Climate change projections for improved management of infrastructure, industry, and water resources in Minnesota

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U of M Humphrey School of Public Affairs
Bonnie Keeler, Terin Mayer, Ryan Noe*, Maggie Rogers

U of M Department of Soil, Water, and Climate
Tracy Twine

U of M Institute on the Environment
Kate Brauman

*Corresponding author: RRNoe@umn.edu

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What sets this research apart, and why is it important for Minnesotans?

Our work improves over current climate projections in two key ways; first, it is much finer spatial resolution, and second, we produce the finer spatial resolution through a dynamic rather than statistical process. Climate models are typically coarse resolution because it is necessary to model the atmosphere globally, which is impractical to do at a high resolution. While these models can inform our understanding of statewide trends in precipitation, questions of how individual communities will be affected demand higher resolution. For example, whether or not an increase in precipitation occurs in the Red River Valley, or further east in the Mississippi River watershed has major implications for flood management. We address this limitation in resolution by using a dynamic downscaling technique that takes broad-scale projections as an input, and simulates future weather conditions at an hourly time step. This computationally intensive process allows us to answer questions about frequency, intensity, and sub-regional variation that a statistical technique cannot.

We further reinforced the robustness of our results by using two techniques, ensemble modeling, and comparisons between 20-year averages. Ensemble modeling is averaging across the five dynamically downscaled climate models that were ran[1]. This reduces the influence of extreme events in any one model. Comparing 20-year averages in the historic, mid-century, and end of century periods rather than any particular year, increases the confidence that the observed patterns are long-term changes. The ensemble approach and 20-year averages allow us to be confident that long-term changes in climate patterns drive the changes we report and not the variability in weather from year to year, or unique properties of a single model.

In addition to projections of future climate, we further modeled the influence of the climate on water cycling and agriculture using an advanced ecosystem process model called Agro-IBIS[2]. Given the inputs of land cover, soil, and future climate projections, the model simulates the uptake of water for specific vegetative covers found throughout the state, and further models plant growth, evaporation, and water runoff. Using these outputs, along with data compiled on groundwater use in the state, we projected where changes in precipitation and demand are most likely to lead to water depletion.

Climate Change Findings

We consulted users of climate data the private, public, and non-profit sectors to help us create data products that would generate the most value to industries and resource managers in the state. Through this consultation, we identified several analyses to present in this report that

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[1] Unless noted in the figure caption, the ensemble consisted of bcc-csm1-1, CCSM4, CNRM-CM5, IPSL-CM5A-LR, and GFDL-ESM2M

[2] https://lter.limnology.wisc.edu/project/agro-ibis

would simply and quickly communicate the impacts of a changing climate, such as the change in the number of days above 95°F, or the change in length of the average dry spell. These outputs represent only a fraction of the available data products from this research.

Our analysis modeled three periods, and two emissions scenarios. The periods included a historical reference period from 1980-1999, a mid-century period from 2040-2059, and an end-of-century period from 2080-2099. For brevity, these are referred to as circa 1990, 2050, and 2090, respectively. To reduce the influence of year-to-year variation in weather, we modeled each year in the 20-year periods, and averaged the result. Thus, the output reflects the climate at each period, but does not project events in specific years. Unless otherwise noted, the maps below display the change from the historical reference scenario to the future scenario.

We also modeled two emissions scenarios defined by climate research community, a moderate emissions scenario (RCP 4.5) and a high emissions scenario (RCP 8.5)[3]. These scenarios do not diverge significantly by mid-century, so we only modeled the moderate emissions scenario in that period. When interpreting the maps below, the circa 2050 output represents the climate changes that communities will experience in the near future (i.e. the next 20 to 40 years). The circa 2090 moderate emissions represent the projected changes if emissions growth slows, while the circa 2090 high emissions represents a business as usual trajectory where emissions continue to grow proportionally with future development.

In consultation with practitioners and climatology experts, we selected the maps below to highlight the most salient impacts of climate change to people and industry. Numerous other variables and temporal aggregations will be available when the underlying data are published[4].

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[3] For more information on specific scenarios, see Graham Wayne's 'The Beginner's Guide to Representative Concentration Pathways' (2013). Available at: https://skepticalscience.com/docs/RCP_Guide.pdf

