

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



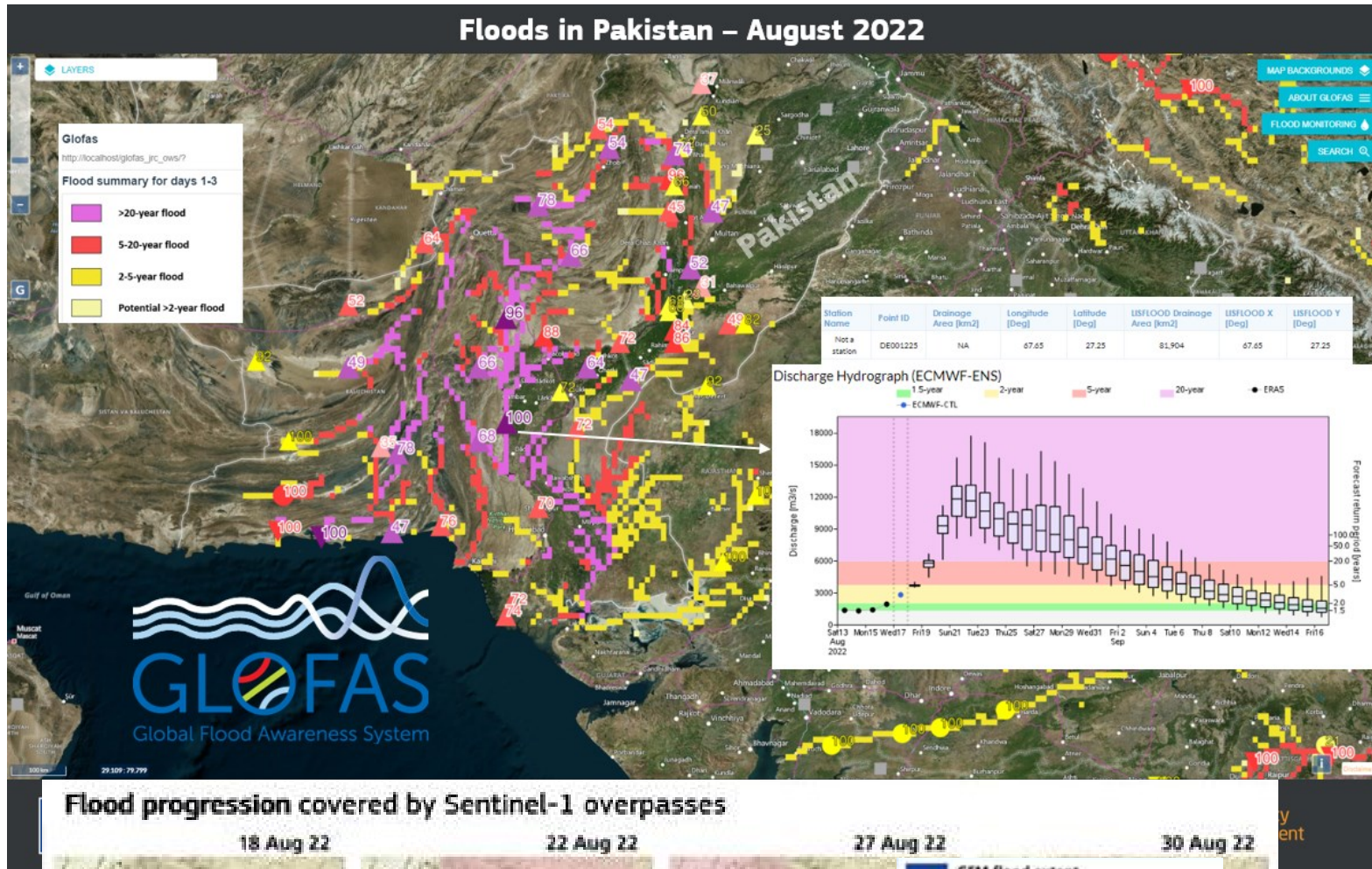
SETTING THE SCENE

GloFAS:

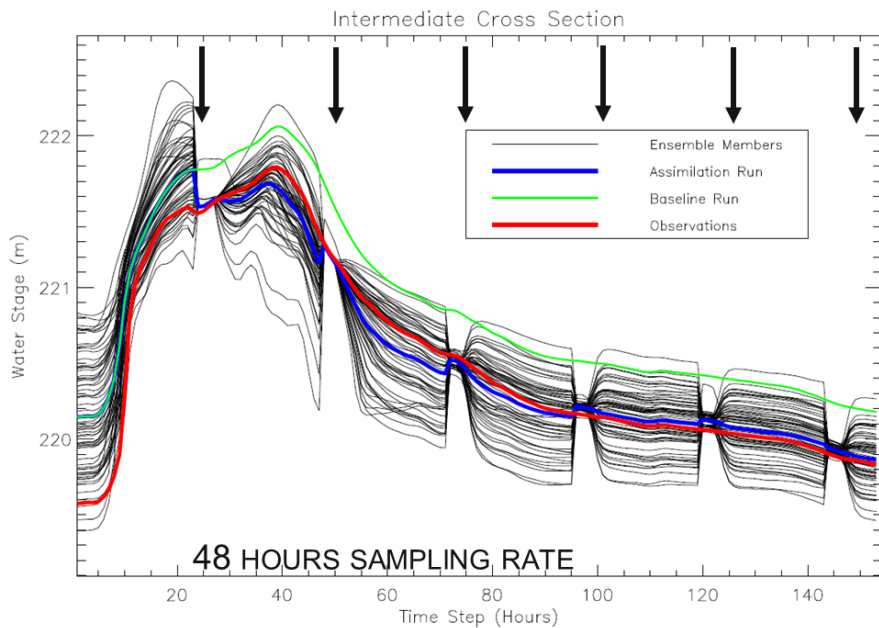
- Extent predictions using pre-computed map catalogue
- Approximation to nearest flood return period map
- Coarse resolution for comprehensive impact assessment

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)

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2020WR027859

Page 1 / 28

Water Resources Research

RESEARCH ARTICLE
10.1029/2020WR027859

A Mutual Information-Based Likelihood Particle Filter Flood Extent Assimilation

Antara Dasgupta^{1,2,3}, Renaud Hostache⁴, RAAJ Ramsankar⁵, Guy J.-P. Schumann⁶, Stefania Grimaldi⁷, Valentijn R. N. Jeffrey⁸, P. Walker⁹

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

Key Points:

- A novel mutual information-based metric is proposed as the 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 to reduce the economic and social impacts of flooding, but uncertainties in inflows propagated from the precipitation forecast and hydraulic flood inundation modeling can be mitigated. Satellite observations of flood extent can be assimilated into a flood forecasting model cascade to improve the accuracy of the model forecasts. This study presents a novel mutual information-based metric as the likelihood function for particle filter-based flood extent assimilation. The assimilation is performed on a coupled hydrologic-hydraulic forecasting model. The results show that the assimilation of SAR-derived flood extent maps into the model forecasts significantly improves the accuracy of the model forecasts. The assimilation time step, the adapted method enables the model forecasts to be updated in real time, and the model forecasts are substantially improved. The results show that the assimilation of SAR-derived flood extent maps into the model forecasts significantly improves the accuracy of the model forecasts. The assimilation time step, the adapted method enables the model forecasts to be updated in real time, and the model forecasts are substantially improved.

Correspondence to: A. Dasgupta, antara.dasgupta@monash.edu

Citation: Dasgupta, A., Hostache, R., Ramsankar, R., Schumann, G., Grimaldi, S., Jeffrey, V., Walker, P., et al. (2021). A mutual information-based likelihood particle filter flood extent assimilation. *Water Resources Research*, 57, e2020WR027859. <https://doi.org/10.1029/2020WR027859>

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2021WR022205

Page 1 / 20

Water Resources Research

RESEARCH ARTICLE
10.1029/2021WR022205

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

Renaud Hostache¹, Marco Chini¹, Laura Giustarini¹, Jeffrey Neal², Dmitri Kavetski³, Melissa Wood^{1,2,4}, Giovanni Corato¹, Ramona-Maria Pelich¹, and Patrick Matgen¹

¹Department of Environmental Research and Innovation, Luxembourg Institute of Science and Technology, Alzette, Luxembourg, ²School of Geographical Sciences, University of Bristol, Bristol, UK, ³School of Civil and Mining Engineering, University of Adelaide, Adelaide, South Australia, Australia, ⁴Faculty of Geosciences, University, 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 impacts 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 extent maps (e.g., generated from SAR sensors such as Sentinel-1) provides opportunities to improve flood forecast quality. This study presents a novel mutual information-based metric as the likelihood function for particle filter-based flood extent assimilation. The assimilation is performed on a coupled hydrologic-hydraulic forecasting model. The results show that the assimilation of SAR-derived flood extent maps into the model forecasts significantly improves the accuracy of the model forecasts. The assimilation time step, the adapted method enables the model forecasts to be updated in real time, and the model forecasts are substantially improved. The results show that the assimilation of SAR-derived flood extent maps into the model forecasts significantly improves the accuracy of the model forecasts. The assimilation time step, the adapted method enables the model forecasts to be updated in real time, and the model forecasts are substantially improved.

