ATM S 111: Global Warming
Extreme Heat

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Day 11: July 6 2010

Assignments

- For this topic: read “Extreme Heat” p.45-57
- The rest of the week: read “Floods and Droughts” p.58-74
- HW 2 due today at 5 PM
- HW 3 posted on class website & handed out.

Part 2: The Symptoms

Extreme heat

Important concepts for heat; Celsius vs Fahrenheit

This year's weather

Heat waves: Chicago 1995, Europe 2003, India 2003, Seattle 2009

The human cost of heat

The urban "heat island" effect

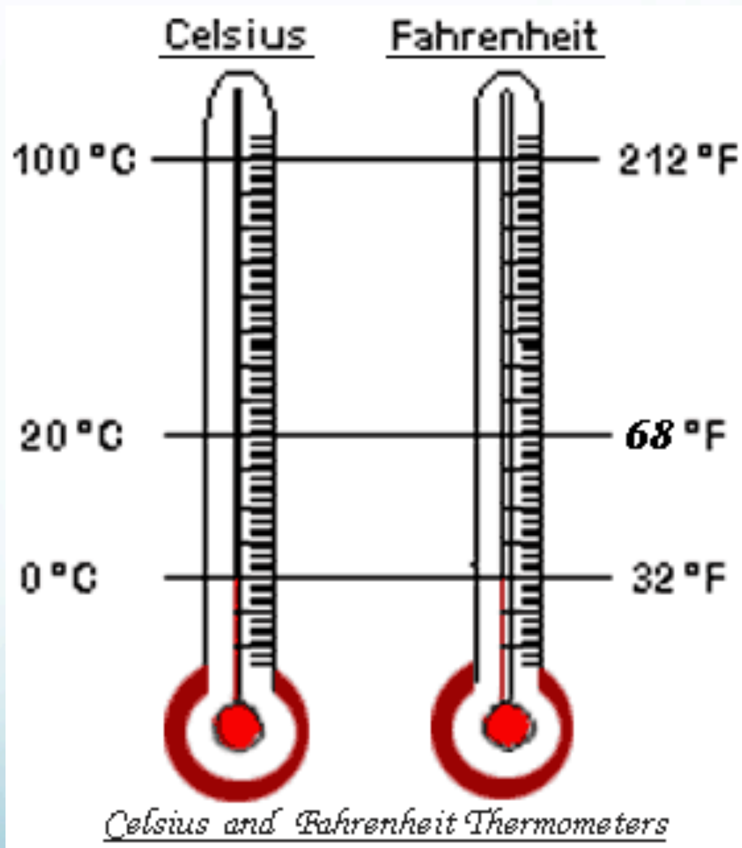
The future of summer sizzle

Celsius and Fahrenheit

- The obligatory Celsius vs Fahrenheit discussion….

Celsius has water boiling point = 100°

And water freezing point = 0°

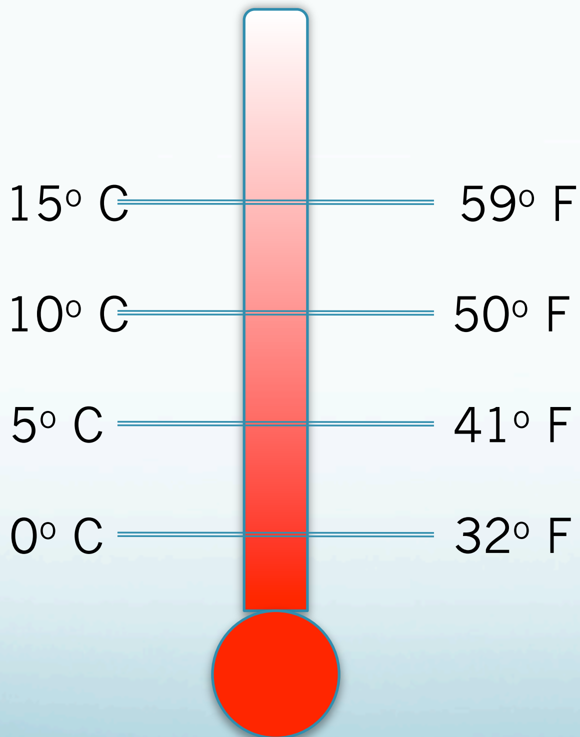


Fahrenheit water boiling point = 212

Fahrenheit freezing point is 32°

Celsius and Fahrenheit

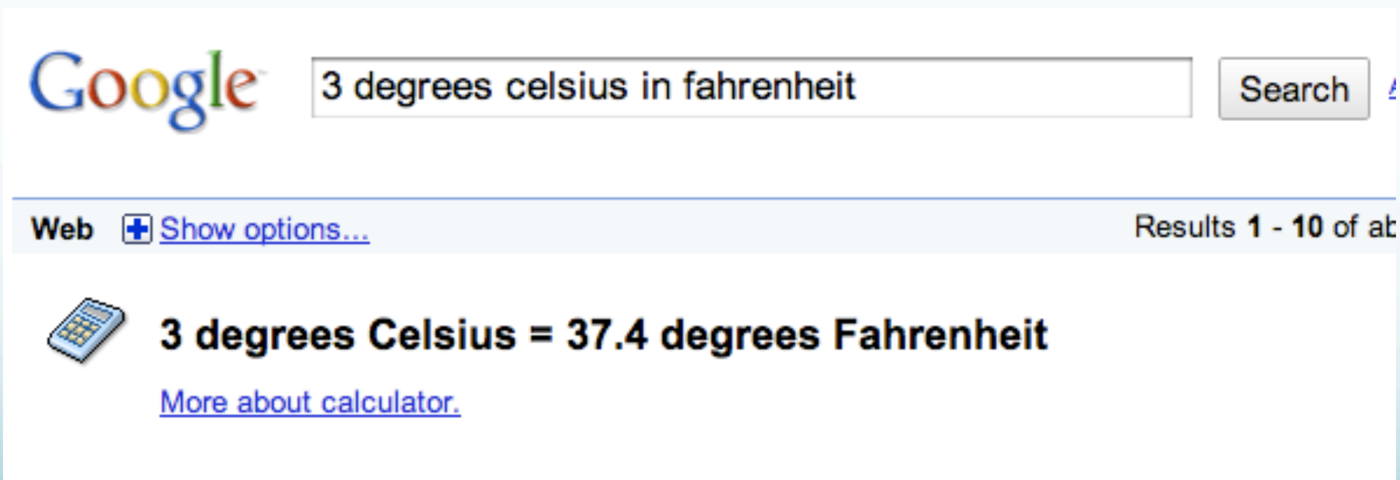
- Every 5 degrees up the Celsius scale = 9 degrees up the Fahrenheit scale
- Every 1 degree up the Celsius scale = 1 degree up the Kelvin scale



A temperature change of **1 degree Celsius** is a little less than **two degrees Fahrenheit**

Don’t Make the Following Mistake!

- “The best estimate of temperature change with doubled carbon dioxide concentration is 3^{o} C (37.4^{o} F)”
  - This was in a very high profile news article one time (it was quickly corrected)



- What’s wrong here?

Celsius versus Fahrenheit

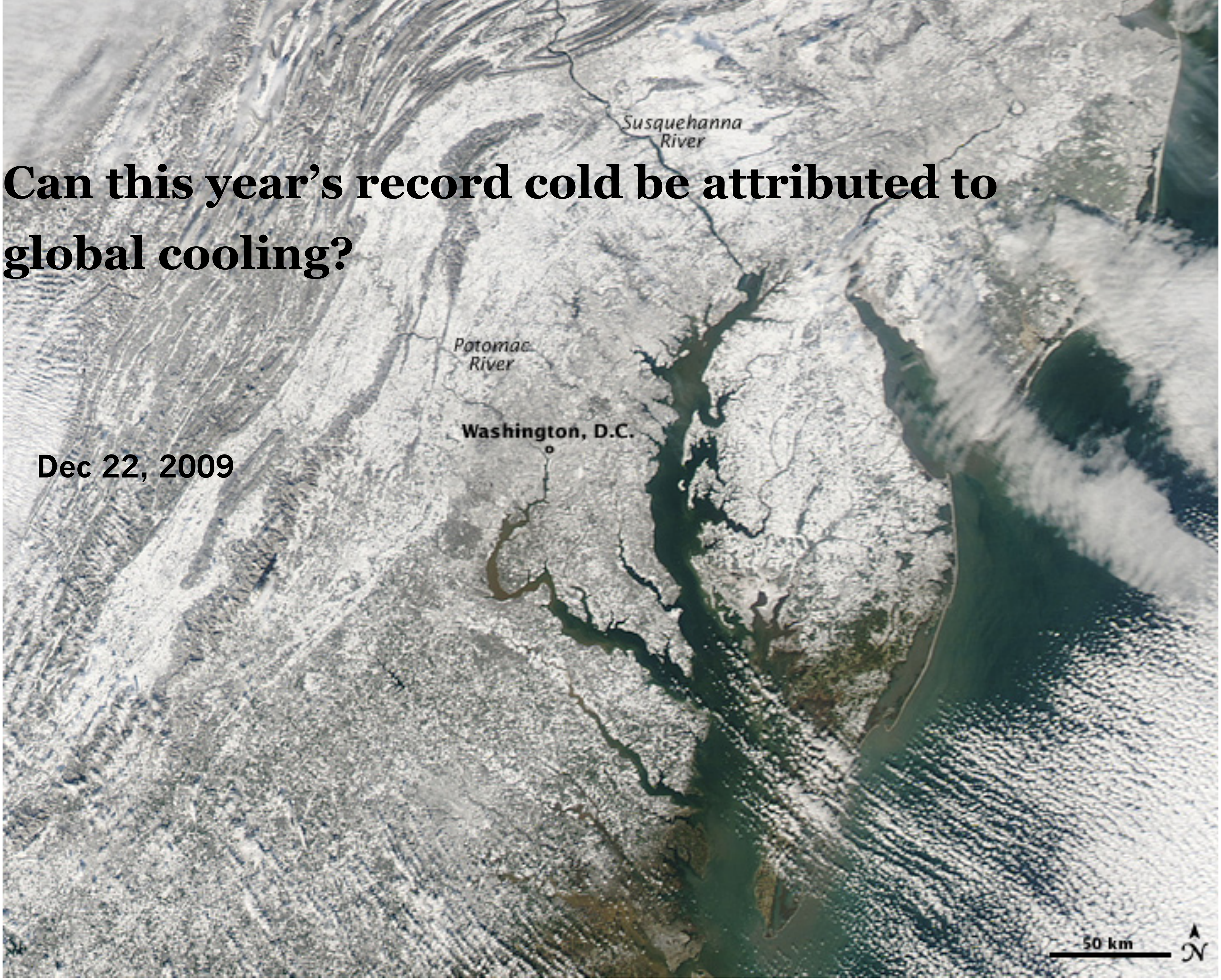
- Problem was mixing up **temperature change** with temperature
  - Again, a 1^o **change** in C = 1.8^o **change** in F
  - Some temperature values I like to remember:

Celsius	Fahrenheit
0^o	32^o
10^o	50^o
20^o	68^o
30^o	86^o
40^o	104^o

- OK, back to extreme temperature changes…

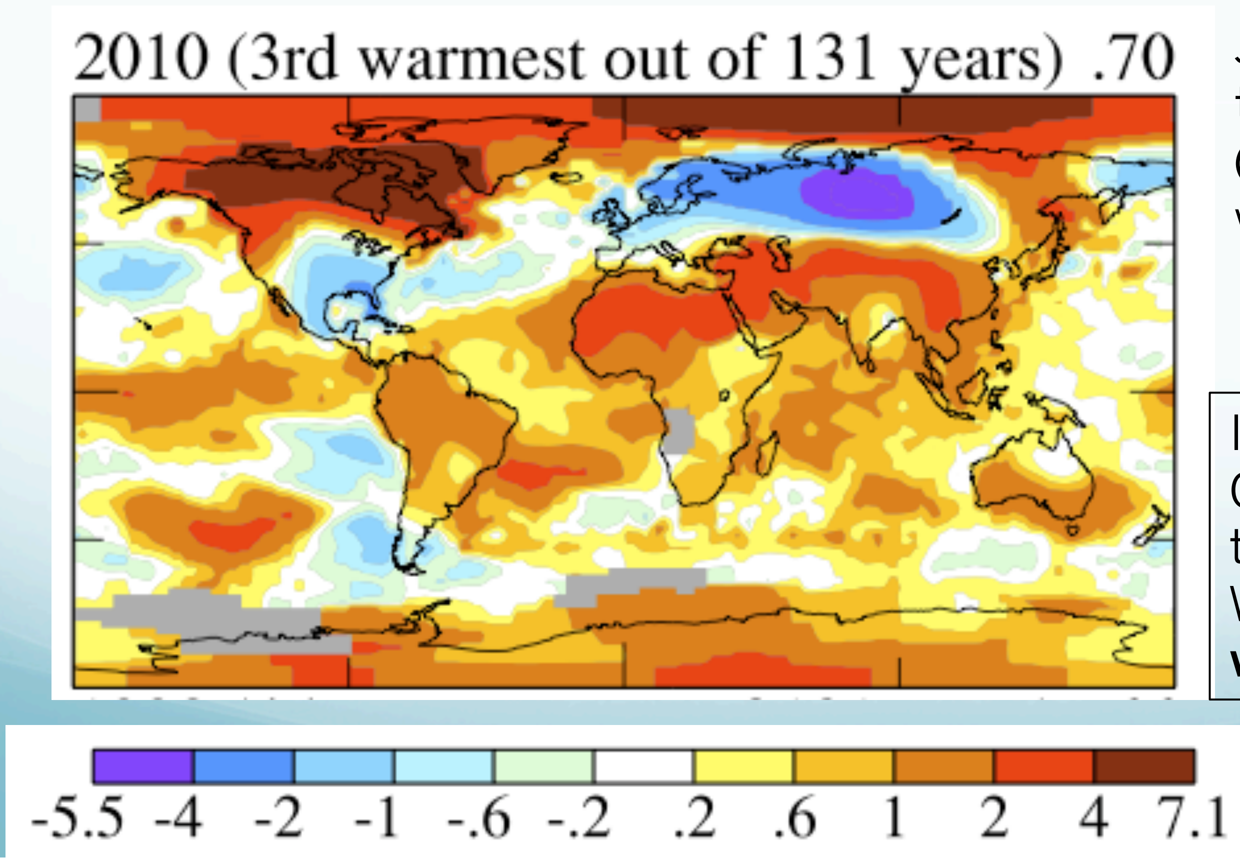
Can this year’s record cold be attributed to global cooling?

