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Graphical representation of global water models

Hannes Müller Schmied[1,2], Simon Newland Gosling[3], Marlo Garnsworthy[4], Laura Müller[1], Camelia-Eliza Telteu[1], Atiq Kainan Ahmed[5], Lauren Seaby Andersen[6], Julien Boulange[7], Peter Burek[8], Jinfeng Chang[9], He Chen[10], Manolis Grillakis[11], Luca Guillaumot[12], Naota Hanasaki[13], Aristeidis Koutroulis[11], Rohini Kumar[14], Guoyong Leng[15], Junguo Liu[16,17,10], Xingcai Liu[15], Inga Menke[18,19], Vimal Mishra[20,21], Yadu Pokhrel[22], Oldrich Rakovec[14,23], Luis Samaniego[14,24], Yusuke Satoh[25], Harsh Lovekumar Shah[26], Mikhail Smilovic[8], Tobias Stacke[27], Edwin Sutanudjaja[28], Wim Thiery[29], Athanasios Tsilimigkras[11], Yoshihide Wada[30], Niko Wanders[28], and Tokuta Yokohata[13]

[1]Institute of Physical Geography, Johann Wolfgang Goethe University Frankfurt, 60438 Frankfurt am Main, Germany
[2]Senckenberg Leibniz Biodiversity and Climate Research Centre (SBiK-F), 60325 Frankfurt am Main, Germany
[3]School of Geography, University of Nottingham, Nottingham, NG7 2RD, United Kingdom of Great Britain and Northern Ireland
[4]Icebird Studio
[5]Institute for Population and Social Research, Mahidol University, Nakhon Pathom, Thailand
[6]Potsdam Institute for Climate Impact Research, Member of the Leibniz Association, Potsdam, Germany
[7]Institute of Agriculture, Tokyo University of Agriculture and Technology, 183-8509 Tokyo, Japan
[8]Water Security Research Group, Biodiversity and Natural Resources Program, International Institute for Applied Systems Analysis (IIASA), A-2361, Laxenburg, Austria
[9]College of Environmental and Resource Sciences, Zhejiang University, Hangzhou, China
[10]School of Environmental Science and Engineering, Southern University of Science and Technology, Shenzhen 518055, China
[11]School of Chemical and Environmental Engineering, Technical University of Crete, Chania, Greece
[12]Water, Environment, Processes and Analyses Division, BRGM – French Geological Survey, Orléans, France
[13]National Institute for Environmental Studies, 305-8506 Tsukuba, Japan
[14]Helmholtz-Centre for Environmental Research, Permoserstraße 15, 04318 Leipzig, Germany
[15]Key Laboratory of Water Cycle and Related Land Surface Processes, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[16]Henan Provincial Key Laboratory of Hydrosphere and Watershed Water Security, North China University of Water Resources and Electric Power, Zhengzhou, 450046, China
[17]School of Water Conservancy, North China University of Water Resources and Electric Power, Zhengzhou, 450046, China
[18]Humboldt Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany
[19]Climate Analytics, Ritterstraße 3, 10969 Berlin, Germany
[20]Civil Engineering, Indian Institute of Technology (IIT) Gandhinagar, Gandhinagar, India
[21]Earth Sciences, Indian Institute of Technology (IIT) Gandhinagar, Gandhinagar, India
[22]Department of Civil and Environmental Engineering, Michigan State University, East Lansing, 48823, United States
[23]Faculty of Environmental Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic
[24]University of Potsdam, Institute of Environmental Science and Geography, Am Neuen Palais 10, 14469 Potsdam, Germany
[25]Moon Soul Graduate School of Future Strategy, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea
[26]AgroCast Analytics Pvt Ltd - Research Park, Indian Institute of Technology Gandhinagar, Palaj, Gujarat, India -382355
[27]Climate Dynamics Department, Max Planck Institute for Meteorology, 20146 Hamburg, Germany
[28]Department of Physical Geography, Faculty of Geosciences, Utrecht University, The Netherlands
[29]Vrije Universiteit Brussel, Department of Water and Climate, Brussels, Belgium

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[30]Biological and Environmental Science and Engineering Division, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

Correspondence: Hannes Müller Schmied (hannes.mueller.schmied@em.uni-frankfurt.de)

Abstract. Numerical models are simplified representations of the real world at a finite level of complexity. Global water models are used to simulate the global water cycle and their outputs contribute to the evaluation of important natural and societal issues, including water availability, flood risk and ecological functioning. Whilst global water modelling is an area of science that has developed over several decades, and individual model-specific descriptions exist for some models, there has to date been no attempt to visualize the ways that several models work, using a standardized visualisation framework. Here, we address this gap by presenting a set of visualizations of several global water models participating in the Inter-Sectoral Impact Model Intercomparison Project phase 2b (ISIMIP2b). The diagrams were co-produced between a graphics designer and 16 modelling teams, based on extensive discussions and pragmatic decision-making that balanced the need for accuracy and detail against the need for effective visualization. The model diagrams are based on a standardized "ideal" global water model that represents what is theoretically possible to represent in the current generation of state-of-the-art global water models participating in ISIMIP2b. Model-specific diagrams are then copies of the "ideal" model, with individual processes either included or greyed out. As well as serving an educational purpose, we envisage that the diagrams will help researchers in and outside of the global water model community to select the suitable model(s) for specific applications, stimulate a community learning process, and identify missing components to help direct future model developments.

1 Introduction

Graphical visualizations (simply referred to as diagrams hereafter) of the water cycle are essential for communicating the system, for researchers, in education, for water management, policy-related processes, and in general for science communication (Linton, 2008; Abbott et al., 2019; Cardak, 2009; Fandel et al., 2018). For example, Linton (2014) showed that the development of such diagrams is associated with an increasing awareness of the social dimensions of water. Some of the water cycle diagrams received much attention in the scientific context, for example the visualization of the terrestrial water balance including model-based quantifications of global fluxes and storages from Oki and Kanae (2006). In an educational experiment, Cardak (2009) explored misconceptions in the understanding of the global water cycle by undergraduate students, from interviews, and by specifically letting them draw the water cycle. Elsewhere, the co-creation of diagrams between environmental modellers, design creatives, and policy-makers, has facilitated the generation of infographics and visuals that improve the understanding and build trust on the modeling results while striking the right balance between academic integrity and detail, and relevance for policy such as the IPCC reports or the EU Green Deal (European Commission, 2023).

There are no commonly accepted guidelines for designing a global water diagram, although best practices for scientific illustration of water cycle diagrams for dryland environments are discussed by Fandel et al. (2018). The design of global water diagrams has in the past been criticised, e.g. Abbott et al. (2019) who explored the water storages, fluxes and processes incorporated in 464 water cycle diagrams and found that human interactions were not included in a majority (85%) of the

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diagrams. In total, they found rather similar diagrams despite differences in the intended target audience and year of creation. The reviews mentioned earlier (Abbott et al., 2019; Linton, 2008; Fandel et al., 2018) also include several very popular diagrams of the global water cycle. Recently, and also as a reflection of the findings of Abbott et al. (2019), a new version of the USGS water cycle diagram has been published (Nell et al., 2023) that illustrates components of human inferences to the water cycle.

Abbott et al. (2019) classified the format of the diagrams into a) three-dimensional, large-scale catchments, b) two-dimensional small scale hillslopes, c) site specific for certain aspects of a catchment and hillslopes and d) schematics that typically consist of boxes and arrows and are the most abstract representations. In the scientific community of global water modelling, it is nowadays common to publish model description papers alongside the output data. Typically, these descriptions also include a graphical representation of the model scheme, namely the water storages, fluxes and processes included in the model. The format and approach differ largely, with the most popular approaches being three dimensional diagrams (e.g. Hanasaki et al., 2018; Lawrence et al., 2019; Burek et al., 2020) and abstract illustrations with boxes and arrows (e.g. Stacke and Hagemann, 2021; Müller Schmied et al., 2021).

When it comes to model inter-comparison exercises, a typical goal is, next to comparing model outputs, the exploration of commonalities and differences between models (Haddeland et al., 2011). This understanding helps to explain why the model outputs differ. The global water sector in the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) consists of around 20 active global water models (Gosling et al., 2023b, a) that follow a specific modelling protocol to ensure a consistent cross-model assessment (Warszawski et al., 2014; Frieler et al., 2017, 2024).

The global water models participating in ISIMIP were developed from multiple backgrounds and as such they contain different concepts and components. In a previous study, Telteu et al. (2021) reviewed the models that participated in the ISIMIP phase 2b, in terms of their components, to analyze which water storages and fluxes are included in the models. Furthermore, they developed a common notation for the equations of each model component, resulting in a compendium of model-specific equations. No visual depictions of the model components were shown though. Even though all the models follow basic hydrological principles, such as the conservation of mass, the individual calculation procedures and the relative complexities of the models differ (Telteu et al., 2021). This previous exercise was a community-driven effort and the modelling groups were intensively involved, leading to a better understanding of each other's models inside the community. Though the exercise created a critical stepping-stone for the global water model community, those who are not familiar with the specific equations and principles used in hydrology, may find the rich information content of Telteu et al. (2021) challenging to interpret. This necessitates the need for a visual depiction of different modelling components which can act as important additional information for model improvement, inter-model comparison, science communication and education.

To this end, herein we present the efforts of the global water community within ISIMIP2b to describe the structure of the computational models in a common diagram scheme, whilst including some of the information from Telteu et al. (2021). The visualization of the models should support:

– Familiarising people outside of the global water model community with the features and concepts included in global water models. This could be lay audiences, university students learning about hydrology and/or modelling, or researchers.

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- Model developers to identify missing model components, which could help to define areas for future model development.
- Researchers, giving them the possibility to reflect structural model uncertainty by visualizing the model structure including storages, processes and fluxes, which builds the basis for assessing model output to generate a multi-model water budget considering this uncertainty.
- Users of the ISIMIP model output data repository who want to conduct and communicate numerical assessments, to select the right models suitable for their analyses. For example, users that are interested in specific components of the water cycle might select only those models that have a certain representation of these processes implemented. We envision that the diagrams will also support the selection of models for the intended purpose, both for historical time periods and also for future projections.
- End users, stakeholders and decision makers towards a better understanding of the benefits and limitations of specific models, in relation to the intended application of the models. For example, a model that is specifically designed as a vegetation model has benefits in simulating such processes but might have limitations in other areas, such as the representation of water management. A visualization could help to identify those features quickly and builds trust in results outside the modeling community.

The expected audience of our diagrams is relatively wide and comprises a) model output users, b) people who are new in the global water modelling community and want to learn about the existing models, c) people in educational settings (in particular academic education), d) policy makers and civil society organisations as well as e) model developers seeking inspiration for improving their models.

The remaining paper is structured as follows. In Sect. 2 we describe the general methodology from the first idea to the finalization of the diagrams. An "ideal" model as well as the individual model diagrams are then shown in Sect. 3. A discussion about limitations and potential improvements, how the diagrams may be used, as well as a future outlook, is in Sect. 4, followed by concluding remarks in Sect. 5.

