Agricultural Weather Study Final Report

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Executive Summary

This final report summarizes the work completed by the University of Minnesota Climate Adaptation Partnership for the Agricultural Weather Study to develop dynamically downscaled climate projections for the state of Minnesota, create an interactive data tool to serve up these data, and provide dedicated training opportunities for how to access and use these data in climate-related decision-making across the state.

Project Overview

Assumptions about climate are embedded in how we design and manage many of the systems and resources we rely on every day. Observed climate data and climate models are used to inform how we design critical infrastructure, determine when it is best to plant crops, assess risks of infectious diseases, and more. However, the climate of the past is no longer the best predictor of future climate in Minnesota. To better understand future climate risks facing Minnesota, we can use future projections of climate derived from global and regional climate models. The Minnesota Legislature supported the University of Minnesota to generate state-specific future climate projections and associated educational resources to support the use of these data across Minnesota's diverse sectors from agriculture to the built environment.

Differentiating the impacts of climate change at a fine spatial scale is particularly important in Minnesota, where we see large south-to-north gradients in warming and have long-duration snow cover, numerous lakes, and other complexities in our climate. To provide reasonable climate projections over Minnesota, we need information that captures these complexities. This project provides climate projections at an approximately 2.5-mile resolution for the entire state using regional climate downscaling techniques (See Task 1).

Leveraging the University's research and Extension capacity, this project was designed to both generate climate model output and build capacity for the use of this information in planning and decision-making. Results from a statewide survey (Clark et al., 2021) and a subgroup of the State's Resiliency and Adaptation Action Team, point to broad, cross-sectoral demand for these projections and a need for increased support for using this information in practice. Over 80% of respondents to a statewide survey felt that fine-scale climate projections like those generated for this project were important for carrying out their work. In addition to high demand from state agency staff, researchers, nonprofits and the private sector have articulated a need for this forward-looking climate information.

To help address these needs, the data generated through this project were made available to the public through an interactive online tool, the Minnesota Climate Mapping and Analysis Tool (MN CliMAT), which includes projections for three future climate scenarios out to the year 2100 (Task 2). Participants from a wide range of sectors including agriculture, natural resources, health, the built environment, and Extension took part in train-the-trainer events (Task 3) to learn about applications and use of future climate information, how to access and utilize these data, and to provide feedback on how to improve the interactive online tool (Subtask 3.3). Participants also provided the project team with valuable insights for how to design and structure future training events for different sectors which are currently being piloted by the University of Minnesota Climate Adaptation Partnership.

Project Highlights

The report is structured primarily around the tasks in the project contract. Highlights of the project are summarized below.

1) Climate Modeling and Data Visualization

- Computer modeling using the Minnesota Supercomputing Institute (MSI) at the University of Minnesota is complete for three future socioeconomic scenarios that factor in potential climate mitigation and adaptation measures (intermediate/SSP270, high/SSP370, and very high/SSP585; see page 12 of this climate model primer and Task 1 below for more information). These pathways are often referred to as future "emissions scenarios." We used the Weather Research and Forecasting Model (WRF) to generate the dynamically downscaled climate projections at approximately 2.5-mile resolution. The project team completed all historical runs as well as running six global climate models and a 1D lake model out to the year 2100 for these three future scenarios. **Figure 1** highlights examples of the model output. A peer-reviewed journal article is currently in development to document our methodology and disseminate results of the modeling effort. See Task 1 for more information on the modeling methodology.

