

Implementation of the Chan-Vese distance in an Ensemble Kalman filter for the assimilation of SAR images as front-type data

Q. Bonassies¹, S. Ricci¹, S. Peña Luque², C. Fatras³, T.H. Nguyen¹, A. Piacentini¹,
R. Rodriguez-Suquet², A. Andral³

1: CECI, CNRS UMR 5318/CERFACS; 2: CNES; 3: CLS

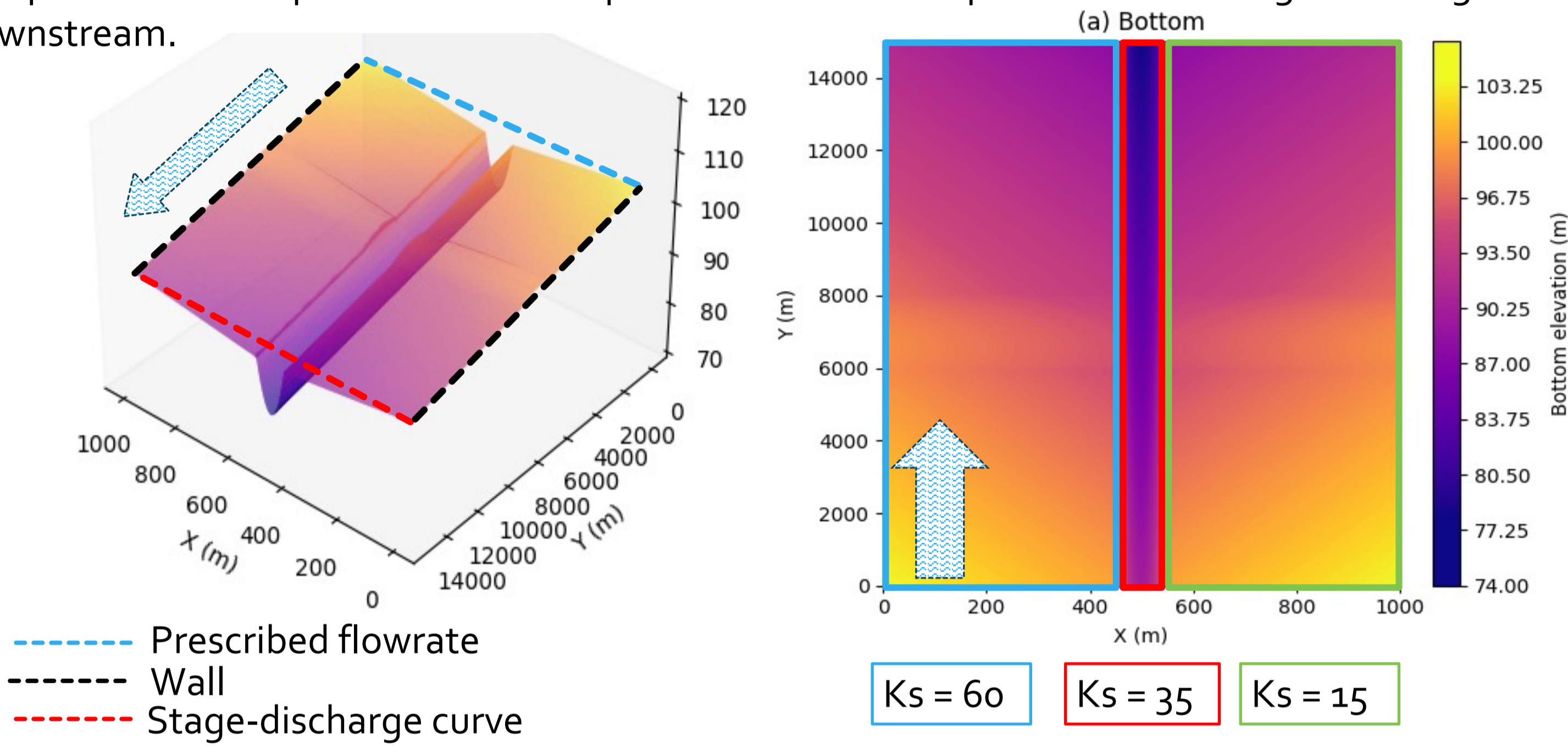
Objectives of the study

The study of flood event and inundation is crucial as it is the most common and devastating natural disasters in the world. The high uncertainty in numerical hydraulic models is a hindrance to their use. Data assimilation (DA) is used to reduce the uncertainty. In this work, the error in the position of the flood extent is reduced.