2 Methods

2.1 Community-driven demand for a structural model intercomparison

In a project funded by the European Union (WATCH project under EU grant number 36946, runtime 2007-2011), the global water model community initiated a model intercomparison and hydrological assessment study. Based on this foundation, the global water sector in ISIMIP was formed and has been active since ISIMIP was started in 2012. There has been a wide range of studies focusing on model evaluation (e.g., Veldkamp et al., 2018; Zaherpour et al., 2018; Zhao et al., 2017; Masaki et al., 2017; Kumar et al., 2022) and impact assessment (e.g., Gudmundsson et al., 2021; Reinecke et al., 2021; Prudhomme et al., 2014; Dankers et al., 2014; Schewe et al., 2014; Thompson et al., 2021; Gosling et al., 2017) but also considering other sectors like agriculture and health (e.g., Schewe et al., 2019; Thiery et al., 2021). The creation phase of such contributions, and specifically

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when trying to explain *why* model results differ, was hindered by the unavailability of a consistent and comparative model overview. This was the motivation for working collaboratively on an overview of the models participating in the global water sector of ISIMIP. In an international paper writing workshop during summer 2018, in Frankfurt am Main (Germany), initial ideas were discussed for conducting a thorough review of the global water models participating in the ISIMIP phase 2b. One of the first outcomes from the workshop was the publication of Telteu et al. (2021) that provided first overview of participating models and their components. Besides the numerical descriptions of the models, the benefits for creating a common diagram further emerged at the workshop.

We decided to generate a three-dimensional diagram of the water cycle that also shows the vertical water balance in a second diagram. The motivation for this separation was to first provide an overview of the individual model's representation of the water cycle but then also to focus on a more detailed level on the vertical water balance.

2.2 From initial drafts to a final diagram

First drawings of the diagrams were discussed at scientific conferences (Telteu et al., 2019b, a) and international ISIpedia (Potsdam Institute for Climate Impact Research (PIK) e. V., 2023) workshops with stakeholders from data scarce regions. In particular, we sought input on the level of detail to include in the diagrams. Whereas discussants with a more scientific view suggested adding more details to reflect the complexity of the water cycle, stakeholder interactions in two ISIpedia workshops in Eastern Europe and West Africa with representatives from governmental organizations, academia and NGOs expressed the wish for a simplified representation and felt overwhelmed by too much complexity. Also, we discussed avoiding some of the classical misconceptions, e.g., to draw the aquifer as a sub-surface lake or river (Fandel et al., 2018). A professional graphics designer and science communicator was included in the discussions.

We first had to find a common basis for such a model diagram and agree on the level of detail to include. This was challenging as the focus of the diagrams is to represent how different model structures represent the global water cycle, rather than representing the entire global water cycle with all possible processes, as intended e.g., in Nell et al. (2023). Hence, the required level of abstraction but also realism was discussed at length. Several iterations with different user groups allowed for the uptake of a variety of needs leading to well-balanced diagrams.

We agreed on generating a diagram of an “ideal” global water model, characterised by its broad inclusion of water fluxes, storages and processes represented in at least one of the models described in Telteu et al. (2021), without implying it to be the most thorough or exhaustive representation. The climatic input variables are shown as well as the vertical and lateral water balance and the sectors considered for human water use. Based on this “ideal” model, we derived the diagrams for the individual models by greying (and for people with color vision deficiency also by "x"ing out) out the components that are not present in the specific individual model. The number of layers in snow, glacier, soil and groundwater storage are considered in the individual model diagrams, for the “ideal” diagram, the notation of "1+n" indicates that at least one layer should be represented. Note that the inclusion of a specific flux, storage or process can be reached in very different levels of complexity. For example, the process that reflects the CO_2 concentration on plant growth and related water use is implemented in the models in different ways and levels of detail, but how exactly cannot be reflected in a binary information (existing or not) in

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such diagrams. In a series of feedback rounds with the individual modelling teams and the graphics designer, the diagrams converged into a final set of illustrations, which are presented in this study.

3 Results

3.1 The “ideal” ISIMIP2b global water model

In the “ideal” model representation, all processes and features that could be included in a global water model based on current modelling capability within ISIMIP2b are shown (Figs. 1, 2). Thus all names, components and input data are displayed in colour. The term “ideal” stands for a global water model that represents all of the fluxes and storages that are included in at least one model participating in ISIMIP2b, but not necessarily that this is the optimal way of representing the water cycle in a model. However, none of the individual models considers all of these components together, so it is a hypothetical representation of the currently “ideal” global water model.

The ideal model shows the vertical water balance (indicated with A), the lateral water balance (B) and the water management components (C) in Fig. 1. The specific illustration of the vertical water balance (Fig. 2) is also provided as, for a number of assessments, the model output of this part of the water cycle (e.g., for indicators of groundwater recharge, runoff or the variation of soil water storage) is not only relevant for society but also exhibits consistency among the models. In contrast, the components of the lateral water balance and the river routing approach differ substantially between the models and this part of the water cycle is also much more integrated with water management than the vertical water balance.

3.2 The individual ISIMIP2b global water models

The individual model diagrams are displayed in an overview for the full water balance (Fig. 3) and the vertical water balance (Fig. 4) in order from the highest number of included fluxes and storages to the lowest. In the Appendix A, the individual models are shown separately, and are ordered alphabetically according to their model name.

The appearance of the 16 model representations next to each other reveals that all models commonly consider snow and soil water storage (Fig. 4). Most models include canopy storage (13 out of 16), groundwater storage (11 out of 16), and only 2 models (different versions of CLM) have a representation of glacier storage. All models consider the water fluxes transpiration, soil evaporation, infiltration and (surface) runoff, which can be considered, together with the storages described above as the core components of the hydrological cycle. Specific processes like capillary rise (5 out of 16) and interflow (5 out of 16) are less implemented, whereas fluxes like groundwater recharge is represented in 15 out of 16 models. Interestingly, groundwater recharge is also presented for some models that lack an explicit representation of groundwater storage. For example, in the case of LPJmL, the seepage from soil is reported as groundwater recharge but at the same time step as runoff, which means that there is no delay to groundwater storage (Telteu et al., 2021).

Other than for the vertical water balance, there is no commonality in the lateral water balance and water use sectors (B- and C-part of Fig. 3, respectively). Whereas a model like WaterGAP2 considers all lateral water storage types of the “ideal”

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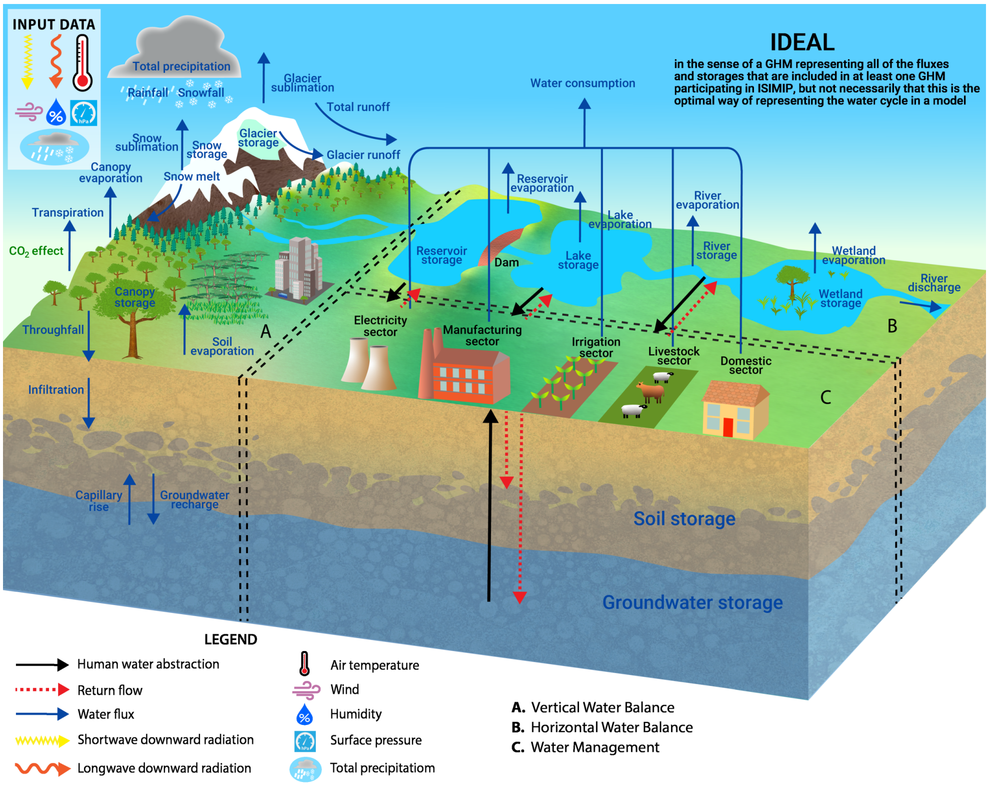

Figure 1. The representation of the components of an "ideal" global water model that participates in ISIMIP.

representation, models like DBH, WAYS and MacPDM do not integrate any storages of the lateral water balance. Nevertheless, even though WaterGAP2 has all the surface water storages included, it does not (and other than e.g. PCR-GLBOWB) include evaporation from rivers and might therefore not be seen as a model that fully represents the lateral part of the water cycle.

For 9 out of 16 models, water use sectors are considered, at least with the irrigation sector. Less models include other sectors, and only 2 models (CWatM and WaterGAP2) consider all 5 water use sectors. Reservoirs are included in 7 models, interestingly also in models without considering any water use sector (e.g. VIC). The effect of varying CO_2 concentrations is included in 8 out of 16 models.

The overview also reveals differences between model versions, in particular for CLM4.5 and CLM5.0, where the different numbers of snow and soil layers are visible.

4 Discussion

Here we reflect on the design process, elaborate on opportunities for improvement and provide an outlook for similar activities (e.g. in the recent ISIMIP phase 3).

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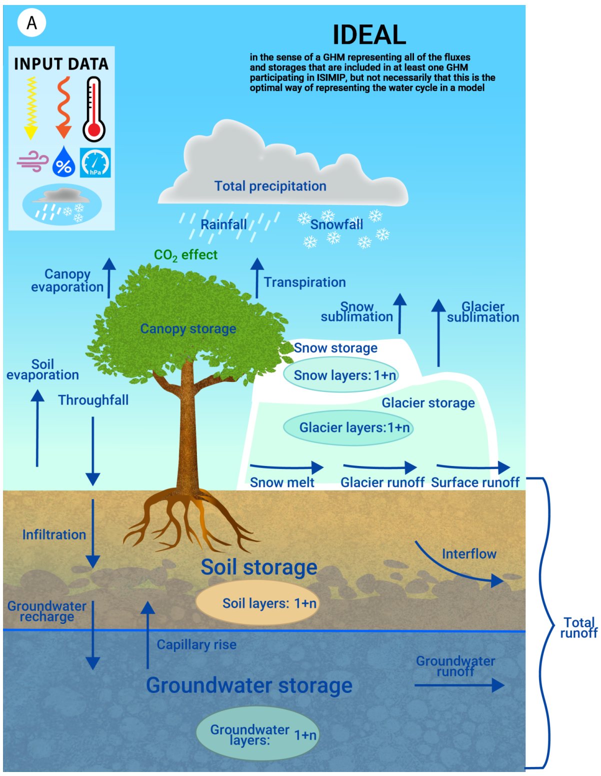

Figure 2. The representation of the vertical water balance for an "ideal" global water model that participates in ISIMIP.

4.1 Reflection of the design process

The stages in developing a visual model description are quite different from the stages involved in describing the models with formulas and equations (Telteu et al., 2021). The latter required individual elements of model processes and parameterisations to be studied and compared between models, while the development of the diagrams required a higher level of aggregation, where individual processes had to be lumped together to a higher order, and consideration given as to whether they fell into any one particular part of the "ideal" model diagram.

