Science of the Total Environment 633 (2018) 470–483

Contents lists available at ScienceDirect

Science of the Total Environment

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

# Estimating land surface variables and sensitivity analysis for CLM and VIC simulations using remote sensing products

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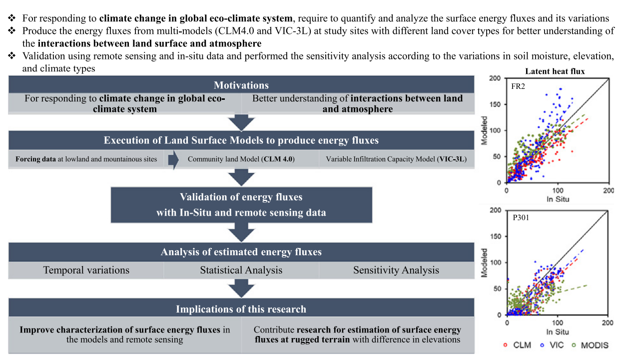
## HIGHLIGHTS

- Evaluated land surface parameterization for CLM and VIC land surface models
- Energy fluxes calculation at two heterogeneous sites with models and MODIS data
- CLM showed better performance for all energy fluxes except Ground heat flux.
- Sensitivity of LE was assessed with elevation, climate, and soil moisture.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 8 December 2017
Received in revised form 6 February 2018
Accepted 13 March 2018
Available online xxxx

Editor: Ouyang Wei

*Keywords:*
Land-atmosphere interactions
Energy fluxes
Topography
Land surface models
Remote sensing

## ABSTRACT

Assessment of Land Surface Models (LSMs) at heterogeneous terrain and climate regimes is essential for understanding complex hydrological and biophysical parameterization. This study utilized the two LSMs, Community Land Model (CLM 4.0) and three layer Variable Infiltration Capacity (VIC-3L), to estimate the interaction between land surface and atmosphere by means of energy fluxes including net radiation ($R_N$), sensible heat flux (H), latent heat flux (LE), and ground heat flux (G). The modeled energy fluxes were analyzed at two sites: Freeman Ranch-2 (FR2) located in the lowland region of Texas (272 m), and Providence 301 (P301) located on the mountains of Sierra Nevada in California (2015 m) from 2003 to 2013. $R_N$ was underestimated by CLM with bias $-25.06$ W m$^{-2}$ due to its snow hydrology scheme at P301. LE was overestimated by the VIC during summer precipitation and had a positive bias of 5.51 W m$^{-2}$, whereas CLM showed a negative bias of $-6.58$ W m$^{-2}$ at the FR2 site. G was considered as a residual term in CLM, which caused weak performance at P301, while VIC calculated G as a function of soil temperature, depth, and hydraulic conductivity. In addition, The MOD16 showed similar results with models at FR2; however, at P301, they yielded a correlation value of 0.85 and 0.21 for LSMs and MOD16, respectively. The later has lower correlation with in situ specifically in summer season caused by erroneous biophysical or meteorological inputs to the algorithms. The sensitivity analysis between soil moisture and turbulent fluxes, exhibited negative trend (especially for LE at P301) due to topography and snow cover. The results from this study are conducive to improvements in models and satellite based characterization of water and energy fluxes, especially at rugged terrain with high elevation, where observational experiments are difficult to conduct.



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https://doi.org/10.1016/j.scitotenv.2018.03.138
0048-9697/

## 1. Introduction

The transfer of heat, water vapors, and gases between the land surface and atmosphere interactions with the global ecosystem (Pielke et al., 1998) primarily depends on net radiation ($R_N$), sensible heat flux (H), and latent heat flux (LE; Yan and Dickinson, 2014). The ecosystem affects weather and climate systems (Sellers et al., 1995); thus, understanding the behavior of surface energy fluxes which change continuously, is important to comprehend accurate terrestrial ecosystem processes (Kustas and Norman, 1996; Boegh et al., 2004; Choi et al., 2008). Furthermore, energy fluxes are influenced by climate, topography, and bio-geophysical differences in land surface interactions with atmosphere (Liaqat and Choi, 2015; Goulden et al., 2012; Stöckli et al., 2008).

Recently, the Community Land Model (CLM 4.0) in Community Earth System Model (CESM) has been widely used for annual and decadal variability of climate, future projections, and paleoclimate studies (Gent et al., 2010). The CLM 4.0 includes hydrology, biogeophysics, and biogeochemistry and was developed by the National Center for Atmospheric Research (NCAR). In addition, three-layer Variable Infiltration Capacity (VIC-3L) a macroscale hydrological model was developed for analysis of water and energy balances between the land surface and the atmosphere at the large-scale and is used for simulation of hydrological variables such as soil moisture, evapotranspiration (ET), runoff, and snow water equivalent (Liang et al., 1994; Cherkauer et al., 2003). Both LSMs have different parameters and structure for simulating energy fluxes and water balance parameters. Additionally, the remotely sensed dataset has been utilized to observe the hydrological fluxes and to enhance the parameterization of the LSMs (Mu et al., 2007, 2011).

Thus, for an accurate understanding of land surface and atmosphere interactions, a physical approach is required through quantification of fluxes. It is indispensable to validate LSMs with in situ and remotely sensed datasets owing to their utilization in simulating regional and global climates and specifically in climate change phenomenon. Therefore, energy fluxes are estimated using land surface parameterizations, which are sub-models in LSMs (Sellers et al., 1997). The parameterizations in climate predictions and weather forecasting models have been developed with various complexity (Famiglietti and Wood, 1994).

