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Flood forecasting and alert system for Arda River basin

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SUMMARY

The paper presents the set-up and functioning of a flood alert system based on SURFEX–TOPODYN platform for the cross-border Arda River basin. The system was built within a Bulgarian-Greek project funded by the European Territorial Cooperation (ETC) Programme and is in operational use since April 2014. The basin is strongly influenced by Mediterranean cyclones during the autumn–winter period and experiences dangerous rapid floods, mainly after intensive rain, often combined with snow melt events. The steep mountainous terrain leads to floods with short concentration time and high river speed causing damage to settlements and infrastructure. The main challenge was to correctly simulate the riverflow in near-real time and to timely forecast peak floods for small drainage basins below 100 km^2 but also for larger ones of about 1900 km^2 using the same technology. To better account for that variability, a modification of the original hydrological model parameterisation is proposed. Here we present the first results of a new model variant which uses dynamically adjusted TOPODYN river velocity as function of the computed partial streamflow discharge. Based on historical flooding data, river sections along endangered settlements were included in the river flow forecasting. A continuous hydrological forecast for 5 days ahead was developed for 18 settlements in Bulgaria and for the border with Greece, thus giving enough reaction time in case of high floods. The paper discusses the practical implementation of models for the Arda basin, the method used to calibrate the models' parameters, the results of the calibration-validation procedure and the way the information system is organised. A real case of forecasted rapid floods that occurred after the system's finalisation is analysed. One of the important achievements of the project is the on-line presentation of the forecasts that takes into account their temporal variability and uncertainty. The web presentation includes a comparison of the forecasted river flow to three predefined alert levels.

1. Introduction

During the last decade, higher attention is paid to natural phenomena like intensive rain events, significant snow accumulation and consecutive snow melting, flash floods and landslides in Bulgaria. Their societal impact is increasing with their frequency and amplitude. It is now widely admitted that the climatic shift over the south-east Balkans is increasing the number of extreme events and affected areas (Bocheva et al., 2009; Papagiannaki et al., 2013). The climatic scenarios show an increase of the 100-year return period discharges by 40% for the winter season (Dankers and Feyen, 2008). Nevertheless, the annual maximum 5-day accumulated rainfall climatic scenarios (P5max) for the basin show controversial results, between +40% (R50-H-B2 scenario) and −40% change for the current century (Dankers and Feyen, 2009). State agencies, academic bodies and the communities are reacting with some delay as it is difficult to respond fast enough to all the needs in that field. Hydrological alert systems for floods, including forecasting systems, have been operating in Bulgaria since 2009. The National Institute of Meteorology and Hydrology – Bulgarian Academy of Sciences (NIMH – BAS) took part in the establishment of an European Union (EU) funded public flood forecasting system (FFS) for the cross-border Maritsa and Tundzha rivers in south Bulgaria (Stoyanova and Artinyan, 2010) and a mirror one in Turkey was

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set up (Tuncok, 2014). Both were based on MIKE-11 family of computer models – lumped for the upper mountain area and hydraulic for the main river channel. Using that experience, NIMH created a consortium of partners from Bulgaria and Greece with the purpose to establish such FFS for the transboundary Arda River basin (ARDAFORECAST). The main settlements endangered by high floods are mostly in the upper Bulgarian part of the basin and in the lower Greek part. Bulgarian towns and villages situated along the rivers experience damage in river vicinity, especially on road and bridge infrastructure. Damage also happens because of landslides occurring after heavy rains or overflows of small dams used by farmers or for industrial purposes. Across Bulgaria 11 fatalities were registered in 2012 and respectively 16 in 2014, circumstantially or directly caused by floods (EC-JRC, 2014). In Greece, where the lower basin's river bed is much wider and bordered by dikes, the high floods are usually preceded by overflows of the dams situated in the Bulgarian middle river course. They may cause losses in farm lands in Greece. An appropriate early warning system for floods enhances the preparedness of the population and authorities for the rapid floods and flash floods and mitigates the risk for the infrastructure and population in river vicinity. For the Bulgarian part of this basin we used coupled spatially distributed open source physical models (see Section 2.3) as an alternative to the proprietary software models (Roelevink et al., 2010) already implemented for other basins in Bulgaria. Distributed models can take into account terrain and climate heterogeneities with a finer spatial step but do not use hydraulic computations for the main river channel. An advantage here, if we compare this to other alternatives as the Neural Network River Forecasting (NNRFs) (Taormina and Chau, 2015), is the possibility to simulate spatially the current state of the snow pack and of soil wetness as analysis variables, which may be interpreted as flood predictors. The scientific basis for the present work is the previous development (Artinyan et al., 2008) of the coupled surface scheme "Interface Soil Biosphere Atmosphere" – (ISBA) (Habets et al., 1999) and the hydrological model MODCOU (Ledoux et al., 1989). In this case, TOPODYN was used instead of MODCOU in order to improve fast floods simulation for small basins (see Section 2.3) and additionally 5 days lead-time flood forecast was implemented. The FFS based on SURFEX–TOPODYN platform (also known as ISBA–TOP coupled system) described in Section 3 was set-up during the ARDAFORECAST project and has been continuously running since 2014. Such a system was first proposed by Bouilloud et al. (2010) for Mediterranean flash flood forecasting in the French Cévennes-Vivarais region. During the calibration procedure a necessity to enhance the TOPODYN model parameterisation appeared. In the current model version, the river velocity is a parameter statically chosen for each modelled cross-section. The sensitivity analyses showed that the computed discharge strongly depends on the chosen speed magnitude. Physically, the velocity depends on the instantaneous streamflow discharge and on the morphological properties. That creates the opportunity to enhance the model's physics by modifying the way by which the river velocity is defined. The establishment of parameters to dynamically adjust the river speed as a function of the streamflow discharge and the preliminary results with the modified model variant are presented in Section 3.6.

