Journal of Hydrology 522 (2015) 274–284

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Investigating the impact of leaf area index temporal variability on soil moisture predictions using remote sensing vegetation data

Min Chen, Garry R. Willgoose *, Patricia M. Saco

Discipline of Civil, Surveying and Environmental Engineering, The University of Newcastle, Callaghan, NSW 2308, Australia

ARTICLE INFO

Article history:
Received 18 February 2014
Received in revised form 6 November 2014
Accepted 13 December 2014
Available online 27 December 2014
This manuscript was handled by Konstantine P. Georgakakos, Editor-in-Chief, with the assistance of Venkat Lakshmi, Associate Editor

Keywords:
Soil moisture
Semi-arid
LAI seasonality
IBIS
HYDRUS

SUMMARY

The impact of leaf area index (LAI) seasonality on three-year (2005–2007) daily soil moisture predictions was investigated for two different land surface models (IBIS and HYDRUS) at the Stanley semi-arid grassland field site. Three daily LAI time series derived from different empirical NDVI–LAI relationships using the MODIS NDVI data were used in the analysis. Calibration results from both models consistently suggested that an average LAI over time, rather than a time varying daily LAI, was sufficient to reproduce daily soil moisture at our site. We did, however, find that the sensitivity of the impact of LAI time variability on soil moisture estimation was a function of soil parameters. The influence of LAI time variation on the soil moisture simulations is controlled by the sensitivity of modelled soil moisture to the average LAI values over that period, and soil parameters affected the sensitivity of the model to LAI. Those parameter sets that were most sensitive to the long-term mean LAI were also those that were the most sensitive to the time variability. In our case, model calibrations using a constant LAI adjusted the soil parameters to reduce the impact of LAI variability. Results also suggested that the LAI variability could be significant if the varying LAI approached a very low level (i.e. LAI < 1) for a significant proportion of the simulation period. This is most likely to be the case for short grasses in grasslands.

1. Introduction

Leaf area index (LAI), defined as one half the total leaf surface area per unit of ground area, is a key parameter required by most land surface models (LSMs), as it controls many physical and biological processes associated with vegetation. It affects the water balance via its control on the evapotranspiration, and evapotranspiration predominantly controls soil moisture dynamics under water-limited conditions (Albertson and Kiely, 2001). Instead of traditionally neglecting the temporal variations of LAI, remotely sensed vegetation observations have been more and more commonly used in land surface modelling studies, due to recently increasing data availability. Therefore, understanding the impact of satellite-based LAI on the land surface simulations is of great significance to efficient hydrological modelling.

The impact of a realistic representation of seasonally varying LAI on fluxes of water, energy and carbon in the land–atmosphere system has been investigated via sensitivities studies or the emerging data assimilation technique. For coupled LSMs, monthly LAI climatology was able to improve the forecasts of evaporation compared with static LAI (Boussetta et al., 2013; Lawrence and Slingo, 2004; Weiss et al., 2012). LSMs have been mostly tested in an offline mode for a thorough analysis of the LAI impact without including extra uncertainties in a coupled system. Assimilating remotely sensed LAI products into LSMs could provide more accurate estimates of land carbon fluxes (Barbu et al., 2011; Demarty et al., 2007; Jarlan et al., 2008) and evapotranspiration (Ghilain et al., 2012) at both local and regional scales, while joint assimilations of LAI and surface soil moisture could further improve modelled root-zone soil moisture (Barbu et al., 2011; Sabater et al., 2008). Evapotranspiration data, considered most directly relevant to LAI, was also able to improve heat flux predictions of LSMs via data assimilation (Pipunic et al., 2008).

However, less attention has been paid to the potential benefit of daily resolution LAI data in the estimation of soil moisture, despite soil moisture being of critical importance to the water, energy and carbon exchanges. Pitman et al. (1999) initially explored the sensitivity of a LSM to LAI within the Global Soil Wetness Project (GSWP), and found that the average monthly LAI data rather than the seasonal variation impacted soil moisture simulations significantly. Van den Hurk et al. (2003) performed comparisons between temporally static LAI and monthly LAI data (both derived from remote sensing observations of vegetation), and found little impact of LAI seasonality on the annual cycles of soil water storage and

* Corresponding author.
E-mail address: garry.willgoose@newcastle.edu.au (G.R. Willgoose).

http://dx.doi.org/10.1016/j.jhydrol.2014.12.027
0022-1694/© 2015 Elsevier B.V. All rights reserved.

runoff averaged over northern and southern hemispheres. These studies were carried out at a monthly resolution. For daily simulations more obvious effects of LAI seasonality have been detected. Montaldo et al. (2005) compared a daily dynamic vegetation model with models using a constant LAI and found large differences in daily evapotranspiration, root-zone soil moisture and drainage simulations, especially during the growing seasons. They found that the use of constant LAI produced large errors in land surface flux predictions. Sabater et al. (2007) found that low LAI values generated by interpolation (interpolated due to the lack of regular LAI measurements) led to an overestimation of the soil moisture during that period, indicating the sensitivity of daily soil moisture simulations to LAI variations, at least for low vegetation densities. Li et al. (2009) demonstrated considerable improvements in daily runoff predictions in a calibrated rainfall–runoff model by explicitly representing vegetation and using daily LAI data. They also found that larger errors were generated by using the yearly average LAI rather than using daily LAI inputs, which suggests that the impact of daily vegetation dynamics on rainfall–runoff modelling is important.

The data of normalized difference vegetation index (NDVI), which is the most commonly used and most intensively studied vegetation index, is freely available regionally or globally from a number of remote sensing projects (e.g. AVHRR, MODIS) (Kerr and Ostrovsky, 2003). LAI is often derived from NDVI due to the strong relationship between them (Garrigues et al., 2008; Gigante et al., 2009; Glenn et al., 2008). Propastin and Erasmi (2010) showed a good consistency between the MODIS NDVI-derived LAI and the MODIS LAI product (MOD15A2) in the spatial distribution and temporal dynamics.

