Uncertainty Reduction in Fluvial Flood Re-analysis by Assimilating SAR-derived Flood Extent Maps

H46D-08

T.H. Nguyen, S. Ricci, A. Piacentini, R. Rodriguez Suquet, G. Blanchet, C. H. David , P. Kettig, and S. Baillarin

15 December 2022 - 16:45 PM (CST)

floodDAM DIGITAL TWIN

CERFACS

cnes

NASA Goddard JPL Langley Research Center

AGU FALL MEETING

SCIENCE LEADS THE FUTURE

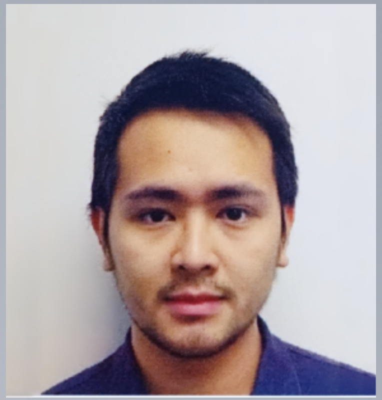
AGU FALL MEETING

THANH HUY NGUYEN

Researcher (PhD) at CECI UMR 5318 CNRS-CERFACS

thnguyen@cerfacs.fr

CERFACS
CENTRE EUROPÉEN DE RECHERCHE ET DE FORMATION AVANCÉE EN CALCUL SCIENTIFIQUE



SCIENCE LEADS THE FUTURE

SCO-FLOODDAM-DIGITAL TWIN

FloodDAM-DT: Flood Detect, Alert & rapid Mapping – Digital Twin

An earth science digital twin architecture based on the water cycle and specifically flood hazards as its first application

floodDAM DIGITAL TWIN

SCO SPACE FOR CLIMATE OBSERVATORY · cnes CENTRE NATIONAL D'ÉTUDES SPATIALES · NASA · Goddard · JPL · Langley Research Center

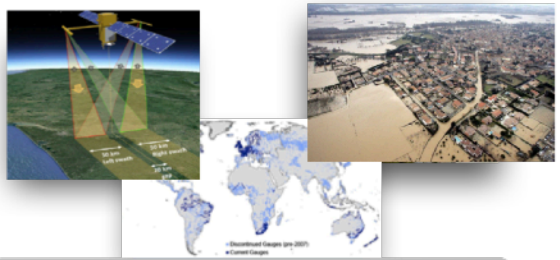
CERFACS · VORTEX.IO · QUANTCUBE TECHNOLOGY · VIGICRUES Service d'information sur le risque de crues des principaux cours d'eau en France

Work-packages:

- Flood detection and alert based on in-situ river stations
- Mapping and monitoring on-going flood events
- Producing flood risk maps on selected zones
- Short-term forecasting using CFD models

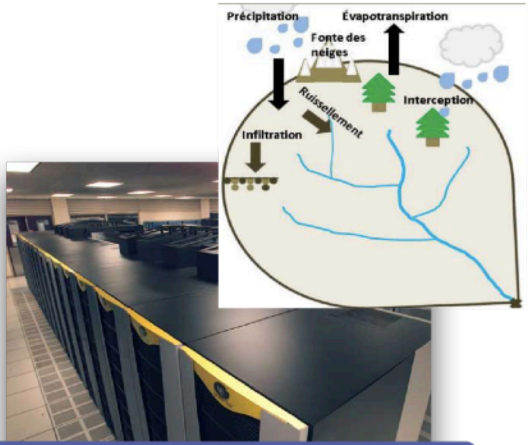
CHALLENGES IN HYDROLOGY

Operational issue
How to predict river discharge for flood forecasting and water balance estimation?



Observations

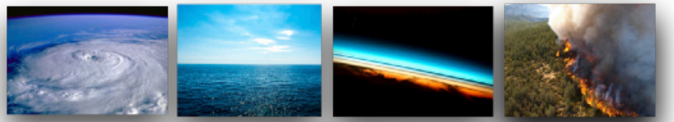
- in-situ : high frequency but sparse
- remote sensing : spatial coverage but low temporal coverage
- Various nature of errors



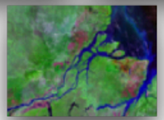
Numerical simulations

- Simplified Navier-Stokes equations 1D, 2D, 3D
- Limited information on bathymetry, topography, friction, hydrology, rainfall and maritime forcing

Data assimilation



Scientific issue
How to apply data assimilation to predict discharge and water level in rivers, estuaries and lakes ?



OBJECTIVES

From large-scale to local-scale:

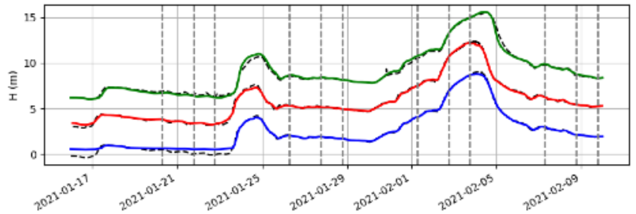
- High-fidelity hydrodynamic models require large amount of input data
- BC forcing from observations or **larger scale hydrologic model** in forecast

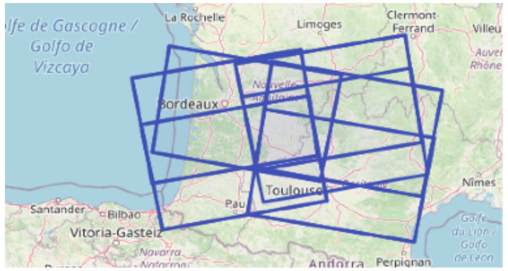
→ Fine spatial and temporal scale for hydraulic state and flood dynamics

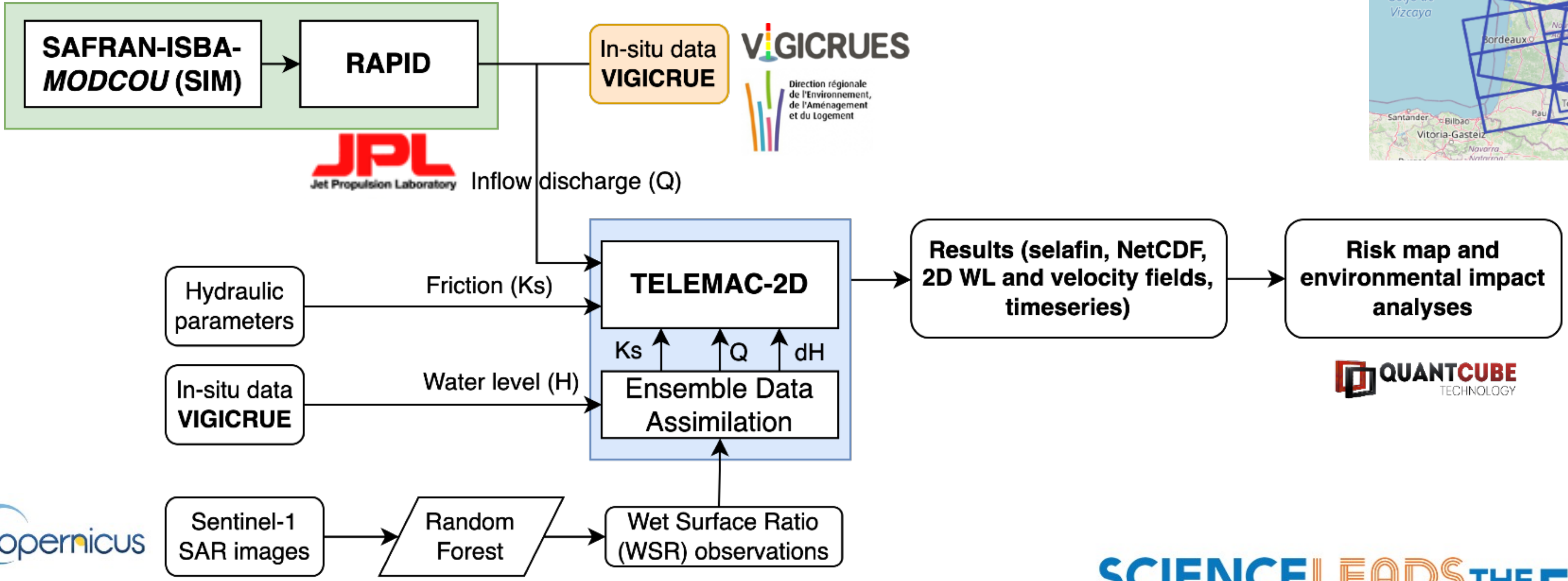
Make the most out of VHR remote sensing data AND numerical models

