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The new integrated hydrological model MOHISE: construction, implementation and results

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ABSTRACT

The development of an integrated hydrological model is presented. This model, named MOHISE, which stands for 'Modèle Hydrologique Intégré pour la Simulation du cycle de l'Eau' (Integrated hydrological model for the simulation of the water cycle), is a part of the project “INTEGRATED MODELLING OF THE HYDROLOGICAL CYCLE IN THE SCOPE OF CLIMATIC CHANGES” supported by Prime Minister’s Office – Federal Office for Scientific, Technical and Cultural Affairs of Belgium, in the scope of the general program ‘Global Change Sustainable Development’.

General structure of MOHISE

MOHISE is a deterministic, spatially distributed, physically-based model, composed of three interacting sub-models: a soil model, a groundwater model and a surface water model, which are linked dynamically and operated in a global structure.

The construction of the global structure of the integrated model required the adaptation of the different sub-models in order to run together and the construction of a meta-structure which controls all the integrated model running operations.

The meta-structure (Master code) has to synchronise the run of the different models on a multi-node parallel computer and to organise the message exchanges between the different sub-models, as the simulations are performed. This approach leads to several advantages. First, it allows to change any of the sub-model as other numerical or conceptual requirements are needed (e.g. the groundwater sub-models MODFLOW or SUFT3D can be used in substitution of each other). Second, it allows a very flexible general structure, with minimal changes required for the sub-models to be run under the integrated environment. At least, they have to be adapted in order to be able to send and receive messages to the Master code (e.g :

water fluxes at different time steps). Third, the water fluxes, at different points in the system, are logged in files for verification and analyses in subsequent post-processing operations.

Coupling principles between the different sub-models

The three submodels are dealing with different compartments of the water cycle. The EPIC-GRID soil model (Sohier et al., 2000) computes a general water budget at the soil surface and in the unsaturated zone, differentiating water between evapotranspiration, overland flow, slow and fast ~~runoff~~ subsurface flows and percolation ; the unsaturated zone includes root zone in relation with crops growth. The surface water model deals with water flows in the river network and the groundwater model deals with the groundwater flows (so with the base-flow at the discharge points). Water fluxes are exchanged between the three sub-models, at different space locations and over time. To handle these exchanges efficiently, some spatial and temporal mapping procedures have to be developed. These procedures are summarised here.

Surface water distribution

The relation between the basin grid cells and the river network is established through 4 different 'parameters' :
- the connectivity matrix : each basin grid cell can be linked to a digitised point in the river network (method of steepest descent on the DTM);
- the distance between the grid cell and the corresponding digitised point in the river network;
- the difference of altitude and the variation of the altitude along each trajectory;
- the delimitation of the watershed located 'upstream' each basin grid cell (and calculation of a "flow accumulation index" for each grid cell).

Starting from the generated connectivity matrixes, the Master code computes the transfer functions from the soil cells (soil sub-model EPIC-GRID) to the river network digitised points (surface water sub-model). These fluxes are logged in files for control and analysis purposes.

Surface water – groundwater exchanges

Interactions between rivers and aquifers (Dassargues et al., 1999) are expressed as computed water flow rate depending on the difference existing between the piezometric head in the aquifer and the water level in the river, dynamic Fourier boundary condition (Carabin & Dassargues, 2000). The interface between the groundwater sub-models and river sub-model is developed taking into account the fact that it has to be compatible with both codes SUFT3D and MODFLOW. The difficulty to obtain this compatibility is related to the use of different numerical methods (finite element in SUFT3D and finite difference in MODFLOW). In the SUFT3D code, the streams are explicitly discretized by a series of nodes where the exchanged water flow rate is computed (Carabin & Dassargues, 1999). In the MODFLOW code, the discretization with rectangular cells does not allow to keep accurately the course of the river and one cell can be crossed by several rivers. A pre-processing command in GMS© allows to automatically assign the river boundary condition to the appropriate cells from the digitised river network.

Soil water – groundwater exchanges

The interface between the EPIC-GRID soil sub-model and the groundwater sub-model has been designed taking into account the two possible choices for the groundwater sub-model. The first step consists in distributing in the horizontal plane the percolation flows computed

by the soil sub-model. As the horizontal spatial discretization of the groundwater sub-model is not generally identical to the regular grid of the soil sub-model, a spatial distribution algorithm of the results has to be designed. In a first time, the simplest algorithm has been implemented : search for the location of the centre of gravity of the upper elements (for the finite element mesh) or of the upper cells (for finite difference grid) and attribution of the recharge computed in the cell of the soil model where this point is located. If some elements (or cells) of the groundwater mesh (or grid) are not covered by the soil grid (for example on boundaries), the recharge computed in the nearest cell is used.
If the discretization of the used groundwater sub-model is grid based (like in MODFLOW), a matrix of connectivity can be simply and straightforwardly deduced. If an unstructured finite element mesh is use (like in SUFT3D), a correspondence table between the mesh element numbers and the associated cell of the soil grid has to be built.
To ensure mass conservation in the water exchanges from a sub-model to another, the grid of the groundwater sub-model is chosen as a subdivision of the grid of the soil sub-model. In the case of a connection with an irregular mesh, the exact transfer cannot be done. Tests were carried out to verify if the algorithm of distribution generates acceptable “ errors ” (i.e. that the eventual error stays in the range of uncertainty of the global water balance).

An irregular 2D mesh (with element sizes varying from 100 m to 800 m) has been built using the conceptual model developed in GMS for the MODFLOW code. Tests were carried out with different spatial distributions of the recharge on the regular soil grid (size of the cells equal to 1 km). The maximal difference between the global flow rate given by the soil model and the global flow rate received by the groundwater model does not exceed 0.16 %. That is obviously an acceptable difference with regards to the uncertainty on the actual transfer. Consequently the chosen algorithm seems convenient but final verifications will be carried out for each application with the SUFT3D sub-model.

The second step consists in adapting the way of transferring the recharge at the adequate depth. Two ways are used according to the used groundwater program :

- with the SUFT3D sub-model, able to model the flow in the unsaturated zone, the recharge is transferred from the EPIC-GRID soil model at a fixed depth corresponding to the top of the groundwater model; and
- with the MODFLOW sub-model, not able to model the flow in the unsaturated zone, the transfer is entirely computed by the soil model up to the water table. As the water table fluctuates, the recharge is computed for different depths and the used value is deduced from these results according to the depth of the water table.

Integrated model application : Water catchment modelling and Global Change

The MOHISE model has been used in its integrated version to simulate the Gette basin and the Geer basin. Main results will be illustrated and commented. Conclusions and perspectives can be drawn in showing that this integrated tool can be used to assess the effects of climatic changes on the hydrologic and water resources systems at the basin scale.

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