[4] Check https://z.umn.edu/climate-change-data for updates on data availability

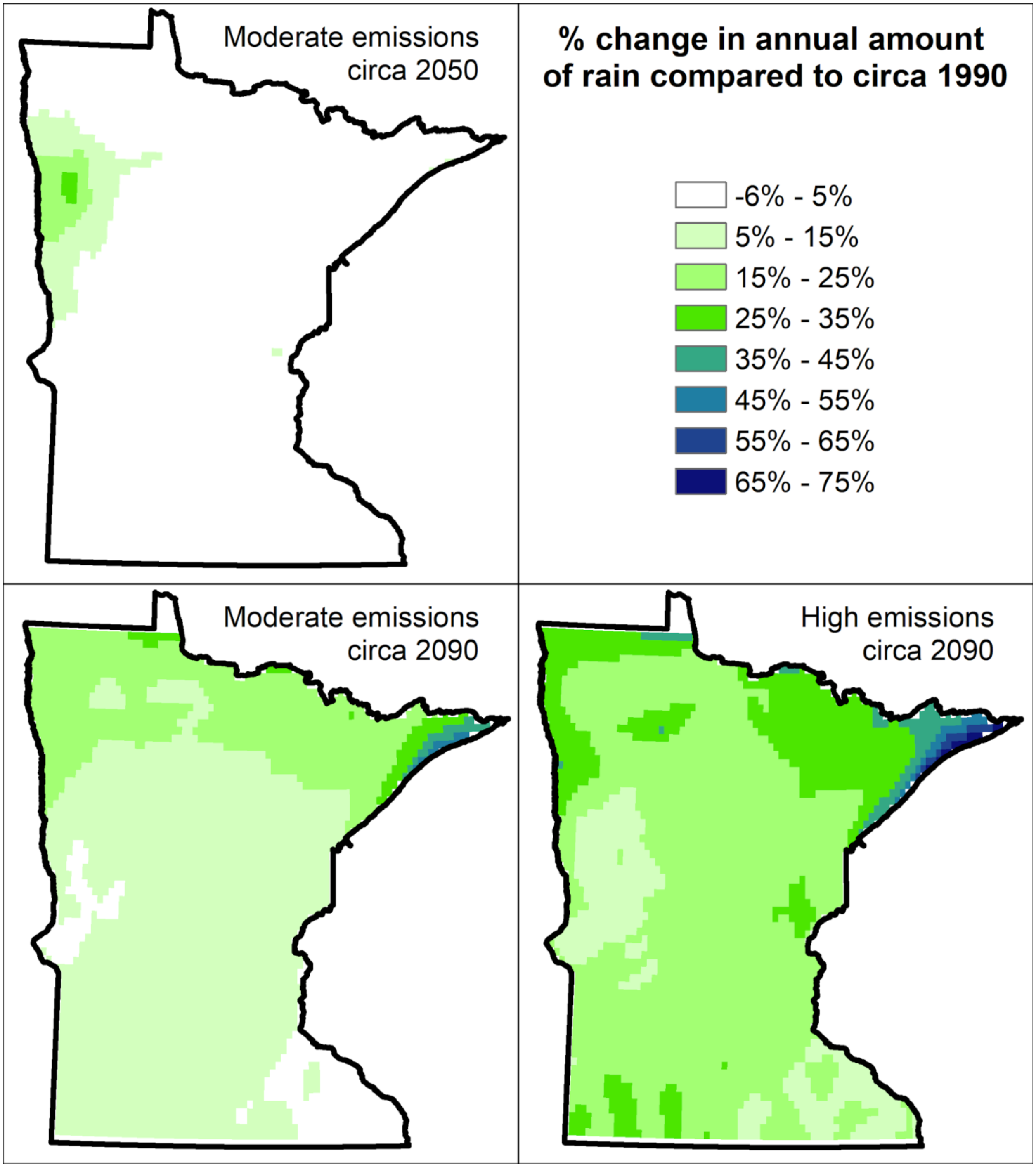

Figure 1. Percent change in annual amount of precipitation relative to circa 1990. Circa 1990 corresponds to the average of 1980-1999 of our modeled climate data. Future scenarios also represent 20-year averages, circa 2050 corresponds to 2040-2059 and circa 2090 corresponds to 2080-2099.

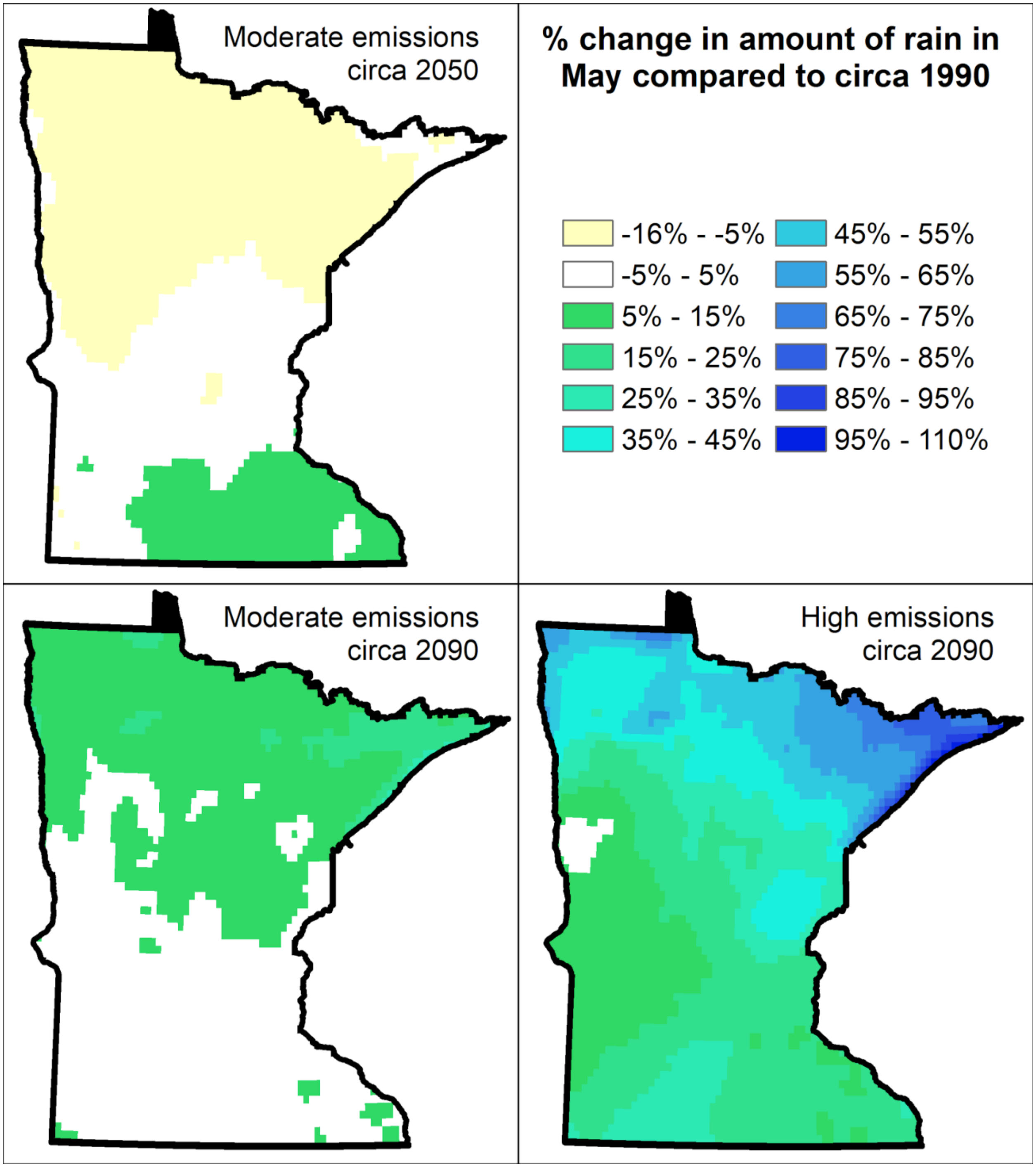

Figure 2. Percent change in amount of precipitation in May.

