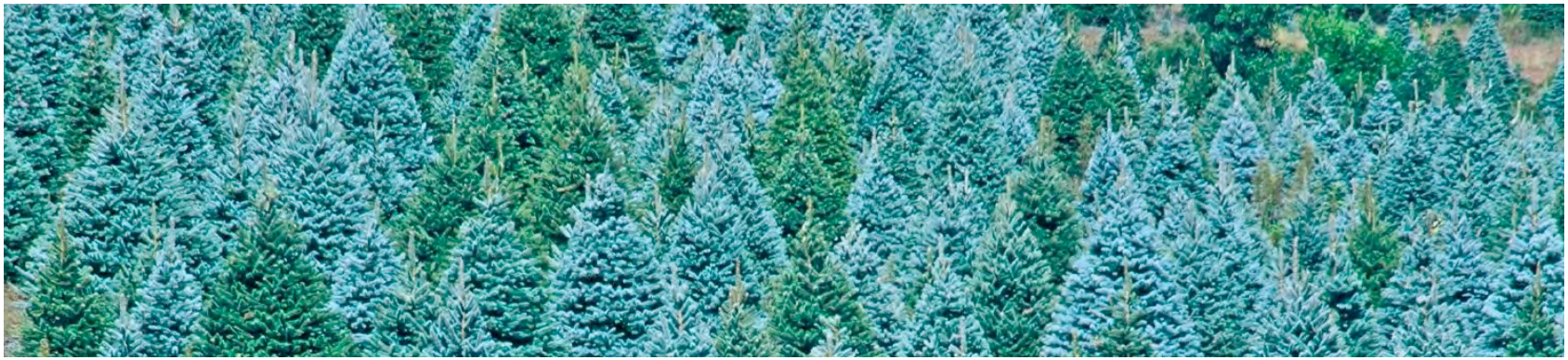


PEERING INTO PANDORA'S BOX

A brief history of high resolution climate projections and their use in impact assessments

KATHARINE HAYHOE

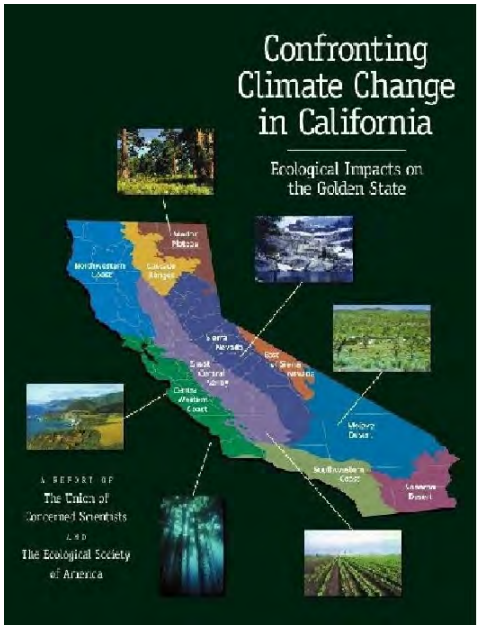
Climate Science Center, Texas Tech University

Our civilization is built on the assumption of a stable climate

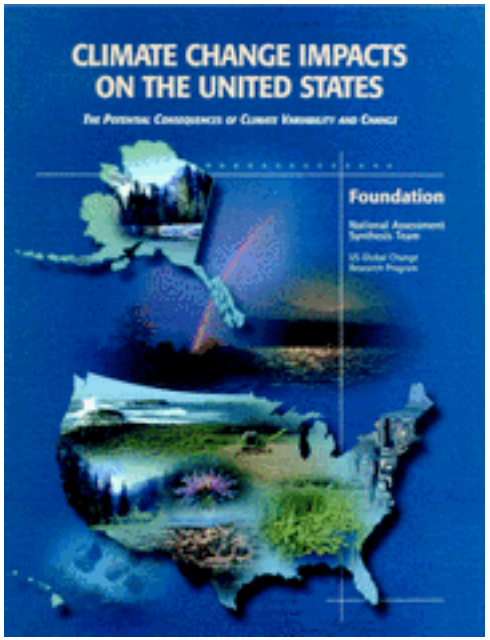
What happens if that climate isn't stable any more?

In the beginning, climate assessments simply asked, “what’s going to happen?!”

1999



2000



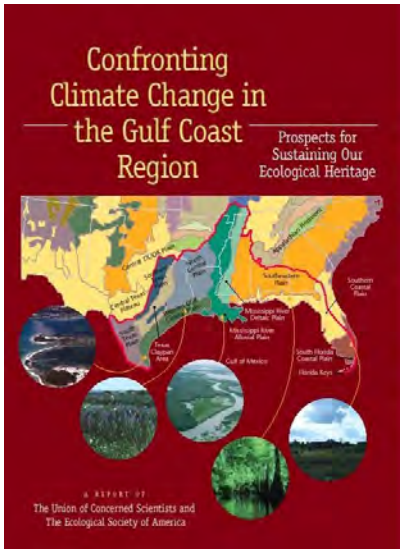
Today, climate impact assessments strive to answer at least one of two key questions:

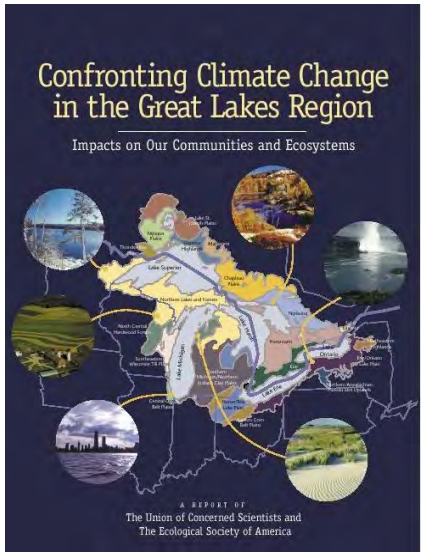
Which impacts are unavoidable under any scenario – for which we should prepare?

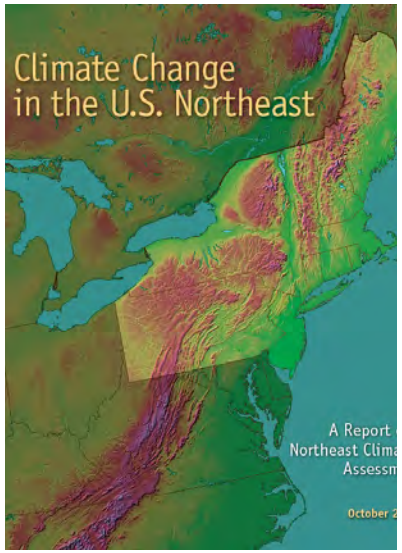
Which impacts could be avoided by following a lower emissions pathway – for which we should mitigate?

The 2000s

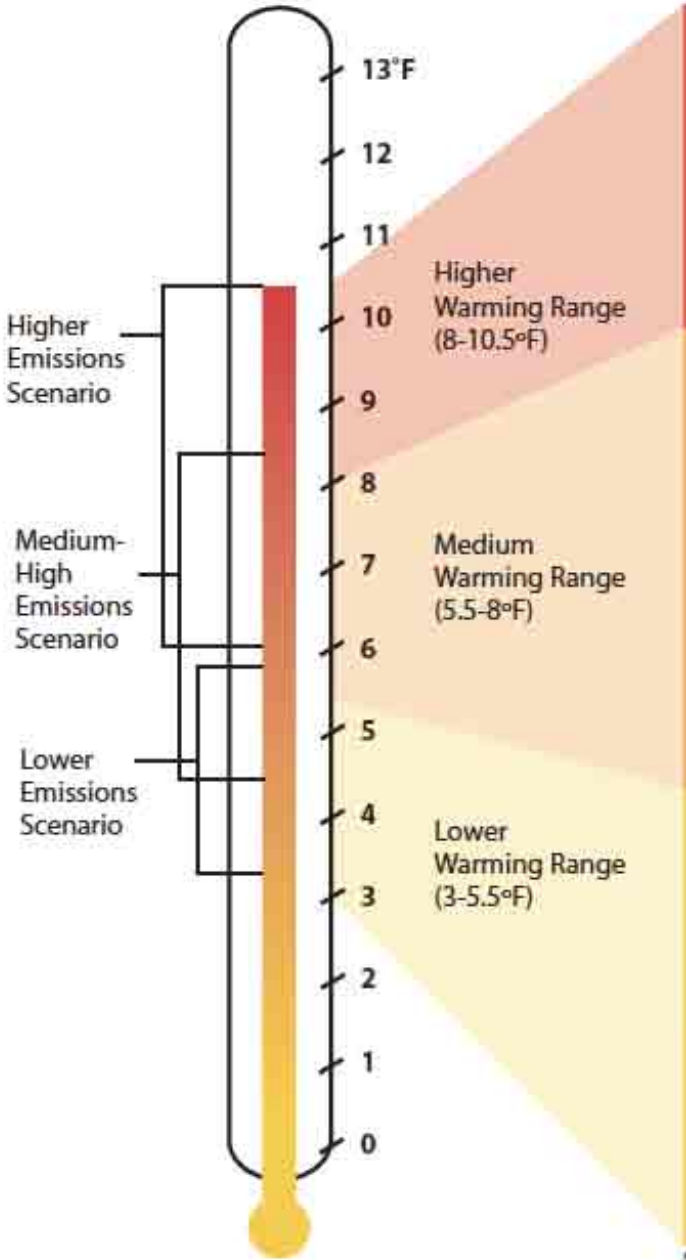
2001 2003 2004 2007







Summary of Projected Global Warming Impact, 2070–2099
(as compared with 1961–1990)



Higher Warming Range (8-10.5°F)

- 90% loss in Sierra snowpack
- 22–30 inches of sea level rise
- 3–4 times as many heat wave days in major urban centers
- 4–6 times as many heat-related deaths in major urban centers
- 2.5 times more critically dry years
- 20% increase in energy demand

Medium Warming Range (5.5-8°F)

- 70–80% loss in Sierra snowpack
- 14–22 inches of sea level rise
- 2.5–4 times as many heat wave days in major urban centers
- 2–6 times as many heat-related deaths in major urban centers
- 75–85% increase in days conducive to ozone formation*
- 2–2.5 times more critically dry years
- 10% increase in electricity demand
- 30% decrease in forest yields (pine)
- 55% increase in the expected risk of large wildfires

Lower Warming Range (3-5.5°F)

- 30–60% loss in Sierra snowpack
- 6–14 inches of sea level rise
- 2–2.5 times as many heat wave days in major urban centers
- 2–3 times as many heat-related deaths in major urban centers
- 25–35% increase in days conducive to ozone formation*
- Up to 1.5 times more critically dry years
- 3–6 % increase in electricity demand
- 7–14% decrease in forest yields (pine)
- 10–35% increase in the risk of large wildfires

* For high ozone locations in Los Angeles (Riverside) and the San Joaquin Valley (Visalia)

Policy Impacts

RGGI Inc.

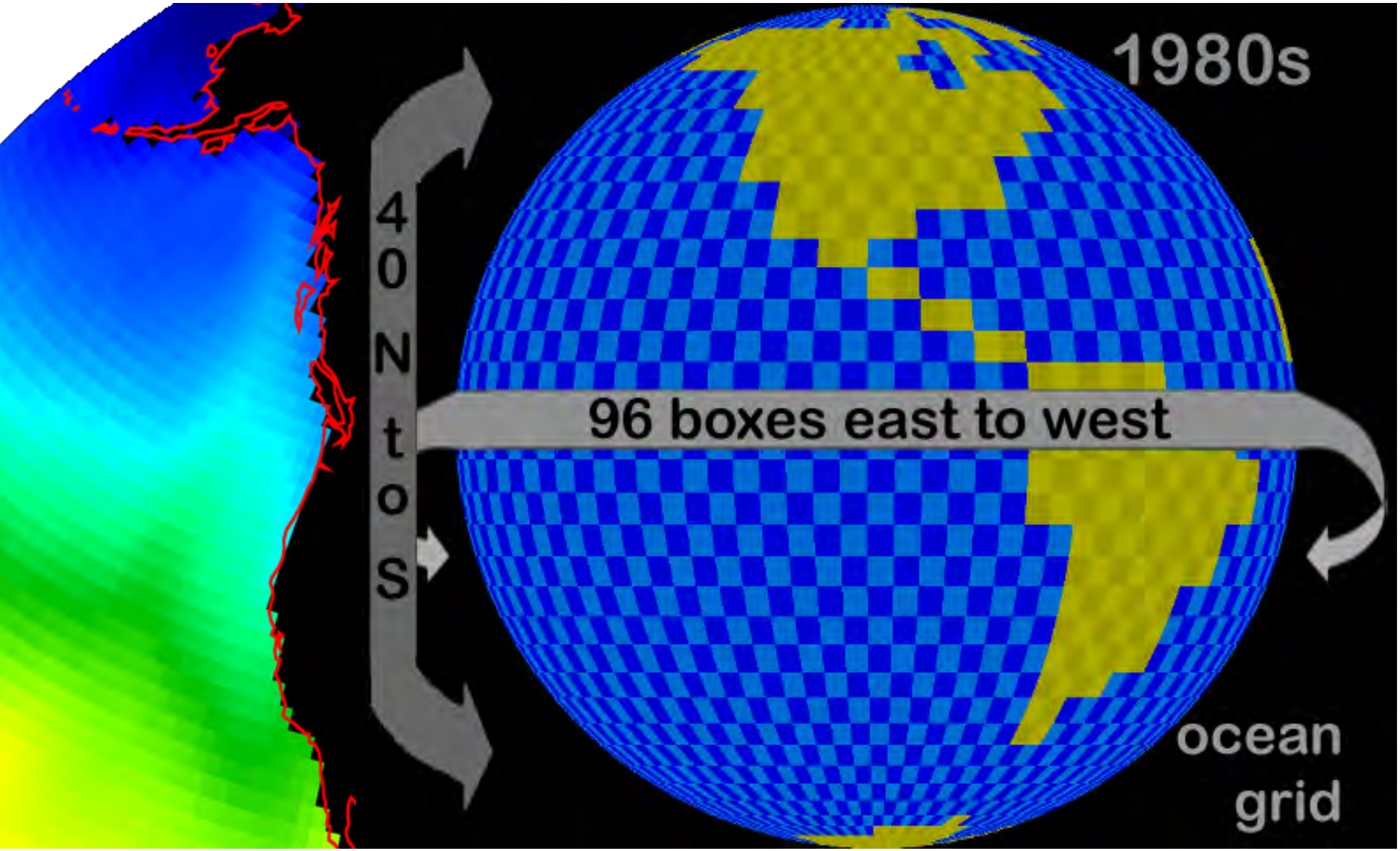
TYPE ONE	TYPE TWO	TYPE THREE
Existing vulnerabilities	Past & future qualitative trends	The whole enchilada detailed high-resolution climate projections