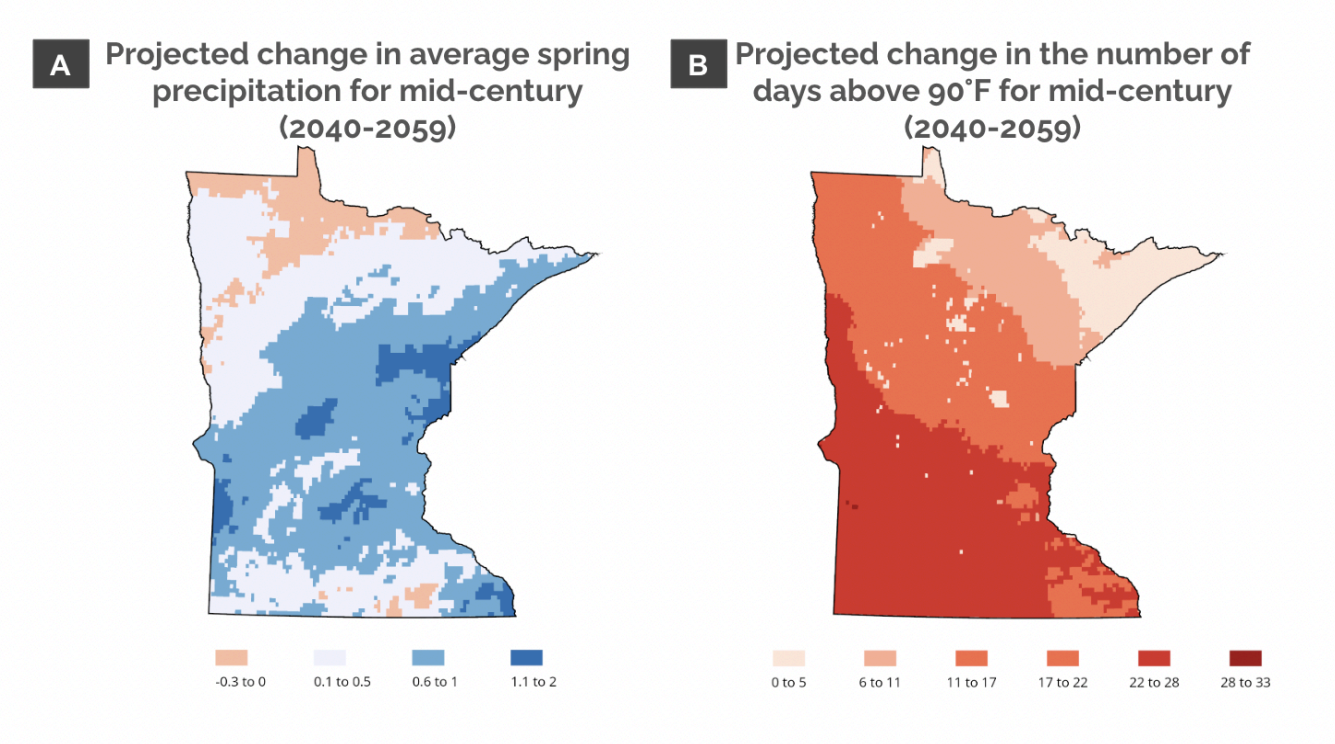

Figure 1: A) *This map shows the projected difference in average spring precipitation (March-May) by mid-century (2040-2059) under a very high emissions scenario (SSP585) relative to historical simulations (1995-2014).* ***B)*** *This map shows the projected change in the number of days per year exceeding 90°F by mid-century (2040-2059) under a very high emissions scenario (SSP585) relative to historical simulations (1995-2014).*

- The project team designed an interactive online tool, MN CliMAT, available at app.climate.umn.edu (**Figure 2**). Designing the tool included discussions with a range of data end users to identify the key variables needed in the tool such as soil temperature, air temperature, precipitation, and lake water temperature. The project team has also interacted with a range of stakeholders to test the tool functionality and improve the user interface. The project team also developed an affinity diagramming process to capture user stories to understand anticipated uses for the new climate projections and communication needs about this climate risk information.

