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Pluvial flood detection using satellite remote sensing and machine learning techniques for the evaluation of surface runoff susceptibility mapping

ONERA THE FRENCH AEROSPACE LAB
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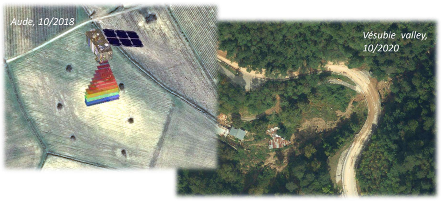
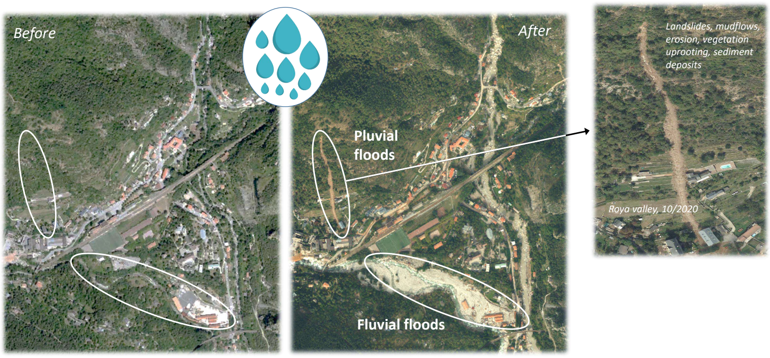
1. Context

- **Pluvial floods (PFs, or Surface Water Floods, SWFs):** floods happening independently of an overflowing water body, as opposed to fluvial floods (FFs)
- Caused by **extreme overland flow of rainwater** after short-term high intensity precipitation events
- PFs account for **half of all flood damage claims** each year, equally with FFs
- Need to **comprehensively evaluate PF susceptibility models** using observational data
- But PFs can appear anywhere and take many different forms: ***in-situ* data are thus scarce**

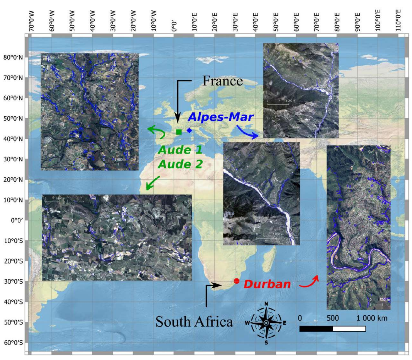
➔ With both very high spatial resolution (VHR) and frequent revisit, satellite remote sensing now offers a new opportunity to automatically and exhaustively detect PFs after heavy weather events, allowing for evaluation of runoff models



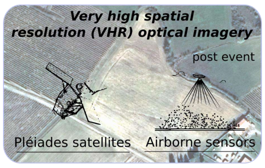


2. Materials and Methods

3 study sites in the South of France and on the Eastern shore of South Africa during **4 flash-flood events** (2018 – 2022)



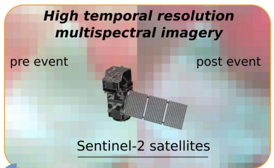
Idea: Combine post-event satellite (or airborne when available) imagery at very high spatial resolution for precision (< 1 m) to high temporal resolution instruments for accurate change detection (~ 5 days)



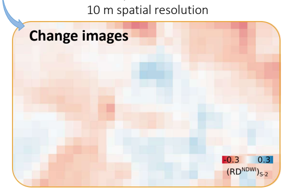
Pléiades satellites	Airborne sensors
Optical (R, G, B, NIR)	Optical (R, G, B)
On-demand acquisition	Flight campaign
0.5 m spatial resolution	0.1 m spatial resolution

Reference data

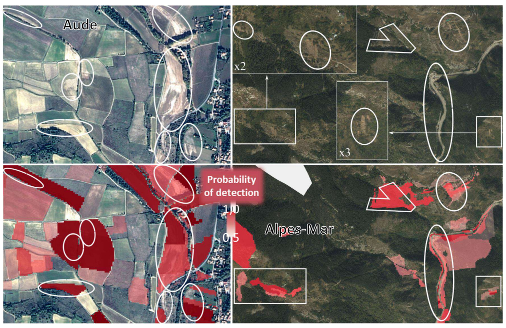
1) Ground truths retrieval (damage claims, field missions, external impact maps for Durban);
2) Manual photo-interpretation of VHR products (except for Durban study area).



