Avoid the Unmanageable, Manage the Unavoidable

Eight Interdisciplinary Lectures on Climate Change

Charles F. Kennel

Monday Evenings, 5:30-7 pm, Martin Johnson House
Scripps Institution of Oceanography, University of California San Diego

Nov 10: How Climate Change could affect us in the next 50-100 years

Can we infer from today's changes and climate models what tomorrow's world might look like?
Regional weather patterns, water availability, floods, drought, wildfires
Impacts on agriculture, ecology, human disease, regional technical systems

A World New to Human Experience

Can we get a feel for Earth's future from observing today's climate change?
What can be learned from dissecting projections of future climate change?
How adequate are contemporary assessments for adaptation purposes?

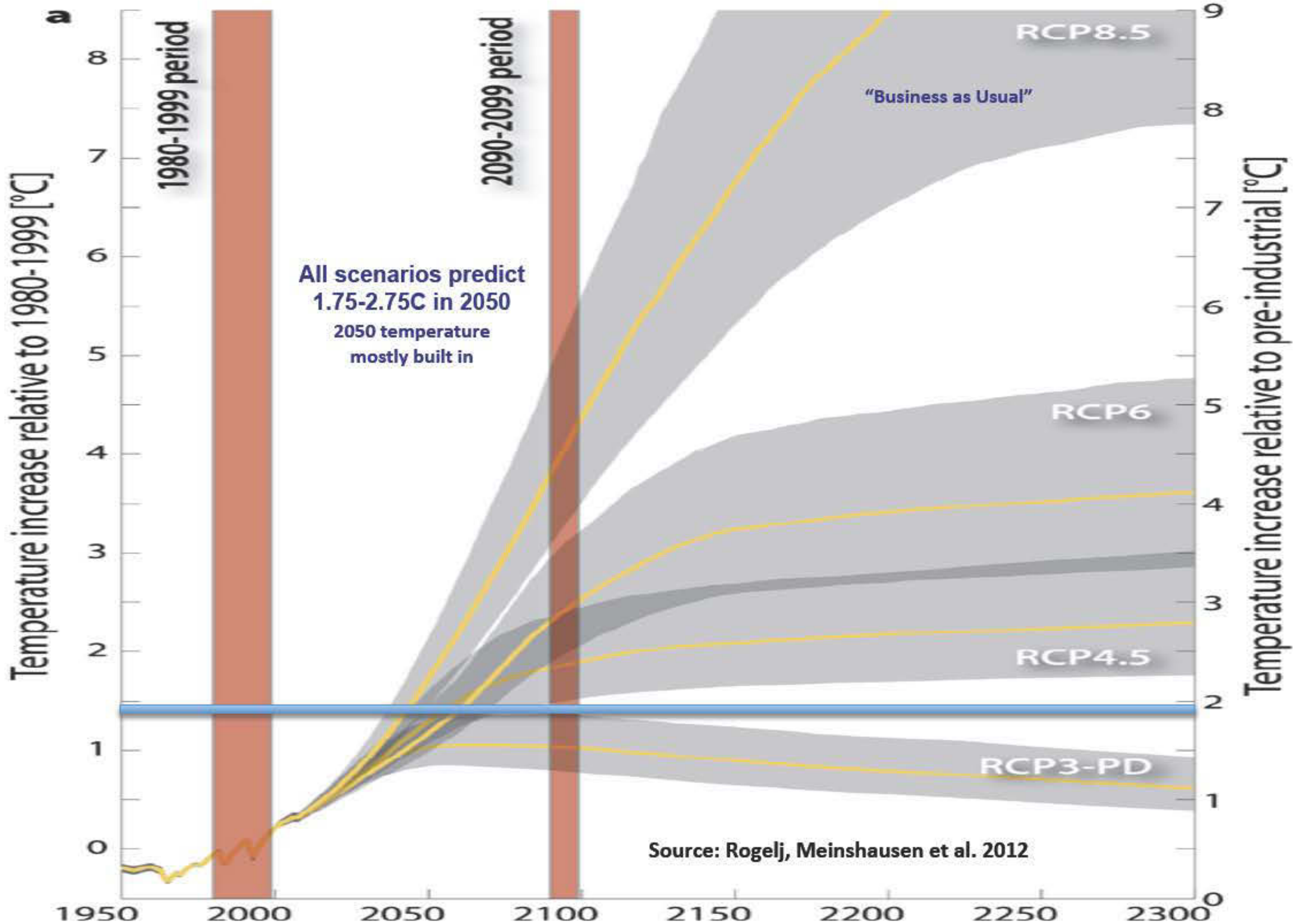
The Past Is *Not* A Guide To The Future

The rate of climate change will double in the next 25 years. We are approaching the time when our empirical experience of the past will be as uncertain a guide to the future as scientific projections. Like it or not, decision-makers will have to rely on them.

That is all there will be.

Alternate Climate Worlds

IPCC AR5 2013 Representative Concentration Pathways



A given global warming potential (W/m2) can be created by different combinations of greenhouse gases, black carbon soot, sulfate aerosols, deforestation, and socio-economic scenarios

Adaptation Knowledge Cascade

Weather and Ocean Patterns

- **Large atmospheric systems**-equator to pole heat transport, polar vortex, atmospheric rivers,…
- **Ocean circulation**-El Nino/La Nina, Pacific Decadal Oscillation, Gulf Stream…
- **Regional characteristics**- temperature, wind, rainfall, relative sea level…
- **Extreme events**-heat waves, cold snaps, storms, droughts, floods,...

Regional Geophysical Systems

- **Cryosphere**-Sea ice, Greenland, Antarctic, mountain glaciers and snows, permafrost…
- **Mountains and Watersheds**-river networks, aquifers, deltas, sediment transport…
- **Deserts**-dust transport,…

Regional Ecosystems

- **Biodiversity**: species distributions and abundances…
- **Biomes**- chaparral, grassland, savannah, forest, tundra, marshlands, coastal zones…
- **Habitats**-invasive species, fragmentation,..

Regional Technical Systems

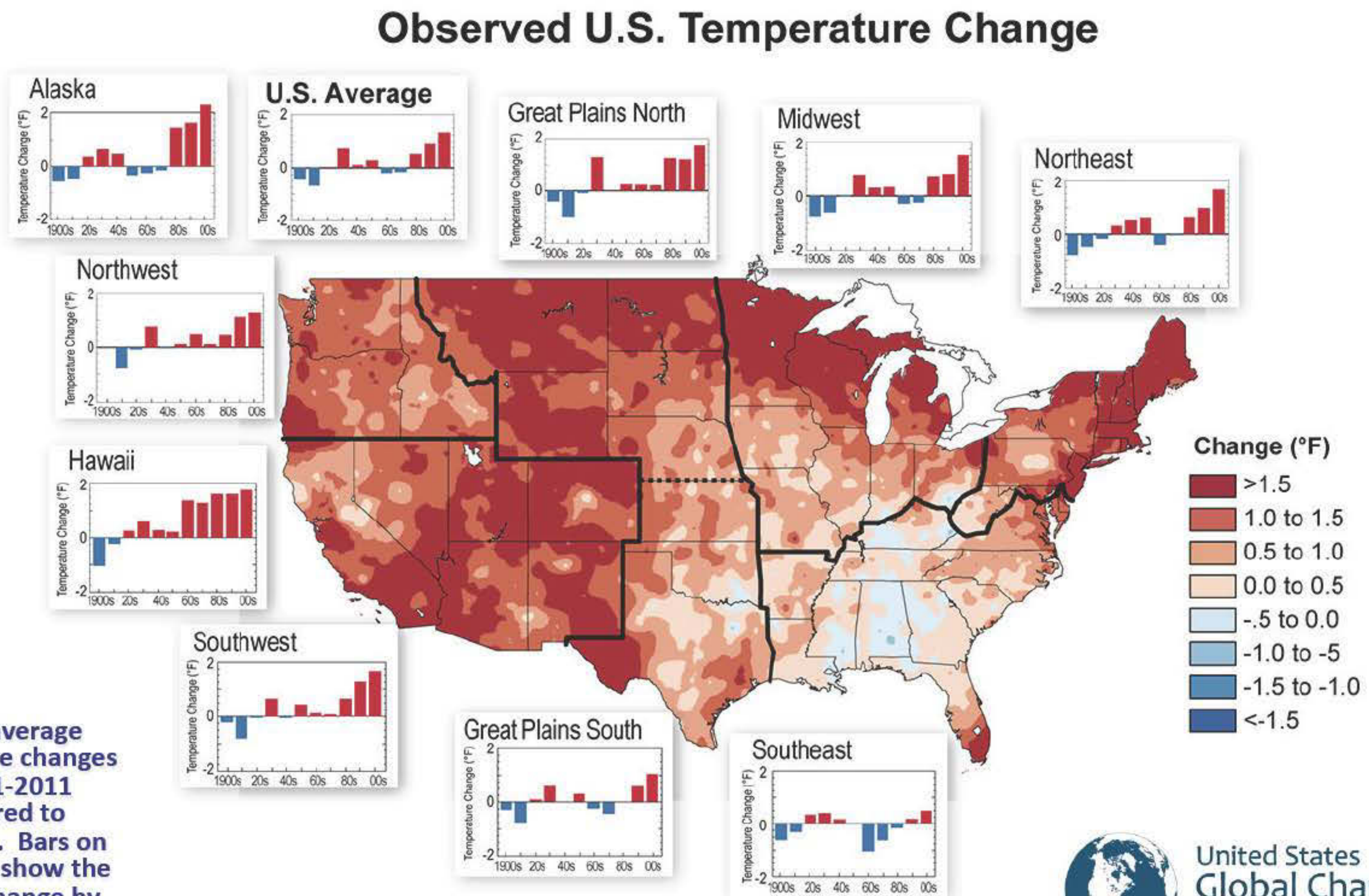
- **Managed Ecosystems**-Agriculture, forestry, fisheries…
- **Managed Water and Air Supplies**-Irrigation, pollution,..
- **Managed Extreme Events**-Disaster response and civil infrastructure…
- **Managed Human Services**-Electricity production and transmission,…

Humans

- **Health**-Malaria, cholera, respiratory diseases, …
- **Security**-Food, water, and energy, environmental conflict, migration
- **Economics**-Industries, trade, investment
- **Welfare**-Socio-Economic Development

US Annual Average Temperature

2001-2011 was warmer than any 20th century decade in every region
Different regions warmed at different rates, the Southeast hardly at all



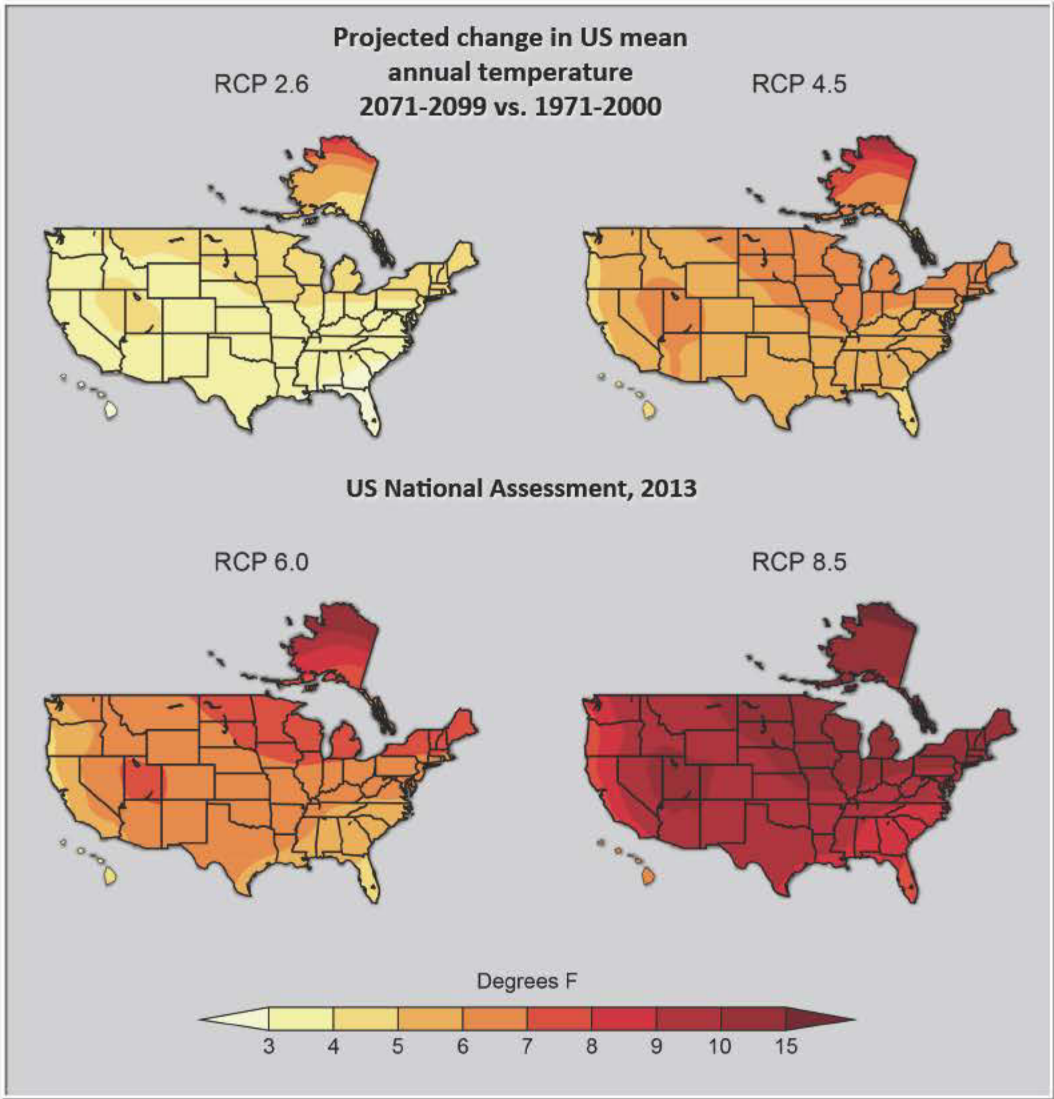
Annual average temperature changes for 1991-2011 compared to 1901-1960. Bars on the graphs show the average change by decade.
US National Climate Assessment, 2013

United States Global Change Research Program

US Mean Annual Temperature in 2100

No cooling anywhere in any model; at least 8deg F warming everywhere in RCP 8.5

70% reduction in emissions between now and 2050



Business as usual

Warmest and coldest days especially likely to be warmer

Very rare cold and hot days defined to have a 5% chance of occurring during any given year

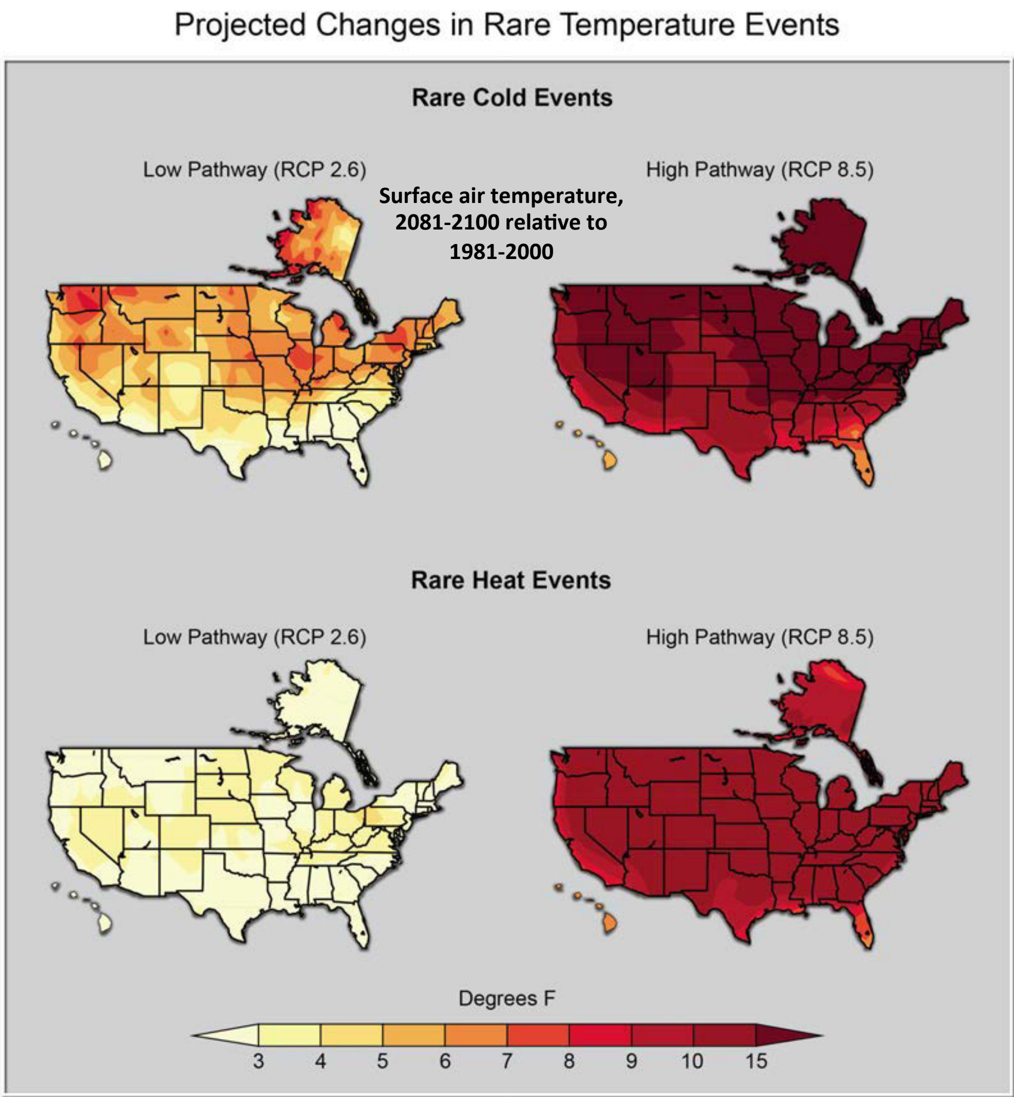


Figure source: NOAA NCDC / CICS-NC. Data from CMIP5; analysis by Michael Wehner, LBNL; based on method from Kharin et al. submitted
US National Climate Assessment, 2013

The temperature increases on both very cold days and very hot days exceed those projected for the average temperature.

