Overview of the Community Land Model (and the Community Earth System Model)

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NCAR Earth System Laboratory

with input from members of LMWG and BGCWG
Terrestrial Processes within the Earth System
Observed terrestrial change

Arctic greening (Bunn et al. 2007)

Permafrost degradation (Akerman, 2008)

NH snow cover anomaly (Rutger’s Global Snow Lab)

Deforestation
How much does a precipitation-induced soil moisture anomaly influence the overlying atmosphere and thereby the evolution of weather and the generation of precipitation?
Fate of anthropogenic CO$_2$ emissions (2002-2011 average)

8.3±0.4 PgC/yr 90%

4.3±0.1 PgC/yr 46%

2.6±0.8 PgC/yr 28%

2.5±0.5 PgC/yr 26%

Calculated as the residual of all other flux components

Source: Le Quéré et al. 2012; Global Carbon Project 2012
Earth System Models

Community Earth System Model (CESM)
Earth System Models are utilized to support a vast and expanding array of scientific research into the climate system:

- Climate change feedbacks and attribution
- Climate variability
- Roles of clouds, aerosols, sea ice, ocean, ozone, etc. on climate
- Climate change impacts on humans and ecosystems
History of Climate Model to Earth System Model Development
http://www.aip.org/history/climate/GCM.htm

- **Mid-1960s**
  - Atmosphere/Land Surface
  - Ocean
  - Sea Ice
  - Coupled Climate Model

- **Mid 1970s-1980s**
  - Atmosphere/Land Surface
  - Ocean
  - Sea Ice
  - Coupled Climate Model

- **1990s**
  - Atmosphere/Land Surface
  - Ocean
  - Sea Ice
  - Coupled Climate Model

- **2000s**
  - Atmosphere/Land Surface
  - Ocean
  - Sea Ice
  - Coupled Climate Model

- **2010s**
  - Atmosphere/Land Surface
  - Ocean
  - Sea Ice
  - Coupled Climate Model

- **Additional Components**
  - Sulfate Aerosol
  - Carbon Cycle
  - Dust/Sea Spray/Carbon Aerosols
  - Interactive Vegetation
  - Biogeochemical Cycles
  - Ice Sheet
Community Earth System Model
Coupled modeling framework

Atmosphere
CAM4, CAM5, WACCM, Fast Chem, Full Chem

Coupler
CPL 7

Ocean
POP 2, Ecosys

Sea Ice
CICE 4

Land ice
CISM

Land
CLM4, CLM4.5
SP, CN, CNDV

Coupled modeling framework
Community Earth System Model (CESM1)

- 0.25°, 0.5°, 1°, 2° resolutions
- 30 minute time step
- 26 atmosphere levels
- 60 ocean levels
- 15 ground layers
- ~5 million grid boxes at 1° resolution
- ~1.5 million lines of computer code
- Data archived (monthly, daily, hourly) for hundreds of geophysical fields (over 400 in land model alone)
- Utilized by hundreds of scientists all around the world
<table>
<thead>
<tr>
<th>Model Name</th>
<th>Normalized ‘distance’ from obs in T and P</th>
</tr>
</thead>
<tbody>
<tr>
<td>CESM1(CAM5)</td>
<td></td>
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<tr>
<td>GFDL-CM2.5</td>
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<tr>
<td>CESM1-BGC</td>
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<td>CCSM4</td>
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<td>CESM1(FASTCHEM)</td>
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<td>EC-EARTH</td>
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<td>MPI-ESM-LR</td>
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<td>HadGEM2-ES</td>
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<td>HadGEM2-CC</td>
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<td>CESM1(WACCM)</td>
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<td>ACCESS1.0</td>
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<td>GFDL-CM3</td>
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<td>MIROC5</td>
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<td>MIROC4h</td>
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<td>NorESM1-M</td>
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<td>NorESM1-ME</td>
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<tr>
<td>ACCESS1.3</td>
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<td>CanESM2</td>
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<td>FGOALS-s2</td>
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<td>IPSL-CM5A-MR</td>
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<td>FGOALS-q2</td>
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<td>GFDL-ESM2G</td>
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<td>FIO-ESM</td>
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<td>MRI-CGCM3</td>
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<td>BCC-CSM1.1</td>
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<td>CSIRO-Mk3.6.0</td>
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<td>GISS-E2-H</td>
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<td>MIROC-ESM</td>
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<td>MIROC-ESM-CHEM</td>
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<td>IPSL-CM5B-LR</td>
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<tr>
<td>INM-CM4</td>
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</tbody>
</table>
Carbon cycle in CESM

