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

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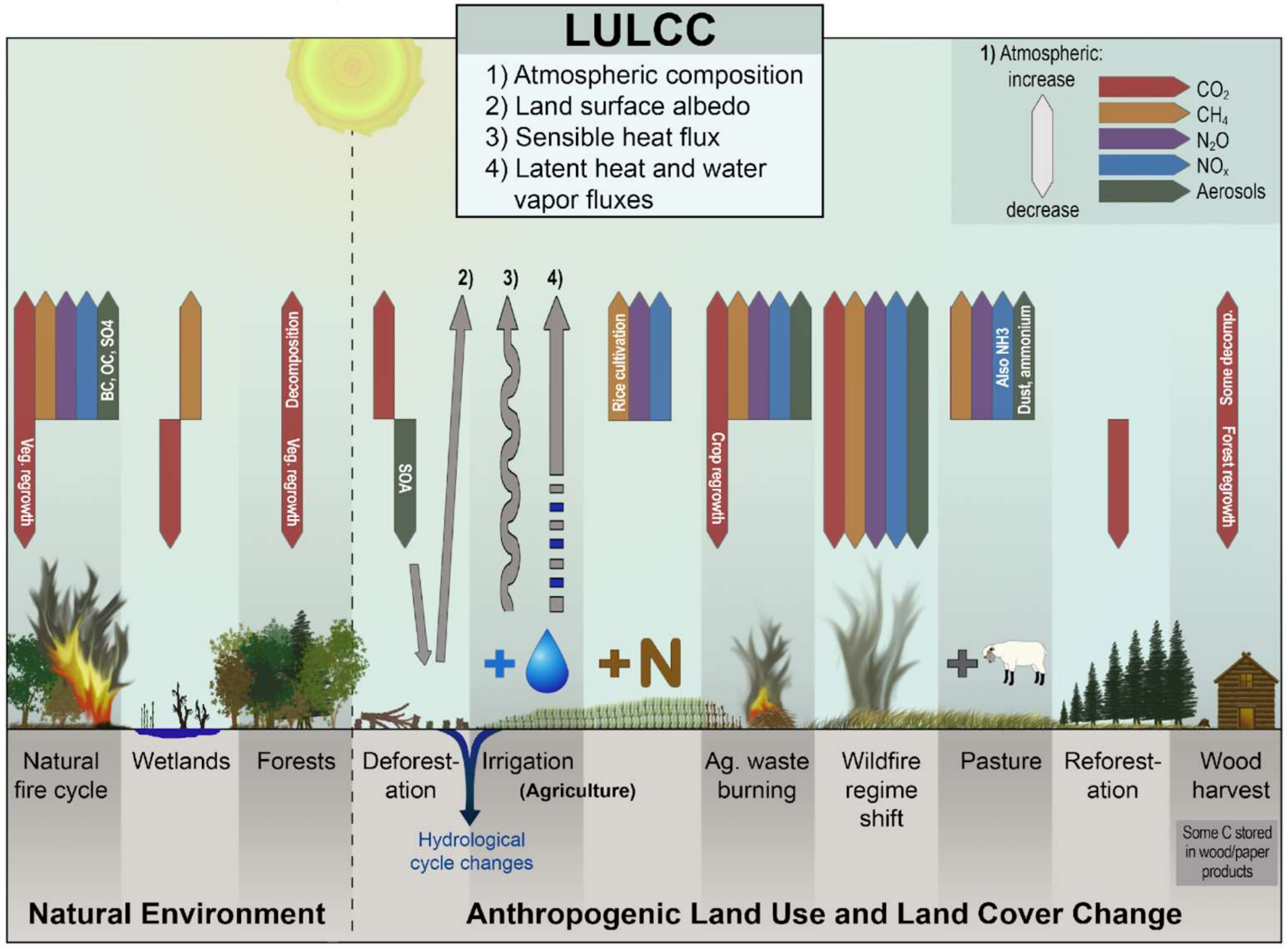
Biogeochemistry Science Friday Webinar

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

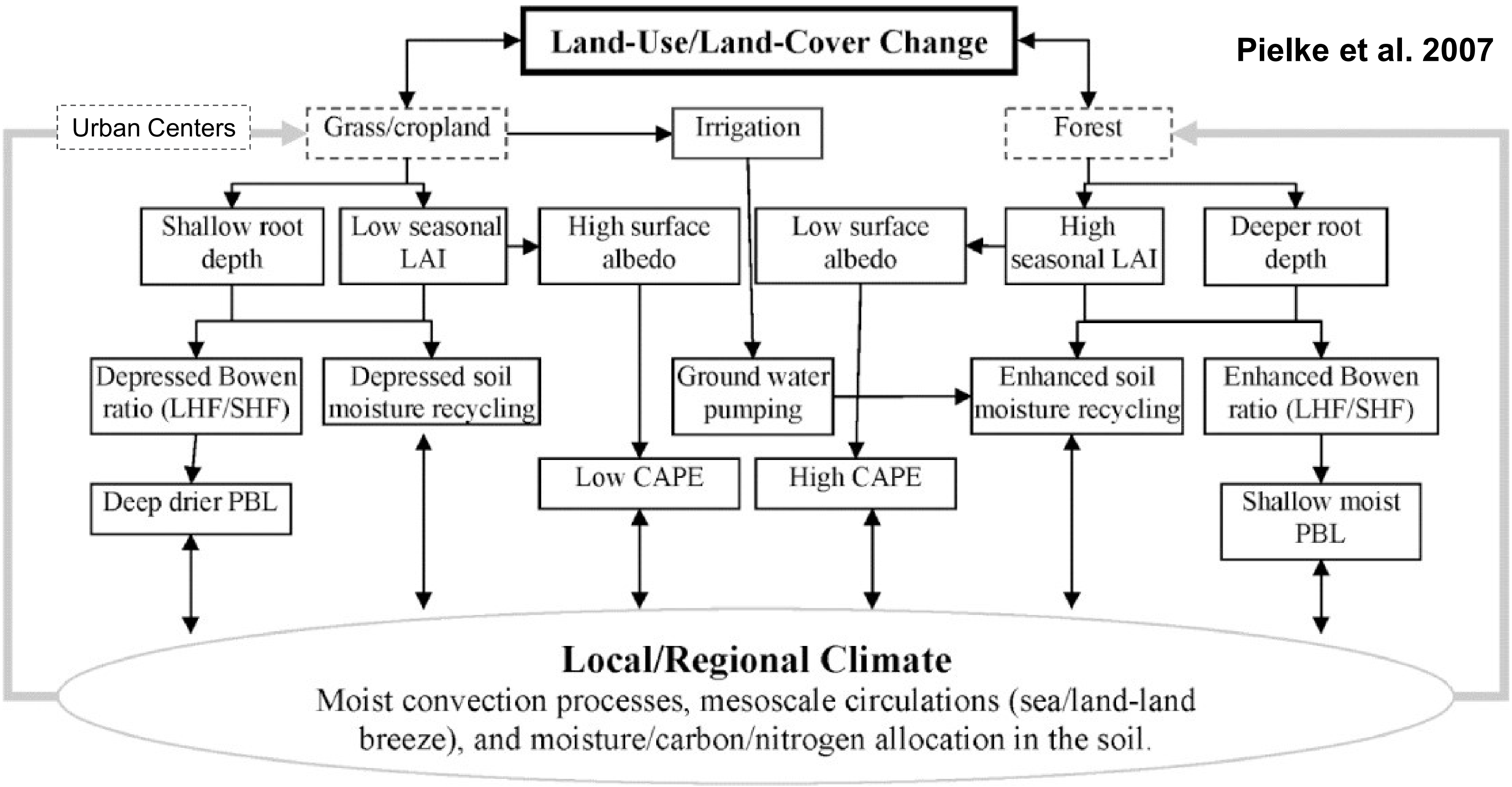


Hibbard et al., 2017, CSSR, 4th NCA

- ❑ 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**)
  - ❑ Direct biogeophysical radiative impact of LULCC on global radiative forcing is small relative to other forcings.
  - ❑ LULCC is a highly regionalized phenomenon with regional-scale climate impacts that can vary in the sign of the change.

Biophysical Processes associated LULCC are local to regional scaled in nature

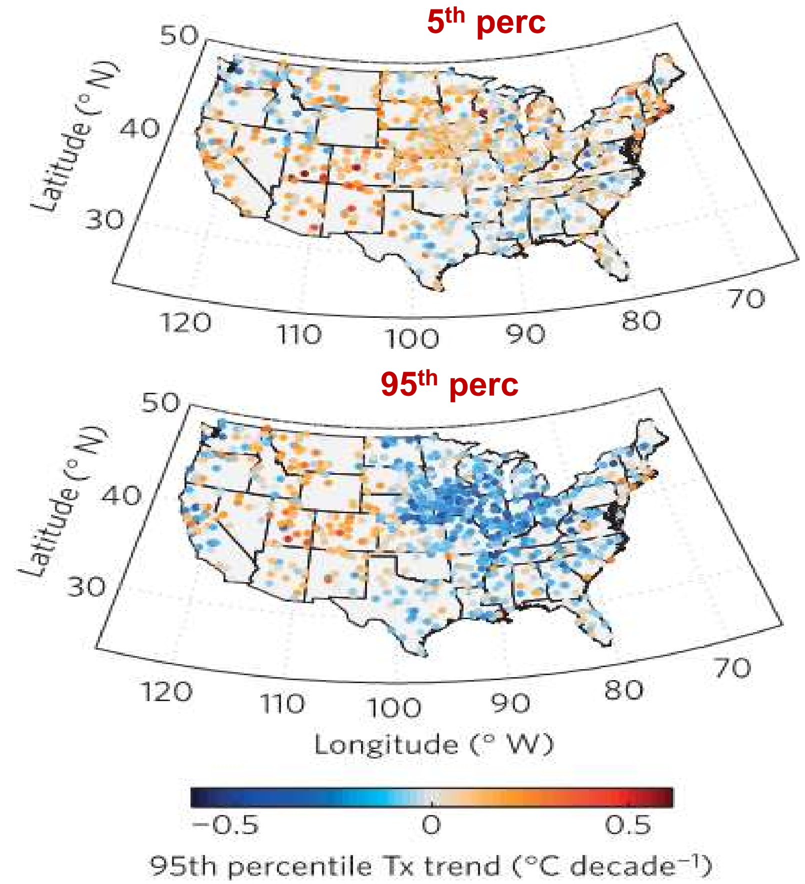
Pielke et al. 2007



These processes are typically better resolved in regional models

Why do we focus on effects of LULCC over CONUS?

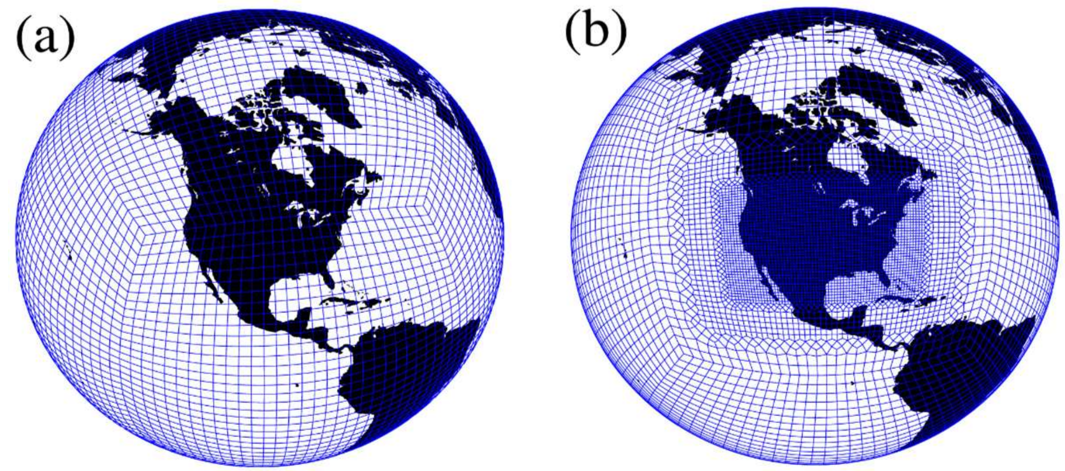
- Most weather forecast and climate models show a common **warm-and-dry bias**, accompanied by the **underestimation of evapotranspiration** and **overestimation of surface net radiation**, over the central U.S. during boreal summer;
- Observational studies suggest that **agricultural intensification** led to a warming hole over the Midwest;
- The central U.S. has been identified as a **land-atmosphere coupling hotspot**;
- We **hypothesize** that the warm-and-dry bias can be reduced by improving simulations of mesoscale convection, better captured in models at higher resolutions and realistic land use representations.



