Improving flood model predictions using satellite EO-derived flood extent maps

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SETTING THE SCENE

Objective

- To reduce uncertainties in numerical modelling-based flood forecasting

Traditional approach

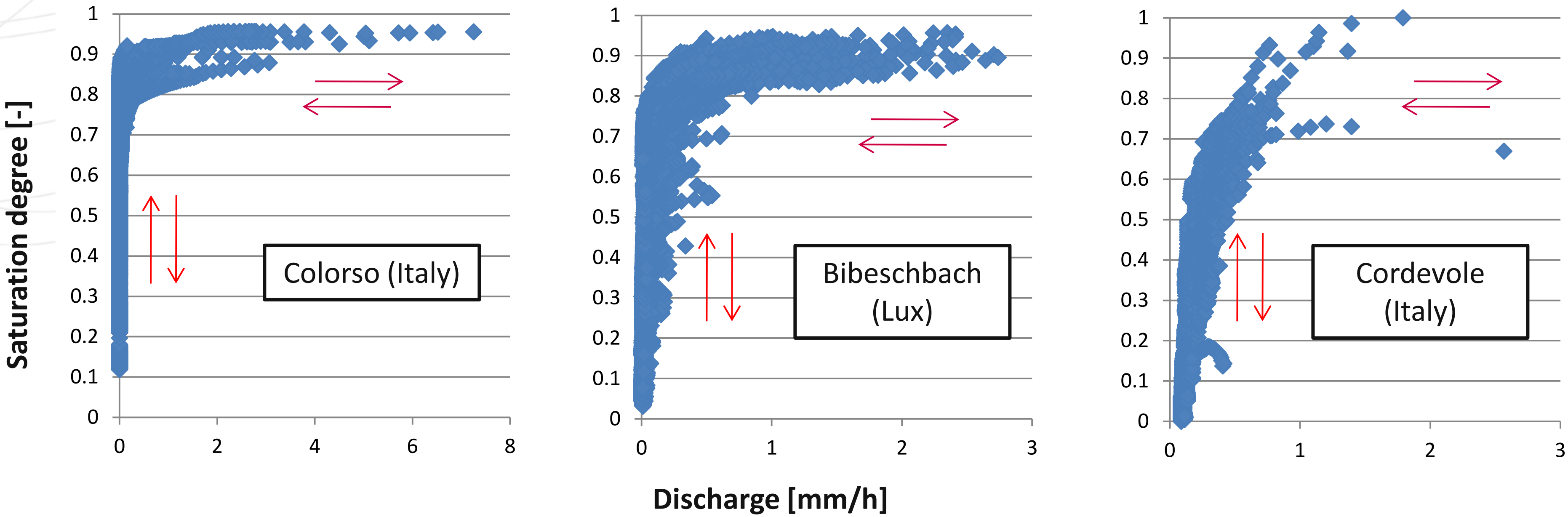
- To regularly control and correct the models by assimilating external observations (i.e. in situ river discharge measurements)

Limitations

- Problem of availability and representativeness of point measurements
- In situ measurements are not evenly distributed and networks globally tend to be in decline
- Uncertainties unknown or poorly understood
- Ground measurements difficult/dangerous to obtain during crises

Hence: There is a need for globally consistent and coherent high resolution observation data with known uncertainties that enable improved hydrological predictions at large scale

THE IMPORTANCE OF FLOOD EXTENT OBSERVATIONS



- Initiation of fast runoff is a threshold process that occurs when soil moisture rises above a critical threshold
- Soil moisture and water level variability are inversely correlated: potentially soil moisture and water level (or flood extent) observations are highly complementary

MICROWAVE REMOTE SENSING

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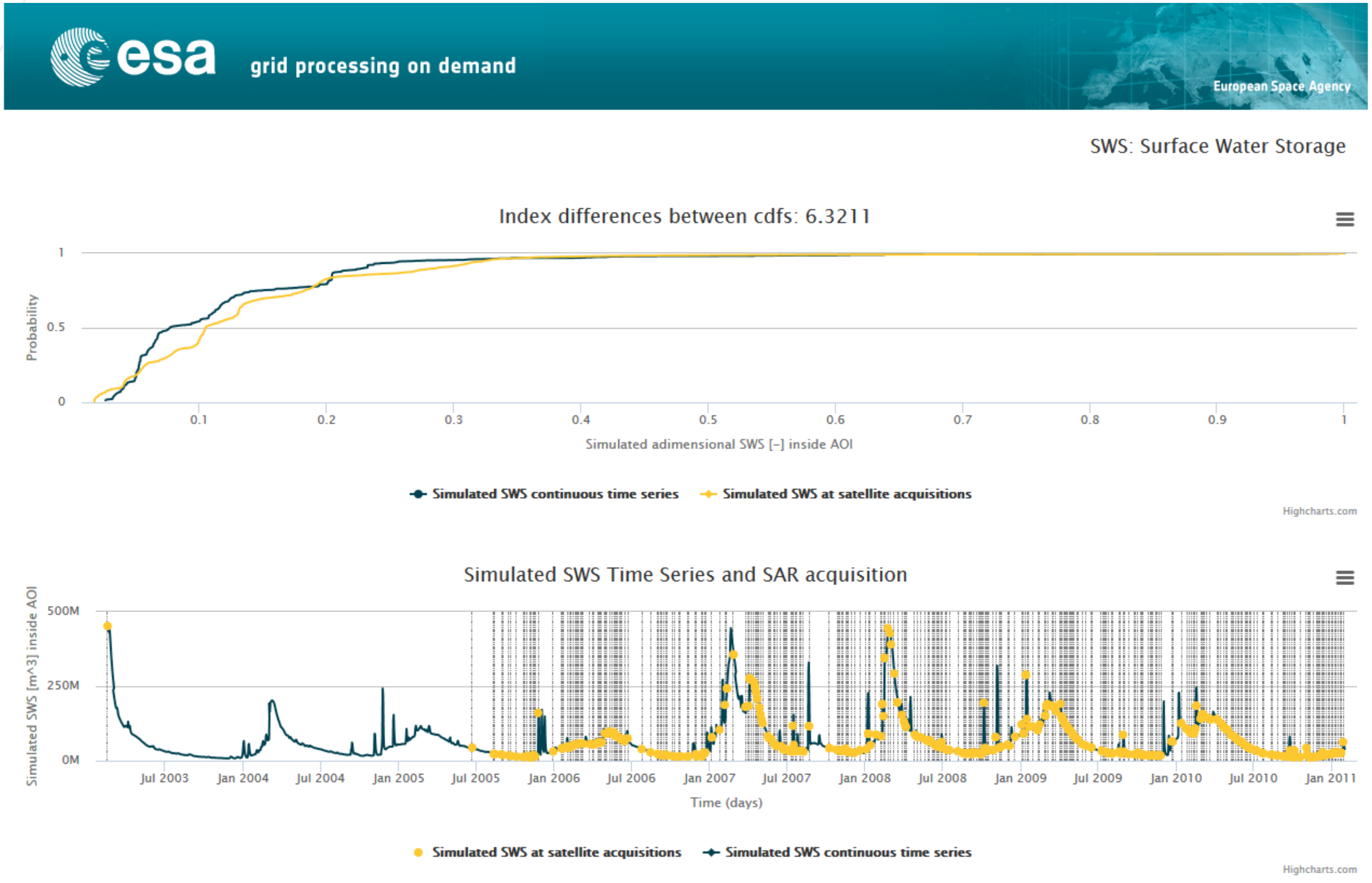


