Earth's Future

Supporting Information for

SSP-Based Land Use Change Scenarios: A Critical Uncertainty in Future Regional Climate Change Projections

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Introduction

This Supplementary Information file contains additional methodology information and supplemental figures and tables.

Text S1. Additional Details Related to the Application of LUCs in WRF

Multiple different delta-type methods for incorporating the LUCs into WRF were tested, within the timeframe allowed by the project. We took into consideration which option produced land-use changes in WRF that were most consistent with what was produced in the LUMs, which combination of WRF land-cover types in the historical climate simulations were spatially most consistent with those from the LUMs, which option made sense to the authors in terms of potential scenario storylines, and which could also be applied to other land-cover dataset options with different land-use categories available in WRF (e.g., MODIS).

As the LUM data do not have the same resolution as WRF, the LUM data were first bilinearly interpolated to the 25-km grid used in WRF. Then, absolute fractional LUC deltas (LUM future minus historical period land cover fraction) were applied to WRF USGS fractional land-use fields. We did not use percent deltas, as they produced LUC fields in WRF that were not consistent with the LUM change fields.

LUM crop change deltas were applied to crop categories 2 and 3 in WRF, non-mixed-type dryland and irrigated crop, respectively, depending on which one was already prevalent in a grid box. Dryland crop was modified if no crop type 2 or 3 was present in the original/historical field. LUM pasture changes were applied to land category 7, grassland, in WRF, and urban changes were applied directly to the urban land category 1. Other fractional land-types in a grid box were increased or decreased proportionally to account for the changes in crop, pasture, and urban land. After the absolute crop and pasture change deltas were applied in WRF, the fields were adjusted by adding or subtracting small uniform values from all crop/pasture points until the changes across the domain in WRF in crop and pasture were within 5% of those projected by the LUM. Urban land and water (category 16) fractions were not allowed to change during the application of crop and pasture changes. Urban LUM change deltas were then applied, and considered to be the dominant changes during the land-use field modification process (i.e. they took precedence over any crop/pasture change at a point). Water fractions were not allowed to change in this step either. Finally, the resulting future land-use fraction fields for WRF were used to produce an updated dominant land-use category field for WRF.

We chose to apply the LUC deltas to cropland categories 2 and 3 instead of just to category 2, or to whichever cropland category between 2-6 was most prevalent in a grid box

already for several reasons. First, adding land to categories 2 or 3, instead of the mixed cropland types 4-6, seemed likely to produce a larger climate change signal, and, as a result, allow us to more easily see how much the LUCs could matter to the future climate. In the Southeast U.S., for example, applying the LUC to whichever cropland category was already most prevalent at a point would have meant that many (roughly half) of the points that changed from dominantly forest to dominantly dryland cropland using our chosen method would have changed to mixed cropland/woodland category 6 instead (not shown). This may have made the LUC climate signal smaller and, therefore, harder to separate from the green-house gas induced climate change signal. Applying crop change to only category 2, and ignoring category 3 if it was present at a point, may have produced a similarly larger effect, but it would not have been consistent with observed historical practices. However, if we wanted to use a similar methodology in WRF if the MODIS land-use categories were used instead of the USGS categories, applying LUC to category 2 only would have made this method more transferable, as there is no irrigated cropland category in MODIS. We decided against greater transferability, and for the methodology that would be somewhat more consistent with historical practices. (While cropland is represented in USGS land-use categories 2-6, with categories 4-6 being mixed cropland types, in MODIS, cropland is only represented in 2 categories: a pure "Croplands" category, and a mixed cropland category. In the WRF vegetation and land-use parameter tables, the "Croplands" category is identical to the USGS dryland cropland category 2, meaning that they share set characteristics like albedo, emissivity, and soil moisture availability.)

While pastureland could also be seen as multiple USGS land-use categories, for simplicity we chose to only change category 7, grassland. Pastureland area change is small relative to the SSP3LUC cropland and SSP5LUC urban land area changes, particularly in the dominant land-use category field, so we suspect that this choice had little overall effect on any of our CONUS-to-regional-scale climate change results (although it would matter at the grid-box level). Under a scenario with more pastureland change, or over a part of the world with more pastureland change, we would suggest exploring other options.

Table S1. WRF Configuration. See WRF User's Guide version 3.5 for details and parameter definitions (https://www2.mmm.ucar.edu/wrf/users/docs/user_guide_V3/contents.html). Where relevant, parameterization option number is given in parentheses after the parameterization's name.

