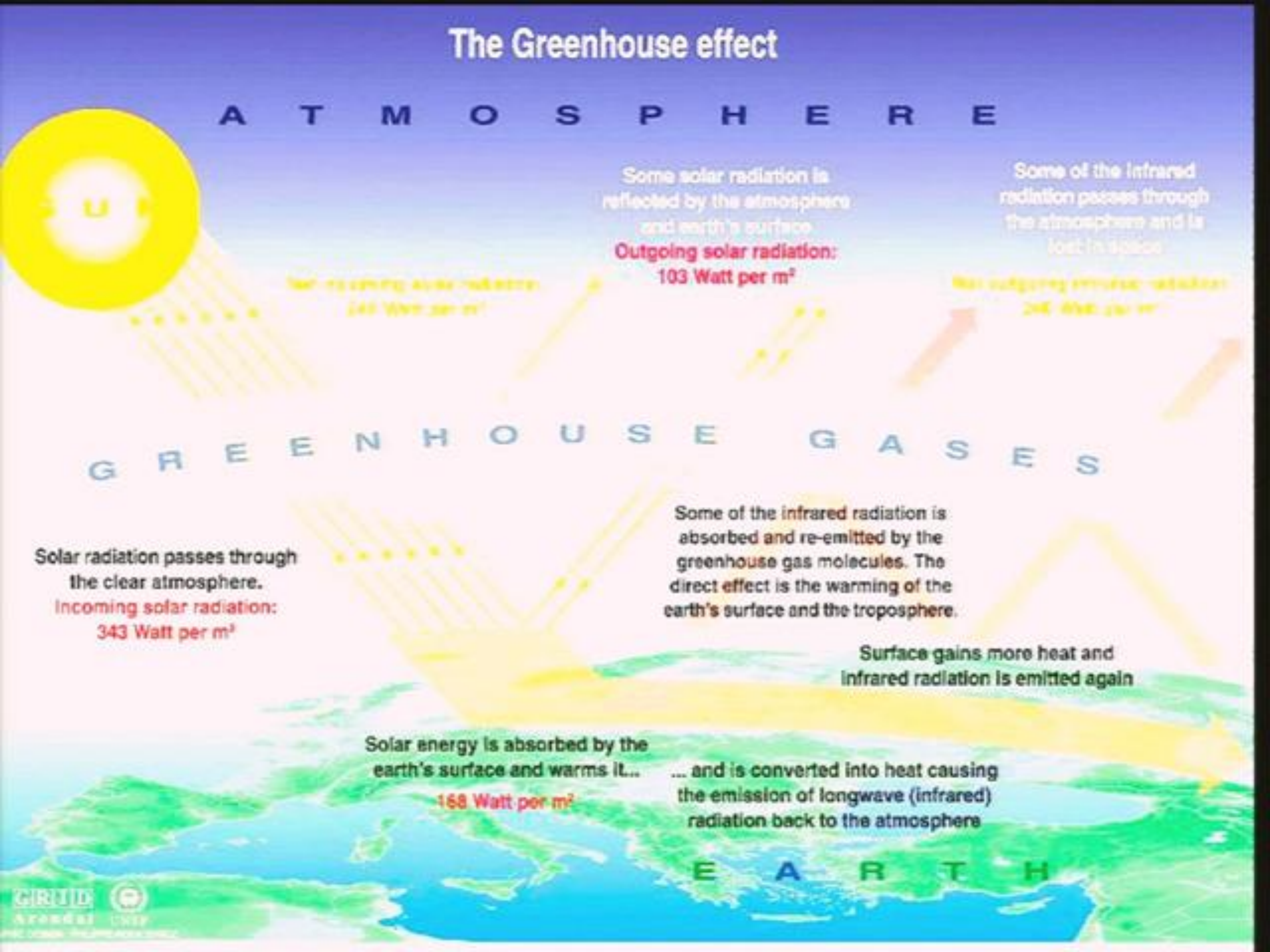
# The science of climate change

# The earth's climate system

- Light from the Sun is absorbed by land and water and converted to heat
- Some heat is emitted back into space as radiant heat, just as heat is radiated from hot pavement on a July day
- Some of this radiant heat is absorbed by water vapor and clouds, carbon dioxide, methane, nitrous oxide and other trace atmospheric gases
- These gases act like glass windows in a car – creating the 'hot car effect'
- Without them…


The Greenhouse effect
ATMOSPHERE
SUN
Some solar radiation is reflected by the atmosphere and earth's surface
Outgoing solar radiation: 103 Watt per m²
Some of the infrared radiation passes through the atmosphere and is lost in space
GREENHOUSE GASES
Solar radiation passes through the clear atmosphere.
Incoming solar radiation: 343 Watt per m²
Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules. The direct effect is the warming of the earth's surface and the troposphere.
Surface gains more heat and infrared radiation is emitted again
Solar energy is absorbed by the earth's surface and warms it...
168 Watt per m²
... and is converted into heat causing the emission of longwave (infrared) radiation back to the atmosphere
EARTH
GRID Arendal

# How do we know this?

- Heat trapping by unknown agents in the atmosphere was first proposed by Fourier in 1827!
- Throughout the $19^{th}$ century, scientists were concerned about the 'radiation balance of the earth'
  - Roentgen
  - Tyndall
  - Maxwell

# The Breakthrough

- Swedish chemist Svante Arhennius calculated in 1896 that the Earth was warmer by ~ 16 deg C than without CO2 – and that a doubling of CO2 would lead to an increase of 5 deg C*
- The current estimate is a doubling would lead to an increase of 1.5 to 4.5 deg C

- Source: 'On the influence of Carbonic Acid in the Air on the Temperature of the Ground." Philosophical Magazine. 1896(41): 237-76

# Early 20th century

- Callendar demonstrated in the 1930s that there seemed to be an increase in temperature records from around the world that were consistent with the increases estimated from CO2!

- His 'theories' were greeted with derision

# Mid 20th century

- 1957: Revelle and Seuss discovered from isotope studies of carbon that much recent CO2 was staying in the atmosphere and not dissolving in the ocean. They concluded: Callendar was right!
- "Human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future." – Revelle

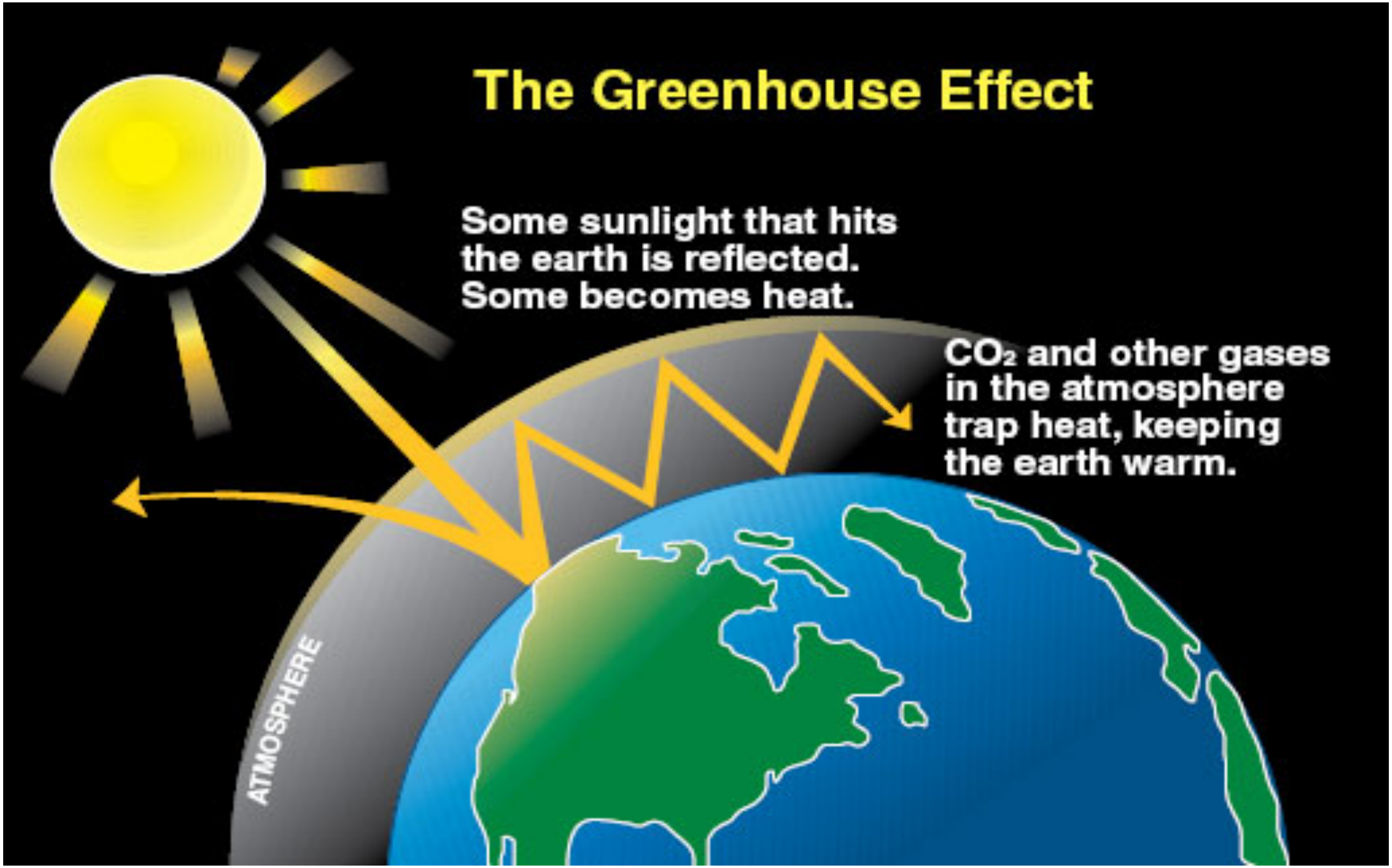
**The one *constant* of climate has been *change* by natural forces.**

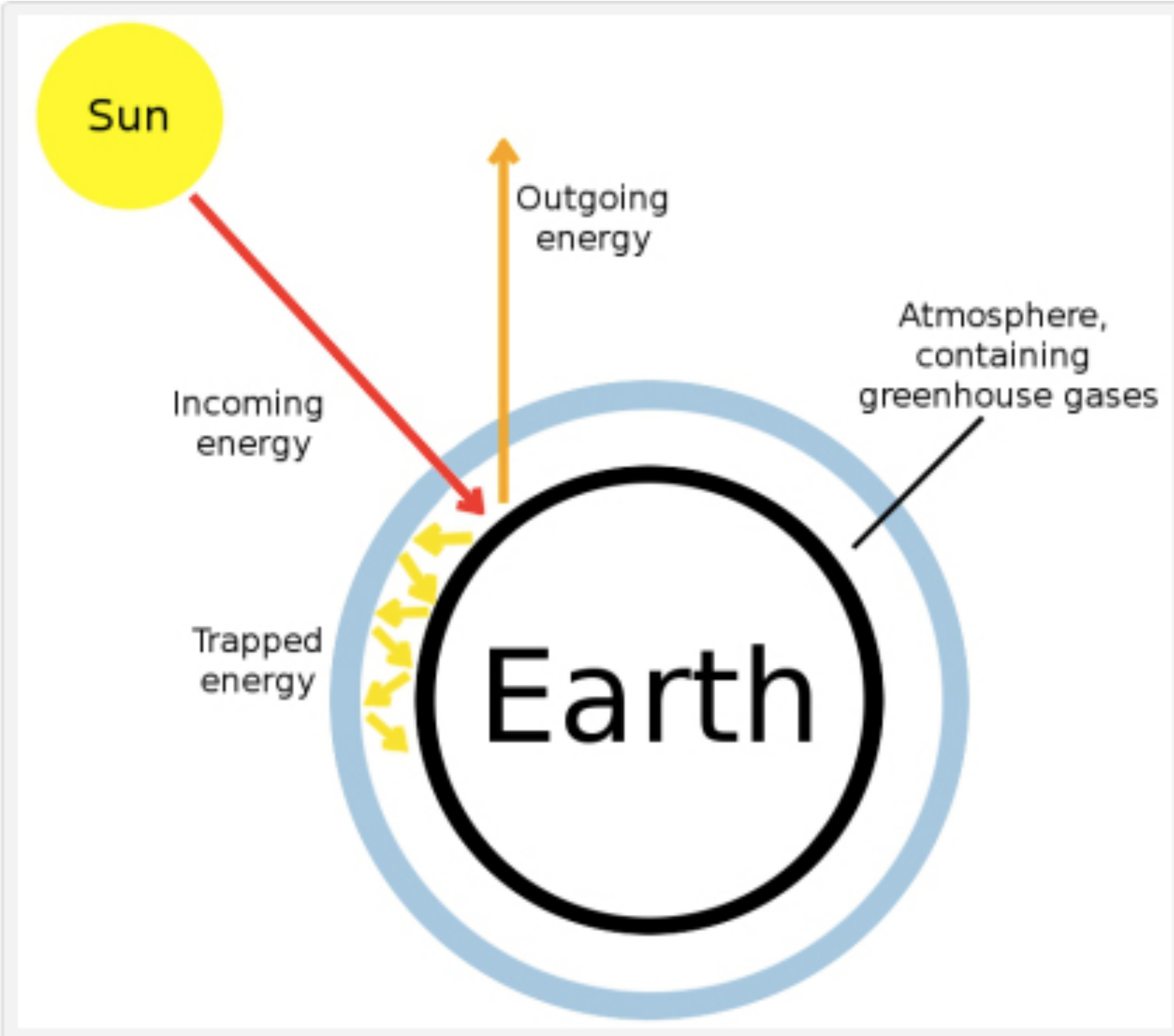
**What is *new* is that *human activities* are altering the composition and size of the atmosphere, the face of the land, and the climate system.**

# Natural climate forces

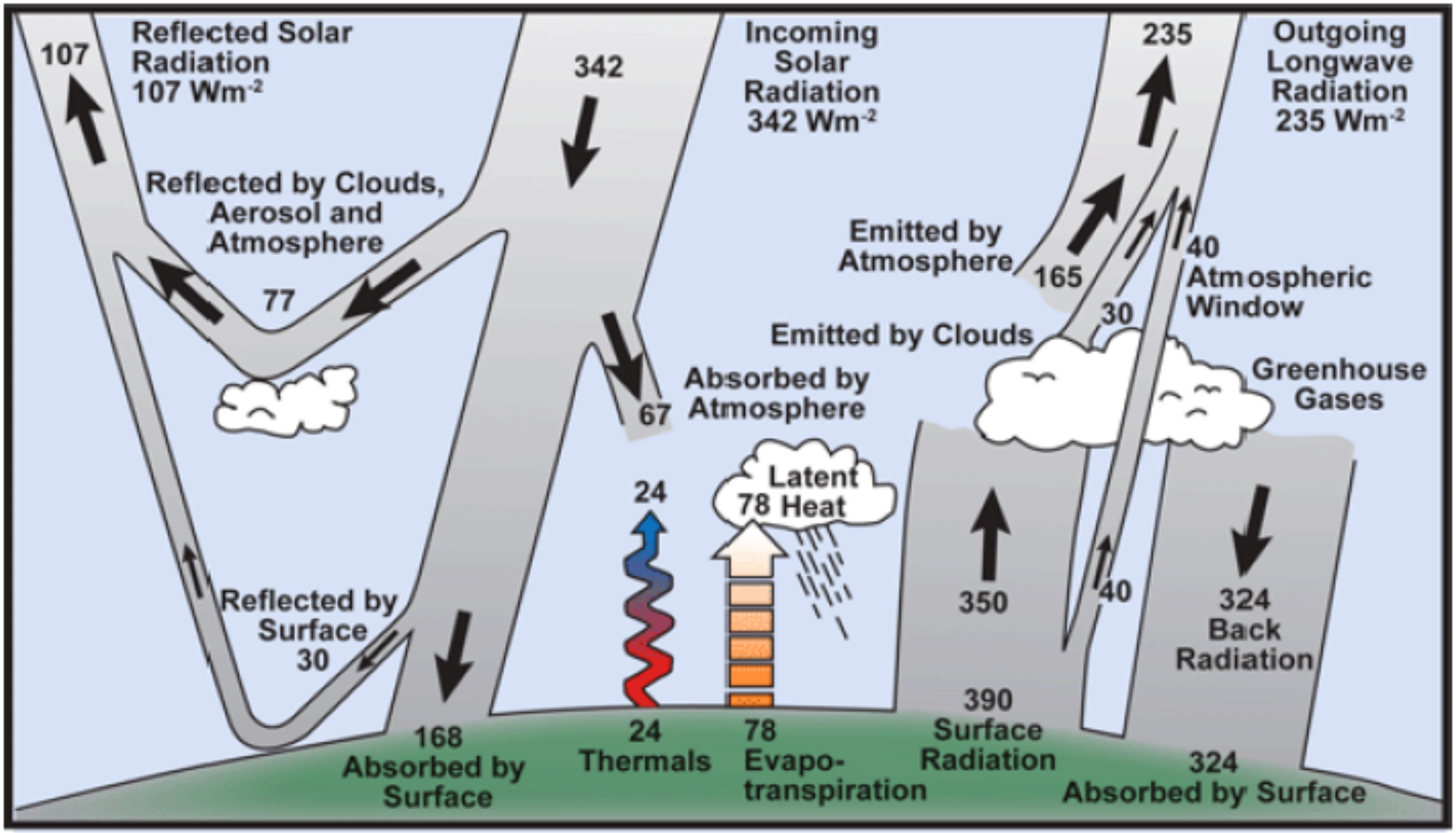
- Natural fluctuations in the sun's intensity
- Complex motion of the Earth around the Sun
- Volcanic eruptions
- Changes in ocean currents
- Shorter-term cycles (eg – El Nino)

# Why is the climate warming?




Sun
Outgoing energy
Atmosphere, containing greenhouse gases
Incoming energy
Trapped energy
Earth

# Global Energy Balance



# Summary of the science of climate change

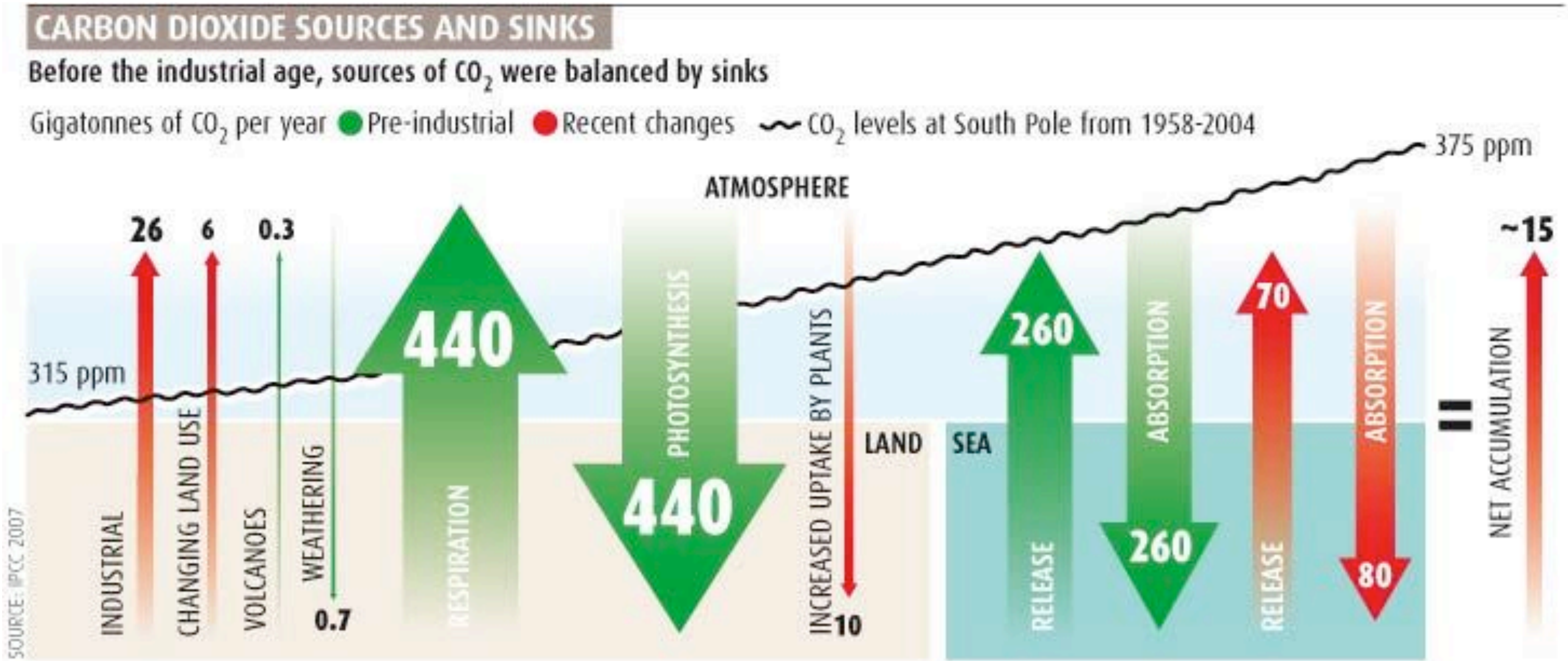
"The Earth is habitable because of a natural greenhouse effect brought about mainly by water vapor (60%) and carbon dioxide (26%). Otherwise its average temperature would be below zero Fahrenheit. Humans are altering the composition of the atmosphere, mainly by burning fossil fuels. As a result carbon dioxide has gone up over 35% since pre-industrial times and over half of that is since 1970. This changes the greenhouse effect and traps radiation that would otherwise escape to space, producing warming. The warming is manifested in many ways, not just increasing surface temperatures, but also melting ice, and changing the hydrological cycle and thus rainfall. Since 1970 the effects are large enough to be outside the bounds of natural variability for global mean temperatures, but global warming does not mean inexorable increases in temperature year after year owing to natural variability."

- Kevin Trenberth, head of the Climate Analysis Section at the US National Center for Atmospheric Research

# How do we know the climate is changing?

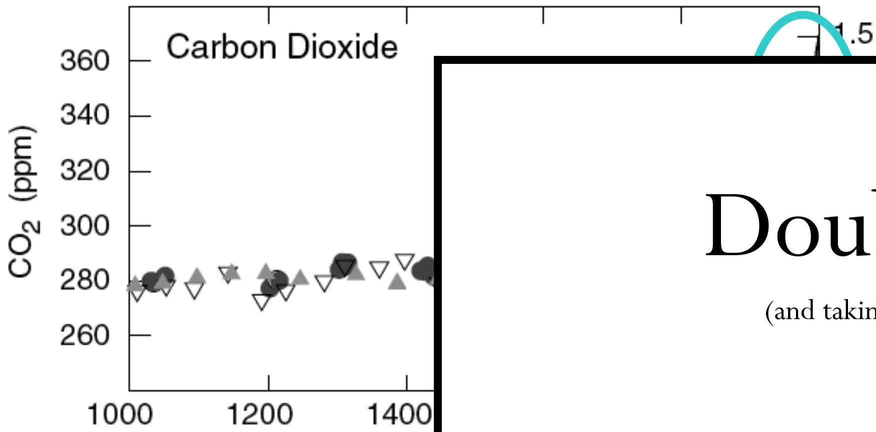
# What is the evidence for human caused climate change?

- Direct measurement of changes in atmospheric composition
- Direct measurement of temperatures
- Direct measurement of precipitation and other climate indicators
- Direct measurement of shifts in species
- Paleoclimate records
- Climate model verification
- Testing models with other planet climates

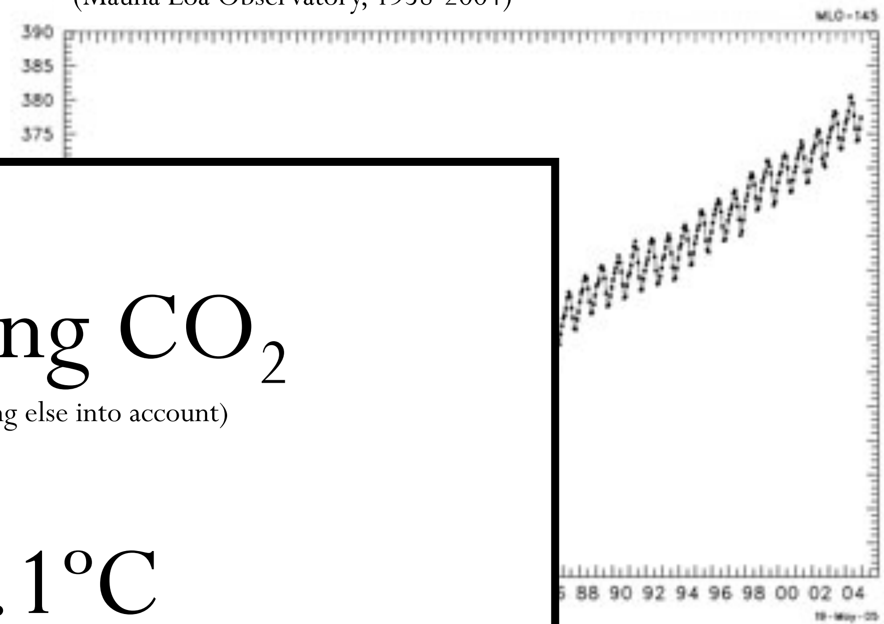

CARBON DIOXIDE SOURCES AND SINKS
Before the industrial age, sources of CO2 were balanced by sinks
Gigatonnes of CO2 per year
Pre-industrial
Recent changes
CO2 levels at South Pole from 1958-2004
375 ppm
315 ppm
ATMOSPHERE
26
6
0.3
INDUSTRIAL
CHANGING LAND USE
VOLCANOES
WEATHERING
0.7
440
RESPIRATION
PHOTOSYNTHESIS
440
INCREASED UPTAKE BY PLANTS
10
LAND
SEA
260
RELEASE
ABSORPTION
260
70
RELEASE
ABSORPTION
80
=
~15
NET ACCUMULATION
SOURCE: IPCC 2007

# Carbon Dioxide Basics

Atmospheric $CO_2$ concentrations:




(Mauna Loa Observatory, 1958-2004)




## Doubling $CO_2$

(and taking nothing else into account)

## +1.1°C

(annual average global surface temperature)

Useful Numbers:

Preindustrial atmospheric $CO_2$: ~ 280 ppm
Current atmospheric $CO_2$ : ~ 390 ppm (see: co2now.org)
Fossil $CO_2$ emissions: ~ 7.2 GtC/yr
$CO_2$ sinks: ~3 GtC/yr (depends on year)
Conversions: 1 ton C ~ 3.7 ton CO2
2.1 GtC ~ 1 ppm CO2 (in atmos.)
Average $CO_2$ lifetime (in atmos.): 5-200+ years

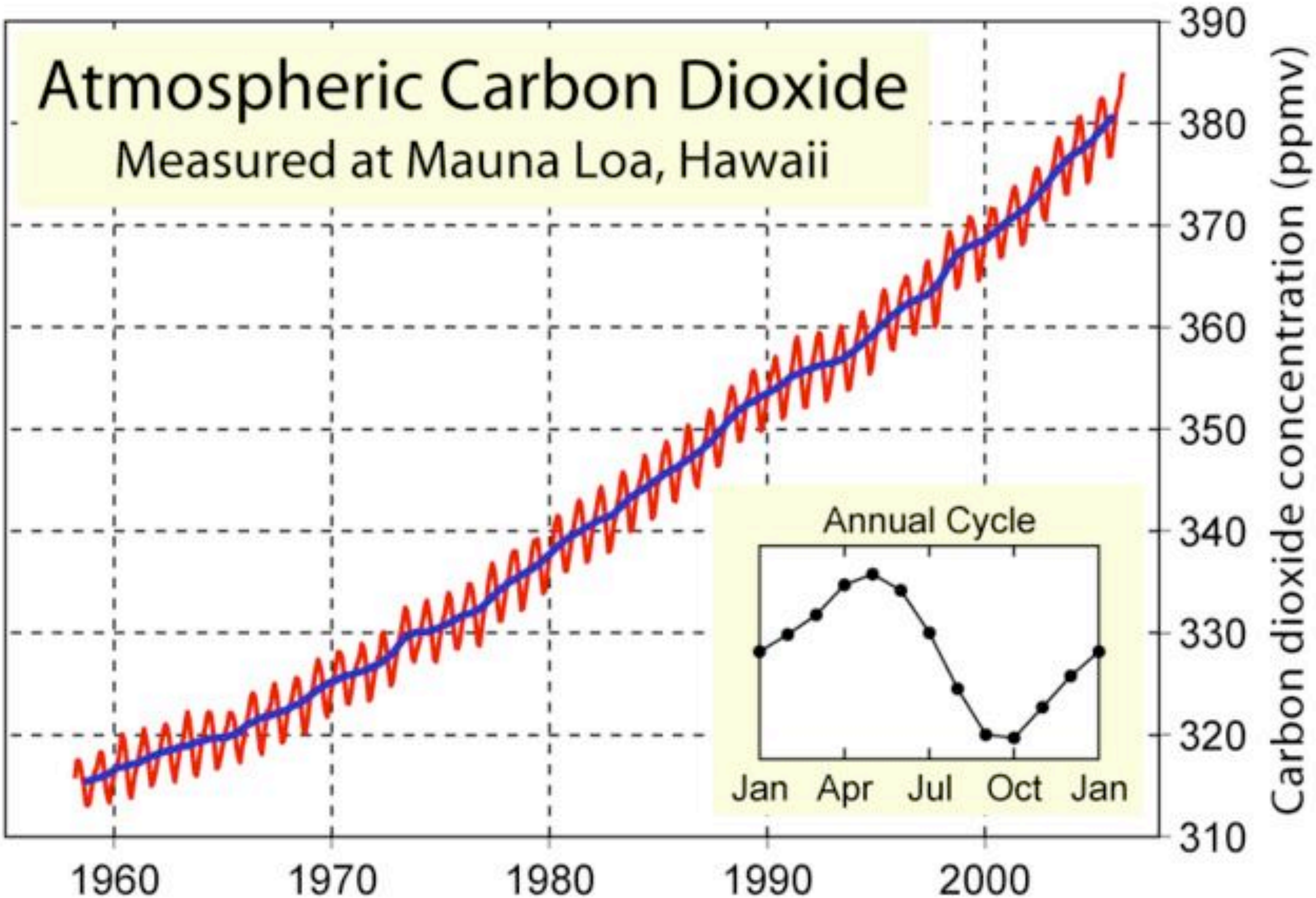
Fossil fuel use
(coal, oil, gas)
Land use changes
(deforestation / forest fires)
Cement production
Natural sources

Biologic utilization
Absorption by seawater
Weathering

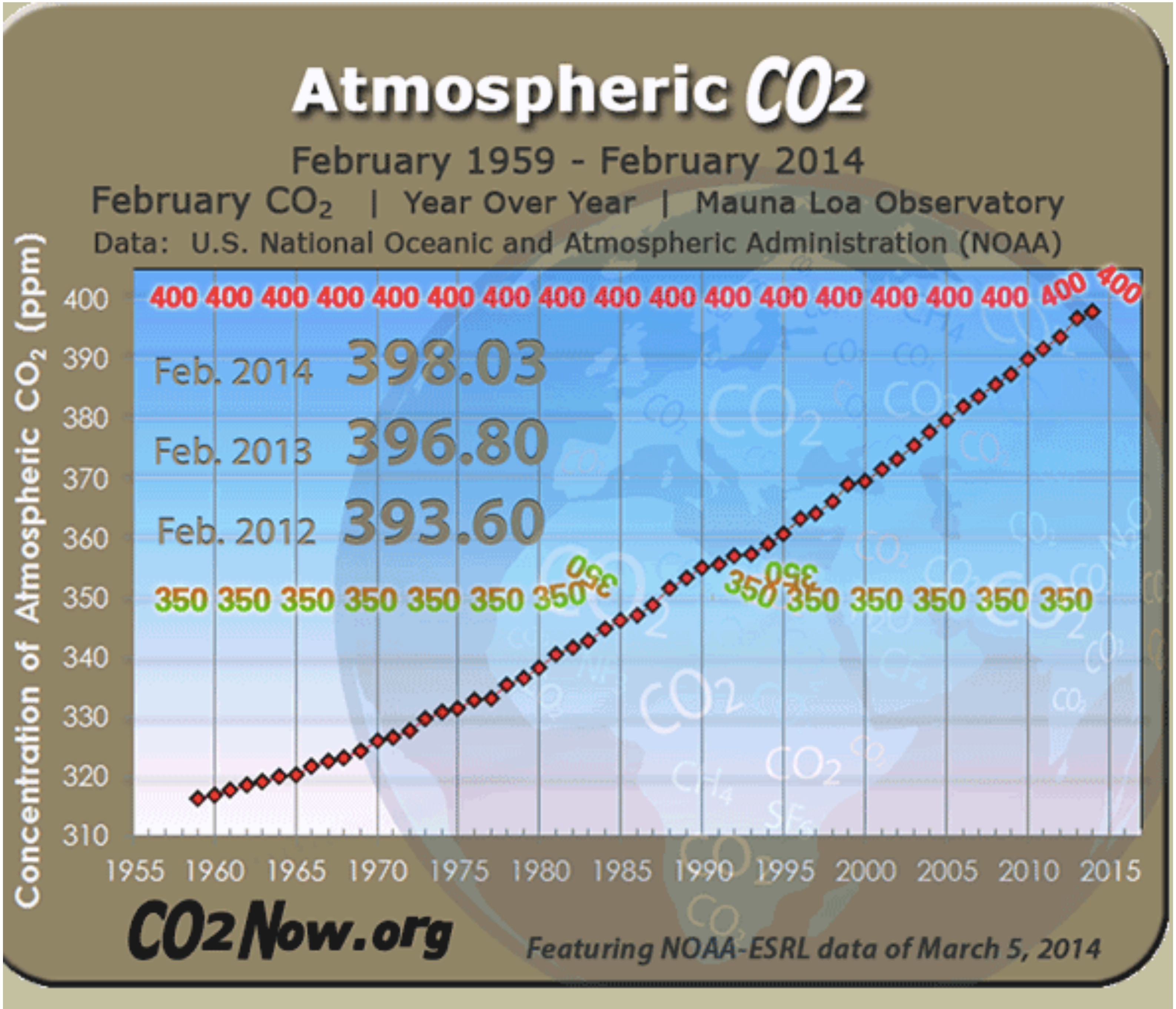
# What human activities are affecting the climate?

