LMWG Activities

David Lawrence
NCAR Earth System Laboratory

with input from members of LMWG and BGCWG

NCAR is sponsored by the National Science Foundation
Potential Arctic terrestrial climate-change feedbacks

- Lakes drain, soil dries
- Arctic warming
- CO$_2$ efflux
- CH$_4$ efflux
- Expanded wetlands
- Permafrost warms and thaws
- Microbial activity increases
- Shrub growth
- Enhanced [nitrogen]
- Carbon sequester
- Arctic runoff increases

Adapted from McGuire et al., 2006
Biases in CLM4: Soil carbon stocks

Obs

CLM4CN

CLM4CN - Obs

CLM4CN

GSDT Obs
Vertically-Resolved C & N Cycle in CLM4.5

- CLM4
  - No vertical structure for C & N dynamics
  - Crude SOM N cycle representation
- For CLM4.5
  - Flexible first-order biogeochemistry, based on CENTURY-like soil BGC structure
Improved Soil Carbon Stocks

- Improvement in steady-state C stocks (note quasi-log scale)
- Large improvement in high latitude C stocks
- Improvement in predicted soil C radiocarbon and age distribution
Process-based CH₄ emissions model

\[
\frac{\partial (RC)}{\partial t} = \frac{\partial F_D^{'}}{\partial z} + P(z, t) - E(z, t) - A(z, t) - O(z, t)
\]

- Net change
- Diffusion
- Production
- Ebullition (bubbling)
- Oxidation
- Aerenchyma (tissue)

Coupling to atmosphere model and atmospheric chemistry ongoing

Riley et al., 2011, JGR-Biogeosciences
Cold region hydrology

Problems: Water permeates icy soil too easily, dry active layer, vegetation grows poorly, river discharge hydrograph poor in permafrost basins

Control

Ice Impedance

Swenson and Lawrence, in prep
Flooding Capability (2-way CLM-RTM interactions) and Surface Water (wetlands)

CLM

Surface Water

Surface Runoff

Baseflow

RTM

Ocean

Flood water taken from RTM is sent back to CLM surface water store
Cold region hydrology

Results: Good hydrographs for both permafrost basins and non-permafrost basins, better active layer hydrology and veg?

Control

Ice Impedance + Wetlands/Flooding

Swenson and Lawrence, in prep
<table>
<thead>
<tr>
<th>Input dataset</th>
<th>CLM4 resolution</th>
<th>Updated resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFT distribution</td>
<td>0.5° (MODIS)</td>
<td>3’ (MODIS)</td>
</tr>
<tr>
<td>LAI / SAI</td>
<td>0.5° (MODIS)</td>
<td>0.5° (MODIS)</td>
</tr>
<tr>
<td>% Glacier</td>
<td>0.5° (IGBP DISCover)</td>
<td>1km (Gardner, avail spring?) [Bill]</td>
</tr>
<tr>
<td>% Lake, Lake depth</td>
<td>0.5° (Cogley, 1991)</td>
<td>3’ (GLWD)</td>
</tr>
<tr>
<td>% Wetland</td>
<td>0.5° (Cogley, 1991)</td>
<td>Prognostic</td>
</tr>
<tr>
<td>% Urban</td>
<td>0.5° (?)</td>
<td>1km (?) [Keith, aggregation issues?]</td>
</tr>
<tr>
<td>Soil texture (%sand, %clay)</td>
<td>5’ (IGBP)</td>
<td>5’ (IGBP for now; ISRIC-WISE for multiple soil classes) [Johann]</td>
</tr>
<tr>
<td>Soil organic matter</td>
<td>1.0° (IGBP)</td>
<td>5’ (ISRIC-WISE) [Dave]</td>
</tr>
<tr>
<td>Soil color</td>
<td>0.5° (MODIS)</td>
<td>0.5° (MODIS)</td>
</tr>
<tr>
<td>Fmax</td>
<td>0.5°</td>
<td>??? [Guo-Yue?]</td>
</tr>
<tr>
<td>RTM Directional Map</td>
<td>0.5°</td>
<td>0.1° (coupled to CESM?)</td>
</tr>
<tr>
<td>Irrigation/Crop types</td>
<td>5’</td>
<td>5’ (Navin) [Sam]</td>
</tr>
<tr>
<td>Topography (for GLCMEC)</td>
<td>10’ (USGS)</td>
<td>1km ?? (USGS)</td>
</tr>
</tbody>
</table>
CLM4.5 (potential release with CESM update, late 2012)

- **Revised cold region hydrology**
  - Impedance factor, perched water table
  - Surface water store (prognostic wetlands)
  - New snow cover fraction param; separate surface energy calc for snow covered, surface water, and bare ground surfaces
  - 2-way CLM grid cell – RTM interactions (flooding)

- **Soil Biogeochemistry**
  - Vertically resolved soil C/N pools, CENTURY-like pool structure

- **Methane emissions model (CLM4Me)**
  - Based on Riley et al. 2011; with options from Meng et al. 2011

- **Revised lake model**
  - New lake physics and lake area dataset, sub-lake soil (Subin et al. 2012)

- **Dynamic Landunits**
  - Glacier to vegetated transitions and vice versa

- **VIC Hydrology option (???)**
Will a large-scale expansion of Arctic shrub extent increase or decrease permafrost vulnerability to climate change?