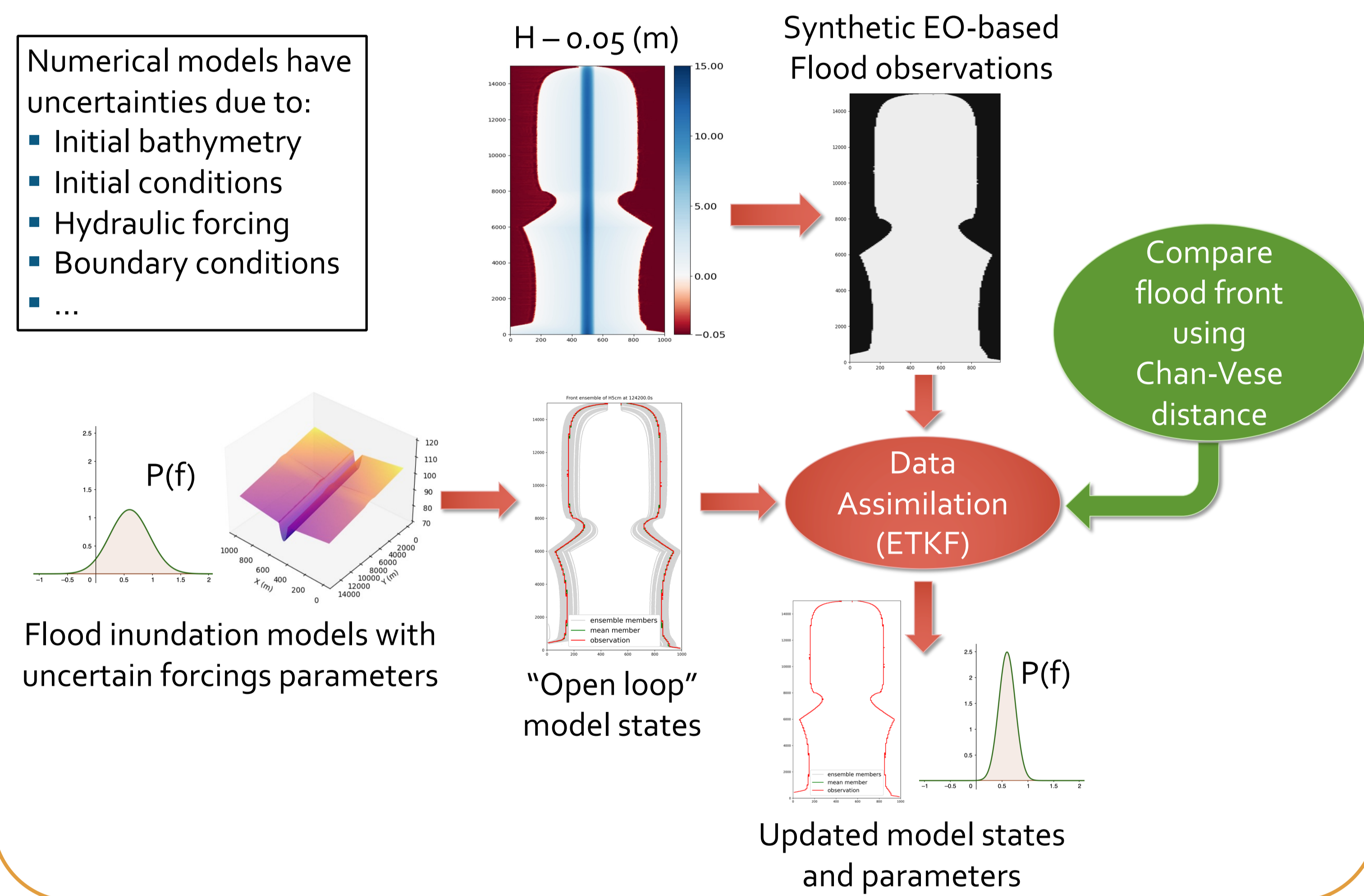
- Develop in Telemac-2D (T2D) code the Chan-Vese distance within an Ensemble Transform Kalman Filter algorithm
- Create a simple T2D toy model
- Test the DA algorithm in an observing system simulation experiments (OSSE) with the T2D model

