Mid-twenty-first century climate change in the Central United States: Extreme events

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Goal

Produce predictions for changes in extreme events that are as accurate, useful, and as reliable as possible

Methodology

Regional climate modeling

- resolution > GCMs; choose parameterizations for given region
- constrained by reanalysis for an accurate present day climate
- future boundary conditions from GCM anomalies

Evaluation of confidence in projections

- validation
- ensembles
- physical processes
- comparison with results from other models

Results from 3 papers:

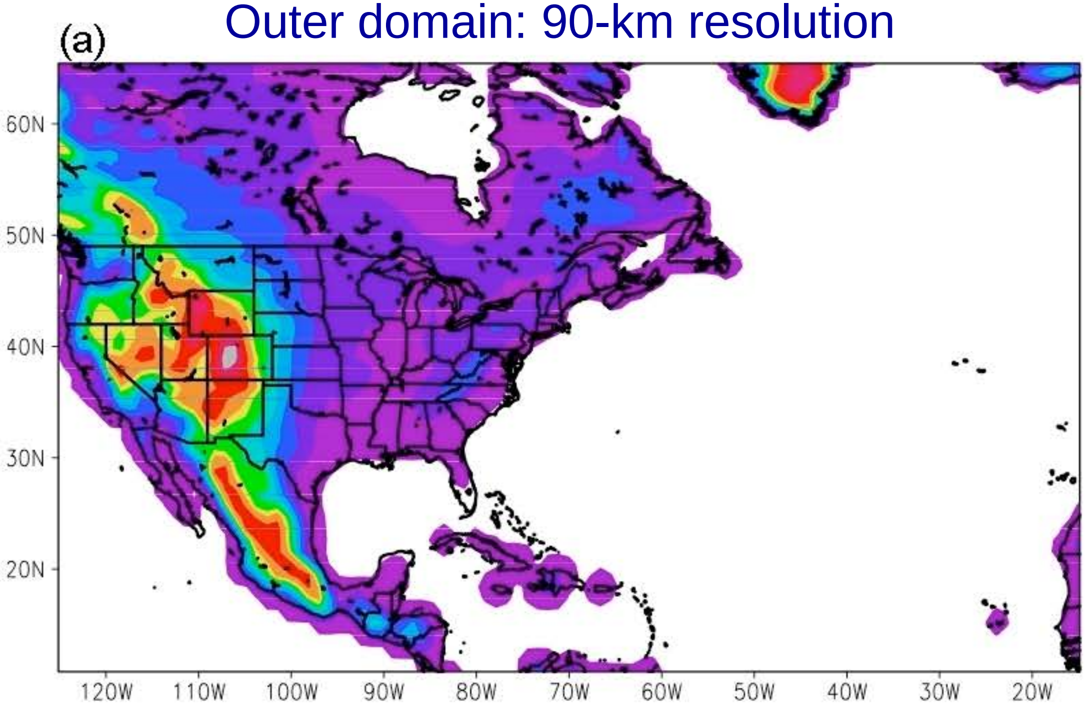
Patricola, C. M., and K. H. Cook, 2011: Regional climate simulations of U.S. climate for the mid-21st century: Projections. Submitted to *Climate Dyn*.

Patricola, C. M., and K. H. Cook, 2011: Regional climate simulations of U.S. climate for the mid-21st century: Processes. Submitted to *Climate Dyn*.

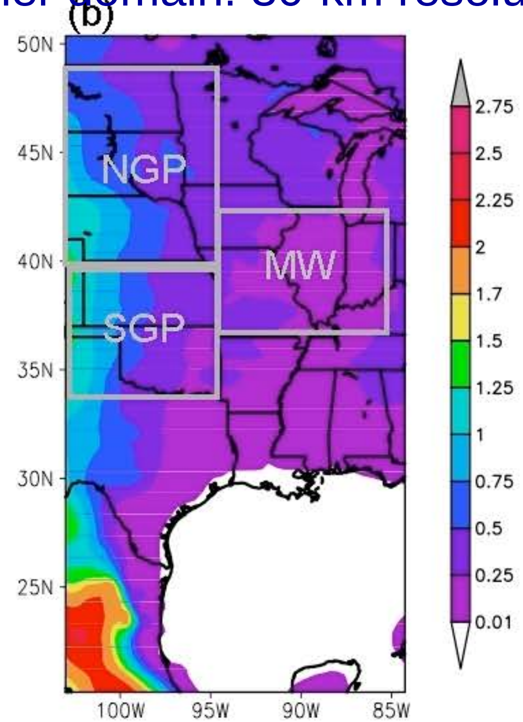
Neupane, N., and K.H. Cook: Predicting changes in extreme rainfall over the U.S.: Relating theory to model simulations

WRF 3.1 with 30 levels
Lin microphysics, CAM longwave and shortwave radiation, Yonsei University (YSU) planetary boundary layer, new Kain-Fritsch cumulus scheme, NOAH land surface model

Outer domain: 90-km resolution



Inner domain: 30-km resolution



Climate Prediction with a Regional Model: Methodology

Late 20th c. simulation (L20C): 1981-2000
20 individual annual simulations = 20-member ensemble

1. One-year spin-up: Model is initialized on 1 January 1980 using soil moisture and temperature from the from the 1980-2000 January average in the NARR in other bcs from the ERA40 reanalysis, and run through 1 December 1980.

2. The annual simulation for 1981 is initialized on 1 December 1980, with ERA40 reanalysis values plus soil moisture and snow fields from the previous year's integration, and run through 31 December 1981, with the first month disregarded for spin-up.

3. Each of the twenty annual integrations for L20C is formed this way.

Mid-21st c. simulation (M21C): 2041-2060

20 individual annual simulations = 20-member ensemble

20 annual integrations spun-up and restarted annually as for L20C.

Atmospheric greenhouse gas concentrations from A2 emissions scenario (IPCC 2000).