ONE. Tornado risk in Oklahoma

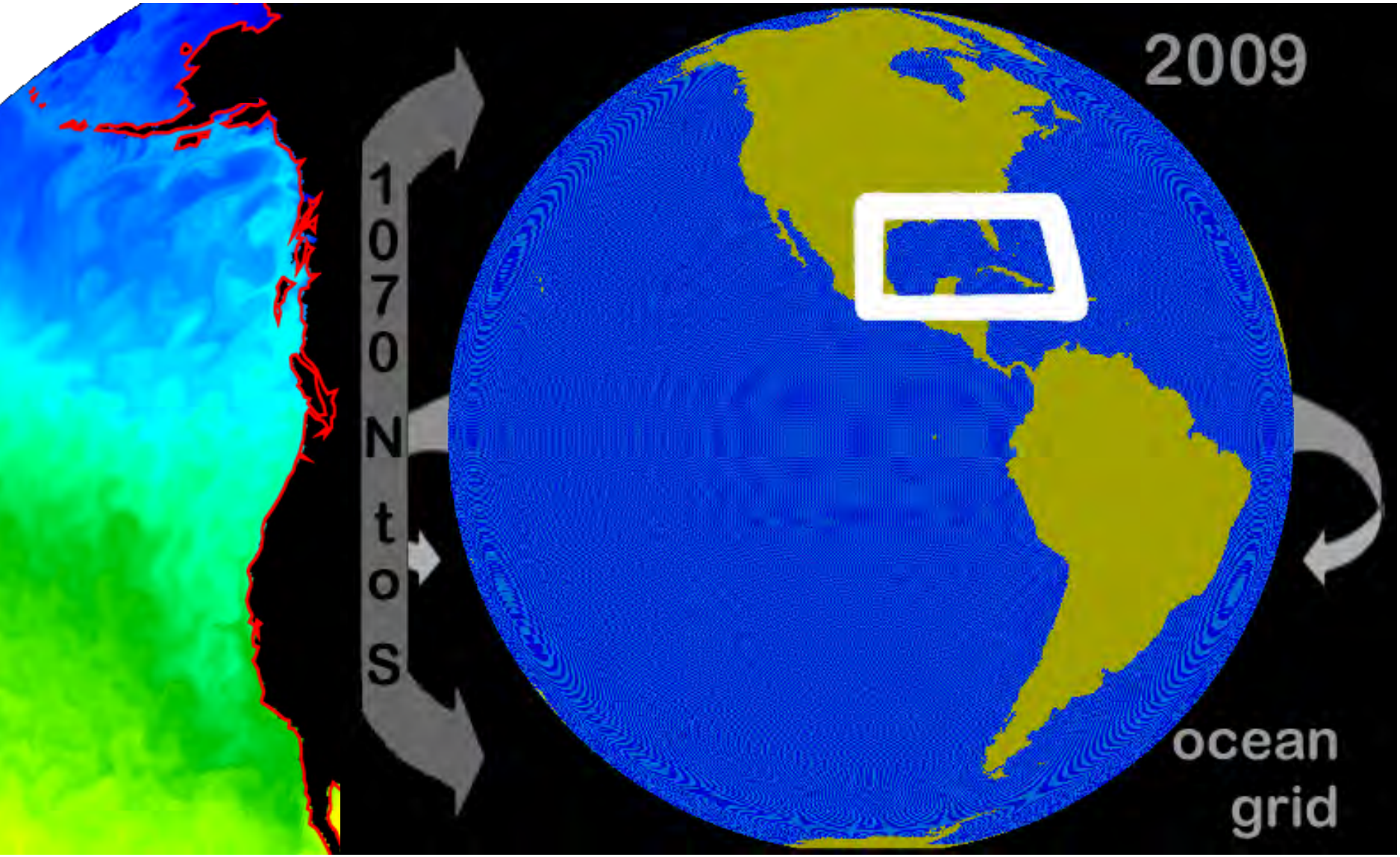
TWO. Heatwave risk in Washington DC

THREE. Water supply and long-term reservoir levels for Austin TX

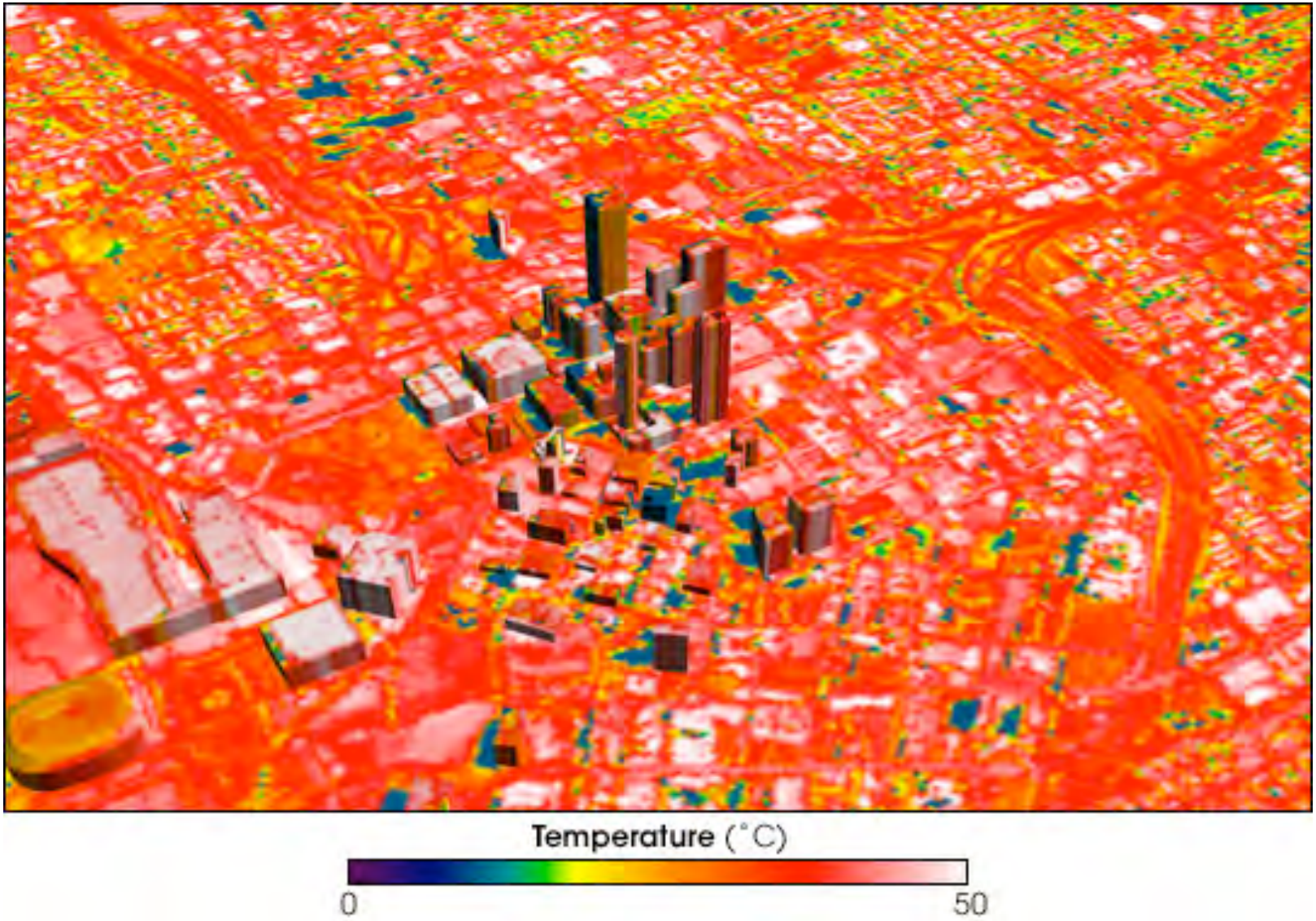
Climate models of the 1980s



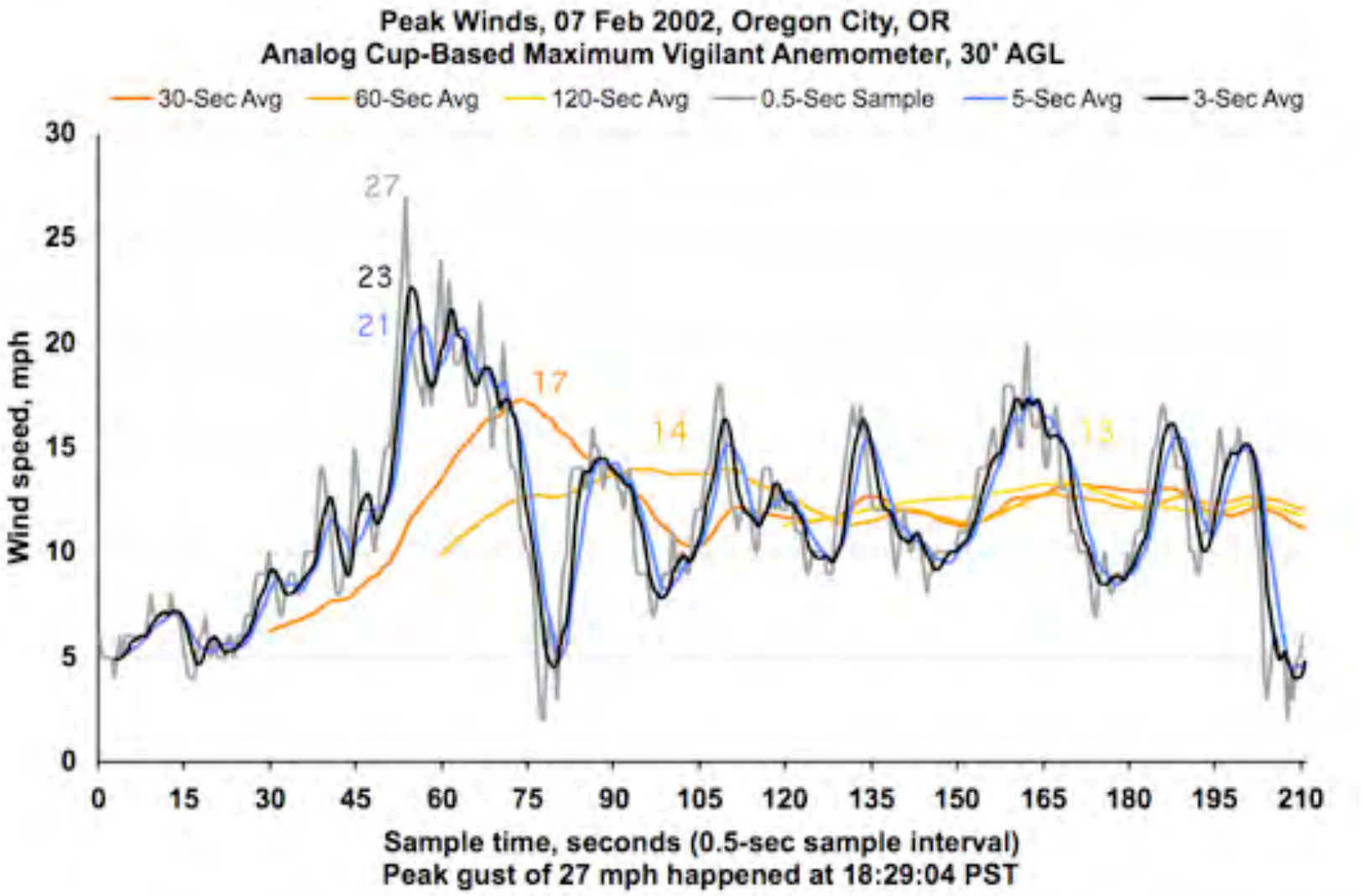
Climate models of the 2010s



SPATIAL RESOLUTION Urban Heat Island



TEMPORAL RESOLUTION 5 min wind gusts



Thresholds and absolute values

What is downscaling?

DOWNSCALING **introduces new information** into global climate model output to generate high-resolution climate projections

What is downscaling?

DOWNSCALING **introduces new information** into global climate model output to generate high-resolution climate projections

Where does this new information come from?

from observations

from higher-resolution modeling of physical processes

What is downscaling?

DOWNSCALING **introduces new information** into global climate model output to generate high-resolution climate projections

Where does this new information come from?

