Evaluation of the Romanian flash flood forecasting system – case study in the Calnau river basin

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Überprüfung des rumänischen Hochwasservorhersagesystems anhand des Einzugsgebiets Calnau

Introduction

Increased frequency of extreme flash flood events that generated significant damages and casualties was reported in the last years. In Romania, such extreme events occurred in different regions of the country and had mostly catastrophic effects. Intensification of the high intensity torrential precipitation events in the last years in many countries was reported e.g. by GAUME et al. (2009). The climate change could cause further increase of the frequency of such extreme events. Therefore, the needs for analysing and simulating the hydrological processes associated with flash floods become one of priorities in scientific hydrological community.

The main causes of the flash floods are the rains with torrential character with very high intensities (STANCALIE et al., 2009). The occurence of the flash floods is also favoured by the high impermeability of a basin, which is especially encountered in the urbanized areas. The frequency and severity of the flash floods are higher at the slopes suffering serious deforestation, bad agricultural practices (e.g. ploughing along the slope) or in the basins with complex topography modified by the large scale urbanization.

The objectives of this paper are:

- presentation of the newly implemented Romanian hydrological forecast and warning system

Zusammenfassung

Der Beitrag beschreibt das neu entwickelte Hochwasservorhersagesystem in Rumänien und zeigt Testergebnisse des operationellen Lenkungssystems. Die Güte des Modells wurde anhand des Hochwassers am Calnau-Fluss am 24. und 25. Juli 2011 geprüft. Das Vorhersagesystem erfasste die raumzeitliche Verteilung des Niederschlags realistisch. Die Berechnungen des Vorhersagesystems liefern Bodenfeuchtekarten, Niederschlagsverteilungen und Abflussvorhersagen für 1, 3 und 6 Stunden. Eine Echtzeitverarbeitung der Daten und die verteilte hydrologische Modellierung ergaben zufriedenstellende simulierte Abflussganglinien. Obwohl noch weitere Tests des Vorhersagesystems notwendig sind, liefern die ersten Tests vielversprechende Ergebnisse hinsichtlich eines verbesserten Hochwasserprognosesystems in Rumänien.

Schlagworte: Hochwasservorhersagesystem Rumänien, kleine Einzugsgebiete.

Summary

The paper describes the new Romanian hydrological and flood forecasting system and presents a test of its component called Flash Flood Guidance System used in the flash flood forecasting. Performance of the Flash Flood Guidance System was evaluated for the flash flood that occurred in the Calnau river basin on 24 and 25 July 2011. The forecasting system correctly indicated spatial and temporal distributions of the rainfall which caused the flash flood. The Flash Flood Guidance System generated products (soil moisture map, estimated recorded rainfalls and guidance values for durations 1, 3 and 6 hours) that allowed issuing correct flash flood warning. Real-time data processing and distributed hydrological modeling provided a hydrograph that was reasonably comparable with measured data. Although further testing in more basins is necessary, the system is a promising tool in improved flash flood forecasting for Romania.

Key words: Flash flood forecasting system, small basin, flash flood.

- evaluation of the performance of the system for the flash flood that occurred in July 2011 in the Calnau river basin.

1 Romanian hydrological forecast and warning system

A new national hydrological forecast and warning system is now in advanced implementation phase, within the Romanian Waters National Administration, in the framework of the DESWAT project (MCHENRY et al., 2005). The DESWAT Hydrological Forecasting and Modeling System (HFMS) relies on the gauge-corrected hourly to sub-hourly radar-based quantitative precipitation estimates which are used as inputs to a series of real-time hydrological forecasting systems.

One very important radar product for flash flood warning generated within the HFSM is the Hydro FutureScan. It represents a quantitative precipitation estimate for the next 2 hours, with 5 minute time step and 1 km spatial resolution. This product is based on the projection of individual radar images into the future taking into account the advection, growth and decay processes to estimate the expected movement of the weather pattern.

The HFMS forecasting system is composed of three main components designed to simulate and forecast hydrological process at different spatial and temporal scales:

- The conceptual hydrological forecasting model – National Weather Service River Forecasting System (NWSRFS) – with global parameters, for basins with areas larger than approximately 200 km^2;
- the distributed hydrological model – NOAH-R – for detailed simulation of the hydrological processes;
- the Romanian Flash Flood Guidance System (ROFFG) – for real-time estimation of flash flood occurrence risk.

