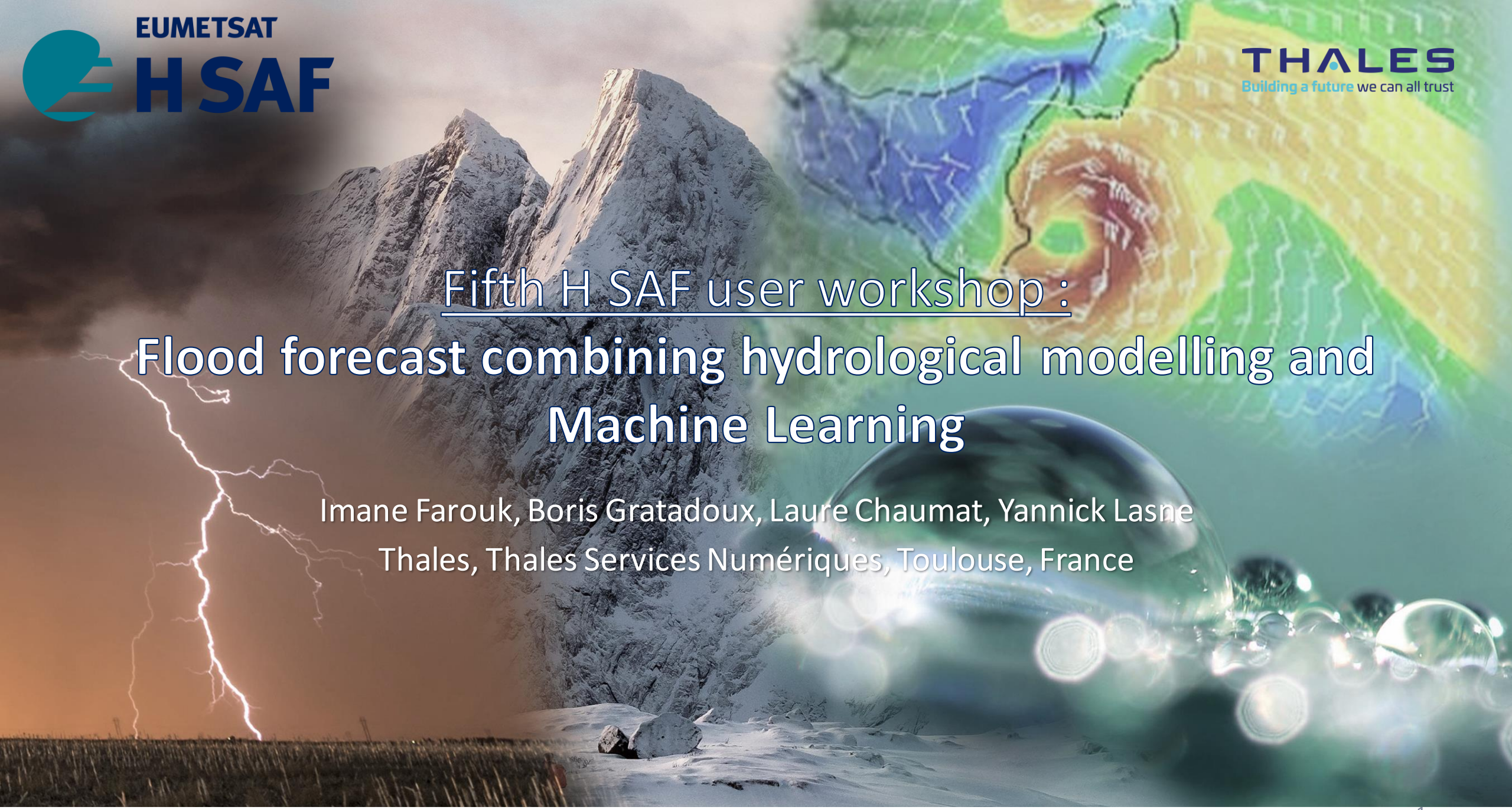

EUMETSAT H SAF

THALES
Building a future we can all trust

Fifth H SAF user workshop :

