

# ENHANCING SHORT- AND MEDIUM-RANGE INUNDATION PREDICTIONS VIA THE INTEGRATION OF GLOFAS AND GFM PRODUCTS

A case study of the Alzette River, Luxembourg

Luxembourg Institute of Science and Technology

April 2025



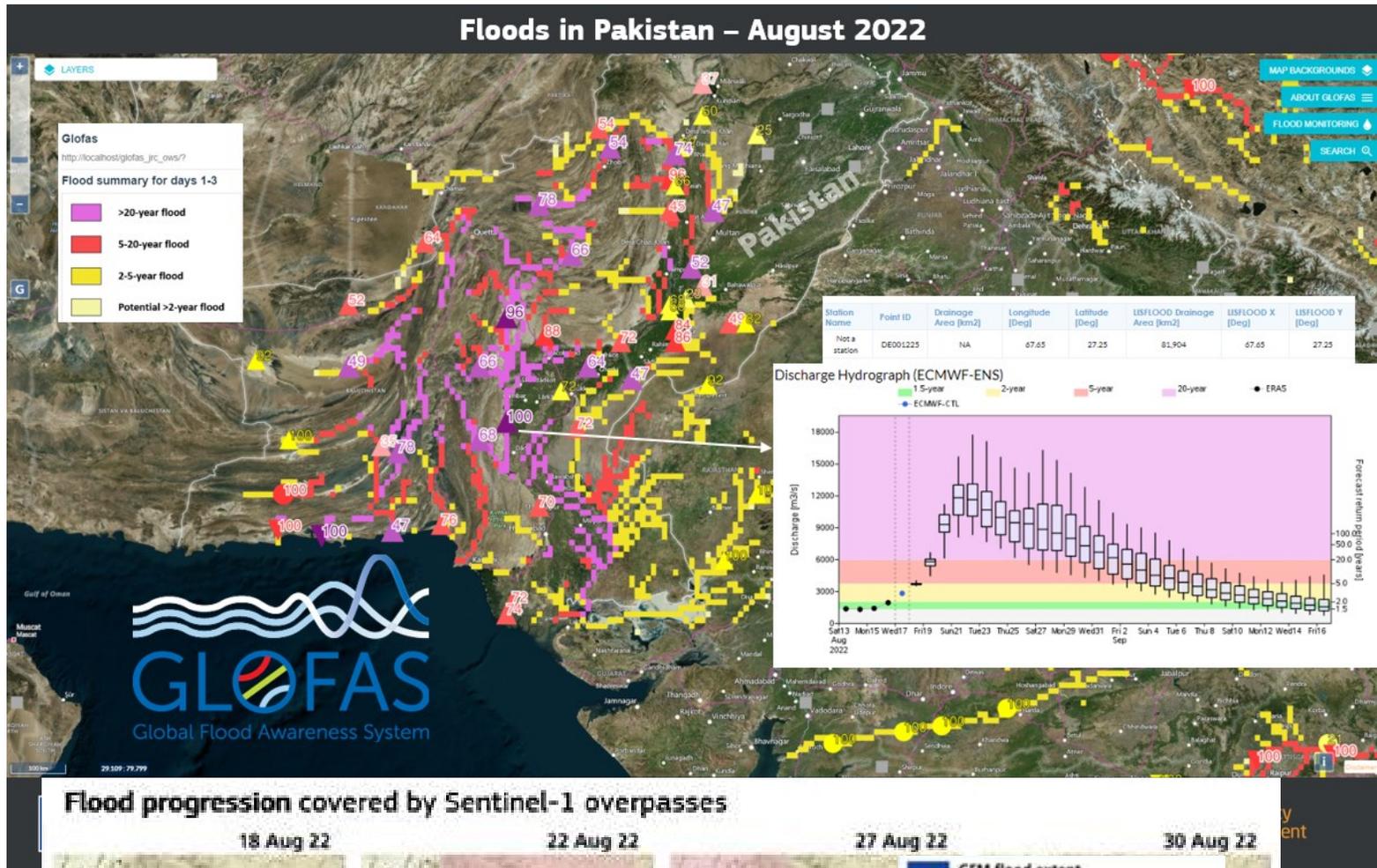
# SETTING THE SCENE

## GloFAS:

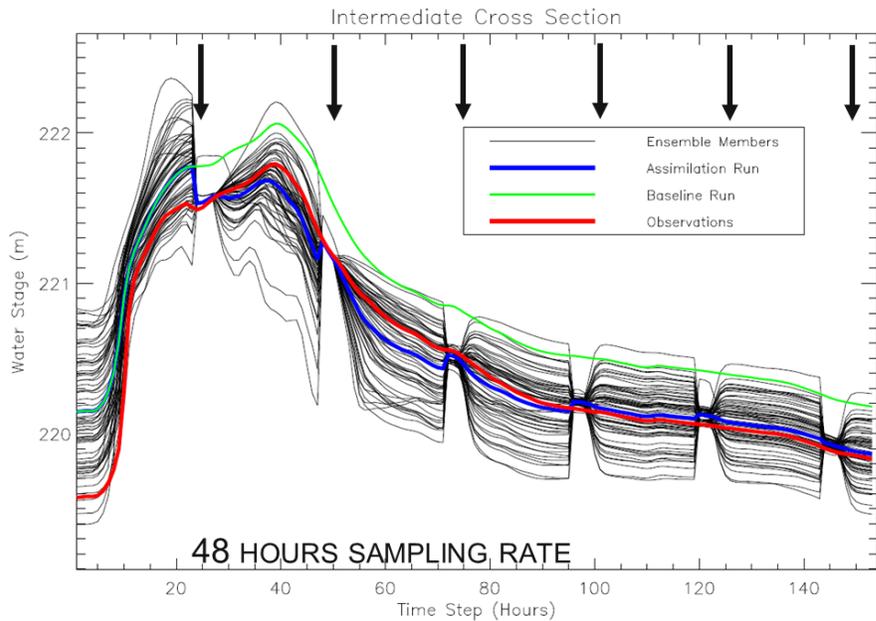
- Extent predictions using pre-computed map catalogue
- Approximation to nearest flood return period map
- Coarse resolution for comprehensive impact assessment

## GFMS:

- Dependent on S1 overpass frequency
- Does not provide urban/forest flooding
- No forecasting capabilities



# ASSIMILATION OF SYNTHETIC APERTURE RADAR-DERIVED FLOOD EXTENT INTO HYDRODYNAMIC MODELS



3 Feasibility study (Matgen et al., 2010)

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## Water Resources Research

RESEARCH ARTICLE  
10.1029/2020WR027859

### A Mutual Information-Based Likelihood Particle Filter Flood Extent Assimilation

Antara Dasgupta<sup>1,2,3</sup>, Renaud Hostache<sup>4</sup>, RAAJ Ramsankar<sup>5</sup>, Guy J.-P. Schumann<sup>6</sup>, Stefania Grimaldi<sup>1</sup>, Valentijn R. N. Jeffrey<sup>7</sup>, P. Walker<sup>8</sup>

<sup>1</sup>ITB-Monash Research Academy, Mumbai, India, <sup>2</sup>Department of Civil Engineering, Bombay, Mumbai, India, <sup>3</sup>Department of Civil Engineering, Monash University of Environmental Research and Innovation, Luxembourg Institute of Science, Luxembourg, <sup>4</sup>School of Geographical Sciences, University of Bristol, Bristol, UK, <sup>5</sup>Department of Environmental Research and Innovation, Luxembourg Institute of Science and Technology, Alzette, Luxembourg, <sup>6</sup>School of Geographical Sciences, University of Bristol, Bristol, UK, <sup>7</sup>School of Civil and Mining Engineering, University of Adelaide, Adelaide, South Australia, Australia, <sup>8</sup>Faculty of Geosciences, University of Utrecht, Utrecht, Netherlands

**Key Points:**

- A novel mutual information-based metric is proposed as a likelihood function for particle filter-based flood extent assimilation
- Distributed impacts of the assimilation on simulated flood depth and flow velocities are illustrated for different lead times
- Improvements in simulated water levels of ~80% over the open loop are shown, persistent for up to one week after the assimilation

**Abstract** Accurate flood inundation forecasts have the potential but uncertainties in inflows propagated from the precipitation forecast. Recent studies suggest that by assimilating independent flood observations into hydraulic flood inundation modeling can be mitigated. Satellite observations of flood extent from Synthetic Aperture Radar (SAR) provide a rich source of data for flood extent assimilation. This study proposes a mutual information-based likelihood particle filter for flood extent assimilation. The proposed method is compared with a standard particle filter (PF) and a tempered particle filter (TPF). Results show that the proposed method outperforms the standard PF and the TPF in terms of accuracy of model outputs. The TPF mitigates degeneracy and enables long-lasting forecast improvements. The TPF outperforms a standard particle filter in terms of accuracy of model outputs.

