Historical and Future Variability in Growing Season Heat Stress and Fall Storage Conditions with Shifts in Planting Date: an Example for Potato Production in Michigan, USA

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Climate Change and the Multi-faceted Components of a Market System

- Michigan is the largest producer of chip-processing potatoes in the United States.
- Contributing factors
  - Favorable growing season conditions
  - Colder climate that facilitates storage during the winter and spring months
  - Location close to eastern and Midwestern population centers

Production Notes

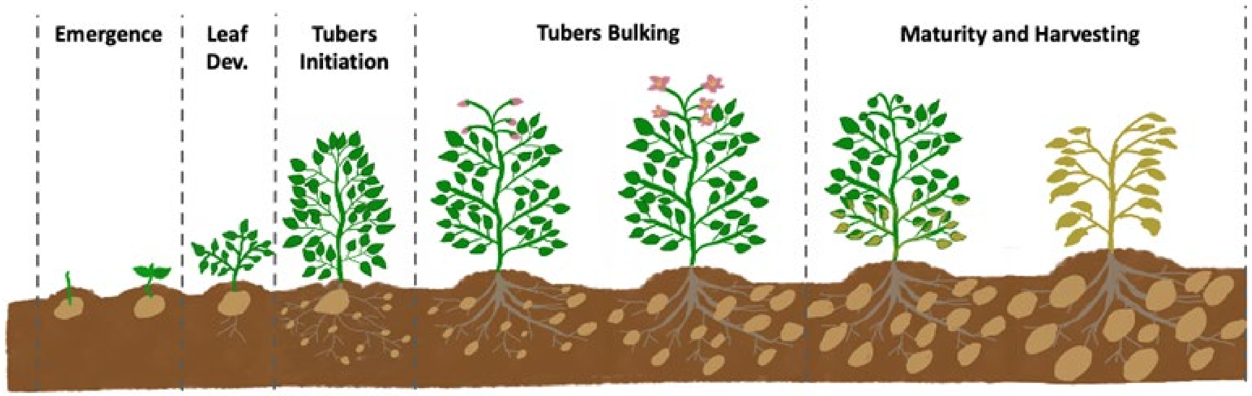
- More than 80 potato growers, over 3000 jobs in potato production, 47,000 acres planted, an annual production of 1.7 billion pounds, and an economic value of $1.24 billion.
- Over 75% of Michigan potatoes are used for chipping, with 6% used for seed, and approximately 18% intended for fresh markets.
- The most popular chipping potato varieties are Snowden and Atlantic, although many growers also produce proprietary FritoLay varieties.
- Potatoes are grown primarily on sandy loam soils, and an estimated 85% of Michigan potato growers irrigate their fields.
- Over 70% of the Michigan potato crop is placed in storage for shipment through the winter and spring.
- Potatoes are stored in bulk piles on the floor of insulated concrete or corrugated buildings.
- Many storage facilities rely on ambient air for cooling the potato pile, and are equipped with forced-air ventilation systems although some facilities are refrigerated.
- Growers typically begin filling storage facilities in mid-September.

Image Source: Techmark, Inc.

Climate Change Vulnerability and Adaptation

Key vulnerabilities

- Changes in heat stress during the growing season
- Warmer temperatures during the storage period



Heat stress is particularly a concern during tuber initiation and bulking.

Challenges for Adaptation

- Climate adaptation strategies chosen to minimize the impact of a future climate on one aspect of the production cycle may reduce adaptive capacity at another production stage.
- For production of chip-processing potatoes:
  - A shift in planting date is an often-proposed strategy for adapting to heat stress during the growing season.
  - However, this adaptation option may lead to earlier harvest, earlier storage of potato crop, and greater costs for ventilation and air conditioning.

Research Objectives

Initial Focus:

- Projected future changes in storage conditions
  - The potential impacts of climate change on crop storage have largely been neglected even though:
    - Storage can be an important component of a grower's marketing strategy
    - Storage is considered a climate change adaptation.
  - *Reference:*
    - Julie A. Winkler, Logan Soldo, Ying Tang, Todd Forbush, David S. Douches, Chris M. Long, Courtney P. Leisner, and C. Robin Buell, 2018. Potential impacts of climate change on storage conditions for commercial agriculture: an example for potato production in Michigan. *Climatic Change* 151:275–287

Current and Ongoing Foci

- Projected future changes in the exposure of potato plants from emergence to vine kill to heat stress.
- Assess, under a range of planting dates, the relative tradeoffs between
  - exposure to heat stress during the growing season and
  - ventilation and cooling requirements for storage after harvest

Study Locations

- Greenville -- located in Montcalm County in central Michigan
- Eau Claire -- located in Berrien County in southwest Michigan

Projected Future Changes in Storage Conditions

Storage Degree Days (SDDs)

- Modified the degree day concept to allow for variable thresholds
- Used thresholds recommended by American Society of Agricultural and Biological Engineers (ASABE 2017)

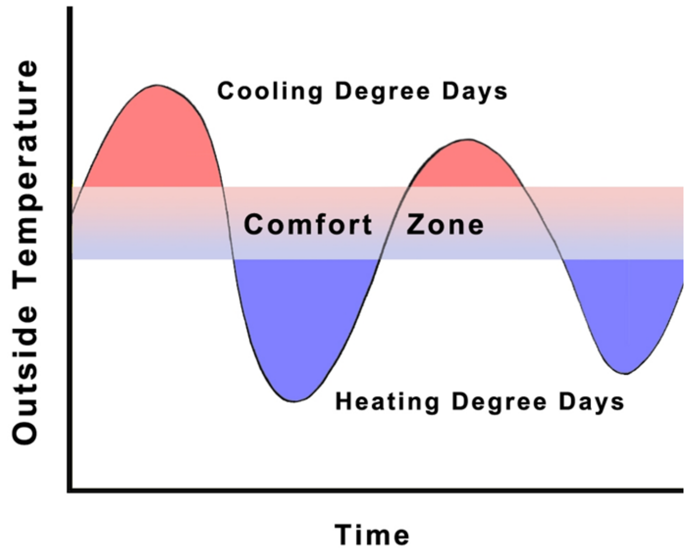


Image source: Image source: https://www.weatherbit.io/blog/tag/degree%20day

Table 1 *Base temperatures for calculating storage degree days.*

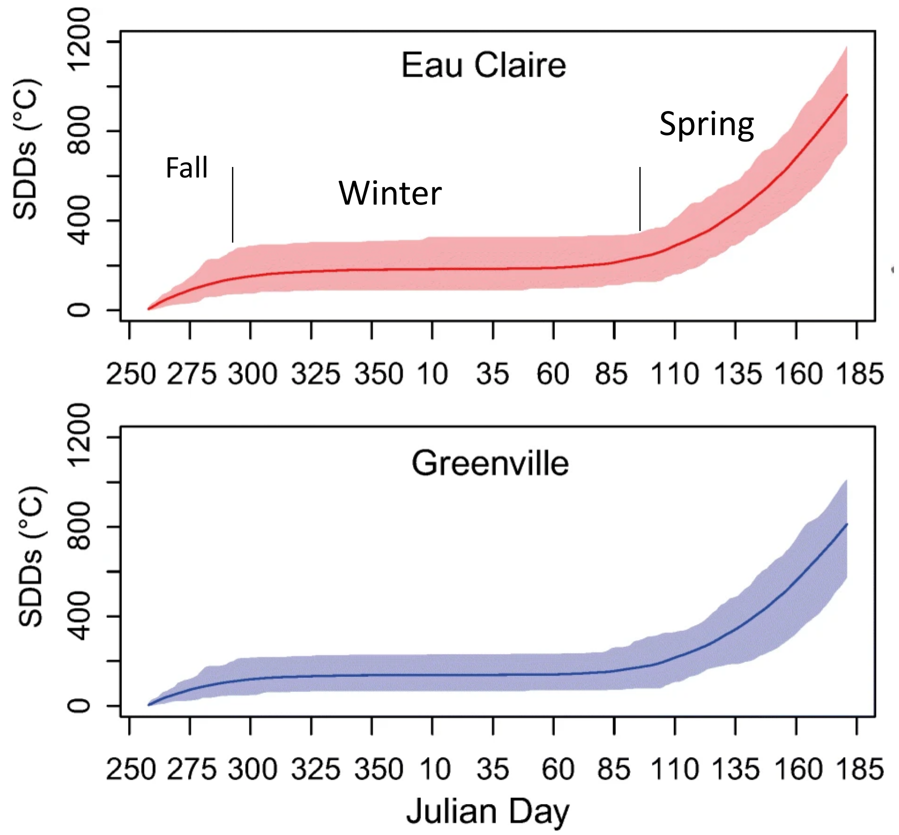
Storage Stage	Base Temperature
Suberization/wound healing/preconditioning stages (September 15-October 31)	12°C
Cool down stage	Decrease by 0.1°C per day
Long-term holding stage	8°C

- SDDs calculated from daily maximum and minimum temperature using the Baskerville and Emin (1969) method
- SDDs accumulated for a September 15-June 30 storage period for:
  - Historical (observed) period, 1960-2010
  - Statistically downscaled CMIP5 control and future simulations

Defining Storage "Sub-periods"

