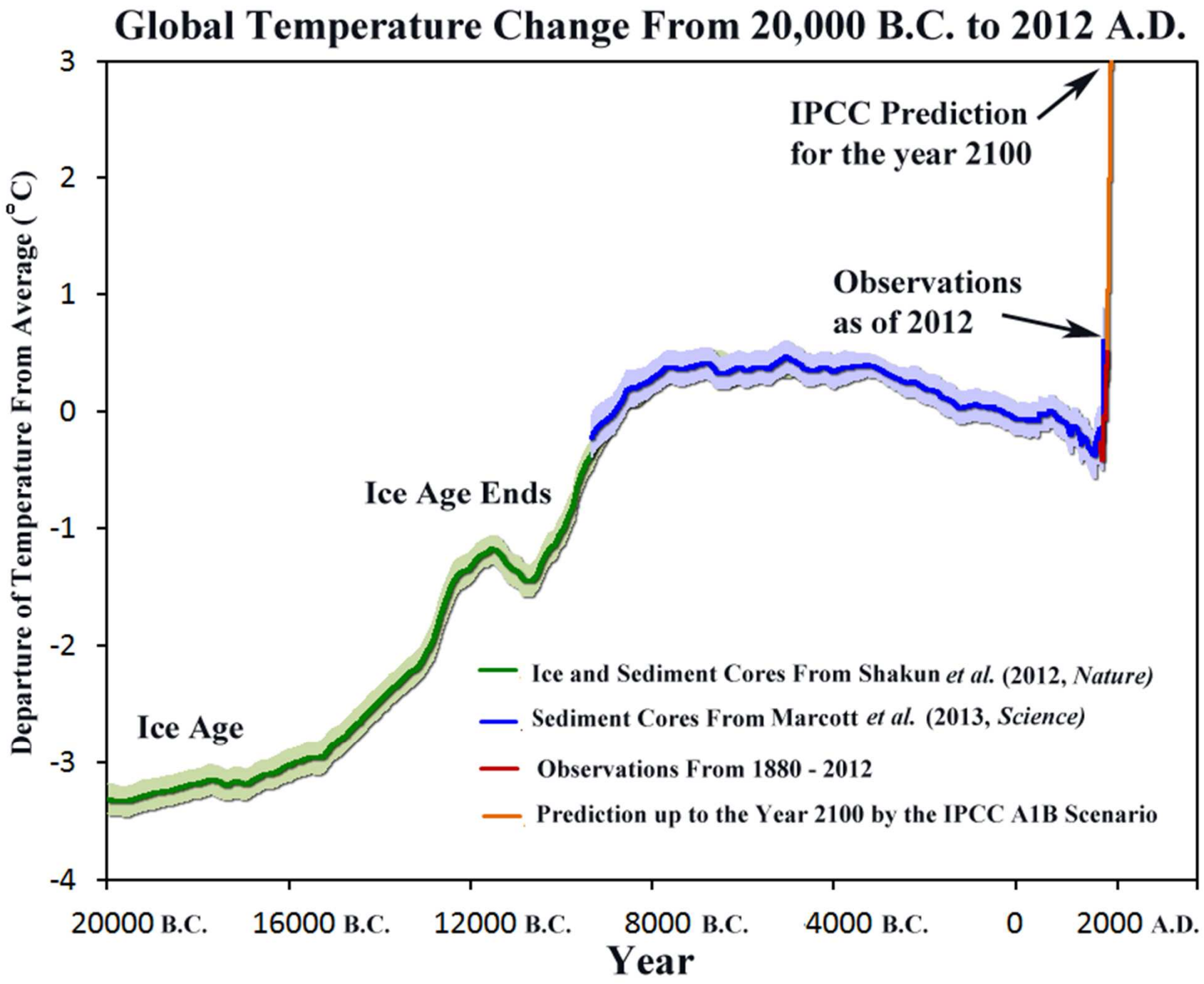
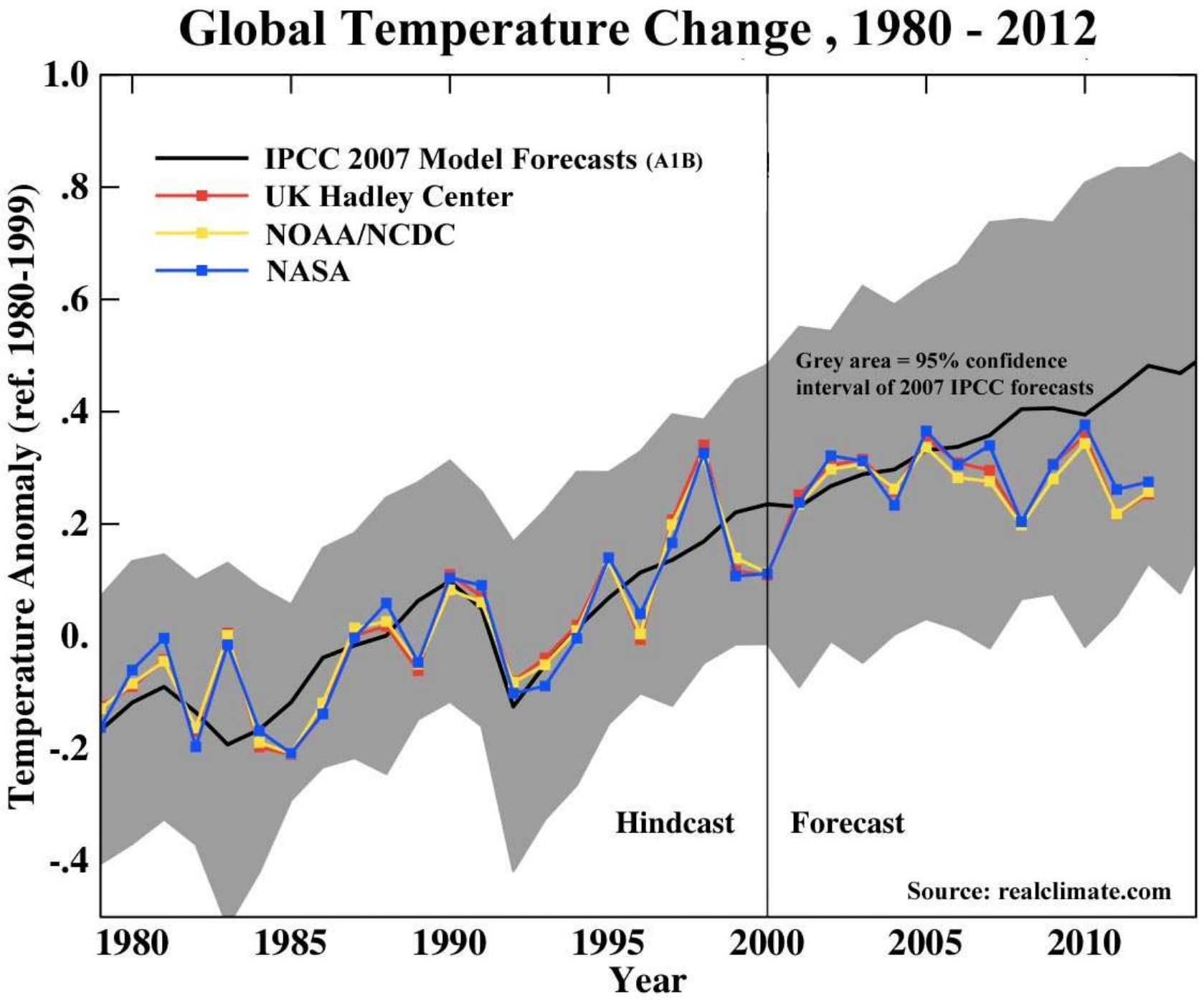
Earth's Climate: Where are We at, and Where are We Headed?

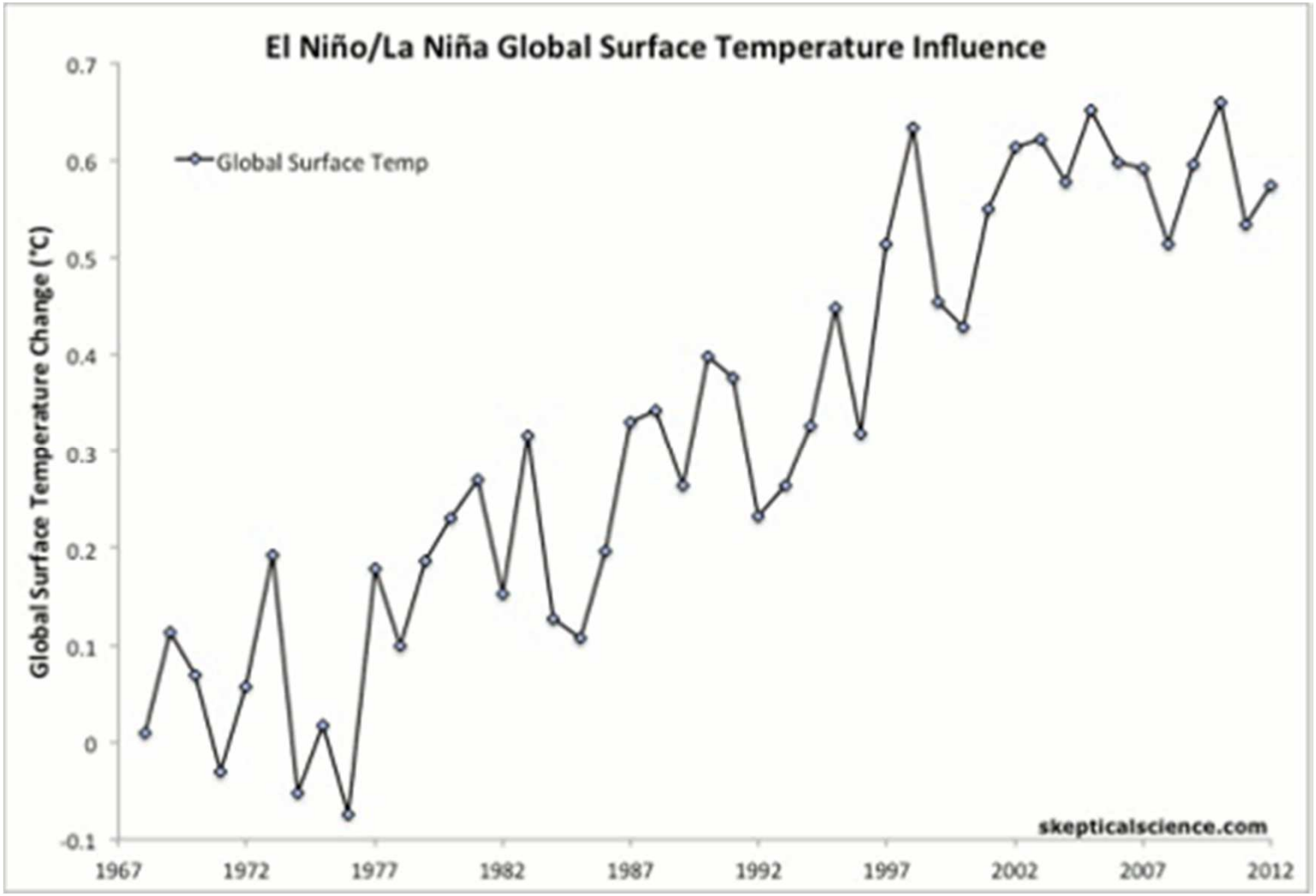
Dr. Jeff Masters
Director of Meteorology
The Weather Underground, LLC
http://www.wunderground.com

The Weather Company

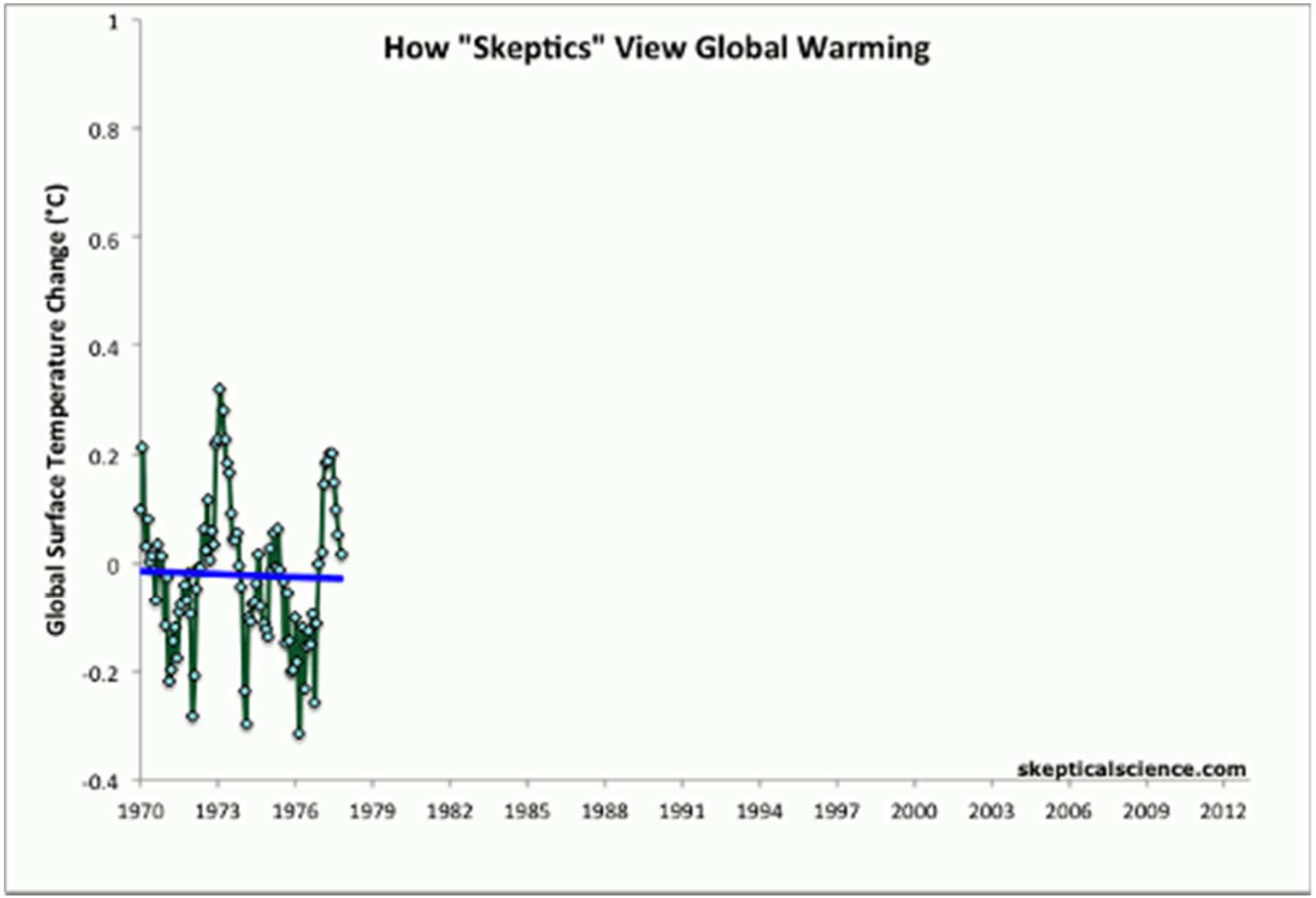

Global Temperature Change From 20,000 B.C. to 2012 A.D.
Departure of Temperature From Average (°C)
3
2
1
0
-1
-2
-3
-4
IPCC Prediction
for the year 2100
Observations
as of 2012
Ice Age Ends
Ice Age
Ice and Sediment Cores From Shakun et al. (2012, Nature)
Sediment Cores From Marcott et al. (2013, Science)
Observations From 1880 - 2012
Prediction up to the Year 2100 by the IPCC A1B Scenario
20000 B.C.
16000 B.C.
12000 B.C.
8000 B.C.
4000 B.C.
0
2000 A.D.
Year


Global Temperature Change , 1980 - 2012
1.0
.8
.6
.4
.2
0.
-.2
-.4
Temperature Anomaly (ref. 1980-1999)
IPCC 2007 Model Forecasts (A1B)
UK Hadley Center
NOAA/NCDC
NASA
Grey area = 95% confidence
interval of 2007 IPCC forecasts
Hindcast
Forecast
Source: realclimate.com
1980
1985
1990
1995
2000
2005
2010
Year

Correcting for El Niño and La Niña Influences Shows the Global Warming Trend More Clearly



How to Abuse Statistics: Choose a Short Time Interval and Ignore the Long-Term Trend



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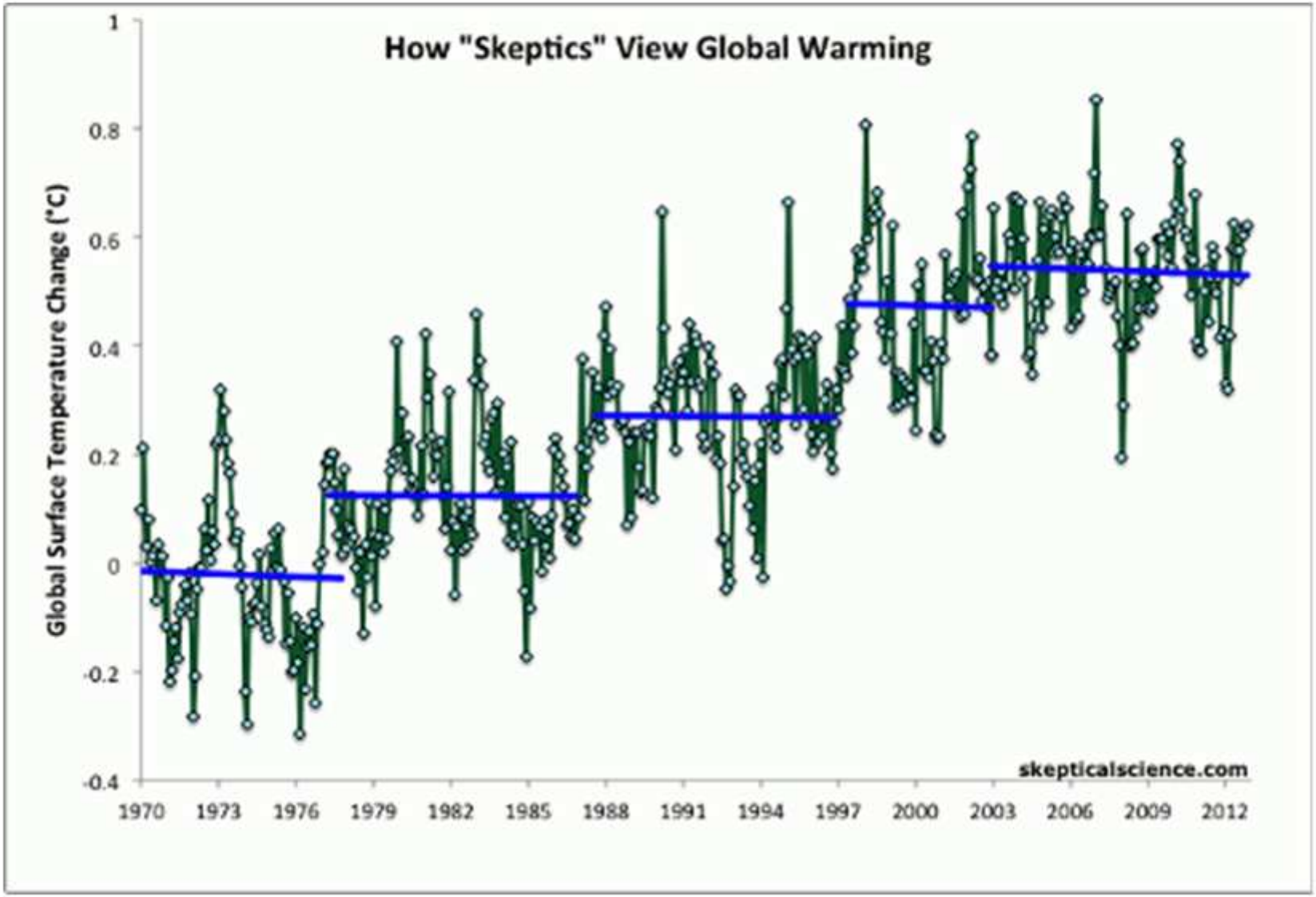
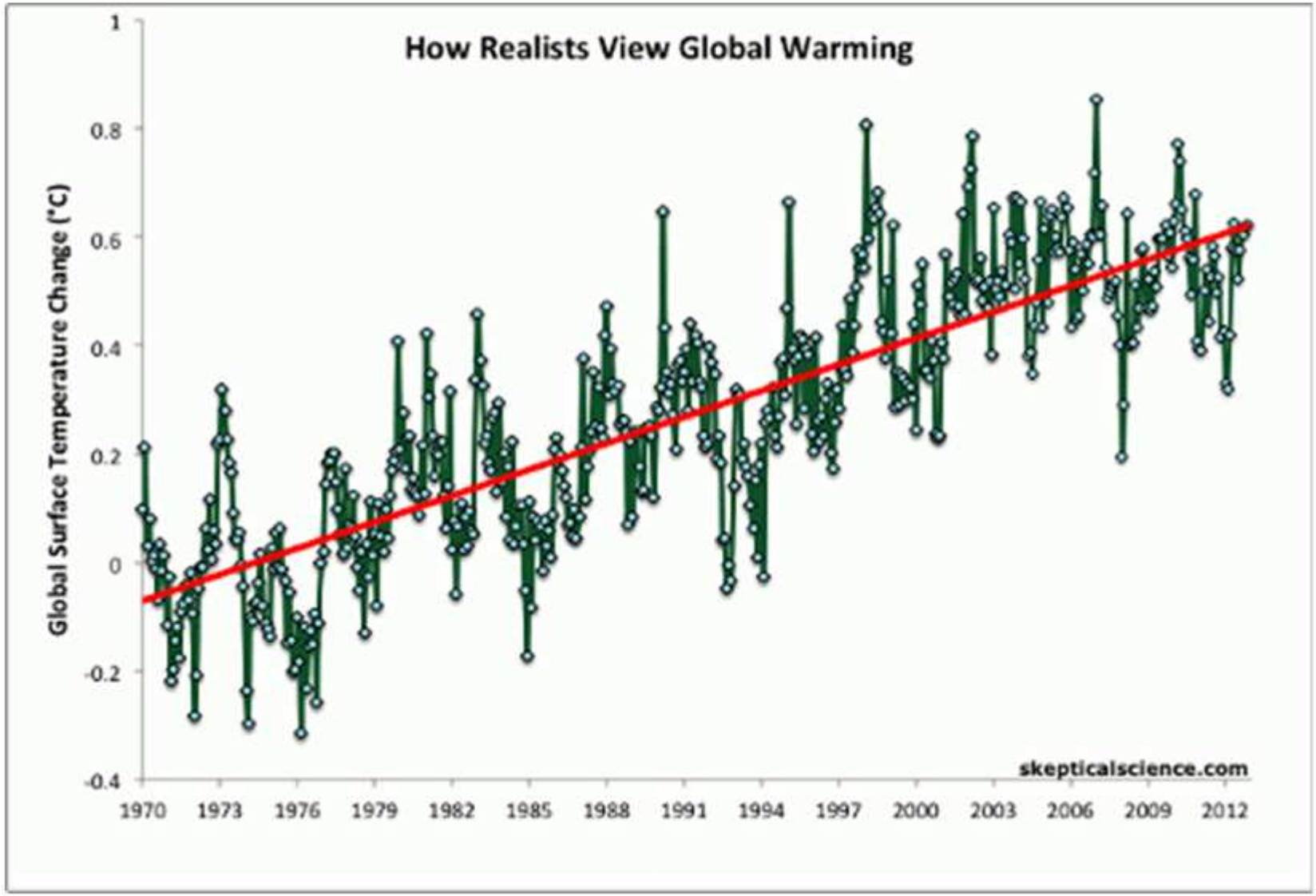
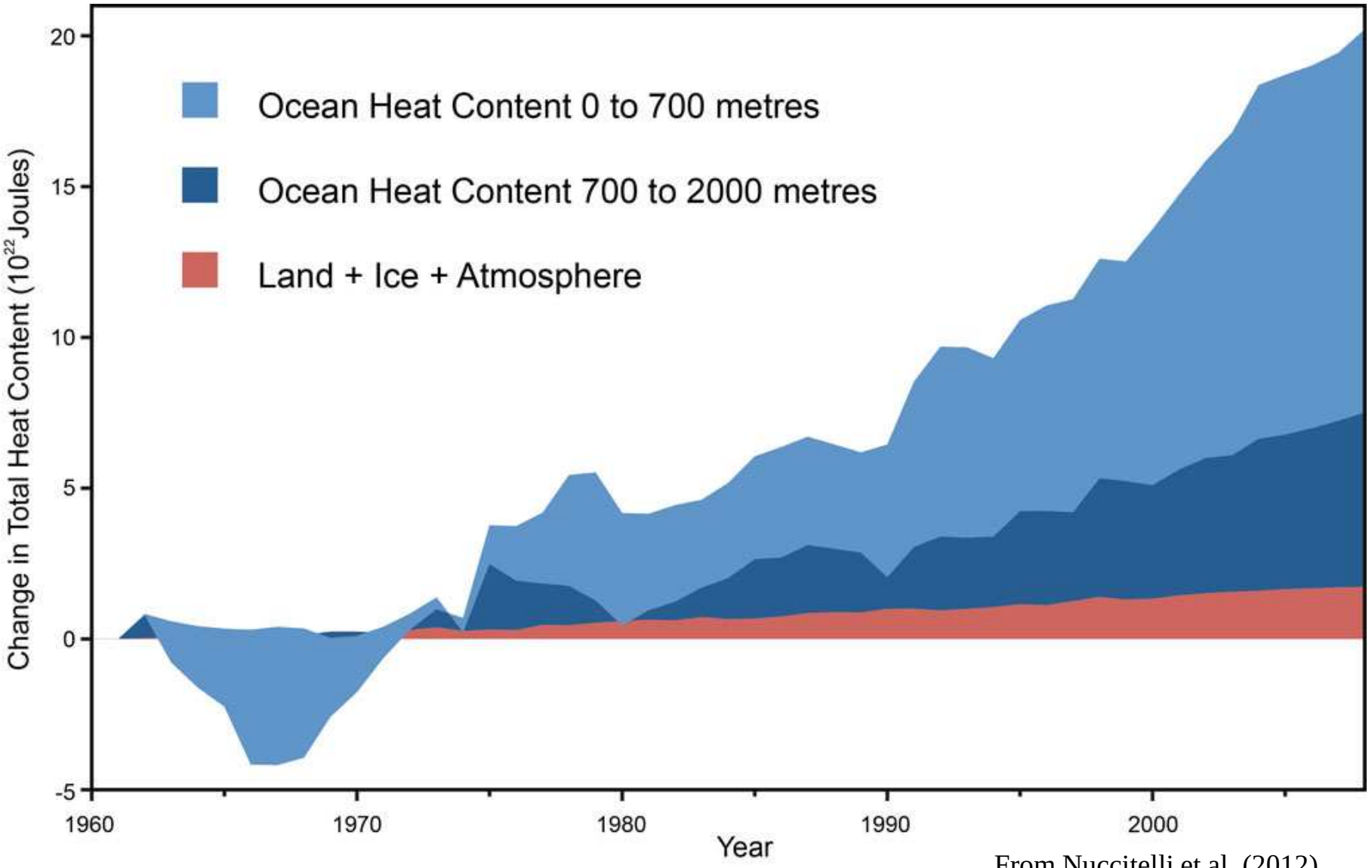