- On model inputs: bathymetry, topography, vegetation, friction
- On model correction : calibration, data assimilation for sequential update
- Risk evaluation based on ensemble approach
- Improve RS data with numerical simulations (data augmentation approach)

WORKFLOW AND DATA







cnes CLS

SCIENCE LEADS THE FUTURE

TELEMAC-2D GARONNE MODEL

Model provided by EDF

- 50-km river reach (simple test case)
- Downstream from the Garonne-Lot confluence
- High flood risk impacting urban area

41,000-node mesh with different triangle size among riverbed, floodplain and dykes.

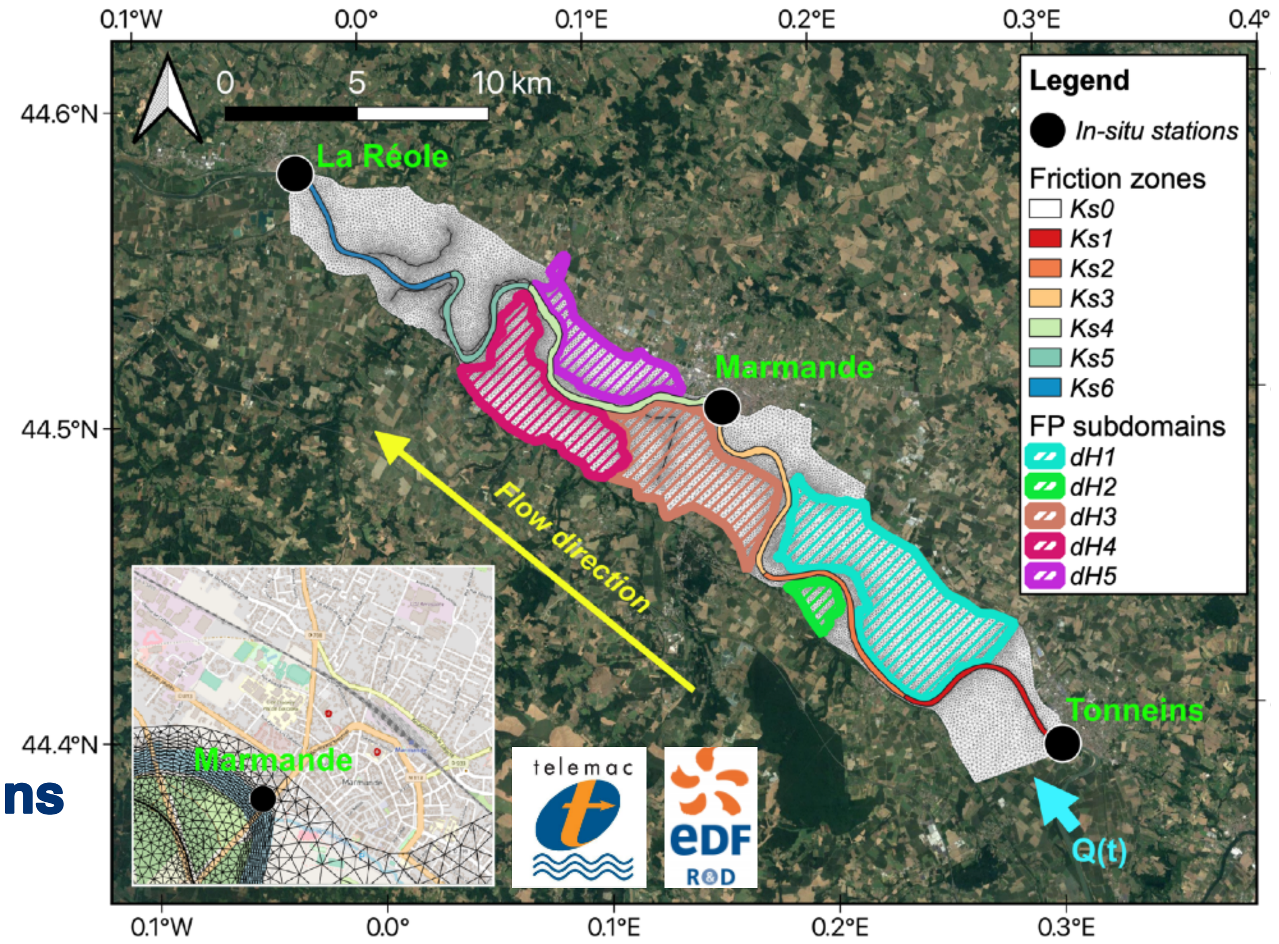
Boundary conditions:

- Upstream hydrograph Q(t) at Tonneins
- Downstream rating curve Z(Q) at La Réole

In-situ water-level data: 3 observing stations

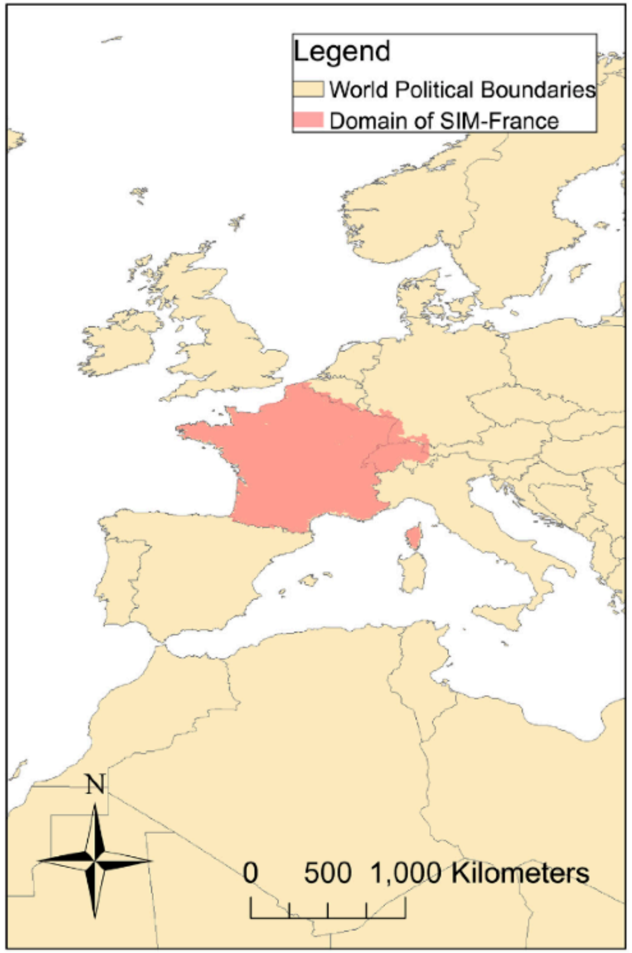
Water level correction in 5 floodplain subdomains

