The Sensitivity of Regional Climate Projections to SSP-Based Land Use Changes in the North American CORDEX Domain

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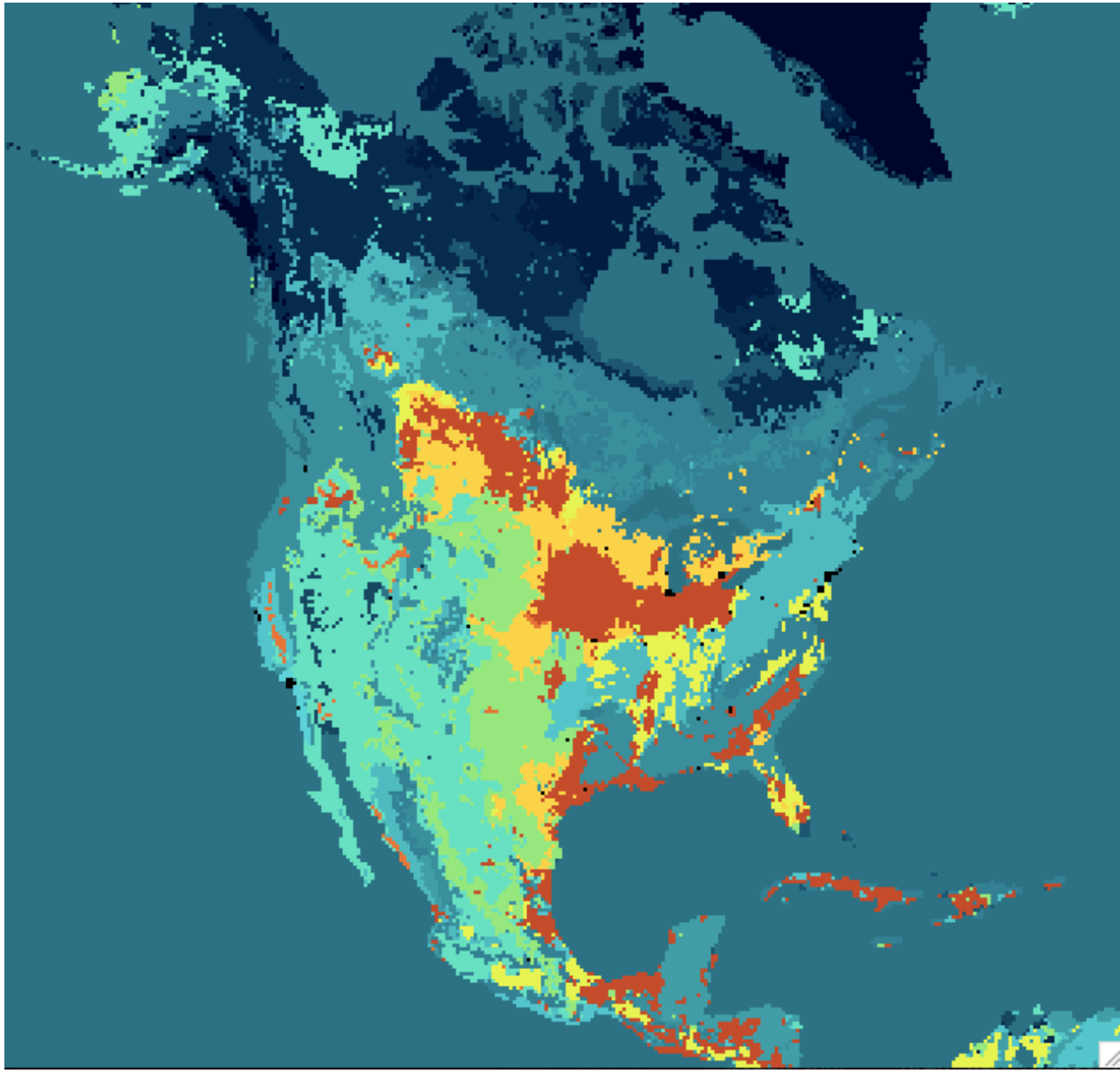
Introduction

- What is the effect of including Shared Socioeconomic Pathway (SSP)-based land-use and land-cover change (LUC) along with the Representative Concentration Pathway (RCP)-based greenhouse gas (GHG) induced climate change in traditional North American (NA)-CORDEX simulations?
  - Or: What is the overlooked projection uncertainty associated with neglecting SSP-based LUC in traditional NA-CORDEX simulations?
- Goal: assess the magnitude of the changes in regional climate forced by SSP-based LUC relative to those produced by increasing greenhouse gas concentrations.

U.S. Department of Energy
FACETS
Framework for Assessing Climate's Energy-Water-Land Nexus using Targeted Simulations

Methods: WRF

- 25km
- NA-CORDEX configuration
  - to leverage existing no-LUC simulations for direct comparison
- Driven by MPI-ESM-LR
- RCP8.5+SSP3 & RCP8.5+SSP5
- 2075-2100
  - Original CORDEX run: 2006-2100



NA-CORDEX Domain, WRF, Dominant Land Type

Bukovsky et al. 2020, EGU

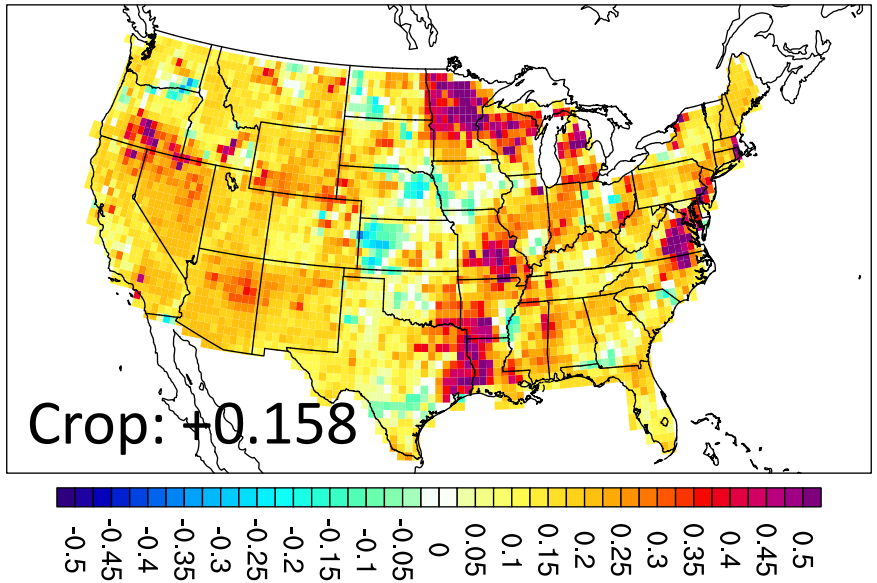
Methods: LULCC Scenarios

- Agricultural Land Use Model
  - Meiyappan et al. 2014: Spatial modeling of agricultural land use change at global scale. *Ecological Modeling*, 291, 152-174.
  - Crop and pasture
  - ½ degree