Advantages:

- Day/Night & all-weather observations
- Systematic observations of large scale flooding events
- High spatial and temporal resolutions

Research question: How to efficiently combine SAR remote sensing information with hydrologic-hydraulic models for improved predictions?

RESEARCH AND DEVELOPMENT

Flood extent mapping from SAR images

Several state-of-the-art methods based on thresholding, region growing, change detection, segmentation…

→ but lack of efficient methods enabling probabilistic flood mapping that are necessary for data assimilation applications

Sequential assimilation in hydrologic/hydraulic models

Past studies only assimilate SAR image derived **water level (model state variable)**

→ Processing of images not straightforward and longer (issue for NRT applications + DEM consistency SAR/model)

Objective: directly assimilate flood extent observations into operational flood prediction model

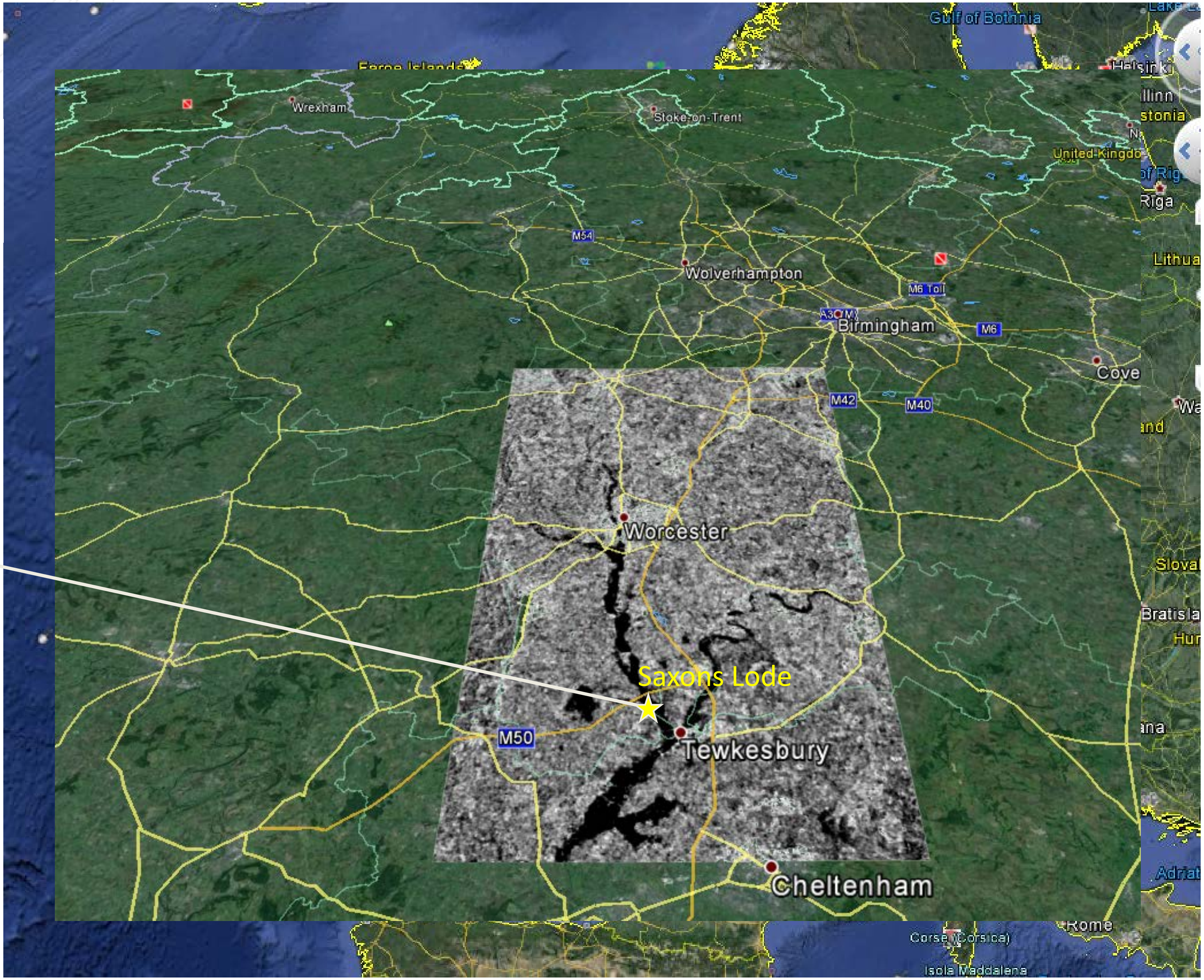
PROOF-OF-CONCEPT STUDY

July 2007
Flood event

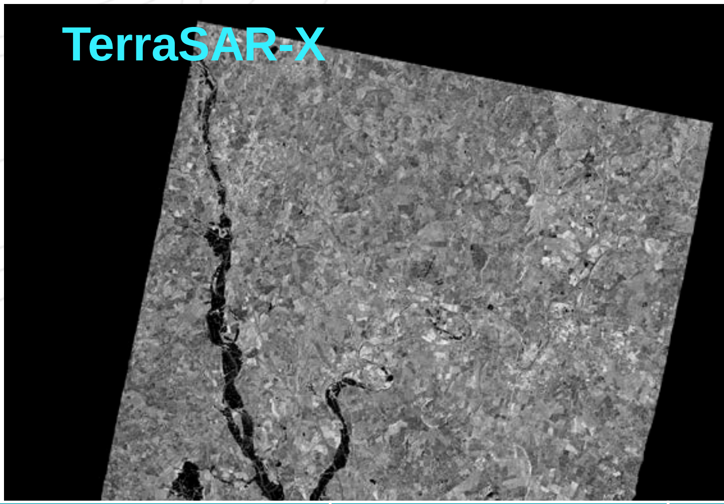
2 Envisat WSM images acquired after flood peak

