Land Surface Modeling

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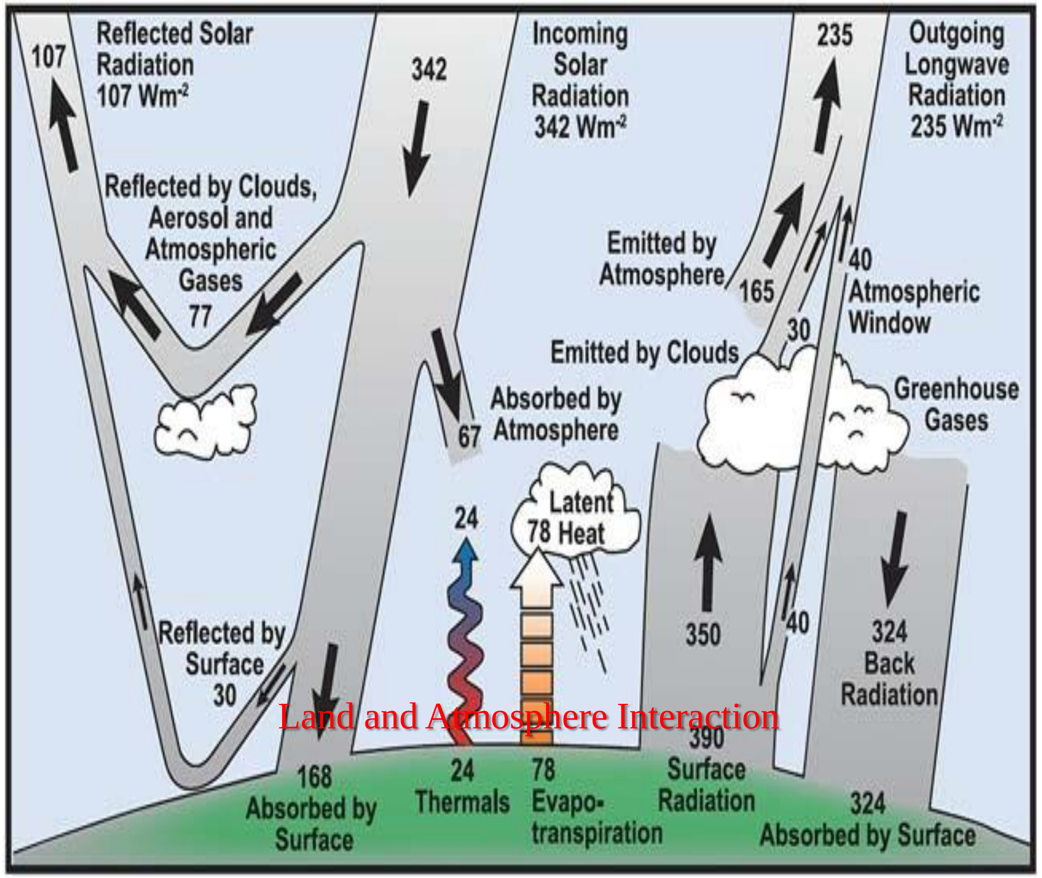
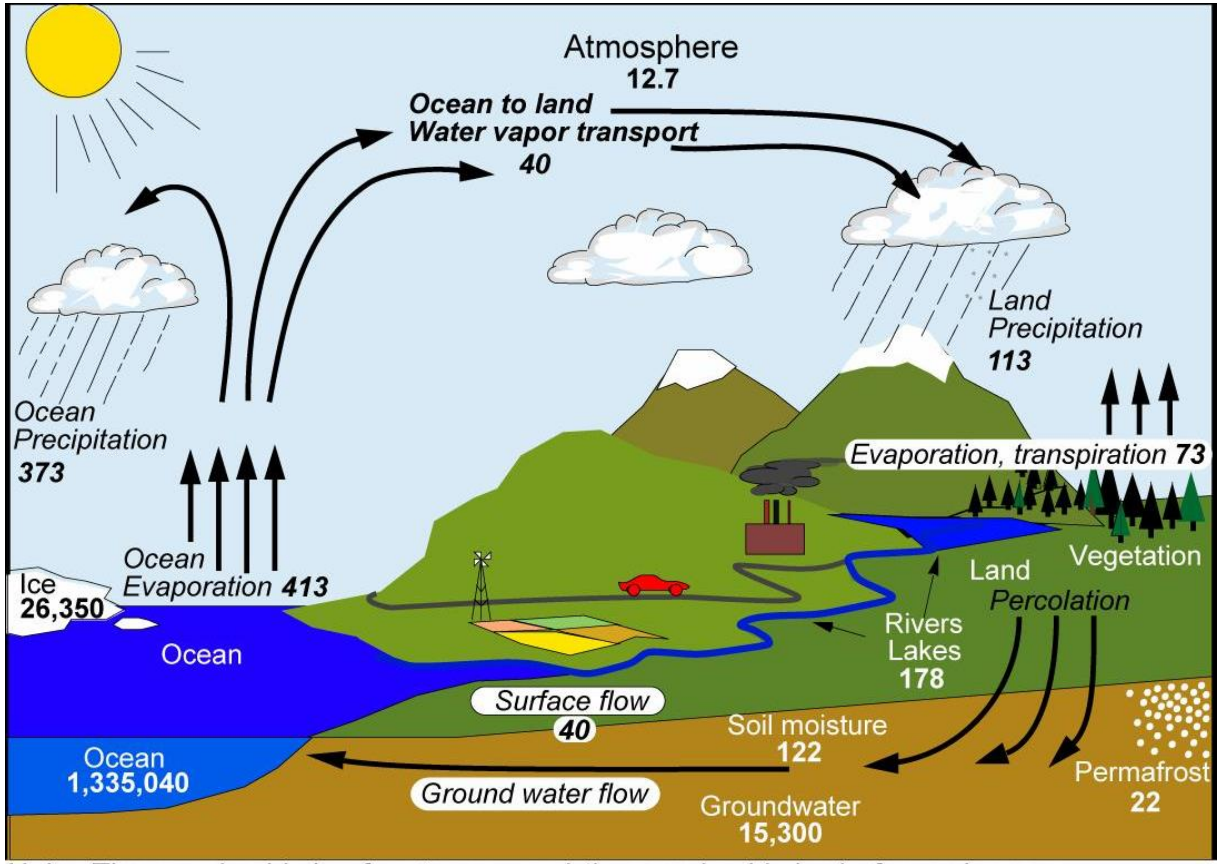
1. Introduction to Land Surface Model (LSM)

