

Global Warming: Coming Ready or Not!

Help!

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NCAR

NCAR Earth System Laboratory
NCAR is sponsored by NSF



Photo Credit/Crédit photographique: Dan Crossie

Climate

The atmosphere is a "global commons."
Air over one place is typically half way round the world a week later, as shown by manned balloon flights.



The atmosphere is a dumping ground for all nations for pollution of all sorts. Some lasts a long time and is shared with all. **One consequence is global warming!**

Running a fever: Seeing the doctor



- **Symptoms:** the planet's temperature and carbon dioxide are increasing
- **Diagnosis:** human activities are causal
- **Prognosis:** the outlook is for more warming at rates that can be disruptive and will cause strife
- **Treatment:** mitigation (reduce emissions) and adaptation (planning for consequences)



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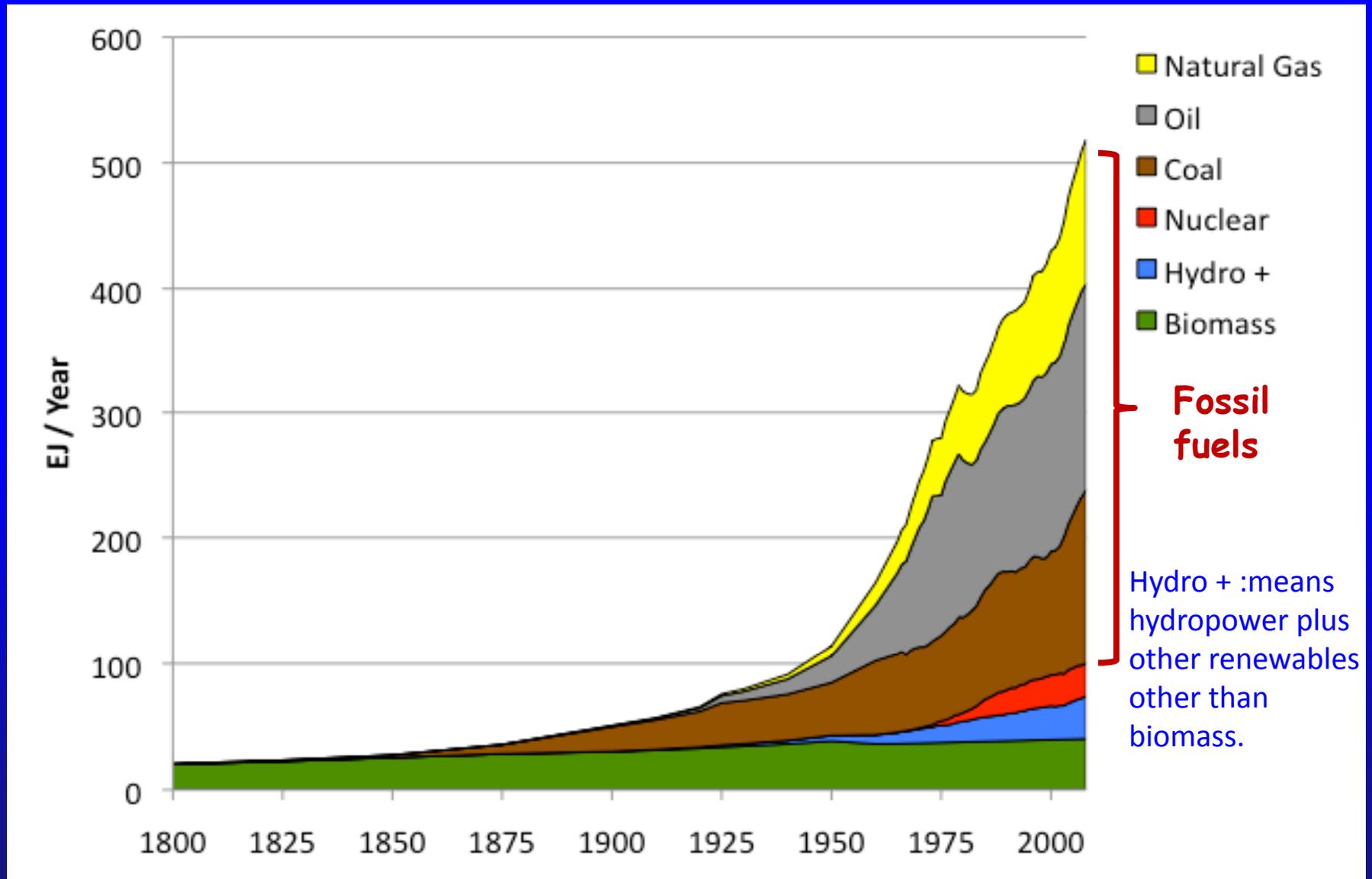
What Is Causing the Warming?



Emissions of carbon dioxide pollution

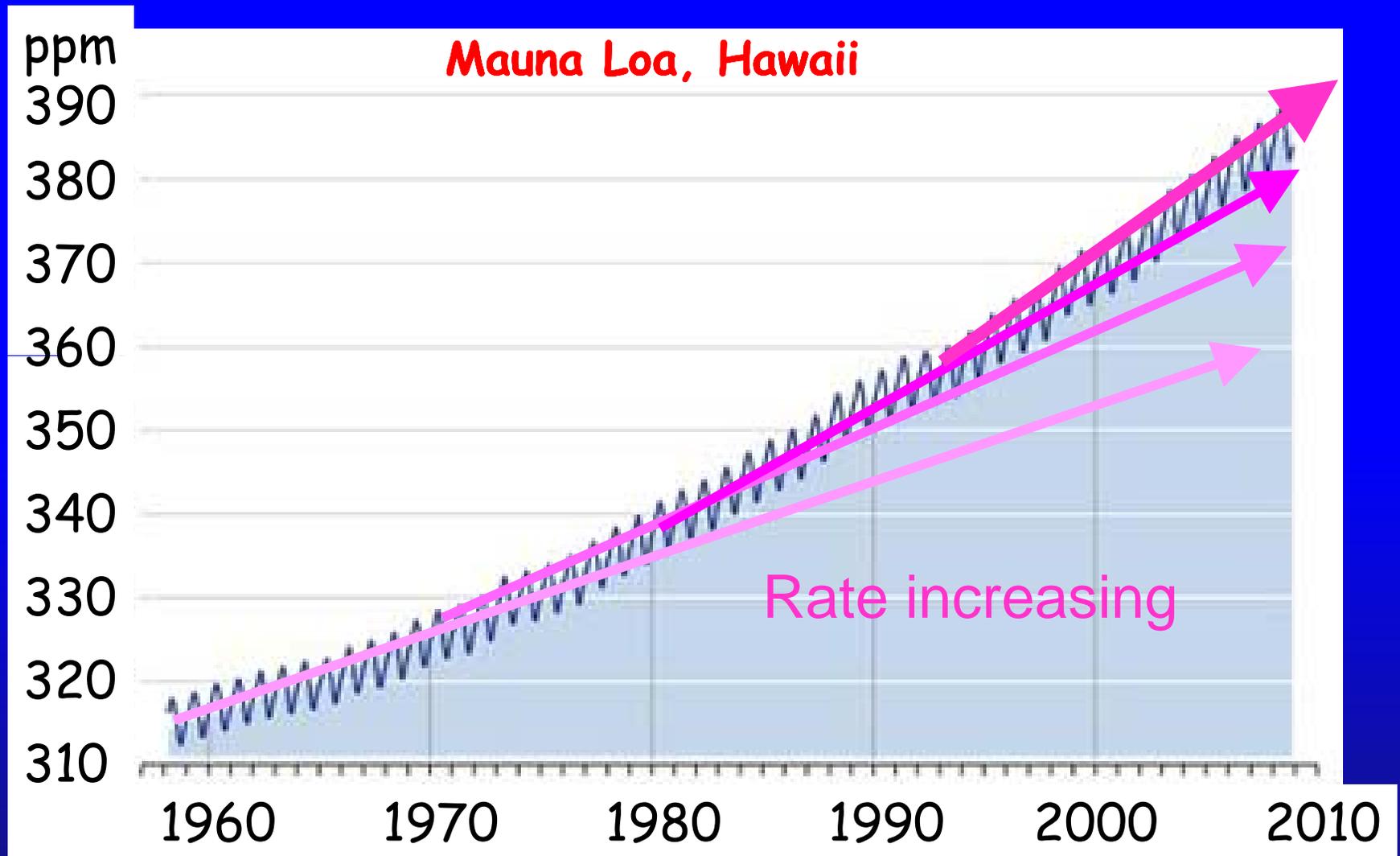
Courtesy Scott Mandia

World Primary Energy Supply: 1800 - 2008



Sources: Grubler (2008) - Energy Transitions, BP (2009) - Statistical Review of World Energy, EIA (2009) - International Energy Annual

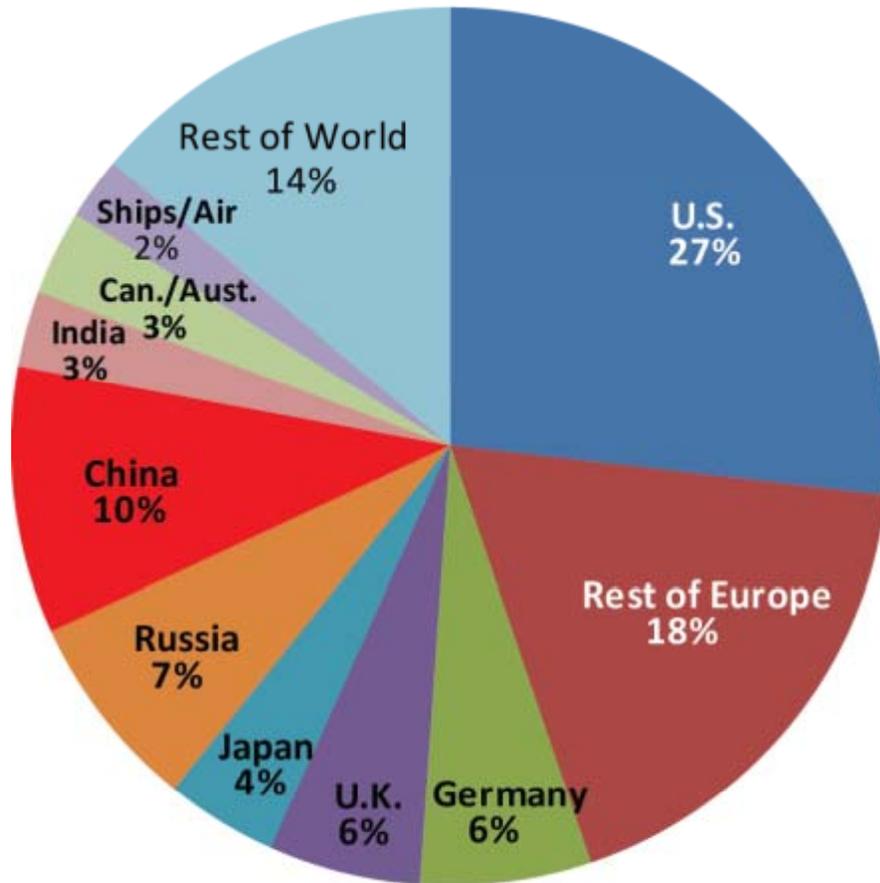
Changing atmospheric composition: CO₂



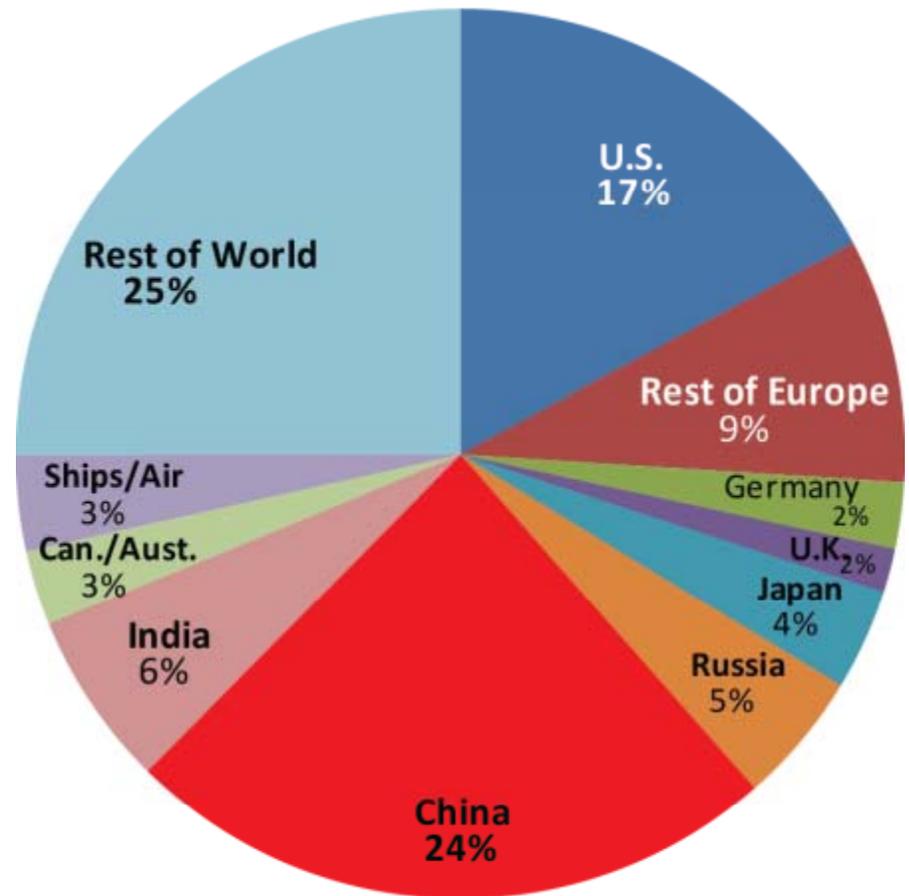
Data from Climate Monitoring and Diagnostics Lab., NOAA. Data prior to 1974 from C. Keeling, Scripps Inst. Oceanogr.