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*, 57, e2021WR022205. <https://doi.org/10.1029/2021WR022205>

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2022WR031940

Page 1 / 19

Water Resources Research

RESEARCH ARTICLE
10.1029/2022WR031940

A Tempered Particle Filter to Enhance the Assimilation of SAR-Derived Flood Extent Maps Into Flood Forecasting Models

Concetta Di Mauro^{1,2}, Renaud Hostache¹, Patrick Matgen¹, Ramona Pelich¹, Marco Chini¹, Peter Jan van Leeuwen^{3,4}, Nancy K. Nichols⁵, and Günter Blöschl^{6,2}

¹Luxembourg Institute of Science and Technology, Luxembourg, ²Institut de Recherche pour le Développement, Université de Guyane, Université d'Antilles, Université de Nouvelle-Calédonie, Montpelier, France, ³Department of Meteorology, University of Reading, Reading, UK, ⁴Department of Atmospheric Science, Colorado State University, Fort Collins, CO, USA, ⁵Department of Mathematics and Statistics, University of Reading, Reading, UK, ⁶Centre for Water Resource Systems, Vienna University of Technology, Vienna, Austria

Key Points:

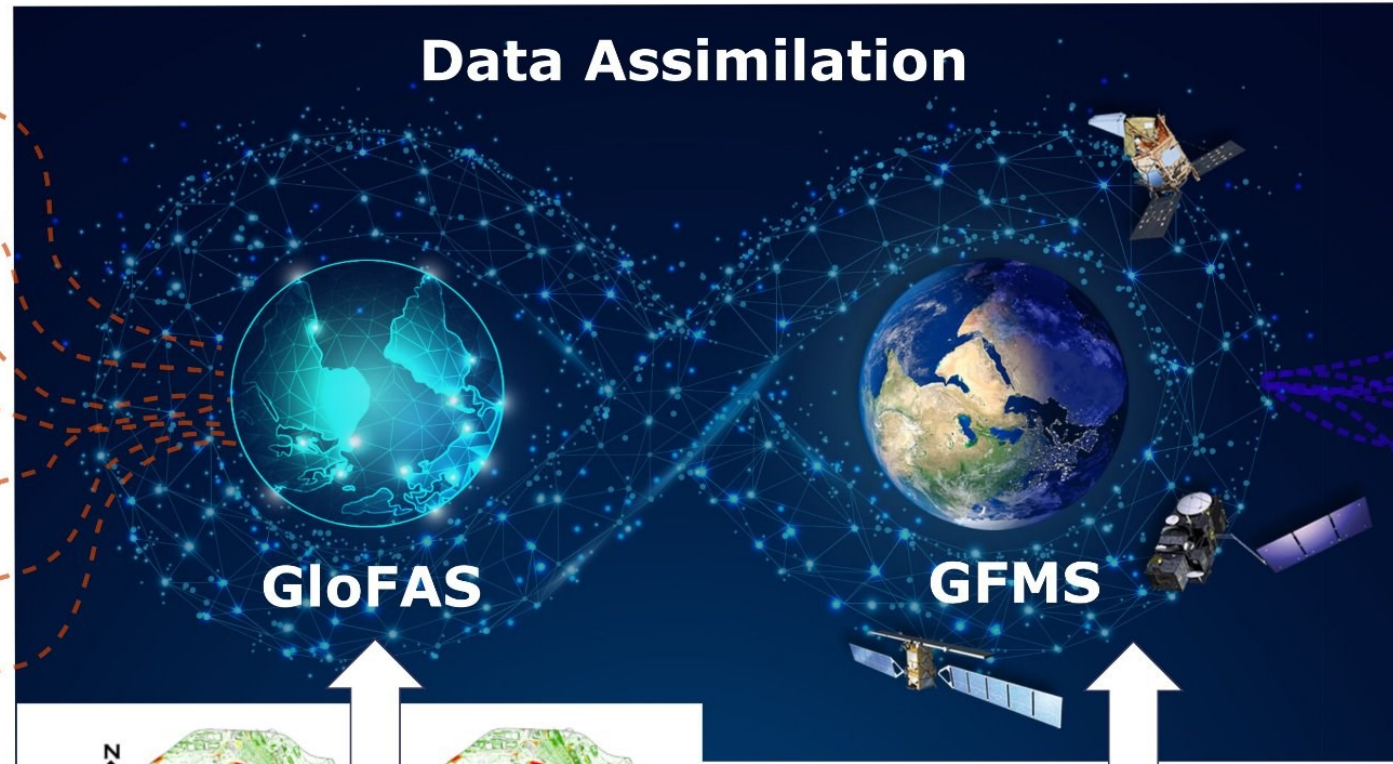
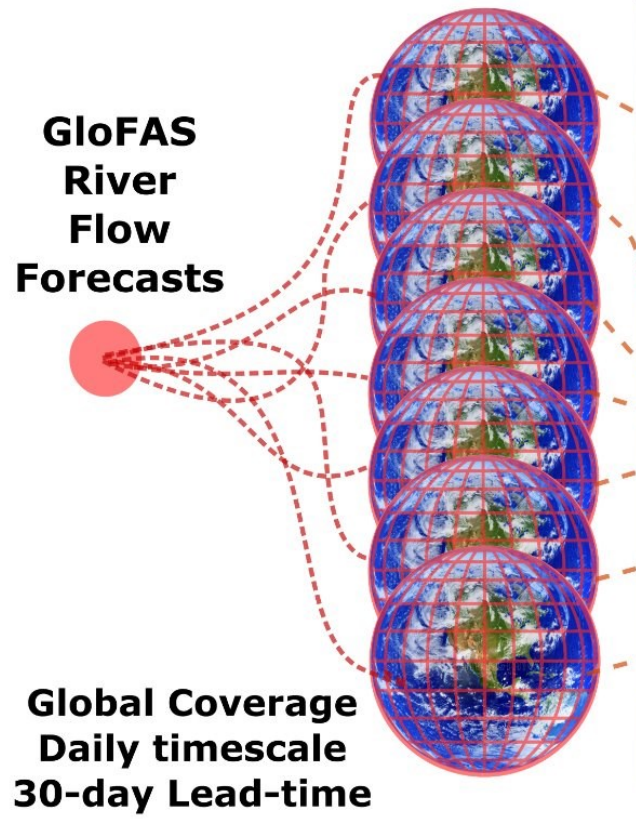
- We assimilate flood extent maps into a flood forecasting system using a tempered particle filter (TPF)
- The TPF mitigates degeneracy and enables long-lasting forecast improvements
- The TPF outperforms a standard particle filter in terms of accuracy of model outputs

Abstract Data assimilation (DA) is a powerful tool to optimally combine uncertain model outputs and observations. Among 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 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: 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: C. Di Mauro, c.dimauro@list.lu, renaud.hostache@list.lu

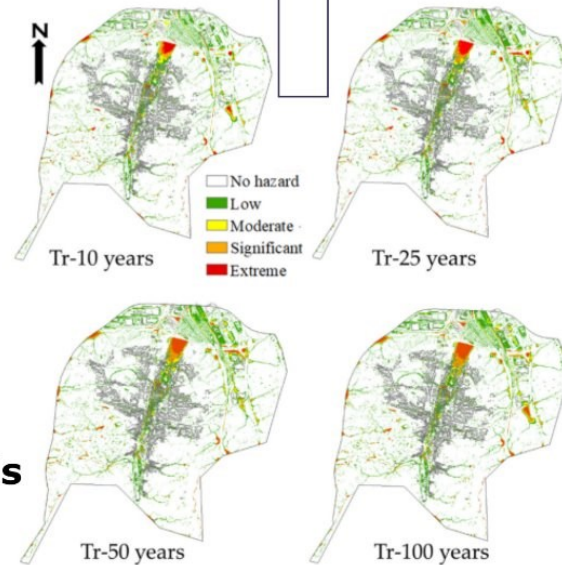
Citation: Di Mauro, C., Hostache, R., Matgen, P., Pelich, R., Chini, M., van Leeuwen, P. J., et al. (2022). A tempered particle filter to enhance the assimilation of SAR-derived flood extent maps into flood forecasting models. *Water Resources Research*, 58, e2022WR031940. <https://doi.org/10.1029/2022WR031940>

Abstract. Coupled hydrologic and hydraulic models represent a powerful tool to predict and mitigate the impacts of flooding. However, uncertainties in inflows propagated from the precipitation forecast and hydraulic flood inundation modeling can be mitigated. Satellite observations of flood extent can be assimilated into a flood forecasting model cascade to improve the accuracy of the model forecasts. This study presents a novel mutual information-based metric as the likelihood function for particle filter-based flood extent assimilation. The assimilation is performed on a coupled hydrologic-hydraulic forecasting model. The results show that the assimilation of SAR-derived flood extent maps into the model forecasts significantly improves the accuracy of the model forecasts. The assimilation time step, the adapted method enables the model forecasts to be updated in real time, and the model forecasts are substantially improved. The results show that the assimilation of SAR-derived flood extent maps into the model forecasts significantly improves the accuracy of the model forecasts. The assimilation time step, the adapted method enables the model forecasts to be updated in real time, and the model forecasts are substantially improved.

