RegCM3-CLM3: Land surface modeling in RegCM and impact on aerosols

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Workshop on Aerosol-Climate Interactions

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What it looks like in Michigan now…
Talk Outline

1. Overview of Land Surface Parameterizations
2. RegCM3-CLM3 simulation results: An improvement in the simulation of the west African monsoon
3. The land surface and aerosols
1. Introduction

Land Surface Parameterizations
1. Introduction

Generations of Land Surface Schemes

<table>
<thead>
<tr>
<th>Generation</th>
<th>Description</th>
<th>Example</th>
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</table>
| First Generation | Basic surface energy & water balance  
1. Radiation exchange  
2. Latent & sensible heats  
3. Surface drag  
4. Soil "bucket" model       | Simple LSPs (e.g., weather forecasting models) |
| Second Generation | Vegetation-soil interactions  
1. Canopy radiation absorption  
2. Vegetation/momentum interaction  
3. Biophysical control of ET (empirical)  
4. Canopy interception of precip  
5. Soil moisture/root systems  
6. Canopy insolation of surface | BATS |
| Third Generation | Interactive biochemistry  
1. Biochemical model for photosynthesis  
2. Coupled photosynthesis-stomatal conductance  
3. Integration of satellite data | CLM |

Sellers et al., 1997
1. Introduction

RegCM Land Surface Schemes

RegCM Version

- **RegCM1**
  - Dickinson et al. (1989)

- **RegCM2**
  - Giorgi et al. (1993a,b)

- **RegCM2.5**
  - Giorgi & Shields (1999)
  - Pal et al. (2000)

- **RegCM3**

Land Model Options

- **BATS 1a**
  - Dickinson et al. (1986)

- **BATS 1e**
  - Dickinson et al. (1993)

- **CLM0**
  - (Steiner et al. 2005)

- **SUBBATS**
  - (Giorgi et al., 2003)

- **CLM3**
  - (Steiner et al., in prep)

*Pal et al., 2007*
1. Introduction

BATS: Biosphere-Atmosphere Transfer Scheme

Dickinson et al., 1993
1. Introduction

CLM0: Common Land Model v. 0

Figure 1. Biogeophysics and hydrology represented in the Community Land Model.

www.cgd.ucar.edu
1. Introduction

CLM0: Common Land Model v. 0

Subgrid land cover and plant functional types

Figure 2. CLM represents a grid cell as a mosaic of up to 5 primary land cover types. Vegetated land is further represented as a mosaic of up to 4 plant functional types. Each subgrid tile is represented as a separate soil-plant-atmosphere column.
1. Introduction

CLM3: Community Land Model v. 3

- Biogeophysics
- Biogeochemistry
- Hydrologic Cycle
- Dynamic Vegetation

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1. Introduction

Biogeophysical changes: BATS vs. CLM

**BATS**
- One canopy layer
- Simple stomatal conductance model
- No photosynthesis
- One snow layer
- 3 soil layers
  - Soil $T$: Force-restore
  - Soil moisture: Diffusive/gravitational

**CLM3**
- One canopy layer
- Sunlit/shaded leaves
- Stomatal conductance-photosynthesis model
- TOPMODEL-based runoff
- Up to five snow layers
- 10 uneven soil layers
  - Soil $T$ and moisture: Solved numerically
  - Includes liquid $H_2O$/ice
2. RegCM3-CLM3 Simulation

Simulation details

- Regional Climate Model (RegCM3; Pal et al., 2007)
- Changed land surface scheme from BATS to CLM3
- 2 year spin-up + 10 year simulations (1992-2001)
- 120x125 grid at 60km resolution
- ERA-40 boundary conditions
- Emanuel precip scheme
2. RegCM3-CLM3 Simulation
Change to CLM3 substantially improves simulation of African monsoon precipitation

![Maps showing precipitation (mm/month) for May, June, July, Aug, Sept for BATS, CRU, CLM3]
2. RegCM3-CLM3 Simulation

Change to CLM3 substantially improves simulation of African monsoon precipitation.
2. RegCM3-CLM3 Simulation

Change to CLM3 substantially improves simulation of African monsoon precipitation.
2. RegCM3-CLM3 Simulation
Change to CLM3 substantially improves simulation of African monsoon precipitation
2. RegCM3-CLM3 Simulation

CLM3 is much drier than BATS simulations in the surface layer (first 10cm)
2. RegCM3-CLM3 Simulation

CLM3 is much drier than BATS simulations in the root zone (1-2 m)

- Drier soils have also been noted in global model comparisons with CLM2 (Bonan et al., 2002; Zeng et al., 2002)
2. RegCM3-CLM3 Simulation

Formation of the African Easterly Jet (AEJ)

Seasonal heating → surface T gradient → thermal wind → forms AEJ
2. RegCM3-CLM3 Simulation

Southern latitude surface temperatures are cooler in RegCM3-BATS simulations.
2. RegCM3-CLM3 Simulation

RegCM3-BATS simulations have stronger meridional surface T gradient
2. RegCM3-CLM3 Simulation

Known soil moisture-precipitation feedbacks

- Wetter soils
- Increased Moist Static Energy (MSE)
- Position of African Easterly Jet (AEJ) at 600 mb
- Increased precipitation