Version	3.5.1
Dynamics	Nonhydrostatic, compressible
Sea Ice Characteristics	Fractional sea ice as a lower boundary condition from GCM
Lake Characteristics	Default interpolation from nearby ocean SSTs
Surface Layer	Eta similarity (2)
Boundary Layer	Mellor-Yamada-Janjic Scheme (2)
Land Surface Model	Noah Land Surface Model (2)
Microphysics	WRF Single-Moment 3-Class Scheme (3)
Cumulus Parameterization	Kain-Fritsch Scheme (1)
Longwave Radiation	Rapid Radiative Transfer Model (1)
Shortwave Radiation	Goddard Shortwave (2)
Spectral Nudging	Yes; wind, temperature, and geopotential nudged above layer 10
Top Wave Number to Nudge	7; wavelengths approximately 1000km and longer
Lateral Boundary Treatment	Linear relaxation
Sponge Zone Depth	5
Timestep (seconds)	150
Model Top (hPa)	50
Number of Vertical Levels	28
Surface Input Source	1 (historical and noLUC), 3 (SSP-based LUC scenarios)

Table. S2 Percent change from Hist to the noLUC or SSP5LUC future scenarios (as noted) in JJA-average precipitation characteristics for the points indicated in Figure 3 and defined in Section 2.3. a) Points that are directly over the urbanization centers, and b) eastward/downstream points that are more "rural". Precipitation characteristics are defined in Section 2.4.

a) Urban	Average (%)	Intensity (%)	%Wet (%)	%Dry (%)	CWH (%)	CDH (%)
CHI noLUC	6.23	28.69	-17.44	4.35	-14.45	7.96
CHI SSP5LUC	31.67	65.95	-20.63	5.15	-5.90	24.42
DFW noLUC	1.18	21.17	-16.49	1.81	-4.50	16.55
DFW SSP5LUC	42.70	39.11	2.60	-0.29	5.26	2.40
FL noLUC	-7.61	3.33	-10.59	3.15	-11.95	1.53
FL SSP5LUC	53.99	36.63	12.72	-3.79	16.56	-0.51
MSP noLUC	29.87	35.42	-4.09	1.11	-11.06	-6.22
MSP SSP5LUC	58.91	86.66	-14.83	4.04	-7.83	12.58
NJ noLUC	-10.93	26.55	-29.61	6.30	-12.21	32.56
NJ SSP5LUC	13.72	46.29	-22.24	4.73	-4.29	28.87
noLUC Average	3.75	23.03	-15.64	3.35	-10.83	10.48
SSP5LUC Average	40.20	54.93	-8.48	1.97	0.76	13.55

b) Rural	Average (%)	Intensity (%)	%Wet (%)	%Dry (%)	CWH (%)	CDH (%)
CHI noLUC	9.13	32.58	-17.68	4.52	-13.33	9.84
CHI SSP5LUC	-0.73	54.04	-35.54	9.09	-18.99	36.85
DFW noLUC	0.25	18.80	-15.61	1.77	-9.21	9.53
DFW SSP5LUC	-0.26	27.48	-21.75	2.46	-9.78	18.17
FL noLUC	-2.57	11.46	-12.57	2.45	-4.97	11.27
FL SSP5LUC	-18.07	13.62	-27.88	5.44	-8.66	33.45
MSP noLUC	26.85	28.44	-1.23	0.37	-10.28	-8.83
MSP SSP5LUC	20.22	51.11	-20.42	6.11	-18.93	8.09
NJ noLUC	-5.87	43.59	-34.43	4.64	-10.47	42.87
NJ SSP5LUC	-15.07	53.21	-44.54	6.01	-7.21	77.30
noLUC Average	5.56	26.98	-16.31	2.75	-9.65	12.93
SSP5LUC Average	-2.78	39.89	-30.03	5.82	-12.72	34.77

