CENTRE EUROPÉEN DE RECHERCHE ET DE FORMATION AVANCÉE EN CALCUL SCIENTIFIQUE

Remote Sensing Data Assimilation with a Chained Hydrological-hydraulic Model for flooding

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Poster Raquel Rodriguez et al.

floodDAM DIGITAL TWIN

https://www.spaceclimateobservatory.org/fr/flooddam-dt

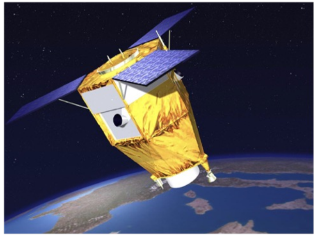
SHF Conference

November 28-30th, 2023, Toulouse

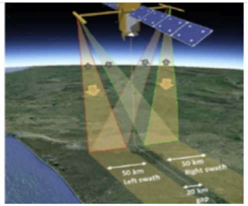
SPACE CLIMATE OBSERVATORY

Non exhaustive picture of continental water observing network

Sentinel 1&2 (ESA-Copernicus)
Synthetic Aperture Radar + Optical imagery for environmental Earth observation from space

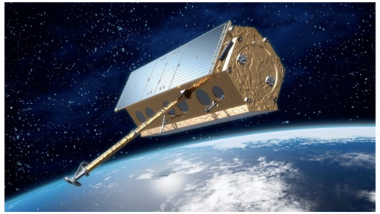


SWOT CNES-NASA
High resolution and global observation of water level with Ka-Band Radar Interferometer



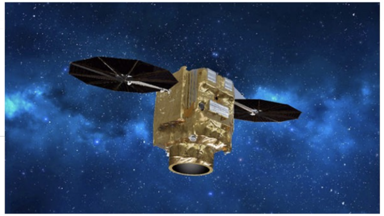
Sentinel-6MF (Copernicus)

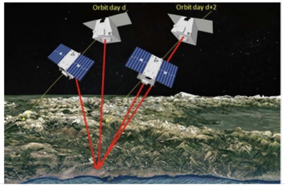
VIGICRUES



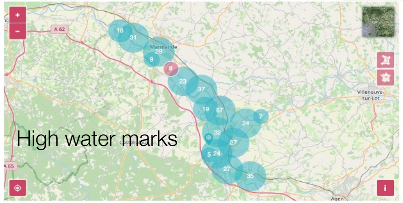
TerraSar-X
Tandem-X
X-band radar
sensor SAR

Pléïades/Pléïades-Néo
High-Resolution Optical Imaging Constellation (CNES - Airbus DS)