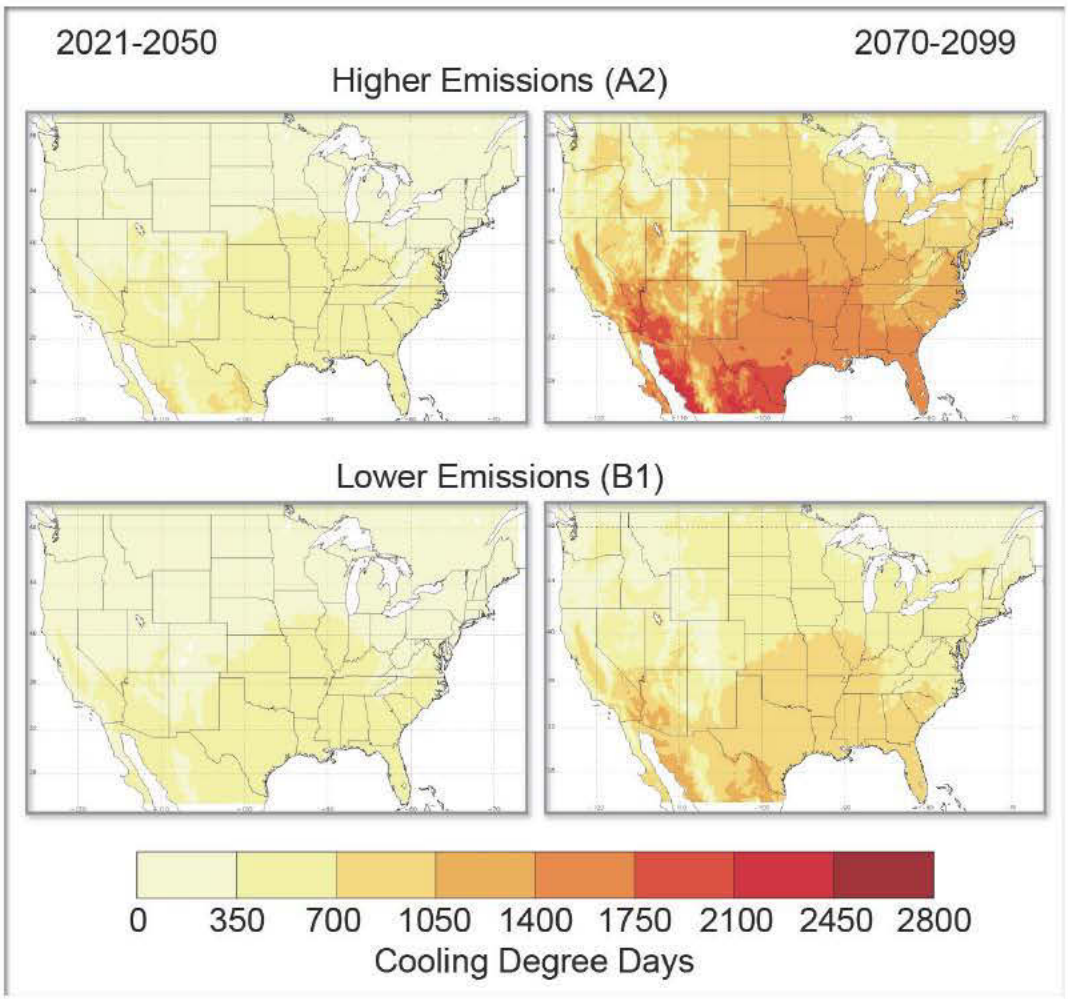
The good news: The largest increases will be on rare cold days-bitter cold winter days will be much less frequent across most of the U.S.

The bad news: The hottest days will be even hotter

The Human Comfort Zone

Plants and animals cannot modify the temperature to stay in their comfort zone

Increasing Numbers of Cooling Degree Days



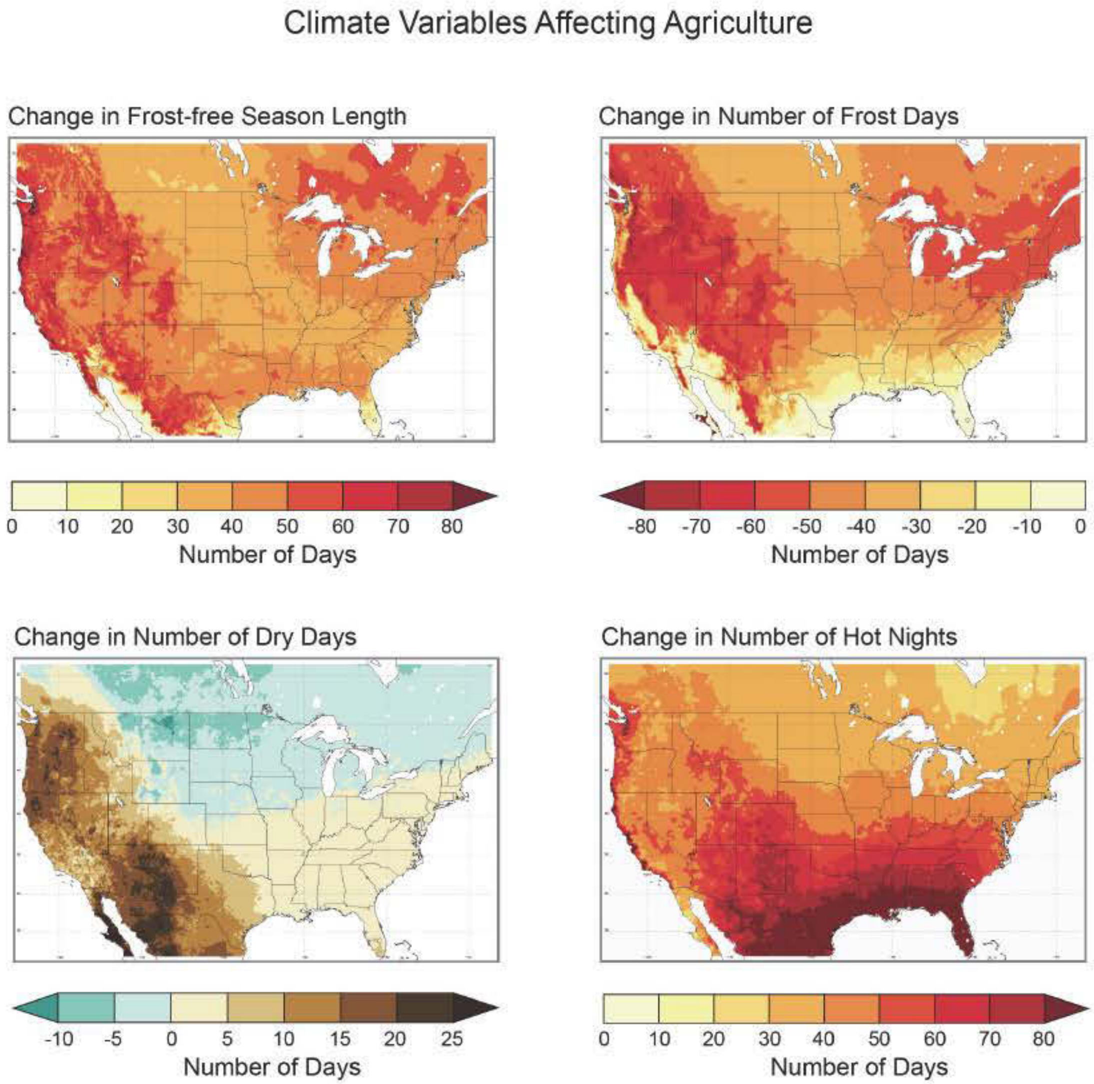
Projected average changes in cooling degree days per year compared to 1971-2000 for 2021-2050 and 2070-2099, assuming business as usual (A2) and significant mitigation (B1). US National Climate Assessment, 2013

A cooling degree day is the daily average temperature minus 65 degF. A warming degree day is 65 DegF minus the daily average temperature.

The more warming or cooling degree days, the more people tend to use air conditioning or central heating (Kunkel et al. 2012b). These numbers are used to estimate how the temperature affects energy and fossil fuel consumption.

Climate Projections for Agriculture

Business as Usual



The growing season length is defined here as the number of consecutive days whose minimum temperature is above freezing.

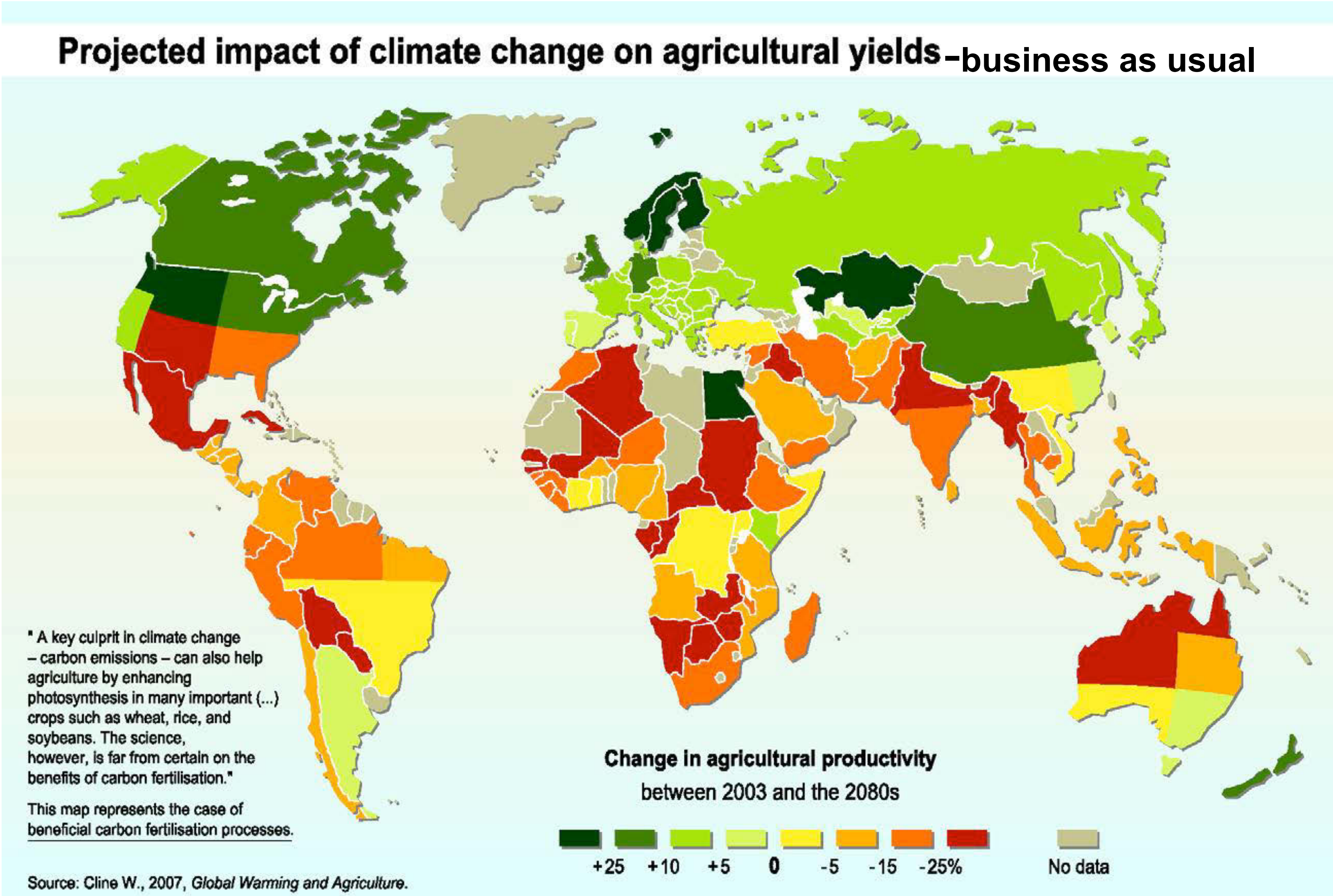
Calculated this way, the average US frost free season in 2001-2011 was about 10 days longer than in 1901-1960. Keeling's atmospheric CO2 measurements show a similar lengthening of the period when Northern Hemisphere vegetation is actually growing.

A longer summer season may create more drying through plant transpiration (and there can be changes in precipitation) so season length is not the only determinant of agricultural productivity.

Lengthening of the growing season and reduction in the number of frost days (days with minimum temperatures below freezing) for 2100, under business as usual (A2). "Hot nights" have minimum temperatures warmer than 90% of the minimum temperatures between 1971 and 1990.(Source: National Climate Assessment, 2013, and Walthall et al. 2012).

Agriculture and Food Security

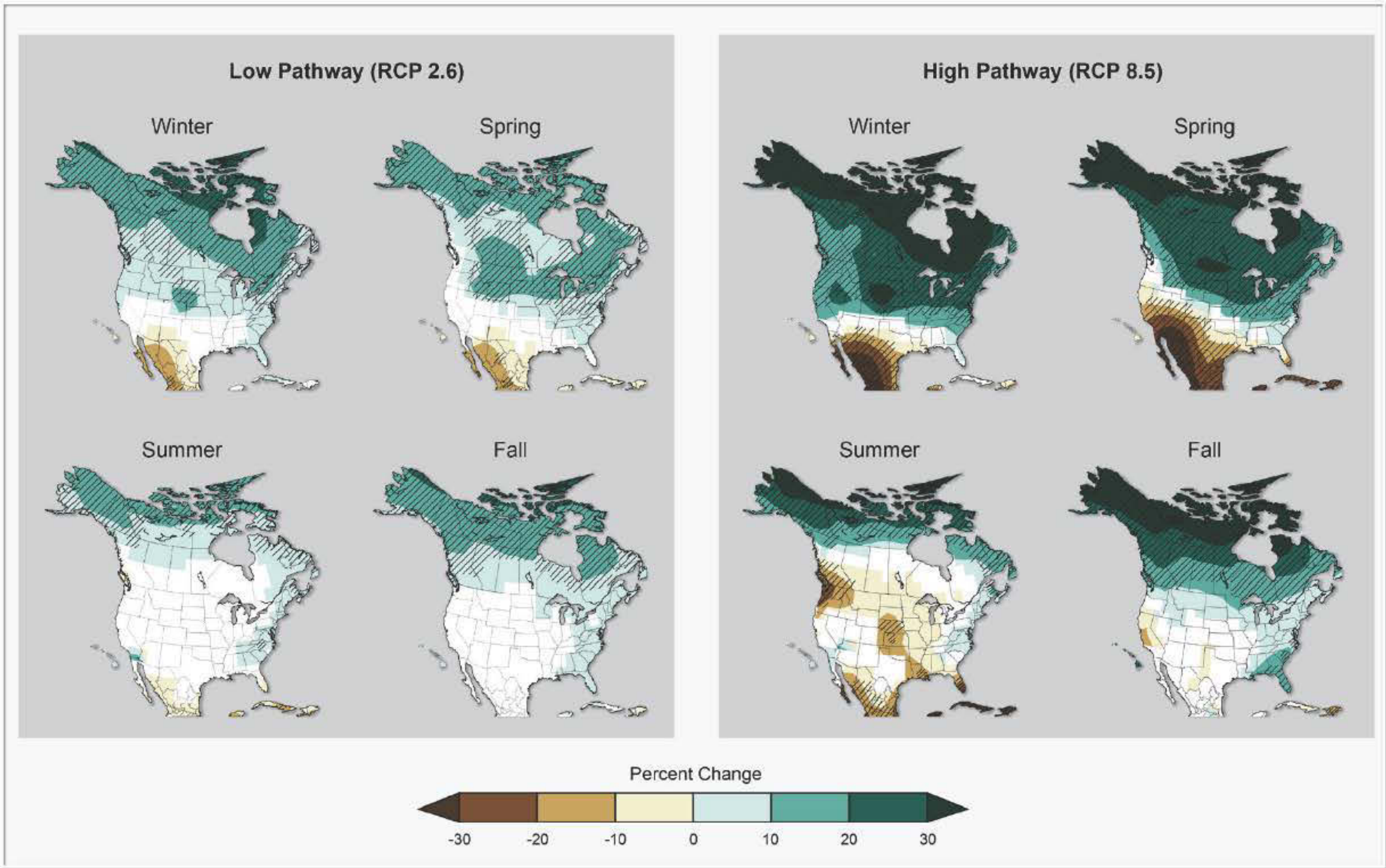
Alexandratos (2009) and Tilman et al. (2011) project a global increase in the demand for crops by about 70-100 percent from 2005 to 2050



Map courtesy of European Environmental Agency, 2010, updated 2012

Northern Regions Will See Largest Precipitation Increase

Precipitation=rainfall + snowfall water equivalent

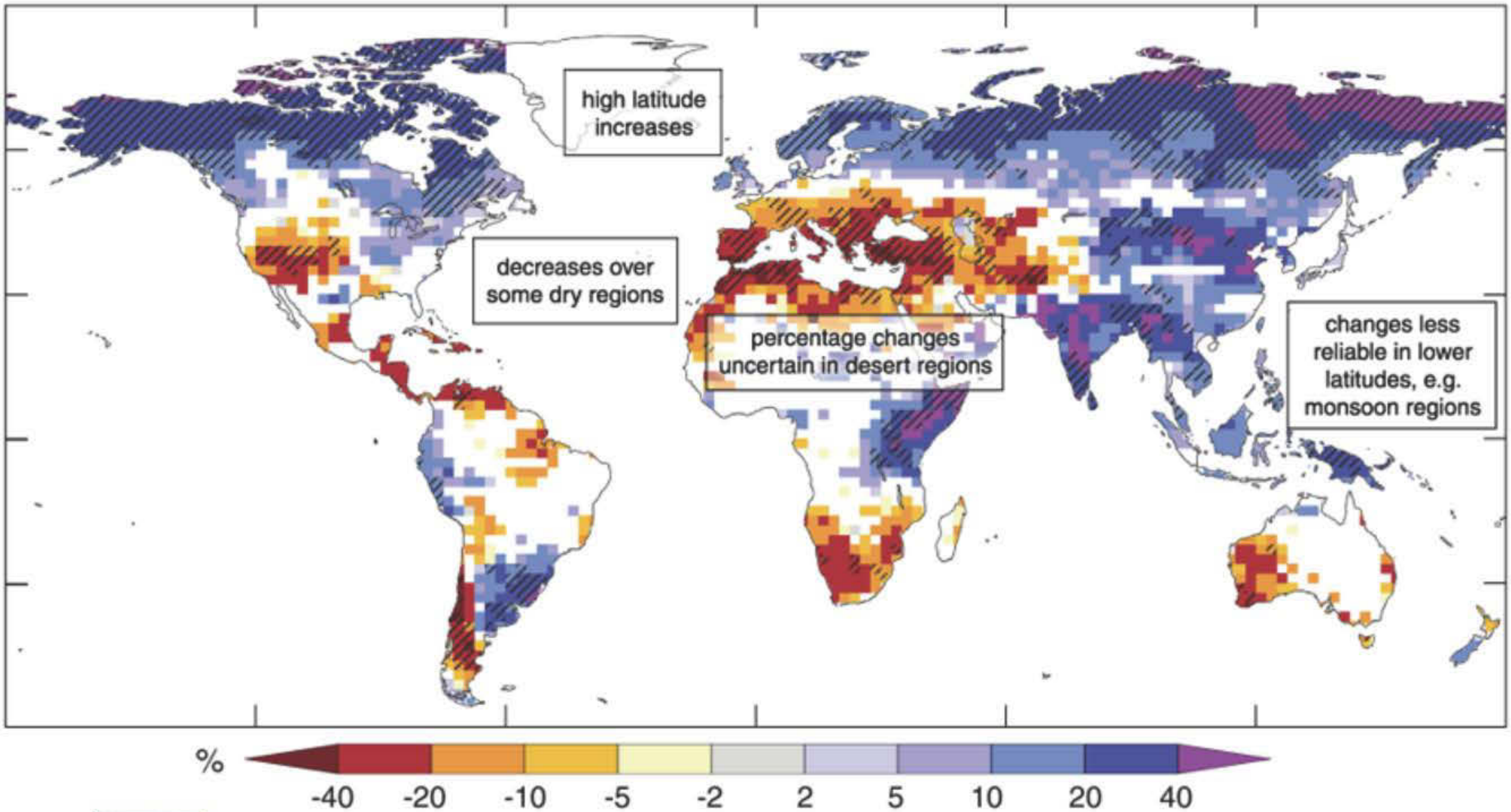


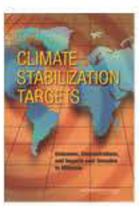
Projected seasonal precipitation change (percent) for 2071-2099 compared to 1901-1960.. Hatched areas indicate confidence that the projected changes are large and are consistently wetter or drier. White areas indicate confidence that the changes are small.