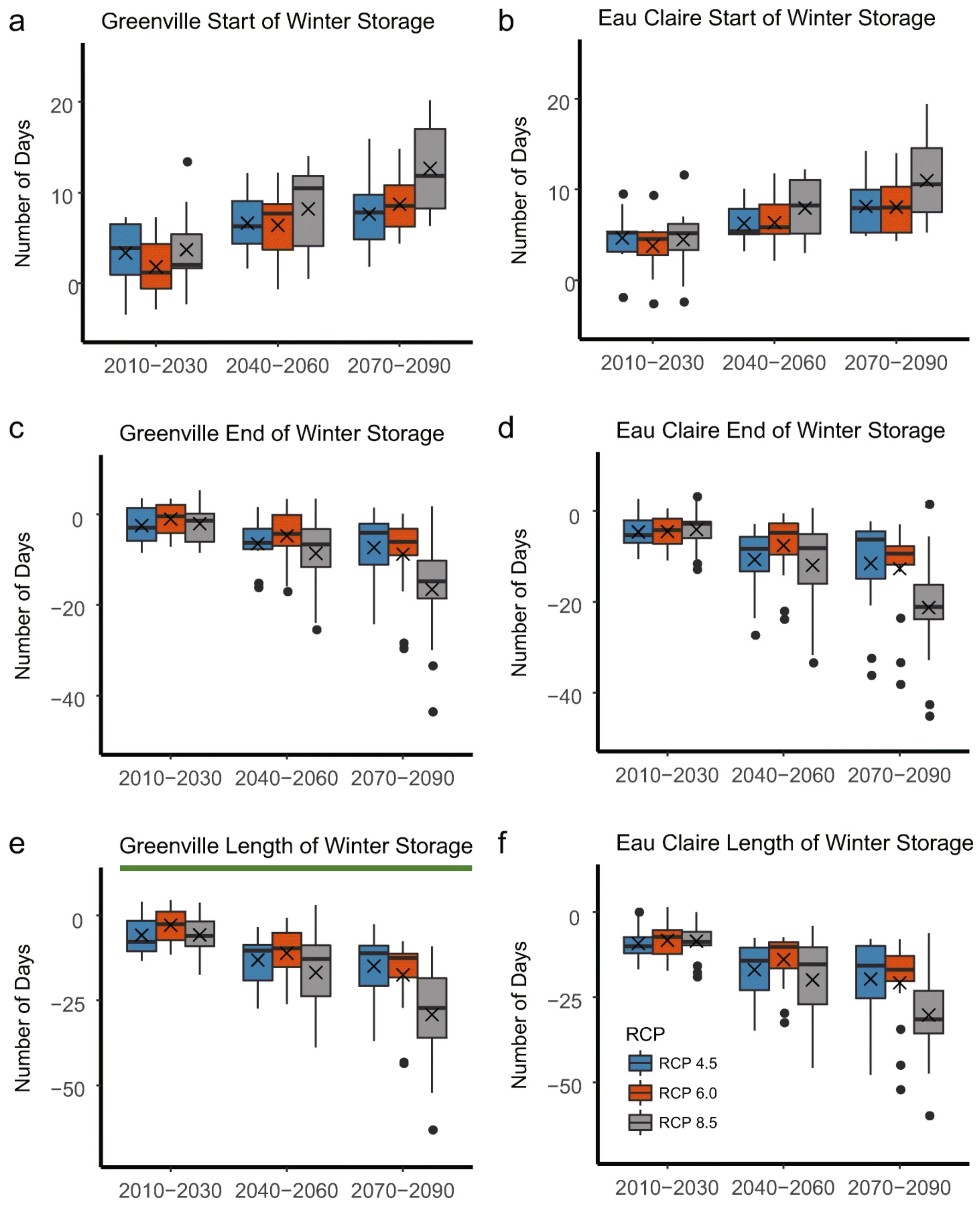
- **Winter sub-period**
  - Extended period of little SDD accumulation (reliably cold temperatures for storage)
    - Beginning of the winter sub-period for a particular year defined as the first day when the daily SDD accumulation fell below 0.25 percent for at least 14 days*
    - End date of winter sub-period defined as the day after which daily SDD accumulation was greater than 0.25 percent for at least 14 days
- **Fall sub-period**
  - Period following harvest of initial SDD accumulation
    - Defined as September 15 until start of the winter sub-period
- **Spring sub-period**
  - Period of SDD accumulation as temperatures warm in late spring and early summer
    - Extends from end of the winter sub-period until June 30

*The 14-day criterion was used to minimize the influence of short-term warm or cold spells.



Mean, maximum, and minimum daily accumulation of storage degree days (SDDs) from September 15 (Julian Day 244) through June 30 (Julian Day 181) for 1960–2010 at Eau Claire and Greenville.

*Daily SDDs were smoothed using a 7-day moving average to minimize day-to-day fluctuations.



Projected Changes: Winter Storage Period

***Table 2** Projected average decrease at **Greenville in the Length of the Winter Storage Period** compared to the 1960-2010 historical period.*

Time slice	Projected change*
Early-century	3-6 days
Mid-century	11-17 days
Late-century	15-19 days

*Range represents different RCPs.

Implications:

- A shorter winter storage period would impact those growers who rely on ventilation-only systems and the length of time that they could potentially hold their crop before selling.
- Growers may need to consider switching from ventilation only to more costly refrigeration earlier in the storage period.

Projected Changes: Spring Storage Period

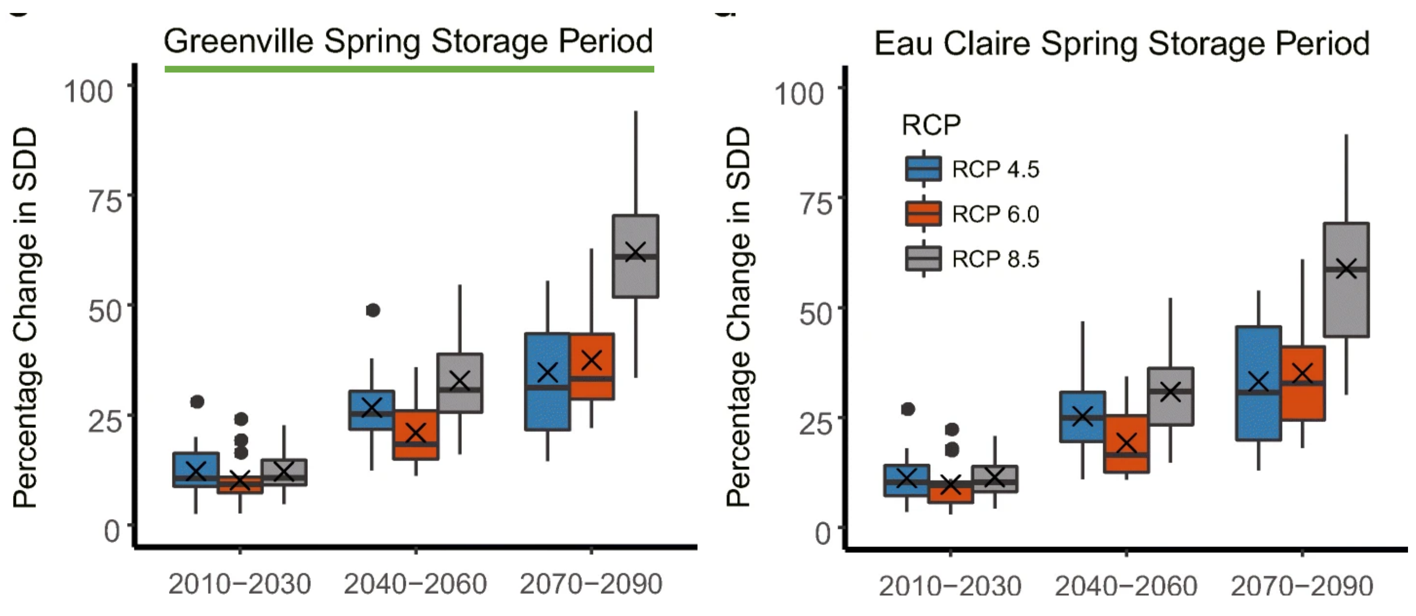


***Table 4** Projected increases in SDD accumulation at **Greenville during the Spring Storage Period** compared to the 1960-2010 historical period.*

Time slice	Projected change
Early-century	10-12 percent
Mid-century	20-33 percent
Late-century	35-62 percent

Implications:

- Larger SDD accumulations during the spring storage period will increase cooling demand and cost of production.
- May force some growers to remove their crop from storage earlier than at present, missing the supply niche that Michigan growers currently fill.