1901-2014 Trends in Tmax
(Excluding Dust Bowl (30's) and Aerosol Induced cooling period (1970-90's)**)**
(Mueller et al, 2015)

Variable resolution configurations of Global Models

ne 30 grid ~ 111 km   ne 240 grid over CONUS ~ 14 km



Source: Lauritzen et al., 2018 (JAMES)

- A new alternative that can be used to study LULCC impacts at finer resolutions, feasible to perform decadal global simulations at 10-30km resolutions in targeted regions;

- Reproduce 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);
- Capture high frequency, high resolution statistics over region of grid refinement (Gettelman et al., 2018);

VR Community Earth System Model 2 (CESM2)

- ❑ CESM2-SE with regional refinement to one eighth degree over the CONUS
- ❑ Land-atmosphere simulations with CAM6-SE and CLM5.0 (BGC and crop modules on)
  - **Compset:** FHIST using CAM6_CLM5_BGC-Crop
- ❑ Historical AMIP type simulations with prescribed SST, atmospheric chemistry and solar variations of 1980-2010
- ❑ Two LULC maps: **Preindustrial (1850) vs. Present day (2000)**
- ❑ **Scale Experiments:**

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)

27 years each
1984-2010

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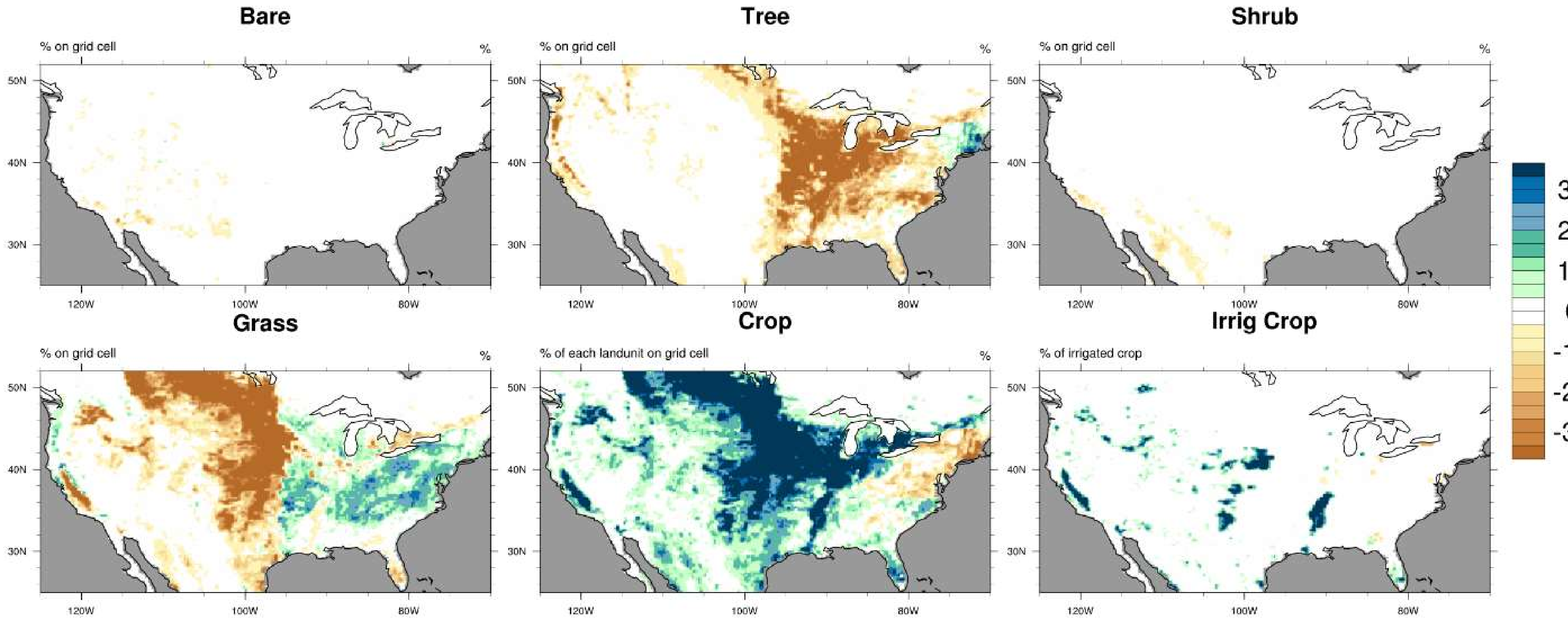
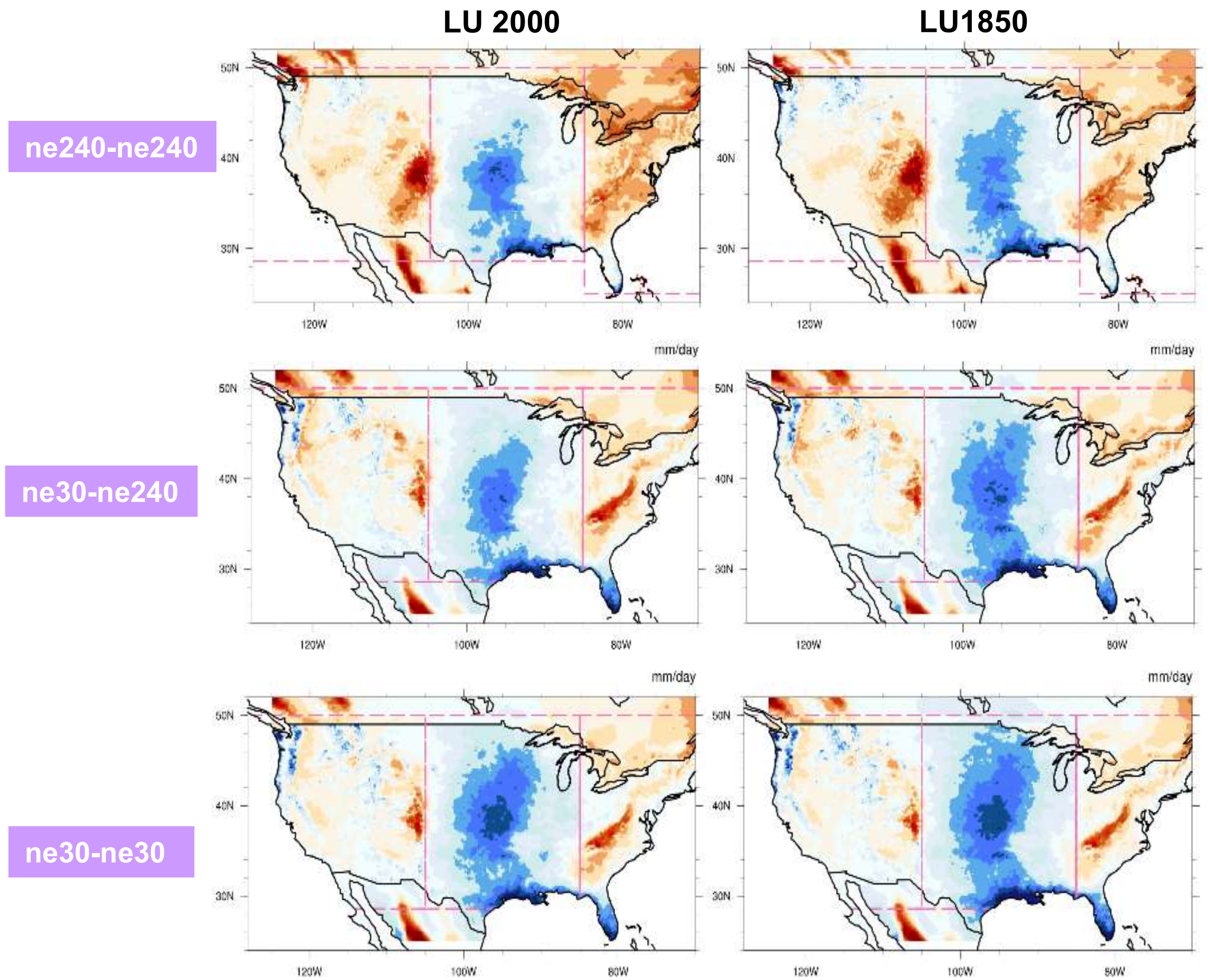
Land use change: Present-day vs. Preindustrial

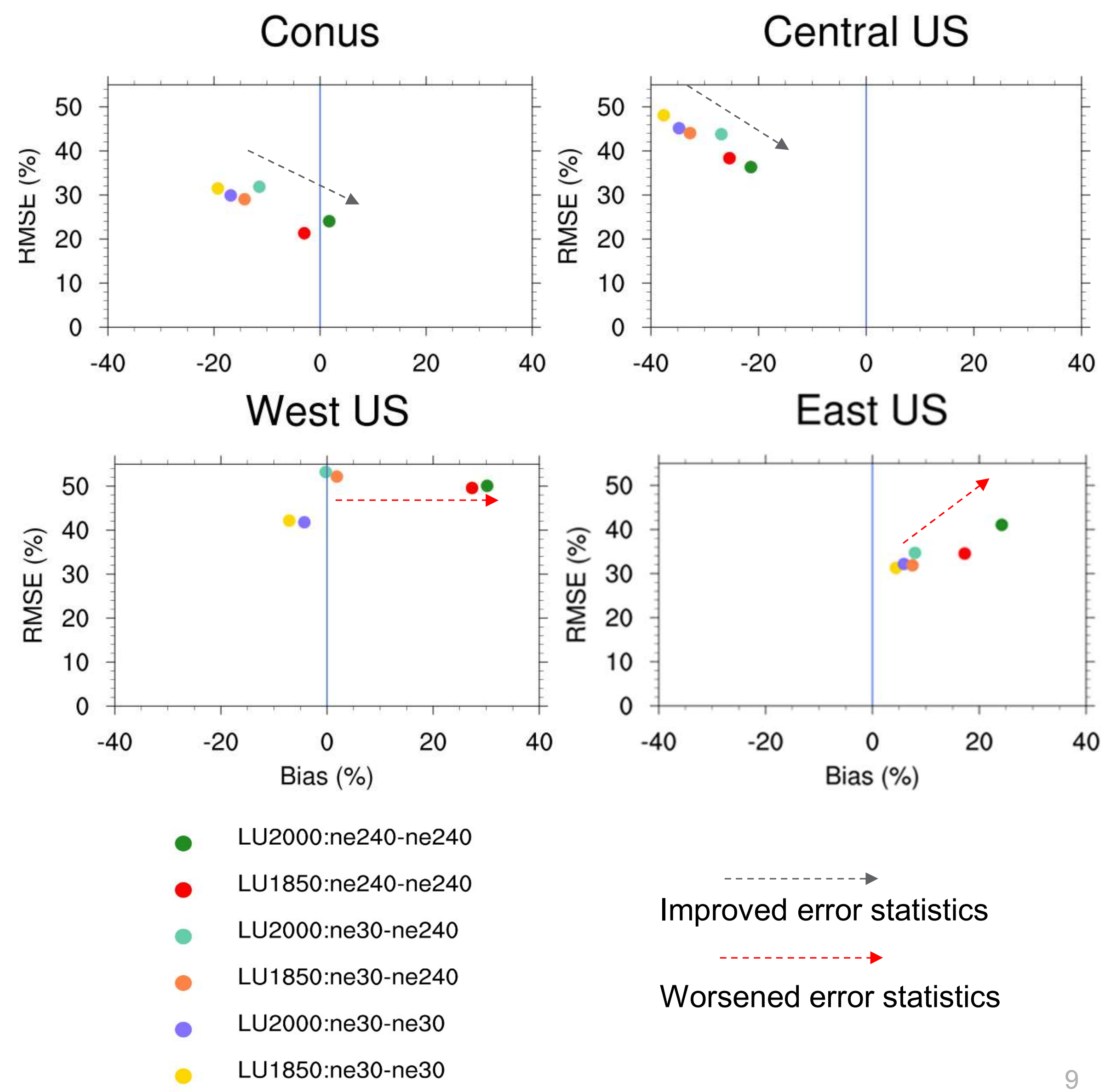


Science questions

- ❑ Can simulations of regional climate over the 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 temperature and precipitation over the CONUS?
  - land cover change
  - Irrigation
  - Agricultural management (planting, fertilizing, harvest)
  - Plant physiology and phenology