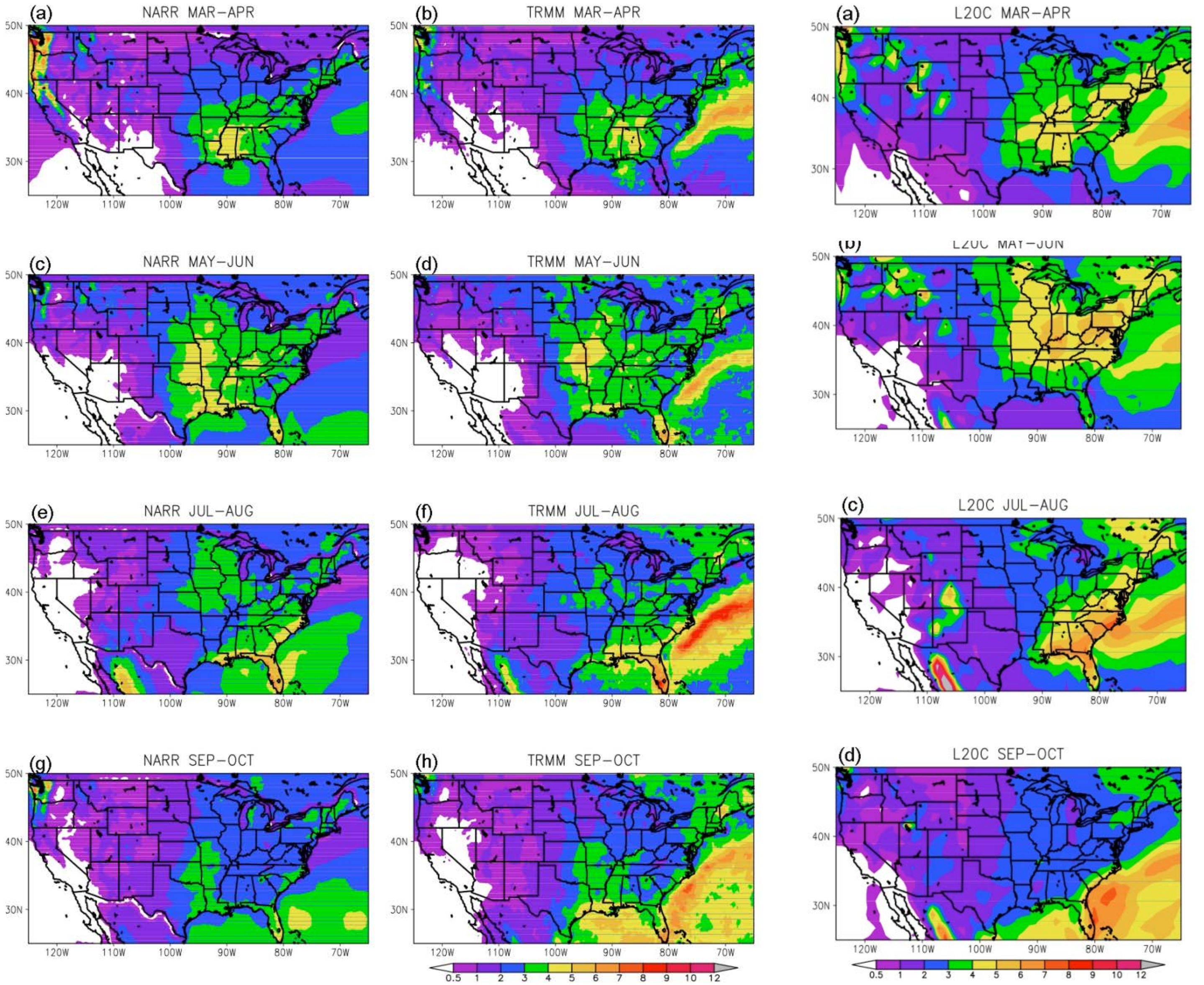
CO_2 updates annually (339.6 -> 370.5 ppm in L20C; 533.0 -> 578.0 ppm in M21C)

N_2O, CH_4, CFC-11, and CFC-12 concentrations prescribed at the 20-year mean

LBCs and SSTs applied as anomalies generated from AOGCM output

- add monthly climatological anomalies derived from AOGCM simulations to the reanalysis used in the L20C simulation (an average of 6 AOGCMs)
- future LBCs account for changes in the mean climate state but do not include changes in transients or interannual variability
- the 20 years of M21C do not represent a specific year, but form an ensemble consisting of 20 years during the 2040 and 2050 decades.

One benefit of this method is that the quality of the control simulation is preserved and the impact of AOGCM error in both the lateral and surface boundaries on the regional climate projections is reduced.