Flood forecast combining hydrological modelling and Machine Learning

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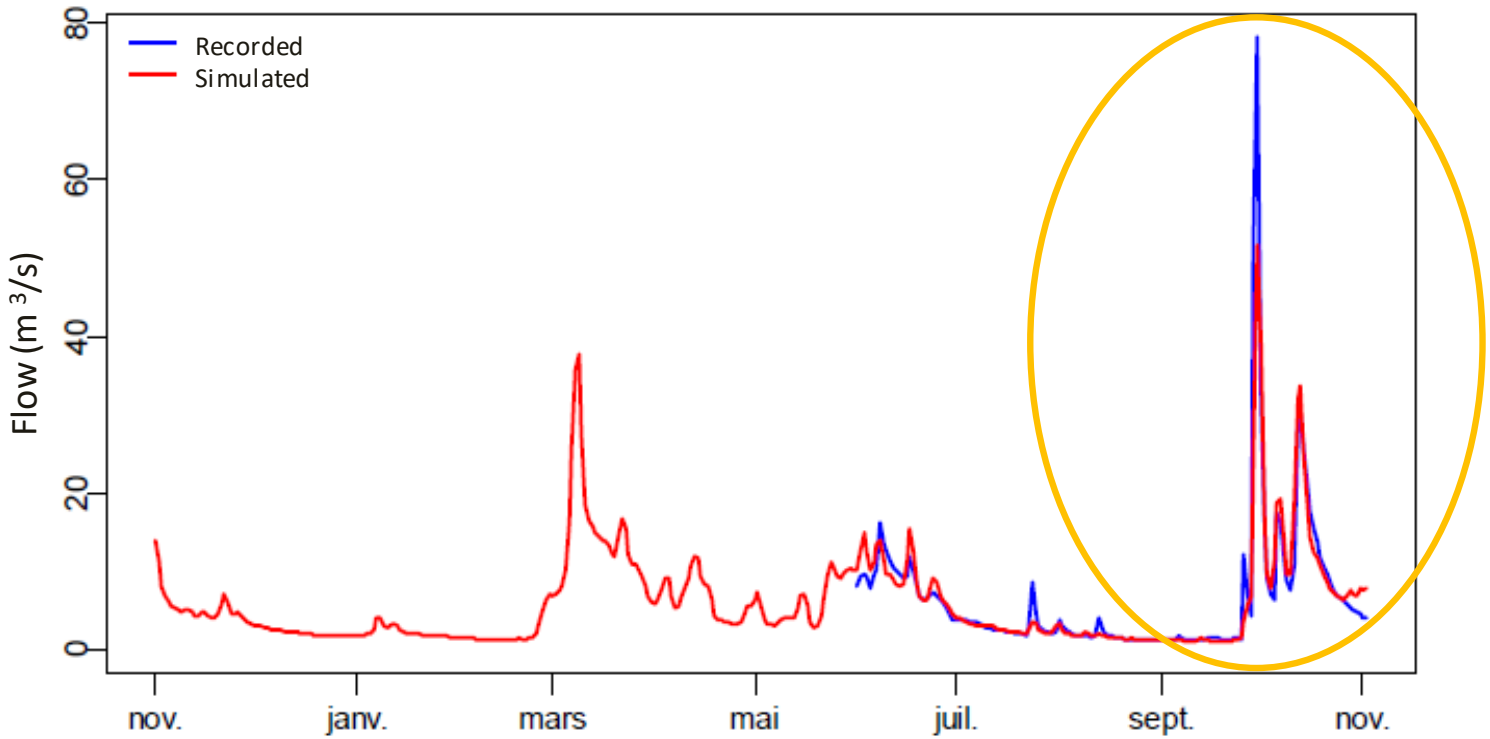
Contents

- Introduction
- Thales flood forecasting tool
  - Hydrological forecast
  - Space-based soil observation
  - Machine-Learning
- Application to a French watershed
- Summary
- Outlook

Introduction

Flood forecast is mostly based on **flow modelling** but models still suffer from many uncertainties :