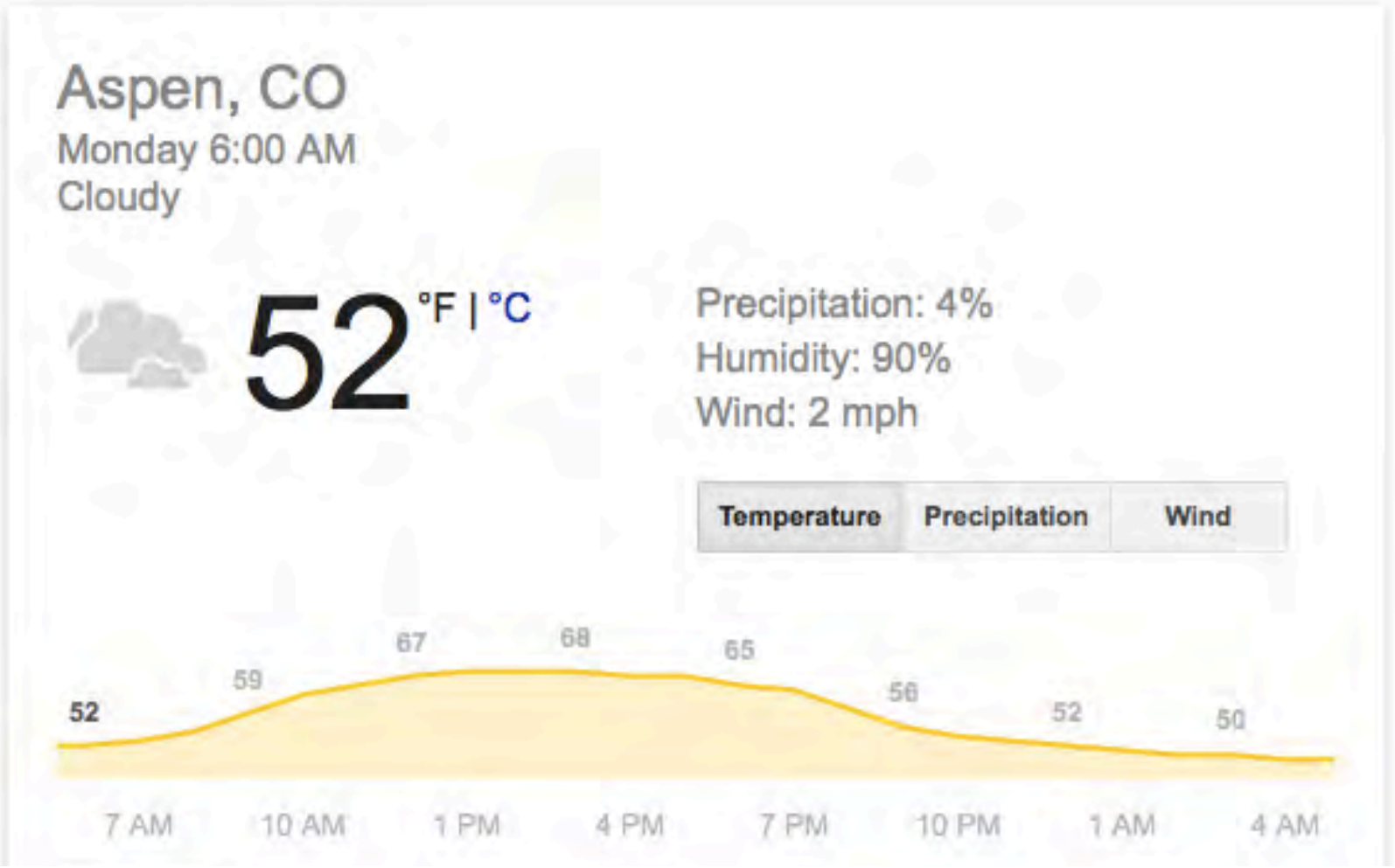
from observations

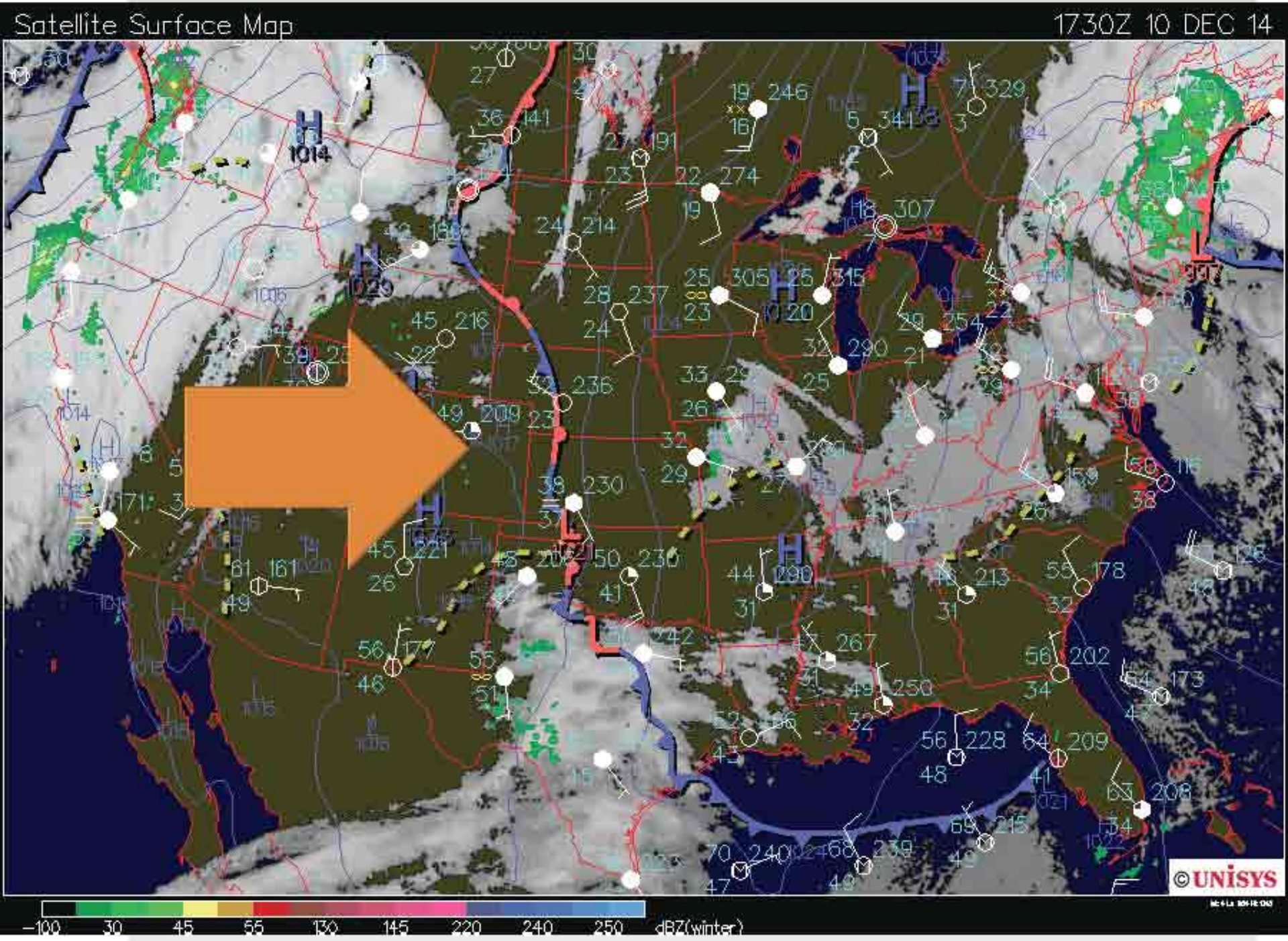
EMPIRICAL-STATISTICAL MODELING

from higher-resolution modeling of physical processes

REGIONAL CLIMATE MODELING

We assume that local conditions ..



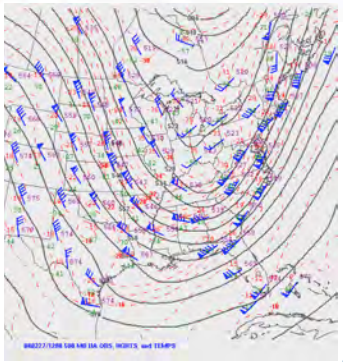
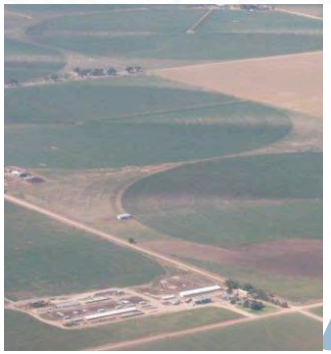
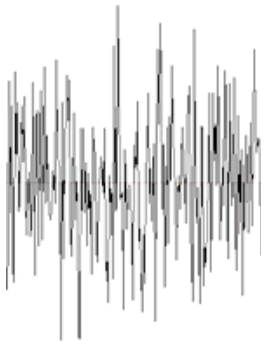

Satellite Surface Map
1730Z 10 DEC 14
−100 30 45 55 130 145 220 240 250 dBZ(winter)
©UNISYS

… are a function of:

Aspen, CO
Monday 6:00 AM
Cloudy

52 °F | °C

Precipitation: 4%
Humidity: 90%
Wind: 2 mph

$= f($  ,  ,  $)$

Large-scale weather systems

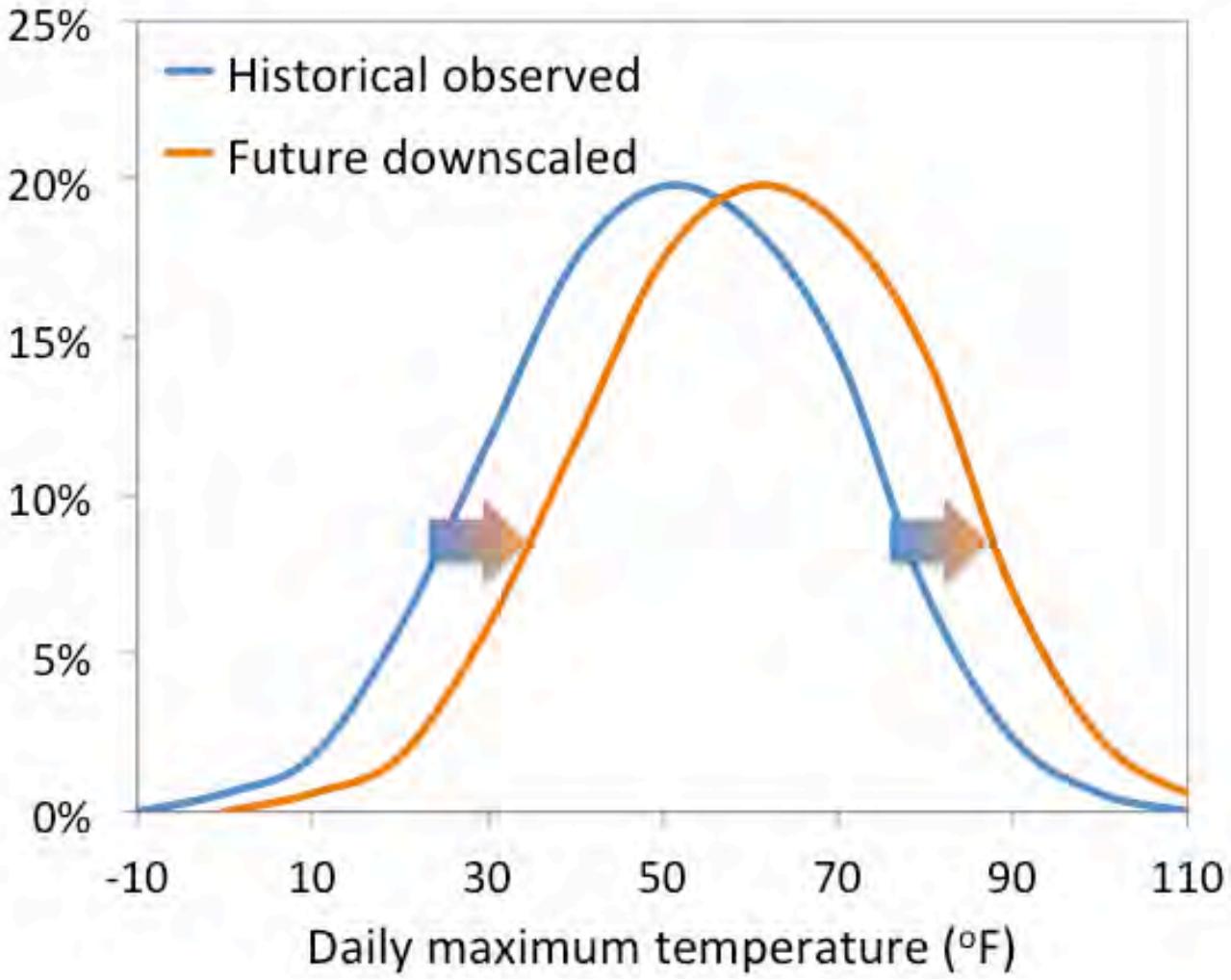
Local orography and other time-invariant features

Stochastic noise

ESDs are based on either DELTA or BIAS CORRECTION methods

Are we adding a "delta" to the observations?

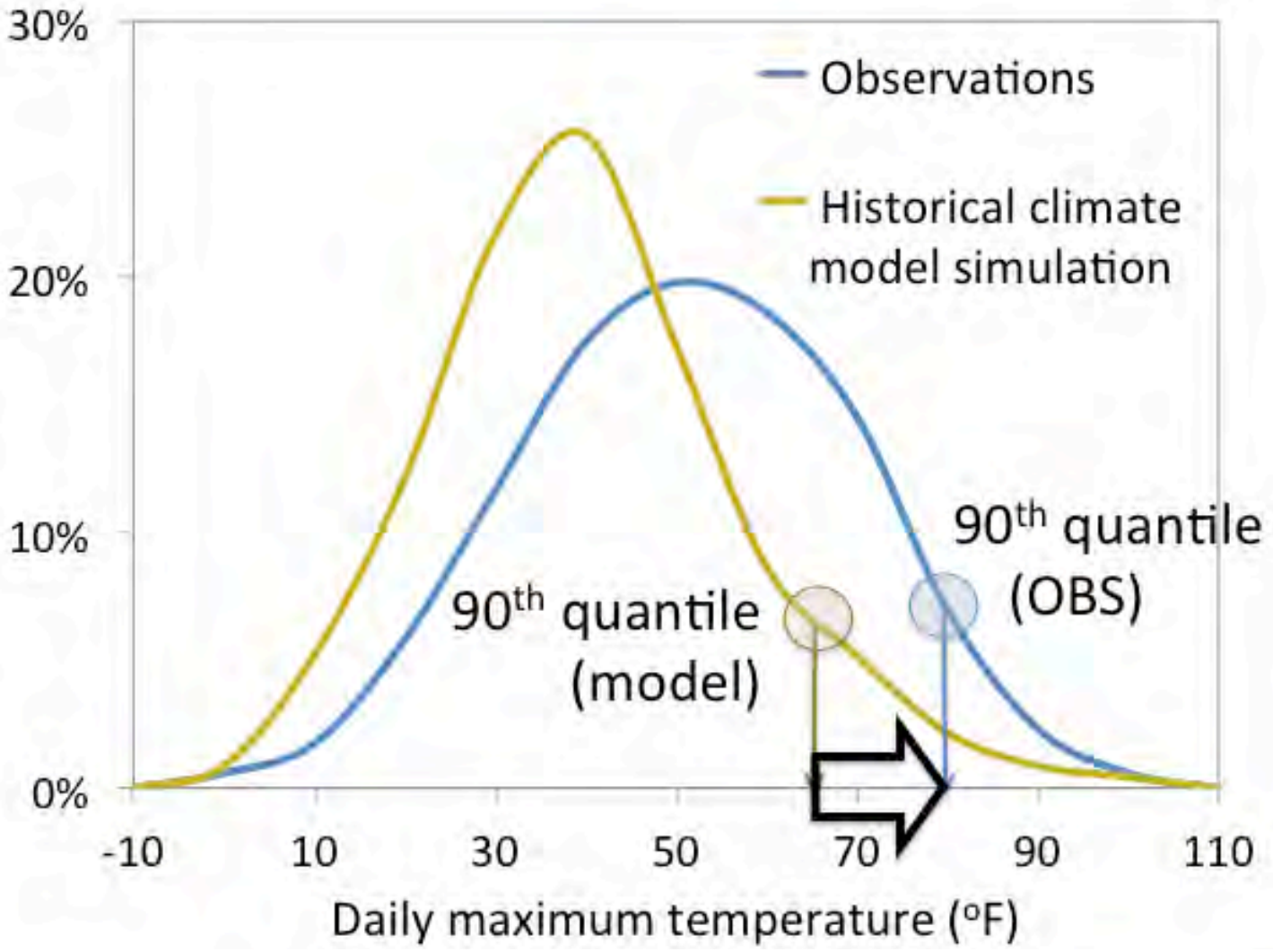
Or bias-correcting the model output?