It became clear that this process could only be successful with a strong commitment of the modelling participants. It was challenging to achieve this, and it is perhaps one of the main reasons why so few studies have been published that compare visual representations of environmental models. Specific challenges included the limited duration of funding to support the activity (a few months) and variability in academic staff contracts (e.g. PhD candidates graduating and then moving to new places of work with new priorities).

Intense interaction with the graphic designer was important for discussing and agreeing on how complex processes could be represented in a relatively simple, visual form. Much time was spent in developing a consensus on the right balance between visual complexity, accuracy, detail, and simplicity. For example, groundwater is often drawn like a large sub-surface lake or

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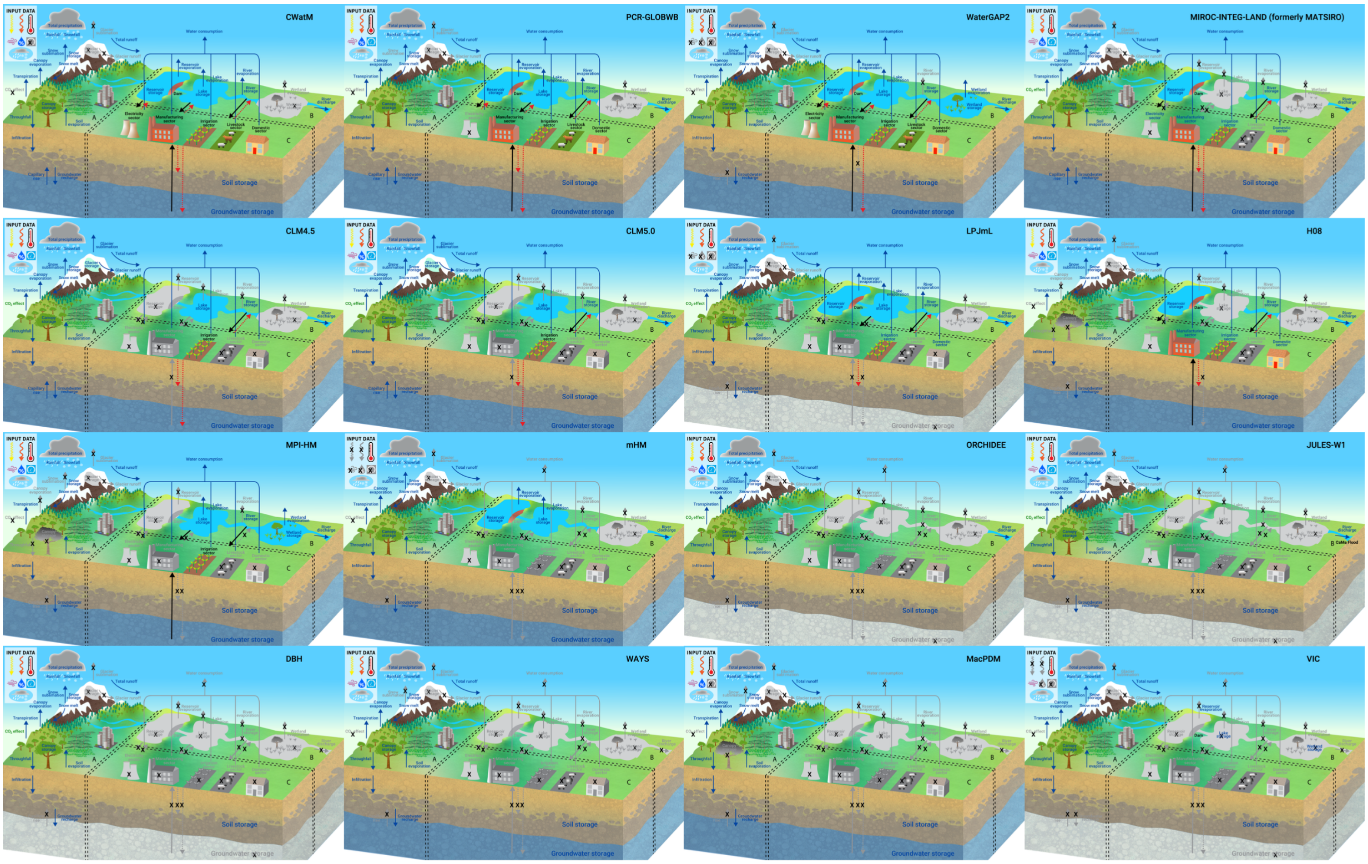

Figure 3. The components of the individual ISIMIP2b global water models, ordered by decreasing number of included fluxes and storages.

river (Abbott et al., 2019; Fandel et al., 2018) but it is not trivial to represent a water-filled bedrock without creating such a misconception. Also, we discussed which shapes and icons could be used to illustrate specific features, such as vegetation. The main intention was to show a tree to represent the canopy storage. Intrinsically, we initially sketched a typical Northern Hemisphere broad-leaf tree but during the discussion, it became clear that this inadvertently ignored the diversity of different canopy types that exist around the world in different biomes (e.g. the vegetation of an African savanna).

It took several general discussion rounds (online meetings), countless bilateral discussions as well as several review rounds to reach a commonly agreed illustration. Through this process and in particular while discussing what should be greyed out or not, the modelling teams achieved an enhanced level of understanding about the representation of specific fluxes and storages in the models, and some of those insights led to slight refinements of the descriptions in (Telteu et al., 2021).

We underestimated the whole effort and think this process could certainly have been improved and streamlined by including an expert who could give guidance in such a collaborative process (e.g., from social science) or by the inclusion of a graphics designer from the beginning. We only involved the graphics designer at a relatively late stage of the overall process.

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4.2 Potential uses of the model diagrams

The development of a consistent design style for visualizing the models has several benefits and uses.

Model evaluation studies show that the outputs from the models differ, even when the models are forced with consistent input data (Veldkamp et al., 2018; Zaherpour et al., 2018; Kumar et al., 2022). Whilst it is useful to understand the extent to which the models perform differently, it is also important to understand *why* the models perform differently. The latter is often challenging to address, largely because the models have been developed by multiple groups over many years (in some cases decades, e.g. MacPDM (Gosling and Arnell, 2011) or WaterGAP (Döll et al., 2003)) and because a detailed knowledge of how each model works is required (Melsen, 2022). The reasons for inter-model differences are thus often only rather vaguely explained in the literature (e.g. Zaherpour et al., 2018; Veldkamp et al., 2018). We anticipate that the model illustrations will be used alongside with the numerical description of different modelling components Telteu et al. (2021). By comparing consistently created diagrams, we can understand the differences among the models at a glance. This will further help researchers understand *why* certain model outputs differ in future model evaluation studies.

One of the underlying rationales of model evaluation studies is that they identify opportunities for model development and improvement. Given that the “ideal” model was co-created by many members of the global water modeling community, it can be used to help plan the integration of missing components or schemes into individual models. The equations and concepts detailed in Telteu et al. (2021) should also help to build the basis for model development planning. We acknowledge that the “ideal” model diagram is missing some components from the observed water cycle, including aspects of water management like flood protection measures (both green and grey (O’Donnell et al., 2021)) and inter-basin water transfer, as well as natural processes like permafrost and the role of animals such as beavers which can significantly modify river hydrology largely through dam construction (Larsen et al., 2021). Thus the “ideal” model should not be seen as the best way to describe the full water cycle. Rather, it should be viewed as a representation of what is currently considered feasible within the realm of environmental modelling capability in ISIMIP2b. The “ideal” model diagram is likely to evolve, also as the spatial and temporal resolution is refined and finer-scale processes are represented, and also as computing power improves along with advances in artificial intelligence (Zaherpour et al., 2019), which are already leading to improvements in the capability of weather and climate prediction (Lam et al., 2023).

Given the range of inherent uncertainties and differences in performance between the models (Zaherpour et al., 2019), it is often difficult to know which of the models are better suited for some applications over others, e.g. for simulating hydrology in dry regions only (see the discussion in Krysanova et al., 2020; Zaherpour et al., 2019), or for analysing only droughts (Kumar et al., 2022). Some studies focus on human interactions with the natural water cycle (Haddeland et al., 2014). The model diagrams we present here, help to illustrate the types of human interactions they include, to what extent, and how. This helps with selecting appropriate models to incorporate into selected studies. For example, if someone would like to assess the amplification of streamflow (river discharge) due to reservoir management and human water use, the user can find this information in the diagrams. Although this information can also be obtained from the equations described in Telteu et al. (2021), the graphical illustration provides a more intuitive and rapid overview of model components and structure. The value

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of the diagrams in the way outlined above is not limited to just human water use, e.g. they will also facilitate the identification of models suitable for studies on energy balance, CO_2 effects, vegetation dynamics, and evapotranspiration.

Previous diagrams of the global water cycle have been criticized (Abbott et al., 2019; Fandel et al., 2018) for not accurately representing the magnitude of uncertainties that exist in current scientific understanding of the fluxes and stores that constitute the cycle. For example, the use of equally thick lines for fluxes, or values of water balances without error, gives the incorrect impression that the water cycle is fully understood and not subject to refinements or scientific discussion. Our diagrams have the same limitation, in that the fluxes and stores do not have an uncertainty range associated with them. This was not the goal of our exercise, but we acknowledge that such information is important. Our diagrams do, however, illustrate the concept of structural uncertainty. The model-specific differences in the diagrams of the individual models (Sect. 3.2) show that the water cycle can be represented in different, yet plausible, ways (Butts et al., 2004). In follow-on studies, the model outputs could be assessed to quantify the magnitude of uncertainty associated with the fluxes and storages. This information could then be incldued in the model diagrams by representing the fluxes and storages with different drawn thicknesses that correspond to the magnitude of uncertainty.

Lastly, the diagrams serve an educational purpose and support end-users. The illustration of the “ideal” global water model helps to show what is potentially feasible based on current modelling capability in the scientific community, while the individual model diagrams help to show the different ways that models approach the process of simplifying the environment and human interactions into a numerical model form. The illustrations also help with understanding the different degrees of complexity that exist in modelling, e.g. the number of soil layers. From an educational standpoint, this helps to support understanding of the underlying basis of modelling the water cycle, and it opens the floor for a more detailed discussion about the way that processes are implemented in the models Telteu et al. (2021). Also, this visualization of the structural model uncertainty of the current generation of global water models which can help to better inform end users such as readers of assessment reports (e.g. those from IPCC).

4.3 Updating the diagrams and future directions

The model diagrams presented here are for the models that have participated in phase 2b of ISIMIP. ISIMIP is currently in phase 3 (Frieler et al., 2024). Some of the models that participated in ISIMIP2b have been updated for phase 3, and in addition, some new models are participating in phase 3 that did not participate in earlier phases. The new models do not represent the water cycle in a completely different way compared to 2b, which means that the model diagrams presented here need to be adapted for the new models. Furthermore, the notation of the equations in Telteu et al. (2021) can also be used. To ensure the sustainability of the visualization approach described here, and to maximize the value of the learning process undertaken in developing the visuals, we have created a tool to automatically generate the model diagrams based on a json-notation of the components included in each model (Müller Schmied, 2024). This tool was finally used to generate the figures represented in this study. In the future, the modelling teams running new or updated models will be able to provide details on the components included in their models in a structured json-format and based on that, a model diagram could easily be created for that model.