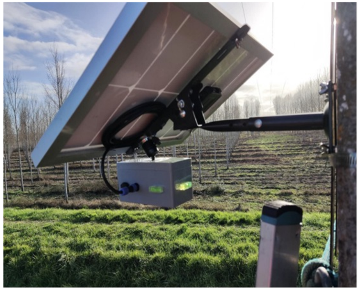




CO3D
High-Resolution Optical 3D Imaging Constellation for DSM

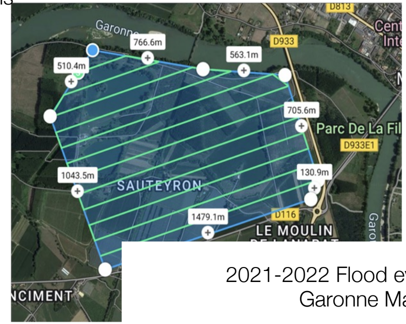


High water marks

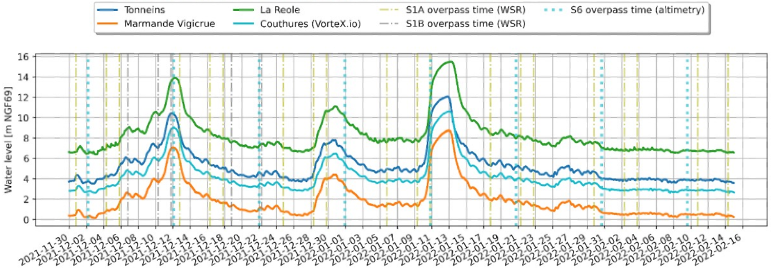


Vigicrue + Vortex IO stations
River gauge and floodplain

Vortex IO - UAV campaign



2021-2022 Flood event for the Garonne Marmandaise

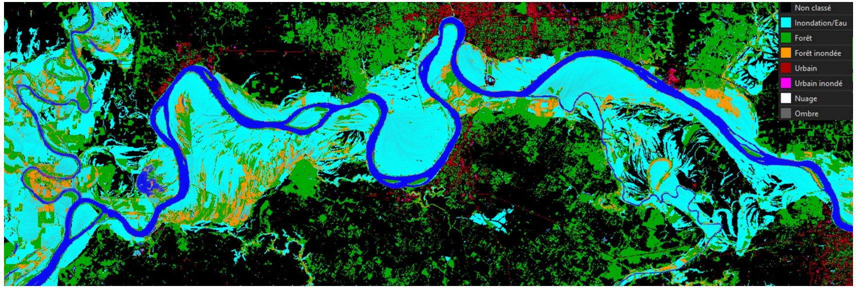


Rapid mapping for flooding from remote Sensing images (FloodML)

Algorithme de detection de l'étendue des inodations (FloodML) basé sur random forest à partir de données satellites SAR et optiques et entrainé sur Copernicus EMSR ayant >90% de présence d'eau

- Données en entrée: Sentinel 1&2, Terrasar-X, Landsat 8/9, MERIT DEM, ESA World Cover
- Couverture globale et automatisé
- Generation systematique de rapport

Satellite	Resolution (m)	Polarisation	Incidence angle (°)	Band
Sentinel-1	10m	VV-VH	29 – 46	C
SAOCOM	23 & 45	VV-VH	25-38	L
NovaSAR-1	2,5 & 20m	HH	16-26	S
TerraSAR-X	2,75m	HH	20-45	X



Trimestrielle SCO, FloodDAM,
Rodriguez et al., 2023

0: no détection
1: inondé
2: forêt
3: forêt inondée
4: urbain
5: urbain inondé
6: Nuage
7: Ombre

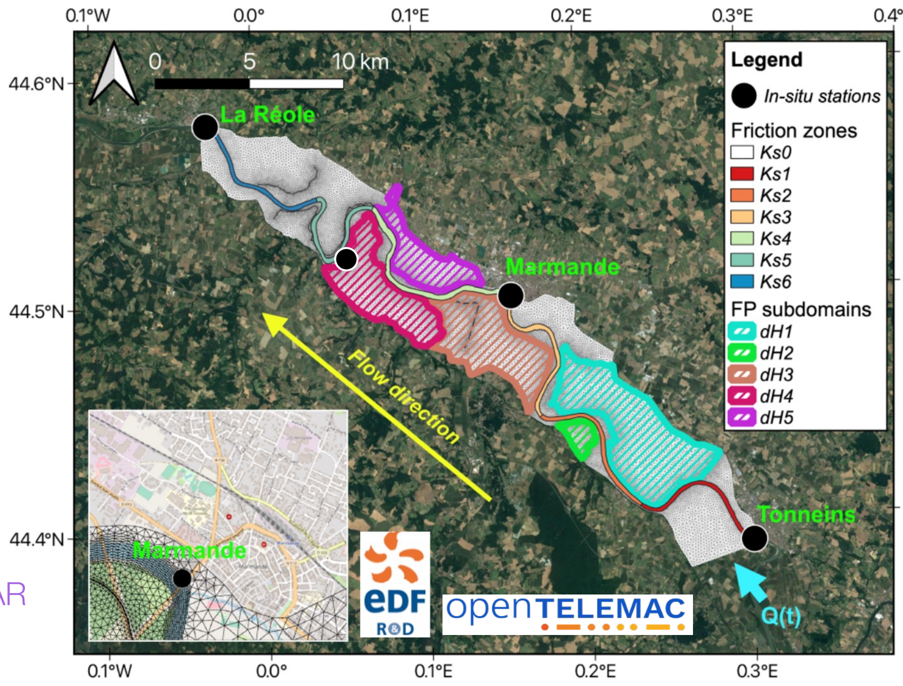
Local scale: TELEMAC-2D Garonne Model

- Garonne marmandaise (EDF model)
  - 50-km river reach
  - Downstream from the Garonne-Lot confluence
  - High flood risk impacting urban area

