Assimilating SAR-derived information into hydraulic models for improving flood prediction

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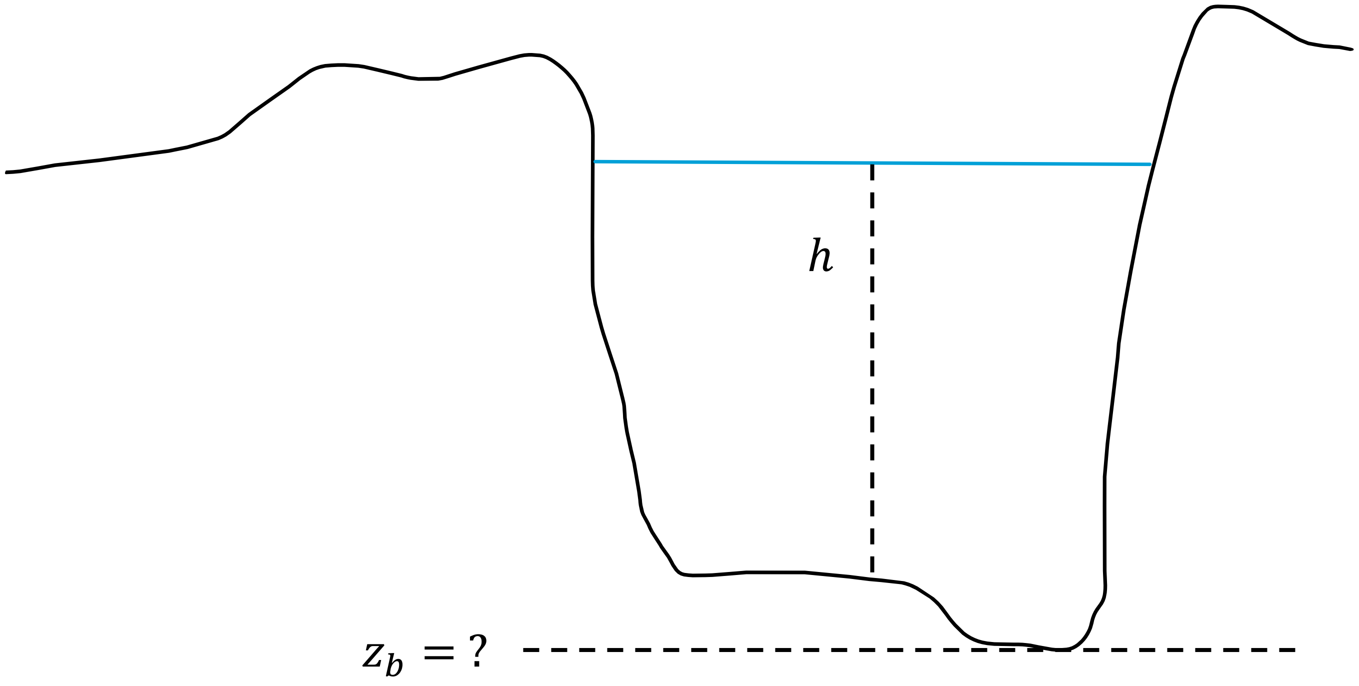
Prediction with hydraulic modelling



- Shallow Water Equations
- Lack of data (Hostache et al. 2015)
- Uncertainty within numerical models

Satellite imagery

- Availability, global coverage
- Water detection on SAR images (Amitrano et al. 2024)

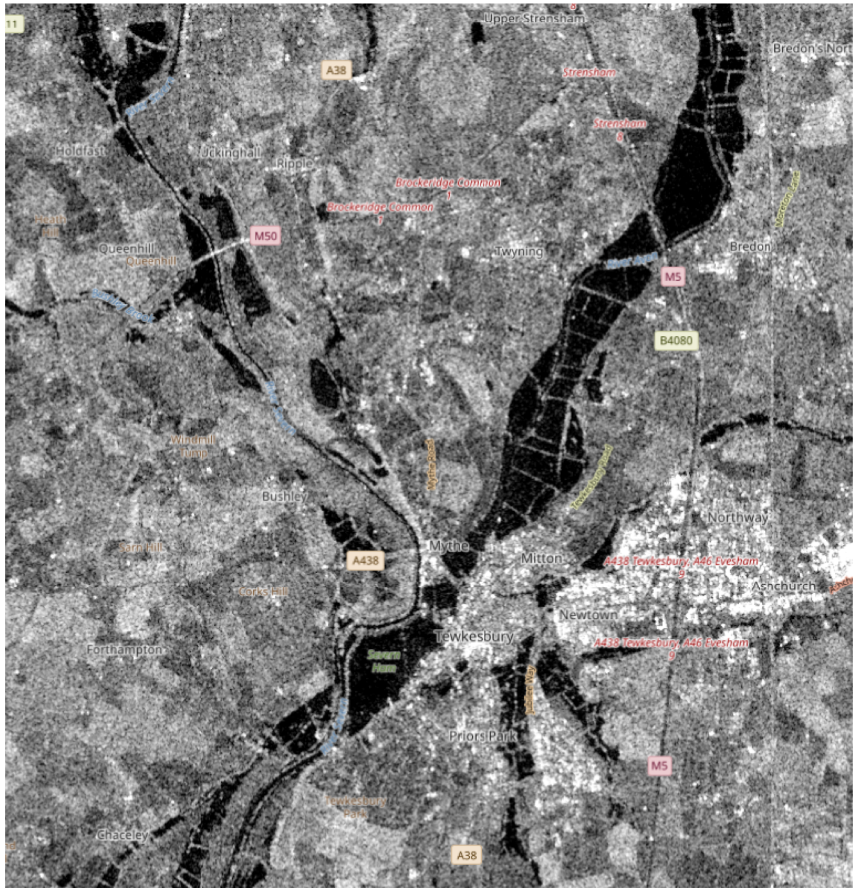
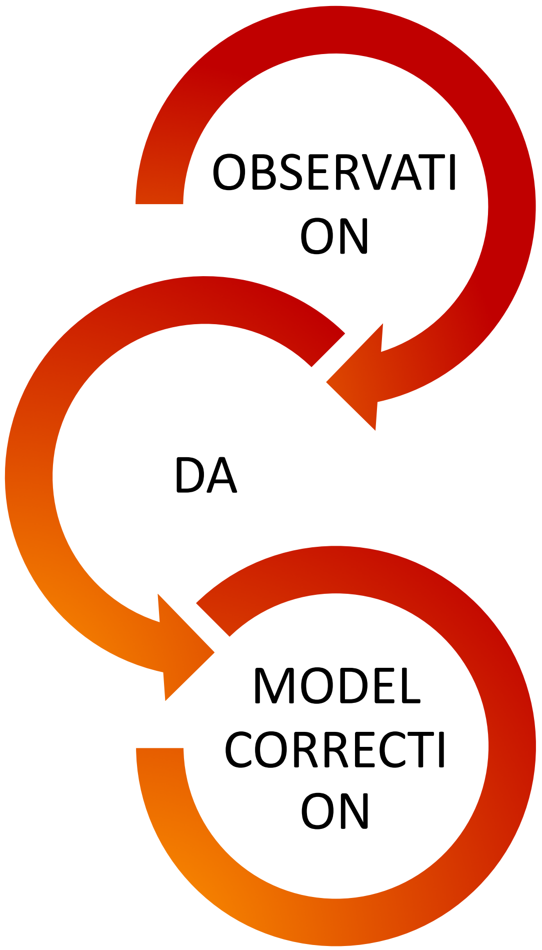


