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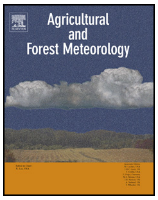

Improving Noah land surface model performance using near real time surface albedo and green vegetation fraction

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ABSTRACT

The current operational Noah land surface model (LSM) uses multi-year climatology of monthly green vegetation fraction (GVF) and the multi-year averages of land surface albedo data for several numerical weather predictions at National Centers for Environmental Predictions of National Oceanic and Atmospheric Administration. However, these static GVF and albedo data can only prescribe the multiannual means and lack the ability to capture near real time (NRT) vegetation status and land surface condition. In this study, the impact of NRT GVF and albedo on Noah LSM (version 3.2) performances are examined against in situ measurements of surface net long wave radiation and net short wave radiation from 7 U.S. Surface Radiation Budget Network stations, and soil temperature and soil moisture from 9 USDA Soil Climate Analysis Network sites. Large differences between the NRT GVF/surface albedo and their climatological averages are found over the global, which have significant influences on Noah LSM simulations. With respect to in situ measurements, the Noah LSM simulation improvements from using the weekly GVF data are 19.3% for surface soil moisture, 9.3% for surface soil temperature. The benefits from the weekly GVF and monthly albedo can reach to 2.7 W m^{-2} for surface net long wave radiation and 2.6 W m^{-2} for surface net short wave radiation. The results suggest to Noah model developers and users that the NRT GVF and albedo should be used for better model performance.

1. Introduction

During the past several decades, a number of advances in land surface models (LSMs) have been made in simulating surface energy, water fluxes and the surface energy and water budgets in response to near-surface atmospheric forcing (Ek et al., 2003). These models typically include water and energy balance formulations based on time-varying meteorological and radiation forcing as well as detailed vertical soil physics to describe sub-surface soil water, soil flux and storage (Crow et al., 2012). The land surface fluxes of LSMs simulations are the necessary lower boundary conditions for numerical weather prediction and climate models which are computationally intensive. And as such the LSMs utilized must be computationally efficient in their representation of land surface processes. In addition, LSMs can track temporal anomalies in root-zone soil water in comparison with remote sensing that is restricted to indirect quantities, low-vegetated regions and the top few centimeters (Sheffield et al., 2006; Mo et al., 2010; Crow et al., 2012; Yin et al., 2014, 2015a, 2015b). Their simulations are quantitatively evaluated using in situ observations and then used to monitor agriculture drought. For instance, current weekly U.S. Drought Monitor and monthly North America Drought Monitor published at U.S. Drought Portal (http://www.drought.gov) by National Integrated Drought Information System (NIDIS) are mainly based on simulations of LSMs and experts' best judgment. Despite recent advances in understanding (Maity et al., 2013; Henley et al., 2013), monitoring and forecasting drought (Hain et al., 2011, 2012; Vernimmen et al., 2012; Pozzi et al., 2013), current drought capabilities still fall short of users' needs, especially the need for skillful and reliable

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drought forecasts with near real time (NRT) surface albedo and green vegetation fraction (GVF) (Mariotti et al., 2013).

The important roles of surface albedo and vegetation condition in interchange of energy and water in land-atmosphere interactions are firstly claimed in the 1970s (Charney et al., 1975, 1977). Eltahir (1998) emphasized that the surface albedo has a potential impact on surface net radiation by increasing/decreasing upward emission of terrestrial radiation, which lead to the surface energy and evapotranspiration are changed. In fact, surface albedo is a crucial parameter in determining the magnitude of energy fluxes in the soil-plant-atmosphere continuum, affecting surface temperature, evaporation and transpiration, cloud formation and precipitation, thus ultimately impacting gross primary productivity (Ollinger et al., 2008; Chapin et al., 2008; Cescatti et al., 2012). Given the relevance of surface albedo in the Earth's climate system, monitoring this parameter in space and time is fundamental for the development of LSM (Alton, 2009; Hollinger et al., 2009) and global climate models (Henderson-Sellers and Wilson, 1983; Colman, 2013).

The GVF is defined as the percentage of vegetation covering the ground area, which can express the horizontal distribution and vertical thickness of vegetation canopies and their variations (Miller et al., 2006). The state of vegetation covering the land surface may have influences on surface temperature that plays a central role in land surface heat fluxes calculations in coupled land-atmospheric models (Kurkowski et al., 2003). And GVF can determine the partitioning of net radiation into sensible, latent and soil heat exchange through their impacts on evapotranspiration, surface roughness and the surface radiation, which are important for energy balance in land surface processes. Accurate description of vegetation in space and time is also fundamental for development of LSM as well as climate and numerical weather prediction models.

Following the recognition of the importance of land surface processes in climate and weather prediction models, a wide spectrum LSMs have been developed in the last 20 years (Chen and Dudhia, 2001). During the 1990s, National Centers for Environmental Prediction (NCEP) greatly expanded its land surface modeling collaborations via several components of the Global Energy and Water Cycle Experiment (GEWEX), the GEWEX Continental-Scale International Project (GCIP) and the Project for Intercomparison of Land-surface Parameterization Schemes (PILPS) (Ek et al., 2003). As an outgrowth of testing over a wide range of space scales and timescales, NCEP substantially enhanced Noah LSM in the Global Forecast System (GFS) (Chen et al., 1996, 1997; Ek et al., 2003). In the last 20 years, the Noah model has been widely used by NCEP in operational weather and climate predictions, by the Weather Research Forecast (WRF) model community, and by the Air Force Weather Agency (Niu et al., 2011; Zheng et al., 2014). The development efforts have improved the model performance in both offline and coupled modes (Ek et al., 2003; Mitchell et al., 2004; Chen et al., 2007).

