Introduction to Global Warming I

– Observations, Causes, and Impact

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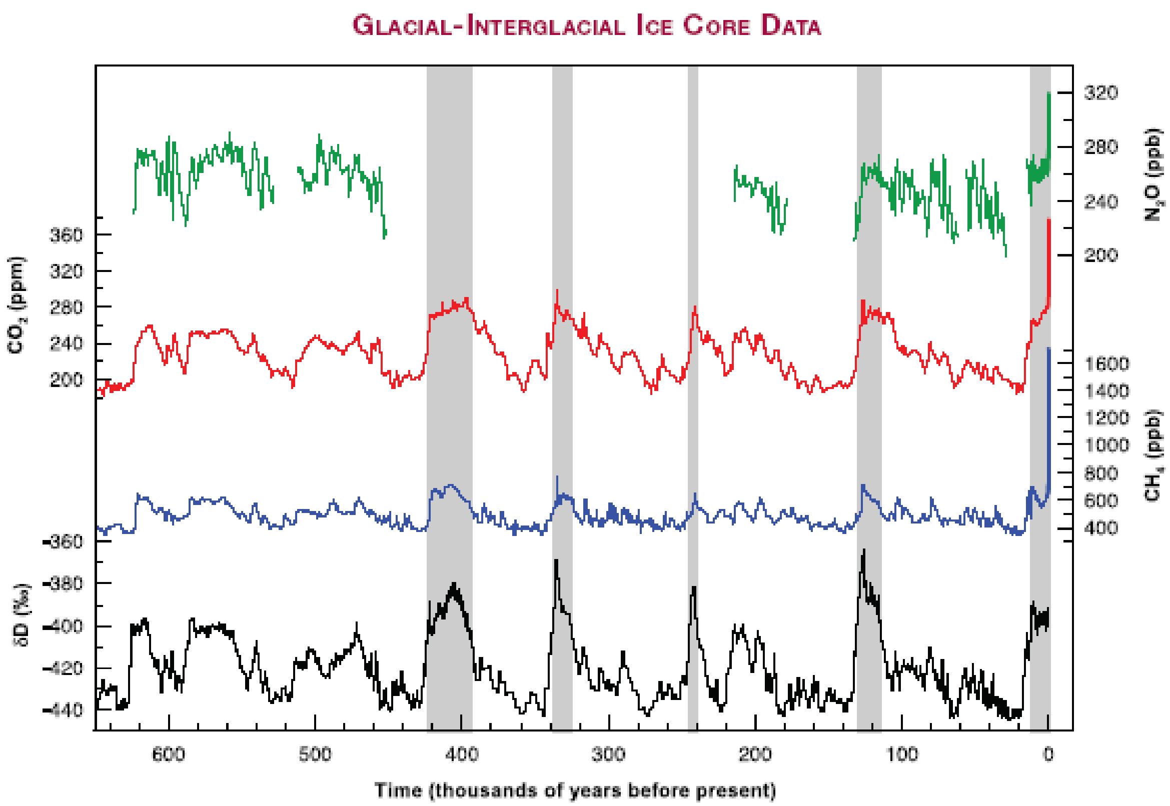
http://home.olemiss.edu/~cmchengs/Global%20Warming/Session%201%20Introduction%20-%20Part%201/

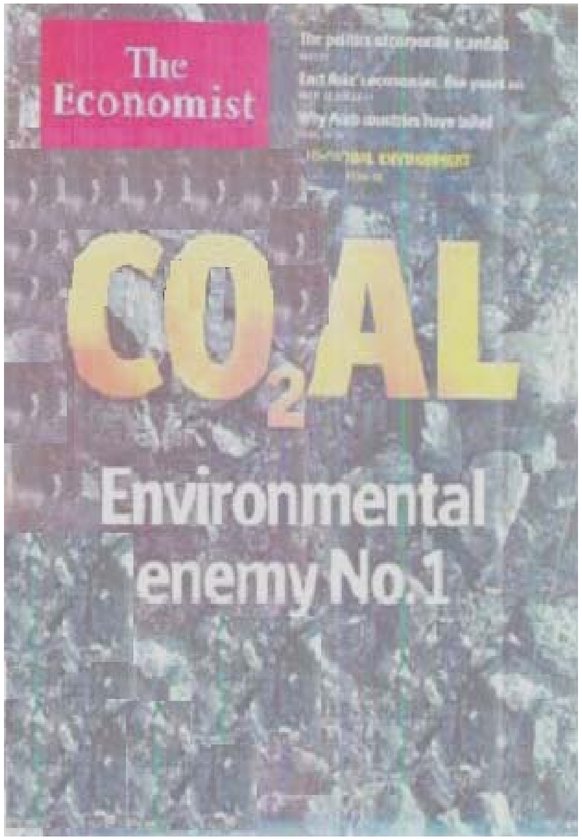
Outline

- Why should we pay attentions to climate change?
- Causes
- Impact
- Solutions

Why should we pay attentions to climate change?

• Climate change is likely to have reached a tipping point – results are potentially catastrophic.





Extreme weather, flooding, human health, biodiversity, … etc.

Why should we pay attentions to climate change?– cont.

- **Task to fix our environment is monumental and costly – the annual anthropogenic CO_2 emission is about 24 billion metric tons.**

• Burning fossil fuels have been an essential foundation (80%) of world energy economy.

• Technological alternatives to replace the fossil fuels are less amenable.

Why should we pay attentions to climate change? – cont.

Its solutions not only are monumentally costly, but also involve all sectors of the society.

- **Alternative energy Infrastructures,**
- **New fossil fuel technologies,**
- **Conservations,**
- **Direct mitigation,**
- **Environmental policy and regulations,**
- **Economy and business structures,**
- **Societal adaptation, and,**
- **Political issues.**

Policy, economical, societal and political issues are all *global* in nature.

Why should we pay attentions to climate change?– cont.

- **Views about how to share the responsibilities to reduce the emissions are different and have generated high emotions - e.g., CNN News 12/15/2007:**

In U-turn, U.S. agrees to global warming deal

BALI, Indonesia (CNN) -- In a dramatic reversal Saturday, the United States rejected and then accepted a compromise to set the stage for intense negotiations in the next two years aimed at reducing carbon dioxide emissions worldwide.

Dutch Environment Minister Jacqueline Cramer holds a hammer during a campaign at the venue of the U.N. Climate Change Conference in Nusa Dua, Bali Island December 14, 2007.

Why should we pay attentions to climate change?– cont.

EDITORIAL

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Education in a warmer world

Engineering graduates are currently "not fit for purpose" in a sustainable world. This must change.

Jonathan Wood | *Editor, Materials Today* | j.wood@elsevier.com

"How many young people aged 15 to 16 think 'I care about the world, I'm going to be an engineer'?" asked Jonathon Porritt, as he issued a call to arms for engineers to put sustainability at the core of their profession. Porritt is founder director of Forum for the Future, and has something of a similar profile in the UK to Al Gore. He has the same clarity in presenting his incontrovertible – never mind inconvenient – truths, but he's been there for longer and his charisma has never been in doubt.

He was speaking at Imperial College London at a forum on the place of sustainability in engineering education. The meeting had been organized in response to concerns that sustainability just isn't getting covered in university courses. Industry is worried that engineering graduates are coming to them without being able to consider the wider issues arising from their work. Certainly there were representatives of Toyota USA and Arup who were willing to subscribe to this picture. Indeed, Porritt described UK graduates as "not fit for purpose" in a sustainable world.

There is no doubt that this situation needs to change. Now that even John H. Marburger, III, President Bush's science adviser, has signed up to this year's Intergovernmental Panel on Climate Change 4th assessment report, no one can doubt that it's as good as certain that we're seeing climate change as a result of manmade factors. It is generally agreed that an atmospheric CO_2 concentration of 450 ppm is likely to keep global warming to an increase of ~2°C over preindustrial levels, where we will avoid 'dangerous' climate change. But we have already put around 1.2–1.3°C into the system and we are heading for 550 ppm. At best, we have a window of 15–20 years in which to put in place the measures to sort this out. Engineering is the pivotal profession in all of this, Porritt believes. And since it is current students who will have to deliver on this, "It is monumentally stupid to let graduates leave [university] in a state of sustainability illiteracy."

It's not as if students don't care about these issues, but they often don't see that they can be important in their future careers. Rather than take part in a huge moan about attracting young people into the profession, Porritt proclaimed, engineering should make sure it brings people into a sense of excitement about the idea of sustainability.

So what can be done? – university courses are already pressurized with content. Well, I agree with Paul W. Jowitt of Heriot Watt University that this is not necessarily about adding more in, but about new assessments that include the wider impact on communities and the environment, as well as technical problem solving. But training doesn't stop at the university gates – there is a role for industry too. As the new UK science minister, Ian Pearson pointed out, 70% of the 2020 workforce is already out of education. The great thing is that bringing in sustainability takes advantage of an issue young people care about. Perhaps then they will decide, "I'm going to be an engineer!"

- **Today's engineers are not ready for a warmer world.**
- **Yet, engineers and scientists are traditionally trained as problem solvers.**

Nobel peace prize - 2007

Albert Arnold (Al) Gore Jr.

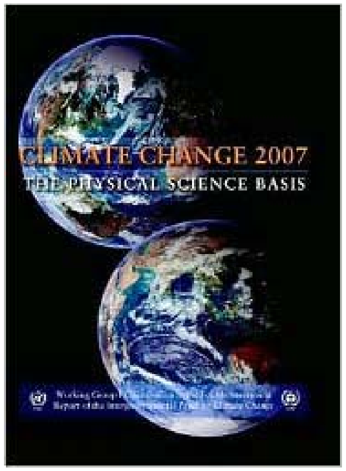
Intergovernmental Panel on Climate Change (IPCC); [chief scientist Dr. Rajendra Pachauri]

December 10, 2007, Oslo, Norway

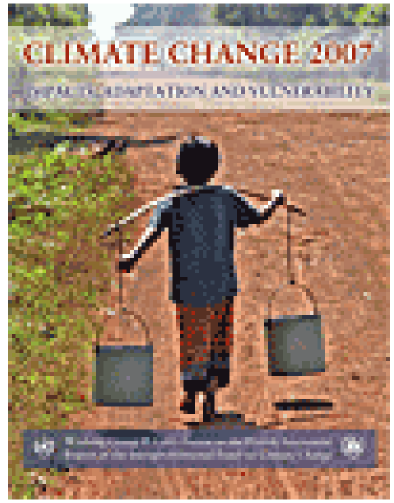
Rajendra Pachauri in Nobel speech:
"Neglect in protecting our heritage of natural resources could prove extremely harmful for the human race and for all species that share common space on Planet Earth.“

Their publications

Climate Change 2007 - the Physical Science Basis: Working Group I Contribution to the Fourth Assessment Report of the IPCC by <u>Intergovernmental Panel On Climate Change</u>

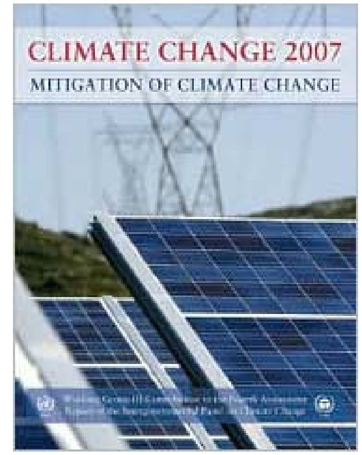


Available at: http://www.ipcc.ch/

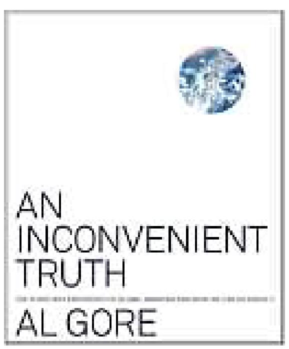


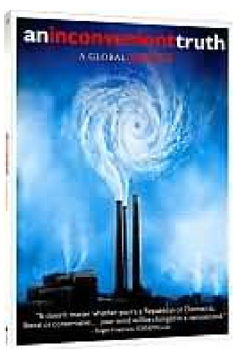
Climate Change 2007 - Impacts, Adaptation and Vulnerability: Working Group II contribution to the Fourth Assessment Report of the IPCC by <u>Intergovernmental Panel On Climate Change</u>

Climate Change 2007 - Mitigation of Climate Change: Working Group III Contribution to the Fourth Assessment Report of the IPCC by <u>Intergovernmental Panel On Climate Change</u>



by Al Gore, Jr.