(Figure source: NOAA NCDC / CICS-NC. Data from CMIP5; analyzed by Michael Wehner, LBNL; US National Climate Assessment, 2013)

Wet Regions Wetter, Dry Regions Dryer

Is pattern preserved because GCMs are incremental and do not do well with tipping points?





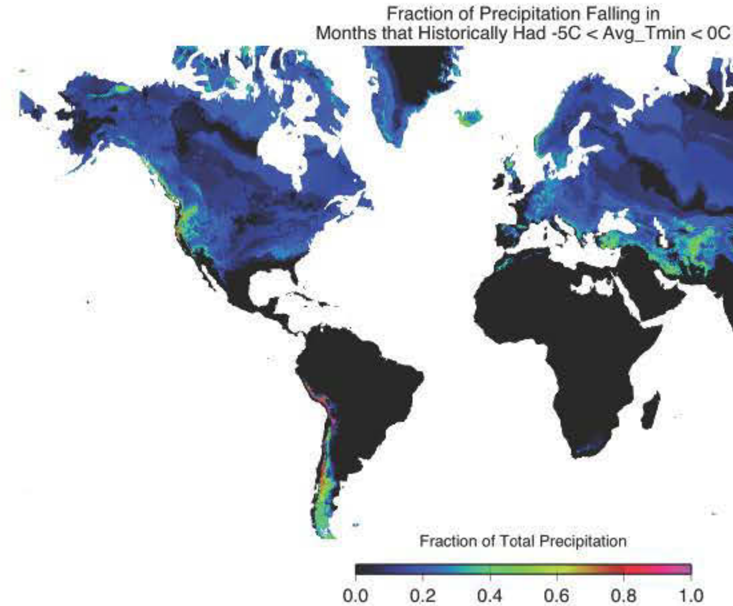
Climate Stabilization Targets: Emissions, Concentrations, and Impacts Over Decades to Millennia, Committee on Stabilization Targets for Atmospheric Greenhouse Gas Concentrations, National Research Council 2010

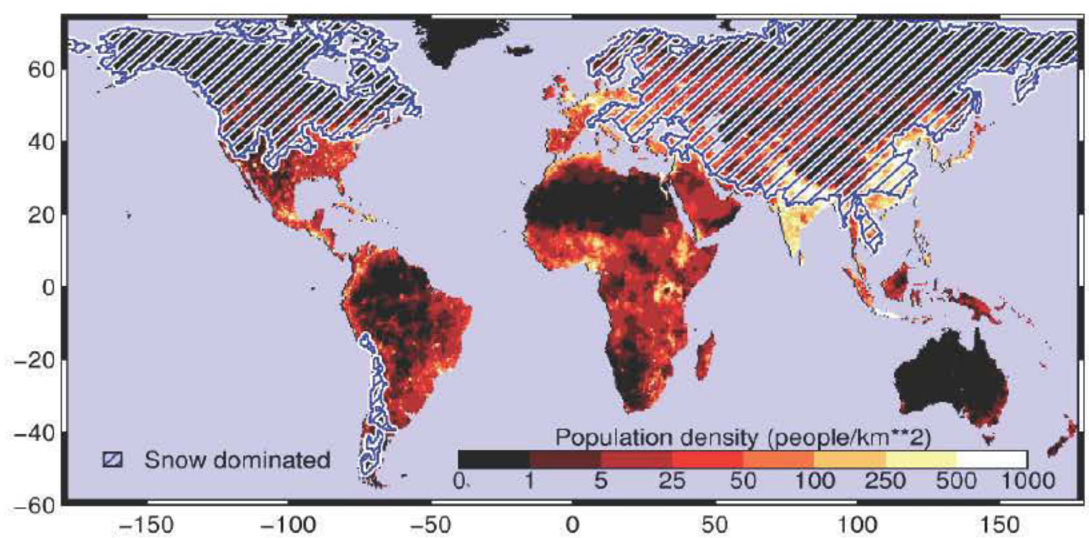
Semi-Arid and Arid Areas

By mid-century, annual average river runoff is projected to decrease by 10-30% over some dry regions at mid-latitudes and in the dry tropics, with consequent large increases in the number of people living in areas of water shortage.

Zbigniew W. Kundzewicz, Review of IPCC 2007 Working Group II, Chapter 3, Royal Geographic Society, 2007

Ice, Snow, and Water





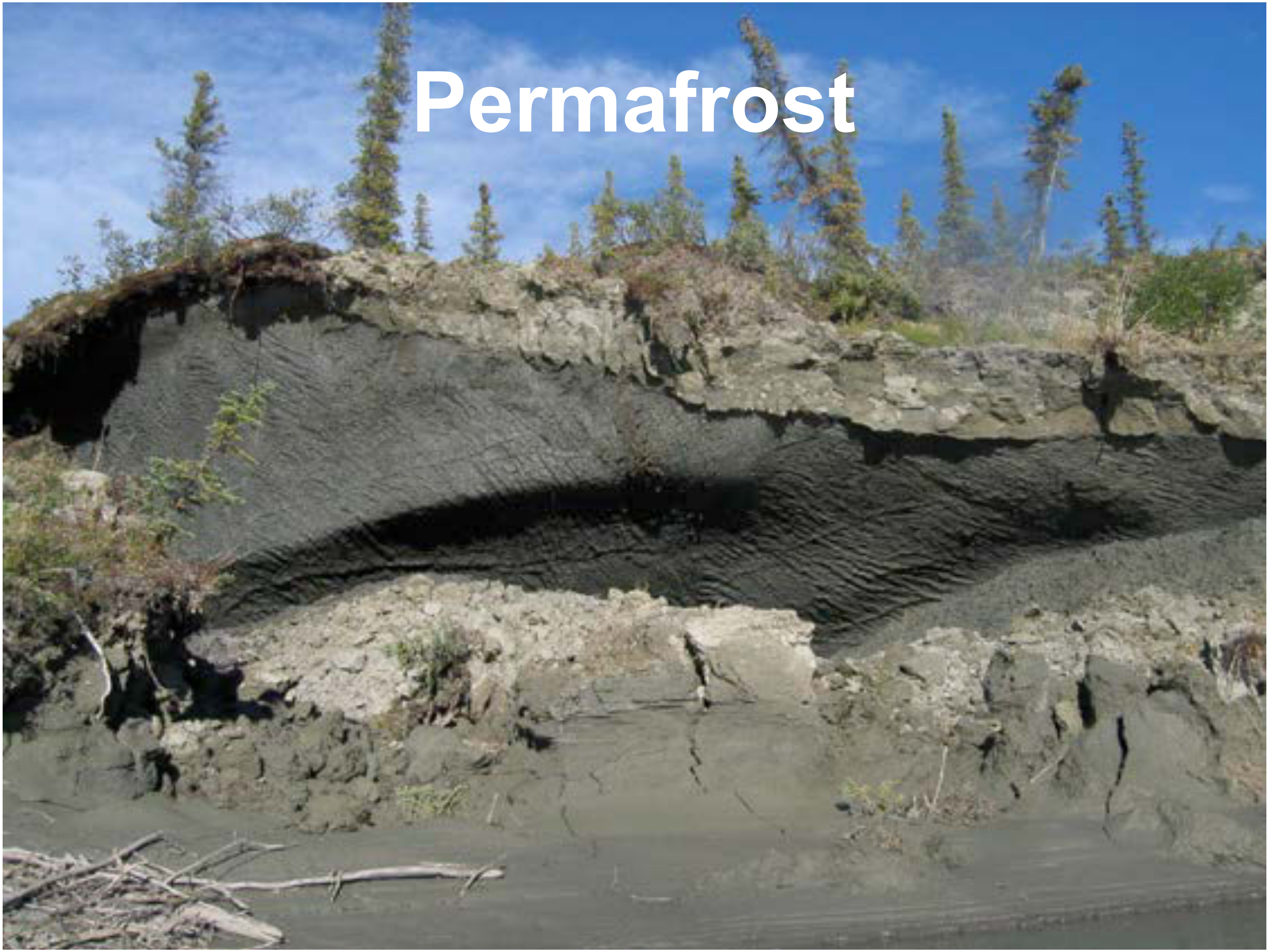
Regions where minimum nighttime temperature is between -5C and 0C. These mountain snows are sensitive to a relatively small regional temperature increase

The 11 largest rivers in Asia have their headwaters in the Himalaya-Hindu Kush

1/6 of the world's population gets some of its water from snowmelt

Barnett, Adam, and Lettenmaier, *Nature*, 2005

Permafrost



Permafrost

Largest part of the Terrestrial Carbon Pool
Twice the Atmospheric Pool

Source: International Permafrost Association, 1998.
Circumpolar Active-Layer Permafrost System (CAPS), version 1.0.

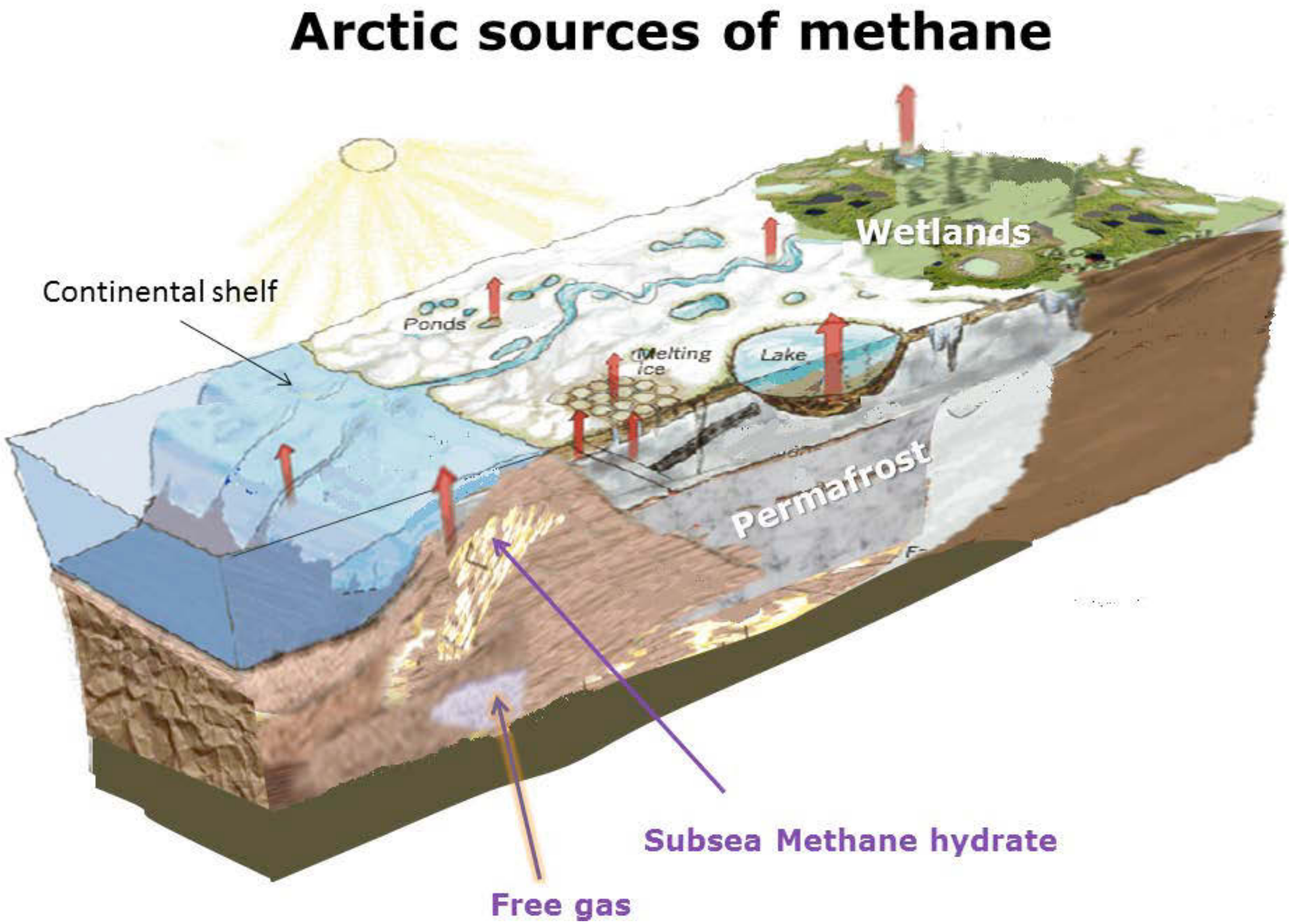
As permafrost thaws, respiration of organic matter within these soils could transfer carbon to the atmosphere. IPCC AR5 is ambivalent.

Significant contribution to climate warming from the permafrost carbon feedback, A. H. MacDougall, C. A. Avis & A. J. Weaver
Nature Geoscience 5, **719–721 (2012), doi:10.1038/ngeo1573**

Possible Tipping Point

Will Arctic Warming release methane to the atmosphere?

On per-molecule basis, methane = 23xCO2



Methane Seeps

Land

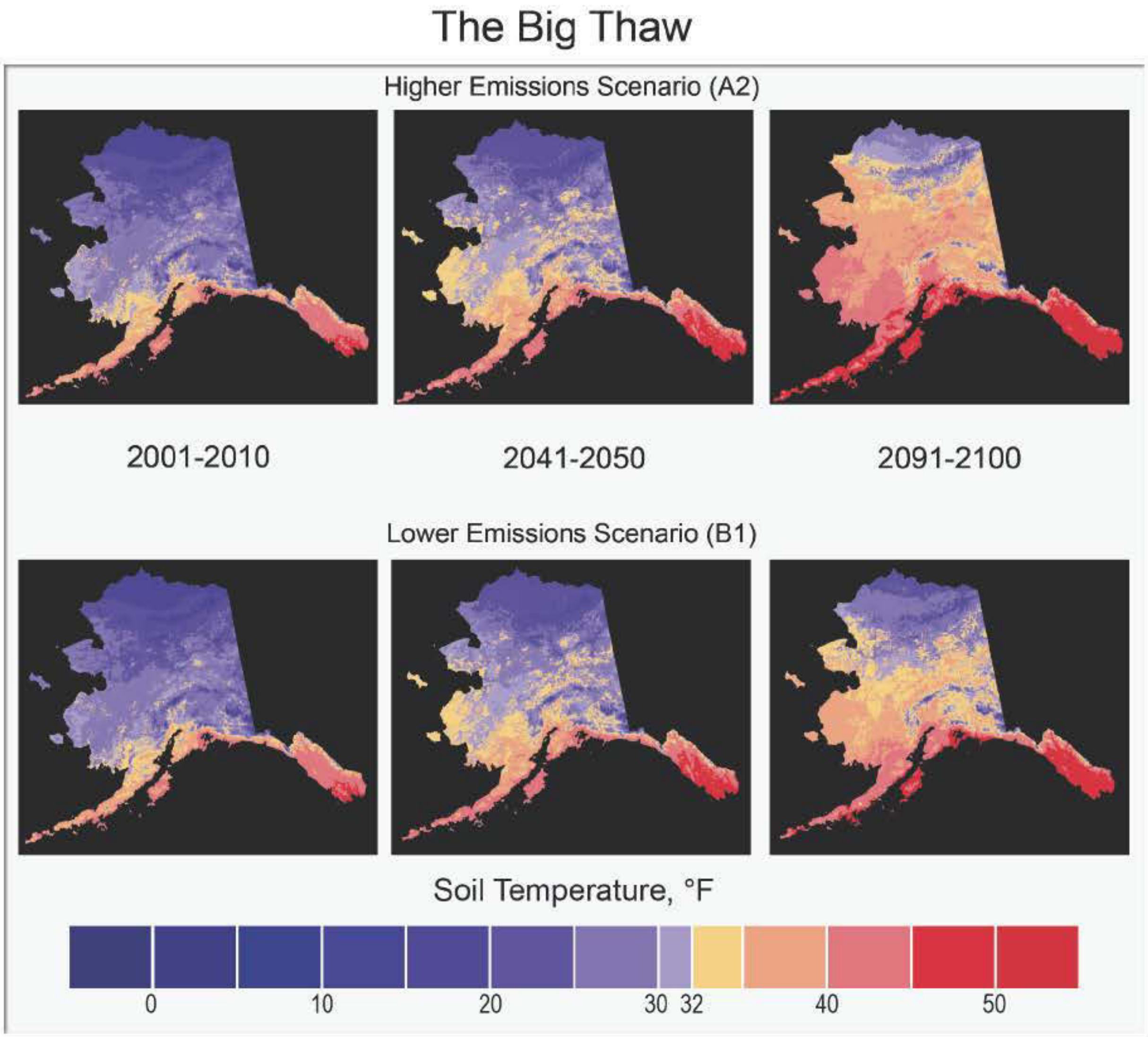
Walter-Anthony, *et al*, Geologic methane seeps along boundaries of Arctic permafrost thaw and melting glaciers, *Nature Geoscience,* 2012, doi: 10.1038/ngoe1480

