The Scale-dependence of Groundwater Effects on Precipitation and Temperature in the Central United States

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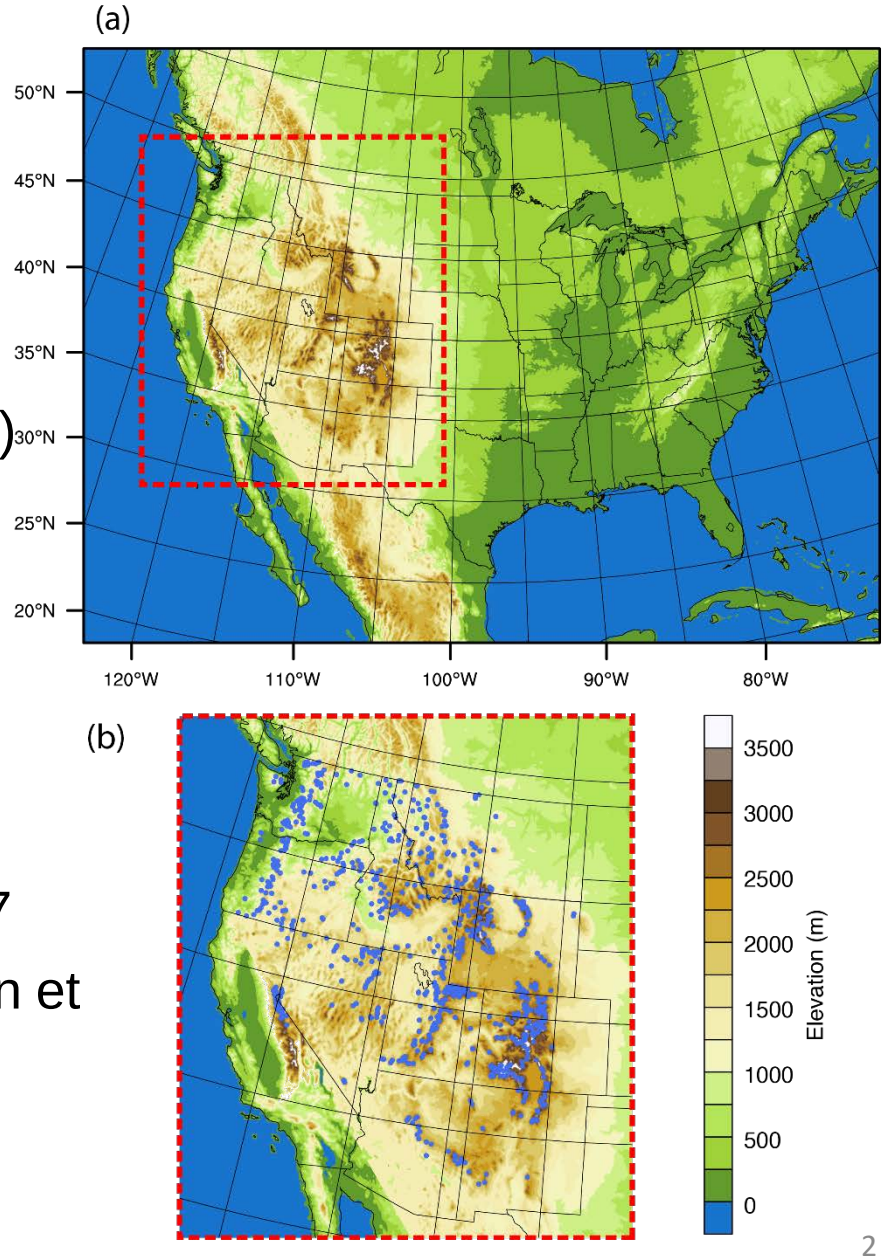
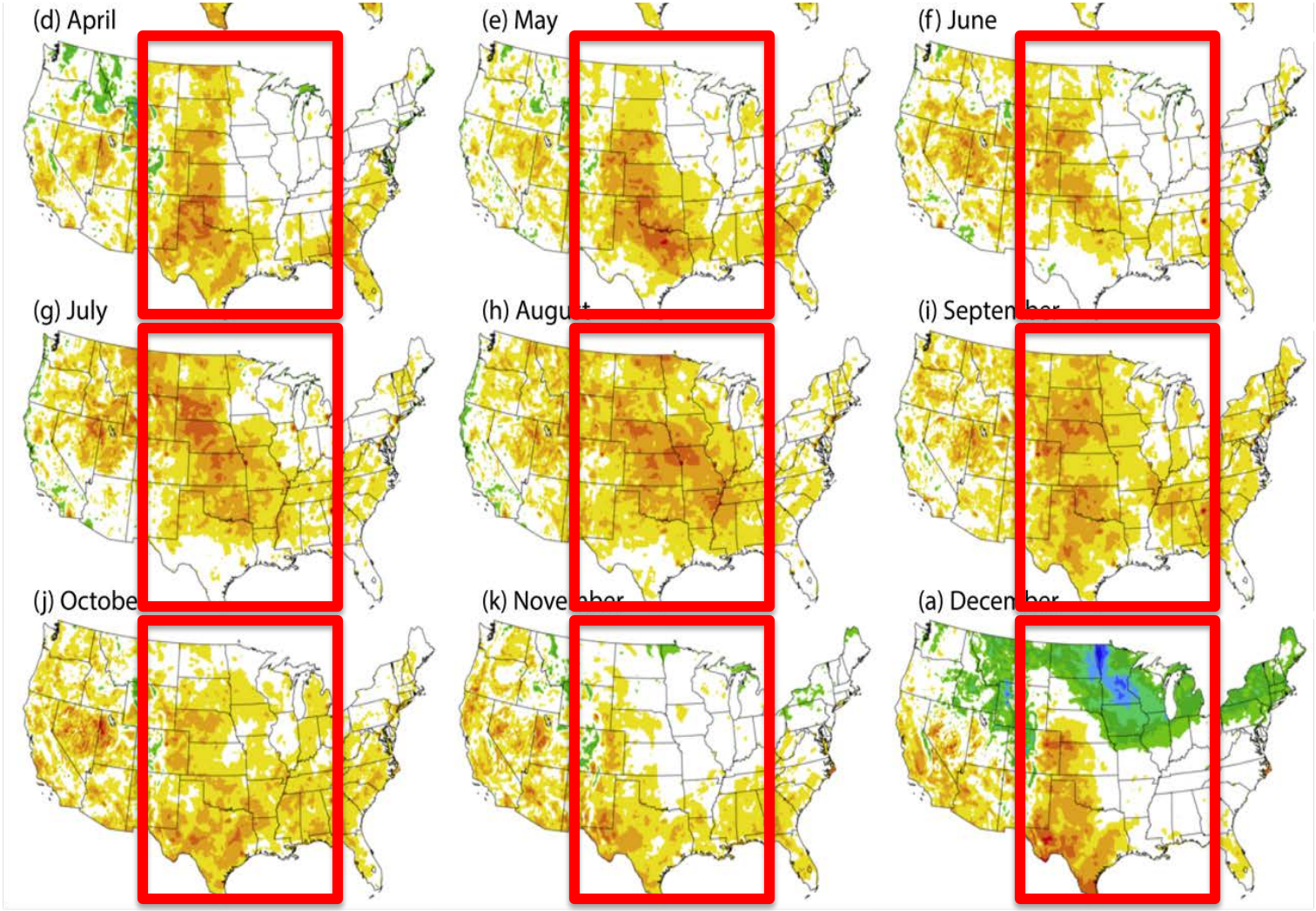
Introduction

- Recent effort to conduct CONUS region climate simulations at convection-permitting scale
- WRF Simulations
  - 4km spatial scale (1360x1016)
  - 51 vertical levels to 50 hPa
  - Thompson, YSU, RRTMG
  - Spectral nudging
  - Noah-MP LSM
  - 13 years (2001 – 2013)
  - Summarized in Liu, et al. 2017
  - Follow-on study of Rasmussen et al. 2014



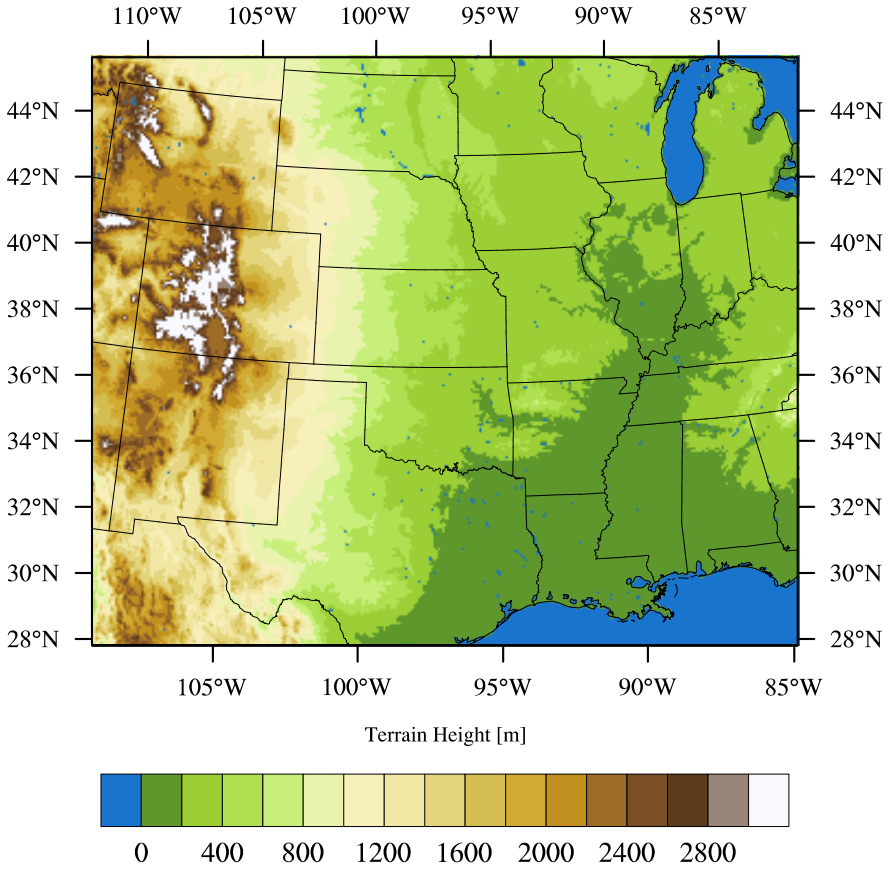
Temperature Bias over Central U.S.

- Temperature bias increases through the summer

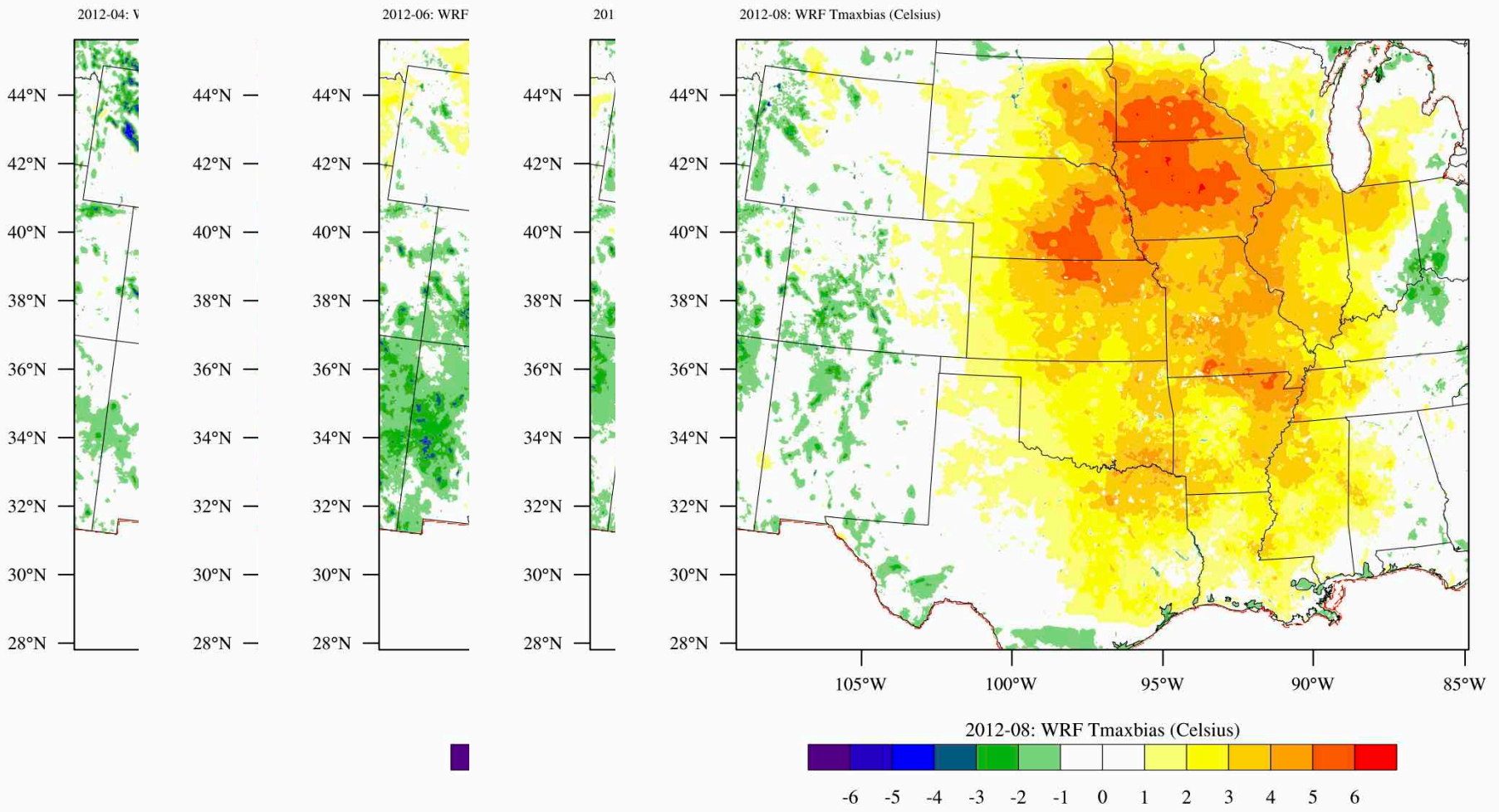


Central U.S. Focused Simulations

- Recent effort to improve region climate simulations at convection-permitting scale
- WRF Simulations
  - 4km spatial scale (501x401)
  - 51 vertical levels to 50 hPa
  - Thompson, YSU, RRTMG
  - NO SPECTRAL NUDGING
  - Noah-MP LSM
  - April – September 2012



Evolving Temperature Bias over Central U.S.

