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

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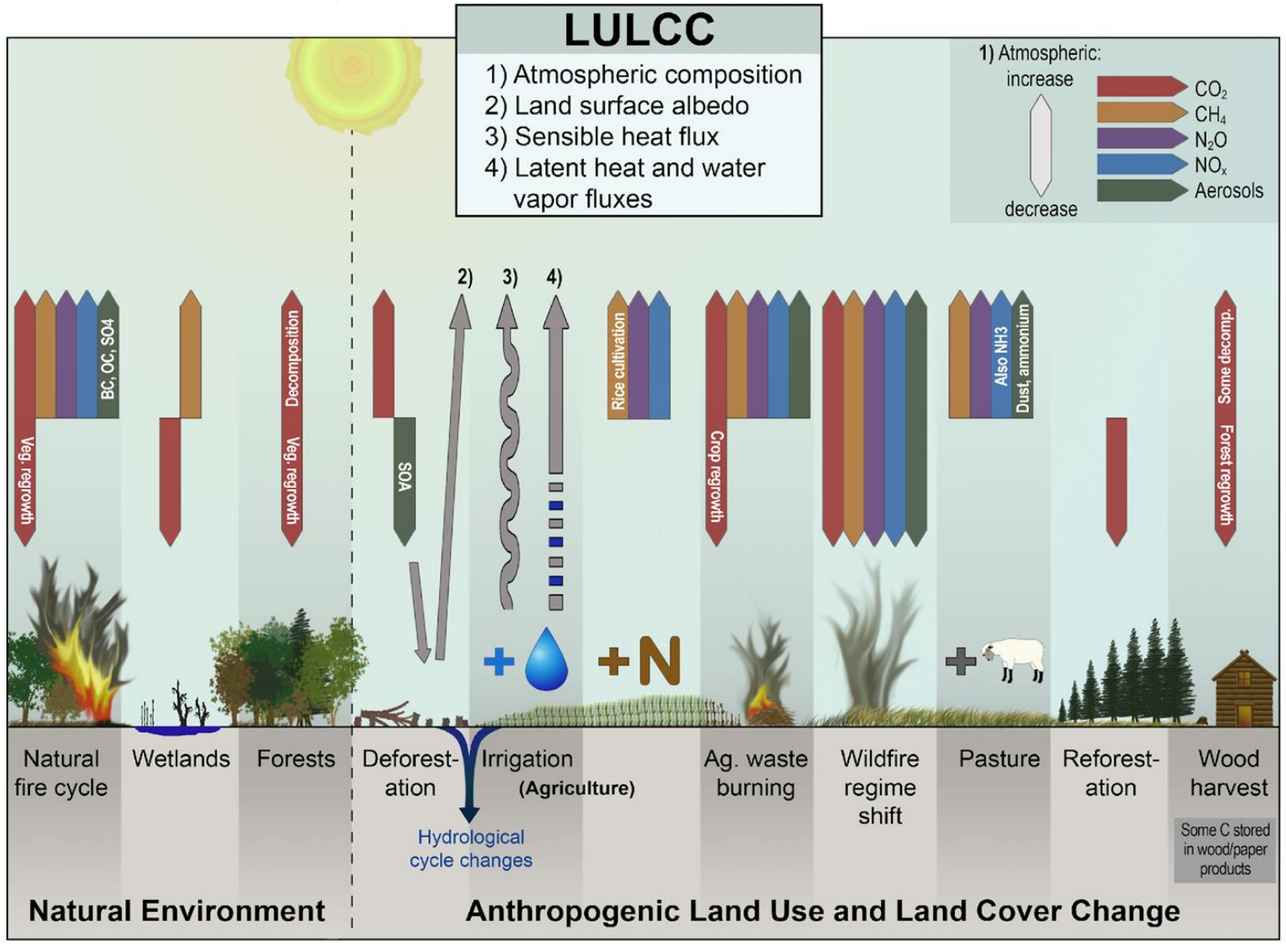
It is essential to better represent the influence of LULCC on Earth system processes



Hibbard et al., 2017, CSSR, 4th NCA

- 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)

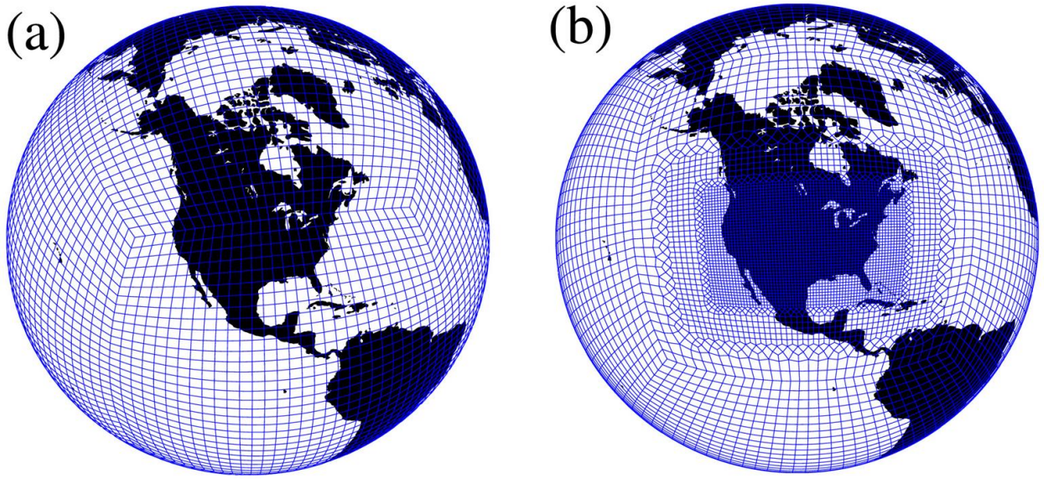
❑ Captures high frequency, high resolution statistics over region of grid refinement (Gettelman et al., 2018)

Community Earth System Model 2 (CESM2) - VR Configuration

- CESM2-SE with regional refinement to ⅛° 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:

ne 30 grid
~ 111 km

ne 240 grid over CONUS
~ 14 km



Source: Lauritzen et al., 2018 (JAMES)

Compset: FHIST using CAM6_CLM5_BGC-Crop
Grid: ne30 & ne240CONUS

Table 1. 2000 vs. 1850 LULCC experiments

Grid combinations		
	Atmosphere	**Land**
ne30 – ne30	**1˚ (~111 km)**	**1˚ (~111 km)**
ne 30 – ne 240	**1˚ (~111 km)**	**0.125˚ (~14 km)**
ne 240 – ne 240	**0.125˚ (~14 km)**	**0.125˚ (~14 km)**

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?