**Correspondence to:** R. Hostache, renaud.hostache@list.lu

**Citation:** Dasgupta, A., Chini, M., Giustarini, L., Neal, J., Kavetski, D., Wood, M., et al. (2021). Near-real-time assimilation of SAR-derived flood maps for improving flood forecasts. *Water Resources Research*, 54, 5516–5535. <https://doi.org/10.1029/2020WR027859>

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## Water Resources Research

RESEARCH ARTICLE  
10.1029/2021WR022205

### Near-Real-Time Assimilation of SAR-Derived Flood Maps for Improving Flood Forecasts

Renaud Hostache<sup>1</sup>, Marco Chini<sup>1</sup>, Laura Giustarini<sup>1</sup>, Jeffrey Neal<sup>2</sup>, Dmitri Kavetski<sup>3</sup>, Melissa Wood<sup>1,2,4</sup>, Giovanni Corato<sup>1</sup>, Ramona-Maria Pelich<sup>1</sup>, and Patrick Matgen<sup>1</sup>

<sup>1</sup>Department of Environmental Research and Innovation, Luxembourg Institute of Science and Technology, Alzette, Luxembourg, <sup>2</sup>School of Geographical Sciences, University of Bristol, Bristol, UK, <sup>3</sup>School of Civil and Mining Engineering, University of Adelaide, Adelaide, South Australia, Australia, <sup>4</sup>Faculty of Geosciences, University of Utrecht, Utrecht, Netherlands

**Key Points:**

- Probabilistic flood maps are derived from SAR images
- Probabilistic flood maps are assimilated into a flood forecasting model cascade
- Water level forecast quality improves substantially in the assimilation time steps, and benefits persist for hours to days

**Abstract** Short- to medium-range flood forecasts are central to predicting and mitigating the impact of flooding across the world. However, producing reliable forecasts and reducing forecast uncertainty remains challenging, especially in poorly gauged river basins. The growing availability of synthetic aperture radar (SAR)-derived flood image databases (e.g., generated from SAR sensors such as Envisat and Sentinel-1) provides opportunities to improve flood forecast quality. This study assesses the development of more accurate global and near real-time remote sensing-based flood forecasts to support flood management. We take advantage of recent algorithms for efficient delineation of flood extent using SAR images and demonstrate that near real-time sequential assimilation of SAR-derived flood extents can substantially improve flood forecasts. A case study based on events of the River Severn (United Kingdom) is presented. The forecasting system comprises a hydrological model and the Hydrologic Engineering Center (HEC) hydraulic model. SAR images are assimilated into the hydrological model. Results show an improvement of the model forecasts accuracy, with respect to the Open Loop (OL) forecast. The root mean square error (RMSE) of water levels decrease by 80% at the assimilation time and by 40% at the forecast time.

**Correspondence to:** R. Hostache, renaud.hostache@list.lu

**Citation:** Hostache, R., Chini, M., Giustarini, L., Neal, J., Kavetski, D., Wood, M., et al. (2021). Near-real-time assimilation of SAR-derived flood maps for improving flood forecasts. *Water Resources Research*, 54, 5516–5535. <https://doi.org/10.1029/2021WR022205>

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https://hess.copernicus.org/articles/25/4081/2021/hess-25-4081-2021.pdf

Hydrology and Earth System Sciences

## Assimilation of probabilistic flood maps from SAR data into a coupled hydrologic–hydraulic forecasting model: a proof of concept

Concetta Di Mauro<sup>1,2</sup>, Renaud Hostache<sup>1</sup>, Patrick Matgen<sup>1</sup>, Ramona Pelich<sup>1</sup>, Marco Chini<sup>1</sup>, Peter Jan van Leeuwen<sup>3,4</sup>, Nancy K. Nichols<sup>5</sup>, and Günter Blöschl<sup>6,2</sup>

<sup>1</sup>Luxembourg Institute of Science and Technology, Esch sur Alzette, Luxembourg  
<sup>2</sup>Institute of Hydrology and Water Resources Management, Vienna University of Technology, Vienna, Austria  
<sup>3</sup>Department of Meteorology, University of Reading, Reading, UK  
<sup>4</sup>Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, USA  
<sup>5</sup>Department of Mathematics and Statistics, University of Reading, Reading, UK  
<sup>6</sup>Centre for Water Resource Systems, Vienna University of Technology, Vienna, Austria

**Correspondence to:** Concetta Di Mauro (concetta.dimauro@list.lu)

Received: 7 August 2020 – Discussion started: 15 September 2020  
 Revised: 4 April 2021 – Accepted: 20 May 2021 – Published: 14 July 2021

**Abstract.** Coupled hydrologic and hydraulic models represent a powerful tool to optimally combine uncertain model outputs and observations. Among data assimilation (DA) techniques, the particle filter (PF) has gained attention for its capability to handle nonlinear systems and for its relaxation of the Gaussian assumption. However, the PF may suffer from degeneracy and sample impoverishment. In this study, we propose an innovative approach, based on a particle filter (PF) with a tempered particle filter (TPF), aiming at mitigating PFs issues, thus extending over time the assimilation of SAR-derived flood extent maps into flood forecasting models. Probabilistic flood maps derived from synthetic aperture radar data are assimilated into a flood model through an iterative process including a particle mutation in order to keep diversity within the ensemble. Results show an improvement of the model forecasts accuracy, with respect to the Open Loop (OL) forecast. The root mean square error (RMSE) of water levels decrease by 80% at the assimilation time and by 40% at the forecast time.

**Key Points:**

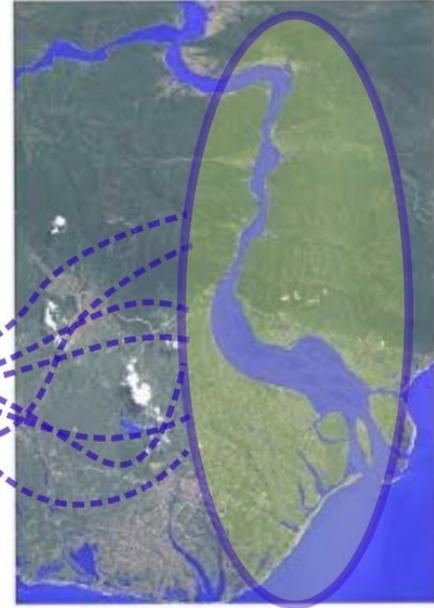
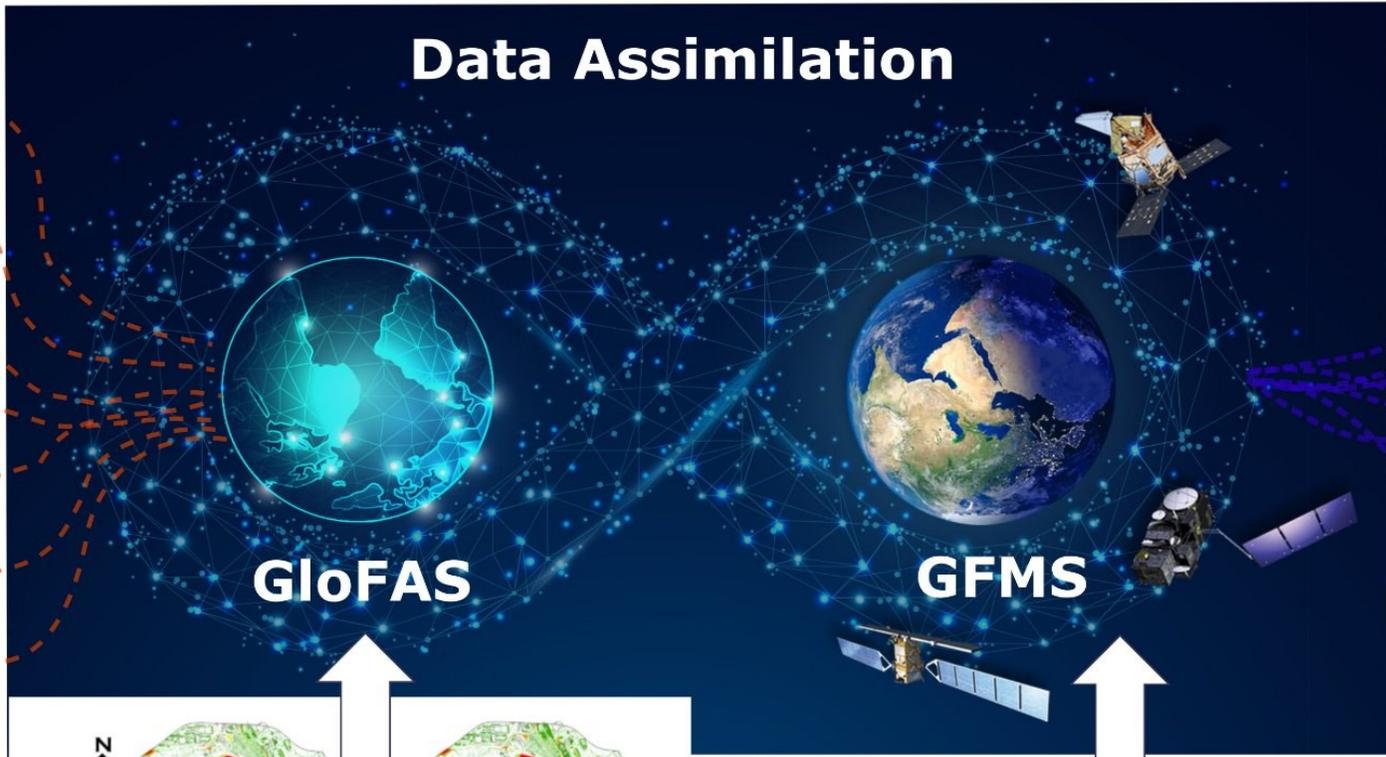
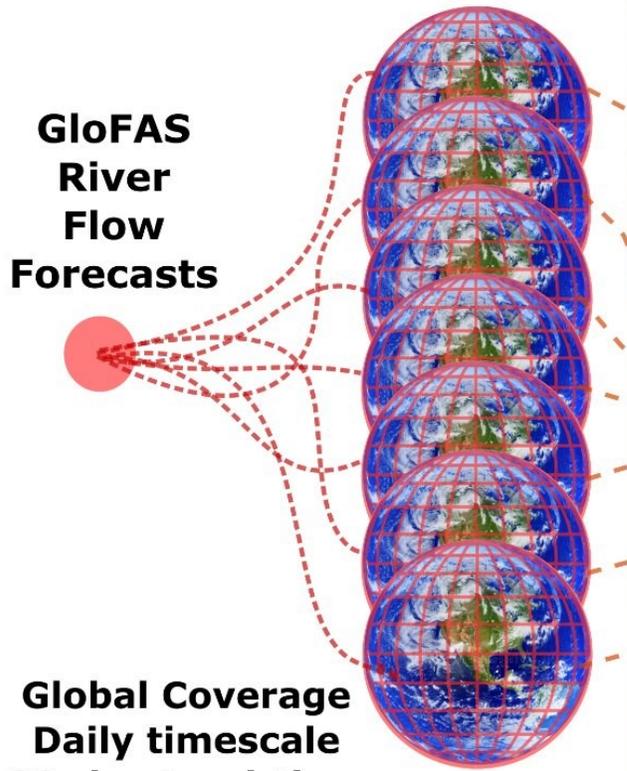
- We assimilate flood extent maps into a flood forecasting system using a tempered particle filter (TPF)
- The TPF mitigates degeneracy and enables long-lasting forecast improvements
- The TPF outperforms a standard particle filter in terms of accuracy of model outputs