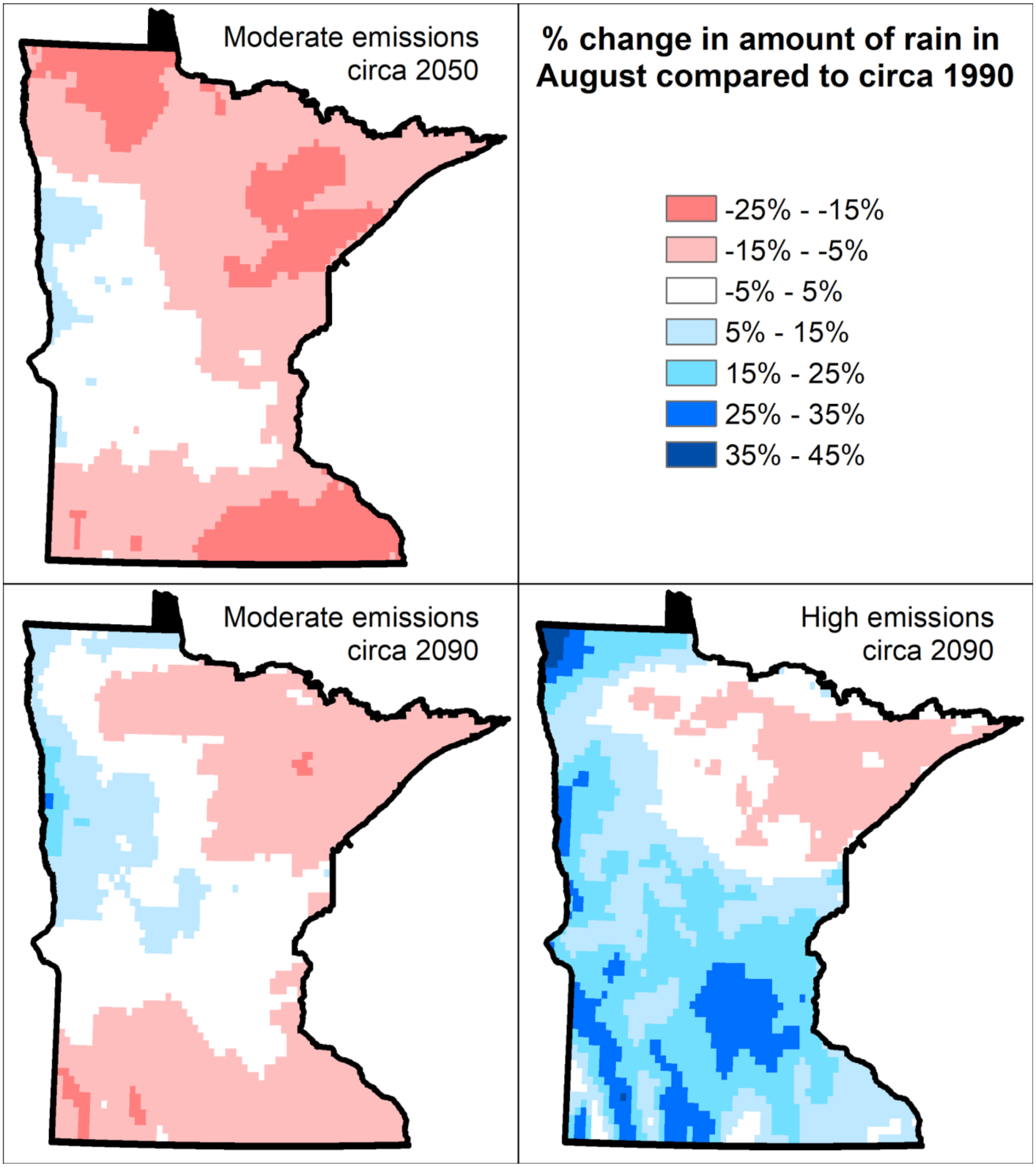

Figure 3. Percent change in amount of precipitation in August.

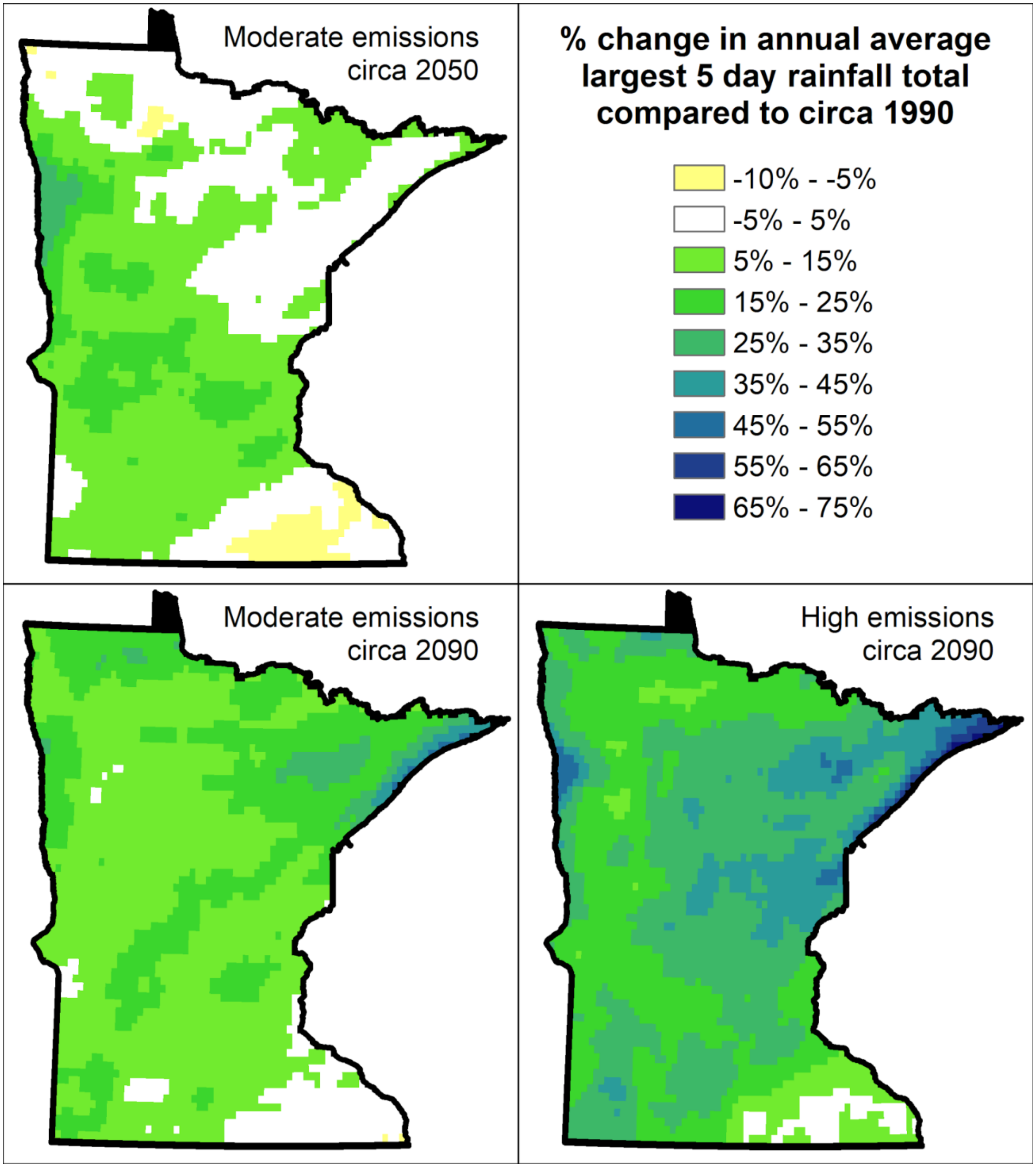

Figure 4. Percent change in annual average largest 5-day rainfall total.

