APPLICATION OF A DISTRIBUTED BIOSPHERE HYDROLOGICAL MODEL TO MEDJERDAH BASIN, NORTHERN AFRICA

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ABSTRACT

To reduce flood damages due to heavy rainfall events, a timely flood alarm warning becomes a crucial issue. Since high potential evaporation can be expected in semi-arid regions, a water and energy budget-based distributed hydrological model was employed. This study attempts to forecast flood peaks using quantitative precipitation forecast and satellite rainfall TRRM, additional to the in-situ data, in order to contribute to the River management and adaptation to climate change. The approach was applied to Medjerdah River basin in Northern Africa showing the feasibility to support flood management.

Keywords: Medjerdah River, Flood forecast, Satellite rainfall, Distributed hydrological model

1. INTRODUCTION

Flood hazards are very likely to be intensified due to the global warming according to the fourth assessment report of the Intergovernmental Panel on Climate Change, IPCC [1]. Heavy rainfall causing floods can be attributed to large water cycle variations at global and regional scales, while flood damages occur at basin scale. The frequency of these events has increased over most land areas, consistent with increases of atmospheric water vapor.

The conventional physical approach to simulate flood events is the usage of distributed hydrological models. They are capable to assimilate rainfall patterns and estimate fluxes like river discharge at selected points, spatial distribution of soil moisture content, evaporation and transpiration. A proper initial soil moisture condition and estimation of evapo-transpiration are crucial for flood forecast. Actually, the energy transfer between land surface and lower atmosphere is neglected by the hydrological models, Yang et al. [2]. However, land surface models focus on this energy transfer in the vertical direction. The recent generation of land surface models describes the vegetation effect with a realistic canopy photosynthesis-conductance. They are key components to improve atmospheric Global Circulation Models (GCM). This generation of land surface models is able to describe the heat transfer and CO2 assimilation physically-based. However, they simplify the water movement; actually, it is considered only in the vertical axis. Then, it makes sense to combine both models to improve the water and energy cycles representation within a basin which can eventually improve the simulation of high and low flow conditions. A very well known land surface model so-called Simple biosphere model (SiB2; Sellers et al. [3]) was embedded in a geomorphology-based hydrological model GBHM (Yang et al. [4]) coming up with a Water and Energy Budget-based Distributed Hydrological Model (WEB-DHM; Wang et al. [5]). The advantages of the coupled model over the GBHM alone were showed at affordable computing cost (Wang and Koike [6]). Also a consistent study using satellite products showed the benefits of using the coupled model, Wang et al. [7]. However, the new distributed biosphere hydrological model was not yet applied in semi-arid basins like in Northern Africa where floods also might take place. The present study attempts to forecast flood peaks using quantitative precipitation forecast and satellite rainfall, additional to the in-situ data, in order to contribute in the River management and adaptation to climate change.

2. METHODS

This study employs global circulation model output and satellite rainfall measurements in order to contribute to societal benefits at basin scale as seen the left path in Fig. 1. It employs the distributed biosphere model WEB-DHM, already tested with success in the Little Washita basin, Oklahoma (Wang et al. [5]) and the upper Tone River in Japan, Wang et al. [7]. The model demonstrated the ability to reproduce point-scale energy fluxes, CO2 flux, and river discharges. Moreover, the model showed the ability to predict the basin-scale surface soil moisture evolution in a spatially distributed fashion.

Actually, WEB-DHM couples the SiB2 with advanced physics, and the grid-based GBHM with physical water movement description. At each model grid SiB2 uses one combination of land use type and soil type to calculate turbulent fluxes between the atmosphere and land surface independently. Then SiB2 updates surface runoff and subsurface flow that make the lateral inflow to the main river channel. Afterward, the GBHM is used to conduct the water flow within the river network using one-dimensional kinematic wave equations.

