Climate Change Impacts on Michigan Agriculture

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Methods and Supplementary Materials

Please visit www.climatehubs.usda.gov/hubs/midwest/topic/assessing-impacts-climate-change-midwest-agriculture for the methods and supplementary materials associated with this report.

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Climate Change Impacts on Michigan Agriculture

Agriculture is a critically important aspect of economic and social life across Michigan. Michigan had approximately 45,600 farms in 2022, with 9.5 million acres of farmland.[1] In the 2022 USDA Census of Agriculture, the estimated market value of agricultural products sold in Michigan totaled more than $12.2 billion, which ranks 17th nationally.[1,2] Michigan has a diverse array of crops produced in the state, as the state ranks 3rd in cut Christmas trees, 6th in fruits/tree nuts, 6th in nursery crops, and 8th in vegetable production.[1,2] The livestock industry in Michigan is predominantly dairy cattle (ranks 6th nationally in milk sales), but also has strong hog/pig ($805 million), cattle/calf ($823 million), and poultry/egg ($736 million) industries.[1,2]

Like other regions in the United States, agricultural productivity in Michigan is vulnerable to weather and climate variability. In recent decades, changes in Michigan's climate have emerged, including enhanced temperature and precipitation variability, with continued change expected in the future. Although some of these shifts may appear minor now, agriculture is already being impacted by observed climate changes. Importantly, the impacts of climate change on the agricultural and forestry sectors extend beyond physical impacts to farms and forestlands but also bring direct and indirect impacts to the overall cultural, social, and economic resilience of Michigan's communities. In 2022, Michigan was the 16th largest agricultural exporting state in the country.[3] Therefore, when considering impacts on the agricultural and forestry sectors in Michigan, climate change-driven stressors and disruptions can emerge well outside the geography of the state.

Observed Changes to Michigan's Climate

Observational changes in Michigan's climate are calculated from gridded meteorological data from 1979 to 2021 (period of record for the dataset) by partners at Michigan State University and GLISA, the Great Lakes CAP/RISA Team (GLISA).[4] A summary of the historical, observed changes in Michigan's climate are described as follows.

Temperature

- Average annual temperature increased by 1.8°F between 1979 and 2021.
- All seasons experienced an increase in average temperature between 1979 and 2021, with the greatest change of 2.6°F occurring in the fall months (Sep. – Nov.).
- Summer temperature extremes in Michigan have not shown a strong trend. Since 1990, there have been a below-average number of hot days (≥ 90°F) and no trend in warm nights (≥70°F).[5]
- Daily minimum and maximum temperatures have increased in all seasons over the past century. Winter minimum temps have increased at the highest rate (+0.4°F/decade; 1895-present).[6]
    - Minimum temps are increasing at a faster rate versus maximum temps across all seasons.

Precipitation

- Average annual precipitation has risen by 4.6" between 1979 and 2021, with the greatest increases observed during the spring (1.8") and winter (1.7").
- Extreme precipitation events (> 2.0") have become more frequent, with an increase of 0.6 days annually between 1979 and 2021.
- Water levels in the Great Lakes have risen rapidly since 2013, with levels in 2020 that were the highest levels observed since the late 1800s.[5]
- Cloud cover during the growing season (May-Sep.) has not shown any significant trends since the mid-20th century, based on gridded historical climate data. Variability in monthly mean cloud cover is large from year-to-year.[7]

Table 1. Observed changes in Michigan's climate based on data from 1979 – 2021. "Average" refers to the 1979-2021 average, and "Change" refers to change in the value between 1979 and 2021 based on a trend analysis.