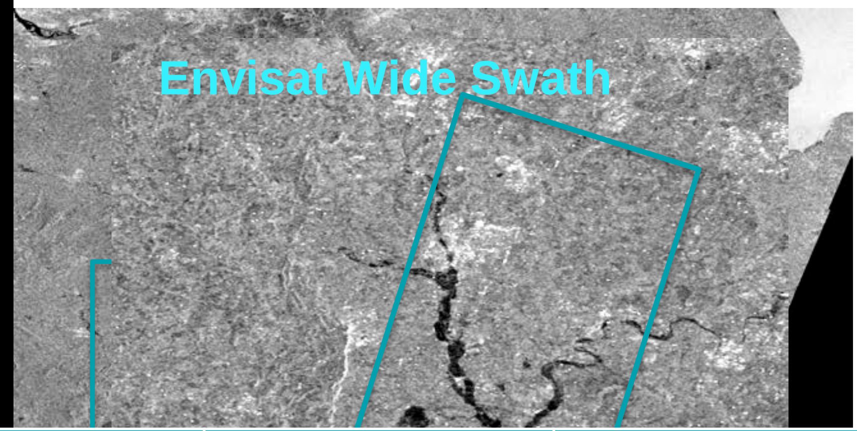
In situ WSE and Q (control)

Aerial photos of maximum food event



RETRIEVING FLOOD EXTENT

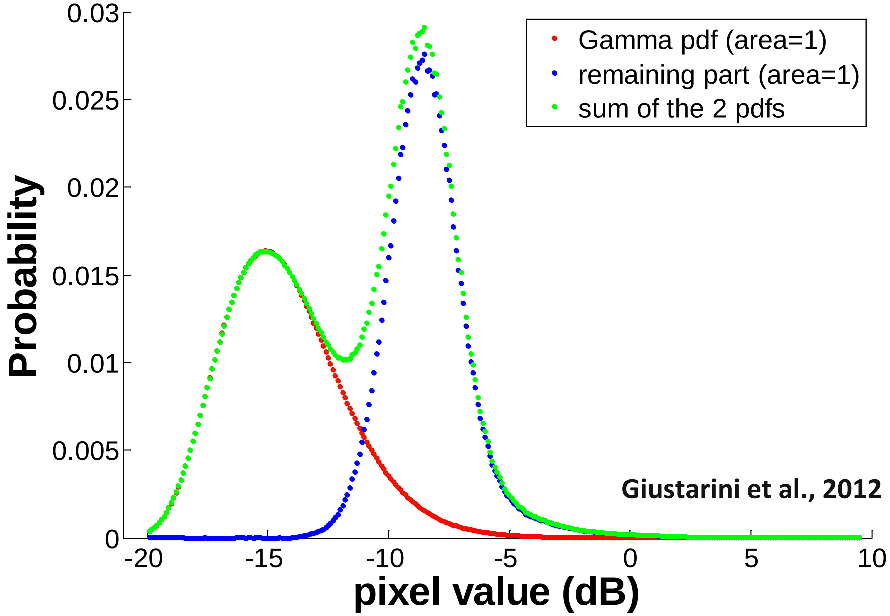


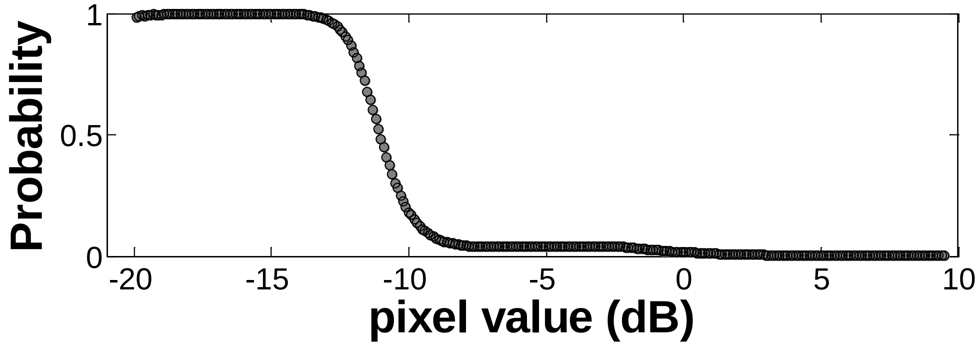


	Resolution (m)	Swath width (Km)	Wavelength (cm)	Flooded pixels
Envisat WS	150	400	5.6	0.05 % (5100x2850)
TerraSAR-X	3	30	3	2% (15135x21294)

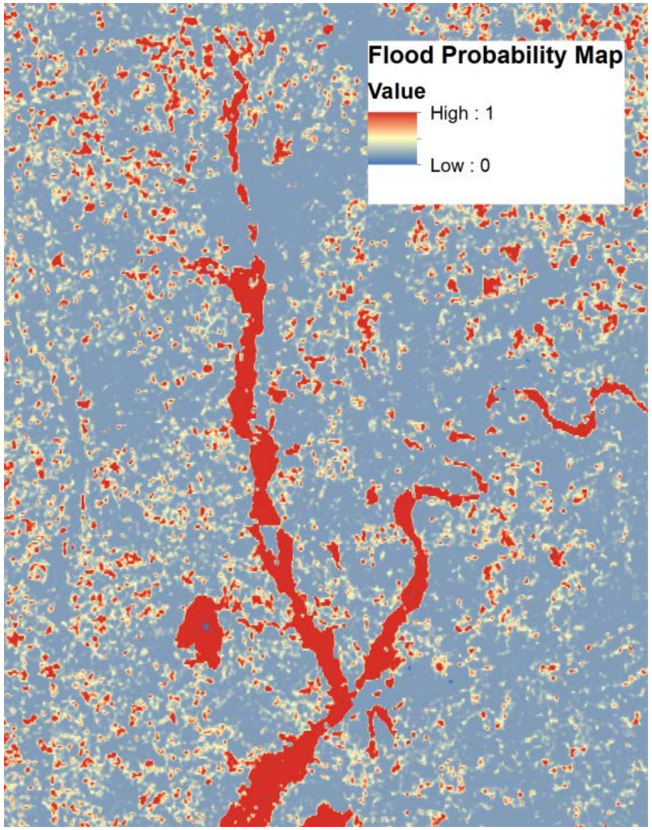
RETRIEVING FLOOD EXTENT

Approach: to parameterize a distribution function of backscatter values attributed to water bodies