Undersea

Shakhova, N., *et al,* Ebullition and storm-induced methane release from East Siberian Arctic Shelf, *Nature Geoscience, 7,* 64-70, 2014 doi: 10.1038/ngeo2007

Alaska Permafrost Melt Projections

Vigilance=Monitoring: Know in advance whether a tipping point is approaching
"Vigilance, Not Panic", *Global Change, 79,* IGBP, October 2012

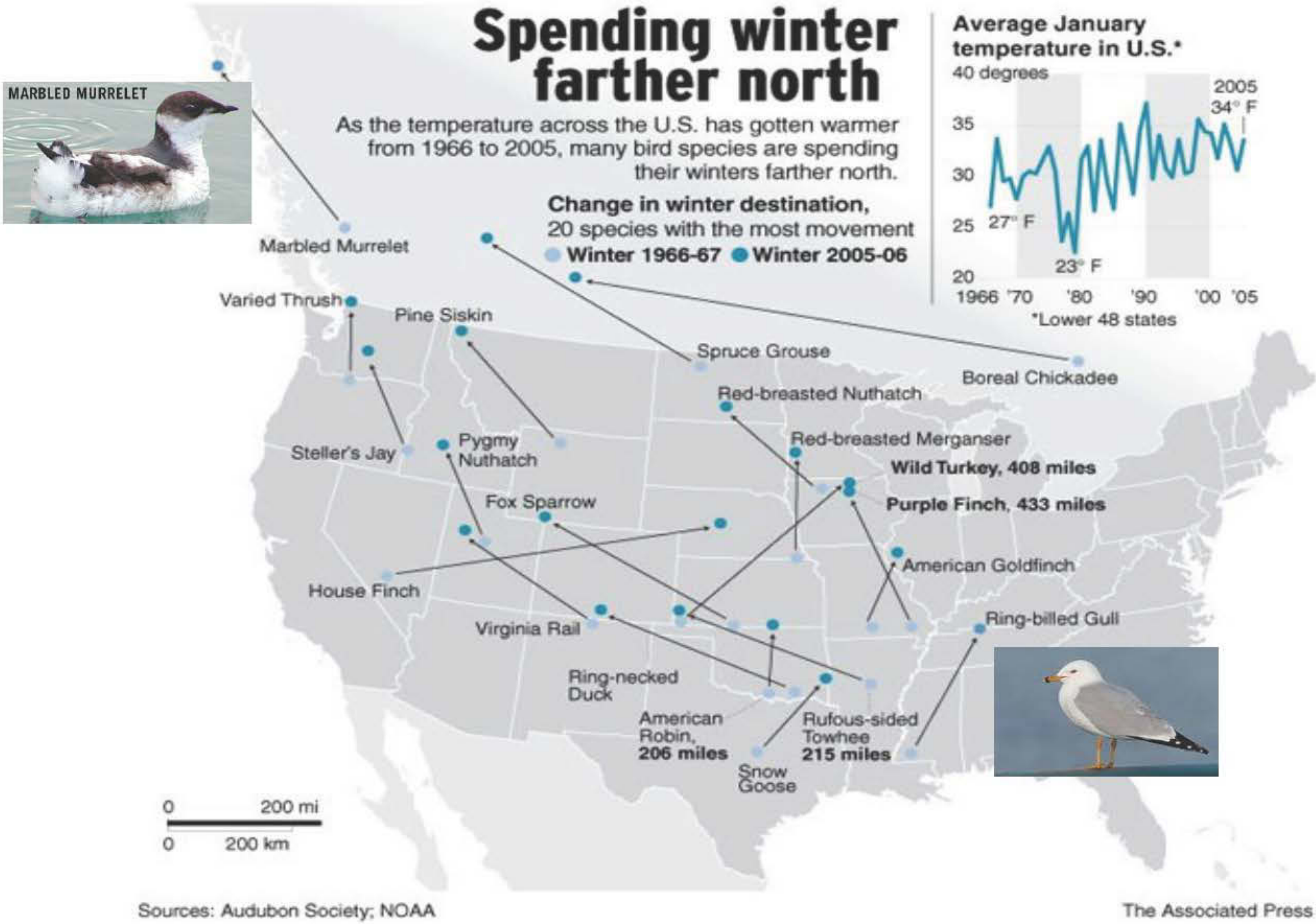


Projections for average annual ground temperature at 3.3-foot (one-meter) depth over time. Blue shades represent areas below freezing (where permafrost is present at the surface), and yellow and red shades represent areas above freezing (permafrost-free at the surface) (Markon et al. 2012).

Ecosystems

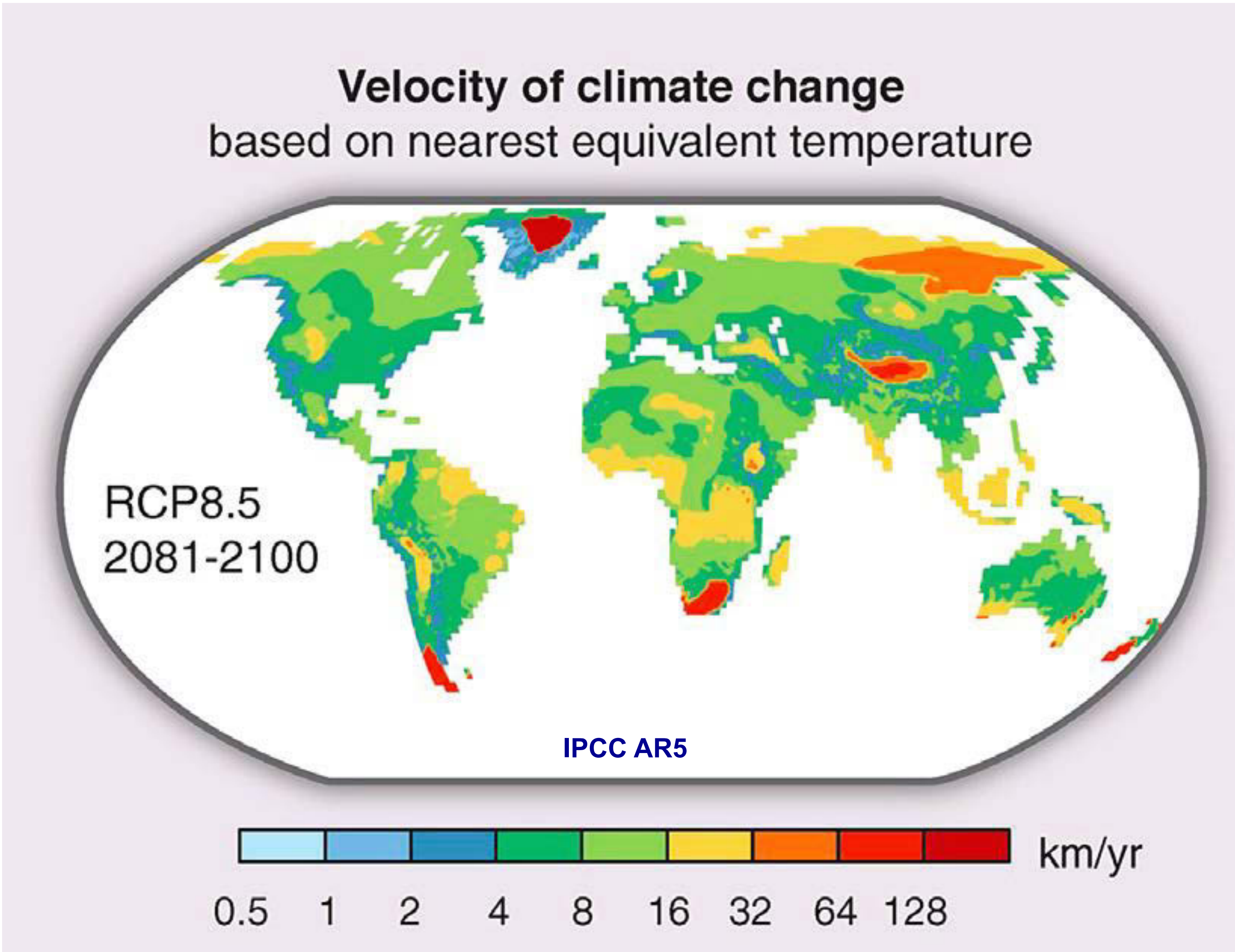
Species change their range to stay in their comfort zone

As did human hunter-gatherers before the agricultural revolution



Velocity Of Climate Change

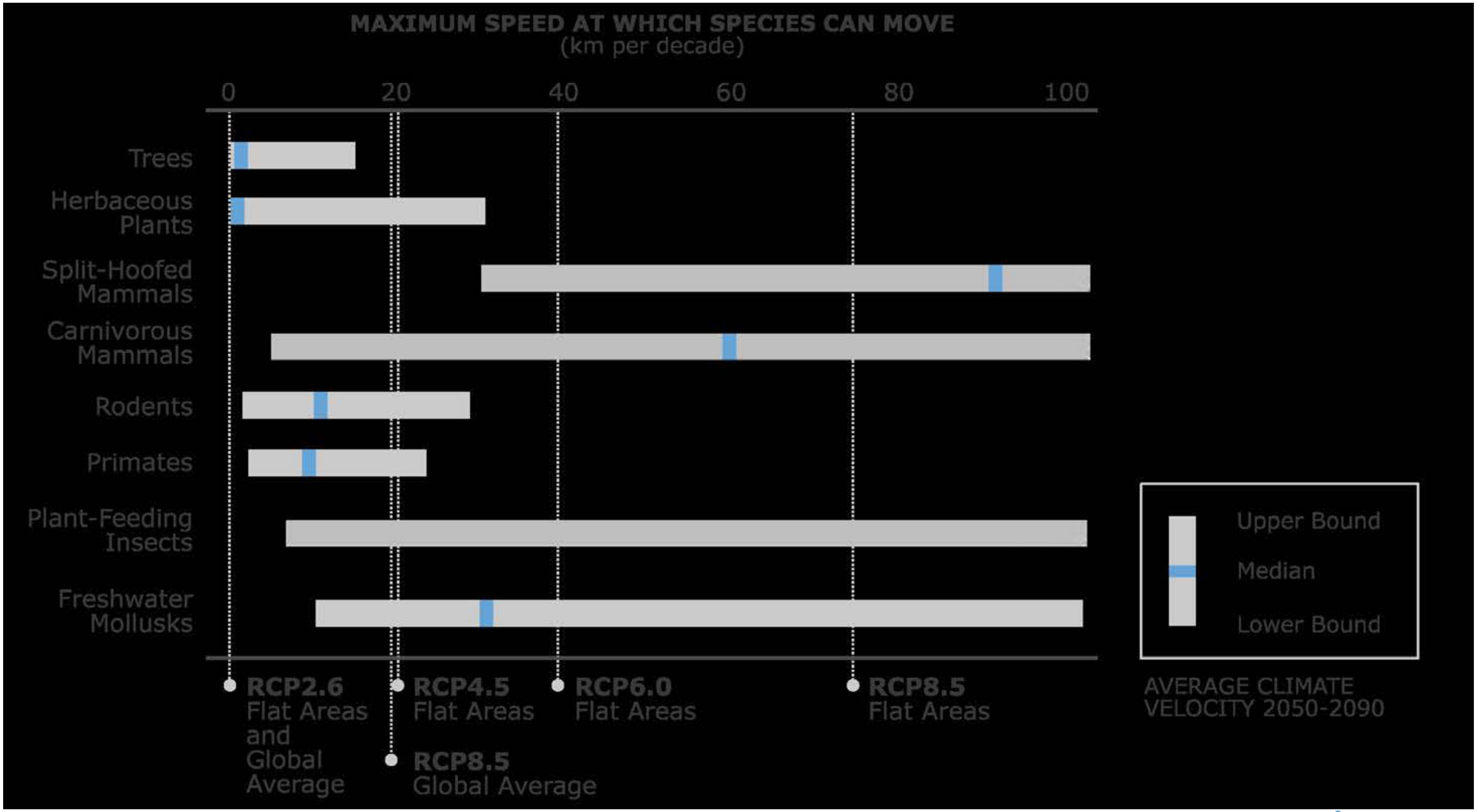
The velocity is calculated by identifying the closest location (to each grid point) with a future annual temperature similar to the baseline annual temperature.



Capacity for Adaptation by Migration

Displacement speeds of mean annual temperature, per degC:

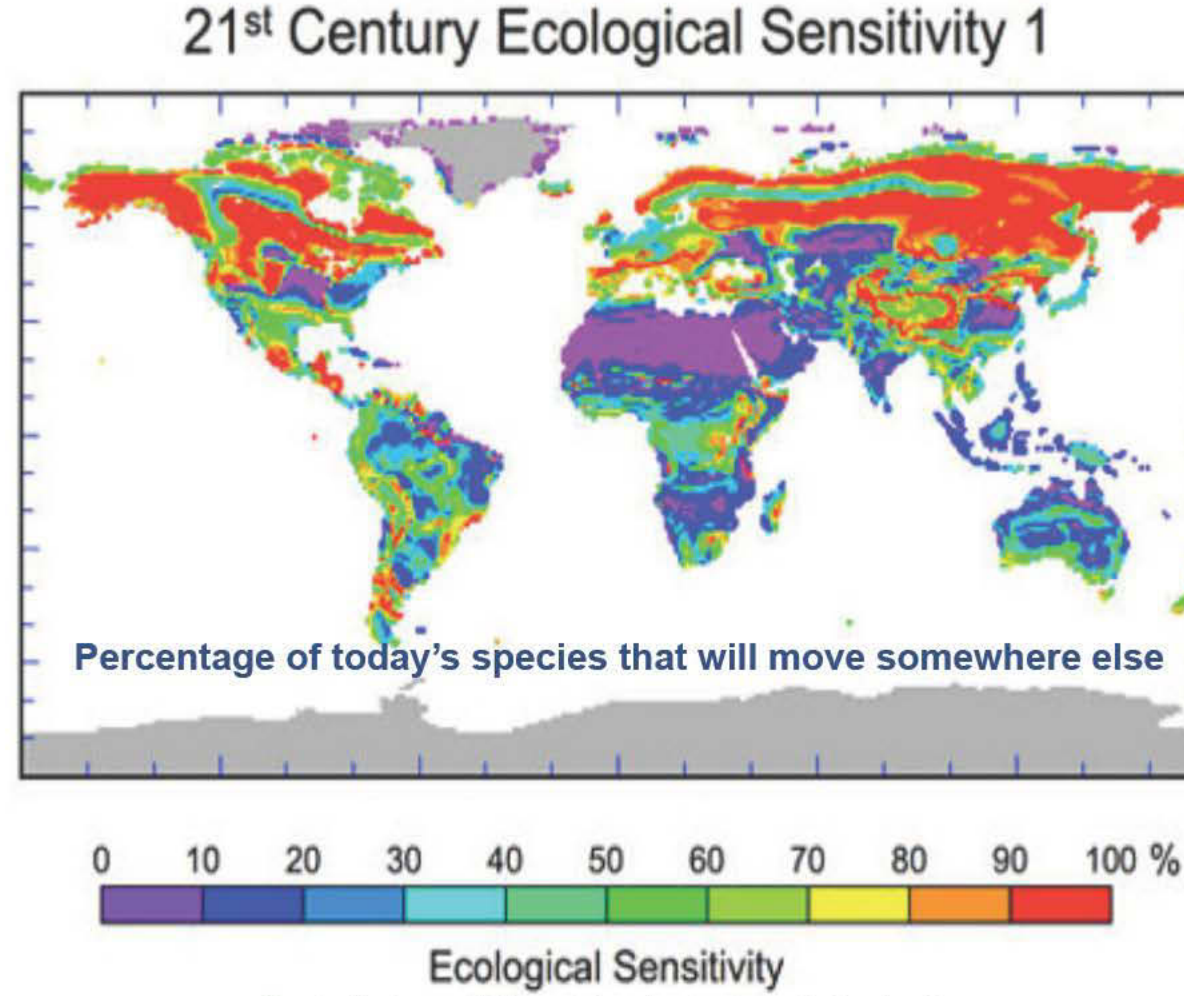
Mountain areas, 3.8 km/decade; global average, 30 km/decade; flat areas, 110 km/decade