Figure 1: Sentinel-1 SAR image, Tewkesbury (UK), acquired on the 6th of January 2025. Source: Copernicus Browser

Data assimilation (DA)



- Largely used, especially with Earth observation data (Cooper et al. 2019)

Can we use SAR-derived information as observation in a DA framework to estimate missing parameters and therefore facilitate the setting up of flood forecasting models?

Methods

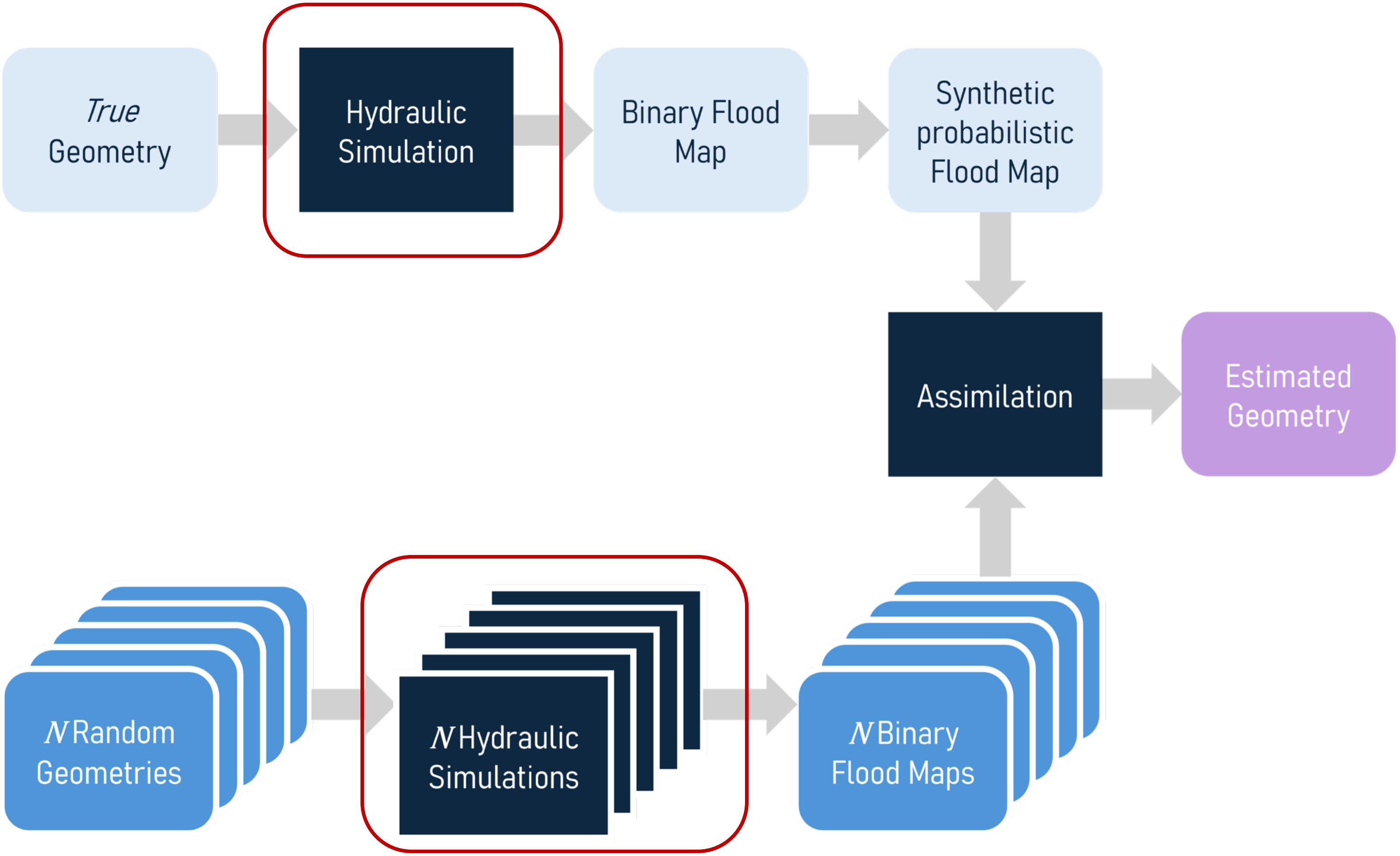


Figure 2: DA Framework for the synthetic twin experiment on the River Severn.