Dec 22, 2009



January-February Temperature Anomalies

- **Really cold** in Eastern US & Northern Europe
- **Really warm** in Northern Canada, Arctic

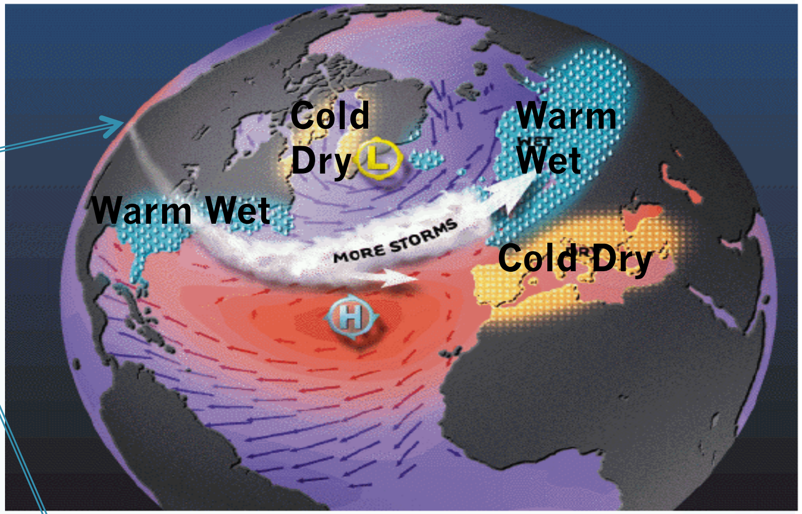


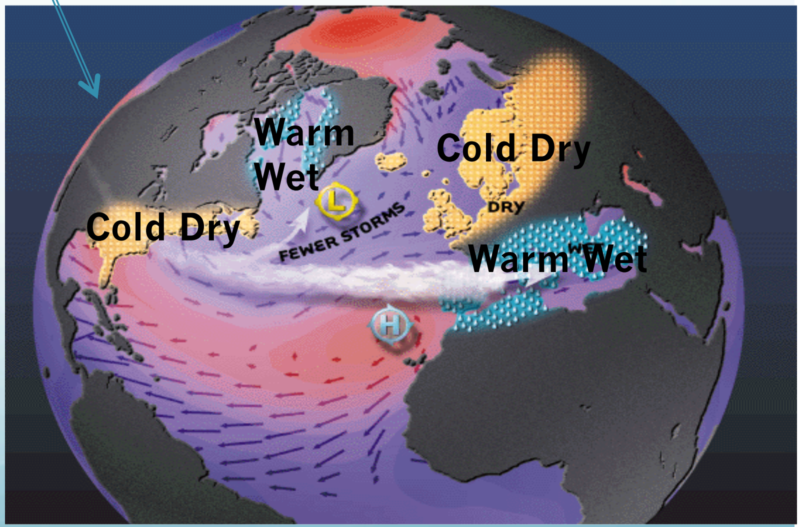
January-February temperature anomaly (degrees C) compared with 1951-1980 average

In Fahrenheit:
Coldest place: **10º F colder** than usual
Warmest place: **13º F warmer** than usual

Why Such A Weird Winter?

- Wobbling back and forth between these two patterns is common (called the **North Atlantic Oscillation**)





This winter has been this phase of the NAO → →

Similar stuff was going on in the **Pacific** this year too: partially explained by El Nino

One Swallow Doesn't Make a Summer

Cold records can be set in a year that is warm in comparison to the long-term global-mean climate.

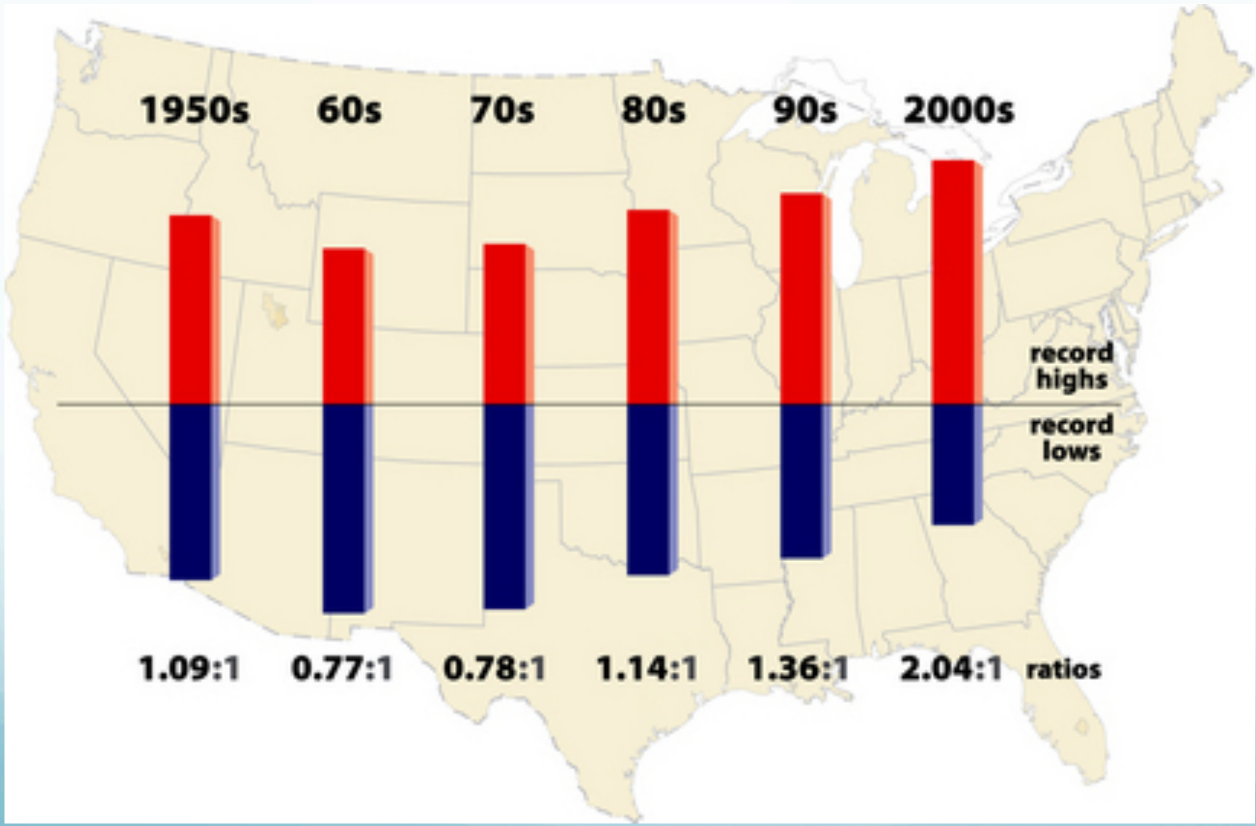
Record heat waves can occur in years in which global-mean temperature is not especially warm.

First: what counts as a heat wave?

- The number of days that exceed some threshold temperature? (e.g., 90 °F)
- Maximum temperature recorded every month?
- Departures from normal: number of days when the temperature rises some given amount above the average for that location and time of year?
- Percentiles: the number of days that are among, say, the hottest 1% (or 5%) of all days for that location and time of year?

Record Highs vs Record Lows

- Have to look at longer periods of time to see a trend



In the US, record highs have been significantly outpacing record lows over the last two decades

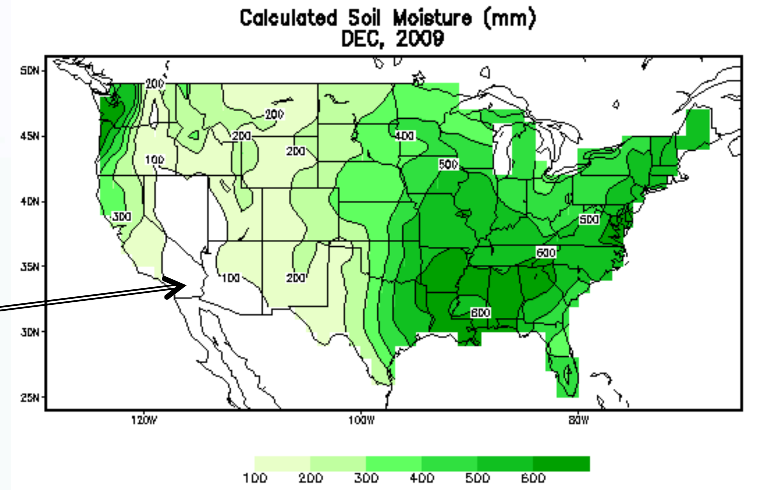
From Meehl et al 2010

Dryness and Extreme Heat

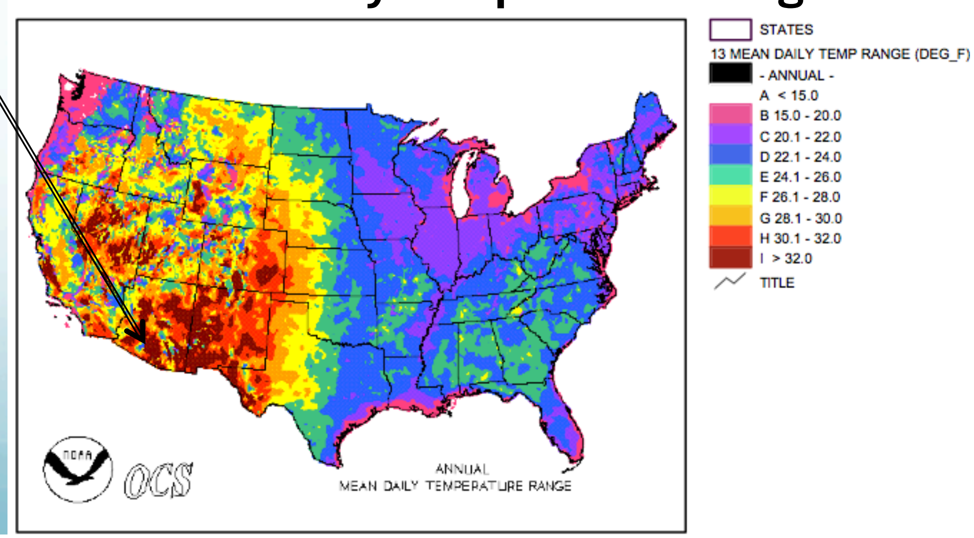
- **Dry climates** tend to have a large daily temperature range
  - Lack of greenhouse effect allows **nights** to **cool** there
  - Also **hotter days** since there's no **evaporative cooling**

Evaporation from trees, lakes, etc lead to milder daytime temperatures in non-desert climates

Soil moisture



Daily temperature range



The Role of Humidity

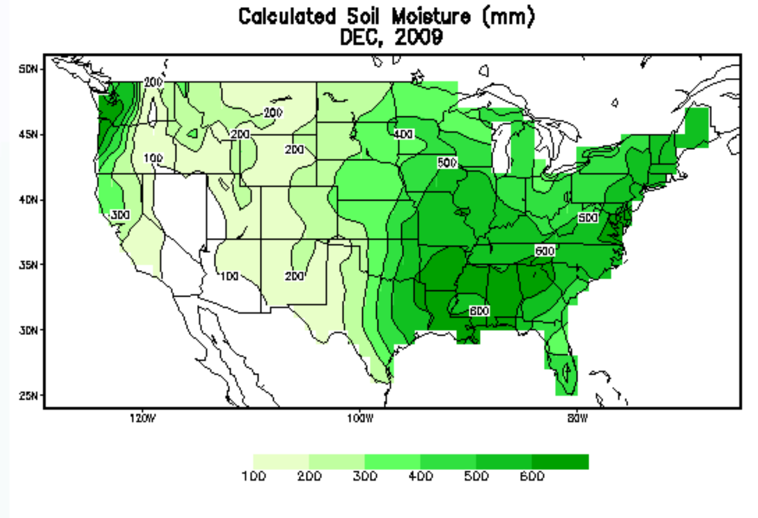
- **Evaporation**: a really effective way to stay cool
  - Sweat, swamp coolers in the desert, etc
  - If there's a lot of vegetation around, it takes a while to heat up during the day, because plants cool evaporatively
- **Humidity**: makes it feel a lot hotter
  - Evaporation can't cool you down any more
  - **Heat index**: takes into account how humidity makes it feel hotter
  - Remember: humidity = moisture = water vapor
- **Greenhouse effect**: keeps nights warm
  - Higher water vapor content → nights stay warmer

Humidity and Extreme Heat

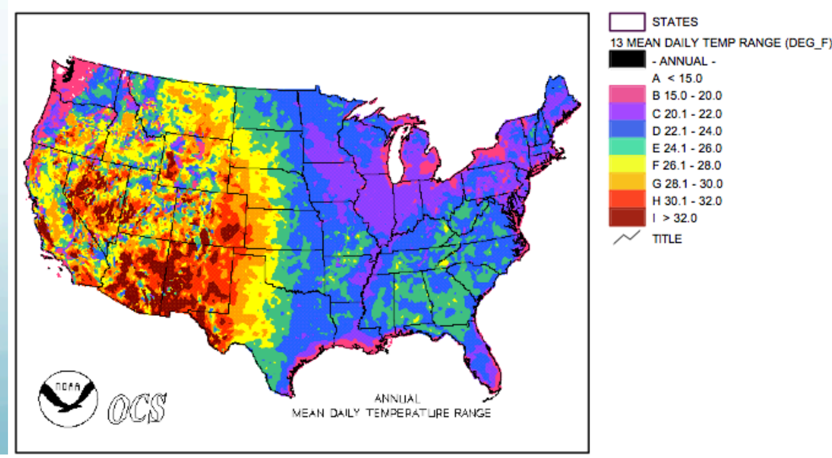
Humid heat waves → higher **heat index** during the day, and **warmer nights** (due to the greenhouse effect).