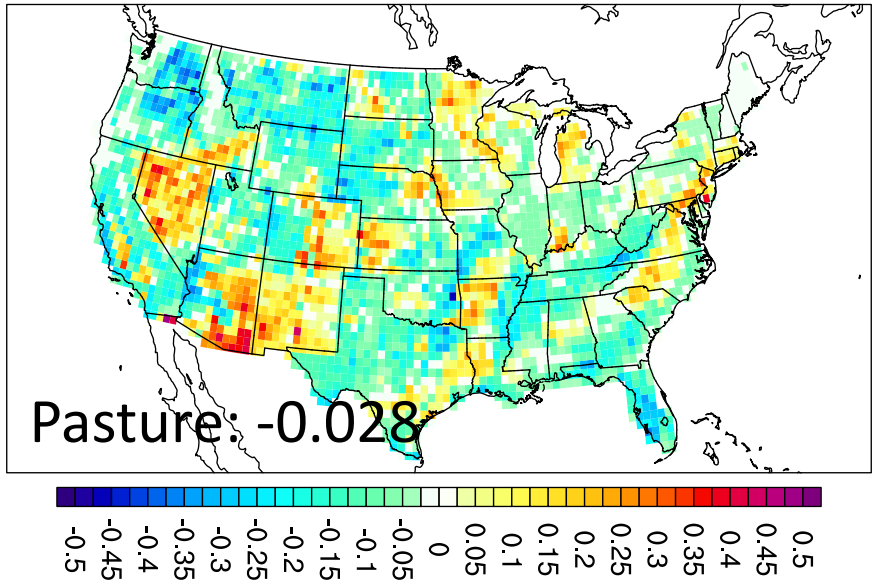
- Urban Model
  - Gao & O'Neill 2019: Spatial modeling of long-term urban land development potential for climatic impact assessment: the SELECT model. *Environmental Modelling & Software*. https://doi.org/10.1016/j.envsoft.2019.06.015
  - 1/8 degree

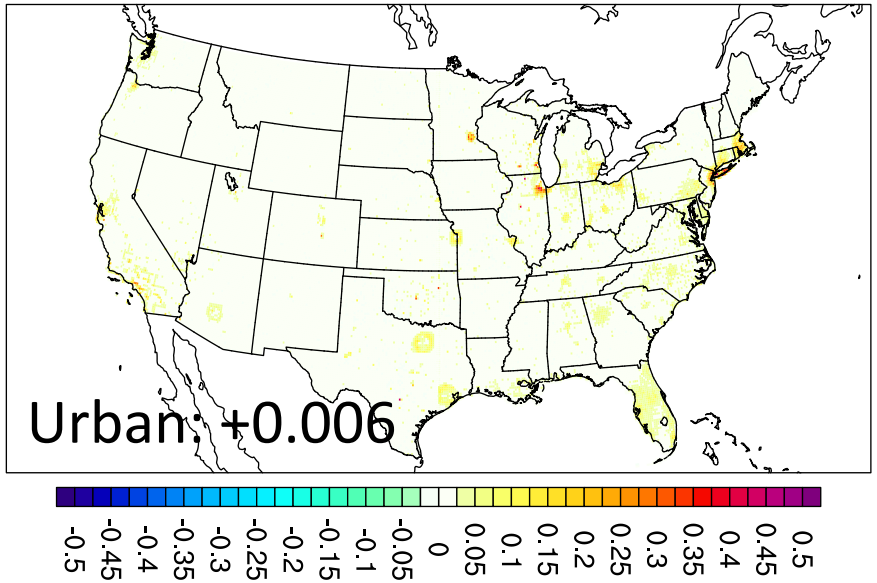
AG & URBAN MODEL RESULTS…

SSP3+RCP8.5: Regional Rivalry



- Countries increasingly focus on domestic issues due to resurgent nationalism.
  - Economic development is slow,
  - Countries focus on energy and food security,
  - Population growth is low in industrialized countries but high in developing countries (yielding high global population growth).



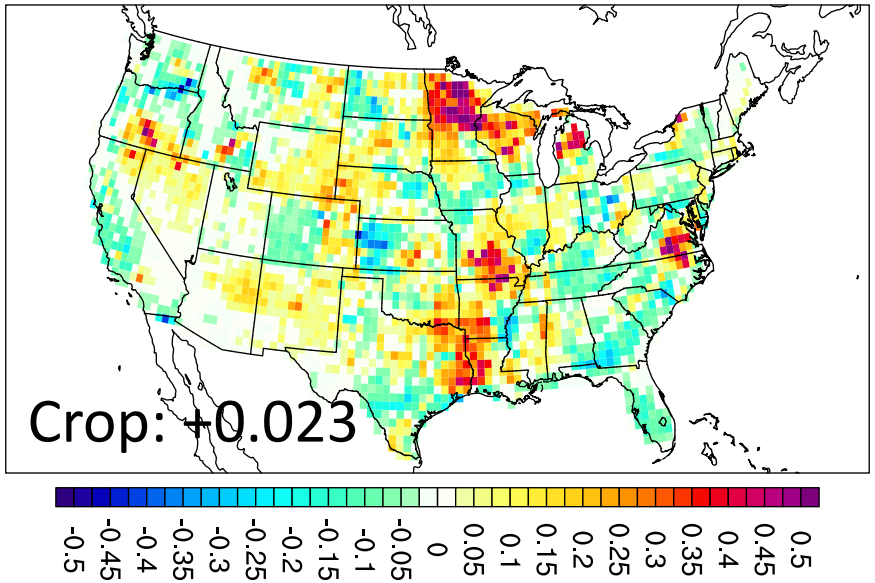


- U.S. sees an increase in domestic crop production but slow population growth and urban land expansion.