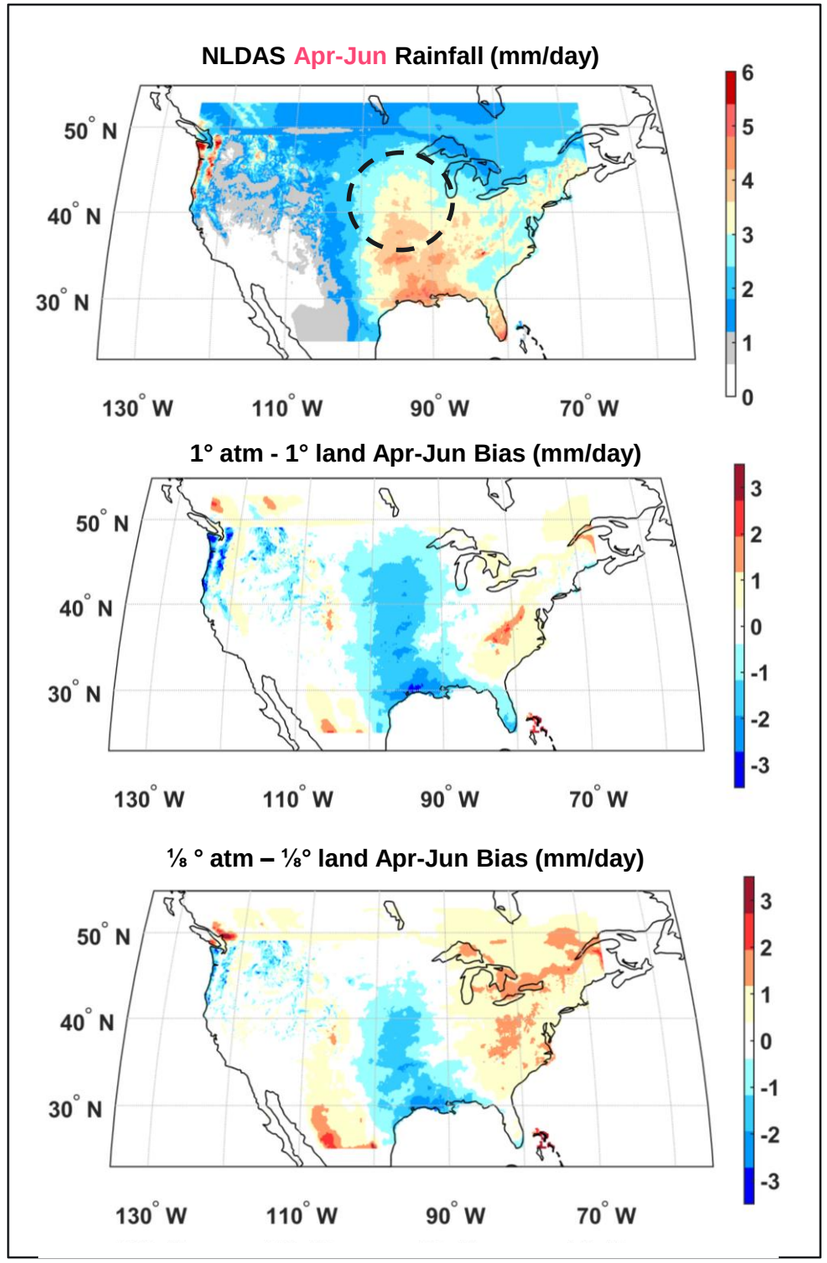
Warm Season biases in spatial patterns of Rainfall

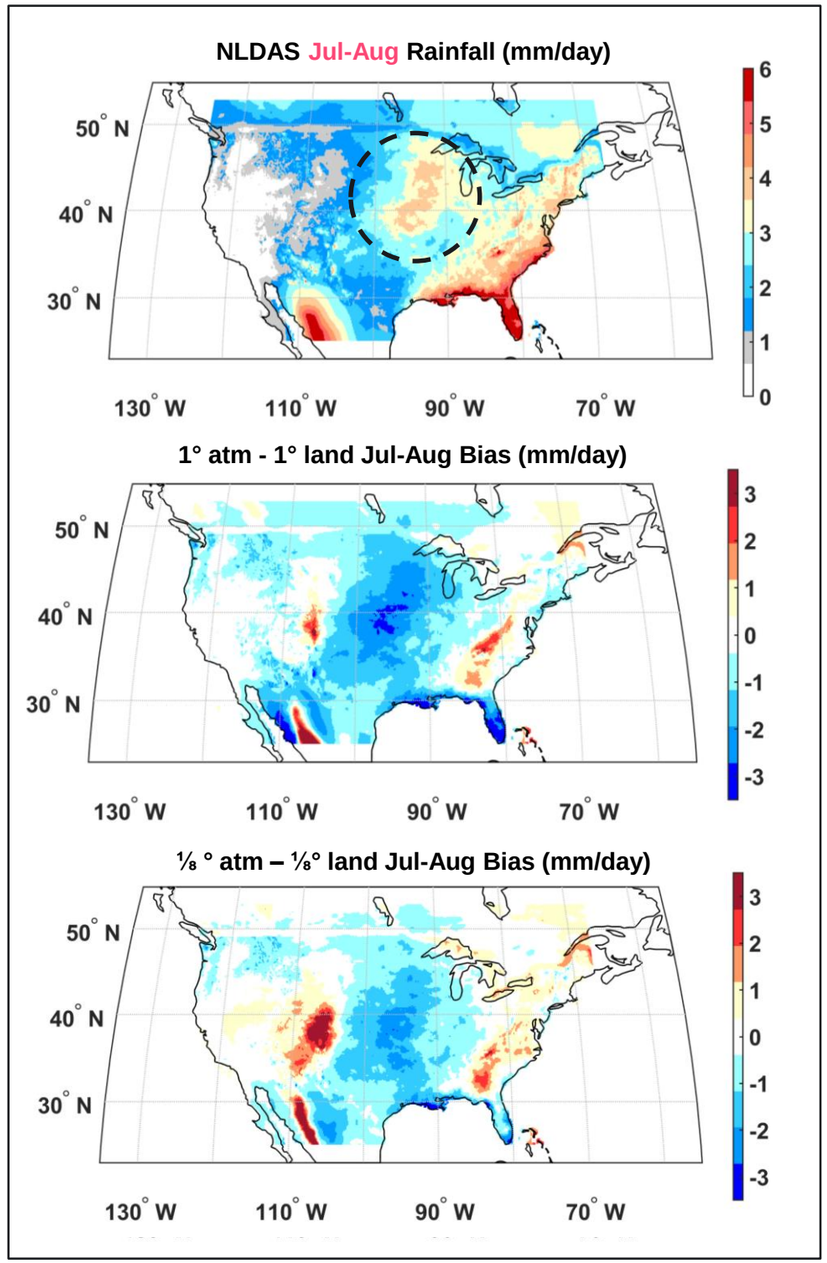
OBS
Mean Rainfall

1° atm - 1° lnd

Model
Bias

⅛° atm – ⅛° lnd

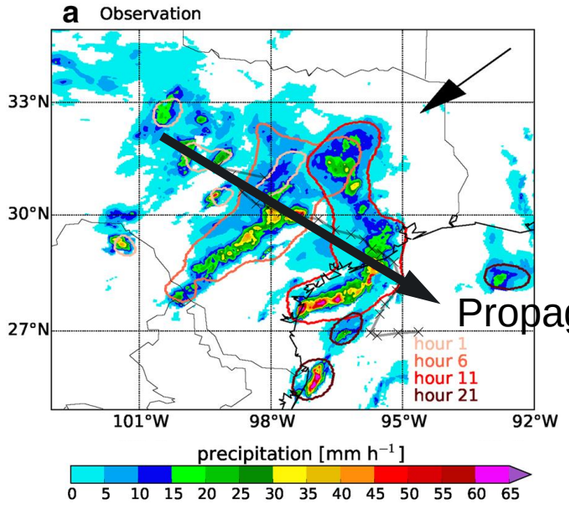




Warm Season biases linked to Mesoscale Convective Systems (MCSs) over the Central United States

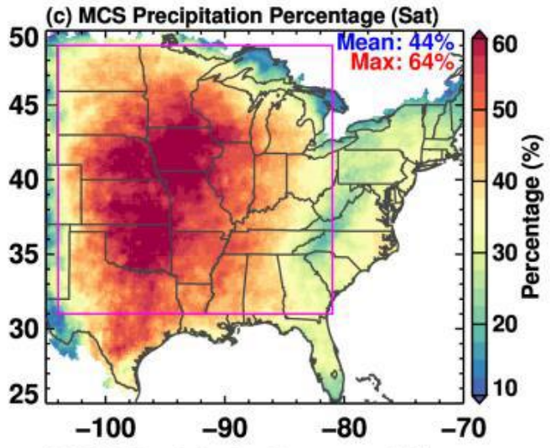
- Organized convective systems that last 10-24h & propagate eastward
- MCS structure consists of convective towers and large areas of stratiform rainfall
- MCSs account for **40-60%** of warm season precipitation over Central US (east of the Rocky Mountains)
- Models with parameterized convection have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