Mar/Apr

May/Jun

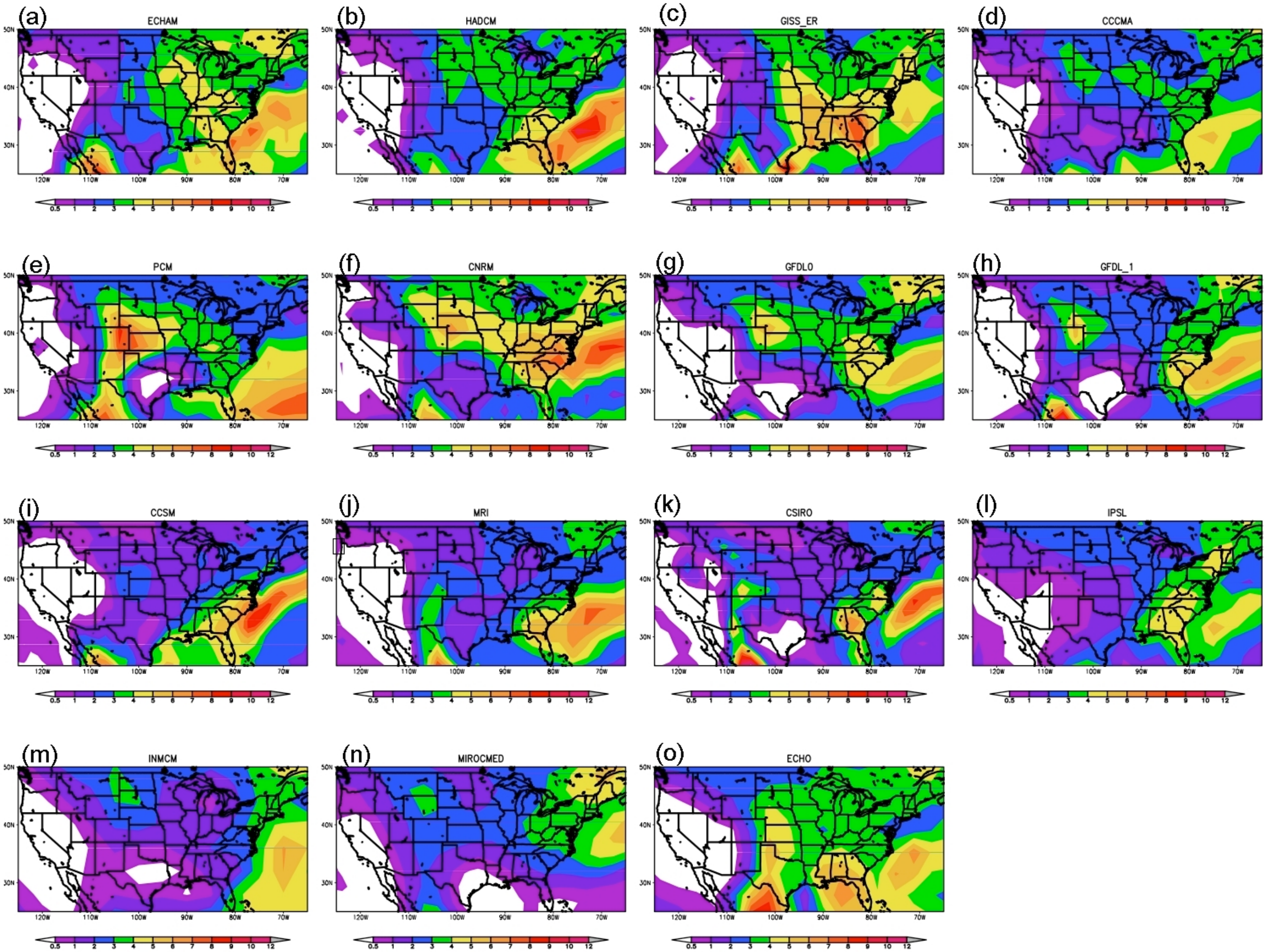
Jul/Aug

Sep/Oct

NARR

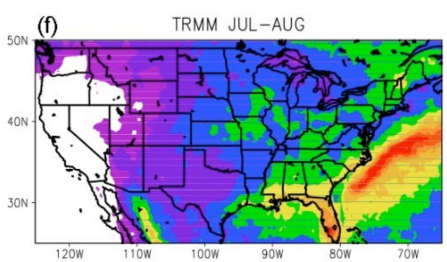
TRMM

Regional model



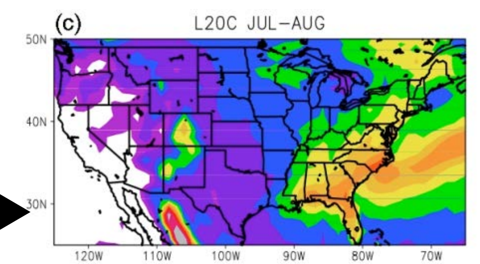
Jul/Aug Rainfall

15 CMIP3 AOGCMs



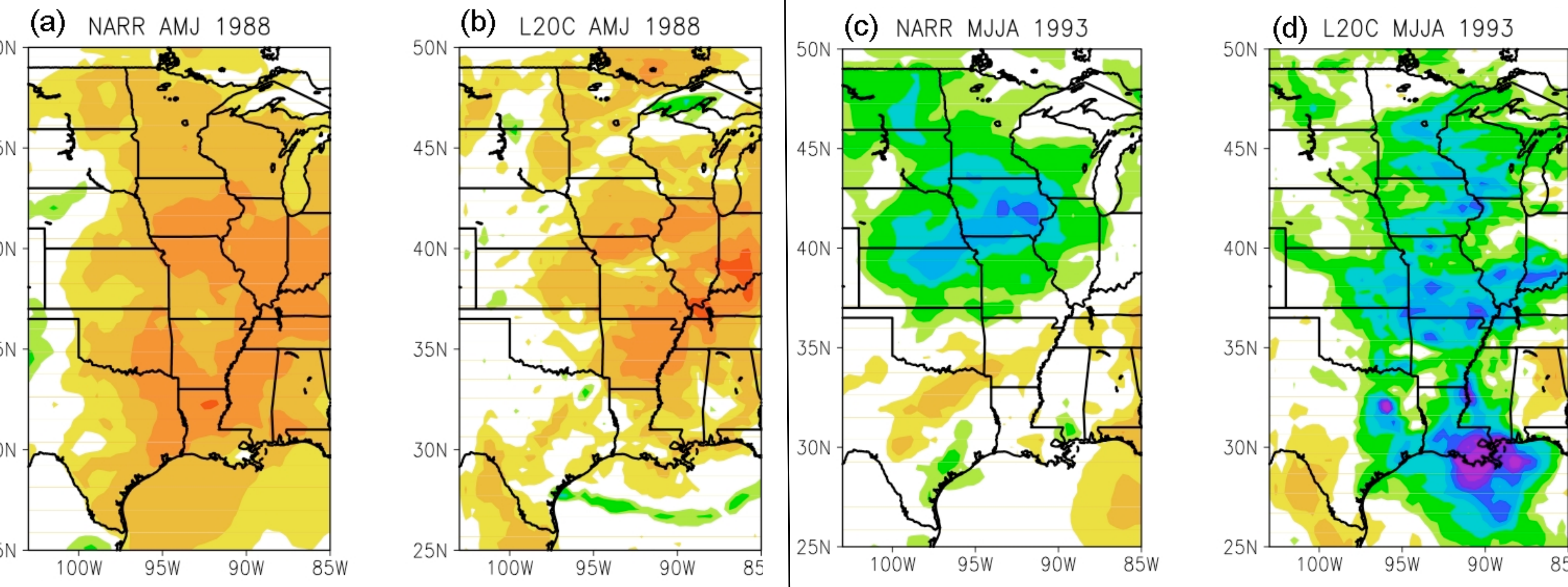
TRMM

RCM



Validation: Capturing Extreme Events in the 20th c. Simulation

Precipitation anomalies (mm/day) relative to the 1981 – 2000 mean; 30-km domain



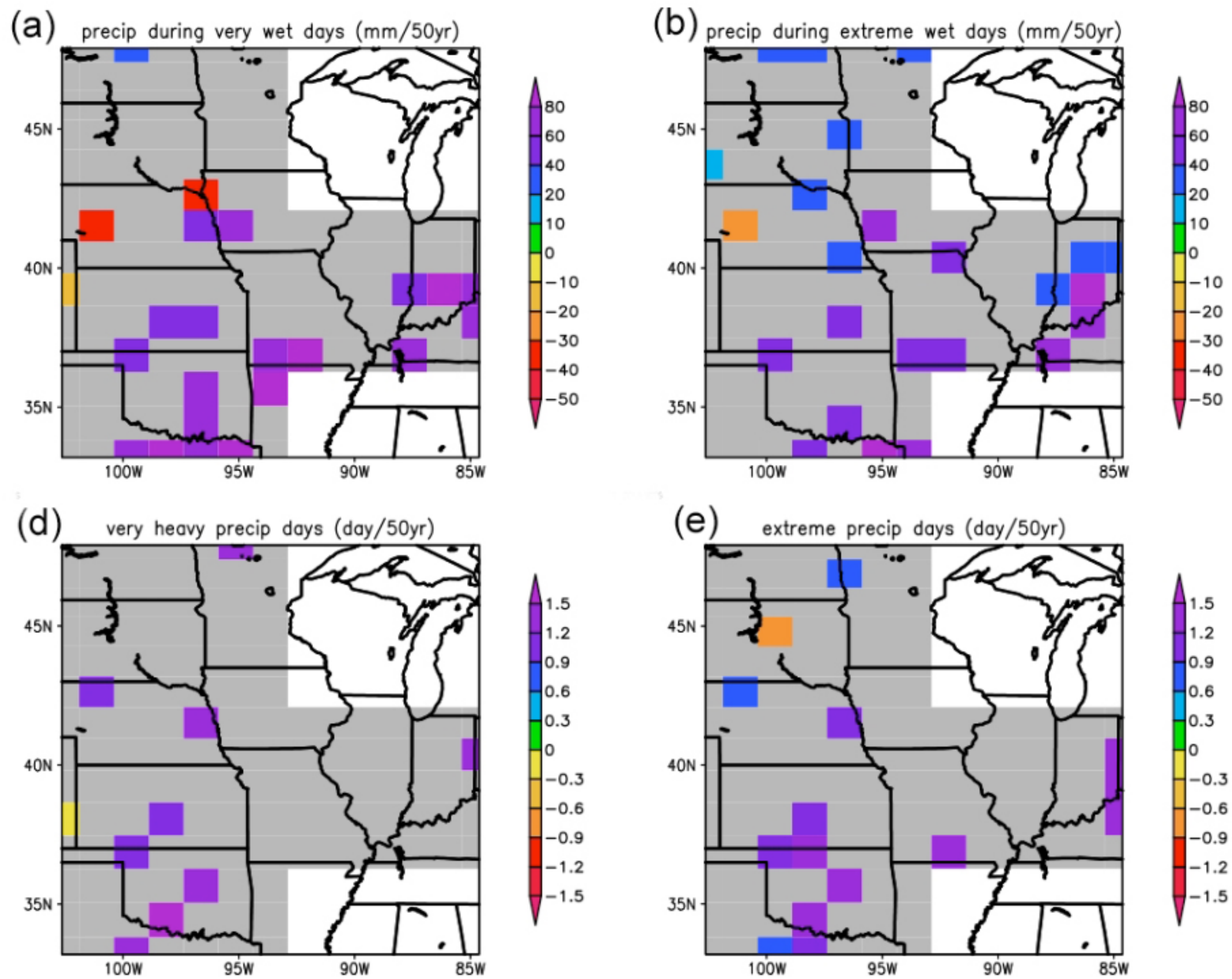
April-June of 1988

May-August 1993

Results: Trends in extreme climate indices > 85% confidence

Trends in precipitation received in very (extremely) heavy events [95^{th} and 99^{th} percentile of 1day rates in L20C]