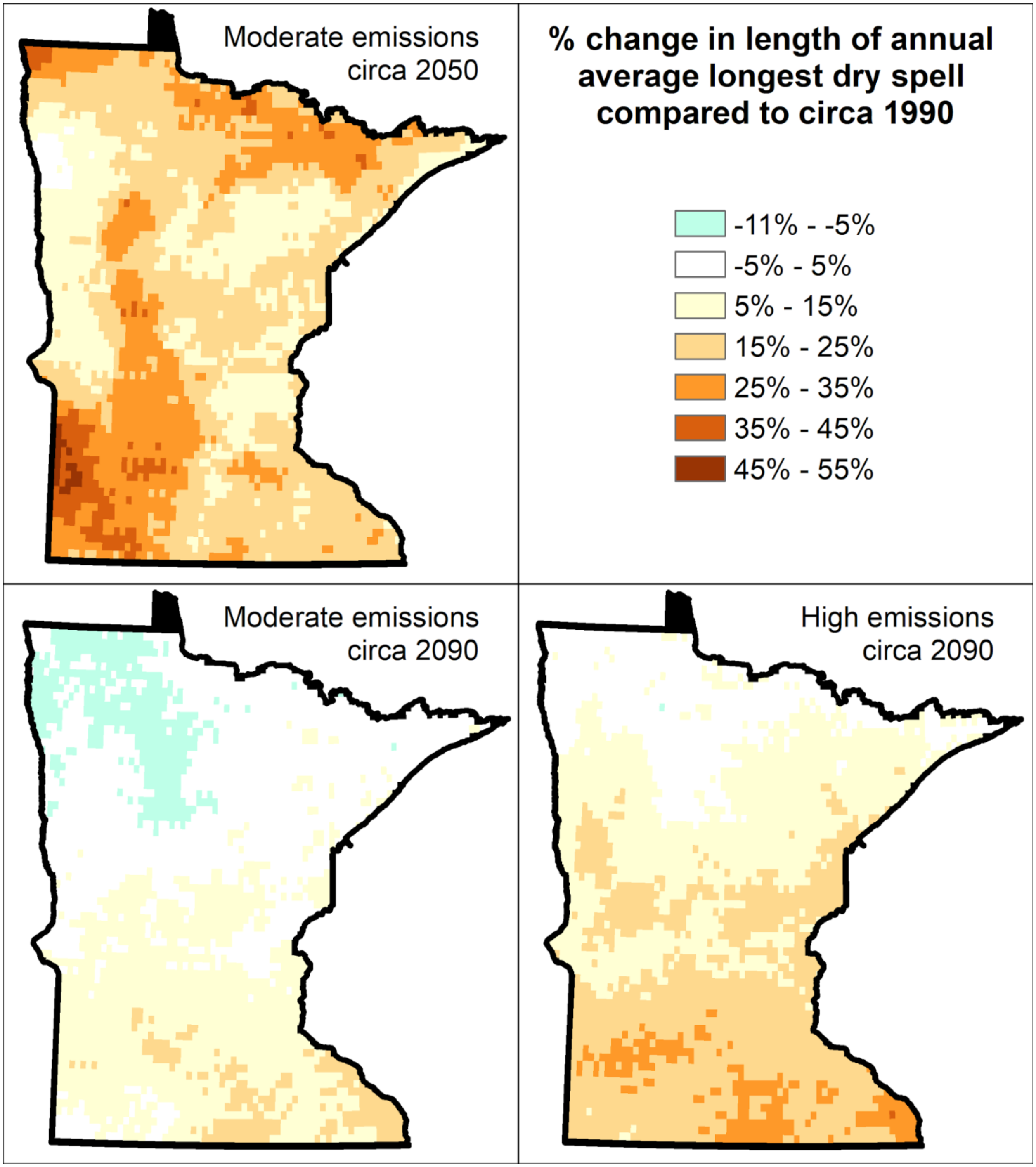

Figure 5. Percent change in length of annual average longest dry spell.