MCS Example from observations



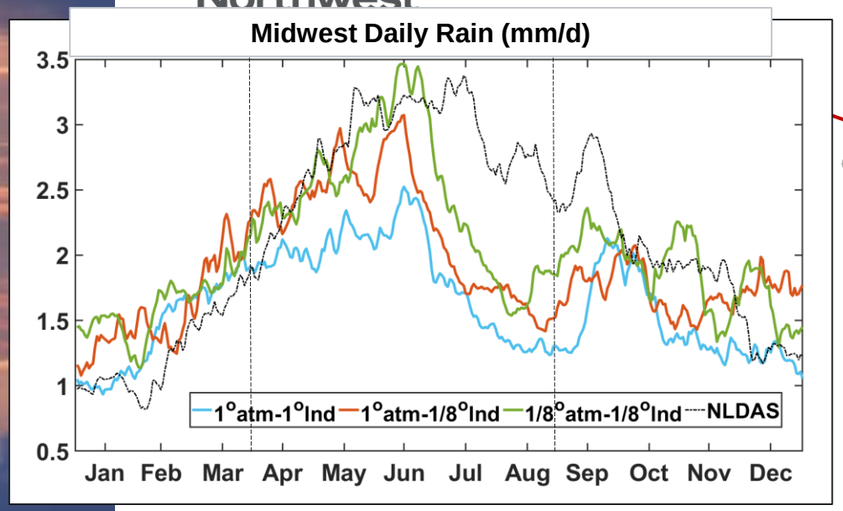
Source: Prein et al. 2017

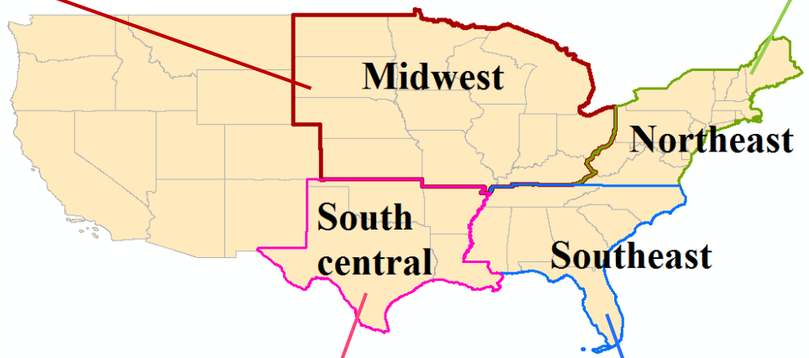
MCSs accounts for 40-60% Total Precipitation

