

Climate change in the Mid-Atlantic Region

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Monitoring and Assessing Impacts of Changes
in Weather Patterns and Extreme Events on
BMP Siting and Design

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Take-home messages

- The Mid-Atlantic has gotten warmer and wetter; precipitation has become more intense
- These trends will likely continue in the coming decades
- There is a large sensitivity to the emissions scenario, but not until mid century
- Natural variability is important, particularly for precipitation
- Expect more streamflow in winter

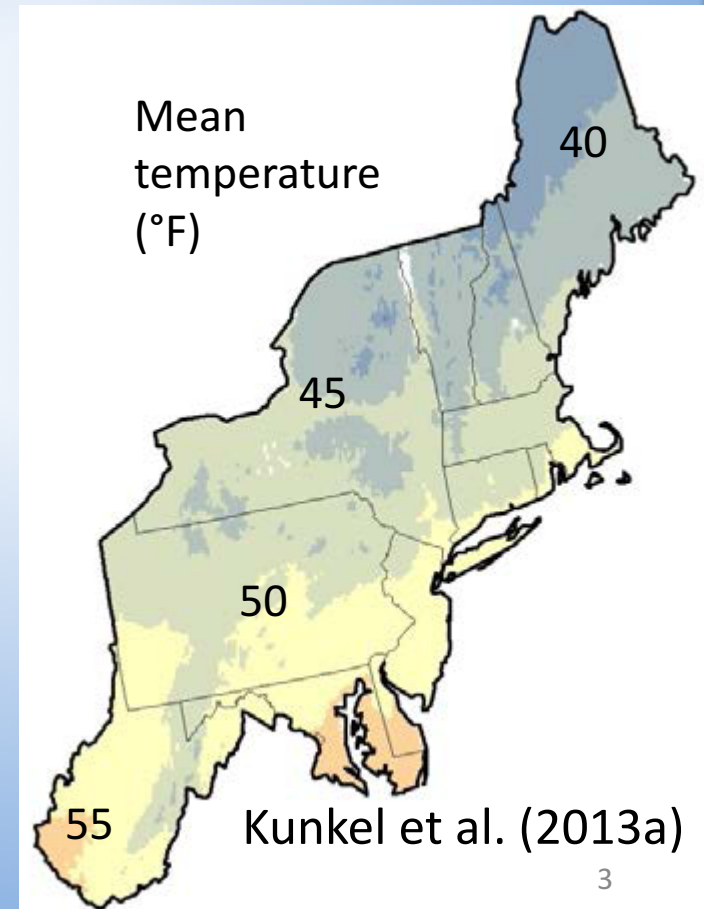


U.S. Global Change Research Program National Climate Assessment

- NCA released in 2014
- Northeast & Southeast climate data and model analysis released January 2013

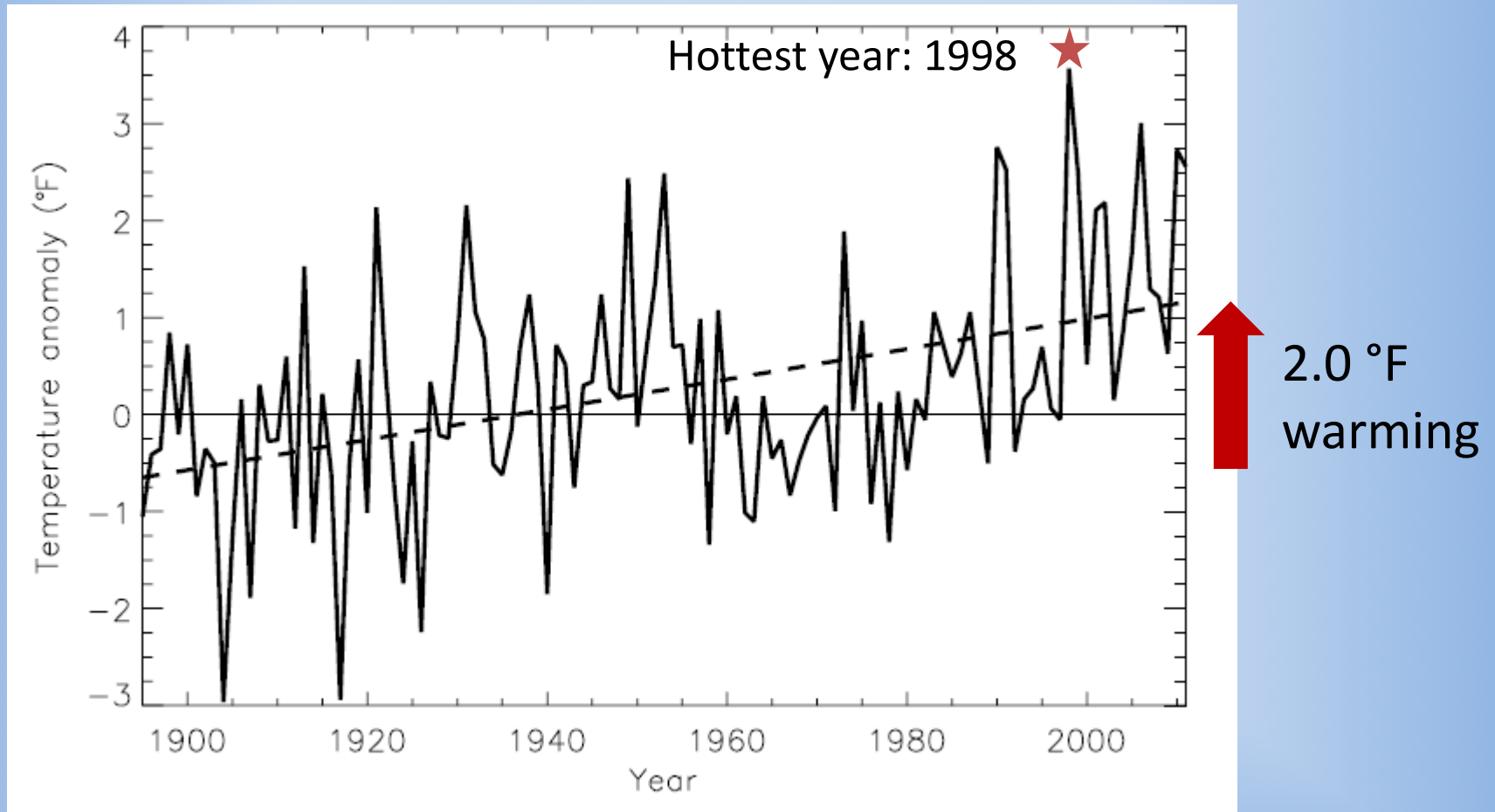


Kenneth Kunkel



The Northeast US has warmed

Temperature anomaly for the Northeast U.S.: 1895-2011

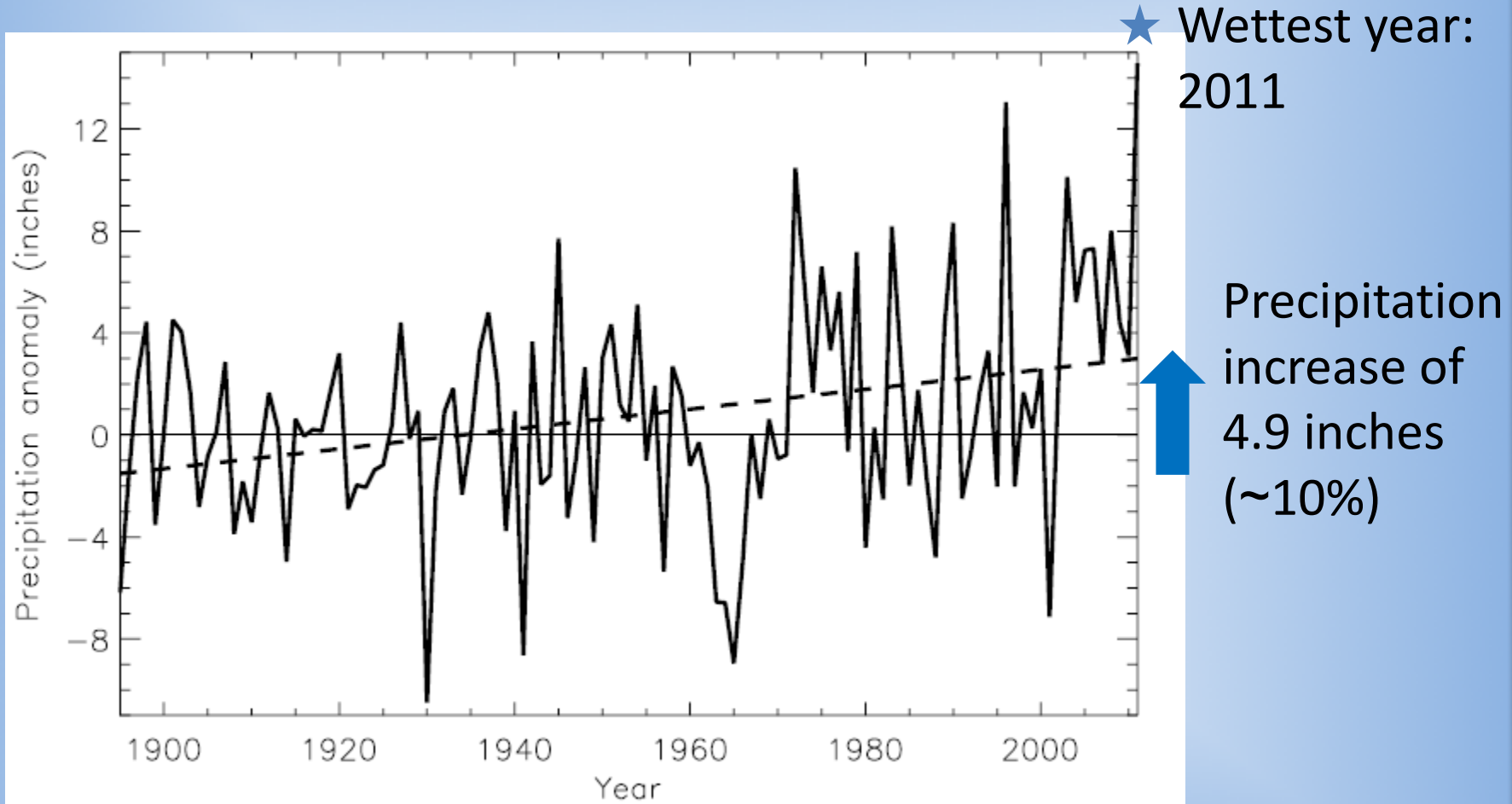


>95% significance annually and in all seasons

Kunkel et al. (2013a)

The Northeast U.S. has gotten wetter

Annual precipitation anomaly for the Northeast U.S.

