ГОДИШНИК НА УНИВЕРСИТЕТА ПО АРХИТЕКТУРА, СТРОИТЕЛСТВО И ГЕОДЕЗИЯ
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AN OPERATIONAL FLOOD FORECASTING SYSTEM FOR MEDIUM SIZE ALPINE CATCHMENTS

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ABSTRACT

The paper introduces the real-time flood forecasting system EFFORS (Enhanced Flood Forecasting System for Critical Infrastructure Protection in Medium Size Alpine Catchments). EFFORS brings together experts in the fields of meteorology, hydrology, hydrodynamics and satellite communication. Within a coherent modelling chain, the EFFORS system couples the individual numerical models and provides, on an hourly basis, 24-hour forecasts.

1. Introduction

Floods are among the most important natural hazards in Austria. Due to the high density of development and infrastructure next to already regulated rivers, usually a lack of natural retention areas is evident. This circumstance increases the difficulty of flood protection for authorities and private stakeholders. Besides constructional flood protection systems like dams, retention basins, etc., nowadays forecast systems gain importance. The improvement of

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numerical codes and the increase of computational power allow for more and more complex model chains. Thus, within EFFORS, additionally to the implementation of state-of-the-art meteorological and hydrological forecasts, a two-dimensional depth averaged model provides predictions of spatially highly resolved water depths and flow velocities in the river and surrounding floodplains. To reduce computational efforts, the two dimensional models are operated only in critical areas and if certain thresholds are exceeded. The EFFORS system is developed by an international group of engineers and researchers and will be operated by the Austrian national weather service ZAMG (Central Institute for Meteorology and Geodynamics).

2. System Design

2.1. System Overview

The EFFORS system produces hourly updated 24-hour forecasts of not only heavy precipitation, discharge within the river but also local flood plains. To achieve this, EFFORS uses earth observations in combination with a numerical model chain. The individual system modules are linked by means of C++/Python programs, which gather required data for the operational service, provide interfaces/coupling between the modules, perform post-processing tasks and store relevant data. In this paper this program is further referred to as the *shell*. At the full hour, the shell first gathers required information from catchment observations and the numerical results of the meteorological model. These data are fed to the hydrological model. The hydrological model performs the rainfall-runoff modelling for the entire catchment and yields the hydraulic boundary conditions for the 2D hydrodynamic model. The latter computes the local floodplains in the zone of interest. The 2D modelling module, with 40 minutes maximum allowed computation time, requires the most resources and thus, represents the bottleneck of the hourly update interval. The model results are post-processed and updated within the web-portal. Furthermore, warnings are sent out if predefined thresholds are exceeded. Fig. 1 shows an overview of the performed tasks, whereas Fig. 2 gives a detailed insight into the architecture of the EFFORS system.

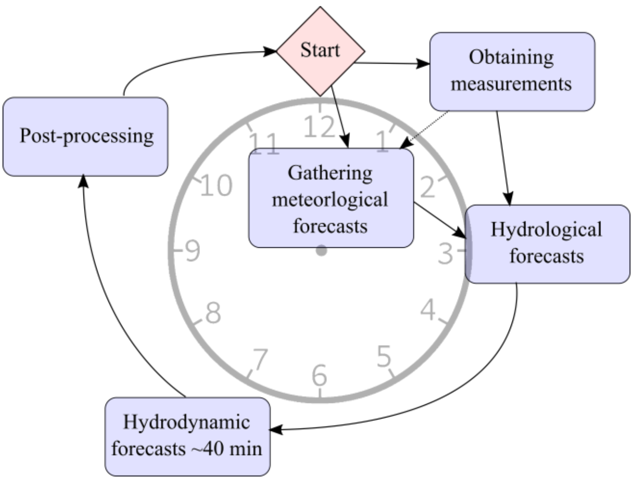

Figure 1. Outline of the model chain

2.2. Catchment Observations

Measurements and earth observations form the first part of the EFFORS system. Generally, it has to be distinguished between static and dynamic catchment data. Static data are all information of the catchment, which are required to build, calibrate and validate the numerical models. All static data are available within the EFFORS database. Contrarily, dynamic data are all information required for the real-time operation of the service, such as meteorological observations or discharge measurements from gauges. The dynamic data are transferred to the servers of the service provider (ZAMG) via terrestrial communication as well as by means of satellite technology in order to allow for a redundant 24/7 service.

