Land Ecosystems and Climate
a modeling perspective

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Why the Land?

• the land surface is a critical interface between atmosphere, lithosphere, hydrosphere, biosphere, cryosphere, anthroposphere

• where humans ↔ environmental change
First a note about complexity…

- Soil moisture… (Levis & Cramer)
- Carbon fluxes… (CCSM BGC Working Group)
CLM-CN: Biogeochemical Cycles in the CLM

Carbon cycle:
- Atmosphere CO₂ (Atm CO₂)
- Photosynthesis
- Respiration
- Litterfall & mortality
- Decomposition
- Soil Organic Matter

Nitrogen cycle:
- Internal (fast): Assimilation
- External (slow): Denitrification, N deposition, N fixation, N leaching

Thornton et al.
CNDV: Dynamic Vegetation in the CLM

**Year 1:**
Bioclimatology accumulators

End of year 1:
Establishment

Year 2+:
Bioclimatology accumulators
Biogeochemistry
Photosynth., respir., growth, mortality

End of year 2+:
Establishment
Competition for Light (space)

Levis et al.
250-year CNDV simulation: CLM3.5 driven with observed weather
20-year avg veg cover from year 2181 to year 2200
Linking Land Models to Other Components…

Diagram:
- atm
- ocean
- coupler
- sea-ice
- land
Linking Land and Ocean Models

SIMULATED RIVER FLOW \( (m^3 s^{-1}) \)
Linking Land and Atmosphere Models
Land-Atmosphere Interactions

LAND-ATMOSPHERE FEEDBACKS

- Climate changes → vegetation responds
- Vegetation changes → climate responds:

A. Biogeophysical feedbacks:
   1. Surface radiation balance \( R_n = S + L \)
   2. Surface heat balance \( R_n = H + \lambda E \)

B. Biogeochemical feedbacks (e.g. carbon cycle)
2 x CO$_2$ climate and vegetation

Image: Graph showing temperature difference and leaf area index in different latitudes with 2xCO$_2$ warming.
Biogeophysical feedbacks

1. Surface radiation balance:
   Trees darken snow-covered surfaces

\[ \alpha_t \approx 0.8 \quad \alpha_b \approx 0.2 \]

\[ T_t < T_b \]
Biogeophysical feedbacks

1. Surface radiation balance
   Trees darken snow-covered surfaces

2. Surface heat balance  \( R_n = H + \lambda E \)
   Vegetation increases the latent heat flux
Trees increase evapotranspiration
...deforestation decreases it

(Shukla et al. 1990)
Sensitivity to I.C.?

Two candidate regions tested:
  – North African Savannah
  – Boreal Forest – Tundra Boundary
Sensitivity to IC: North Africa

Figure 1. The stable solutions obtained in ECHAM-BIOME model for (a,b) present-day and (c) mid-Holocene in terms of background albedo. The solid line represents the areas where multiple equilibria solutions appear.

Brovkin et al. 1998
Sensitivity to IC: Boreal Regions

• Not found
Atmosphere-Vegetation interactions

...short time scales
FIG. 3. Average surface daily maximum temperature (dashed line, right scale) and average thickness-derived hypsometric temperature (solid line, left scale) for indicated days after first leaf event (smoothed by a nine-point binomial filter).
DGVM as evaluation tool

- LPJ-dgvm in NCAR-LSM (Bonan et al. 2003)
- LPJ-dgvm in the CLM (Levis et al. 2004)
DGVM as evaluation tool

- Bioclimatic limits: $T$
- GPP: $T$, $\theta$, radiation, $\text{CO}_2$, phenology
- Respiration: $T$
- Nutrients...

