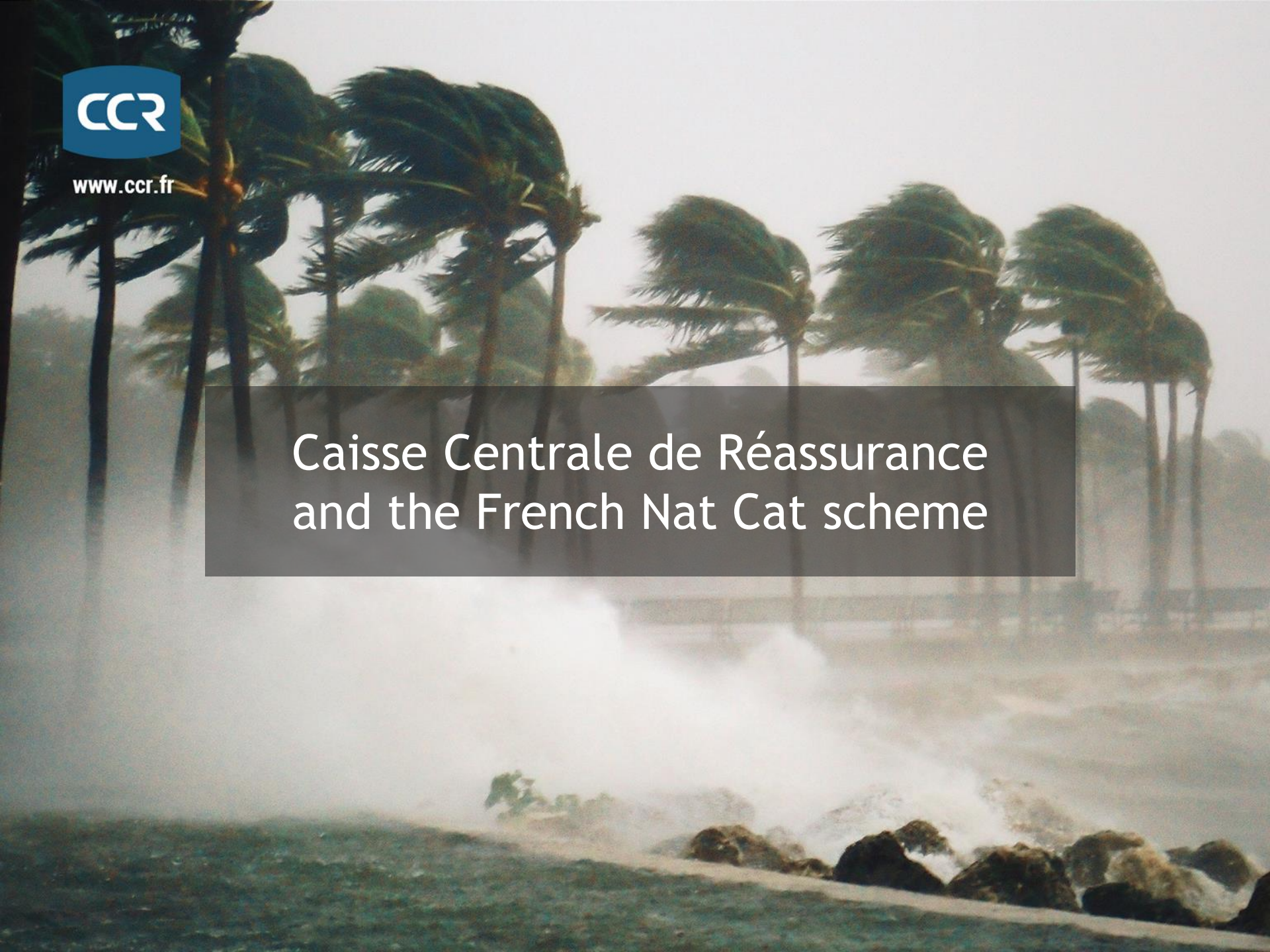
Coupling Hydrological Overflow Model and EO-data: Benefits on Hazard and Damage Estimation for Floods in France

Department R&D modélisation Cat & Agro – Public Reinsurances (CCR)

Thomas Onfroy *tonfroy@ccr.fr*
Pierre Tinard *ptinard@ccr.fr*
Anas Nassih *anasnassih93@gmail.com*

30/04/2020



Caisse Centrale de Réassurance and the French Nat Cat scheme

Caisse Centrale de Réassurance (CCR)

- CCR is a public reinsurer providing private insurers operating in France, for the public interest, with insurance coverage especially against natural and anthropological hazards

- The company has been allowed to reinsure natural disasters risks since the natural disasters compensation scheme creation in 1982

- CCR leverages its central role in the natural disasters compensation scheme by developing an expertise on natural hazards and knowledge on the vulnerability of the exposed territories

- CCR also manages Public Funds on behalf of the French State such as the Fonds National de Garantie des Risques en Agriculture (FNGRA – Agricultural Risk Guarantee Fund) or the Fonds de Prévention des Risques Naturels Majeurs (FPRNM – Major Natural Hazard Prevention Fund)

CCR's reinsurance solution

Natural and anthropological hazard compensation procedures under the French Nat Cat scheme

1 AN ADVERSE EVENT
occurs. *List of **perils normally covered** included below

2 THE MAYOR
has 18 months from the date of occurrence to file a request with the prefect demanding that the event be declared a Natural Disaster

3 THE PREFECT
submits the request to the Interministerial Commission.

4 THE INTERMINISTERIAL COMMISSION
determines whether the event may be declared a disaster or not. The list of municipalities recognized by decree is published in the Official Journal

5 THE CLAIMS ADJUSTER
assigned by the insurer assesses the cost of the damages.

6 THE INSURER
indemnifies the insured within the 3 months following the date of remittance of the estimated cost of the damages.

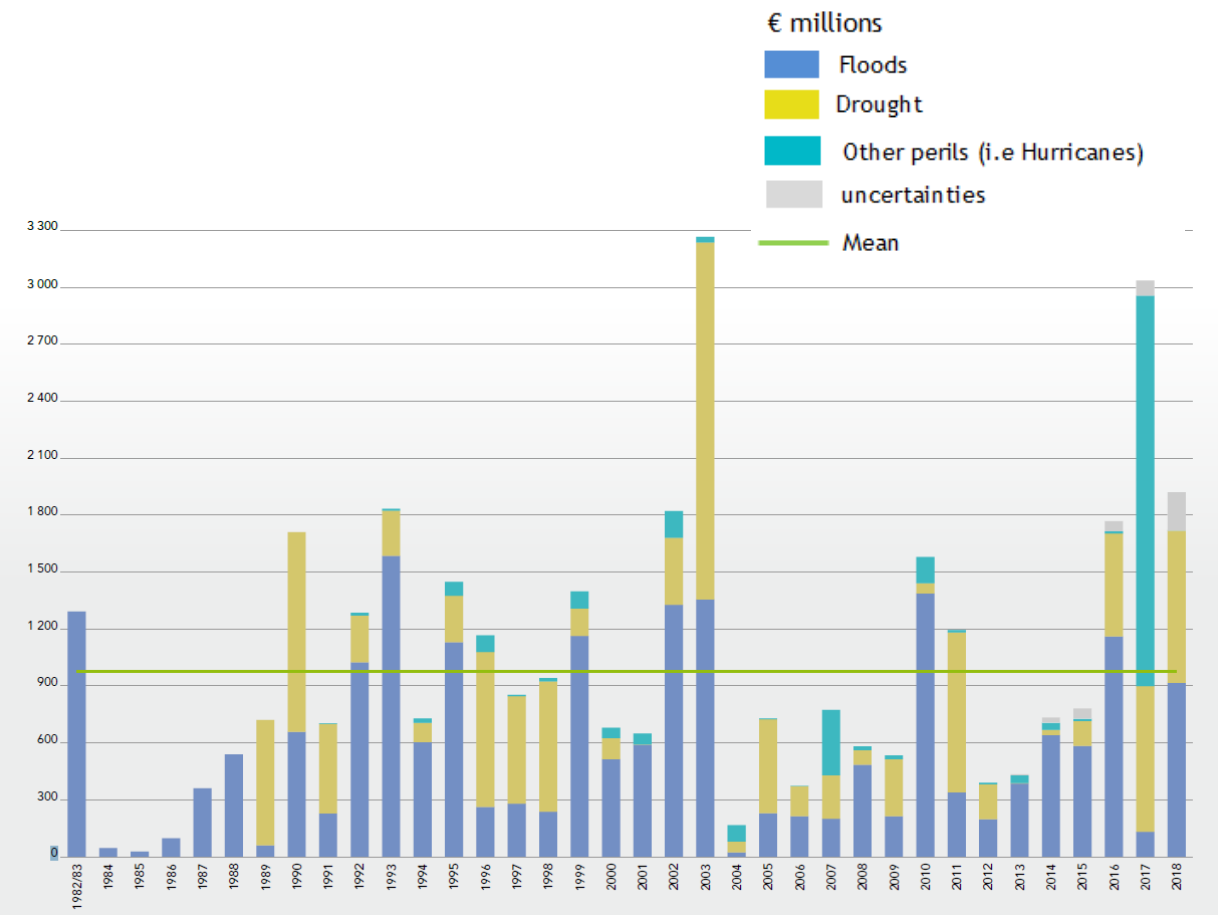
7 CCR
reinsures the insurers and pays approximately 50% of the total amount of the losses. It ensures the pooling of the risks and the solidarity of the entire national territory.