- Boundary conditions:
  - Upstream hydrograph Q(t) at Tonneins from Vigicrue OR CTRIP
  - Downstream rating curve Z(Q) at La Réole

- Friction in river bed and floodplain
- In-situ water-level data: 4 observing stations (Vigicrue + Vortex io)
- Compute Wet Surface Ratio (WSR) over 5 subdomains of the floodplain from S1-derived water extents

- On going work @CERFACS : update model with new in-situ, LIDAR and remote sensing data (collab. SCP Tlse, SCHAPI, EDF, ARTELIA, CNES)



Large scale hydrology modeling with ISBA (LSM) – CTRIP (RRM) @CNRM

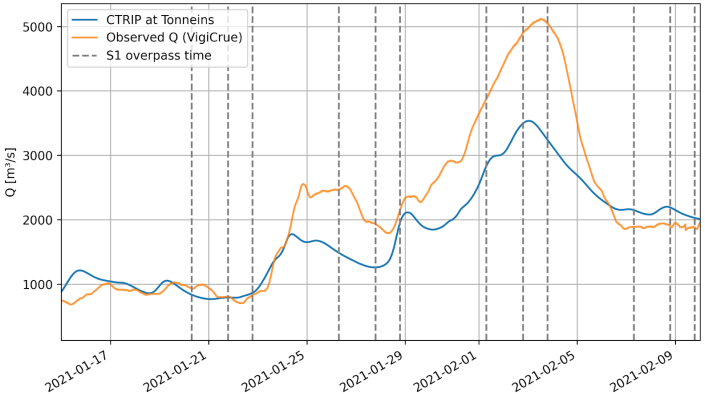
ISBA simulates the exchanges of heat and water balance at the soil-atmosphere-vegetation and hydrology interfaces over a 0.5°×0.5° regular grid

➡ Surface run-off and gravitational drainage used as forcing for RRM

CTRIP is defined on a regular latitude-longitude grid at 1/12°. It follows a river network to describe the lateral transfer of freshwater towards from one cell to another down to the interface with the ocean

➡ Discharge time series Q(t) (hourly) used as forcing for Telemac

Discharge at Tonneins Jan. 2021-Feb. 2021 (CTRIP vs Vigicrue)

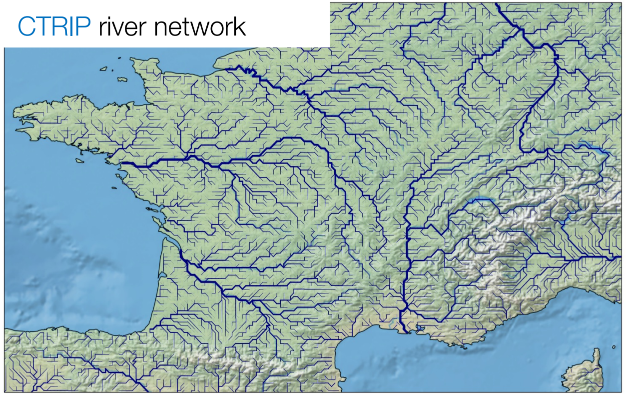


- Good general behavior
- CTRIP underestimates flood peaks

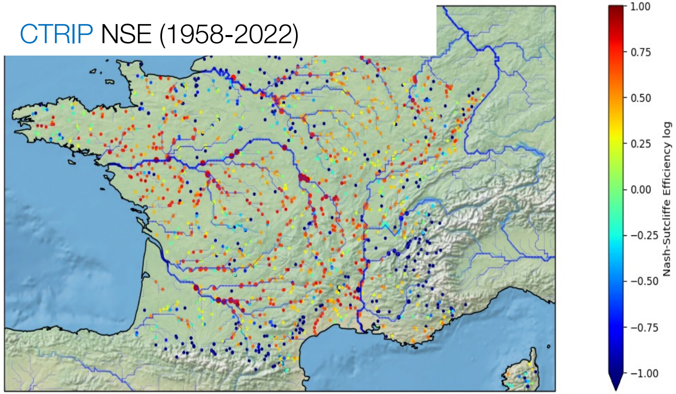
➢ Multi-physics, multi-scales CTRIP – Telemac2D one way coupled model