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We are also considering to develop an interactive, web-based version of the diagrams. This would link to the underlying equations for each part of the diagram. There could also be an option to download the model outputs. We also envisage a search facility, which would allow users to select a specific component of interest and then obtain more information about the model(s) that consider that component, as well as the available model output. Once integrated in the general ISIMIP workflow, this would simplify the usability of output data and also increase the visibility and up-to-date status of the contributing models.

In the longer term, we anticipate exploring the feasibility of applying the “ideal” model and model visualization to some of the other types of models that participate in other ISIMIP sectors, e.g. global gridded crops models, biomes models, and global water quality models. This could then lead to improvements in cross-sectoral understanding of the models and support assessments of model outputs accordingly.

5 Conclusions

This study provides insights from a community effort to illustrate the components of the global water cycle that are currently simulated by a set of state-of-the-art global water models participating in the ISIMIP phase 2b exercise. Based on inclusive discussions between the modelling teams and a graphics designer, we co-developed an “ideal” representation of the global water cycle that several of the current generation of global water models can theoretically simulate. We then showed how individual models include/exclude some of the processes that appear in the “ideal” model by greying out processes where they do not appear, and also by adding the number of layers for different storages.

The process has highlighted the challenges and opportunities in creating a set of standardized model description diagrams. The process has been lengthy and required multiple iterations with different user groups, but the final set of diagrams has many potential uses. These include helping to assist with understanding differences in model performance, and identifying which models to include in future studies. The diagrams also serve an educational purpose, foster a better understanding of modeling results and their potential use in e.g. policy making or adaptation planning, and they provide a basis for future model development.

Although the models included in our study are not exhaustive (not all global water models participate in ISIMIP2b), they provide a point of reference for what is currently achievable from a large set of global water models, some of which have been developed over several decades. Looking to the future, the automated creation of the diagrams enables continuation and adapting of such graphical representations as models are updated and as new models join the ISIMIP exercise. We also hope that our experience and results will provide inspiration for other earth system science modellers who are interested in other aspects of the environment, to produce similar model ensemble visualizations that enhance understanding of each others’ models.

Appendix A: Individual model diagrams

https://doi.org/10.5194/egusphere-2024-1303
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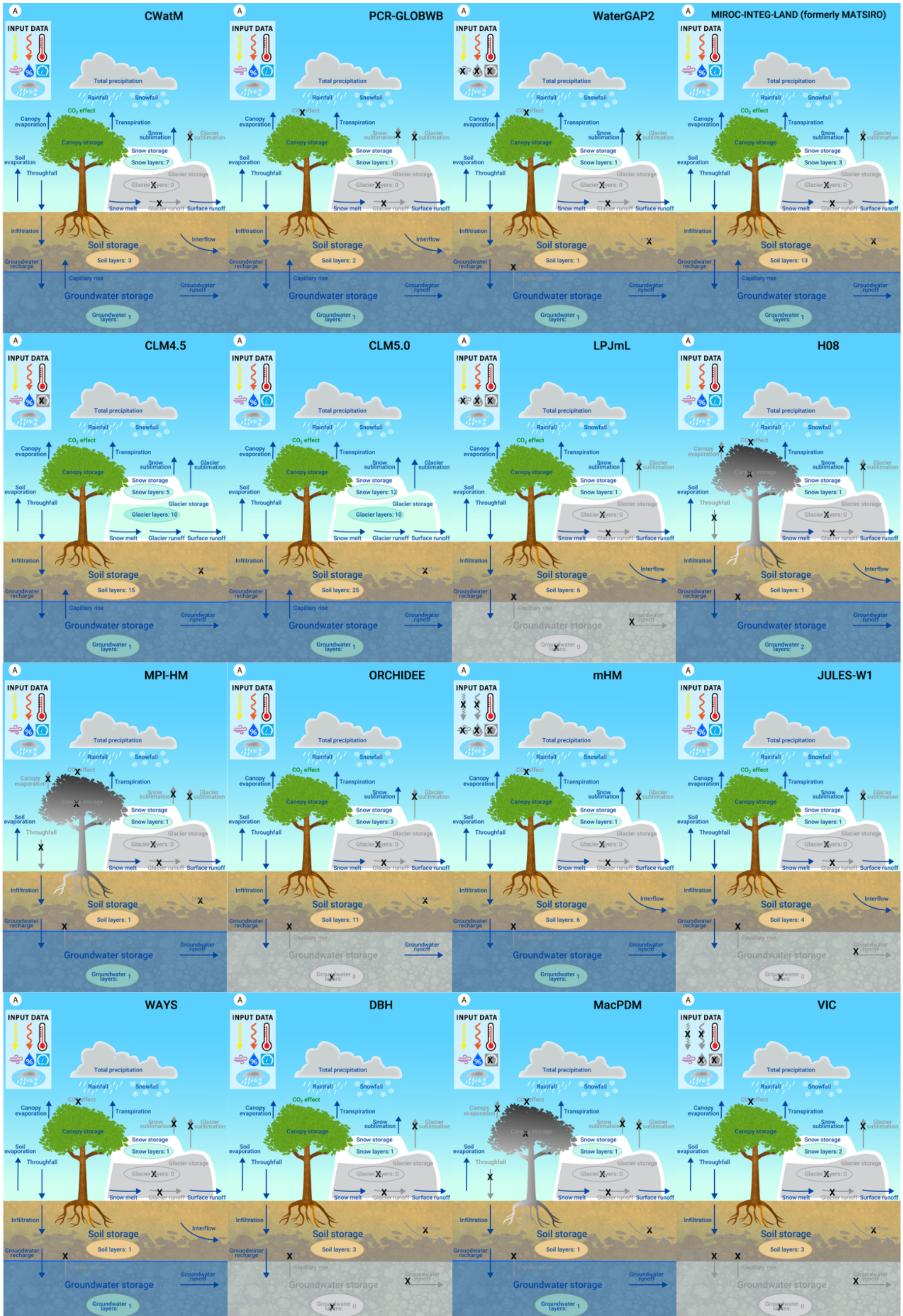

Figure 4. The components of the vertical water balance of the individual ISIMIP2b global water models, ordered by decreasing number of including fluxes and storages.

https://doi.org/10.5194/egusphere-2024-1303
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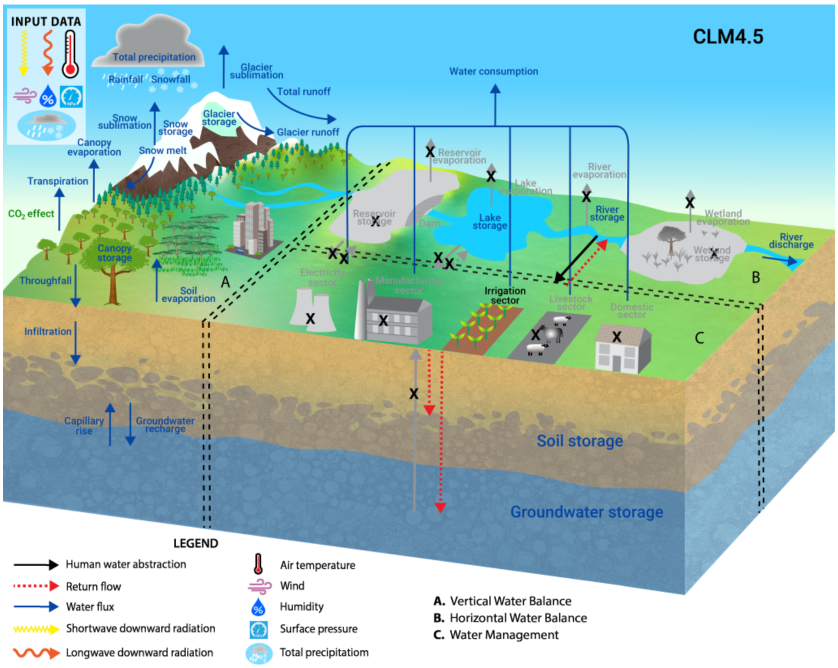

Figure A1. The "CLM4.5" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey). Please note that lake evaporation is computed in terms of the surface energy balance as the latent heat flux. But it does not affect the lake water balance as it is deliberately counteracted by an equally large flux with opposite sign, to avoid drifting lake levels. River storage and river discharge is calculated by MOSART. The irrigation module from CLM is taking the water from the river storage, the irrigation flux is transferred between both models through the coupler.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

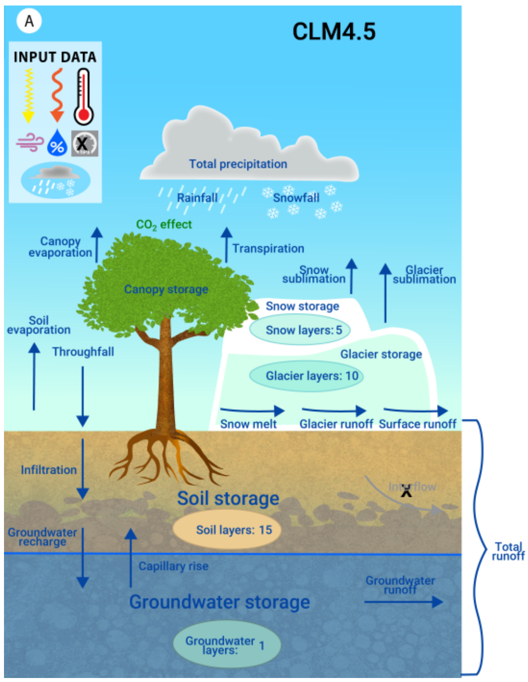

Figure A2. The "CLM4.5" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

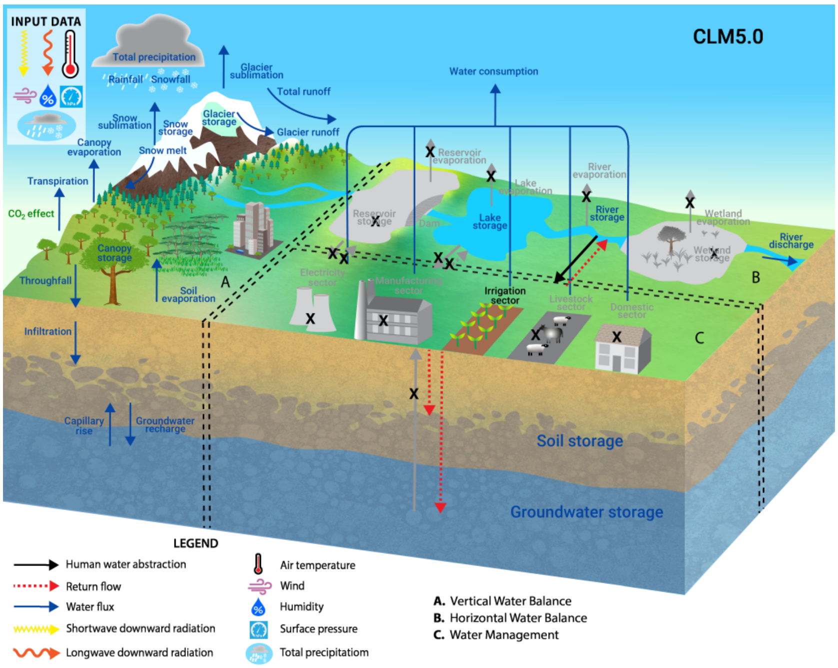

Figure A3. The "CLM5.0" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey). Please note that lake evaporation is computed in terms of the surface energy balance as the latent heat flux. But it does not affect the lake water balance as it is deliberately counteracted by an equally large flux with opposite sign, to avoid drifting lake levels. River storage and river discharge is calculated by MOSART. The irrigation module from CLM is taking the water from the river storage, the irrigation flux is transferred between both models through the coupler.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