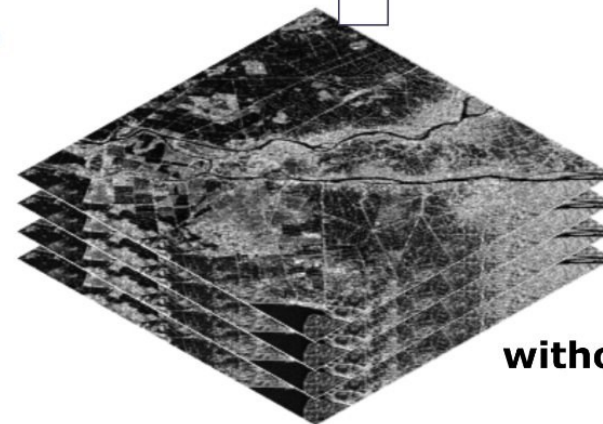


**Assimilated Flood Maps
(Daily, 100m,
30-day lead time,
with urban and
vegetated flooding)**

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



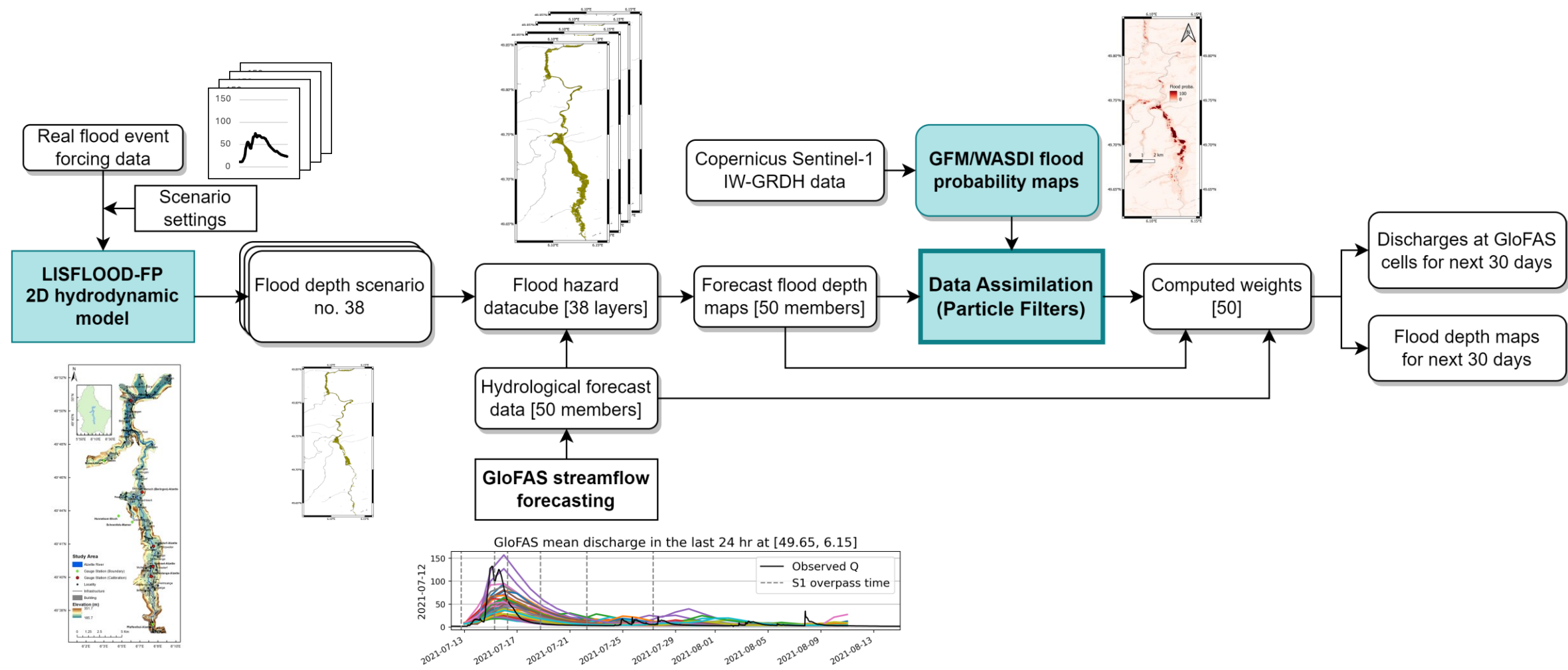
time ↑



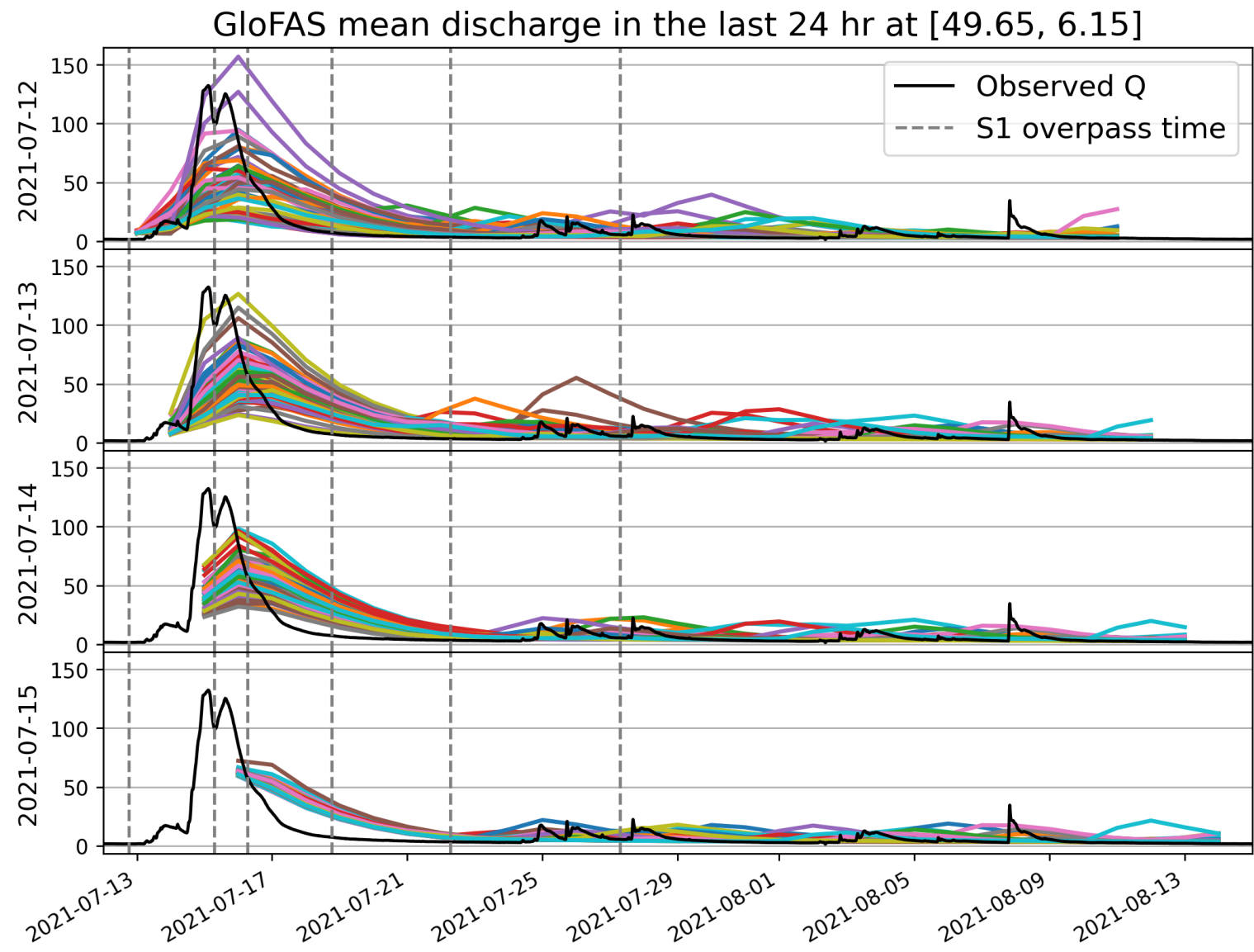
**Sentinel-1 NRT
Flood Maps
20 m/6days
without urban/vegetation**

Best of different approaches?