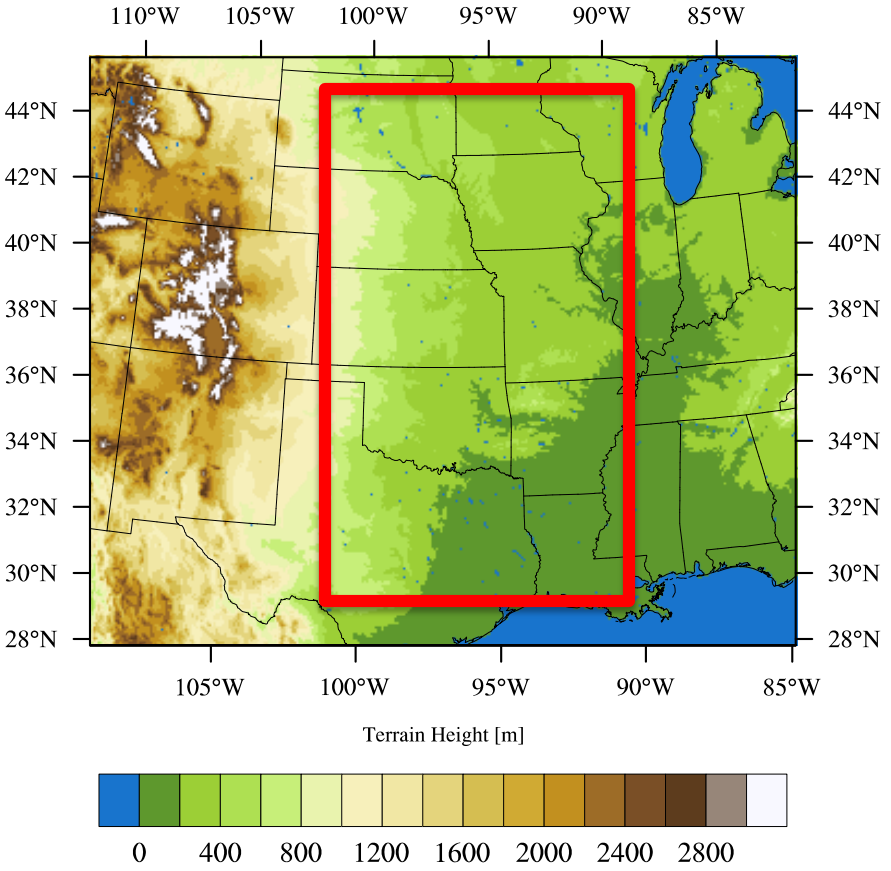


Tem T Temp Te Temperature bias relative to PRISM

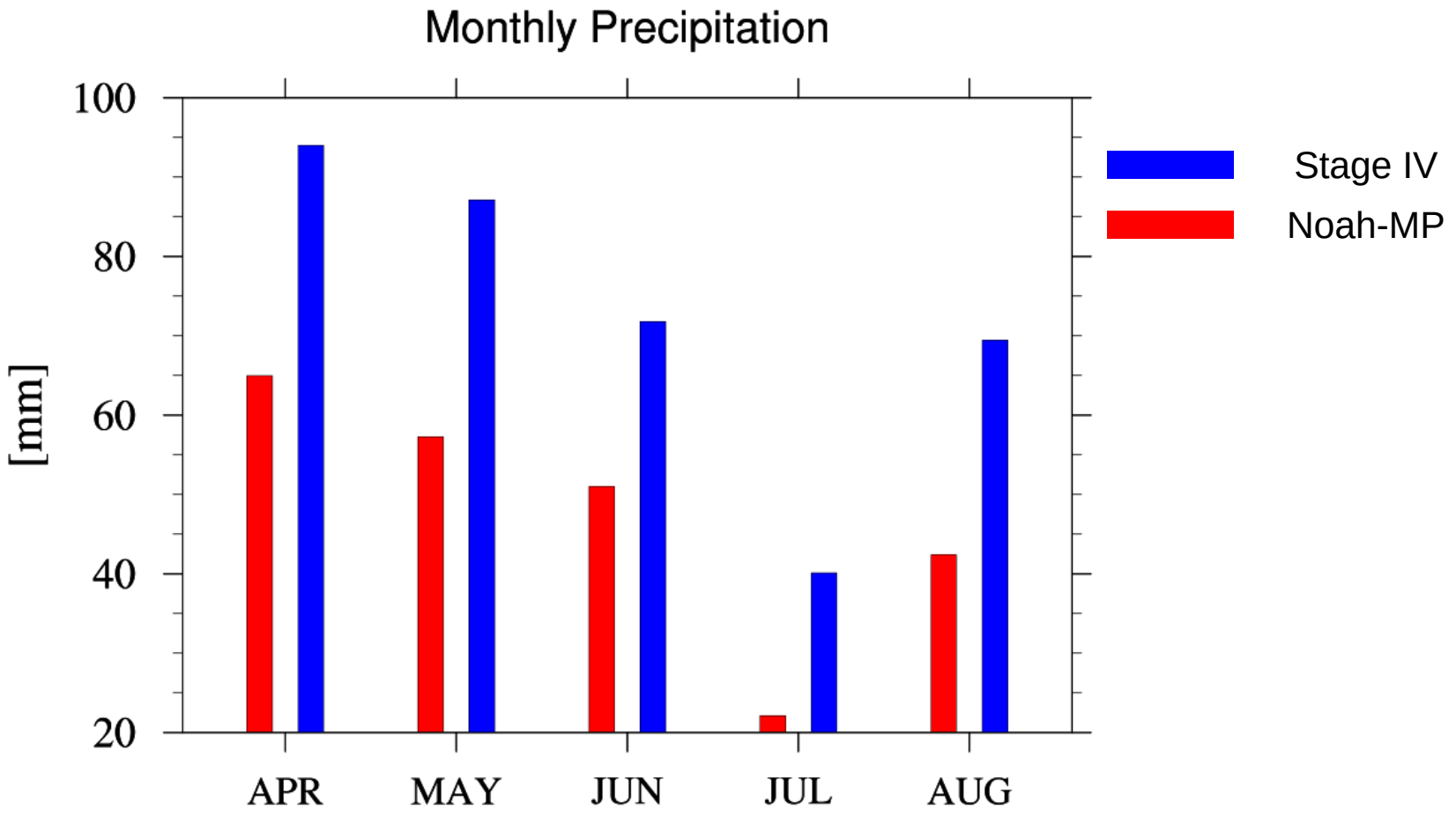
August

Central U.S. Focused Simulations

- Analyze precipitation and ET over Central Plains
- Stage IV radar/gauge precipitation analyses
  - 4km regridded to model domain
  - Convert hourly to monthly
- MODIS ET (MOD16A2)
  - 500m regridded to model domain
  - Convert 8-day to monthly