Hydraulic simulation

$$\phi_\Omega(z) = \frac{1}{\Omega}\int_\Omega \varepsilon(x,y,z)d\Omega$$

$$\phi_\Gamma(z) = \frac{1}{\Gamma}\int_\Gamma \varepsilon(x,y,z)d\Gamma$$

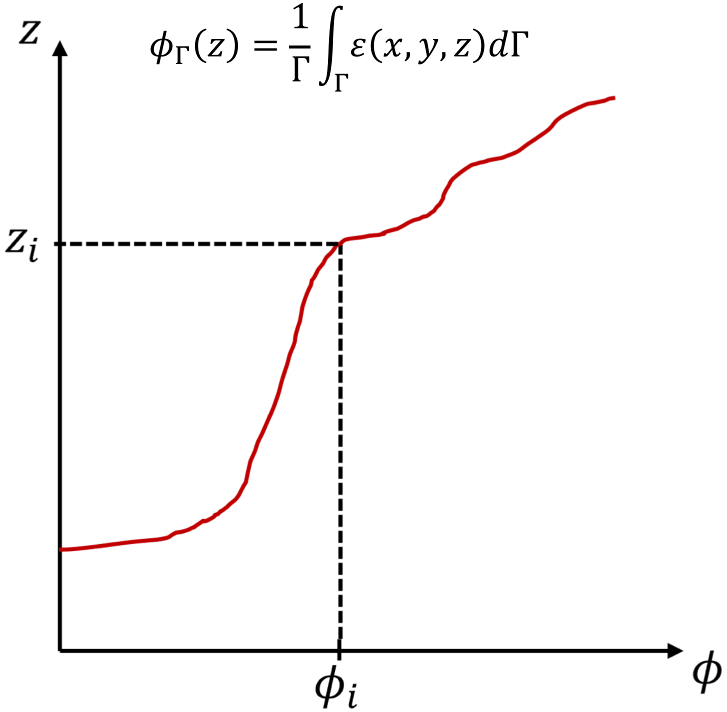
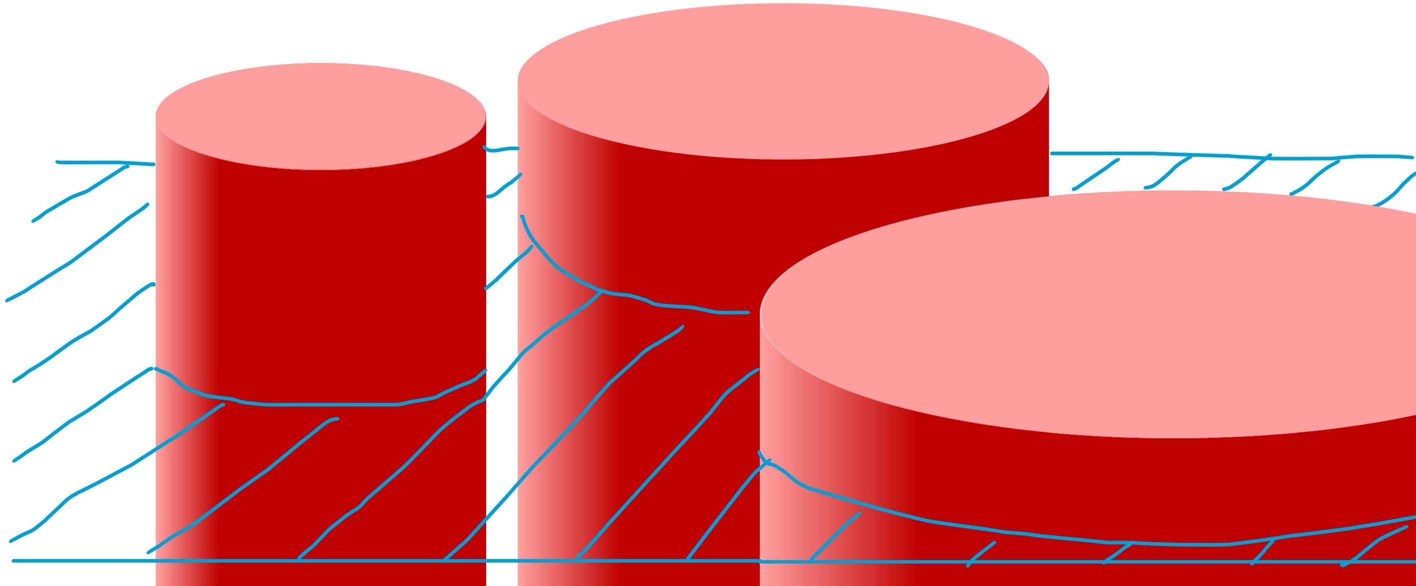


Figure 3: Example of a porosity law showing the elevation with respect to the porosity

- SW2D-DDP (Depth Dependant Porosity)
- Porosity $= \frac{\text{Volume of void}}{\text{Volume of space}}$
- Coarser mesh => faster simulations (Ayoub et al. 2022)