1.1. Earth System

Earth energy budget



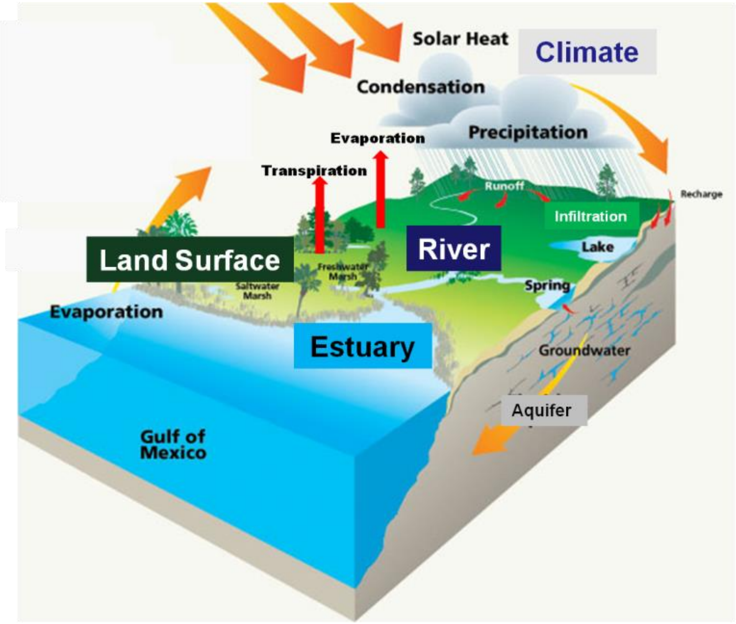
Earth water budget

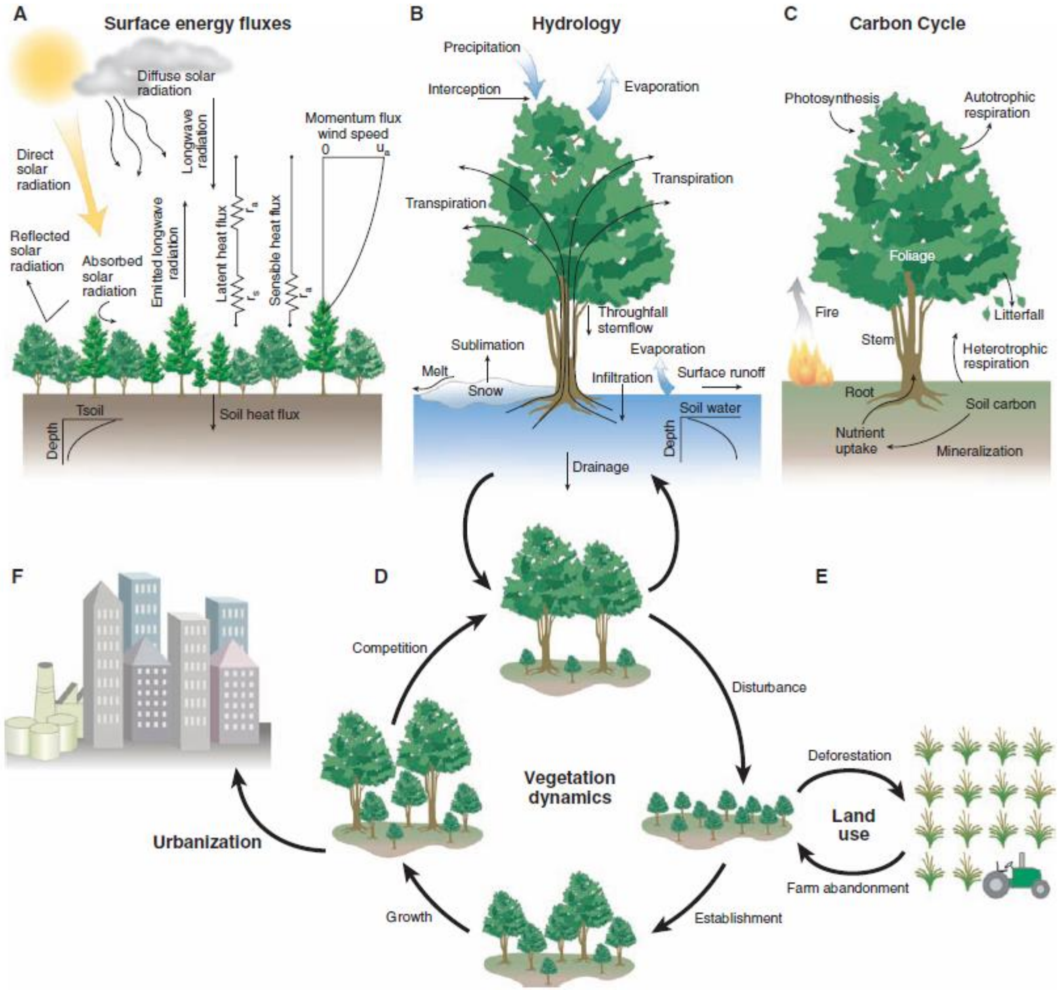


Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges

1.2. Land Surface Processes

1. Interactions between land and atmosphere
   : Momentum, Energy, Water Vapor, and other Gases
2. Interactions between land and Ocean
   : Fresh water, Nutrients, and Sediments
3. Changes of land surface
   : Snow cover, vegetation, and soil moisture
4. Human Activities on land
   : Urbanization, agriculture, and air/water pollutions





1.5. Recent Developments in LSM

Improved understanding in physical hydrology

- Snow albedo, snow cover, and snow thermal/hydrologic processes
- Topographic controls on soil moisture/runoff
- Groundwater hydrology
- Terrain routing and river flow hydraulics (flood modeling)

Enhanced linkage with biogeochemistry/ecology

- Carbon and nitrogen (soil chemistry, BVOC, secondary organic aerosols)
- Vegetation phenology/species competition
- Dust emissions/aerosols

Land use and land cover change

- Urban canopy
- Air / Water quality
  - Advanced techniques for using remotely-sensed land parameters(AVHRR, MODIS, AMSR, GRACE…)
  - Extended *in situ* field datasets and ensemble model calibration/evaluation

CLM3 (2004) --> CLM3.5 (2008)

- Surface runoff (Niu, Yang et al., 2005)
- Groundwater (Niu, Yang, et al., 2007)
- Frozen soil (Niuand Yang, 2006)
- Canopy integration, canopy interception scaling, and pft-dependency of the soil stress function

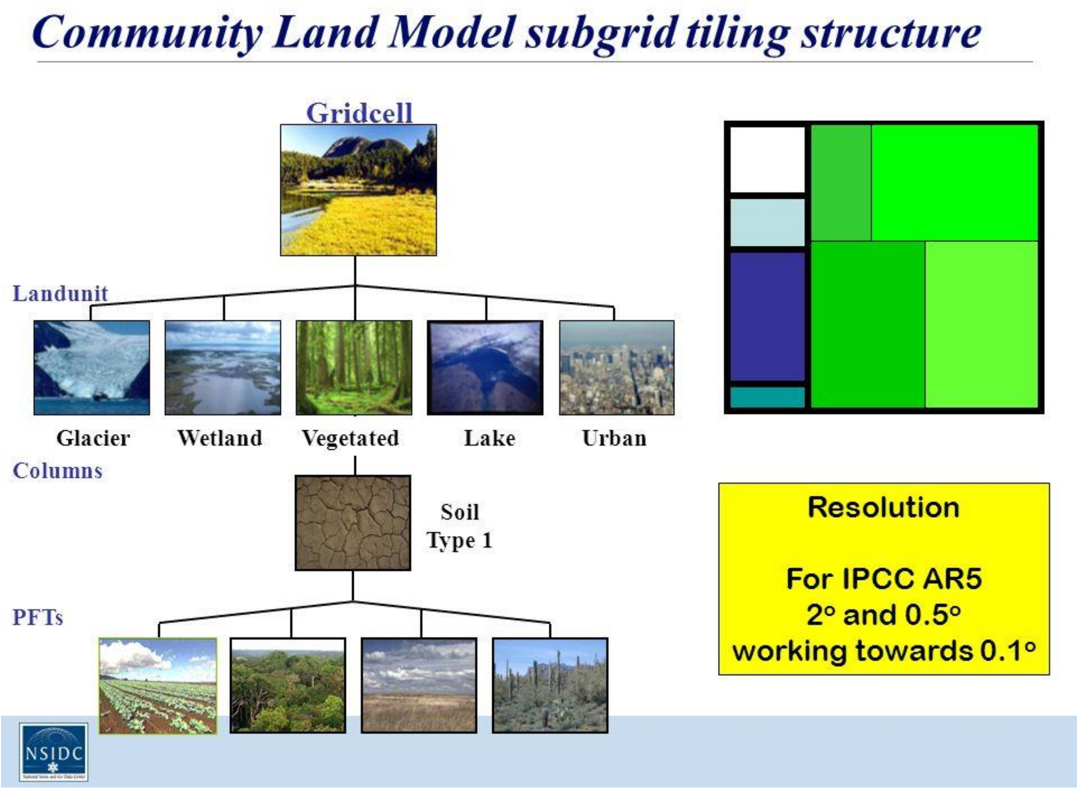
CLM3.5 --> CLM4 (2010)