FLOOD EXTENT

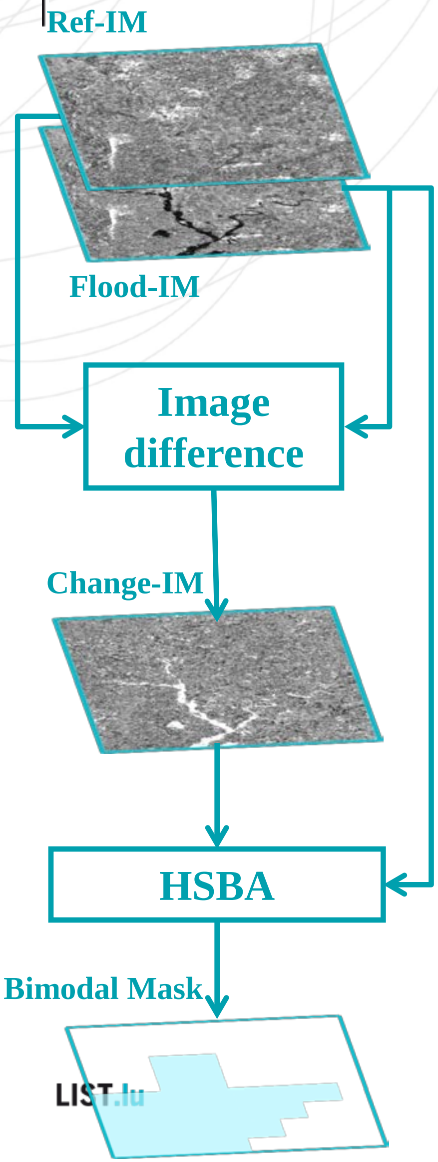


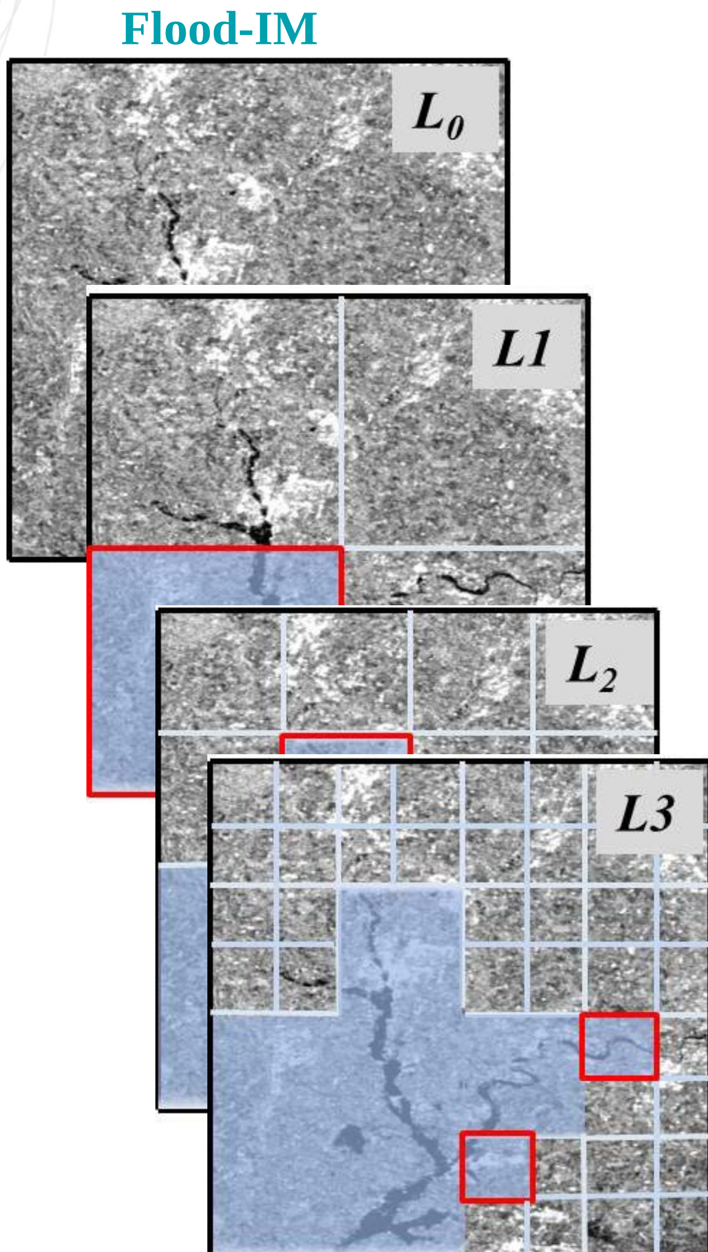
$$p(w|\sigma^0) = \frac{p(\sigma^0|w)p(w)}{p(\sigma^0|w)p(w) + p(\sigma^0|d)p(d)}$$

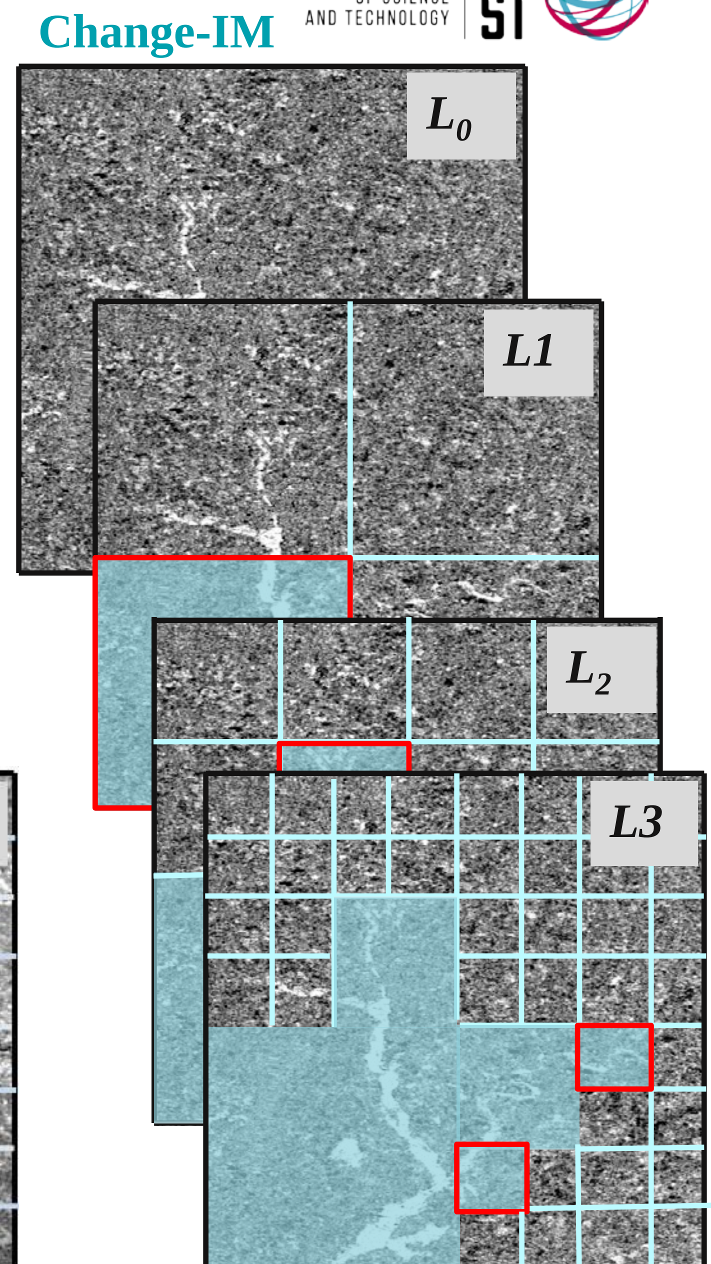
Matgen et al., PCE, 2011
Giustarini et al., IEEE TGRS, 2016