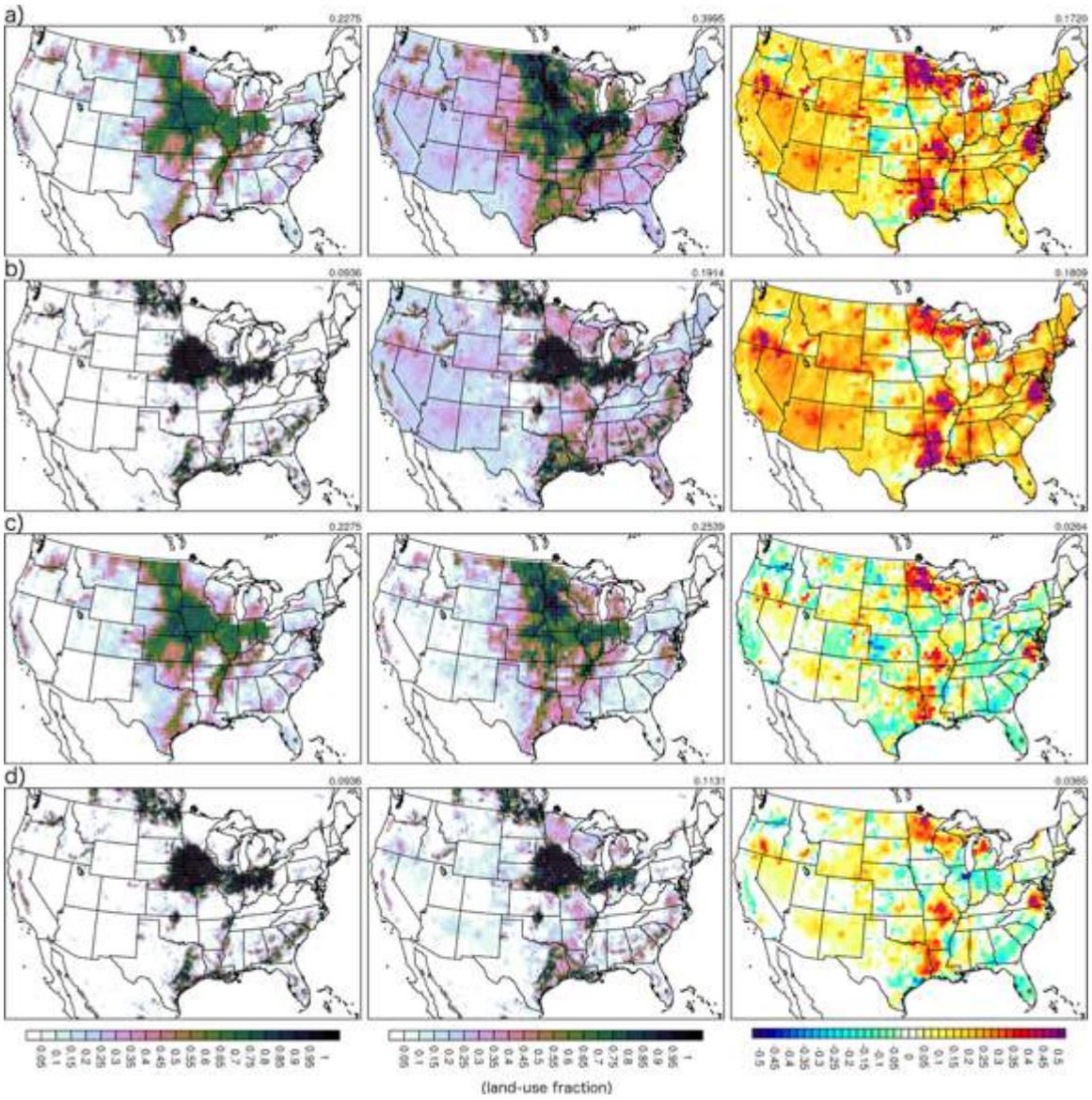

Figure S1. Left column: Historical crop fraction from a) LUM, b) WRF, c) LUM, d) WRF. In WRF, crop fraction is the total of land-use categories 2 and 3. Center column: as in the left column, but for the future crop fraction under a) and b) SSP3LUC, and c) and d) SSP5LUC. Right column: Change in crop fraction from the historical period to the future under a) and b) SSP3LUC, and c) and d) SSP5LUC. Values in the upper right corner of each panel represent the area average for that panel. Note that values outside of the U.S. in WRF have not been masked.