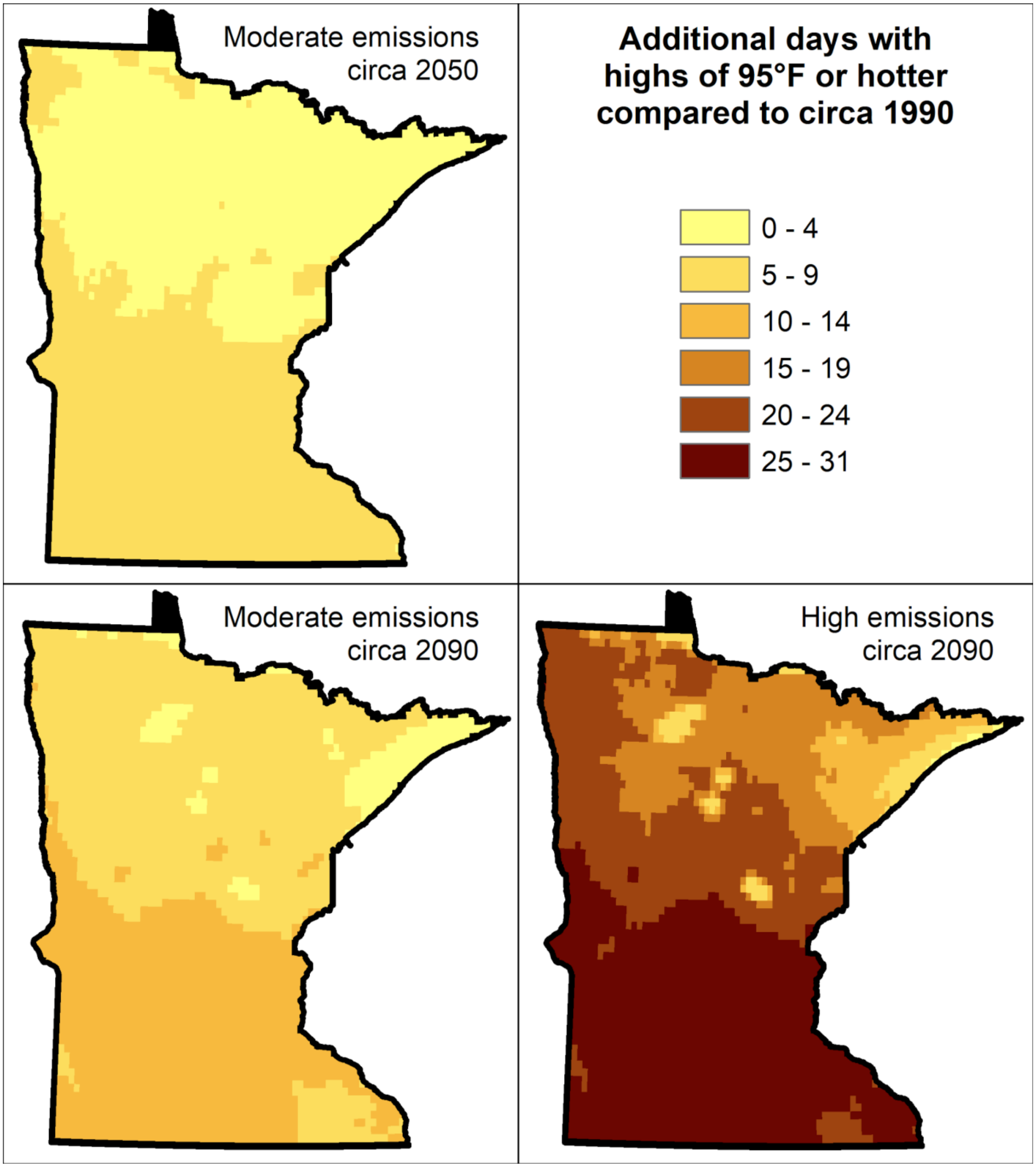

Figure 6. Number of additional days with highs greater than or equal to 95°F.

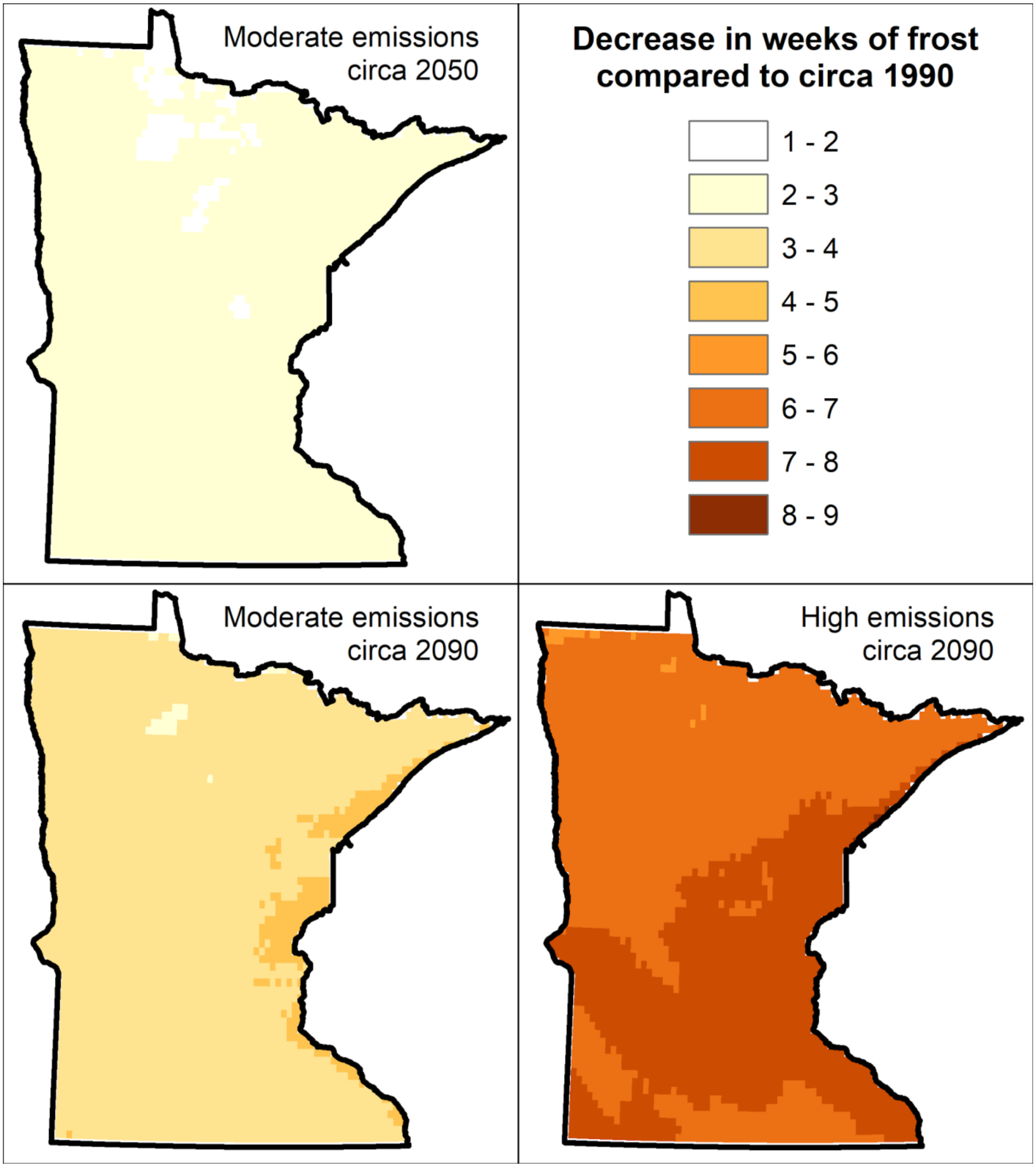

Figure 7. Decrease in the number of weeks of frost.

Assessment of water depletion and its impacts

Projecting future precipitation patterns provides only the first step in assessing potential water scarcity. We must also anticipate future consumption and the location of that consumption relative to the movement of water throughout the state. Our analysis of water depletion employed techniques developed by co-PI Kate Brauman[5]. In applying Brauman's scarcity metrics to Minnesota, we improved on the global methods by taking advantage of the Minnesota Permitting and Reporting database (MPARS) to better represent actual water withdrawals. We also consider the net change in water balance in upstream watersheds when calculating the water available at each downstream watershed. Thus, less precipitation and more consumption upstreams results in less water available downstream.

Future consumption is heavily influenced by several unknowns that are outside the scope of this project, including technology, adoption of irrigation, and crop selection. We created a regression based upon state demography office population projections, growing season precipitation, and growing season temperature values to estimate plausible future withdrawals. We trained the regression on historical withdrawals records in the MPARS database. We estimated withdrawals for every watershed, use type, and withdrawal type (i.e., surface or ground). Once withdrawal numbers were predicted, we applied a consumption coefficient which estimates the amount of a withdrawal that is not returned to the local water supply because it typically lost to evaporation. These coefficients are based on peer-reviewed literature review and are available in an appendix to this report. One assumptions we hold is that no new wells have been added. Well interaction (cones of depression) may also cause water tables to fall in ways that are not shown here.

