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Parallel global hydrology and water resources PCR-GLOBWB-MODFLOW model at hyper-resolution scale (1 km): first results

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PCR-GLOBWB (https://github.com/UU-Hydro/PCR-GLOBWB_model) is a global hydrology and water resources model being developed over the past two decades at the Department of Physical Geography, Utrecht University, The Netherlands. The latest version of the model has a spatial resolution of 5 arcmin (less than 10 km at the equator), covering all continents except Greenland and Antarctica, and runs with daily time-steps. The model includes a two-layer MODFLOW model to simulate lateral groundwater flow for assessing global scale groundwater dynamics, including regions with declining groundwater heads due to overexploitation.

Within the hydrologic scientific community there is a strong need for hyper-resolution global hydrological modelling, requiring spatial resolutions ranging from 100 m to 1 km (http://www.hyperhydro.org/). It is expected that such models will aid scientists in making advances in modelling, e.g., regarding global biogeochemical cycling, along-river sediment transport, global flood hazard and risk, and process understanding within catchments. Another reason, yet technology pushed, for pursuing hyper-resolutions models is that our current post-petascale and next-generation exascale supercomputers, having thousands to millions of computational cores, should make such models possible. However, from a computer science point of view, realising such models is a far from trivial task, since this involves big data handling and solving a huge system with millions to billions of cells, where highly efficient parallel algorithms and numerical methods are pre-requisite.

In this work, some first promising results are presented for the two-layer global scale MODFLOW model consisting of more than 250 million active cells having 30 arcsec resolution (less than 1 km resolution). We consider a steady-state groundwater model only and our results focus on the numerical challenge to solve this model in parallel. For this, parallel MODFLOW 6 is used that is being developed together with the United States Geological Survey. This code includes an additive Schwarz parallel preconditioner and uses the Message Passing Interface (MPI) to couple the submodels. A sub-optimal load-balancing partition method is evaluated where the computational grid is initially partitioned into a large number of subdomains, where one or more subdomains exactly form a surface water catchment area. The resulting MODFLOW (multi-)model is kept fixed and for each parallel run one or more submodels are uniquely assigned to a processor core (MPI rank). Motivations for doing this are: a) to meet the hydrologist who models at catchment level, b) to reduce error checking to a single model, c) to save pre-processing time which can be large for highly transient input data, d) to simplify future parallel coupling of the MODFLOW model to the PCR-GLOBWB land surface and surface water routing modules. All experiments are carried out on the Dutch national supercomputer Cartesius using up to 1000 computational cores.