UNIVERSITY OF GEORGIA
Warnell School of Forestry & Natural Resources

Publication WSFNR-23-27A

August 2023

Tree Health Care & Climate Variability

Dr. Kim D. Coder, Professor of Tree Biology & Health Care / University Hill Fellow for Distinguished Outreach
University of Georgia Warnell School of Forestry & Natural Resources

A constant feature of biological and ecological systems is change. Trees and their sites are always changing. Part of a tree health care provider's role is managing change. Variability in climate is bringing new challenges for trees and their sites. Do you want to know what is coming at you and changing tree growth expectations? In this publication outlining basic changes expected with trees and tree sites (concentrated in the Northern Hemisphere and North America) will be described.

Traces

Climate variability is being driven by rapidly accelerating changes in trace gas concentrations like carbon-dioxide (CO2), and by associated changes in transparency of the atmosphere to heat radiation. CO2 at very small concentrations, acts as a greenhouse gas blocking heat radiation. Figure 1 combines two trend lines for carbon dioxide (CO2) and global temperatures showing a close relationship and a rapid rise in both. There are a number of other natural and human-caused greenhouse gases in addition to CO2.

Trace gases in the atmosphere continue to increase. The three most important trace gases representing roughly 59% of greenhouse gas impacts are carbon-dioxide (CO2) with 42% of current greenhouse impacts, methane (CH4) with 13% of current greenhouse impacts (1 CH4 = ~34 CO2), and nitrous-oxide (N2O) with 4% of current greenhouse impacts (1 N2O = ~298 CO2). These trace gases impact energy balance in our atmosphere with only minor changes in their concentrations. All of these trace gases help hold heat in the atmosphere.

CO2 Enrichment

Carbon-dioxide (CO2) concentration has increased about 40% in the last 200 years since the beginnings of the industrial revolution. For trees, increasing CO2 alone can lead to an enrichment of growth activities through improved water use efficiency and photosynthesis. This "CO_2 fertilization" leads to many positive changes in growth performance of trees. But, CO_2 increases can also change atmosphere transparency to heat radiation leading to temperature increases.

Temperature changes can bring increased heat loads to trees and sites. Figure 2. In urban / suburban areas especially, increased heat loads can generate ground level ozone (O_3), a severe oxidative air pollutant which can damage tree surfaces, membranes, and life functions. Ozone air pollution can negate any CO_2 fertilization which could occur. Ozone increases can predispose trees to both biotic and abiotic stress. Site temperature changes, and associated humidity and tree-soil evaporation changes, will further constrain tree growth.

A New Environment

Trees and their supporting sites will need to function under a new environment. At a minimum, elevation of CO_2, increased heat loads, and damaging O_3, combined with variable water and nitrogen availability, will force new solutions for tree success and failure. Tree growth constraints under this new ecology are not simply CO_2 controlled.

For example, with CO_2 concentrations elevated in the atmosphere, tree photosynthesis should increase by 50% and tree respiration should increase by 25%. With increases of CO_2 alone, tree growth accelerates. Under combined CO_2 and temperature increases, tree photosynthesis should increase by 20% and tree respiration increase by 40%. Tree photosynthesis can quickly decline with temperature increases while tree respiration accelerates until death.

New Trees

Changing CO_2 concentrations, temperature increases, and a lengthening growing season, will change tree growth. Expectations, if adequate water is available, show tree foliage increasing +28% with most new growth concentrated inside and lower in the crown, more branches surviving, and increased tree height. These new changes in growth will have an impact on tree form, causing a shift to taller, less tapered tree stems.

If trees are going to grow more, additional nitrogen and phosphorous will be needed. Faster nitrogen and phosphorus cycling from both temperature increases and growth acceleration will increase soil organic matter generation and recycling, increase potential nitrogen loss, increase fine root mass, and change mycorrhizae relationships. With almost four times soil respiration increases from heat loads, nitrogen and phosphorus availability imbalances will occur.

For example, any tree growth increase due to CO_2 fertilization, temperature changes, and growing season expansion would be substantially reduced by nitrogen shortages (-19% growth reduction) and phosphorus shortages (-6% growth reduction). With addition of water availability and drainage issues, ozone increases, and a changing pest environment, tree growth would be slowed. Better essential element tuning for site enrichment will be critical.

From The Frying Pan...

Temperature changes increasing tree-site heat loads are not expected to be evenly applied across a growing season, day to night, and through the whole year. Heat load trends will increase, but low and high temperature variability can be large. Models show over the next two generations of arborists, average temperatures, maximum temperatures, and minimum temperatures will all increase in temperate and boreal zones. Temperature variability trending upward will occur most in Fall and Winter, and least in Summer.

In several conservative models, yearly temperatures are projected to increase +5^{o}F (2.7^{o}C) over the next 80 years. This level of temperature change means tree respiration increases will tend to outpace photosynthesis gains by ~1.7 times. Heat load stress on trees will be accelerated by an additional +10-30 hot days a year. For example, Figure 3 provides the increase in number of days with temperatures over 90^{o}F (~32^{o}C) and over 100^{o}F (~38^{o}C) projected for the middle of the United States (St. Louis, MO). These heat load increases will impact trees and sites, as well as human health and well-being.

Thinking Heat

To summarize temperature variability and heat load on trees, the average number of days with temperatures over 100^{o}F (~38^{o}C) are expected in most temperate, continental areas to increase by 2-3 times by year 2100. In the same areas, the number of nights with temperatures less than 32^{o}F (0^{o}C) are projected to decrease by 23%. Figure 4. Extreme warmth for both days and nights will become more common, and extreme cold will become less common. Fewer frost nights and more multi-day heat waves will occur.

As minimum winter temperatures continue to climb, tree hardiness zones will continue to move northward and upward in elevation. For example historically from the eastern United States covering the 22 years between 1990 and 2012, hardiness zones moved northward by 75-125 miles or more. Figure 5. How large will be any changes in hardiness zones over the next 30 years? Average winter temperature changes will lead to more rapid hardiness zone changes, but will still present extreme cold events. For native tree ranges, new hardiness zones suggest the southern edge of a tree's native range will fragment and may disappear, and the northern edge of the range will be left behind. Trees cannot move their growth ranges as fast as climate change is occurring.

Drying To Death

Another tree related issue regarding heat loads involves water – its availability through rainfall and its loss through evaporation. If a location has normal rainfall amounts but heat loads are greater, more drought conditions can be generated. If rainfall amounts decline and heat loads increase, much more drought can occur. Projections are for more frequent droughts within the growing season and more land area covered by drought conditions. The area of severe drought conditions are expected to increase by +10-30%.

Models suggest precipitation events will be more intense but less often. Figure 6. In some cases, rainfall amounts may remain the same or may increase by 5-10%, but come in fewer rain events separated by longer dry periods during the growing season. Drought will off-set any tree growth advantage of increased CO2 and longer growing seasons. Heat load impacts on sites, and heat generated over hardscapes which drift onto tree-covered landscapes (i.e. advected heat), will greatly influence soil water evaporation and tree transpiration.

Stormy Weather

Trees must stand and adjust to local wind loads. Elevated temperatures will generate more extreme weather events. Under expected temperature changes (low-moderate projections) over the next 80 years, storm energy could increase ~22-30%. This will generate increased:

1. Hurricanes (greater frequency and intensity);
2. Ice storms (greater frequency and intensity – moved farther north than current ice storm bands);
3. Lightning ground strikes (greater frequency and current); and,
4. Thunderstorm winds loads (greater frequency and intensity).

Expectations for hurricanes over the coming years include a +11% increase in category 3-5 major hurricanes, and a +3.6 times increase in category 5+ storms. Average hurricane wind loads are expected to increase by +6%. These storms are expected to spin-up faster over the ocean, move across water and land 20% slower, and deliver 24% more rainfall. Temperature increases on the sea surface will bring bigger storms which will stay over one spot longer with more wind and rain. Hurricane impacts on trees are also expected to be seen much farther inland before dissipating. Figure 7.

Shock & Awe

Greater wind speeds generate exponentially greater wind loads on trees. Figure 8. Mechanically, trees will be challenged by +60% greater average wind speeds and additional large gusts in thunderstorms. These wind loads can be associated with heavy soil saturation (temporary root anchorage decline), and increased crown mass and tree height from elevated CO2, producing increases in overall drag or wind loads. Tree damage and catastrophic failures from extreme wind loads will increase.

