Proxy data of surface water floods in rural areas: application to the evaluation of the IRIP intense runoff mapping method based on rainfall radar, satellite remote sensing and machine learning techniques

Pascal Breil, Arnaud Cerbelaud, Gwendoline Blanchet, Xavier Briottet, Laure Roupioz

Proxy data of surface water floods in rural areas: application to the evaluation of the IRIP intense runoff mapping method based on rainfall radar, satellite remote sensing and machine learning techniques

A. Cerbelaud[1,2,3], G. Blanchet[2], L. Roupioz[1], P. Breil[3], X. Briottet[1]

[1] Onera, DOTA, Université de Toulouse ; F-31055 Toulouse, France - arnaud.cerbelaud@onera.fr
[2] Centre National d'Etudes Spatiales (CNES), EO Lab ; 31400 Toulouse - arnaud.cerbelaud@cnes.fr
[3] Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement (INRAE), UR RiverLy ; 69100 Villeurbanne

Context

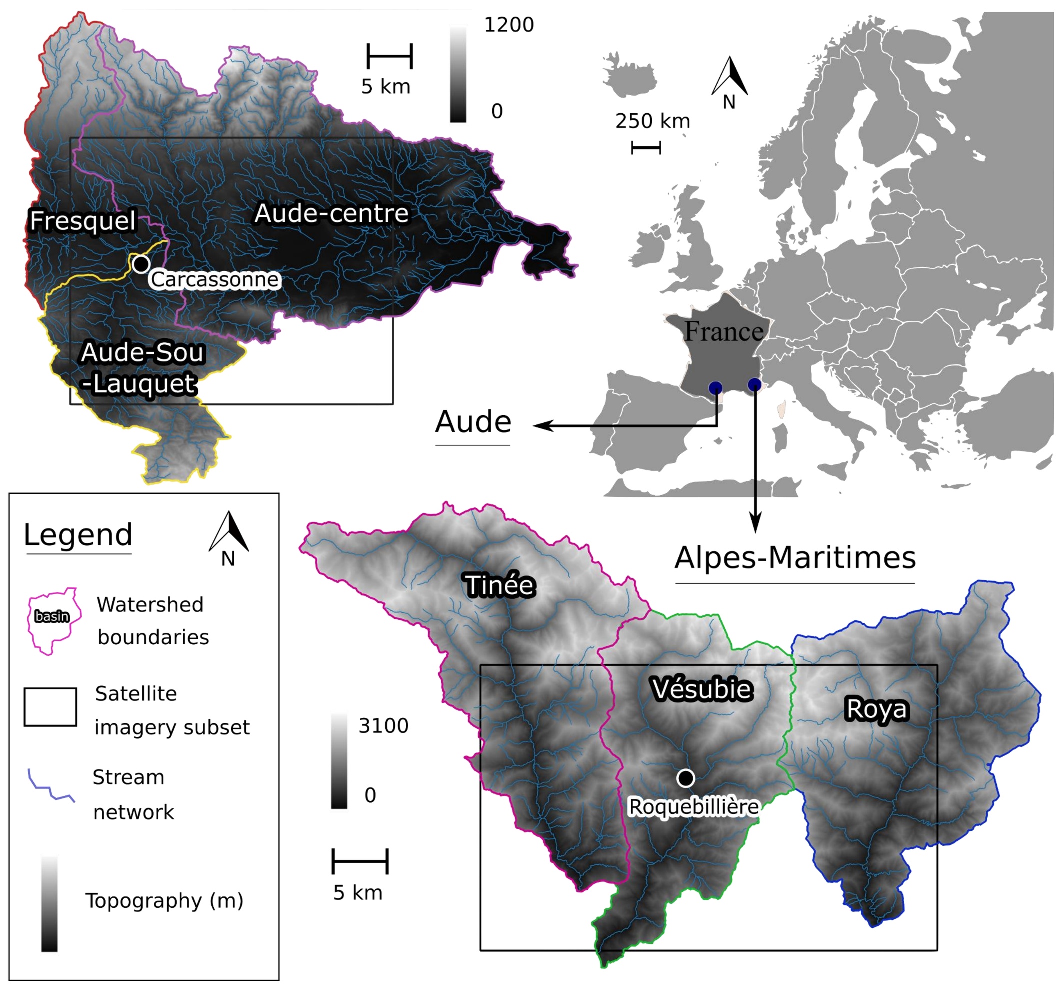
Surface water floods (SWFs) caused by extreme overland flow account for **half of all flood damage claims** each year, equally with fluvial floods. **Geomatics hydrological approaches** have been developed to easily map susceptibility towards intense surface runoff without explicit physical modeling. However, to be applicable for prevention purposes, they need to be **comprehensively evaluated using proxy data of runoff-related impacts**.