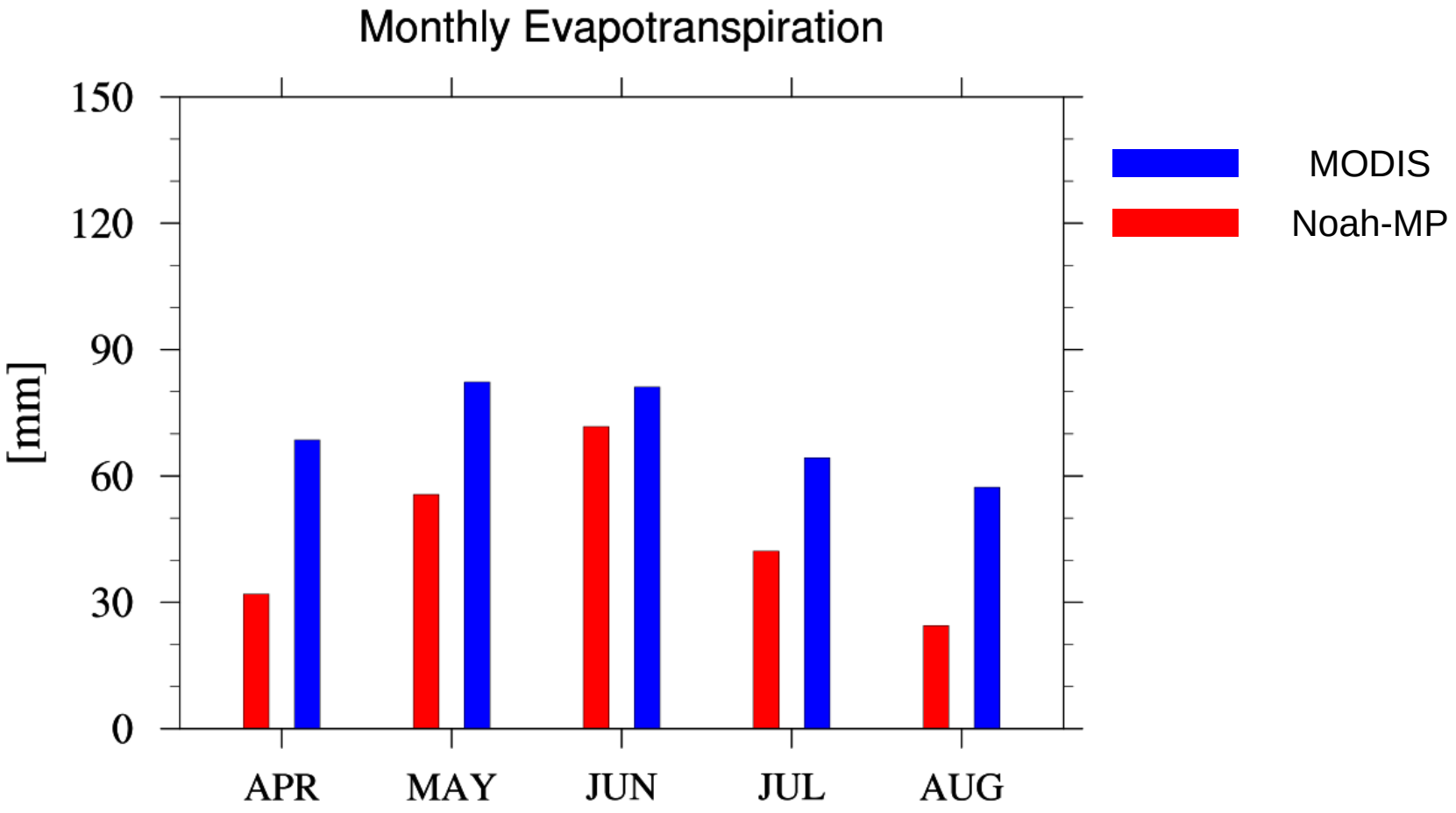


Precipitation Results



Precipitation compared to Stage IV

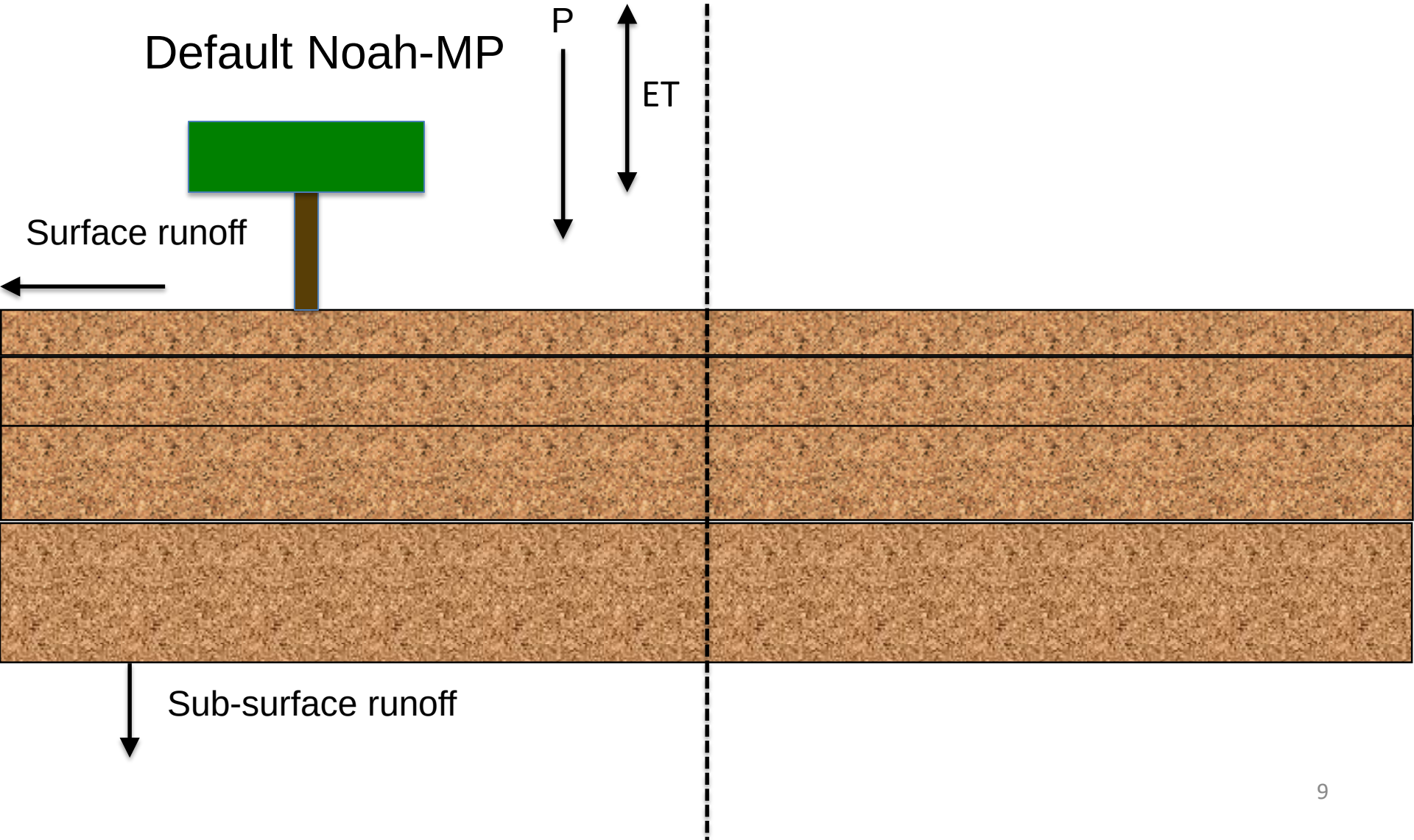
Evapotranspiration Results



Evapotranspiration compared to MODIS ET

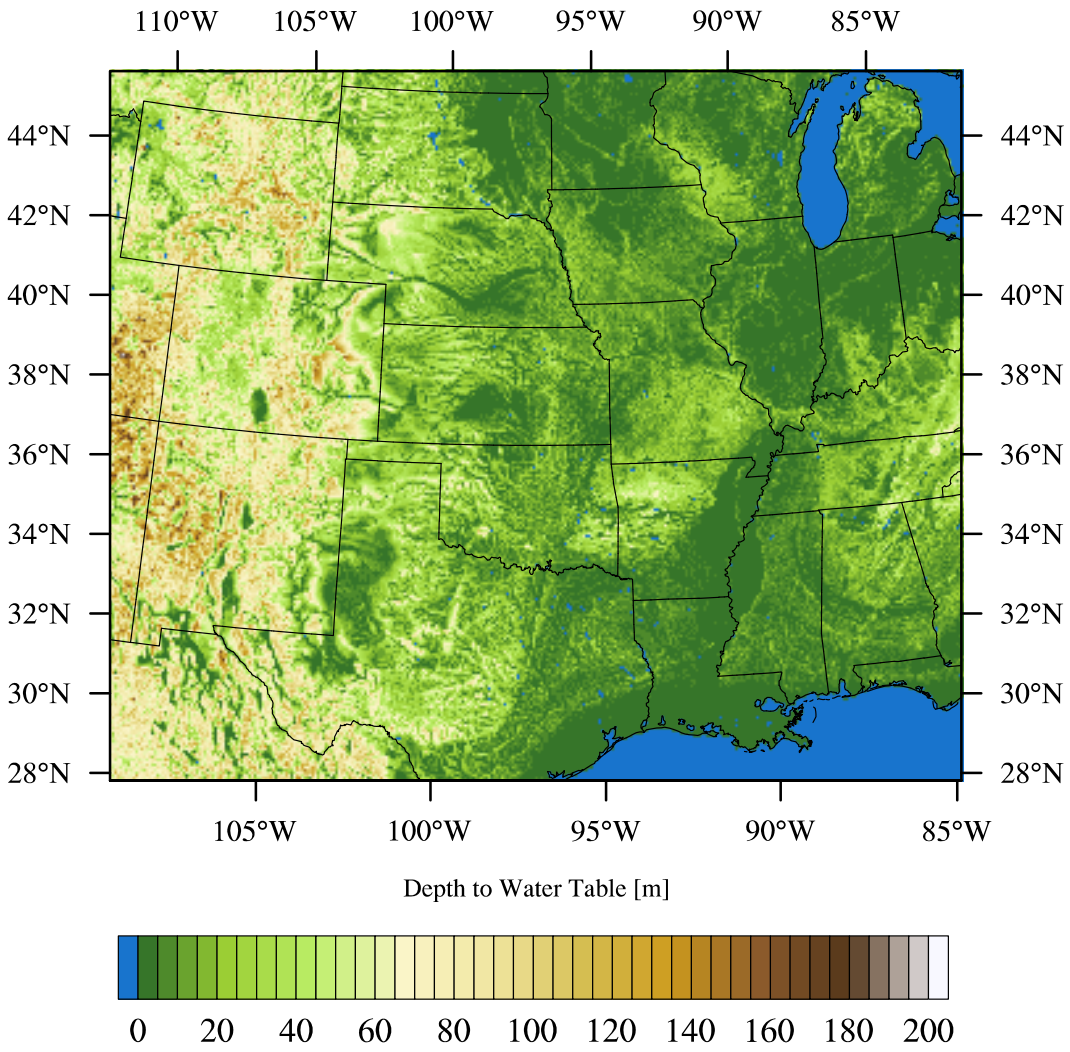
Missing Processes?

Default Noah-MP LSM in WRF uses 2-meter soil with free drainage LBC



Depth to Water Table

Region of warm bias consistent with locations where water table near surface



New Groundwater Representation in Noah-MP

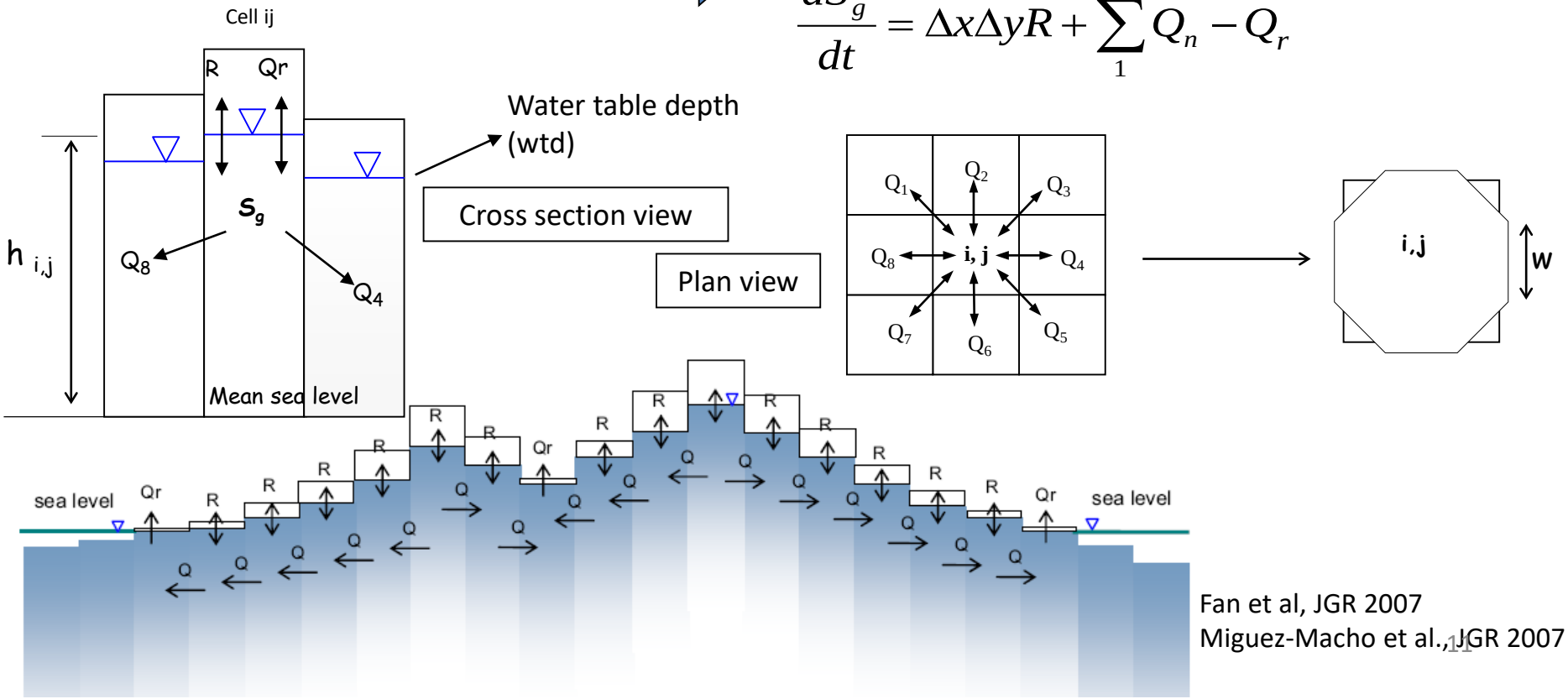
Noah-MP options exist for

- free drainage soil lower boundary condition
- 1D aquifer interaction
- new option added for 1D interaction with horizontal aquifer transport

User note: not a river routing, overland flow scheme (see WRF-hydro)

Mass balance in groundwater storage:

$$\frac{dS_g}{dt} = \Delta x \Delta y R + \sum_1^8 Q_n - Q_r$$

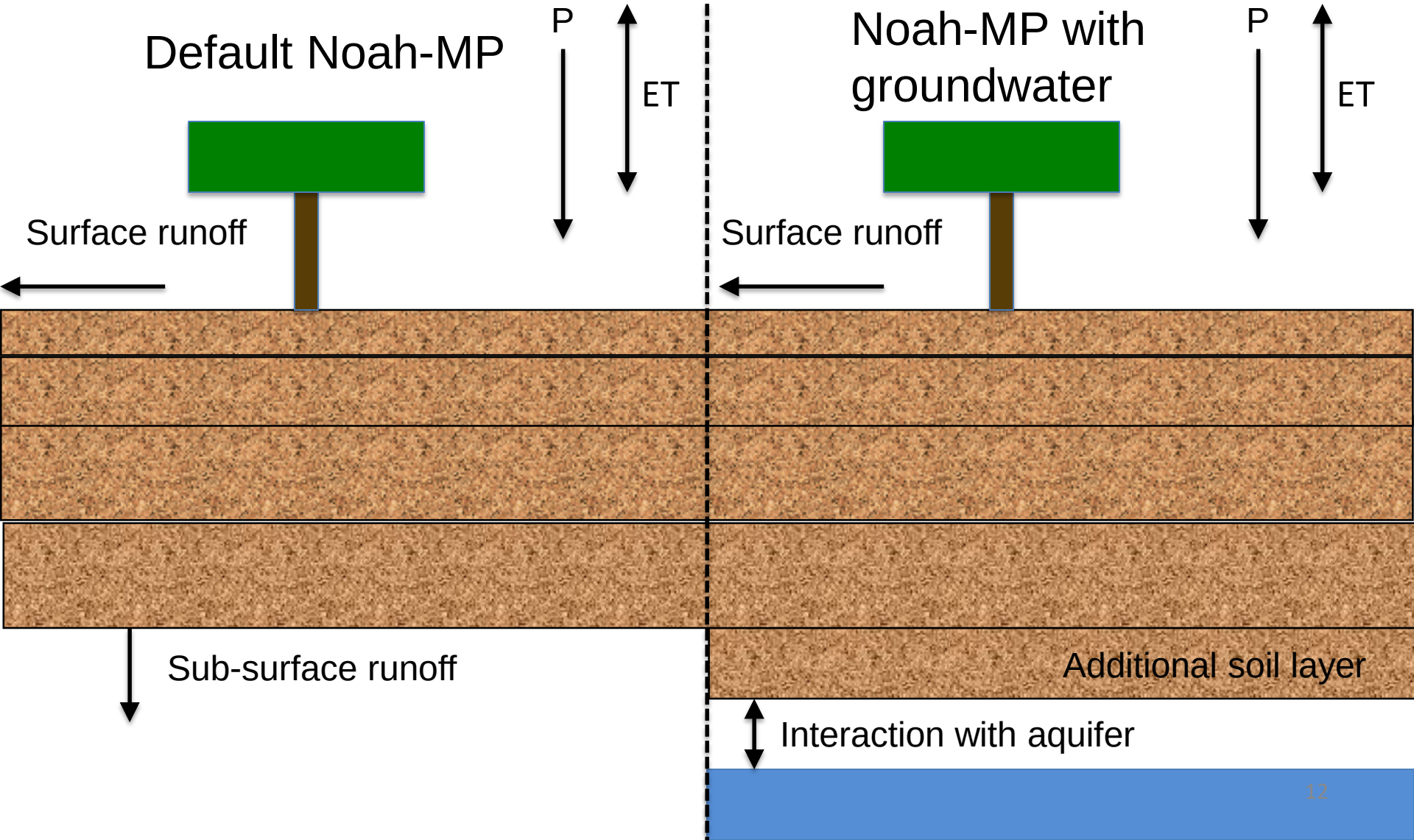


Fan et al, JGR 2007

Miguez-Macho et al., JGR 2007

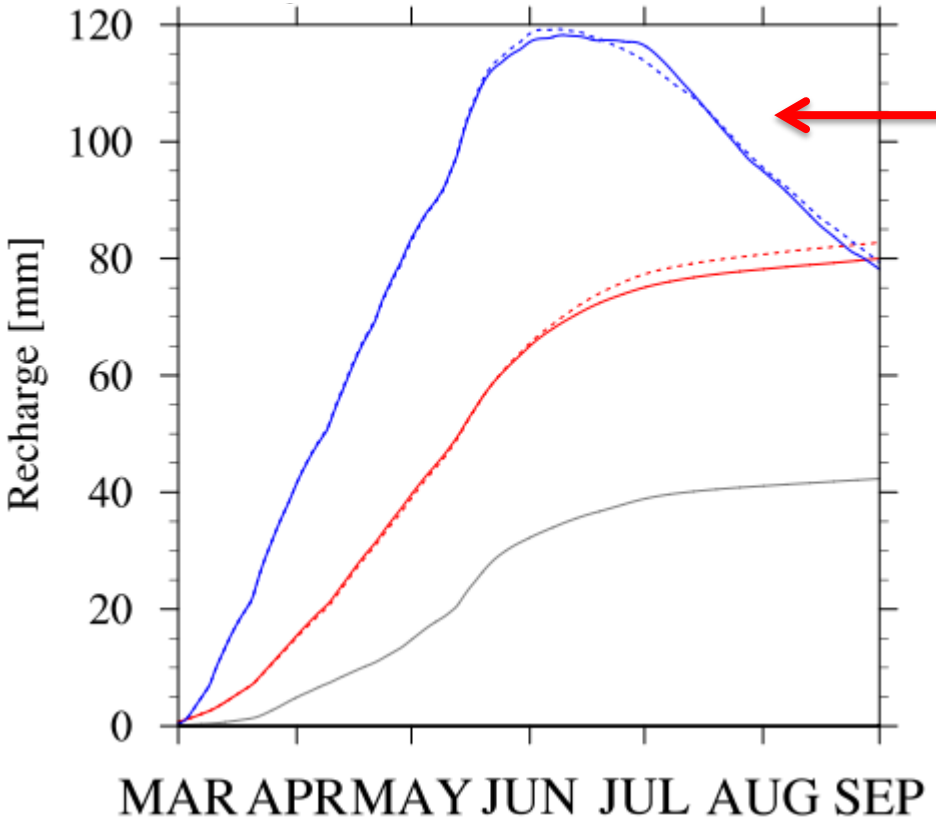
Missing Processes?