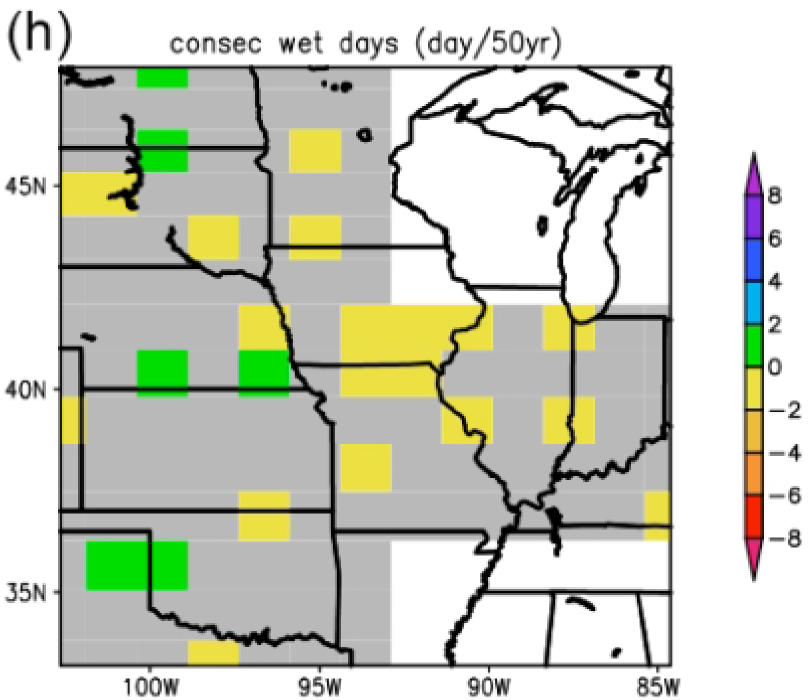
Trends in number of very (extremely) heavy precipitation days [95^{th} and 99^{th} percentile of numbers in L20C]

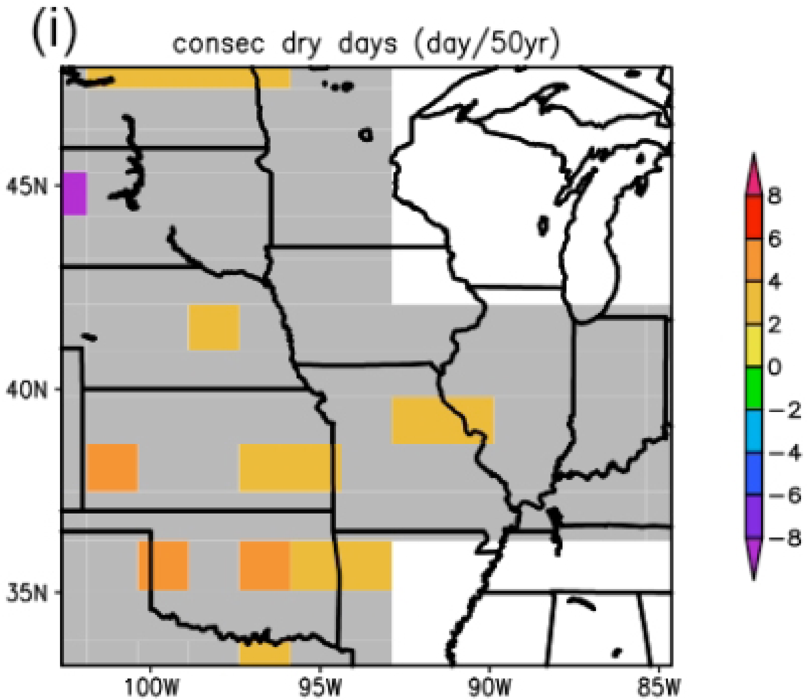


Changes in extreme precipitation are assessed with the climate change indices of the ETCCDI/CRD (Expert Team on Climate Change and Detection Indices/Climate Research Division; Karl et al. 1999, Peterson and Coauthors 2001, Peterson 2005).

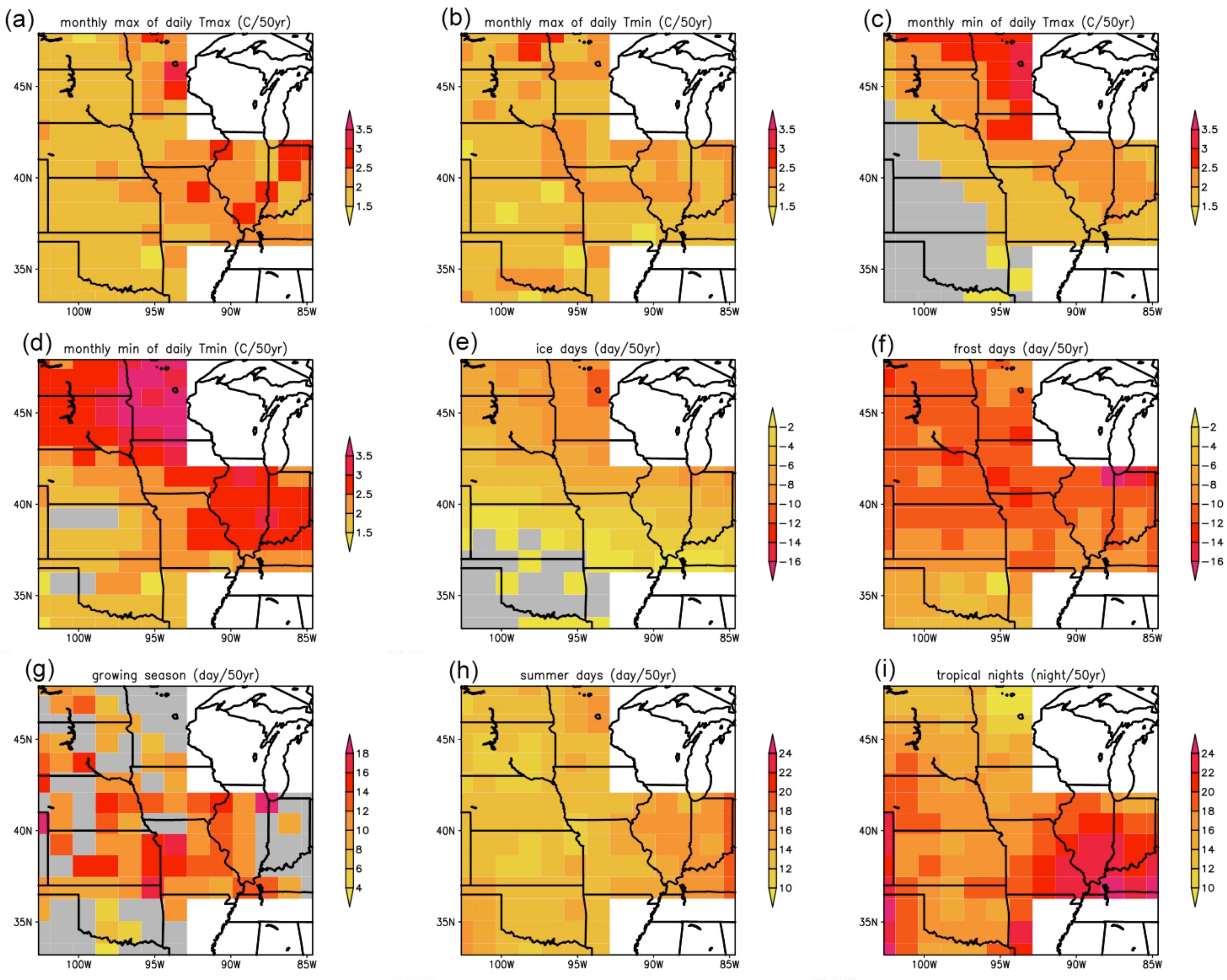
Small decreases in the number of consecutive wet days over parts of the Midwest

2-6 day increases in the number of consecutive dry days by the mid-21st century over parts of the southern Great Plains and Midwest





Changes in the extreme temperature indices



Changes in the extreme temperature indices

Annual number of ice days decreases by 1 week
Annual number of frost days decreases by 2 weeks
Temperature-based growing season length increases 1 - 2 weeks,

Annual number of warm days (Tmax > 90th percentile of the late-20th century)
increase by about 1 week
Annual number of cool days (Tmax<90^{th} percentile of the late 20^{th} c) decreases by 1-3 da
=> increase in the variability of daily extreme temperatures

Warm spell duration lengthens by 1.5 – 3 weeks
Cold spell duration is shortened by only 1 – 3 days

Levels of agreement on monthly precipitation predictions for the mid 21st century over the northern Great Plains from 15 AOGCMs, 7 NARCCAP RCMs, the 22 AOGCMs and NARCCAP RCMs together, and the percent change from M21C-L20C. Criteria for "uncertain," "likely," and "very likely" correspond to 33-66%, greater than 66%, and greater than 90% of the models predicting the same sign of precipitation change.

