Agricultural and Forest Meteorology 218–219 (2016) 288–297

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Validation of the global land data assimilation system based on measurements of soil temperature profiles

Lei Wang[a,b,*], Xiuping Li[a,*], Yingying Chen[a,b], Kun Yang[a,b], Deliang Chen[c], Jing Zhou[a], Wenbin Liu[a], Jia Qi[a], Jianbin Huang[d]

[a] Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing, China
[b] CAS Center for Excellence in Tibetan Plateau Earth Sciences, Beijing, China
[c] Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden
[d] Ministry of Education Key Laboratory for Earth System Modeling, and Center for Earth System Science, Tsinghua University, Beijing, China

ARTICLE INFO

Article history:
Received 3 April 2015
Received in revised form
25 December 2015
Accepted 6 January 2016

Keywords:
Soil temperature profile
GLDAS
Noah land surface model
Community land model
In situ measurements

ABSTRACT

Soil temperature is a key parameter in the soil–vegetation–atmosphere system. It plays an important role in the land surface water and energy cycles, and has a major influence on vegetation growth and other hydrological aspects. We evaluated the accuracy of the soil temperature profiles from the Global Land Data Assimilation System (GLDAS) using nine observational networks across the world and aimed to find a reliable global soil temperature profile dataset for future hydrological and ecological studies. In general, the soil temperature profile data generated by the Noah model driven by the GLDAS forcing data (GLDAS_Noah10 and GLDAS_Noah10_v2) were found to have high skills in terms of daily, monthly, and mean seasonal variations, indicated by smaller bias and root-mean-square-error (RMSE) (both <3 °C) and correlation coefficients larger than 0.90. Conversely, the Community Land Model (CLM) results (GLDAS_CLM10) generally showed larger bias and RMSE (both >4 °C). Further analysis showed that the overestimation by GLDAS_CLM10 was mainly caused by overestimation of the ground heat flux, determined by the thermal conductivity parameterization scheme, whereas the underestimation by GLDAS_Noah10 was due to underestimation of downward longwave radiation from the forcing data. Thus, more accurate forcing data should be required for the Noah model and an improved thermal parameterization scheme should be developed for the CLM. These approaches will improve the accuracy of simulated soil temperatures. To our knowledge, it is the first study to evaluate the GLDAS soil temperatures with comprehensive in situ observations across the world, and has a potential to facilitate an overall improvement of the GLDAS products (not only soil temperatures but also the related energy and water fluxes) as well as a refinement of the land surface parameterization used in GLDAS.

1. Introduction

Soil temperature is a key parameter in the soil–vegetation–atmosphere transfer system. It plays an important role in the surface water and energy exchange during land–atmosphere exchanges (e.g., Cheviron et al., 2005; Yang et al., 2013) because of its strong influence on soil physical properties (Chen and Kling, 1996; Or and Wraith, 1999; Grant and Or, 2004; Bachmann and van der Ploeg, 2002; Schneider and Goss, 2011). As a result, it is also determined by energy flux and soil properties. Soil temperature is also a primary control on CO_2 production in most soils across different spatial and temporal scales (Lloyd and Taylor, 1994; Peterjohn et al., 1994; Raich and Potter, 1995; Rustad and Fernandez, 1998; Kirschbaum, 2000; Risk et al., 2002; Riveros-Iregui et al., 2007). Accurate knowledge of soil temperature is needed for numerous studies such as short-term forecasts (Godfrey and Stensrud, 2008; Fan, 2009), sub-seasonal and seasonal forecasts (Mahanama et al., 2008) and vegetation growth (McMichael and Burke, 1998). However, soil temperature profiles remain difficult to measure at regional to global scales, although land surface temperatures can be retrieved from satellites with acceptable accuracy (e.g., Sun and Pinker, 2003; Wan, 2008; Li et al., 2013).

* Corresponding authors at: Key Laboratory of Tibetan Environment Changes and Land Surface Processes, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Building 3, Courtyard 16, Lin Cui Road, Beijing, China. Tel.: +86 10 84097107; fax: +86 10 84097079.
E-mail addresses: wanglei@itpcas.ac.cn (L. Wang), lixiuping@itpcas.ac.cn (X. Li).

http://dx.doi.org/10.1016/j.agrformet.2016.01.003
0168-1923/

Table 1
The observed soil temperature from nine observational networks and global land surface model outputs used in this study.