- Modelling
- Setting
- Initial state
- Input data



From 01 nov. 1990 to 02 nov. 1991

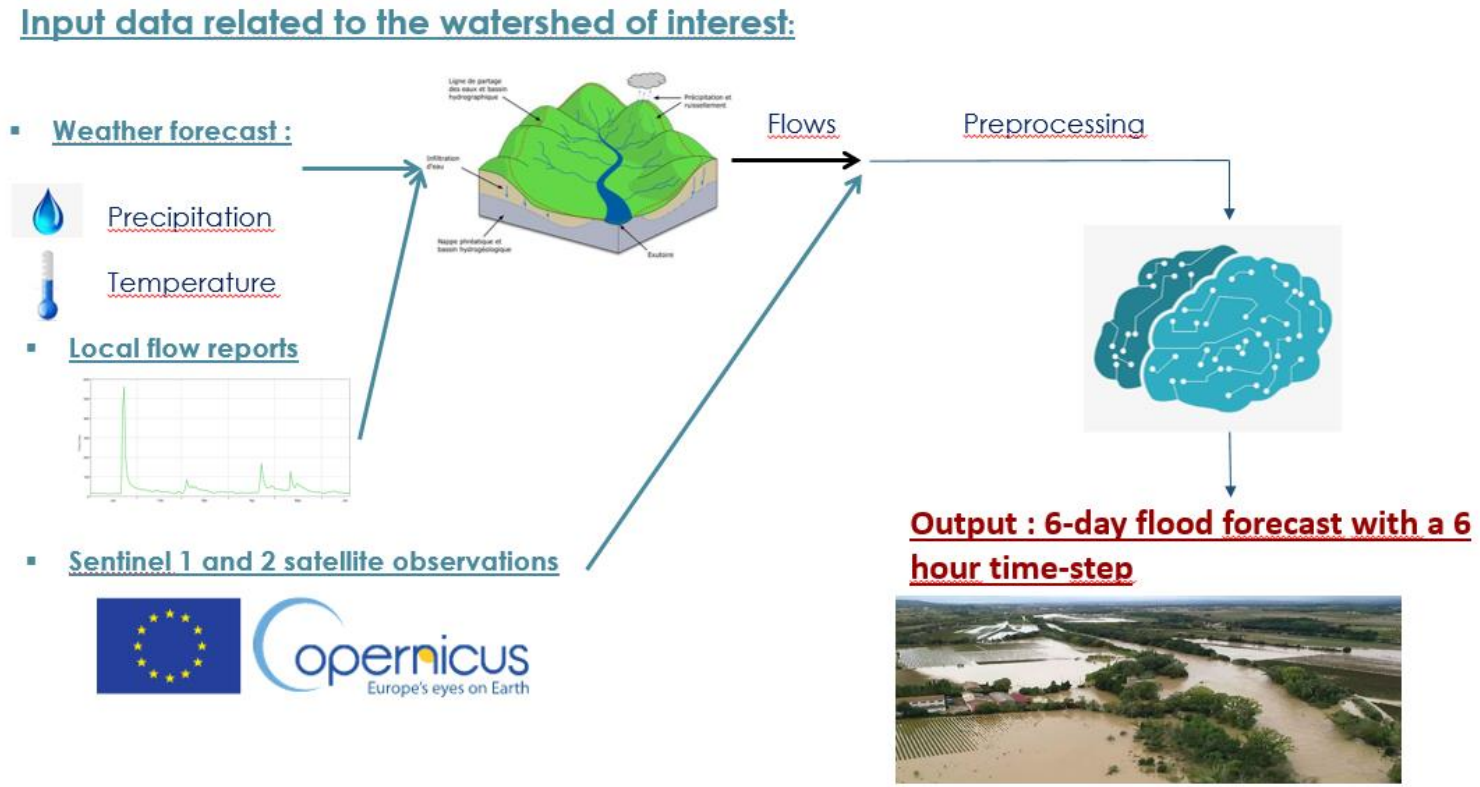
Issue

How can atmospheric uncertainties be reduced in flow forecasting and how can this information be used for an automatic flood forecasting?