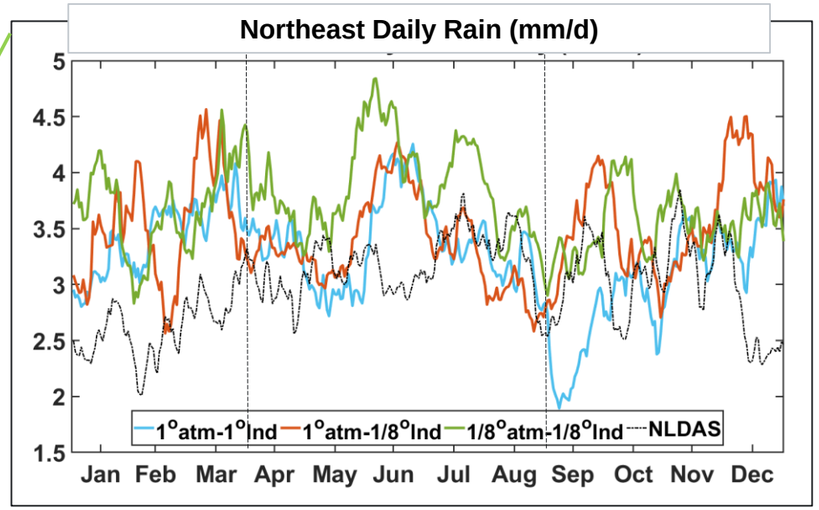


Source: Feng et al. 2016

Regional Precipitation

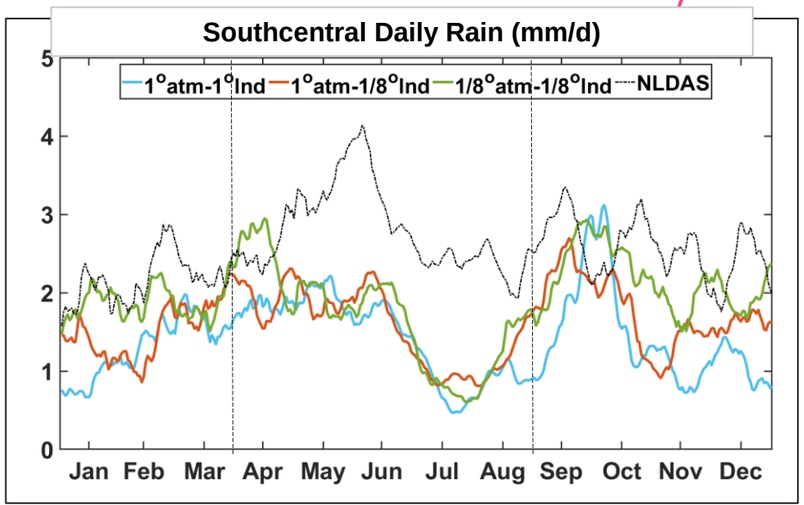


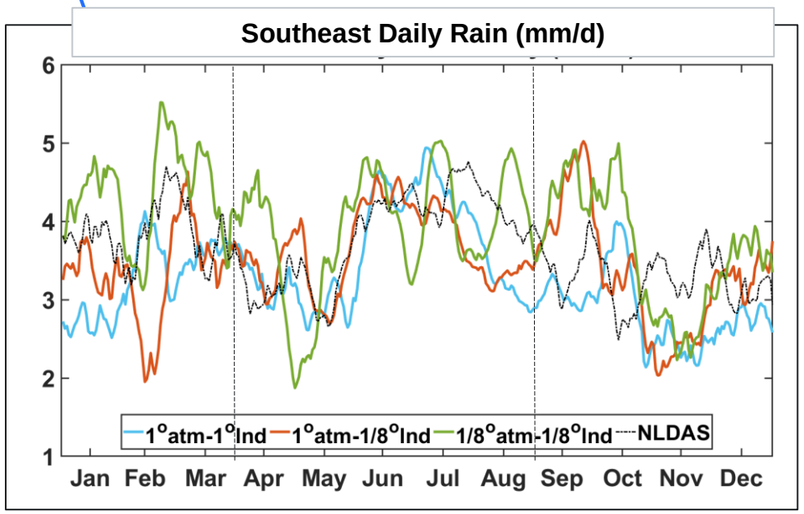




Higher Resolution -> Better precipitation simulation during April-Jun

Overestimation of precipitation - Enhanced at high resolution

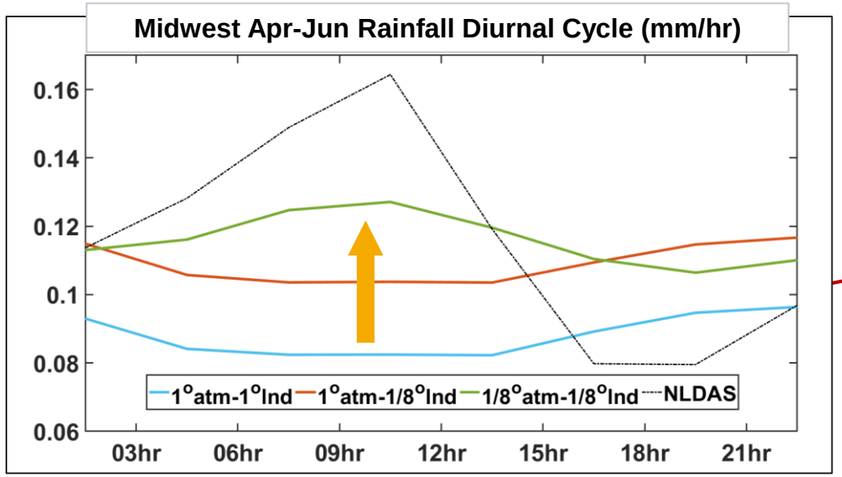


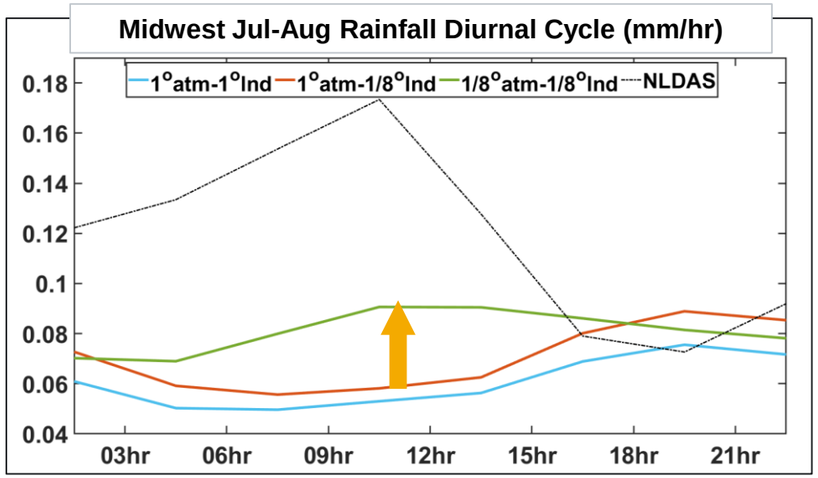


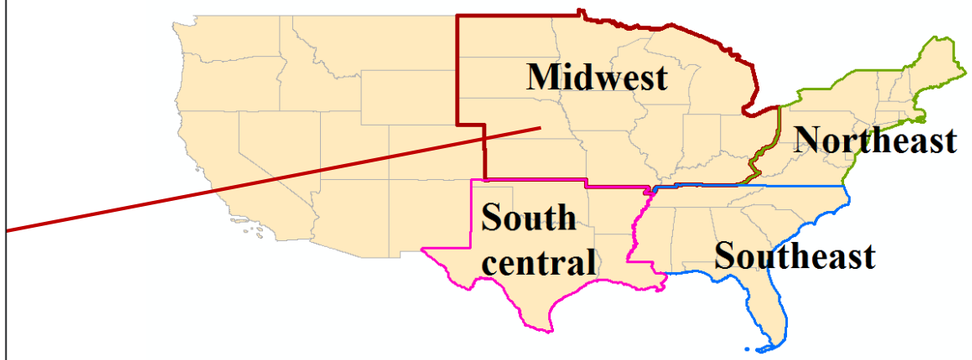
Warm season dry bias persists at all resolutions

Simulated precipitation in line with observations

Regional Precipitation: Diurnal cycle



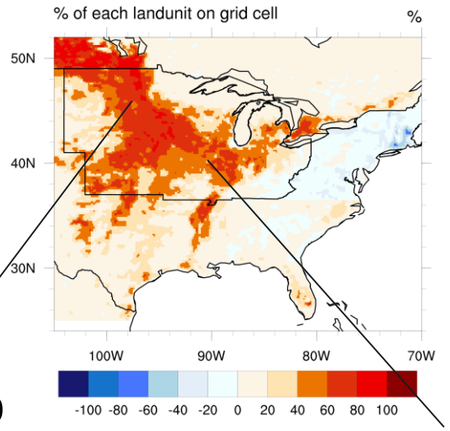




- **Higher resolution** in **land model** increases precipitation **amount**
- **Higher resolution** in **atmospheric model** further changes the **phase** of the precipitation **diurnal cycle**

LULCC Changes over CONUS: 2000 - 1850

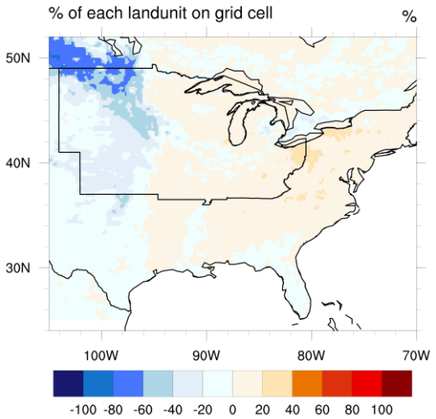
CROP on Grid cell (%)
LU 2000 - 1850



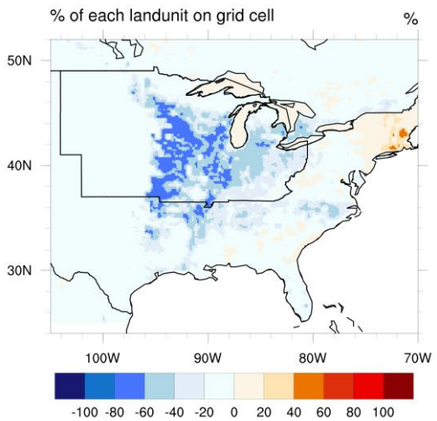
Grass to crop

Tree to crop

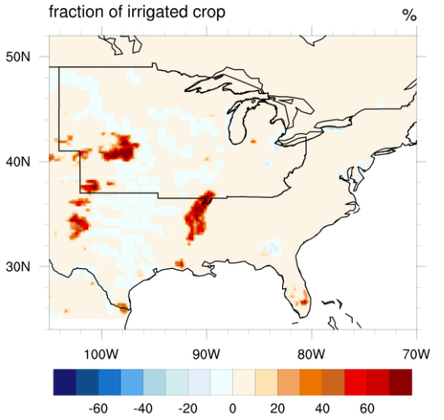
GRASS on Grid cell (%)
LU 2000 - 1850



TREE on Grid cell (%)
LU 2000 - 1850



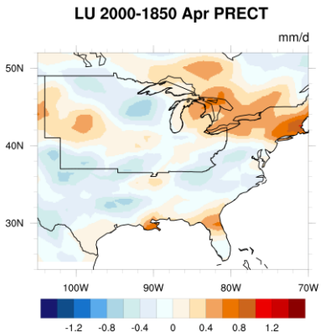
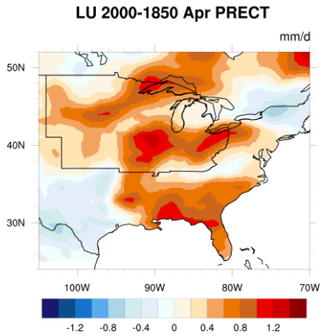
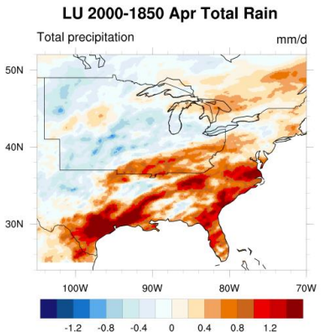
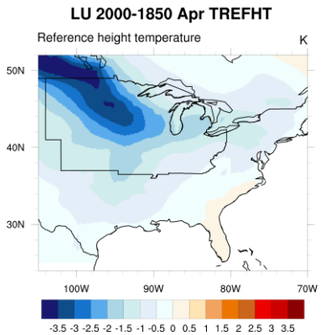
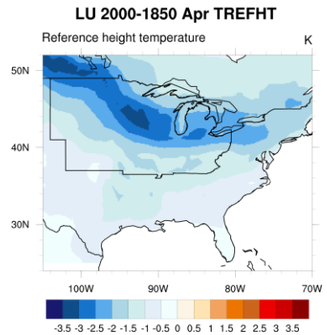
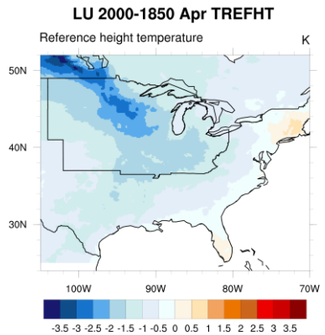
Irrigated CROP on Grid cell (%)
LU 2000 - 1850