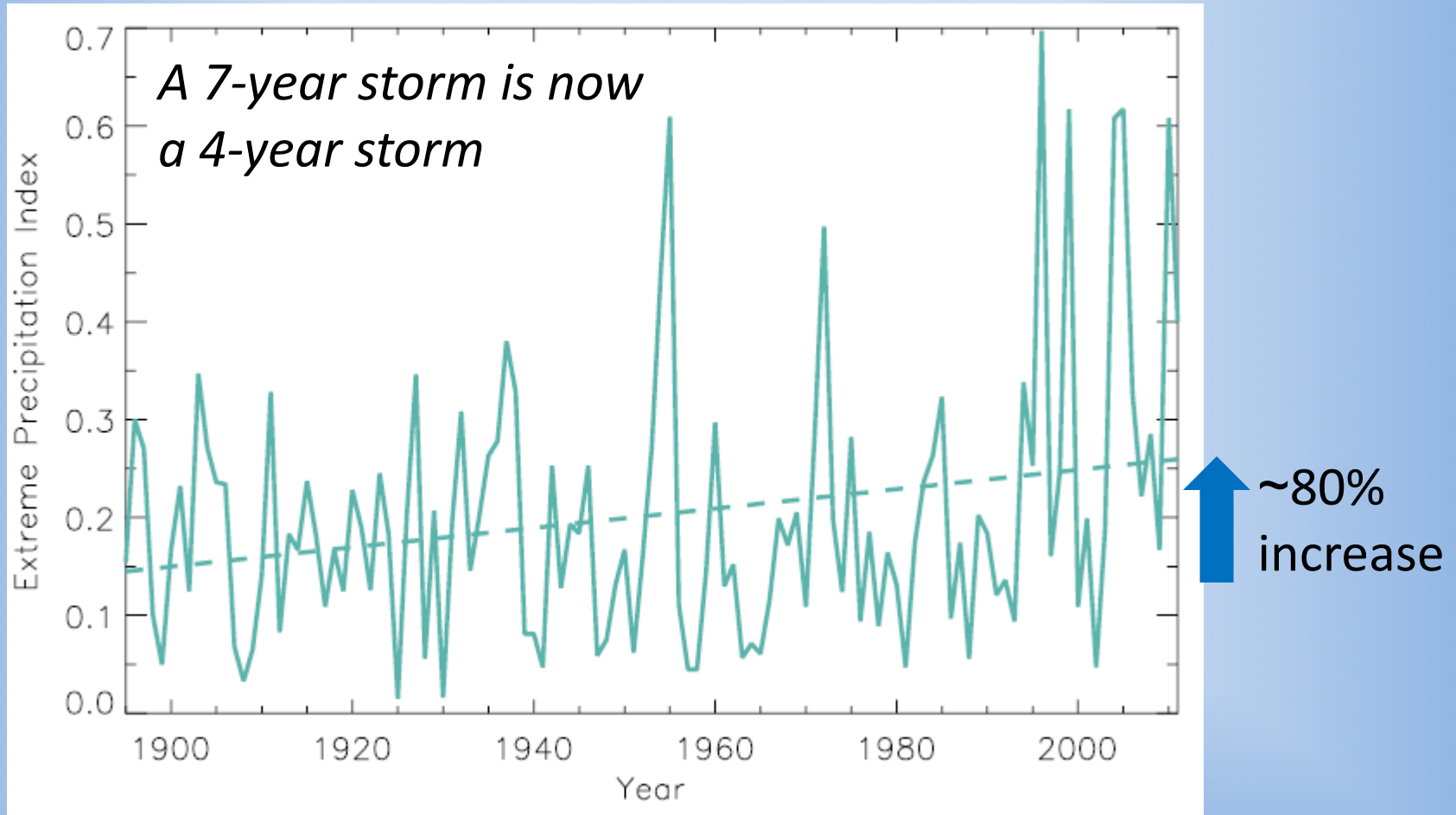


>95% significance in annually and in the fall

Kunkel et al. (2013a)

Precipitation has become more extreme

Extreme precipitation index for the Northeast, 1895-2011, based on daily precipitation events with a five-year recurrence interval

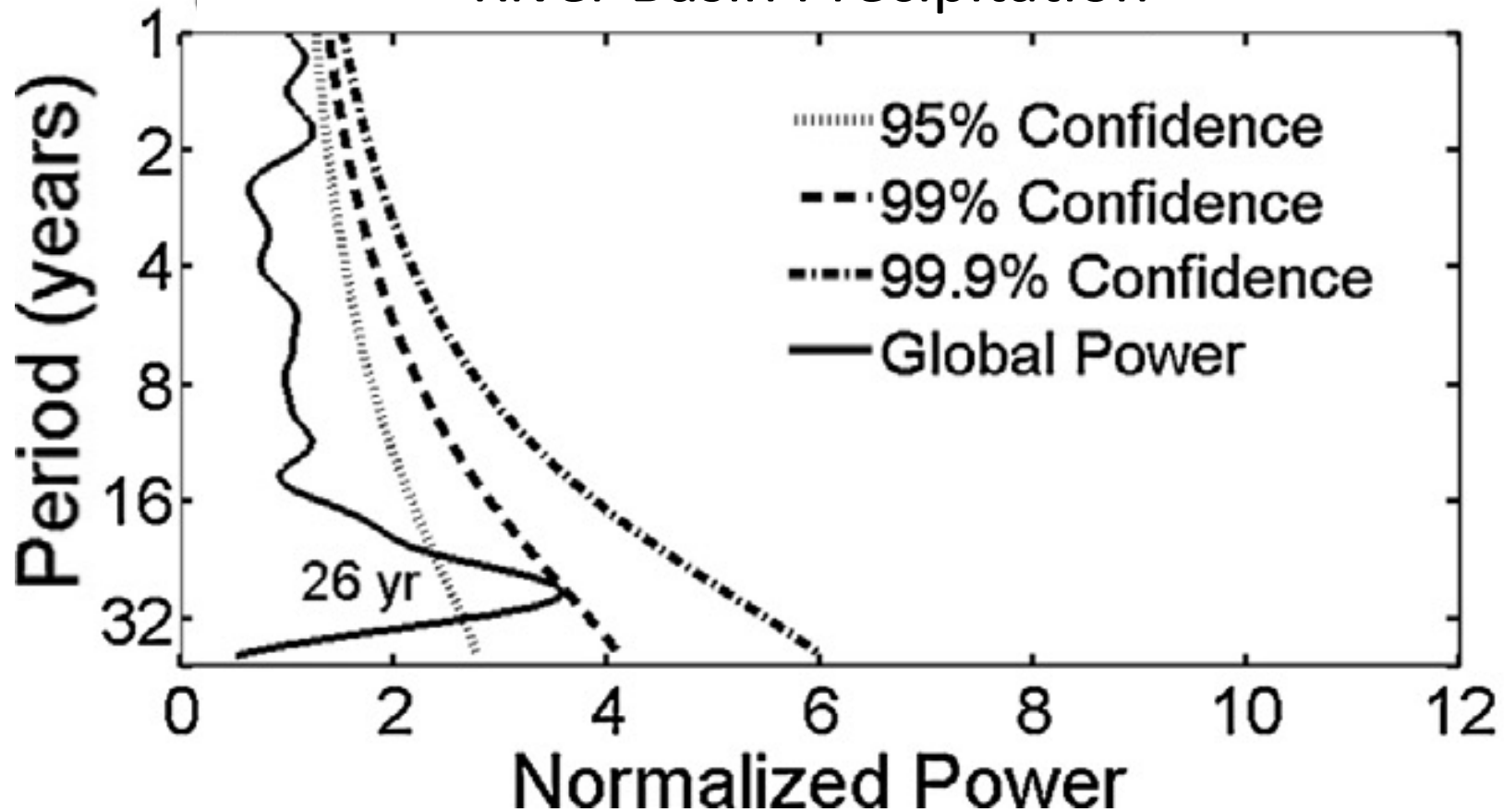


Not >95% significance!

Kunkel et al. (2013a)

Natural variability is important

Global Wavelet Power of Susquehanna River Basin Precipitation



Significant power at a period of 20-30 years. Related to Pacific Ocean climate modes (PDO and ENSO).

US Climate Projections



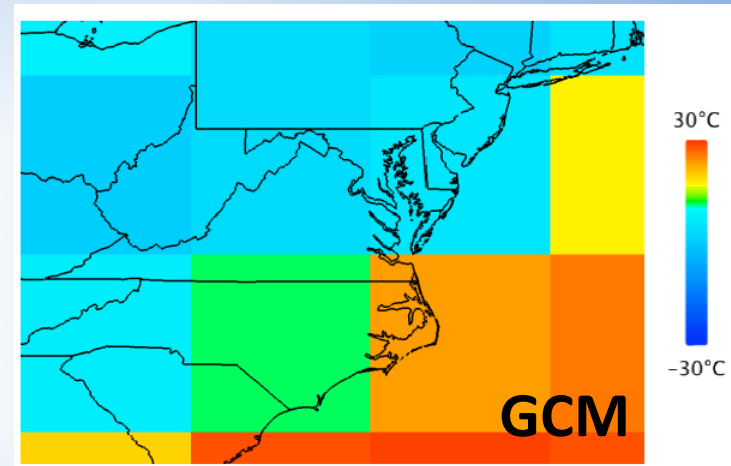
U.S. Global Change Research Program

National Climate Assessment

Surface air temperature

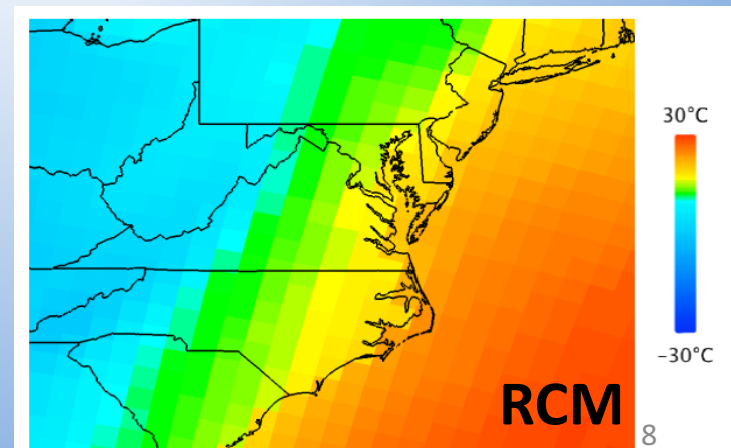
15 Global Climate Models (GCMs)