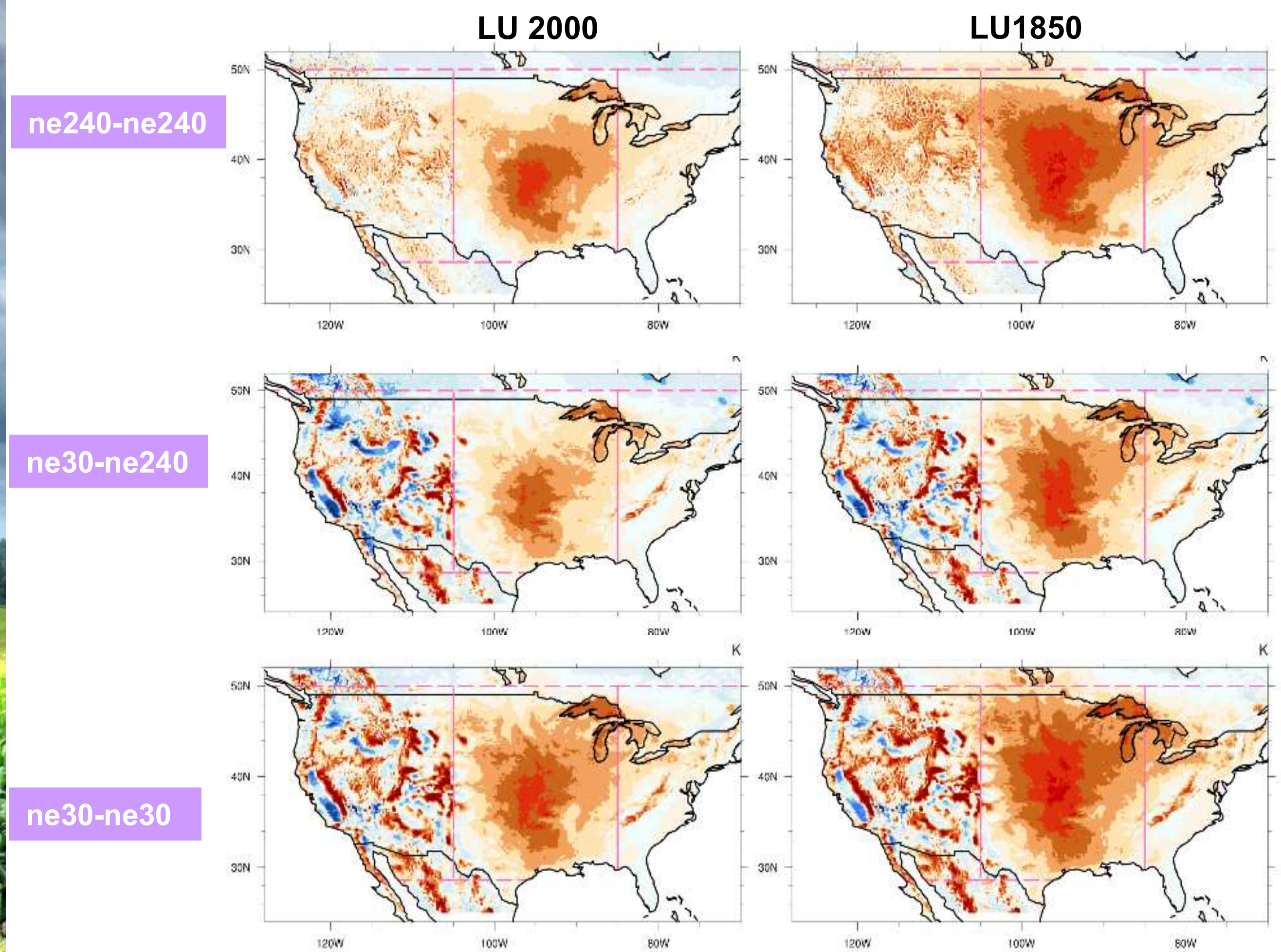
Skill in simulating warm-season precipitation:
comparison to NLDAS, April to August



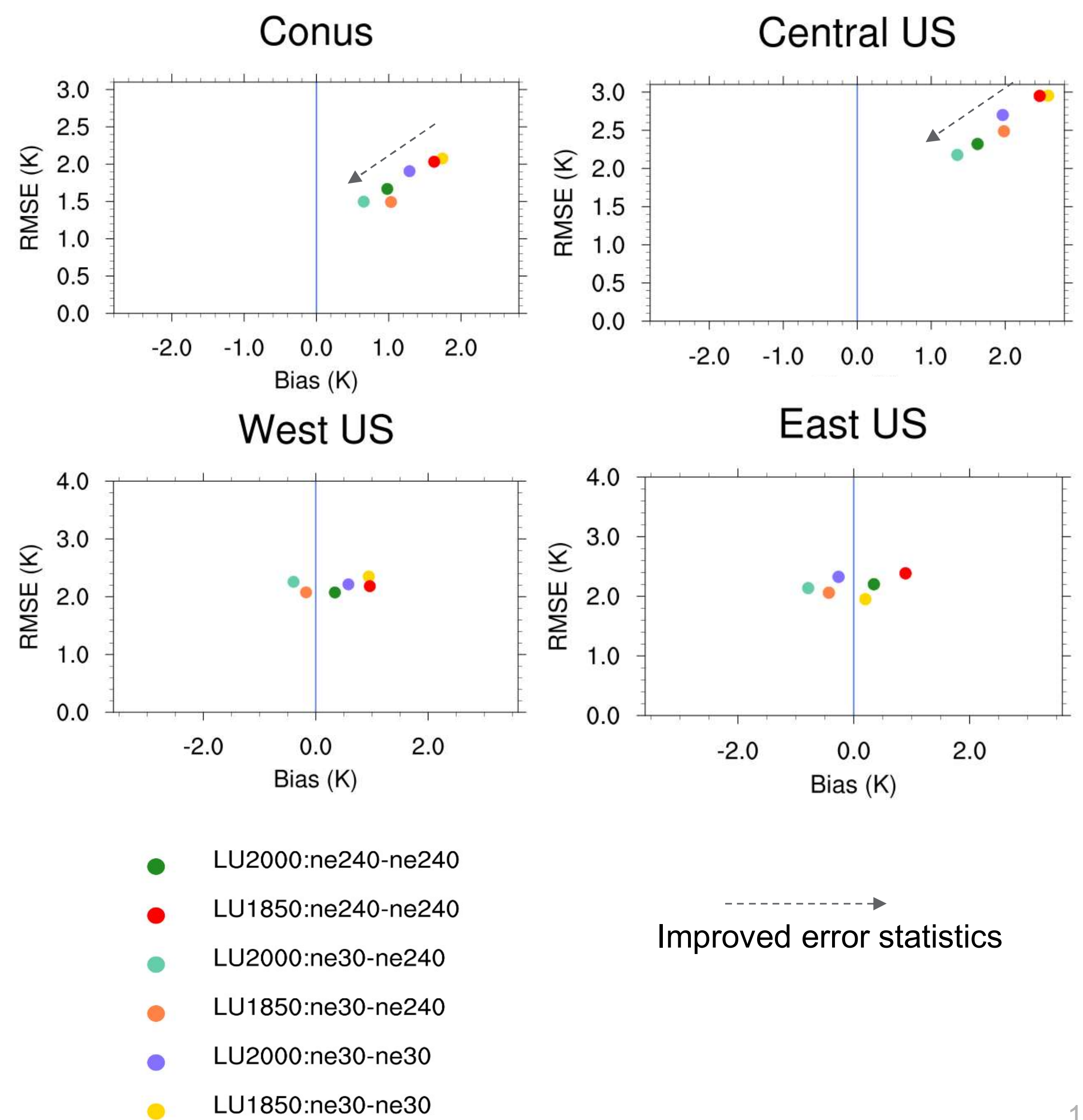


CONUS and Central US: Precipitation improves with resolution
(At the same res, more accurate LU shows lower errors)
Western and Eastern US : Deteriorates

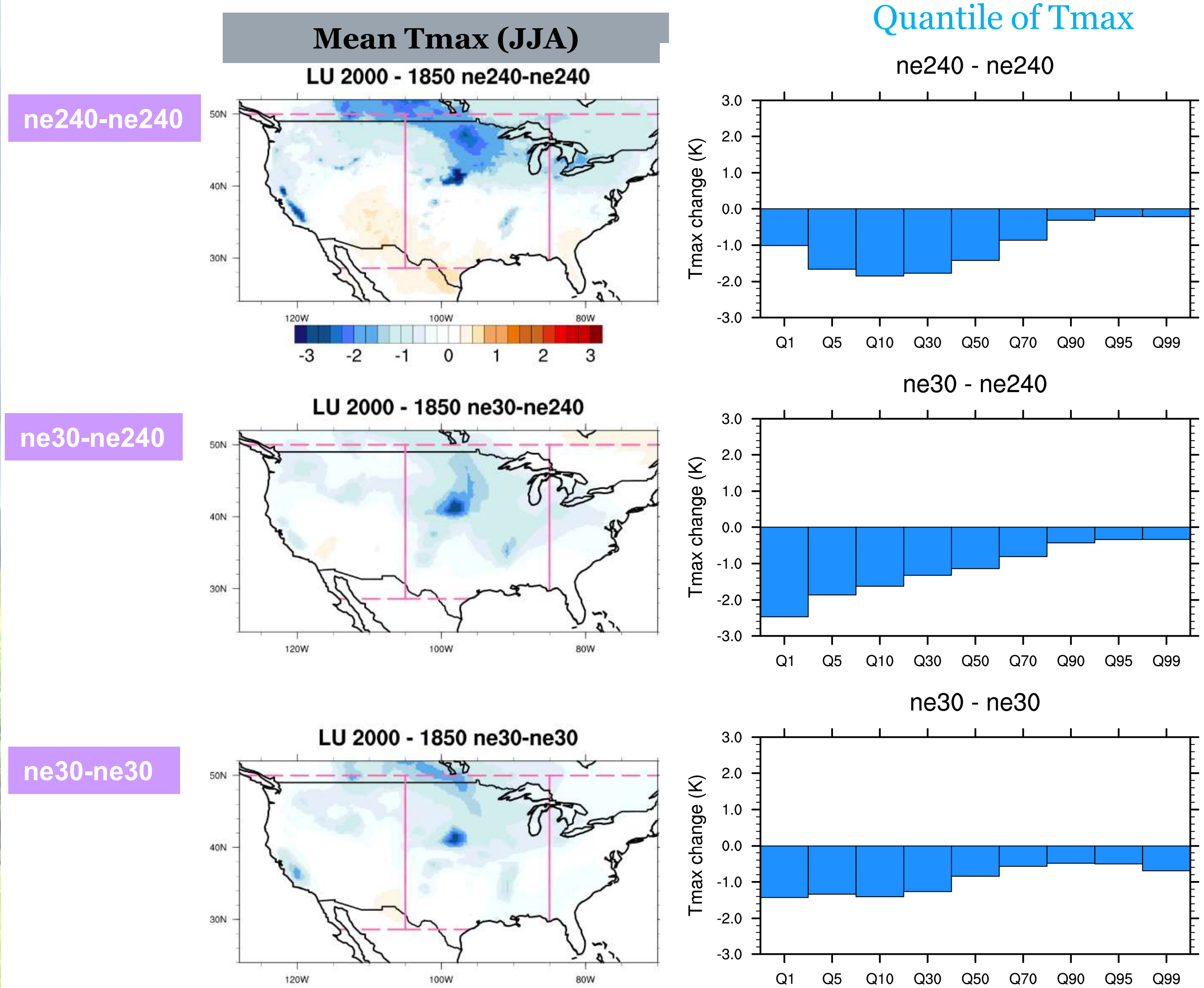
Skill in simulating warm-season daily maximum T-2m: comparison to NLDAS , April to August

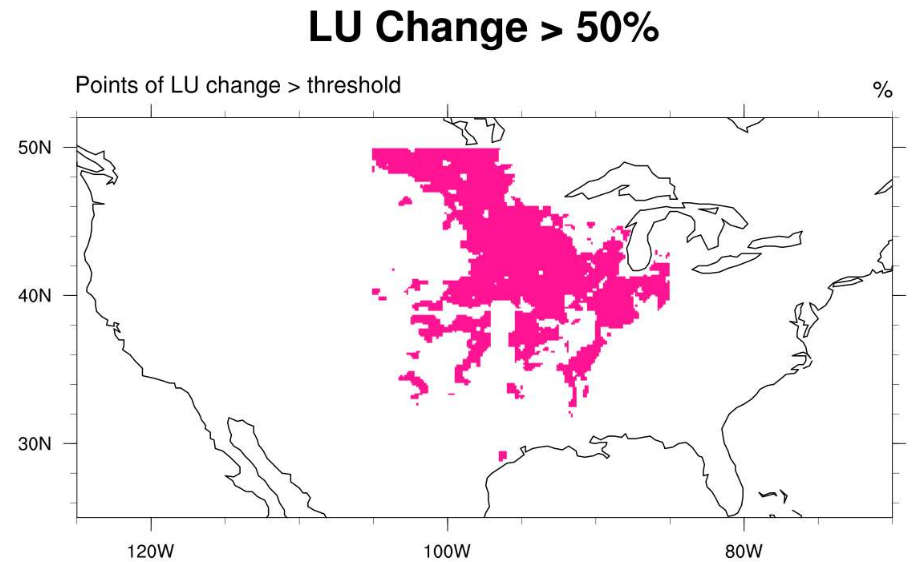


- Land-use is the dominant factor influencing temperature skill: simulations using a more accurate LU shows lower error stats



LULCC Effect on Summer daily max T-2m





- Cooling in T-2m max primarily over areas of crop expansion over the Midwest;
- Larger cooling effect are at the lower quantiles of max T-2m – up to the 50th percentile.