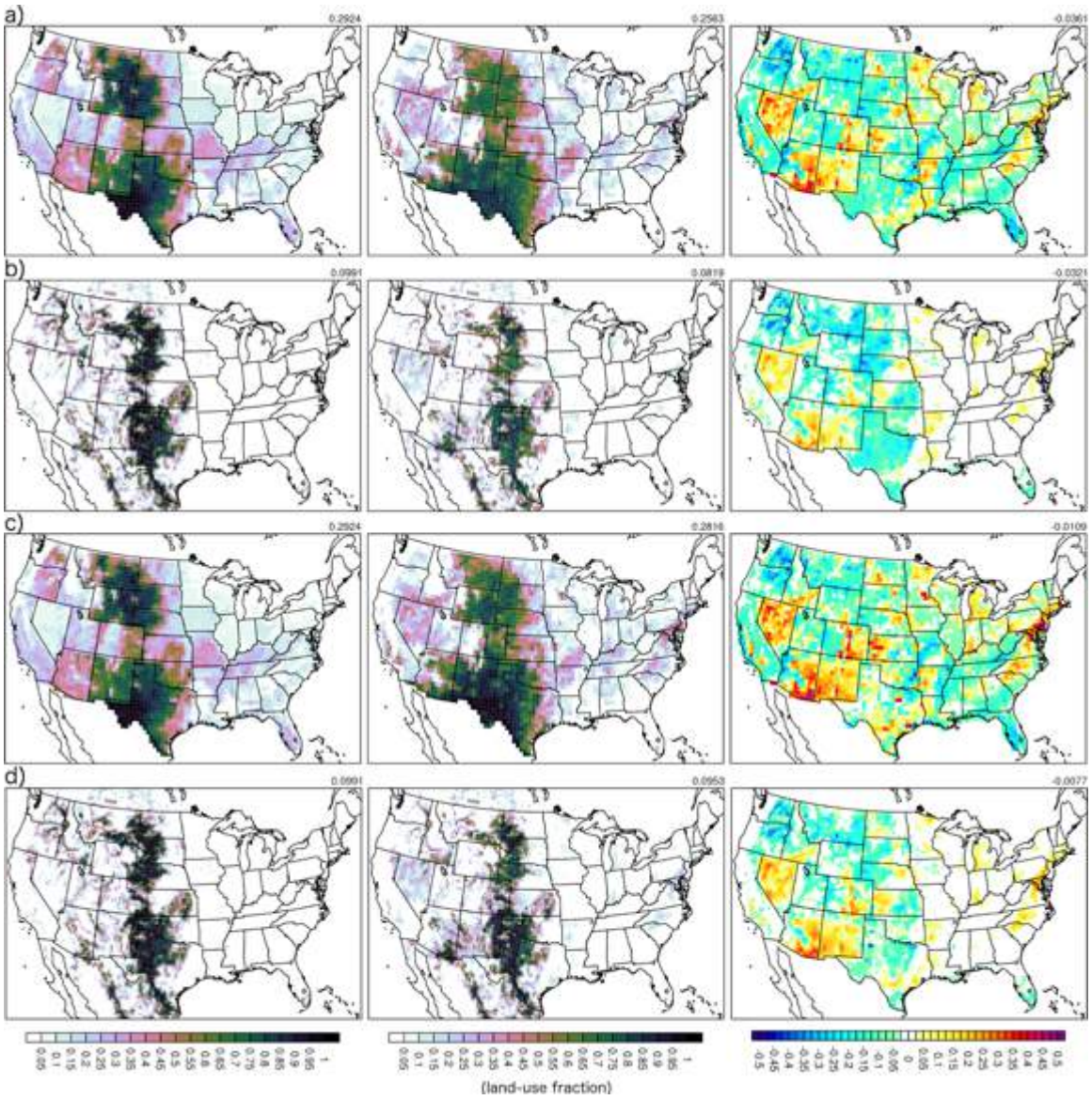

Figure S2. Left column: Historical pasture fraction from a) LUM, b) WRF, c) LUM, d) WRF. In WRF, pasture fraction is represented by land-use category 7. Center column: as in the left column, but for the future pasture fraction under a) and b) SSP3LUC, and c) and d) SSP5LUC. Right column: Change in pasture fraction from the historical period to the future under a) and b) SSP3LUC, and c) and d) SSP5LUC. Values in the upper right corner of each panel represent the area average for that panel. Note that values outside of the U.S. in WRF have not been masked.

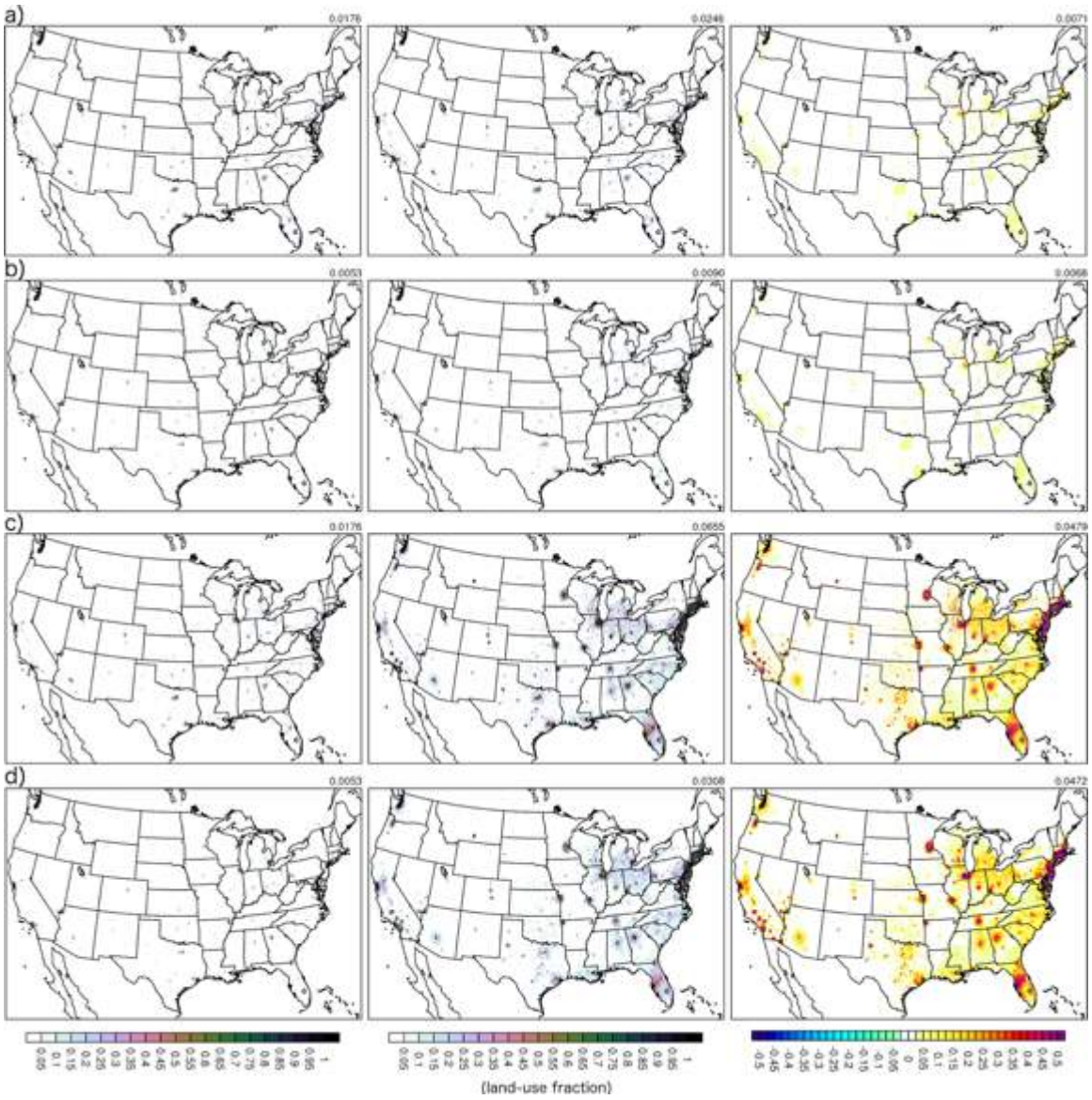

Figure S3. Left column: Historical urban land fraction from a) LUM, b) WRF, c) LUM, d) WRF. In WRF, urban land fraction is represented by land-use category 1. Center column: as in the left column, but for the future urban fraction under a) and b) SSP3LUC, and c) and d) SSP5LUC. Right column: Change in urban land fraction from the historical period to the future under a) and b) SSP3LUC, and c) and d) SSP5LUC. Values in the upper right corner of each panel represent the area average for that panel. Note that values outside of the U.S. in WRF have not been masked.