Projected Changes: Fall Storage Period

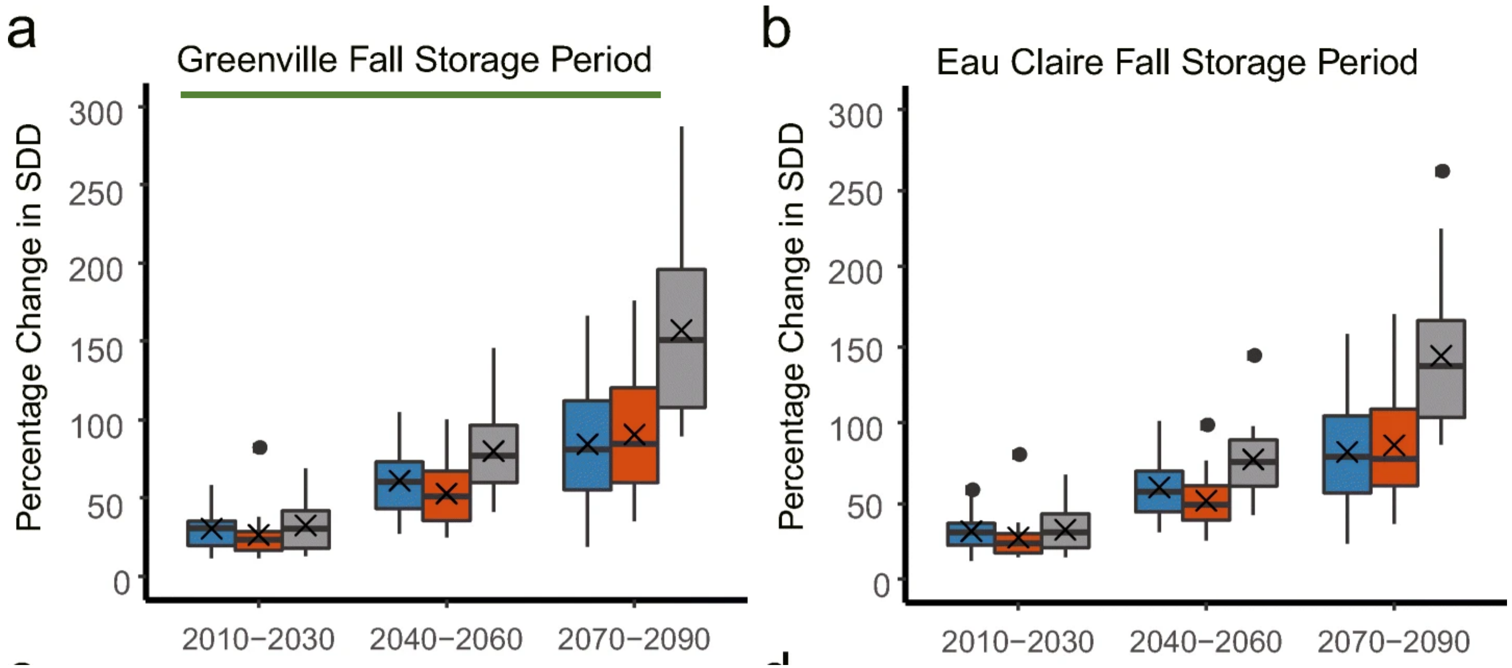


***Table 3** Projected average increase in SDD accumulation at **Greenville during the Fall Storage Period** compared to the 1960-2010 historical period.*

Time slice	Projected change
Early-century	27-33 percent
Mid-century	53-80 percent
Late-century	84-157 percent

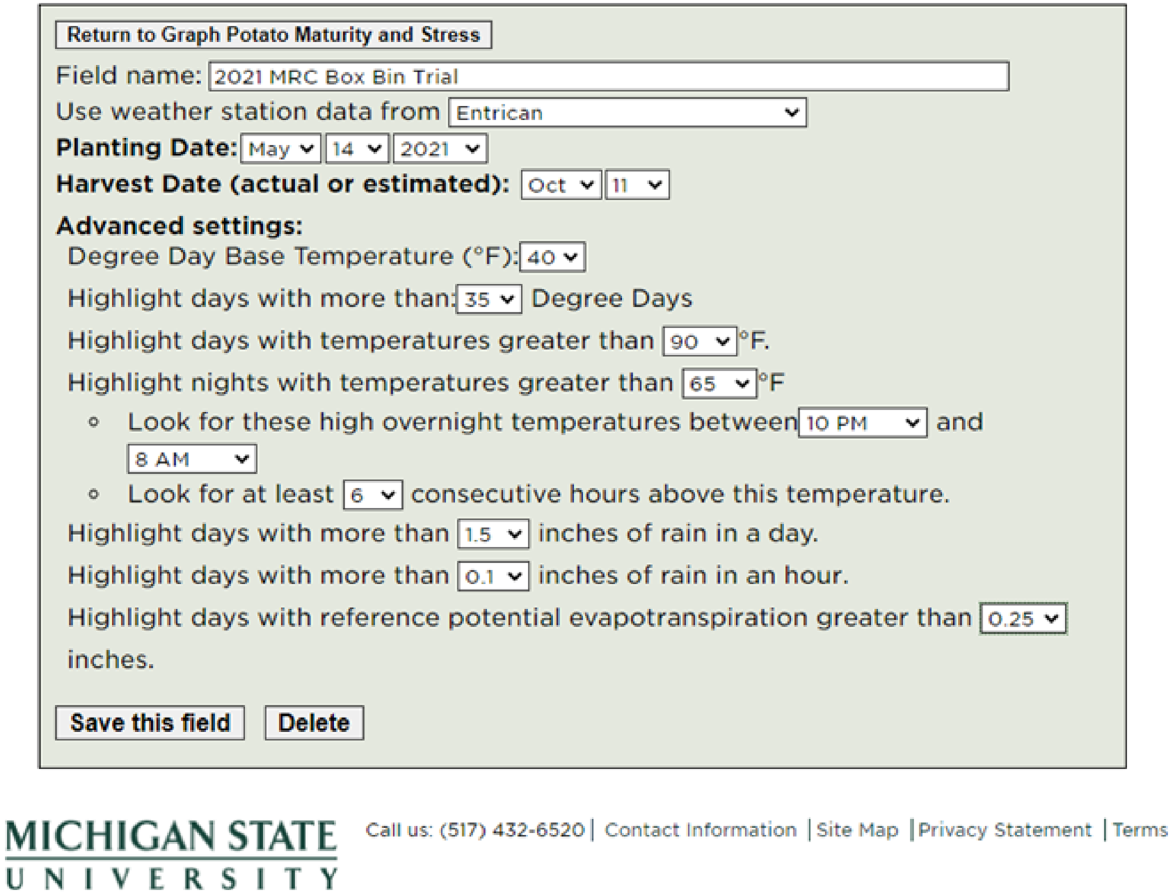
Implications:

- Increased SDD accumulations in the fall storage period may force growers to plant later, so that the crop enters storage when temperatures are cooler.
- That, in turn, may place the crop at greater risk of heat stress during vulnerable growth stages.

Historical and Future Heat Stress

Assessing Heat Stress

- Two thresholds to estimate the timing, frequency, and persistence of heat stress to capture cultivar differences and the uncertainty in the threshold values.
  - **Daily accumulation of ≥20 growing degree days (base 4.4°C)**
  - **Daily minimum temperatures ≥21°C**
- Thresholds recommended by local extension (Chris Long) and industry (Todd Forbush) stakeholders
  - Based on multi-year observations of temperature during the growing season and acceptable potato chip production for extended storage.
- The selected heat stress thresholds also feature in the MSU Enviroweather Potato Heat Stress Tool.
- Used a weekly (7-day) time step, beginning January 1, to assess heat stress.



Climate Data for Heat Stress Analysis

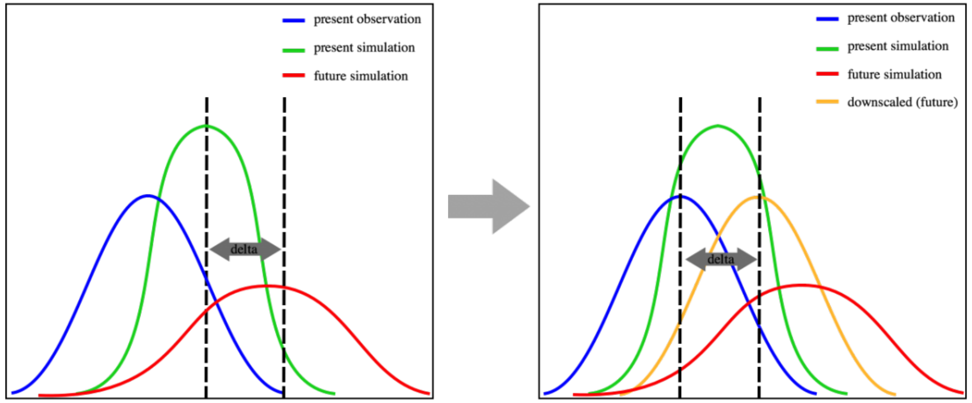
Temperature Observations

- Daily maximum (Tmax) and minimum (Tmin) temperature at Greenville and Eau Claire
- 1960-2009
    - **Daily COOP observations** from the National Centers for Environmental Information Global Historical Climatology Network-Daily (GHCN-D) Database
- 2010- 2020
    - **PRISM** (Parameter elevation Regression on Independent Slopes Model) maximum and minimum temperature interpolated to the locations of Greenville and Eau Claire