Introduction

Methods

Severn

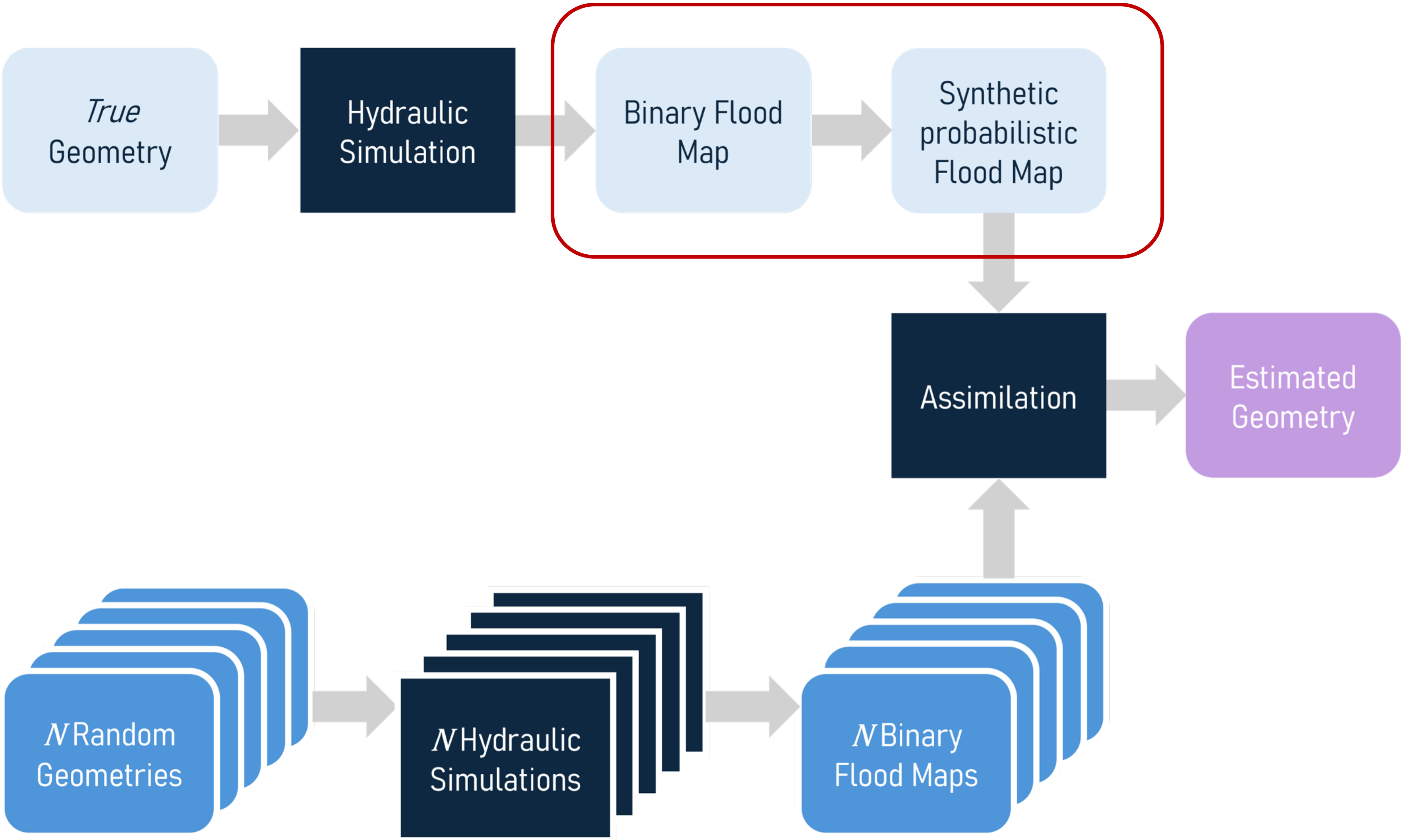
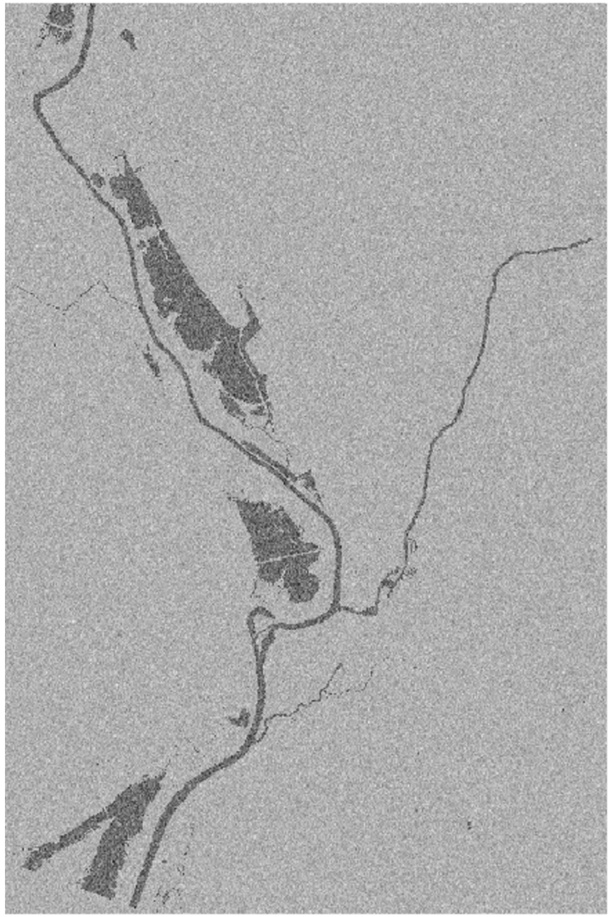


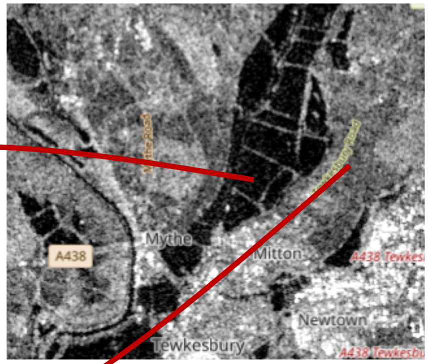
Figure 2: DA Framework for the synthetic twin experiment on the River Severn.