INTERGOVERNMENTAL PANEL ON climate change

Turnover in Plant Distribution

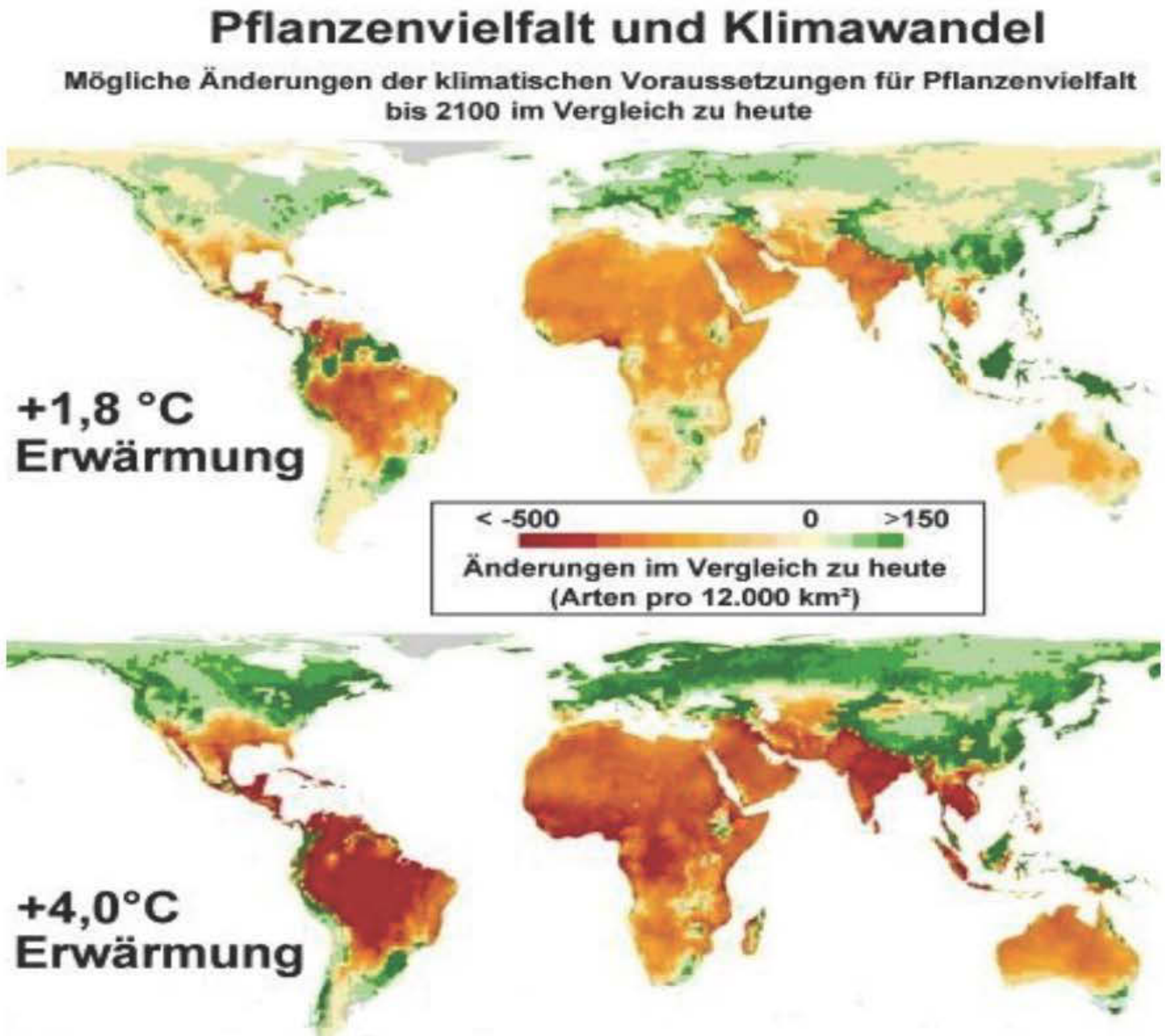
Equilibrium vegetation models assume ecological processes come into balance
Results tell you to expect change but do not describe new ecosystems
In the red zones, every species an invasive species



Ecological sensitivity: a biospheric view of climate change
Jon C. Bergengren, Duane E. Waliser and Yuk L. Yung
Climatic Change Volume 107, Numbers 3-4, 433-457, DOI: 10.1007/s10584-011-0065-1

Species Diversity

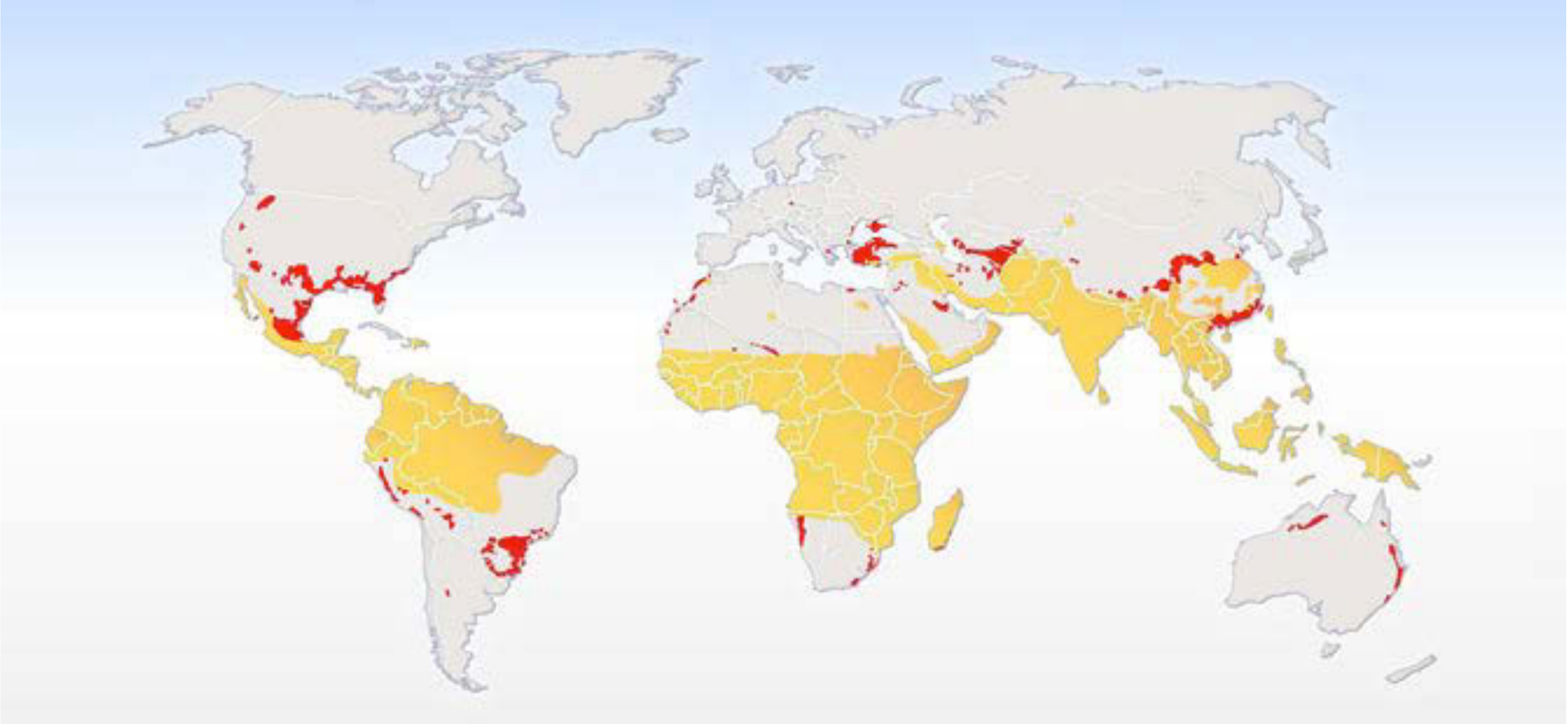
Plant species richness models assume ecological processes equilibrate



Sommer, J.H., et al. (2010). Projected impacts of climate change on Regional Capacities for global plant species Richness. Proceedings of the Royal Society B: Biological Sciences, published online March 24. DOI: 10.1098/rspb.2010

Vector-Borne Diseases

Malaria the classic example



Distribution of the primary Malaria agent

Current distribution

Possible extended distribution by 2050 (suitable climate)

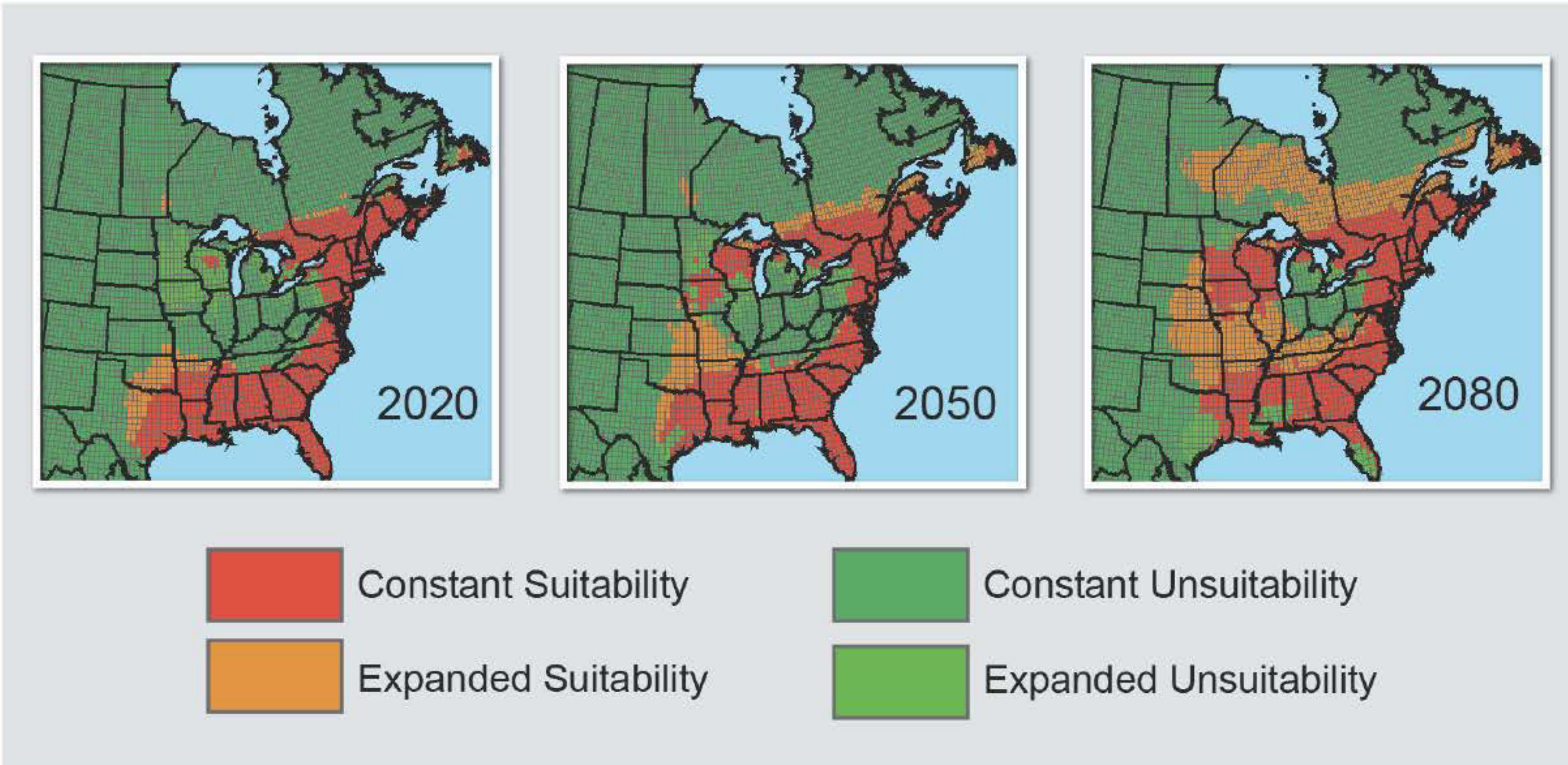
Current distribution, represents maximum extent of the distribution of the *falciparum* Malaria parasite. For 2050, areas within the current maximum extent has been excluded from the map.

The scenario is based on the high scenario from the HadCM2 experiment.

Source: Rogers. Randolph. *The Global Spread of Malaria in a Future, Warmer World*. Science (2000: 1763-1766).

Lyme Disease

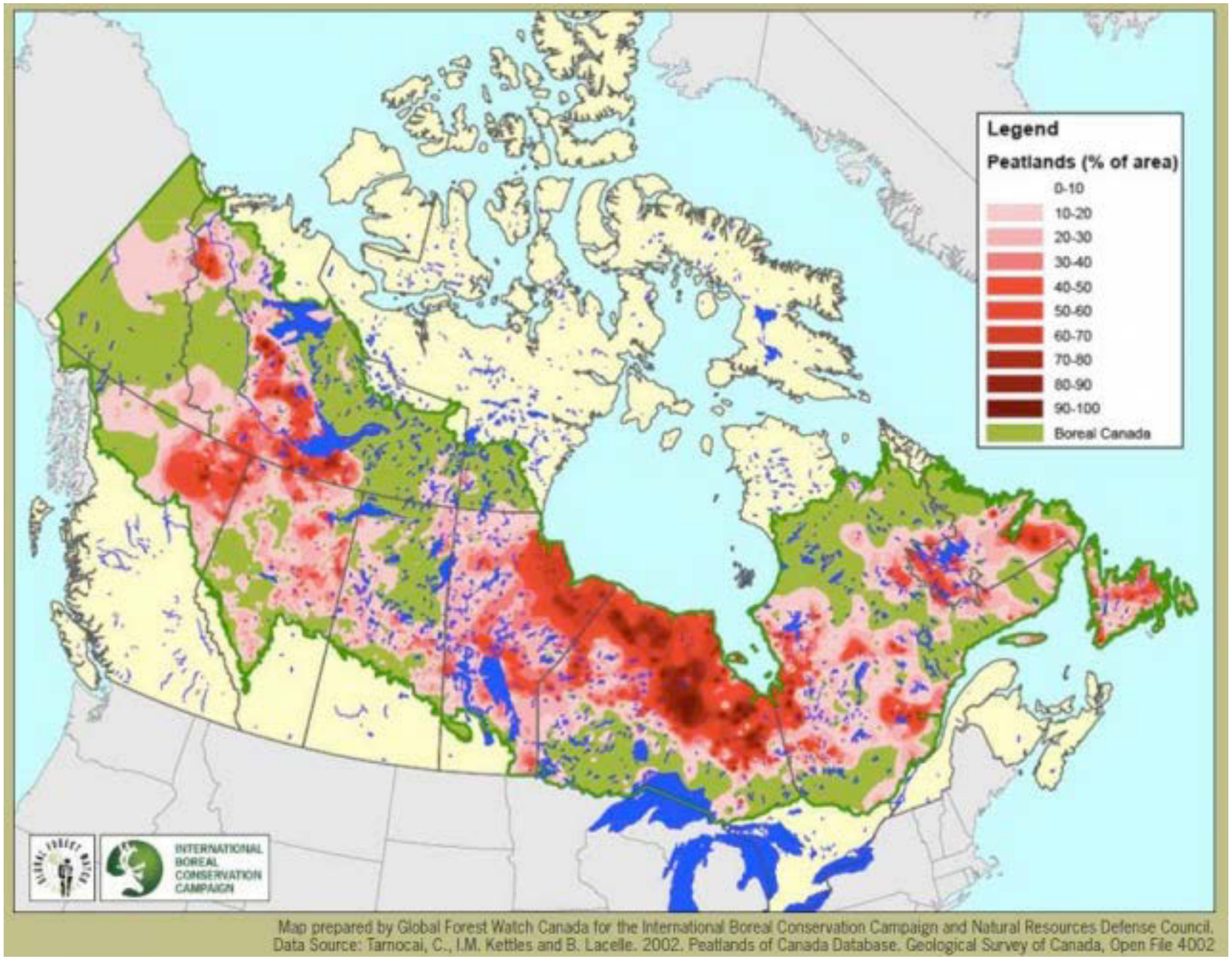
Changes in Tick Habitat



Projected change in habitat for the tick that transmits Lyme disease for the 2020s, 2050s, and 2080s. The areas in orange are projected to be newly suitable habitat for the tick, with this expansion including Illinois, Kentucky, West Virginia, Tennessee, Arkansas, Missouri, Oklahoma, Kansas, and Nebraska by 2080. Parts of Florida, Mississippi, and Texas are projected to see a reduction in habitat by 2080 (Ogden et al. 2008; US National Climate Assessment, 2013).

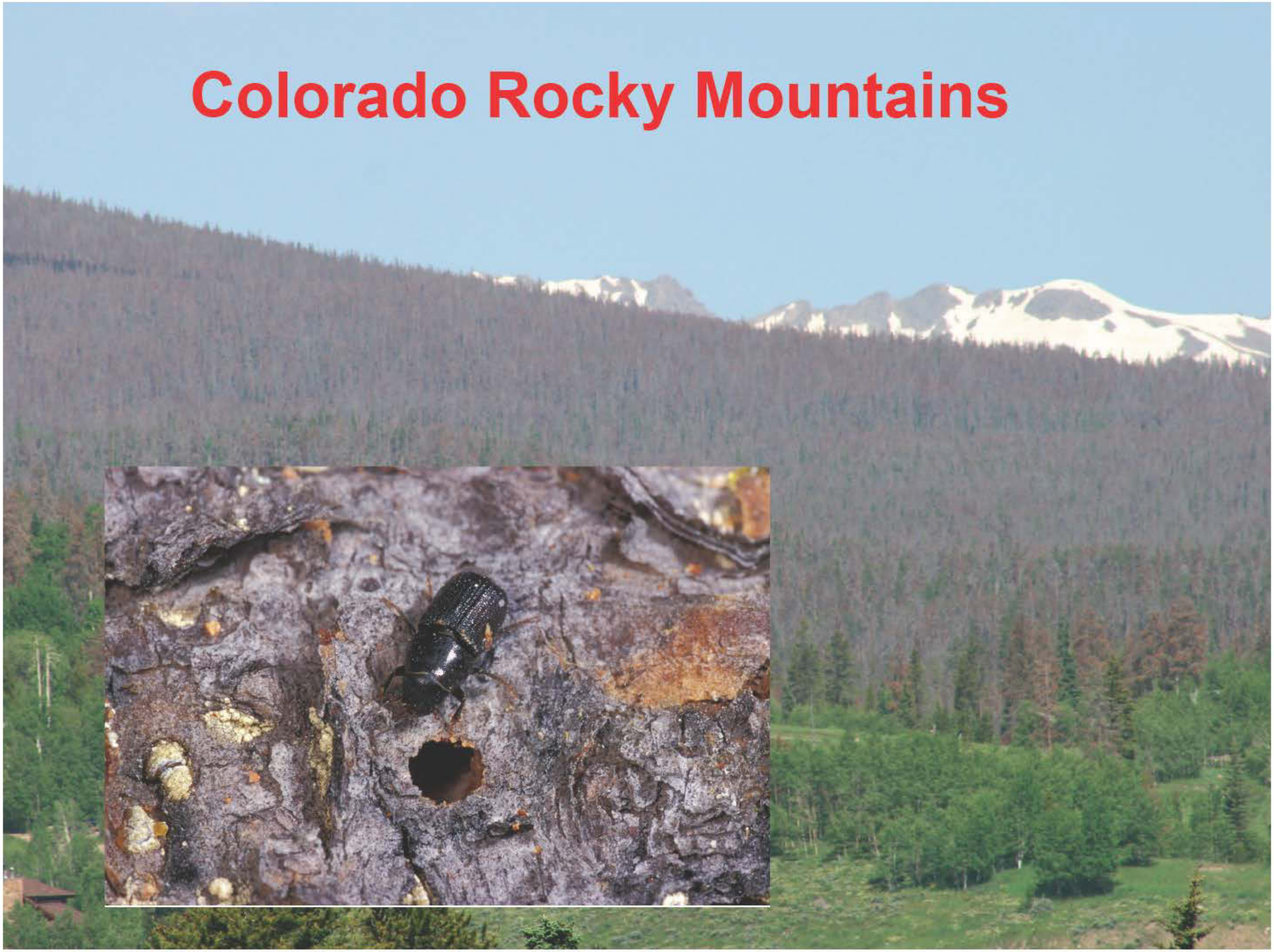
Canada's Boreal Forests

Seasonal patterns of temperature, precipitation, and drying but also soil ecology, pests,…



The 1.2 billion acre Canadian boreal forest is the largest intact forest and wetland ecosystem remaining on earth. Rivaling the Amazon in size and ecological importance, Canada's boreal supports the world's most extensive network of pure lakes, rivers and wetlands and captures and stores twice as much carbon as tropical forests. It teems with wildlife—including billions of migratory songbirds, tens of millions of ducks and geese, and millions of caribou.