Fossil Fuel Emissions

Accumulated Emissions: 1751-2010



2010 Emissions

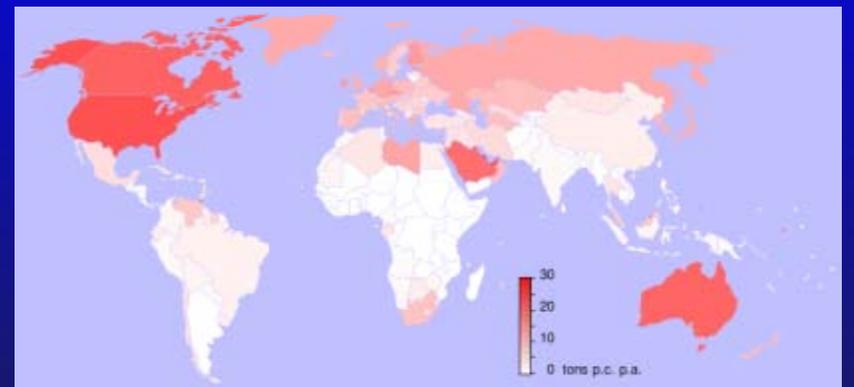
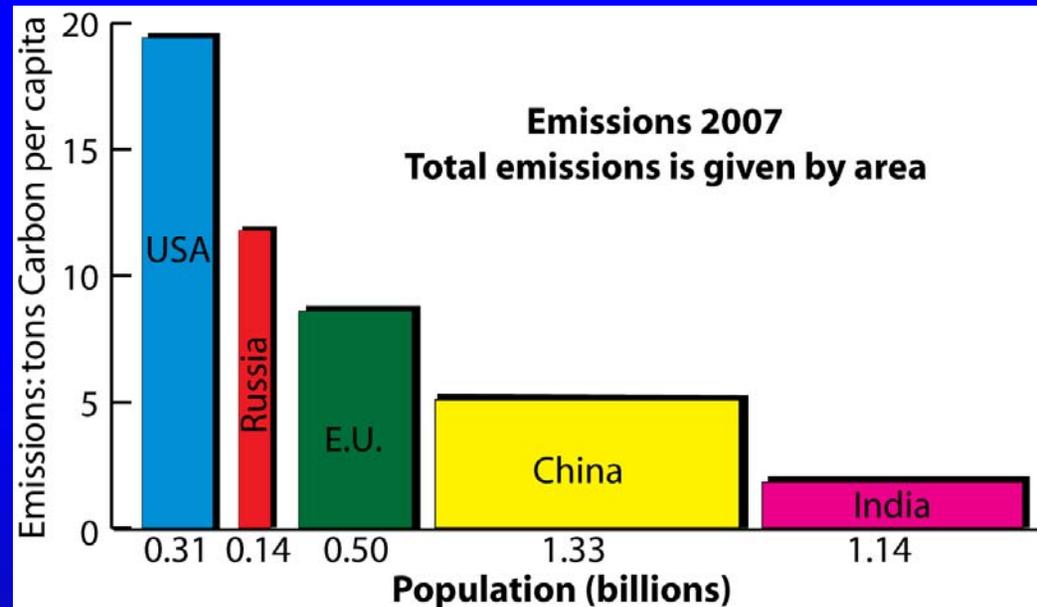


2007 emissions: Population matters

China biggest emitter

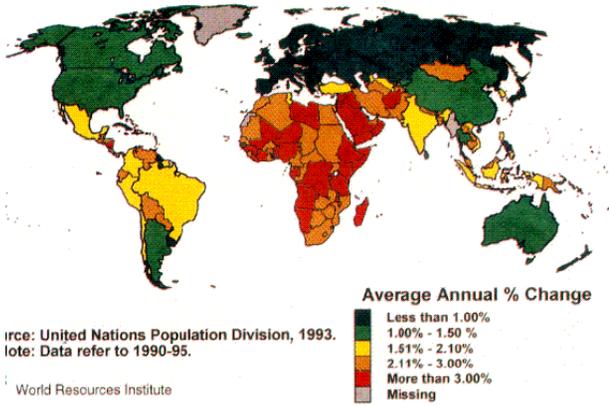
- 14% more than US

| <u>Per capita</u> | | <u>Pop.</u> |
|-------------------|------|-------------|
| U.S.: | 19.4 | 0.31 |
| Russia: | 11.8 | 0.14 |
| E. U.: | 8.6 | 0.50 |
| China: | 5.1 | 1.33 |
| India: | 1.8 | 1.14 |
| | tons | Billions |

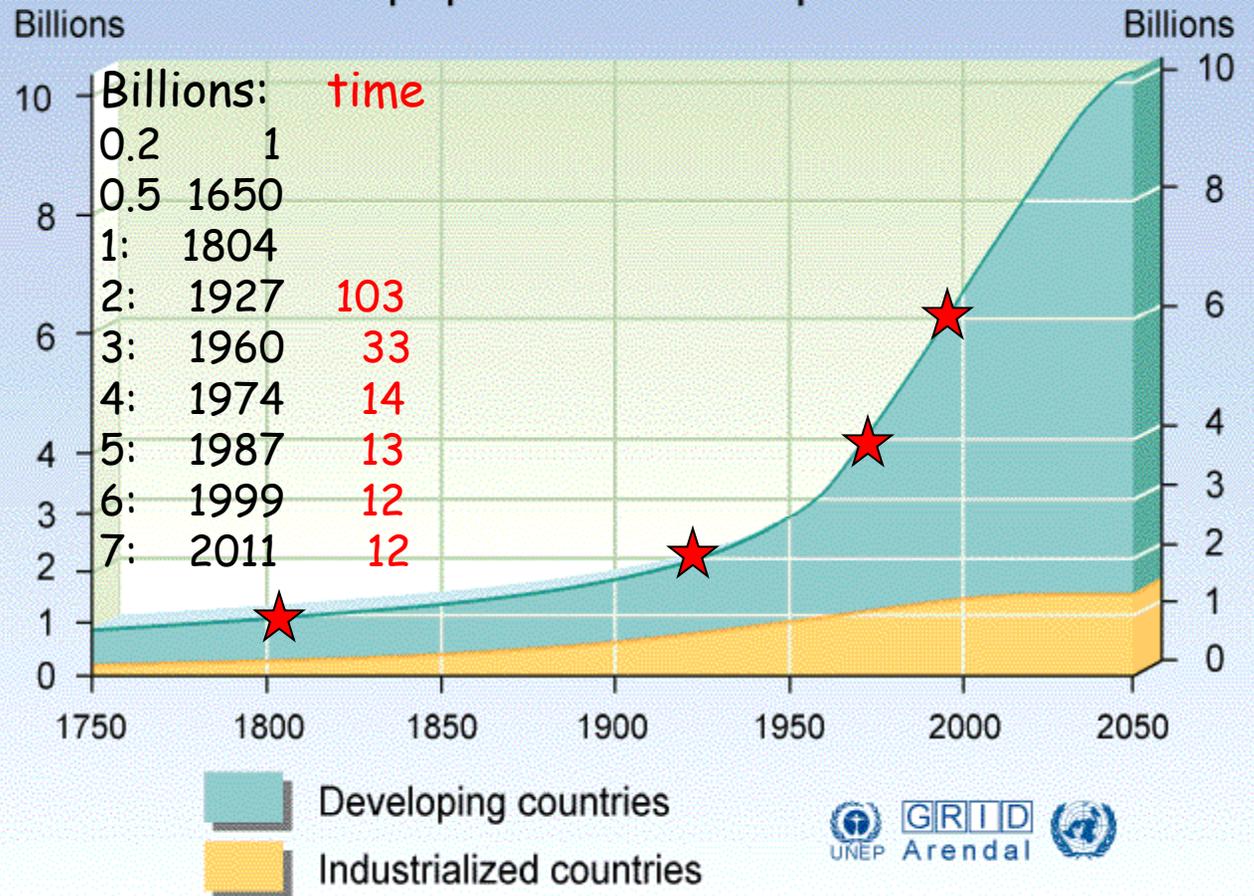




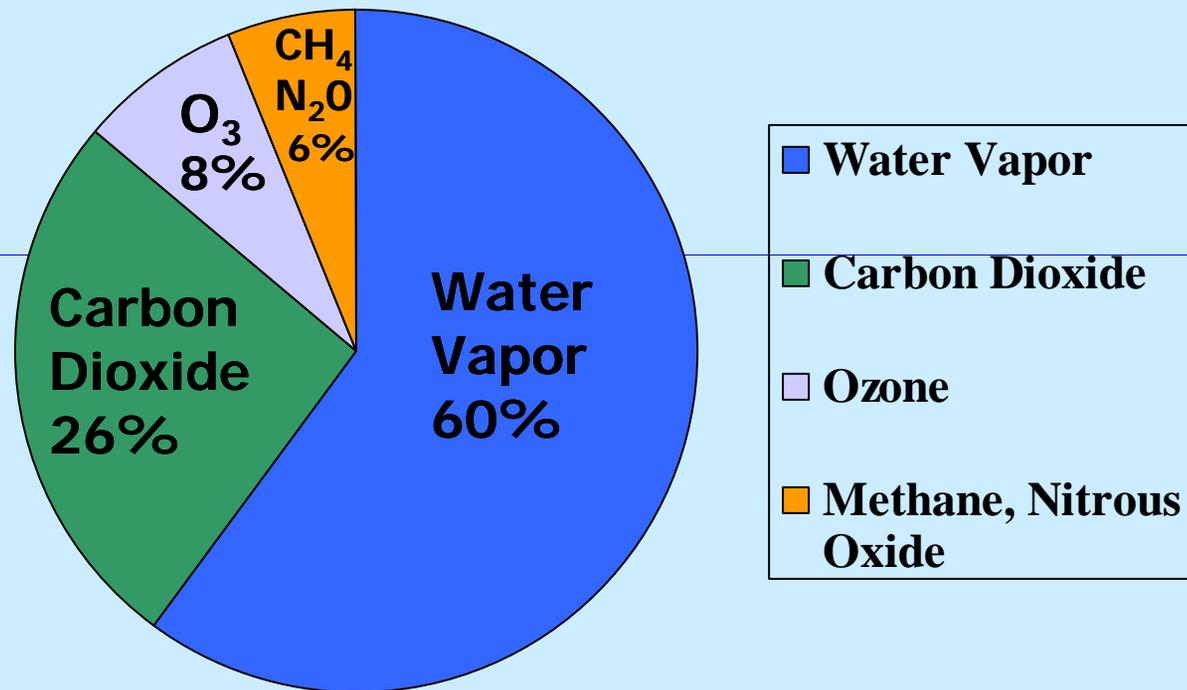
Population Growth Rate



World population development



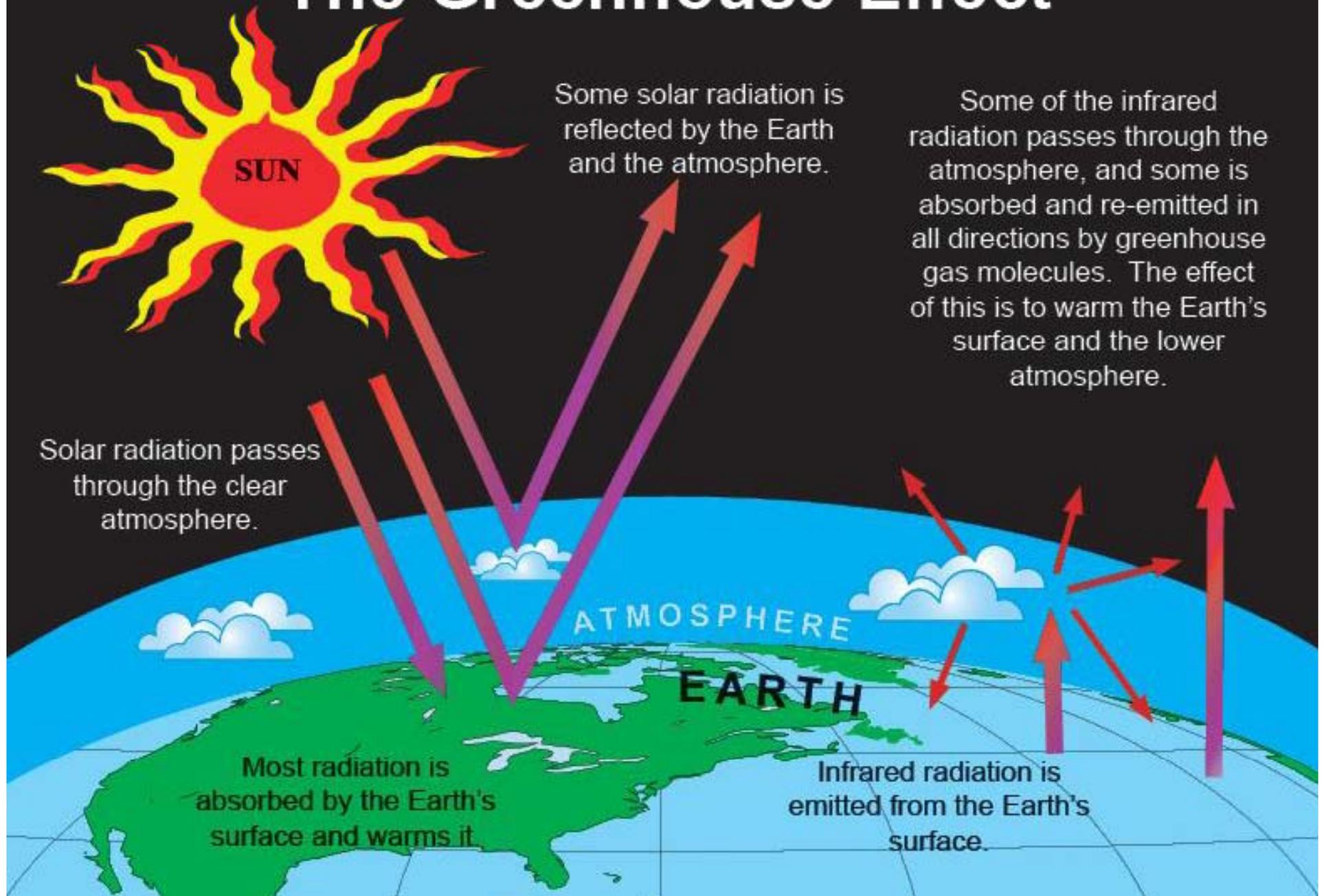
The Natural Greenhouse Effect: clear sky



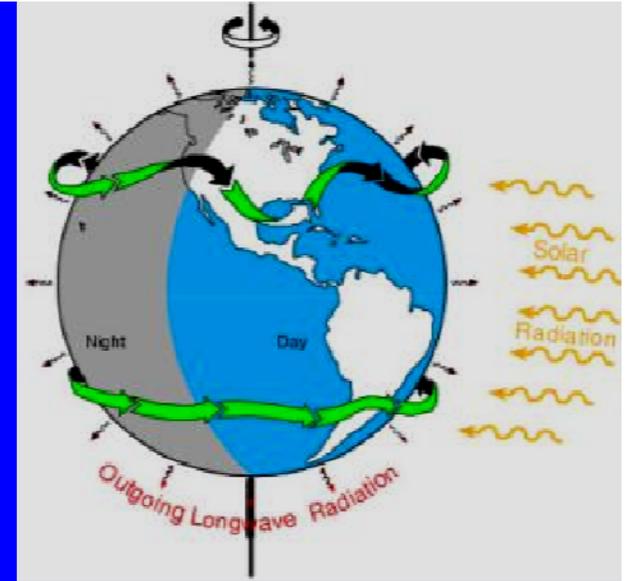
Clouds also have a greenhouse effect

Kiehl and Trenberth 1997

The Greenhouse Effect



The incoming energy from the sun amounts to 175 PetaWatts
=175,000,000 billion Watts.
About 122 PW is absorbed.

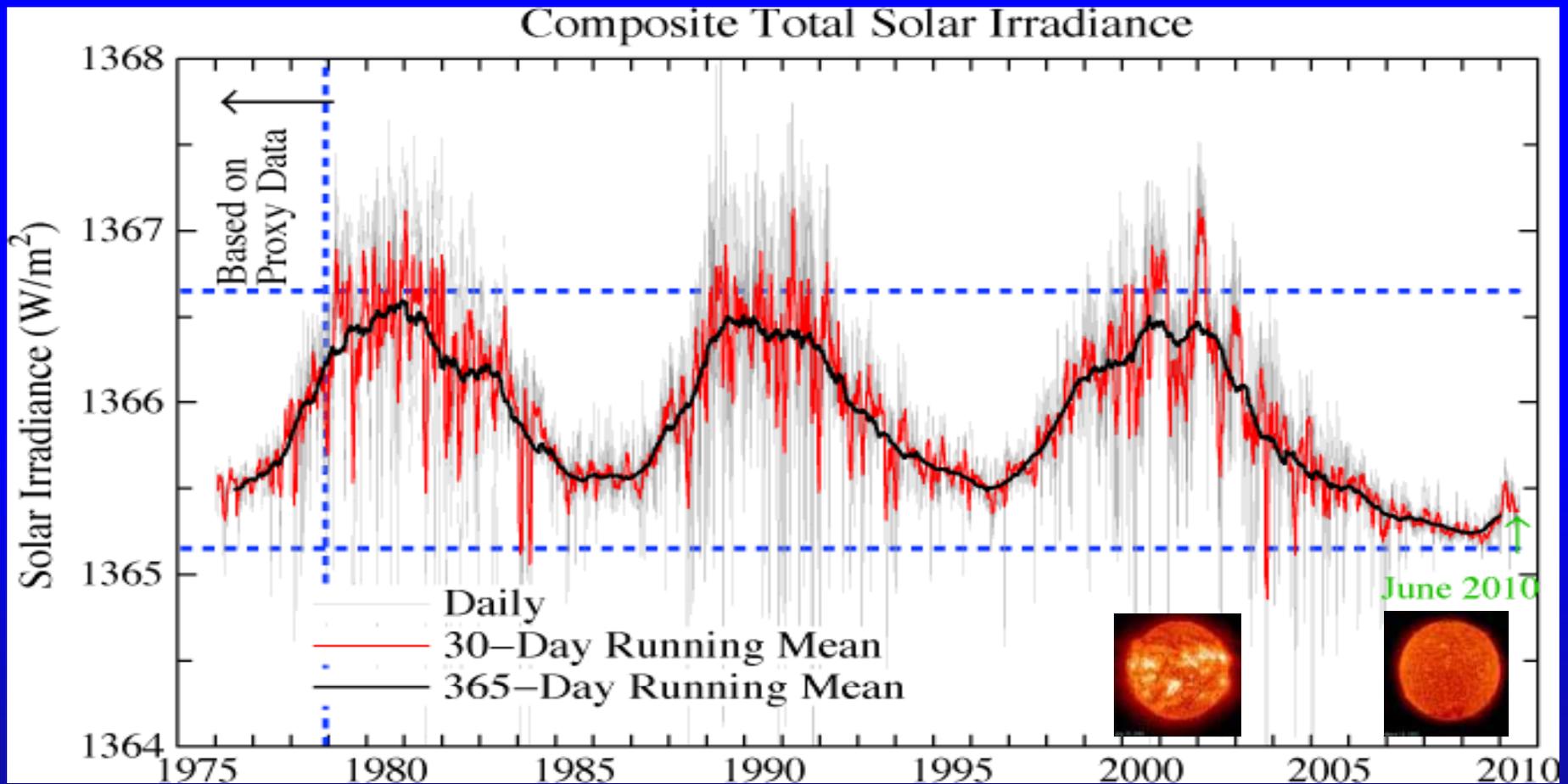


The biggest power plants in existence are 1000 MegaWatts and we normally think of units of 1 KiloWatt (= 1 bar heater), or a 100 W light bulb.