2.3. Numerical model Chain

Meteorology

As for the meteorological part the forecasting model INCA is used. INCA provides information of temperature, precipitation, relative humidity, global radiation and wind speed with a spatial grid resolution of 1 km. The temporal resolution is one hour. Additionally, INCA provides the option to work with a 5-minute resolution with a maximum forecast period of 1 hour in order to predict convective, heavy precipitation events. For these short term forecasts the observations are obtained mostly by weather radar measurements.

Hydrology

Within EFFORS two different hydrological models are used. One is DHI Mike Hydro, the other one is WaSiM-ETH. The WaSiM model is operated on a Linux based operating system, whereas Mike Hydro is running on a Microsoft Windows operating environment.

Hydrodynamic

The 2D depth averaged hydrodynamic modelling is carried out by means of the open source software TELEMAC-2D. The software is highly adaptable, scales well even with high number of processing cores and, thus, is excellently suited for operating in real-time. Because of the very limited available computation time, high quality numerical grids are required. Furthermore, appropriate numerical settings and schemes are chosen to allow efficient computation (timewise) whilst providing maximum accuracy and stability. To save computational resources, the two-dimensional model is only operated if a certain discharge is forecasted by the hydrological model. After the decay of the hydrograph the model stops operation and is set back to its initial state. Resetting the model is required since certain physical processes like infiltration or evaporation are not accounted for.

2.4. Post Processing

Within the post-processing module, user specific data are extracted from the modelling results. The results are visualized in the web-portal but also warnings via SMS or E-Mail, which are based on individual thresholds, can be sent out. Furthermore, all relevant data for reproducing historical events are stored in a database.

