

# ***Is Climate Change Influencing the Biosphere?***



***5<sup>th</sup> Jeremy Grantham Lecture  
Indian Institute of Science  
Divechi Center for Climate Change***

***Steven W. Running  
Numerical Terradynamic Simulation Group  
University of Montana USA***

***27 March 2013***

# Montana, a cool, dry mountain region



2005 8 17

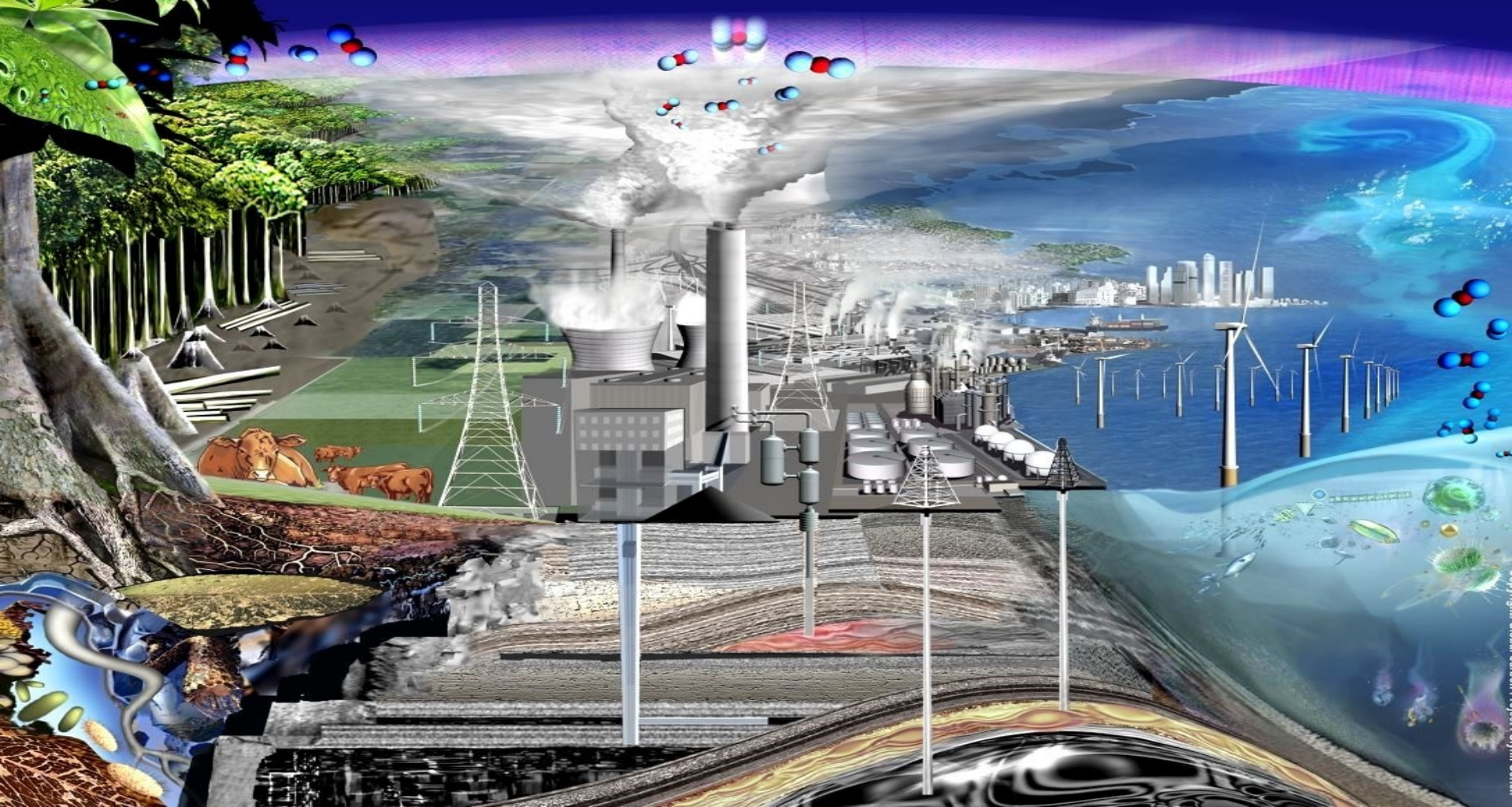
# Carbon dioxide has risen by 36% since accurate measurements began in 1958



318 ppm (1958)

388 ppm (2008)

Mauna Loa Observatory on Hawai'i



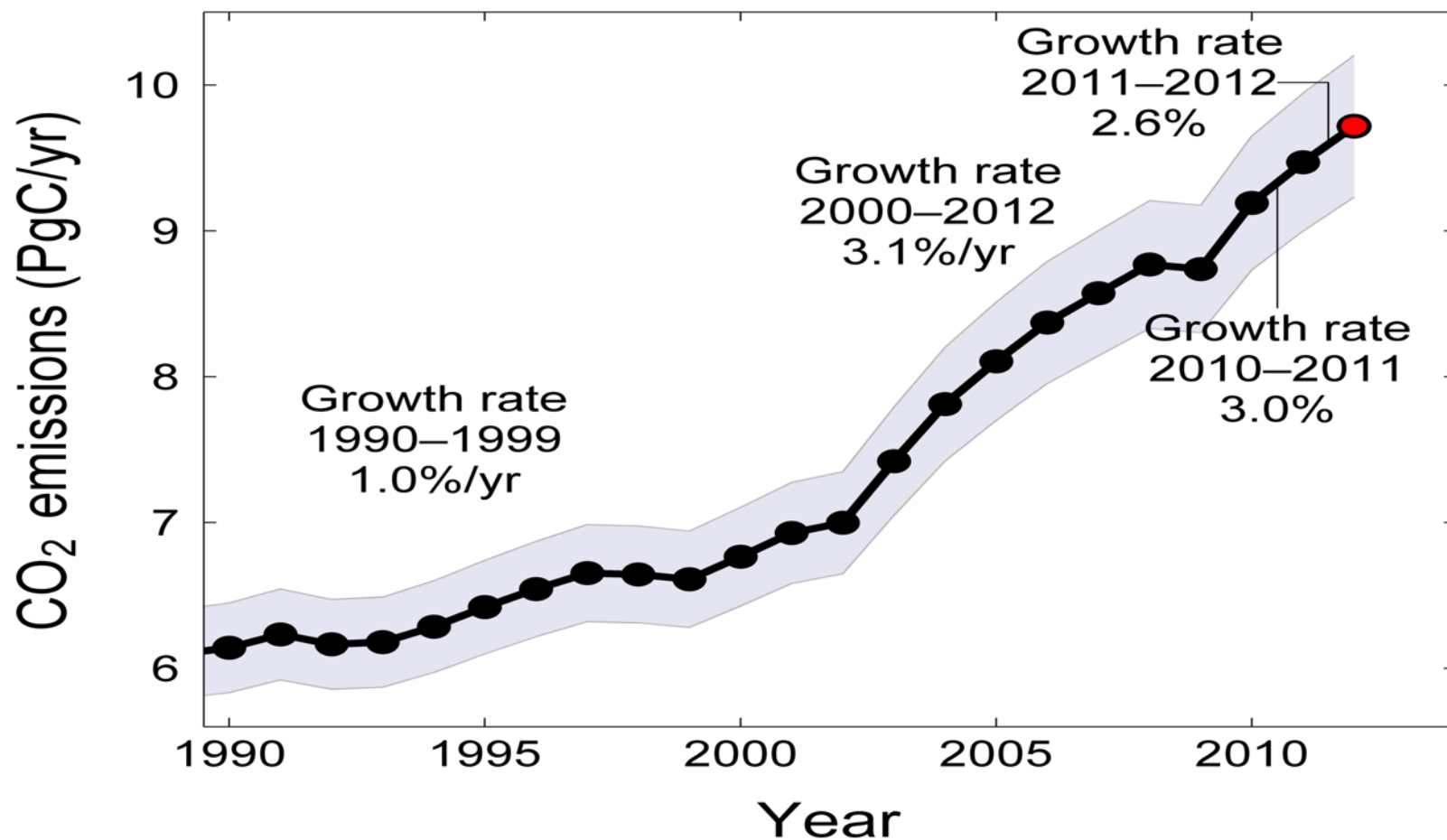
*“The rise in  $CO_2$  is proceeding so slowly that most of us today will, very likely, live out our lives without perceiving that a problem may exist”*

*Keeling CD, Harris TB, Wilkins EM, 1968. Concentration of atmospheric carbon dioxide at 500 and 700 millibars. J. Geophys. Res. 73:4511-28*

# Fossil and Cement Emissions

Global fossil and cement emissions:  $9.5 \pm 0.5 \text{PgC}$  in 2011, 54% over 1990

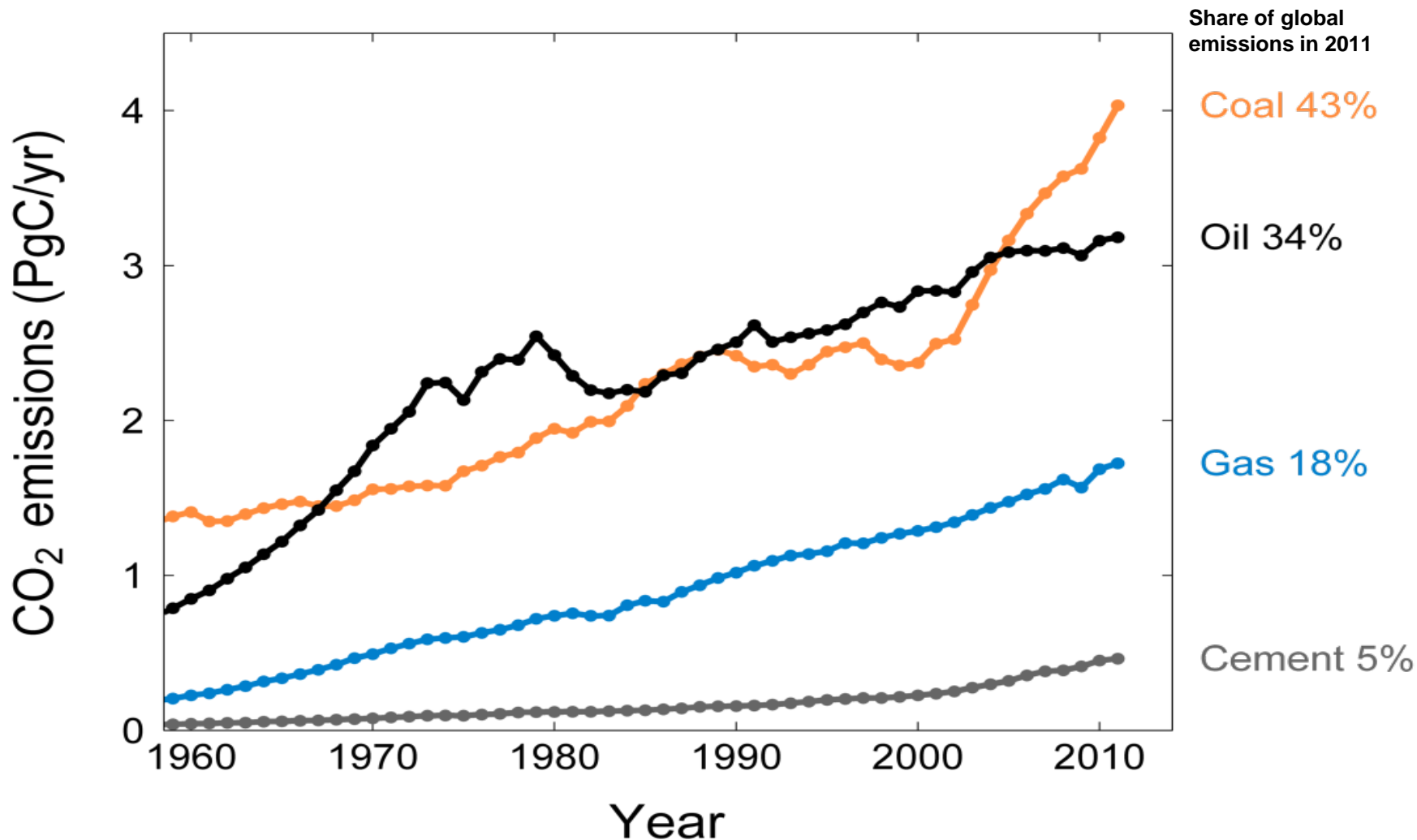
Projection for 2012:  $9.7 \pm 0.5 \text{PgC}$ , 58% over 1990



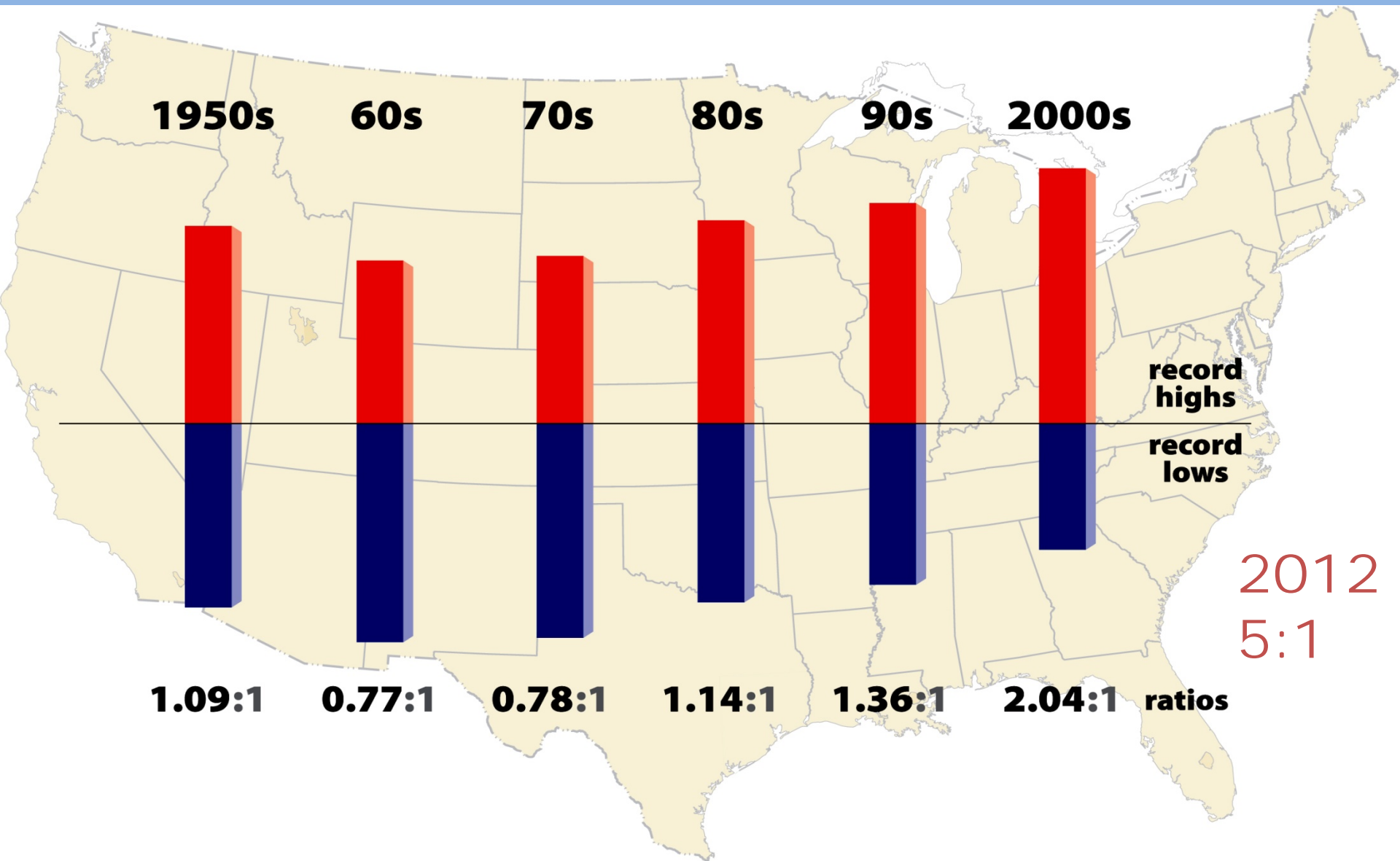
Uncertainty is  $\pm 5\%$  for one standard deviation (IPCC “likely” range)