- Vegetation responds to
  - Means...
  - Annual cycles...
  - Interannual variability...
  - Extremes
CLM-DGVM: offline simulations

(A) SIMULATION OV
NEEDLELEAF EVERGREEN TREES

(B) SIMULATION OVM
BROADLEAF EVERGREEN TREES

SIMULATED VEGETATION (percent cover)

Bonan & Levis (2006)
CLM-DGVM: offline simulations

(A) SIMULATION OV

DECIDUOUS TREES

(B) SIMULATION OVM

GRASSES

SIMULATED VEGETATION (percent cover)

Bonan & Levis (2006)
CLM-DGVM: coupled simulations

(A) SIMULATION CV

NEEDLELEAF EVERGREEN TREES

(B) SIMULATION CVM

BROADLEAF EVERGREEN TREES

SIMULATED VEGETATION (percent cover)

Bonan & Levis (2006)
CLM-DGVM: coupled simulations

(A) SIMULATION CV

DECIDUOUS TREES

(B) SIMULATION CVM

GRASSES

SIMULATED VEGETATION (percent cover)

Bonan & Levis (2006)
Biosphere-Atmosphere interactions

OV and CV become modified to OVM and CVM

Ec… ↓
θ… ↑
R… ↑ (=> less water remains for local recycling)
Et… ↑ (by not as much as Ec declined)
ET = Ec + Et + Eg ↓

Atmosphere-Biosphere responses in Amazonia within 2 years in CVM

P… ↓ (as less water remains for local recycling)
Forest → Grassland
ET = Ec + Et + Eg ↓
P… ↓

Atmosphere responses in Amazonia without DGVM

P… no decrease => dynamic veg played a role in the reduction in CVM
Lessons learned

• Improvement of offline model does not guarantee improvement in coupled model
• Do not wait long to test coupled model
• No quick fix to CLM’s dry bias. Result: CLM3 \(\rightarrow\) CLM3.5 \(\rightarrow\) CLM4 and CCSM distinguished achievement award
Atmosphere-Vegetation interactions

...land use
Vegetation-snow albedo feedback

CAM3/CLM3.5 ensemble average

Increased surface albedo $\rightarrow$ cooling

Bonan et al., unpublished
Mid-latitude summer

CAM3/CLM3.5 ensemble average

Decrease in daily maximum is offset by increase in daily minimum temperature

Feedbacks with clouds & precip

Bonan et al., unpublished
Future land use effect on temperature
(SRES land cover + SRES atmospheric forcing) - SRES atmospheric forcing

**A2** - Most arable land used for farming by 2100 to support a large global population

**B1** - Temperate reforestation due to declining population and farm abandonment in the latter part of the century

Summer temperature change by 2100

Feddema et al. (2005) Science 310:1674-1678
Future land use effect on temperature

Biogeophysical

A2 - widespread cropland

B1 - temperate reforestation

Biogeochemical

Net effect similar

$\Delta T_{2100}$
Land use policies to mitigate climate change

- Arable land converted to C storage or biofuels
- Reforestation to sequester carbon
- Biofuel plantations to substitute fossil fuels

IPCC A1B scenario PLANTATIONS in 2100

Green = carbon plantations
Green + red = biofuel plantations


Plantations reduce $CO_2 \rightarrow$ cooling
Reduce surface albedo $\rightarrow$ warming
Carbon plantations have lower albedo than biofuels
Biofuels - research needs

Carbon cycle
Crop management
Land cover change

Nitrogen cycle
Beth Holland, NCAR

Water systems

Aerosols and biogenic emissions

Maize/Poplar/Switchgrass

Center pivot irrigation, northern California

BEACCHON project, NCAR
Land management

- **Irrigation:** Sacks *et al.* (2008)
- **Fertilization:** papers by Kucharik *et al.*
- **Rotation:** Twine *et al.* (2004), Lamptey *et al.* (2005)
- **Tillage:** Lobell *et al.* (2006) incr. albedo for no till case
Urban systems

Represent climate change where people live

Energy fluxes are modeled for an idealized urban canyon. Key model parameters are:

- **H/W** - ratio of building height and street width
- **W_{roof}** - fractional roof area
- **f_{pervious}** - fractional greenspace
- Building materials - thermal and radiative properties

Summary and Conclusions

- Human dimensions: a new frontier in CCSM research

- Land use & mgmt, urbanization: steps in that direction

- Still also resolving more basic issues: biogeophysical & biogeochemical processes