	Annual (Jan – Dec)		Summer (Jun – Aug)		Fall (Sep – Nov)		Winter (Dec – Feb)		Spring (Mar – May)	
	Average	**Change**	**Average**	**Change**	**Average**	**Change**	**Average**	**Change**	**Average**	**Change**
Temperature	45.2 °F	+1.8 °F	66.9 °F	+1.7 °F	47.7 °F	+2.6 °F	22.5 °F	+1.9 °F	43.3 °F	+0.1 °F
Precipitation	34.0"	+4.6"	10.1"	+1.0"	9.8"	+0.2"	5.8"	+1.7"	8.3"	+1.8"
Vapor Pressure Deficit	4.7 mb	+0.2 mb	8.5 mb	+0.7 mb	4.0 mb	0.0 mb	1.2 mb	0.0 mb	5.0 mb	-0.3 mb
Extreme precipitation (days with 2")*	0.3 days	+0.6 days								
Growing Season Length (frost-free days)	153.6 days	+5.8 days								

*The average value being less than 1 means that, on average, these events do not happen every year. On average, Ohio observed one of these events every 2 years between 1979 and 2021. The change value represents the slope of the linear regression performed on the extreme precipitation frequency data, showing an increase in the frequency of events.

Observed Impacts on Agriculture

- Longer growing seasons and increased temperature provide opportunities to plant alternative varieties of crops and trees.
- Increased crop water demand in recent decades, due largely in part to rising temperatures.[8,9]
  - There is some push-pull between increasing humidity (reduces demand) and increasing temperatures (increases demand). Over the past 30-40 years, the trend has been towards increasing evaporative demand in the Great Lakes region.[8,9]
- Greater frequency of heat stress on trees, crops, livestock, and farmworkers.
- Increased risk of both drought and seasonal flooding.
- Increased weed, pest, and disease pressure as well as animal pathogens.
- More erratic spring freeze/thaw cycles that may damage trees and fruit crops.
- Erratic springs can damage fruit blossoms or impact pollination success, both of which lead to yield loss.
- Higher production costs and lower yields for some crops.[10,11]
- Wetter soils, resulting in delayed agricultural planting, higher erosion, and nutrient loss.

Michigan's Future Climate

Models of future climate indicate that temperatures are projected to continue to warm, precipitation is expected to become more variable and extreme, and the growing season is anticipated to continue to lengthen. The climate projections in this section are based on the average of 17 different regional climate models.[4] Two possible futures are presented:

1. An intermediate scenario in which greenhouse gas emissions peak around mid-century and then slowly decline (RCP 4.5)[12]
2. A very high scenario in which emissions continue to rise throughout the 21st century (RCP 8.5)[12]

Careful planning and adaptive actions can lower the risks of climate change impacts for producers and the agricultural and forestry sectors more broadly. There are many ways to adapt to climate change based on emerging impacts and the needs of a particular farm, crop, or community. Some examples are presented below.

Temperature

All available climate model projections indicate that Michigan can expect to see continued warming in the future, with fewer extremely cold nights, more very warm nights, and more very hot days (Table 2). Climate models project that annual average temperatures in Michigan will increase by 2.7°F to 7.0°F by mid-century (2040-2059) under an intermediate scenario, and by as much as 8.8°F under a higher emissions scenario. By late century (2080-2099), temps could rise as much as 15.8°F under a higher emissions scenario.

Although these changes are most pronounced at the end of the century and in the high-emissions scenarios, even the moderate, mid-century projections indicate major changes in Michigan's cold- and hot-weather climatologies that could have important ramifications for agriculture and forestry.

Table 2. Modeled mean change (compared to the 1979 – 2005 period) in the number of days per year that meet or exceed a specified temperature threshold for Michigan. Values are provided for mid- and late-century and for two future scenarios of projected climate change. Included below the average change is the range of all model projections that make up the modeled mean change.

	Low temp. ≤ 32°F	Low temp. ≥ 80°F	High temp. ≥ 86°F	High temp. ≥ 95°F
Mid-century, intermediate	-36.9 days (-62.2 to -21.9)	+0.1 days (0.0 to +0.4)	+63.8 days (+45.2 to +74.5)	+4.0 days (+0.8 to +7.7)
Mid-century, very high	-43.7 days (-78.1 to -19.4)	+0.3 days (0.0 to +1.1)	+72.2 days (+51.9 to +82.7)	+6.8 days (+1.7 to +12.4)
Late century, intermediate	-49.1 days (-79.7 to -25.5))	+0.5 days (0.0 to +2.7)	+74.0 days (+52.9 to +93.2)	+8.0 days (+1.6 to +21.2)
Late century, very high	-79.4 days (-114.8 to -47.4)	+5.2 days (+0.2 to +20.6)	+103.8 days (+73.6 to +122.7)	+29.5 days (+6.3 to +63.2)

What Does This Mean for Agriculture and Forestry?