RETRIEVING FLOOD EXTENT

HSBA

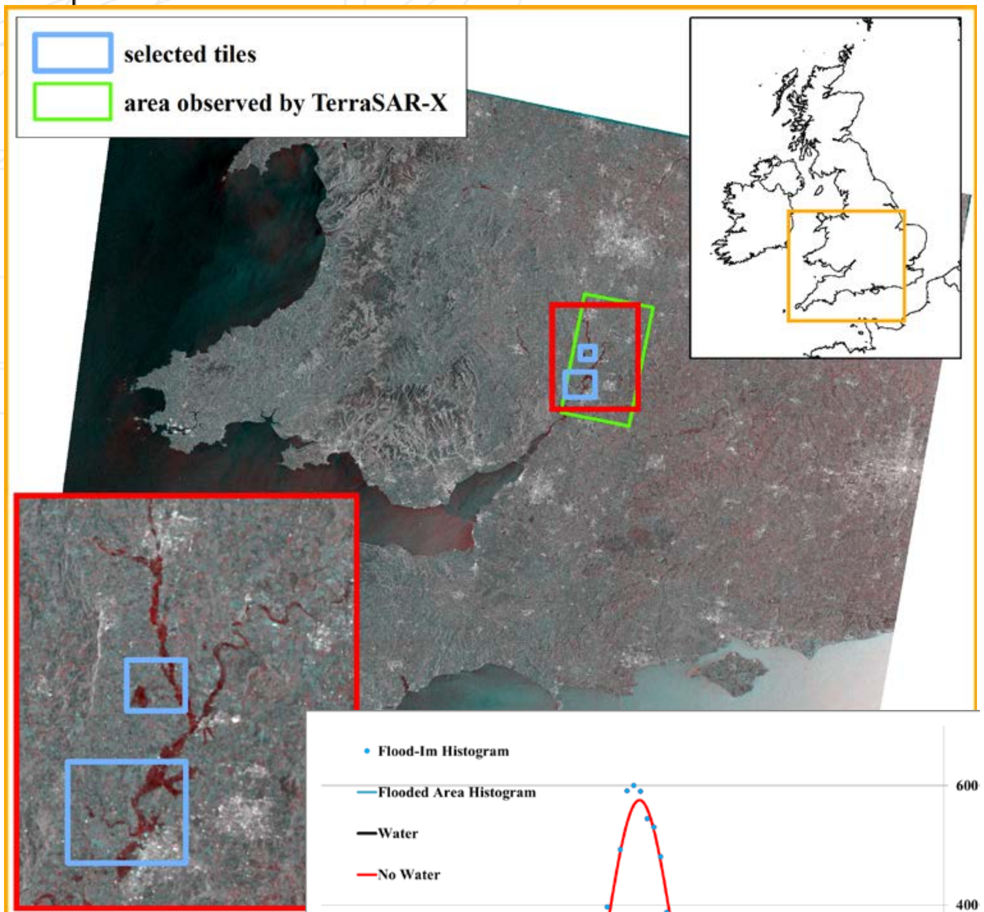


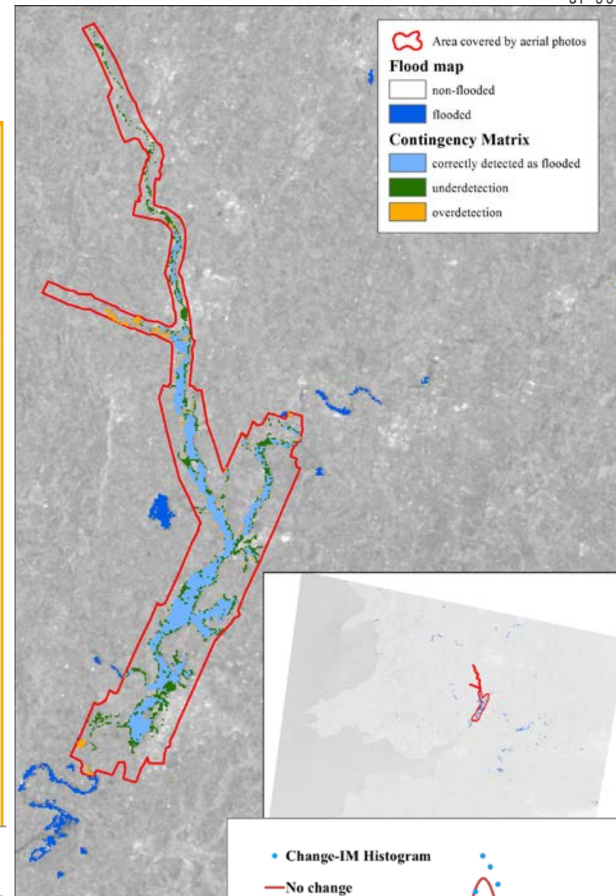


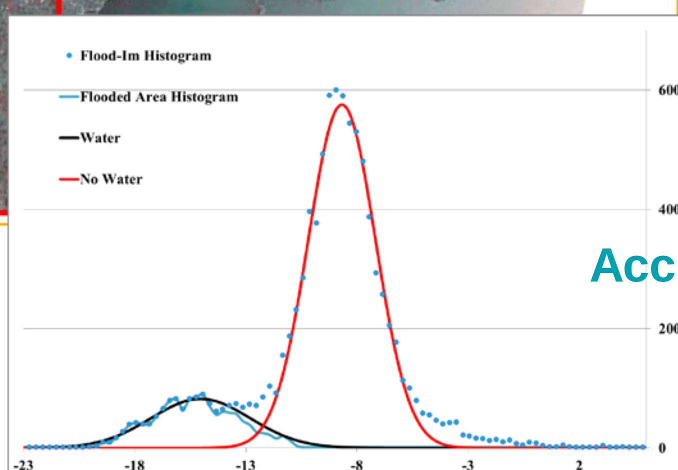


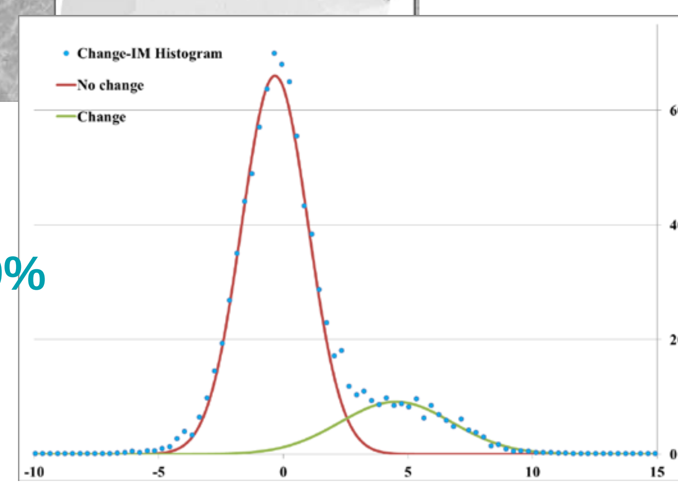
CASE STUDY

Envisat WS









Accuracy: 89%

CASCADE OF NUMERICAL MODELS

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Meteo Forcings (perturbed ERA interim)

