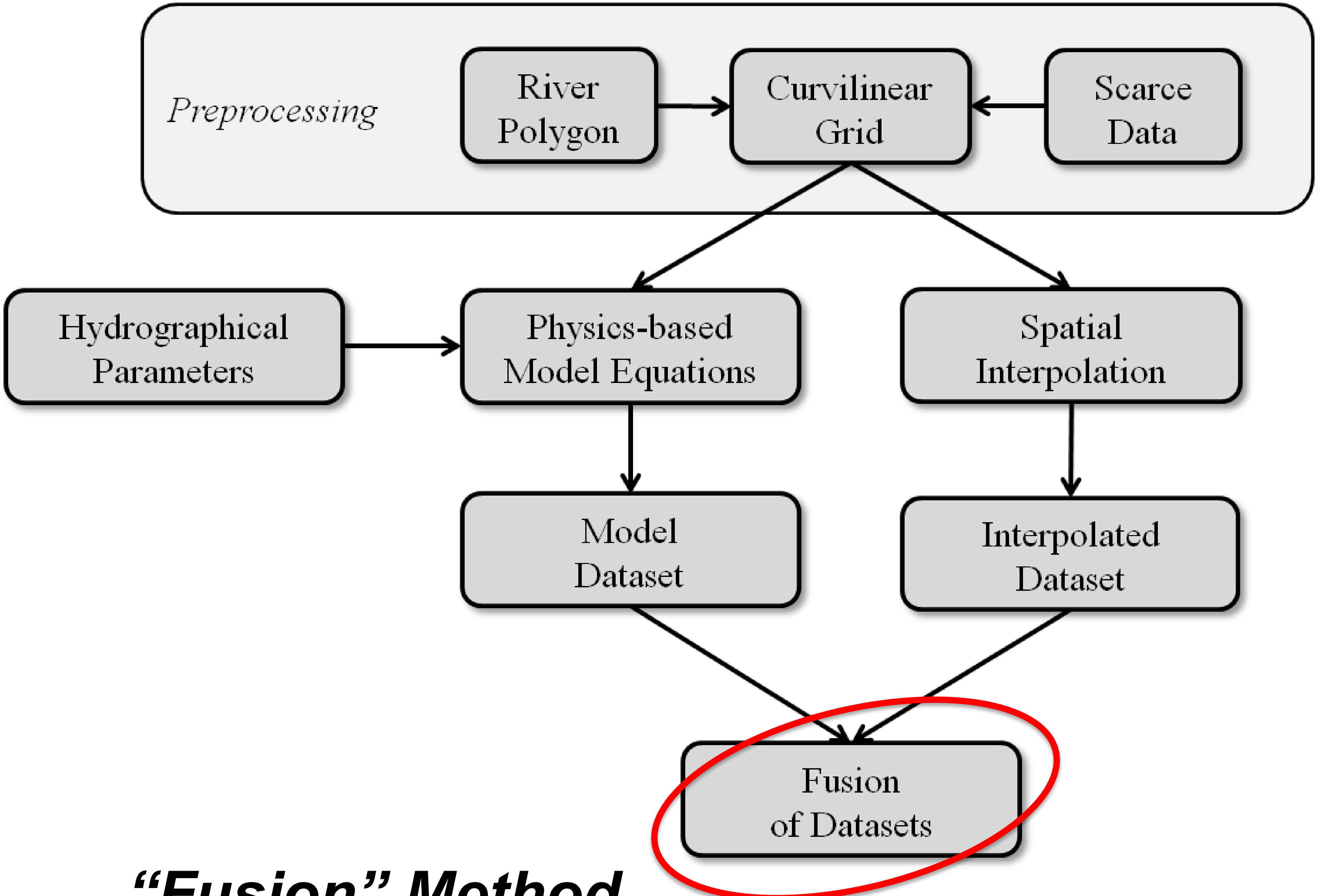
Methodology

Methodology



TU Delft

Proposed Method



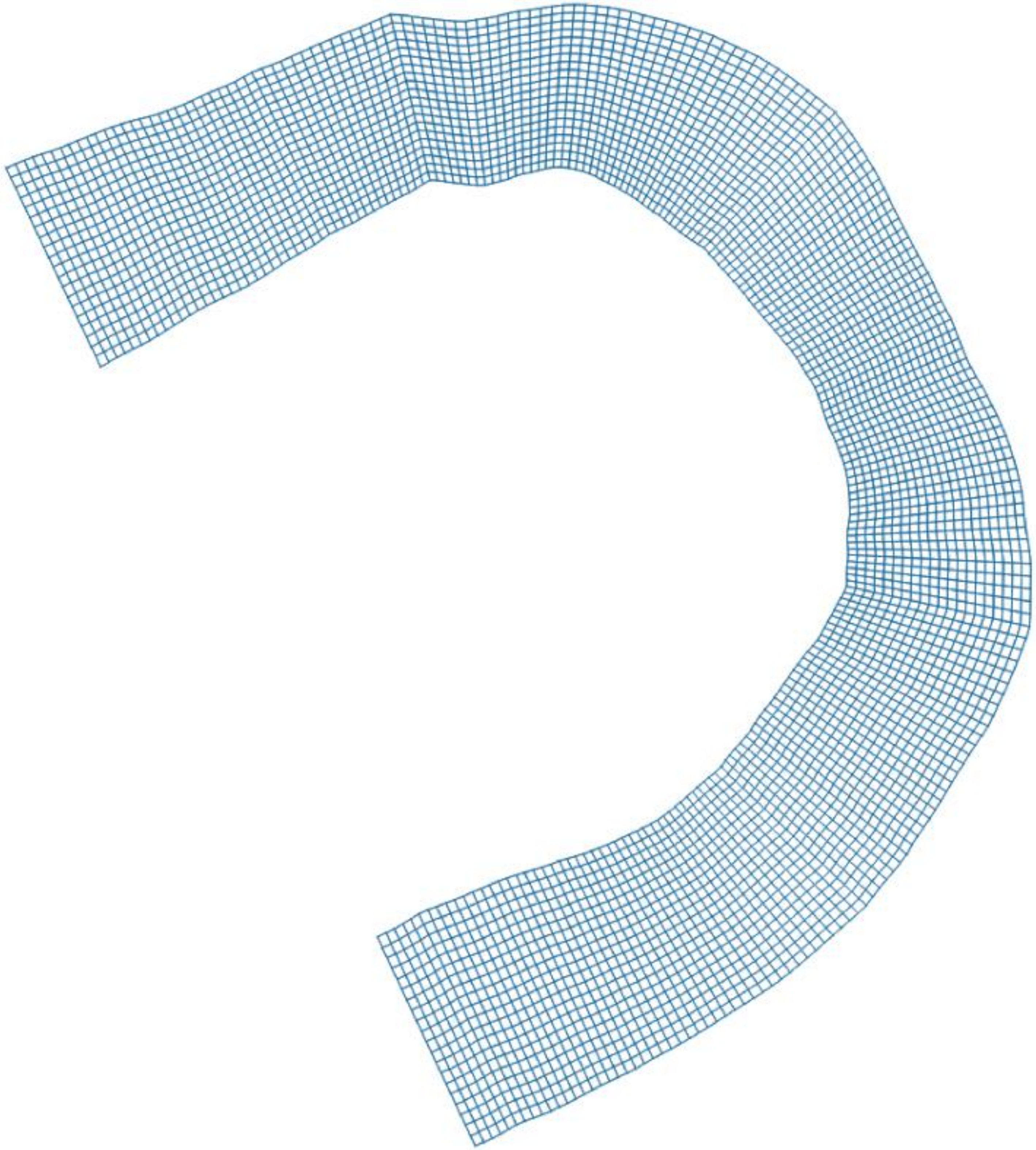
"Fusion" Method

TU Delft

Pre-processing

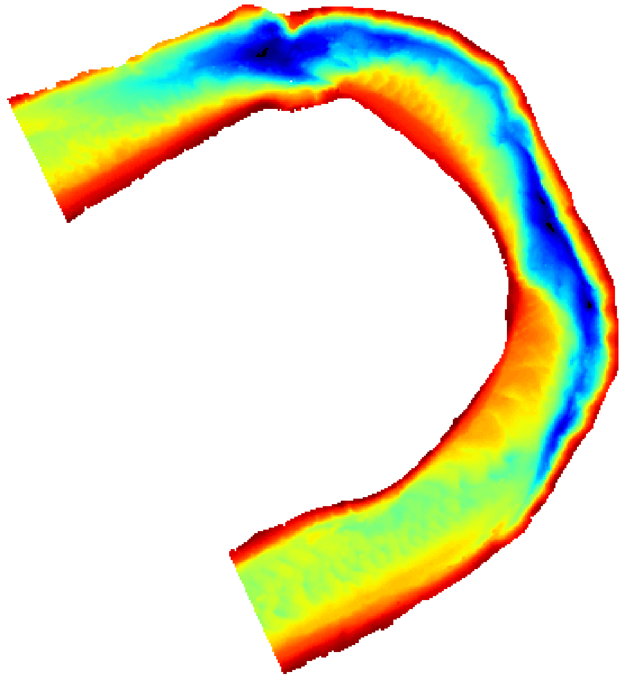
TU Delft

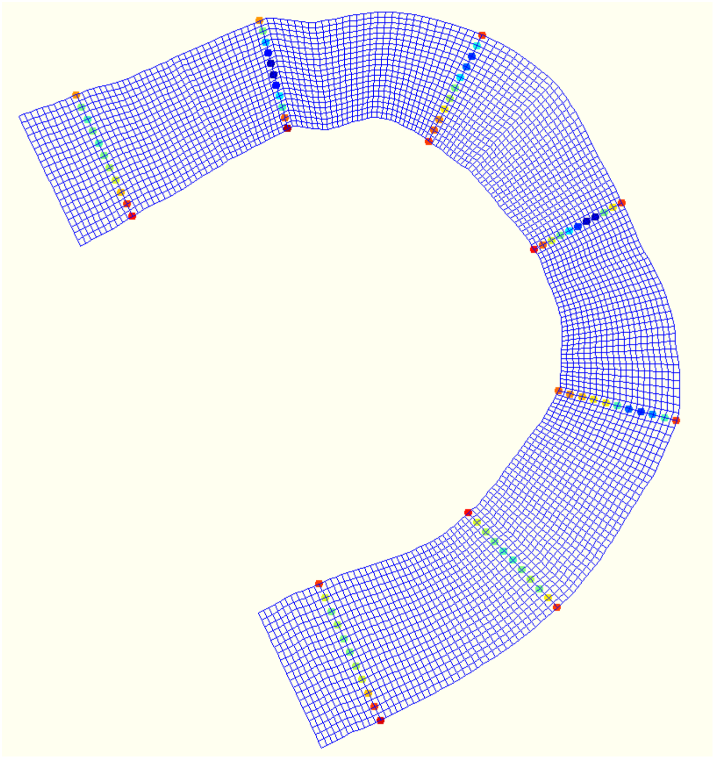
Curvilinear Grid



Data on the Grid

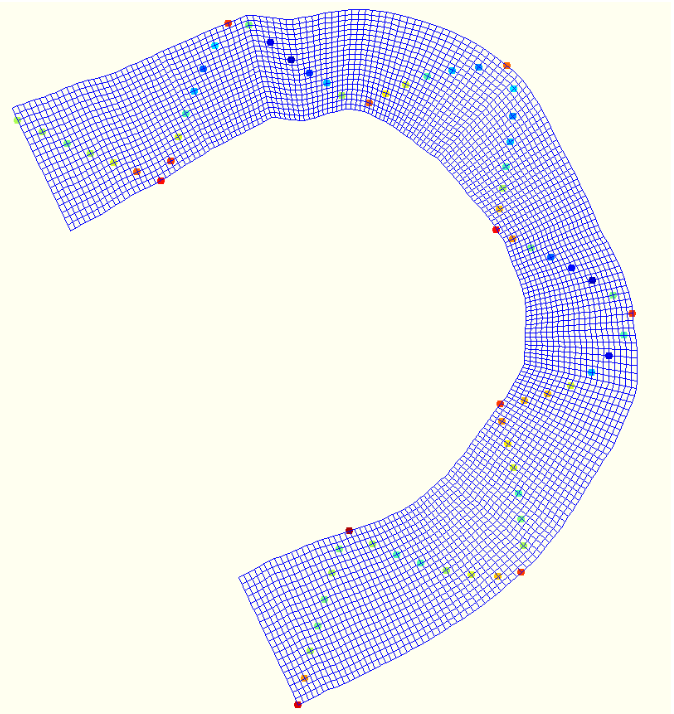
Ground-Truth





cross-sections

“tracklines”