So areas with more moisture don't get quite so hot, but the extra humidity adds to human discomfort.

Soil moisture



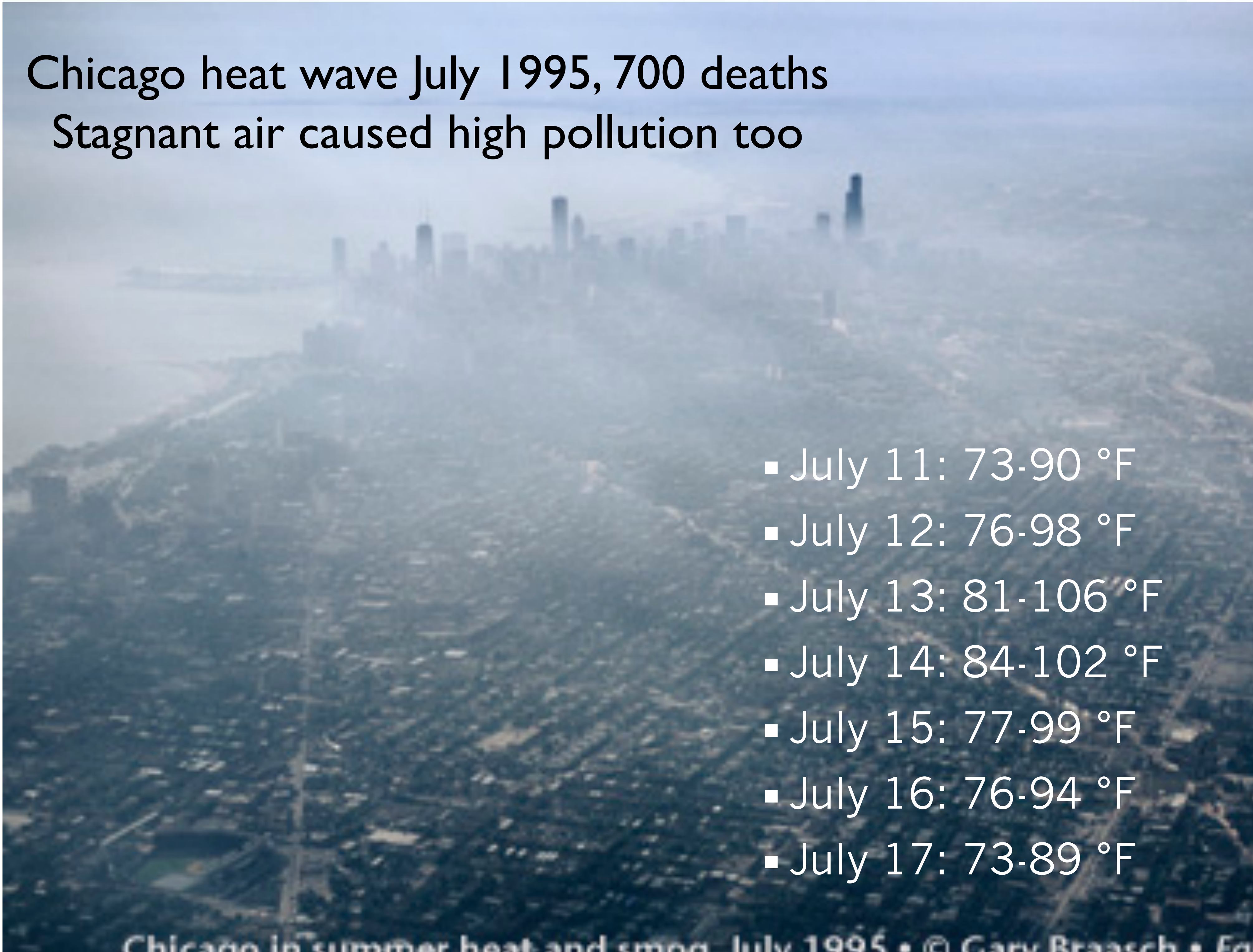
Daily temperature range



Warm nights are actually a major problem in heat waves: cool nighttime temperatures provide relief

Remember individual heat waves cannot be caused by global warming. But let's start by examining some recent extreme heat waves and their effect on human health.

Chicago heat wave July 1995, 700 deaths
Stagnant air caused high pollution too



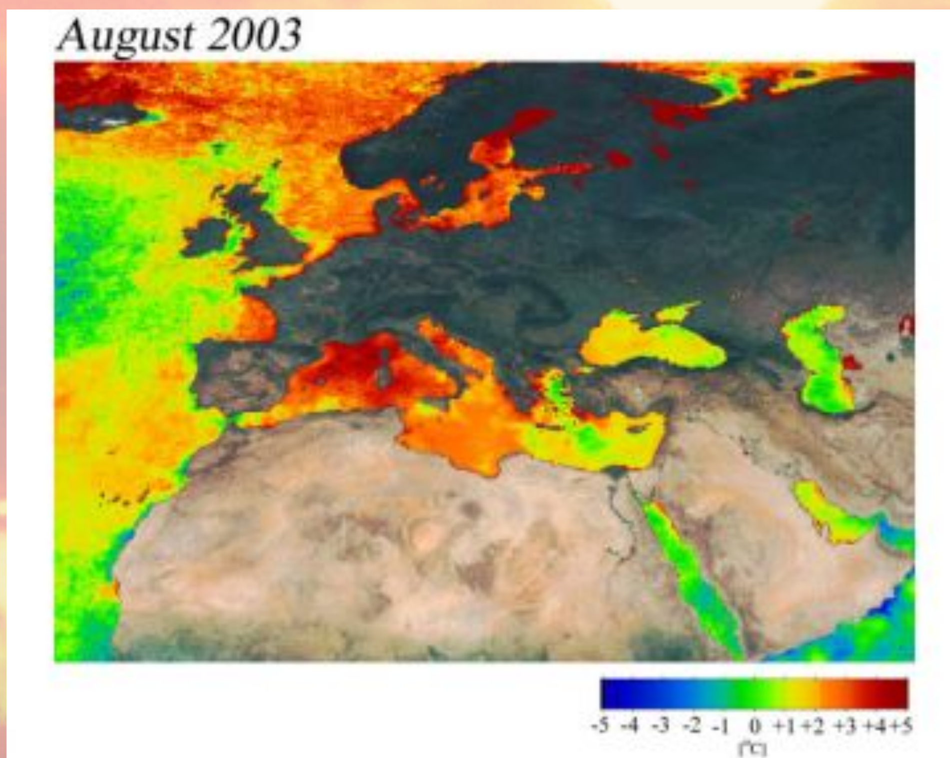
- July 11: 73-90 °F
- July 12: 76-98 °F
- July 13: 81-106 °F
- July 14: 84-102 °F
- July 15: 77-99 °F
- July 16: 76-94 °F
- July 17: 73-89 °F

Chicago July 1995

- High humidities were key
  - Both for high **heat index** and for **overnight lows** being hotter
- Urban heat island also accentuated impacts
- Most victims were elderly with no air conditioning
  - Connection to a social circle was important

2003:

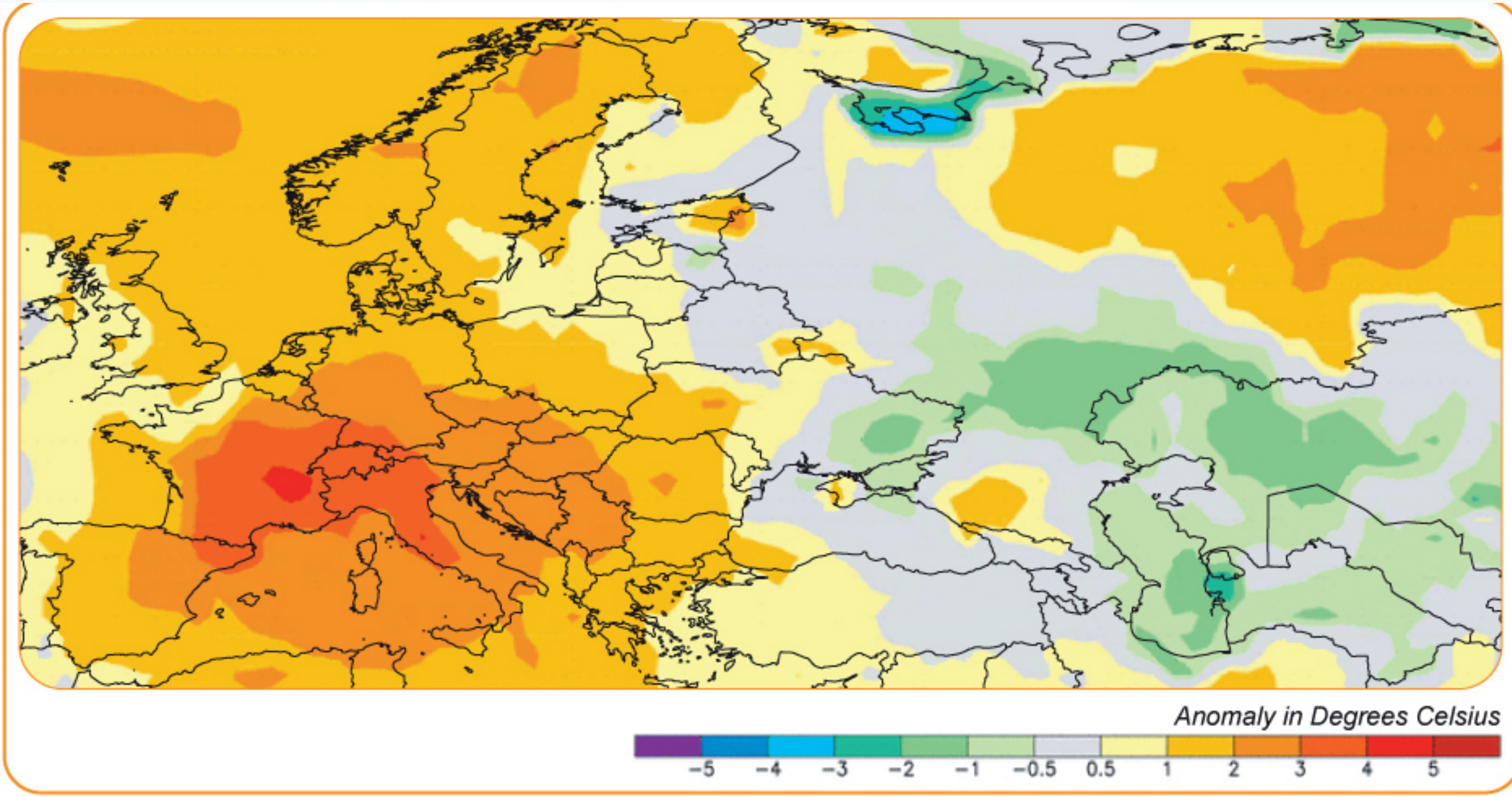
The great European heat wave - **50,000 deaths**