Philippon & Fontaine, 2002
2. RegCM3-CLM3 Simulation

Greater Moist Static Energy (MSE) in northern latitudes in RegCM3-BATS

Surface MSE (kJ/kg)
2. RegCM3-CLM3 Simulation
MSE leads to a northward shift in the RegCM3-BATS African Easterly Jet (~600mb)
2. RegCM3-CLM3 Simulation

RegCM3-CLM3 simulation produces jet more like the driving ERA-40 conditions.
2. RegCM3-CLM3 Simulation

AEJ location impacts large scale circulation

BATS JJA 600mb winds

CLM JJA 600mb winds
2. RegCM3-CLM3 Simulation

RegCM-CLM3 circulation looks more like ERA-40 winds

CLM JJA 600mb winds  ERA-40 JJA 600mb winds
2. RegCM3-CLM3 Simulation
Also impacts the 200 mb level (Tropical Easterly Jet)
2. RegCM3-CLM3 Simulation

What drives the difference in soil moisture?

- Water balance terms are different
  - BATS has greater precip, greater evapotranspiration and greater runoff than CLM3
  - When normalized to incoming precip, terms are similar
- Difference in soil column description
  - soil texture (% sand, silt, clay)
  - sandier soil allows more drainage
  - clayey soil has more surface area, holds more water
  - BATS = old FAO dataset (1980s)
  - CLM3 = IGBP Global Soil Data Task 2000
2. RegCM3-CLM3 Simulation

Soil texture is driving most of the land surface differences - CLM3 more sand

BATS % Sand

CLM3 % Sand
2. RegCM3-CLM3 Simulation

Soil texture is driving most of the land surface differences - CLM3 less clay
2. RegCM3-CLM3 Simulation

Conclusions

• Changing the RegCM3 land surface parameterization from BATS to CLM3 caused:
  - drier soils
  - improved timing of African monsoon
  - reduced magnitude of precipitation during monsoon
  - improved simulation of large scale circulation

• Differences in soil moisture due to new and revised soil texture description of CLM3

• Selection of land surface parameterization can have significant impacts on regional climate simulations in regions of strong land-atmosphere coupling
3. Land Surface-Aerosol Interactions

Aerosol types

• Natural or biogenic emissions
  - Dust
  - Primary biogenic particles
  - Secondary biogenic particles

• Anthropogenic emissions
  - Urban and industry (function of land cover type)
  - Biomass burning
3. Land Surface-Aerosol Interactions

Impact of land surface on dust

Dust emissions are a function of:
1. Soil texture
   - c.f. Zakey et al., 2006 Table 1
2. Wind shear
   - wind speed
   - boundary layer conditions (friction velocity)
3. Soil moisture

Optical properties are also likely affected by soil color
3. Land Surface-Aerosol Interactions
Potential dust emission changes due to change to CLM3

1. Soil texture
   • CLM3 more sandy in northern Africa, less clay
   • Could shift to larger size distribution (clay particles are smaller)

2. Soil moisture
   • CLM3 drier soils, more dust emissions

3. Wind shear
   • CLM3 slower surface winds, less dust
Biogenic Primary Particles: Pollen

- Size range >10 µm
- Composition: organic carbon
- Emitted seasonally from trees, grasses & crops
- Human health impacts
- Radiative impacts
  - Direct
  - Indirect (CCN ability unknown, proven to be ice nuclei)
3. Land Surface-Aerosol Interactions

Biogenic Primary Particles: Pollen

- Pollen count = number of grains/cm$^3$ of a particular species (24 hour average)
3. Land Surface-Aerosol Interactions

Biogenic Primary Particles: Bacteria & Fungi

- **Bacteria** (unicellular microorganisms)
  - Size range 0.25-8 $\mu$m
  - Emitted from desert and crop areas
  - Can act as CCN and IN

- **Fungi**
  - Can cause chemical transformations in the atmosphere
  - Can act as CCN

- Don’t know very much about these emissions or their impact on atmospheric processes!
3. Land Surface-Aerosol Interactions

Secondary organic aerosols (SOA)

Isoprene
OxVOCs
Terpenes
Sesquiterpenes

\[
\text{Oxidation products} \quad \text{Nucleation} \quad \text{Condensation} \quad \text{Coagulation} \quad \text{Particle Phase Secondary Organic Aerosol}
\]

Gas Phase

\[
\begin{align*}
\text{OH} & \quad \text{O}_3 \\
\text{NO}_3 & \end{align*}
\]
3. Land Surface-Aerosol Interactions

Biosphere-Atmosphere Feedbacks

SURFACE FLUXES
- Evapotranspiration
- Sensible heat flux
- Soil moisture

ATMOSPHERE
- Radiation
- Air temperature
- Relative humidity
- Cloud
- Precipitation

DIRECT

INDIRECT

Biogenic POA
- Pollen, Fungi, Spores

Biogenic SOA

Biogenic VOC
- Isoprene
- Monoterpenes

Biogenic AEROSOLS

FORCINGS

FEEDBACKS
Conclusions

• Land surface parameterization plays an important role in atmospheric dynamics

• Change of land surface parameterization can have significant impacts on regional climate simulations (e.g., case of the west African monsoon)

• Land surface will also impact emissions of natural aerosols and need to be considered on the regional scale