	AOGCMs	NARCCAP	AOGCM +NARCCAP	M21C-L20C
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Jul	uncertain	likely wet	uncertain	-10.2%
Aug	uncertain	uncertain	uncertain	-13.0%
Sep	uncertain	likely wet	uncertain	-7.4%
Oct	uncertain	uncertain	uncertain	-1.4%
Nov	uncertain	uncertain	uncertain	-4.4%
Dec	likely wet	very likely wet	likely wet	1.7%

Analysis of Physical Processes

Added confidence/understanding by further evaluating the physical processes of change and, as much as possible, relating the simulated climate change to forcing functions.

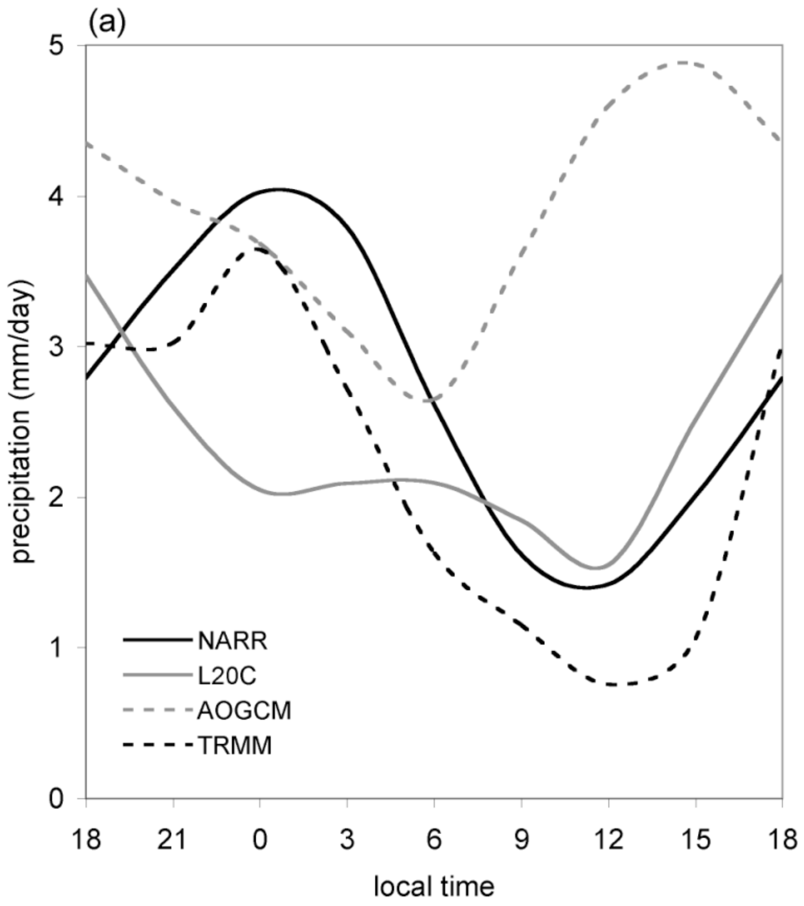
(1) use atmospheric moisture budget to relate precipitation anomalies to circulation anomalies, especially via the GPLLJ for the central U.S. which provides a nice connection with the NASH

(2) examine the diurnal cycle

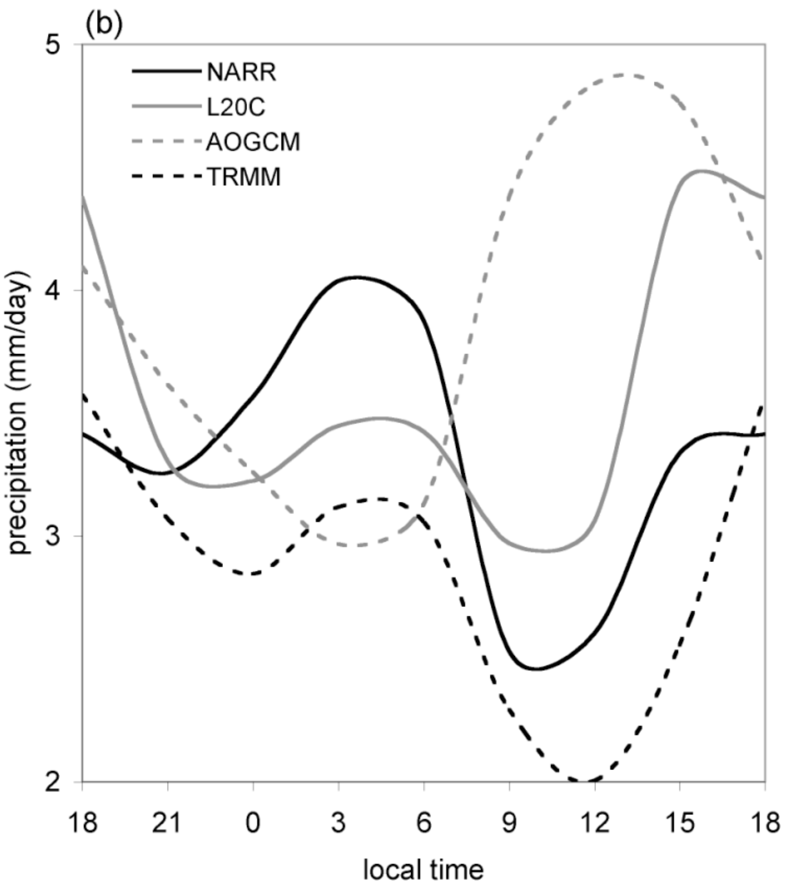
- afternoon changes in precipitation => changes in local convection (can cross reference with the moisture budget)
- changes during the night => change in rainfall associated with the GPLLJ and/or systems propagating in from the west