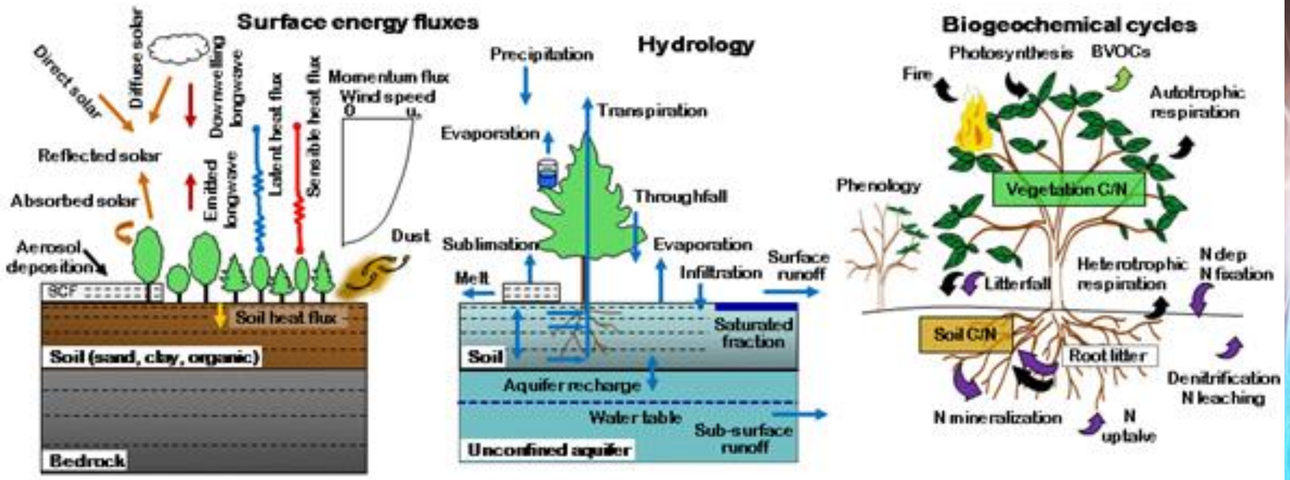
- Prognostic in carbon and nitrogen (CN) as well as vegetation phonology
- Urban component
- BVOC component
- Updated hydrology and ground evaporation
- New density-based snow cover fraction, snow burial fraction, snow compaction
- Conserving global energy by separating river discharge into liquid and ice water streams

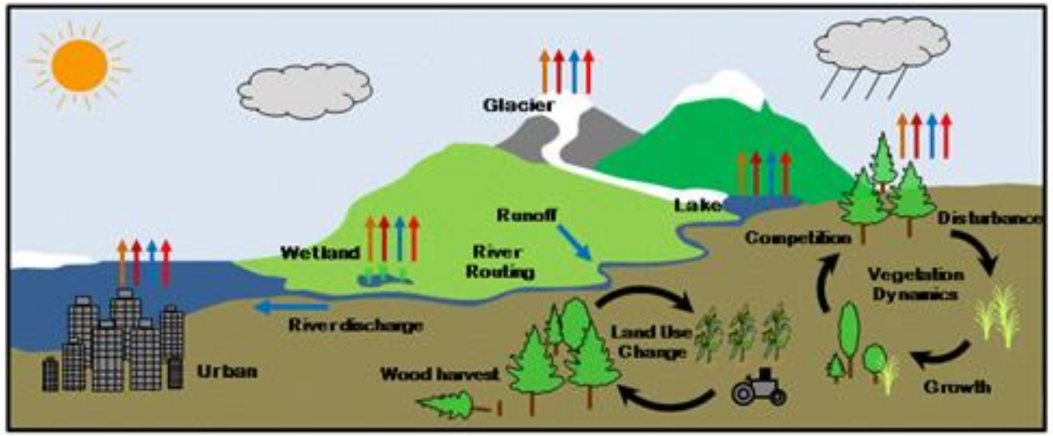
1.7. CLM descriptions

Community Land Model (CLM)

- CLM has 15 soil layers (the top 10 for active hydrologycal processes and 5 layer at the bottom for soil temperature dynamics.
- CLM uses Monin-Obukhov Similarity Theory (MOST) for calculating water vapor fluxes. The model is initialized with surface data including soil colors, soil texture, organic matter density, and Plant Functional types (PFTs).







1.7. CLM descriptions

Community Land Model 4.0

The Community Land Model version 4 in CESM1.0 is the latest in a series of land models developed through the CESM project.

Community Earth System Model

The CommunityEarth System Model (CESM) is a coupled climate model for simulating the earth's climate system. Composed of four separate models simultaneously simulating the earth's atmosphere, ocean, land surface and sea-ice, and one central coupler component, the CESM allows researchers to conduct fundamental research into the earth's past, present and future climate states.

1.7. CLM descriptions

Community Land Model 4.0

The Community Land Model version 4 in CESM1.0 is the latest in a series of land models developed through the CESM project.

What's new in CLM4.0

Surface Datasets

- New cropping datasets and reduce a high grass PFT bias
- Grass and crop PFT optical properties have been adjusted

Miscellaneous Changes

- Change to the atmospheric reference height
- Change a vastly improved and smooth diurnal cycle of incoming solar radiation that conserves the total incoming solar radiation from the forcing dataset

Biogeochemistry

- Extend a carbon-nitrogen biogeochemical model (CLMCN)

Biogeophysics and Hydrology

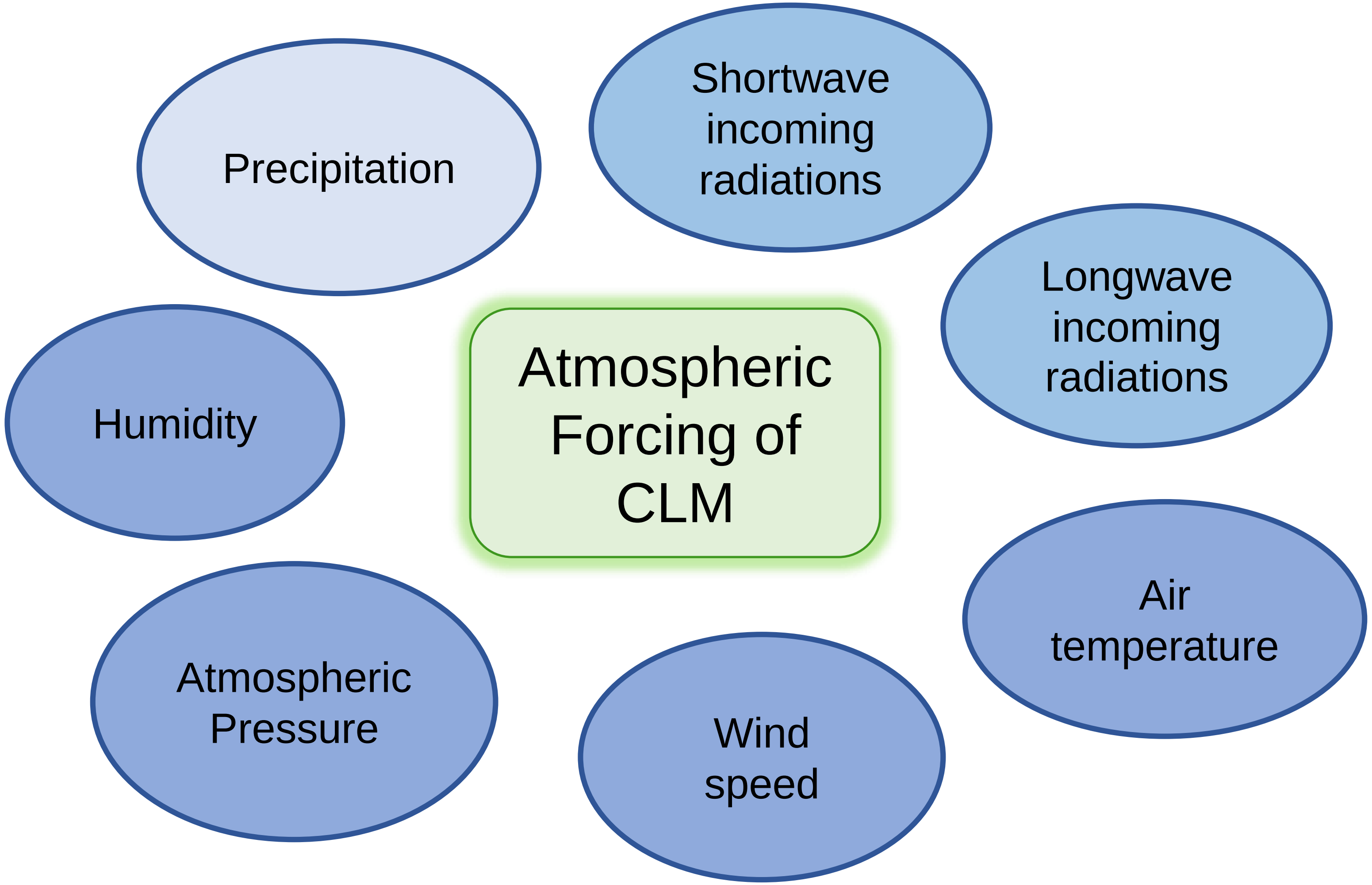
- Revised numerical solution of the Richards equation
- Revised soil evaporation parameterization that removes the soil resistance
- Ground column has been extended to ~50-m depth by adding five additional hydrologically inactive ground layers