Heat Stress

- Increased heat stress (from heat and humidity) severely impacts farmers and animals. Among livestock, high heat stress can decrease meat and milk quality and quantity, and egg production.[10,13,14,15]
- Farm workers who work predominantly outdoors are also particularly vulnerable to heat-related illness.
- The frequency of short-term and rapid onset drought during the summer is potentially higher due to warmer temperatures and increased precipitation variability.[16]
- Higher temperatures during the growing season may stress cool season crops like lettuce, broccoli, and cabbage.[15] Prolonged, extreme heat can impact warm season crops like tomatoes and peppers by negatively impacting pollination at temperatures above 86°F.[17]

Soil Impacts

- Decreased soil moisture affects agricultural plant physiology, potentially leading to an increased risk of reduced yields or crop losses, but uncertainty about these impacts remains.[10,15] Crop genetics and field management will be key to mitigating these potential yield losses.
- Increased soil temperatures affect the appropriate timing and form of fertilizer application. Areas of the state where fall nitrogen applications are effective management will likely shift to spring and/or in-season application timings.
    - With soils remaining above 50°F later into the fall season and potentially early in the spring, fields are prone to nitrogen loss and subsequent water quality impacts following nitrogen applications.[18]

Growing Conditions

- Elevated overnight temperatures affect corn development and vegetable crops, negatively impacting yields.[15]

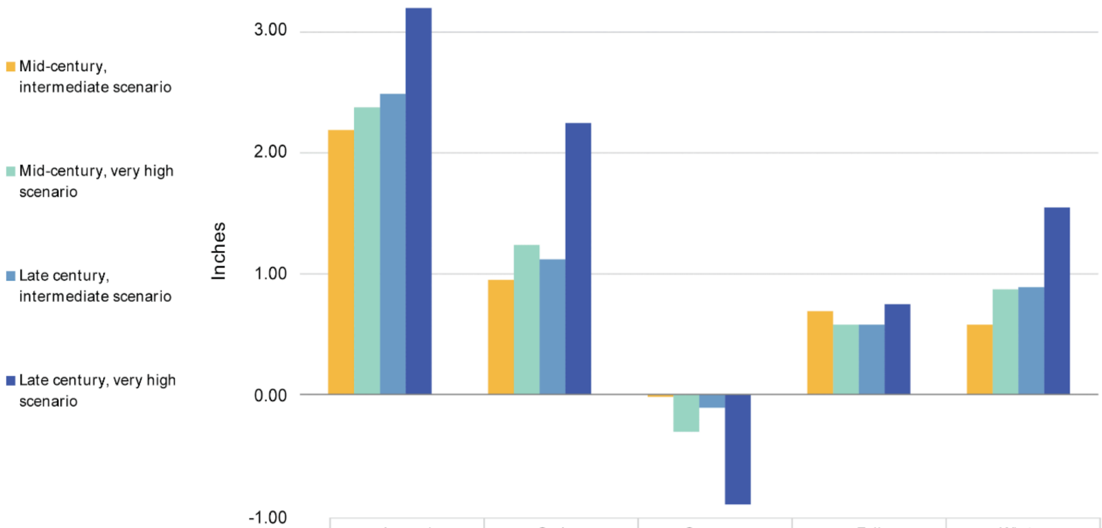
- Research suggests warm and dry years shorten windows with optimal growing conditions for corn while soy has a higher tolerance for heat.
- Application of pesticides will become more challenging with the temperature changes and variability of soil saturation.
- Warming is expected to increase the severity and frequency of crop and animal diseases. Certain diseases (charcoal rot, pod & stem blight, etc.) can also become more problematic when the crops are under stress.