Intense surface runoff can potentially occur anywhere and often over short time periods. Consequently, it is **scarcely observed** and SWF proxy information are **rarely exhaustive**.

➔ **With high spatial resolution and frequent revisit, satellite remote sensing now offers a new opportunity to automatically and exhaustively detect SWFs after heavy weather events, allowing for evaluation of runoff models.**

Study areas

Six watersheds in the Aude and Alpes-Maritimes departments in the South of France are investigated over more than 2.000 km^2 of rural and periurban areas during three flash-flood events (2018 – 2020).



Materials and Methods

The **IRIP© hydrological geomatics mapping model**, or "Indicator of Intense Pluvial Runoff", is confronted with past extreme events for which **rainfall radar measurements** were acquired and **damage maps** were derived from **multispectral bi-temporal satellite imagery** (Sentinel-1 and 2) and **machine learning (ML) supervised classification algorithms**.

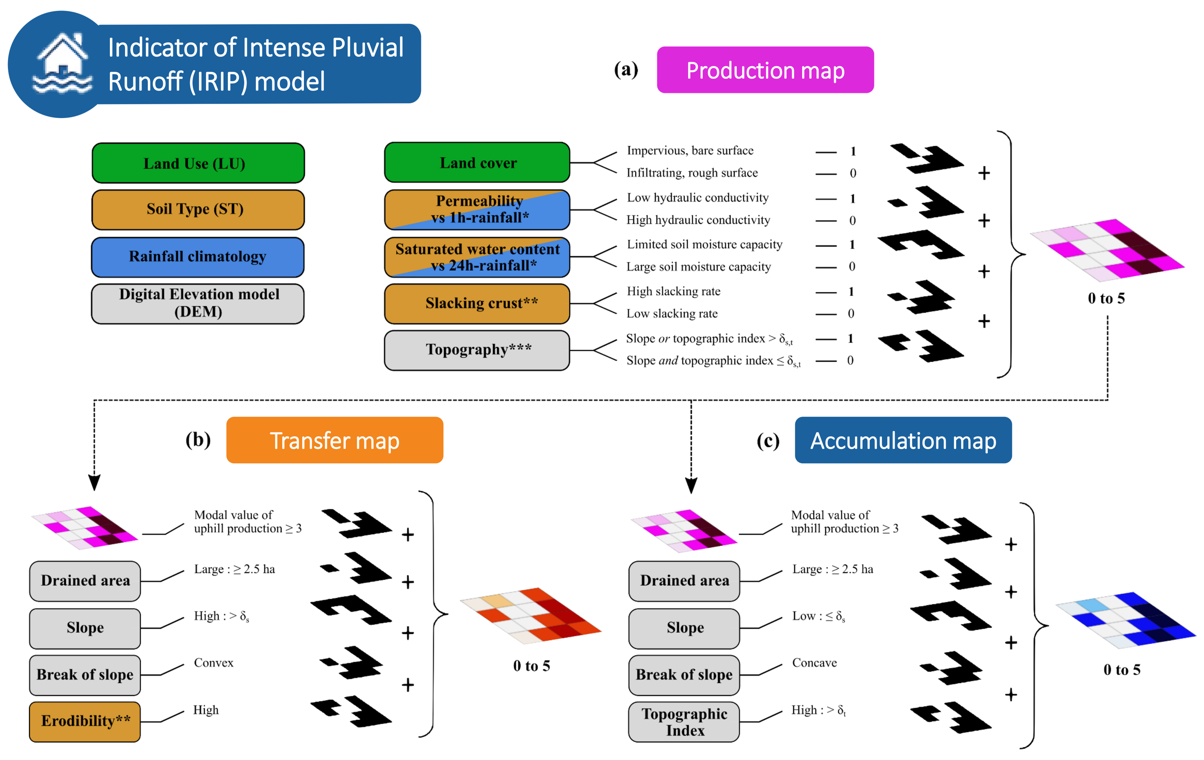


Figure 2: Framework of the IRIP method for generation of intense runoff susceptibility maps: (a) production, (b) transfer and (c) accumulation.

* "Permeability" and "Saturated water content" indicators are computed by comparing the values found respectively for the saturated hydraulic conductivity (K_s) and the saturated water content over the first 30 cm of the soil (θ_{sat}) (using ESDAC hydrodynamic characteristics) to the 30-year 1-h and 24-h rainfall intensities (30-year recurrence interval).
** "Slacking crust" and "Erodibility" indicators are computed according to Cerdan et al. using a soil texture triangle and a simple threshold (favorable to runoff if ≥3).
*** For topography indicators, slope and (Beven) topographic index are compared to thresholds δ_s and δ_t derived using a k-means clustering algorithm (k = 2).