Snow model

- Modified via incorporation of SNICAR (SNow and Ice Aerosol Radiation) which represents the effect of aerosol deposition (e.g. black and organic carbon and dust) on albedo, introduces a grain-size dependent snow aging parameterization, and permits vertically resolved snowpack heating
- Dust emissions/aerosols

2. Running Process of CLM

2.1. Input for running CLM



Forcing variables are acquired from nearby weather stations, flux tower or reanalysis data such as GLDAS to run the model.

2.2. Pre-process Steps in Running CLM

Steps:

1. Preparation surface datasets
2. Preparation atmospheric forcing files

(1) Preparation surface datasets

Required:

- Selecting Resolution
- Determined the edges coordinates
- Determined the datasets name

```
> cd models/lnd/clm/tools/ncl_scripts
> getregional_datasets.pl -sw 52,190 -ne 73,220 -id 13x12pt_f19_alaskaUSA -mycsmdata $CSMDATA
```

s: South edge

w: west edge

n: North edge

e: east edge

13x12pt: number of pixel

f19: dataset resolution

alaskaUSA: location or ID

Location of global surface data

(2) Preparation atmospheric forcing files

- If using default atmospheric forcing data in CLM 4, which is **Qian data**, no need to create new atmospheric file
- If using other reanalysis data such GLDAS or flux tower data, it is required to make atmospheric forcing files with **netcdf format**. We can make a code using matlab or other programming language.
- **Example of stream namelist with your own atmosphere forcing:**

```
&shr_strdata_nml
  dataMode       = 'CLMNCEP'
  domainFile     = '$DOMAINFILE'
  streams        = 'clm1PT.1x1pt_lapazMEX.solar.stream.txt  1 2004 2009 ',
                   'clm1PT.1x1pt_lapazMEX.precip.stream.txt 1 2004 2009 ',
                   'clm1PT.1x1pt_lapazMEX.other.stream.txt  1 2004 2009 ',
                   'presaero.stream.txt 1 2000 2000'
  vectors        = 'null','null','null','null'
  mapmask        = 'nomask','nomask','nomask','nomask'
  mapalgo        = 'nn','nn','nn','nn'
  tintalgo       = 'coszen','nearest','linear','linear'
  taxmode        = 'cycle','cycle','cycle','cycle'
 /
```

Example of setting up case with your own atmosphere forcing:

```
> cd scripts
# First make sure you have a inputdata location that you can write to
# You only need to do this step once, so you won't need to do this in the future
> setenv MYCSMDATA $HOME/inputdata     # Set env var for the directory for input data
> ./link_dirtree $CSMDATA $MYCSMDATA
# Next create and move all your datasets into $MYCSMDATA with id $MYUSRDAT
# See above for naming conventions

#  Now create a single-point case
> ./create_newcase -case my_atmforc_test -res pt1_pt1 -compset I1850 \
-mach bluefire
> cd my_atmforc_test
# Set the data root to your inputdata directory, and set CLM_PT1_NAME and CLM_USRDAT_NAME
# to the user id you created for your datasets above
> ./xmlchange -file env_run.xml -id DIN_LOC_ROOT_CSMDATA -val $MYCSMDATA
> ./xmlchange -file env_conf.xml -id CLM_PT1_NAME -val $MYUSRDAT
> ./xmlchange -file env_conf.xml -id CLM_USRDAT_NAME -val $MYUSRDAT
# Set the land-mask to USGS, so both clm and DATM can find files
> ./xmlchange -file env_conf.xml -id CLM_BLDNML_OPTS -val '-mask USGS'
# Then set DATM_MODE to single-point mode so DATM will use your forcing datasets
# Put your forcing datasets into $MYCSMDATA/atm/datm7/CLM1PT_data/$MYUSRDAT
> ./xmlchange -file env_conf.xml -id DATM_MODE -val CLM1PT
> ./configure -case
# If the list of fields, or filenames, filepaths, or fieldnames are different
# you'll need to edit the DATM namelist streams file to make it consistent
> $EDITOR Buildconf/datm.buildnml.csh
```

2.3. Process Steps in Running CLM

Steps:

1. Create new case
2. Configure case
3. Build the case
4. Run the case

(1) Create New Case

```
> cd scripts
> create_newcase -case cr_f10_TmpltI1850CN -res f10_f10 -compset I1850CN -mach bluefire
```

- Required to selecting **compset** and **resolution**
- **"case"** is the name and location of the case being created
- **"res"** specifies the model resolutions (grid)
  - Format is **[atm/lnd grid]_[ocn/ice grid]**
  - Equivalent short and long names **(f19_g16 == 1.9x2.5_gx1v6)**
- **"compset"** specifies the "component set"
  - component set specifies **component models**, **forcing scenarios** and **physics options**
  - Equivalent short and long names **(B1850CN == B_1850_CN)**
- **"mach"** specifies the machine that will be used.

(2) Configure the Case

```
# Configure
> configure -case
```

- Modify **env_conf.xml** and **env_mach_pes.xml** before running configure
- Generates:
  - **Buildconf** directory with **buildnml, buildexe**, and **input_data_list** files
  - case ***.build** and ***.run** scripts

`./configure -case`
- Configures the case

`./configure -cleanall`
- Unlocks **`env_conf.xml`** and **`env_mach_pes.xml`**
- Backs up **`Buildconf/`** and run scripts
- Modify **`env_conf.xml`** and **`env_mach_pes.xml`** and type **`configure -case`** again

`./configure -cleanmach`
- Unlocks only **`env_mach_pes.xml`**
- Backs up run scripts
- Modify **`env_mach_pes.xml`** and type **`configure -case`** again

(3) Build the Case

```
> cr_f10_TmpltI1850CN.bluefire.build
```

The *.build script used for:

- Checks for missing input data. Aborts if any input data is missing
- Creates directory for executable code and model namelist files
- Locks **env_build.xml**
- Builds the individual component libraries and model executable

(4) Run the Case

```
> bsub < cr_f10_TmpltI1850CN.bluefire.run
```

- Edit **env_run.xml** file before running (e.g. change **run length time, resubmit number**)
- Modify component namelist settings in the **Buildconf/*.buildnml.csh** files
- **The run script used for:**
  - Generates the namelist files in $RUNDIR
  - Verifies the existence of input datasets

Noted:

- Various Spin-up process required different running time

2.4. Post-process Steps in Running CLM

Check status of job and output files

```
bjobs
ls -lFt $RUNDIR
ls -l logs
```

A job completed successfully if **"SUCCESSFUL TERMINATION OF CPL7-CCSM"** appears near end of the cpl.log file

Several outputs from CLM

Output from Models	Unit
Net radiation	($W\ m^{-2}$)
Sensible heat flux	($W\ m^{-2}$)
Latent heat flux	($W\ m^{-2}$)
2-m air temperature	K
Ground temperature	K
Gross primary production	$gC/m^2/s$
net primary production	$gC/m^2/s$
Soil moisture	(m^3/m^3)
	Etc.