**Correspondence to:** C. Di Mauro and R. Hostache, concetta.dimauro@list.lu; renaud.hostache@list.lu

**Citation:** Di Mauro, C., Hostache, R., Matgen, P., Pelich, R., Chini, M., van Leeuwen, P. J., et al. (2021). A tempered particle filter to enhance the assimilation of SAR-derived flood extent maps into flood forecasting models. *Water Resources Research*, 58, e2022WR031940. <https://doi.org/10.1029/2022WR031940>

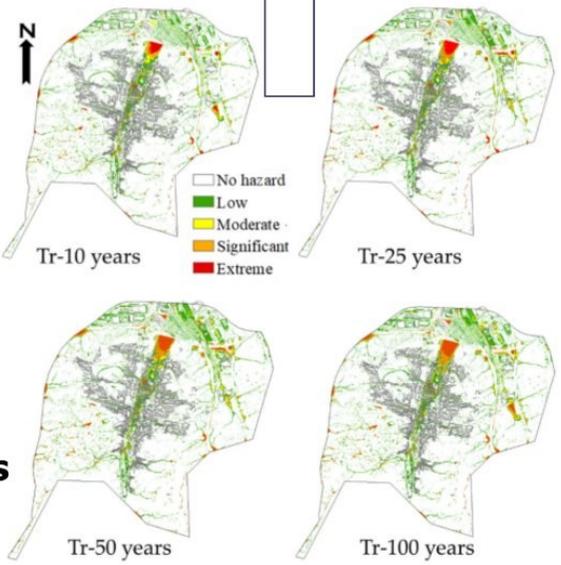
**GloFAS  
River  
Flow  
Forecasts**

**Global Coverage  
Daily timescale  
30-day Lead-time**

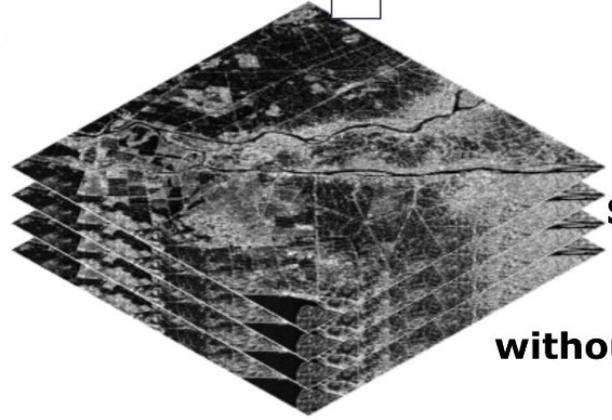


**Assimilated Flood Maps  
(Daily, 100m,  
30-day lead time,  
with urban and  
vegetated flooding)**

**Pre-computed  
Flood Hazard  
Map Catalogue  
100 m daily,  
fixed return periods**



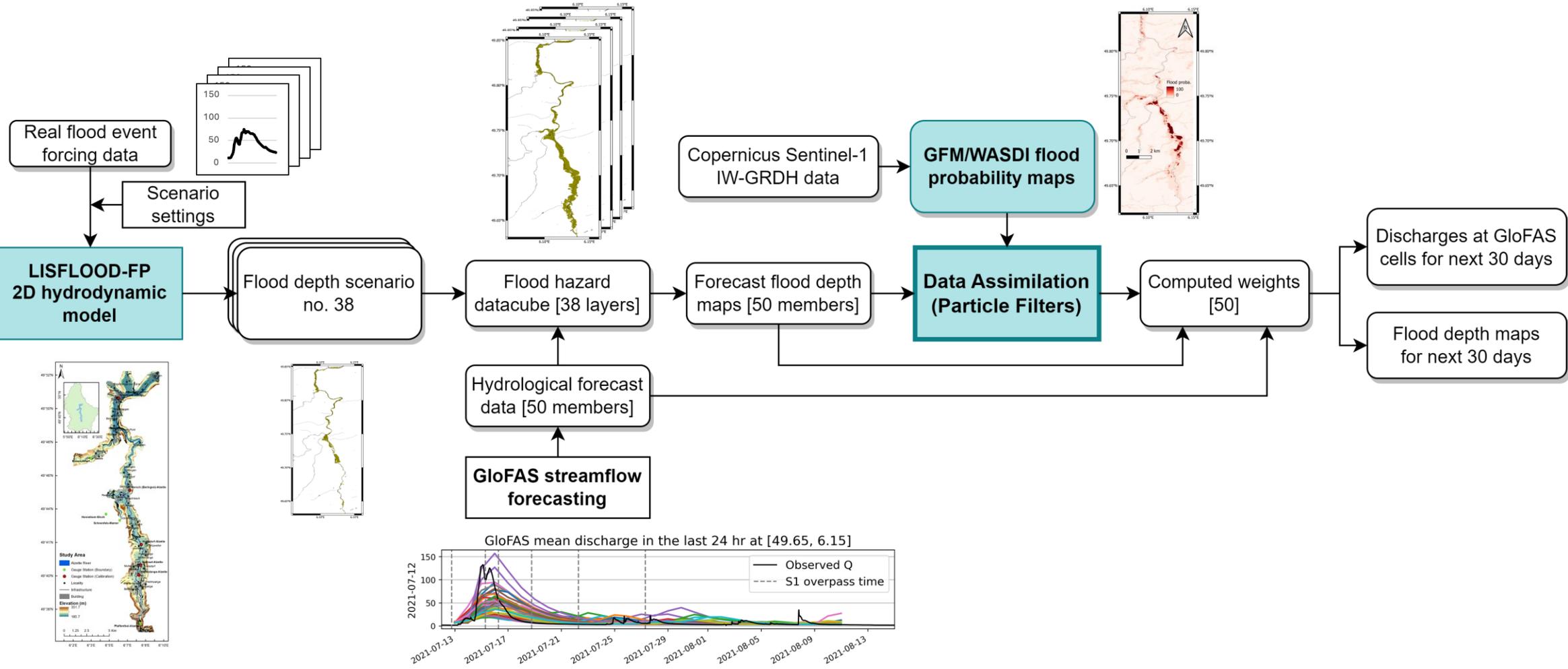
time ↑



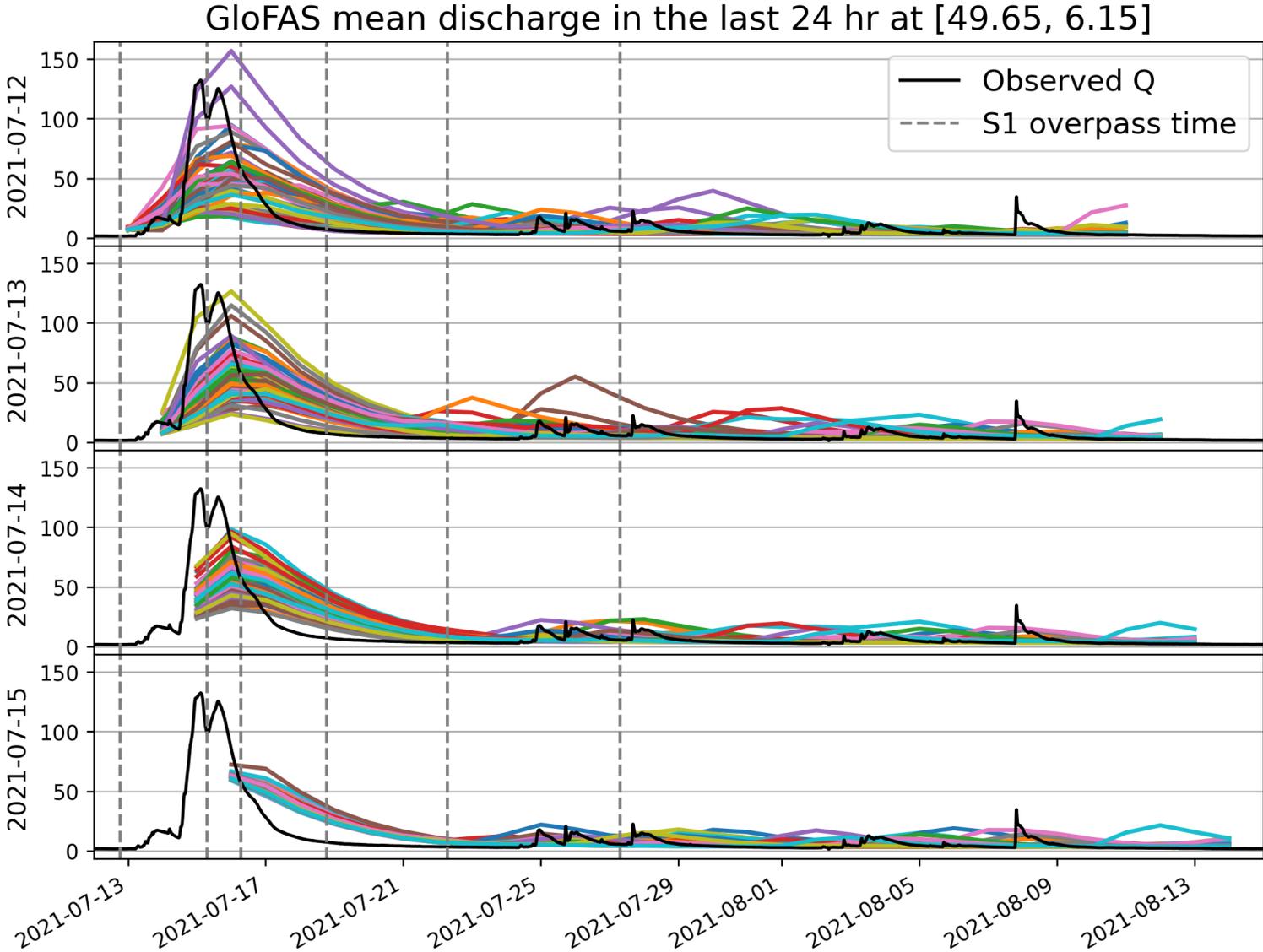
**Sentinel-1 NRT  
Flood Maps  
20 m/6days  
without urban/vegetation**

