Reviewing the State of the Climate: Science and Policy Perspectives

CLIMATE LEADERS
5th Anniversary Partners Meeting

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World Resources Institute

http://www.wri.org

World Resources Institute

- An independent nonprofit policy research organization with a staff of more than 130 scientists, economists, policy experts, business analysts, statisticians, mapmakers, and communicators working to protect the Earth and improve people's lives.
- Four key areas of work:
  - Climate and energy
  - Ecosystems
  - Governance
  - Sustainable Enterprise

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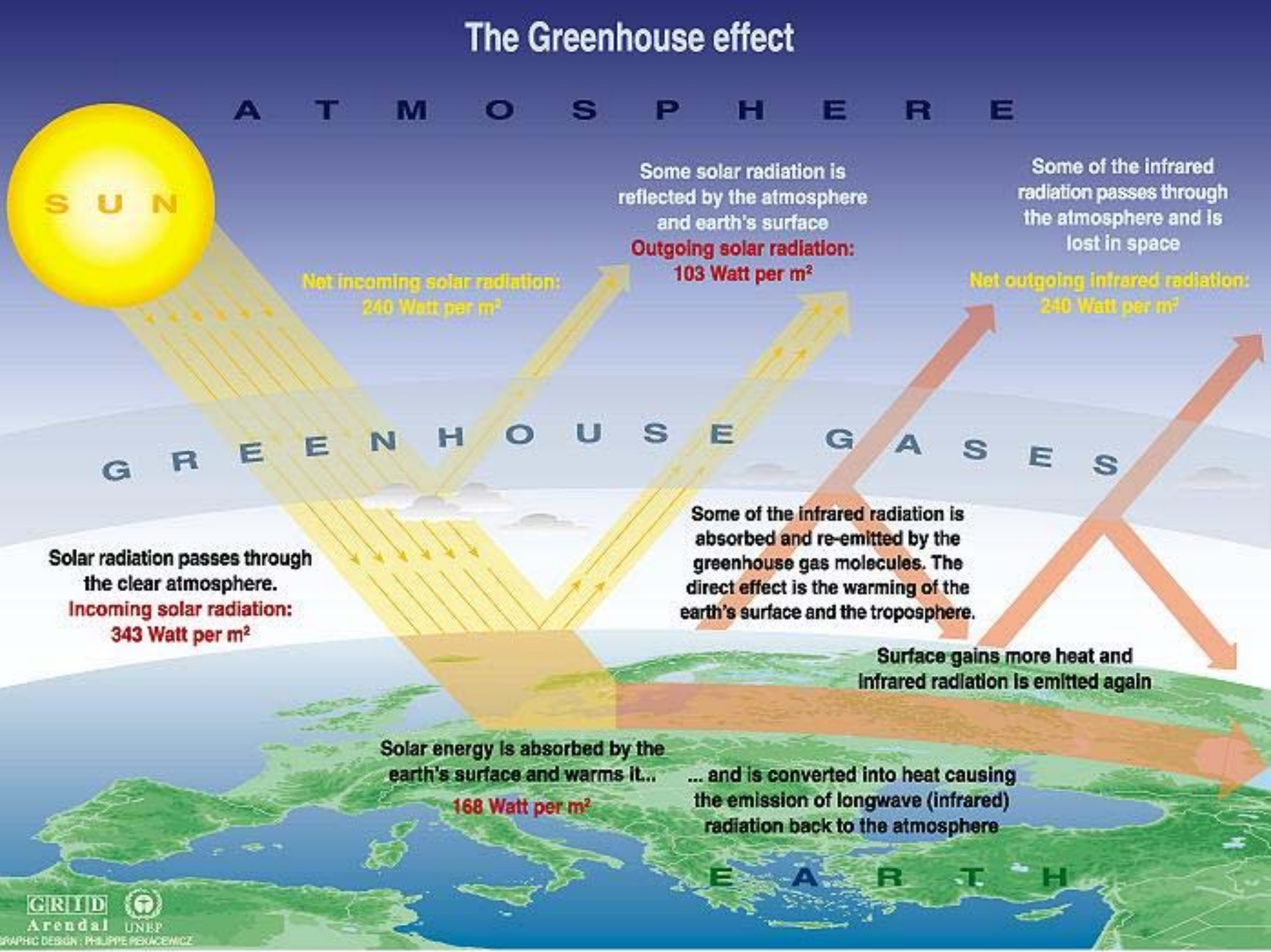
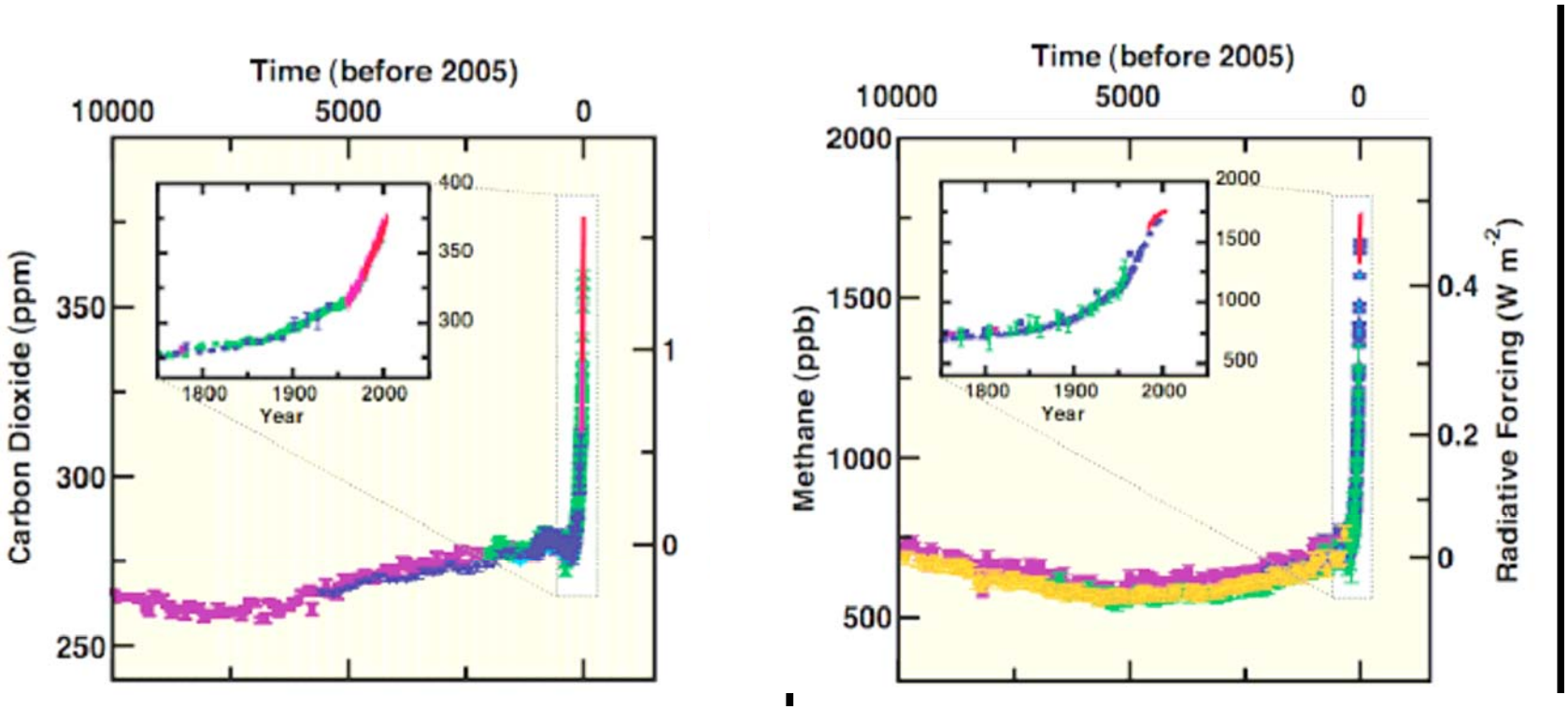
The Greenhouse effect



GRID Arendal UNEP
GRAPHIC DESIGN : PHILIPPE REKACEWICZ

Change in GHG Concentrations



Source: IPCC, 2007

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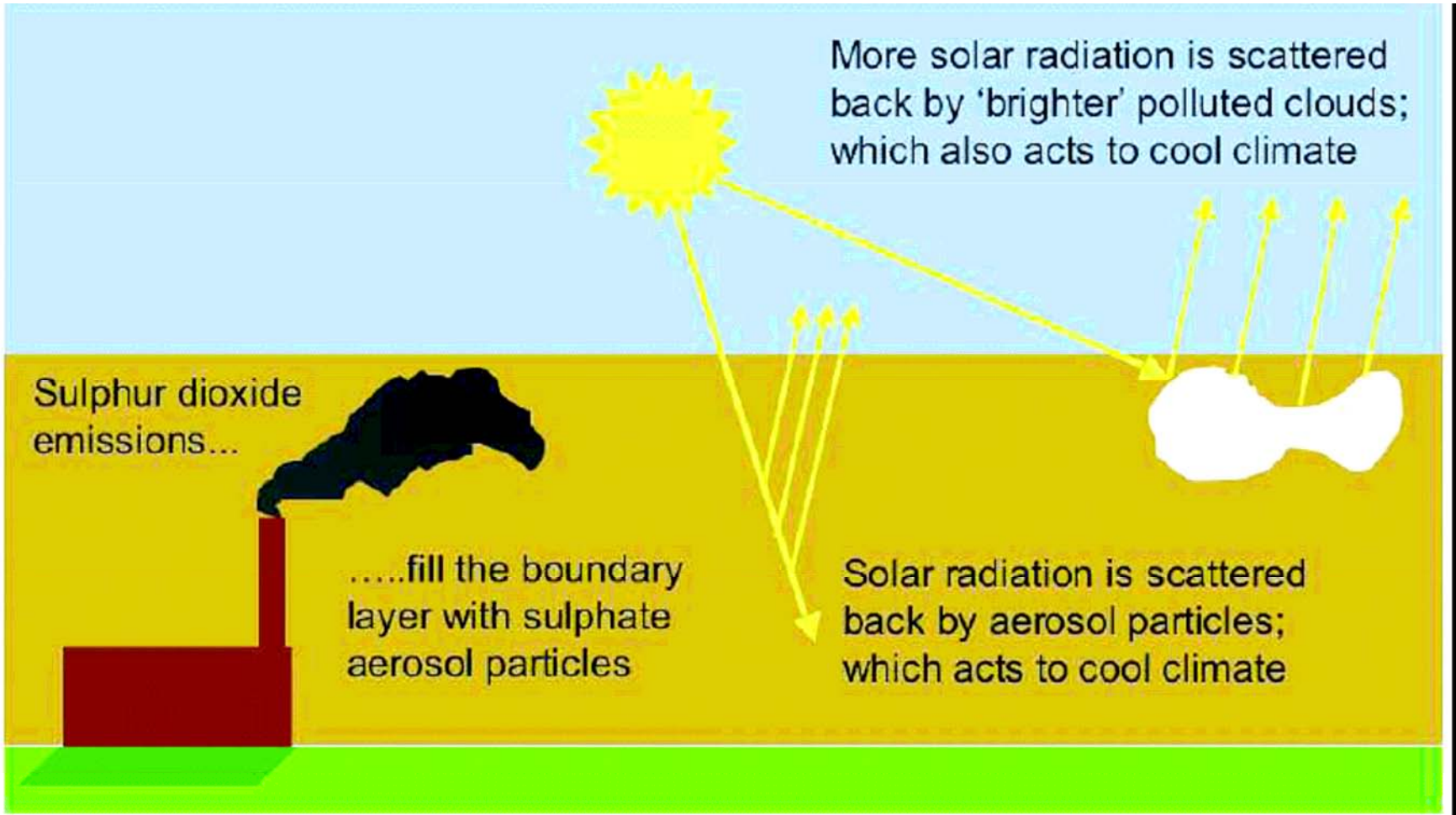
A Word on Aerosols….



Source: UK Hadley Center, 2007

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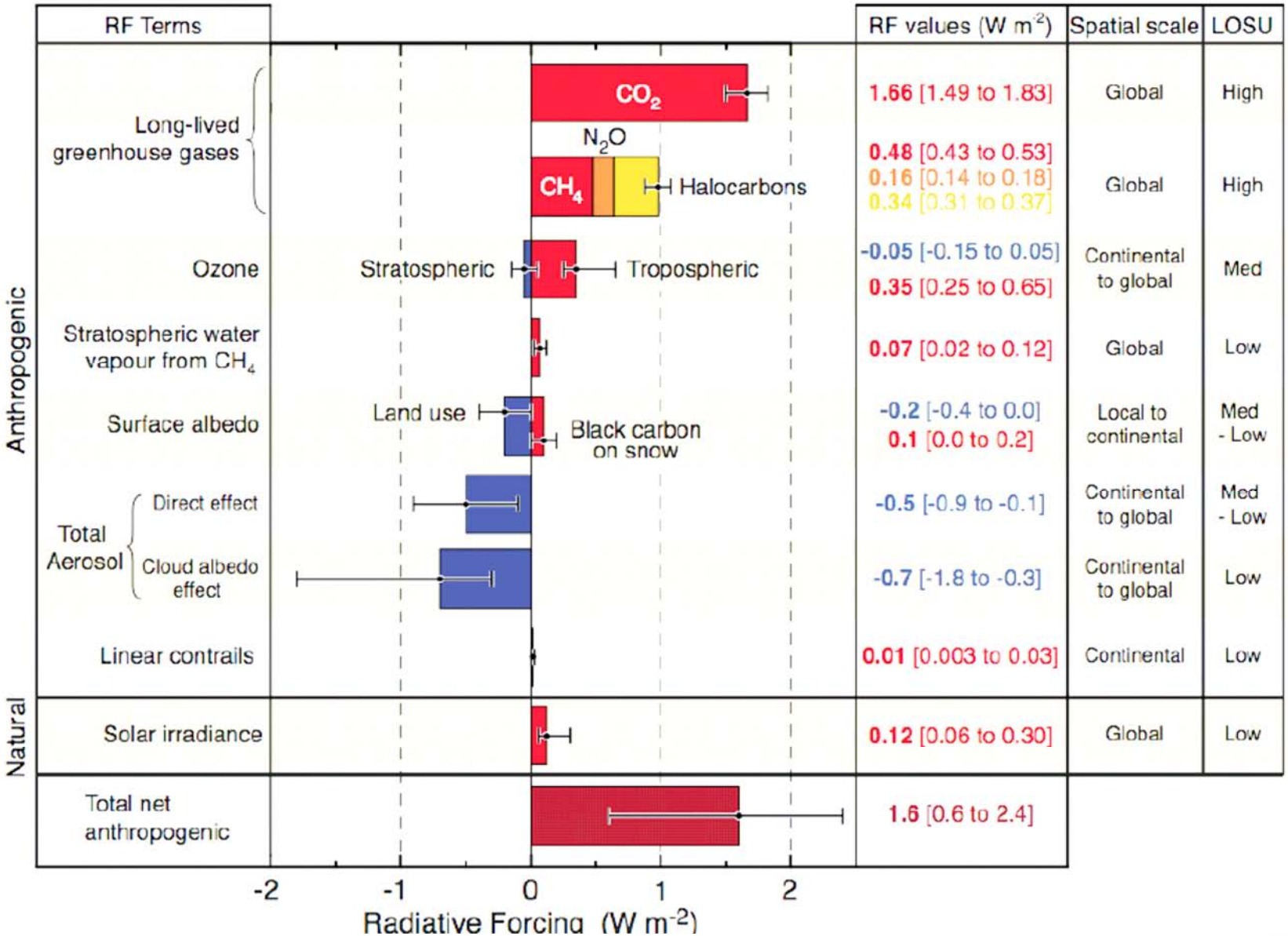
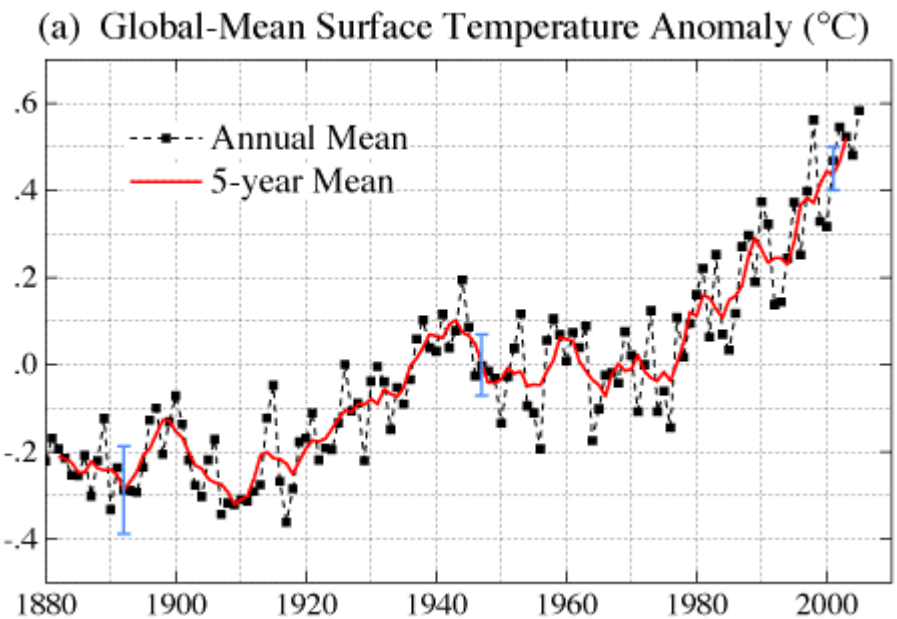
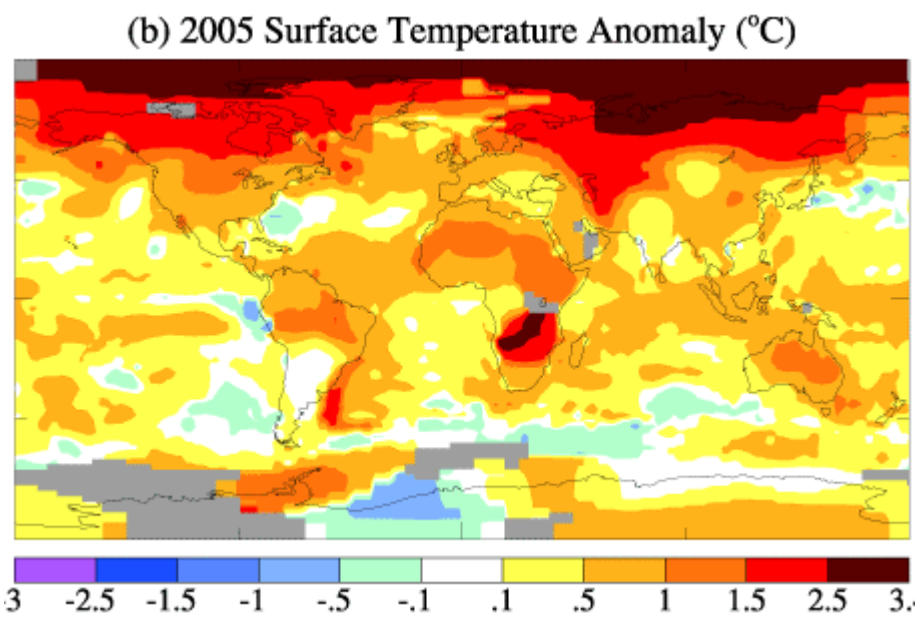
Radiative Forcing Components



Temperature Records

(Deviation from 1951- 1980 mean)





Source: NASA Goddard Institute for Space Studies Surface Temperature Analysis at data.giss.nasa.gov/gistemp/

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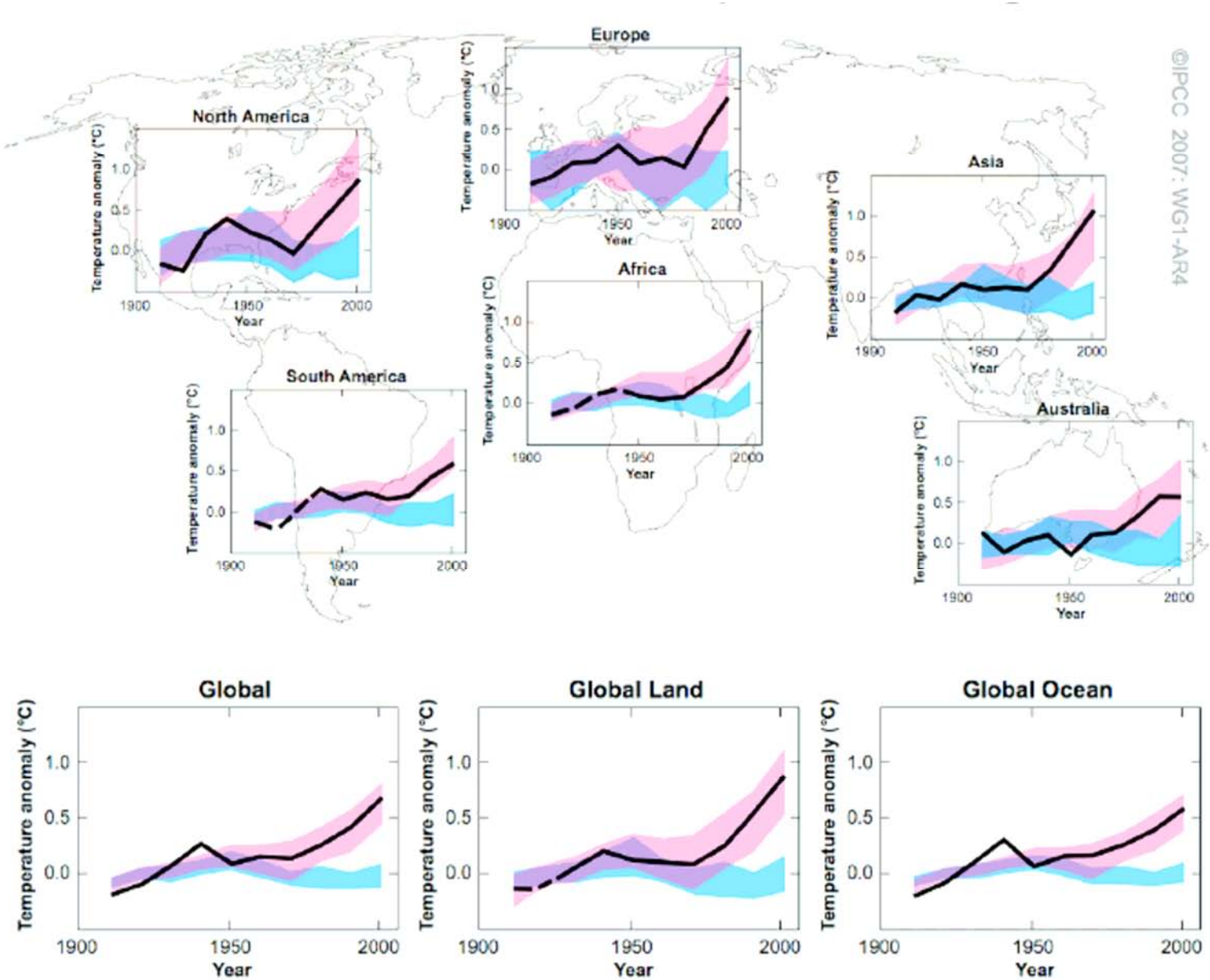
Global Temperature Changes



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"More" recent data

GHG CONCENTRATION INCREASES

- As of December 2006, atmospheric concentrations of CO2, measured at Mauna Loa in Hawaii by NOAA were 382.43 ppm (http://www.cmdl.noaa.gov/projects/web/trends/co2_mm_mlo.dat)
  - Over the past few years, CO2concentrations have increased by as much as 2.5 ppm/year – much faster than in earlier years, when concentrations seldom increased by more than 1.0 to 1.5 ppm a year.
- Global emissions in 2005 were approximately 7.9 billion tons of carbon, an increase of more than 2.5 percent over 2004. (http://www.csiro.au/csiro/content/standard/ps2im.html),
  - This represents a rapid increase; in the 1990s, annual CO2emissions growth was less than 1 percent per year.