There were various previous studies for evaluation of hydrological variables from the CLM and VIC models. Stöckli et al. (2008) simulated energy fluxes using the CLM 3.5 with the modified parameterization schemes from CLM 3.0 and made an effort to improve the surface energy partitioning, hydrological and bio-geophysical parameterization at several sites in north boreal, the Mediterranean, temperate, and tropical regions along with the validation with FLUXNET data (Baldocchi et al., 1996, 2001). The recommended improvements were further enhanced in parameterization for CLM 4.0. Zhang et al. (2017) evaluated the CLM with FLUXNET data at 20 different sites with eight different vegetation types for energy fluxes and studied details of LE and H partitioning. However they only evaluated CLM parameterization without validating using remotely sensed and other models' approach. Partitioning between sensible and latent heat fluxes was also affected by soil moisture (Hou et al., 2012). In addition, CLM and VIC models were evaluated at a mountainous watershed with flux tower observations to evaluate model's performance and explore problems related to elevated regions in simulation of energy fluxes (Li et al., 2011; Kim et al., 2017a). Kim et al. (2017a) research for CLM and VIC used older version of CLM with elevation difference only (234 m) between study sites which was not enough to address the parameterization affects for elevation. Xiang-Dong et al. (2017) used the VIC model to study the energy, water and soil carbon to discuss the impacts of lower boundary conditions of Richards' equation.

Moreover, previous studies have estimated various parameters such as albedo, leaf area index, and gross primary production using the CLM and MODIS (Zhou et al., 2004; Mao et al., 2012, Goulden et al., 2012). However, very few studies have involved remotely sensed water vapor flux and focused on different topography (elevation difference greater than 1500 m), plant functional types (PFTs), and climate zones using CLM 4.0 and VIC-3L. It is necessary to understand and improve parameterization of LSMs by evaluating them at point scale before running the models at regional and global scale to avoid expensive computations.

In this study, the CLM 4.0 and VIC-3L simulated energy fluxes such as $R_N$, H, LE, and G at daily time scale in a humid subtropical climate in Texas and a cool summer Mediterranean climate in Sierra Nevada, California. The estimation of fluxes was evaluated against an in situ dataset from the flux tower and MOD16 dataset. The bio-geophysical differences at both sites were studied in response to changing climate and elevation. Moreover, the parameterization for both models was discussed to elaborate the differences between LSMs. Sensitivity analysis was also performed to examine models' response according to soil moisture, altitude, and different climate regimes.

## 2. Materials and methods

### 2.1. Study area

This study was conducted at two sites. Freeman Ranch-Mesquite Juniper (FR2) site in Texas is part of the FLUXNET network (Baldocchi et al., 1996) associated with the AmeriFlux grid. The second site is Providence 301 (P301) in the Providence Creek sub-catchment of the Kings River Experimental Watershed (KREW), located in the southern Sierra Nevada Mountains, California, USA, and part of the Southern Sierra Critical Zone Observatory (CZO) project (Fig. 1). The various bio-geophysical properties, elevations and climate types of the study sites are presented in Table 1. Geographically, the FR2 site is located on flat terrain, whereas P301 is located on the mountainous terrain of Sierra Nevada. Elevation ranges from 272 m to 2015 m at the FR2 and P301 sites, respectively. The biome types differ as FR2 has Woody Savannas, while P301 has an elevated mixed conifer forest with dominant vegetation of White Fir, Pine and Cedar. According to the Koppen climate classification (Peel et al., 2007), the climate differs from humid subtropical with no dry season and hot summer (Cfa) to cool summer Mediterranean (Csb) in the Texas and California sites, respectively. The sites have similar soil texture (HWSD: Harmonized World Soil Database) with 47% sand, and 24% clay (Nachtergaele et al., 2009). Mean annual temperature from 2003 to 2013 ranged from 13.4 to 26.4 °C and 5.7 to 13.4 °C at FR2 and P301, respectively. FR2 received average annual precipitation of 942 mm year$^{-1}$ with 70% falling in the summer months, while 80% of the annual precipitation at P301 (1292 mm year$^{-1}$) falls in winter months from November to April.

### 2.2. Data and methodology

#### 2.2.1. Flux tower data

AmeriFlux which is affiliated with FLUXNET network (Baldocchi et al., 2001) has been managed by multiple countries since 1996 to represent key climate and ecological biomes. AmeriFlux provides continuous measurements of water, $CO_2$, and energy fluxes at half-hourly to hourly time scale from more than 110 active sites across the world. The time interval considered in this study for model validation was 2005–2008 at FR2 and 2009 to 2013 at P301.

Turbulent heat fluxes were measured from the flux towers, measured at the tops of aluminum or steel towers having a triangular cross-section with height of 5 to 10 m more than the tallest surrounding trees. Solar panels were used for power supply. $CO_2$ and water vapor fluxes were calculated using the eddy covariance (EC) technique at 30-minute intervals using wind velocity determined through a sonic anemometer, Campbell Scientific Inc. (CSAT-3) and water vapor density form Infrared Gas Analyzers (LiCor LI7000 for P301, LiCor LI6262 for FR2; Goulden et al., 2012, Heinsch et al., 2004).