Soil temperature datasets	Type	Land use	Number of stations	Soil layers depth (cm)	Temporal resolution	Temporal extent
GLDAS_CLM10	Numerical product	Global product	Global product	0–1.8, 1.8–4.5, 4.5–9.1, 9.1–16.6, 16.6–28.9, 28.9–49.3, 49.3–82.9, 82.9–138.3, 138.3–229.6, and 229.6–343.3	3 h	200,201–201,212
GLDAS_Noah10	Numerical product	Global product	Global product	0–10, 10–40, 40–100, and 100–200	3 h	200,201–201,212
GLDAS_Noah10_v2	Numerical product	Global product	Global product	0–10, 10–40, 40–100, and 100–200	3 h	200,201–201,012
SGP (North America)	In-situ observation	Crop and grass	20 Stations	5, 15, 25, 35, 60, 85, 125, and 175	60 min	200,210–200,910
Mongolia (Mongolia)	In-situ observation	Grass	16 Stations	3, 10, 40, and 100	30 min	200,210–200,412
MDB (Australia)	In-situ observation	Crop	18 Stations	3.5, 15, 45, and 75	30 min	200,210–200,805
SASMAS (Australia)	In-situ observation	Grass and crop	14 Stations	0–5	30 min	200,602–200,712
TP (China)	In-situ observation	Grass	38 Stations	0–5, 10, 20, and 40	30 min	201,008–201,212
MAQU (China)	In-situ observation	Grass	20 Stations	5	30 min	200,807–200,908
HOBE (Denmark)	In-situ observation	Crop and forest	30 Stations	0–5, 20–25, and 50–55	30 min	201,001–201,106
REMEDHUS (Spain)	In-situ observation	Crop with some patchy forest	24 Stations	5	30 min	200,504–201,212
SMOSMANIA (France)	In-situ observation	Crop	21 Stations	5, 10, 20, and 30	60 min	200,803–201,112

Currently, in situ soil temperature observational networks are few and are sparsely distributed across the global. Thus, model-based soil temperature products are considered a reasonable alternative. The Global Land Data Assimilation System (GLDAS) (Rodell et al., 2004; Rodell and Kato, 2006) was produced with the goal of realistically simulating the transfer of mass, energy, and momentum between the soil and vegetation surfaces and the atmosphere. The GLDAS may be used to improve understanding of soil water dynamics, plant physiology, micrometeorology, and the controls on atmosphere–biosphere–hydrosphere interactions. Currently, GLDAS drives four land surface models: Mosaic (Koster and Suarez, 1992a, 1992b), Noah (Chen et al., 1996; Koren et al., 1999; Ek et al., 2003; Betts et al., 1997), the Community Land Model (CLM; Dai et al., 2003) and the Variable Infiltration Capacity model (VIC; Liang et al., 1994). The output variables include soil moisture and temperature at multiple layers, and all major land surface water and energy fluxes. However, soil temperature profile data are only available from the CLM model and the Noah model.

The objective of this study is to fully investigate the accuracy of global soil temperature profile products from the GLDAS by comparison with large-scale (greater than $1^\circ \times 1^\circ$) and small-scale (less than $1^\circ \times 1^\circ$) in situ observations from nine networks under different geographical settings and climatic controls.

2. Material and methods

2.1. Observational networks for the soil temperature profile

Unlike other routinely available hydro-meteorological variables (e.g., air temperature, and precipitation), the soil temperature profile is rarely observed on a regular basis at meteorological stations. It is even harder to build and maintain a larger scale (especially greater than $1^\circ \times 1^\circ$) observational network for multi-site measurements of soil temperature profiles.

Nine in situ soil temperature profile datasets derived from large-scale (greater than $1^\circ \times 1^\circ$) and small-scale (less than $1^\circ \times 1^\circ$) observational networks were used in this study (Table 1 and Fig. 1). Three networks were distributed through the Coordinated Enhanced Observing Period (CEOP) (Bosilovich and Lawford, 2002; Koike, 2004; Lawford et al., 2006), located in the Southern Great Plains (SGP, USA), Murray-Darling Basin Murrumbidgee (MDB, Australia) and Mongolian Plateau (Mongolia, Kaihotsu et al., 2003),

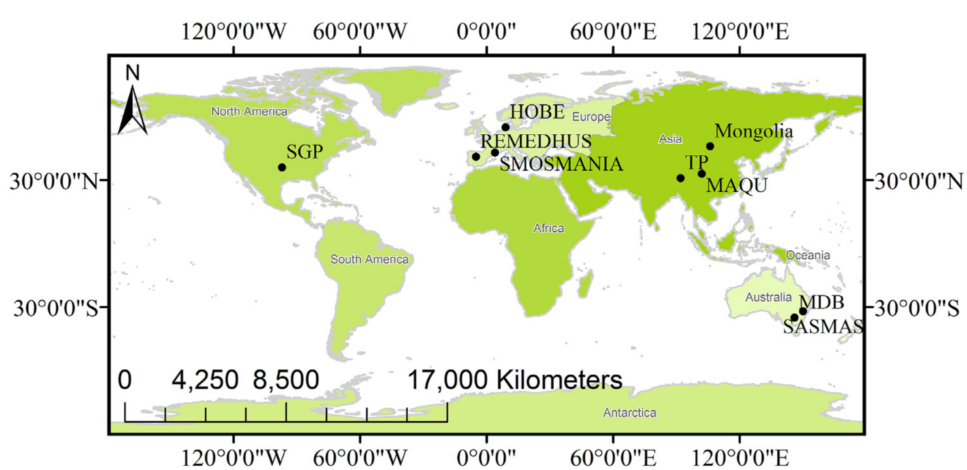

Fig. 1. The soil temperature observational networks used in this study, including SGP in USA, Mongolia in Mongolia, TP and MAQU in China, MDB and SASMAS in Australia, as well as HOBE, REMEDHUS and SMOSMANIA in European.