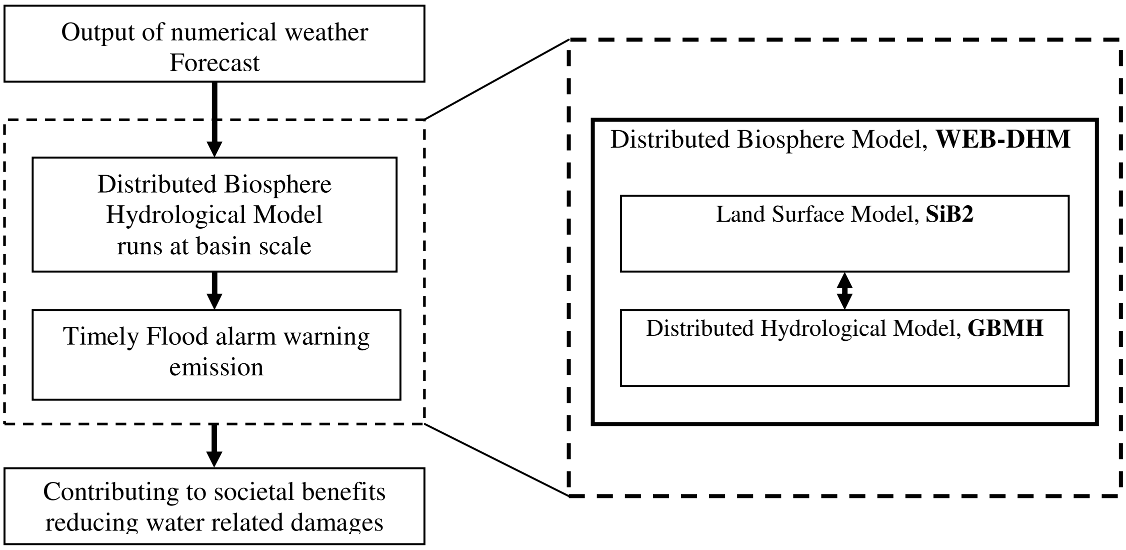

Fig. 1 Overview of the proposed approach

3. APPLICATION

The headwaters of the Medjerdah River basin are located in eastern part of Algeria while the middle reaches and outlet are in Northern Tunisia as displayed in Fig. 2. The Medjerdah River is a very important source of water supply, irrigation and power generation mainly for Tunis Metropolitan area and surroundings, Rodier et al. [8]. Therefore, its management is crucial for the region. The delineated watershed reaches 23,140 km^2. The elevation varies from sea level to about 1680 m. Heavy rainfalls events occur from January to March and are commonly associated with seasonal front activities. One of the latest heavy rainfall event recorded in the region was in January 2003 with 72 mm within 4 days. This catastrophic flood affected thousands of people. During that event, the embankment was surpassed causing the flooding area to also include Tunis metropolitan area. Owing to these deficiencies, emphasis was then made on the development of reservoir operation as well as embankment improvements at middle and lower reaches.

3.1 Spatial data

The first step in building the described model is to delineate the modelling area from a digital elevation model (DEM) using a geographic information system (GIS). The DEM is crucial in tracking the flow direction and defining the river network in the basin. Here, the geomorphology was obtained using a global DEM with a horizontal grid spacing of 30 arc seconds (approximately 1 km) so-called GTOPO 30 arc-sec (http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info), see left part of Fig. 3. Then, Global land cover characteristics at 1-km resolution (http://edc2.usgs.gov/glcc/glcc.php) were prepared and clipped to the delineated watershed using GIS tools. Land use data was reclassified according to SiB2 categories, where dwarf trees and agriculture were found to be the dominant upstream and downstream respectively as seen in right part of Fig. 3. The soil type was determined from the Food and Agriculture Organization global soil maps [9], which include derived soil water parameters associated with each soil unit (available at: http://www.fao.org/AG/agL/agll/dsmw.stm). The parameters used were the saturated hydraulic conductivities, saturated and residual water content, and Van Genuchten's constants. Similarly as for land use, the soil unit data was clipped to the delineated watersheds using GIS.