**Best of different approaches?**

# EXPERIMENT DESCRIPTION

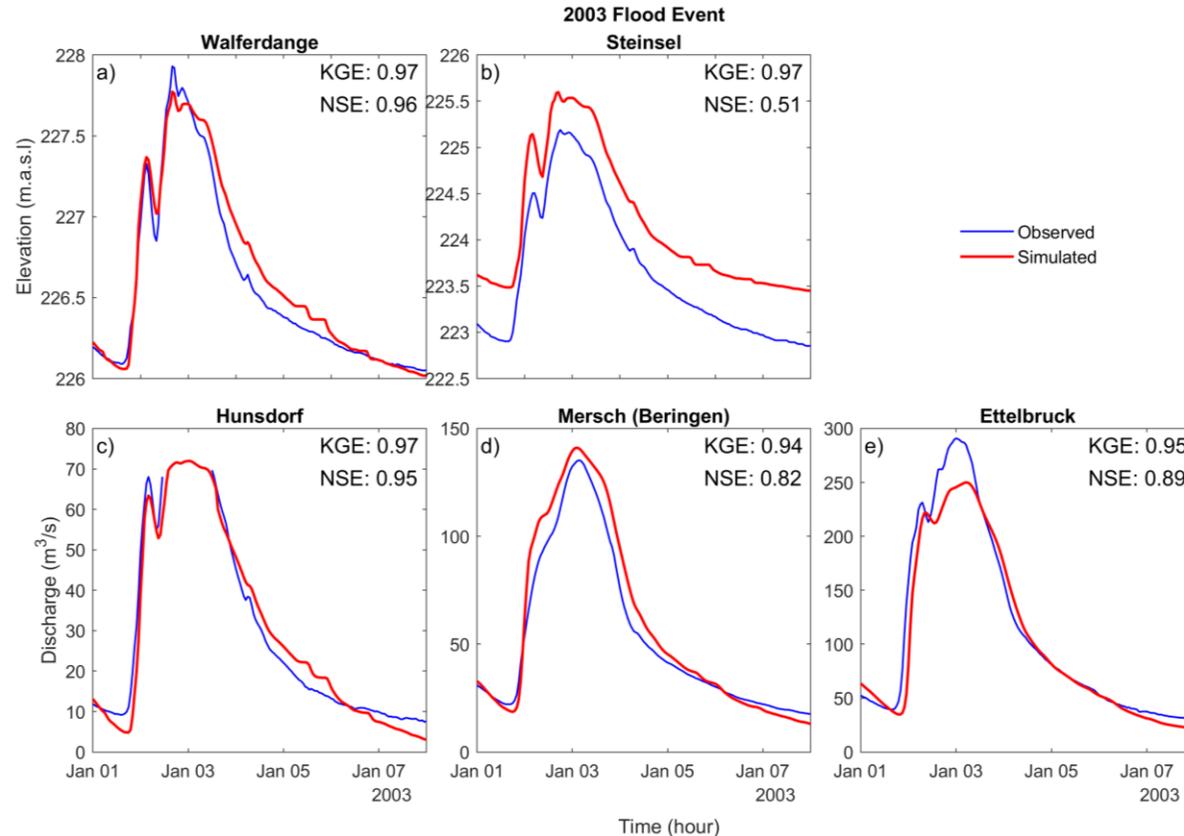
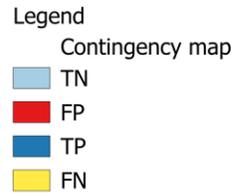
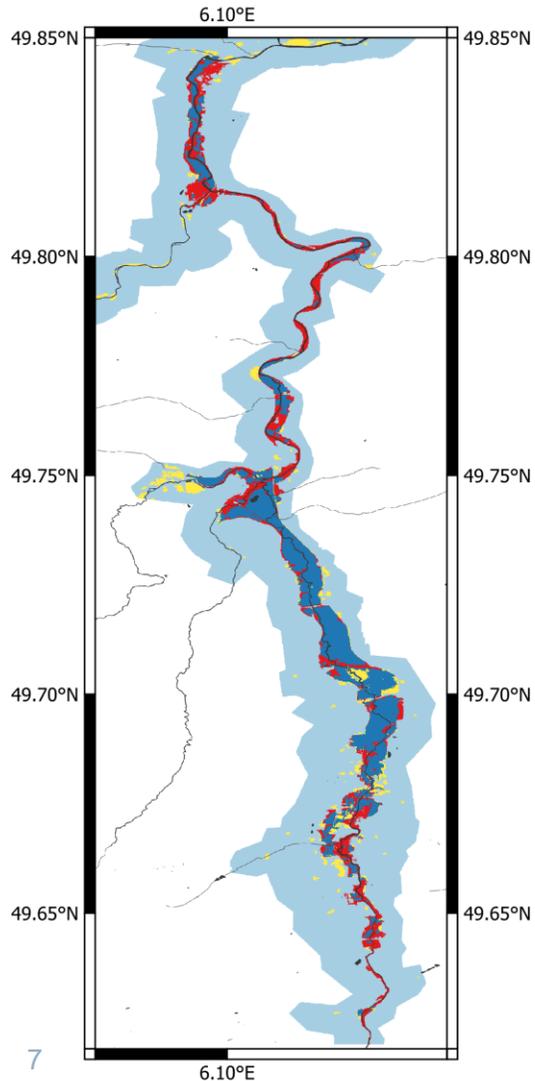


# INPUT DATA – GLOFAS STREAMFLOW FORECASTS



# HYDRODYNAMIC MODEL – LISFLOOD-FP

- Results (Model run @ 5m)



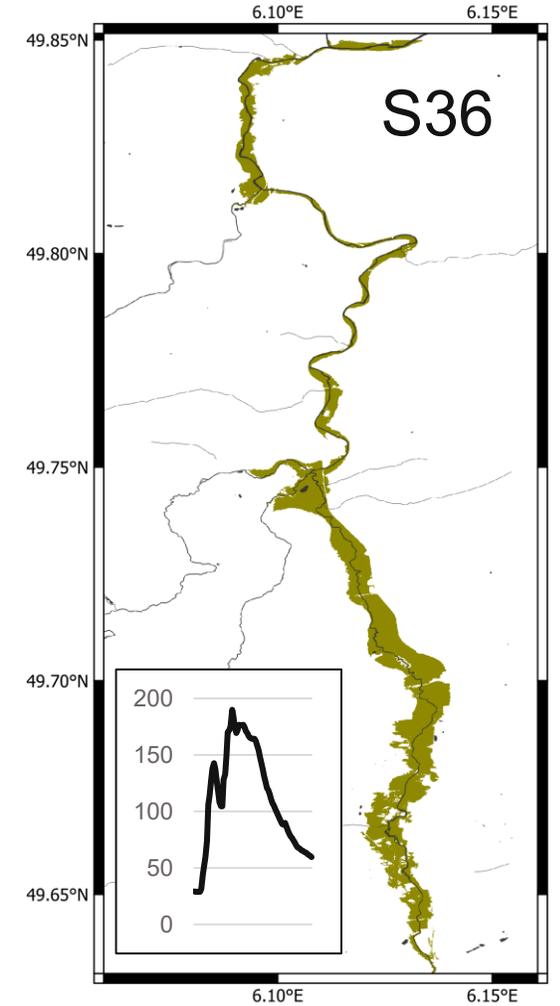
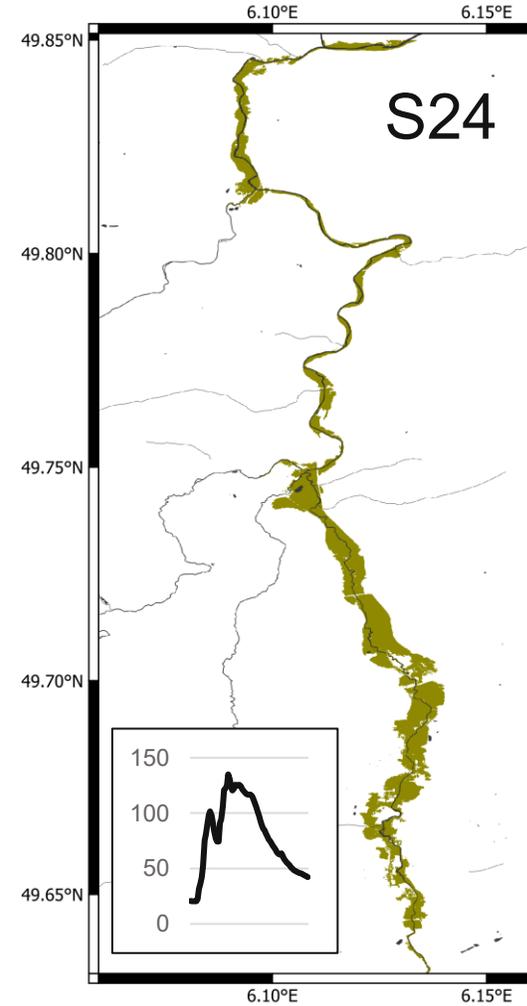
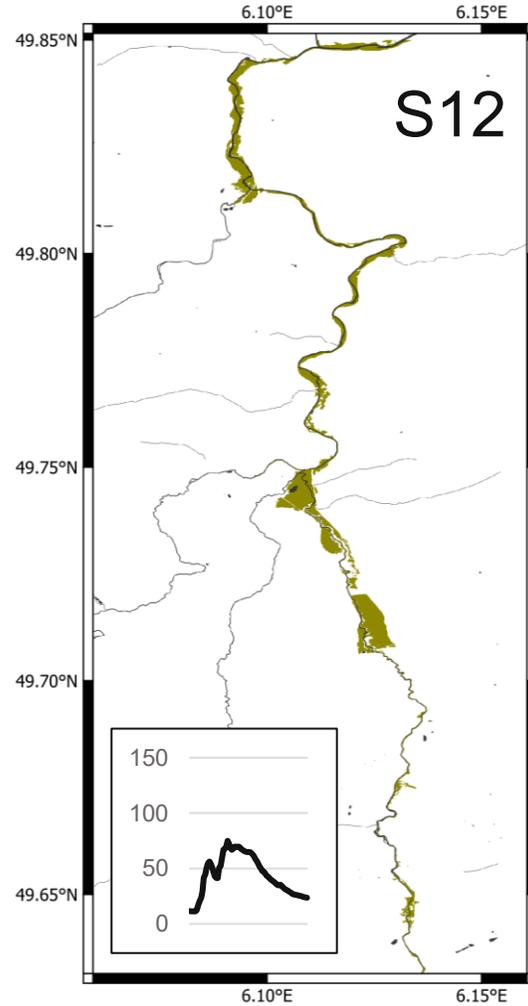
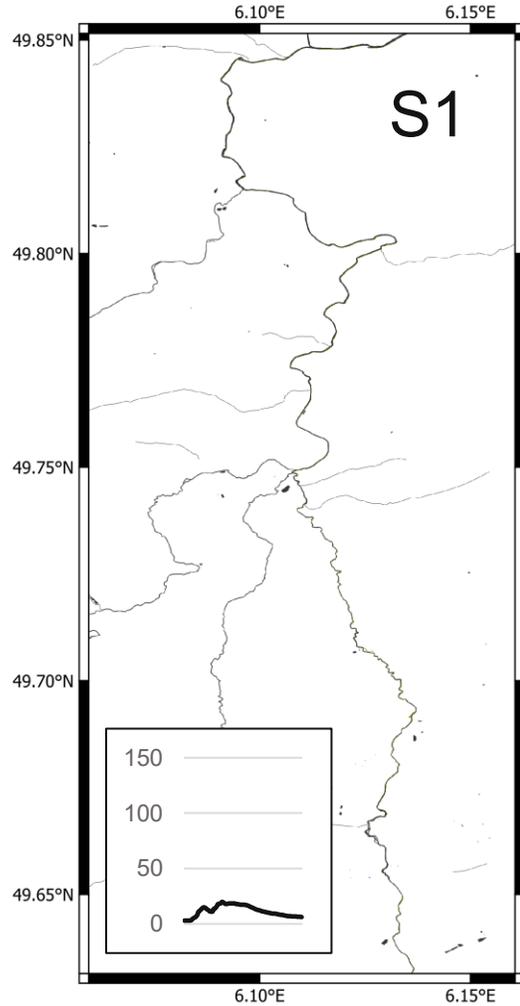
## Comparison with measured water height/discharge and satellite-derived water extent:

- rising and falling limbs well reproduced
- tendency to slightly underestimate the peaks
- model performance rather good over entire model domain



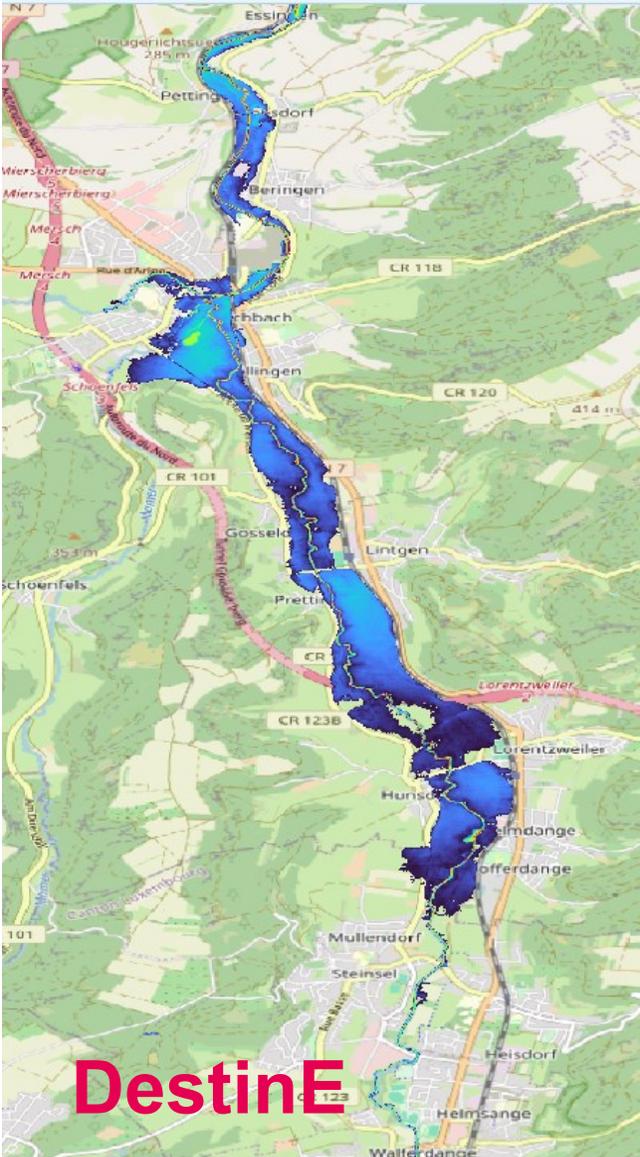
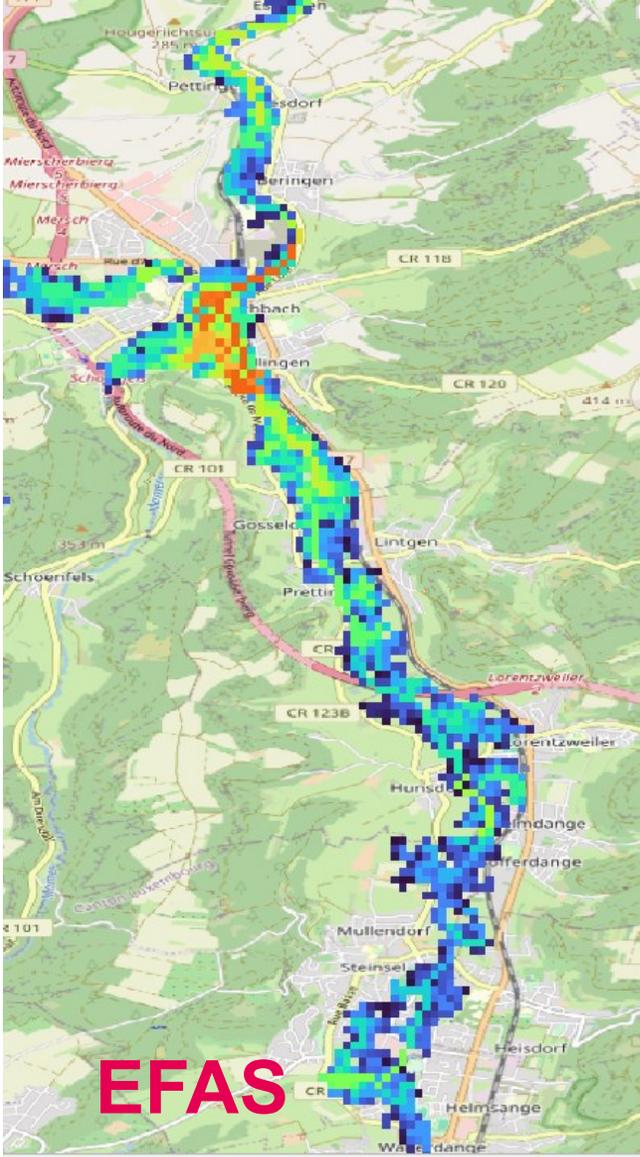
# INPUT DATA - PRE-COMPUTATION OF SCENARIOS

- 38 scenarios:  $Q=5$  to  $190 \text{ m}^3/\text{s}$ , interval =  $5 \text{ m}^3/\text{s}$
- Spatial resolution: 5 m