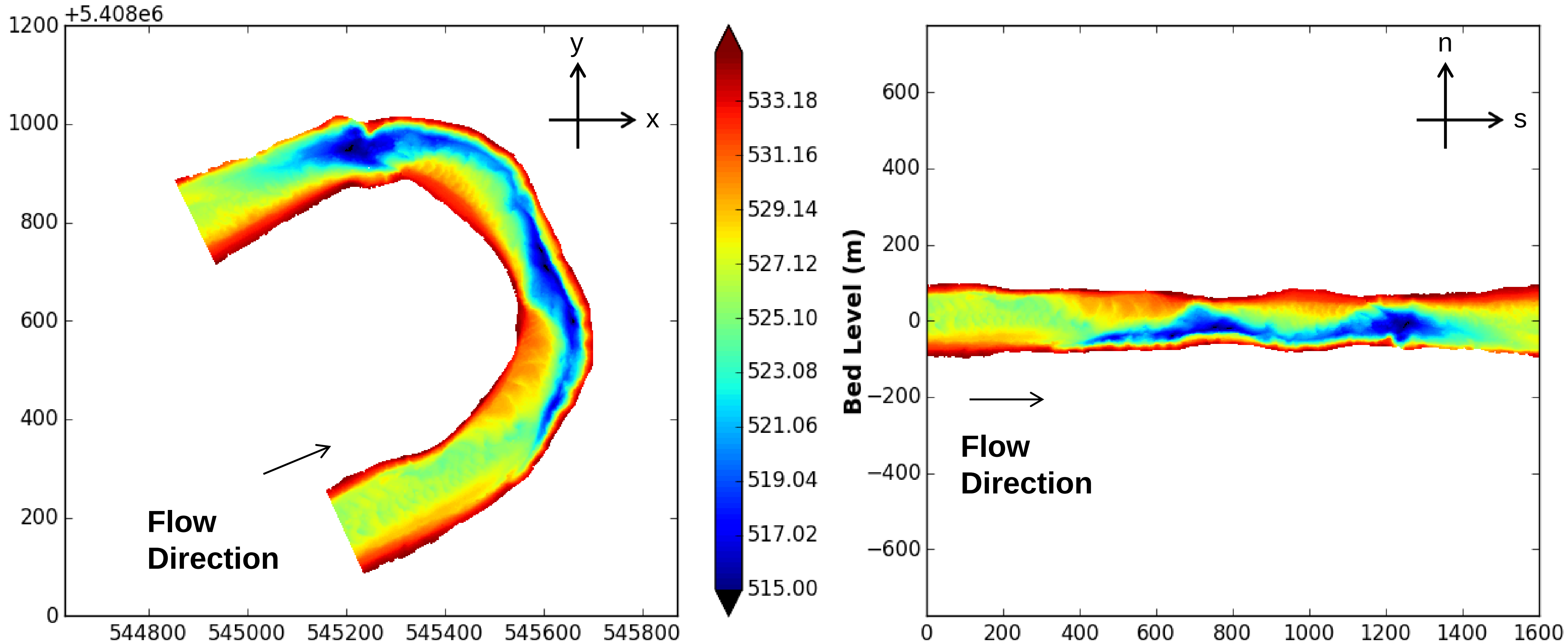


TU Delft

Spatial Interpolation

Spatial Interpolation in Rivers

- **Interpolation Methods** – many, existing and tested.
- In relevance to rivers, feedback is given by Merwade (2006, 2008 & 2009).
- Use a **flow-oriented coordinate system** and account for the **anisotropy** in river bed morphology.



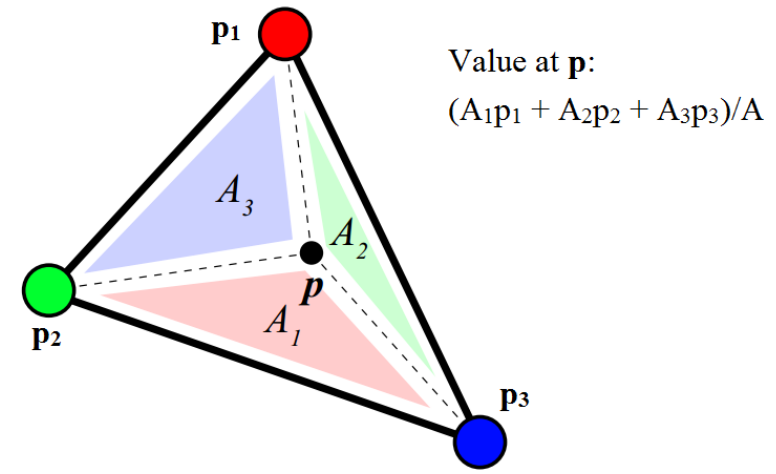
TU Delft

Spatial Interpolation Methods

- <u>Excluded</u>: Kriging, Thin Plate Splines, Natural Neighbour

- <u>Included</u>:

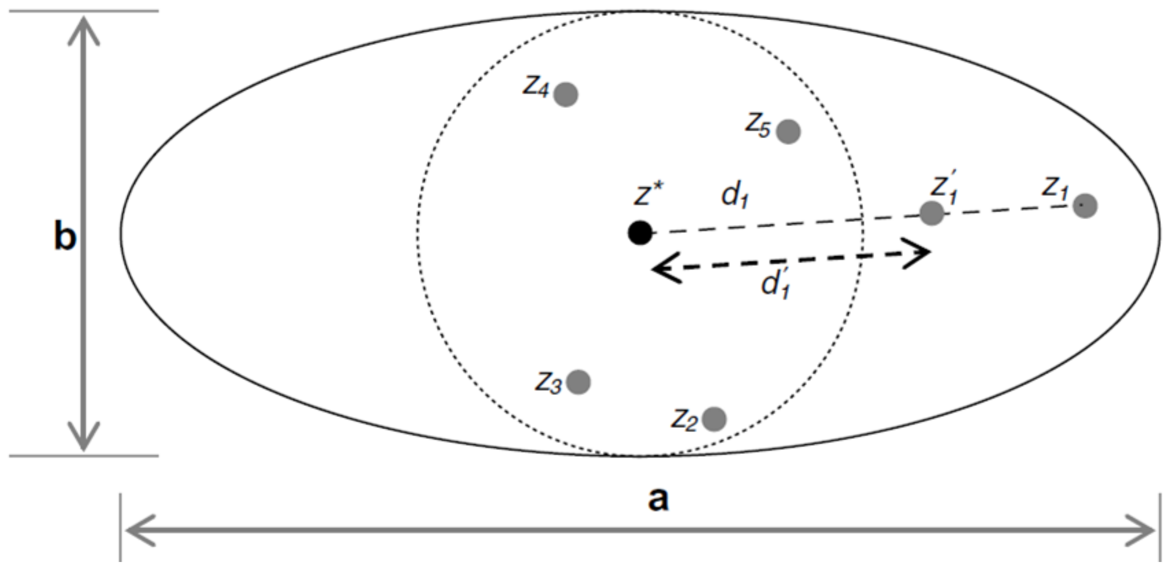
1. Linear Barycentric Interpolation
2. Nearest Neighbour "Interpolation"
3. Inverse Distance Weighting (IDW)
4. Elliptical IDW (EIDW)



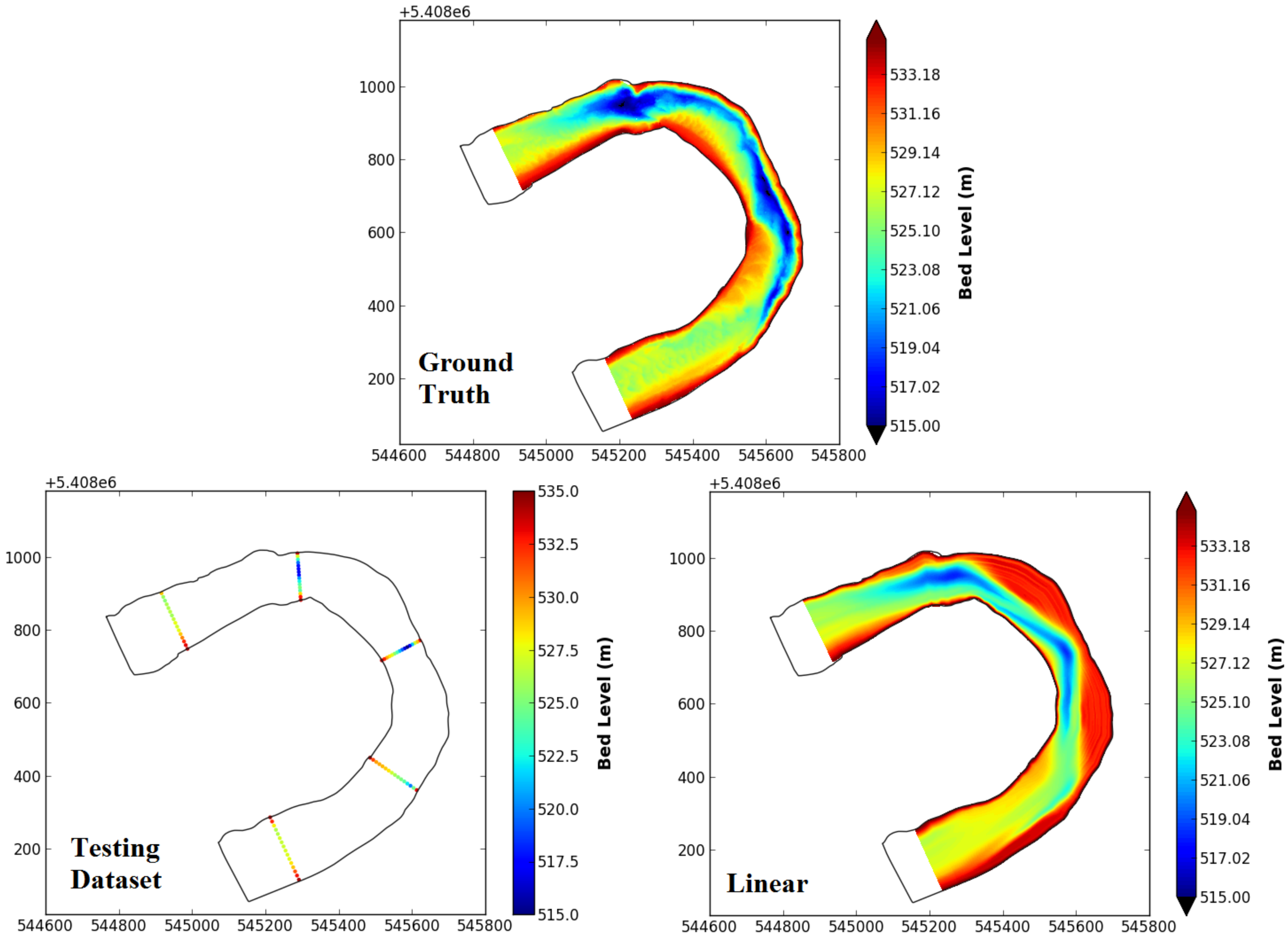
$$z_c = \sum_{i=1}^{N} w_i * z_i \quad , \qquad w_i = \frac{\frac{1}{d_i^p}}{\sum_{i=1}^{N} \frac{1}{d_i^p}}$$

$$d_i = \sqrt{\left(\frac{1}{a_r}\,(s_i - s_c)\right)^2 + (n_i - n_c)^2}$$

$$a_r = \frac{a}{b}$$



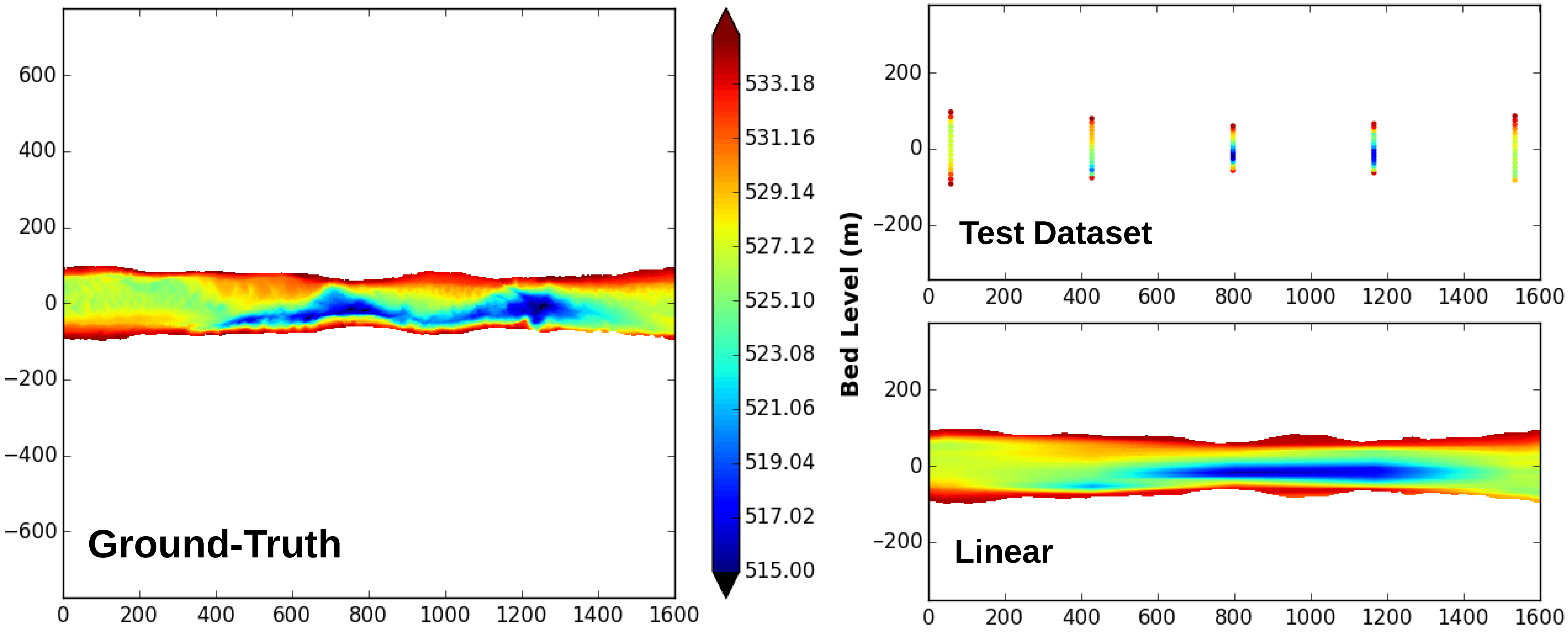
Interpolation – Cartesian System (x,y)



- Interpolation fails because river morphological features are directional (along water flow) and not global.

