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Comment on "Hyperresolution global land surface modeling: Meeting a grand challenge for monitoring Earth's terrestrial water" by Eric F. Wood et al.

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[1] *Wood et al.* [2011, hereafter W2011] promote the development of hyperresolution global land surface models ("1 km^2 or finer, say to 100 m at continental scale," p. 2) as the "Grand Challenge" for the hydrological community. Grand Challenges are useful in several ways: as a way of exciting the hydrological community; as a way of encouraging the community to work together for a common aim; as a way of persuading funding agencies to devote resources into a particular area. We certainly endorse the objective of creating a global effort for improving our ability to predict and monitor land surface hydrology. However, we believe that the Grand Challenge as laid out in W2011 is incomplete in some important ways.

[2] In particular it neglects to mention that there are fundamental issues of lack of knowledge which remain in catchment hydrological modeling including: lack of knowledge about input and boundary conditions; lack of knowledge in the representation of process; and inadequate knowledge about the errors in observational data. Applying hydrological models to the continental and global scale has demonstrated that this lack of knowledge has a significant effect on predictive capability [e.g., *Widén-Nilsson et al.*, 2007; *Sperna Weiland et al.*, 2010; *Fischer et al.*, 2011; *Prudhomme et al.*, 2011]. Over much of the globe we cannot close the water balance on the basis of the observations available without allowing for significant uncertainty in the observed variables. Changing the scale of implementation of hydrological models does not, in itself, resolve the issues arising from fundamental lack of knowledge. Indeed, it is not clear how these issues will be resolved in the future, even when SWOT and other high resolution satellite data might be available, and even in the various hydrological and critical zone observatory catchments that are being developed around the world. Remote sensing images require an interpretative model to provide useful (if uncertain) information for hydrological applications; while the unknown nature of the detailed characteristics of experimental catchments still makes it difficult to define adequate process representations. Very often, as in the case of discharges interpreted from sensing of water levels, or soil moisture interpreted from surface emissivity, the information will be associated with significant uncertainty.

[3] These lack of knowledge (or epistemic uncertainty) issues are not recognized in W2011 and we would argue that explicit consideration of epistemic uncertainty is absolutely fundamental to a successful scientific hydrology [e.g., *Pappenberger and Beven*, 2006]. Furthermore we would argue resolution is not the only problem. We can agree of course that finer resolution models would allow for "much better representation of the effects of spatial heterogeneity in topography, soils, and vegetation on hydrological dynamics at large scales" (W2011, p. 2) but the heterogeneities that are important are not only those that can be identified from high resolution remote sensing (or other spatial data). They are also not only those that are resolved at scales of 100 m. There will still be subgrid heterogeneities at the sub-100 m scale that are not properly resolved by using homogeneous soil and vegetation properties at that scale (as is all too evident in current practice of applying hydrological models at small catchment scales). Therefore there will still be a need for some more realistic subgrid-scale parameterization of the processes.

[4] The problem is much more than a need to "develop ... fine-scale process parameterizations" (W2011, p. 8). Even the physics tells us this. A heterogeneous unsaturated zone will not average linearly in its parameters even if the Darcy-Richards equation was the correct process equation [*Beven*, 1989, 2001]. But it is not (except in some rather exceptional circumstances). Normally preferential flows of some type will have an important effect on the flux of water to deeper layers and therefore on the water balance partitioning [*Beven and Germann*, 1982; *Uhlenbrook*, 2006; *Jarvis*, 2007; *Allaire et al.*, 2009]. This has been shown to be the case even in the constructed Chicken Creek catchment [*Holländer et al.*, 2009] and will also be true for hyperresolved hydrological models of all the basins that make up the continents and the global land surface.

[5] We would consequently argue that regardless of scale, the main challenge is not hyperresolution but instead it is much more one of an appropriate scale-dependent subgrid parameterisation that recognizes the epistemic uncertainties in knowing and representing the characteristics of a

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grid element, and the nonlinearity and hysteresis in its dynamics [*Beven*, 2006a]. This is true at current global modeling scales, but it will still be true at 100 m. The visualization of Figure 1 in W2011 only looks more impressive because of the resolution of the graphics. There is absolutely no reason why the more detailed topography and other data, that are already available, could not have been used in a larger-scale processes representation. Indeed, there is no reason why the hydrology should not match current or future grid resolutions of an atmospheric model, providing that the subgrid effects on fluxes to atmosphere, groundwater and the river network are represented properly. This, in fact, should *always* have been the case. It is just that allowing relatively little computer and staff resources to land surfaces processes in atmospheric circulation models, relative to other demands, has limited the complexity of the description of the near surface hydrology to a (generally) hydrologically unrealistic collection of homogeneous subgrid tiles.