1.1. Current state and upgrades in the hydro-meteorological network and forecasts in the Arda River basin

NIMH monitors levels and discharges at 14 hydrometric sections in the river basin. In the framework of the project, five of them where equipped with automatic sensors and telemetry. Precipitation is measured by 14 standard (manual) and 14 automatic telemetric stations, six of them were installed in the course of the project. The last ones measure precipitation intensity, air temperature, air relative humidity and solar radiation. Some of the meteorological and hydrological monitoring stations are owned by the Energy System Operator (ESO). The stations are quite evenly distributed across the Arda River basin with a distance of about 20 km between them (Fig. 1). Data from telemetric stations, including hourly precipitation total, air temperature and humidity, and water level, are transferred to the computing centre of NIMH in Plovdiv every hour. The continuous data collection allows for the preparation of input data for the model but also for the generation of alerts based only on registered intensive precipitation and high water levels. Since 2006, the ESO has been working with NIMH to develop and operate a hydrological forecast system for energy production purposes. It aims to forecast three days ahead the water inflow into the three reservoirs of the Arda Reservoir Cascade (ARC) but not to compute peak discharges in endangered zones. The system uses ISBA–MODCOU coupled models and a cascade of two soil reservoirs that simulate the base flow (Artinyan et al., 2008). Streamflow forecasts are computed by the model using numerical forecasts for precipitation and other meteorological fields required by ISBA with a 3 h time step coming from the high resolution (7 km grid size) limited short range atmospheric model Aladin-BG (Aire Limitée Adaptation dynamique Développment International – Bulgaria). The latter was developed and is being used by NIMH in collaboration with Météo-France. Bulgaria, as a member of Co-operating States, started receiving the numerical forecasts of the European Centre of Medium Range Forecasts (ECMWF) during the last years. Deterministic model ECMWF forecast fields have a 3 h time step until the 144th h and a 6 h time step till 240th h with a grid size of about 12 km over Bulgaria. These data were not used for hydrological simulations before 2014.

1.2. The project partners, funding, tasks

The partners of NIMH in this project were: the East Aegean River Basin Directorate (EARBD) from Bulgaria as well as the Democritus University of Thrace department of civil engineering (DUTH) and the Regional Development Fund East Macedonia & Thrace (RDF) from Greece. The project was funded by the ETC Programme "Greece Bulgaria 2007–2013". It started in March 2012 with a planned duration of two years and a budget or €823 $\times$ 10^3, including €123 $\times$ 10^3 national co-financing. The project's tasks were organised according to each partner's role. The institutional partners EARBD and RDF had to establish the need of communities in both countries and to assure that concerned stakeholders were informed and trained in how to use the system, while the academic partners carried out the research and development tasks. For instance, EARBD defined, with the municipalities, the extent of the endangered areas in Bulgaria. NIMH created the Information System (IS) of the ARDAFORECAST project and ensured its maintenance. DUTH developed a set of hydraulic models and flood hazard maps for several discharge scenarios related to 0.1%, 1% and 5% probabilities of the maximum streamflow discharge of the Arda River for the Greek side. For the same probabilities, NIMH prepared flood hazard maps for the town of Smolyan in Bulgaria (NIMH-BAS, 2014).

2. Materials and methods

2.1. Brief description of the basin hydrology, floods generation and anthropogenic factors

The Arda River basin covers 5201 km^2 in south-east Bulgaria and 594 km^2 in north-east Greece (Fig. 1). The basin includes most of the Eastern Rhodopy Mountain zone with snow accumulation, mostly in its west and south-west areas (the highest peak Golyam