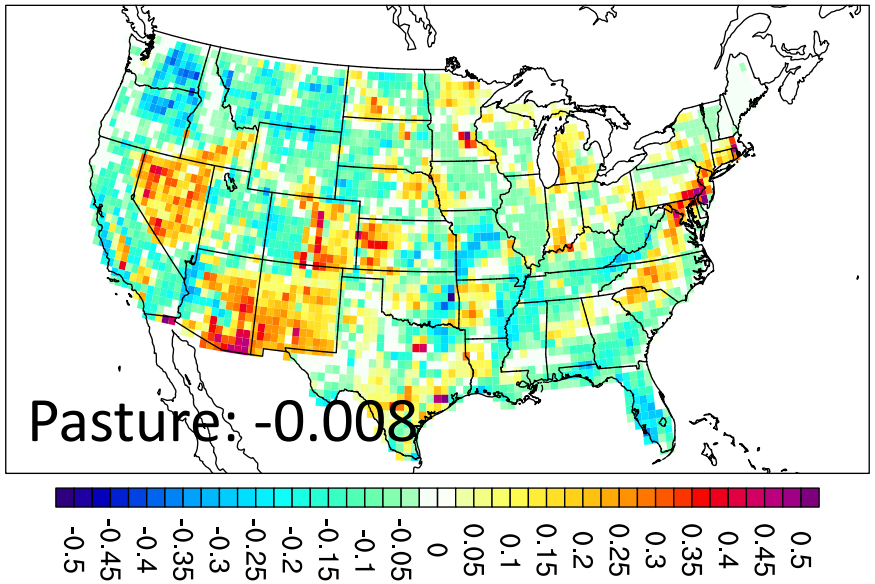
Fractional change in land types from 2005 to 2090.

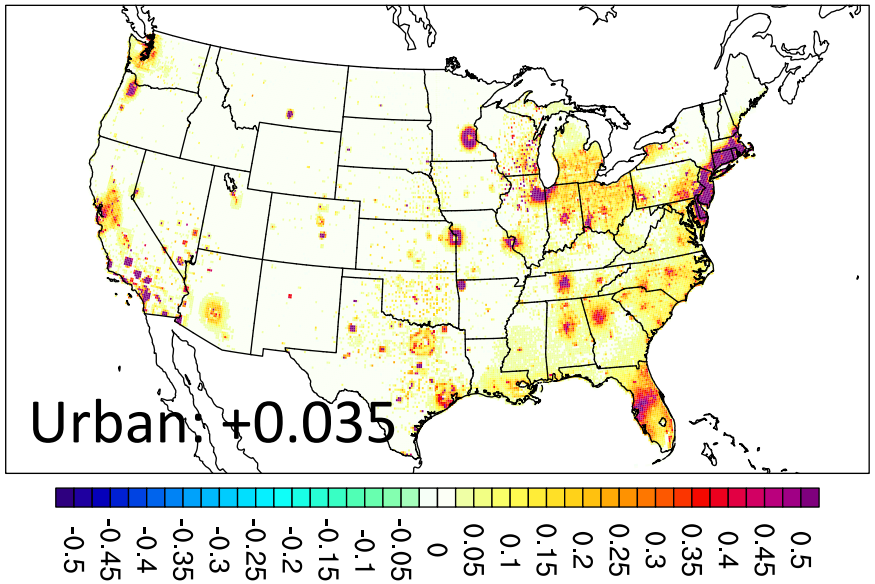
Bukovsky et al. 2020, EGU

SSP5+RCP8.5: Fossil-Fueled Development



- The global economy grows quickly fueled by continued fossil fuel exploitation.
  - Global population growth is relatively low compared to other SSPs, but in the U.S. and other high-income countries, the population grows rapidly under optimistic economic outlooks.





- The U.S. sees an expansion of urban land that is greater than that in the SSP3 scenario and a smaller increase in domestic crop production.

Fractional change in land types from 2005 to 2090.

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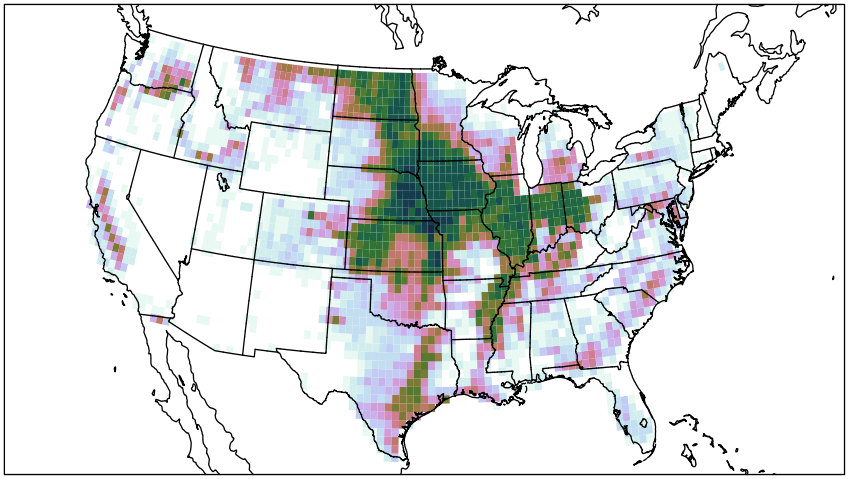
Implementation in WRF

- The 25-km resolution configuration of WRF used the 24-Category USGS Land Use types.
  - Crop and Pasture fall into more than 2 categories.
- Used the delta-method to apply Crop/Pasture/Urban model changes.
  - Absolute changes were applied to type 2 or 3 (depending on which one existed with the greatest fraction at a grid box) for crop, type 7 for pasture, and type 1 for Urban. Total at any grid box not allowed to exceed 1.
  - Each field was then adjusted so that the total change in WRF fell within 5% of that given by the Ag. and Urban models.
- Many variations were tested before deciding on this approach!

