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Remotely sensed evapotranspiration to calibrate a lumped conceptual model: Pitfalls and opportunities

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SUMMARY

Physically representative hydrological models are essential for water resource management. New satellite evapotranspiration (ET_{obs}) data might offer opportunities to improve model structure and parameter identifiability, if used as an independent calibration set. This study used a modelling experiment on 4 catchments in New South Wales, Australia, to investigate whether MODIS (16A3) ET_{obs} can be used to improve parameter calibration for low parameter conceptual models. The catchment moisture deficit and exponential routing form of the model IHACRES was used to test calibration against streamflow, MODIS ET_{obs} or a combination setoff the two. Results were compared against a regionalized parameter model and a model using MODIS ET_{obs} directly as input. Firstly, the results indicated that the observed water balance of the catchments has, currently unexplained, large positive differences which impact the calibrated parameters. More generally, using MODIS ET_{obs} as a calibration set, results in a reduction of the model performance as all residuals of the local water balance and timing differences between the water balance and the outflow need to be resolved by the routing component of the model. This is further complicated by variations in land cover affecting the MODIS ET_{obs}. Finally this study confirms that the calibration of models using multiple environmental timeseries (such as MODIS ET_{obs} and Q) can be used to identify structural model issues.

1. Introduction

Appropriate planning of water resources is needed due to increased food demands from a growing population, decreasing supplies of agricultural land, and increasing climate variability (Droogers et al., 2010). Hydrological models can increase knowledge of available water resources by extrapolation of observed data in time, and allow for scenario studies such as investigating the effect of future climates.

Calibration of these models is based on observed streamflow and uses ground-based data, such as precipitation and temperature, as model inputs, to fine tune the model parameters to account for the inputs and losses of water in a catchment (Sun et al., 2012; Zhang et al., 2009). In contrast, ungauged basins lack observed streamflow, and alternative methods must be developed to allow prediction of water resources (Immerzeel et al., 2008; Sivapalan, 2003; Yang et al., 2005), and this is commonly achieved by regionalisation (Oudin et al., 2008). Transferability of results between catchments requires a model which represents catchment processes, rather than being a purely statistical fit. Moreover, for scenario development, correct representation of catchment processes is essential.

Following the emphasis on prediction in ungauged basins (PUB) over the last decade, new questions have been raised about the applicability of common regionalisation methods (Kling and Gupta, 2009) and model calibration and uncertainty (Gupta et al., 2012; Renard et al., 2010). Remotely sensed actual evapotranspiration (*ET*) in data scarce or ungauged catchments can be valuable as it captures information specific to the catchment (Sun et al., 2010). Mallick et al. (2007) used daily *ET* based on remotely sensed and ground level data to calculate the mean water balance. Immerzeel and Droogers (2008) and Immerzeel et al. (2008) showed that MODIS products can be used to estimate *ET* to calibrate a distributed hydrological model on a monthly time-step. Winsemius et al. (2008) showed that satellite *ET* data can be used to identify structural limitations in simple hydrological models, and Muthuwatta et al. (2009) showed excellent results with a semi-distributed version of HBV, calibrated solely on surface energy balance estimates of *ET* based on MODIS. Finally, the model

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SimHYD calibrated with both streamflow and remotely sensed *ET* performed better than models calibrated with only observed streamflow (Zhang et al., 2009), for at least some of the 120 catchment studied.

As an alternative, several studies (Li et al., 2009; Stehr et al., 2009) highlight how results could be further improved by modifications to model structures to directly incorporate remotely sensed data.

One way to conceptualise rainfall runoff processes is to separate a rainfall–runoff model into a soil moisture accounting module (SMA) and routing module, such as in the Hydromad framework (http://hydromad.catchment.org/, Andrews et al., 2011). Generalised, this model structure means that the SMA separates total rainfall into effective rainfall and losses and calculates the water balance, while the routing component distributes this effective rainfall through time to the catchment outlet. Models such as GR4J, IHACRES and AWBM fall into the "SMA – routing" category (Boughton, 2004; Croke et al., 2006; Perrin et al., 2003), even though further routing losses can be applied in some models. In contrast, the model SimHYD is structured slightly different (Chiew et al., 2009), and the routing is more integrated with the water balance components (see for example Fig. 1 in Zhang et al., 2009).

The modular structure, which separates the routing component from the SMA, can be useful as the SMA can be calibrated on information unique to a catchment gathered by remote sensing (such as vegetation cover, land use, and evapotranspiration), while routing component parameter values can possibly be donated from a neighbouring or similar catchment.