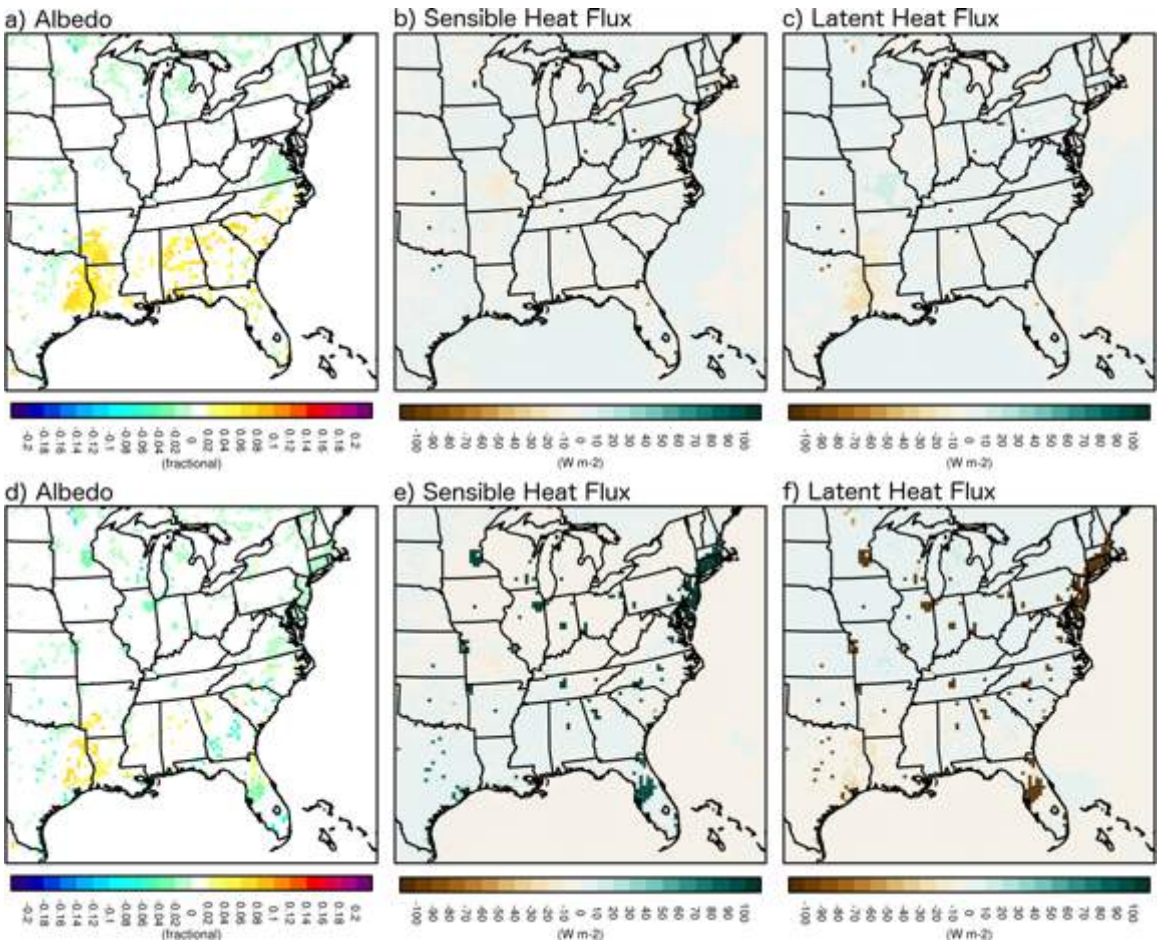

Figure S4. JJA-average absolute difference between projections from the SSP5LUC and noLUC future scenarios for a-c) SSP3LUC-noLUC and d-f) SSP5LUC-noLUC. a) and d) Albedo, b) and e) sensible heat flux, c) and f) latent heat flux.