How to Abuse Statistics: Choose a Short Time Interval and Ignore the Long-Term Trend

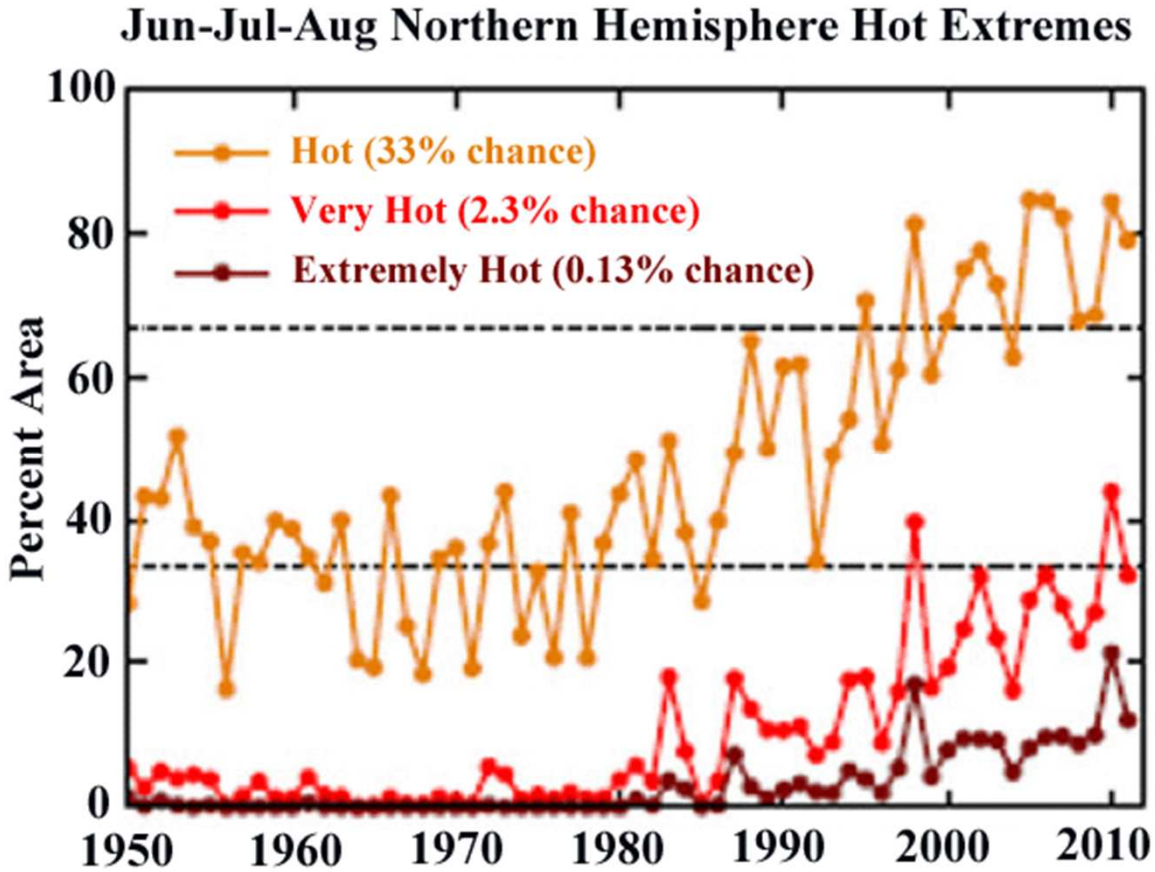


Where is the Missing Energy Going? Into the Ocean



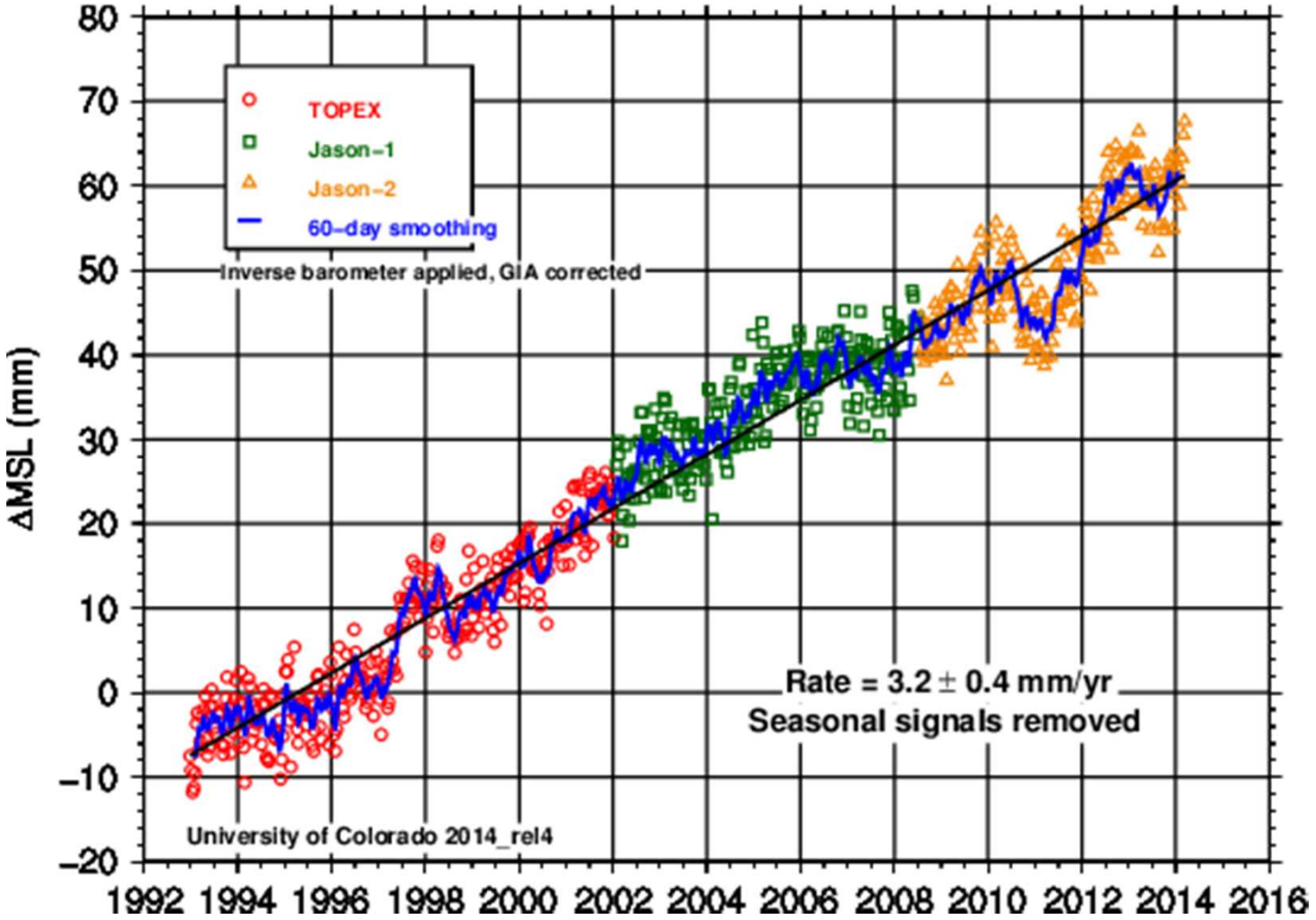
From Nuccitelli et al. (2012)

Since 2006, Dangerously Hot 1-in-700 Year Summers Have Expanded by 50 Times Compared to 1951 - 1980



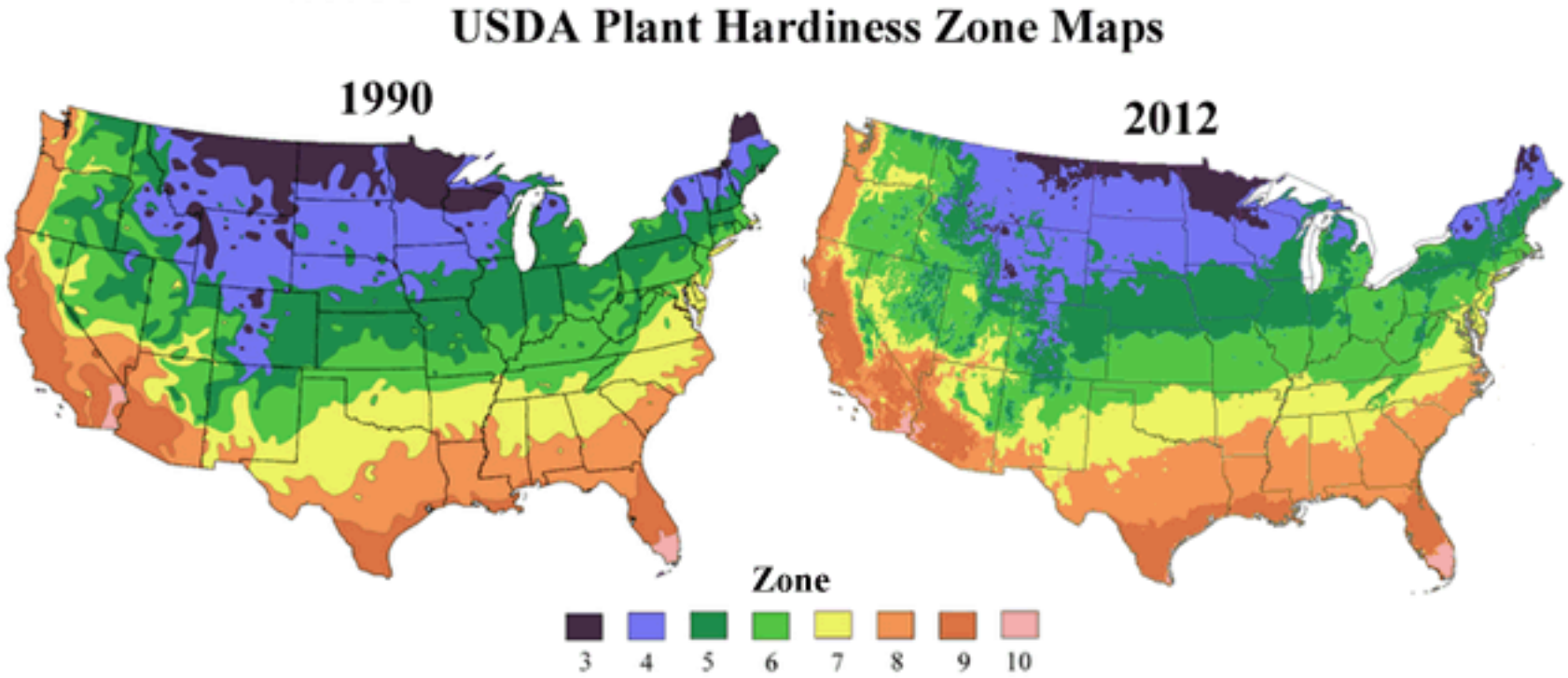
Percent area covered by summer temperature anomalies in categories defined as hot (> 0.43 standard deviations, 33% chance), very hot (> 2 standard deviations, 2.3% chance), and extremely hot (> 3 standard deviations, .13% chance.) Anomalies and standard deviation computed from a 1951 - 1980 climatology. Extremely hot 3-standard deviation summers covered 0.1-0.2% of Earth's surface in 1951-1980, but now cover 4-13%. From Hansen et al., 2012, "Perception of Climate Change."

Global Sea Level Rose 7” in the 20th Century, and Accelerated to Nearly 2x That Rate in the Past 20 Years



Source: http://sealevel.colorado.edu/

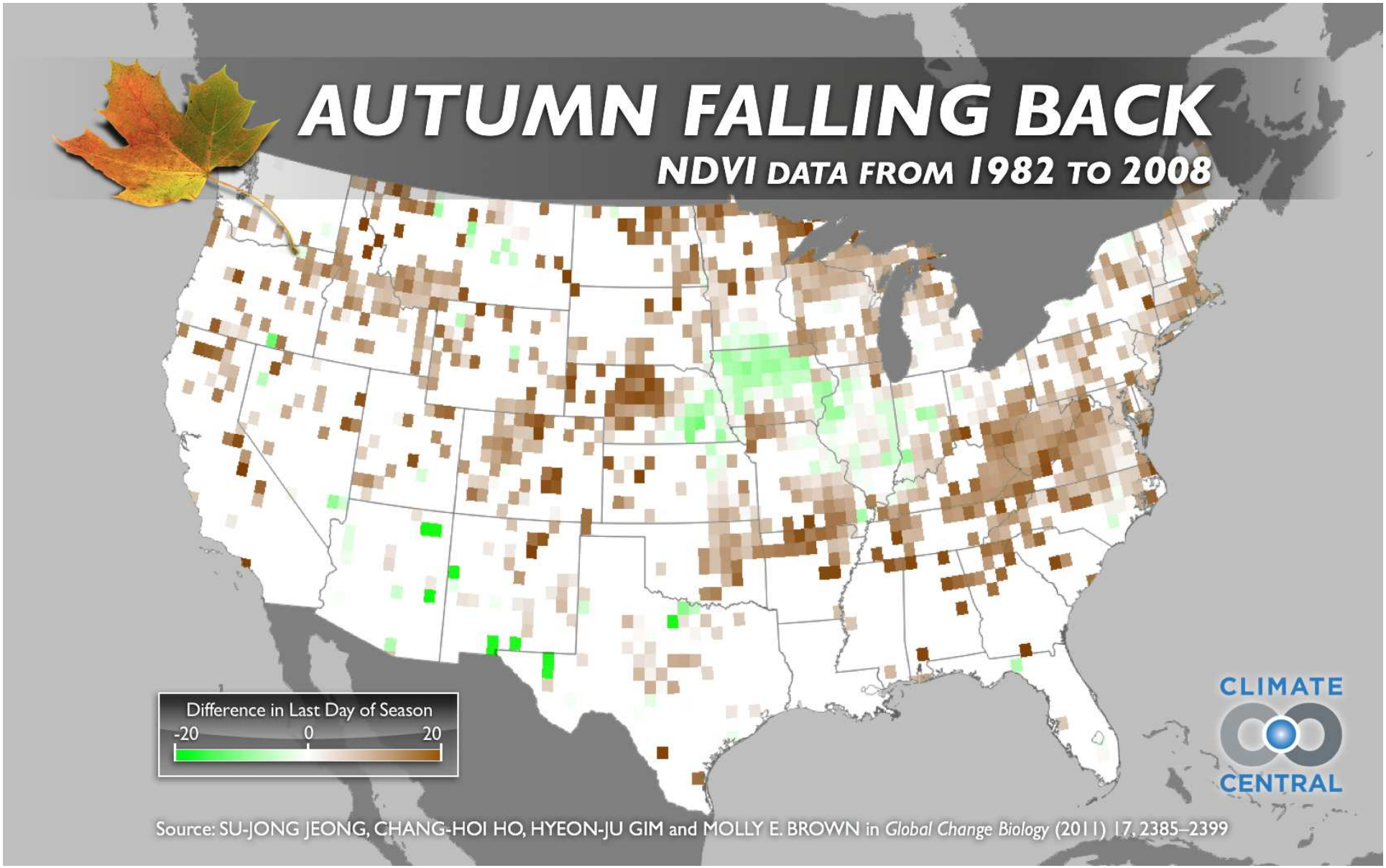
Plants and Animals are Responding to a Warming Climate

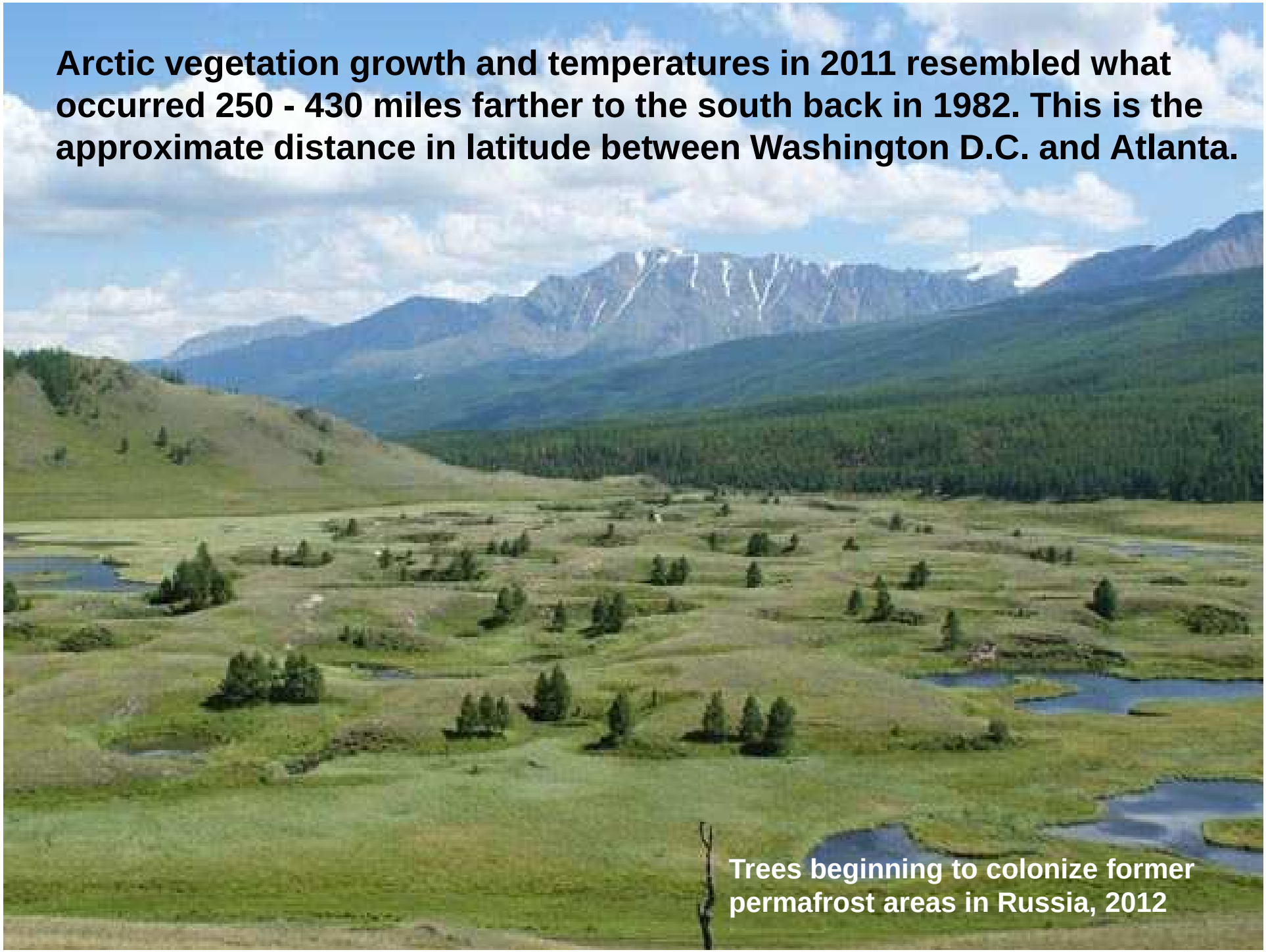


Spring is springing forward: Spring events, like bird and butterfly migrations, flower blooming times, and frog mating, have been advancing by about three days per decade over the past 30 years.