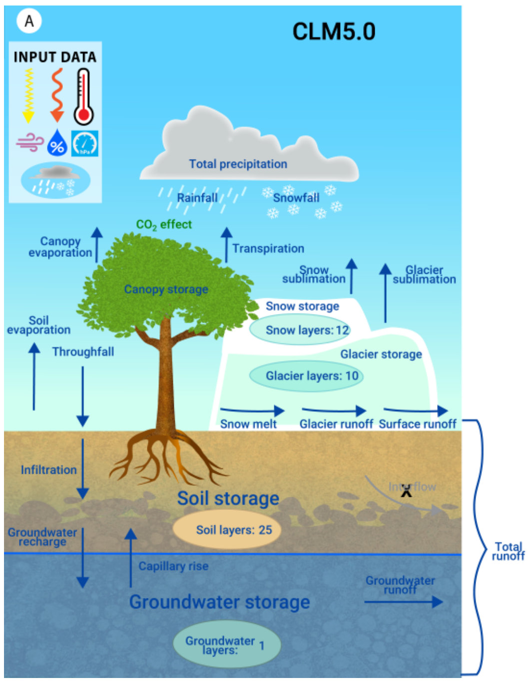

Figure A4. The "CLM5.0" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

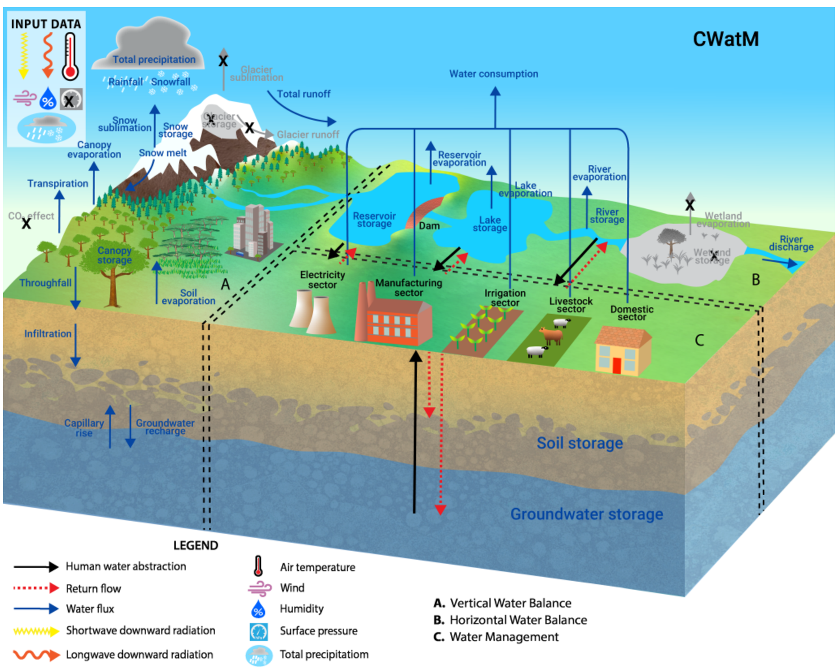

Figure A5. The "CWatM" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

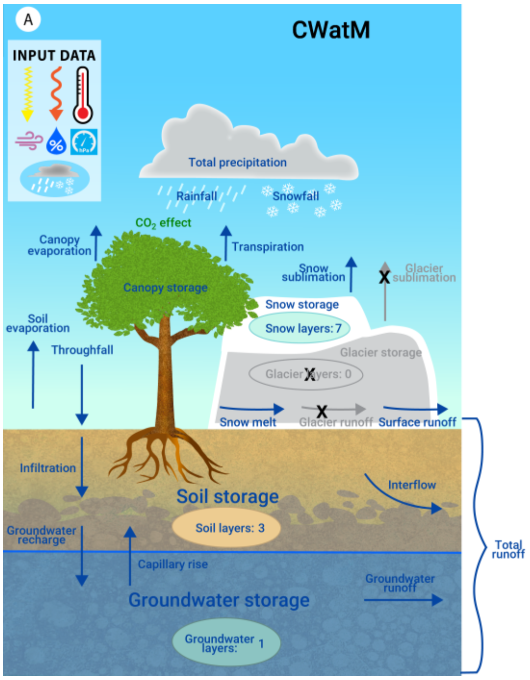

Figure A6. The "CWatM" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

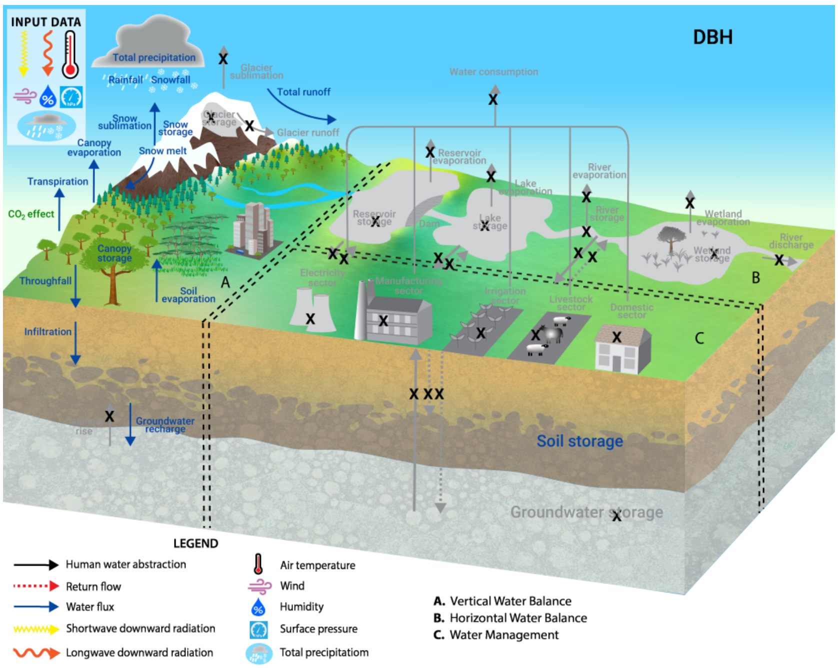

Figure A7. The "DBH" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

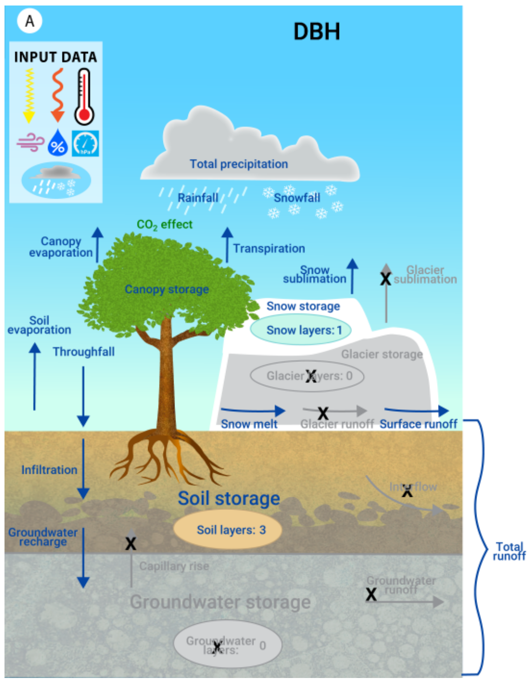

Figure A8. The "DBH" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

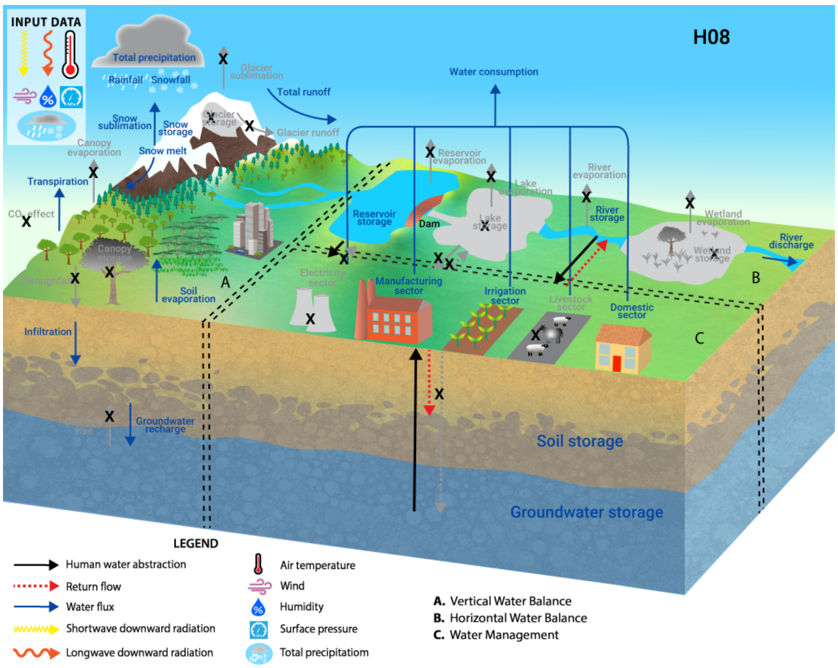

Figure A9. The "H08" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

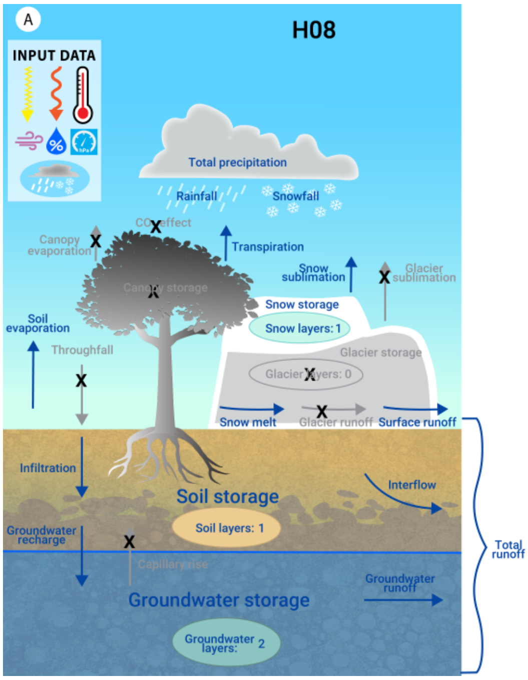

Figure A10. The "H08" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

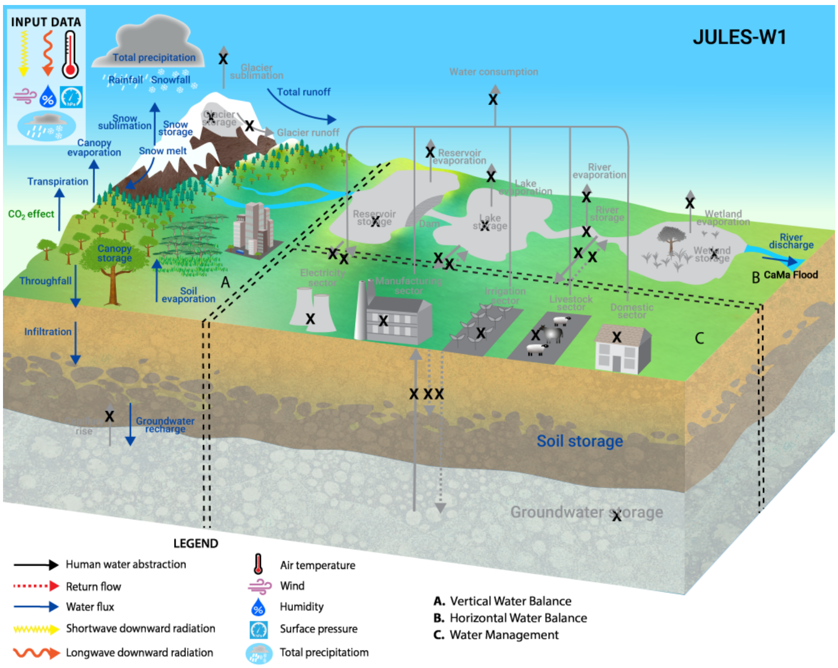

Figure A11. The "JULES-W1" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
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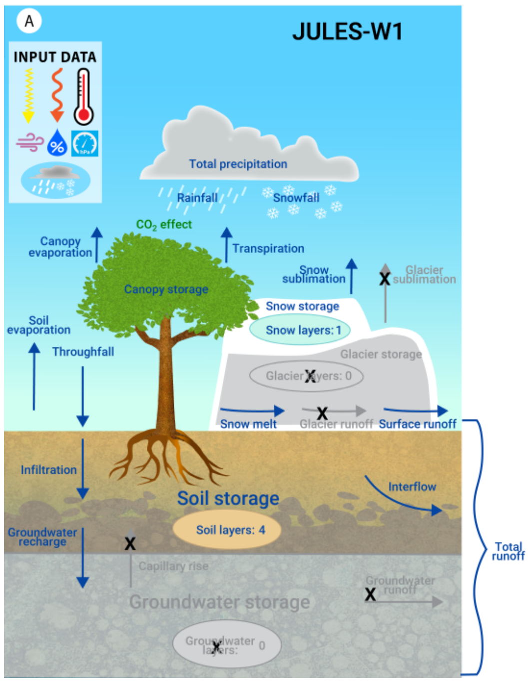

Figure A12. The "JULES-W1" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

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Preprint. Discussion started: 6 May 2024