Increased storm energy will also generate more lightning ground strikes per area, and generate greater average current (amperage) per strike. Multiple models projecting out to 2080 show a +11% average annual increase in lightning ground strikes for every +1.8^{o}F (+1^{o}C) temperature increase. These lightning strike values would mean a +50% increase in ground strikes by the end of the century. As lightning ground strike frequency and average current per strike increase, more tree damage will occur.

Getting Wet

Along the coasts tide gauges have been showing a progression of sea level rise. Six different models all project sea level rise of at least one (1) foot, with a maximum of seven (7) feet rise by the turn of the century. Average sea level rise among all models was projected as 3.3 feet. Most conservative projections show a sea level rise of about two (2) feet. Figure 9. Spring tides, king tides, and high tides will impact storm water drainage infrastructures and tidal waterways, leading to greater fair weather flooding of tree sites.

New research is showing an even quicker acceleration of sea level rise. This will have a significant impact on water drainage issues and salt water intrusion into irrigation wells and across tree covered landscapes along shorelines, across flatwoods, and around islands. Figure 10 shows projections of high tide flooding increases over the next 50 years. Tree impacts will become more serious as sea level rises are coupled with more intense hurricanes and greater storm surges, all concentrated on coastal communities and their trees.

Surging

More energy in hurricanes will generate greater storm surges. Category 3-5 major hurricanes, depending upon local sea floor forms, could see storm surges of 9-18 feet of water or more, plus flooding caused by rain water drainage backed-up by elevated seawater levels. Brackish or salt water can cause tree problems if it pools-up over tree roots. Storm surge can be made worse by sea level rise. Figure 11 places historic storm surge events onto pending sea level rise changes. For example, what once was a major storm surge event every 27 years, combined with a two feet rise in sea level, becomes a surge flood event occurring almost every other year.

Growing Season

Many gardeners dream of a longer growing season between early late frosts. Trees having earlier spring growth and later fall senescence seems to be ideal, but genetic constraints have locked many trees into seasonal time limits. Climate variability is expanding growing season length (i.e. frost free days) in many places by 1-2.5 days per year. Genetic limitations can prevent native trees from growing earlier and making use of any extra growing time. In addition, if winter length is significantly shortened, tree dormancy and chilling requirements may not be meet, disrupting budburst, leaf expansion, and flowering.

Tree Enemies

Increased winter temperatures will help some pests and hinder others. Tree pest populations which are more effective surviving and moving northward supported by increased winter temperatures, will impact more trees and sites. Tree pests which are assisted in survival and reproducing by higher winter temperatures could be both common pests or rare species seldom seen. Stimulation of reproduction, reduced mortality, and extended ranges will all place more pests into Plant Health Care monitoring programs.

With trees under a new set of environmental conditions, some trees will be predisposed to new guilds of stressor agents. Increased intensity and frequency of pest impacts on trees can be seen in four examples: 1. bark beetles and ambrosia beetle populations are projected to increase; 2. defoliators are projected to increase +3% for every 1^{o}F (~0.55^{o}C) average temperature increase; 3. scale insects and mites are projected to increase; and, 4. mistletoe range expansion northward with hardiness zones changes will occur. As trees have more foliage, more sugars generated, quicker nitrogen cycling, and less defense, opportunities for more pest attacks will increase.

Selecting Trees

Tree genetic variability and plasticity, and reproductive reach, are not enough to keep pace with rapid climate shifts. The northern edges of tree ranges will be moving North and up in elevation too slowly to remain in equilibrium with climate. The southern edge of tree ranges will be breaking apart, leaving fragments and residual populations in climatic refuges from which they cannot escape. Assisted migration programs (range expansion plantings) are needed to help trees increase their range northward. Test nurseries in communities must be installed. In addition, invasive tree control must be deemed critical to ecosystem health and made an even more important priority.

City Living

Tree issues will be much more apparent and critical within larger cities than in smaller communities. City heat island effects (Figure 12) will magnify temperature increases, generating an additional +5^{o}F (~2.7^{o}C) average temperature increase and potentially as much as +20^{o}F (~11^{o}C) warmer evenings. A city's energy environment change will produce: greater ozone (O3) levels; greater tree and soil respiration; reduced tree photosynthesis (-12%); power more soil evaporation and tree water loss; and, a longer growing season tied with a longer tree pest season. Soil organic matter will cycle faster and ecologically burn away quicker.

Tree Health Care Providers

Tree health specialist should be focused on the tree impact triangle for climate change shown in Figure 13. Trace gases are at its center, with heat, growing season length, and drought at each corner. These primary tree impacts help generate secondary impacts including storm energy changes, ozone generation, nitrogen and phosphorus cycle acceleration, tree and soil respiration increases, pest population changes, and invasive species population changes. These primary and secondary tree impacts must be made part of any Plant Health Care / tree health program.

Tree environments will have many new and modified climate inputs. Each input will be more varied over time with more energy impacting trees than before, including increased severity of drought, floods, storms, and heat loads. Over the next two generation of arborists, projections are for more drought, more warm nights, longer periods between rains (>20%), and more overall variability in expected extreme weather events. Expect greater wind loads, more sudden large rains, more erosion of soil surfaces, more Spring and Summer droughts, and greater heat loads, all of which will trouble trees and tree health care providers.

Tree Treatments

The results of various stress and strains suggested by the tree impact triangle will be for more tree decline, dieback and death. To mitigate these expected outcomes, more effective arboricultural treatments will be required. Water management will be the most important site considerations for availability, evaporation, and soil drainage. Careful site management with nitrogen and phosphorus will become more critical. Pest management and PHC will be challenging. Soil health and organic matter inputs (like compost / mulch) must be highlighted. Additional lightning conduction / tree protection systems, and more intense structural pruning programs, need to be installed. A centerpiece of tree management will be heat load control and dissipation.

Simple Solutions

Do not wait for change, but anticipate impacts to trees and sites. Clearly more tree planting, more site renovation of ecologically exhausted sites, more mature tree maintenance, more shading of hardscapes, and more intense and disciplined tree health care to help combat pests and disasters are needed. Tree health care providers must increase both healthy trees and soils now in preparation of things to come. The future will not be worse or better, but it will be different!

Selected References & Readings

Bravo, F., V. LeMay, & R. Jandl (editors). 2017. **Managing Forest Ecosystems: The Challenge of Climate Change** (2nd Edition – Vol. 34). Springer International Publishing, Switzerland.

*Coder, K.D. 2021a. Hardiness zone changes across the eastern United States from 1990 to 2012, and across Georgia from 2001 to 2012. University of Georgia Warnell School of Forestry & Natural Resources Outreach Publication WSFNR-21-56C. Pp. 11. (website)

*Coder, K.D. 2021b. Trees and storm wind loads. University of Georgia Warnell School of Forestry & Natural Resources Outreach Publication WSFNR-21-55C. Pp. 47. (website)

Coder, K.D. 2022a. Hurricane storm surge & seawater damage to trees (Hurricane & Trees Series). University of Georgia Warnell School of Forestry & Natural Resources Outreach Publication WSFNR-22-35C. Pp.14. (website)

Coder, K.D. 2022b. Hurricanes: Current storms, future expectations & tree damage (Hurricanes & Trees Series). University of Georgia Warnell School of Forestry & Natural Resources Outreach Publication WSFNR-22-34C. Pp.30. (website)

Coder, K.D. 2022c. Storms and lightning ground strike numbers and locations. University of Georgia Warnell School of Forestry & Natural Resources Outreach Publication WSFNR-22-08. Pp.12. (website)

*Emanual, K. 2018. **What We Know About Climate Change** (updated edition). MIT Press, Cambridge, MA. Pp.69.

Englander. 2014. **High Tide On Main Street: Rising Sea Level and the Coming Coastal Crisis.** The Science Bookshelf, Boca Raton, Florida. Pp.227.

Hine, A.C., D.P. Chambers, T.D. Clayton, M.R. Hafen & G.T. Mitchum. 2016. **Sea Level Rise In Florida: Science, Impacts, & Options**. University Press of Florida, Gainesville, FL. Pp.179.

Ingram K.T , K. Dow, L. Carter & J. Anderson (editors). 2013. **Climate of the Southeast United States: Variability, Change, Impacts, and Vulnerability.** NCA Regional Input Report book series. Island Press, Washington D.C. Pp.356.