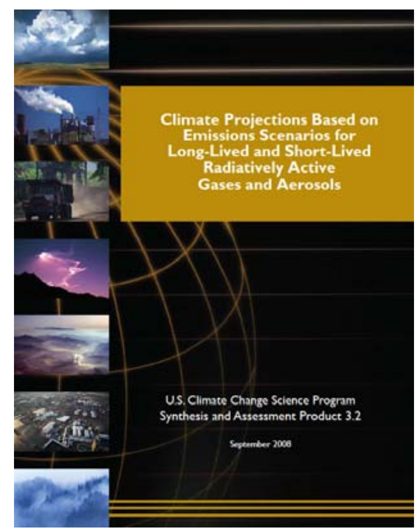




Climate Projections Based on Emissions Scenarios for Long-Lived and Short-Lived Radiatively Active Gases and Aerosols

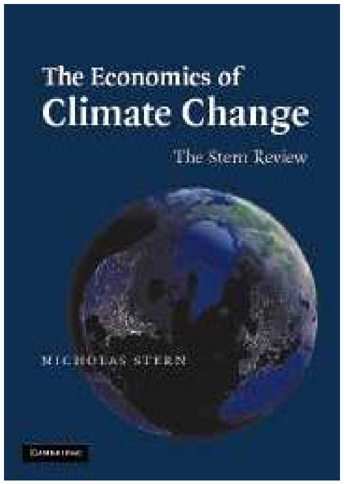
By U.S. Climate Change Science Program Synthesis and Assessment Product 3.2

September, 2008



Ethical issue

The Economics of Climate Change
The Stern Review, by Nicholas Stern, Cambridge University Press, 2007.



The Ethics of Climate Change, by John Broome, Scientific American, pp.97-102, June, 2008.

- Future generations will suffer most of the harmful effects of global climate change. Yet if the world economy grows, they will be richer than we are.

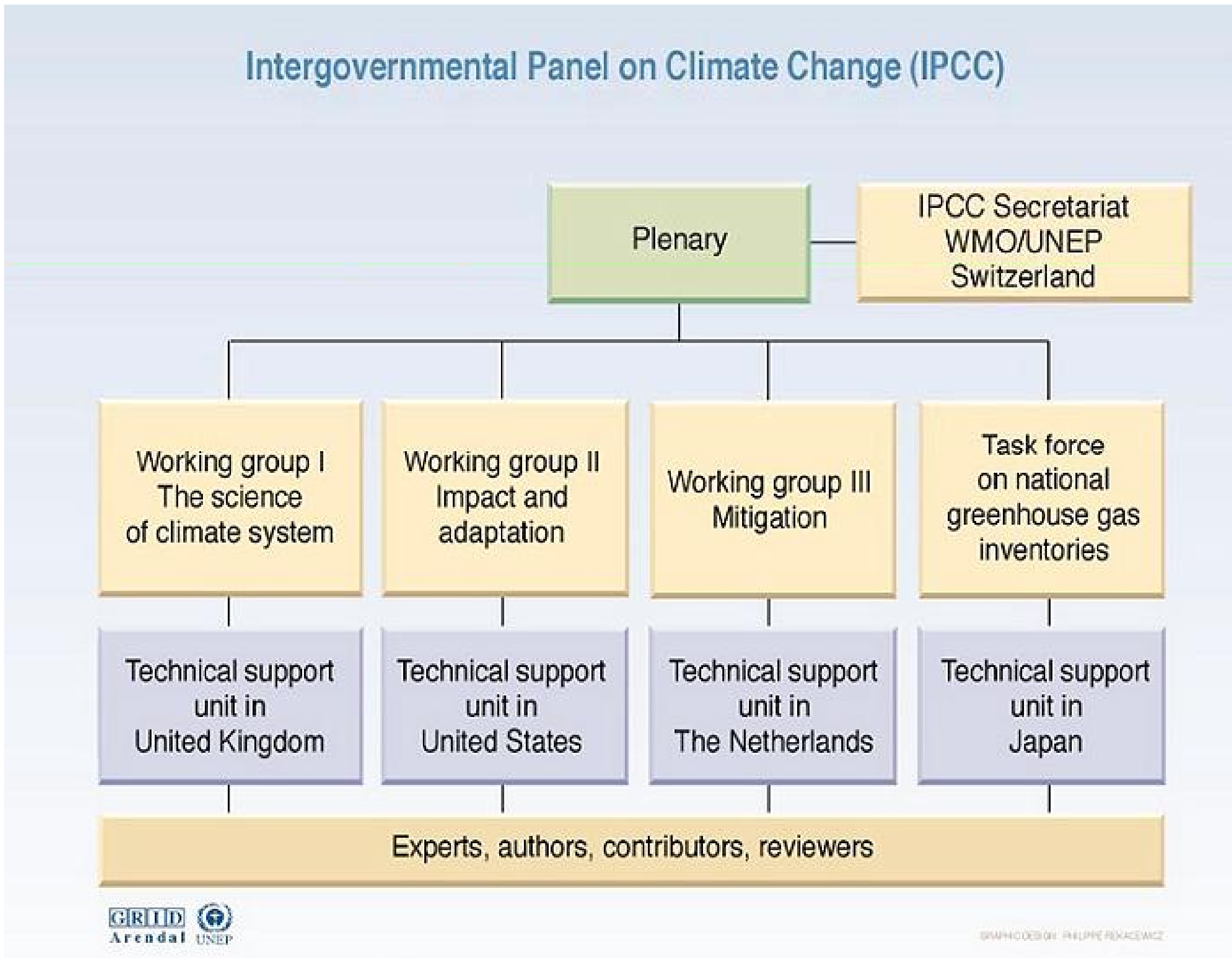
- The present generation must decide, with the help of expert advice from economists, wehther to aggressively reduce the chances of future harm or to let our richer descendants largely fend for themselves.

- Economists cannot avoid making ethical choices in formulating their advices.

- Even the small chance of utter catastrophe from global warming raises special problems for ethical discussion.

Intergovernmental Panel on Climate Change (IPCC) was was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), two organizations of the UN.

IPCC is a scientific body tasked to evaluated the risk of climate change by human activities.

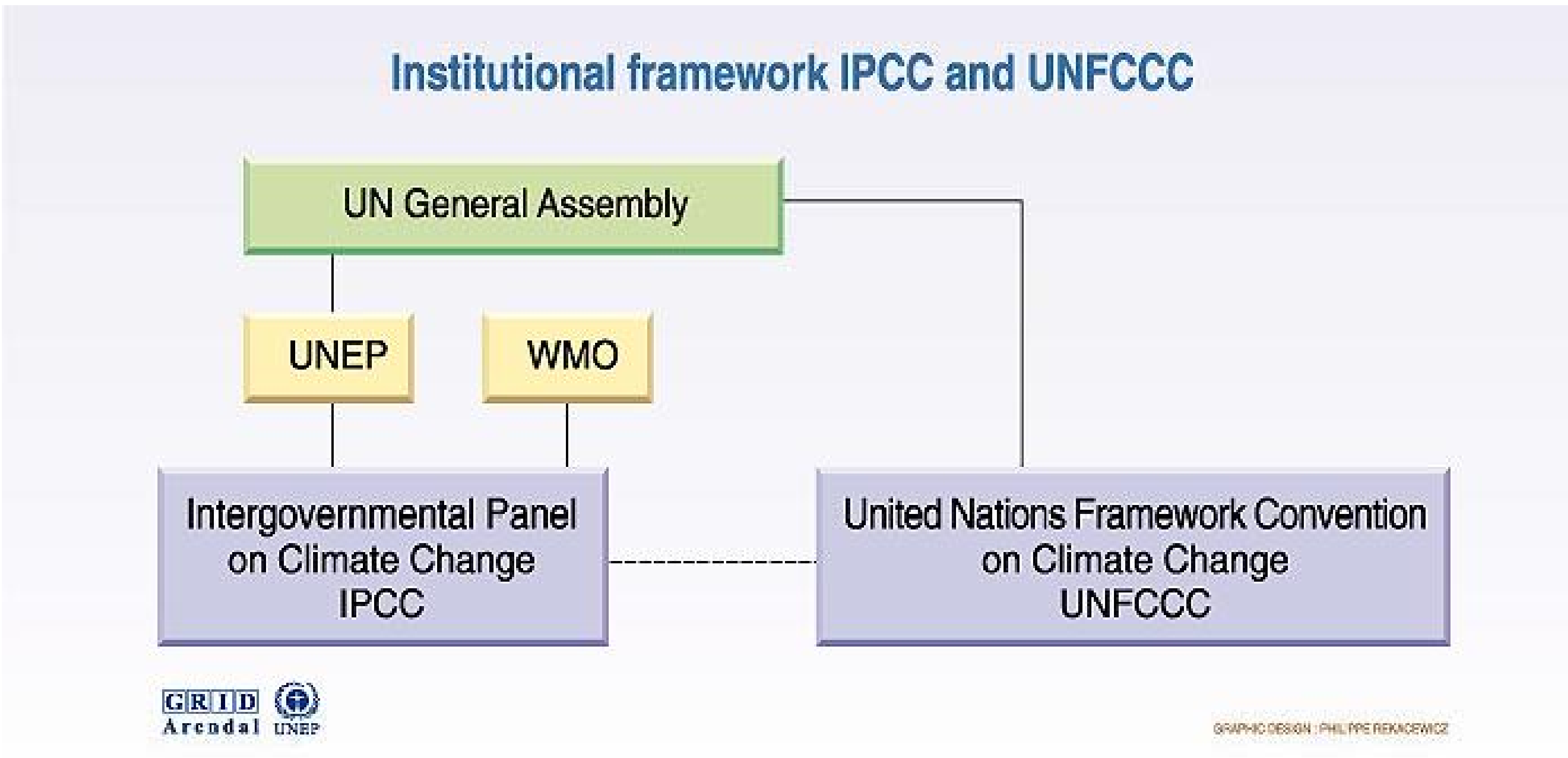


Source: United Nations framework convention on climate change (UNFCCC).