- Observed $\text{CO}_2^{\text{atm}}$
- Modeled $\text{CO}_2^{\text{atm}}$

Model overshoots $\text{CO}_2$ increase

$\text{CO}_2$ flux [Pg C yr$^{-1}$]

Year

1920 1950 1980 2010 2040 2070 2100

- Fossil fuel emissions
- Land use change
- Ocean
- Land
Community Land Model

www.cesm.ucar.edu/models/Ind
The land is a critical interface through which climate, and climate change impacts humans and ecosystems and through which humans and ecosystems can effect global environmental and climate change.

**Goals of CESM Land Model and Biogeochemistry Working Groups:**

Improve and expand our capability to simulate ecological, hydrological, biogeochemical, and socioeconomic forcings and feedbacks in the earth system.
Submodels of CLM

- Biogeophysics
  - Photosynthesis and stomatal resistance
  - Hydrology
  - Snow
  - Soil thermodynamics
  - Surface albedo and radiative fluxes

- Biogeochemistry
  - Carbon / nitrogen pools, allocation, respiration
  - Vegetation phenology
  - Decomposition
  - Plant Morality
  - External nitrogen cycle
  - Methane production

- Urban model
- Crop and irrigation model
- Lake model
- Glacier model
- Fire model
- Dust emissions model
- River model
- Biogenic Volatile Organic Compounds model
Community Land Model (CLM4.5)

Surface energy fluxes
- Absorbed solar
- Diffuse solar
- Downwelling longwave heat flux
- Emitted longwave heat flux
- Reflected solar
- Sensible heat flux
- Latent heat flux
- Momentum flux
- Direct solar
- Wind speed
- Evaporation
- Transpiration
- Surface runoff
- Ground heat flux
- Throughfall
- Infiltration
- Surface water
- Subsurface runoff
- Bedrock

Hydrology
- Precipitation
- Groundwater
- Water table
- Aquifer recharge
- Soil
- Saturated fraction
- Subsurface runoff
- Litterfall
- Root litter
- N mineralization
- N uptake
- N fixation
- CH₄
- BVOCs

Biogeochemical cycles
- Photosynthesis
- Heterotrophic respiration
- Autotrophic respiration
- Fire
- N uptake
- N leaching
- Denitrification
- N₂O

Aerosol deposition
- Soil (sand, clay, organic)
- Subsurface runoff
- Aquifer recharge
- Unconfined aquifer
- Bedrock

Vegetation C/N

SCF

Surface water

Ground heat flux
Surface energy balance

\[ S_{\downarrow} - S_{\uparrow} + L_{\downarrow} - L_{\uparrow} = \lambda E + H + G \]

- \( S_{\downarrow}, S_{\uparrow} \) are down(up)welling solar radiation,
- \( L_{\uparrow}, L_{\downarrow} \) are up(down)welling longwave rad,
- \( \lambda \) is latent heat of vaporization,
- \( E \) is evaporation,
- \( H \) is sensible heat flux,
- \( G \) is ground heat flux
Surface water balance

\[ P = E_S + E_T + E_C + R + \left( \frac{\Delta W_{soi} + \Delta W_{snw} + \Delta W_{can}}{\Delta t} \right) \]

- \( P \) is rainfall/snowfall,
- \( E_S \) is soil evaporation,
- \( E_T \) is transpiration,
- \( E_C \) is canopy evaporation,
- \( R \) is runoff (surf + sub-surface),
- \( \Delta W_{soi} / \Delta t, \Delta W_{snw} / \Delta t, \Delta W_{can} / \Delta t \) are the changes in soil moisture, snow, and canopy water, water over a timestep.
The ability of a land-surface scheme to model evaporation correctly depends crucially on its ability to model runoff correctly. The two fluxes are intricately related.