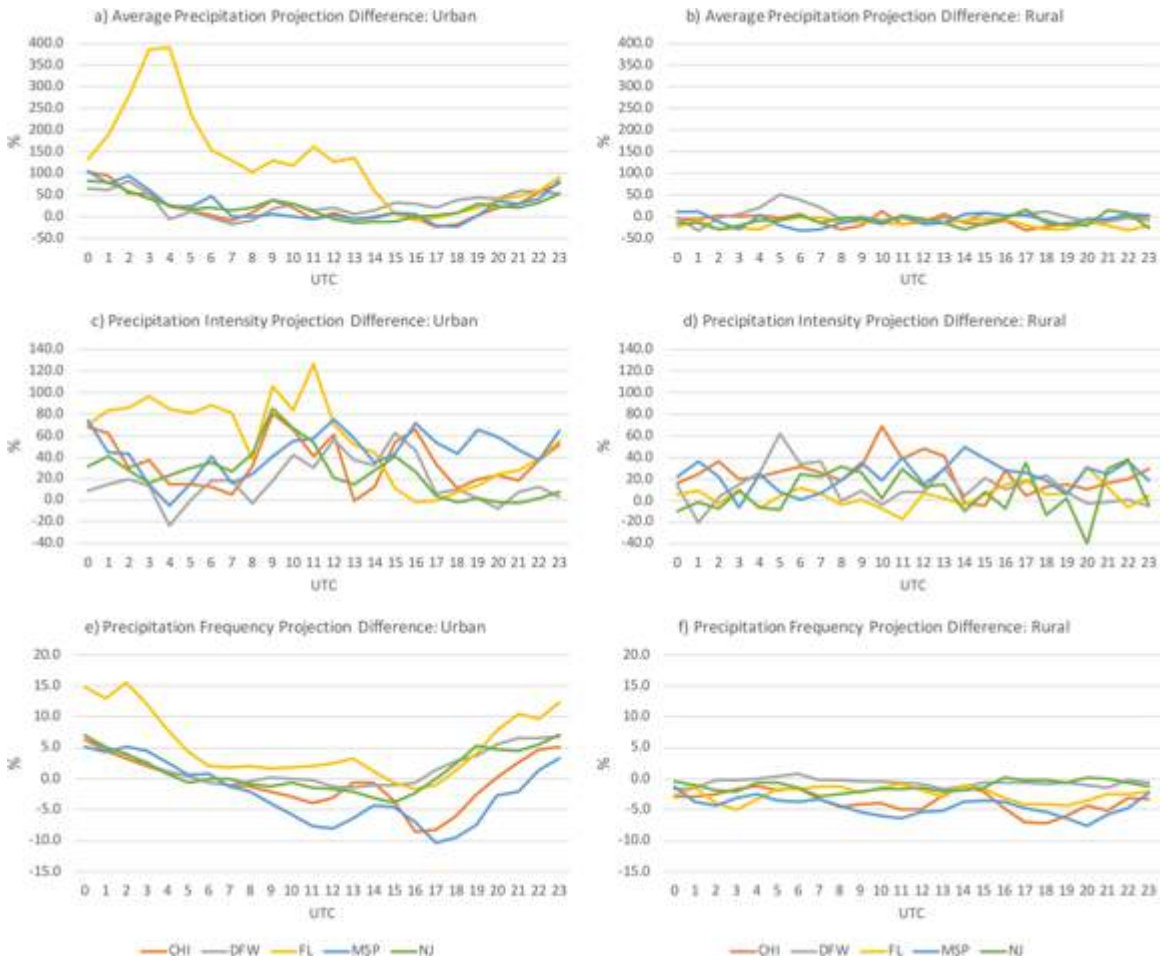

Figure S5. JJA-average absolute difference between projections from the SSP5LUC and noLUC future scenarios for the percent change in a-b) average precipitation, c-d) precipitation intensity, e-f) precipitation frequency, for the full diurnal cycle, using hourly precipitation. The different plot lines reflect the different points indicated in Figure 3 and defined in Section 2.3. a, c, and e) Points that are directly over the urbanization centers, and b, d, and f) eastward/downstream points that are more "rural". Precipitation characteristics are defined in Section 2.4.