Increase in cropland over Midwest
Majorly unirrigated

Results:
LULCC Induced Changes in PRCP and T-2m

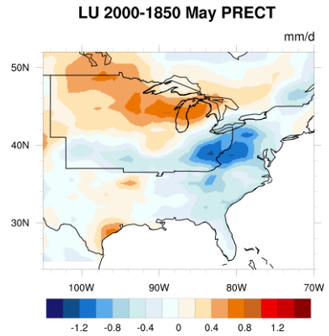
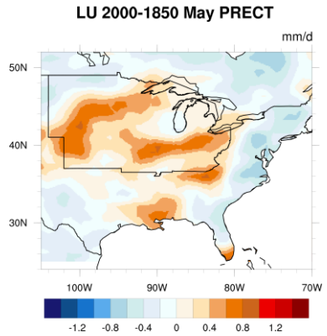
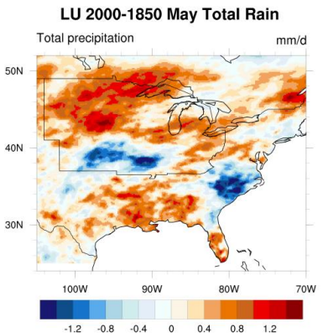
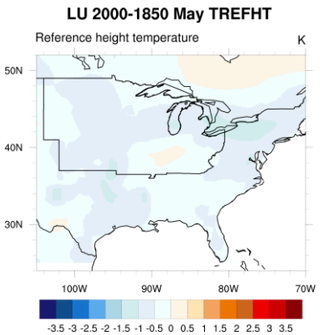
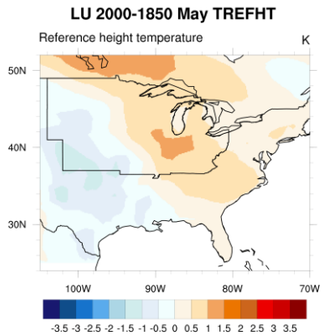
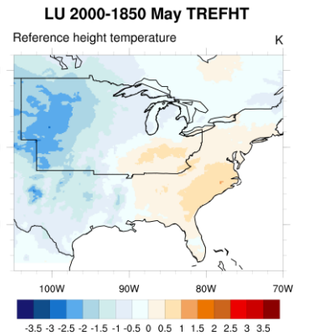
April

	1° atm - 1° land	1° atm – ⅛° land	⅛° atm - ⅛° land
PRCP Changes			
T-2m Changes			

Increase over Central U.S.

Near surface cooling

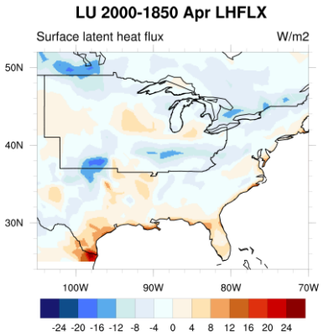
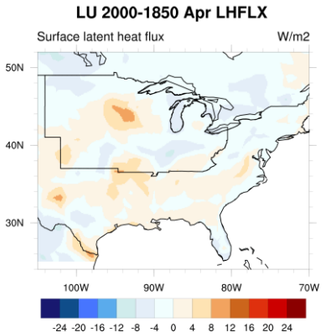
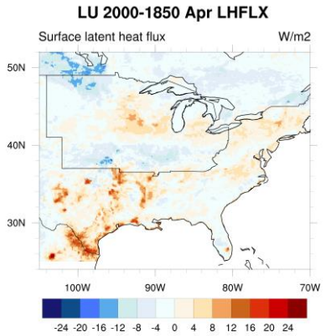
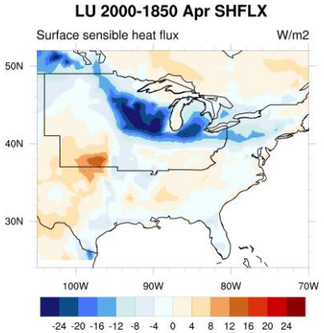
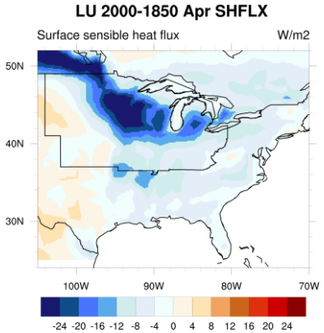
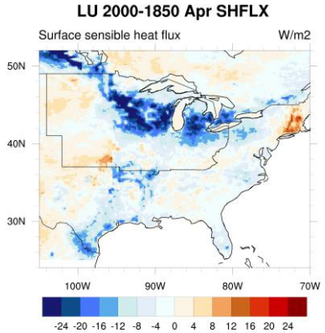
May

	1° atm - 1° land	1° atm – ⅛° land	⅛° atm - ⅛° land
PRCP Changes			
T-2m Changes			

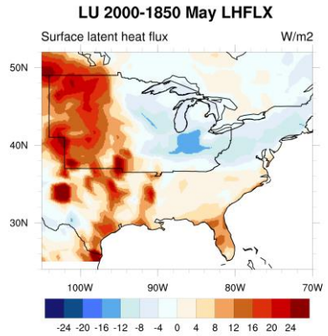
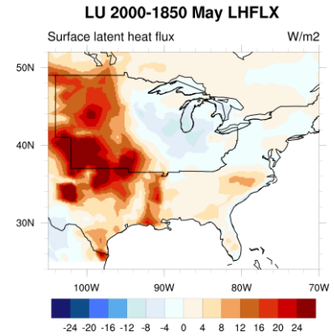
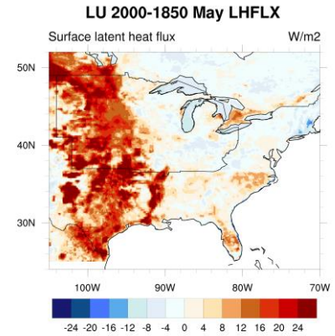
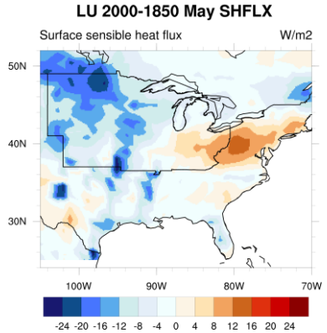
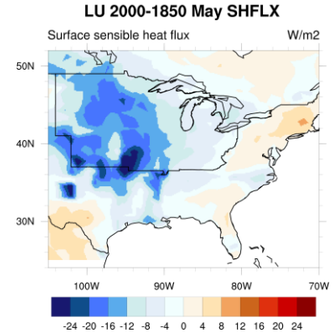
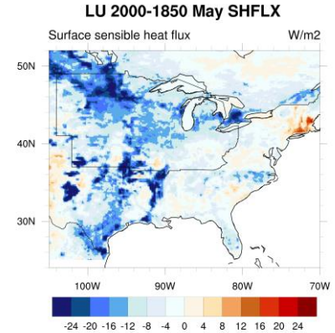
Results

