Weathering water extremes in the changing climate of the Mid-Atlantic region

past trends and a glimpse into the future

Anthony Buda

USDA Agricultural Research Service

University Park, PA

University of Maryland Extension's Agricultural Nutrient Management Program Webinar Series

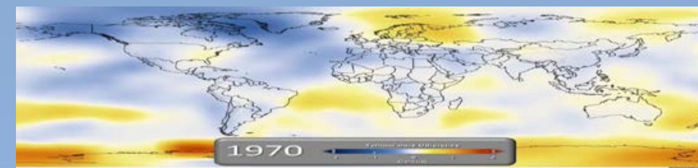
Monday, March, 27 2017

2:00 to 3:00 PM

Today's presentation

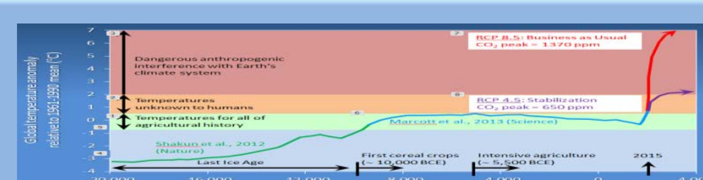
Climate change: from global to local

Anthropogenic climate change:
a view of recent national trends

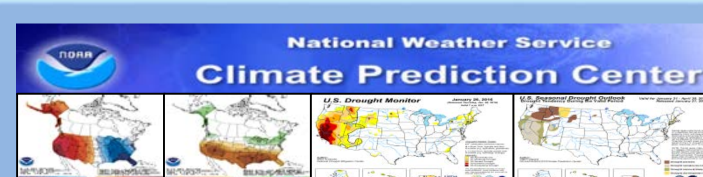


Recent climate change in PA:
evidence from a headwater basin

Projected climate change in PA:
what pathway are we on?

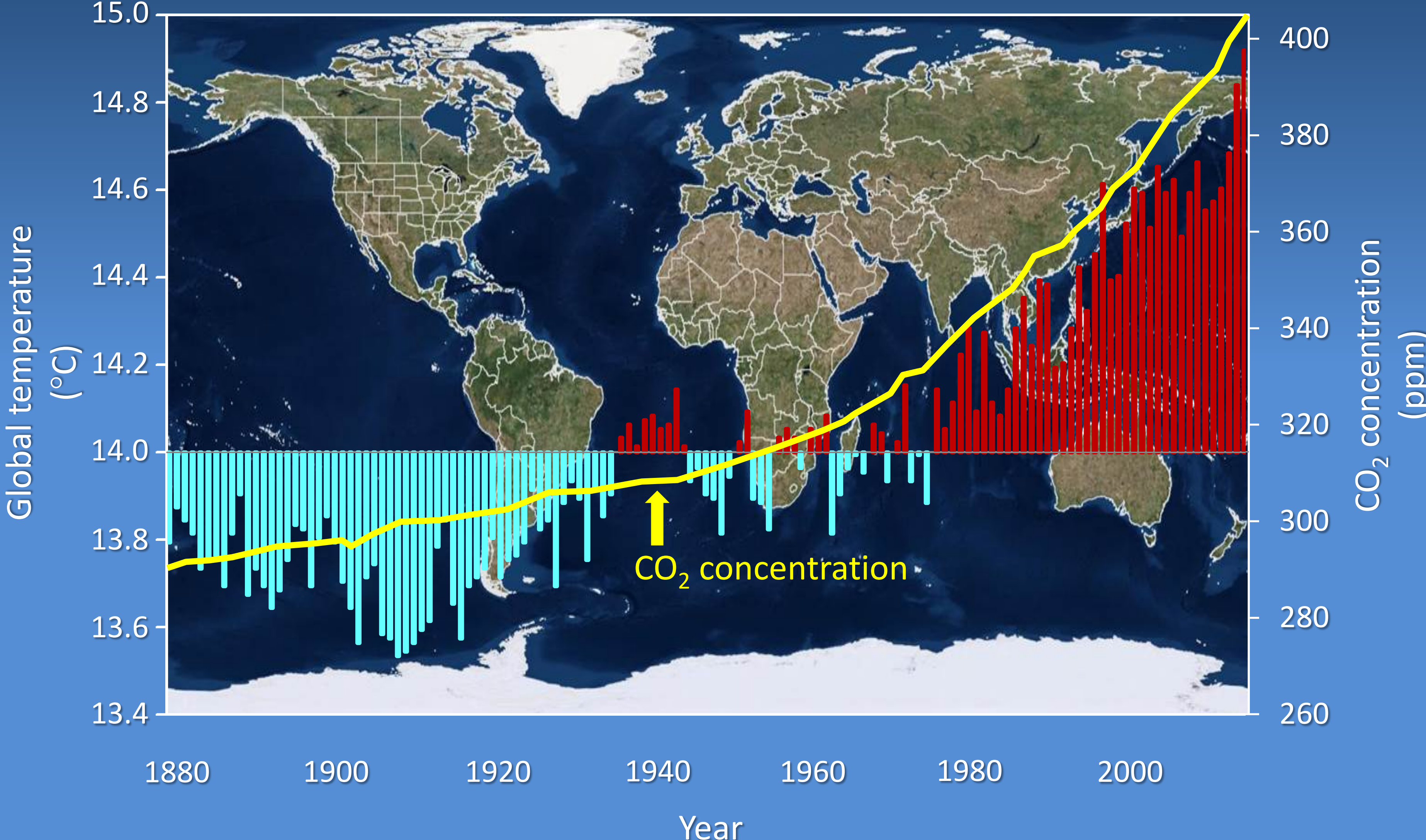


Where can I find more info?
viewing climate data online



The warming of the planet is unequivocal

global temperature is increasing in lock-step with CO_2



US National Climate Assessment, 2014; Karl et al., 2009

The relentless rise of atmospheric CO_2

a rise that's unprecedented over the past 800,000 years

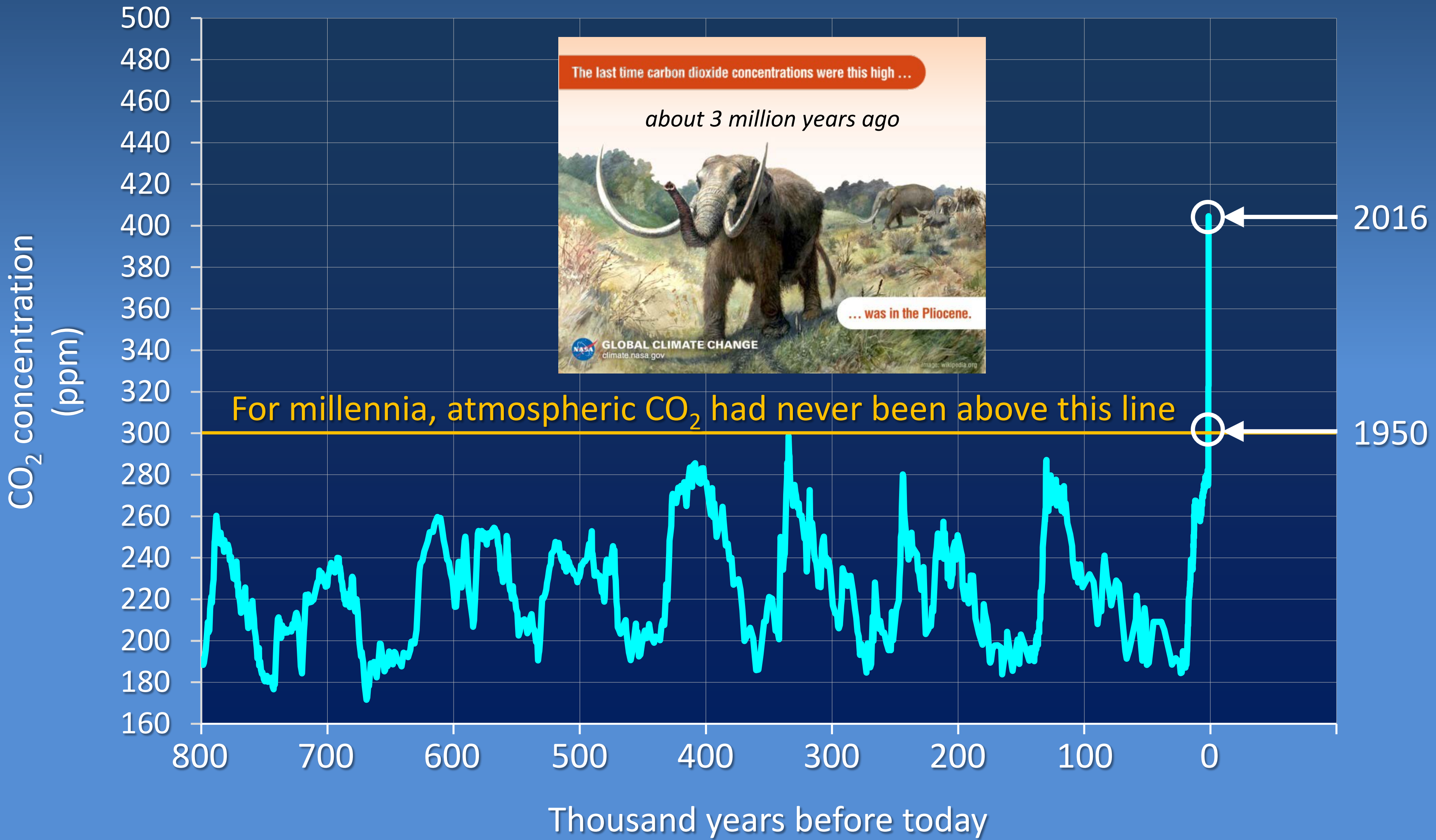


Image credit: http://climate.nasa.gov/evidence/. Data: blend of Vostok ice core data and Mauna Loa CO_2 record

2016, an incredibly warm year

Perhaps the warmest summer in several thousand years

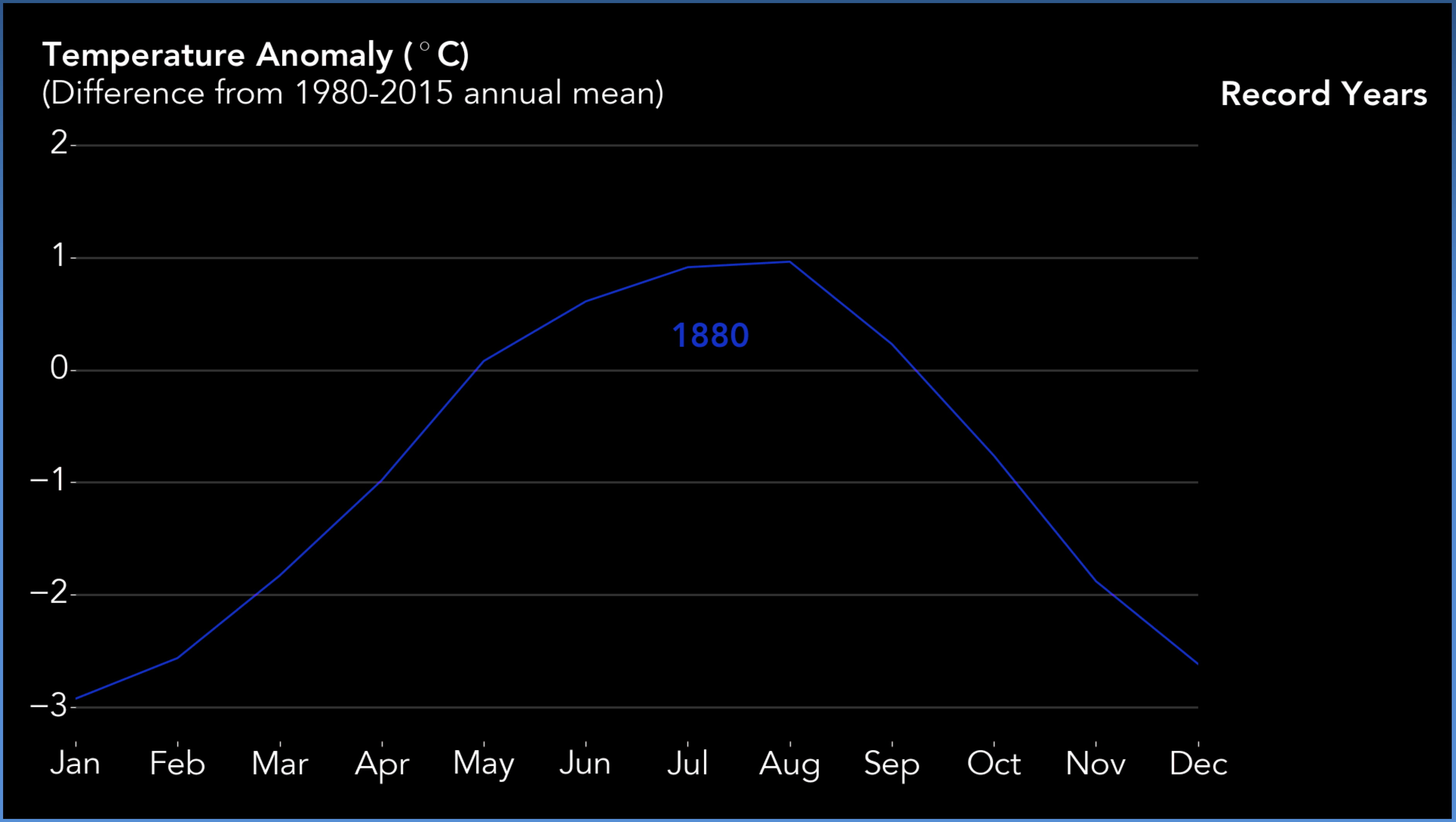


Chart by Joshua Stevens; based on data from the NASA Goddard Institute for Space Studies.

And the global records keep on falling

A few temperature streaks worth watching

2015

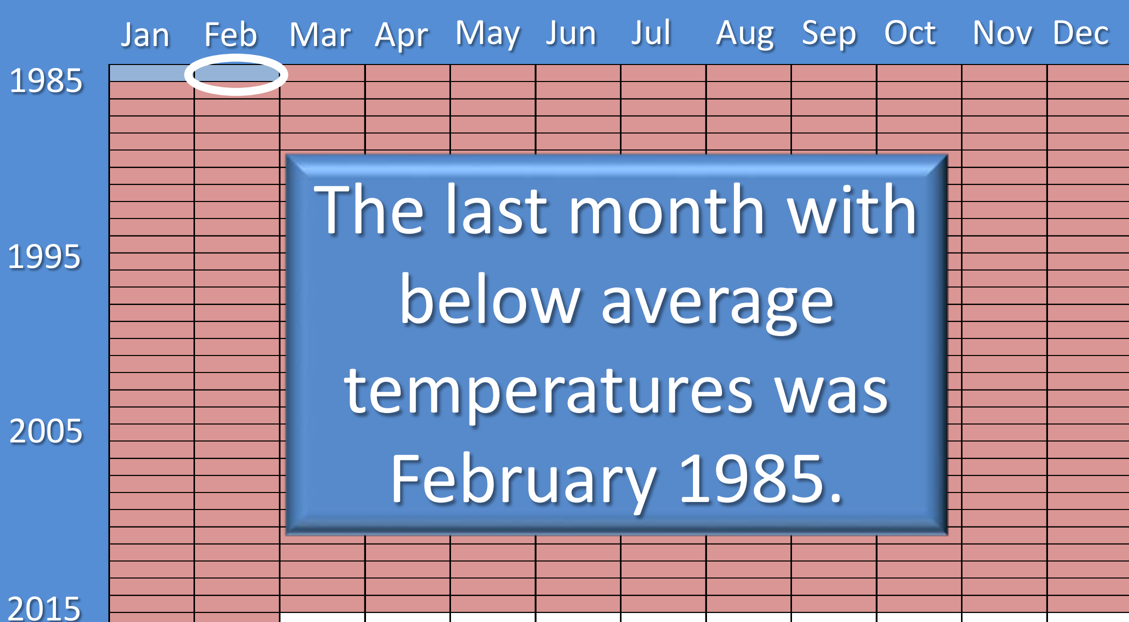
January	February	March
Above normal	Above normal	Above normal
April	**May**	**June**
Above normal	All time record*	All time record*
July	**August**	**September**
All time record*	All time record*	All time record
October	**November**	**December**
All time record	All time record	All time record

2016

January	February	March
All time record	All time record	All time record
April	**May**	**June**
All time record	All time record	All time record
July	**August**	**September**
All time record	All time record	Above normal
October	**November**	**December**
Above normal	Above normal	Above normal

*Set the all time temperature record at that time before being broken in 2016.

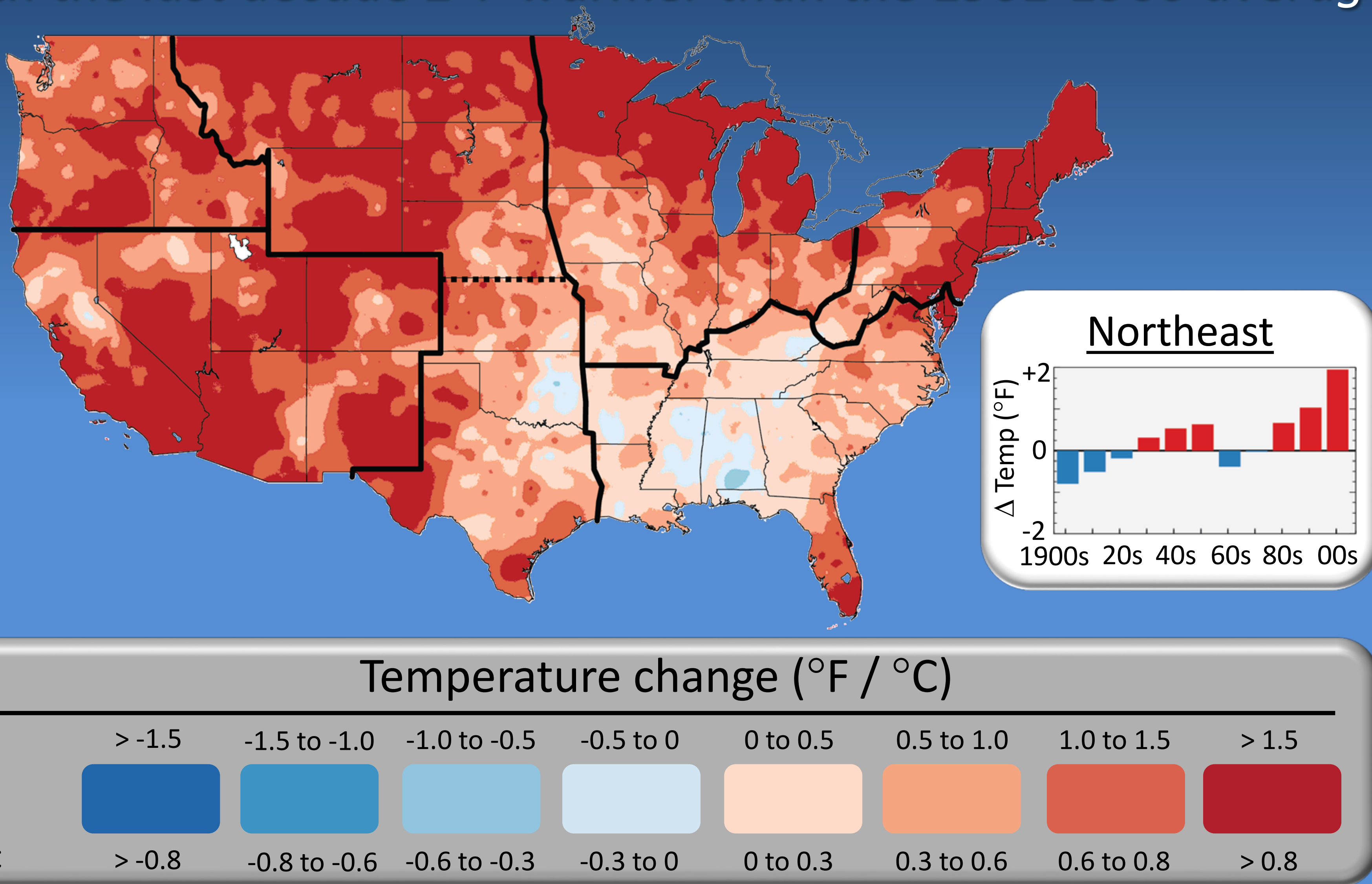
All-time monthly temperature records were broken for 16 straight months (May 2015 to August 2016).



February 2017 was the 386th consecutive month with temperatures at least nominally above the 20th century average.

Temperatures are rising all across the US

with the last decade 2°F warmer than the 1901-1960 average



US National Climate Assessment, 2014

Extreme summer heat is more common

temperature distributions are shifting toward hotter extremes

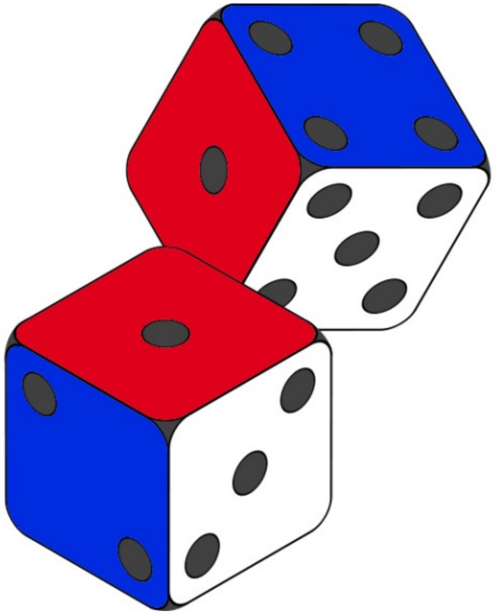
National Aeronautics and Space Administration
Goddard Institute for Space Studies

Goddard Space Flight Center
Sciences and Exploration Directorate
Earth Sciences Division

The New Climate Dice: Public Perception of Climate Change

By James Hansen, Makiko Sato, and Reto Ruedy – August 2012

Our climate dice, featuring two sides red for "hot", two sides blue for "cold", and two sides white for "normal" in 1951-1980, are now loaded. *We need four red sides to characterize 21st Century climate*.