Unusually warm surface ocean temperature

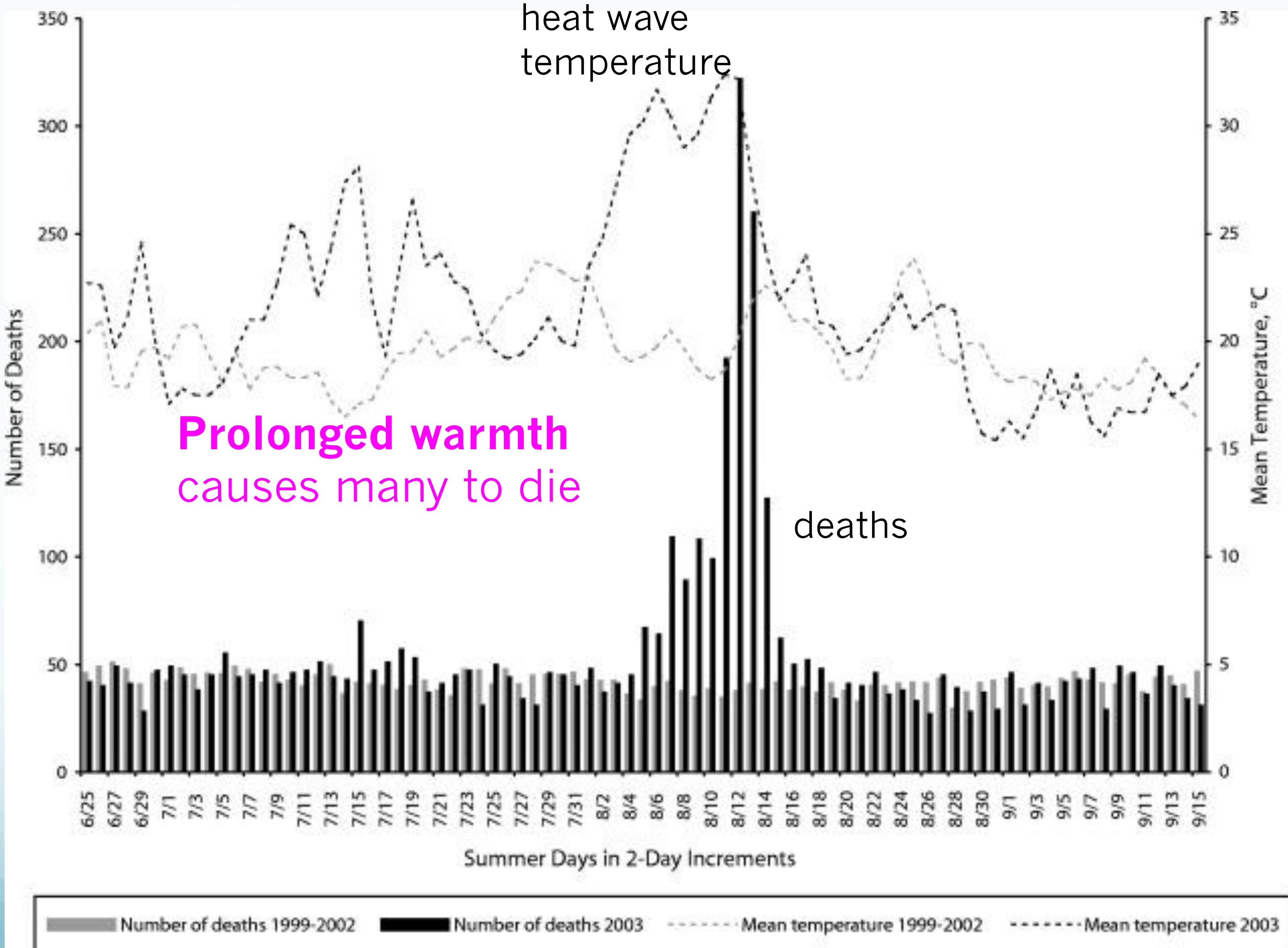
August water temperatures in the Mediterranean was over 9° F warmer than normal in places

Unusually warm air temperature as well

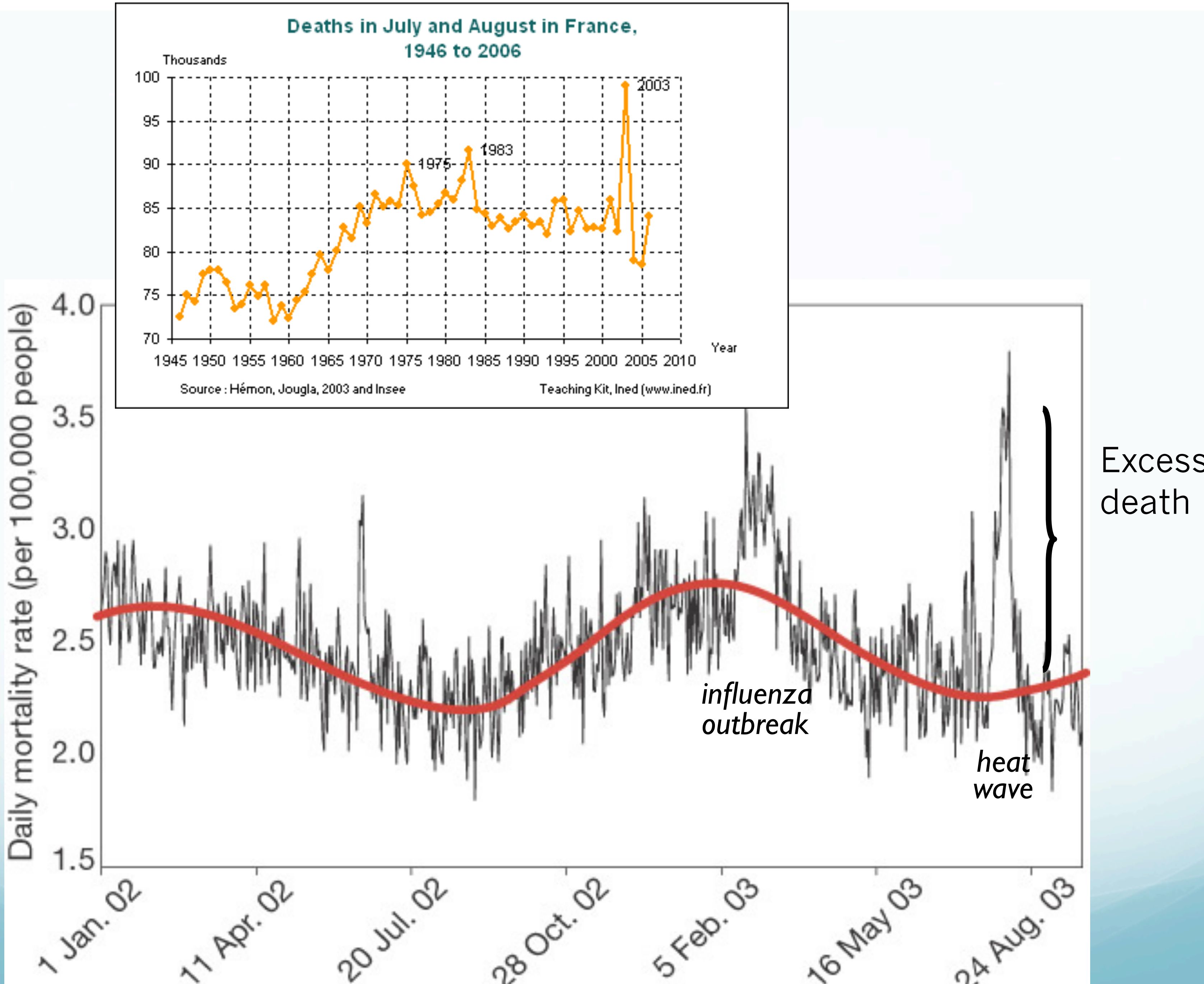


This map, produced from both in situ and satellite information (NDC/NOAA), shows the extreme deviation from the average as recorded from June to August 2003. In some areas the difference exceeds 4°C. Climatological base period is 1988-2003.

June-July-August average exceeded 7° F in places


heat wave
temperature
Prolonged warmth
causes many to die
deaths
Number of Deaths
Mean Temperature, °C
Summer Days in 2-Day Increments
Number of deaths 1999-2002
Number of deaths 2003
Mean temperature 1999-2002
Mean temperature 2003

Paris 2003



daily mortality rate in Baden-Württemberg, Germany

2003 heat wave in India

- The hottest temperatures there are typically in May and June, before the onset of the monsoon rains
- Temperatures ~ 5 °C (9°F) above normal
- Record high 51.3°C (124°F)
- Lasted a record 27 days
- At least 1065 heat-related deaths in state of Andhra Pradesh

- Most fatalities were people over 50 but some children died as well.
- Many of the victims were daily wage laborers, rickshaw pullers or construction workers and were from Below Poverty Line households.
- The monsoon typically starts in June, but onset was late.

2003 heat wave in India: Andhra Pradesh

Lack of monsoon rains were key to this heat wave.

Less soil moisture → no evaporative cooling during the day

Another heat wave in Rajasthan this spring.
Rajasthan heat wave
Monsoon delayed till early July (started a few days ago)

Seattle, July 2009, 4-day heat wave (above 90 F)

July 29 **all time** records broken at SeaTac:

103 F highest temp
71 F highest minimum nighttime temp

Dozens of cooling centers were opened

1 death

OWSC Office of the Washington State Climatologist

Why do some places fare better?

High population density is a benefit because people help each other – though the urban heat island effect can make heat waves worse.