LULCC Induced changes in Surface fluxes

April

	1° atm - 1° land	1° atm – ⅛° land	⅛° atm - ⅛° land
LH			
SH			

May

	1° atm - 1° land	1° atm – ⅛° land	⅛° atm - ⅛° land
LH			
SH			

LH

Increase with start of growing season

SH

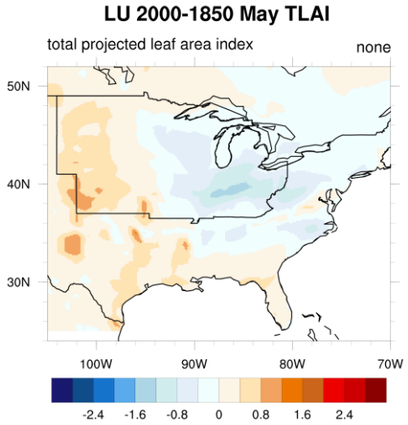
Decrease - Pattern change across months

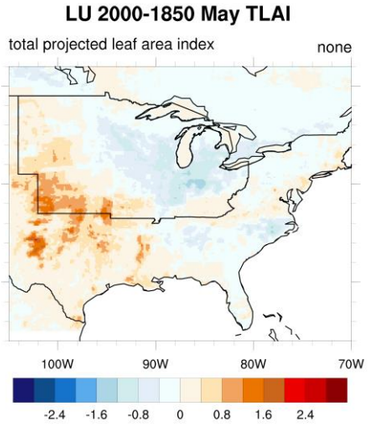
Results
Changes of LH Flux and LAI in May

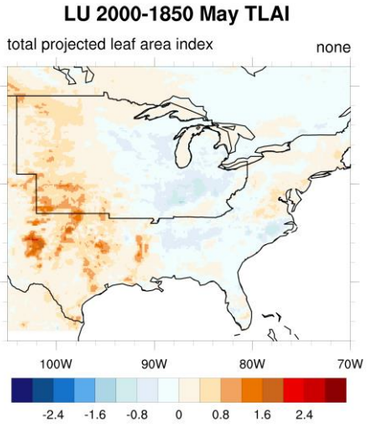
May

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

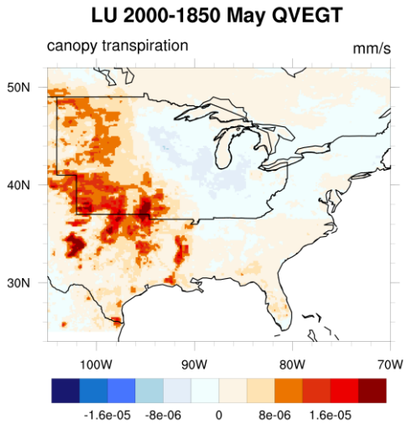
LAI Changes

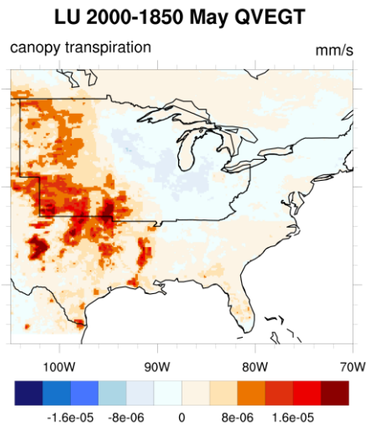


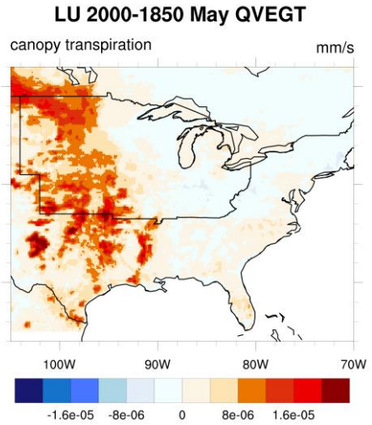




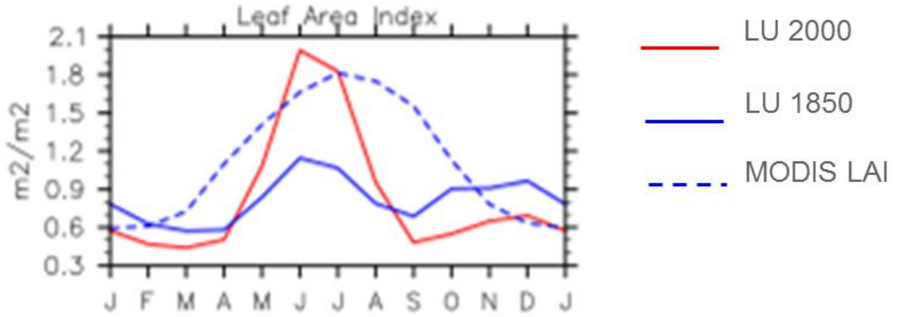
Vegetation Transpiration Changes







Model simulated LAI over Central US matches MODIS observations



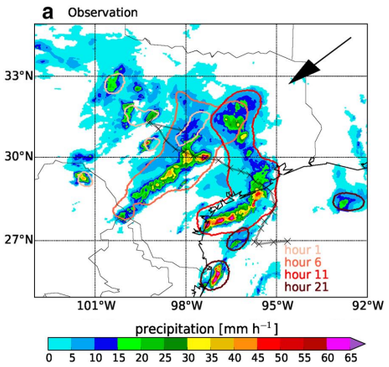
Latent heat flux increases – comes from vegetation transpiration – due to increase in crop LAI

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

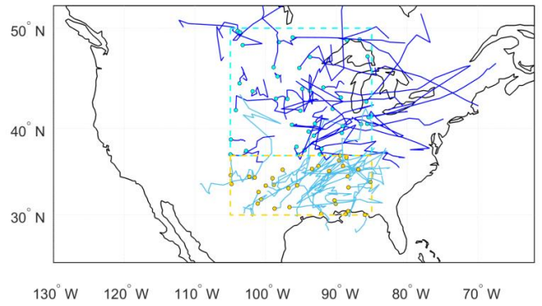
MCS Example



Source: Prein et al. 2017

- **1° atm - 1° land & 1° atm - ⅛ ° land :** No trackable features
- **⅛° atm - ⅛° 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

MCS-like Feature tracks in May
⅛° atm - ⅛° land



Results

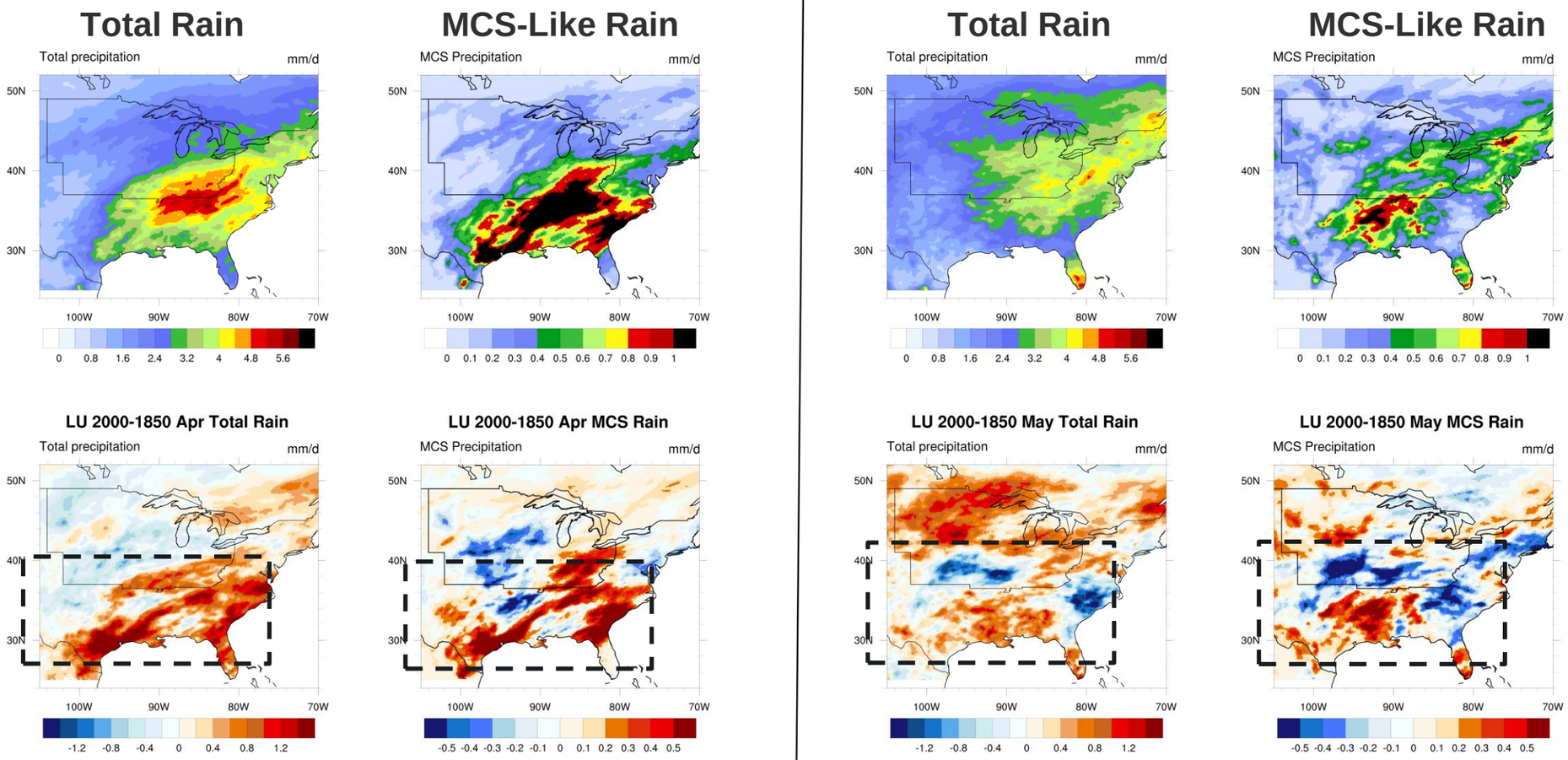
LULCC Induced differences in MCS-Like Features: ⅛° atm - ⅛° land