# Emissions from coal, oil, gas, cement

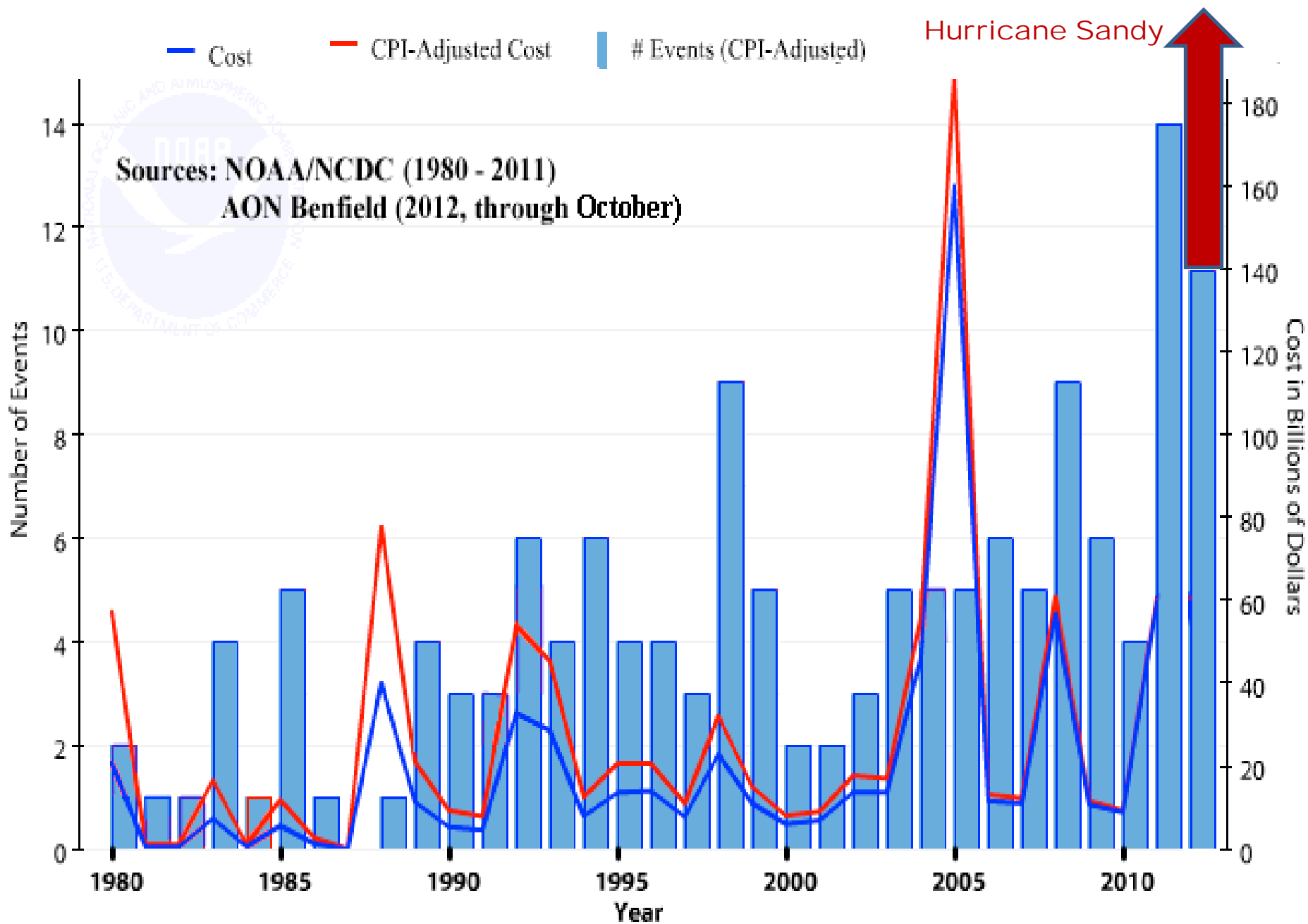
Emissions growth 2000-2011: coal (4.9%/yr), oil (1.1%/yr), gas (2.7%/yr), cement (6.9%/yr), flaring (4.3%/yr, not shown)



# # of RECORD Daily HIGH/LOW Temperatures

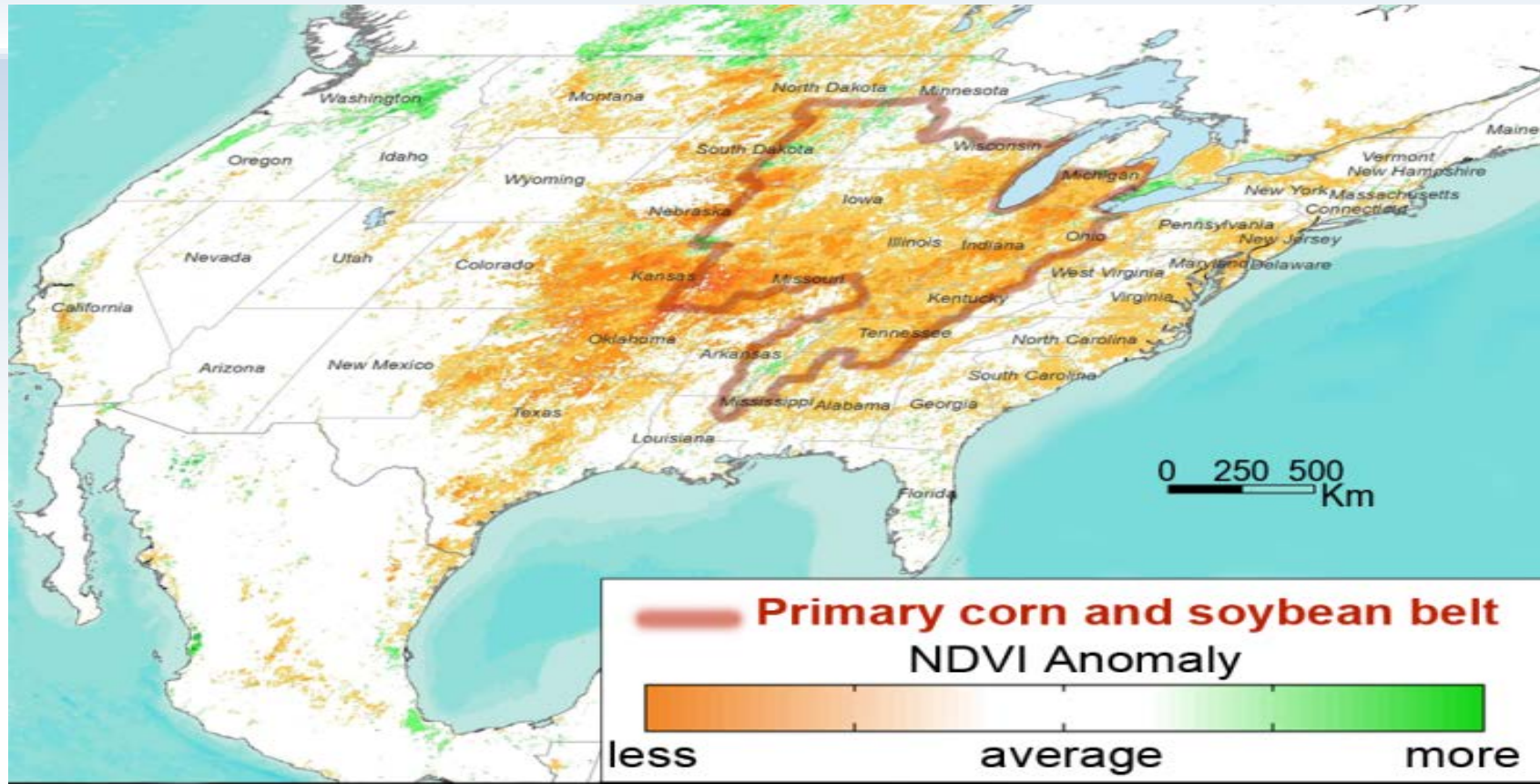


# Billion-Dollar U.S. Weather Disasters, 1980 - 2012

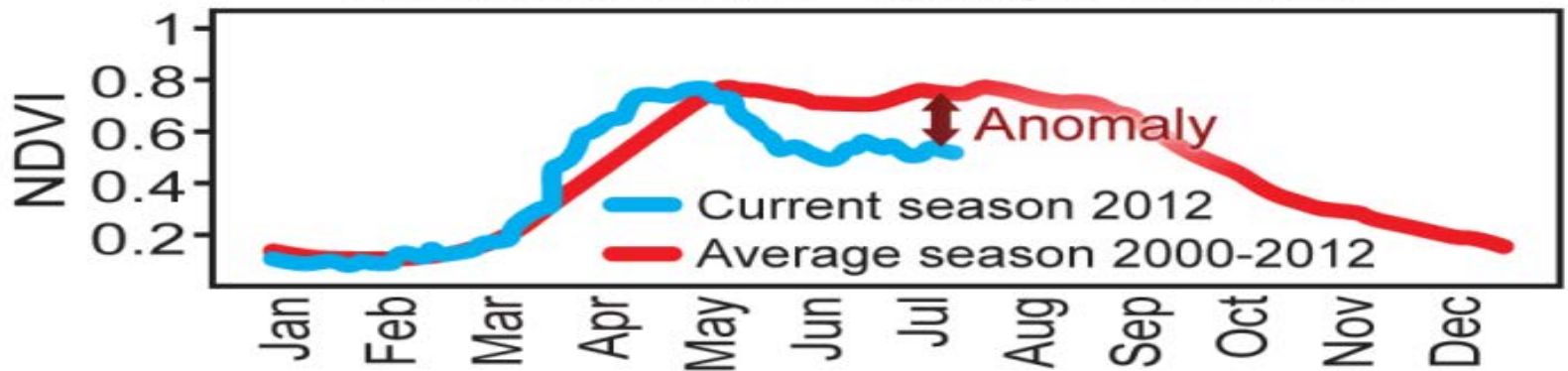




# U.S. Drought of 2012



NDVI time series - example in Kansas



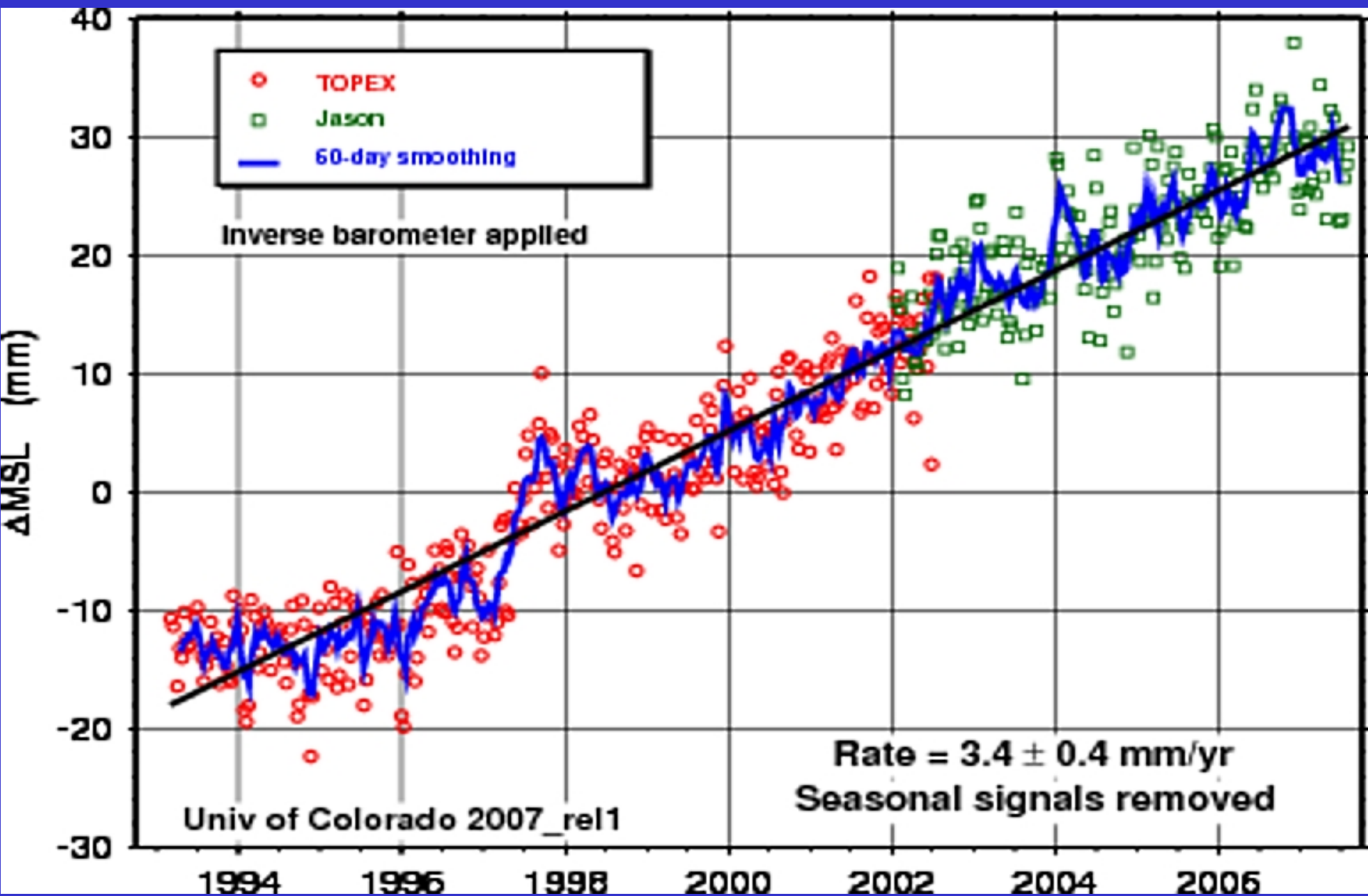
From MODIS data.  
Courtesy of I. Becker-Reshef, E. Vermote, M. Claverie and C. Justice, University of Maryland.



# HURRICANE SANDY \$60 BILLION



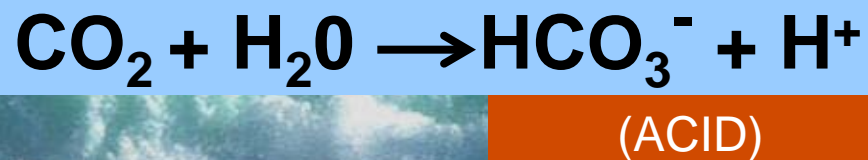
# SEA LEVEL RISE



# Ocean Acidification

Over the last 200 years, about **50%** of all CO<sub>2</sub> produced on earth has been **absorbed by the ocean**. (Royal Society 6/05)

Dissolves in sea water



Water becomes more acidic.