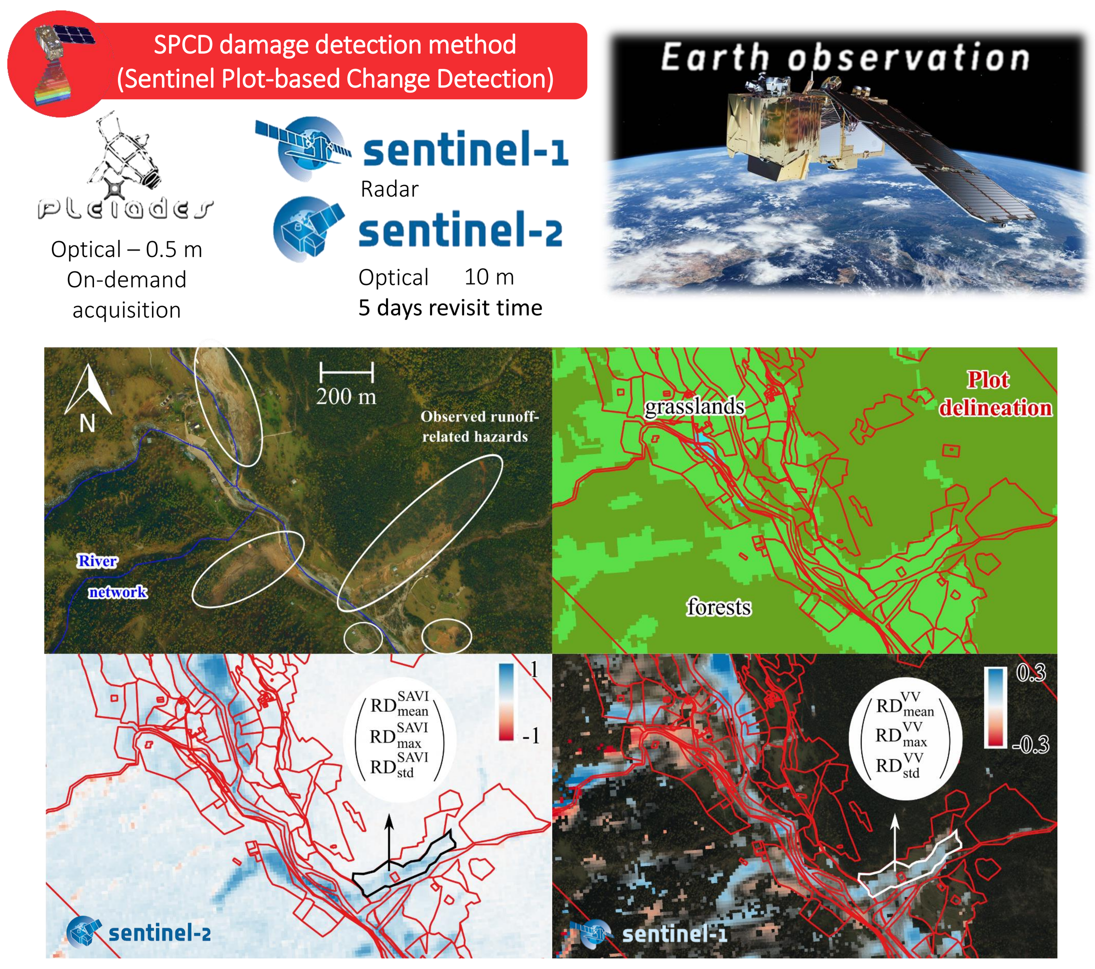


Figure 3: SWF damages caused by intense rainwater runoff following the "Alex" storm on Oct. 3, 2020. Classification strategy based on plot-specific change pixel statistics is displayed in the bottom images. Top left: IGN orthophotos Oct. 5, 2020, post event, with river network. Top right: OSO land cover on land cadastre. Bottom left: Sentinel-2 RD^{SAVI} Sept. 28 - Oct. 8. Bottom right: Sentinel-1 RD^{VV} where NDVI < 0.25, Sept. 26 - Oct. 8

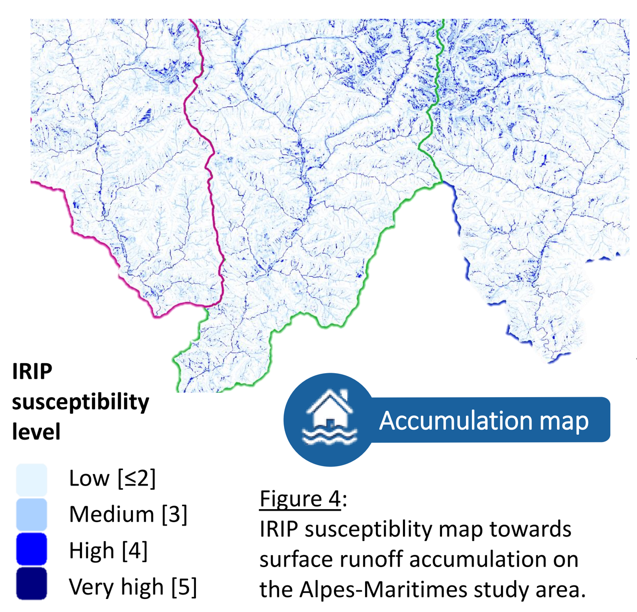