Effects of different LU transitions on Summer daily max T-2m

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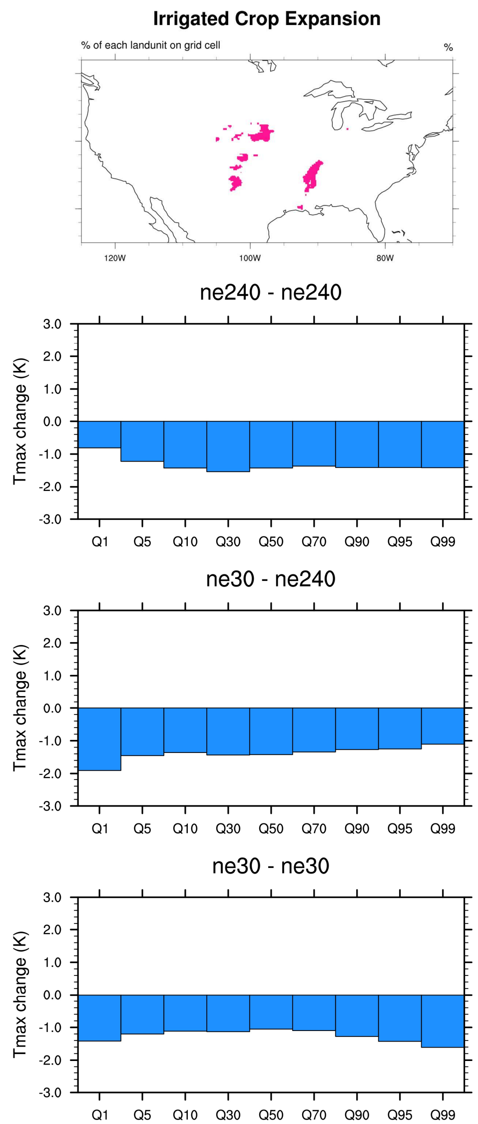
ne240-ne240

ne 30-ne240

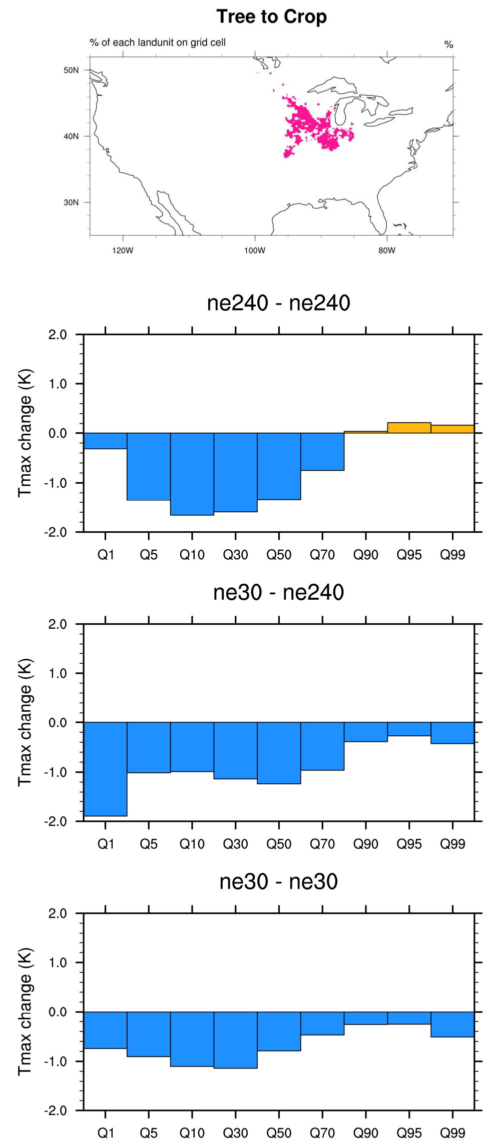
ne 30-ne30

Irrigated cropland (at least 30% of grid cell irrigated)



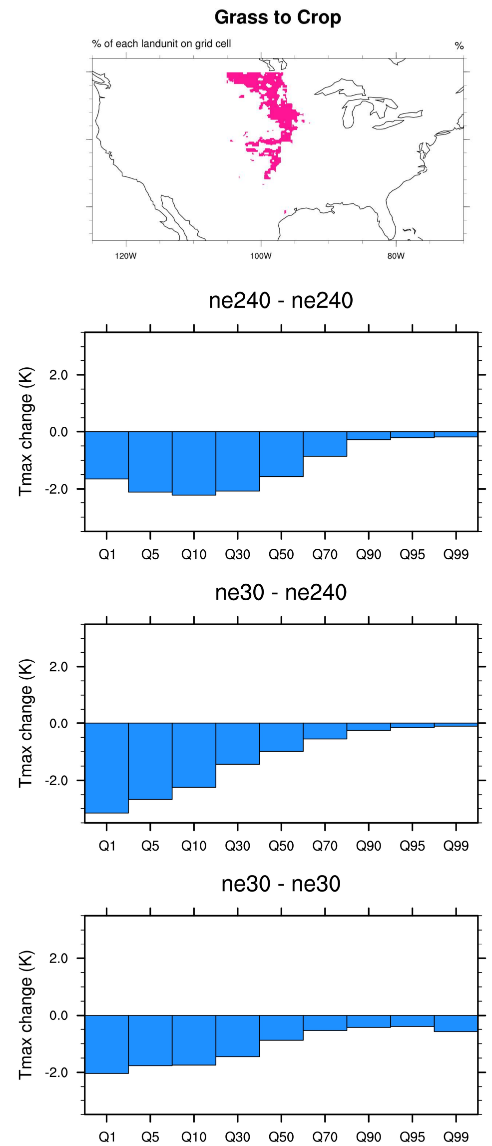
Sustained cooling

Conversion of tree to crop > 50% of grid cell



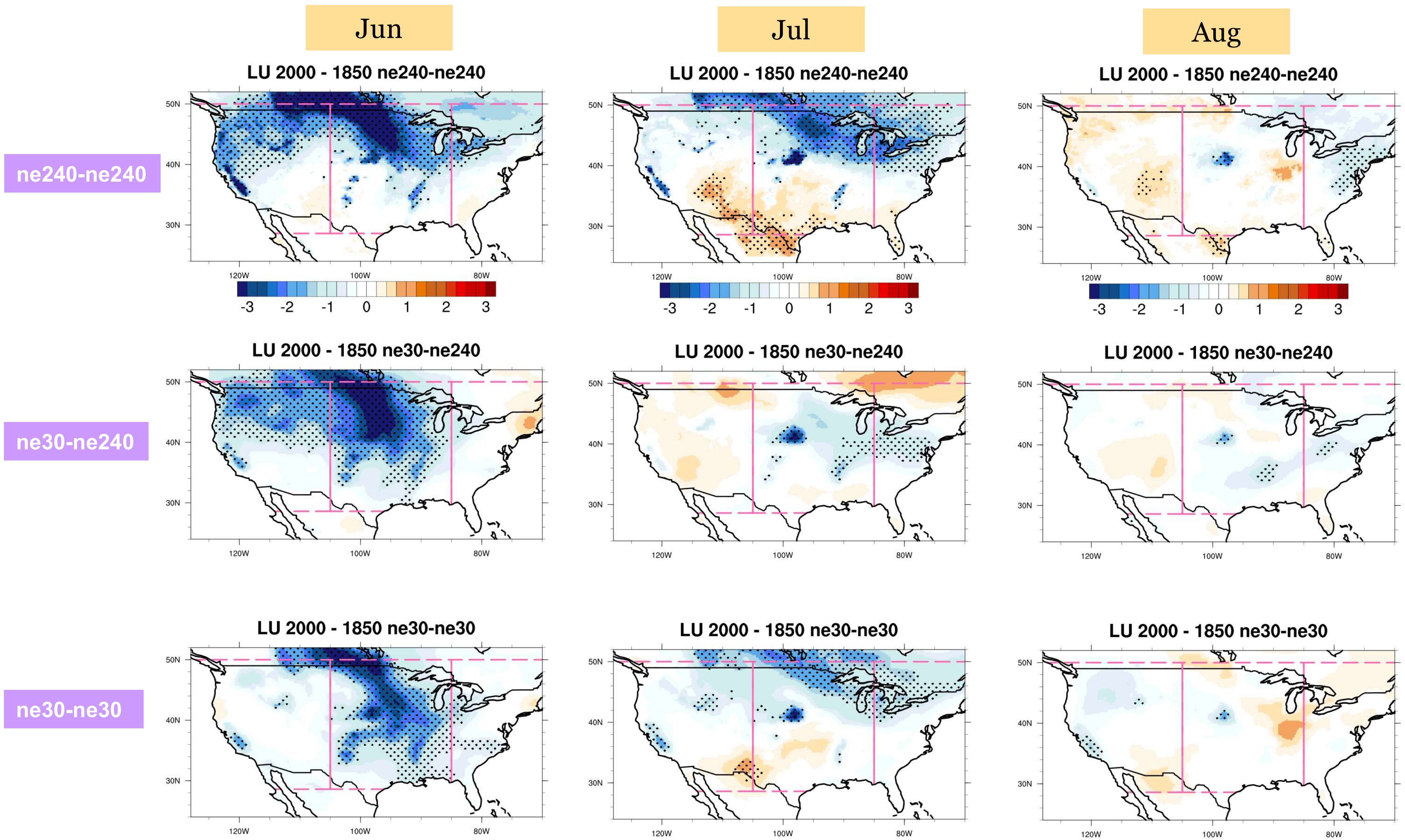
High Res – warming at higher Q

Conversion of grass to crop > 50% of grid cell



Higher cooling at lower quantiles upto 50th perc

LULCC Effect on Daily Max T-2m by Month



- Maximum cooling in June
- Stronger cooling at high res

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Variation in the Cooling Effect at Different Quantiles

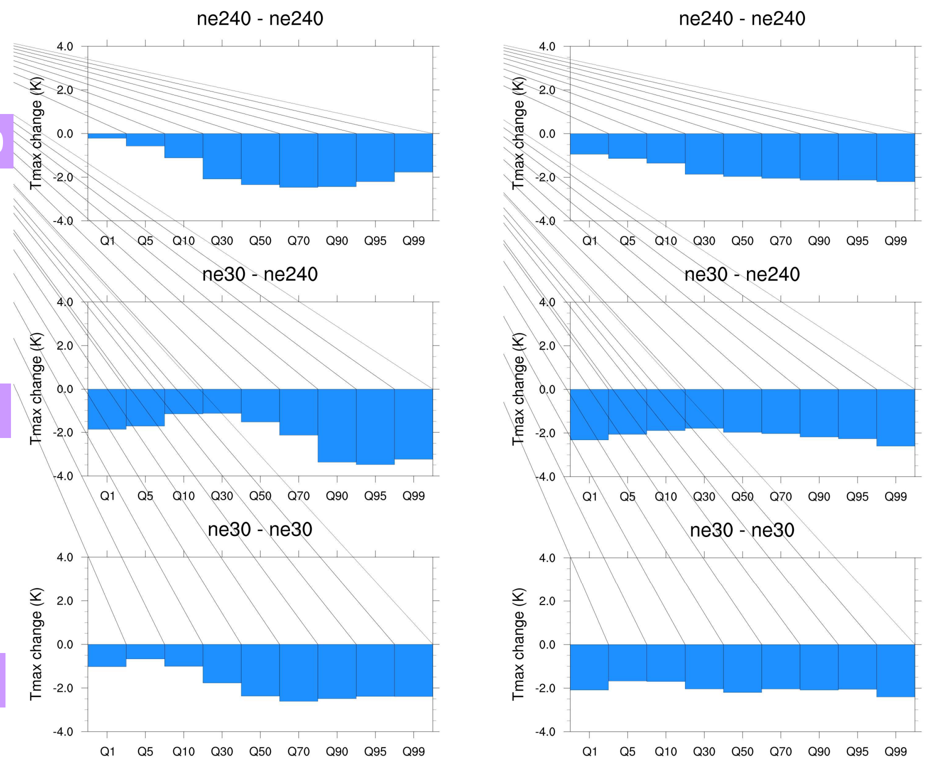
Jun: Cooling at higher quantiles

Tree –> Crop Grids | **Irrigated Crop**

ne240-ne240

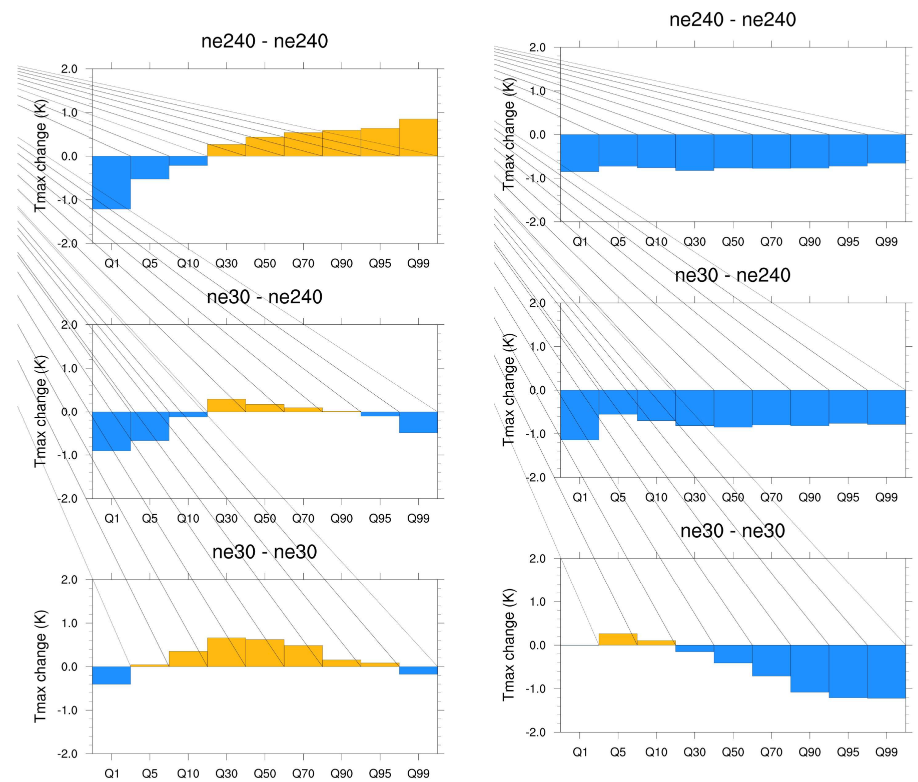
ne30-ne240

ne30-ne30



Aug: Warming over Tree->Crop, Cooling over Irrig

Tree –> Crop Grids | **Irrigated Crop**



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Temperature Decomposition

- Land Surface Energy Balance – Partitioning of incoming energy into surface energy fluxes, influencing Ts
- Decomposition of the budget: To understand the contributions of the multiple influences on the Surface Temperature

$$R_n = SW_{in} - LW_{out} + LW_{in} = LH + SH + G$$

$$R_n = (1 - alb)SW_{down} - const * T_s{}^4 + LW_{down} = LH + SH + G$$

$$\Delta T_s = \frac{1}{const * T_s^3}\left[[-SW_{in}\Delta(alb)] + [(1 - alb)\Delta SW_{in}] + [\Delta LW_{in}] + [-\Delta LH] + [-\Delta SH] + \Delta R\right]$$