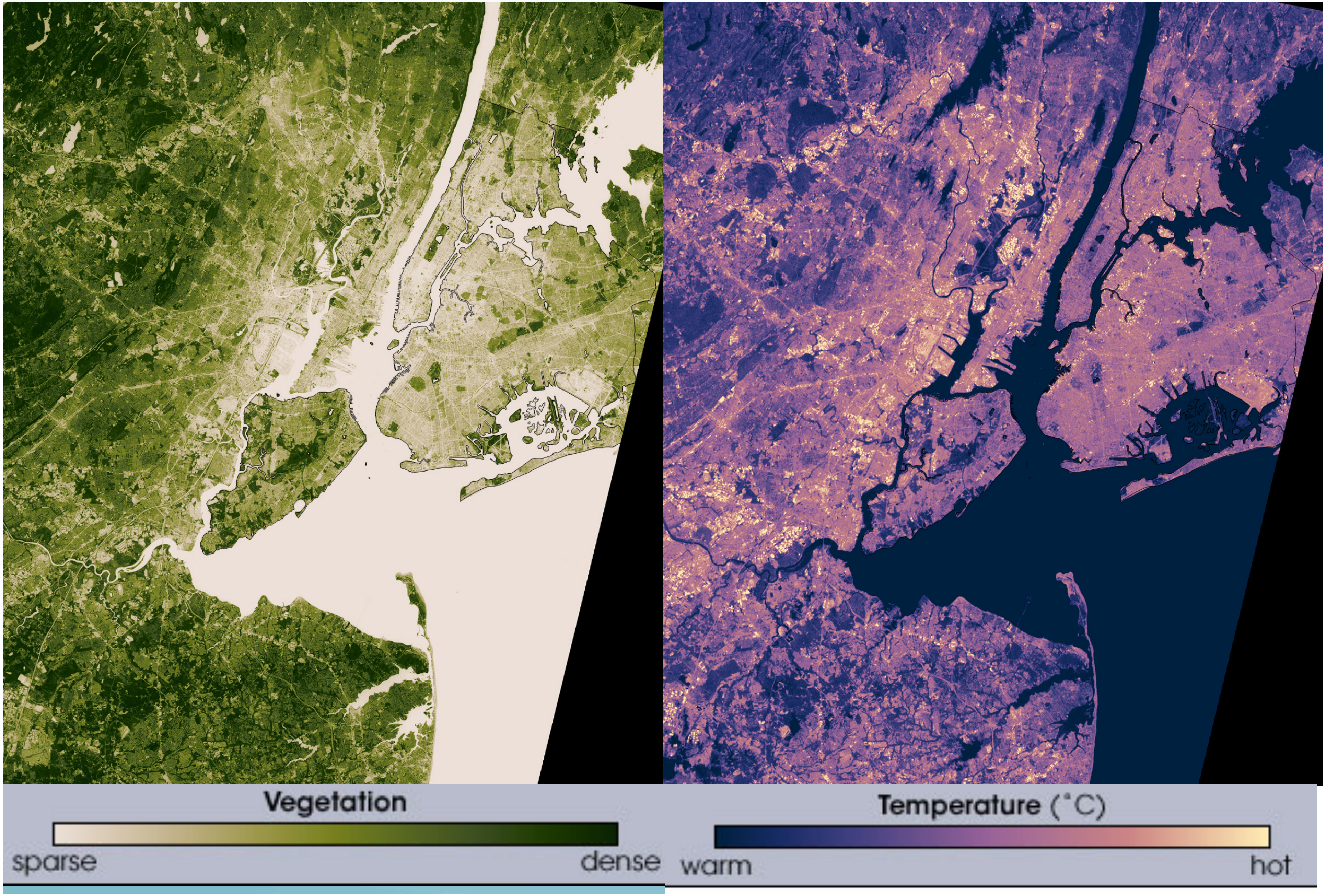
Air conditioning

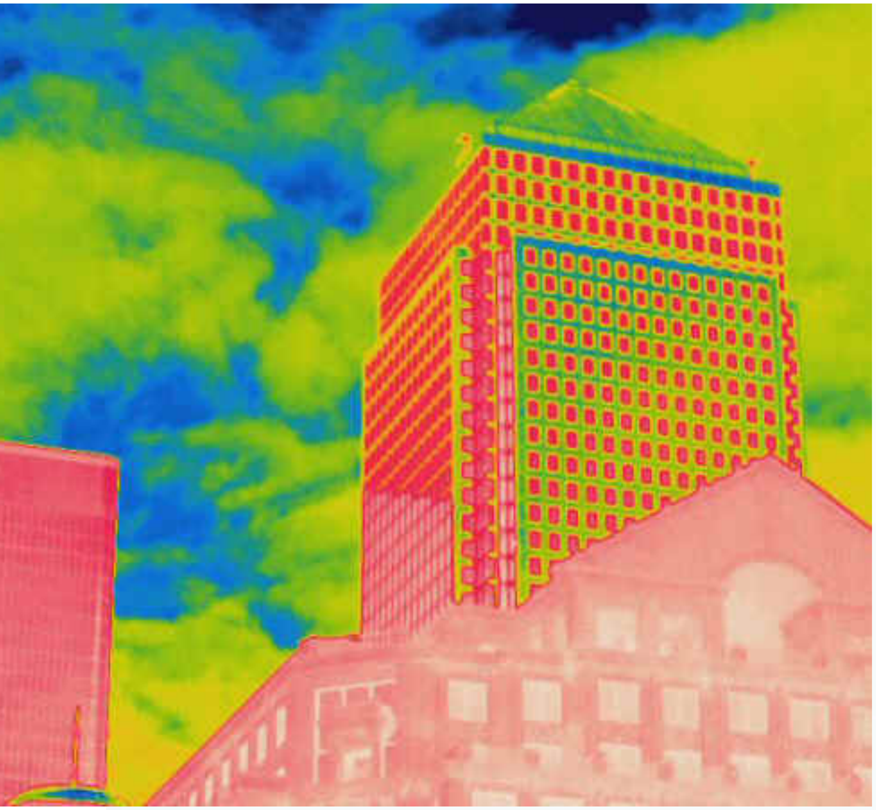
Social planning

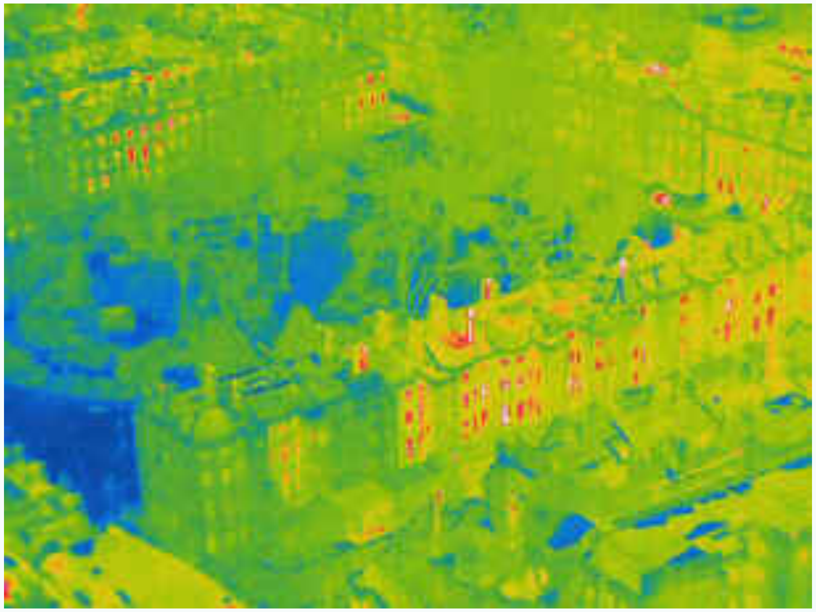
Places that are often hot are usually better prepared, all else being equal.

Like many natural disasters, the impact of heat waves is determined by social, political, and technical factors as well as environmental ones.

New York City, one day in summer 2002



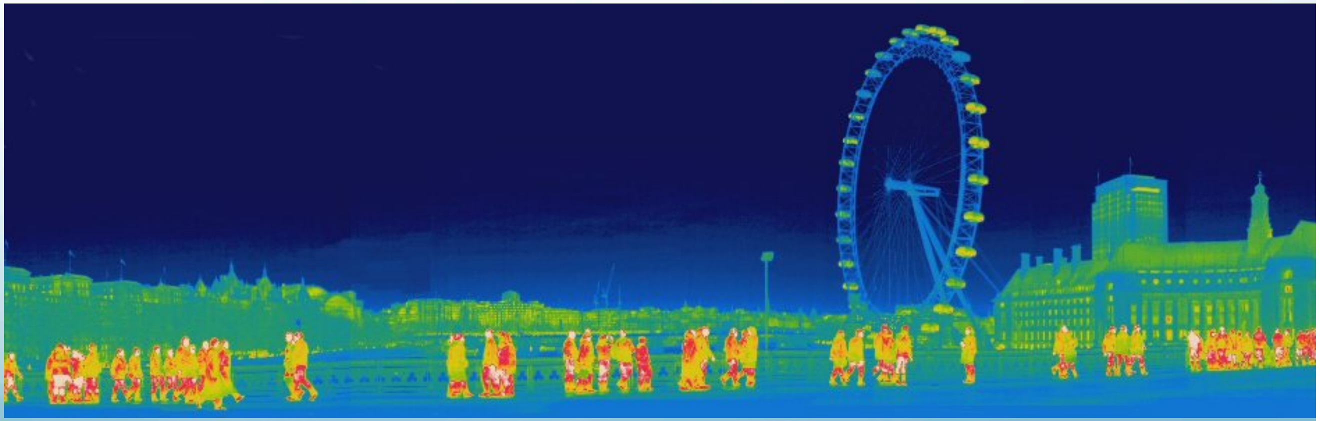




Bedford Square, London
greenspace in square

Buildings act like low clouds to return longwave back towards surface

Here
pink=hottest
blue=coolest



http://www.seedgen.com/thermallondon/

Urban Heat Island Effect

- Bigger effect at **night**, when air is more stagnant
- By the way: thermometer records strongly affected by the urban heat island effect are **not** used to calculate global temperature trends
  - And other less affected records are corrected before inclusion

Attribution of Extreme Heat to Global Warming

- Actual Temperature = **Natural** climate influence on temperature + **Human** influence on temperature
- The latter is now **0.7° C** globally averaged (more over continents: around 1° C). Will likely grow to 3°C or more by 2100 if no emissions controls.
- The natural range may be quite large compared to human influence depending on averaging area.
- The smaller the area you average over, the more natural variability is a factor.

Attribution of Extreme Heat to Global Warming

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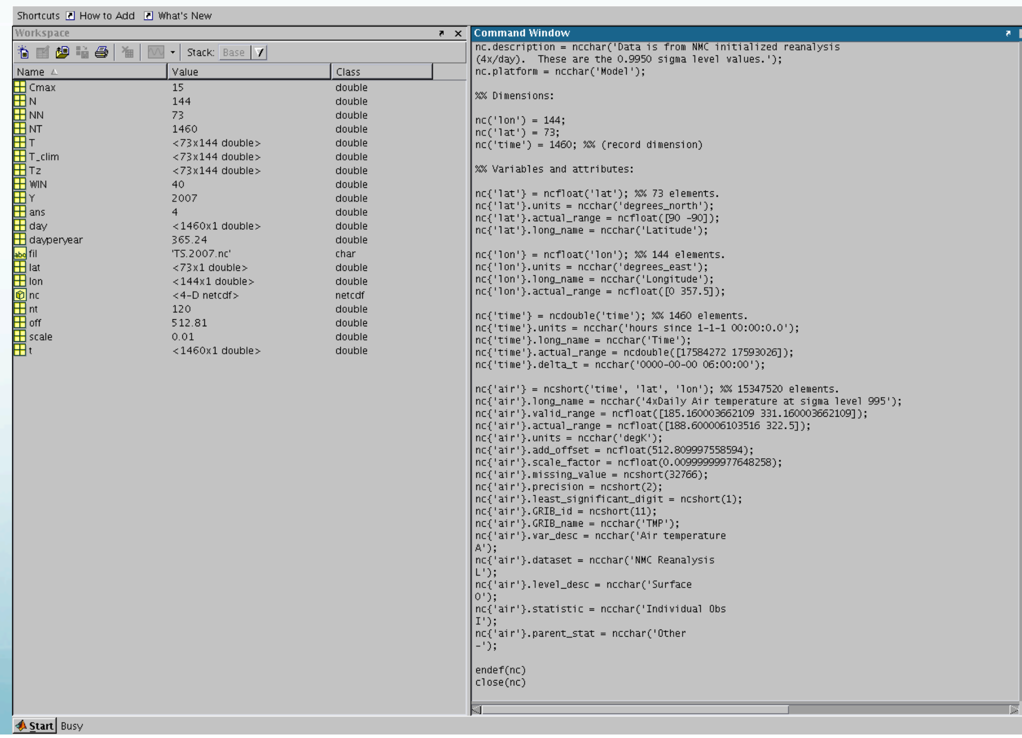
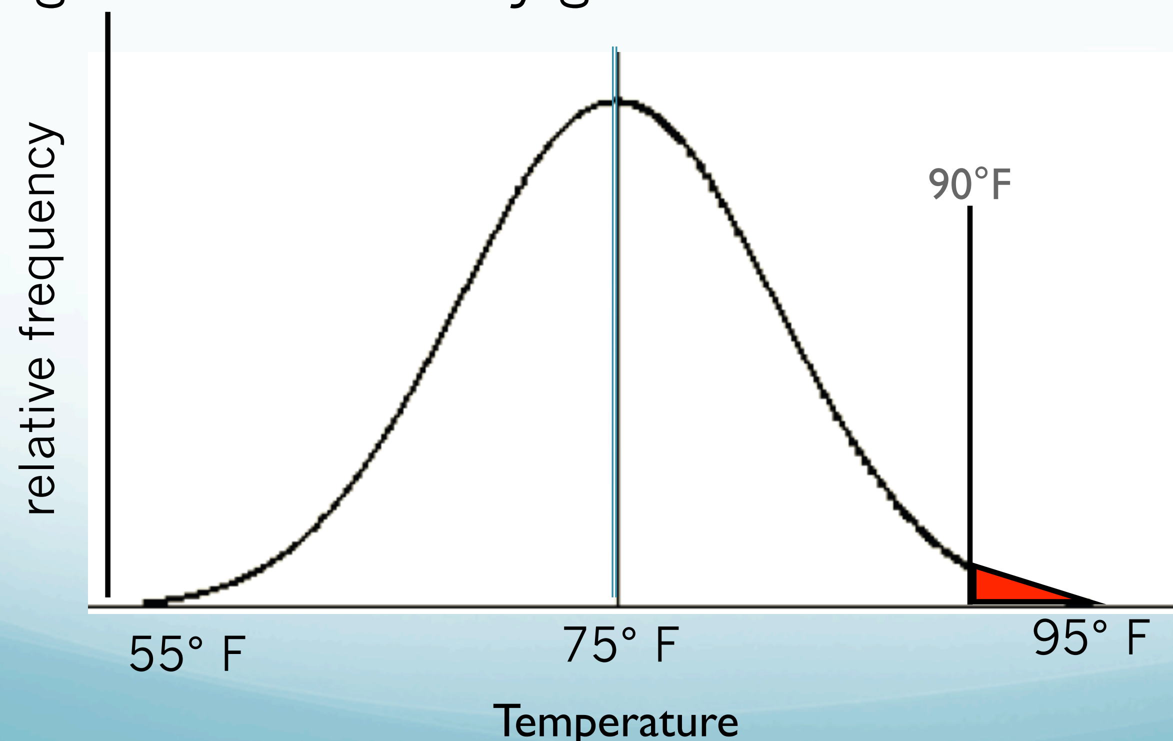


Probability of Temperatures

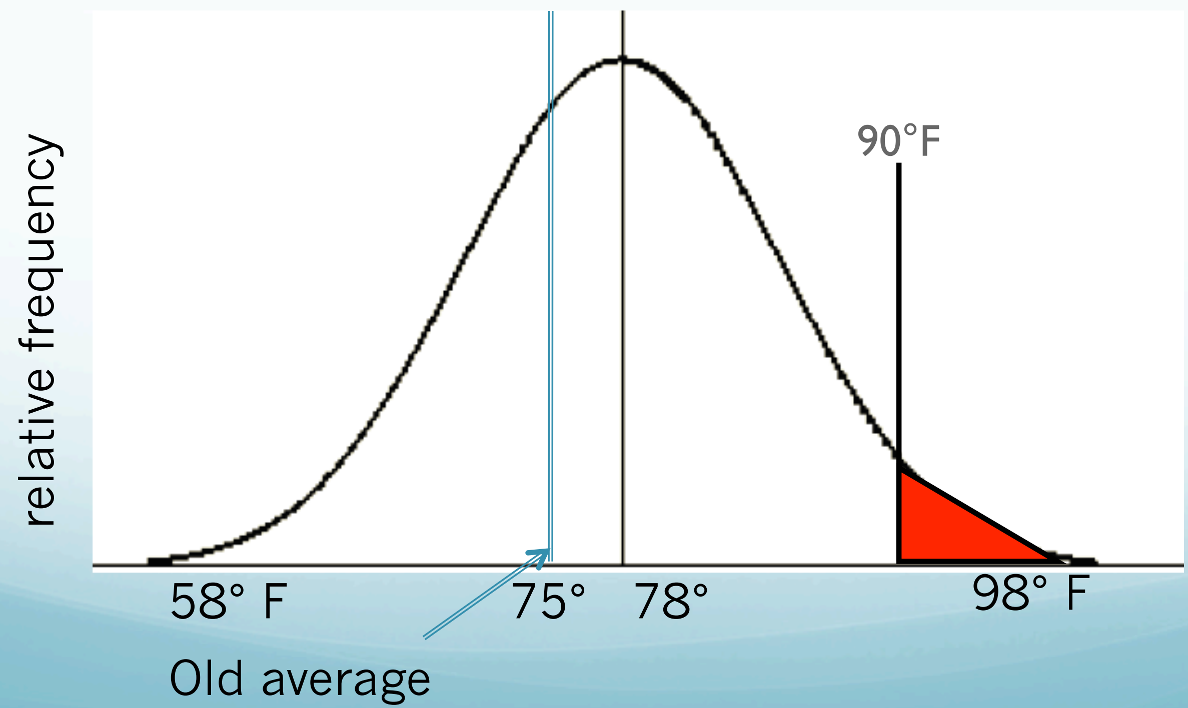
Imagine Seattle summertime daily high temperatures here for instance

Average is 75° F. Rarely gets above 95° or below 55°.