Telemac-2D and the Valley test case

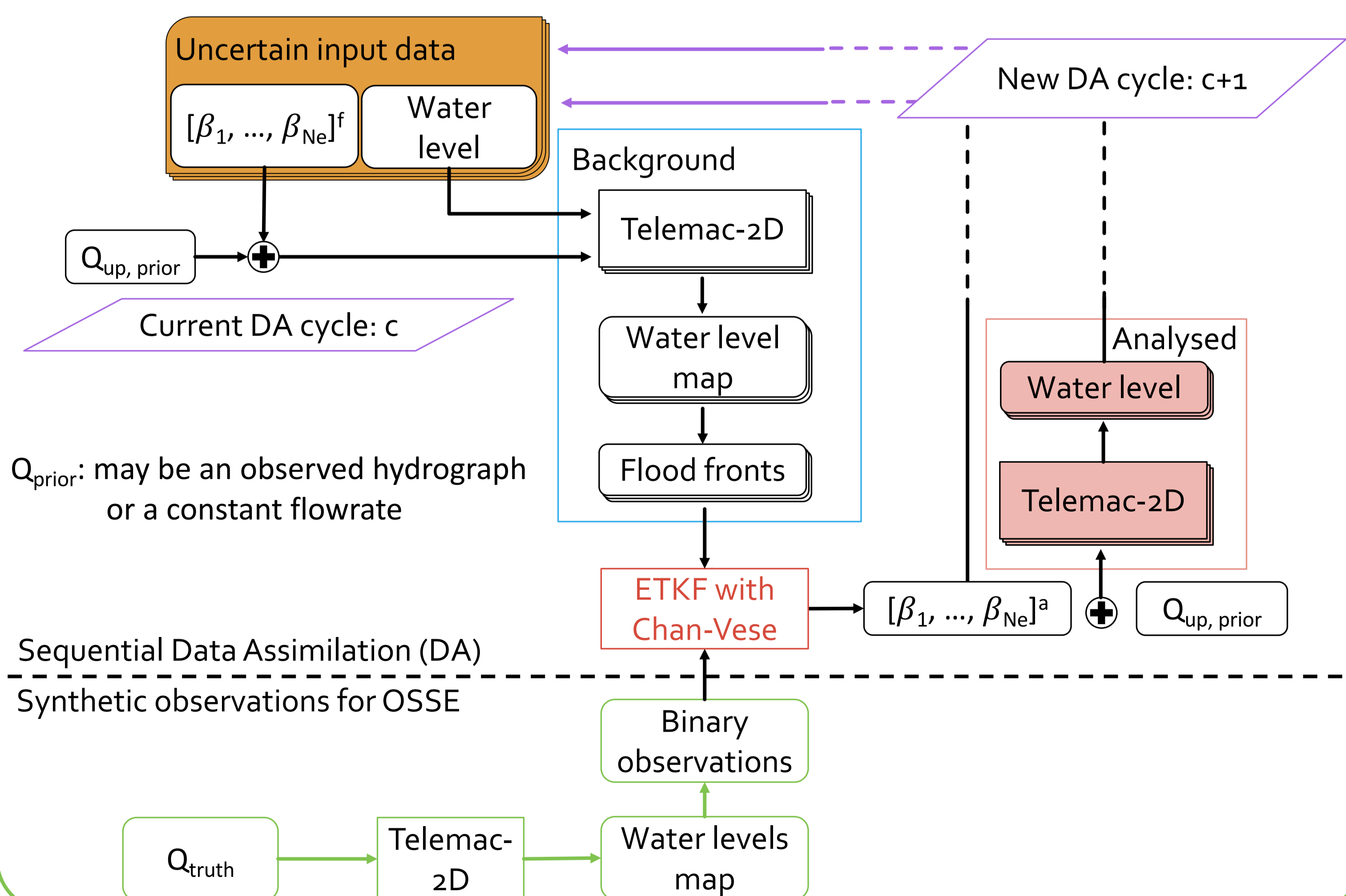
The T2D numerical model represents a straight channel of 15km length and 1km width with two floodplains on each side of the channel. The mesh is composed of about 115,000 nodes. There are three Strickler coefficients, one in the riverbed and two for each floodplain. The model is composed of two liquid boundaries: a prescribed flowrate upstream and a stage-discharge curve downstream.