Study Area and Model



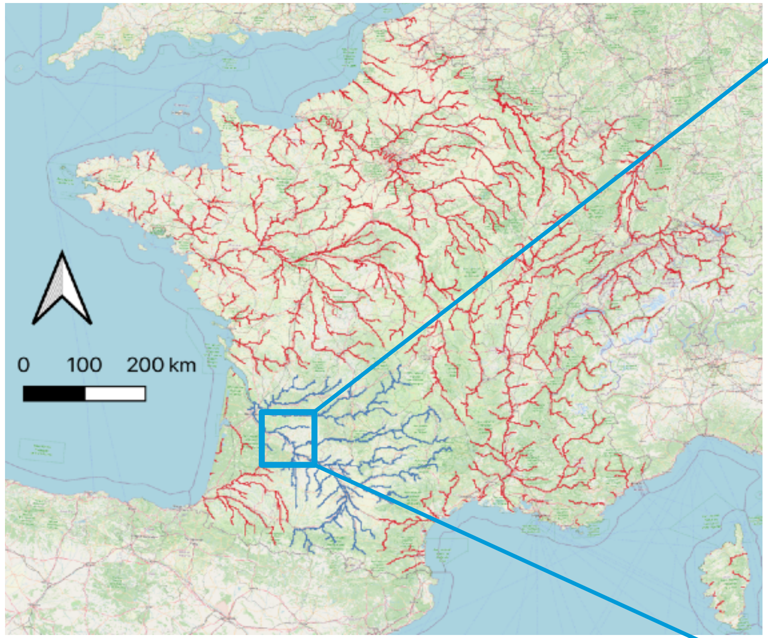
CHAINING HYDROLOGIC-HYDRAULIC MODELS

- Routing Application for Parallel computatIon of Discharge (http://rapid-hub.org/)
- Replacing the river routing scheme in MODCOU from SAFRAN-ISBA-MODCOU (SIM) hydrometeorological model applied over France
- Divided by drainage basins
- 3-hourly timestep



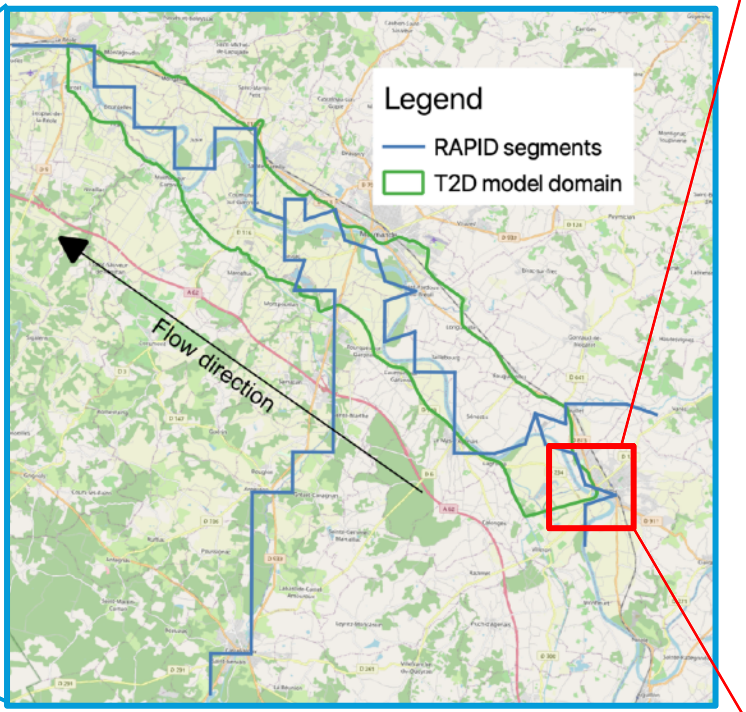
Reference: David et al (2011), RAPID applied to the SIM-France model, Hydrological Processes, 25(22), 3412-3425. DOI: 10.1002/hyp.8070.

