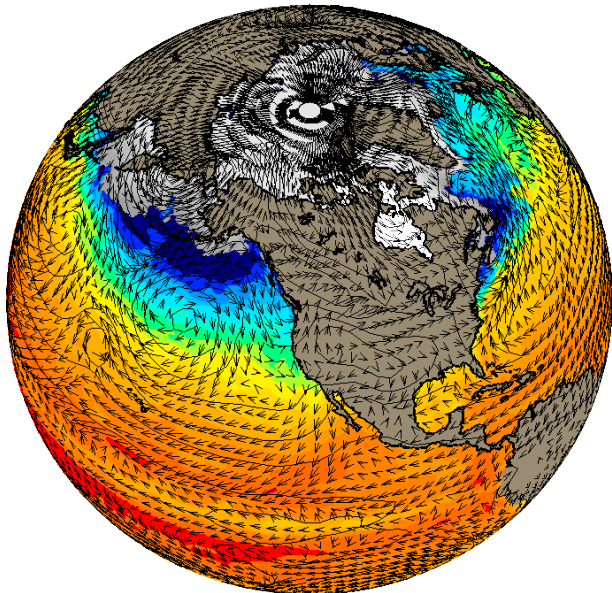


Weather Extremes in a Changing Climate

Gerald A. Meehl

National Center for Atmospheric Research
Boulder, CO



NCAR

Heat Wave Breaks Records

July 22, 2011: The record-breaking heat wave that began in the central United States earlier in the week had spread east by Thursday.

This heat wave is exceptional not only for its strength, but also for its breadth and duration. More than 1,400 record-high temperatures have been broken or tied around the country in July alone...and that number was expected to rise on Friday as ***132 million people were living under an excessive heat warning or heat advisory.***



Extreme heat wave continues

Wednesday, August 3, 2011

Austin is in for another day of extreme heat, and the National Weather Service has extended a heat advisory until midnight Sunday.

August has seen its hottest start ever, with two straight days of 107-degree highs, breaking records set for the same dates in 1923. ***The southern sections of the central U.S. could see one of its hottest weeks ever with frequent records set in Texas, the southern Plains, and nearby areas of the deep South.***

Associated Press headline:

Los Angeles bakes at record 113 degrees

September 27, 2010 LOS ANGELES — ***California's blistering fall heat wave sent temperatures to an all-time record high of 113 degrees in downtown Los Angeles*** on Monday, and many sought refuge at the beach. The historic mark was part of an onslaught of temperatures well over 100 degrees Fahrenheit in many cities ranging from Anaheim, home of Disneyland, to San Luis Obispo on the usually balmy Central Coast. The giant Los Angeles Unified School District canceled all outdoor activities, including sports competitions and practices. Thousands of heat-related power outages were reported.



2010 was the hottest summer on record in Washington, D.C., Baltimore, New York City and 10 states - including Maryland, Virginia, Delaware and New Jersey.

Washington D.C. set a new record for most 90° F plus days in a year, with 67.

2010 Russian heat wave

Smoke from hundreds of fires over a thousand miles of western Russia, August 2

Over 2,000 houses destroyed by fires and about 4,000 people left homeless, wildfires burned in 17 Russian regions, and a state of emergency was declared.

A heavy smog from the wildfires blanketed Moscow, concentration of toxic particles reached dangerous levels.

More than 20 daily temperature records were broken including the absolute maximum temperature in Moscow (101F)

Estimates put the death toll at about 55,000



2010 heat wave in Japan

By early September, reports were calling the stubborn heat wave the worst since records began in 1898.

In Tokyo, the mean daily temperature since the start of summer was 84.5 F, or 8.4 F above normal

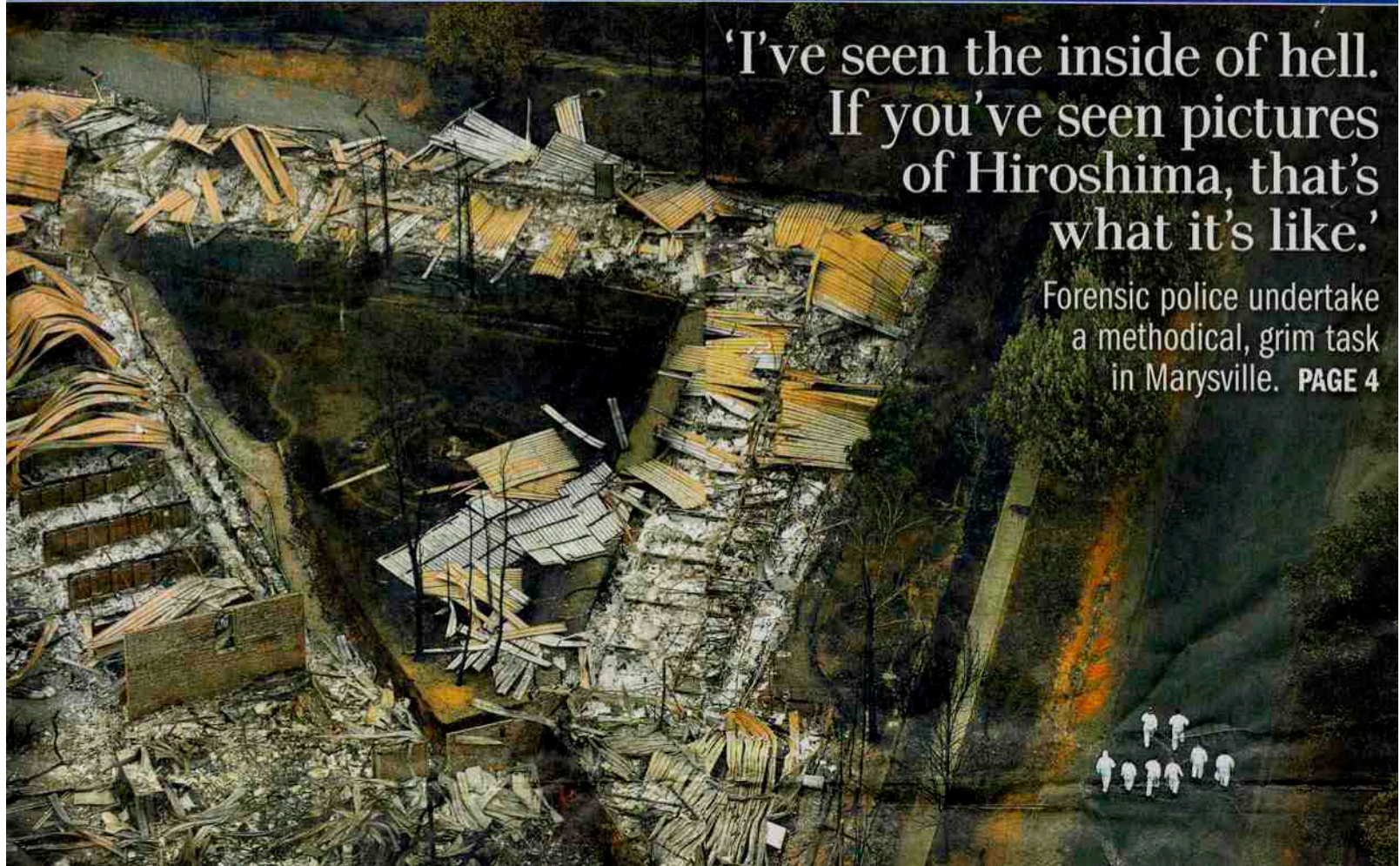
After July 17, only 8 out of 43 days failed to reach 90 degrees

The hottest day, Aug. 17, had a high of 99 F in Tokyo
Five other days topped out at 97 F, which is 11 F above the highest normal temperature

adverse health effects included more than 52,000 heatstroke cases necessitating hospital care

the death toll was said to be 168.





'I've seen the inside of hell.
If you've seen pictures
of Hiroshima, that's
what it's like.'

Forensic police undertake
a methodical, grim task
in Marysville. **PAGE 4**

Australian bushfires February 7, 2009: over 240 dead
~1800 houses destroyed, ~200 businesses and other buildings destroyed,
largest natural disaster in Australia's history

Context of the Australian bushfire disaster:

8 years of severe drought in southern Australia

Record-setting heat wave the week before, three days in a row above 43° C (109° F)

The day of the fires, Melbourne set an all-time record high temperature of 46.4° C (115.5° F) associated with strong high pressure and north winds

Editorial cartoon in Melbourne newspaper the week after the fires indicating Australians know that high pressure in the summer equals extreme heat that is conducive to fires



Is it global warming? There is an awareness in Australia that global warming has something to do with it:

Face global warming or firefighters' lives will be ever at risk

PETER MARSHALL

We will be fighting more fires unless we tackle the problem's source

DEAR Mr Rudd and Mr Brumby, On behalf of more than 13,000 firefighters and support staff in Australia, I write this open letter to request a review of Australia's fire risk and our readiness to meet future catastrophic events.

The fires in Victoria have ripped through towns and suburbs, farms and forests, destroying lives and livelihoods. Ashen remains are the sorrowful legacy of the devastation they caused. Never before in Australian history have we been

confronted with such destruction at the hands of fire.

Firefighters work in conditions that most of the public try to flee. We often put our lives on the line. We understand that our job is dangerous by its very nature. However, we are gravely concerned that current federal and state government policies seem destined to ensure a repeat of the recent tragic events.

Consider the devastation in Victoria. Research by the CSIRO, Climate Institute and the Bushfire Council found that a "low global warming scenario" will see catastrophic fire events happen in parts of regional Victoria every five to seven years by 2020, and every three to four years by 2050, with up to 50 per cent more extreme danger fire days. However, under a "high global

warming scenario", catastrophic events are predicted to occur every year in Mildura, and firefighters have been warned to expect up to a 230 per cent increase in extreme danger fire days in Bendigo. And in Canberra, the site of devastating fires in 2003, we are being asked to prepare for a massive increase of up to 221 per cent in extreme fire days by 2050, with catastrophic events predicted as often as every eight years. Given the Federal Government's dismal greenhouse gas emissions cut of 5 per cent, the science suggests we are well on the way to guaranteeing that somewhere in the country there will be an almost annual repeat of the recent disaster and more frequent extreme weather events.

Something is going on. As we battle blazes here in Vic-

toria, firefighters are busy rescuing people from floods in Queensland. Without a massive turnaround in policies, aside from the tragic loss of life and property, we will be asking firefighters to put themselves at an unacceptable risk. Firefighters know that it is better to prevent an emergency than to have to rescue people from it, and we urge state and federal governments to follow scientific advice and keep firefighters and the community safe by halving the country's greenhouse gas emissions by 2020.

Unfortunately, the scientists are advising that no matter what we do, a "low global warming" scenario is almost inevitable, and so we must make fire plans accordingly. Fire does not respect state borders and we need a national inquiry into the state of readi-

ness of the country's fire services to meet this century's challenges.

Our existing resources cannot be expected to cope with even the "low global warming" scenario of a 25 per cent increase in extreme fire days — and catastrophic fire events

Government policies seem destined to ensure a repeat of the recent tragic events.

every five years — in major Victorian country locations in just under 12 years' time. Likewise, when the scientists tell us that under a "low warming" scenario in 2020, Wagga Wagga faces "very extreme" events every two years, warning bells must surely be ringing.

Climate change, however, is

only one factor. There are many other pressures on our fire services. As cities expand into formerly rural areas and "growth corridors", many volunteer brigades find their new members have full-time jobs in the city and all the pressures of urban life, and therefore less time to devote to firefighting. These areas need more resources. And professional firefighters routinely perform duties from rescue to emergency medical response, and we are now trained to be part of the front-line response to any terrorist attacks: duties we are proud to perform but which will increasingly put us under strain as we respond to more and more fires.

The real question now must be whether the nation as a whole is devoting the resources it needs to fire prevention and

suppression. We are gravely concerned that the royal commission to be set up in Victoria will have a narrow brief to investigate a geographically specific disaster. It cannot have the scope needed to provide an overview of Australia's fire readiness. Further, we want to ensure that it is not a white-wash, with narrow terms of reference designed to ensure political cover for the Victorian Government. The proposed Victorian royal commission should be folded into a broader national inquiry into the nature of Australia's fire risk and our preparedness to meet that risk.