1.1 Romanian Flash Flood Guidance system ROFFG

The Romanian Flash Flood Guidance system is an adaptation of the San Diego Hydrologic Research Center's (http://www.hrc-lab.org) Flash Flood Guidance System used in various regions of the world to help forecasters cope effectively with flash flood warnings (GEORGAKAKOS, 2006).

The Flash Flood Guidance system utilizes the soil-moisture deficits estimated in a continuous way by a conceptual hydrological model for every small basin (mean area of approximately 30 km^2). The soil moisture deficits are used together with the up-to-date (1 hr, 3 hr and 6 hr) precipitation data to estimate the amount of additional precipitation needed for streams to reach the bankfull conditions. The ROFFG is designed to provide flash flood guidance products on a small basin scale across entire Romania (8851 small basins).

The ROFFG system provides the following products:

- **RADAR** – 1, 3, 6 and 24 hours precipitations estimates, 1 km resolution grid
- **MERGED MAP** – mean areal precipitation for each basin for 1, 3, 6 and 24 hours accumulations based on bias corrected radar rainfall estimates the using in-situ gauge observations
- **GMAP (Gauge MAP)** – mean areal precipitation for each basin for 1 hour accumulation based on available gauge data interpolation
- **ASM (Average Soil Moisture)** – average soil water content for each basin (fraction of saturation for the upper soil layer, nominally 20 cm)
- **FFG (Flash Flood Guidance)** – flash flood guidance values, representing the estimated amount of rainfall for a given duration (1, 3, 6 hours) over a small basin, needed to create minor flooding conditions at the outlet of the basin
- **FFT (Flash Flood Threat)** – amount of recorded rainfall of a given duration in excess of the previous computed corresponding FFG value, for the same duration, indicating flooding conditions already occurred in the basin.

1.2 NOAH-R model

The second component that could be used for flash flood forecasting, and for detailed simulation of hydrological processes in small basins in general, is the distributed modelling component which is mainly based on the NOAH-R model. The NOAH-R contains five primary interacting physical process sub-models, a land surface model (LSM) running at the radar-scale (1 km), and overland and channel routing model, nested within the LSM, at 100 m resolution.

The Noah land surface model is a state-of-the-art land surface scheme that dynamically predicts soil temperature, soil water/ice, canopy water, snow cover and surface and subsurface runoff. Predicted state variables are calculated by simultaneously solving energy and water balance equations for a one-dimensional soil/land/snow/vegetation column (MITCHELL, 2005).

The NOAH-R distributed model runs in the HMFS:

- operationally every 30 minutes in the Land Data Assimilation mode (LDAS) to update the model state variables using the best available meteorological input data in real time.
- in the forecasting mode every 6 hours to generate the hydrological forecast for the next 48 hours using the last available numerical meteorological forecasted data.

2 Case study – Calnau river basin flash flood from 24–25 July 2011

2.1 Flash flood on the Calnau river

The flash flood event occurred on 24 and 25 July 2011 in the Calnau river basin (area 208 km^2, mean altitude 336 m, mean slope 8 %, percentage of forest12 %) in south-eastern Romania (Fig. 1a).

There are two hydrometric stations in the basin – Costomiru (area, 39 km^2) and Potarnichesti (area, 193 km^2). Maximum recorded water levels at both stations exceeded the flood defense related threshold levels (CA – watch level, CI – flood level, CP – danger level). Recorded peak discharges corresponded to return periods of 20–100 years. The recorded water level and discharge hydrographs at Costomiru station are presented in Figure 1b.

The flash flood was generated by a torrential rain in the upper part of the basin. Maximum rain intensities exceeded 70 mm/hour, 100 mm/3hours (Figure 2). Total daily (24 hours) basin rainfall estimated from the rain-gauge and radar data exceeded 150 mm.

The spatial and temporal distribution of this very intense rain event was correctly indicated in the real-time with 1–2 hours lead time by the Hydro FutureScan, the HFMS specific radar products.