Add lower boundary that interacts with groundwater below



Additional Source of Water

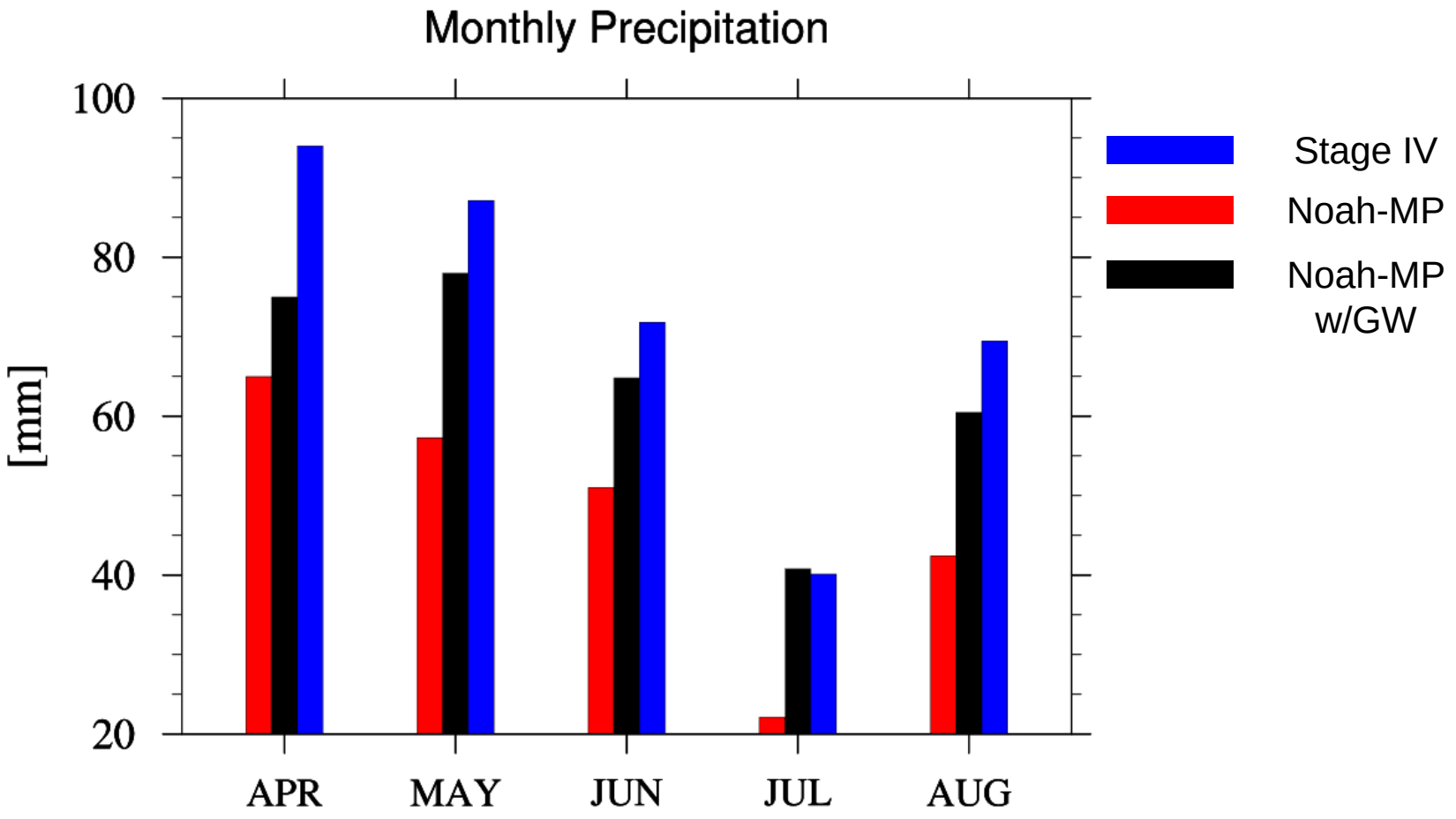
Activating groundwater provides a source of moisture in mid- to late-summer (negative slope of the blue line)



Negative slope implies upward transport

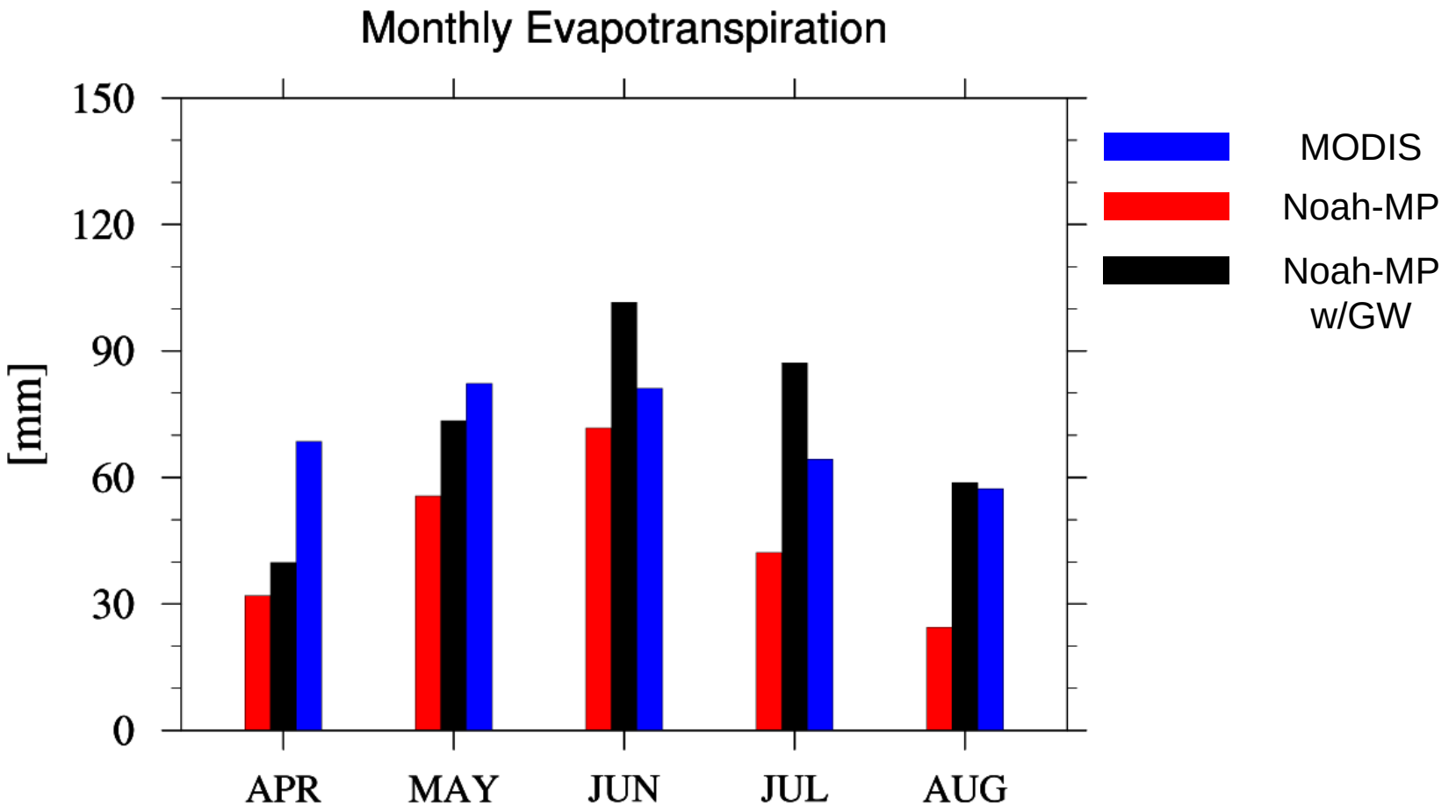
Noah
Noah-MP Free
Noah-MP GW

Precipitation Results



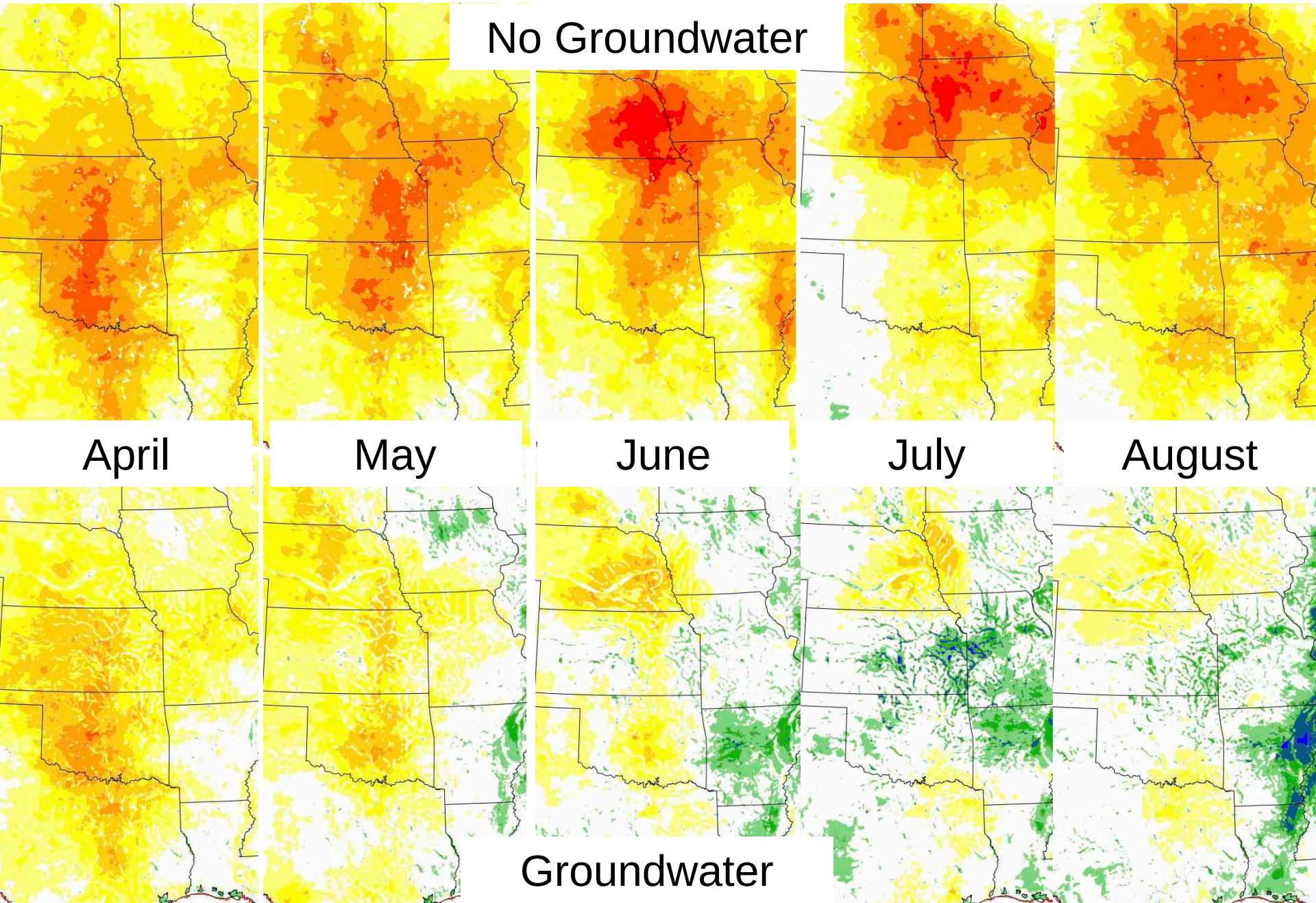
Precipitation compared to Stage IV

Evapotranspiration Results



Evapotranspiration compared to MODIS ET

Evolving Temperature Bias over Central U.S.

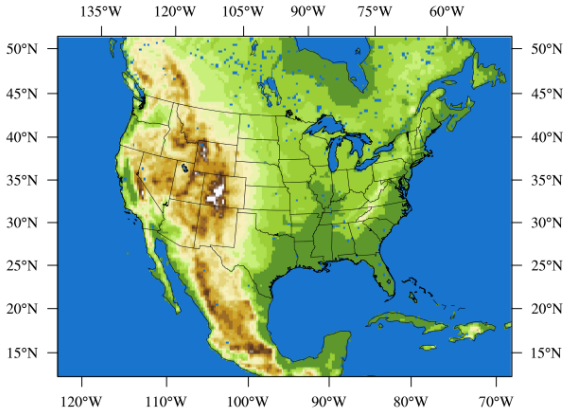


Scale Dependencies

Noah-MP vs. Noah-MP w/groundwater

Surface Verification

- Six-month 30km WRF simulations - 2010
- Spin-up soil for one year using offline HRLDAS
- IC/BC from NARR
- Verification against ~2600 surface stations



Model	Season	Output field	Day bias	Day RMSE	Night bias	Night RMSE
Noah-MP	MAM	T_{2m}	0.5	1.0	0.2	0.8
w/GW	MAM	T_{2m}	**0.4**	1.0	0.2	0.8
Noah-MP	JJA	T_{2m}	1.7	1.9	0.5	1.0
w/GW	JJA	T_{2m}	**1.1**	**1.6**	**0.1**	**0.9**