FORCING BY RAPID SIMULATION

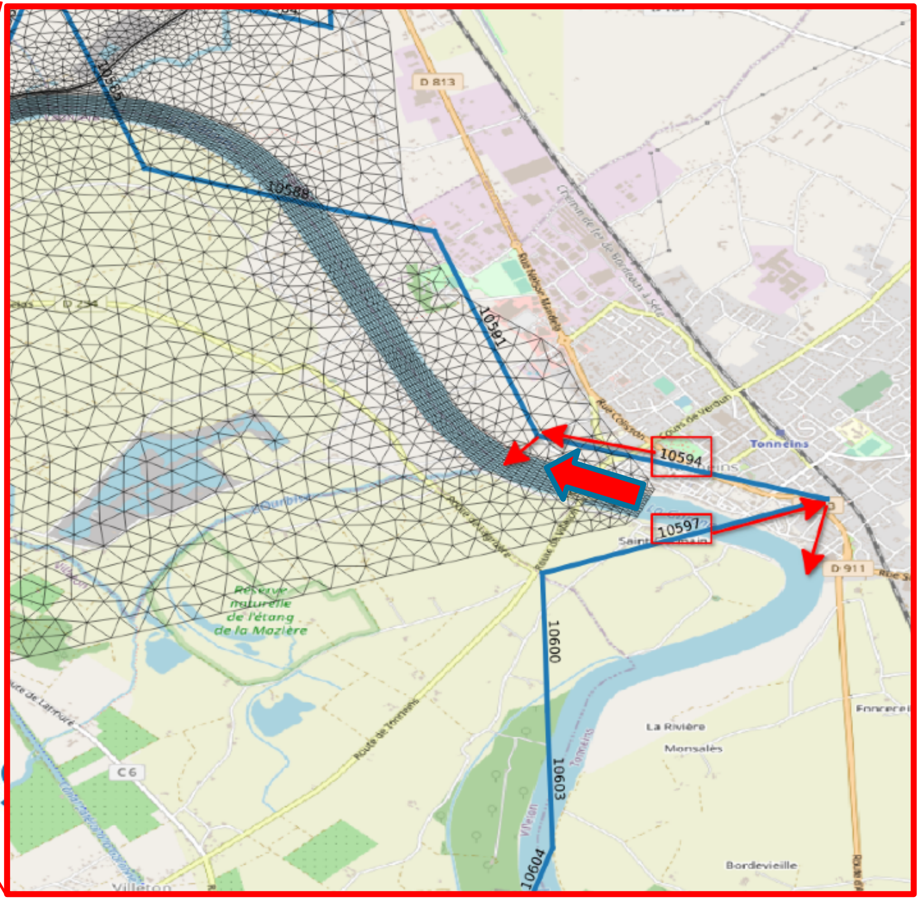


Garonne watershed

Garonne Marmandaise
T2D domain

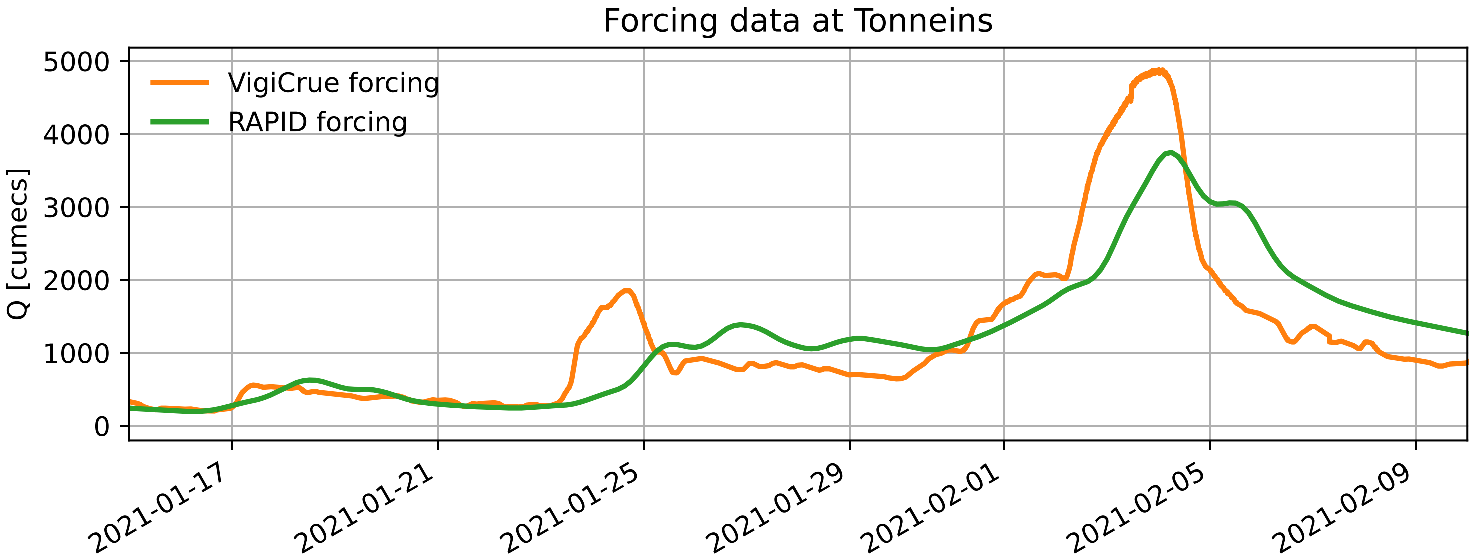


Tonneins (upstream BC)



AGU FALL MEETING

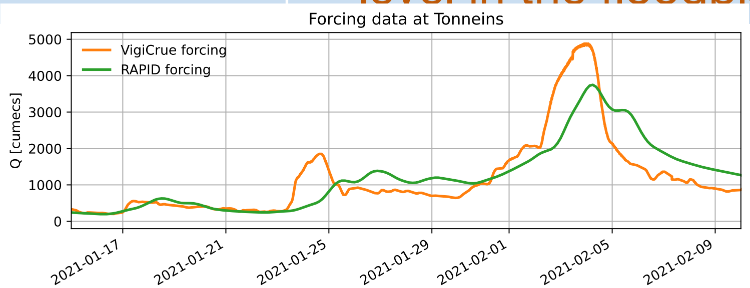
CHAINING HYDROLOGY WITH HYDRAULIC MODELS



SCIENCE LEADS THE FUTURE

CHAINING HYDROLOGY WITH HYDRAULIC MODELS

	Using measured **VigiCrue** data as forcing	Using **RAPID** simulation as forcing
No assimilation	**FR^V** • VigiCrue forcing + T2D model	**FR^R** • RAPID forcing + T2D model
Only assimilates in-situ obs	**IDA^V** • VigiCrue forcing + T2D model • Corrects frictions + upstream Q	**IDA^R** • RAPID forcing + T2D model • Corrects frictions + upstream Q
Assimilates in-situ obs and WSR obs	**$IGDA^V$** • VigiCrue forcing + T2D model • Corrects frictions + upstream Q + water level in the floodplain	**$IGDA^R$** • RAPID forcing + T2D model • Corrects frictions + upstream Q + water level in the floodplain



SCIENCE LEADS THE FUTURE

QUANTITATIVE RESULTS

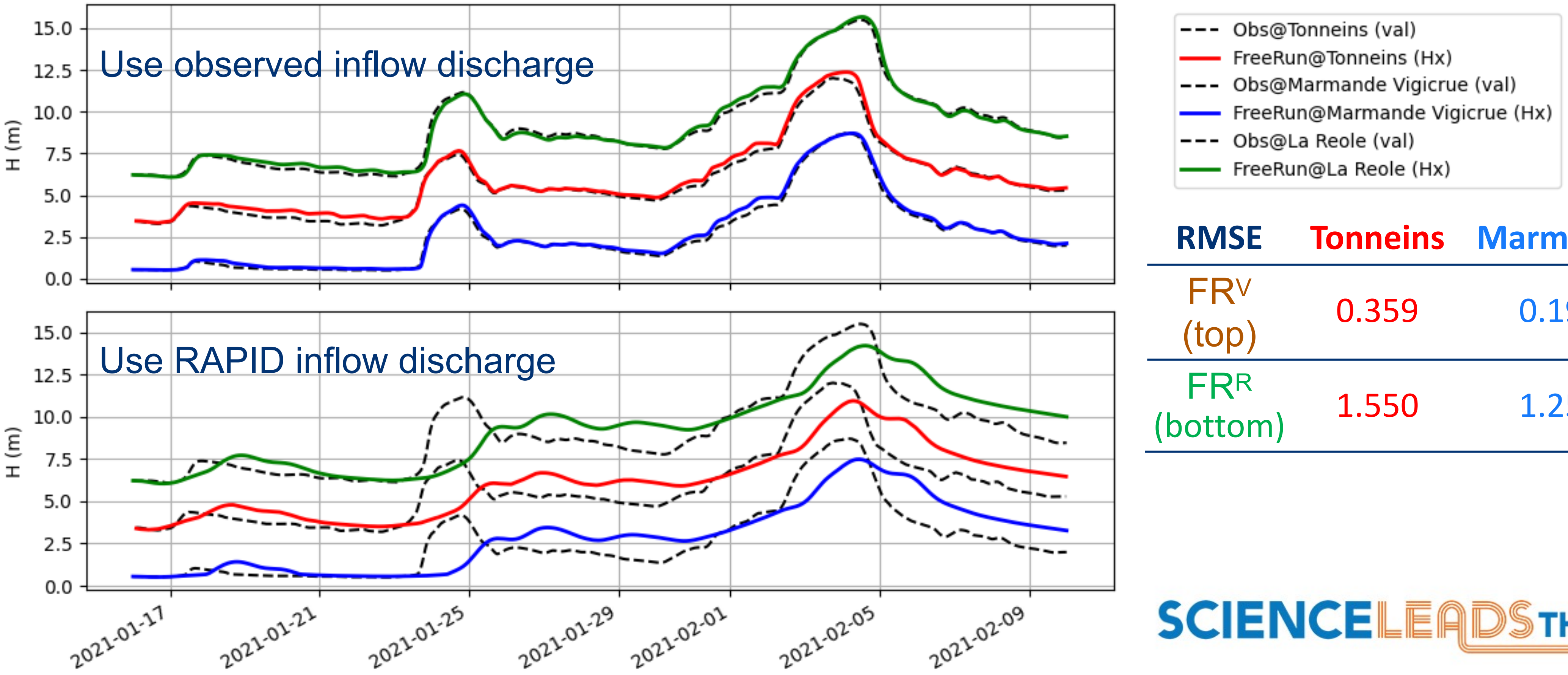
	Assimilated obs.	Control vector	1D RMSE			2D Critical Success Index		
			Tonneins	Marmande	La Réole	02/02 19h00	03/02 19h00	07/02 07h00
FR^V	-	-	0.359	0.193	0.225	49.65%	67.90%	74.53%
IDA^V	Insitu WL	Friction + Q	<u>0.053</u>	0.036	<u>0.080</u>	48.67%	68.30%	76.10%
$IGDA^V$	Insitu WL + WSR	Friction + Q + FP	0.059	<u>0.035</u>	0.087	<u>95.41%</u>	<u>92.32%</u>	<u>88.28%</u>
FR^R	-	-	1.550	1.254	1.370	46.06%	36.63%	63.24%
IDA^R	Insitu WL	Friction + Q	0.467	0.292	0.635	48.77%	57.90%	77.63%
$IGDA^R$	Insitu WL + WSR	Friction + Q + FP	<u>0.326</u>	<u>0.229</u>	<u>0.440</u>	<u>95.76%</u>	<u>94.34%</u>	<u>88.38%</u>