… which rapidly increase in complexity

BCSD/BCCA

Projects PDFs for monthly or daily simulated GCM variables onto historical observations



… and even more complexity

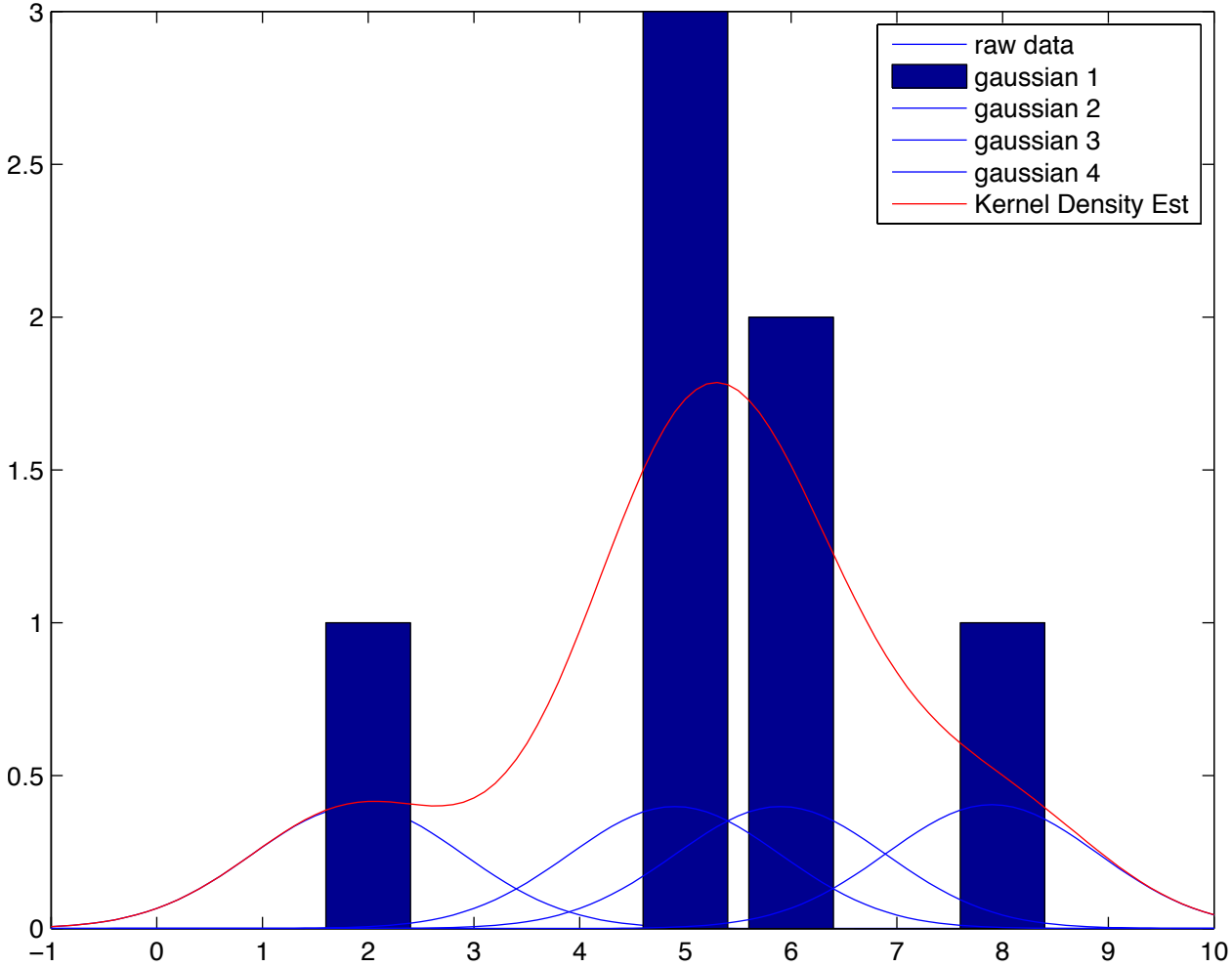
ARRM2

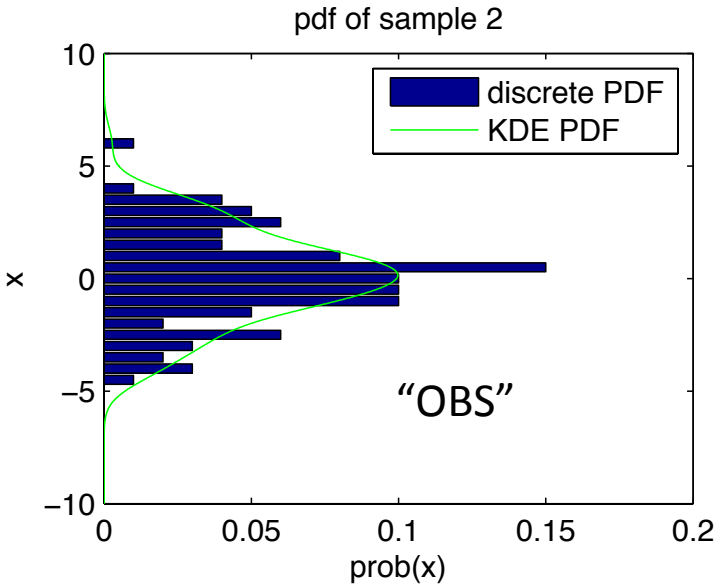
Parametric Kernel Density Distribution Mapping

Replace each discrete measurement with a continuous (typically gaussian) range of values centered at the measurement point

Sum up all (gaussians) to arrive at a continuous distribution for each data set (modeled or observed)

Create a look-up table of continues Model/Observation mapping by matching points of equal cumulative probability between the distributions




pdf of sample 2
discrete PDF
KDE PDF
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prob(x)
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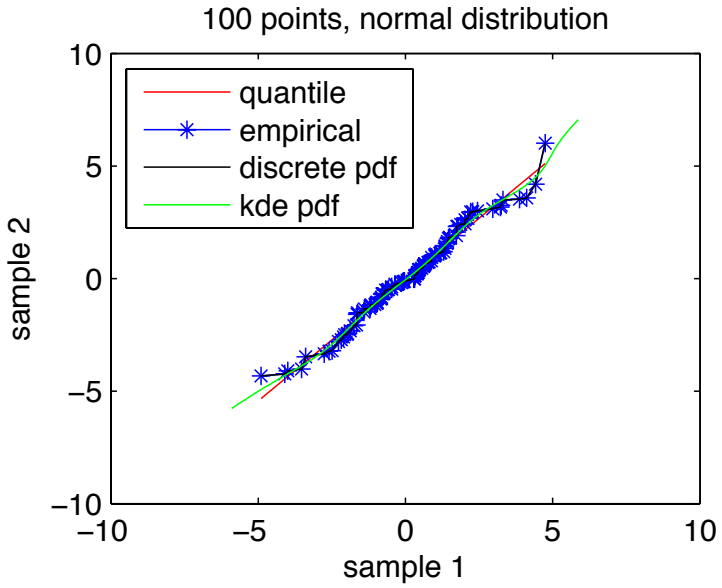
0
−5
−10
0
0.05
0.1
0.15
0.2


100 points, normal distribution
quantile
empirical
discrete pdf
kde pdf
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sample 1
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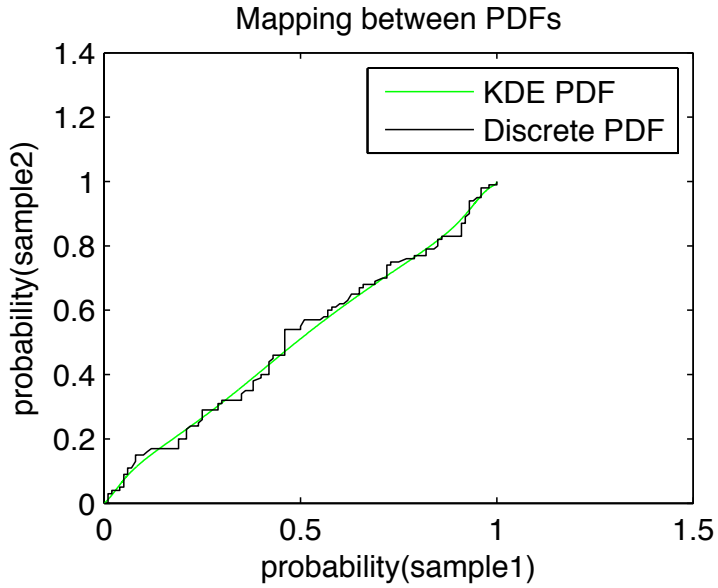
Mapping between PDFs
KDE PDF
Discrete PDF
probability(sample2)
probability(sample1)
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1.2
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0.6
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0.2
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0
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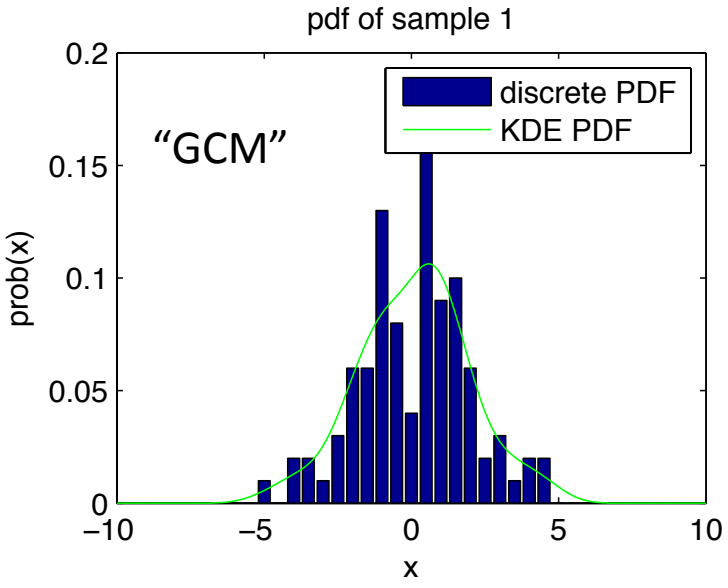
1
1.5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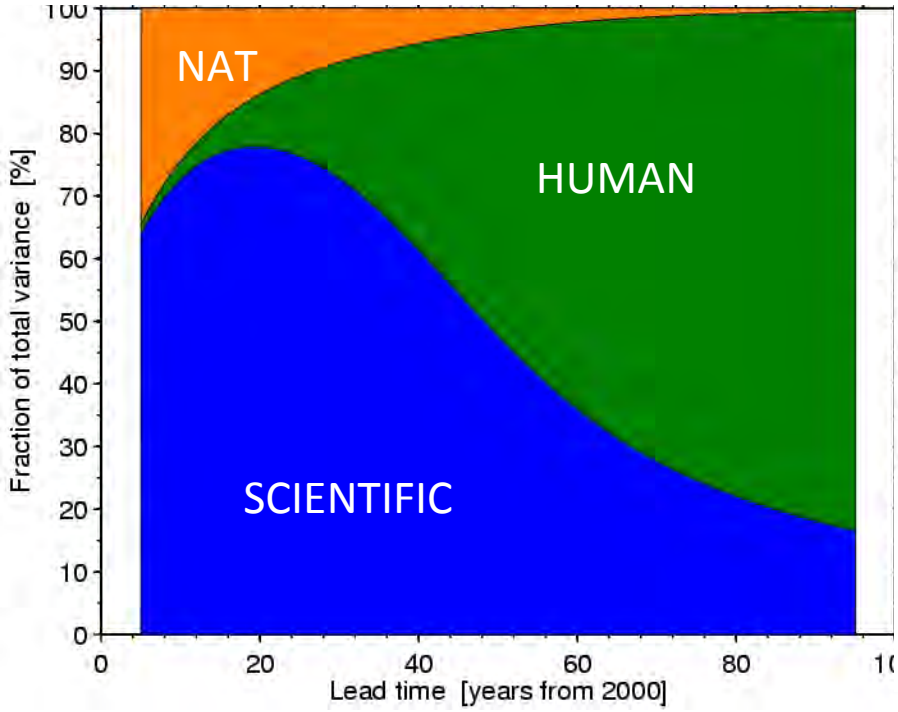
UNCERTAINTIES IN ALL PROJECTIONS

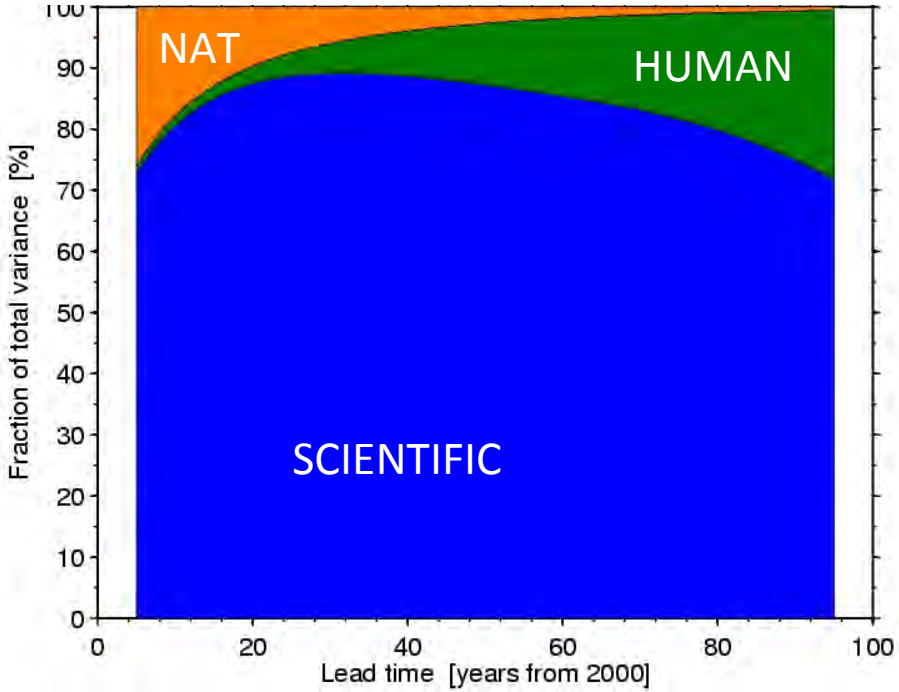
- **INTERNAL VARIABILITY**
- **BOUNDARY CONDITIONS (CLIMATE MODELS)**
- **SCENARIOS**
- **OBSERVATIONS DO NOT CONTAIN ERRORS**
- **PREDICTORS ARE RELEVANT TO LOCAL CLIMATE AND GLOBAL CHANGE**
- **STATISTICAL RELATIONSHIPS REMAIN STATIONARY (VALID) AS CLIMATE CHANGES**

The importance of each different source of uncertainty varies in time

GLOBAL TEMPERATURE



GLOBAL PRECIPITATION

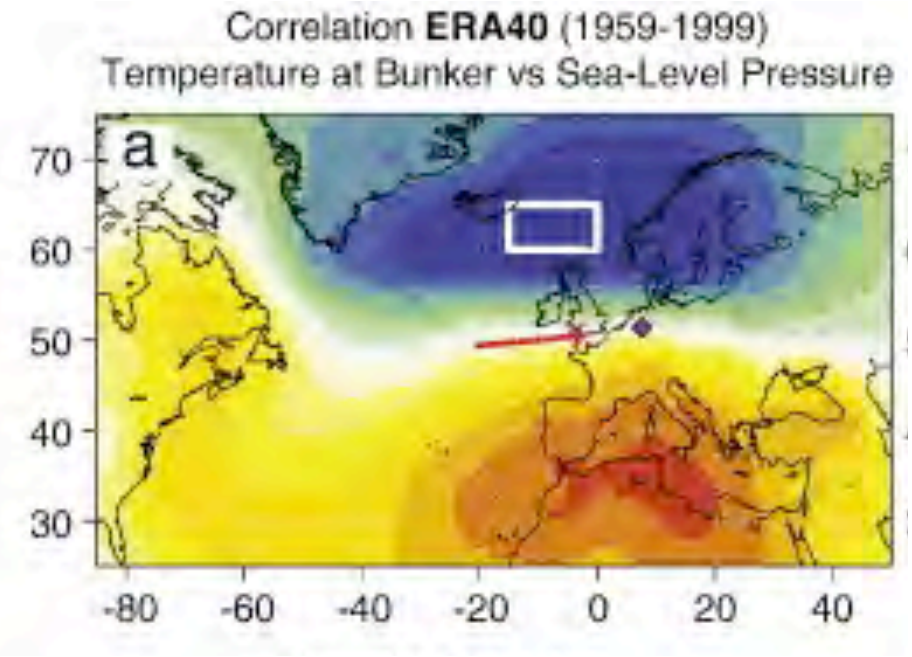


Hawkins & Sutton 2009, 2011

UNCERTAINTIES IN ESDs

- INTERNAL VARIABILITY
- BOUNDARY CONDITIONS (CLIMATE MODELS)
- SCENARIOS
- **OBSERVATIONS DO NOT CONTAIN ERRORS**
- **PREDICTORS ARE RELEVANT TO LOCAL CLIMATE AND GLOBAL CHANGE**
- **STATISTICAL RELATIONSHIPS REMAIN STATIONARY (VALID) AS CLIMATE CHANGES**

Do predictors represent climate signal?