Synthetic flood maps generation

- Binary flood map
- $I_b = \begin{cases} 1 & \text{if } z \geq z_{\text{DEM}} + h_{\min} \\ 0 & \text{otherwise} \end{cases}$

Synthetic flood maps generation

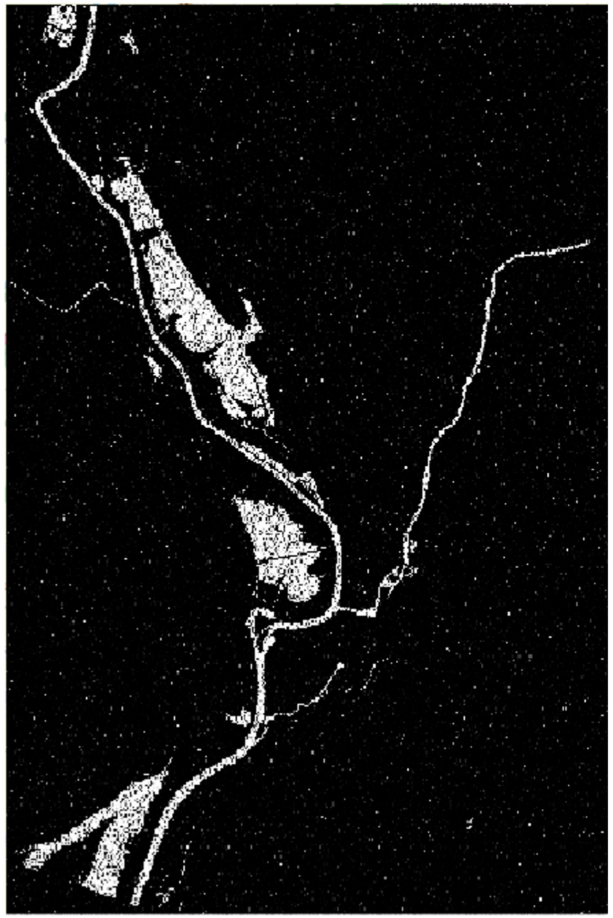




- SAR flood map
- $X_W \sim \mathcal{N}(\mu_W, \sigma_W)$ and $X_{NW} \sim \mathcal{N}(\mu_{NW}, \sigma_{NW})$ (from fig. 1)
- $I_s = I_b x_W + (1 - I_b) x_{NW}$

with x_W and x_{NW} being realisations of X_W and X_{NW}.