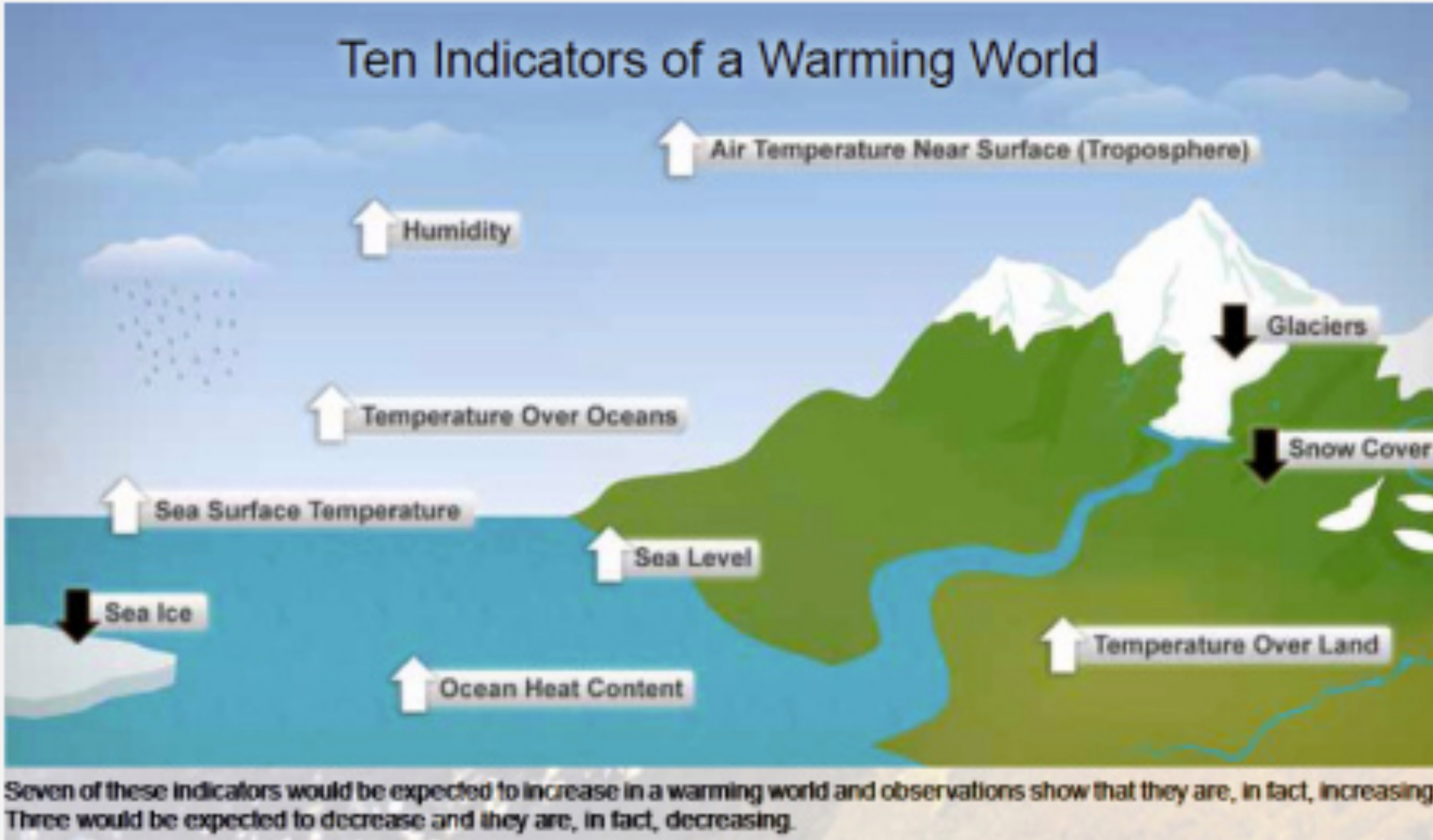
- Carbon dioxide from fossil fuels
  - At least: 6 billions of carbon each year released
- Methane from agriculture, livestock, landfills and industry
- Nitrous oxide from agriculture and industry
- Change in Land use and land cover
  - Release another 1 billion tons of carbon and other gases

## Burning fossil fuels, like coal and oil, and deforestation are the primary source of the increasing carbon dioxide.



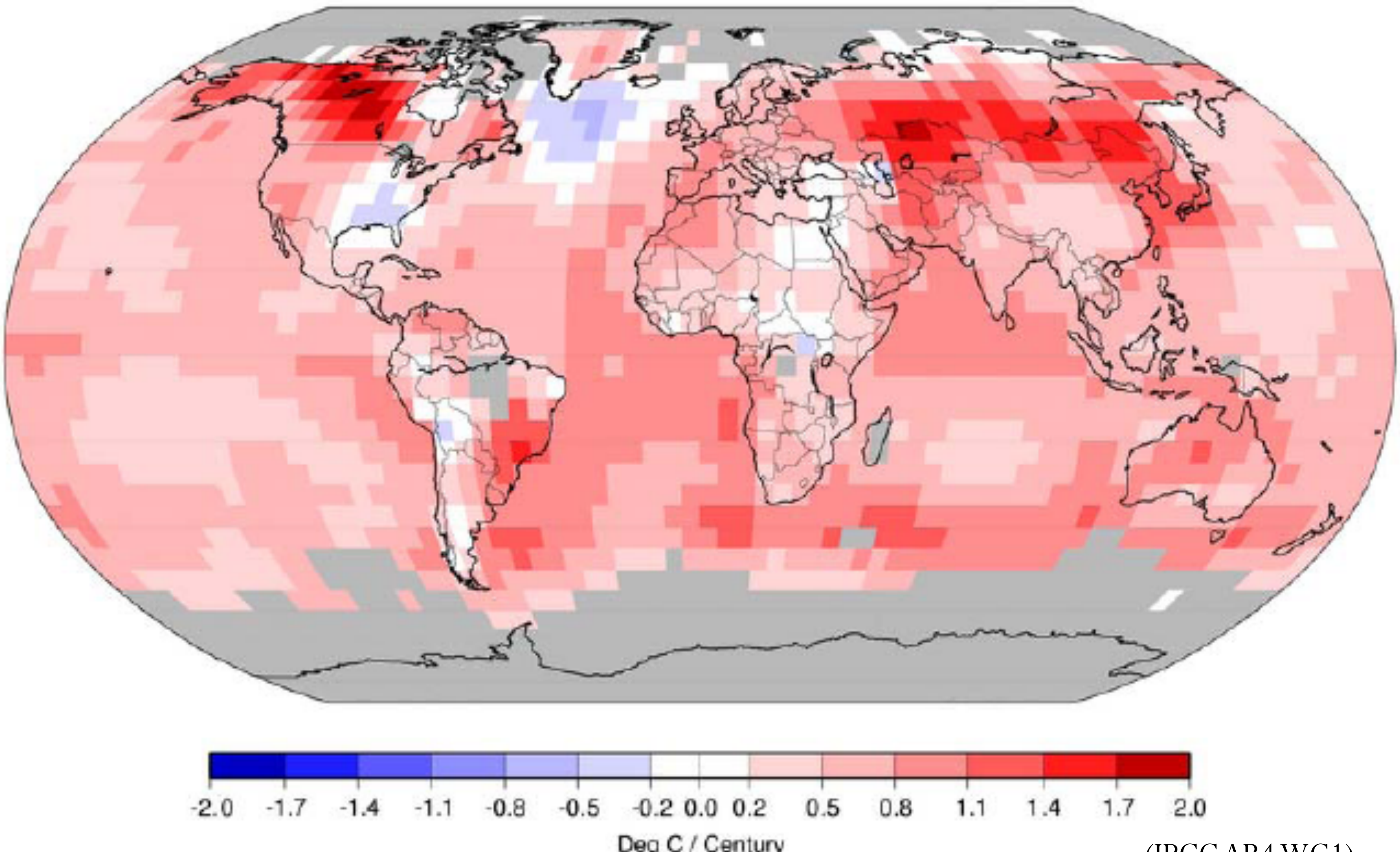
Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii
Annual Cycle
Jan
Apr
Jul
Oct
Jan
390
380
370
360
350
340
330
320
310
Carbon dioxide concentration (ppmv)
1960
1970
1980
1990
2000


Atmospheric CO2
February 1959 - February 2014
February CO₂ | Year Over Year | Mauna Loa Observatory
Data: U.S. National Oceanic and Atmospheric Administration (NOAA)
Concentration of Atmospheric CO₂ (ppm)
Feb. 2014 398.03
Feb. 2013 396.80
Feb. 2012 393.60
400
350
310
320
330
340
350
360
370
380
390
400
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
CO2Now.org
Featuring NOAA-ESRL data of March 5, 2014




Ten indicators with increasing or decreasing values that demonstrate that the planet is warming. Credit: NOAA

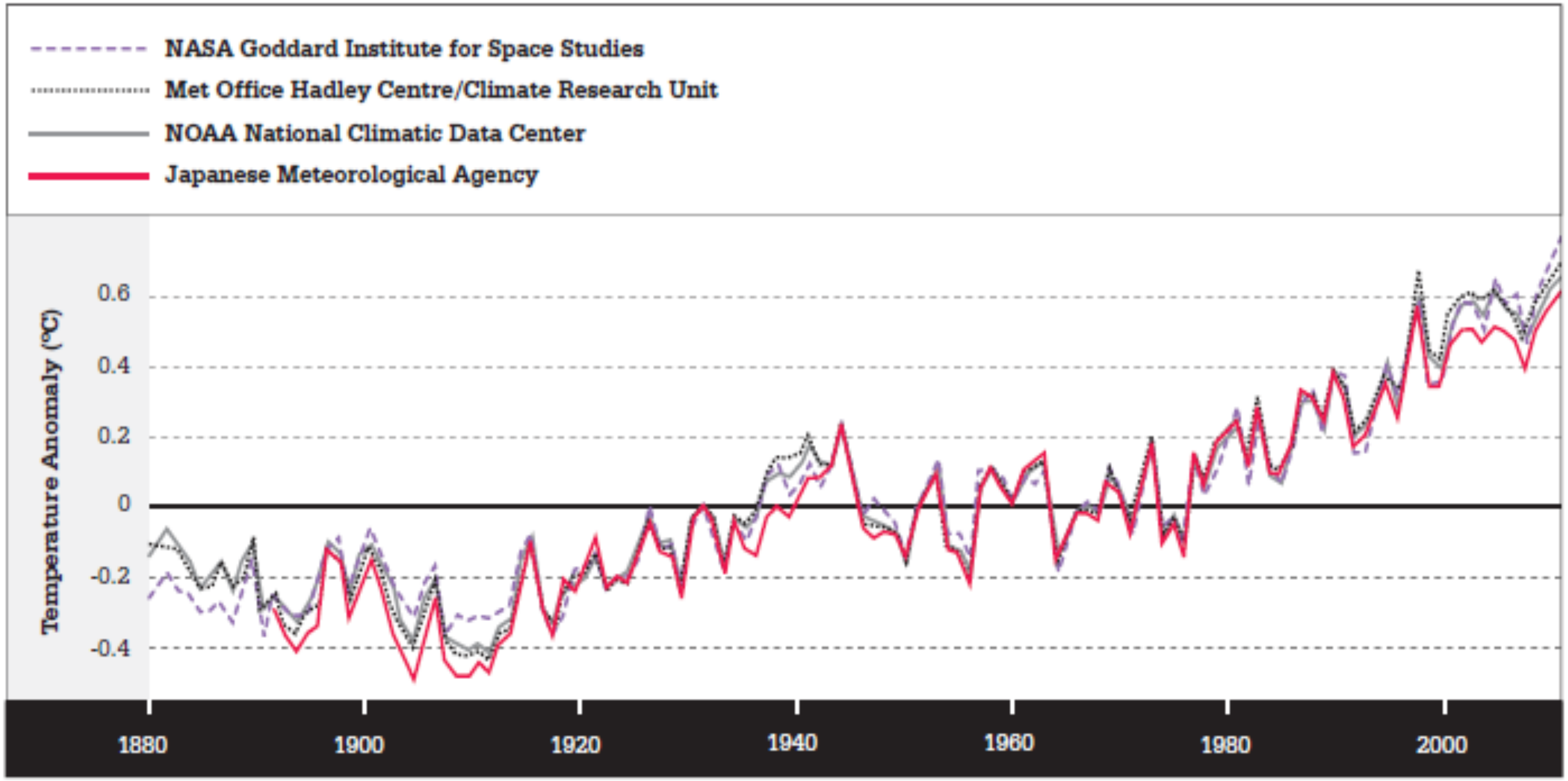
# Without a Doubt, Earth is Warming




(IPCC AR4 WG1)

Why? And how much additional warming do we expect?

# There is no doubt that the climate is changing.




Source: NASA GISS Surface Temperature Analysis.

The atmosphere is warming, the ocean is warming, ice is being lost from glaciers and ice caps, and sea levels are rising.

"The highest global surface temperature in more than a century of instrumental data was recorded in the 2005 calendar year in the GISS annual analysis. However, the error bar on the data implies that 2005 is practically in a dead heat with 1998, the warmest previous year." NASA http://data.giss.nasa.gov/gistemp/2005/.

# IPCC SPM 4 AR 2007

- Eleven of the twelve warmest years since 1850 have occurred in the past twelve years (1995-2006).
- Total temperature rise from 1850-1899 to 2001-2006 is 0.76 deg C (plus or minus 0.2)
- Rate of warming in past 50 years is double the average for the last 100.

# Global Temperature Update

March 8, 2014

Globally, January 2014 was the 4th warmest January since global temperature records began in 1880. The coolest was January1893. [NOAA Global Monthly Analysis]

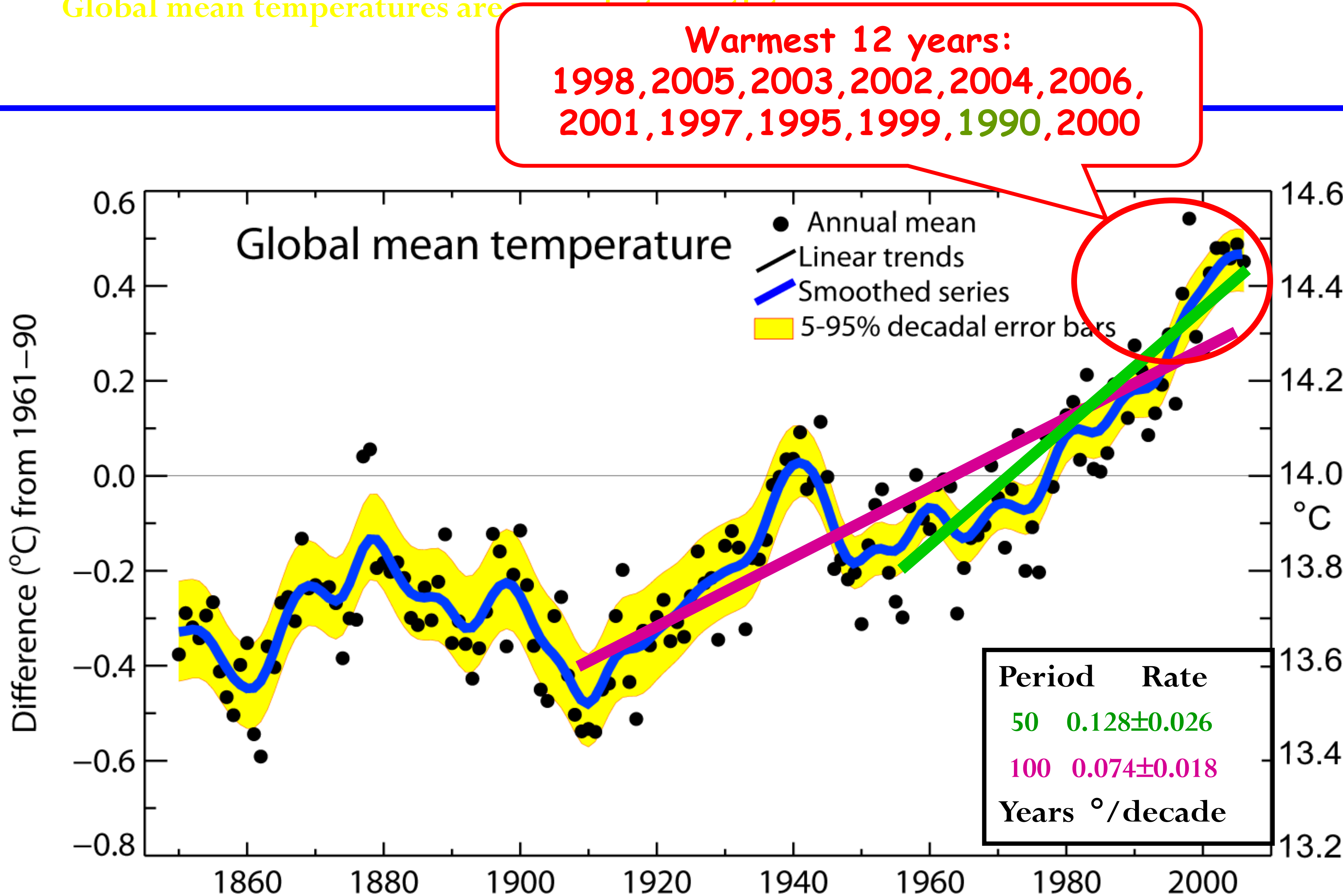
Annually, 2013 tied 2003 as the 4th warmest year globally since 1880. Nine of the ten warmest years in the past 134 years occurred in the 21st Century. Only one year during the 20th Century--1998--was warmer than 2013. [NOAA Global Analysis 2013]

> *"The science is sobering—the global temperature in 2012 was among the hottest since records began in 1880. Make no mistake: without concerted action, the very future of our planet is in peril."*
>
> *~ Christine Lagarde, Managing Director*
> *International Monetary Fund*
>
> *[video][text]*

# IPCC SPM 4 AR 2007

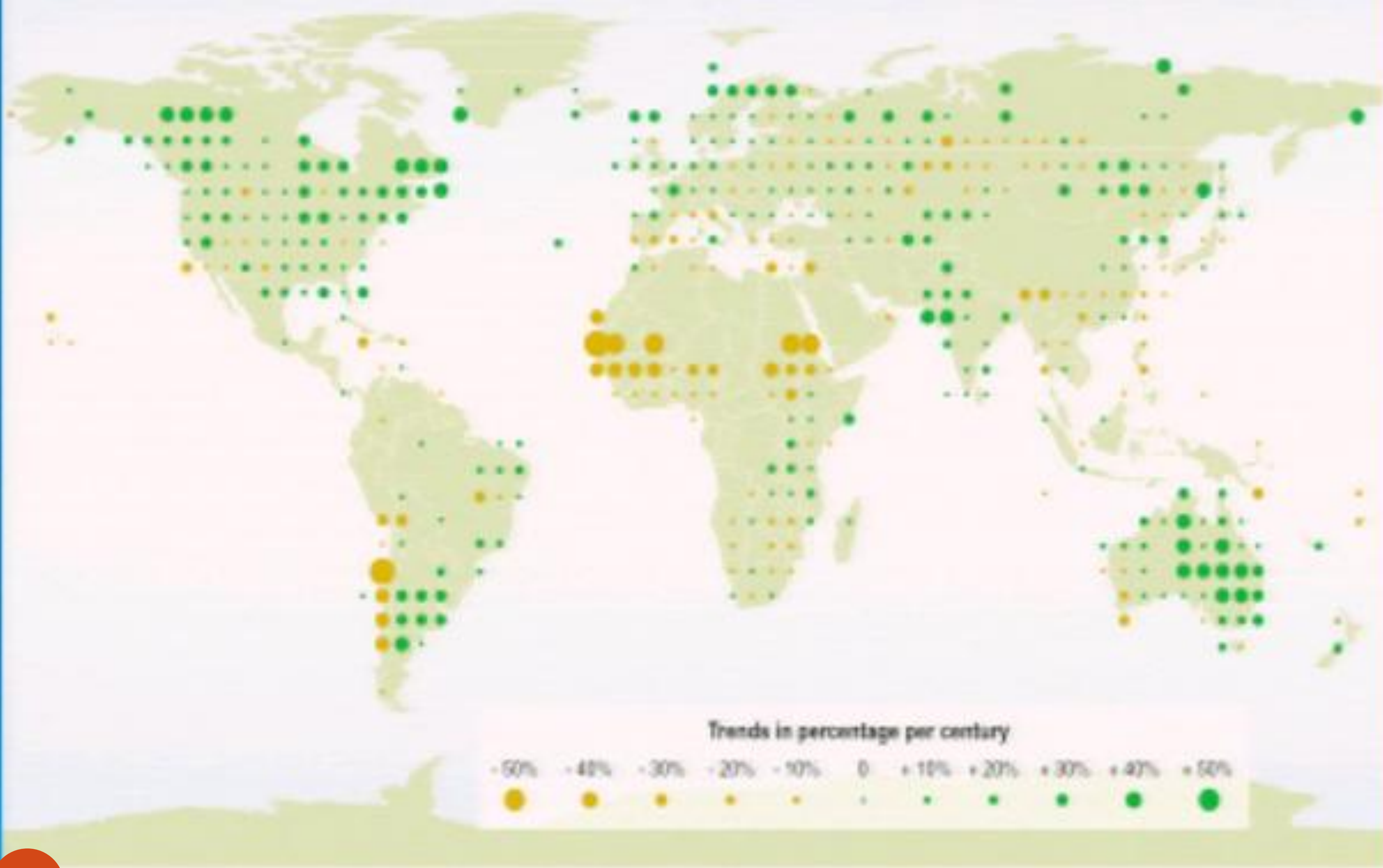
- "Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."

## Global mean temperatures are

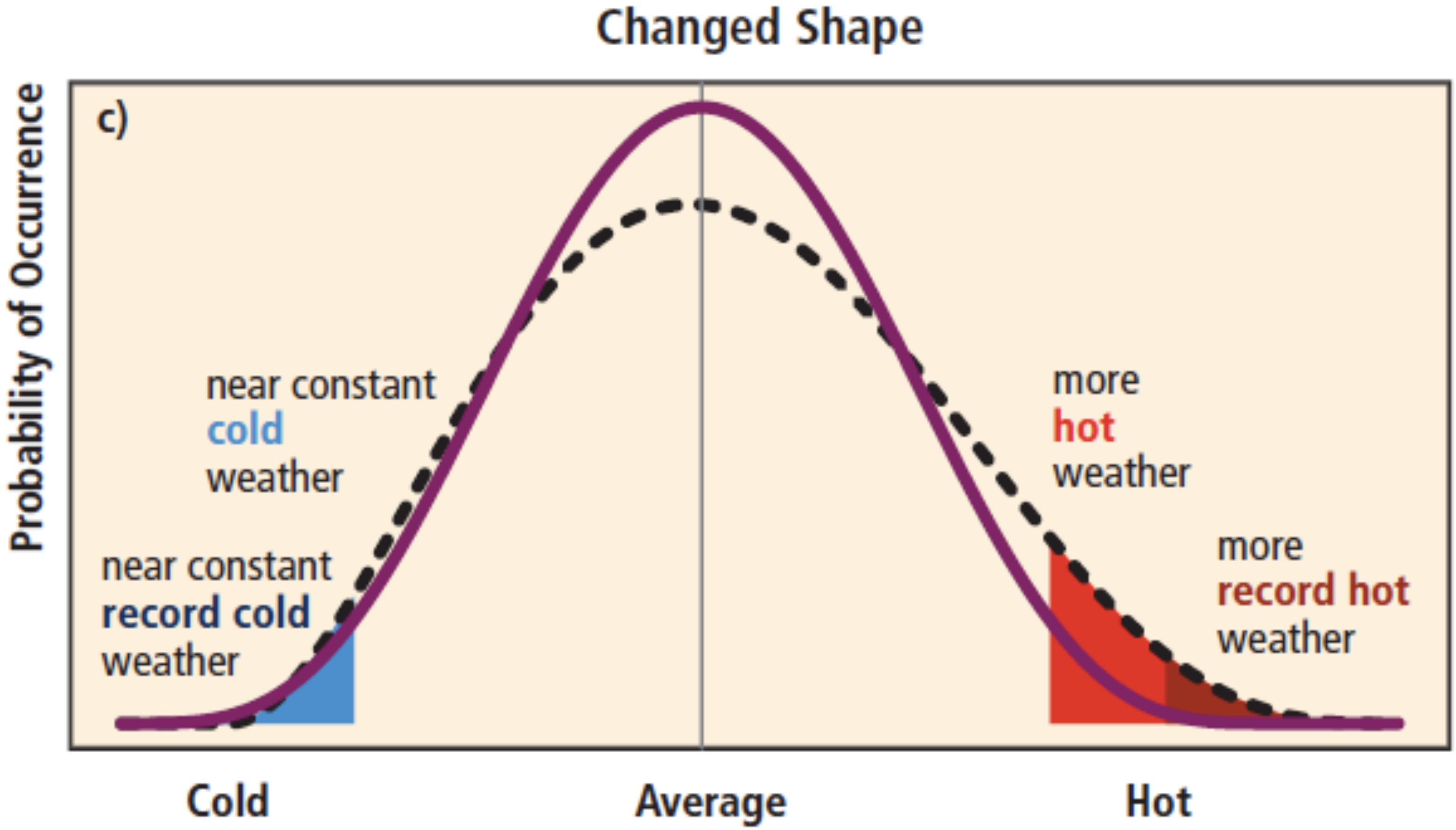


# Annual temperature trends: 1976 to 2000

# Annual precipitation trends: 1900 to 2000



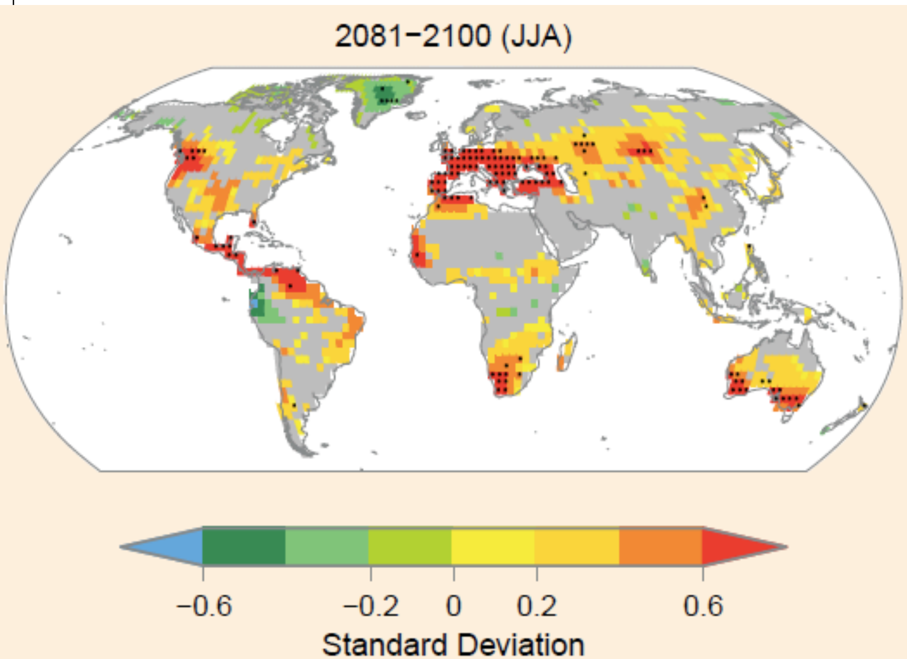
# New climate event occurrence



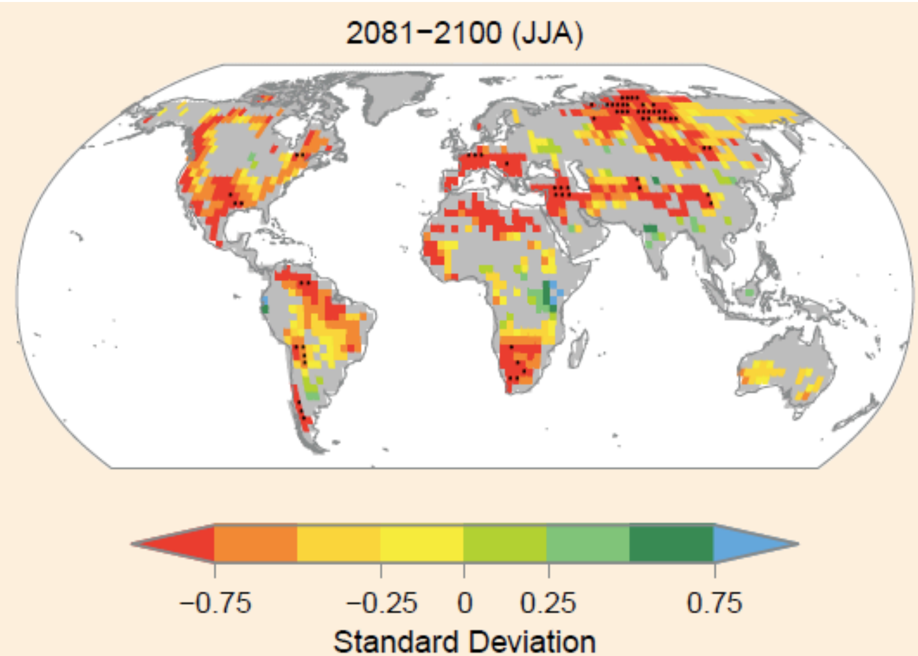

**Source IPCC 2012**

# Dry future

Consecutive dry days




Soil dryness anomalies



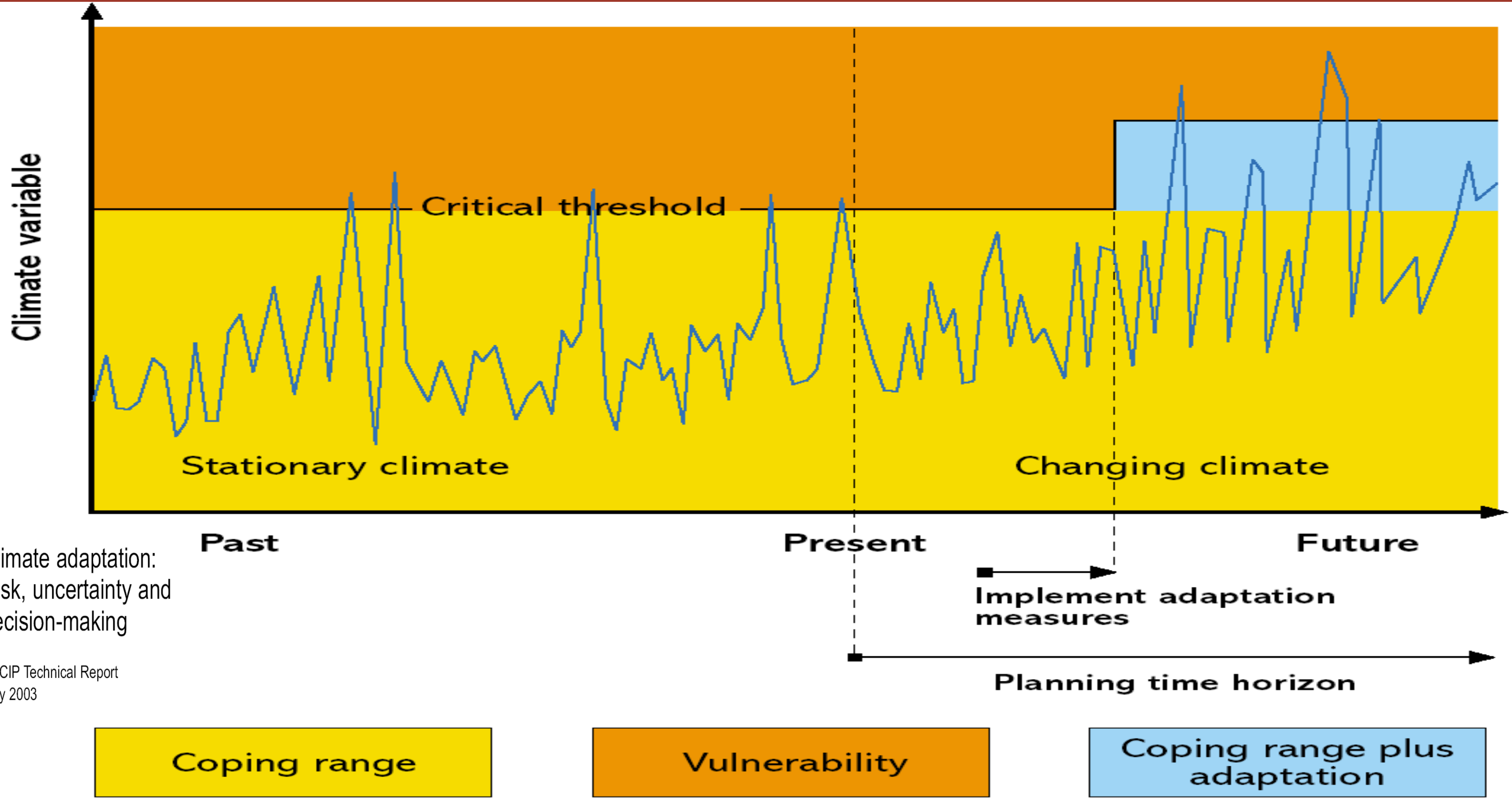

**Source IPCC 2012**

# Wet future?

- The degree of confidence in predicting heavy rainfalls or extreme climatic events is far less than prediction of dryness.
- Although these events are local and statistically much harder to predict on large scale (territory, timeframe), the climate science is now able to predict an increased occurrence for both types of extreme

