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The sense and non-sense of plot-scale, catchment-scale, continental-scale and global-scale hydrological modelling

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Hydrological models aim at quantifying the hydrological cycle and its constituent processes for particular conditions, sites or periods in time. Such models have been developed for a large range of spatial and temporal scales.
One must be aware that the question which is the appropriate scale to be applied depends on the overall question under study. Therefore, it is not advisable to give a general applicable guideline on what is “the best” scale for a model. This statement is even more relevant for coupled hydrological, ecological and atmospheric models. Although a general statement about the most appropriate modelling scale is not recommendable, it is worth to have a look on what are the advantages and the shortcomings of micro-, meso- and macro-scale approaches. Such an appraisal is of increasing importance, since increasingly (very) large / global scale approaches and models are under operation and therefore the question arises how far and for what purposes such methods may yield scientifically sound results.
It is important to understand that in most hydrological (and ecological, atmospheric and other) studies process scale, measurement scale, and modelling scale differ from each other. In some cases, the differences between theses scales can be of different orders of magnitude (example: runoff formation, measurement and modelling). These differences are a major source of uncertainty in description and modelling of hydrological, ecological and atmospheric processes. Let us now summarize our viewpoint of the strengths (+) and weaknesses (-) of hydrological models of different scales:
Micro scale (e.g. extent of a plot, field or hillslope):
(+) enables process research, based on controlled experiments (e.g. infiltration; root water uptake; chemical matter transport);
(+) data of state conditions (e.g. soil parameter, vegetation properties) and boundary fluxes (e.g. rainfall or evapotranspiration) are directly measurable and reproducible;
(+) equations based on first principals, partly pde-type, are available for several processes (but not for all), because measurement and modelling scale are compatible
(-) the spatial model domain are hardly representative for larger spatial entities, including regions for which water resources management decisions are to be taken; straightforward upsizing is also limited by data availability and computational requirements.

Meso scale (e.g. extent of a small to large catchment or region):
(+) the spatial extent of the model domain has approximately the same extent as the regions for which water resources management decisions are to be taken. I.e., such models enable water resources quantification at the scale of most water management decisions;
(+) data of some state conditions (e.g. vegetation cover, topography, river network and cross sections) are available;
(+) data of some boundary fluxes (in particular surface runoff / channel flow) are directly measurable with mostly sufficient certainty;
(+) equations, partly based on simple water budgeting, partly variants of pde-type equations, are available for most hydrological processes. This enables the construction of meso-scale distributed models reflecting the spatial heterogeneity of regions/landscapes;
(-) process scale, measurement scale, and modelling scale differ from each other for a number of processes, e.g., such as runoff generation;
(-) the process formulation (usually derived from micro-scale studies) cannot directly be transferred to the modelling domain. Upscaling procedures for this purpose are not readily and generally available.

Macro scale (e.g. extent of a continent up to global):

(+) the spatial extent of the model may cover the whole Earth. This enables an attractive global display of model results;
(+) model results might be technically interchangeable or at least comparable with results from other global models, such as global climate models;
(-) process scale, measurement scale, and modelling scale differ heavily from each other for all hydrological and associated processes;
(-) the model domain and its results are not representative regions for which water resources management decisions are to be taken.
(-) both state condition and boundary flux data are hardly available for the whole model domain. Water management data and discharge data from remote regions are particular incomplete / unavailable for this scale. This undermines the model's verifiability;
(-) since process formulation and resulting modelling reliability at this scale is very limited, such models can hardly show any explanatory skills or prognostic power;
(-) since both the entire model domain and the spatial sub-units cover large areas, model results represent values averaged over at least the spatial sub-unit's extent. In many cases, the applied time scale implies a long-term averaging in time, too.

We emphasize the importance to be aware of the above mentioned strengths and weaknesses of those scale-specific models. (Many of the) results of the current global model studies do not reflect such limitations. In particular, we consider the averaging over large model entities in space and/or time inadequate. Many hydrological processes are of a non-linear nature, including threshold-type behaviour. Such features cannot be reflected by such large scale entities. The model results therefore can be of little or no use for water resources decisions and/or even misleading for public debates or decision making.
Some rather newly developed sustainability concepts, e.g. "Planetary Boundaries" in which humanity may "continue to develop and thrive for generations to come" are based on such global-scale approaches and models. However, many of the major problems regarding sustainability on Earth, e.g. water scarcity, do not exhibit on a global but on a regional scale. While on a global scale water might look like being available in sufficient quantity and quality, there are many regions where water problems already have very harmful or even devastating effects.
Therefore, it is the challenge to derive models and observation programmes for regional scales. In case a global display is desired future efforts should be directed towards the development of a global picture based on a mosaic of regional sound assessments, rather than "zooming into" the results of large-scale simulations. Still, a key question remains to be discussed, i.e. for which purpose models at this (global) scale can be used.