Ricci et al., SHF 2023

CTRIP river network



CTRIP NSE (1958-2022)



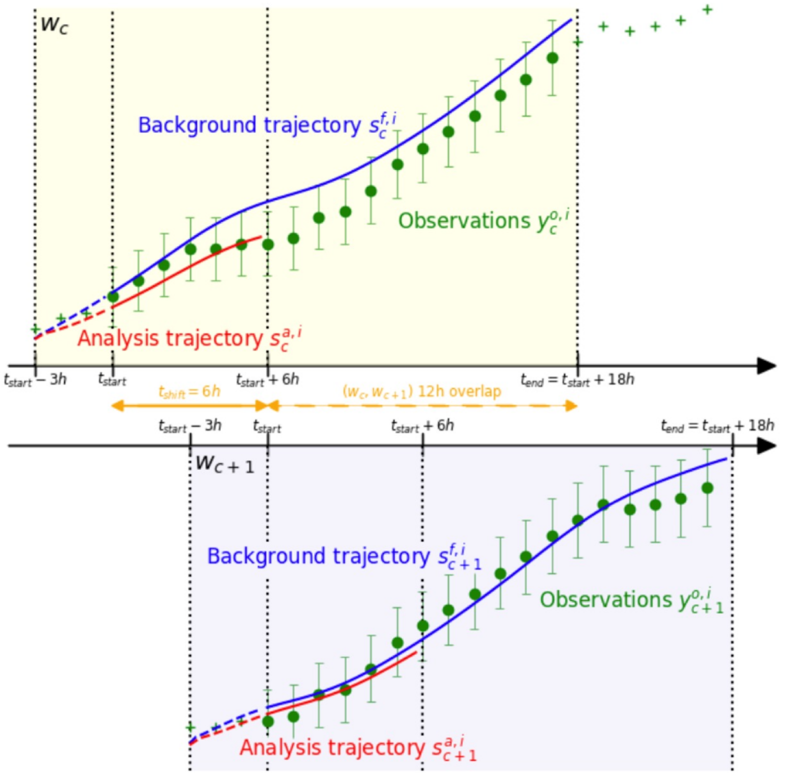
Decharme et al., JAMES 2019
Munier et al., ESSD 2022

Ensemble based Data Assimilation with Telemac

- Garonne marmandaise (EDF model)
  - 50-km river reach
  - Downstream from the Garonne-Lot confluence
  - High flood risk impacting urban area
- Boundary conditions:
  - Upstream hydrograph Q(t) at Tonneins from Vigicrue OR CTRIP
  - Downstream rating curve Z(Q) at La Réole
- Friction in river bed and floodplain
- In-situ water-level data: 4 observing stations (Vigicrue + Vortex io)
- Water level correction in 5 subdomains of the floodplain

