International Conference on Hydroinformatics

2014

Coupling Spatial And Time Scales In The Hydrological Modelling Of Mediterranean Regions: WiMMed

Javier Herrero

Agustín Millares

Cristina Aguilar

Marta Egüen

Miguel A. Losada

See next page for additional authors

Authors
Javier Herrero, Agustín Millares, Cristina Aguilar, Marta Egüen, Miguel A. Losada, and María José Polo

11th International Conference on Hydroinformatics
HIC 2014, New York City, USA

COUPLING SPATIAL AND TIME SCALES IN THE HYDROLOGIC MODELING OF MEDITERRANEAN REGIONS: WIMMED

HERRERO, J. (1), MILLARES, A. (1), AGUILAR, C. (1), EGÜÉN, M. (1), LOSADA, M.A. (1), POLO, M.J. (2)

(1): Fluvial Dynamics and Hydrology, IIISTA University of Granada, CEAMA, Avda del Mediterráneo s/n, Granada, 18006, Spain.

(2): Fluvial Dynamics and Hydrology, IIISTA University of Córdoba, Campus de Rabanales, Área de Ingeniería Hidráulica, Córdoba, 14071, Spain.

Mountainous Mediterranean catchments usually exhibit strong gradients of weather variables and soil properties and uses, which add complexity to their hydrologic modeling. WiMMed (Water integrated Management model for Mediterranean regions) was designed to include that variability of scales in an operational suite capable of connecting GIS-based representations of the catchment with advanced algorithms for simulating its energy and water balance on a physical basis. WiMMed efficiently represents the spatial patterns of meteorological inputs on an hourly basis by means of specific interpolation algorithms. It is also capable of incorporating the actual evolution of vegetation and snow cover fraction by the optional inclusion of data derived from remote sensing. These high resolution data inputs to the physical equations of the energy and water balance performed at different control volumes allow the distributed characterization of water and sediment dynamics. WiMMed's physical basis together with its high resolution multiscale scheme provides managers with an advanced support tool for flood/drought studies, natural regime restitution, short to long term water resource planning, evaluation of changes in soil use, etcetera. This work shows WiMMed capabilities from its use in selected watersheds throughout Andalusia (Spain) performed on the available free-distributed users' interface designed for technicians.

INTRODUCTION

Water resource management requires models that: 1) describe the integral response of the watershed, 2) reproduce the behavior of all processes involved in the most realistic way, and 3) consider spatial and temporal scale effects in all the processes involved. In order to achieve these objectives, physically-based models are preferred as they are not subject to wholly empirical calibration [1]. This also allows the development of methodologies applicable to non-monitored areas or under different management conditions from those used for the calibration of the model. As for the spatial modeling approach, mountainous Mediterranean catchments usually exhibit a high variability of the soil properties and uses, as well as strong gradients of the weather data at different time scales [2] [3] [4]. Their hydrologic modeling is especially complex and challenging. The computing power of present computer systems makes it possible to apply modeling on smaller spatial units in a reasonable execution time. Thus, a distributed implementation of physical models is feasible, although it demands advanced algorithms capable of correctly representing the spatial patterns of meteorological inputs on an hourly and/or daily basis. The rigorousness and accuracy of the results will depend on the quality of the spatially-distributed inputs available to the model and the suitability of the global and/or analytical model for the spatial and temporal scale of the research [5]. It should not be forgotten that terrestrial water balance is known to be a highly nonlinear and spatially variable process, especially because of the key role of soil moisture and its spatial and temporal variability [6] [7].

Spatial and temporal quantification of water flows in a watershed constitutes the first step in the determination of sediment fluxes and associated substances [8]. Thus, scale effects in the former will determine scale effects in the latter. On the other hand, scale effects are especially important in heterogeneous watersheds where spatial variability of parameters and inputs, processes determining intermediate variables, and the heterogeneous temporal frequency of datasets for model calibration, make such effects even greater.