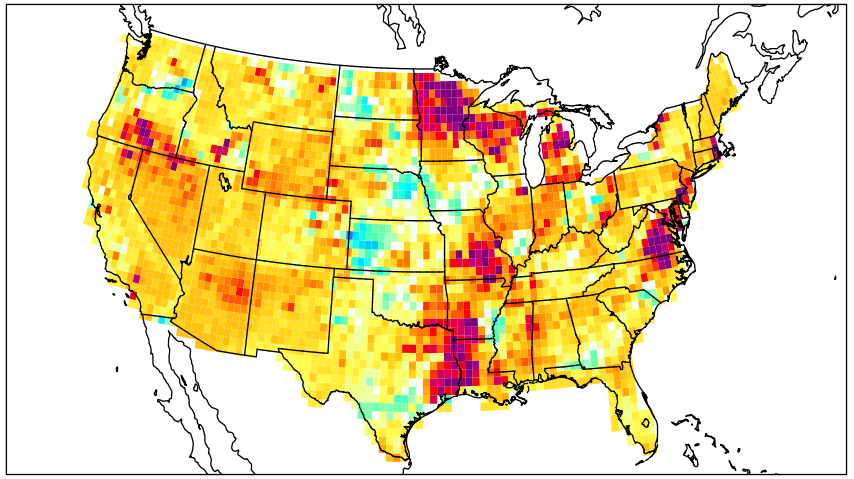
24-Category USGS Land Use	
1	Urban and Built-Up Land
2	Dryland Crop
3	Irrigated Crop
4	Mixed Dryland/Irrigated Crop
5	Cropland/Grassland Mosaic
6	Cropland/Woodland Mosaic
7	Grassland
8	Shrubland
9	Mixed Shrubland/Grassland
10	Savanna
11	Deciduous Broadleaf Forest
12	Deciduous Needleleaf Forest
13	Evergreen Broadleaf
14	Evergreen Needleleaf
15	Mixed Forest
16	Water Bodies
17	Herbaceous Wetland
18	Wooded Wetland
19	Barren or Sparsely Vegetated
20-23	Tundra Types + Snow or Ice

Example comparing crop and crop changes between Ag. model and results as applied in WRF under SSP3

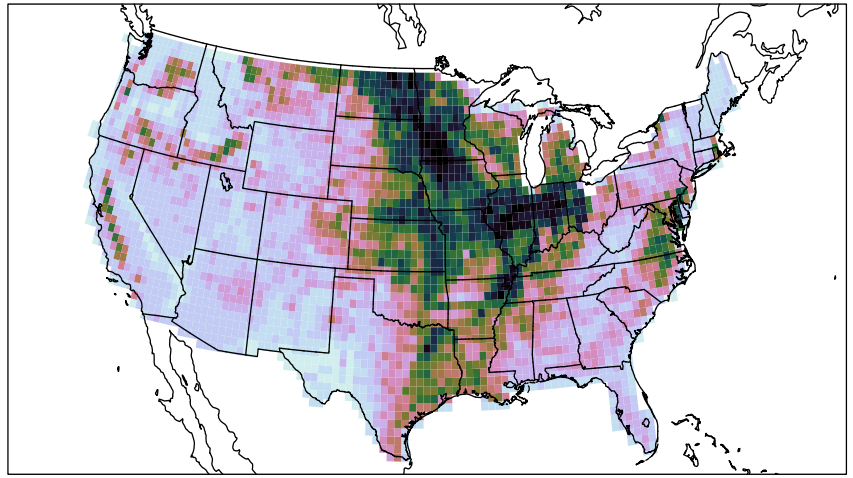
Ag. Model: Baseline Crop



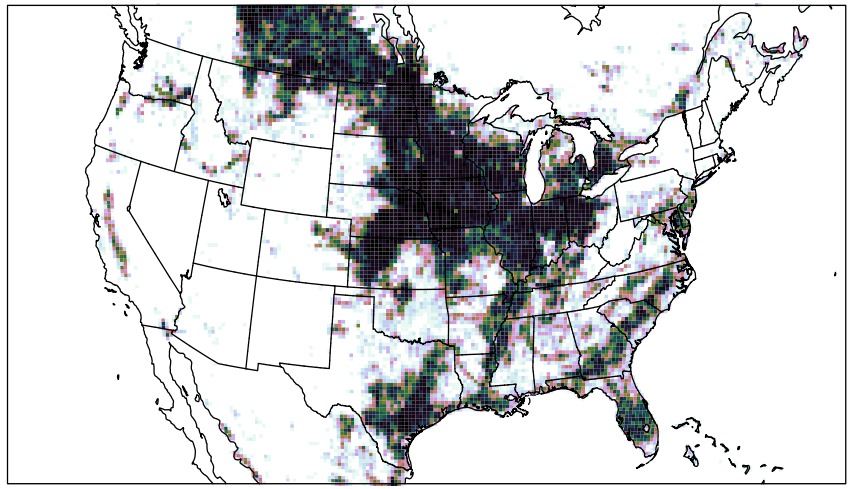
Baseline-to-Future Change



Future



WRF: Baseline Crop



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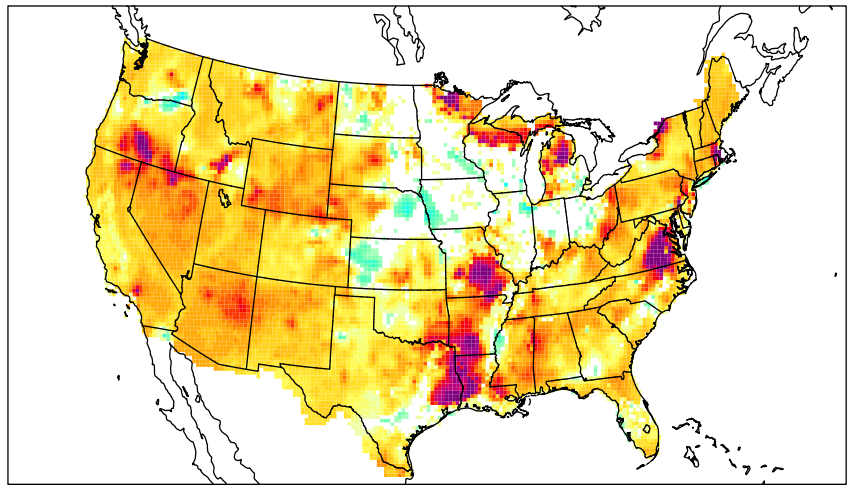

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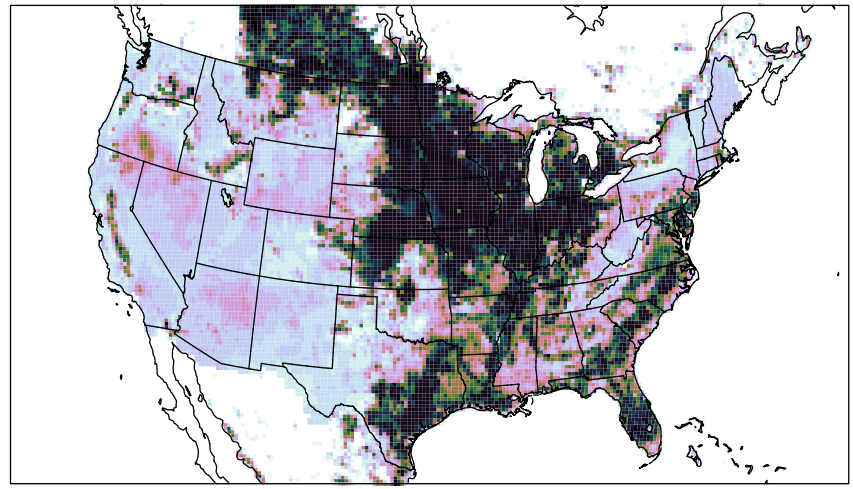