Two Treaties Established by United Nations:

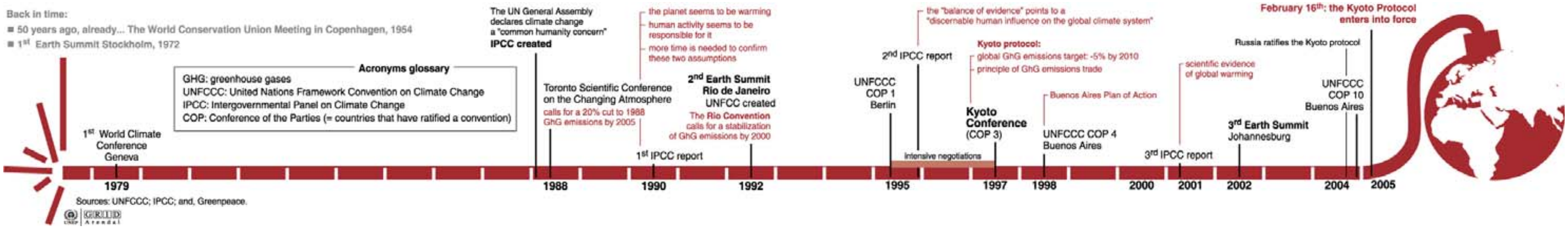
UN Framework Convention on Climate Change (UNFCCC) is an international treaty produced by UN Conference on Environment and Development (UNCED), or the Earth Summit, in 1992.

Kyoto Protocol is an amendment of UNFCCC and was established in 1997.



Source: United Nations framework convention on climate change (UNFCCC).

Timeline of Two Treaties - UNFCCC and Kyoto Protocol



UNFCCC – United Nations Framework Convention on Climate Change

Objective: Stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system … with a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner.

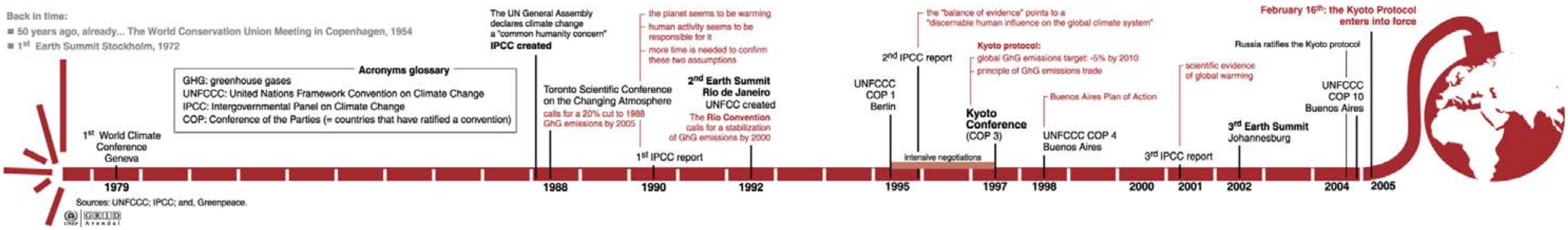
Principle: Common but differentiated responsibility; intended to be a starting point for more specific and binding measures to be negotiated.

Signed in 1992, entered into force in 1994, ratified by 190 countries including the US.

Commitments: reporting current and projected emissions and supporting climate-related research; a general obligation to take measures to limit emissions and report on these, but not specified; only for the industrialized nations (or the "annex1 countries") did this general obligation also include the specific aim of returning emissions to 1990 levels by 2000, but not legally binding.

Results: little more than exhortations for voluntary action and re-labelings of existing programs.

Timeline of Two Treaties - UNFCCC and Kyoto Protocol (Continued)



Kyoto Protocol

Objective: to establish stronger measures for binging national greenhouse-gas emission limits.

Signed in 12/1997, entered into force in 2/16/2005 after ratified by 55 countries that contributed at least 55% industrialized-country emissions in the baseline year 1990, i.e., all industrialized countries if US does not not ratify. 182 nations have ratified the Protocol.

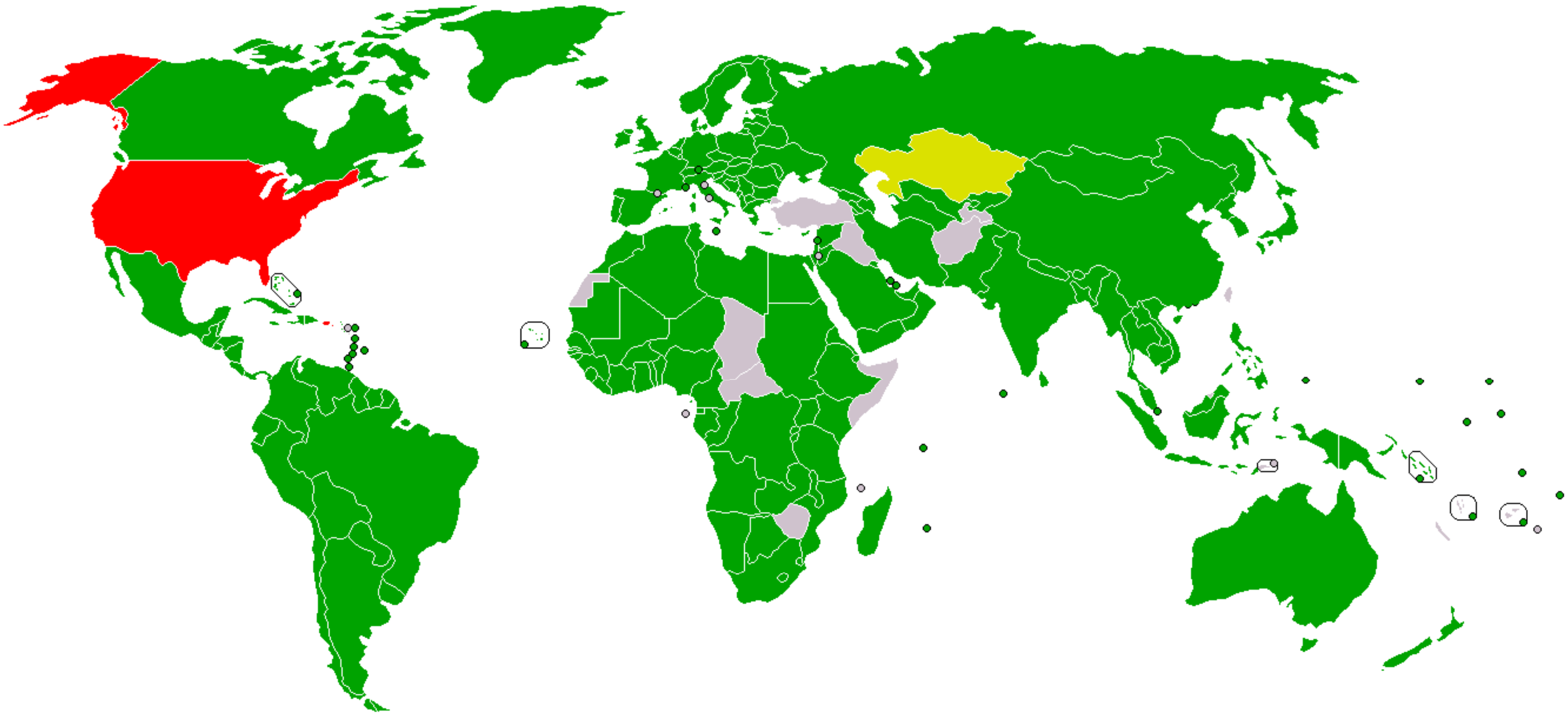
Cap: Specific emission-reduction targets for each industrialized nation over a five-year commitment period of 2008-2012. If target is met, the total emissions from these countries would be 5.2% below 1990 levels (7% for US). No emission limits for developing countries.

Trade: Mechanisms to exchange emission-reduction obligations between nations through allowing one nation to make less than its required reduction by paying the cost of a larger cut elsewhere. Details of this provision are left to be solved later. Negotiations continued after signing.

US: Signed in 1997 but remains the only industrialized nation that does not ratify the Protocol. Bush administration proposed in 2/2002 a reduction in emission per $ of GDP by 2012 by 18%, funding for research and tax incentives for renewable energy, high-efficiency vehicles and volunteer activities.

Beyond Kyoto: More flexible mechanisms for compliance in 2002, emission limits after 2012.

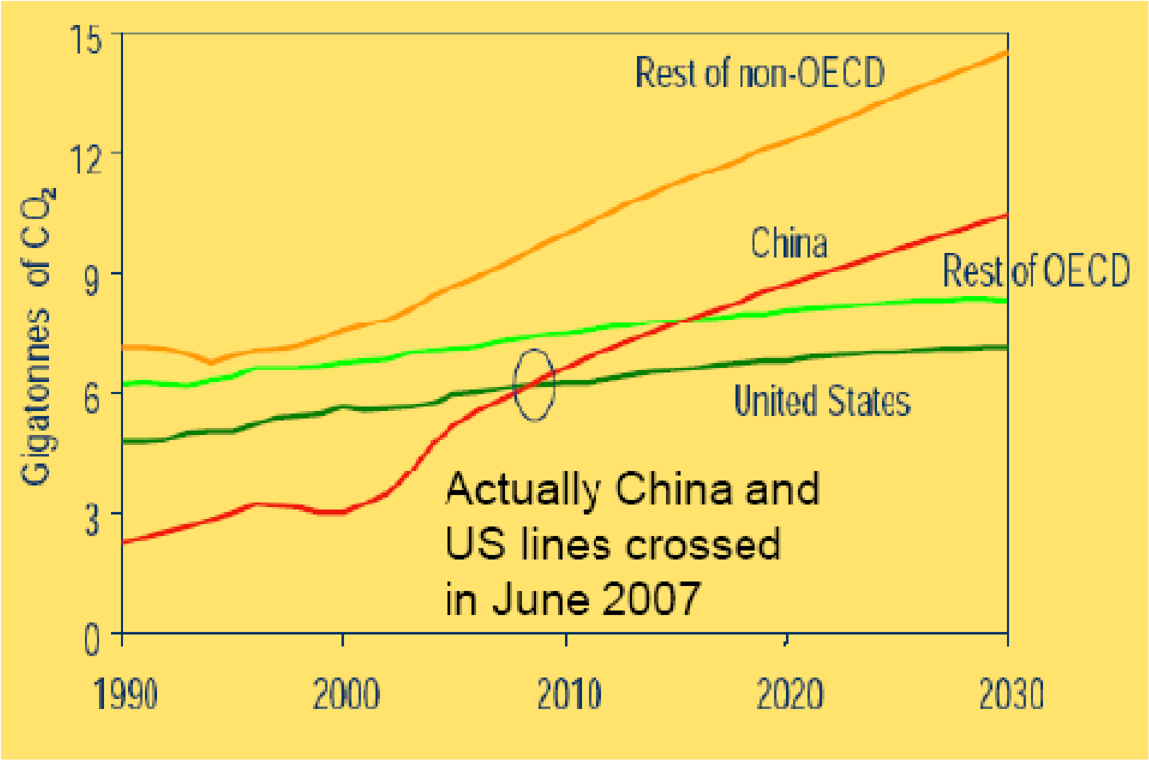
Participation in the Kyoto Protocol:



green indicates states parties
yellow indicates states with ratification pending
red indicates those that signed but declined ratification of the treaty.