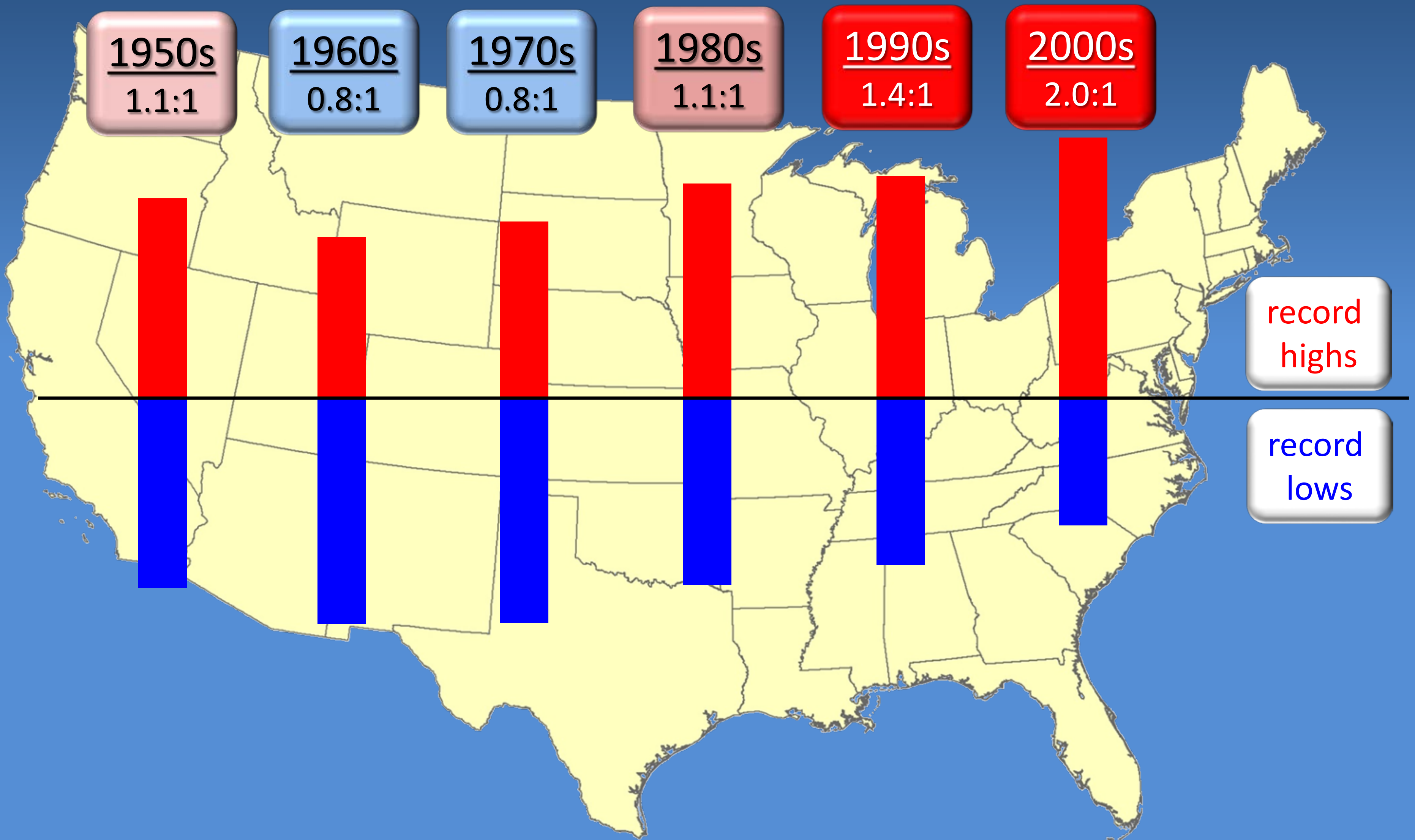


http://www.giss.nasa.gov/research/briefs/hansen_17/

NASA/Goddard Space Flight Center GISS and Scientific Visualization Studio; Hansen et al., 2013 (PNAS)

Record highs outpacing record lows

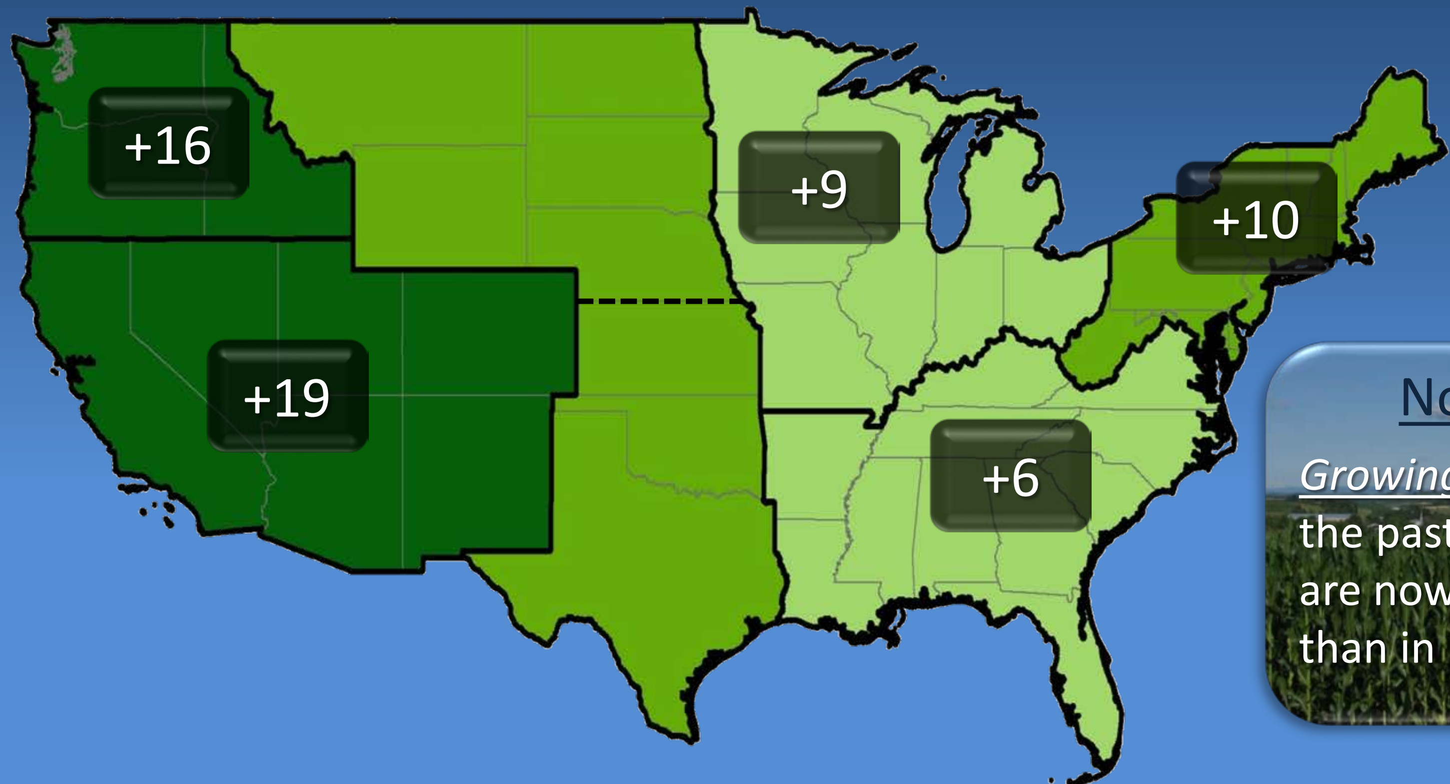
with highs exceeding lows by 2:1 over the past decade



Meehl et al., 2009 (Geophysical Research Letters)

Seasons are shifting

with higher temperatures affording longer growing seasons



Northeast

Growing seasons over the past two decades are now *10 days longer* than in 1901 to 1961.

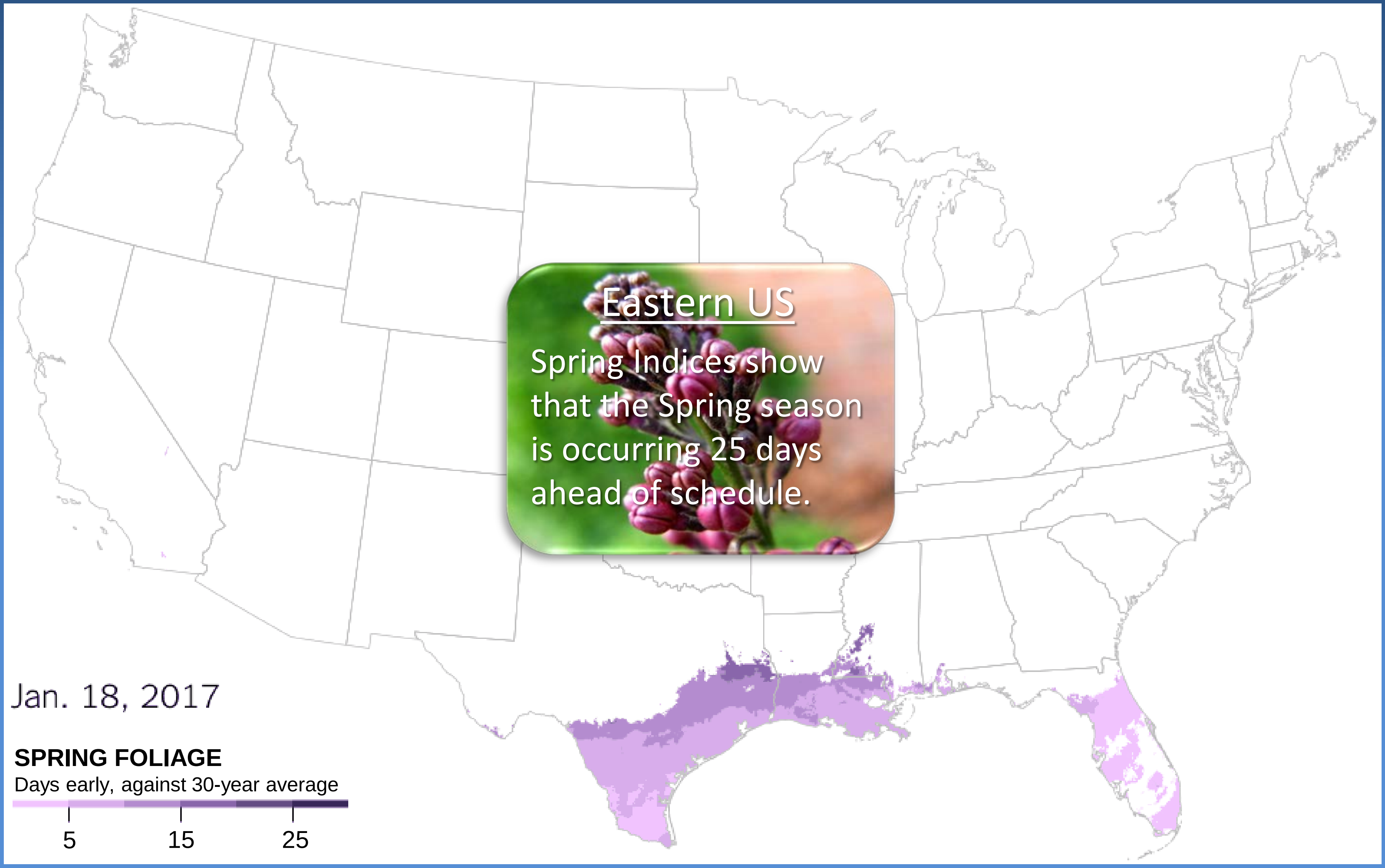
Change in growing season length (days)

0 to 4 | 5 to 9 | 10 to 14 | >15

Menne et al., 2012; US National Climate Assessment, 2014

Spring is advancing much faster

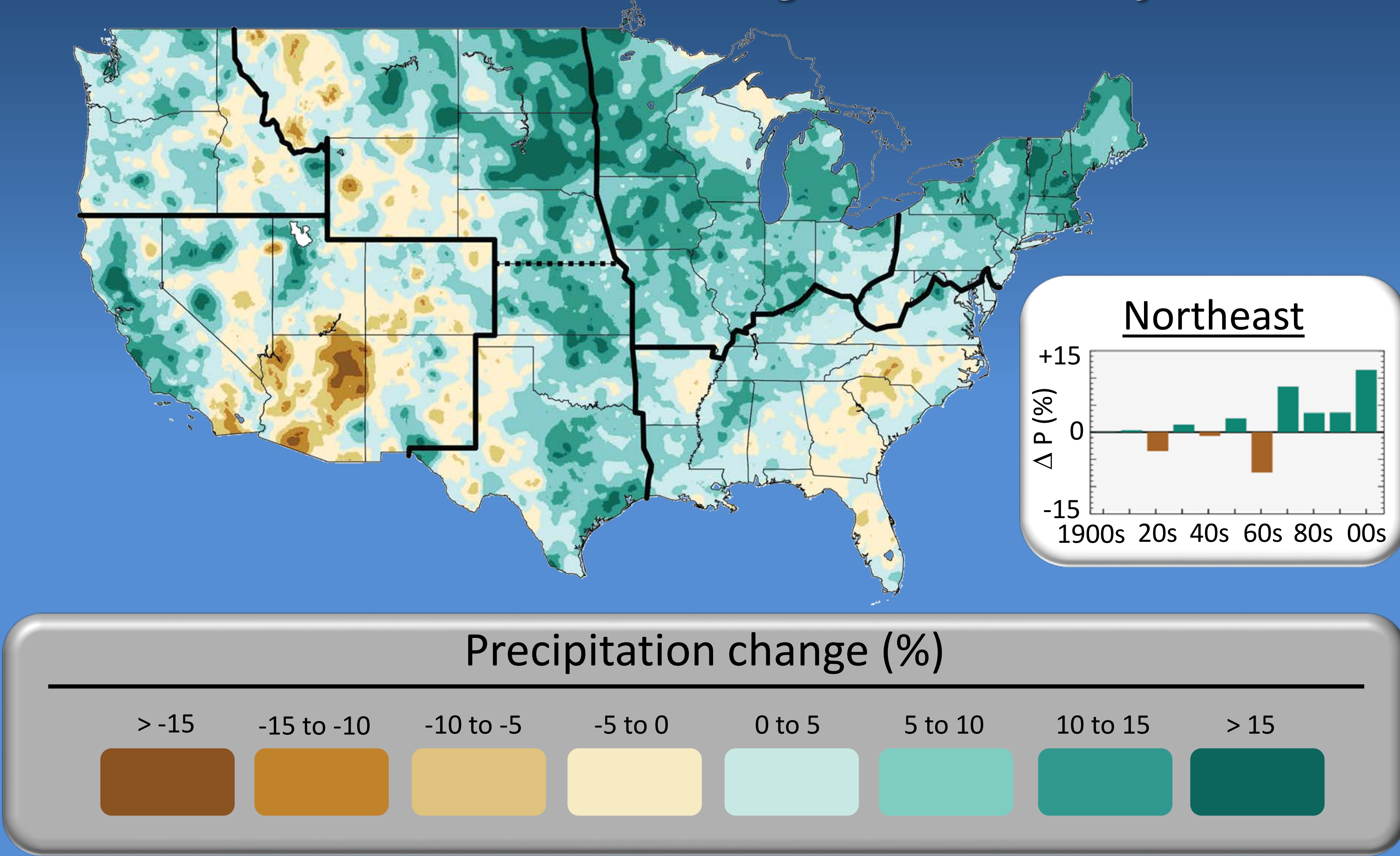
with Spring 2017 occurring up to 25 days earlier than normal



New York Times; USA National Phenology Network, 2017; World Weather Attribution

Annual precipitation amounts are changing

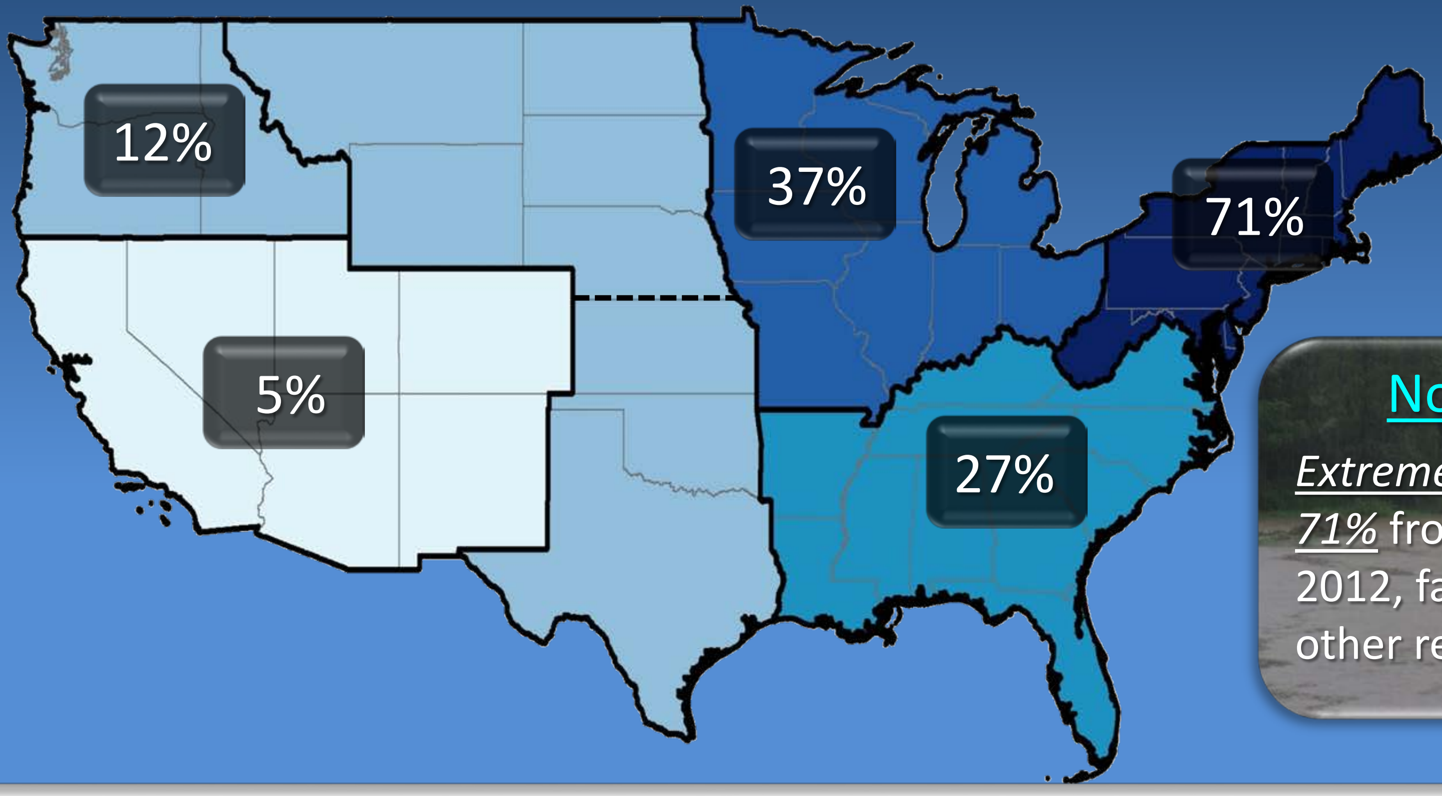
with the Northeast seeing increased rainfall



US National Climate Assessment, 2014

Extreme rainfalls are more frequent, too

especially in the Northeast



Northeast

Extreme rains rose by 71% from 1958 to 2012, faster than any other region in the US.

