A new observational-modeling framework for flash-flood forecasting in complex-terrain watersheds.

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Abstract

The watershed determined by Aburrá Valley system, located in northwestern Colombia, has significant urban development and steep hills. These features, together with the typical intense storms of the region, make the watershed prone to the occurrence of flash floods during the rainy seasons, affecting vulnerable communities. We propose a hybrid observational-modeling strategy to generate 30-minute discharge forecasts in different locations of the watershed, using an operational distributed hydrological model, information from stream gauges, and weather radar-derived precipitation using a quantitative precipitation estimation (QPE) technique. The forecast methodology is triggered when any stream gauge of interest reports levels over a predefined threshold. As a first step, the model uses different rainfall scenarios for the following 30 minutes. Every 5 minutes, the model forecast is executed after updating the observed rainfall and the rainfall scenarios. The scenarios correspond to (i) a lagrangian extrapolation of the precipitation fields, (ii) to a cellular automata-based extrapolation and to (iii) the last observed rain field multiplied by a time-varying ad-hoc factor based on historical event analysis. To parametrize the hydrological model and to validate the prediction methodology, we use 173 storm events from 2013 to 2018. The methodology is evaluated using the Nash coefficient, the Klin-Gupta index, differences in time-to-peak discharge, peak-discharge differences, and total storm-event volume differences. Operationally, the forecasted streamflow corresponds to the scenario with the best historical performance, given the total amount of observed rainfall. The overall results suggest that the described approach is promising. However, there are still some cases in which the method leads to discharge underestimation. Considering the forecast uncertainty, the results show that it is possible to design flash floods alerts using this simple but robust methodology.

A new observational-modeling framework for flash-flood forecasting in complex-terrain watersheds

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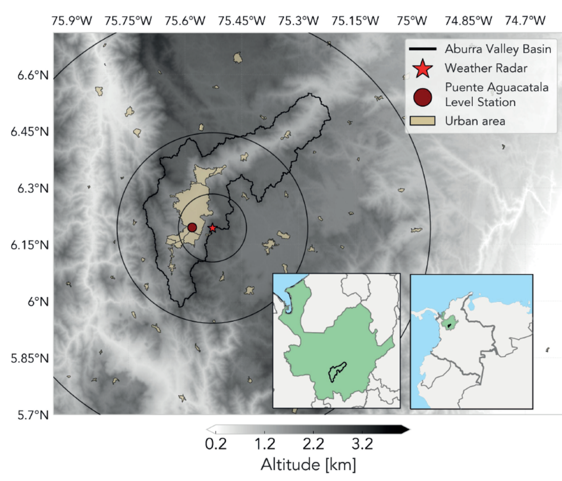
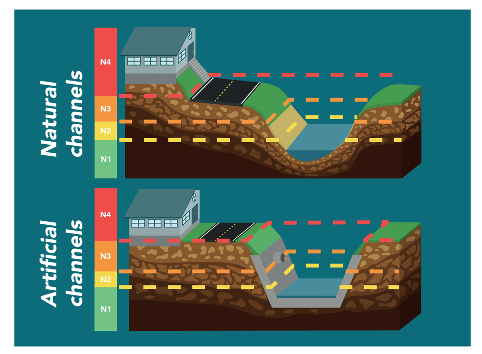
Introduction

The watershed determined by Aburrá Valley system, located in northwestern Colombia, has 24% of its area occupied by urban development, the mean slope is 24%, but some hillslopes are as steep as to reach 50% and 500m of height above nearest drainage. These features, together with the typical intense storms of the region, make the watershed prone to the occurrence of flash floods during the rainy seasons, affecting vulnerable communities.

Local and regional localization.



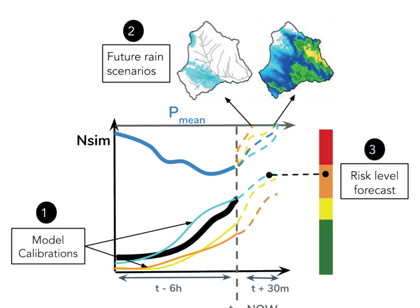
Example of emergencies caused by floods.