Adaptation Options

- Integrate alternative crop species via conservation crop rotations to maintain or improve soil health.[19]
- Work with your advisor(s) to select crop varieties and species that are well-suited for the conditions in your area, and that will be able to tolerate higher heat and increased water stress.
    - Choose longer maturity corn cultivars to take advantage of the longer growing season (potentially increasing yields), or plant shorter maturity corn varieties earlier in the season to avoid reproductive stages happening during worst risk of drought in later summer (likely to give average, but more consistent yields).[19]
- Utilize cover crops or reduce tillage to bolster soil health and increase water-holding capacity.
- Be prepared to enact farming strategies that manage excess soil moisture in the spring (such as cool season cover crops or improved drainage) and not enough soil moisture during late summer (such as high-cover crop residue systems, drainage water recycling, irrigation, or controlled drainage structures).
- Deploy precision agriculture, which may enhance efficient use of fertilizers and nutrient testing in order to minimize loss of nutrients, and may provide adequate amounts of nutrients during peak crop removal.
- Explore options to reduce forest and farmworkers' exposure to high temperatures like providing shade, improved personal safety equipment, access to drinking water, and alternative working hours.
- Monitor for pathogens or insect pests that are currently found further south.

Precipitation

Annual precipitation is expected to increase in the future, with the largest seasonal increases likely during spring. Decreases in precipitation are projected during the summer for all scenarios. These changes are larger under the very high scenario and for the late 21st century (2080-2099) (Figure 1). It is projected that by mid-century, annual precipitation will become more variable (i.e., increases in heavy precipitation days and consecutive dry days).[20]



	Annual	Spring	Summer	Fall	Winter
Mid-century, intermediate scenario	2.19 (7%)	0.95 (12%)	-0.02 (-0%)	0.69 (7%)	0.58 (10%)
Mid-century, very high scenario	2.38 (7%)	1.24 (16%)	-0.31 (-3%)	0.58 (6%)	0.87 (15%)
Late century, intermediate scenario	2.49 (8%)	1.12 (14%)	-0.11 (-1%)	0.58 (6%)	0.89 (16%)
Late century, very high scenario	3.63 (11%)	2.25 (28%)	-0.91 (-9%)	0.75 (8%)	1.55 (28%)

Figure 1. Projected precipitation changes for Michigan, annually and seasonally, in inches (with percent change in parentheses) based on two different emission scenarios (intermediate (RCP4.5) and very high (RCP8.5)).

What Does This Mean for Agriculture?

- Winter and spring increases in precipitation will lead to further loss of field and forest workdays, impaired root growth and function, and prolonged field wetness.[15] Moreover, more intense and sporadic rainfall events can cause ponding that leads to root disease and loss of plants.
- When soils are wet during the spring, there is an increased risk of soil compaction from machinery traffic.
- Wetter pastures and paddocks increase susceptibility to animal foot diseases and may impact livestock nutrition maintenance schedules and gestational weight.[21,22]
- Decreased soil moisture in summer will likely lead to greater crop stress and irrigation demand.
- Increase in wildfires in the continental US and Canada with increased fuel aridity (i.e., dry vegetation). Upper-level wind patterns could move smoke from fires outside of the Midwest over the Midwest.[23]
    - Some studies suggest corn and soybean yield impacts from smoke coverage in the sky. However, there is uncertainty as to how yields will be impacted by future smoke events.[24]

Adaptation Options

- Consider planting earlier in the season, which may be possible due to small increases in field workability days in late March to early April, coupled with an earlier last frost date.[19] Early planting can also lead to greater root development and more resilience to ponding.
- Utilize cover crops or reduce tillage to bolster soil health and increase water-holding capacity.
- Increase soil health by improving soil structure and organic matter content to enhance precipitation infiltration of soil, increase water-holding capacity, and maintain plant-available water during periods of dryness. Management to

improve soil health can reduce risk of climate-related impacts as well as improve productivity.[15] Options include conservation crop rotations, cover crops, and reduce tillage.

- Be prepared with farming strategies that help manage too much soil moisture in the spring (such as cool season cover crops or improved drainage) and not enough soil moisture during late summer (such as high-cover crop residue systems, drainage water recycling, irrigation, or controlled drainage structures).
- Consider 'redefining the field edge' in perennially flood prone areas by replacing row crops with perennial grasses for haying/grazing or native mixes.[25,26]
- Consider using machinery traffic control and mapping to minimize the impact of machinery on compaction because of wetter soil conditions during harvest and planting times.