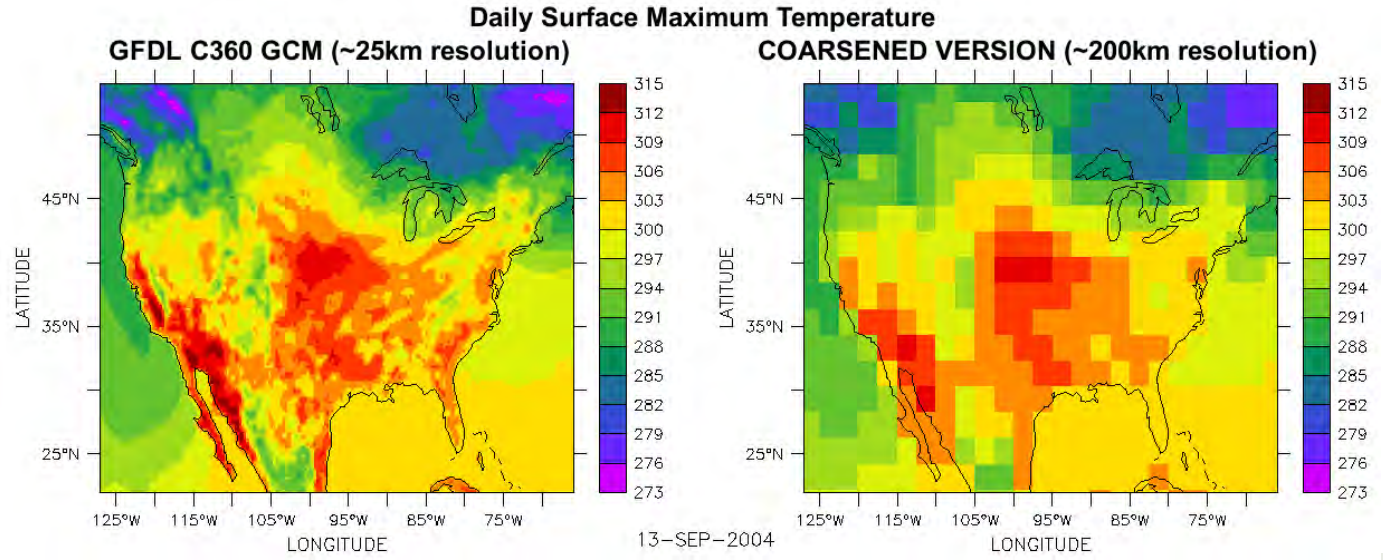
Correlation between winter temperature at a European weather station and sea level pressure over the North Sea

- There may be an excellent correlation between a large-scale variable (such as sea level pressure) and local temperature
- But is sea level pressure expected to change much in the future due to climate? Not much!

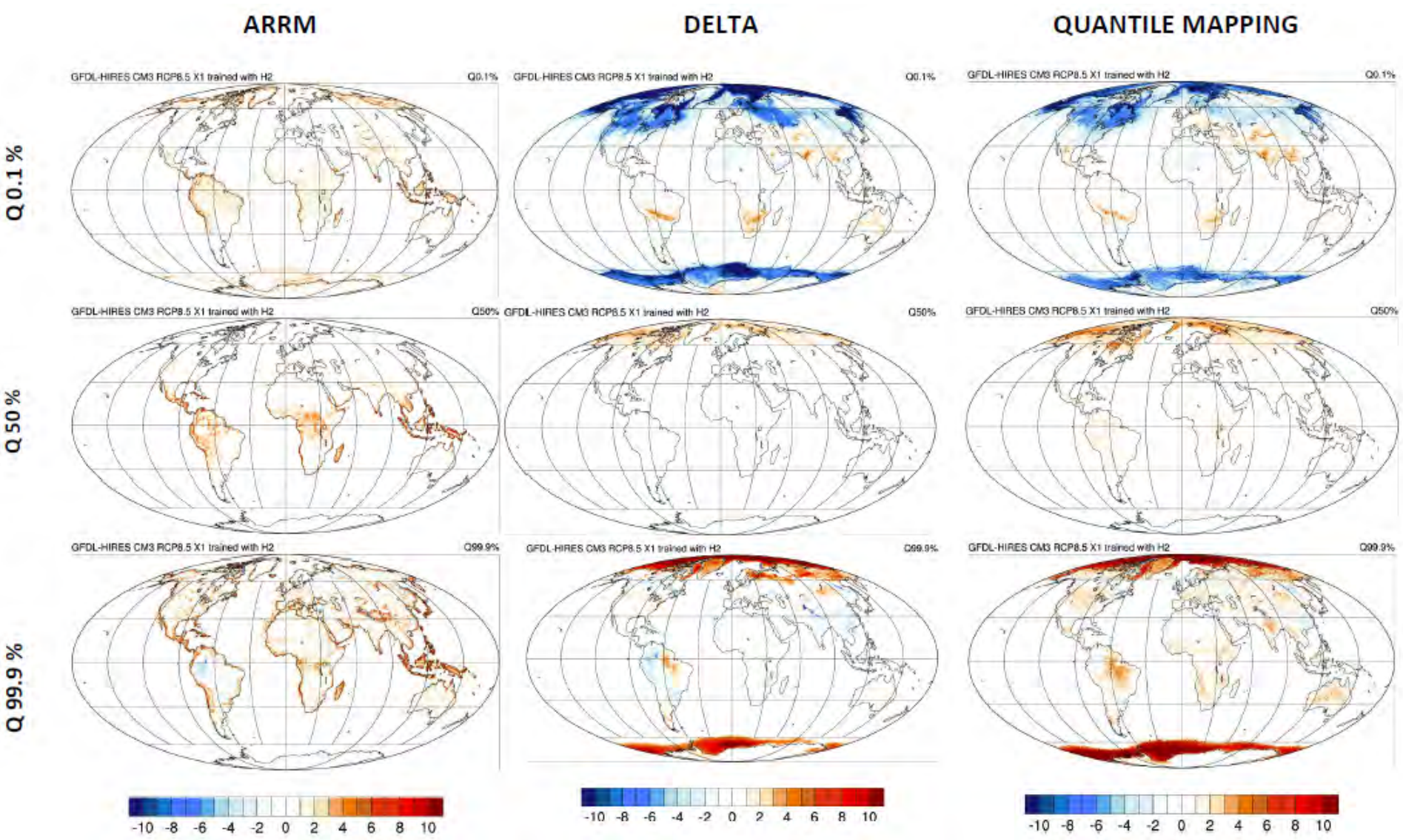
Are statistical relationships stationary?

EXPERIMENTAL DESIGN

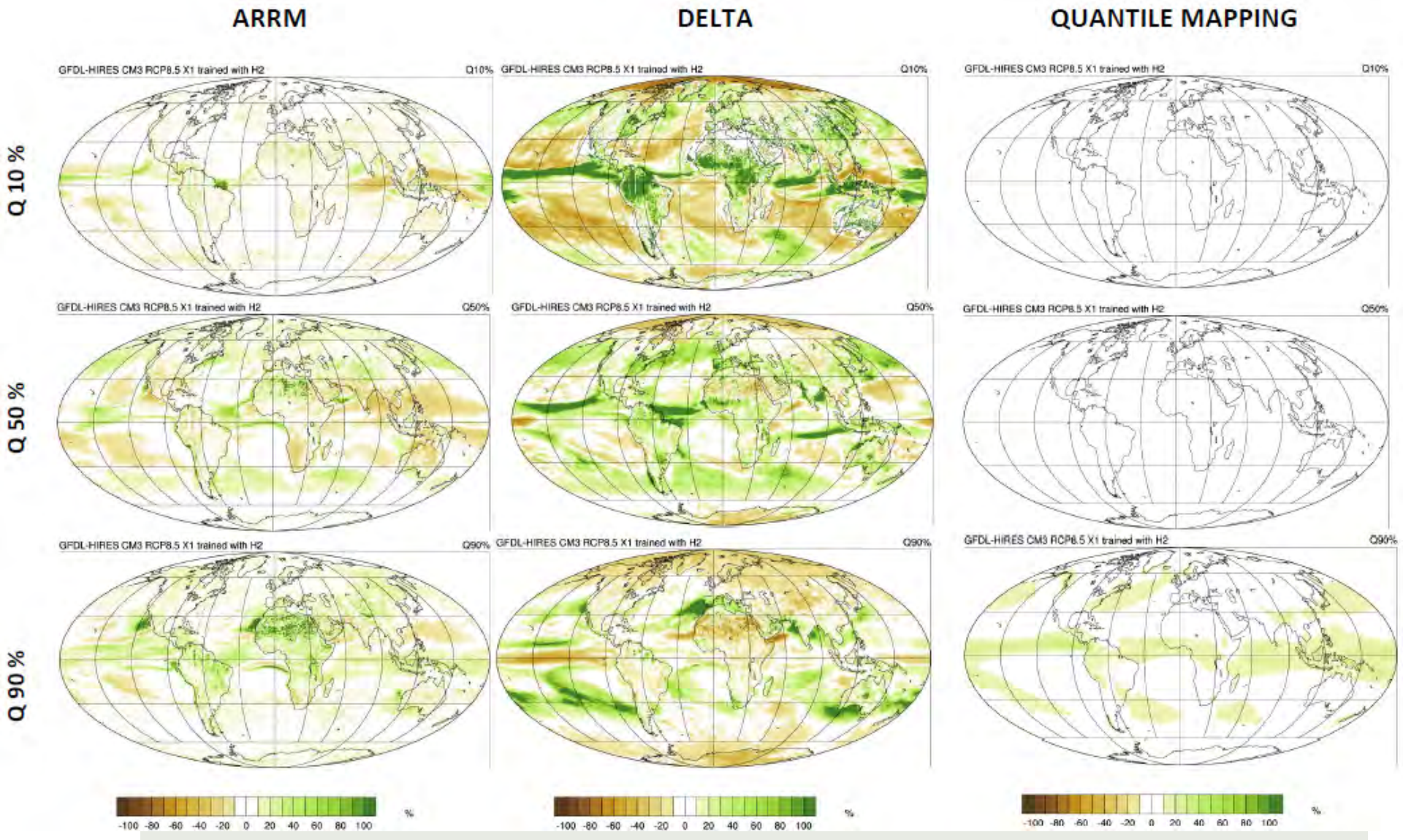
1. Use an ultra-high-resolution global model at 25km as past and future “OBS”
2. Use typical coarse-resolution global model at 2 degrees as past and future “MODEL”