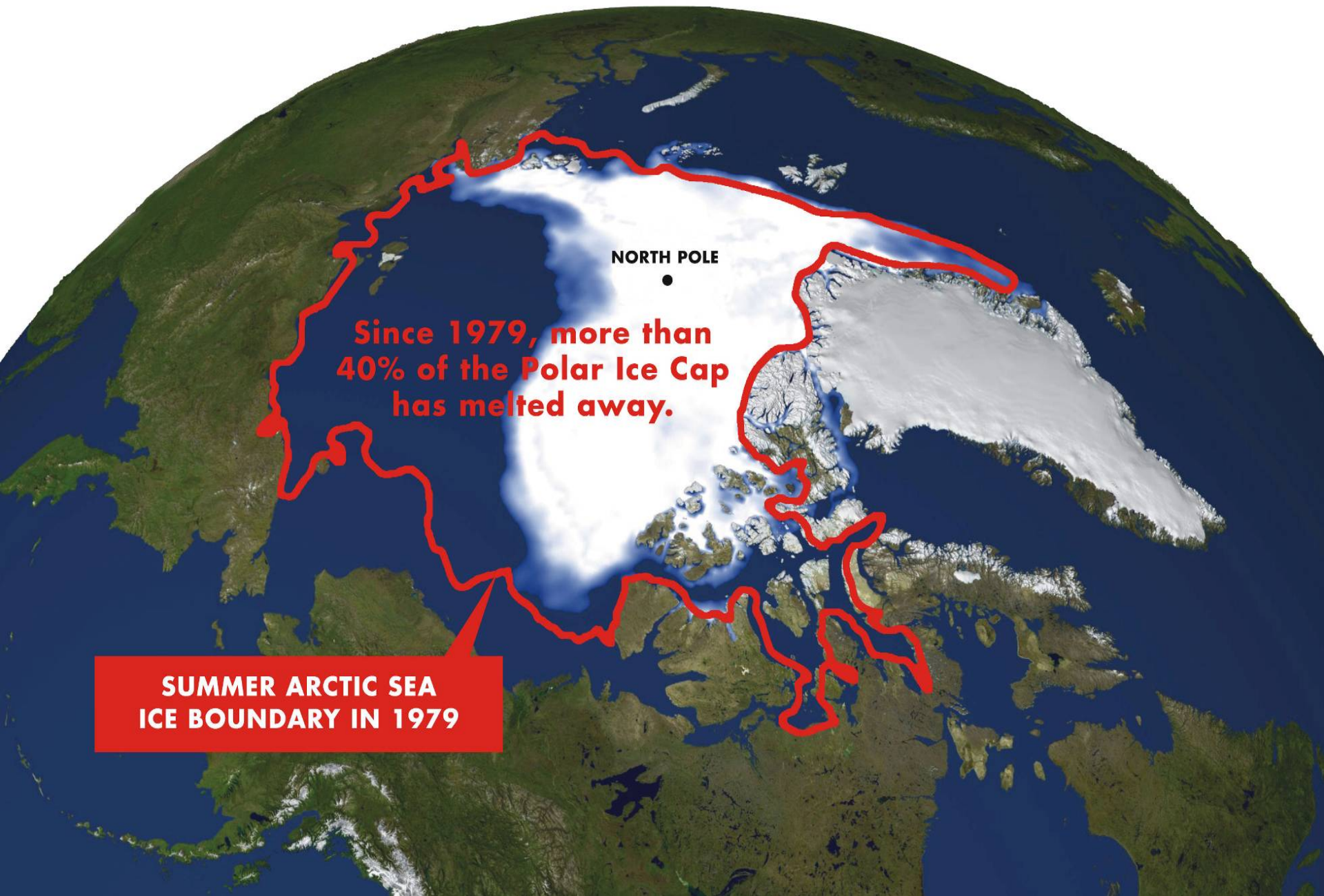
Remains in the atmosphere (greenhouse gas)

CO<sub>2</sub>

CO<sub>2</sub>



# Arctic Sea Ice Loss



NORTH POLE

Since 1979, more than  
40% of the Polar Ice Cap  
has melted away.

SUMMER ARCTIC SEA  
ICE BOUNDARY IN 1979

# Warming Winters in US

Average Low Temp. in Coldest Month (1895-2010)

22.5°F

20°

17.5°

15°

1900

1925

1950

1975

2000

Linear Trend

25yr Average

# Sperry Glacier

## Glacier National Park, MT



**1913** *W. C. Alden photo, courtesy GNP Archives*



**2008** *Lisa McKeon photo, USGS*

*In 1913, Sperry Glacier's mass spanned across the entire basin and the glacier's terminus was recorded at over 150 ft. tall. Contemporary images show how the glacier has receded and separated into fragments.*

# Glacier National Park, Montana, United States



## Grinnell Glacier from Mt. Gould 1938 - 2006



**1938**

*Hileman photo  
GNP Archives*



**1981**

*Key photo  
USGS*



**1998**

*Fagre photo  
USGS*

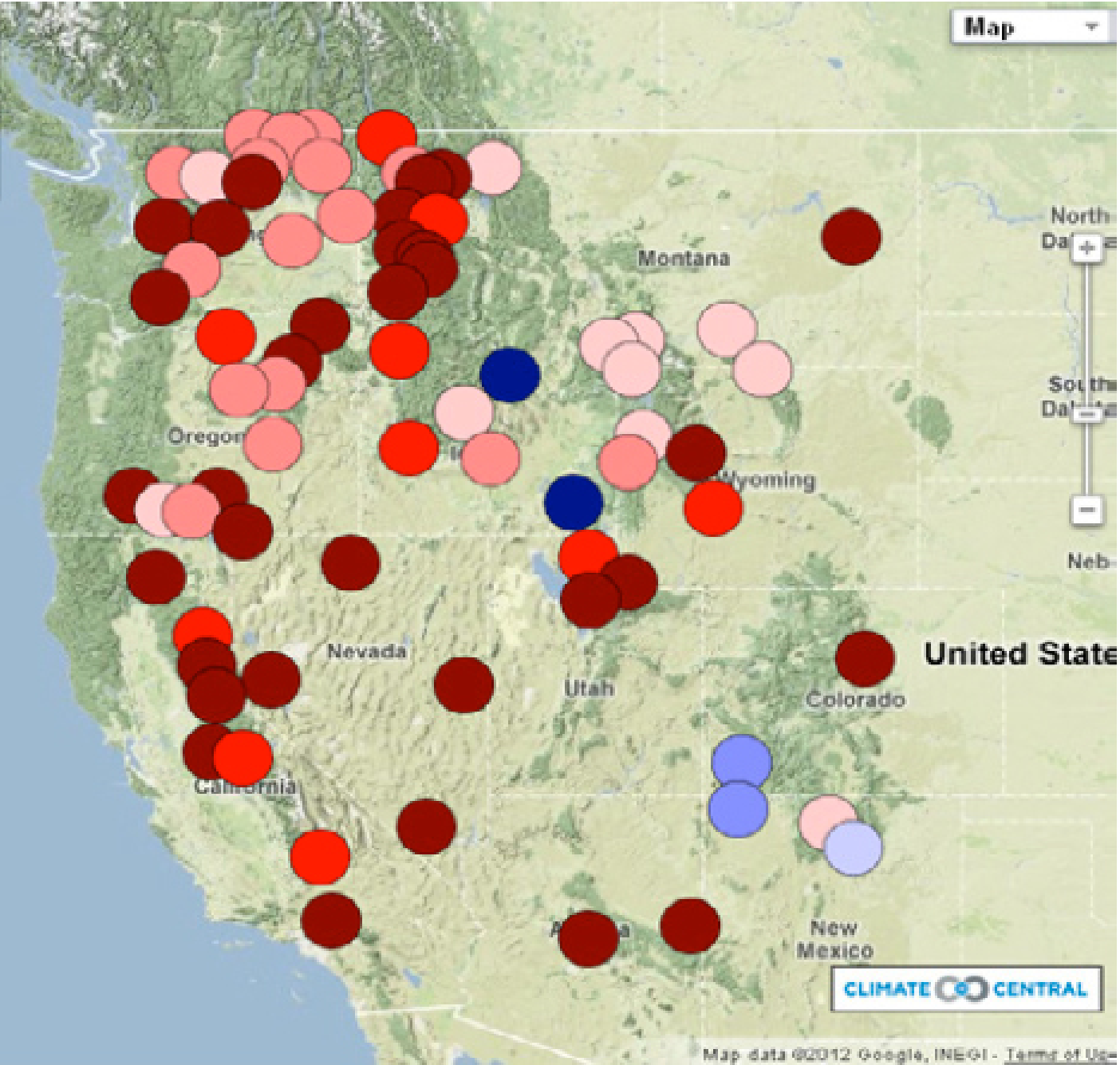
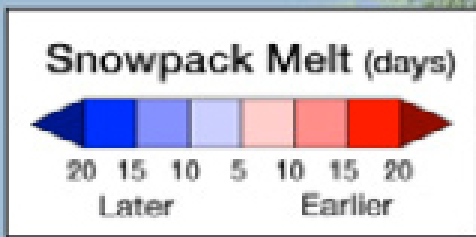


**2006**

*Holzer photo  
USGS*



# Snowmelt is Happening Earlier in the Spring in the West



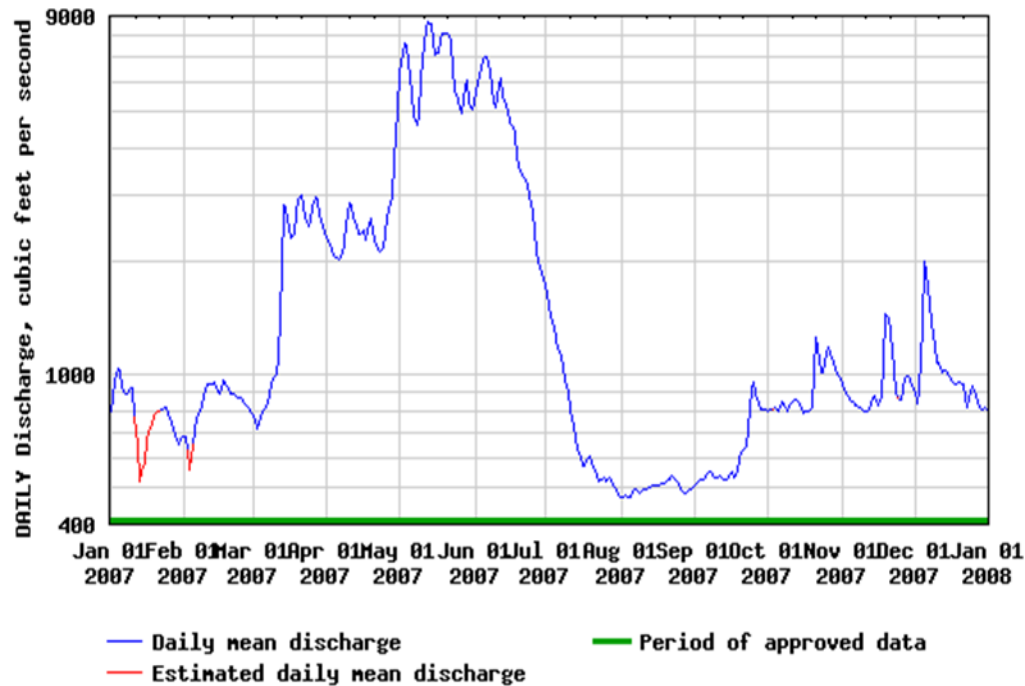
March 4 2007, 7,000ft, North-slope  
Bitterroot Mtns, Montana



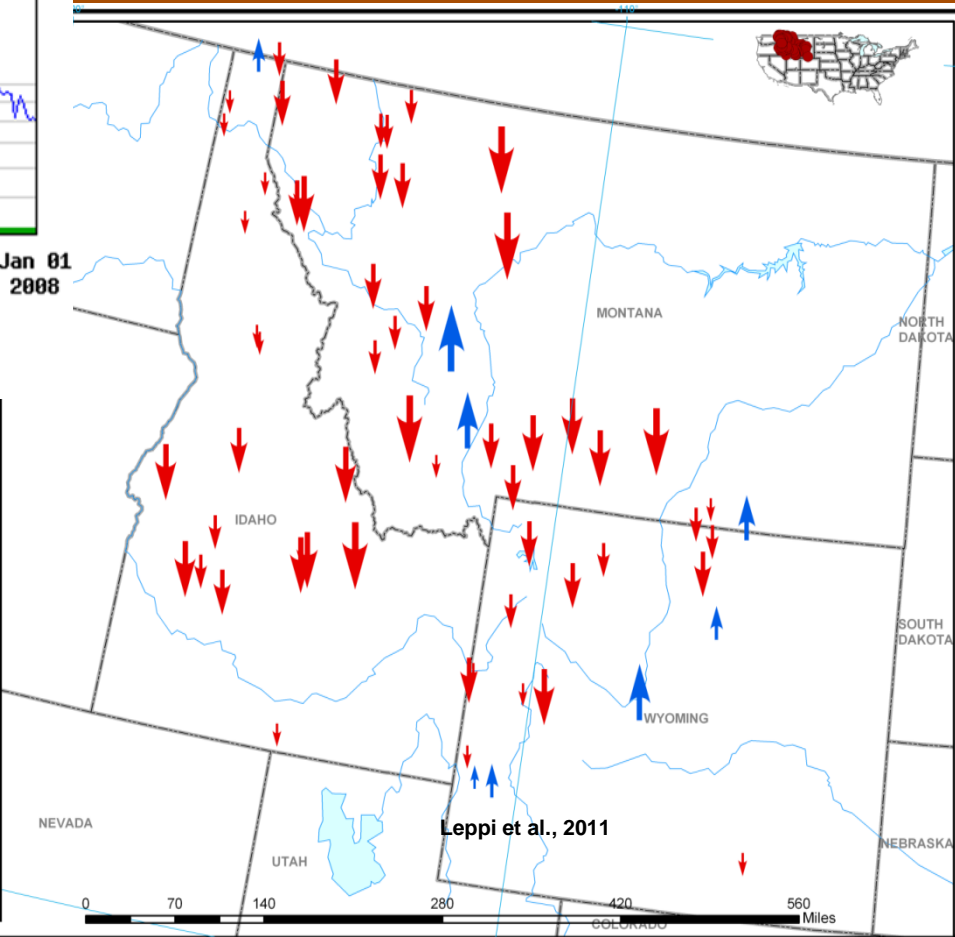
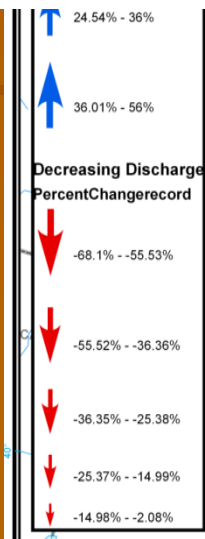
2007 4 3