3. Our publications

(1) Using CLM4.0 – Water and energy fluxes

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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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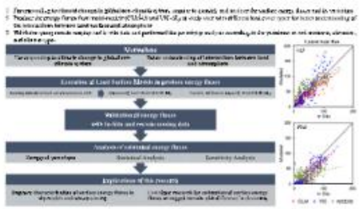
HIGHLIGHTS

- 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



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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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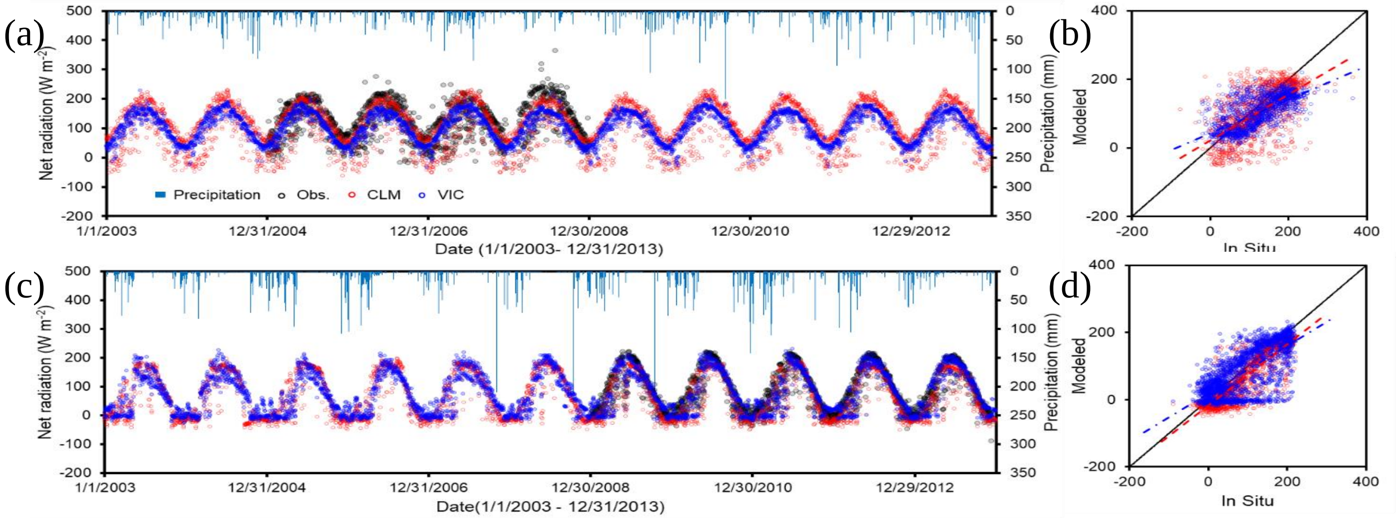
- Simulating energy fluxes at daily time scale using CLM 4.0 and VIC-3L
- Evaluating the performances LSMs againts flux tower and remotely sensed data
- Demonstrating the sensitivity analysis based on soil moisture, elevation, and different climate characteristics.

3.1. Previous studies

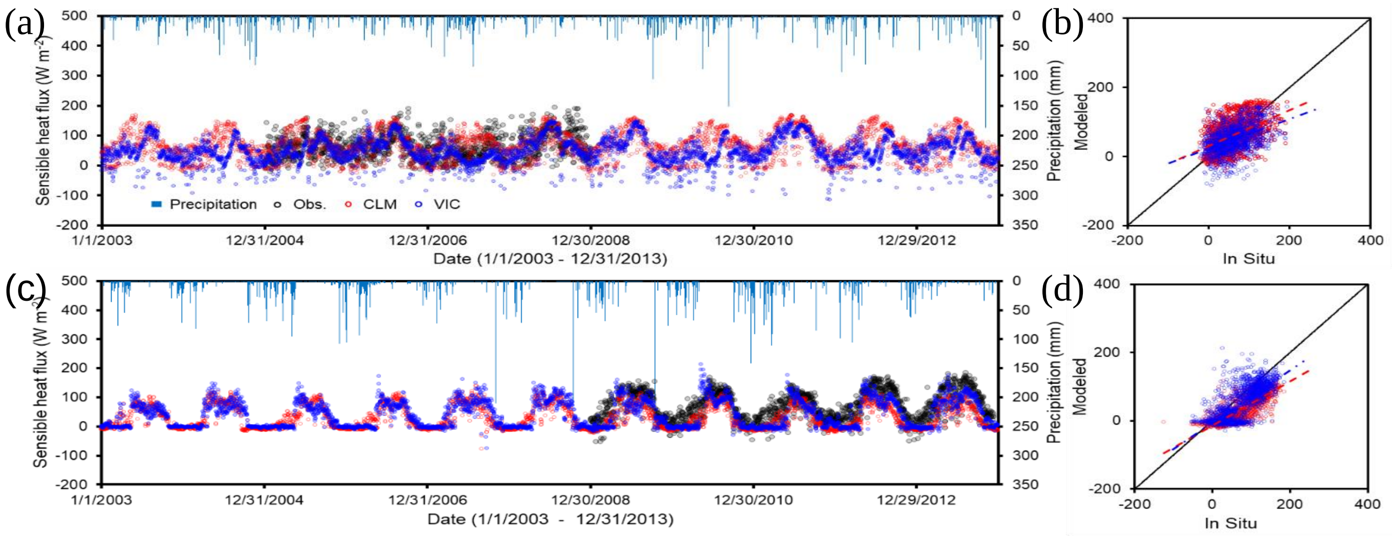


a. Net Radiations

Figure 3. Daily temporal variations of net radiations using CLM and VIC model at FR2 and P301 (a, c) and scatter plots (b, d) respectively, with precipitation

b. Sensible Heat Flux

Figure 4. Time series and scatter plots of sensible heat flux using CLM and VIC model at FR2 and P301 (a, c) and (b, d) respectively, with precipitation