TEMPERATURE INCREASES

- 2006 tied for 5th warmest year on record globally http://www.ncdc.noaa.gov/oa/climate/research/2006/dec/global.html#Temp
- 2006 the warmest on record for the contiguous United States (http://www.ncdc.noaa.gov/oa/climate/research/2006/ann/us-summary.html)

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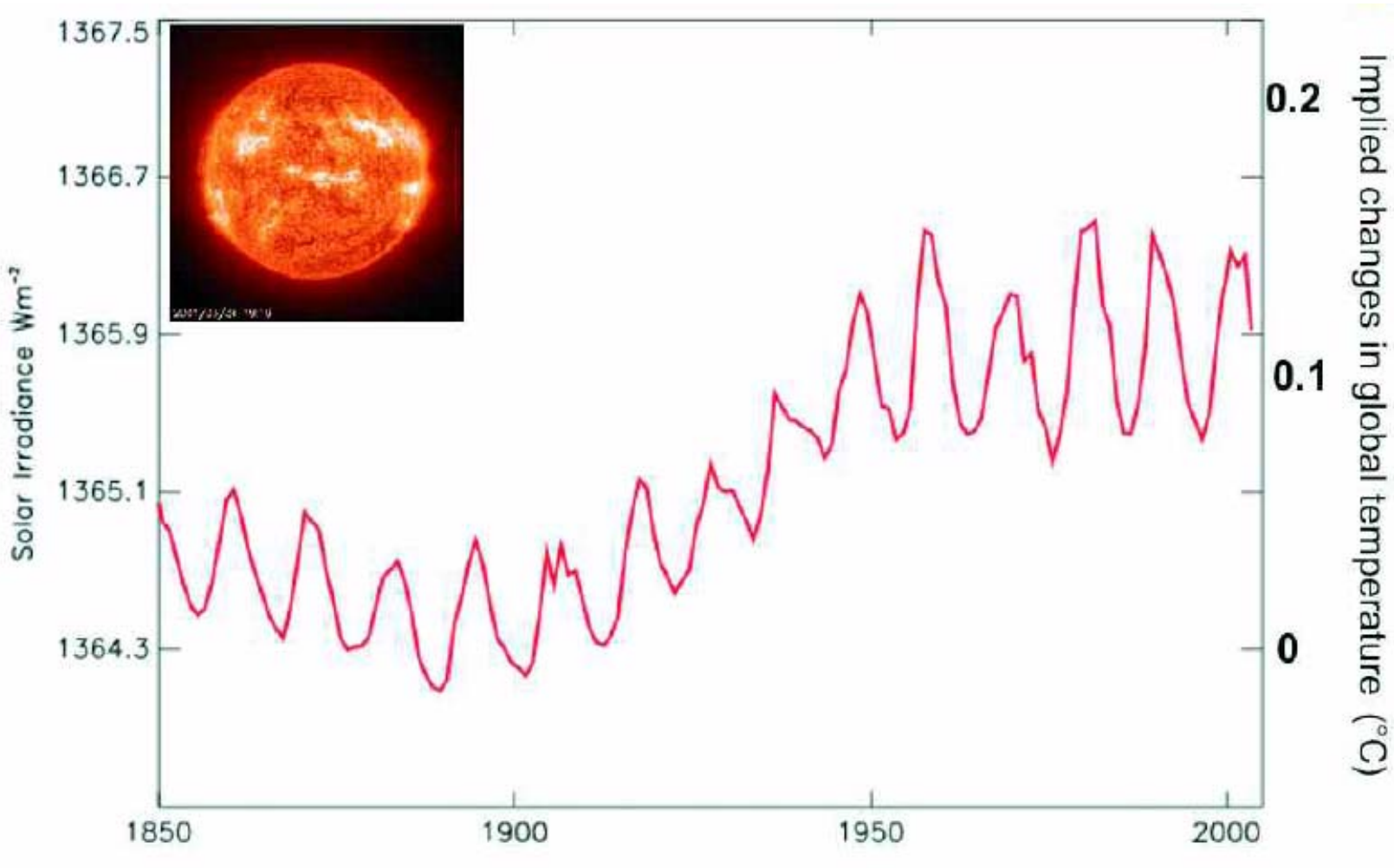
It is NOT a change in solar radiation…



Source: UK Hadley Center, 2007

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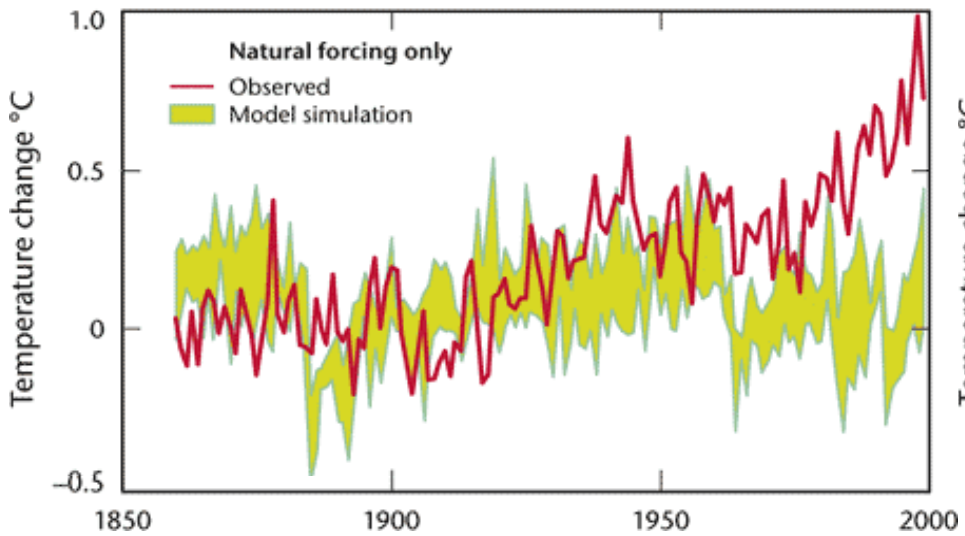
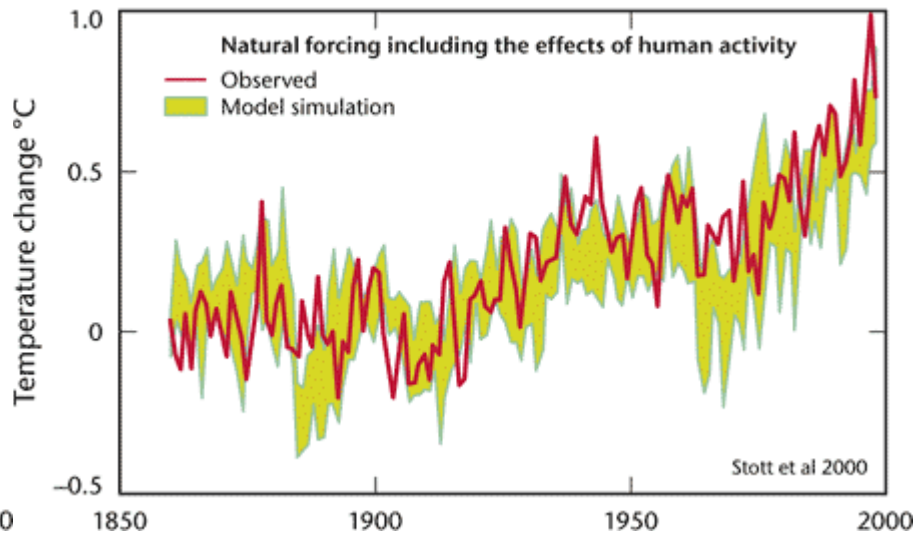
Human Activity is Changing Forcing

Source: UK Hadley Center, 2007





"The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report (TAR), leading to very high confidence [>90%] that the globally averaged net effect of human activities since 1750 has been one of warming…" **IPCC, 2007**

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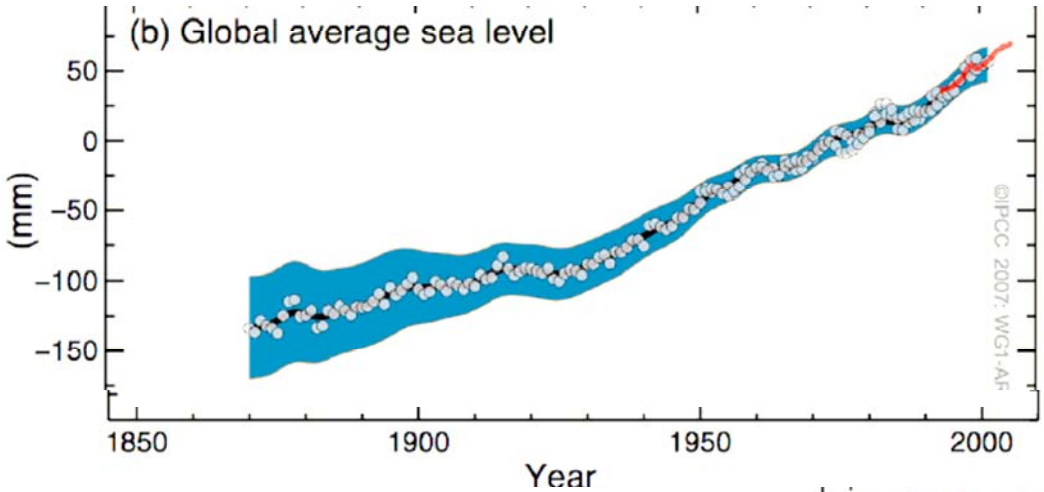
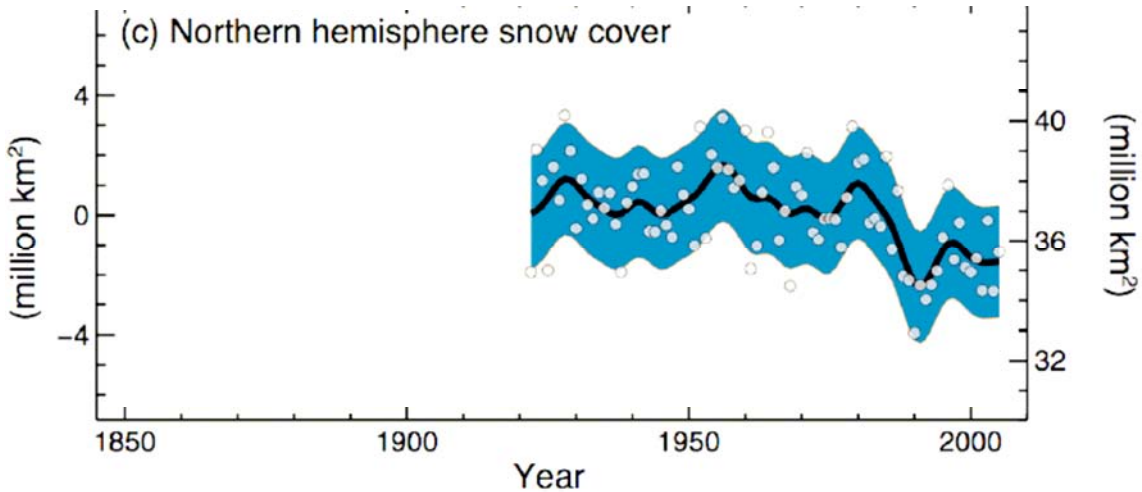
Sea Level Rise and Snow Cover

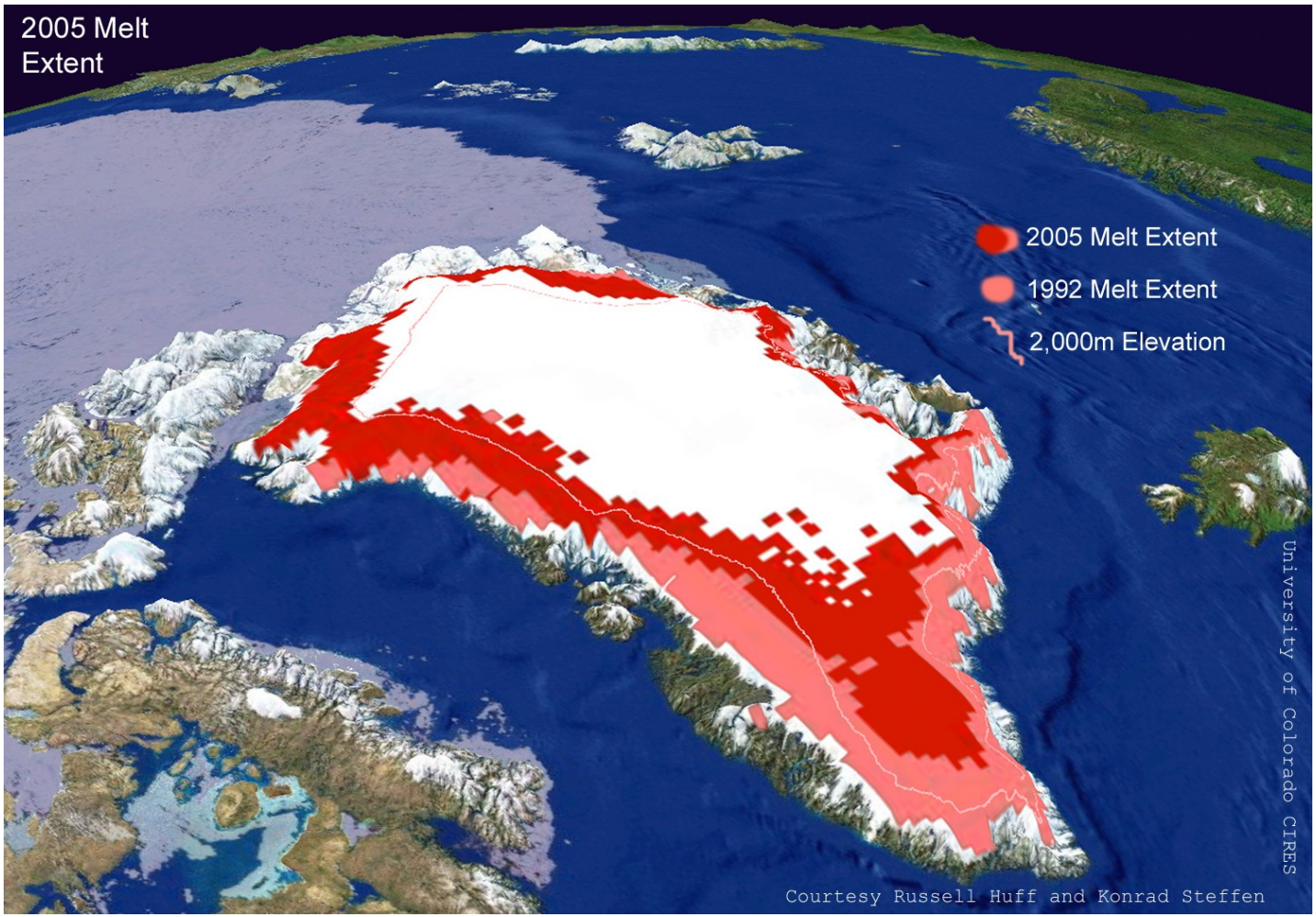
1850 - 2000





Source: IPCC AR4, 2007

Ice Melt in Greenland



Source: http://cires.colorado.edu/science/groups/steffen/greenland/melt2005/

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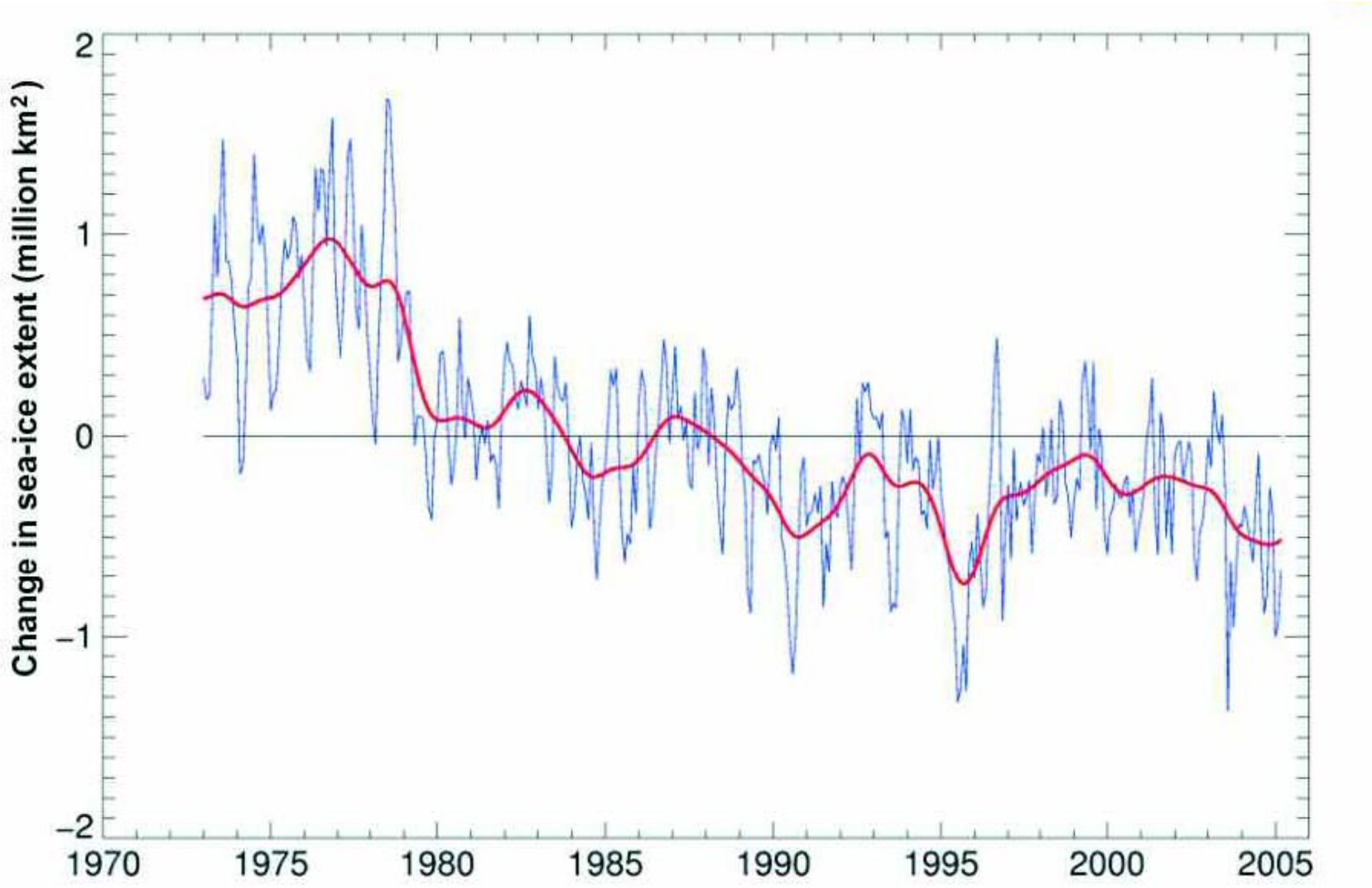
Arctic Sea Ice Declining



Source: UK Hadley Center, 2007

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Antarctic Glacial Melt

- **Measurements of Time-Variable Gravity Show Mass Loss in Antarctica,**
  - Isabella Velicogna and John Wahr. Science, 24 March 2006

- Using measurements of time-variable gravity from the Gravity Recovery and Climate Experiment satellites, to determine mass variations of the Antarctic ice sheet during 2002–2005, found that the mass of the ice sheet decreased significantly, at a rate of 152 ± 80 cubic kilometers of ice per year, which is equivalent to 0.4 ± 0.2 millimeters of global sea-level rise per year.
- Most of this mass loss came from the West Antarctic Ice Sheet.

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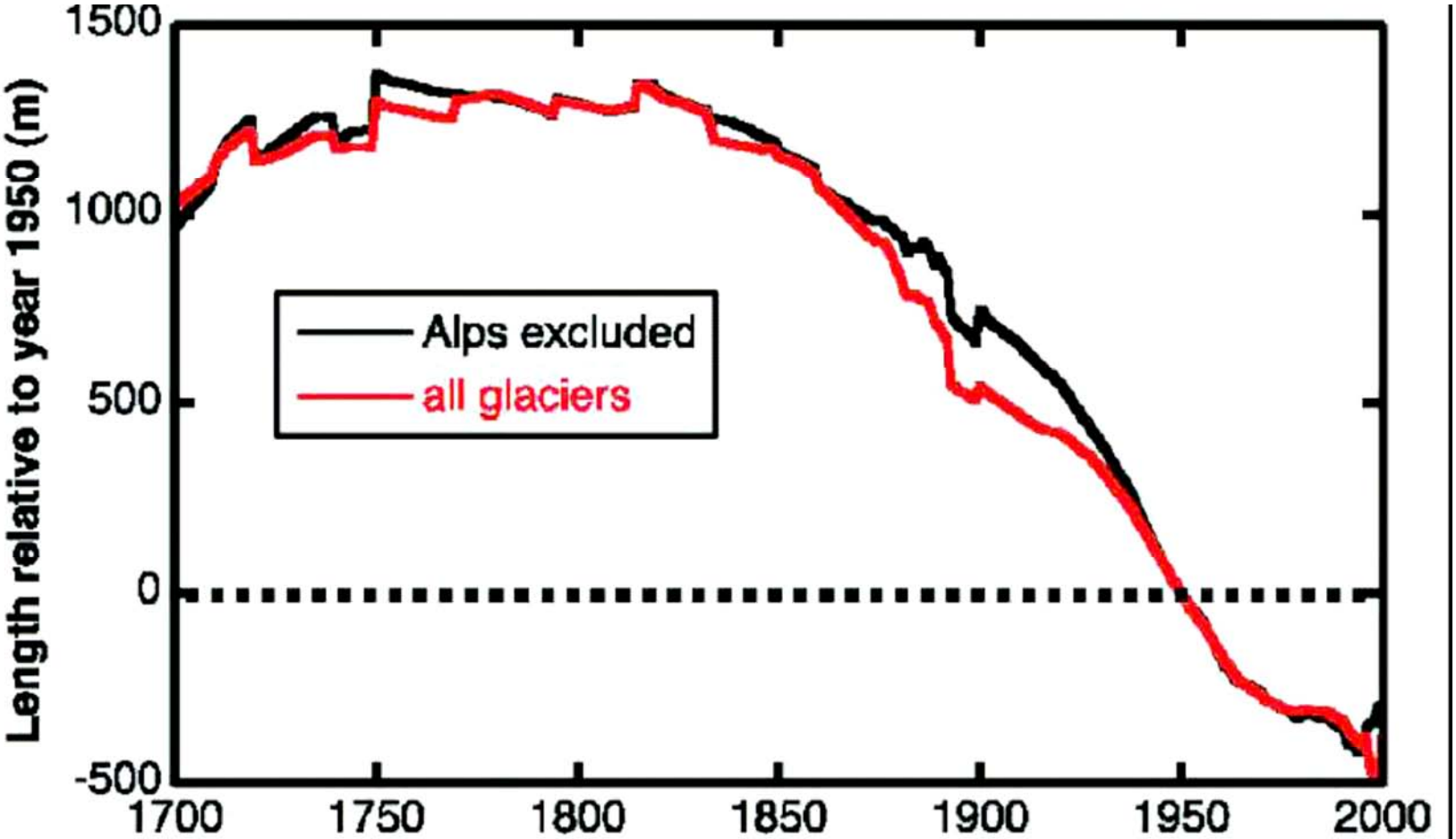
Global Glacier Retreat



Oerlemans, H. Extracting a climate signal from 169 glacier records. Science 308 675–677 (2005).

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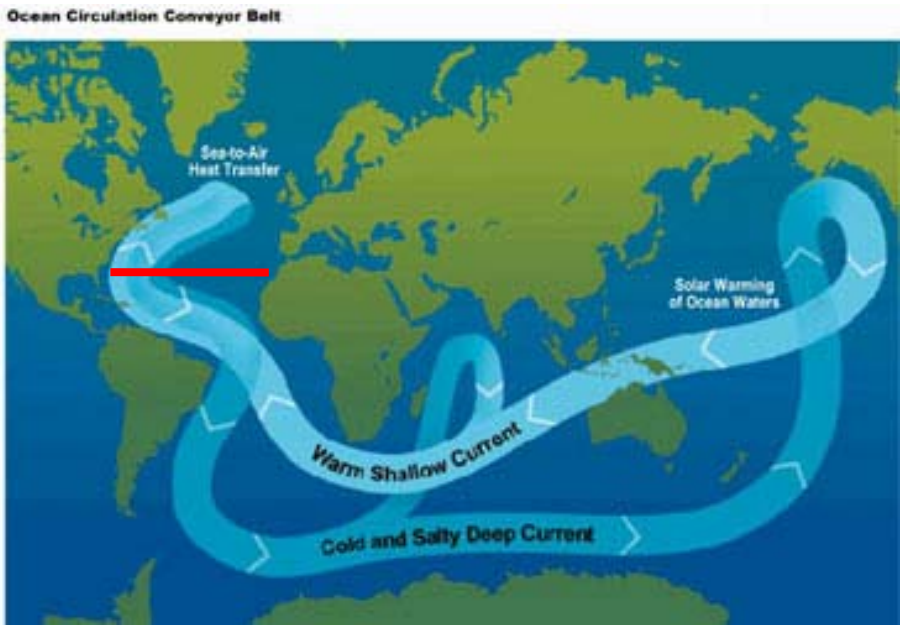
Thermohaline Circulation



Measurements taken at 23º N Lat in 1957, 1981, 1992, 1998, 2004

- Warming temperatures in the Arctic are leading to ice melt and increased river runoff.
- New science describes link between Arctic River runoff and thermohaline circulation.
- Between 1936 and 1999, river discharge increased by 7% and between 1957 and 2004, the thermohaline circulation, measured in the North Atlantic, had apparently slowed by 30%.

Rennermalm et al (Geophysical Research Letters, Vol. 33, 2006) and *Bryden, Harry L. et al. "Slowing of the Atlantic meridional overturning circulation at 25° N." Nature 438: 655-657. 1 December 2005*

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Ocean Circulation

- **Abrupt reversal in ocean overturning during the Palaeocene/Eocene warm period,**
  - Flavia Nunes1 and Richard D. Norris1, Nature, 5 january 2006
- An exceptional analogue for the study of the causes and consequences of global warming occurs at the Palaeocene/Eocene Thermal Maximum, 55 million years ago.
  - A rapid rise of global temperatures during this event accompanied turnovers in both marine and terrestrial biota, as well as significant changes in ocean chemistry and circulation.
- Evidence for an abrupt shift in deep-ocean circulation using carbon isotope records from fourteen sites indicate that deep-ocean circulation patterns changed from Southern Hemisphere overturning to Northern Hemisphere overturning at the start of the Palaeocene/Eocene Thermal Maximum; this shift in the location of deep-water formation persisted for at least 40,000 years.
- Results corroborate climate model inferences that a shift in deep-ocean circulation would deliver relatively warmer waters to the deep sea, thus producing further warming. Greenhouse conditions can thus initiate abrupt deep-ocean circulation changes that may have lasting effects

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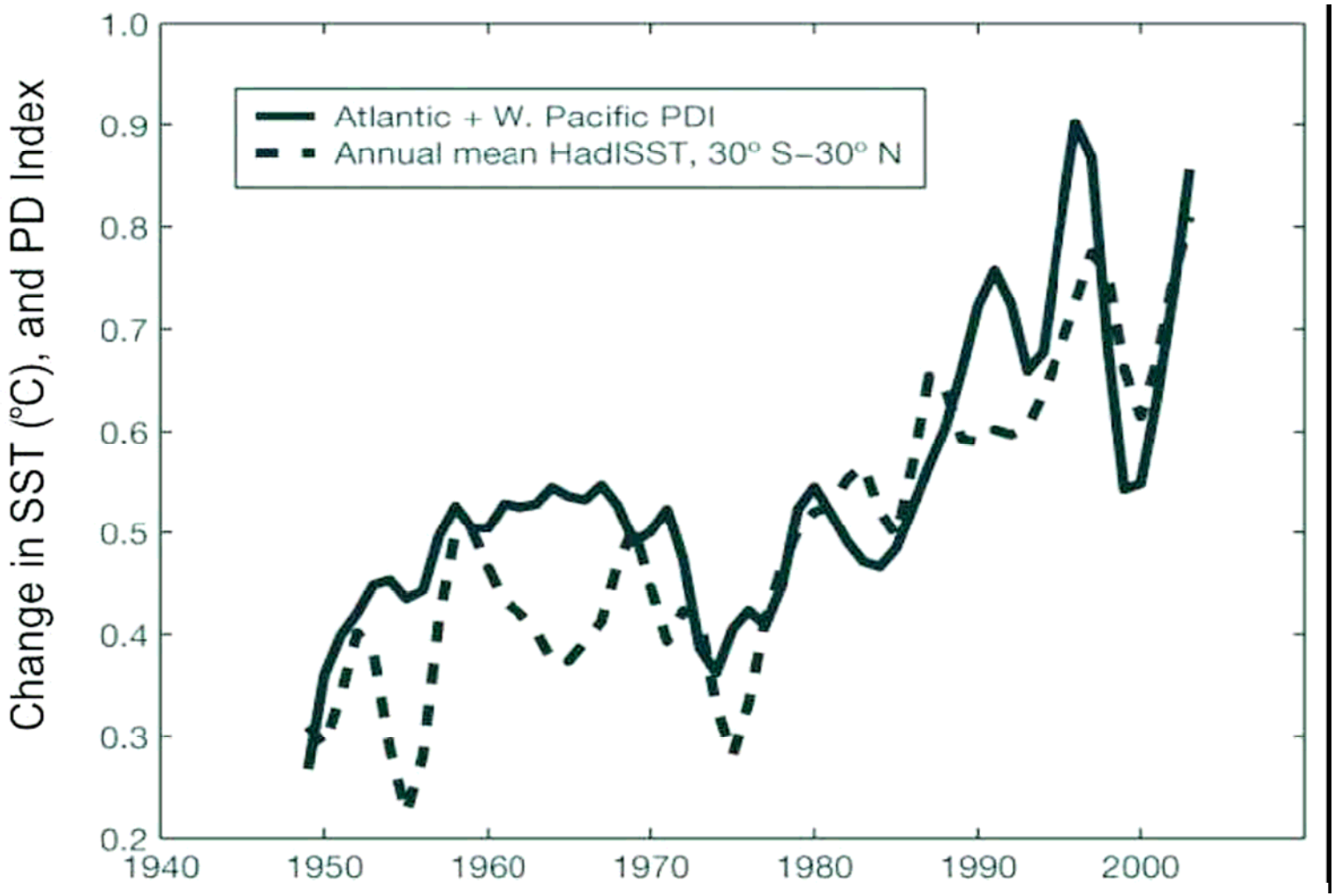
Warming Sea Surface Temperature



Source: UK Hadley Center, 2007

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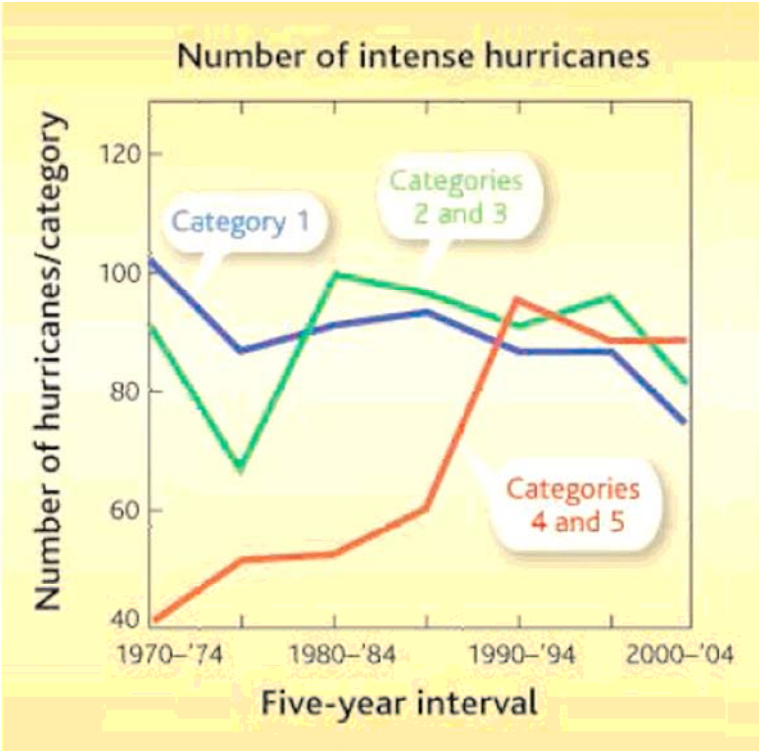
Hurricane Trends



Source: Webster et al, *SCIENCE* 16 September 2005

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More recent work on Hurricanes…

- **Deconvolution of the Factors Contributing to the Increase in Global Hurricane Intensity**
  - **C. D. Hoyos,* P. A. Agudelo, P. J. Webster, J. A. Curry**
  - http://www.sciencemag.org/cgi/content/abstract/312/5770/94
- Show that the trend of increasing numbers of category 4 and 5 hurricanes for the period 1970–2004 is directly linked to the trend in sea-surface temperature
  - Other aspects of the tropical environment, although they influence shorter-term variations in hurricane intensity, do not contribute substantially to the observed global trend.
  - Methodology based on information theory, isolating the trend from the shorter-term natural modes of variability.