Hydrologic Model

Discharge
Soil moisture
GW

Hydraulic Model

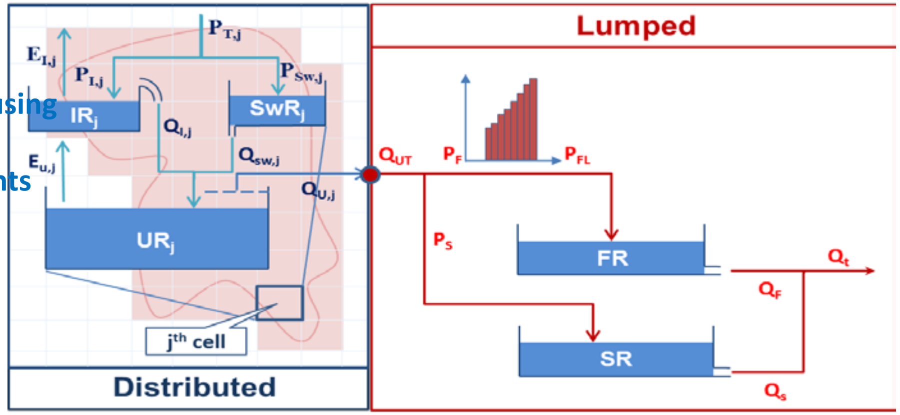
WSE,
FE,
Vel

Hydraul. DA

Flood probability maps

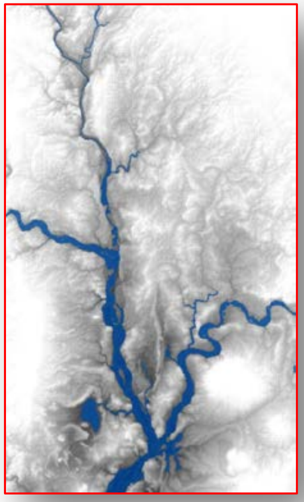
Model set up: SuperFlex (Fenicia et al., WRR, 2010)

- Calibration using in situ measurements

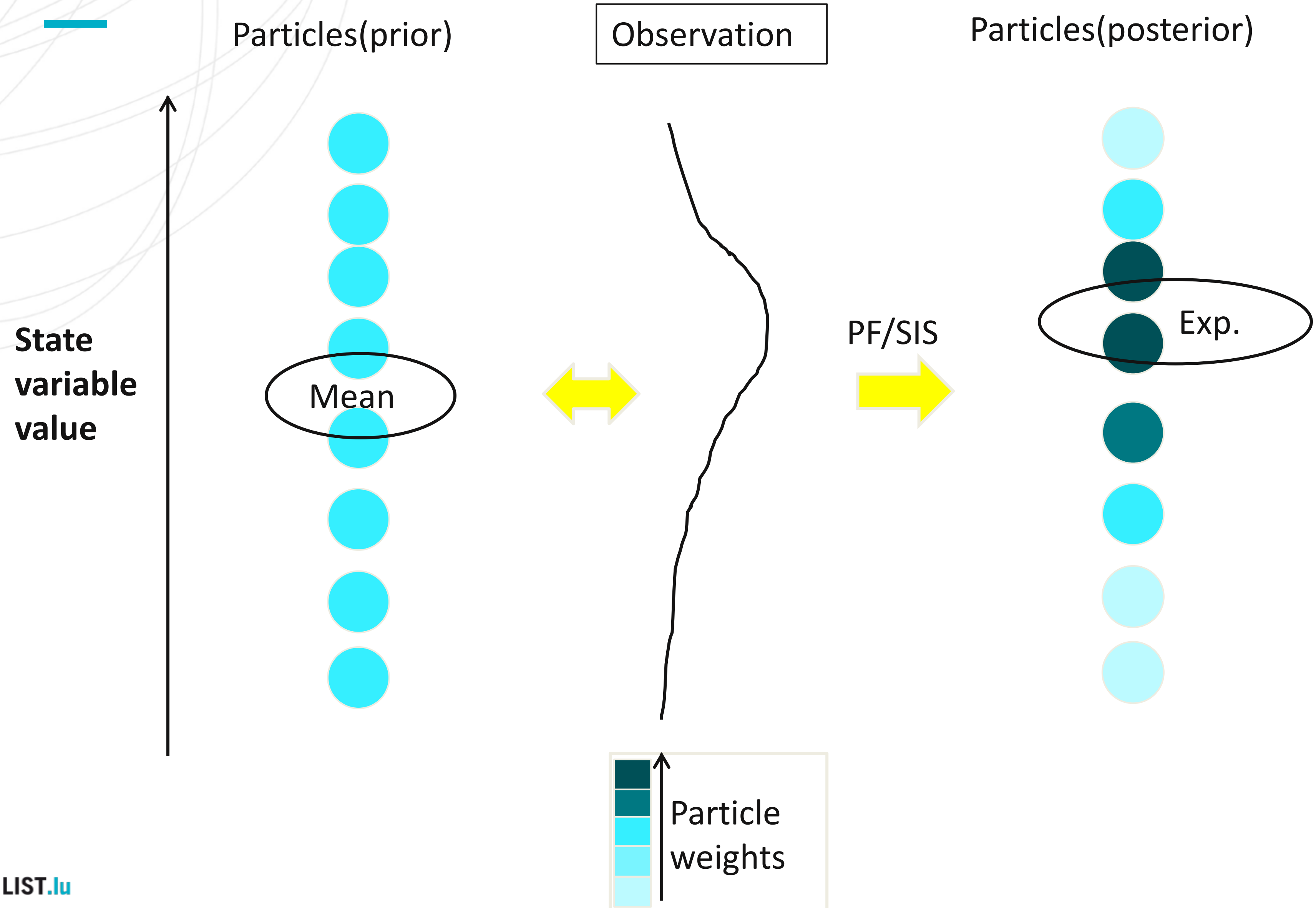


LISFLOOD-FP SubGrid (Neal et al 2012)