⇒ T2D-EnKF dedicated classes available on Telemac git

⇒ Test cases and studies available on git tools4telemac



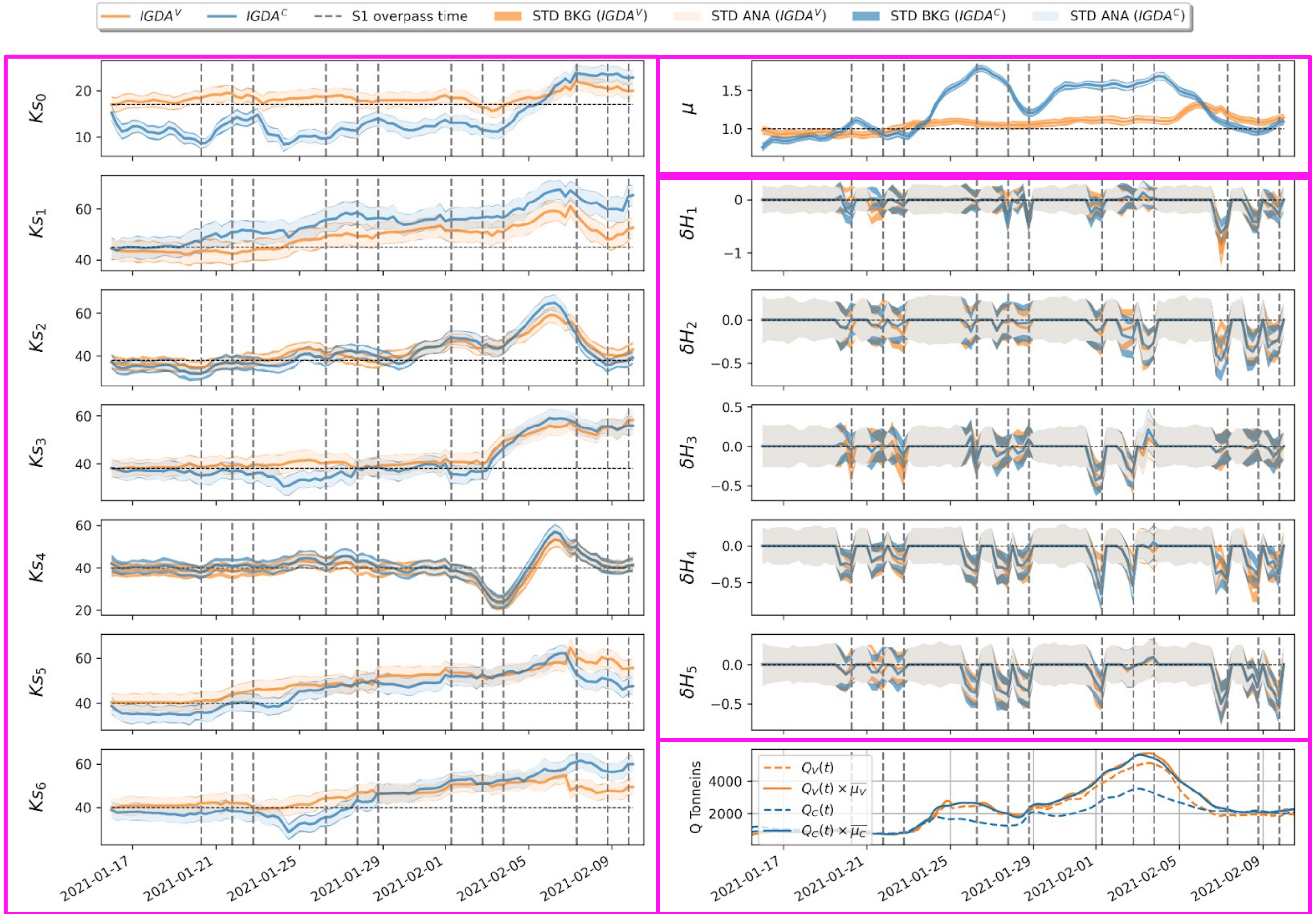
Nguyen et al. 2022 TGRS
Nguyen et al. 2022 WRR
Nguyen et al. 2023 TGRS

Data Assimilation experimental settings for 2021 event

	In-situ observations	Sentinel-1 observations
Time	Every 5-15 minutes	1 image every 2-4 days
Location/Spatial coverage	4 locations	Covers the whole catchment
Spatial resolution	-	GSD: 20x22 m
Measurement	Water level/Discharge	Flood extent

Exp.		DA	Assimilated obs.	Nb of members	Control variables
FR^v	FR^c	No	-	1	-
IDA^v	IDA^c	Yes	In-situ WSE	75	$Ks_{0..6}$, Q_Vigicrue or Q_CTRIP
$IGDA^v$	$IGDA^c$	Yes	In-situ WSE S1 WSR	75	$Ks_{0..6}$, Q_Vigicrue or Q_CTRIP, $\delta H_{1..5}$

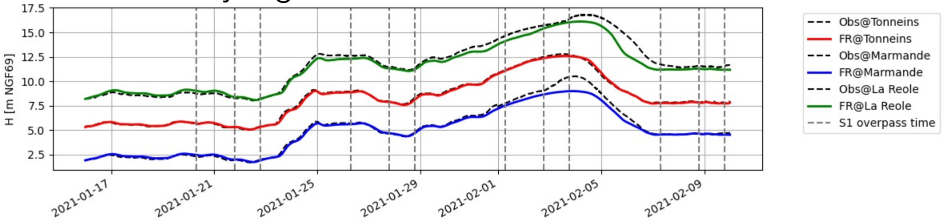
Data Assimilation Results in the control space