So the energy from the sun is 122 million of these power stations. It shows:

- 1) Direct human influences are tiny vs nature.
- 2) The main way human activities can affect climate is through interference with the natural flows of energy such as by changing the composition of the atmosphere

Solar irradiance



The drop of 1.2 W m^{-2} since 2001 is equivalent to -0.2 Wm^{-2} in radiative forcing

Global Warming is Unequivocal

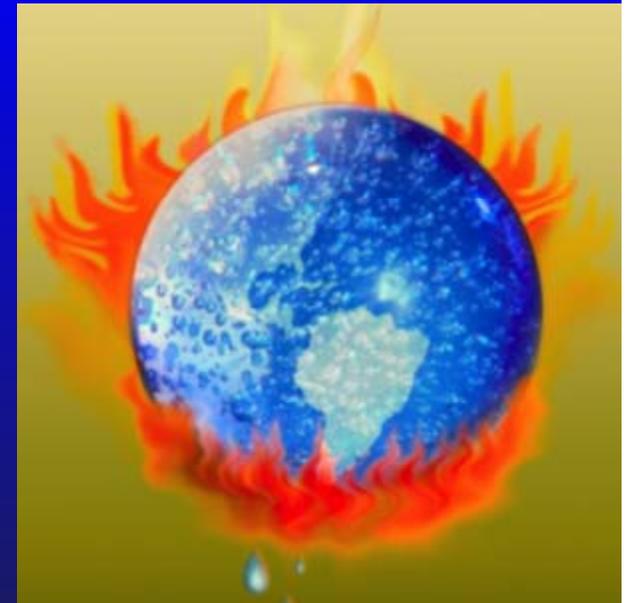
IPCC: approved 113 govts

Since 1970, rise in:

- ❖ Global surface temperatures
- ❖ Tropospheric temperatures
- ❖ Global SSTs, ocean Ts
- ❖ Global sea level
- ❖ Water vapor
- ❖ Rainfall intensity
- ❖ Precipitation extratropics
- ❖ Hurricane intensity
- ❖ Drought
- ❖ Extreme high temperatures
- ❖ Heat waves
- ❖ Ocean acidity

Decrease in:

- NH Snow extent
- Arctic sea ice
- Glaciers
- Cold temperatures



The seas are warming up, turning sour, and losing breath

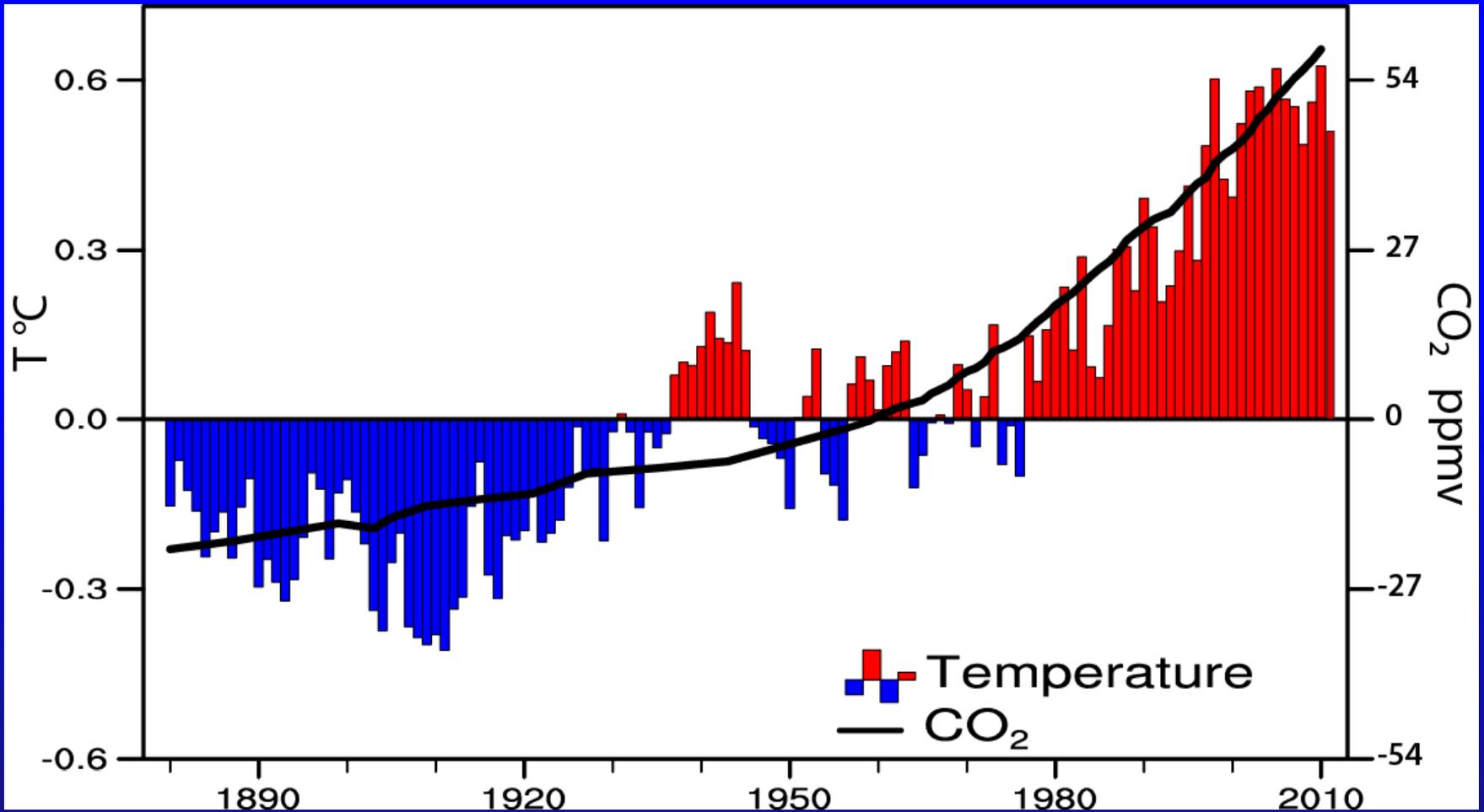
Nocolas Gruber (Phil Trans Roy Soc 2011)

- ❖ Higher SSTs, higher ocean Temperatures,
- ❖ Sea ice melt
- ❖ Increased stratification
- ❖ Global sea level rise
- ❖ Acidification (increased dissolved CO₂)
- ❖ Oxygen loss (deOxygenation: nutrients from land)
- ❖ Corals in hot water: bleaching
- ❖ Phytoplankton on the wane
- ❖ Dead zones increasing

Phytoplankton bloom off Norway,
MODIS, NASA 24 Jul 2004

Porites coral
Kirabati, May 2010

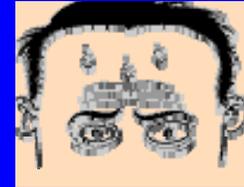
Global temperature and carbon dioxide: anomalies through 2011



Base period 1900-99; data from NOAA

Controlling Heat

Human body: sweats



Homes: Evaporative coolers (swamp coolers)

Planet Earth: Evaporation (if moisture available)

e.g., When sun comes out
after showers,



the first thing that happens is
that the puddles dry up:
before temperature increases.



Human impacts on climate related to water

- Warming: more heat, higher temperatures
- The atmosphere can hold more water vapor
 - 4% per °F = observed
- Over wet areas (ocean) => more moisture
- More heat → more evaporation → more precipitation
- Longer dry spells, more drought (where not raining)
- More intense rains/snows
- More intense storms

More floods and droughts

Most precipitation comes from moisture convergence by weather systems

Rain comes from moisture convergence by low level winds:



More moisture means heavier rains

Declining Snow Pack in many mountain and continental areas contributes to drought

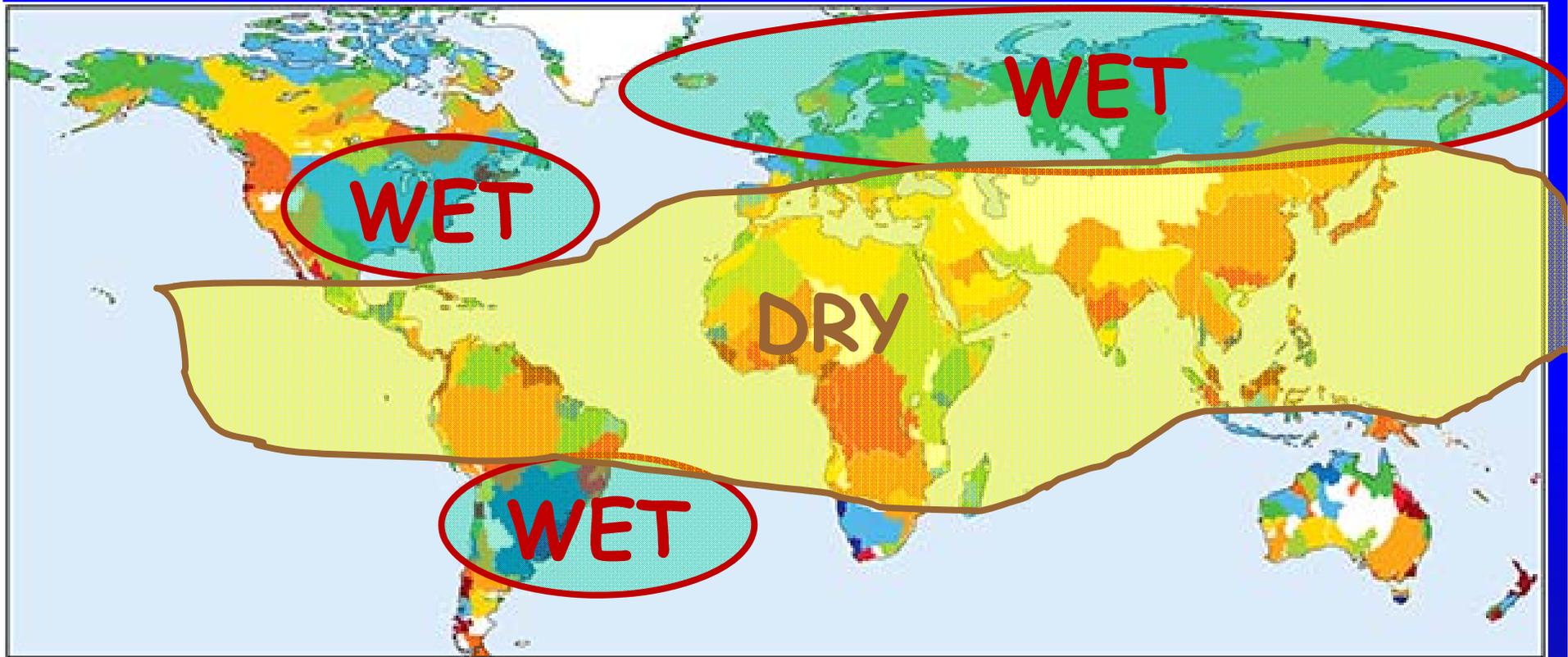
- more **precipitation** falls as rain rather than snow, especially in the fall and spring.
- **snow melt** occurs faster and sooner in the spring
- earlier runoff and peak streamflow
- **snow pack** is therefore less
- **soil moisture** is less as summer arrives

- the risk of **drought** increases substantially in summer
- Along with wild fire