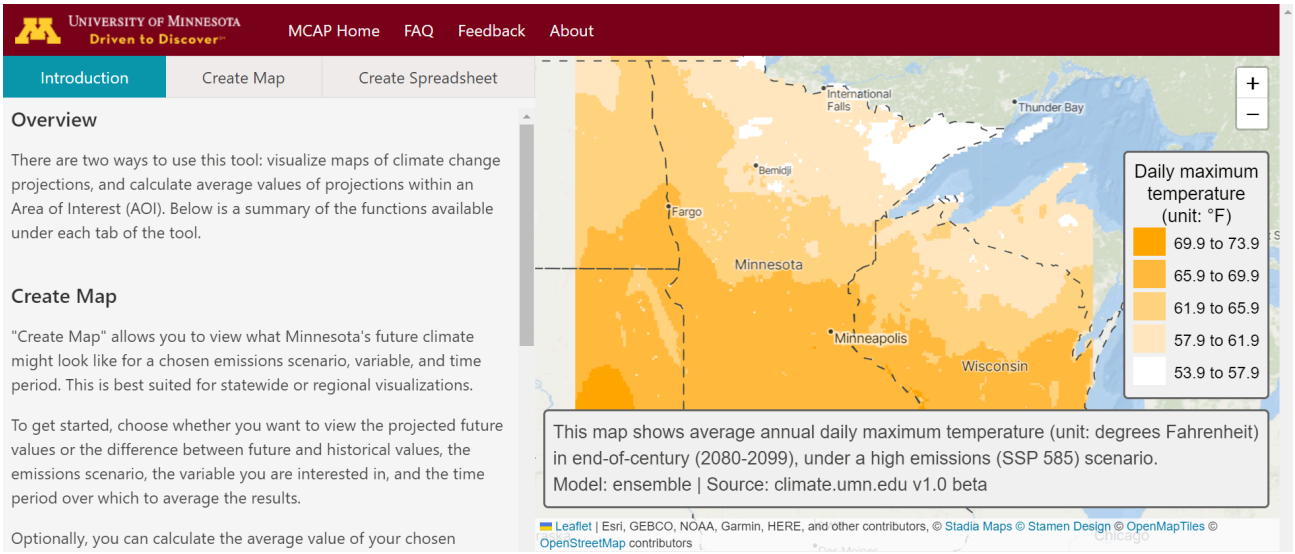

Figure 2: *A screenshot of the MN CliMAT tool which displays the climate projections for use by end users. Users can also directly download the data from this online tool.*

2) Capacity and Training

- A Climate Resilience Researcher was hired to assist with the development of the tool design, develop the affinity diagramming process, climate modeling, and to support communication materials development. This researcher also assisted with a literature scan to understand use cases for the tool and data, and reviewed data platforms in other states to help inform the design and delivery of MN CliMAT.

- Three Climate Resilience Extension Educators and several graduate and undergraduate students focused on climate modeling, agriculture, public health, natural resources, and water resources provided support to the Agriculture Weather Study project team. The team designed and piloted train-the-trainer events to help a wide range of end-users from agricultural, natural resources, built environment, public health, and Extension use and apply these data in their different sectoral contexts (Task 3.2).

3) Communication, Engagement and Future Planning

- The project team has communicated about this project with a range of audiences across the state and Midwest region. This included conversations with public and private sector end users throughout Minnesota through presentations and train-the-trainer workshops. We also shared the project with end users and experts across the Midwest and nationally, including a presentation to colleagues at the National Weather Service, National Oceanic and Atmospheric Administration (NOAA), and the US Department of Agriculture at the 2022 Climate Prediction Applications Science Workshop (CPASW). We presented this work at the U.S. National Adaptation Forum in October 2022 in Baltimore, and conducted a training workshop at the 2023 Midwest Climate Resilience Conference in October 2023 in Duluth, MN. The data were shared with the climate science research community at the 2023 American Geophysical Union Fall meeting held in San Francisco, CA in December. The project team also shared this research internally at the University of Minnesota through venues like the 2022 and 2023 MSI Research Exhibitions and University of Minnesota Extension staff development meetings. We have also presented the tool to a variety of audiences including the MN Department of Natural Resources Division of Fish and Wildlife, the South Central Minnesota Clean Energy Council, MN Pollution Control Agency, The Nature Conservancy, and others.