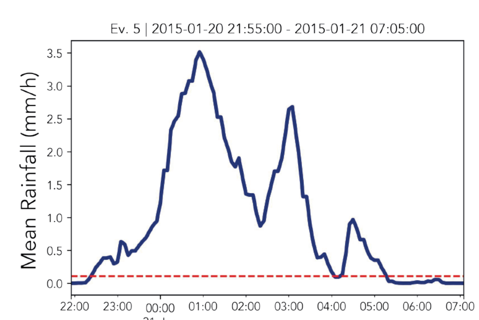
Risk levels definition are needed for each section.

Experimental methodology

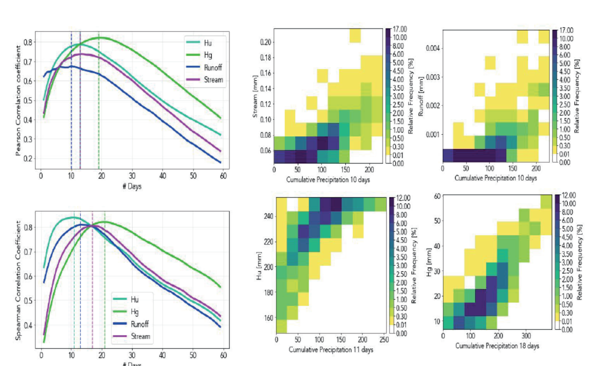
Overall scheme of methodology for risk level forecast.



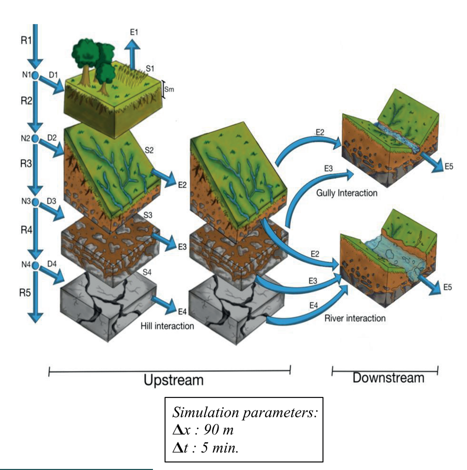
Model trigger execution: *The mean accumulated rainfall for the last 3 hours is evaluated. It must exceeds a threshold for the model execution.*



Initial conditions rules for simulation: *With the results of a mid-term simulation, the number of days for which the accumulated precipitation showed the highest correlation with the simulated humidity was found. The rules are constructed with the relationship between this variables.*

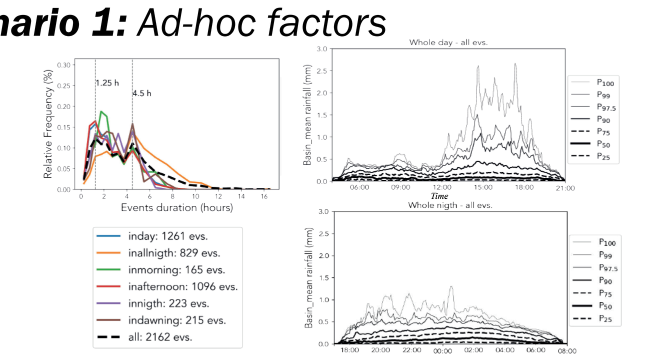


Hydrological distributed simulation: *The hydrological simulation is executed with a distributed tank model (Watershed modelling framework, Velásquez, et al., 2019) using two rain parameterization scenarios for the forecast period (30 min.).*

