FLOOD WATER DEPTH ESTIMATION AND FLOOD EXTENT ENHANCEMENT USING A PHYSICALLY CONSTRAINED GRADIENT-BASED OPTIMIZATION METHOD

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Sep 16, 2025

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BACKGROUND AND MOTIVATIONS

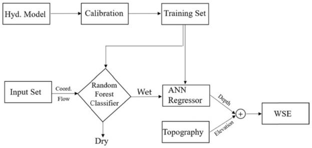
Flood Depth Estimation Methods

(1) Hydrological-Hydraulic Modelling

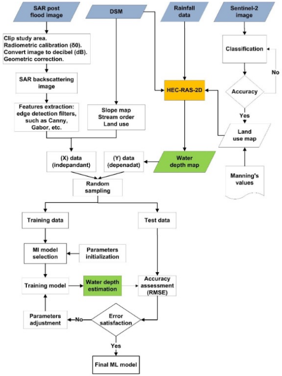
- Flood inundation models
- Hybrid hydraulic-machine learning (ML)

Challenges & Limitations

- Large data requirements
- High computational cost
- Infeasible for quick large-scale mapping



Hosseiny et al., (2020)



Elkhrachy (2022)

BACKGROUND AND MOTIVATIONS

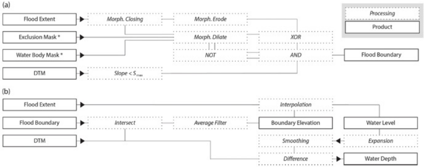
Flood Depth Estimation Methods

(2) Flood Extent Map + Digital Elevation Model (DEM)

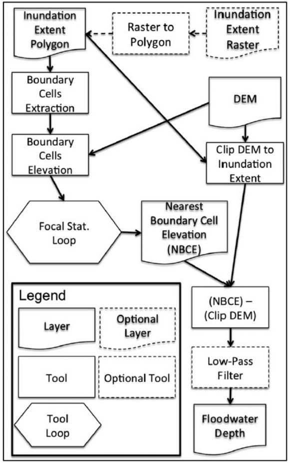
- Thresholding of DEM / HAND
- Geostatistical interpolation

Challenges & Limitations

- Strong hydraulic assumptions
- Reliance on flood boundary
- Scenario-specific calibration



Betterle & Salamon (2024)



Cohen et al., (2018)

OBJECTIVE

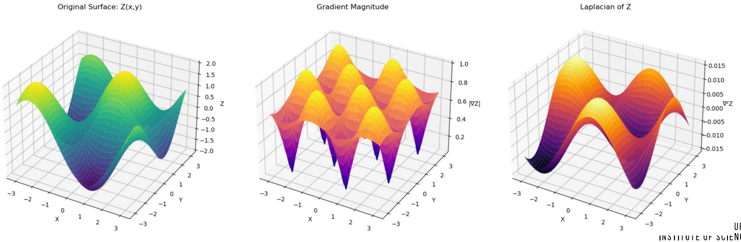
Develop a gradient-based optimization framework for water depth estimation and flood extent enhancement

Observed Data

- DEM
- Flood extent map

Physical Principles

- Smooth, coherent, and terrain-aware flood water surfaces
- Discouraging sharp discontinuities in water elevation



METHODOLOGY – GRADIENTHYDRO

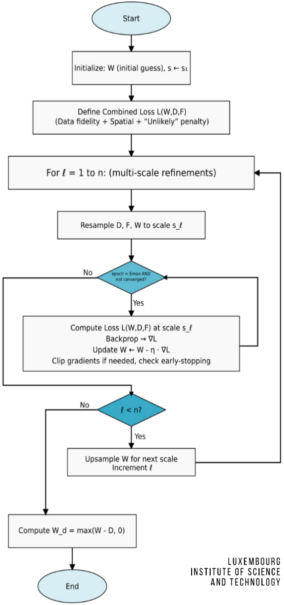
Optimization Framework

Objective Function

- Data fidelity term
- Physical constraints
- Unlikely flood regions

Iterative Gradient-based Multi-scale Refinement

- Refines water surface elevation (WSE) while preserving hydrological plausibility
- Captures both global patterns and local nuances



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METHODOLOGY – GRADIENTHYDRO

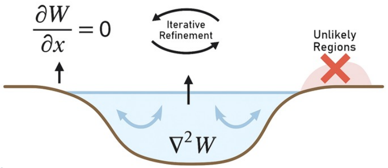
Objective Function – Combined Loss Function

Data Fidelity

- Ensure the extent of the predicted water surface aligns with the input observed flood extents

Physical Constraints

- Gradient penalty (∇W)
  - Penalizes steep slopes that contradict realistic water flows
- Laplacian (Curvature) penalty ($\nabla^2 W$)
  - Controls rapid curvature changes, preventing unnatural “ripples” in the water surface