- Resources developed by the project team about MN CliMAT include a primer on climate modeling, information about future training workshops, and a FAQ document — all of which are available at climate.umn.edu/MN-CliMAT.

Updates on Project Tasks and Deliverables

Task 1. Computer Modeling

This task required using resources at the Minnesota Supercomputing Institute (MSI) to analyze high-performing weather model projections to develop a series of projections of temperature, precipitation, snow cover, and other climate parameters out to the year 2100 for the state of Minnesota at a scale of approximately 2.5 miles.

Subtask 1.1. Select model scenarios for analysis

Status: We ran six global climate models from the Coupled Model Intercomparison Project 6 (CMIP6; Eyring et al., 2016) to create downscaled climate projections for the state of Minnesota out to the year 2100 at an approximately 2.5-mile resolution. This downscaling was completed using the Weather Research and Forecasting (WRF) model. We selected three different future climate 'pathways' intended to span the lower and higher ranges of possible future climate outcomes, including ambitious adoption of adaptation and mitigation measures globally (less planetary warming) to continued development of fossil fuels (more planetary warming). We used the Shared Socioeconomic Pathways (SSPs) as the future climate scenarios following the CMIP6 modeling process and the Intergovernmental Panel on Climate Change (IPCC). This work updates the downscaling of the previous generation of global climate model projections for Minnesota (Liess et al., 2022).

Subtask 1.1 Deliverables	Due Date	Status
Select model scenarios	12/31/2023	Complete

Subtask 1.2. Identify and delineate projection parameters

Status: In parallel with testing our simulations on the Supercomputer, we consulted with other regional climate data experts and climate data end users at a range of organizations, businesses, state agencies, and the University of Minnesota to understand use cases, data needs and priority variables for inclusion in the interactive online tool, MN CliMAT. These discussions involved staff and others in local, state, and tribal governments, businesses, and nonprofits. These discussions included identification of the climate variables of most relevance to stakeholders, as well as discussions on model characteristics including selection of a lake model to represent lake surface temperatures and temperatures within lakes. We also engaged with experts from other states who have led the development of similar data projects and tools to help incorporate lessons learned throughout this project. All of these conversations informed the selection of the projection parameters.

Subtask 1.2 Deliverables	Due Date	Status
Identify projection parameters	12/31/2023	Complete

Subtask 1.3. Perform projections

Status: Simulations using the resources of the Minnesota Supercomputing Institute were completed utilizing all resources available for our project. We processed the CMIP6 models, utilizing the WRF model to ingest these data, and tested and refined the models to correctly perform across the state. We increased the horizontal resolution from the previous data for the state (Liess et al. 2022) by a factor of six per area from 10km x 10km (~6 miles) to 4km x 4km (~2.5 miles). We improved projections through the 21st century using the most recent future scenarios used by the IPCC (SSPs) and provided data for three different time periods out to 2100 for three different future scenarios. For more information on the previous work using the Coupled Model Intercomparison Project 5 model products and a similar downscaling technique, see Liess et al., 2022.

Subtask 1.3 Deliverables	Due Date	Status
Model analysis and series of year 2100 projections	12/31/2023	Complete

Task 2. Interactive Online Tool Development

This task involved the development of an interactive online tool to facilitate access and use of the climate projections. The tool, Minnesota CliMAT, is hosted by the University of Minnesota College of Food, Agriculture and Natural Resource Sciences (CFANS) and made accessible via the University of Minnesota Climate Adaptation Partnership on the following website: app.climate.umn.edu

Subtask 2.1. Outline goals for user interface and experience

Status: We collaborated with U-Spatial and the University of Minnesota Office of Information Technology (OIT) to conduct focus groups with key data users across a broad range of sectors to identify data needs and guide the development of MN CliMAT. We utilized affinity diagramming as a method to capture and apply input from these focus groups to optimize user experience with the tool. Beta testing and inviting feedback from a variety of different sectors and Extension faculty who participated in three train-the-trainer sessions were also used to refine the interactive online tool.