Coarse resolution, multiple emissions scenarios, full 20th-21st century



11 Regional Climate Models (RCMs)

finer resolution, single emissions scenario, late 20th / mid 21st century

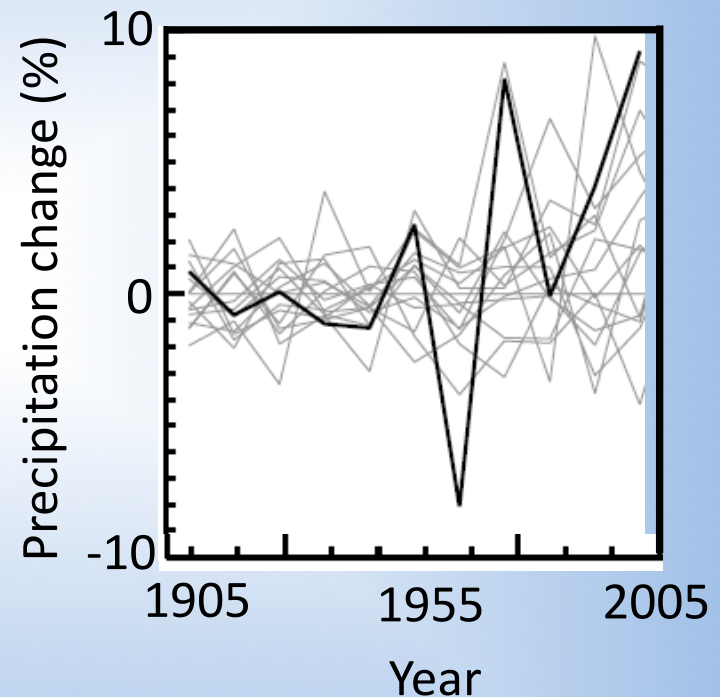
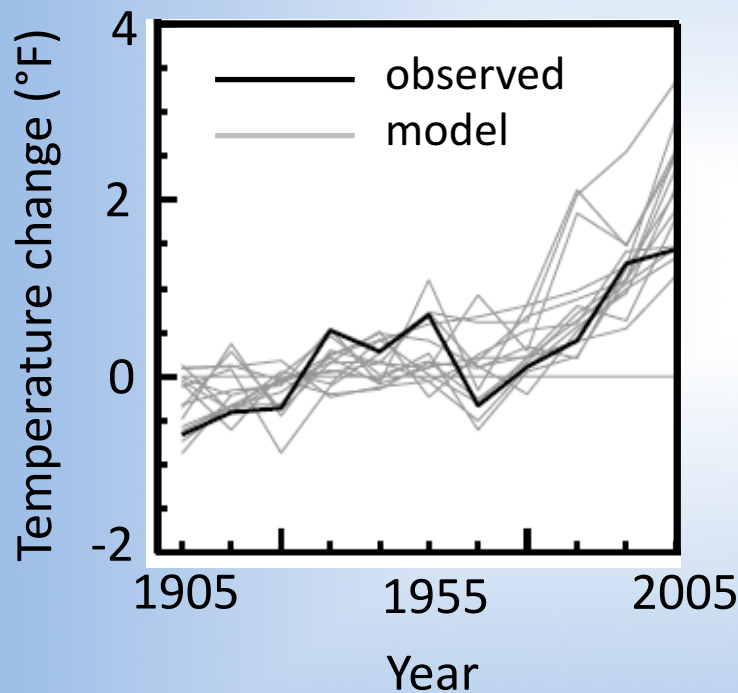


Graphics courtesy Andrew Ross

Models suggest past warming is human induced and

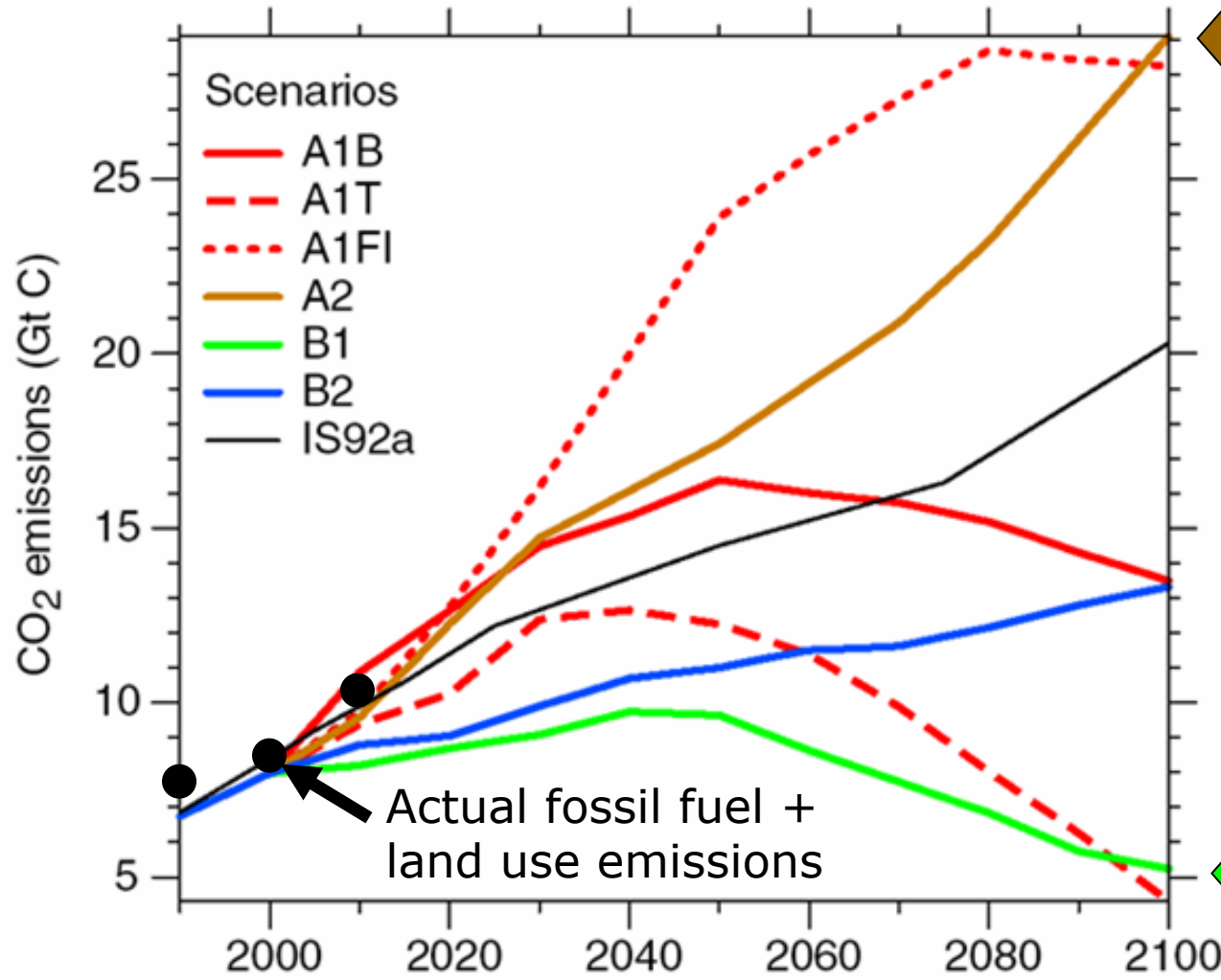
past precipitation change is mostly natural

Observed and simulated temperature and precipitation change in the Northeast U.S.