Figure 4: IRIP susceptiblity map towards surface runoff accumulation on the Alpes-Maritimes study area.

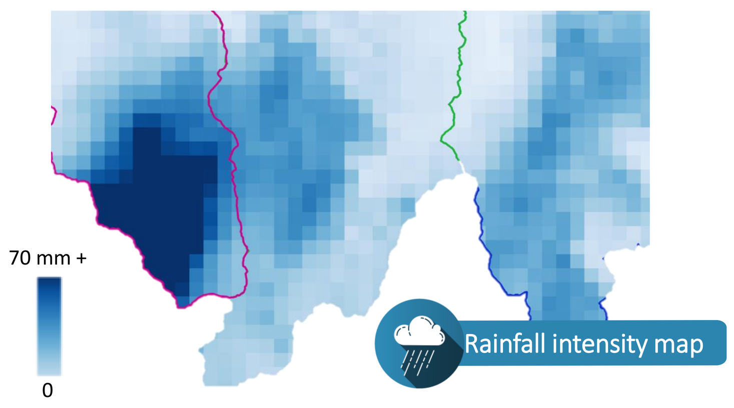


Figure 6: Maximum 1-hour quantitative precipitation estimation measured by PANTHERE radar products from *Météo-France* for the "Alex" storm (Oct. 2020)

(i) How well does the IRIP model predict SWFs?
(ii) Is there a rainfall intensity threshold that triggers SWF?
(iii) Which IRIP input indicator is the most relevant?
(iv) How can the model be improved?