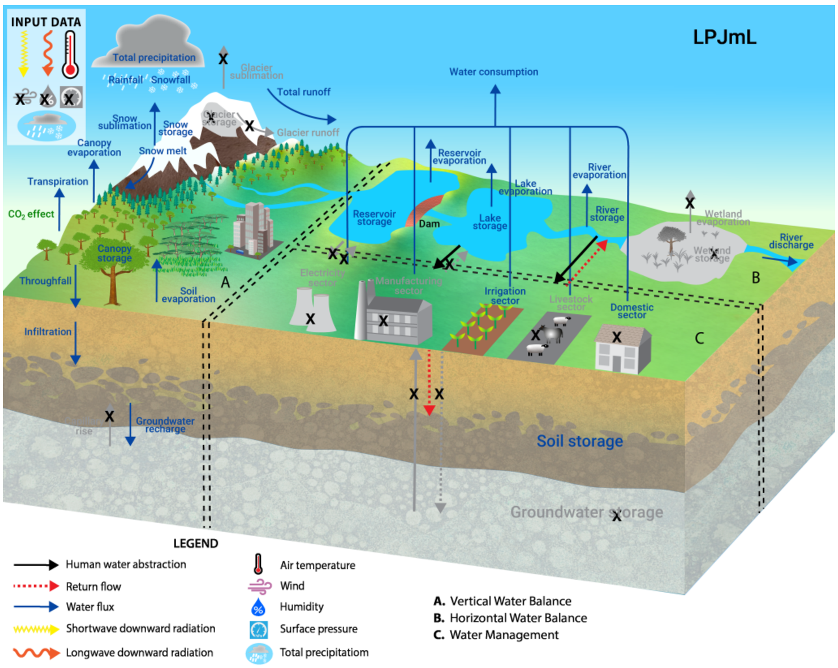

Figure A13. The "LPJmL" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey). Domestic sector is not simulated by the model itself but considered as input data.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

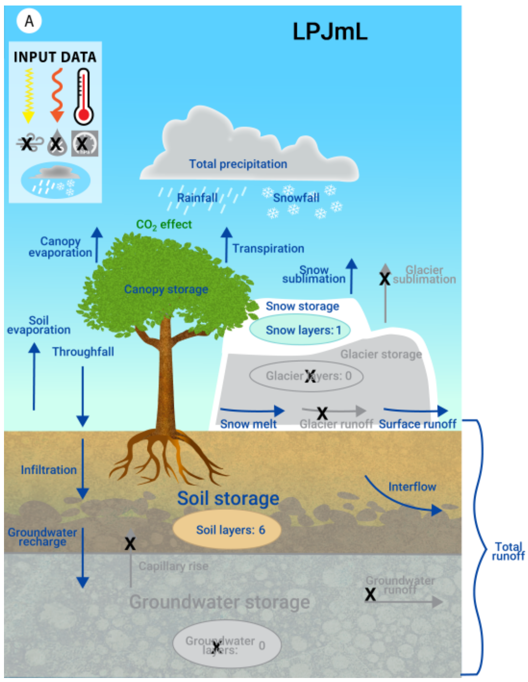

Figure A14. The "LPJmL" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance. There 5 hydrological active layers and the 6th is a thermal layer.

https://doi.org/10.5194/egusphere-2024-1303
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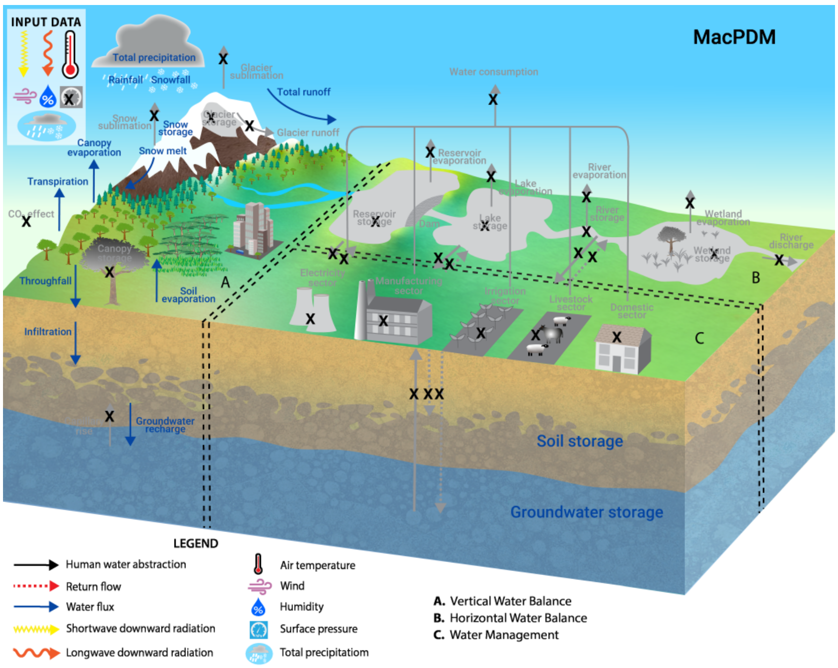

Figure A15. The "MacPDM" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

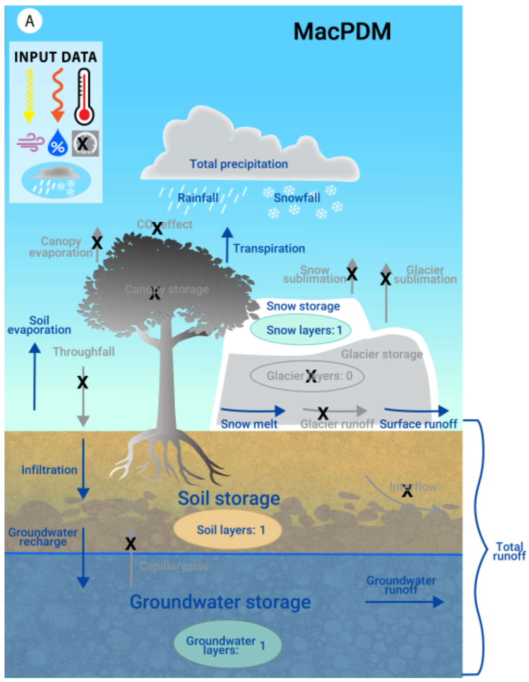

Figure A16. The "MacPDM" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

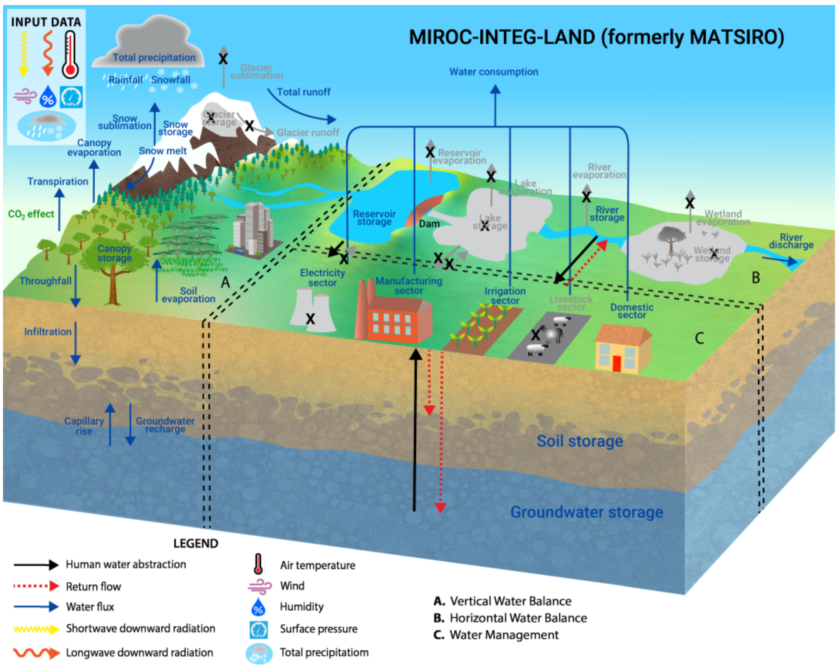

Figure A17. The "MATSIRO" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

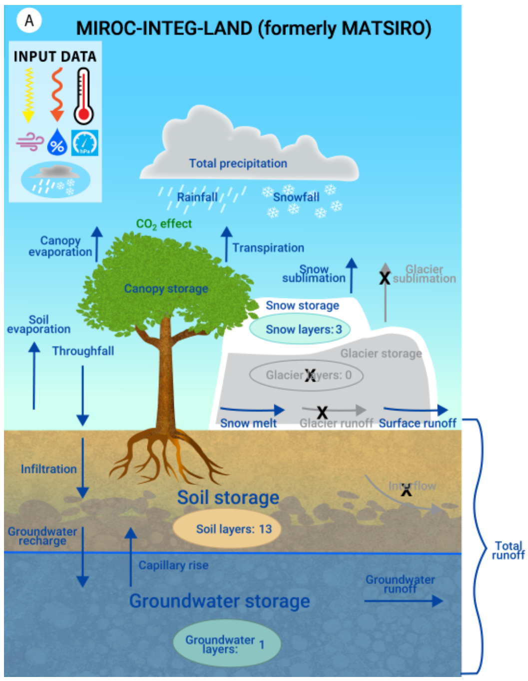

Figure A18. The "MATSIRO" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance. MATSIRO does not separately deal with groundwater storage and soil layer. Saturated soil layer (separated in up to 13 layers) is regarded as groundwater storage.

