Journal of Hydrology 528 (2015) 652–667

Contents lists available at ScienceDirect

Journal of Hydrology

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

Global Land Data Assimilation System data assessment using a distributed biosphere hydrological model

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ARTICLE INFO

Article history:
Received 5 March 2015
Received in revised form 3 June 2015
Accepted 4 July 2015
Available online 9 July 2015
This manuscript was handled by Konstantine P. Georgakakos, Editor-in-Chief, with the assistance of Alon Rimmer, Associate Editor

Keywords:
Energy cycle
GLDAS
Meteorological data
MODIS
Water cycle
WEB-DHM

SUMMARY

Observed water and energy fluxes are sparse in many regions of the world. The overall aim of this study is to demonstrate the applicability of Global Land Data Assimilation System–Noah (GLDAS/Noah) data for basin scale water and energy studies in terms of input, output, seasonal and spatial distributions. A Water and Energy Budget-based Distributed Hydrological Model (WEB-DHM) is employed to evaluate the output of GLDAS/Noah and the simulations of seasonal and spatial distributions of fluxes after calibration with discharges and MODIS land surface temperatures (LSTs) in a semiarid catchment. GLDAS/Noah air temperatures and humidity agree well with observations, but GLDAS/Noah overestimates downward solar radiation and wind speed. LSTs and upward long wave radiation from GLDAS/Noah and WEB-DHM are comparable, but GLDAS/Noah shows larger upward shortwave, net radiation, latent heat, sensible heat fluxes and smaller ground heat flux amplitude. Two correction functions are developed for downward solar radiation and wind speed. The accuracy of discharges and LSTs is improved after corrections. The simulated seasonal and spatial distributions of water and energy fluxes and states (LSTs, evapotranspiration, surface, root, deep soil wetness, ground heat flux, latent heat flux, sensible heat flux, upward long wave radiation and upward shortwave radiation) show high accuracy using corrected GLDAS/Noah data. The findings provide an insight into the applicability of GLDAS/Noah.

1. Introduction

Accurate estimation of water and energy fluxes is important for understanding the water and energy cycles and thus water resources management and climate change studies (Liang et al., 1994; Chen et al., 1996; Sellers, 1997; Sorooshian et al., 2005). Water and energy fluxes can be measured at meteorological stations but at a point scale only; they are rather sparse in developing countries and rural areas. Other available land surface water and energy flux data should be found to compensate for the deficits of observations.

Land surface models (LSMs) are key means of simulating interactions between land surface and atmosphere (Rodell et al., 2004), and they can provide estimates of water and energy fluxes at a basin scale (Zaitchik et al., 2010). It has been reported that coupling LSMs and distributed hydrological models (DHMs) can provide more reliable water and energy fluxes through improved land surface representation and use of flow data or satellite data for model calibration (Liang et al., 1994; Wang et al., 2009b,c, 2011; Xue et al., 2013). Usually the coupled models need more meteorological forcing data than traditional DHMs, e.g., precipitation, radiation, pressure, wind, humidity and near surface air temperature data. The accuracy of model simulations cannot be improved if the forcing data are inaccurate, even for a model with fine resolution and good depiction of land surface processes (Cosgrove, 2003; Luo, 2003; Mitchell, 2004). However, fine resolution and realistic forcing data are not usually available from meteorological stations and limited in spatial and temporal coverage. Alternative data sets, e.g., data from Global Land Data Assimilation System (GLDAS) (Rodell et al., 2004), can potentially be used.

GLDAS is a result of the extension of the existing North American land data assimilation system project (Rodell et al., 2004), and is a collection of land surface water and energy fluxes. It integrates satellite-based and ground-based data sets for parameterizing, forcing and constraining a suite of offline land surface models, which aims to generate optimal fields of land surface states and fluxes. At present, GLDAS has been used to drive four LSMs: Mosaic (Koster and Suarez, 1992), Noah (Chen et al., 1996; Betts et al., 1997; Koren et al., 1999; Ek, 2003), the community land model (Dai et al., 2003) and variable infiltration capacity model

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http://dx.doi.org/10.1016/j.jhydrol.2015.07.011
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(Liang et al., 1994). Among them, the GLDAS version 1/Noah LSM product (GLDAS_Noah025SUBP_3H) has a 3-h $0.25^0 \times 0.25^0$ resolution, which makes it desirable for basin scale applications. Evaluations and applications of GLDAS/Noah data have generally been limited to data-rich regions (Kato et al., 2007), and just a few studies have been carried out to assess the accuracy of GLDAS/Noah outside North American (Zaitchik et al., 2010; Wang et al., 2011; Zhou et al., 2013). These studies assess either GLDAS/Noah input or GLDAS/Noah output, and seldom apply GLDAS/Noah to simulate seasonal and spatial distributions of water and energy fluxes. There is a need to comprehensively investigate the applicability of GLDAS/Noah water and energy fluxes in terms of input, output, seasonal and spatial distributions at a basin scale.

The overall aim of this paper is to demonstrate the applicability of GLDAS/Noah water and energy fluxes in terms of input, output, seasonal and spatial distributions. A distributed biosphere hydrological model is employed, which enables the evaluation of the output of GLDAS/Noah and the simulations of seasonal and spatial distributions of fluxes. The distributed biosphere hydrological model is calibrated with flow observations and MODIS land surface temperatures (Wan, 2008) to provide accurate water and energy cycle simulations. This paper is unique in that it evaluates and corrects fine-resolution global scale water and energy fluxes (GLDAS/Noah) for basin scale water and energy cycle studies in terms of seasonal and spatial distributions of fluxes and basin average. The results provide an insight into the confidence we can place in the applicability of GLDAS/Noah.