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What can we expect in the future?

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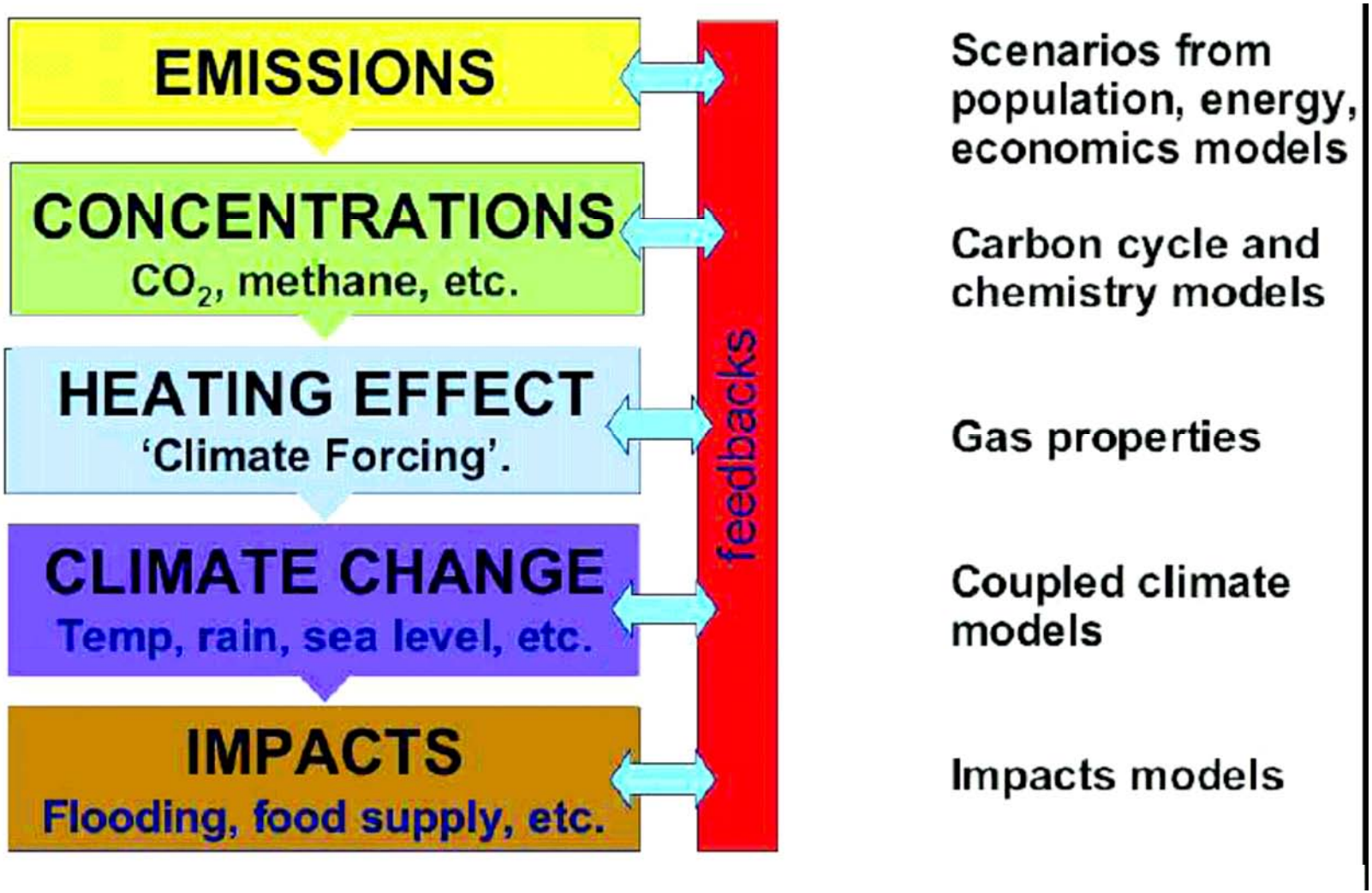
Projecting Climate Change



Source: UK Hadley Center, 2007

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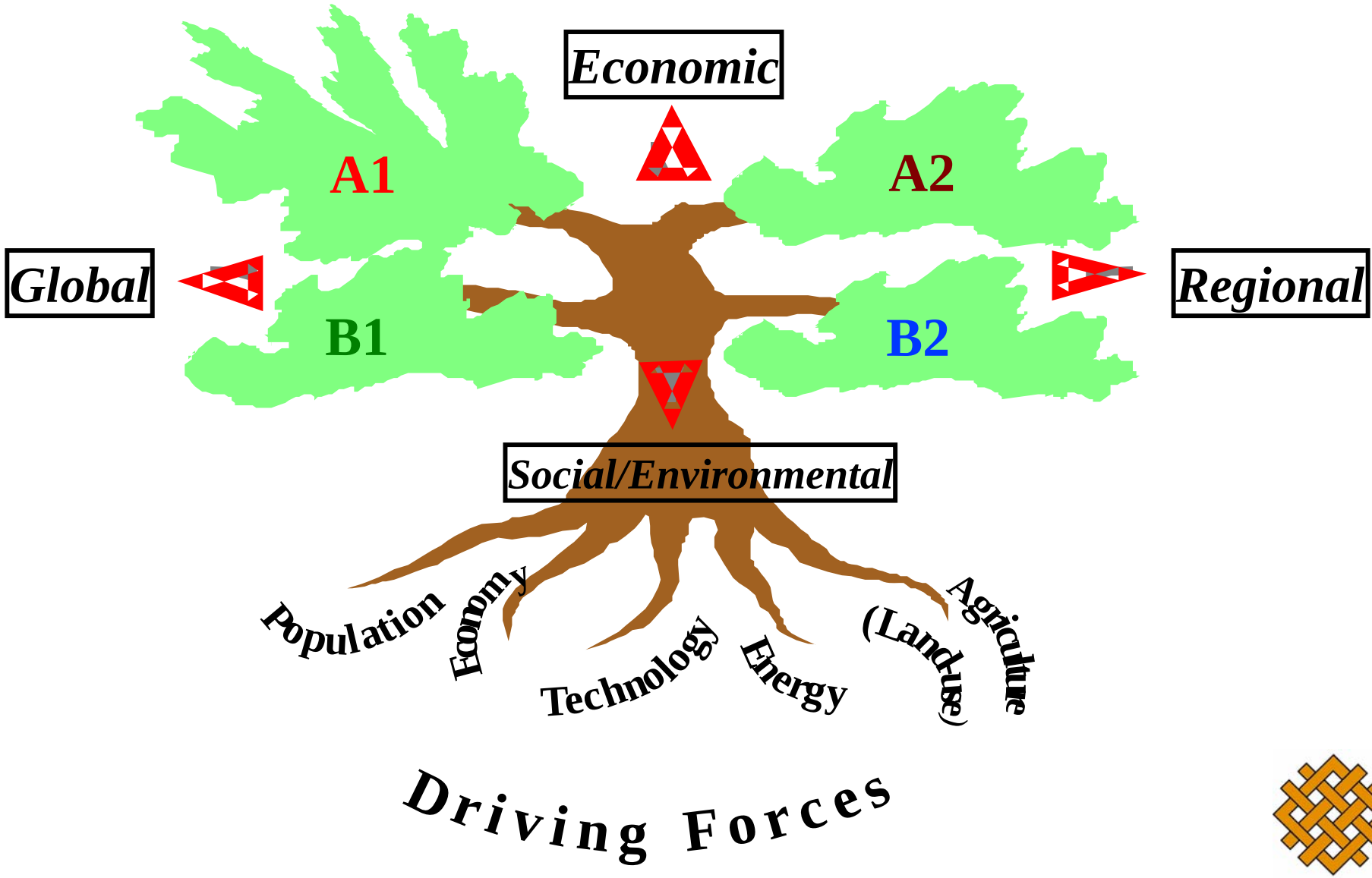
IPCC/SRES Reference Scenarios



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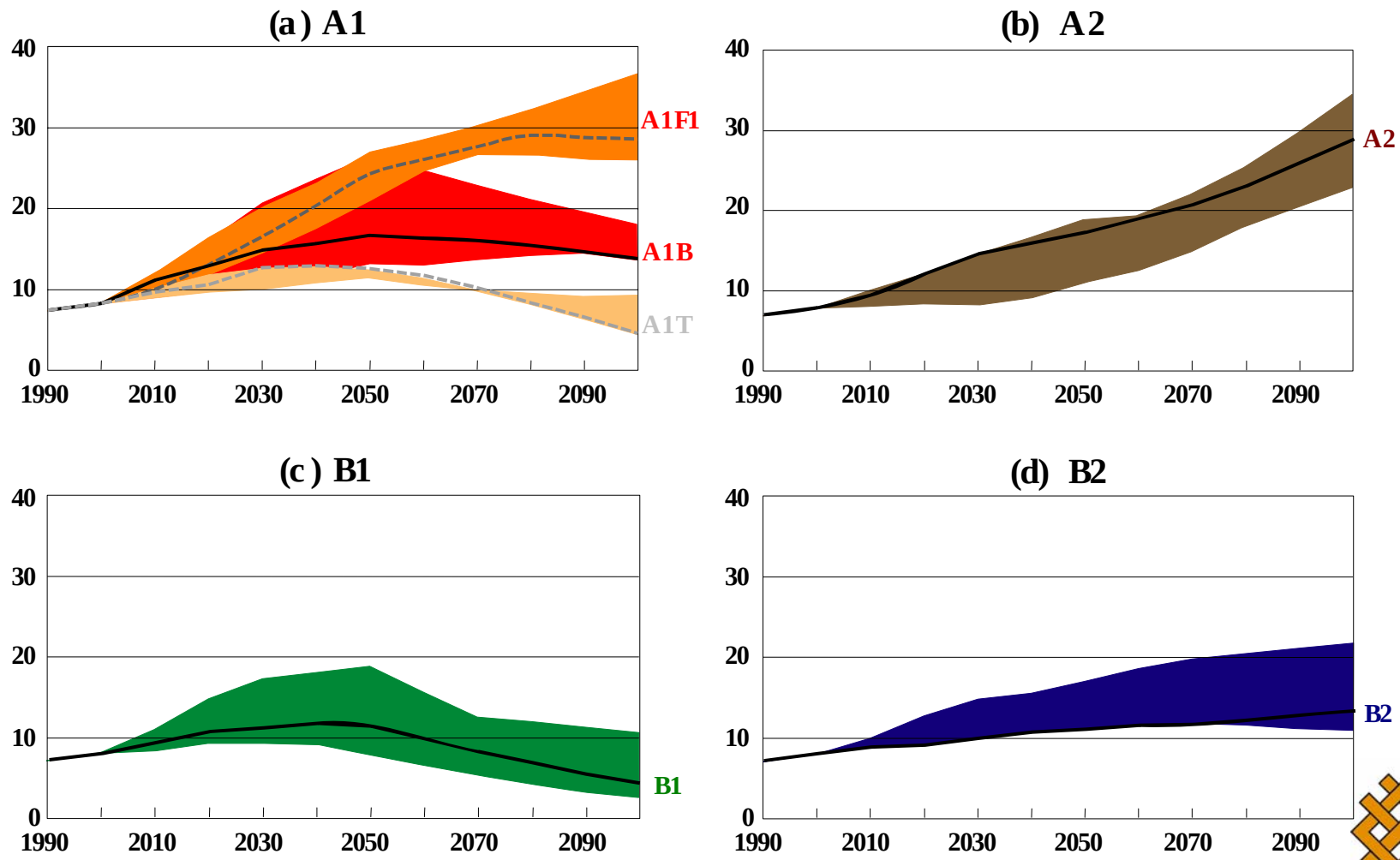
GLOBAL CO_2 EMISSIONS FOR IPCC/SRES SCENARIO GROUPS



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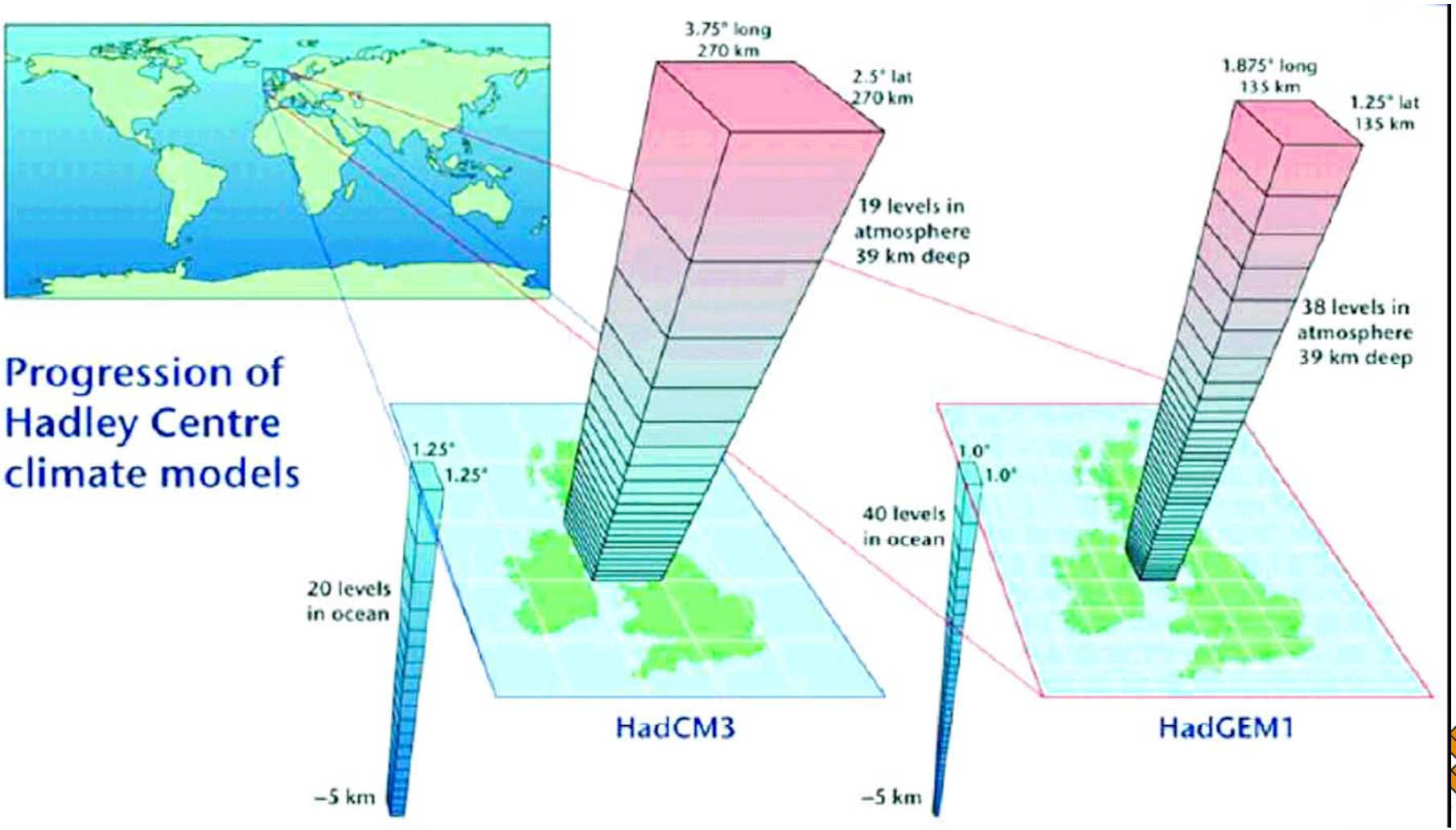
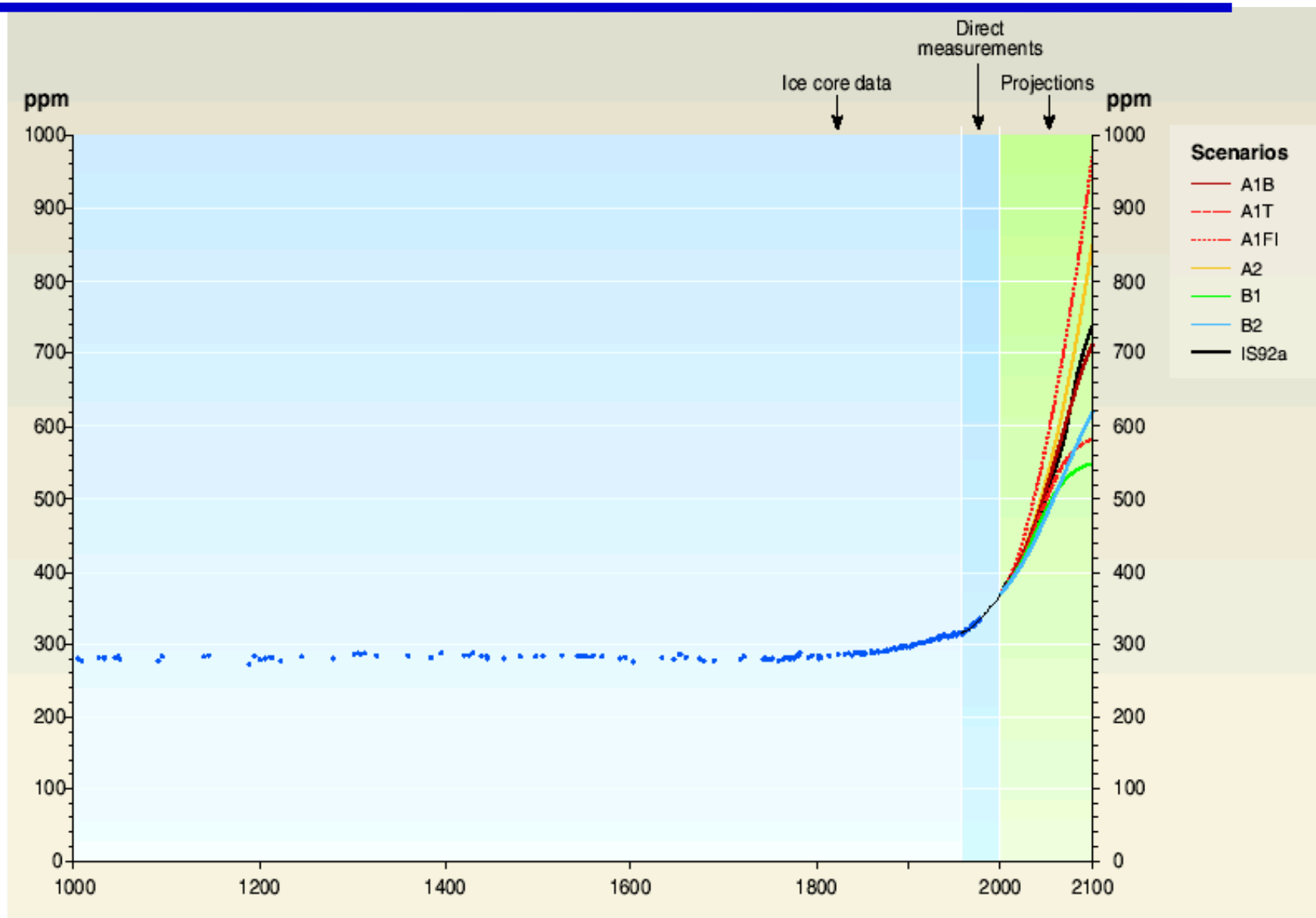
Modelling Improvements

Source: UK Hadley Center, 2007



Projected future concentrations…



Source: IPCC, Climate Change, 2001

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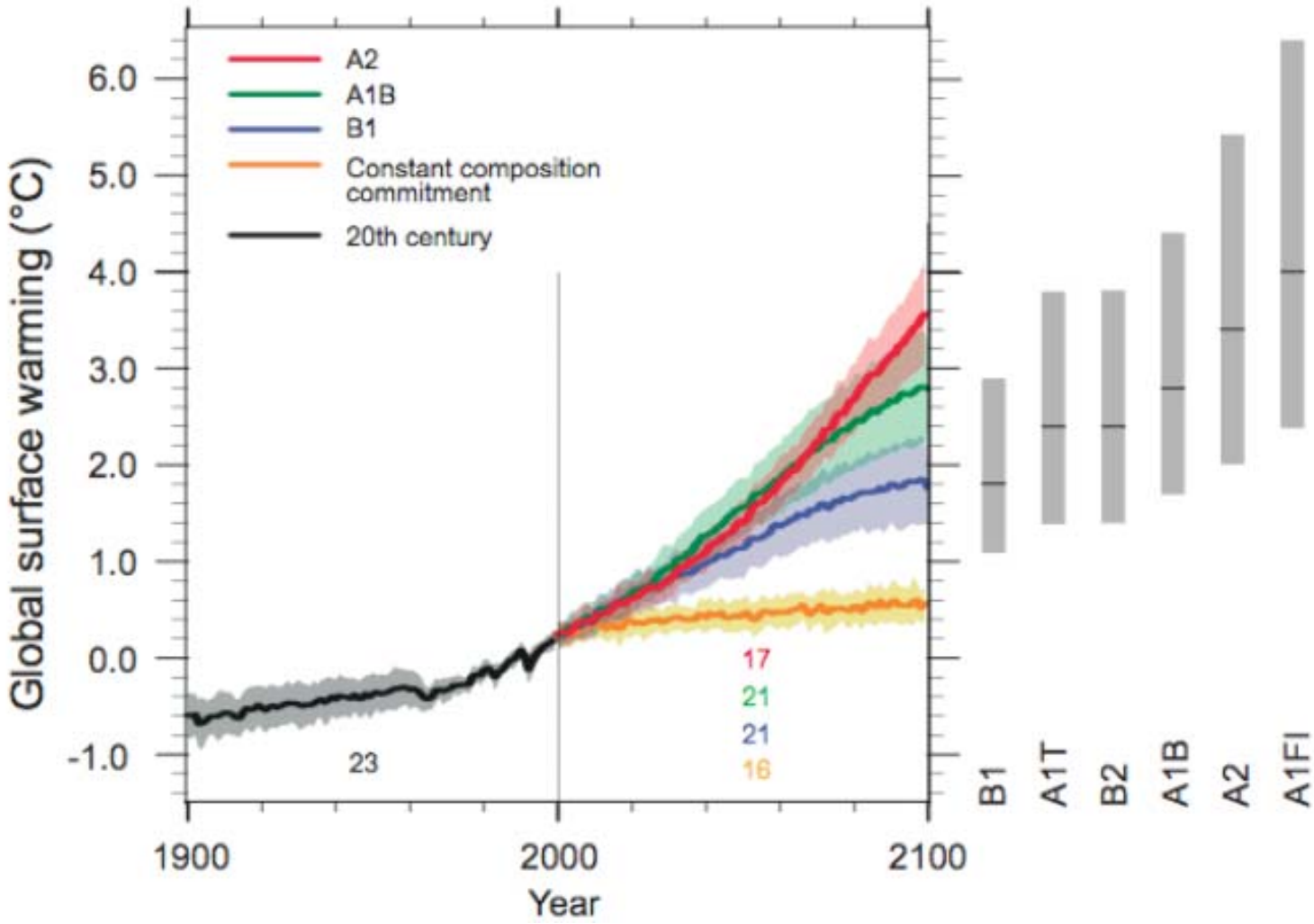
…and temperature



Source: IPCC, 2007

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Climate Sensitivity

- Climate sensitivity constrained by temperature reconstructions over the past seven centuries,
  - Gabriele C. Hegerl, Thomas J. Crowley, William T. Hyde and David J. Frame, Nature, 20 April 2006
- The magnitude and impact of future global warming depends on the sensitivity of the climate system to changes in greenhouse gas concentrations; the commonly accepted range for the equilibrium global mean temperature change in response to a doubling of the atmospheric carbon dioxide concentration (termed climate sensitivity), is 1.5–4.5 K
- A number of observational studies have found a substantial probability of significantly higher sensitivities, yielding upper limits on climate sensitivity of 7.7 K to above 9 K
- This study combines large-ensemble energy balance modeling and simulations of the temperature response to past solar, volcanic and greenhouse gas forcing to determine which climate sensitivities yield simulations that are in agreement with proxy reconstructions. Using these, the 5–95 per cent range shrinks to 1.5–6.2 K.

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New Feedback?