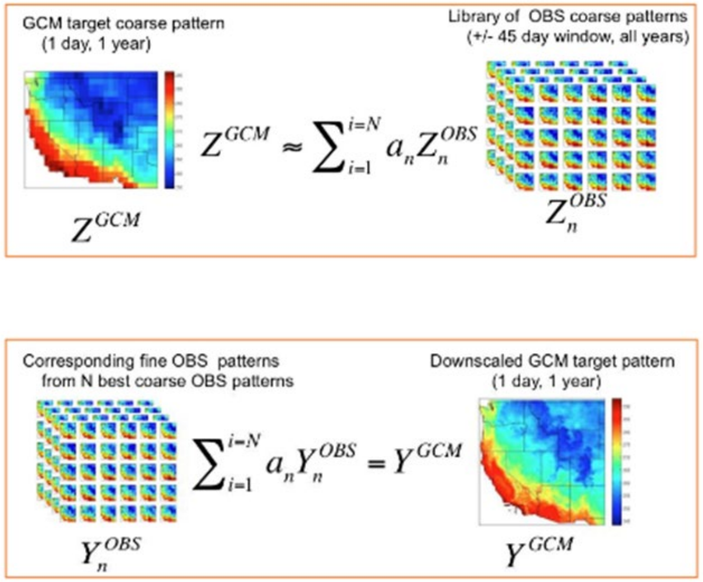
**Times series were checked for discontinuities.*

Temperature Projections

- Two sets of future projections of Tmax and Tmin from downscaled CMIP5 simulations.
  - **Delta** projections from previous study on climate change impacts on storage.
    - Only consider changes in the mean; ignore potential changes in temperature variability.
  - **Multivariate Adaptive Constructed Analogs (MACA)** projections (Abatzoglou and Brown 2012) of Tmax and Tmin
    - Allow for changing variability.
    - Interpolated to the locations of Greenville and Eau Claire from gridded 1/24-degree (4 km) downscaled fields.
- Number of CMIP5 models differs for the two projection types (16 for the Delta projections and 20 for MACA projections)
- Two time slices (2040-2060 and 2070-2090)
- Two greenhouse gas emissions pathways (RCP4.5 and RCP8.5)

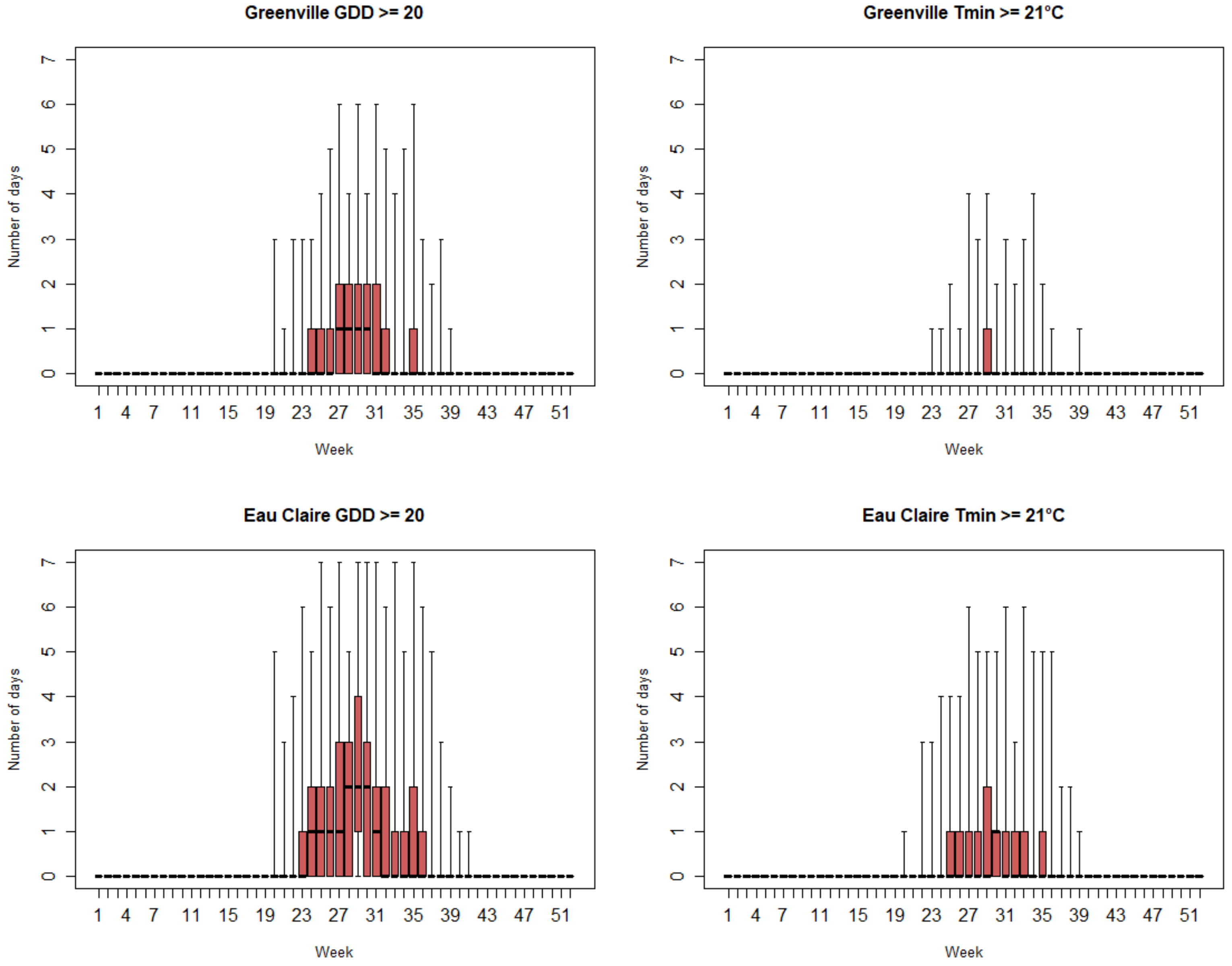


Delta: *Image source: https://rcmes.jpl.nasa.gov/content/statistical-downscaling*



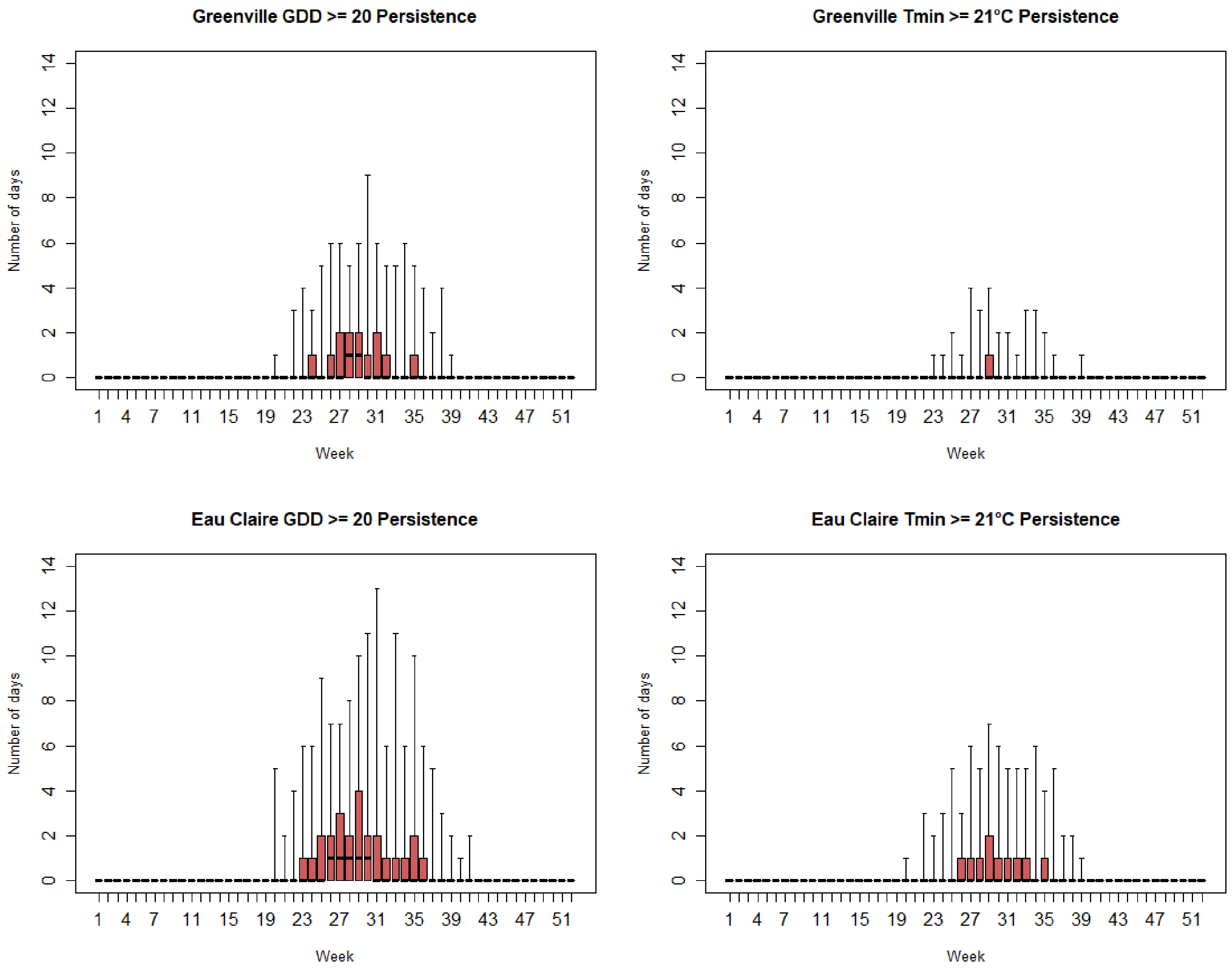
MACA: *Image source: Herrmann and Najjar, 2017*