# August Streamflow Trends 1950- 2007

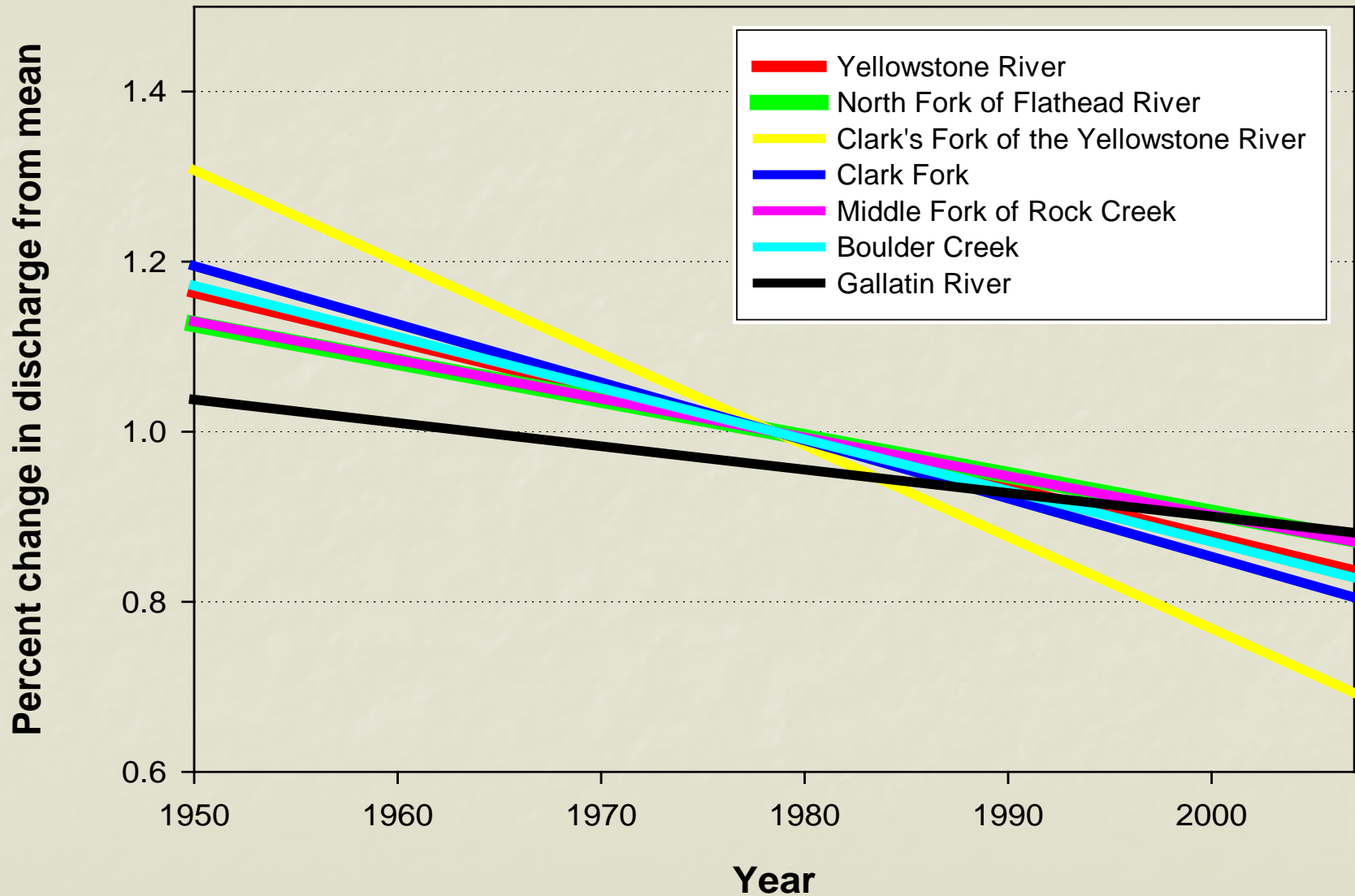
USGS 12352500 Bitterroot River near Missoula MT



Normalized change in discharge for non-regulated sites



# Montana Mean August stream Discharge 1950-2007



# Low Water on the Mississippi Causes Barge Backup

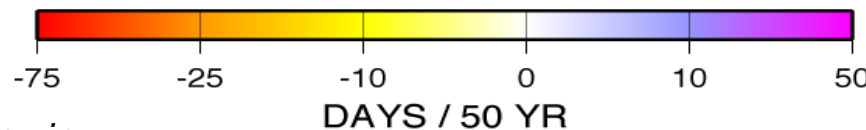
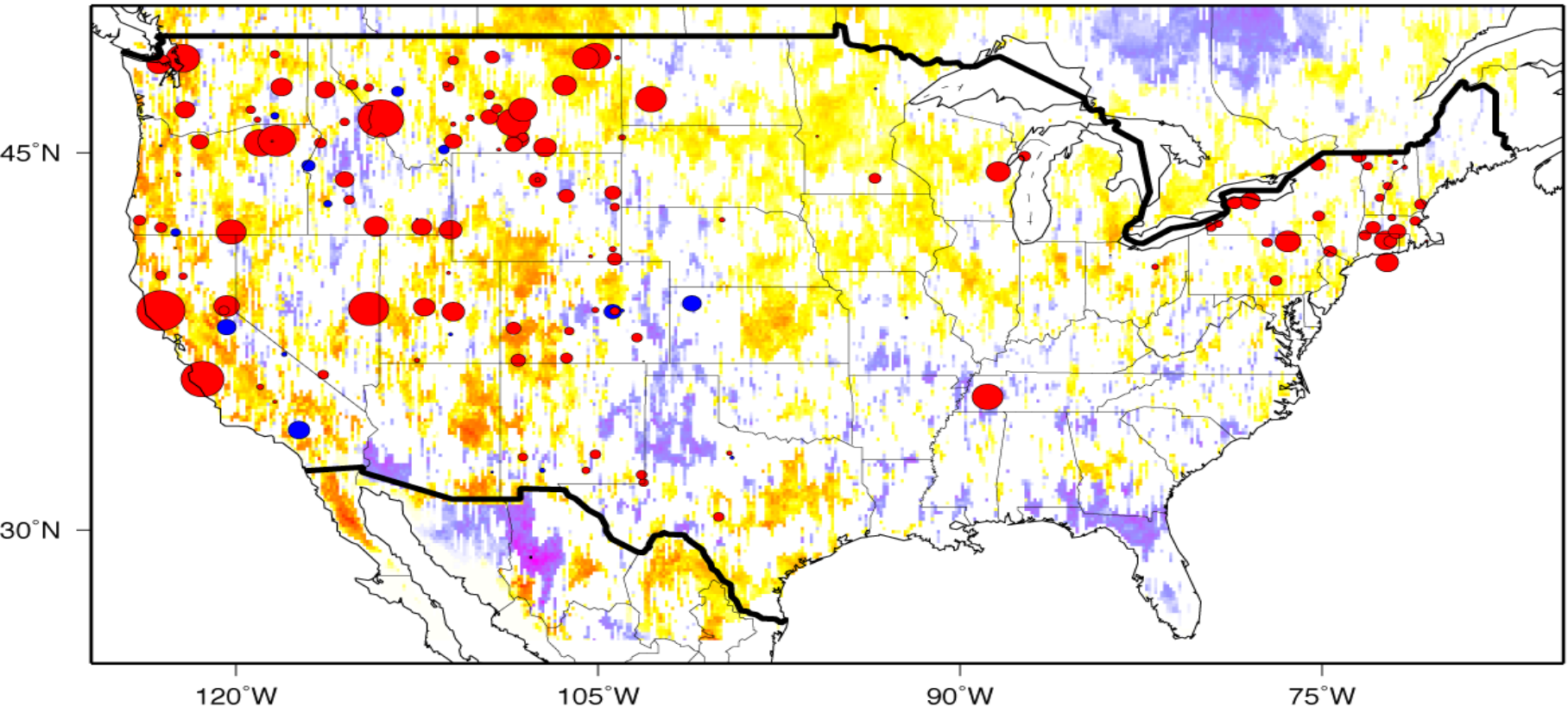
## August 23, 2012

(river level 7.6ft, normal is 19.4ft)



# The warming has lengthened growing seasons and hastened green-up dates.

SHADES: TRENDS OF BEGIN DATE OF GROWING SEASON, 1950-99, FROM TEMPERATURES  
DOTS: TRENDS IN LILAC FIRST-BLOOM DATES (Sites with 20+ yrs of record)



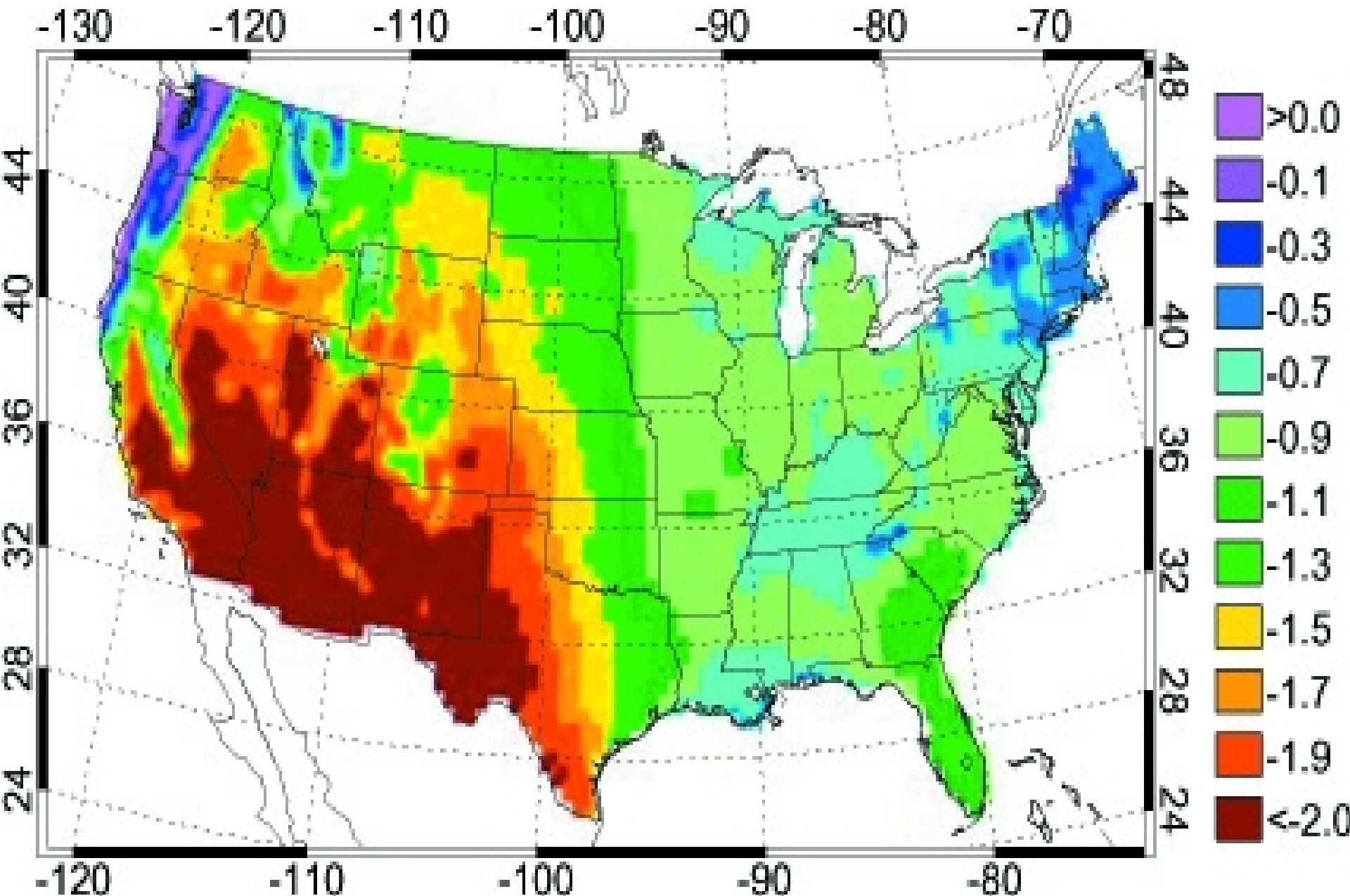
*Start Date = First day in longest run of days each year with  $T_{avg} > 5C$*



Cayan et al., BAMS, 2001

# Geographic Variation in Annual Water Balance

(Precip - Potential ET, meters per year)



# ECOSYSTEM RESPONSES to changing Land Water Balance

Water balance and  
Disturbance dynamics  
Will be more important than  
pure temperature responses