8 THE STATE
By means of the guarantee granted to CCR, the State intervenes as a last resort in the event of an exceptional loss.

***PERILS NORMALLY COVERED:**
- Floods and mudslides
- Landslides (including subsidence)
- Earthquakes and volcanic eruptions
- Tsunamis and marine submersions
- cyclonic winds (> than average of 145 km/hour over 10 minutes or gusts of 215 km/hour)
- Avalanches

NATURAL DISASTER COVERAGE IS COMPULSORY
in all property insurance policies. Almost all victims of natural disasters therefore benefit from the coverage.

1982 - 2018 disaster events for the French Nat Cat scheme



Nat cat losses in France (non-auto) from 1982 to 2018

Major Nat Cat events since 1982 (estimated losses)

- Floods and drought (shrinking-swelling clay) in 2003 (€3.3 billion)
- Floods and drought in 2016 (€1.8 billion)
- Hurricane Irma, floods and drought in 2017 (nearly €3.3 billion)
- Flood frequency and associated losses are significant

CCR Nat Cat modelling activities

R&D, Cat & Agriculture Modelling Departement

- Since the mid 2000's, Cat models have been developed to quantify the exposure of French municipalities
- Deterministic models : Events losses estimation at Day +5
- Probabilistic models : Financial exposure measurement of insurance companies and French State to a number of probabilistic events
- R&D, Cat & Agriculture Modelling Departement, a multidisciplinary team (6 permanents + doctoral students and interns)

Hydrological models	Meteorological models	Geological models	Anthropological models
Floods *Storm Surge*	*Hurricanes* *Agricultural risks*	Drought Earthquakes	*Terrorism* *Nuclear plants (Civil Responsibility)*

GIS - Remote Sensing - Historical events - Climate Change

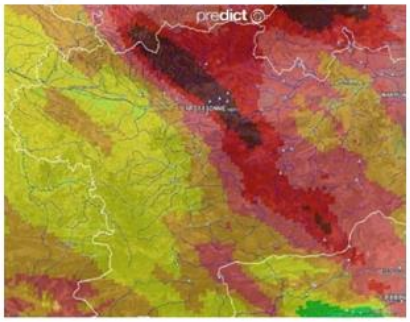
Scientific partners

METEO FRANCE · brgm (Géosciences pour une Terre durable) · irstea · IGN (Institut National de l'Information Géographique et Forestière) · sertit · predict

Flood event near real time monitoring and data acquisition

METEO FRANCE

predict



Predict's report 14th Oct.

- Copernicus service Emergency activated
- Access to ESA, Sertit and NASA/USGS imagery

Aude flood peak at Trèbes 7,68m on **14th Oct (D0)**

Modelling mechanisms for events

Modelled costs Languedoc (M€): [130-180] **D+2**

- Hazard characterisation
- Damage inventory
- Land surveys

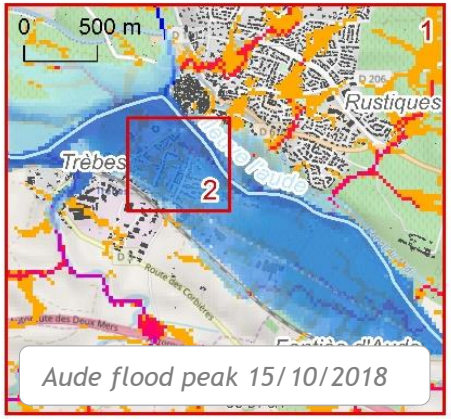
- Sharing event note: **D+5**
- Flood monitoring mission
- CCR event database
- Actuarial provisioning
- Risk prevention

Objective: providing a short time damage assessment based on the expertise of the partners and operational network (Météo-France, Predict, Sertit, ESA Copernicus EMS, Vigicrues, …)

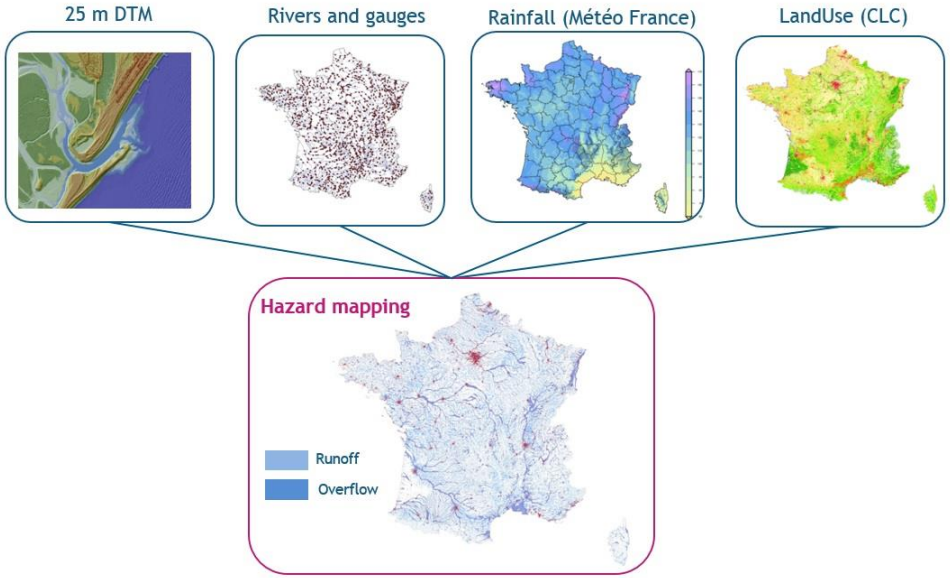
The CCR flood model

- Riverine and flash flood modelling
- Flood Model calibrated on 1999 – 2019 major events
- Overflow model: flow and water level simulation (gauged main rivers)
- Runoff model: for the non-gauged rivers
- CCR flood model outputs : 25 m resolution

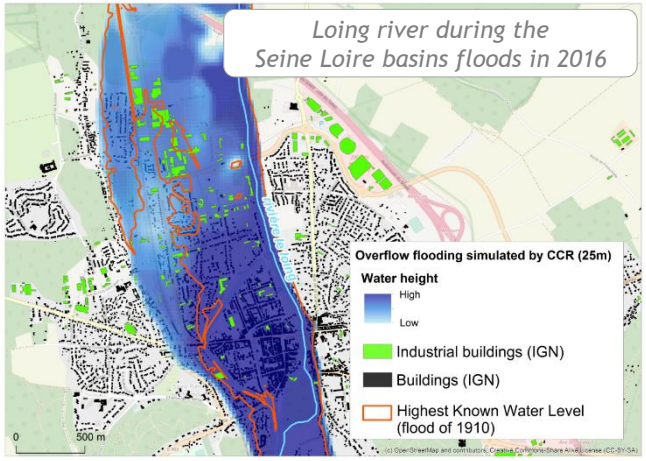
- Simulation results (hazard and insurance damage estimation) provided to CCR's clients and public authorities, minimum at D+5