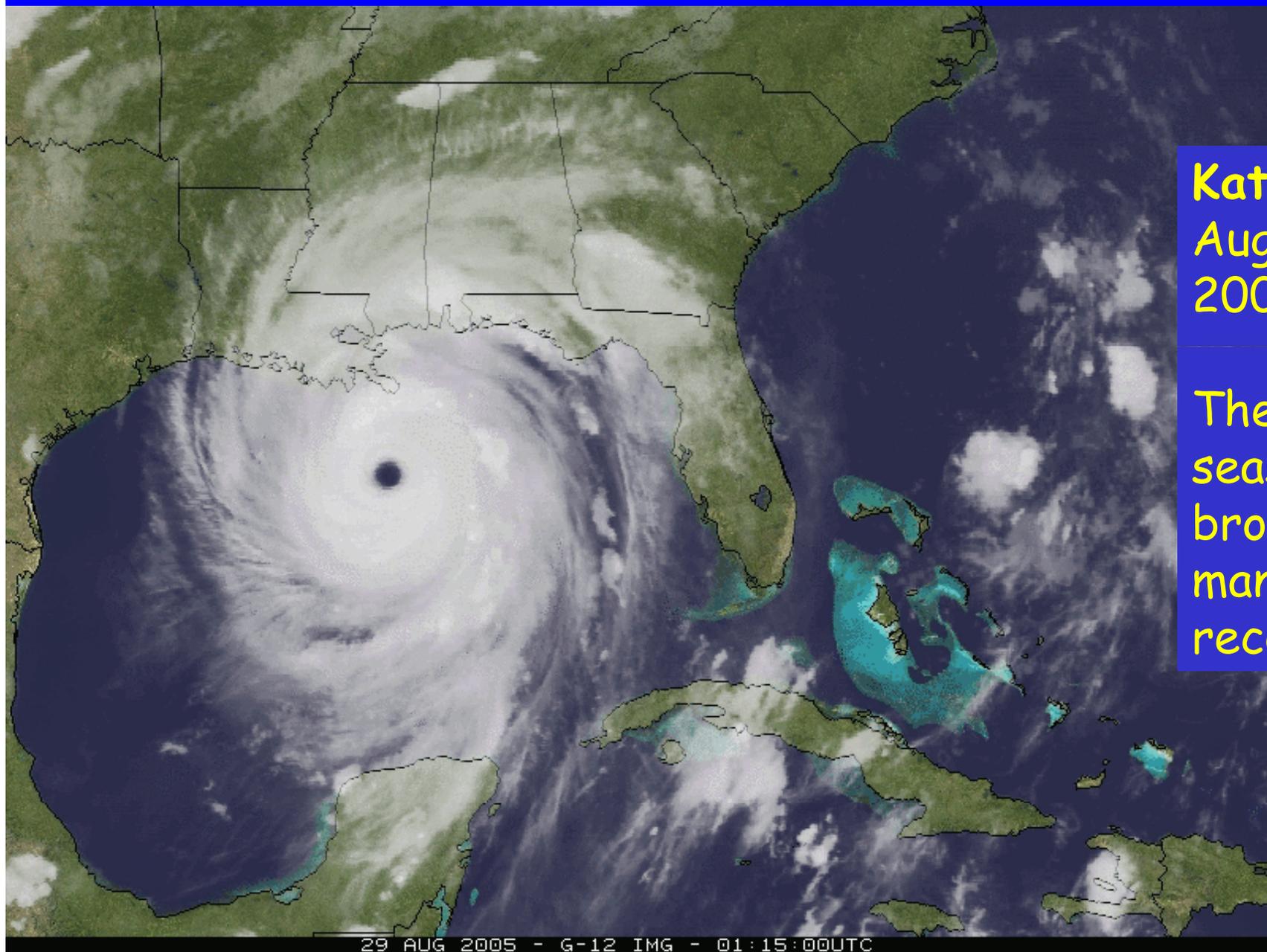


Trends 1948-2004 in runoff by river basin

Based on river discharge into ocean



North Atlantic hurricanes have increased with SSTs

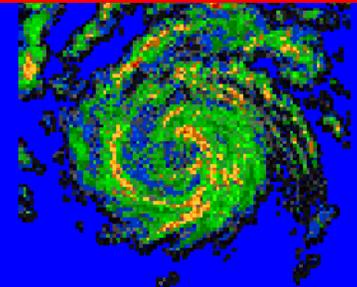
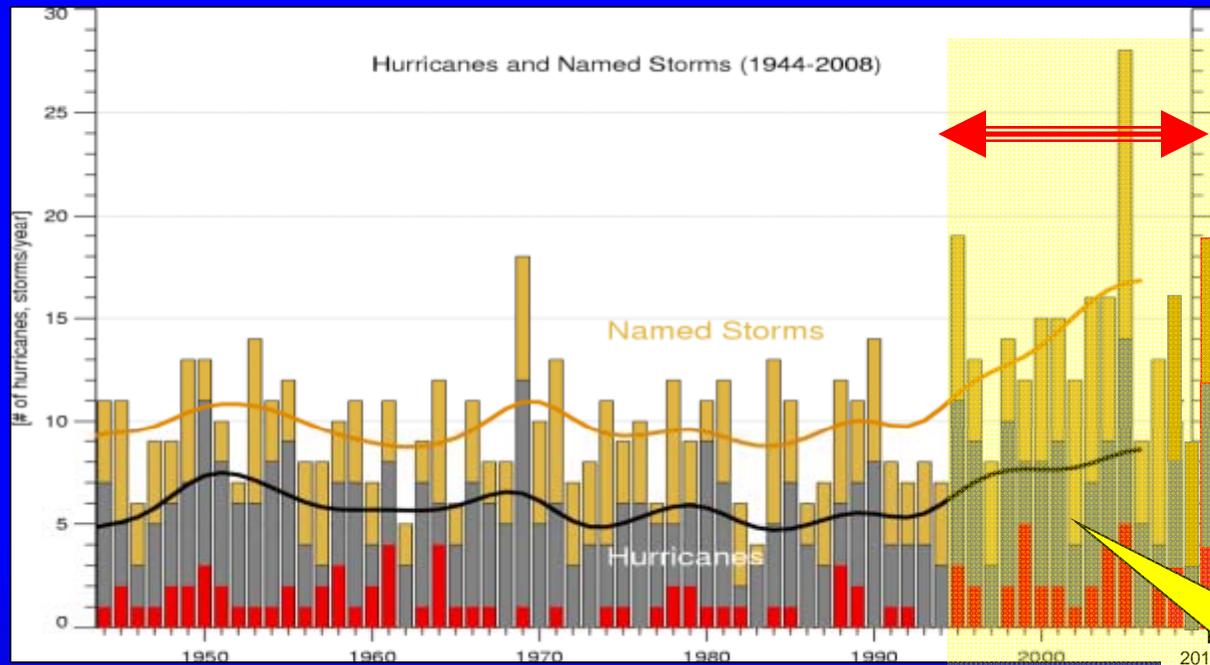


Katrina
August
2005

The 2005
season
broke
many
records

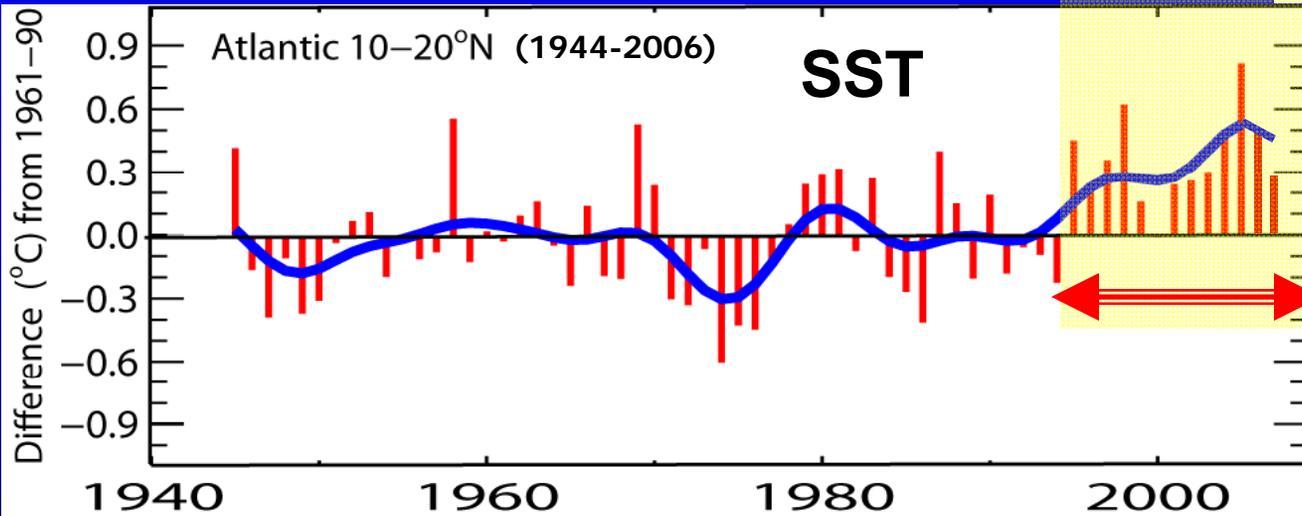
29 AUG 2005 - G-12 IMG - 01:15:00UTC

North Atlantic hurricanes have increased with SSTs



N. Atlantic hurricane record best after 1944 with aircraft surveillance.

Marked increase after 1994



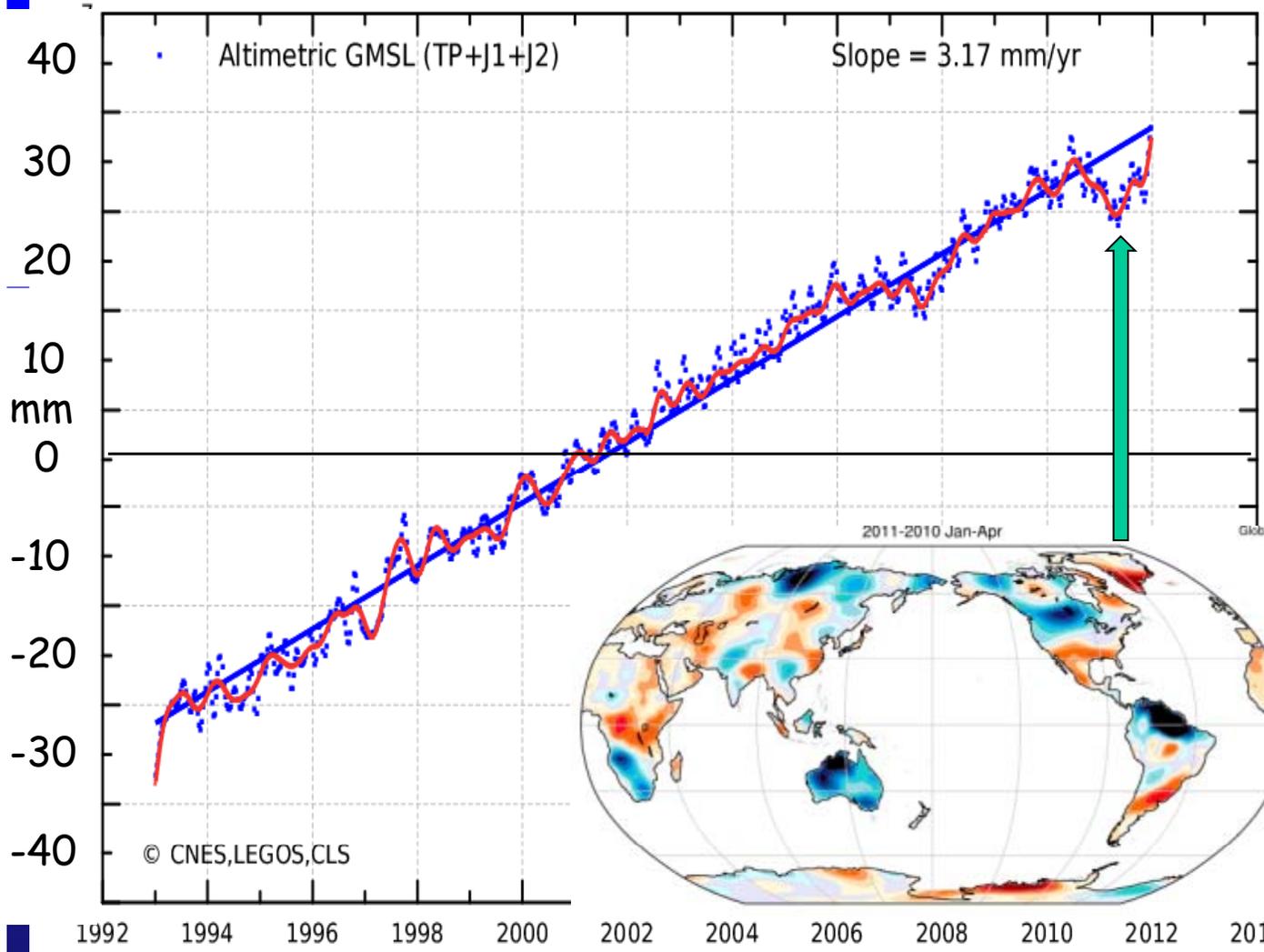
percentage of intense hurricanes is increasing
Thru 2011

Isaac Aug 28, 2012



Courtesy NASA

Sea level is rising: from ocean expansion and melting glaciers



Since 1992 Global sea level has risen 55 mm (2.2 inches)

To 2003: 60% from expansion (ocean temperatures)
40% from melting glaciers/land ice.

2003-10: 1.5 mm/yr from melting land ice.

2010-11: big dip contribution from rain on land.

AVISO: from TOPEX, Jason 1, Jason 2. Ann cy removed, IB, GIA applied

Evidence for reality of climate change

Glaciers melting



1909



Toboggan
Glacier
Alaska

2000



1941



2004

Muir Glacier, Alaska



A. Circa 1900
Photo Source: Munich Society for Environmental Research

1900



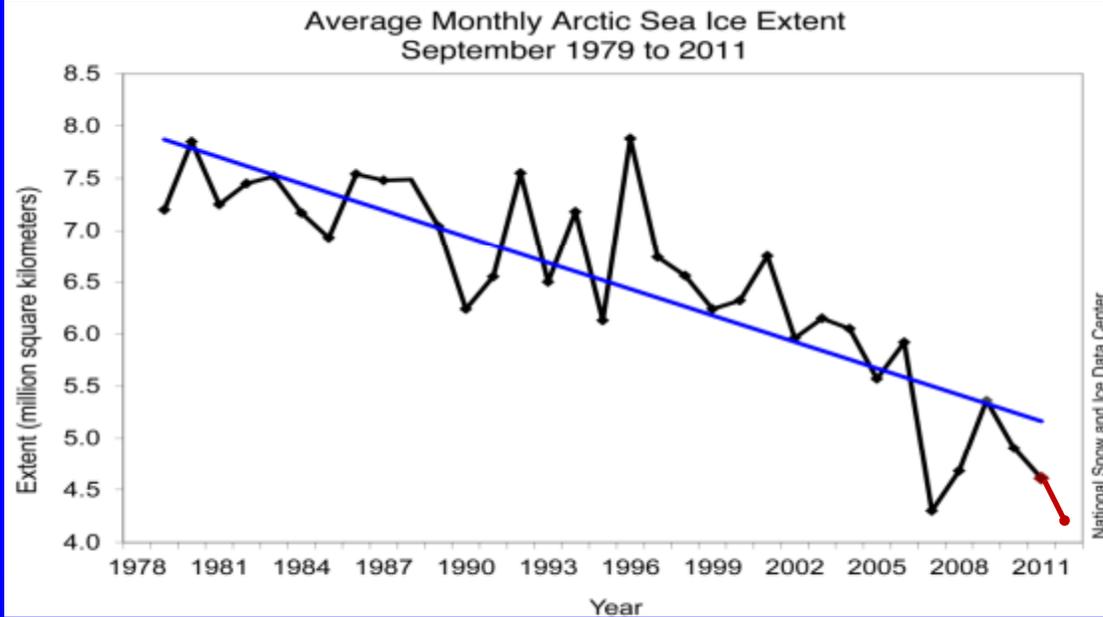
B. Recent

2003

Alpine glacier, Austria

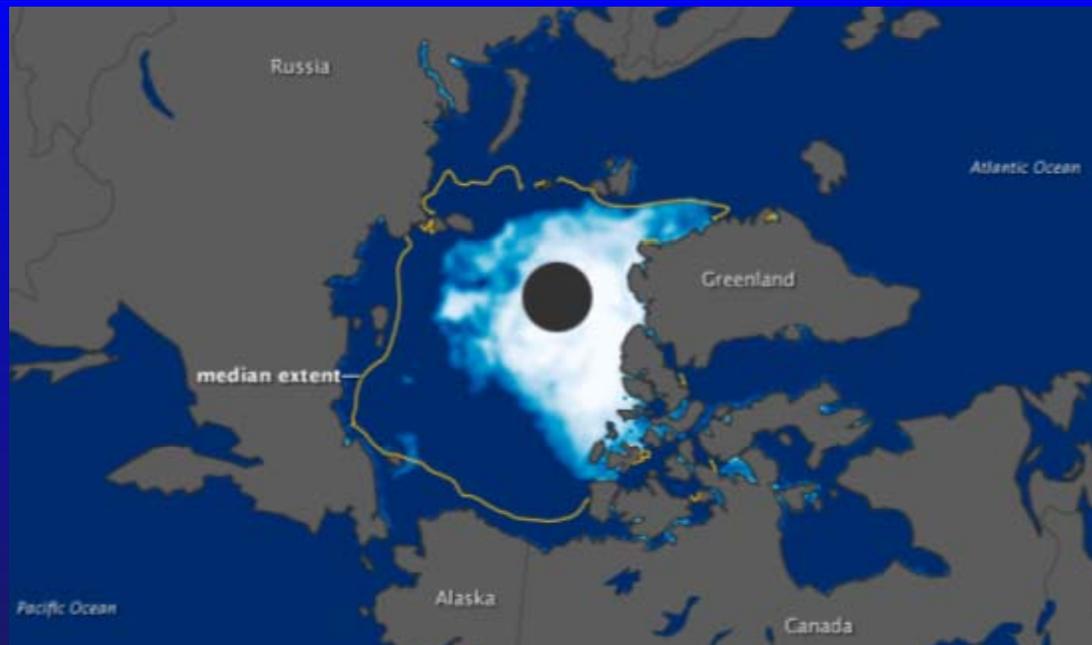
Increased Glacier retreat
since the early 1990s

Snow cover and Arctic sea ice are decreasing



Arctic sea ice
area decreased by
40% in summer
2007: 22% (10^6 km²)
lower than 2005