2007 6 8



# IN THE SEMI-ARID WEST, FIRE IS NATURE'S RECYCLING MECHANISM



# Space Shuttle picture of Montana Fires August 13, 2007



Livingston, MT



**Since 1986:**

**Western Fire Season 78 days longer**

**4X Increase in Fires > 1000acres**

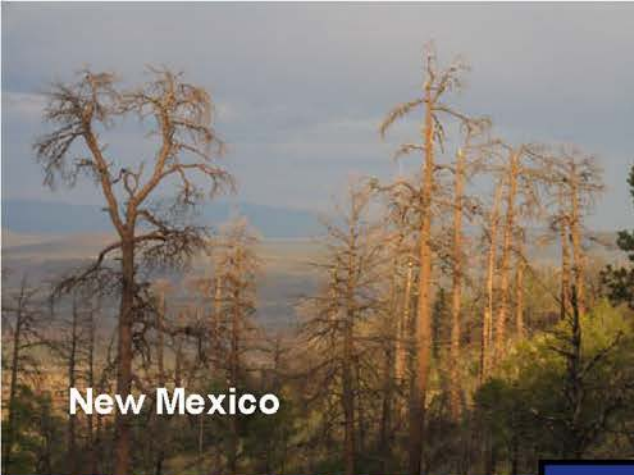
**6X Increase in Acres Burned**

**> Increase in Forests above 6500ft**



Larger Fraction of the Landscape Fire Vulnerable  
for a Longer period of Time

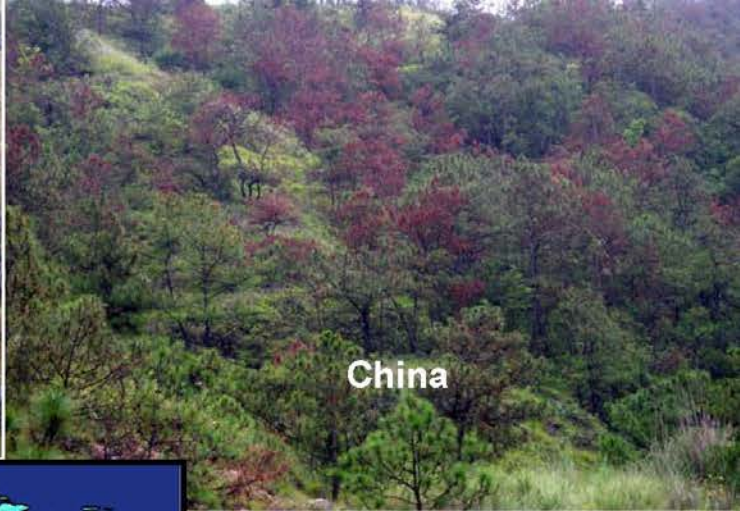




New Mexico



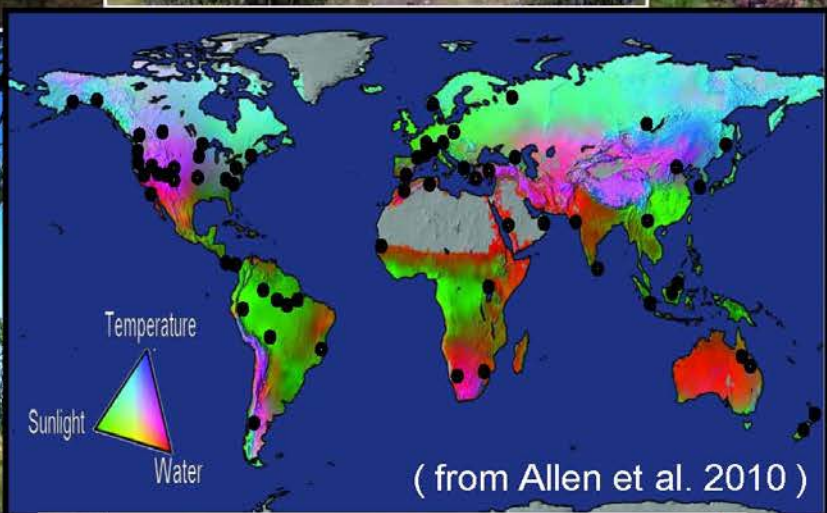
Alberta



China



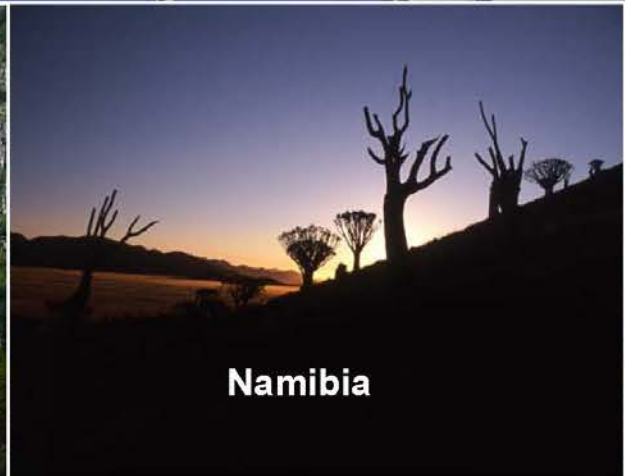
Australia



Spain



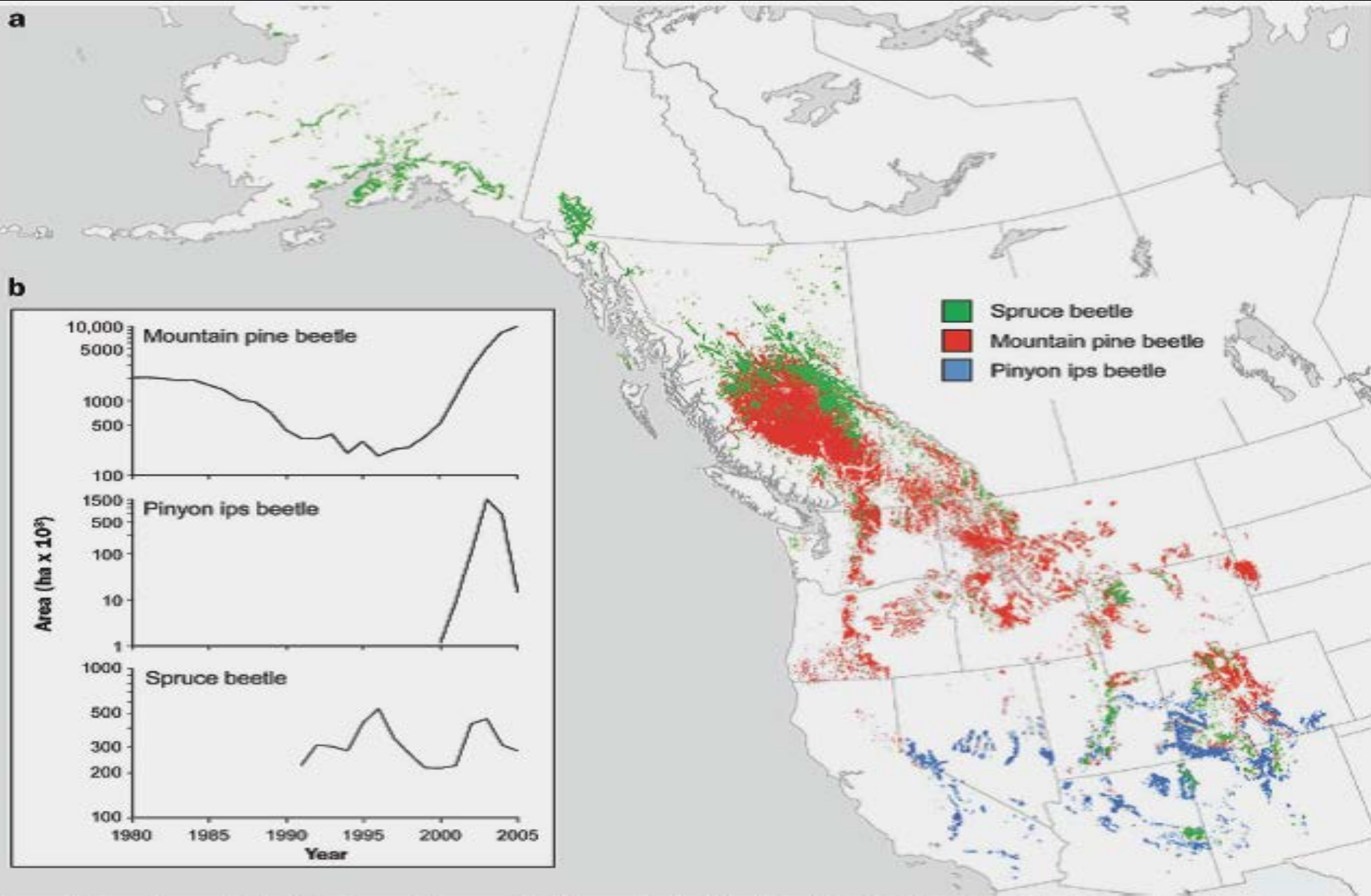
Argentina



Namibia

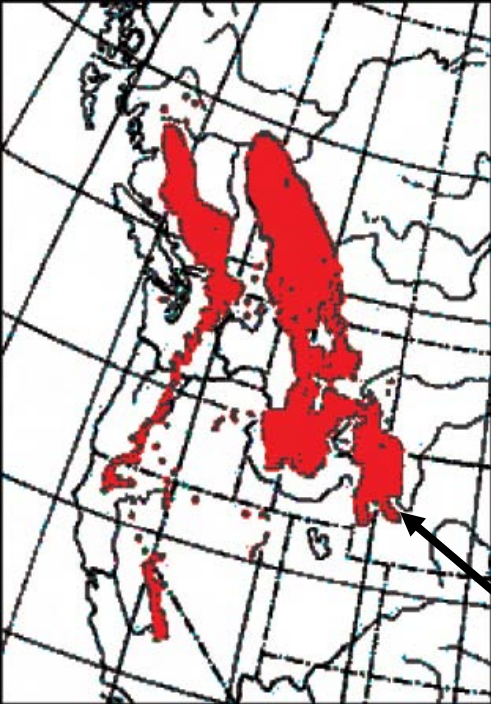


Algeria



**Figure 1. Recent mortality of major western conifer biomes to bark beetles. (a) Map of western North America showing regions of major eruptions by three species. (b) Sizes of conifer biome area affected by these three species over time. Data are from the Canadian Forest Service, the British Columbia Ministry of Forests and Range, and the US Forest Service.**