Percent change in extreme rainfall (heaviest 1% of daily events)

<0	0 to 9	10 to 19	20 to 29	30 to 39	>40

Karl et al., 2009; US National Climate Assessment, 2014

For instance: the flash floods in Ellicott City

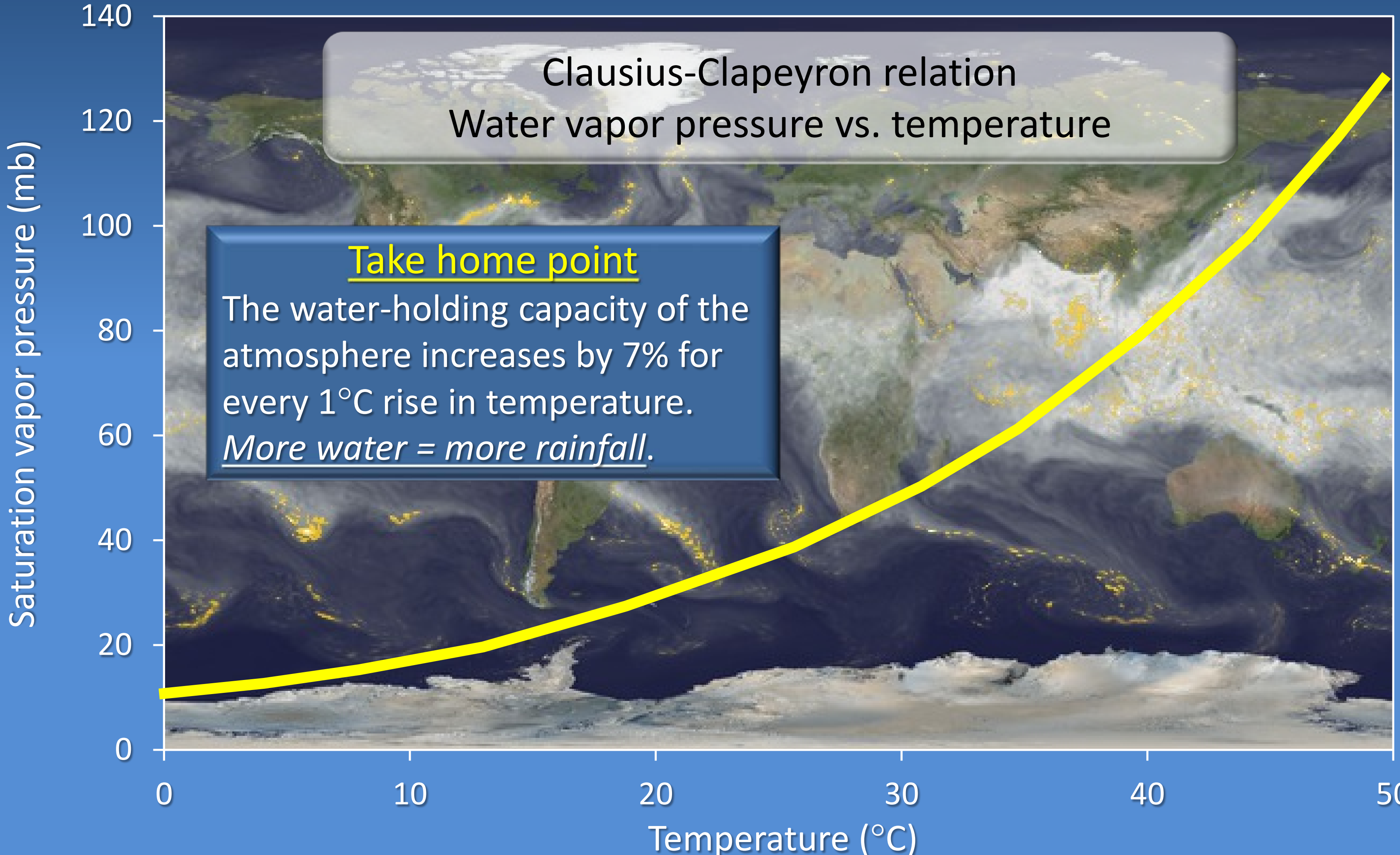
A 1,000-year storm that yielded 3 months of rain in 2 hours

Flash flooding in Ellicott City, MD
on July 30, 2016

Photo credit: Scott Weaver via the Capital Weather Gang – Washington Post)

The atmosphere now holds more water

a consequence of increasing atmospheric temperatures



US National Climate Assessment, 2014

We have entered a new normal

all weather events are affected by climate change

nature climate change

PERSPECTIVE

PUBLISHED ONLINE: 22 JUNE 2015 | DOI: 10.1038/NCLIMATE2657

Attribution of climate extreme events

Kevin E. Trenberth[1], John T. Fasullo[1] and Theodore G. Shepherd[2]

"The climate is changing: we have a new normal. The environment in which all weather events occur is not what it used to be. All storms, without exception, are different. Even if most of them look just like the ones we used to have, they are not the same."

Trenberth et al., 2015 (Nature Climate Change)

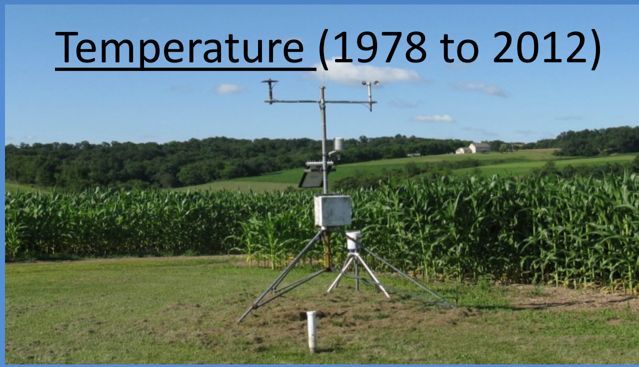
USDA's LTAR Network

serving as a sentinel to changes in climate and hydrology

LTAR Shared Research Strategy, 2013

The Mahantango Creek Watershed

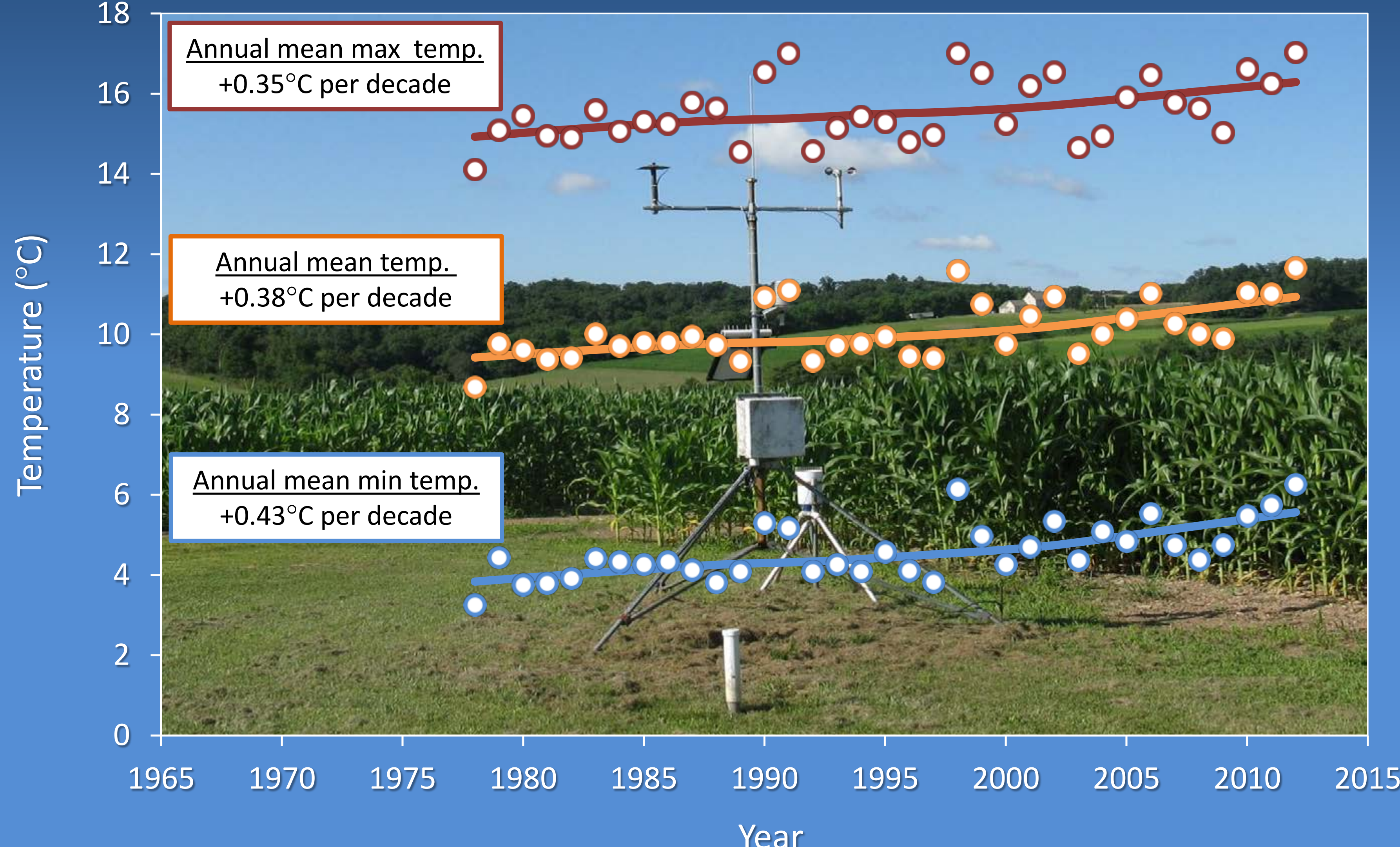
an ideal place to assess long-term trends in hydroclimate



Buda et al., 2011a, b (WRR)

Steadily rising temperatures

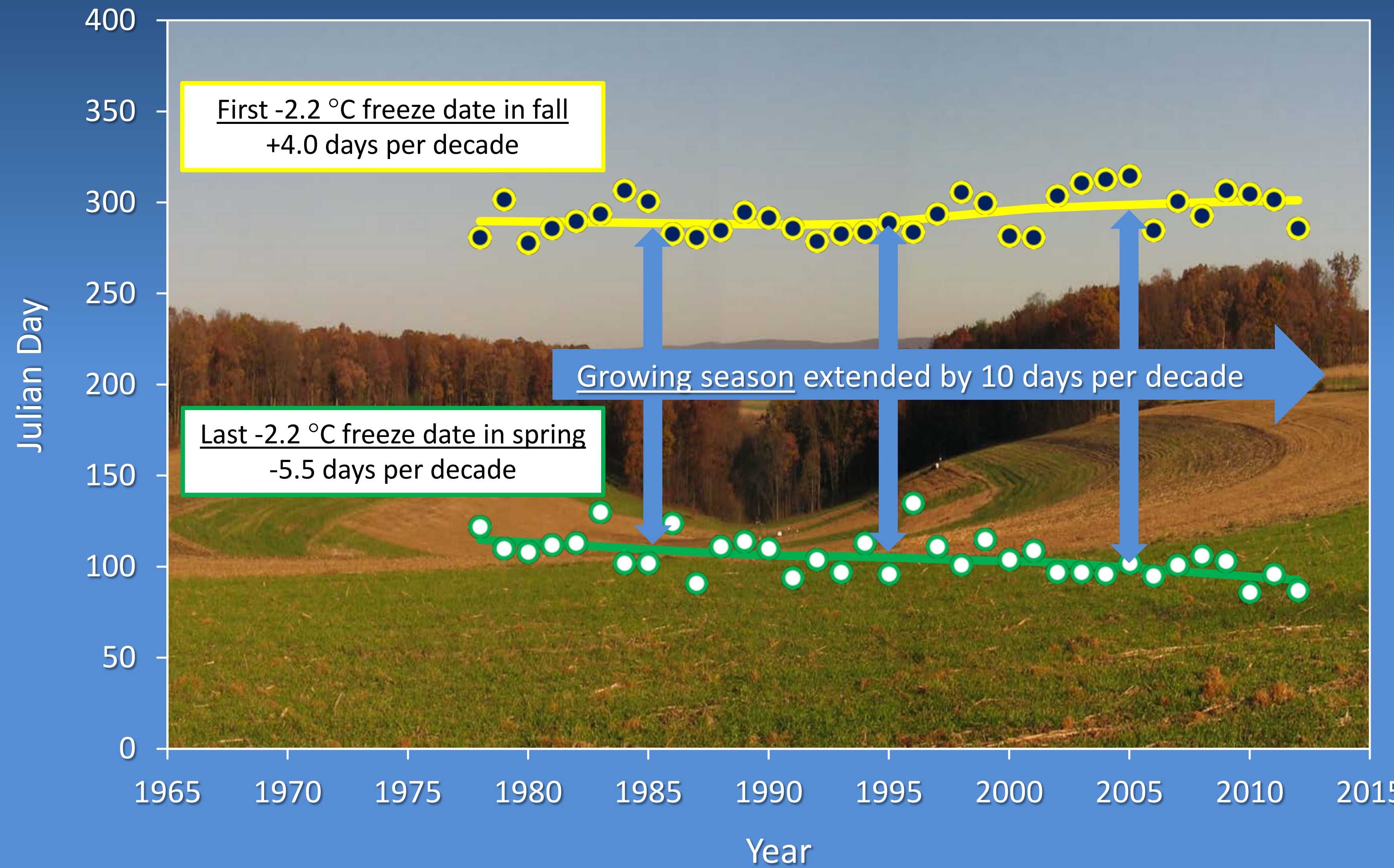
disproportionate increase in minimum temperatures



Lu et al., 2015 (J. Hydrol: RS)

Shifting seasons

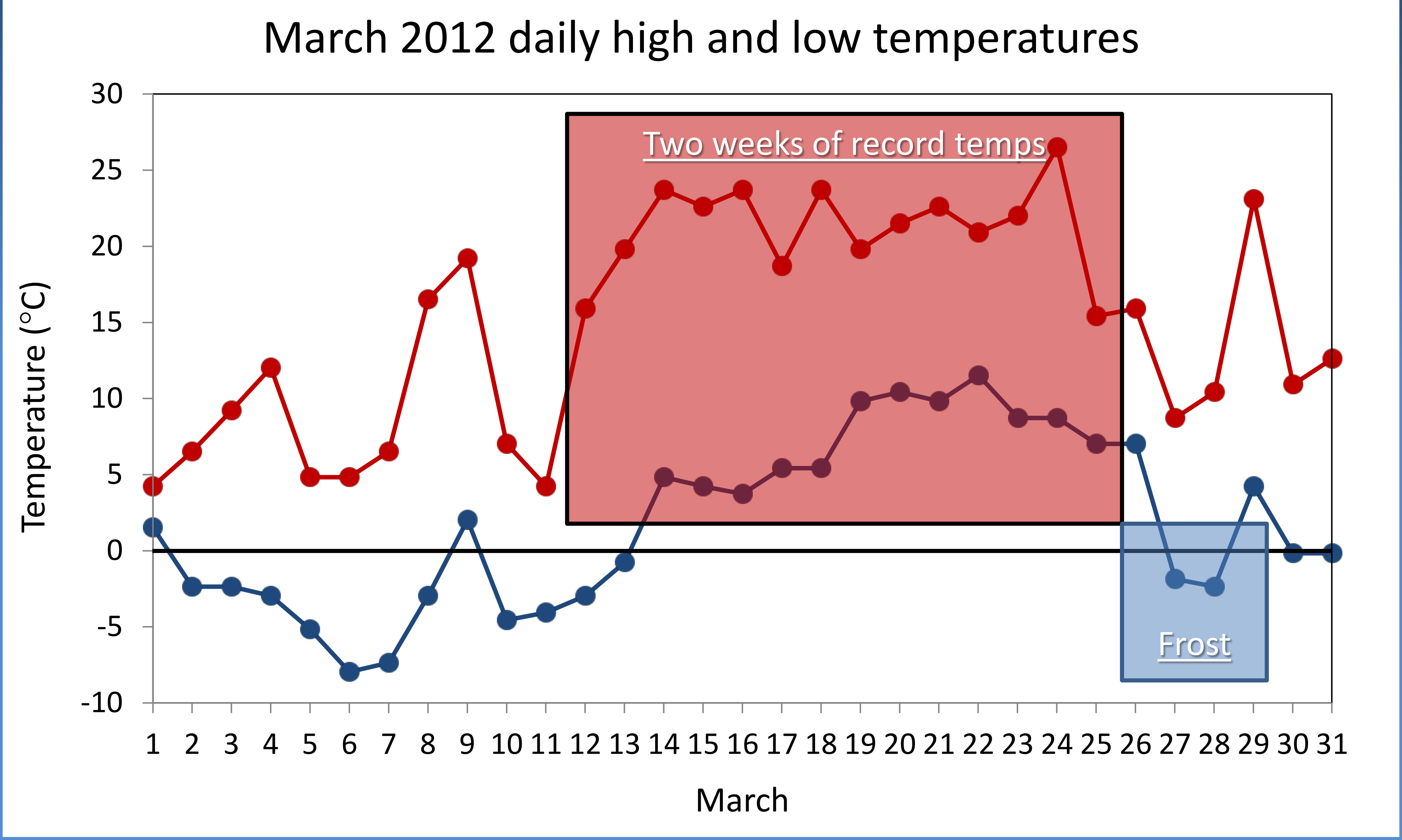
growing season has increased from 180 to 200 days per year



Lu et al., 2015 (J. Hydrol: RS)

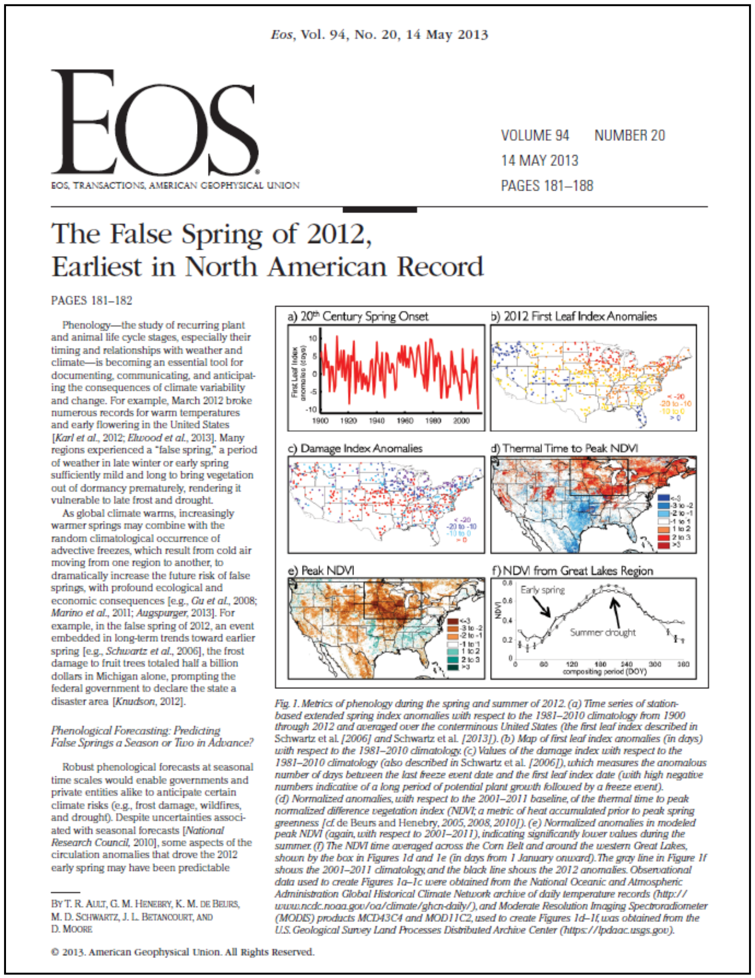
Shifting seasons

Summer in March, 2012; record heat followed by frost



Shifting seasons

false springs and late season frosts still threaten crops



Eos, Vol. 94, No. 20, 14 May 2013

EOS
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 94 NUMBER 20
14 MAY 2013
PAGES 181–188

The False Spring of 2012, Earliest in North American Record

PAGES 181–182

Phenology—the study of recurring plant and animal life cycle stages, especially their timing and relationships with weather and climate—is becoming an essential tool for documenting, communicating, and anticipating the consequences of climate variability and change. For example, March 2012 broke numerous records for warm temperatures and early flowering in the United States [*Karl et al.*, 2012; *Elwood et al.*, 2013]. Many regions experienced a "false spring," a period of weather in late winter or early spring sufficiently mild and long to bring vegetation out of dormancy prematurely, rendering it vulnerable to late frost and drought.

As global climate warms, increasingly warmer springs may combine with the random climatological occurrence of advective freezes, which result from cold air moving from one region to another, to dramatically increase the future risk of false springs, with profound ecological and economic consequences [e.g., *Gu et al.*, 2008; *Marino et al.*, 2011; *Augspurger*, 2013]. For example, in the false spring of 2012, an event embedded in long-term trends toward earlier spring [e.g., *Schwartz et al.*, 2006], the frost damage to fruit trees totaled half a billion dollars in Michigan alone, prompting the federal government to declare the state a disaster area [*Knudson*, 2012].

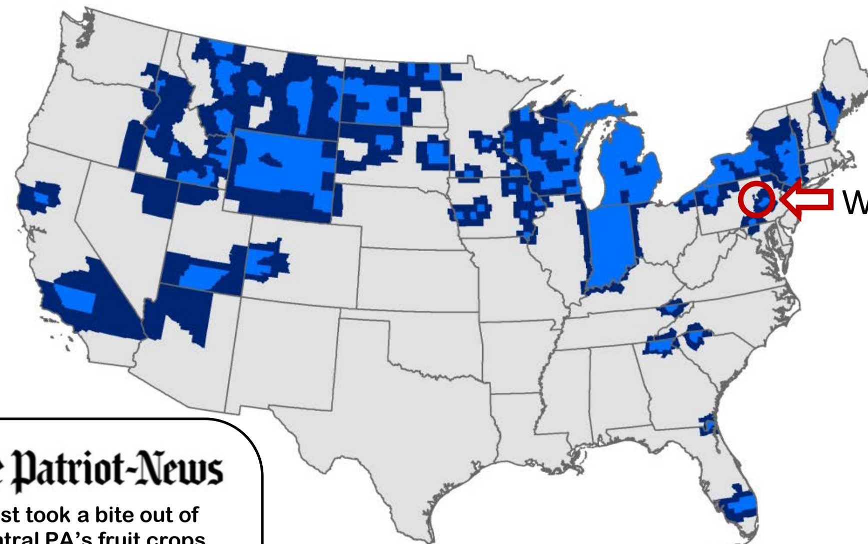
Phenological Forecasting: Predicting False Springs a Season or Two in Advance?