*Kelbaugh, D. 2019. **The Urban Fix: Resilient Cities in the War Against Climate Change, Heat Islands & Overpopulation**. Routledge – Taylor & Francis, New York, NY. Pp.307.

Kellomaki, S. 2017. **Managing Boreal Forests in the Context of Climate Change: Impacts, Adaptation, and Climate Change Mitigation**. CRC Press, Boca Raton, FL. Pp.357.

*Mann, M.E. & L.R. Kump. 2015. **Dire Predictions: Understanding Climate Change – The Visual Guide to the Findings of the IPCC** (2nd edition). DK - Penguin Random House, New York, NY. Pp.224.

*Manning, W.J. 2020. **Trees & Global Warming: The Role of Forests in Cooling and Warming the Atmosphere.** Cambridge University Press, New York, NY. Pp.330.

Mathews, D. 2020. **Trees In Trouble: Wildfires, Infestations, and Climate Change**. Counterpoint, Berkeley, CA. Pp.285.

Mutter, J.C. 2020. **Climate Change Science: A primer for sustainable development.** The Earth Institute – Columbia University, Columbia University Press, New York, NY. Pp.194.

Peterson, D.L., J.M. Vose, & T. Patel-Weynand (editors). 2014. **Climate Change & United States Forests** (Advances in Global Change Research Vol. 57). Springer Dordrecht Publishing, New York, NY.

Pilkey, O.H., L. Pilkey-Jarvis & K.C. Pilkey. 2016. **Retreat from a Rising Sea: Hard Choices in an Age of Climate Change**. Columbia University Press, New York, NY. Pp.214.

*Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (editors). 2018. **Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.** U.S. Global Change Research Program. Washington, DC, USA.

*Stiles, W.A. 2012. “Toolkit” for sea level rise adaption in Virginia. Chapter 6 in Ayyub, B.M. & M.S. Kearney (editors). **Sea Level Rise and Coastal Infrastructure: Prediction, Risks, and Solutions**. American Society of Civil Engineers (ASCE) Council on Disaster Risk Management, Monograph.

Tausz, M. & N. Grulke (editors). 2014. **Trees In A Changing Environment: Ecophysiology, Adaptation, & Future Survival** (Plant Ecophysiology Vol. 9). Springer Dordrecht Publishing, New York, NY.

*Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (editors). 2017. **U.S. Global Change Research Program Climate Science Special Report: Fourth National Climate Assessment, Volume I.** U.S. Global Change Research Program, Washington, DC, USA.

* = key references

Citation:

Coder, Kim D. 2023. Tree Health Care & Climate Variability. University of Georgia, Warnell School of Forestry & Natural Resources Outreach Publication WSFNR-23-27A. Pp.23.

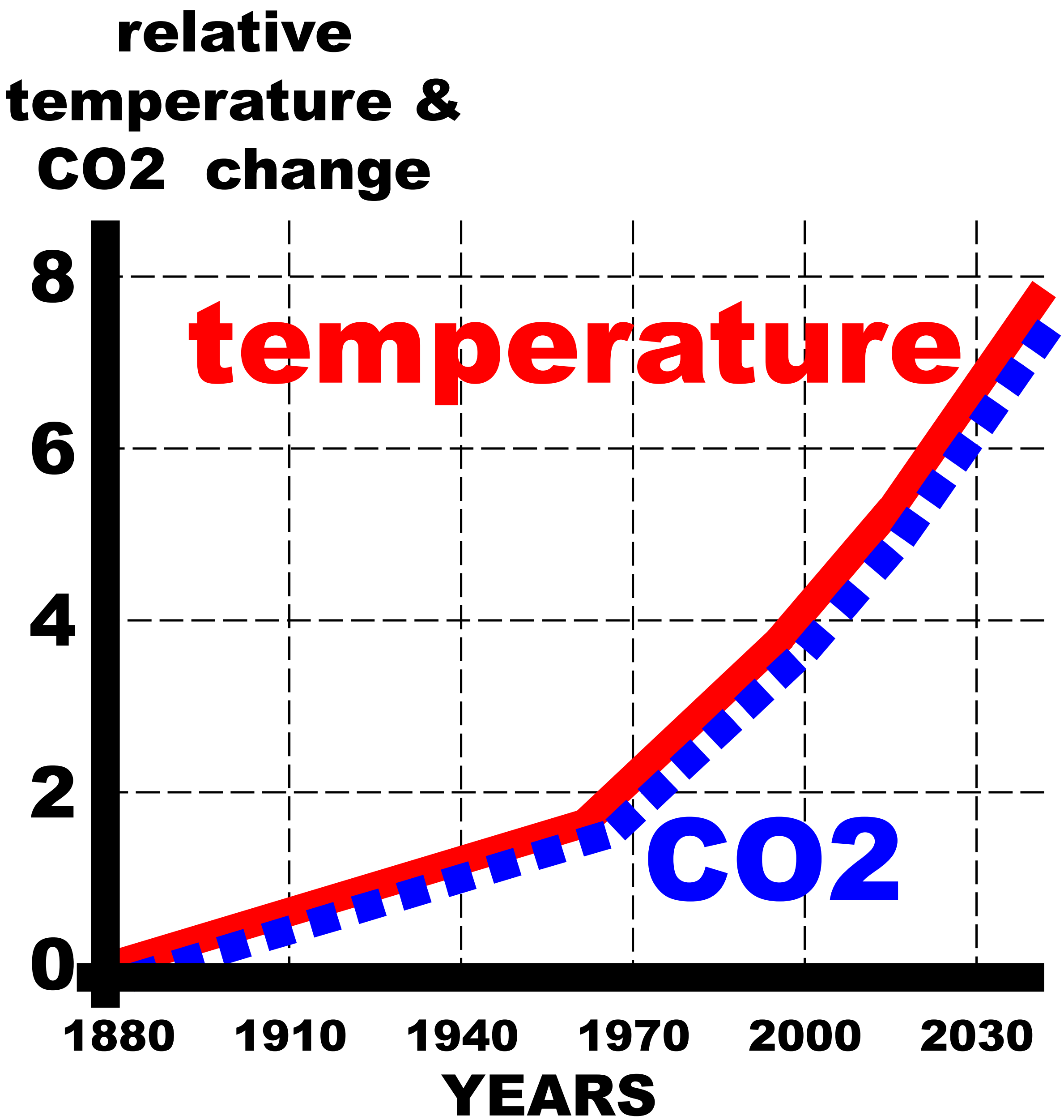

Figure 1: Combined relative carbon dioxide (CO2) concentration and global average surface temperture history and trend. (Emanuel 2018)