Example: Changes in the diurnal cycle of precipitation

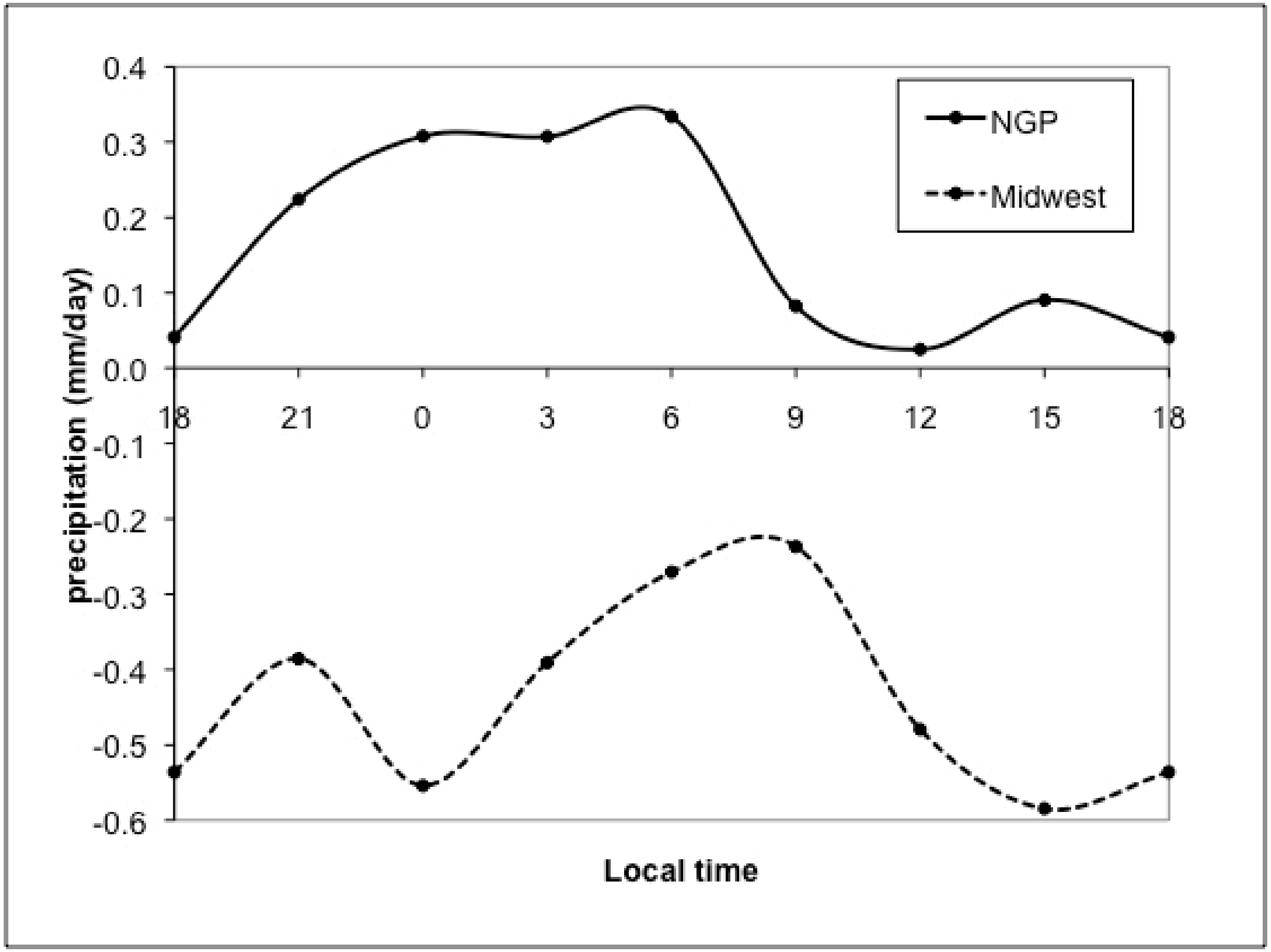
Validation: Simulation of the diurnal cycle of rainfall



Great Plains



Midwest



Increase in rainfall at night, associated with intensification of GPLLJ and westward extension of NASH

Decrease in rainfall At night

… also and in the afternoon associated with decreases in convection

Anomalies (M21C – L20C) in precipitation (mm/day) averaged over June on the 3-hourly timescale for the northern Great Plains (solid) and Midwest (dashed).

Summary and Conclusions

Projected central U.S. precipitation changes are related to different physical processes during the spring and summer.

Great Plains

April and May: afternoon and evening increases are supported primarily by anomalous moisture convergence due to transient eddies, indicating enhanced daytime convection, e.g., as a result of warming and/or moistening the surface air, associated directly or indirectly with local greenhouse gas forcing.

June: increases are strongest from 0000 - 0600 LT supported by anomalous time-mean meridional moisture convergence related to a strengthening of the GPLLJ, especially in the jet exit region., accompanied by an intensification of the western portion of the North Atlantic subtropical high. Related to greenhouse gas forcing through Atlantic SSTAs and, in particular, the differential low-level warming over continental and ocean surfaces (Cook et al. 2008).

Midwest summer drying

decreased rainfall strongest at 1500 LT and 0000 LT, supported by anomalous moisture divergence due to transient eddies and anomalous time-mean zonal divergence, indicating the importance of both suppressed daytime convection as well as changes in the zonal flow in the GPLLJ exit region.

Great Plains drying (July, August, September)

- Weakened daytime convection, as suggested by the significant contribution from anomalous moisture divergence due to transient eddies and the occurrence of the maximum anomaly in the afternoon.
- Drying over the northern Great Plains persists throughout August and September when the deficit in soil moisture and strong land-atmosphere feedbacks dominate.

Can we understand increases in extreme events as climate warms in terms of the basic thermodynamic argument?

Claussius-Clapeyron equation =>
(approximately) 7% increase
in the saturation vapor pressure for a 1K increase in temperature

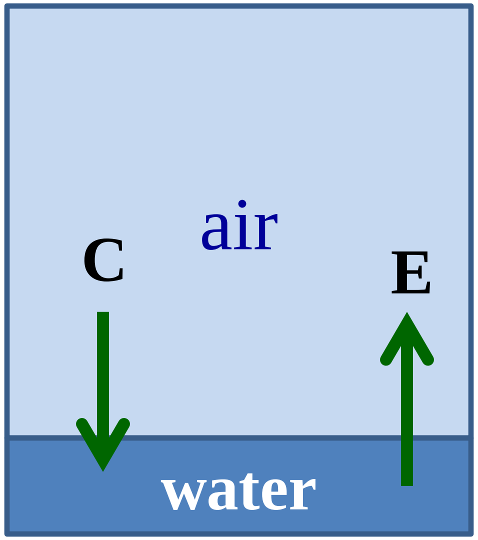
+

Constant RH as climate warms

=

Increase in mixing ratio 7%/K ("thermodynamic argument")
(observational support over oceans)
Increase of precipitation 7%/K? Intensity changes?
Helpful for understanding/becoming more convincing about regional changes in extreme events over the U.S.?

Claussius-Clapeyron equation => (approximately) 7% increase in the saturation vapor pressure for a 1K increase in temperature

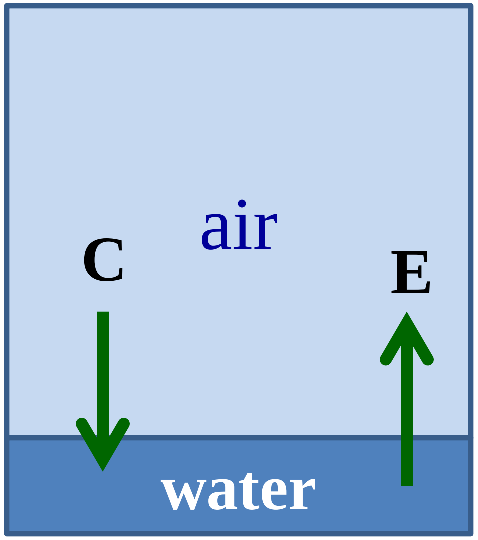


Isothermal, closed system

Claussius-Clapeyron equation => (approximately) 7% increase in the saturation vapor pressure for a 1K increase in temperature