2.2 Simulation results of the ROFFG System and the NOAH-R distributed model

All the products generated in real time that could be used in the flash flood warning decision process were analyzed for this particular flash flood event. First we analyzed the soil

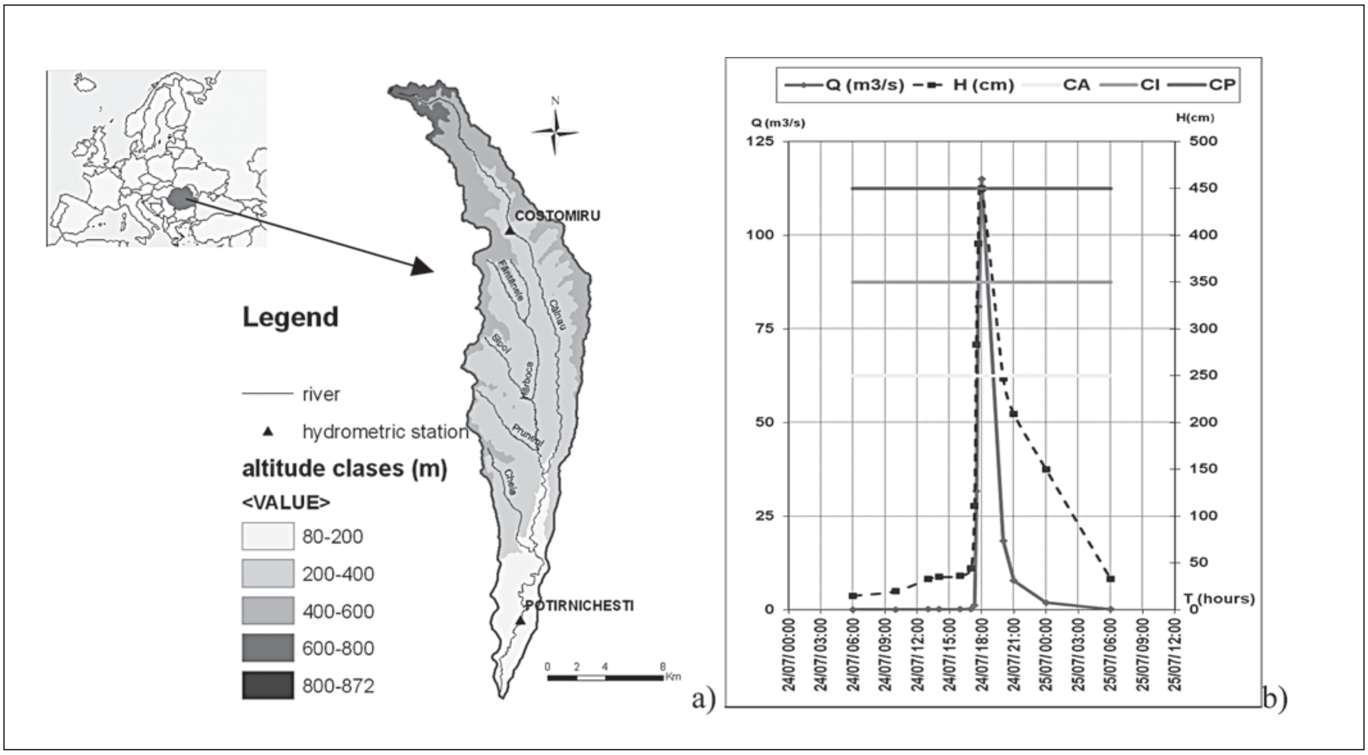

Figure 1: The Calnau River Basin: hypsometric map, river network and gauging stations location (a), 24–25 July 2011 flood event on Calnau River at Costomiru station (b); CA, CI and CP are thresholds for river levels explained in the text

Abbildung 1: Das Calnau Flussgebiet: (a) Höhenkarte, Flussgebiet und Beobachtungsstationen. (b) Hochwasserereignis 24.–25. Juli 2011 am Pegel Costomiru. Schwellenwerte CA, CI und CP werden im Text erläutert