Pine Bark Beetle
In winter, temperatures must be below -35 to -40 C (-31 to -40 F) for several straight days to kill off large portions of beetle larvae. In the early fall or late spring, sustained temperatures of -25 Celsius (-13 F) freeze mountain pine beetle populations to death.
Since 2003, fires and tree death from pine bark beetle have turned 150,000 acres into a source rather than a sink of CO2 emissions.


Colorado Rocky Mountains

Extreme Weather Events

Low Probability/High Impact, “Long-Tail” Events

People do not experience annual average temperature, they can recollect the average summer temperature, but they really notice weather events. When conspicuous, such events temporarily mobilize the will to act.

Extreme events have large secondary impacts on ecosystems and society. Repeated often enough, they lead to ecological changes that are hard to reverse and increasing stress on society.

Our present focus on adaptation requires that we pay attention to extreme events.

Extreme Weather Events-Attribution

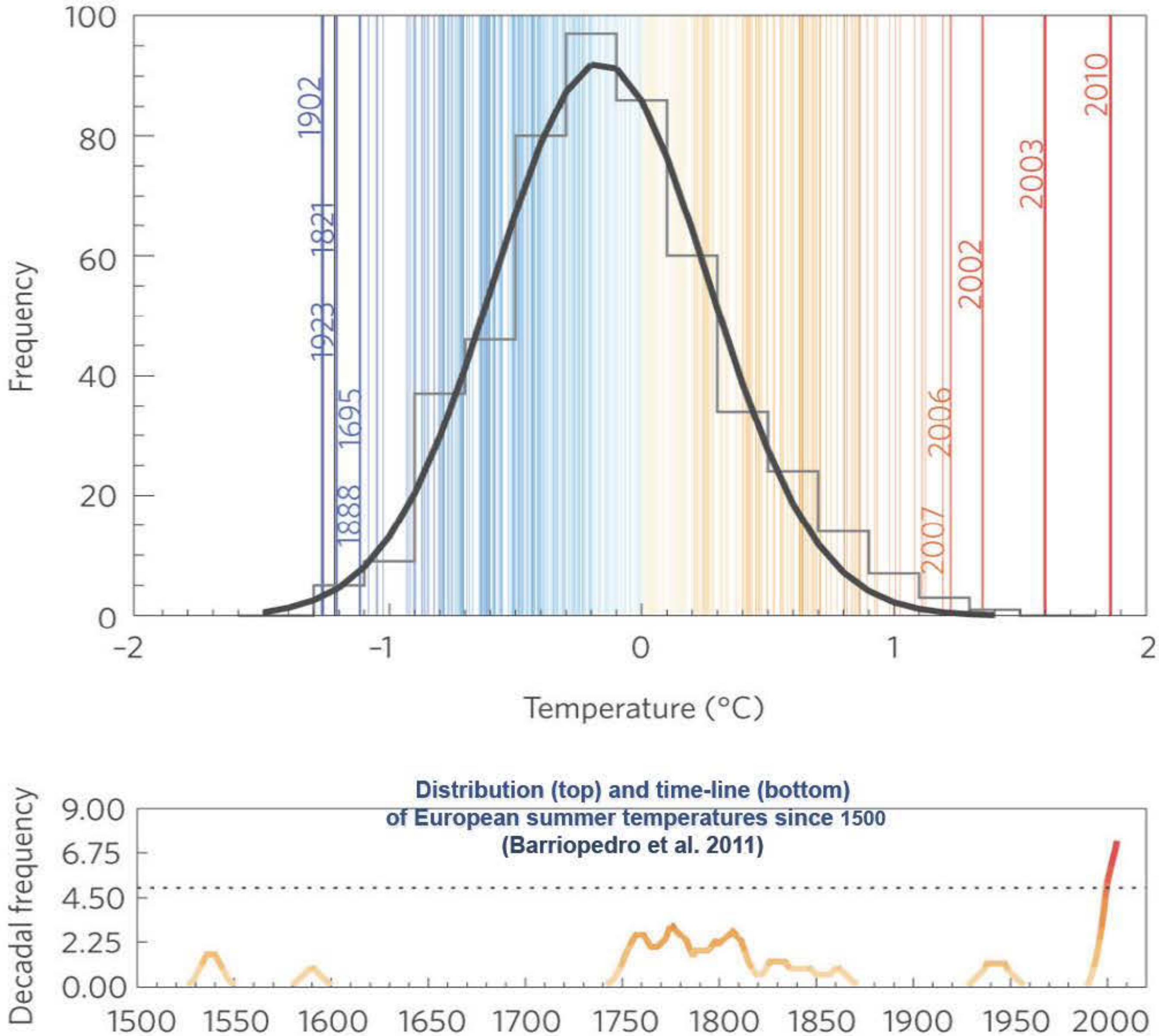
No single extreme event has yet been linked rigorously to human-caused climate change. Extreme events are adventitious outcomes of intersecting causes, "perfect storms". The concatenation of causes, each probabilistic, would have to be sewn up by extremely laborious hierarchical Bayesian computations.

A secular change in pattern and intensity would be an indicator. This search has been a major preoccupation of climate assessments to date. Only the extreme events familiar from previous experience have been considered. No new types have emerged. If a new type occurred, it would suggest a climate tipping point had arrived.

Extreme European Summers

Turn Down The Heat! The World at 4C

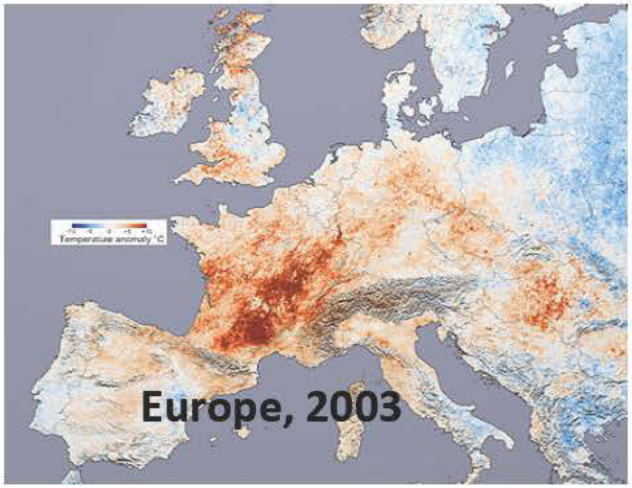
World Bank-Potsdam Institute for Climate Research

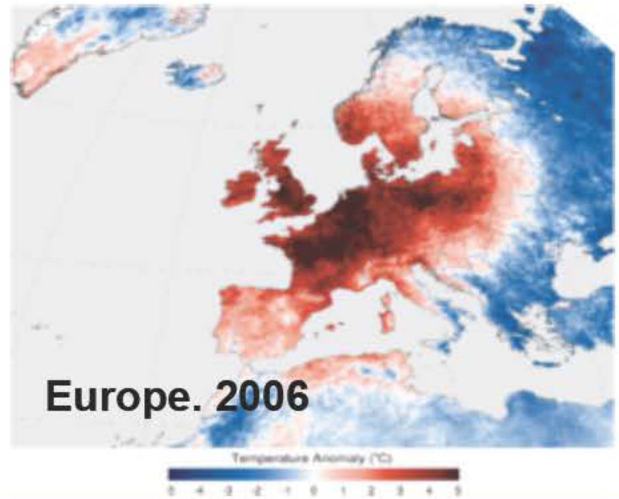


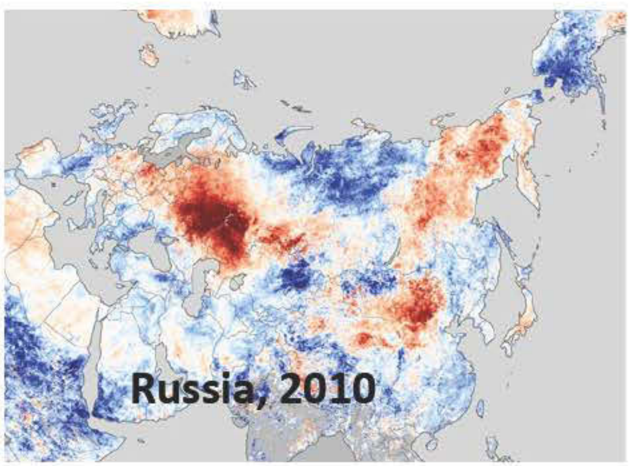
Distribution (top) and time-line (bottom)
of European summer temperatures since 1500
(Barriopedro et al. 2011)

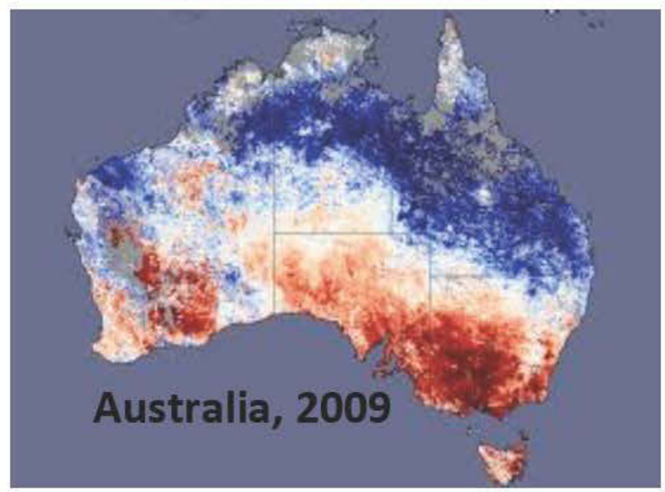
Heat Wave Trend

In the 1960s, summertime extremes of more than three standard deviations warmer than the mean of the climate were practically absent, affecting less than 1 percent of the Earth's surface. The area increased to 4–5 percent by 2006–08, and by 2009–11 occurred on 6–13 percent of the land surface. Now extremely hot outliers typically cover about 10 percent of the land area (Hansen et al. 2012).









“1 in 100 Year” Events In Last 10 Years

10C = 18F above average

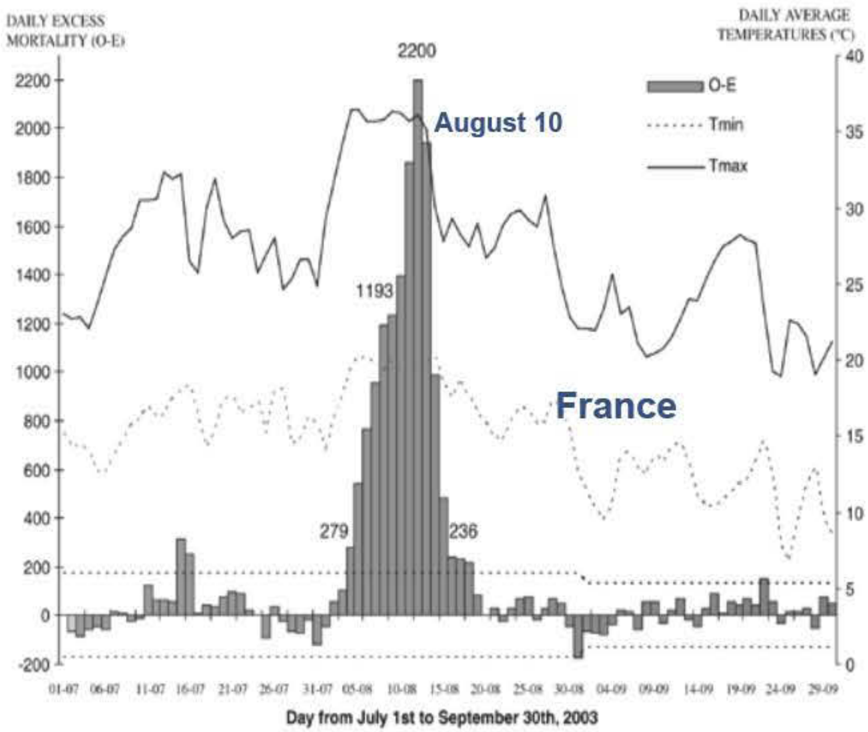
Europe* 2003 (Stott et al. 2004)
Greece 2007 (Founda and Giannaopoulos 2009)
Australia* 2009 (Karoly 2009)
Russia 2010* (Barriopedro et al. 2011)
Texas 2011 (NOAA 2011; Rupp et al. 2012)
US 2012* (NOAA 2012, 2012b)
Australia* 2013 (News Media)

* Discussed here

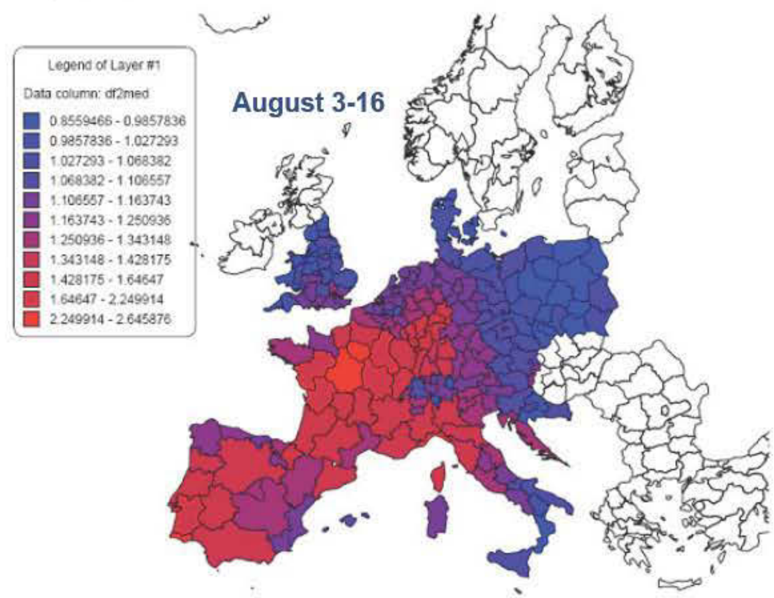
European Heat Wave Excess Mortality, 2003

Maximum temperatures above 40C (104F)

5-day period in France with *daily average* temperature of 36C (98F)



Map 1: Daily death frequencies cumulated from August 3rd to 16th 2003, divided by fourteen times the daily reference median frequency for 1998-2002 summer period, sixteen European countries, NUTS 2.



The total European death toll was about 70,000 (Field *et. al.,* 2012)
Daily mortality reached 2,200 in France, and 14,802 died (Fouillet *et. al.,* 2006).

Forest Fires

2003 European Heat Wave and Drought, IPCC 2007

Anomalously High Near-Arctic Sea Surface Temperatures (Coumou and Rahmstorf, 2012)

Area burned was unprecedented

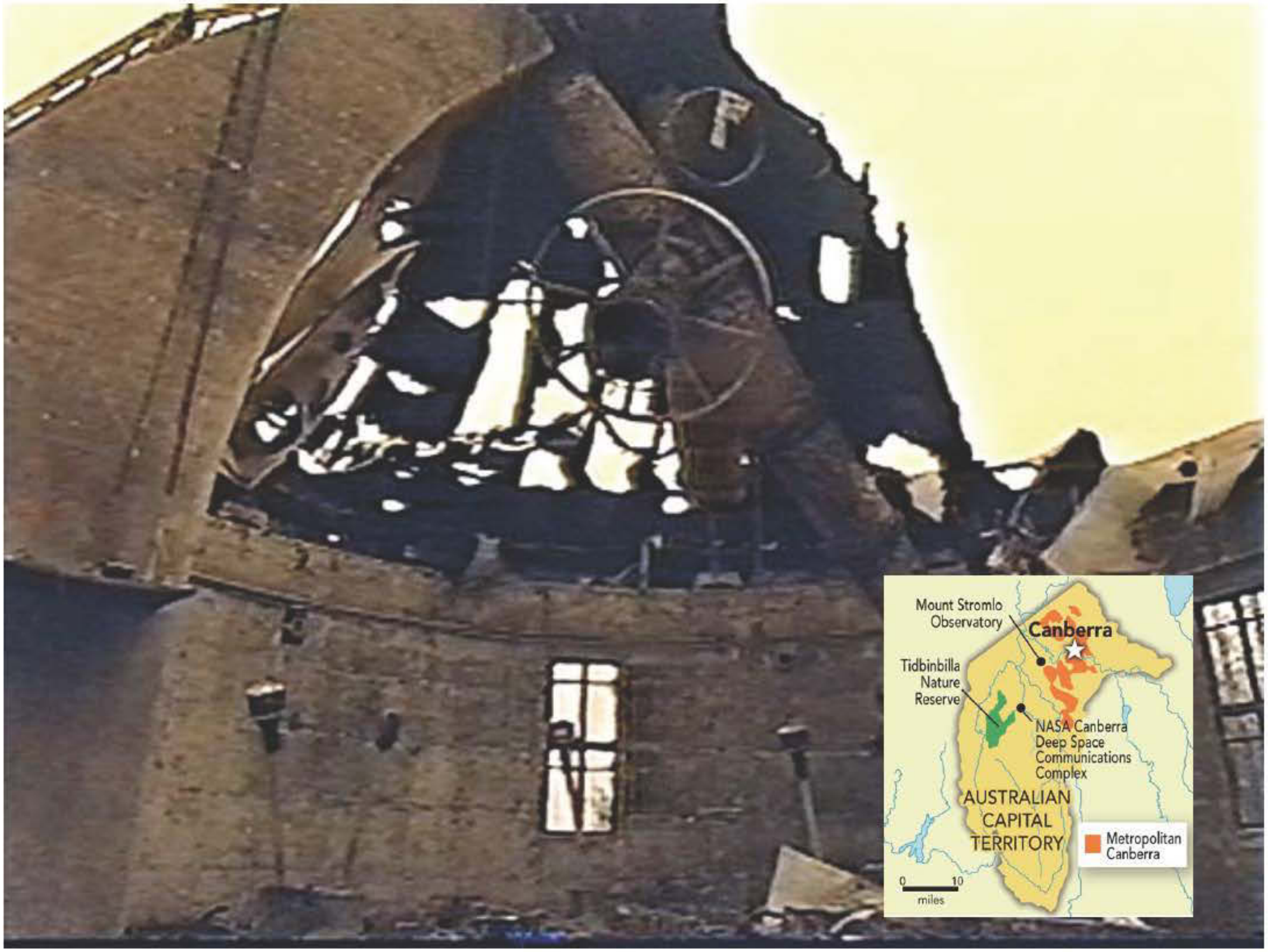
- 650,000 hectares, or about 2 million acres
- Twice the previous extreme (1998), 4 x 1980-2004 average
- 5% of Portugal's total forest area burned

Number of fires was not exceptional

- Proximate causes-lightning, humans-did not change
- Fire-vulnerable area increased due to heat and drought
- .