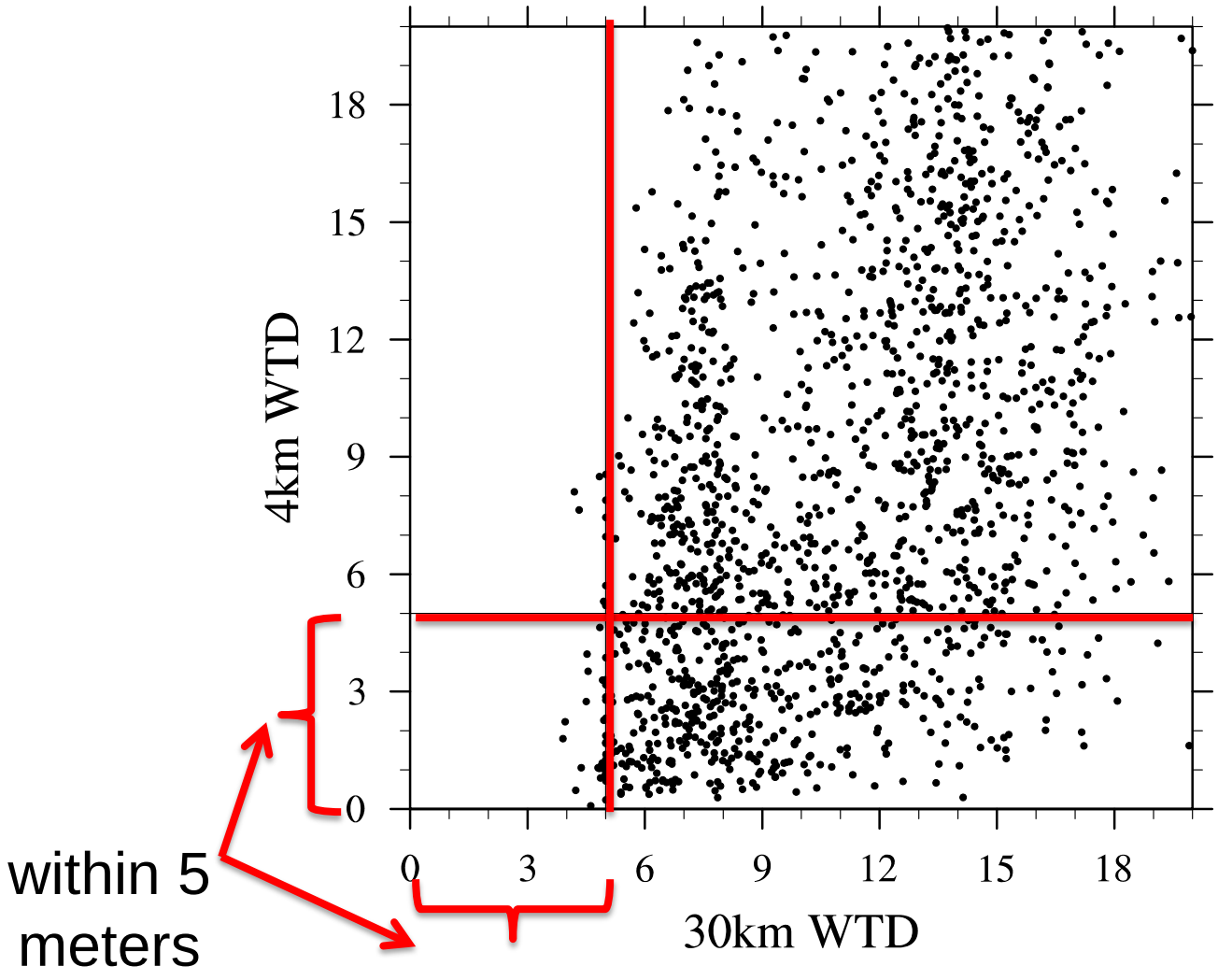
Regional bias improvements of 1.5°C

Barlage, et al. 2015

Green: Noah-MP w/GW improves Red: Noah-MP w/GW degrades

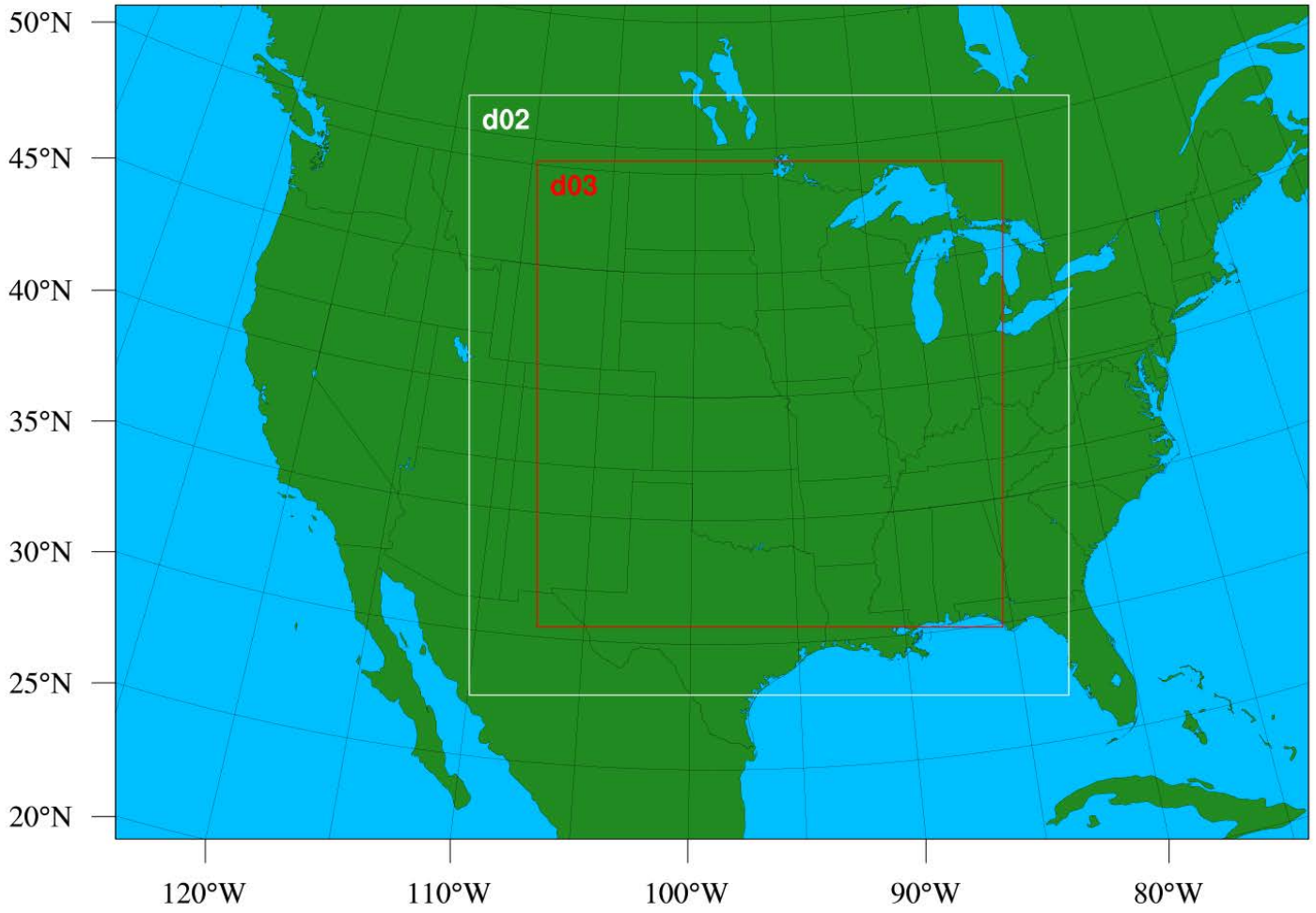
Scale Dependencies

- Significant sub-grid variability is missed when using coarse resolution



Scale Dependencies – Experiment

- Test multiple domains at 27km, 9km, and 3km for Apr – Aug 2012
- Use same physics in all simulations including scale-aware KF convection



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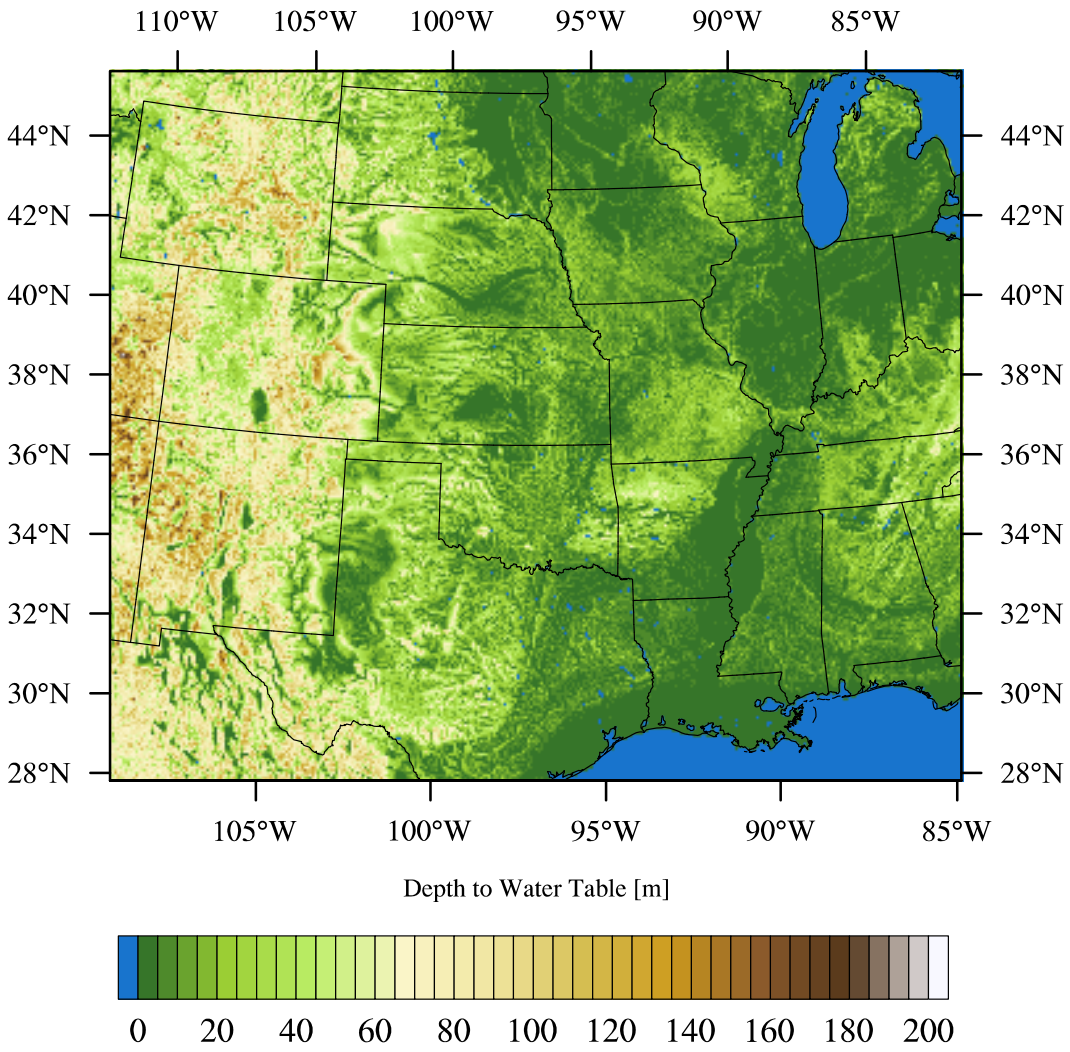
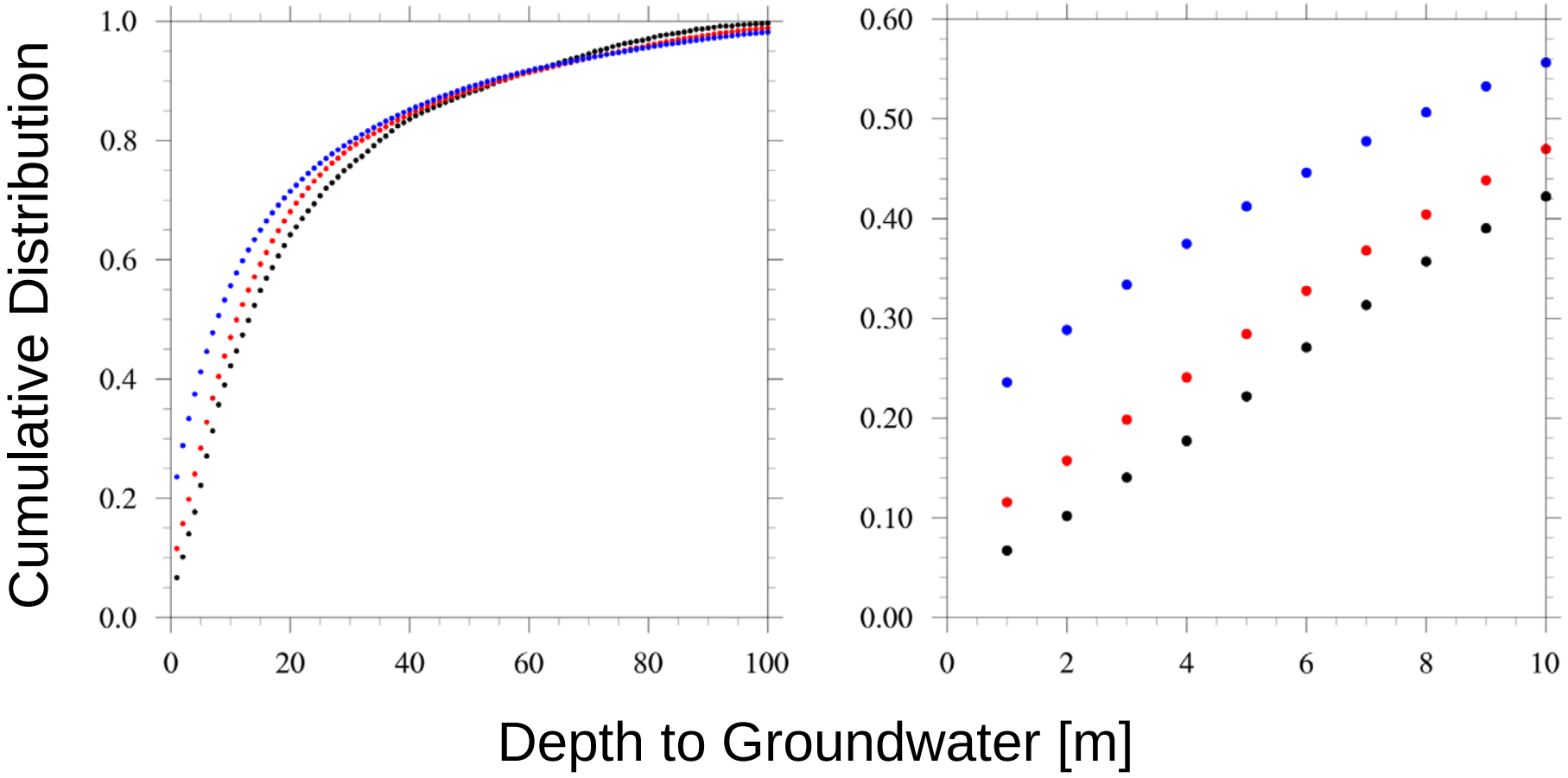


Scale Dependencies – Experiment

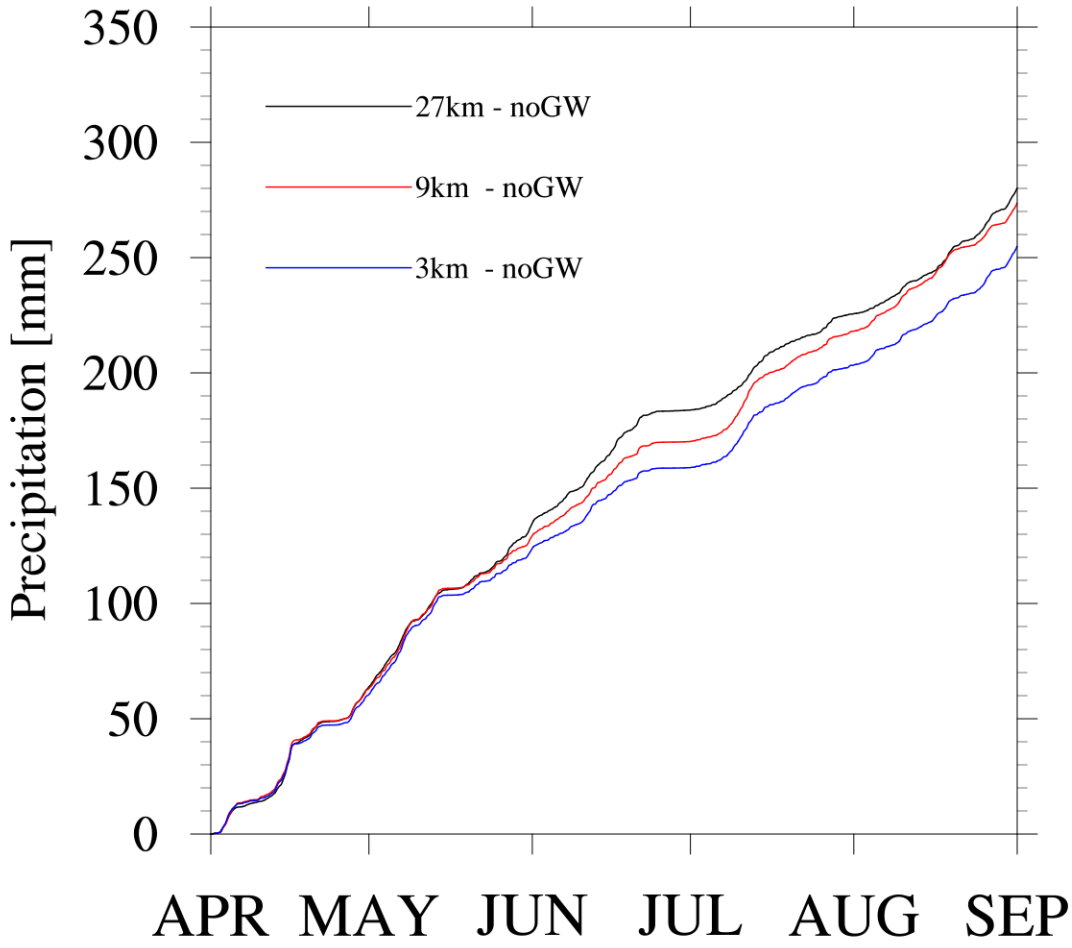
- Cumulative distribution of depth to groundwater in the Central U.S.