https://doi.org/10.5194/egusphere-2024-1303
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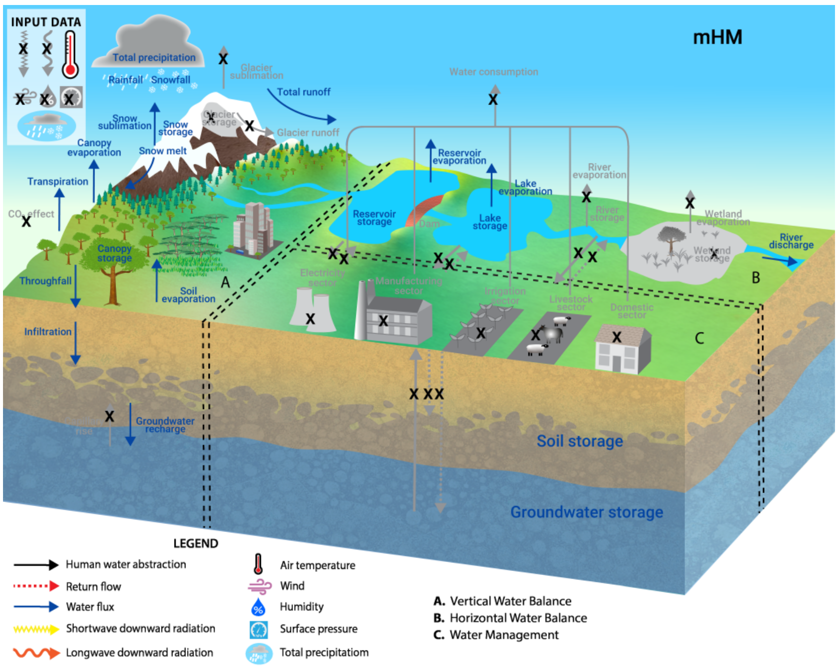

Figure A19. The "mHM" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

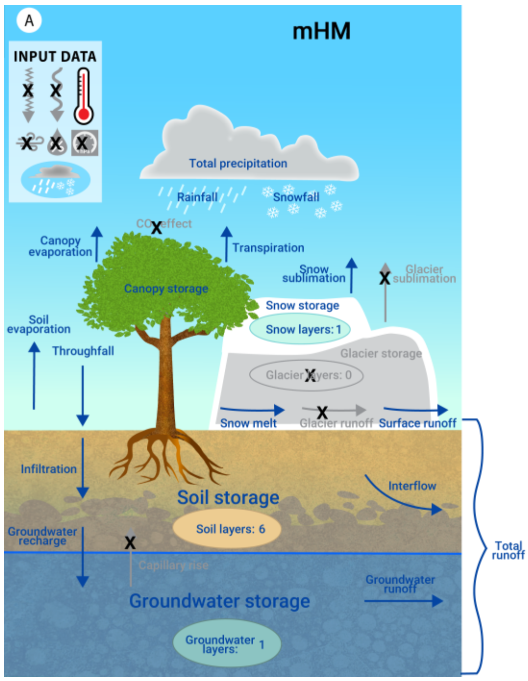

Figure A20. The "mHM" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

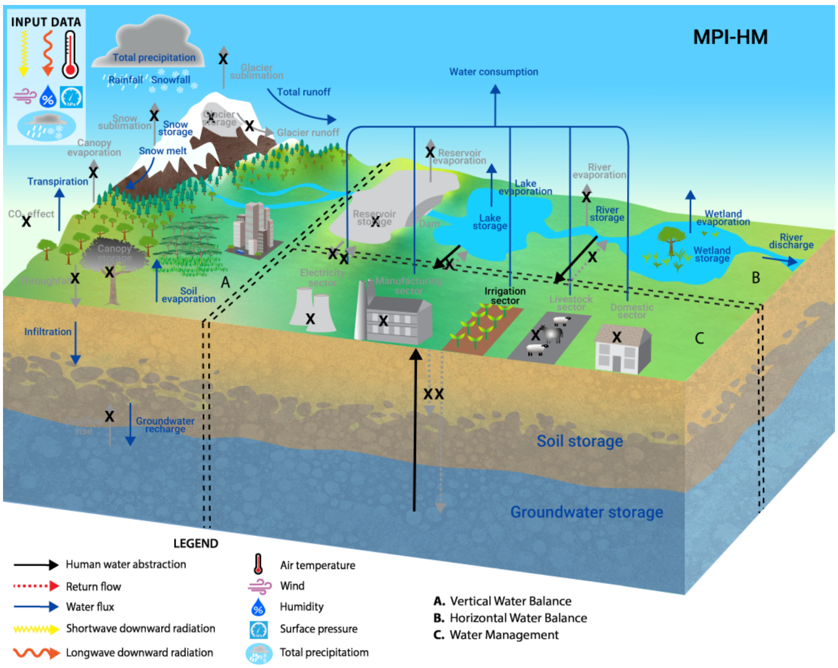

Figure A21. The "MPI-HM" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

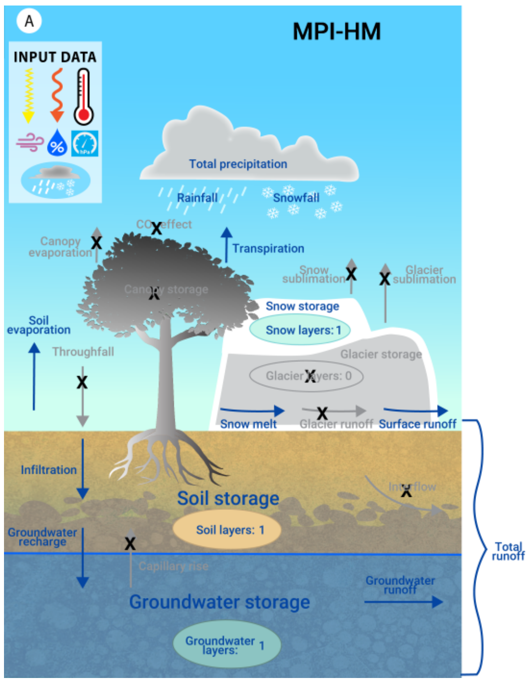

Figure A22. The "MPI-HM" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

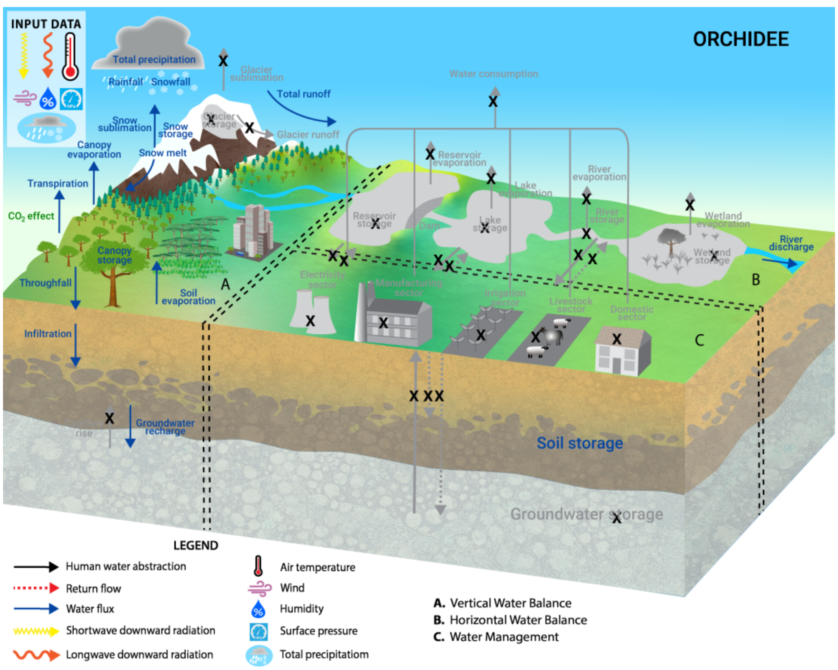

Figure A23. The "ORCHIDEE" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

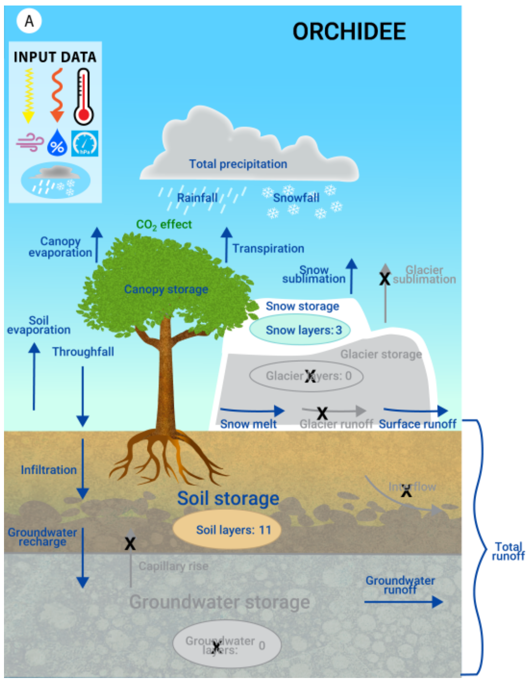

Figure A24. The "ORCHIDEE" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

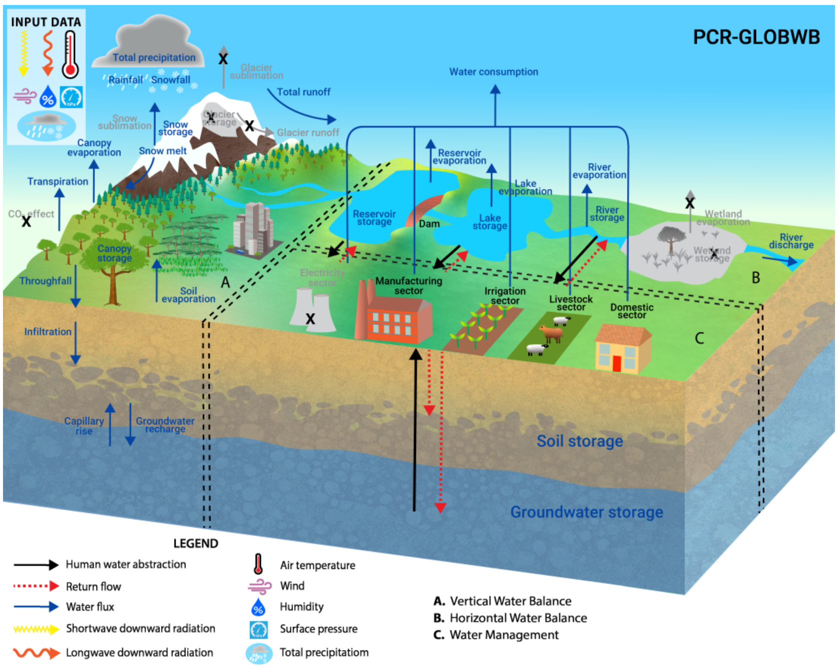

Figure A25. The "PCR-GLOBWB" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

