CLM Update

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with input from members of LMWG and BGCWG
First CLM Tutorial, Feb. 18-21
www2.cesm.ucar.edu/events/tutorials/clm/2014

40 students, 15 lectures (incl. 5 by TSS postdocs), 5 practical sessions
all materials available online
**CMIP6 planning**

**Terrestrial processes in CMIP6**

- LUMIP, C4MIP, ScenarioMIP likely to contain aspects that address land role in and response to climate change
- Pushing for land-only simulations; with/without land use change
- Are there critical land-focused science questions that were not dealt with in CMIP5 and could fall through cracks again?
CAM5-CLM4.5BGC coupling

First stage of goal to complete a CESM1.2 carbon cycle simulation

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

CESM1 overshoots CO$_2$ increase by ~20ppm

CESM1.2?
Fire problem has been resolved and fix is coming in a near-term tag, followed by a CESM tag with a CAM5-CLM4.5BGC compset.

* New fire model depends on SM in root zone and atm RH to determine fire spread
* Fire suppression dependent on pop density/GDP, low in Amazon
* Low rainfall and low humidity are amplifying the problem
Dynamic Landunits: Glacier and crop transitions working!

Fast deglaciation experiment: 100% to 0% in 5 years

<table>
<thead>
<tr>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glacier Area</td>
<td><img src="image" alt="Year 1 Glacier Area" /></td>
<td><img src="image" alt="Year 2 Glacier Area" /></td>
<td><img src="image" alt="Year 3 Glacier Area" /></td>
<td><img src="image" alt="Year 4 Glacier Area" /></td>
</tr>
<tr>
<td>Natural Veg. Area</td>
<td><img src="image" alt="Year 1 Natural Veg. Area" /></td>
<td><img src="image" alt="Year 2 Natural Veg. Area" /></td>
<td><img src="image" alt="Year 3 Natural Veg. Area" /></td>
<td><img src="image" alt="Year 4 Natural Veg. Area" /></td>
</tr>
</tbody>
</table>

% of grid cell

No-snow Albedo

Albedo (fraction)
CESM Planning
CESM2 Targets

For “scientifically supported” versions -

• Configurations:
  – Physical Climate w/CAM5.5
  – Physical Climate w/CAM6,
  – Physical Climate w/WACCM,
  – Carbon Cycle/BGC with enhanced atm chem coupling,
  – Coupled Ice Sheet integrations (level of coupling TBD – particularly for ocean)

• Plan to use CAM5.5 atmosphere for WACCM, Carbon Cycle, CISM Model Versions
CLM Development Plans
Software development guidelines

- Software developer’s guide: read this for general information on the steps in the development process including information on coding standards, maintaining and testing, and working with the CLM Code Management Team
  - Coding practices
  - Using SVN to work with development branches
  - CLM testing
  - Upcoming CLM branch and trunk tags
  - Recent CLM code refactoring
CLM/RTM Trello page
Development targets for CLM5+

Ecosystem disturbance
- Ecosystem Demography model; add soil BGC, land use change, +++
- Fire model updates including trace gas and aerosol emissions

Landscape dynamics
- Dynamic landunits
- iESM infrastructure

Evapotranspiration, partitioning of ET
- Soil evap, canopy turb, canopy evap
- Rooting depth
- Water isotopes

Hydrology
- MOSART routing model
- Revised solution to Richard’s eqn, variably saturated flow
- Progress on lateral flow processes

Nutrient dynamics
- Plant N uptake / competition
- N-gas emissions
- Leaching and riverine transport
- Phosphorous dynamics

Carbon allocation
- Replace dynamic allocation with fixed allocation params based on field observations

Agriculture
- Extend crops to global
- Additional crop management processes as options

Urban
- New building energy model
- New urban surface dataset

Canopy processes
- Canopy snow radiation, unloading
CLM Development Timelines: The path towards CLM5/CESM2

1/2014

- Hydro: New soil evap, BTRAN can turb parameterization test/eval
- Interann LAI SP
- CLM(ED) v0 to trunk
- Urban update
- CLM(ED) v1/2 w/ harvest, soil bgc, N?
- Dynamic landunits
- MOSART decision/implementation
- Anom forcing, CO₂ datm
- Restart regrid online
- CAM5-CLM4.5BGC eval/tuning

1/2015

- Canopy snow invert abs
- CLM(ED) v1/2 w/ harvest, soil bgc, N?
- 18O, reactive trans
- N-comp refact
- N-comp test/eval
- MOSART decision/implementation
- Flood/wetland full implement
- DGVM(or ED)/crop DynLand test
- Stress-decid phenology
- Urban update
- Global crops, manure, fert
- N-comp refact
- N-comp test/eval
- CAM5-CLM4.5BGC eval/tuning