Thales flood forecasting tool

The tool:

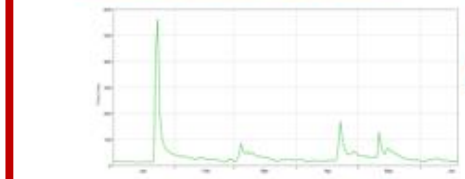
- **Combines hydrological physical model and Machine Learning**
- **Uses available COPERNICUS data**
- **Is based on a protocol adaptable to any watershed**

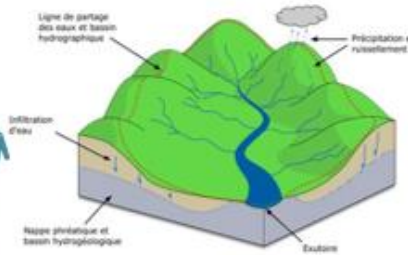


Hydrological forecast

Input data related to the watershed of interest:

- Weather forecast :
  - Precipitation
  - Temperature
- Local flow reports





Flows

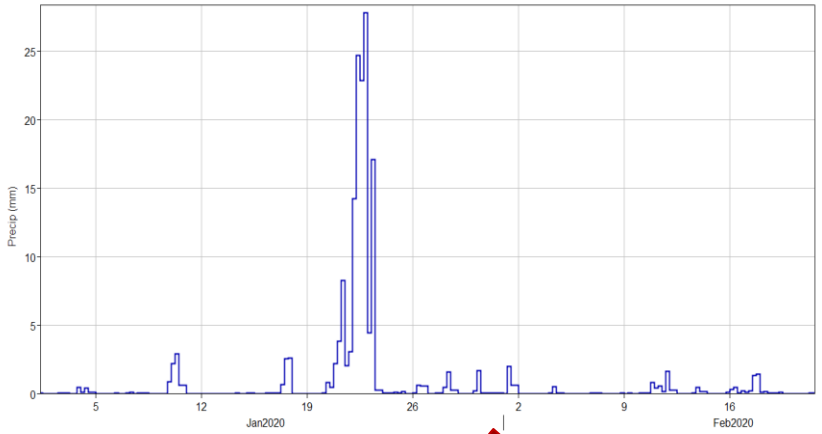
- Sentinel 1 and 2 satellite observations