25m simulated runoff and overflow for the Aude 2018 event



CCR's 25 m flood model input/output data



25m simulated overflow for the Seine Loire 2016 event

Main EO-data benefits for the (re)insurance industry

Main EO-data benefits for the (re)insurance industry

Hazard extent
and claim areas
Delimitation

Direct damage
Quantification
Rebuilt
Monitoring

Ex-post
Cross-validation

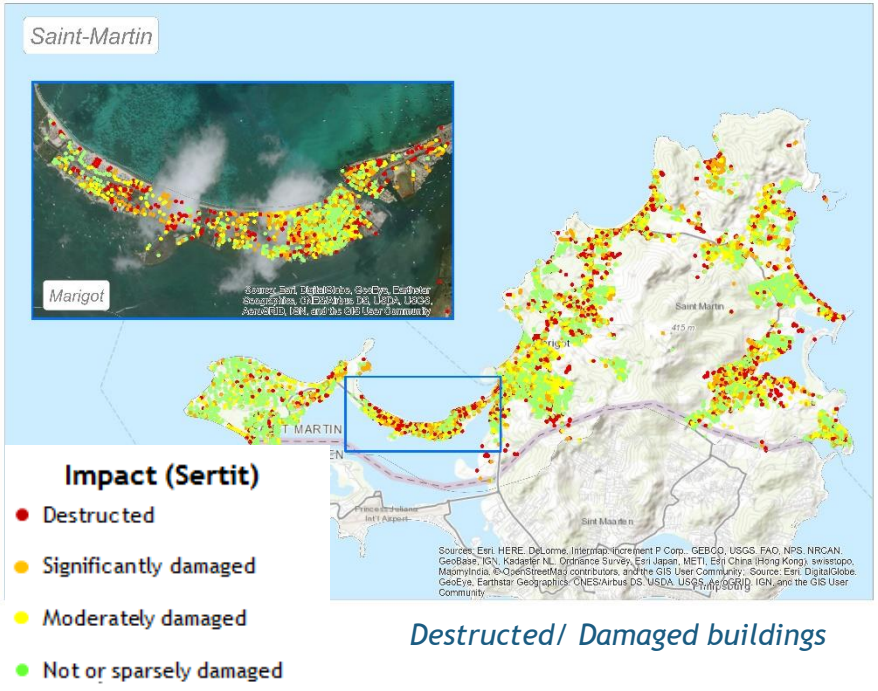
Ex-ante
Cross-validation

EO-data

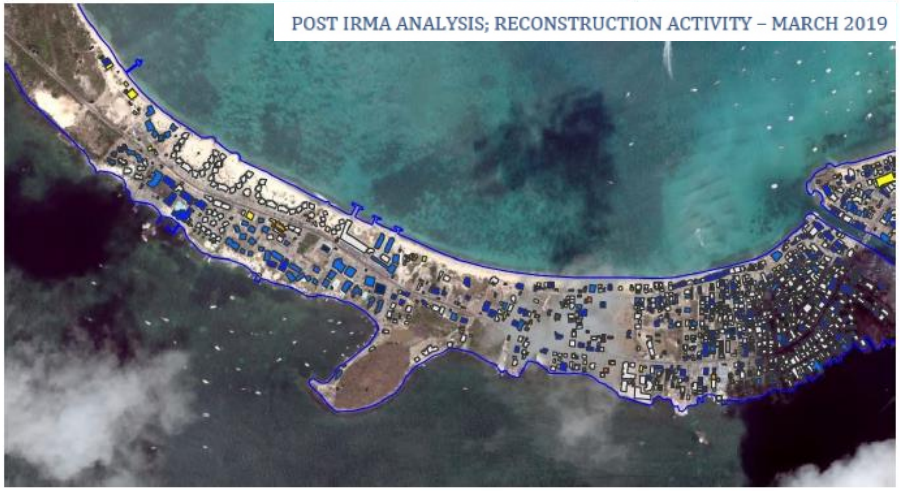
Indirect insured values
Measurement

Residential industrial
goods vulnerability
Evaluation

Hurricane Irma in September 2017 : post-event evaluation and reconstruction monitoring



Destructed/ Damaged buildings



Rebuilt delays

sertit

Damaged buildings identification (Sertit)

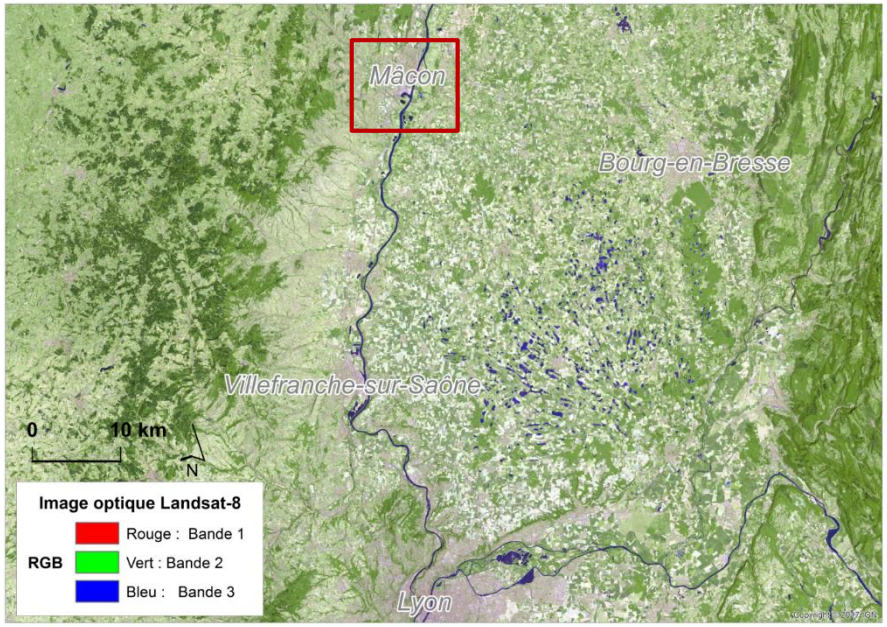
opernicus Europe's eyes on Earth

Reconstruction monitoring in St Martin and St Bart. from 2017 to 2019 (EMS Copernicus)

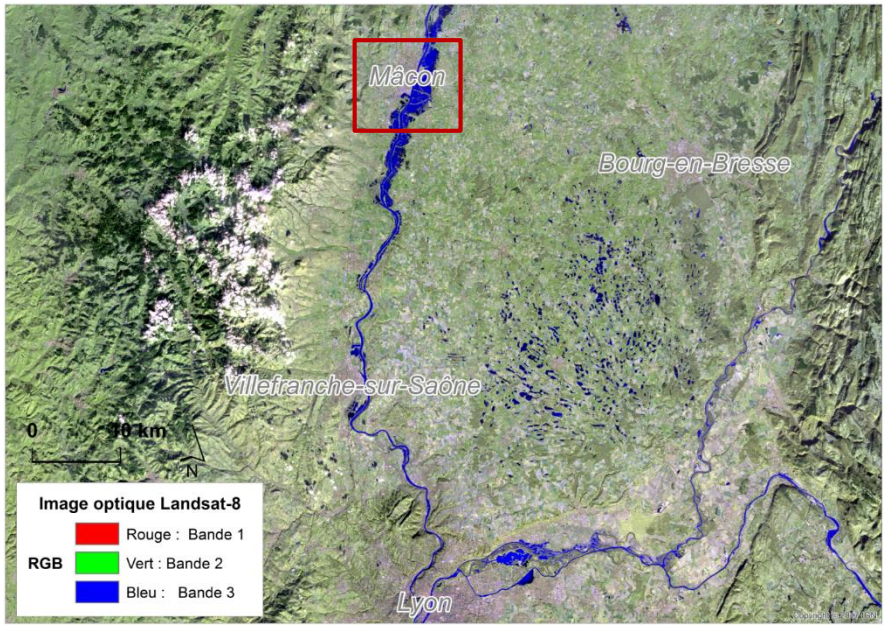
Landsat Multispectral imagery
Saône flood extent mapping in January/February 2018

Landsat-8 © USGS

Before - July 2017

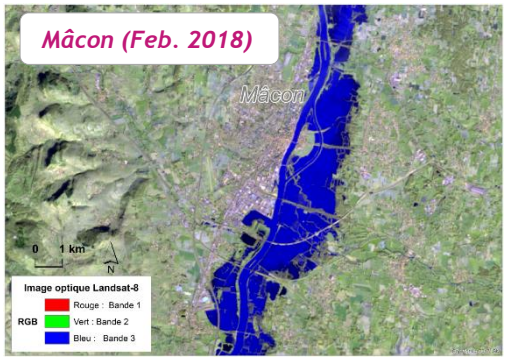


Event D+1 - February 2018



Mâcon (July 2017)

Mâcon (Feb. 2018)

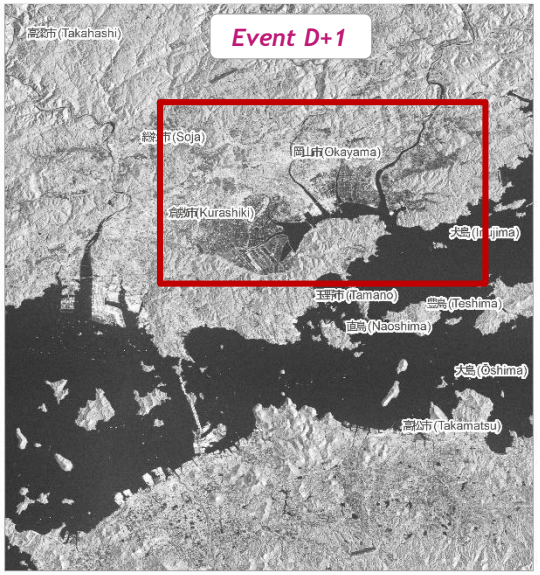


- Flood extent delineation (30 m resolution)

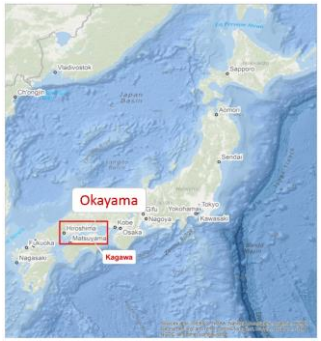
Sentinel-1 SAR imagery
Japan floods July 2018