- Particular concern about permafrost thawing, which emits methane and carbon dioxide, and changes in soil carbon storage.
- Extra 15-78% warming should be added to future projections as a result of taking potential feedbacks into account.
- Temperature associated with doubled CO_2 should be revised upward to 1.6 to 6 °C warming.

Scheffer, Marten; Brovkin, Victor and Peter M. Cox (Geophysical Research Letters, 2006) and Torn, Margaret S. and John Harte (Geophysical Research Letters, 2006)

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Climate Impacts

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[e]	*Virtually certain*[e]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[d]	*Likely (nights)*[e]	*Virtually certain*[e]
Warm spells / heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f, h]	*Likely*[i]

Source: IPCC AR4, February 2007

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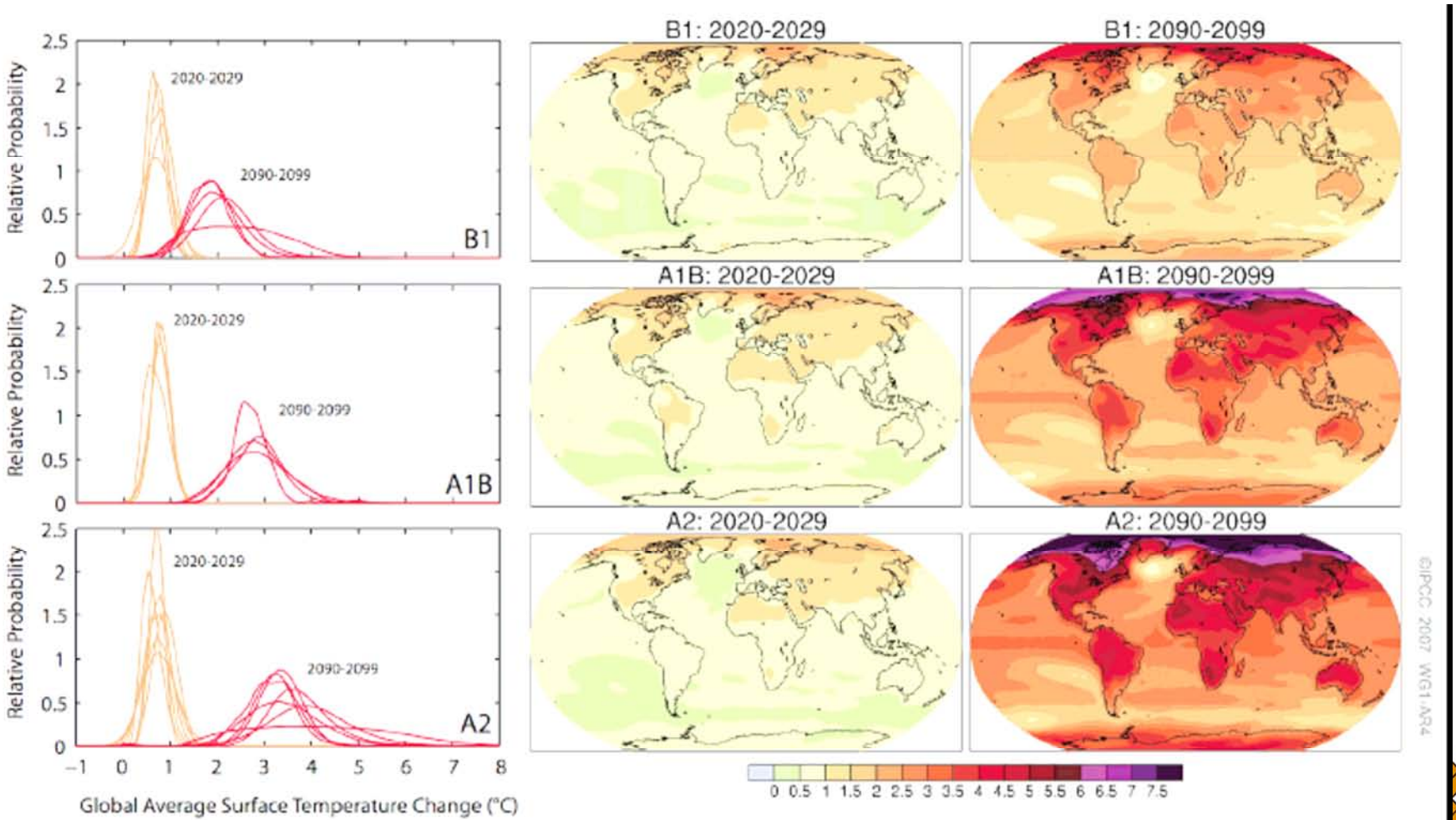
Projections of Surface Temperature



Source: IPCC, 2007

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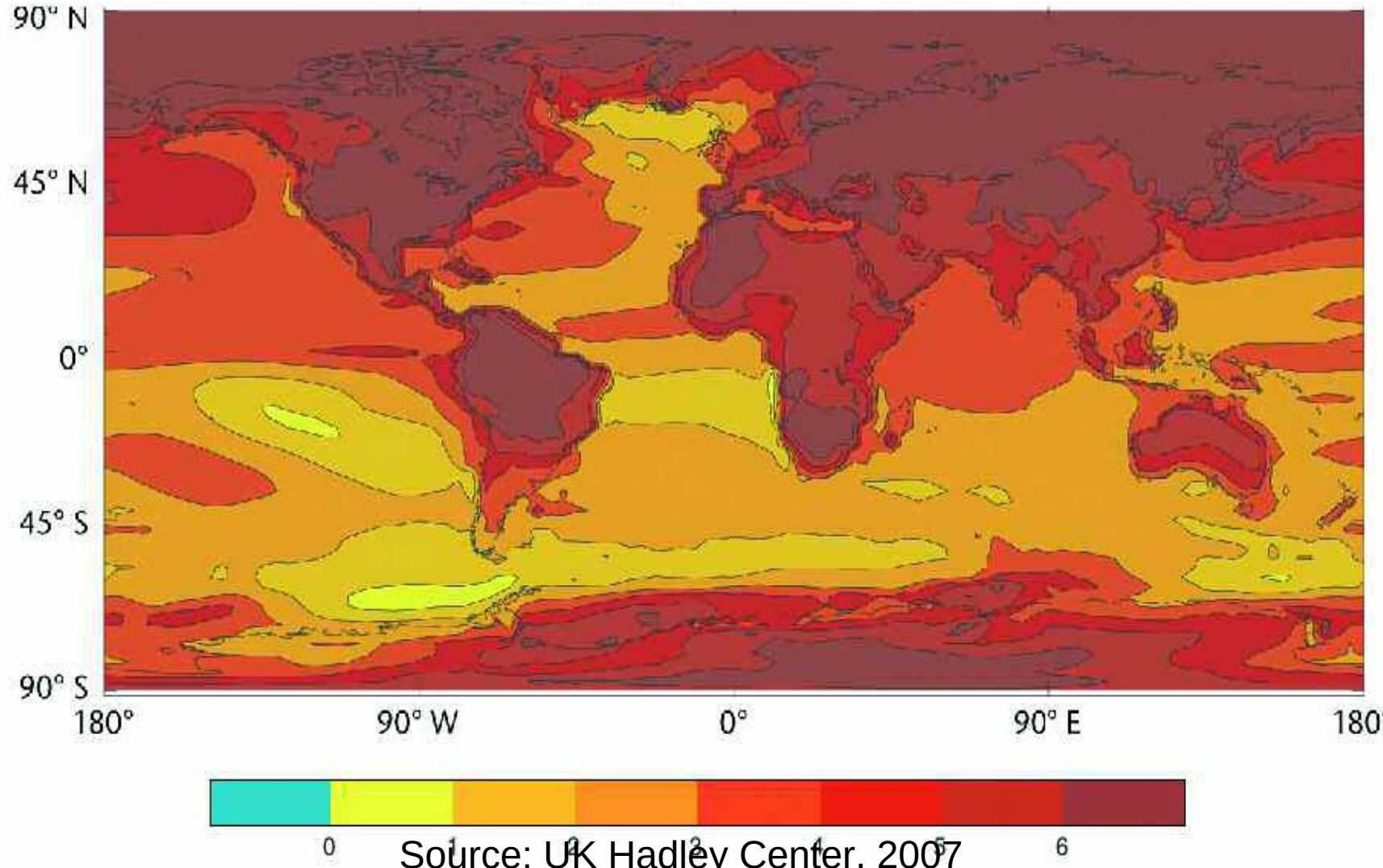
We are on the A1 FI Path: Temperature in 2080



Source: UK Hadley Center, 2007

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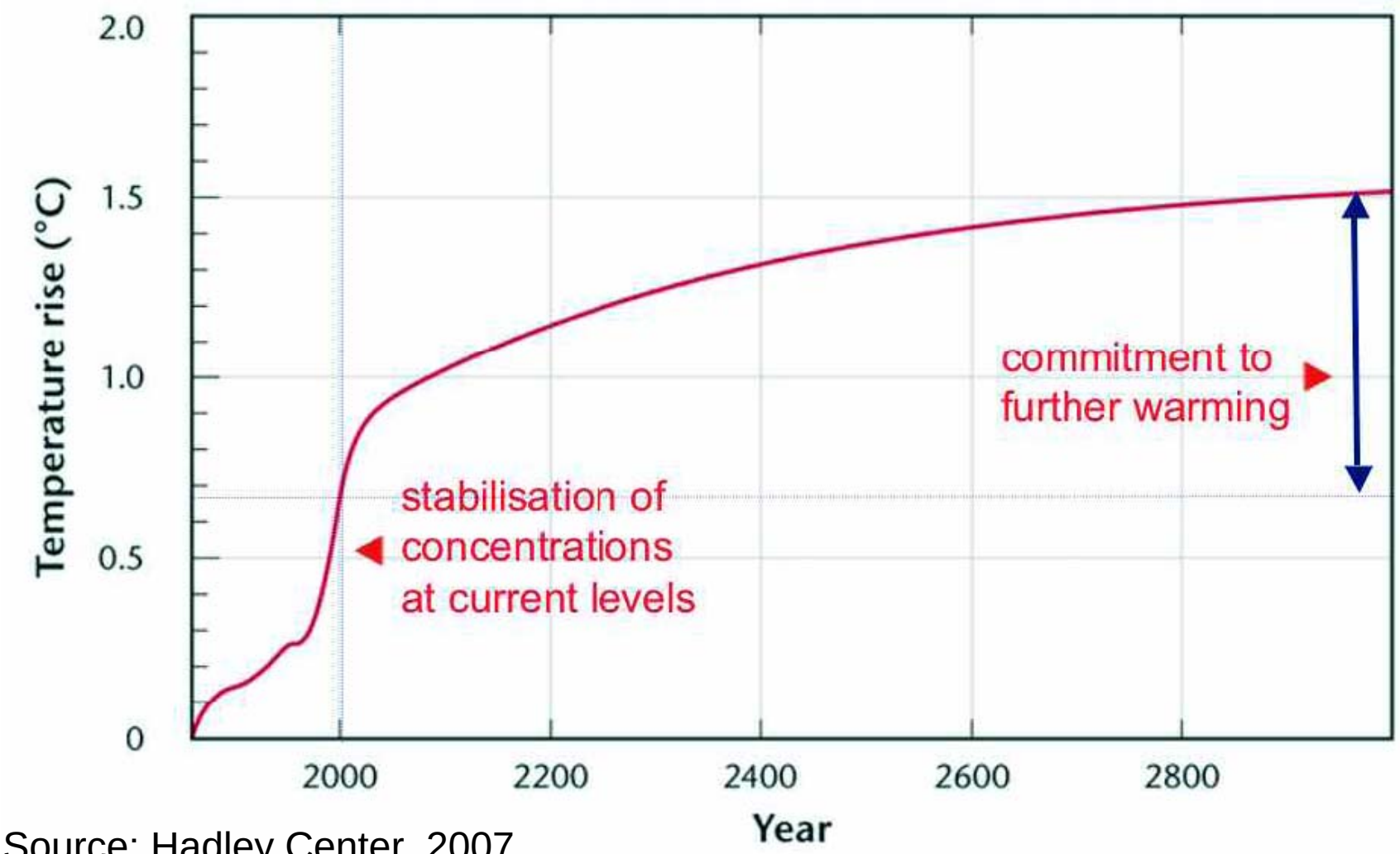
Even once concentrations stabilize, inertia will increase warming



Source: Hadley Center, 2007

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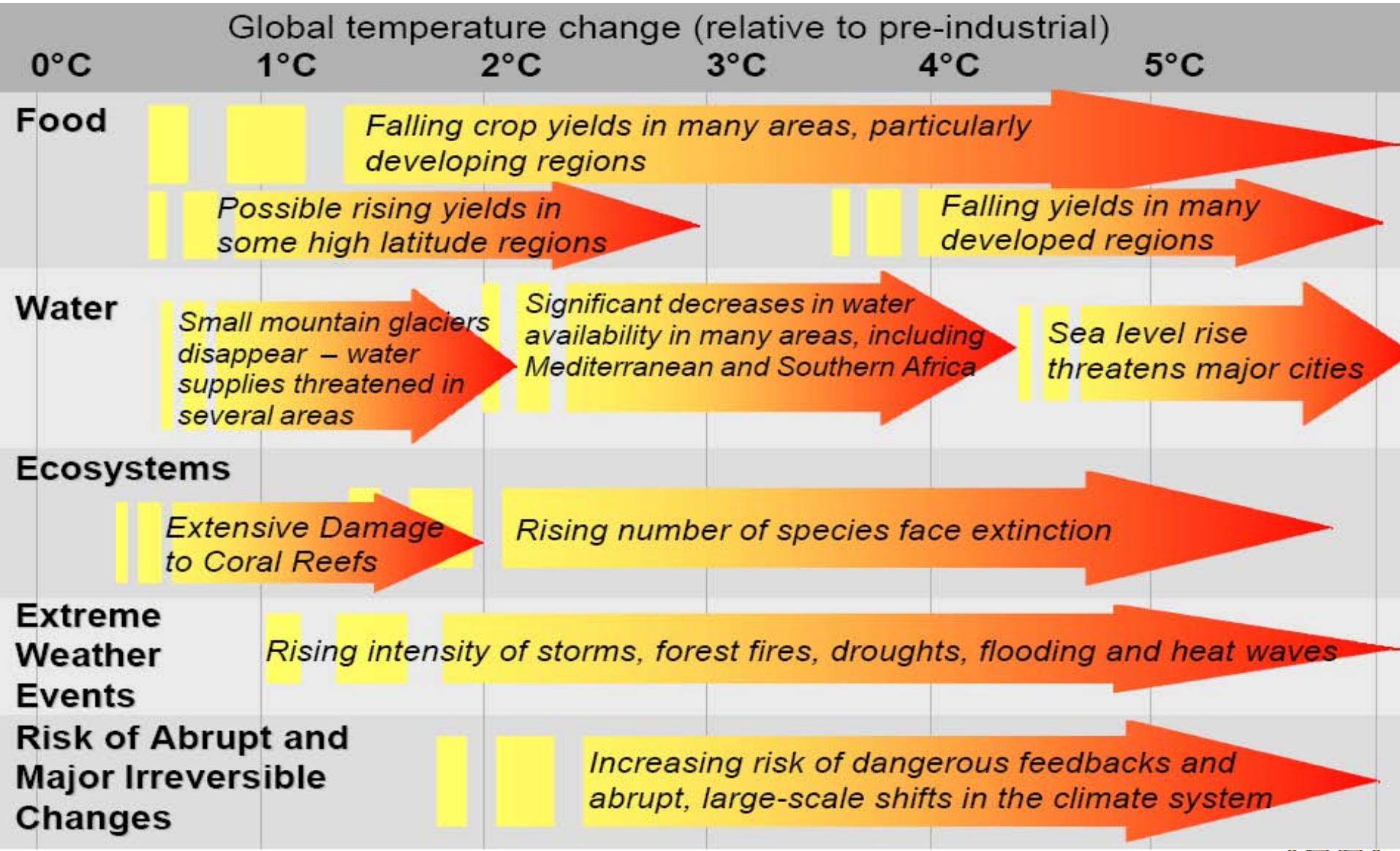
Climate Impacts



Source: Stern review, 2006

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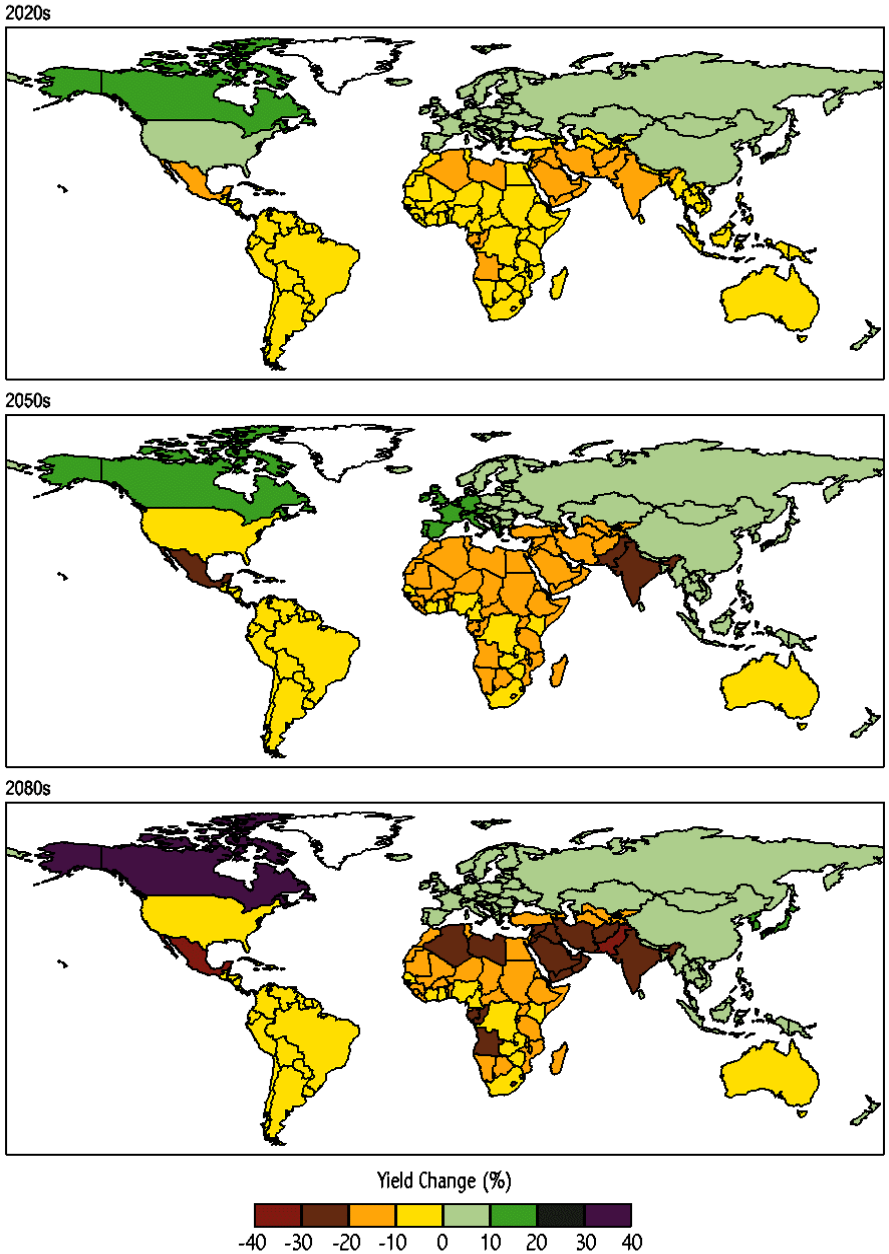
Crop Yield Change



- Percentage change in average crop yields for the climate change scenario. Effects of CO_2 are taken into account. Crops modeled are: wheat, maize and rice.
- This scenario is only one of a range of possible outcomes; changes in yield will be a function of technology, local weather patterns , etc.
- Crop yield changes may be linked to political instability, with potential for resource /immigration conflicts globally.

Source: IPCC TAR

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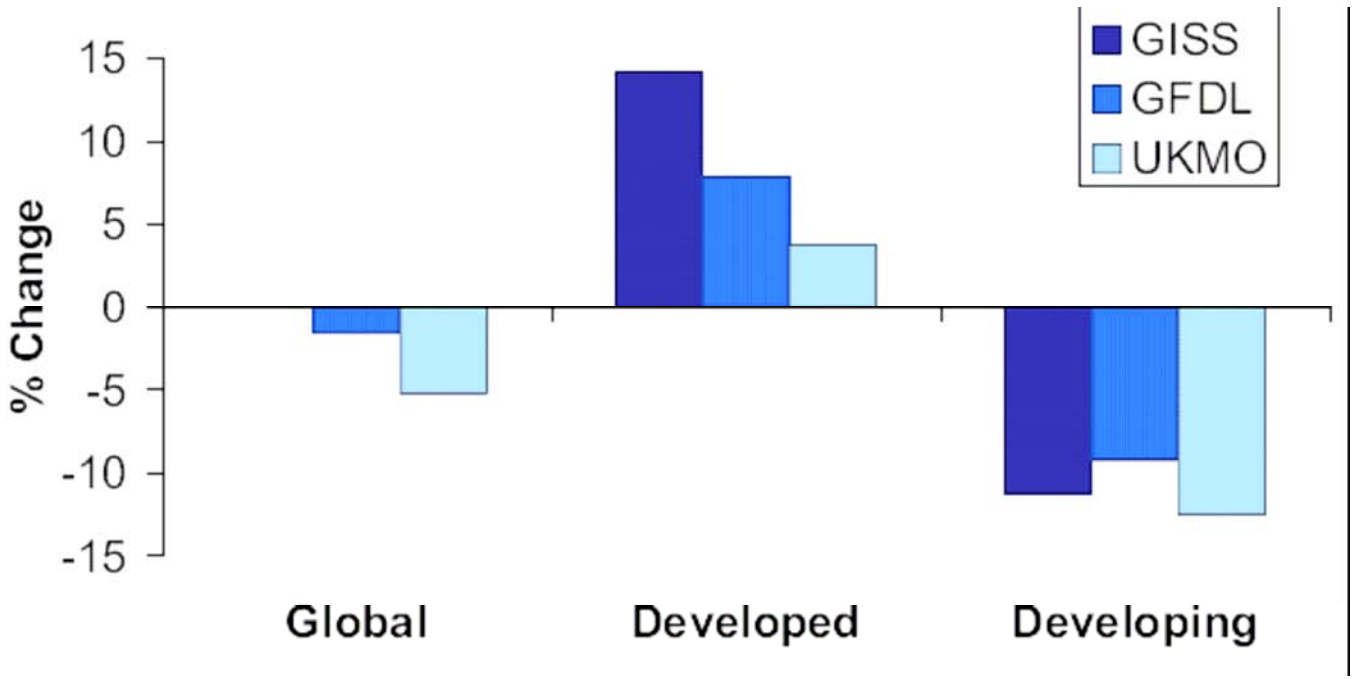
Change in Cereal Production

(2X CO2)



Source: Stern Repot, 2005

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Food

Food for Thought: Lower-Than-Expected Crop Yield Stimulation with Rising CO2 Concentrations

- Stephen P. Long, Elizabeth A. Ainsworth, Andrew D. B. Leakey, Josef Nösberger, Donald R. Ort, Science, 30June 2006

- Model projections suggest that although increased temperature and decreased soil moisture will act to reduce global crop yields by 2050, the direct fertilization effect of rising carbon dioxide concentration (CO2) will offset these losses

BUT…

- CO2 fertilization factors used in models to project future yields were derived from enclosure studies conducted approximately 20 years ago. Free-air concentration enrichment (FACE) technology has now facilitated large-scale trials of the major grain crops at elevated [CO2] under fully open-air field conditions.
- In those trials, elevated CO2-enhanced yield is 50% less than in enclosure studies.
- This casts serious doubt on projections that rising CO2 will fully offset losses due to climate change.