Preprocessing

Output : 6-day flood forecast with a 6 hour time-step

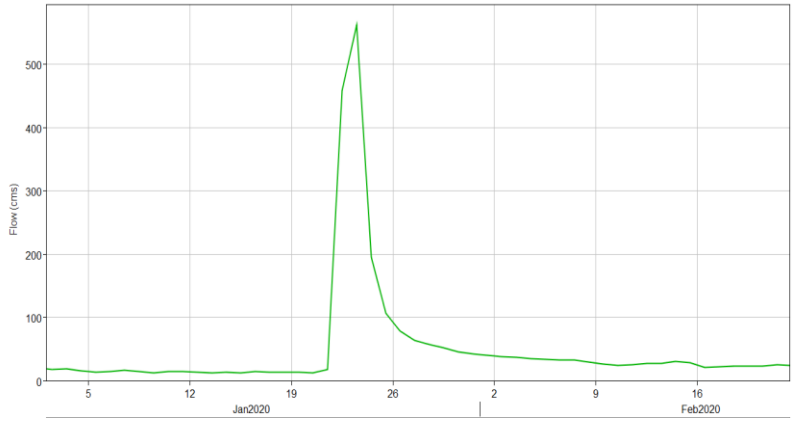
Hydrological forecast

Meteorological forecast



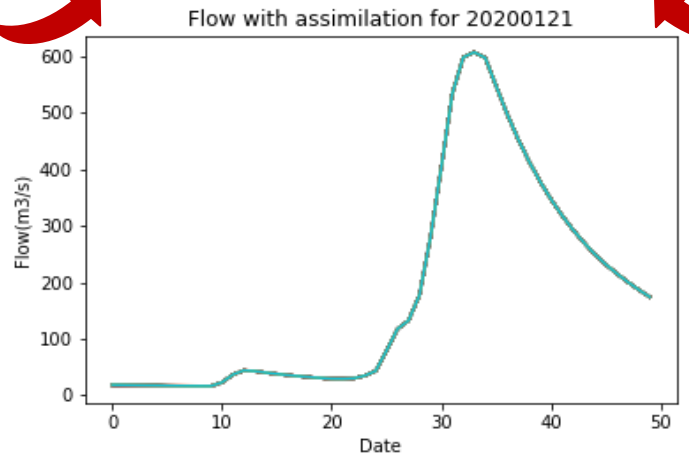
Precipitation

Local flow reports



Flow

Hydrologic model with ensemble data assimilation



Modelled Flow

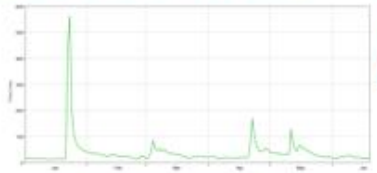
First step:

- A semi-distributed **hydrological model**
- **Input**: temperature and precipitation
- **Ensemble data assimilation** with a particle filter
- **Better initial state** for the flow forecasting
- **A set of predicted flows at the outlet of the river basin**

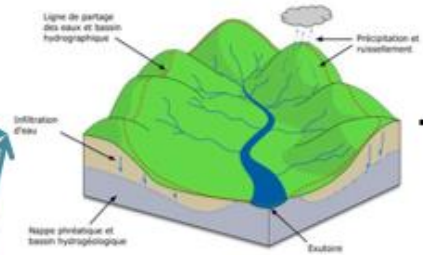
Space-based soil observation

Input data related to the watershed of interest:

- **Weather forecast :**
  - Precipitation
  - Temperature
- **Local flow reports**



- **Sentinel 1 and 2 satellite observations**



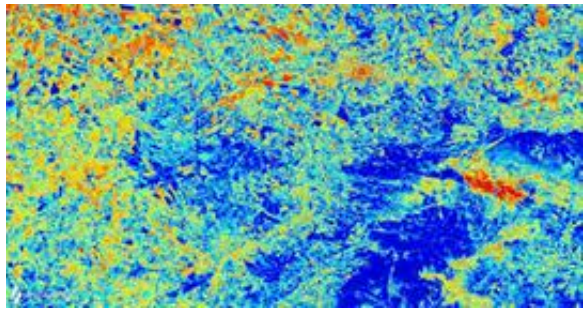
Flows

Preprocessing

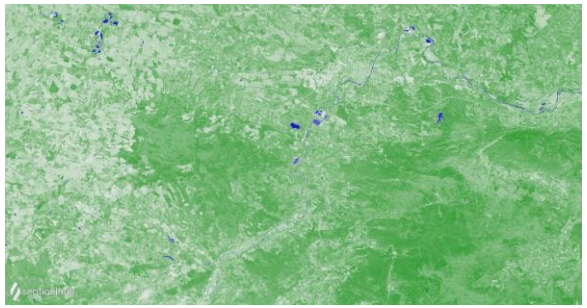
Output : 6-day flood forecast with a 6 hour time-step

Space-based soil observation

Sentinel-2 data

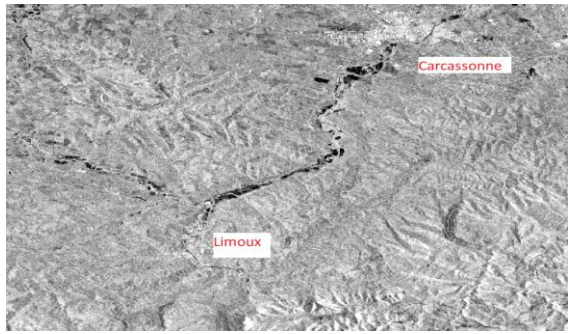


Soil Moisture Index (SMI)



Normalized Difference Water Index (NDWI)

Sentinel-1 data



Backscattering coefficient

Second step:

- Use of available Copernicus data
- **Computation of the curent soil state information** throught space observation
- **Allows a combination of different sources of information** each with their strengths