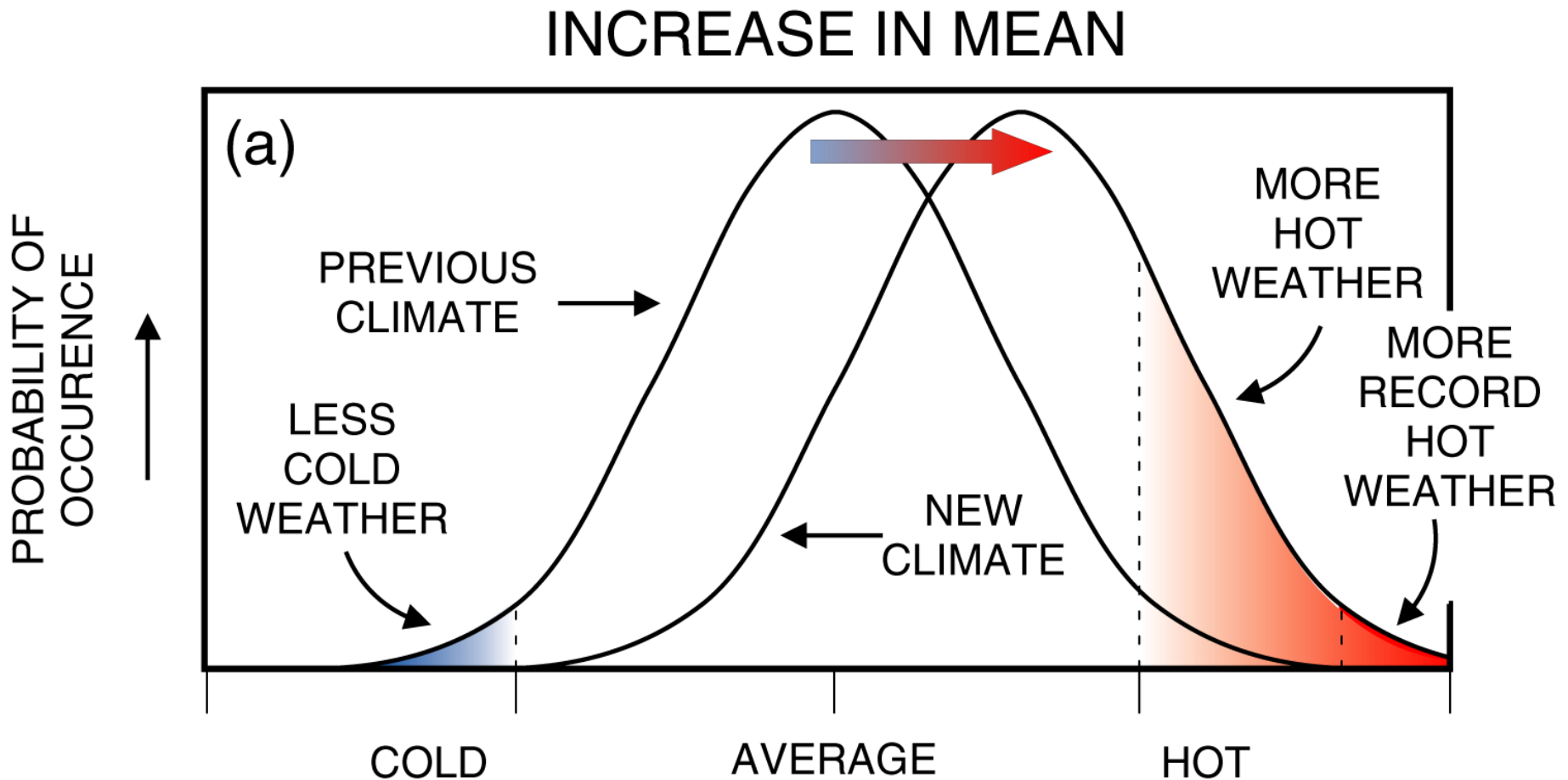
Consideration must also be given to massive new federal and state investment in infrastructure and firefighters. A portion of any stimulus package must go towards preventing future disaster, as well as

rebuilding after the current one.

Finally, now is not the time to play a "blame game" with respect to the Victorian fires. But at the appropriate time, we hope to be able to publicly air the concerns we have been conveying over many years to those in power about the state of readiness of our fire services. A national inquiry would allow Australia to get to the bottom of what happened, but also to work out how to ensure that nowhere in the country will it happen again. We urge state and federal governments to make sure this tragedy wasn't completely in vain: grasp this opportunity to develop Australia's first-ever national approach to fire and rescue.

Peter Marshall is national secretary of the United Firefighters Union of Australia.

How global warming affects extremes: a relatively small shift in the average temperature produces a very large increase in extreme high temperatures and a decrease in extreme low temperatures

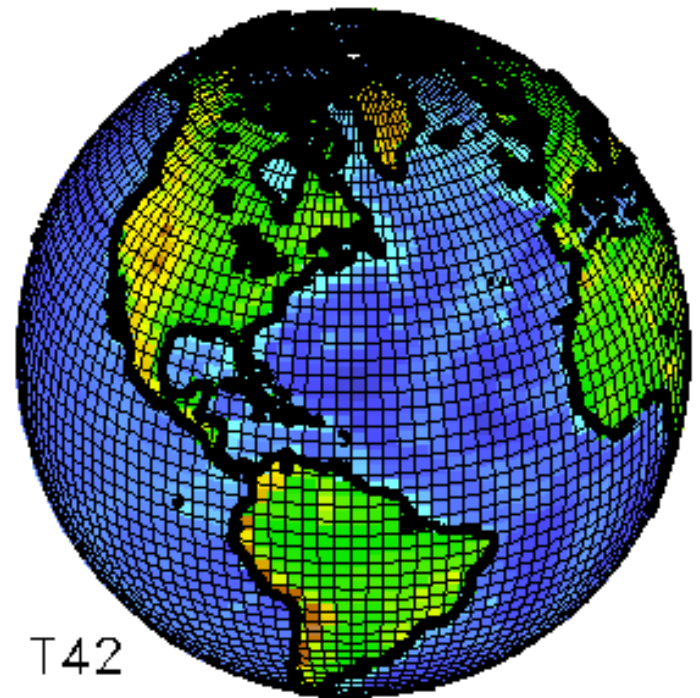
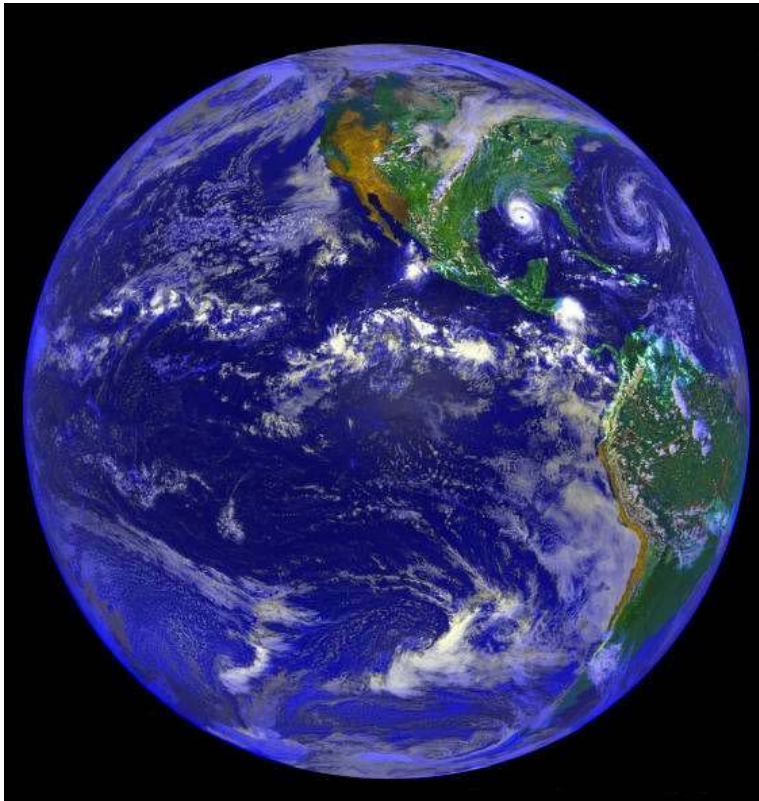


Southern Australia is naturally susceptible to extreme heat and bushfires, but with global warming, there is a shift to drier conditions and warmer temperatures, thus increasing the risk of record-setting extreme heat and record bushfires

Global warming by itself doesn't cause extreme conditions, but it makes naturally occurring events even more extreme

We quantify possible future changes in weather and climate extremes with **climate models**

The challenge of simulating the earth's climate with equations



T42

Resolution of climate models is improving:

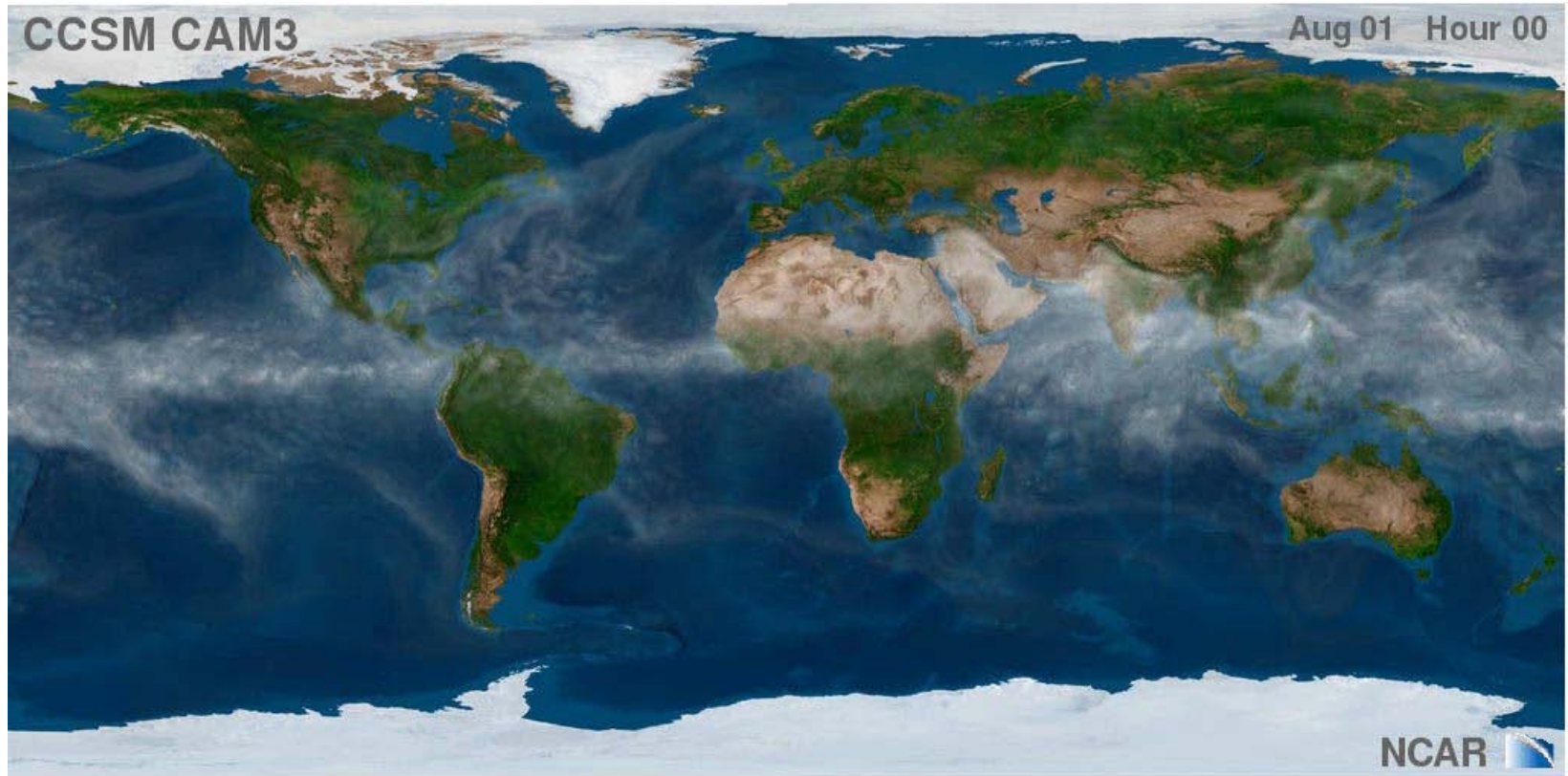
1995: about 500 km

2000: about 250 km

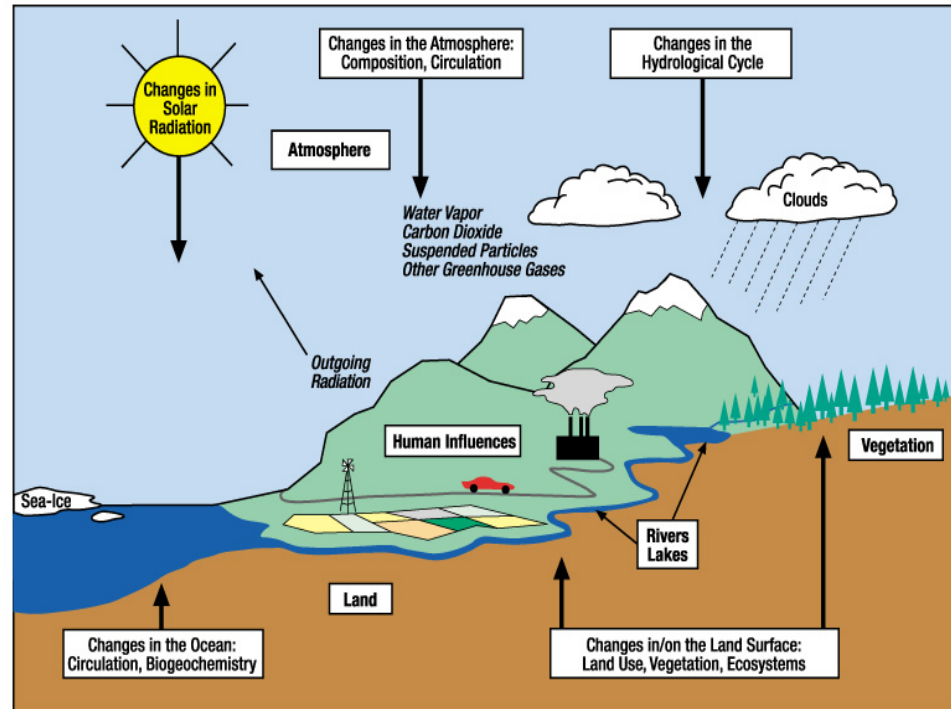
2005: about 150 km

2010: about 50 km

Climate Model Simulation



A climate model has an atmospheric component a lot like a weather forecast model, but with lower resolution.



It also includes interactive ocean, land surface, and sea ice models, and accounts for changes in atmospheric constituents like greenhouse gases, changes in solar input, volcanoes, visible air pollution, etc.

Heat Waves

Impacts on human health and mortality, economic impacts, ecosystem and wildlife impacts



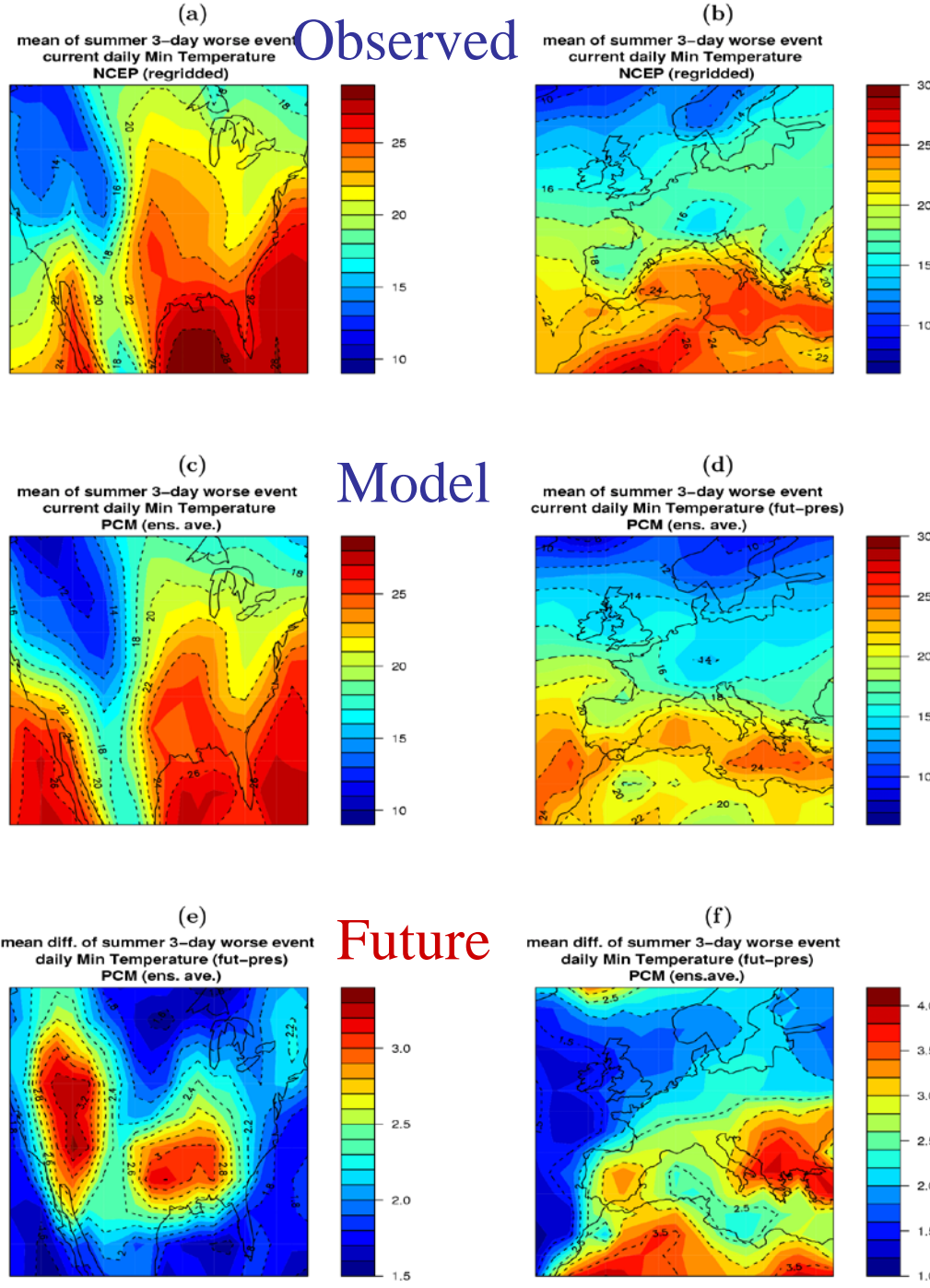
Climate models can be used to provide information on changes in extreme events such as heat waves

Heat wave severity defined as the mean annual 3-day warmest nighttime minima event

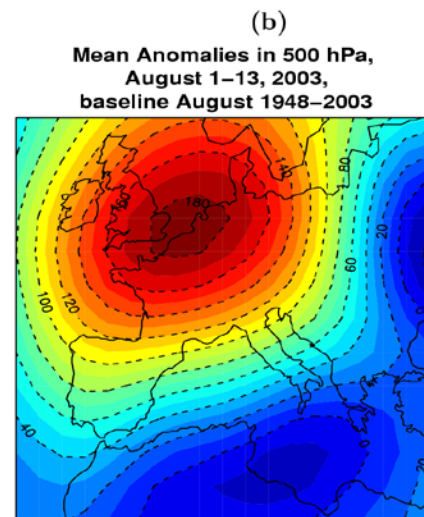
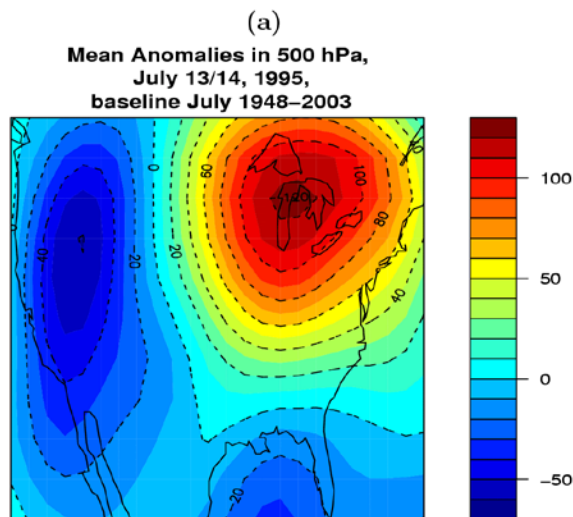
Model compares favorably with present-day heat wave severity

In a future warmer climate, heat waves become more severe in southern and western North America, and in the western European and Mediterranean region

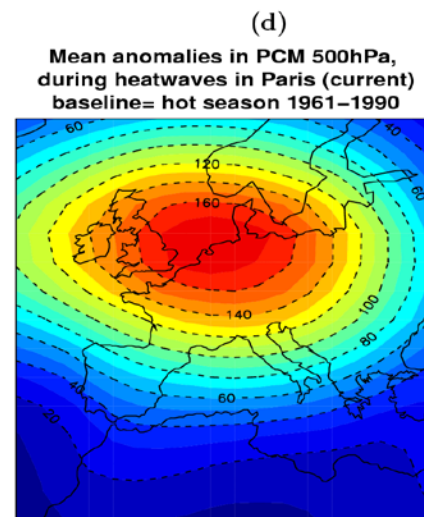
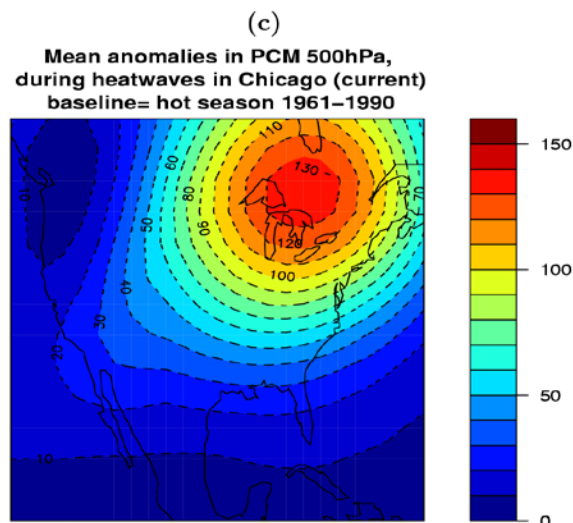
(Meehl, G.A., and C. Tebaldi, 2004: More intense, more frequent and longer lasting heat waves in the 21st century. *Science*, **305**, 994--997.)



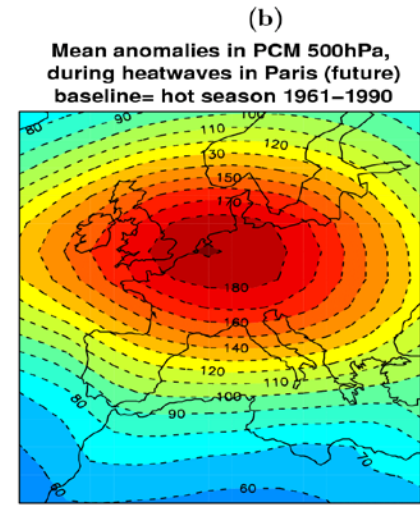
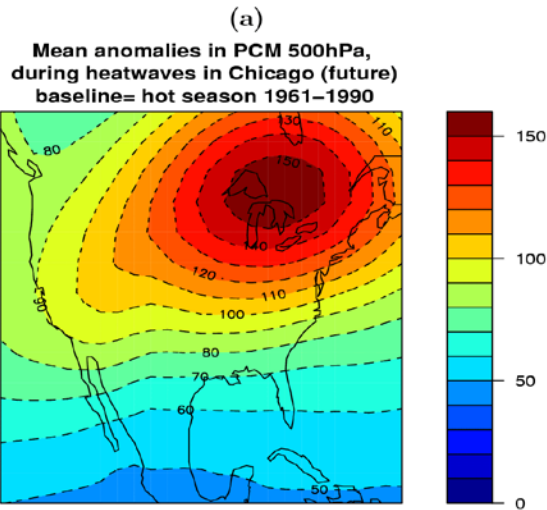
The Chicago (1995) and Paris (2003) heat waves show large positive 500 hPa height anomalies



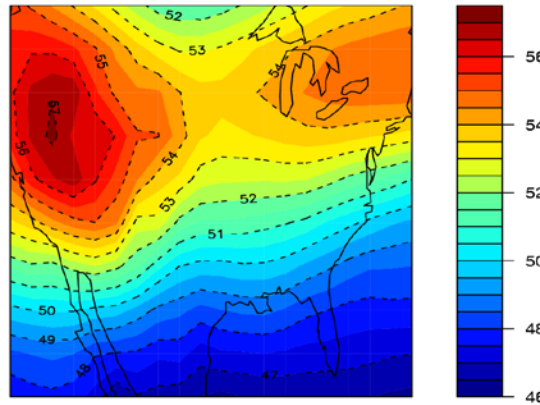
For present-day heat waves near Chicago and Paris, the climate model also simulates large positive 500 hPa height anomalies



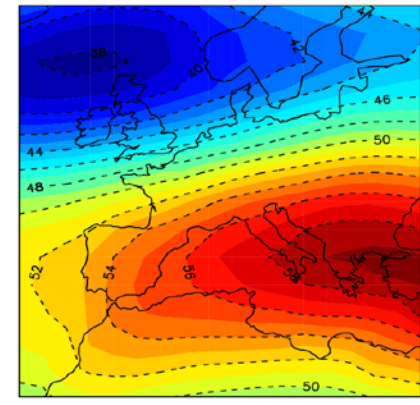
Atmospheric circulation in heat waves becomes more intense for future climate (2080-2099) compared to present-day (1961-1990)



(c)
mean difference in Z500, future - present, PCM (ens.ave.)