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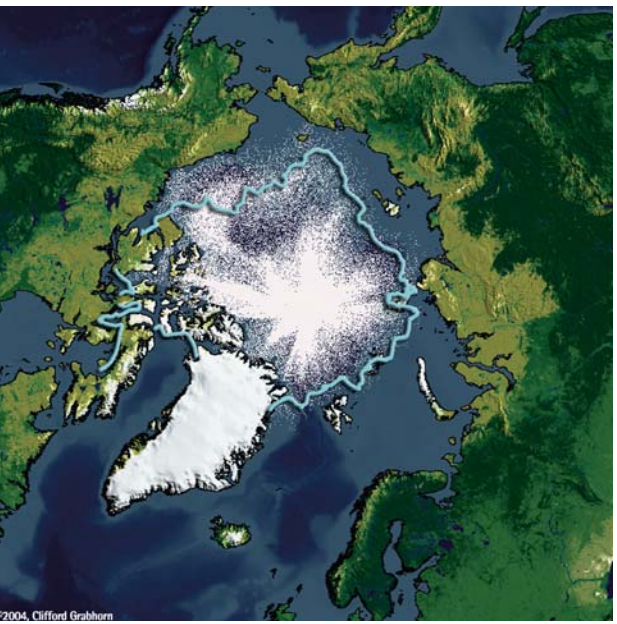
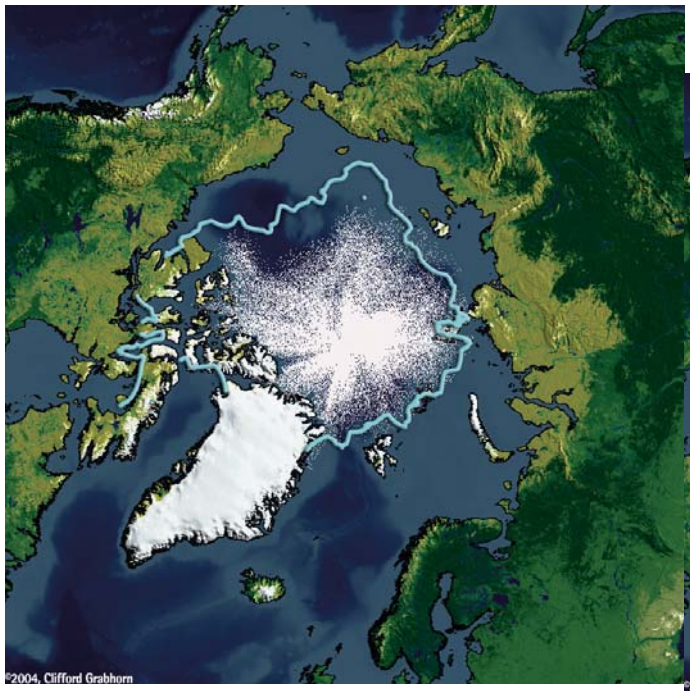
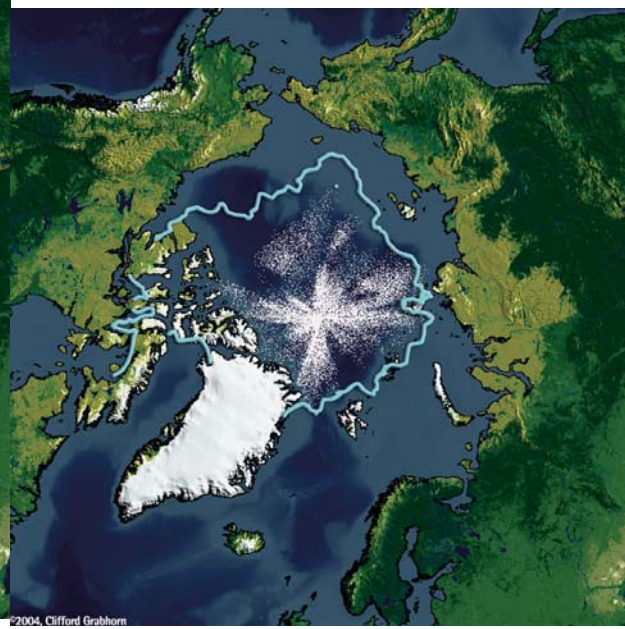
Arctic Sea Ice : The future







2010 - 2030 2040 - 2060 2070 - 2090

Source: Arctic Climate Impact Assessment, 2004

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Polar Ice Melt

- Polar warming by the year 2100 may reach levels similar to those of 130,000 to 127,000 years ago that were associated with sea levels several meters above modern levels; both the Greenland Ice Sheet and portions of the Antarctic Ice Sheet may be vulnerable.
- The record of past ice-sheet melting indicates that the rate of future melting and related sea-level rise could be faster than widely thought.
- Increasing frequency and magnitude of glacial quakes suggest more rapid glacial flow – and melting

-- Jonathan T. Overpeck, Bette L. Otto-Bliesner, Gifford H. Miller, Daniel R. Muhs, Richard B. Alley, Jeffrey T. Kiehl, *Science* 24 March 2006:

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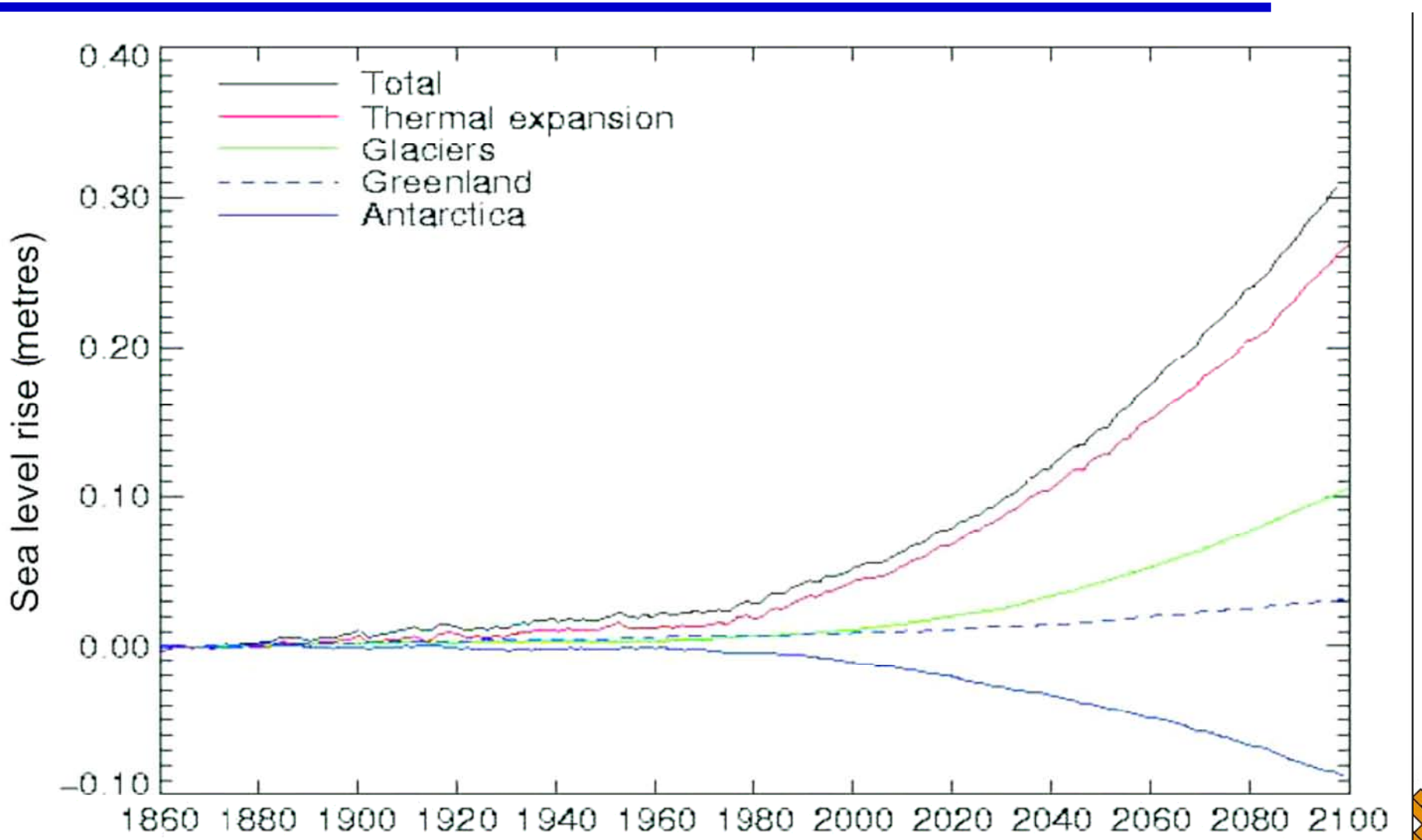
Commitment to Sea Level Rise



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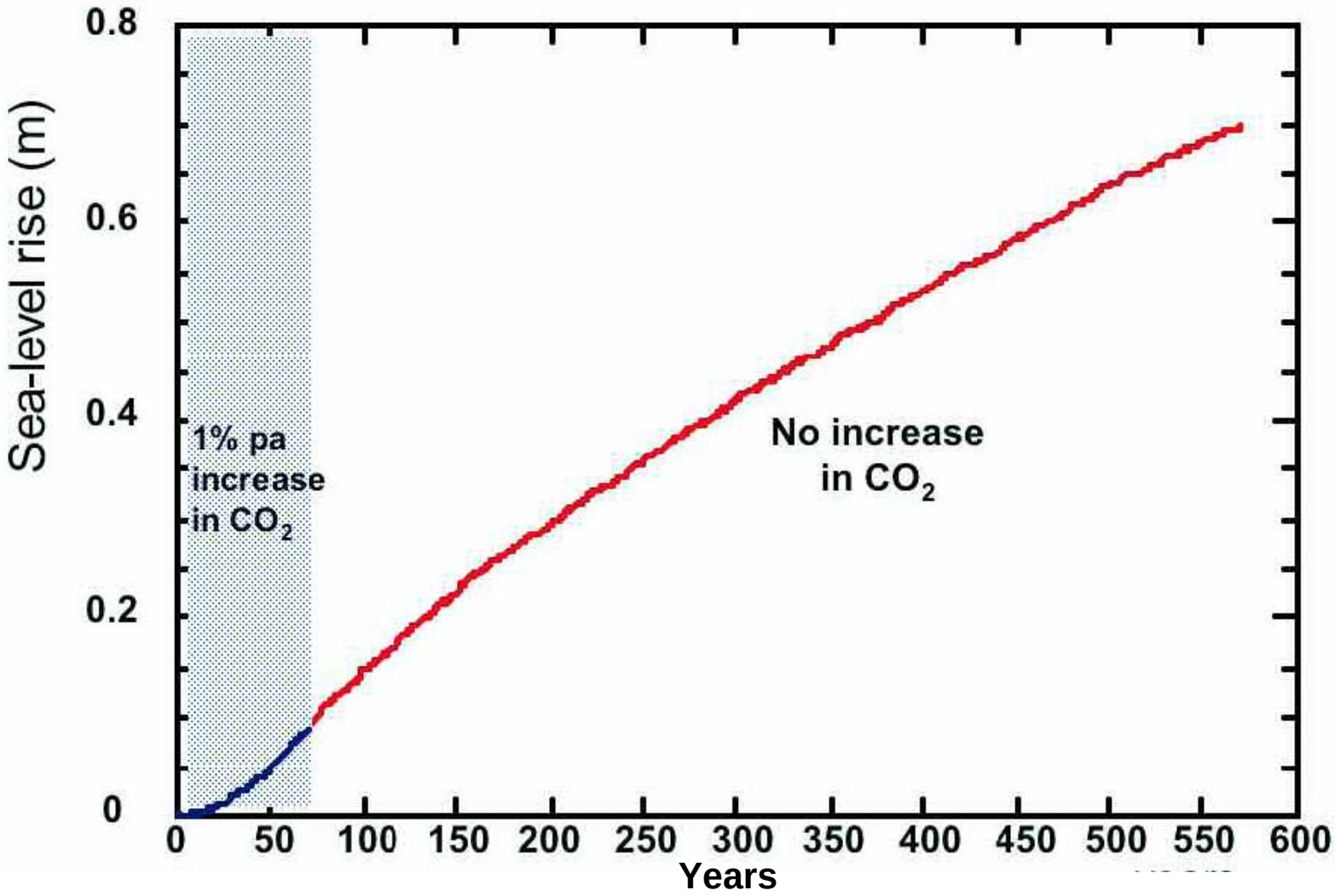
Sea Level Rise



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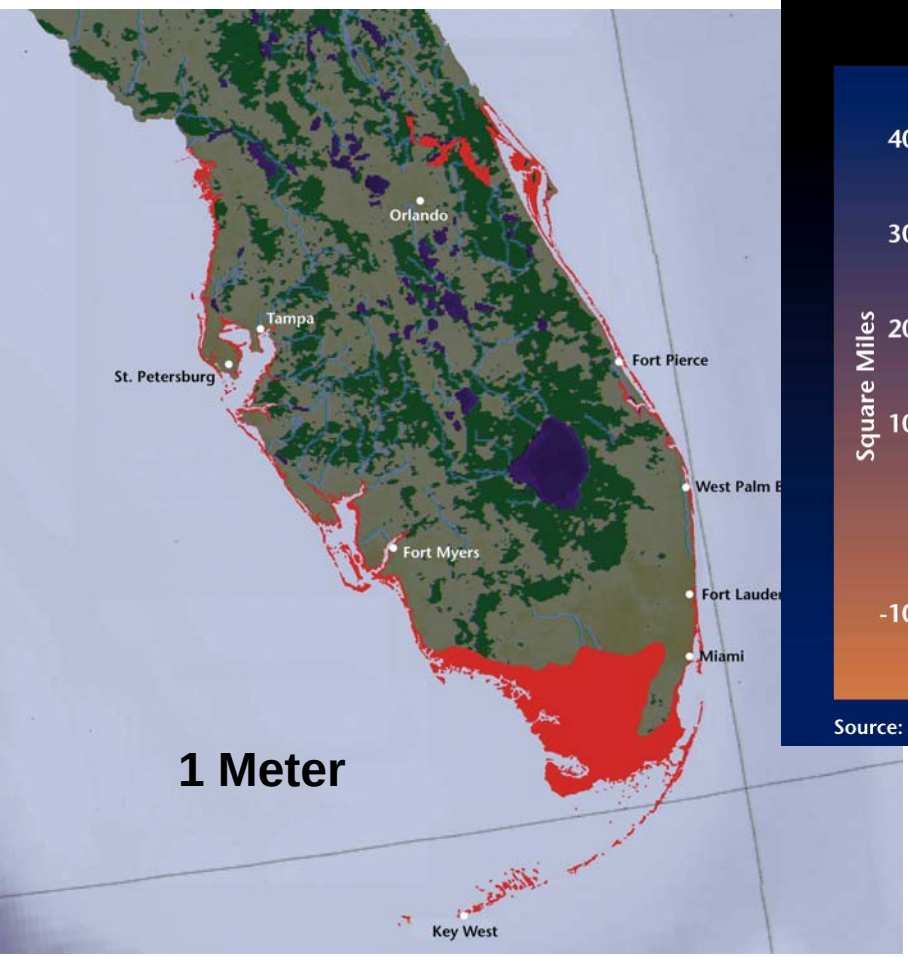
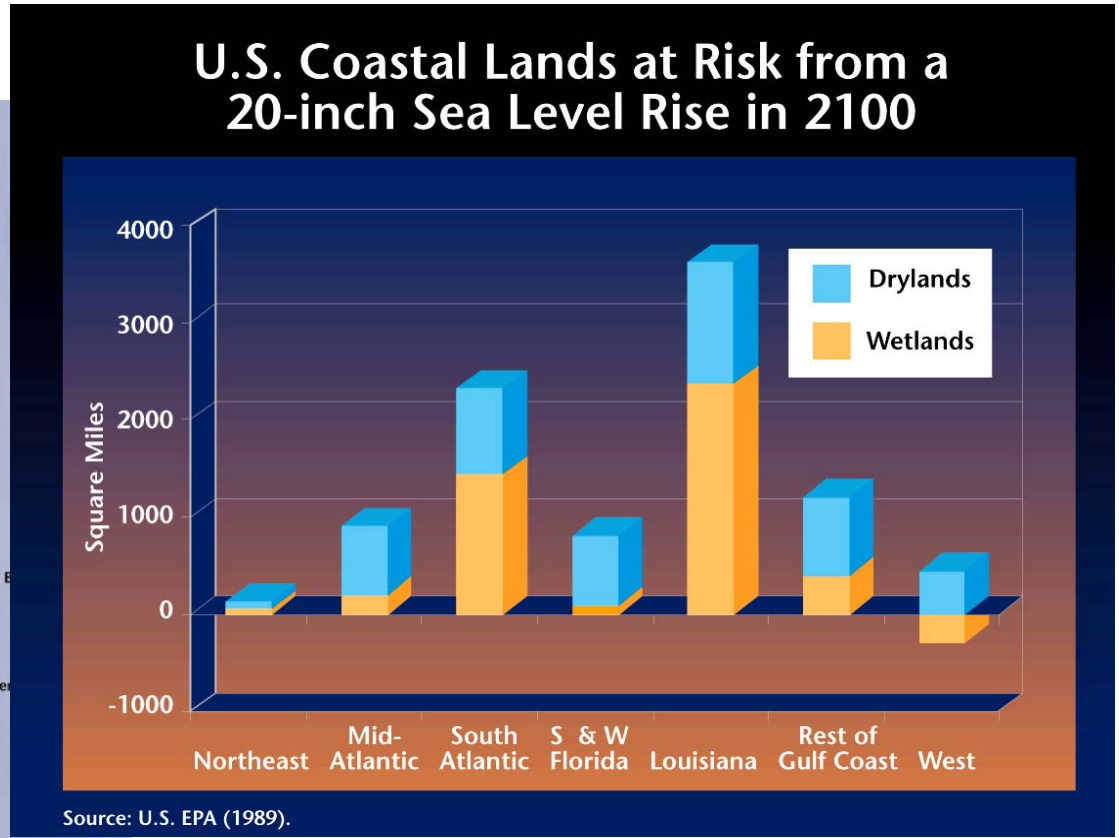
Sea level rise





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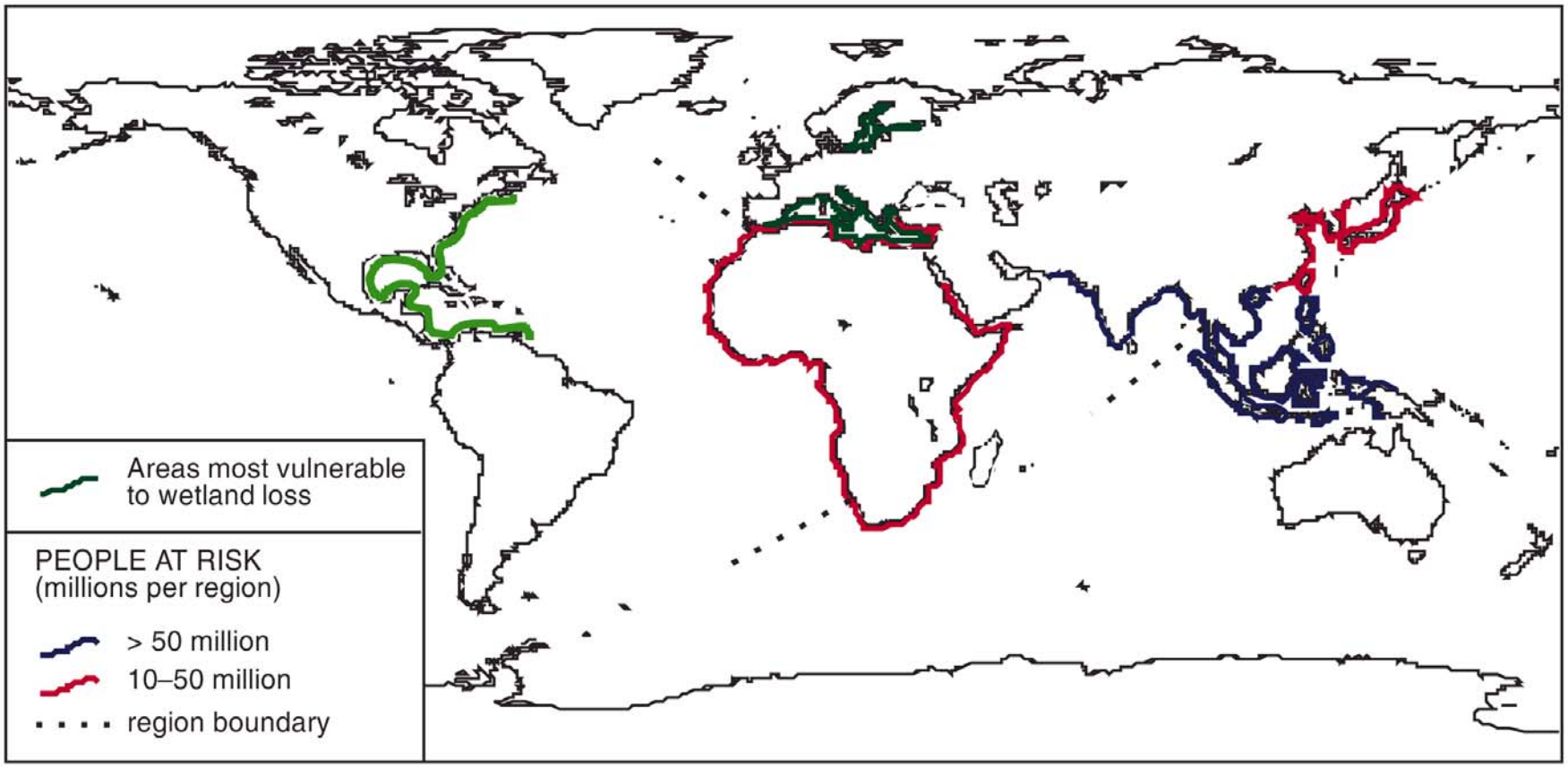
People at Risk from a 44 cm sea-level rise by the 2080s

(Assuming 1990s Level of Flood Protection)



Source: IPCC TAR.

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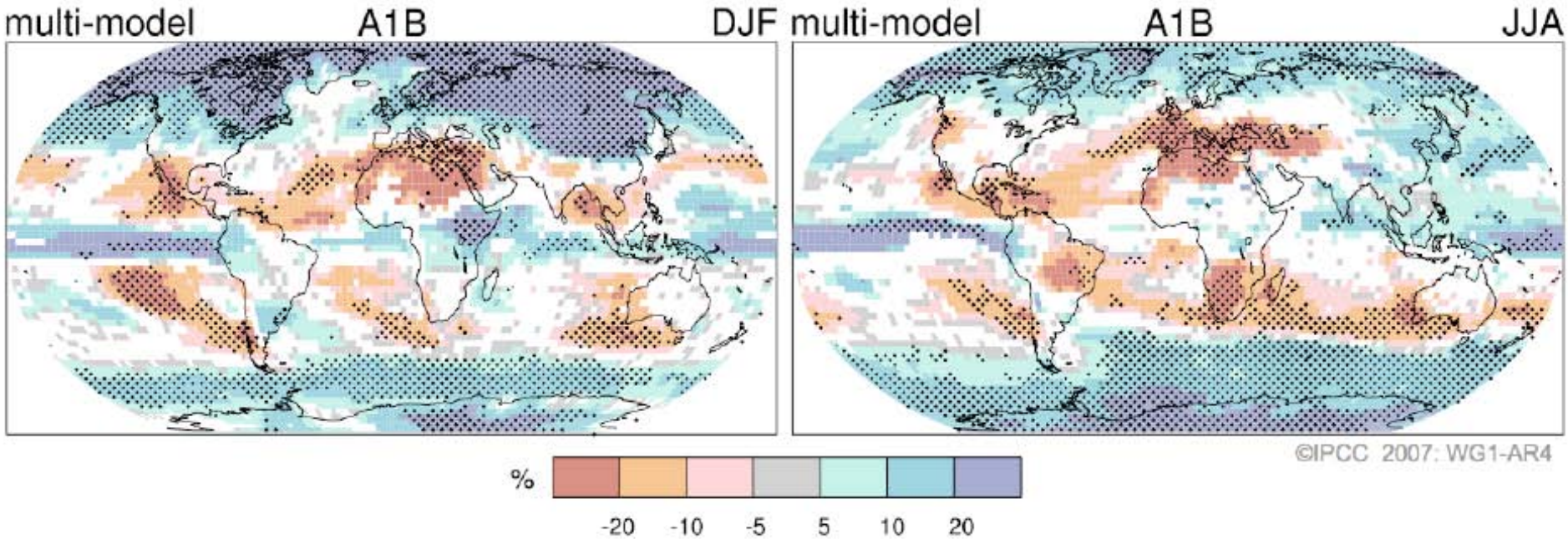
Projected Precipitation Changes

(% Change1980-99 vs. 2090-99)



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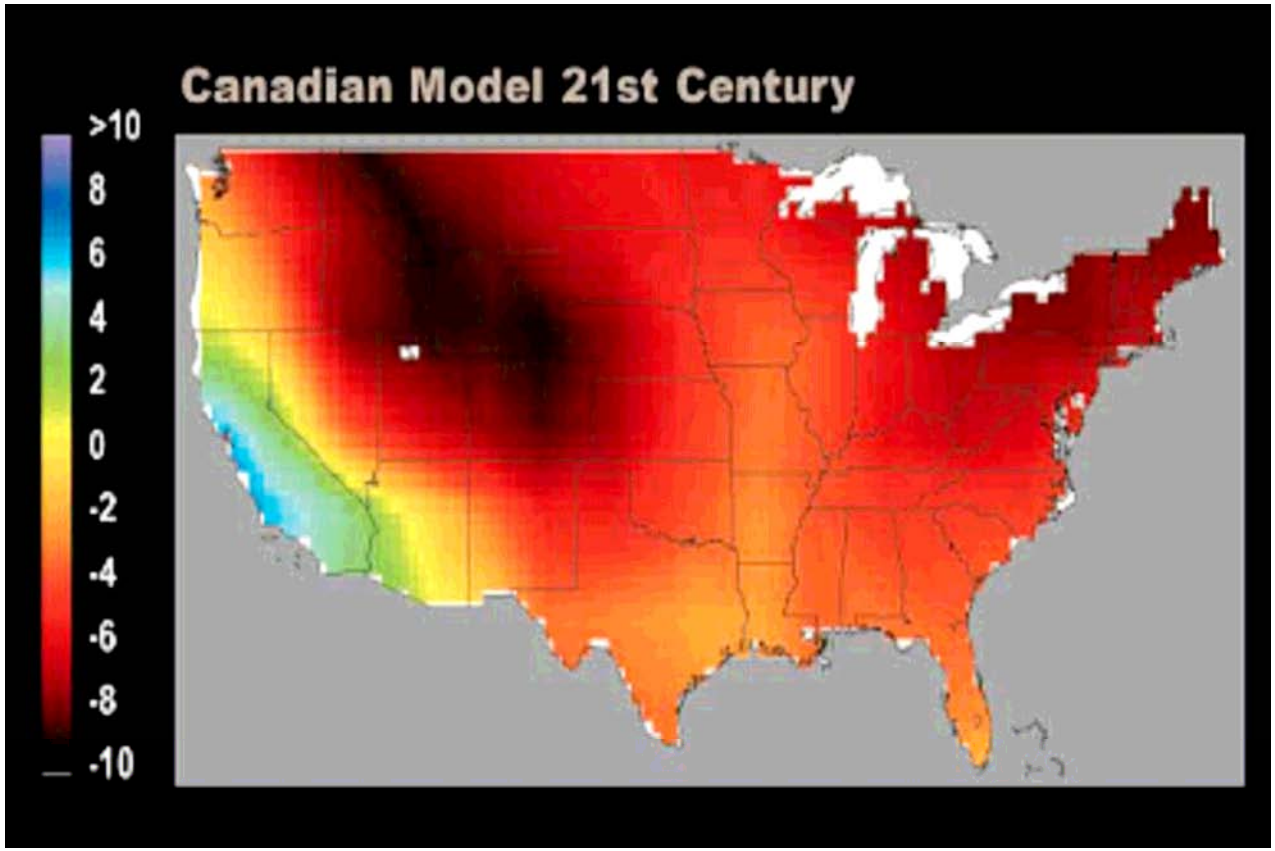
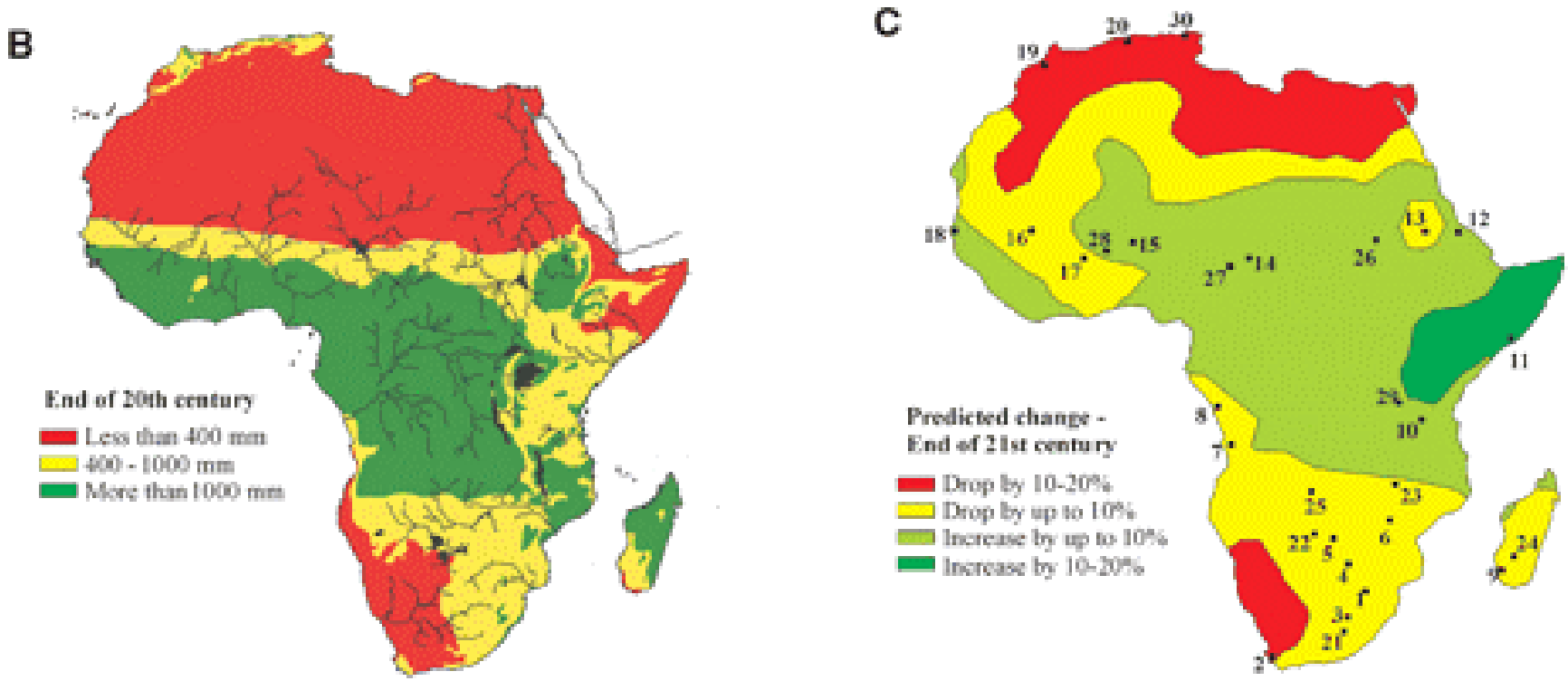
Drought Expectations



The Palmer Index is most effective in determining long term drought—a matter of several months—and is not as good with short-term forecasts (a matter of weeks). It uses a 0 as normal, and drought is shown in terms of minus numbers; for example, minus 2 is moderate drought, minus 3 is severe drought, and minus 4 is extreme drought.