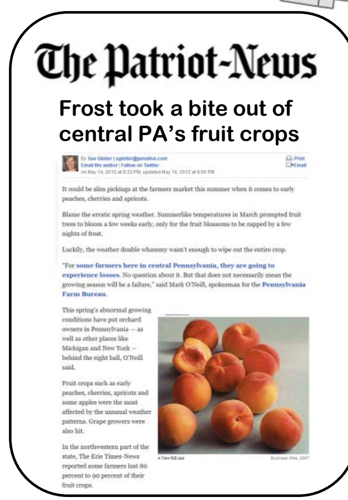
Robust phenological forecasts at seasonal time scales would enable governments and private entities alike to anticipate certain climate risks (e.g., frost damage, wildfires, and drought). Despite uncertainties associated with seasonal forecasts [*National Research Council*, 2010], some aspects of the circulation anomalies that drove the 2012 early spring may have been predictable

BY T. R. AULT, G. M. HENEBRY, K. M. DE BEURS, M. D. SCHWARTZ, J. L. BETANCOURT, AND D. MOORE

Fig. 1. Metrics of phenology during the spring and summer of 2012. (a) Time series of station-based extended spring index anomalies with respect to the 1981–2010 climatology from 1900 through 2012 and averaged over the conterminous United States (the first leaf index described in Schwartz et al. *[2006] and* Schwartz et al. *[2013]). (b) Map of first leaf index anomalies (in days) with respect to the 1981–2010 climatology. (c) Values of the damage index with respect to the 1981–2010 climatology (also described in* Schwartz et al. *[2006]), which measures the anomalous number of days between the last freeze event date and the first leaf index date (with high negative numbers indicative of a long period of potential plant growth followed by a freeze event). (d) Normalized anomalies, with respect to the 2001–2011 baseline, of the thermal time to peak normalized difference vegetation index (NDVI; a metric of heat accumulated prior to peak spring greenness [cf.* de Beurs and Henebry, *2005, 2008, 2010]). (e) Normalized anomalies in modeled peak NDVI (again, with respect to 2001–2011), indicating significantly lower values during the summer. (f) The NDVI time averaged across the Corn Belt and around the western Great Lakes, shown by the box in Figures 1d and 1e (in days from 1 January onward). The gray line in Figure 1f shows the 2001–2011 climatology, and the black line shows the 2012 anomalies. Observational data used to create Figures 1a–1c were obtained from the National Oceanic and Atmospheric Administration Global Historical Climate Network archive of daily temperature records (http://www.ncdc.noaa.gov/oa/climate/ghcn-daily/), and Moderate Resolution Imaging Spectroradiometer (MODIS) products MCD43C4 and MOD11C2, used to create Figures 1d–1f, was obtained from the U.S. Geological Survey Land Processes Distributed Archive Center (https://lpdaac.usgs.gov).*

2012 fruit crop losses due to frost/freeze





The Patriot-News

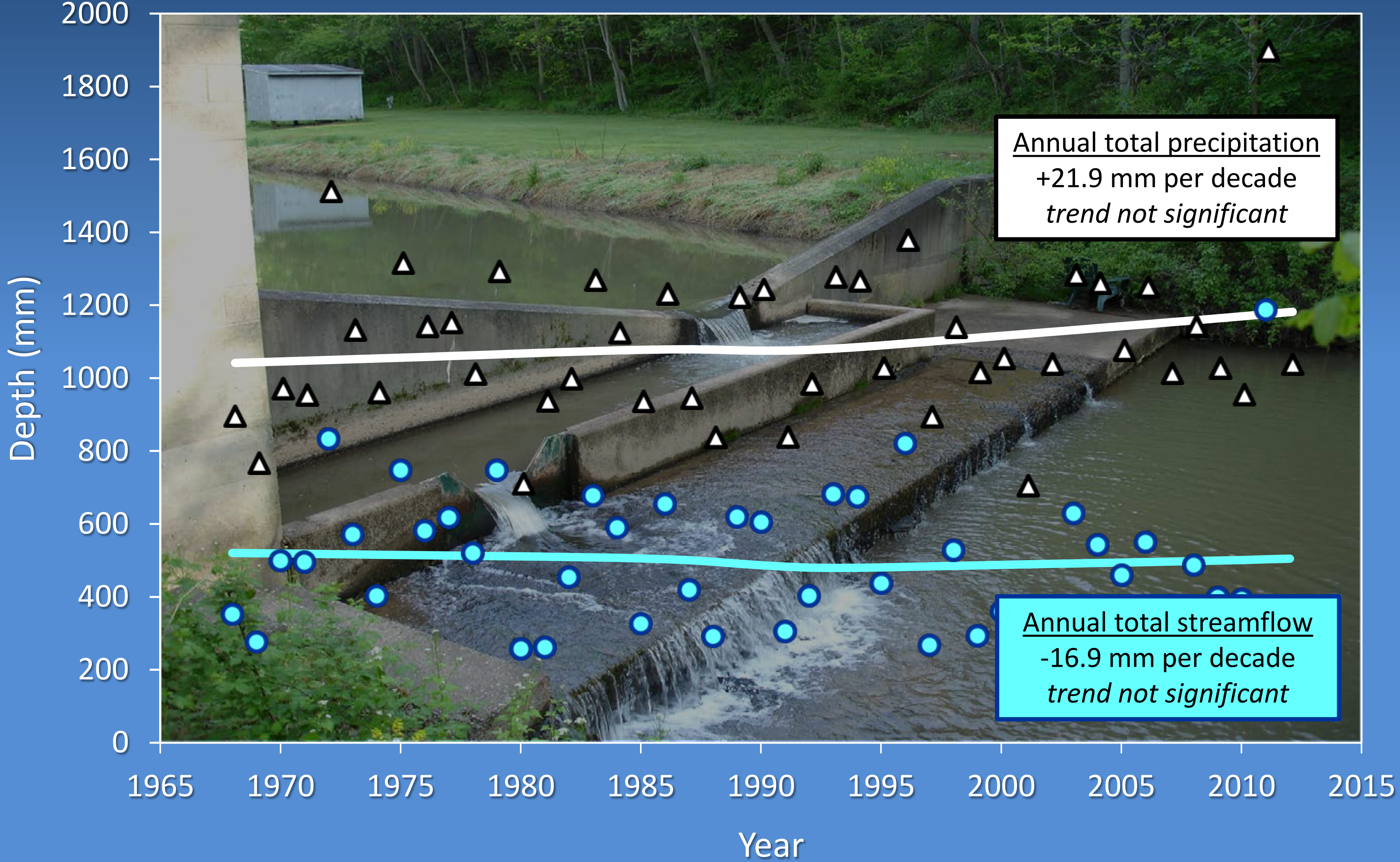
Frost took a bite out of central PA's fruit crops

In the northeastern US, about 100 counties were declared disaster areas, including Northumberland County in PA, which contains the WE-38 basin.

Aust et al., 2013; Knutson et al., 2013; Farm Service Agency, 2014

Annual changes in watershed hydrology

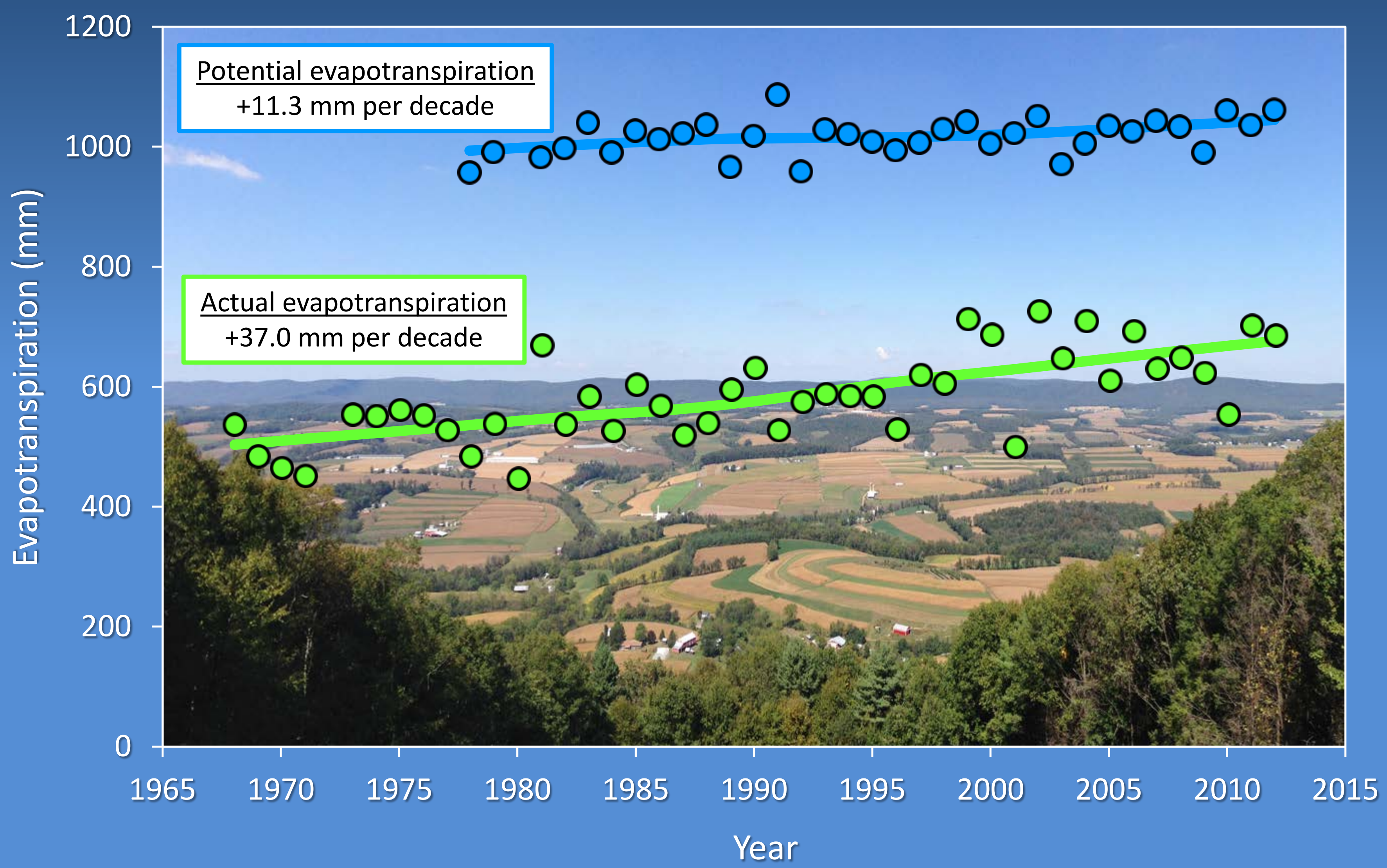
slightly divergent trends in precipitation and streamflow



Lu et al., 2015 (J. Hydrol: RS)

Increasing watershed evapotranspiration

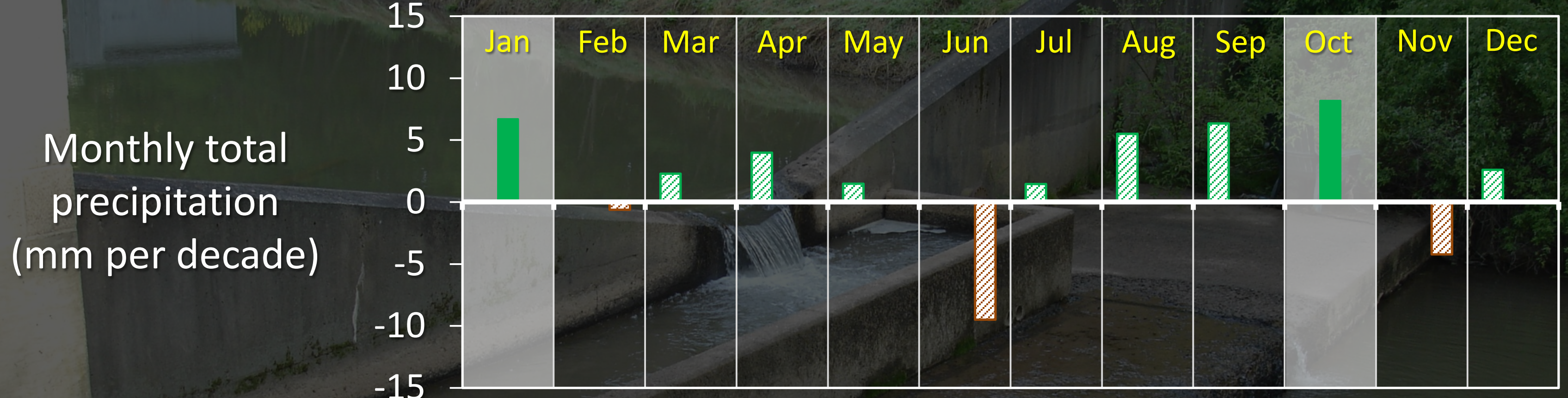
actual evapotranspiration is becoming more efficient

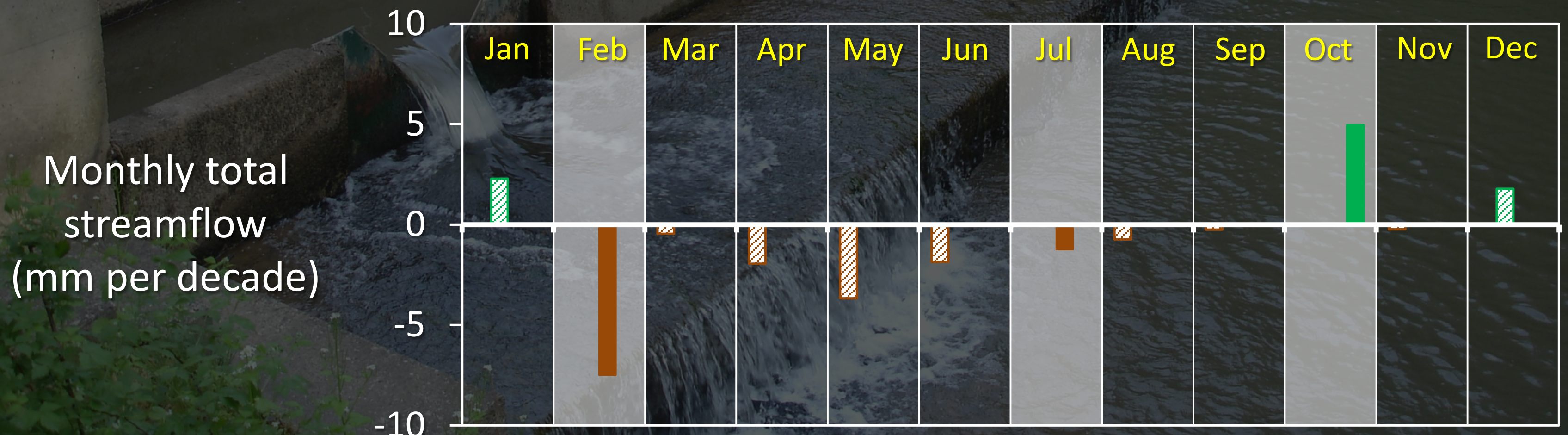


Lu et al., 2015 (J. Hydrol: RS)

Seasonal trends in hydroclimate

substantial increases in fall rainfall and streamflow

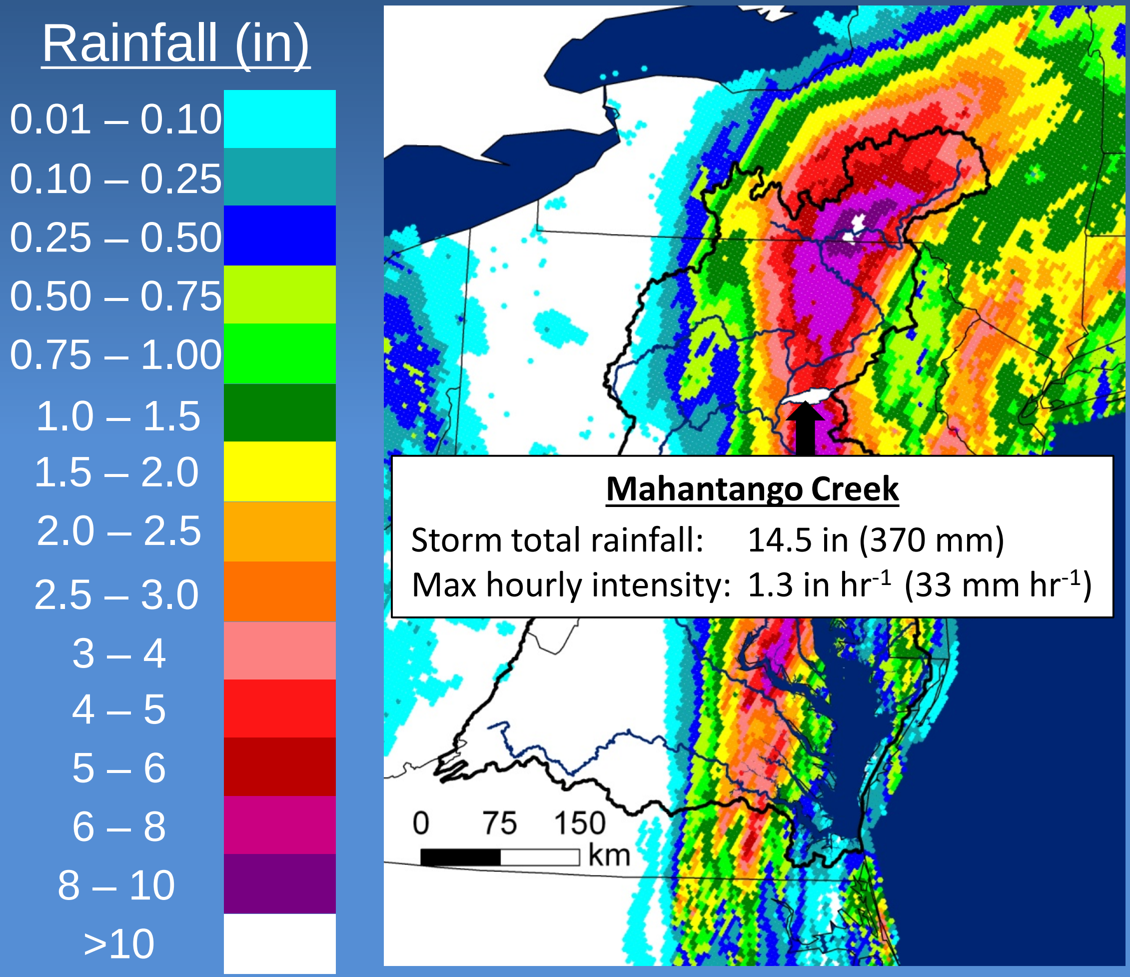


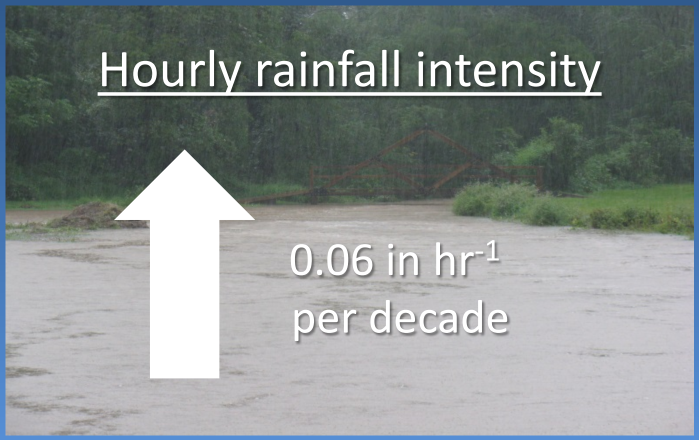


Lu et al., 2015 (J. Hydrol: RS)

Heavier rains and higher flows in early fall

Tropical Storm Lee (September 7-8, 2011)