Albedo term | SW term | LW term | LH term | SH term | Residual

Potential LU change influences:

- Change in Surface Albedo
- Change in cloud cover influencing SW & LW rad
- Change in Surface energy partitioning
- Residual (eg: Subsurface energy storage)

- In literature, the method has been applied on monthly data to understand the monthly mean T changes
- Here we apply it on **Composite mean of days > Q90**

(to understand changes during extreme temperature days)

References:

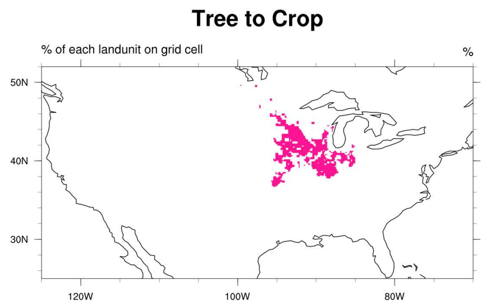
Juang et al. (2007, GRL)

Luyssaert et al. (2014, Nat. Clim. Ch.)

Thierry et al. (2017, JGR)

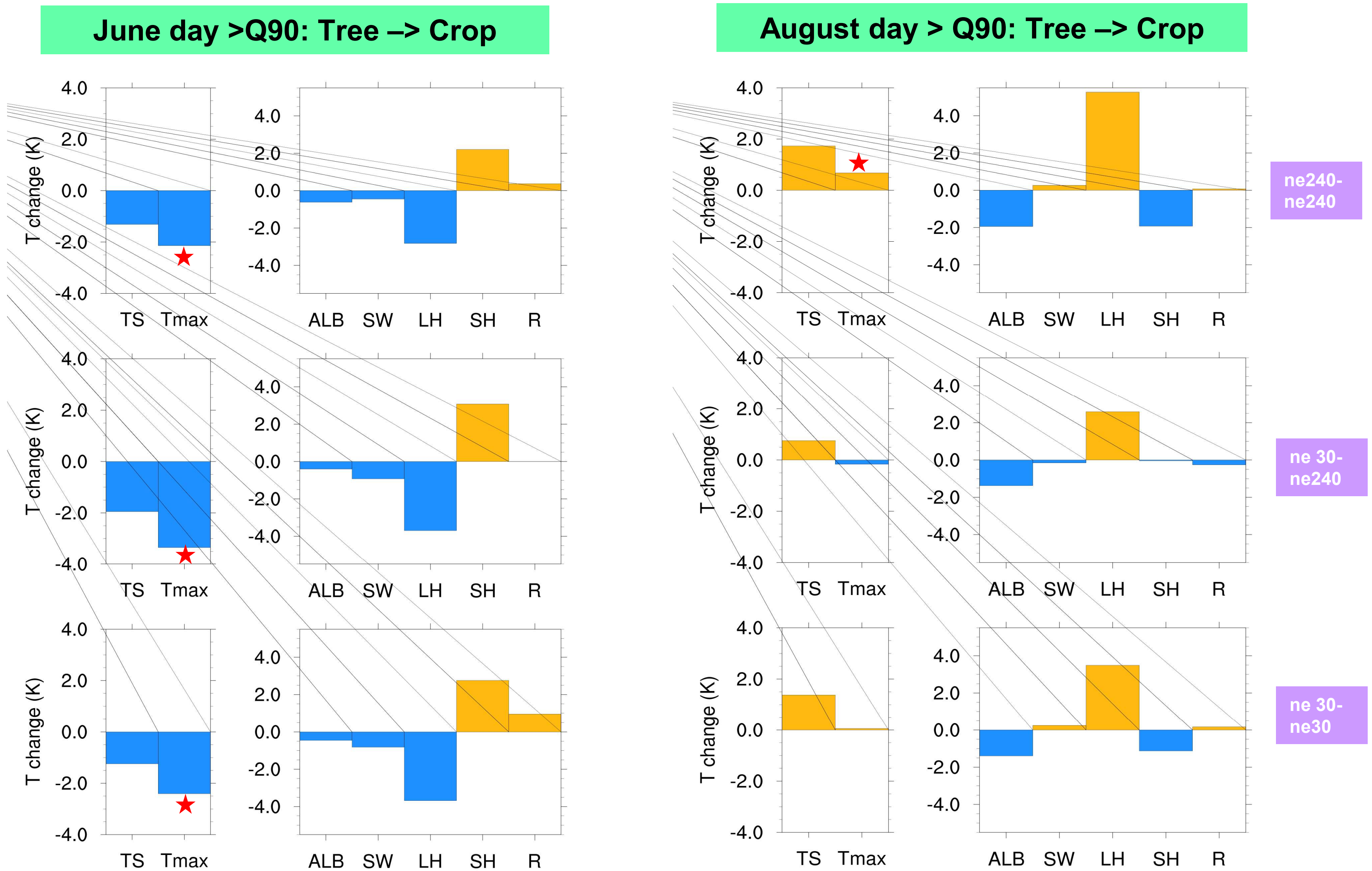
Temperature Decomposition:

Composite of Days with Tmax > 90th over cell with Tree to Crop Transitions



TS: Surface Temp
Tmax: Tmax
ALB: Albedo Term
SW: SW Term
LH: Latent Heat Term
SH: Sensible Heat Term
R: Residual (Includes LW term as well)

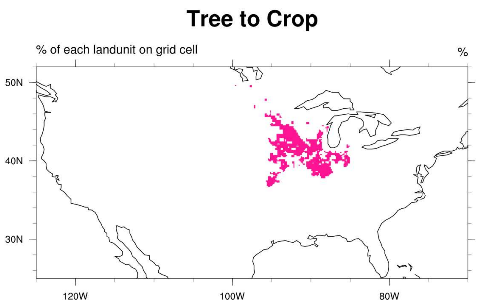
- Change in **LH-SH partitioning** is the dominant forcing influencing surface temperature
- **Change of sign in LH** forcing from June to Aug result in warming



★ At least 75% of the grids show changes significant at 95%

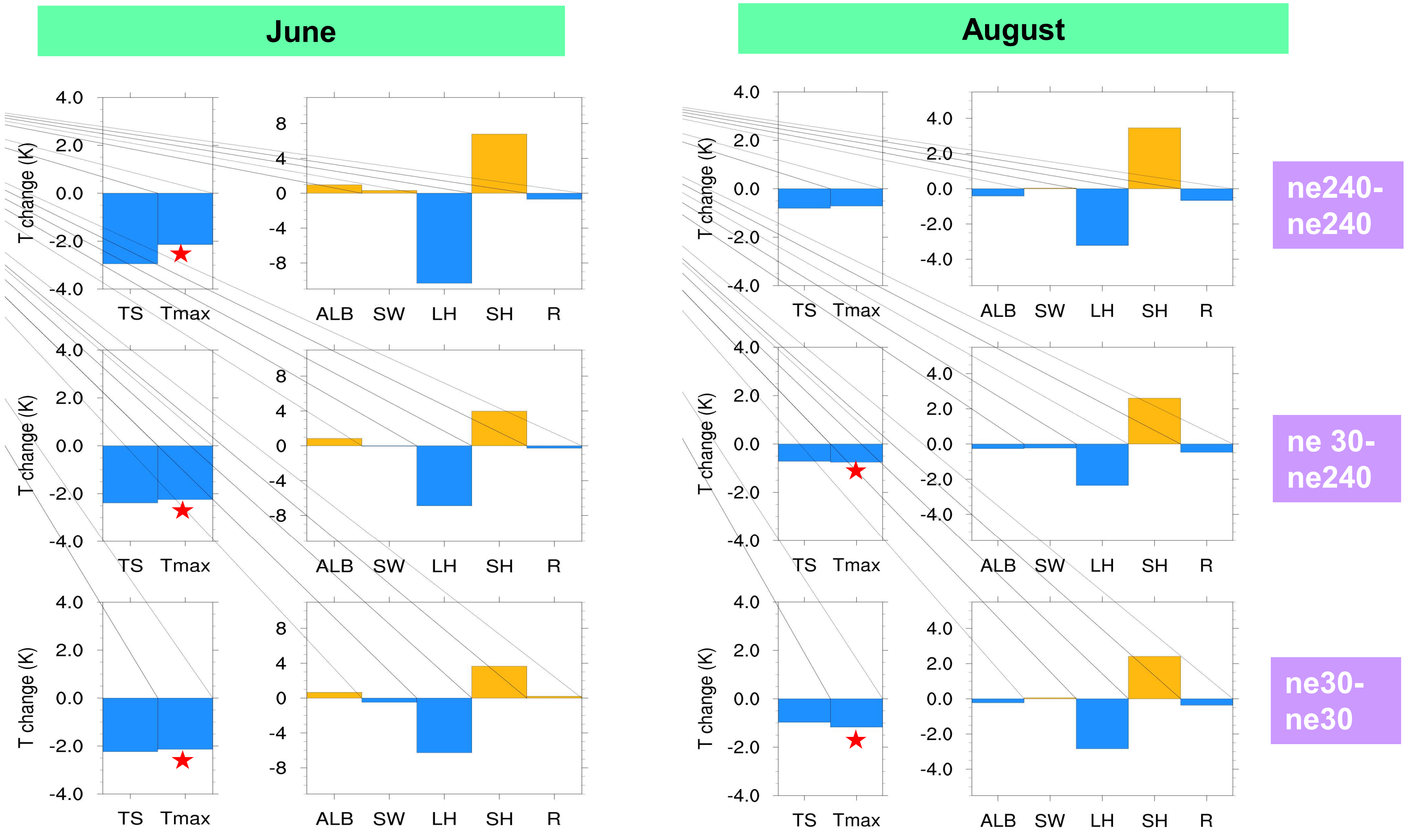
Temperature Decomposition:

Composite of Days with Tmax > 90th over cell with Irrigated Crop Expansions



TS: Surface Temp
Tmax: Tmax
ALB: Albedo Term
SW: SW Term
LH: Latent Heat Term
SH: Sensible Heat Term
R: Residual (Includes LW term as well)

- Sign of changes in **LH-SH partitioning** remain the same – and it is the dominant forcing on surface temperature
- **Lower magnitude in Aug** compared to June



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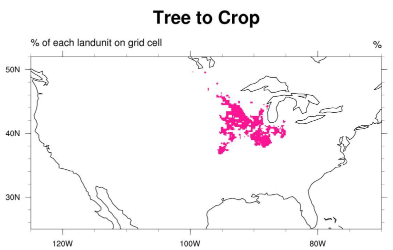
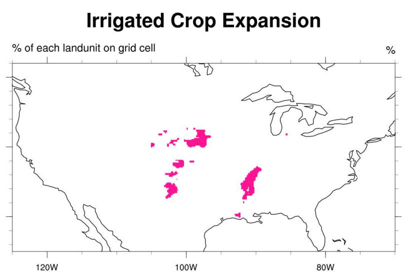
Mechanism of LH flux changes: Composite of days with Tmax > 90th percentile

ne240-ne240



ne240-ne240



Note: the Y-Axis of Aug changes are set to half of the June changes

T2-Max: Tmax (K)
LH: Latent Heat Flux (W/m2)
PREC: Precipitation (mm/day)
EVAP: Total Evaporation (mm/day)
QSOIL: Soil Evaporation (mm/day)
QVEGT: Vegetation Transpiration (mm/day)
TLAI: Leaf Area Index (m2/m2)
GPP: Gross Primary Productivity (gC/m2/s)

Mechanism of LH flux changes: Effect of resolution

- Broadly, **same conclusions** can be drawn from the ne30-ne240 and ne30-ne30 experiments
- **Aug Tree to Crop – Changes are of lower magnitude** in the coarse atm simulations – resulting in insignificant T-changes