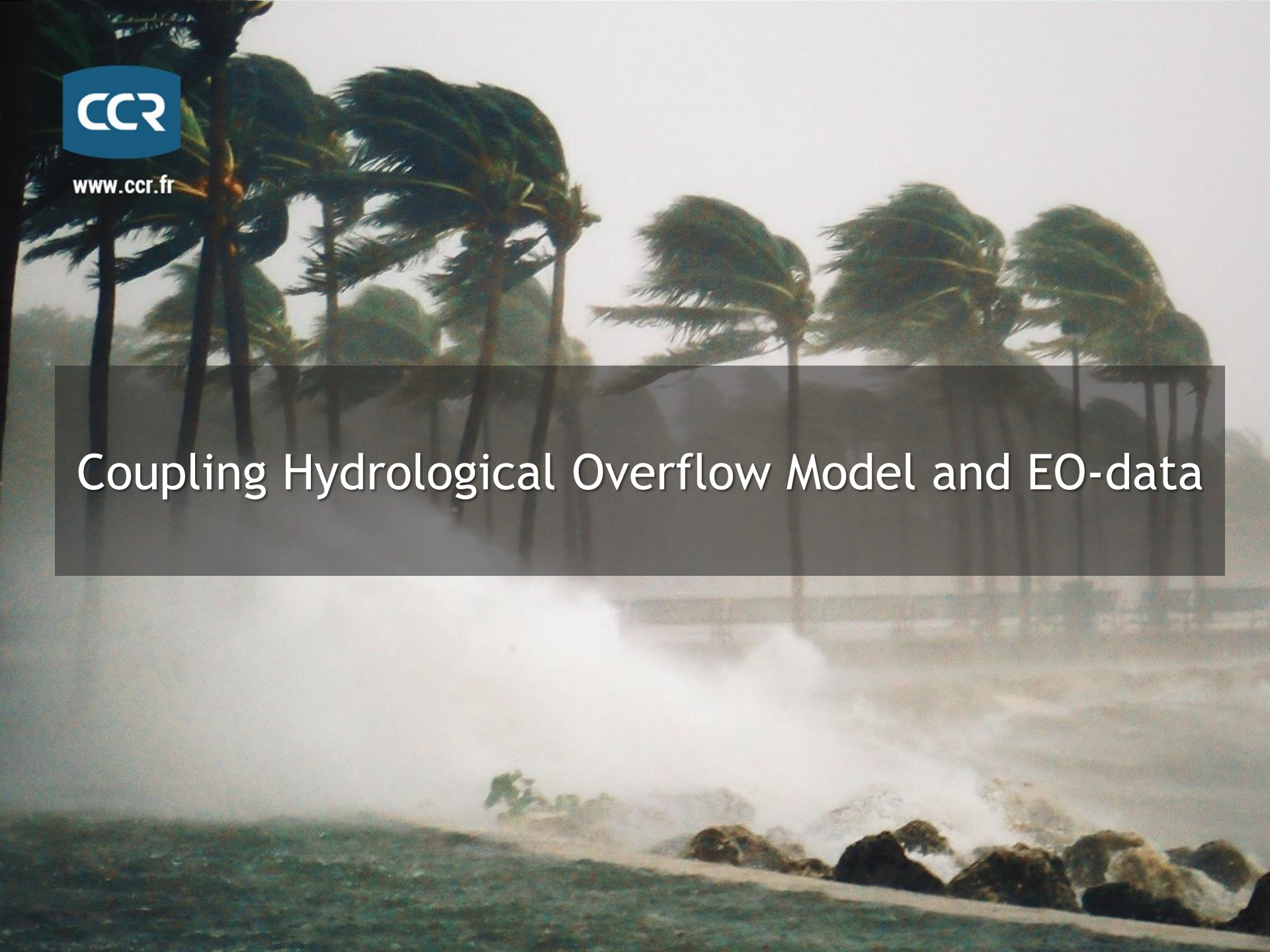
Landsat-8 © USGS **multi-spectral optical imagery**

Sentinel-1 SAR © ESA
SAR radar imagery



- July 2018 major floods in Okayama (Honshu - Japan)
- Near 50 % cloud cover on the Landsat-8 multispectral imagery :
  Flood extent precise mapping with Sentinel-1 SAR radar imagery





Coupling Hydrological Overflow Model and EO-data

Coupling Hydrological Overflow Model and EO-data

- Between 1995 and 2020, more than one hundred significant floods has been recorded in France (CCR Ceres - 2019)

- Nowadays, flood related EO-data, mainly ESA and USGS radar and optical imagery from 10 to 30 m resolution, can be freely downloaded. Remote sensing methods and algorithms can be performed via dedicated EO-data applications and softwares such as ESA SNAP, ENVI, ArcGIS Pro, Google Earth Engine, …

- Each year, flood events occur and CCR hazard and damage simulation results have to be validated shortly after an event (at D+2 / D+3)

- EO-data, notably satellite imagery, enable to precisely delineate flood extents, especially for riverines floods. Flood remote sensing can contribute to the overflow hazard result enhancement and cross-validaton

- Flood extents produced by remote sensing water extraction methods can be merged with hydrological models simulated extents and contribute to operational damage estimation

- As such, by coupling hydrological model outputs and flood remote sensing methods, simulated hazard and damage estimation can be completed and enhanced

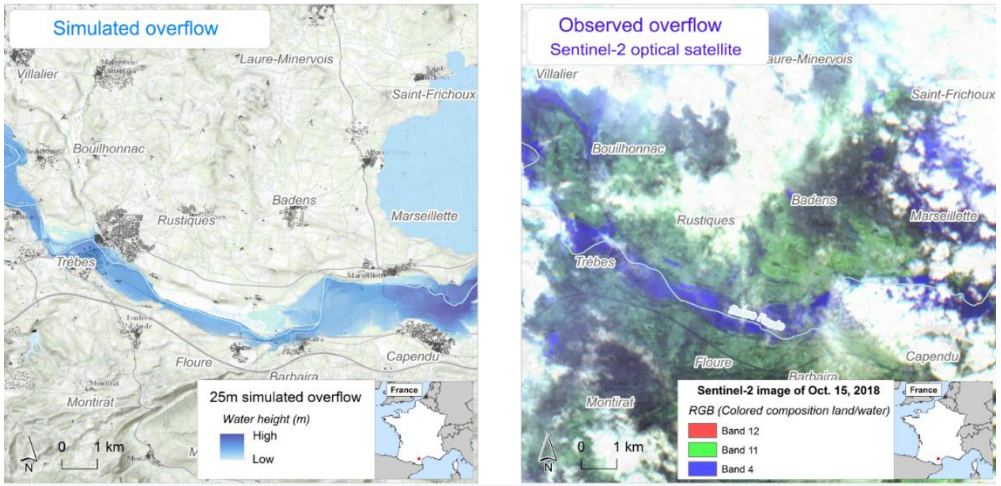
Flood remote sensing for 2016 and 2018 main events in France

- In 2019, an intern (Anas Nassih) from Ecole Nationale des Sciences Géographiques (ENSG) has evaluated the potential benefits of flood remote sensing methods on hazard and damage estimation for 3 major floods that occurred in France from 2016 to 2018

Event	Seine Loire 2016	Seine Marne 2018	Languedoc 2018
Insured losses	900 to 1200 € millions	180 to 220 € millions	250 to 300 € millions

Insured losses estimated by CCR for the French insurance market

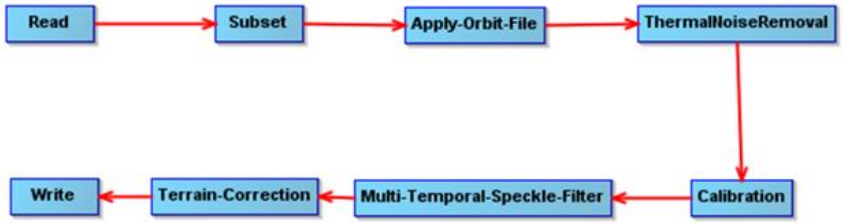
- Events studied : Languedoc floods in October 2018, Seine and Marne basin floods in January/February 2018 and Seine and Loire basin floods in May/June 2016 : 3 major riverine floods