(Koster and Milly, 1997).

Runoff and evaporation vary non-linearly with soil moisture.
Carbon exchange

**NEE = GPP – HR – AR – Fire – LUC**

- **NEE** is net ecosystem exchange
- **GPP** is gross primary productivity
- **HR** is heterotrophic respiration
- **AR** is autotrophic respiration
- **Fire** is carbon flux due to fire
- **LUC** is C flux due to land use change
Carbon exchange

\[ \text{NEE} = \text{GPP} - \text{HR} - \text{AR} - \text{Fire} - \text{LUC} \]
Features of the Community Land Model

• Submodels and parameterizations
• Structural aspects (surface and input datasets)
  – Heterogeneity of landscape (vegetated, urban, lake, glacier, crop)
  – Plant Functional Types and associated parameters (optical, morphological, photosynthetic)
  – Soil texture (sand, silt, clay, organic matter) and color (albedo)
  – River directional map and mean slope
  – Urban characteristics
  – CO₂
  – Land cover/use change (changes in PFTs over time, wood harvest)
  – Aerosol and nitrogen deposition datasets
  – Population density and Gross Domestic Productivity
Landscape-scale dynamics
Long-term dynamical processes that affect fluxes in a changing environment
(disturbance, land use, succession)
Community Land Model subgrid tiling structure

Gridcell

Landunit
- Vegetated
- Lake
- Urban
- Glacier
- Crop

Column
- Soil
- Roof
- Sun Wall
- Shade Wall
- Impervious

PFT
- PFT1
- PFT2
- PFT3
- PFT4...

Unirrig
- Crop1
- Crop1
- Crop2
- Crop2...

Irrig
- Crop1
- Crop1
- Crop2
- Crop2...

V PFT1
- V PFT2
- V PFT3
- V PFT4

G
- L
- UT, H, M
- TBD
- MD
- HD

PFT1
- PFT2
- PFT3
- PFT4...

Crop1
- Crop1
- Crop2
- Crop2...

Unirrig
- Irrig
- Unirrig
- Irrig
Community Land Model subgrid tiling structure

Plant Functional Types:
0. Bare

Tree:
1. Needleleaf Evergreen, Temperate
2. Needleleaf Evergreen, Boreal
3. Needleleaf Deciduous, Boreal
4. Broadleaf Evergreen, Tropical
5. Broadleaf Evergreen, Temperate
6. Broadleaf Deciduous, Tropical
7. Broadleaf Deciduous, Temperate
8. Broadleaf Deciduous, Boreal

Herbaceous / Understorey:
9. Broadleaf Evergreen Shrub, Temperate
10. Broadleaf Deciduous Shrub, Temperate
11. Broadleaf Deciduous Shrub, Boreal
12. C3 Arctic Grass
13. C3 non-Arctic Grass
14. C4 Grass
15. Crop
CLM Development

http://www2.cesm.ucar.edu/working-groups/lmwg/developer-guidelines
Scientific goals driving CLM development and use

- Improve understanding of carbon and nitrogen cycle interactions and their impact on long term trajectory of terrestrial carbon sink
- Assess response and vulnerability of ecosystems to climate change and disturbances (human and natural)
- Evaluate utility of ecosystem management as mechanism to mitigate climate change
- Ascertain vulnerability of water resources under climate change; establish role of land in drought and flood
- Quantify land feedbacks to climate change: e.g. permafrost-carbon, snow- and vegetation-albedo, soil moisture-ET feedbacks
Scientific goals driving CLM development and use

- Assess urban-rural differences in climate change impacts
- Prognose anthropogenic and natural land cover/land use change and LULCC impact on climate and trace gas emissions
- Investigate role of surface heterogeneity in land-atmosphere interaction and carbon cycling, including scale issues
- Model – data fusion; Exploitation of experimental ecosystem data
- Uncertainty Quantification, parameter optimization
Model Development Process

- **Model release (CESM1/CLM4)**
  - Detailed model assessment (identify strengths and weaknesses)