Historical Inter-annual and Intra-annual Variability of the Frequency of Heat Stress Days

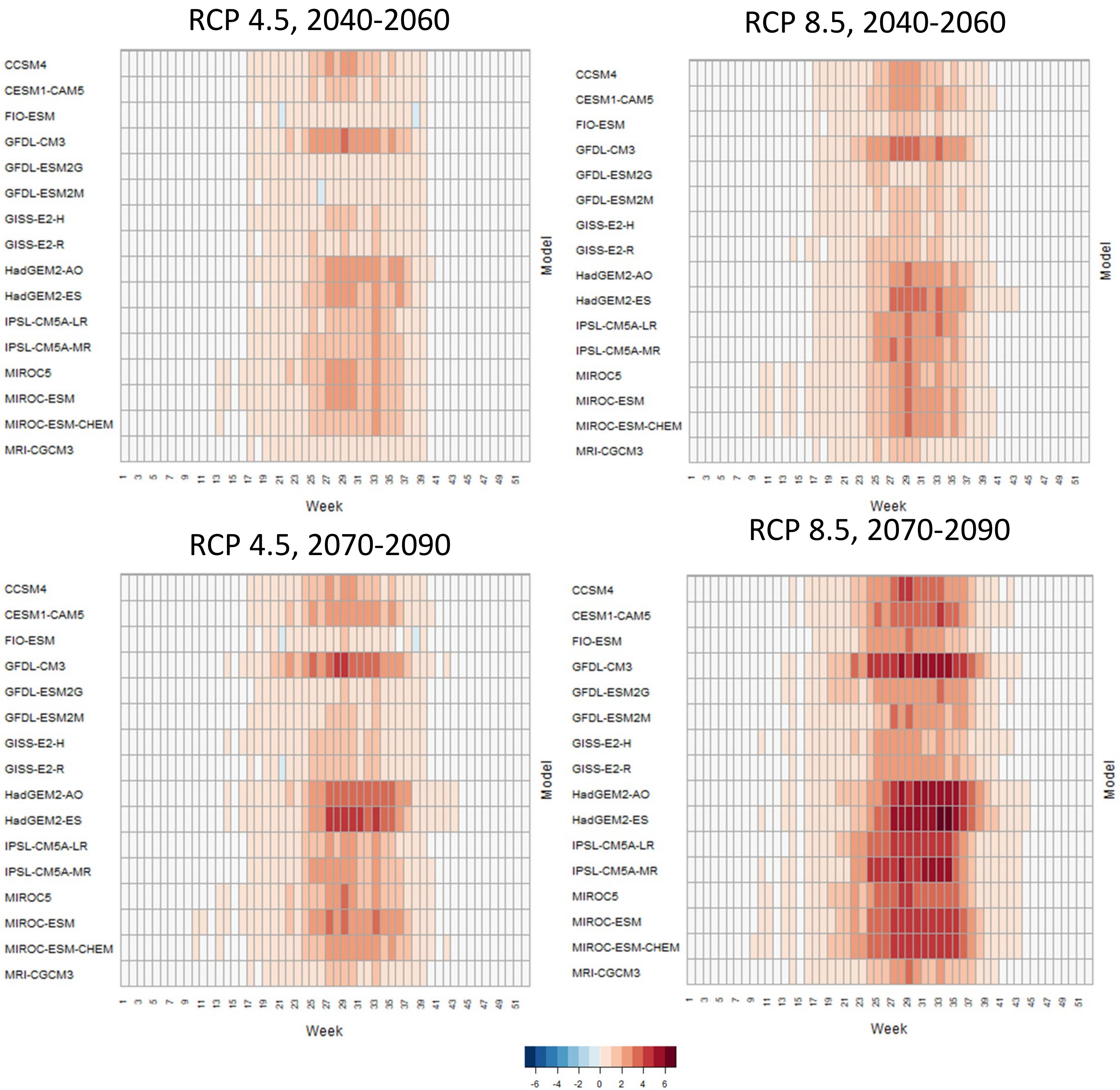


	Greenville	Eau Claire
Daily accumulation of ≥20 GDD (base 4.4°C)		
Earliest heat stress	Week 20 (May 14)	Week 20 (May 14)
Latest heat stress	Week 39 (Sep 24)	Week 41 (Oct 8)
Earliest $Q_{75} > 0$	Week 24 (Jun 11)	Week 23 (Jun 4)
Latest $Q_{75} >0$	Week 35 (Aug 27)	Week 36 (Sep 3)
Daily minimum temperatures ≥21°C		
Earliest heat stress	Week 23 (Jun 4)	Week 20 (May 14)
Latest heat stress	Week 39 (Sep 24)	Week 39 (Sep 24)
Earliest $Q_{75}> 0$	Week 29 (Jul 16)	Week 25 (Jun 18)
Latest $Q_{75}> 0$	Week 29 (Jul 16)	Week 35 (Aug 27)

Historical Inter-annual and Intra-annual Variations in the Persistence of Heat Stress Days



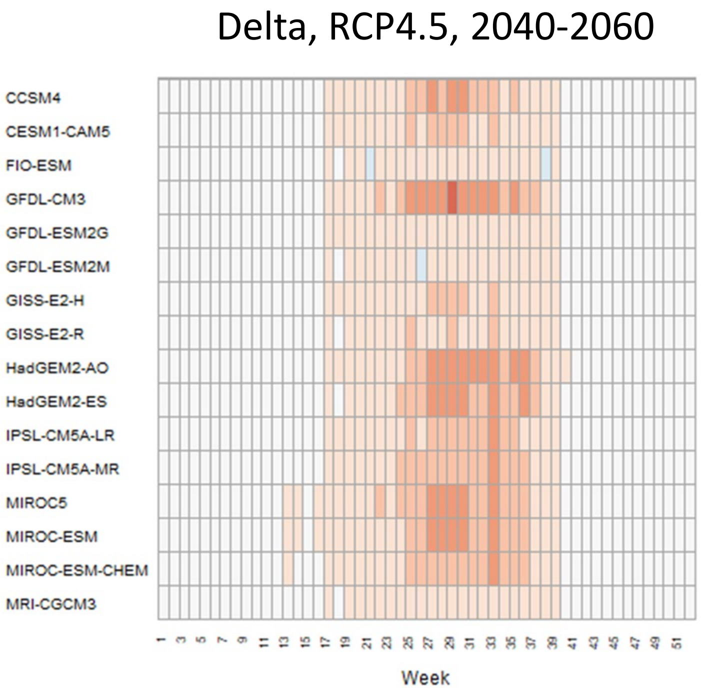
	Greenville	Eau Claire
Daily accumulation of ≥20 GDD (base 4.4°C)		
Maximum Persistence	9 days (Week 30; July 23)	13 days (Week 31; July 30)
Largest Q_{75}	2 days	4 days (Week 29; July 16)
Daily minimum temperatures ≥21°C		
Maximum Persistence	4 days (Weeks 27 and 29; July 2 and July 16)	7 days (Week 29; July 16)
Largest Q_{75}	1 day (Week 29; July 16)	2 days (Week 29; July 16)

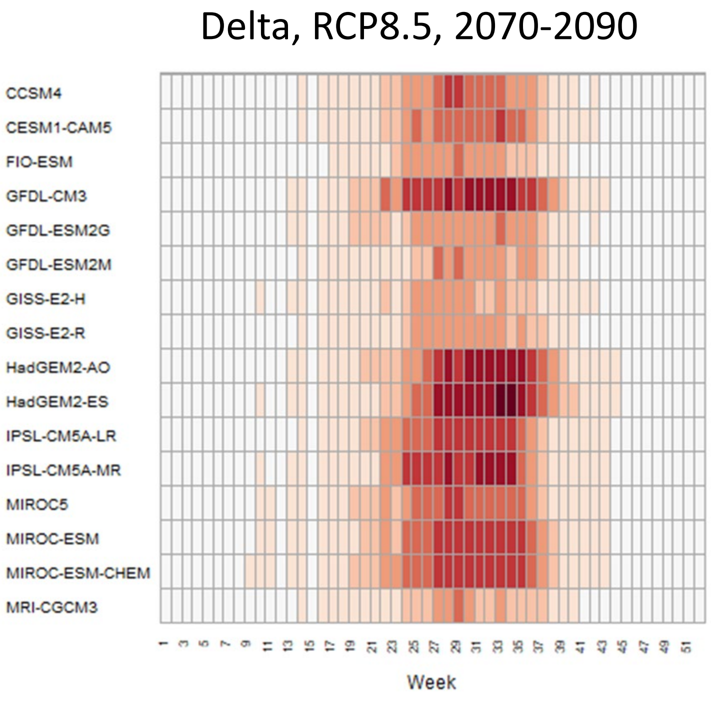


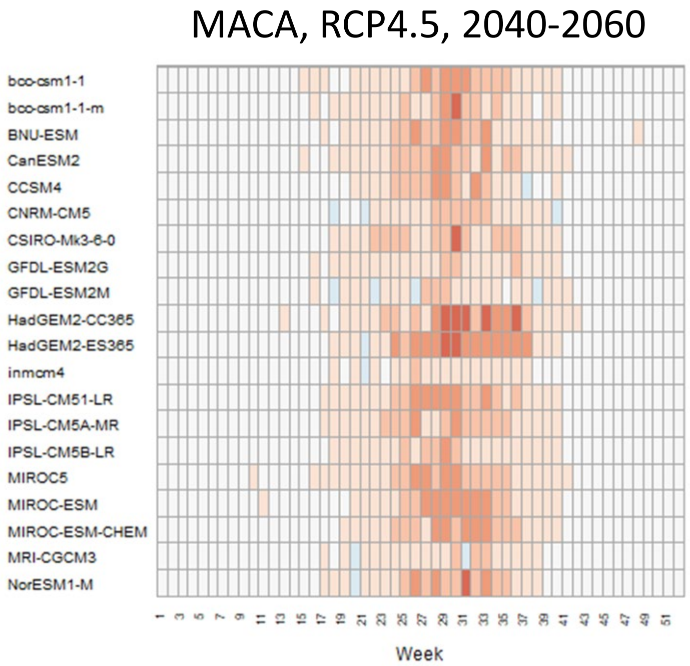
Projected Change in the Average Number of Heat Stress Days (GDD ≥20) Per Week at Greenville: Delta Projections