Decadal averages; deviation from 1901-1960 average

Future emissions scenarios

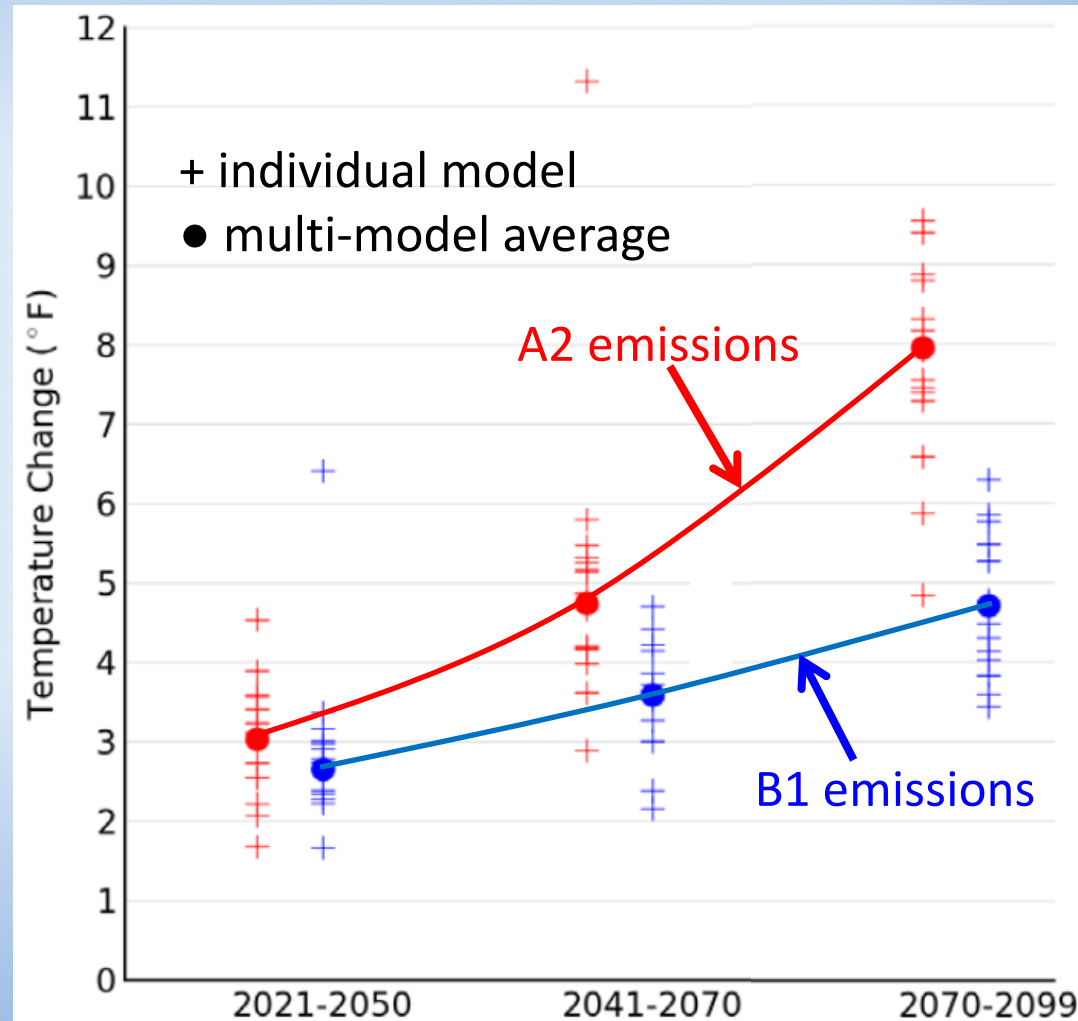


“High”
emissions A2
scenario

“Low”
emissions B1
scenario

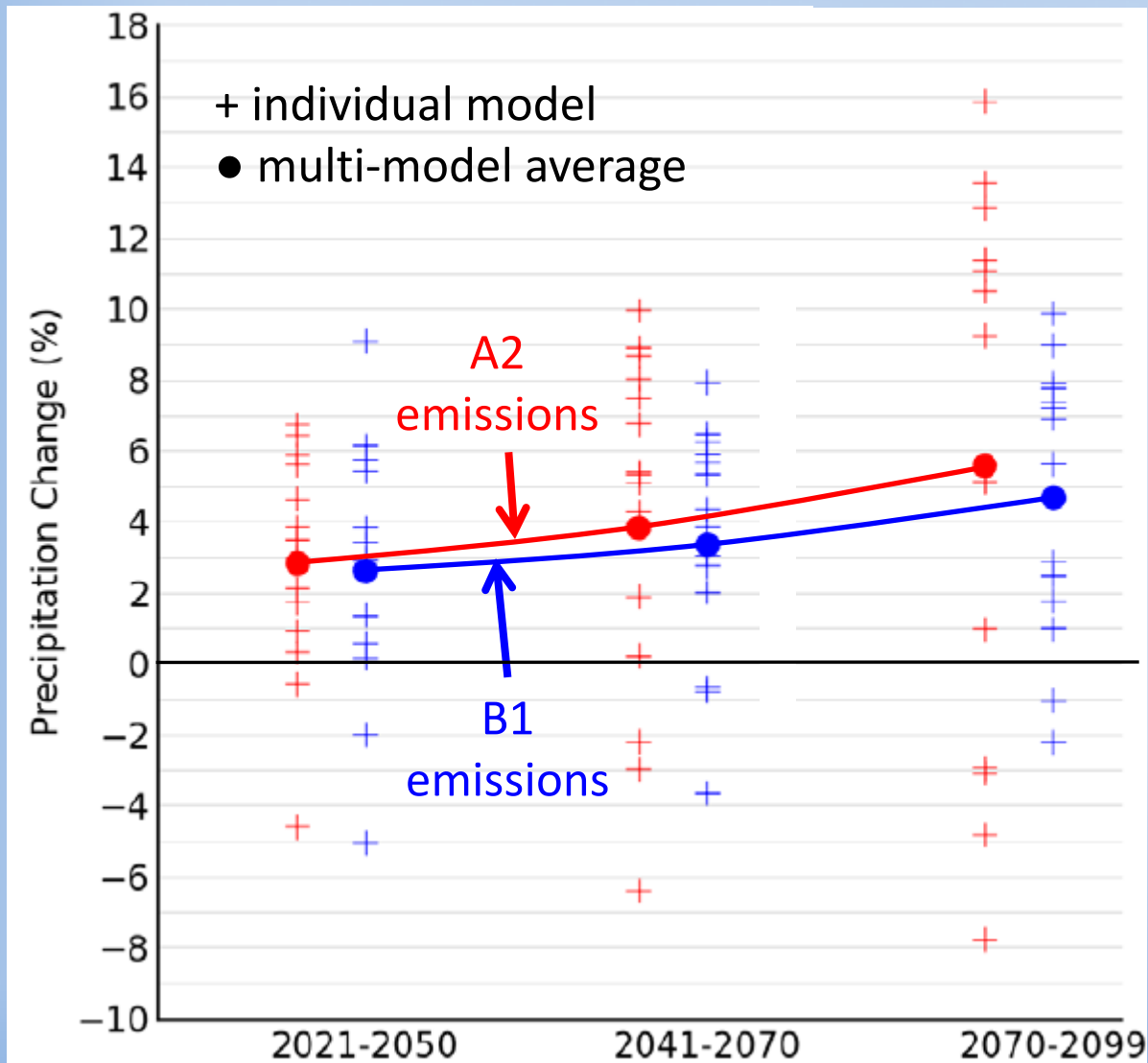
- Continued warming is projected
- Emissions scenario really matters by mid century

Projected 21st century temperature change from 15 global climate models under two climate scenarios



Kunkel et al. (2013a)

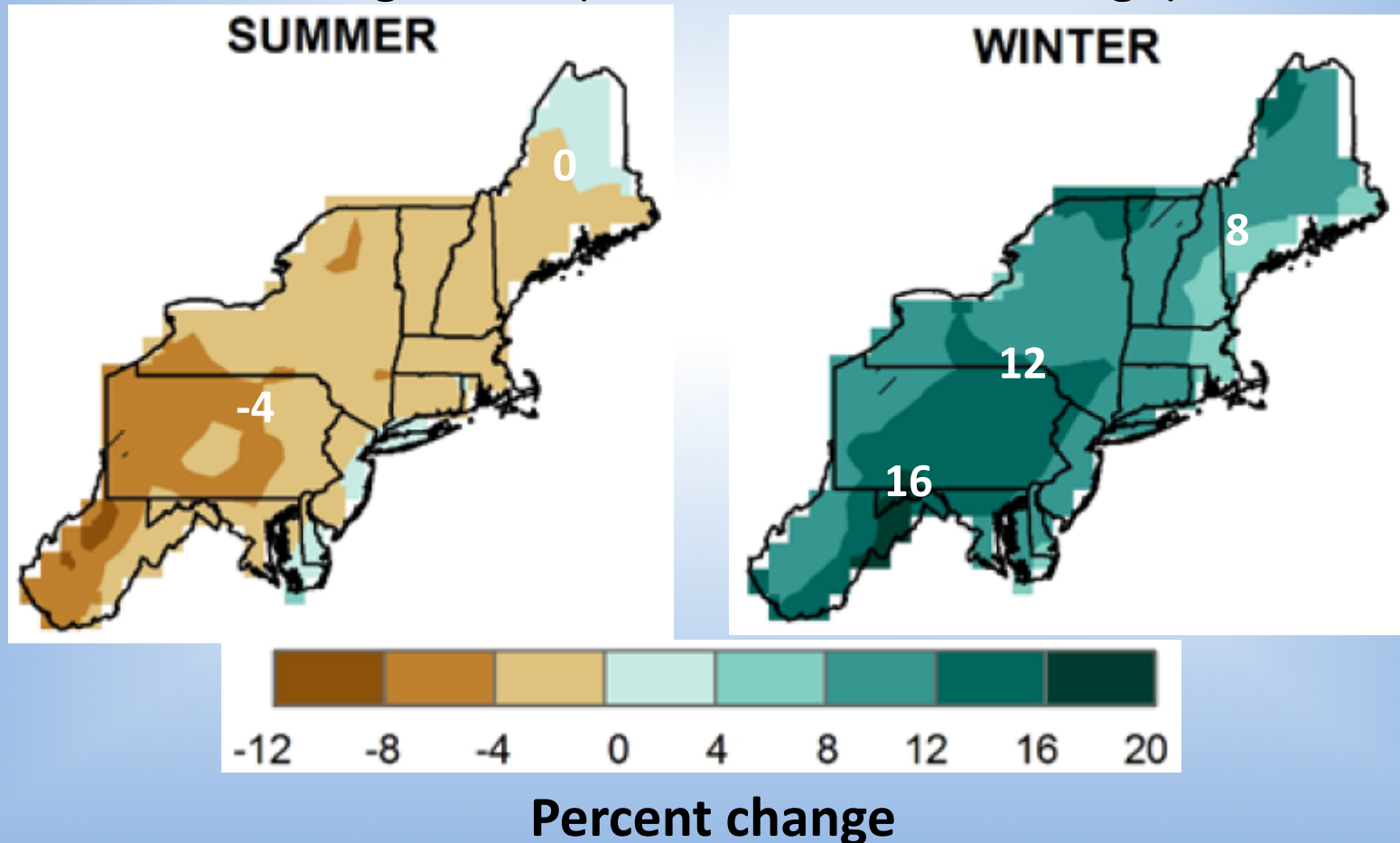
Continued precipitation increases are projected, though with less certainty than projected warming



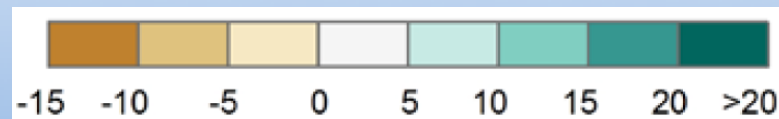
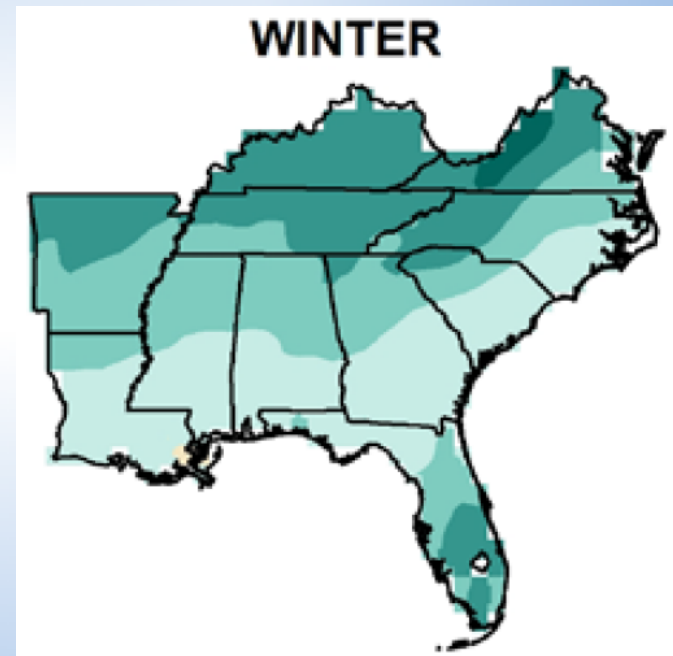
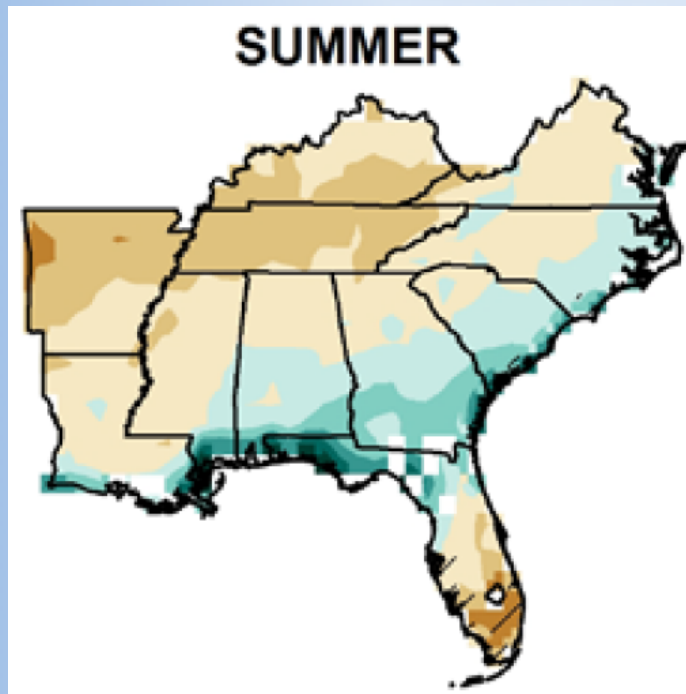
Kunkel et al. (2013a)