- See: IPCC 2012, Managing the risks of estreme events and disasters to advance climate change adaptation

# A new occurrence for climate extremes

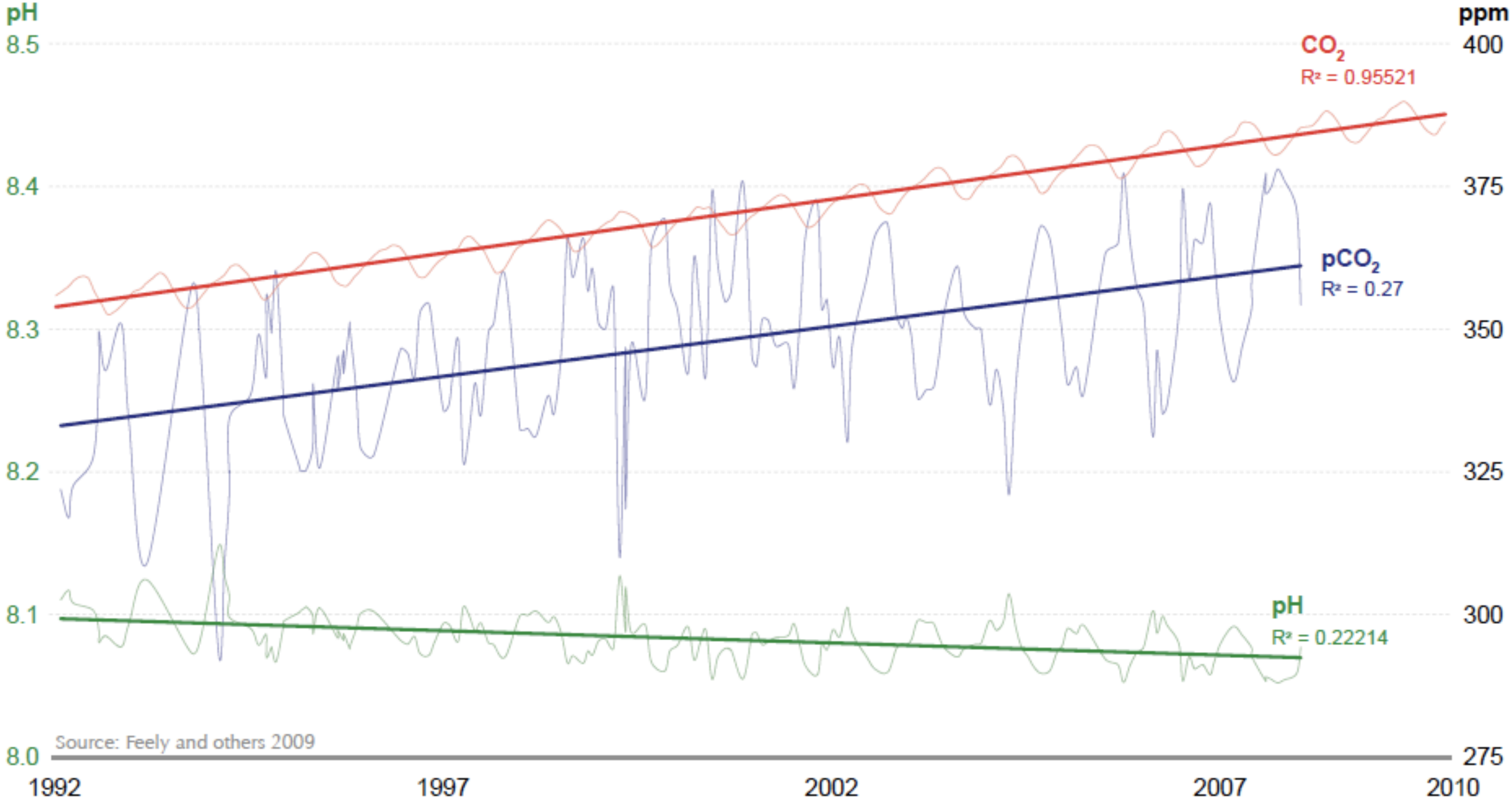



Climate adaptation:
Risk, uncertainty and decision-making

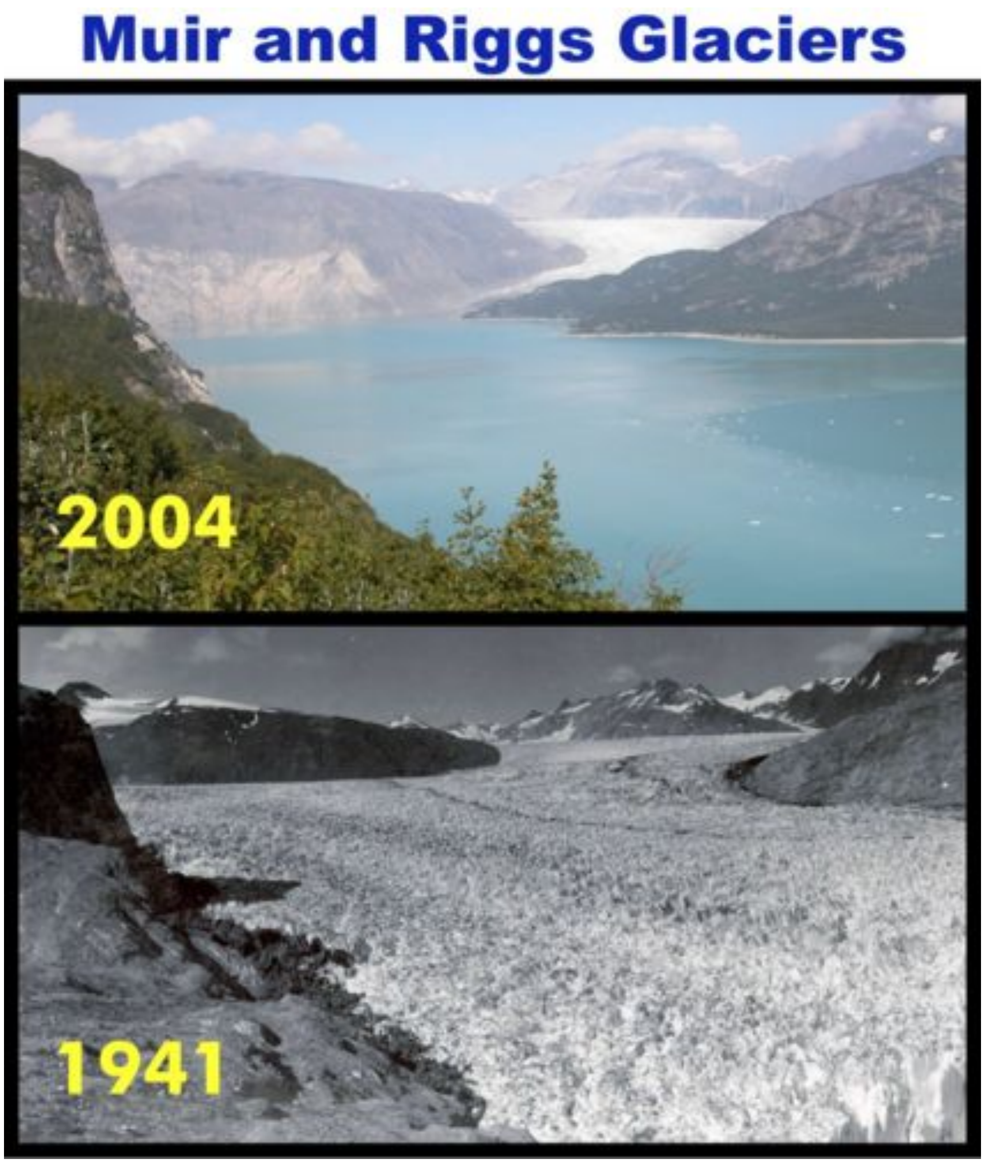
UKCIP Technical Report
May 2003

Claude_Villeneuve@uqac.ca

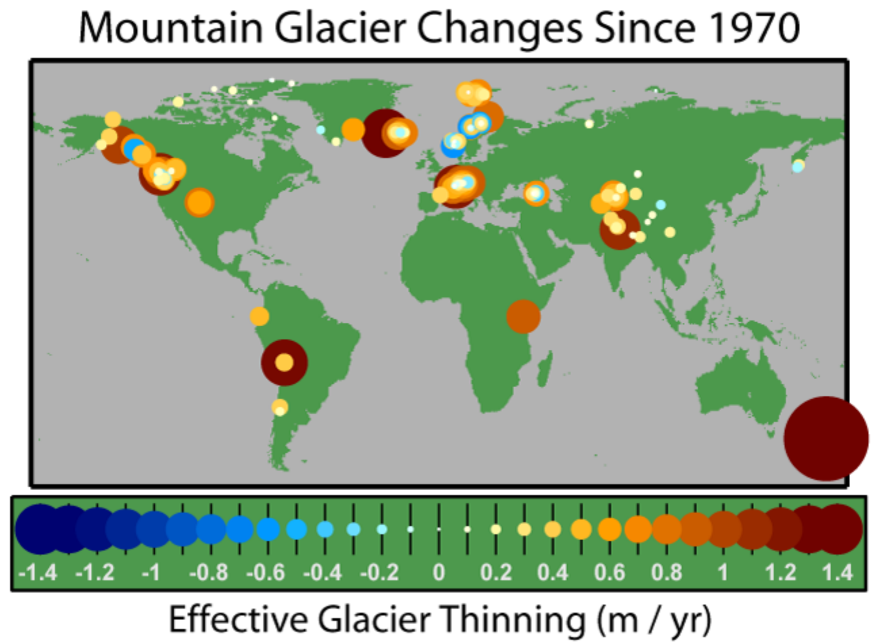
# Ocean Acidification

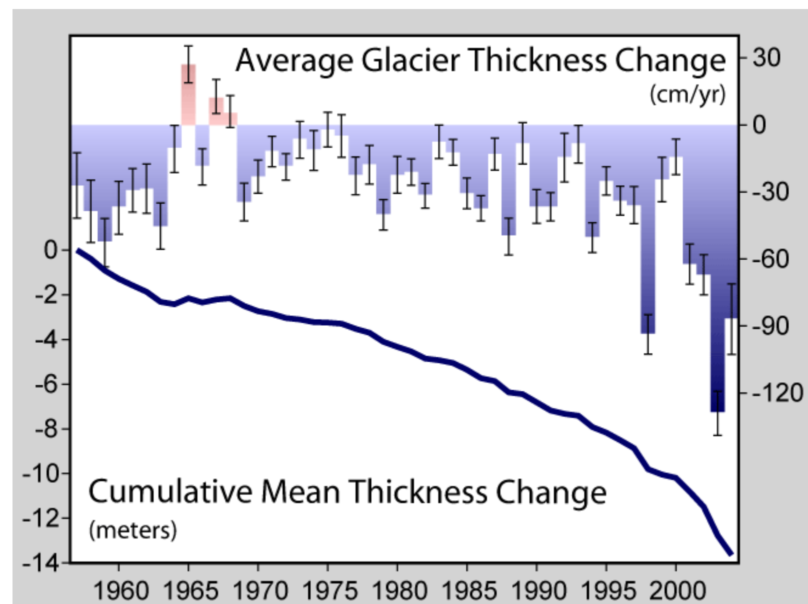


# Glacial Retreat

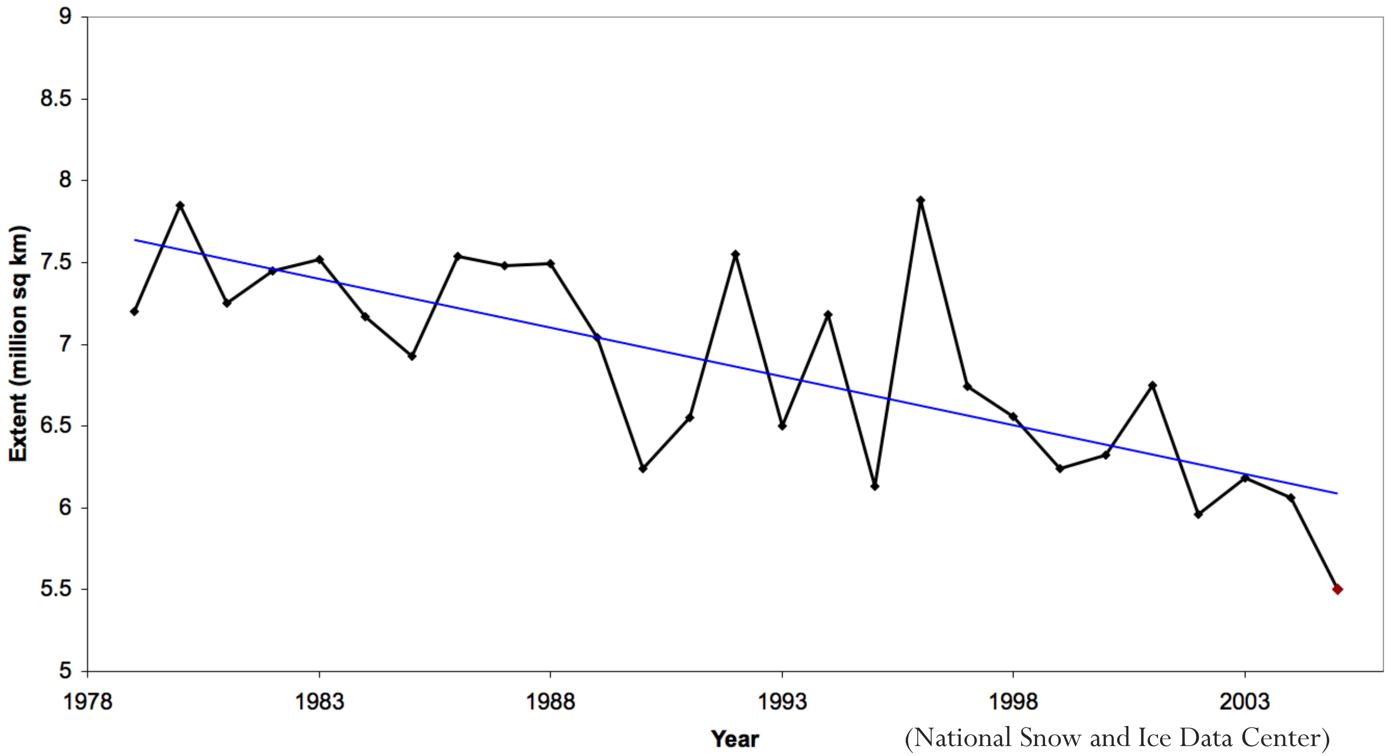



www.globalwarmingart.com

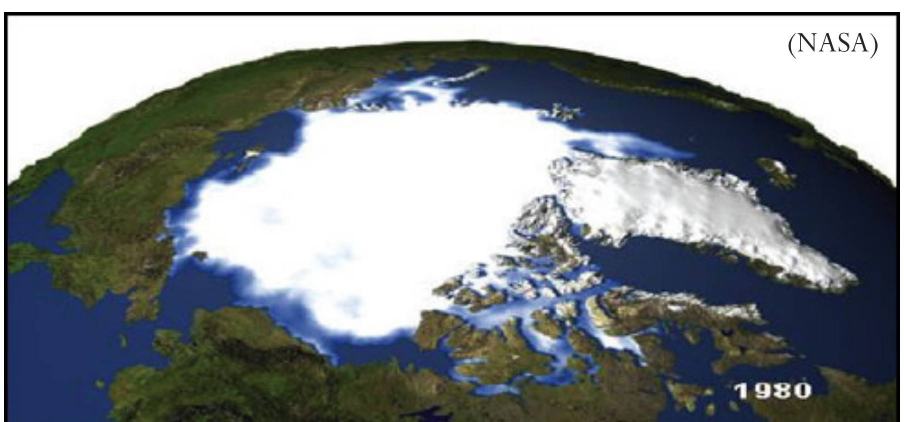


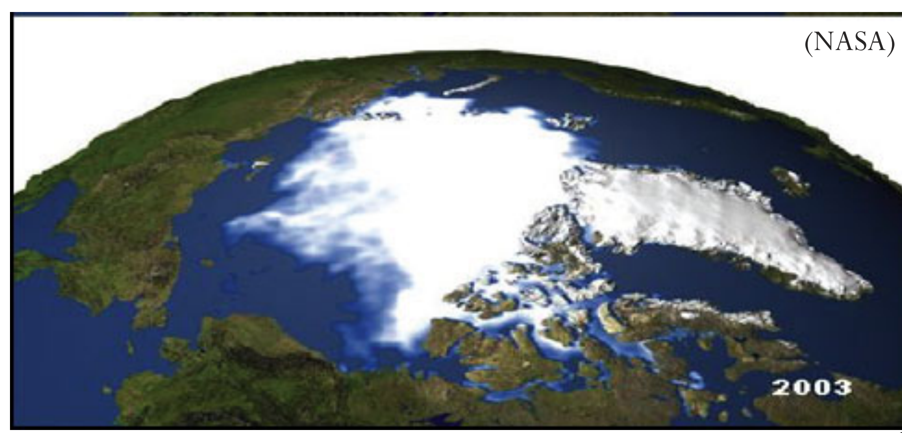



# Historic September Sea Ice Extent

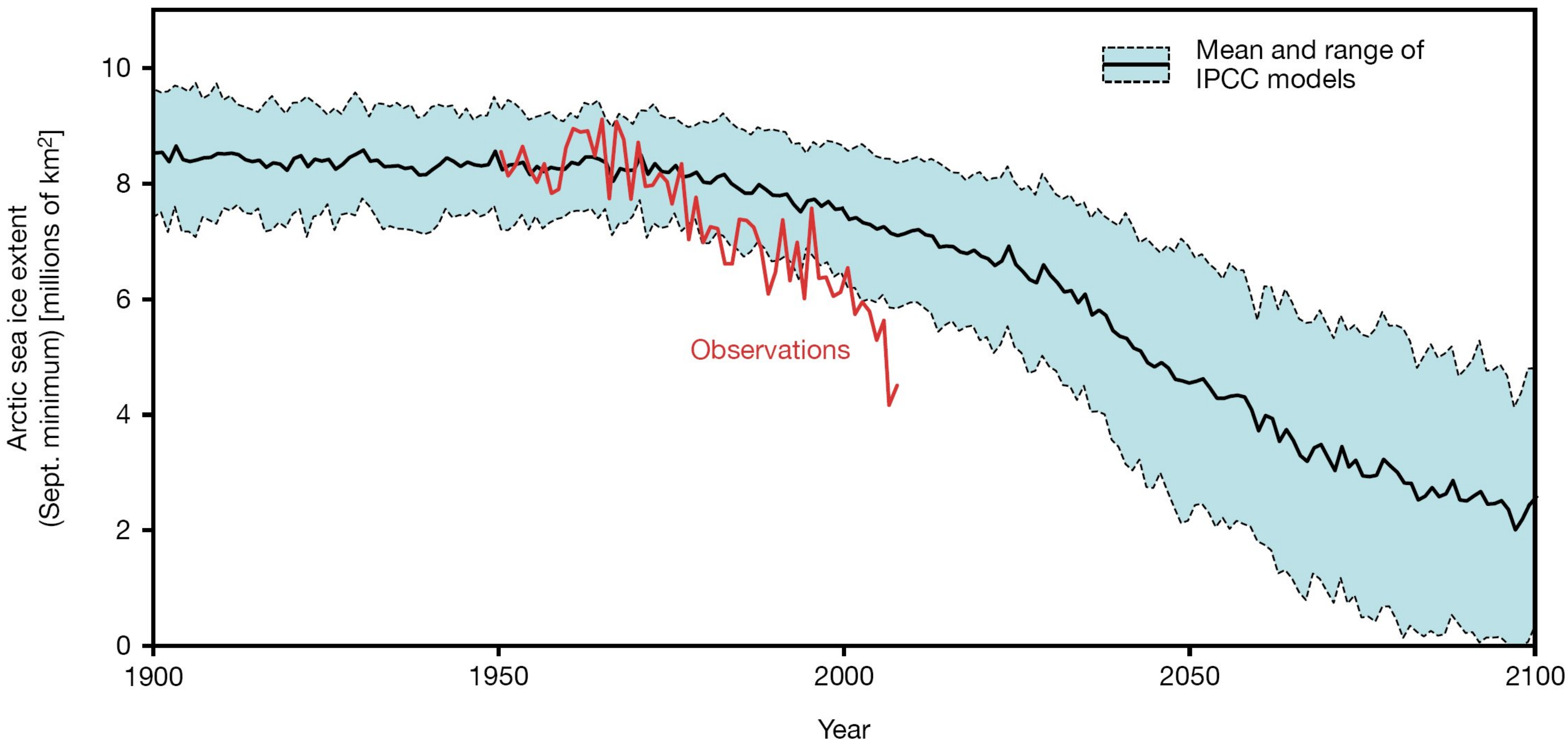



(National Snow and Ice Data Center)

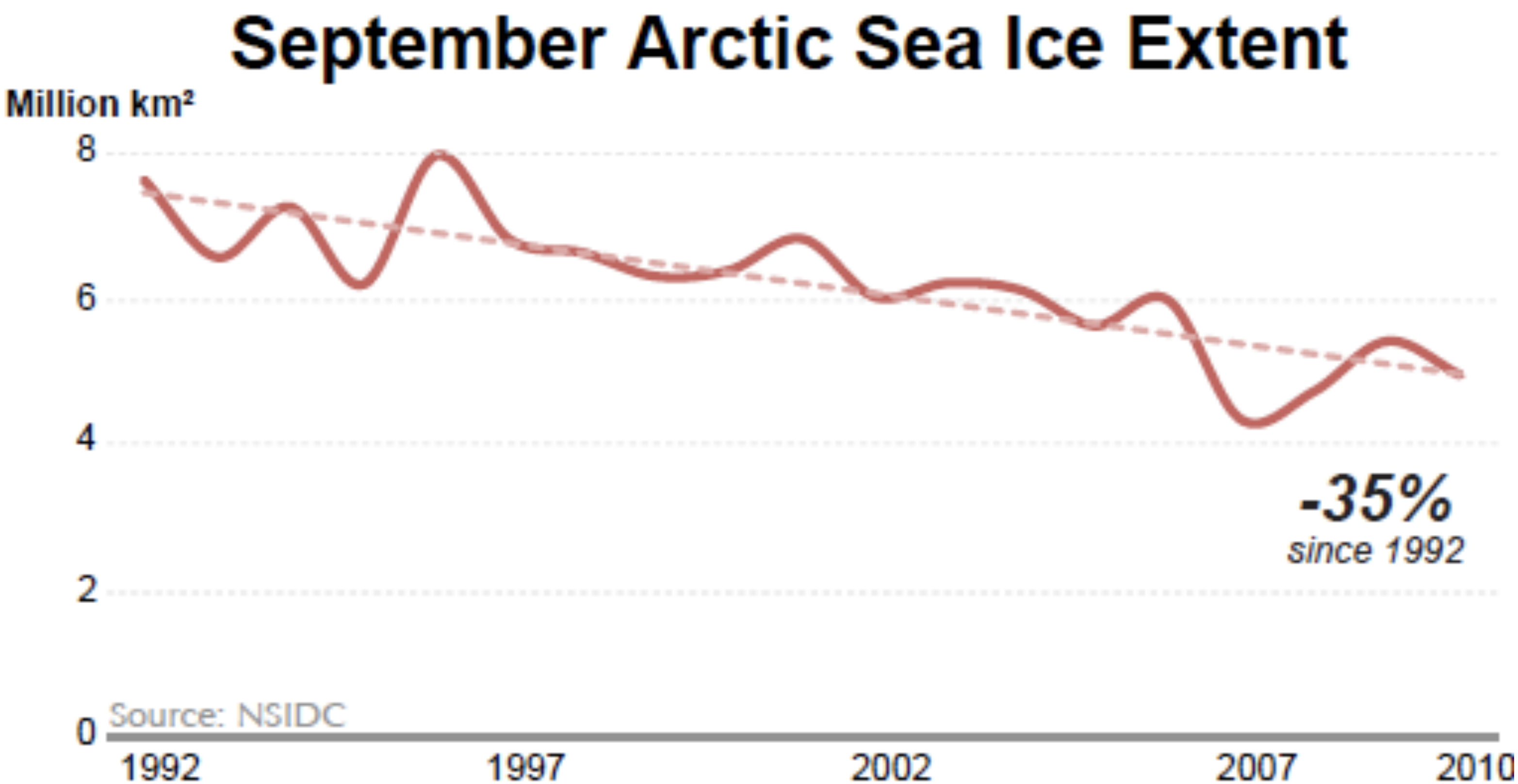


# Arctic sea ice



# Trends




August 2012 has been the smallest iArtic ice cover ever since satellital observations (NASA-GISS)

# Greenland (and Antarctic) Ice and Sea Level Rise

The concern:

(NASA)

Greenland Ice Sheet

~ 7 meters

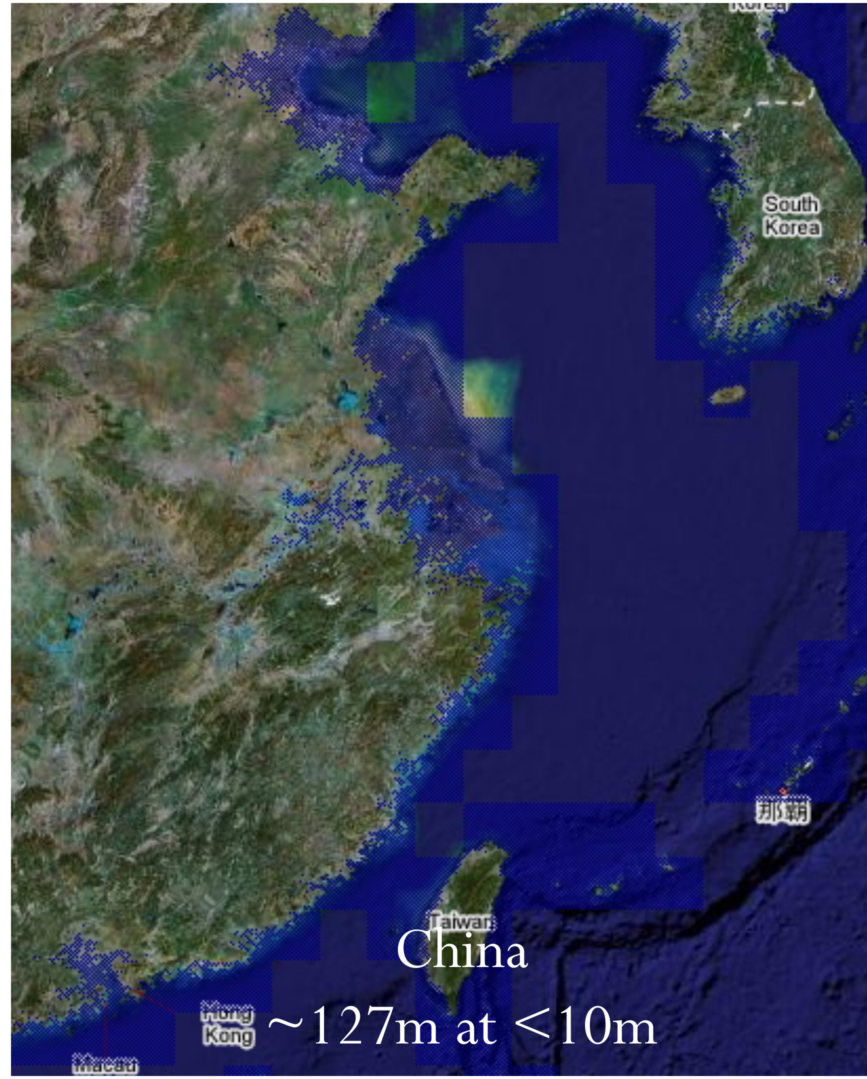
(Wikipedia)

West Antarctic Ice Sheet

~ 4-7 meters

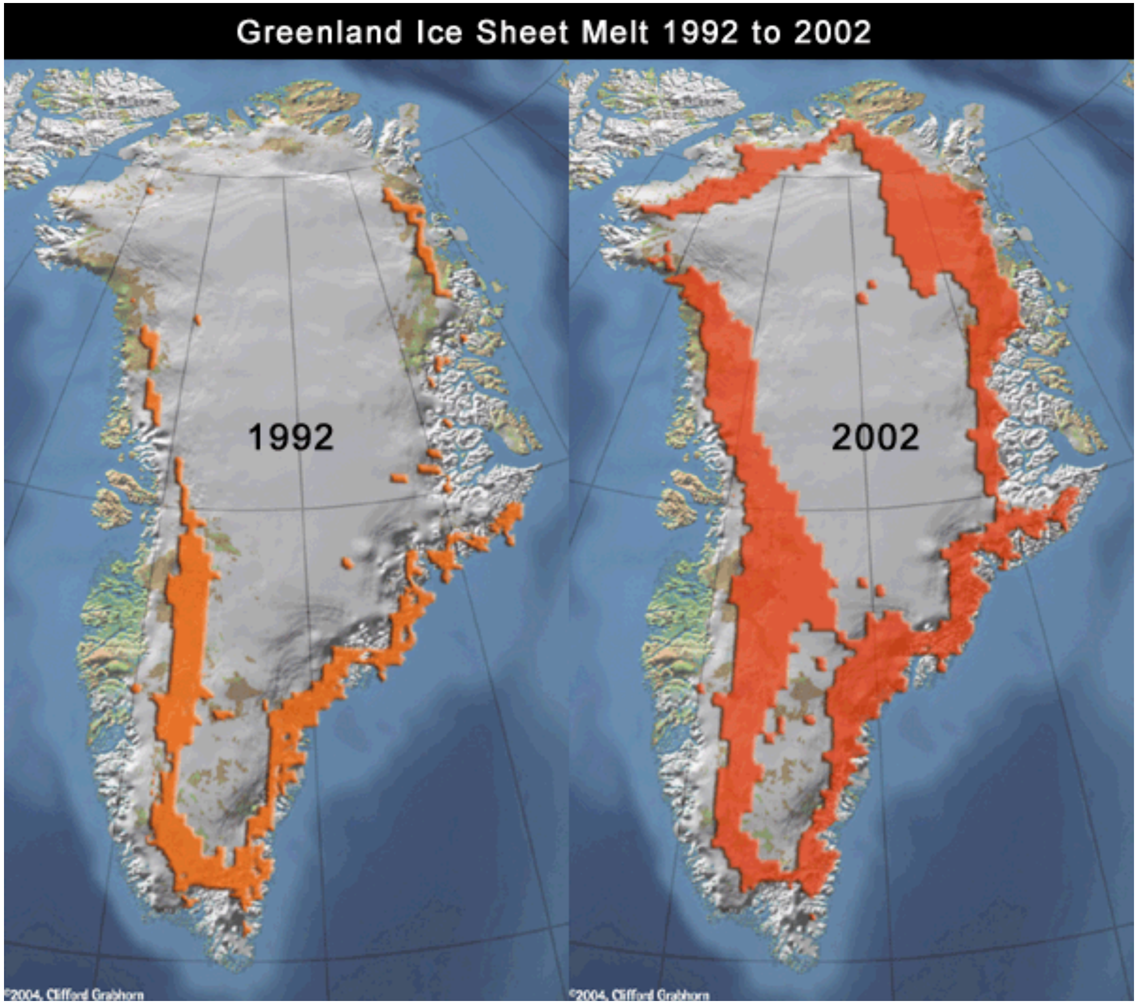
# rising sea levels


# 10m sea level rise? (http://flood.firetree.net)


~600 million people live at elevation of <10m

# Recently, we have begun to measure notable ice loss

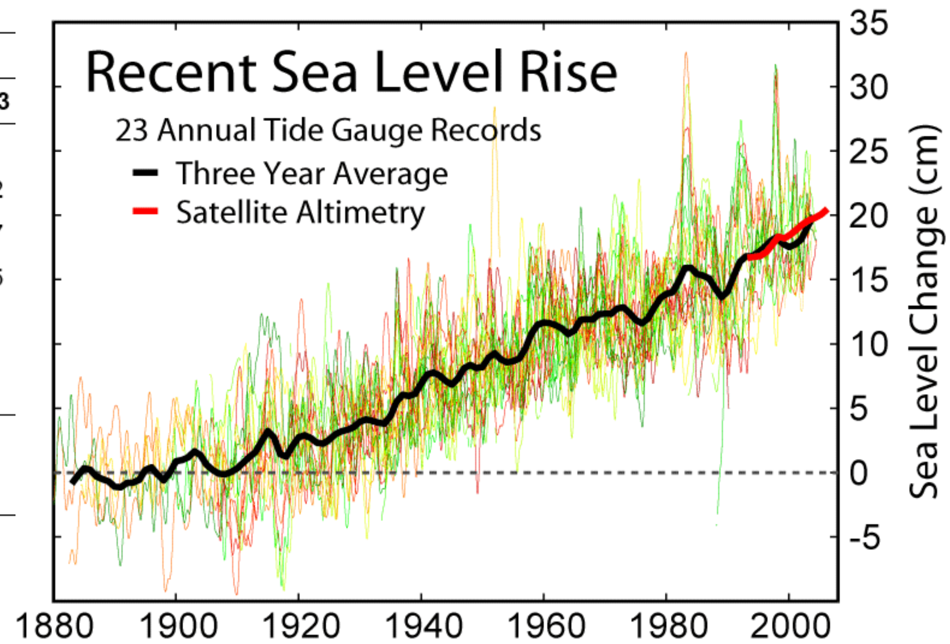



(Melt Area; Impacts of a Warming Arctic, 2004)

# … for a sense of timing and probability

| Source of sea level rise | Rate of sea level rise (mm per year) 1961 – 2003 | 1993 – 2003 |
|---|---|---|
| Thermal expansion | 0.42 ± 0.12 | 1.6 ± 0.5 |
| Glaciers and ice caps | 0.50 ± 0.18 | 0.77 ± 0.22 |
| Greenland ice sheet | 0.05 ± 0.12 | 0.21 ± 0.07 |
| Antarctic ice sheet | 0.14 ± 0.41 | 0.21 ± 0.35 |
| Sum of individual climate contributions to sea level rise | 1.1 ± 0.5 | 2.8 ± 0.7 |
| Observed total sea level rise | 1.8 ± 0.5[a] | 3.1 ± 0.7[a] |
| Difference (Observed minus sum of estimated climate contributions) | 0.7 ± 0.7 | 0.3 ± 1.0 |

(IPCC AR4 WG1, 2007)




(Douglas 1997 + TOPEX/Poseidon)

Notes:

Biggest contribution from thermal expansion

Behavior of Greenland and Antarctica Ice?