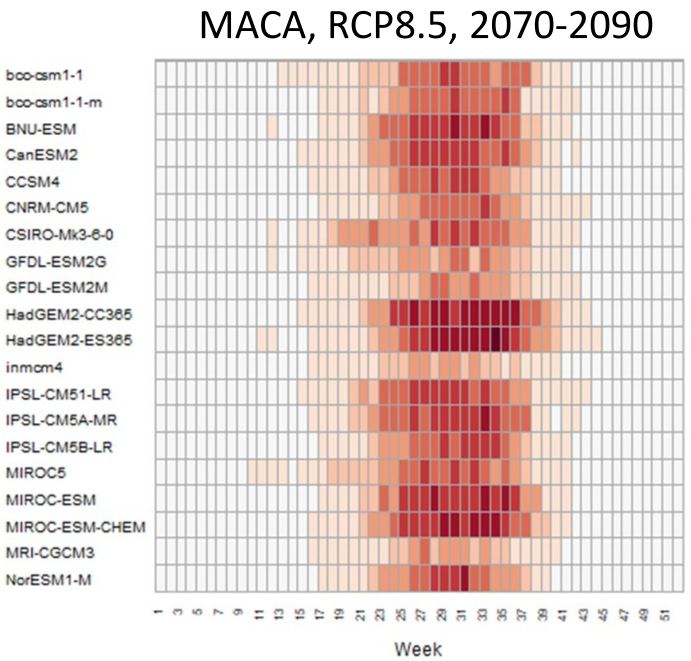
- Considerable inter-model difference in magnitude but not timing of increased frequency of heat stress
- **2040-2060**
  - **RCP 4.5:** Projected average increase of 3 heat stress days per week from approximately Week 25 (June 18) to Week 36 (September 3)
  - **RCP8.5:** For some models projected average increase of 4 heat stress days per week between Week 27 (July 2) and Week 34 (August 20)
- **2070-2090**
  - **RCP4.5:** Projected average increase of 4 heat stress days per week from approximately Week 25 (June 18) to Week 38 (September 17)
  - **RCP8.5:** Projected average increase of 5 heat stress days per week from Week 24 (June 11) to Week 38 (September 17).

Projected Change in the Average Number of Heat Stress Days (GDD ≥20) Per Week at Greenville: Delta vs MACA Projections



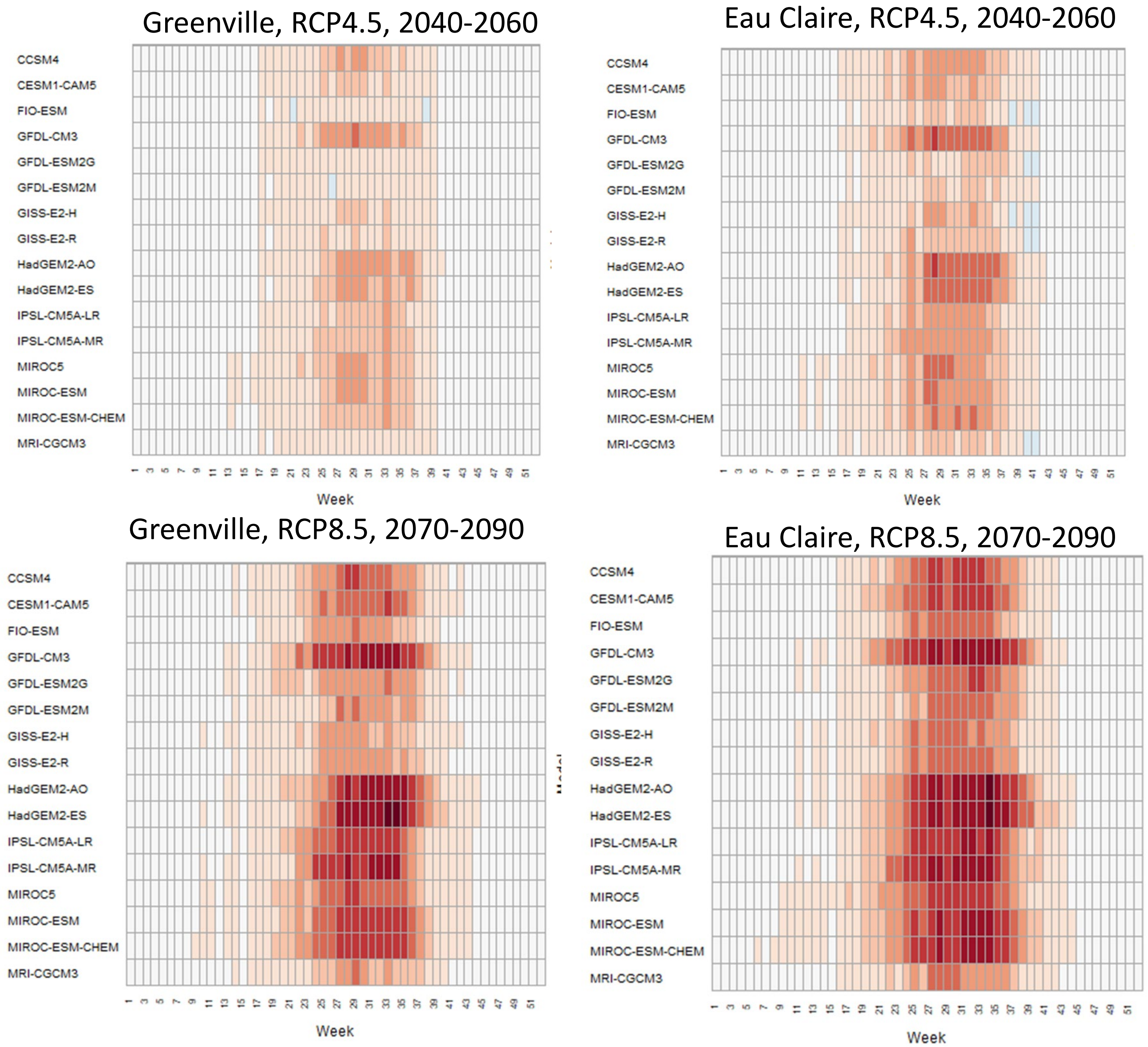




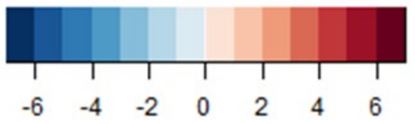


- Considerable similarity in the projected changes from the Delta and MACA projections.
- More week-to-week variability evident for the MACA projections compared to the Delta projections.