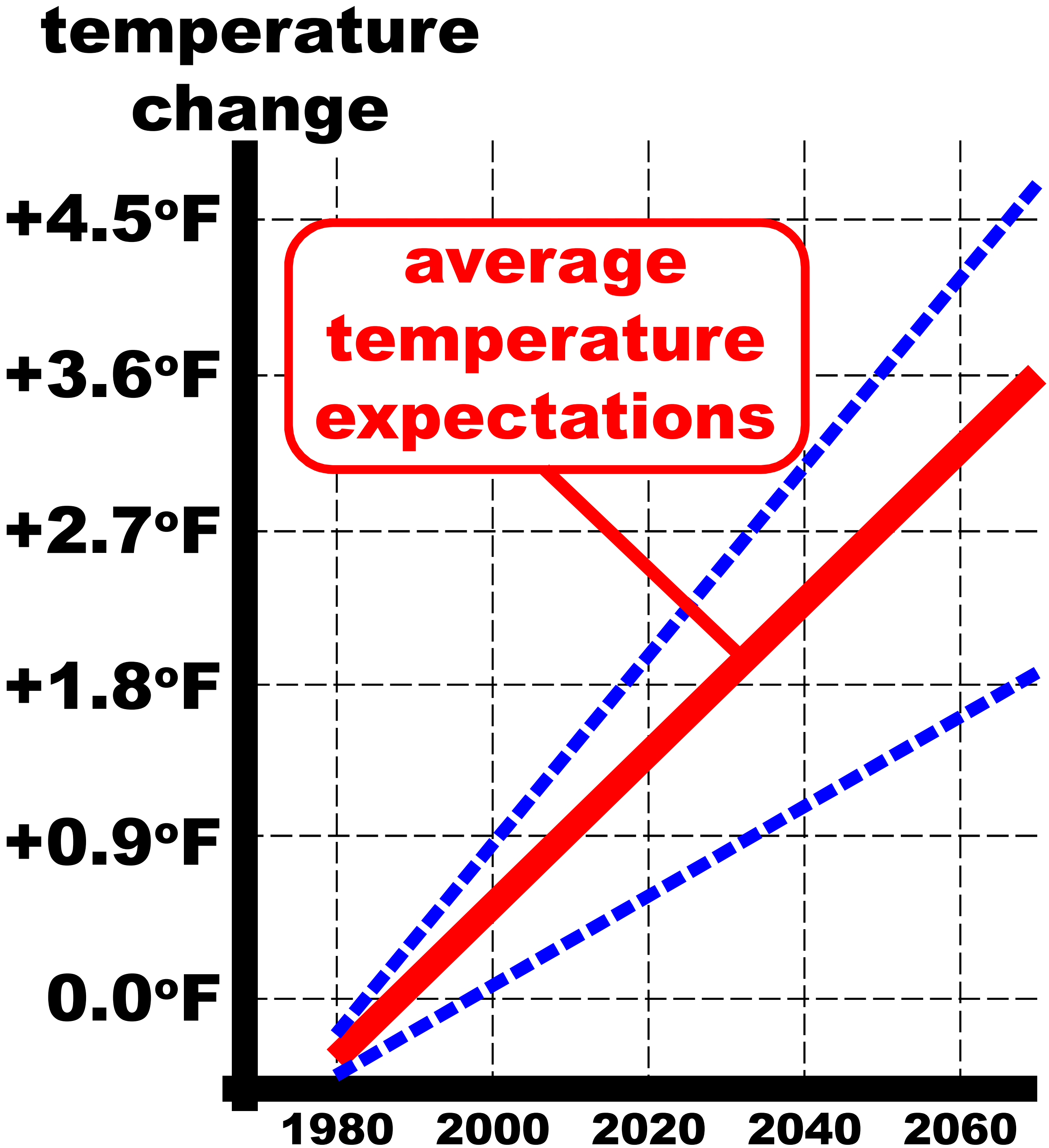

Figure 2: Conservative temperature change projection and 95% expectation boundaries. (after Mann & Kump 2015)

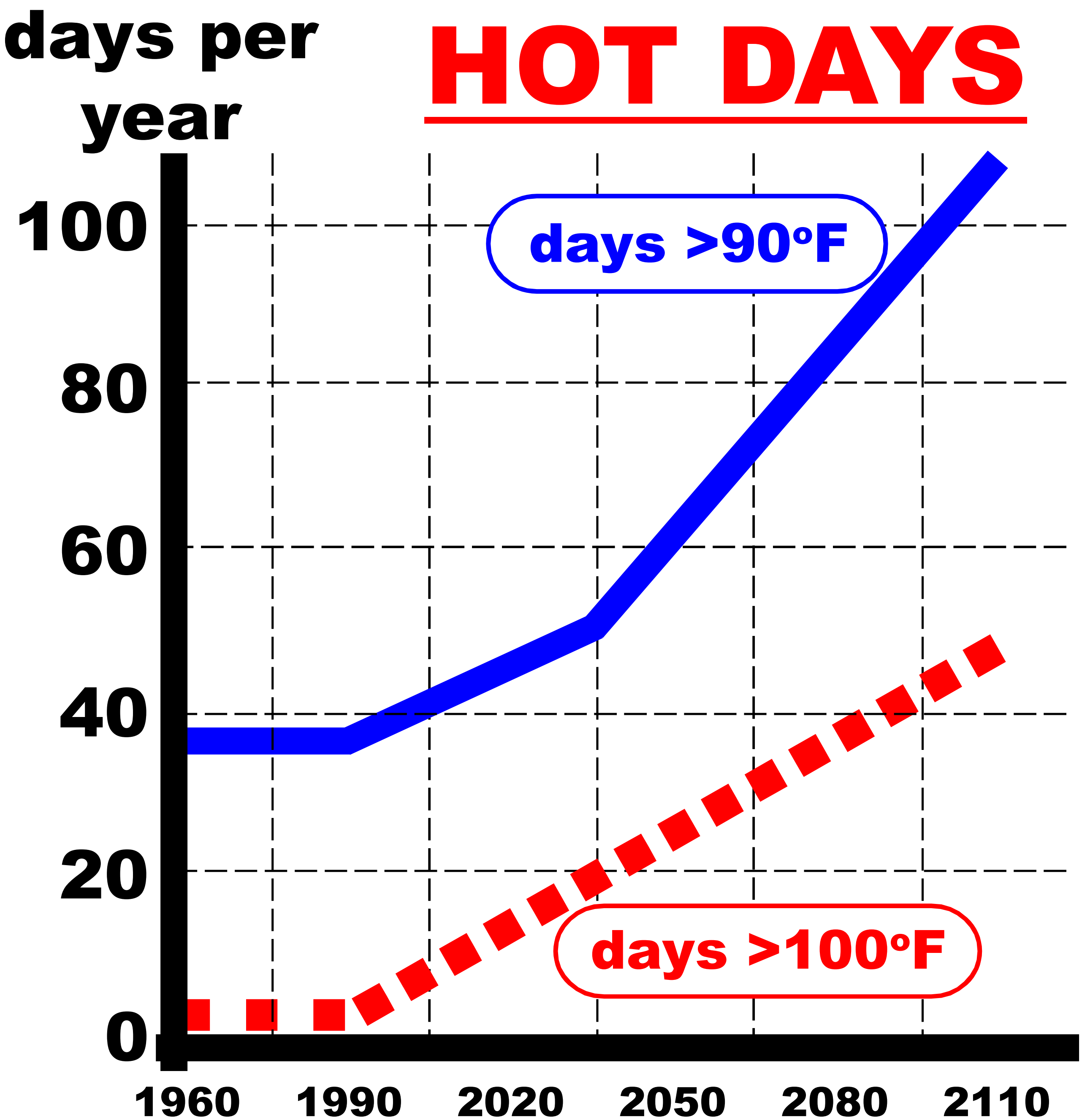

Figure 3: Example high temperature days projection for a central United States city. (after Mann & Kump 2015)