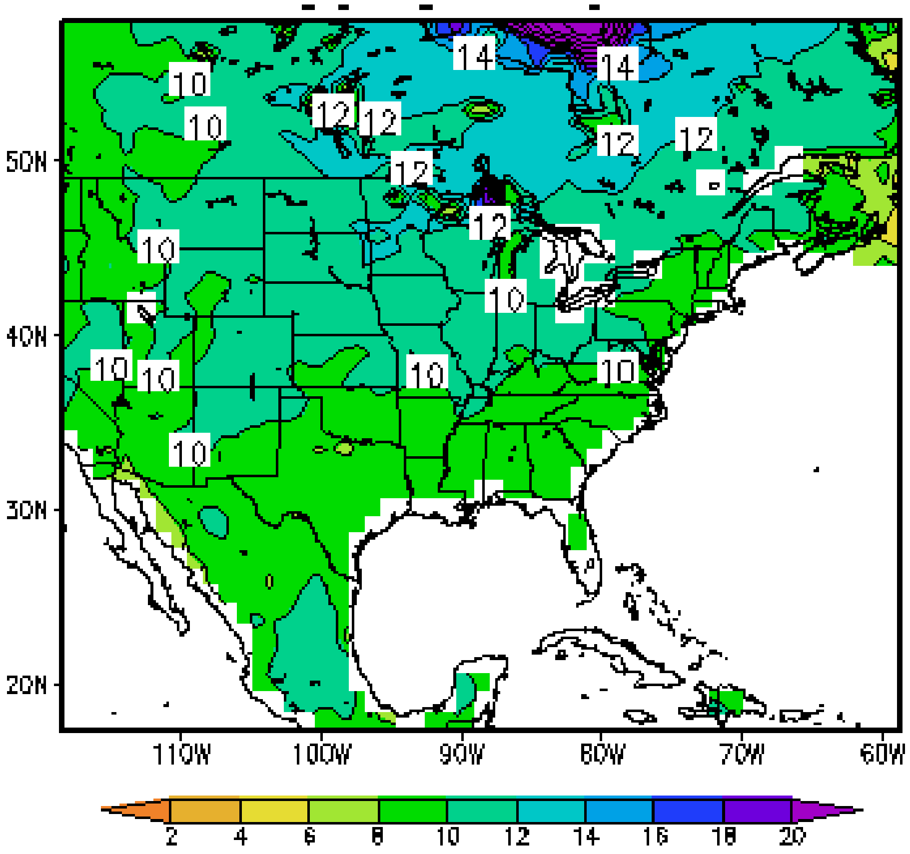
No

Advection
Convection
Precipitation
Radiation
etc.



Isothermal, closed system

% change in es predicted by the C-C equation using predicted changes in surface temperature from outer domain (90 km)



"theory"

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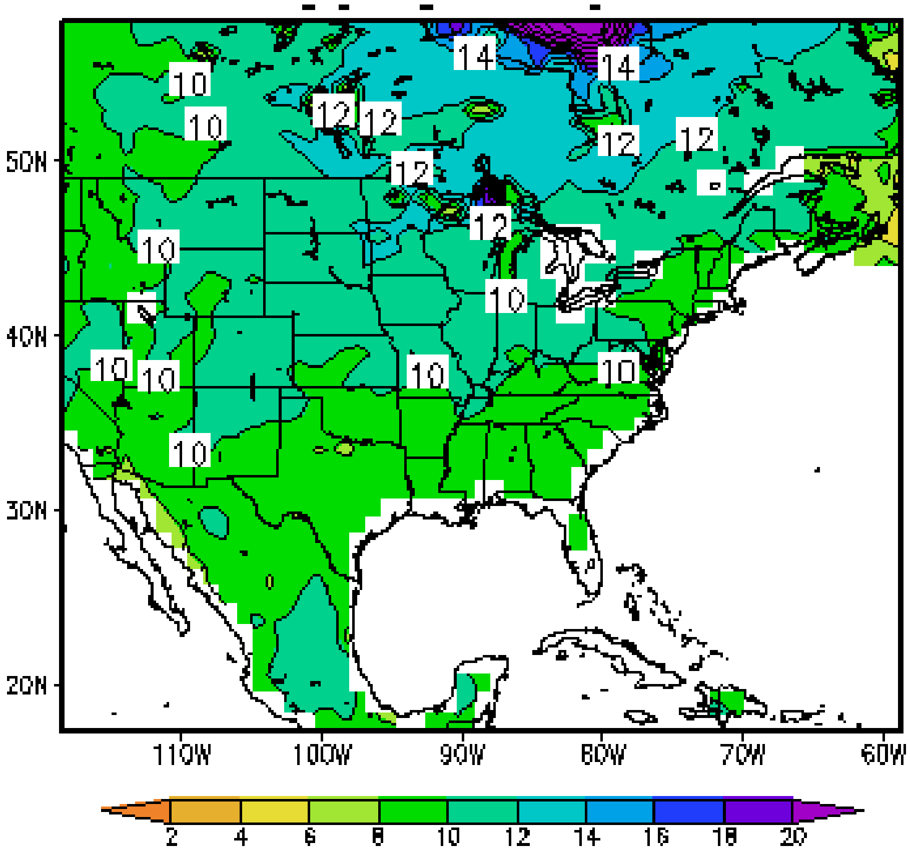
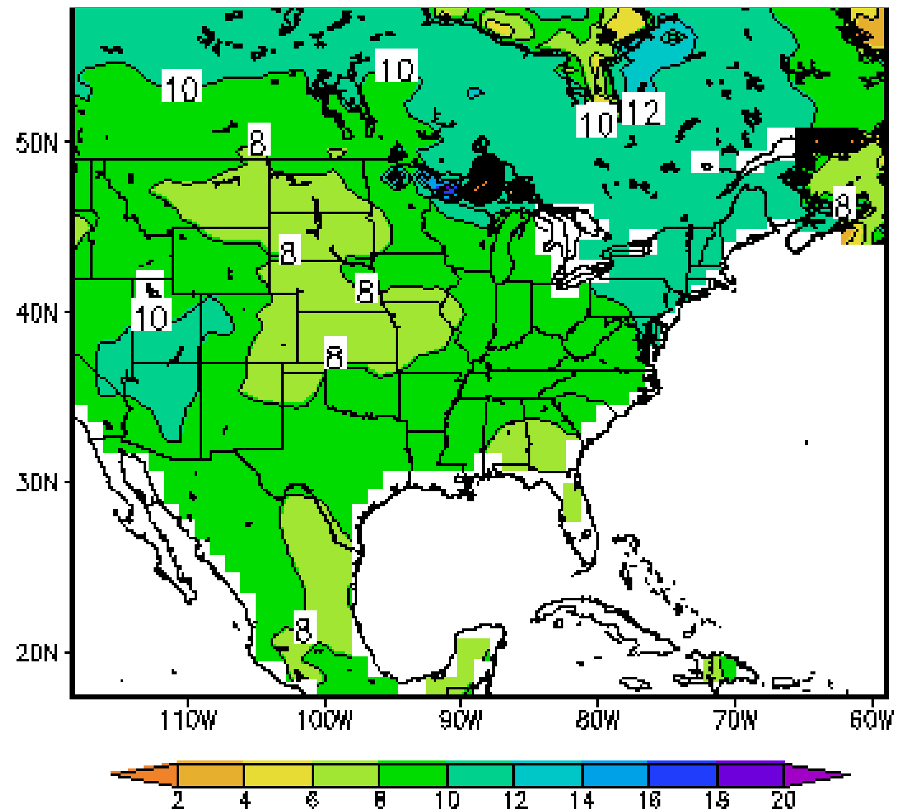