27km 9km 3km



Scale Dependencies – Precipitation with no Groundwater

- For simulation without groundwater, 3km simulation shows the least precipitation
- 9km and 27km simulations have a similar total precipitation



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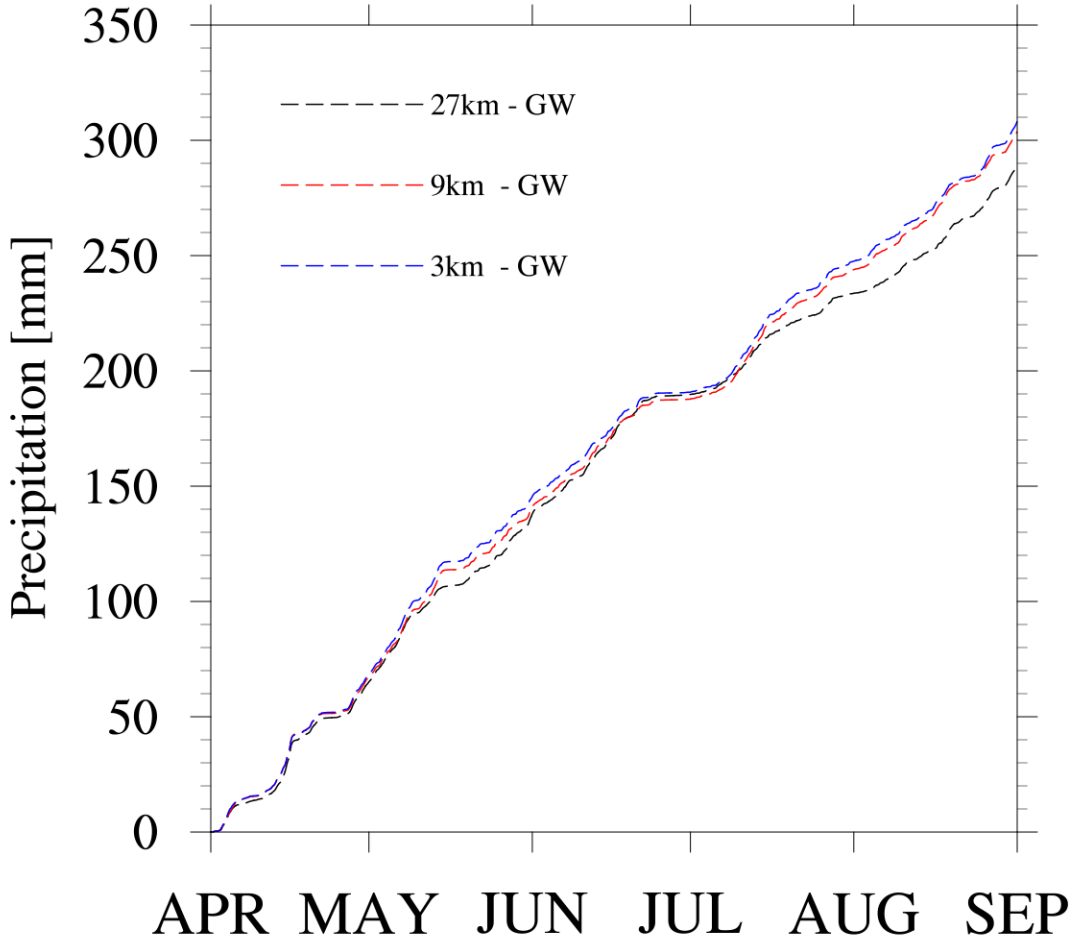
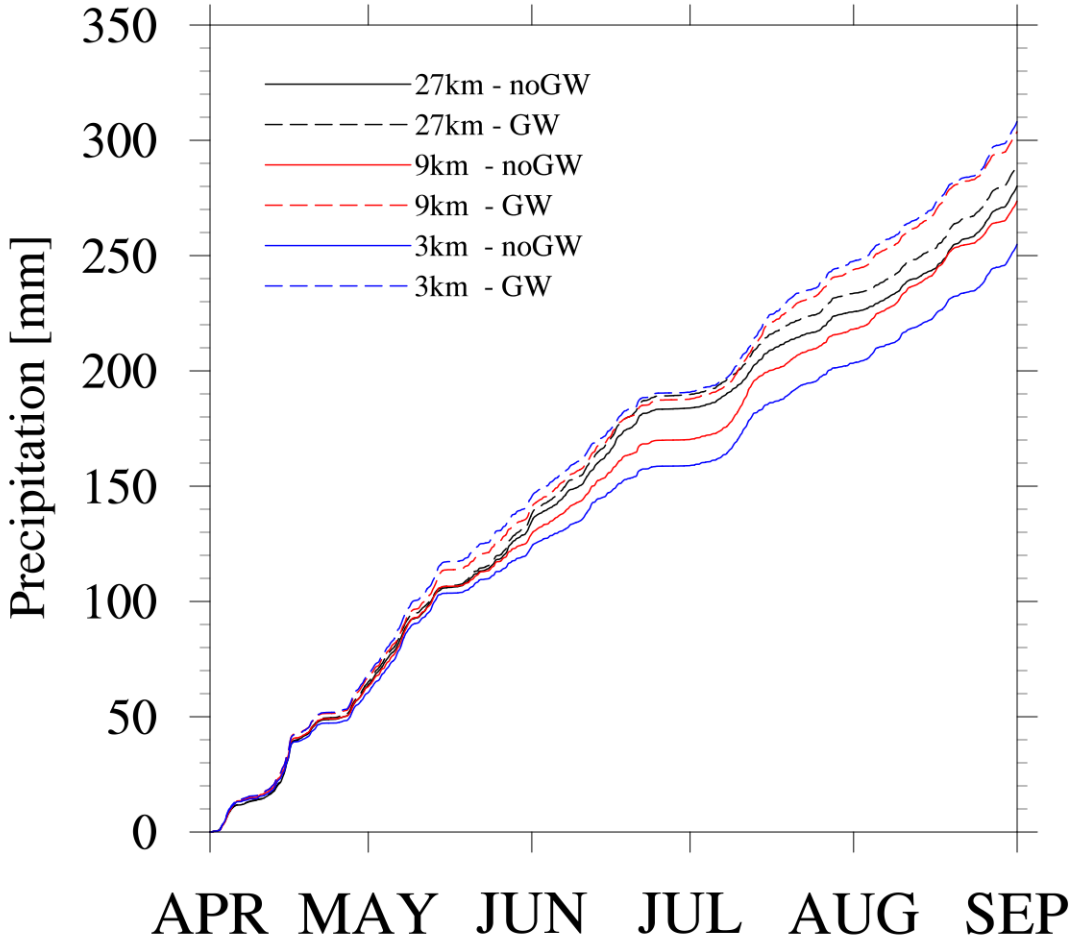


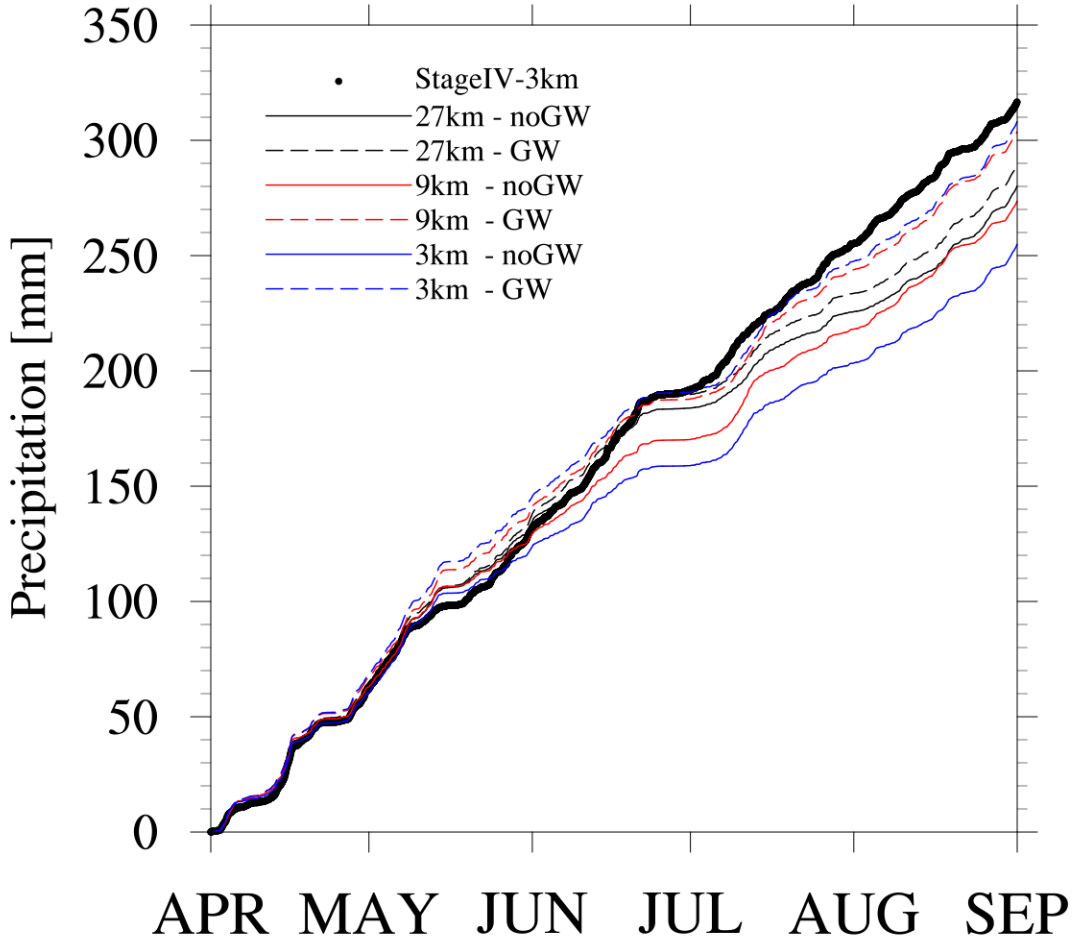
Scale Dependencies – All Precipitation

- All groundwater simulations have an increased precipitation relative to no GW
- Groundwater effect is scale-dependent



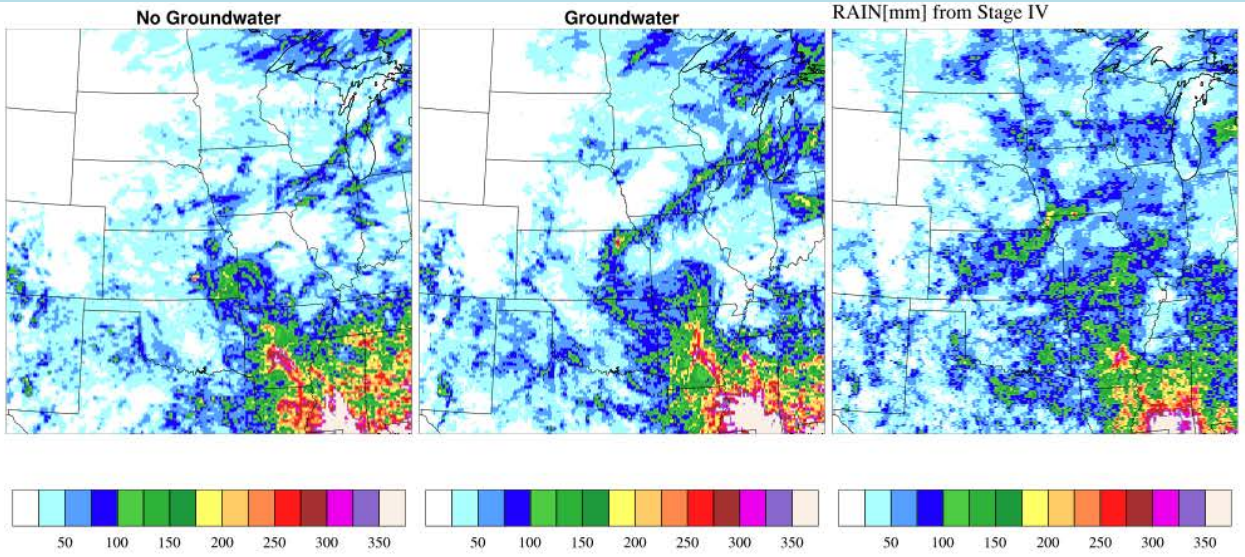
Scale Dependencies – Precipitation with Observations

