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Quantitative comparison of spatial fields for hydrological model assessment—some promising approaches

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Abstract

The current practice for assessing spatial predictions from distributed hydrological models is simplistic, with visual inspection and occasional point observations generally used for model assessment. With the increasing availability of spatial observations from remote sensing and intensive field studies, the current methods for assessing the spatial component of model predictions need to advance. This paper emphasises the role that spatial field comparisons can play in model assessment. A review of the current methods used in hydrology, and other disciplines where spatial field comparisons are widely used, reveals some promising methods for quantitatively comparing spatial fields. These promising approaches—segmentation, importance maps, fuzzy comparison and multiscale comparison—are for local comparison of spatial fields. They address some of the weaknesses with the current approaches to spatial field comparison used in hydrological modelling and, in doing so, emulate some aspects of human visual comparison. The potential of these approaches for assessing spatial predictions and understanding model performance is illustrated with a simple example.

Keywords: Spatial; Fields; Patterns; Comparison; Quantitative; Model assessment

1. Introduction

Distributed hydrological models produce spatially explicit predictions that allow more detailed analysis in decision-making than lumped models. Managers in the environmental field can now not only query the magnitude of a hydrological attribute, they can also query the spatial distribution of the attribute and ask 'where' type questions. The presence of spatial predictions has grown out of the increased availability of spatial data sets and cheaper computing power required to process these data [20]. However, there are issues relating to the uncertainty in such predictions due to uncertainty in model inputs and structure. Quantifying the uncertainty in these predictions has been the subject of continued research and debate, due to the large number of degrees of freedom inherent in these models [5,36,51]. Recognition of the limitations with distributed hydrological modelling has resulted in several general methodologies for assessing uncertainty being proposed. Methodologies such as generalised likelihood uncertainty estimation (GLUE) [4] and the 'alternative blueprint' [3], which can address the limitations while still utilising the strengths of distributed hydrological models, focus on trying to quantify the uncertainty in the predictions made [37,59]. These methods use many models and parameter sets that could represent 'reality' to make predictions. Model and parameter combinations that do

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not 'fit' the observations are termed 'non-behavioural' and are rejected. The 'more likely' parameter sets (and/or models) remain and are used to provide the measure of uncertainty.

Grayson et al. [22] point out that in response to these methodologies for assessing uncertainty and numerous calls for data collection, spatial observations for assessing distributed hydrological models are becoming increasingly available. Furthermore, advances in remote sensing are providing improved spatial and temporal measurements of hydrological attributes that are of increasing value [54]. Spatial fields of hydrological attributes—for example, soil moisture [40,69], snow cover [46,58], saturated area [18,24], runoff [67], erosion [57], precipitation [17,50] and ocean suspended sediment [62]—have been observed and predicted for various study sites. These studies have provided insights about the hydrological processes involved and their function under different conditions, but the tools required to utilise such data have not developed accordingly. As such, spatially-distributed models are still being assessed using the more readily available point measurements (which often represent an integrated response of a larger area). These point measurements can be replicated using many different spatial fields, which makes them poor for constraining the distributed predictions [23].

At present, the value of observed spatial fields for distributed hydrological modelling has been recognised and the use of data from remote sensing and improved field measurements continues to grow. To fully realise the potential of spatial fields for model assessment, the absence of appropriate comparison methods must be addressed [20,22,35]. This paper defines spatial fields as used in hydrology and then reviews the common ways that they have been used in assessing model predictions. Where comparisons of observed and predicted spatial fields are undertaken, we focus on the methods used for comparison and the information thus garnered. The dominant characteristics of human visual comparisons are identified, with a view to emulating these with quantitative comparison methods. Approaches to comparison from the broader image- and pattern-related literature shows how other disciplines approach the problem of comparison. Drawing from these disciplines, some promising methods for quantifying the comparison of spatial fields are detailed. The potential of these methods for providing quantitative measures useful for hydrologic interpretation are illustrated with a simple example and discussed in reference to their use in hydrological model assessment.

2. Observed spatial fields in hydrology

Spatial fields are being increasingly generated in hydrological studies, via both observation and model simulation. Spatial fields are primarily used for model input, but with increasing data availability, they are also being used for model assessment. Spatial observations are usually made at variably spaced points and then interpolated onto a regular grid to produce a complete spatial field. Both the density of the observations and the interpolation method used contribute to how representative the observed spatial field is of reality. Where sufficient point samples are made to represent the spatial field of interest, then the interpolation step can be avoided. For example, if a spatial observation is made for every model element, then this spatial data may be sufficient for assessing the model. When spatial observations are obtained via remote sensing, the spatial field is represented with a regular grid, having a resolution (or pixel size) that defines the density of observation points. Spatial models in hydrology can be based on both regular grids and unstructured networks. In all cases, the model domain is discretised into model elements that have a spatial link to neighbouring elements. When comparing observed and predicted spatial fields, it is desirable for them to be commonly discretised (i.e. have the same structure and resolution). This allows any processing to be applied similarly to both data sets and ensures that spatially coincident values are compared. Throughout this paper, the spatial fields used in the discussion and demonstrations are regular grids. This is due to them being both computationally simple and common, thus making them ideal for presenting the methods.

Spatial observations are usually based on measurements of categorical data (e.g. presence/absence of snow cover [58], low/medium/high level of rill erosion [35]) or continuous data (e.g. soil moisture [69]). The data type is controlled by both the measurement method and logistical factors (e.g. time, personnel). In all spatial analysis tasks (including comparison), the data type determines the methods that can subsequently be applied for analysis [12], although a higher level data type can always be converted into a lower level data type (i.e. a continuous field can be categorised). In this paper, the methods discussed vary in their applicability, although we have attempted to focus on methods for continuous spatial fields (i.e. the higher level data type).

Hydrological spatial observations are obtained in different ways and encompass varied levels of processing (to produce the spatial fields from the raw measurements). In general, observed spatial fields are produced from exhaustive field measurements, remote sensing (such as satellites or ground-based radar) and/or surrogate data (that have correlation with the attribute of interest). Strictly speaking, all measurements are surrogates of some kind, yet those specifically referred to here have low correlations with the hydrological attribute being represented [22]. One of the most common surrogates used in hydrology is terrain, which can be used as a