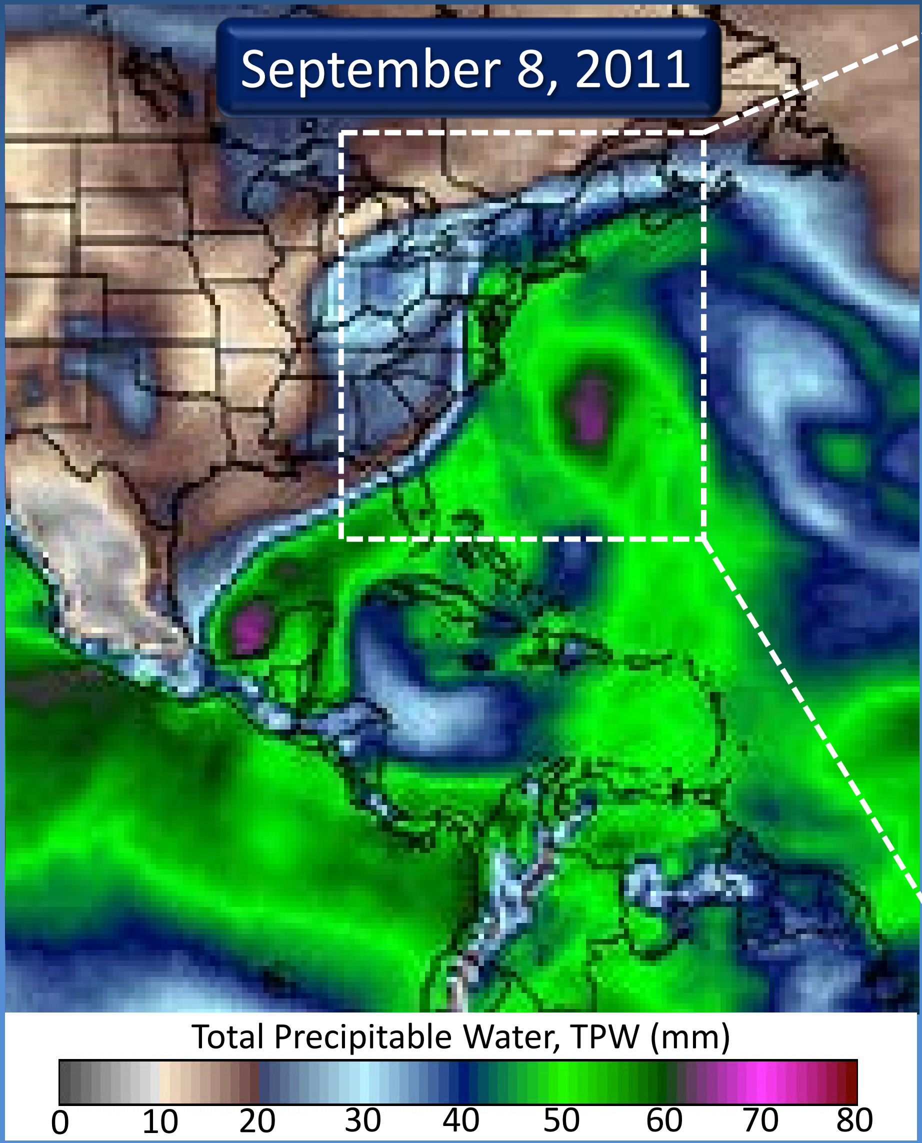


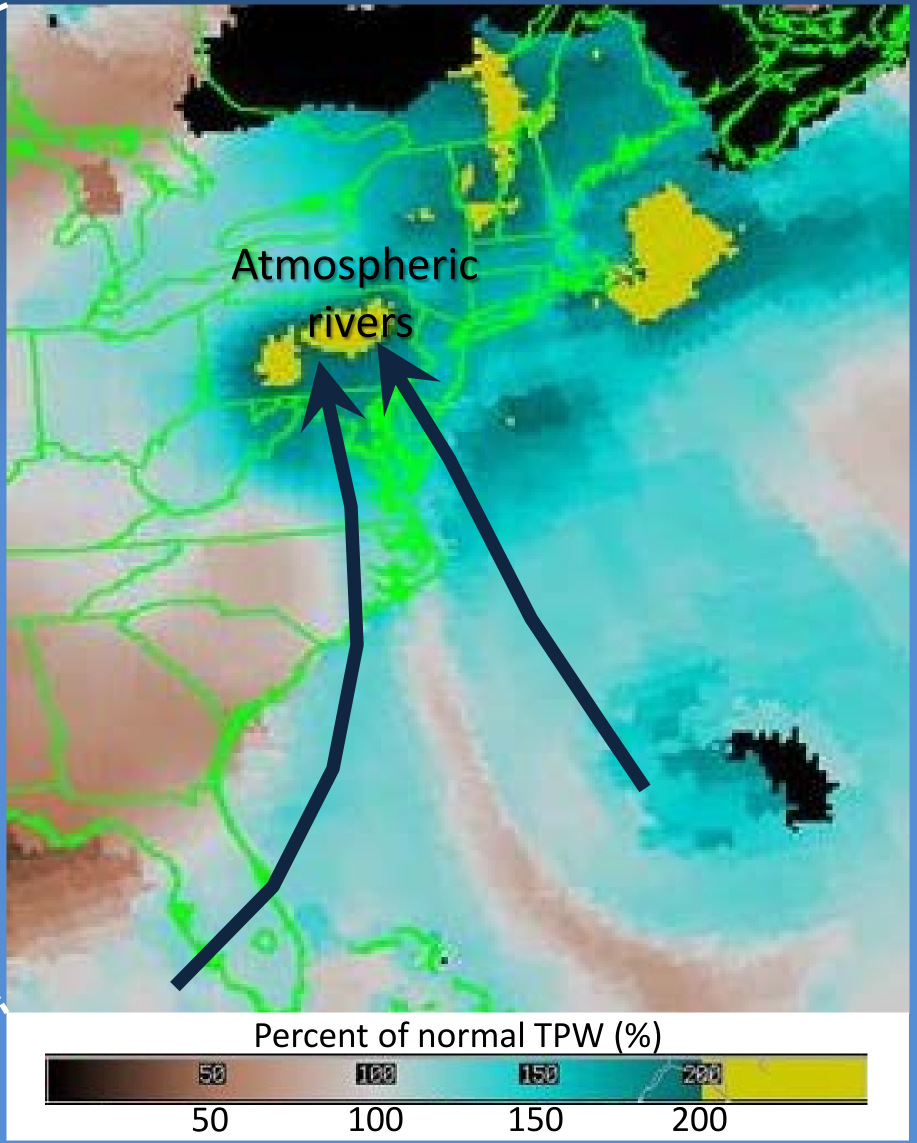


Lu et al., 2015 (J. Hydrol: RS)

Atmospheric rivers and extreme rains

A connection that produces some of our worst floods





ClimateReanalyzer.org; Gitro et al., 2014 (J. Operational Meteorology)

Tropical Storm Lee's rainfall was extreme

An average recurrence interval of once every 980 years

What about less extreme storms
that occur every 50 to 100 years?

JOURNAL OF APPLIED METEOROLOGY AND CLIMATOLOGY

Time-Dependent Changes in Extreme-Precipitation Return-Period Amounts in the Continental United States

ARTHUR T. DEGAETANO

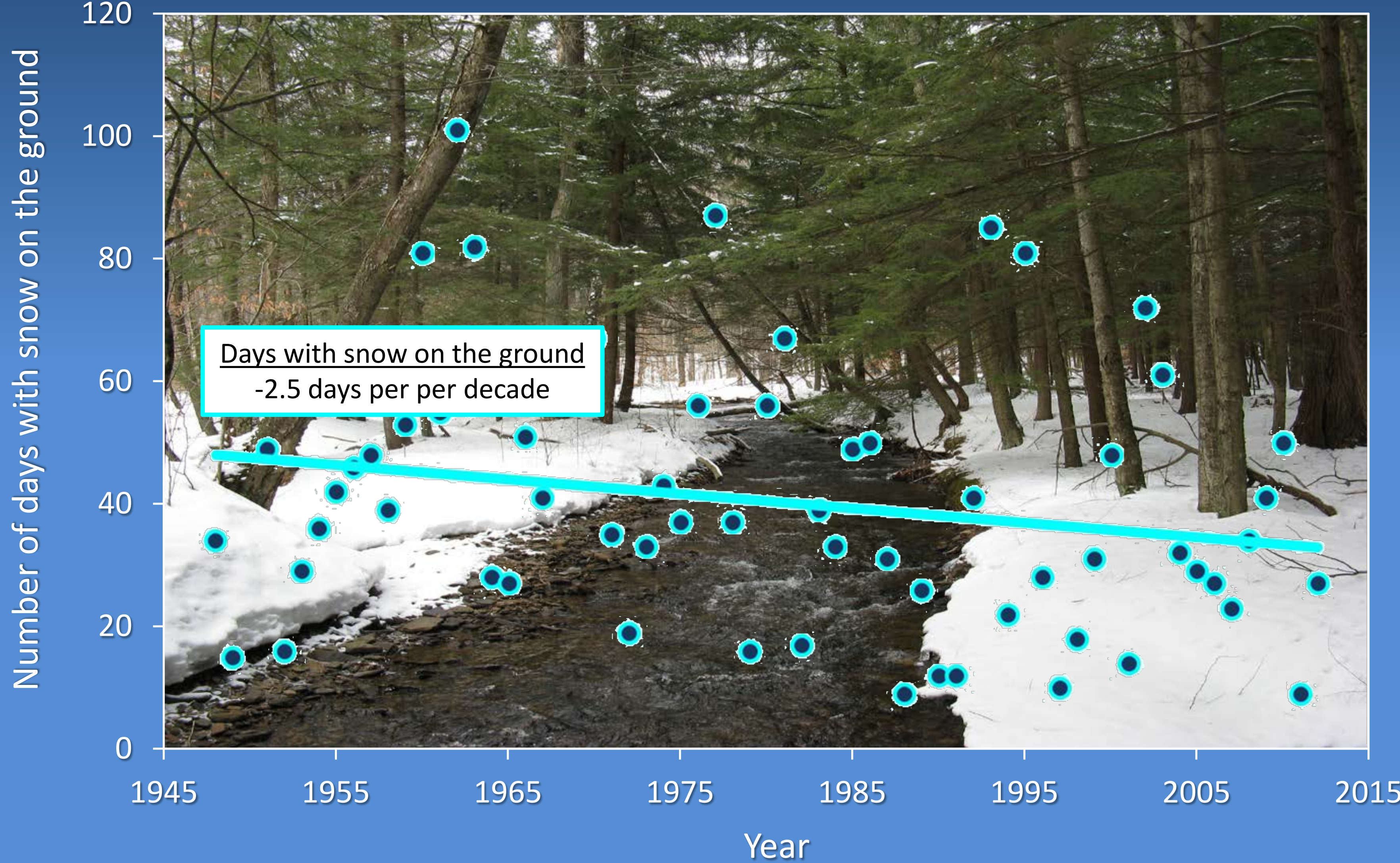
Northeast Regional Climate Center, Department of Earth and Atmospheric Science, Cornell University, Ithaca, New York

"In the Northeast, the median decrease of both the 50- and 100-yr recurrence interval is nearly 40%. Thus what would be expected to be a 100-yr event based on 1950-79 data occurs with an average return interval of 60 yr when data from 1978-2007 are considered"

NOAA Atlas 14 Precipitation Frequency Data Server; DeGaetano, 2009

Fewer days with snow on the ground

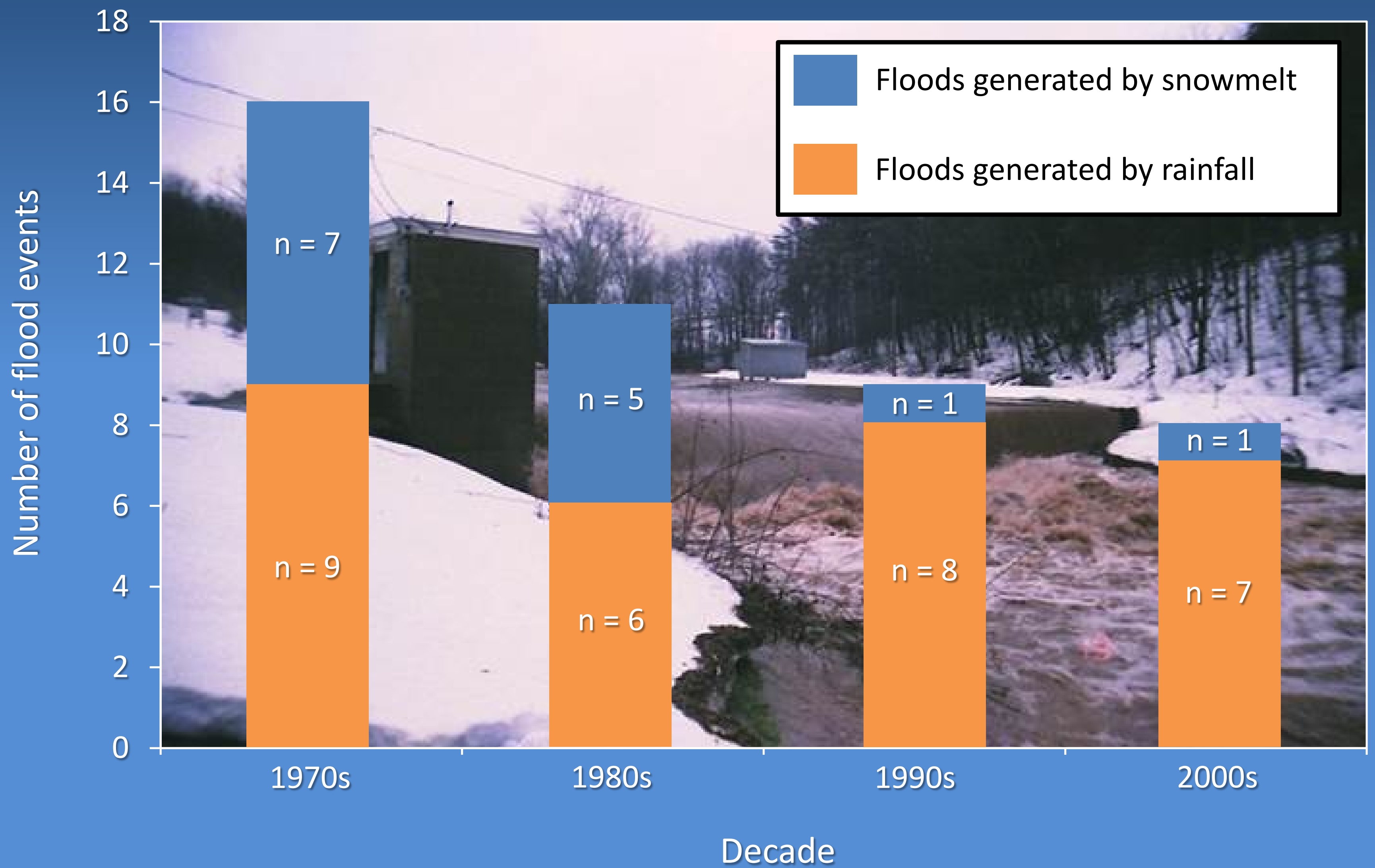
Reflecting a wider trend occurring in the Northeast



Burakowski et al., 2008 (JGR Atmospheres)

Snowmelt runoff floods are declining

an expected trend as minimum temps increase in the winter



Lu et al., 2015 (J. Hydrol: RS)

To summarize: climate change is here

Steadily rising temperatures and a lengthening growing season are consistent with a warming climate.

At the basin level, evapotranspiration increases represent the clearest change in hydroclimate over the past 45 years.

Larger, more intense rain storms in the fall have led to augmented streamflow, but not necessarily increased flooding.

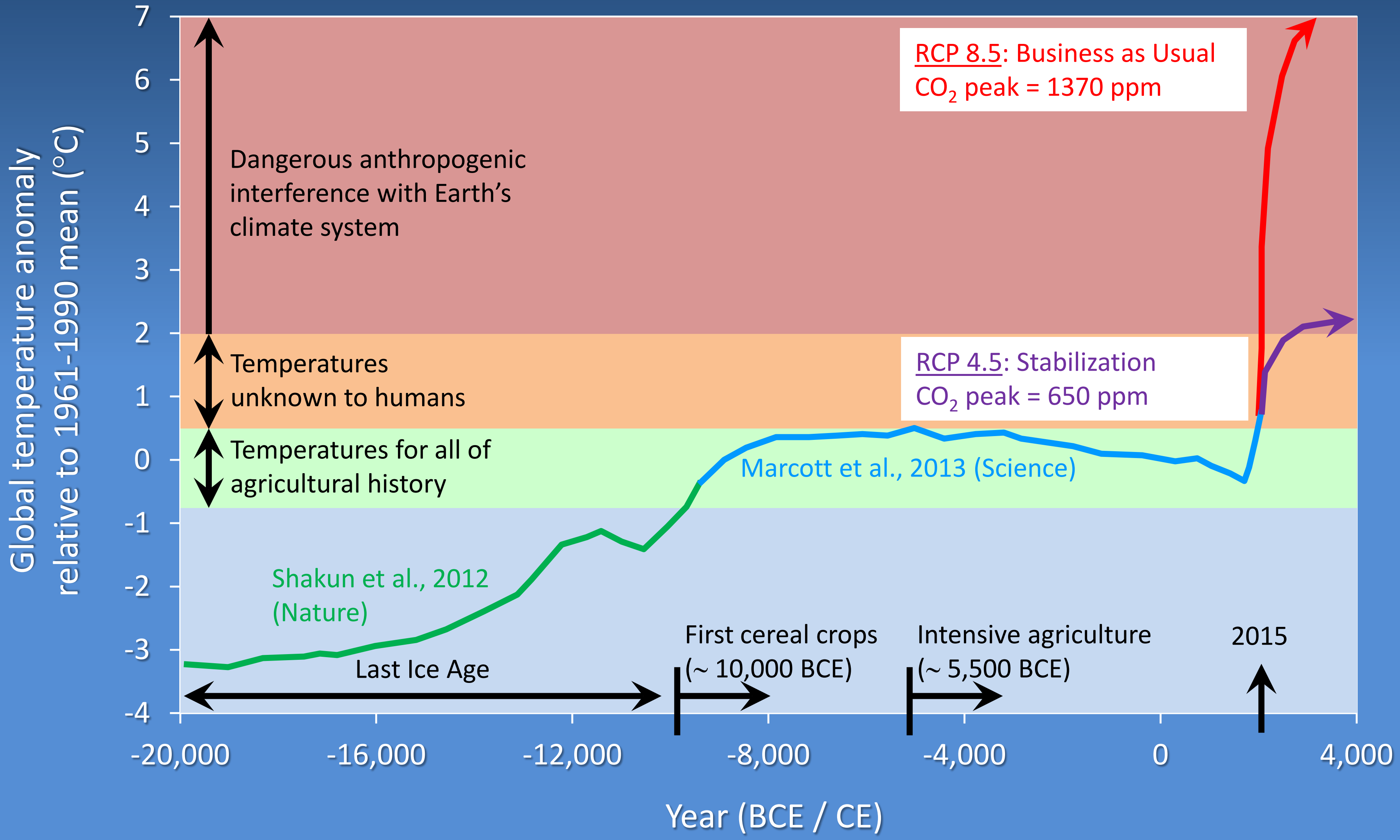
Snowmelt runoff events are declining in the winter as warmer weather leads to fewer days with snow on the ground.

A glimpse of our climate future

What pathway are we on if we follow business as usual?

Earth's climate history

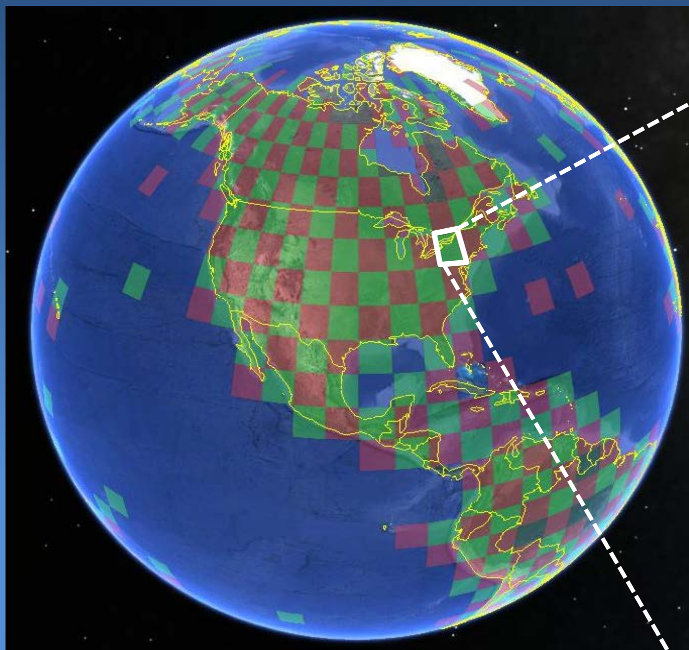
where we've been, and where we're likely heading