Winter projected to get significantly wetter, summer slightly drier

Projected precipitation change in the Northeast U.S. by 2041-2070
using RCMs (A2, multi-model average)

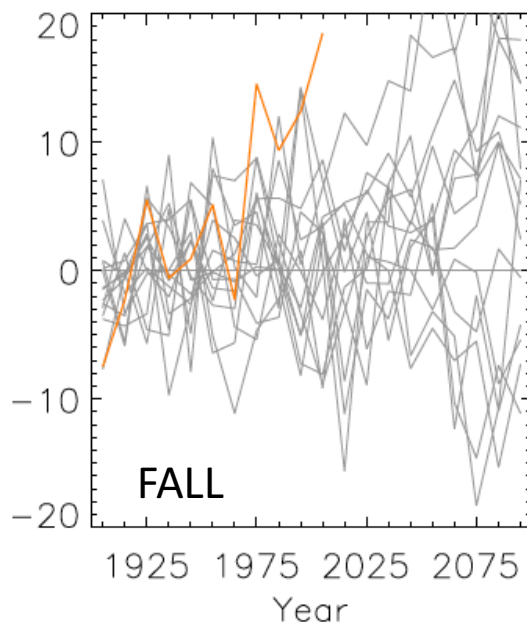
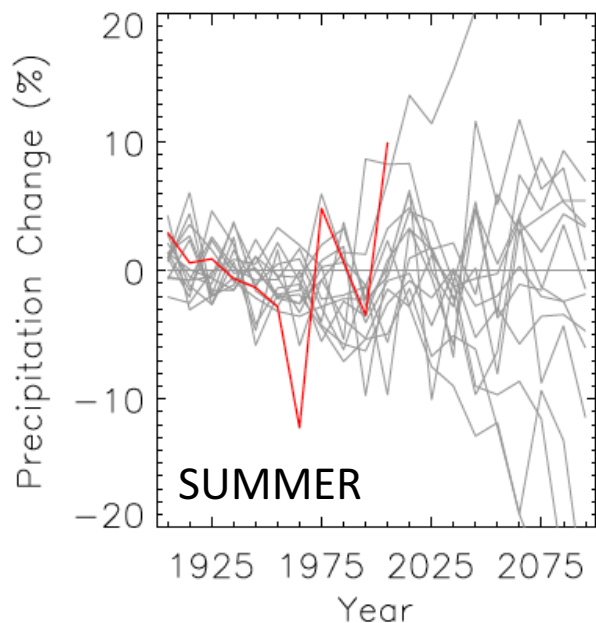
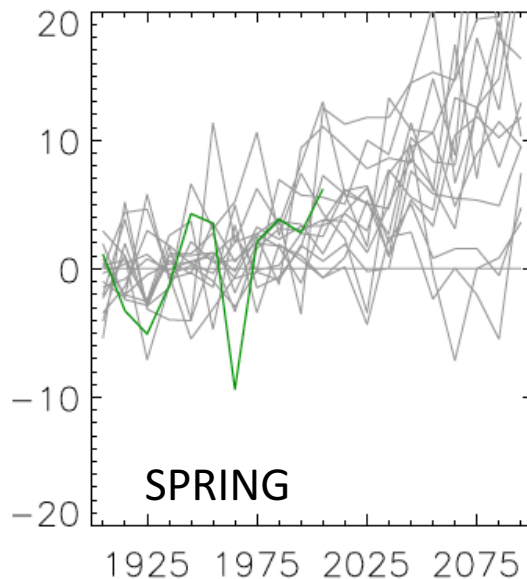
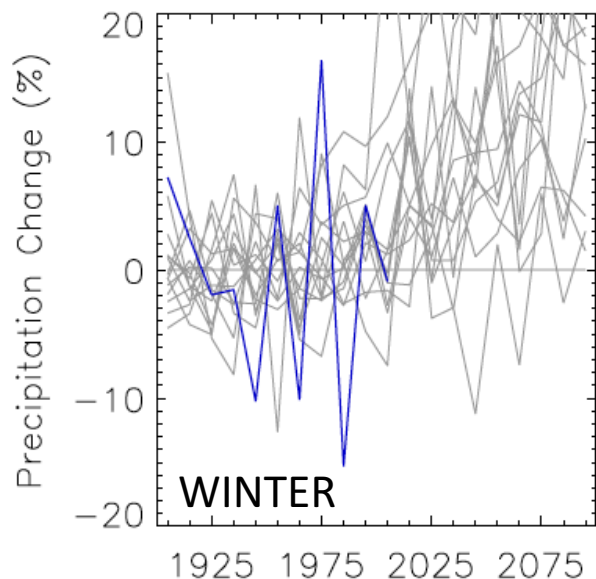


Projected precipitation change in the Southeast U.S. by 2041-2070 using RCMs (A2, multi-model average)



Percent change

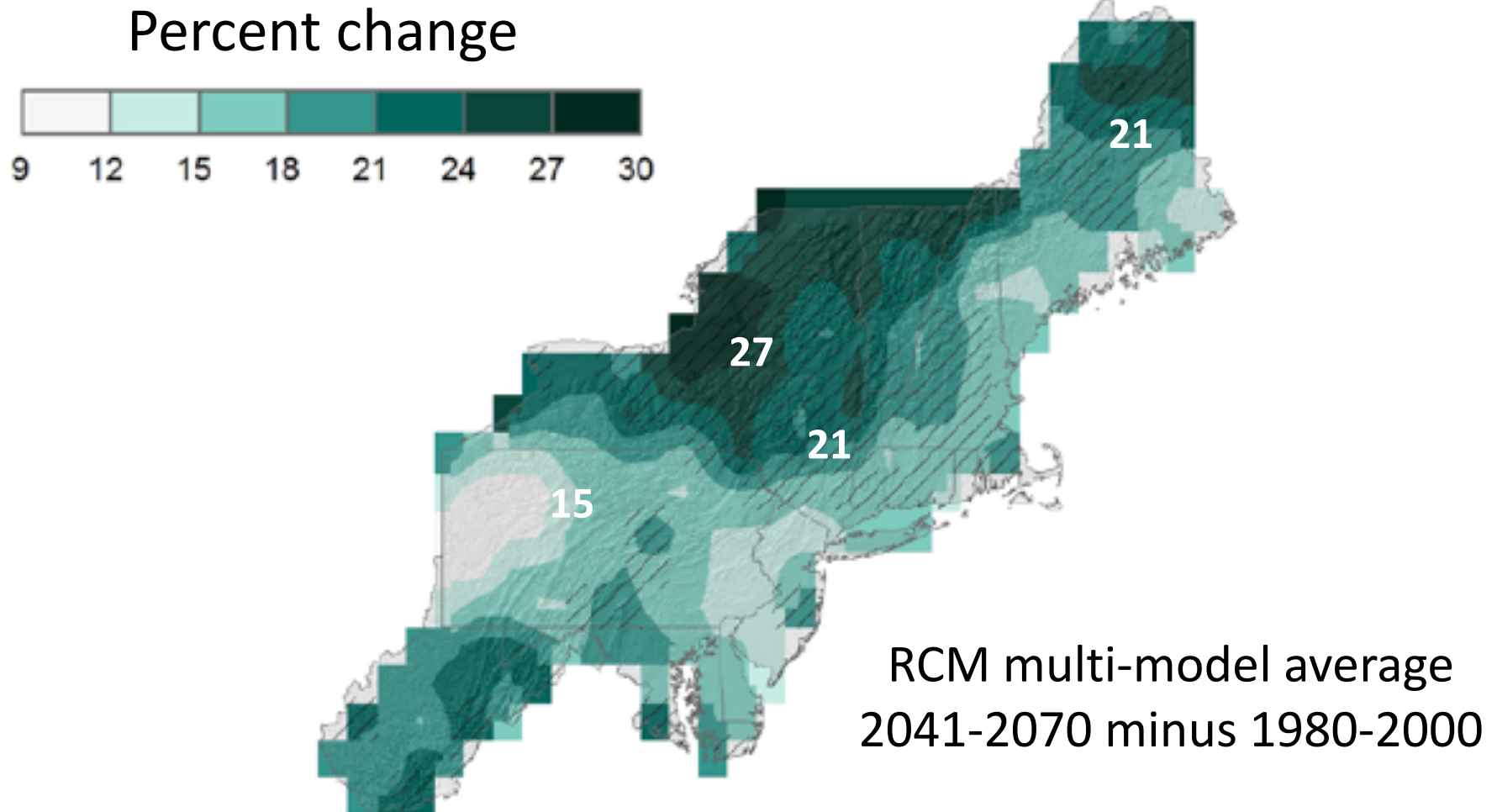
Colors = observed; Gray = models



Precipitation:
past NE US
increases were
in the fall;
future increases
are projected to
be in the winter
and spring