All EnKF runs have 75 members
Q: correction on upstream forcing
FP: correction on water level in the floodplain

AGU FALL MEETING

FR^V VS FR^R

- Open-loop simulation or FREE RUN (w/o assimilation)
- Use calibrated values for friction (constant) and observed forcing at boundary condition

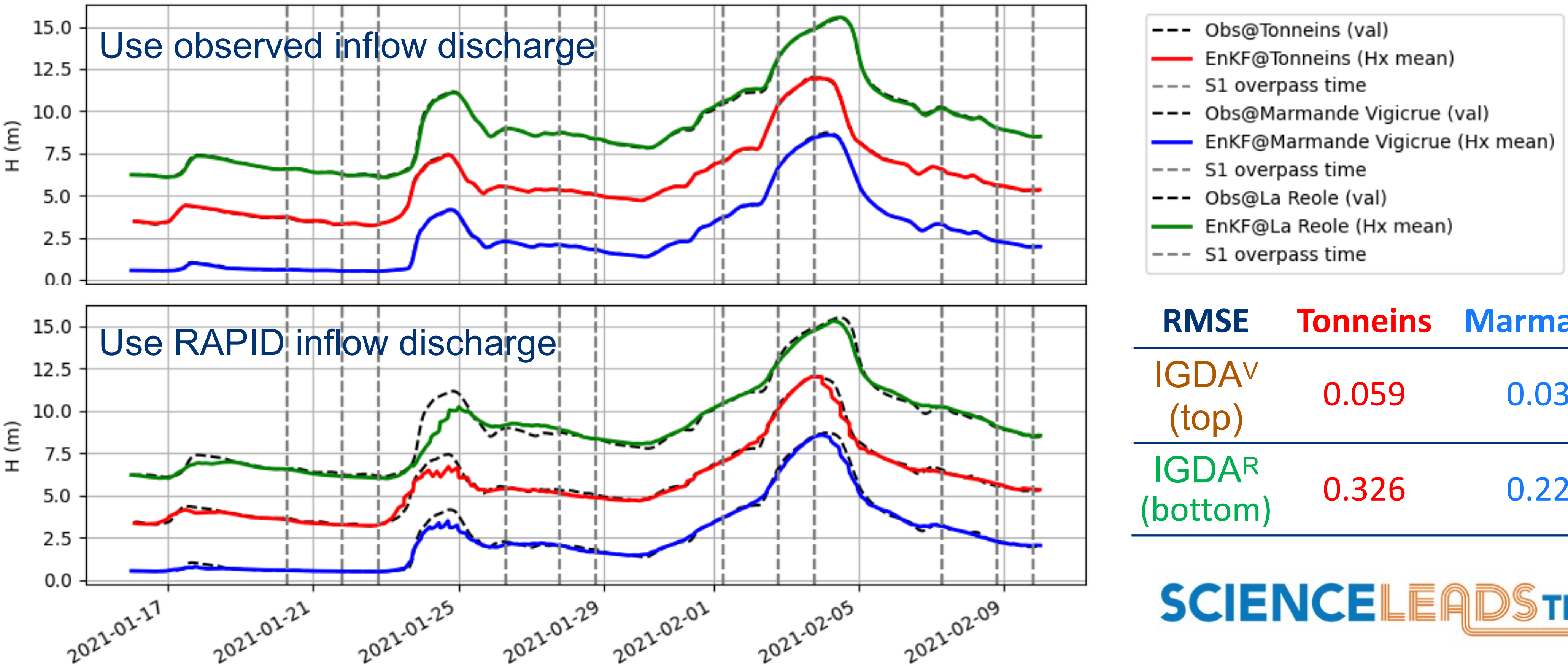


RMSE	Tonneins	Marmande	La Réole
FR^V (top)	0.359	0.193	0.225
FR^R (bottom)	1.550	1.254	1.370

SCIENCE LEADS THE FUTURE

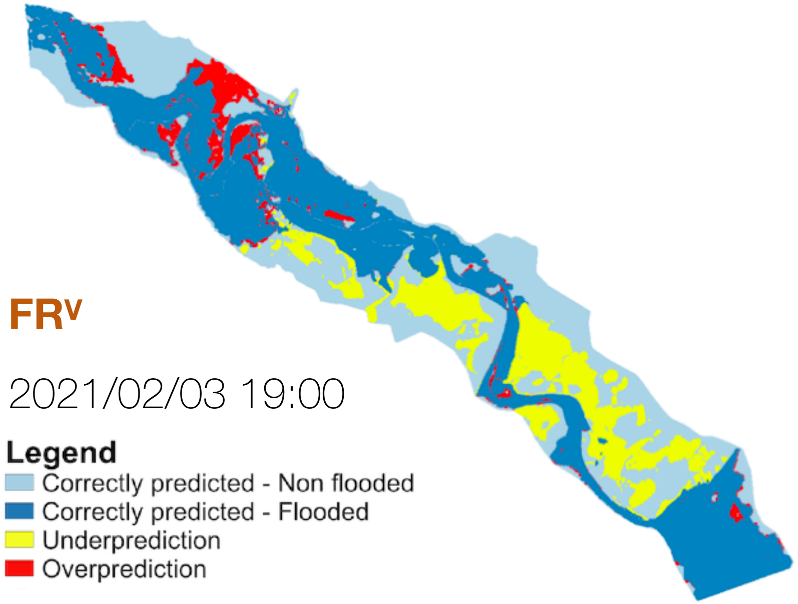
IGDA^{V} VS IGDA^{R}

- Cycled EnKF DA of in-situ and RS-derived WSR
- Applied a Gaussian anamorphosis (variable change)