Growing Season Length

Growing season trends across Michigan since 1950 are variable but generally getting longer across the state (Figure 2). Many counties have seen an increase of one to a few days per decade; most of Michigan's counties have experienced a statistically significant increase in growing season length (Figure 2, right). This is a result of later first frosts in the fall and earlier onset of frost-free conditions in spring.

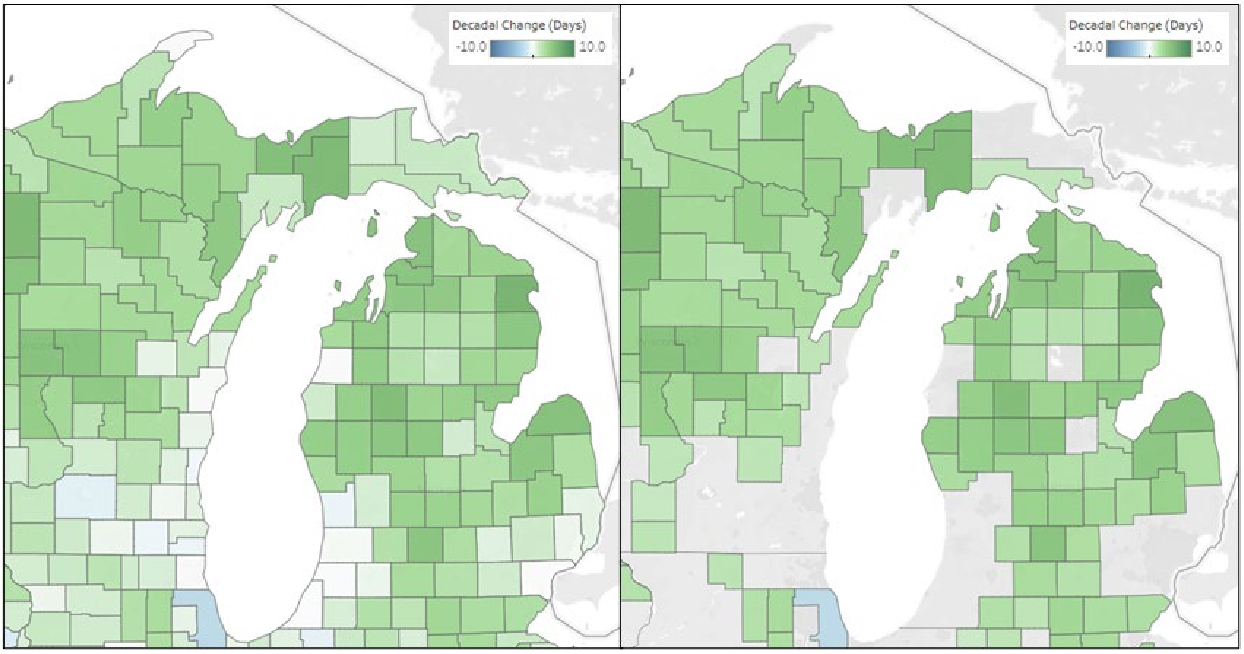


Figure 2. Historical changes in average annual growing season length for Michigan counties, 1950-2023 based on gridded Applied Climate Information System data. The right-hand image displays only those counties with a statistically significant trend ($p<0.05$). Image source: Freeze Date Tool, Midwestern Regional Climate Center, https://mrcc.purdue.edu/freeze/freezedatetool.html. Original data source is https://www.rcc-acis.org/.

What Does this Mean for Agriculture?

- Pests, diseases, and weeds may expand their ranges. Additionally, the number of pest generations per season may increase, resulting in a greater impact on forests, crops, or livestock. An increased need for chemical treatments to address these impacts may lead to greater pesticide and herbicide resistance and greater input costs for farmers. Increased tree loss due to pest damage may increase wildfire risk.
- Longer growing season length may provide additional time for agricultural harvest and other end-of-season processes. Also, cover crops may experience increased post-harvest growth. Both will be heavily influenced by fall soil moisture trends.

- Later first frosts in the fall and earlier frost-free conditions in spring may shorten the winter harvest timber period, as well as making it more difficult to harvest some species that primarily inhabit wetter habitats.