The watersheds in Andalusia, southern Spain (Fig. 1), are a very clear example of manifold heterogeneity. Elevations in the region range from 3480 m to sea level. The areas modeled with WiMMed here are, mostly, coastal and mountainous basins, with a concentration time of under 10 hours. The Mediterranean climate is shaped by the proximity of the Atlantic Ocean, the high mountain climate and continental influence. Thus, these watersheds are recurrently subjected to torrential rain storms at the beginning of the autumn as well as to persistent hyper annual droughts. Snow has an important hydrologic incidence too, and there is a high rate of sediment generation and soil loss. The combination of such characteristics together with the altitudinal gradients, meteorological variability, and the large amount of vegetation, landforms and soil types, produces a complex mountainous territory with variable hydrologic behavior in space and time.

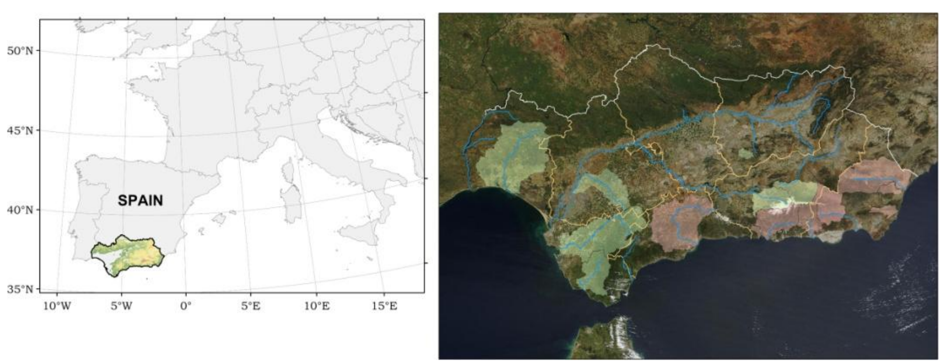

Figure 1. Location of Andalusia, in Southern Spain, and watersheds modeled with WiMMed.

The WiMMed model is an essential part of the results obtained by the Guadalfeo Project (http://www.cuencaguadalfeo.com). This study, started in 2004, was promoted by the Andalusian Water Agency, belonging to the Regional Government of Andalusia. The motivation for the Guadalfeo Project was to propose a global management model for Mediterranean basins in Andalusia. Therefore, the WiMMed model was originally conceived as a technological tool for management: a connection between the present hydrologic knowledge in the scientific world and the managers that have to make decisions based on an accurate comprehension of reality. In fact, we deliver periodic workshops on the program that are mainly intended for staff related to water management in the regional administration. That is the reason why WiMMed is implemented with a user-friendly interface, whose current second version, including water fluxes and sediment generation and transport, is presented in this work.

MODEL DESCRIPTION

Theoretical background

WiMMed (Watershed Integrated Model in Mediterranean Environments) is a physically-based, fully distributed hydrologic model designed to include the variability of scales in the space and time characteristic of the Mediterranean climate in an operational suite. It is capable of connecting GIS-based representations of the catchment with advanced algorithms to simulate the energy and water balance on a physical basis. It works with a detailed representation of the soil physical and hydraulic characteristics, vegetation cover and snow dynamics at a changeable cell size, which typically ranges in our studies from 20x20 to 100x100 m^2. Widely used throughout the south of Spain, WiMMed efficiently represents the spatial patterns of meteorological inputs on an hourly basis, the daily evolution of the vegetation cover fraction, and the soil use changes observed over the study period, by means of specific interpolation algorithms and the assimilation of data derived from remote sensing. These high resolution data inputs are processed through physical equations to characterize the water and sediment dynamics on different serial control volumes: canopy, snowpack, two-layered soil, groundwater systems, surface routing and storage. Each one of these systems has its own characteristic temporal and spatial scales that are suitably coupled inside the model. Thus, it is able to provide the hourly value of the main flows and state variables simulated, such as rainfall interception, snowmelt, snow storage, temperature and density, infiltration, runoff, circulating surface water, groundwater storage, plain flooded surfaces, river flow, reservoir level, rill erosion, sediment transport, etc. A detailed description of the theoretical background of the model can be found in Herrero *et al.* [9], Aguilar *et al.* [2], Herrero *et al.* [10], Herrero [11], Millares [12], Aguilar [13] and Avila [14]