3.1. Previous studies

c. Latent Heat Flux

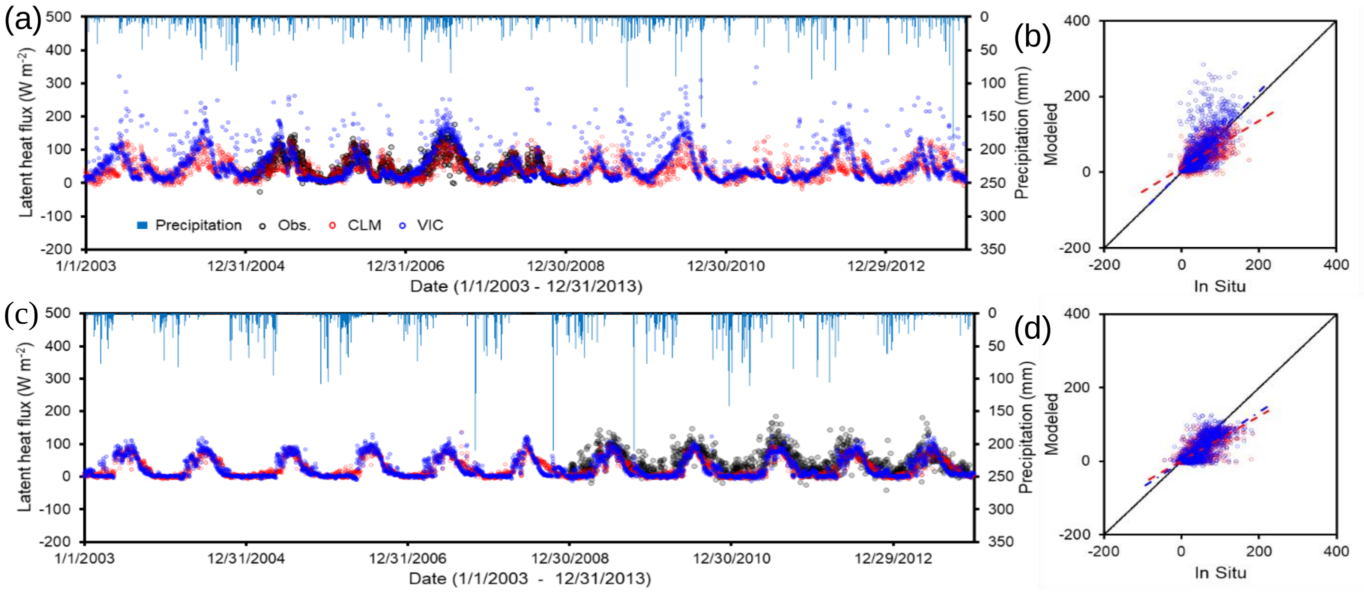


Figure 5. Time series of latent heat flux using CLM and VIC model at FR2 and P301 (a, c) and scatter plots (b, d) respectively, with precipitation.

d. Ground Heat Flux

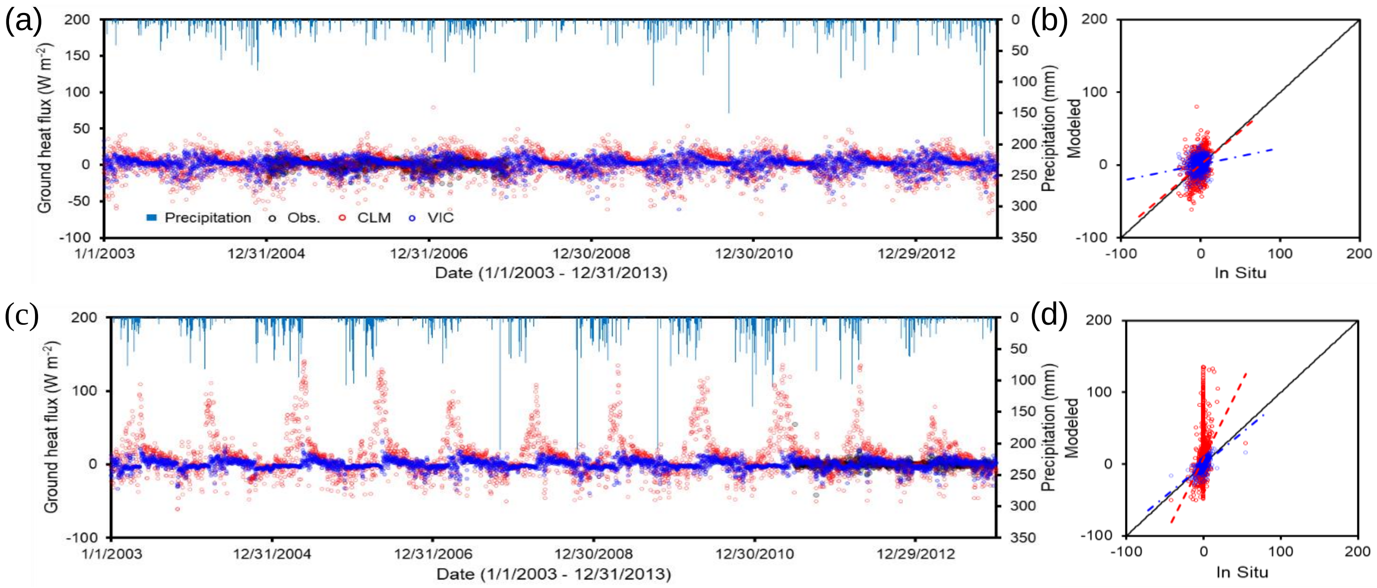


Figure 6. Daily temporal variations of ground heat flux using CLM and VIC model at FR2 and P301 (a, c) and scatter plots (b, d) respectively, with precipitation.

3.1. Previous studies

Table 3. Comparison of models in estimation of energy fluxes Net Radiation (RN), Latent heat flux (LE), Sensible heat flux (H) and Ground heat flux (G) at daily time scale with in-situ. (2003-2013)

LSMs		CLM vs. In-situ					VIC vs. In-situ				
Energy Fluxes	Sites	Slope	RMSE	NMAE	Bias	R	Slope	RMSE	NMAE	Bias	R
			Wm^{-2}		Wm^{-2}			Wm^{-2}		Wm^{-2}	
Net Radiation	FR2	**0.67**	61.43	0.37	**-18.79**	0.62	0.49	**52.20**	**0.35**	-20.34	**0.66**
	P301	**0.91**	44.11	0.37	-25.06	**0.88**	0.86	**37.37**	**0.31**	**-6.82**	0.87
Sensible heat flux	FR2	**0.52**	**44.25**	**0.55**	**0.45**	**0.47**	0.43	45.38	0.55	-14.07	0.44
	P301	0.65	48.61	0.60	-39.01	**0.81**	**0.76**	**42.25**	**0.48**	**-22.59**	0.74
Latent heat flux	FR2	0.62	**26.21**	**0.40**	-6.58	**0.70**	**1.04**	37.95	0.50	**5.51**	0.69
	P301	0.61	30.09	**0.48**	-17.90	0.71	**0.68**	**29.78**	0.49	**-17.14**	**0.73**
Ground heat flux	FR2	**0.93**	14.25	55.25	0.57	**0.38**	0.22	**9.56**	**35.07**	**1.06**	0.17
	P301	2.15	27.39	-502.7	8.87	0.26	**0.88**	**5.94**	**-130**	**-0.59**	**0.43**

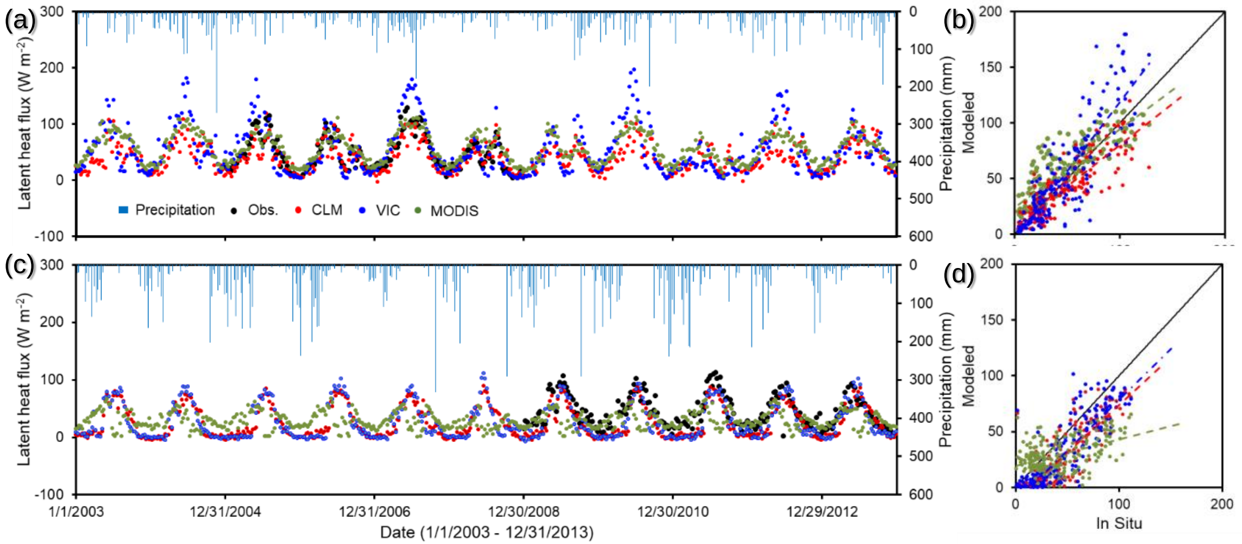


Figure 7. 8-day time series of LE using CLM, VIC and MOD16 data at FR2 (a, b) and P301 (c, d)