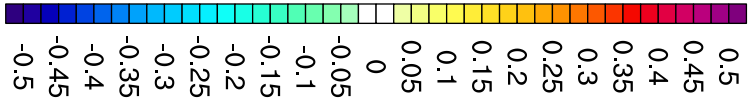

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WRF SSP3 Dominant Land Type Changes

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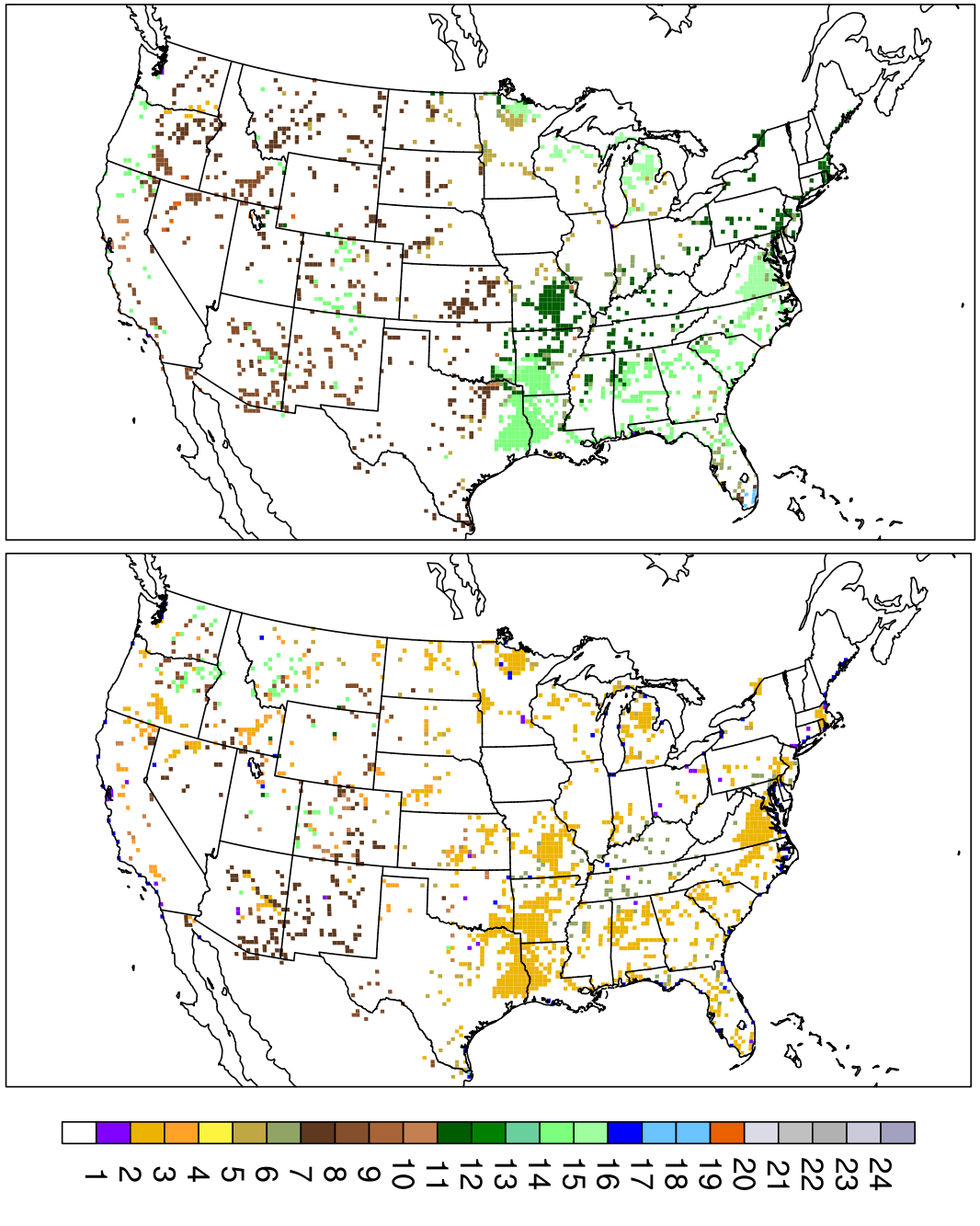

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WRF SSP5 Dominant Land Type Change

