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Effect of baseline meteorological data selection on hydrological modelling of climate change scenarios

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SUMMARY

This study evaluates how differences in hydrological model parameterisation resulting from the choice of gridded global precipitation data sets and reference evapotranspiration (ETo) equations affects simulated climate change impacts, using the north western Himalayan Beas river catchment as a case study. Six combinations of baseline precipitation data (the Tropical Rainfall Measuring Mission (TRMM) and the Asian Precipitation – Highly Resolved Observational Data Integration Towards Evaluation of Water Resources (APHRODITE)) and Reference Evapotranspiration equations of differing complexity and data requirements (Penman–Monteith, Hargreaves–Samani and Priestley–Taylor) were used in the calibration of the HySim model. Although the six validated hydrological models had similar historical model performance (Nash–Sutcliffe model efficiency coefficient (NSE) from 0.64 to 0.70), impact response surfaces derived using a scenario neutral approach demonstrated significant deviations in the models' responses to changes in future annual precipitation and temperature. For example, the change in Q10 varies between −6.5% and −11.5% in the driest and coolest climate change simulation and +79% to +118% in the wettest and hottest climate change simulation among the six models. The results demonstrate that the baseline meteorological data choices made in model construction significantly condition the magnitude of simulated hydrological impacts of climate change, with important implications for impact study design.

1. Introduction

Understanding the current and future temporal dynamics of the hydrological behaviour of rivers is vital for management of hydro-power generation, irrigation systems, public water supply and flood control structures (Jain et al., 2010). However, there is a widely recognised cascade of uncertainty in top-down climate change impact studies (Wilby and Dessai, 2010) that affects the certainty in future water resource assessments (Refsgaard et al., 2007). Many elements of the uncertainty cascade within climate impacts modelling have been quantitatively assessed, highlighting the uncertainty associated with climate model (RCMs or GCMs) choice (Fowler and Kilsby, 2007; Woldemeskel et al., 2012), emissions scenario (Maurer, 2007), downscaling method, model choice, etc. (Pappenberger and Beven, 2006; Buytaert et al., 2009; Kay et al., 2009; Chen et al., 2011; Xu, 1999; Wilby et al., 2004; Wood et al., 2004).

However, quantification of the hydrological impacts of climate change requires quality baseline data to enable meaningful comparison between present and future, but there is a paucity or lack of coverage of land based measurements of meteorological variables in many parts of the world. Data sparsity tends to be exacerbated in mountainous regions where very steep temperature and precipitation gradients are poorly characterised by the limited spatial and temporal extents of raingauge and weather station networks (Legates and Willmott, 1990), leading to significant uncertainty in precipitation and evapotranspiration.

Recently, many global/regional datasets have been developed as an alternative or supplement to ground-based data over basins with severe climate data scarcity (Meng et al., 2014) for use in hydrological modelling studies (Andermann et al., 2012; Meng et al., 2014). These data sets include the Asian Precipitation – Highly Resolved Observational Data Integration Towards Evaluation of Water Resources (APHRODITE) data and satellite-based precipitation products such as the Tropical Rainfall Measuring Mission (TRMM). However, there are considerable temporal and spatial differences between such data products in comparison to weather station precipitation (Tian et al., 2007; Habib et al., 2009; Andermann et al., 2011; Li et al., 2012; Lu

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et al., 2013; Jamandre and Narisma, 2013), although these may partly be due to the difficulties in gauge-radar assimilation or comparison (Vasiloff et al., 2009). A number of studies have used TRMM and APHRODITE for hydrological simulation in large river catchments whilst also detailing their uncertainties – for example, Collischonn et al. (2007, 2008) used TRMM rainfall data in modelling the Tapajós river basin in Brazil; and APHRODITE precipitation data were used in hydrological modelling of the Aksu River basin, North-Western China (Zhao et al., 2013) and Himalayan rivers in Nepal (Andermann et al., 2012). Meng et al. (2014) highlighted that TRMM (3B42V6) daily data sets were more appropriate for monthly hydrological modelling in hilly regions of the Tibetan Plateau within the Yellow river basin, but studies by Xue et al. (2013) have shown a clear improvement of 3B42V7 data sets over 3B42V6 in hydrological applications in the Wangchu Basin in Bhutan. Their study demonstrated that 3B42V7 provided better basin-scale agreement with observed (2001–2010) monthly and daily rain gauge data and improved rainfall intensity distribution than 3B42V6. Andermann et al. (2011) compared APHRODITE with TRMM-3B42 (and 3B43 data) along with other remote sensing based precipitation datasets along the Himalayan front and suggest that estimation of precipitation in high elevations regions such as the Himalaya is challenging and that significant inconsistencies exist between different remote sensing data products.

