OPERATIONAL HYDROLOGICAL–HYDRODYNAMIC FLOOD FORECASTING SYSTEM FOR URBAN AREAS IN ESPÍRITO SANTO, BRAZIL

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INTRODUCTION

Extreme flood events have increasingly affected urban catchments worldwide, especially in regions characterized by steep topography, rapid hydrological response, and high exposure of vulnerable populations. In southeastern Brazil, intense rainfall combined with narrow valleys and densely occupied floodplains frequently produces severe inundation events with substantial social and economic impacts. These characteristics reinforce the need for robust operational forecasting systems capable of supporting early warning and disaster risk reduction.

The south of the state of Espírito Santo is particularly susceptible to flash floods and river flooding due to its complex topography, short response times of its watersheds, and the concentration of urban areas along river valleys. Recent extreme events have highlighted the importance of integrating hydrological forecasting with flood inundation modeling to provide timely and spatially explicit information for civil protection authorities (Ribeiro, 2022).

SIMEPAR (Technology and Environmental Monitoring System of Paraná) has developed and operated an integrated flood forecasting system for the Espírito Santo State Agency for Water Resources (AGERH). The operational service includes hydrological monitoring, streamflow forecasting, and automatic flood inundation forecasting for five flood-prone municipalities in the state.

This study presents the operational hydrological–hydrodynamic forecasting framework developed for these municipalities. The system integrates the GR4J rainfall–runoff model (Perrin et al., 2003) with automatic two-dimensional hydrodynamic simulations using HEC-RAS (Brunner, 2025). Operational streamflow forecasts are generated daily from ECMWF ensemble precipitation forecasts with lead times of up to 15 days. The resulting discharge forecasts are automatically converted into flood inundation maps, providing actionable information for emergency managers and supporting flood preparedness and response.

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METHODOLOGY

Streamflow forecasting was performed using the GR4J conceptual rainfall–runoff model, calibrated for the basins using historical precipitation, streamflow, and potential evapotranspiration data. Daily forecasts were generated by forcing the calibrated models with ECMWF ensemble precipitation forecasts, providing streamflow predictions with lead times of up to 15 days.

A set of Python routines developed by the authors was used to automate the entire forecasting workflow, including data acquisition, pre-processing, execution of two-dimensional HEC-RAS hydraulic simulations, post-processing of model outputs, and generation of flood inundation maps. The automated workflow enables the daily production of operational flood forecasts with minimal human intervention. The system also estimates inundated areas and the potential impacts on buildings, schools, and health facilities by intersecting flood maps with spatial exposure datasets, providing decision support for flood preparedness and emergency response.

RESULTS

The hydrological model was calibrated using observed hydrometeorological data from the study basins, achieving average Nash–Sutcliffe Efficiency (NSE) values of 0.71 and Kling–Gupta Efficiency (KGE) values of 0.84, indicating satisfactory performance for operational applications. The forecasted streamflows automatically feed the hydrodynamic model, which generates flood extent and water depth predictions for river channels and urban floodplain areas.

An example of the system performance is the flood event of 6 January 2026 in Cachoeiro de Itapemirim. Using the ECMWF ensemble forecast issued two days in advance, the median predicted peak discharge was 574 $m^3\ s^{-1}$, compared with an observed peak of 558 $m^3\ s^{-1}$, corresponding to an error of approximately 3%. The automated workflow successfully generated flood inundation maps and operational geospatial products, demonstrating the capability of the system to provide timely information for early warning and emergency response.

Figure 1 shows examples of the flood inundation products generated by the system for historical flood events in the municipalities of Iconha and Mimoso do Sul. These retrospective simulations demonstrate the system's capability to automatically transform hydrological forecasts into spatially explicit inundation products for operational use.