Synthetic flood maps generation



- Probabilistic flood map
- $I_p = p(F|I_s) = \frac{p(I_s|F)p(F)}{p(I_s)}$

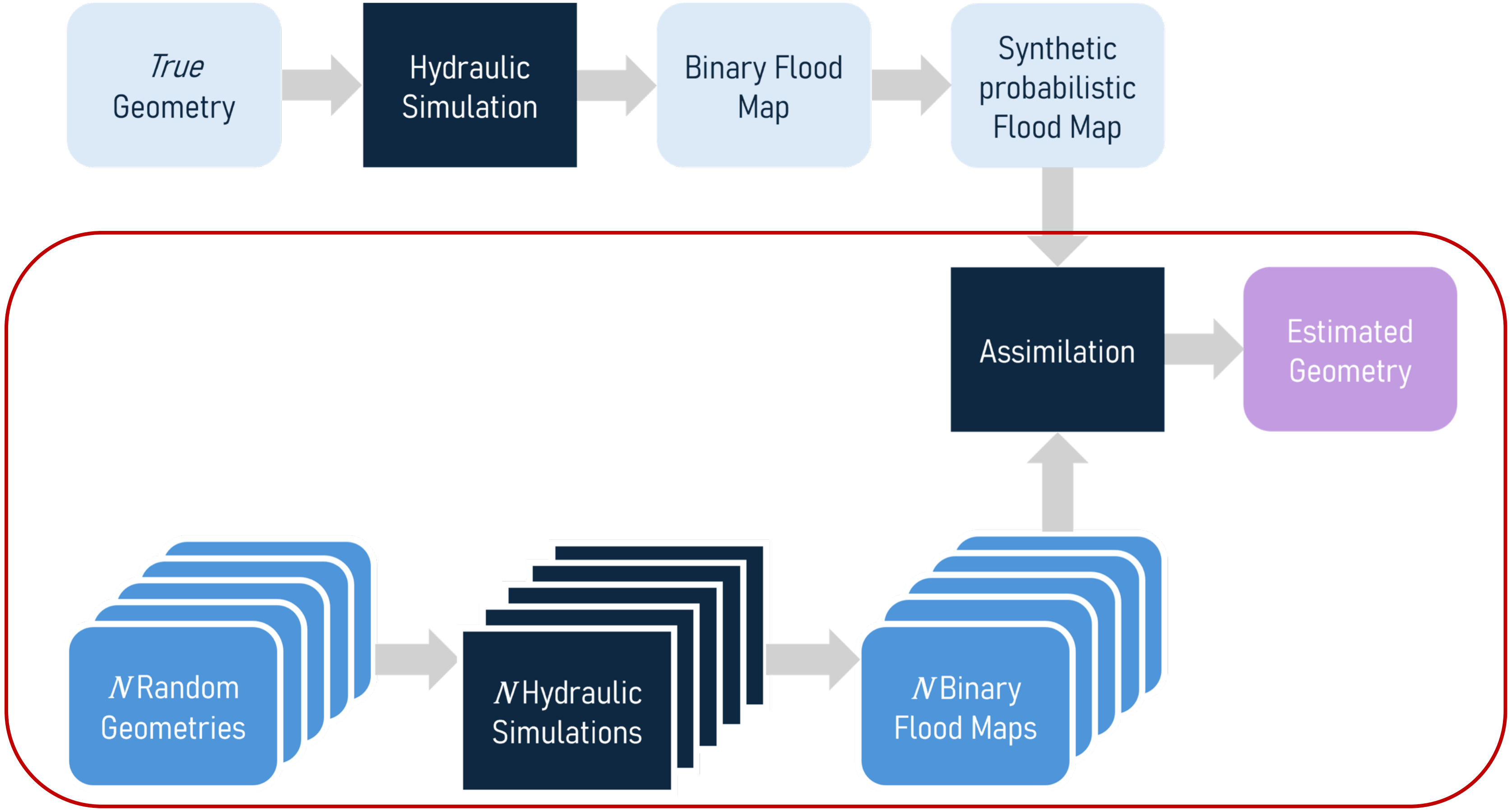
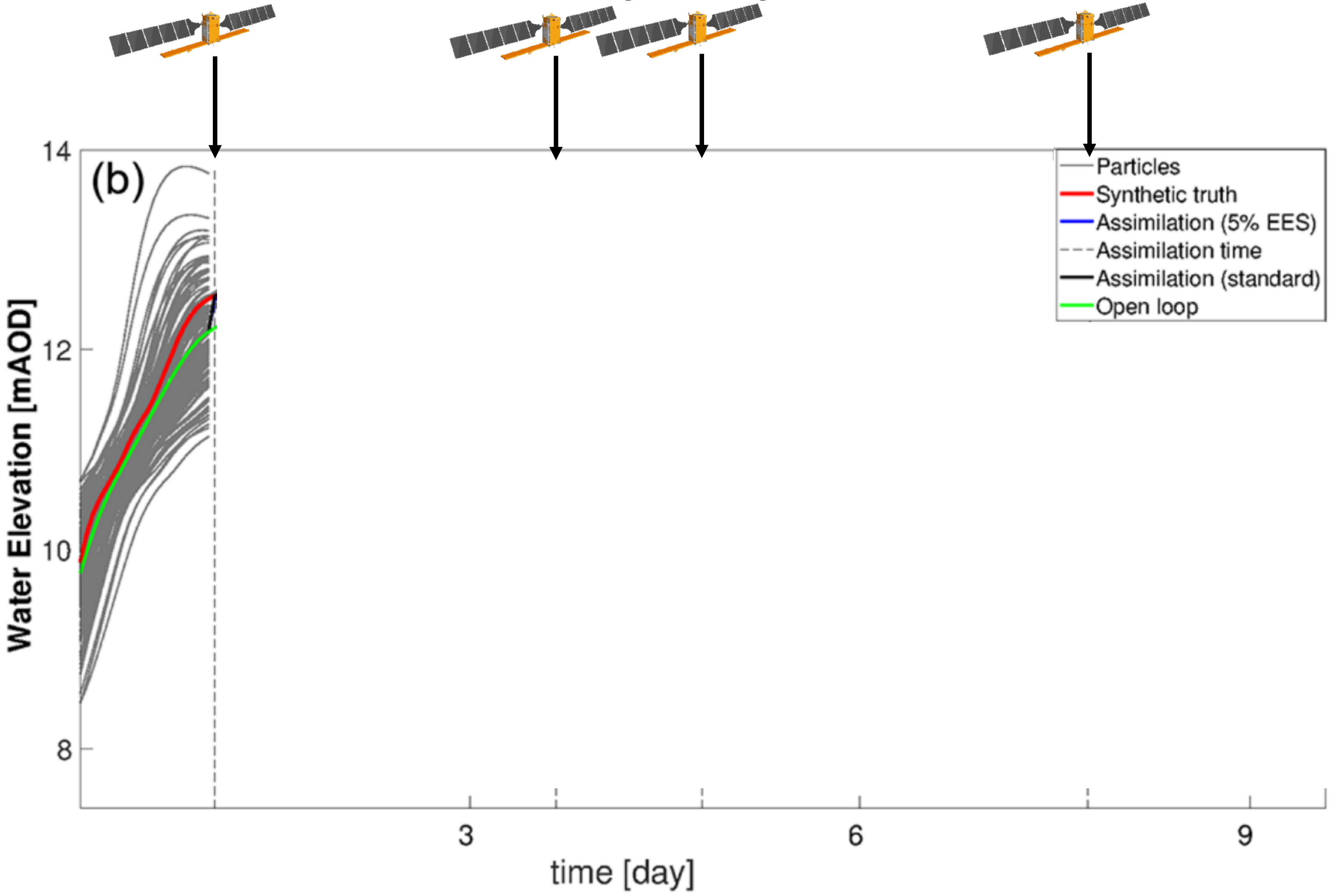


Figure 2: DA Framework for the synthetic twin experiment on the River Severn.

Data assimilation (DA)



Experiment on the River Severn

Study area and experimental design

- Estimate the bathymetry with synthetic probabilistic flood extent maps
- Simplifications: no input flow from the River Avon, no weirs
- Synthetic experiment: more control over the model
- Bathymetry is linearly interpolated between 3 control points: Saxons Lode, Confluence and Deerhurst

Figure 4: Sentinel-2 satellite imagery (22m resolution) acquired on the 30th of January 2025 (Source: Copernicus Browser) showing the town of Tewkesbury with its location in the UK (upper-right corner). The locations of the control points used during the experiment are also shown.