January 18 2003 Aussie Wildfire Destroys Mt. Stromlo Observatory

The 2003 wildfires burnt 70% (164,914 hectares) of the ACT including 90% of Namadgi National Park and Tidbinbilla Nature Reserve. The fires also affected the urban fringe and some natural areas within the city limits. The geographic extent and severity of the fires was unprecedented in the ACT and is likely to have significant short and long-term consequences for the natural ecosystems of the Territory.



Amanda Carey, Murray Evans, Peter Hann, Mark Lintermans,Trish MacDonald, Peter Ormay, Sarah Sharp, David Shorthouse, Nicola Webb, Wildfires in the ACT 2003: Report on initial impacts on natural ecosystems, Technical Report 17, Environment ACT, 2003

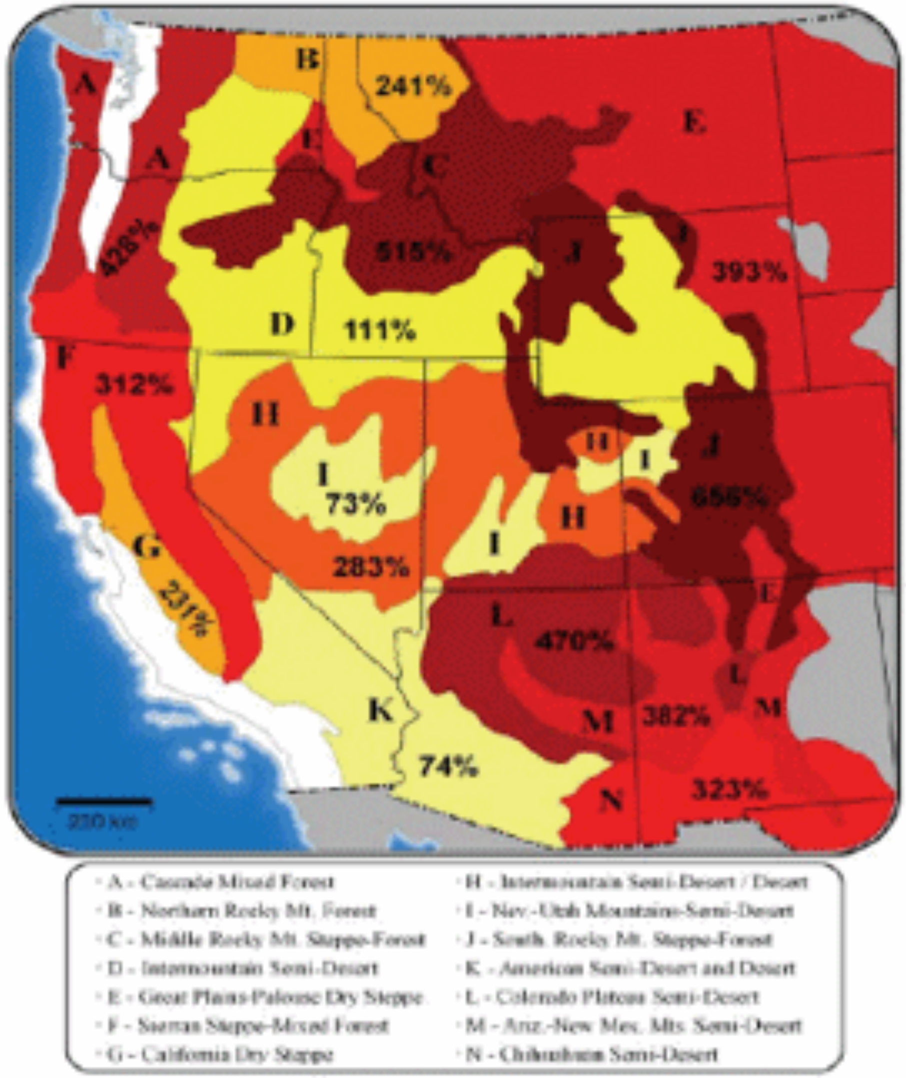
Great Alaskan Wildfires of 2007

Normally, the tundra is wet in summer because of permafrost melt below the surface, but 2007 was exceptionally hot and dry. September sea ice area was 38% below the long-term average. The wildfires that year consumed 50 years of vegetation growth in the burn area and put as much CO_2 into the atmosphere as the state's vegetation absorbs in a year. If such fires recur once every 100 years, ecosystem can recover. If they recur every 10 years, all bets are off.


2007 San Diego Wildfire
UC San Diego Medical Center treated more than 50 burn victims during the 2007 fire. Dozens more sought help for shortness of breath, tightness in the chest and coughing caused by breathing smoke.
1500 structures lost, 640,000 evacuated

What's expected: worse wildfires

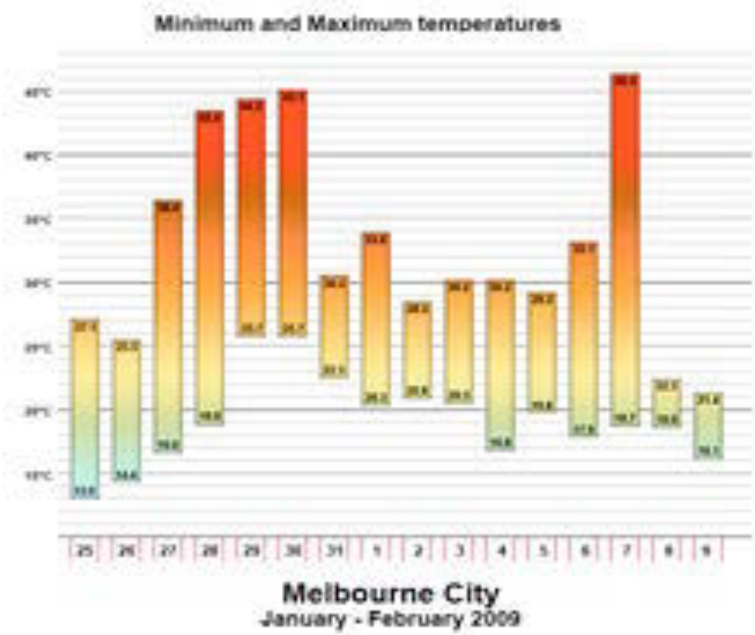
Percentage increases in median annual area burned for a 1°C increase in global average temperature



National Academies, Stabilization Targets, 2010

Climate Stabilization Targets: Emissions, Concentrations, and Impacts Over Decades to Millennia, Committee on Stabilization Targets for Atmospheric Greenhouse Gas Concentrations,
National Research Council, 2010

2009 Southeastern Australia Heat Wave



Feb 7, 2009, was the hottest day in Melbourne since recording began in 1859

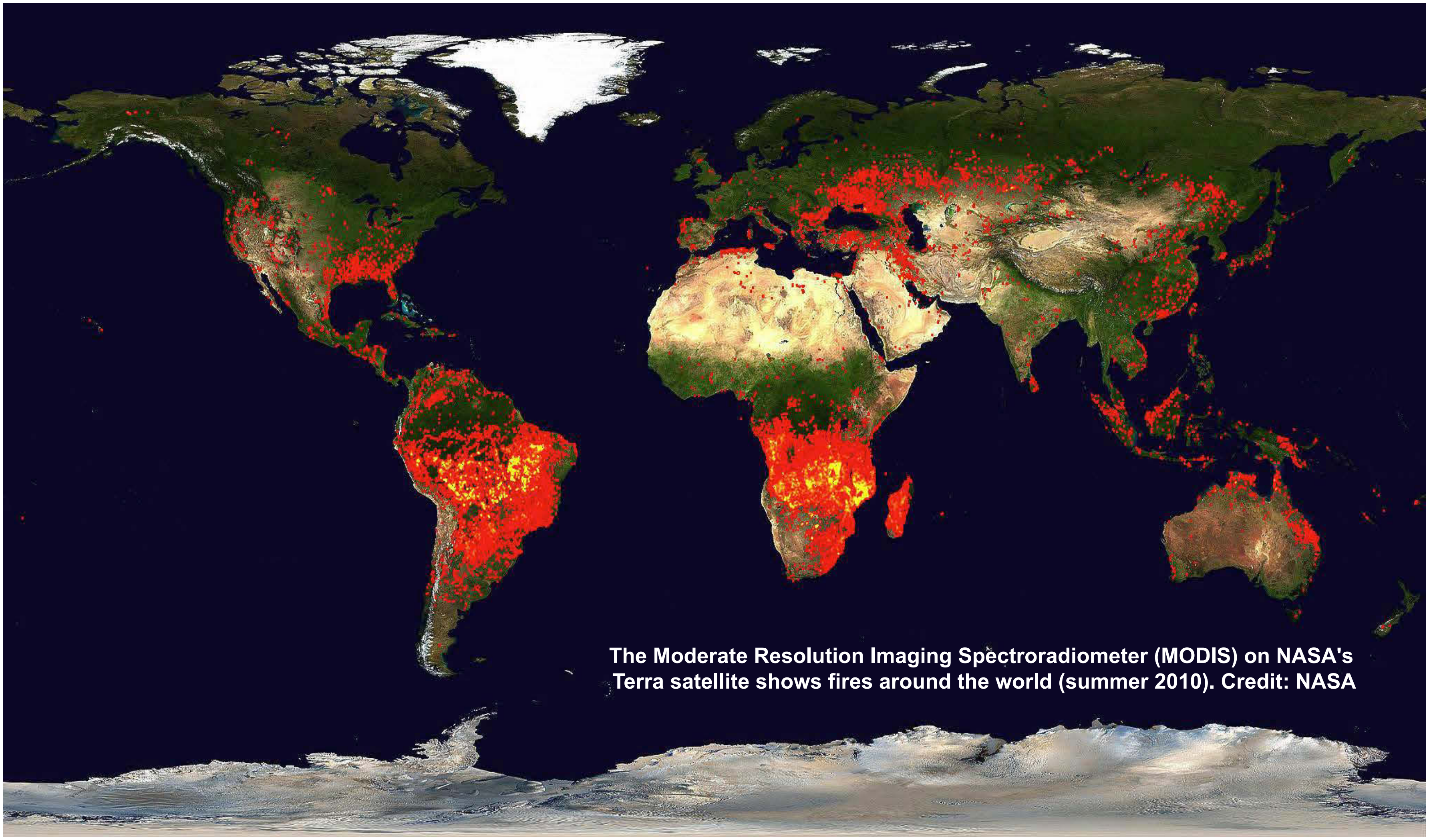
The temperature reached 46.1C=116F

The bushfires started that day killed 173 people in Victoria

The heat accounted for 980 premature deaths in all

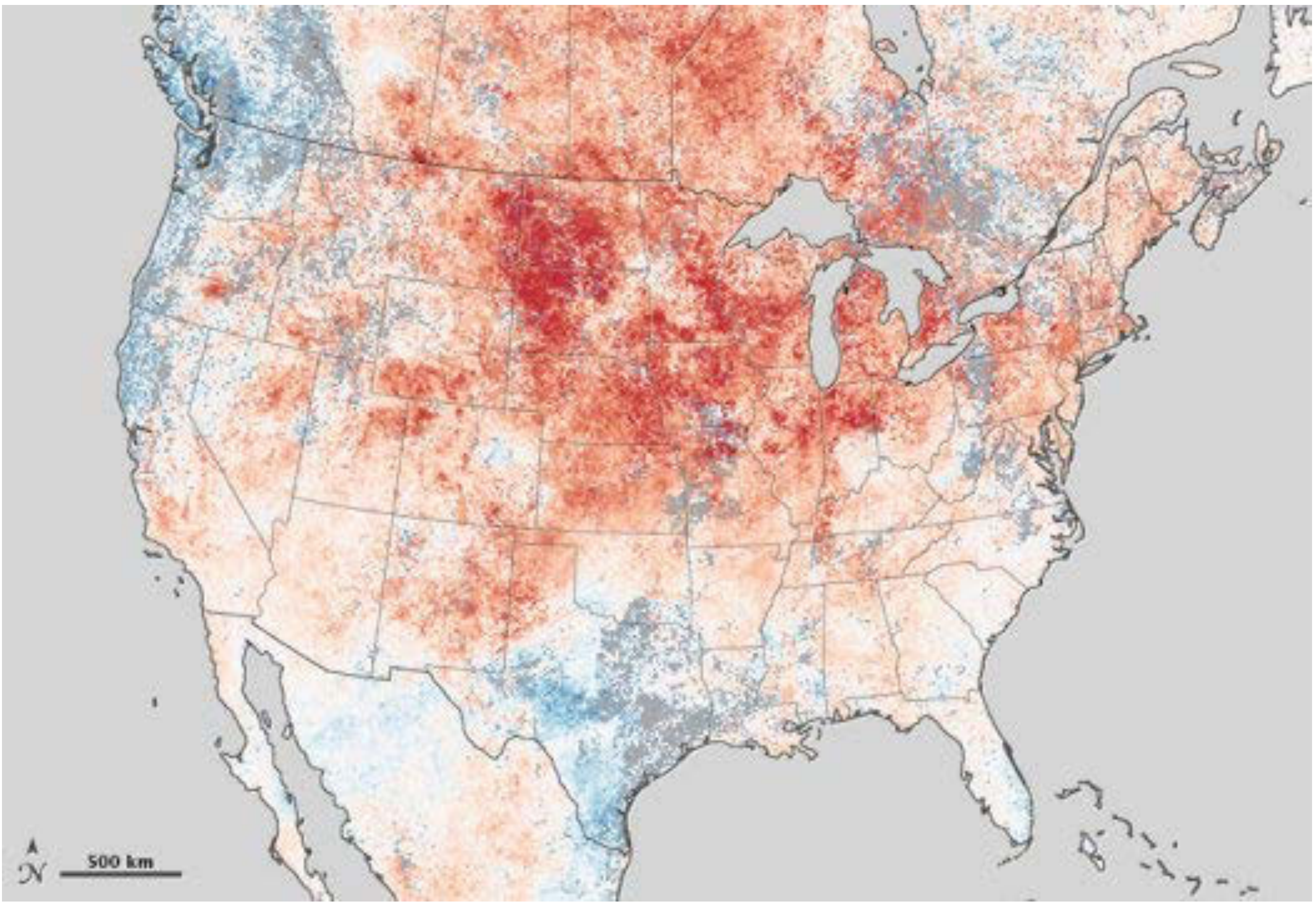
Wildfires, Summer 2010

Vegetation density, prior rainfall, soil moisture, humidity, heat, wind, lightning



The heat wave in Russia in 2010 resulted in an estimated death toll of 55,000, of which 11,000 deaths were in Moscow alone, and more than 1 million hectares of burned land.

North American Heat Wave, 2012



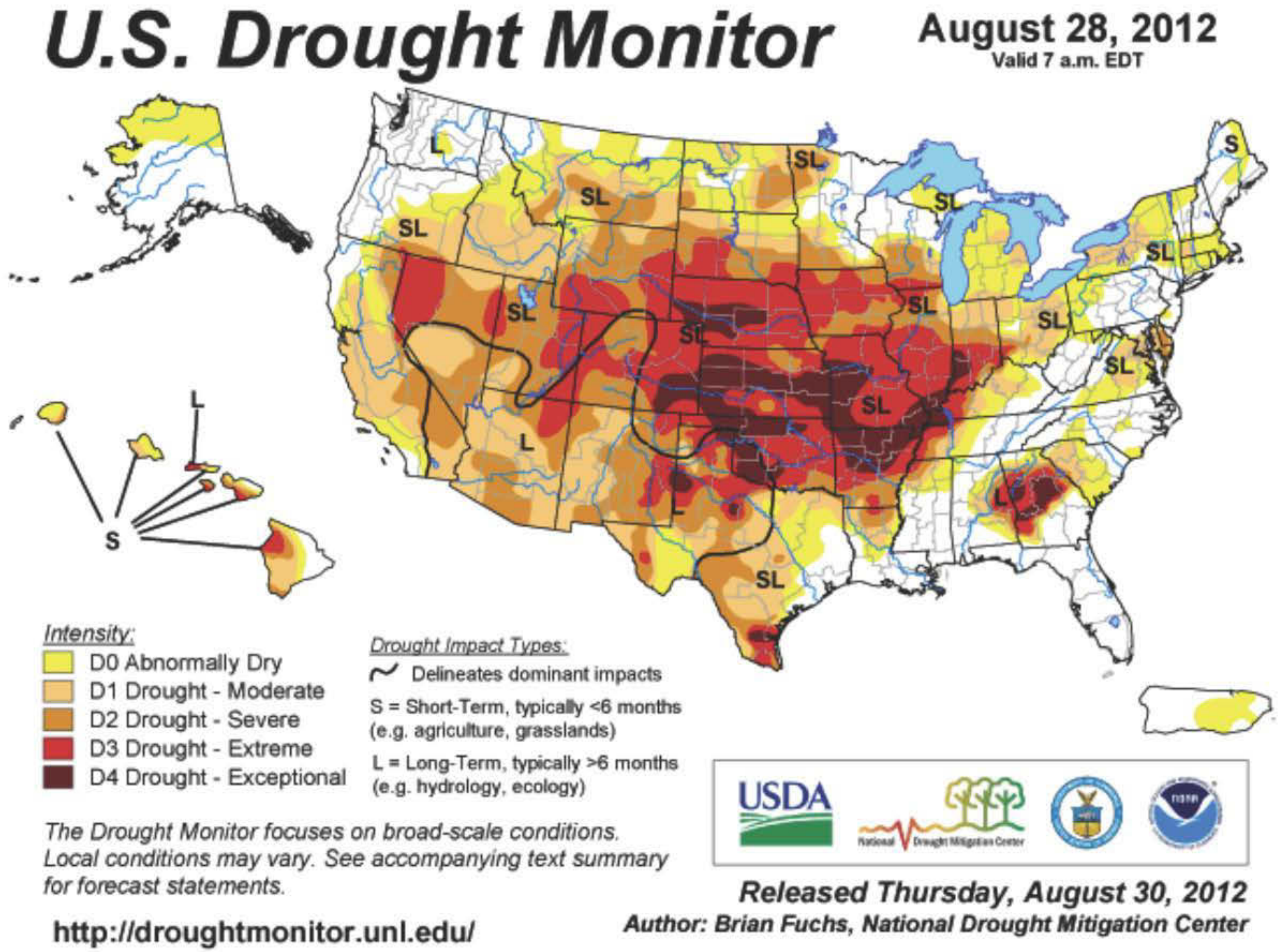
The January to August period was the warmest ever recorded. March 2012 saw exceptionally early plant flowering.*

On August 28, about 63 percent of the contiguous United States was affected by drought.