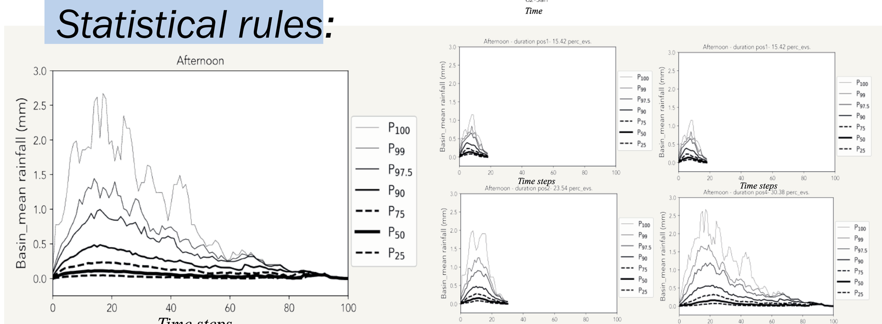


Rainfall Scenarios

Scenario 1: Ad-hoc factors

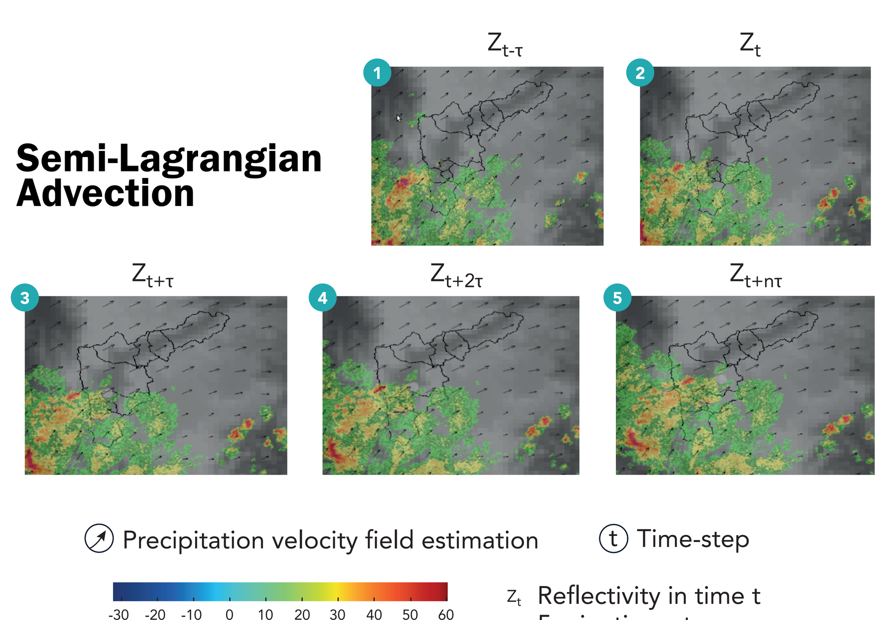


Statistical rules:



Scenario 2: Lagrangian extrapolation

Semi-Lagrangian Advection



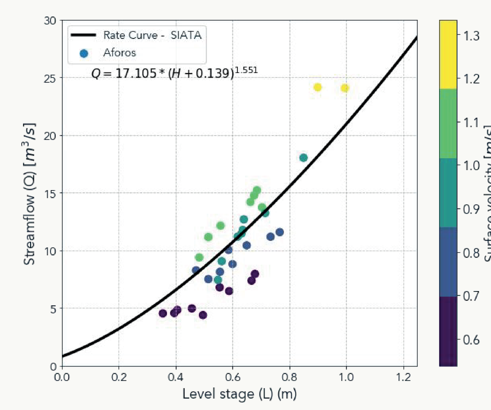
Data

Rainfall fields derived from C-band radar and non-parametric Quantitative Precipitation Estimation (Sepúlveda, et al., 2017).

Δ *t : 5 min*

Level stage
Δ *t : 5 min*

Surface velocity
Δ *t : 5 min*

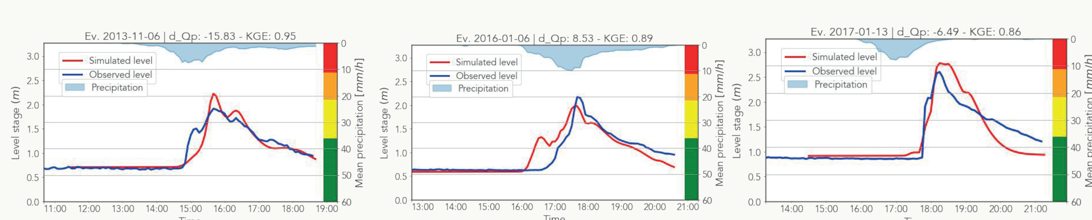


Robust rate curve for real-time streamflow data generation.

The strategy is applied in one river stage station: Est. 94 Puente de La Aguacatala.