2012 lowest on record



Late August 2012

NSIDC; NASA

Climate change and extreme weather events

Changes in extremes matter most for society and human health

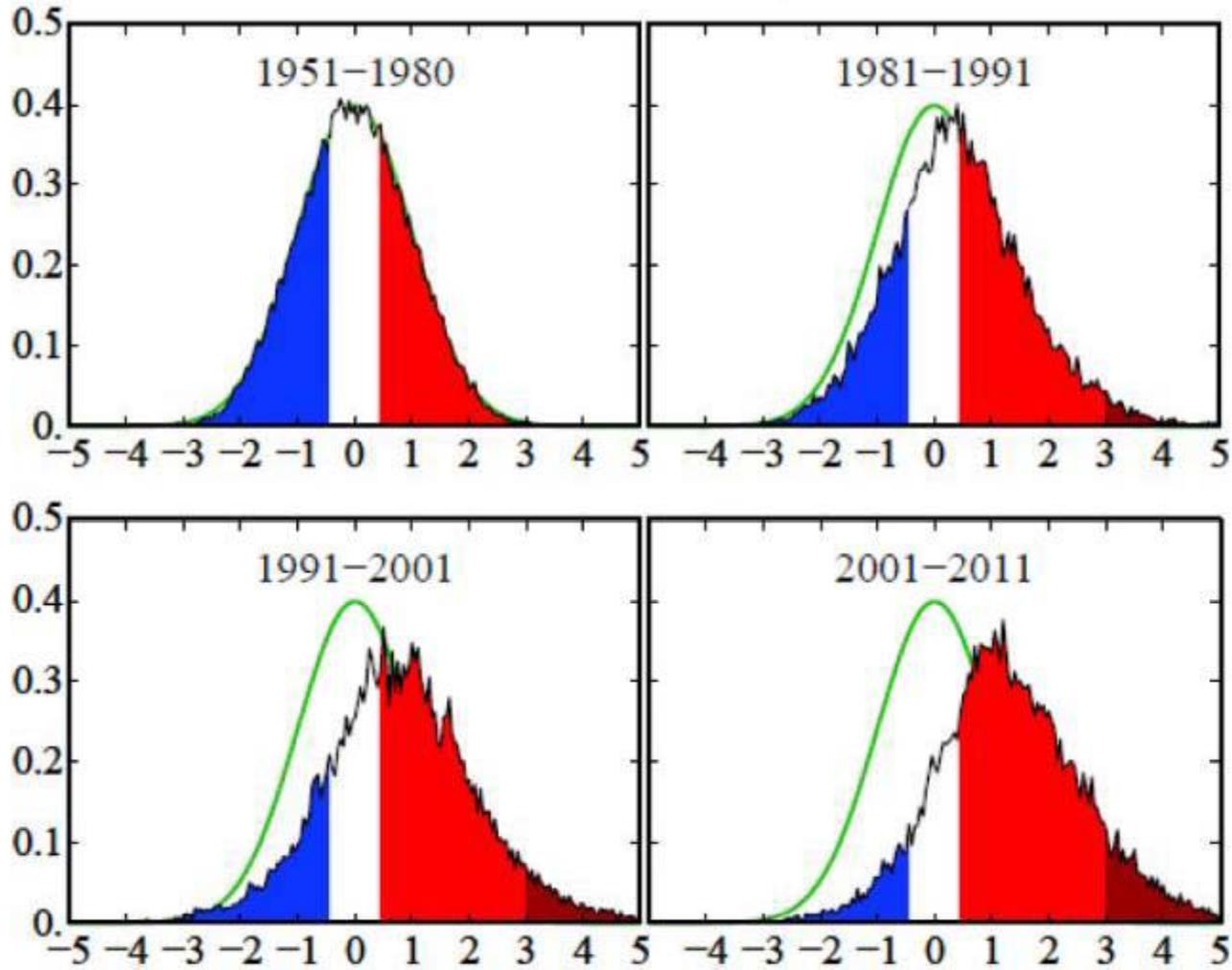
With a warming climate:

- More high temperatures, heat waves
- Wild fires and other consequences
- Fewer cold extremes.
- More extremes in hydrological cycle:
 - Drought
 - Heavy rains, floods
 - Intense storms, hurricanes, tornadoes



The environment in which all storms form has changed owing to human activities.

Shifting Distribution of Summer Temperature Anomalies



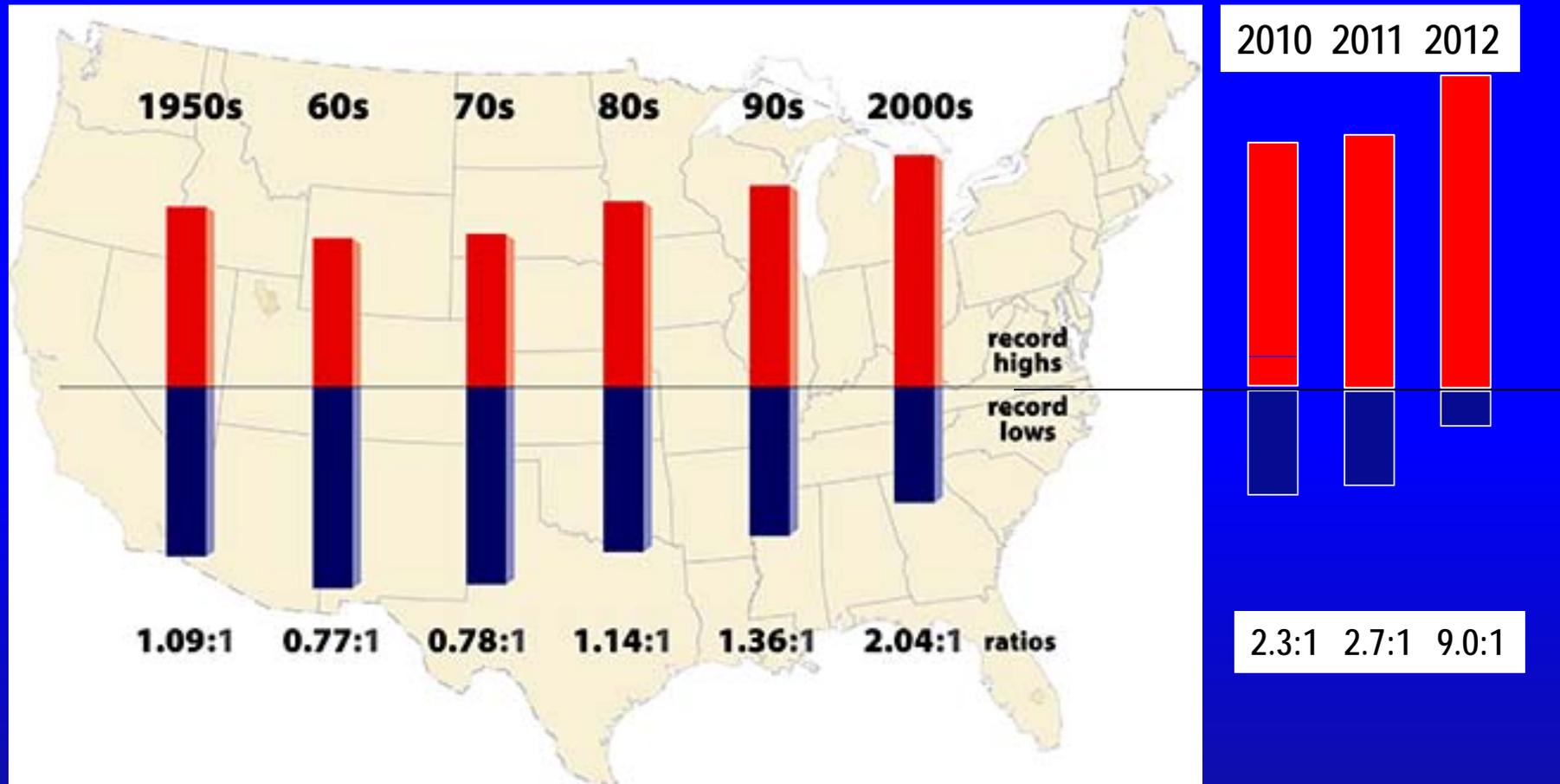
JJA

NH

Frequency of summer temperature anomalies (how often they deviated from the historical normal of 1951-80) over the summer months in the northern hemisphere.

Source: NASA/ Hansen et al. 2012 <http://climatecrocks.com/2012/08/05/hansen-on-the-new-math-of-extreme-events/>

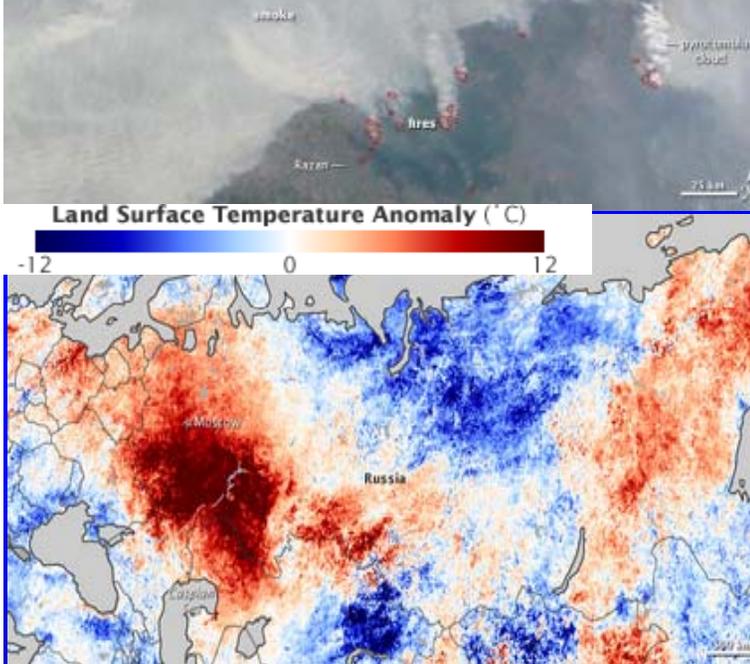
U.S. daily temperature extremes



The ratio of record daily highs (red) to record daily lows (blue) at about 1,800 weather stations in the 48 contiguous United States from Jan. 1950 to Sept. 2009. [Meehl et al. GRL 2009](#).
Update using NOAA data: Climatecommunication.org

Russia Aug 2010

>50,000 lives lost
Record heat
Wild fires



India: Jul-Aug 2010

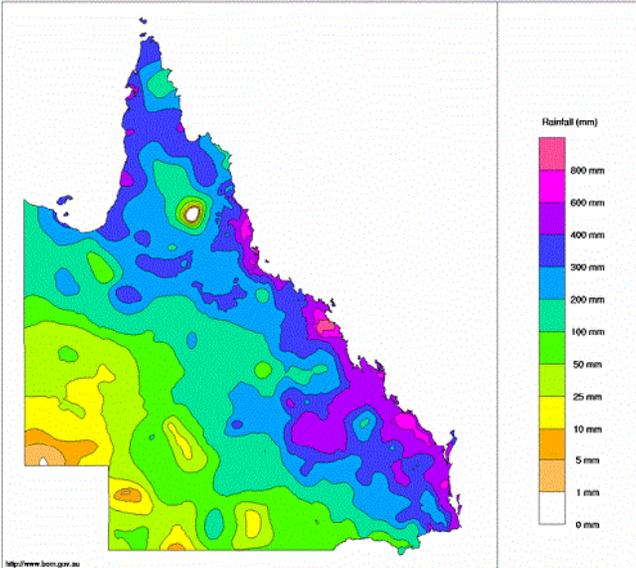


Pakistan: Jul-Aug 2010



Australia

Queensland Rainfall Totals (mm) December 2010
Product of the National Climate Centre



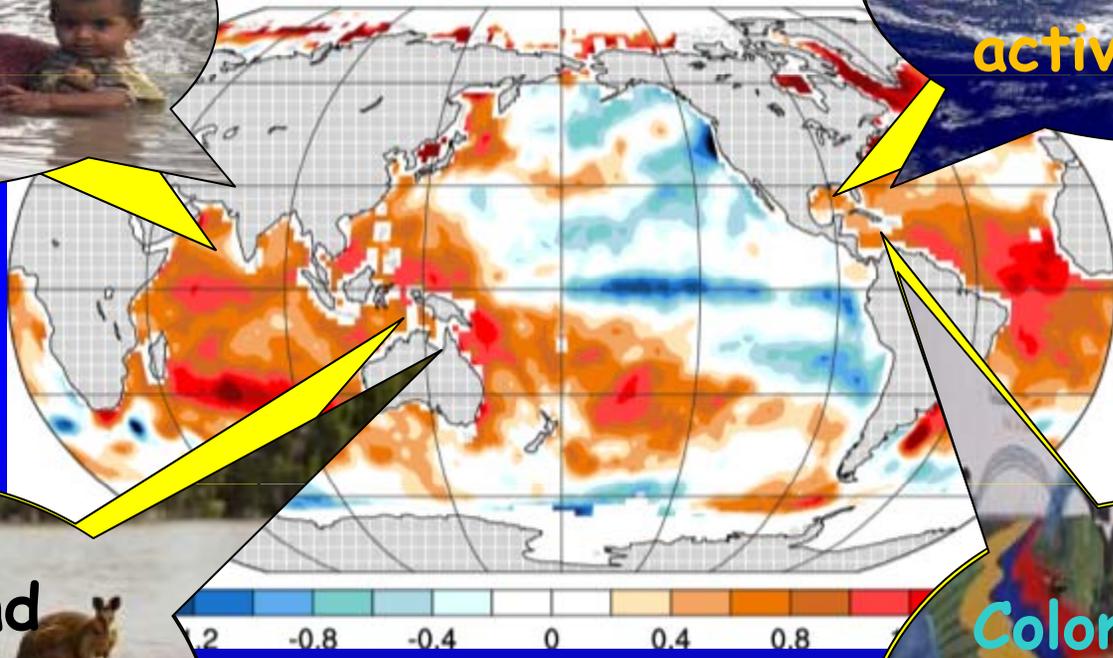
<http://www.bom.gov.au>
© Commonwealth of Australia 2010, Australian Bureau of Meteorology

Issued: 31/12/2010

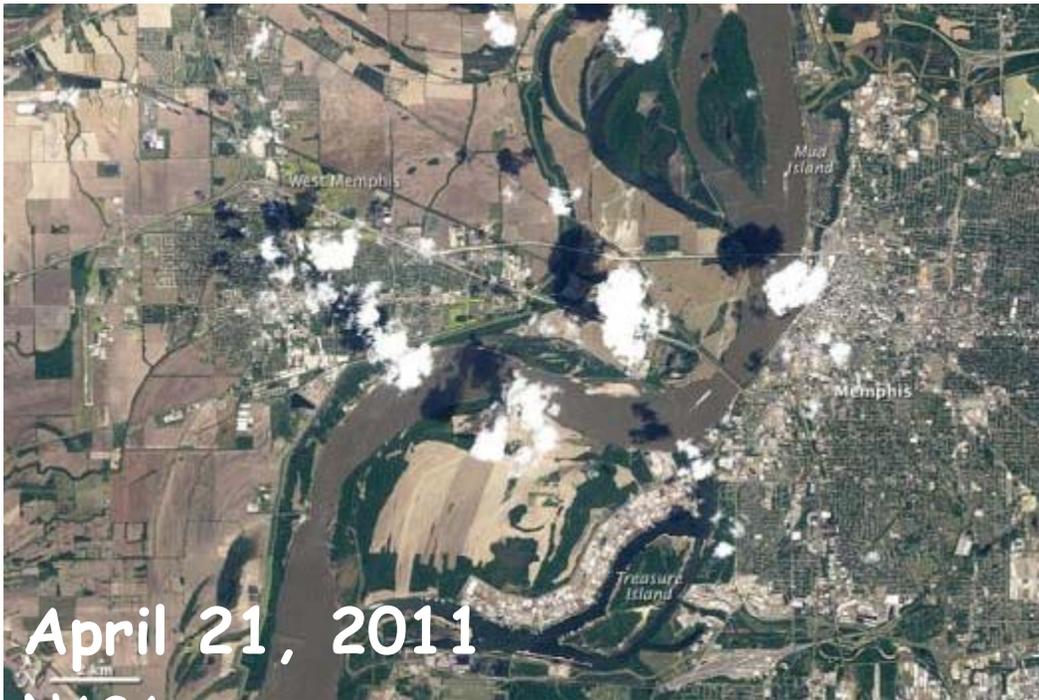
Flooding Queensland Early Jan 2011



SSTs: JJA 2010



Mississippi River



April 21, 2011

NASA



Tornadoes galore



May 1, 2011





Flooding on the Mississippi:



There were multiple "1-in-500 year" or "1-in-100 year flood events within a few years of each other in parts of the Basin...

1993

Then again in **2008**.

And now: **2011**

AP 2000; NYT 2011

Peter Gleick



Arizona on fire June 7-14, 2011

Biggest fire ever
(also Mexico)



Drought, heat, worst wild fire in Texas history!