6/2015

- CLM5 BGC eval/tune (fire, CH₄, flood, dust)
- Fully coupled BGC eval/tune of CLM5 and/or CAM5.5
- CAM5-CLM4.5BGC eval/tuning
- Fully coupled BGC eval/tune of CLM5 and/or CAM5.5

1/2016

- CLM5 control sims (BGC-crop, SP, ED?)
CLM Development Timelines: The path towards CLM5/CESM2

- Ecosystem Demography (CLM-ED) development
- CAM5-CLM4.5BGC eval/tuning
- Fully coupled CESM1.2 BGC simulations
- CLM5 in CESM2 (CAM5.5, CAM6)

Biogeochern

- C, N refactor and updates (fire, CH₄, flood, dust)
- Soil hydrology refactor and updates (reactive transport modeling, water isotopes)
- Canopy snow updates
- Urban updates

Biogeohys

- MOSART river model
- Dynamic landunits
- Interannual LAI SP; Anomaly forcing
- Land model benchmark system
- Flood/wetland full implement
- CLM5 BGC eval/tune of CLM5 and/or CAM5.5

RTM

- Fully coupled BGC eval/tune (fire, CH₄, flood, dust)
- CLM5 control sims (BGC-crop, SP, ED?)
- Extension of crops to global, fertilization
- Soil hydrology refactor and updates

Coupled model / capabilities

- CAM5-CLM4.5BGC eval/tuning
- Fully coupled CESM1.2 BGC simulations

Timeline:
- 1/2014
- 6/2014
- 1/2015
- 6/2015
- 1/2016
- 6/2016
Offline vs Coupled Model Tuning of CLM

- CLM5 will include several features that are non-linearly dependent on the climate simulation (especially precip)
  - Fire, CH₄ emissions, river flooding, dust emissions

<table>
<thead>
<tr>
<th></th>
<th>CLM4.5</th>
<th>CAM5-CLM4.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire area:</td>
<td>~370 Mha/yr</td>
<td>~700 Mha yr⁻¹</td>
</tr>
<tr>
<td>River discharge</td>
<td>~28,000 km³/yr</td>
<td>~44,000 km³/yr</td>
</tr>
</tbody>
</table>

- In past, we have tuned CLM offline only and used these parameters in all coupled simulations
- For CESM2, the LWMG tentatively propose that there could/should be a separate set of parameters for offline and coupled simulations
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
Forcing uncertainty: Precipitation and annual discharge to the global oceans

New DATM capability to do anomaly forcing
- Can run with multiple P datasets
- Can force model with monthly anomalies/scale factors for quick climate change studies
Timeline

- CESM2 Development
  - Coupled CAM5+ Runs
  - CAM5+ Finalized
  - Possible CAM5 + Release
  - CESM2 Components Finalized
  - CESM2 Finalized
  - CESM2 Release
  - Control Runs
  - CESM2 Release
  - CESM2 Release
  - Additional Runs
  - Data Processing/Publishing

- CESM1.2 BGC, CH₄
  - Jan 2015
  - CESM1.2 BGC, CH₄

- CESM2 Development
  - Jan 2016
  - CESM2 Finalized
  - CESM2 Finalized
  - CESM2 Finalized
  - CESM2 Finalized

- Jan 2017
  - CESM2 Finalized
  - CESM2 Finalized
  - CESM2 Finalized
  - CESM2 Finalized