Projections:

TAR SPM 2100: + 9cm - 88cm

AR4 SPM 2100: + 18cm - 59cm

"Catastrophic" sea-level rise (e.g. >1m) from Greenland / Antarctic melting? Lots of uncertainty + melting largely irreversible

# Greenland Ice Sheet

- Glaciologists believe there is a one-in-20 chance of sea levels rising by a metre or more by 2100, and a metre rise in sea level is really very serious.
- "The impacts of sea-level rise of this magnitude are potentially severe, implying a conceivable risk of the forced displacement of up to 187 million people within this century."

- "A major gap in predictive capability concerning the future evolution of the ice sheets was identified in the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change. As a consequence, it has been suggested that the AR4 estimates of future sea-level rise from this source may have been underestimated. Various approaches for addressing this problem have been tried, including semi-empirical models and conceptual studies. Here, we report a formalized pooling of expert views on uncertainties in future ice-sheet contributions using a structured elicitation approach. **We find that the median estimate of such contributions is 29 cm—substantially larger than in the AR4—while the upper 95th percentile value is 84 cm, implying a conceivable risk of a sea-level rise of greater than a metre by 2100**. On the critical question of whether recent ice-sheet behaviour is due to variability in the ice sheet–climate system or reflects a long-term trend, expert opinion is shown to be both very uncertain and undecided."
- "An expert judgement assessment of future sea level rise from the ice sheets." Bamber and Aspinall. *Nature Climate Change* 3, 424–427 (2013) Published online 06 January 2013

## more ice leaves Antarctica by melting from the underside of submerged ice shelves than was previously thought, as much as 90% in some areas.

- Iceberg calving has been assumed to be the dominant cause of mass loss for the Antarctic ice sheet, with previous estimates of the calving flux exceeding 2,000 gigatonnes per year. More recently, the importance of melting by the ocean has been demonstrated close to the grounding line and near the calving front. So far, however, no study has reliably quantified the calving flux and the basal mass balance (the balance between accretion and ablation at the ice-shelf base) for the whole of Antarctica. The distribution of fresh water in the Southern Ocean and its partitioning between the liquid and solid phases is therefore poorly constrained. Here we estimate the mass balance components for all ice shelves in Antarctica, using satellite measurements of calving flux and grounding-line flux, modelled ice-shelf snow accumulation rates and a regional scaling that accounts for unsurveyed areas. We obtain a total calving flux of 1,321 ± 144 gigatonnes per year and a total basal mass balance of −1,454 ± 174 gigatonnes per year. This means that about half of the ice-sheet surface mass gain is lost through oceanic erosion before reaching the ice front, and the calving flux is about 34 per cent less than previous estimates derived from iceberg tracking. In addition, the fraction of mass loss due to basal processes varies from about 10 to 90 per cent between ice shelves. We find a significant positive correlation between basal mass loss and surface elevation change for ice shelves experiencing surface lowering8 and enhanced discharge. We suggest that basal mass loss is a valuable metric for predicting future ice-shelf vulnerability to oceanic forcing."

- "Calving fluxes and basal melt rates of Antarctic ice shelves." Depoorter et al. *Nature (2013) Published online 15 September 2013*

# Leaked IPCC draft

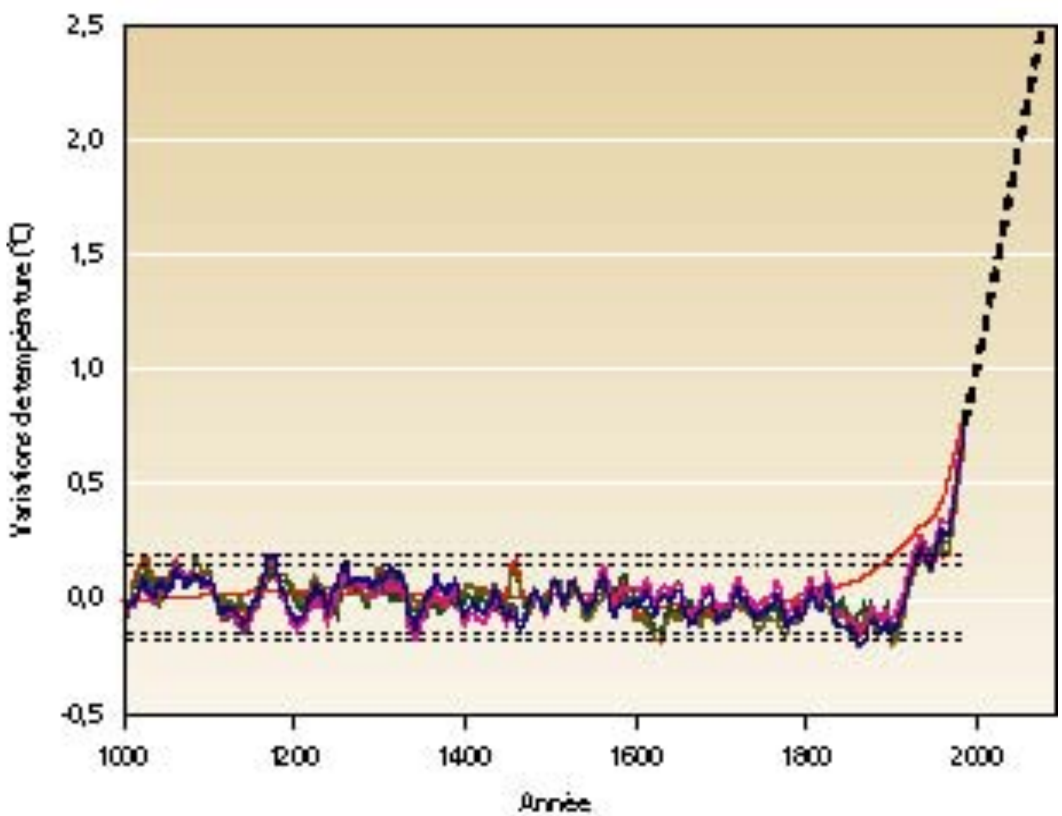
- **Climate change will reduce renewable surface water and groundwater resources significantly in most dry subtropical regions, exacerbating competition for water among sectors**
- **A large fraction of terrestrial and freshwater species faces increased extinction risk under projected climate change during and beyond the 21st century, especially as climate change interacts with other pressures, such as habitat modification, over-exploitation, pollution, and invasive species**
- **Due to sea-level rise throughout the 21st century and beyond, coastal systems and low-lying areas will increasingly experience adverse impacts such as submergence, coastal flooding, and coastal erosion**
- **By 2100, due to climate change and development patterns and without adaptation, hundreds of millions of people will be affected by coastal flooding and displaced due to land loss**
- **Ocean acidification poses risks to ecosystems, especially polar ecosystems and coral reefs, associated with impacts on the physiology, behavior, and population dynamics of individual species**
- **Without adaptation, local temperature increases of 1°C or more above preindustrial levels are projected to negatively impact yields for the major crops (wheat, rice, and maize) in tropical and temperate regions, although individual locations may benefit**

# Leaked IPCC document

- **Heat stress, extreme precipitation, inland and coastal flooding, and drought and water scarcity pose risks in urban areas for people, assets, economies, and ecosystems, with risks amplified for those lacking essential infrastructure and services or living in exposed areas**
- **Major future rural impacts will be felt in the near-term and beyond through impacts on water supply, food security, and agricultural incomes, including shifts in production of food and non-food crops in many areas of the world**
- **Global mean temperature increase of 2.5°C above preindustrial levels may lead to global aggregate economic losses between 0.2 and 2.0% of income**
- **Until mid-century, climate change will impact human health mainly by exacerbating health problems that already exist (very high confidence), and climate change throughout the 21st century will lead to increases in ill-health in many regions, as compared to a baseline without climate change**
- **Climate change indirectly increases risks from violent conflict in the form of civil war, inter-group violence, and violent protests by exacerbating well-established drivers of these conflicts such as poverty and economic shocks**
- **Throughout the 21st century, climate change impacts will slow down economic growth and poverty reduction, further erode food security, and trigger new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger**

# Upcoming global warming

5.17

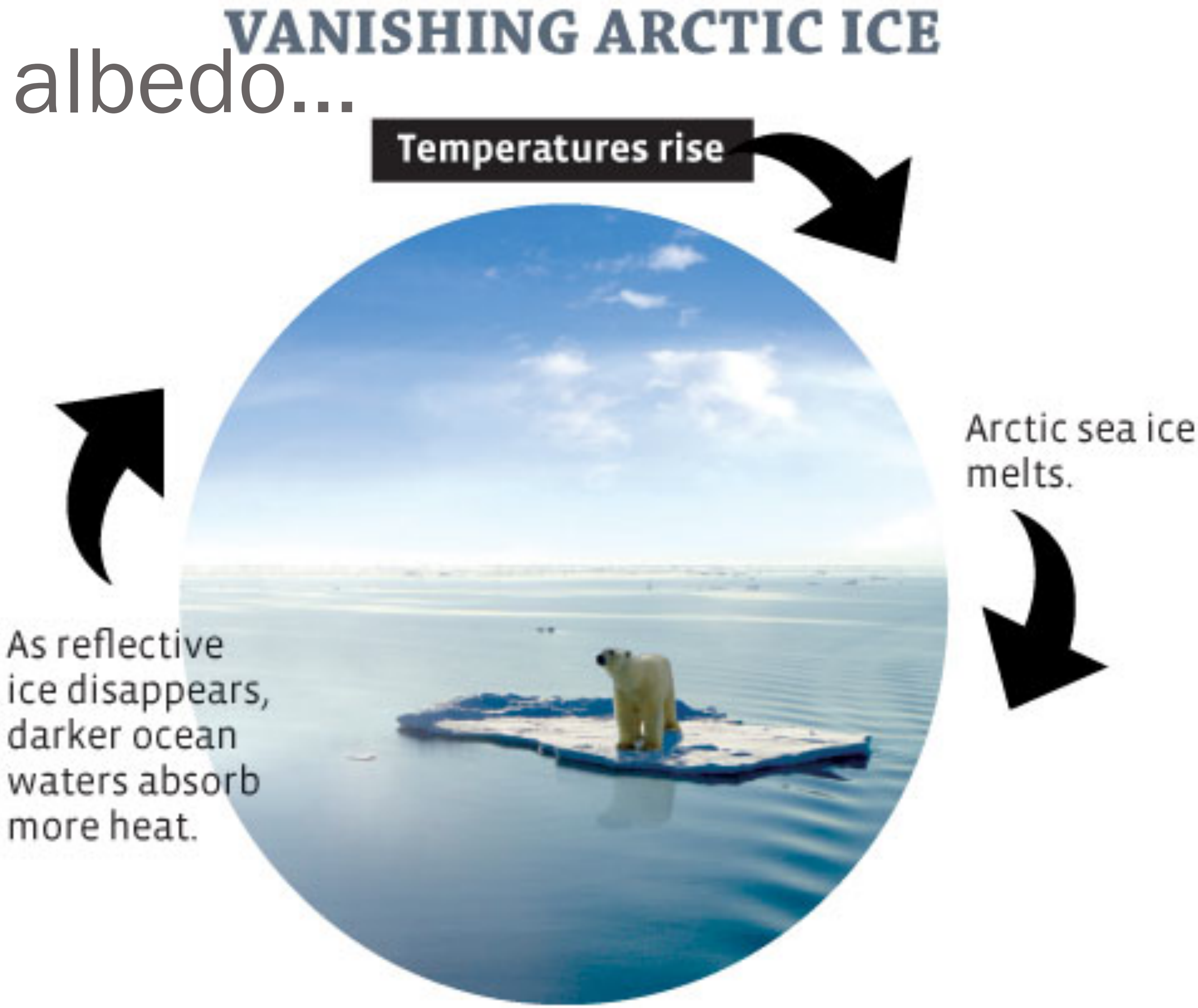



*« We already have in bank a 2,4˚C global warming in the XXIst century even with the most ambitious GHG reduction programs, it is unavoidable. »* . (Ramanhatan, V et Y. Feng (2008) *On avoiding dangerous anthropogenic interference with the climate system: Formidable challenge ahead* PNAS, **105**:58:14245-14250

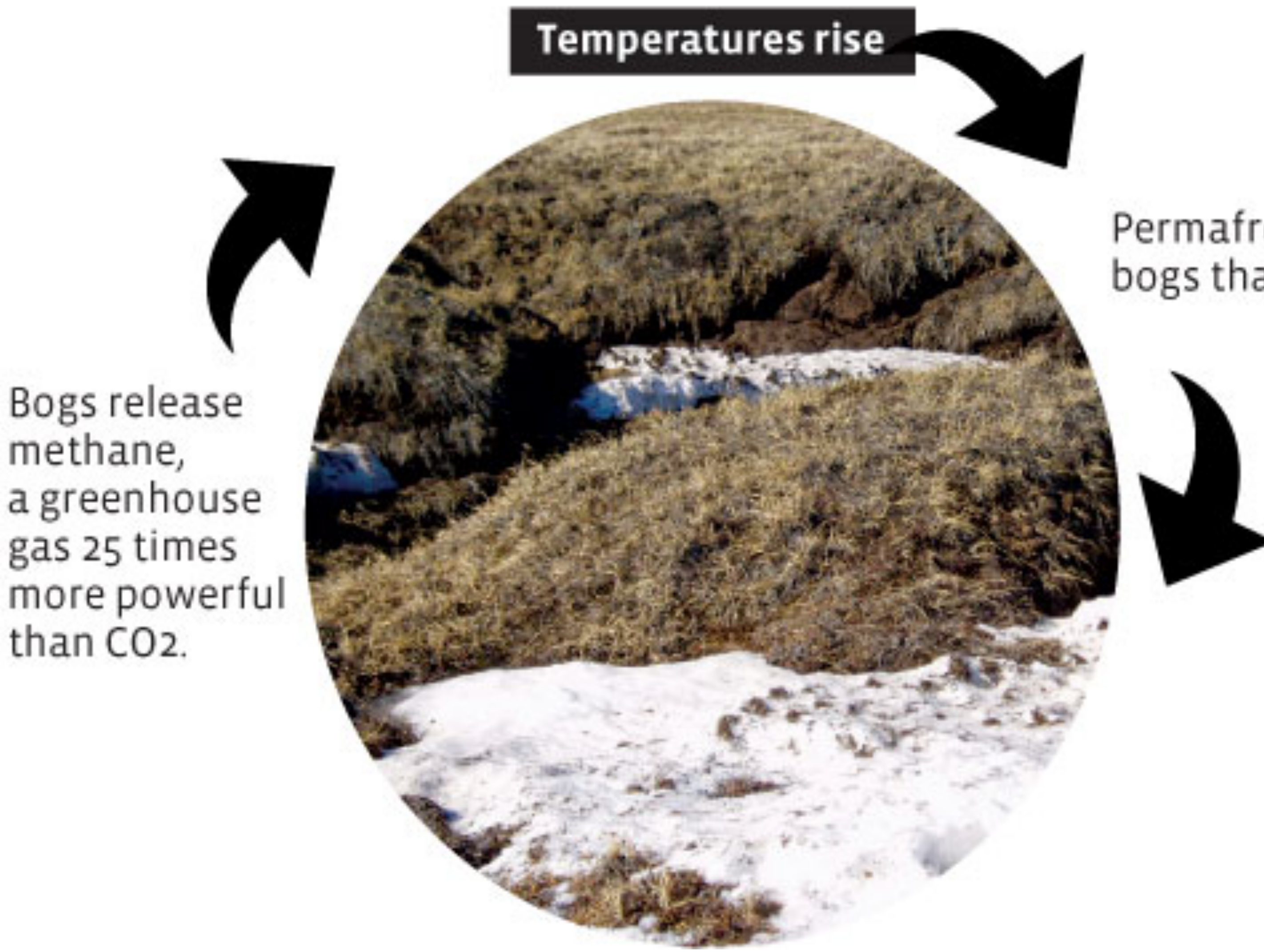
*« The Copenhagen accord is not going to influence significantly the GHG emission patterns towards 2020 »* OECD Environmental trends, 2012

# Positive feedback loops

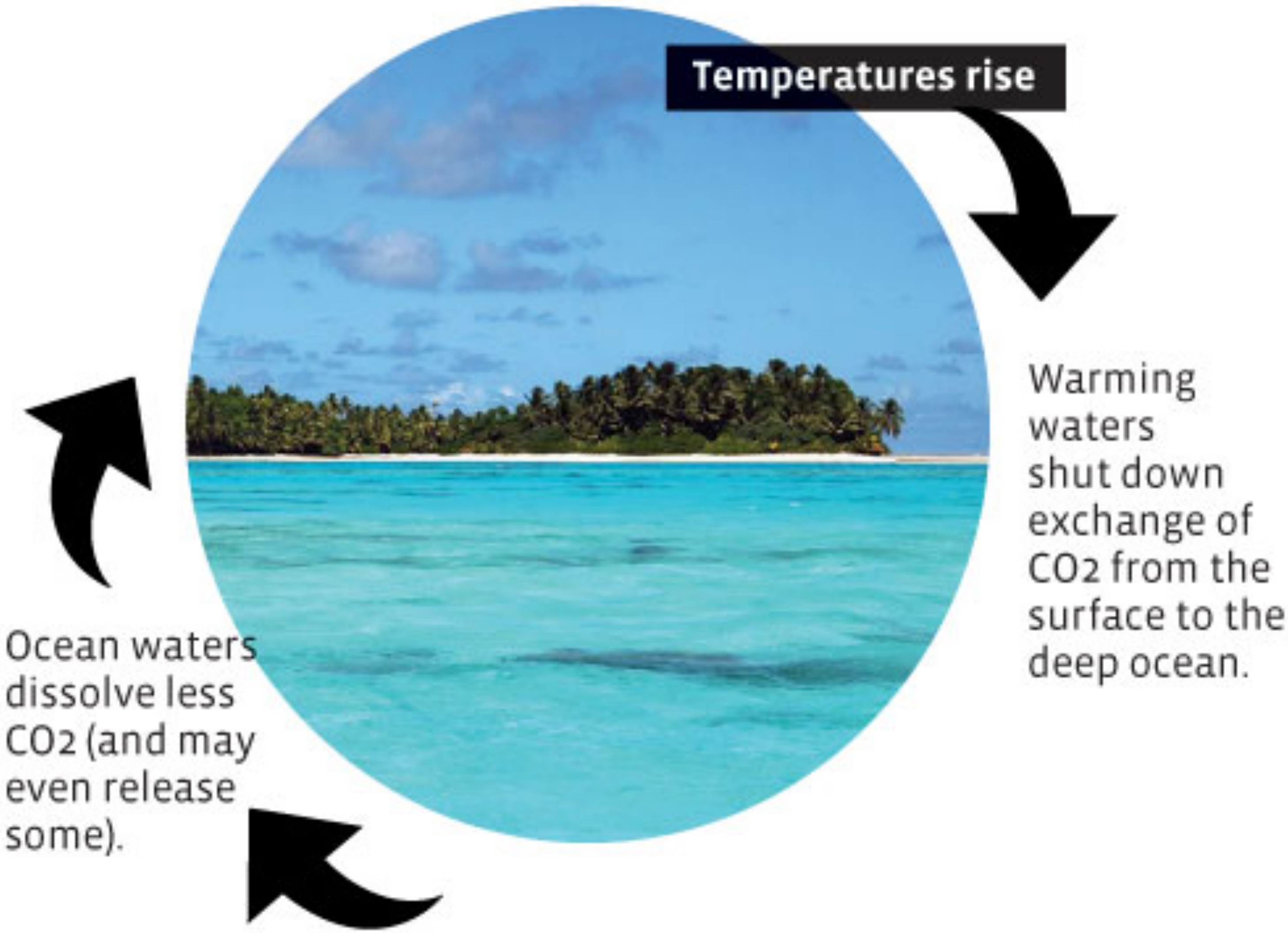
# Ice albedo...

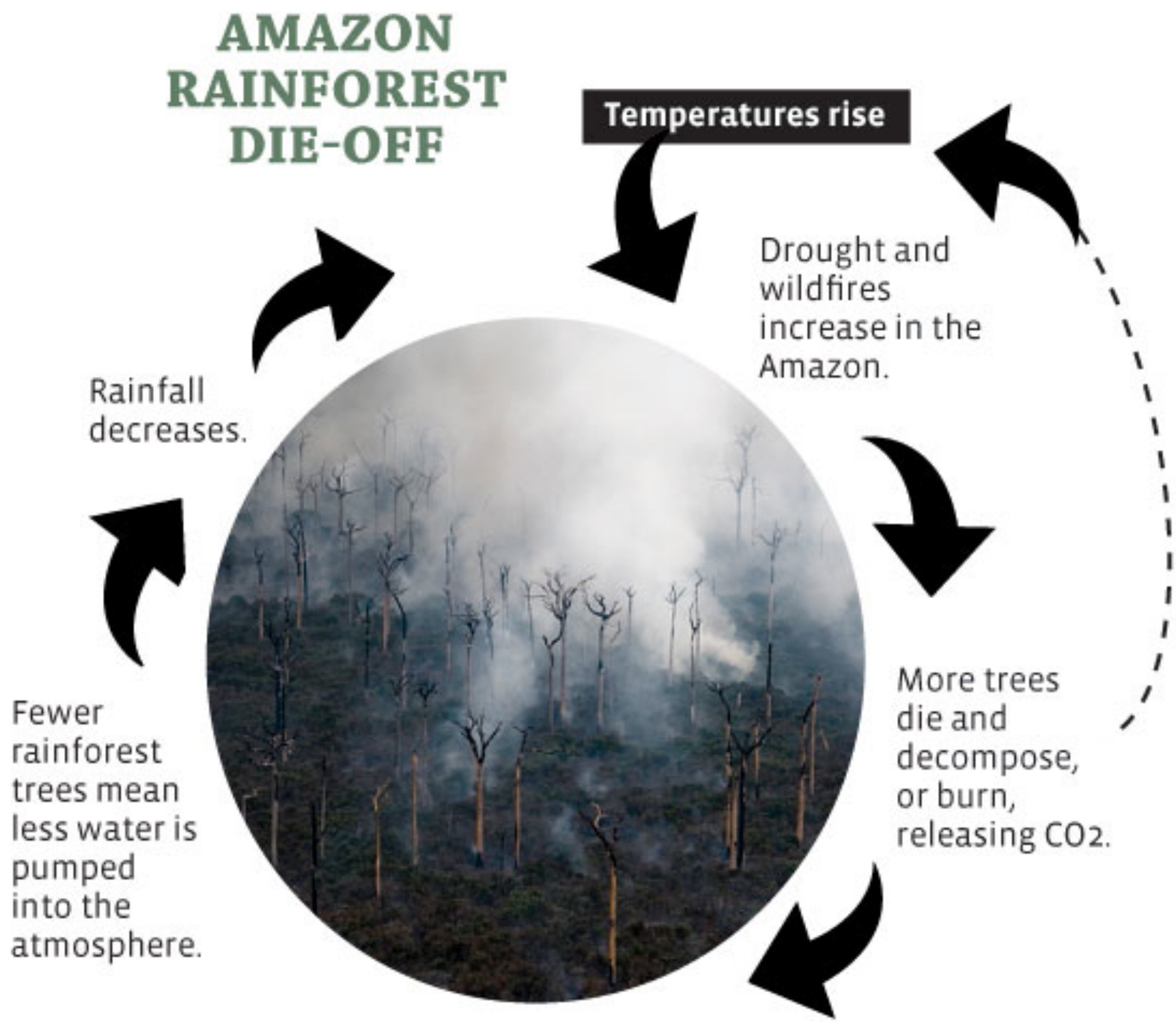

VANISHING ARCTIC ICE
Temperatures rise
Arctic sea ice melts.
As reflective ice disappears, darker ocean waters absorb more heat.

# MELTING PERMAFROST

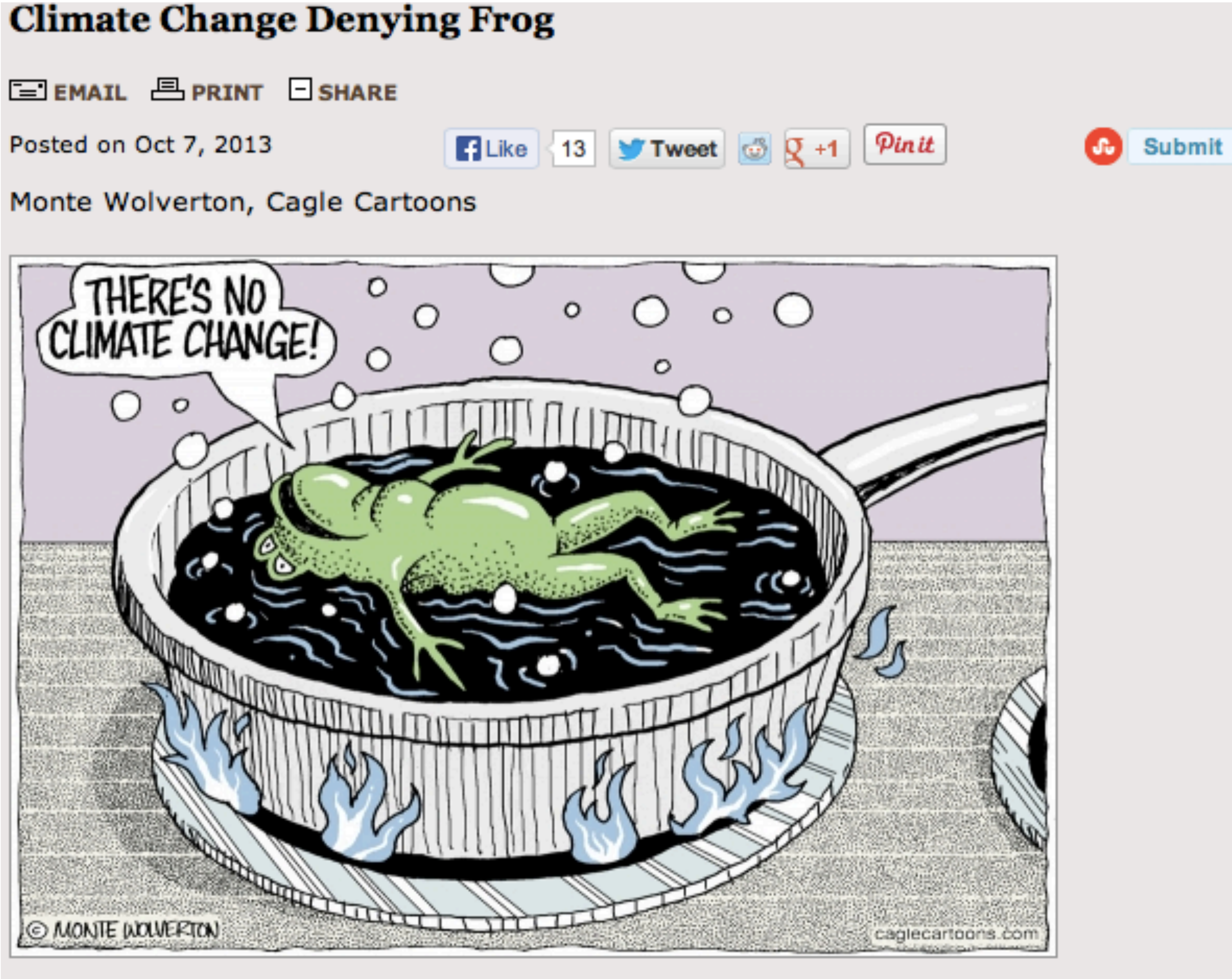


# CLOGGING THE OCEAN SINK




AMAZON RAINFOREST DIE-OFF
Temperatures rise
Drought and wildfires increase in the Amazon.
More trees die and decompose, or burn, releasing CO2.
Fewer rainforest trees mean less water is pumped into the atmosphere.
Rainfall decreases.