2. Materials and methodology

2.1. Biliu basin

Northeast China, as one of the most populous areas in China, plays an important role in food production for supporting the living of the population, and is a significant industrial region as well with many heavy industries. This region frequently suffers from droughts, which poses a threat to the regional sustainable development. The insufficient number of meteorological stations influences the hydrological and meteorological analyses of the water resource problem. Thus this study is carried out in a river basin, Biliu basin, in northeast China to investigate the potential utility of GLDAS/Noah in this region.

Biliu basin (2814 km^2), located in a coastal region between Bohai Sea and Huanghai Sea, covers longitudes from 122.29°E to 122.92°E and latitudes from 39.54°N to 40.35°N (Fig. 1). This basin is characterized by a snow – winter dry – hot summer climate (Koppen climate classification) and summer (July to September) is the major rainy season. The average annual precipitation is 746 mm, and the average annual temperature is 10.6 °C. There are eleven rain gauges and one flow gauge. Three meteorological gauges are located near the basin. There are eleven GLDAS/Noah grids in this basin. The distributions of the gauges and GLDAS/Noah girds are shown in Fig. 1(c).

2.2. WEB-DHM

The Water and Energy Budget-based Distributed Hydrological Model (WEB-DHM) (Wang et al., 2009a,b,c), was developed by coupling a simple biosphere scheme (SiB2) (Sellers et al., 1986) with a geomorphology-based hydrological model (Yang, 1998) to describe water, energy and CO_2 fluxes at a basin scale. It calculates evapotranspiration based on both water and energy balances in each model grid and therefore has a more solid physical foundation relative to the traditional hydrological models. Several evaluations and applications have been carried out with WEB-DHM (Wang et al., 2010a,b, 2012; Shrestha et al., 2013; Xue et al., 2013; Hu et al., 2014), generally showing good performance in simulating basin-scale water and energy fluxes.

The overall structure of WEB-DHM model is shown in Fig. 2. Fig. 2(a) describes the sub-basins; Fig. 2(b) illustrates subdivision from a sub-basin to flow intervals comprising several model grids; Fig. 2(c) explains discretization from a model grid to a number of geometrically symmetrical hillslopes; and Fig. 2(d) details process descriptions of the water moisture transfer from atmosphere to river, including downward solar radiation (R_{sw}), downward long wave radiation (R_{lw}), the sensible heat flux (H) and the latent heat of vaporization (λ). A more detailed description of the model structure can be found in Wang et al. (2009b).

WEB-DHM estimates land surface temperatures based on land surface soil temperatures and canopy temperatures (Wang et al., 2009c)

$$T_{\rm sim} = [V \times T_c^4 + (1 - V) \times T_g^4]^{1/4} \tag{1}$$

$$V = \mathrm{LAI}/\mathrm{LAI}_{\max} \tag{2}$$

where V is green vegetation coverage; $T_{\rm sim}$, T_c and T_g are simulated land surface temperatures, canopy temperatures and soil surface temperatures respectively; LAI and $\mathrm{LAI}_{\max}$ are Leaf Area Index and the maximum Leaf Area Index defined by Sellers et al. (1996b).

2.3. Data sets

2.3.1. Observed meteorological data

WEB-DHM input data include precipitation, air temperature, downward solar radiation, downward long wave radiation, air pressure, wind speed and humidity. Precipitation data are available from March 2000 to December 2007 in this basin. Meteorological gauge observations are obtained from China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/home.do). Hourly precipitation data are downscaled from daily rain gauge observations using a stochastic method (Wang et al., 2011). Hourly air temperatures are calculated from daily maximum and minimum temperatures using TEMP model (Parton and Logan, 1981). The estimated temperatures are also further evaluated using daily average temperatures. Downward solar radiation data are estimated from sunshine duration, temperatures and humidity using a hybrid model (Yang et al., 2006). No downward long wave radiation data are available and the data from GLDAS/Noah are employed. Air pressure data are estimated according to altitudes (Yang et al., 2006). These meteorological data are then interpolated to 300 m model cells. Surface air temperatures are further modified with a lapse rate of 6.5 K/km considering elevation differences between model cells and meteorological gauges.

2.3.2. DEM and satellite data

Digital elevation data were obtained from the NASA Shuttle Radar Topographic Mission with a resolution of 30 m × 30 m. We resampled the resolution to 300 m in model calculation to reduce computation cost, while the model processed finer DEM (30 m grid) to generate subgrid parameters (such as hillslope angle and length). The basin average elevation is 240 m. The maximum elevation is 1043 m in northern part which is a mountainous region and the minimum is 7 m in southern part (Fig. 3(a)). The grid slopes vary from 0° to 38° (Fig. 3(b)).

Land-use data were obtained from the USGS (http://edc2.usgs.gov/glcc/glcc.php). The land-use types have been reclassified to SiB2 land-use types for the study (Sellers et al., 1996a). There are six land-use types, with broadleaf trees, needle leaf trees and short vegetation being the main types (Fig. 3(c)). Soil data were obtained from the Food and Agriculture Association (FAO) (2003) global data product, and there are two types of soil in the basin (Fig. 3(d)).