WRI

Changes in available water



Source: Maarten de Wit and Jacek Stankiewicz, *Science* 31 March 2006,
http://www.sciencemag.org/cgi/content/figsonly/311/5769/1917

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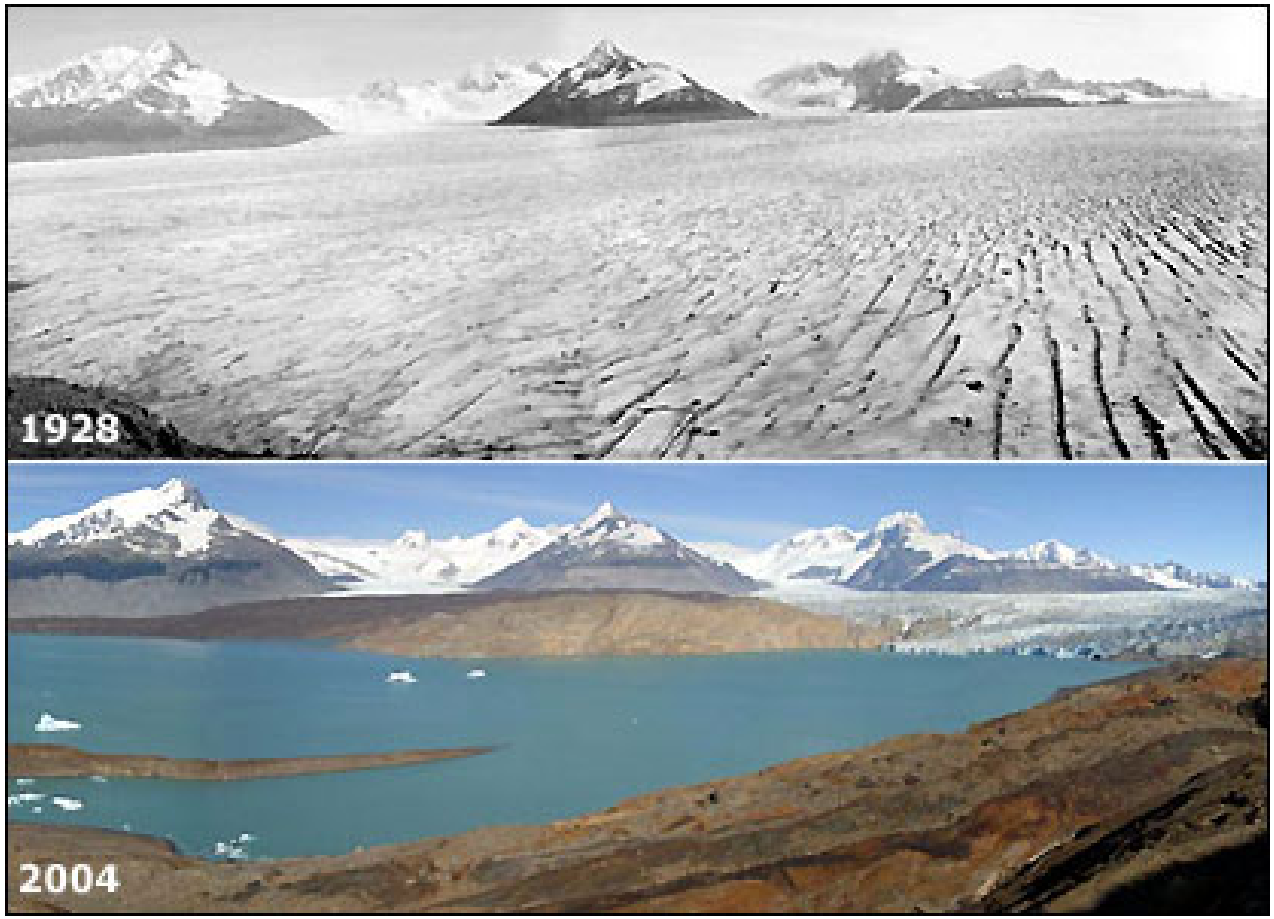
Andean Glaciers

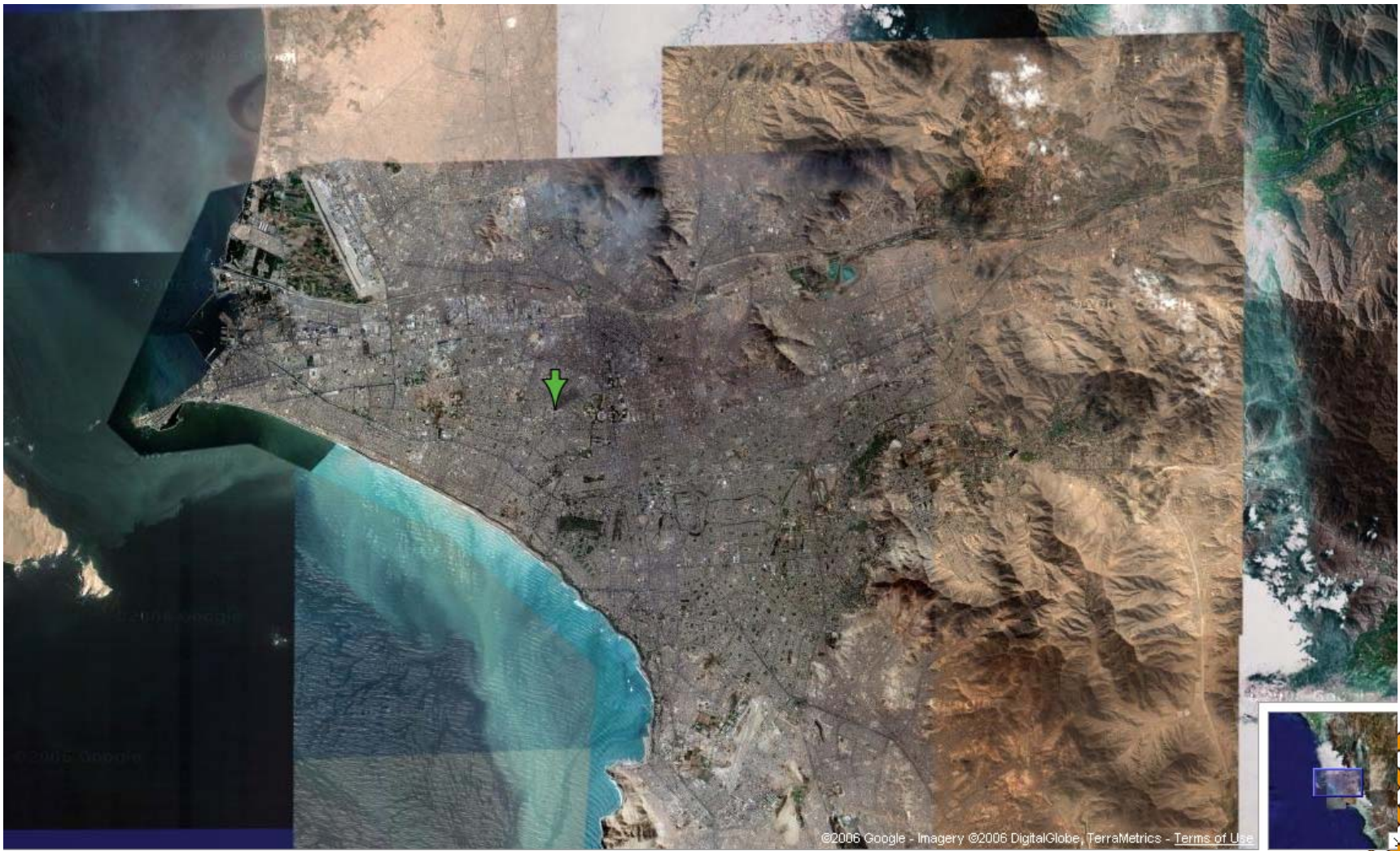


Source: http://news.bbc.co.uk/1/shared/spl/hi/picture_gallery/05/sci_nat_how_the_world_is_changing/html/1.stm

WRI

Lima, Peru

(population ~7 million, 50 mm/yr rainfall)



WRI

Water Supplies

- **Threats to Water Supplies in the Tropical Andes, Raymond S. Bradley, Mathias Vuille, Henry F. Diaz, Walter Vergara, Science, 23 June 2006**
  - http://www.sciencemag.org/cgi/content/summary/312/5781/1755?maxtoshow=&HITS=10&hits=10&RESULTFORMAT=&fulltext=andes&searchid=1&FIRSTINDEX=0&issue=5781&resourcetype=HWCIT
- Climate models predict that greenhouse warming will cause temperatures to rise faster at higher than at lower altitudes. In the tropical Andes, glaciers may soon disappear, with potentially grave consequences for water supplies.

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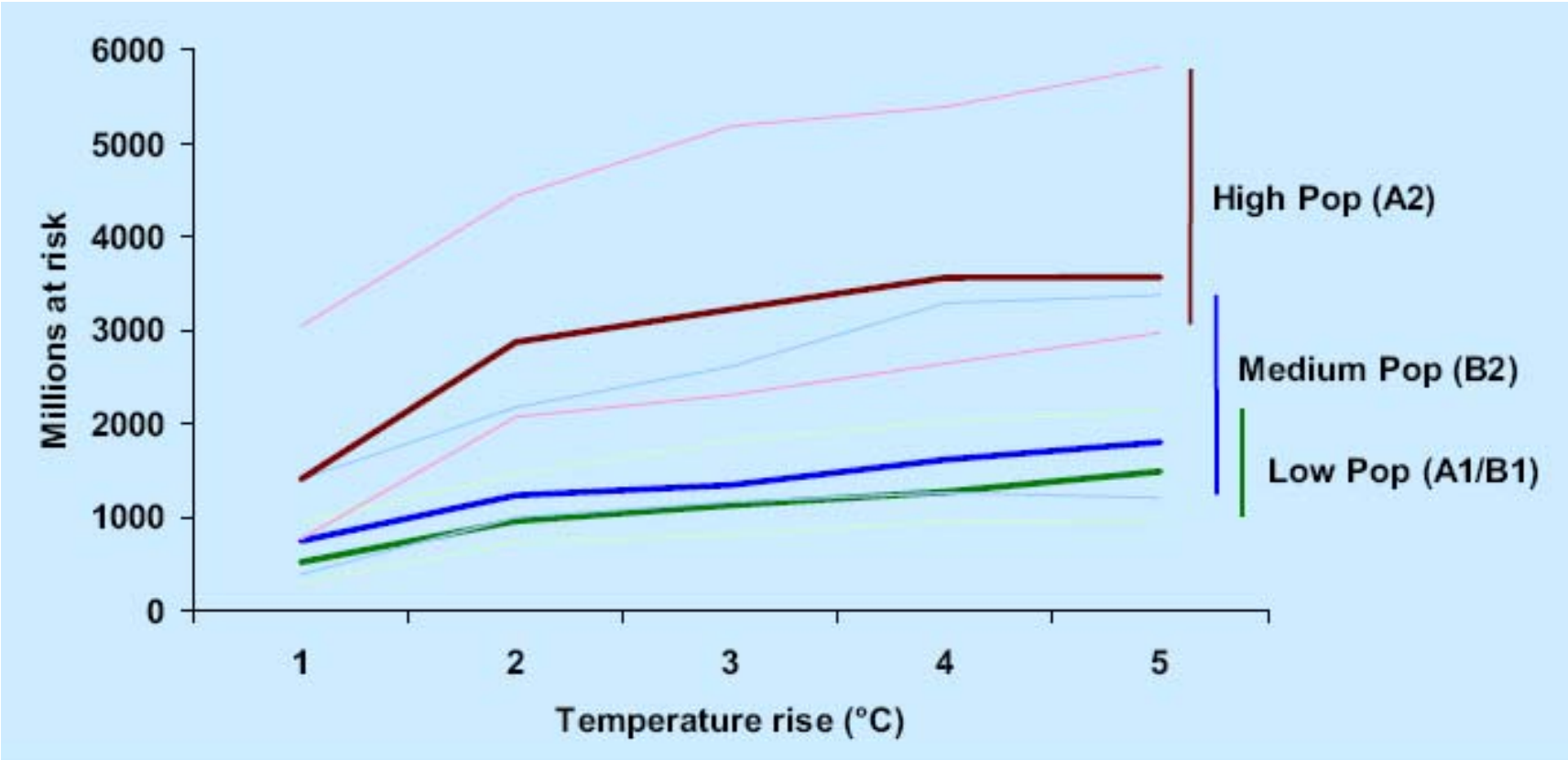
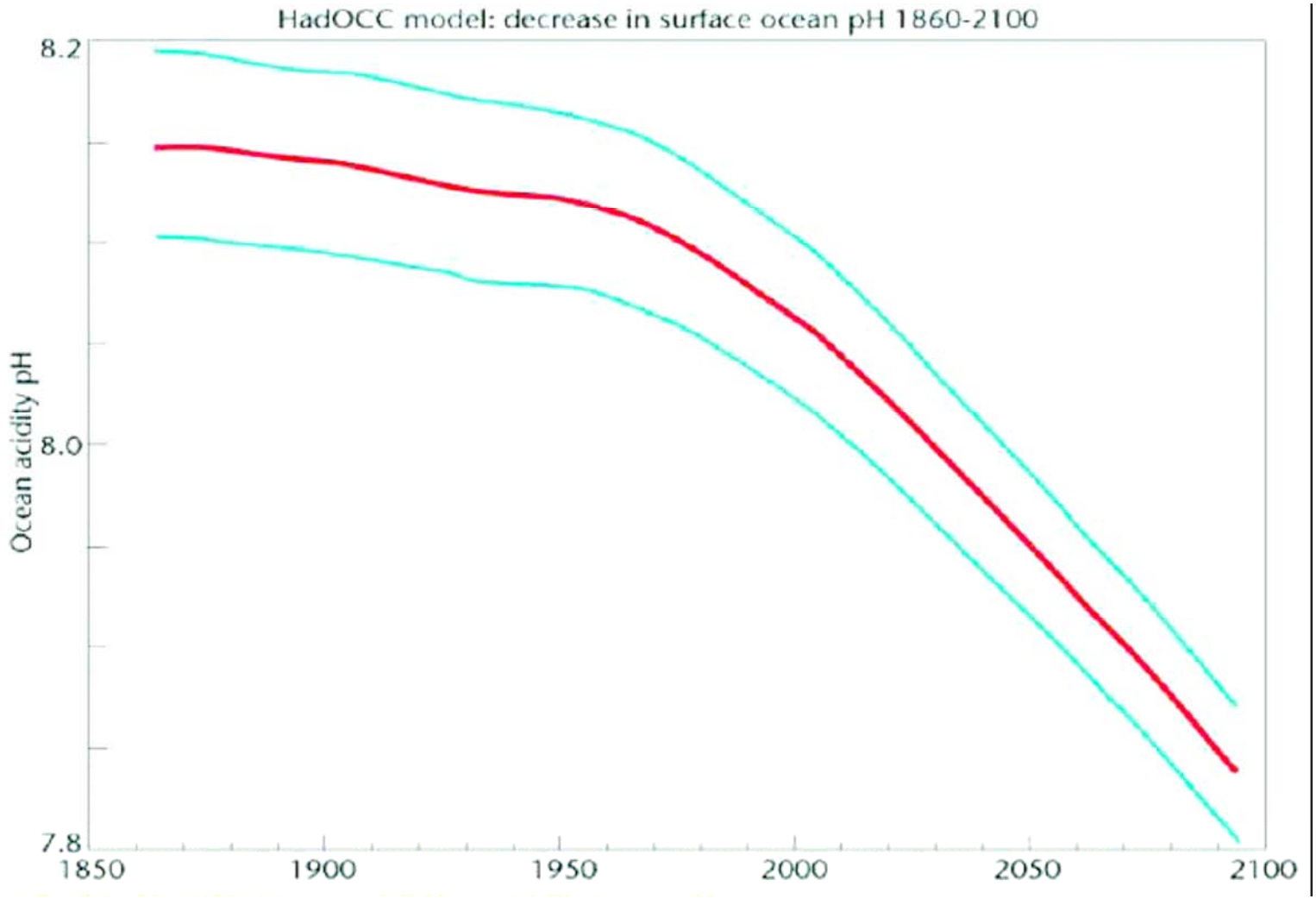
Population at Risk from Water Scarcity



Source: Stern Report, 2006

WRI

Ocean Acidification



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Vector (insect)-borne Diseases

Disease	*Vector*	*Population at risk (millions)*	*Present distribution*	*Likelihood of altered distribution with warming*
Malaria	mosquito	2,100	(sub)tropics	✓✓
Schistosomiasis	water snail	600	(sub)tropics	✓✓
Filariasis	mosquito	900	(sub)tropics	✓
Onchocerciasis (river blindness)	black fly	90	Africa/Latin America	✓
African trypanosomiasis (sleeping sickness)	tsetse fly	50	tropical Africa	✓
Dengue	mosquito	unavailable	tropics	✓✓
Yellow fever	mosquito	unavailable	tropical South America & Africa	✓

Likely ✓
Very likely ✓✓

Source: IPCC TAR

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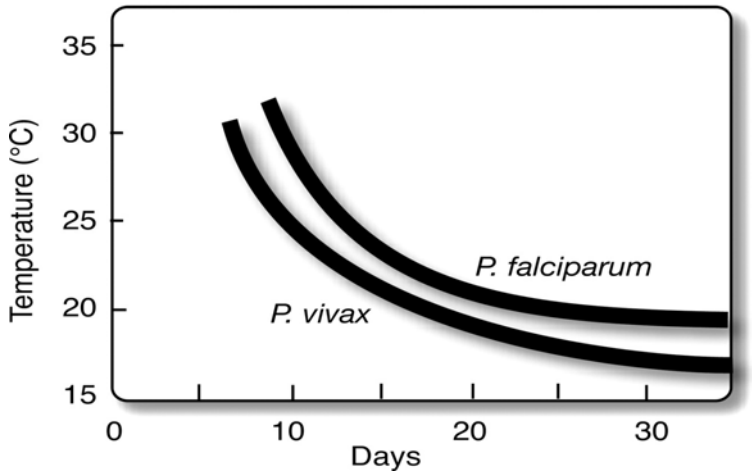
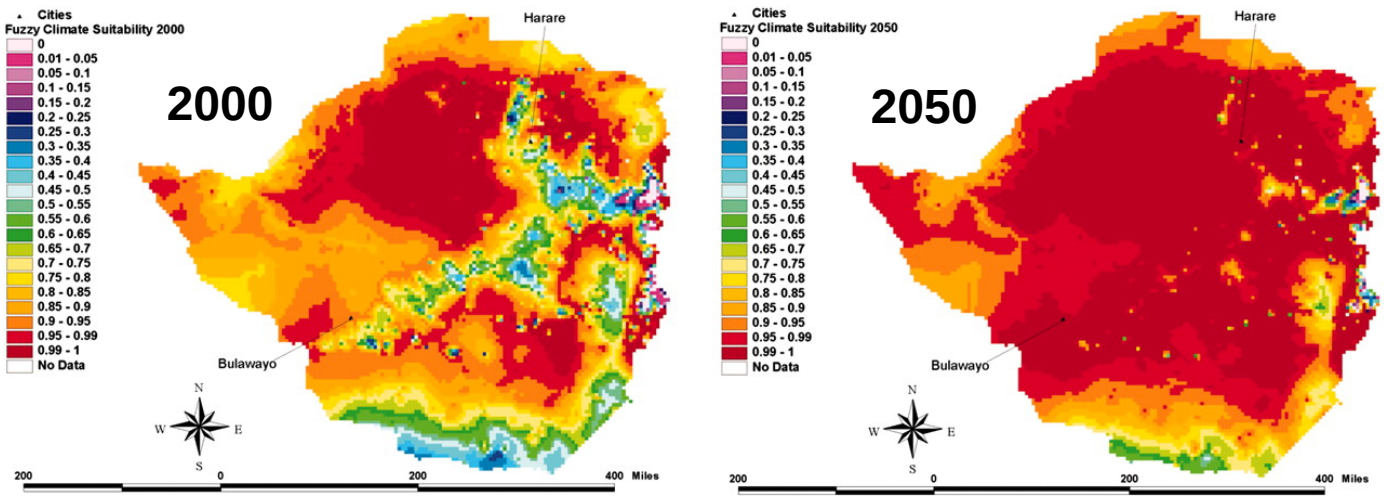
Malaria and Climate



Relationship between temperature and malaria parasite development time

Climate suitability for stable malaria transmission across the diverse topography of Zimbabwe, determined by fuzzy logic analysis and based on United Kingdom Meteorological Office (UKMO) global climate scenarios



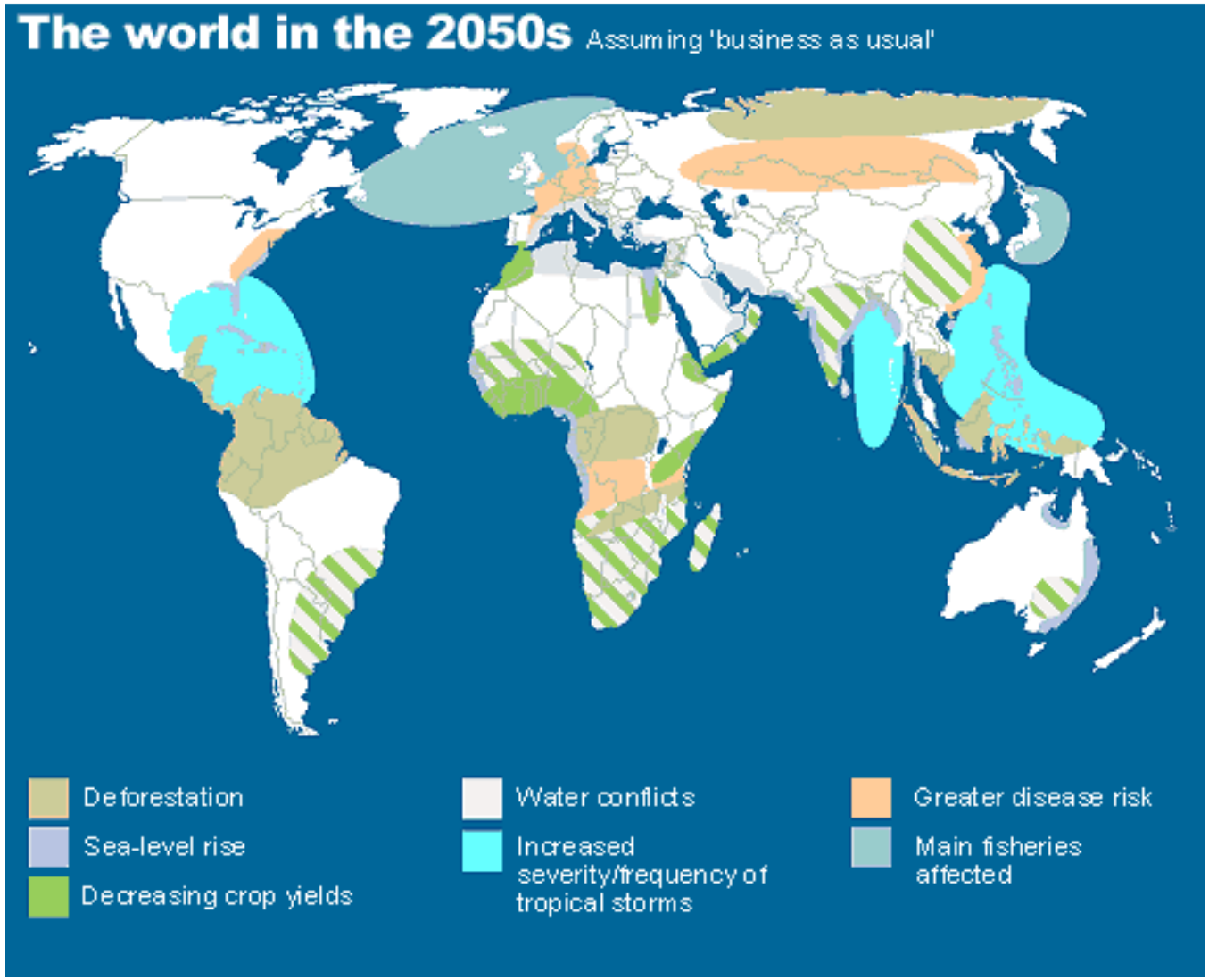
Source: Patz, Jonathan A. and Olson, Sarah H. (2006) Proc. Natl. Acad. Sci. USA 103, 5635-5636

Extinctions and Climate

- **Widespread amphibian extinctions from epidemic disease driven by global warming:** Pounds et al, Science, 2006
- Seventeen years ago, in the mountains of Costa Rica, the Monteverde harlequin frog vanished along with the golden toad. A pathogenic chytrid fungus is implicated.
- Analyzing the timing of losses in relation to changes in sea surface and air temperatures, the study concludes with 'very high confidence' (> 99%) that large-scale warming is a key factor in the disappearances.
- Temperatures at many highland localities are shifting towards the growth optimum of the fungus, thus encouraging outbreaks.