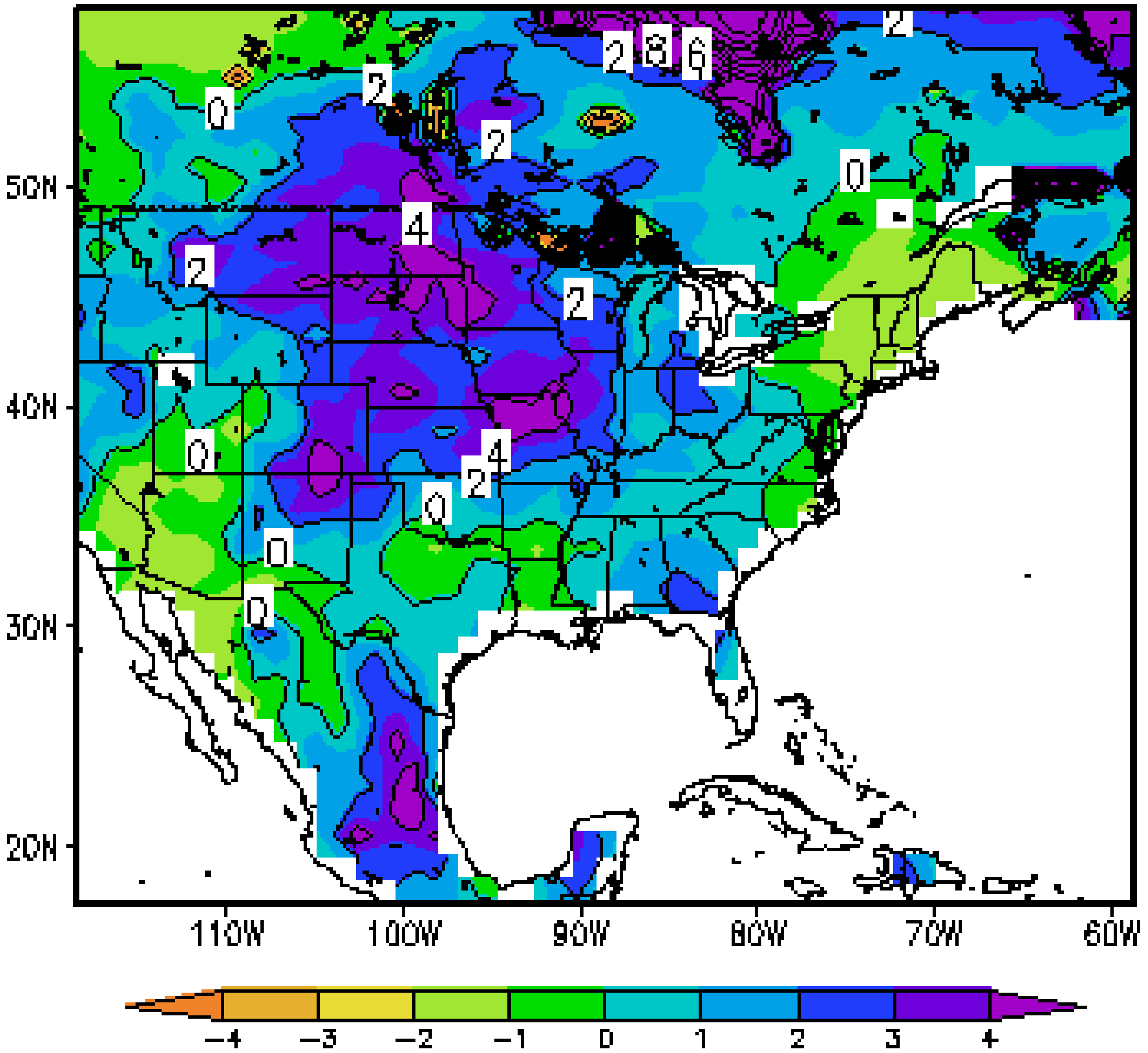
“theory”

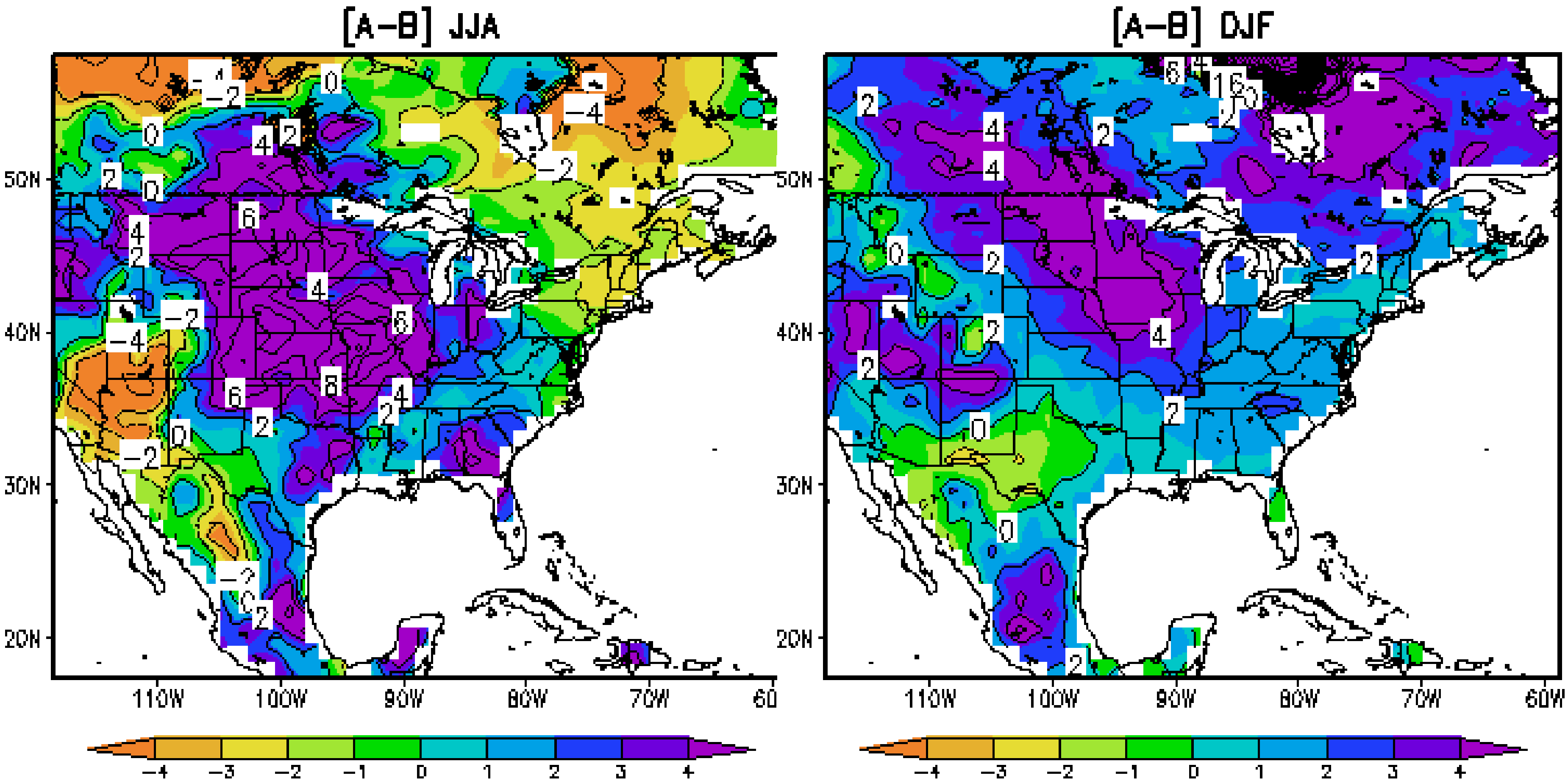
% change in 2-m mixing ratio predicted in the model simulation



“prediction”

“theory” minus “prediction”





[A–B] JJA
[A–B] DJF
50N
40N
30N
20N
110W
100W
90W
80W
70W
60W
–4
–3
–2
–1
0
1
2
3
4

Levels of agreement on monthly precipitation predictions for the mid 21st century over the northern Great Plains from 15 AOGCMs, 7 NARCCAP RCMs, the 22 AOGCMs and NARCCAP RCMs together, and the percent change from M21C-L20C. Criteria for “uncertain,” “likely,” and “very likely” correspond to 33-66%, greater than 66%, and greater than 90% of the models predicting the same sign of precipitation change.

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