Bastrop State Park: 14,000 acres,
Nearly 600 homes destroyed. 5 Sept
2011



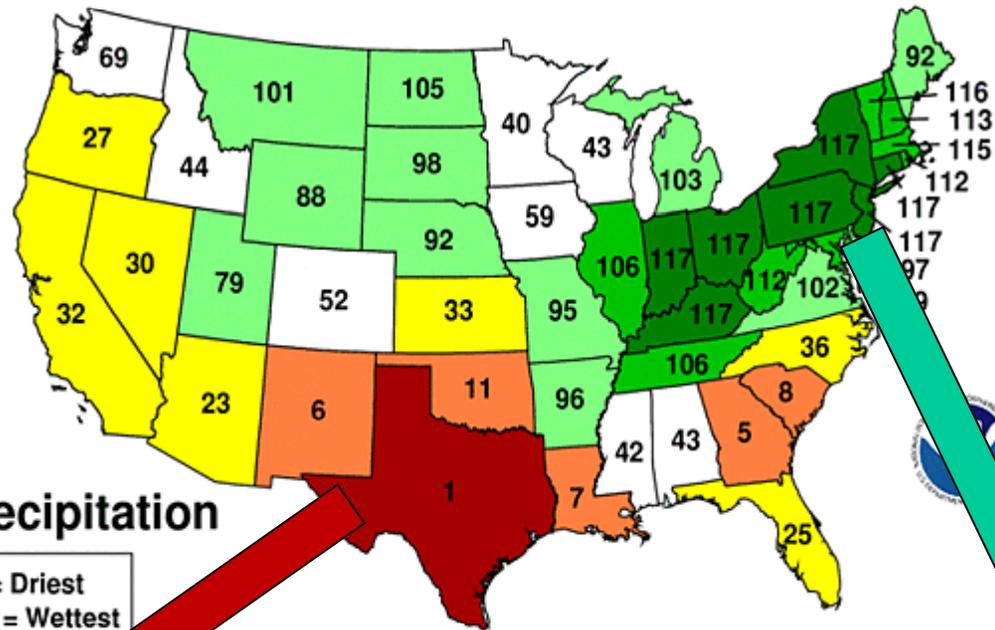
JJA 2011: Hottest on record



U.S. Annual Precipitation: 2011

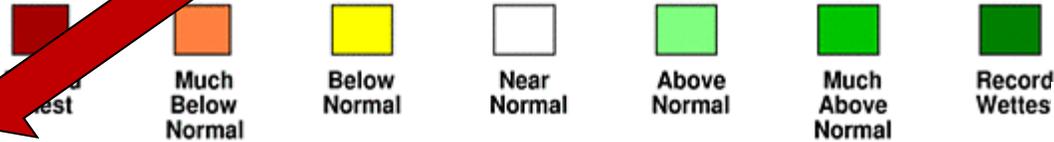
January-December 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA

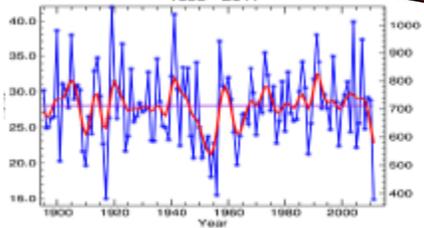


Precipitation

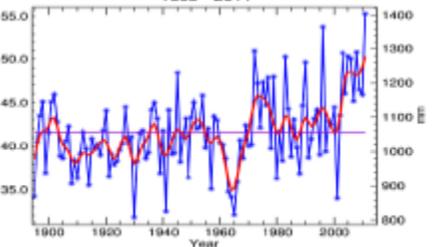
1 = Driest
117 = Wettest



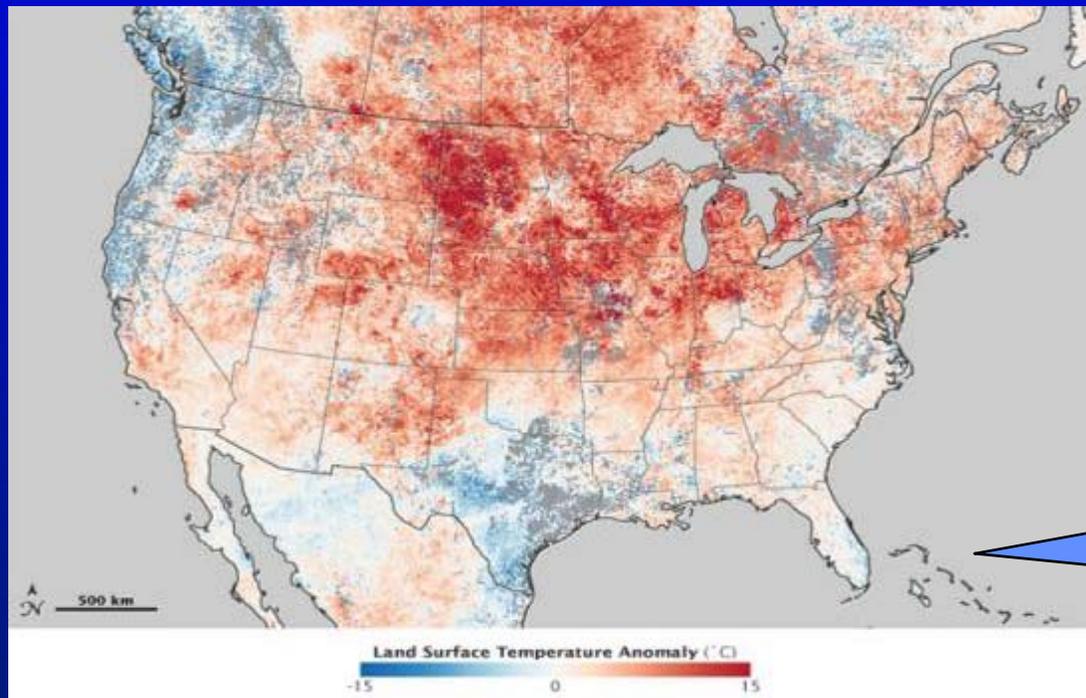
Texas Statewide Precipitation 1895 - 2011



Northeast Region Precipitation 1895 - 2011



Recent US climate extremes



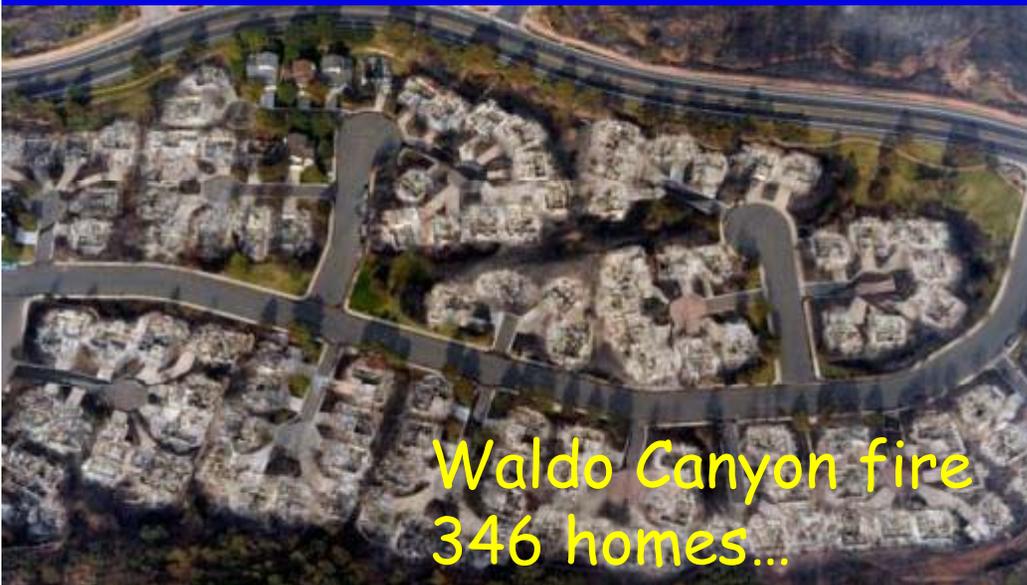
June
in
March

March 2012

Colorado on Fire: June 2012



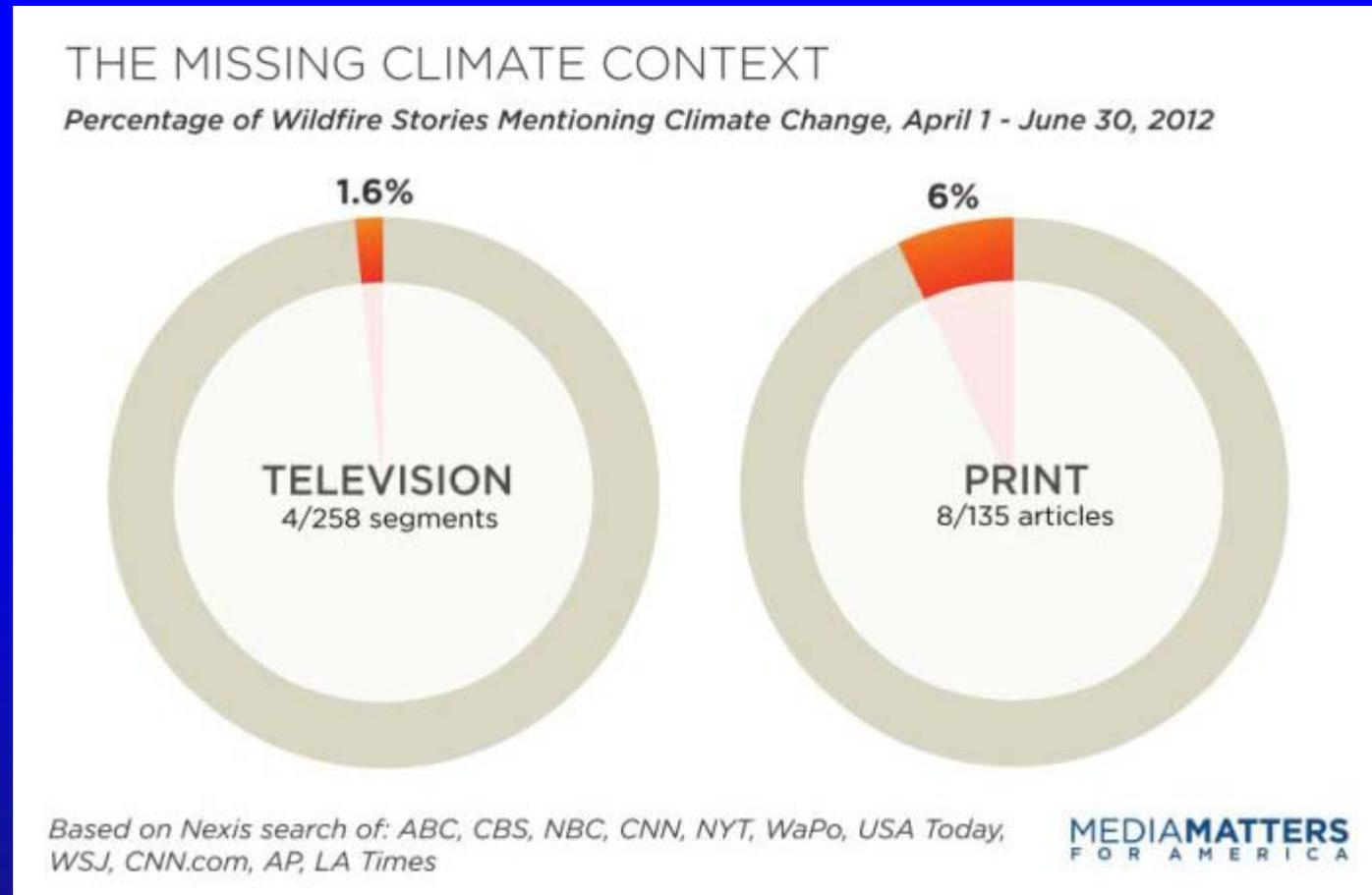
Flagstaff fire: above NCAR, circled.
High Park fire 259 houses, 1 death



Waldo Canyon fire
346 homes...



News Outlets Avoid Topic Of Climate Change In Wildfire Stories



<http://mediamatters.org/research/2012/07/03/study-media-avoid-climate-context-in-wildfire-c/186921>

U.S. Temperatures

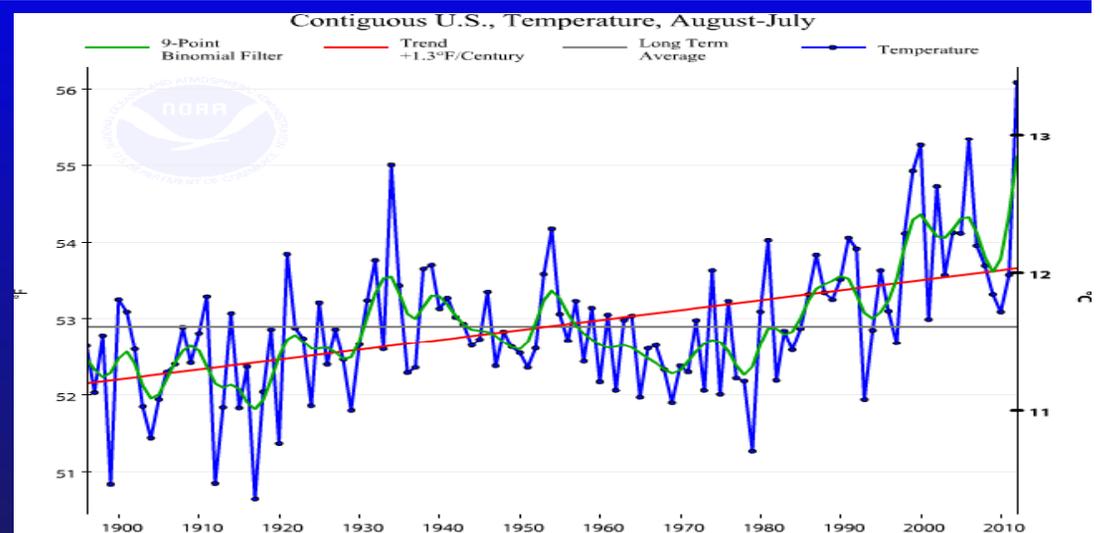
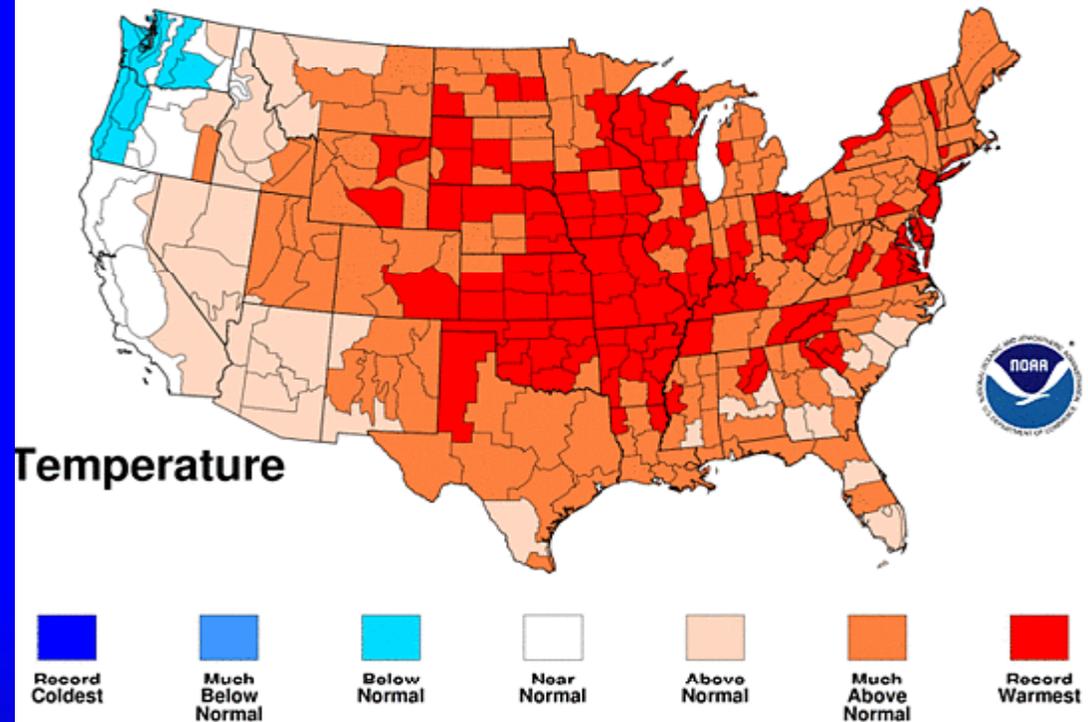
Jan-Jul 2012
Hottest on record

Aug 2011-Jul 2012
Hottest year
on record

NCDC, NOAA

Jan - Jul 2012

National Climatic Data Center/NESDIS/NOAA



Meanwhile: record flooding elsewhere:

Southern Russia

Early July 2012
172 dead
11 inches of rain
Water rose 12 feet in mins
Poor warnings



Southern Japan

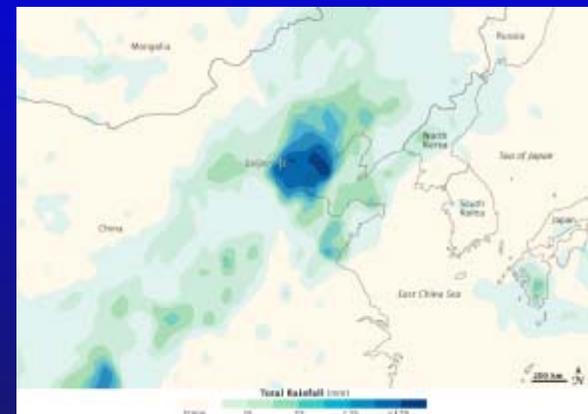
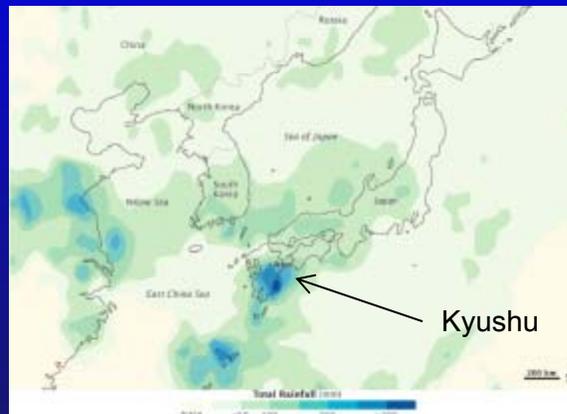
6-12 July 2012
Torrential rain (> 10"): flash floods, mudslides
>32 dead or missing.
400,000 evacuated.