T2-Max: Tmax (K)
LH: Latent Heat Flux (W/m2)
PREC: Precipitation (mm/day)
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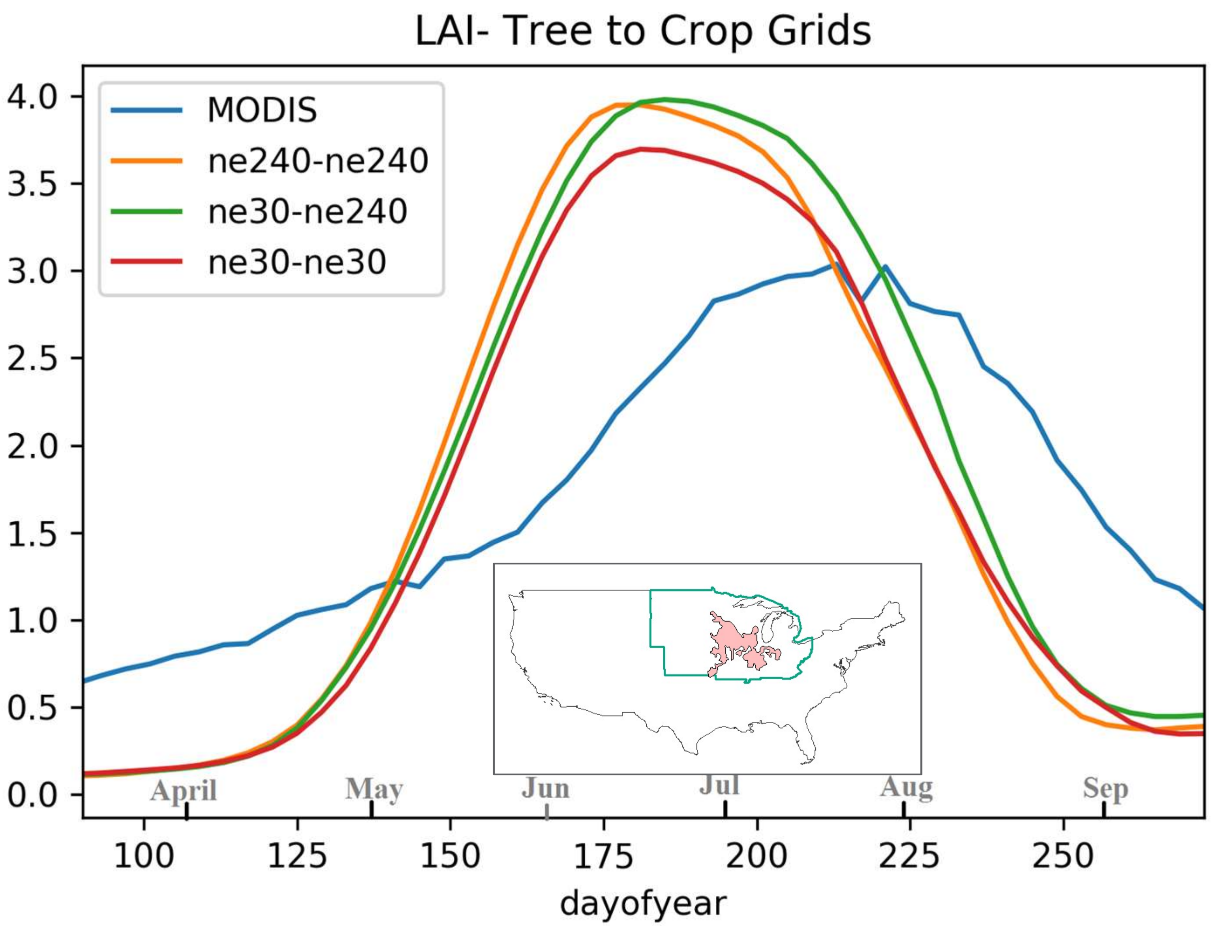
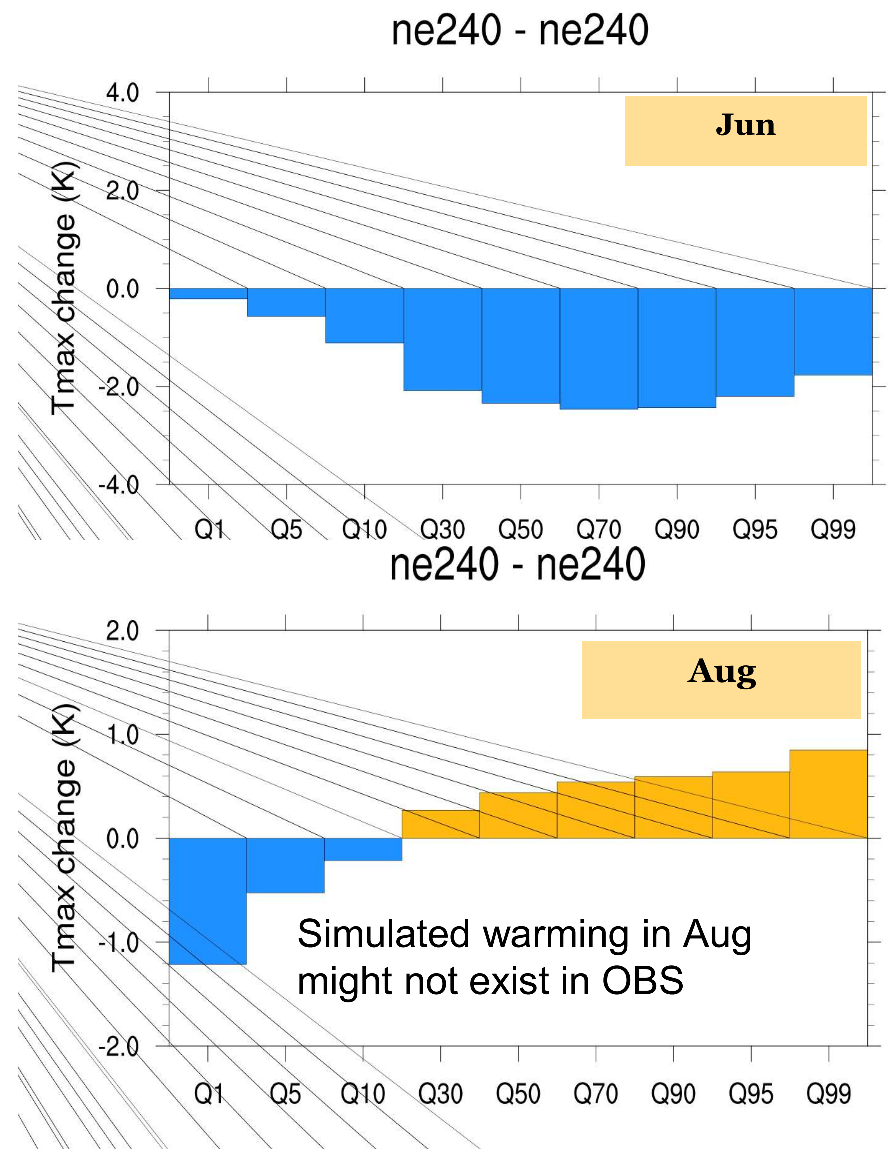
Shift in Crop Phenology compared to Observations

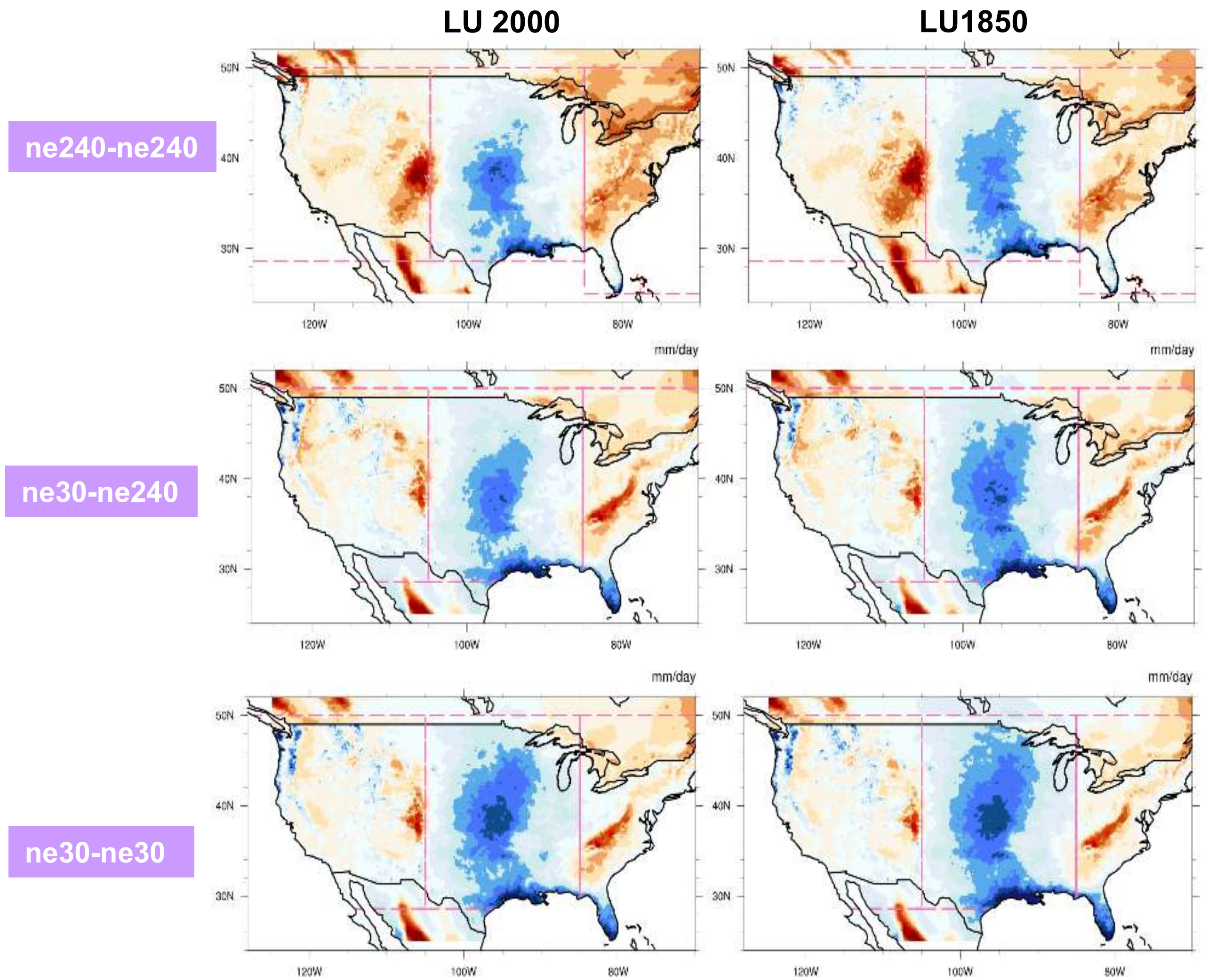


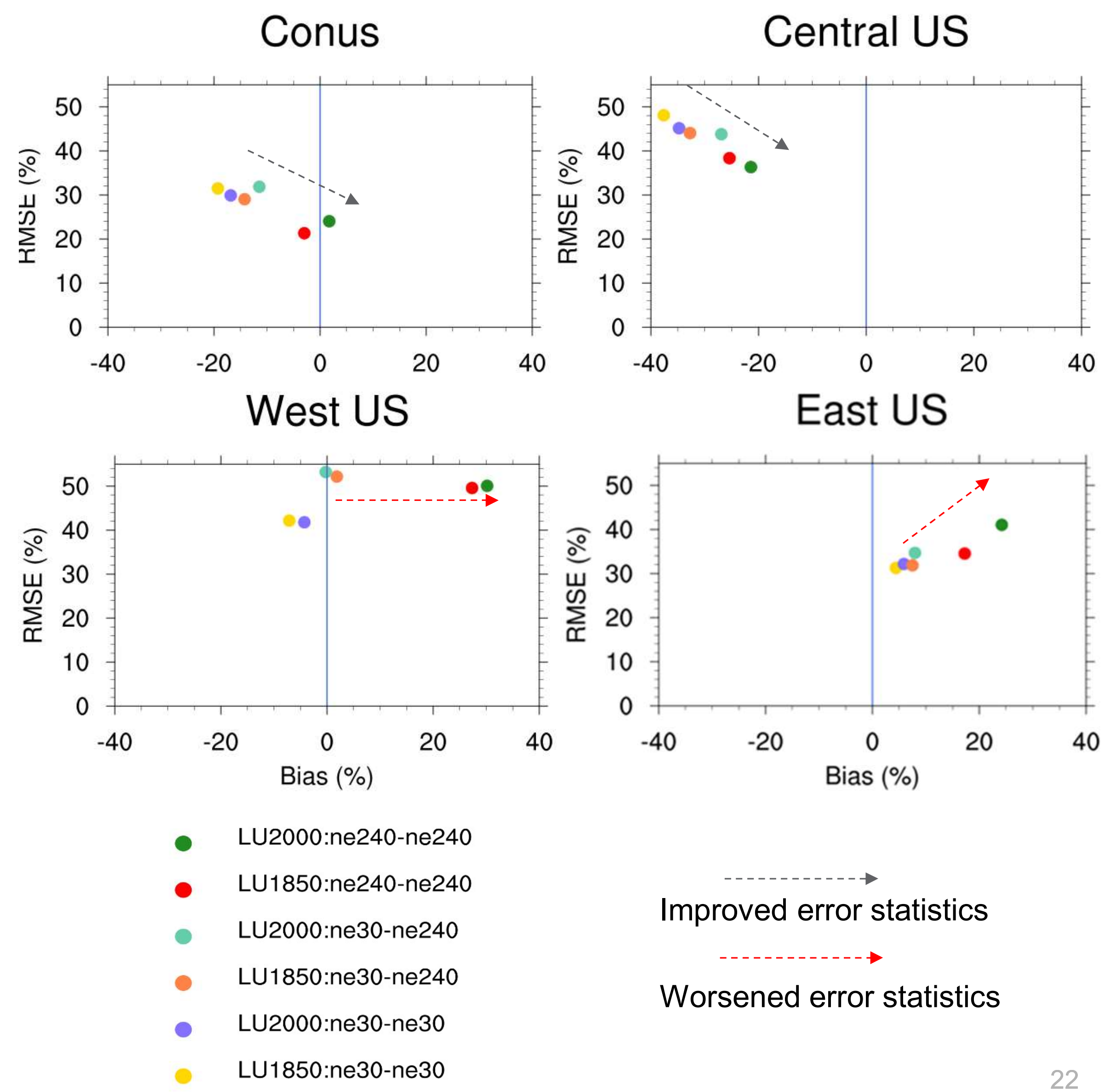


Summary of LULCC effect on temperature

- ❑ Cooling over the Central US is clearly caused by land use change:
  - Irrigated grids : show persistent cooling at all quantiles of Tmax, throughout the summer
  - Areas of tree to crop transitions show cooling at higher quantiles during the peak growing season in the model. With drop in LAI and productivity of crops (harvest) towards the end of model growing season, this changes to a significant warming (at high-res).
- ❑ Increasing land model resolution is key to reduce temperature bias over the central U.S.;
- ❑ Surface temperature decomposition shows that the change in SH-LH partitioning is the dominant influence on surface T change.
- ❑ The LH changes are dominated by vegetation transpiration, and hence the effect on Tmax extremes is strongly tied to agricultural intensification.

