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CMF - An open source hydrological modelling toolkit

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In the past four decades, hundreds (if not thousands) of hydrological models have been developed to predict the transfer of water through landscapes. Despite this variety of models, the basic challenge for all kind of models is the same: solve the dynamic local to global water mass balance of a landscape. However, the transport processes, surface flow, subsurface flow, snow drift, evaporation and transpiration can be modelled with differing complexity, theory and parameterizations. Clark et al. (2011) denote, that a hydrological model is therefore not one hypothesis of process behaviour, but a multitude of interconnected hypotheses, which remain untested, since only the global model behaviour is tested against observation data. Hence, model intercomparison studies are difficult to interpret, since the origin of the different model performances is not really tested. Despite, the decisions of the modeller might have a stronger impact on the results than the chosen model itself, as indicated by the Chicken Creek model experiment (Holländer et al., 2009). Is this the reason “why we can’t do better than TOPMODEL” as Buytaert et al. (2008) ask? The authors formulate three different requirements that new model developments in hydrology should fulfil to advance the modelling of water transport: accessibility, portability and modularity. Accessibility means, all processes, and essentially the source code of the model, needs to be available and transparent. A model is portable, if the usage of new model codes runs on different platforms – from the Windows desktop PC to the supercomputer for uncertainty studies. Modularity is given if only parts of the model (modules) are interchangeable to account for the effect of different process descriptions, without changing other parts. This is in line with Clark et al.’s call for testable multi-hypotheses through extremely fine grained modularity and interchangeability of submodels.

While hydrologist are still seeking for robust descriptions of water transport, biogeochemistry and other geosciences need hydrological models as a transport agent for landscape based solute fate models. As such, the ability to interface with models from differing disciplines is another feature for the future of hydrological models, which we call connectability.

Based on the rejectionist framework by Vaché and McDonnell (2006) and the finite volume method approach for a mass conservation problem as lined out by Qu and Duffy (2007), the Catchment Modelling Framework (CMF) (Kraft et al., 2011) has been developed. It is implemented as a C++ library for the Python programming language, exporting the building blocks for a wide range of hydrological models, from process based Richards equation based models over to large scale lumped models with optional solute transport routines. The main building blocks of a model are nodes, like water storages (soil layers, surface water bodies, aquifers), boundary conditions (eg. rainfall, area outlet, deep groundwater and evapotranspiration) and flux connections, holding the mathematical description of the water transport processes between the nodes. The sum of the fluxes in and out of a water storage is the change rate of the water content and can be handled as a system of ordinary differential equations (Kraft et al., 2011; Qu and Duffy, 2007). This system can be solved by one of the provided implicit and explicit solvers, according to the system’s complexity. With this approach, extremely fine grained modularity is achieved for hypothesis testing. As the code uses only standard C++ and Python, any system with a standard conformant C/C++ compiler can be used to run and
compile CMF (portability). The source code is provided for download under the GPL licence (accessibility) (Kraft, 2011).

As the setup code including the runtime loop is written as a Python script, the model can exchange data at any time step to any parameter, flux and state variable with other models covering a different spatial domain (e.g. a groundwater model), or a different functional domain (like a nutrient turnover model) (Haas et al., 2012; Kraft et al., 2010; Multsch et al., 2011) using an operator split approach. As such, the catchment modelling framework provides also connectability.

In this presentation, we will show briefly the structure and theoretical background of CMF, as well as some recent applications of modularity and connectability.


Holländer, H. M., Blume, T., Bormann, H., Buytaert, W., Chirico, G. B., Exbrayat, J. F., Gustafsson, D., Hölzel, H., Kraft, P., Stamm, C., Stoll, S., et al.: Comparative predictions of discharge from an artificial catchment (Chicken Creek) using sparse data, Hydrolearth Systsci, 13(11), 2069–2094, 2009.


