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Regionalisation of land surface hydrological model parameters in subarctic and arctic environments

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ABSTRACT

The need for improved processes understanding to develop enhanced knowledge and modelling strategies is a central issue within the Prediction in Ungauged Basins (PUB) initiative. Prediction of snow-cover depletion and spring-melt runoff in arctic basins is particularly challenging due to the spatial heterogeneity of the snow-cover as a result of topographic and vegetation effects on snow accumulation, wind redistribution, and ablation processes. Additionally the remote location and winter inaccessibility of Arctic basins contribute to the lack of proper data to model the hydrology of these sites. This study was conducted in two topographically distinct cold regions research basins in the north-west of Canada characterised as tundra environments, one an alpine mountain tundra at 60°N and the other a rolling planar tundra at approximately 70°N.

This paper examines the transference of parameters of a distributed physically based land surface hydrological model from one site to another across 1350 km using a step-wise calibration procedure. The transference methodology uses a physiographic similarity criterion to identify similar landscapes units and makes use of landcover-based parameters rather than the usual relationships between parameters and basin characteristics.

Results showed that simulations using regionalised vegetation parameters performed better than those using default parameters and accurately described both snow-cover ablation and snowmelt runoff in both basins.

1. Introduction

One of the main challenges for the hydrological modelling community is to produce accurate and reliable predictions in ungauged or poorly-gauged basins. This issue had led to the IAHS initiative on Prediction in Ungauged Basins (PUB) (Sivapalan et al., 2003) which mainly focuses in the need of improved processes understanding as a framework to developed enhanced knowledge and modelling strategies.

Current debate is also centred on the difficulty of incorporating landscape heterogeneity and finding distributed information that can fulfill the requirements of distributed physically based models. These issues have forced hydrologists to conceptualise the physics of distributed models and seek effective parameter values typically at the catchment scale. As a result, hydrological models are usually calibrated against observed streamflow data (Klemeš, 1986). The importance of parameter calibration in regionalisation methods was stressed by Blöschl (2005) by showing that calibrated parameters were able to represent regional differences in the hydrological conditions and suggesting that is possible to derive regional relationships between calibrated parameters and basin attributes.

Alternative methods for parameter estimation such as regionalisation techniques or the transference of information from other basins or sources are needed where the lack of streamflow data does not allow for calibration of hydrological models. Regionalisation methods usually imply the transference of model parameters from a basin that is expected to behave similarly to the basin of interest. The similarity measure can be based on spatial proximity, basin attributes, or similarity indices Blöschl (2005). Typically, regionalisation techniques involve the definition of relationships based on regression methods between calibrated model parameters and basin attributes (Abdulla and Lettenmaier, 1997). The difficulty is that the relationships are likely to be weak due to parameter equifinality since many parameter sets might produce similar simulations. For example, Kuczera and Mroczkowiski (1998) suggested that the problem of parameter identifiability in

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conceptual catchment models due to the existence of multiple optima and high correlation amongst model parameters, makes the regionalisation of model parameters in ungauged basins virtually impossible.

Hydrological regionalisation studies have so far shown limited success and in general depend on the degree of similarity between the basins and on the type of the data used in the regional analysis (Littlewood, 2003). Fernandez et al. (2000) addressed this issue by performing a regional calibration approach where parameters were identified by both minimising model biases and maximising goodness of fit of relationships between parameters and basin characteristics. Regional calibration techniques were also performed by Hundecha and Bárdossy (2004) using a semi distributed conceptual model in 95 sub-basins of the Rhine basin where the coefficients of the relationships between basin attributes and parameters were calibrated rather than the model parameters, however, a limitation of these methods could be the large number of coefficients to be calibrated. Alternatively, Parajka et al. (2007) proposed an iterative regional calibration method as a solution to the dimensionality of the calibration problem where local information such as streamflow data was combined with regional information such as an a priori distribution of the model parameters from gauged basins in the area in one objective function. Götzinger and Bárdossy (2007) showed that regionalisation methods using conditions imposed on the parameters by basin characteristics in distributed conceptual models were the ones that performed best due to the reduction of parameter space. Merz and Blöschl (2004) after comparing several regionalisation methods in 308 Austrian basins found that methods based on spatial proximity performed better than regression methods based on basin attributes. Similarly Parajka et al. (2005) showed that both a kriging approach (i.e. based on spatial proximity) and a similarity approach had similar performance. Goswami et al. (2007) demonstrated that the regionalisation of rainfall-runoff model parameters which were calibrated against regional pooling of streamflow data of twelve basins in France was the one that performed best amongst three methods involving calibration, concluding that the assessment of regional homogeneity and analysis of data are very important for regionalisation approaches using calibration methods.