2012 also saw numerous wildfires, setting a new record for total burned area —exceeding 7.72 million acres

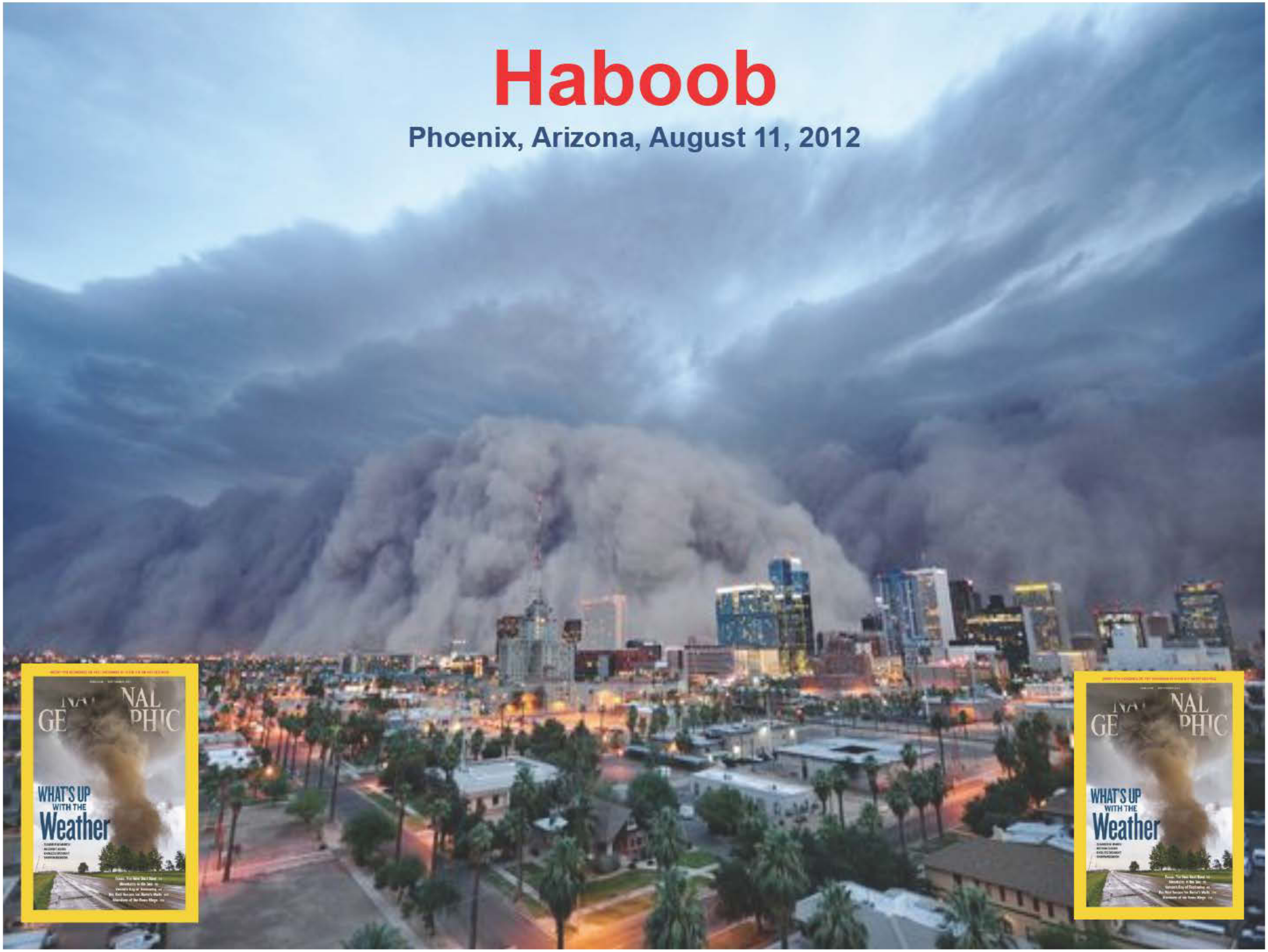
***Karl, T., *et al., U.S. Temperature and Drought: Recent Anomalies and Trends, EOS, Trans. AGU,93(47), 473-474;*
Elword, E.R., *et al,* Record-breaking early flowering in the eastern United States, PloS One, 8, e53788**

North American Drought, 2012

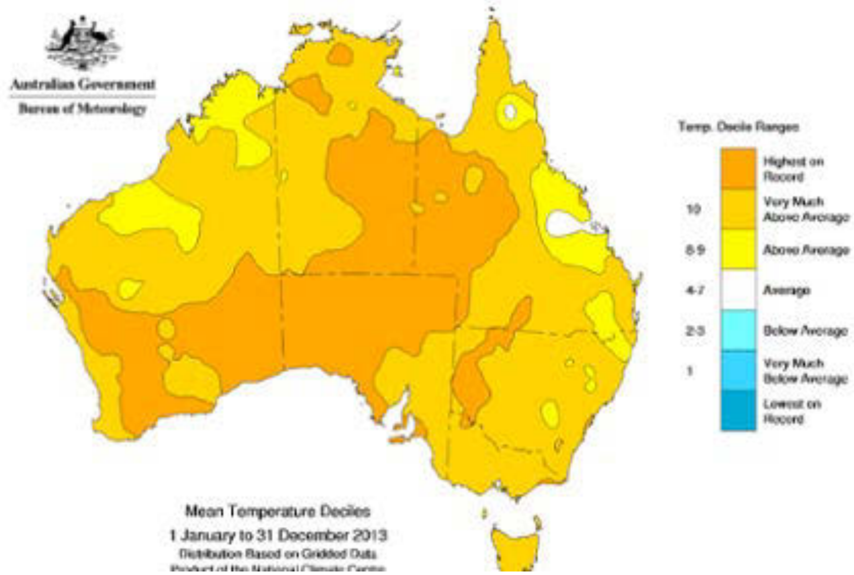


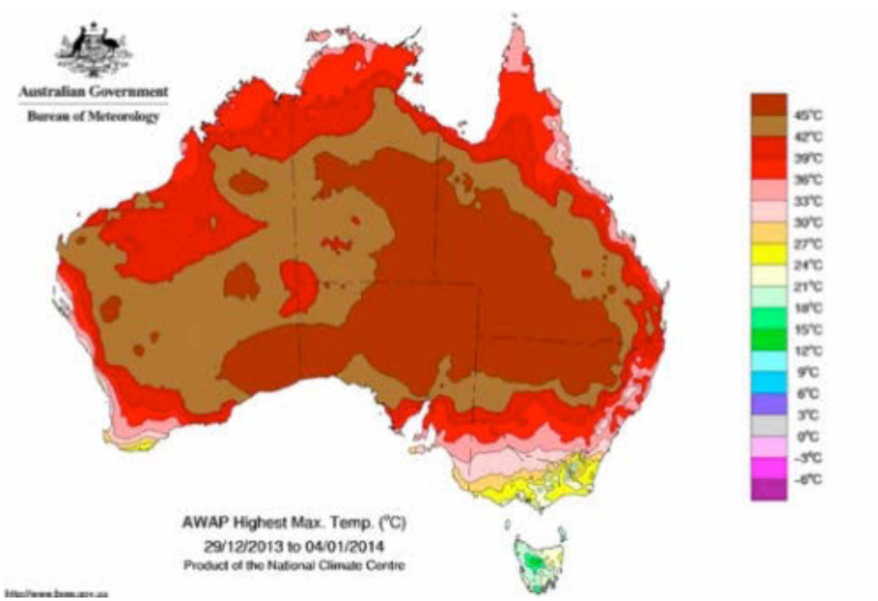
Haboob

Phoenix, Arizona, August 11, 2012

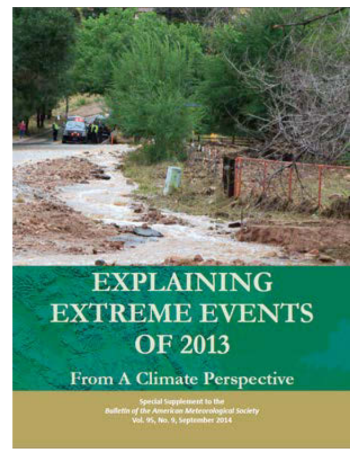


Great Australian Heat Wave, 2013/2014





Jan 1-Dec 31 2013
Hottest year on record



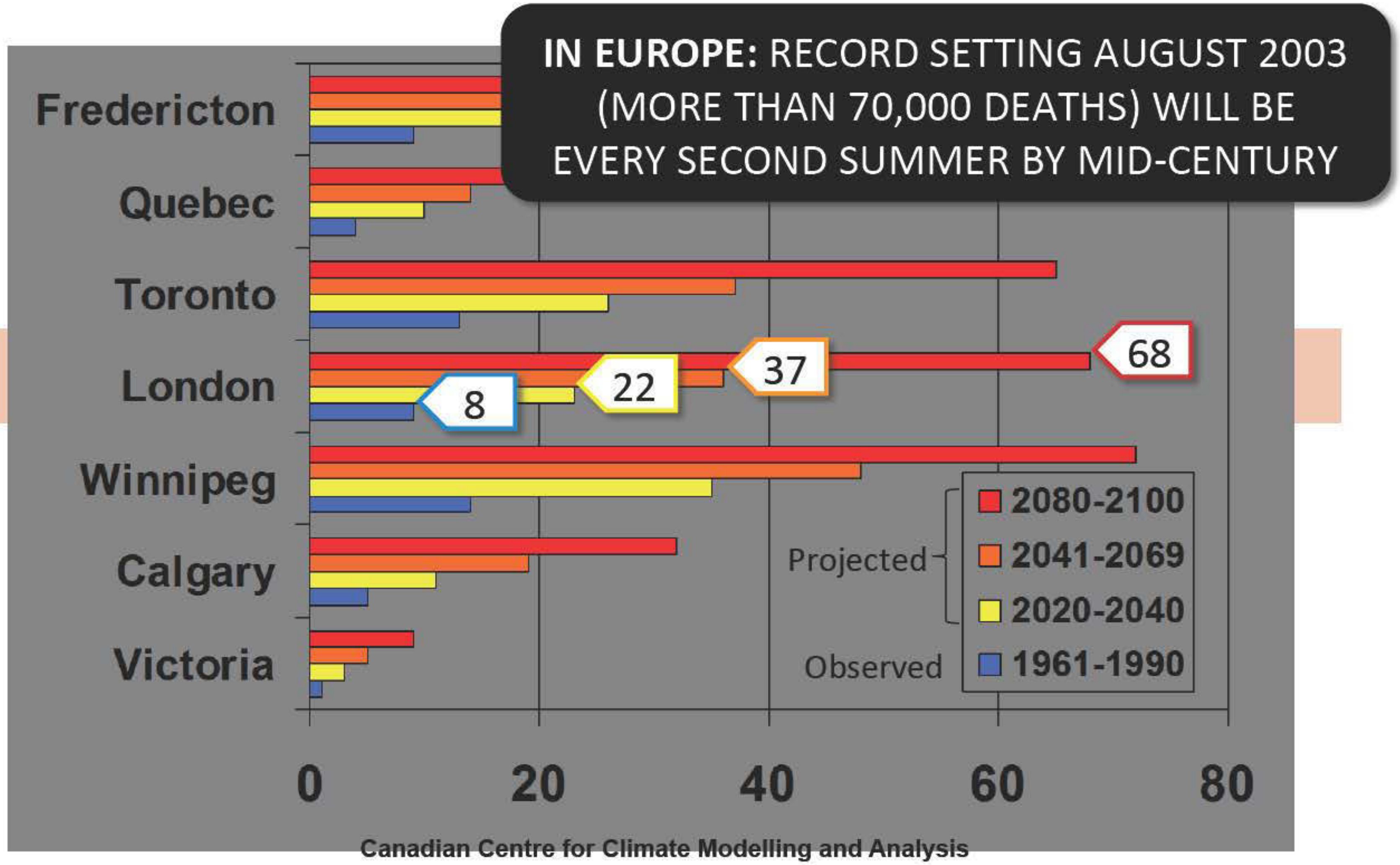
Dec 29, 2013- Jan 4, 2014
Temperatures exceeded 45C over vast area


"We can't conclusively say whether man-made carbon dioxide emissions are contributing to climate change."


"Whether carbon dioxide is quite the environmental villain that some people make it out to be is not yet proven."


The G20 and climate change

Number Of Canadian Hot Days (T>30C) Per Year



*A hot day is defined as a day with a maximum temperature above 30C = 87F

Environment Canada Environnement Canada

Powerpoint courtesy of Gordon McBean
Present to "Bacon and Eggheads", a breakfast meeting with Canadian legislators

IBC BAC

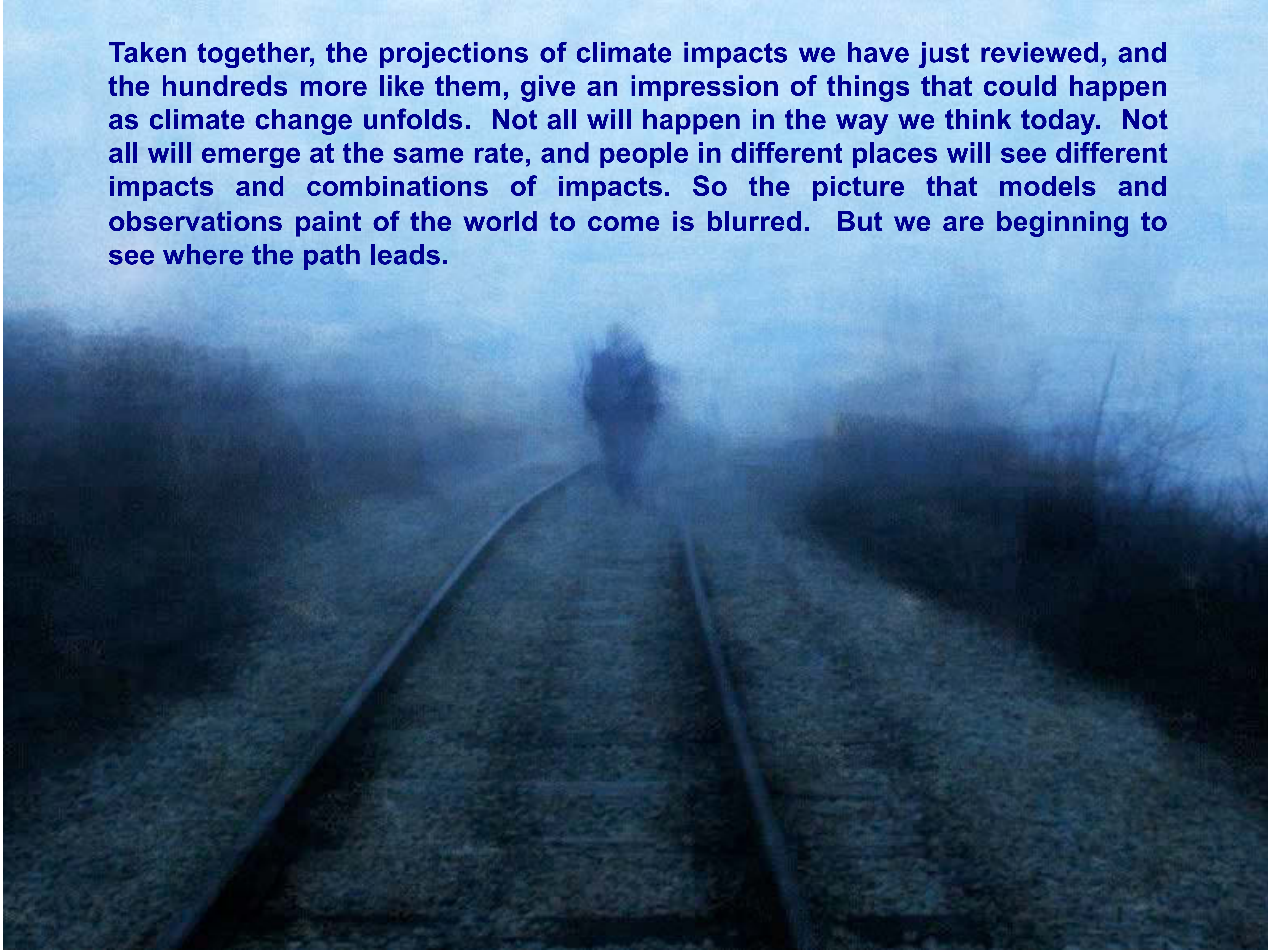
By 2100, “In this new high temperature climate regime (4C=7F), the coolest months are likely to be substantially warmer than the warmest months at the end of the 20th century. In regions such as the Mediterranean, the Middle East, and the Tibetan Plateau, almost all summer months are likely to be warmer than the most extreme heat waves presently experienced.”

Ecosystem Vulnerability

"In a 4°C world climate change seems likely to become the dominant driver of ecosystem shifts, surpassing (other forms) of habitat destruction as the greatest threat to biodiversity. Recent research suggests that large-scale loss of biodiversity is likely … with climate change and high CO2 concentration driving a transition of the Earth´s ecosystems into a state unknown in human experience"

Turn Down The Heat! The World at 4C
World Bank-Potsdam Institute for Climate Research

Taken together, the projections of climate impacts we have just reviewed, and the hundreds more like them, give an impression of things that could happen as climate change unfolds. Not all will happen in the way we think today. Not all will emerge at the same rate, and people in different places will see different impacts and combinations of impacts. So the picture that models and observations paint of the world to come is blurred. But we are beginning to see where the path leads.



"Continued emission of greenhouse gases will cause further warming and long lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive, and irreversible impacts for people and ecosystems"

IPCC AR5, Nov 1, 2014