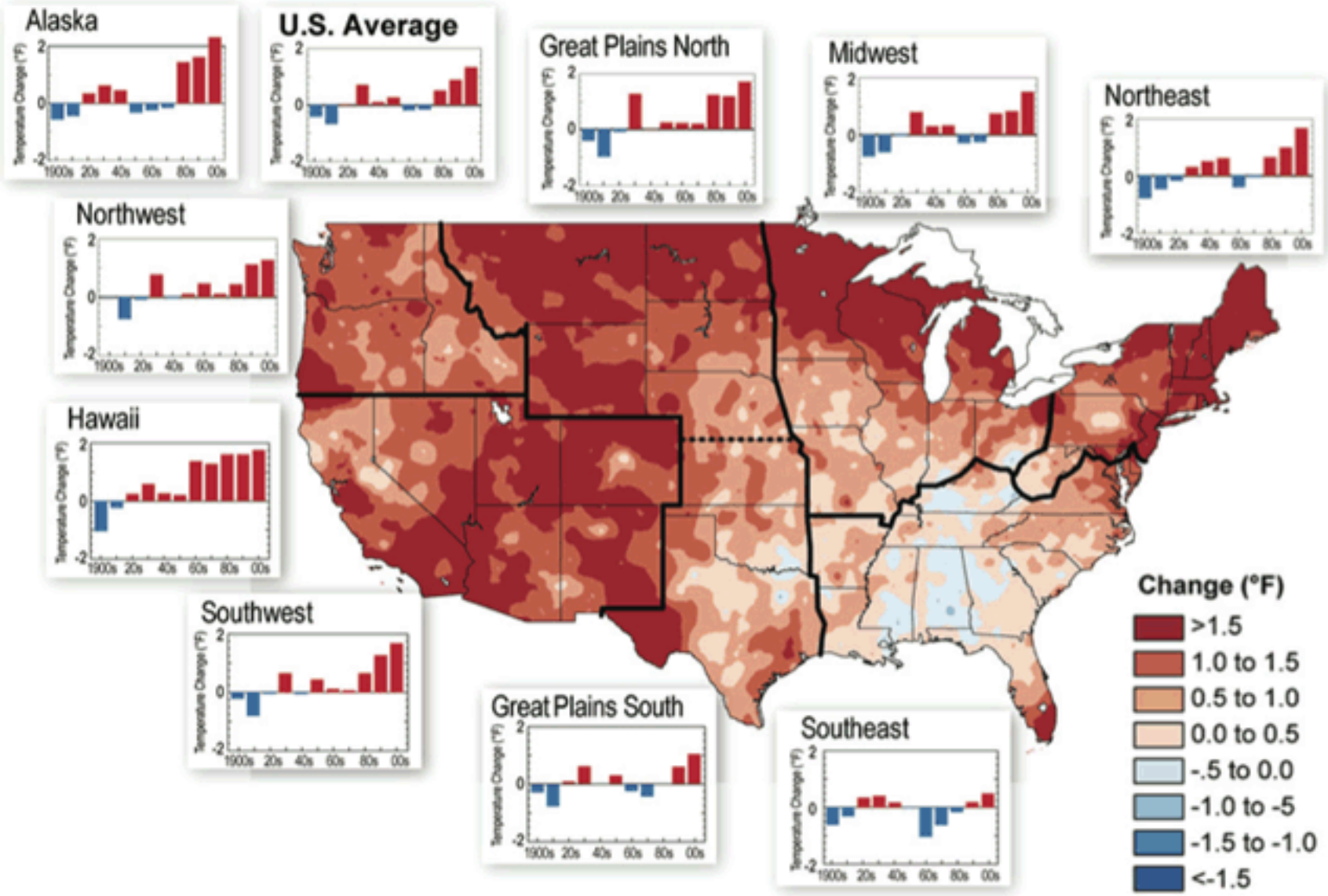
Source: Jeong et al., 2011, "Phenology shifts at start vs. end of growing season in temperate vegetation over the Northern Hemisphere for the period 1982–2008"

Fall is falling back: From 2000 - 2008, the end of the growing season was delayed by 2.3 days. In the U.S., fall now occurs ten days later than it did 30 years ago.




Arctic vegetation growth and temperatures in 2011 resembled what occurred 250 - 430 miles farther to the south back in 1982. This is the approximate distance in latitude between Washington D.C. and Atlanta.
Trees beginning to colonize former permafrost areas in Russia, 2012

U.S. Temperature Change, 1900 - 2011

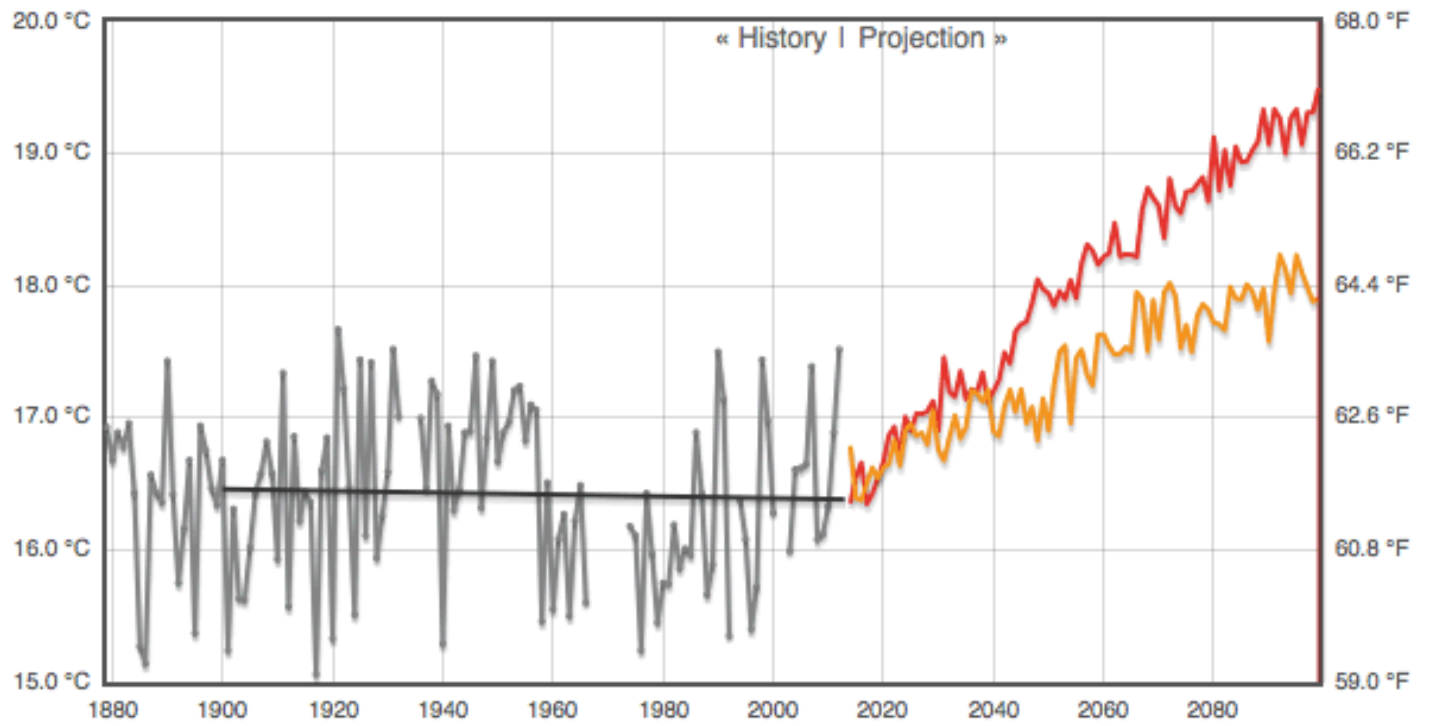


Local Climate Change for Chattanooga

Average Temperature

Average Temperature | Precipitation | Snow

Data sources: GHCN; Maurer et al. (2009)



Show post-1900 trend: **-0.1 °C (-0.1 °F) per century**

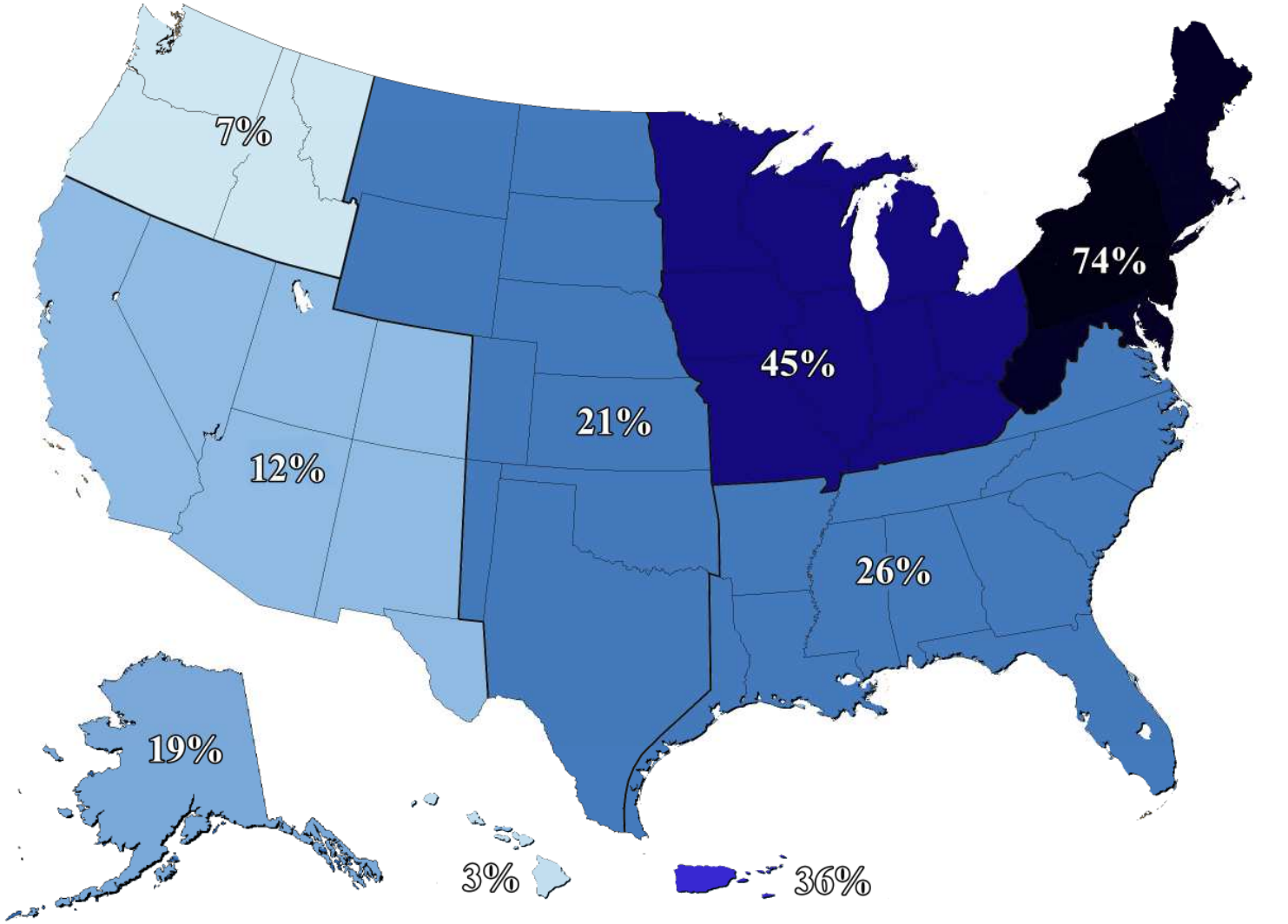
Year: 2099

- Avg. Temperature: (N/A)
- High Emissions: 19.5 °C (67.1 °F)
- Low Emissions: 17.9 °C (64.2 °F)

Average Temperature Disclaimer

The above plot is average annual temperature for the selected station. Switch stations by using the map below. In grey is historical data from the Global Historical Climatology Network (GHCN). The post-1900 trend is in black. GHCN includes approximately 6,000 temperature stations across the globe, and is the primary source for temperature data for global temperature records. Records in this GHCN database date back to as early

Increases in Amounts of Very Heavy Precipitation, 1958 - 2011

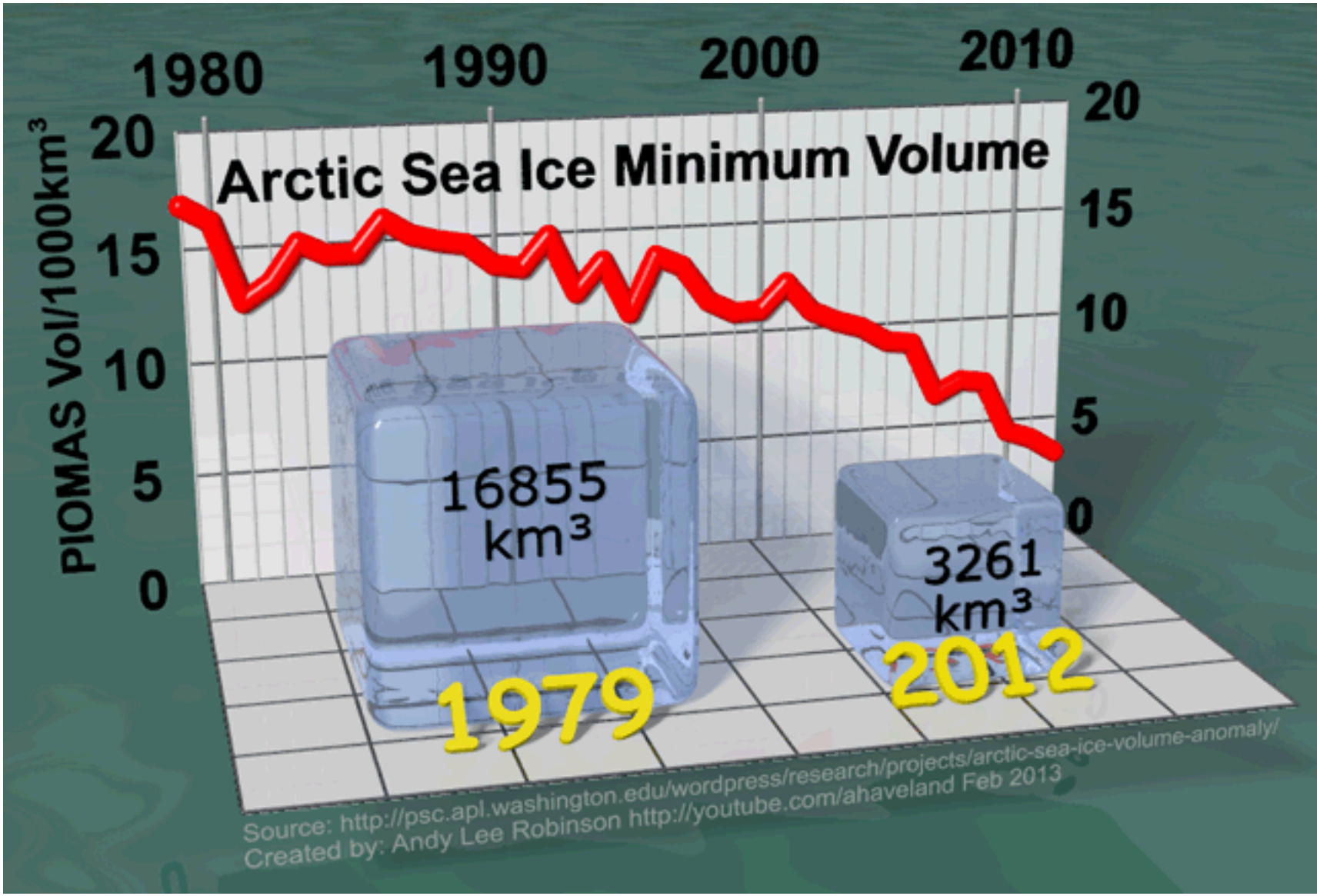


Percentage Change in Very Heavy Precipitation

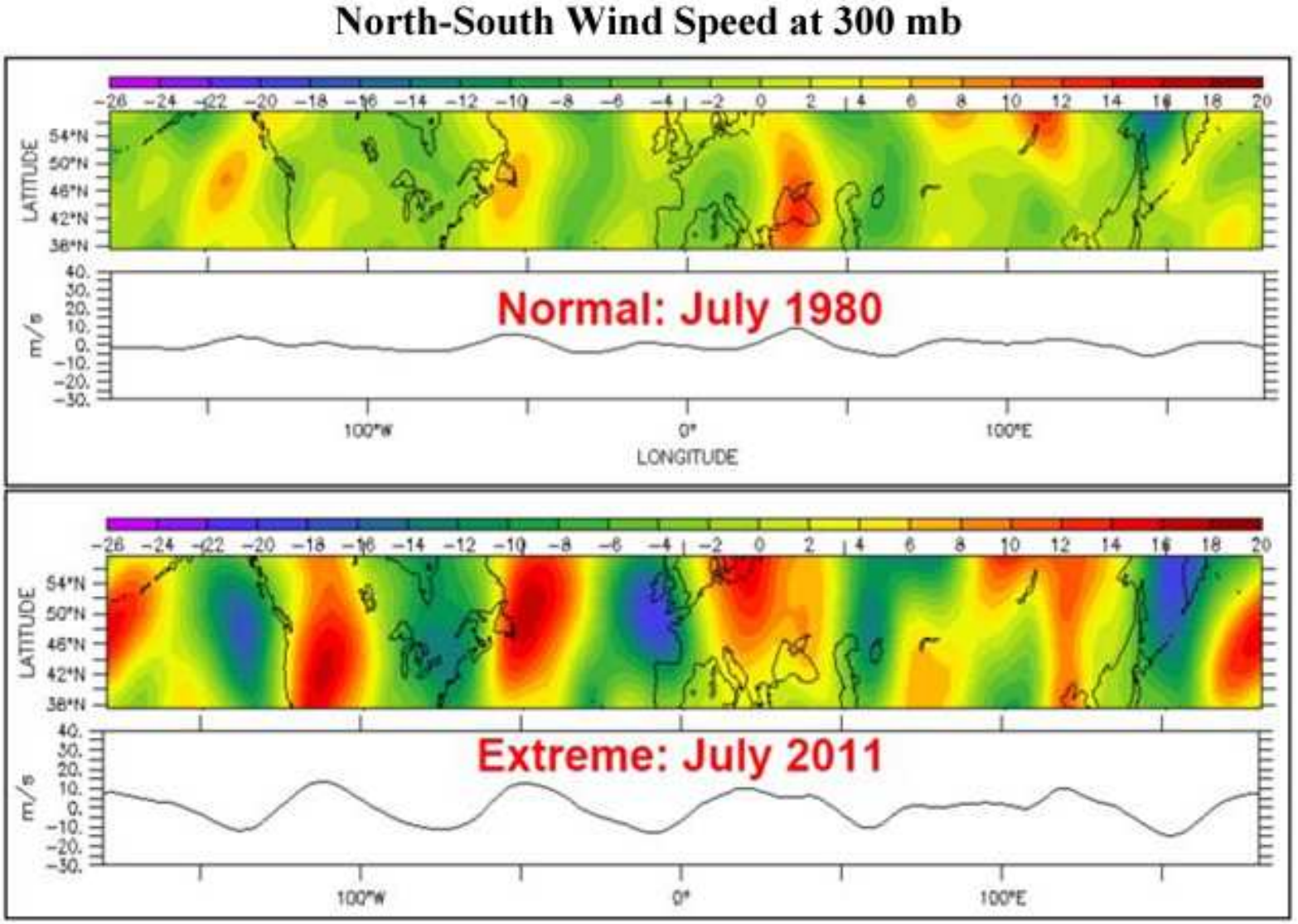
0 - 10 %	10 - 20%	20 - 30%	30 - 40%	40- 50%	> 60%

U.S. Global Change Research Program, 2012 http://globalchange.gov/

Arctic Sea Ice Volume has Shrunk by 5x; Extent by 2x



Extreme Summer Jet Stream Patterns Have Doubled in Frequency in the Past 11 Years



Petoukhov et al., (2013), "Quasi-resonant amplification of planetary waves and recent Northern Hemisphere weather extremes"

A Better Way to Measure Extremes: Use the National Climatic Data Center's Climate Extremes Index (CEI):

1) Percentage of U.S. with max temperatures much below normal and much above normal.

2) Percentage of U.S. with min temperatures much below normal and much above normal.

3) Percentage of U.S. in severe drought and with severe moisture surplus.

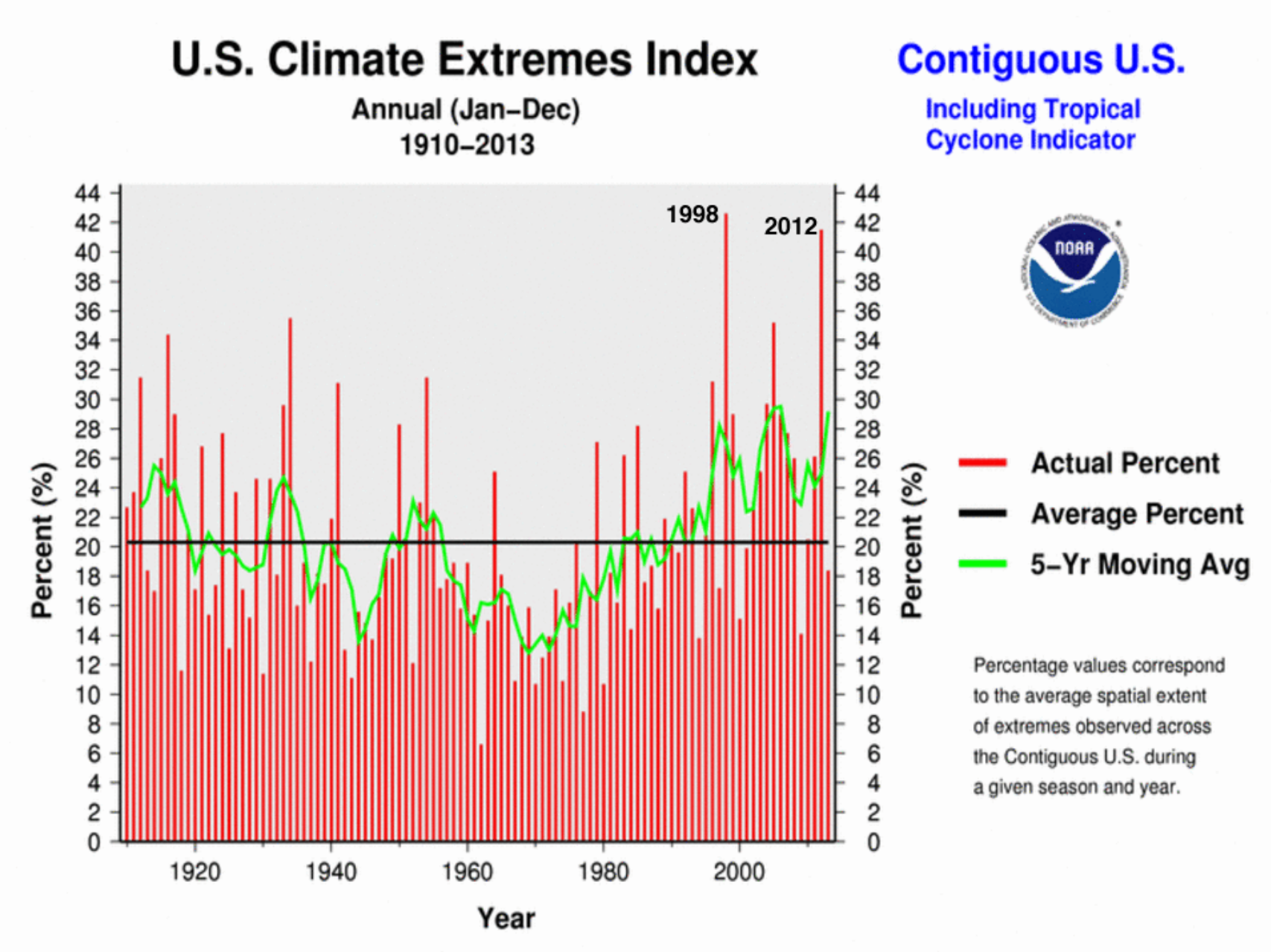
4) Percentage of U.S. with a much greater than normal proportion of precipitation derived from extreme (equivalent to the highest tenth percentile) 1-day precipitation events.