Preprocessing

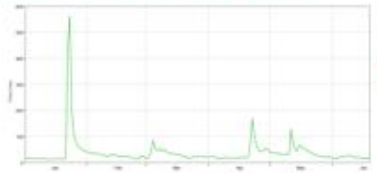
- Soil state characteristics:
  - Moisture Stress Index (MSI) from Sentinel-2 images
  - Normalized Difference Vegetation Index (NDVI) from Sentinel-2 images
  - Normalized Difference Water Index (NDWI) from Sentinel-2 images
  - Soil Surface Moisture (SSM) from Sentinel-1 images
  - Soil Moisture (SM) from SMOS images

- Predicted flows
  - Use of a lagging method to :
    - Increase time information
    - Stabilize the average (closer to zero)

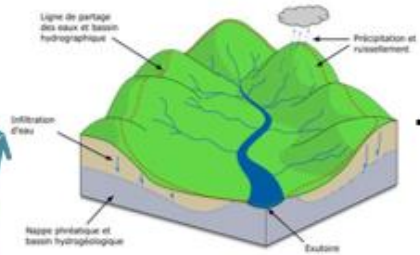
Machine Learning

Input data related to the watershed of interest:

- **Weather forecast :**
  - Precipitation
  - Temperature
- **Local flow reports**



- **Sentinel 1 and 2 satellite observations**



Flows

Preprocessing

Output : 6-day flood forecast with a 6 hour time-step

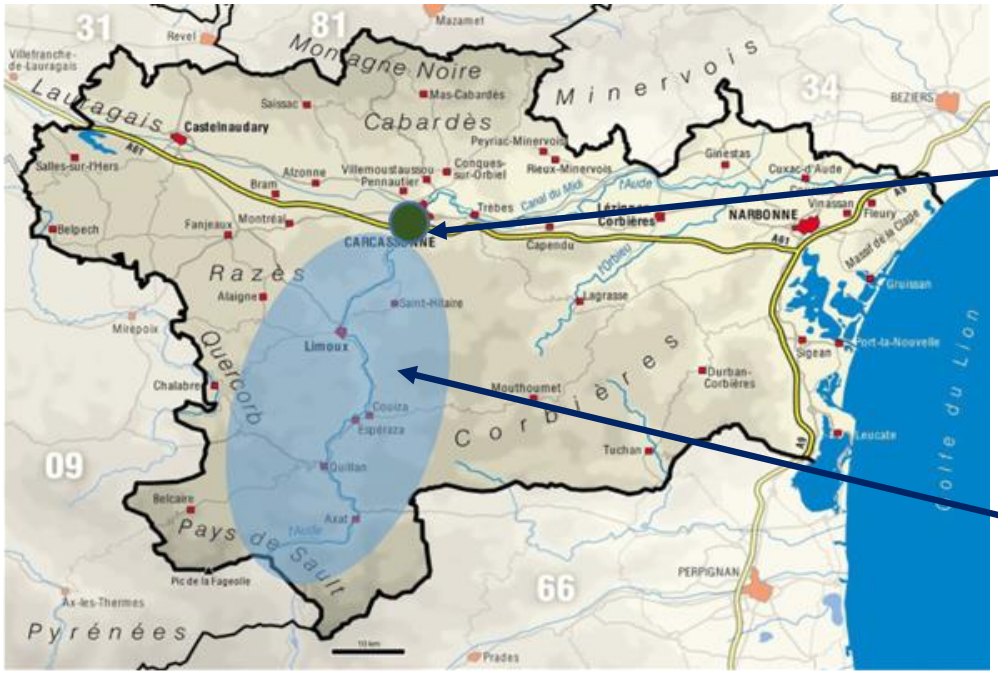
Machine Learning

Third step:

- Using of **the set of flow forecasts** together with **soil indices** from space-based observation
- A **training dataset** with past flood events and high flow events
- To provide 6-day flood forecast with a 6 hour time-step, together with **confidence indices** associated to each time-step