- Use model for scientific studies
  - LMWG members develop parameterizations or add features
  - Present ideas/results at LMWG meetings
  - Publish papers
  - Evaluate competing parameterizations

- Build and test beta version of offline model
  - Finalize and test within CESM

- Plans for next (and next next) model version discussed at LMWG meetings
  - Document; Control integrations
CLM as a community modeling tool

AGU presentations with CLM in abstract or title

% of AGU presentations that included CLM

CLM3.5 [Oleson et al., 2008] (236 citations)
CLM4.0 [Lawrence et al., 2011] (164 citations)
Reduced biases in CLM4.5

ANN Latent Heat bias (obs: FLUXNET MTE)

<table>
<thead>
<tr>
<th></th>
<th>CLM4</th>
<th>CLM4.5</th>
</tr>
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<tbody>
<tr>
<td>LH (W m⁻²)</td>
<td>8.9</td>
<td>5.9</td>
</tr>
<tr>
<td>GPP (gC m⁻² d⁻¹)</td>
<td>0.41</td>
<td>0.07</td>
</tr>
<tr>
<td>Albedo (%)</td>
<td>-0.41</td>
<td>-0.52</td>
</tr>
</tbody>
</table>
Carbon stock trajectory

Change in global terrestrial C (Pg)

Year


CLM4.0
CLM4.5 + old BGC
CLM4.5 + new BGC
Obs

Koven et al. 2013
Evaluating and Improving the model with Tower Flux data
Abracos tower site (Amazon)

Latent Heat Flux

\[ r^2 = 0.91 \\ \text{slope} = 0.67 \\ \text{rmse} = 87.73 \\ \text{bias} = -28.89 \]

Model

OBS

Latent Heat Flux

\[ r^2 = 0.93 \\ \text{slope} = 1.05 \\ \text{rmse} = 48.80 \\ \text{bias} = 13.00 \]

Model

OBS

Total soil water

CLM3.5/4

CLM3
Tower flux statistics (15 sites incl. tropical, boreal, mediterranean, alpine, temperate; hourly)

<table>
<thead>
<tr>
<th></th>
<th>Latent Heat Flux</th>
<th>Sensible Heat Flux</th>
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<tbody>
<tr>
<td></td>
<td>$r$</td>
<td>RMSE (W/m²)</td>
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<tr>
<td>CLM3</td>
<td>0.54</td>
<td>72</td>
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<tr>
<td>CLM3.5</td>
<td>0.80</td>
<td>50</td>
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<tr>
<td>CLM4SP</td>
<td>0.80</td>
<td>48</td>
</tr>
<tr>
<td>Class</td>
<td>Variable</td>
<td>Obs dataset</td>
</tr>
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<td></td>
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<tr>
<td>Global or regional</td>
<td>LH</td>
<td>FLUXNET-MTE</td>
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<tr>
<td></td>
<td>SCF</td>
<td>AVHRR</td>
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<tr>
<td></td>
<td>Albedo</td>
<td>MODIS</td>
</tr>
<tr>
<td></td>
<td>Biomass</td>
<td>NBCD (US), Tropical Biomass</td>
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<tr>
<td></td>
<td>Burnt Area</td>
<td>GFED3</td>
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<td></td>
<td>P</td>
<td>CMAP</td>
</tr>
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<td></td>
<td>T&lt;sub&gt;air&lt;/sub&gt;</td>
<td>CRU</td>
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<tr>
<td>Site level</td>
<td>NEE</td>
<td>FLUXNET</td>
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<tr>
<td></td>
<td>GPP</td>
<td>FLUXNET</td>
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<tr>
<td></td>
<td>SH</td>
<td>FLUXNET</td>
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<td></td>
<td>R / P</td>
<td>riv disc, CMAP</td>
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<tr>
<td>Total</td>
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</table>
Potential development targets for CLM5+

**Landscape dynamics**
- Dynamic landunits
- iESM infrastructure

**Hydrology**
- MOSART routing model
- Progress on lateral flow processes
- Human management and withdrawals

**Agriculture**
- Extend crops to global
- Additional crop management processes

**Evapotranspiration, partitioning of ET**
- Address unrealistic hydrologic response to land cover change
- Soil evap, canopy turbulence, canopy evapor
- Water isotopes