EXPERIMENT DESCRIPTION

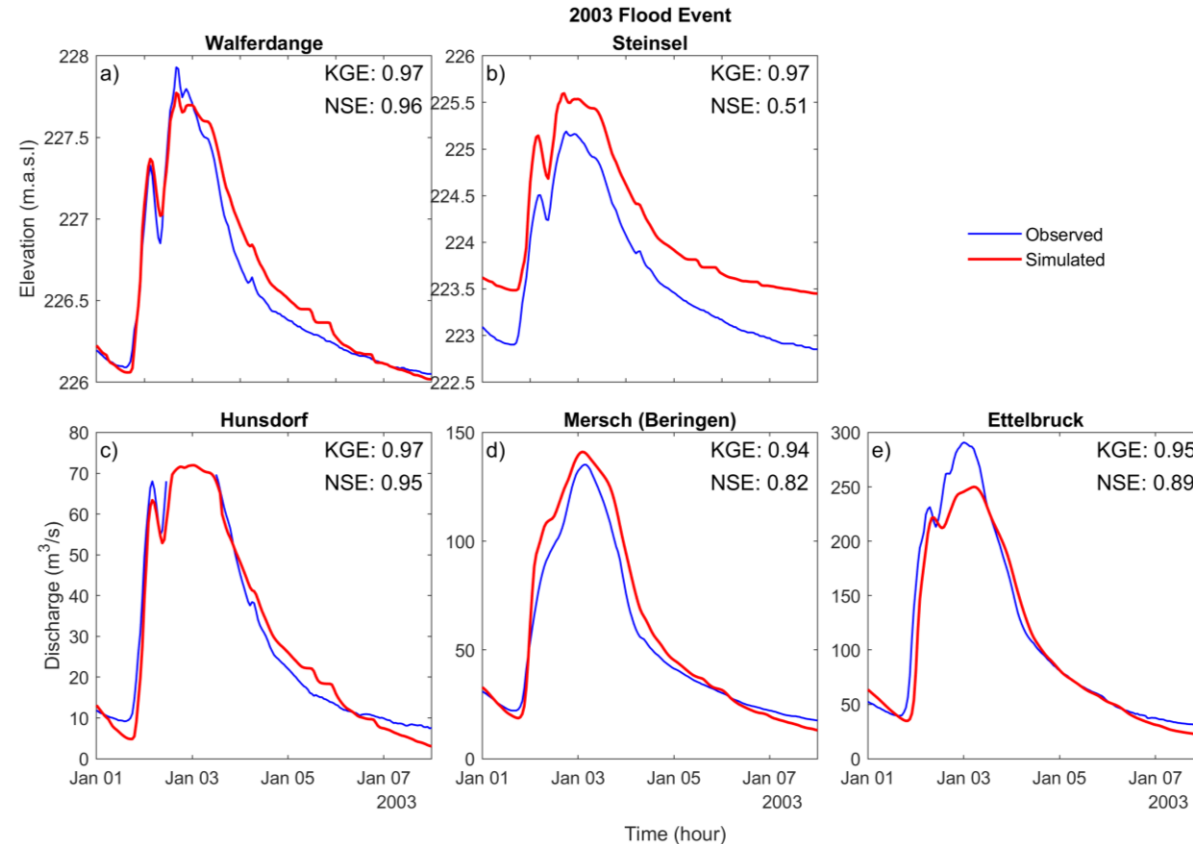
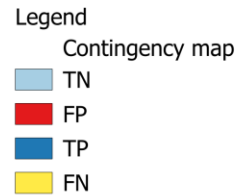
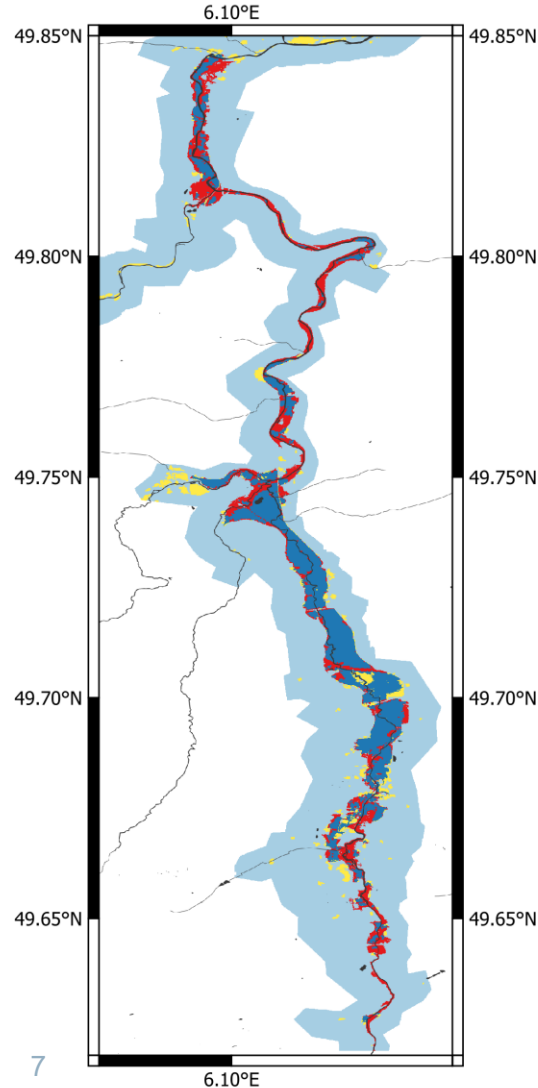


INPUT DATA – GLOFAS STREAMFLOW FORECASTS



HYDRODYNAMIC MODEL – LISFLOOD-FP

- Results (Model run @ 5m)



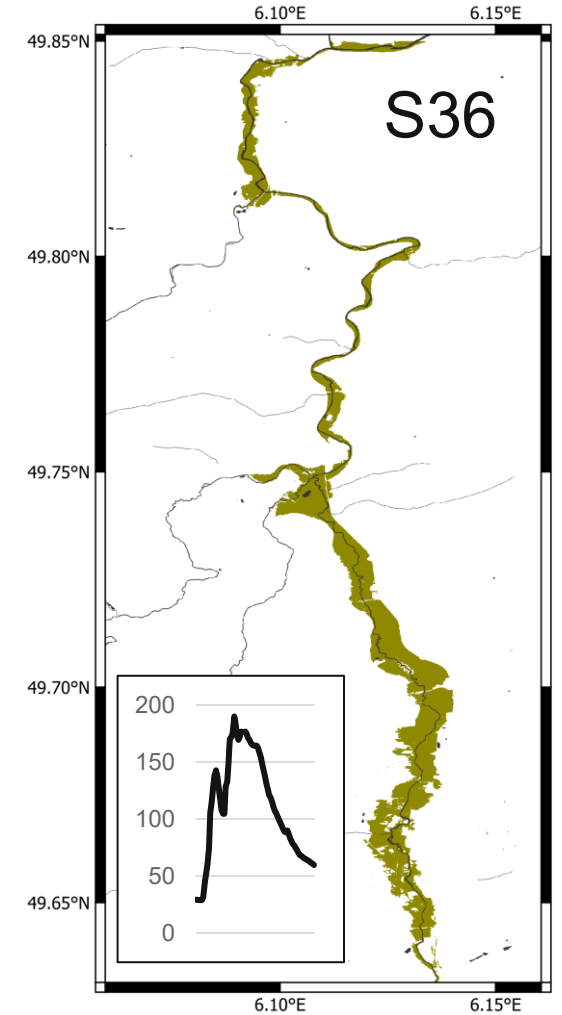
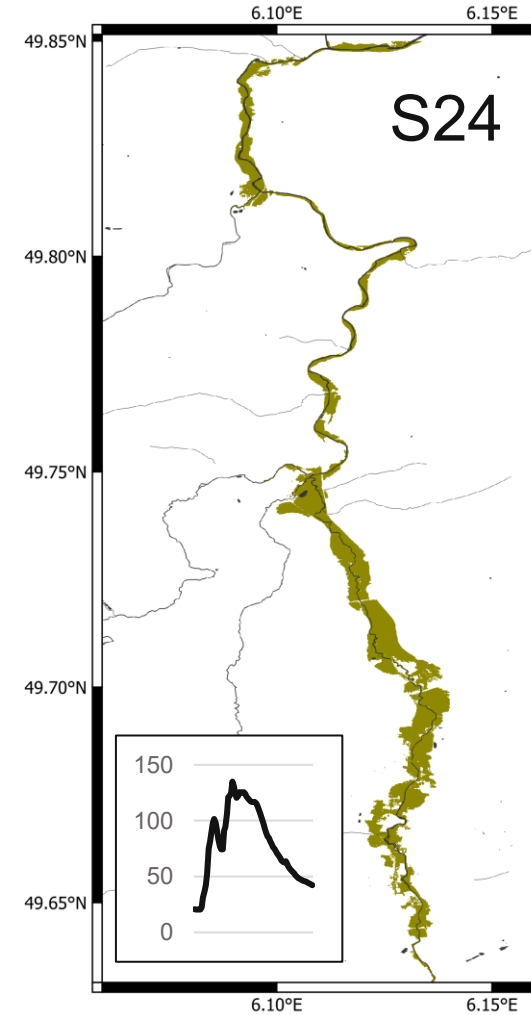
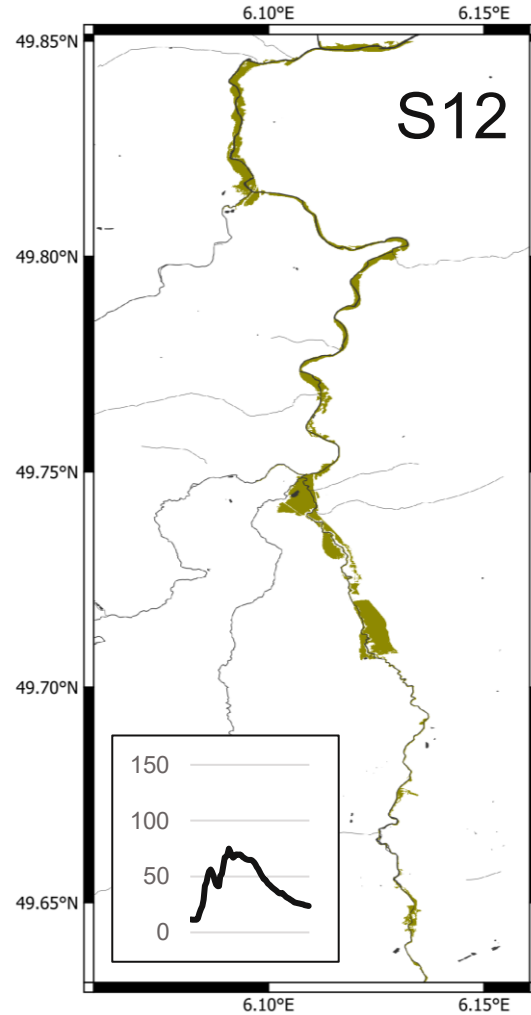
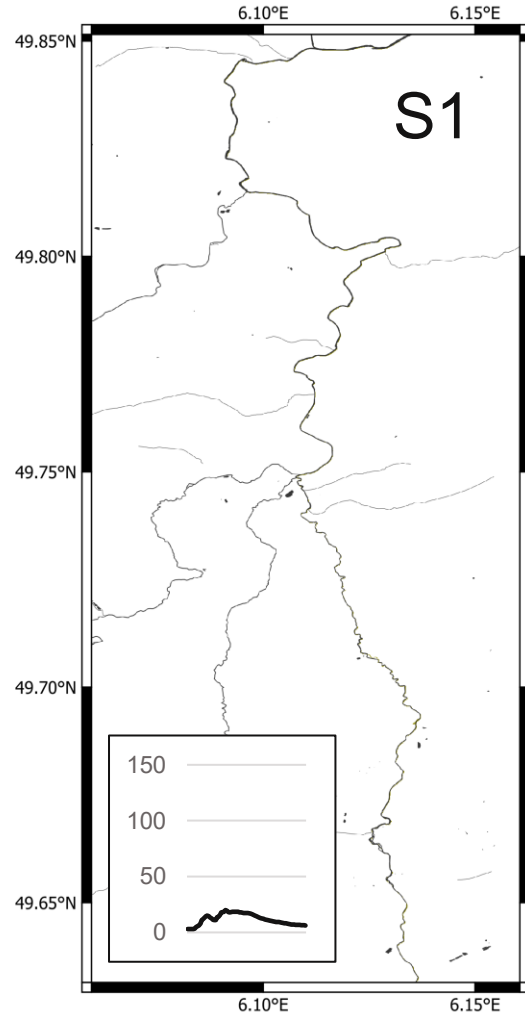
Comparison with measured water height/discharge and satellite-derived water extent:

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



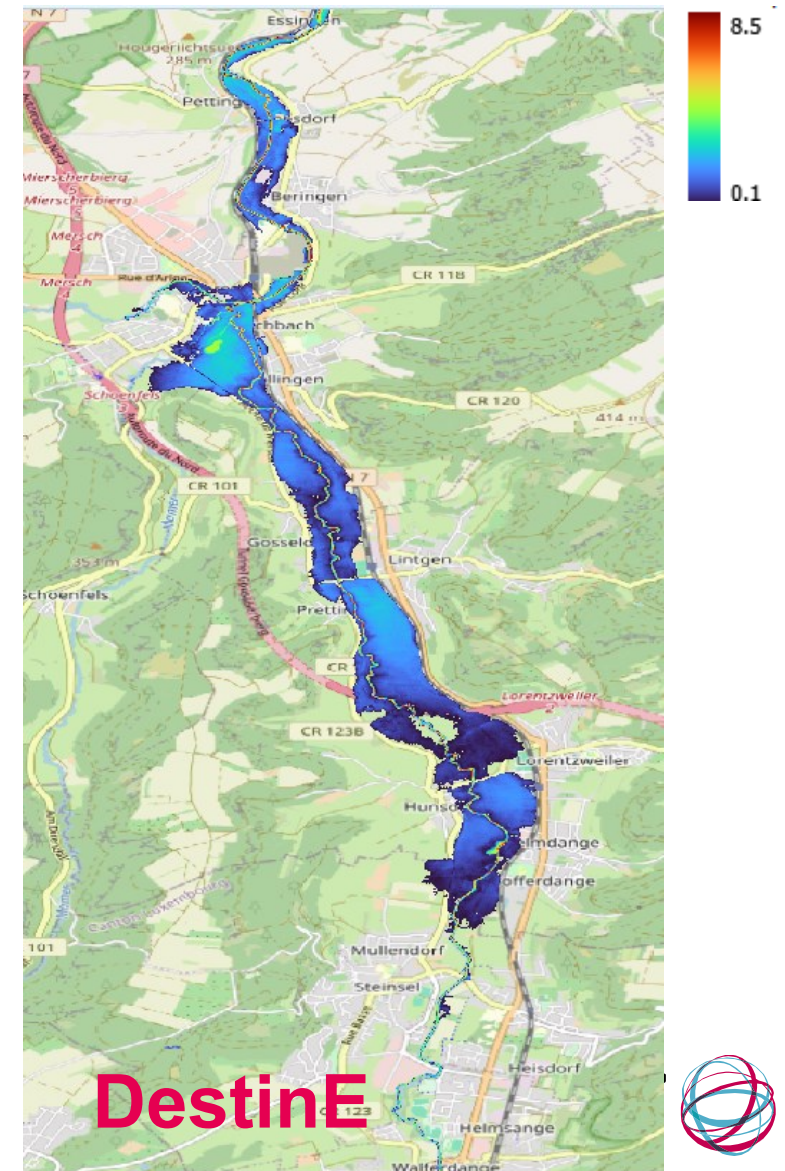
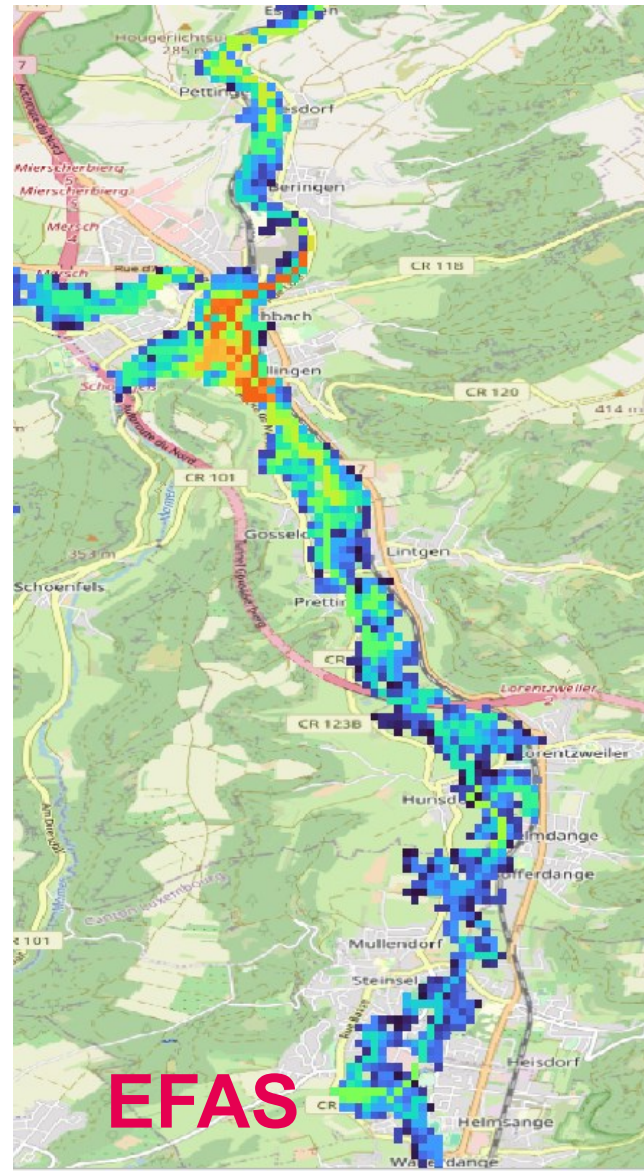
INPUT DATA - PRE-COMPUTATION OF SCENARIOS