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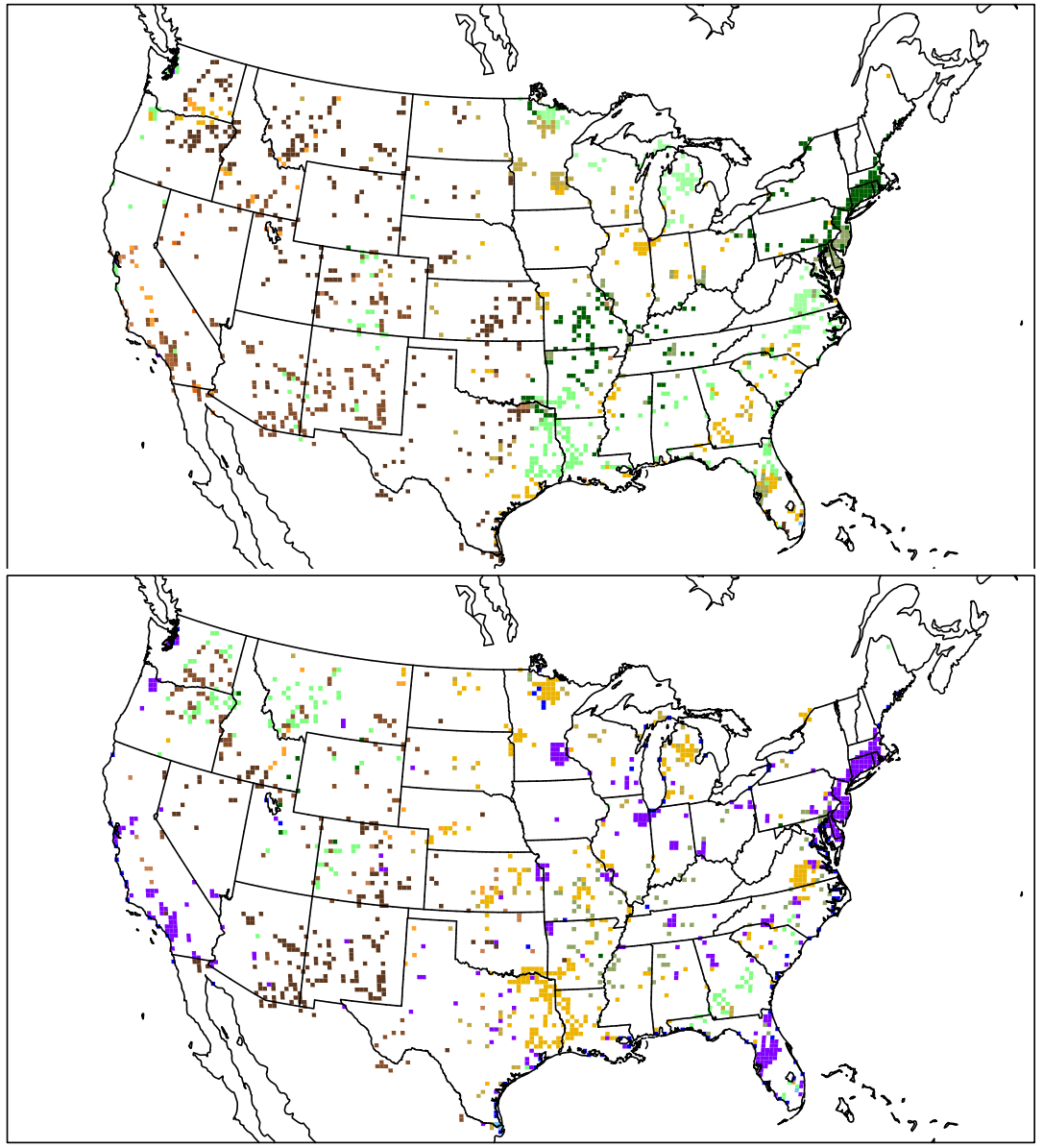

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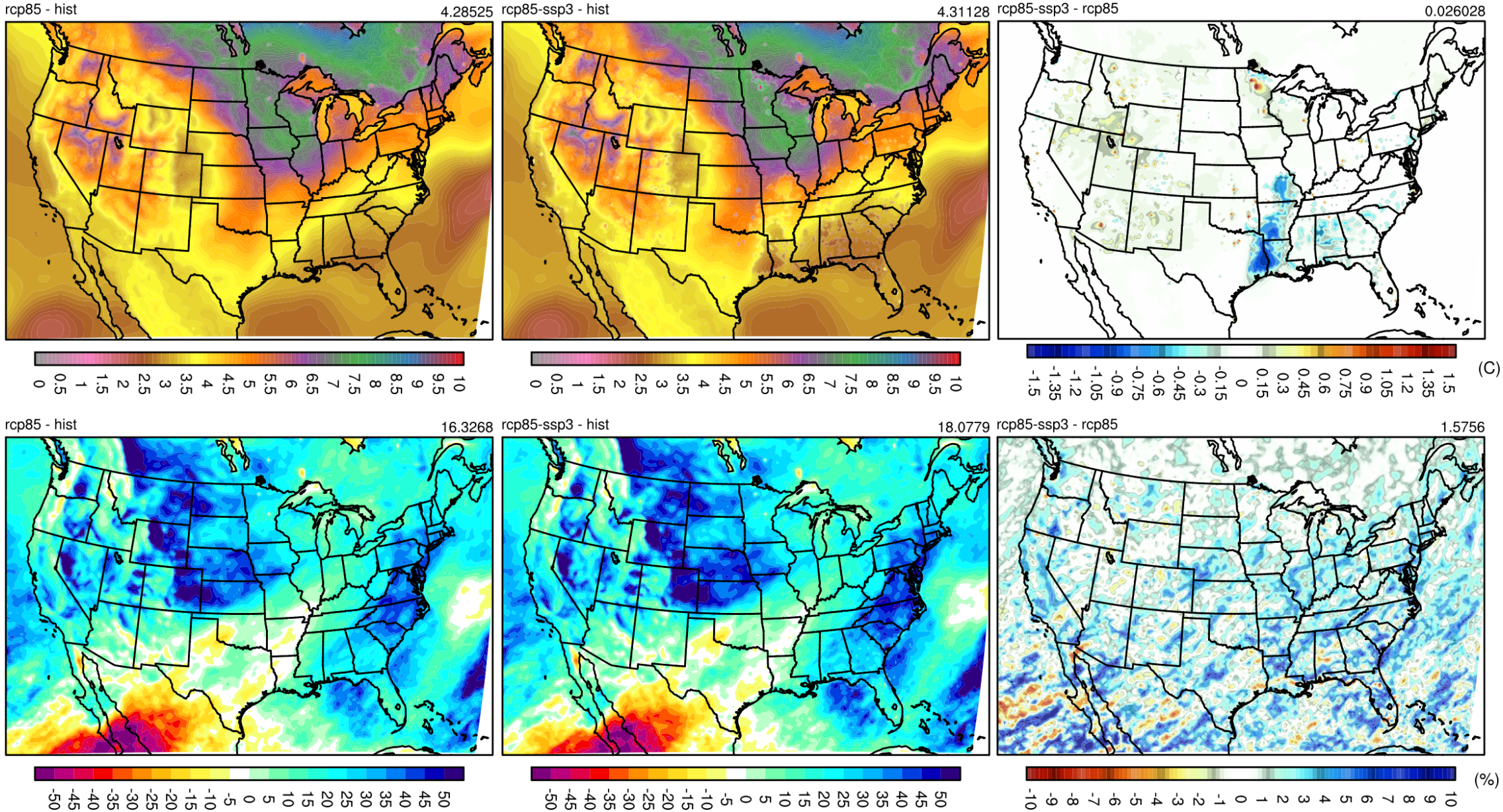
WRF MODEL RESULTS…



Near-Surface Temperature (deg C)

*plot area average in upper right corner

Precipitation (%)

- RCP8.5 vs. RCP8.5+**SSP3** LULCC, **DJF**, 1980-2005 vs. 2075-2100
- Left-to-Right: GHG-only climate change, GHG+LULCC climate change, GHG+LULCC – GHG-only difference.