The Noah model has 33 parameters. Ten of them are related to vegetation (Hogue et al., 2005). However, the GVF dataset used in current Noah LSM are 5-year (1985–1991) climatological maps derived from the top of atmosphere monthly averaged Normalized Difference Vegetation Index (NDVI) from the Advanced Very High Resolution Radiometer (AVHRR) aboard NOAA polar-orbiting satellites (Gutman and Ignatov, 1998; Peters-Lidard et al., 2007; Jiang et al., 2010). Likewise, at present, the surface albedo data used in the Noah LSM are multi-year averages of monthly maps. But these static GVF and albedo lack the ability of capturing current dynamic vegetation status while only prescribing the multiannual means (Jiang et al., 2010). Thus, the objectives of our work are threefold: (1) to assess the differences between weekly GVF (monthly albedo) and multi-year averages of monthly GVF (albedo), (2) to evaluate the influences of the differences between static and dynamic GVF/albedo on Noah 3.2 model simulations, and (3) to quantify the improved model performance due to NRT GVF/albedo products.

2. Noah land surface model

The Noah land surface model (LSM) has a long history of development through multi-insitutional cooperation (Mahrt and Ek, 1984; Mahrt and Pan, 1984; Chen et al., 1996, 1997; Ek et al., 2003; Niu et al., 2011) and is currently used for the operational Global Forecast System (GFS) and North American Mesoscale (NAM) models by the NCEP (Ryu et al., 2008). The forerunner Noah LSM advances have yielded improved model performance, both in an offline mode as well as coupled in the fully three-dimensional operational mesoscale analysis and forecast system (Ek et al., 2003). In particular, four soil layers of increasing thicknesses of 10 cm, 30 cm, 60 cm, and 100 cm are used to model soil temperature (ST) and soil moisture (SM) dynamics with layer-based formulations of the heat diffusion equation (for energy) and of the standard diffusion and gravity drainage equations (Reichle et al., 2010). The first three soil layers form the root zone in non-forested regions, with the fourth soil layer included in forested regions (Kumar et al., 2009; Xia et al., 2012). The surface energy balance equation in Noah LSM can be written as (Chen et al., 2010)

$$R_{net} = (1-\alpha)S^{\downarrow} + \varepsilon(L^{\downarrow} - \sigma T_{suf}^{4}) \tag{1}$$

this equation is the radiation budget description, where R_{net} is net radiation, $S^{\downarrow}$ and $L^{\downarrow}$ are the downward solar and long wave radiation, respectively, providing inputs of essential forcing; T_{suf} is the land surface temperature; σ is the Stefan–Bolzmann constant; and α and ε are the surface albedo and the ground surface emissivity, respectively.

The total evaporation (E) in Noah model is formulated as (Chen and Dudhia, 2001)

$$E = E_{dir} + E_c + E_t \tag{2}$$

where the direct evaporation from the top shallow soil layer (E_{dir}), evaporation of precipitation intercepted by the canopy (E_c) and transpiration via canopy and roots (E_t) are determined by (Mahrt and Ek, 1984; Noilhan and Planton, 1989; Jacquemin and Noilhan, 1990; Mahfouf and Noilhan, 1991; Chen and Dudhia, 2001)

$$E_{dir} = (1-f_g)\frac{\Theta_1 - \Theta_w}{\Theta_{ref} - \Theta_w}E_p \tag{3}$$

$$E_c = f_g\left(\frac{W_c}{W_{c,max}}\right)^{0.5} E_p \quad \text{and} \quad \frac{\partial W_c}{\partial t} = f_g P - S_P - E_c \tag{4}$$

$$E_t = f_g E_p\left(1-\left(\frac{W_c}{W_{c,max}}\right)^{0.5}\right)\frac{1+\frac{RH_s}{R_r}}{1+R_cC_h+\frac{RH_s}{R_r}} \tag{5}$$

where E_p is the potential evaporation, Θ indicates soil moisture content, Θ_{ref} and Θ_w are the field capacity and wilting point, respectively, W_c is the intercepted canopy water content, $W_{c,max}$ is the maximum canopy capacity, P is the input total precipitation, S_p is reaching the ground precipitation when W_c exceeds $W_{c,max}$, C_h and R_c, are the surface exchange coefficient for heat and moisture, canopy resistance, respectively, RH_s depends on the slope of the saturation specific humidity curve, R_r is a function of surface air temperature and surface pressure, f_g is the green vegetation fraction that is critical for the partitioning of total evaporation between bare soil direct evaporation and canopy transpiration.

Both the surface albedo [α in Eq. (1)] and GVF [f_g in Eqs. (2)–(5)] in Noah LSM are all multi-year averages of monthly (seasonal) maps. To better descript land surface and vegetation conditions, the dynamic surface albedo and GVF are employed in this paper as

$$R_{net} = (1-\alpha<x,y,m,j>)S^{\downarrow} + \varepsilon(L^{\downarrow} - \sigma T_{suf}^{4}) \tag{6}$$