Adaptation Options

- Plant agricultural crops earlier in the spring or consider options for double cropping.[25]
- Address pest, weed, and disease issues by diversifying crop rotations, enhancing use of Integrated Pest Management (IPM) techniques, and planting species and varieties that are resistant to pests and disease.[25]
- Consider planting fruit species and varieties which require fewer chilling hours, while keeping in mind the potential risk of trees and shrubs breaking dormancy during late-winter warm spells resulting in crop loss.

Relative Humidity

Despite increased water vapor in the atmosphere and precipitation, uncertainty remains in whether current trends of relative humidity will continue. This uncertainty is due to relative humidity's dependence on both air temperature and absolute moisture content in the air. A larger increase in temperature would decrease relative humidity, and a larger increase in absolute moisture content would increase relative humidity. Models indicate that relative humidity is projected to decrease annually and across all seasons in Michigan. However, if minimum (nighttime) temperature trends continue to outpace maximum (daytime), vapor pressure deficits will not increase, and relative humidity will stay higher.

What Does this Mean for Agriculture?

If relative humidity decreases:

- Plants will be more prone to wilting and stunted growth because of increased water use.
- Certain animal respiratory viruses may have a longer survival duration.[27]
- Tree mortality may increase, especially for younger trees.[28]

If relative humidity increases:

- Wetness duration may increase leading to enhanced disease potential for crops.[29]
- Plants will have less ability to evaporate water (part of the transpiration process) or take up nutrients dependent on the flow of water from the soil.[30]
- The ability for animals to utilize evaporative cooling will be reduced, increasing the effects of heat stress related health and performance issues.[31]

Humidity trends have major implications for crop water demand:

- If daily minimum temps (a good approximation of dew point temps) continue to outpace increases in daily maximum temps, vapor pressure deficits will not increase, and crop water demand will not increase.[32]
- If daily minimum & maximum temps increase at a similar rate in the future, vapor pressure deficits can be expected to increase and crop water demand will subsequently increase.[32]
- Decreases in summer rainfall also have the potential to increase crop water demand. Thus, precipitation and humidity together must be considered together and makes this a complex issue.[32]

Adaptation Options

- Consider irrigation to provide adequate water for the crops demand during periods of drought.
- Plant varieties adapted to drier or wetter climates (or those that may withstand high variability) if available (including crops, pasture grasses, and tree fruit).[25]
- Use of mulch, cover crops, no-till, or reduced tillage to retain soil moisture and reduce soil temperatures during the summer.[25]

- Where appropriate, the establishment of trees to reduce evaporative water loss from the soil surface. Additionally, soils within agroforestry systems are better able to infiltrate and store water, which will be critically important in climates with warmer, drier summers.[33]

Fruit Crop Considerations

Michigan has a thriving perennial fruit crops industry, and the trees, bushes, and vines that bear this fruit are susceptible to negative impacts of climate change. Along with what has been mentioned above, below are a few more variables & potential management options to consider.

- The frequency of very cold nights (daily low ≤-4°F (-20°C)) has been decreasing across Michigan since the 1960s (Figure 3).
- Despite the warming winters, “rapid” cold snaps (≥45°F drop over 48 hours) have shown no significant trends over the last several decades at most observing sites, occurring 1-3 times per decade on average (Figure 4).
- Late season freeze events (daily minimum of ≤32°F on or after May 1st) occur, on average, ≥50% of years across Michigan counties (Figure 5). These events occur less frequently closer to the Great Lakes.
- Counties with a significant change in late freeze frequency (Figure 5) are experiencing a decline of <1 year/decade with a late freeze.