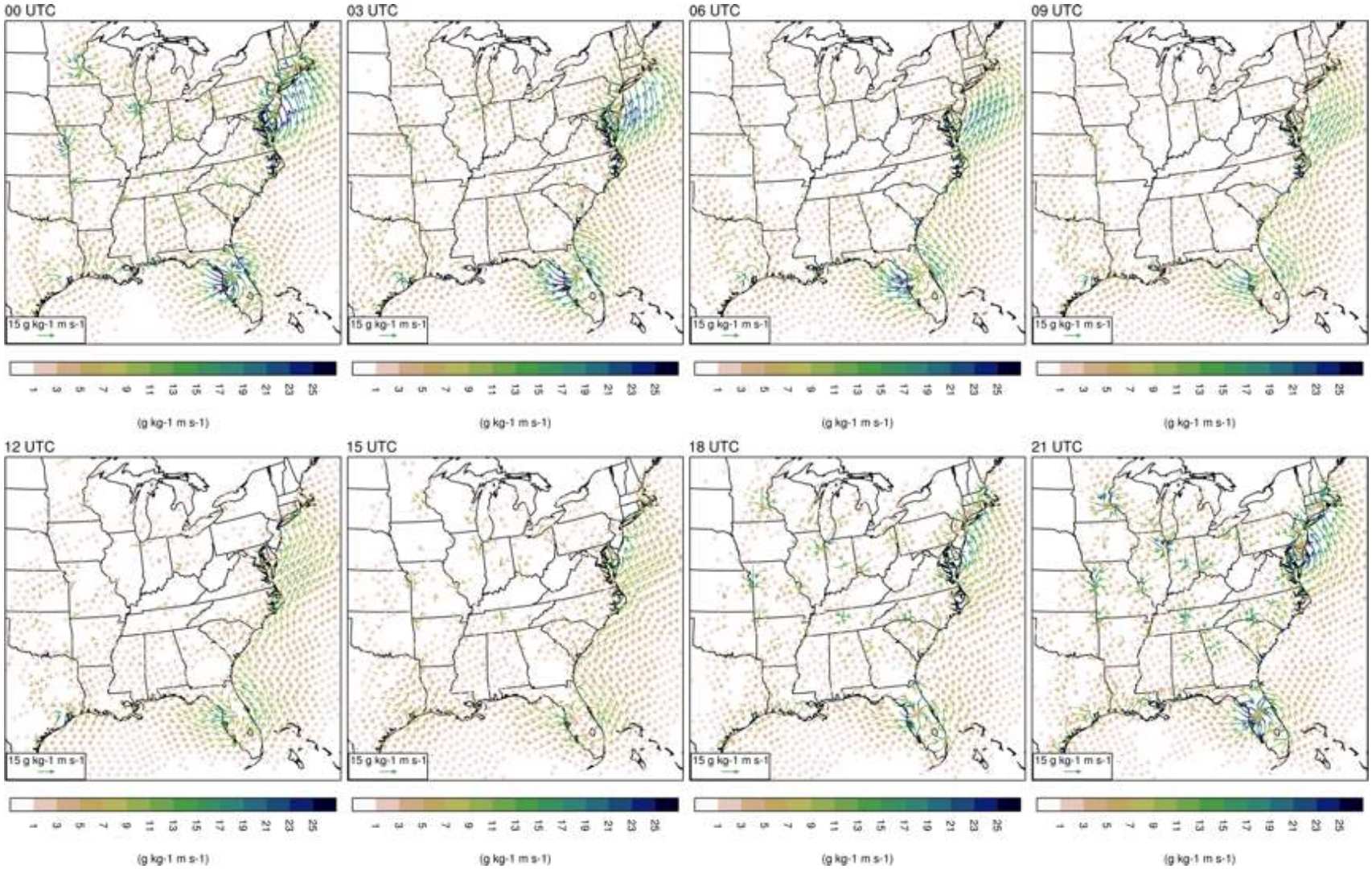

Figure S6. JJA-average absolute difference between projections from the SSP5LUC and noLUC future scenarios for 3-hour average near-surface moisture flux.