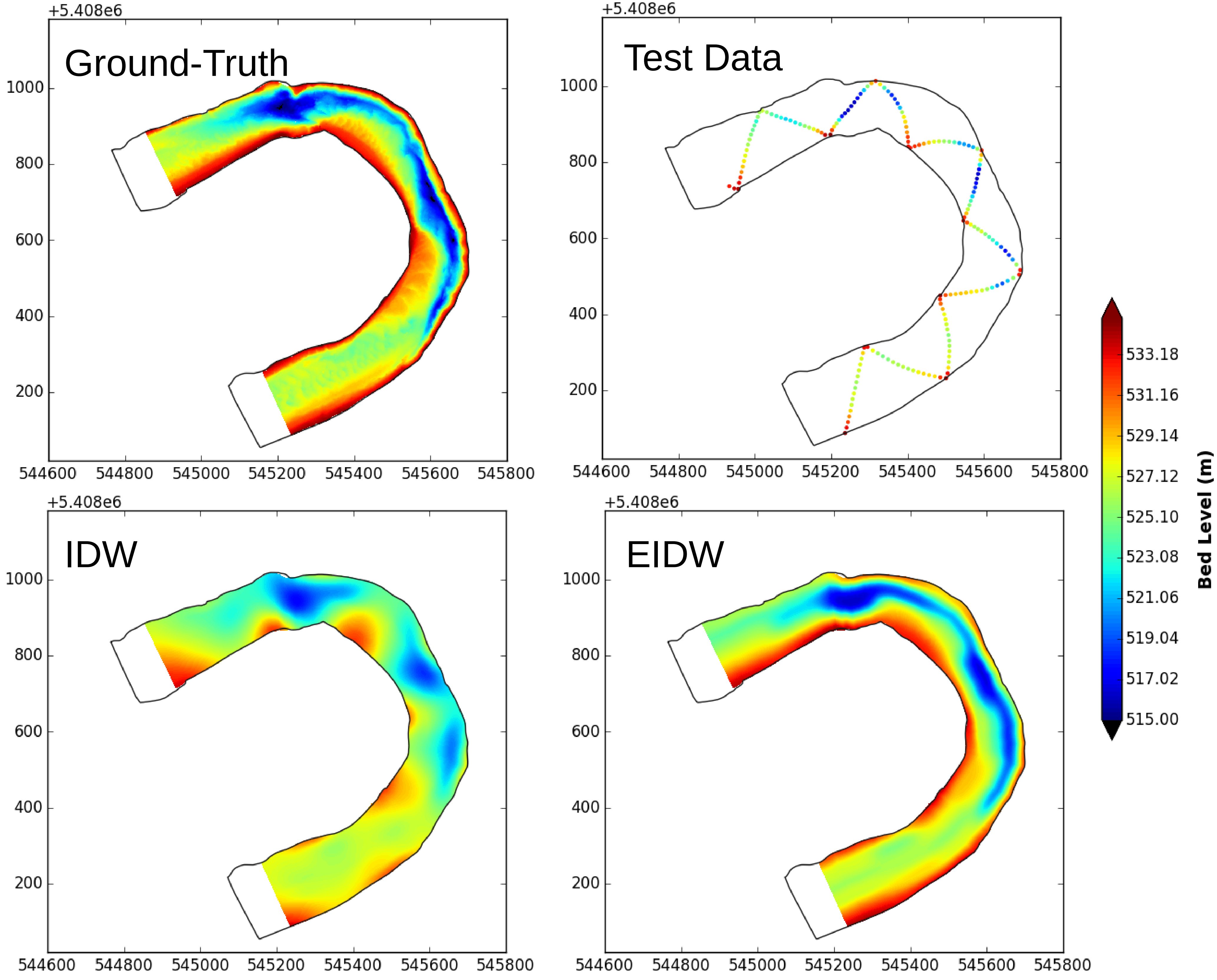
TUDelft

Interpolation – Flow-Oriented System (s,n)



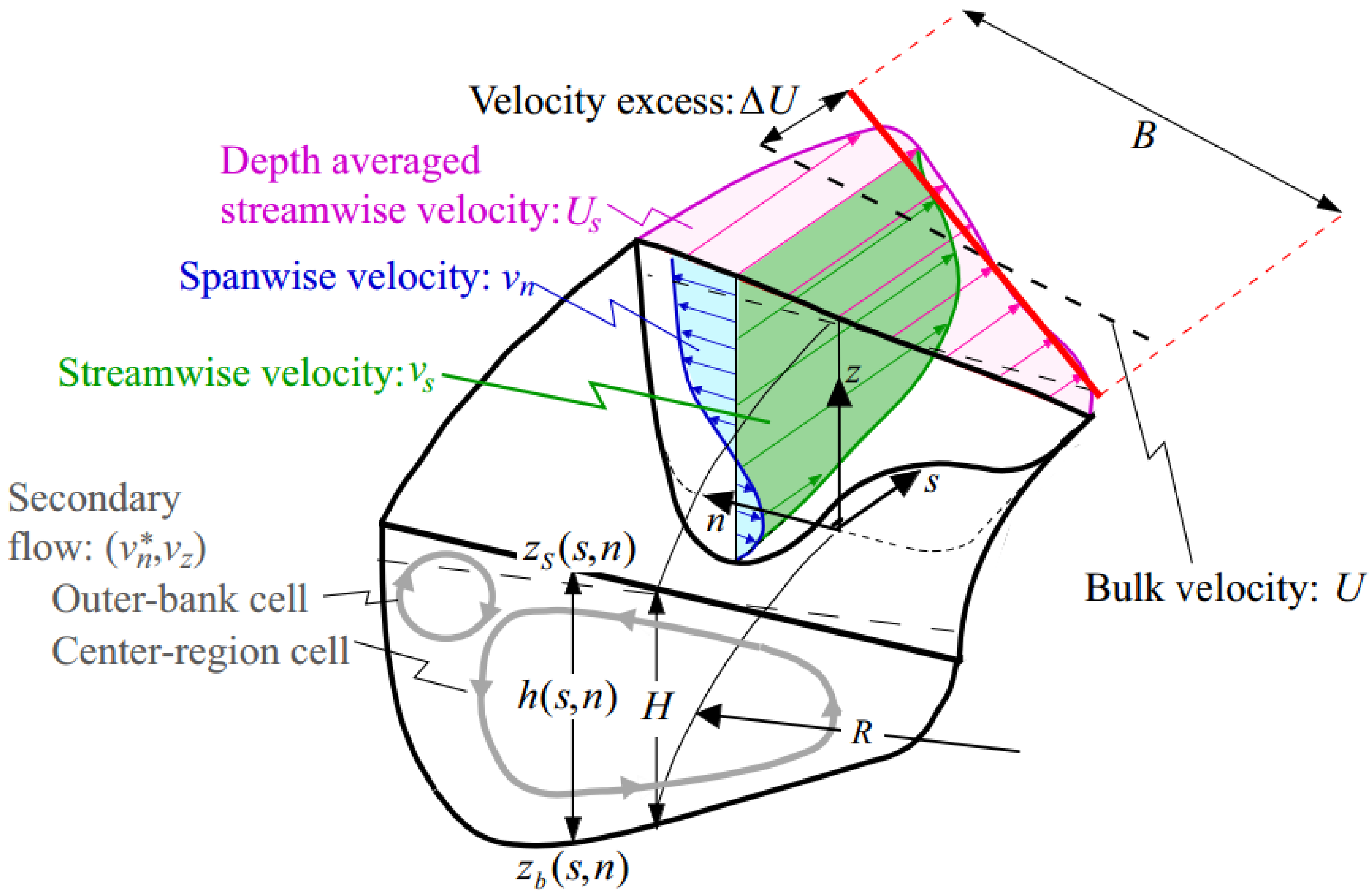
- The data is transformed to the flow-oriented coordinate system (s,n) prior to any spatial interpolation.

Anisotropy


Ground-Truth
Test Data
IDW
EIDW
+5.408e6
1000
800
600
400
200
544600 544800 545000 545200 545400 545600 545800
Bed Level (m)
533.18
531.16
529.14
527.12
525.10
523.08
521.06
519.04
517.02
515.00

Physics-based Model

River Physics Framework I

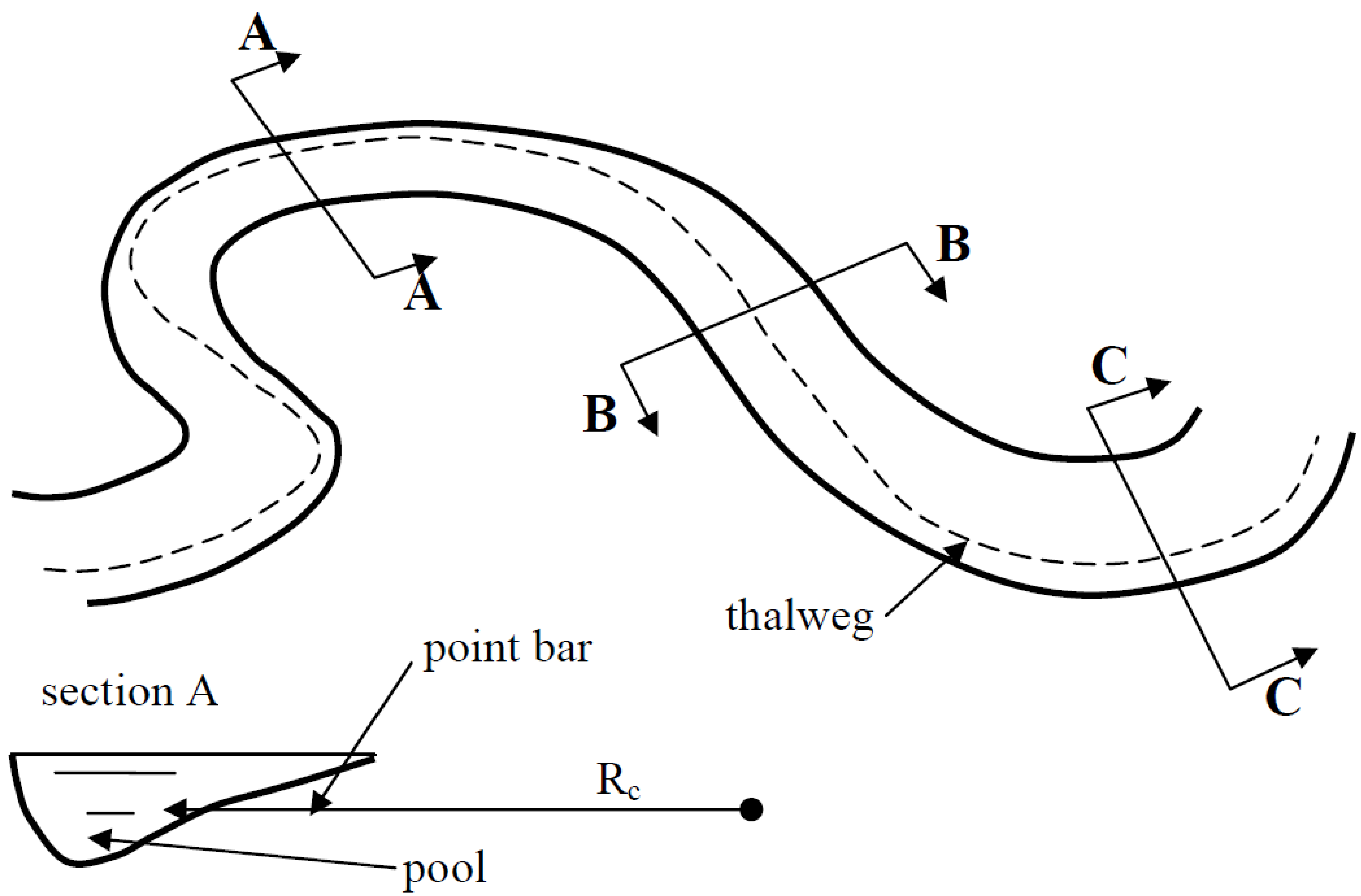


Approximations are needed!

