



Supplement of

On the representation of water reservoir storage and operations in largescale hydrological models: implications on model parameterization and climate change impact assessments

Thanh Duc Dang et al.

Correspondence to: Stefano Galelli (stefano_galelli@sutd.edu.sg)

The copyright of individual parts of the supplement might differ from the CC BY 4.0 License.

S1. Representation of water reservoirs in VIC-Res

To represent the location of dams and upstream impoundments, VIC-Res exploits the organization of the modelling domain into a discrete number of computational cells. In particular, VIC-Res uses a two-dimensional array that has the same number of rows and columns of the flow direction matrix. As illustrated in Figure S1, each cell of the reservoir location matrix indicates whether a given area contains a dam, part of the upstream impoundment ("Res"), or other land uses (blank). The specifications of each reservoir are contained in dedicated files. These specifications include both design aspects (e.g., storage capacity) and parameters characterizing the reservoir operations. More details of VIC-Res implementation are available at https://github.com/thanhiwer/VICRes.



(a) VIC cells

`	-	\mathbf{X}	*	*	*	*
$\mathbf{\hat{x}}$	-	-	ł	*	*	-
$\mathbf{\tilde{x}}$	\mathbf{X}	-	ł	*	*	-
-	-	1	-	ł	t	◄
	/	1	-	ł	*	◄
×	*	1	-	ł	•	-
>	\mathbf{X}	ł	/	*	×	-



(b) Flow direction matrix

(c) Reservoir location matrix

Figure S1. Panel (a) illustrates the discretization of the model spatial domain into a number of computational cells. Specifically, the domain is organized into one dam cell, reservoir cells (blue borders), and cells characterized by other land uses (yellow borders). The corresponding flow direction and reservoir location matrices are shown in Panels (b) and (c).

S2. Sensitivity analysis

We use the extended Fourier Amplitude Sensitivity Test (eFAST) to determine the influence of soil parameters on the output of the Variable Infiltration Capacity (VIC) model, implemented with and without water reservoirs. Specifically, we used the Nash-Sutcliffe efficiency (NSE) and Transformed Root Mean Square Error (TRMSE), which account for errors on the high and low flows, respectively. Since we have a total of six parameters (Ds, Dmax, Ws, b, d1, and d2; also called variables in eFAST), we used a minimum sampling size equal to 393 (Cukier et al., 1978; Saltelli et al., 1999). As a result, we carried out a total of 1,572 simulations, given by the two scenarios (with / without reservoirs) and two model outputs. These experiments were implemented with the Python version of the SAFE toolbox (Pianosi et al., 2015).

As illustrated in Figure 1, results reveal a few important insights. First, all parameters appear to influence the model output (either NSE, TRMSE, or both). The only exception is the thickness of the second soil layer (d2), which is indeed the only parameter that does not seem to depend on the presence / absence of water reservoirs (see Figure 6). Second, the spread of some parameters observed in Figure 6 can be explained by looking at the sensitivity of the model output. If we consider Dmax, for example, we note that the parameterizations of the model with reservoirs belong to a narrow range, suggesting that the model output is strongly influenced by its value. This intuition is confirmed in the figure below, where we see that Dmax influences more the output (especially high flows) of the model with reservoirs. A similar observation applies to the parameter d1 of the model without reservoirs.



Figure S2. Bar plots of main effect (first-order) sensitivity indices for each of the six soil parameters in the VIC model implemented with (blue bars) and without (red bars) reservoirs. Left and right plots report the results for two different output, namely NSE and TRMSE.

S3. Data for climate change impact assessment

The climate change impact assessment is based on the CMIP5 climate projections for the period 2050-2060. We consider five Global Circulation Models (GCMs: ACCESS1-0, CCSM4, CSIRO Mk3.6, HadGEM2-ES, and MPI-ESM-LR) and two Representative Concentration Pathways (RCPs: 2.6 and 4.5). We interpolate the GCMs outputs to the spatial resolution of the VIC model ($0.0625^{\circ} \times 0.0625^{\circ}$) with the bilinear interpolation method. The delta method, which is applied in a similar study site in Lauri et al. (2012), is used to bias-correct the GCMs outputs. Figures S2 and S3 show the projected changes in total annual precipitation, and maximum and minimum temperature under future change (2050-2060) compared to the baseline (1996-2005).



Figure S3. Projected changes in total annual precipitation (%) under future climate (2050-2060) compared to the baseline (1996-2005). These changes are produced by five Global Circulation Models (GCMs) and two Representative Concentration Pathways.



Figure S4. Projected changes in daily maximum and minimum temperature under future climate (2050-2060) compared to the baseline (1996-2005). These changes are produced by five Global Circulation Models (GCMs) and two Representative Concentration Pathways.

References

Cukier, R.I., Levine, H.B., and Shuler, K.E. (1978), Nonlinear Sensitivity Analysis of Multiparameter Model Systems. Journal of Computational Physics, 16, 1-42.

Lauri, H., de Moel, H., Ward, P. J., Räsänen, T. A., Keskinen, M., and Kummu, M. (2012). Future changes in Mekong River hydrology: impact of climate change and reservoir operation on discharge. Hydrology and Earth System Sciences, 16, 4603–4619.

Pianosi, F., Sarrazin, F., and Wagener, T. (2015). A Matlab toolbox for global sensitivity analysis. Environmental Modelling & Software, 70, 80–85.

Saltelli, A., Tarantola, S. and Chan, K.P.S. (1999), A Quantitative Model-Independent Method for Global Sensitivity Analysis of Model Output. Technometrics, 41(1), 39-56.