Fig. 2 Location of study Area

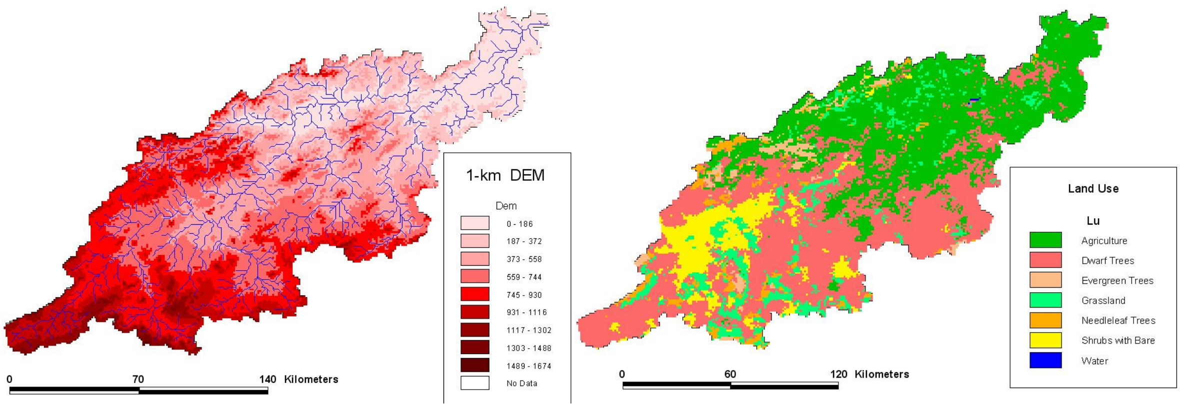

Fig. 3 Topography (left) and Land use (right)

Thematic maps such as surface terrain slope, topsoil depth, and hillslope length were then derived from the basic data above using GIS commands. The dynamic vegetation parameters such as Leaf Area Index (LAI) and Fraction of Photo synthetically Active Radiation (FPAR) were obtained from satellite MODIS data (ftp://*primavera*.bu.edu/pub/datasets/*MODIS*/). The air temperature, wind speed, relative humidity, air pressure and sunshine duration were obtained from the 25-year global Japanese re-analysis project (JRA25) (http://jra.kishou.go.jp/JRA-25/index_en.html). Downward solar radiation was estimated from sunshine duration, temperature, and humidity, following Yang et al. [10]. Longwave radiation was then estimated from temperature, relative humidity, pressure, and solar radiation following Crawford and Ducho [11].

3.2 Temporal data

Once the drainage area of the basin was defined, observed time series data were prepared. The rainfall amounts recorded by the rain gauge network, indicated with red dots while stream flow gauges with triangles as shown in Fig. 4, were used as input data for the model. It can be noticed that the Mellegue sub-basin is much larger than the other two. Actually it represents the intake from Algeria.

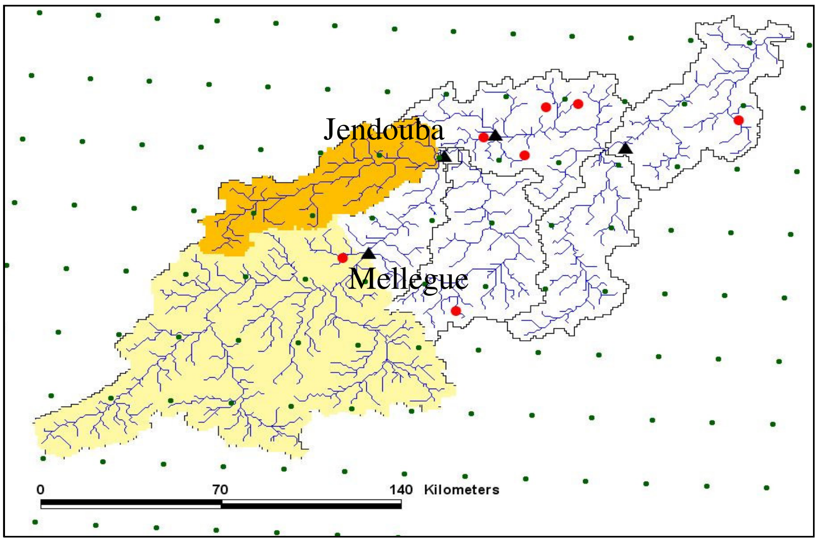

Fig. 4 Location of rain gauges (red dots), TRMM distribution (green dots) and river discharge gauges (black triangles)

Besides observed values at the surface, observed satellite values from the Tropical Rainfall Measuring Mission (TRMM) were also used to improve the spatial distribution. The TRMM is a joint mission between NASA and the Japan Aerospace Exploration Agency to monitor and study tropical rainfall and energy exchange, Kummerow and Simpson [12]. The satellite has been in orbit for more than 10 years. The efforts to improve estimations of TRMM multi-satellite precipitation analysis