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

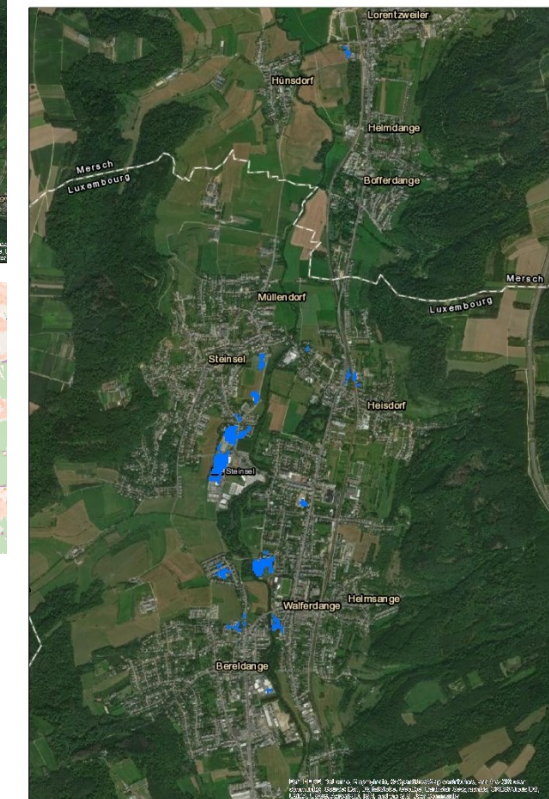
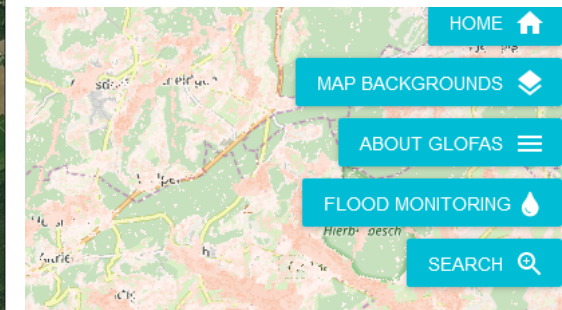
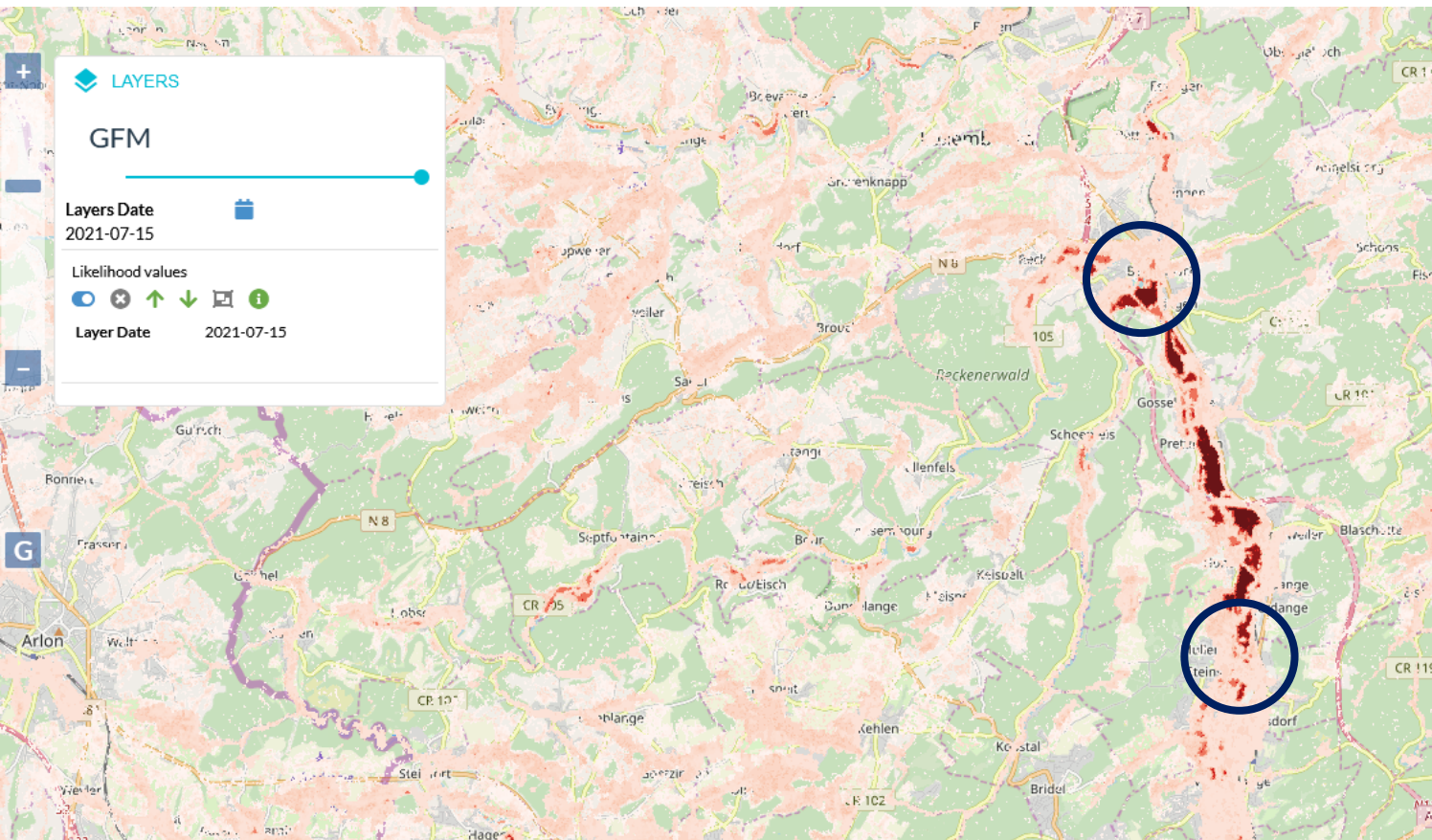


COMPARISON WITH EFAS FLOOD HAZARD MAP

1-in-100 years flood event



INPUT DATA – SATELLITE DATA



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

→ **PF1** experiment

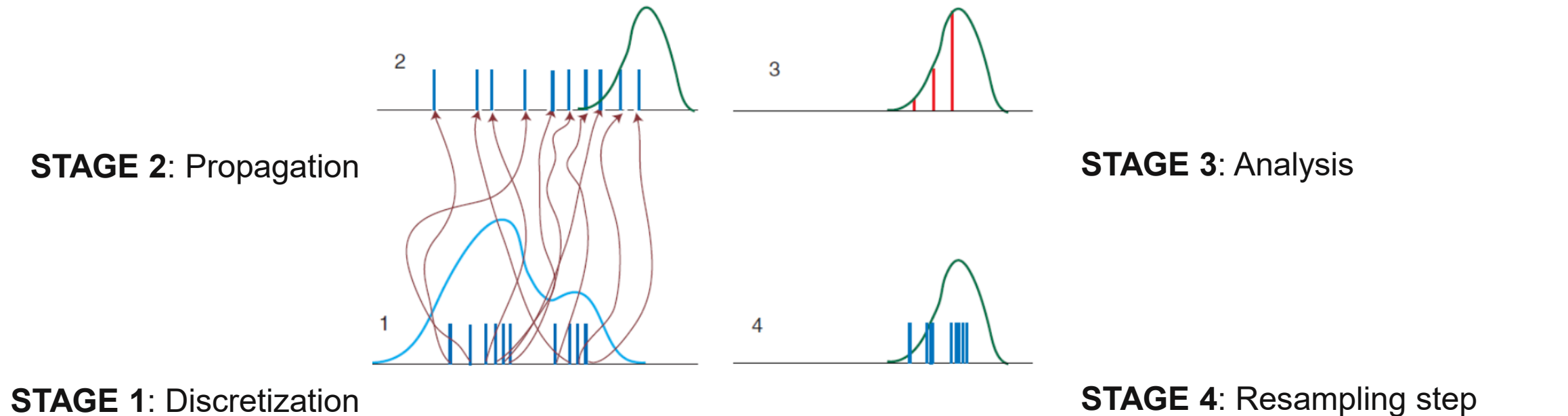
Floodwater in built up areas through WASDI (added to GFM-based flood extent in 'open' areas)

→ **PF2** experiment

DATA ASSIMILATION FRAMEWORK

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

- 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^{t,n}

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

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

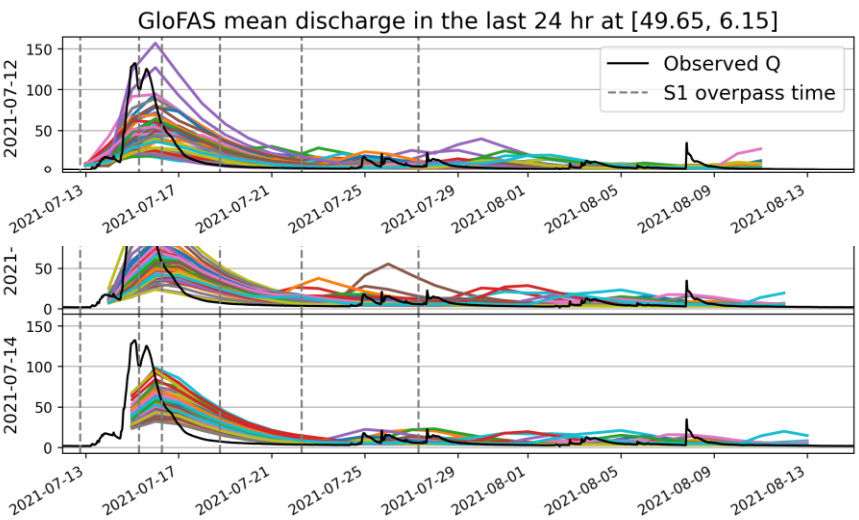
- Hostache, R., Chini, M., Giustarini, L., Neal, J., Kavetski, D., Wood, M., Corato, G., Pelich, R., & Matgen, P. (2018). Near-Real-Time Assimilation of SAR-Derived Flood Maps for Improving Flood Forecasts. *Water Resources Research*, 54(8), 5516–5535. <https://doi.org/10.1029/2017WR022205>
- Di Mauro, C., Hostache, R., Matgen, P., Pelich, R., Chini, M., van Leeuwen, P. J., Nichols, N., & Blöschl, G. (2022). A Tempered Particle Filter to Enhance the Assimilation of SAR-Derived Flood Extent Maps Into Flood Forecasting Models. *Water Resources Research*, 58(8), 1–19. <https://doi.org/10.1029/2022WR031940>