Languedoc 2018 simulated (CCR) and observed (ESA Sentinel-2) Aude river overflow

Languedoc 2018 floods

Inundated areas remote sensing with ESA Sentinel-1 SAR radar imagery

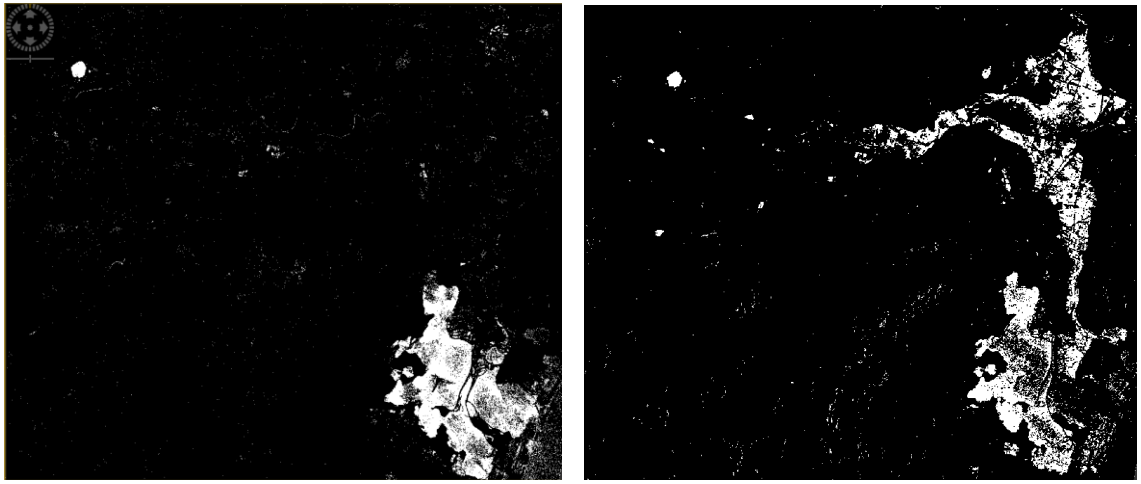


Sentinel-1 SAR ESA SNAP automated workflow

- Sentinel-1 SAR pre-processing workflows achievable with ESA SNAP, ENVI, …

Before the event *(04/10/2018)*

Event D+1 *(16/10/2018)*



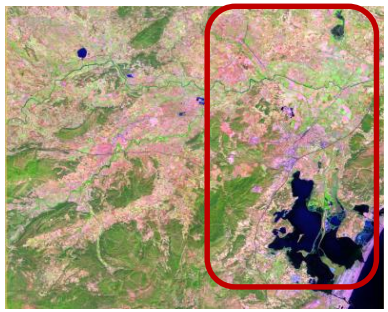
ESA SNAP screenshots

- Radiometric thresholding method (*Twele et al., 2016*)
- Effective water/non –water discrimination

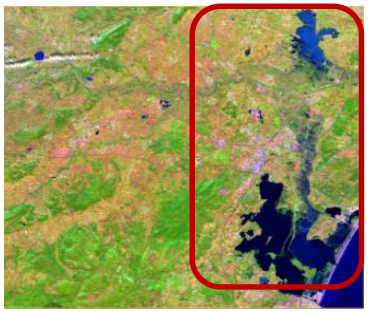
Languedoc octobre 2018

After a study of the existing water extraction index, NDWI and MNDWI indexes have been computed with ESA Sentinel-2 pre and post event imagery :

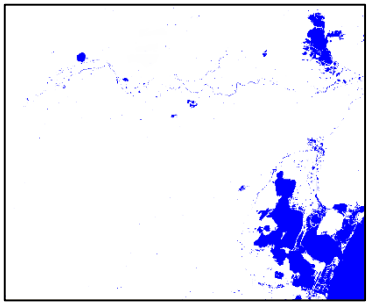
NDWI (Normalized Difference Water Index. Mc.Feeters, 1996): $NDWI = \frac{pGreen - pNIR}{pGreen + pNIR}$



16/08/2018 ***before***



20/10/2018 ***D+5***



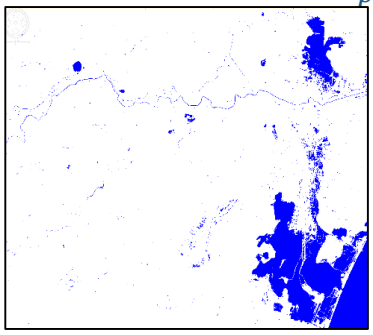
NDWI

Inundated areas: **25,8 Km²**

MNDWI (Mofified Normalized Difference Water Index. Xu and al., 2006): $MNDWI = \frac{pGreen - pSWIR1}{pGreen + pSWIR1}$

16/08/2018 ***before***

20/10/2018 ***D+5***



MNDWI

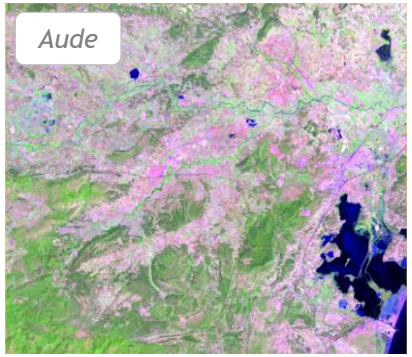
Inundated areas **42,4 km²**

Choice of the MNDWI:

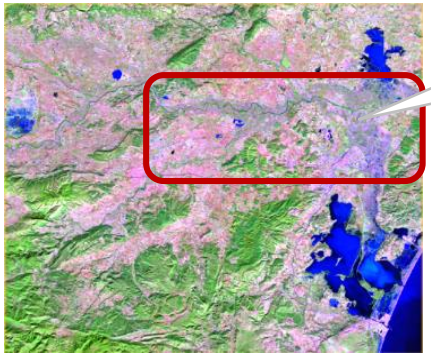
- Better water features delineation
- Effective water /non water discrimination

Languedoc octobre 2018

Inundated areas delineation with USGS Landsat- and 8 Random Forest supervised classification (*Ho et al., 1995*). Water marks visible at event D+8 (Landsat-8 SWIR colored composition). It appears necessary to perform a supervised classification to map the event maximum water level area



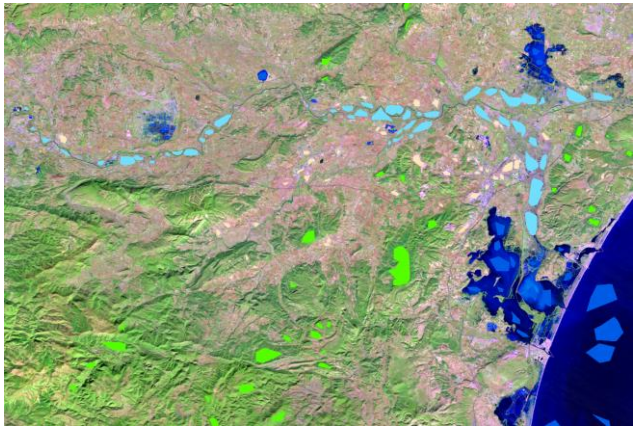
19/07/2018 ***before***



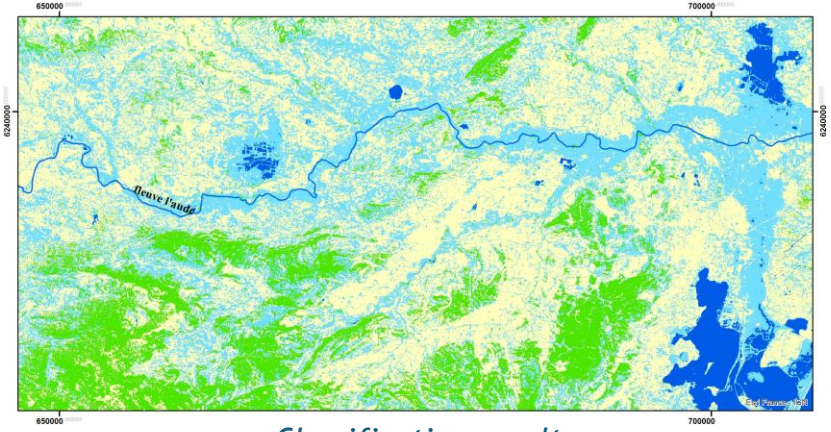
23/10/2018 ***D+8***

4 categories classification (cf. learning areas):

- Visible water
- Humid areas (2018 flood extent)
- Vegetation (forest and schrubs)
- Agriculture *and built areas*



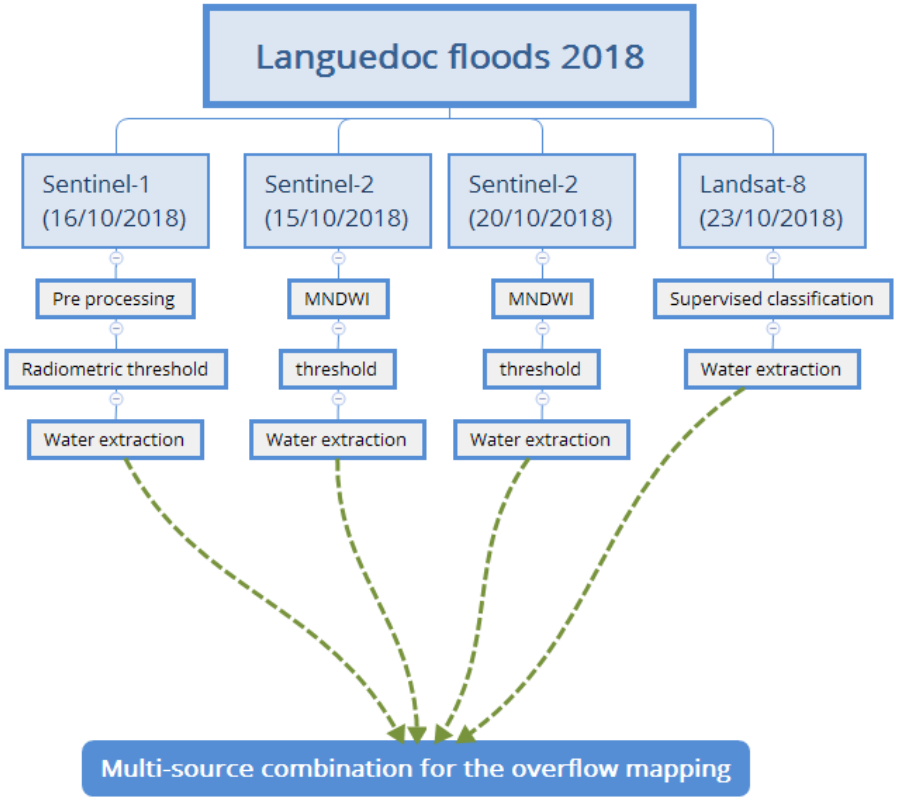
Learning areas (shapefiles)