**Nutrient dynamics**
- Plant nitrogen uptake and allocation
- N-gas emissions
- Leaching and riverine transport
- Phosphorous dynamics

**Ecosystem disturbance**
- Ecosystem Demography model
- Trace gas emissions from fire

**Canopy processes**
- Multi-layer, turbulence, optimization
Where to find information about CLM and CESM
CESM1.2: CLM DOCUMENTATION

INTRODUCTION

The Community Land Model versions 4.0 and 4.5 in CESM1.2 are the latest in a series of land models developed through the CESM project. More information on the CLM project and access to previous CLM model versions and documentation can be found via the CLM Web Page.

www.cesm.ucar.edu/models/cesm1.2/clm

DOCUMENTATION

- User’s Guide for CLM4.5 and CLM4.0 in CESM1.2.0 [html] [pdf] (Last update: [an error occurred while processing this directive])
- Technical Description for CLM4.5 (Last update: Aug 1/2013)
- Technical Description for CLM4.0, CLM4.0 Urban Model, CLM4.0 Crop and Irrigation Model
- Explanation of supported configurations in CLM4.5 and CLM4 in CESM1.2
- What’s new in CLM in CESM1.2 (CLM4.5 release) Science, CESM1.2 (CLM4.5 release) Software, CESM1.1.1, CESM1.1.0, CESM1.0.5, CESM1.0.4, CESM1.0.3, CESM1.0.2, CESM1.0.1, CESM1.0, CCSM4.0 (CLM4.0 release).
- Known bugs in CLM in CESM1.2.0, CESM1.1.0, CESM1.0.4, CESM1.0.3, CESM1.0.2, CESM1.0.1, CESM1.0.
- Known limitations in CLM in CESM1.2.0, CESM1.1.0.

MODEL OUTPUT AND OFFLINE FORCING DATA AND DIAGNOSTIC PLOTS

- CLM4.0 and CLM4.5 offline control simulations: Diagnostic plots
- CLM4.0 and CLM4.5 offline control simulations (links need to be updated and data posted to ESG): Model output data
- CLM4.0 and CLM4.5 offline control simulations (links need to be updated and data posted to ESG): Model forcing data
- CLM4.0 and CLM4.5 offline historical and RCP simulations: CCSM4 coupler history forcing data
CLM configurations in CESM1.2

- CLM4.5SP  Prescribed Satellite Phenology
- CLM4.5BGC Prognostic vegetation state / biogeochemistry
- CLM4.5BGCDV Prognostic BGC with dynamic vegetation

Options: Prescribed land use change
Crops and irrigation,
VIC hydrology
CLM4.5 Technical Description

~420 pages
27 chapters

Papers – Over 300 papers in CLM Bibliography
Thanks and welcome to the CESM/CLM research community!

Considering a “Cornice Parameterization” for CLM

CLMers Hard at work
Potential metrics for inclusion in a comprehensive land benchmarking system

- Large-scale state and flux estimates
  - LH, SH, total water storage, albedo, river discharge, SCF, LAI, soil and veg C stocks, GPP, NEE, ER, burnt area, permafrost distribution, $T_{2m}$, $P$, ...
  - RMSE, annual cycle phase, spatial pattern corr, interannual variability

- Functional relationships and emergent properties
  - soil moisture – ET, soil moisture – runoff, stomatal response to VPD, transient carbon storage trajectory, runoff ratio, land cover change

- Experimental manipulation (testing model functional responses)
  - N additions, FACE, artificial warming, rainfall exclusion
The role of CLM in CESM: Land to Atmosphere