Our water depletion metric is defined as the water that is consumed over the water that is available. Water consumed is defined using the withdrawal and consumption coefficients described above. Water available is defined by the outputs of the Agro-IBIS which partition water in groundwater recharge and runoff into surface water. This depletion metric can also be specified to look solely at the ratio groundwater consumed over available groundwater, and similarly for surface water. If consumption is greater than or similar to inputs regularly, the water table may be lowered, thus impacting groundwater sensitive ecosystems such as wetlands, fens, and trout streams. We apply this approach to all watersheds to assess broad-scale, statewide water availability. Our analysis showed that the maximum total depletion within the state was at 16%. This value is not indicative of water scarcity annually (Figure 9).

We also found that in some watersheds, even though there was no total depletion, there was some groundwater depletion. This indicates that there is enough water, however the infrastructure using that water is more heavily reliant on groundwater than surface water. When

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[5] Brauman, K.A., Richter, B.D., Postel, S., Malsy, M. and Flörke, M., 2016. Water depletion: An improved metric for incorporating seasonal and dry-year water scarcity into water risk assessments. *Elem Sci Anth*, 4, p.000083. DOI: http://doi.org/10.12952/journal.elementa.000083

this occurs, transitioning some withdrawals to surface water can ensure continued groundwater availability during dry periods.

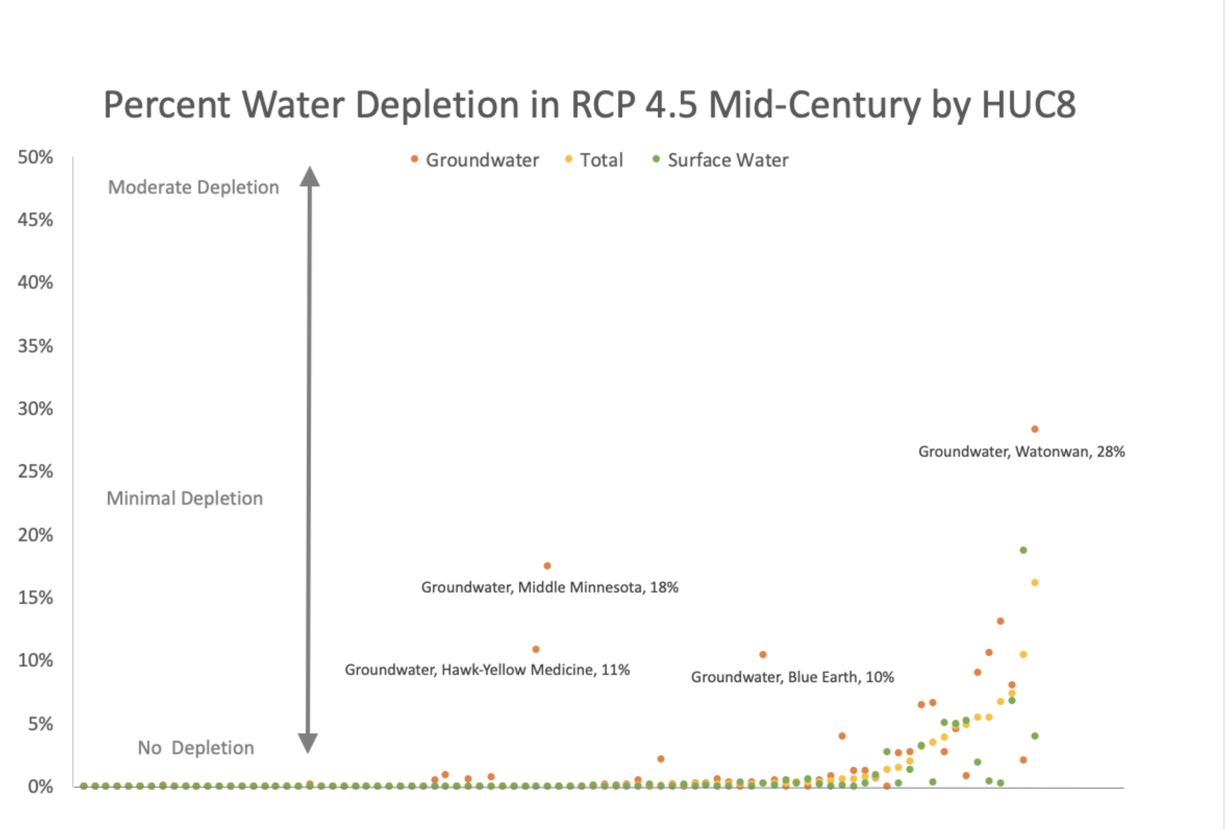

Figure 8. Percent Water Depletion in RCP 4.5 Mid-Century by HUC8 watershed
Each watershed (HUC8) has 3 dots (all vertically aligned), one for total depletion, surface water, and groundwater. They have been ordered by total depletion. Due to processing resource constraints, the ensemble for this analysis consisted of four models; bcc-csm1-1 CCSM4, CNRM-CM5, and GFDL-ESM2M.

Not observing annual water scarcity does not mean that water scarcity is not occuring at the monthly basis. Statewide data availability limits the detail with which we can model groundwater movement. Groundwater travel that is dependent on the local geology. Improving our understanding of this travel time would allow us to consider if excessive water depletion is happening in some months, but being masked by larger inputs in other months. Performing this analysis at the monthly time is important to understand the impacts on groundwater dependent ecosystems given our findings that precipitation timing will change. For example, trout depend on base flow in months like August to maintain water levels and low temperatures at the end of hot summers. Precipitation in August is also important for maximizing crop yields. Our climate projections indicate less precipitation in August, especially in the northeast portion of the state where trout streams are numerous and important to the local economy. The compounding effects of high demand and lower supply in some months could produce water use conflicts that are not visible when analyzing water availability annually. Local geology and groundwater flow need to be modeled and mapped in detail to make fine scale predictions on how individual surface features are likely to be impacted by changes in water availability and timing.

We provide the best available projections of climate and precipitation patterns available in Minnesota, as well as the water balance data products of an advanced land surface model to practitioners for application in future local studies.