RESULT - FLOOD FORECASTING

Forecast waterdepth at gauging station

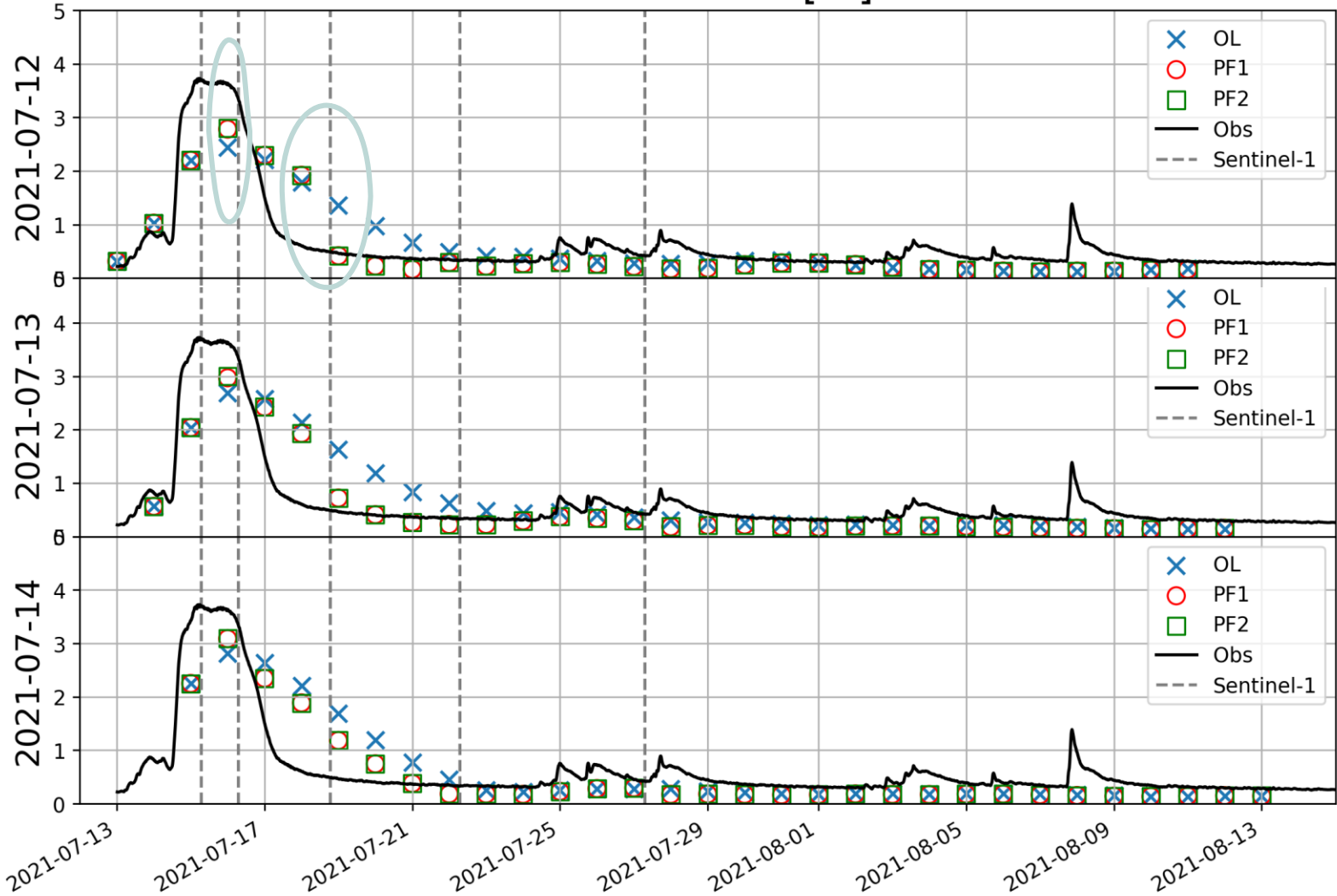
Hunsdorf - $H[m]$

Upstream boundary conditions

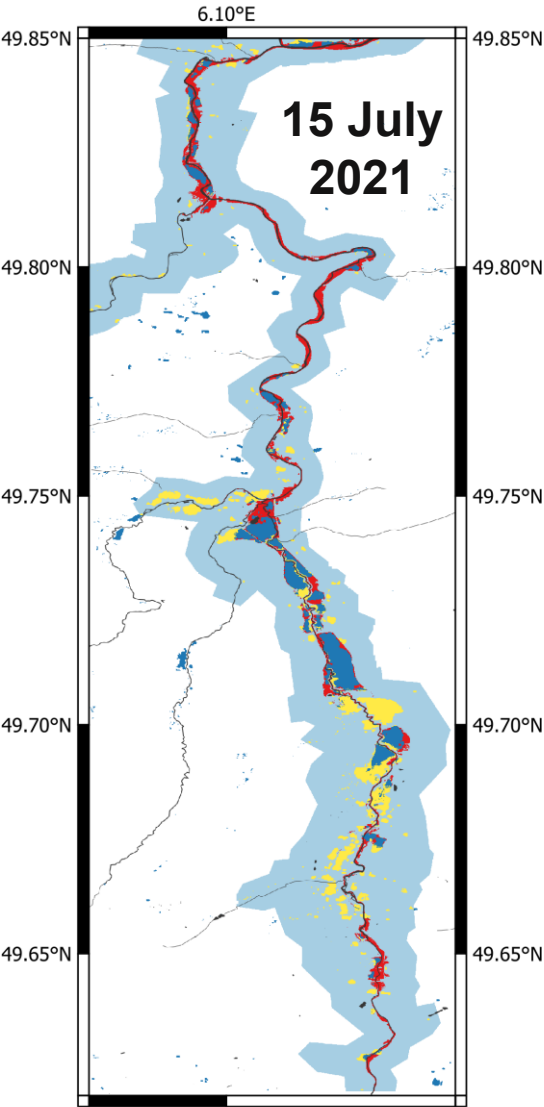


RMSE [m] over 30 days

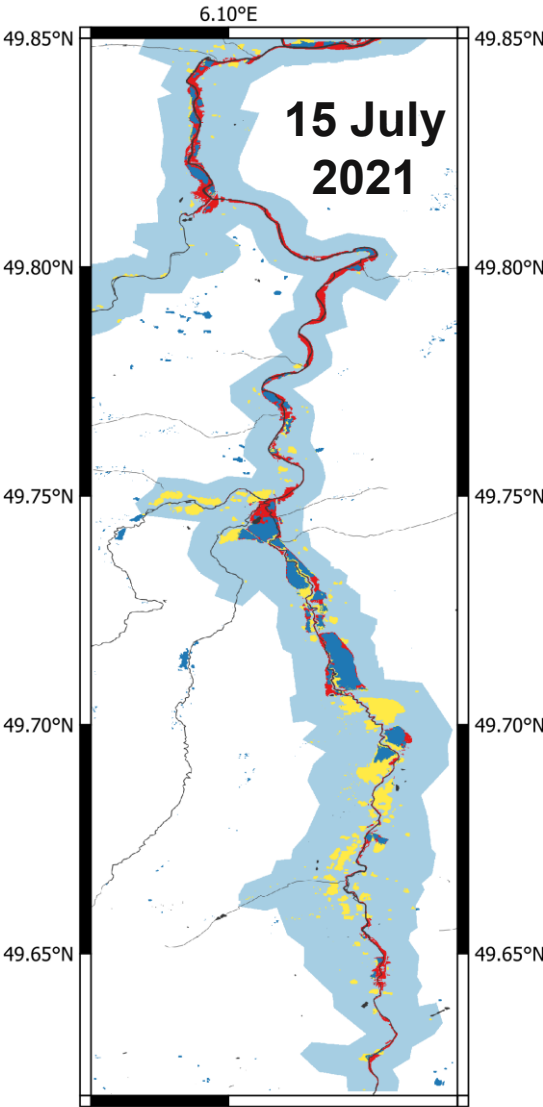
Exp.	GloFAS forecast issue date								
	July 12			July 13			July 14		
	OL	PF1	PF2	OL	PF1	PF2	OL	PF1	PF2
Hunsdorf	0.179	0.151	0.151	0.191	0.127	0.127	0.206	0.143	0.144
Steinsel	0.181	0.141	0.139	0.145	0.106	0.104	0.130	0.103	0.102