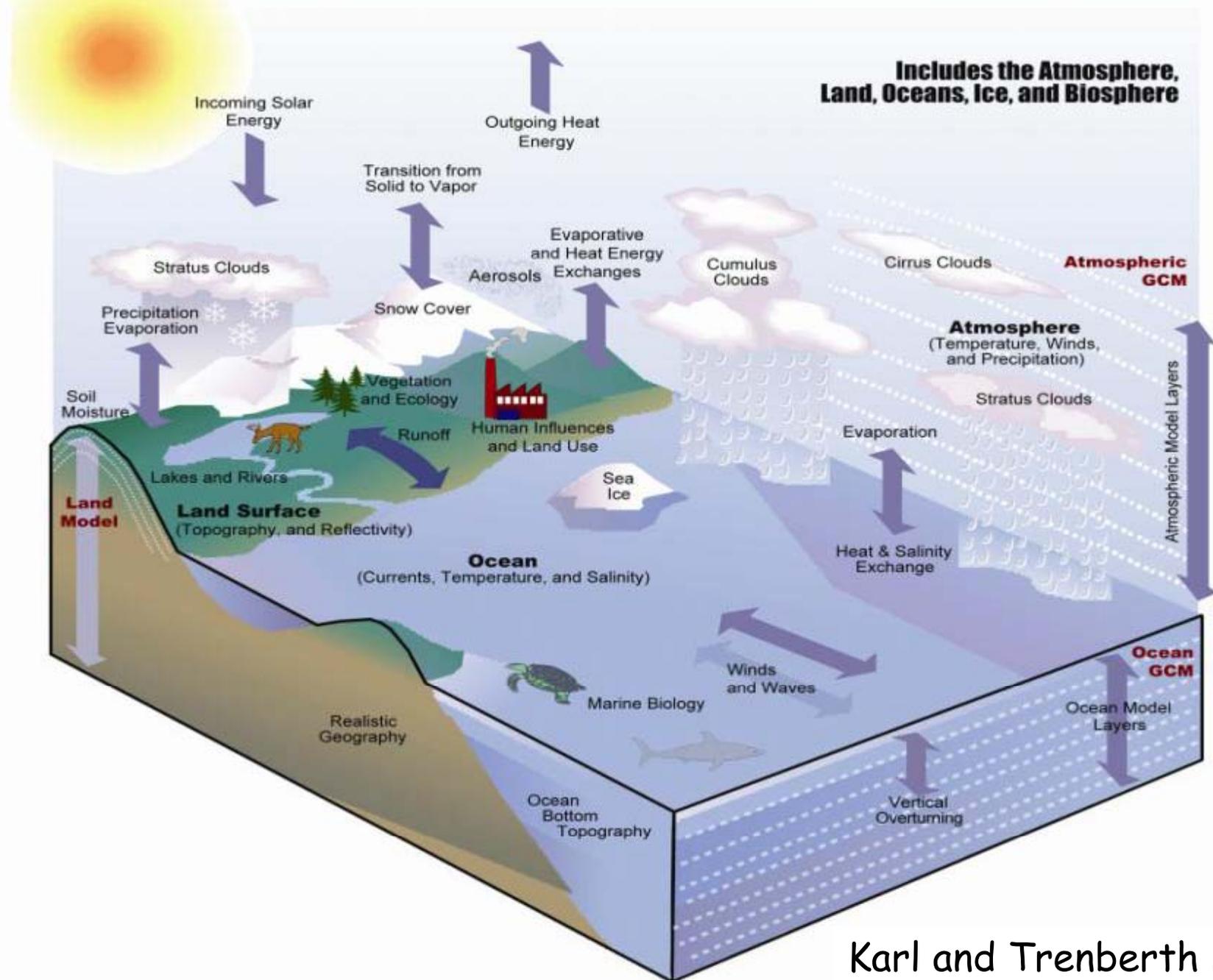
Torrential Rain + Landslides
Kyushu, Japan | 2012

Beijing

21-22 July 2012
\$2B damage
Worst rains in 61 years:
(up to 18 inches)



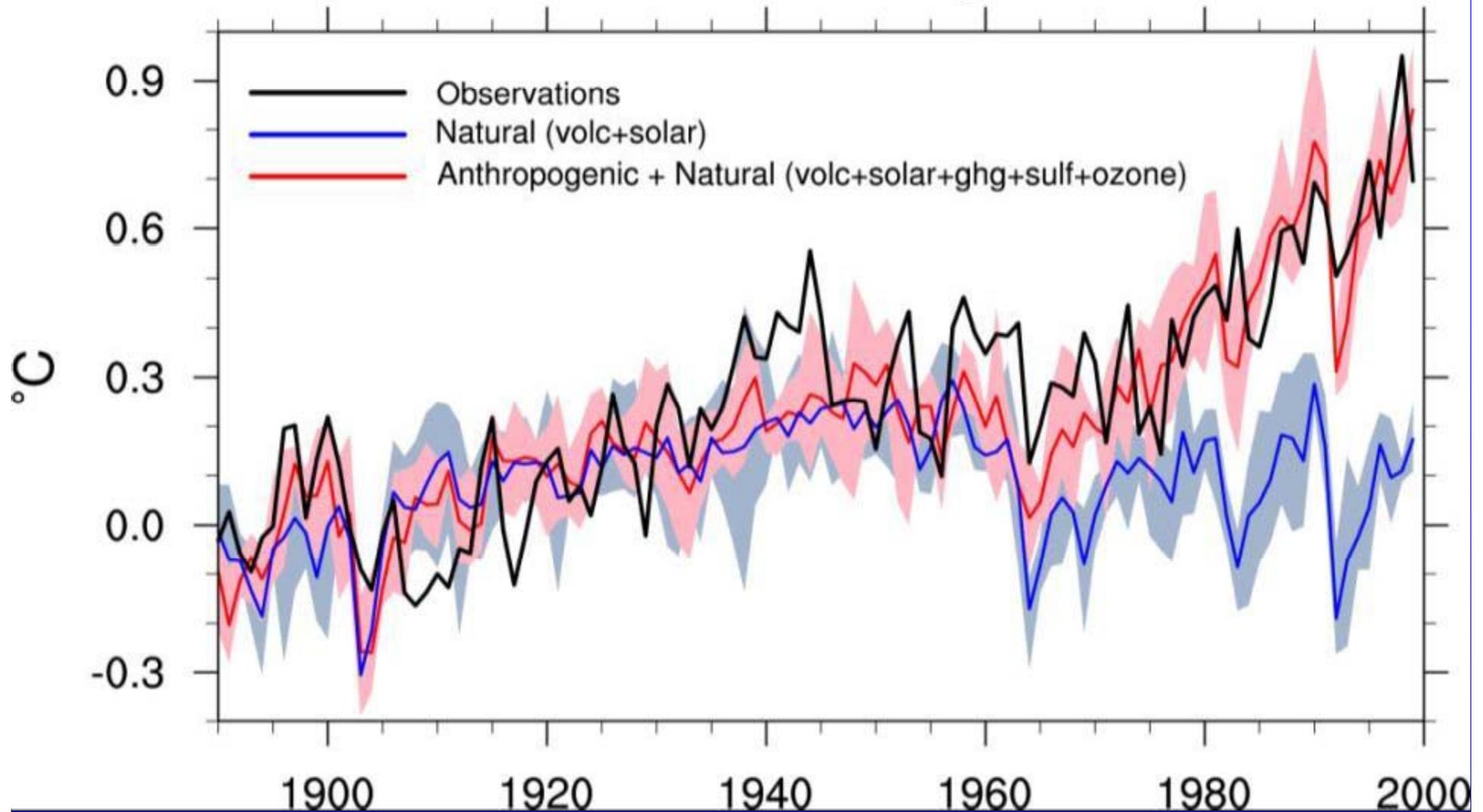
Modeling the Climate System



Karl and Trenberth 2003

Natural forcings do not account for observed 20th century warming after 1970

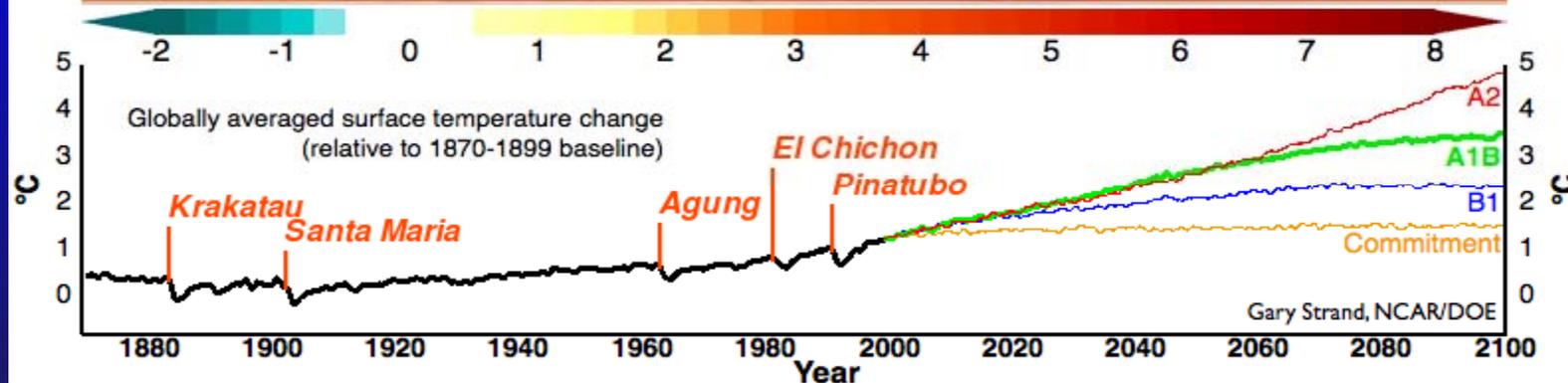
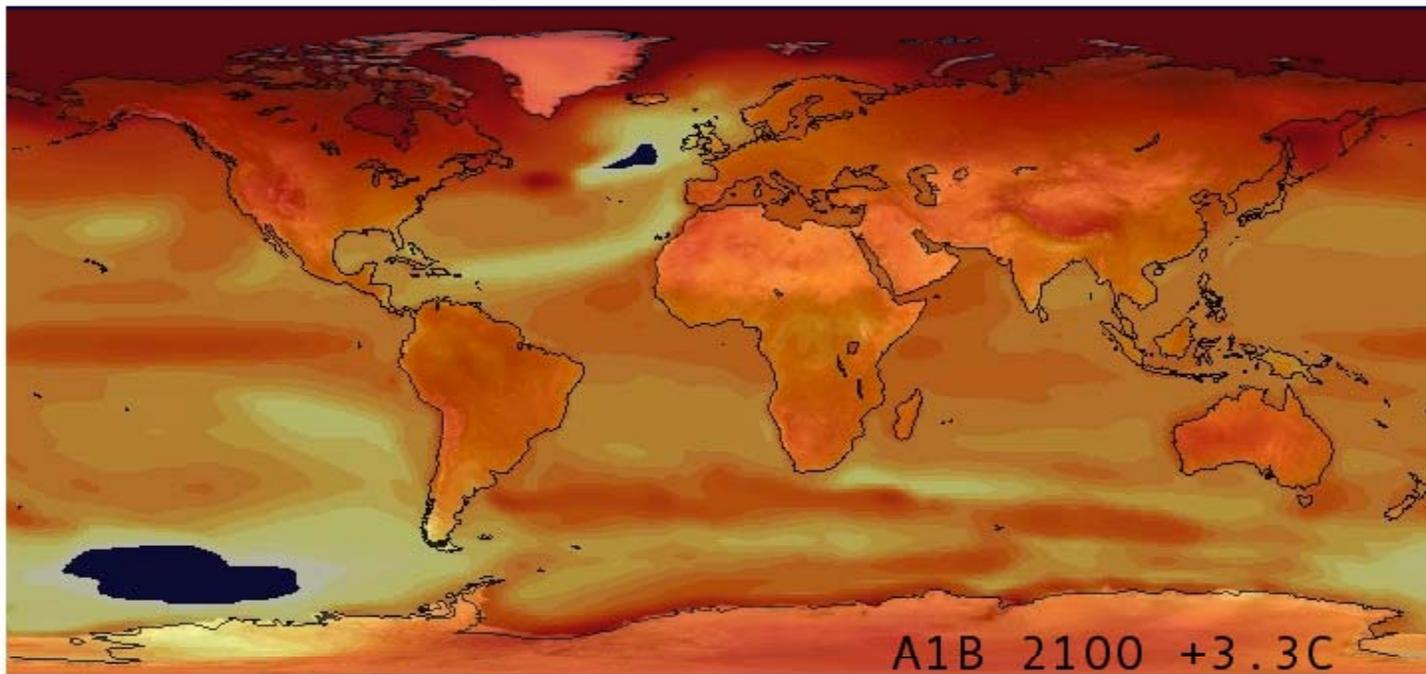
Global Temperature Anomalies
from 1890-1919 average