- Sediment balance
- Shallow-water approximations
- Depth-averaging
- Flow-coordinate system (*s*,*n*,*z*)

TU Delft

River Physics Framework II



Cross-sections show a “snapshot” of a channel at a particular span

TUDelft

River Physics Framework III

- Water Steady Flow:
  - Zero-order approximation to momentum & continuity equations (Crosato 2008)

$$h_c = \left(\frac{Q}{B\,C\,\sqrt{i}}\right)^{\frac{2}{3}}$$,where:

h_c - water depth at the centerline [m]
Q - the river discharge [m^3/s]
B - the width [m]
C - the Chézy roughness [$m^{1/2}/s$]
i - the slope [-]

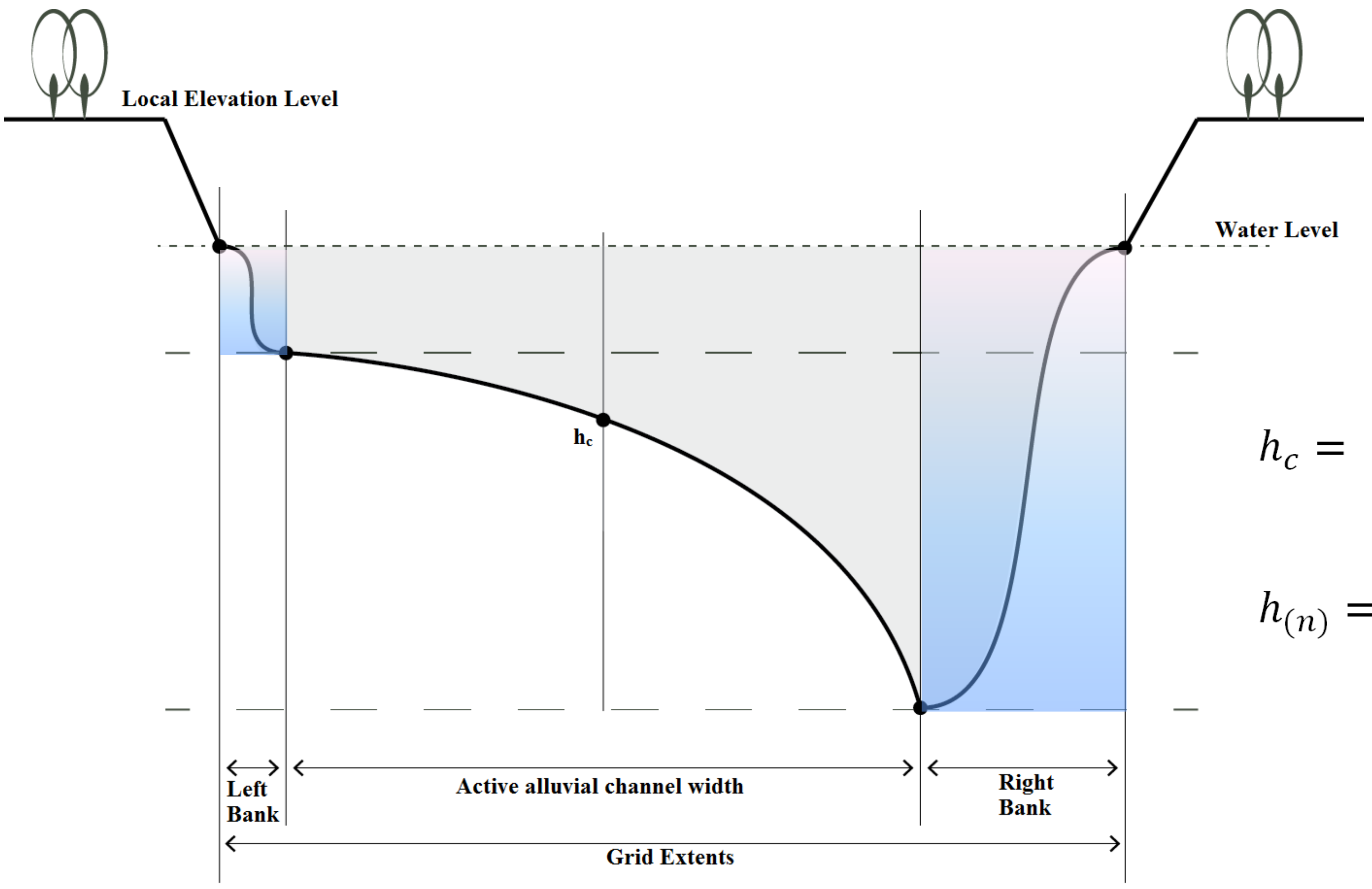
- Bed Level in River Bends:
  - Axi-symmetric solution (Crosato 2008)

$$h_{(n)} = h_c\, e^{A\, f(\theta)\, n\, /\, R_c}$$,where:

h - water depth along n [m]
h_c water depth at the centerline [m]
A - coefficient weighing the influence of the helical flow
f(θ) - weighing function
n - coordinate orthogonal to the streamline [m]
R_c - Radius of curvature [m]

TU Delft

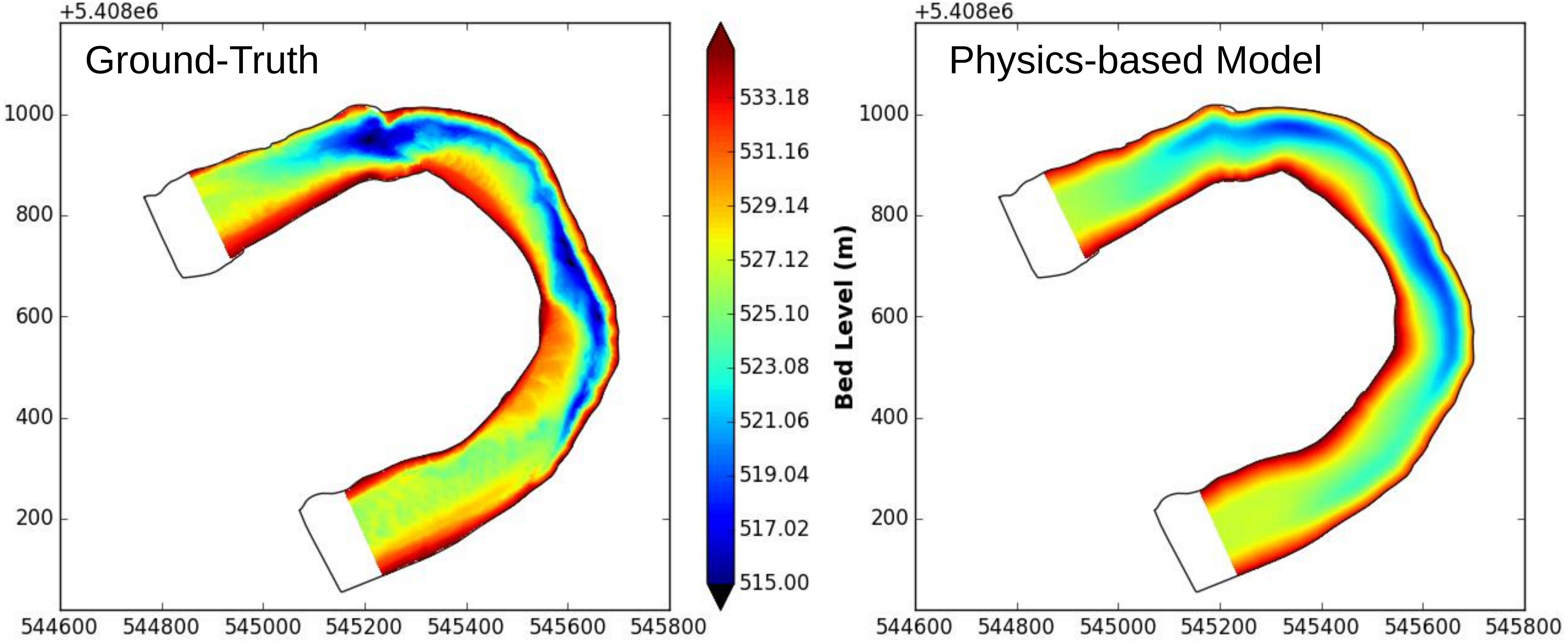
Physics-based Model



$$h_c = \left(\frac{Q}{B\ C\ \sqrt{i}}\right)^{\frac{2}{3}}$$

$$h_{(n)} = h_c\ e^{A\ f(\theta)\ n\ /\ R_c}$$

Model Dataset



TU Delft

Fusion Method

Fusion Method

EIDW

$$F_{(s,n)} = w_{(s,n)}\, B_{(s,n)} + (1 - w_{(s,n)})\, I_{(s,n)}$$

$F_{(s,\,n)}$: fusion result at (s, n)

$B_{(s,n)}$: model result at (s,n)

$I_{(s,n)}$: interpolation result at (s,n)

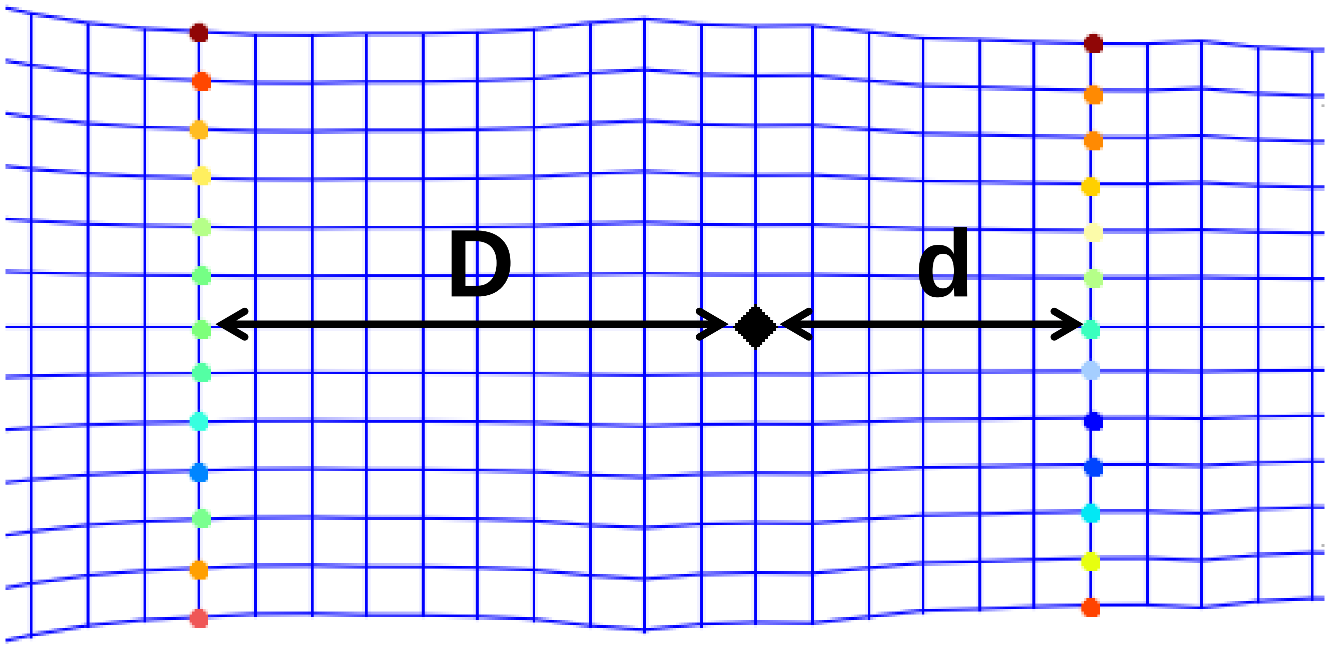
$w_{(s,n)}$: model weight at (s,n)

- Basic assumption: The closest an unsampled point lies to a sampled point, the more the interpolation's result needs to be taken into consideration. The further away it is, the more the physics-based model's result is significant.