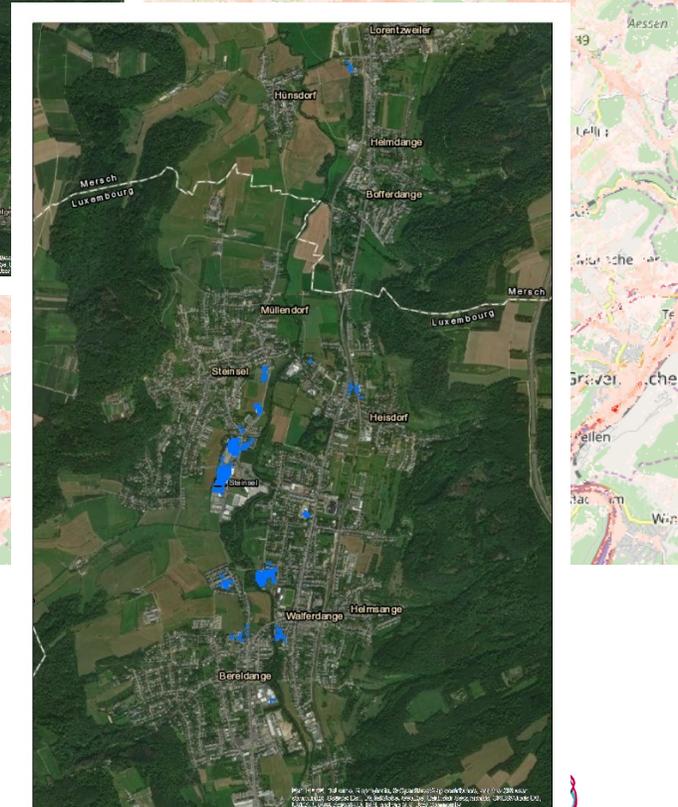
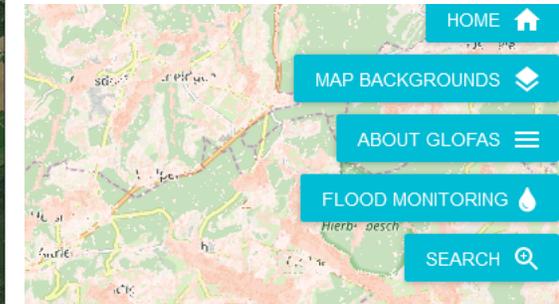
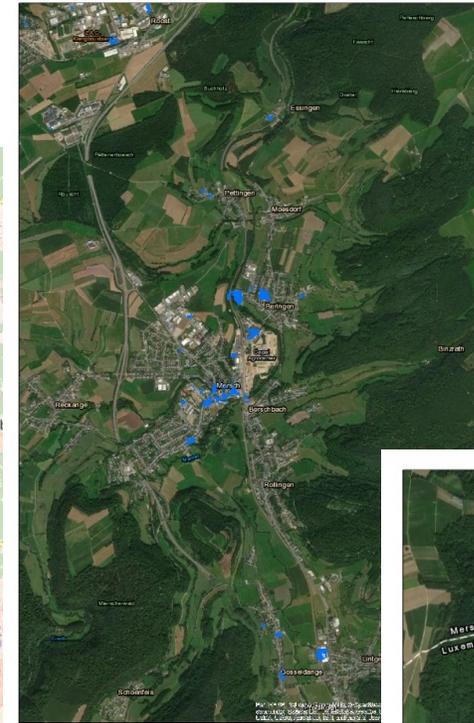
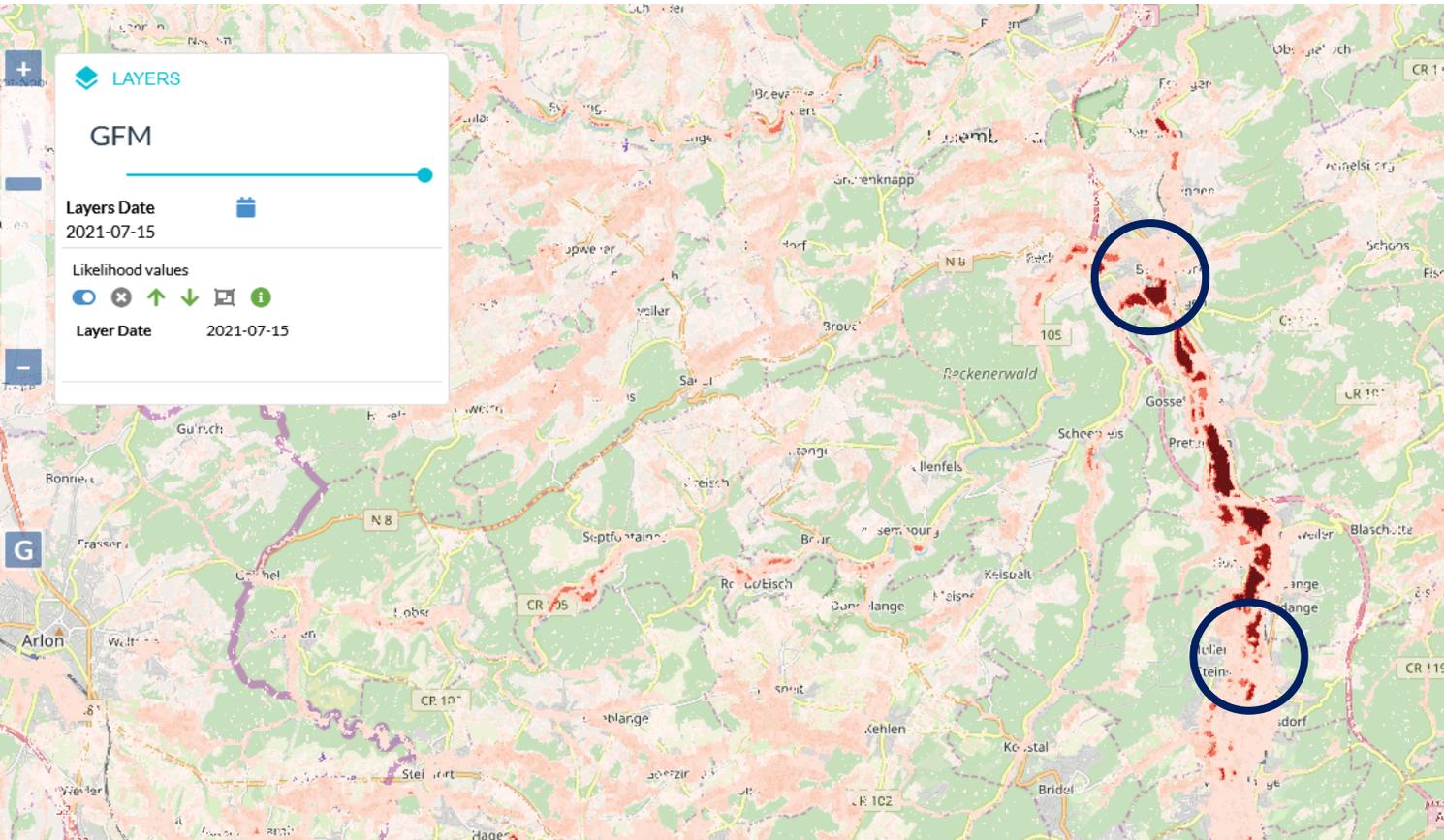


# COMPARISON WITH EFAS FLOOD HAZARD MAP

1-in-100 years flood event



# INPUT DATA – SATELLITE DATA



Flood probabilities published by the Global Flood Monitoring System (15 July 2021)

→ PF1 experiment

Floodwater in built up areas through WASDI (added to GFM-based flood extent in 'open' areas)

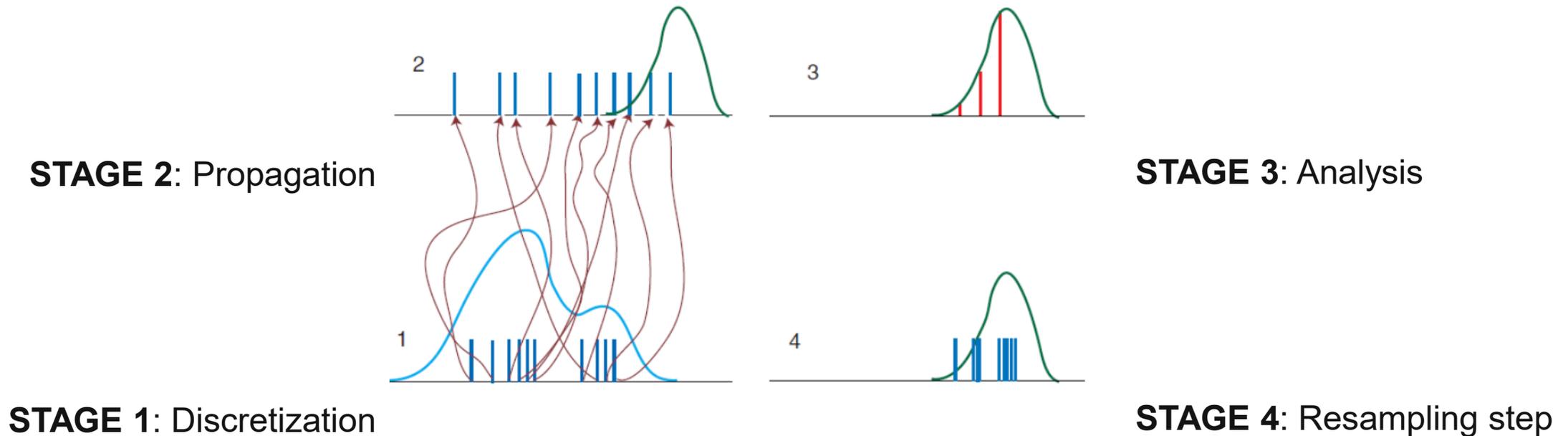
→ PF2 experiment



# DATA ASSIMILATION FRAMEWORK

Bayes' Theorem: 
$$p(\theta|\mathbf{o}) = \frac{p(\mathbf{o}|\theta)}{p(\mathbf{o})}p(\theta)$$

- Prior and posterior probability is approximated by a set of particles.
- Posterior probability is computed using weights.



# DATA ASSIMILATION – PARTICLE WEIGHT COMPUTATION

$$p(\theta|o) = \frac{p(o|\theta)}{p(o)} p(\theta)$$

Model<sup>t,n</sup>

1	0	1
0	1	1
1	0	0

$$w_{1,1}^{t,n} = \theta_{1,1}$$

Simulated wet pixel

$$w_{3,3}^{t,n} = 1 - \theta_{3,3}$$

Simulated dry pixel

Satellite observation



$\theta_{1,1}$	$\theta_{1,2}$	$\theta_{1,3}$
$\theta_{2,1}$	$\theta_{2,2}$	$\theta_{2,3}$
$\theta_{3,1}$	$\theta_{3,2}$	$\theta_{3,3}$

Prob (Obs | Model)

$w_{1,1}^{t,n}$	$w_{1,2}^{t,n}$	$w_{1,3}^{t,n}$
$w_{2,1}^{t,n}$	$w_{2,2}^{t,n}$	$w_{2,3}^{t,n}$
$w_{3,1}^{t,n}$	$w_{3,2}^{t,n}$	$w_{3,3}^{t,n}$