(d)
mean difference in Z500, future - present, PCM (ens.ave.)



Future change in base state (average) atmospheric circulation due to increased CO2 is conducive to more intense heat waves

Australia: 20 towns cut off or flooded across an area larger than France and Germany

(January 2011): A senior official has described the flooding in Queensland, Australia, as a disaster of "biblical proportions".

The floods, Queensland's worst in 50 years, were triggered by Australia's wettest spring on record. At least six river systems across Queensland have broken their banks. The floods have affected about 200,000 people, and many have been evacuated.



2010 Pakistan floods

More than 15 million across Pakistan affected by the floods, which submerged one-fifth of the country and laid waste to infrastructure and crop land; The monsoon-triggered floods that began late July spread from the north to the south of the country, swelling rivers and submerging hundreds of villages.



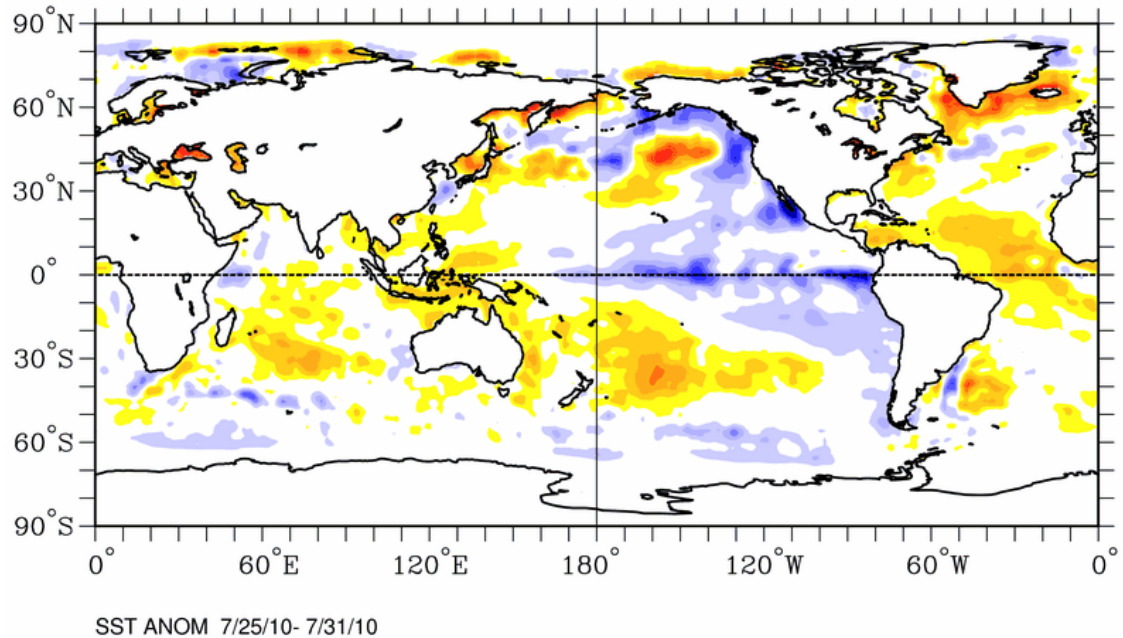
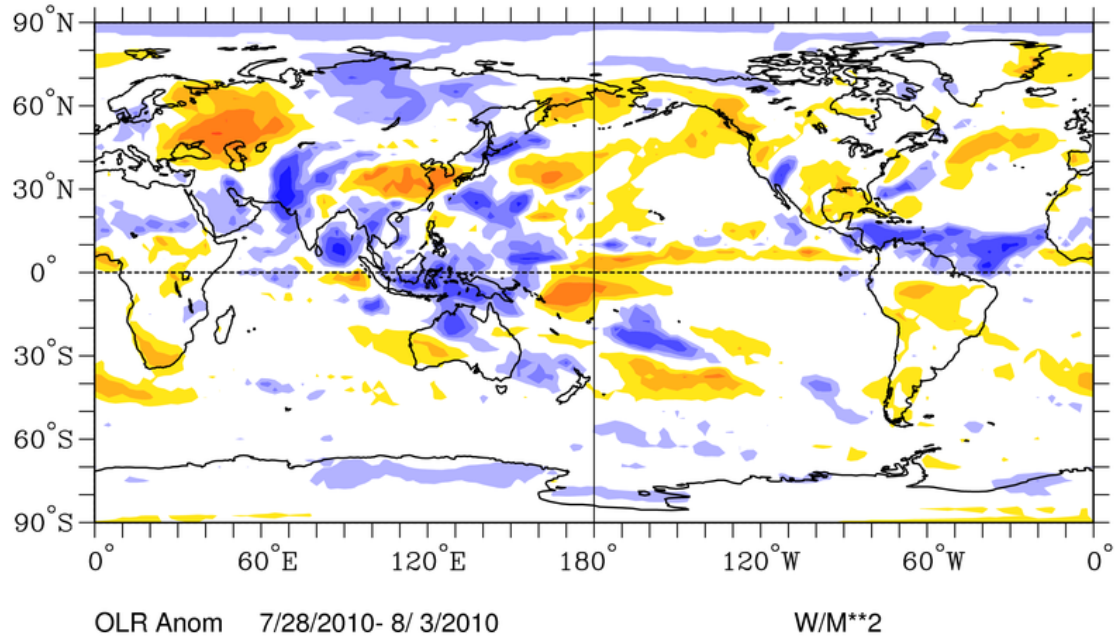
Flooding near Multan in Punjab Province, Pakistan, August 15, 2010

An example of intense precipitation with devastating consequences: 2010 Pakistan floods

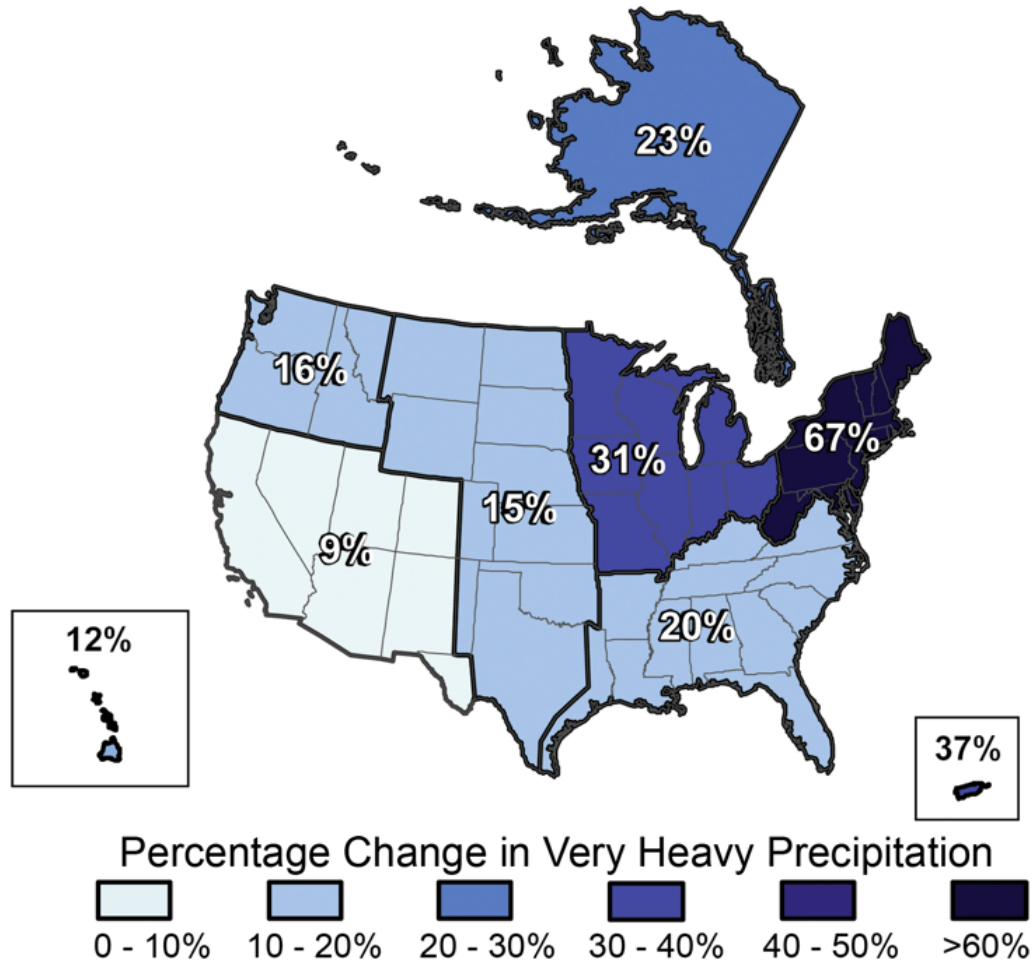
Were they natural, or was there a contribution from global warming?



The large-scale context to the Pakistan floods: above normal monsoon rainfall over much of south Asia, and a La Niña event in equatorial eastern Pacific,

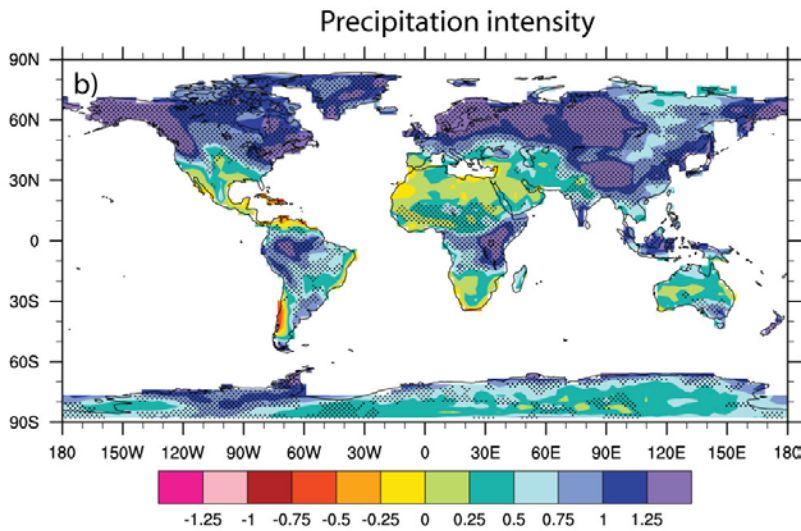


There has been an observed increase in precipitation intensity over the U.S. as the climate has warmed

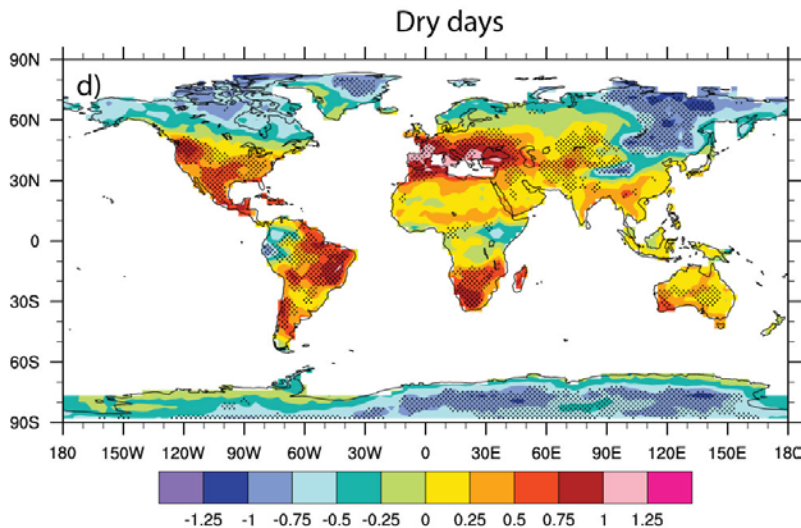


Updated from Groisman *et al.*¹¹³

The map shows the percentage increases in very heavy precipitation (defined as the heaviest 1 percent of all events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.