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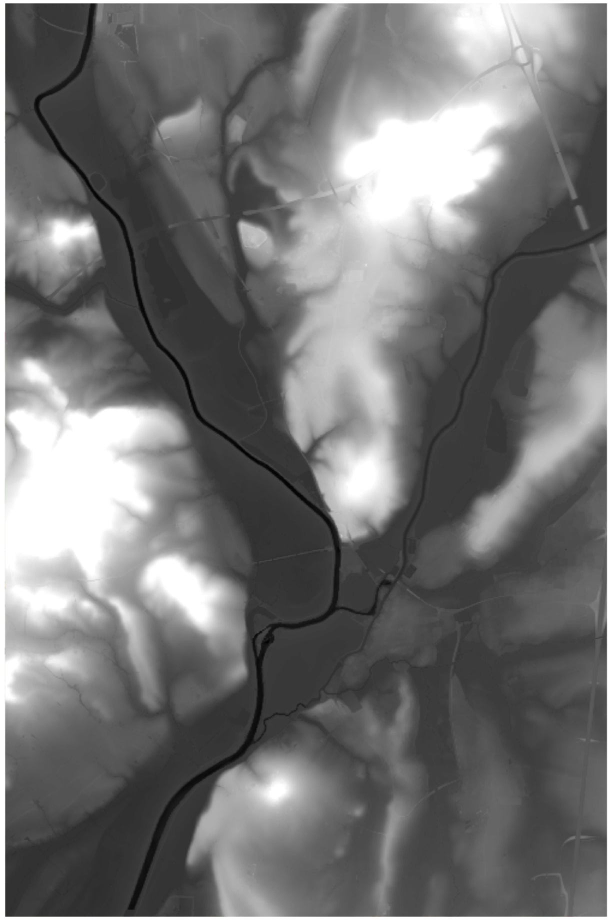
Available data



- DEM (with the bathymetry of the River Severn)
- Hydrometric data (flow, water depth) at Saxons Lode (SL) and Deerhurst (DH) + gauge at Mythe Bridge (MB)

Results

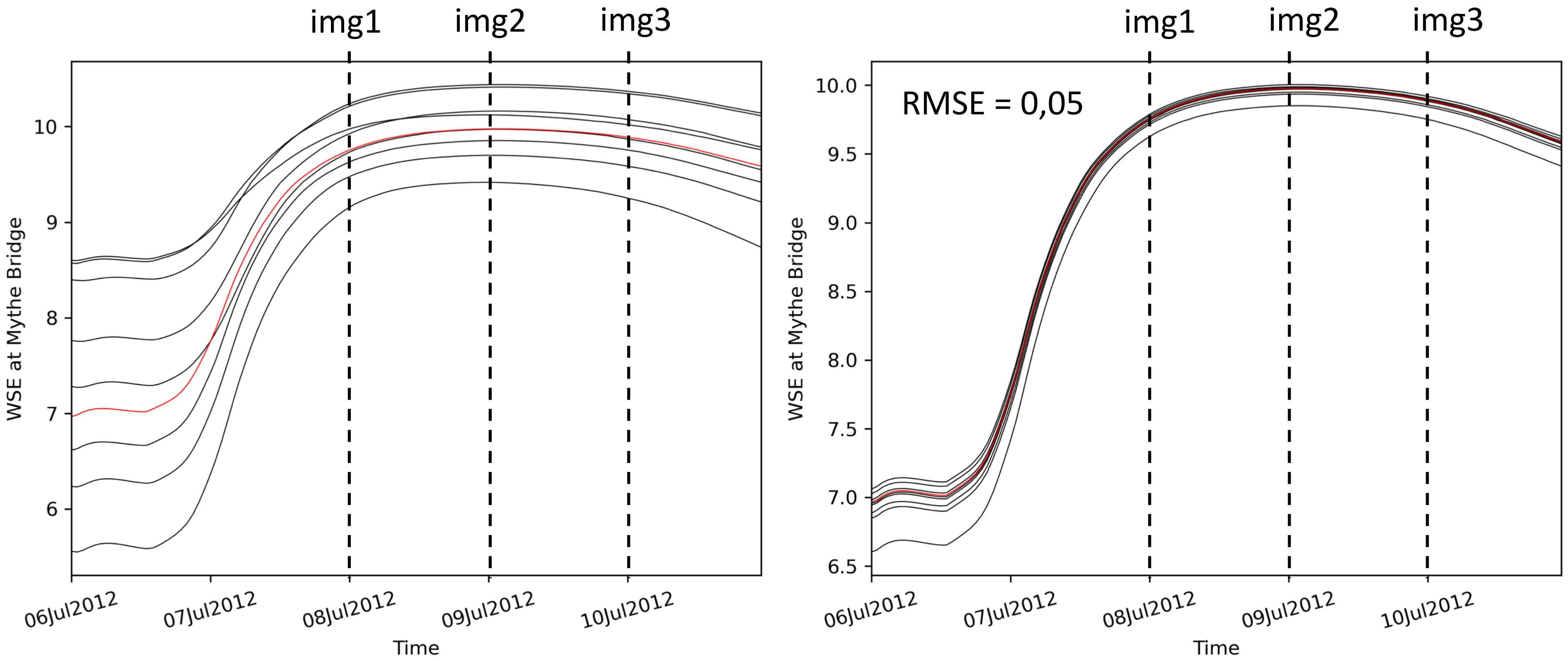


Figure 5: WSE (m) time series of all particles at Mythe Bridge (MB) (in black) compared to control run's WSE time series (in red). On the left: result at Open Loop (OL) or first guess. On the right: result at the last iteration of the TPF.