5) Percentage U.S. with a much greater than normal number of days with precipitation and without precipitation.

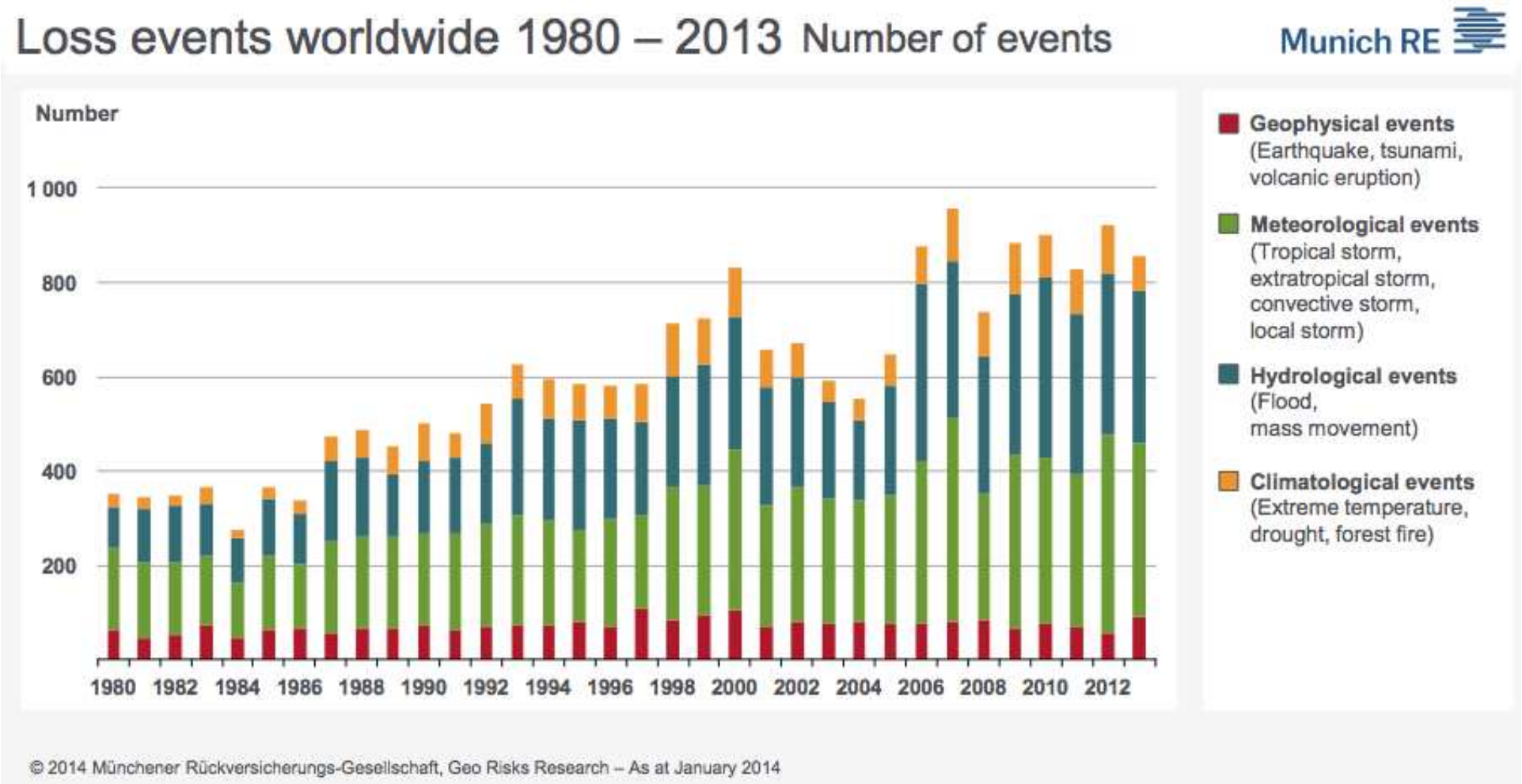
6) Optionally, toss in land falling tropical storms and hurricanes.

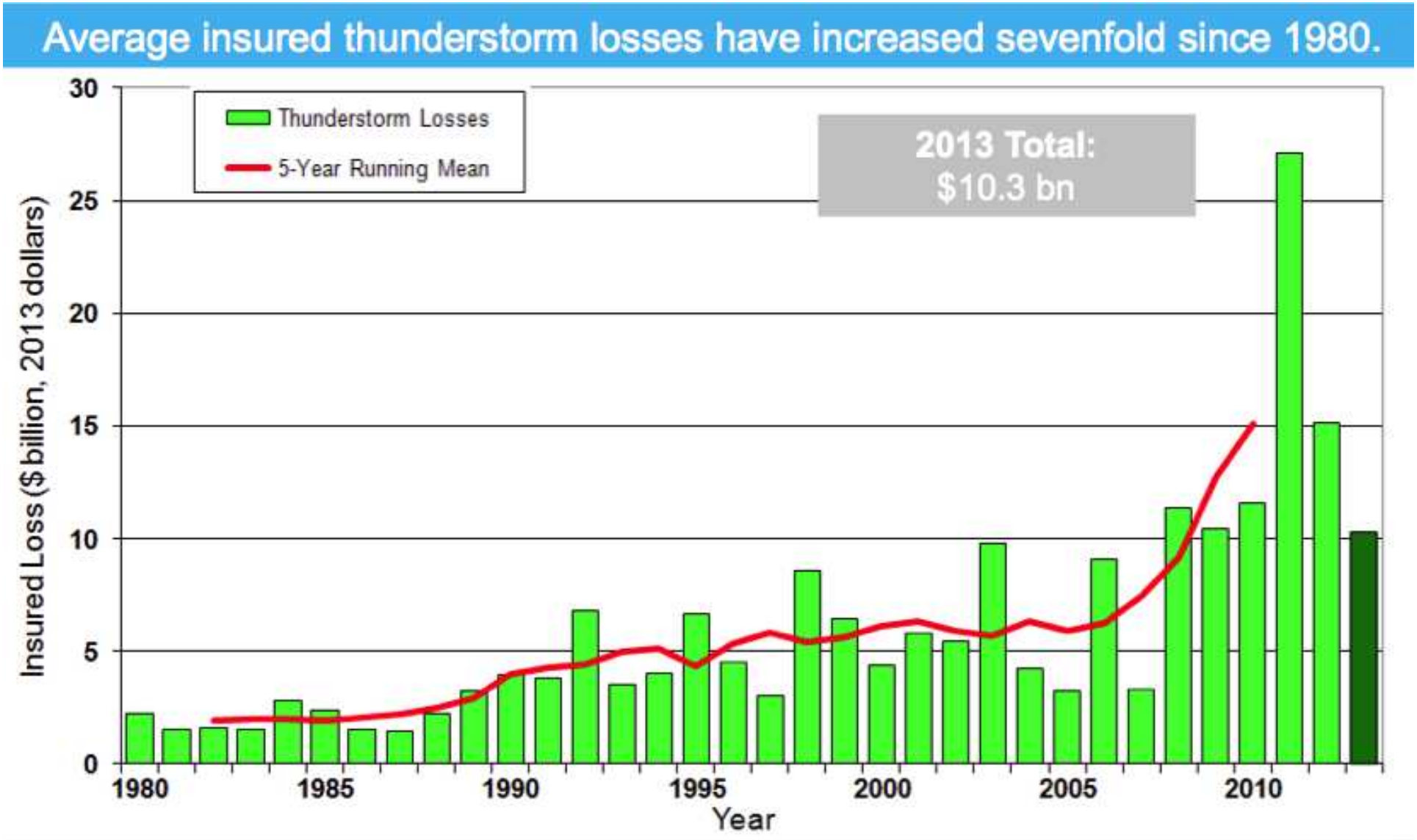
http://www.ncdc.noaa.gov/oa/climate/research/cei/cei.html

Extremes Have been Rising Since the 1970s, and the Two Most Extreme Years in U.S. History Were Also the Two Warmest Years: 2012 and 1998



The Number of Natural Catastrophes has Risen, but This Might be Due to Increased Population and Communication Ability



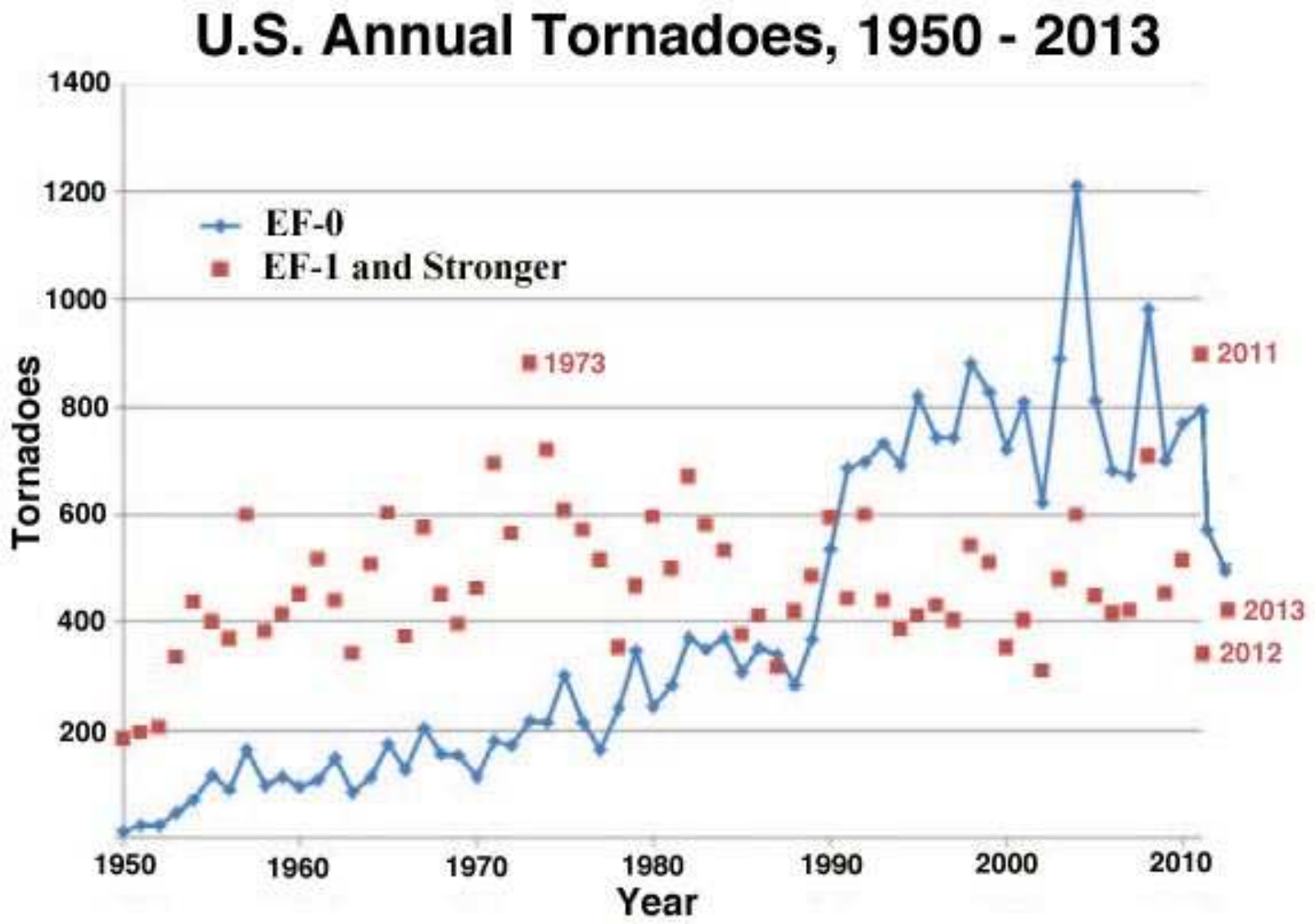


However, rising disaster costs may not be due to an increase in extreme weather. Bouwer (BAMS, 2010) reviewed 22 disaster loss studies world-wide, published 2001 - 2010; in all 22 studies, increases in wealth and population were the "most important drivers for growing disaster losses." Conclusion: human-caused climate change "so far has not had a significant impact on losses from natural disasters."

We Can’t Say Yet if Tornadoes are Responding to Climate Change

2007 United Nations IPCC report: "There is insufficient evidence to determine whether trends exist in small scale phenomena such as tornadoes, hail, lighting, and dust storms."

The Tornado Database is Highly Unsuitable for Detecting Long-Term Trends, but Shows no Change in EF-1 and Stronger Tornadoes



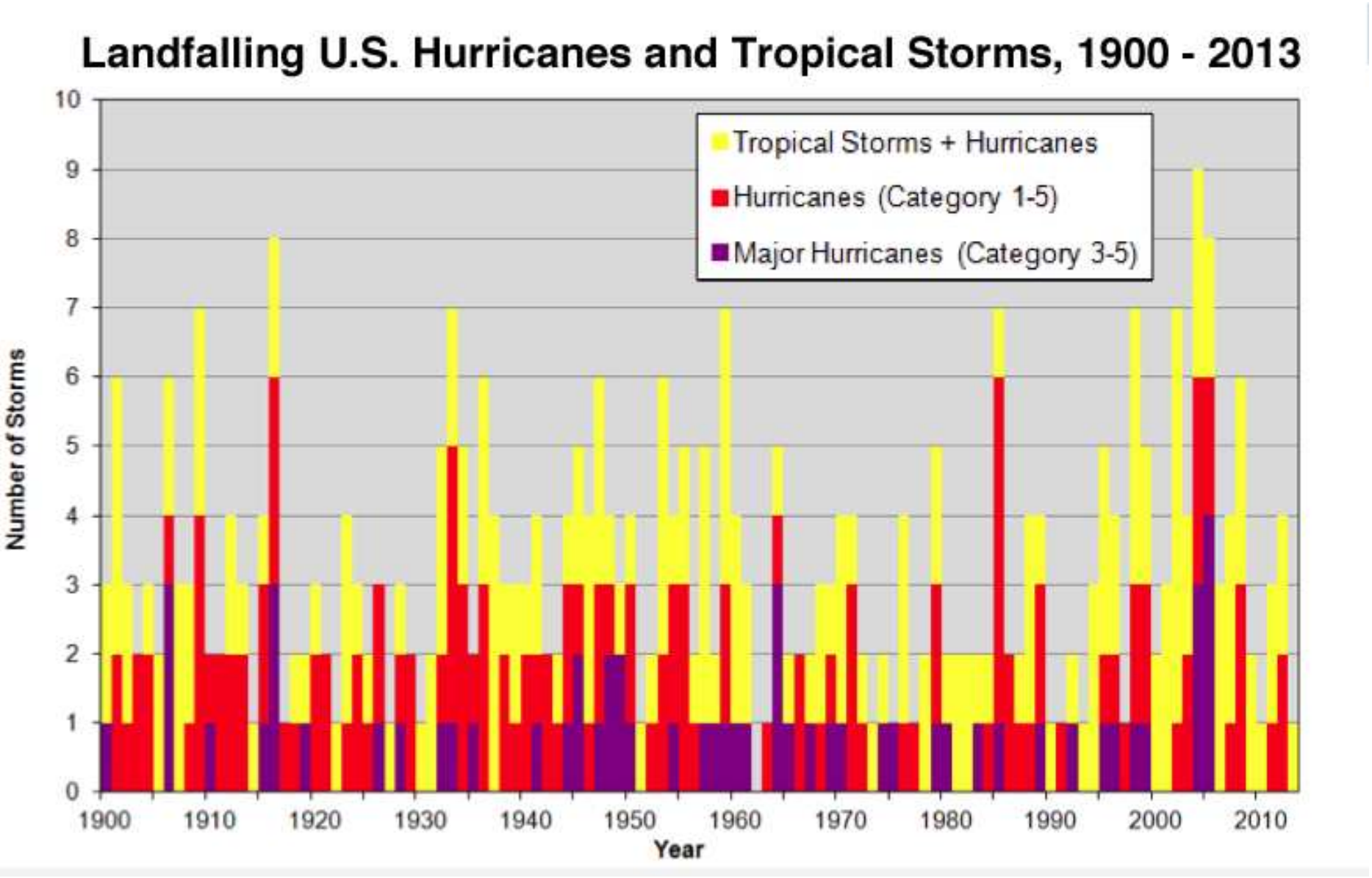
We Can't Say Yet if Hurricanes are Responding to Climate Change

"It remains uncertain whether past changes in any tropical cyclone activity (frequency, intensity, rainfall, and so on) exceed the variability expected through natural causes"

- 2010 Review Article by Ten Top Hurricane Scientists, "Tropical cyclones and climate change"

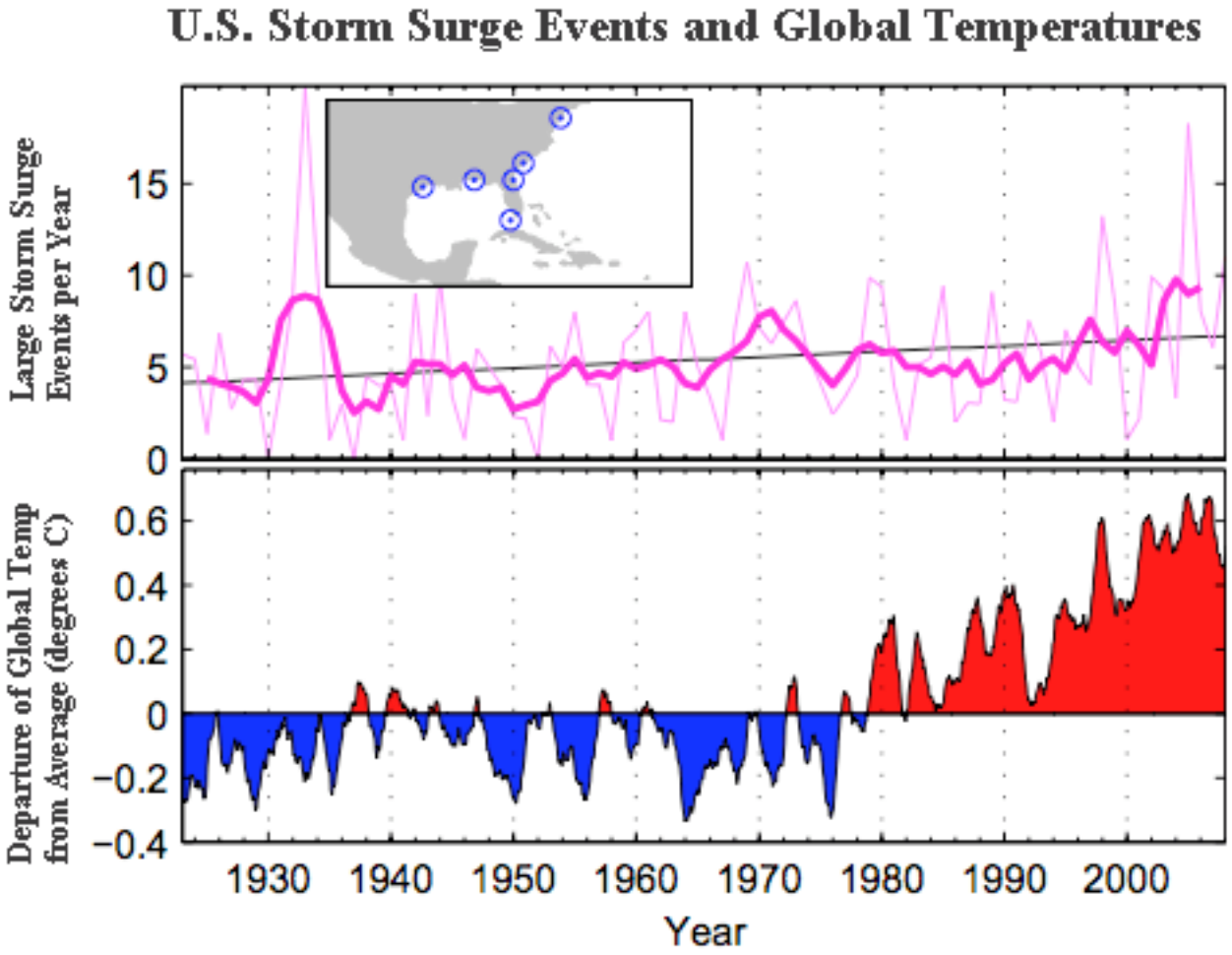
Hurricane Igor of 2010 as seen from the International Space Station

There Has Been no Increase in Landfalling U.S. Hurricanes



Credit: Munich Re

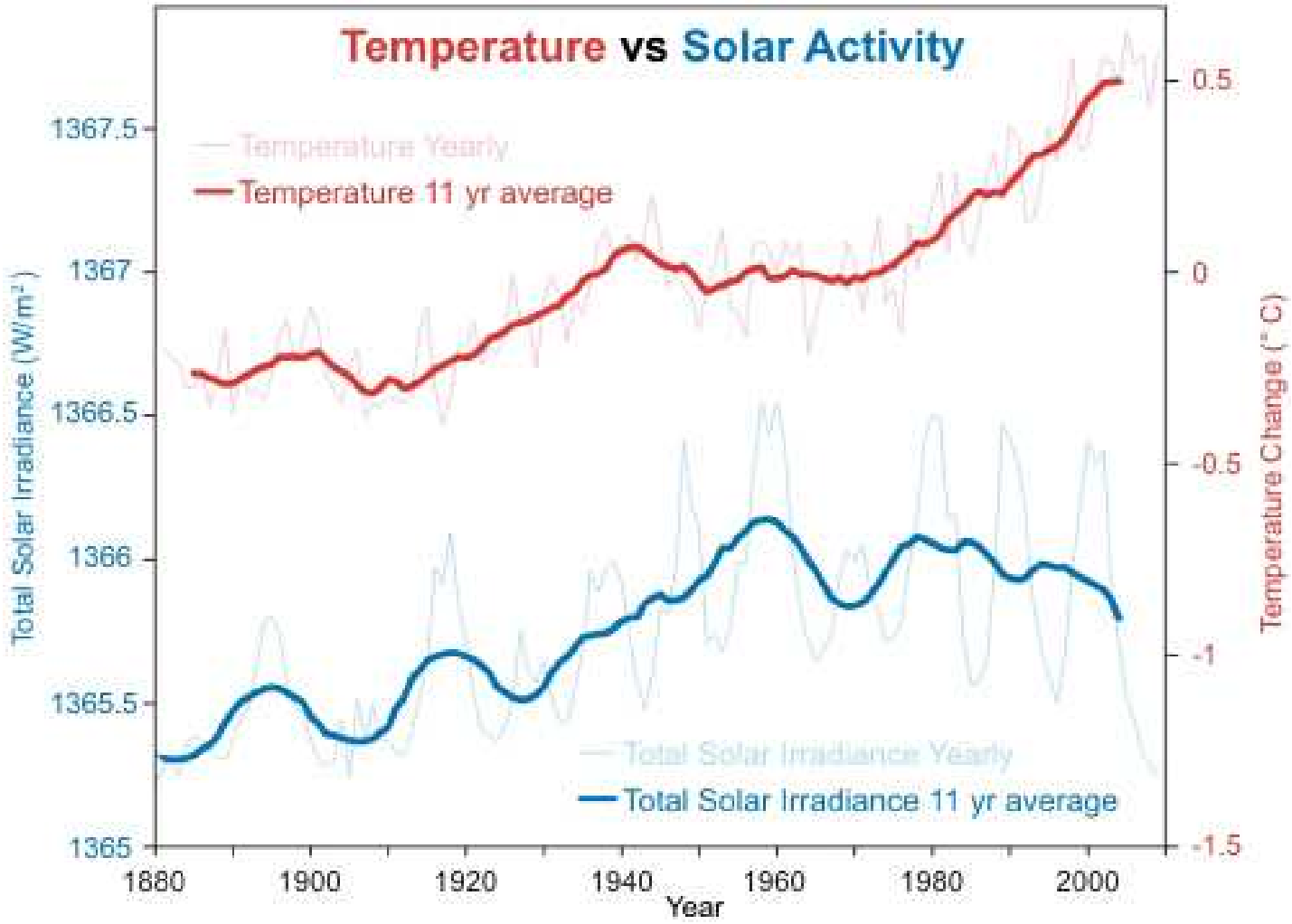
But, 1-in-20 Year Storm Surges are Increasing, and are Twice as Likely in Warm Years



Grinsted et al. 2012, "A homogeneous record of Atlantic hurricane surge threat since 1923."