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Expression</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latent heat flux</td>
<td>$\lambda_{\text{vap}} E_v + \lambda E_g$</td>
<td>W m$^{-2}$</td>
</tr>
<tr>
<td>Sensible heat flux</td>
<td>$H_v + H_g$</td>
<td>W m$^{-2}$</td>
</tr>
<tr>
<td>Water vapor flux</td>
<td>$E_v + E_g$</td>
<td>mm s$^{-1}$</td>
</tr>
<tr>
<td>Zonal momentum flux</td>
<td>$\tau_x$</td>
<td>kg m$^{-1}$ s$^{-2}$</td>
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<tr>
<td>Meridional momentum flux</td>
<td>$\tau_y$</td>
<td>kg m$^{-1}$ s$^{-2}$</td>
</tr>
<tr>
<td>Emitted longwave radiation</td>
<td>$L \uparrow$</td>
<td>W m$^{-2}$</td>
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<tr>
<td>Direct beam visible albedo</td>
<td>$I \uparrow_{\text{vis}}^{\mu}$</td>
<td>-</td>
</tr>
<tr>
<td>Direct beam near-infrared albedo</td>
<td>$I \uparrow_{\text{nir}}^{\mu}$</td>
<td>-</td>
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<tr>
<td>Diffuse visible albedo</td>
<td>$I \uparrow_{\text{vis}}$</td>
<td>-</td>
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<tr>
<td>Diffuse near-infrared albedo</td>
<td>$I \uparrow_{\text{nir}}$</td>
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<tr>
<td>Absorbed solar radiation</td>
<td>$\bar{S}$</td>
<td>W m$^{-2}$</td>
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<tr>
<td>Radiative temperature</td>
<td>$T_{\text{rad}}$</td>
<td>K</td>
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<tr>
<td>Temperature at 2 meter height</td>
<td>$T_{2m}$</td>
<td>K</td>
</tr>
<tr>
<td>Specific humidity at 2 meter height</td>
<td>$q_{2m}$</td>
<td>kg kg$^{-1}$</td>
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<tr>
<td>Snow water equivalent</td>
<td>$W_{\text{sno}}$</td>
<td>m</td>
</tr>
<tr>
<td>Aerodynamic resistance</td>
<td>$r_{am}$</td>
<td>s m$^{-1}$</td>
</tr>
<tr>
<td>Friction velocity</td>
<td>$u_*$</td>
<td>m s$^{-1}$</td>
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<tr>
<td>Dust flux</td>
<td>$F_j$</td>
<td>kg m$^{-2}$ s$^{-1}$</td>
</tr>
<tr>
<td>Net ecosystem exchange</td>
<td>NEE</td>
<td>kgCO$_2$ m$^{-2}$ s$^{-1}$</td>
</tr>
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The role of CLM in CESM: Atmosphere to Land

<table>
<thead>
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<th>Parameter</th>
<th>Symbol</th>
<th>Unit</th>
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<tr>
<td>Reference height</td>
<td>$z'_{atm}$</td>
<td>m</td>
</tr>
<tr>
<td>Zonal wind at $z_{atm}$</td>
<td>$u_{atm}$</td>
<td>m s$^{-1}$</td>
</tr>
<tr>
<td>Meridional wind at $z_{atm}$</td>
<td>$v_{atm}$</td>
<td>m s$^{-1}$</td>
</tr>
<tr>
<td>Potential temperature</td>
<td>$\bar{\theta}_{atm}$</td>
<td>K</td>
</tr>
<tr>
<td>Specific humidity at $z_{atm}$</td>
<td>$q_{atm}$</td>
<td>kg kg$^{-1}$</td>
</tr>
<tr>
<td>Pressure at $z_{atm}$</td>
<td>$P_{atm}$</td>
<td>Pa</td>
</tr>
<tr>
<td>Temperature at $z_{atm}$</td>
<td>$T_{atm}$</td>
<td>K</td>
</tr>
<tr>
<td>Incident longwave radiation</td>
<td>$L_{atm} \downarrow$</td>
<td>W m$^{-2}$</td>
</tr>
<tr>
<td>Liquid precipitation</td>
<td>$q_{rain}$</td>
<td>mm s$^{-1}$</td>
</tr>
<tr>
<td>Solid precipitation</td>
<td>$q_{sno}$</td>
<td>mm s$^{-1}$</td>
</tr>
<tr>
<td>Incident direct beam visible solar radiation</td>
<td>$S_{atm} \downarrow_{vis}^\mu$</td>
<td>W m$^{-2}$</td>
</tr>
<tr>
<td>Incident direct beam near-infrared solar radiation</td>
<td>$S_{atm} \downarrow_{nir}^\mu$</td>
<td>W m$^{-2}$</td>
</tr>
<tr>
<td>Incident diffuse visible solar radiation</td>
<td>$S_{atm} \downarrow_{vis}$</td>
<td>W m$^{-2}$</td>
</tr>
<tr>
<td>Incident diffuse near-infrared solar radiation</td>
<td>$S_{atm} \downarrow_{nir}$</td>
<td>W m$^{-2}$</td>
</tr>
<tr>
<td>Carbon dioxide (CO$_2$) concentration</td>
<td>$c_a$</td>
<td>ppmv</td>
</tr>
<tr>
<td>Aerosol deposition rate</td>
<td>$D_{sp}$</td>
<td>kg m$^{-2}$ s$^{-1}$</td>
</tr>
<tr>
<td>Nitrogen deposition rate</td>
<td>$N_{ndep _sminn} F$</td>
<td>g (N) m$^{-2}$ yr$^{-1}$</td>
</tr>
</tbody>
</table>
Plant Function Type distribution in CLM4 based on MODIS/Crop datasets