With further warming, precipitation is projected to become even more intense almost everywhere



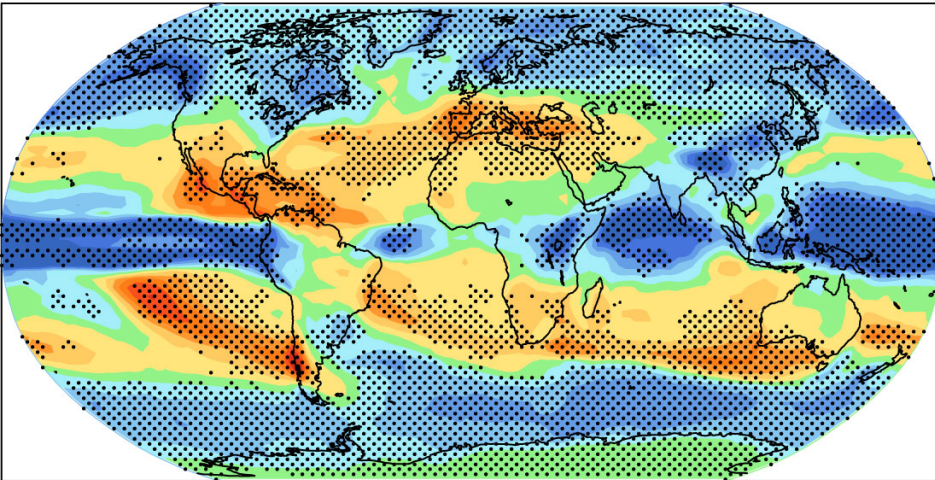
In some areas the projections show an increase of “dry days” (number of days between precipitation events)

(Tebaldi , C., J.M. Arblaster, K. Hayhoe, and G.A. Meehl, 2006: Going to the extremes: An intercomparison of model-simulated historical and future changes in extreme events. *Clim. Change*, **79**, doi 10.1007/s10584-006-9051-4.)

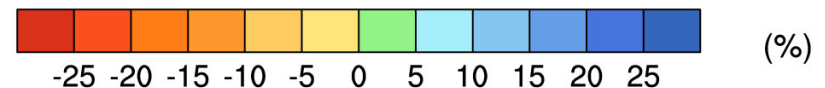
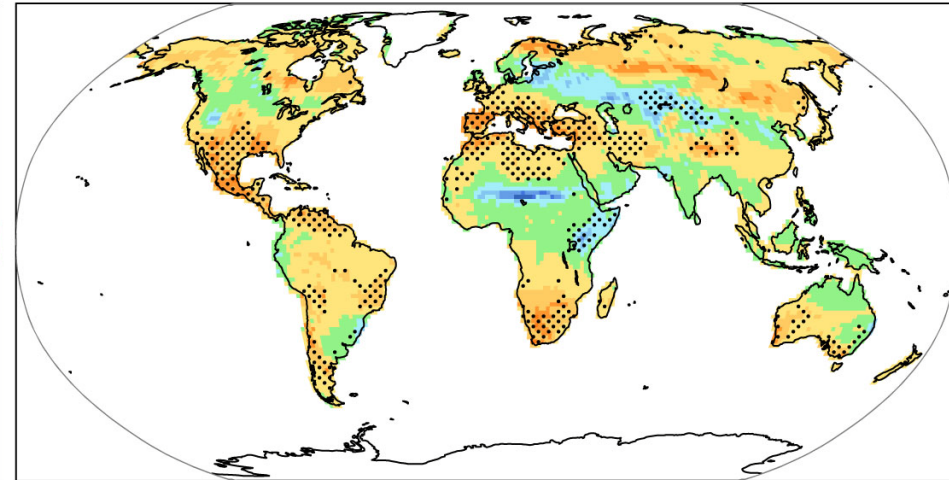
Combined effects of precipitation intensity and dry days contribute to average precipitation changes:

More precipitation in the deep tropics and mid- to high latitudes; less precipitation in the subtropics (“wet areas get wetter, dry areas get drier”)

a) Precipitation

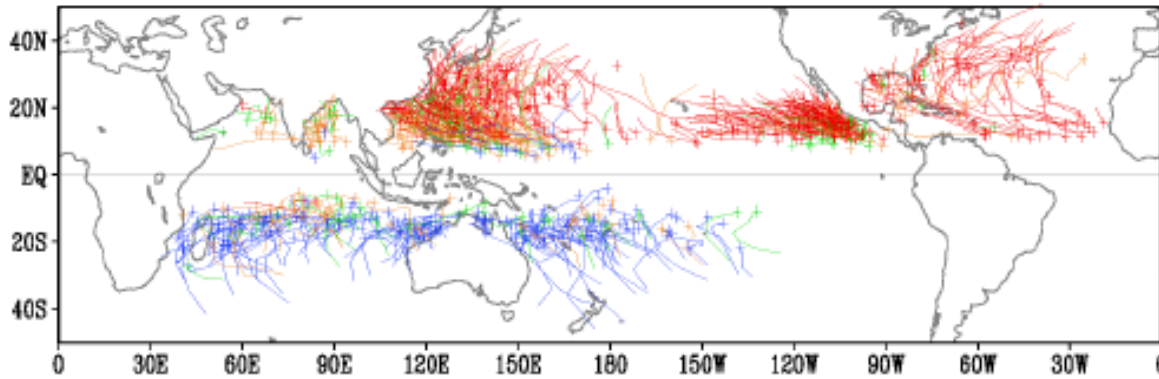


b) Soil moisture



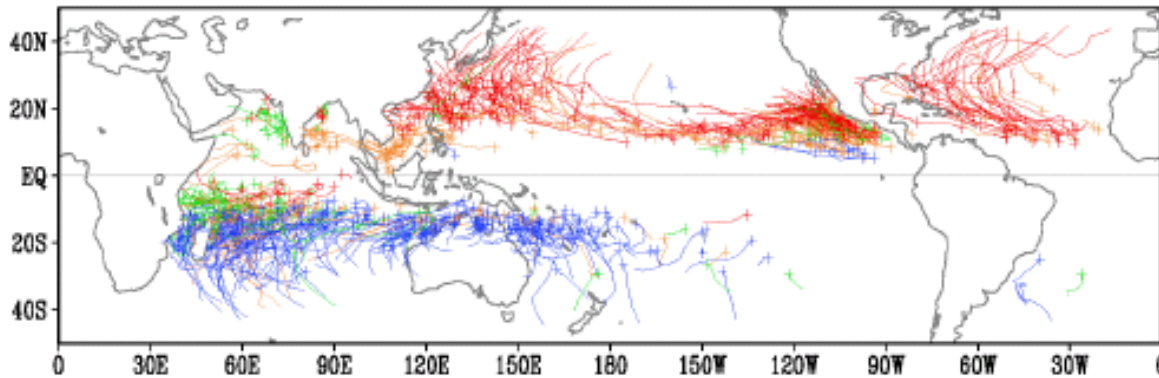
Observation 1979–1988

10 years



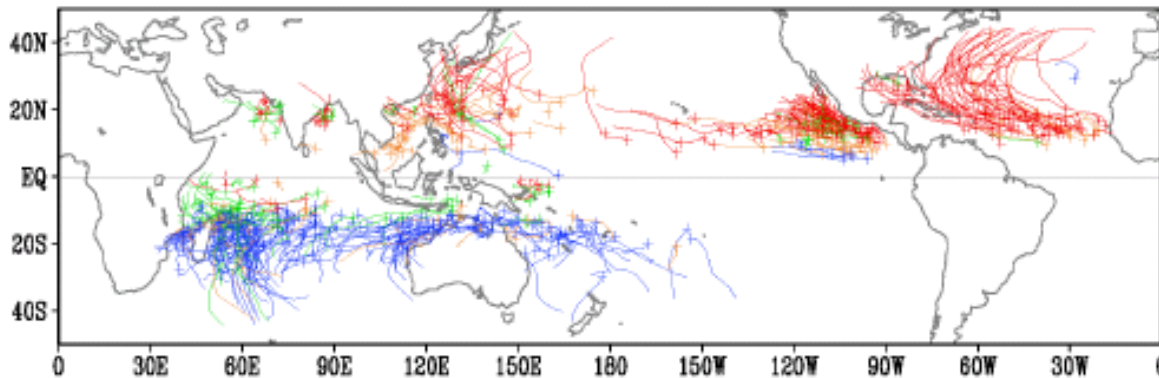
Present-day expt.

10 years



Future expt.

10 years



What about future hurricanes?

the indications so far: fewer total, but the ones that form will be more intense

(Tropical cyclone tracks from a global 20 km resolution atmospheric model)

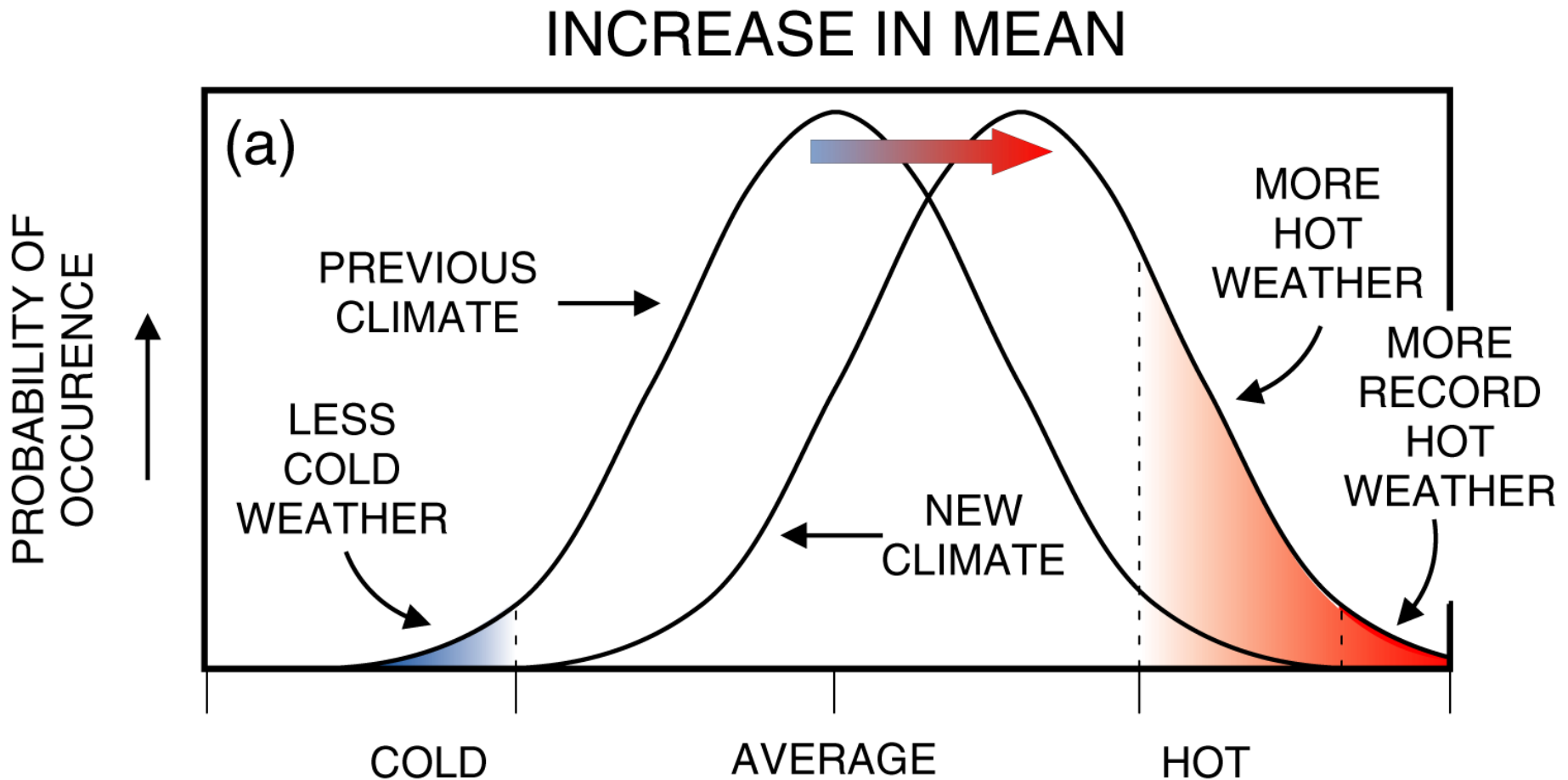
(Oouchi et al., 2006)

If the climate is warming, do daily temperature records show it?