David Lawrence
NCAR Earth System Laboratory
Boulder, CO

NCAR is sponsored by the National Science Foundation
Potential Arctic terrestrial climate-change feedbacks

Vegetation
Radiative forcing of complete conversion tundra to shrubland
+8.9W m⁻² (4.2W m⁻² GHG)
(Chapin et al., 2005)
Since 1950, 13% to 20% cover
(Sturm et al., 2005)

Global warming

Arctic warming

Carbon sequester

Shrub growth

Enhanced [nitrogen]

Microbial activity increases

Wetlands

Lakes drain, soil dries

Arctic runoff increases

Adapted from McGuire et al., 2006
Shrub cover increasing in Arctic

- Shrub cover increasing in N. Alaska at 1.2% per decade since 1950, 15% to 20% cover (Sturm et al. 2001)
- Similar increases seen in Canada
- No studies for Siberia, but satellite NDVI data indicates that Siberia is getting ‘greener’ and one explanation for this is increasing shrub cover

Figure 1. Increasing abundance of shrubs in arctic Alaska. The photographs were taken in 1948 and 2002 at identical locations on the Colville River (68° 57.9' north, 155° 47.4' west). Dark objects are individual shrubs 1 to 2 meters high and several meters in diameter. Similar changes have been detected at more than 200 other locations across arctic Alaska where comparative photographs are available. Photographs: (1948) US Navy, (2002) Ken Tape.
Impact of shrubs on climate and permafrost

- Enhanced microbial activity increases
- Shrub growth
- Permafrost warms and thaws
- Microbial activity increases
- Carbon sequester

Adapted from McGuire et al., 2006
These results suggest that the expected expansion of deciduous shrubs in the Arctic region, triggered by climate warming, may reduce summer permafrost thaw.

Evaluate this hypothesis using CAM4/CLM4
Community Land Model subgrid tiling structure

Gridcell

Landunit
- Glacier
- Wetland
- Vegetated
- Lake
- Urban

Columns

Soil
Type 1

PFTs
Examining impact of shrubs on permafrost using CAM4/CLM4

SB_LOW: Shrub – Grass

SB_HIGH – SB_LOW: Grid cell mean

SB_LOW Boreal Shrub

SB_HIGH Boreal Shrub
Impact of shrubs on permafrost

Model replicates results from field manipulation study (Blok et al. 2010)

But, if climate feedbacks are considered, ground actually gets warmer, suggesting that shrub area expansion may increase rather than decrease permafrost vulnerability.
Summary (Lawrence and Swenson, ERL, 2011)

Will expanding Arctic shrub cover decrease permafrost vulnerability to climate change?

A. Not necessarily. Depends on whether the direct local cooling or the indirect climate warming dominates. Our results indicate that shrub expansion may increase rather than decrease permafrost vulnerability to climate change.
Community Land Model (CLM4)

Surface fluxes
- Direct solar
- Diffuse solar
- Reflected solar
- Absorbed solar
- Aerosol deposition

Hydrology
- Momentum flux
- Wind speed
- Precipitation
- Evaporation
- Transpiration
- Throughfall
- Infiltration
- Surface runoff

Hydrology components
- Soil heat flux
- Soil heat flux
- Aquifer recharge
- Water table
- Sub-surface runoff

Biogeochemical cycles
- Photosynthesis
- BVOCs
- Heterotrophic respiration
- N uptake
- N mineralization
- Denitrification
- N fixation

Geographic components
- Glacier
- Wetland
- Runoff
- Lake
- Wood harvest
- Urban

Earth system processes
- Fire
- Vegetation C/N
- Soil C/N
- Litterfall
- Root litter
- Phenology
- BVOCs
- Water table
- River discharge
- Aquifer recharge

Land Use Change
- Competition
- Disturbance
- Vegetation Dynamics
- Growth

Lawrence et al. 2011, JAMES
Ways in which shrubs can affect above and belowground climate

**Shrubs compared to tundra**
- absorb more solar
- earlier snowmelt
- shade the ground
- deeper snow drifts (insulation)
- higher transpiration

(Sturm et al. 2005)

Radiative forcing of complete conversion tundra to shrubland

+8.9 W m\(^{-2}\) \((4.2 W m\(^{-2}\) GHG)

(Chapin et al., 2005)