If the glove doesn't fit, you must acquit!

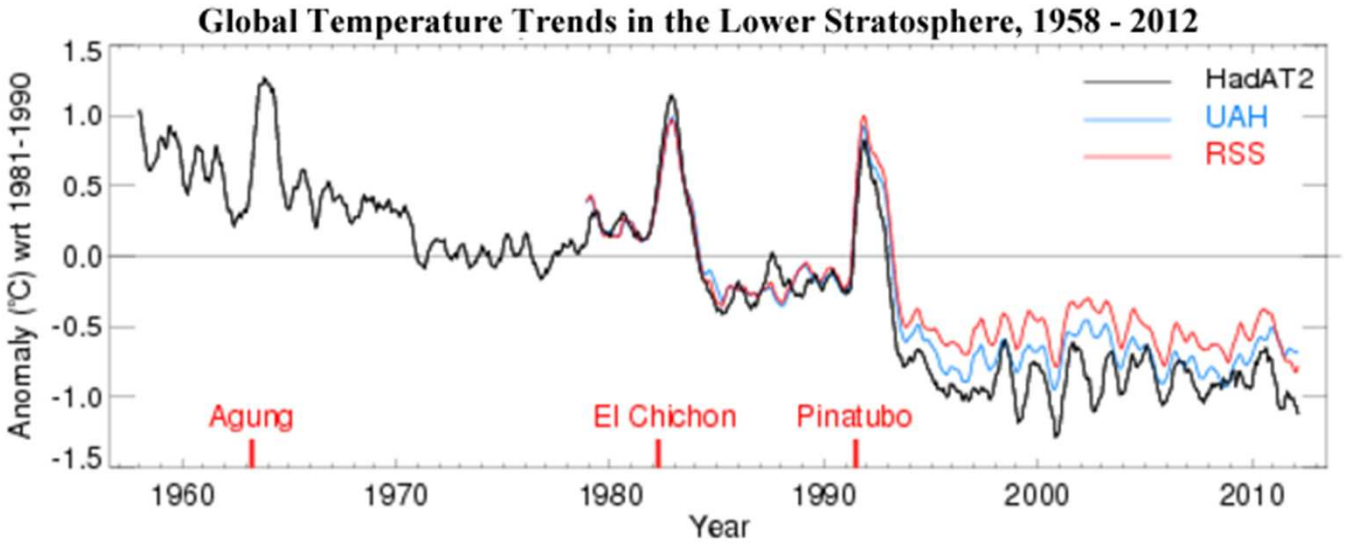
The amount of incoming solar energy has been falling in recent decades, so the sun cannot be causing global warming.

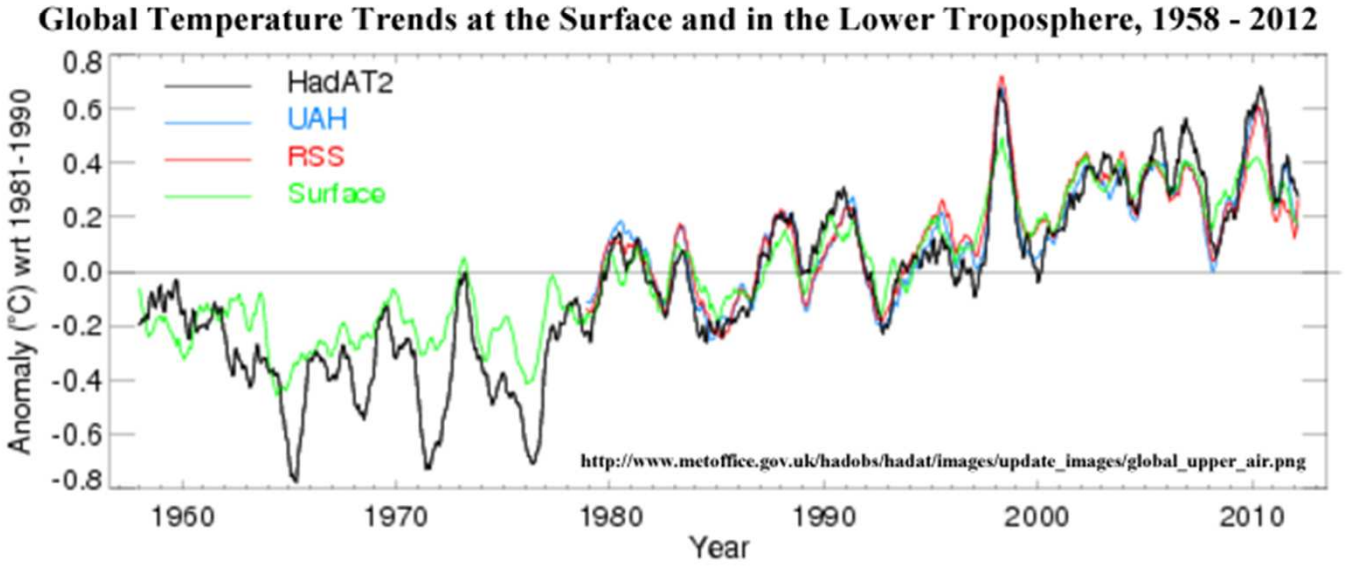


Source: http://www.wunderground.com/climate/facts/sun_is_not_to_blame.asp

If the glove doesn't fit, you must acquit!

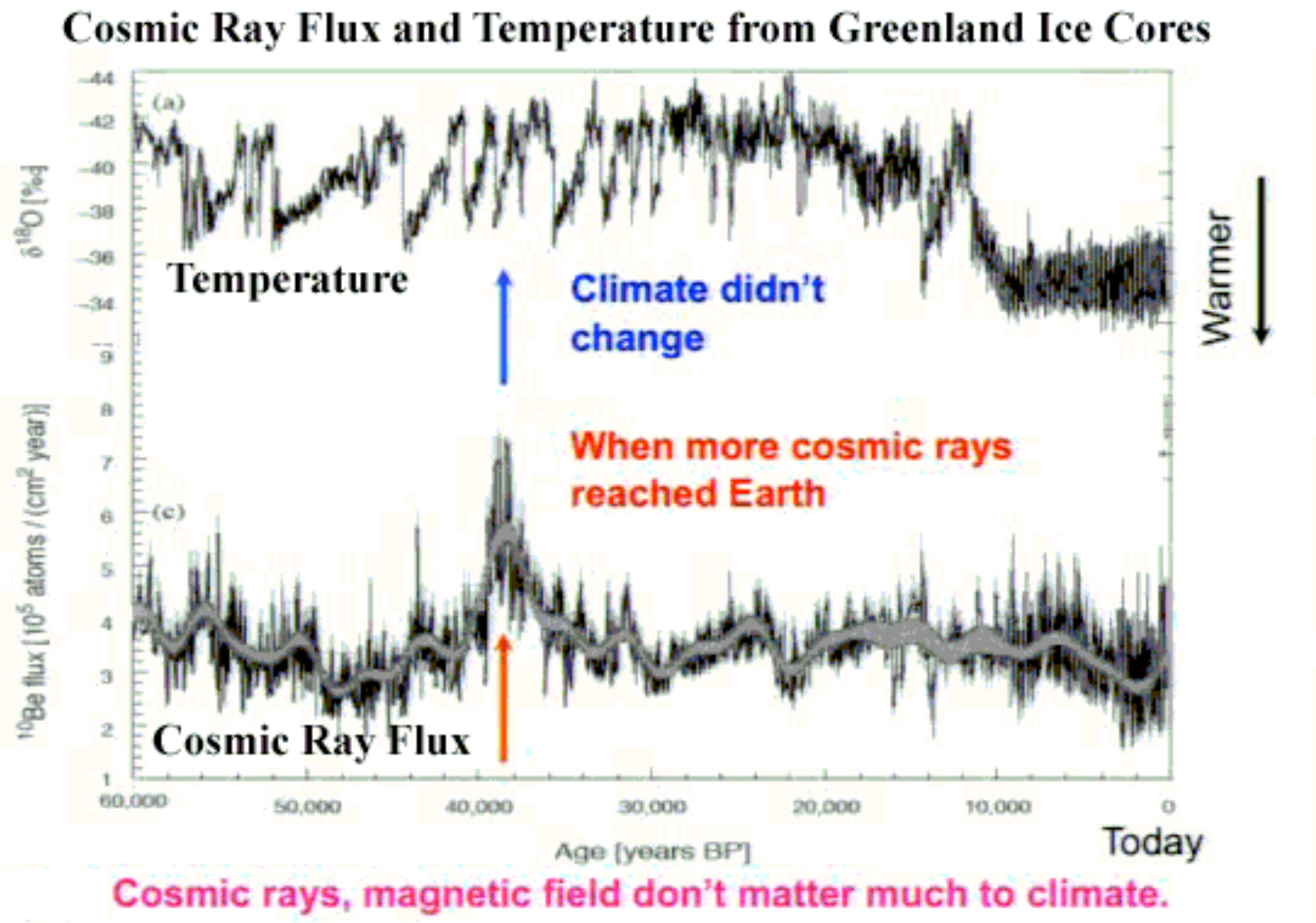
Temperatures at the surface have been rising, but not in the upper atmosphere, so the sun cannot be causing global warming.





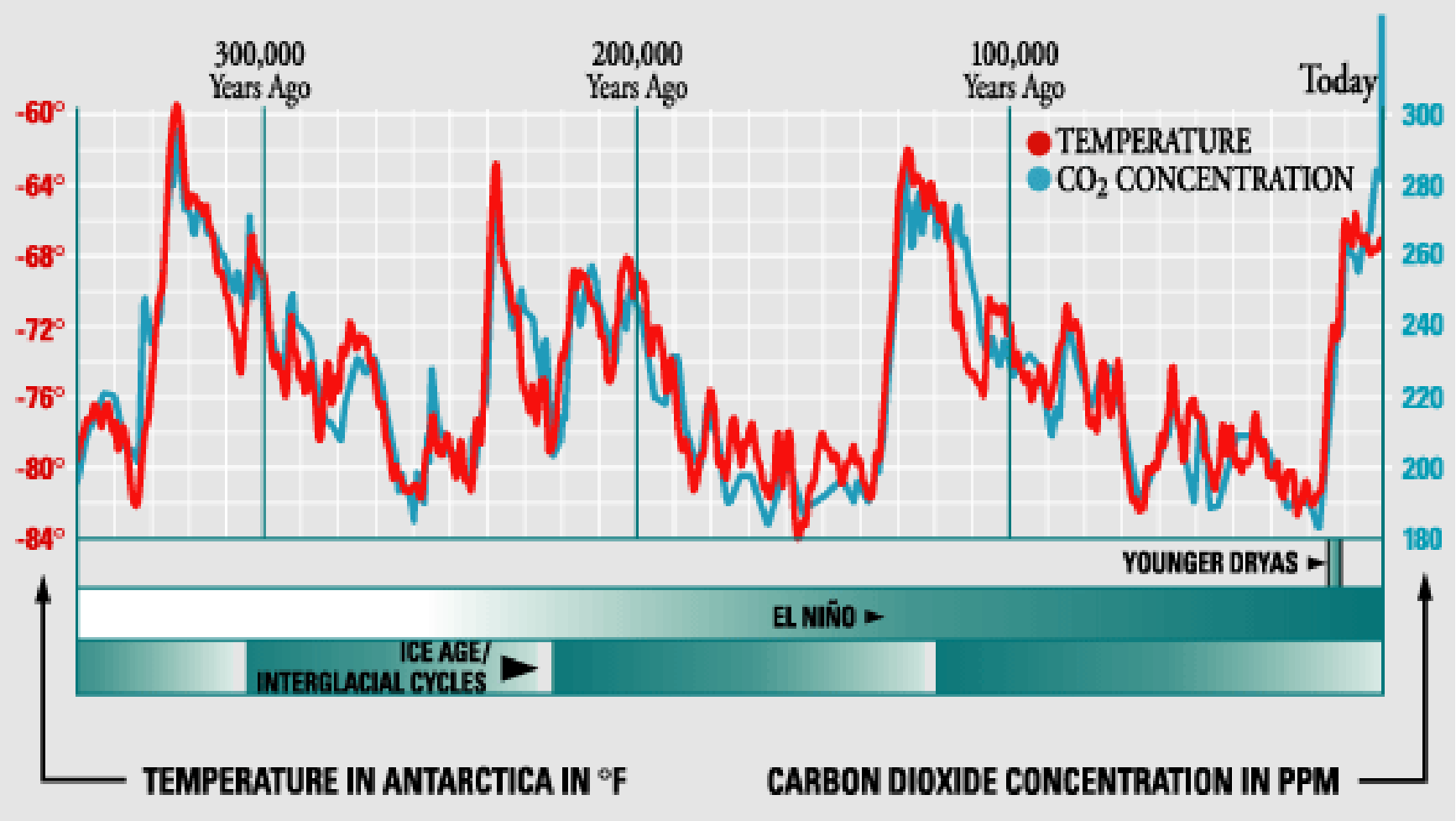
If the glove doesn't fit, you must acquit!

Cosmic rays, which can theoretically change cloud cover, do not correlate well with changes Earth's global temperature



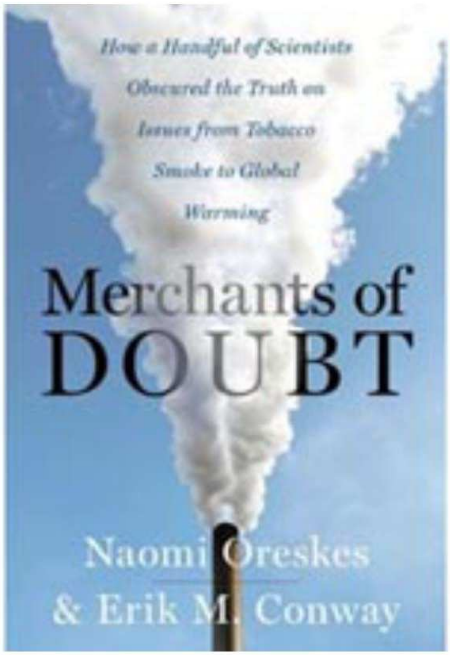
But the glove does fit for CO2!

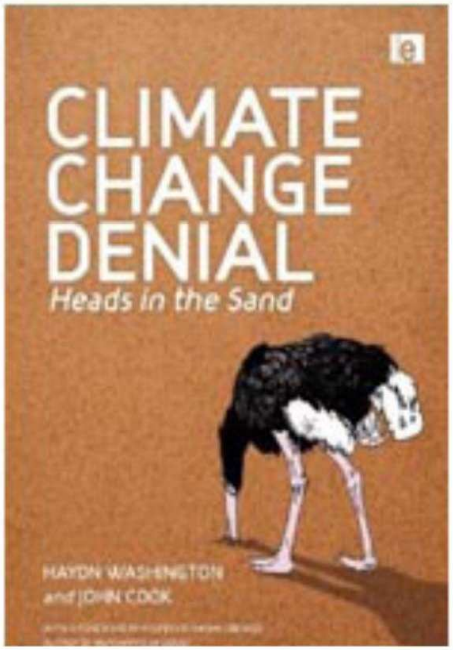
Ice core and other paleohistory records show a strong link between CO2 and global temperatures

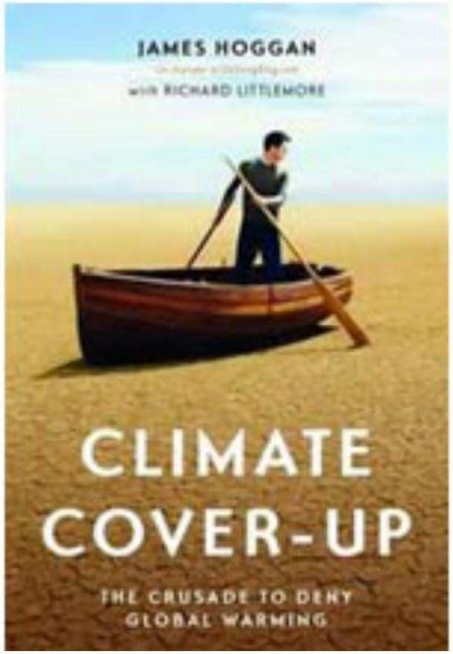


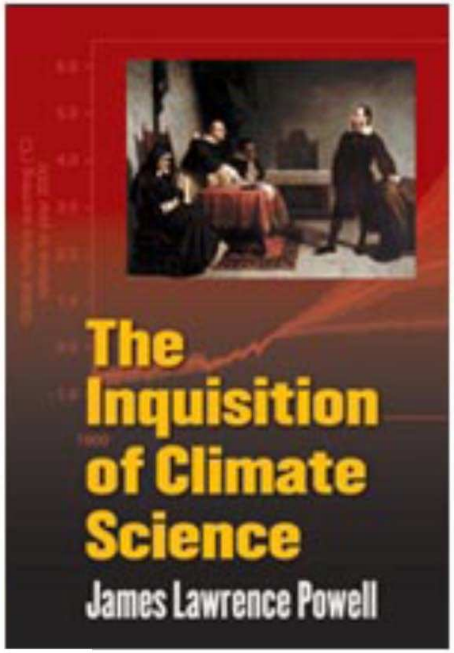
Q: Why is there such widespread doubt that Earth's climate is warming, humans are mostly responsible, and the overwhelming majority of climate scientists agree?

A: Because of a well-funded PR campaign by the oil, coal, and gas industries, amplified by sympathetic media outlets and politicians. Most of the public is in no position to distinguish good science from bad, so if you can create doubt, uncertainty, and confusion, you can win.



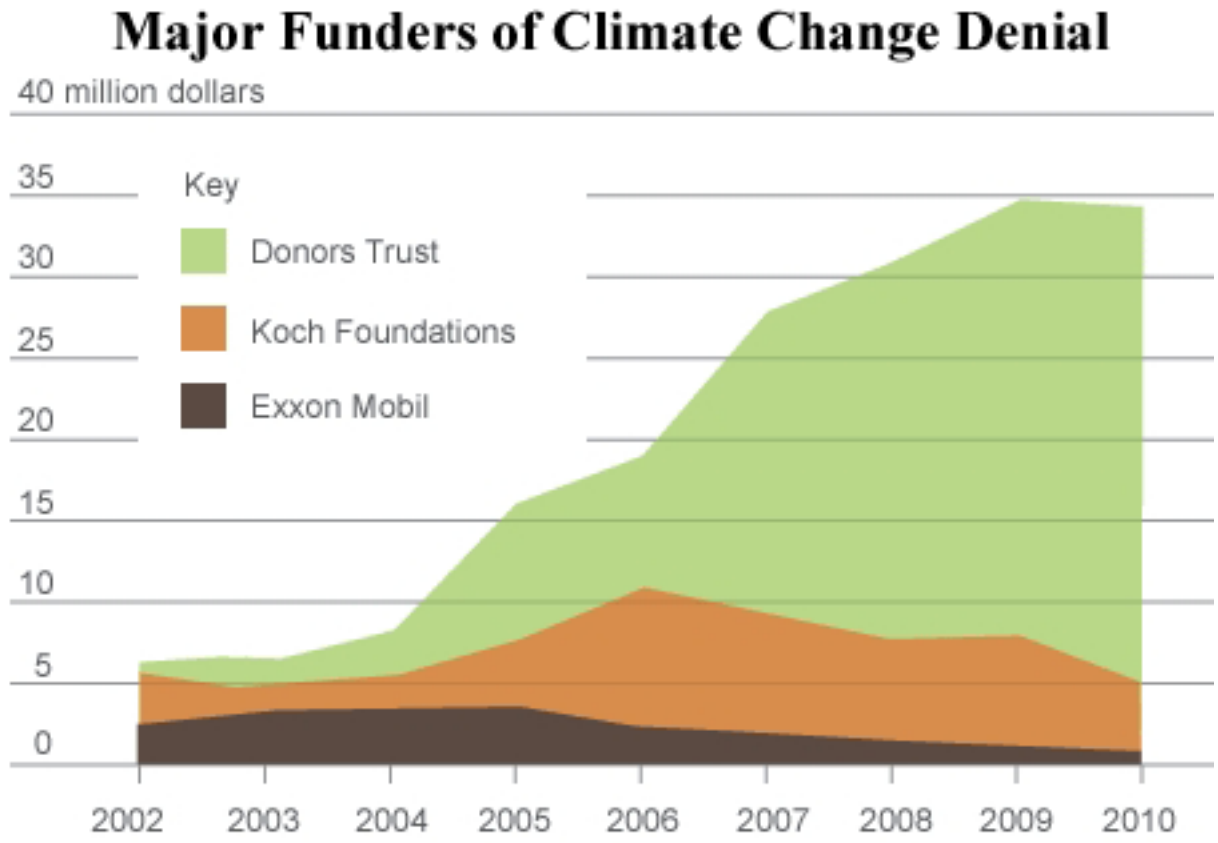






From 2003 to 2010, $500 million was given to anti-climate science organizations by the fossil fuel industry. Biggest donors: Koch Foundation, Scaife Foundation, Donors Trust.