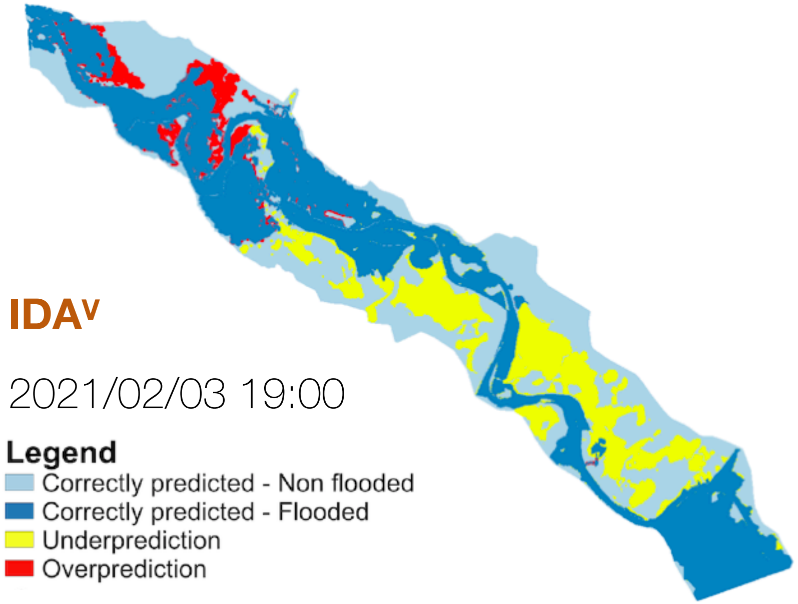
RMSE	Tonneins	Marmande	La Réole
IGDA^{V} (top)	0.059	0.035	0.087
IGDA^{R} (bottom)	0.326	0.229	0.440

COMPARISON FR^V - IDA^V - $IGDA^V$



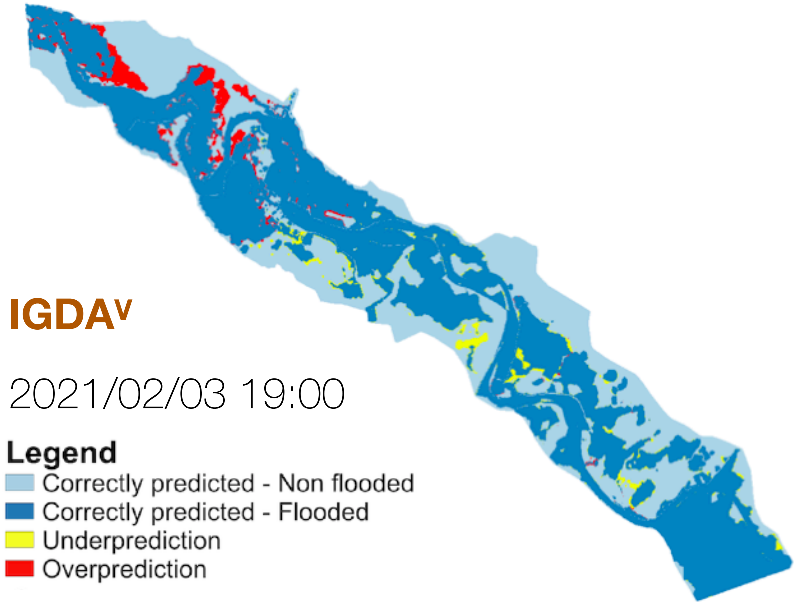
FR^V

2021/02/03 19:00



IDA^V

2021/02/03 19:00

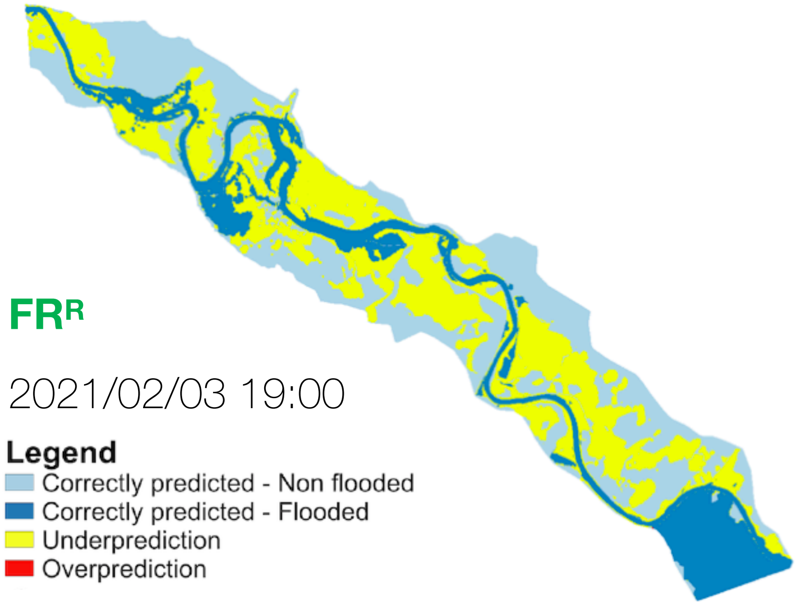


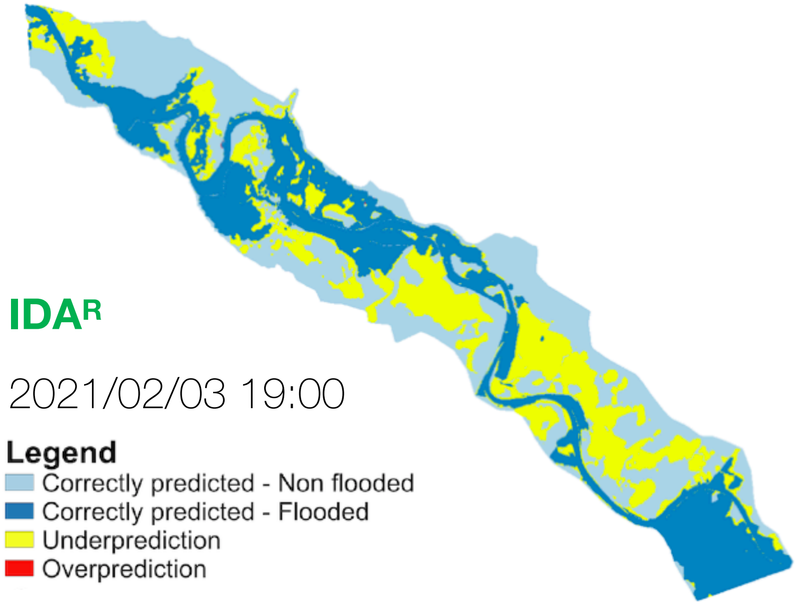
$IGDA^V$

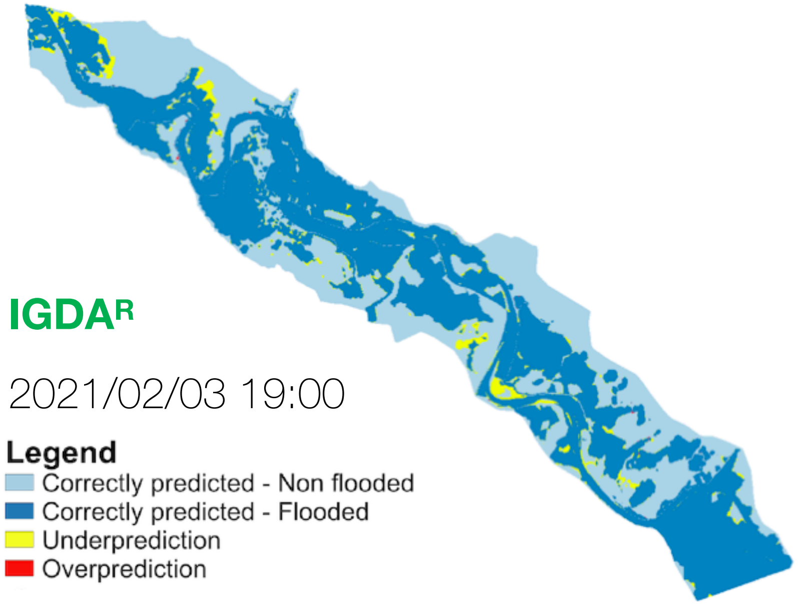
2021/02/03 19:00

	FR^V (left)	IDA^V (mid)	$IGDA^V$ (right)
CSI	67.90%	68.30%	92.32%

COMPARISON FR^R - IDA^R - IGDA^R







	FR^R (left)	IDA^R (mid)	IGDA^R (right)
CSI	36.63%	57.90%	94.34%

SCIENCE LEADS THE FUTURE

CONCLUSIONS AND PERSPECTIVES

- ✓ When gauge data are not available, RAPID simulations can be used as **forcing** and corrected with the **assimilation** of RS-derived WSR and in-situ WL data.
  - – The assimilation of in-situ data improves in the river bed only.
  - – The assimilation of RS-derived flood extent observations improves in the floodplain.
- ✓ Demonstrated in OSSE using synthetical data (in-situ and RS)
- ✓ Fabricated flood event based on 2003
- ✓ Implemented in hindcast mode