Unlikely Flood Regions

- Suppresses spurious inundations in high or disconnected areas

METHODOLOGY – GRADIENTHYDRO

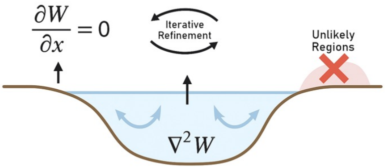
Iterative, Gradient-based Optimization

Adjustment Process

- Adjusts the WSE using automatic differentiation tools
- Computes derivatives of the loss function

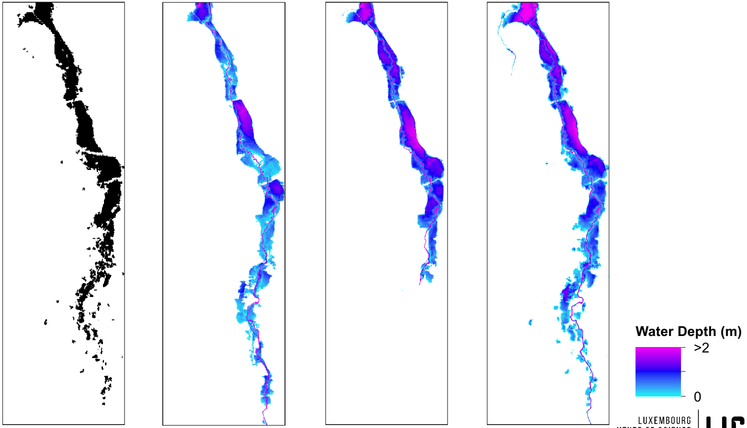
Multi-scale Refinement

- Hierarchical optimization
  - Begins at coarse resolution to capture board flood patterns
  - Progressively refines at finer scales



PRELIMINARY RESULTS

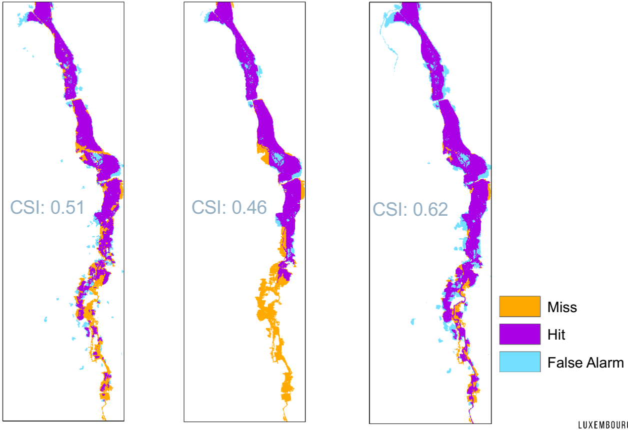
Luxembourg Flood (15/07/2021)



SAR Flood Map | Hydraulic Simulation | DEM Thresholding | GradientHydro

PRELIMINARY RESULTS

Luxembourg Flood (15/07/2021)



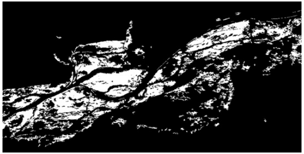
SAR Flood Map

DEM Thresholding

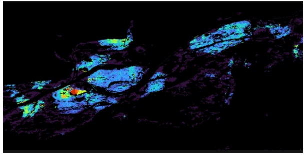
GradientHydro

PRELIMINARY RESULTS

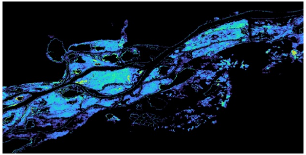
Mariupol Dam Explosion, Ukraine (06/06/2023)



SAR Flood Map



DEM Thresholding

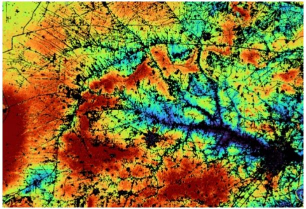


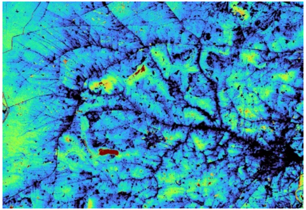
GradientHydro

PRELIMINARY RESULTS

Pakistan Floods (08/2022)


SAR Flood Map


DEM Thresholding


GradientHydro

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CONCLUDING REMARKS

GradientHydro

Model Performance

- Improved flood extent
- Water depth

Ongoing Works

- Further evaluation against in-situ water surface elevation
- Applications to other study areas (e.g., River Severn, UK)
- Comparison with existing flood extent mapping (e.g., three ensemble members in GFM)
- Comparison with existing flood depth estimation methods (e.g., FwDET (Cohen et al., (2018), FLEXTH (Betterle & Salamon 2024)