The quantification of Reference Evapotranspiration (ETo) is also associated with significant uncertainties that can affect water and energy budgeting. Recent PET based studies including FLUXNET (Baldocchi et al., 2001) and LandFlux-EVAL (Mueller et al., 2011, 2013) have addressed evapotranspiration uncertainty quantification and evaluation. These studies principally aimed to compare satellite-based estimates, IPCC AR4 simulations, land surface model (LSM) simulations and reanalysis data products to produce an ensemble of global benchmark PET datasets. Kay and Davies (2008) found important differences between ETo estimates using Penman–Monteith, a simpler temperature-based potential evapotranspiration (PET) method and the UK Meteorological Office Rainfall and Evapotranspiration Calculation System (MORECS) when applied to data from five global and eight regional climate models. However, whilst Thompson et al. (2014) have demonstrated that the choice of ETo method affected the simulated hydrology of the Mekong and Andermann et al. (2011) highlighted the significant inconsistencies that exist between different precipitation data products, including APHRODITE with TRMM-3B42 (and 3B43 data), no studies have assessed the combined effects of these two uncertainties for future climate change simulations. There is therefore a lack of understanding concerning the effect that the modeller's subjective choice of historical meteorological data, as determined by their selection of both baseline weather data products and the methods to derive meteorological variables such as ETo, have on the uncertainty in future hydrological impacts.

This study evaluates how the choice of gridded global precipitation data sets and reference evapotranspiration (ETo) method affects baseline hydrological model parameterisation and thereby the uncertainty in simulated future climate change impacts using scenario-neutral impact response surfaces. Six combinations of baseline daily precipitation datasets (TRMM and APHRODITE) and ETo methods (Penman–Monteith, Hargreaves–Samani and Priestley–Taylor) were used in the calibration/validation of the HySim model (Manley and Water Resource Associates Ltd., 2006), using the north western Himalayan Beas river catchment as a case study.

2. Study area and methods

The Beas River is one of the five major rivers of the Indus basin in India and originates in the Himalayas, flowing for approximately 470 km before joining the Sutlej River. The catchment area, upstream of the Pong reservoir, is around 12,560 km^2, and varies in elevation from 245 to 6617 metres above sea level (m asl). The catchment is bounded by Latitude 31°28′–32°26′N and Longitude 75°56′–77°48′E (Fig. 1). Soils in the catchment are young and relatively thin, with their thickness increasing in the valleys and areas with gentle slopes (Pandey, 2002). The major land cover classes include forest, snow and bare rock, with about 65% of the area covered with snow during winter (Singh and Bengtsson, 2003). The Beas catchment is under the influence of western disturbances that bring snowfall to the upper sub-catchment during winter (December–April), whilst the monsoon provides around

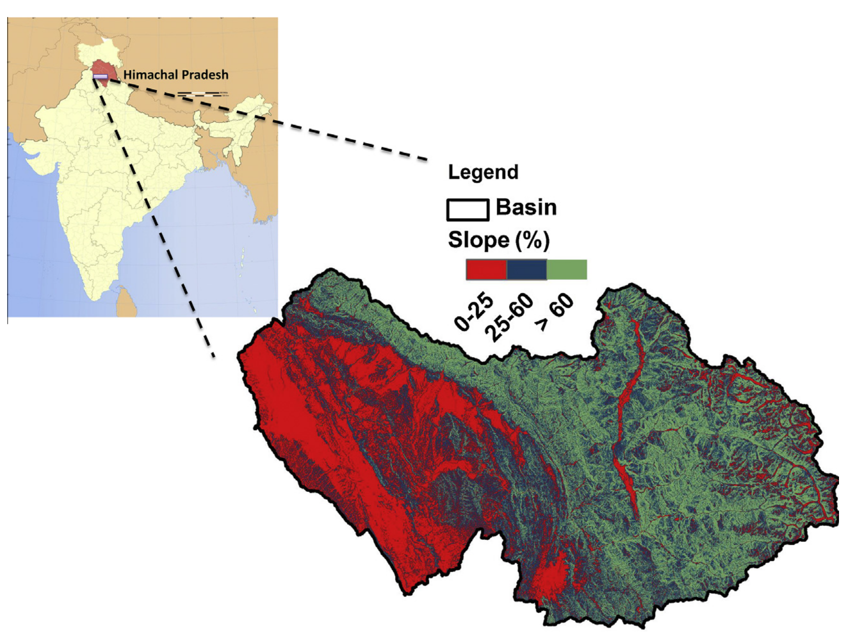

Fig. 1. The study area of the Beas river basin in northern India.