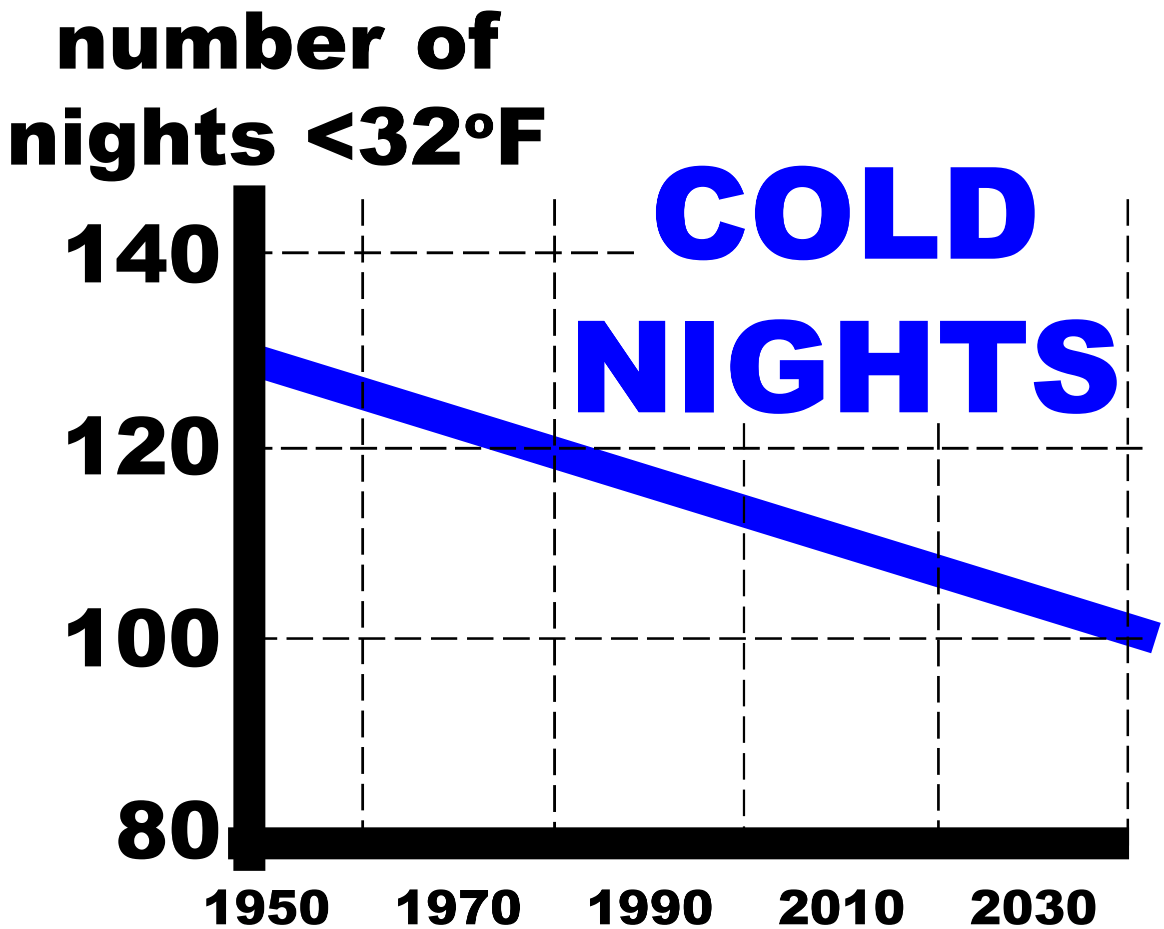

Figure 4: Trend line for number of nights per year below freezing in the central United States. (Mann & Kump 2015)

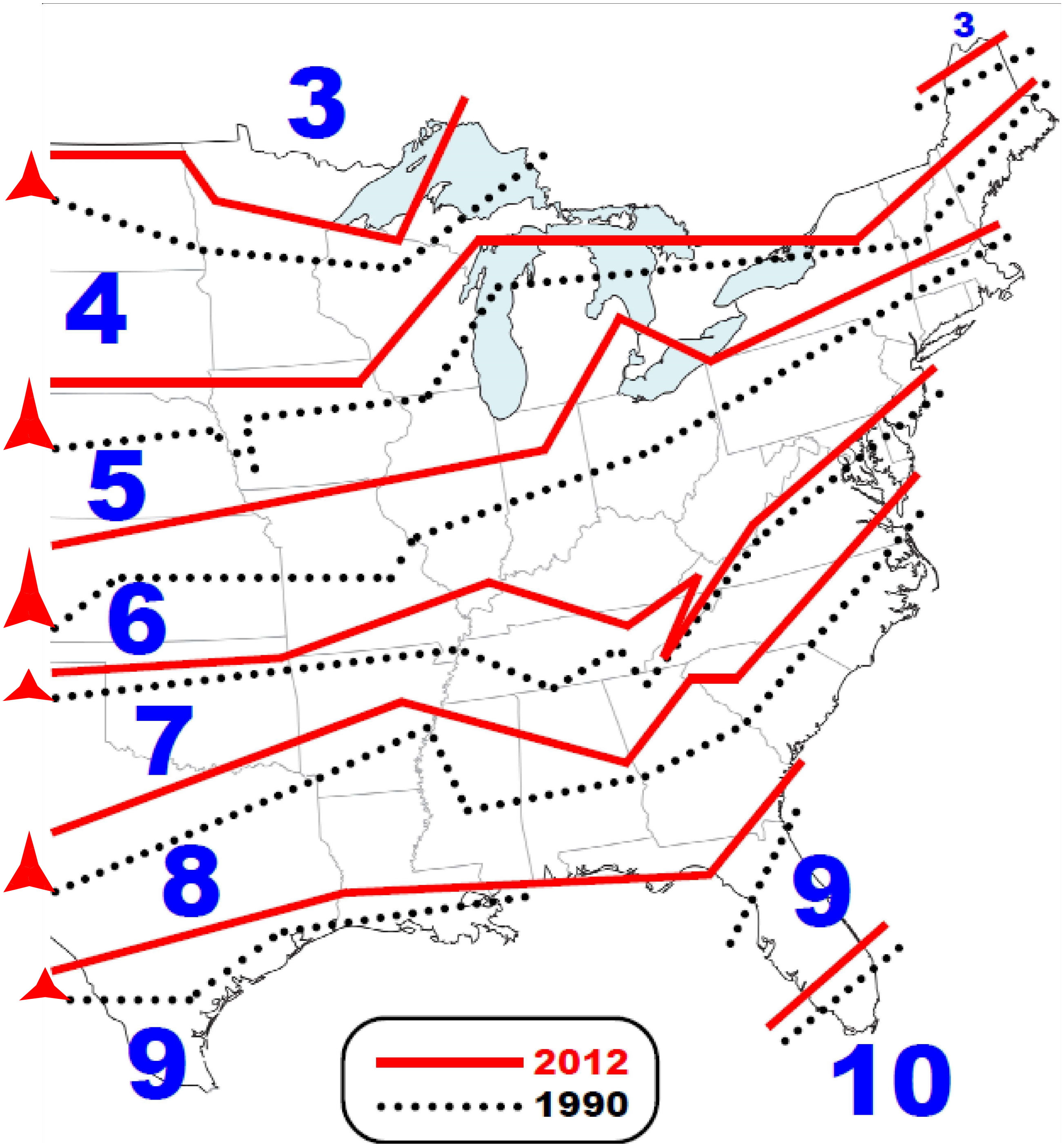

Figure 5: Northward change trends in USDA plant hardiness zones between 1990 and 2012 in the eastern United States.
(Coder 2021a)

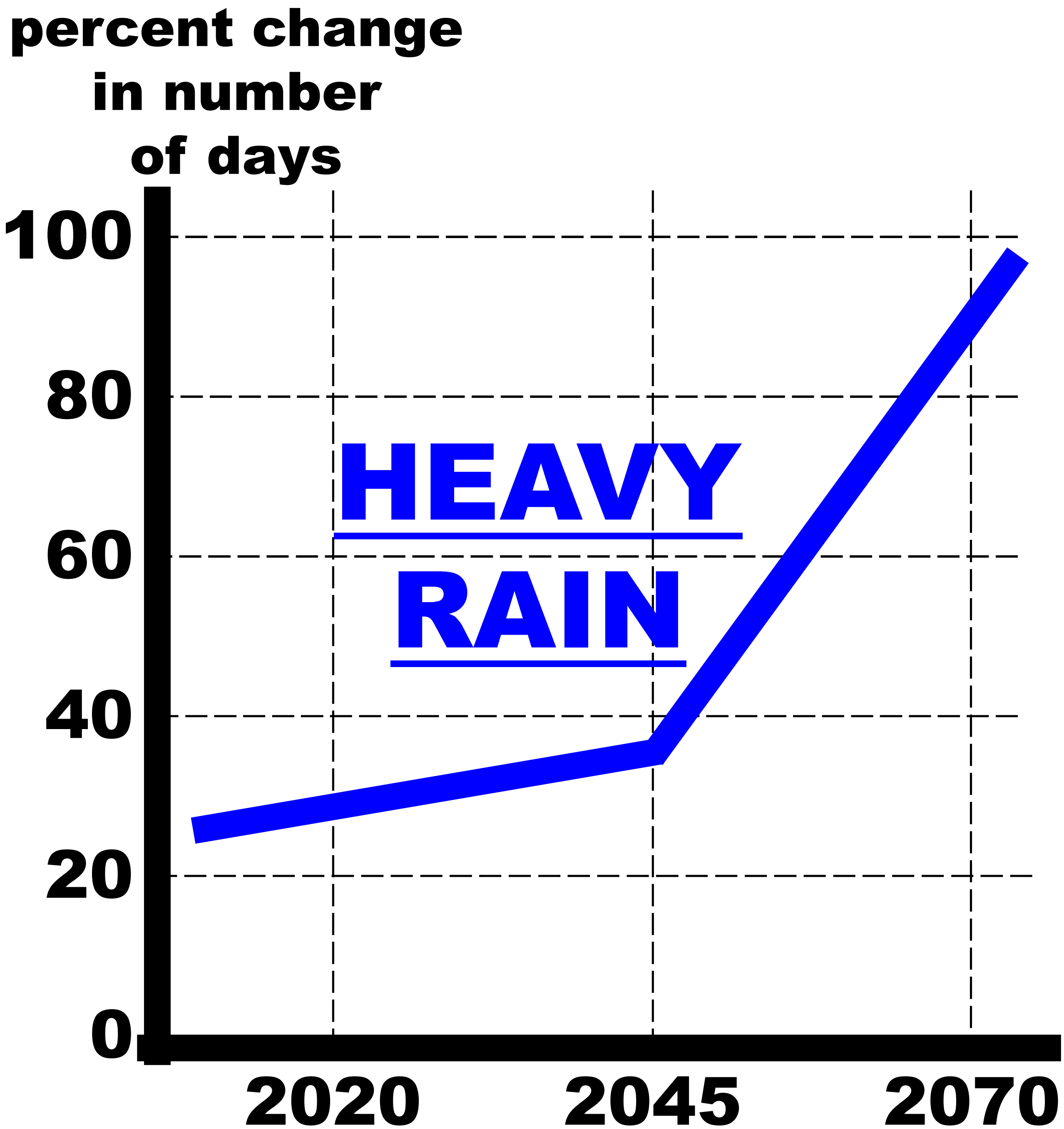

Figure 6: Percent change in the number of days per year with more than four (4) inches of rain.
(Reidmiller et.al. 2018 -- 4th NCA)