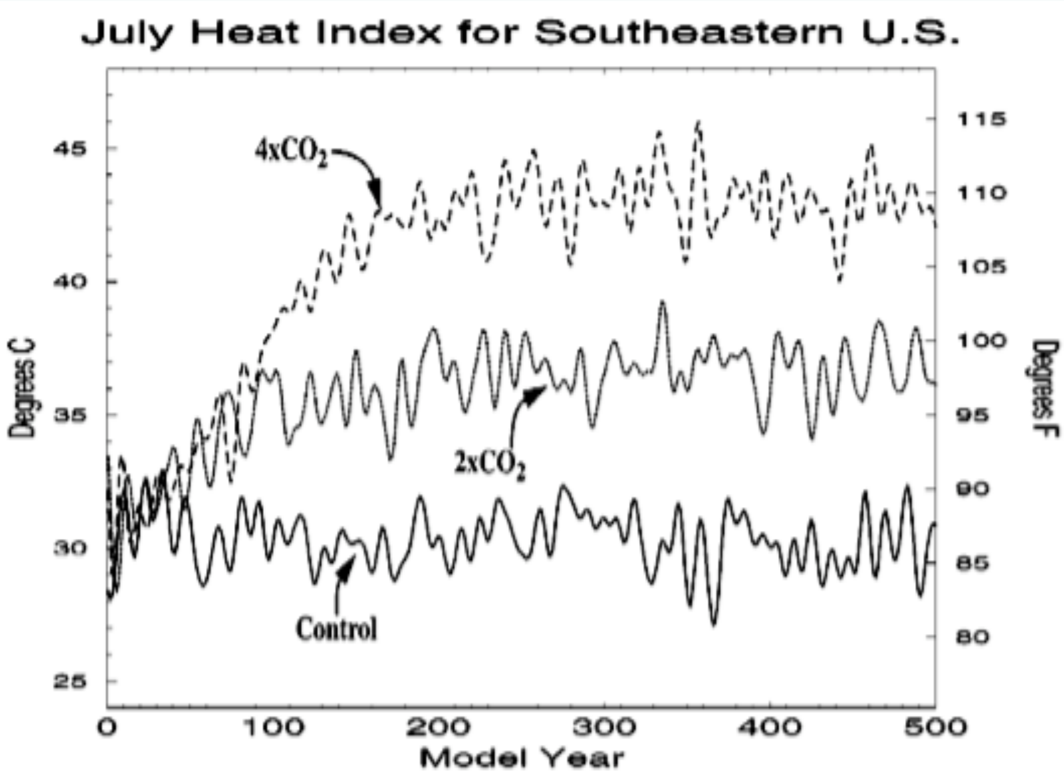
Shifting the Distribution

- Simplest expectation of global warming: the distribution is shifted towards hotter temperatures
  - And the chance of a heat wave is much **more probable**



Increases in Heat Index

- Also, over the world as a whole, **moisture content** is expected to rise
  - Because warmer air can hold more water vapor



Expect higher **heat index** due to this

From Delworth et al 1999 study of average heat index changes

Other Influences on Temperatures

- Changes other than just shifting the distribution and increasing the heat index are expected if:
  - **Surface drying** occurs
  - Many land areas are expected to dry with global warming

- Drying can have a large influence on temperature changes
  - No more **evaporative cooling** during the day: **much hotter days**
  - No more **greenhouse warming** at night
  - Smaller increase in heat index

During what decade did the US experience the most serious heat waves?

"Dust Bowl" of the 1930s

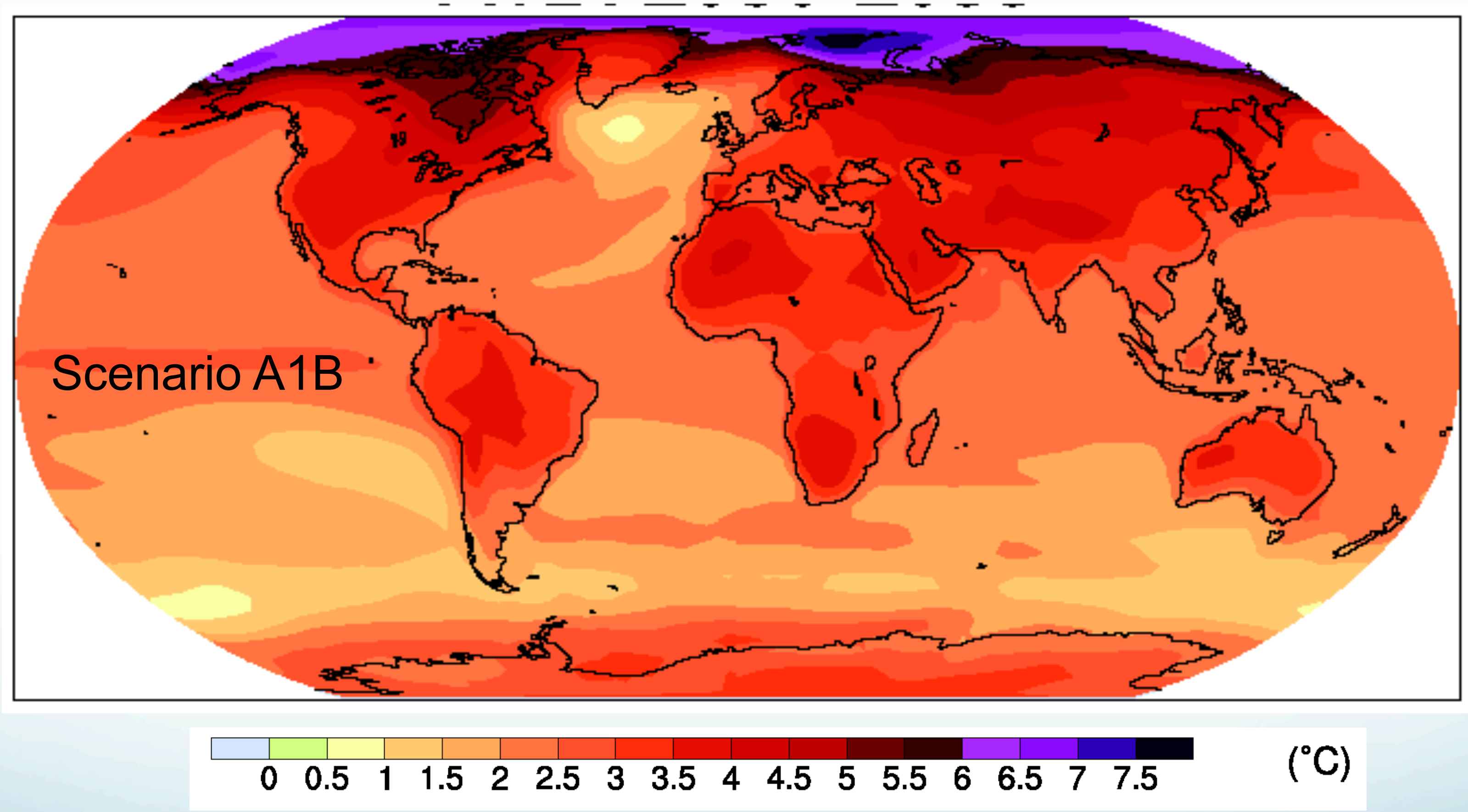
- Severe drying of the American prairie
- Drying out of

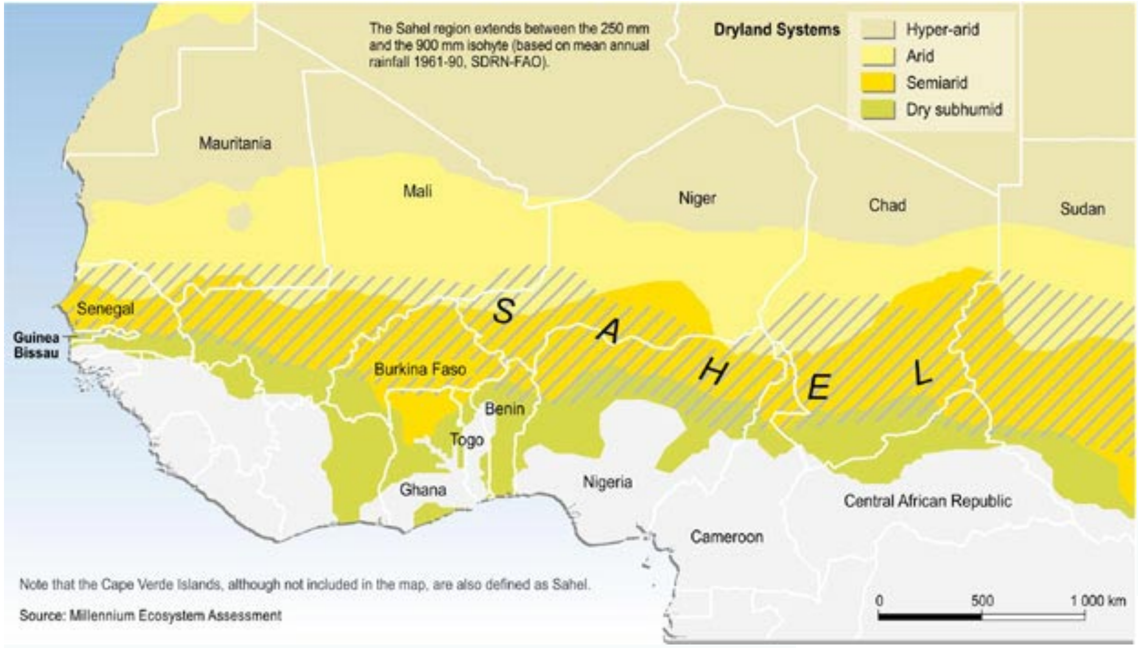
the land led to

more extremes

in temperature

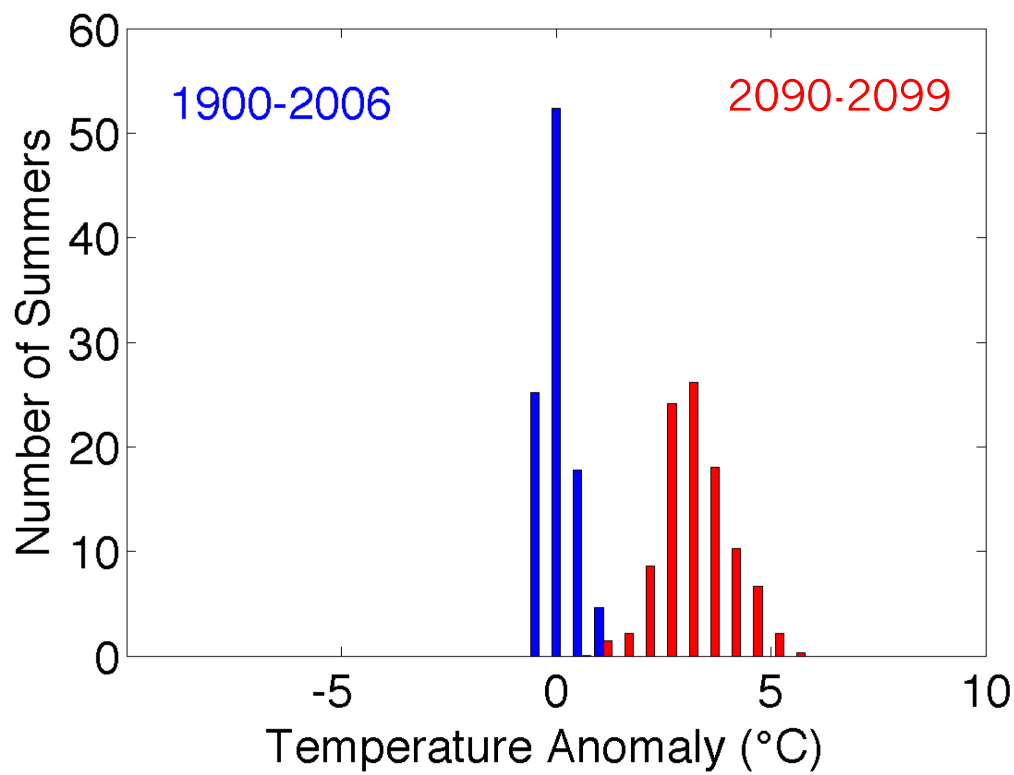
Projected Annual Average Surface Temperature Change:
"2080-2099" minus "1980-1999"





