Merged satellite information and ground measurements of the precipitation for hydrological modeling

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The availability of detailed well distributed in space information on precipitation is of essential importance for the hydrological modeling. Conventional measurements of precipitation are in a limited number of points represented by synoptic, climatic and precipitation stations. This information is not sufficient for correct spatial distribution of precipitation. The distribution of the ground stations are quite irregular and thus distances between stations could be quite big, sometimes more then 30 km. On the other hand, precipitation has high variability in space. The results of the spatial distribution depend on the density of the ground measurements. Precipitation estimated from satellite information includes spatial information that could be used to ameliorate precipitation field based only on ground stations. This paper presents the results of an application that merges satellite information with conventional ground measurements of the precipitation for hydrological modeling purpose. Hydrological simulation will be performed with 3 types of precipitation fields. Simulation using satellite information for precipitation, simulation with real measured precipitation and with merged information for precipitation. Geographic Information System (GIS) and ArcInfo techniques will be applied for spatial distribution and spatial analysis of the precipitation data. Relevant analyses and conclusions will be provided.

Introduction

In this study 24 h accumulated precipitation was tested. The tested period is rainy period 11.04 - 21.04.2011. The study areas are:

Watershed of the Iskar river basin up to the hydrometric station Novi Iskar with area 3553 km². Iskar river is the largest Bulgarian tributary of the Danube, with a total length of 368 km and a catchment area of 8 684 km². Its headwaters lie up in the passes of the Rila Mountain. The mainstream flows through the outskirts of Sofia, and the Balkan Mountains. The study area is a part of Iskar river watershed and is 3558,462 km². The main tributaries are Lesnovska river, Vladaiska river, Bankenska river and Blato river (Fig. 1). Two big towns are situated along the river – Sofia and Novi Iskar. The adequate and on time flood forecasting information is very important for the flood prevention of these towns. Floods were a major problem for Bulgaria in 2005. In the study area some of the biggest floods that ever happened in our country, occurred in the above mentioned year – in June and August.

The catchment of the Varbitsa River up to hydrometric station Djebel with area 1151 km². The Varbitsa River is situated in the South Bulgaria and is part of the Arda’s catchment – its right tributary. Its springs are situated just below the peak Martazyan in the South-East Rodopi Mountain. The length is 98 km, the catchment area is 2207 km². and flows in the Studen Kladenets Dam (Fig.1).
Data availability and preparation

For this study were used 18 meteorological stations in Iskar river basin and 7 meteorological stations in Varbica river basin. It should be mentioned that for Varbica river basin 3 of the meteorological stations are automatic ones. All data used were either 24 hours totals (for the precipitation) or daily means values (temperatures, discharges).

The product which is used was PR-OBS-05. It is based on frequent precipitation measurements as retrieved by blending LEO MW-derived precipitation rate measurements and GEO IR imagery (products PR-OBS-3 and PR-OBS-4). The product covers area of 900 by 1900 pixels (fig. 2).
Fig. 2. The H-SAF required coverage in the Meteosat projection

The data from this product are stored in GRIB2 format developed by the World Meteorological Organization. It is the newest format and is used to carry out the EUMETSAT - SAF products.

Using the produced code for decoding this format into ASCII files, in our institute we modified a little the code and thus we are able now to get data from a specified by an operator rectangular region. Thus we simplified the task of working with enormous files. After that using the produced by the authors numerous macros and programs in Visual Basic by means of which we are able to calculate different statistical parameters. On the picture below (fig. 3) are given the product pixels which are over the studied areas together with all the meteorological and hydrological stations used in this study.

Fig. 3 Studied Watersheds with the satellite pixels and the available hydrometeorological data over them

Ground data for 24h measured precipitation for the period 11.04-21.04.2012 was spatially distributed using GIS techniques. ArcGIS Geostatistical Analyst was used
for spatial data exploration. It is well known that the altitude influences the formation of precipitation amount. Rainfall is higher over the mountains. Cokriging is an advanced interpolation method that improves interpolation by taking into account secondary variable. In this study DEM (Digital Elevation Model) is included to improve spatial distribution of the precipitation. The results are presented in Fig. 4.