- Designed for modeling flood flows in large catchments as well.
- Uses DEM file as geometry.
- Models 1D- 2D dimensional flows.
- Calibration using in situ measurements and archived flood extent observations



DATA ASSIMILATION



DATA ASSIMILATION

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Assumption : binomial pdf $$p(k, n \backslash \Theta) = \binom{n}{k} \Theta^k (1-\Theta)^{n-k}$$

k = # successes
n = # trials (n=1)

MOD$_{t,i}$

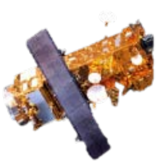
1	0	1
0	1	1
1	0	0

$$w_{1,1}^{t,i} = \Theta_{1,1}$$

Simulated Water pixel (k=1)

$$w_{3,3}^{t,i} = 1 - \Theta_{3,3}$$

Simulated Dry pixel (k=0)



Satellite observation

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

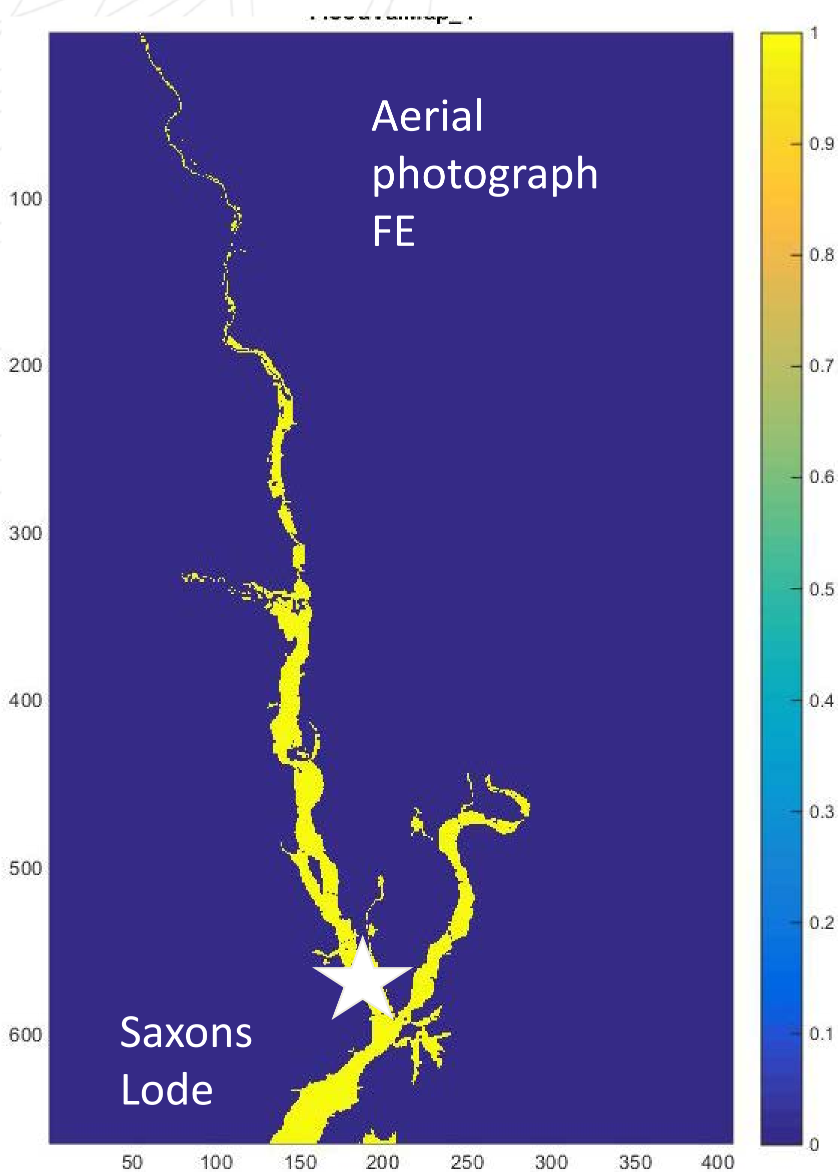
$w_{1,1}^{t,i}$	$w_{1,2}^{t,i}$	$w_{1,3}^{t,1}$
$w_{2,1}^{t,i}$	$w_{2,2}^{t,i}$	$w_{2,3}^{t,i}$
$w_{3,1}^{t,i}$	$w_{3,2}^{t,i}$	$w_{3,3}^{t,i}$