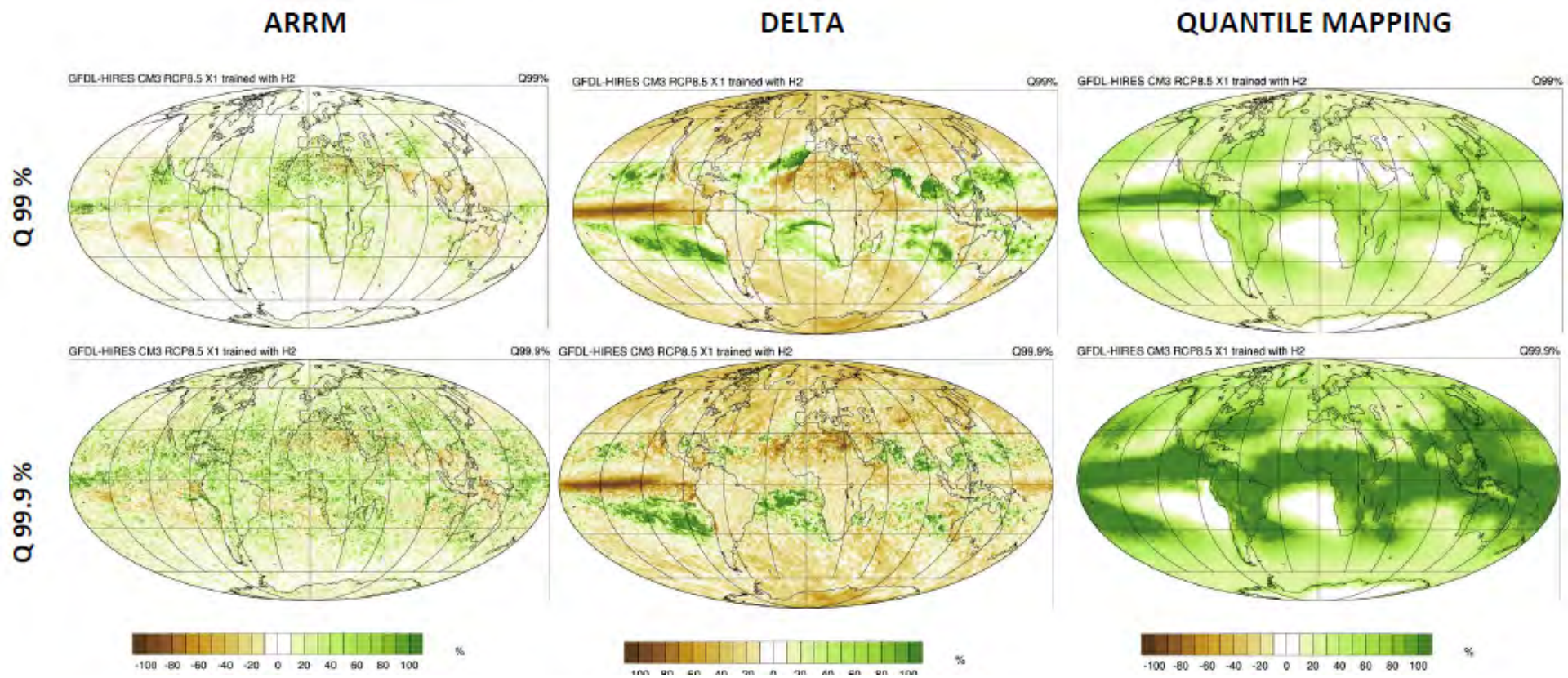
Maximum temperature



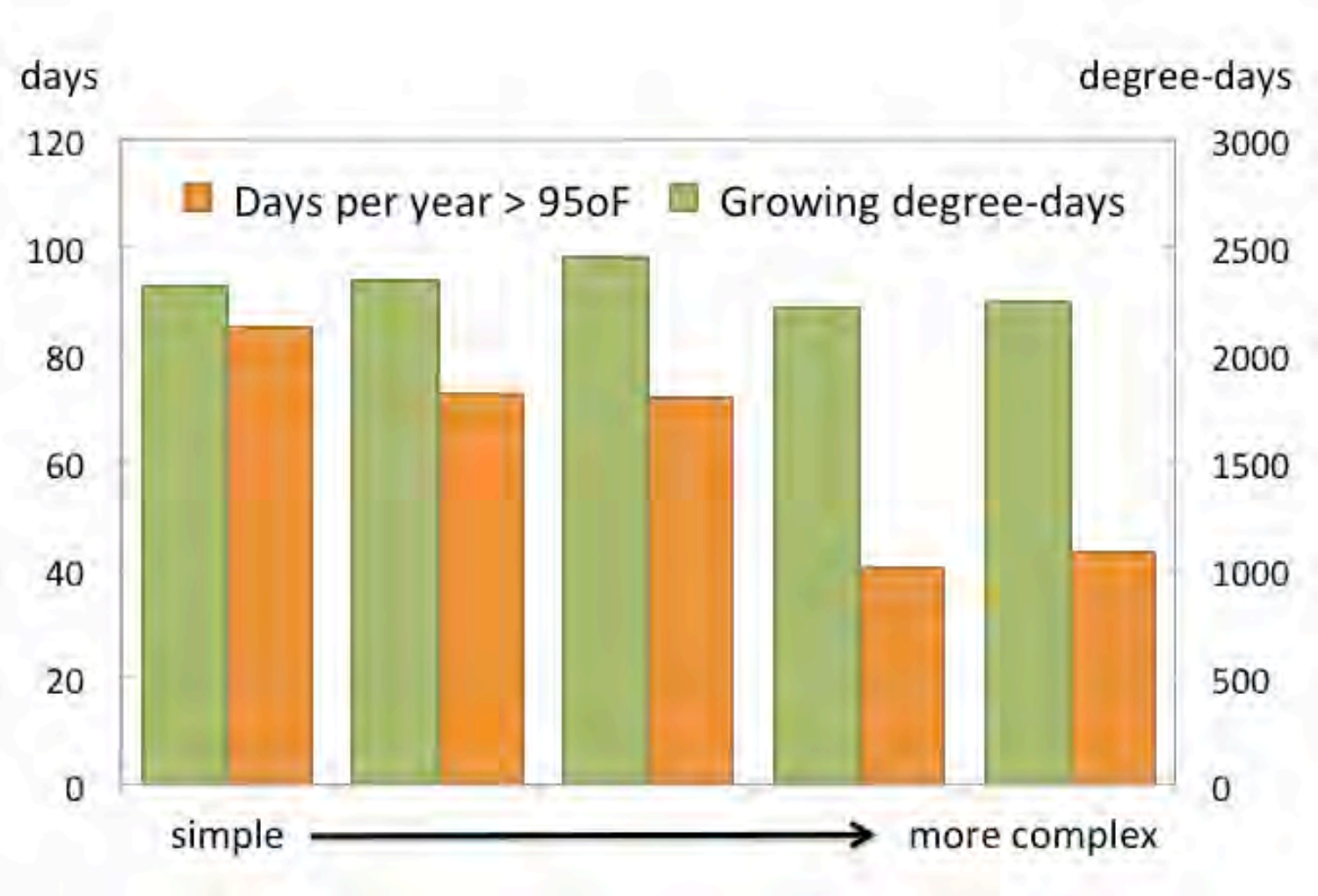
Daily wet-day precipitation



Daily wet-day precipitation



Which method you pick depends on which question you are asking



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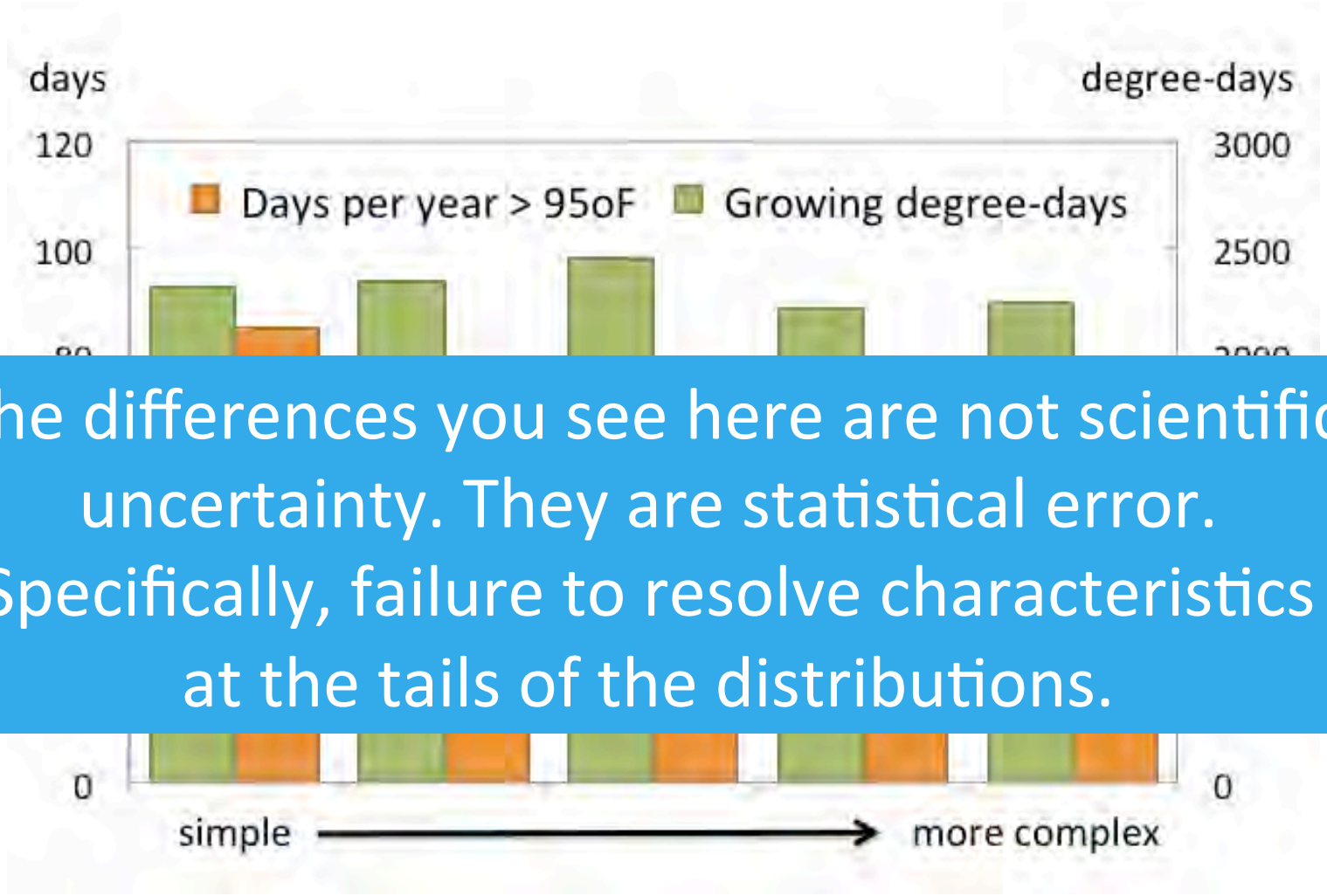
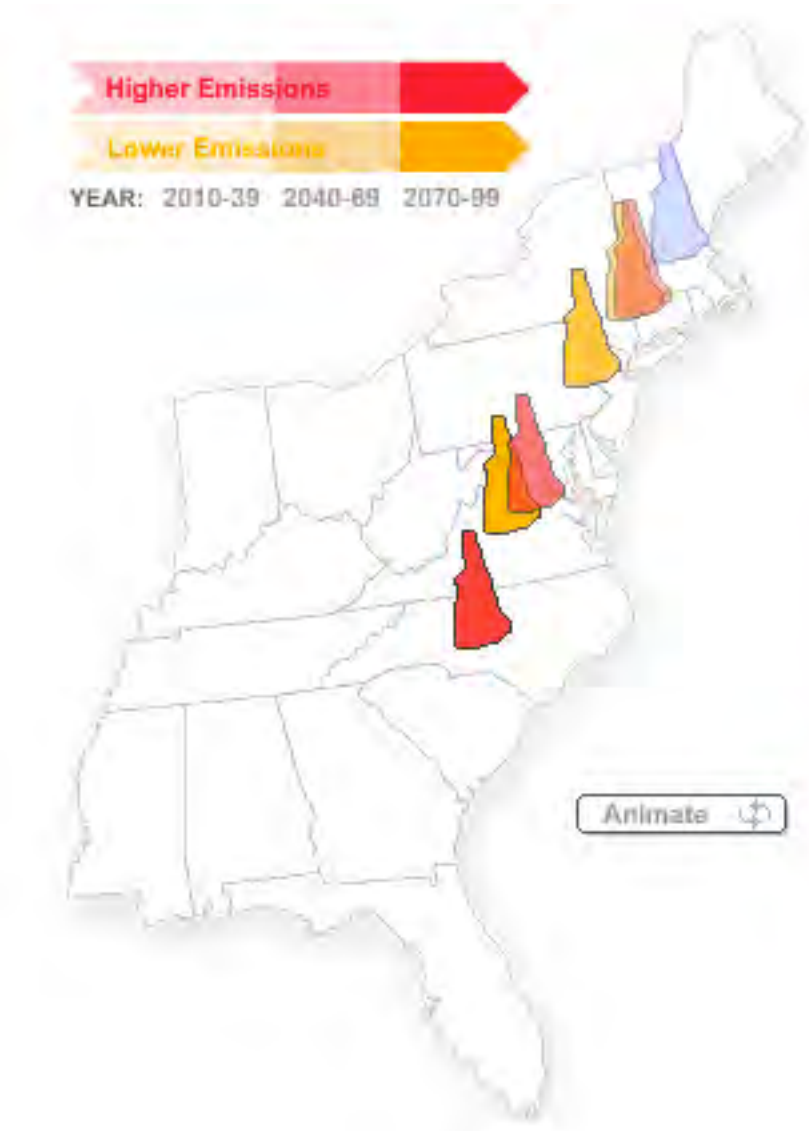


The differences you see here are not scientific uncertainty. They are statistical error. Specifically, failure to resolve characteristics at the tails of the distributions.

The bottom line on downscaling

- Nearly any downscaling method is better than using climate model output directly
- Simple methods are (surprisingly) reliable for simulating climatological means
- More complex methods are needed to simulate changes in thresholds and extremes
- Understanding limitations & biases in methods can help select appropriate method or interpret results

What a given climate will feel like



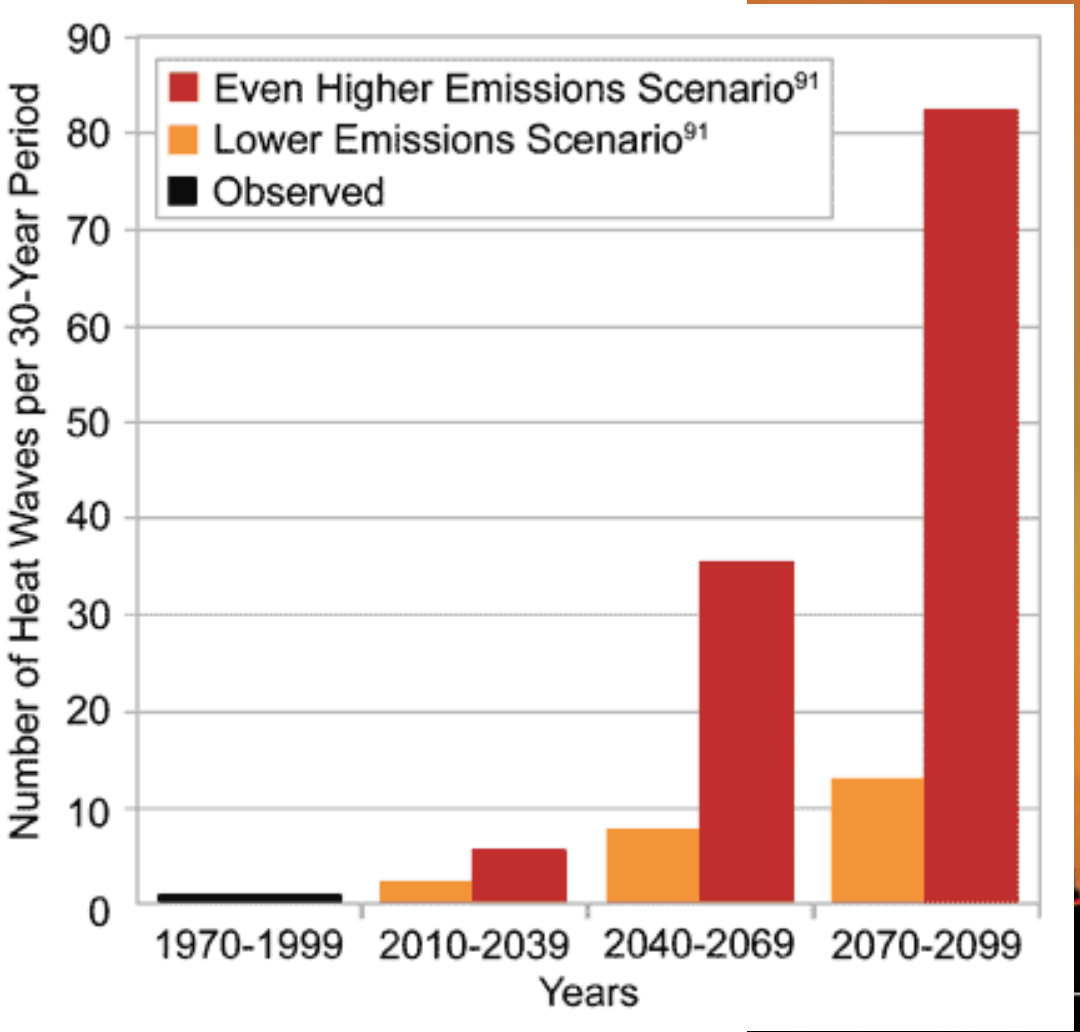
Summer in New Hampshire could feel like the typical summer in North Carolina by the end of the century unless we take action to reduce heat-trapping emissions today.