Fusion – Cross-sections

$$F_{(s,n)} = w_{(s,n)}\, B_{(s,n)} + (1 - w_{(s,n)})\, I_{(s,n)}$$

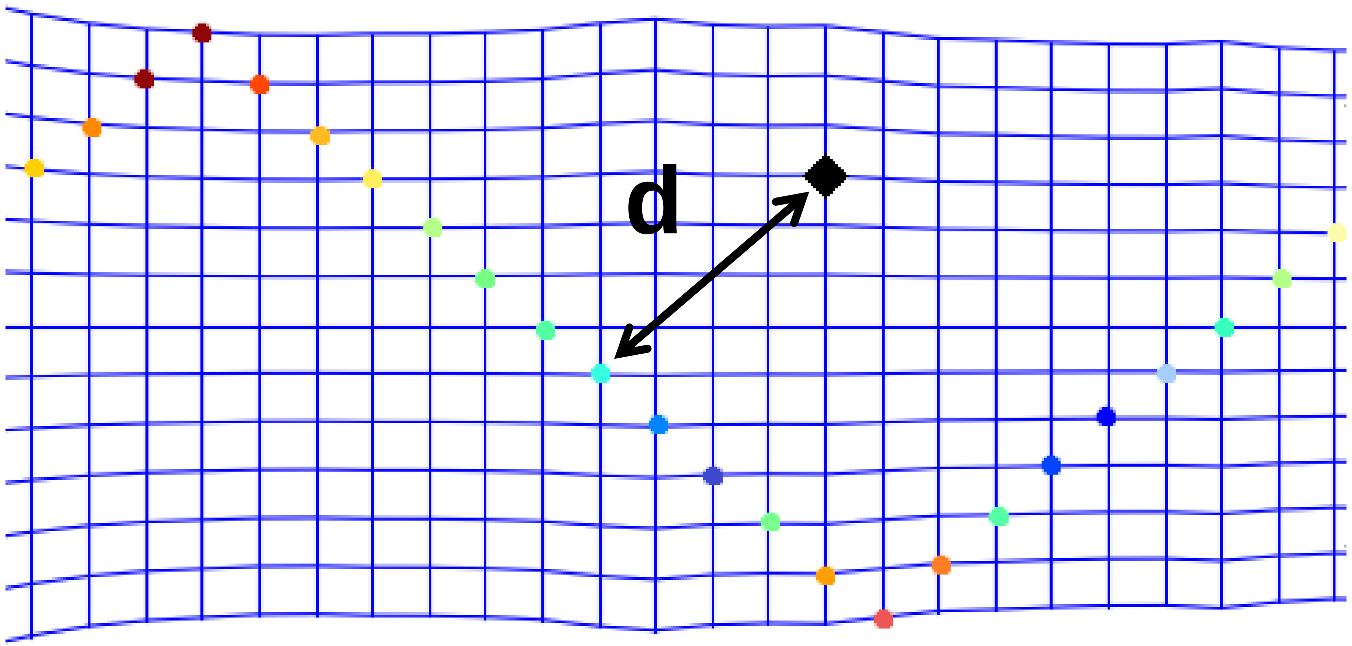
$$w_{(s,n)} = \begin{cases} 0 \quad , & d = 0 \\ \dfrac{1}{1 + \left(\dfrac{D-d}{2d}\right)^2}, & otherwise \end{cases}$$



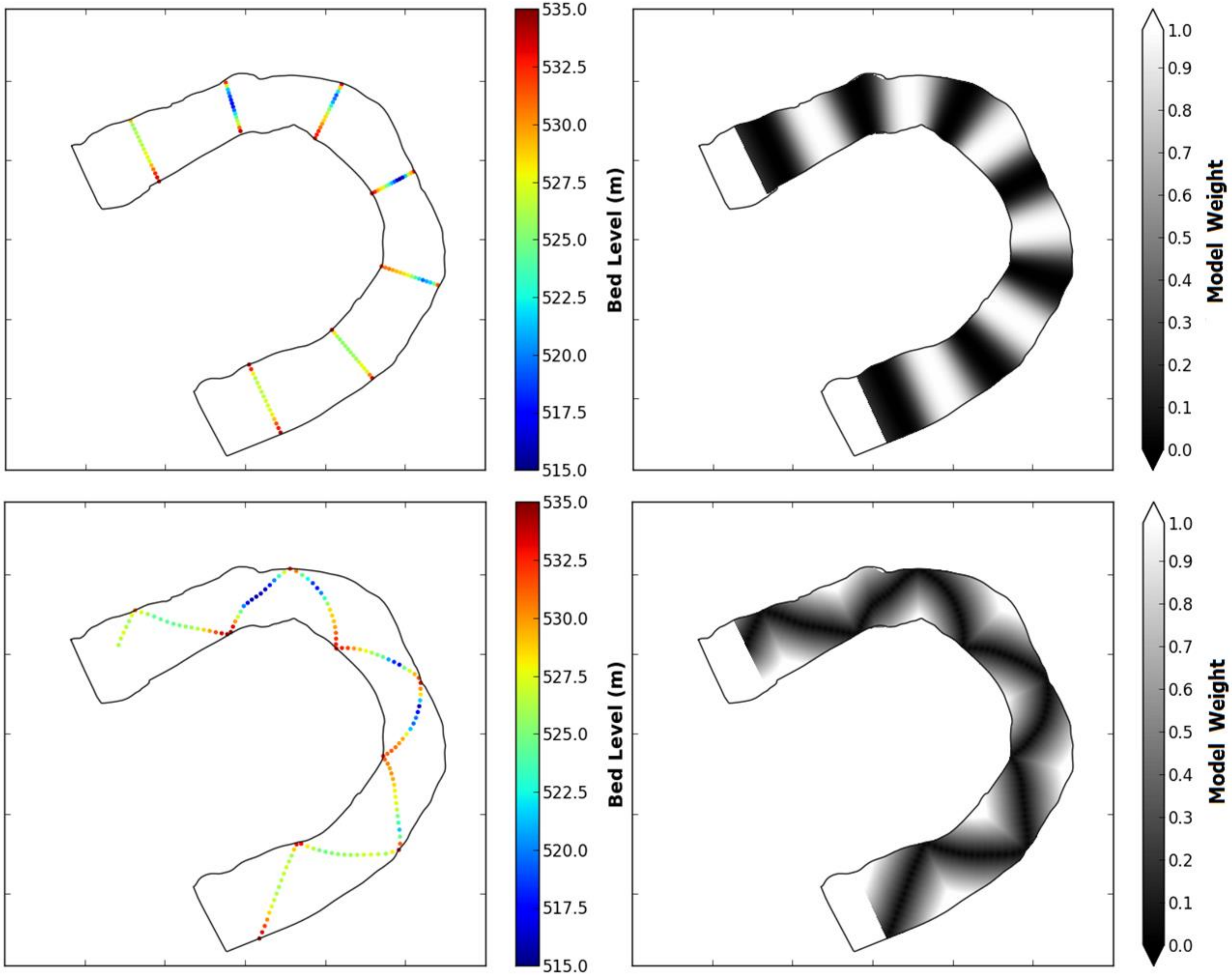
Fusion – Tracklines

$$F_{(s,n)} = w_{(s,n)}\, B_{(s,n)} + (1 - w_{(s,n)})\, I_{(s,n)}$$

$$\textbf{\textit{if } } \boldsymbol{d \geq D_{thres}}:$$
$$w_{(s,n)} = 1$$
$$\textbf{\textit{else}}:$$
$$w_{(s,n)} = \frac{d}{D_{thres}}$$



