

Fire station operational data for fast flood model validation

Données opérationnelles des casernes de pompiers pour la validation rapide des modèles d'inondation

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RÉSUMÉ

Les précipitations extrêmes et les inondations dues aux tempêtes risquent de devenir plus fréquentes et plus intenses, rendant indispensables des modèles de simulation rapides et fiables. Cependant, une validation rigoureuse reste cruciale, même si les données observées – telles que les niveaux d'eau – sont souvent rares ou incomplètes. L'utilisation de sources de données non conventionnelles devient donc de plus en plus importante. Cette étude explore le potentiel des données opérationnelles des pompiers pour valider le modèle d'inondation rapide Dynamic CA-ffé à travers trois études de cas autrichiennes (Innsbruck, Kufstein, Feldbach). La validation basée sur les registres opérationnels se concentre sur l'identification des bâtiments touchés et la comparaison de l'étendue des inondations avec des photos d'événements réels. En outre, une validation de référence des bâtiments touchés a été effectuée à l'aide d'un modèle SWMM 1D/2D couplé. Les résultats montrent que, bien que limitées aux bâtiments signalés, les données des pompiers fournissent une indication fiable de la situation globale. Les taux de détection des bâtiments touchés varient entre 34 % et 89 % et correspondent également aux taux de réussite du modèle de référence 1D/2D. Dans l'ensemble, ces données sont utiles pour une validation approximative, mais des informations supplémentaires (bâtiments non signalés, niveaux d'eau, documentation photographique) sont nécessaires pour tirer des conclusions plus solides.

ABSTRACT

Extreme precipitation events and the resulting pluvial flooding are expected to become more frequent and more intense in the future. Advanced and fast flood modelling is therefore indispensable. However, to properly assess the performance and reliability of flood models, robust validation is essential. Validation data, such as surface water level measurements, are rare, often incomplete, or entirely absent. Consequently, there is a growing shift toward the use of unconventional data sources. This study investigates the potential of fire station operational data as a validation source for the Dynamic CA-ffé fast flood modelling approach across three Austrian case studies: Innsbruck, Kufstein, and Feldbach. The validation based on operational records focuses on identifying affected buildings and comparing flood extent with photos from real events. Additionally, a reference validation of affected buildings was conducted using a coupled 1D/2D SWMM model. The results show that although fire station records allow comparisons only for documented affected buildings, they still provide a reliable indication of the general flood situation. Hit rates on affected buildings range from 34% to 89%, depending on the precipitation event and case study and also fit with the hit rates in the 1D/2D reference model. Overall, fire brigade operational data can be considered useful for coarse validation of urban flood models. However, more definitive conclusions require expanding data collection to include non-reported flooded buildings, unaffected buildings, water level information, and more extensive photographic documentation.

KEYWORDS

Dynamic CA-ffé, Fast flood modelling, Fire station operational data, Model validation, Pluvial flooding

1 INTRODUCTION

Heavy precipitation events and resulting pluvial flooding are a major threat to urban environments. Particularly surface flooding in combination with an overwhelmed drainage network is a huge problem in urban areas. Advanced and fast flood modelling becomes therefore more and more important. There are numerous types of models, from one-dimensional (1D) models (Henonin et al., 2013) of the drainage network, two-dimensional (2D) models solving the 2D Shallow water equations (Mignot et al., 2020) up to coupled 1D/2D models (Leandro et al., 2009). Current research also focuses on fast flood modelling approaches (Li and Willems, 2020) using cellular automata (CA), artificial intelligence (AI) or machine learning (ML) technology (Wan et al., 2019). All model types require robust validation to ensure reliable real-world application (Cea et al., 2025), typically using observed water levels, inundation depths (Molinari et al., 2019) or detailed reference simulations to compare simulated flood inundations, extent or flow dynamics. However, such datasets are often scarce during extreme events, making proxy data like satellite imagery, photographs, insurance records, or event reports essential.

This study investigates the potential of fire-station operational data to validate the fast flood model Dynamic CA-ffé using three Austrian case studies.

2 METHODS

1.1 Dynamic CA-ffé model

The Dynamic Cellular Automata Fast Flood Evaluation (Dynamic CA-FFE) modelling approach, developed by Gholami Korzani et al. (submitted) and based on Jamali et al. (2019), was used to develop fast flood models for three case studies in Austria: Innsbruck, Kufstein und Feldbach. Dynamic CA-ffé offers a hybrid, time-efficient approach for urban flood simulation. It applies a cellular-automata framework to simulate surface flood propagation efficiently based on the continuity equation and terrain data and is coupled with a 1D Stormwater Management model (SWMM). By that, it enables a dynamic and bidirectional coupling between surface and drainage network and allows for an efficient tool for operational flood management. The version used in this study is an adapted Dynamic CA-ffé model (Hauser et al., 2025) that incorporates buildings, runoff coefficients, and multiple rain gauges.

1.2 Validation

As hydrodynamic models and other data sources are often unavailable for comparison purposes, this study focuses on validation using operational data from fire stations. For reference, an additional validation was carried out using an existing 1D/2D hydrodynamic SWMM model for one case study.

1.2.1 Validation based on operational data

Operational data from fire stations, recorded by the local emergency control center, documents all incoming emergency calls, including time, alarm number, type of event, address, coordinates, and additional caller information. Before use, the dataset must be filtered to retain only flood-related operations. Many fire stations also collect photos and videos of the events.