Skill in simulating warm-season precipitation:
comparison to NLDAS, April to August

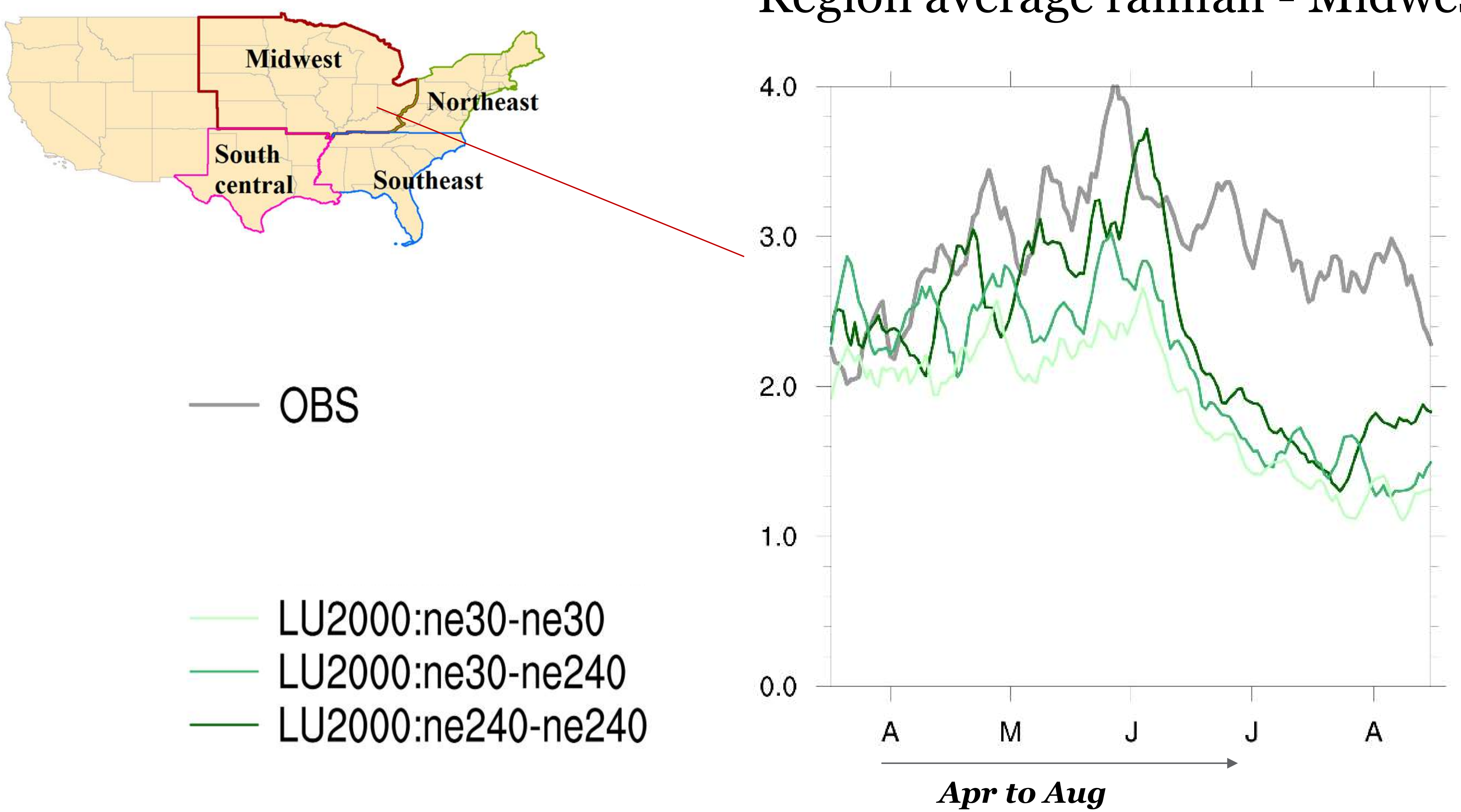




CONUS and Central US: Precipitation improves with resolution
(At the same res, more accurate LU shows lower errors)
Western and Eastern US : Deteriorates

Skill in simulating warm-season precipitation:
comparison to NLDAS, April to August

Region average rainfall - Midwest



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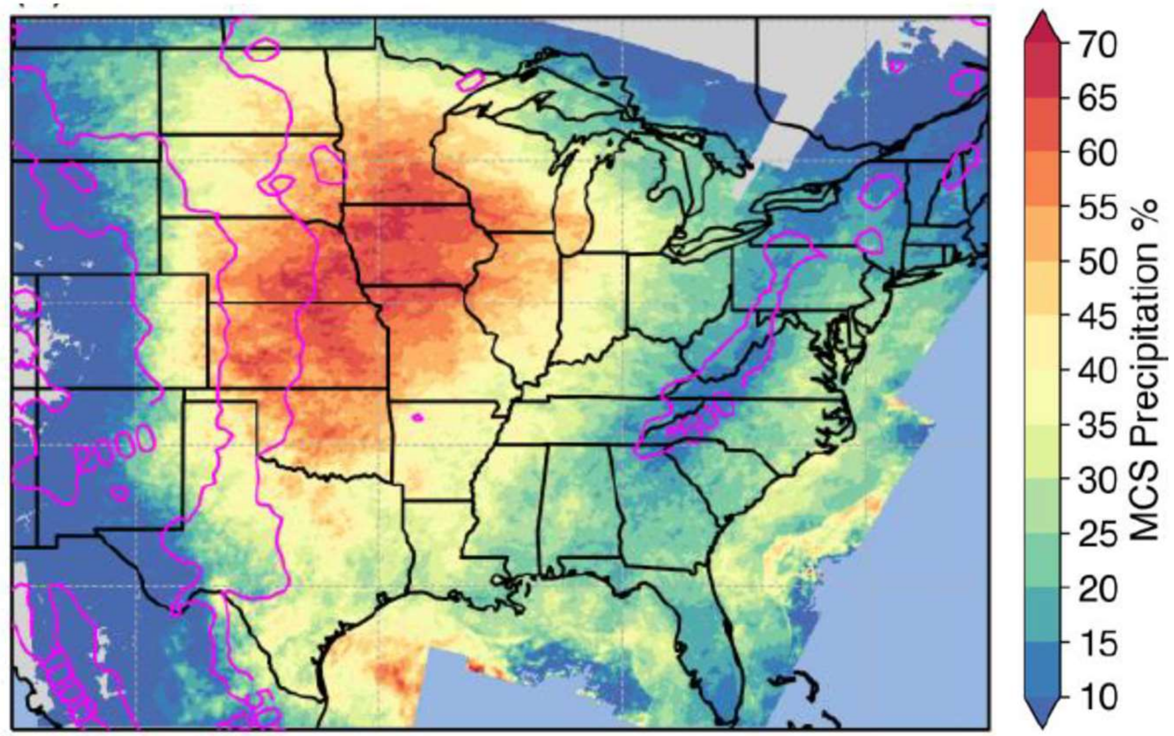
Tracking Mesoscale Convective System (MCS)–Like Features

- ❑ MCSs account for over 50% of warm season precipitation in the central U.S., which can only be captured in high-res models;
- ❑ Underestimated convective clouds could result in excessive downward shortwave radiation and hence enhanced heating of the surface layers.
- ❑ Lack of prolonged and intense convective precipitation from MCSs could lead to drier soils and hence overestimated Bowen ratios, further enhancing the excess heating of the surface.



Spatial distribution of the fraction of summer MCS precipitation (2004–2016) (Feng et al., 2016)

- ❑ The FLEXTRKR algorithm developed by Feng et al. 2016 is used to track MCSs.

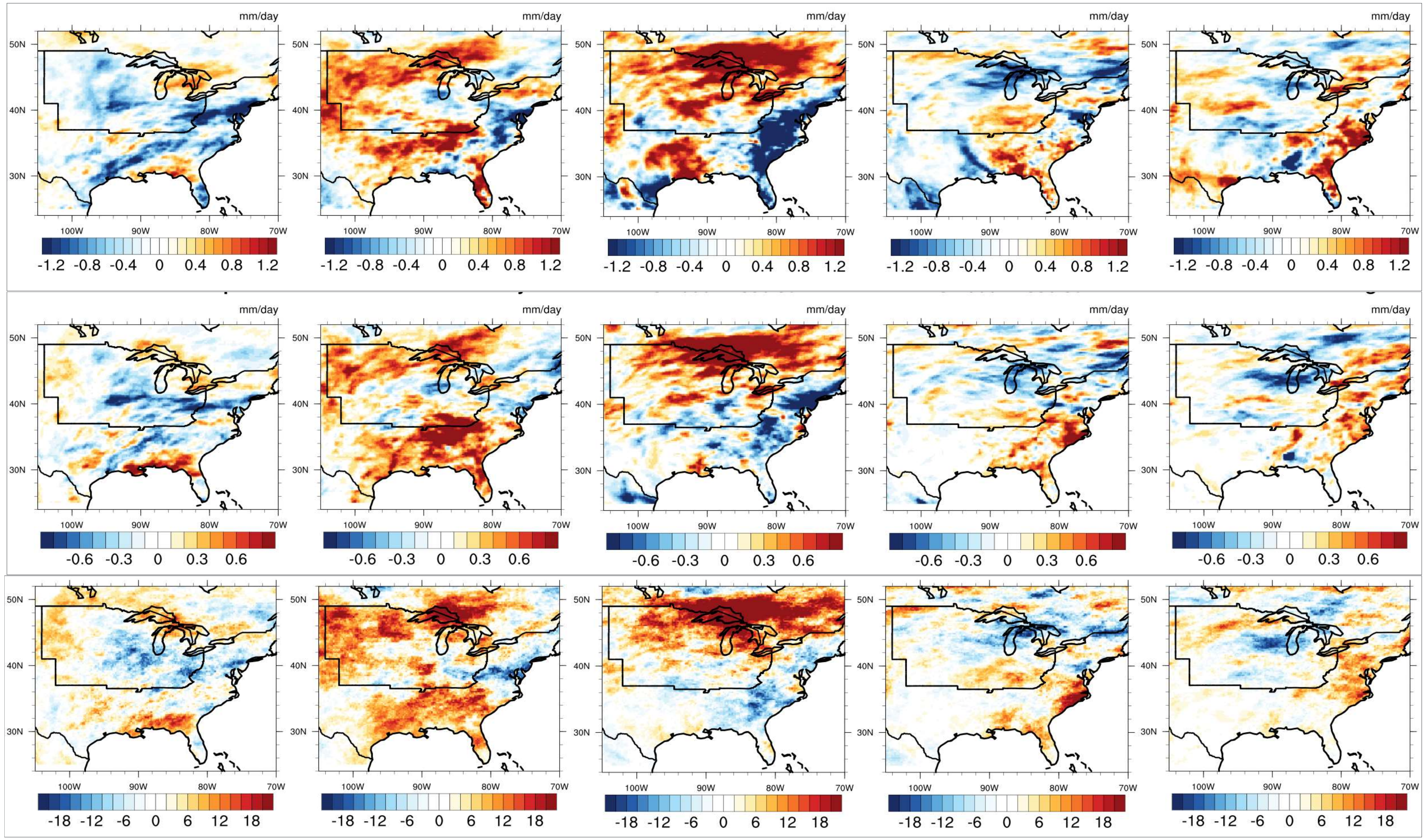
LULCC-induced total and MCS precipitation changes LU2000 vs. 1850 for the period of 1999-2010

April | **May** | **June** | **July** | **Aug**

Δ P (mm)