Fusion Concept

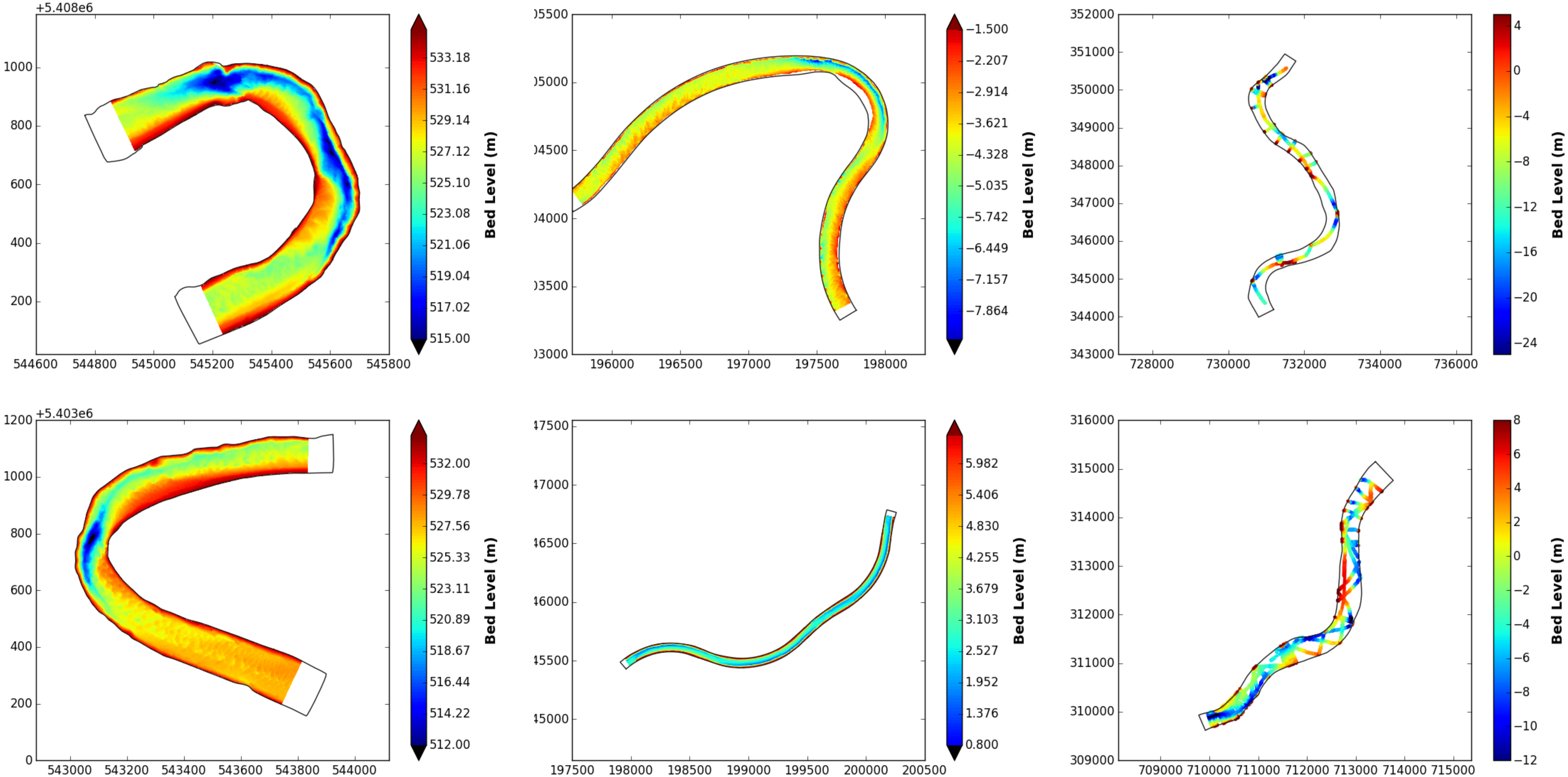


Analysis of Results

TU Delft

Experiments Datasets

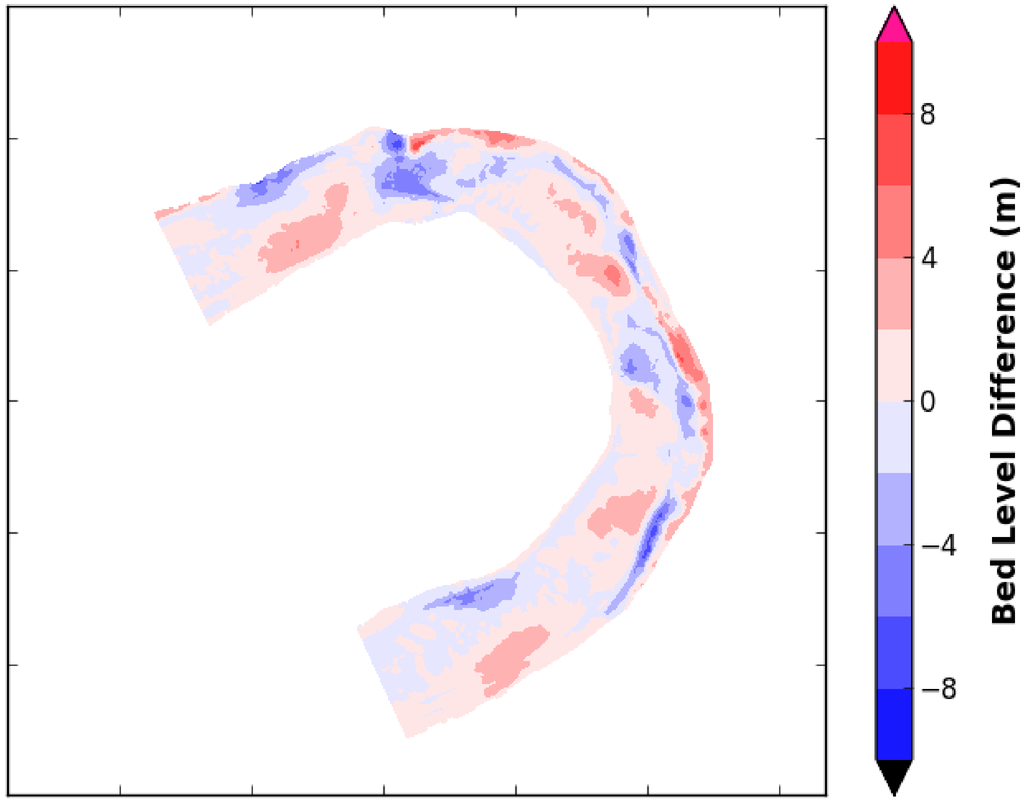
Kootenai | IJssel | Danube



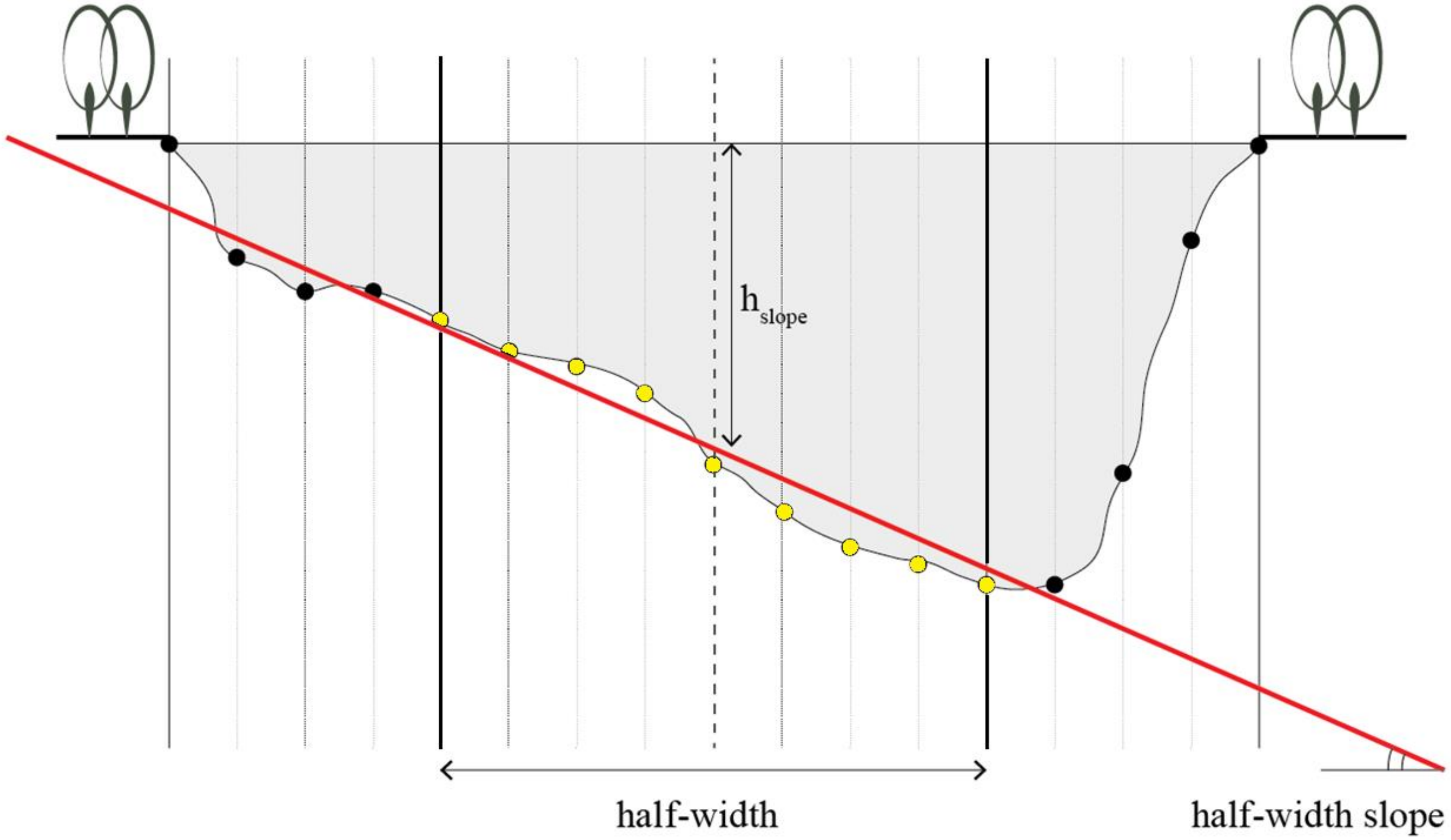
Evaluation Methods

Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(z_i - z_i')^2}$$



Error Maps

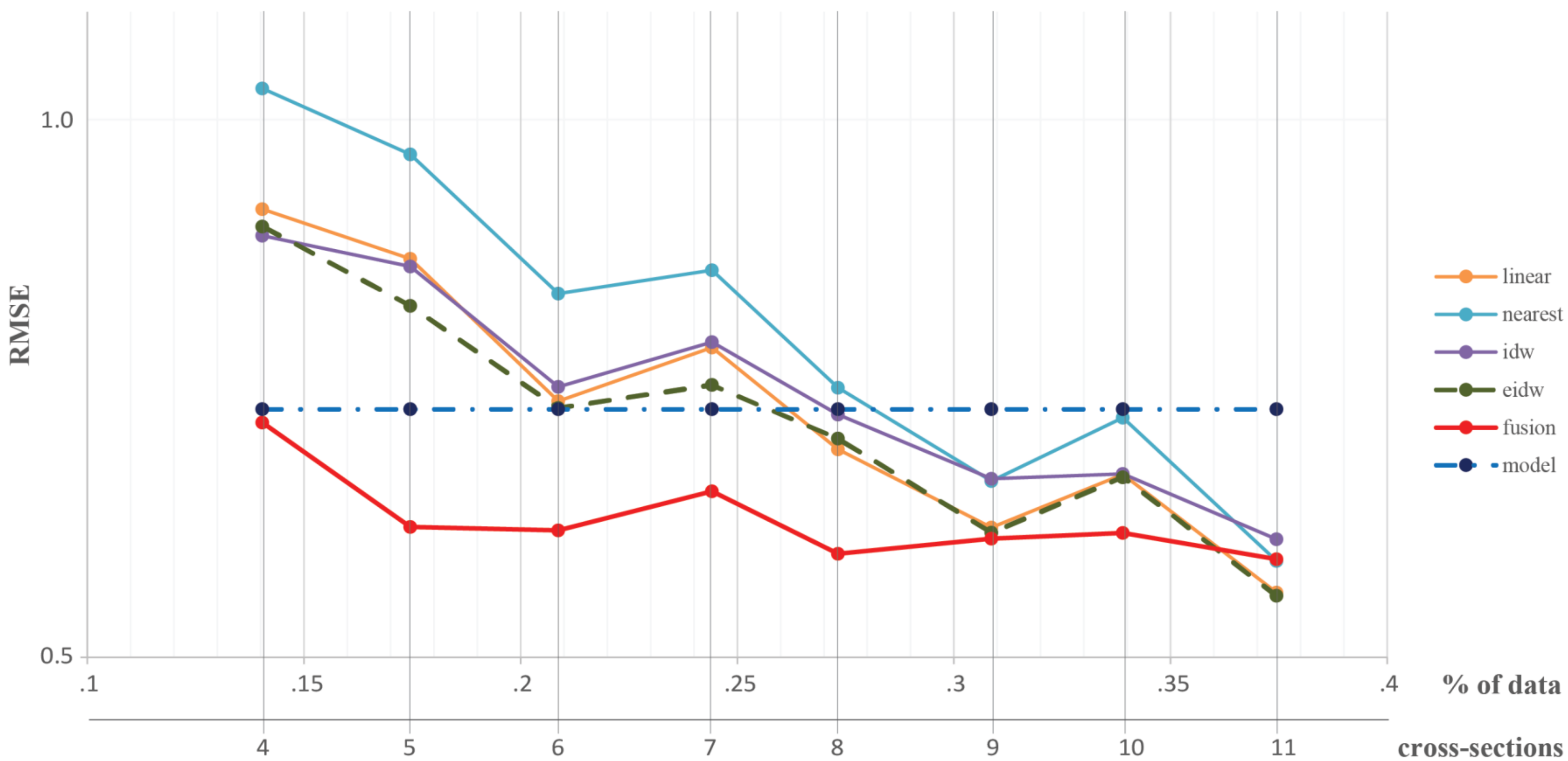


Normalized Half-Width Slope (NHWS)