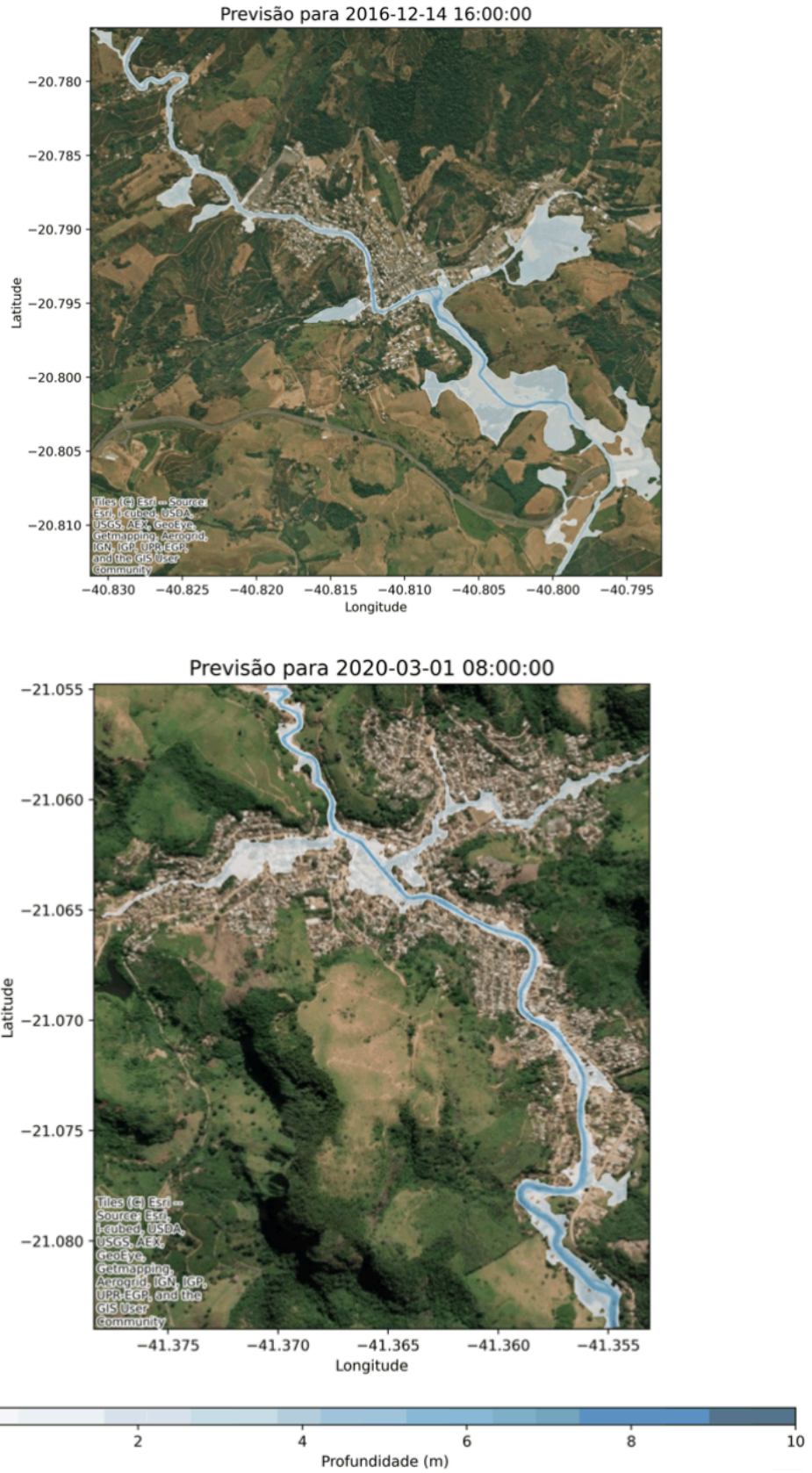


Figure 1 - Examples of hindcast flood inundation forecasts for historical flood events for the municipalities of Iconha (top) and Mimoso do Sul (bottom), Espírito Santo State, Brazil. Source: Authors.

CONCLUSIONS

This study presented an operational hydrological–hydrodynamic forecasting system capable of automatically producing streamflow forecasts, flood inundation maps, and impact-oriented geospatial products. The satisfactory forecasting performance and the successful daily operation demonstrate the applicability of the framework for flood early warning in small and medium-sized catchments.

The modular architecture allows continuous improvements and facilitates replication in other regions, contributing to more effective disaster risk management through the integration of hydrological forecasting, hydraulic modeling, and automated geospatial processing.

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