Model calibration

Example of calibration sample's events



Summary of events calibration process

Performance Summary Lsim - Lobs d_Lp - 94

d_Lp (%)	[-60,-30]	[-30,-10]	[-10,0]	[0,10]	[10,30]	[30,60]
	0.00	6.25	9.82	18.75	51.79	13.39

Performance Summary Lsim - Lobs KGE - 94

KGE (%)	[-1,-0.5]	[-0.5,-0.3]	[-0.3,0]	[0,0.3]	[0.3,0.5]	[0.5,1.0]
	0.93	0.93	5.56	4.63	10.19	77.78

Acknowledgements

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Results, validation and monitoring strategy

Summary of the strategy's validation process : 173 events were used.

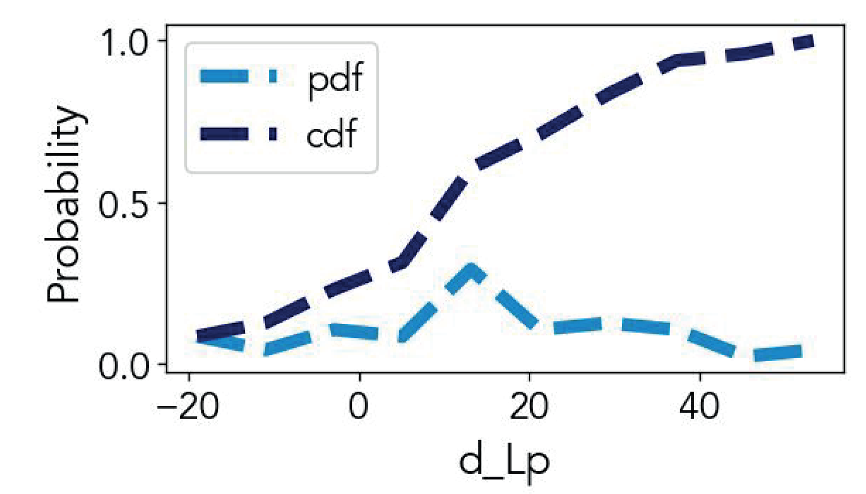
Performance Summary Lsim - Lobs d_Lp - 94

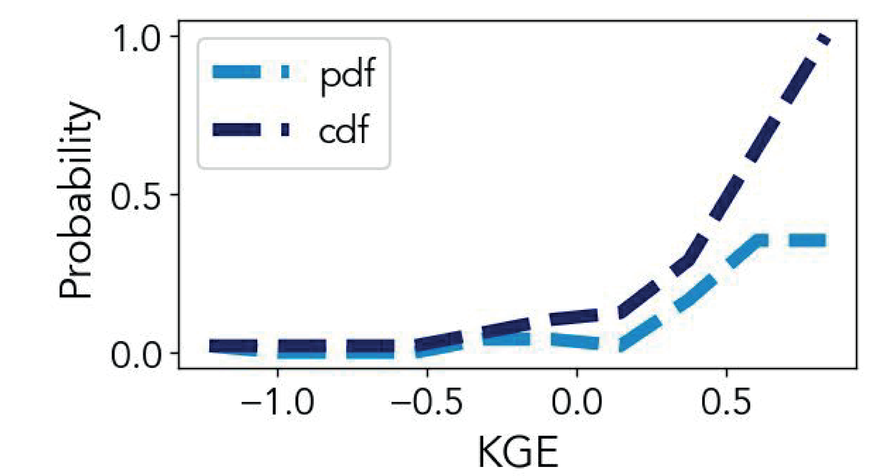
d_Lp (%)	[-60,-30]	[-30,-10]	[-10,0]	[0,10]	[10,30]	[30,60]
	0.00	2.17	15.22	19.57	50.00	13.04

Δ Lpeak. reference

Performance Summary Lsim - Lobs KGE - 94

KGE (%)	[-1,-0.5]	[-0.5,-0.3]	[-0.3,0]	[0,0.3]	[0.3,0.5]	[0.5,1.0]
	0.00	2.33	2.33	2.33	6.98	86.05





Performance was assessed using 3 criteria: Kling-Gupta Efficiency (KGE), Peak Levels difference (d_Lp) and Risk Level difference. d_Lp was estimated as the quotient of the difference between observed and simulated peak levels and the difference between green and red levels (Lpeak reference).

Results show that more than 80% of the events were skillfully simulated: Almost 90% of the events show a KGE > 0.3 and for approximately 80% of the events the KGE>0.5 (good performance threshold). The strategy is good enough to represent most of flood events but slightly suffers sub-estimation of peak level reached.