Source: Drexel University sociologist Dr. Robert Brulle on PBS's FRONTLINE show, October 2012



http://www.guardian.co.uk/environment/2013/feb/14/funding-climate-change-denial-thinktanks-network

The Future of Climate Change: The Great Unknown

"We are now ready to start our way down the Great Unknown. We have an unknown distance yet to run, an unknown river to explore. What falls there are, we know not; what rocks beset the channel, we know not; what walls rise over the river, we know not. Ah well! We may conjecture many things."

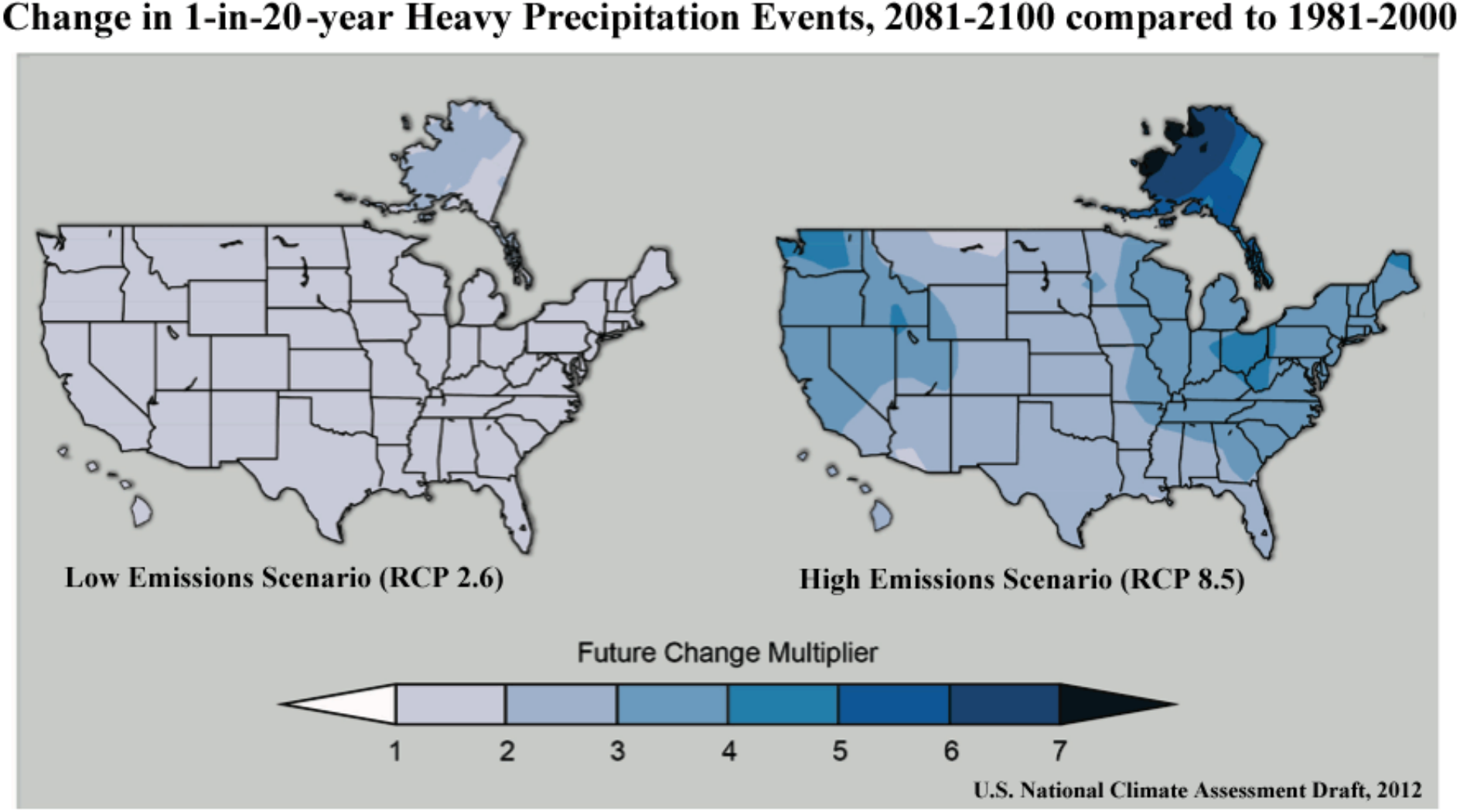
- John Wesley Powell's description of his 1869 trip through the Grand Canyon in his book, *The Exploration of the Colorado River and Its Canyons*

Most Expensive U.S. Weather Disasters Since 1980

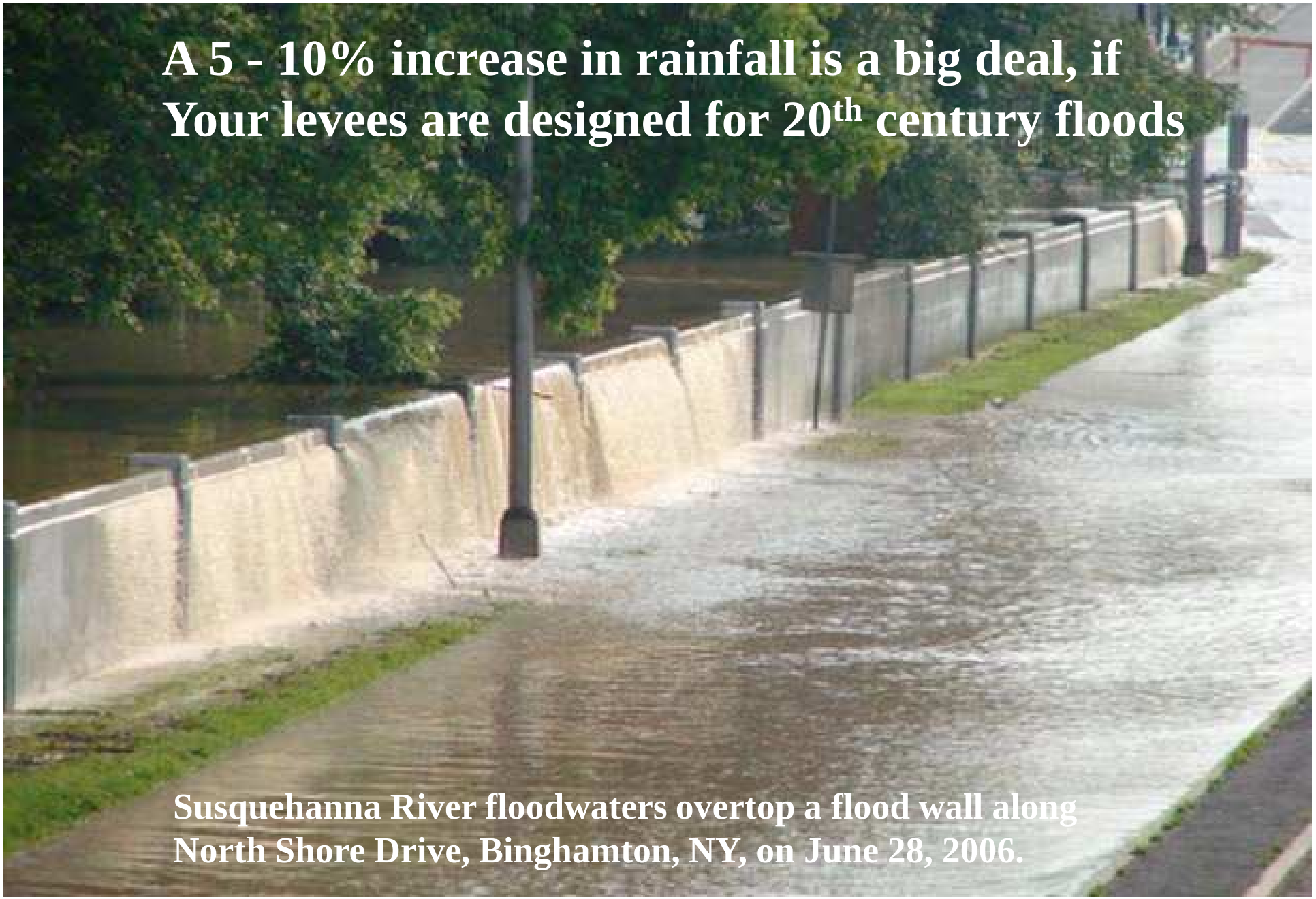
Rank	Disaster	Year	Deaths	Damage (2013 dollars)
1.	Hurricane Katrina, LA/MS/AL	2005	1200	$149,000,000,000
2.	Drought, Midwest/East	1988	7,500	$79,000,000,000
3	Hurricane Sandy, Northeast	2012	131	$65,000,000,000
4.	Drought, Midwest/East	1980	10,000	$56,000,000,000
5.	Hurricane Andrew, FL/LA	1992	26	$45,000,000,000
6.	Flood, Mississippi River	1993	48	$34,000,000,000
7.	Drought, Midwest/West	2012	123	$30,000,000,000
8.	Hurricane Ike, TX/LA/MS	2008	112	$29,000,000,000
9.	Hurricane Wilma, FL	2005	35	$19,000,000,000
10.	Hurricane Rita, LA/TX	2005	119	$19,000,000,000

Source: http://www.ncdc.noaa.gov/billions

Climate Change's 3rd Greatest Threat: More Extreme Fresh Water Floods

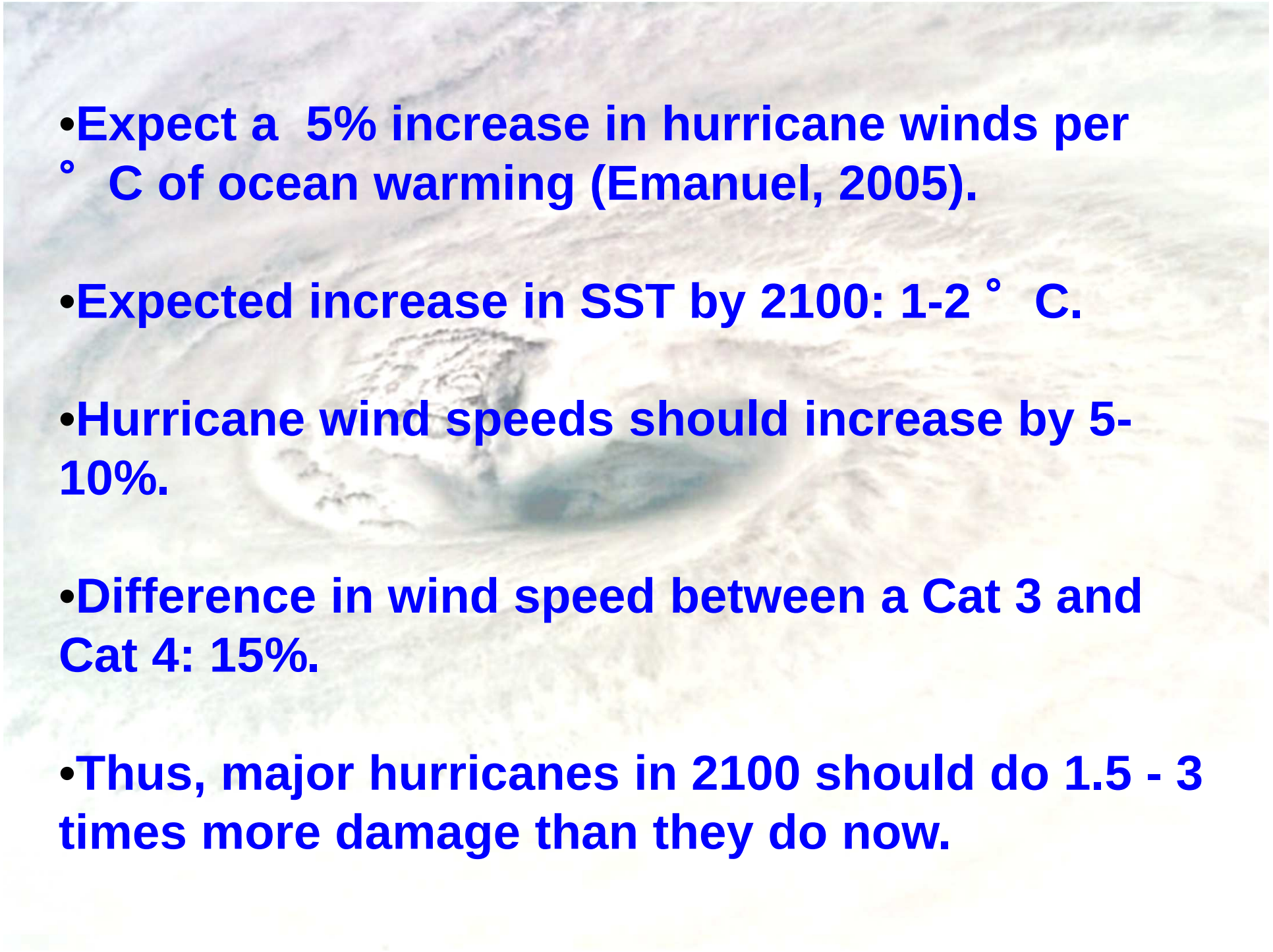


A 1-in-200-year Flood Like the 1862 California "Arkstorm" May be a 1-in-60-year Flood by 2100

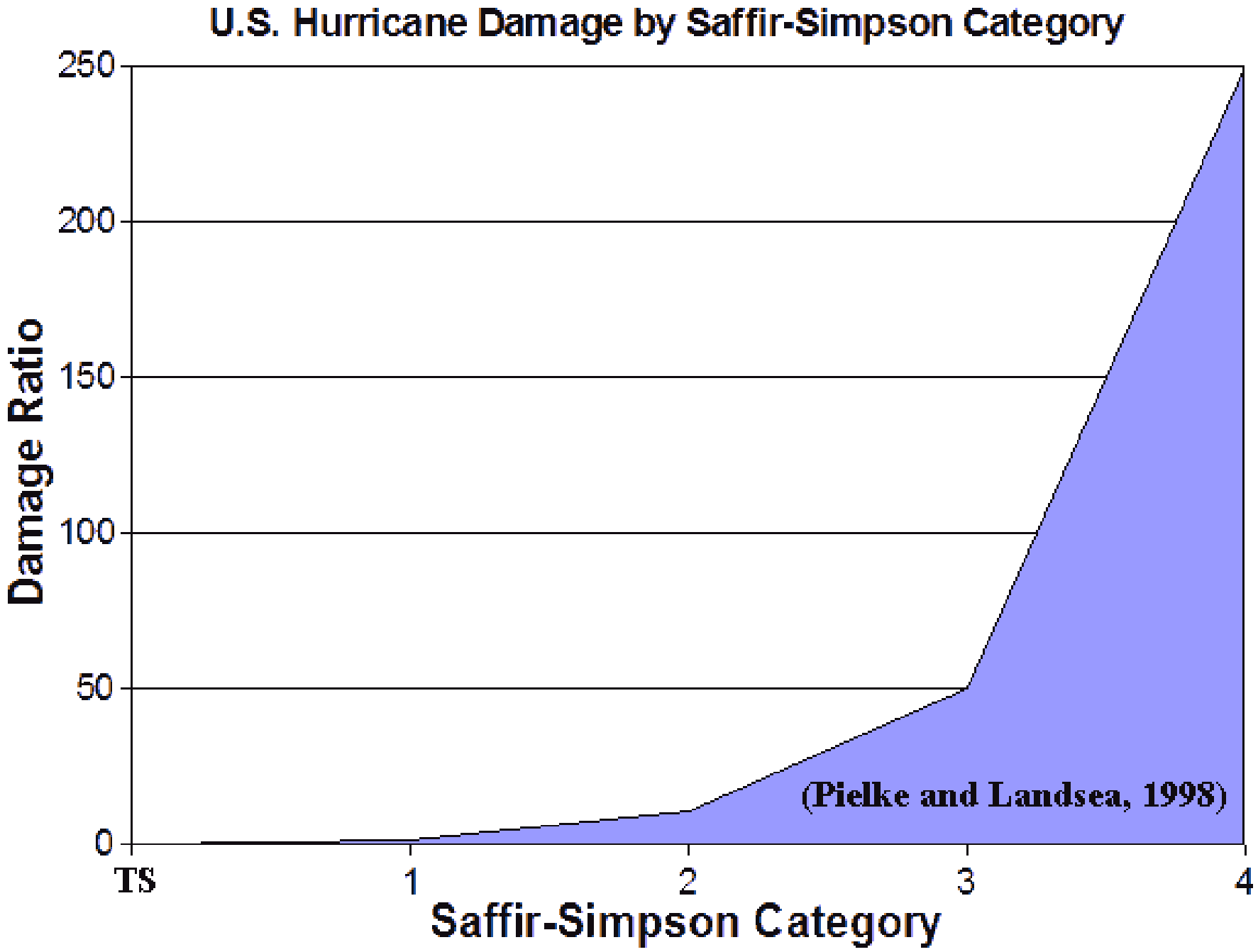


http://www.wunderground.com/blog/JeffMasters/comment.html?entrynum=2002

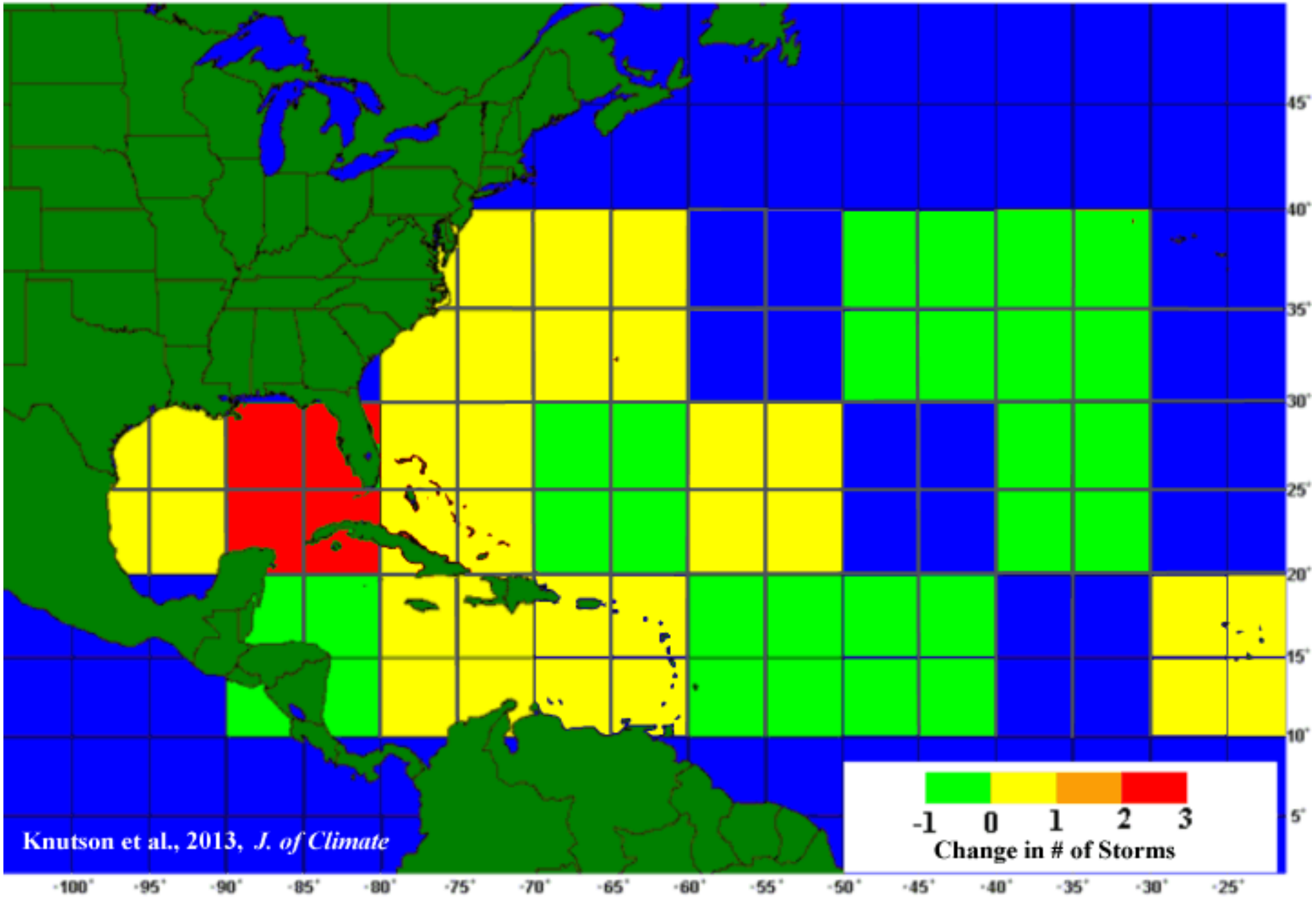
Climate Change's 2nd Greatest Threat: Sea Level Rise Combined With Stronger Storms

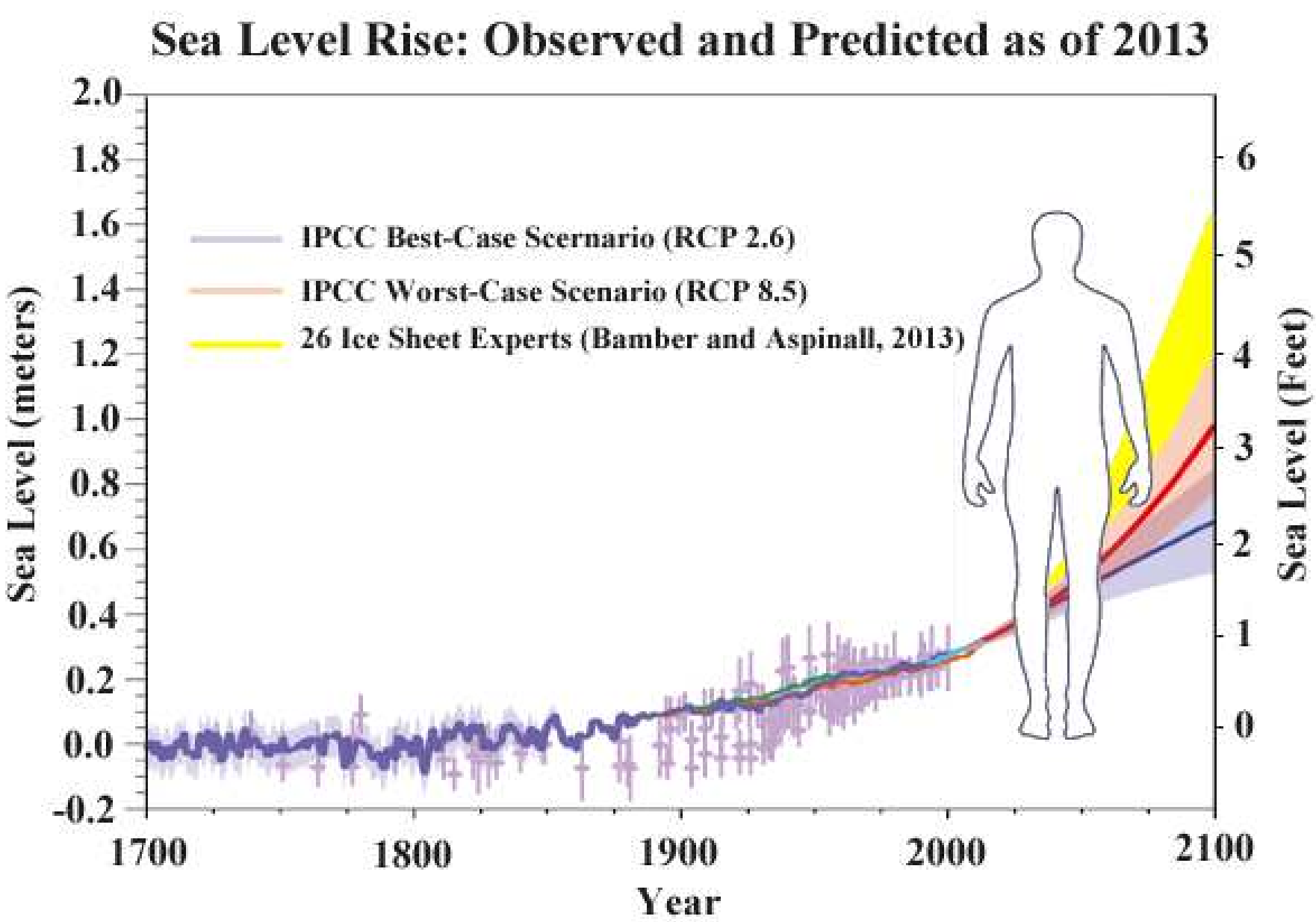


- Expect a 5% increase in hurricane winds per ° C of ocean warming (Emanuel, 2005).
- Expected increase in SST by 2100: 1-2 ° C.
- Hurricane wind speeds should increase by 5-10%.
- Difference in wind speed between a Cat 3 and Cat 4: 15%.
- Thus, major hurricanes in 2100 should do 1.5 - 3 times more damage than they do now.