A typical depiction of daily temperatures on a local newscast (in this case, December 3, 2009 from Denver during a cold snap)



In a warming climate, there should be more record hot weather and less record cold weather



Blizzard Paralyzes New York City, Boston

(Dec 27, 2010) A powerful winter storm slammed the I-95 corridor from Philadelphia to Boston on Sunday. Through today, the blizzard will bring travel to a standstill along the coastline of northern New England as well. The storm unleashed around a foot of snow and howling winds in cities and towns from Philadelphia through New York City to Boston as it advanced northward offshore Sunday and Sunday night.



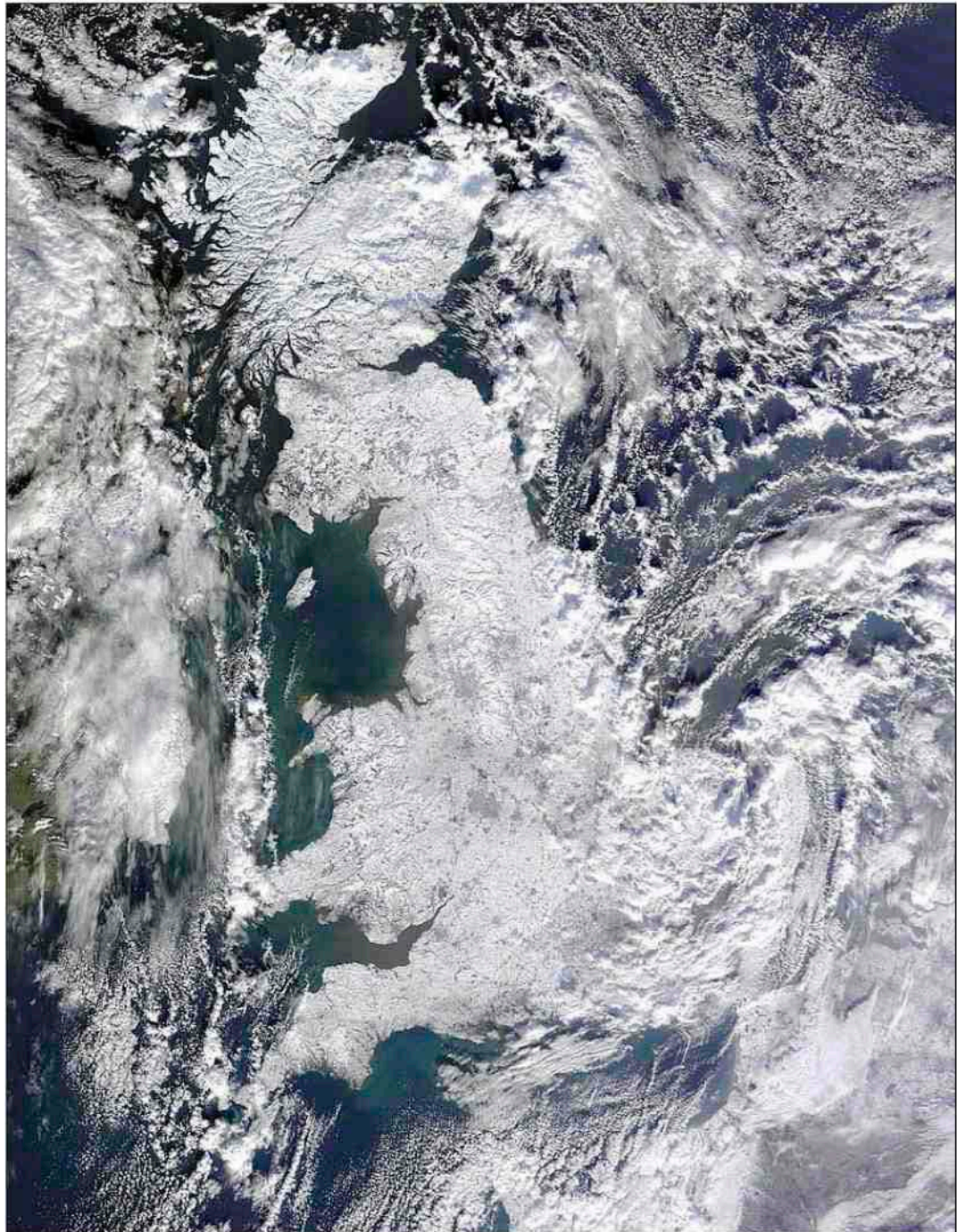
Nearly a foot of snow piled up in the Boston area on Sunday, December 26, 2010.

London Comes to a Standstill During the Holiday Season Because of Snow and Ice

LONDON, UNITED KINGDOM--(Dec. 29, 2010) - December is expected to go down as the coldest on record. With reports of 5 inches of snow in London, Gatwick Airport cancelled all flights and Heathrow cancelled all incoming flights on the weekend but had a few selected flights depart from the airport instead. This left many passengers planning on spending the Holidays overseas to find other plans until the snow is completely cleared.

...but some
recent winters
seemed really
cold ...

snow-covered
Britain, January 7,
2010



National Climatic Data Center web site archives observed annual daily record high maximum and record low minimum temperatures from weather stations across the U.S.

<http://www.ncdc.noaa.gov/oa/climate/research/records/>

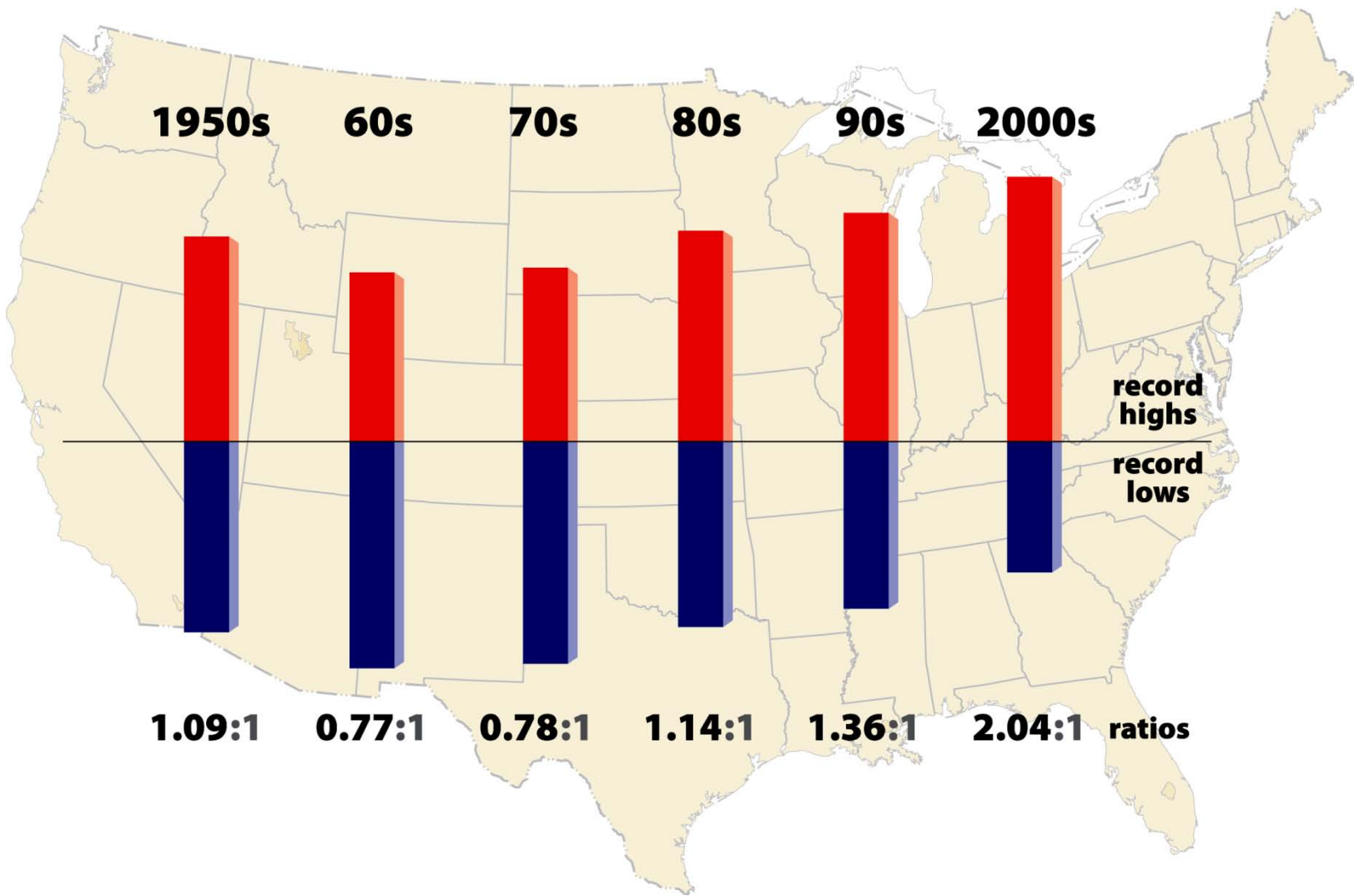
As of July 31, 2011:

January 1, 2000 to January 1, 2010: 313,799 record daily high maximum temperatures set, and 154,388 record daily low minimum temperatures, a ratio of roughly two to one (2.03 : 1).

January 1, 2010 to January 1, 2011: 19,213 record highs and 8,374 record lows, a ratio of a bit more than two to one (2.3 : 1).

Since January 1, 2011: 16,004 record highs, 6,316 record lows (2.5 : 1)

Is there something special about the two to one ratio of record high maximum temperatures to record low minimum temperatures, and why does this ratio appear to be increasing?