# Welcome back



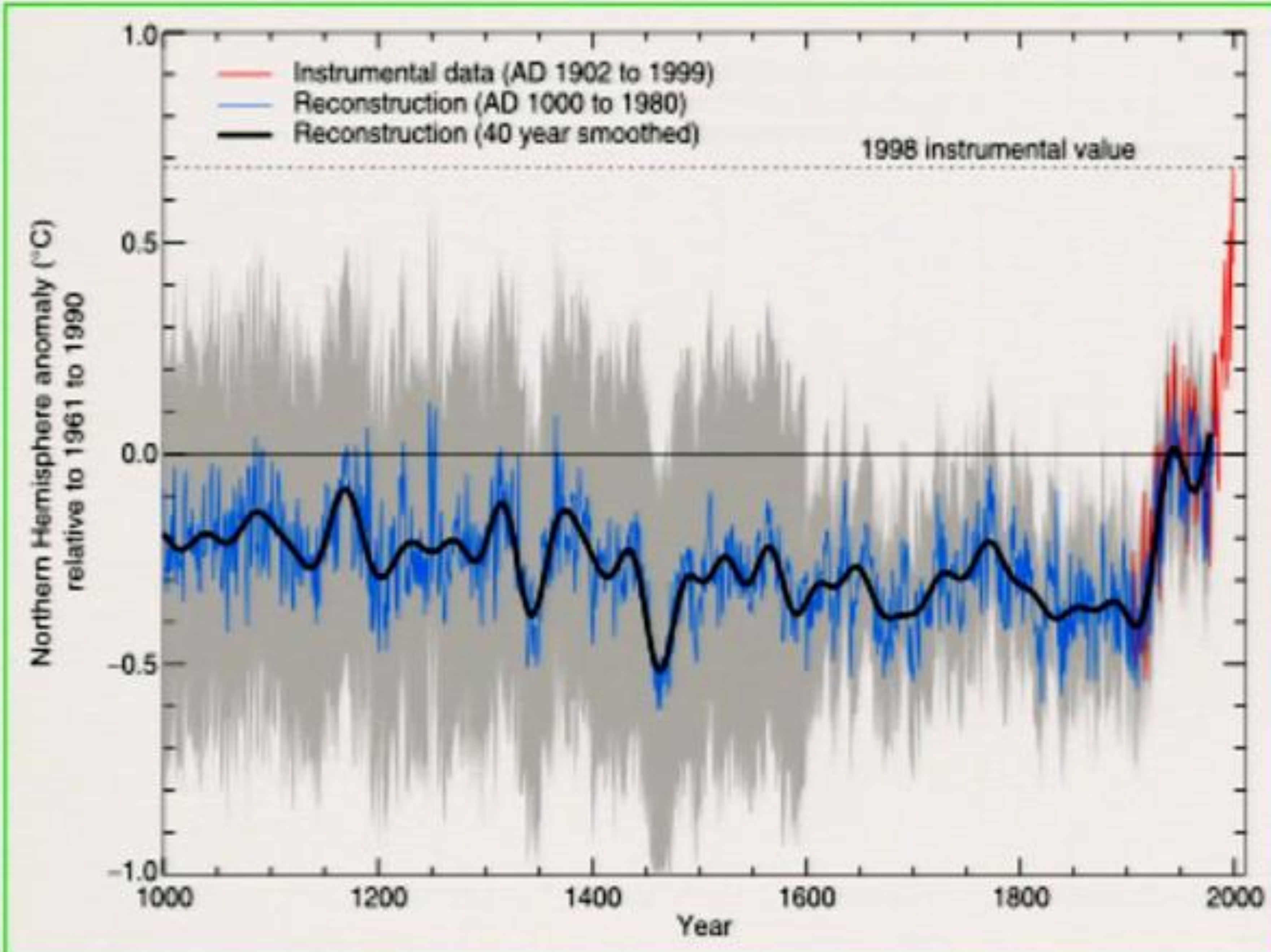
# Global warming potential

- a relative measure of how much heat a greenhouse gas traps in the atmosphere
  - Amount of heat trapped by a certain mass of the gas – compared to the amount of heat trapped by a similar mass of $CO_2$
  - Calculated over a specific time interval (20, 100, 500 years)
  - Expressed as a factor of $CO_2$
  - 20 year GWP of methane is 86 → if the same mass of methane and $CO_2$ were introduced into the atmosphere, methane would trap 86 times more heat than $CO_2$ over the next 20 years
  - Source: IPCC, 2013, Physical Science Basis

# Looking to the Future

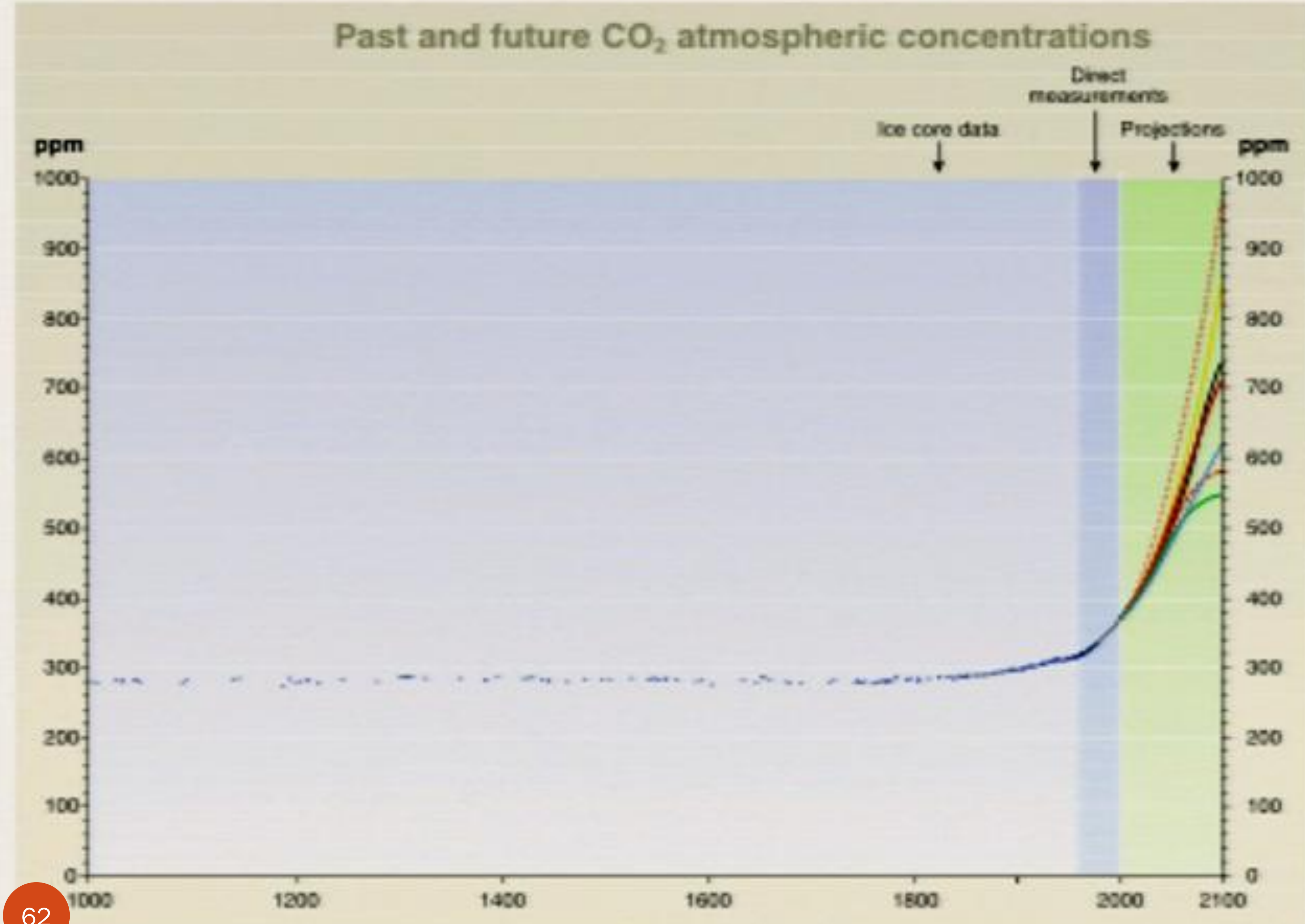
- What will happen to concentrations of climate altering gases such as carbon dioxide if we fail to act?

- What will happen to planetary temperatures if we fail to act?



Instrumental data (AD 1902 to 1999)
Reconstruction (AD 1000 to 1980)
Reconstruction (40 year smoothed)
1998 instrumental value
Northern Hemisphere anomaly (°C) relative to 1961 to 1990
1.0
0.5
0.0
−0.5
−1.0
1000
1200
1400
1600
1800
2000
Year

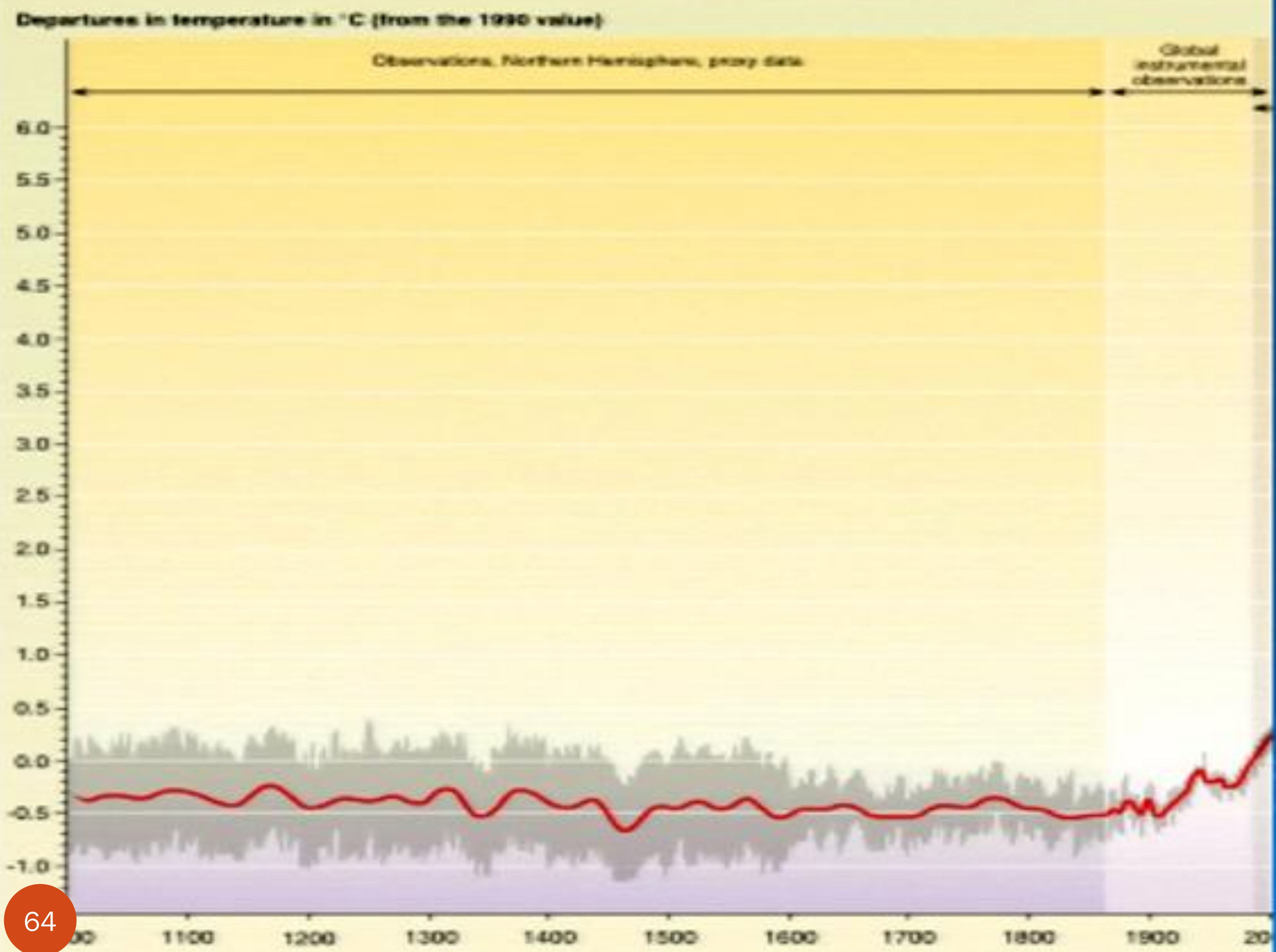
# Past and future $CO_2$ atmospheric concentration



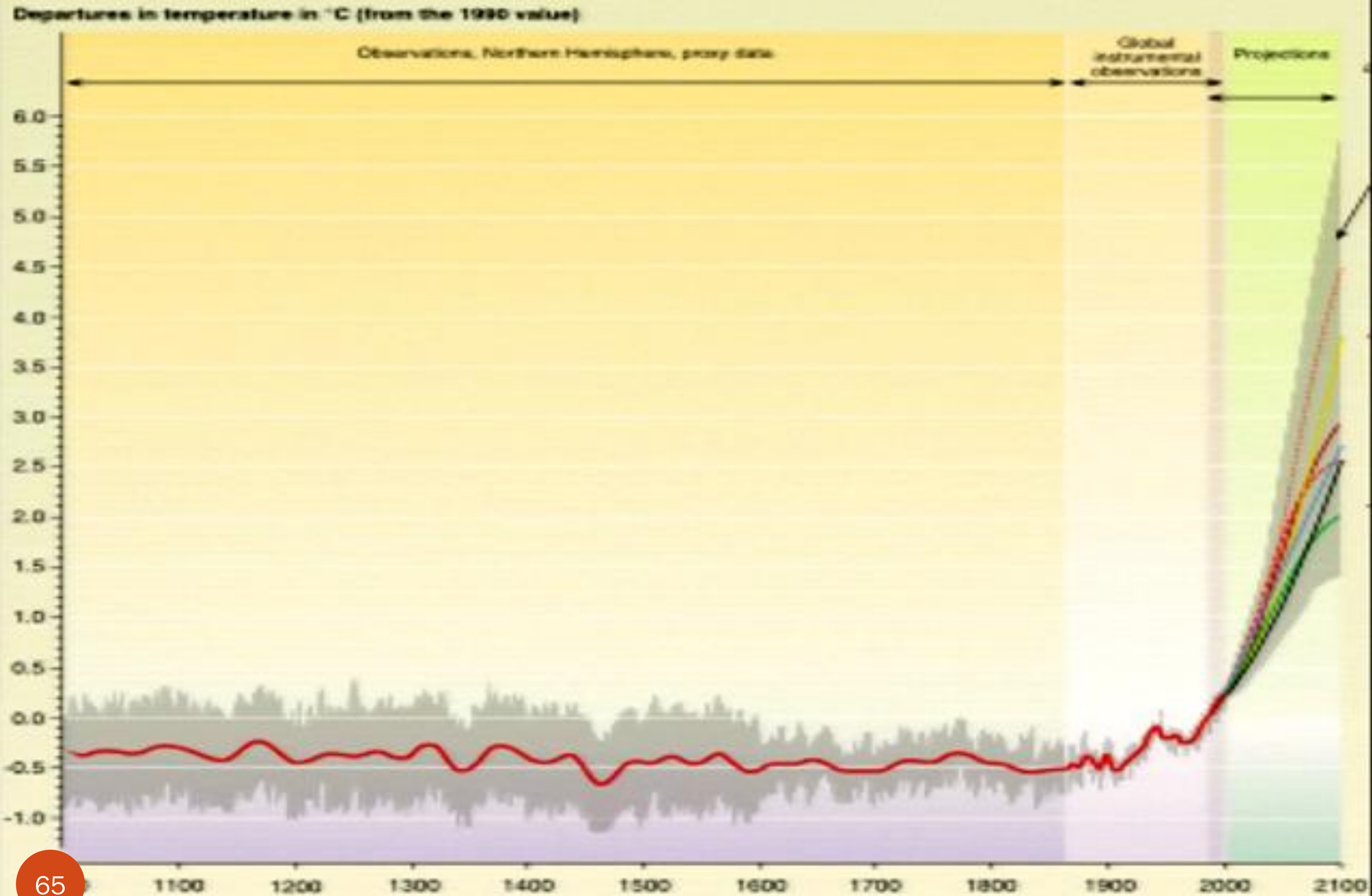
Past and future $CO_2$ atmospheric concentrations
Direct measurements
Ice core data
Projections
ppm
ppm
1000
900
800
700
600
500
400
300
200
100
0
1000
1200
1400
1600
1800
2000
2100

| | |
|---|---|
| **1.93** **ppm per year** parts per million | **Atmospheric $CO_2$ \| Average Annual Rise \| 1994 - 2003**<br>**September Data Only**<br>**Calculations by CO2Now are based on Scripps $CO_2$ data (Mauna Loa Observatory) dated October 8, 2013** |
| **2.03** **ppm per year** parts per million | **Atmospheric $CO_2$ \| Average Annual Rise \| 2004 - 2013**<br>**September Data Only** The rate of increase for this past decade is higher than any decade since the start of the atmospheric $CO_2$ instrument record in March 1958.<br>**Calculations are based on Scripps $CO_2$ data (Mauna Loa Observatory) dated October 8, 2013**<br>More Info:<br>$CO_2$Now \| Acceleration of Atmospheric $CO_2$ |

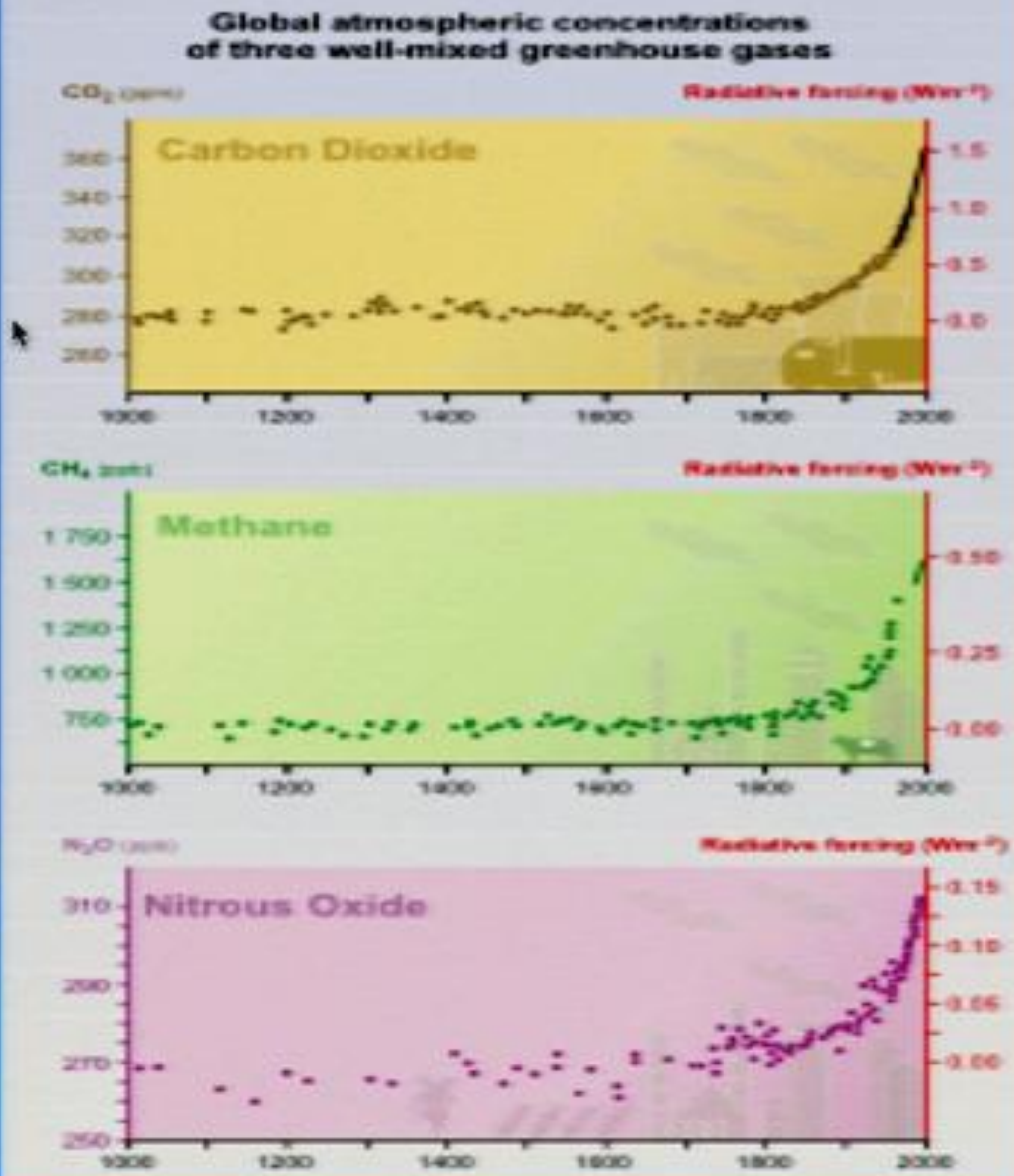
# Variations of the Earth's surface temperature: years 1000 t



# Variations of the Earth's surface temperature: years 1000 to 2100



# Indicators of the human influence on the atmosphere during the industrial era

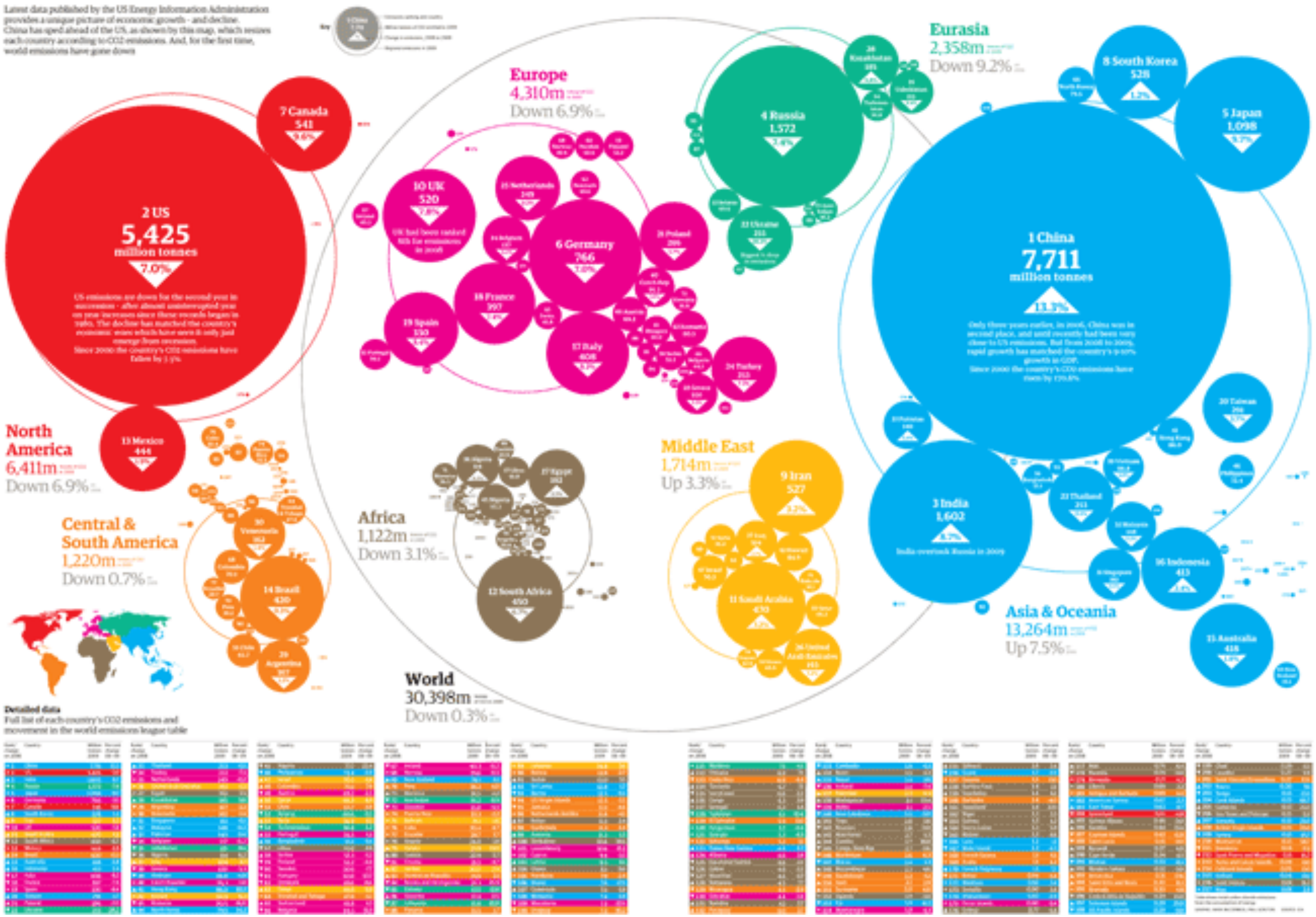


| | |
|---|---|
| **280 ppm** | **Atmospheric CO2 \| Pre-Industrial Revolution**<br>Atmospheric CO2 was stable at about 280 ppm for almost 10,000 years until 1750. |
| **300 ppm** | **Atmospheric CO2 \| Highest level in at least 2.1 million years (pre-industrial)**<br>Circa 1912, atmospheric CO2 levels breached the 300 ppm threshold for the first time in at least 2.1 million years. |
| **350 ppm** | **Atmospheric CO2 \| Upper Safety Limit**<br>*"If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO2 will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that… If the present overshoot of this target CO2 is not brief, there is a possibility of seeding irreversible catastrophic effects."*<br>~ J Hansen et al<br>Source 1: Open Atmospheric Science \| *Target Atmospheric CO2* \| 2008<br>Source 2: Nature \| A Safe Operating Space for Humanity \| 2009<br>Source 3: SRC Ecology & Society \| Planetary Boundaries \| 2009<br>More Info: 350.org \| Science of 350 |
| **391.14 ppm** | **Atmospheric CO2 \| September 2012 \| Mauna Loa Observatory**<br>Data dated **October 8 2013** at Scripps.<br>$CO_2$Now links to source datasets \| Atmospheric $CO_2$ data from NOAA & Scripps |
| **393.31 ppm** | **Atmospheric CO2 \| September 2013 \| Mauna Loa Observatory**<br>**Preliminary data released**<br>Data dated **October 8, 2013** at Scripps<br>**$CO_2$Now links to source datasets \| Atmospheric $CO_2$ data from NOAA & Scripps** |
| **885 ppm** | **Atmospheric CO2 \| Projection for Year 2100**<br>This projection is made in C-ROADS, a scientifically reviewed climate simulator. The analysis accounts for the voluntary emissions reductions pledges of parties to the UNFCCC. This CO2 level represents a global temperature increase of about 4.5 °C.<br>Source: Climate Interactive Analysis as of April 2013<br>Implications: The Royal Society \| Four Degrees and Beyond \| 2011 |

# Official prophecy of doom: Global warming will cause widespread conflict, displace millions of people and devastate the global economy


Leaked draft report from UN panel seen by The Independent is most comprehensive investigation into impact of climate change ever undertaken - and it's not good news

# An atlas of pollution: the world in carbon dioxide emissions



# Donuts, Deodorants, Deforestation





- Worldwide – destruction of tropical forests account for ~10% of annual global warming emissions
- Palm oil plantations expanding – (1) tropical forests; (2) carbon-rich peatlands (Indonesia and Malaysia) – peat stores 18-20 times the carbon stored in trees; when drained…

- Report by the Union of Concerned Scientists released this month

© Flickr/Ryan Woo- CIFOR

*This peat swamp vegetation (in Kalimantan, Indonesia) is in the process of being cleared, drained, and burned to prepare the land for growing oil palm trees. Destruction of peat swamp forests for palm oil production is particularly harmful to the climate, as it releases the carbon stored both in the rich peat soils and in the forest vegetation they support.*



*The animal pictured is a critically endangered Sumatran orangutan—only an estimated 7,000 remain in the wild. As oil palm plantations encroach on tropical forests, orangutans and many other forest-dependent species lose their habitat and are at risk of extinction.*

© Rhett Butler/Mongabay.com

*An oil palm plantation abuts a natural forest. Because of complexities in the palm oil supply chain and deficiencies in pertinent standards, producers regularly cut down existing forests to make room for plantations without being accountable to end users. Companies need to overcome such problems—to develop the capability to trace palm oil along the length of the supply chain—to ensure that their palm oil is deforestation- and peat-free.*

| Company | Example Brands | Total Score (out of a possible 100) | Deforestation-free | Peat-free | Traceability | Transparency | Early Action |
|---|---|---|---|---|---|---|---|
| | | | (out of a possible 20) | | | | |
| **Nestlé** | Toll House<br>PowerBar | 85.5 | 20 | 20 | 15 | 20 | 10.5 |
| **Unilever** | Ben and Jerry's<br>Popsicle<br>Slimfast | 83.5 | 20 | 20 | 15 | 20 | 8.5 |
| **Mondelēz** | Oreo<br>Ritz<br>Nutter Butter | 68.6 | 20 | 15 | 15 | 13 | 5.6 |
| **Kellogg's** | Pop-Tarts<br>Nutri-Grain | 52.8 | 10 | 15 | 10 | 10 | 7.8 |
| **Danone** | Danimals | 51.5 | 10 | 5 | 15 | 13 | 8.5 |
| **General Mills** | Pillsbury<br>Nature Valley | 42.6 | 10 | 15 | 0 | 13 | 4.6 |
| **HJ Heinz** | Ore-Ida<br>Smart Ones | 37.1 | 10 | 5 | 0 | 13 | 9.1 |
| **PepsiCo** | Quaker | 33.7 | 10 | 5 | 5 | 13 | 0.7 |
| **ConAgra Foods** | Act II popcorn<br>Marie Callender's | 35.5 | 10 | 5 | 5 | 13 | 2.5 |
| **Kraft Foods** | Cool Whip<br>JELL-O | 0 | 0 | 0 | 0 | 0 | 0 |

**Strong commitment** **Some commitment** **Little commitment** **No commitment**

| Company | Restaurant Chains | Total Score (out of a possible 100) | Deforestation-free | Peat-free | Traceability | Transparency | Early Action |
|---|---|---|---|---|---|---|---|
| | | | (out of a possible 20) | | | | |
| Subway | - | 38 | 20 | 15 | 0 | 3 | 0 |
| McDonald's | - | 21.1 | 0 | 0 | 10 | 10 | 1.1 |
| Burger King | - | 0 | 0 | 0 | 0 | 0 | 0 |
| CKE Restaurants | Carl's Jr./Green Burrito<br>Hardee's/Red Burrito | 0 | 0 | 0 | 0 | 0 | 0 |
| Dairy Queen | - | 0 | 0 | 0 | 0 | 0 | 0 |
| Domino's | - | 0 | 0 | 0 | 0 | 0 | 0 |
| Dunkin' Brands | Baskin-Robbins<br>Dunkin' Donuts | 0 | 0 | 0 | 0 | 0 | 0 |
| Starbucks | - | 0 | 0 | 0 | 0 | 0 | 0 |
| Wendy's | - | 0 | 0 | 0 | 0 | 0 | 0 |
| Yum! Brands | KFC<br>Pizza Hut<br>Taco Bell | 0 | 0 | 0 | 0 | 0 | 0 |

Strong commitment · Some commitment · Little commitment · No commitment

# Other sources

- Co2now.org
- Climatechange2013.org

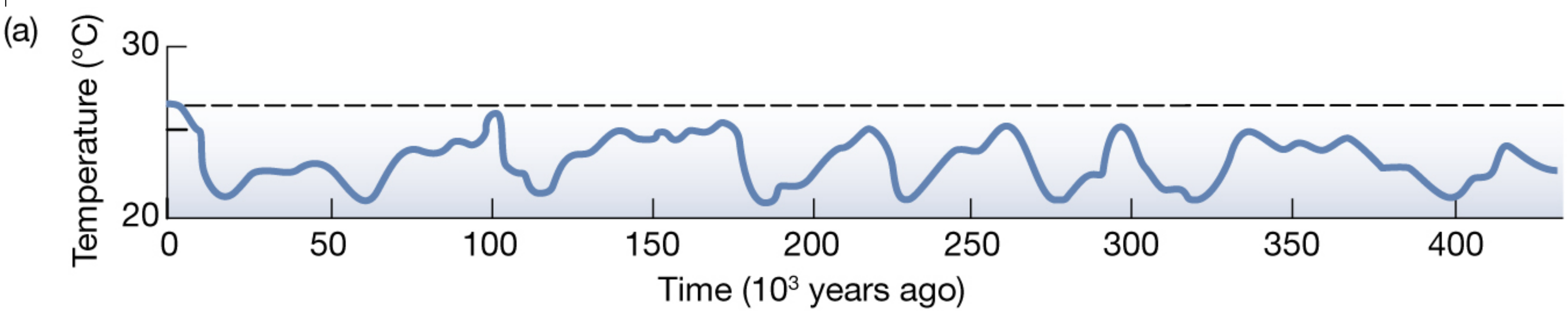
# Climate and biology

# Climate and Biology

- Climate is a fundamental factor influencing biology
- Thus…
- Can use biology to learn about certain aspects of climate
- And
- Biology can influence climate

# From cold climate…

- For most of the past 2-3 million years, the Earth has been quite cold
- Evidence from the distribution of oxygen isotopes in cores taken from deep ocean floor → as many as 16 glacial cycles, each lasting up to 125,000 years with intervals of only 10,000 to 20,000 years