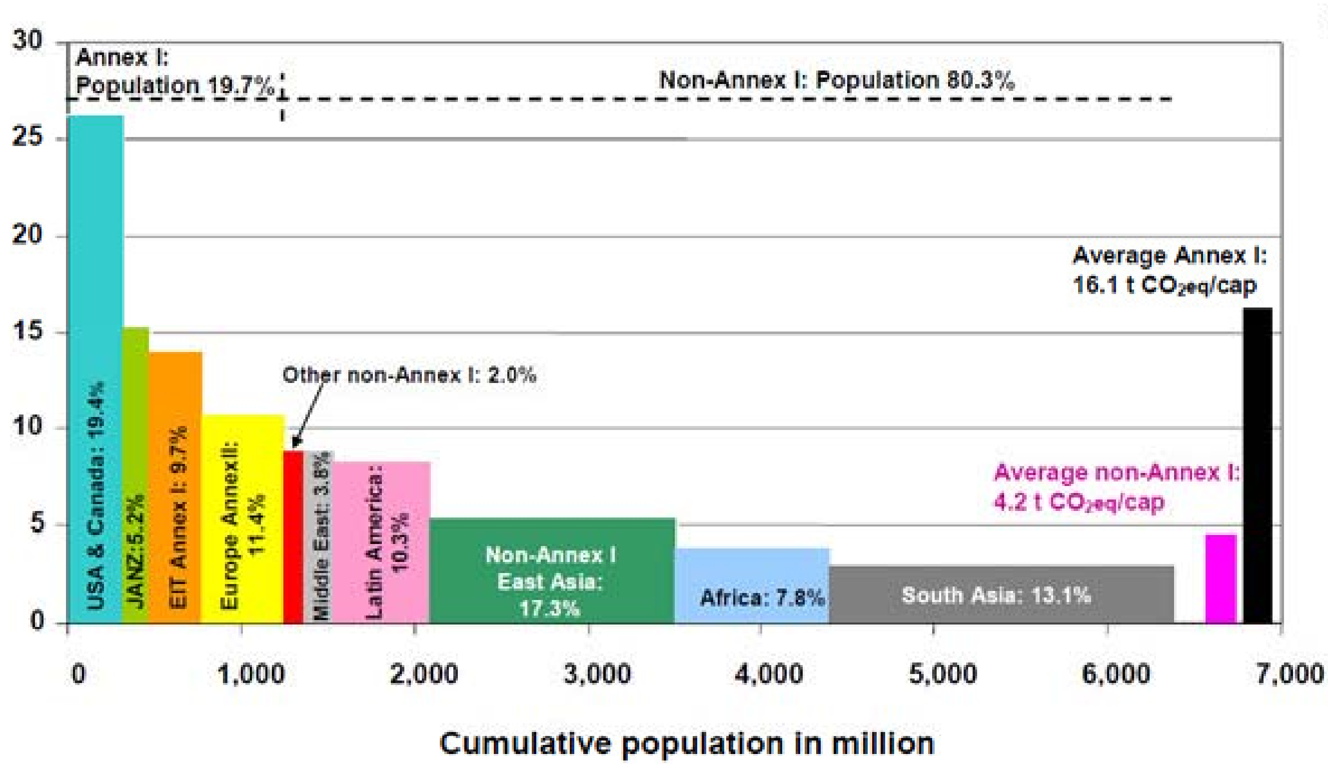
Discussion of reduction of CO_2 emission has been one of the most controversial and emotional issues surrounding the climate change.

CO_2 emission projections, all sectors.



- **China is is currently constructing the equivalent of two, 500 MW, coal-fired power plants per week and a capacity comparable to the entire UK power grid each year.**

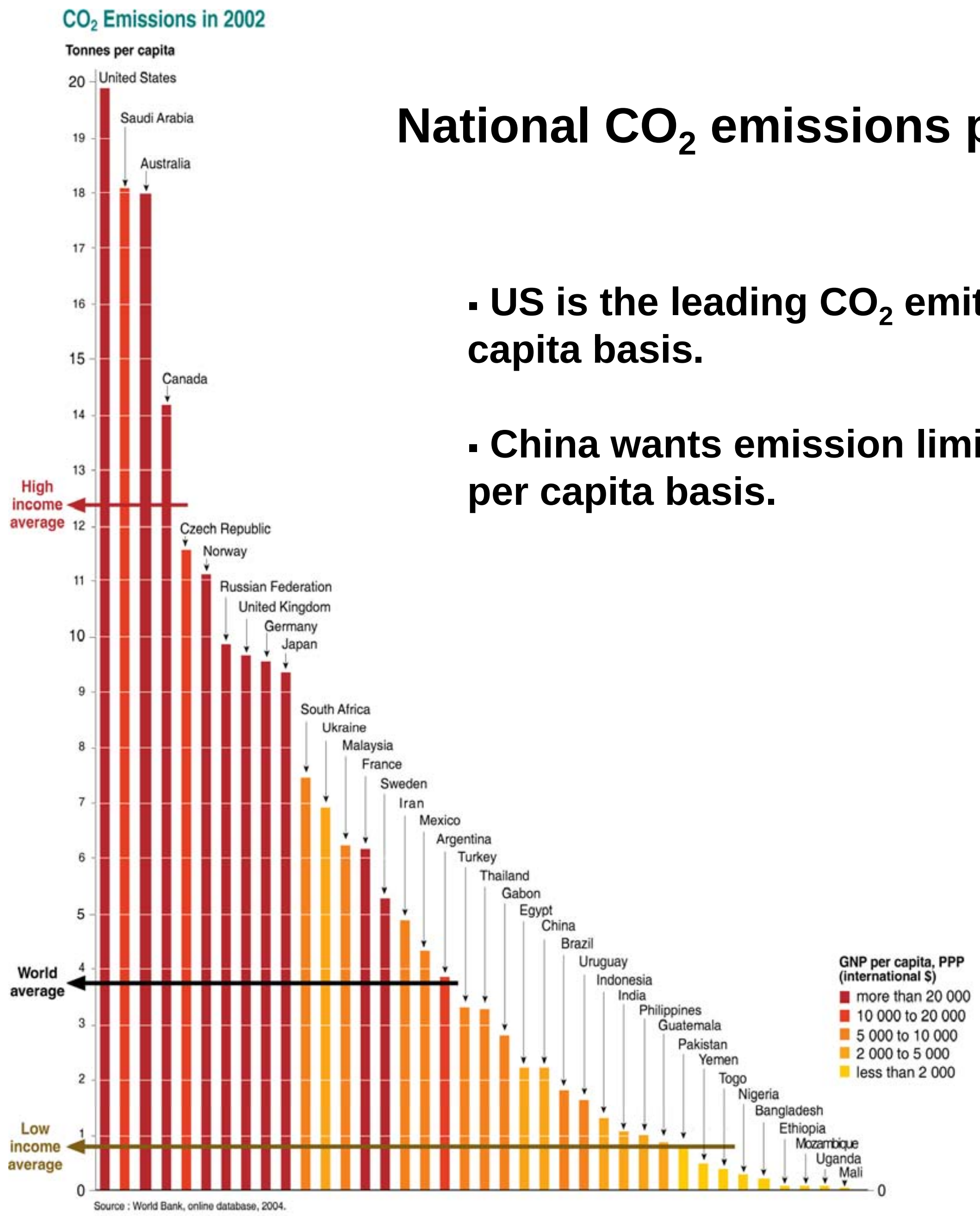
- **US has been hostile to the Kyoto Protocol because it contains no emission limits for the developing countries, and China is emitting more CO_2 than the US.**



Carbon Dioxide Emissions per Capita and Country

Annex 1 of the Kyoto Protocol forces industrialized countries to reduce their GHG emissions. Annex 1 countries represent only one fifth of mankind but are responsible for about 44 percent of all GHG emissions. If seen from an individual perspective, the average U.S. and Canadian citizen emit the biggest amount of carbon dioxide. People living in Japan, New Zealand and Europe still account for huge amounts of CO_2, but generally stay below carbon caps set by Annex 1. People living in Africa and South Asia are the least responsible for global warming. They make up nearly half of the world's population, but only one fifth of all GHG emissions (Graphic: IPCC).

National CO_2 emissions per capita



- US is the leading CO_2 emitter on a per capita basis.

- China wants emission limits set based on per capita basis.

Homework

- **Read the textbook: Vanek, F.M., Albright, L.D., Energy Systems Engineering: Evaluations and Implementation," McGraw-Hill, New York, 2008.**

- **Browse the web (such as but not limited to Wikipedia) for the understandings of the following terms:**

  - **global warming, climate change, greenhouse effect, greenhouse gas (GHG), thermohaline circulation (the great ocean conveyer), shutdown of thermohaline circulation, ice age, Milankovitch cycles, El Nino,**

  - **Kyoto protocol, IPCC (Intergovernmental Panel on Climate Change), WMO (World Meteorological Organization), UNEP (United Nations Environment Programme), UNFCCC (United Nations Framework Convention on Climate Change).**

- **Browse the IPCC web site at:**
  http://www.ipcc.ch/index.htm
  Their latest (4th) assessment reports (AR4)can be viewed at:
  http://www.ipcc.ch/ipccreports/assessments-reports.htm
  It is free!

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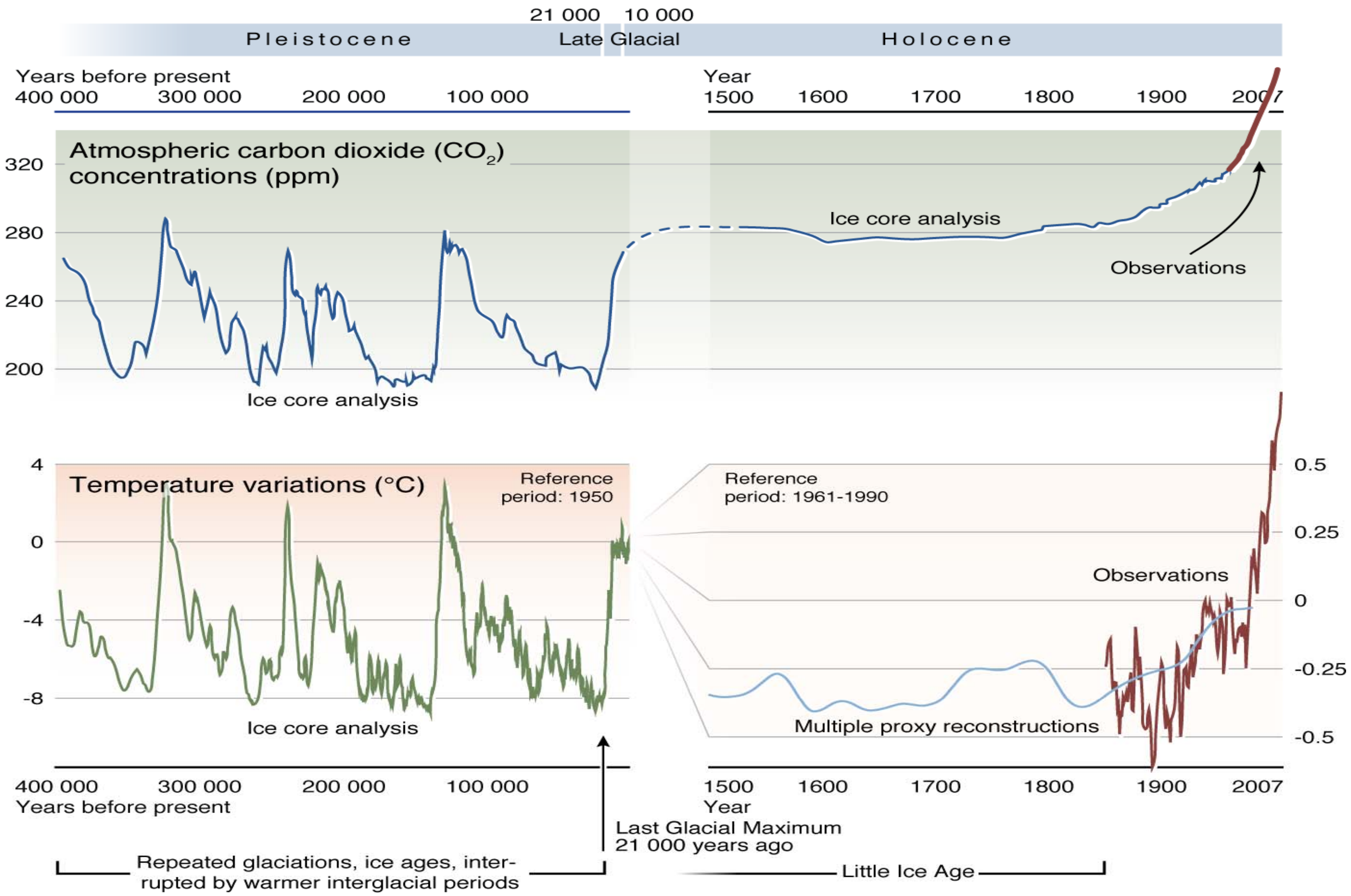
- UNEP, http://maps.grida.no/theme/climatechange
- US Department of Energy, http://www.netl.doe.gov/technologies/carbon_seq/
- International Energy Agency, http://www.ieagreen.org.uk/
- National Academy of Science, http://www.koshland-science-museum.org/exhibitgcc/carbon01.jsp
- Allinaz, http://knowledge.allianz.com/en/