1950s

60s

70s

80s

90s

2000s

**record
highs**

**record
lows**

1.09:1

0.77:1

0.78:1

1.14:1

1.36:1

2.04:1

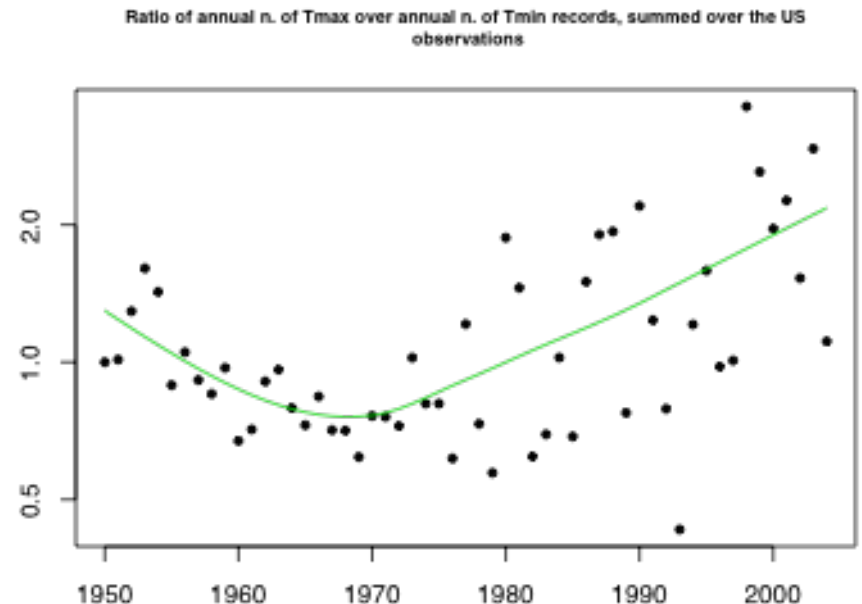
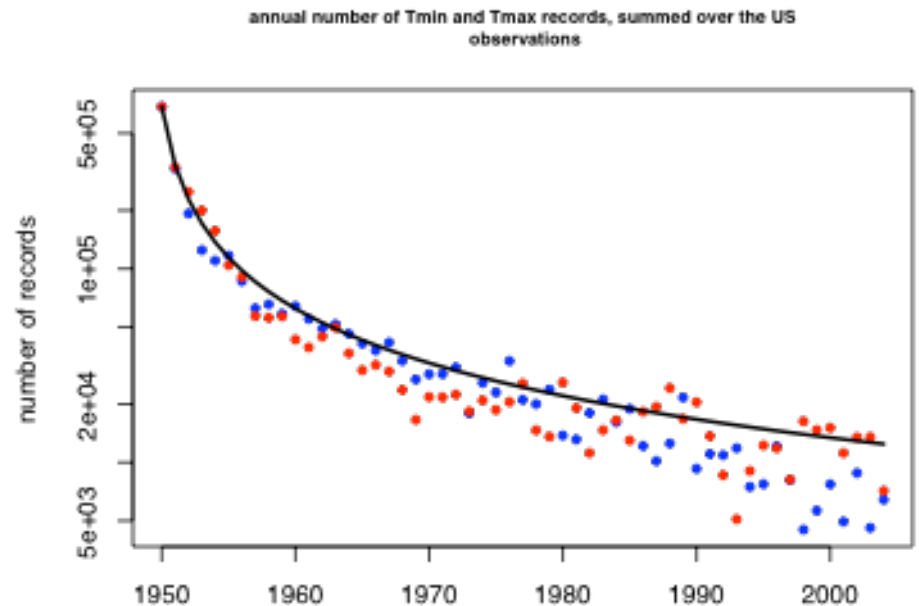
ratios

Records should decay by $1/n$ over time

In a stationary climate, ratio of record high maxima to record low minima should be roughly 1.0

However, average climate has been warming, and the ratio is now about 2 to 1

(Meehl, G.A., C. Tebaldi, G. Walton, D. Easterling, and L. McDaniel, 2009: The relative increase of record high maximum temperatures compared to record low minimum temperatures in the U.S. *Geophys. Res. Lett.*, **36**, L23701, doi:10.1029/2009GL040736.)

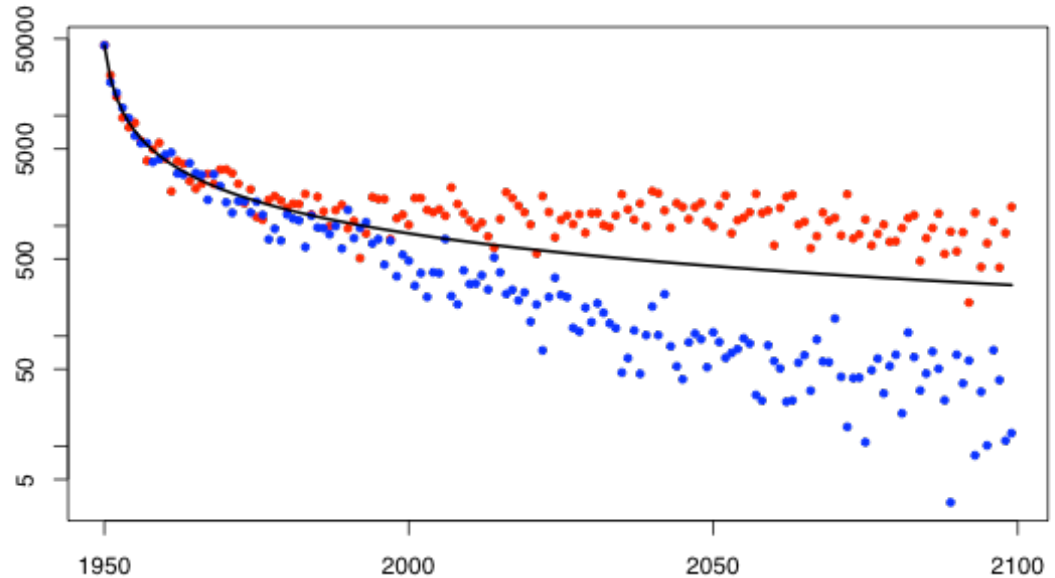


In the future:

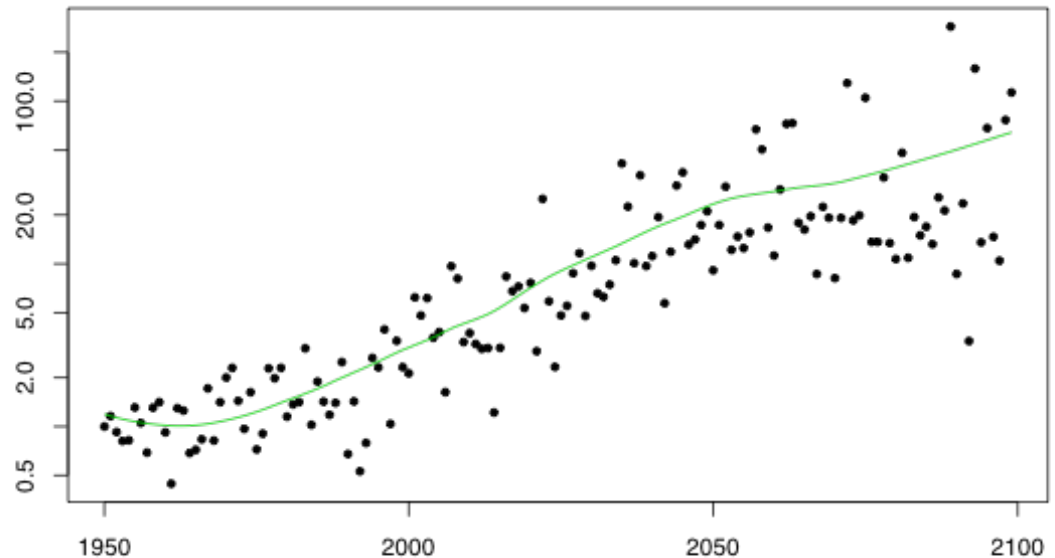
Ratio of record high maxima to record low minima about 20 to 1 by mid-century, and roughly 50 to 1 by the end of the century

Even in a much warmer climate, some record low minimum temperatures still occur

Annual number of Tmin and Tmax records, summed over the US
CCSM, A1B



Ratio of annual n. of Tmax over annual n. of Tmin records, summed over the US
CCSM, A1B



Summary

A relatively small shift in the average produces a very large change in extremes—more extreme heat and less extreme cold, and more record high maximum temperatures and fewer record low minimum temperatures

Global warming by itself doesn't cause extreme conditions, but it makes naturally occurring events even more extreme

In a future warmer climate:

Increased heat wave intensity, duration and frequency

Decreased cold spells (extreme cold weather will still occur, but less frequently)

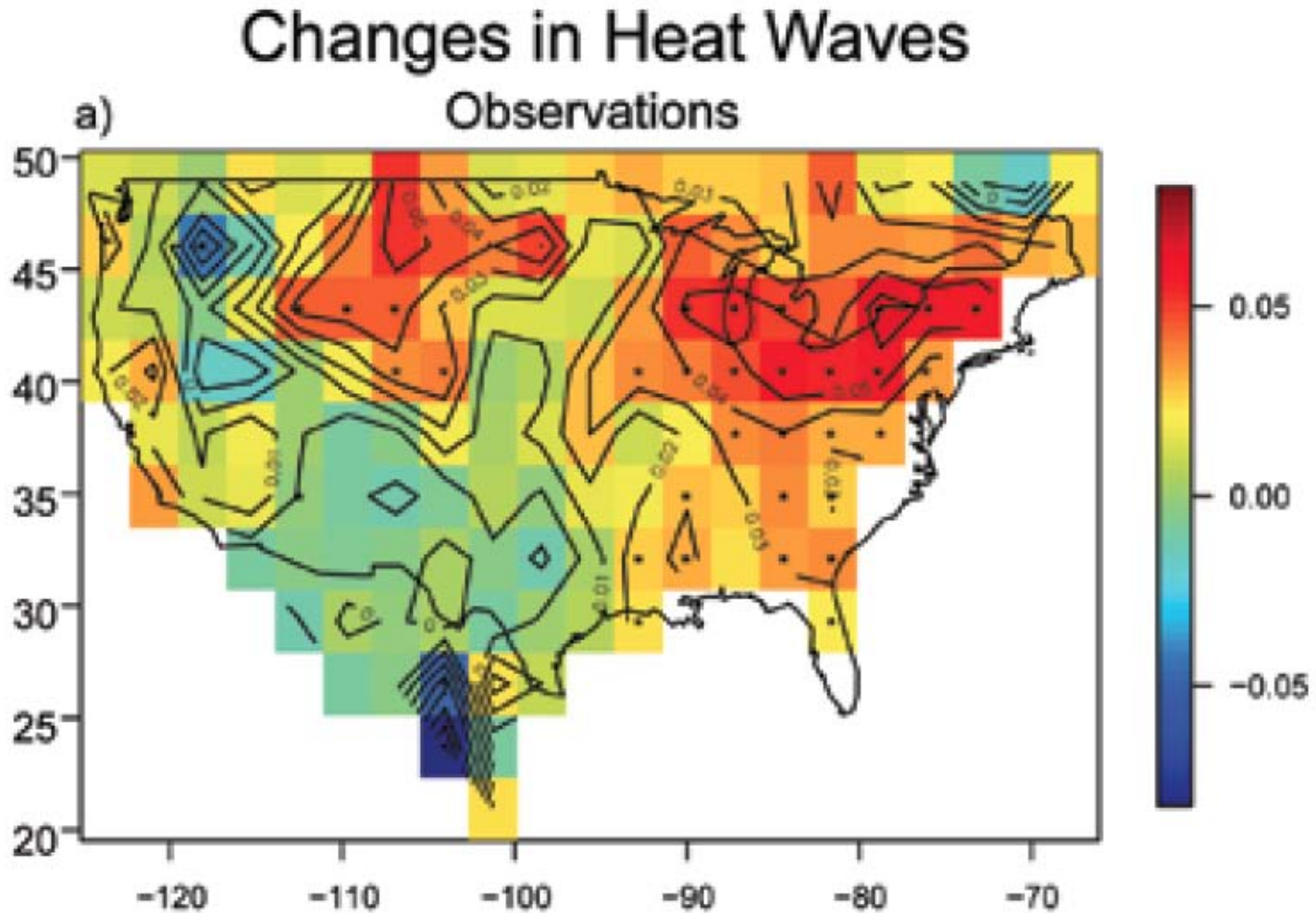
Increased precipitation intensity, but increases in dry days in some locations combines to produce areas of both average increase (midlatitudes) and decrease (subtropics) of precipitation

Future hurricanes: indication so far is for fewer total, but the ones that form would be more intense, but better modeling tools needed