WhiteBark Pine, Union Pass, WY August 2008



Photo, Diana Six

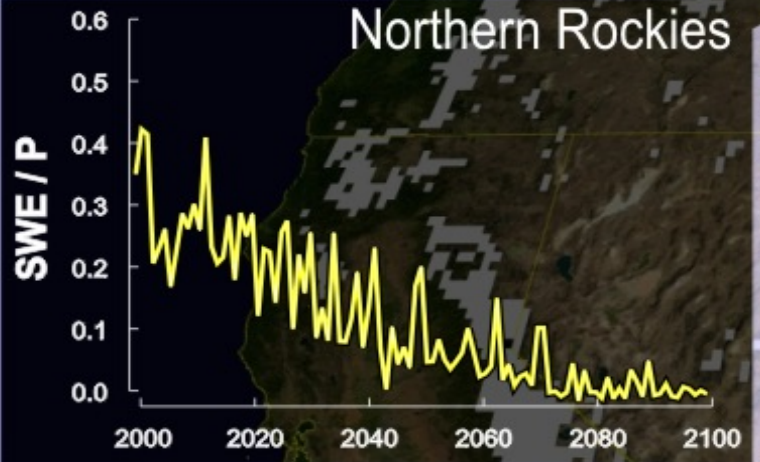


# THE FUTURE

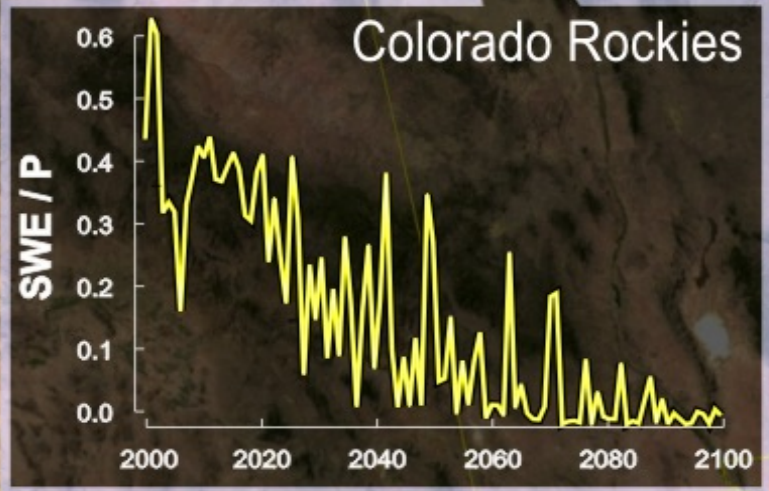


# April 1<sup>st</sup> snowpack 2000 - 2100

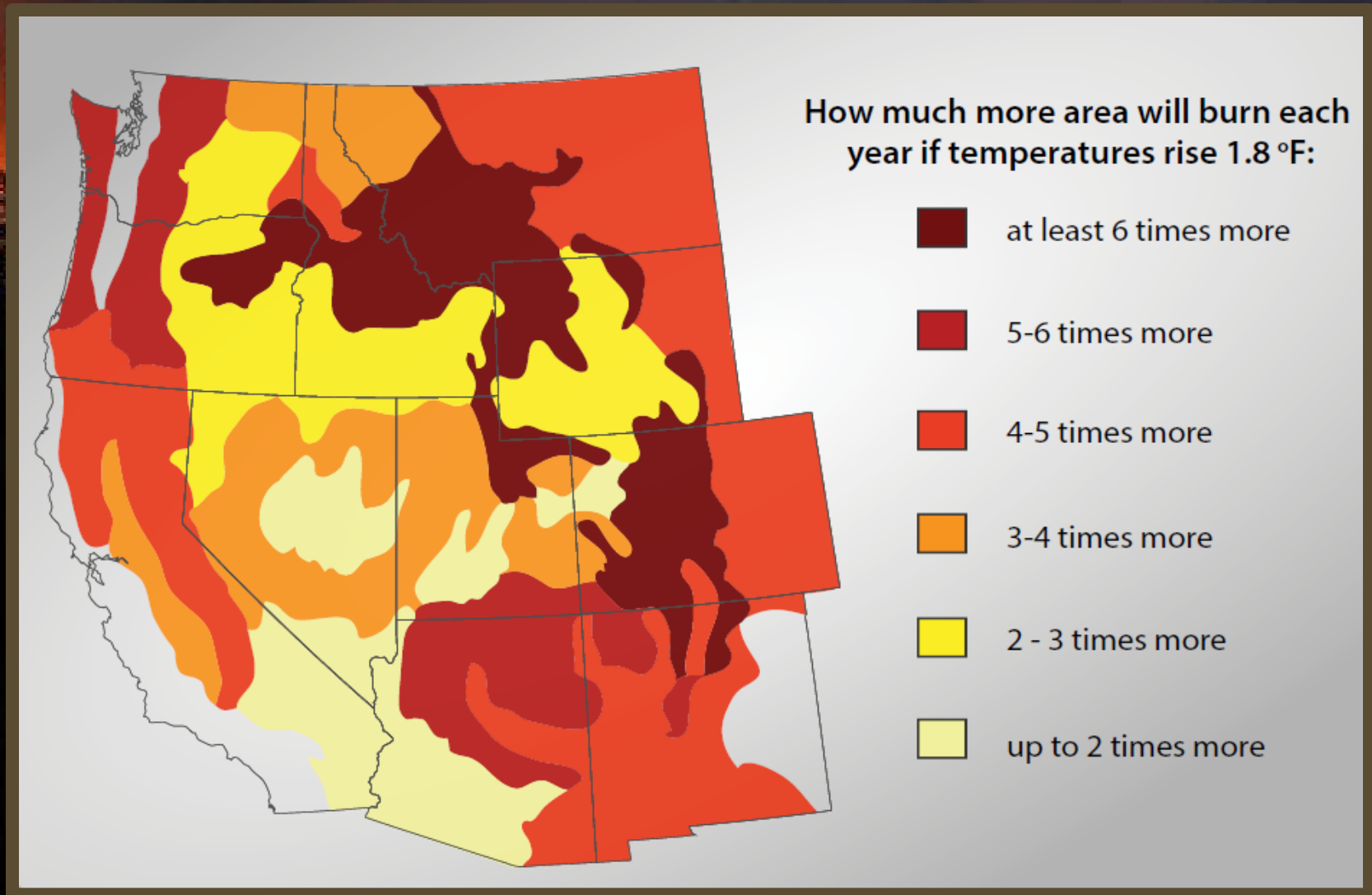
Northern Rockies



Colorado Rockies



# Higher temperatures will increase burn areas in the West



# The Human Perturbation of the CO<sub>2</sub> Budget (2000-2009)

7.7±0.5 PgC y<sup>-1</sup>



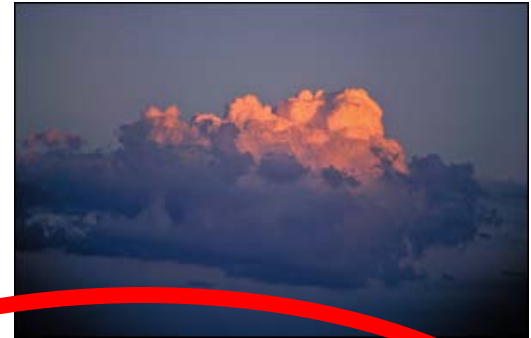
1.1±0.7 PgC y<sup>-1</sup>

+



4.1±0.1 PgC y<sup>-1</sup>

47%



2.4 PgC y<sup>-1</sup>

27%

Calculated as the residual



26%

2.3±0.4 PgC y<sup>-1</sup>

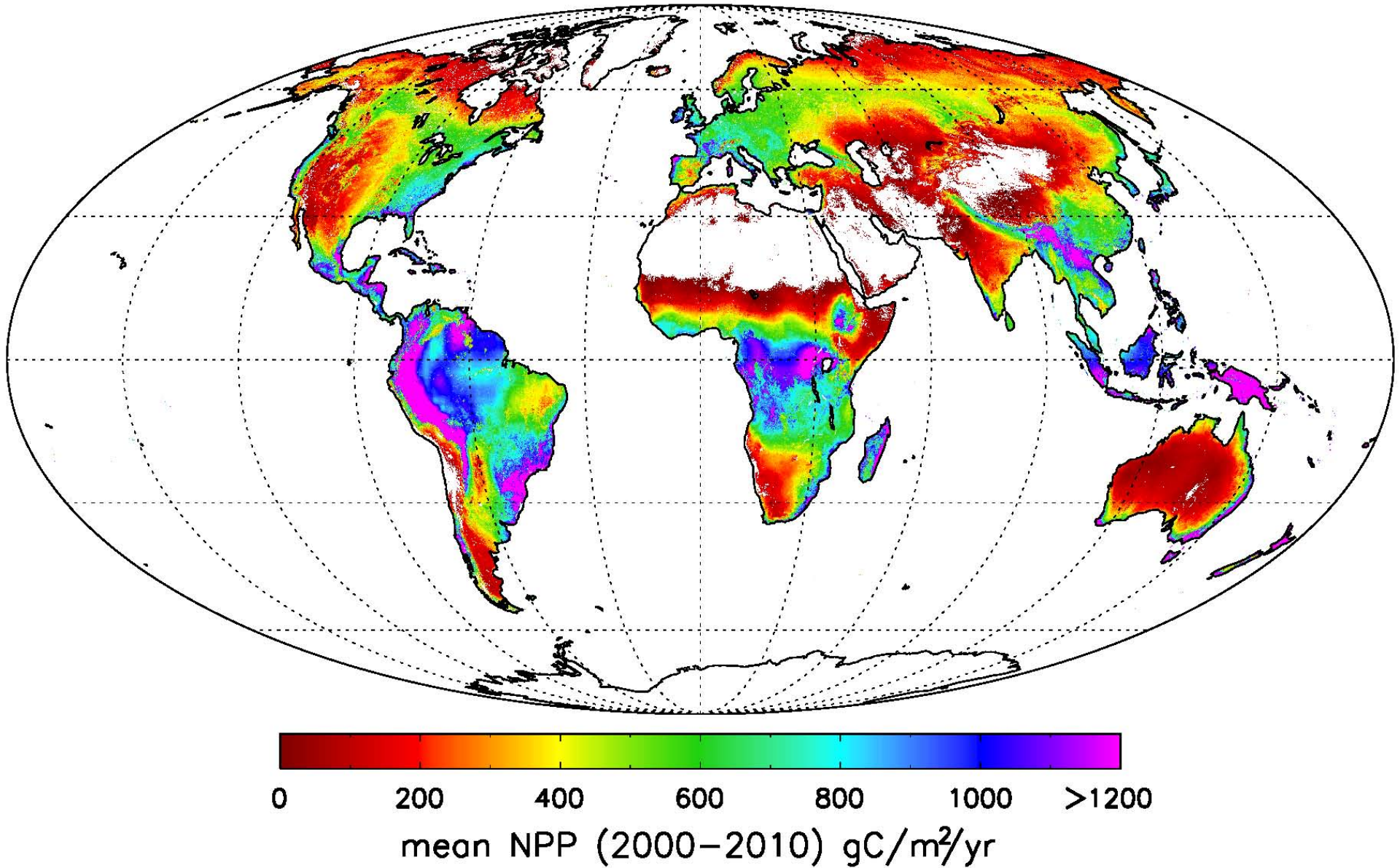




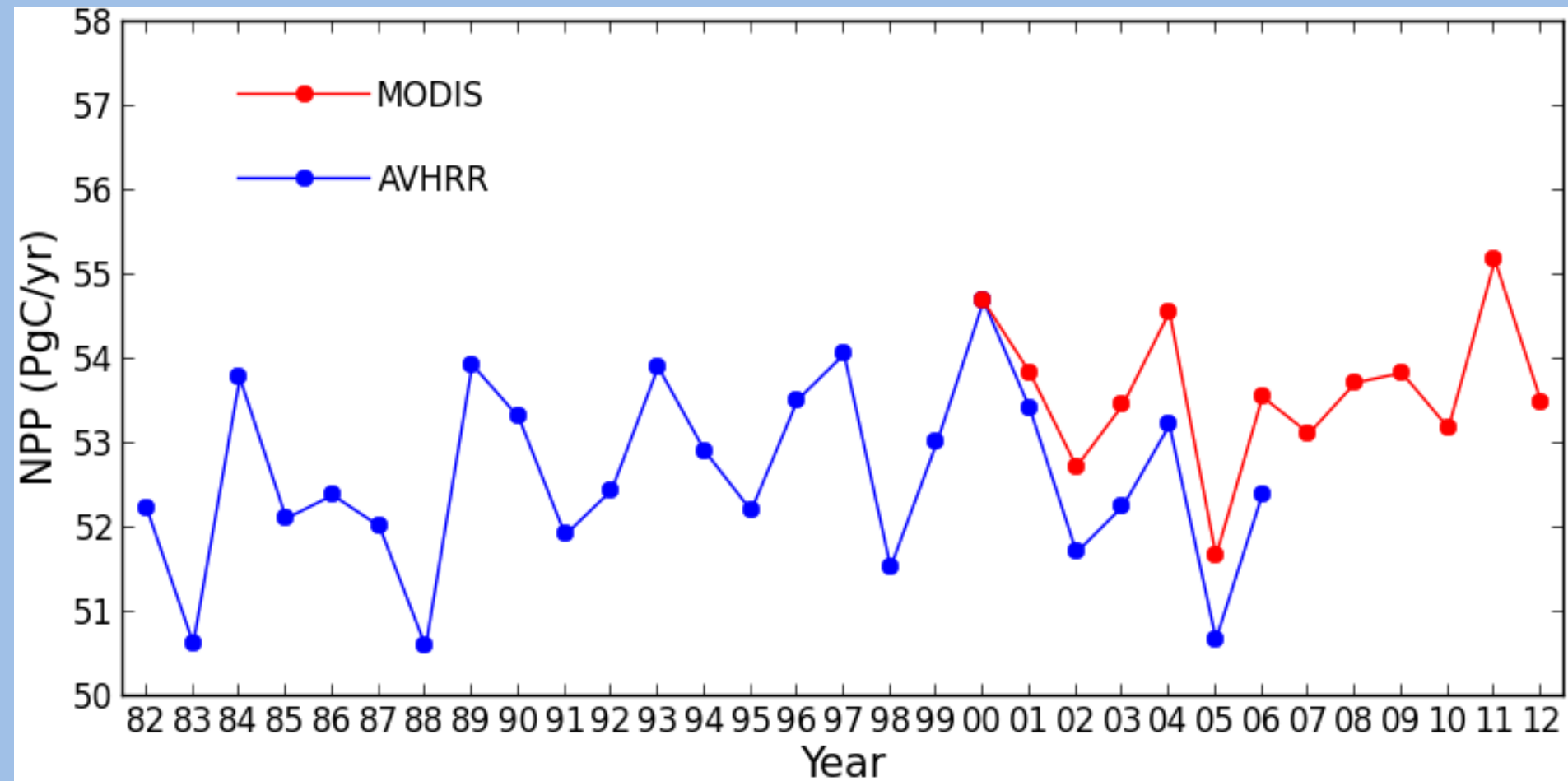
IS OUR CURRENT  
CONSUMPTION OF Biospheric  
NPP Sustainable\*?

\*Meeting needs and values of today's generation, while preserving the planet's life-support systems for the needs and values of future generations.

# GLOBAL NET TERRESTRIAL PRIMARY PRODUCTION



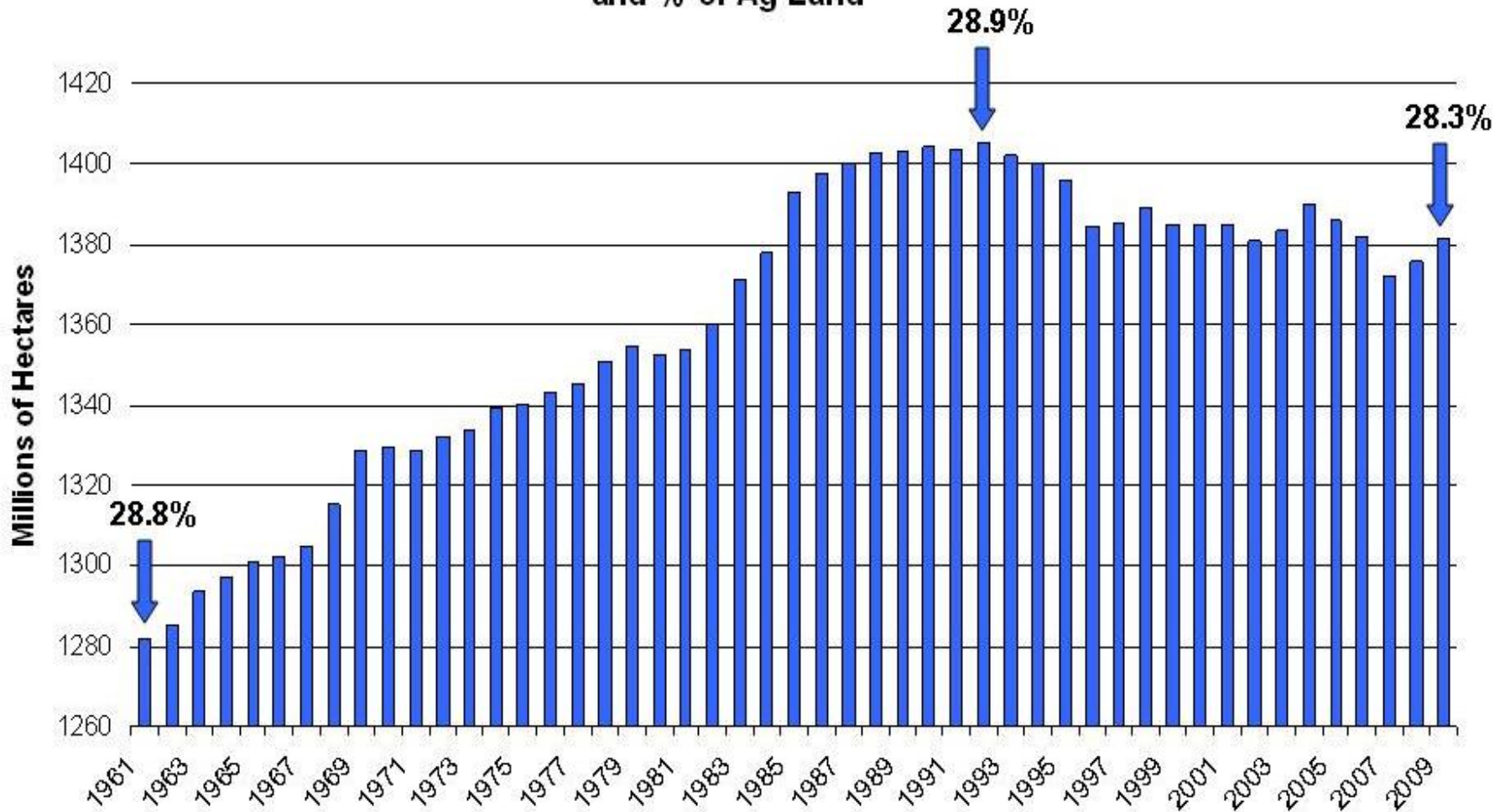
# Global Terrestrial Net Primary Production (1982-2012)



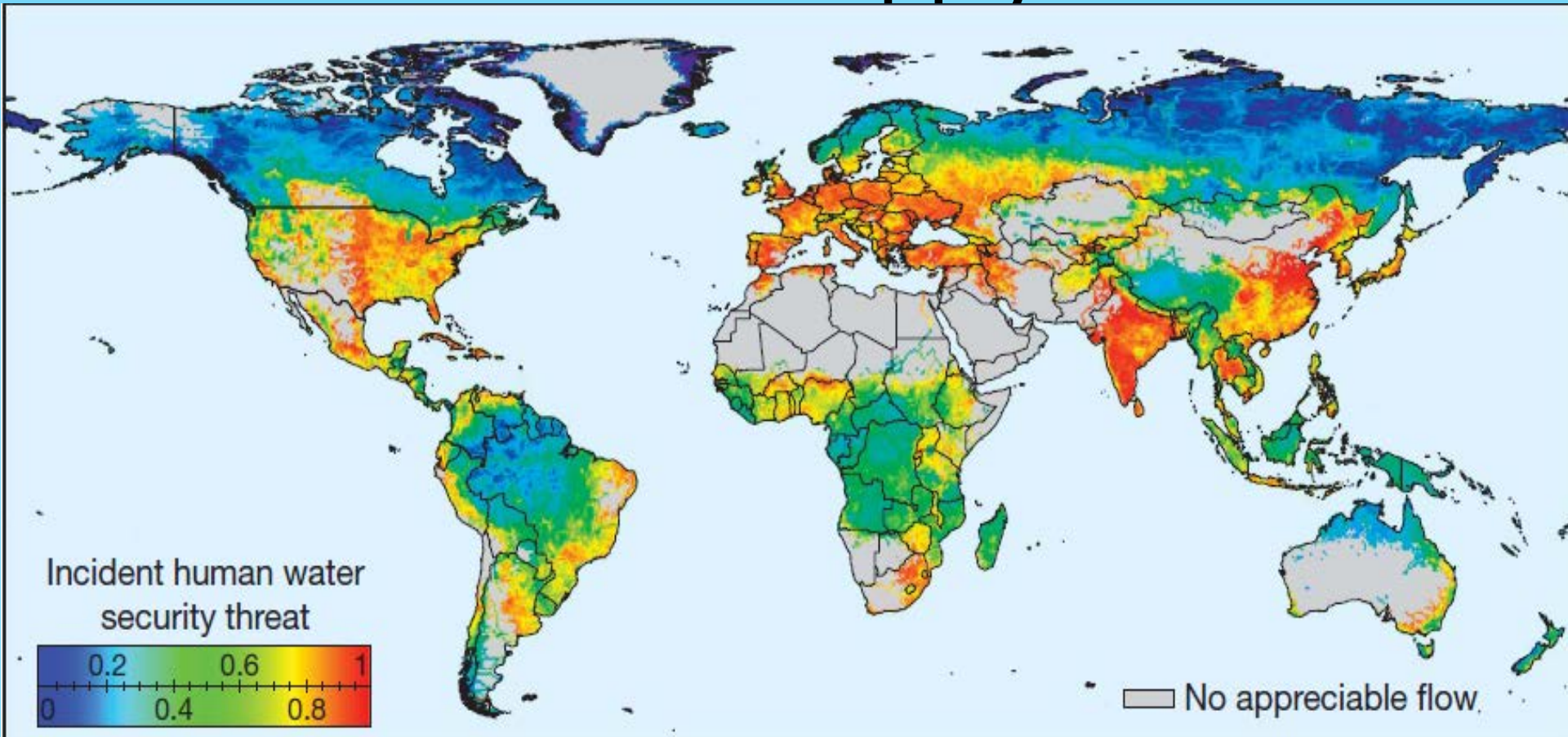
+/- 1Pg or about 2%

# Land area is NOT increasing

Global Arable Land  
and % of Ag Land



# Global Water Supply Threat



Vorosmarty et al *Nature* 2010

*The global percentage of dry areas has increased by about 1.74% (of global land area) per decade (11%) from 1950 to 2008.*