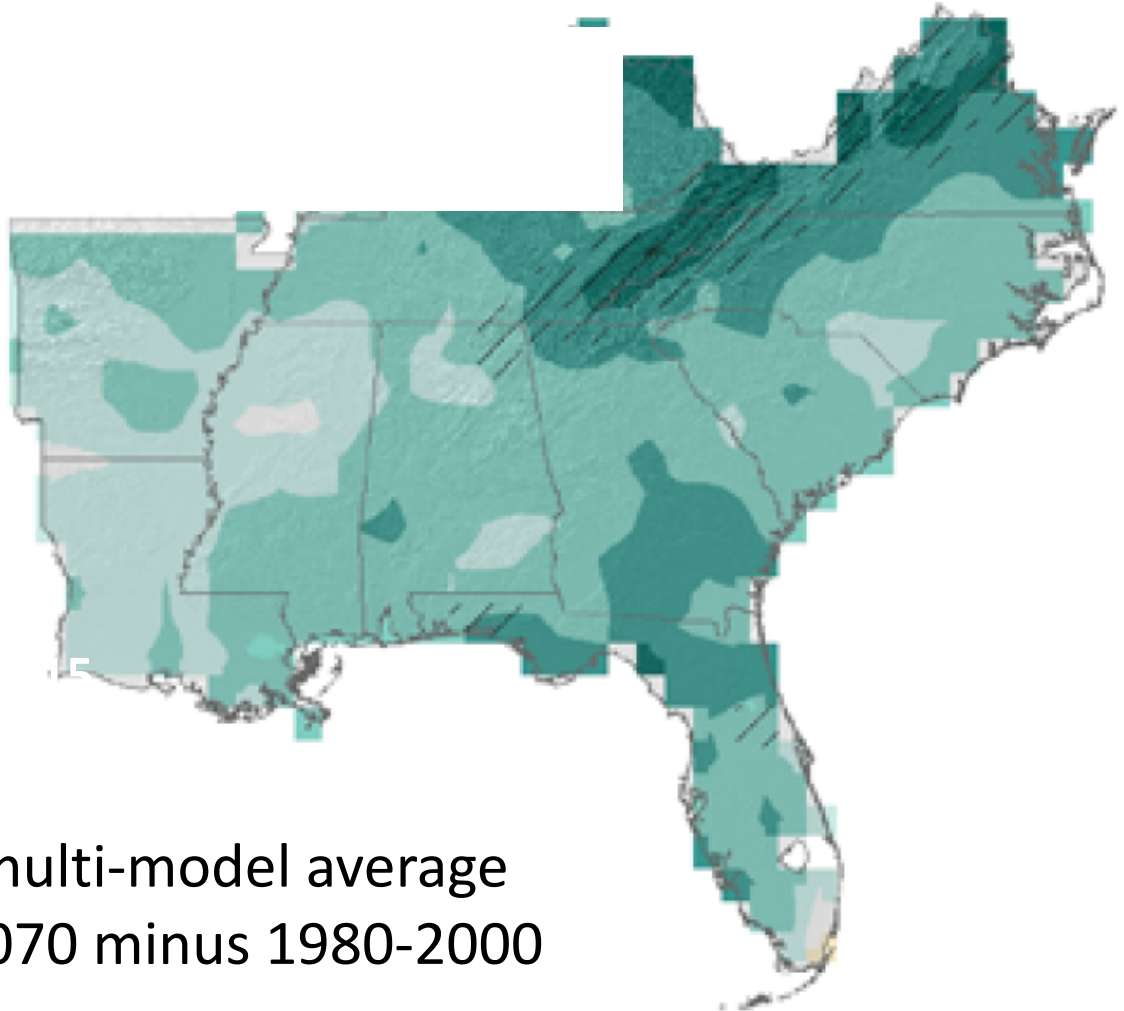
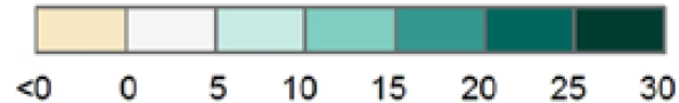
Precipitation projected to be more extreme

Change in extreme precipitation: number of days > 1 inch



Change in extreme precipitation: number of days > 1 inch

Percent change



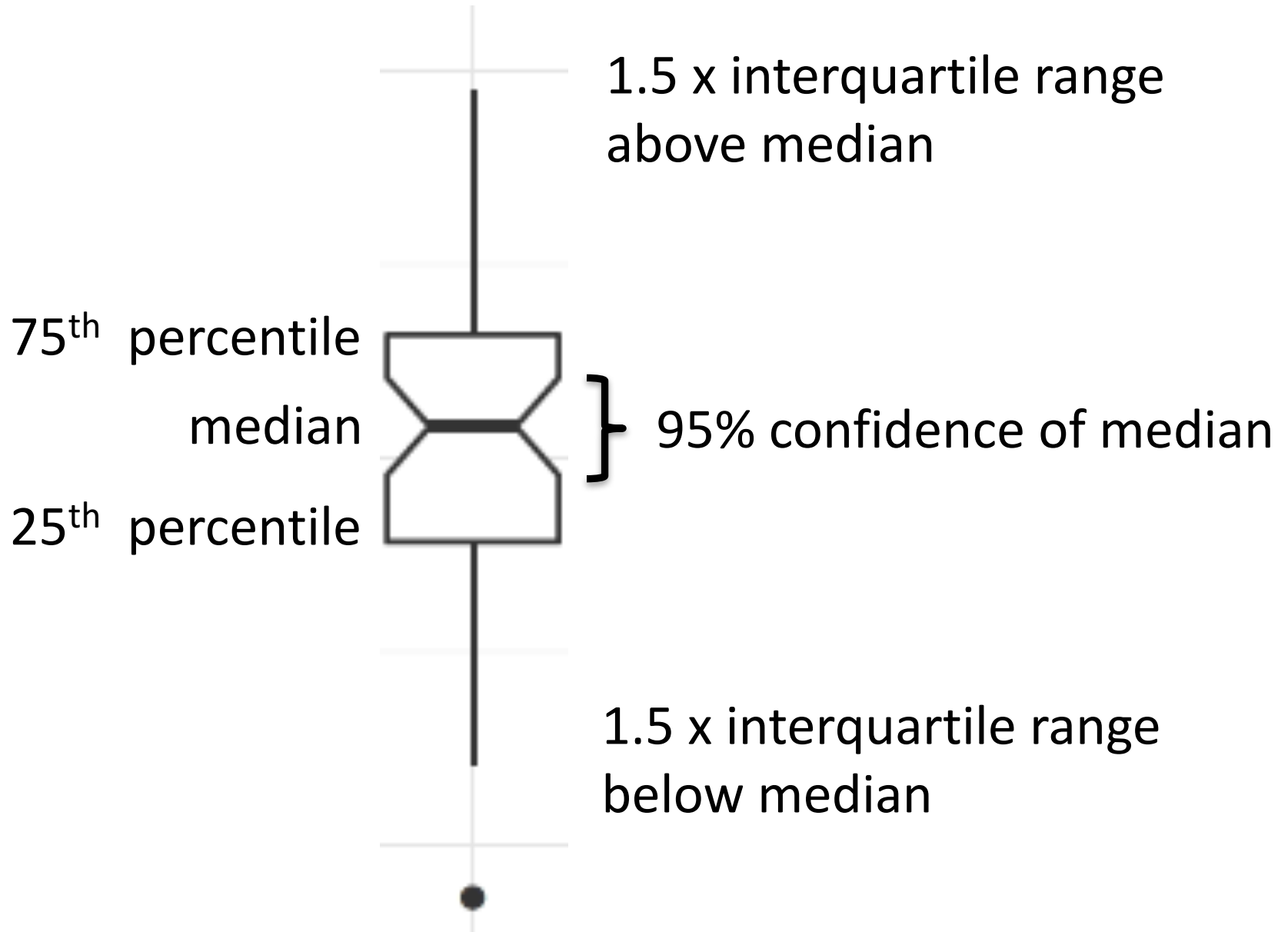
RCM multi-model average
2041-2070 minus 1980-2000

Models for predicting future streamflow



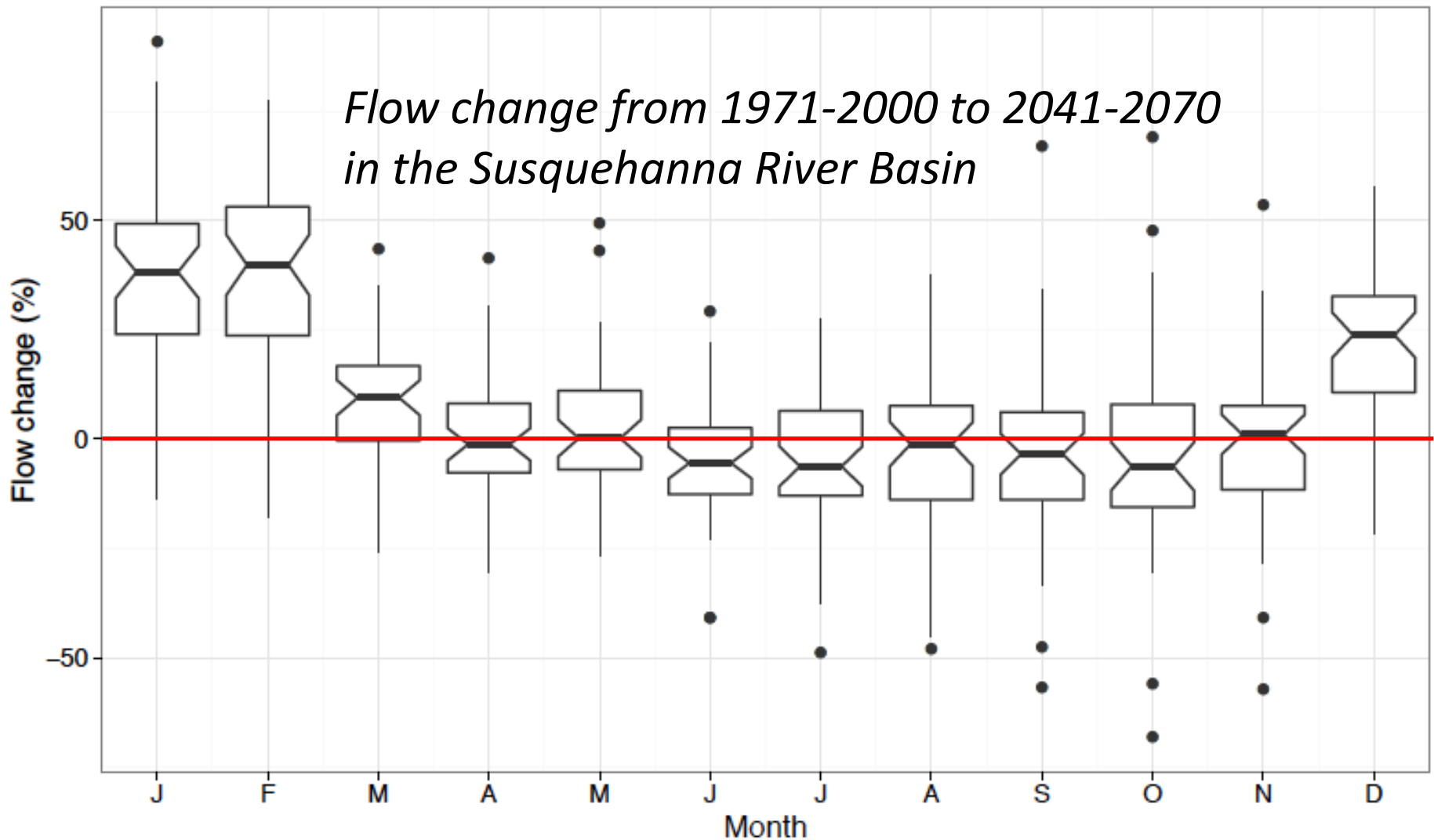
Andrew Ross

- 29 global climate models (CMIP5) → downscaled to $1/8^\circ$ → input to hydrological model (VIC)
- 10 regional climate models with land surface model, 50 km grid spacing (NARRCAP)
- 6 regional climate models (NARRCAP) → bias corrected → input to hydrological models (SWAT & HSPF)
- “Business as usual” emissions scenarios
- Funding: Pennsylvania Sea Grant