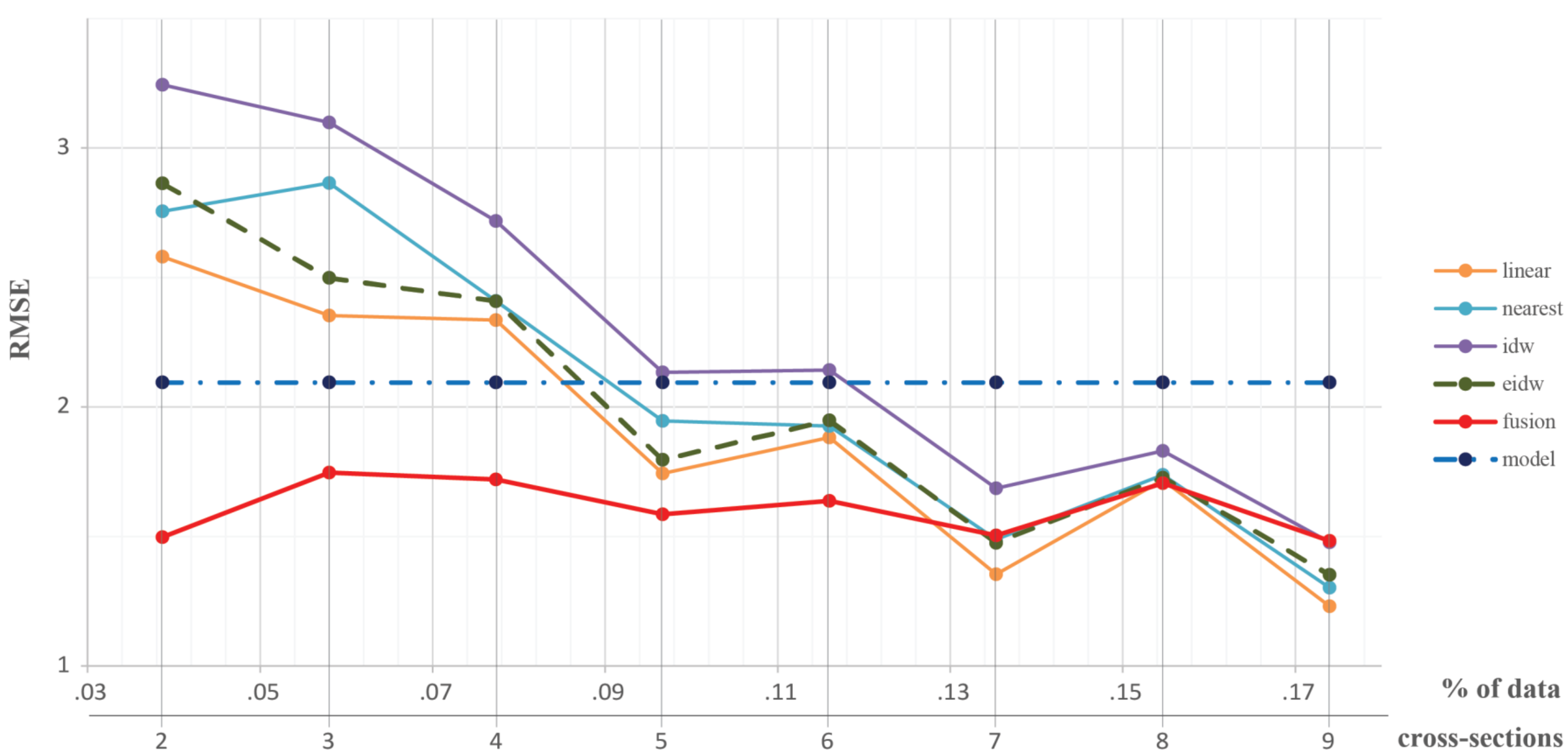
TU Delft

RMSE

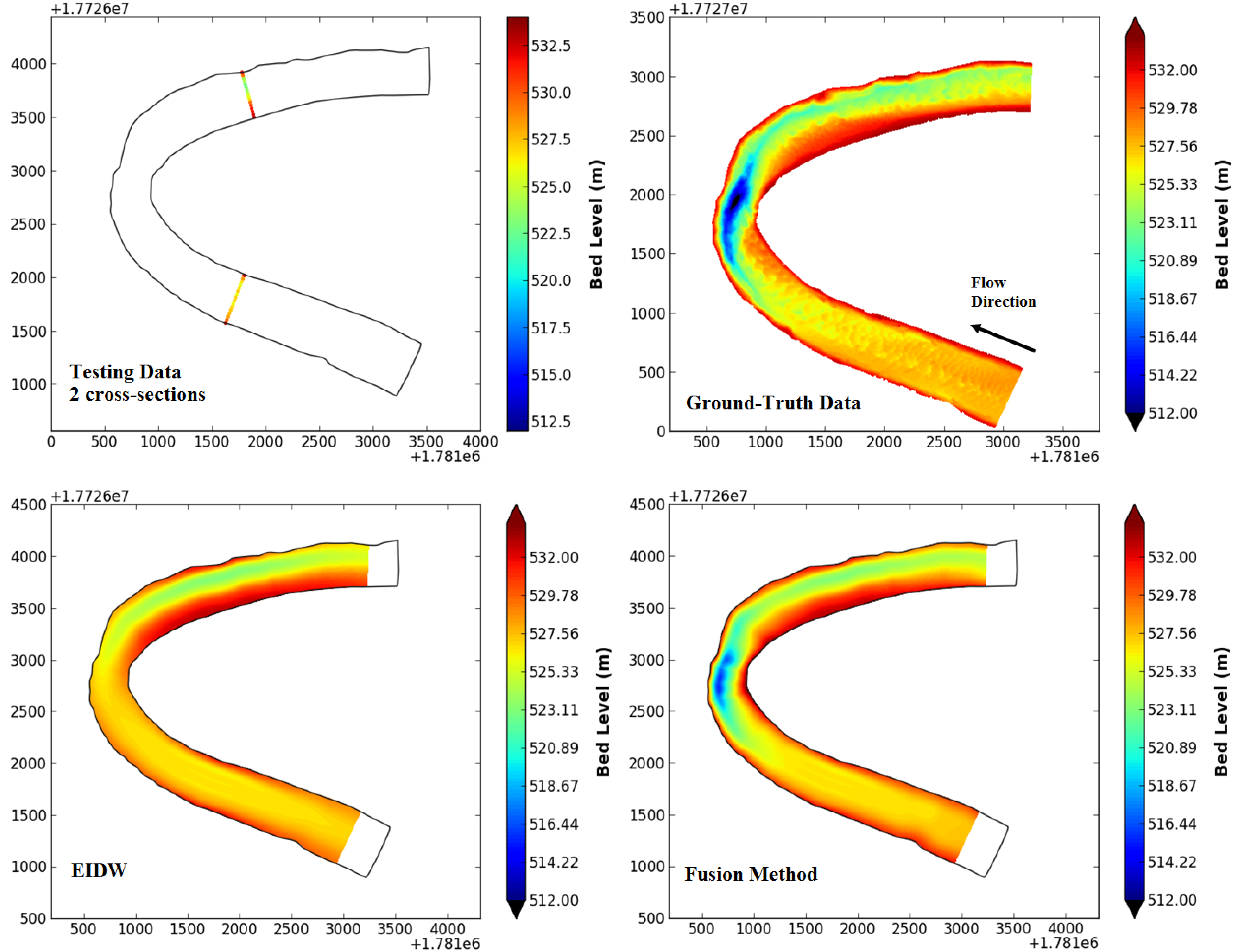
RMSE of Cross-Sections [IJssel #1, North]



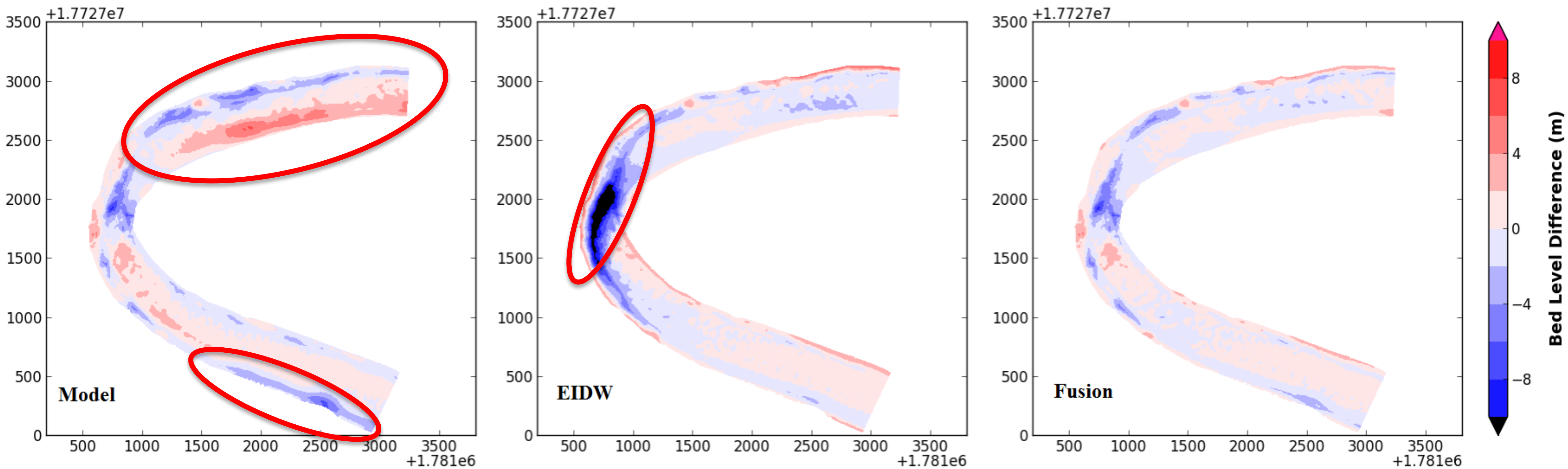
RMSE of Cross-Sections [Kootenai #2, South]