Heat waves in the Sahel

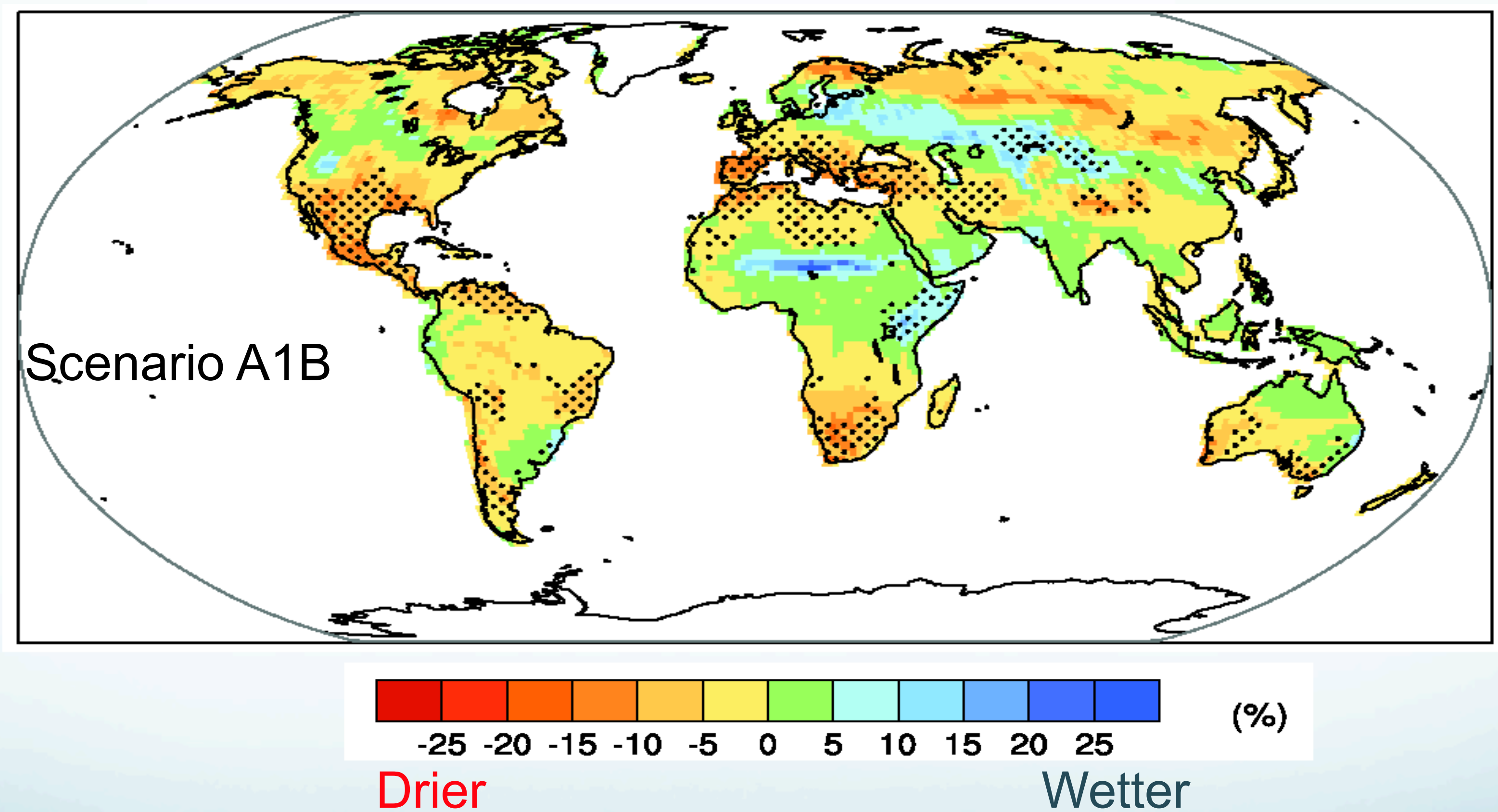
The Sahel



Blue = observations

Red = projections from many models to accumulate ~100 estimates

Projected Soil Moisture Change: "2080-2099" minus "1980-1999"



drying --> even higher daytime temperature

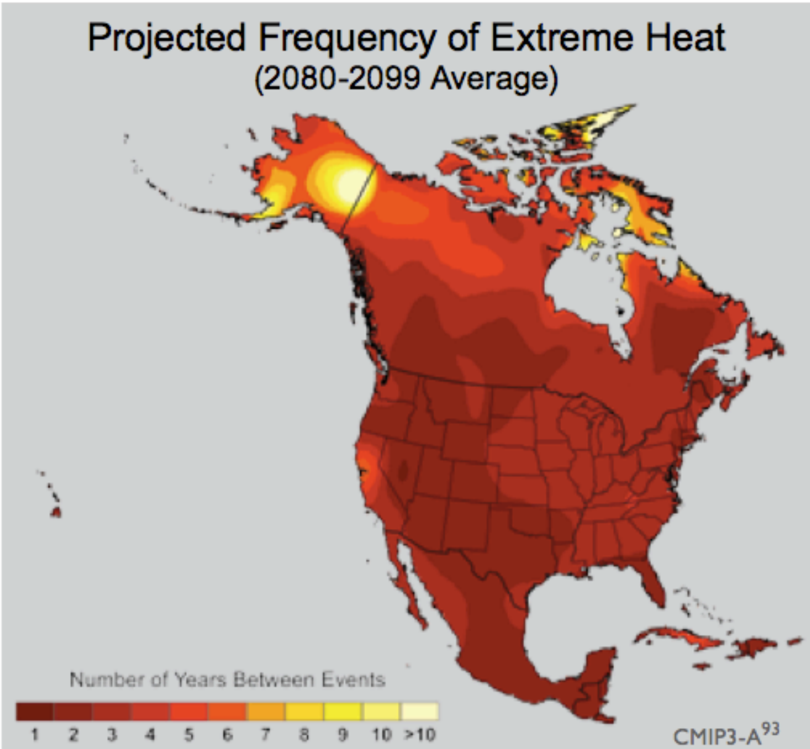
moistening --> even higher nighttime temperatures

Additional Model Predictions: Europe

- Summer of 2003 will become average summer by 2040
  - And by the end of the century the summer of 2003 would be considered unusually cool
- Days per summer that reach 30° C (86° F) in Paris:
  - From 6-9 days now to **50 days** by 2100
- Consecutive days over 30° C in Paris:
  - From max of 3 to max of 19
- Drier summers over Europe lead to more warming there

Model Predictions of Extreme Heat: US

- Frequency of 20 year heat waves:



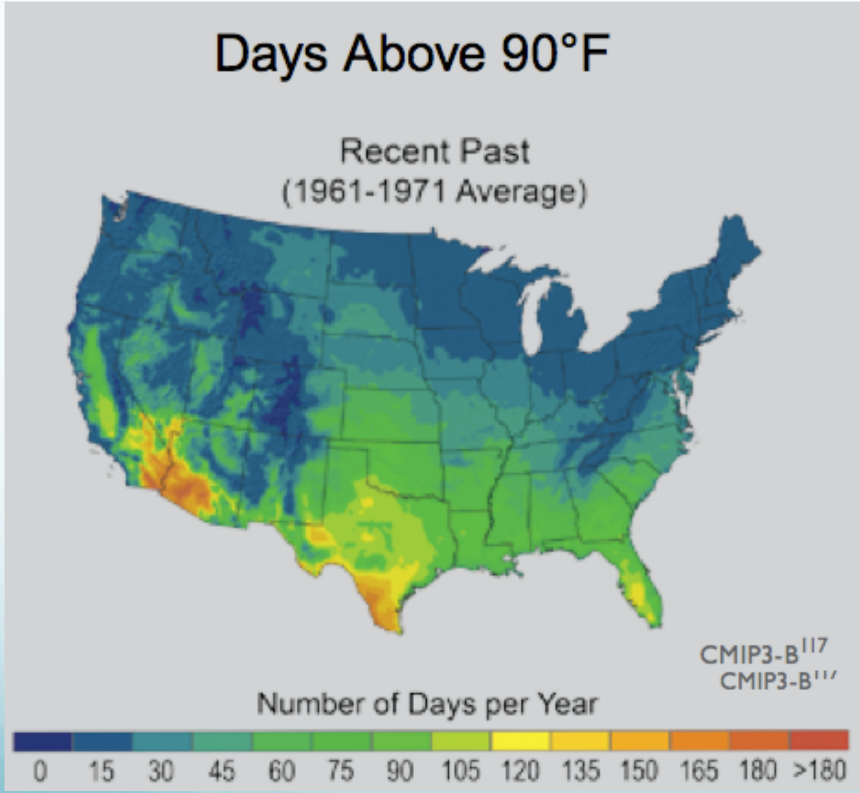
Simulations for 2080-2099 indicate how currently rare extremes (a 1-in-20-year event) are projected to become more commonplace. A day so hot that it is currently experienced once every 20 years would occur every other year or more frequently by the end of the century under the higher emissions scenario.[91]

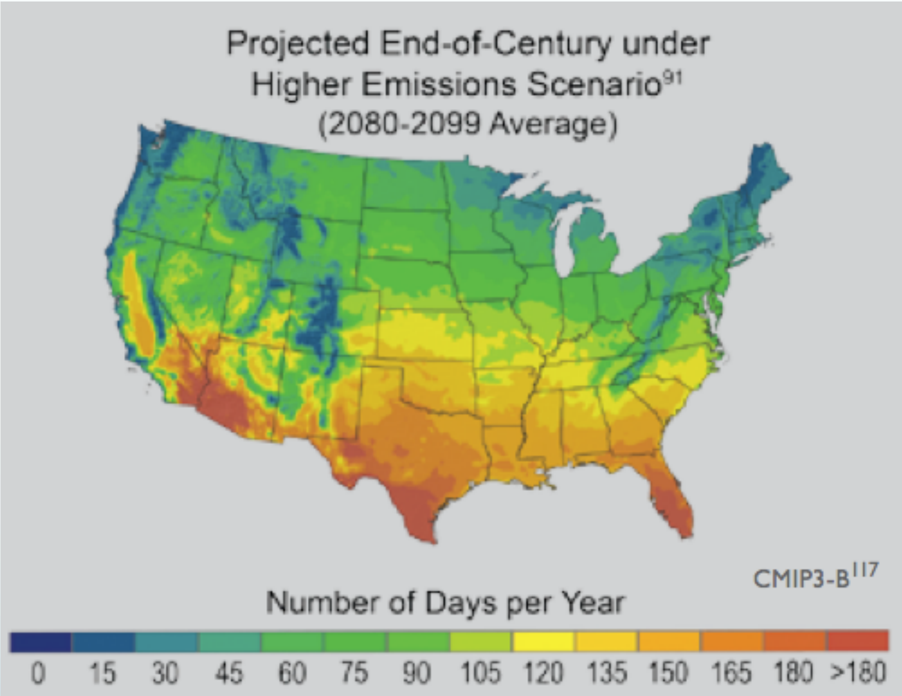
1-in-20-year heat waves happen **every other year** over much of the country by the end of 21st century

Next few slides from Global Climate Change Impacts in the US by US Global Change Research Program, 2009