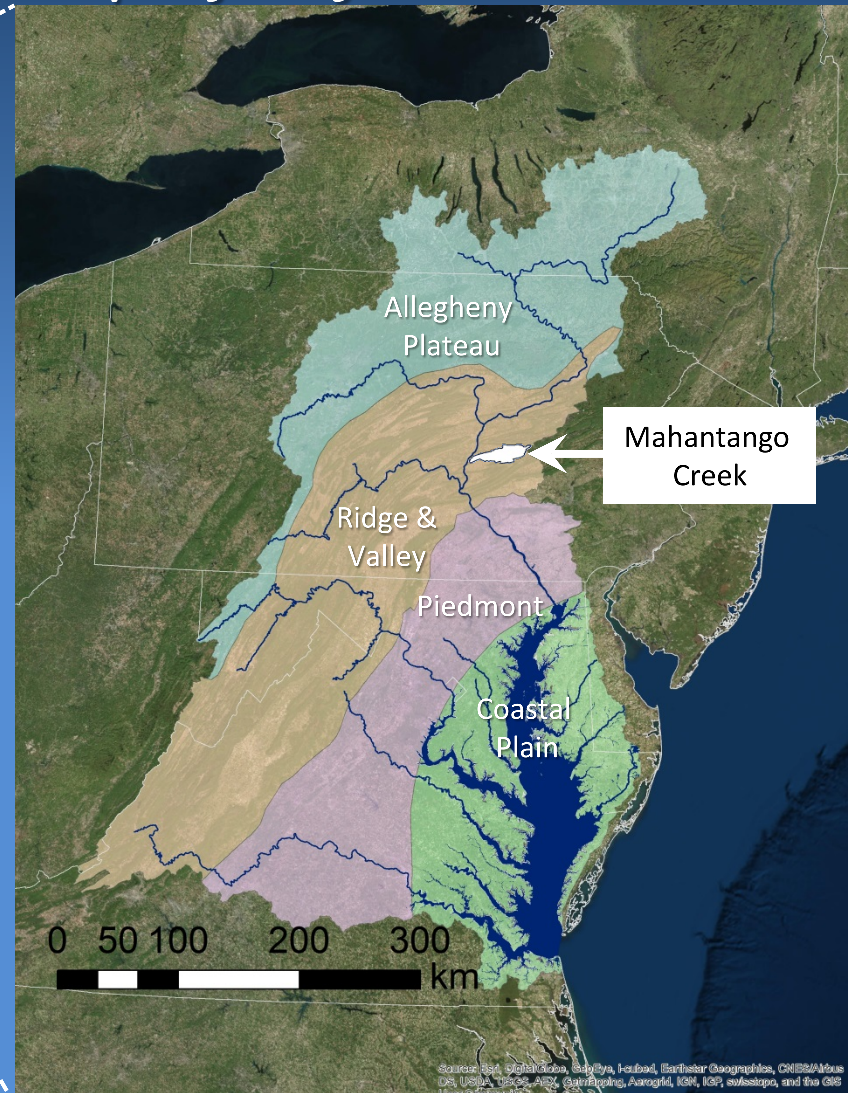


Original image conceived by Jos Hagelaars and modified by Paul Price

Implications for the Northeast

Using downscaled climate data to project future scenarios



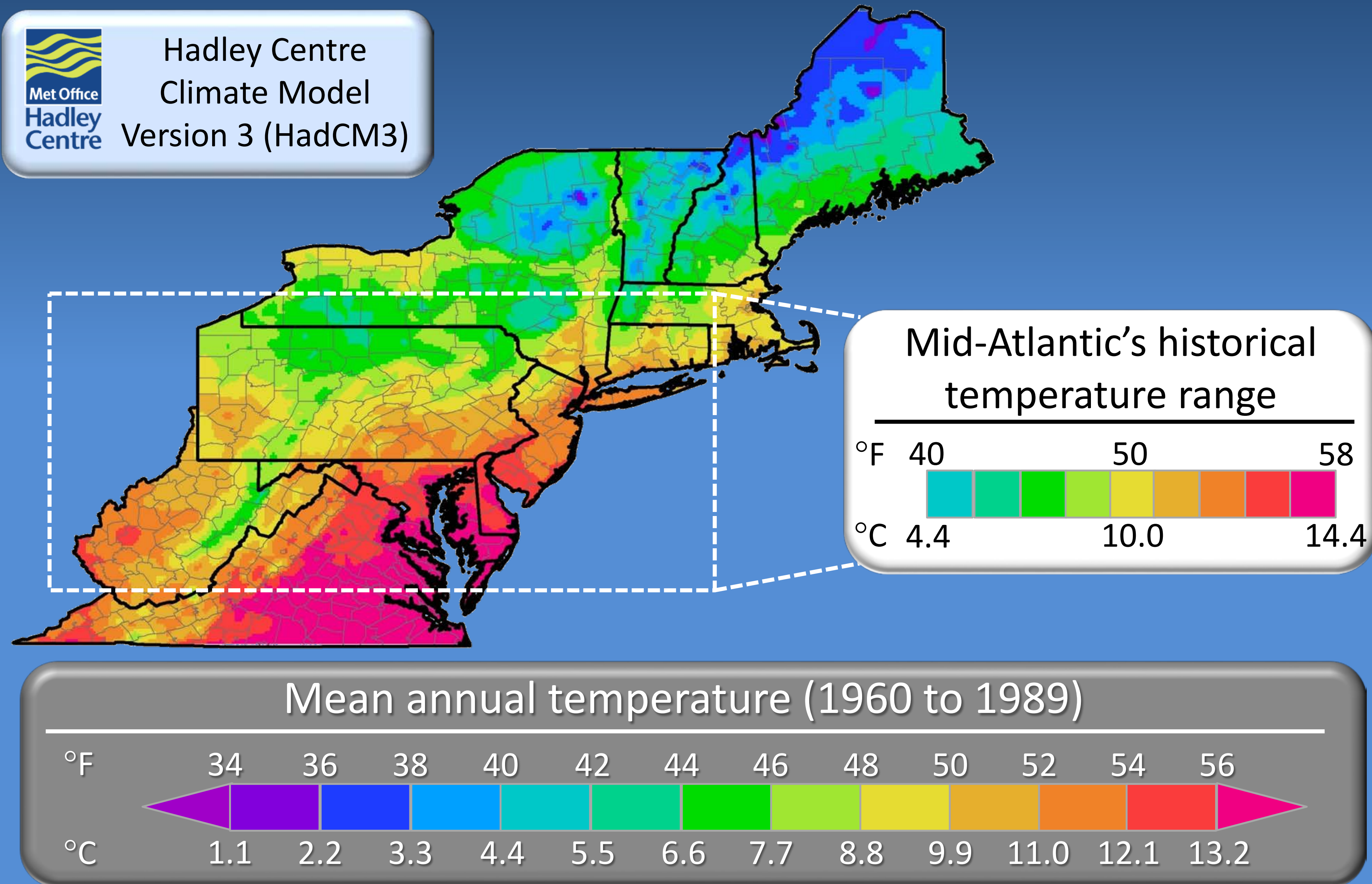


Downscale 9 models from the Coupled Model Inter-comparison Project Phase 5 (CMIP5) for the business as usual pathway (RCP 8.5).

Hayhoe et al., 2007 (Climate Dynamics); Stoner et al., 2013 (International J. Climatology)

The Mid-Atlantic climate is temperate

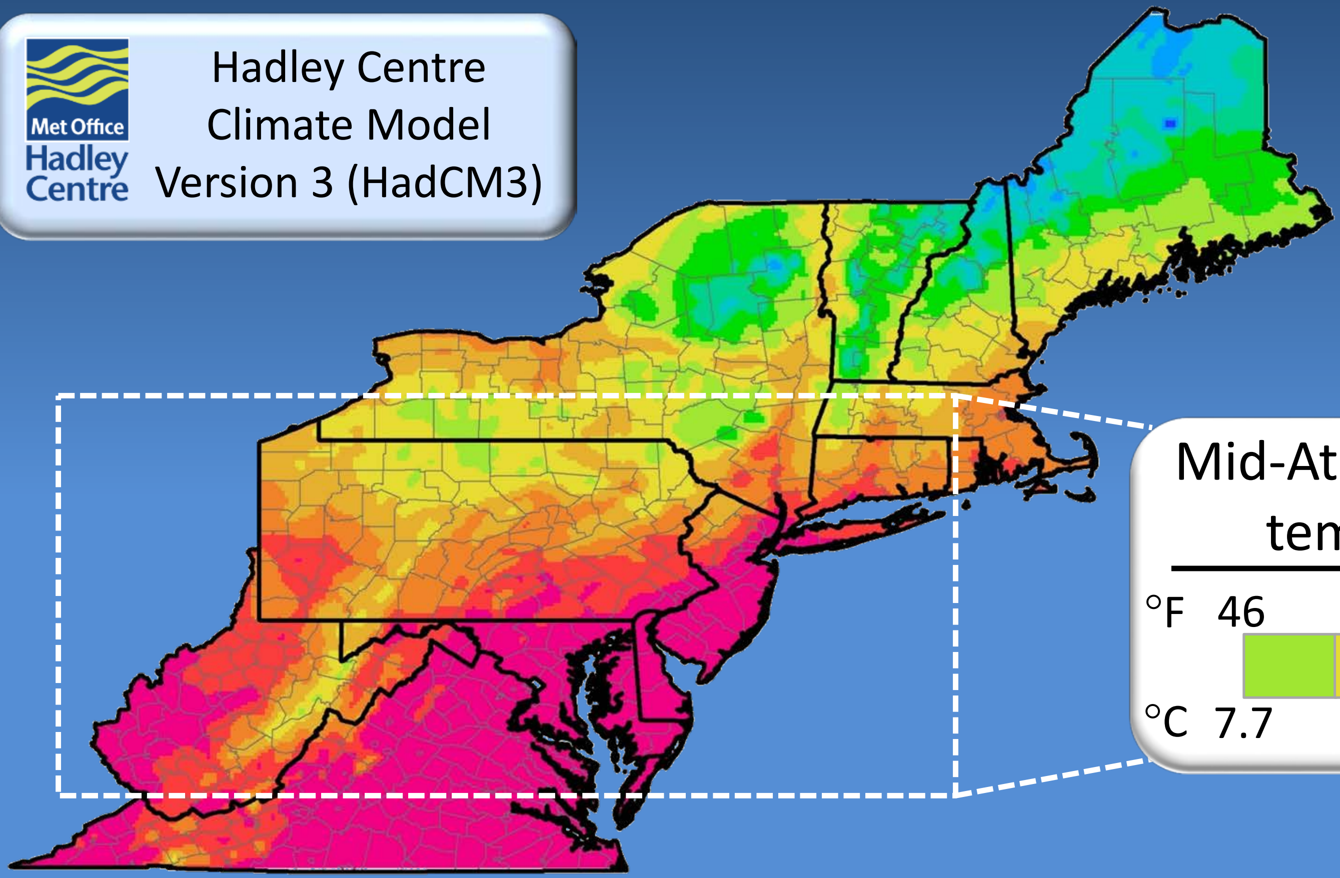
mean annual temperatures range from 40 to 58℉



Mid-century temperatures will be warmer

with the new range shifting from 46 to as high as 60 °F

Hadley Centre
Climate Model
Version 3 (HadCM3)



Mid-Atlantic's mid-century temperature range

°F	46	52	58
°C	7.7	11.0	14.4

Mean annual temperature (2015 to 2044)

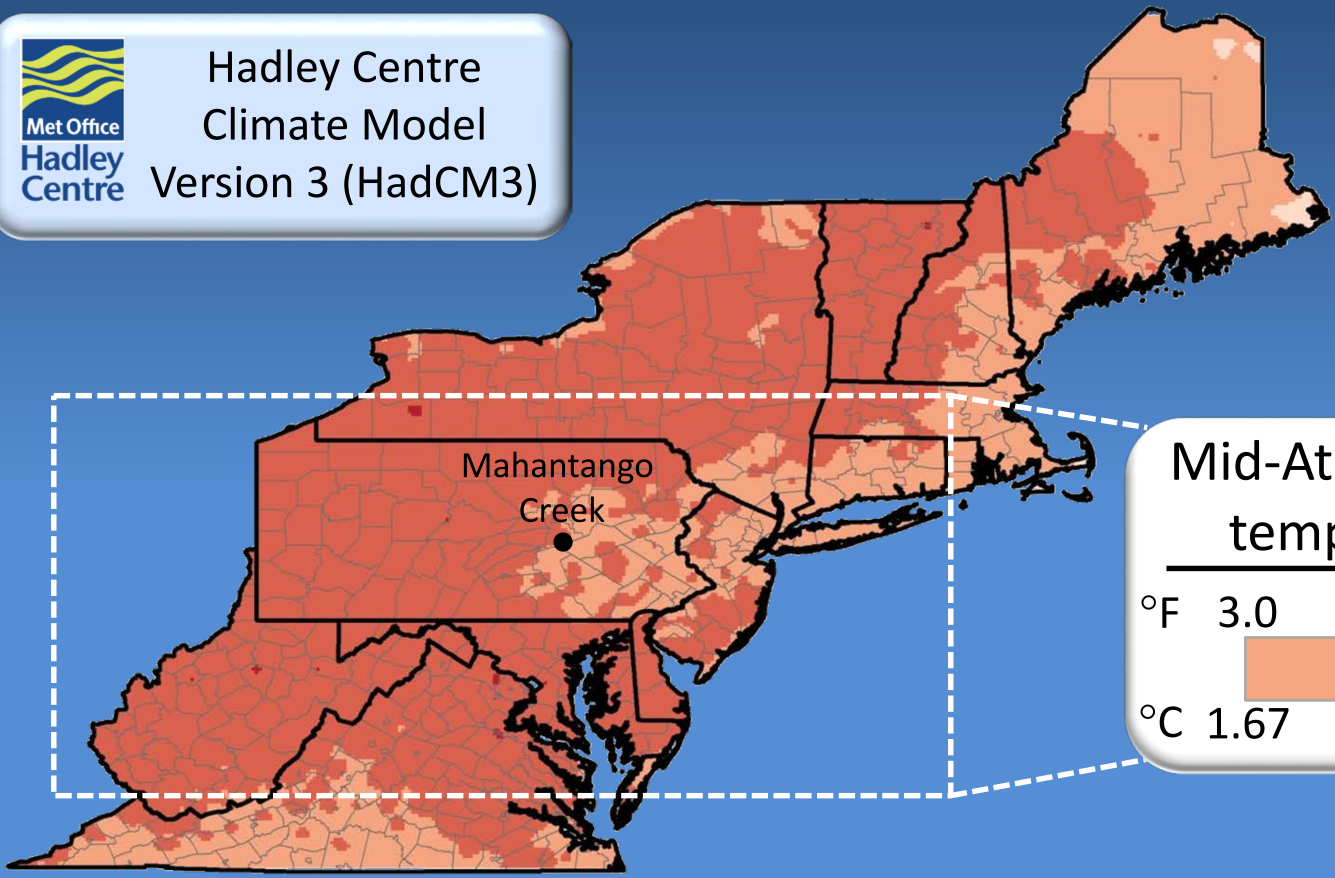
°F	34	36	38	40	42	44	46	48	50	52	54	56
°C	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0	12.1	13.2

Mid-century temperatures will be warmer

with increases ranging from 3 to 4℉ relative to past norms

Met Office Hadley Centre

Hadley Centre Climate Model Version 3 (HadCM3)



Mid-Atlantic's mid-century temperature increase

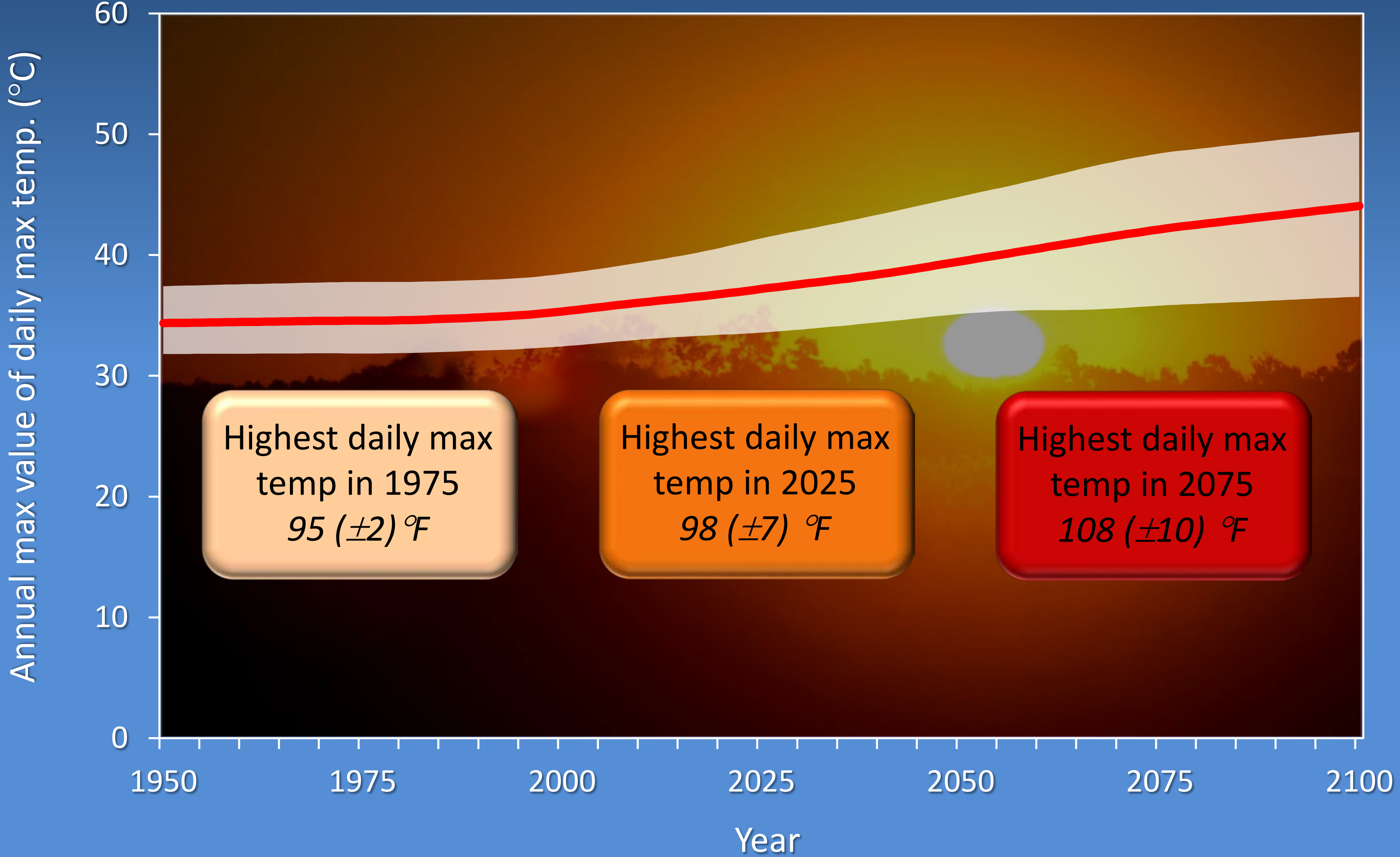
°F	3.0	3.5	4.0
°C	1.67	1.94	2.22

Mid-century increase in mean annual temperature

°F	3.0	3.5	4.0
°C	1.67	1.94	2.22

A warmer climate means more extremes

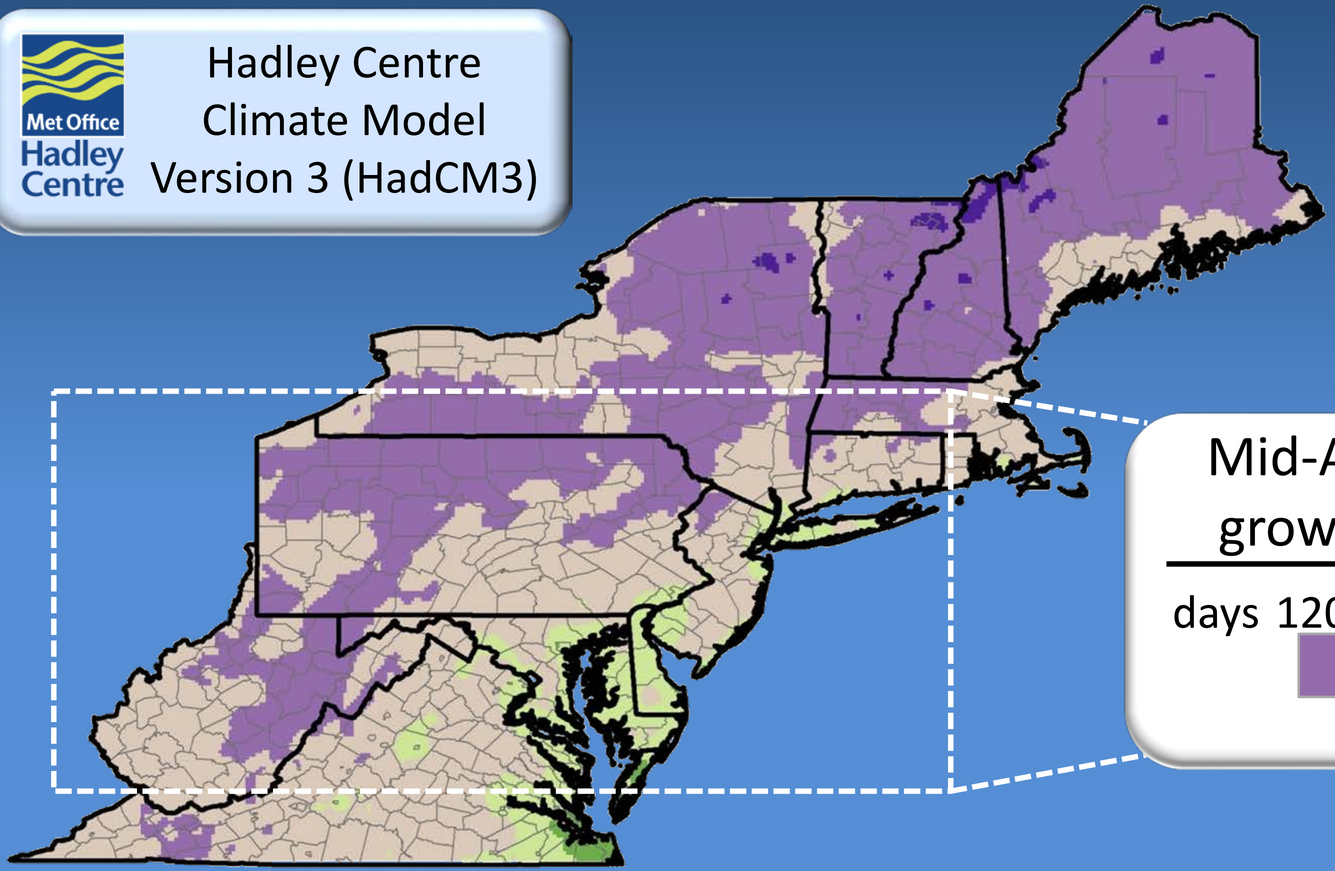
daily max temperatures may approach 111 °F by century's end



Mid-Atlantic growing seasons are modest

with the average length being 200 days (Apr. 15 to Oct. 30)

Hadley Centre
Climate Model
Version 3 (HadCM3)



Mid-Atlantic's historical growing season length

days 120 195 270

Mean growing season length (1960 to 1989)

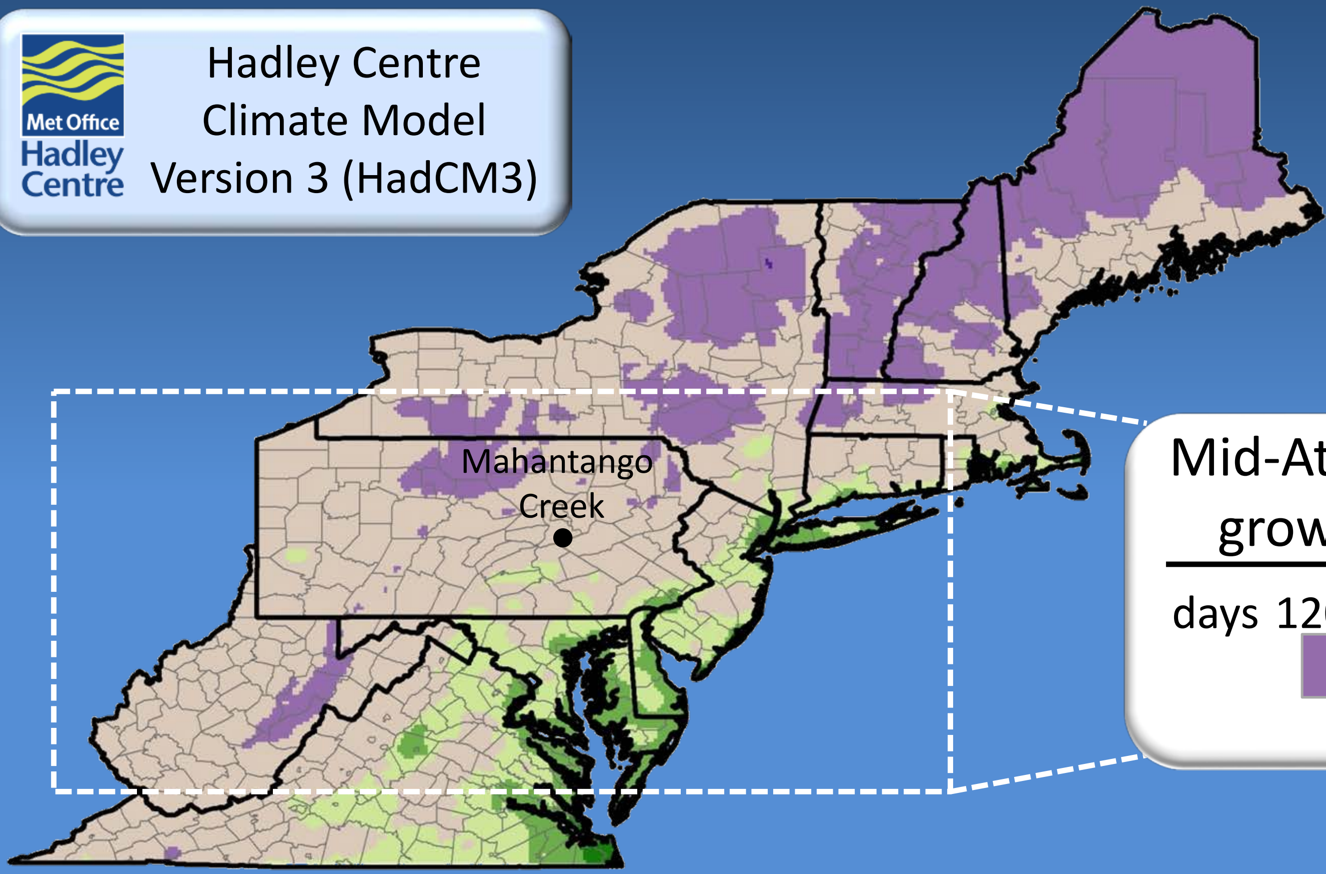
days 120 180 240 270 300

Mid-century growing seasons will expand

with the average season approaching 240 days

Met Office Hadley Centre

Hadley Centre Climate Model Version 3 (HadCM3)