[6] Therefore, we would define the Grand Challenges of providing better hydrological predictions at global and continental scales in rather a different way to that in W2011. In particular we would separate the problem of process representation at a particular scale and a particular environment from that of identifying appropriate parameterizations at a particular location, allowing for the uncertainty in the sources of information to do so. Both are quite independent from the Challenge of simply moving to finer resolutions; indeed both already apply to the current scales of GCMs. The two challenges are the following:

[7] 1. defining the appropriate parameterisations at current and future grid resolutions and for different types of physioclimatic region;

[8] 2. defining methodologies (including ensemble simulation) for taking account of the lack of knowledge involved in evaluating and constraining the uncertainty in those parameters given current and future data availability.

[9] These challenges are difficult because they involve epistemic uncertainties, particularly in defining subsurface processes and parameters. This is as applicable to land surface modeling as it is to other types of hydrological modeling and we believe it should be taken seriously by the land surface community if the predictions are to have value. This gives rise to issues of robustness in prediction within the limitations of uncertainty and appropriate levels of complexity. It is well understood that more complex models will not always give more robust predictions than simpler models (e.g., see *Schulz et al.* [2001] and the virtual Little Washita example of *Bashford et al.* [2002], where it was assumed that 1 km^2 measurements of actual evapotranspiration were available from a virtual satellite sensor) but there is still a lot to be learned about appropriate parameterisations for land surface hydrology. *Beven* [2006a] called this the "Holy Grail" of hydrological science. Similar issues arise in forest and crop models and in predicting water quality, except that the epistemic uncertainties will arguably be even greater. The limitations of current water quality models are only too easy to demonstrate [e.g., *Dean et al.*, 2009].

[10] Having said that, there are reasons why we might wish to implement process representations at finer resolutions (although for quite different reasons to those suggested in W2011). This is because appropriate parameterizations will not be universal. They will vary from place to place and can only be tested for specific places. The better resolution of visualizations that results from using finer resolution models allows local stakeholders and decision makers to assess the model predictions more directly for the places they are specifically interested in. In particular, it allows local stakeholders to assess where the model predictions are clearly wrong. This is not so easy when results are presented at larger scales for which there is no direct experience with which to compare or where the local observations and grid-scale predicted variables are incommensurate [*Pappenberger et al.*, 2009].

[11] This type of local evaluation could lead to a more critical attitude to global modeling and a learning process that will lead to more appropriate local parameterisations, [e.g., *Beven*, 2007; *Beven and Alcock*, 2011]. In addition, it will allow us to make better use of high-resolution data sets by fostering the understanding of the commensurability errors and uncertainties of interpretative models in the context of a global hydrological framework. This could be expected to lead to better parameterizations at larger grid scales in coupling to meteorological models where a recognition of the generic uncertainties suggested that ensemble simulation was more important than achieving a finer resolution.

[12] Many forecasting institutions, according to their research plans, will be moving to hyperresolution within the next few years. However, there will be a practical conflict between achieving finer resolution and reflecting uncertainty through ensemble and multimodel prediction. As yet, we do not know how properly to parameterize hydrological processes as a function of scale, and we do not know how properly to test models as hypotheses in the face of epistemic uncertainties [*Beven*, 2006b, 2010]. These are issues that will not be resolved simply by moving to finer resolutions when the level of epistemic uncertainty is not fundamentally changed by doing so.

[13] But epistemic uncertainties are often defined as uncertainties that can, at least in principle, be reduced by further research. So a challenge to the community should then be how to prioritise that research within the context of the Grand Challenges set out here and by W2011. Refining grid scales will not by itself resolve many of the very real problems in hydrological and other predictions. We believe that it would be a very positive initiative to bring the community together to discuss setting priorities in addressing the challenges involved in defining parameterisations at different scales and testing them as hypotheses (including whether advances in measurement techniques and parallel computing allow us to reject lower-resolution (or lumped) approaches). We believe that such an approach will also lead to improved predictions in skill for the disciplines that depend on coupled hydrological predictions and a more realistic evaluation of prediction uncertainties.

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