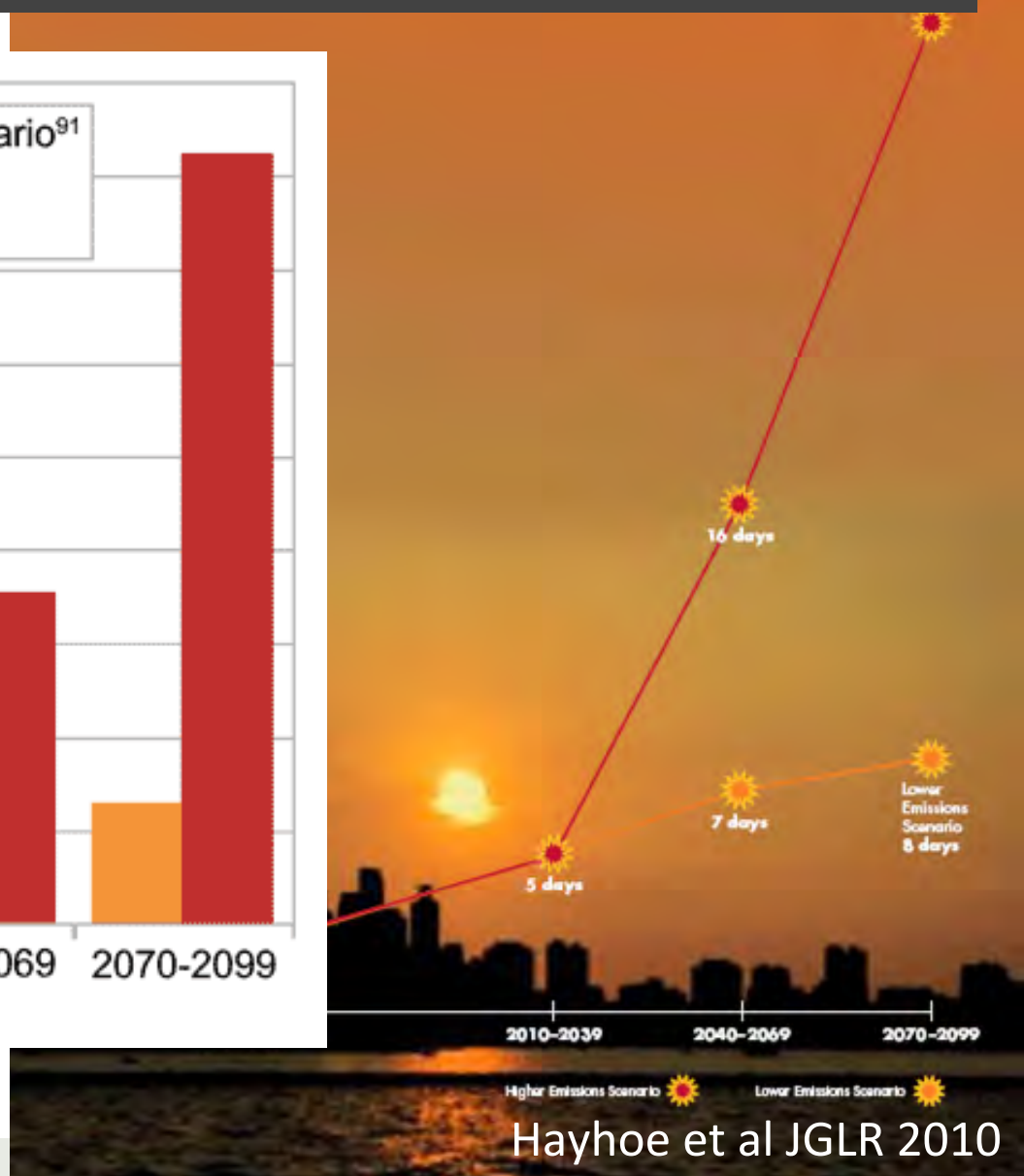
Lower-Emissions Scenarios: *a shift away from fossil fuels in favor of clean energy technologies, causing heat-trapping emissions to decline by mid-century*

Higher-Emissions Scenarios: *continued heavy reliance on fossils fuels, causing heat-trapping emissions to rise rapidly over the century*