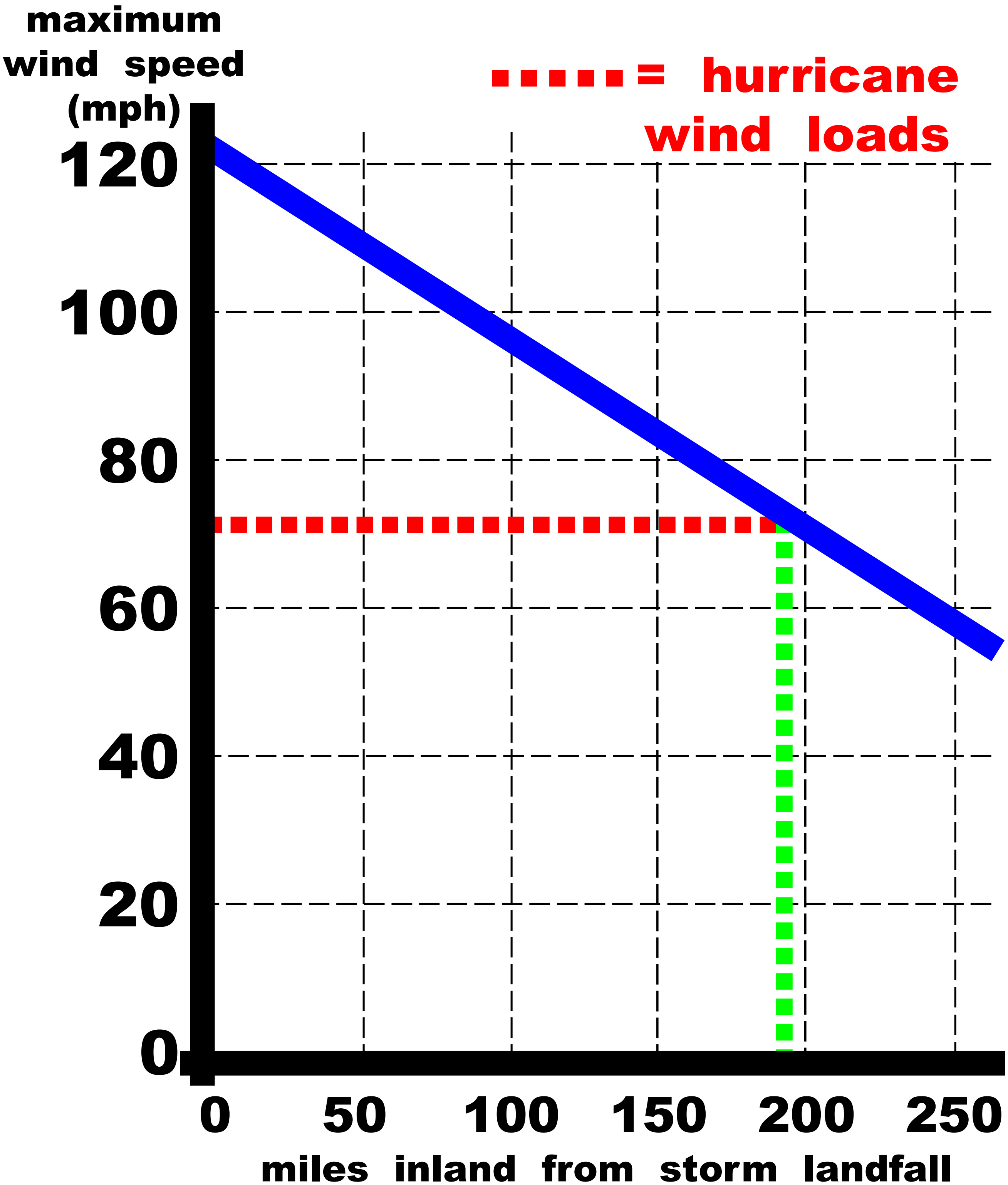

Figure 7: Estimated maximum wind speed at various distances inland from a category 3 hurricane landfall.
(NOAA web site data; Coder 2021b)

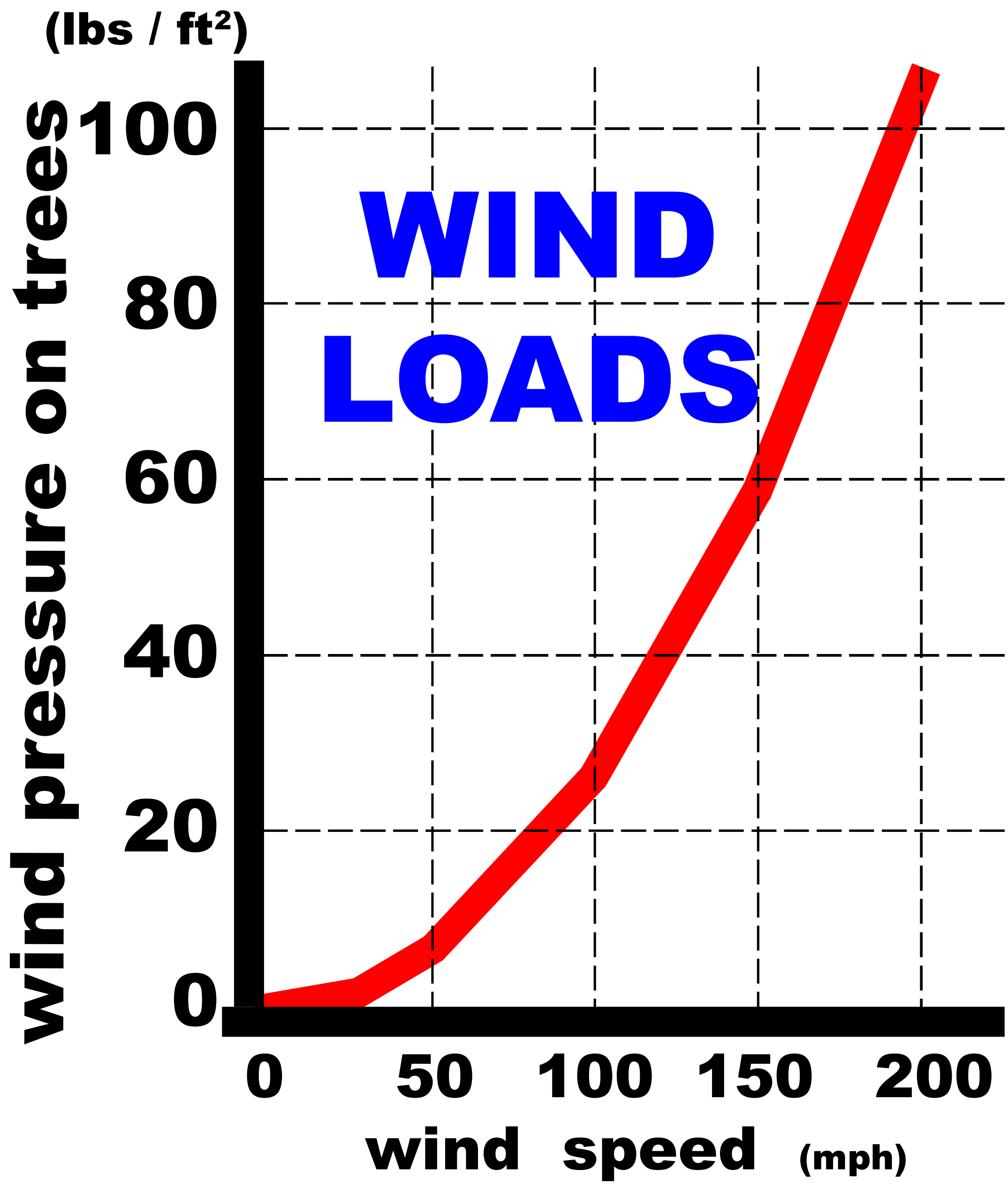

Figure 8: Estmated pressure of storm winds on trees in pounds per square feet of tree surface area across different wind speeds. (Coder 2021b)