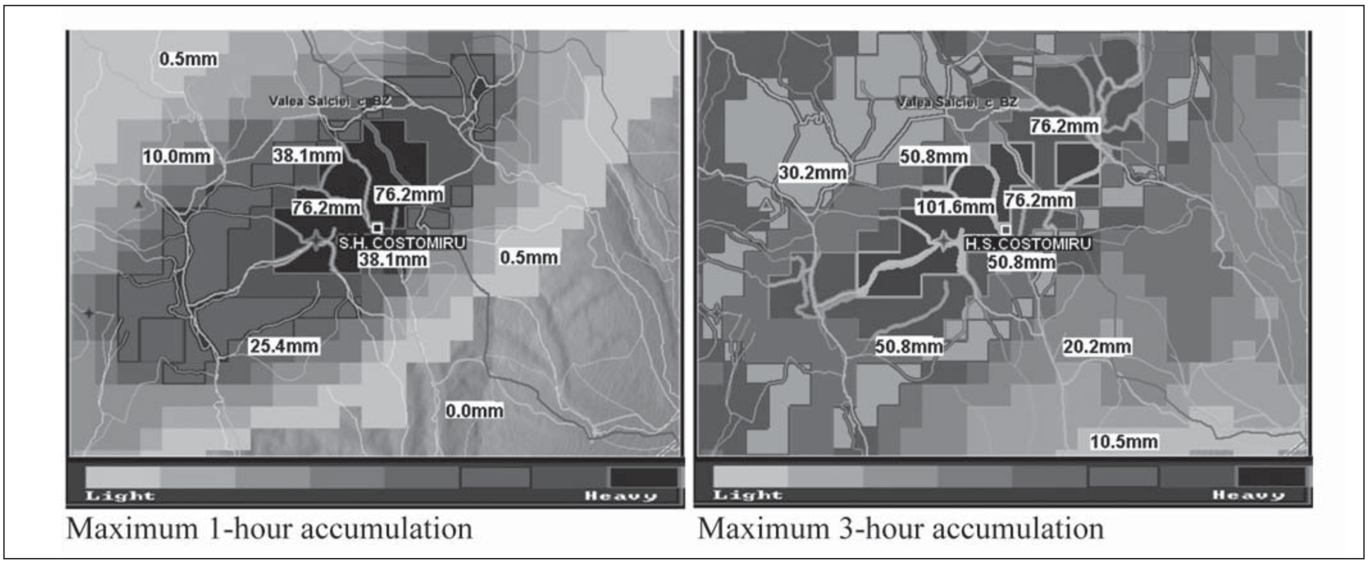

Figure 2: Maximum 1 and 3 hour cumulated rainfall (Radar Product) on 24 July 2011 for the upper Calnau river basin area (mainly upstream of the Costomiru hydrometric station)

Abbildung 2: Maximale Niederschlagssumme für 1h und 3h (aus Radar) am 24. Juli 2011 für das obere Calnau-Flussgebiet (Referenzpegel Costomiru)

moisture and the Flash Flood Guidance products. The soil moisture product indicated saturated soil conditions for most small basins in the area. The 1 hour Flash Flood Guidance product indicated that in the upper part of the basin a small precipitation (less than 10 mm) can result in flooding (Figure 3).