Encouraged by the results from Zhang et al. (2009), we set out to further explore the utility of satellite derived *ET* data as a daily calibration data set for lumped conceptual rainfall–runoff models. It focuses on lumped conceptual models because these are still the most commonly used models for water resource assessment in data scarce regions (Chiew et al., 2009; Oudin et al., 2008; Zhang et al., 2009), and all of the fluxes and state variables can be easily decomposed and analysed.

The objectives of this paper therefore are:

1. To test whether using MODIS (16A3) ET_{obs} data as calibration data in addition to observed streamflow data would improve model performance and catchment representation.
2. To analyse, if any, limitations and opportunities related to using MODIS (16A3) ET_{obs} as calibration data.

2. Methods

2.1. Study area

Four sub-catchments located in the Murrumbidgee Catchment, in south-eastern New South Wales (NSW), Australia were chosen for this study (Fig. 1). These catchments are fairly large, but are free from major effects of regulation by dams, and provide different physical characteristics.

Muttama and Jugiong are large, flat landscapes situated in the Mid-Murrumbidgee, predominantly cleared and used for rainfed cropping and grazing (Bureau of Rural Sciences, 2010). Average annual rainfall is between 600 and 900 mm, distributed evenly throughout the year, with a slight dominance in winter. In contrast, Goodradigbee and Corin average 900–1100 mm annually, are located in the mountainous Upper Murrumbidgee, and are primarily used for conservation and forestry purposes (Bureau of Rural Sciences, 2010).

2.2. Data

2.2.1. Streamflow and meteorological data

Most daily streamflow data was obtained from the NSW Government WaterInfo website (realtimedata.water.nsw.gov.

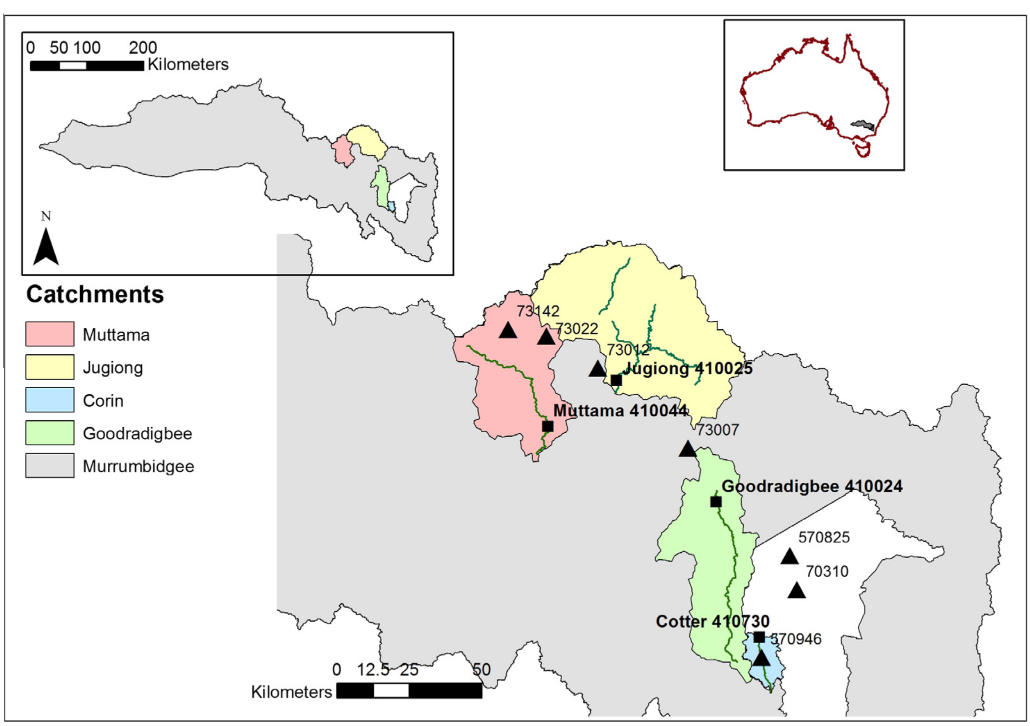

Fig. 1. Location of the four sub-catchments and gauging stations (black squares) and climate stations (black triangles) used in this study, within the Murrumbidgee catchment, with main rivers of each catchment. The white space inside the Murrumbidgee catchment is the Australian Capital Territory, which sits inside the state of NSW.