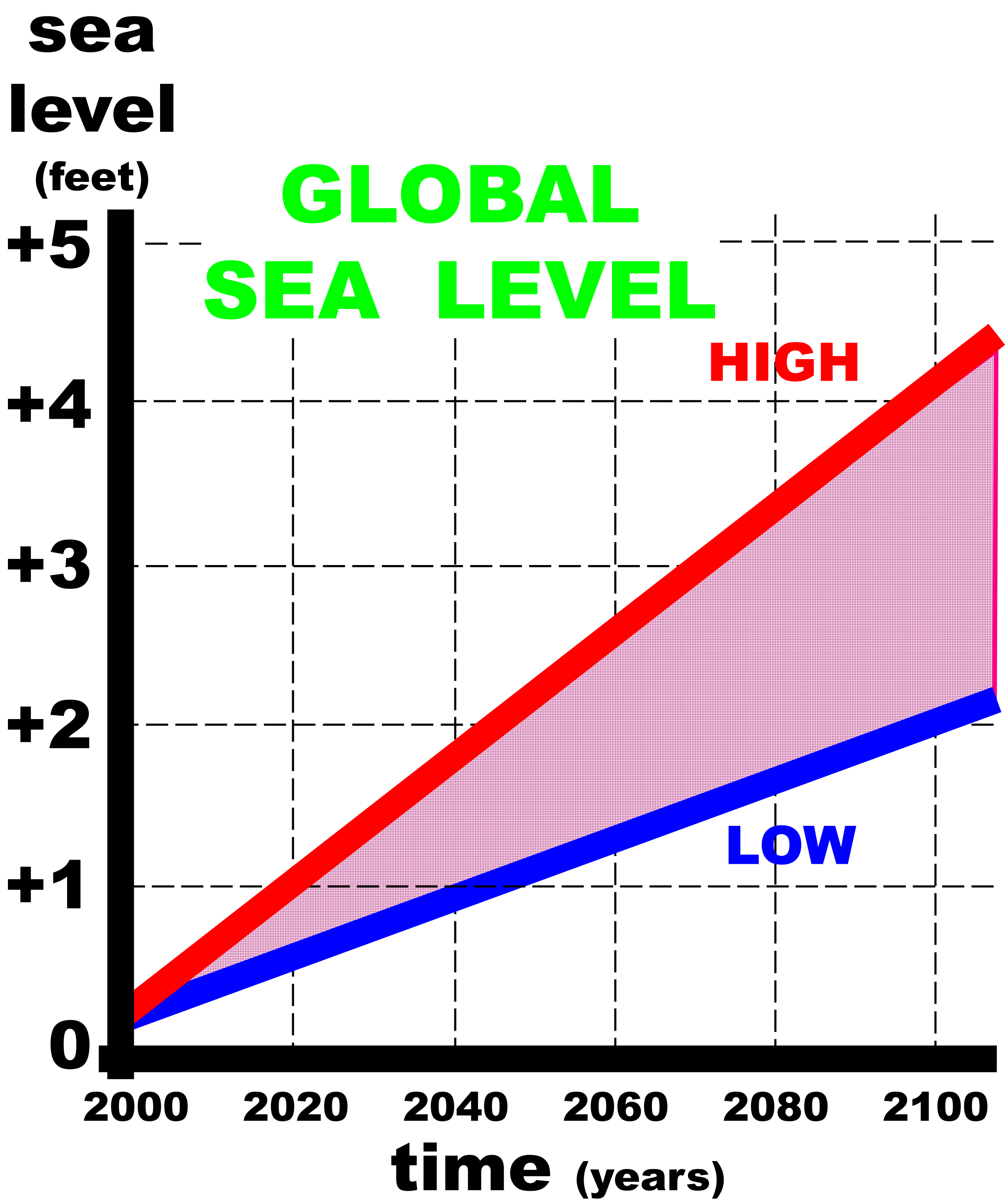

Figure 9: NOAA projected sea level increases in feet using an intermediate high and an intermediate low sea level change model. (after Hine et.al. 2016)

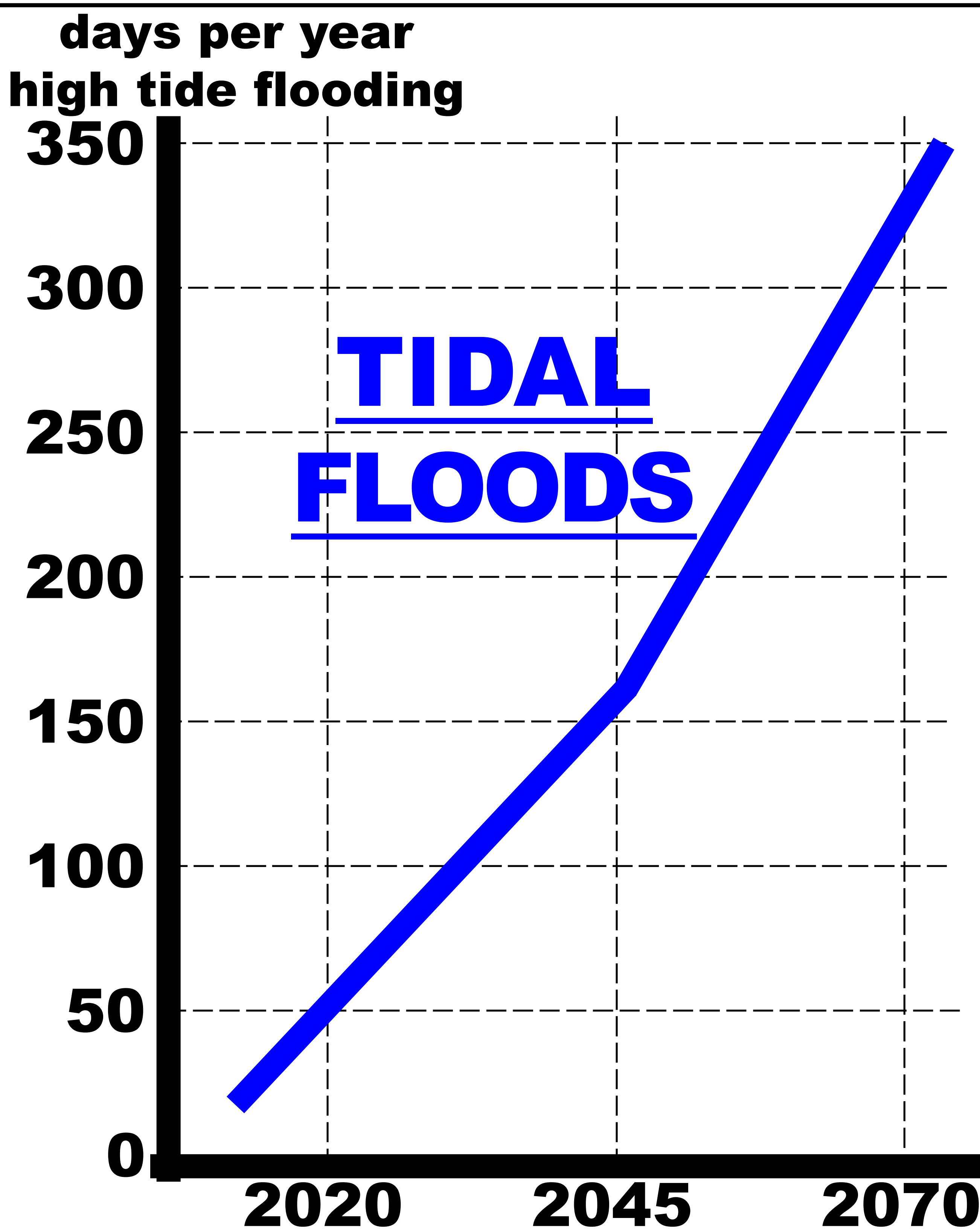

Figure 10: Number of days per year with high tide flooding under intermediate sea rise projections.
(Reidmiller et.al. 2018 -- 4th NCA)