DA is used to reduce the uncertainties in the numerical models and the observations. An Ensemble Transform Kalman Filter (ETKF) algorithm combined with the Chan-Vese distance is used to compare the observed front-lines and the ensemble of simulated front-lines. The control vector of the DA algorithm is composed of β , an additive factor to the inflow discharge.

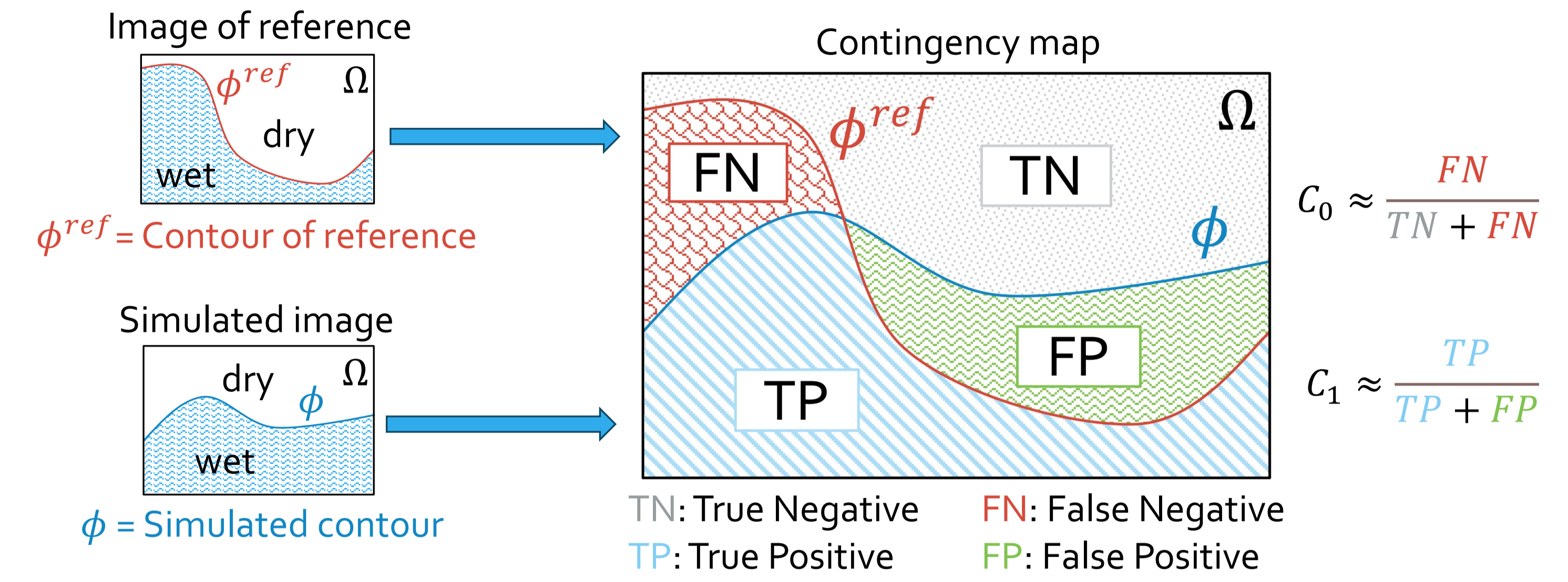


The Ensemble Transform Kalman Filter (ETKF) Framework



The Chan-Vese distance

The Chan-Vese distance is based on contingency maps which defined four areas in the image: False positive, True positive, False negative and False positive. From those areas, two scalars are defined to compute the Chan-Vese distance.