CONCLUSIONS AND PERSPECTIVES

- ✓ When gauge data are not available, RAPID simulations can be used as **forcing** and corrected with the **assimilation** of RS-derived WSR and in-situ WL data.
  - The assimilation of in-situ data improves in the river bed only.
  - The assimilation of RS-derived flood extent observations improves in the floodplain.
- ✓ Demonstrated in OSSE using synthetical data (in-situ and RS)
- ✓ Fabricated flood event based on 2003
- ✓ Implemented in hindcast mode

- ❑ Simulate more recent events with RAPID over flood events when Sentinel-1 observations are available
- ❑ Extend to other catchment of interest (e.g. Ohio-Wabash, Adour River, Rhine River)
- ❑ Run simulation in forecast mode

REFERENCE

1. Besnard, A., & Goutal, N. (2011). Comparison between 1D and 2D models for hydraulic modeling of a floodplain: case of Garonne river. *Houille Blanche-Revue Internationale De l'Eau*, (3), 42-47.
2. P. Kettig, B. Simon, G. Blanchet, C. Taillan, S. Ricci, T. H. Nguyen, T. Huang, A. Altinok, N. T. Chung, G. Valladeau, R. Goeury, and A. Roumagnac, "The SCO-FLOODDAM project: New observing strategies for flood detection, alert and rapid mapping," in *2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS* (pp. 1464-1467). IEEE.
3. Mirouze, I., Ricci, S. & Goutal, N. (2019). The impact of observation spatial and temporal densification in an ensemble Kalman Filter. *In XXVIth TELEMAC-MASCARET User Conference.*
4. Ricci, S., Piacentini, A., Thual, O., Pape, E. L., & Jonville, G. (2011). Correction of upstream flow and hydraulic state with data assimilation in the context of flood forecasting. *Hydrology and Earth System Sciences*, *15*(11), 3555-3575.
5. Nguyen, T. H., Delmotte, A., Fatras, C., Kettig, P., Piacentini, A., & Ricci, S. (2021). Validation and Improvement of Data Assimilation for Flood Hydrodynamic Modelling Using SAR Imagery Data. In *Proceedings of 2020 TELEMAC-MASCARET User Conference October 2021* (pp. 100-108).
6. Nguyen, T. H., Ricci, S., Fatras, C., Piacentini, A., Delmotte, A., Lavergne, E., & Kettig, P. (2022). Improvement of Flood Extent Representation with Remote Sensing Data and Data Assimilation. *IEEE Transactions on Geoscience and Remote Sensing*, 60, 1-22, 2022, Art no. 4206022, https://doi.org/10.1109/TGRS.2022.3147429
7. Nguyen, T. H., Ricci, S., Piacentini, A., Fatras, C., Kettig, P., Blanchet, G., Peña Luque, S., & Baillarin, S. (2022). Dual state-parameter assimilation of SAR-derived wet surface ratio for improving fluvial flood reanalysis. *Water Resources Research*, 58, e2022WR033155. https://doi.org/10.1029/2022WR033155

THANK YOU

for your attention

Contact: thnguyen@cerfacs.fr

Acknowledgments:

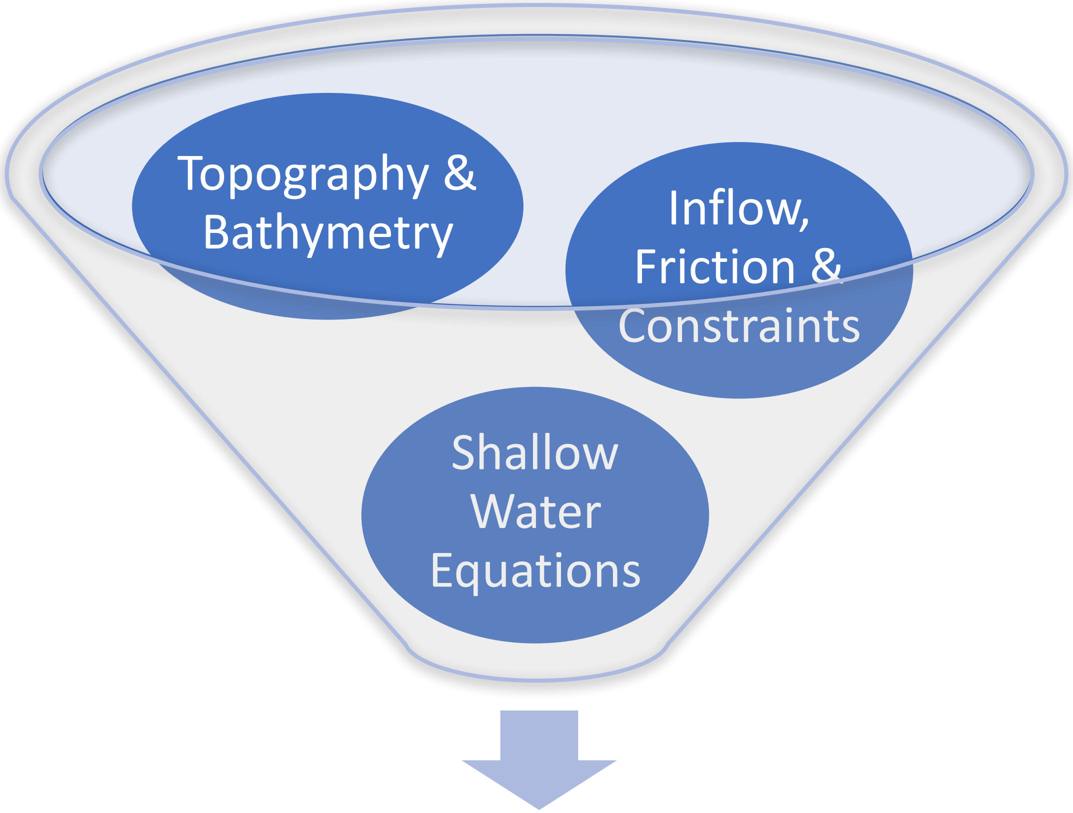
SCO SPACE FOR CLIMATE OBSERVATORY

eDF R&D

VIGICRUES

Direction régionale de l'Environnement, de l'Aménagement et du Logement

TELEMAC-2D – OVERVIEW

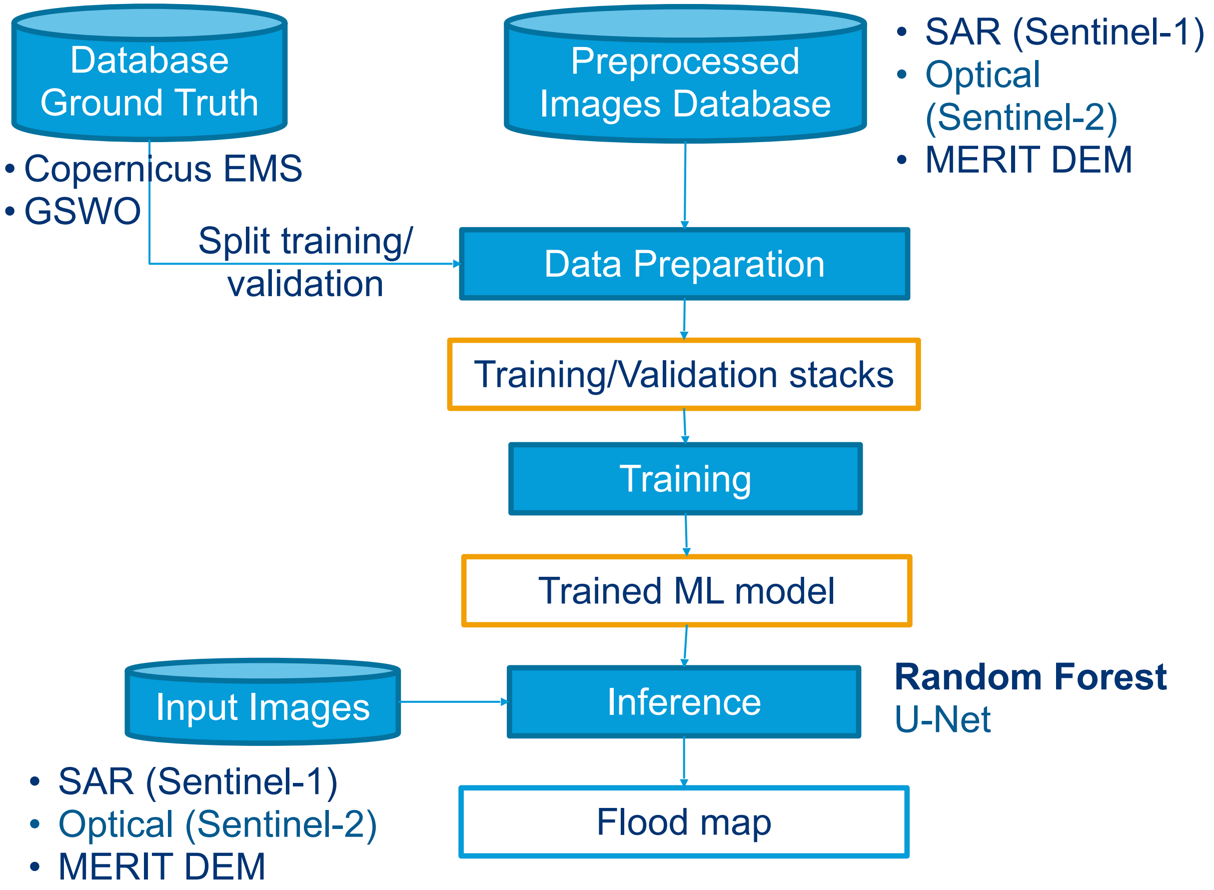


Flow velocity, Water level,
Water surface elevation, etc.

telemac

EDF R&D

FLOODML FRAMEWORK – FLOOD MAP INFERENCE CHAIN

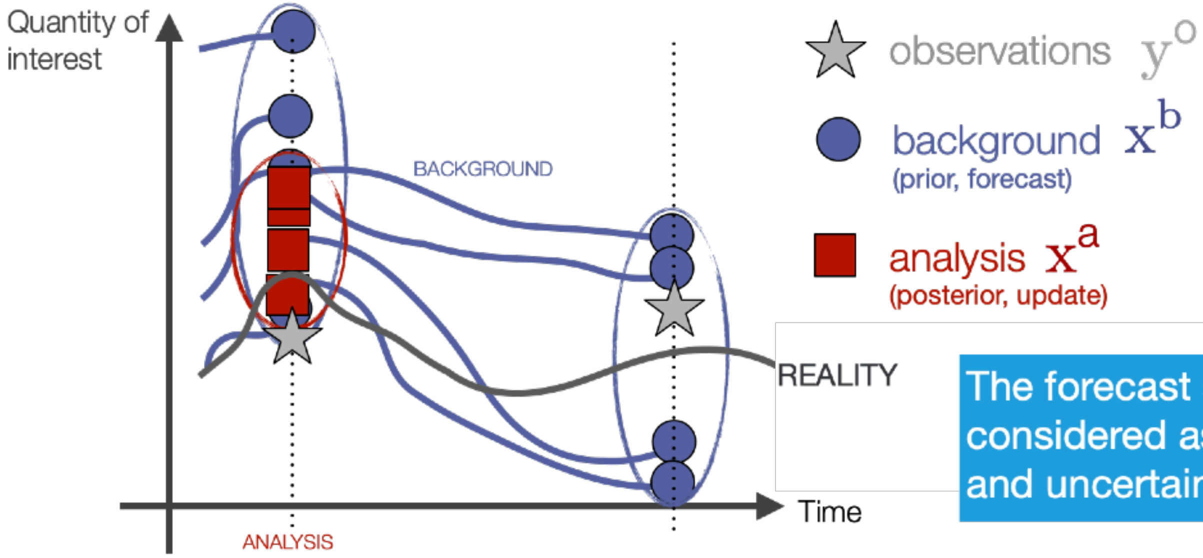


- Preprocessing: calibration, orthorectification, reprojection.
- Training database: 223 S-1 images from past flood events (EMS) + 90% GSWO labels.
- Random Forest applied on VV and VH S-1 images (resolution 10 x 10 m).
- CuML library for rapid computation: **3-4 mins/image.**
- **Accuracy** on 5 test cities averages **87%.**
- Postprocessing: majority filtering.

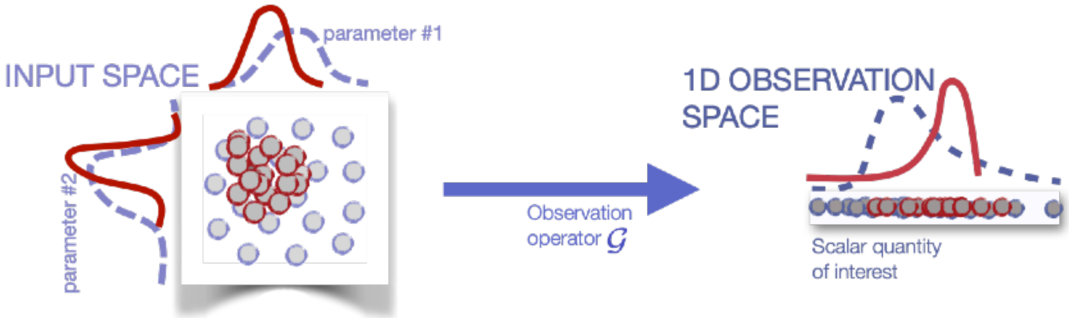
Copernicus EMS: Emergency Mapping Service
GSWO: Global Surface Water Occurrence
MERIT: Multi-Error-Removed Improved-Terrain
DEM: Digital Elevation Model

ENSEMBLE DATA ASSIMILATION

Stochastic viewpoint



The forecast step can be considered as a sensitivity analysis and uncertainty quantification step.



Important questions

Choice of perturbed variables
Size/variety of the ensemble
Sampling strategy
Physical model sensitivity