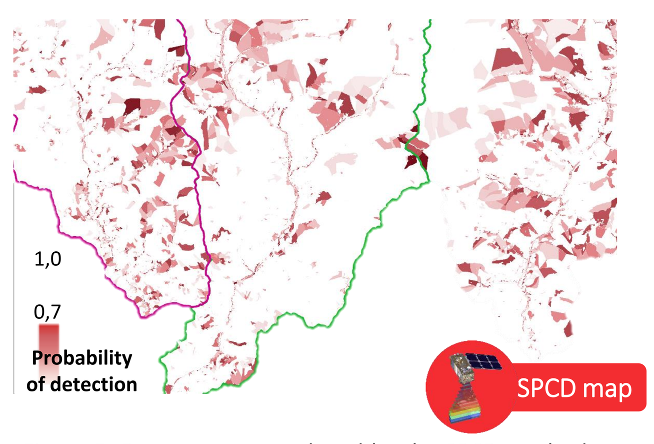
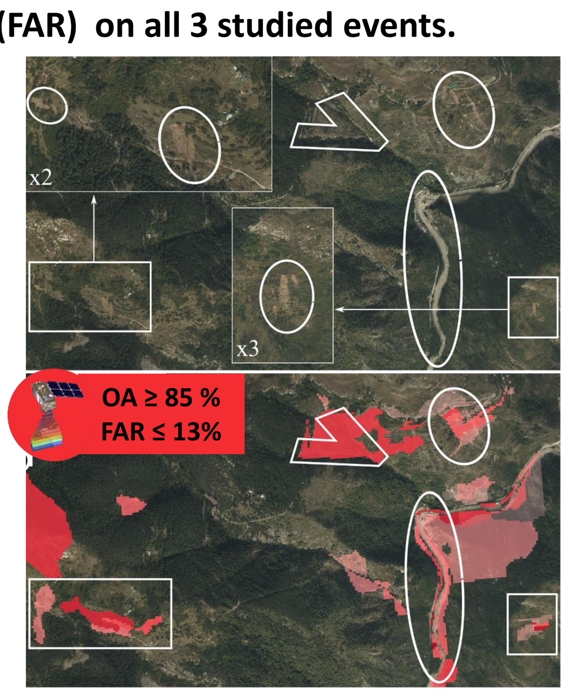


Figure 5: Damage map produced by the SPCD method on the Alpes-Maritimes 2020 event.

The color bar indicates the probability given by Gaussian Process Classifier (GPC) that a pluvial flood damage is detected (0.5 low confidence, 1.0 very high confidence). Both SWFs and FFs are identified in these maps.

Results

SPCD method: a Gaussian Process Classifier **trained only on one event** yielded a min. **85 % overall accuracy (OA)** and a max. **13 % false alarm rate (FAR) on all 3 studied events.**



(i) & (ii): The greater the IRIP susceptibility scores, the more SWFs are detected by the SPCD detection method. Proportions of damaged plots **become even larger** when considering areas which experienced heavier precipitations (35 mm.h^{-1} and more).

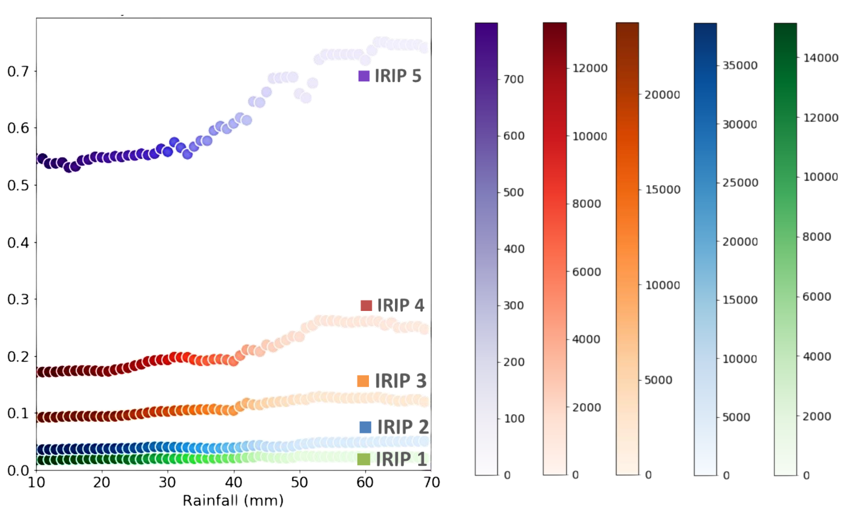


Figure 8: Ratio of SPCD-identified damaged plots among all plots featuring a given IRIP accumulation score. The X-axis represents the minimum threshold considered for rainfall intensity over 60 min. Color bars refer for each scatter point to the number of plots over which the ratio is computed.