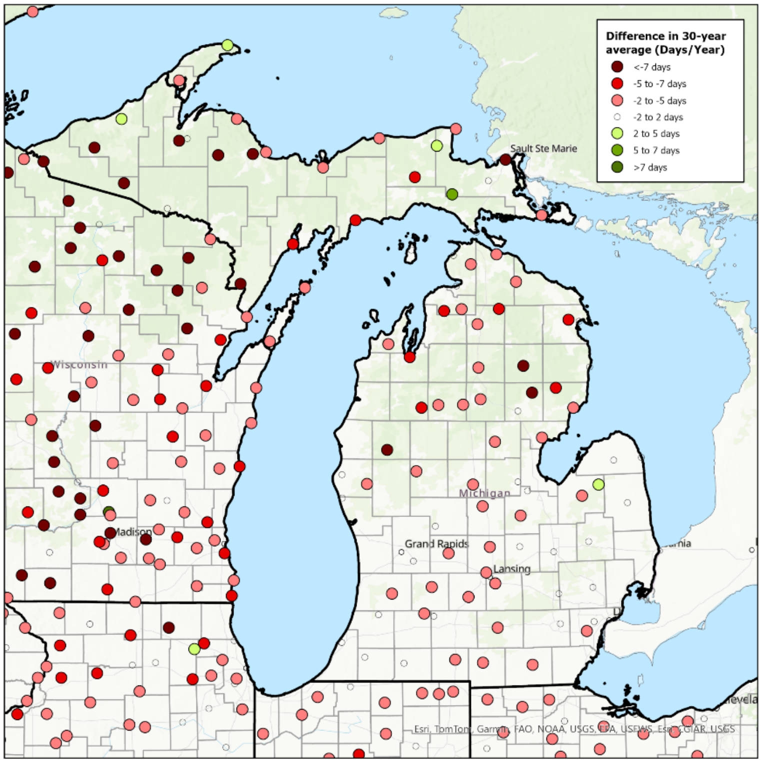


Figure 3. Change in the 30-year average number of days (per year) with a daily low temperature of ≤ -20°C (-4°F) between (1961-1990) & (1991-2020). Data source: Applied Climate Information System (ACIS), http://www.rcc-acis.org/. Data compiled with the assistance of the Midwestern Regional Climate Center (MRCC).

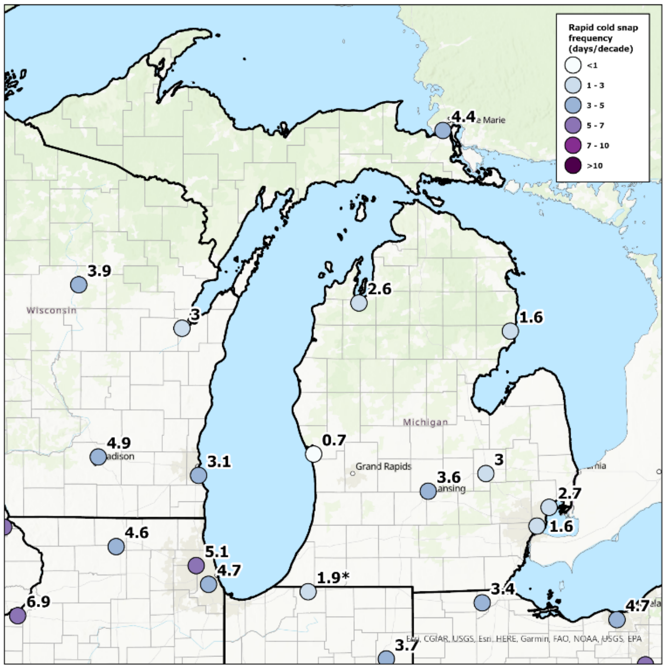


Figure 4. Frequency of winter "rapid" cold snaps (≥45°F drop over 48 hours) at Automated Surface Observing Systems (ASOS) sites, 1951-2020.
*Significant increase in cold snap frequency ($p<0.05$); no significant decreasing trends were observed. Data source: Iowa Environmental Mesonet (IEM), https://mesonet.agron.iastate.edu/request/daily.phtml.