![Fig. 4. Spatial distribution of the daily precipitation measured at meteorological stations](image)

Satellite data was spatially distributed using Radial Basis Functions (RBF) via ArcGIS Geostatistical Analyst. The result is presented in Fig. 5.

![Fig. 5. Spatial distribution of the daily precipitation at the satellite points](image)
Difference between satellite data and ground measured data was calculated in GIS environment using grids with pixel size 200 m of spatially distributed satellite and measured data. The resulted differences are presented in fig.6.

Fig. 6. Calculated difference between grid of satellite and grid of measured ground precipitation data

For each meteorological station the value was extracted from resulted grids. These values were spatially distributed using Radial Basis Functions (RBF) over the two studied watersheds and converted in grids. The result is presented in Fig.7.

Fig. 7. Extracted points for creating difference between satellite and ground measured precipitation data
Combined grids were obtained after subtracting grid with distributed differences from grid of spatially distributed satellite precipitation data. Resulted grids were calculated using Raster calculator in Spatial Analyst. The merged precipitation maps for studied watersheds are presented in Fig.8.

Fig. 8. Merged precipitation maps for studied watersheds

Precipitation data from merged precipitation maps were used in hydrological modeling. For this purpose cell values of the combined grid were extracted to the satellite points. The values at satellite points are presented in Fig.9.

Fig. 9. Extracted values from merged precipitation maps at satellite points
Hydrological modeling

Two types of streamflow simulations were provided using Artificial Neural Networks (ANN) and NAM module of MIKE11 modelling platform.

Artificial Neural Networks (ANN) are applied for simulating of streamflow at a hydrologic station Novi Iskar based on observations at the hydrometric station and rainfall values at meteorological stations located in the study catchment. Artificial Neural Networks treat the hydrological system as a black box and try to find a relationship between historical inputs (rainfall, temperature, etc.) and outputs (runoff). Recently Artificial Neural Networks are widely used as a potentially useful way for modeling complex process such as a runoff.

Daily mean discharge data measured at the hydrological station, daily accumulated precipitation data measured at the meteorological stations was used for established ANN model. The length of records is 15 years covered period 1991-2006. The test simulation was performed with 3 types of precipitation fields. Simulation using satellite information for precipitation, simulation with real measured precipitation and with merged information for precipitation. The results are presented on Fig. 10.

The NAM hydrological model simulates the rainfall-runoff processes occurring at the catchment scale. NAM forms part of the rainfall-runoff (RR) module of the MIKE 11 river modelling system. The NAM is a set of linked mathematical statements describing, in a simplified quantitative form, the behaviour of the land phase of the hydrological cycle. NAM represents various components of the rainfall-runoff process by continuously accounting for the water content in four different and mutually interrelated storages and several parameters accounting for the different complex processes of the cycle. Each storage represents different physical elements of the catchment. NAM can be used either for continuous hydrological modeling over a range of flows or for simulating single events.

Here the daily mean discharge data was also used over the period of 8 years (2000-2007) for the calibration of the model with ground data. Additional data like daily
mean temperature, daily sums of precipitation and estimated monthly values for evapotranspiration were used for establishment of the model.

The simulation was performed with 3 types of weighted precipitation daily totals: Simulation using satellite information for precipitation, simulation with real measured precipitation and with merged information for precipitation. The results are presented on Fig. 11.

Fig. 11 Simulated discharge with NAM model

Conclusions
This study presents investigation of the effectiveness of combining conventional ground measurements of the precipitation and satellite precipitation data in stream flow simulation.

The study shows that the satellite products together with ground data could be very useful for prediction of flash floods which could occur in areas with no ground data coverage.

This techniques (of merging ground and satellite data) is very useful for spatial distribution in mountainous areas.

The authors consider that this techniques could be very useful in building warning systems for flood prevention.
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