Subtask 2.1 Deliverables	Due Date	Status
Outline goals for UI/UX	12/31/2023	Complete

Subtask 2.2. Develop interface components

Status: We conducted a review of existing online climate data tools (e.g. CalAdapt) to identify common interface components. Subtask 2.1 describes further input on the tool components.

Subtask 2.2 Deliverables	Due Date	Status
Develop interface components	12/31/2023	Complete

Subtask 2.3. Perform preliminary testing on user interface

Status: While the new projections were being developed, we incorporated existing data to make the interactive online tool available for beta testing. We conducted user interface testing as part of three train-the-trainer workshops with over 100 participants from a variety of different sectors and university Extension disciplines, including a workshop at the 2023 Midwest Climate Resilience Conference (see Task 2.1). Examples of groups represented included local and state government, university faculty, and private sector leaders from architecture and engineering, housing, energy, public health, agriculture, natural resources, and emergency management. Participants were asked to complete a series of planned scenarios as well as use the tool for their own purposes. We both observed their utilization process and gathered their feedback to help us target and implement design tool improvements.

Subtask 2.3 Deliverables	Due Date	Status
Functional interactive data tool	12/31/2023	Complete

Task 3. Training

Task 3 included designing and holding at least two train-the-trainer events to increase access to and understanding of the data, and how to use and apply them in different contexts. This included providing written materials and communication resources about the data and their use for others to access outside of these training opportunities.

Subtask 3.1. Identify and publicize training opportunities to potential stakeholders

Status: Input on training needs, priority user groups, and potential training opportunities were derived from focus group discussions and results from affinity diagramming, described in Subtask 2.1. Using this input, we identified groups of professionals and university Extension faculty, and extended invitations to participate in three different user feedback sessions and trainings. We also highlighted the training opportunities in the University of Minnesota Climate Adaptation Partnership's monthly newsletter reaching 1,000+ climate-interested contacts and hosted a training workshop at the 2023 Midwest Climate Resilience Conference. A dedicated website with information about future training opportunities was developed to accompany the online interactive tool: climate.umn.edu/climate-data-workshops.

Subtask 3.1 Deliverables	Due Date	Status
Identify and publicize training opportunities	10/31/2023	Complete

Subtask 3.2. Schedule and host training events

Status: We hosted three train-the-trainer events in April, June, and October 2023 engaging over 100 professionals in these events. The main goals were to share how to access and understand the data, and how to use and apply them in different professional and educational contexts. We also developed a short primer to help users better understand the nature and use of climate change projections and climate modeling. This primer is publicly available on the climate.umn.edu website (https://climate.umn.edu/climate-modeling-primer) and is being integrated into Extension programming to help end-users of the data have access to easy-to-understand resources about the source of the data, the downscaling methodology and climate projections basics.

Subtask 3.2 Deliverables	Due Date	Status
Schedule and host training events	10/31/2023	Complete

Subtask 3.3. Solicit and compile feedback from attendees, address questions and incorporate results into reporting and data tool refinements

Status: Feedback collected through various stakeholder engagements as described in Task 3.2 was incorporated into the MN CliMAT tool design.

Subtask 3.3 Deliverables	Due Date	Status
Functional interactive data tool	10/31/2023	Complete

Task 4. Project Reporting

This task relates to project reporting.

Subtask 4.1. Provide an interim report highlighting project progress and results to date

Subtask 4.1 Deliverables	Due Date	Status
Interim report to the Minnesota State Legislature	6/30/2022	Complete
Interim report to the Minnesota Department of Commerce	6/30/2023	Complete

Subtask 4.2. Produce a written final report that includes sufficient detail for technical readers and a clearly written summary for nontechnical readers

Subtask 4.2 Deliverables	Due Date	Status
Final report to the Minnesota Department of Commerce	12/31/2023	Complete
Final report to the Minnesota State Legislature	6/30/2024	This report; complete at time of submission.