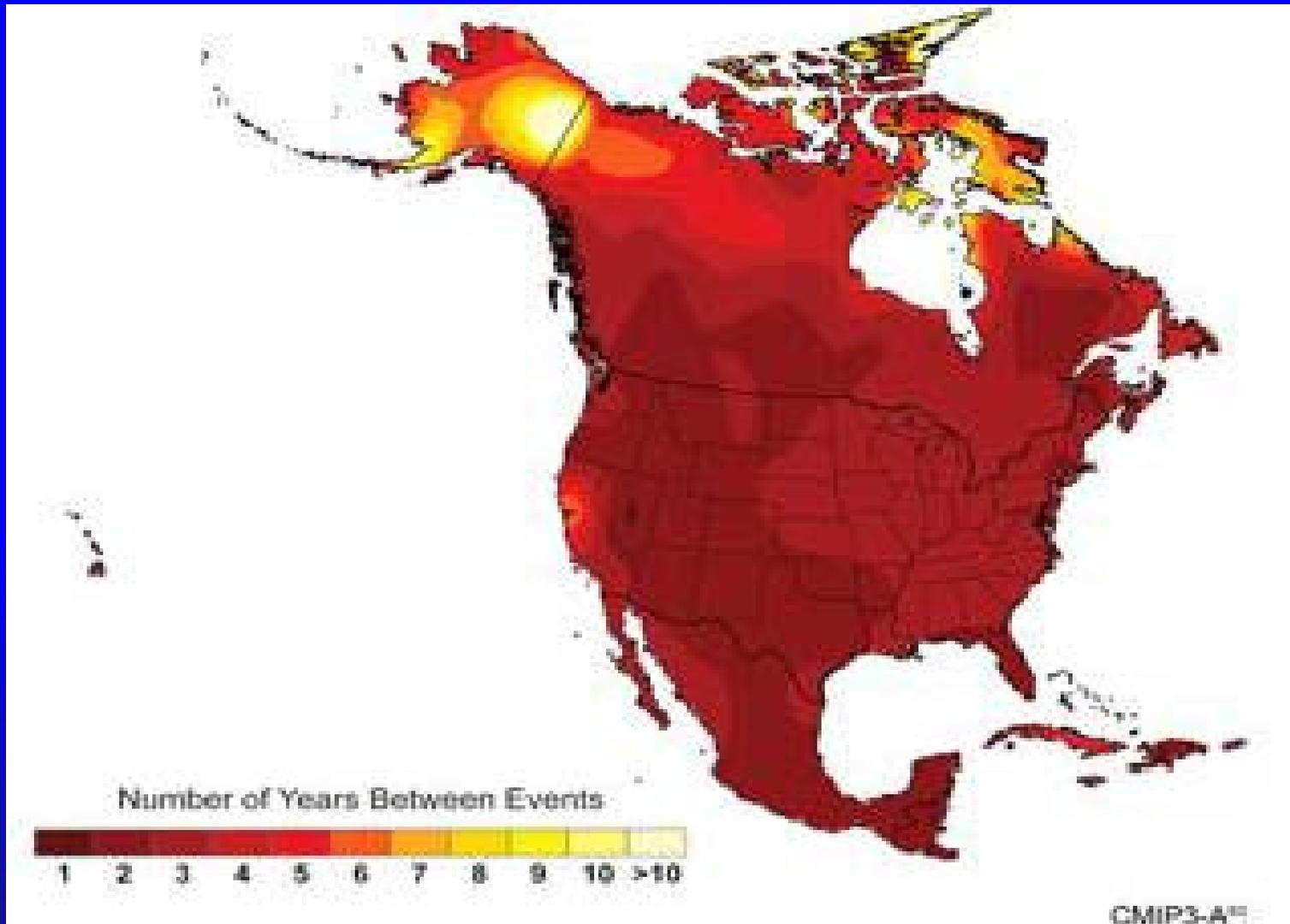


Projected temperature change

CCSM Movie

Surface temperature change relative to 1870-1899 baseline CCSM3 IPCC AR4

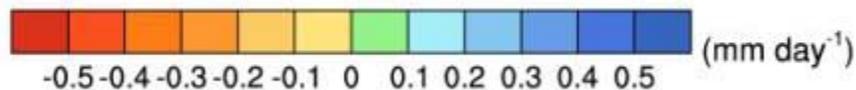
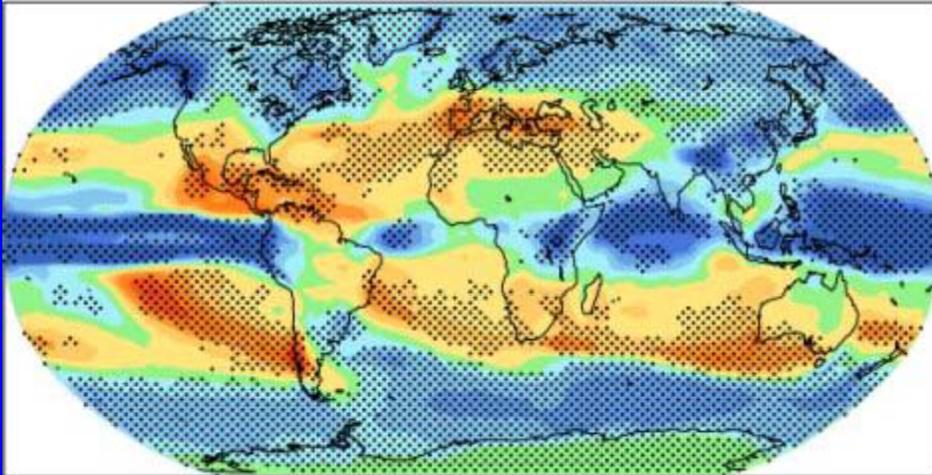




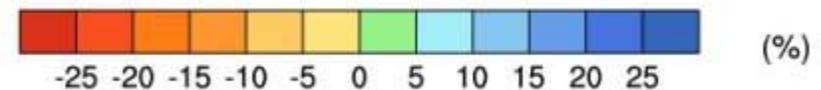
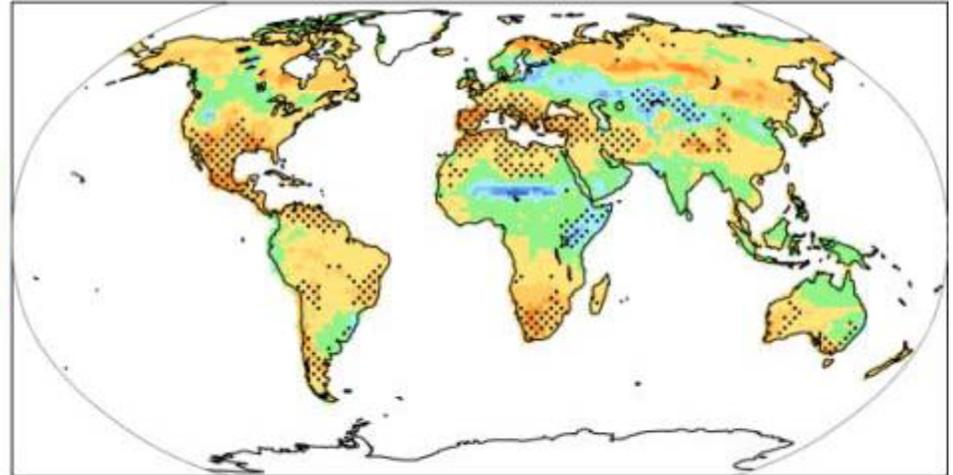
Projected Frequency of Extreme Heat: 1-in-20 Year Events. By the end of this century, a once-every-20 year heat wave is projected to occur every other year Source: U.S. GCRP

Projected Patterns of Precipitation Change 2090-2100

a) Precipitation

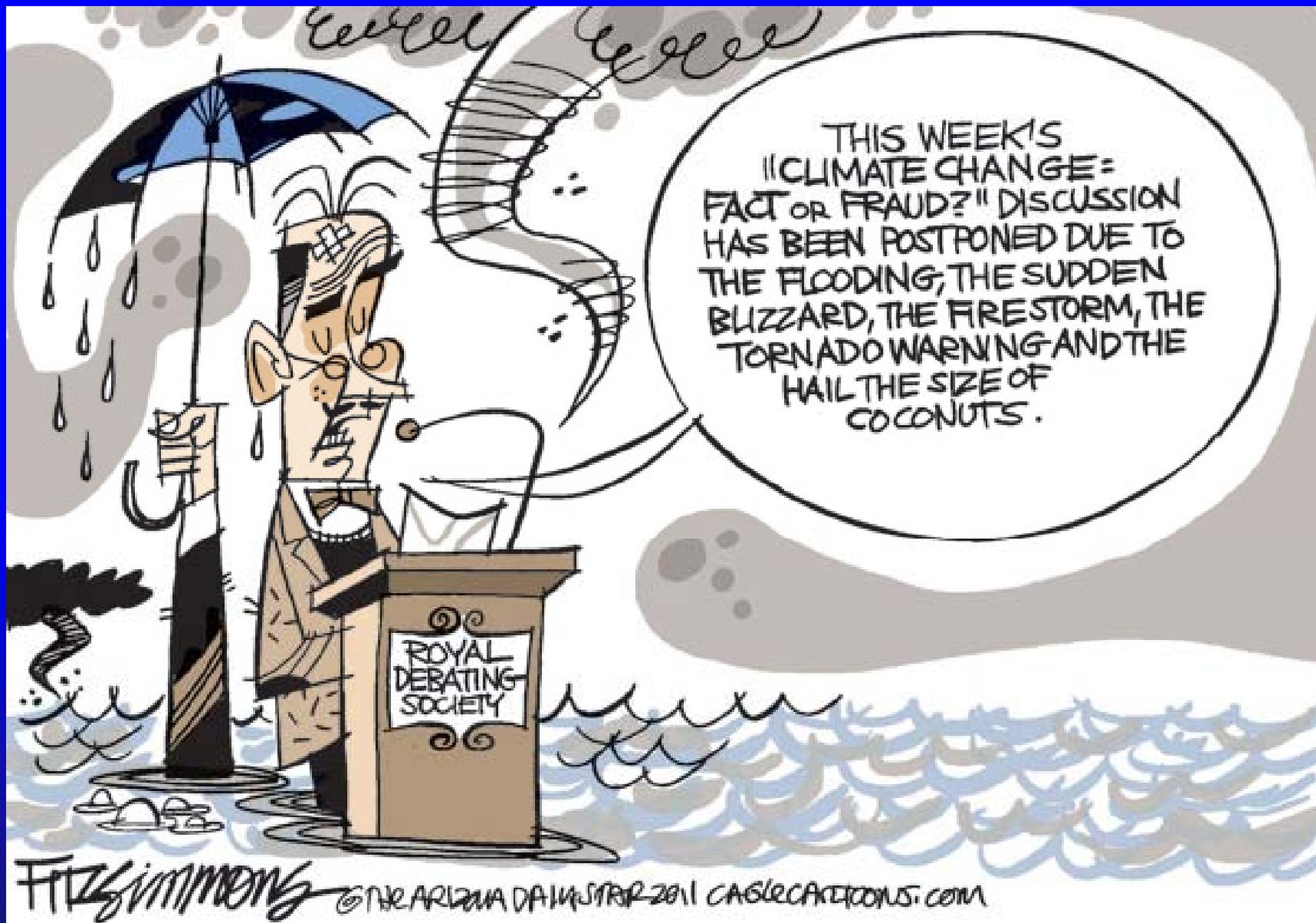


b) Soil moisture



Rich get richer and poor get poorer:

Combined effects of increased precipitation intensity and more dry days contribute to mean precipitation changes, increased evaporation also important for soil moisture.



Future prospects

To avoid disastrous climate, "the scientific view is that the increase in global temperature should be below **2°C**": about 3.6°F.

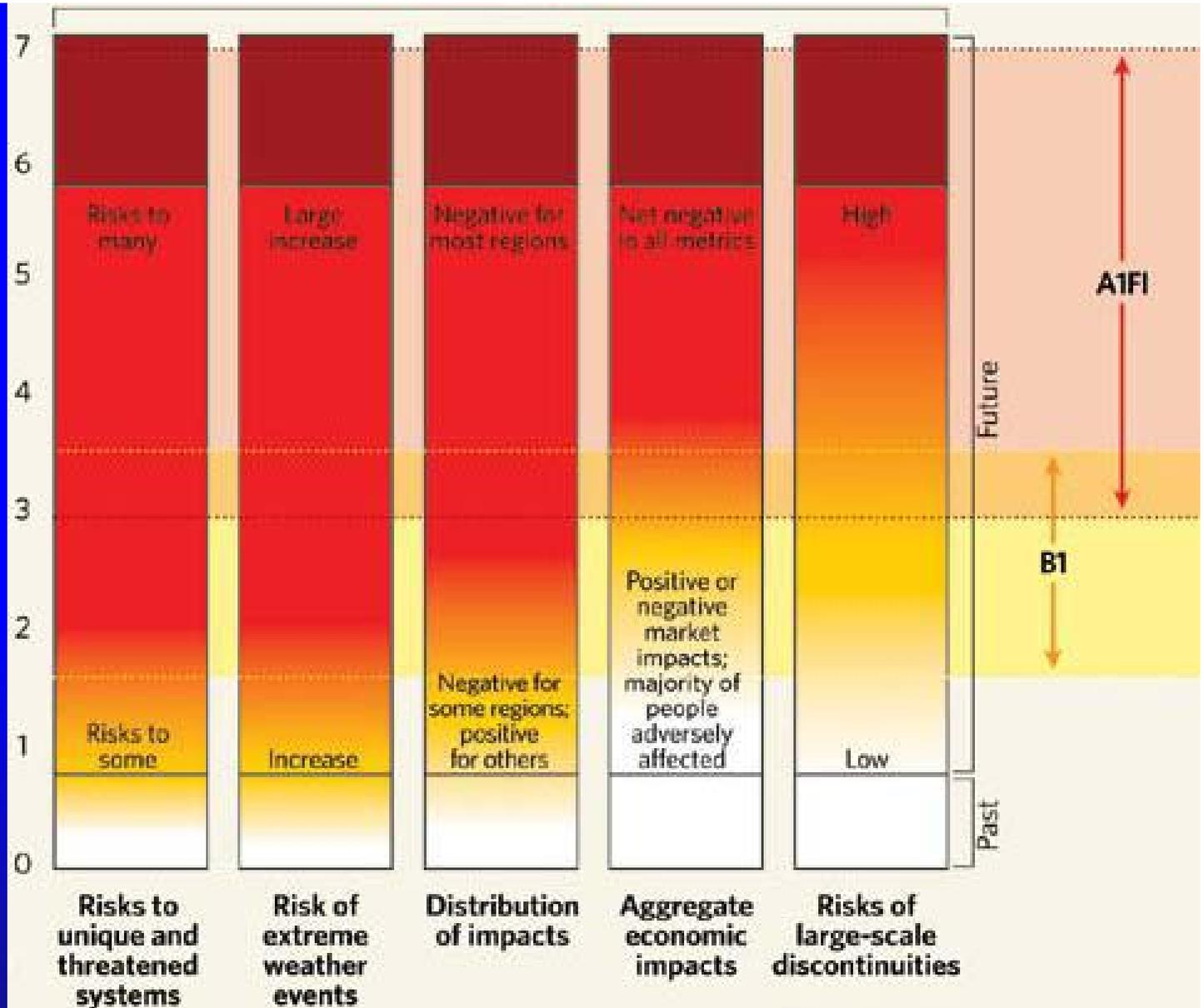
To achieve that "deep cuts in global emissions are required" **Copenhagen Accord, 2009.**

So far, temperatures have risen 0.8°C. But we are committed already to at least 0.6°C more owing to the slowly warming oceans and long lifetime of CO₂.

In fact 2°C is programming in many problems...

Future impacts

Smith et al
PNAS 2009



AIFI: risk from tripling CO₂ to about 950 p.p.m. by 2100

Future prospects

Scientists estimate that the total warming depends mostly on the total emissions of greenhouse gases and for 2°C the limit is **565 more gigatons** of carbon dioxide into the atmosphere by midcentury.

Allen et al: Nature 2009

CO₂ emissions last year rose to **31.6 gigatons**, up 3.2% from the year before. (Intl Energy Agency)

- US emissions fell slightly (warm winter, recession)
- China's emissions rose 9.3%

At current rates: we will go through that limit in **16 years!**

How much is available? **2,795 Gigatons** in proven coal, oil and natural gas reserves.

Bill McKibben 2012

Multi-dimensional problem

- Environmental
- Economic
- Human strife
- Trade (tariffs)
- Foreign policy
- Security
- Sustainability

Security and Climate Change

9 Aug 2009

- "We will pay for this one way or another. We will pay to reduce greenhouse gas emissions today, and we'll have to take an economic hit of some kind. Or we will pay the price later in military terms. And that will involve human lives."

GEN. ANTHONY C. ZINNI, former head of the Central Command, on climate change.

Global Warming Actions

**Sustainable
Development**

Adapt
Technological
Fix

Mitiga
Pr

Tragedy of the Commons

future generations

Precautionary Principle

Do Nothing
No
Problem

We need a price on carbon emissions!

As we have seen this year, there are major costs: \$billions, to climate change via droughts and wildfires, and floods. [Lives lost, crop loss, crop insurance, wild fire losses, costs of fighting fires, property damage, dislocation, disease, etc]

The costs are not borne by those who cause the problem.

Explicit and implicit subsidies for fossil fuels do not make the playing field level for renewable energy.

The U.S. is a major part of the problem.

Skepticism and denial

Several studies find a widespread relationship between **belief in free markets** and rejection of climate science.

Endorsement of **conspiracy theory** also goes with rejection of climate science

e.g. NASA faked the moon landing
FBI killed Martin Luther King...

Lewandowsky et al 2012

Skepticism and denial

There are widespread well financed denial campaigns to

- Maintain the status quo
- Undermine scientists
- Oppose possible government regulations

- US Chamber of Commerce
- Exxon Mobile
- American Petroleum Inst
- Western Fuels
- Koch Bros, Scaife,

Often through third parties with euphemistic names:

- Citizens for a Sound Economy
- Americans for Prosperity
- Competitive Enterprise Inst
- Heartland Inst
- Cooler Heads Coalition...

Oreskes and Conway 2010
Dunlap and McCright 2011

WHICH MAKES MORE SENSE?



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Many things you can
do:

Going
Green!





There is no Planet B