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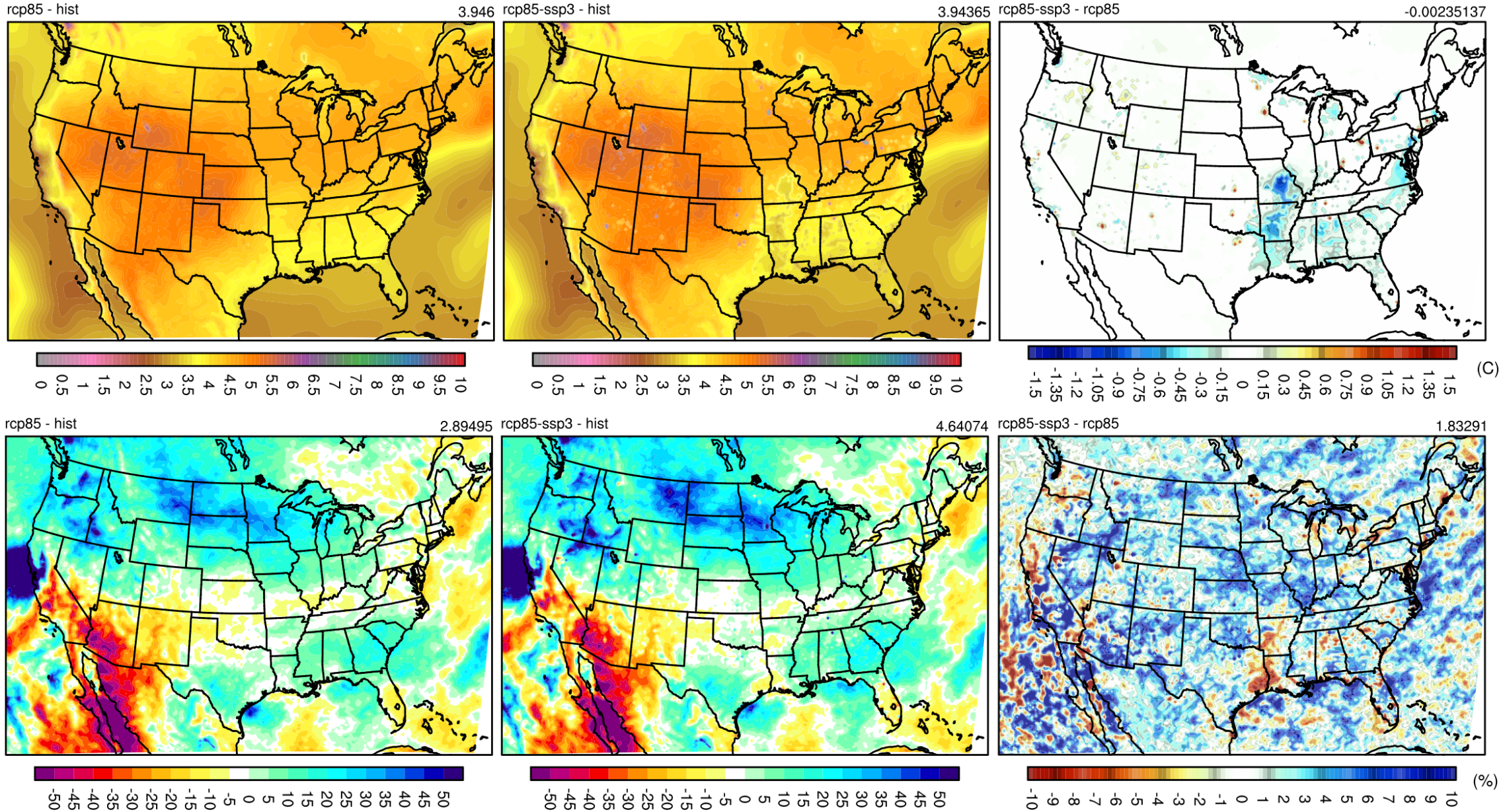

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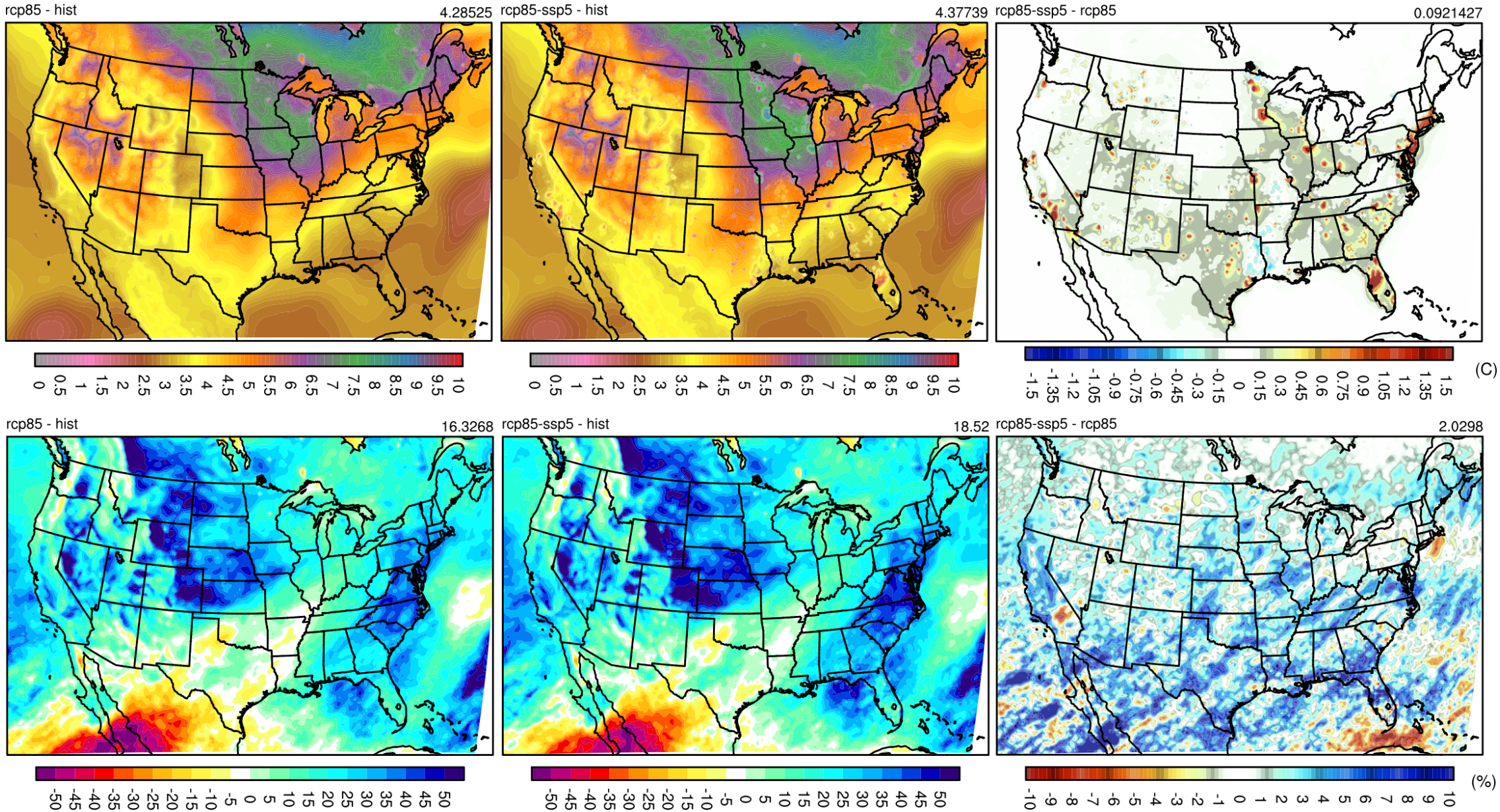