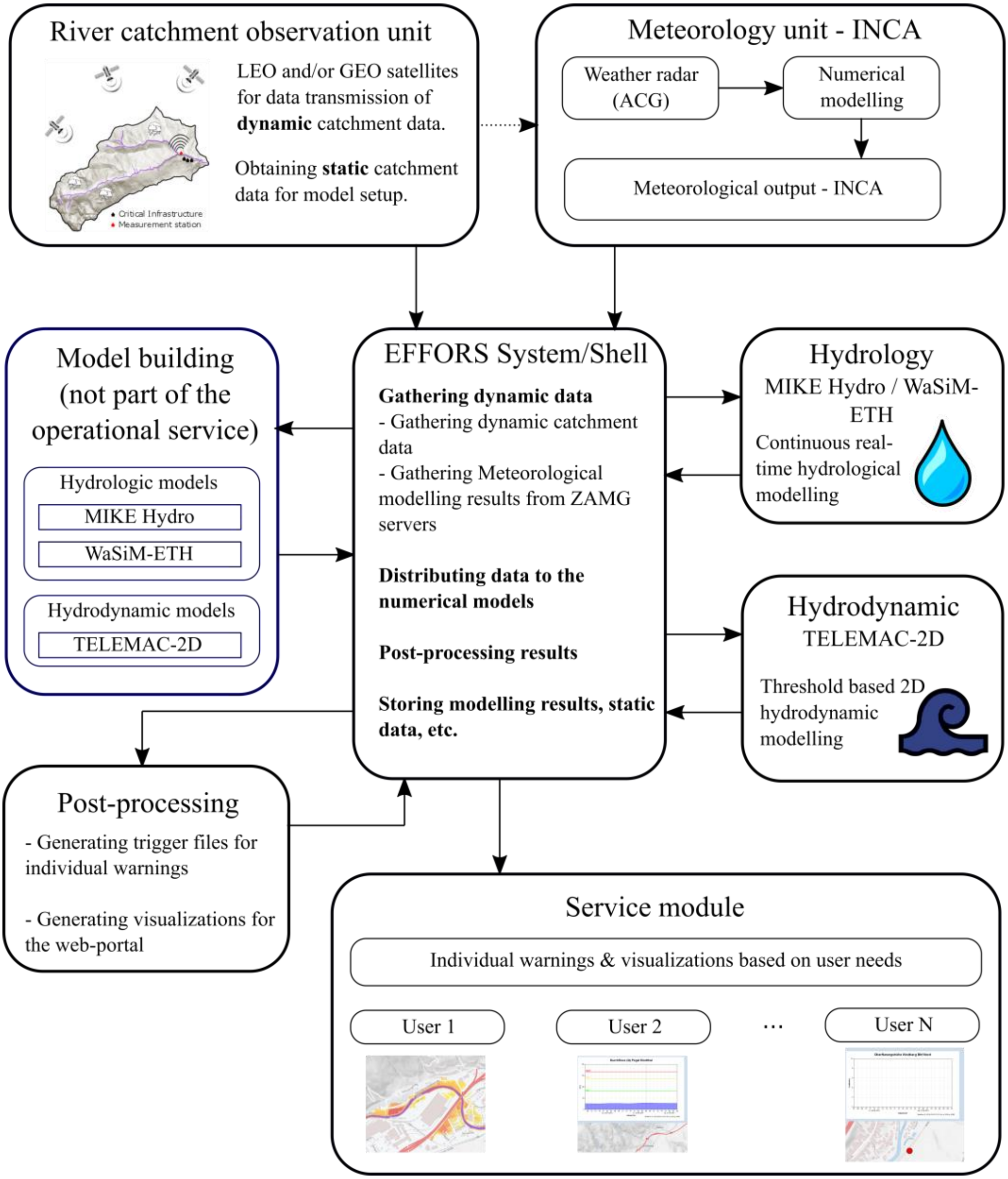

Figure 2. EFFORS system architecture

3. Current State of the EFFORS Project

Currently, EFFORS is in the demonstration phase in which the system is setup for three selected pilot catchments and the service is tested by potential users. Two of the catchments are located in Austria (Mürz and Kainach) and one in Germany (Berchtesgaden). The selected pilot catchments are visualized in Fig. 3.

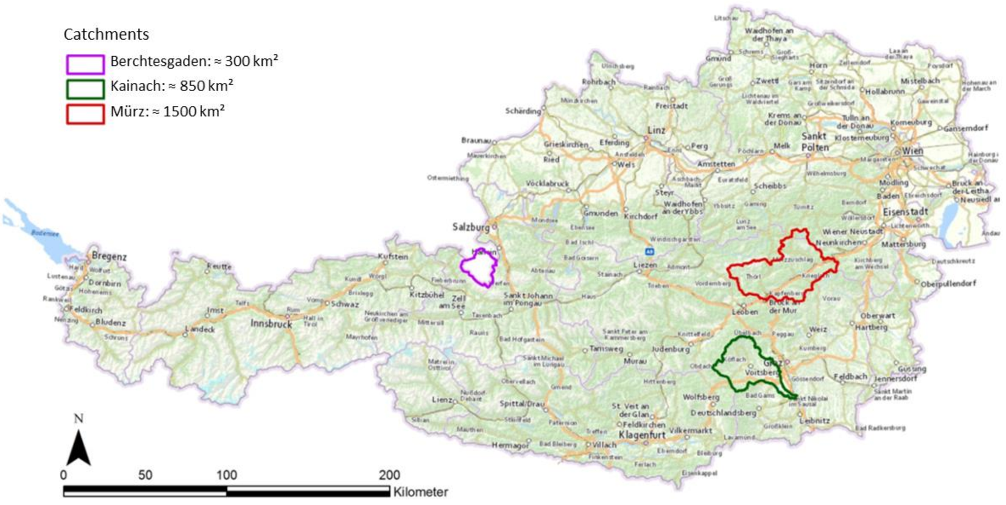

Figure 3. Pilot catchments

EFFORS is developed in close cooperation with potential users. Already at the beginning of the project in 2014, a workshop with owners of critical infrastructure, authorities, disaster management services and other stakeholders was held. The workshop gave valuable insights to the very specific user needs and had a large impact on the development of EFFORS. It showed that distinct user groups had different requirements to the system. For example, owners and operators of critical infrastructure named the following requirements:

- Sufficient lead time for warning of flood events;
- Information of temporal evolution of discharge and water levels for given thresholds;
- Forecasts of discharges and water levels at point locations.

Whereas authorities and disaster management services are mostly interested in:

- The improvement of existing flood forecasting systems for small and medium sized catchments;
- Improvement of preparation for floods;
- Fulfilling the goals of the EU Water Framework Directive;
- Warning of communities and authorities to increase the safety against damages caused by floods;
- Transmission of information via SMS and E-Mail.

4. User-Specific Results

The results of the numerical models contain a lot of spatially and temporarily highly resolved information. This allows for highly customized visualizations and warnings of individual users. The currently available forecast results are described hereafter.

Weather Information

Within the web-portal spatially distributed meteorological forecasts of temperature, precipitation and the snow line are available. The forecast horizon is 3 days and the temporal resolution is one hour. Additionally, higher resolution forecasts are available for the next hour. This highly resolved forecast is also used to generate E-mail and SMS warnings for heavy rain events. Fig. 4 (left) shows the forecast of precipitation at a certain time. Furthermore, the meteorological modelling results provide point information of temperature, precipitation, accumulated precipitation and the snowline. The data are available in the form of time series plots and are exemplary visualized in Fig. 4 (right).