Model Predictions of Extreme Heat: US

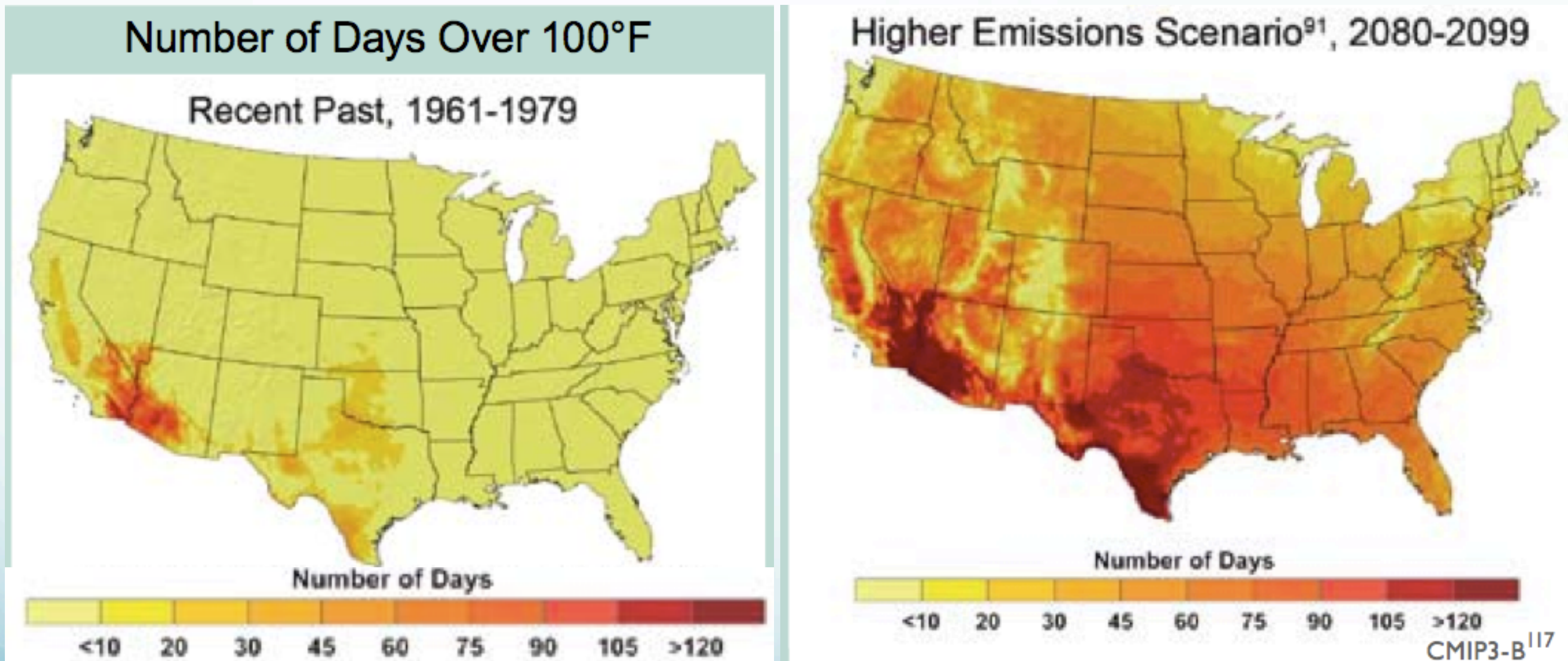
- Days over 90º F





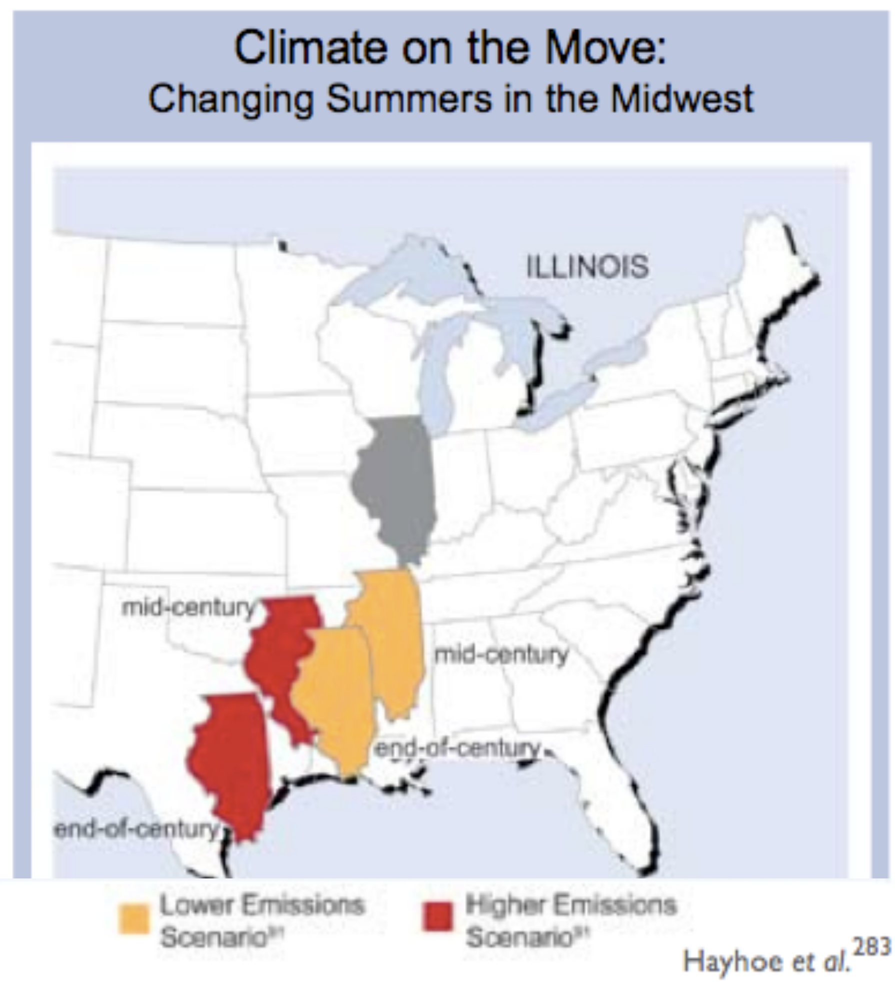
Model Predictions of Extreme Heat: US

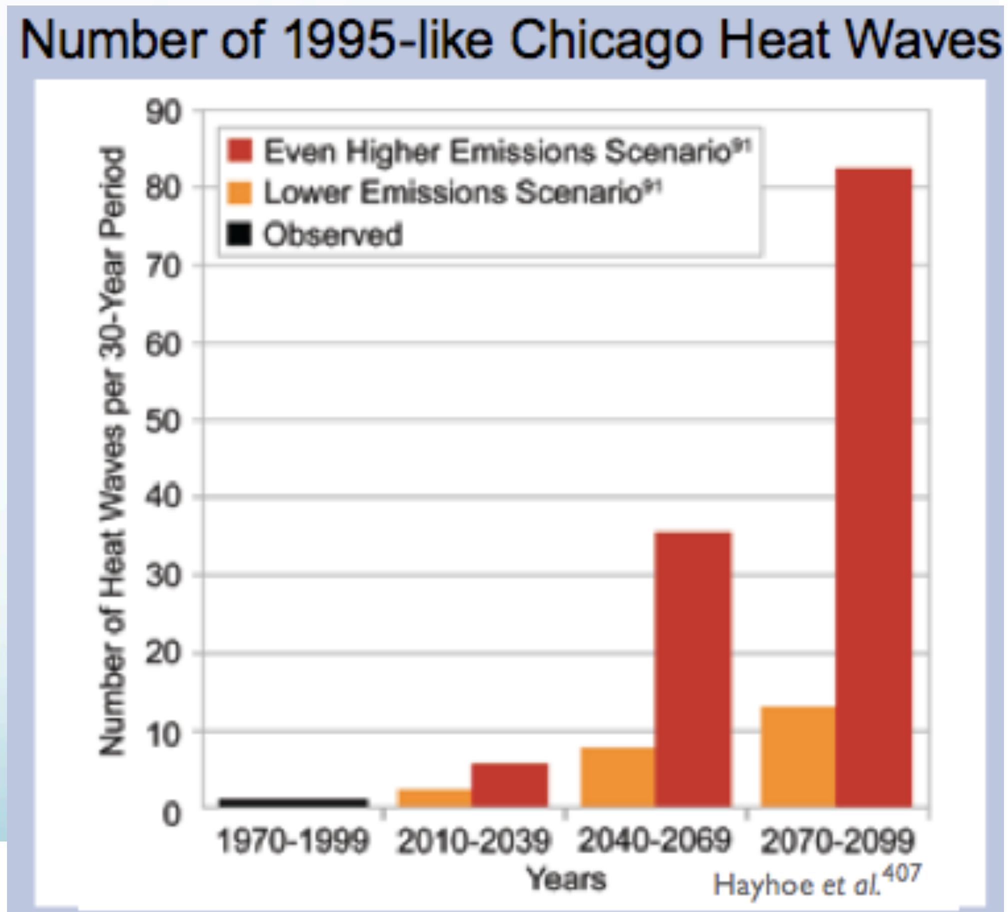
- Days over 100º F



Model Predictions of Extreme Heat: US

- Shifting climate zones

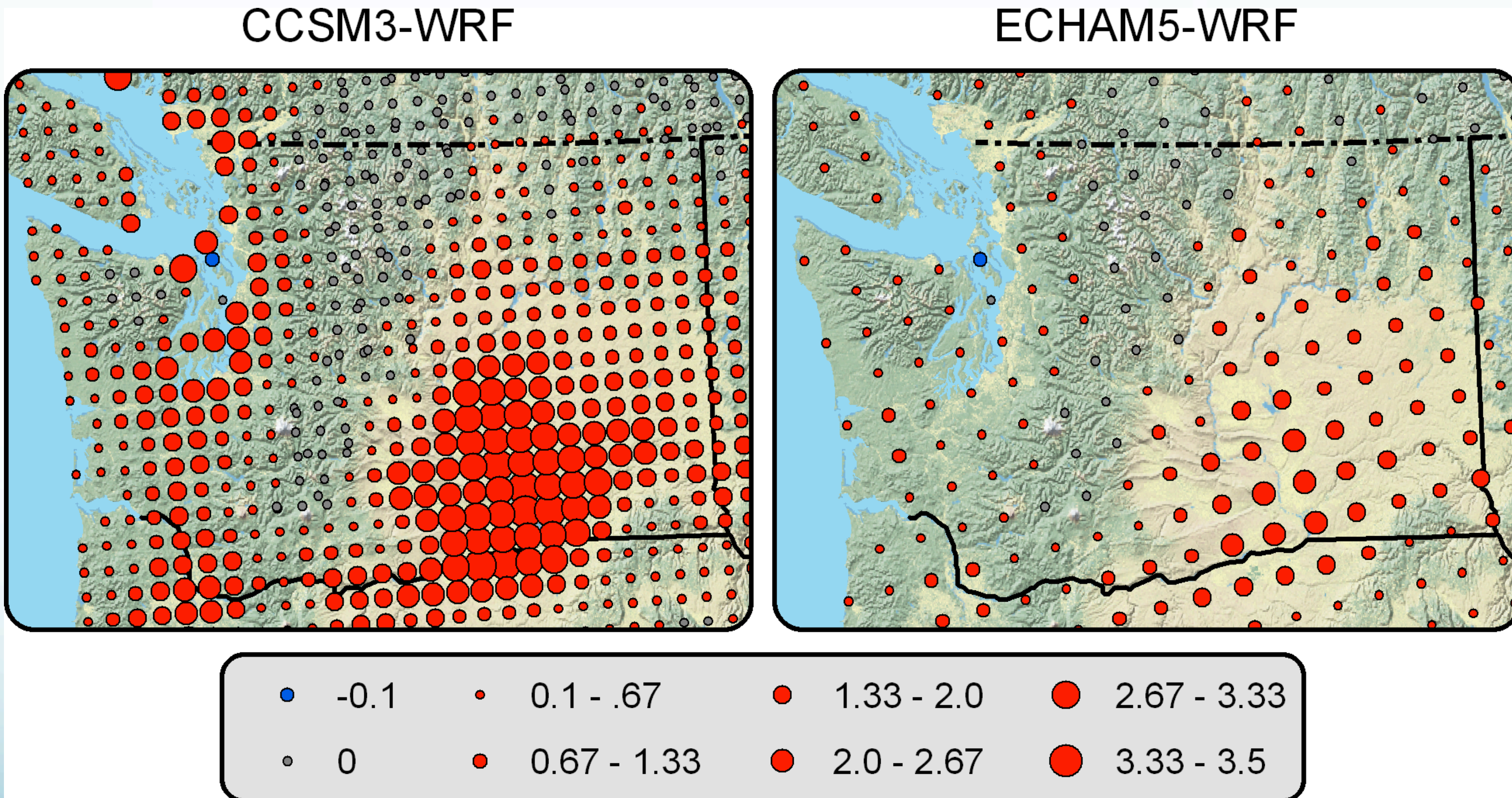




Washington State Predictions

- Predictions of 2030-2059 compared with 1970-1999

Change in **number of heat waves** (heat wave = 3 straight days with heat index over 90° F)



From Climate Impacts Group report, part of UW's Joint Institute for the Study of the Atmosphere and Oceans.

Washington State Predictions

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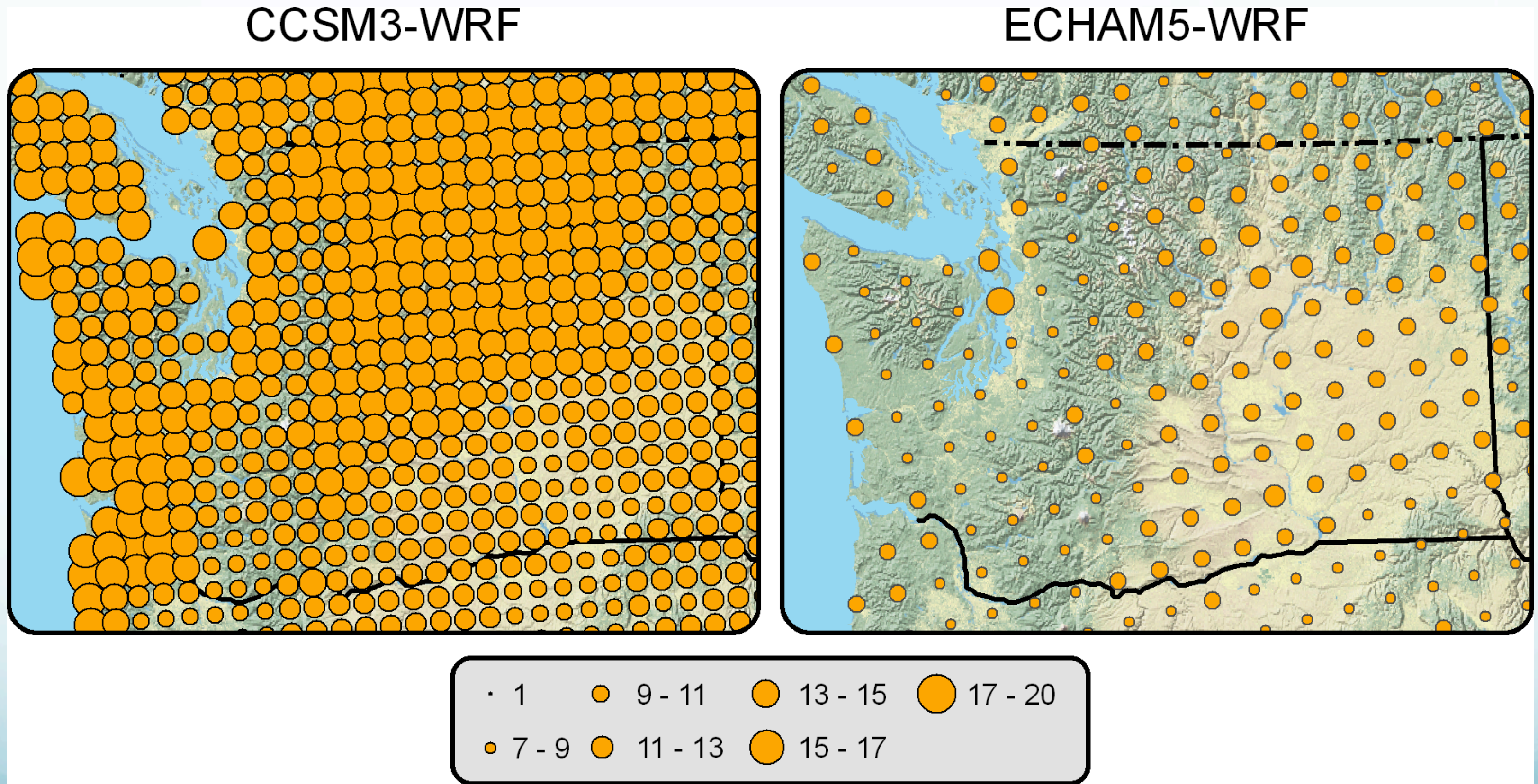
Change in number of **very warm nights**



From Climate Impacts Group report, part of UW's Joint Institute for the Study of the Atmosphere and Oceans.

The future of summer sizzle

- the worst heat waves will be more intense
- heat waves of a prescribed intensity will occur more frequently
- some regions may become more susceptible to heat waves
- shift toward higher daytime summer temperatures
- more water vapor will increase the heat index in many places
- in some places, vegetated land may give way to desert.