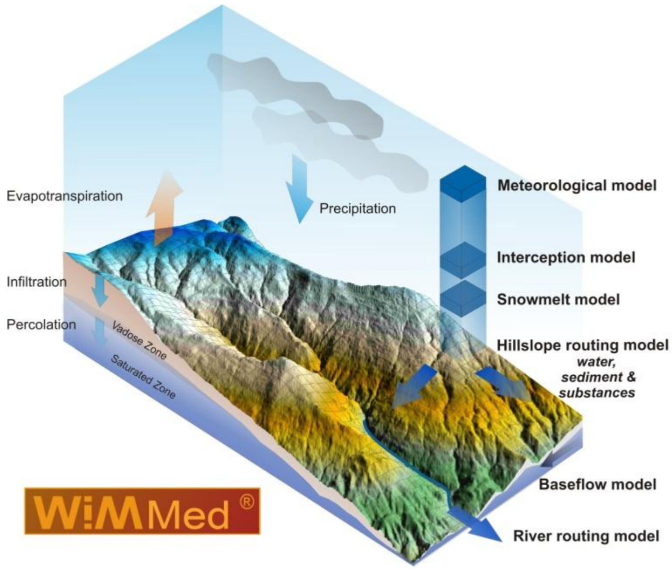

Figure 2. Schematic representation of main physical processes included in WiMMed.

User interface

WiMMed model core runs as a command line program that reads all the inputs from text files and, conversely, saves all the required results in the same format. It is programed in standard C++ and compiled with Visual C++. Its object-orientated programming results in high modularity in line with the physical processes that it represents. It also allows efficient error handling and easy upgrading after the improvements in processes and equations proposed by ongoing research works. A graphical user interface with GIS capabilities was also developed for pre- and post-processing of all the data, in Visual C++ for Windows. The current user version of WiMMed 2.0 is freely downloadable from http://www.uco.es/dfh.

Different levels of simulations can be selected, according to the depth of processing needed for a particular result desired, as well as different groups of resulting variables in terms of their spatial and temporal resolution. The aspect of the screen and menu design of the GUI follows a pattern familiar to GIS software users. The front end pays special attention to data visualization and exporting options.

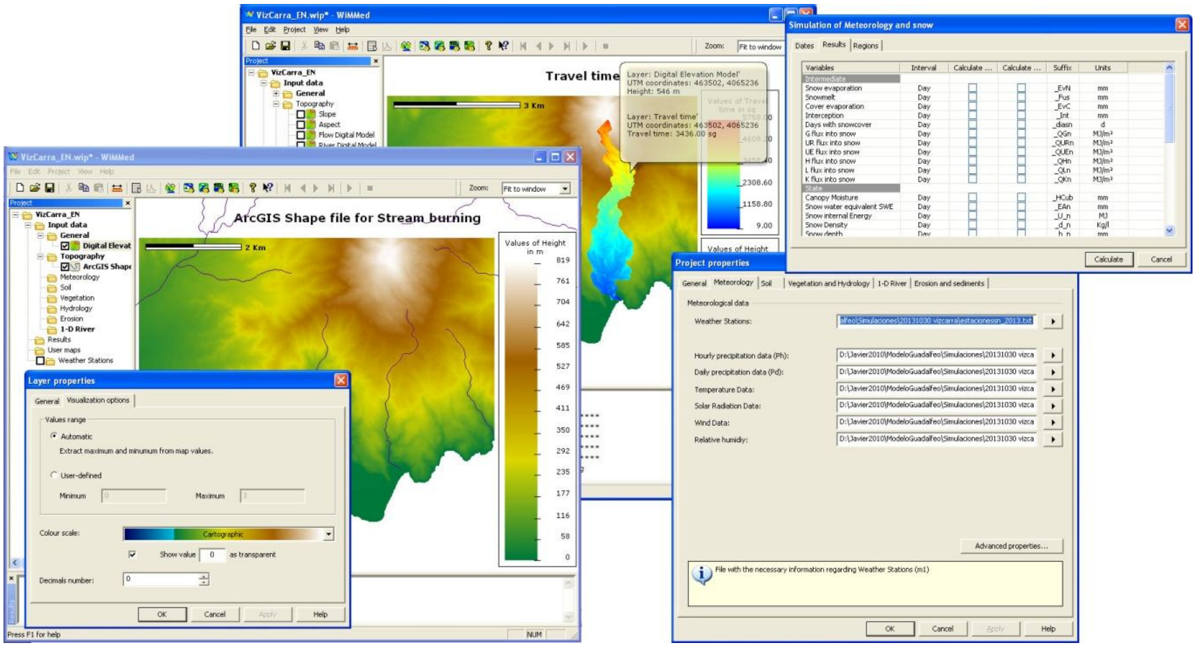

Figure 3. Examples of WiMMed user version screens.