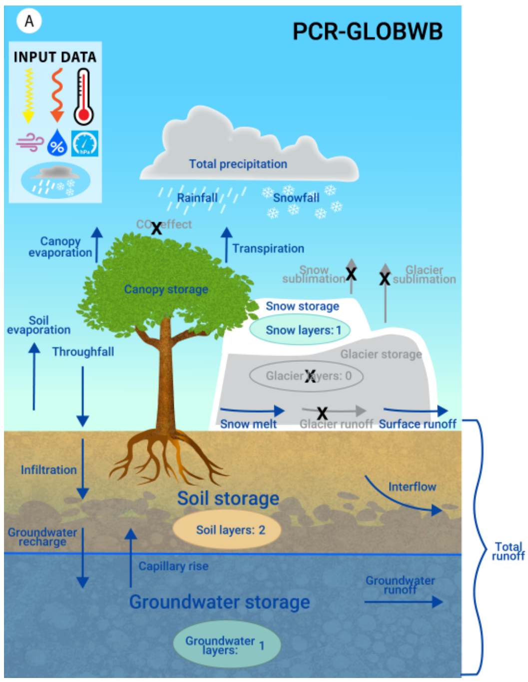

Figure A26. The "PCR-GLOBWB" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

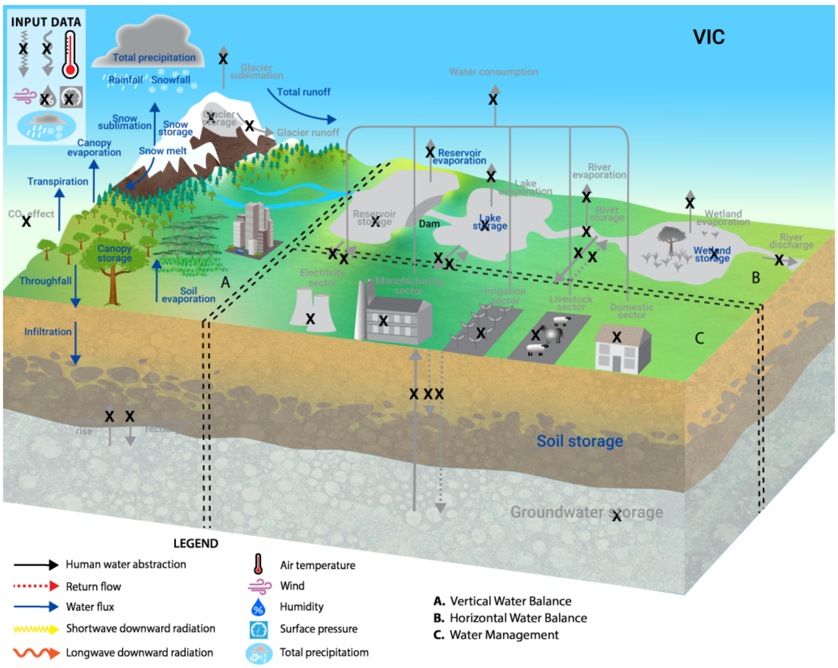

Figure A27. The "VIC" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

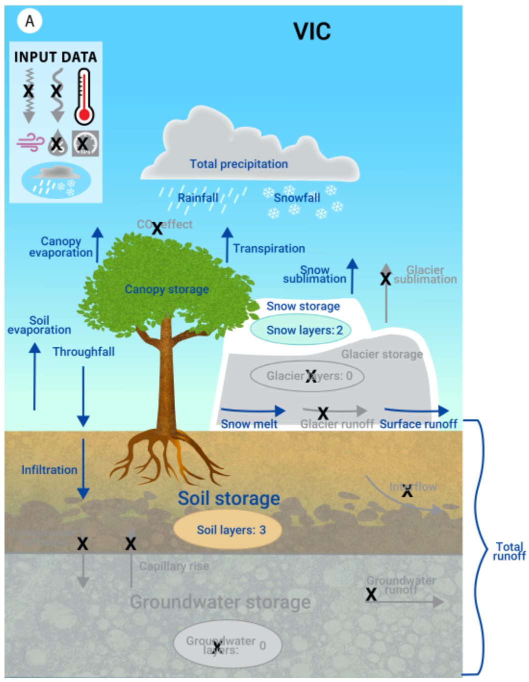

Figure A28. The "VIC" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

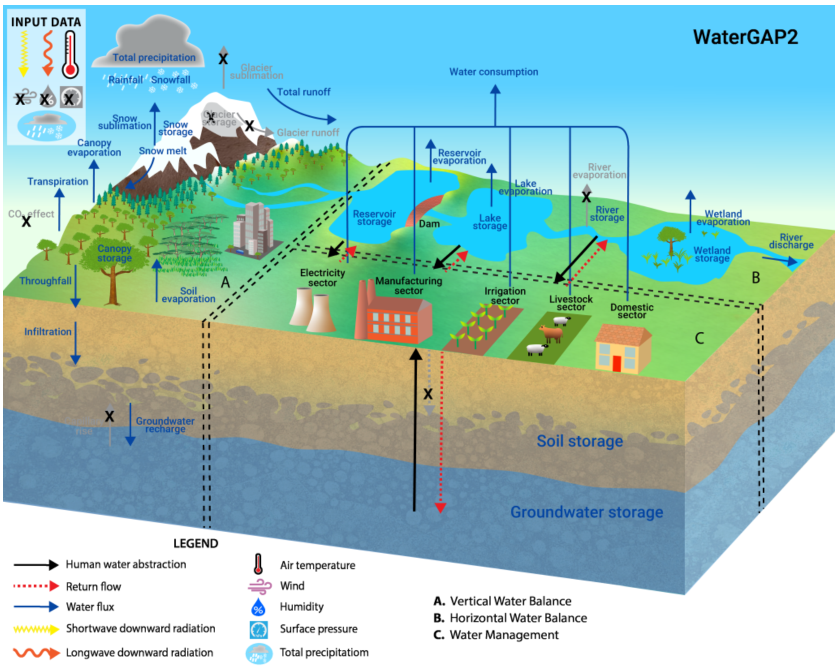

Figure A29. The "WaterGAP2" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

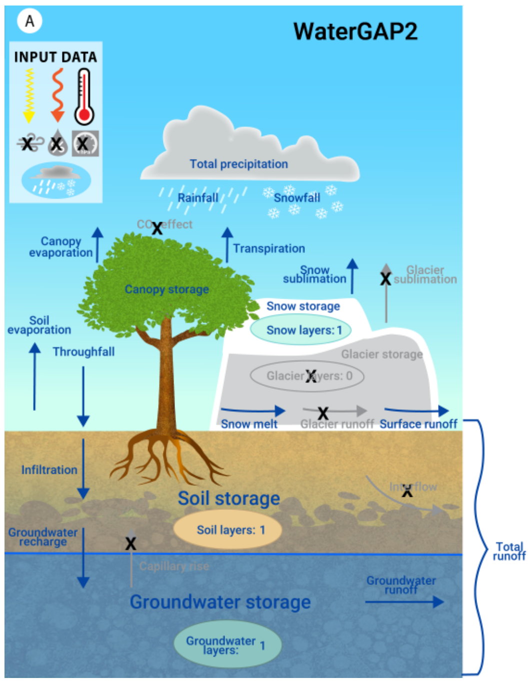

Figure A30. The "WaterGAP2" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

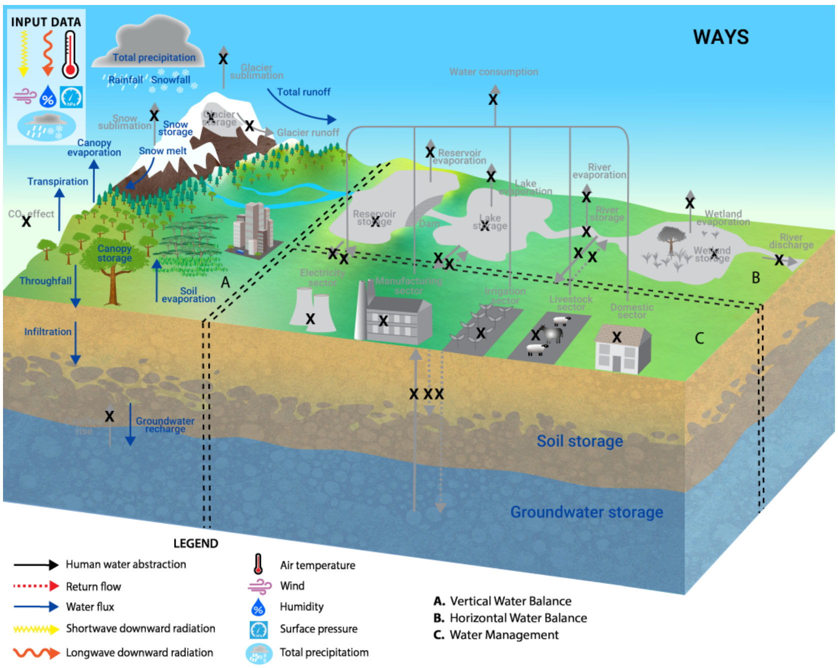

Figure A31. The "WAYS" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey).

https://doi.org/10.5194/egusphere-2024-1303
Preprint. Discussion started: 6 May 2024

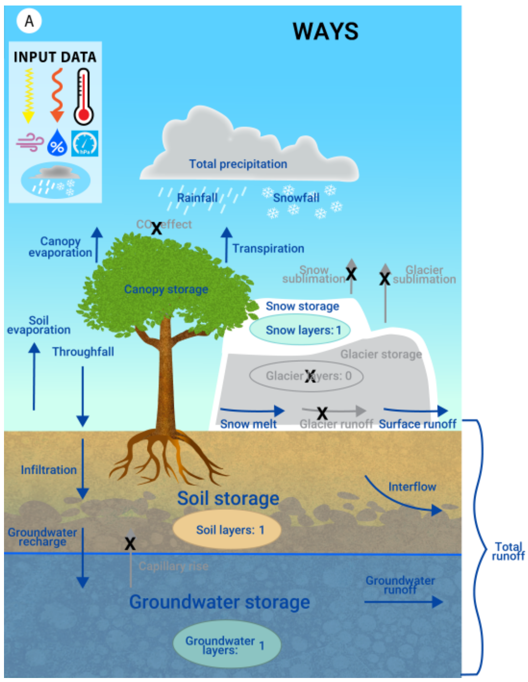

Figure A32. The "WAYS" model representation of included components (fluxes, storages and processes) (shown in color) and of components that are not represented (shown in grey) for the vertical water balance.

https://doi.org/10.5194/egusphere-2024-1303
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Code availability. The diagrams are initially drawn by using Adobe Illustrator. The single elements have then been extracted and composed within a Python-script and based on a json notation of the components of the ideal and individual models. The Github repository with this code is available at Müller Schmied (2024).

Data availability. No model output is used in this particular study. The resulting diagrams are available on request and will be made publically available with the final version of the manuscript

Author contributions. CET led the conceptualization and organization of the graphical representation of the ISIMIP2b models under guidance of HMS starting in 2018, and HMS took over the process in 2022. The initial idea to commonly provide the graphical representation of the ISIMIP2b models was proposed by HMS, who also obtained funding for the graphics designer. MG initially created the graphics with input and feedback obtained from CET and HMS, who both collected the feedback from the individual modelling teams. All other co-authors (and including CET, SNG, HMS) directly provided feedback to the representation of the "ideal" models, and in the particular models of the modelling teams. HMS created the script to automatize the creation of the final figures presented here. CET led and conducted the stakeholder interaction. HMS wrote the initial draft of the manuscript and LM and SNG critically reviewed and revised it. All authors reviewed, commented on and contributed to the final draft.

Competing interests. The authors declare that no competing interests are present

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