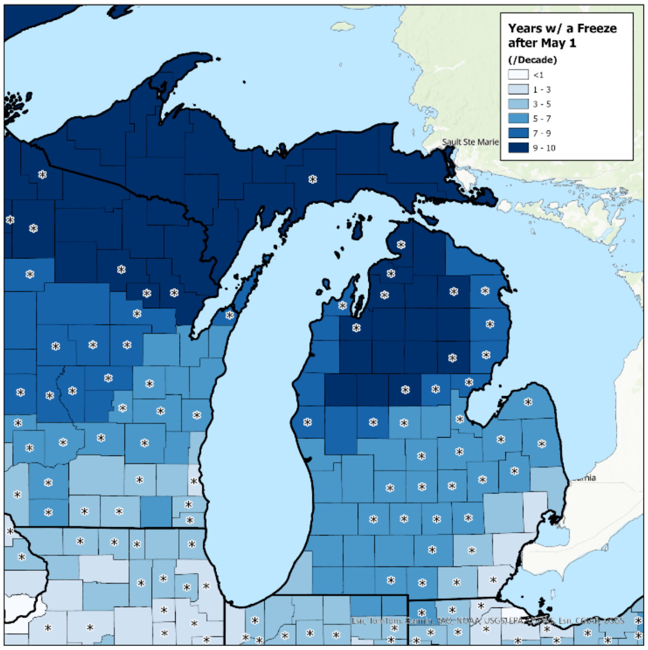


Figure 5. Late season freeze (32°F; May 1st or later) frequency per decade, averaged by county, for 1951-2020.
*Significant decreasing trend in late frosts ($p<0.05$) Data source: Freeze Date Tool, Midwestern Regional Climate Center, https://mrcc.purdue.edu/freeze/freezedatetool.html.

What Does This Mean For Fruit Production?

- Warmer winters and late season frosts increase risk of spring freeze injury and crop loss by “rapid” cold snaps and/or accelerated development of buds.
- Chilling hour accumulation for fruit has been on the rise in Michigan in recent decades, and the time required to reach certain thresholds may become shorter (e.g., happen earlier in the spring) with warming winters.34
- Insects, diseases, & weeds may have a longer period of activity, possibly an increase in the number of pest generations, or both with a warmer environment.
- Pest range expansion
- Increased spring precipitation could lead to:
    - Reduction of pollen availability and pollinator activity during the blooming period.
    - Saturated soil, leading to issues of reduced nutrient uptake, root growth, & overall development.
    - More favorable conditions for certain diseases and pests.
- Warmer temperatures in summer, resulting in a higher risk for plant stress and fruit sunburn.

Adaptation Options

- Mitigation of spring freeze damage with the use of wind machines, heaters, and/or overhead sprinkler irrigation.
- Consider installing irrigation in crops which historically might not have required it.
- Consider planting fruit species and cultivars which require greater chilling hours to mitigate the potential risk of trees and shrubs breaking dormancy during late-winter warm spells.
- Increasing the use of IPM strategies, including:
    - Implementing strategies that were successful in the original range of the pest.
    - Adapting scouting frequency for insects known to thrive in more extreme conditions; and/or
    - Adjust degree day models to more accurately track insect phenologies that have also shifted with climate change.
- The use of cover crops and/or mulches that will increase water infiltration while also conserving moisture during the dry periods.
- Use of protective netting over the tree canopy to provide shade during hot periods.
- Application of chemical compounds to fruit to block or dissipate solar radiation (e.g., kaolin clay, calcium carbonate, etc.)

Michigan Climate Change Resources and Extension Programs

- MSU Enviroweather: https://enviroweather.msu.edu/
- Ag Weather Forecast: https://www.canr.msu.edu/agriculture/Weather/
- US Drought Monitor (MI): https://www.drought.gov/states/michigan
- GDD Tracking Tool: https://gddtracker.msu.edu/
- MRCC Ag Climate Tools: https://gddtracker.msu.edu/
- MRCC Freeze Date Tool: https://mrcc.purdue.edu/freeze/freezedatetool
- Great Lakes Integrated Sciences and Assessments (GLISA): https://glisa.umich.edu/
- EnviroImpact Tool: https://enviroimpact.iwr.msu.edu/
- Irrigation Scheduling Tools: https://www.canr.msu.edu/news/irrigation_scheduling_tools_provided_by_purdue_and_msu_extension
- ClimateReady Farms: https://climateready.rsgisnext.msu.edu/
- MSU Farm Stress Website: https://www.canr.msu.edu/managing_farm_stress/index
- MI Soil Health Progress Report: https://www.canr.msu.edu/resources/michigan-soil-health-progress-report

For more Michigan climate change tools & resources, please visit climateready.rsgisnext.msu.edu/resources for more information.

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