Mid-Atlantic's mid-century growing season length

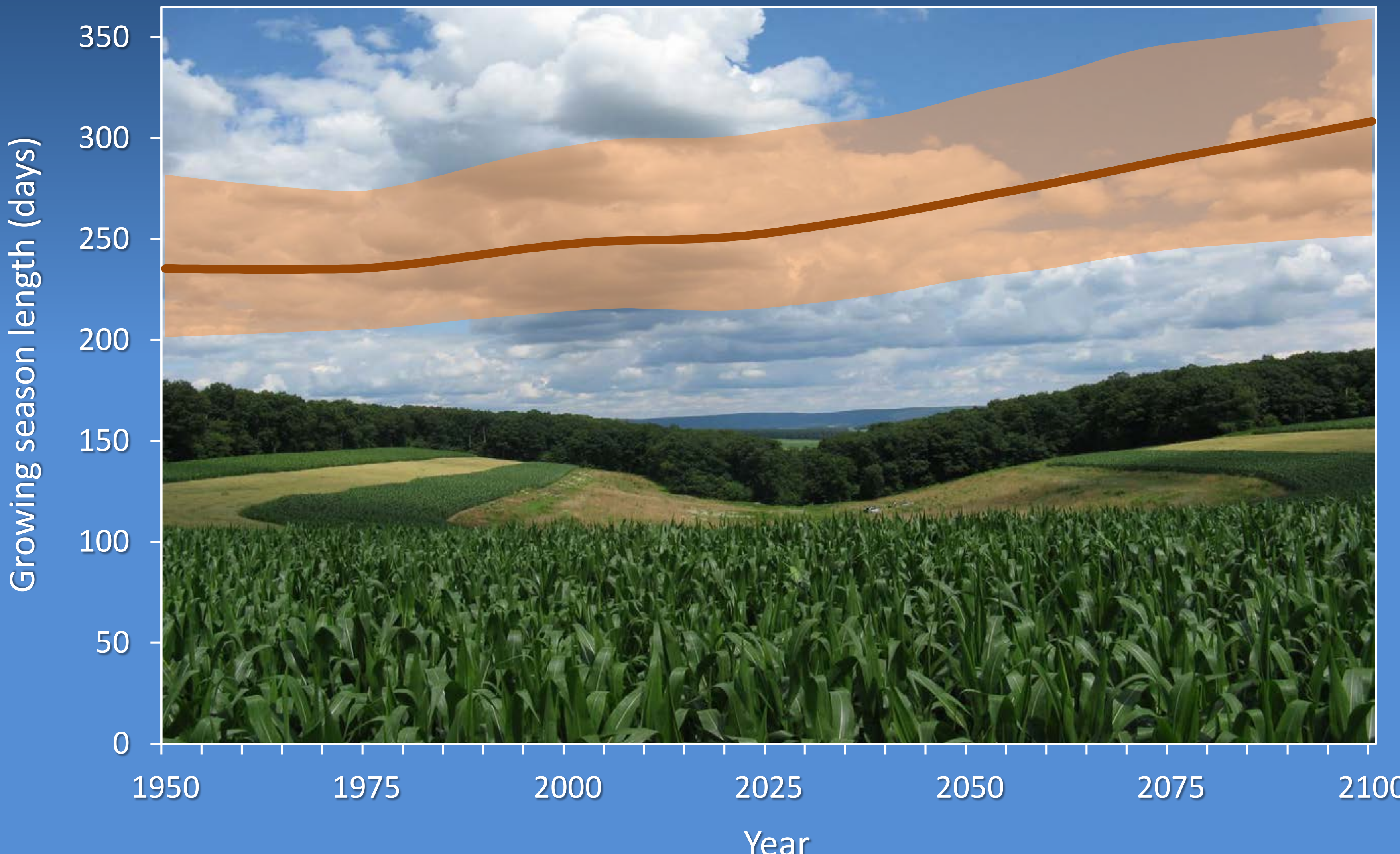
days 120 240 300

Mean growing season length (2015 to 2044)

days 120 180 240 270 300

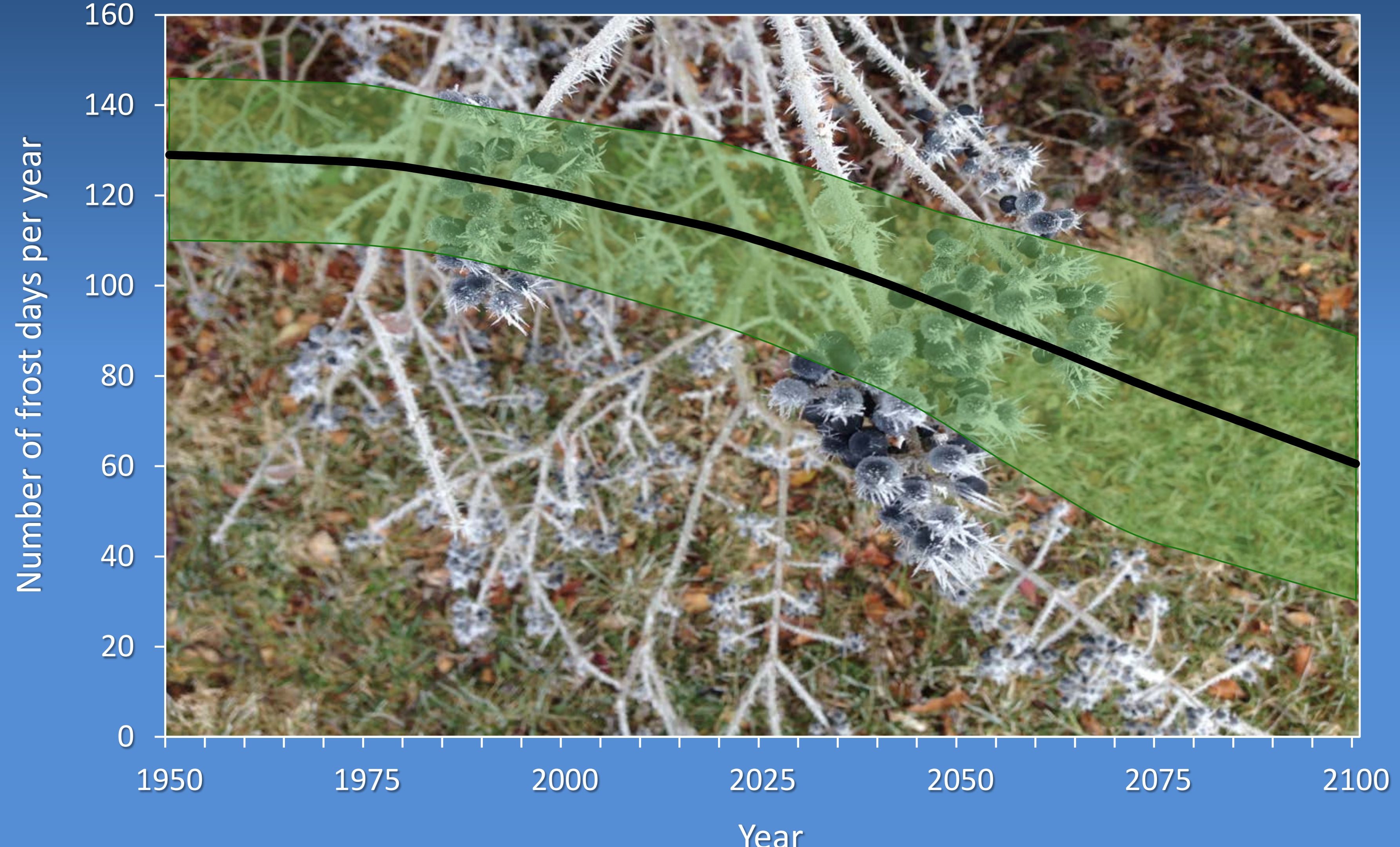
Unabated expansion through late century

By 2100, the growing season could encompass the entire year



Days with frost will greatly diminish

By 2100, only 60 days per year may be cold enough for frost

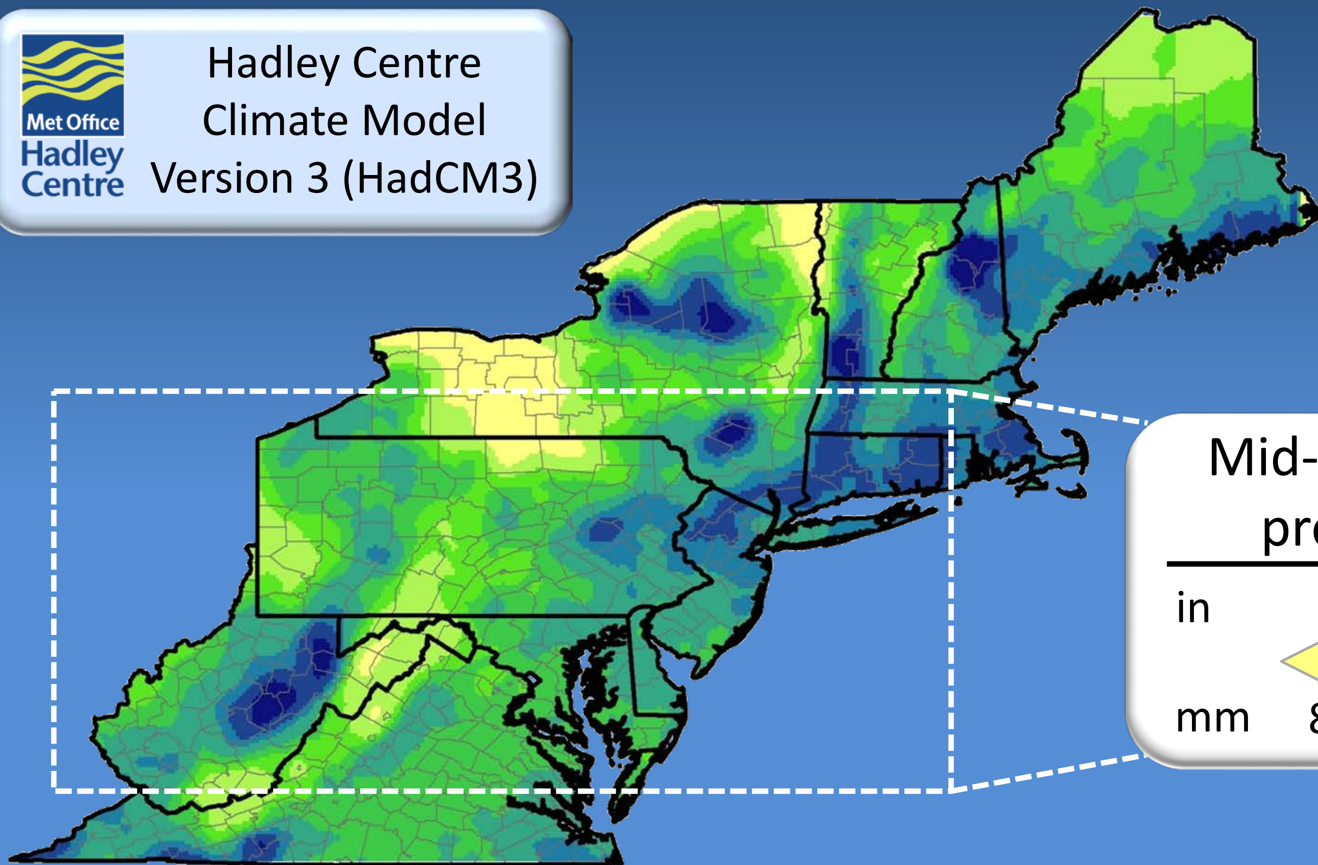


The Mid-Atlantic gets year-round rainfall

mean annual precipitation is about 42 in per year

Met Office Hadley Centre

Hadley Centre Climate Model Version 3 (HadCM3)



Mid-Atlantic's historical precipitation range

in	35	42	50
mm	889	1067	1270

Mean annual precipitation (1960 to 1989)

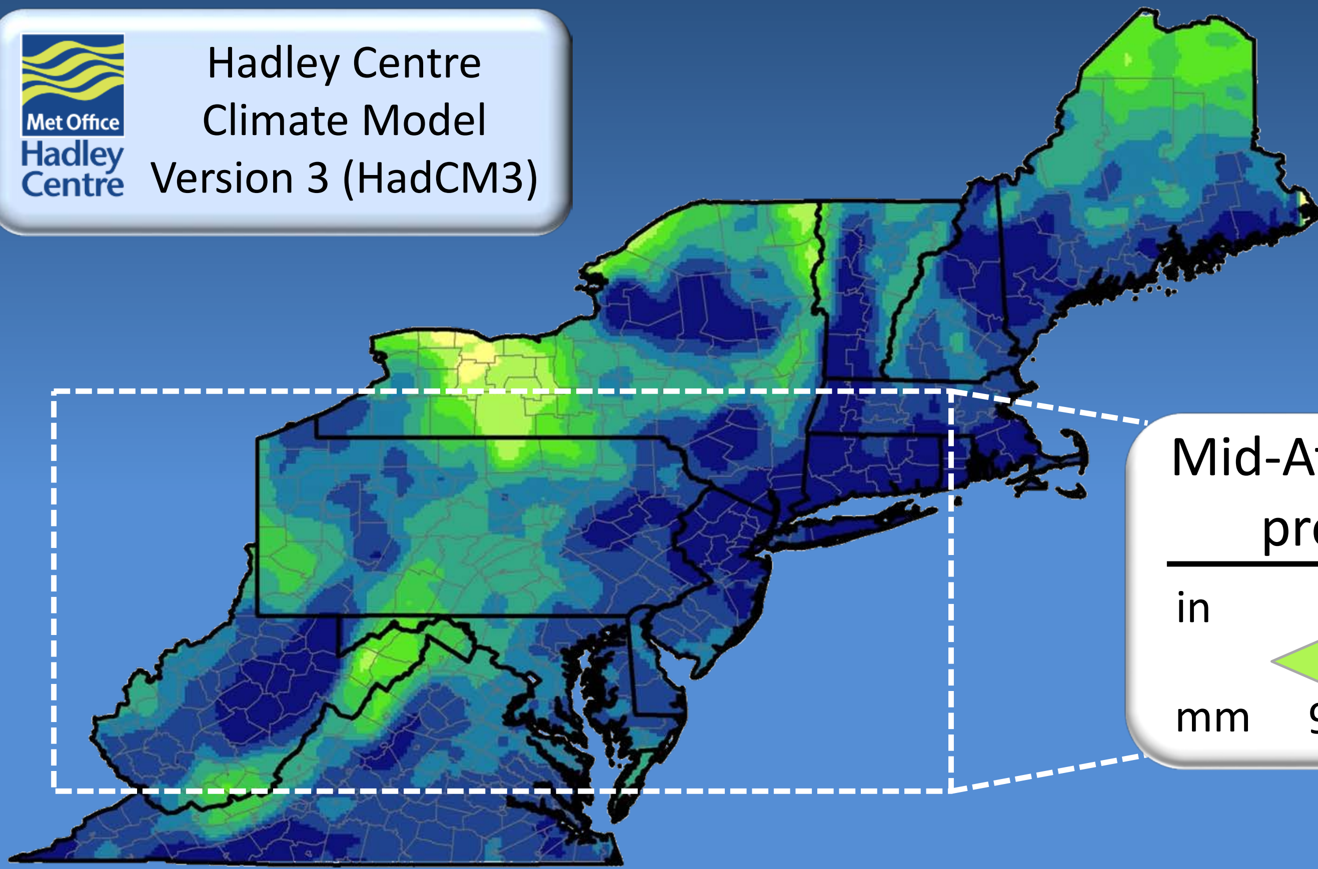
in	35	38	40	42	45	47	50
mm	889	965	1016	1067	1143	1194	1270

Mid-century will be wetter

with the region-wide average rising to 44 in per year

Met Office Hadley Centre

Hadley Centre Climate Model Version 3 (HadCM3)



Mid-Atlantic's mid-century precipitation range

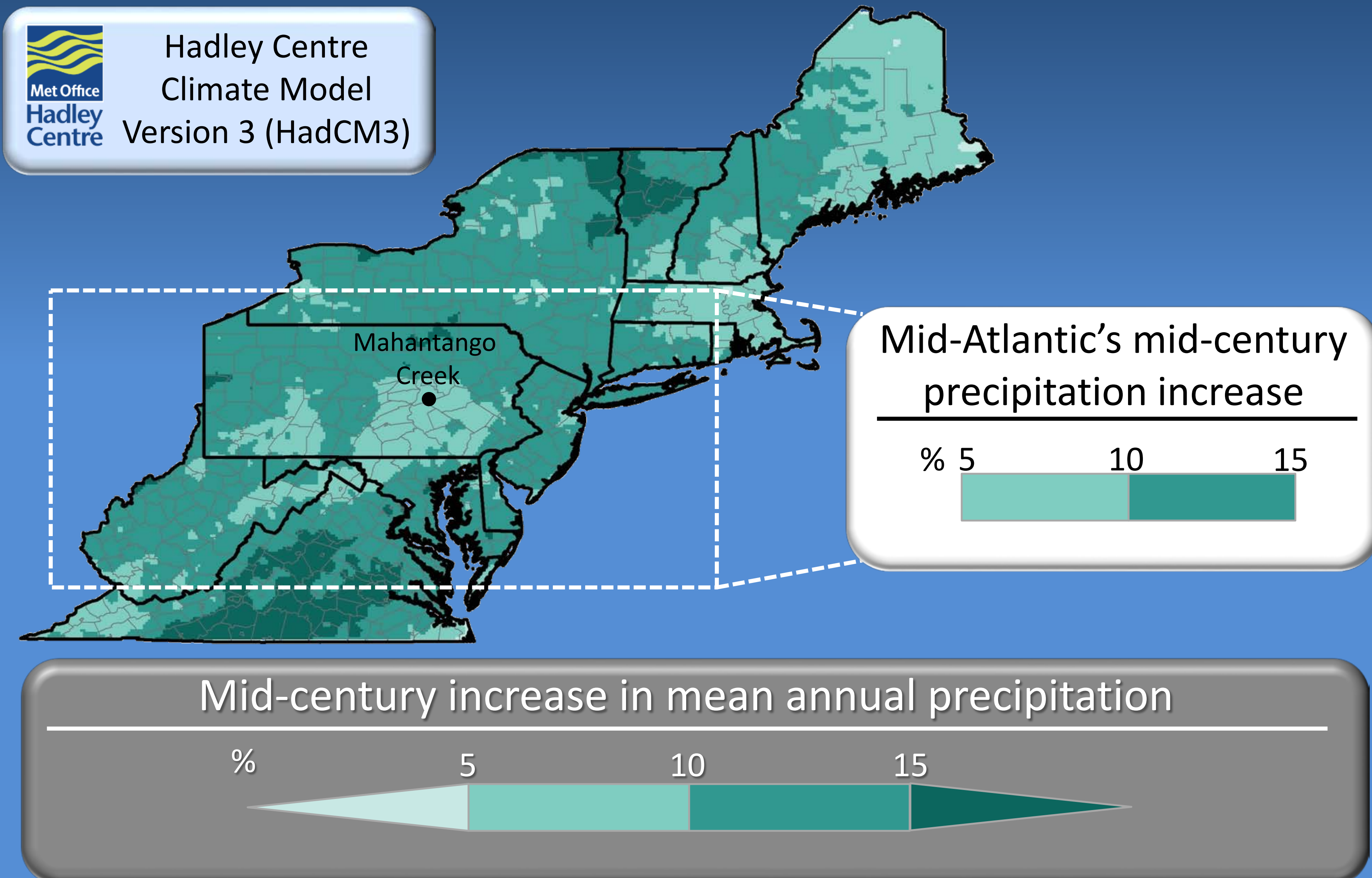
in	38	44	50
mm	965	1118	1270

Mean annual precipitation (2015 to 2044)