TMPA) with different applications was reported by Huffman et al. [13]. The 3B42 version 6 product, which includes calibration with monthly merged rainfall from the Global Precipitation Climatology Project (GPCP), was used in this study. The TRMM product has a 3 hourly temporal resolution and 0.25° spatial resolution. (http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=TRMM_3-Hourly). Recent literature (Islam and Uyeda [14]; Chokngamwong and Chiu [15] and Saavedra et al. [16]) reported the potential of TRMM datasets especially in humid basins such as in Bangladesh, Thailand and Vietnam; however, it would be also interesting to extend the application of TRMM product in semi-arid regions. The Japanese Meteorological Agency global scale model (GSM) provides, among other weather variables, quantitative precipitation; i.e., the grid point value (GPV) at 1.25° spatial resolution issued every 12 h and recorded with different lead times. The dataset is archived from July 2002 to present and can be accessed from the archiving system at the University of Tokyo at http://gpv.tkl.iis.u-tokyo.ac.jp/GPV/.

4. RESULTS

The river network of the Medjerdah River obtained using global datasets was introduced in previous section. The delineated area obtained using the 1-km DEM was very close to that obtained using a fine DEM. Due to its magnitude; this study targeted the heavy rainfall event of January 10-13, 2003. The situation before and during the main flood was targeted. The hydraulic conductivities of top soil layers, surface storage and anisotropy were calibrated by running the model for a couple months ahead. The calibrating method was trial-and-error reduction of the root mean square difference between simulated and observed river discharges. Three different types of rainfall data were used: rain gauge, observed satellite TRMM and global forecast GPV data with 24 h lead-time. Simulation results from the Medjerdah River basin were examined for the stream flow values as in Figs. 5, 6.