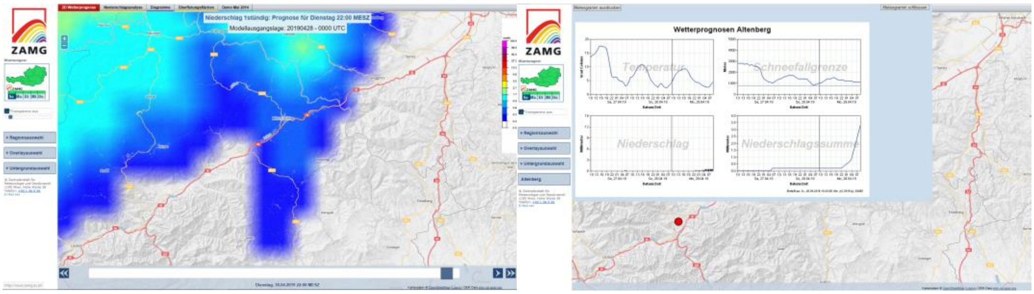

Figure 4. Forecast of precipitation (left); Forecast of meteorological data for a user defined point (right)

Discharge Information

Information about discharge in the river is available for a forecast period of 24 hours. The temporal resolution is 1 hour. Similarly to the point information of the meteorological data, users are able to define points of interest within the river for which the discharge is extracted. Fig. 5 (left) shows an overview of user points in the Mürz River. Fig. 5 (right) shows the discharge time series of one of the points.

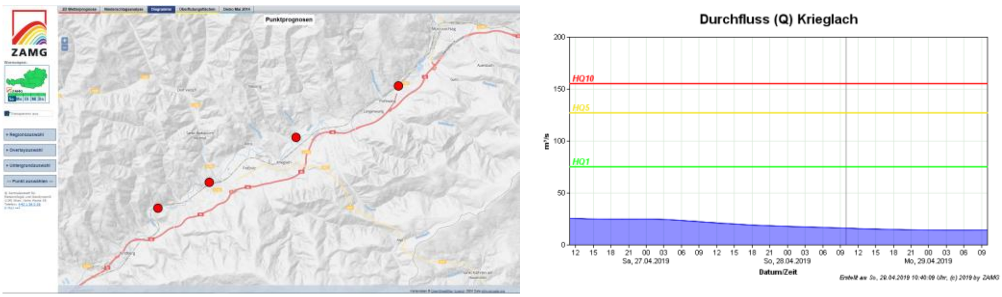

Figure 5. User points for discharge (left); discharge time series (right)

Spatially Distributed Hydrodynamic Information

Besides meteorological and hydrological forecasts, EFFORS offers 24-hour forecasts of hydrodynamic information in flood plains. EFFORS provides contour plots of water depth with a temporal resolution of 1 hour. Additionally, users can define points of interest within the computational domain and get a forecast of the water depth at that specific point. A threshold for the water depth can be set; hence, at exceedance the responsible authority can be warned. Other valuable information of the two-dimensional results is the time and location of the first overflowing of the floodplain. This information allows efficient use of manpower, e.g. civil protection, in case of flood events. Fig. 6 (left) shows exemplary results of the 2D simulated flood forecast within the EFFORS web-portal. Information of water depth of the operational model of one user point is shown in Fig. 6 (right).

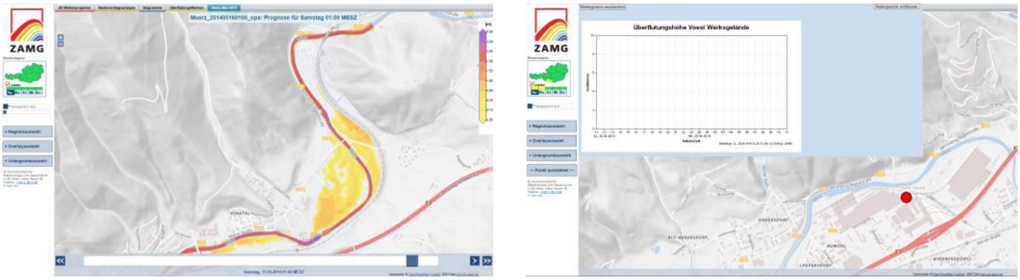

Figure 6. 2D simulation result (left); Forecast of water depth at a certain user point (right)

5. Conclusion

A real-time flood forecasting system is developed and is operated at the computational center of the ZAMG. Within EFFORS the challenging task of real-time forecasting of spatially highly resolved hydrodynamic data is tackled. Currently three selected catchments are implemented and tested by potential users. EFFORS will support public and private stakeholders at their task of flood protection.

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