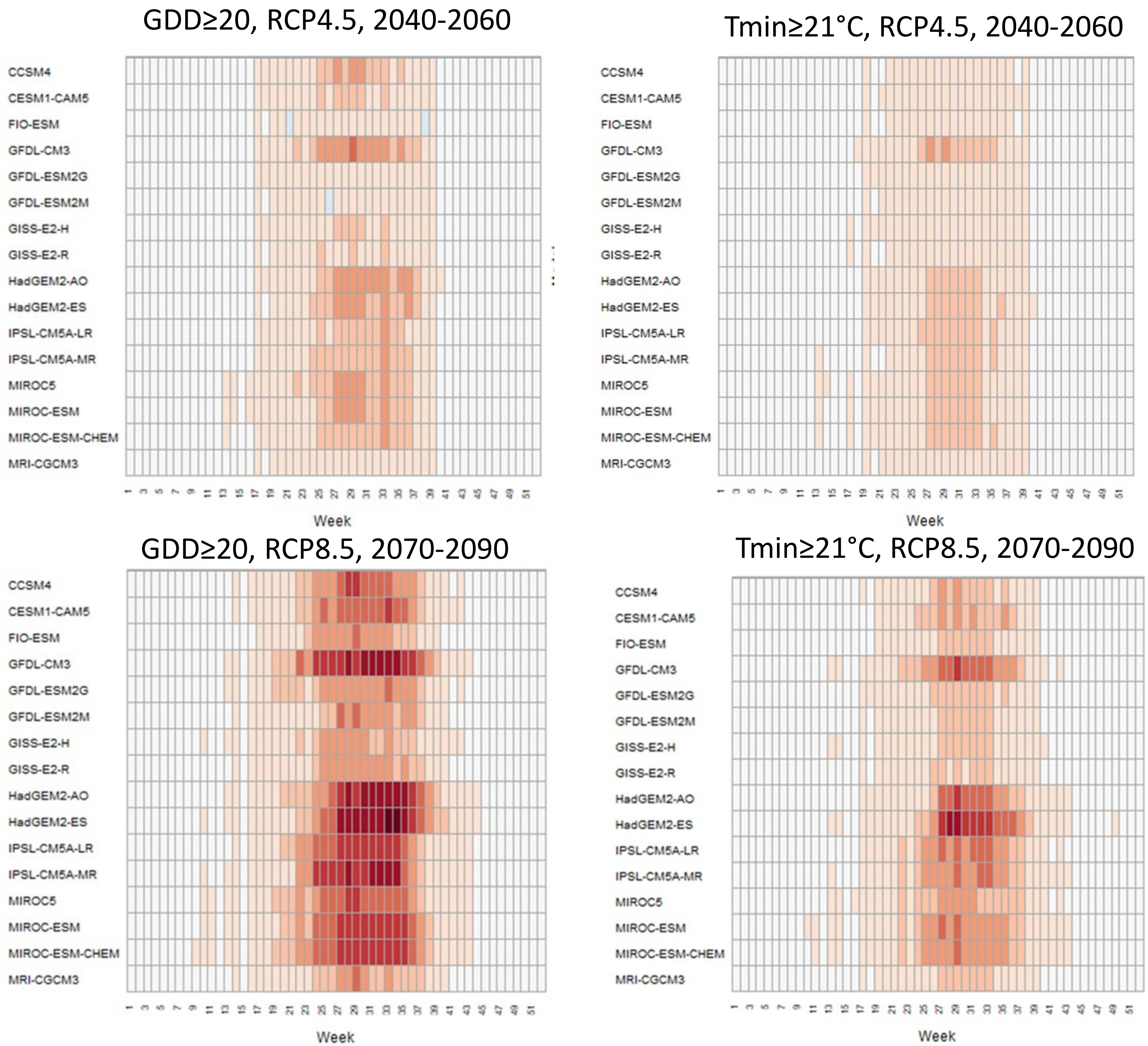
Projected Change in the Average Number of Heat Stress Days (GDD ≥20) Per Week: Delta Projections, Greenville vs Eau Claire



In general, larger projected changes for Eau Claire compared to Greenville.

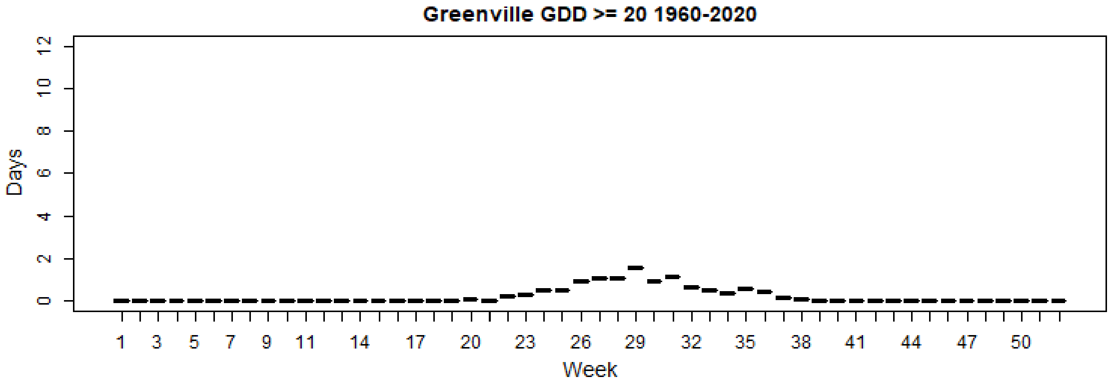


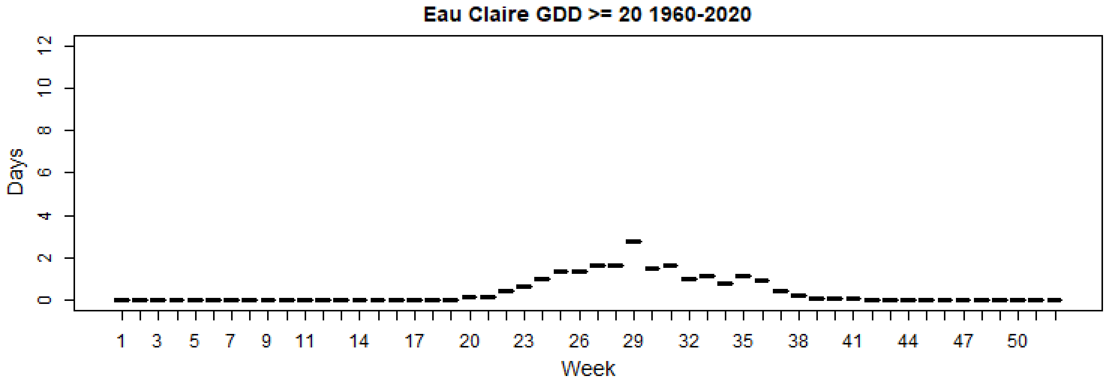
Projected Change in the Average Number of Heat Stress Days at Greenville: Delta Projections, GDD ≥20 vs Tmin ≥21°C

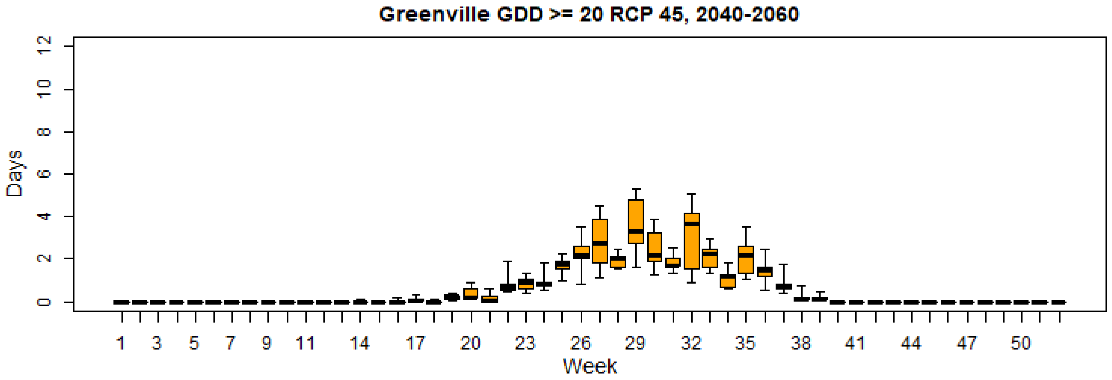


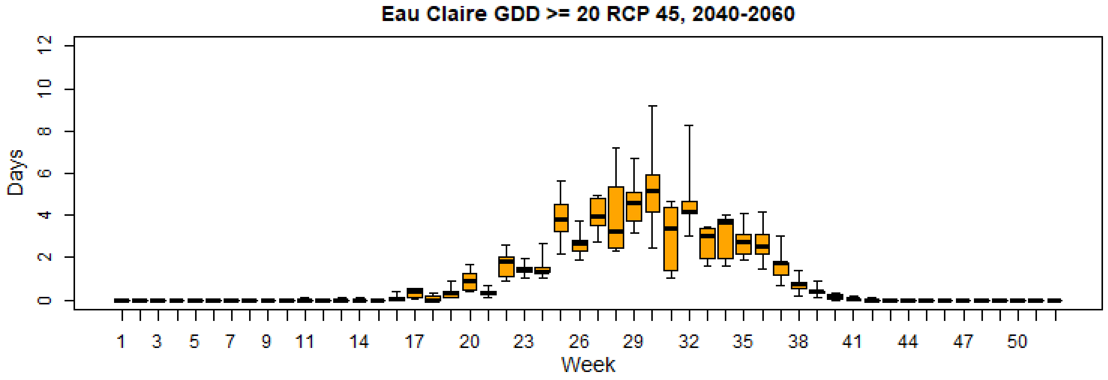
- Projected changes are small (1-2 days) for the Tmin ≥21°C definition of a heat stress days by mid-century under RCP 4.5.
- Average increases of 3-4 days are projected by the end of the century for RCP 8.5 for heat stress days defined as Tmin ≥21°C.