# … to a warmer climate

- During the 20,000 years since the peak of the last glaciation, global temperatures have risen by ~ 8 C
- Analysis of buried pollen can show how vegetation has changed during this period
- Migrations of trees in eastern North America from 18,000 years ago to present are known from pollen grains deposited in bogs and lakes:
  - the compositions of communities shifted as species migrated across the landscape
  - in particular, the composition of forests during the past 18,000 years has:
    - included combinations of species that do not occur today
    - lacked combinations of species that do occur at present

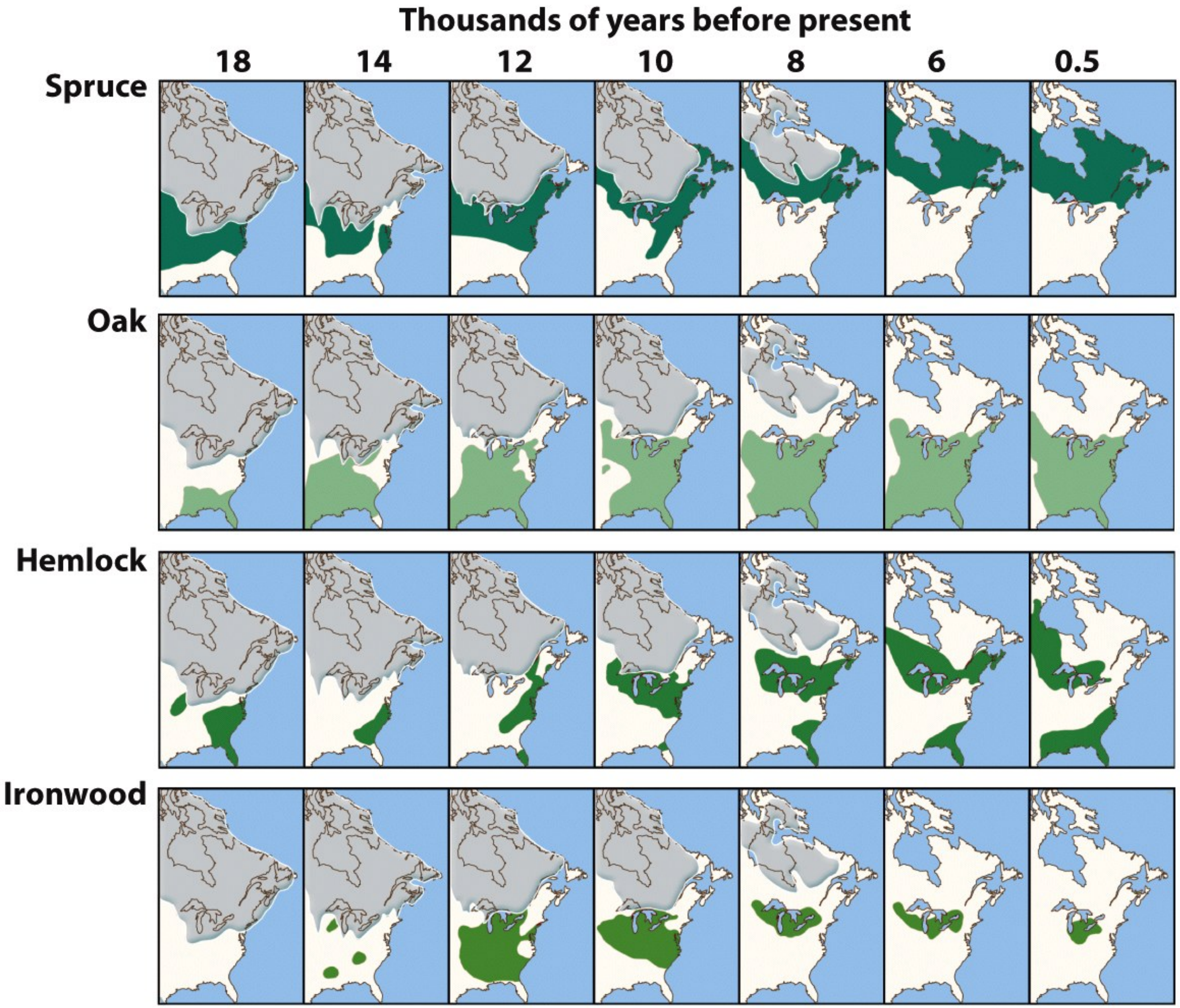



**Figure 21.8**
***The Economy of Nature*, Sixth Edition**

# Climate change…

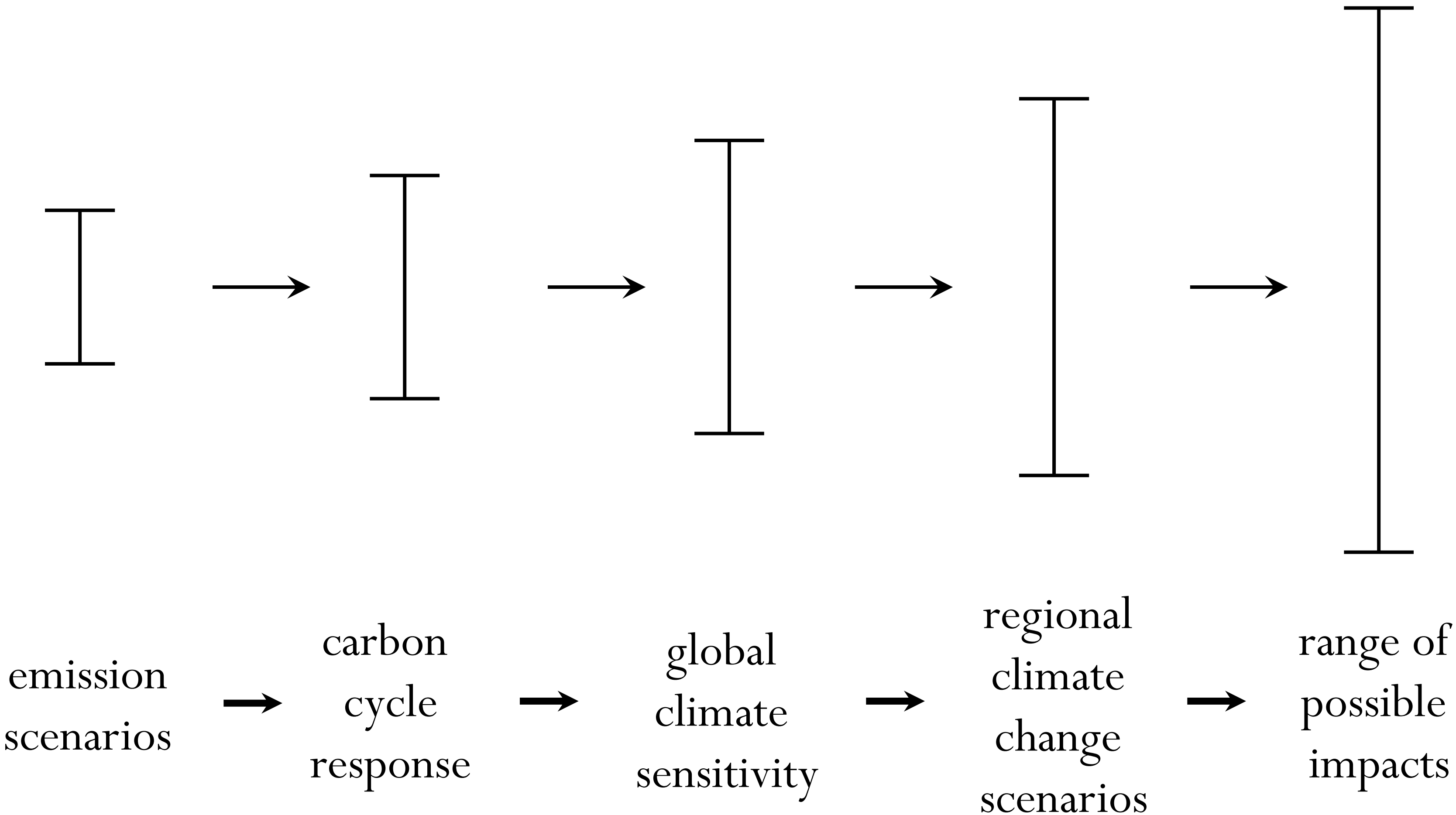
- Naturally – with the change in plants → change in animals
- Even in regions never glaciated, pollen deposits record complex changes in distribution
  - In the mountains of Nevada – woody species show different patterns of change in elevational range
  - Species composition of vegetation is continually changing – and is still changing
- So what could happen in the next 100 years?
  - Temperatures predicted to rise between 2 to 7 C in 100 years
  - Postglacial warming of 8 C occurred over 20,000 years
  - Now: trees will have to move at 300-500 km/100 years
  - Typically: trees move 20 – 40 km/100 years

- “On every continent except Antarctica there are examples of deserted settlements and evidence of long-extinct civilizations. These are societies that once flourished but have now gone, due primarily to a change in climate.”

# The projected impacts (beyond the observations)

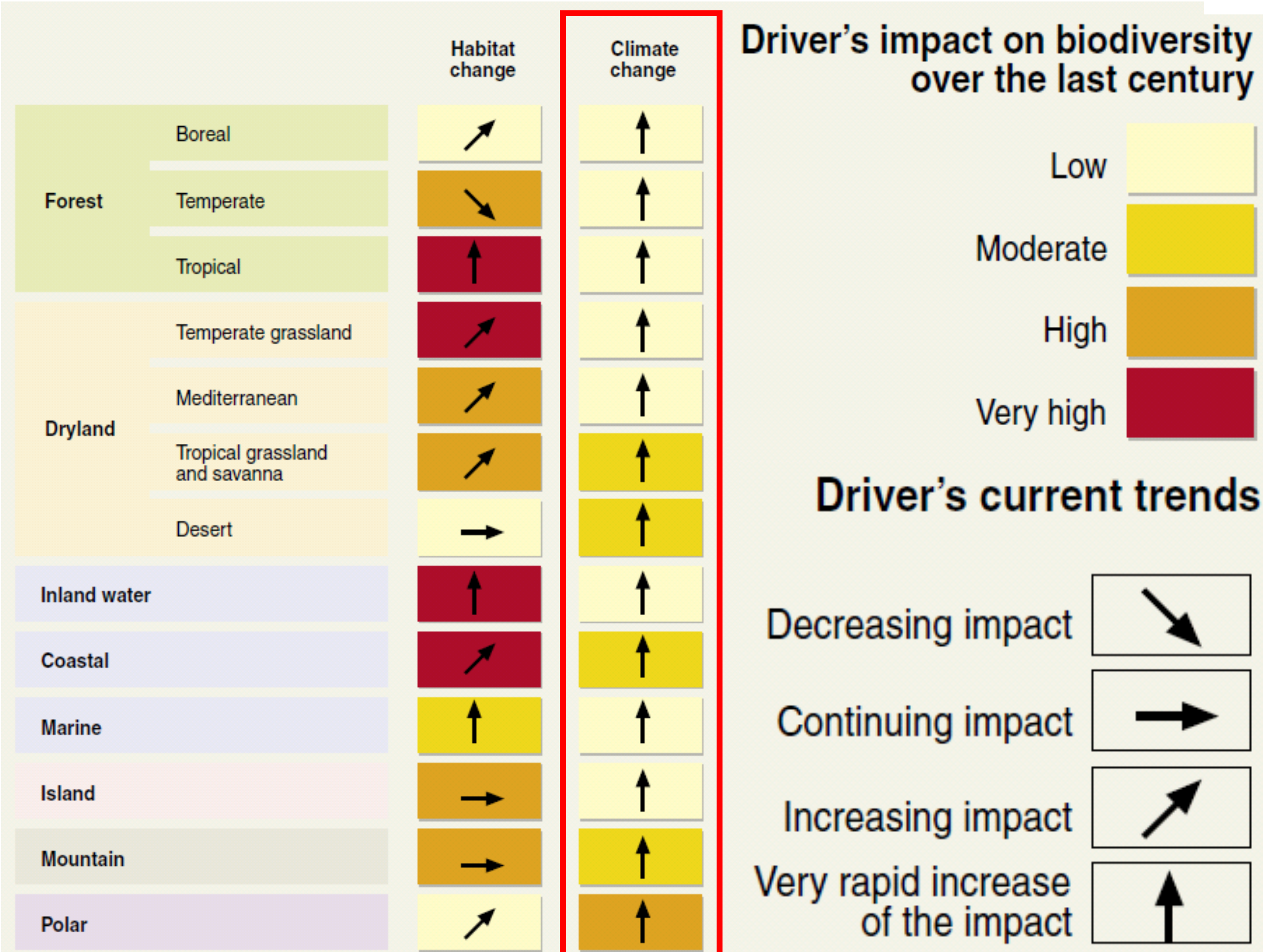
# Cascade of Uncertainty

There is an "explosion" of uncertainty as you go to the regional scale and potential impacts.




(Adapted from Moss and Schneider 2000)

Ecosystems and Human Well-being: Synthesis.
(Millennium Ecosystem Assessment, 2005)



Ecosystems and Human Well-being: Synthesis.
(Millennium Ecosystem Assessment, )

| | | Habitat change | Climate change | Invasive species | Over-exploitation | Pollution (nitrogen, phosphorus) |
|---|---|---|---|---|---|---|
| Forest | Boreal | ↗ | ↑ | ↗ | → | ↑ |
| | Temperate | ↘ | ↑ | ↑ | → | ↑ |
| | Tropical | ↑ | ↑ | ↑ | ↗ | ↑ |
| Dryland | Temperate grassland | ↗ | ↑ | → | → | ↑ |
| | Mediterranean | ↗ | ↑ | ↑ | → | ↑ |
| | Tropical grassland and savanna | ↗ | ↑ | ↑ | → | ↑ |
| | Desert | → | ↑ | → | → | ↑ |
| Inland water | | ↑ | ↑ | ↑ | → | ↑ |
| Coastal | | ↗ | ↑ | ↗ | ↗ | ↑ |
| Marine | | ↑ | ↑ | → | ↗ | ↑ |
| Island | | → | ↑ | → | → | ↑ |
| Mountain | | → | ↑ | → | → | ↑ |
| Polar | | ↗ | ↑ | → | ↗ | ↑ |

# Projected impacts on the Arab world

- The Mediterranean Basin -


California
Mediterranean
Basin
Chile
South
Africa
Australia

# Climate change impacts in the Mediterranean basin - what the IPCC 4th Assessment Report has found:

- Mediterranean ecosystems may be among the most impacted by global change drivers.
- **Range size reductions increase species' extinction risks, with up to 30 to 40% facing increased extinction probabilities beyond the year 2050.**
- Temperature increases greater than about 2°C could result in desert and grassland expansion at the expense of shrublands, and mixed deciduous forest expansion at the expense of evergreen conifer forest [4.4.4]
  - **60 and 80% of current species are projected not to persist in the southern European Mediterranean region if the global mean temperature increases 1.8°C.**
  - **.Any carbon fertilization due to rising atmospheric $CO_2$ appears unlikely to have a major impact in Mediterranean ecosystems over the next decades, especially because of consistent projections of reduced rainfall.**

- Semi-arid and arid areas are particularly exposed to the impacts of climate change on freshwater (high confidence) and will suffer a decrease of water resources due to climate change [3.4, 3.7].
  - **Less rainfall is projected for some Mediterranean regions which will exacerbate drought conditions. These conditions have already been observed in the eastern Mediterranean.**
  - **Greater fire frequencies are likely the in Mediterranean Basin regions under a warmer and drier climate.**

# Climate change impacts in the Mediterranean basin - what the IPCC 4th Assessment Report has found:

- Warmer and drier conditions are partly responsible for reduced forest productivity and increased forest fires. Both agriculture and forestry have shown vulnerability to recent trends in heat waves, droughts and floods [1.3.6].
- In response to warmer temperatures shifts have been noted in the kelp forests / macroalgae communities [1.3.4.3].
- Computed groundwater recharge decreases dramatically by more than 70% along the south rim of the Mediterranean Sea (reference climate normal 1961-1990 and the 2050s) [3.4.2]
- Most areas experience 20-34% increase in number ≥7day periods with Forest Fire Weather Index > 45: increased fire frequency converts forest & Macquis to scrub, causes more pest outbreaks with 2.6°C above pre-industrial levels [Table 4.1]
- Coastal vegetated wetlands are sensitive to climate change and long-term sea-level change [6.4.1.4]
- Increased sea temperatures may trigger large scale disease-related mortality events of dolphins in the Mediterranean [12.4.6].

# And our wines…

- "Climate change has already influenced the wine-making industry with a corresponding threat to Mediterranean ecosystems. Climate impacts everything from harvest quality and quantity to whether a vineyard can produce whites or red varieties. Because of the warmer climate, vineyards are being moved to higher elevations or to cooler coastlines"

- “Mediterranean ecosystems are among the most threatened on Earth. More than 41 percent of their land has been converted to farmland and urban uses. Worldwide, only 5 percent of their natural area is protected. Most people understand the plight of tropical rainforests, where habitat loss exceeds habitat protection by 2 to 1. In other words, for every acre of rainforest saved, two have been lost to conversion or development. In Mediterranean habitats, the disparity is much greater. **For every acre of Mediterranean habitat saved, eight acres have been permanently lost” (Shaw, 2010).**“By 2100, the Mediterranean biome is projected to experience the largest proportional loss of biodiversity of all terrestrial biomes due to its significant sensitivity to multiple biodiversity threats and interactions among these threats” (Klausmeyer and Shaw , 2009).

# The Arab region is projected to…

- Face an increase of 2 to 5.5 C in surface temperature by 2100
- Face a decrease in precipitation from 0 to 20%
- → shorter winters
- → dryer and hotter summers
- → higher rate of heat waves
- → higher level of weather variability
- → more frequent occurrence of extreme weather events

- recent studies found that the Arab region experienced an uneven increase in surface air temperature ranging from 0.2 to 2.0°C that occurred from 1970 to 2004

# Impact high…

- Semi-arid and arid regions are highly vulnerable to climate change
- If temperature gets higher
- If precipitation gets lower
- ➔ pressure on natural and physical systems would be intensified

# Focus on water impacts

# Impact on freshwater sources

# Status of freshwater here

- Reminder: most of the Arab countries are located in arid and semi-arid regions; low and limited water resources + high evaporation
- Total water resources = total renewable ground water + internal surface water resources + external surface water resources

# First order impacts…

- Mediterranean hydrological systems
  - Wetter winters
  - Dryer and hotter summers
  - Increase in evaporation from water bodies…
  - Increase Evapotranspiration from crops
- Egypt
  - Increase the potential irrigation demand by 6 to 16% by 2100

# Drought

# Drought frequency

- Increased during the last 20 to 40 years in Morocco, Tunisia, Algeria and Syria
  - Of the 22 drought years in the 20th century, 10 occurred in the last 20 years, and three were successive (1999, 2000, 2001) in Morocco
  - Recent droughts in Jordan and Syria worst ever recorded
- Varying conditions of water shortage in Lebanon in the last 10 years

# But not just droughts

# Yemen: recent floods (October 2008)

Dubbed the 'Manhatten of the desert', Shibam's 2,000-year-old mud-brick buildings are in danger of collapsing after recent floods

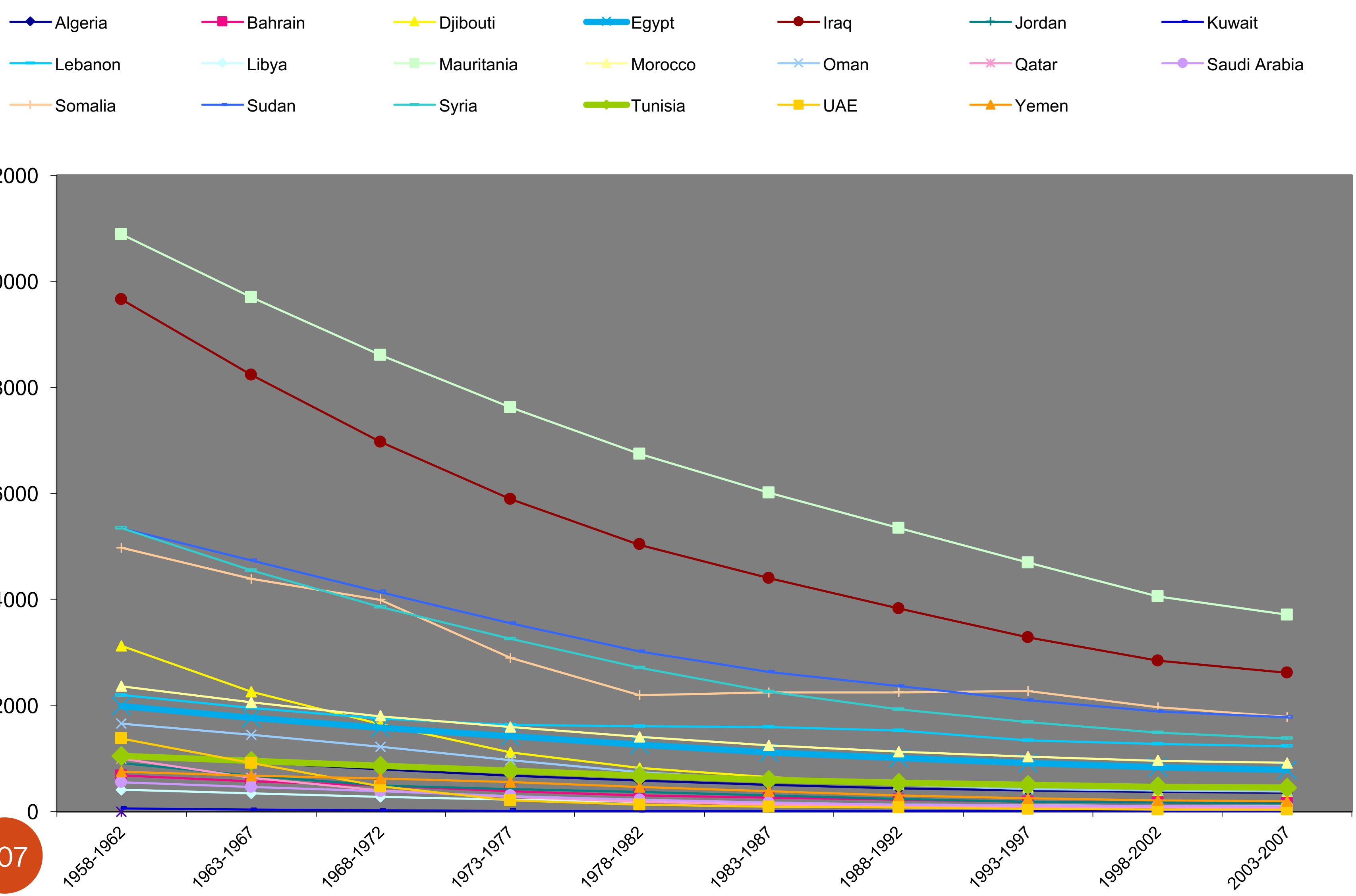
# Let’s look at water in more depth

How to study impacts?

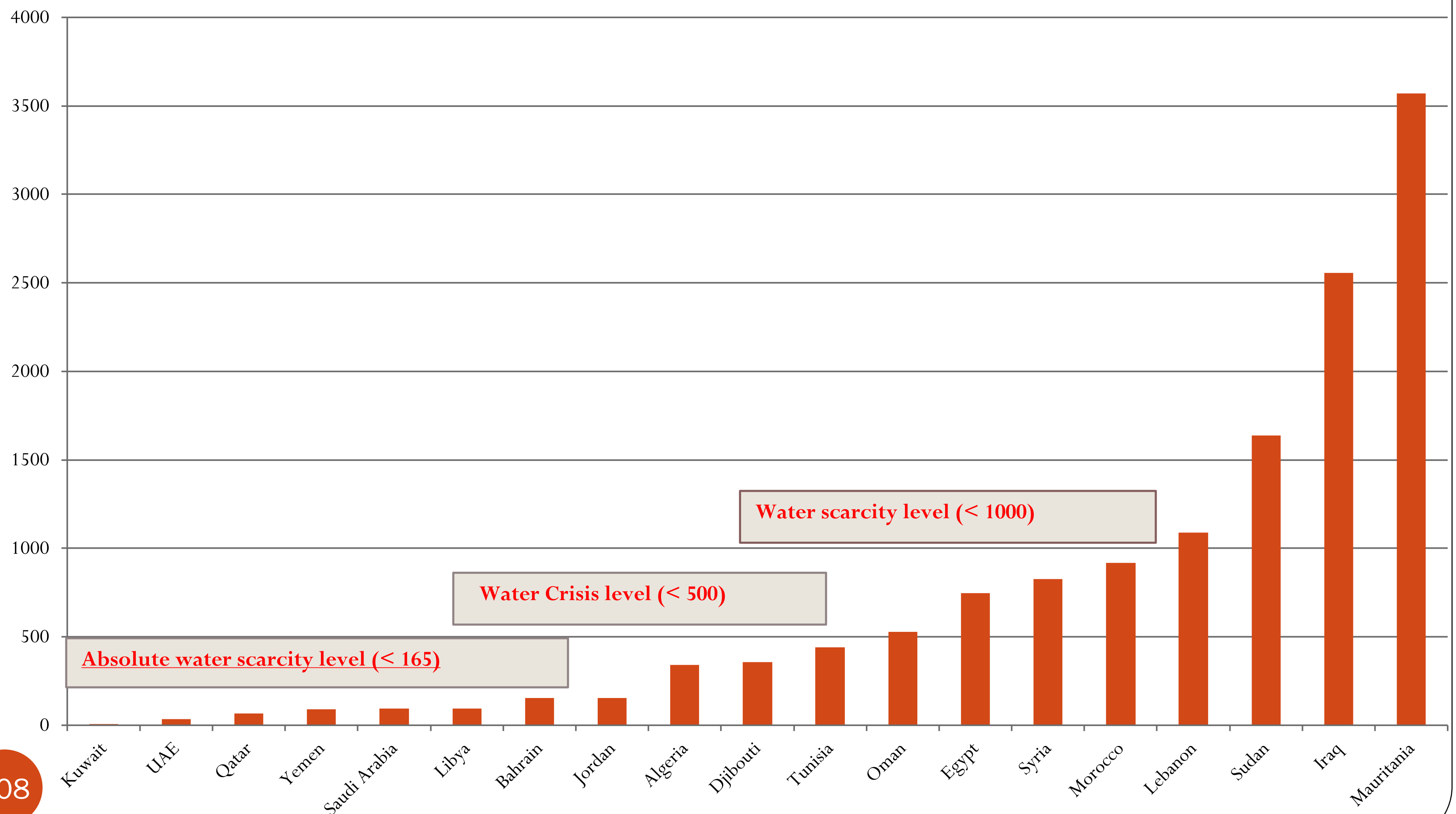
# State of our water commons: Where are we now?

Litani, Lebanon

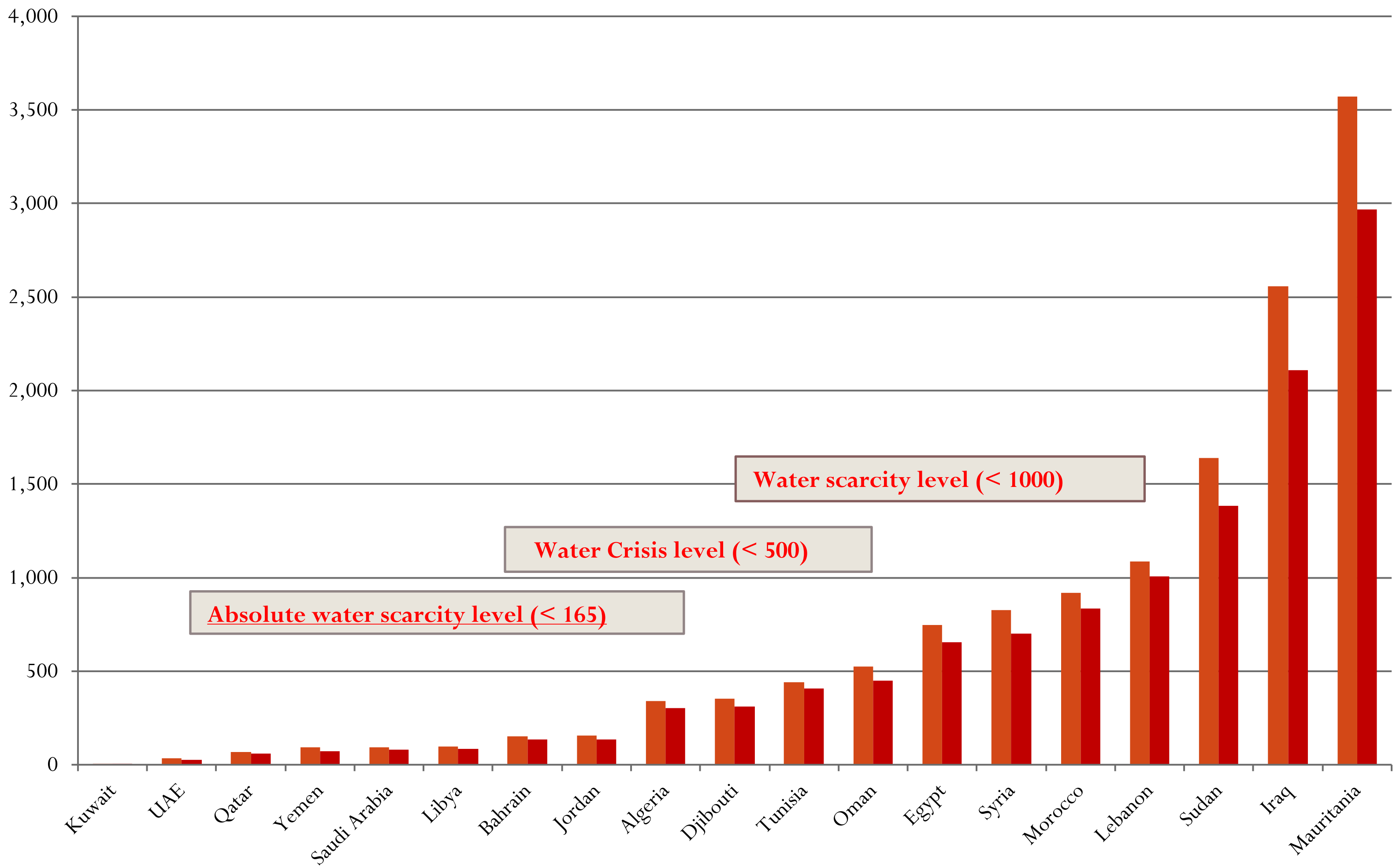
# Total renewable water resources per capita, 1958-2007 (m3/capita/yr)