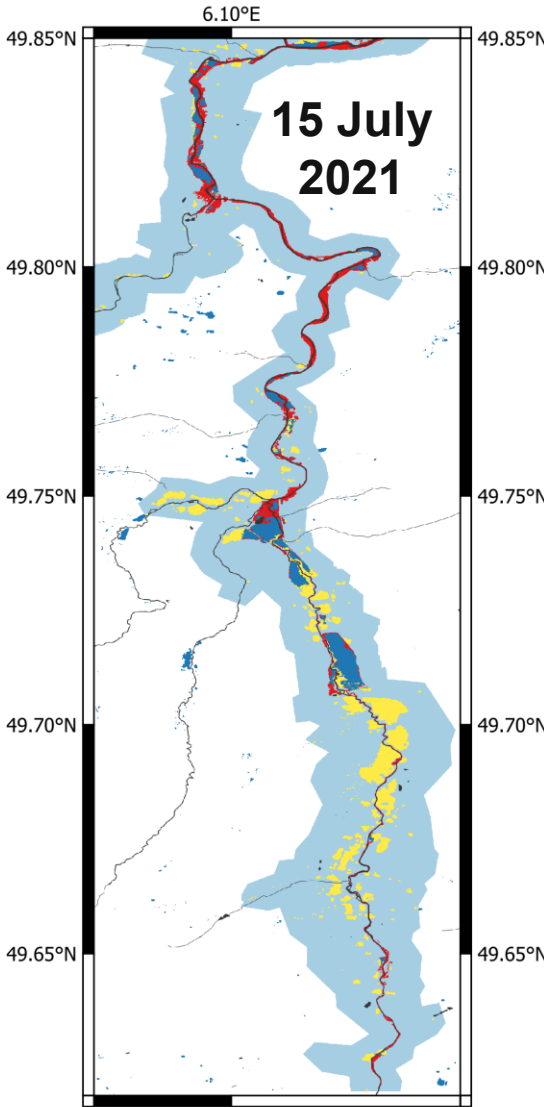
RESULT - FLOOD FORECASTING



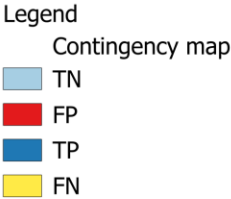
Model run 12 July



Model run 13 July

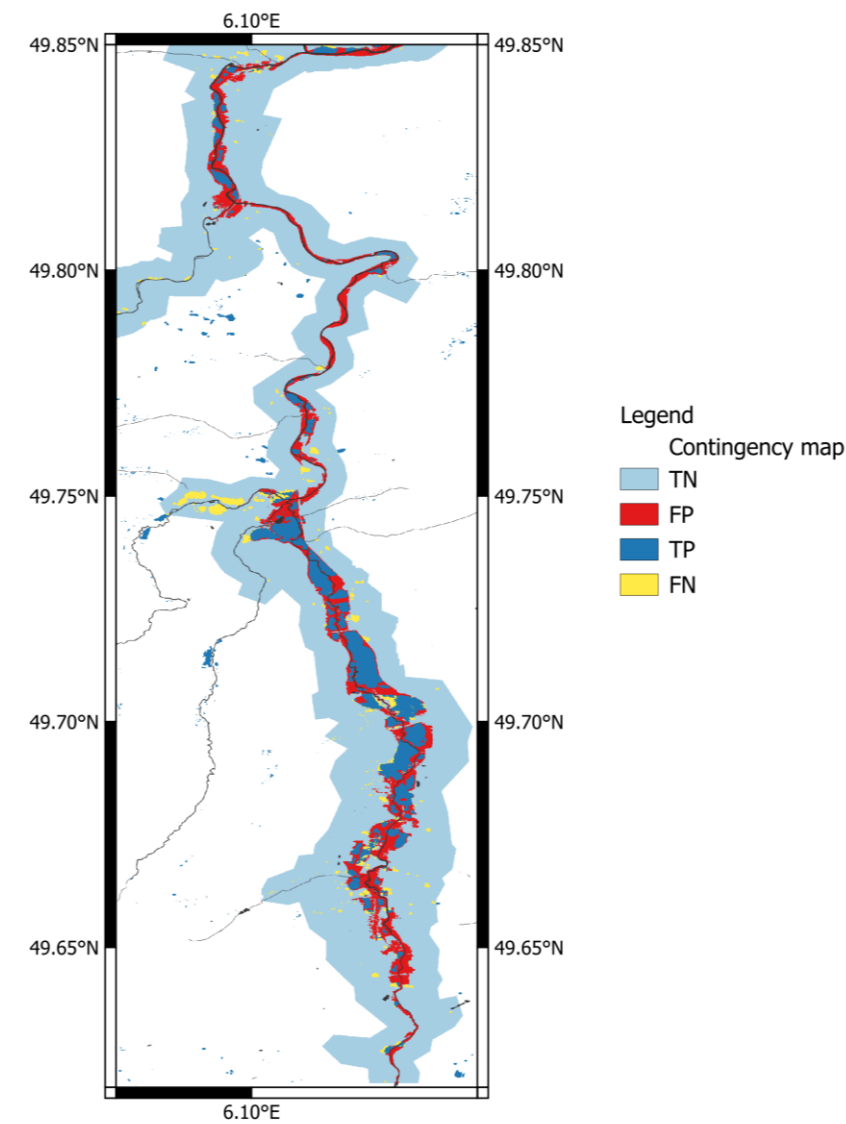
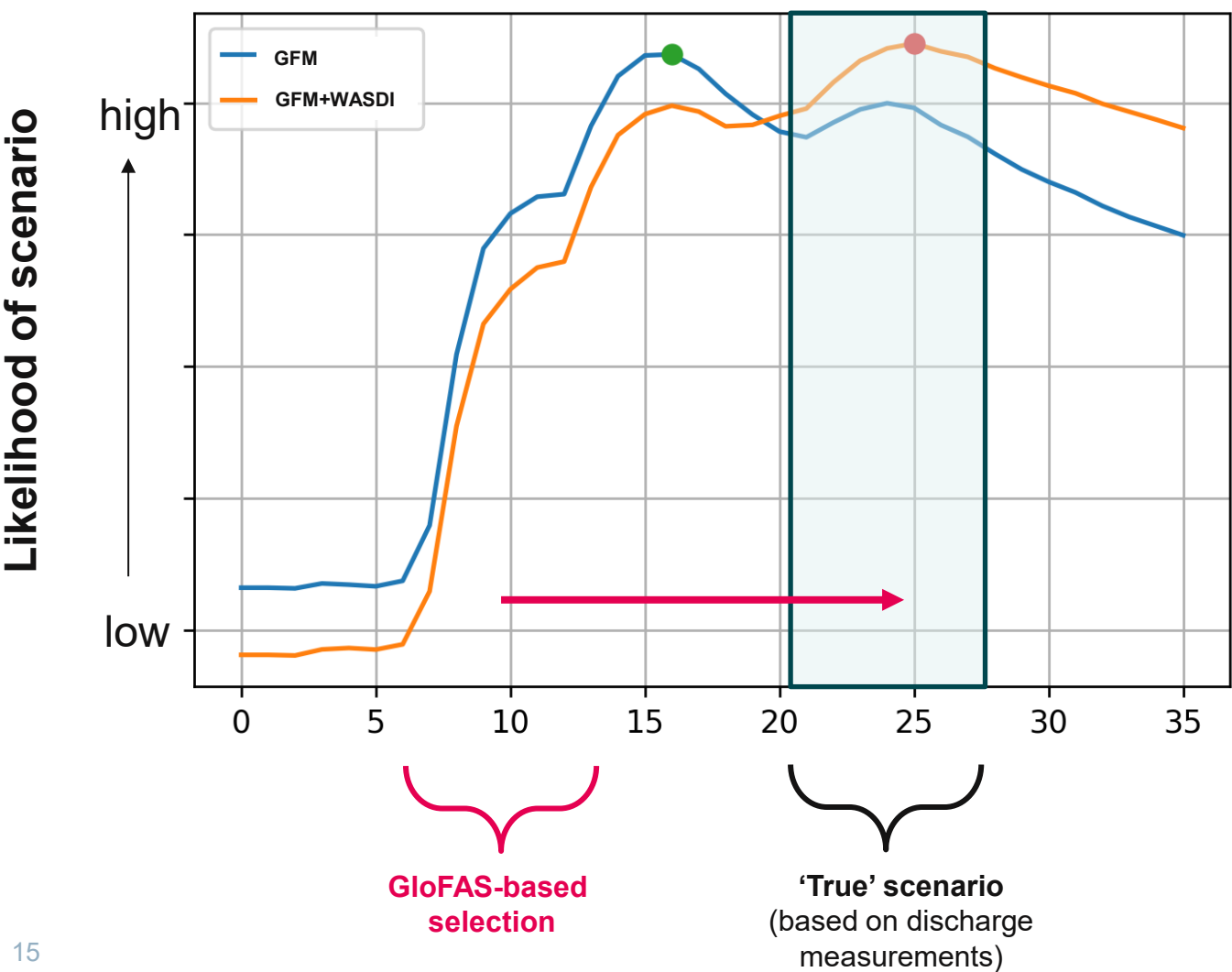


Model run 14 July



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