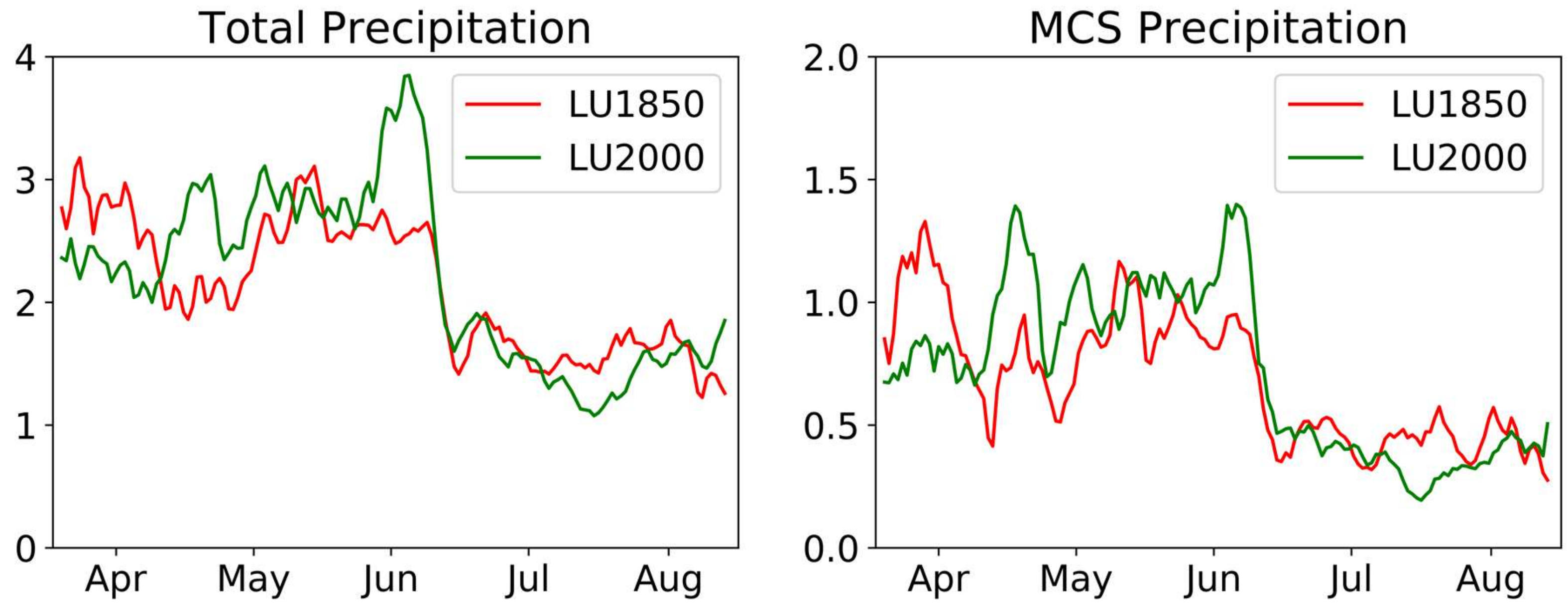
Δ MCS P (mm)

Δ MCS Frequency (Average #/cell)



Midwest: Changes in Total and MCS Precipitation (1999-2010)

- MCSs are the main contributor of total precipitation changes in May;
- Their contribution in June is lower but still significant.



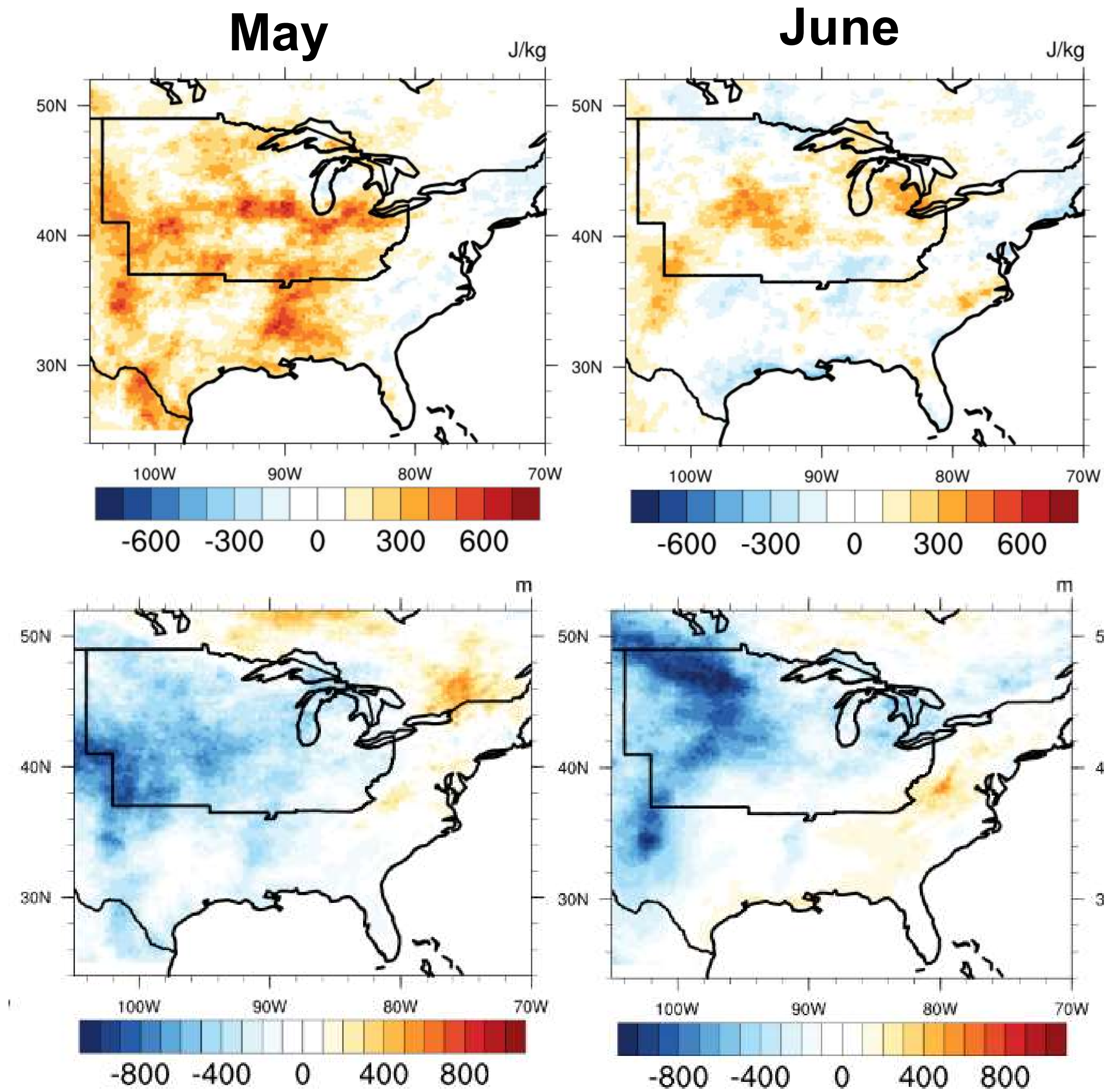
Statistically Sig Changes (@ 95%)			
Month	**Total P LU2000 – 1850**	**MCS P LU2000-1850**	**% of Total P change from MCSs**
May	+0.28 mm/day*	+0.21 mm/day	76%
Jun	+0.44 mm/day	+0.19 mm/day	43%

* *Statistically sig @ 90%, other Total P and MCS P numbers sig @ 95%*

Difference in CAPE and LCL at local time 6pm LU2000 vs. 1850 for the period of 1999-2010

Δ CAPE

Δ LCL



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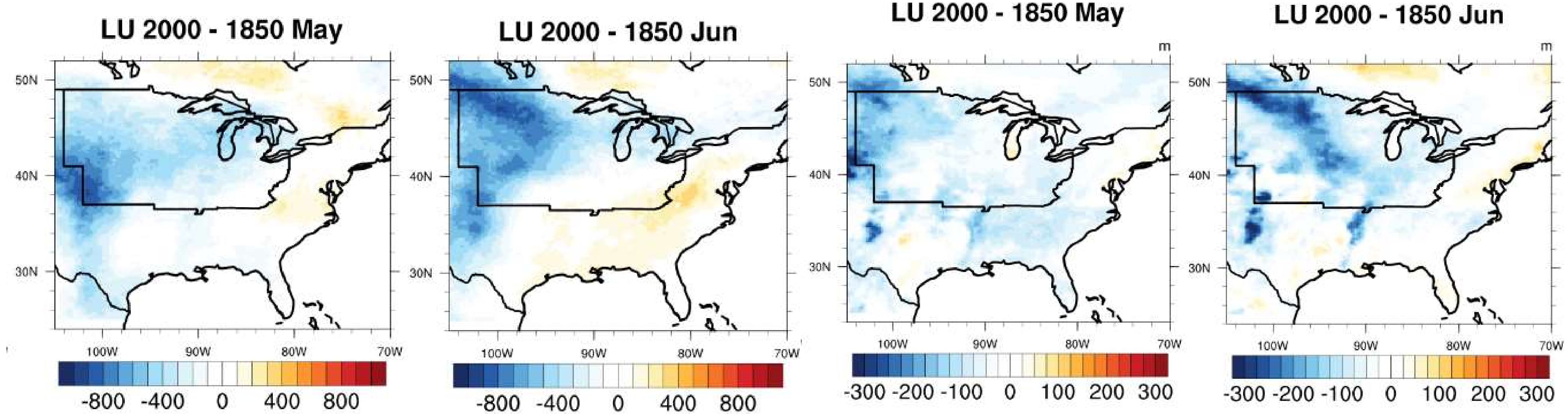
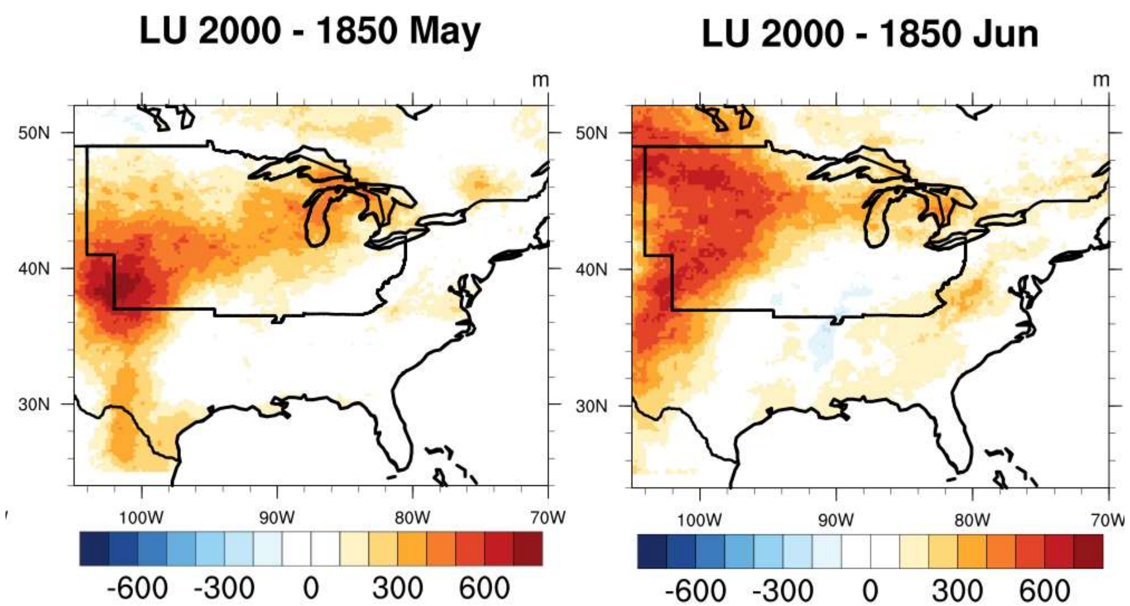
The reduction in LCL is larger that in PBL allowing more parcels to cross LCL

ΔLCL



ΔPBL

$|\Delta LCL| - |\Delta PBL|$



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Conclusion

- Skills in simulating mean **temperature and precipitation over the CONUS** increases with resolution and more accurate land use
- **Land use, through both land cover and land management (irrigation and fertilization) changes, is the dominant factor** influencing temperature skill in central US;
- **Resolution is the dominant factor** influencing precipitation skill;
- When computational resource is a constrain, a **higher land resolution still enhances skill in simulating regional mean climate;**
- **High-res land-atm simulations** show consistently better **spatial patterns of temperature**;
- The ability of high-res models in simulating **LULCC-induced surface energy budget changes, land-atmosphere coupling, and mesoscale convection systems** is the major contributor to improved precipitation and temperature simulations over the central U.S.

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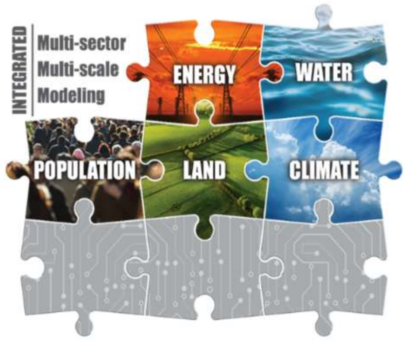

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