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Assessment of the effects of DEM gridding on the predictions of basin runoff using MIKE SHE and a modelling resolution of 600 m

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Summary A 586-km^2 catchment was modelled with the distributed hydrologic model MIKE SHE. Coarse digital elevation models (DEMs) having a 600-m resolution and gridded from a set of elevation points geographically distributed with a much finer resolution were used in the modelling with the purpose of investigating potential effects of the DEM generation methods on (i) model parameter values; (ii) adequacy of model global predictions; and (iii) the evaluation of internal state predictions. To address these aspects, this paper describes the DEM gridding methods, assesses the accuracy of the DEMs and examines systematically the sensitivities of parameter values and predictions of the distributed model with respect to the DEMs. Three types of gridding methods were applied. Methods type I were based on the use of the MIKE SHE interpolation tool (Bilinear algorithm) for processing input elevation data distributed about the periphery of the gridded DEM cells. Input elevation data distributed about the centre of the gridded DEM cells were processed in gridding methods type II. The third type was based on the use of the TOPOGRID algorithm that considers landscape features, such as digitised streams, to improve the drainage structure of the gridded DEMs. A multi-criteria protocol was applied for assessing the elevation quality of DEMs and their suitability for hydrologic purposes. It was found that the quality of the DEM products of the MIKE SHE interpolation tool were poorer. The independent calibration of the assembled hydrologic models revealed (i) important variations of

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model predictions; and (ii) from average to important variations of effective parameter values, as a function of the different DEMs. A multi-criteria protocol analysing discharge time series, peak flows and piezometric levels showed that model performance is in broad terms in agreement with the elevation and slope quality of the DEMs.

Introduction

Digital Elevation Models (DEMs) are important tools in hydrologic research and water resources management owing to the relevance that geo-morphological features intrinsic in the DEMs have for the simulation of important water flow processes such as surface runoff, evaporation and infiltration. However, DEMs, as source of spatially distributed ground elevations, are not free of errors and limitations. DEM square-grid structures have limitations for handling discontinuities in elevation and representing adequately all of the landscape features. Indeed, either triangulated irregular networks (TIN) or contour lines should be preferred for representing a surface for hydrologic purposes (Wise, 2000; Vivoni et al., 2005). However, square-grid DEMs are still widely used for hydrologic purposes owing mainly to their simplicity and computational efficiency.

In this context, the referred limitations of grid DEMs for handling discontinuities in elevations and representing appropriately landscape features are reduced by decreasing as much as possible their grid size (Walker and Willgoose, 1999; Wise, 2000). Particularly, in catchment distributed modelling using grid DEMs, research has enabled to recommend the use of DEM grid sizes smaller than 50 m for adequate flow pathway analysis at the hillslope scale (Saulnier et al., 1997a; Beven and Freer, 2001). Thus, using the distributed code TOPMODEL (Beven et al., 1995), Zhang and Montgomery (1994) selected a 10-m grid size for the adequate simulation of geomorphic and hydrologic processes in two small catchments (0.3-km^2 and 1.2-km^2). Beldring (2002) used a 10-m DEM for modelling a 6.2-km^2 catchment. Braud et al. (1999) modelled a 5.47-km^2 mountainous catchment with the ANSWER code (Beasley et al., 1980) using a 30-m grid size. Güntner et al. (1999) applied TOPMODEL on a well-monitored 40-km^2 catchment considering a 50-m grid size.

The use of DEM grid sizes smaller than 50 m is however not always possible in catchment distributed modelling. This is in part due to the lack of world-wide data with the appropriate resolution. Other important reason is related to computational efficiency, which is sensitive to the number of horizontal and vertical (modelling) computational units and, as such, to the size of the modelled catchment. In this respect, Xevi et al. (1997) and Christiaens and Feyen (2002) modelled a 1-km^2 well-monitored experimental catchment with the code MIKE SHE (Refsgaard and Storm, 1995) considering a grid size of 100 m. Refsgaard (1997) and Madsen (2003) considered grid sizes larger or equal to 500 m for modelling a 440-km^2 catchment. Refsgaard and Knudsen (1996) modelled a 1090-km^2 catchment with a 1000-m grid size using MIKE SHE and Jain et al. (1992) modelled with the same hydrological code the 820 km^2 Kolar catchment in India with grid sizes ranging from 500 to 4000 m.

The use of such coarse grid sizes in catchment distributed modelling implies important spatial scale differences among the scale to which the physical structure of the hydrologic codes were obtained, the scales to which the different data are collected and the coarse scales to which the hydrologic codes are applied (Bergström and Graham, 1998; Vázquez et al., 2002; Vázquez, 2003). The following are therefore important issues that are related to the impact of grid scale on the predictions of catchment modelling:

(i) what is the adequate grid resolution for achieving accurate model predictions, while keeping computational times under reasonable limits?
Prior sensitivity analyses demonstrated that using (more or less) different data for the same modelling variable lead to significant differences in both effective parameter values and model performance (Vázquez et al., 2002; Vázquez and Feyen, 2003b).
(ii) Given that geomorphologic features intrinsic in the DEMs (i.e. elevation, slope, curvature, etc.) are important for the simulation of flow processes such as surface runoff, infiltration and evaporation, and provided that different DEM accuracies are expected from the application of different DEM gridding methods, do the effective parameter values reflect the differences of these DEM generation methods when using a coarse modelling resolution?
(iii) Is the adequacy of global predictions affected by different DEM generation methods? and
(iv) Is the evaluation of internal state predictions affected by the DEM generation methods?

The assessment of the first of these grid-scale issues will demand the consideration of various aspects such as parameter error, model structural error and data (input and evaluation) measurement error. In this context, Vázquez et al. (2002), after using 300, 600 and 1200-m modelling grid sizes, found that an acceptable compromise between accuracy of model predictions and computational (i.e. running) time was reached when using a grid size of 600 m for the modelling of the Gete catchment (Belgium) with the MIKE SHE model. This study did not consider model structural error owing to the lack of access to the structure of the MIKE SHE model (access limitations linked to the commercial nature of the software). However, the main conclusions of the referred study were based on parameter calibration, the evaluation of internal state predictions and a brief assessment of data measurement error concerning piezometric data (for evaluation).

With regard to the other grid-scale issues, previous studies have used topographically driven codes such as TOPOG (Vertessy et al., 1993) and TOPMODEL for examining the effects of both the scale of the input elevation data and the resolution of the gridded DEMs on model performance