WRI

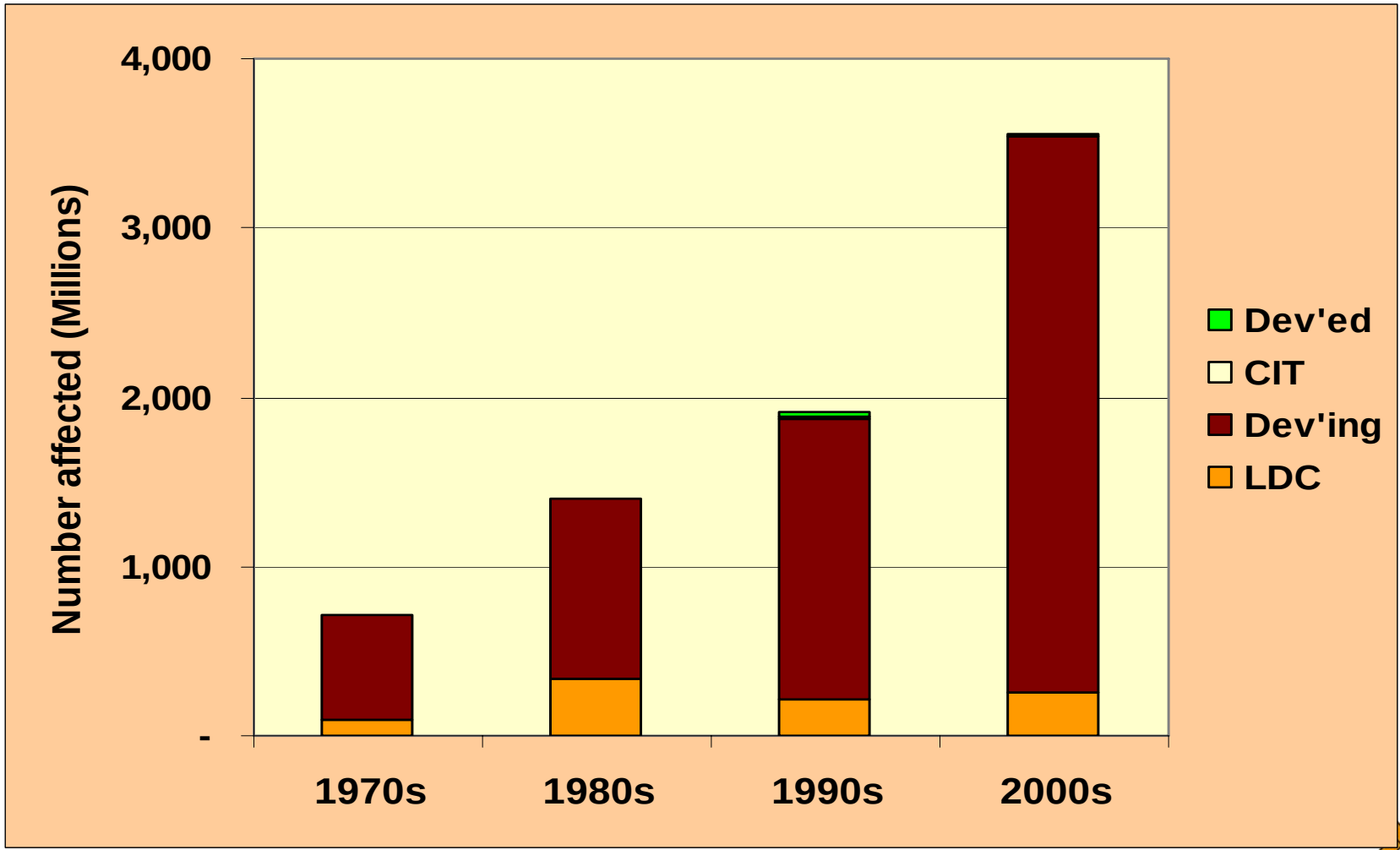
Scenario of damages in 2050



Source: The Guardian, based on Pentagon report

WRI

Most Impacts Will Be Felt in Developing Countries



Source: UK Embassy, based on World bank data

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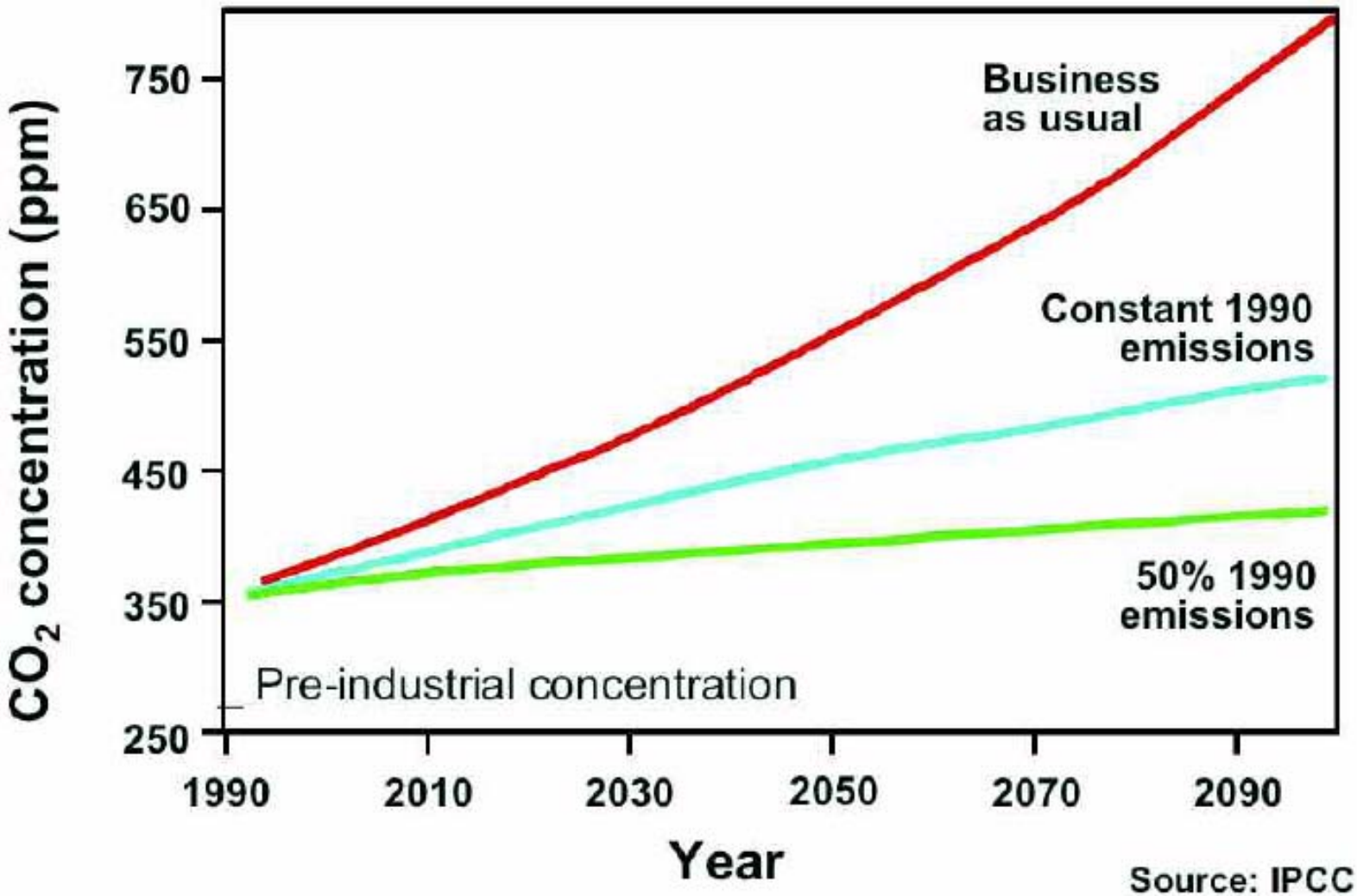
Stabilizing Concentrations Requires Stabilizing Emissions



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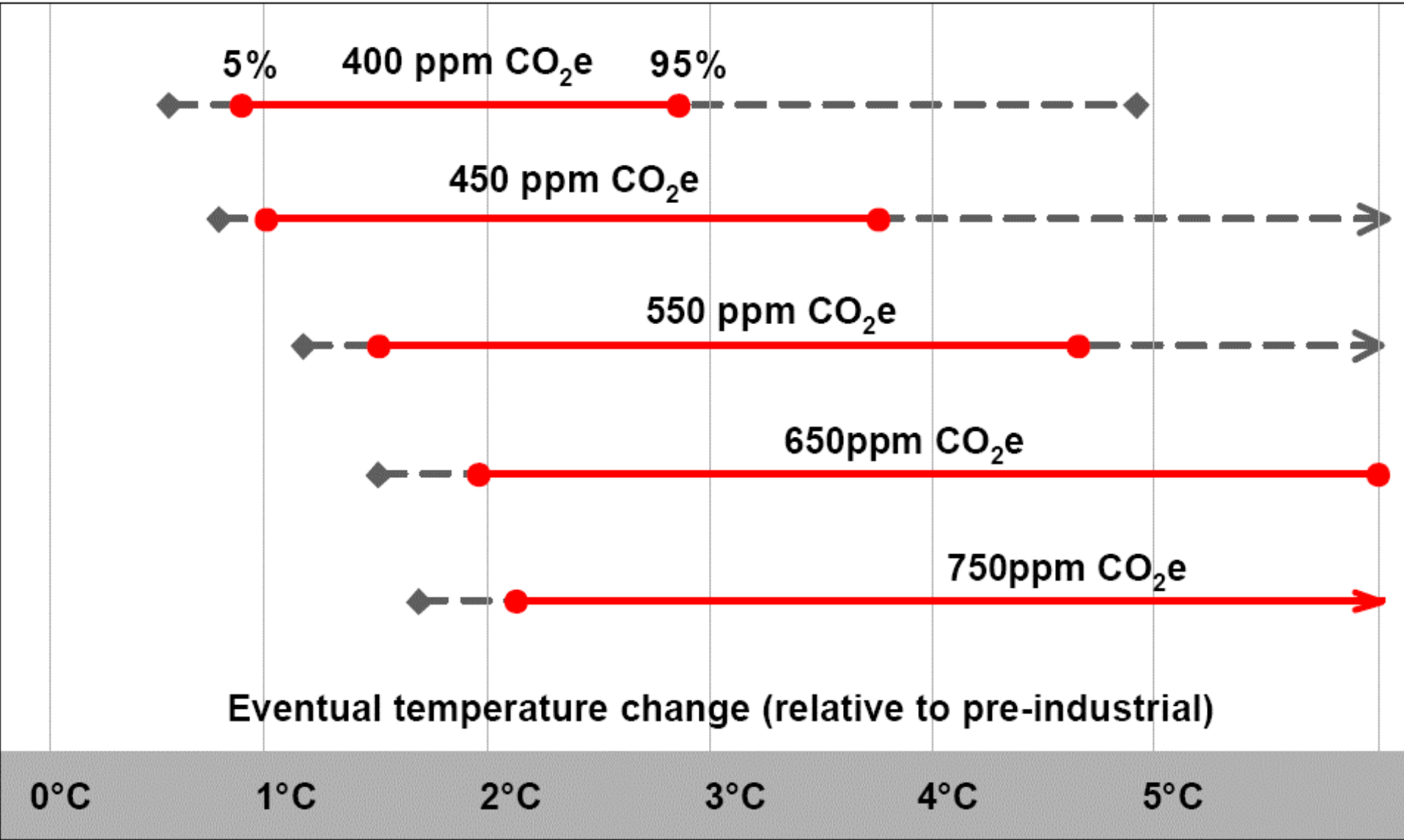
Avoiding Damages Requires Limiting Concentrations



The emissions space for stabilising CO_2 concentrations

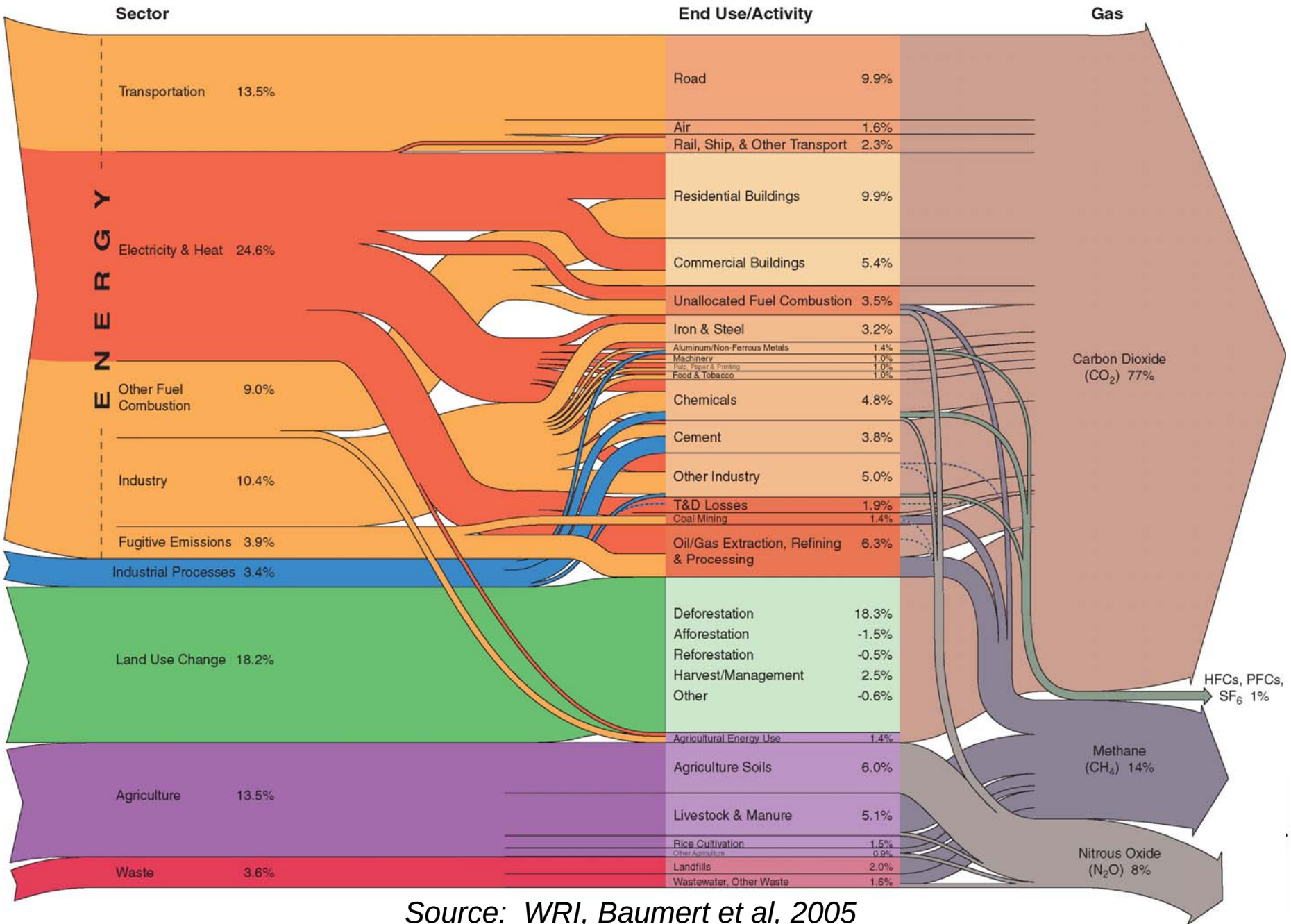
WRE CO_2 Stabilisation profiles	**Year in which global emissions peak**
450	2005 – 2015
550	2020 – 2030
650	2030 – 2045
750	2040 – 2060
1000	2065 – 2090

Source: IPCC-TAR Synthesis Report

Emissions: Where do they come from?

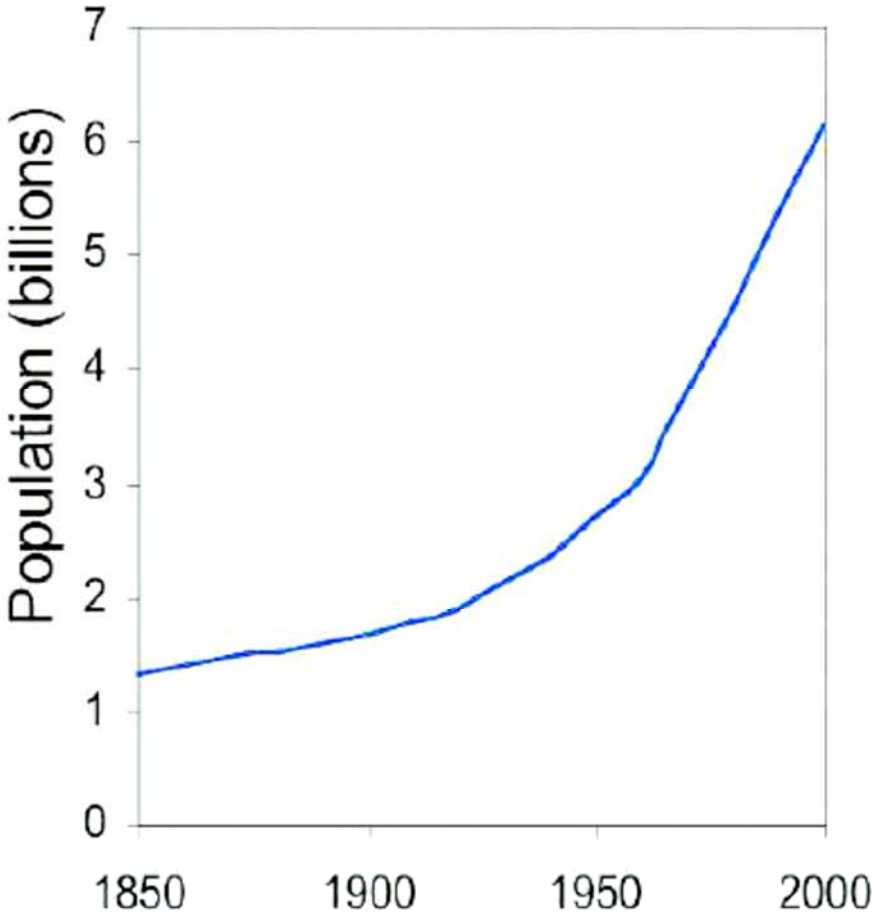
WRI

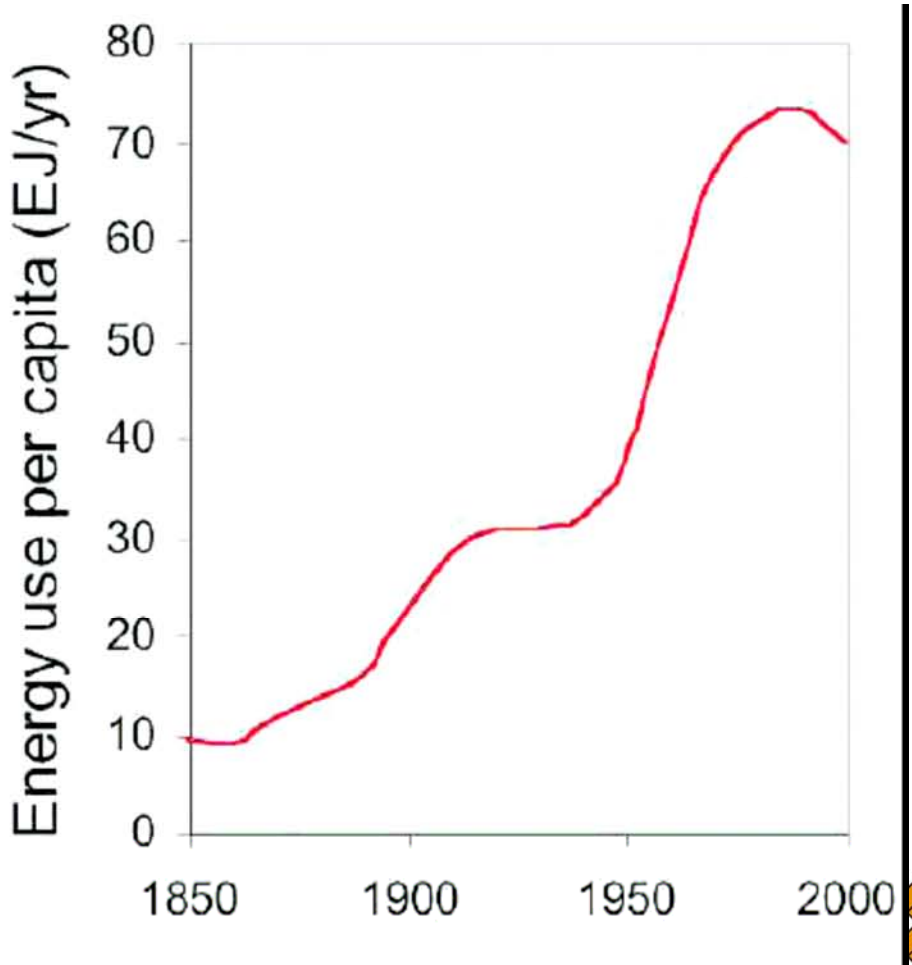
GHG Flow Diagram: Global Emissions



Source: WRI, Baumert et al, 2005

Population and Energy Use: Key Emission Drivers

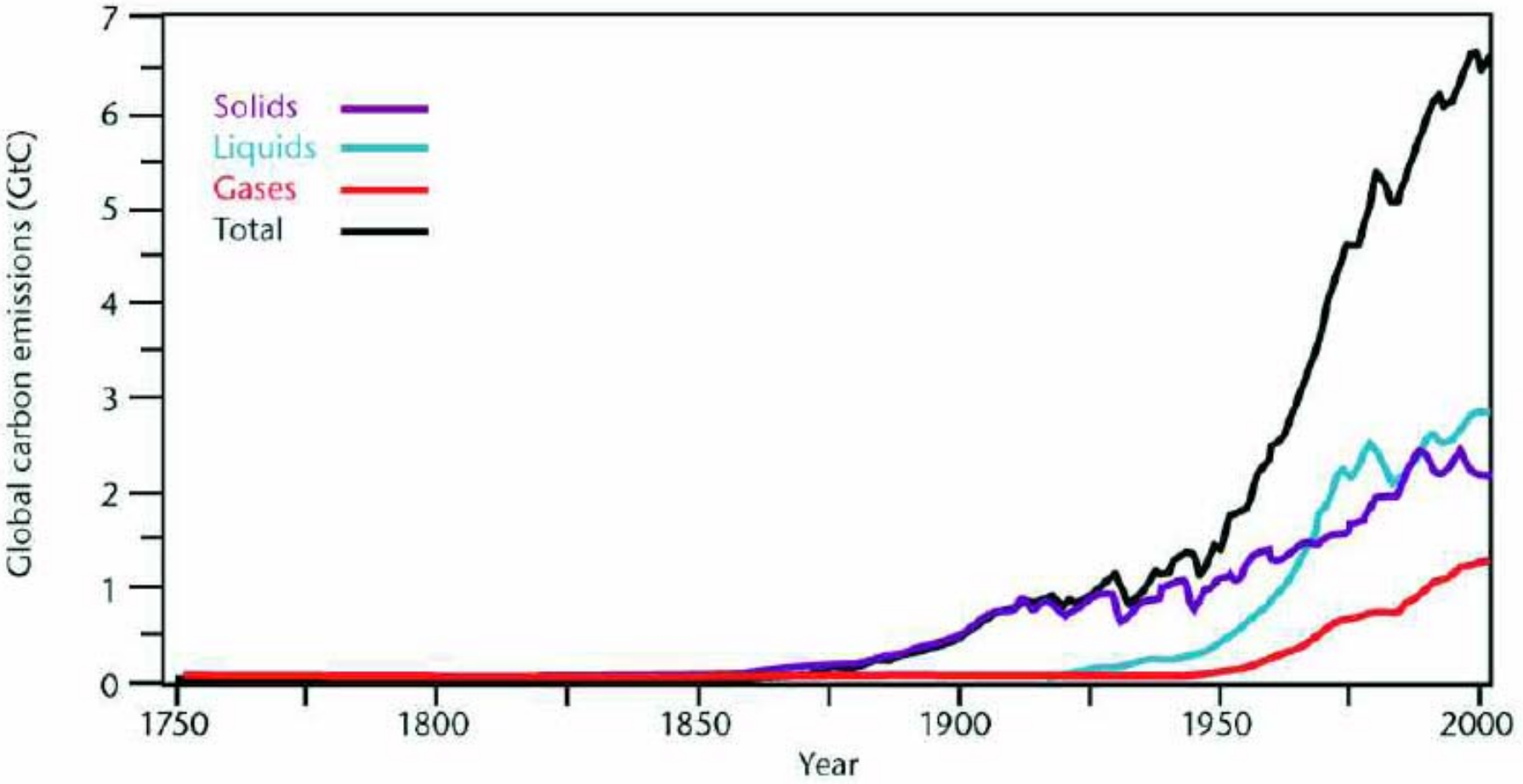




Source: UK Hadley Center, 2007

WRI

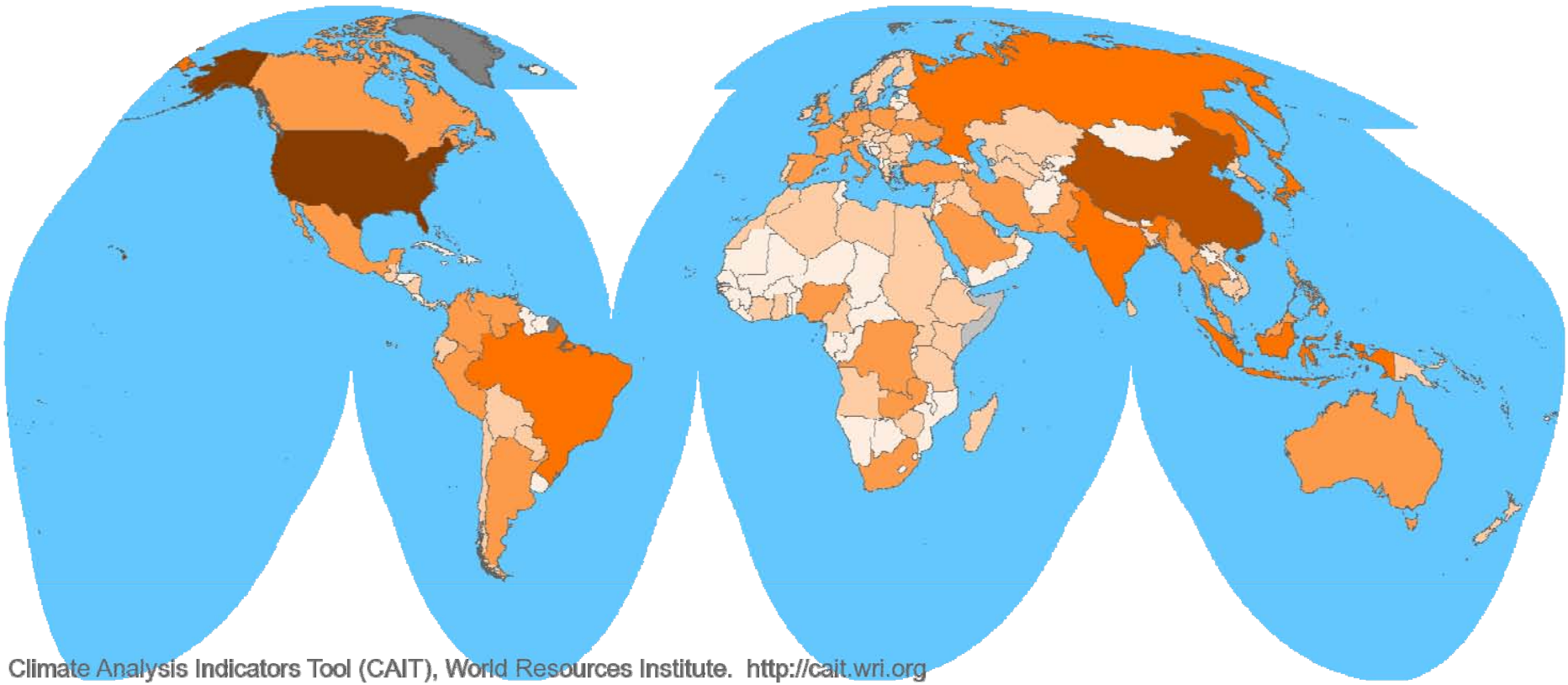
Fossil Fuels are the Primary Source of Global Carbon Emissions