Chan-Vese contour fitting distance is defined as:

$$D(\phi^{ref}, \phi) = D^+(\phi^{ref}, \phi) + D^-(\phi^{ref}, \phi)$$

Where:

$$D^+(\phi^{ref}, \phi) = Hv(\phi) (\phi^{ref} - Cmax(\phi^{ref}, \phi))$$

$$D^-(\phi^{ref}, \phi) = (1 - Hv(\phi)) (\phi^{ref} - Cmin(\phi^{ref}, \phi))$$

Hv is a Heaviside function returning 1 if the pixel is flooded, 0 elsewhere. $Cmax$ and $Cmin$ are respectively the max and min of the scalar C_0 and C_1 .

Analytical metrics

Three metrics are used to analyse the results. The first two moments of the control vector are the first metrics: the mean and standard deviation. The last one is the Chan-Vese functional which compare two images.

$\bar{\beta}$: ensemble mean of β

$$\bar{\beta} = \frac{1}{60} \sum_{i=1}^{60} \beta_i$$

σ : ensemble standard deviation (std) of β

$$\sigma = \sqrt{\frac{\sum_{i=1}^{60} (\beta_i - \bar{\beta})^2}{60}}$$

\mathcal{J} : mean Chan-Vese functional (similarity score between two images)

$$\mathcal{J} = \mathcal{J}^+ + \mathcal{J}^-$$

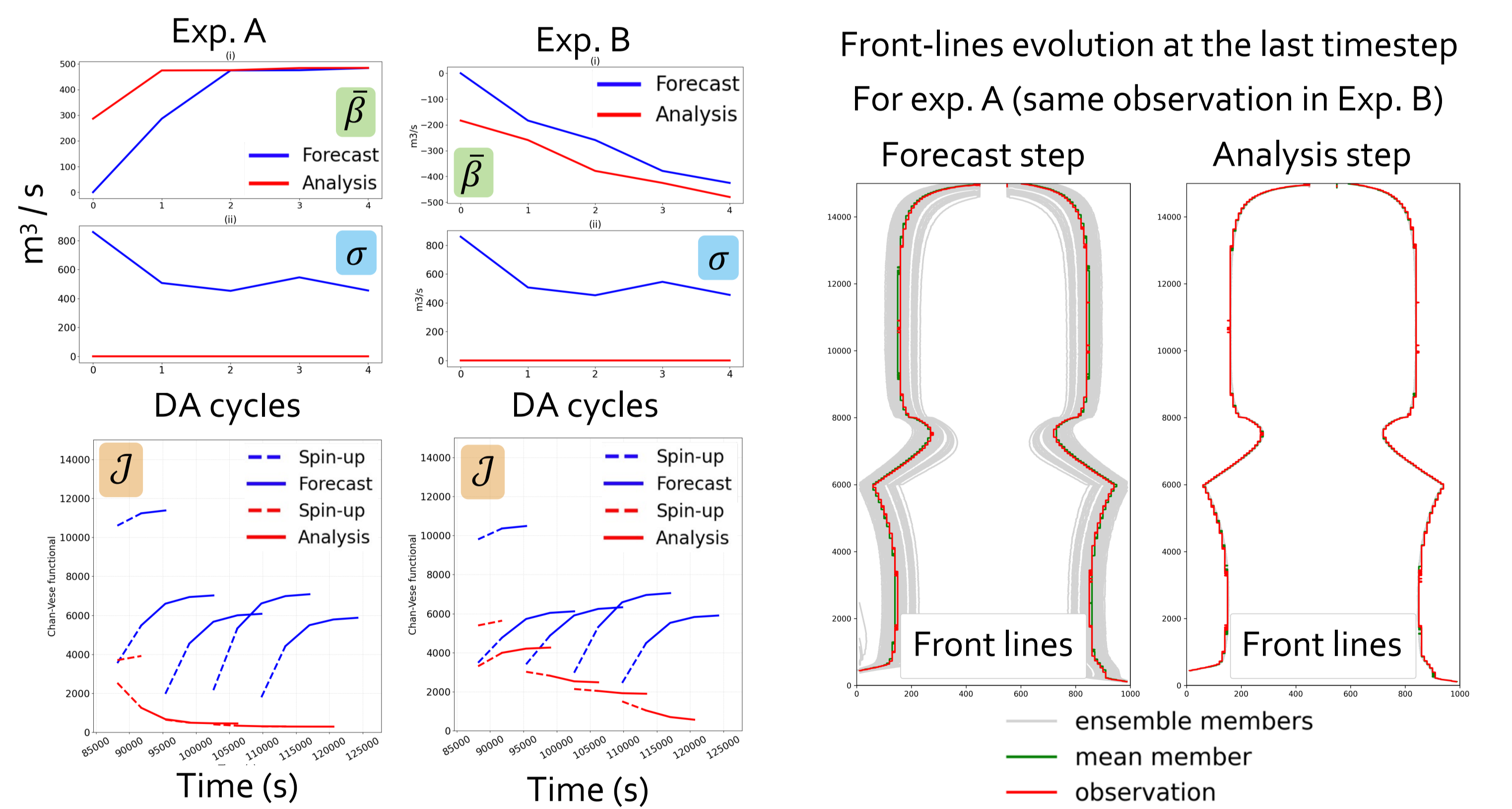
With:

$$\mathcal{J}^+(\phi^{ref}, \phi) = \int_{\Omega} Hv(\phi) (\phi^{ref} - Cmax(\phi^{ref}, \phi))^2 dxdy$$

$$\mathcal{J}^-(\phi^{ref}, \phi) = \int_{\Omega} (1 - Hv(\phi)) (\phi^{ref} - Cmin(\phi^{ref}, \phi))^2 dxdy$$

OSSE settings and results

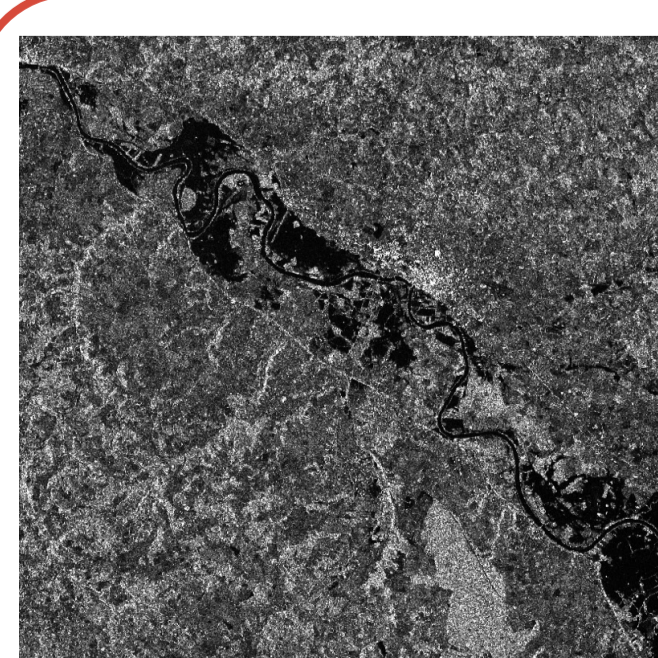
Ensemble size	Truth setting	Control Vector	a priori settings	
60 members	$Q_{up, truth} = 5000 \text{ m}^3/\text{s}$	$x = [\beta]$ with $\beta \sim \mathcal{N}(0, 700^2)$	Exp. A	$Q_{up, prior} = 4500 \text{ m}^3/\text{s}$
			Exp. B	$Q_{up, prior} = 5500 \text{ m}^3/\text{s}$



For both experiment, $\bar{\beta}$ reaches a value that, added to the prior setting goes to the truth value of the upstream flow. \mathcal{J} show similar result, it is reducing with the simulation.

After the analysis steps, σ is reduced to zero. This mean that the ensemble collapse to one value.

The front-lines evolutions is comforting with $\bar{\beta}$ and \mathcal{J} evolutions.



Perspectives on Chan Vese-ETKF work

- New experiment with an observation created with a different topography;
- Add spatial control vector;
- Test with a more realistic synthetic SAR observation;
- Test on the Garonne catchment model on 2019/2021 flood events.