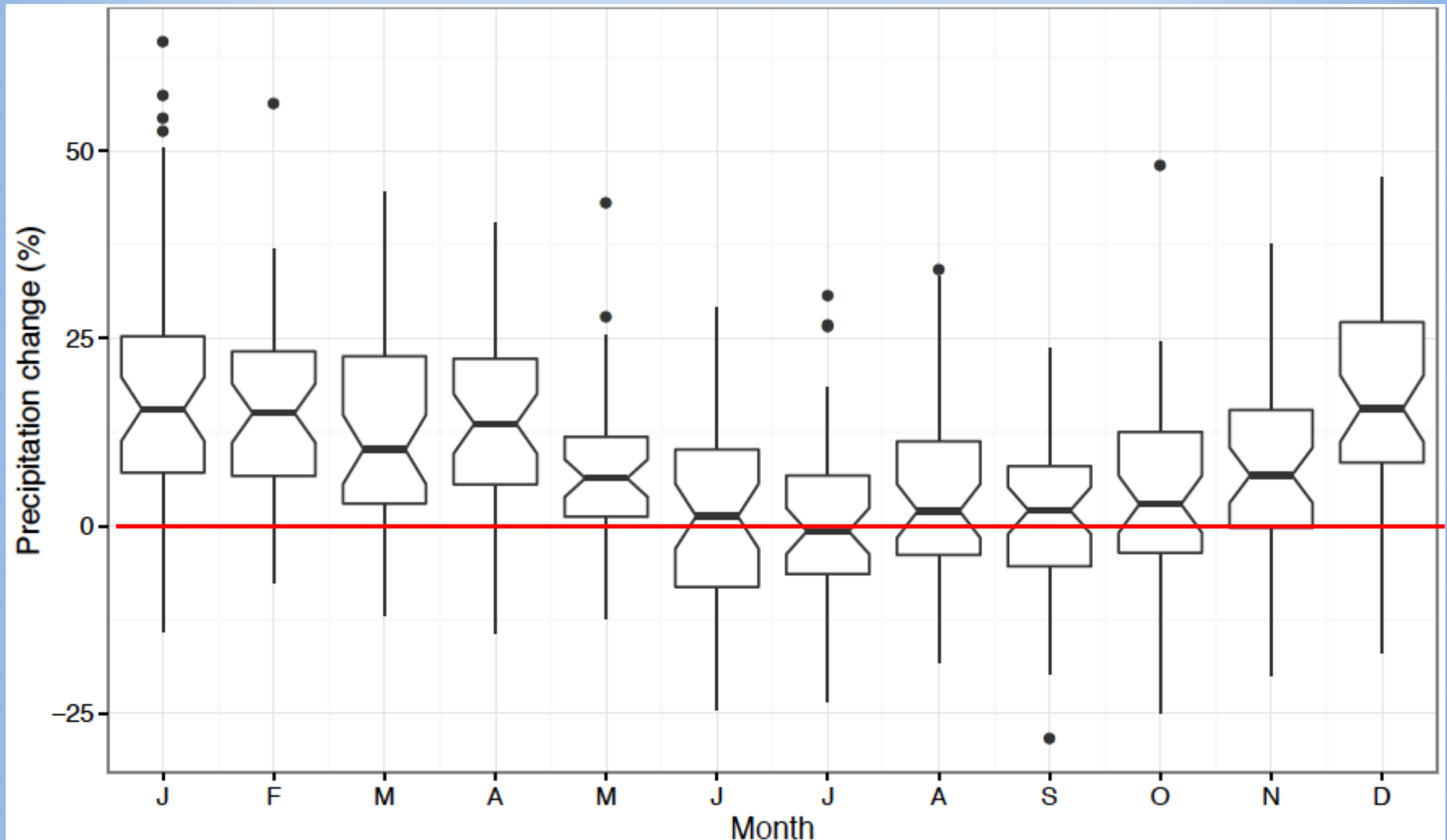


Expect more streamflow in winter, maybe less in early summer

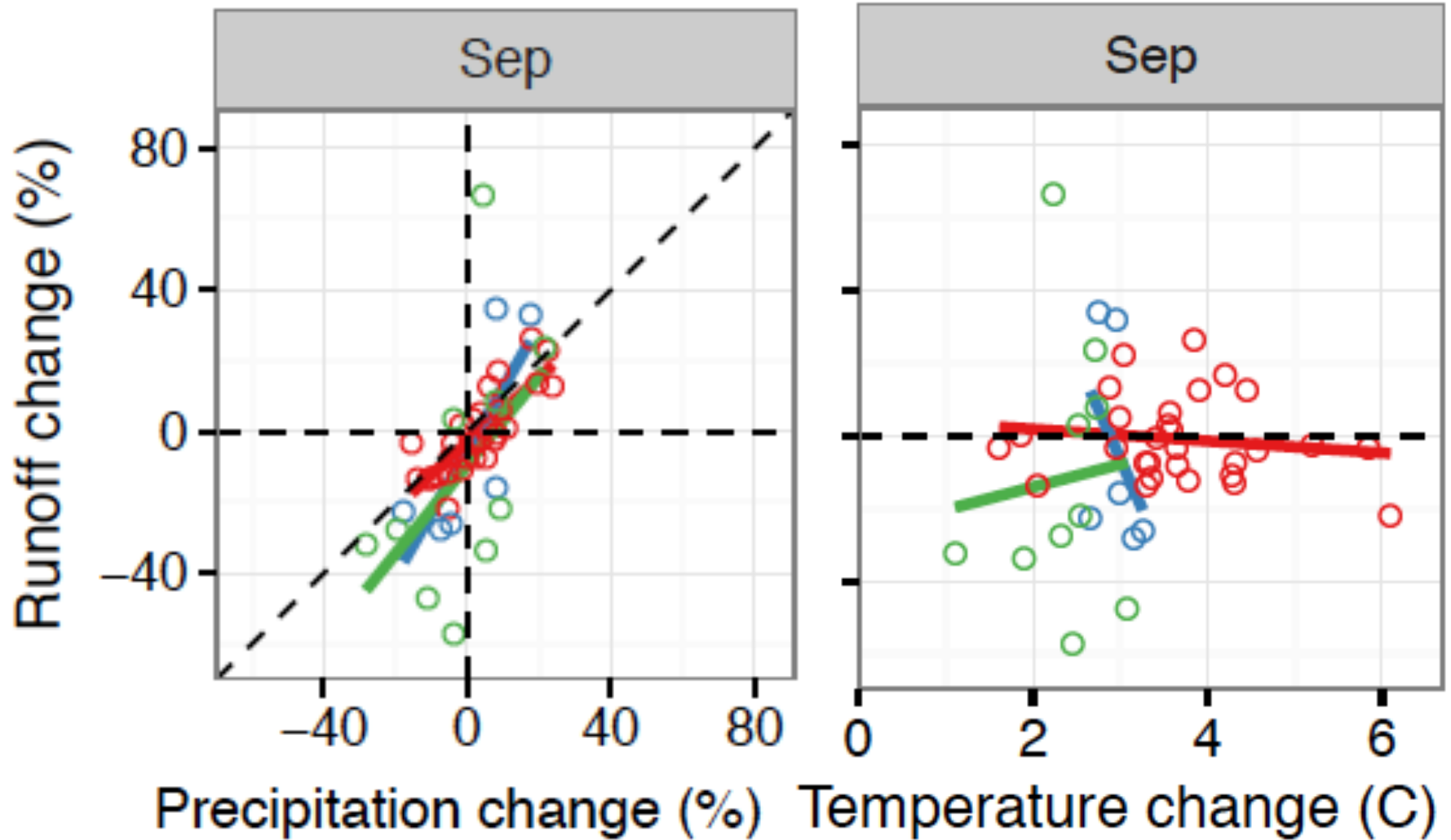
*Flow change from 1971-2000 to 2041-2070
in the Susquehanna River Basin*



The mean streamflow response follows the mean precipitation response with an offset due to increased evapotranspiration



Variability in streamflow among models is mainly due to precipitation



Sea level projections

Summary projections: Sewells Point, VA

RSL rise from 2000 to:	Likely (17-83%)	1-in-20 (95%)	1-in-200 (99.5%)	Max. poss. (99.9%)
2020	5"-7" (12-19 cm)	9" (19 cm)	10" (24 cm)	11" (27 cm)
2030	7"-12" (18-30 cm)	13" (34 cm)	16" (40 cm)	17" (43 cm)
2050	13"-21" (34-53 cm)	24" (60 cm)	29" (73 cm)	33" (85 cm)
2100, RCP 8.5	30"-53" (77-134 cm)	62" (158 cm)	86" (219 cm)	121" (307 cm)
2100, RCP 2.6	21"-38" (55-96 cm)	46" (116 cm)	72" (183 cm)	101" (255 cm)

Projections through to 2050 use RCP 8.5, since difference between emissions pathways is minimal (<2") until second half of the century.

From Kopp et al. (2014). Accounts for ice sheets, glaciers, thermal expansion, ocean dynamics, land water storage, and non-climatic sea-level change.