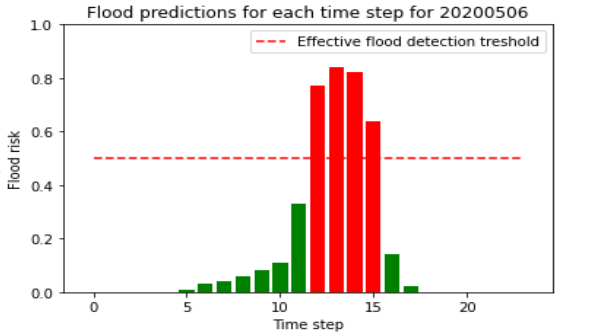
Application to a French watershed

- Hydrological model setting based on ground-truth data (flow reports) and meteorological forecast
- ML Training dataset combining flow forecast and space-based observations

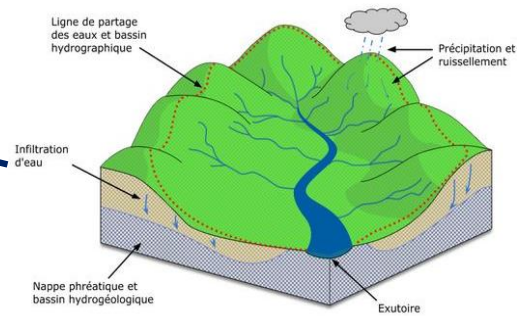


Modelled basin

Forecast at the basin outlet



Flood forecast with confidence indices



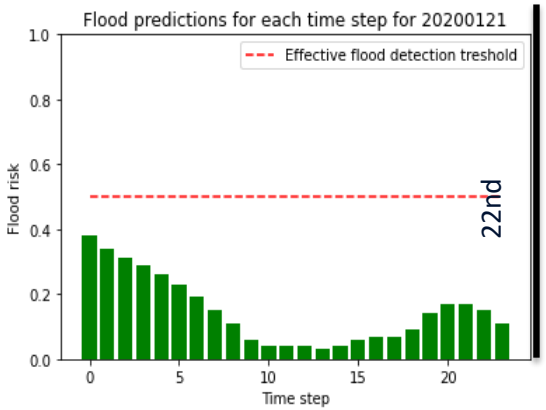
Hydrological model

Output example

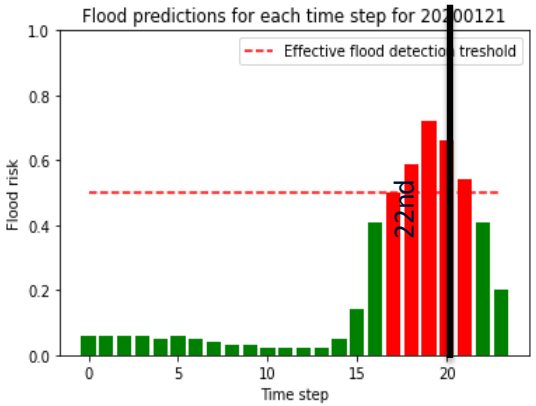
6-day flood forecast with a 6 hour time-step and associated confidence indices

Flood events recorded on January 22nd and 23rd 2020

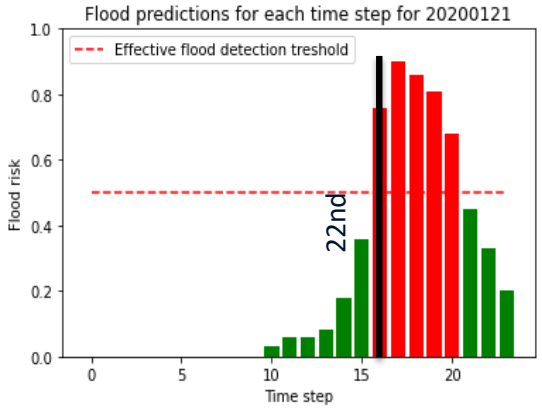
with meteorological data of January 16th official report