Classification results

Confusion matrix :
Kappa index = 97.7%

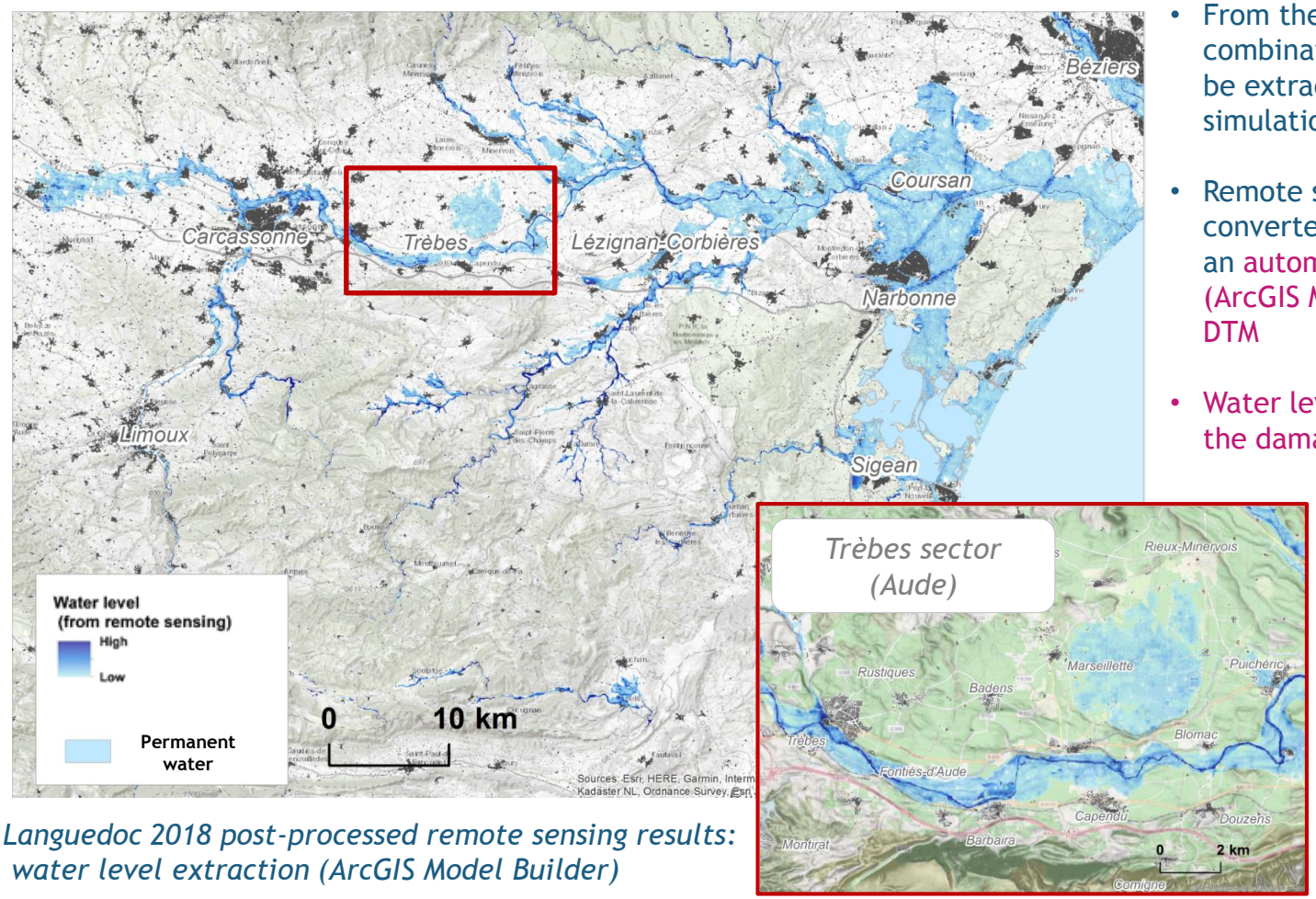
Languedoc octobre 2018



Languedoc 2018 event adopted approach plan

A multi-source approach for an exhaustive overflow mapping of the event

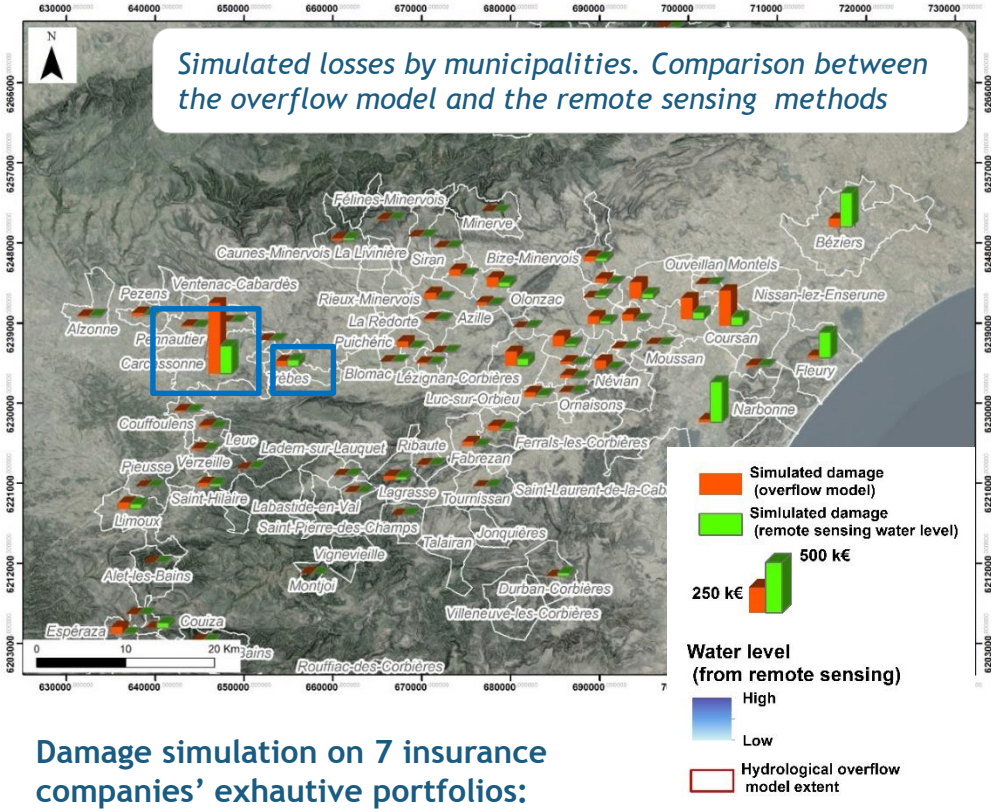
Languedoc octobre 2018

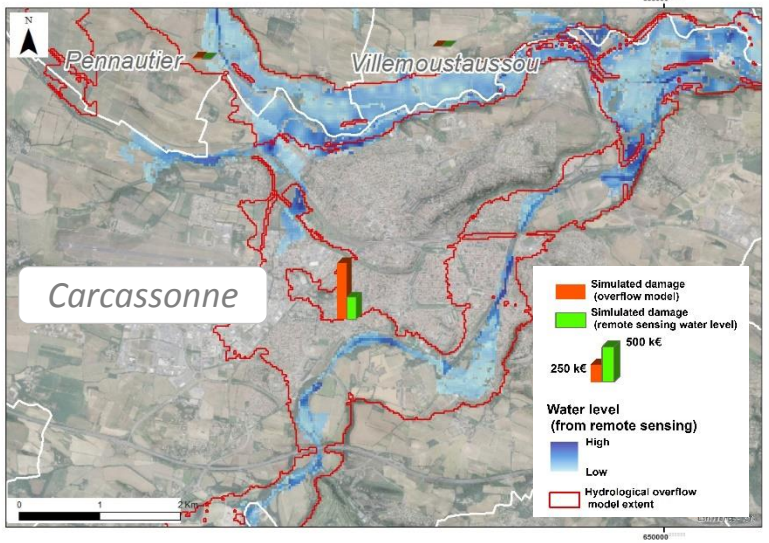


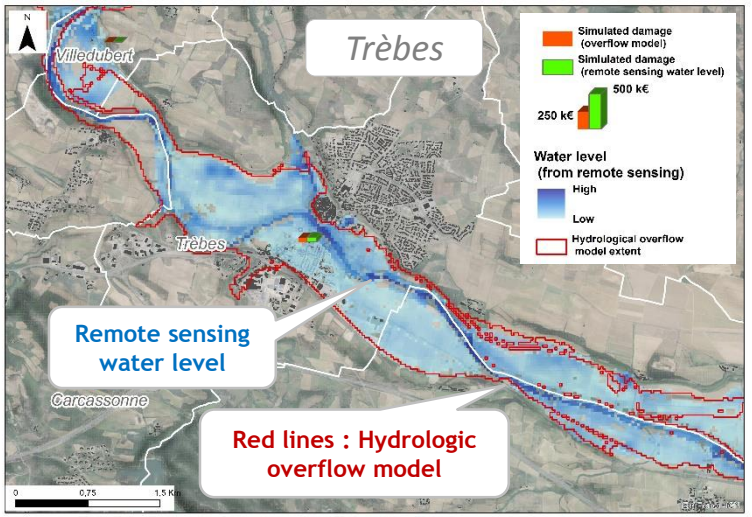
Languedoc 2018 post-processed remote sensing results: water level extraction (ArcGIS Model Builder)