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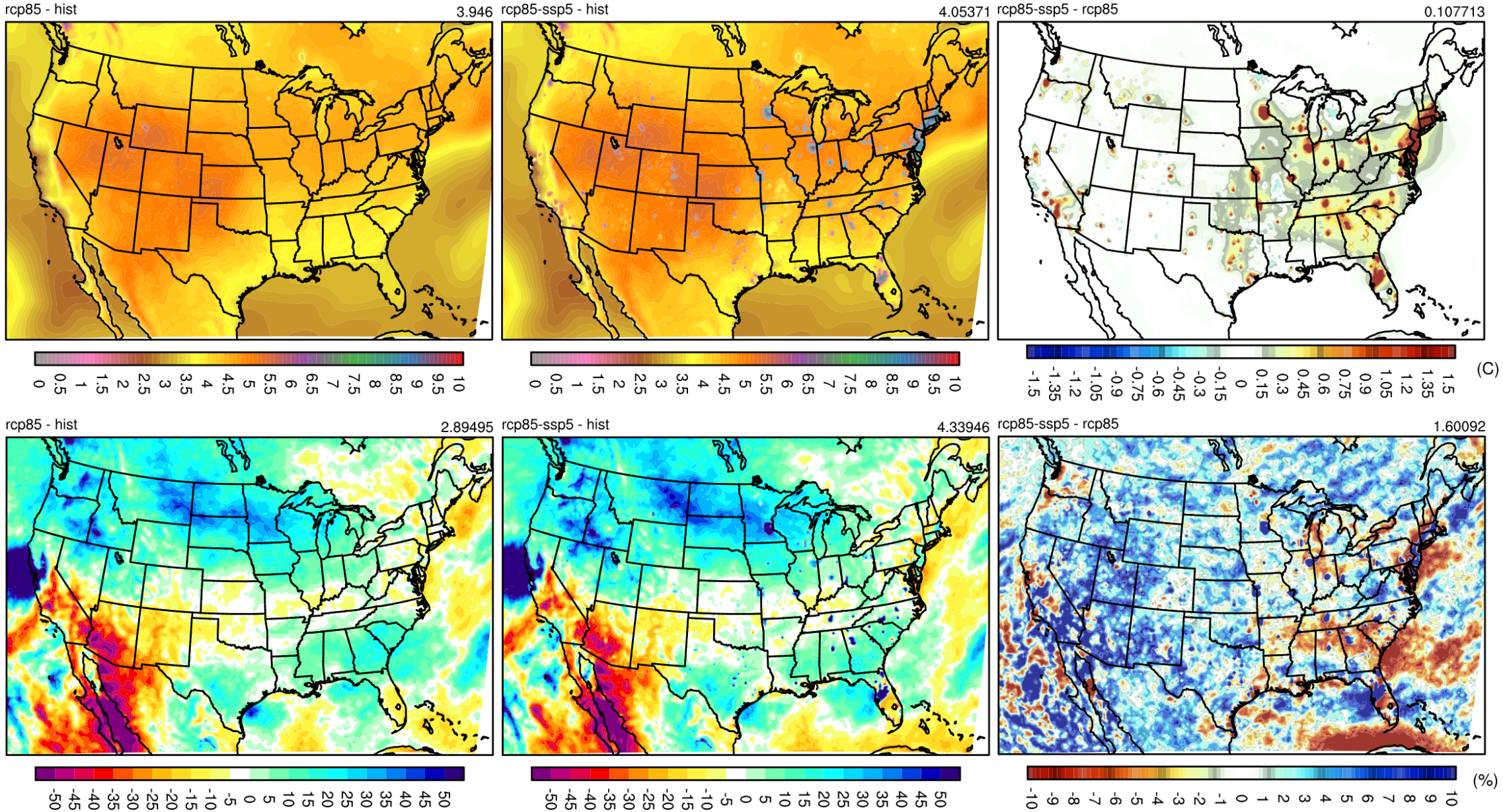

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Summary

- Regional climate change projections are sensitive to SSP-based land-cover changes.
  - In regions of significant crop expansion, like the Southeast, projected temperature increases are around 0.5-1.5℃ less, for example.
  - In areas of high urbanization, projected temperature increases are much greater (up to 4-5℃ greater in JJA), and in SSP5, projected temperature increases are up to 0.2-0.4 ℃ greater in-between urbanization centers in the eastern half of the U.S. too.
- Temperature differences are likely caused by differences in land-cover albedo, and are representative of above canopy changes.
  - As in e.g. the LUCAS experiment (Davin et al. 2019: https://doi.org/10.5194/esd-2019-4)
- Enhanced mean precipitation over cities in JJA under SSP5 is largely due to an increase in precipitation intensity and the length of the rainfall events. Downstream from those cities, decreased precipitation can predominantly be linked to a decrease in the number of rainfall hours overall, but also a decrease in the length of events/an increase in the number of consecutive dry hours, and a decrease in intensity. Over Florida urbanization, there is also a strong change in the diurnal cycle of precipitation, likely due to changes in the land-sea temperature contrast and breeze.

Discussion

- For a better sampling of uncertainty in future regional climate projections, we may need to consider the land-use change that underlies the SSP-RCP framework, and not just the GHG concentration scenarios.
  - Requires sub-national land-use change scenarios at the resolution of the regional models over the full region of interest.