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Effects of detailed soil spatial information on watershed modeling across different model scales

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Abstract

Hydro-ecological modelers often use spatial variation of soil information derived from conventional soil surveys in simulation of hydro-ecological processes over watersheds at mesoscale (10–100 km^2). Conventional soil surveys are not designed to provide the same level of spatial detail as terrain and vegetation inputs derived from digital terrain analysis and remote sensing techniques. Soil property layers derived from conventional soil surveys are often incompatible with detailed terrain and remotely sensed data due to their difference in scales. The objective of this research is to examine the effect of scale incompatibility between soil information and the detailed digital terrain data and remotely sensed information by comparing simulations of watershed processes based on the conventional soil map and those simulations based on detailed soil information across different simulation scales. The detailed soil spatial information was derived using a GIS (geographical information system), expert knowledge, and fuzzy logic based predictive mapping approach (Soil Land Inference Model, SoLIM). The Regional Hydro-Ecological Simulation System (RHESSys) is used to simulate two watershed processes: net photosynthesis and stream flow. The difference between simulation based on the conventional soil map and that based on the detailed predictive soil map at a given simulation scale is perceived to be the effect of scale incompatibility between conventional soil data and the rest of the (more detailed) data layers at that scale. Two modeling approaches were taken in this study: the lumped parameter approach and the distributed parameter approach. The results over two small watersheds indicate that the effect does not necessarily always increase or decrease as the simulation scale becomes finer or coarser. For a given watershed there seems to be a fixed scale at which the effect is consistently low for the simulated processes with both the lumped parameter approach and the distributed parameter approach.

Keywords: Geographic information systems; Remote sensing; Scale; Soils; Hydrology; Environmental modeling; Model bias; SoLIM

1. Introduction

Increasingly geographic information systems (GIS) are used to parameterize the landscape for hydro-ecological models operating at the mesoscale level (10–100 km^2). One of the emergent stumbling blocks in the integration of GIS and watershed models is the problem of combining data sets of varying levels of spatial details (Ehleringer and Field, 1993; Blöschl, 1998;

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Thieken et al., 1999; Western and Blöschl, 1999; Zhu, 2005). In other words, spatial data needed for hydro-ecological models at the mesoscale level are not always available at that level of spatial detail. For example, information on the spatial variation of soils are often derived from the *conventional* 1:24,000 scale soil maps (which often have a minimum mapping unit between 2.5 and 5 ha), while information on the spatial variation of vegetation are often derived from remotely sensed imagery at 30 m resolution (or finer). Consequently, the level of spatial detail in conventional soil maps are often much coarser than the level of spatial detail in the corresponding vegetation map. Thus the levels of spatial details between the two maps are incompatible. This incompatibility is referred to as scale incompatibility because it is a result of the difference in map scale and/or spatial resolution among the data layers.

When using data sets of varying scales, researchers are often faced with the question of '... what is the appropriate scale at which to simulate hydro-ecological processes over mesoscale watersheds?' (Band, 1993; Wolock and Price, 1994; Zhang and Montgomery, 1994; Van Gardingen et al., 1997; Koren et al., 1999; Georges and Chen, 2002; Haddeland et al., 2002; Ranjan and Wurbs, 2002). Since GIS allows rapid processing and parameterization of spatial data, it is tempting to operate the model at the scale of the most detailed data layers involved in the modeling effort, even if other data layers do not match that scale.

It is important to note that this scale incompatibility can cause the spatial co-variation of model parameters to be characterized incorrectly (Zhu, 2000), and thus lead to incorrect model output and result interpretation. One common example of scale incompatibility results from the use of soil data in hydro-ecological models, which require variables about local soil water storage capacity and transmissivity. Soil information are typically derived from conventional polygon-based soil maps, with a scale likely to be substantially lower than that of other data used by the model, such as terrain data derived from standard digital elevation models (DEMs). Modelers often overlay (spatially combine) high resolution (10–30 m) topographic and vegetation data with generalized soil information derived from the conventional soil survey (1:24,000) to estimate the co-variation of terrain, vegetation, and soil conditions over space. This overlay can result in poor local correspondence between key soil variables such as available moisture and other model parameters such as leaf area index or solar insolation. In such cases, the scale of the original soil survey prevents the parameterization of small areas where soil properties deviate from those of the larger, surrounding soil body. Band and Moore (1995) identified scale incompatibility as a potential problem in extending hillslope hydrologic models to regional scales.

Some of the effect of scale incompatibility among data layers may be dependent on the scale at which the model is run. In this paper, we refer to this as the *simulation scale*. Data sets are not often available at a resolution that will permit realistic process simulations at very fine simulation scales (meters or less). As a result, watershed models that simulate these processes over large spatial extents must find a way to describe environmental conditions using effective parameters rather than directly observed values. For some models, these parameters are produced by partitioning the landscape into *hillslope* units and aggregating the spatial data within each hillslope unit. The degree to which landscape heterogeneity is generalized and aggregated by the model can be thought of as the size of these hillslope units which in turn can be thought of as the model simulation scale.

Hillslope partitioning is one of the more flexible methods of varying simulation scale. Hillslopes – the areas in a watershed that drain to each stream link on either bank side – capture much of the spatial variation of incident short-wave radiation and seem particularly suitable for landscape parameterization in mountainous terrain (Band et al., 1991; Moore et al., 1991) (Fig. 1). Varying the extent of the stream network can change the number and size of the hillslopes in any given watershed.

This research examines how watershed modeling responds to the scale incompatibility between the generalized soil property information and the other but more detailed environmental information at different model simulation scales as approximated by different levels of hillslope partitioning. The Regional Hydro-Ecological Simulation System (RHESSys) (Running et al., 1989; Band et al., 1991, 1993) is used in this research for the simulation of two watershed processes: net photosynthesis and stream flow. Two commonly used general modeling frameworks (the lumped parameter approach and the distributed approach (Maidment, 1993)) are used to simulate these processes and to examine the effect of scale incompatibility.

Two versions of spatial soil information each at different level of spatial details are used for comparison in examining the effects of scale incompatibility on the simulated processes. The first version is a conventional soil map and the second is soil information derived from a soil-land inference approach (Soil Land Inference Model, SoLIM) (Zhu, 1997, 1999; Zhu et al., 2001).