Hayhoe, for NECIA 2007

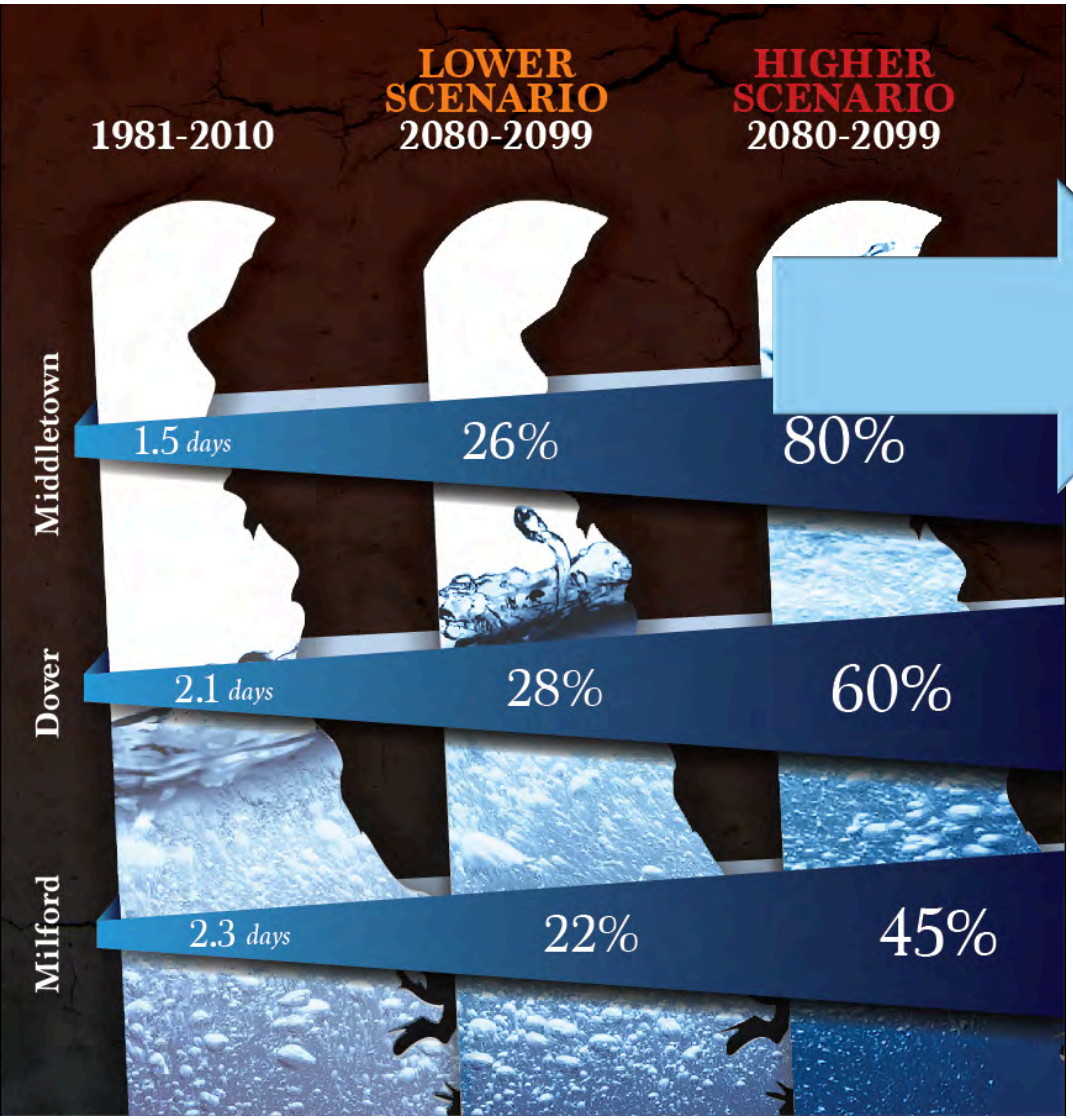
How often heat waves will occur



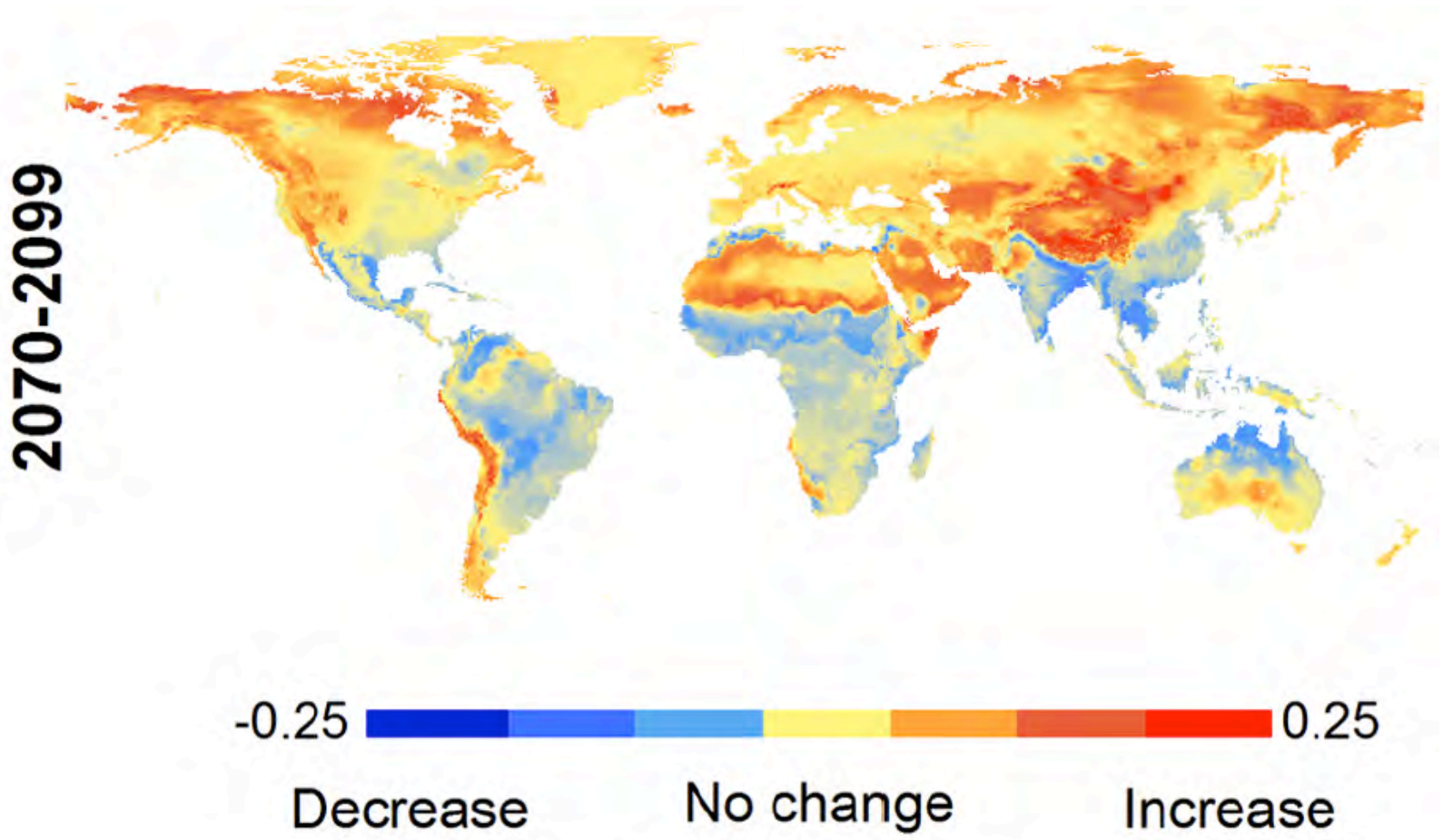


Hayhoe et al JGLR 2010

More frequent extreme precipitation

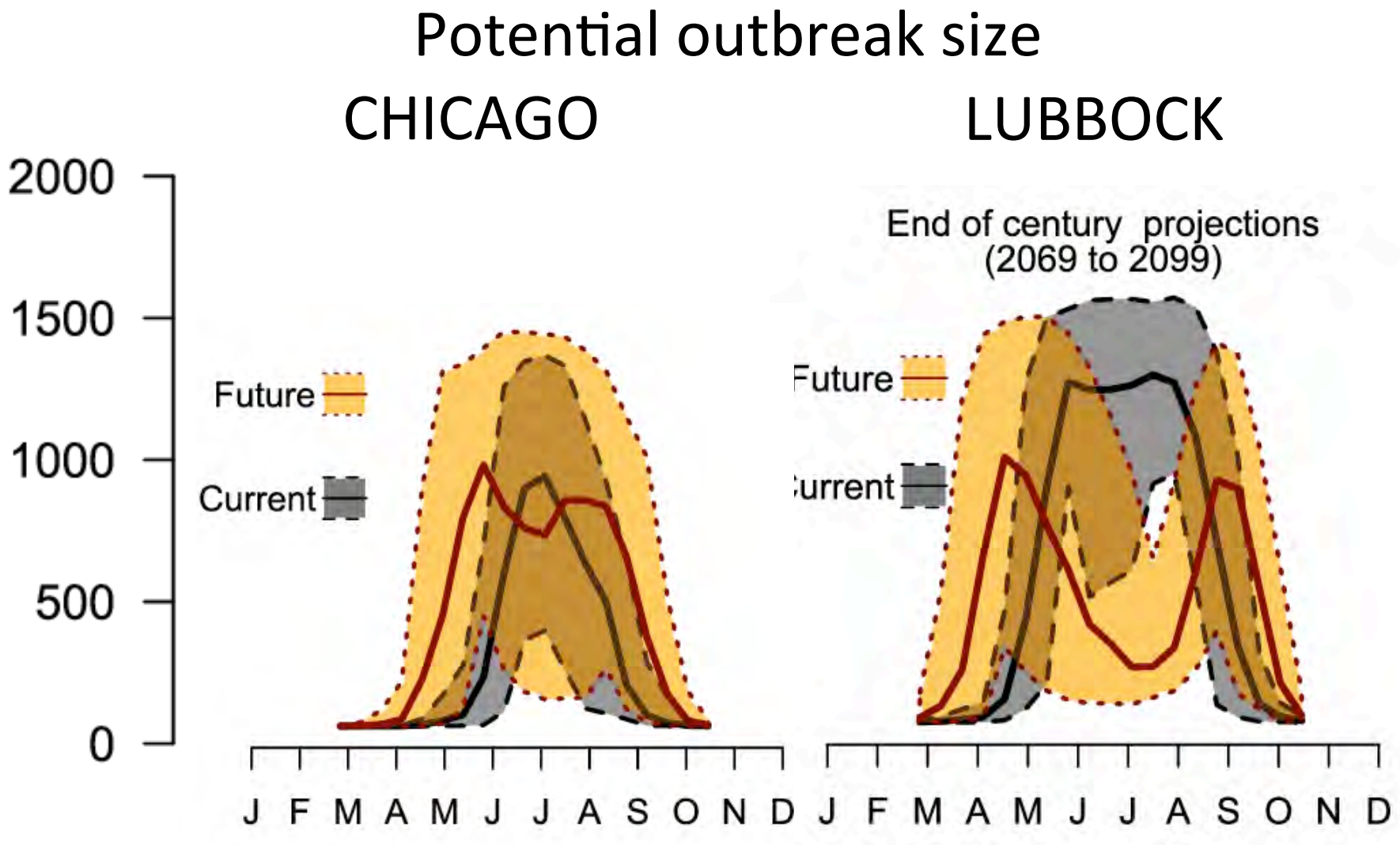


Disruption in global wildfire activity



Moritz et al. 2013

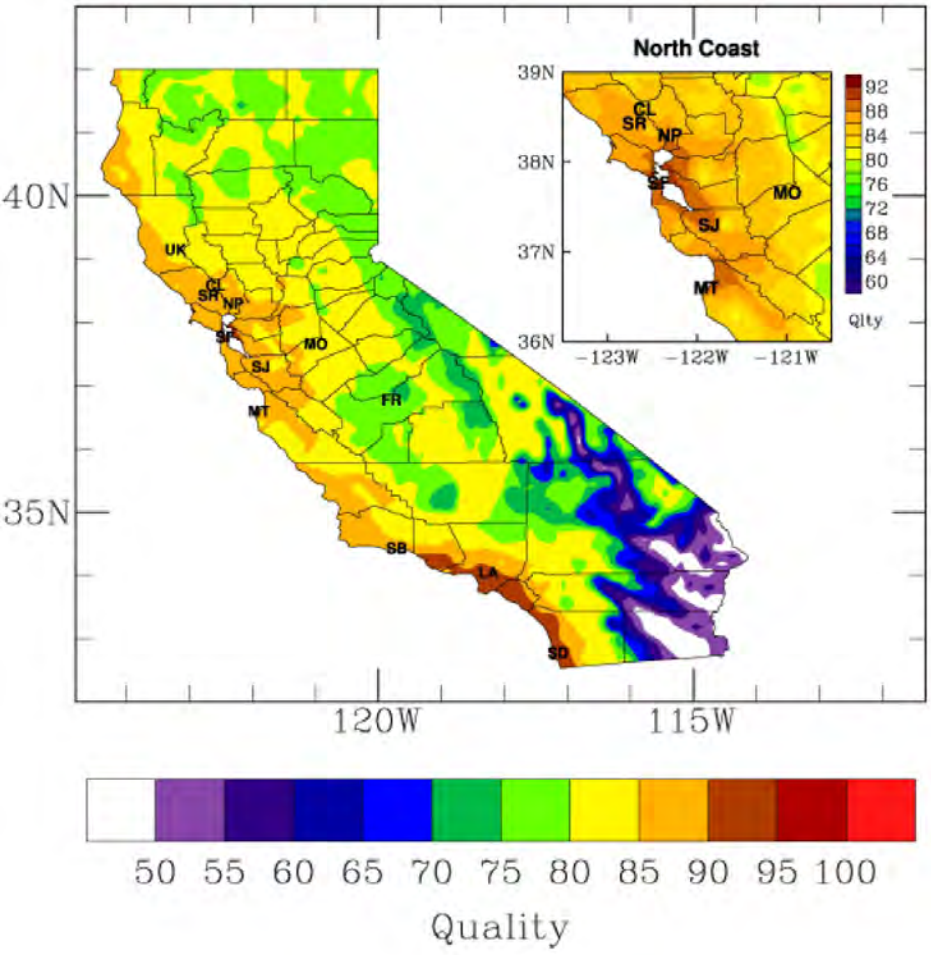
Shifts in dengue outbreaks



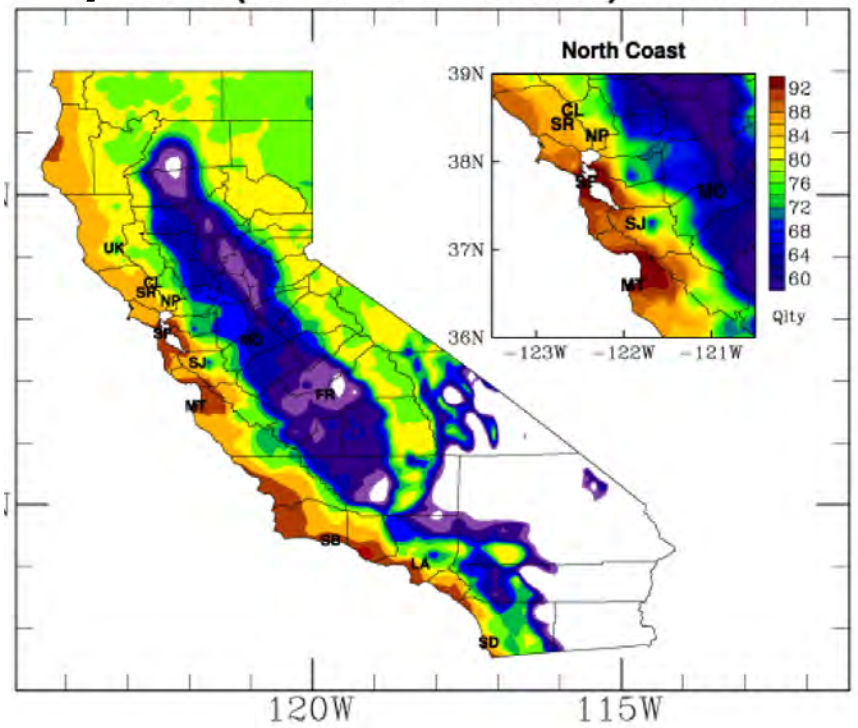
Erickson et al. 2013

… even wine grape quality (!)

Now

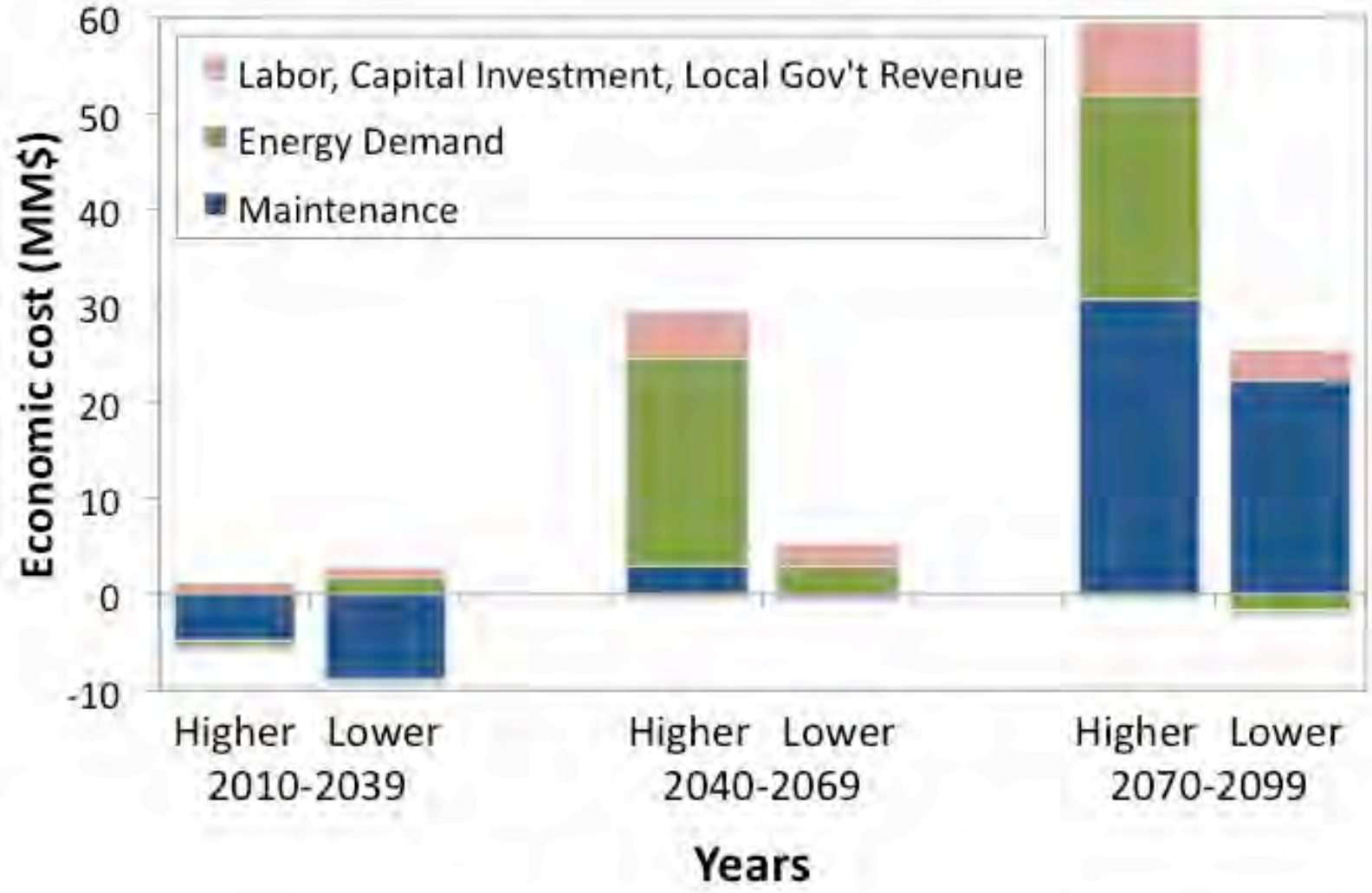


50 years from now



Block, Reisman et al. (submitted)

And the costs of adaptation



$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial r} + \frac{v}{r}\frac{\partial u}{\partial \lambda} + w\frac{\partial u}{\partial z} - \frac{v^2}{r} - fv = -\frac{1}{\rho}\frac{\partial p}{\partial r},$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial r} + \frac{v}{r}\frac{\partial v}{\partial \lambda} + w\frac{\partial v}{\partial z} + \frac{uv}{r} + fu = -\frac{1}{\rho r}\frac{\partial p}{\partial \lambda},$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial r} + \frac{v}{r}\frac{\partial w}{\partial \lambda} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g,$$

$$\frac{\partial \rho}{\partial t} + \frac{1}{r}\frac{\partial \rho r u}{\partial r} + \frac{1}{r}\frac{\partial \rho v}{\partial \lambda} + \frac{\partial \rho w}{\partial z} = 0,$$

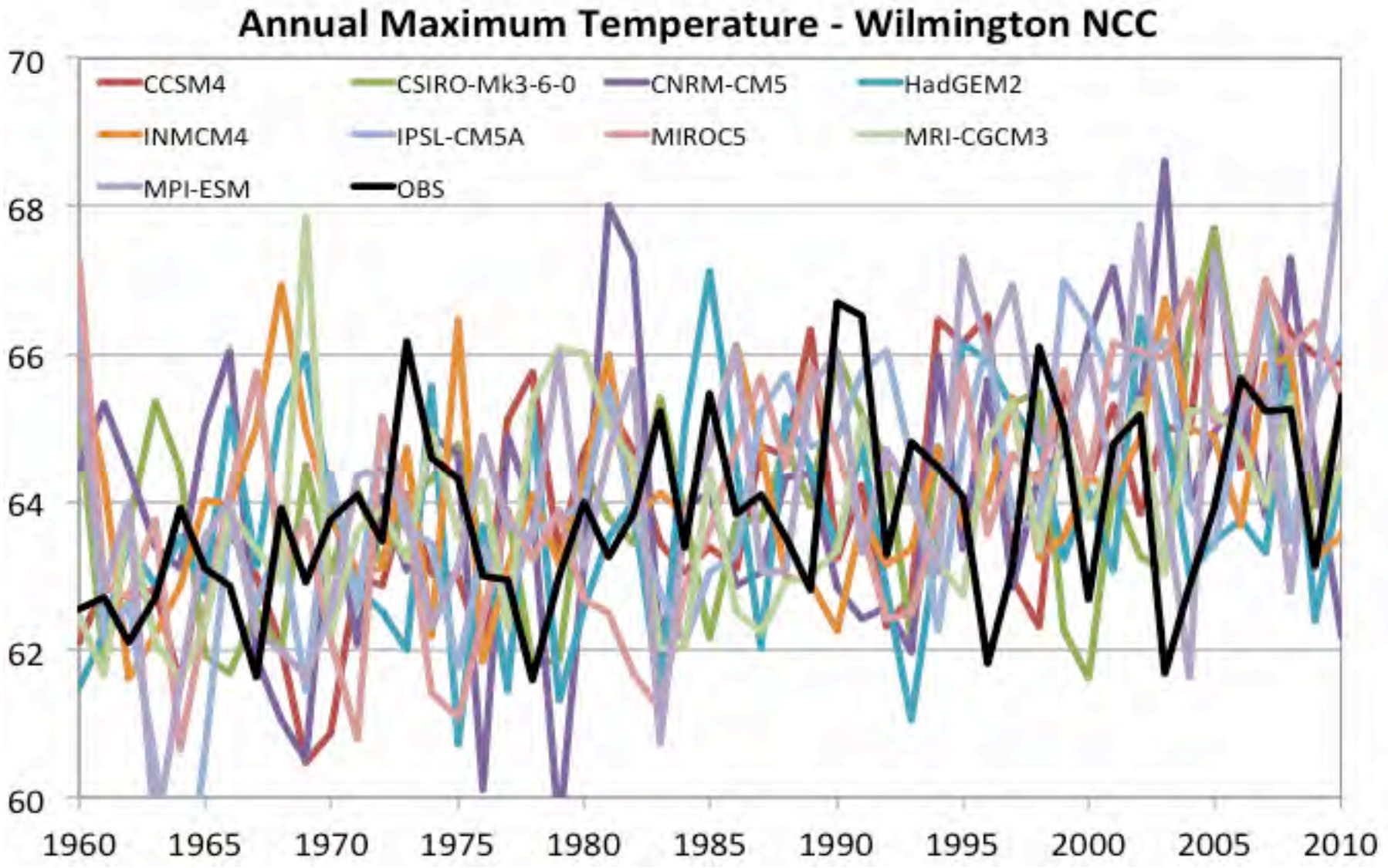
$$\frac{\partial \theta}{\partial t} + u\frac{\partial \theta}{\partial r} + \frac{v}{r}\frac{\partial \theta}{\partial \lambda} + w\frac{\partial \theta}{\partial z} = \dot{\theta}$$

$$\rho = p_* \pi^{\frac{1}{\kappa}-1}/(R_d\theta)$$

THE END

www.katharinehayhoe.com

Use appropriate time scales



OUR PURPOSE

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that can be used to assess the impacts of climate variability and change

on human and natural systems

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many of whose processes operate at finer spatial and/or temporal scales than a typical global model and are sensitive to absolute rather than relative values.