- Robust analysis on Ks : Similar correction on Ks with V and C forcing
- Equifinality between Ks and Q correction
- Increase of the upstream forcing to overcome inflow understimation with CTRIP
- DA tends to empty the flood plain to overcome lack of evapotranspiration process
- The analyzed CTRIP forcing matches the Vigicrue observed forcing

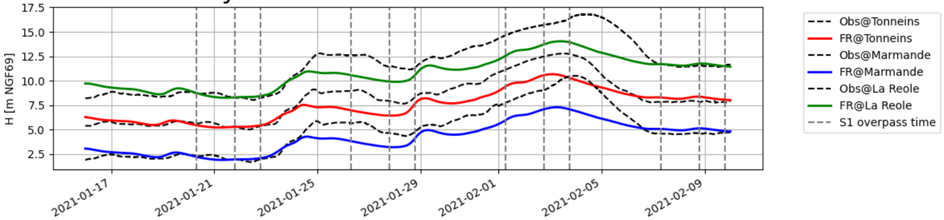
Data Assimilation Results in the WSE in-situ observation space

FR forced by Vigicrue



Vigicrue forcing leads to an underestimation of WSE at obs. stations around the flood peak

FR forced by CTRIP

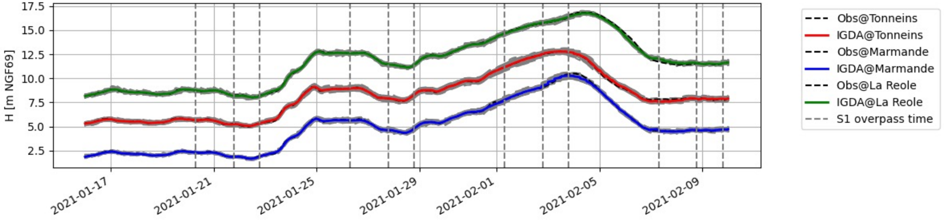


CTRIP forcing leads to clear underestimation of WSE at obs. stations

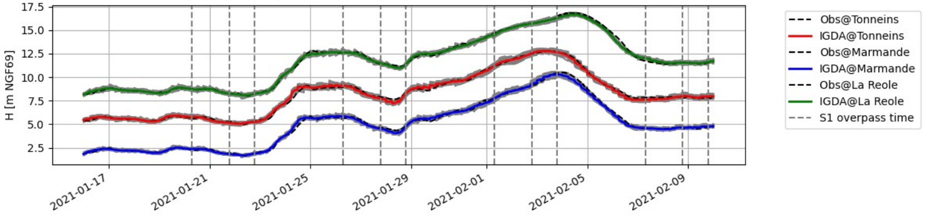
Ricci et al., SHF 2023

Data Assimilation Results in the WSE in-situ observation space

IGDA forced by Vigicrue



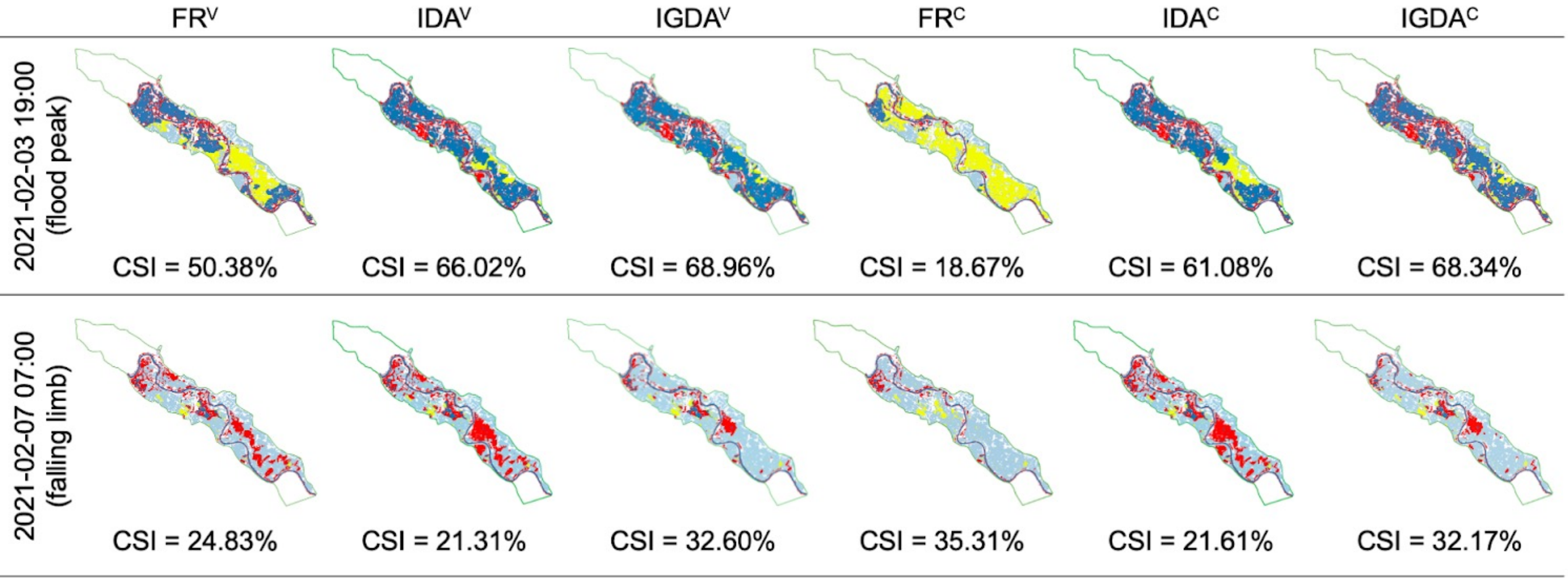
IGDA forced by CTRIP

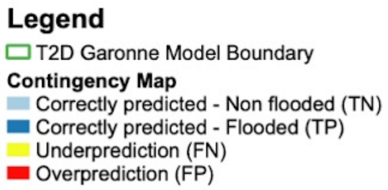


Exp.	RMSE [m]			
	Tonneins	Marmande	La Réole	Gain vs OL
OL^{V}	0.106	0.392	0.536	-
IDA^{V}	0.062	0.071	0.081	69.43 %
IGDA^{V}	0.073	0.074	0.090	65.15 %
OL^{C}	1209	1.405	1598	-
IDA^{C}	0.160	0.148	0.130	89.37%
IGDA^{C}	0.166	0.160	0.141	88.69 %

The assimilation of in-situ data suffices to correct the Ks and forcing to improve the WSE at observing stations when T2D is forced by Vigicrue or CTRIP

DA Results in the S6 WSE Sentinel-6 obs. space along river center line