April

May

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

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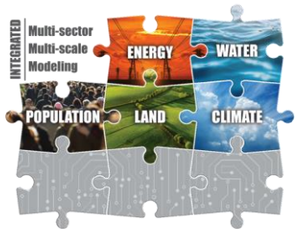
Thank You

DOE Office of Science

Multisector Dynamics,
Regional and Global Model Analysis,
Earth and Environmental System Modeling Program



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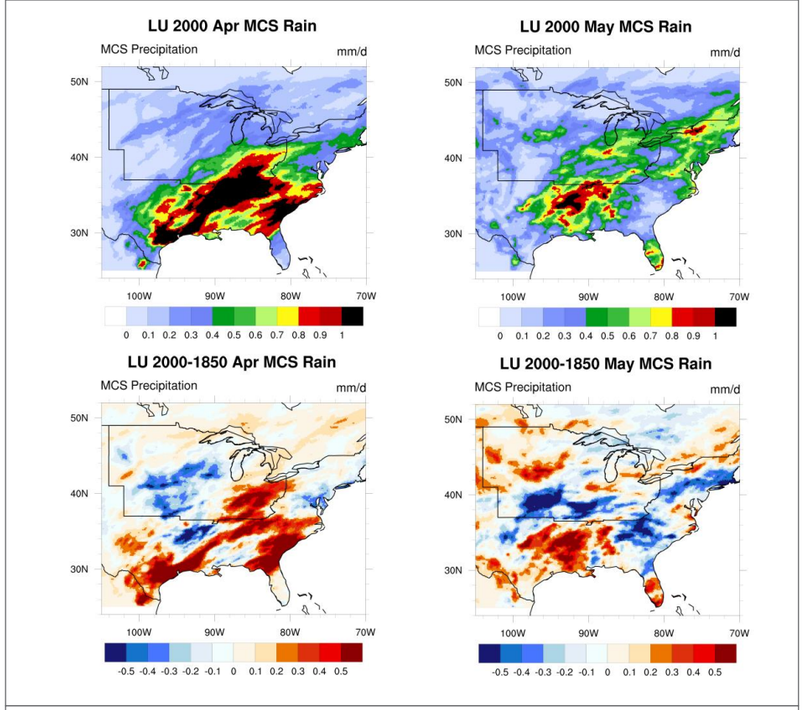
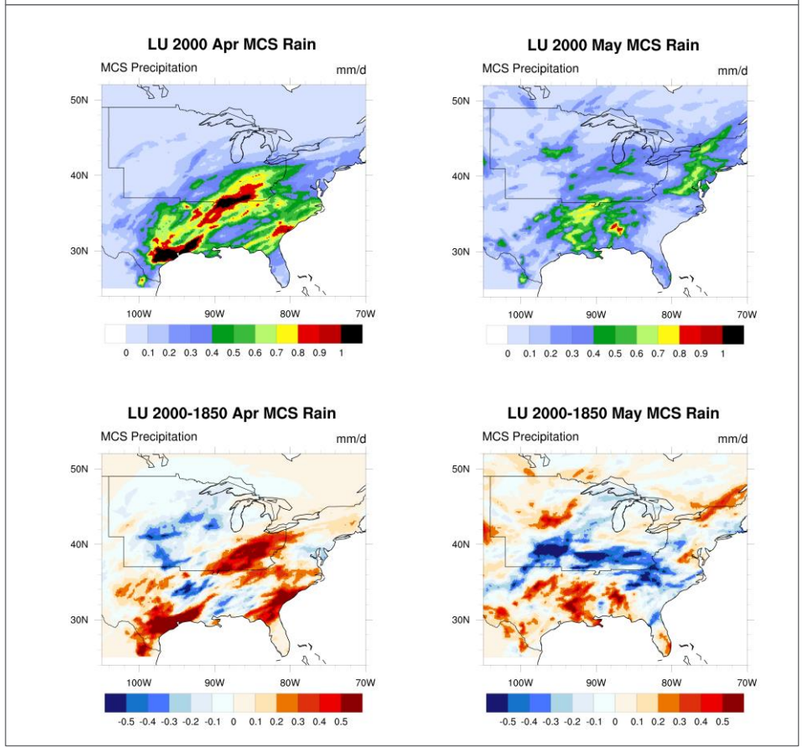
Mean MCS rain