Average Years Between Storm Surge Flood Events

severity	historic	2' rise	3' rise
moderate	7	0.3	0.1
major	27	1.7	0.3
record	81	7.3	1.7

Figure 11: Average number of years between historical storm surge flooding events with projections of two sea level rises. (Stiles 2012)

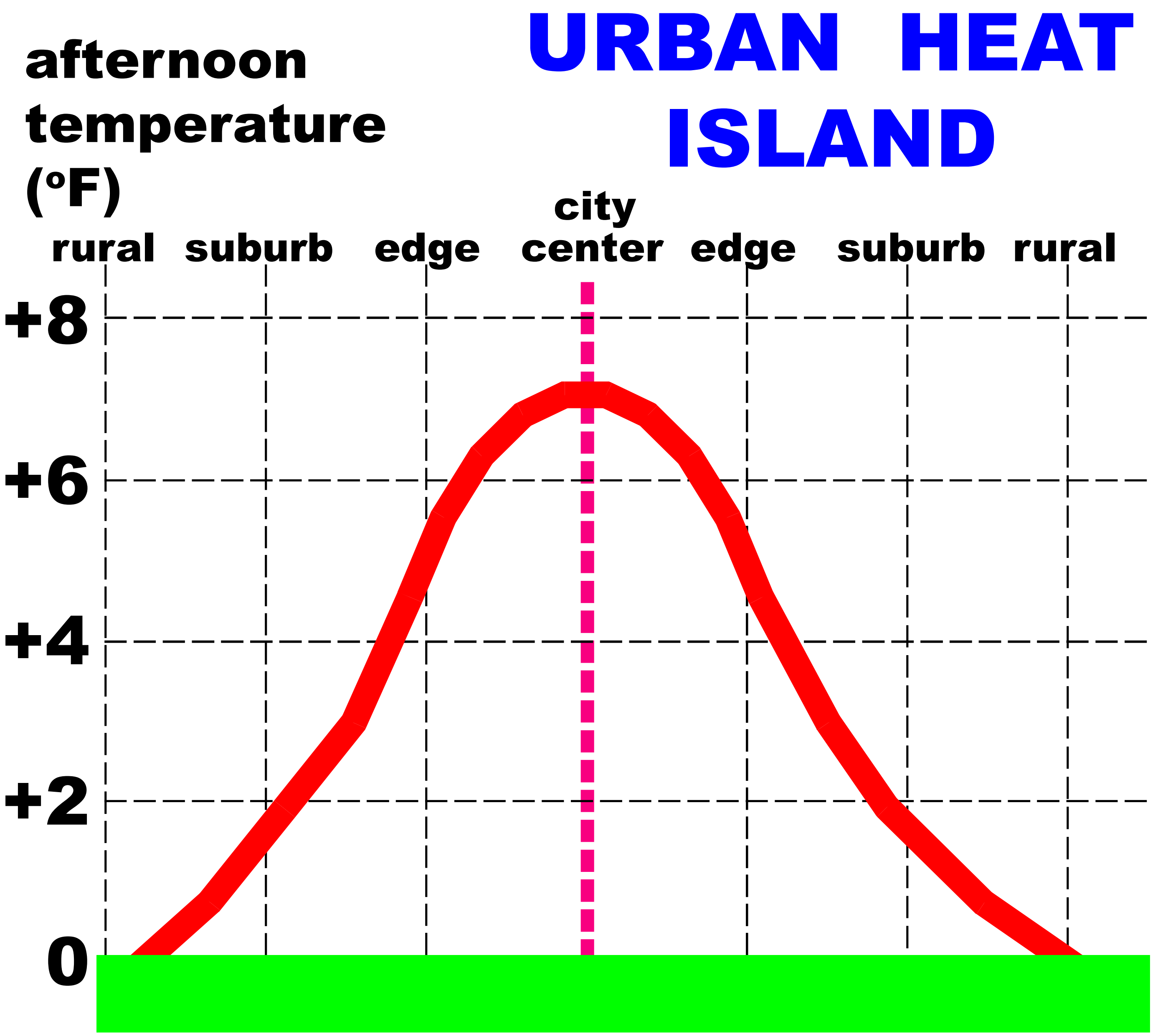

Figure 12: Late afternoon summer heating differences along a rural / urban gradient. Temperature differences double (2X) under extreme heat events.
(after Kelbaugh 2019)

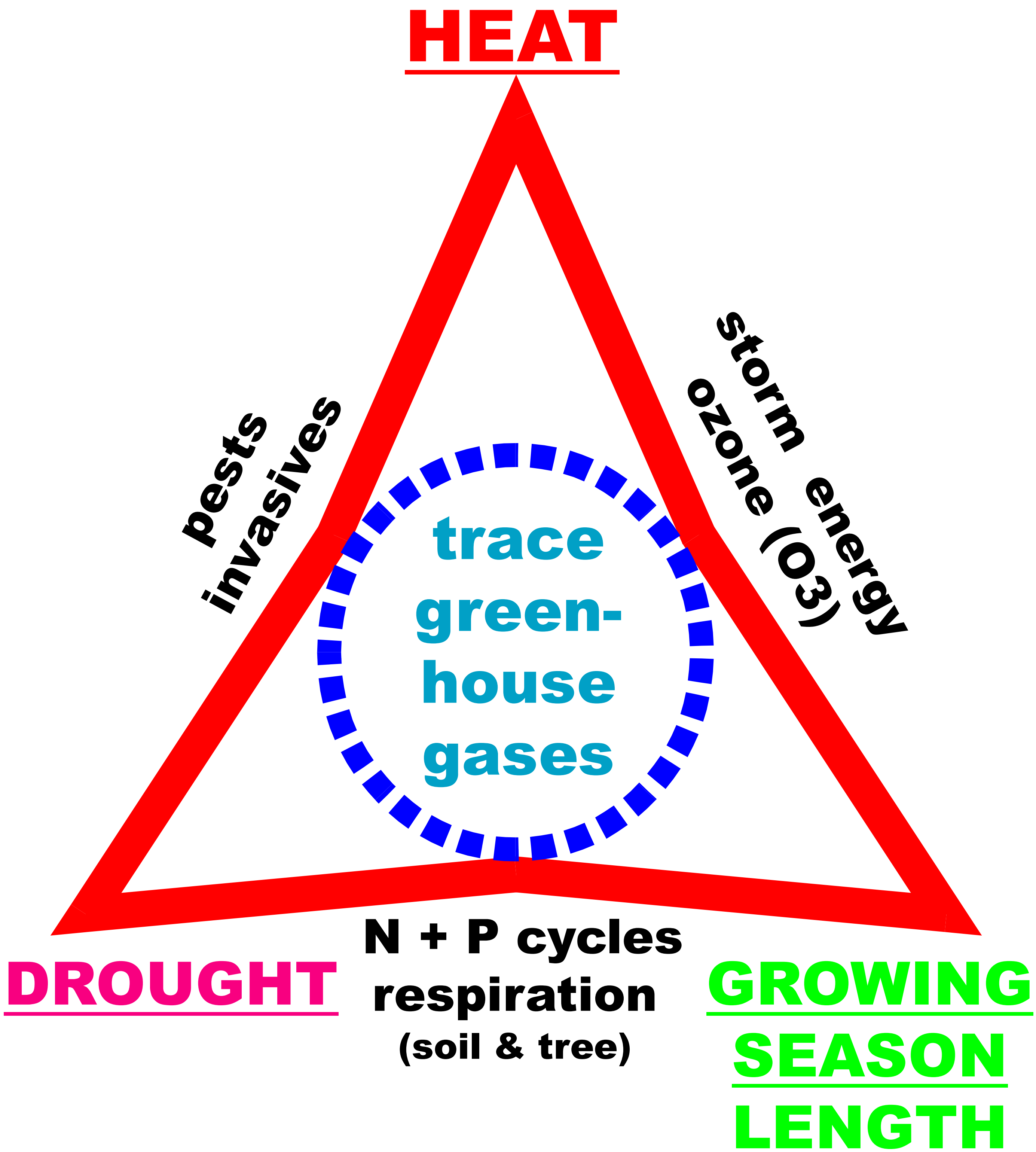

Figure 13: Primary and secondary components of climate variability impacts on trees.
(derived from Manning 2020)