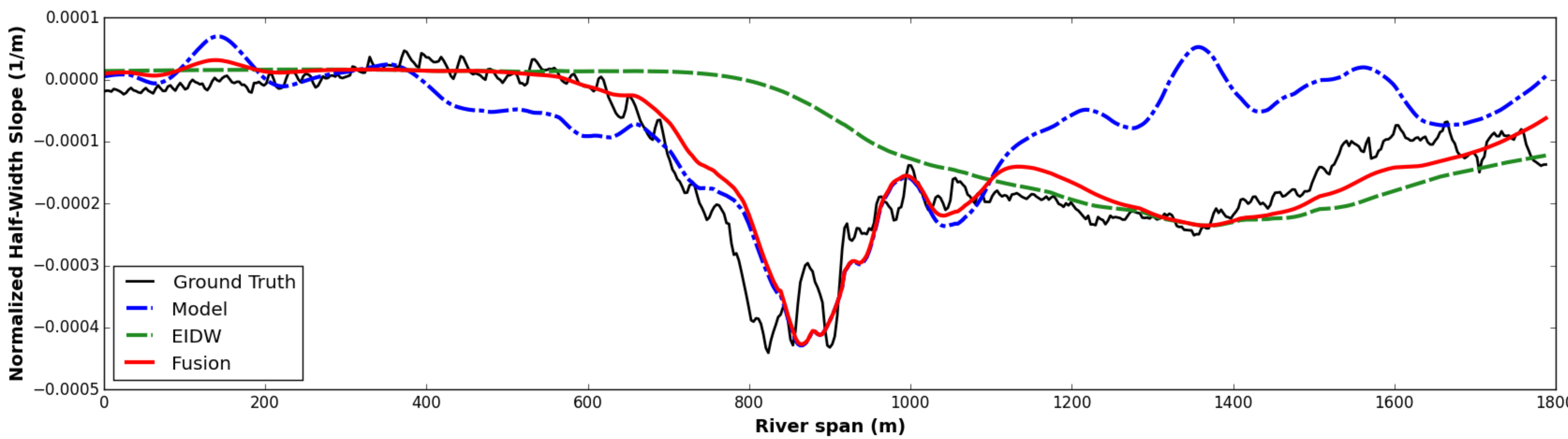


Extreme Cases

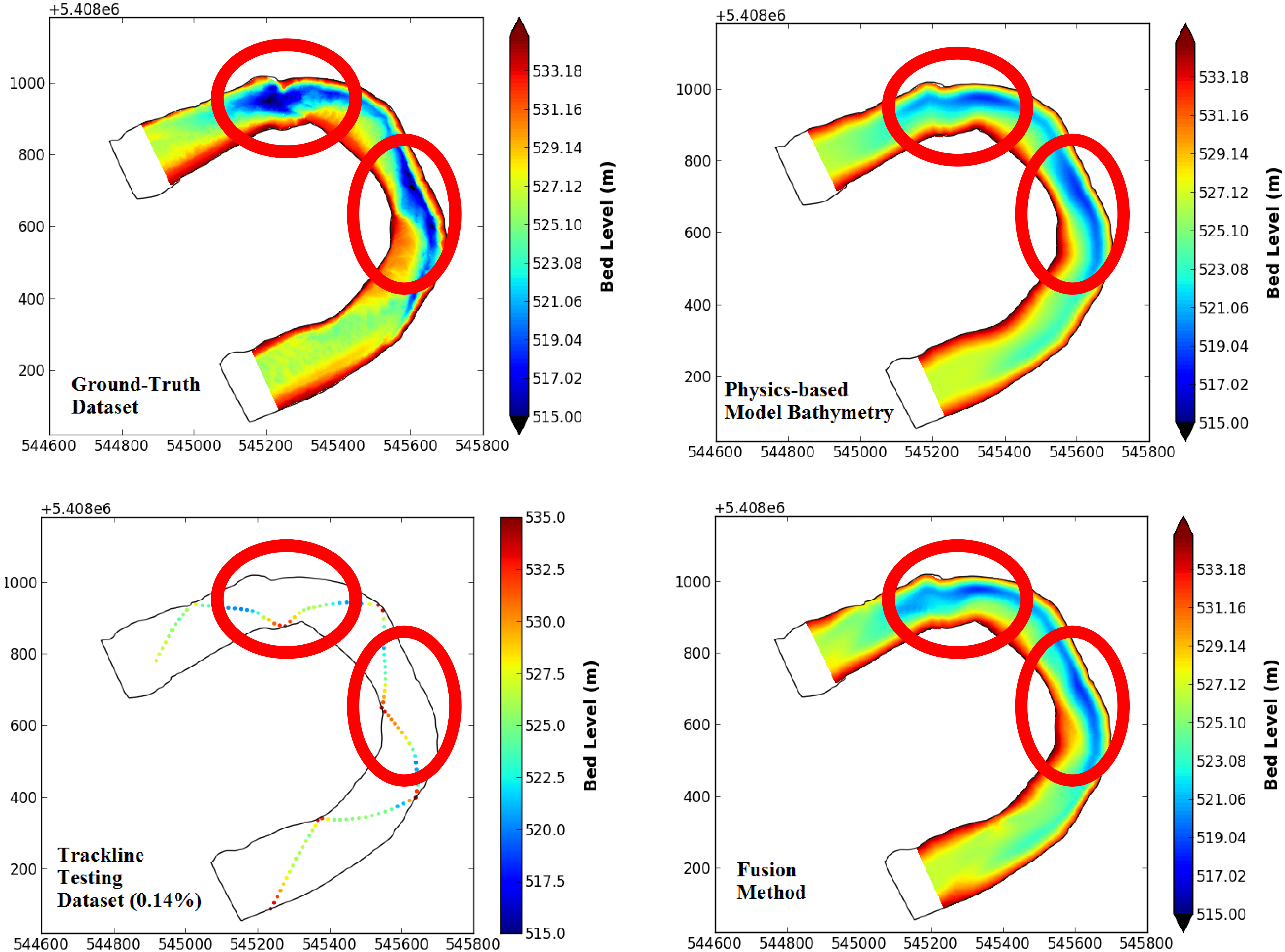


Error Maps and NHWS



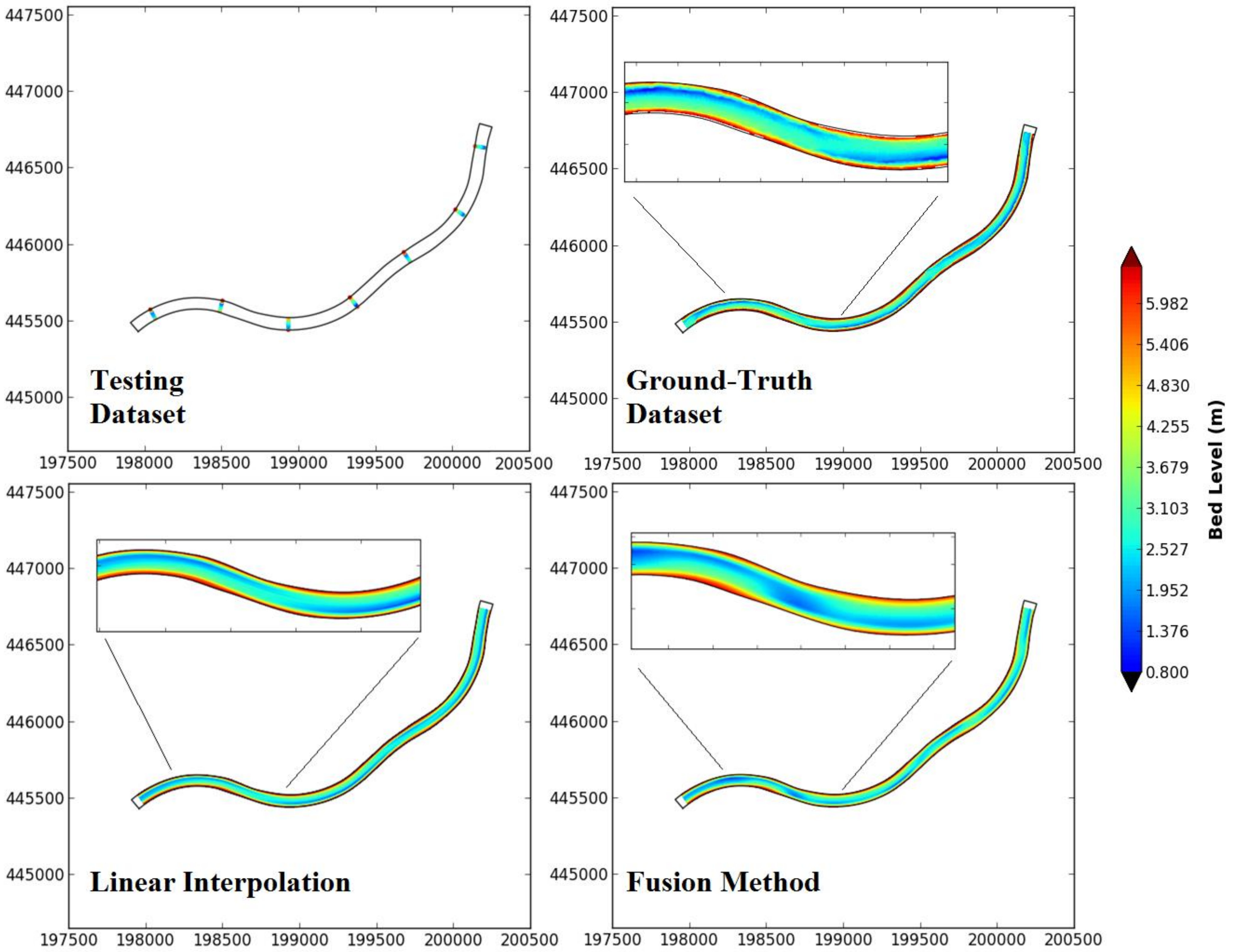


Success and Failure

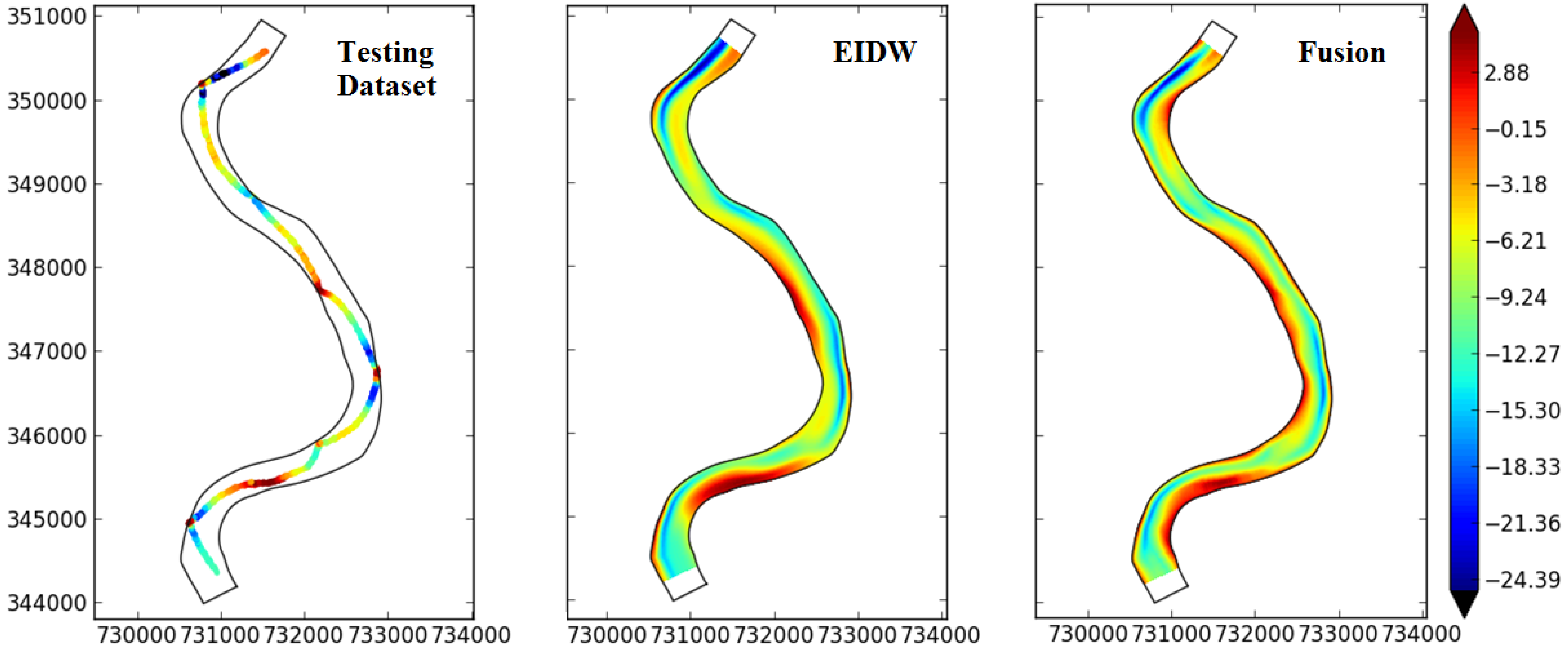


TU Delft

"Soft" failures



Danube and Lag Effects



Conclusions

Conclusive Remarks

- Interpolation with scarce data in rivers is problematic.
- A physics-based model alone does not secure a result.
- Flow-oriented interpolation is a necessity in rivers.
- Anisotropy should be considered during interpolation.
- Space lag effects cannot be predicted by a simplified physics-based model.

Research Question Answers

How can a spatial interpolation method be coupled with river morphology physics in order to approximate better the river bed topography when input data are scarce?

- ***Fusion Method***: Combination of a simplified physics-based model and spatial interpolation that accounts for anisotropy. Spatial considerations based on distances/patterns of sampled data.

- *What is an objective function to measure 'goodness-of-fit' of the method?*
  - RMSE (numerical), Error Maps (qualitative), NHWS (targeted). **=> RMSE (stricter)**

- *What coordinate system allows for better predictions on riverbed topography?*
  - Flow-Oriented Coordinate System (*s,n,z*). Special significance with **scarcer data.**

- *How much of the full data can be thinned out and still have a successful outcome?*
  - **Varies.** But interesting observations made as to where the collection should be denser/thinner.

TU Delft

Recommendations

- Fusion method:
  - Choice of Interpolation: EIDW *vs* Linear.
  - Sample data types: Regular cross-sections *vs* Tracklines / irregular data.
  - Can be used on larger channel stretches.

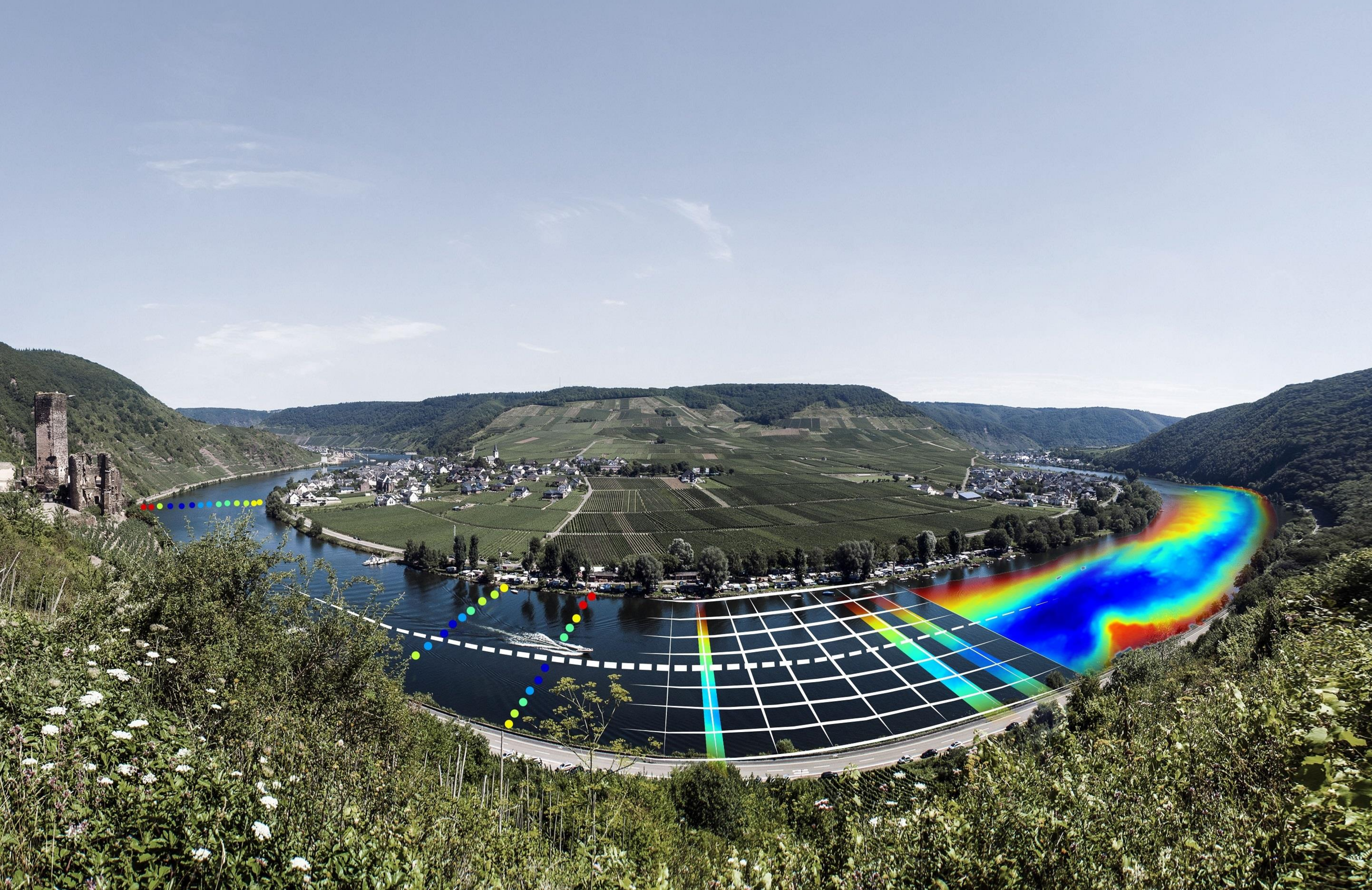
Future Work

- Further validation through more test cases.
- Implement space lag and other natural effects.
- Fusion Method on classified river segments:
  - Piecewise implementation
  - Vary Interpolations
  - Minimize cross-sectional data collection.

- Use different physics-based model.
- Implement interpolation within the physics-based model.
- Application: compute/predict navigational routes for ships.

TU Delft

Thank you for your attention



Referenced Pictures

- p.1, 45: “donnosch”, Mosel River Curve, https://interfacelift.com/wallpaper/details/3527/mosel_river_curve.html
- p.3: “svetik”, Tuscany Italy, http://mediatravel.xyz/cat2/chto-posmotret-v-toskane-italiya.html
  PLPT (Pyramid Lake Paiute Tribe), http://plpt-waterquality.net/about.html
  MERI (Meadowlands Environmental Research Institute), http://meri.njmeadowlands.gov/projects/continuous-water-monitoring-stations/
  NOAA, Coast Survey (multibeam), https://noaacoastsurvey.wordpress.com/about/
- p.6: Simonas Vaikasas, barge in Danube river, at evening sky, http://www.shutterstock.com/pic.mhtml?id=64675078
  DEME, CFE, http://en.cfe.be/p%C3%B4les/dredging/deme.aspx
  Reuters, Missouri, http://www.ibtimes.com/missouri-river-flooding-threatened-americas-nuclear-plant-photos-707275
- p.17: EIDW scheme, Merwade V., Maidment D.R., & Goff J.A. (2006). Anisotropic considerations while interpolating river channel bathymetry. Journal of Hydrology, 331(3–4), 731–741.
- p.22: 3D schematized bend flow, Ottevanger W., (2013). Modelling and parameterizing the hydro- and morphodynamics of curved open channels. PhD Thesis, TU Delft.
- p.23: Typical river cross-sections, Crosato, A., (2008). Analysis and modeling of river meandering, PhD Thesis, TUDelft.

TU Delft