Arctic environments due to their remote location, inaccessibility, and importance of the winter processes (e.g. snow accumulation and redistribution) in the hydrological cycle, are generally poorly-gauged or ungauged (Pomeroy et al., 2005). Thus, improved regionalisation approaches in these environments are even more important for accurate predictions of snow-cover ablation and snowmelt runoff.

The objective of this paper is to evaluate the transference of landcover-based parameters of a distributed and physically based Land Surface Hydrological (LSH) model between two basins in northern cold regions. This approach is intended for use in distributed models where typical basin-wide regionalisation relationships are conceptually unsuitable due to scale issues. The study focuses on the application of detailed physically based process descriptions developed in cold region environments within modelling units which are delimited based on a basin-wide understanding of the responses of the main hydrological processes. This study extends from the Dornes et al. (2008b) paper, where landscape-based snowmelt parameters were calibrated and validated in a subarctic basin to analyse the regional representativeness of these parameters.

2. Study area

The study area embraces two basins located in the north-west of Canada (Fig. 1). Granger Basin (GB) is a small sub-basin ($8\ km^2$) of the Wolf Creek Research Basin located 8 km south of Whitehorse at 60°31'N, 135°07'W. It is in a subarctic mountainous environment in the southern part of Yukon. The landscape varies from sparsely-vegetated open tundra composed of grasses, mosses, and isolated short shrubs with exposed mineral soils in the high elevation areas, to shrub tundra vegetation characterized by tall shrubs (1–2.8 m) and soils capped with an organic layer in wet and lower elevation areas. Intermediate areas with better drainage such as the plateau area (PLT) have short shrubs (<1 m) whereas north facing (NF) and south facing (SF) slopes are covered by shrubs of intermediate height (0.5–1.5 m). Elevation ranges from 1310 to 2035 m.a.s.l. and the basin is underlain by discontinuous permafrost which is mainly located at higher elevations and on the NF slope.

The second basin is Trail Valley Creek (TVC) Research Basin. TVC is an arctic basin with an area of $63\ km^2$ and lies approximately 55 km north-east of Inuvik in the Northwest Territories at 68°45'N, 133°30'W. The area has a low relief characterized by gently rolling hills with some deeply incised river valleys. The landscape is dominated by open tundra in the upland areas, whereas shrub tundra is along streams, lake edges, and river valleys, as well as some upland areas. Elevation ranges from 40 to 187 m.a.s.l. and the basin is underlain by continuous permafrost.

Despite topographic differences, both basins experience extensive wind redistribution of snow (Pomeroy et al., 1997, 2004; Essery et al., 1999; Essery and Pomeroy, 2004a; Pohl et al., 2005b; McCartney et al., 2006). There are common features in both basins, including open tundra areas that act as source of blowing snow, whereas shrubs behave as sinks or snow traps that result in the formation of characteristic snow drifts in the direction of the prevailing winds that play a significant role in the timing (i.e. lengthering) of the snowmelt runoff. Both basins also show a similar snowmelt pattern, with higher snowmelt rates on the SF slopes than in the NF slopes due to the increased incident solar radiation whereas observations of the streamflow show that peak flows are due to snowmelt, and the timing of the peak is associated with the timing of the snowmelt in the shrub tundra vegetation zone, while the duration of the peak is associated with the duration of the snowmelt on the NF slopes and high elevation zones.

3. Methodology

3.1. Model descriptions

Two models were used in this study. The Canadian Land Surface Scheme (CLASS) version 3.3 introduced by Verseghy (1991) and Verseghy et al. (1993) was applied in GB to simulate snow-cover depletion, whereas the MESH model was used to simulate both snow-cover depletion and snowmelt runoff in TVC basin. As part of the MEC (Modélisation Environmentale Communautaire) system developed by Environment Canada (Pietroniro et al., 2007), MESH (MEC – Surface and Hydrology) is a stand-alone LSH model configuration that couples CLASS (version 3.3) with hydrological routing schemes (Kouwen et al., 1993; Soulis et al., 2000, 2005). Pre-processing corrections for slope and aspect effects on the incoming short wave radiation were performed using the Cold Regions Hydrological Model (CRHM) (Pomeroy et al., 2007; Dornes et al., 2008a).

The spatial discretisation is based on the Group Response Unit (GRU) approach (Kouwen et al., 1993) where a parameter set is identified for each landscape class. The definition of the GRU can vary and it is left to the hydrologist to define "*a priori*". The concept relies on our hydrological understanding of the region and requires that similar areas in the model domain share the same parameterisation. In this mosaic approach, the land surface scheme (LSS) is