Table 4. Comparison of models and MOD16 with in-situ in estimation of 8-day latent heat flux (LE) (2003-2013).

Models and MOD16	FR2					P301				
	Slope	RMSE	NMAE	Bias	R	Slope	RMSE	NMAE	Bias	R
		Wm^{-2}		Wm^{-2}			Wm^{-2}		Wm^{-2}	
CLM vs. In-situ	0.74	**16.86**	**0.26**	-6.24	**0.86**	0.85	23.48	0.45	-18.00	**0.85**
VIC vs. In-situ	**1.24**	24.14	0.36	**5.56**	**0.86**	**0.91**	**22.8**	**0.43**	-16.3	**0.85**
MOD16 vs. In-situ	0.70	18.98	0.32	10.20	0.85	0.11	31.94	0.49	**14.26**	0.21
CLM vs.MOD16	**0.80**	**22.60**	**0.33**	-15.76	**0.80**	0.01	**31.06**	**0.89**	-3.86	0.006
VIC vs.MOD16	1.24	28.51	0.39	**-3.59**	0.75	**0.13**	32.89	0.90	**-1.77**	**0.06**

3.1. Previous studies

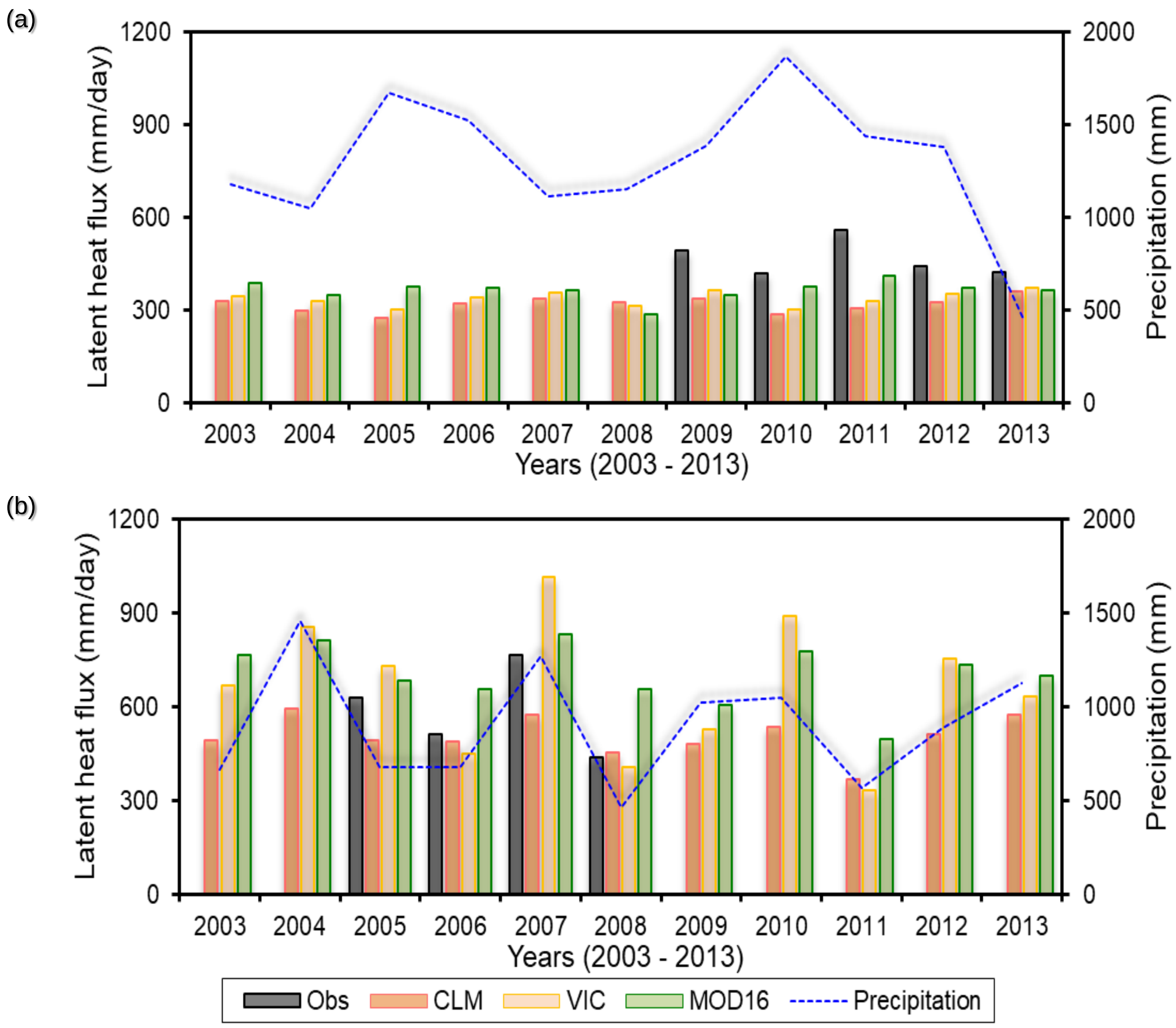


Figure 10. Yearly accumulated latent heat flux values from models, MOD16 and EC flux tower data at; a) P301 and b) FR2

(2) Other studies using CLM previous version

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Land Surface Models Evaluation for Two Different Land-Cover Types: Cropland and Forest

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ABSTRACT

Land Surface Model (LSM) is an important tool used to understand the complicated hydro-meteorological flux interaction systems between the land surface and atmosphere in hydrological cycles. Over the past few decades, LSMs have further developed to more accurately estimate weather and climate hydrological processes. Common Land Model (CLM) and Noah Land Surface Model (Noah LSM) are used in this paper to estimate the hydro-meteorological fluxes for model applicability assessment at two different flux tower sites in Korea during the summer monsoon season. The estimated fluxes such as net radiation (R_N), sensible heat flux (H), latent heat flux (LE), ground heat flux (G), and soil temperature (T_s) were compared with the observed data from flux towers. The simulated R_N from both models corresponded well with the *in situ* data. The root-mean-square error (RMSE) values were 39 - 44 W m^{-2} for the CLM and 45 - 50 W m^{-2} for the Noah LSM while the H and LE showed relatively larger discrepancies with each observation. The estimated T_s from the CLM corresponded comparatively well with the observed soil temperature. The CLM estimations generally showed better statistical results than those from the Noah LSM, even though the estimated hydro-meteorological fluxes from both models corresponded reasonably with the observations. A sensitivity test indicated that differences according to different locations between the estimations from models and observations were caused by field conditions including the land-cover type and soil texture. In addition the estimated R_N, H, LE, and G were more sensitive than the estimated T_s in both models.