New Thresholds
MCS Rain (mm/d)
Apr-Aug by month



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

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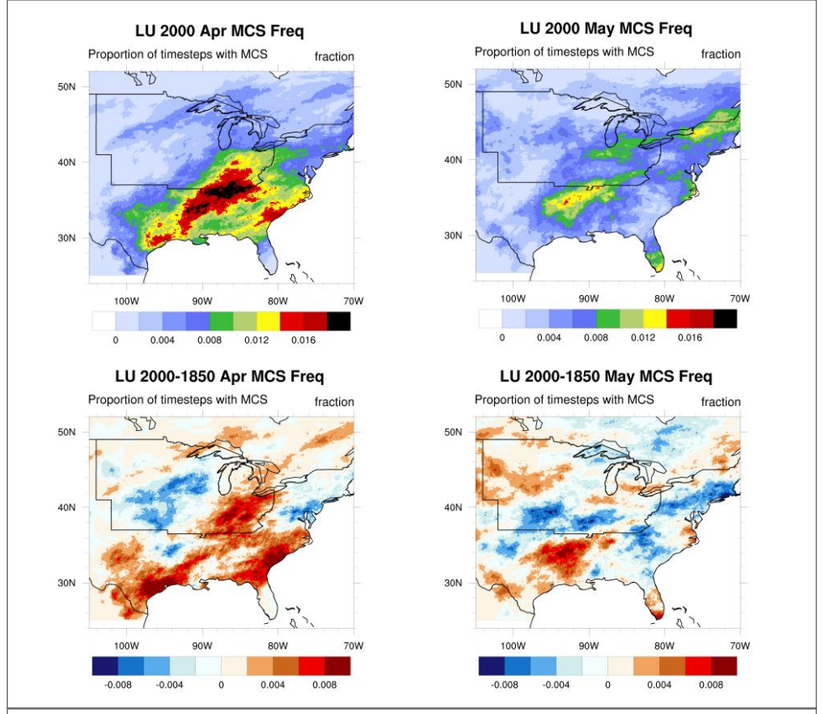
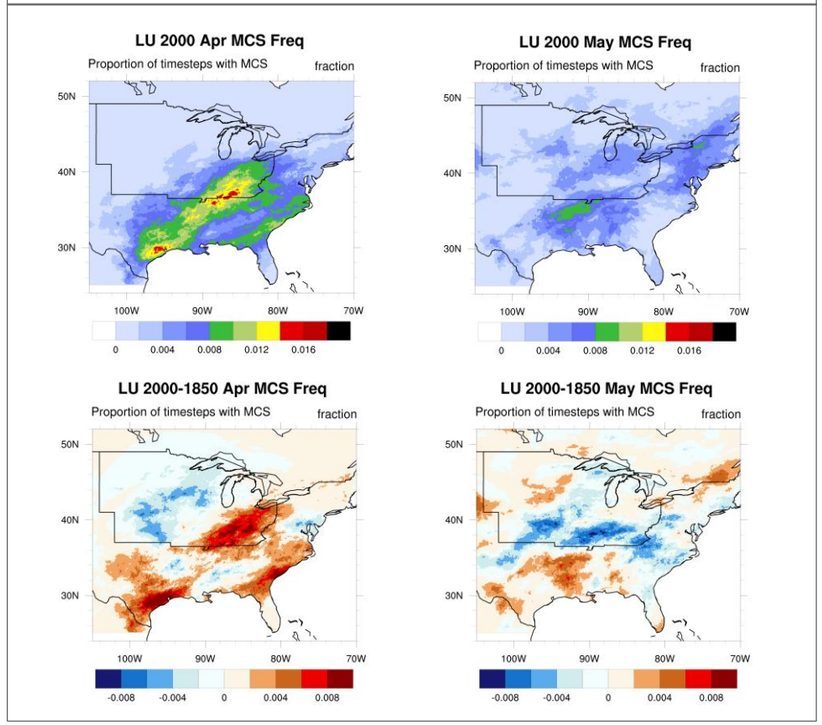
MCS Frequency

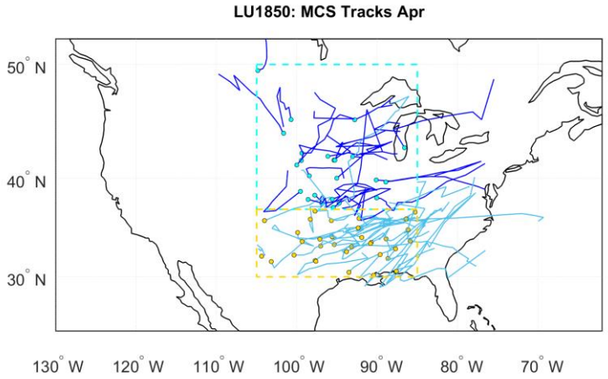
*No. of timesteps when MCS exists/Total number of timesteps – calculated using MCS mask to set a 1/0 flag

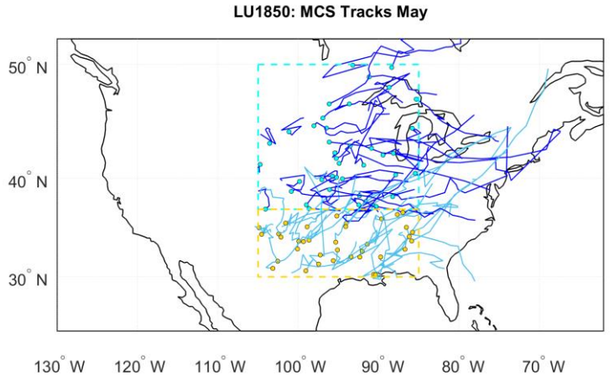


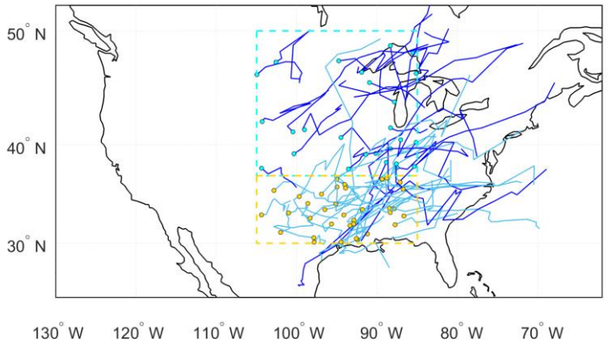
New Thresholds
MCS Frequency (fraction)
Apr-Aug by month

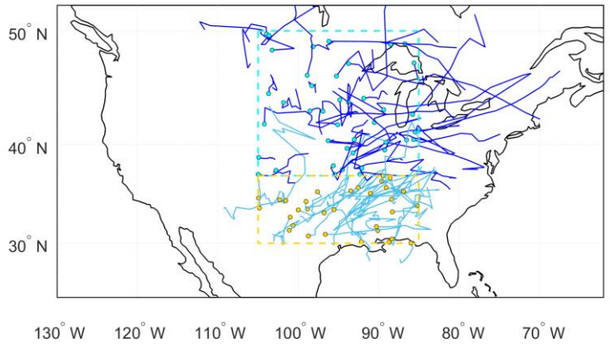


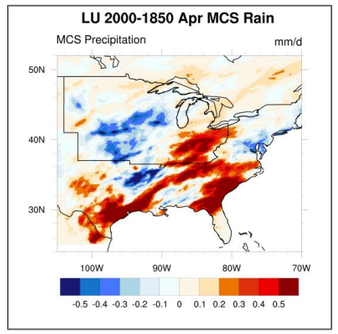
Default Thresholds
MCS Frequency (fraction)
Apr-Aug by month

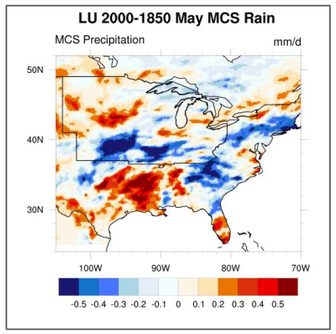

LU1850: MCS Tracks Apr
50° N
40° N
30° N
130° W
120° W
110° W
100° W
90° W
80° W
70° W


LU1850: MCS Tracks May
50° N
40° N
30° N
130° W
120° W
110° W
100° W
90° W
80° W
70° W


LU2000: MCS Tracks Apr
50° N
40° N
30° N
130° W
120° W
110° W
100° W
90° W
80° W
70° W


LU2000: MCS Tracks May
50° N
40° N
30° N
130° W
120° W
110° W
100° W
90° W
80° W
70° W


LU 2000-1850 Apr MCS Rain
MCS Precipitation
mm/d
50N
40N
30N
100W
90W
80W
70W
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5


LU 2000-1850 May MCS Rain
MCS Precipitation
mm/d
50N
40N
30N
100W
90W
80W
70W
-0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5

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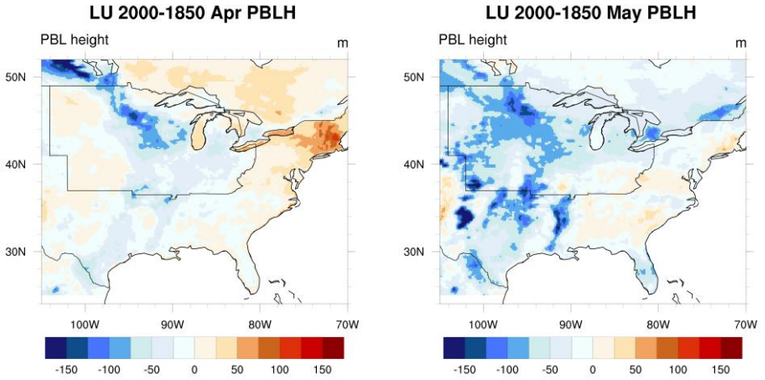

LCL