Source: CDIAC, 2005

WRI

National GHG Emissions, 2000



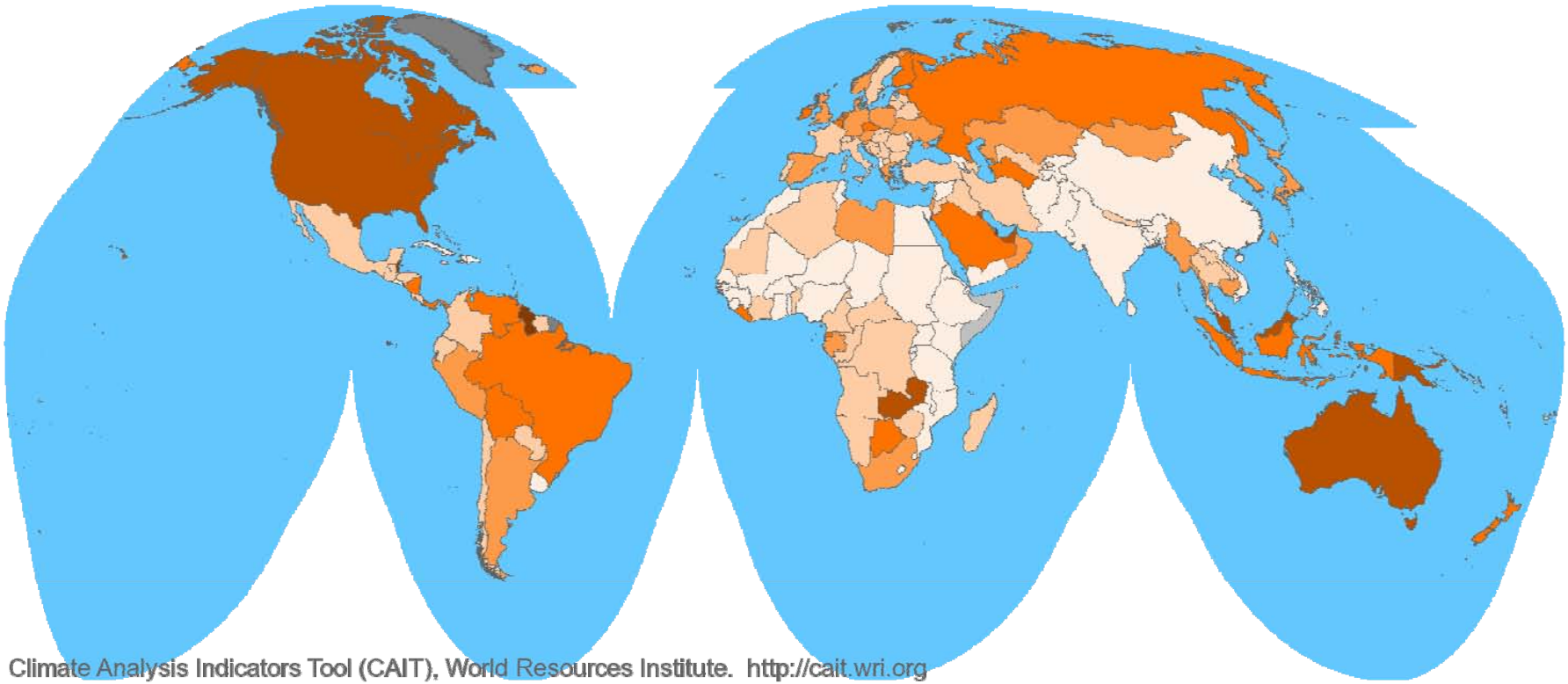
Climate Analysis Indicators Tool (CAIT), World Resources Institute. http://cait.wri.org

Millions Tons CO2 Eq.

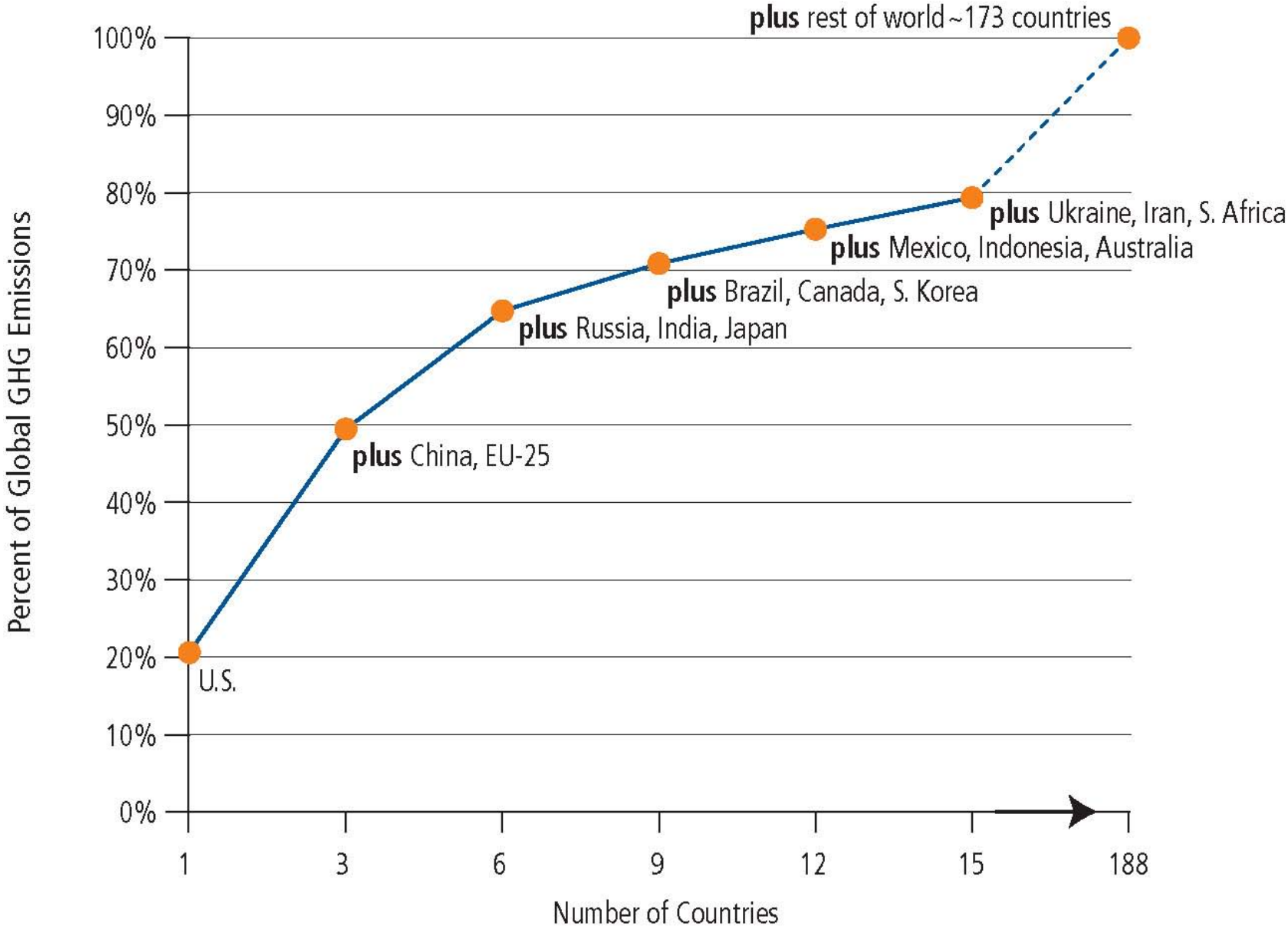
6,525	215 - 1,009	NA	
4,890	47 - 181		
1,321 - 3,066	0 - 44		

WRI

Per Capita Emissions, 2000

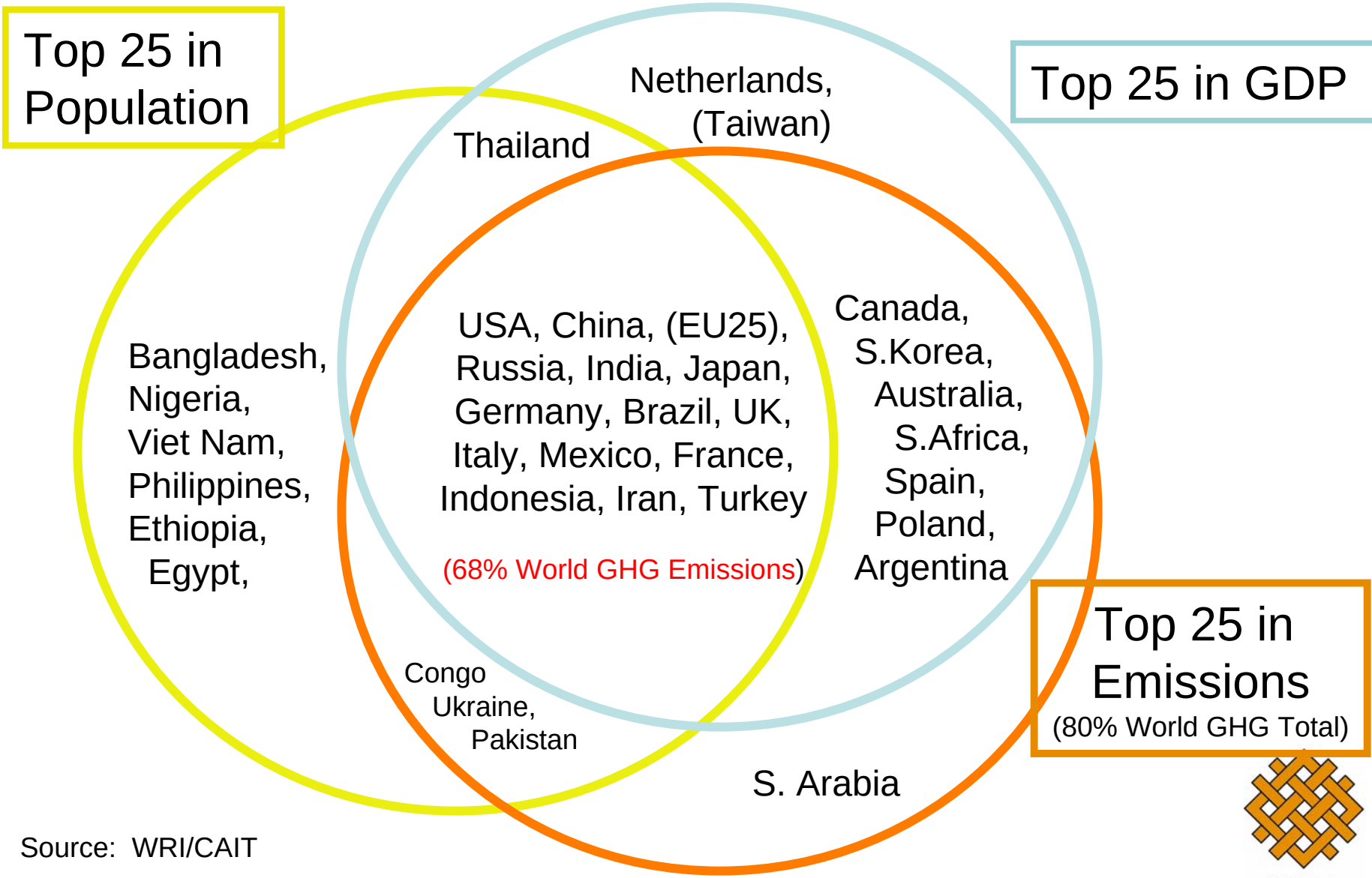


Largest Emitters: *Developed & Developing*



WRI

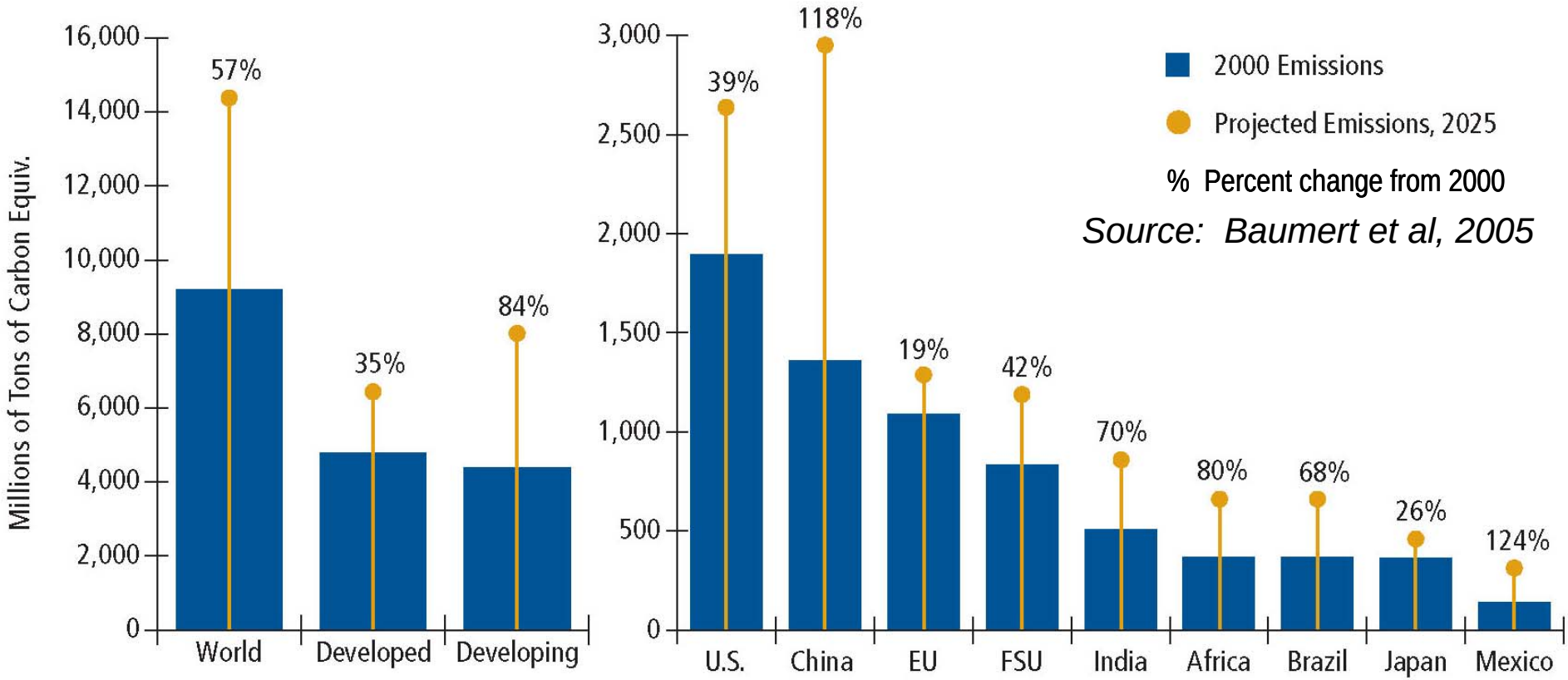
The top 25 overlap



Source: WRI/CAIT

WRI

Projected Future GHG Emissions Growth



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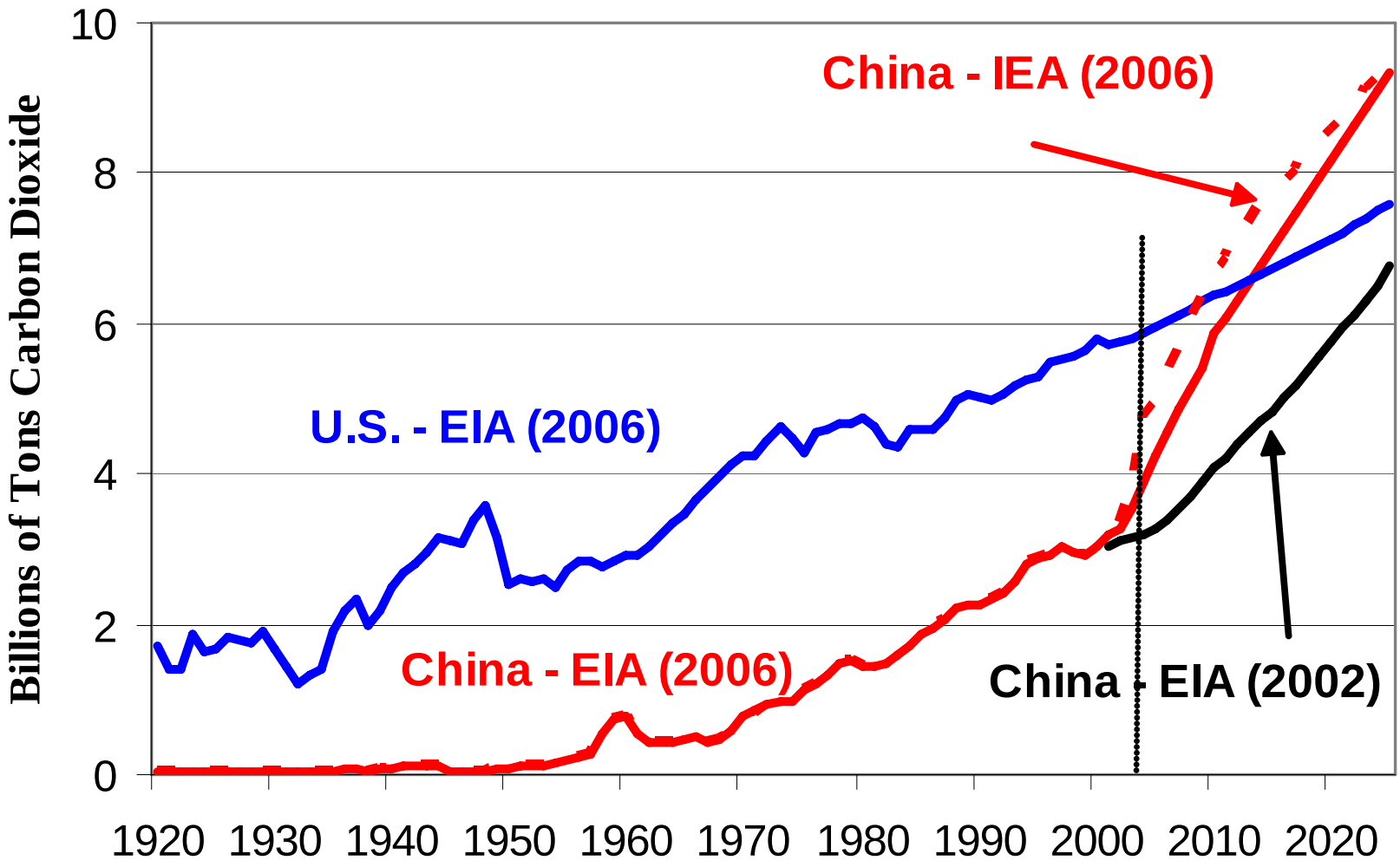
China to Surpass U.S. by 2010



…but cumulative emissions from 1920-2025 will be only 60% as large

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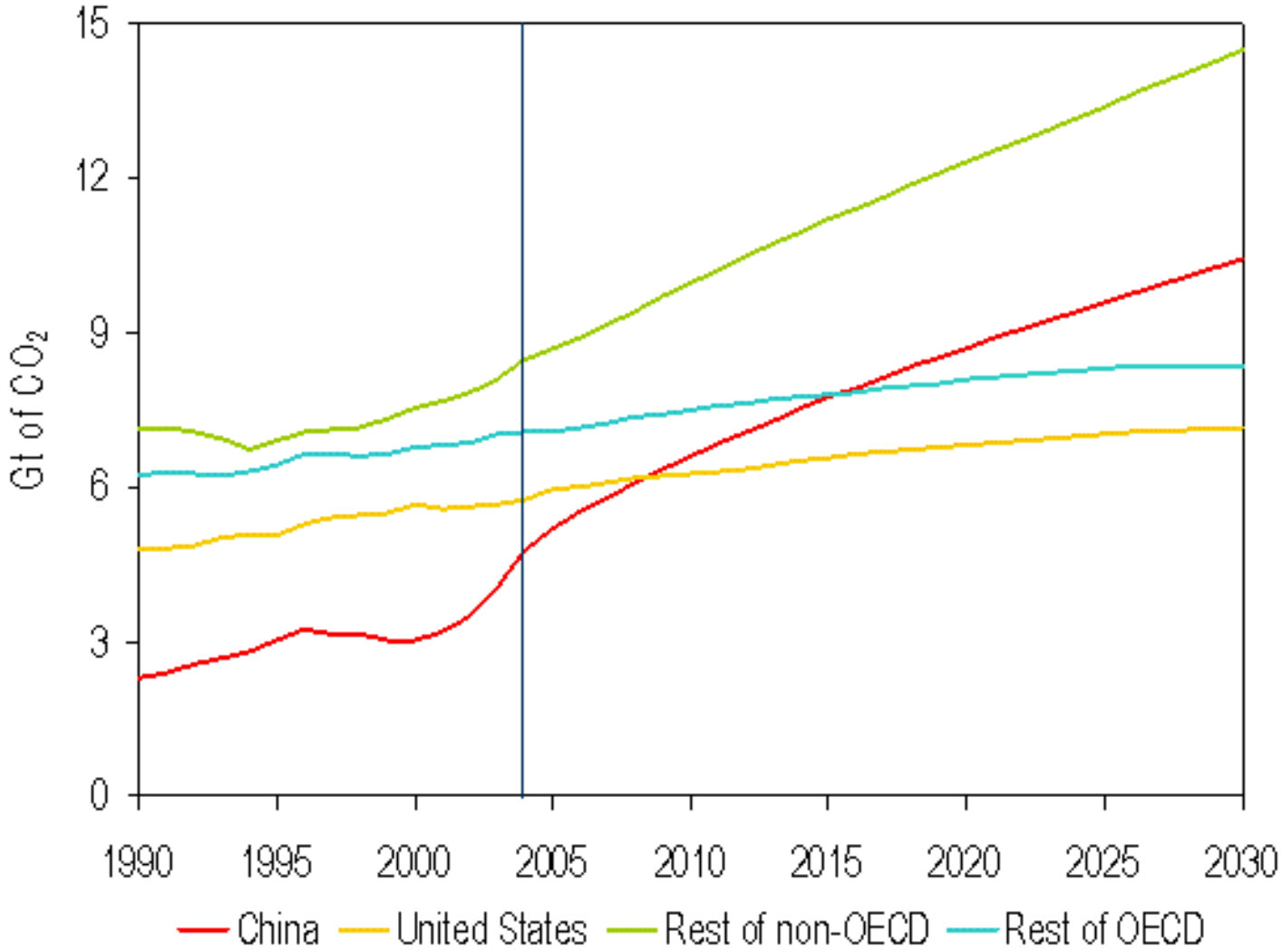
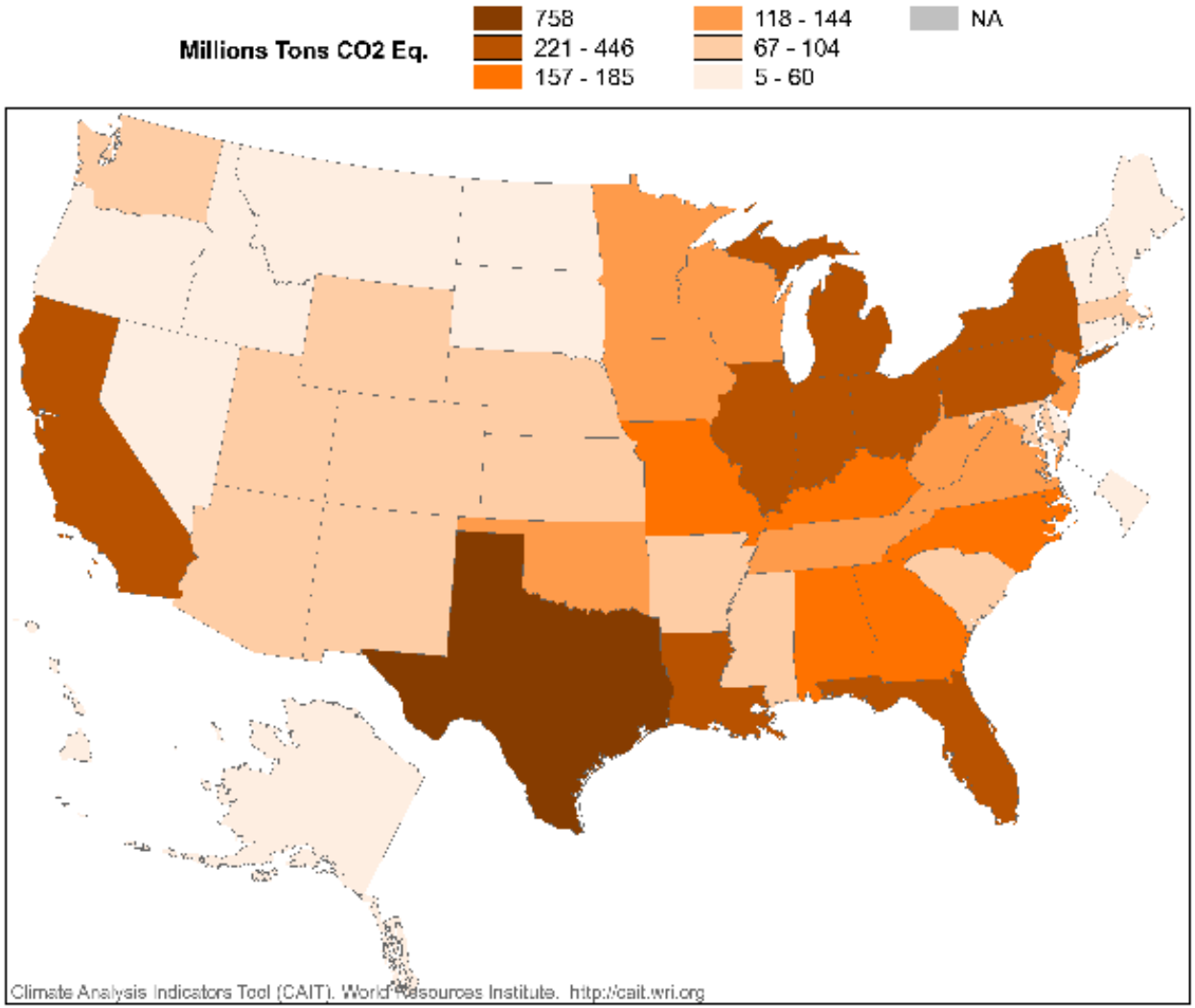
CO_2 Emissions Trends 2005 - 2030



Source: IEA WEO, 2006

WRI

US GHG Emissions



WRI

Summary

- The science is real
  - While there are questions, the basic understanding of the climate system is not in dispute
- Warming is occurring, and without significant changes in emissions will continue
- Emissions from fossil fuels and other GHGs are rising
  - US is still number 1, but not for long

WRI