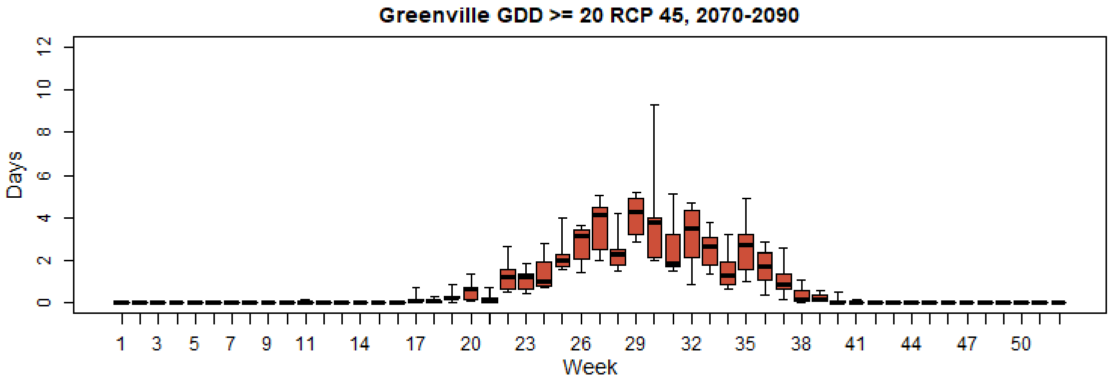
Projected Changes in the Average Persistence of Heat Stress Spells for RCP4.5, Delta Projections

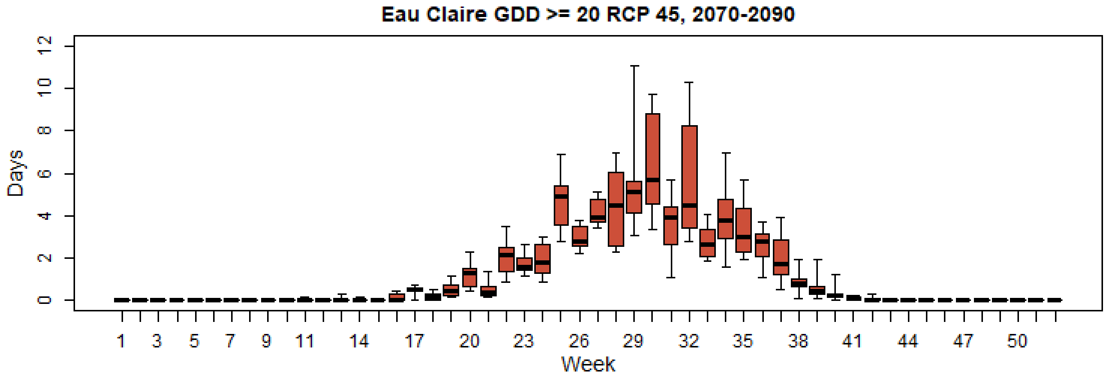




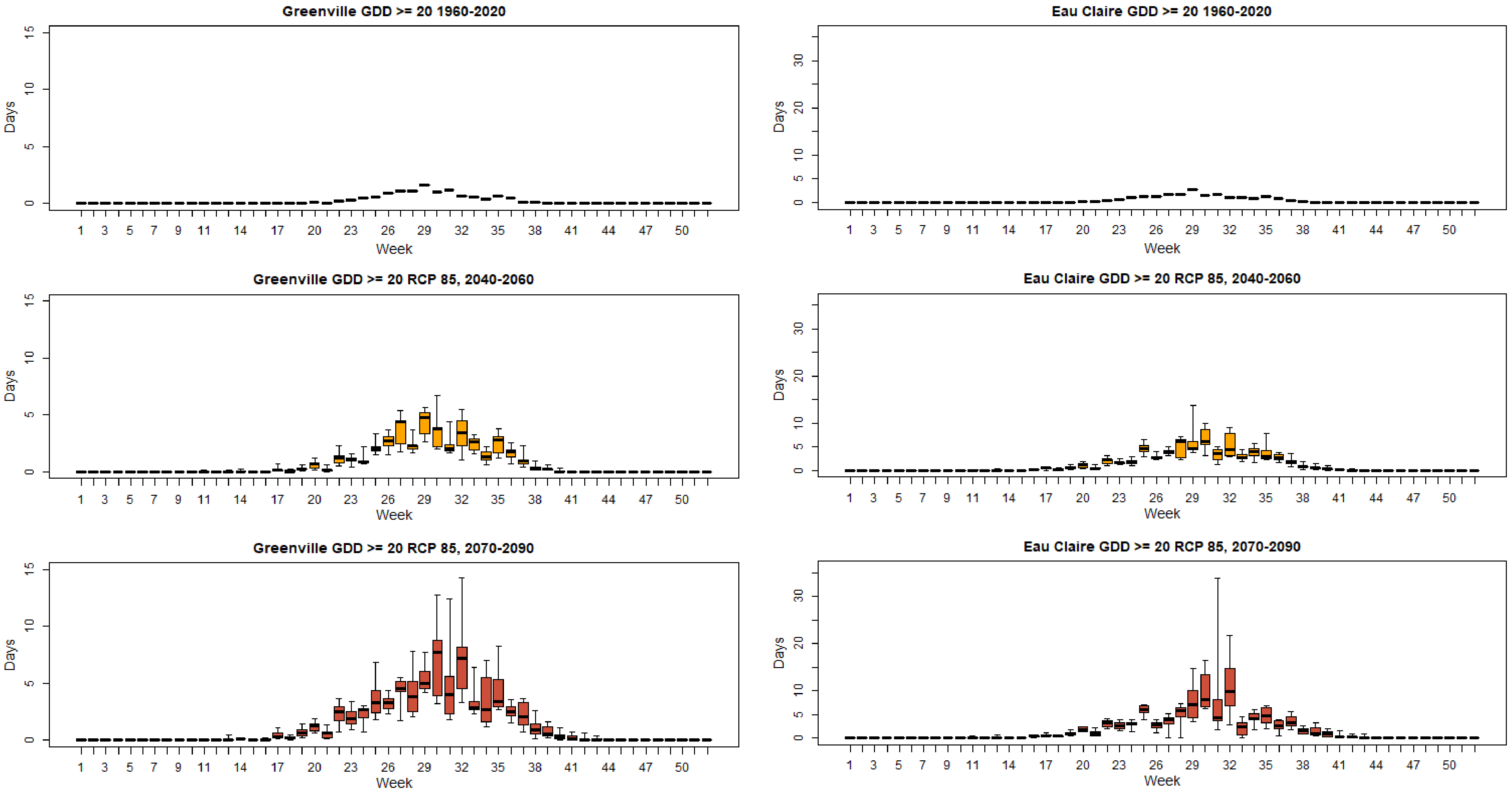








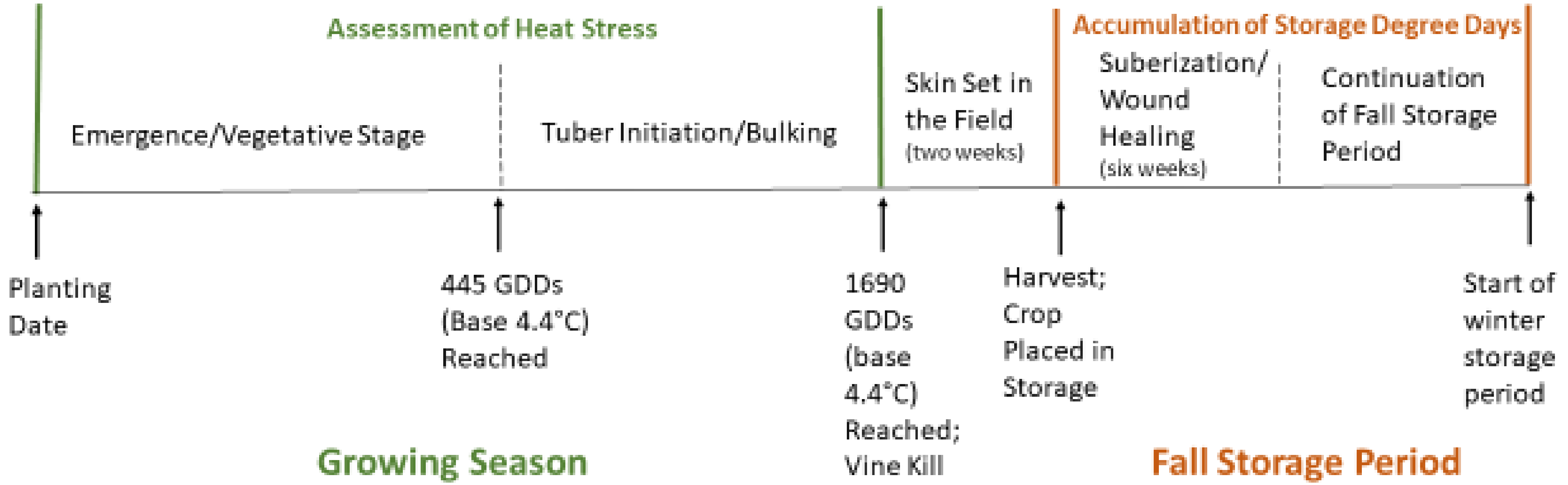
Projected Changes in the Average Persistence of Heat Stress Spells for RCP8.5, Delta Projections



Note change in vertical axis for Eau Claire.

Ongoing Work

- For different planting dates, assess timing and frequency of heat stress with respect to plant physiological stage.
- Integrate potential impacts of heat stress and warmer fall temperatures on Michigan chipping potato production.



Closing Remarks

- Assessing potential impacts of climate change on production systems for which storage is an important component is complex.
- A further complication is that the marketing and storage strategy of Michigan producers is affected by the production cycle of other potato-producing regions, whose planting and harvesting dates may advance to an earlier date under warmer conditions.

Funding Sources

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- Project GREEEN, Michigan State University

Thank you!