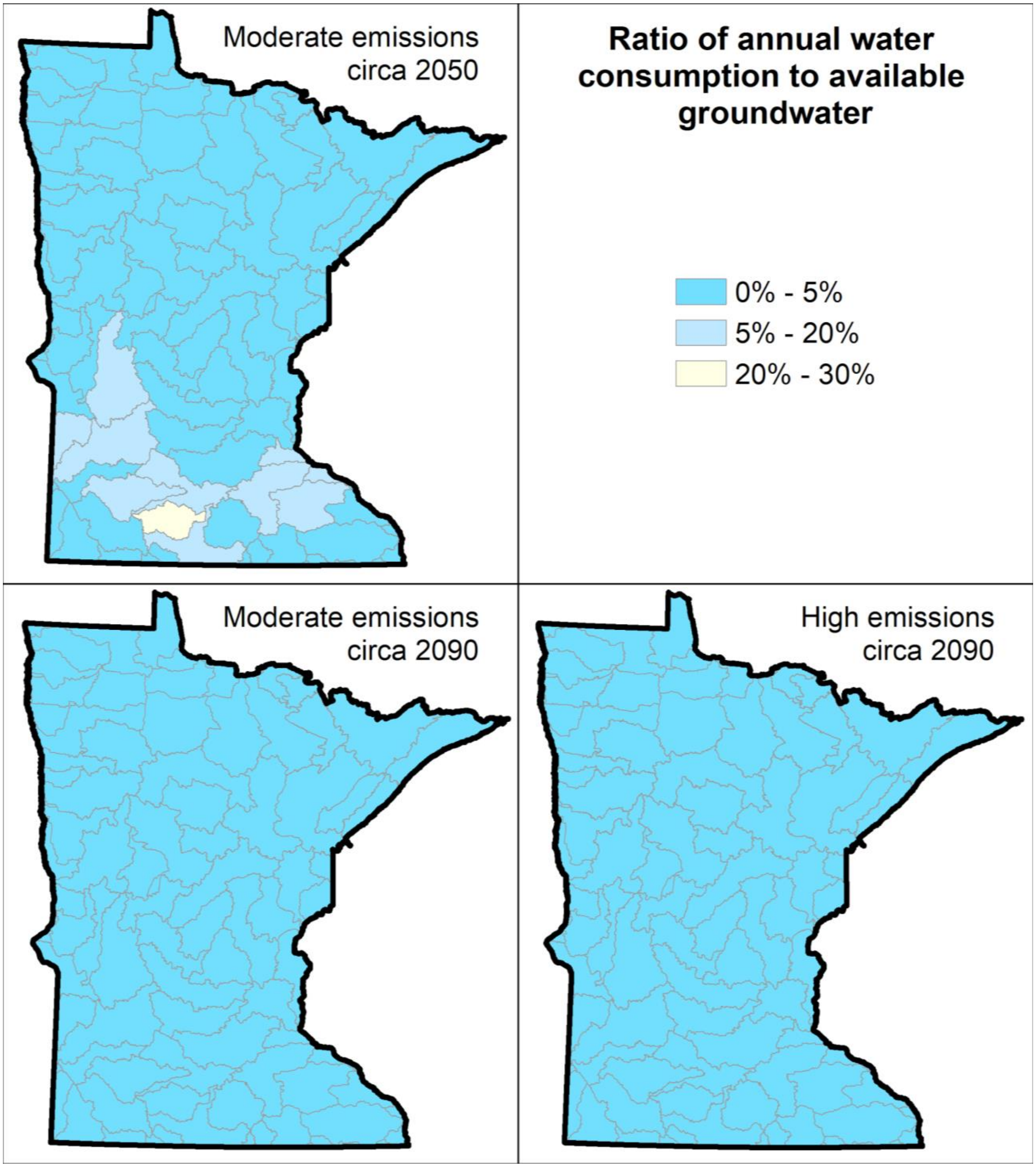

Figure 9. Groundwater depletion under climate change.
Although withdrawals and consumption of water are projected to increase, this is offset by projected increases in precipitation. The increases in precipitation were smallest in the mid-century scenario so depletion is more apparent. Although we found little evidence for depletion annually, monthly or seasonal depletion may still exist. Due to processing resource constraints, the ensemble for this analysis consisted of four models; bcc-csm1-1 CCSM4, CNRM-CM5, and GFDL-ESM2M.