U.S. Hurricane Damage by Saffir-Simpson Category
Damage Ratio
250
200
150
100
50
0
TS
1
2
3
4
Saffir-Simpson Category
(Pielke and Landsea, 1998)

Predicted Change in Category 4 and 5 Hurricanes per Decade by 2100, 2013 IPCC Models

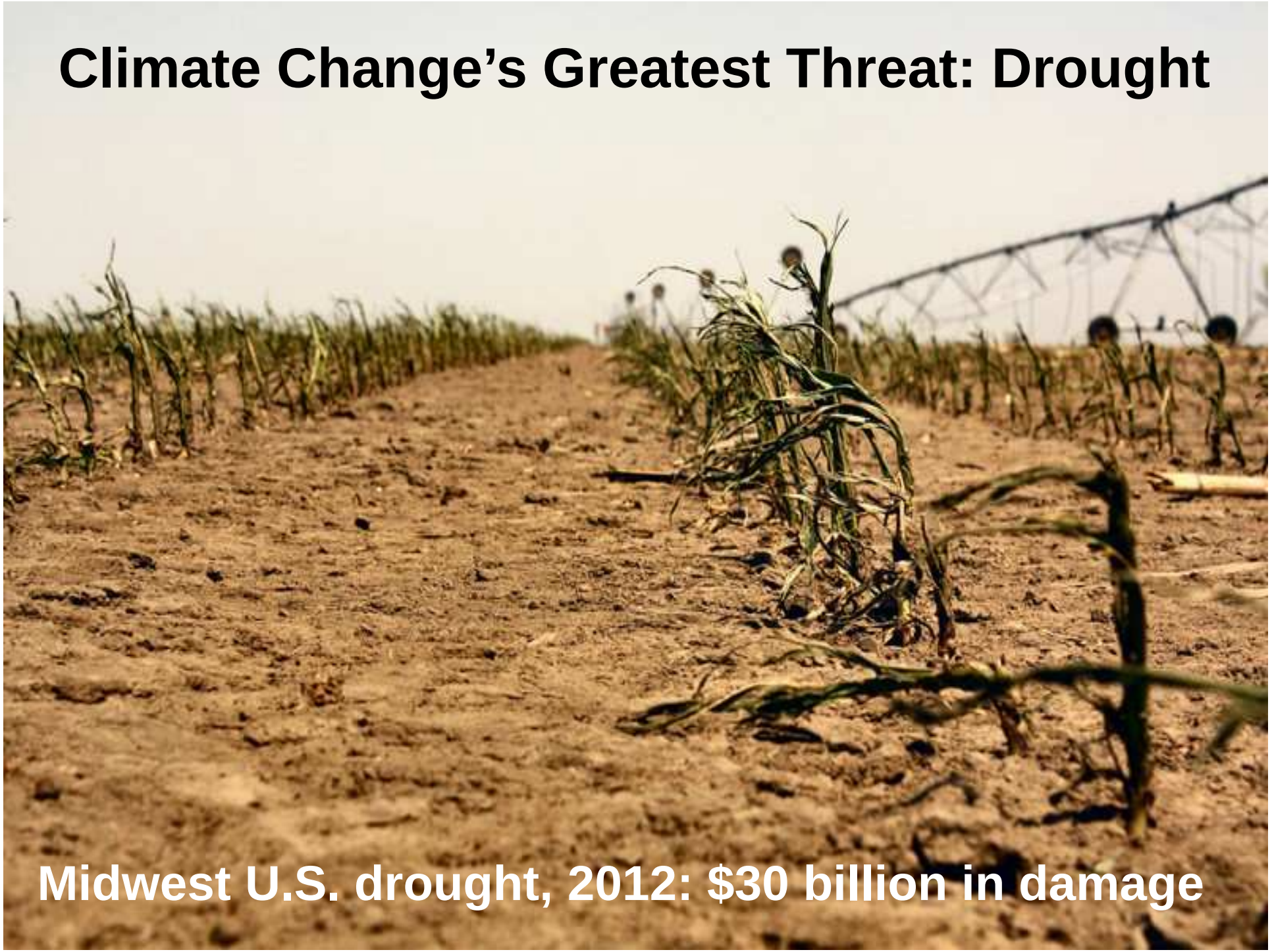



Sea Level Rise: Observed and Predicted as of 2013
IPCC Best-Case Scernario (RCP 2.6)
IPCC Worst-Case Scenario (RCP 8.5)
26 Ice Sheet Experts (Bamber and Aspinall, 2013)
Sea Level (meters)
Sea Level (Feet)
Year
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
6
5
4
3
2
1
0
1700
1800
1900
2000
2100

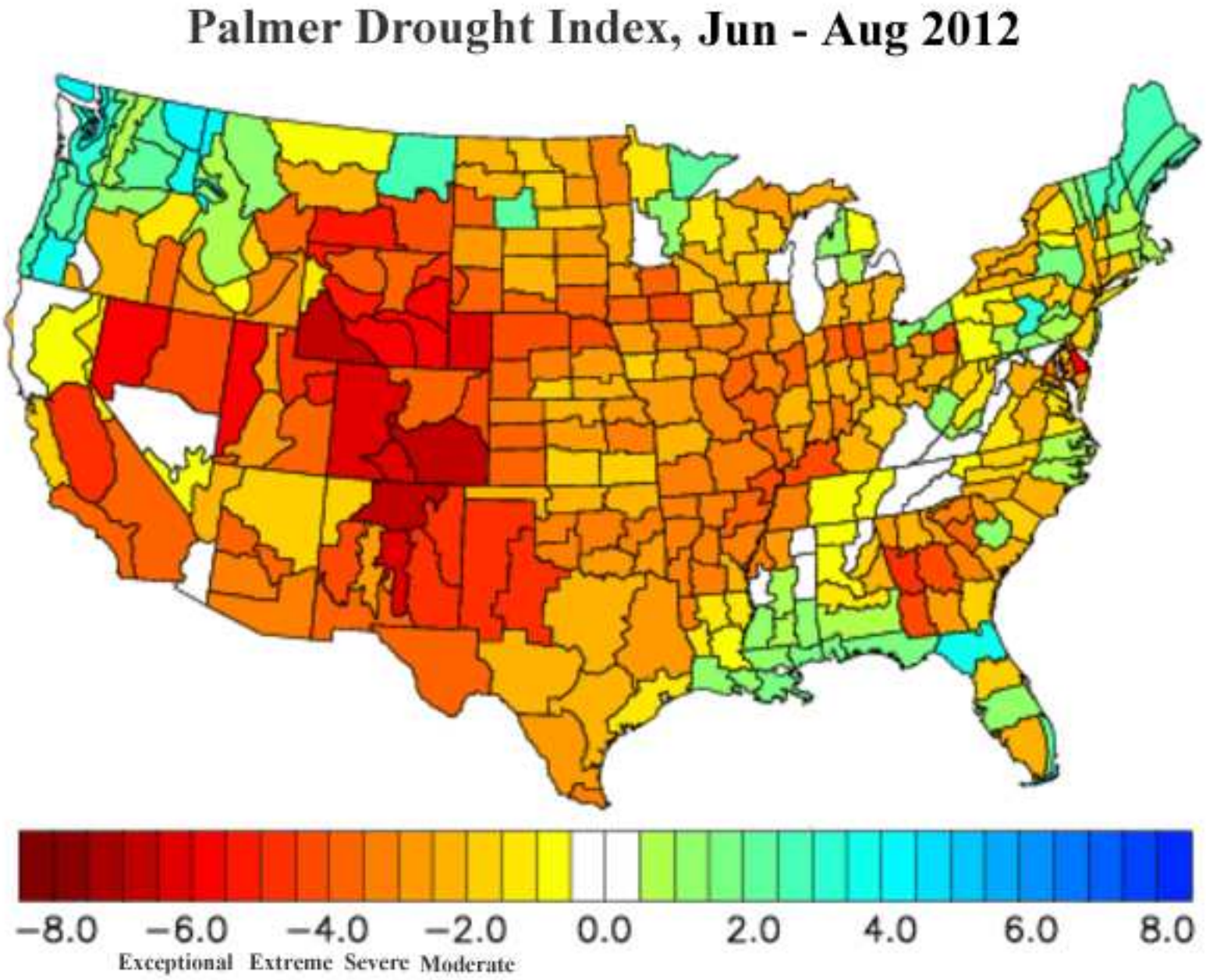
Casino Pier in Seaside Heights, N.J. on Oct. 30, 2012, after Hurricane Sandy.

South Ferry station after Hurricane Sandy; damage: $600 million

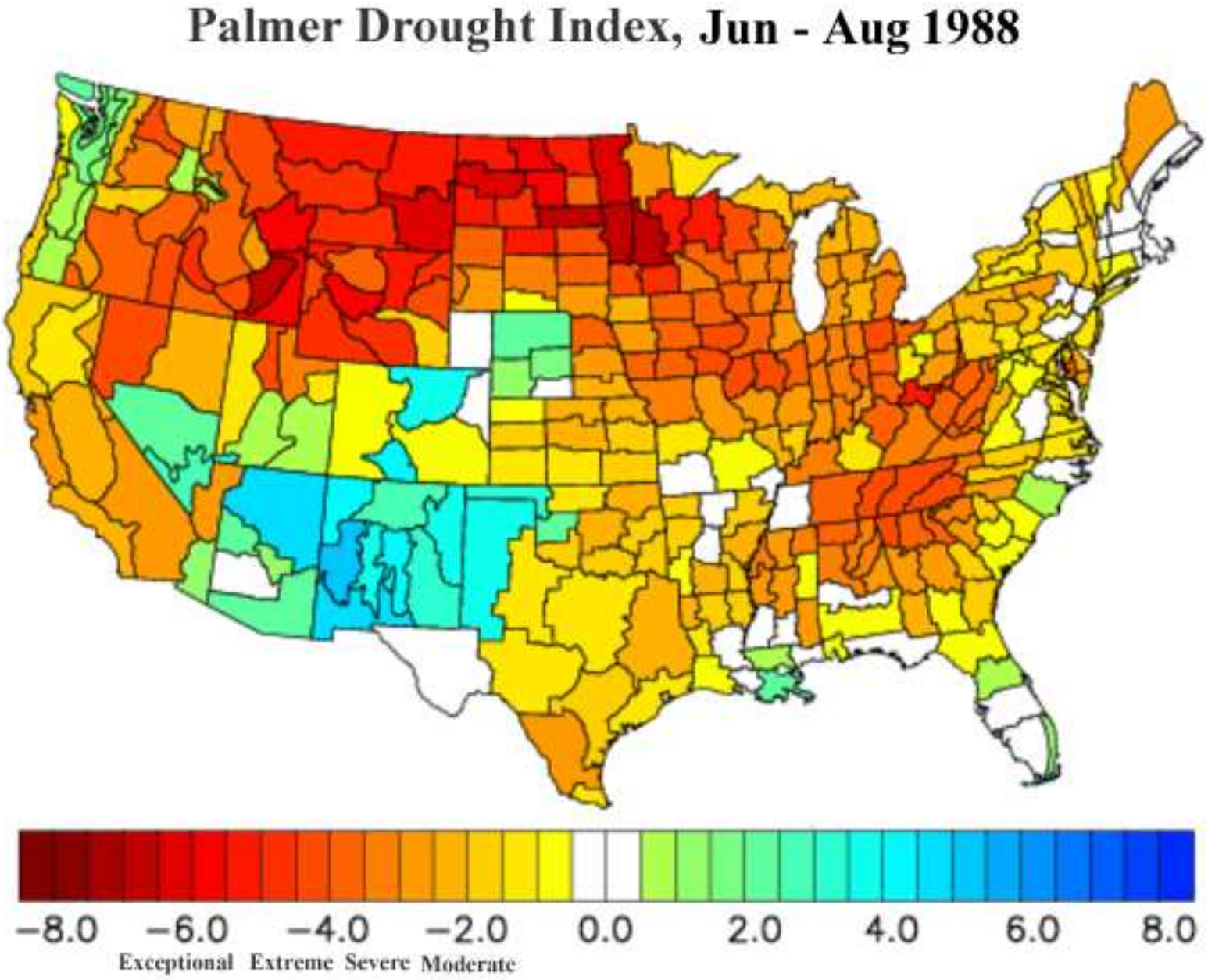
Climate Change's Greatest Threat: Drought



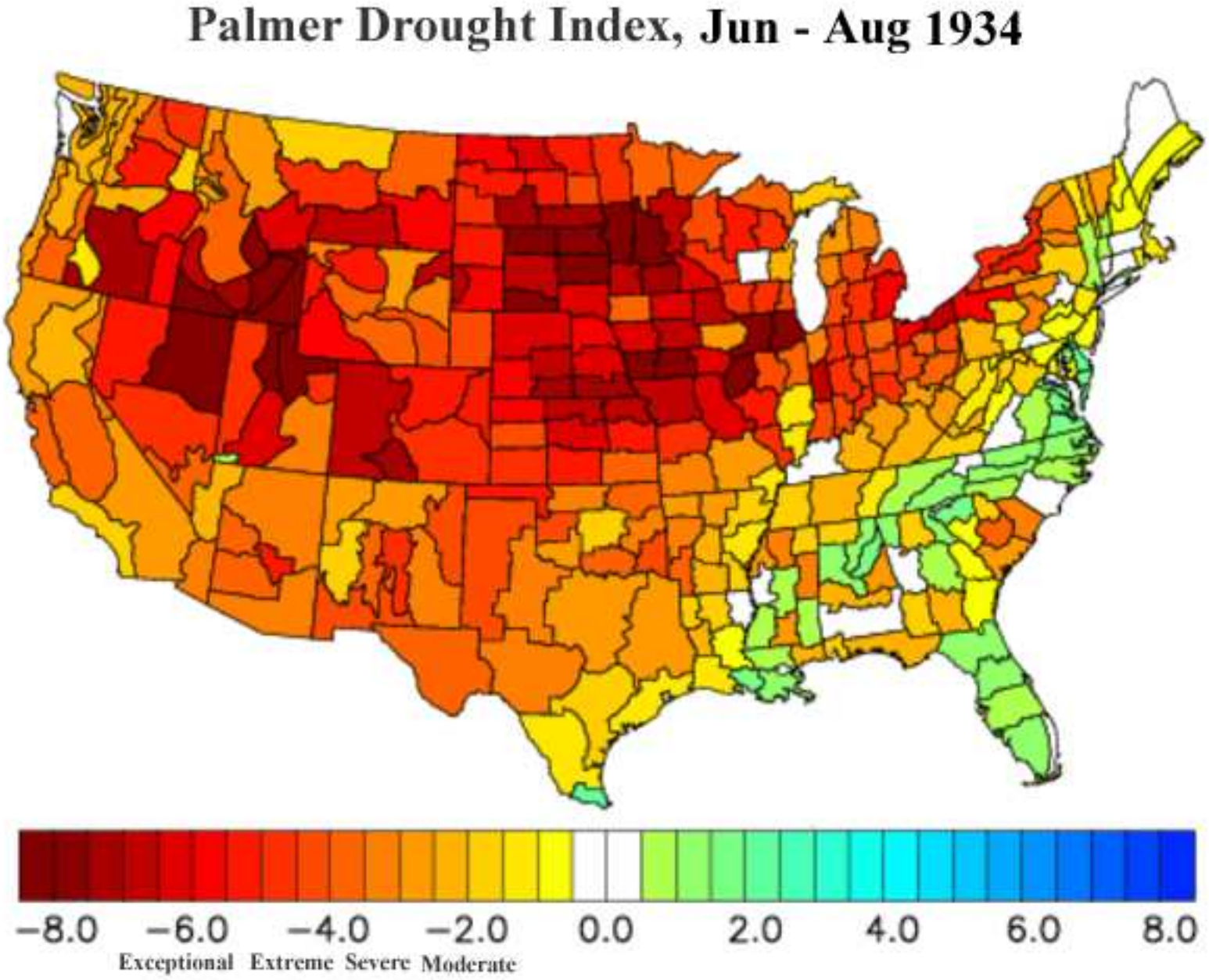
Midwest U.S. drought, 2012: $30 billion in damage



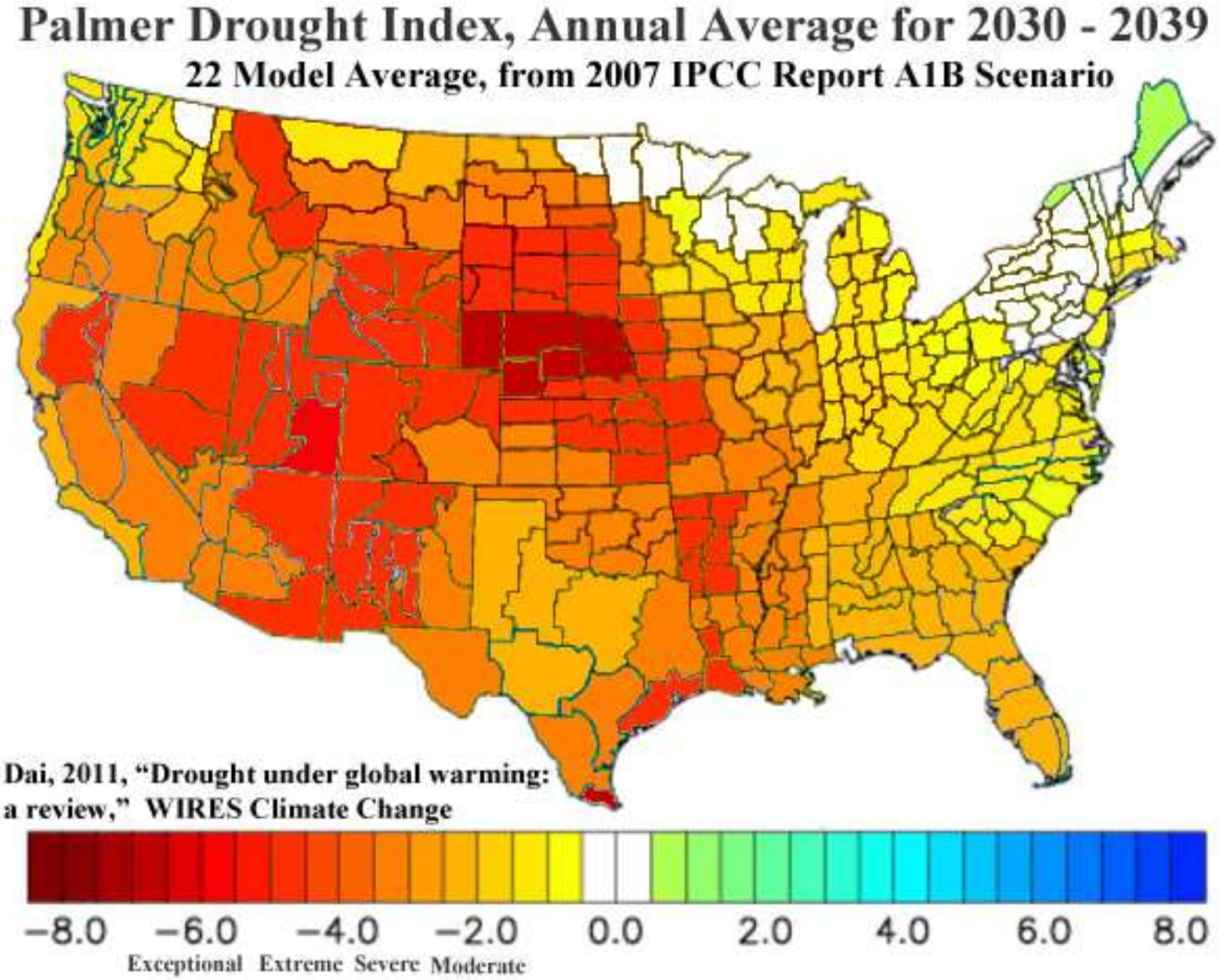
2012 Drought: 123 killed, $30 billion in damage



1988 Drought: 7,500 killed, $71 billion in damage

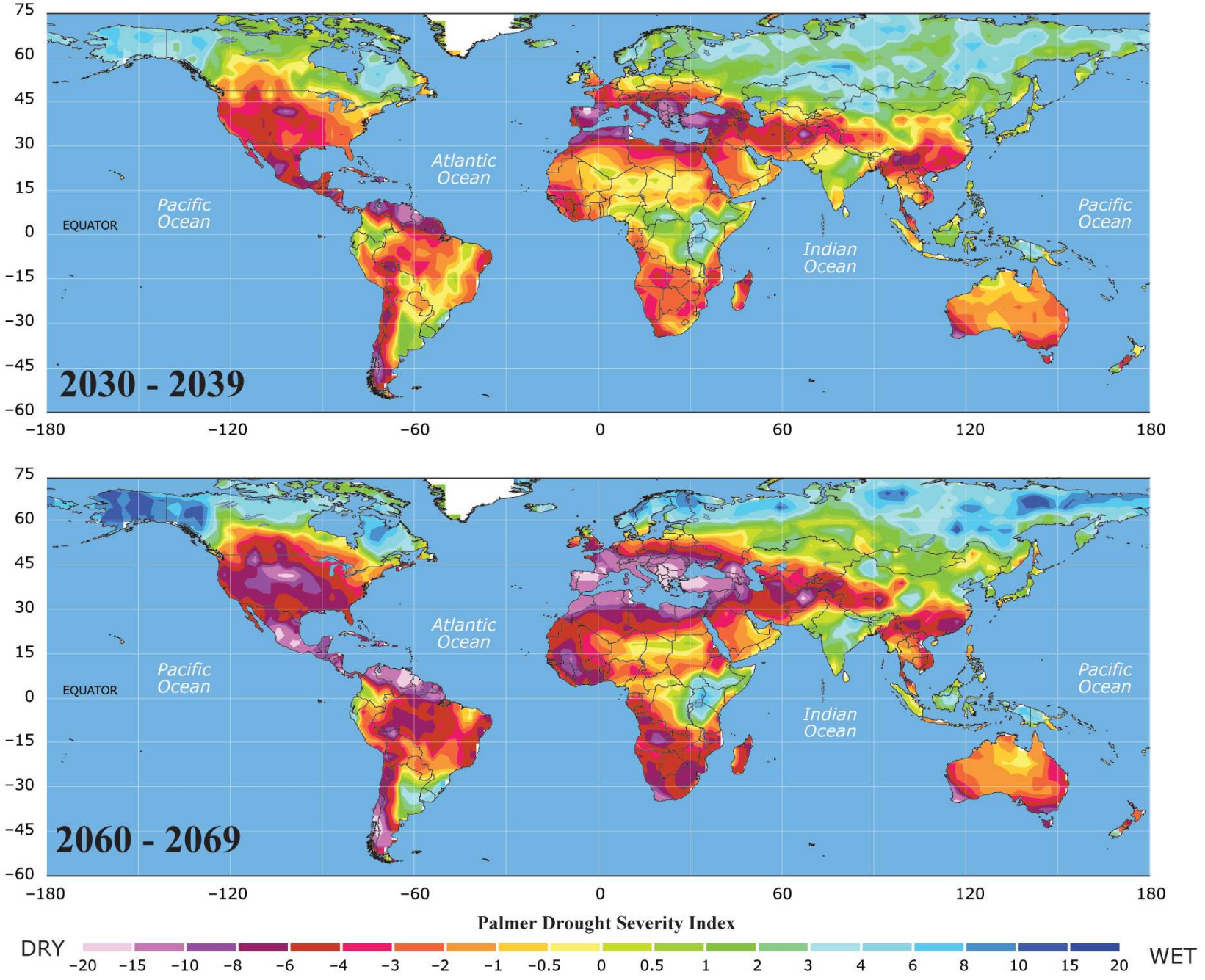


Dust Bowl Drought: 5,000 killed, 2.5 million people displaced



The future of drought, 30 years from now?