A negative relationship between the mean IRIP accumulation scores and the intensity of rainfall is found among damaged plots, confirming that **SWFs preferably occur over potentially riskier areas where rainfall is lower.**

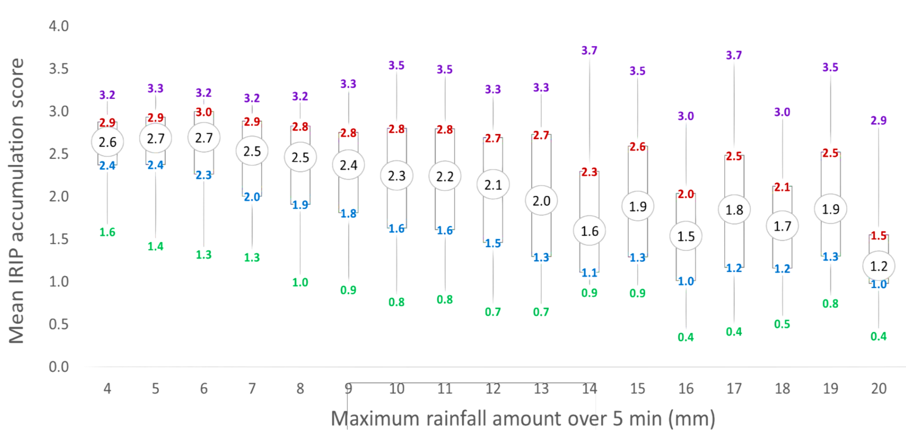


Figure 9: Mean IRIP accumulation scores of SPCD-identified damaged plots (5th, 25th, 50th, 75th and 95th percentiles) as a function of the maximum rainfall amount measured in 5 min (Aude and Alpes-Maritimes, ~19,000 plots).

(iii) & (iv): Multivariate logistic regression is used to determine **the relative weights** of **upstream and local topography, uphill production areas** and **rainfall intensity** for explaining SWF occurrence.