In this paper, we used measured seasonal LAI data in two different LSMs (IBIS and HYDRUS), to investigate the impact of seasonal vegetation dynamics on the soil moisture predictions at a daily timescale for the Stanley semi-arid catchment. Three daily LAI time series (derived using three different empirical NDVI–LAI relationships) were used and their impact on the hydrology was compared. The soil moisture time series simulated by the models were calibrated against daily observations of 2005–2007 and validated against data of 2008 at our Stanley site. Two calibrations for each model were performed, (1) with a constant LAI and (2) with a seasonally varying LAI time series. We compared the two types of calibrations to address this question: Is the representation of a realistic daily resolution and time varying of LAI important if we are to predict daily resolution soil moisture in a water-limited grassland and if so, how important?

2. Site and data

The Stanley field site (32.10°S, 150.14°E) is a microcatchment (175 ha) within the Goulburn River experimental catchment (Rüdiger et al., 2007), located in the Upper Hunter Region of New South Wales, Australia (Fig. 1). The vegetation at Stanley is native grass, with a very sparse eucalypt tree cover. It is currently a biodynamic beef cattle grazing property, with low intensity grazing. The catchment is underlain with Tertiary basalt and forms part of the Merriwa Plateau. Soils are Vertisols, which are clay soils with shrink-swell properties that cause deep and wide cracking upon drying.

There are seven soil moisture monitoring sites (S1–S7) with a weather station at S2 (Fig. 1). The long-term average annual

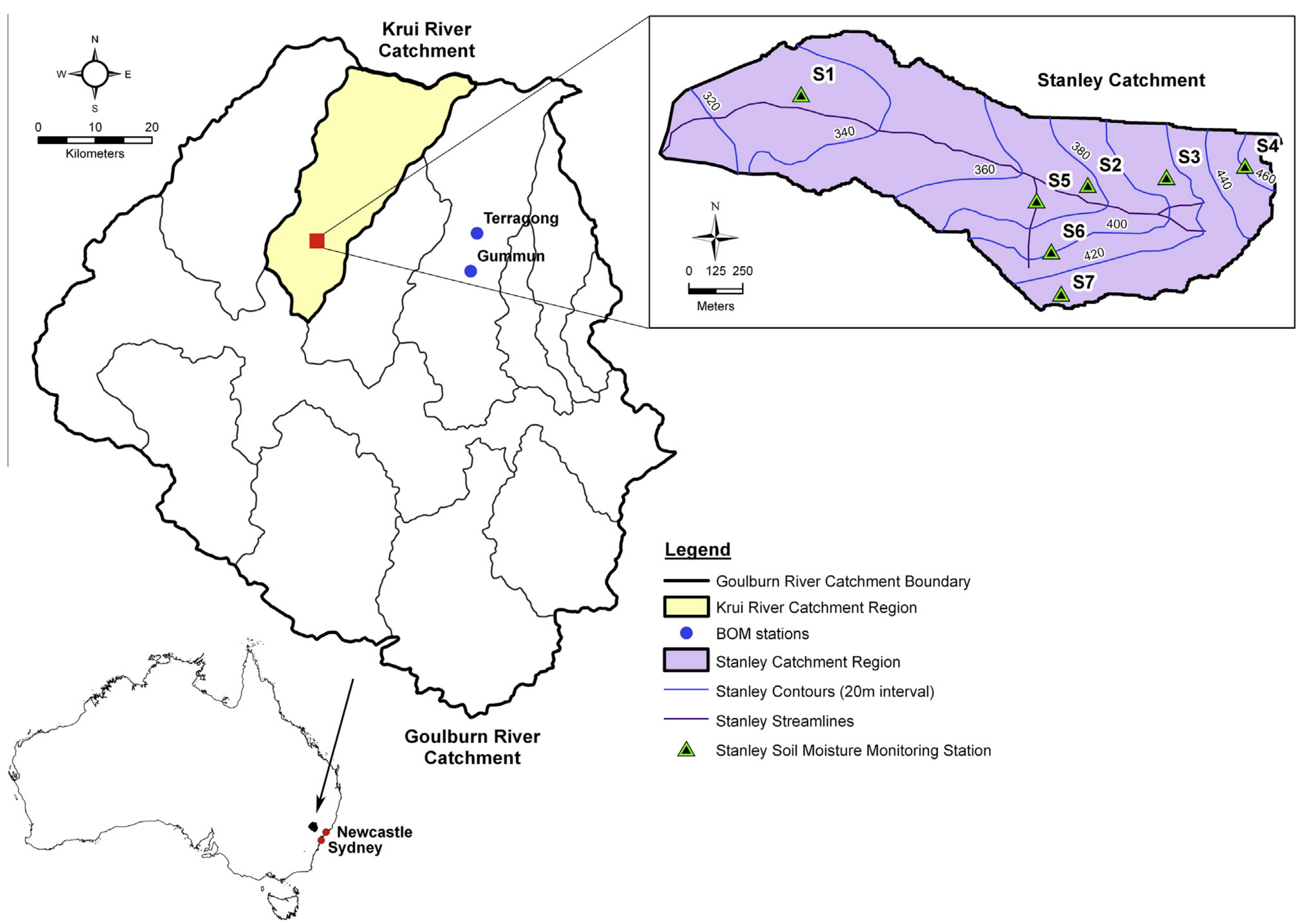

Fig. 1. Location of the Goulburn, Krui River catchments and the Stanley microcatchment, and the soil moisture monitoring sites in Stanley.