Almost the 45% of the events correctly represented the Risk Level that was reached by the flood event.

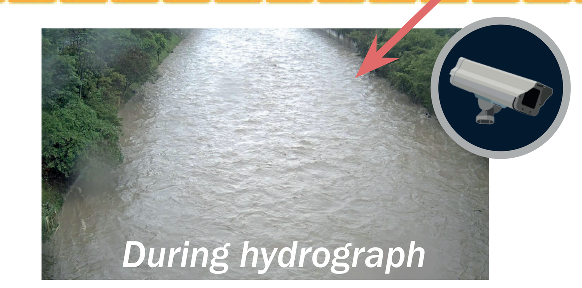
Performance Summary RLobs - RLsim d_RL - 94

d_RL (%)	[-2]	[-1]	[0]	[1]	[2]
	1.83	6.42	44.95	37.61	9.17

Operational tools for floods early warning

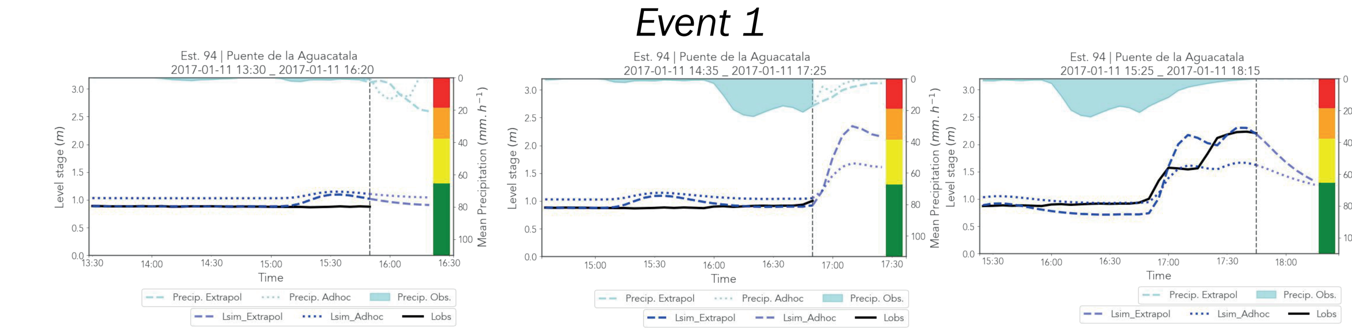
A risk levels matrix is updated in real-time (each 5 min. step) to show the risk evolution in the analysed channel section, predicted risk level is included in the forecast window.

In-situ real-time validation using river stage data and cameras installed alongside the station.

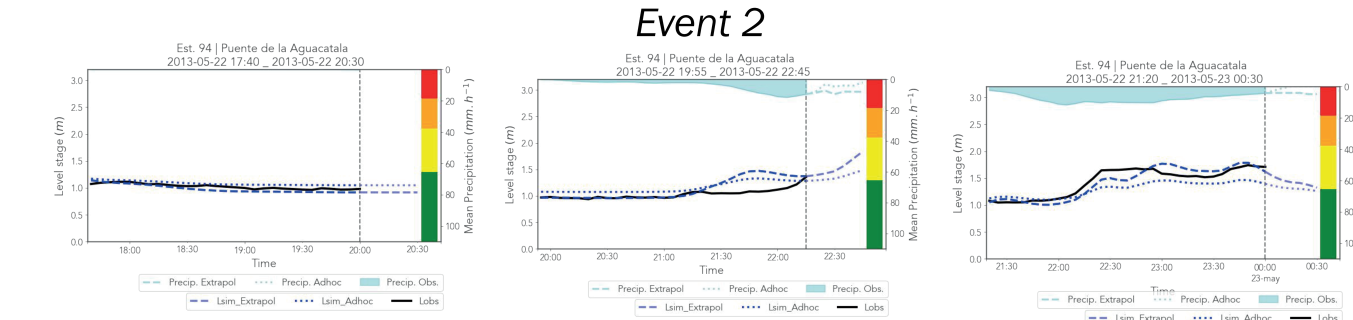


Example of validation cases

Event 1



Event 2



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