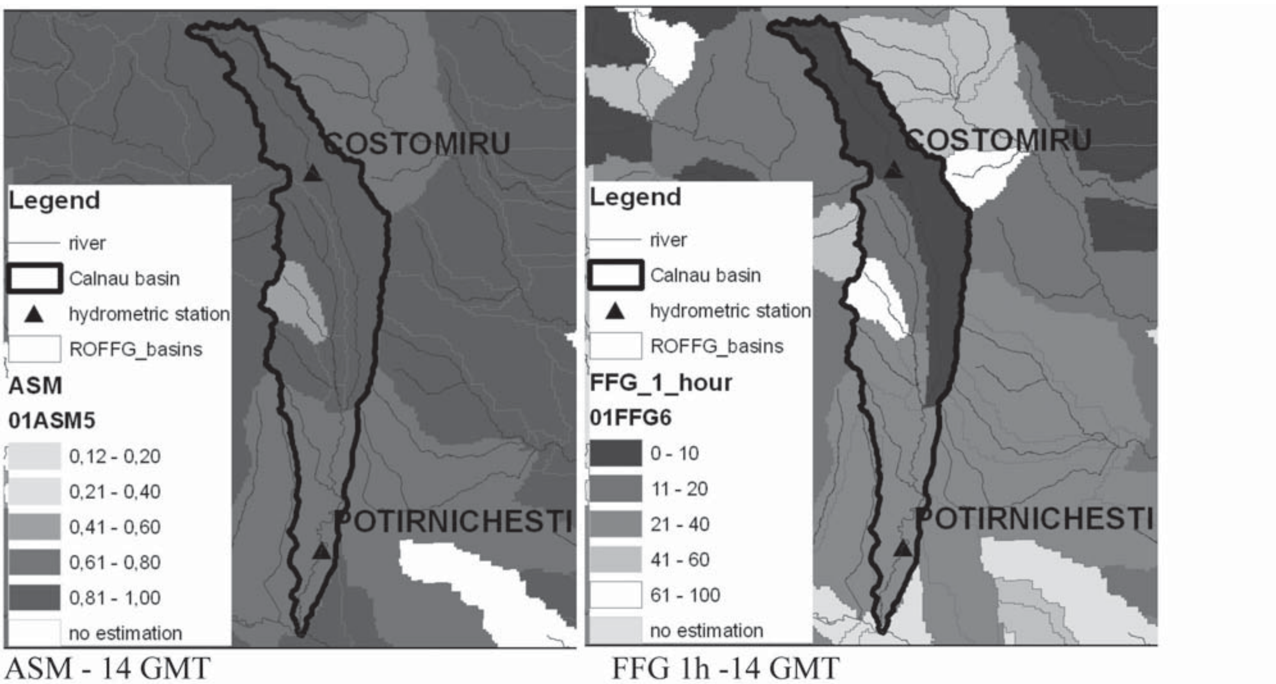

Figure 3: Average soil moisture content (left) and 1-hour FFG (right) products, generated in real time by the ROFFG System on 24 July 2011; the right panel shows the precipitation needed in the next hour to cause the flooding

Abbildung 3: Mittlerer Bodenwassergehalt (links) und 1h-Vorhersage der Bodenfeuchte (aus Vorhersagesystem) für den 24. Juli 2011

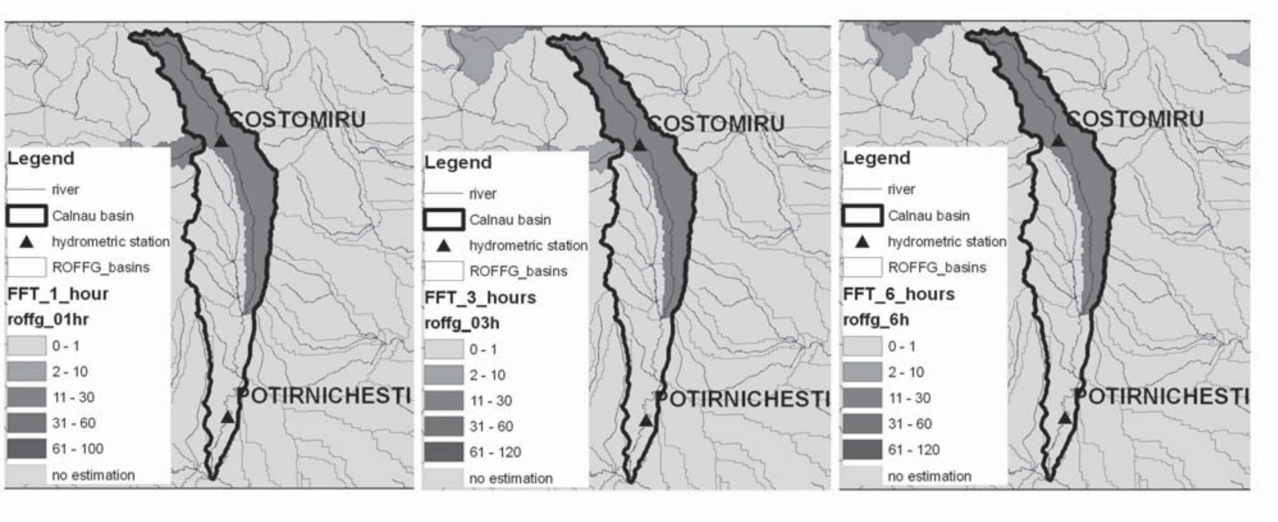

Figure 4: The ROFFG 1, 3 and 6 hours Flash Flood Threat Product, for the Calnau river basin area – 15 GMT on 24 July 2011; the products show amounts of rainfalls in excess of the previous computed corresponding FFG value
Abbildung 4: Hochwassergefahrenkarte für die 1-h-, 3-h- und 6-h-Prognose für den 24. Juli 2011

Based on these products, and the Hydro Future Scan radar products which indicated the persistence of very high intense rain, the forecaster could decide to issue a Flash Flood warning message.