Key words: Water and energy fluxes, Common Land Model, Noah Land Surface Model

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1. INTRODUCTION

Land surface fluxes produced by Land Surface Models (LSMs) represent the physical processes that adjust the transfer of water and energy into the atmosphere after precipitation and solar radiation reach the land surface (Zeng et al. 2002; Rodell et al. 2005). Recently, bucket-type LSMs have been further developed for the purpose of designing an effective tool to estimate the hydrological processes and components of weather and climate systems (Bastidas et al. 2003). Over the past few decades the focus of LSMs research studies has been land-surface developments and parameterizations (Avissar and Pielke 1989; Li and Avissar 1994; Oleson et al. 1997; Liang and Guo 2003; Kahan et al. 2006; Han et al. 2008; Patil et al. 2011). A number of experiments have been conducted to develop and evaluate LSMs with the goal of facilitating their advancement (Hogue et al. 2005).

The Common Land Model (CLM) and Noah Land Surface Model (Noah LSM) have been developed so that the Global Energy and Water Experiment (GEWEX) can be applied to forecast climate components along with other models such as the Variable Infiltration Capacity model (VIC; Liang et al. 1994; Peters-Lidard et al. 1997) and the National Aeronautic and Space Administration (NASA)'s Mosaic LSM (De Haan et al. 2007). The CLM, a Soil-Vegetation-Atmospheric Transfers (SVAT) model, was developed by the National Center for Atmospheric Research (NCAR) and is recognized as one of the most advanced NCAR LSM types

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Land Response to Atmosphere at Different Resolutions in the Common Land Model over East Asia

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ABSTRACT

Towards a better understanding of hydrological interactions between the land surface and atmosphere, land surface models are routinely used to simulate hydro-meteorological fluxes. However, there is a lack of observations available for model forcing, to estimate the hydro-meteorological fluxes in East Asia. In this study, Common Land Model (CLM) was used in offline-mode during the summer monsoon period of 2006 in East Asia, with different forcings from Asiaflux, Korea Land Data Assimilation System (KLDAS), and Global Land Data Assimilation System (GLDAS), at point and regional scales, separately. The CLM results were compared with observations from Asiaflux sites. The estimated net radiation showed good agreement, with $r = 0.99$ for the point scale and 0.85 for the regional scale. The estimated sensible and latent heat fluxes using Asiaflux and KLDAS data indicated reasonable agreement, with $r = 0.70$. The estimated soil moisture and soil temperature showed similar patterns to observations, although the estimated water fluxes using KLDAS showed larger discrepancies than those of Asiaflux because of scale mismatch. The spatial distribution of hydro-meteorological fluxes according to KLDAS for East Asia were compared to the CLM results with GLDAS, and the GLDAS provided online. The spatial distributions of CLM with KLDAS were analogous to CLM with GLDAS, and the standalone GLDAS data. The results indicate that KLDAS is a good potential source of high spatial resolution forcing data. Therefore, the KLDAS is a promising alternative product, capable of compensating for the lack of observations and low resolution grid data for East Asia.

Key words: Common Land Model, Korea Land Data Assimilation System, Global Land Data Assimilation System, Asiaflux, hydro-meteorological fluxes

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1. Introduction

Recently, the exchange of energy and water fluxes between the land surface and the atmosphere has been recognized as a crucial factor in understanding the hydrological cycle (Betts et al., 2000; Cox et al., 2000; Pielke, 2001; Friedlingstein et al., 2003; Seneviratne and Stöckli, 2006; Betts et al., 2007; Stöckli et al., 2008; Lei et al., 2011). Previous studies have attempted to estimate land–atmosphere interactions using climate models in accordance with more accurate quantification of heat and water fluxes (Chen et al., 1996; Sellers et al., 1996; Dai et al., 2003; Lim et al., 2012).

Previous studies have considered Land Surface Models (LSMs) coupled with other models to compute hydro-meteorological fluxes with high accuracy (Rihani et al., 2010). In addition, LSMs have greatly progressed in terms of calibration procedures, parameter optimization, and adoption of other LSMs (Dai et al., 2003; Choi et al., 2010). These models contain several schemes, including: dynamic vegetation (Dickinson et al., 1998); a transfer system for water, radiative and turbulent transfer; and a physiological system for stomatal processes. Previous researches on LSMs have incorporated complex lateral heterogeneity in addition to the significant advances in computational complexity (Famiglietti and Wood, 1994) and increased understanding of physio-

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ORIGINAL ARTICLE

Simulations of energy balance components at snow-dominated montane watershed by land surface models

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Abstract The quantification of energy interactions among land surface, atmosphere, and surface vegetation is significant to comprehend the hydrological cycle in montane watersheds. Moreover, elevation change is an essential in causing variations in energy fluxes. Thus, estimating the major components of energy interactions is essential for better understanding of the hydrological process. The advanced land surface models (LSMs); the common land model (CLM) and variables infiltration capacity (VIC) are used to estimate accurate hydrometeorological variables. These hydrometeorological variables such as net radiation and sensible, latent, and ground heat fluxes were estimated using CLM and VIC at upper and lower meteorological stations in Sierra Nevada Mountain, California, USA. The estimated fluxes were compared with observations at each site. The estimated daily and monthly net radiation and sensible heat flux from both models showed good agreement with the observations ($R \geq 0.84$). The CLM-modeled estimates showed lower trends during the rainfall periods, which occurred mainly during winter at both sites. In comparison, the estimated daily and monthly latent heat flux from CLM at both sites showed better results with lower RMSE and bias than that from VIC, which underestimated latent heat flux. Both models overestimated ground heat flux, and the variation trend was similar to observation. For sensitivity analysis, according to elevation change, all the estimated energy fluxes had slightly different values at the upper and lower met stations. In future studies, parameterization for the LSMs will be conducted for more robust estimations of hydrometeorological variables in montane watersheds.

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Keywords CLM · VIC · Energy fluxes · Montane watershed · Sierra Nevada

Introduction

In montane watersheds, changes in vegetation density and distribution not only have direct effects on evapotranspiration (ET) rates, soil moisture storage, groundwater storage, and streamflow, but also on energy exchanges. Among the challenges in understanding and predicting hydrological interactions in montane watersheds, analysis of the spatiotemporal distributions of energy variations is the key component for understanding the regional hydrological cycle. In addition, in areas of complex topography, variations in elevation and aspect create a large spatial heterogeneity in solar radiation distribution, which determines the latent heat, sensible heat, soil and air temperatures, and land-air exchanges (Chen et al. 2013). Surface solar radiation is an important parameter in energy balance models and is used to estimate ET and other energy and water balance components. Energy and mass exchange processes occurring at the land surface–atmosphere interface affect the hydrological cycle and runoff, especially in montane watersheds where snowmelt is dominated by energy exchange processes (Grossi and Falappi 2003).

In addition, Gao et al. (2009) conducted a study over the relatively flat region and found that the net radiation

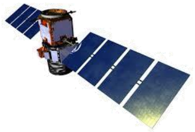
(1) Using CLM4.0 – Runoff and energy components

- Estimating runoff and energy flux partitioning to evaluate the robustness of CLM with satellite-derived land use/land cover (LULC) data

- Comparison between CLM4.0 with default LULC data and MODIS-based, high-resolution LULC data for the year 2010 to assess climate change impacts on energy and water cycles associated with changes in LULC

(2) Using CLM4.0 – Urban Heat Island (UHI)

- Analyzing the contributions of the major biophysical drivers to the magnitude of UHI based on the first derivation of the linearized energy balance and compared to the derived UHI from Moderate Resolution Imaging Spectroradiometer (MODIS) Land Surface Temperature products
- Implementation of biophysical mechanism analysis of important factors related to urbanization, such as the characteristics of cities related to the landscape
- Analyzing the variant in the driving factor and intensity of UHI during El Niño-Southern Oscillation phenomena that occurred in those cities



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