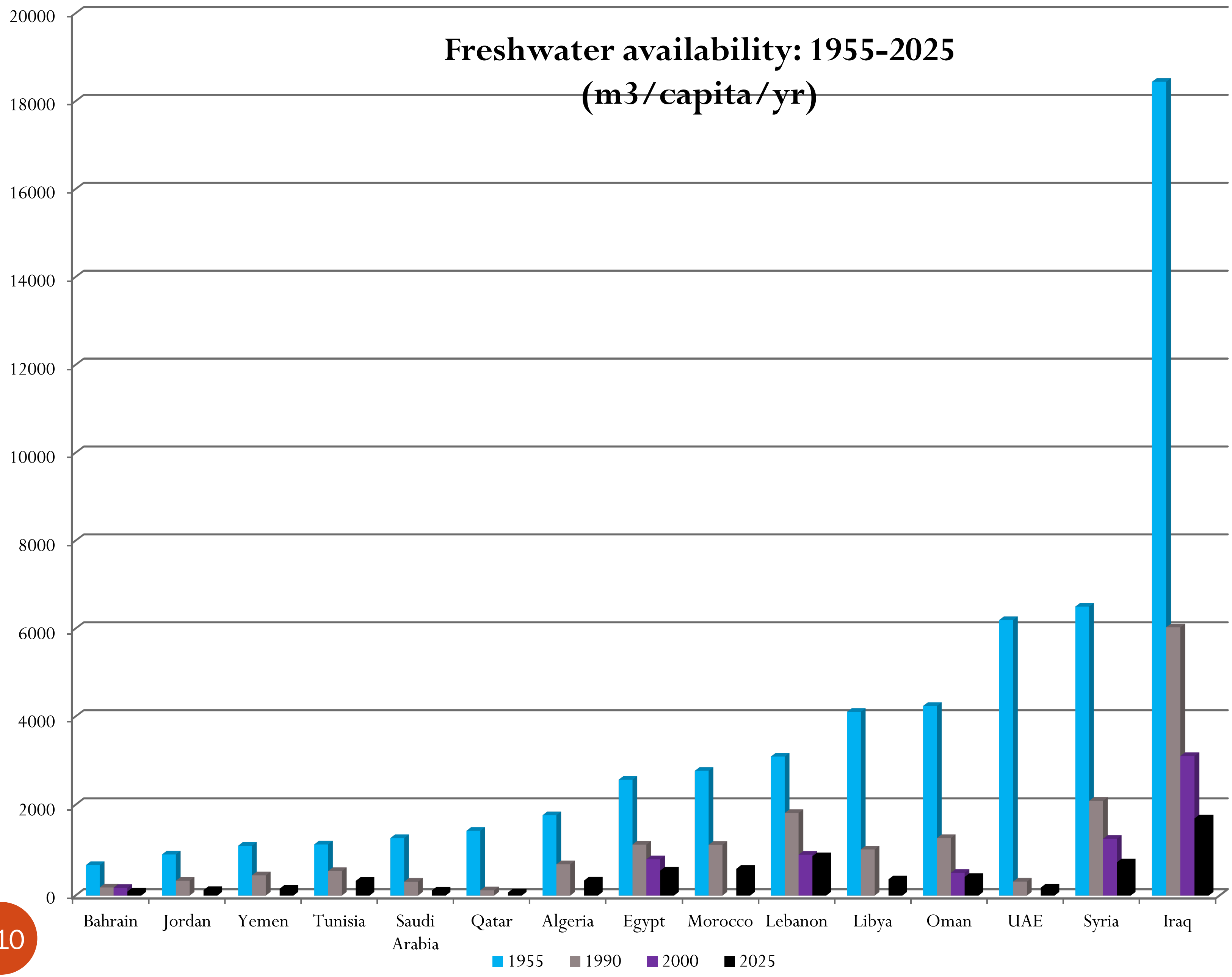


# Total renewable water resources per capita (2008) (m3/capita/yr)

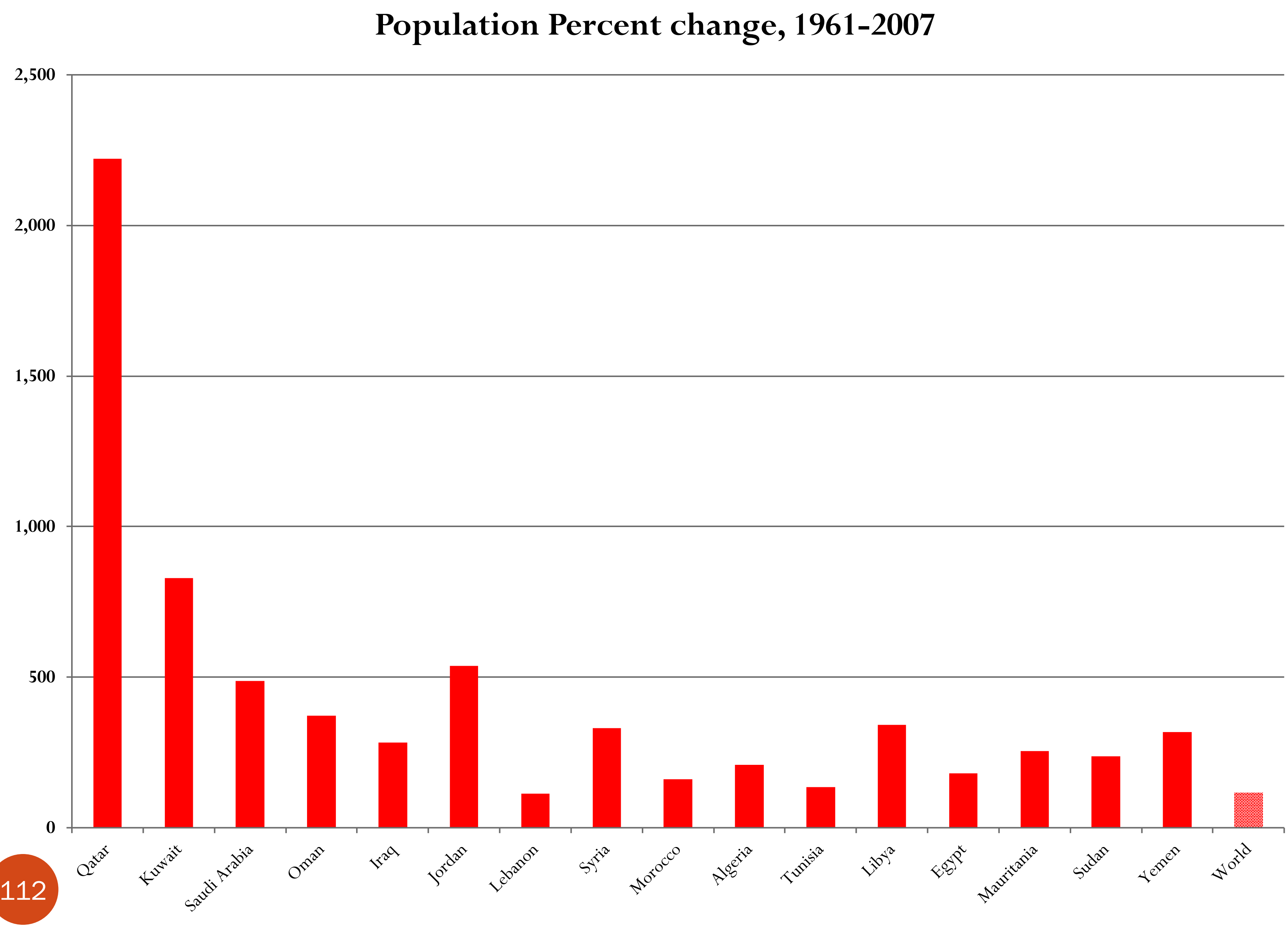


## Projections: Total renewable water resources per capita (2008 and 2016) (m3/capita/yr)



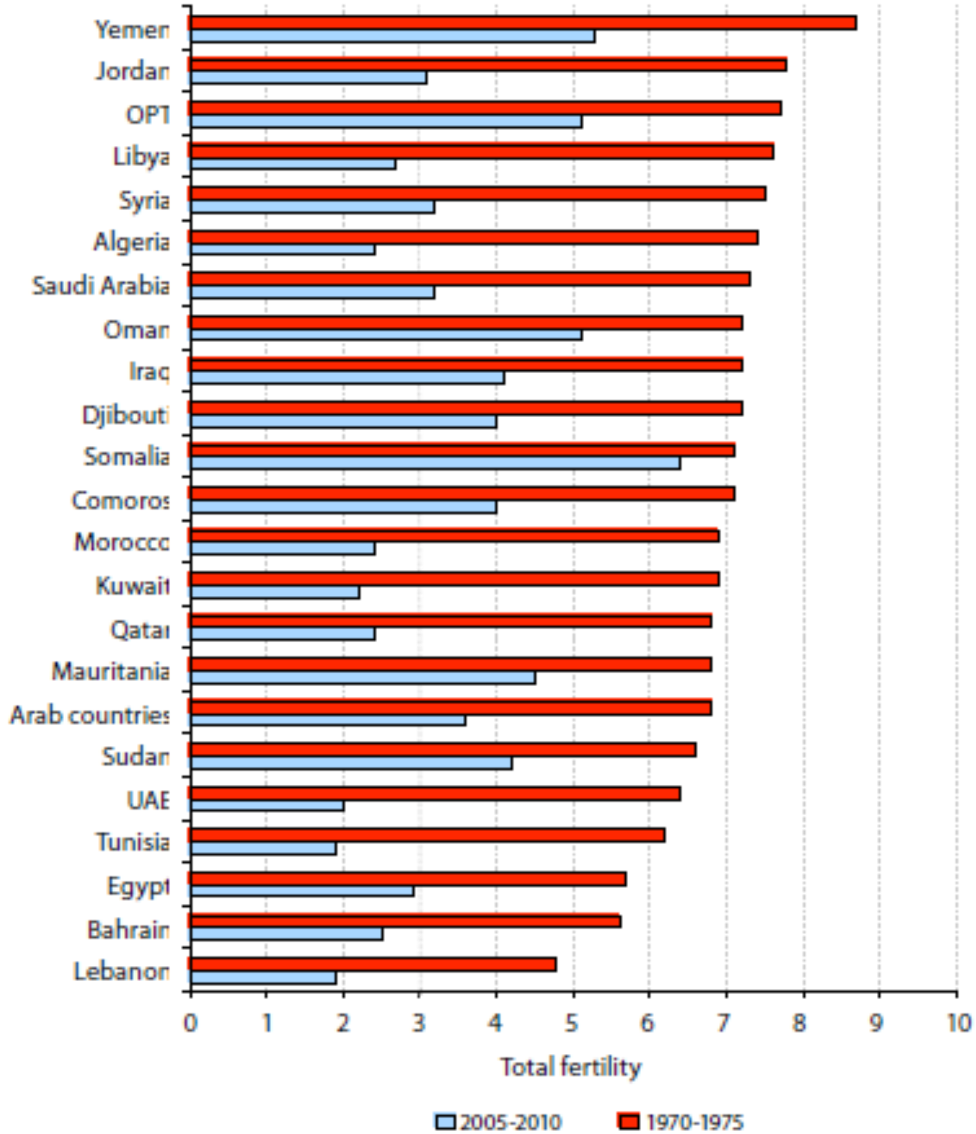

Freshwater availability: 1955-2025
(m3/capita/yr)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Bahrain
Jordan
Yemen
Tunisia
Saudi Arabia
Qatar
Algeria
Egypt
Morocco
Lebanon
Libya
Oman
UAE
Syria
Iraq
1955
1990
2000
2025

## Available Renewable Water Resources per capita, 1950 -

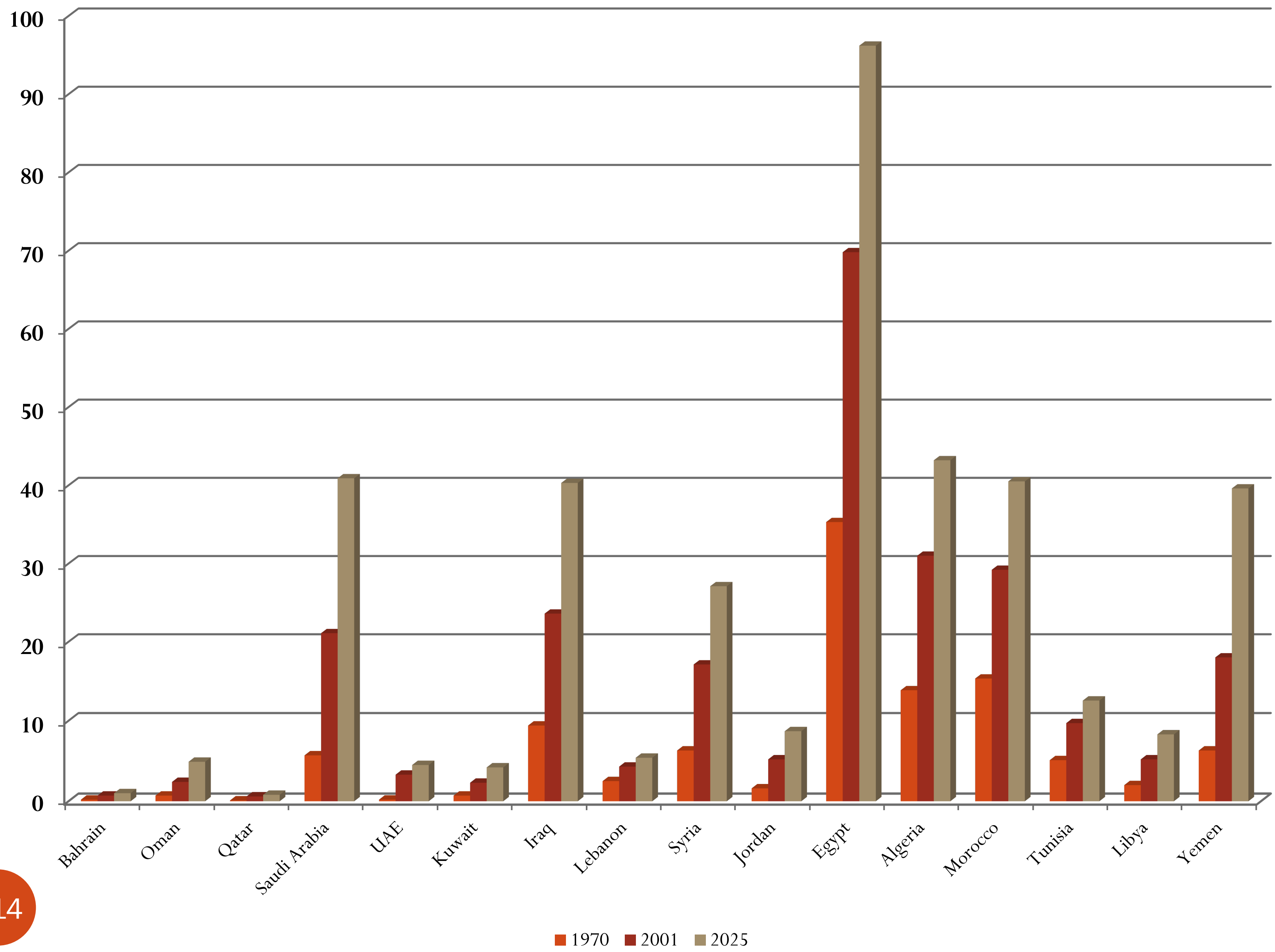

Population Percent change, 1961-2007
2,500
2,000
1,500
1,000
500
0
Qatar
Kuwait
Saudi Arabia
Oman
Iraq
Jordan
Lebanon
Syria
Morocco
Algeria
Tunisia
Libya
Egypt
Mauritania
Sudan
Yemen
World

Although fertility rates in the Arab world are declining…

## Total fertility in the Arab world: 1970 - 2010



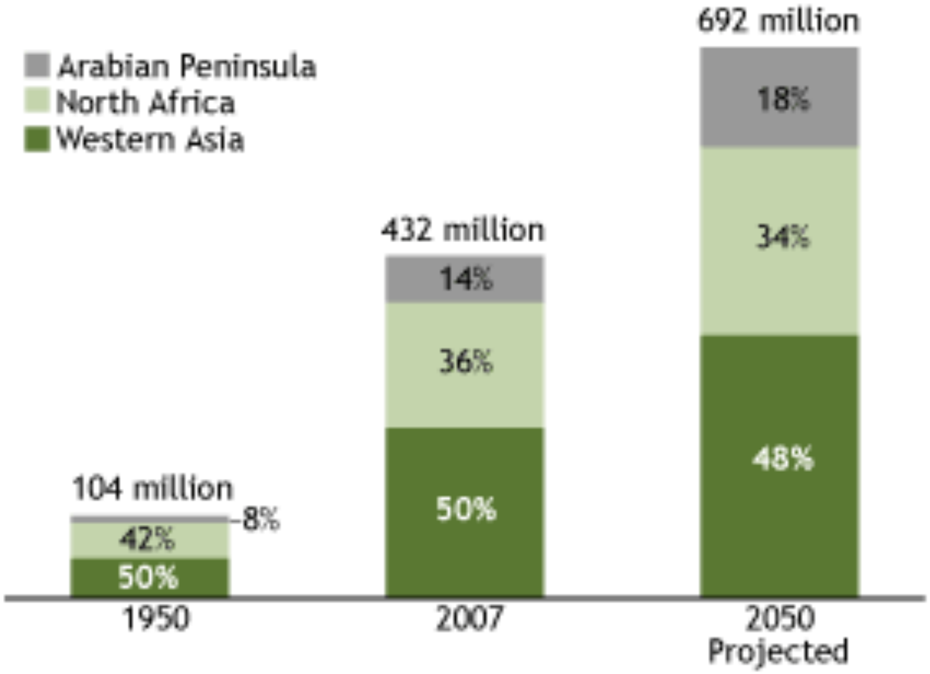
# Population growth (millions): 1970 - 2025



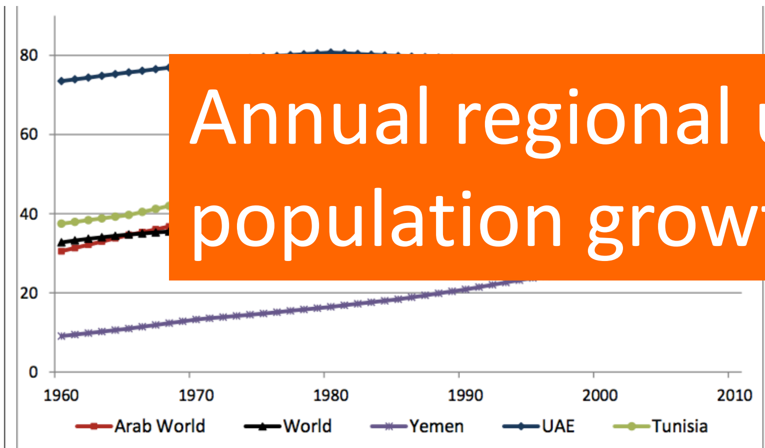
# population growth: 1950-2050

Arab region: among the fastest population growth rates (> 2%/year)

- GCC population: to double by 2040
- Maghreb population: to double by 2060

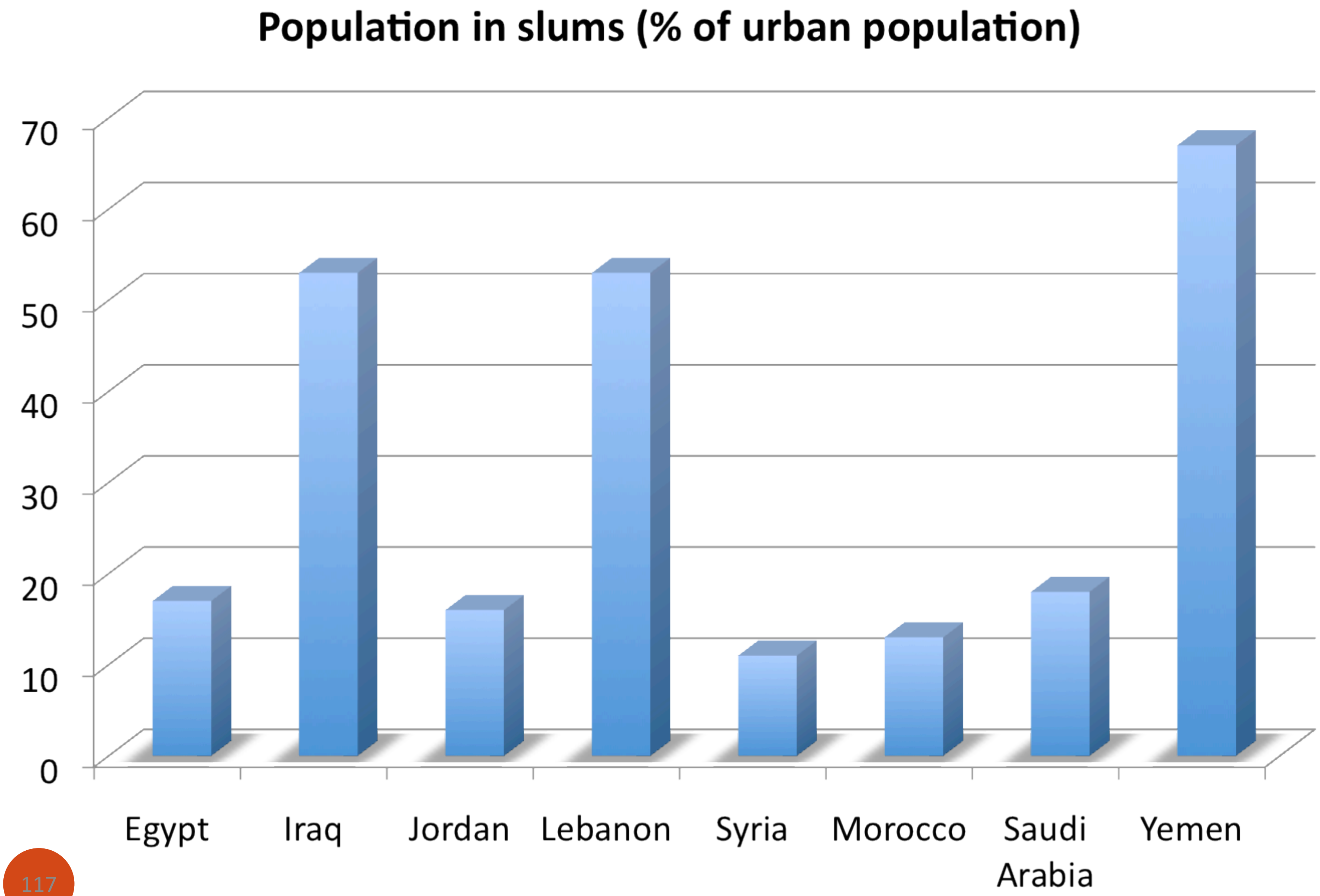


# Urbanization rates in the Arab world




*Source*: Adapted from World Bank World Development Indicators, 2011.

Annual regional urban population growth: 2- 6%

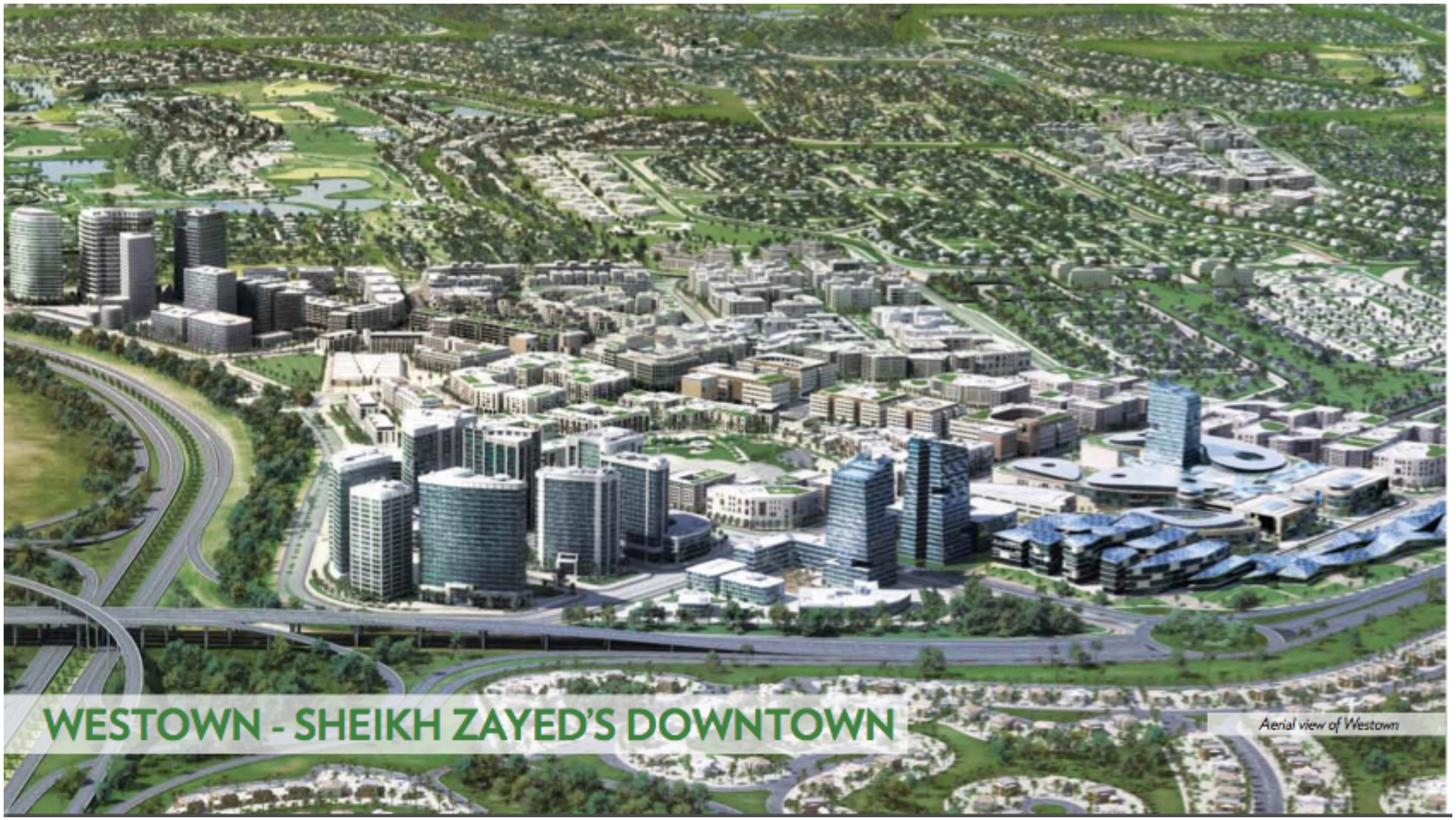



Source: UN Habitat 2008

# Threats to our water commons

- Decreasing supply
  - Aquifers and groundwater heavily mined (Yemen)
- Increasing demand (decreasing supply per capita)
  - Population growth
  - Increasing urbanization, Increasing economic and social demands

# Increasing exclusive developments …



… extravagant water use


Welcome to the
Greener Side
of Life

# Who gets water?

# The political economy of water

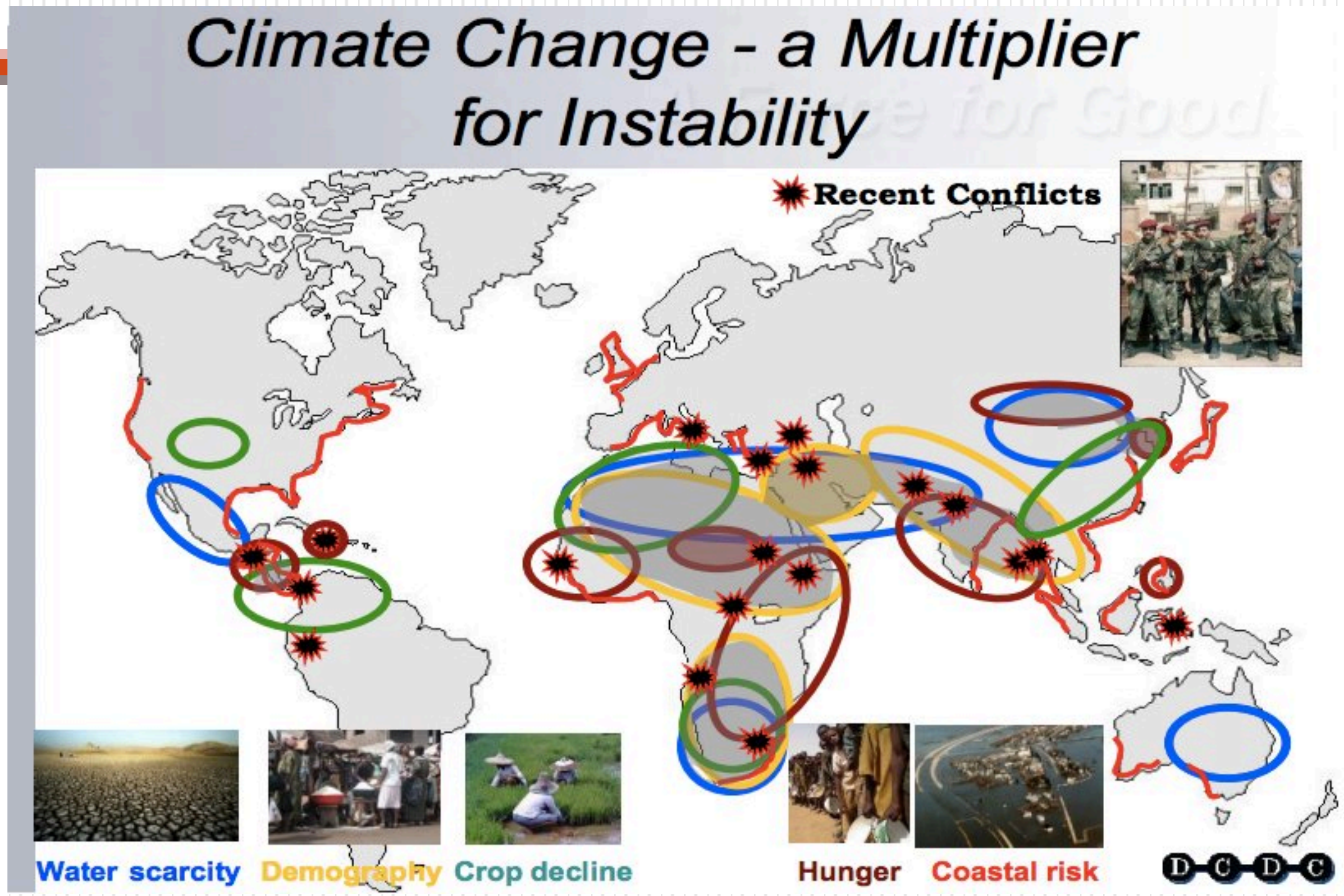
The scarcity of water, like any resource scarcity, imposes the inevitable questions:

- Who gets how much?
- At what cost?
- And at what price, if any?

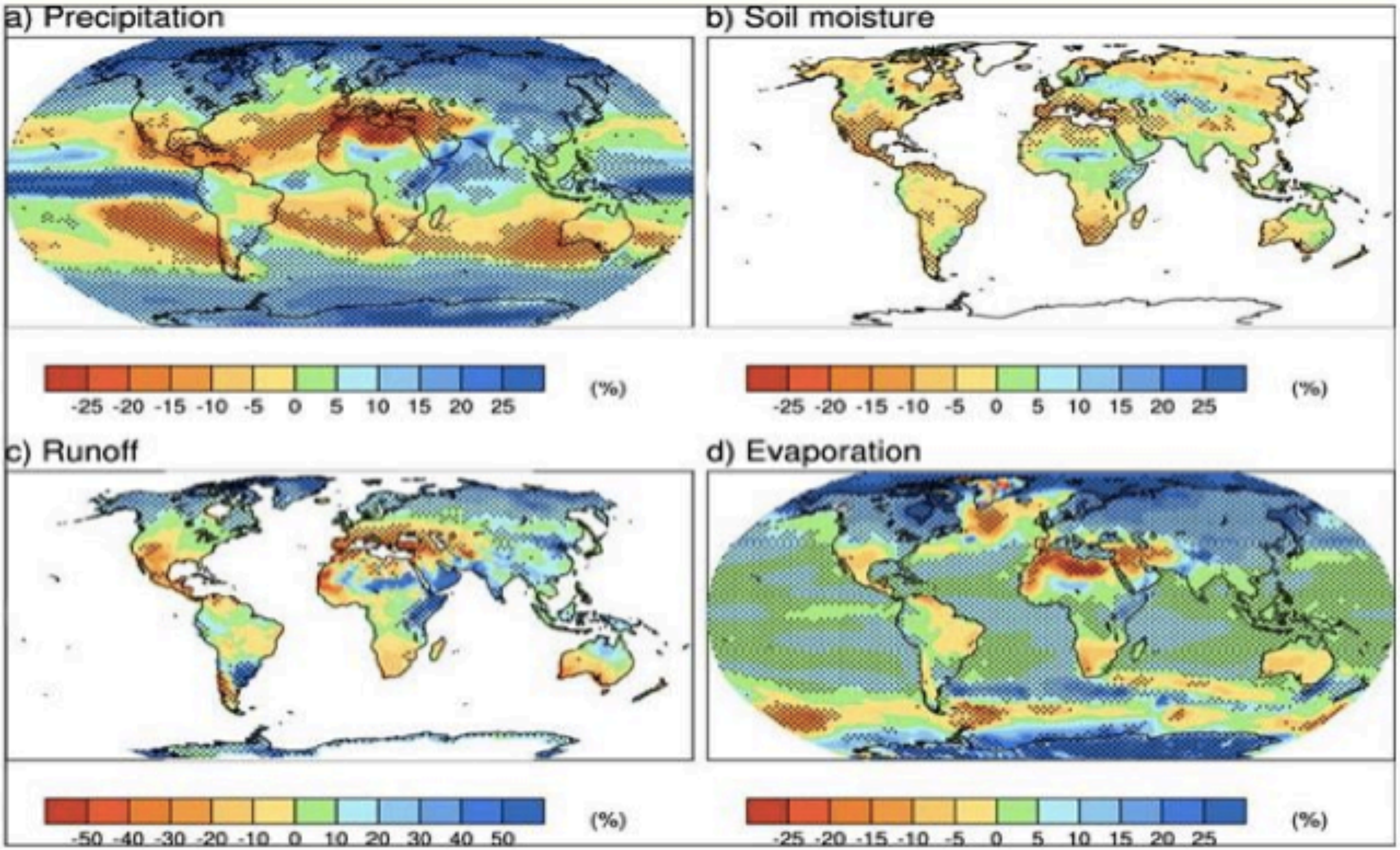
But there are deeper questions that also need to be addressed:

- Who decides?
- By what procedures?
- What features of governance will most likely produce management decisions that are fair, effective, and environmentally sustainable?