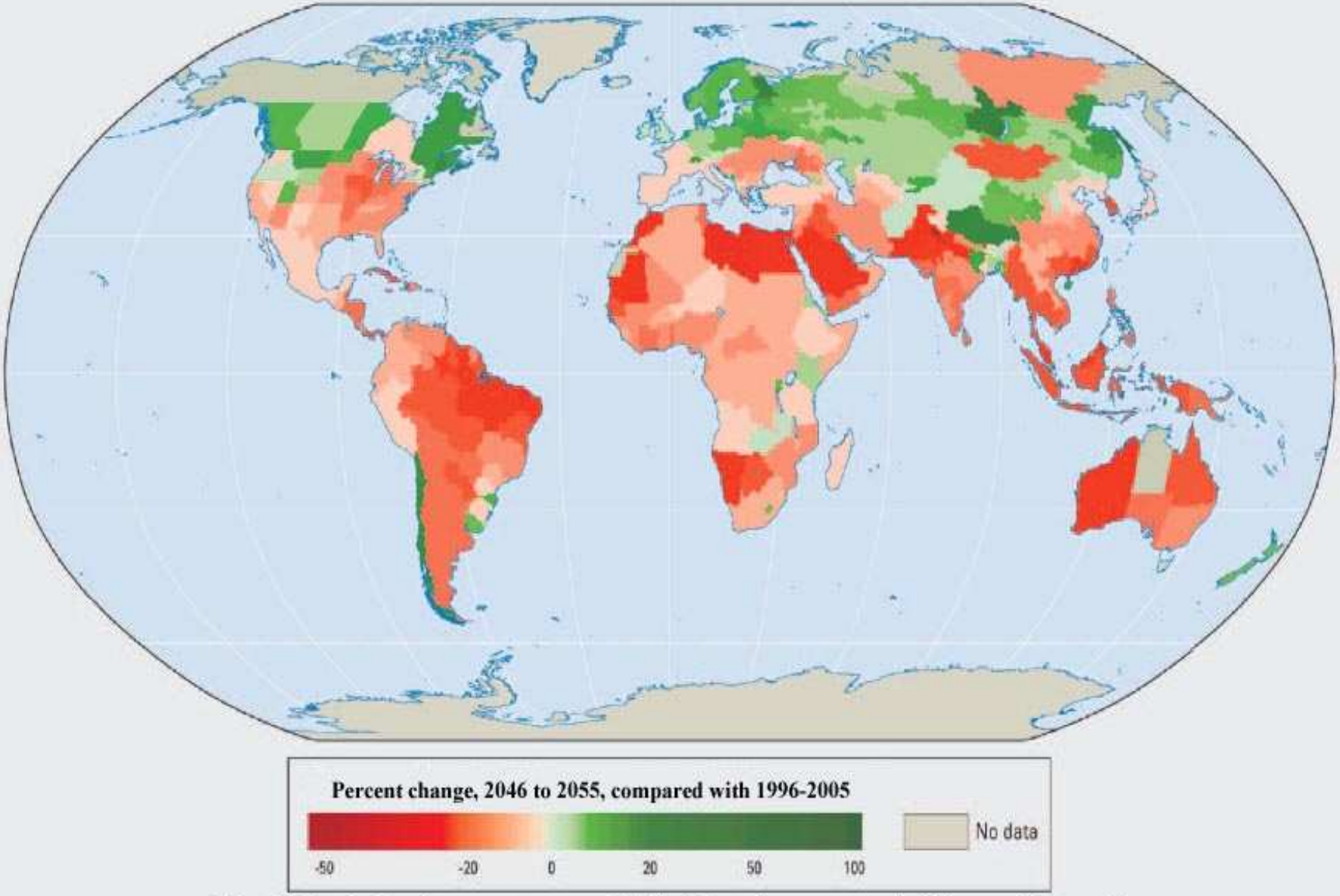
Predicted Palmer Drought Severity Index, 22-model mean, IPCC 2007 A1B Scenario



A $100 billion, 1-in-100-year U.S. drought would seriously strain world food prices

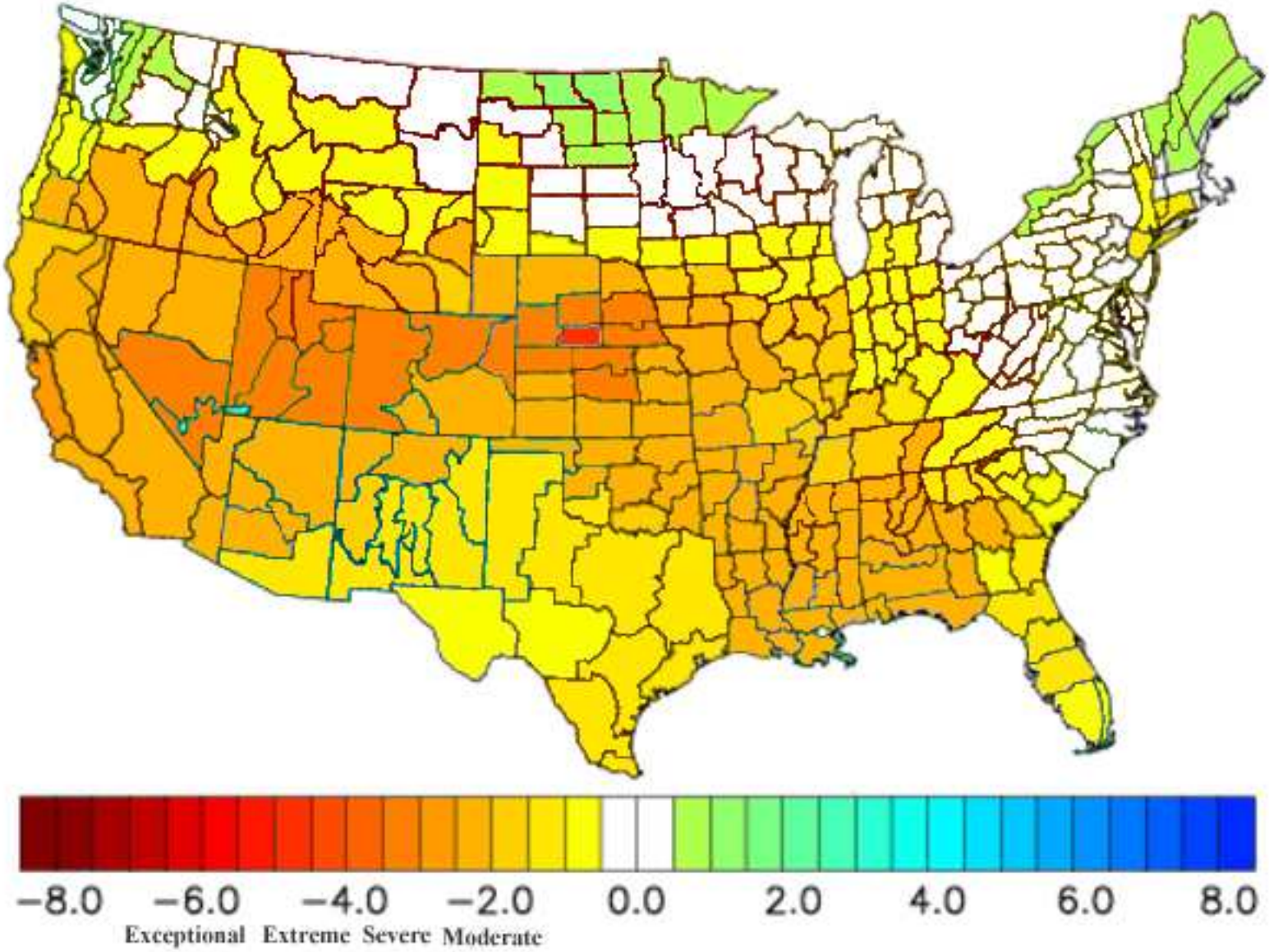
Global agricultural production must increase by 60% to feed the world's 2050 population of 9 billion (Swiss Re 2013, "Partnering for food security in emerging markets.")

Percentage Change in Yields of 11 Major Crops From 2000 to 2050

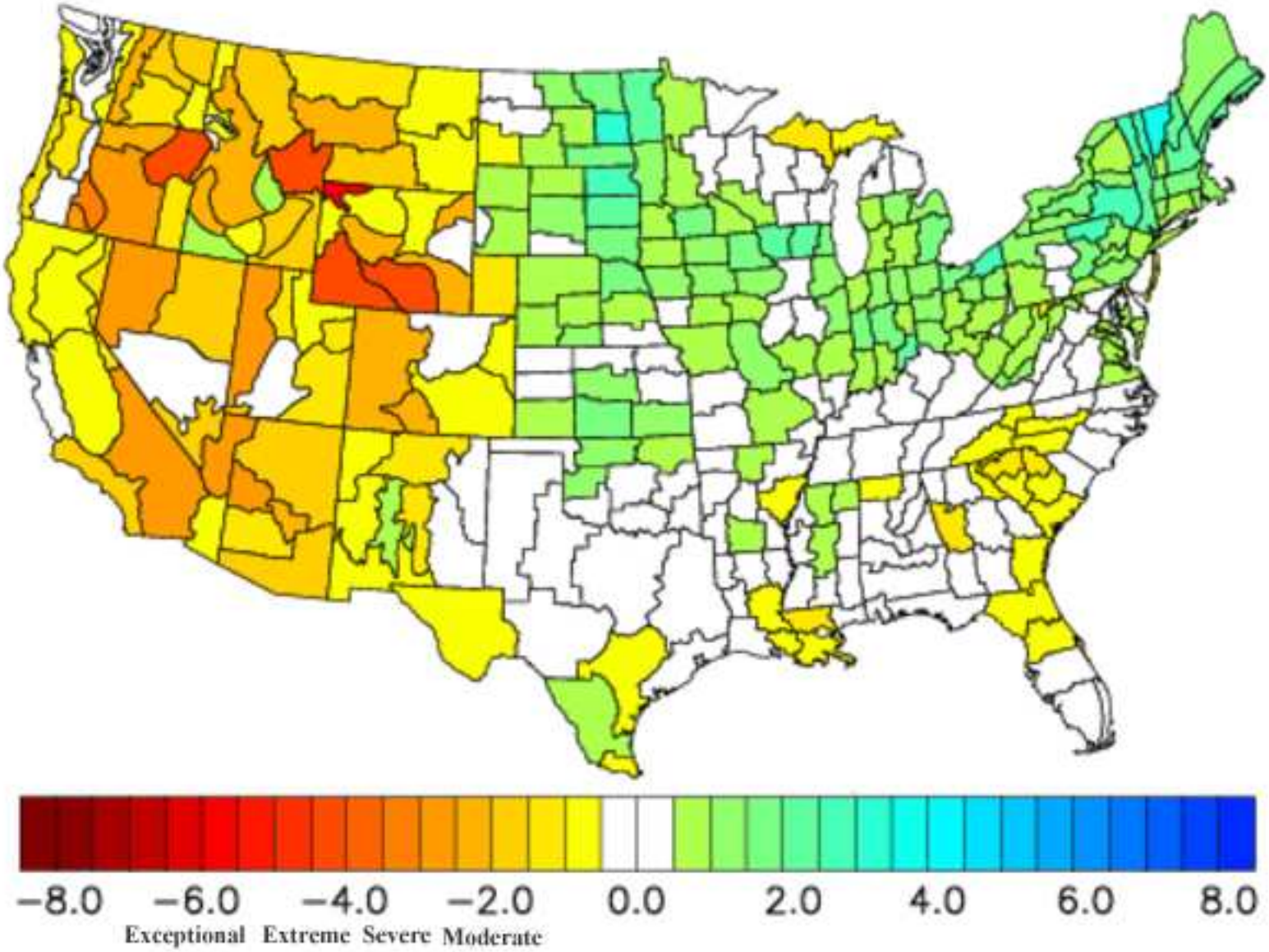


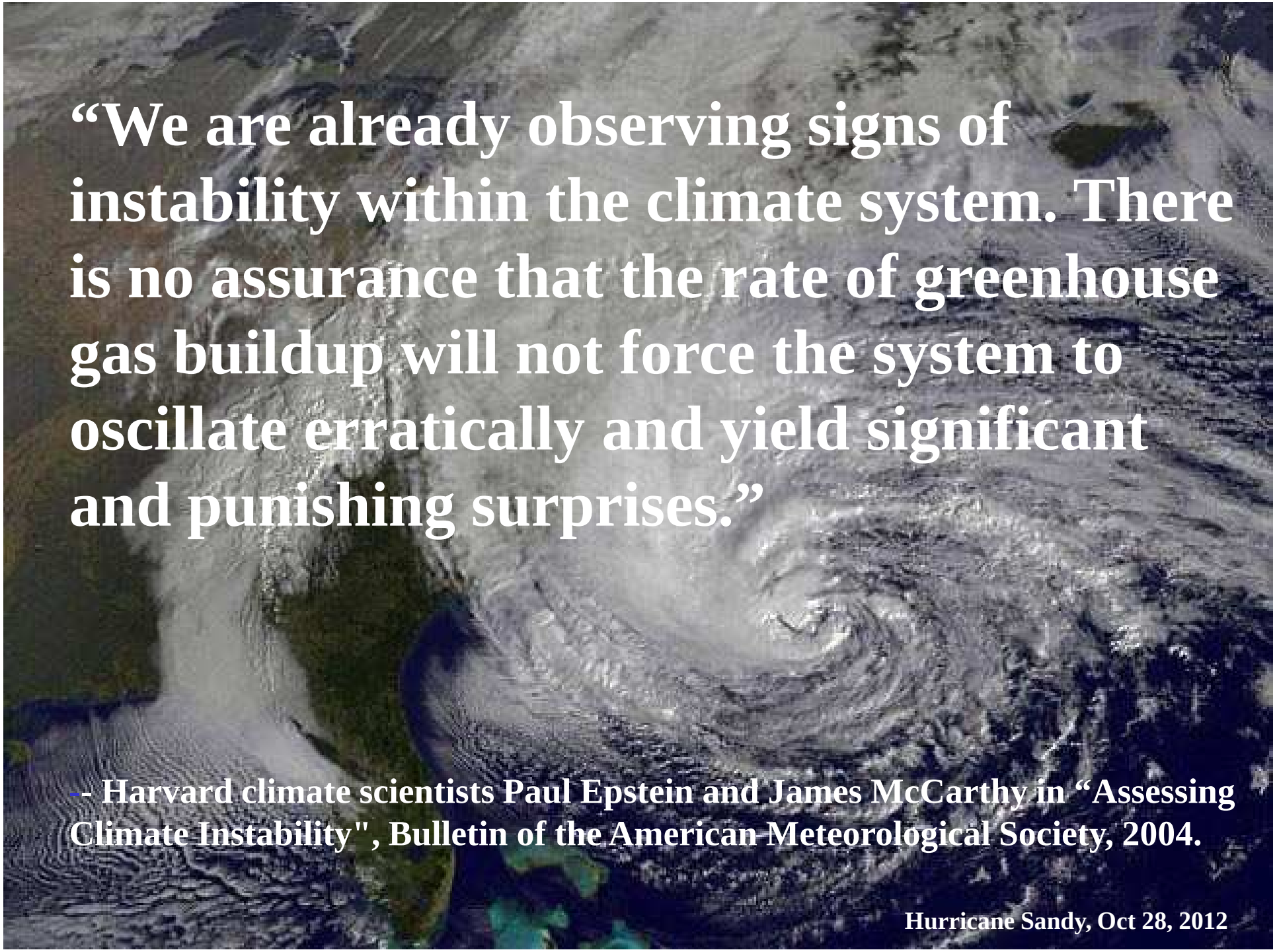
World Bank development report 2010, "Development and Climate Change"

Palmer Drought Index, 2000 - 2009, Predicted



Palmer Drought Index, 2000 - 2009, Observed

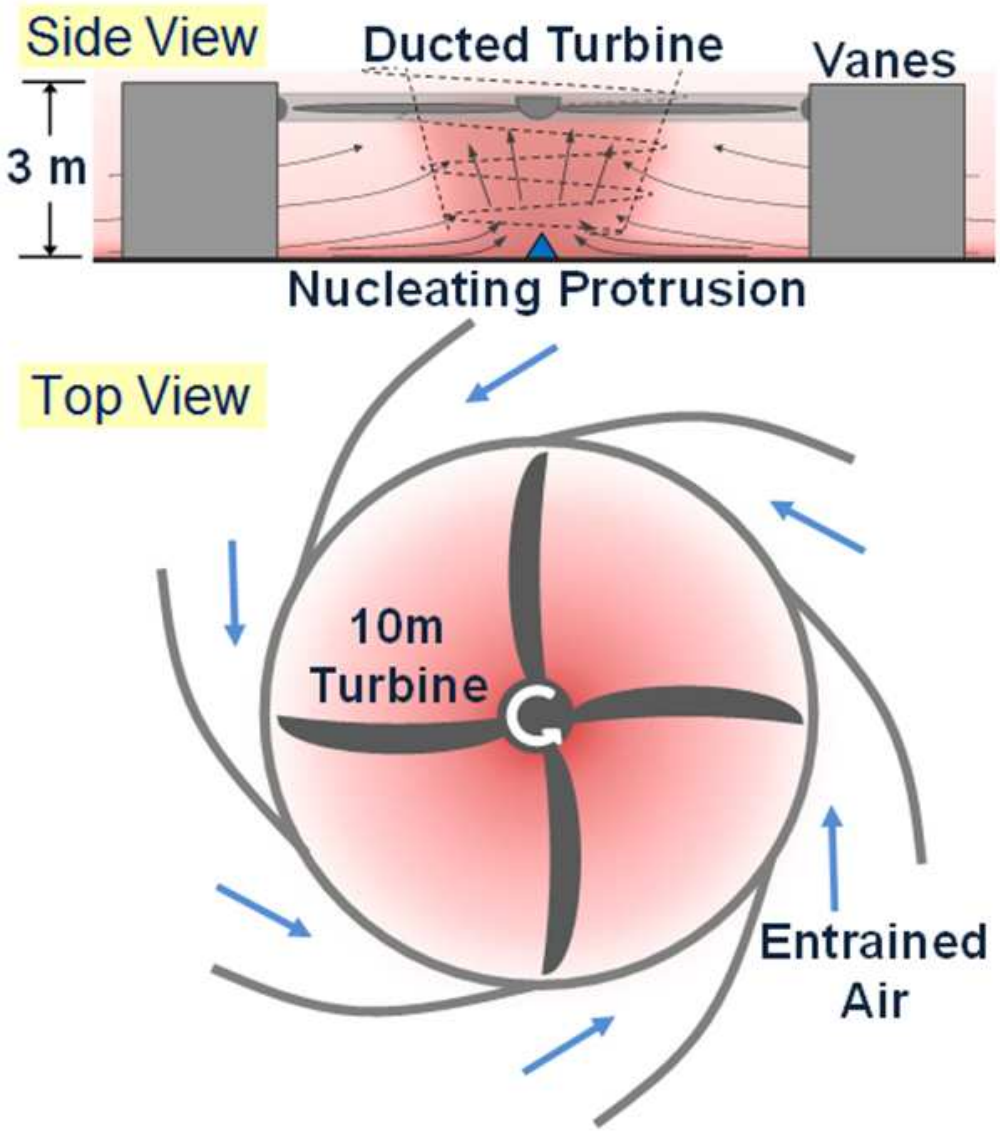



“We are already observing signs of instability within the climate system. There is no assurance that the rate of greenhouse gas buildup will not force the system to oscillate erratically and yield significant and punishing surprises.”
-- Harvard climate scientists Paul Epstein and James McCarthy in “Assessing Climate Instability", Bulletin of the American Meteorological Society, 2004.
Hurricane Sandy, Oct 28, 2012

Mother Nature's new weather dice:

It is now possible to roll a "13"!

But There is Reason to be Optimistic—Many Dedicated Creative People are Working on Solutions



Solar Vortex concept, developed at Georgia Tech, uses dust devil like vorticies to turn Turbine blades and generate power


Thanks for listening!
The Weather Company