Impact of Land use and Land cover Change on Regional Climate over the Contiguous United States using Variable-Resolution CESM2

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It is essential to better represent the influence of LULCC on Earth system processes

- LULCC interacts with local, regional, and global Earth system processes. The resulting ecosystem responses are a mix of biogeophysical and biogeochemical feedbacks to climate change;

- Combined LULCC effects account for 40% ± 16% of the human-caused global radiative forcing from 1850 to present day (high confidence)
Background
VR-meshes in Global Models

➢ **LULCC relevant processes:** urban centers, cropping systems and irrigation, topographic and LU patterns

➢ **Limited area models:** traditionally used to study regional impacts of LULCC needs lateral boundary conditions

➢ **VR meshes in global models:** new alternative that can be used to study LULCC impacts at finer resolutions, feasible to perform decadal global simulations at 10-30km resolutions

Regionally refined simulations:

- Are Computationally Feasible
- Reproduces the global climatology of the uniform low resolution simulations (Zarzycki et al., 2015), without the need for retuning the global model (Gettelman et al., 2018)
- Captures high frequency, high resolution statistics over region of grid refinement (Gettelman et al., 2018)
Community Earth System Model 2 (CESM2) - VR Configuration

- CESM2-SE with regional refinement to $^{1/8}\circ$ over the Contiguous United States (CONUS)
- Land-atmosphere simulations with CAM6-SE and CLM5.0 (BGC and crop modules turned on)
- Historical AMIP type simulations with prescribed SST, atmospheric chemistry and solar variations of 1980-2015
- Two alternate LULC data:
  - Preindustrial : Year 1850
  - Present day : Year 2000
- Scale Experiments:

### Table 1. 2000 vs. 1850 LULCC experiments

<table>
<thead>
<tr>
<th>Grid combinations</th>
<th>Atmosphere</th>
<th>Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>ne30 – ne30</td>
<td>1° (~111 km)</td>
<td>1° (~111 km)</td>
</tr>
<tr>
<td>ne 30 – ne 240</td>
<td>1° (~111 km)</td>
<td>0.125° (~14 km)</td>
</tr>
<tr>
<td>ne 240 – ne 240</td>
<td>0.125° (~14 km)</td>
<td>0.125° (~14 km)</td>
</tr>
</tbody>
</table>

Compset: FHIST using CAM6_CLM5_BGC-Crop

Grid: ne30 & ne240CONUS

Source: Lauritzen et al., 2018 (JAMES)

15 years each 1984-1998
Science questions

➢ Can simulations of regional climate over CONUS be improved using high-resolution simulations?

➢ What is the response of regional climate to LULCC in high resolution simulations compared to more conventional resolution ESM simulations?

➢ What is the effect of LULCC on warm season precipitation over Central United States?
Warm Season biases in spatial patterns of Rainfall

OBS
Mean Rainfall

1° atm - 1° Ind

Model
Bias

⅛° atm – ⅛° Ind

NLDAS Apr-Jun Rainfall (mm/day)

NLDAS Jul-Aug Rainfall (mm/day)
Warm Season biases linked to Mesoscale Convective Systems (MCSs) over the Central United States

- Organized convective systems that last 10-24h & propagate eastward
- MCS structure consists of convective towers and large areas of stratiform rainfall
- MCSs account for 40-60% of warm season precipitation over Central US (east of the Rocky Mountains)
- Models with parameterized convection have difficulty capturing MCSs over Central US, resulting in low precipitation bias
Regional Precipitation

Higher Resolution -> Better precipitation simulation during April-Jun

Overestimation of precipitation - Enhanced at high resolution

Warm season dry bias persists at all resolutions

Simulated precipitation in line with observations
Regional Precipitation: Diurnal cycle

- Higher resolution in land model increases precipitation amount
- Higher resolution in atmospheric model further changes the phase of the precipitation diurnal cycle
LULCC Changes over CONUS: 2000 - 1850

- CROP on Grid cell (%)
  - LU 2000 - 1850

- GRASS on Grid cell (%)
  - LU 2000 - 1850

- TREE on Grid cell (%)
  - LU 2000 - 1850

Grass to crop

Tree to crop

Irrigated CROP on Grid cell (%)

- LU 2000 - 1850

Increase in cropland over Midwest
Majorly unirrigated
Results: LULCC Induced Changes in PRCP and T-2m

PRCP Changes
Increase over Central U.S.

T-2m Changes
Near surface cooling

April

1° atm - 1° land
1° atm – ½° land

LU 2000-1850 Apr PRECT
LU 2000-1850 Apr PRECT
LU 2000-1850 Apr Total Rain

May

1° atm - 1° land
1° atm – ½° land

LU 2000-1850 May PRECT
LU 2000-1850 May PRECT
LU 2000-1850 May Total Rain

Increase over Central U.S.
Near surface cooling
Results
LULCC Induced changes in Surface fluxes

**LH**
Increase with start of growing season

**SH**
Decrease - Pattern change across months
Results
Changes of LH Flux and LAI in May

May

1° atm - 1° land
1° atm – ⅛° land
⅛° atm - ⅛° land

Latent heat flux increases – comes from vegetation transpiration – due to increase in crop LAI
Results
Mesoscale Convective System (MCS)–Like Features

MCS-like features are tracked using:

• Precipitation Feature tracking algorithm developed by Feng et al. 2016
  - Based on characteristics of MCS rainfall in observations
• Uncertainty: due to 3 hourly model outputs used for feature tracking

• $1^\circ \text{ atm} - 1^\circ \text{ land}$ & $1^\circ \text{ atm} - \frac{1}{8}^\circ \text{ land}$: No trackable features
• $\frac{1}{8}^\circ \text{ atm} - \frac{1}{8}^\circ \text{ land}$: MCS-like features exist
• But fewer tracks that seen in observations
  - Could be due to 3 hourly temporal resolution of output or deficiency of model in simulating these systems

Source: Prein et al. 2017
Results
LULCC Induced differences in MCS-Like Features: $\frac{1}{8}^\circ$ atm - $\frac{1}{8}^\circ$ land

Mean LU2000 Rainfall

Changes LU2000-LU1850

Total precipitation changes over the Southern Great Plains may come from changes in MCS-like precipitation
Summary & Future Work

➢ Finer resolution simulations represent the precipitation over Midwest better

➢ LULCC leads to:
  ➢ Over the Central, increase in cropland-> increase in LAI->increase in LH->surface cooling;
  ➢ Apr-May precipitation increase over Central US, some patches of decrease in May
  ➢ Changes over Southern Great Plains in finer resolution simulations comes from changes in MCS-like features there

➢ Need to output precipitation at 1-hourly to have more confidence on MCS-tracking.

➢ Plan to look at mechanisms behind the LULCC-induced precipitation changes
Thank You

DOE Office of Science
Multisector Dynamics,
Regional and Global Model Analysis,
Earth and Environmental System Modeling Program
New Thresholds
MCS Rain (mm/d)
Apr-Aug by month

Default Thresholds
MCS Rain (mm/d)
Apr-Aug by month
**MCS Frequency**

*No. of timesteps when MCS exists/Total number of timesteps – calculated using MCS mask to set a 1/0 flag*

**New Thresholds**

**MCS Frequency (fraction)**

Apr-Aug by month

**Default Thresholds**

**MCS Frequency (fraction)**

Apr-Aug by month
PBLH

LU 2000-1850 Apr PBLH
LU 2000-1850 May PBLH

LCL

LU 2000-1850 Apr LCL
LU 2000-1850 May LCL