

## ***Interactive comment on “HESS Opinions “Hydrologists, bring out shovels and garden hoses and hit the dirt”” by M. G. Kleinhans et al.***

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We thank the reviewers for their constructive and positive comments. Below we summarise and address each reviewer comment and explain how we modify the paper in response.

Minor comments were appreciated and are incorporated in our new version. See our reply to reviewer 1 for the discussion about field experiments.

Comment 1: What do we mean by the statement The laws of physics can seldom be applied directly to the initial conditions to check whether they explain the observations, because they must be applied in models with many different simplifications that provide

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different answers?

Reply 1: We will clarify this in the manuscript. We mean that many relevant laws of physics, including the Navier-Stokes equations, cannot directly be solved given realistic boundary conditions, because no analytical solution is available. Furthermore, models that solve the NS-equations are inherently instable and highly sensitive to minor changes in boundary conditions. For the spatial and temporal scales usually required, the NS-equations must be simplified. But there are various simplifications possible, including Manning, St. Venant, etc. And to illustrate that numerical problems are significant, we may mention that many flow routing codes are based on the same physics but provide different answers, and the same is true for fluvial and coastal morphology. So we cannot be certain that a (mis)match between model results, based on the laws of physics, and observations are not due to the simplifications and numerical issues.

Comment 2: One cannot use a model to test whether observations conflict with physical laws; both are based on physical principles. Rather, a model can be used to test our perception of, for instance, hillslope structure.

Reply 2: Our statement is exactly that: using a model we test whether a hypothesis (or perception, but not observations) agree or conflict with the presumed laws of physics that hypothetically explain the observations. This excludes laws of physics that are, according to the hypothesis, unnecessary to explain the observations. Note, however, that observations are usually based on different physical principles. For instance, one may test a surface runoff model with surface runoff data collected with acoustic or electromagnetic instruments. One could argue that the test includes the auxiliary physical laws of acoustics or electromagnetics, and that a mismatch between observations can be due to the surface runoff model or due to the auxiliary laws. However, such instruments are usually calibrated and tested extensively so this is not an issue.

Furthermore it is important to realise that laws are not that lawful. To illustrate, the Manning law is called law, but is a simplification of the NS-equations. As a result of the

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simplifications, the law can only be applied in certain conditions and with certain validity ranges. Thus a law cannot be perceived as something that is always valid and correct. Even the NS-equations has limited applicability: namely for a one-phase flow that can be considered a continuum. Surface tension is not included and the law breaks down if the flow length scale approaches that of the discrete particles.

Comment 3: We can build physical models that are valid in general, as is shown, for example, in the REW approach that separates effects of first principles from effects of site specific features and closures. In meteorology models are not discarded because closure relations do not work; rather, meteorologists try to improve these.

Reply 3: We do not understand exactly what the reviewer means. Confusion may arise because of the less general and more precise meaning of these words in philosophy, such as the word law discussed above. Valid here means flawless and internally consistent, e.g. without errors in the code. For simple codes, all flaws can be found and corrected whereas for complex codes Oreskes et al. (1994) argue that this is impossible. The example of the reviewer is not about valid but about work, that is, not about validation but about verification. Verification means proving that the physics-based model represents the natural phenomena of interest correctly by the correct physics. Again, strictly speaking this is impossible because of the underdetermination problems including the closure relations and because models are inherently simplifying reality. We believe that physics-based models, controlled experiments and observation are equally useful approaches to study structure in nature.

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 6, 6581, 2009.