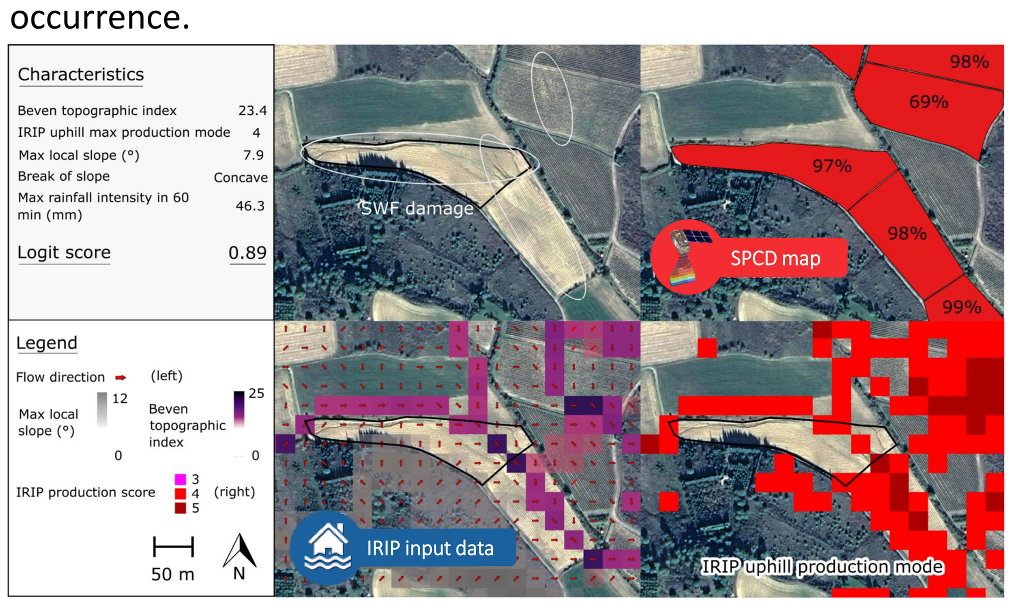
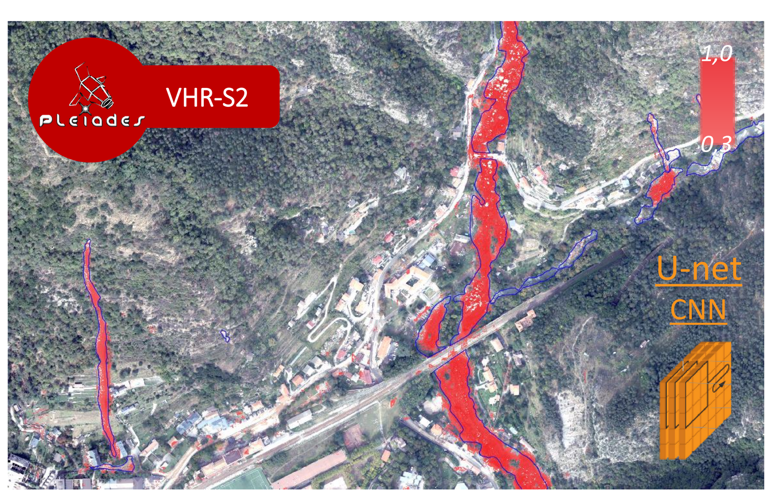


Figure 10: Examples of lands affected by SWFs with gullies in Aude. Top, from left to right: (1) panel indicating max rainfall intensity in 60 min, IRIP input data and resulting logit score on an affected plot; (2) Pléiades image from 3/11/2018 ; (3) probability of damage detection by SPCD method. Bottom left : Flow direction, local slope (°) and Beven topographic index (DEM-derived). Bottom right : IRIP uphill production mode used in the generation of IRIP accumulation map.

Conclusion and perspectives

This work overall confirms the **relevance of satellite-based SWF detection** and the **performance of IRIP methodology** while suggesting improvements to its core framework.

A second method, **VHR-S2**, has been implemented and is being tested. It uses **fusion of VHR post event imagery** (Pléiades, 0.5 m) with **bitemporal Sentinel-2 data** to provide an enhanced detection capability using **U-net** based convolutional neural networks (CNN).



Publications and References

[1] **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).
[2] **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.
[3] **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.

[4] Bernet et al., 2017. Surface water floods in Switzerland: What insurance claim records tell us about the damage in space and time. *Nat. Hazards Earth Syst. Sci.* 17, 1659–1682.
[5] Lagadec, L.-R. Développement et Evaluation de la Méthode IRIP de Cartographie Du Ruissellement Intense Pluvial, Application Au Contexte Ferroviaire. Ph.D. Thesis, Doctoral School Earth, Universe, Environment Communauté Université Grenoble Alpes, Saint-Martin-d'Hères, France, 2017; 336p.
[6] Dhakal et al., 2002. Detection of areas associated with flood and erosion caused by a heavy rainfall using multitemporal Landsat TM data. *Photogramm. Eng. Remote Sens.* 68 (3), 233–239.
[7] Bernet et al., 2018. Modeling the extent of surface water floods in rural areas: Lessons learned from the application of various uncalibrated models. *Environ. Model. Softw.* 109, 134–151.
[8] Dehotin and Breil, 2011. Technical Report of the IRIP Project: Surface Runoff Flood Hazard Mapping; Technical Report; IRSTEA Hydrology-Hydraulic Research Unit: Lyon, France.
[9] Bernet et al., 2019. Characterizing precipitation events leading to surface water flood damage over large regions of complex terrain. *Environ. Res. Lett.* 14, 064010.