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


• Surface runoff (Niu, Yang et al., 2005)
• Groundwater (Niu, Yang, et al., 2007)
• Frozen soil (Niu and 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 phenology
• 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 hydrological processes and 5 layers 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).

Community Land Model subgrid tiling structure

Resolution
For IPCC AR5 2° and 0.5° working towards 0.1°
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 Community Earth 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.

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

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)
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
2.2. Pre-process Steps in Running CLM

(1) Preparation surface datasets

Required:

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

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

- \( s \): South edge
- \( w \): west edge
- \( n \): North edge
- \( e \): east edge

- \( 13x12pt \): number of pixels
- \( f19 \): dataset resolution
- \( \text{alaskaUSA} \): location or ID
- Location of global surface data
2.2. Pre-process Steps in Running CLM

(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 as 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:

```
&hr_strdata_nml
  dateMode = 'CLMCEP',
  domainfile = 'climpt_lapaz mexico_solar_stream.txt 1 2004 2008 ',
  streams = 'climpt_lapaz mexico_precip_stream.txt 1 2004 2008 ',
  'climpt_lapaz mexico_other_stream.txt 1 2004 2008 ',
  'pressaero_stream.txt 1 2004 2008 '
  vectors = 'null', 'null', 'null', 'null'
  mapmask = 'nomask', 'nomask', 'nomask', 'nomask'
  mapalgo = 'nn', 'nn', 'nn', 'nn'
  tintaalgo = '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 MYCSDATA $HOME/inputdata # Set env var for the directory for input data
> ./link_dirtree $CSDATA $MYCSDATA
# Next create and move all your datasets into $MYCSDATA with id $MYUSRDATA
# See above for naming conventions
# Now create a single-point case
> ./create_newcase -case my_atmforc_test -res pt1_pt1 -comset 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 if you created for your datasets above
> ./xmlchange -file env_run.xml -id DSSM_ROOT_CSMDATA -val $MYCSDATA
> ./xmlchange -file env_conf.xml -id CLM_PT1_NAME -val $MYUSRDATA
> ./xmlchange -file env_conf.xml -id CLM_USRDAT_NAME -val $MYUSRDATA
# set the land-mask to USGS, so both CLM and DATH can find files
> ./xmlchange -file env_conf.xml -id CLM_LSMPM_OPTS -val '-mask USGS'
# Then set DATH_MODE to single-point mode so DATH will use your forcing datasets
# Put your forcing datasets into $MYCSDATA/atm/atm7/CLMPT_data/$MYUSRDATA
> ./xmlchange -file env_conf.xml -id DATH_MODE -val CLMPT
> ./configure -case
# If the list of fields, or filenames, filepathes, or fieldnames are different
# you'll need to edit the DATH namelist streams file to make it consistent
> $EDITOR Buildconf/datm.buildmml
```
2.3. Process Steps in Running CLM

Steps:

1. Create new case
2. Configure case
3. Build the case
4. Run the case
2.3. Process Steps in Running CLM

(1) Create New Case

```bash
> 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/ind 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.
2.3. Process Steps in Running CLM

(2) Configure the 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

```bash
./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
```
2.3. Process Steps in Running CLM

(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
2.3. Process Steps in Running CLM

(4) Run the Case

- 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

```bash
> bsub < cr_f10_TmpltI1850CN.bluefire.run
```
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/m²/s
Net primary production | gC/m²/s
Soil moisture | (m³/m³)
Etc.
3. Our publications
(1) Using CLM4.0 – Water and energy fluxes

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

**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

**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

d. Ground 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.

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)

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


| Models and MOD16 | FR2 |       |      |      |      |     | P301 |       |      |      |      |     |
|                 |     | Slope | RMSE | NMAE | Bias | R   |       | Slope | RMSE | NMAE | Bias | R   |
| 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 | 0.06 |
| VIC vs.MOD16    | 1.24 | 28.51 | 0.39 | -3.59 | 0.75 | 0.13 | 32.89 | 0.90 | -1.77 | 0.06 |

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

Other studies using CLM previous version

Introduction

Land surface processes in the Land Surface Models (LSMs) represent the physical processes that affect the transfer of water and energy into the atmosphere after precipitation and soil moisture evolution. LandGEM et al. (2002, 2007) and (2013) have recently published a comprehensive manual on the physics of land surface processes. The studies have been based on the LandGEM approach to understanding the physical processes of land surface fluxes. The studies have been based on the LandGEM approach to understanding the physical processes of land surface fluxes. land-gem has been developed and used in a wide range of applications, from regional to global models, in order to improve the representation of the land surface processes in climate models.

Simulations of energy balance components at snow-dominated mountain watersheds by land surface models

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Abstract

The goal of this study is to evaluate the performance of the land surface models in simulating the energy balance components at snow-dominated mountain watersheds. The study compares the simulated energy balance components (latent heat flux, soil heat flux, sensible heat flux, shortwave radiation, longwave radiation) with observations from the region of interest. The results indicate that the land surface models overestimate the latent heat flux and soil heat flux, while the sensible heat flux and shortwave radiation are underestimated. The longwave radiation is well simulated by the models. These results suggest that the land surface models need further improvements to better represent the energy balance components at snow-dominated mountain watersheds.

Key words: energy balance, snow-dominated, mountain watersheds, land surface models

Introduction

Snow-dominated mountain watersheds are important regions that contribute significantly to the energy balance of the Earth system. The energy balance components, such as latent heat flux, soil heat flux, sensible heat flux, shortwave radiation, and longwave radiation, are crucial for understanding the climate and hydrological processes in these regions. Accurate representation of these components in land surface models is essential for improving the predictions of the energy balance at snow-dominated mountain watersheds.

1. Introduction

The energy balance components at snow-dominated mountain watersheds are complex and highly variable, depending on the season, topography, and climate conditions. Therefore, it is crucial to improve the representation of these components in land surface models. The land surface models, such as the Community Land Model (CLM) and the Weather Research and Forecasting (WRF) model, are widely used in climate and hydrological simulations. However, these models have limitations in simulating the energy balance components, particularly at snow-dominated mountain watersheds.

1.1. The Community Land Model (CLM)

The Community Land Model (CLM) is a coupled model that simulates the energy balance components at snow-dominated mountain watersheds. The model includes a variety of processes, such as vegetation growth, soil moisture dynamics, snow accumulation and melt, and solar radiation. The model is designed to simulate the energy balance components at different spatial and temporal scales. However, the model has limitations in simulating the energy balance components, particularly at snow-dominated mountain watersheds.

1.2. The WRF Model

The Weather Research and Forecasting (WRF) model is a non-hydrostatic numerical weather prediction model that simulates the energy balance components at snow-dominated mountain watersheds. The model includes a variety of processes, such as atmospheric dynamics, cloud physics, and land surface processes. The model is designed to simulate the energy balance components at different spatial and temporal scales. However, the model has limitations in simulating the energy balance components, particularly at snow-dominated mountain watersheds.

2. Simulation of energy balance components

The simulation of energy balance components at snow-dominated mountain watersheds is a critical aspect of climate and hydrological simulations. Accurate representation of these components is essential for improving the predictions of the energy balance at snow-dominated mountain watersheds. The simulations were conducted using the CLM and WRF models, and the results were compared with observations from the region of interest. The results indicate that the CLM model overestimates the latent heat flux and soil heat flux, while the sensible heat flux and shortwave radiation are underestimated. The longwave radiation is well simulated by the models. These results suggest that the land surface models need further improvements to better represent the energy balance components at snow-dominated mountain watersheds.
(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
Thank You
For Your Attention