*Aiguo Dai. J. Geophysical Res 2011*



# Unsustainable groundwater withdrawal

Depletion rate 4cm/yr

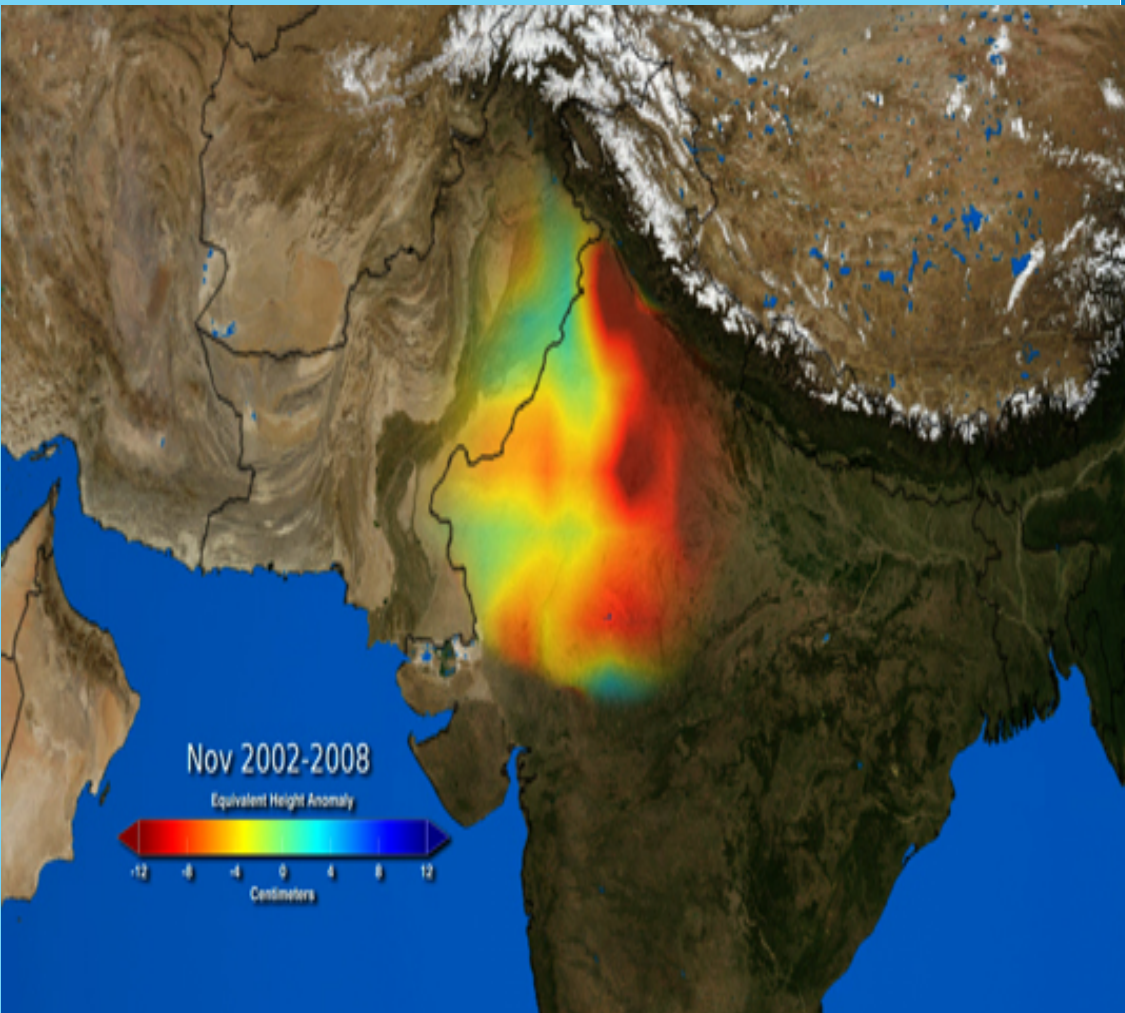
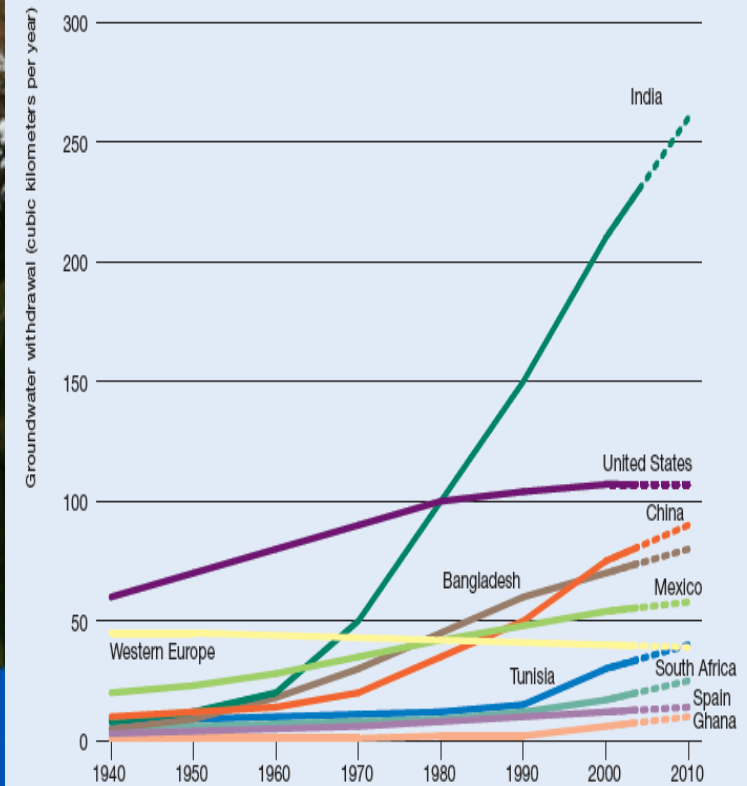


figure 10.1 Development in groundwater withdrawal in selected countries



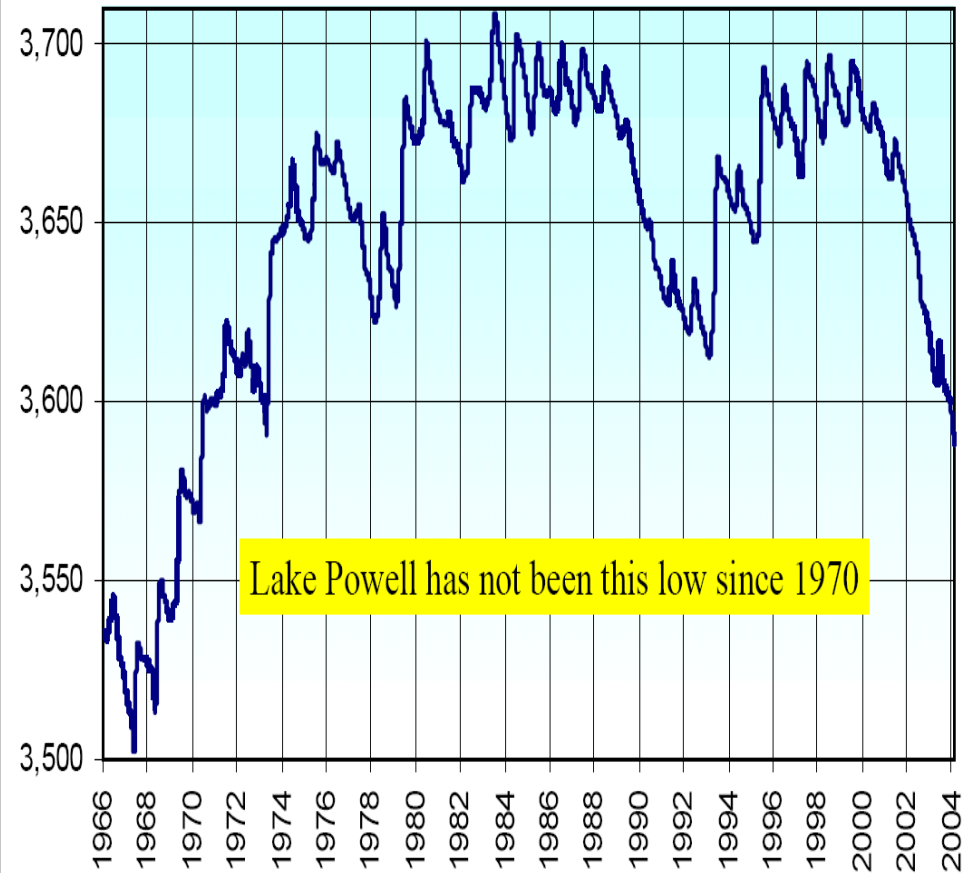
Source: Shah 2005.

Groundwater withdrawals as % of recharge, 2002-2008.  
Rodell et al Nature 2009

# Lake Powell, AZ Colorado River Basin



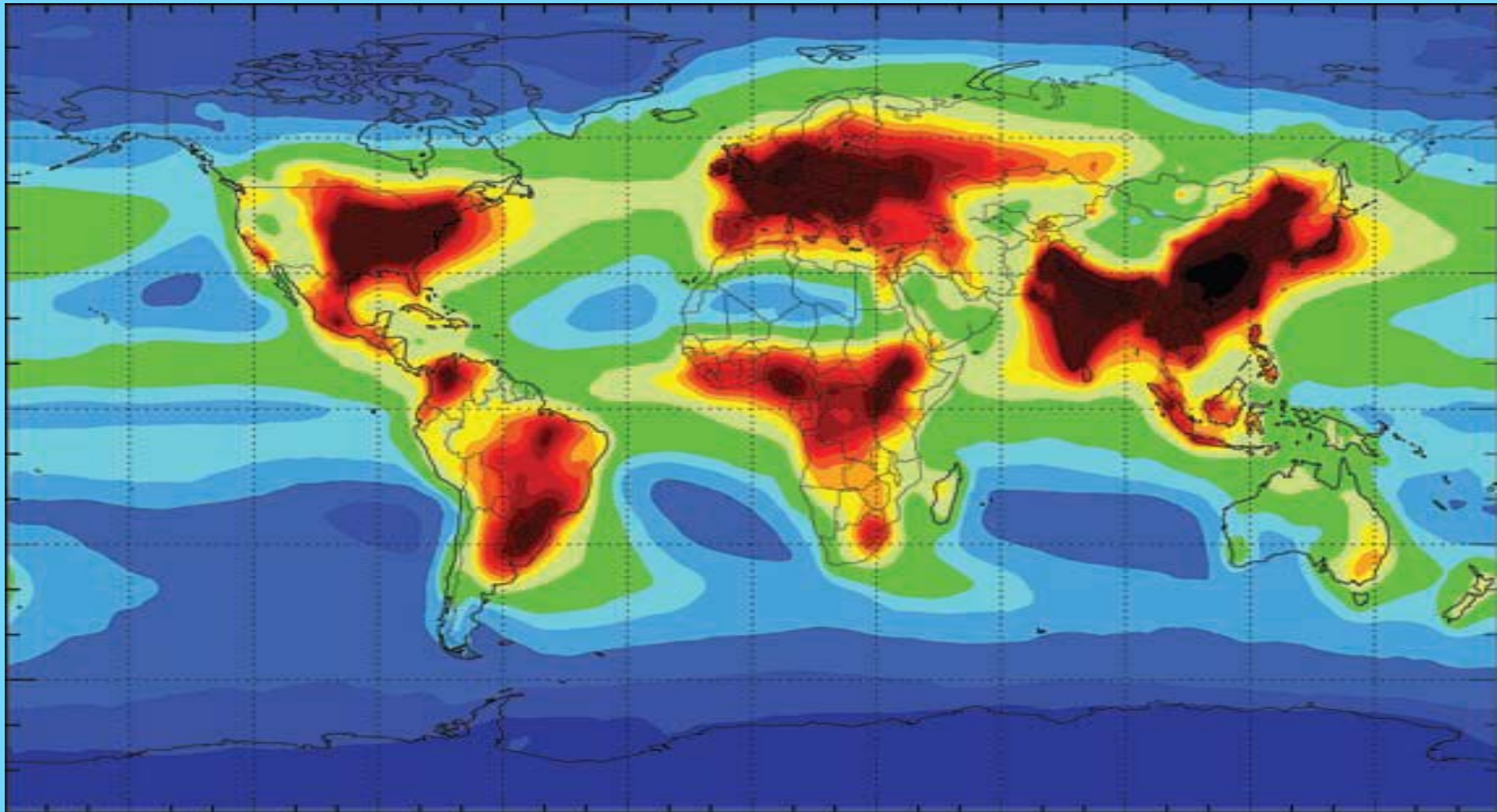
Lake Powell Water Surface Elevations  
1966 through Present



Lake Powell has not been this low since 1970

# Nitrogen Loading is already damaging the biosphere

N Deposition rates ( 0 – 60kg/ha/yr )