- Higher resolution groundwater simulations show the best performance

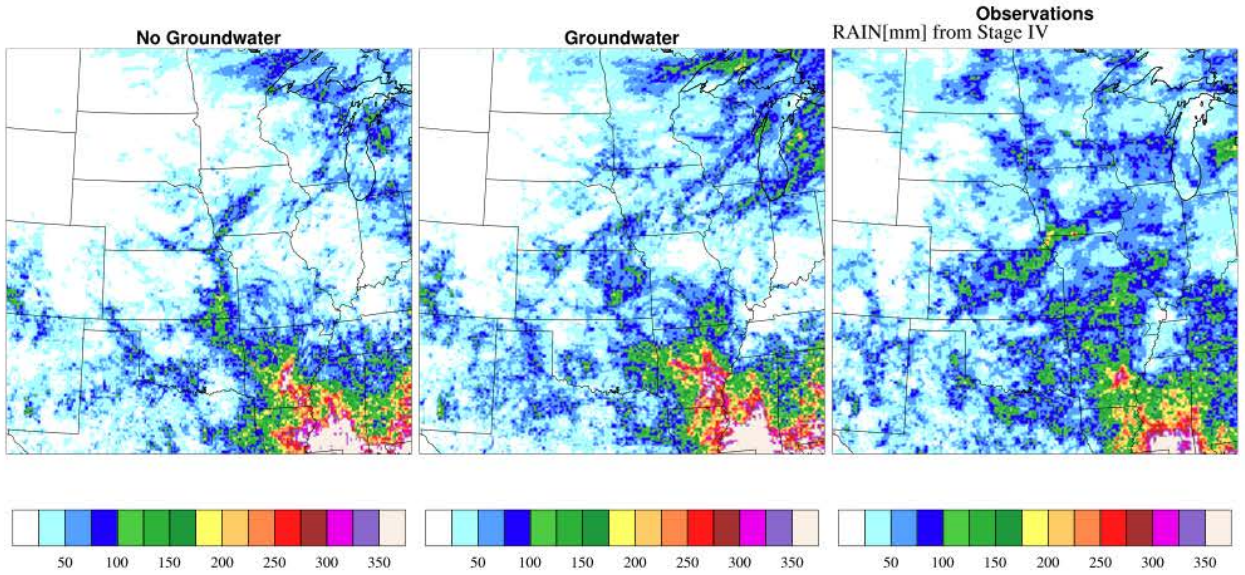


Scale Dependencies – Experiment

- August precipitation increased with groundwater in both resolutions



9km

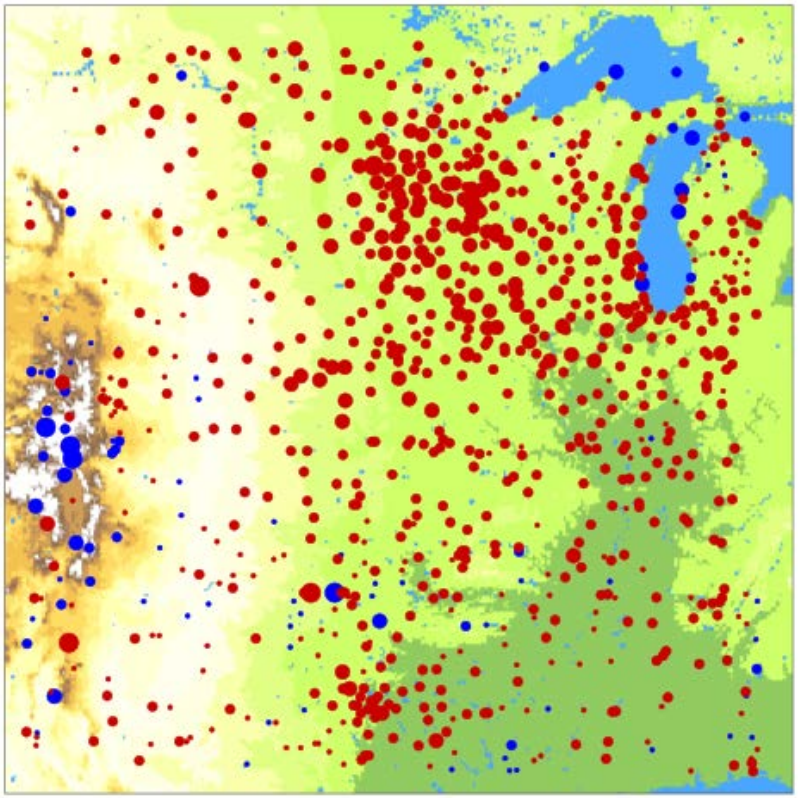


3km

METAR Station Comparison – 2-meter Temperature

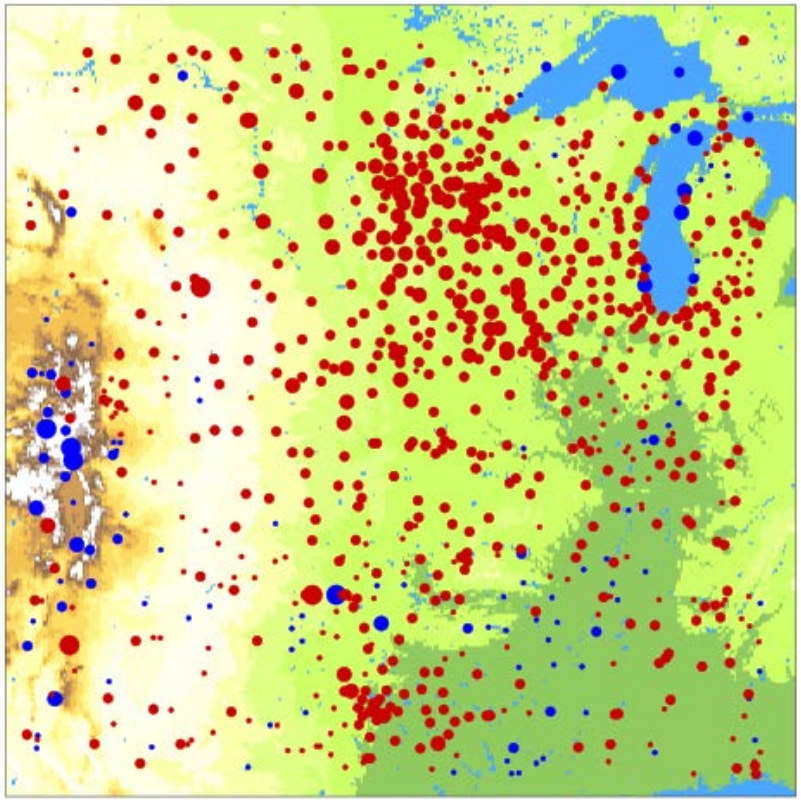
- 27km simulations show little effect on August warm bias

nogw_d1



August

gw_d1



August

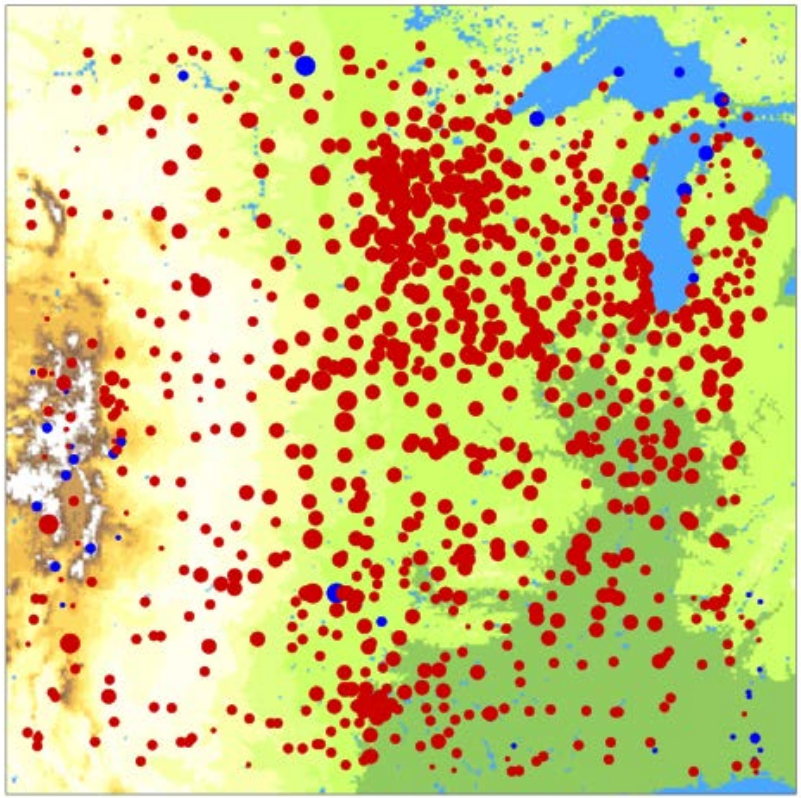
bias < -5 | -3 <= bias < -1 | 0 <= bias < 1 | 3 <= bias < 5

-5 <= bias < -3 | -1 <= bias < 0 | 1 <= bias < 3 | bias >= 5

METAR Station Comparison – 2-meter Temperature

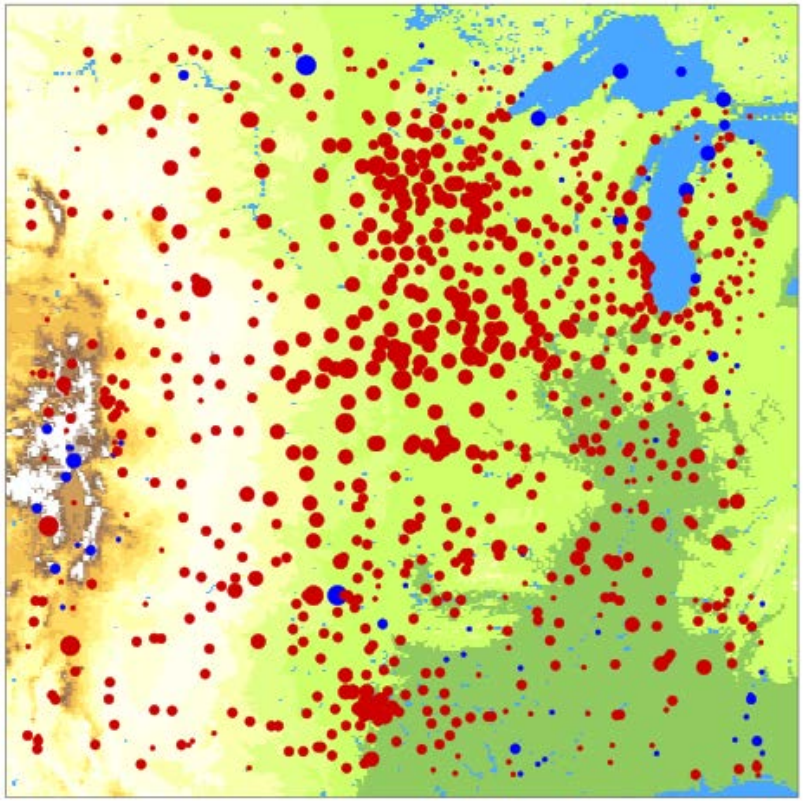
- 9km simulations show increasing effect of groundwater on bias reduction
- 9km simulations without groundwater warmer than 27km

nogw_d2



August

gw_d2



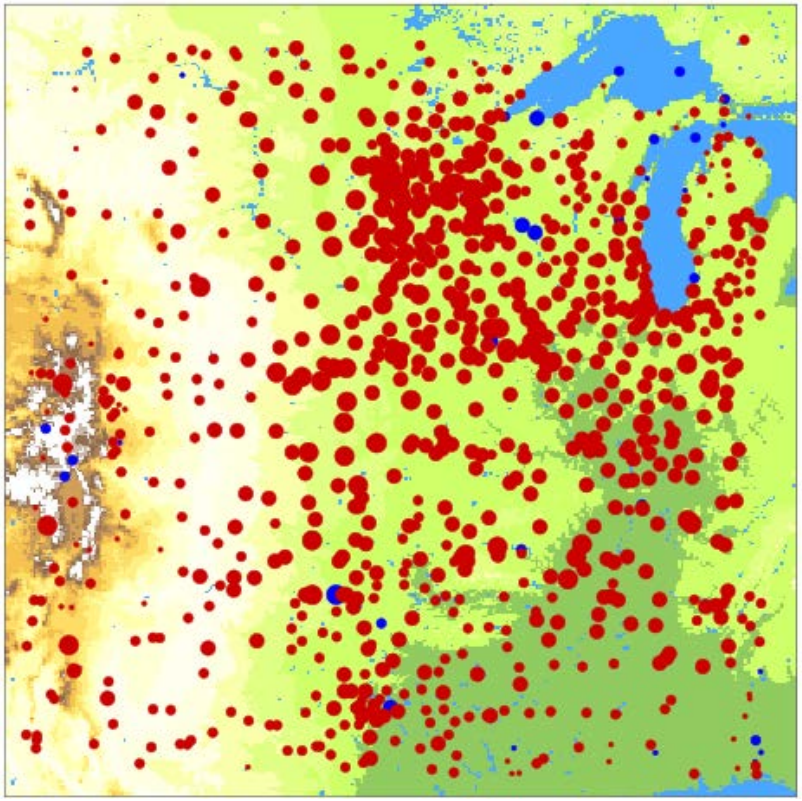
August

- bias < -5
- -5 <= bias < -3
- -3 <= bias < -1
- -1 <= bias < 0
- 0 <= bias < 1
- 1 <= bias < 3
- 3 <= bias < 5
- bias >= 5