- From the remote sensing multi-source combination map, water level has to be extracted for flood damage simulation purposes
- Remote sensing observed hazard is converted into water levels (in m) with an automated GIS extraction method (ArcGIS Model Builder) from the 25 m DTM
- Water level : an essential input for the the damage simulation model

Languedoc octobre 2018







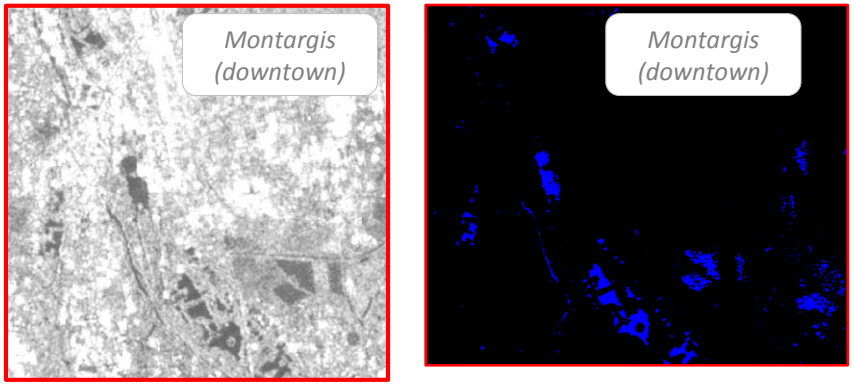
Damage simulation on 7 insurance companies' exhautive portfolios:

- Hydrological model's damage estimation : **3.8 € millions**
- Post remote sensing damage estimation : **3.6 € millions**

- Damage difference main explanation: water extent/level difference between the hydrological overflow model and remote sensing methods

Seine Loire basins floods in May/June 2016

- Sentinel-1 SAR exploitation for the Seine Loire 2016 overflow mapping
- Too much cloud cover on the multi-spectral imagery for that event



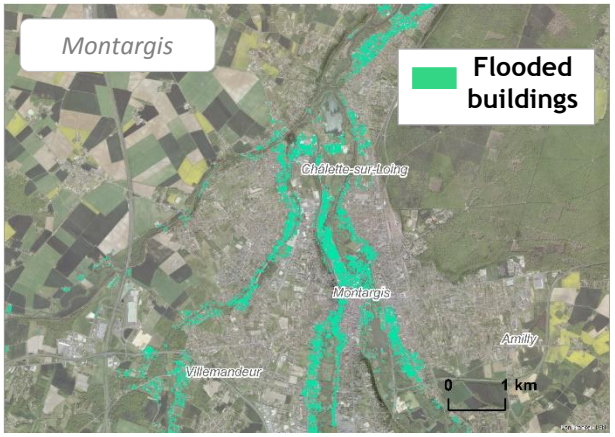
Sentinel-1 radiometric thresold in donwtown Montargis

- Effective water extraction over open areas with Sentinel-1
- Difficulties in dense built-up areas and cities downtown
- Interferometric coherence method utilisation (Chini and al., 2019) to discriminate flooded buildings from no-flooded buildings in dense built-up areas

2 dates :

19/05/2016
before

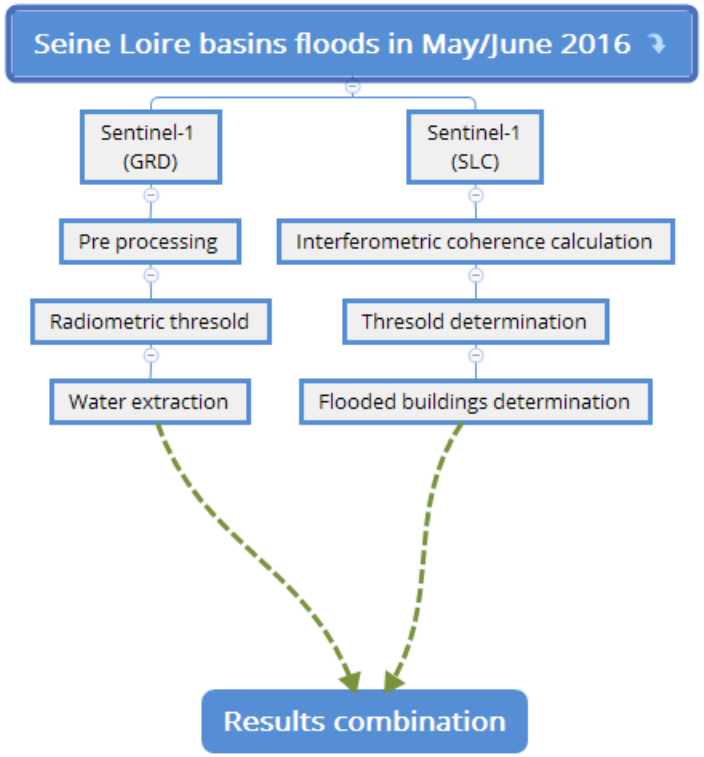
31/05/2016
D0



Interferometric coherence results in donwtown Montargis

- Interferometric coherence method is a cross-correlation between 2 images (one before, one during the flood)
- The method provides infomation on a surface stability over time. Values between 0 et 1 (very near 1 for the buildings normaly)
- During a flood, building's coherence value decrease from 0.6 to 0.5 (optimal thresold for the 2016 event is near 0.5/0.55)
- The method was validated ex-post with the event geolocalised claim data (near 10 000 claims avaible in 2019)

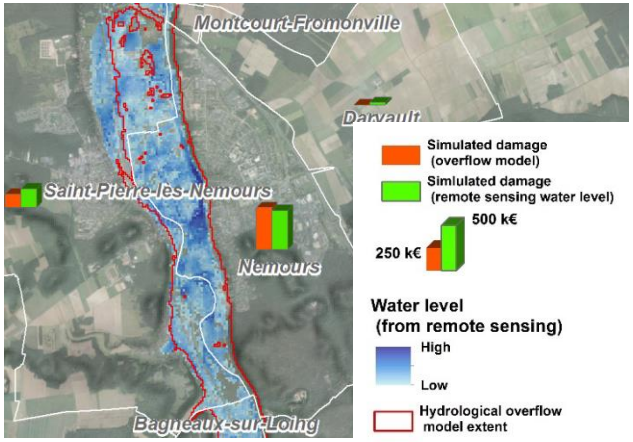
Seine Loire basin floods in May/June 2016

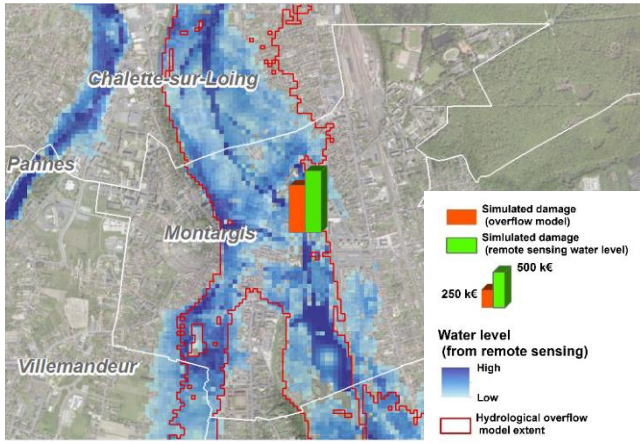


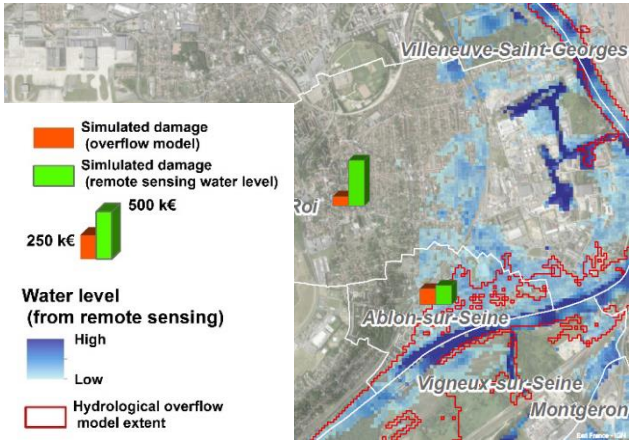
Seine Loire 2016 event adopted approach plan