Observations and Causes



The most recent geological history, in the last hundred thousand years, has been characterised by cycles of glaciations, or ice ages. The historic temperatures, through these times, have been low, and continental ice sheets have covered large parts of the world. Through ancient air, trapped in tiny bubbles in the Antarctic ice, we have been able to see what the temperature cycle was at that time, and also the concentration of carbon dioxide (CO_2). The more recent history, from the middle ages and up until now, show increasing temperatures, rising as the world emerged from the Little Ice Age (LIA), around 1850. With the industrial era, human activities have at the same time increased the level of carbon dioxide (CO_2) in the atmosphere, primarily through the burning of fossil fuels. Carbon dioxide is one of the main greenhouse gases, and scientists have been able to connect human activities as one of the drivers to climate change and global warming. The top part of the CO_2 measurements, the observations, are what is referred to as the 'Mauna Loa curve' or the 'Keeling curve'.

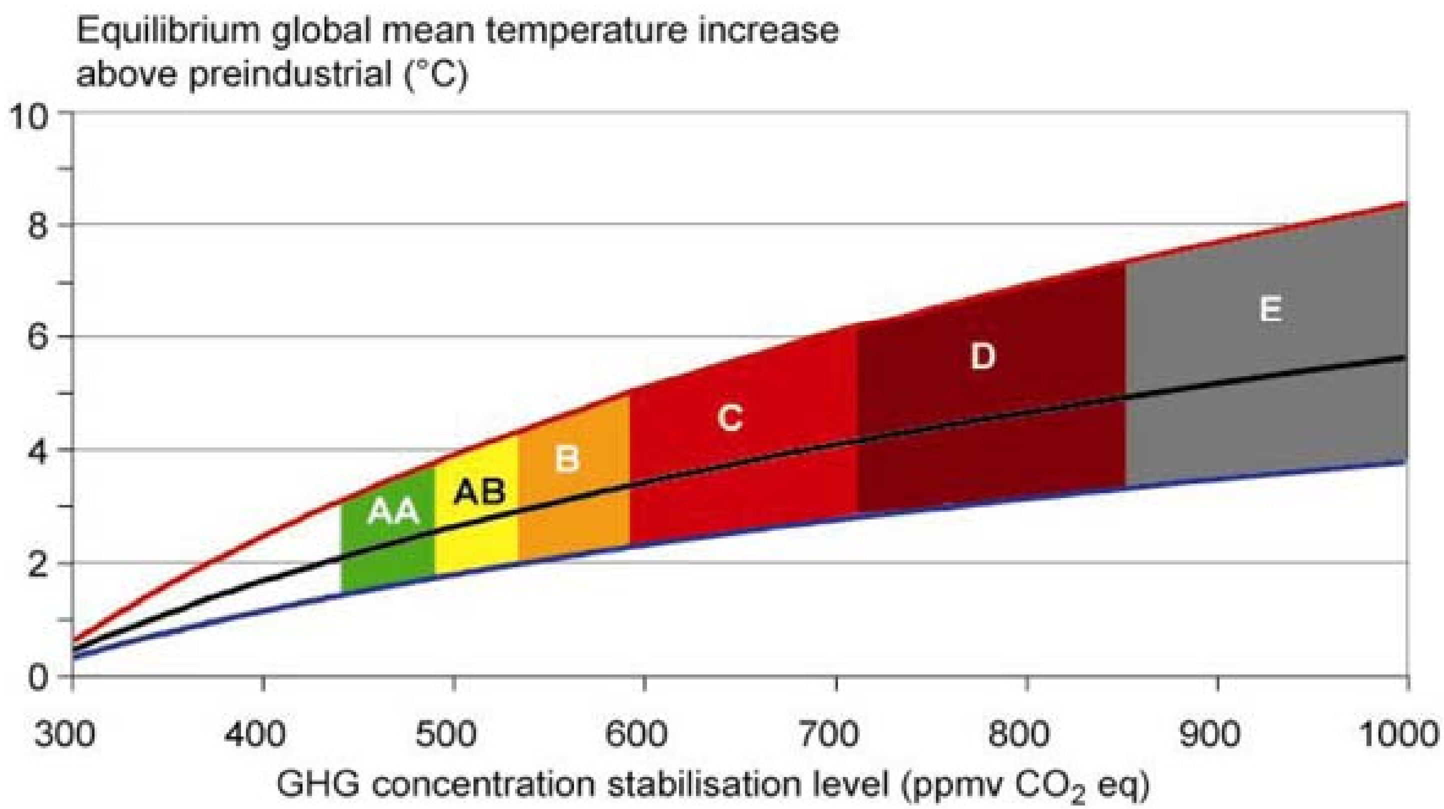
Evidences of global warming trend

Table 3.1. *A summary of measurements of changes in the Earth's temperature*

Type of data	Direction of twentieth-century change	Size of change, comments
Direct surface air temperature	Warming	Average surface air temperature increased about 0.6 °C (1 °F) over the twentieth century, with about half this warming occurring between 1980 and 2000.
Glaciers	Warming	Glaciers have been receding on average for a few centuries, with evidence of faster retreat in the twentieth century. The warming implied by this recession is about two-thirds of a degree Celsius per century, consistent with the surface record.
Sea-level change	Warming	Sea level rose about 15 cm total over the twentieth century. About half this rise probably came from the expansion of ocean water as it has warmed.
Sea ice	Warming	The area of Arctic sea ice in spring and summer has decreased by 10–15 percent over the past 50 years. Average thickness of Arctic sea ice has decreased by 40 percent over the same period.
Ocean temperature	Warming	The top 300 m of the ocean has warmed 0.18 °C over the past 50 years.
Climate proxies	Warming	Combined data from many climate proxies shows gradual Northern Hemisphere cooling from the year 1000 to the nineteenth century, then strong warming during the twentieth century.
Satellite temperature measurements	Warming	Satellite instruments show warming of 0.06–0.26 °C per decade

Climate proxies include tree rings, ice cores, corals, ocean sediments, and boreholes.

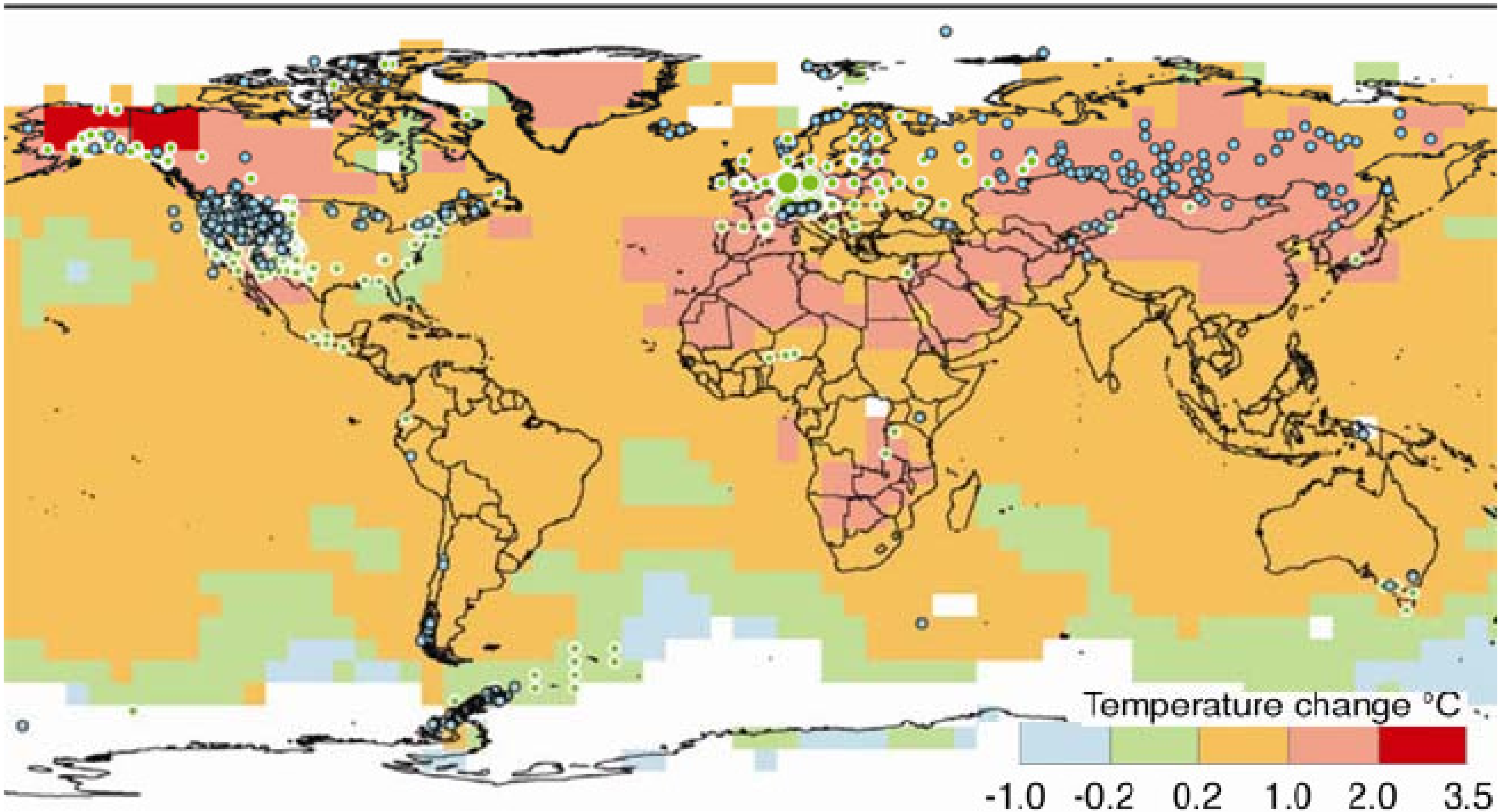
From: Dessler and Parson, 2007



Average Global Temperatures

According to the UN's Intergovernmental Panel on Climate Change (IPCC) global average air temperatures rose 0.74 +/- 0.18 degrees Celsius during the past century. Several climate scenarios illustrate how temperatures might increase during the 21st century (Graphic: IPCC). Which of these scenarios becomes reality depends on how much carbon dioxide (CO_2) and other greenhouse gases will be emitted. Pre-industrial levels were around 280 CO_2 parts per million (ppmv) molecules of dry air; they have since risen to the current level of some 380 ppmv. If global warming is to be limited to 2 degrees Celsius, carbon dioxide concentration has to be stabilized at 400-450 ppmv or less (Graphic: IPCC).