METAR Station Comparison – 2-meter Temperature

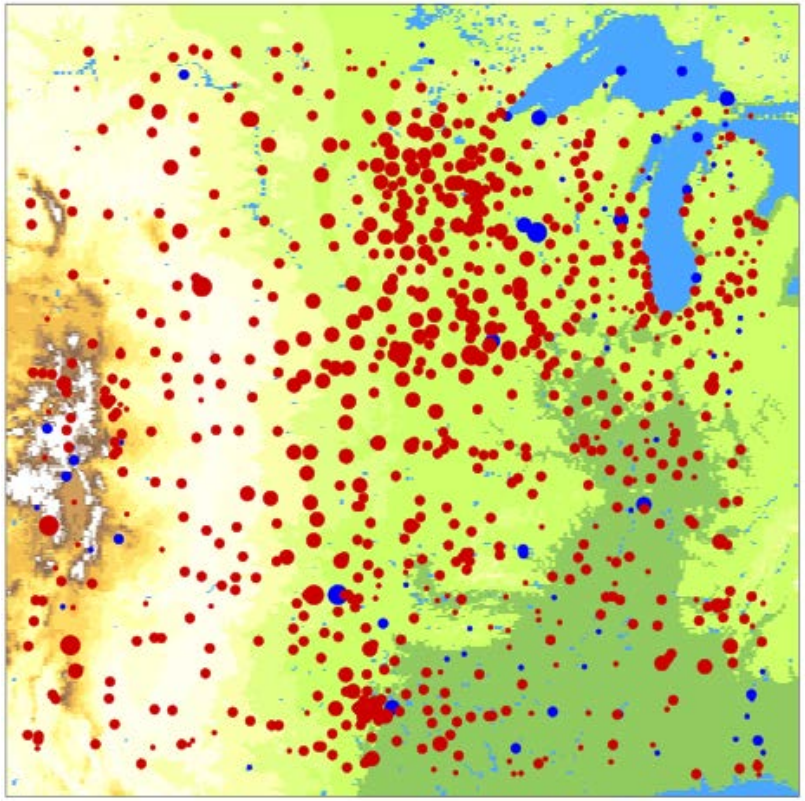
- 3km simulations show increasing effect of groundwater on bias reduction
- 3km simulations without groundwater warmer than 9km and 27km

nogw_d3



August

gw_d3

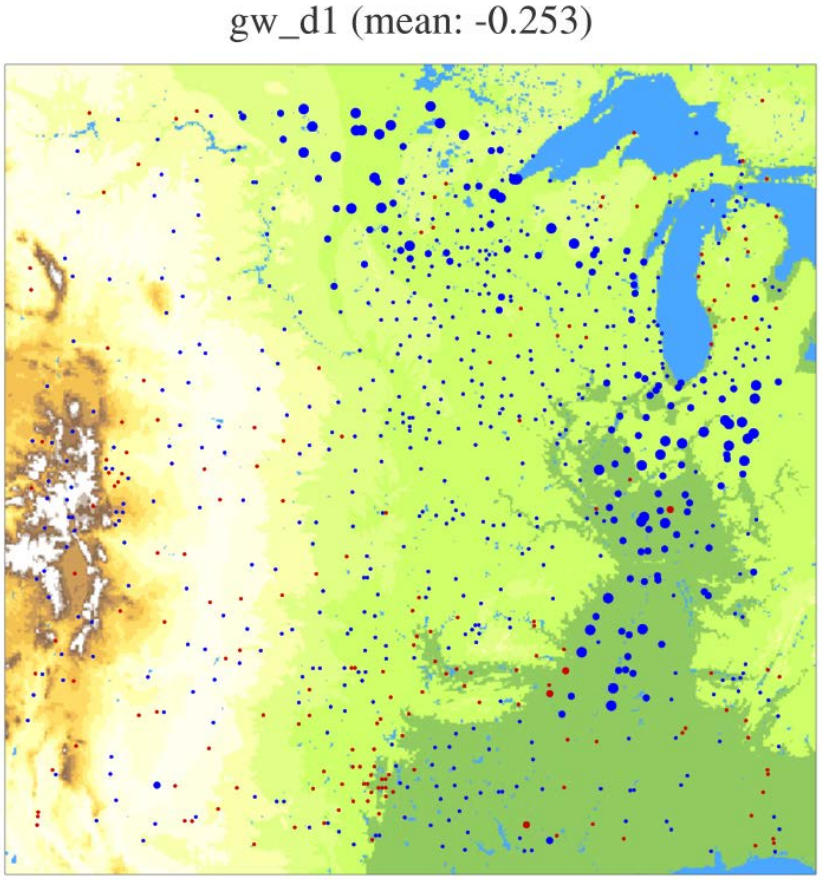


August

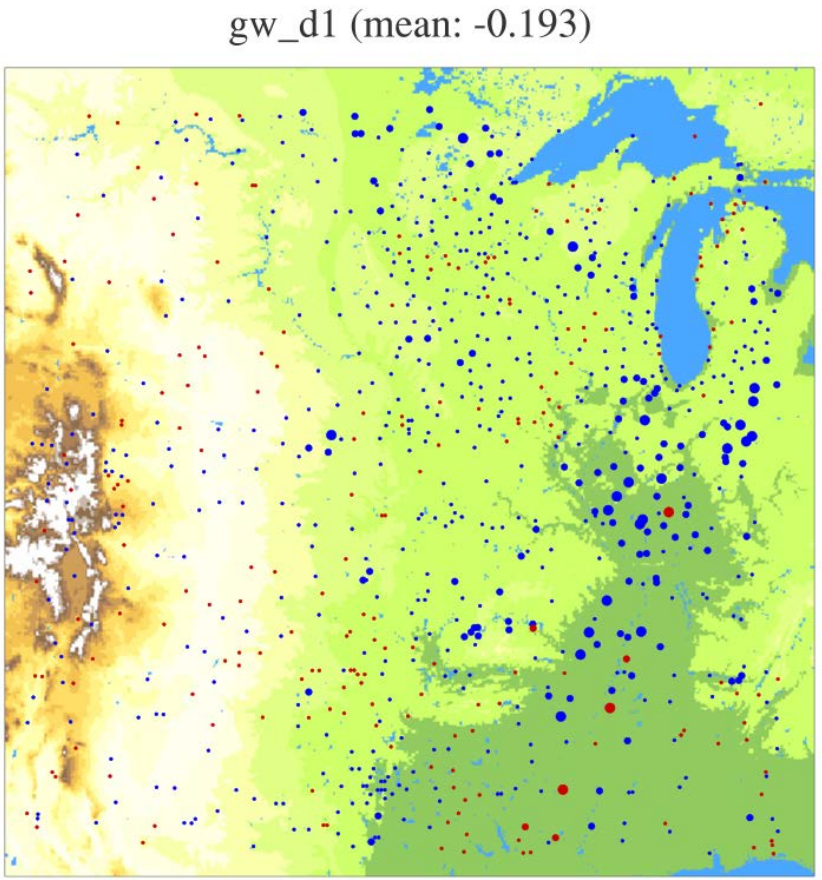
- bias < -5
- -5 <= bias < -3
- -3 <= bias < -1
- -1 <= bias < 0
- 0 <= bias < 1
- 1 <= bias < 3
- 3 <= bias < 5
- bias >= 5

METAR Station Comparison – 2-meter Temperature

- 27km simulations with groundwater don't have much improvement
- Blue is good, meaning bias is reduced



July

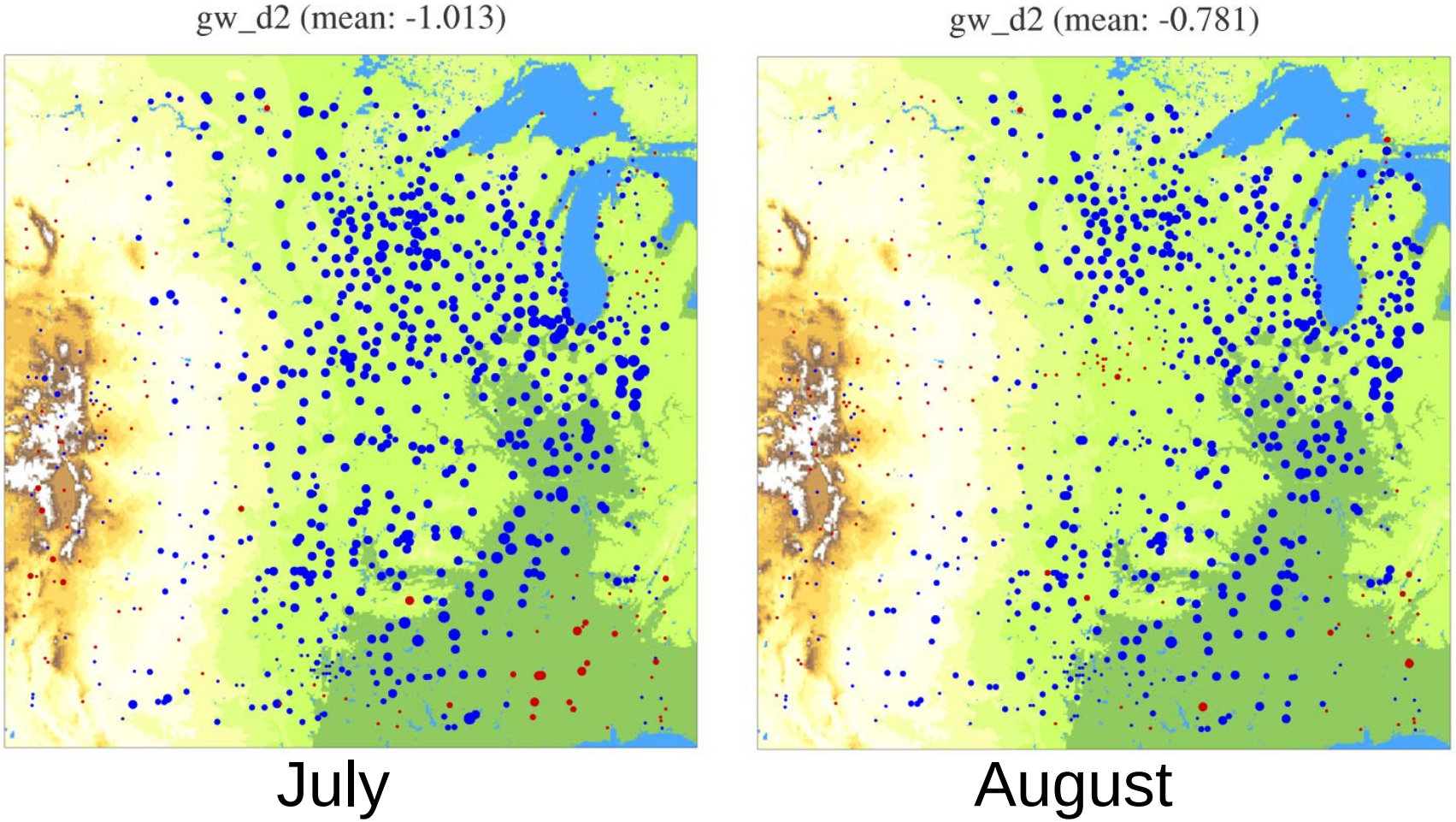


August

- bias < -2.5
- -2.5 <= bias < -1
- -1 <= bias < -0.5
- -0.5 <= bias < 0
- 0 <= bias < 0.5
- 0.5 <= bias < 1
- 1 <= bias < 2.5
- bias >= 2.5

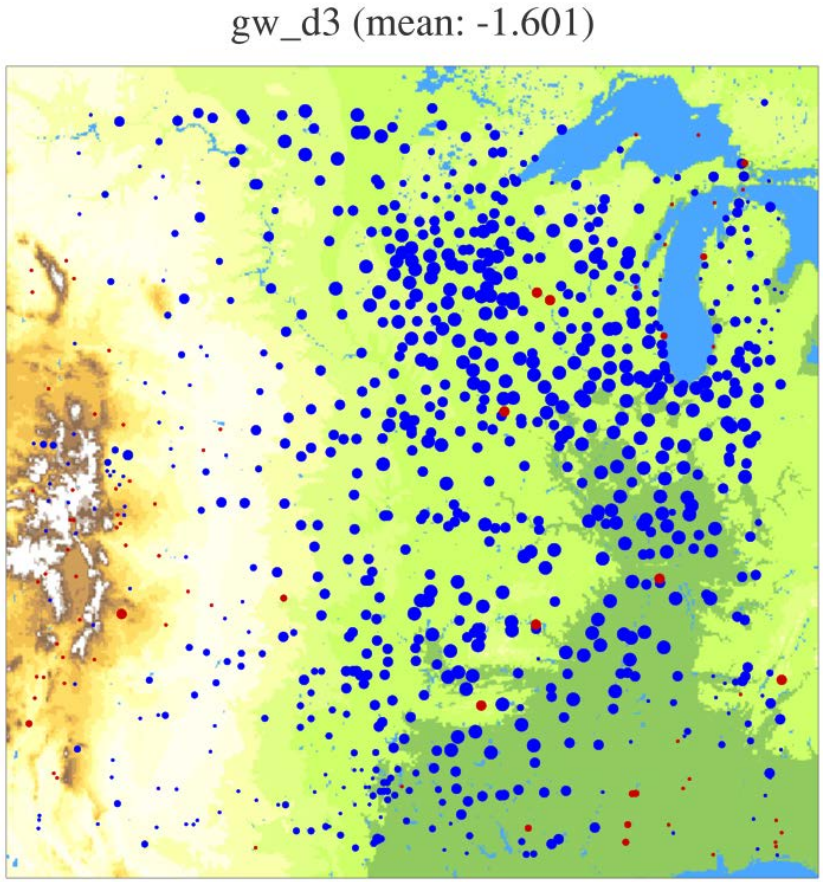
METAR Station Comparison – 2-meter Temperature

- Much larger groundwater impact with 9km simulations

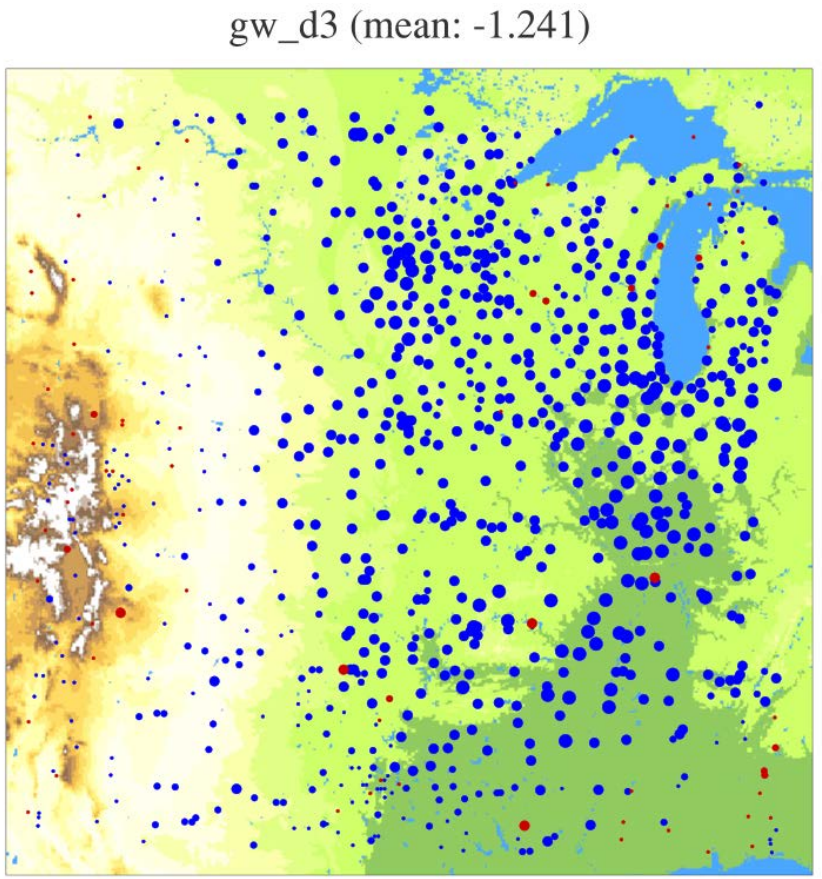


METAR Station Comparison – 2-meter Temperature

- Groundwater impact even larger in 3km simulations



July



August

- bias < -2.5
- -2.5 <= bias < -1
- -1 <= bias < -0.5
- -0.5 <= bias < 0
- 0 <= bias < 0.5
- 0.5 <= bias < 1
- 1 <= bias < 2.5
- bias >= 2.5

Conclusions and Future Work

- Inclusion of groundwater in Noah-MP is beneficial in addressing late summer warm bias in central US
- Provides access to deep soil water in regional climate simulations and increases soil memory
- Additional years of simulation needed
  - Continuing with 2013 and 2014
  - What happens at 1km?
- Additional verification and analysis
  - Flux tower and soil moisture