Optical (R, G, B, NIR, SWIR)
5 days revisit time
10 m spatial resolution



3. Results: Two ML/DL detection methods and evaluation of the IRIP© runoff model

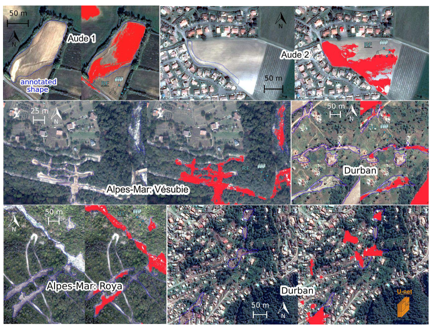


SPCD (Sentinel Plot-based Change Detection)

- Object-based Gaussian Process classifier
- Plot statistics on the time variations of spectral indices (= NDWI, SAVI, VV etc.)

sentinel-2 — Optical (R, G, NIR, SWIR)
sentinel-1 — Radar (VV/VH)

Overall accuracy ≥ 85 %
False discoveries ≤ 13%

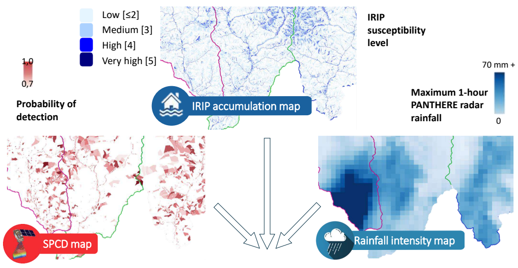


FuSVIPR (Fusion of Sentinel-2 and Very high resolution Imagery for Pluvial Runoff)

U-net
Random Forest

sentinel-2 — Optical (R, G, NIR, SWIR)
Pléiades — Optical (R, G, B)

Detection rates ≥ 75 %
False positives ≤ 2%



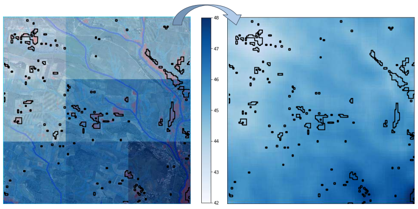
IRIP© model evaluation & improvement

(i) The greater the IRIP susceptibility scores, **the more PFs detected by SPCD**
Even larger proportions of damaged plots for areas **with heavier precipitations**
(ii) Negative relationship between mean IRIP accumulation scores and intensity of rainfall among damaged plots: **intense runoff is triggered at lower rainfall intensity thresholds over more susceptible areas**
(iii) **Higher weight of upstream topography** and **uphill runoff production areas** compared to local topography for explaining PF occurrence → towards improvements to IRIP©

4. Conclusions

This PhD overall confirms the **performance and transferability of 2 satellite-based PF detection methods** called **SPCD** and **FuSVIPR**. It also highlights **IRIP's relevance** to map susceptibility towards intense surface runoff.

Perspectives:
(i) **Downscaling of extreme precipitations** from radar measurements by informing rainfall stochastic simulators on the **distribution of PFs**.
(ii) Definition of **PF-triggering rainfall thresholds** according to **local susceptibility**.
(iii) **Improvements** to **IRIP©**



Peer-reviewed publications

- **Cerbelaud, A.,** Blanchet, G., Roupioz, L., Breil, P., Briottet, X., 2022. Mapping pluvial flood-induced damages with multi-sensor optical remote sensing: a transferable approach using change detection, very high spatial resolution and machine learning. ***Remote Sens. Environ.*** Under review.
- **Cerbelaud, A.,** Breil, P., Blanchet, G., Roupioz, L., Briottet, X., 2022. Proxy data of surface water floods in rural areas: application to the evaluation of the IRIP intense runoff mapping method based on satellite remote sensing and rainfall radar. ***Water*** 14 (3), 393.
- **Cerbelaud, A.,** Roupioz, L., Blanchet, G., Breil, P., Briottet, X., 2021. A repeatable change detection approach to map extreme storm-related damages caused by intense surface runoff based on optical and SAR remote sensing: evidence from three case studies in the South of France. ***ISPRS J. Photogramm. Remote Sens.*** 182, 153-175.
- **Cerbelaud, A.,** Favro, A., Roupioz, L., Blanchet, G., Briottet, X., Delvit, J.-M., Breil, P, 2020. Potentiel de l'imagerie optique satellitaire à haute résolution pour détecter les dommages engendrés par des épisodes pluvieux extrêmes. ***La Houille Blanche*** 6, 66-74. (French only).