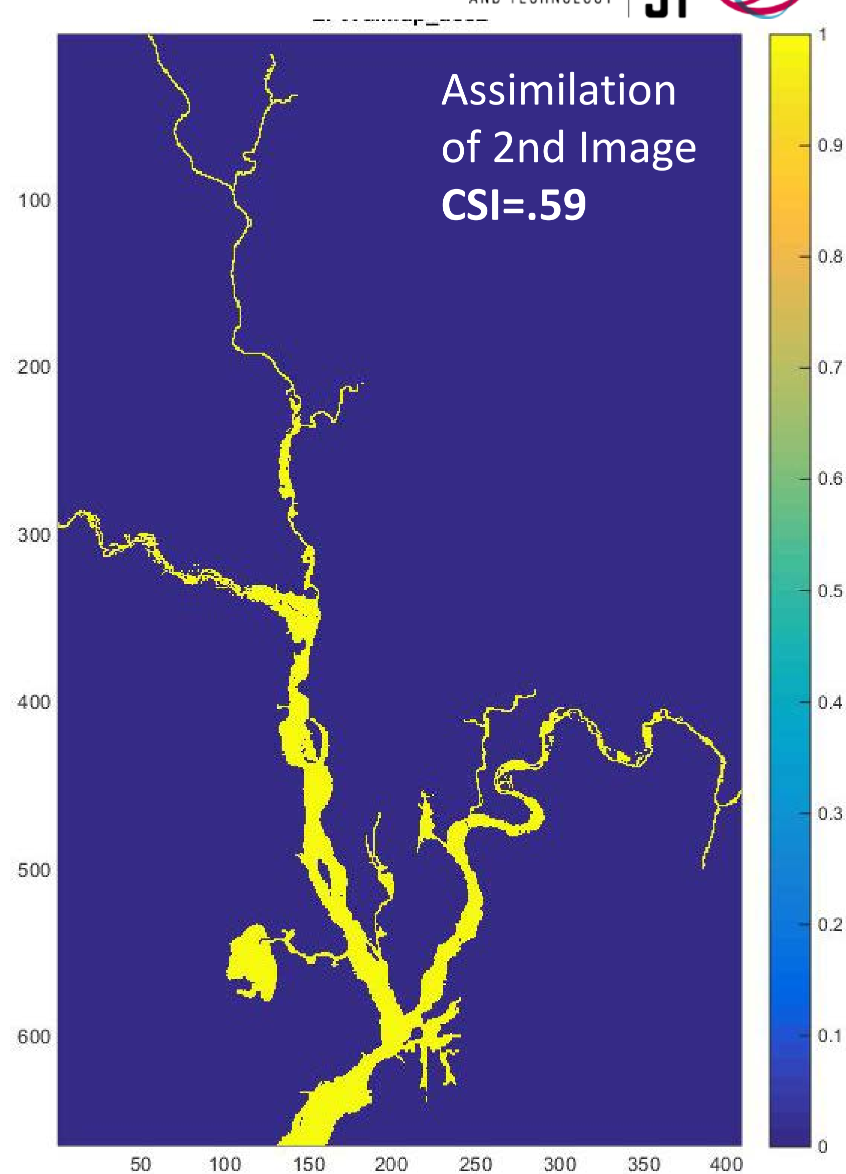
Spatial Weights aggregations

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

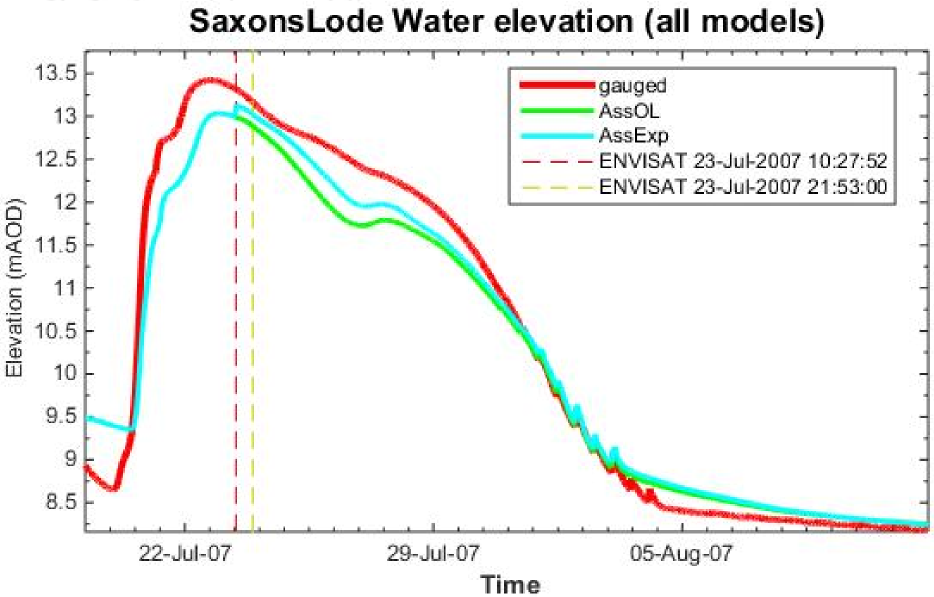
Applicable for independent observations

RESULTS

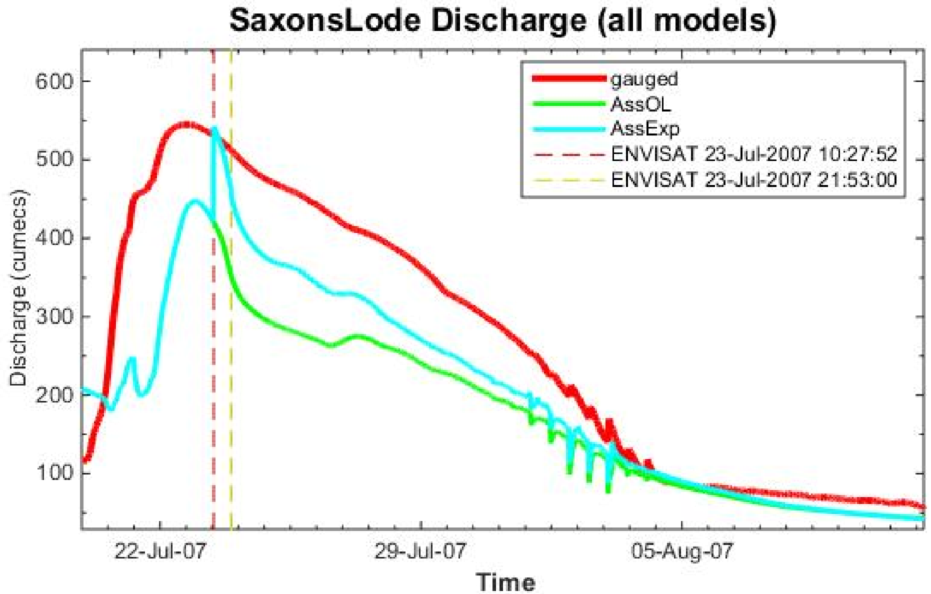

Aerial photograph FE
Saxons Lode
100
200
300
400
500
600
50
100
150
200
250
300
350
400
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


Assimilation of 2nd Image
CSI=.59
100
200
300
400
500
600
50
100
150
200
250
300
350
400
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

RESULTS



RMSE (WSE) [cm]
1. Open loop: 31 cm
2. 1st image assimil.: 23 cm
3. 2nd image assimil.: 21 cm



NSE(Q) [-]:
1. Open loop: .64
2. 1st image assimil.: .88
3. 2nd image assimil.: .86

SUMMARY & PERSPECTIVES

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We introduce a new method for assimilating in NRT SAR-derived flood extent maps into hydrological-hydraulic models:

→ To exploit continuously growing satellite image collections with faster repeat times and processing

First results:

- The approach improves simulated flood extent over several time steps
- The approach further improves simulated discharge and water surface elevation hydrographs over several time steps

Perspectives:

- Not restricted to NRT sequential assimilation, but potentially useful for improved reanalyses over many years (using catalogue of historic flood extent obs.)
- Further testing in operational context
- Investigate complementarity of various satellite EO data sets (flood extent, soil moisture, ET, snow water equivalent, etc.)
- Critical to reduce data latency!