Effects on corn and soy productivity

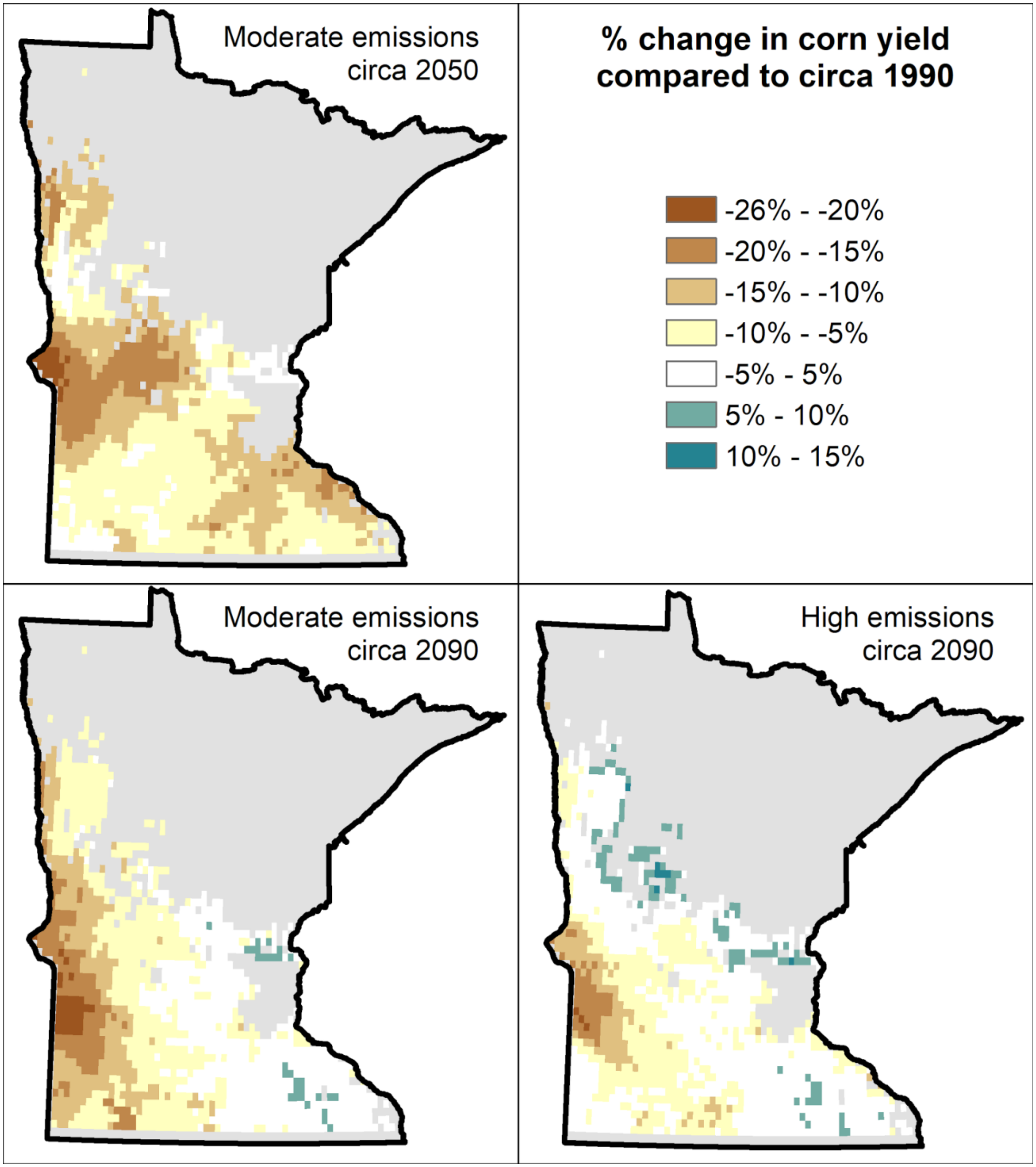

Figure 10. Percent change in corn yield.

Due to processing resource constraints, the ensemble for this analysis consisted of four models; bcc-csm1-1 CCSM4, CNRM-CM5, and GFDL-ESM2M.

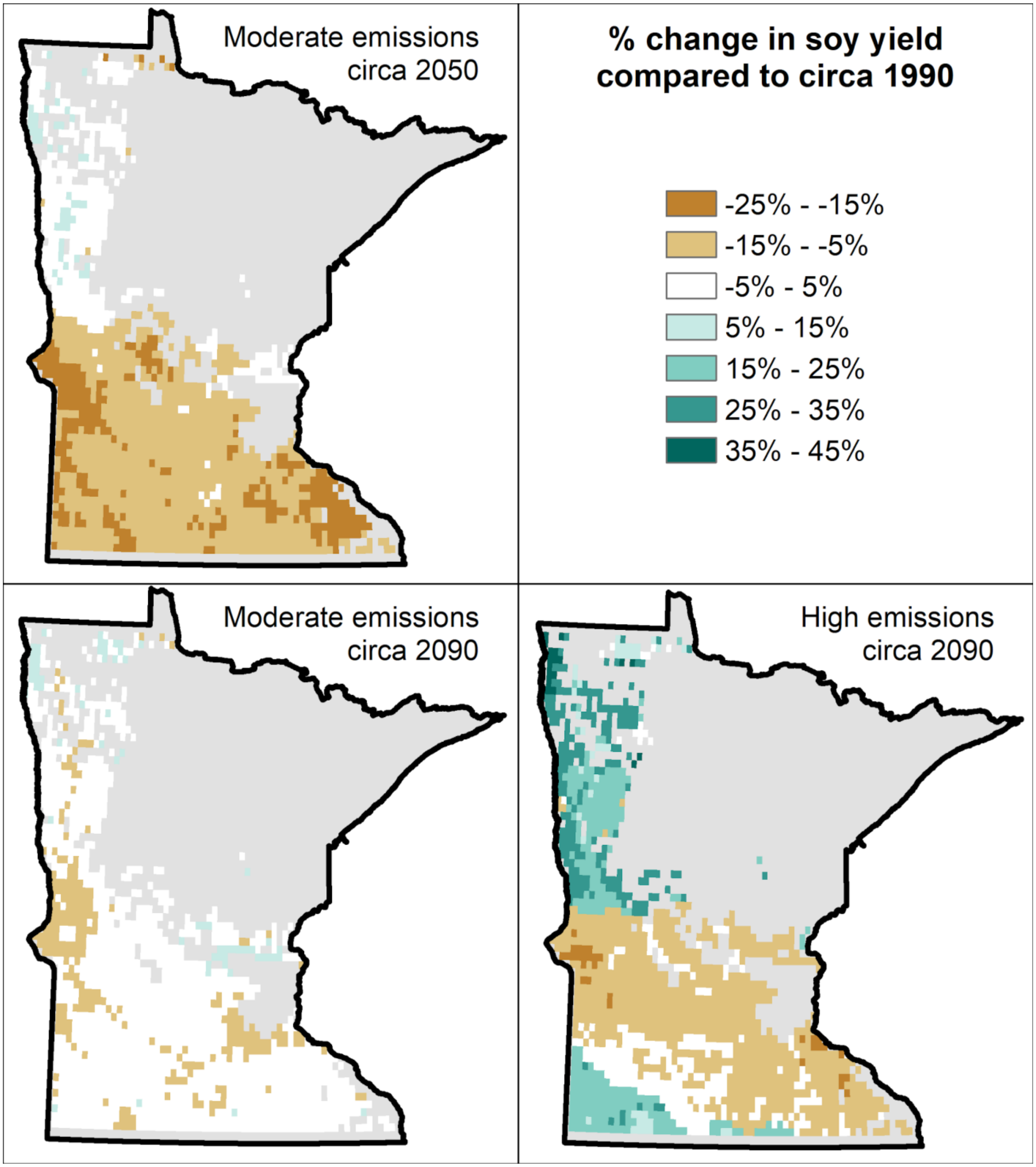

Figure 11. Percent change in soy yield.

Due to processing resource constraints, the ensemble for this analysis consisted of four models; bcc-csm1-1 CCSM4, CNRM-CM5, and GFDL-ESM2M.

Conclusions

From an annual average perspective, Minnesota is projected to be warmer with a consistent or greater quantity of precipitation relative to circa 1990. By dynamically downscaling global projections, we find that precipitation timing and intensity changes are likely. Although the annual quantity of precipitation will be similar or greater, we project similar or fewer days of precipitation and longer maximum dry spells. This results in more intense events that stress infrastructure and crop production. Corn yield declined in almost all regions and climate change scenarios, sometimes by as much as 25%. Warming trends will shorten winters, affecting winter recreation activities. In the summer, the state is projected to experience far more days with highs greater than or equal to 95°F.

With regards to water depletion, we did not find evidence for depletion annually. We found one watershed that had water consumption equivalent to 28% of its available groundwater in the mid-century period. This was the highest of any of the watersheds or scenarios analyzed, but is not extreme. Communities, especially those with elevated annual groundwater depletion, may have greater depletion on a short-term base and should consider surface water sources when expanding withdrawals. Our annual analysis is unable to detect short term depletion that could occur in response to longer dry spells under climate change. Our data products should be used in conjunction with models that include local geology to capture the influence of short term events on local features.

In an effort to provide tools for local communities to plan for climate change, we will make available the underlying data for this analysis after it has gone through the peer review process. Future updates can be found at https://z.umn.edu/climate-change-data.