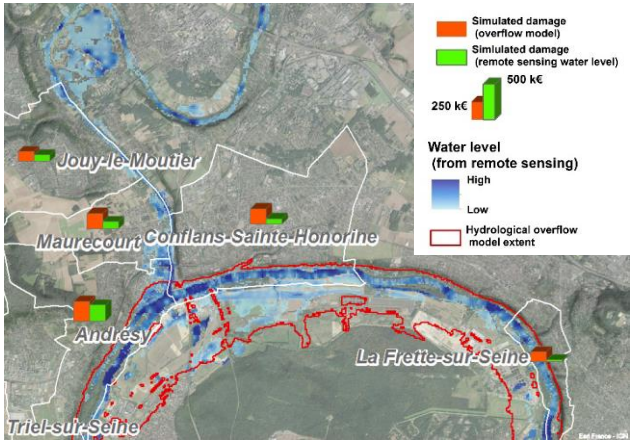
2 Sentinel-1 SAR methods combined for the event overflow mapping

Seine Loire basins floods in May/June 2016









Damage simulation on 7 insurance companies' exshautive portfolios:

Hydrological overflow model damage: **13 € millions**

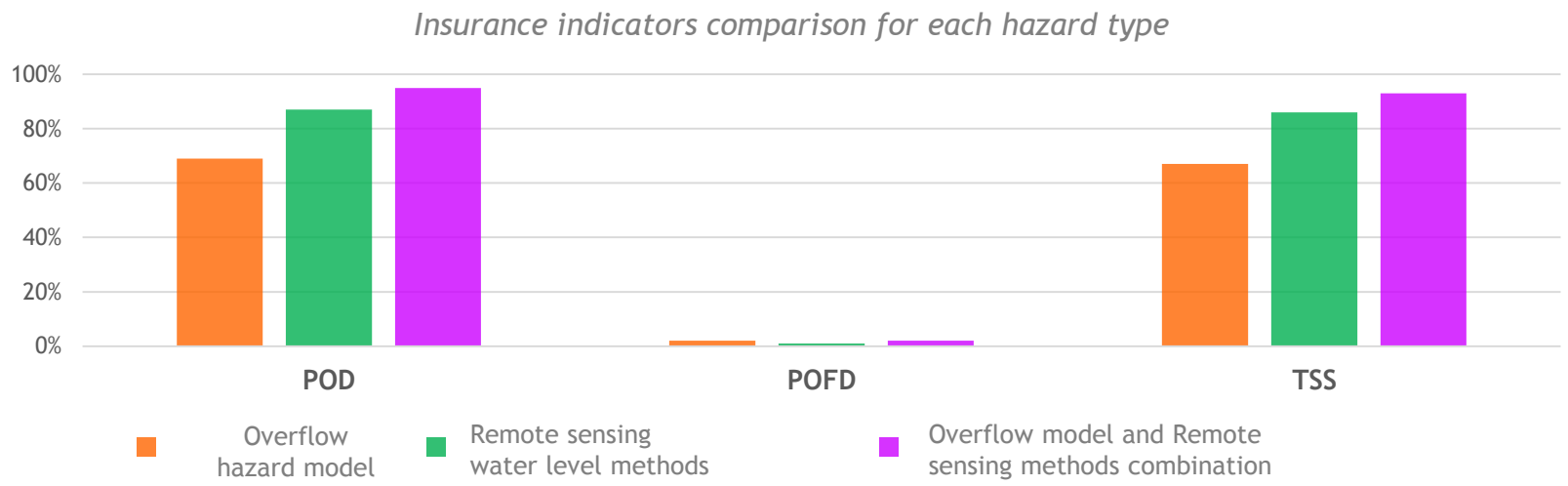
Remote sensing water level damage : **22 € millions**

Again, the damage difference is explained by water extent and water level differences between the 2 hazard types

Simulated losses by municipalities comparison according to the hydrological overflow model (orange) and the post remote sensing water levels (green)

Seine Loire basin floods in May/June 2016

- The 2016 floods, studied in 2019 were an important event to validate the remote sensing methods which we tabled previously
- Indeed, the number of geolocalised claims data avaible 3 years after this event allowed us to perform an ex-post cross-validation. To that end, near 10 000 geolocalised claims has been used
- To following chart present insurance indicators genreally used to evaluate the precison of an hazard model
- POD from 69 % (overflow model) to 87 % (remote sensing methods) and 95.4 % for the 2 hazard type combination. The True Skill Score is at 93 %



- Probabilty of detection (POD) : % of geolocalised claims in the water extent on the total number of the event claims
- Probabilty of false detection (POFD) : % of geolocalised insured policies in the water extent but have never been flooded
- The True Skill Score (TSS) : (POD – POFD). This final score enables to measure the efficiency of an hazard model

Major findings and perspectives

Major findings and perspectives

- Remote sensing methods have been explored in order to obtain the best possible results for each studied event
- Multi-source EO-data can be used to rapidly delineate riverines floods extent
- Remote sensing of riverines floods extent and floodplain delineation are efficient and well documented
- Insurance indicators such as POD, POFD, True Skill Score for both CCR overflow model and remote sensing data model were calculated and the benefits of this methodology has been verified
- The systematic EO-data integration as a complement to an hydrological model allows to complete the simulated hazard and enhance the damage estimation
- Remote sensing studies will eventually be extended to others Nat Cat hazards

Limitations encountered

- Image unavailability for events at D0 or D+1 (cloud cover, revisit times, …)
- Flashs flood and runoff hazard extents stays hard to extract with remote sensing methods. Indeed, the speed of such phenomena makes them difficult to be observed in the next few hours after their occurrence
- The use of a unique thresold for a vast flood event may cause misclassification errors (water/non-water errors)
- Vegetation cycle and activities on ground (cars/truks movements, material deposits,…) may cause false detection especially for the Interferometric coherence method. Results extraction only in buildings footprints is a good solution.
- VHR (Very High Resolution) EO-data (near 1m resolution) stays hard to access

References

Moncoulon, D., D. Labat, J. Ardon, E. Leblois, T. Onfroy, C. Poulard, S. Aji, A. Rémy, and A. Quantin. 2014. “Analysis of the French Insurance Market Exposure to Floods: A Stochastic Model Combining River Overflow and Surface Runoff.” Natural Hazards and Earth System Sciences

Nassih, A. 2019. “Apports de l’imagerie satellitaire dans la caractérisation des inondations en France : cartographie de l’aléa et estimation des dommages.” Rapport de stage. Paris, France: Caisse Centrale de Réassurance/ENSG M2 IGAST.

Boni, G. et al., 2009. The OPERA project: EO-based flood risk management in Italy, Geoscience and Remote Sensing Symposium, 2009 IEEE International,IGARSS 2009: 929-932.

Baig, M.H.A., and al. 2013. Comparison of MNDWI and DFI for water mapping in flooding season. IEEE International Geoscience and Remote Sensing Symposium

Rosser, J.F., Leibovici, D.G., Jackson, M.J., 2017. Rapid flood inundation mapping using social media, remote sensing and topographic data. Naturel Hazards: 103-120.

Twele, A., Cao, W., Plank, S., Martins, S., 2016. Sentinel-1-based flood mapping: a fully automated processing chain. The International Journal of Remote Sensing.

Chini, M., Pelich, R., Pulvirenti, L., Pierdicca, N., Hostache, R., 2019. Sentinel-1 InSar Coherence to Detect Floodwater in Urban Areas: Houston and Hurricane Harvey as a Test Case. Remote Sensing

Xu et al. 2006. *"Modification of Normalized Difference Water Index (NDWI) to Enhance Open Water Features in Remotely Sensed Imagery"* International Journal of Remote Sensing

Hanssen, R. F., 2001. *"Radar Interferometry - Data Interpretation and Error Analysis"*, 308 pp., Kluwer Academic Publishers, Dordrecht, The Netherlands

Landis et al. 1977. The Measurement of Observer Agreement for Categorical Data. International Biometric Society

Thomas Onfroy tonfroy@ccr.fr

Pierre Tinard ptinard@ccr.fr

Anas Nassih anasnassih93@gmail.com

CCR Réassurance

@CCR_Reassurance

CCR Réassurance

CCR ™
Caisse Centrale de Réassurance
157 boulevard Haussmann 75008 Paris - France
Tél. : +33 1 44 35 31 00 - http://www.ccr.fr
SA au capital de 60 000 000 € - 388 202 533 RCS Paris

www.ccr.fr

Disclaimer

This presentation and all the content hereof (including text, publications, images, photographs and graphic or cartographic elements) are the exclusive property of CCR or of third parties having expressly authorised their use.

Any reproduction, representation or use of all or any part of the presentation is expressly prohibited, unless CCR's prior written consent has been obtained.

The content of the presentation is strictly for information purposes only and has no contractual value.

CCR accepts no responsibility for any direct or indirect loss or damage, whatever the cause or nature, associated with the presentation and incurred because of the use or possible inaccuracy of the information contained in the presentation.