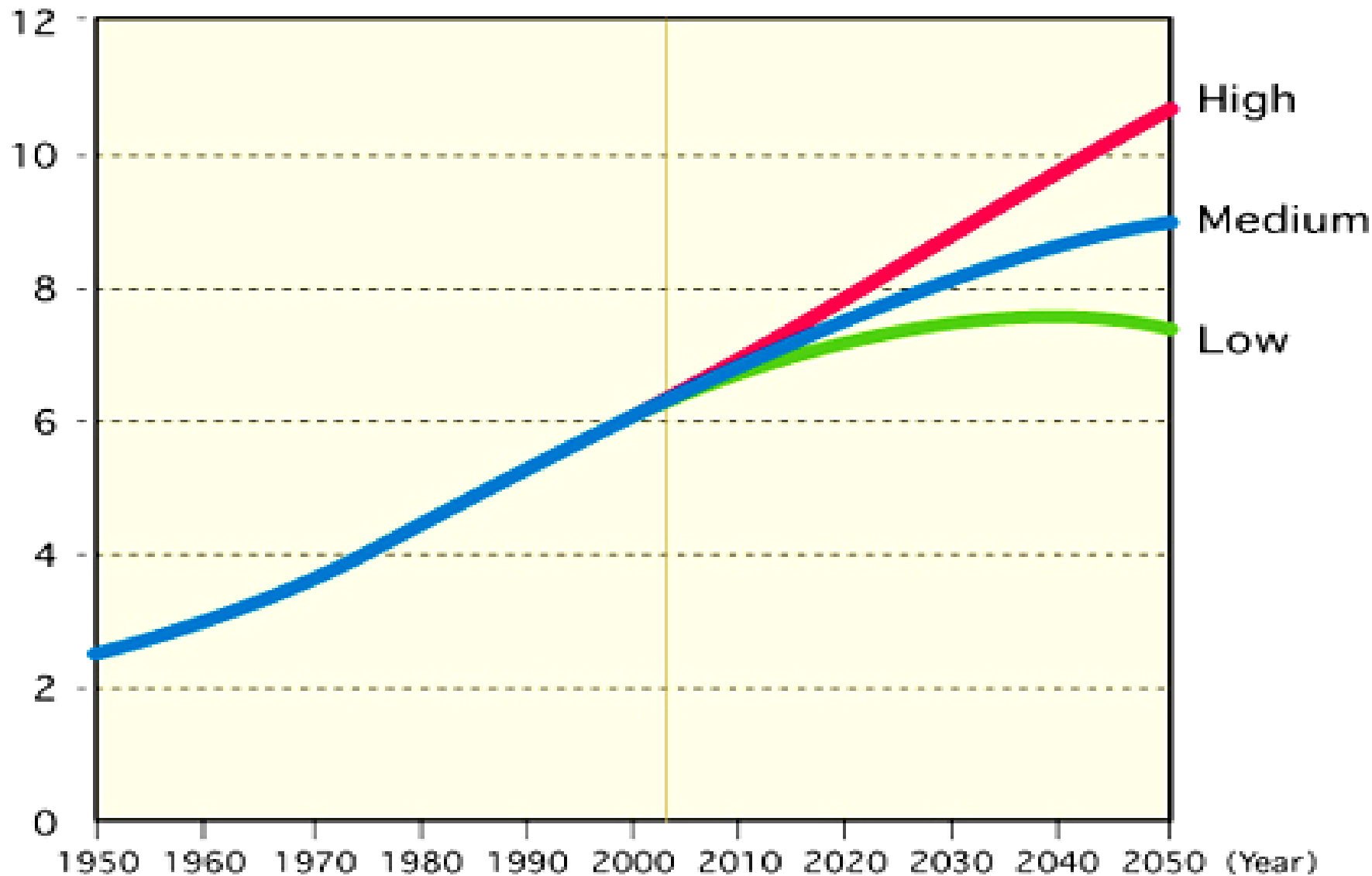


Galloway et al. *Science* 2008

# Figure 1 United Nations World Population Projections, 1950-2050

Source: World Population Prospects

Population (in

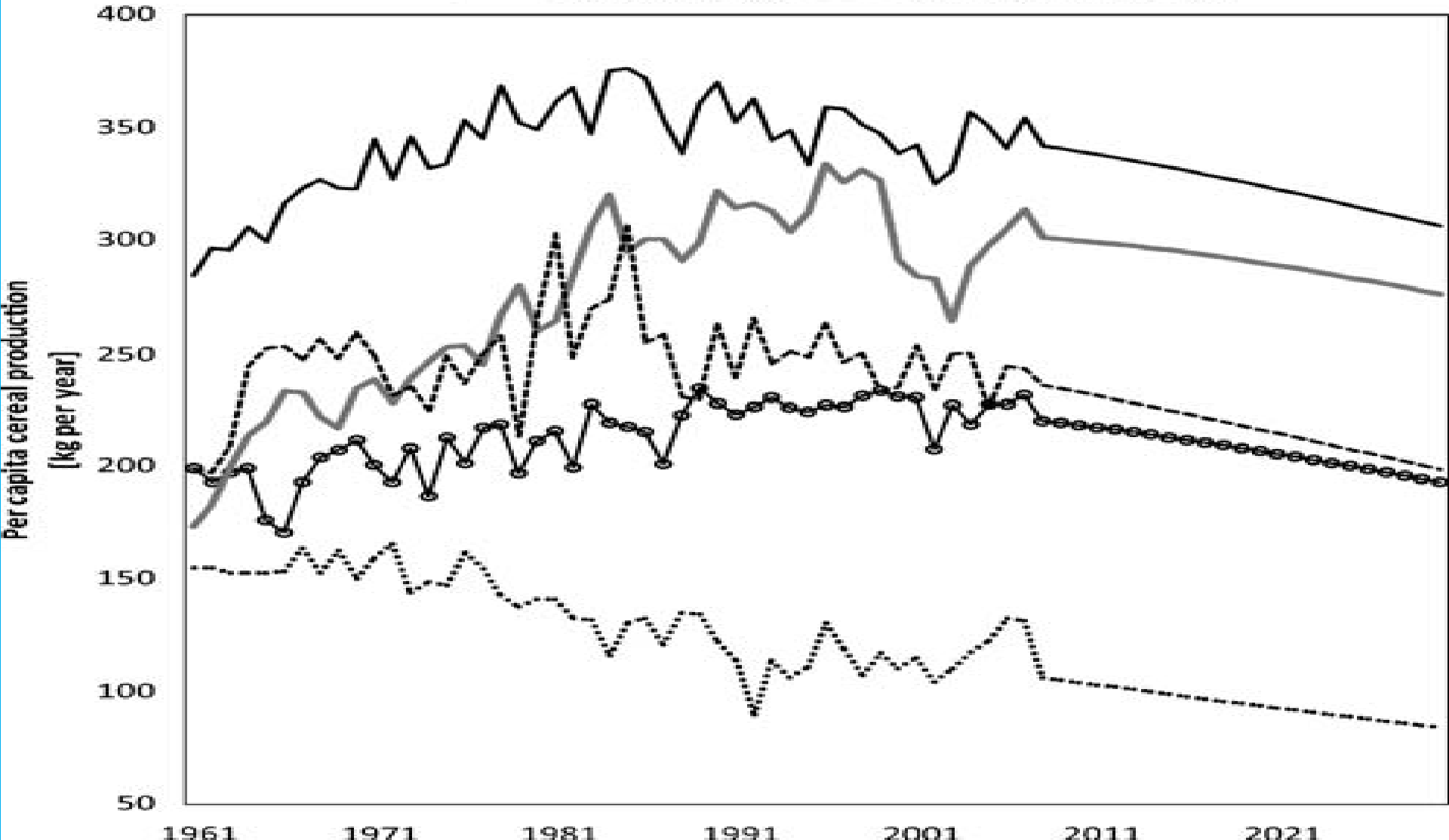


# Per Capita Agricultural Production trends.

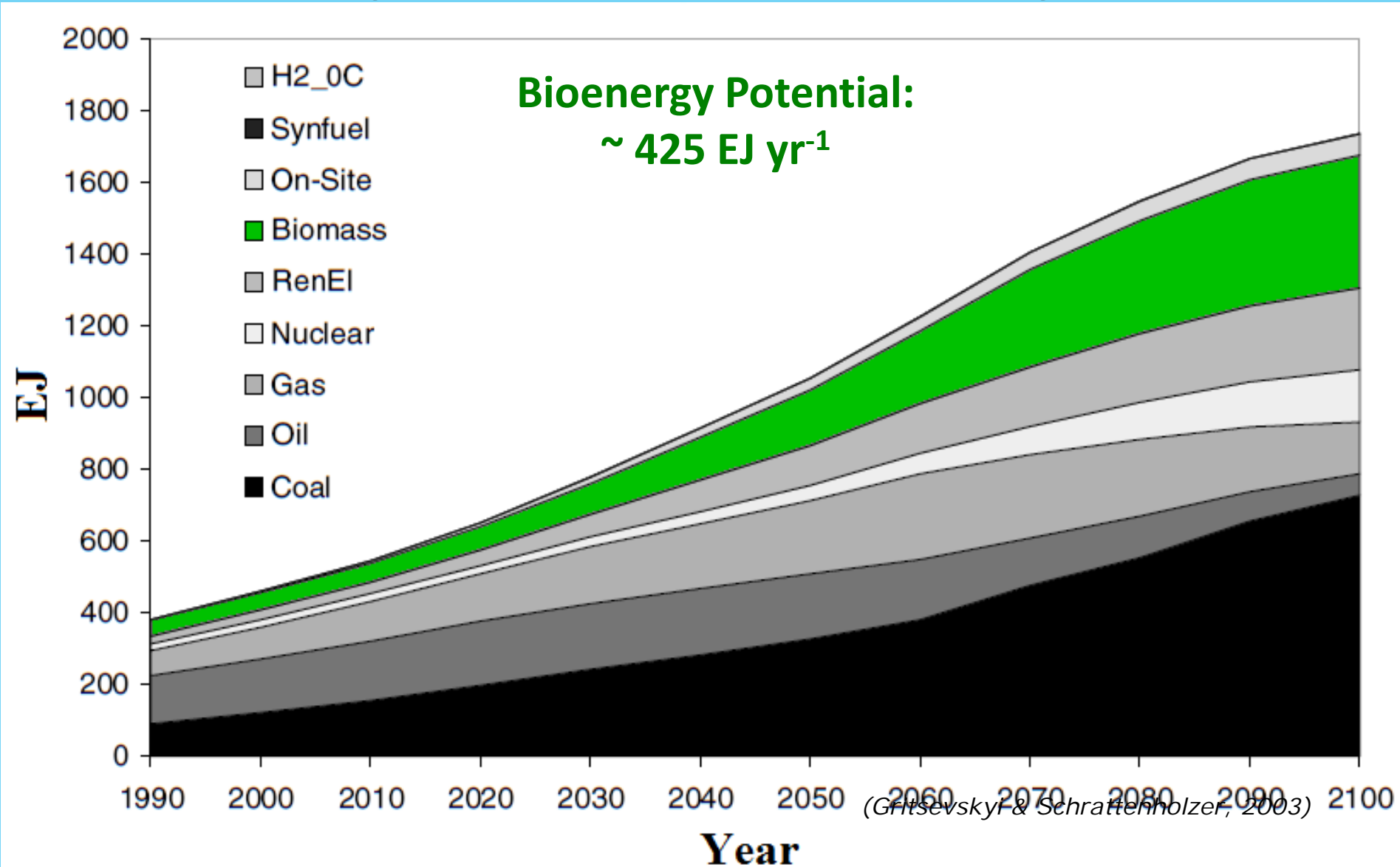
*Global 14% Per capita reduction projected by 2030*

Funk and Brown. *Food Security* (2009)

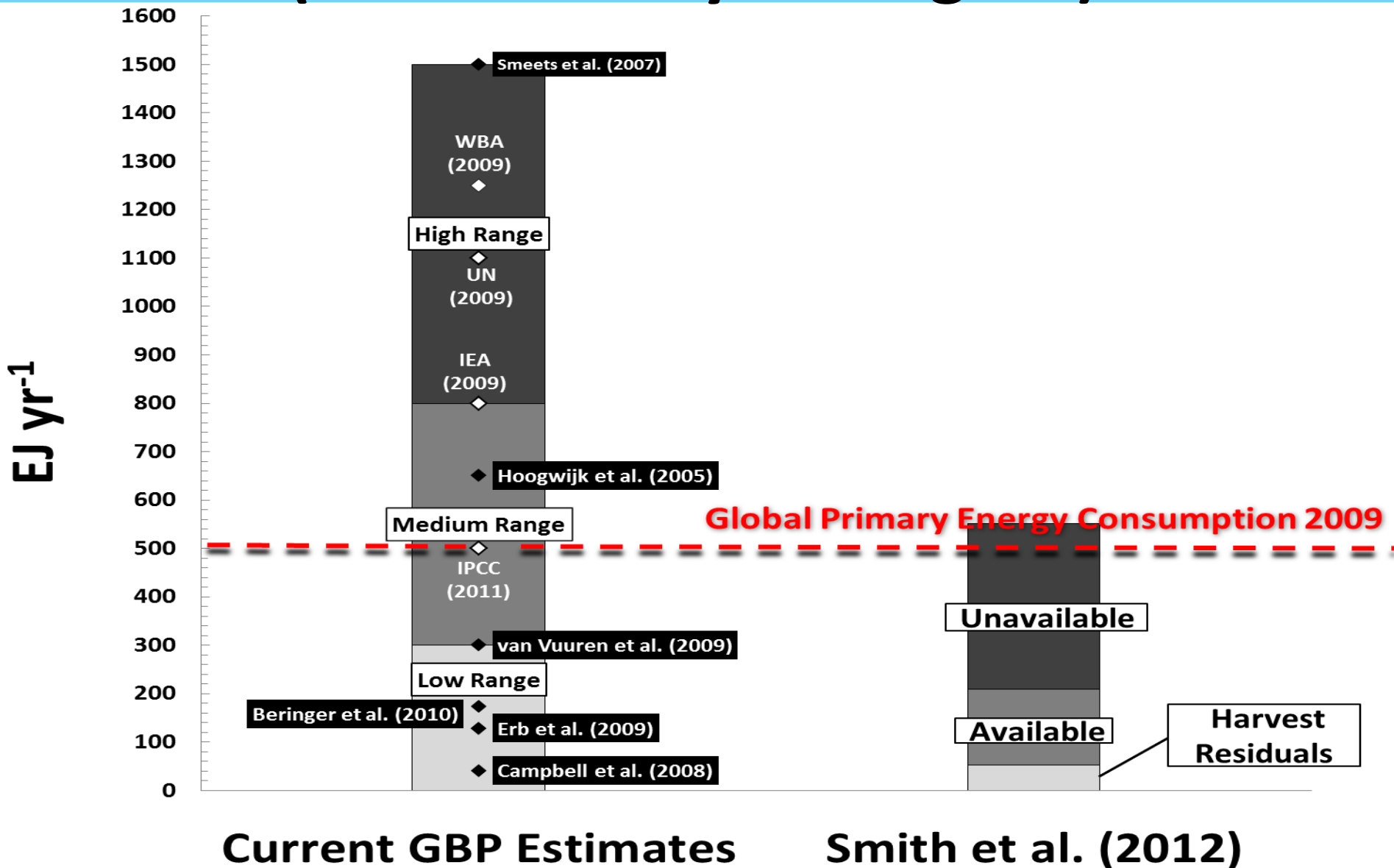
— World ..... Eastern Africa —●— Southern Asia  
— Eastern Asia - - - - Central America



# Future Bioenergy Potential (estimated by economists)



# Capacity for Bioenergy Production (estimated by ecologists)



# HUMAN APPROPRIATION OF NET PRIMARY PRODUCTION

## HANPP

Units: % of NPP



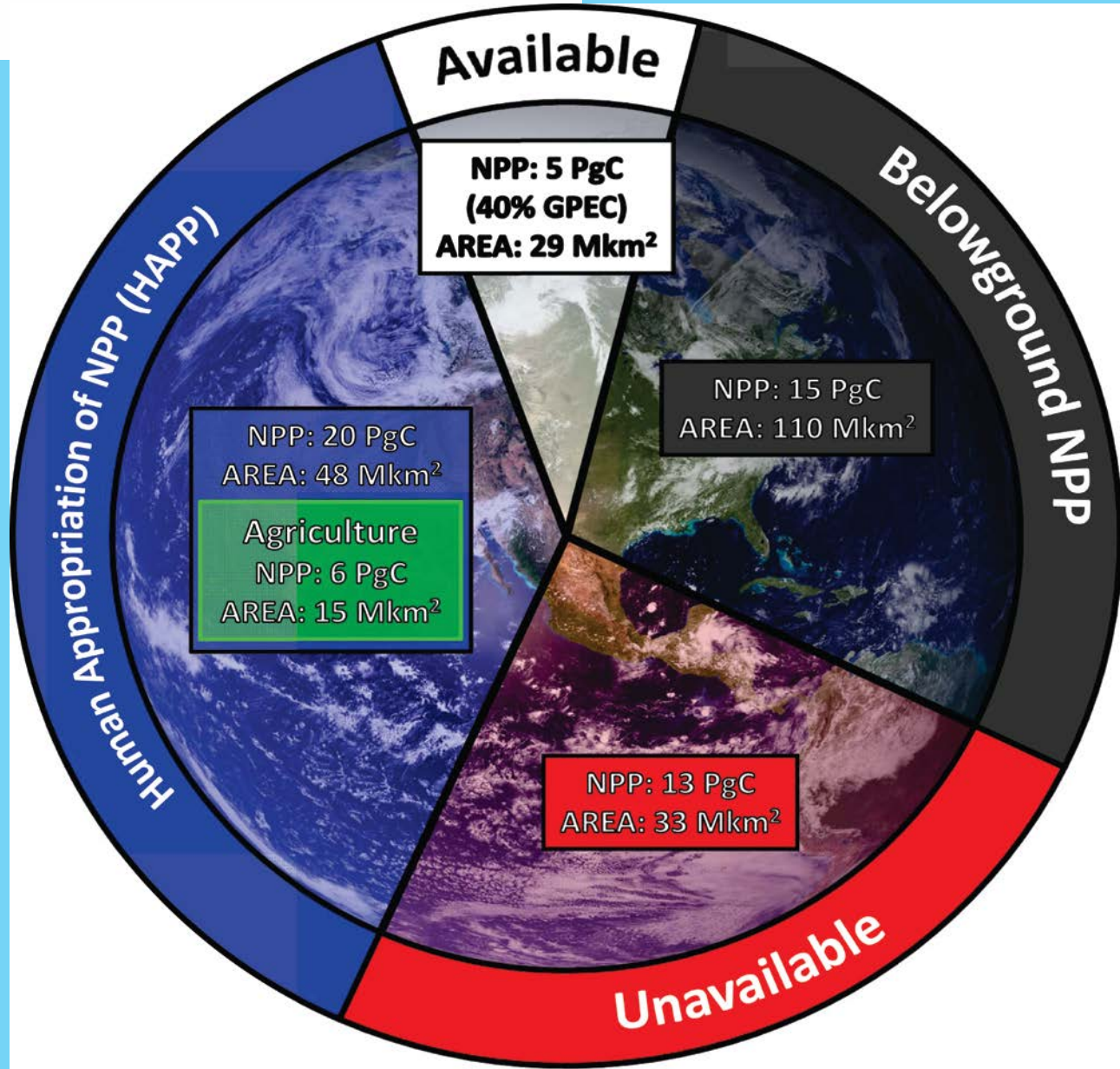


# A Measurable Planetary Boundary for the Biosphere

Steven W. Running

From Running, SW. *Science* 337 p1458-1459, 2012

Terrestrial net primary (plant) production provides a measurable boundary for human consumption of Earth's biological resources.



A landscape photograph showing a range of mountains in the background. The mountains are covered in green vegetation, with some peaks having patches of snow. In the foreground, there is a field of tall green grass and numerous bright yellow wildflowers. The sky is blue with scattered white clouds.

**THE BIOSPHERE SUPPORTS HUMAN  
LIFE, WE CANNOT IGNORE ITS  
BOUNDARIES**