Changes in physical and biological systems and surface temperature 1970-2004



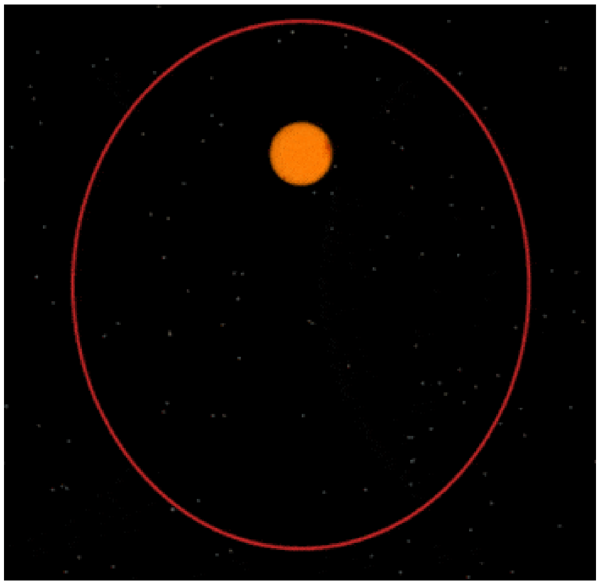
Local Differences in Global Warming

Although scientists talk about global warming, temperature increases are not evenly distributed geographically. The image shows that parts of the southern hemisphere have even witnessed some cooling, while the Arctic, Greenland, and Alaska went through a period of significant warming. And while South America saw only small temperature increases, warming was stronger in Asia, North Africa, and the Mediterranean (Graphic: IPCC).

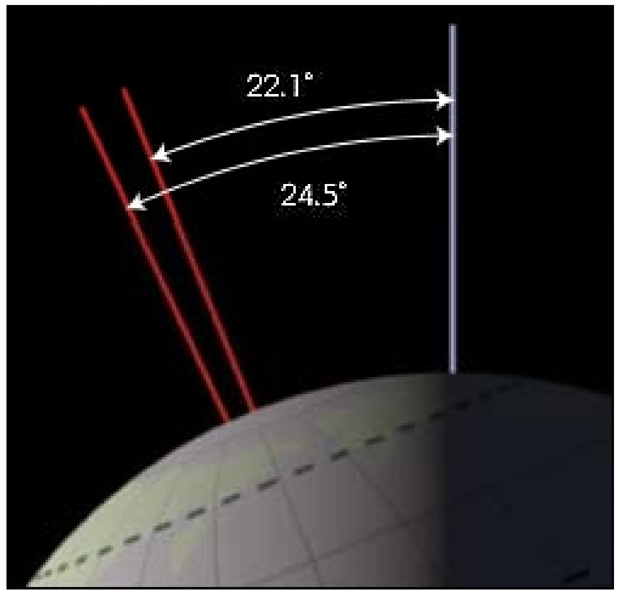
Causes of ice age

- Variations in earth’s orbit (Milankovich cycles)
- Changes in earth’s atmosphere
- Position of the continents
- Variations in the sun’s energy output
- Volcanism

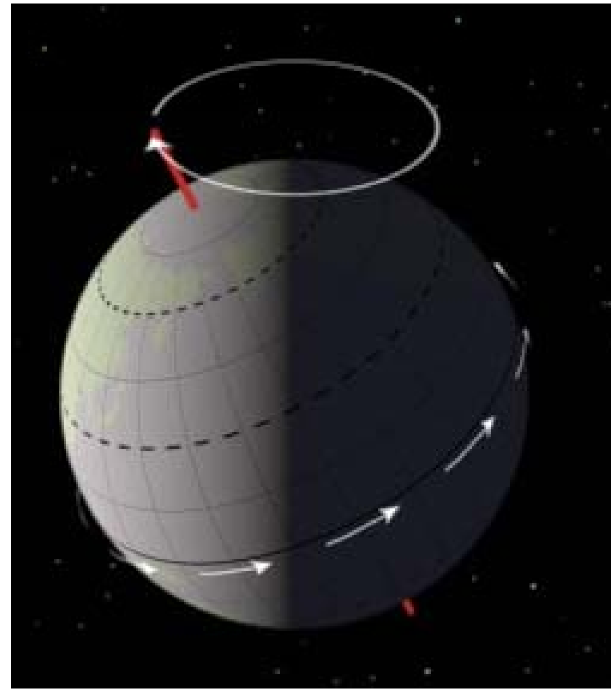
Cause of ice age - Milankovitch cycles, or solar forcing



Orbit with 0.5 eccentricity (eccentricity)

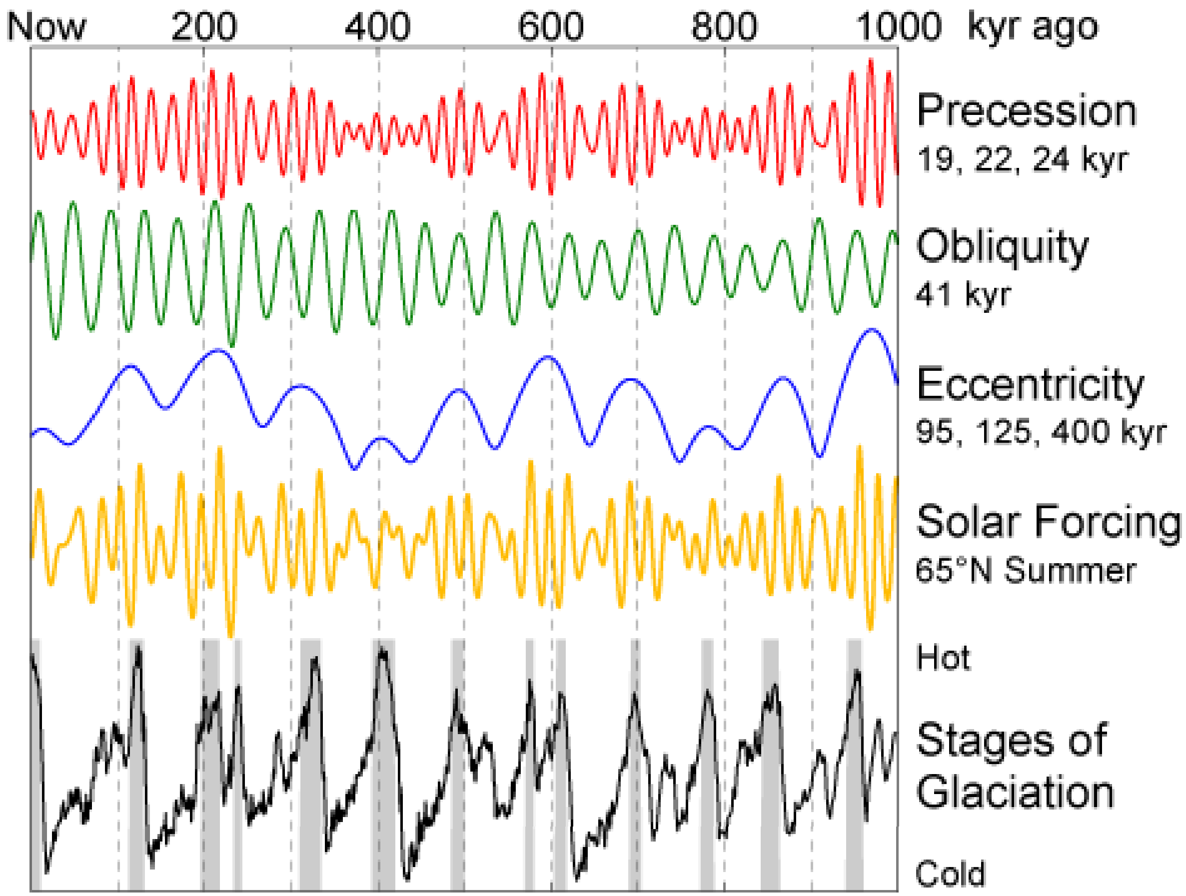


Earth's axial tilt (obliquity)