Spatial aggregation of local weights

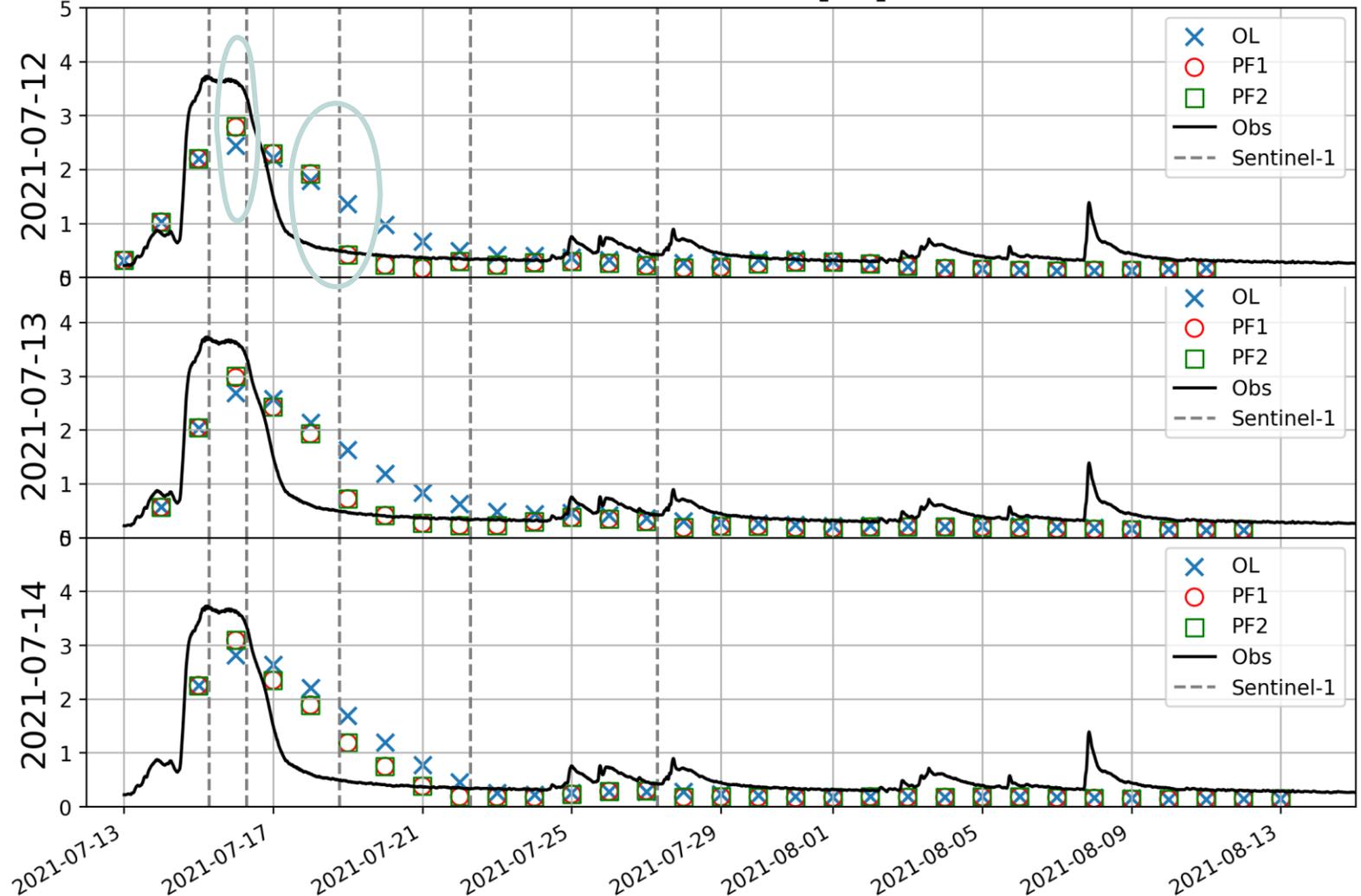
$$W^{t,n} = \frac{\prod_{i,k} (w_{i,k}^{t,n})^\varphi}{\sum_i \left( \prod_{j,k} (w_{j,k}^{t,n})^\varphi \right)}$$

- Hostache, R., Chini, M., Giustarini, L., Neal, J., Kavetski, D., Wood, M., Corato, G., Pelich, R., & Matgen, P. (2018). Near-Real-Time Assimilation of SAR-Derived Flood Maps for Improving Flood Forecasts. *Water Resources Research*, 54(8), 5516–5535. <https://doi.org/10.1029/2017WR022205>
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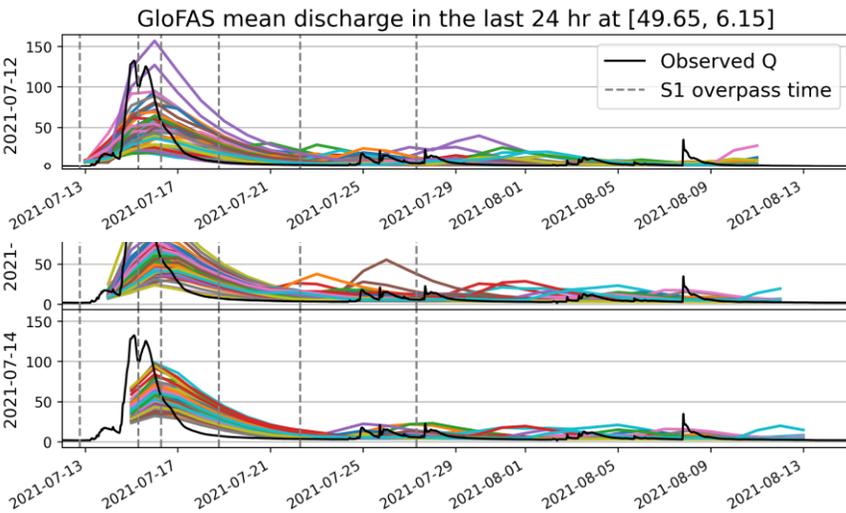
# RESULT - FLOOD FORECASTING

## Forecast waterdepth at gauging station

Hunsdorf -  $H[m]$



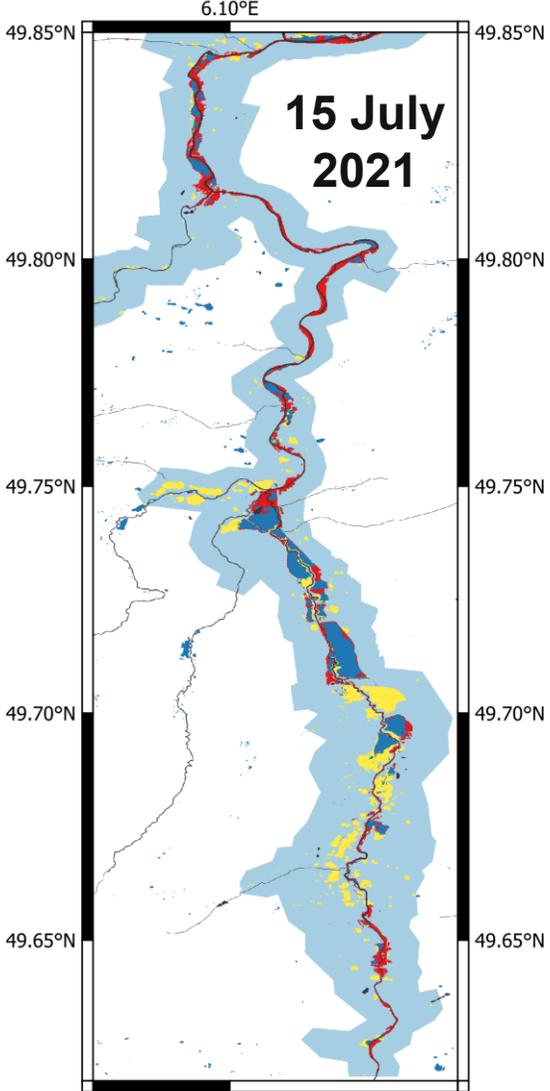
## Upstream boundary conditions



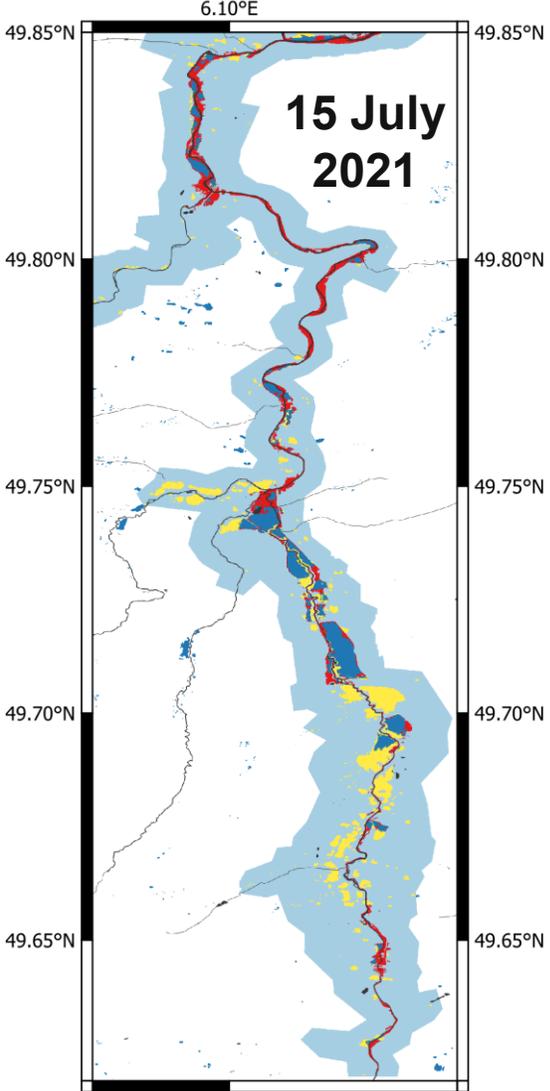
## RMSE [m] over 30 days

Exp.	GloFAS forecast issue date								
	July 12			July 13			July 14		
	OL	PF1	PF2	OL	PF1	PF2	OL	PF1	PF2
Hunsdorf	0.179	<b>0.151</b>	0.151	0.191	<b>0.127</b>	0.127	0.206	<b>0.143</b>	0.144
Steinsel	0.181	0.141	<b>0.139</b>	0.145	0.106	<b>0.104</b>	0.130	0.103	<b>0.102</b>