- June 2014
  - Jan 2015
  - June 2015
  - Jan 2016
  - June 2016
  - Jan 2017
Land Model Benchmarking / Metrics
<table>
<thead>
<tr>
<th>Class</th>
<th>Variable</th>
<th>Obs dataset</th>
<th>W (1-5)</th>
<th>CCSM4</th>
<th>CLM4 CN</th>
<th>CLM4.5 BGC</th>
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</thead>
<tbody>
<tr>
<td>Global or regional</td>
<td>LH</td>
<td>FLUXNET-MTE</td>
<td>4</td>
<td>0.68</td>
<td>0.63</td>
<td>0.71</td>
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<tr>
<td></td>
<td>SCF</td>
<td>AVHRR</td>
<td>3</td>
<td>0.68</td>
<td>0.75</td>
<td>0.74</td>
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<tr>
<td></td>
<td>Albedo</td>
<td>MODIS</td>
<td>4</td>
<td>0.62</td>
<td>0.65</td>
<td>0.66</td>
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<tr>
<td></td>
<td>Biomass</td>
<td>NBCD (US), Tropical Biomass</td>
<td>3</td>
<td>0.65</td>
<td>0.59</td>
<td>0.63</td>
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<tr>
<td></td>
<td>Burnt Area</td>
<td>GFED3</td>
<td>3</td>
<td>0.39</td>
<td>0.38</td>
<td>0.43</td>
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<tr>
<td></td>
<td>P</td>
<td>CMAP</td>
<td>2</td>
<td>0.48</td>
<td>0.93</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>T_{air}</td>
<td>CRU</td>
<td>2</td>
<td>0.91</td>
<td>0.93</td>
<td>0.93</td>
</tr>
<tr>
<td>Site level</td>
<td>NEE</td>
<td>FLUXNET</td>
<td>3</td>
<td>0.19</td>
<td>0.23</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>GPP</td>
<td>FLUXNET</td>
<td>3</td>
<td>0.66</td>
<td>0.76</td>
<td>0.80</td>
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<tr>
<td></td>
<td>SH</td>
<td>FLUXNET</td>
<td>4</td>
<td>0.73</td>
<td>0.80</td>
<td>0.79</td>
</tr>
<tr>
<td>Functional relationship</td>
<td>R / P</td>
<td>riv disc, CMAP</td>
<td>5</td>
<td>0.63</td>
<td>0.57</td>
<td>0.59</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>21.76</td>
<td>22.98</td>
<td>23.86</td>
</tr>
</tbody>
</table>
Hillslope routing to account for event dynamics and impacts of overland flow on soil erosion, nutrient loading etc.;

Sub-network routing: scale adaptive across different resolutions to reduce scale dependence;

Main channel routing: explicit estimation of in-stream status (velocity, water depth etc).

(Li et al., JHM, 2013)
Model for Scale Adaptive River Transport (MOSART)

MOSART is more skillful in simulating streamflow compared to RTM

NS coeff. for monthly mean streamflow – grid based representation

Large drainage area → Small drainage area
Nitrogen-cycle

**CLM4CN**

- N Deposition, (22 Tg N/yr), N fixation (145 Tg N/yr)
- Litterfall, Mortality
- Uptake
- SMINN
  - Leaching (0.01 Tg N/yr)
  - Denitrification (128 Tg N/yr)
- Immob.
- Min.
  - Fire (5 Tg N/yr)
- SOM, Litter

**CLM4.5BGC**

- N Deposition, (22 Tg N/yr), N fixation (134 Tg N/yr)
- Litterfall, Mortality
- Uptake
- Veg
  - Fire, Landuse (30 Tg N/yr)
- NH4
  - Nitr.
  - NO3
  - Leaching
  - Denitrif. (100 Tg N/yr)
  - N2O (4 Tg N/yr)
- Immob.
- Min.
  - Fire (15 Tg N/yr)
- SOM, Litter

**Obs (preindustrial, Galloway et al. 2004)**

- Deposition 17; BNF 120; Denitrification 98; Export to Rivers 70; N$_2$O 6
Net Primary Productivity response to N fertilization

% ANPP response to N fertilization

- N fertilization
- N limitation relieved

Observations (Magill et al. 2004; Pregitzer et al. 2008)

CLM-CN 4.0

CLM-CN Mod.

Thomas et al. 2012
CLM4.5 Performance at Tower Sites

Howland Forest Main July, 1996 NET-T

Morgan Monroe July, 2001 BDT-T

Thanks to D.M. Ricciuto, D. Wang, P.E. Thornton, W.M. Post, R.Q. Thomas, E. Kluzek for PTCLM!
Reduced biases in CLM4.5

ANN Latent Heat bias (obs: FLUXNET MTE)

Green: Improved in CLM4.5
Red:     Degraded in CLM4.5

<table>
<thead>
<tr>
<th></th>
<th>CLM4</th>
<th>CLM4.5</th>
</tr>
</thead>
<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>
Forcing uncertainty: RH during rain events

Obs (USA) CLM offline (Global)

Amazon

Obs (FLUXNET-MTE)
CLM4.5 control
CLM4.5 w/ RH at 95% during rain

Figs. A. Slater, S. Kumar, S. Swenson
RH Histogram during rainy hours, JJA

**Coupled**

- **P < 1 mm/day**
- **1 < P < 5**
- **P > 5**

**Offline**

- **P < 1 mm/day**
- **1 < P < 5**
- **P > 5**