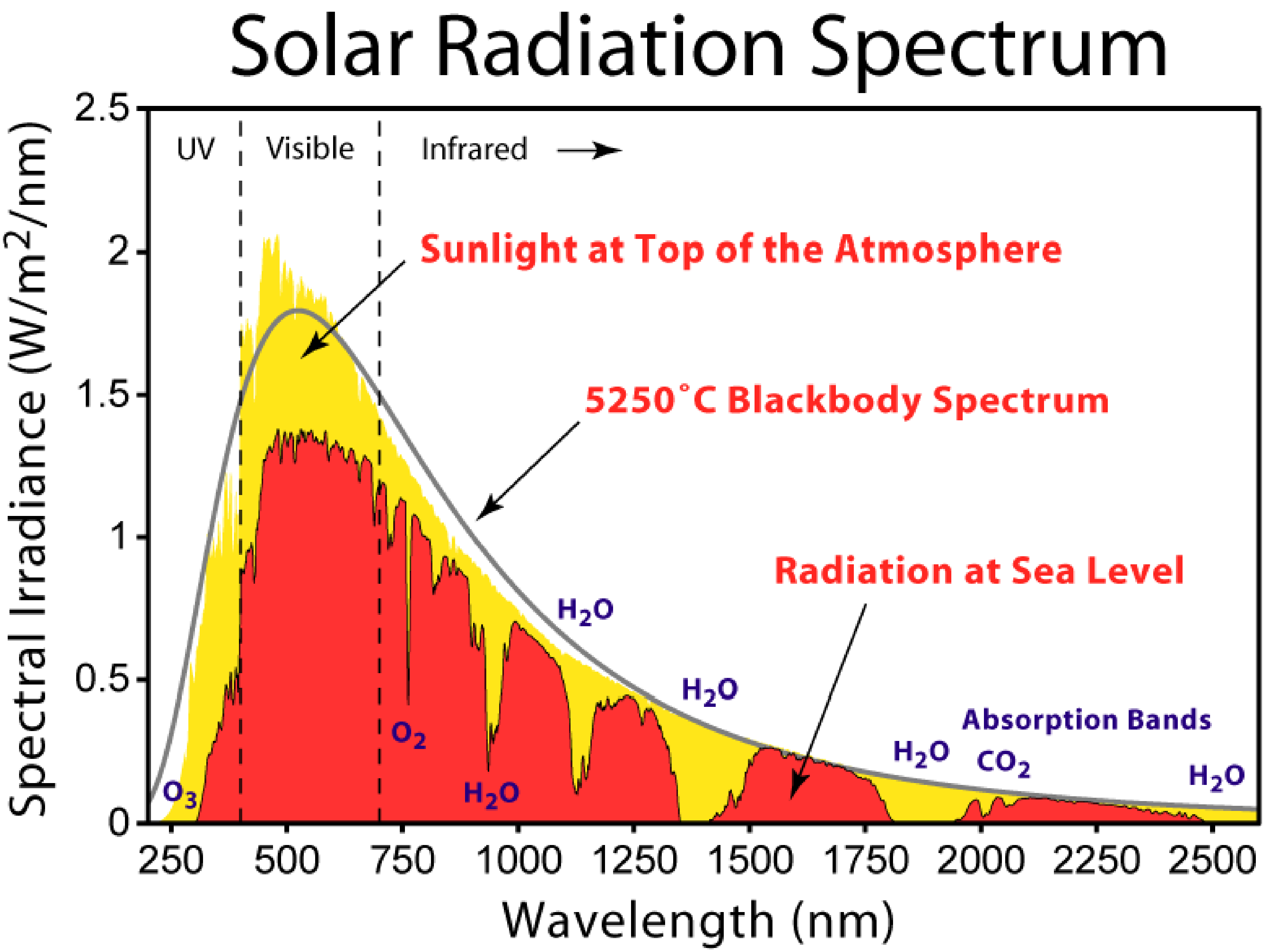


Earth's axis of rotation relative to the fixed stars (Precession, Wobble)

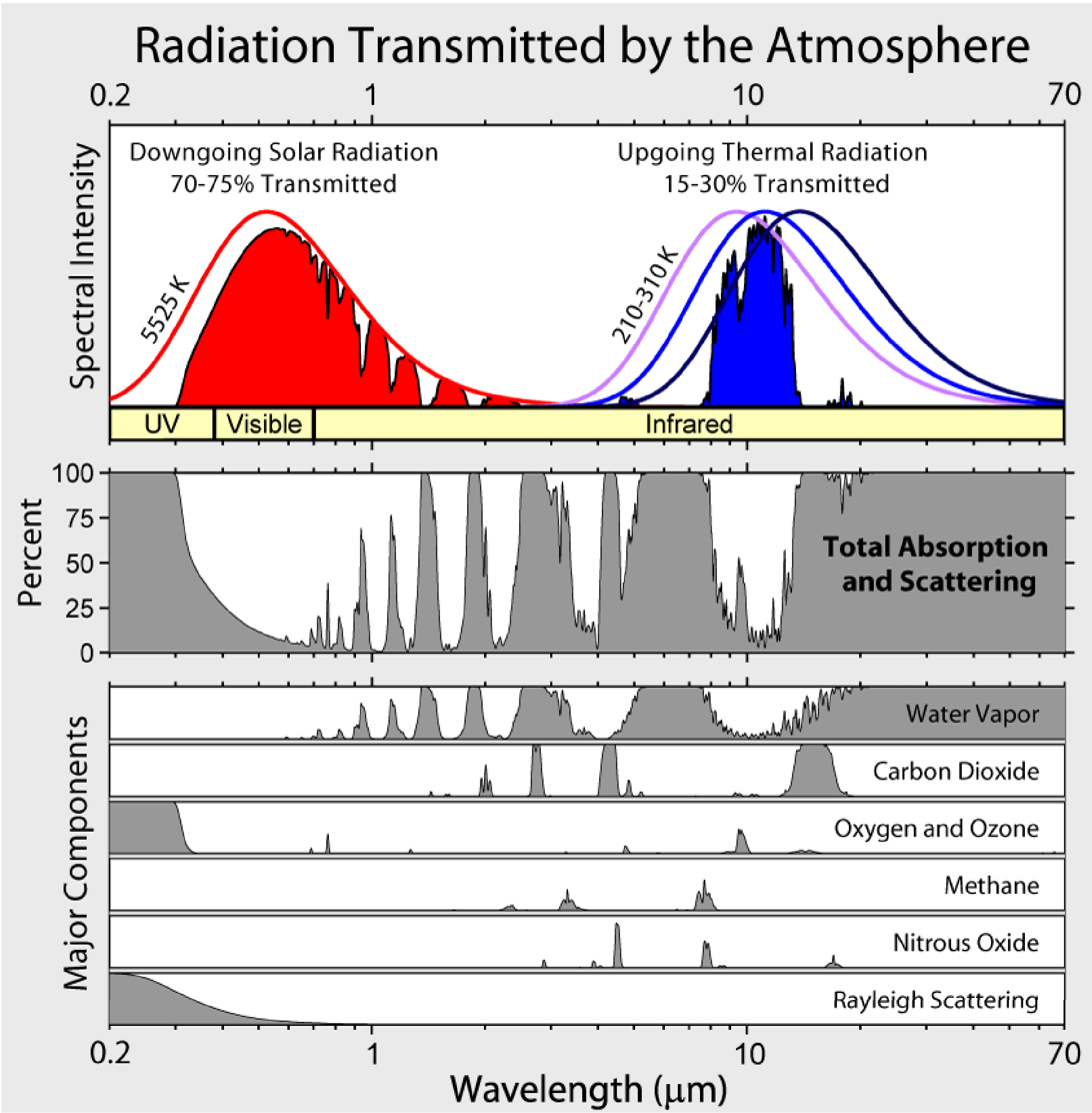
Cause of ice age - Milankovitch cycles (cont.)



Milankovitch's theory is consistent with many critical observations. However, the theory its self is not sufficient to explain the complexity of the overall solar forcing that causes the observed global warming.



Solar Radiation Spectrum
Spectral Irradiance (W/m²/nm)
2.5
2
1.5
1
0.5
0
UV
Visible
Infrared
Sunlight at Top of the Atmosphere
5250°C Blackbody Spectrum
Radiation at Sea Level
O_3
O_2
H_2O
H_2O
H_2O
H_2O
H_2O
Absorption Bands
CO_2
250
500
750
1000
1250
1500
1750
2000
2250
2500
Wavelength (nm)