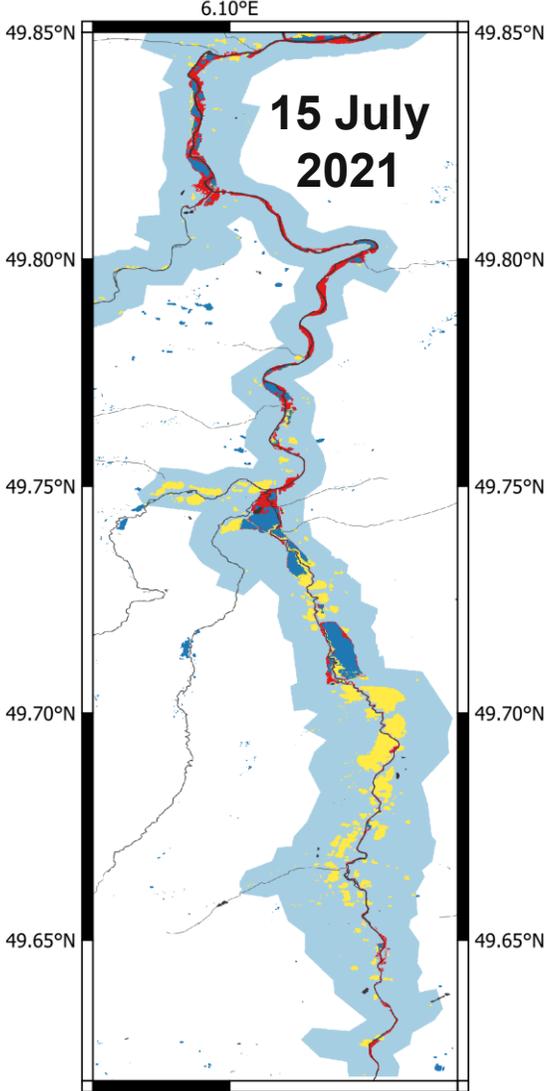
# RESULT - FLOOD FORECASTING



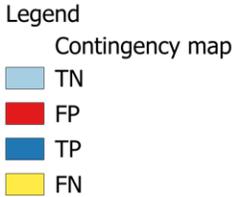
Model run 12 July



Model run 13 July

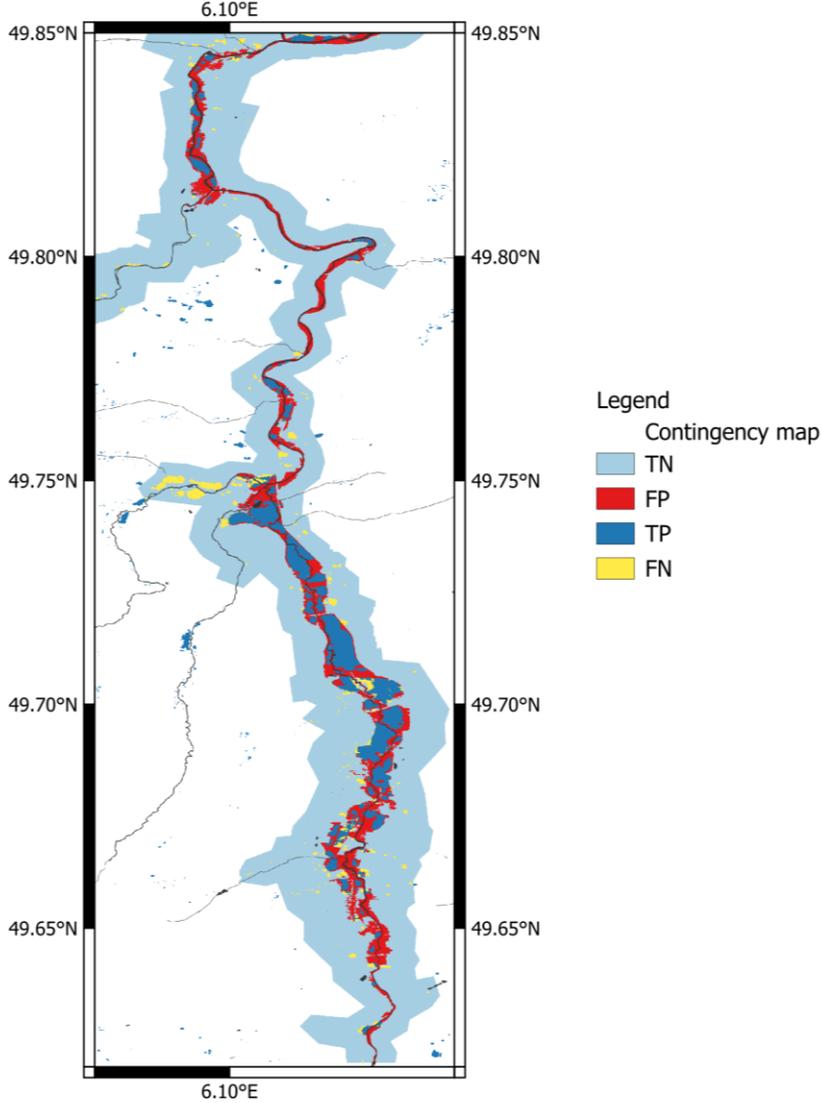
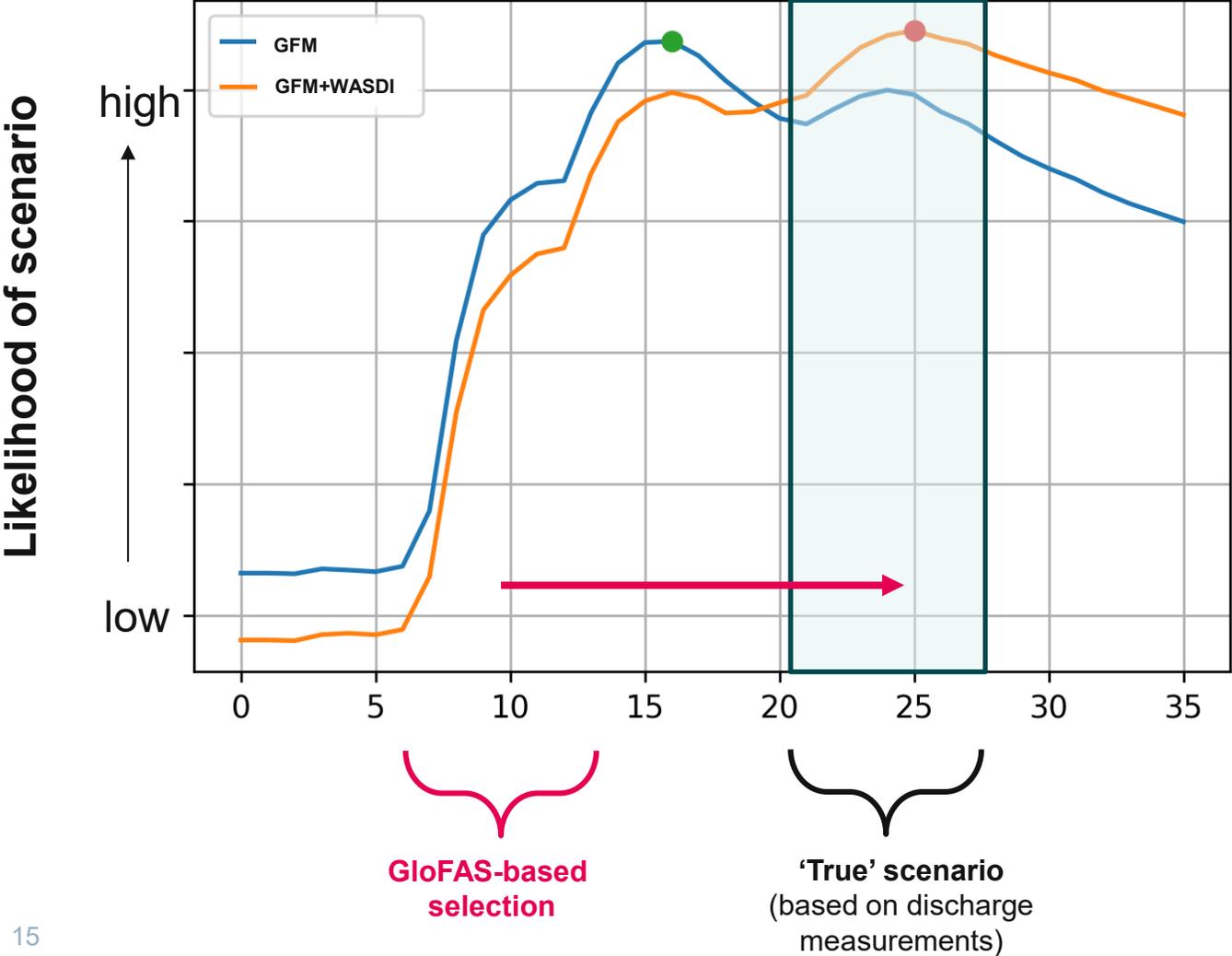


Model run 14 July



# ADDED VALUE OF SATELLITE DATA ASSIMILATION

Comparison of model runs with and without GFM+WASDI data assimilation on 15 July



Scenario of the highest weight w.r.t. WASDI+GFM map

# CONCLUSION

- Data assimilation framework enabling integration of GloFAS and GFM
- ‘à la carte’ modelling framework where GloFAS streamflow forecasts can be converted into inundation forecasts using regional hydrodynamic model (complementing GloFAS’ own inundation products)
- Results show that integration of satellite data enables selection of ‘true’ flood scenario, thereby reducing predictive uncertainty and confirming potential of GFM-GloFAS integration for enhanced inundation predictions

# PERSPECTIVES

- Repeating experiment with GloFAS pre-computed hazard cube
- Connecting floodhazard datacube and discharge particles via return period
- Improving PF weight computation scheme (e.g. enabling refinements at sub-reach level)
- Upscaling requires localization of DA filters (i.e. to connect GloFAS-based streamflow predictions with relevant GFM observations)

(+ improvements of GloFAS and GFM products)

# THANK YOU FOR YOUR ATTENTION

*Funded by the LSA through an ESA Contract in the Luxembourg National Space programme (LuxIMPULSE),  
Contract No. 4000140965/23/NL/VR.*

*Contact: [patrick.matgen@list.lu](mailto:patrick.matgen@list.lu)*