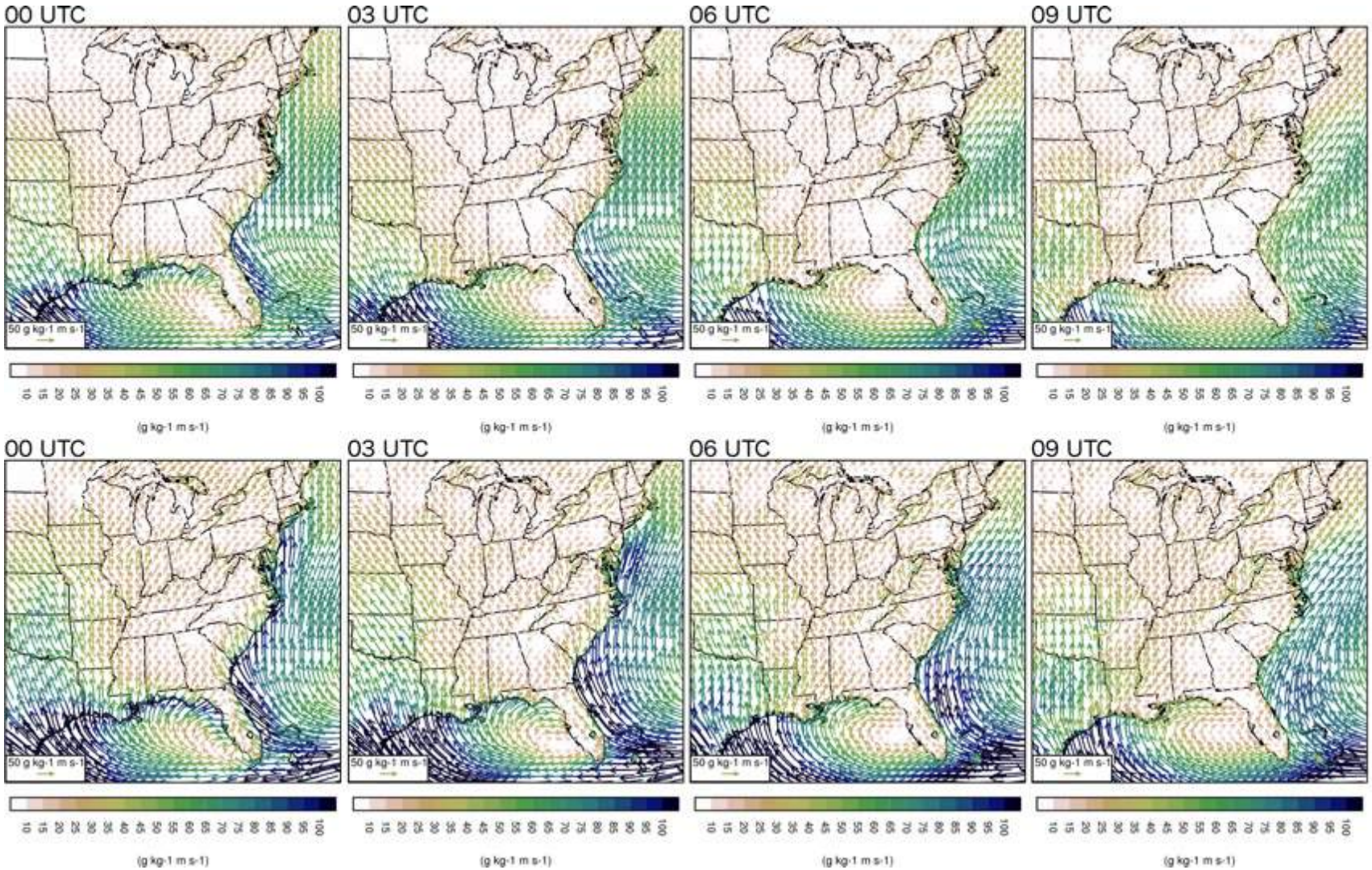

Figure S7a. JJA-average Hist (top row) and SSP5LUC (bottom row) 3-hour average near-surface moisture flux for 00-09 UTC. See Figure 7b for 12-21 UTC.

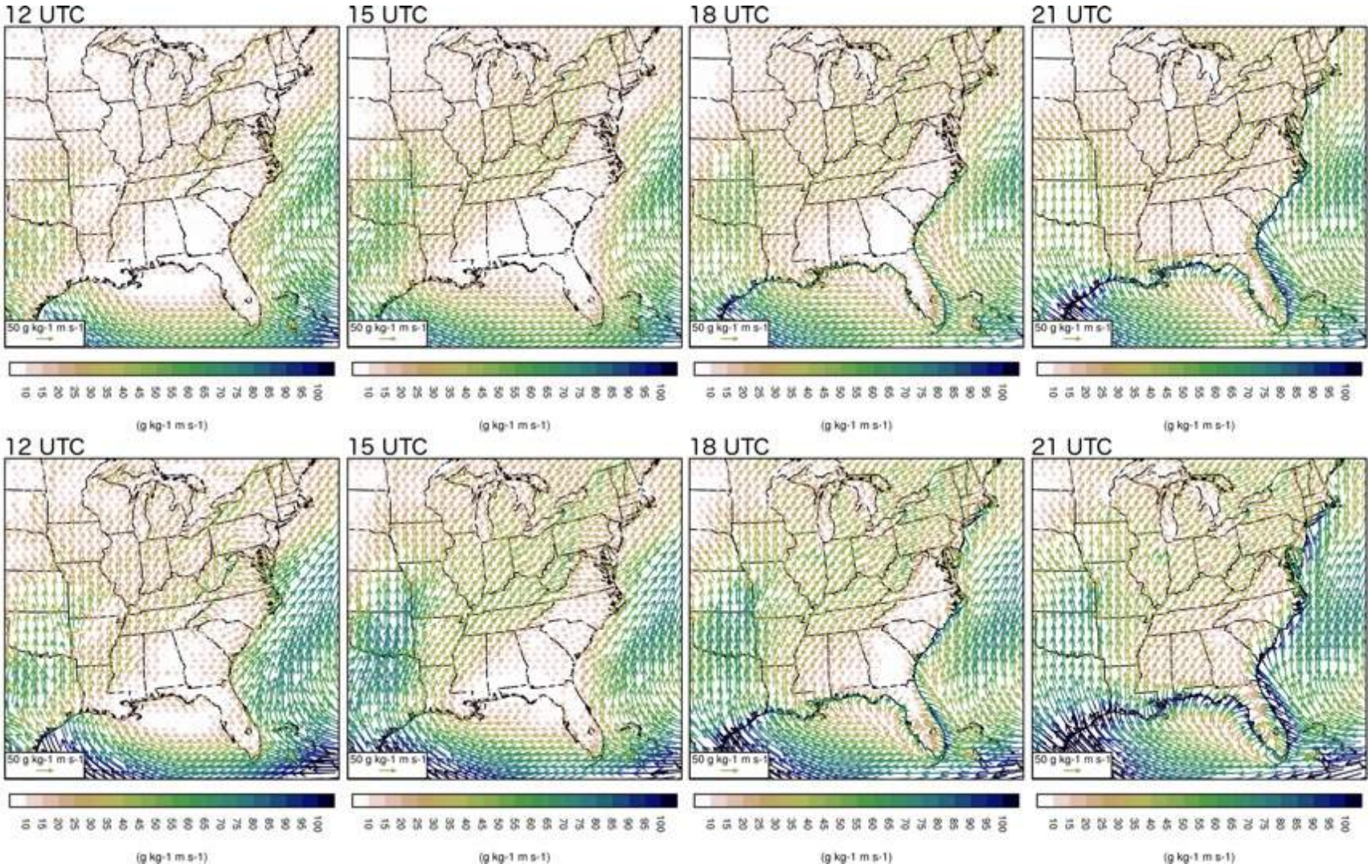

Figure S7b. As in Figure 7a, but for 12-21 UTC.