After processing the data available in real-time, with no user intervention and/or adjustment, the ROFFG System detected the flash flood event. All the flash flood threat products (for the last 1, 3 and 6 hours) indicated the exceeding of the threshold FFG values (Figure 4), so based on the ROFFG estimates, the recorded rainfall before 24 July 2011, 15 GMT exceeded the rainfall guidance values for all the intervals (1, 3 and 6 hours) which represent the detection of a severe flash flood event occurring in the basin. Comparing the pattern distribution from FFT with the previous ASM and FFG products pattern, we could notice that the FFT was exceeded only in a small number of basins.

The distributed model NOAH-R run in the operational mode simulated the discharge hydrograph for the Costomiru station. The simulation was based on the real-time input data. The magnitude of the flash flood event was simulated reasonably well (Figure 5). Also other gridded products generated by the NOAH-R model (soil moisture state, overland runoff, subsurface runoff) are very useful as supplementary and/or support information during the flash floods warning decision process. They can be especially helpful in better estimation of the severity of the expected flash flood event.

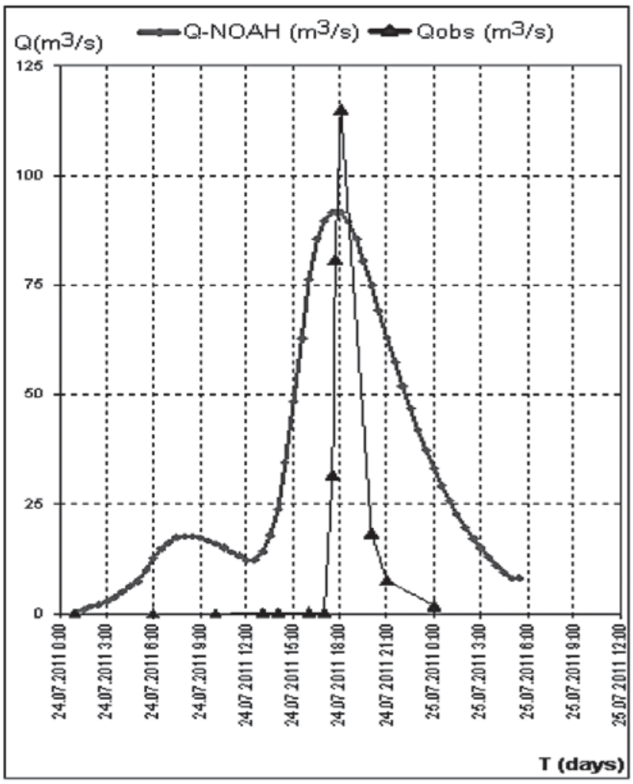

Figure 5: The NOAH-R distributed model simulation compared with the observed hydrograph at the Costomiru station
Abbildung 5: Vergleich der Modellsimulation mittels verteilten Modells NOAH-R mit den Abflussbeobachtungen am Pegel Costomiru

Conclusions

The ROFFG system correctly (in real time) indicated the flash flood occurrence in the upper part of Calnau River Basin.

The NOAH-R model simulations based on the real-time input data were close to the observed hydrograph at Costomiru station.

The results of the analyses indicate that the existing ROFFG products together with the Future Scan radar products and the NOAH-R distributed model real-time simulations could be efficiently used for issuing the flash floods warnings. However, a more detailed evaluation is needed to understand the strong and weak points of the system. In the near future, we plan to do a first preliminary general assessment of the ROFFG system performance by extending the analyses to all the flash floods events recorded since the system implementation. The assessment could help to the increase of the flash flood warning lead time (in direct relation with the precipitation nowcasting capabilities), improve calibration of the NOAH-R model and reduce the errors associated with the quantitative precipitation real-time estimates. The ultimate targets are increased probability of the flash flood occurrence forecasts and acceptable number of the false alarms.

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