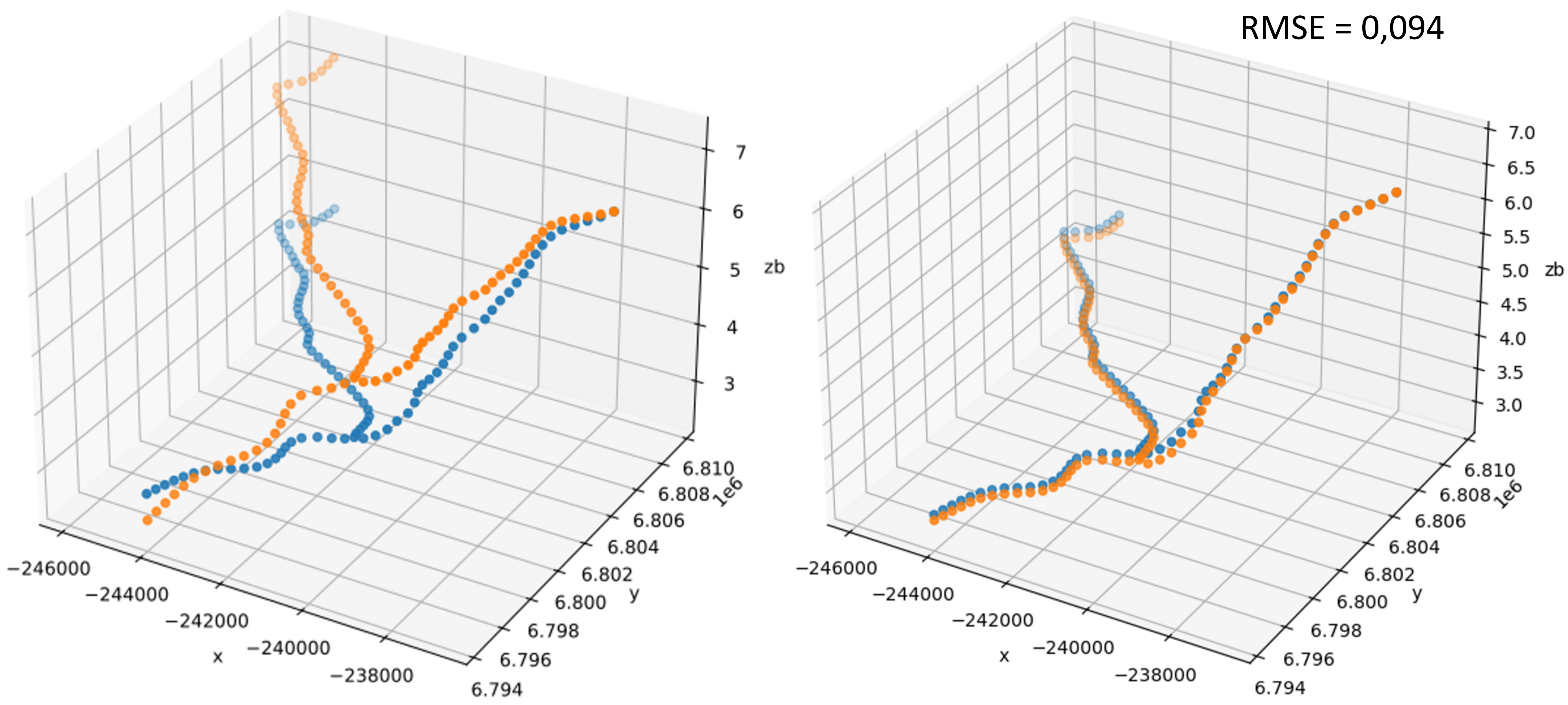


Figure 6: 3D representation of the bathymetry of the River Severn and the River Avon at the Open Loop (OL) on the left and at the last iteration of the TPF on the right. Blue dots represent the ground elevation of each cell in the control run, and the orange dots represent the expected ground elevation at each cell.

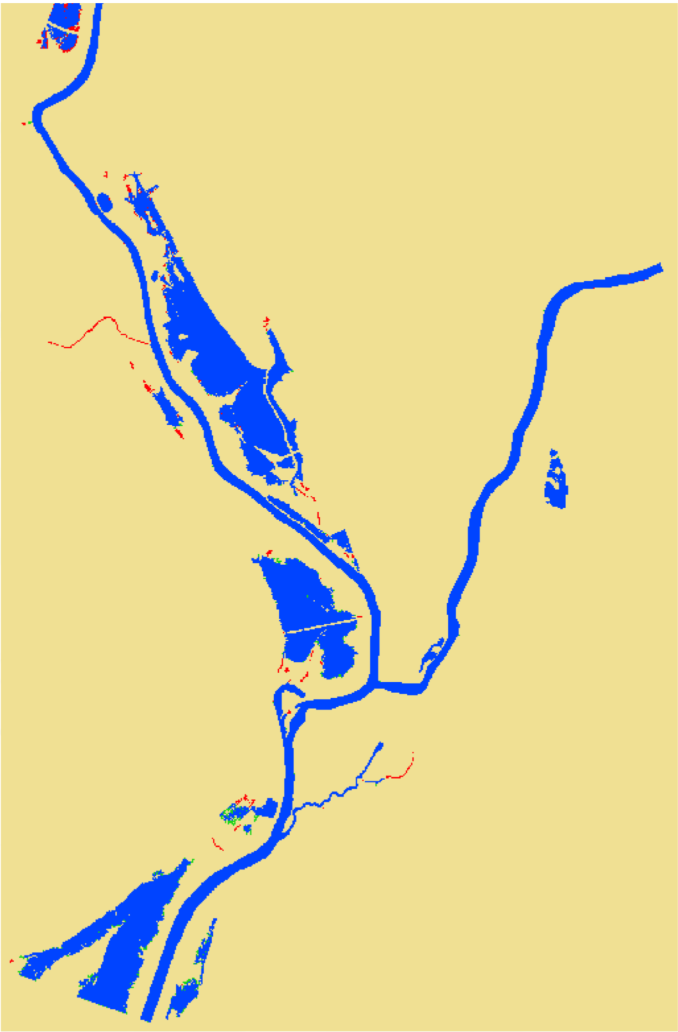


Figure 7: Contingency map between reference and expectation on the 8th of July 2012 after data assimilation

- CSI = 0,97