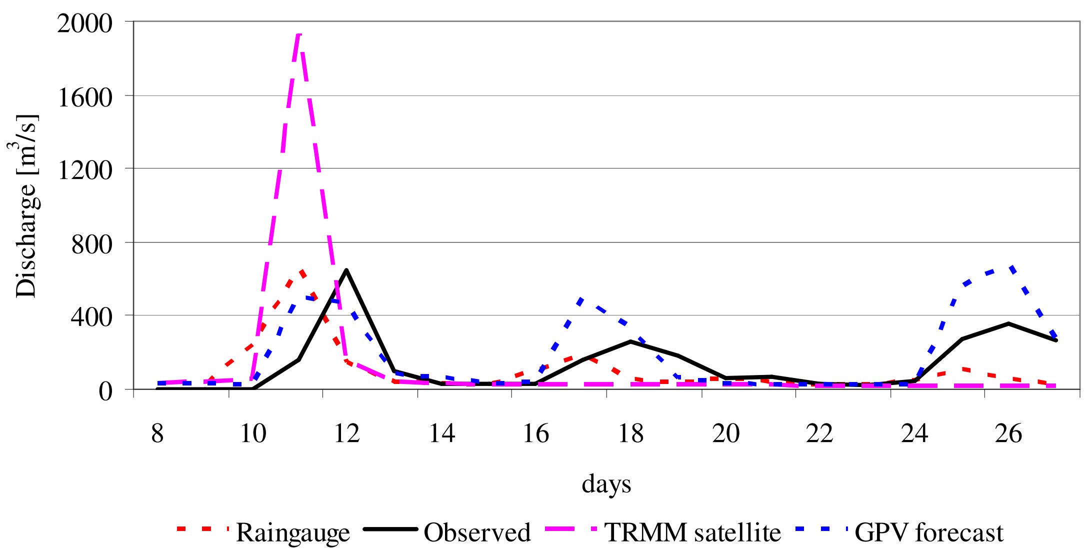

Fig. 5 Flood events at Jendouba station in January 2003

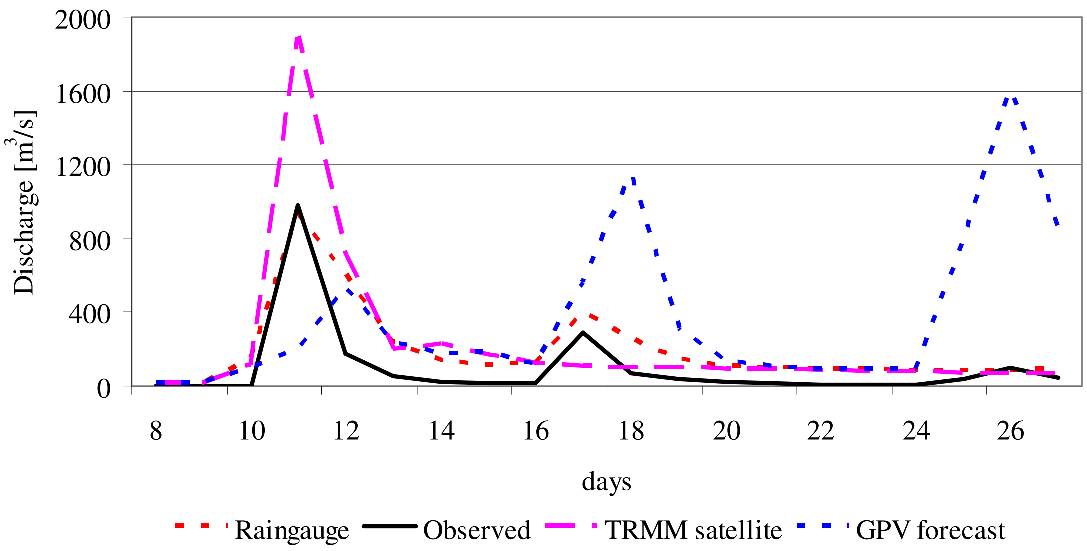

Fig. 6 Flood events at Mellegue station in January 2003

It can be noticed that the simulated discharge using rain gauge stays close to the observations for almost whole month. The simulated flow using TRMM overestimates the main event but correctly identifies the timing of the peak. On the other hand, the GPV data underestimate the main peak and overestimates the following two.

5. CONCLUSIONS

It can be concluded that the new distributed biosphere hydrological model is able to intake quantitative precipitation forecast and satellite measurements in semi-arid basins. The application of flood simulations using global rainfall forecasts showed promising results compared with observed values. Besides rain gauge data, satellite TRMM data were used as observed rainfall. The performance of the global forecast is indeed very valuable to the extension of the lead-time. Actually, a flood warning would have been activated with 24 h prior to the occurrence of the anticipated event. Then, the lead-time at Tunis area would have been extended up to 40 h allowing taking the proper countermeasures like start evacuation. This is a crucial advantage in using global forecasts for the specific heavy rainfall event in January 2003 and cannot necessarily be generalized. This should be confirmed by analyzing more events in the future and continuing the exploitation of global forecasts. Simulated stream flow using observed satellite TRMM data was found to be overestimated with the ground-based measurements during the simulated flood peak of 10-13, but the timing was identified. Actually, using measurements upstream, the concentration time would allow also activating the flood warning. In this case the level of flood alarm would have overreacted compared to the actual stream flow. TRMM Satellite rainfall might support the few existing gauges. Again, these findings need to be validated with more events.

Since the missed/overestimated precipitation pattern might be located in the surroundings of the basin, a weighting of the forecast error could be extended to a wider domain accounting location, intensity and extension. Moreover, the single signal of the quantitative precipitation forecast could be perturbed according to the inaccuracy of the forecast generating ensemble members of rainfall. After forcing the distributed biosphere hydrological model, an ensemble stream flow can be obtained to feed the system and get the flood warning instructions associated with uncertainty.

In this study only quantitative precipitation forecast was used as real-time forcing data; however, it is feasible to include other atmospheric model output data in future developments such wind speed and direction. Other valuable application is long-term simulation of evapo-transpiration and soil moisture which is critical for semi-arid basins such Medjerdah. Finally, the improvement of soil moisture representation this system could be beneficial for Land Data Assimilation Systems (LDAS) to get better initial surface condition crucial for atmospheric prediction, e.g. Boussetta et al. [17]. The approach presented here could be applied and extended at semi-arid river basins located in Egypt for flood warning alert system support or water resources management according to the specific needs.

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