(a) Current Day (2000) Tree PFTs

(e) Current Day (2000) Grass PFTs

(c) Current Day (2000) Shrub PFTs

(g) Current Day (2000) Crop PFT

Lawrence and Chase, 2007
Plant Functional Type Parameters

- **Optical properties (visible and near-infrared):**
  - Leaf angle
  - Leaf reflectance
  - Stem reflectance
  - Leaf transmittance
  - Stem transmittance

- **Morphological properties:**
  - Leaf area index (annual cycle)
  - Stem area index (annual cycle)
  - Leaf dimension
  - Roughness length/displacement height
  - Canopy height
  - Root distribution

- **Land-surface models are parameter heavy!!!**

- **Photosynthetic parameters:**
  - Specific leaf area ($\text{m}^2 \text{ leaf area g}^{-1} \text{ C}$)
  - $m$ (slope of conductance-photosynthesis relationship)
Land cover / land use change (prescribed)

Wood harvest

Land Use Change

BET

C4 Grass

Crop

BET

Crop

C4 Grass
Deforestation across Eastern North America, Eastern Europe, India, China, Indonesia, SE South America for Crops

Lawrence, P et al. J. Climate, 2012
River Discharge

Annual discharge into Global ocean

River flow at outlet Top 50 rivers (km$^3$ yr$^{-1}$)

Accumulated discharge from 90°N (10$^6$ m$^3$ s$^{-1}$)

- Obs
- CLM4CN
- CLM4SP
- CLM3.5

CLM3: r = 0.86
CLM3.5: r = 0.87
CLM4SP: r = 0.94
CLM4CN: r = 0.77
Soil (and snow) water storage (MAM – SON)

GRACE satellite measures small changes in gravity which on seasonal timescales are due to variations in water storage.

CCSM3 and CCSM4 data from 1870 and 1850 control.
Global Partitioning of Evapotranspiration

- CLM3
- CLM4SP
- CLM4CN
- GSWP

% of Transpiration, Ground Evap, Canopy Evap
River Transport Model (RTM)

20-yr average river flow (m\(^3\) s\(^{-1}\))
Total Land Water Storage (CCSM vs GRACE)

Mean Seasonal Cycle

Mean Annual TWS

Amazon

Mississippi

Ob

S [mm]

S [mm]

S [mm]

S [mm]

Jan Apr July Oct

Jan Apr July Oct

1850 1900 1950 2000

1850 1900 1950 2000

1850 1900 1950 2000

GRACE

CCSM4

CCSM3
The roles of the land model in an Earth System Model

- exchanges of energy, water, momentum, carbon, nitrogen, dust, and other trace gases/materials between land surface and the overlying atmosphere (and routing of runoff to the ocean)

- states of land surface (e.g., soil moisture, soil temperature, canopy temperature, snow water equivalent, C and N stocks in veg and soil)

- characteristics of land surface (e.g., soil texture, surface roughness, albedo, emissivity, vegetation type, cover extent, leaf area index, and seasonality)