- OL : The OL significantly underestimate the flood extent when forced by Vigicrue, and even more by CTRIP
- IDA : The assimilation of in-situ data does not suffice to correct flood extent
- IGDA : The assimilation of WSR and associated correction of the hydraulic state in the flood plain allows to improve the representation of the flood dynamics

Conclusions and Perspectives

- Multi-physics and Multi-scales coupling with ensemble data assimilation on hydrodynamics
- RS data allows to improve the dynamics of flood plain
- Demonstration in re-analysis mode

- Use independent data for validation (HWM, S2 images, S6 WSE, …)
- Demonstration in forecast mode with increasing lead time
- Integrate S6 (nadir WSE) and SWOT data (river products and pixelclouds)
- DA on both CTRIP-T2D model parameters and states

Thank you for your attention

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Acknowledgments:

cnes CENTRE NATIONAL D'ÉTUDES SPATIALES
SCO SPACE FOR CLIMATE OBSERVATORY
eDF R&D
VIGICRUES
Direction régionale de l'Environnement, de l'Aménagement et du Logement

1. 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
2. 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
3. Nguyen, T. H., Ricci, S., Piacentini, A., Simon, E., Suquet, R. R., & Luque, S. P. (2023). Gaussian Anamorphosis for Ensemble Kalman Filter Analysis of SAR-Derived Wet Surface Ratio Observations. *arXiv preprint arXiv:2304.01058*. https://arxiv.org/abs/2304.01058