CONCLUSION

The criteria for developing a hydrologic distributed model especially focused on spatial and temporal variability of Mediterranean watersheds have culminated in WiMMed. Its performance has been tested in different basins across Mediterranean environments in southern Spain. WiMMed's potential to estimate the hydrologic response under situations of lack of measured water flow data is derived from its physical basis, GIS-based structure and specific interpolation algorithms included, together with the variable time step resolution.

REFERENCES

[1] *Polo, M.J., Herrero, J., Aguilar, C., Millares, A., Moñino, A., Nieto, S., Losada, M.A,. "WiMMed, a distributed physically-based watershed model (I): Description and validation", in "Environmental Hydraulics: Theoretical, Experimental & Computational Solutions", CRC Press/Balkema, (2009), pp 225-228.*

[2] *Aguilar, C.,Herrero, J., Polo, M.J., "Topographic effects on solar radiation distribution in mountainous watersheds and their influence on reference evapotranspiration estimates at watershed scale", Hydrology and Earth System Sciences, 14, (2010), pp 2479-2494.*

[3] *Aguilar, C., Polo, M.J., "Generating reference evapotranspiration surfaces from the Hargreaves equation at watershed scale", Hydrology and Earth System Sciences, 15, (2011), pp 2495-2508.*

[4] *Herrero, J. and Polo, M. J., "Parameterization of atmospheric longwave emissivity in a mountainous site for all sky conditions", Hydrol. Earth Syst. Sci., 16, (2012), pp 3139-3147.*

[5] *Blöschl G. and Sivapalan, M., "Scale issues in hydrological modelling-a review", Hydrol. Processes, Vol. 9, (1995), pp. 251-290.*

[6] Wood, E.F., "Scale analyses for land-surface hydrology", in "Scale Dependence and Scale Invariance", G. Sposito (ed.), Cambridge UP, New York, (1998).
[7] Rodríguez-Iturbe I., Porporato, A., Laio, F. and Ridolfi, L,. "Plants in water-controlled ecosystems: active role in hydrologic processes and response to water stress. I. Scope and general outline", Adv. Water Resour., Vol. 24, (2001), pp. 695-705.
[8] Merritt, W.S., Letcher, R.A. and Jakeman, A.J., "A review of erosion and sediment transport models", Envir. Model. & Soft., Vol. 18, (2003), pp. 761-799.
[9] Herrero, J., Polo, M.J., Moñino, A. and Losada, M.A., "An energy balance snowmelt model in a Mediterranean site", J. Hydrol., Vol. 371, (2009), pp. 98-107.
[10] Herrero J., Millares, A., Aguilar, C., Díaz, A., Polo, M.J., Losada, M.A., "WiMMed. Theoretical background", Fluvial Dynamics and Hydrology. University of Cordoba and Granada. (In Spanish), (2011), available at www.uco.es/dfh.
[11] Herrero, J., "Physical model of snowmelt. Application at Sierra Nevada (Spain)", Ph. D. Thesis, University of Granada. (In Spanish), (2007), available at www.ugr.es/local/herrero.
[12] Millares, A., "Integration of base flow into a distributed watershed model. Study of groundwater discharge in mountainous rivers", Ph.D. Thesis, University of Granada (In Spanish), (2008), available at http://www.ugr.es/local/mivalag.
[13] Aguilar, C., "Scale effects on hydrological processes. Application at Guadalfeo River watershed (Granada)", Ph.D. Thesis, University of Cordoba. (In Spanish), (2008), available at www.cuencaguadalfeo.com.
[14] Ávila, A., "Multiple scale processes in coastline evolution", Ph. D. Thesis, University of Granada. (In Spanish), (2007), available at www.cuencaguadalfeo.com.