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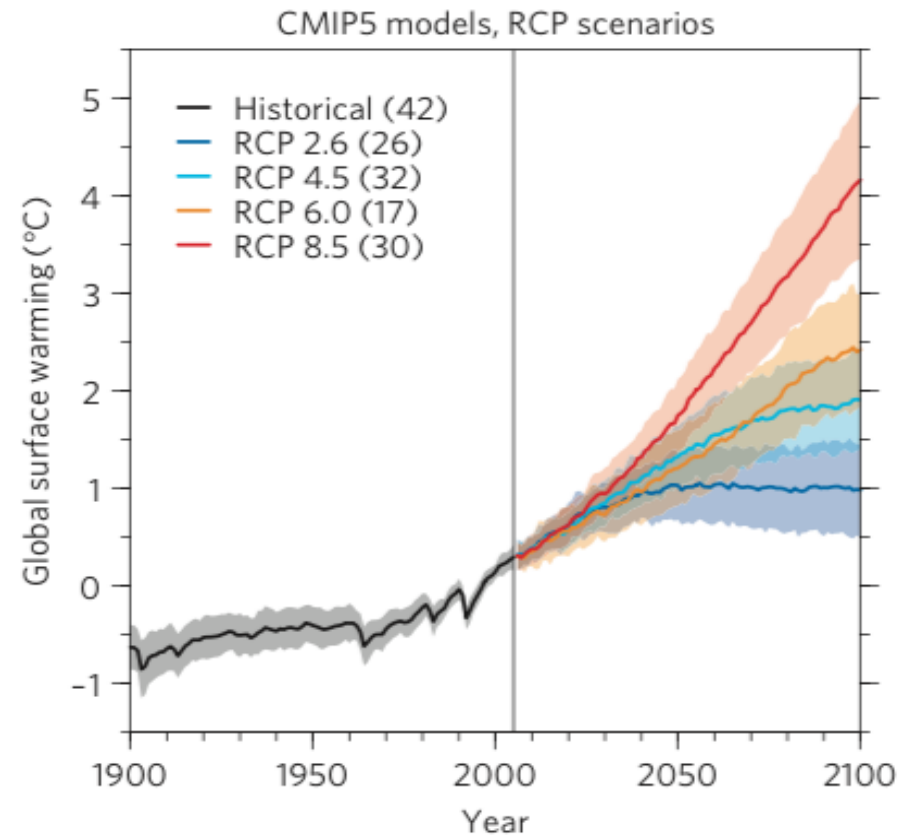
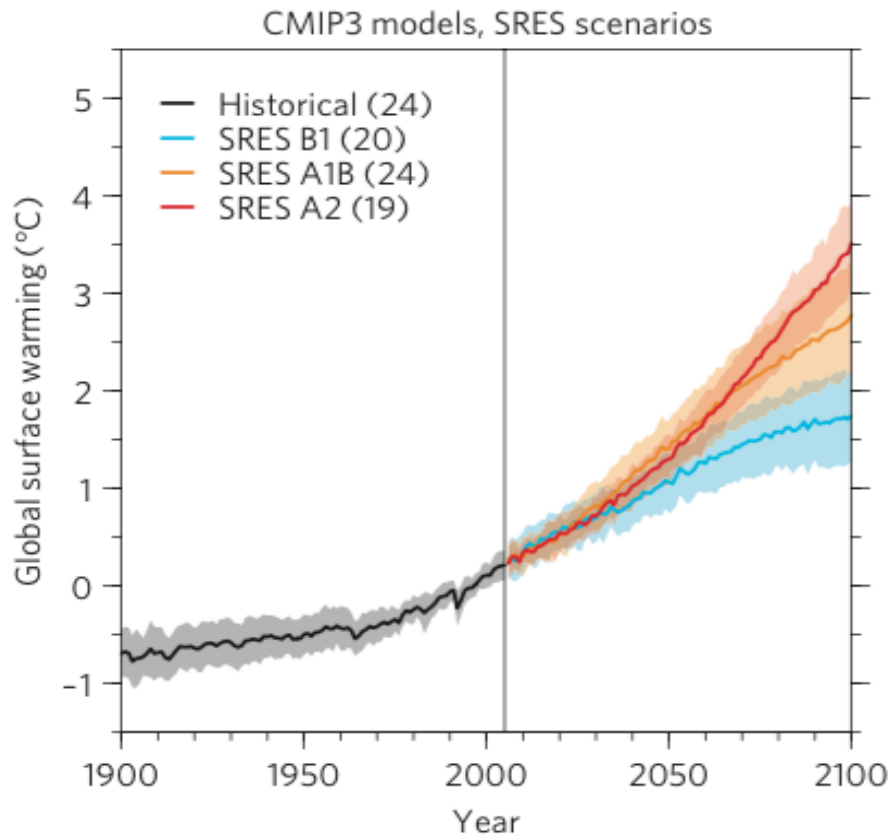
References

- IPCC, 2013. Summary for Policymakers. In: T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, P.M. Midgley (Editors), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Knutti, R., Sedláček, J., 2013. Robustness and uncertainties in the new CMIP5 climate model projections. *Nature Climate Change* 3, 369-373.
- Kopp, R.E., Horton, R.M., Little, C.M., Mitrovica, J.X., Oppenheimer, M., Rasmussen, D., Strauss, B.H., Tebaldi, C., 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future* 2, 383-406.
- Kunkel, K.E., Stevens, L.E., Stevens, S.E., Sun, L., Janssen, E., Wuebbles, D., Rennells, J., DeGaetano, A., Dobson, J.G., 2013a. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment, Part 1. Climate of the Northeast U.S., NOAA Technical Report NESDIS 142-1. U.S. Department of Commerce, Washington, D.C., 79 pp.
- Kunkel, K.E., Stevens, L.E., Stevens, S.E., Sun, L., Janssen, E., Wuebbles, D., Konrad II, C.E., Furhrman, C.M., Keim, B.D., Kruk, M.C., Billot, A., 2013b. Regional Climate Trends and Scenarios for the U.S. National Climate Assessment, Part 2. Climate of the Southeast U.S., NOAA Technical Report NESDIS 142-2. U.S. Department of Commerce, Washington, D.C., 94 pp.
- Nakićenović, N., Swart, R., 2000. Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 599 pp.
- Schulte, J., Najjar, R.G., Li, M., 2016. The influence of climate modes on streamflow in the Mid-Atlantic Region of the United States. *Journal of Hydrology: Regional Studies* 5, 80-99.

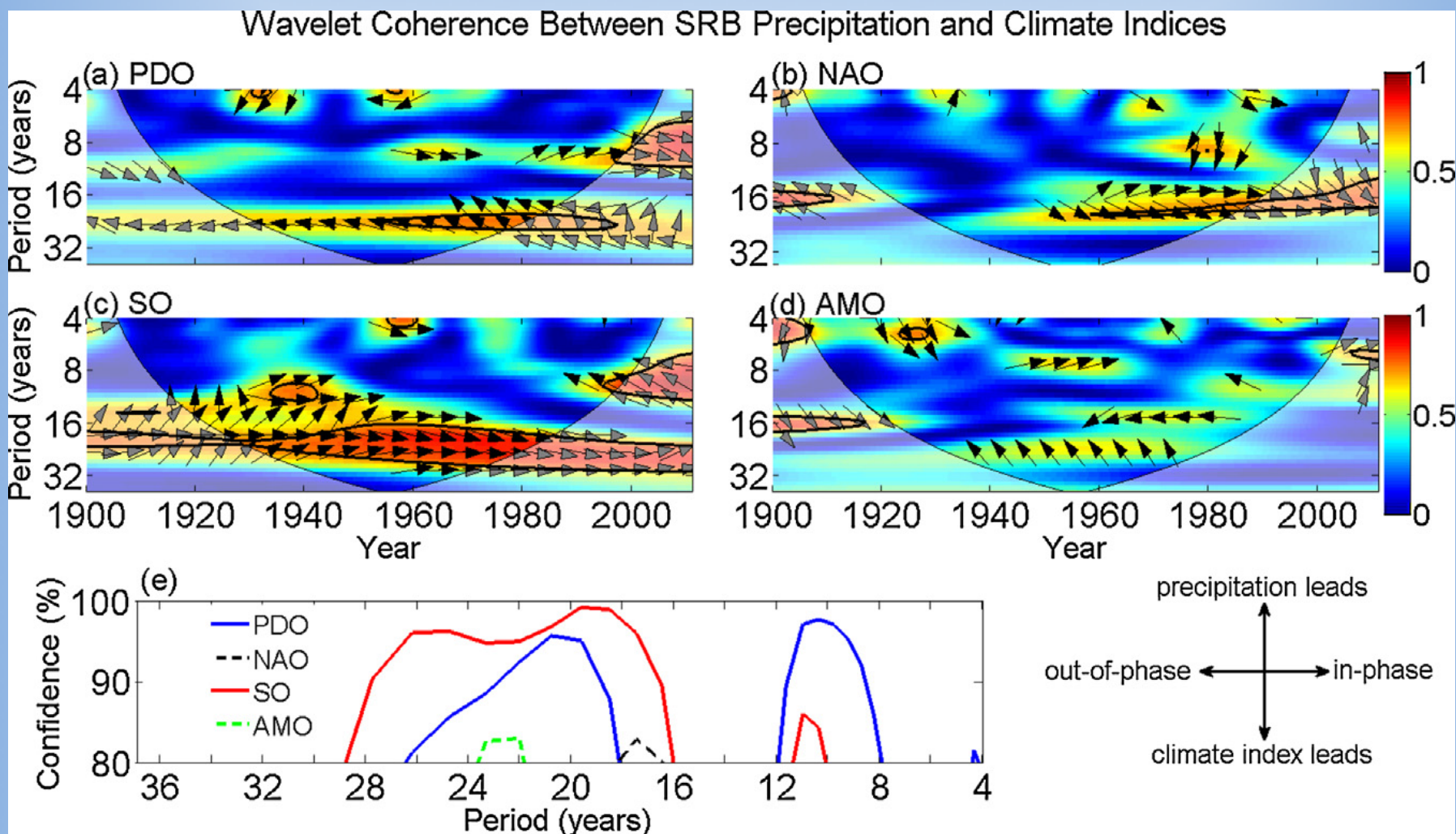
Extra slides

Newer scenarios (RCP) have greater range

SRES and RCP Scenarios: Impact on global mean surface temperature



Decadal-scale variability in Susquehanna Basin precipitation is linked to the Pacific Ocean climate modes



Schulte et al. (2016)