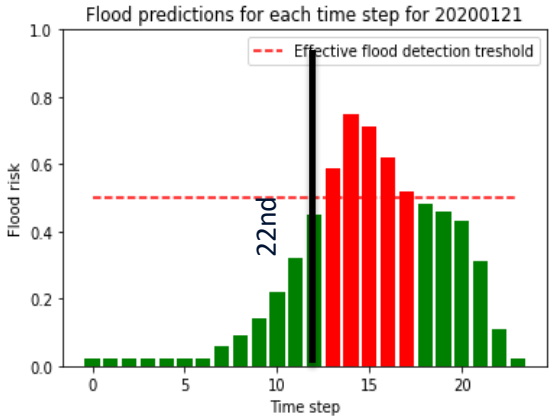
with meteorological data of January 17th official report



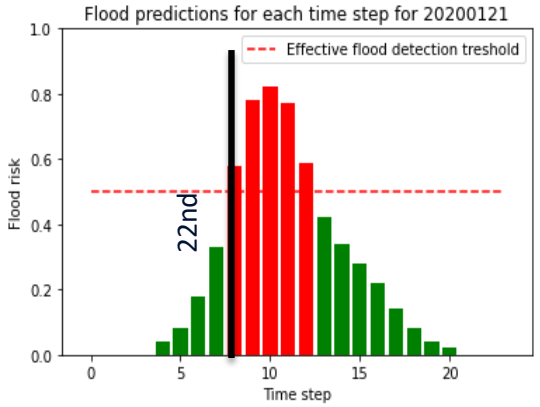
with meteorological data of January 18th official report



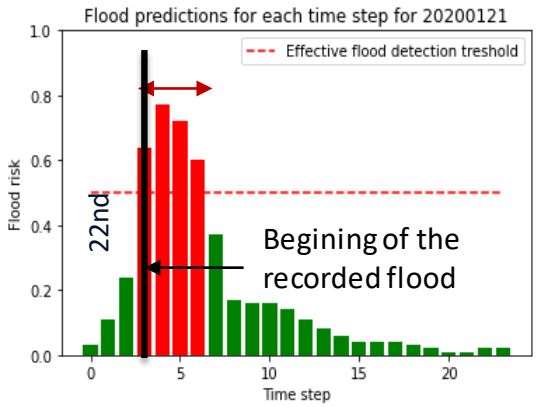
with meteorological data of January 19th official report



with meteorological data of January 20th official report



with meteorological data of January 21th official report



Preliminary performance

- **Selection of relevant indices :**

	Score	Mean	Mean standard error on 6 cross-validations
Score without satellite data	AUC*	0,736	0,10
	Correct forecast	92,19 %	4,1%
Score with all the indices	AUC*	0,736	0,12
	Correct forecast	92,41 %	3,71%
Score with NDWI, MSI and SSM	AUC*	0,746	0,12
	Correct forecast	92,77 %	4%

*AUC = Area Under the Curve ROC, curve representing the true positive rate as a function of the false positive rate.

- **Selected indices :**
  - NDWI
  - MSI
  - SSM

Summary

- **Easy to use with weak ressources need**

- **Adaptation to any watershed :**
  - Hydrological model
    - Initial state with **data assimilation**
      - **Precipitation and temperature (**or available from ECMWF) **:**
        - » Two months of reanalyses to initialize the hydrological model
      - **Flow reports** at the prediction outlets (location of the measurement stations)
    - Forecast
      - **Precipitation and temperature**
        - » 6-day forecast

  Or use **your own hydrological model** and provide flow forecast as input of the Machine Learning algorithm.

  - Machine Learning training dataset
    - Select **past flood events and high flow events without flood**
    - Provide the corresponding input for the selected dates:
      - **Precipitation and temperature** (or available from ECMWF)
      - **Flow reports**
      - **Sentinel-2 and Sentinel-1 images available from Copernicus**

Outlook

Future improvements:

- Improve temporal resolution by reaching 1-hour time-step, to allow better flash floods prediction
- Add prediction locations on the sub-basin, especially on the tributaries
- Transpose the protocol to various watersheds
- Package as a service on a scalable environment based on Kubernetes

Thank you for your attention!

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boris.gratadoux@thalesgroup.com