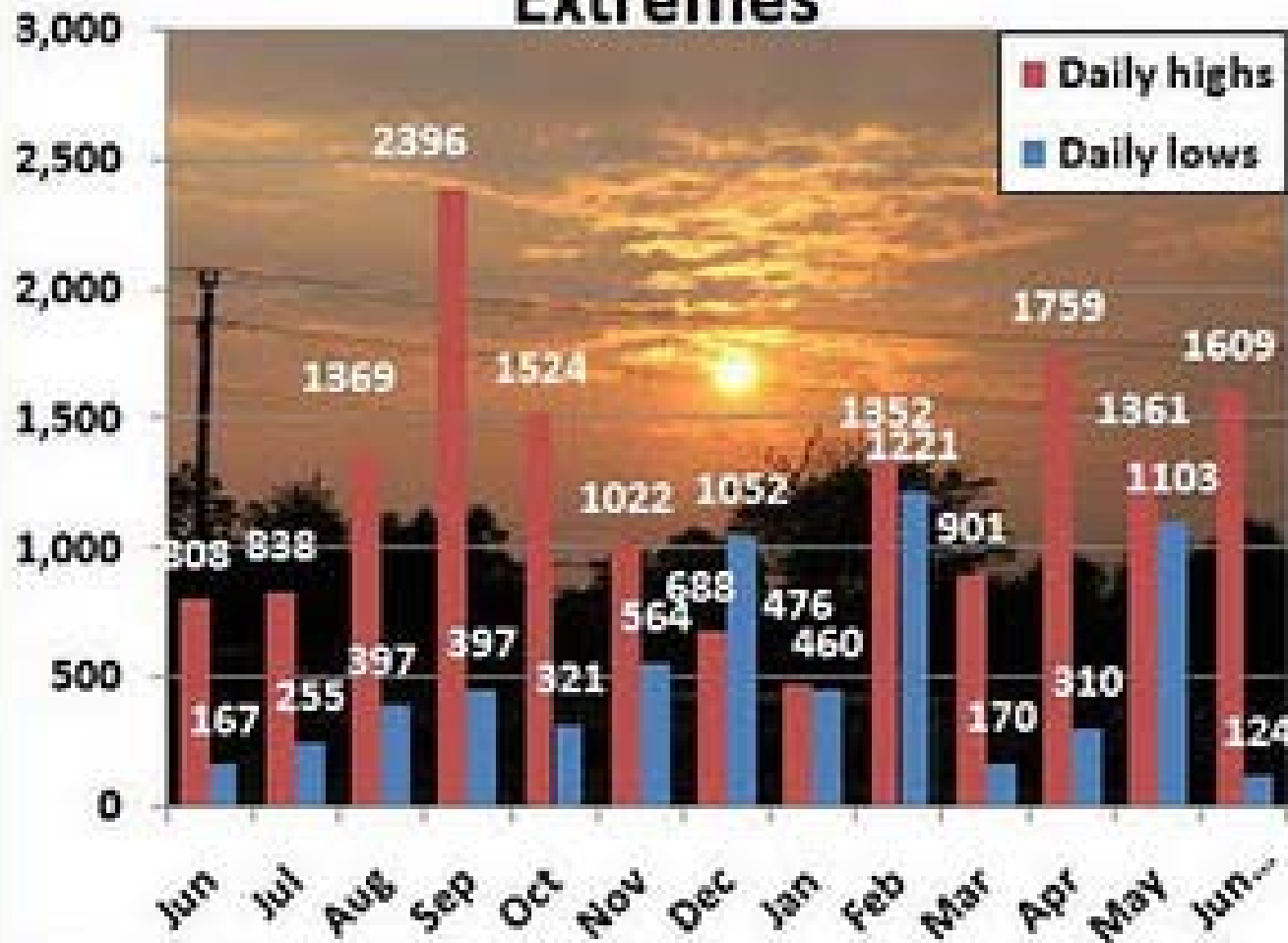
Current ratio of 2 to 1 for record high maximum temperatures to record low minimum temperatures over the U.S. is symptomatic of an ongoing warming of average temperatures; ratio projected to increase as the climate warms: about 20 to 1 by mid-century, 50 to 1 by late century

Heat wave intensity has been increasing over the U.S.

(trend from 1961-1990 in the Karl-Knight heatwave index, which tracks the warmest average minimum temperature over three consecutive nights in a year)



2010-11 U.S. Temperature Extremes



CapitalClimate

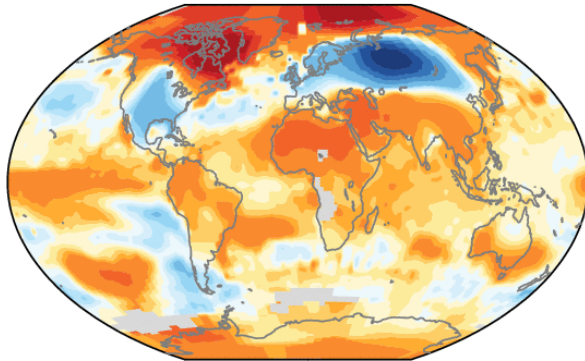
Arctic Oscillation (AO) Impact on Northern Winter Temperature

Total Observed

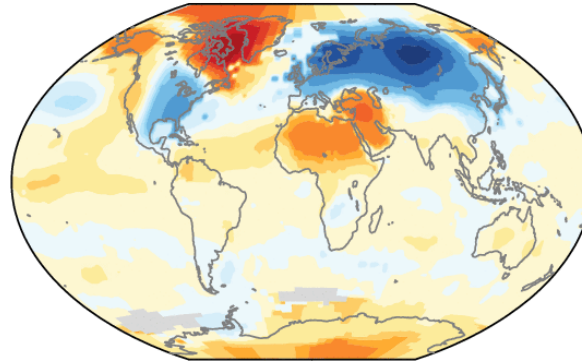
AO Influence

Residual

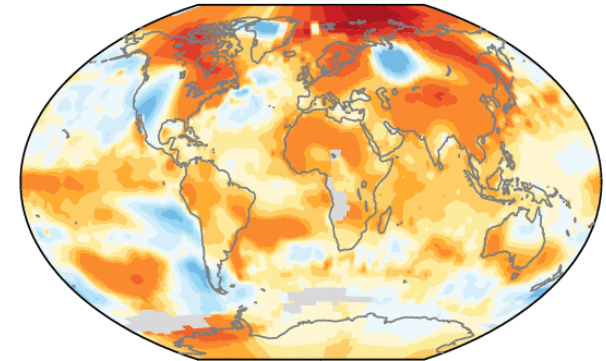
2010



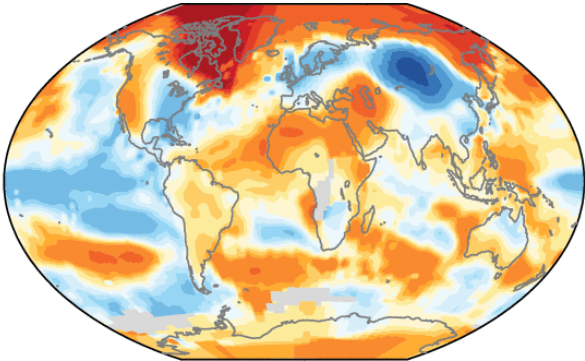
2010



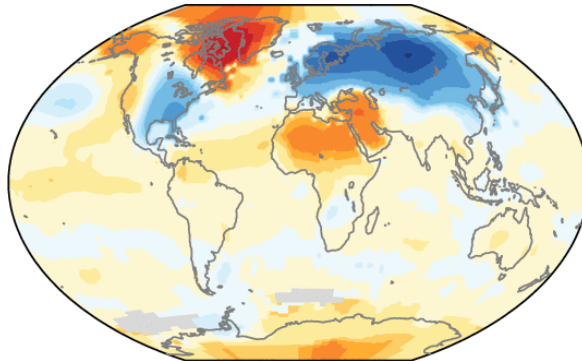
2010



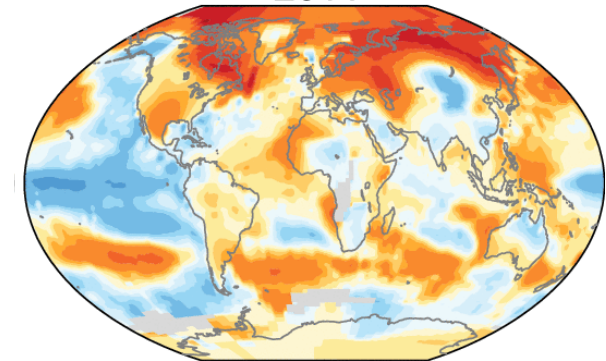
2011



2011



2011



- AO explains large temperatures anomalies over much of Northern Hemisphere
- El Niño (2010) and La Niña (2011) also played significant roles

Impacts on Agricultural and Biological Systems related to Frost Days

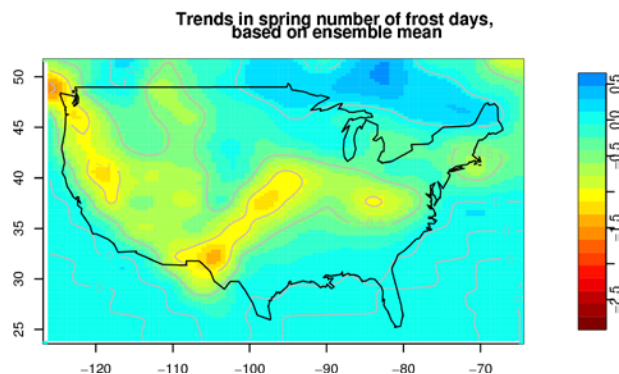
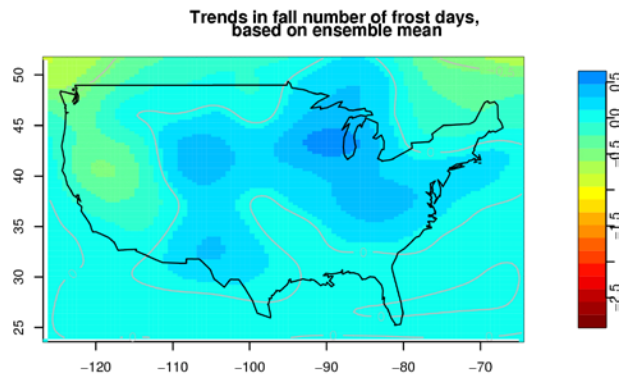
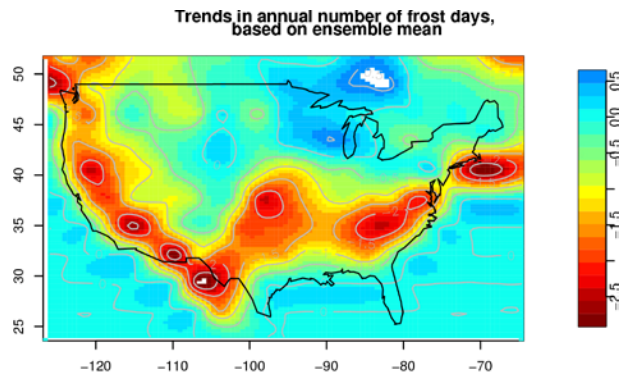
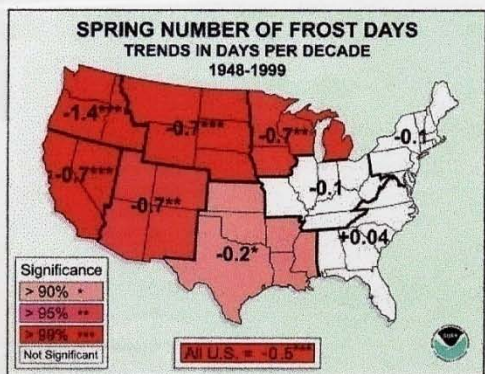
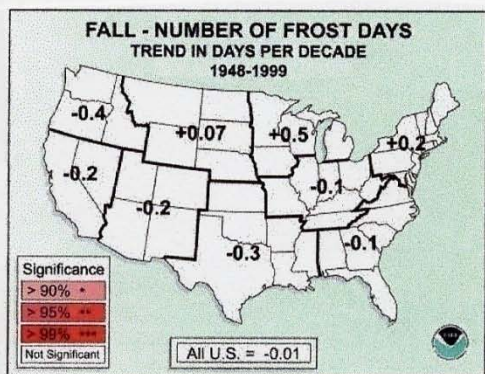
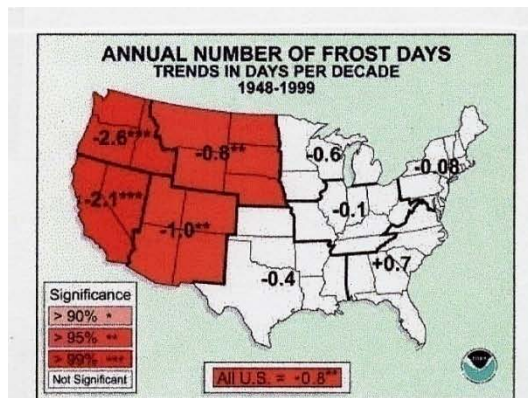
(Meehl, Tebaldi and Nychka, 2004: Changes in frost days in simulations of twentyfirst century *Climate Dynamics*, 23, 495--511)

Changes in frost days affect:

- ◆ Range shifts (latitudinal or altitudinal)
- ◆ Change in growing season length
- ◆ Water resources (change in snow melt season)
- ◆ Earlier flowering; emergence of insects; earlier mating; loss of habitat, shorter hibernation



Changes in frost days in the late 20th century show biggest decreases over the western and southwestern U.S. in observations and the model



Future changes in frost days from the climate model show greatest decreases in the western and southwestern U.S., similar to late 20th century