Subtask 4.3. Final reports, any mid-project status reports, and renewable development account financial reports will be posted online on a public website designated by the commissioner of commerce and will adhere to state accessibility standards

Subtask 4.3 Deliverables	Due Date	Status
Publicly available report materials provided to the Minnesota Department of Commerce	12/31/2023	Complete

Task 5. Project updates and invoices

This task entails regular status updates and supplying project invoices. Regular updates and required invoicing are occurring in accordance with the project contract and requests from the Project Manager at the Minnesota Department of Commerce.

Subtask 5.1. Conduct phone conferences as needed with the State's Authorized Representative to apprise him/her of progress, accomplishments and issues encountered

Subtask 5.1 Deliverables	Due Date	Status
Regular phone conferences with State's Authorized Representative	Ongoing	Complete

Subtask 5.2. Schedule project update meetings as necessary to inform the State's Authorized Representative of deviations to the project schedule, the need to modify the scope of the project or at the request of the State's Authorized Representative to discuss any item related to the project's progress

Subtask 5.2 Deliverables	Due Date	Status
Update State's Authorized Representative on deviations from schedule or scope	Ongoing	Complete

Subtask 5.3. Quarterly Reporting and Status Updates

5.3.1 Status updates to the state for the preceding period's work detailing progress made toward completing individual project tasks as well as any deviations from the project schedule
5.3.2 Invoices and supporting documentation to the State for the preceding period's work completed within the project scope; and
5.3.3 Budget overview for the preceding period's expenses and expenses to date

Subtask 5.3 Deliverables	Due Date	Status
5.3.1 Status updates	Ongoing	Complete
5.3.2 Invoices	Ongoing	Complete
5.3.3 Budget review with State's Authorized Representative	Ongoing	Complete

Subtask 5.4. Upon project completion, submit the final invoice with supporting documentation

Subtask 5.4 Deliverables	Due Date	Status
Final invoice	8/31/2023	Complete

Ongoing & Future Work

The University of Minnesota Climate Adaptation Partnership continues to build resources, advance research, and develop robust training and technical assistance to support the use of these data across Minnesota. Below are a few examples of how we are expanding access to, and use of, the Agricultural Weather Study deliverables:

- Developing regional and county climate summaries to provide easy-to-access overviews of observed climate trends, future climate projections, and climate impacts-related information. The aim is that these summaries can provide useful information for communication efforts, grant funding applications, or the completion of the climate section of the State's Environmental Assessment Worksheet (EAW).
- Along with project partners at the University of Minnesota Center for Sustainable Building Research (CSBR) and HGA, a Minneapolis-based architecture and engineering firm, we are developing a methodology for accessing and using this data for building and site design, with a goal of creating a model that is replicable for national use. This process will be integrated into the State of Minnesota's B3 Guidelines.
- The new data are being used in continued modeling efforts by the University of Minnesota Climate Adaptation Partnership and partners to help create additional future impacts-related information for sectors and communities across the state including:
    - Developing intensity-duration-frequency (IDF) curves that include future climate for use in water resources management, transportation planning, and engineering design.
    - Developing improved decision-support information for watershed management by evaluating future changes in the duration, frequency, and magnitude of heavy precipitation and drought extremes.
    - Developing projections of future groundwater availability and change across the state using a Soil-Water-Balance model in partnership with the United States Geological Survey.
    - Creating an online interactive decision-support program for the agricultural sector to help those in the sector understand future climate risks and potential management strategies and responses.
- Developing and providing training and technical assistance for communities and local units of government and others in how to use and apply these new future climate data. This includes a new Extension training for professionals called the Climate Adaptation Specialist Training intended to help build skills in appropriately using and applying these future climate data in planning and decision-making.

Additionally, the project team is involved in the submission of several federal grant proposals seeking to utilize the future climate projections to inform planning, regional collaboration, and infrastructure design with a variety of proposal partners representing the University of Minnesota and other state agencies, as well as local units of government and the private sector.

Per the requirements of Minnesota Statute 3.197, the cost to prepare this report was $451.