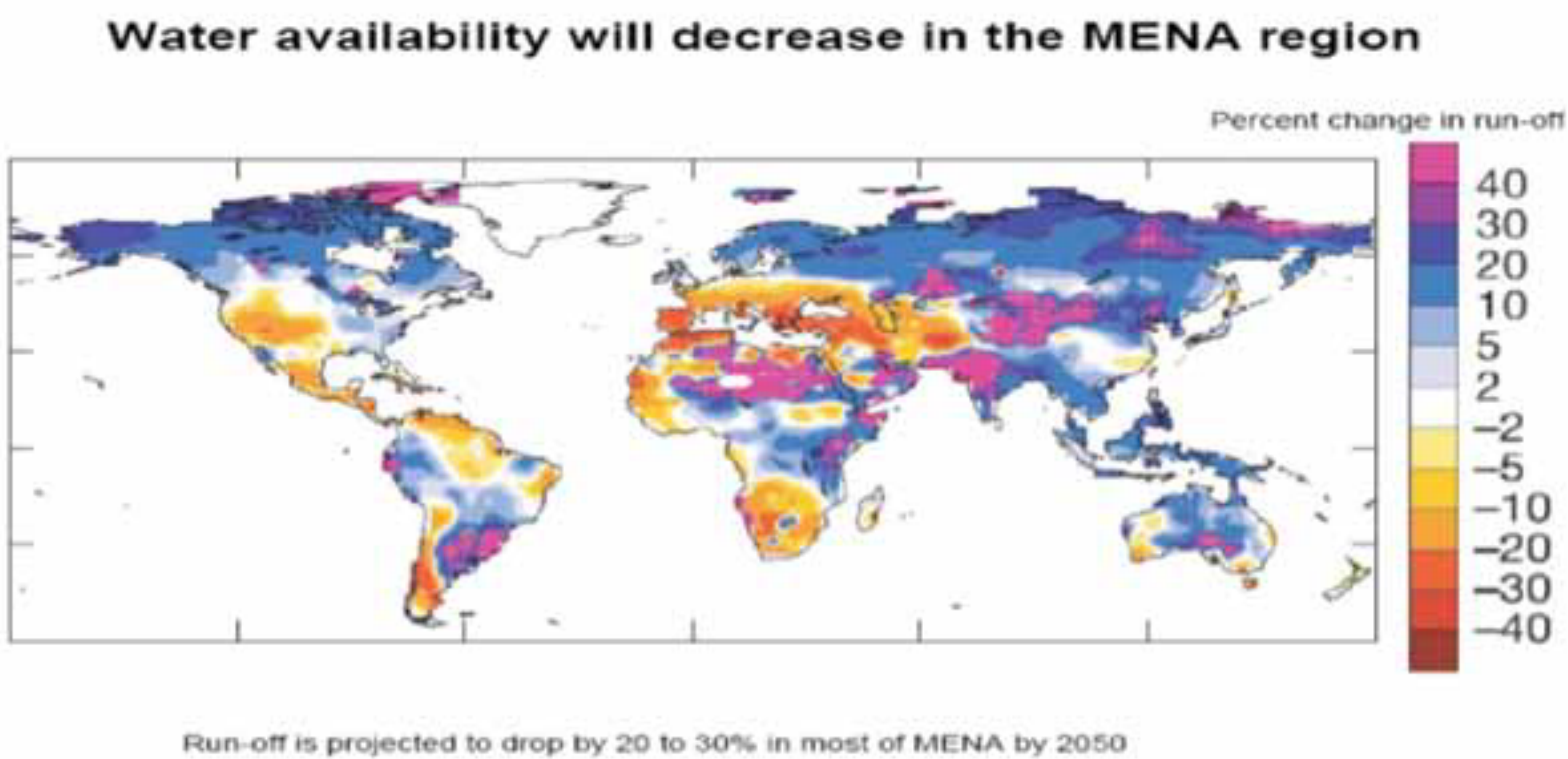
# State of our water commons: impact of climate change



## Annual Mean Changes in Hydrometeorological Variables for the Period 2080–2099 Relative to 1980–1999 – using a middle-path emissions scenario (A1B)




*Note:* Based on simulation results from 15 GCMs for the GHG emissions scenario A1B. Stippled areas indicate those where at least 80% of the GCMs agree on the direction of change. *Source:* Bates et al. 2008.




Impact of climate change on water availabilit y in Middle East and North Africa in 2050
*Source: Milly et al., published in Nature.*

# How can climate change impact lives in cities?
# How has it already?

# Urban flooding

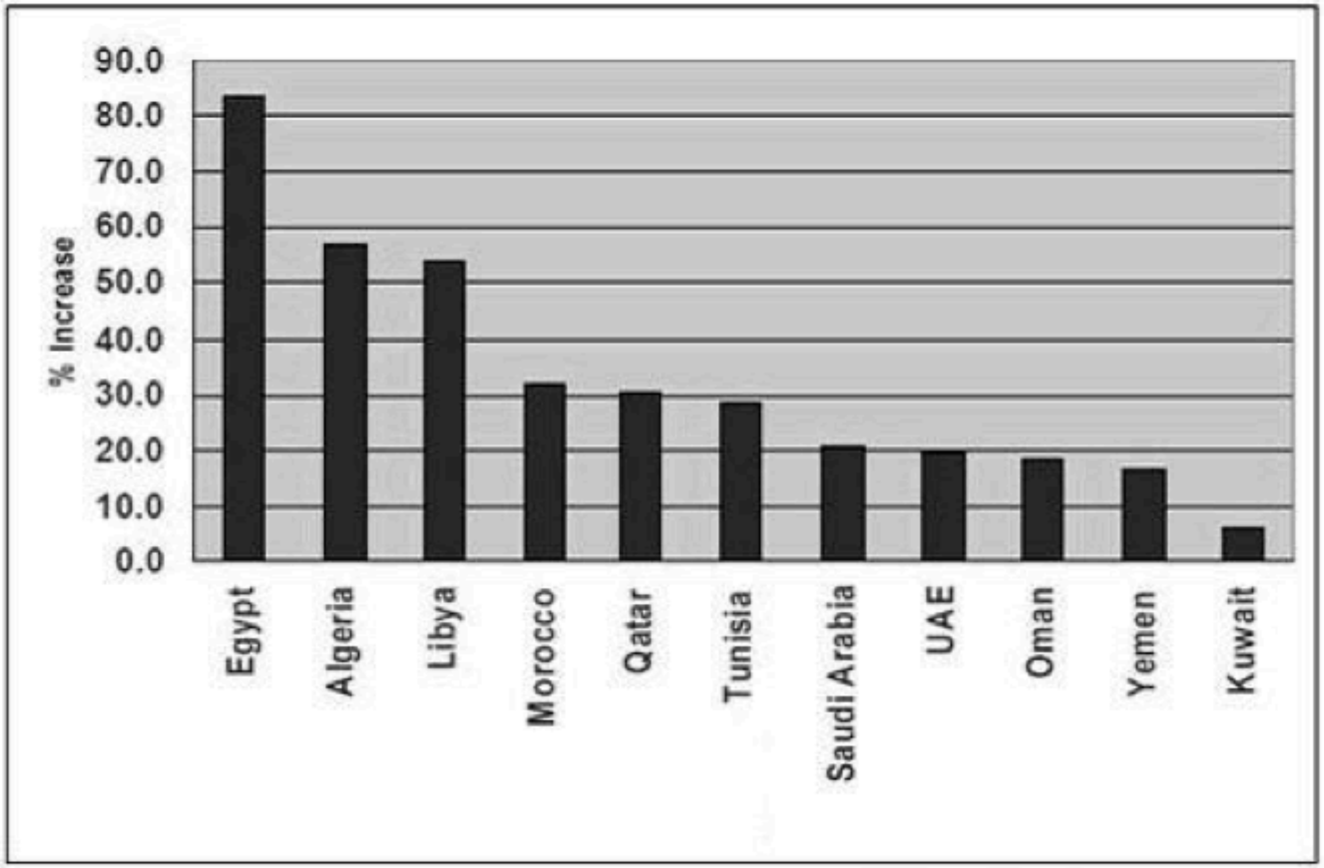
* ~ 75 % of built structures are at risk of sea-level rise, storm surges, and heat impacts.

- **Urbanization increases vulnerability to floods**
  - (i) coastal flooding,
  - (ii) major rivers,
  - (iii) small streams, and
  - (iv) inadequate drainage

# Areas in Alexandria vulnerable due to exposure and poor housing (in red and purple)

*Source*: World Bank 2010.
*Note:* Estimated potential effects on the coastal zone of Arab countries (based on a 1 meter SLR) are also substantial (Dasgupta et al. 2009).

# Estimated % increase in storm surge zone

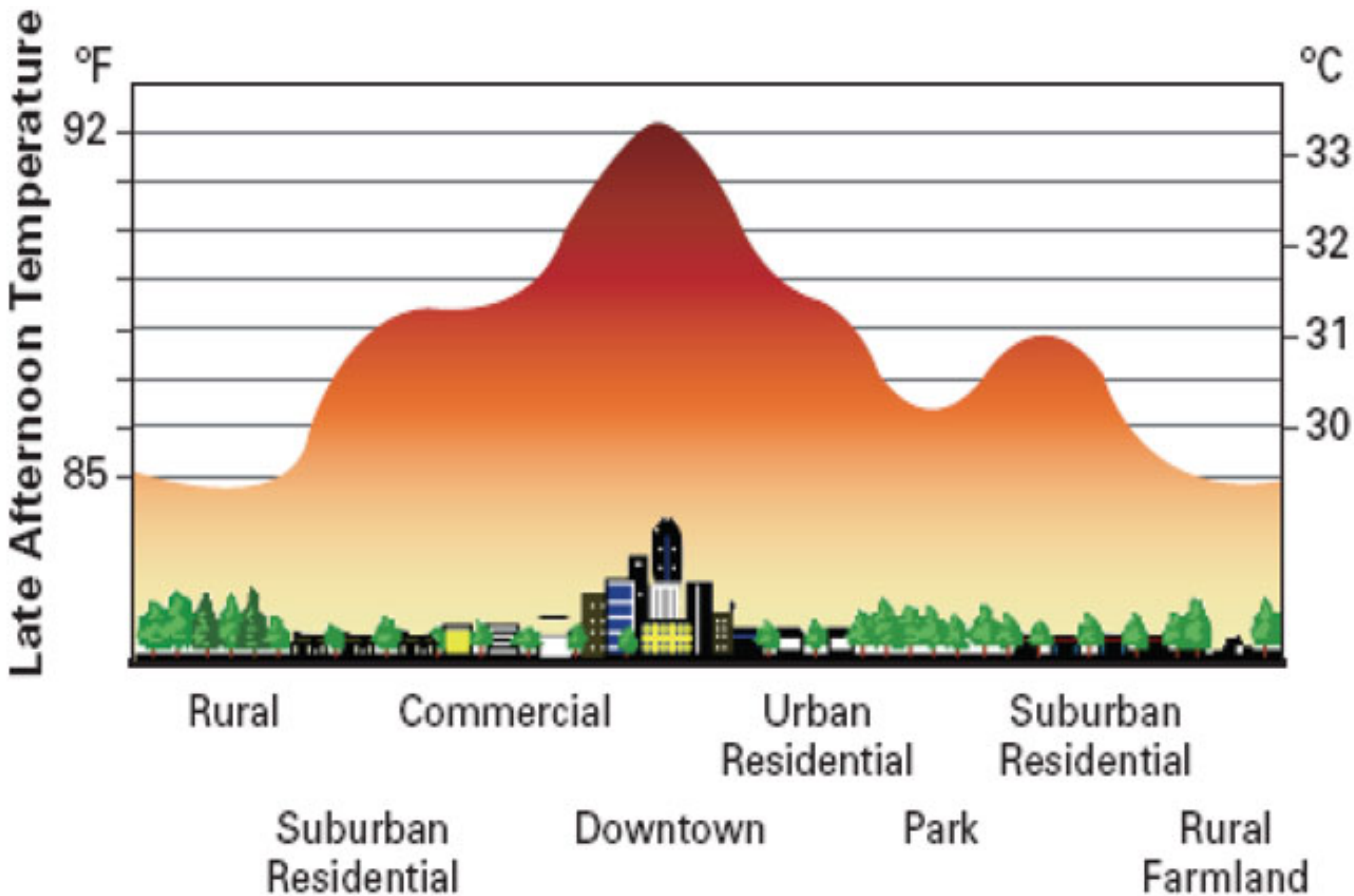



*Source*: Modified after Dasgupta et al. 2009.

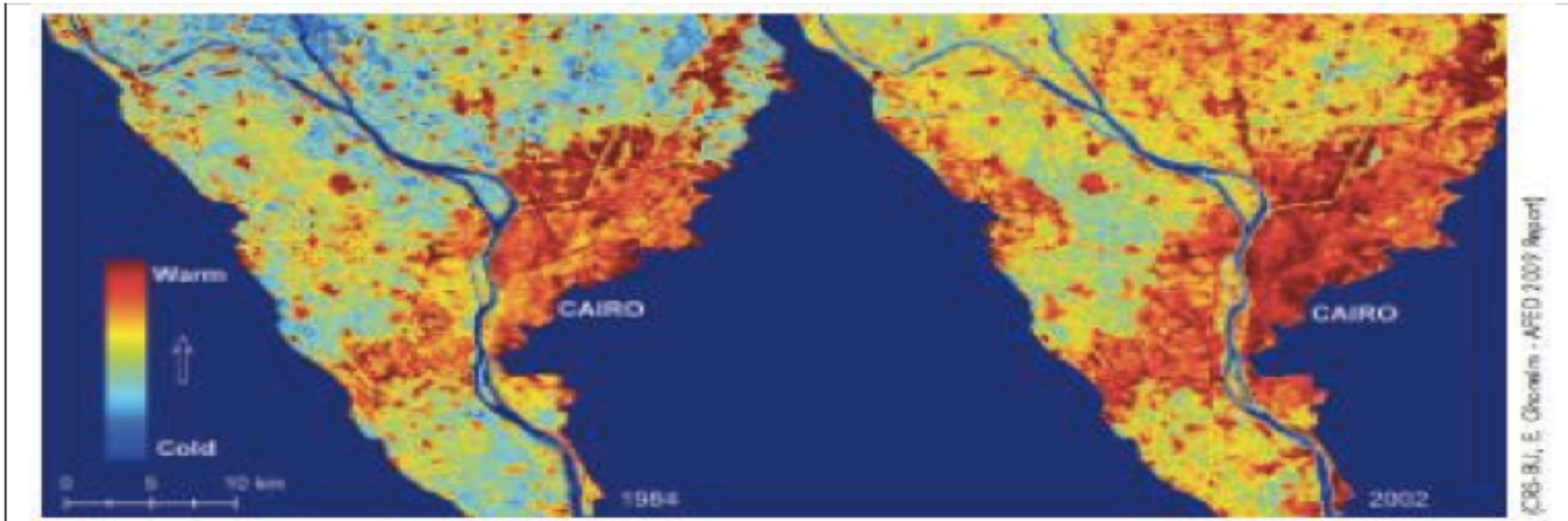
# Flooding in Jeddah, (inadequate drainage) January 2009

Source: Arabia Today, http://arabia2day.com/local/hundreds-detained-in-saudi-arabia-over-protests/.

# Urban heat islands

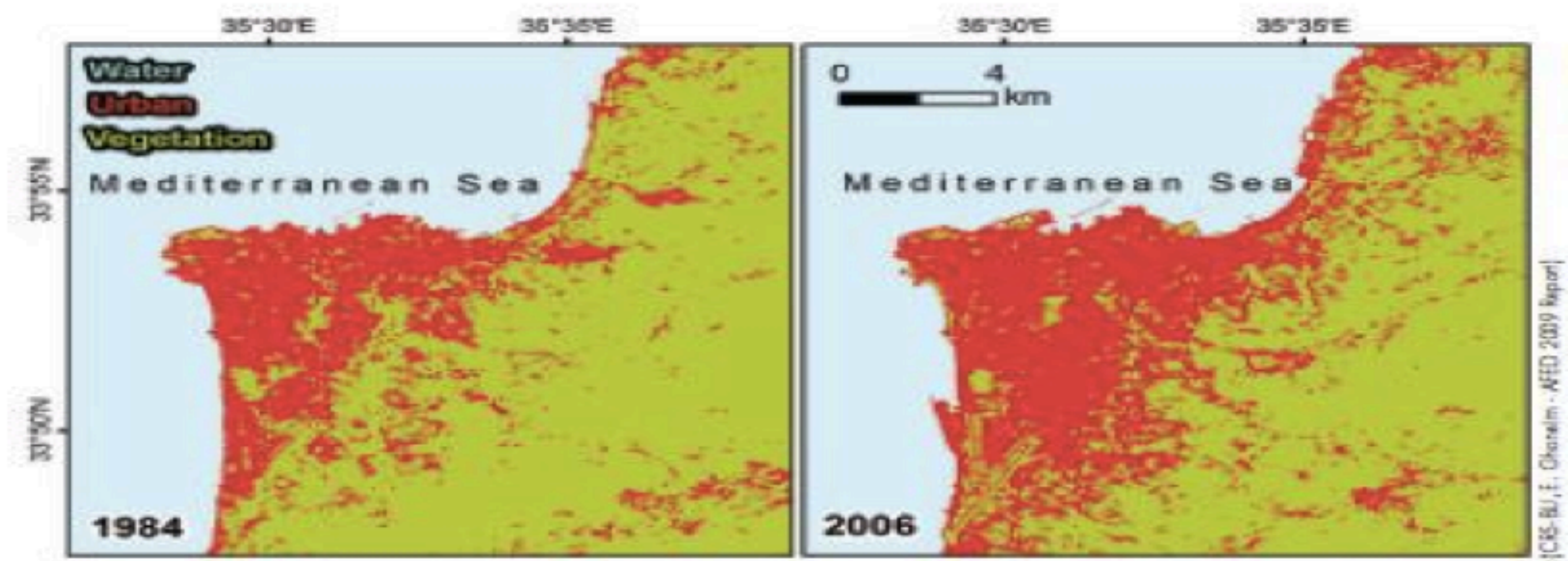


# Rise in Cairo temperature due to urban growth (1984 and 2002)



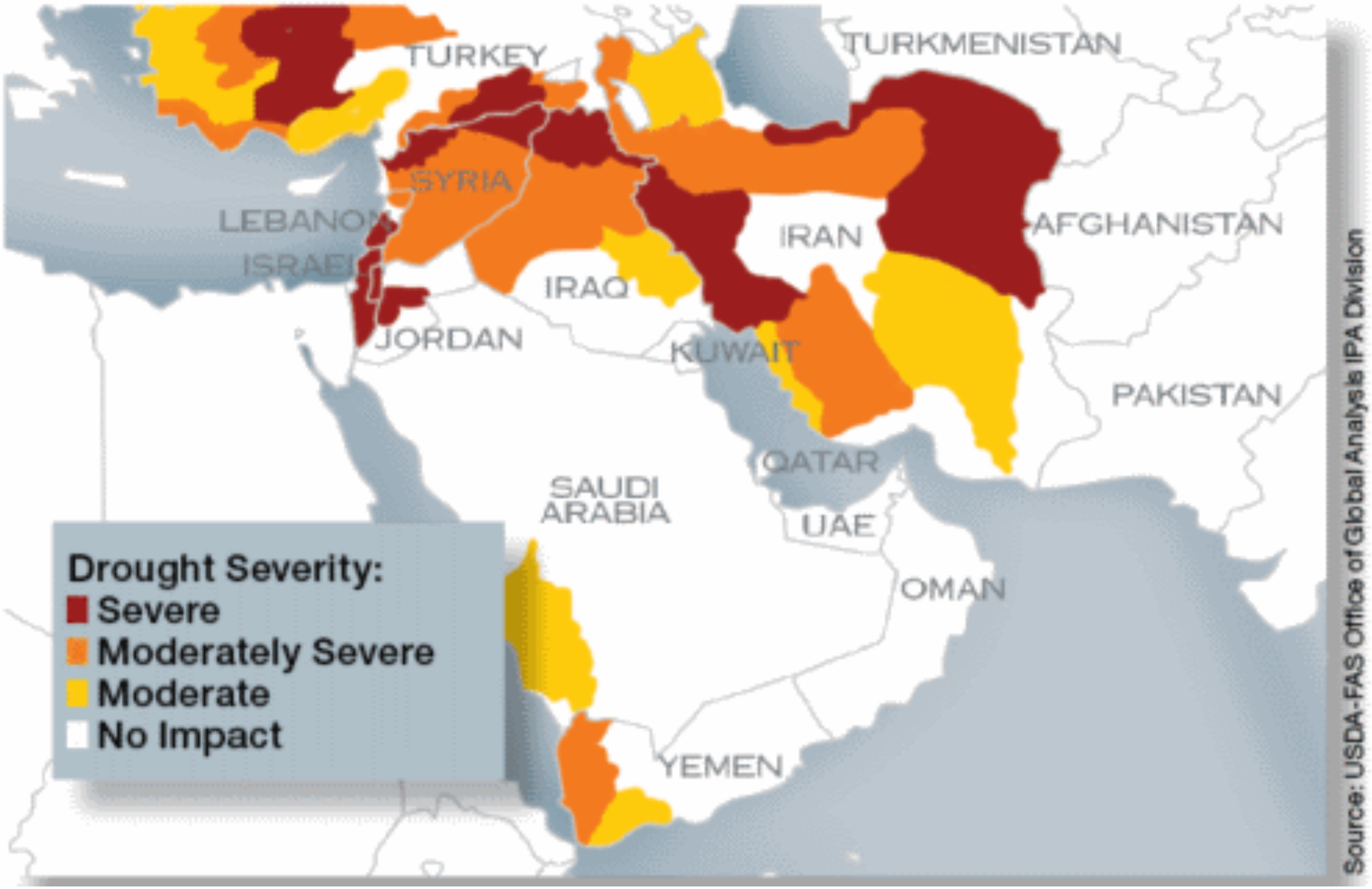

*Source:* Ghoneim 2009.

# Urban expansion in Beirut: 1984 and 2006




*Source:* Ghoneim 2009.

# 2008 Regional Drought Impact

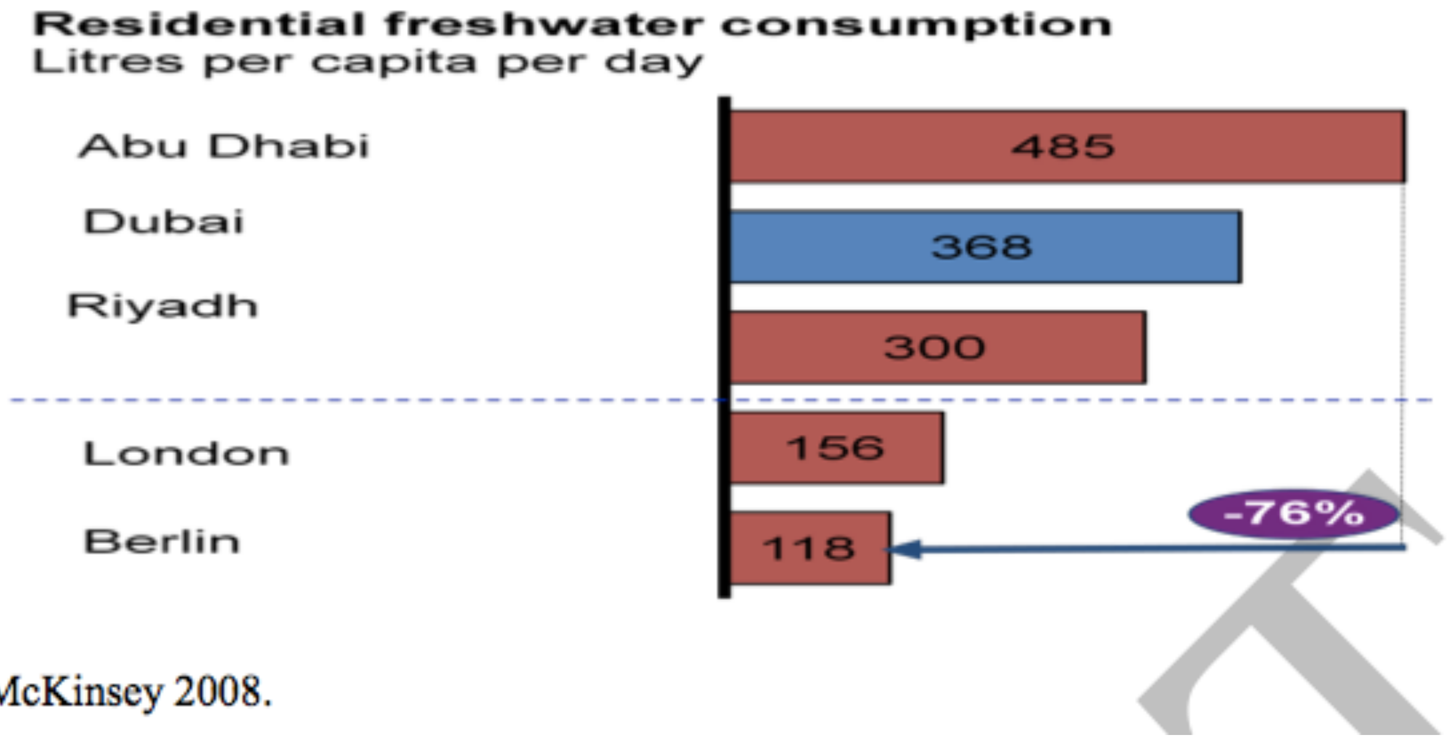


# From farming to urban poverty?

# (direct) Climate change impacts in urban areas

- Increased temperature
  - Heat waves
  - Fires
- Decreased precipitation
  - Drought
  - Fires
- Increased precipitation
  - Flooding
  - Mudslides
  - Epidemics
- Sea Level Rise
  - Storm surges
  - Flooding

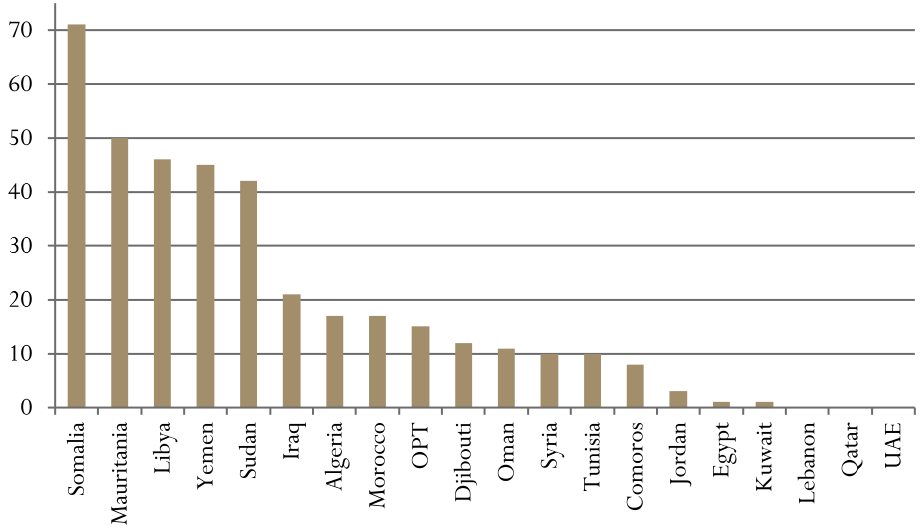
# High per capita water consumption – for some




*Source:* McKinsey 2008.

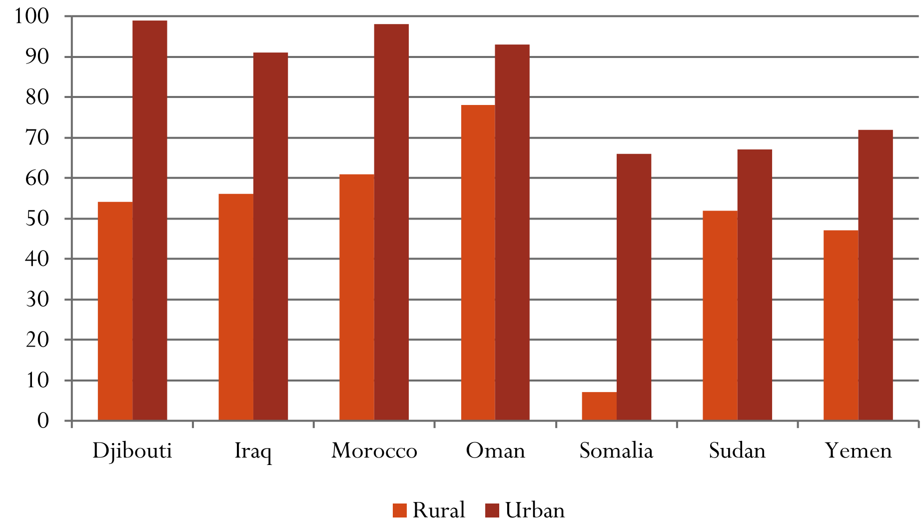
# our water crisis: Political economy of Water

# Impact of water crisis: who gets water?

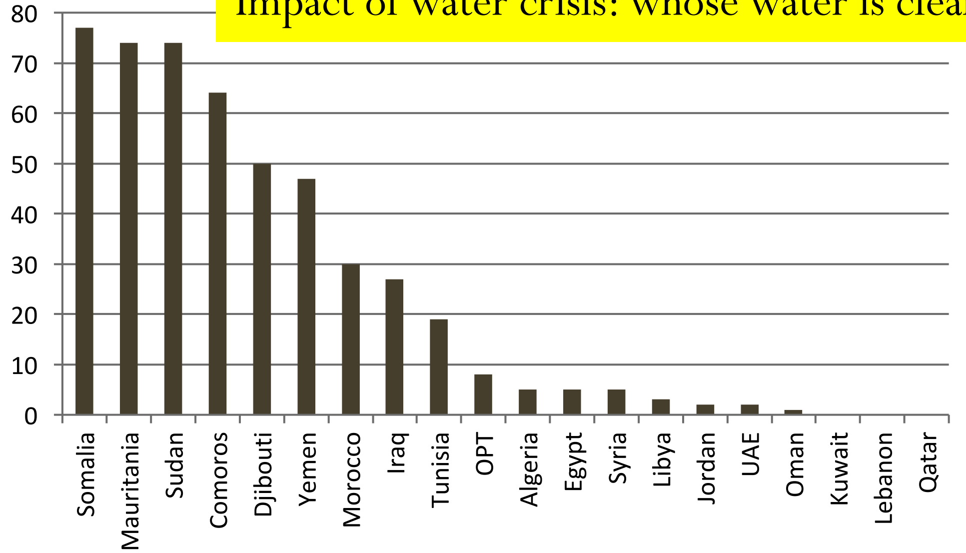



Population without access to improved water sources (2010)

Internal differences in access to improved water sources (2010)

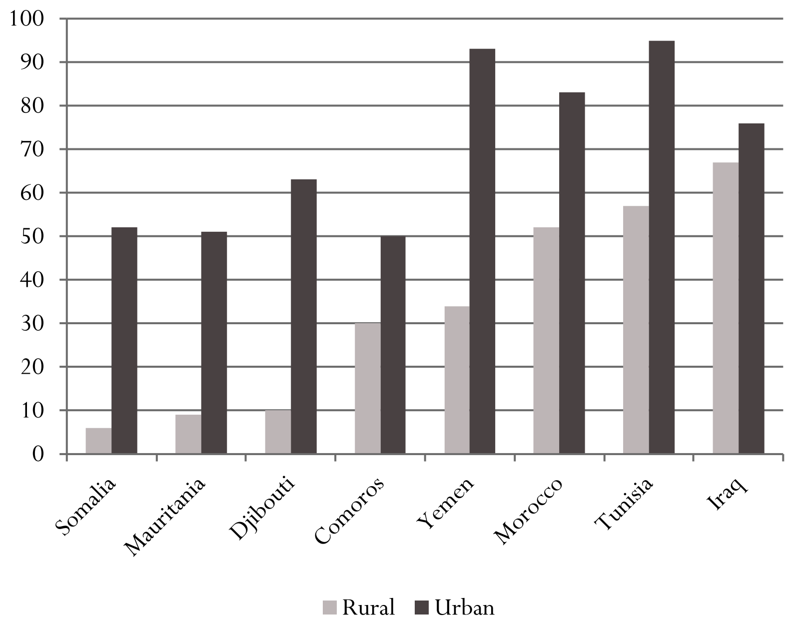


## Impact of water crisis: whose water is clean?




Population without access to improved sanitation facilities (2010)

Internal differences in access to improved sanitation facilities (2010)



# (Potential) impacts of Decreased Supply and Increased Demand on Water

- Direct impacts
  - … increased cost
  - … decreased quality (eg: increased salinization)
- Indirect impacts
  - … increased poverty
  - … increased health risks
  - …risk to livelihoods in agricultural sector
- Decreased ecosystem health … and all the impacts