in	35	38	40	42	45	47	50
mm	889	965	1016	1067	1143	1194	1270

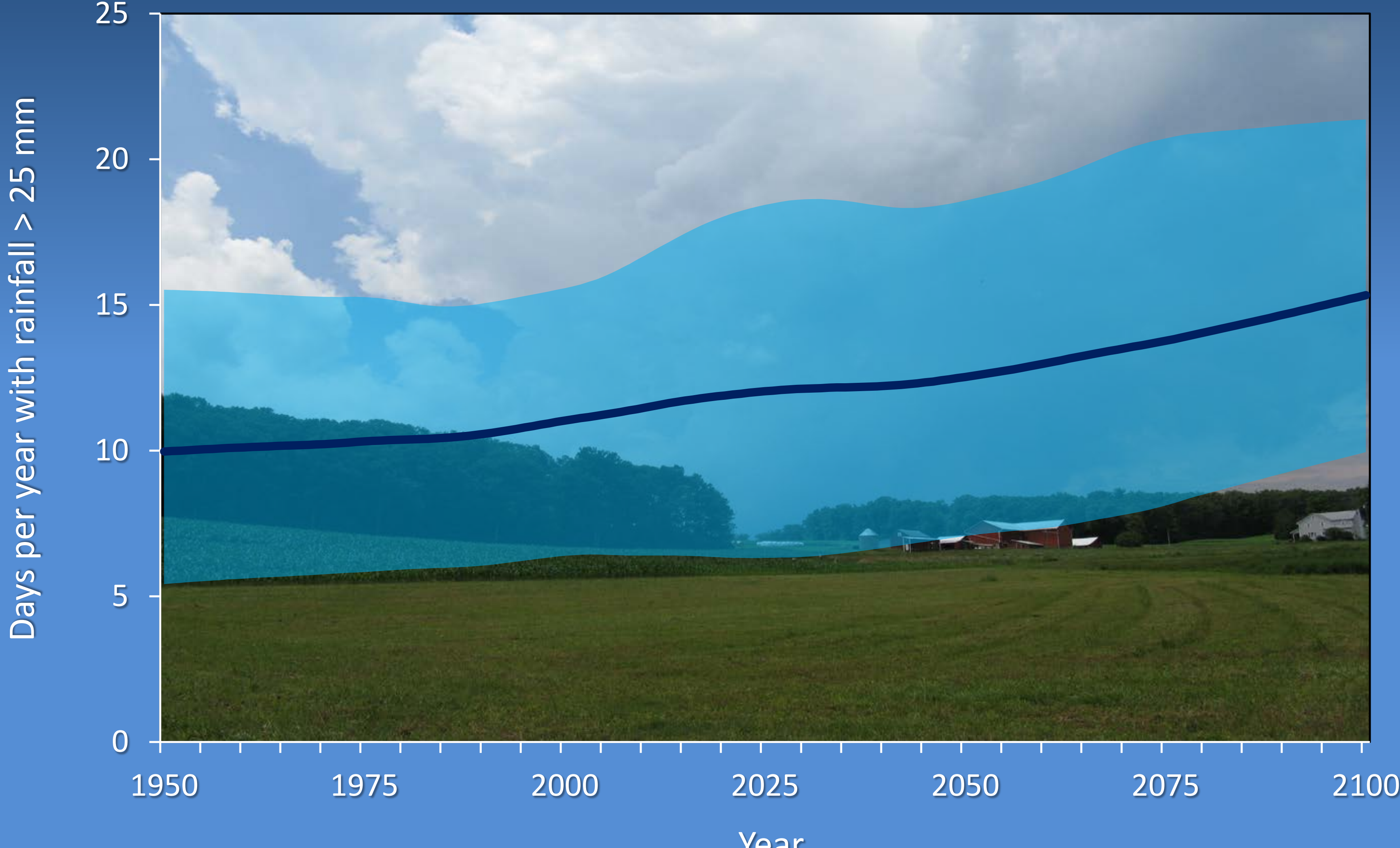
Mid-century will be wetter

increases will range from 5 to 15% relative to historical norms



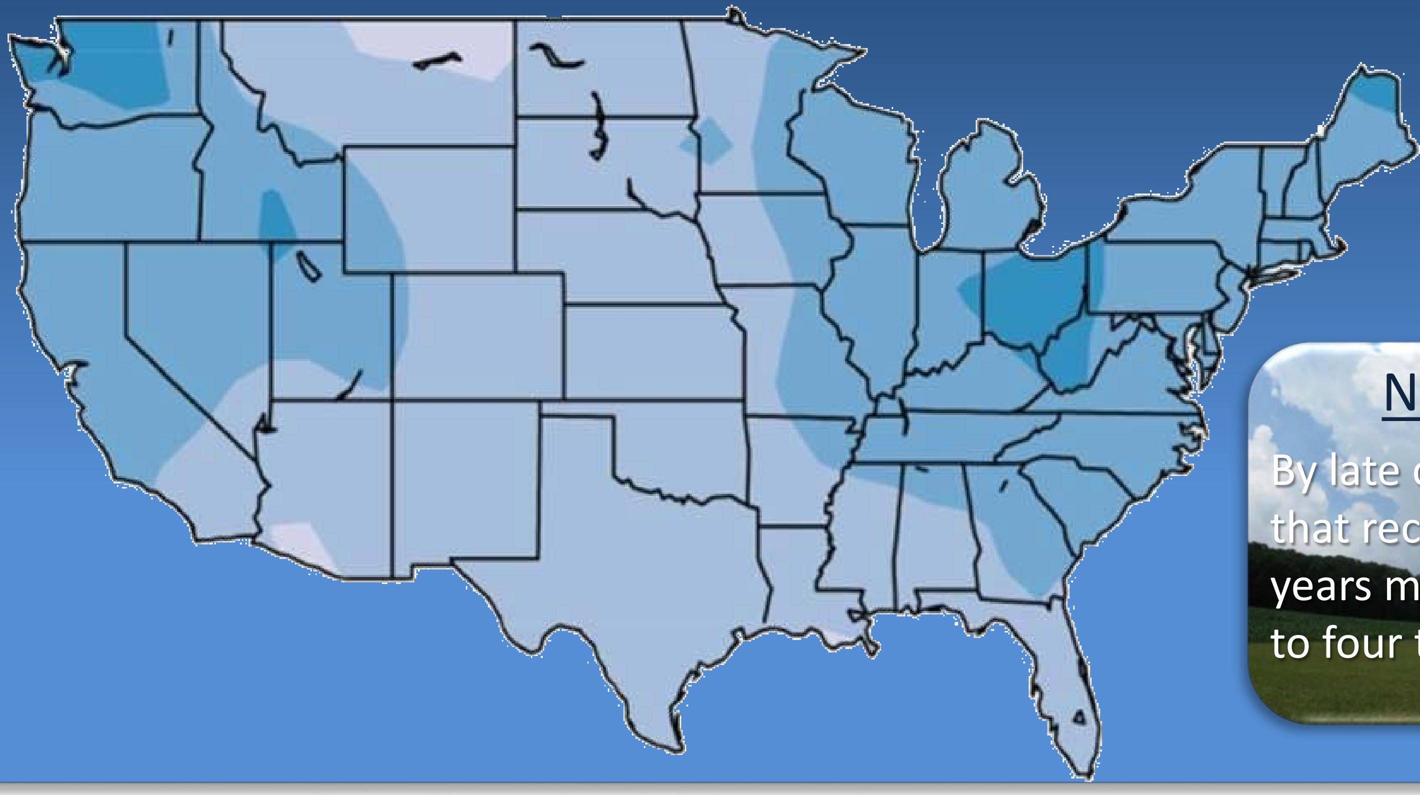
Daily rains of one inch will be more routine

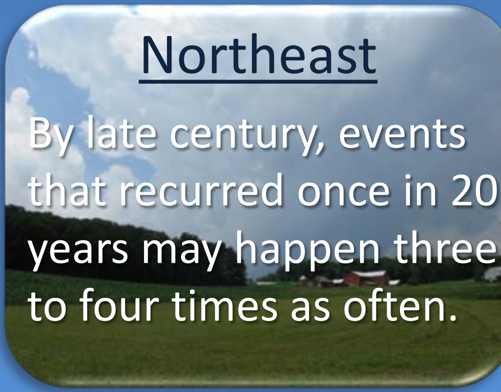
with 5 more such days by the year 2100

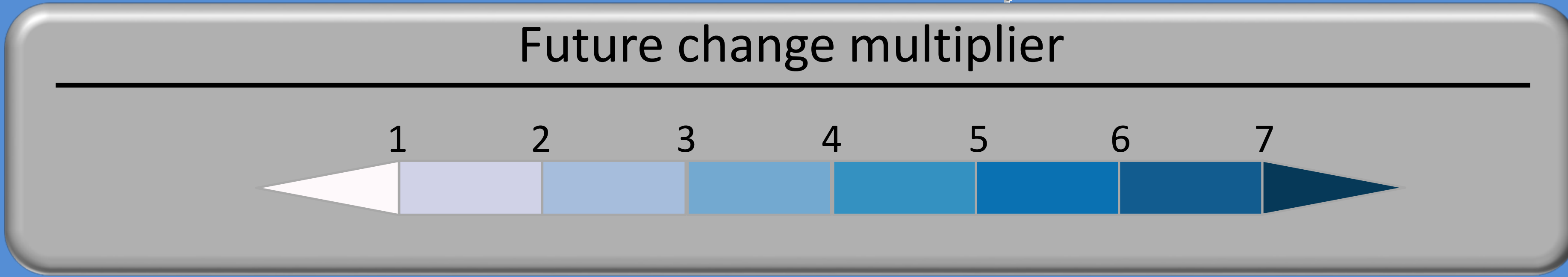


More frequent 20-year storms (~5 in/day)

with a 3-fold increase in frequency expected by 2100



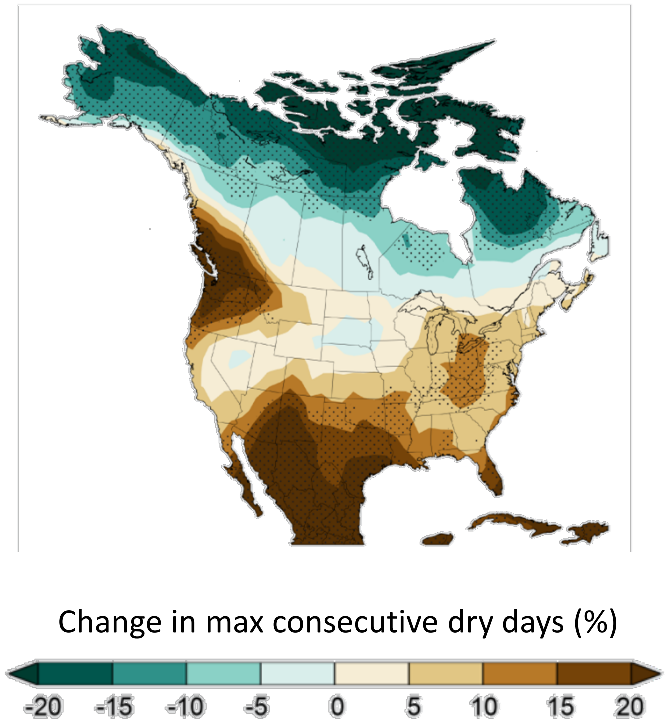




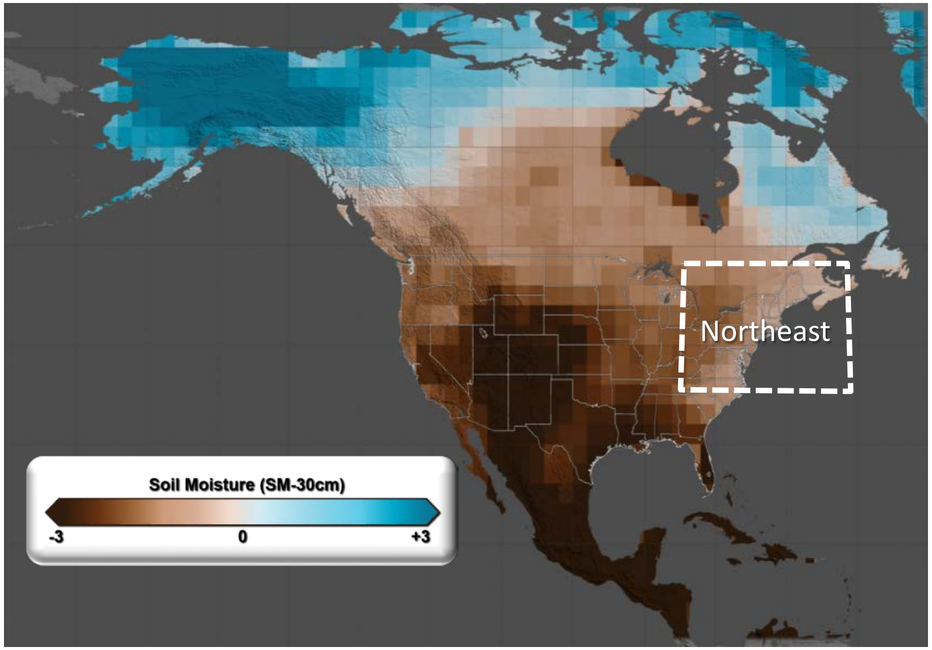
Paradoxically, the future also will be drier

Evaporative demand will greatly overwhelm inputs from rain

Longer dry spells



Increased risk of drought



Standardized soil moisture (0-30 cm; deviations from 20th century mean) for 2090 to 2099 using the RCP 8.5 emissions scenario (Cook et al., 2015; Science Advances).

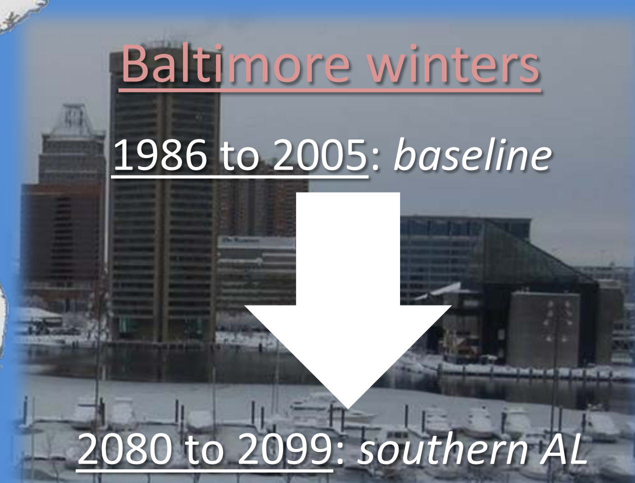
More than 80% of climate models suggest that successive dry days will rise by 5 to 10%.

Take home point: more rain is needed to keep pace with rising evaporative demand (Sherwood and Fu, 2014).

US National Climate Assessment, 2014; Sherwood and Fu, 2014

In summary, our climate is on the move

with late-century climates resembling those of the deep south

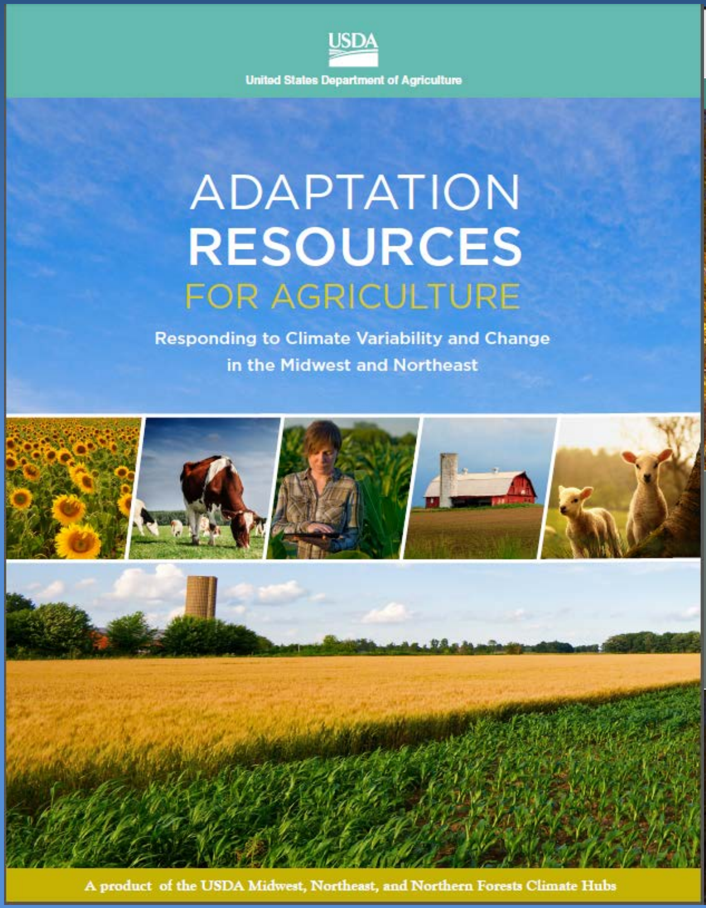


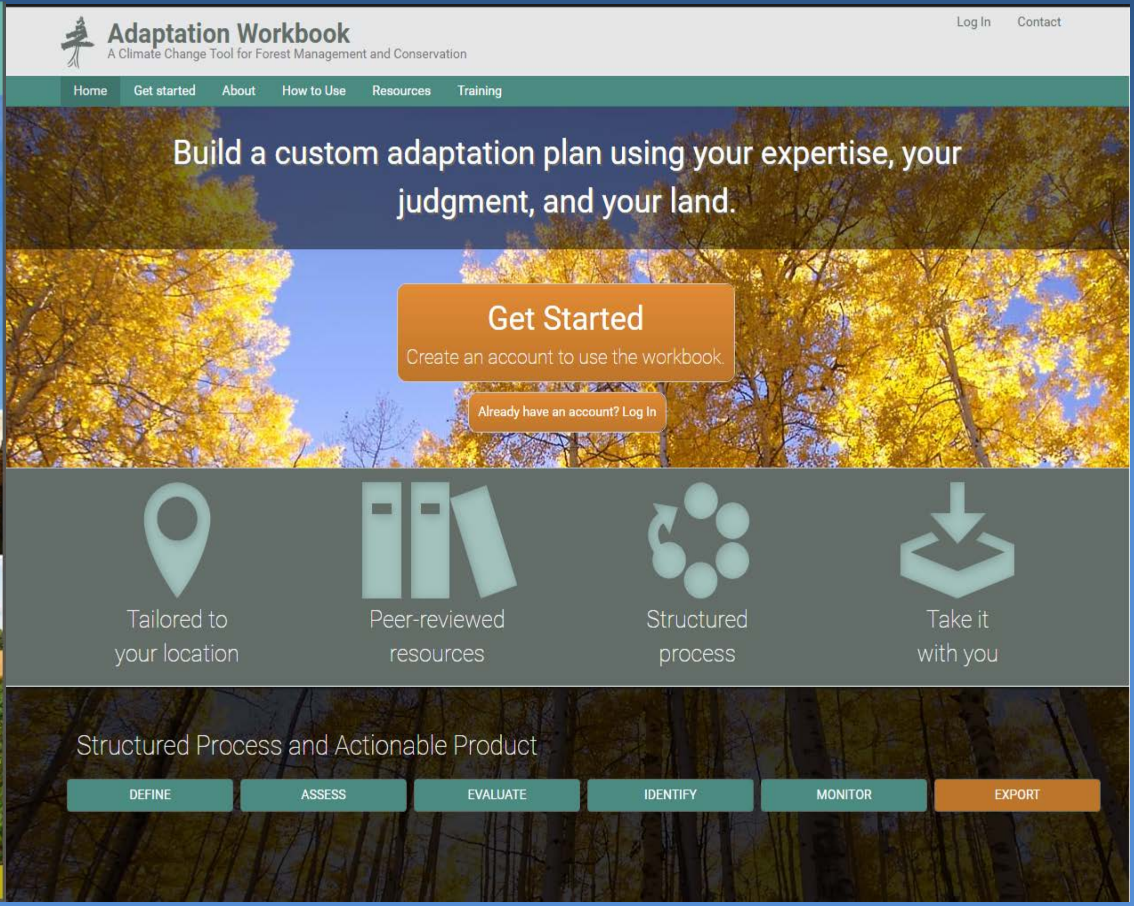
Climate Central: Winter Loses Its Cool

Climate Central: 1001 Blistering Future Summers

USDA-NRCS Adaptation Workbook

Helping land-owners adapt to and mitigate climate change





Online version of the workbook is now available via Adaptation Assistance on the USDA Climate Hubs website: http://www.climatehubs.oce.usda.gov/

Slide courtesy of Dan Dostie (PA-NRCS)

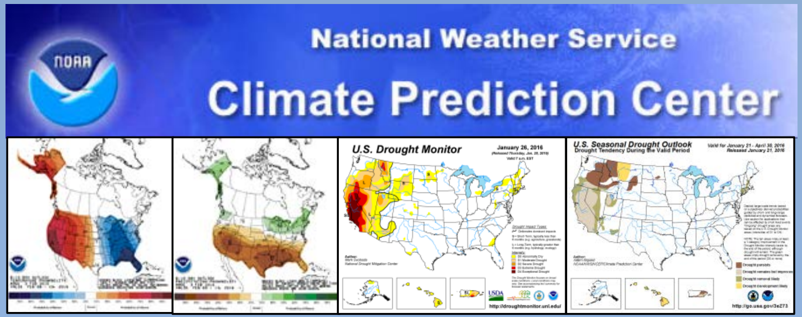
How can I track projected changes?

some tools to track short- and long-term climate projections

Short term (weeks to one year)

NOAA's National Weather Service Climate Prediction Center (CPC).

http://www.cpc.ncep.noaa.gov/



Short term (weeks to months)

Cornell's Climate Smart Farming: Decision Support Tools for farmers.

http://climatesmartfarming.org/

CSF
Climate Smart Farming
A project of Cornell University

Long-term (1880 through 2100)

NOAA's Climate Resilience Toolkit for the continental United States.

https://toolkit.climate.gov/

U.S. Climate Resilience Toolkit

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