Validation compares simulated affected buildings with the operational data and available photos. Cells with water depths >20 cm are classified as flooded, and buildings with at least one such cell within 5 m are considered affected. These relatively large thresholds account for reporting uncertainties and inaccuracies in caller-reported locations. A confusion-matrix approach is applied to compare affected buildings in the simulation and the operational data. However, a full matrix cannot be constructed because unaffected buildings are not reliably known: the absence of an intervention does not necessarily mean that a building remained unflooded. It may also indicate that no call was made, that the intervention was not recorded, or that firefighters were already present in the neighbourhood and addressed issues without logging a separate incident. Where possible, flood extent is additionally evaluated using event photos.

1.2.2 Reference validation based on a 1D/2D model

As a reference, to proof the effectiveness of validation based on operational data, a validation using an existing 1D/2D SWMM model was done. This analysis compares affected buildings identified by the Dynamic CA-ffé model, the SWMM model and the operational data. Since the SWMM model uses hexagonal cells of varying resolution, while the CA-ffé output is provided as a 1×1 m grid, the mean raster value was used to ensure comparability between both spatial representations.

1.3 Data basis

The study uses three different case studies in Austria: Innsbruck, Kufstein and Feldbach. All these case studies are characterized by an interplay of topography, climate, and urbanization that elevates pluvial flood risk, as it is for many cities worldwide. Different events were simulated, as described in Table 1.

Table 1. Overview of the case studies, case study area, events and number of operational spots

Case study	Case study area	Event year	Max. peak of the event	Operational spots
Innsbruck	51.3 km ²	2010	43mm/10 min	346
Innsbruck	51.3 km ²	2016	50mm/10 min	291
Feldbach	1.8 km ²	2020	11.6mm/10min	26
Kufstein	47.2 km ²	2021	7.4mm/10 min	135

3 RESULTS AND DISCUSSION

3.1 Validation based on fire station operational data

3.1.1 Endangered buildings

The results show a high hit rate for identifying affected buildings (Table 2), which is promising. However, a substantial number of affected and documented buildings were not detected (FN), meaning that some buildings with fire-station interventions did not appear affected in the simulation. In addition, many buildings were incorrectly identified as affected (FP), indicating that the simulation predicts more affected buildings than were actually documented. It should be noted that this value (FP) is highly uncertain, as operational data only documents real operational locations and does not provide a comprehensive overview of the flood situation. However, the number of affected buildings varies greatly depending on how an 'affected building' is defined. This means that a lower water level for declaring flooded cells would improve the hit rate, but also increases the total number of flooded buildings.

Table 2. Hit rate and percentage of total flooded buildings

	Hit rate (% of detected buildings from operational data)	Flooded buildings (% of total buildings)
Innsbruck -2010	72	55
Innsbruck -2016	34	19
Feldbach - 2020	89	52
Kufstein - 2021	75	56

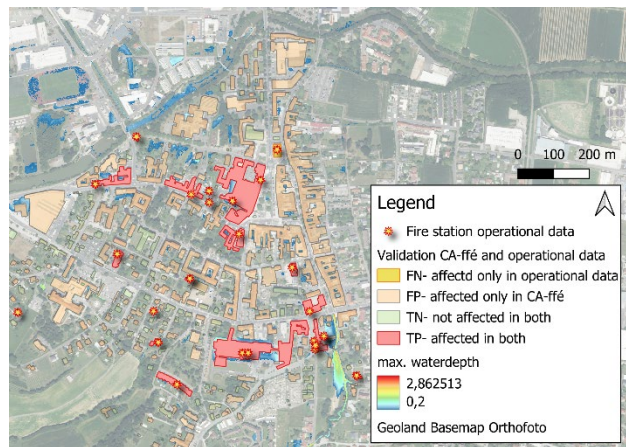


Figure 1. Feldbach 2020: Affected buildings based on Dynamic CA-ffé, compared with operational data

3.1.2 Comparison with Photos

This evaluation focuses on the benefit of additional use of photos for validation of flood simulation results. It compares some example pictures of the flood events in 2016 (Innsbruck) and 2021 (Kufstein). Some results demonstrate good agreement between the simulated and the estimated (out of the photo) water level. However, some results also demonstrated great differences between simulation and reality. This might be due to influencing factors such as external streams, sediment blockage or actions of the fire station to redirect flow paths. However, affected buildings in the photos were mostly also affected in the simulation, which indicates, that operational data is useful to validate affected buildings but additional material, such as photos, is necessary to evaluate flood extent or flood depth.

3.2 Reference validation based on a 1D/2D model

As a reference, a comparison with a 1D/2D model was conducted for one case study, to classify the performance of validation based on fire station operational data. Results show a good agreement in affected buildings between the operational data and both simulation models. Comparing SWMM and Dynamic CA-ffé shows that both models identified 79 buildings as affected and 199 as unaffected. However, out of 384 buildings in total, Dynamic CA-ffé identified 48 more buildings affected than the SWMM model. Of the 19 documented affected buildings in the operational data, 13 were found by both models, three only by CA-ffé, and one only by SWMM. Two documented cases were missed by both models.

4 CONCLUSION

The validation using fire station operational data shows generally good agreement in identifying affected buildings, although uncertainty remains because the data captures only documented interventions. When available, photo documentation further enhances the understanding of flood extent and water depths. Overall, the validation results are adequate for obtaining a quick and reliable overview of the flood situation and potentially endangered buildings. Future work should aim to enrich operational datasets by recording water levels, adding photographic evidence, and documenting unaffected buildings as well.

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