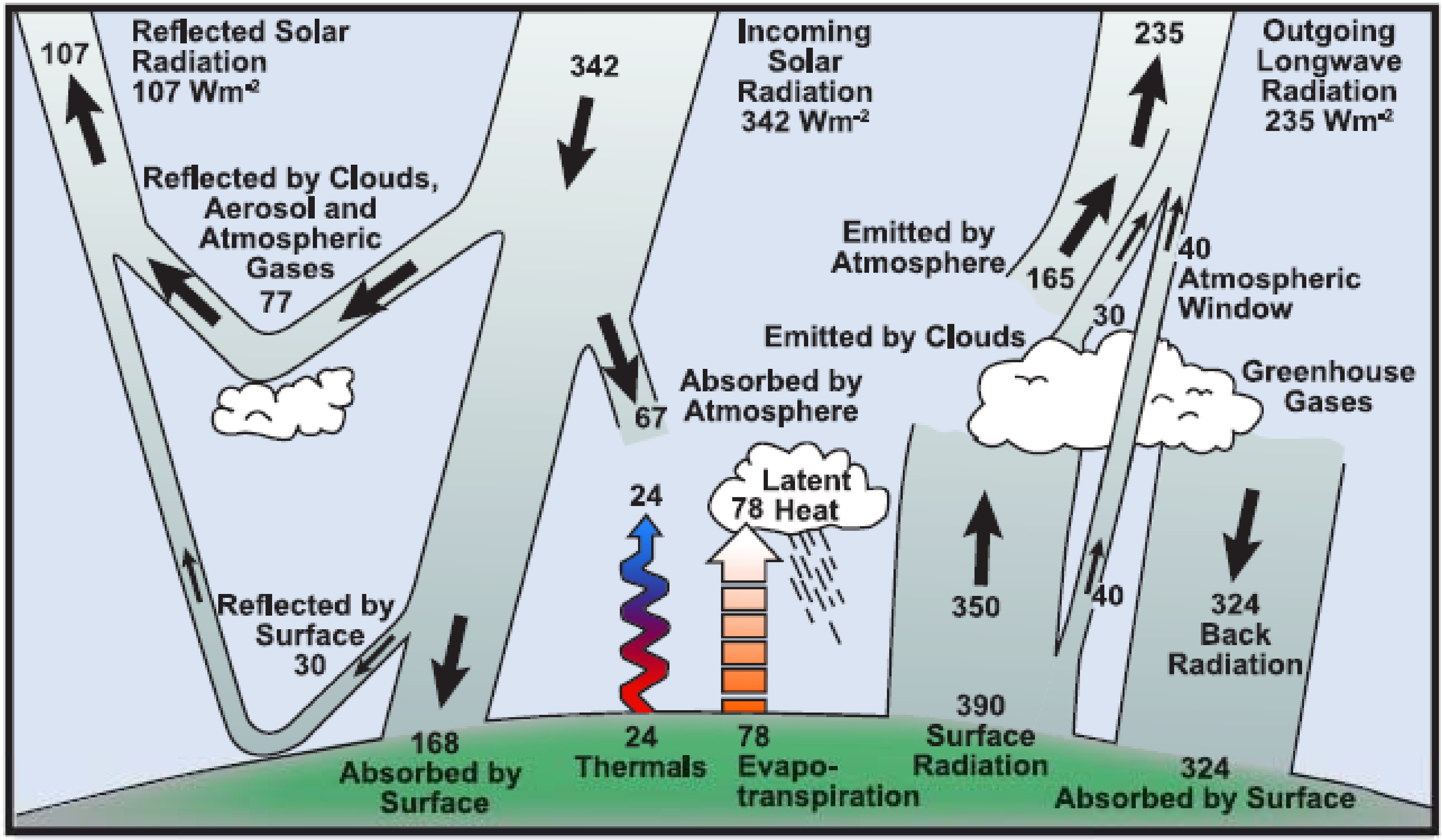


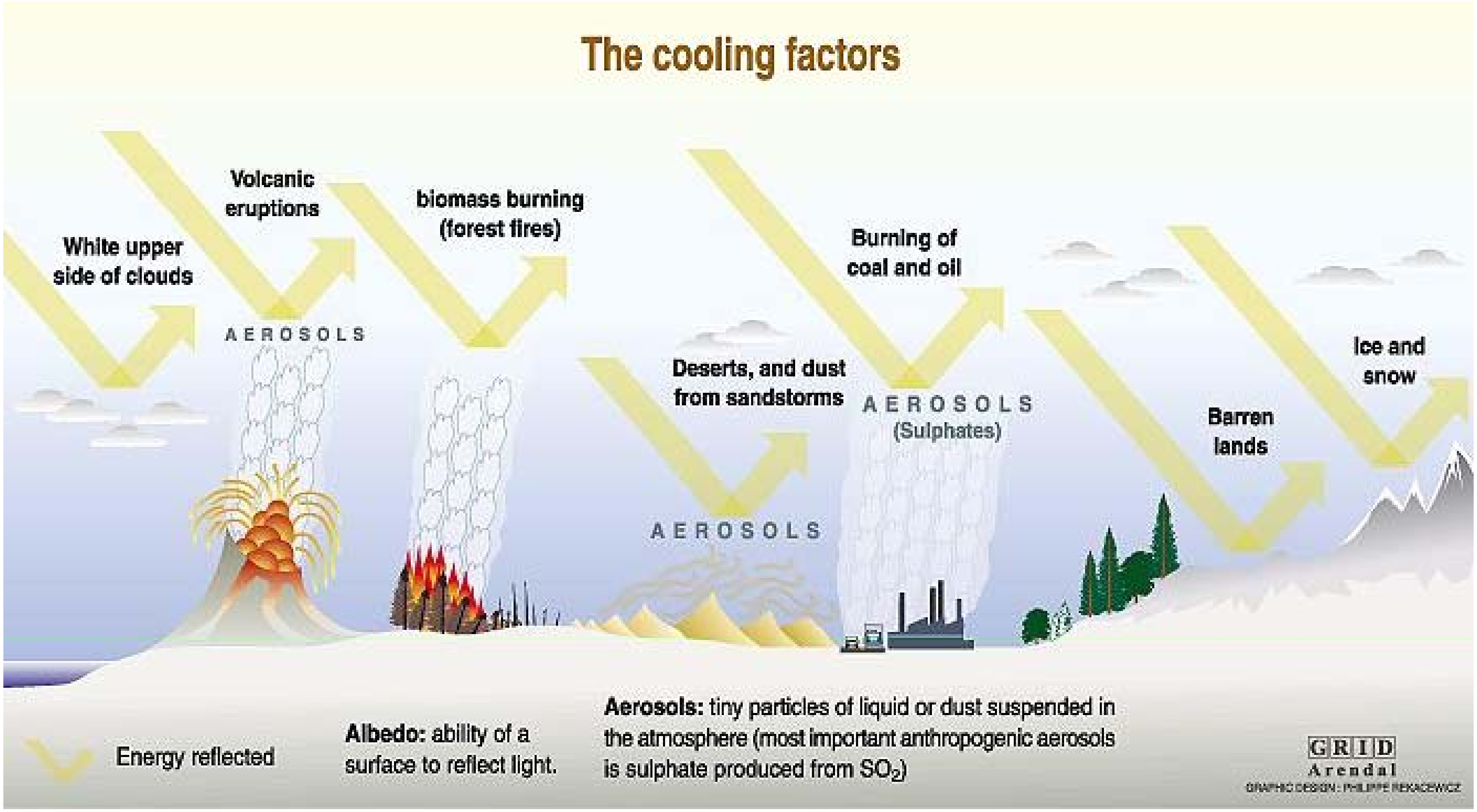
Solar radiation at 5525 K covers uv, visible and infrared regions, while the thermal radiation from the earth at low temperature is mainly infrared.

Red indicates the radiation from the sun detected on the earth surface; blue the radiation from the earth detected above the atmosphere.

Water, CO_2, CH_4 and N_2O absorb the radiation from the earth, which cause the greenhouse effects.

Detailed energy balance surrounding the earth

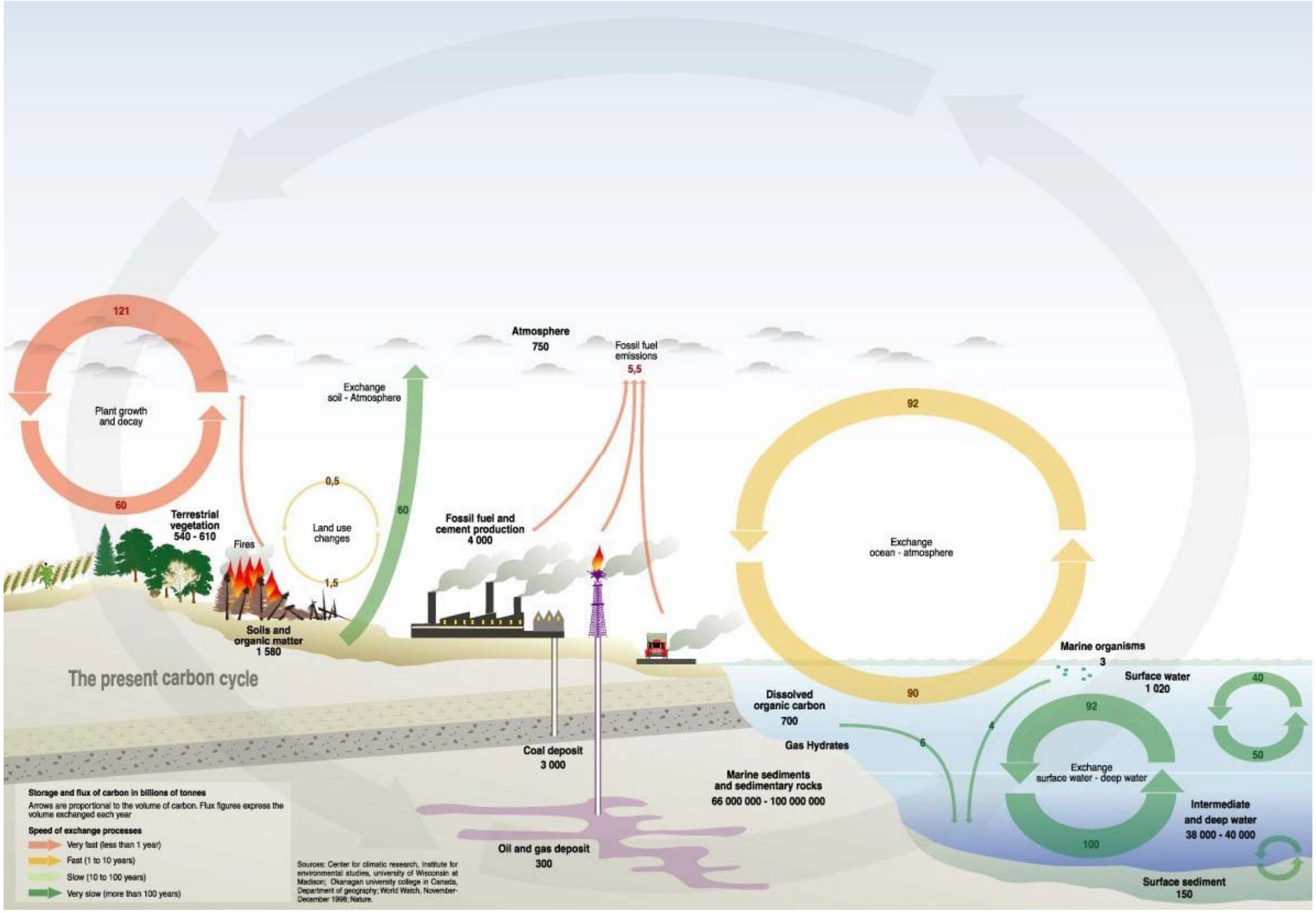




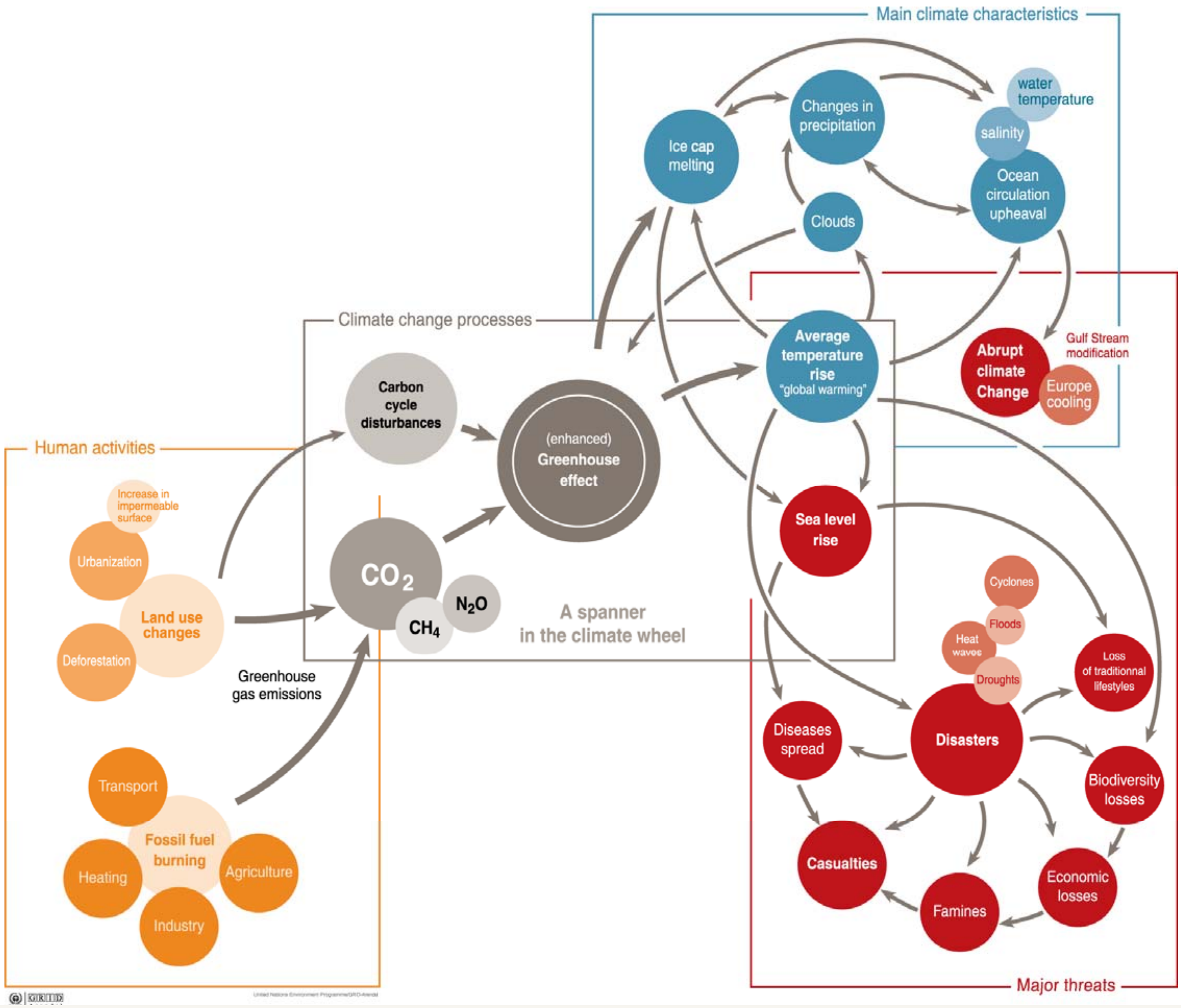
Sources: Radiative forcing of climate change, the 1994 report of the scientific assessment working group of IPCC, summary for policymakers, WMO, UNEP; L.D. Danny Harvey, Climate and global environmental change, Prentice Hall, pearson Education, Harlow, United Kingdom, 2000.

The amount of aerosols in the air has direct effect on the amount of solar radiation hitting the Earth's surface. Aerosols may have significant local or regional impact on temperature. Water vapour is a greenhouse gas, but at the same time the upper white surface of clouds reflects solar radiation back into space. Albedo - reflections of solar radiation from surfaces on the Earth - creates difficulties in exact calculations. If e.g. the polar icecap melts, the albedo will be significantly reduced. Open water absorbs heat, while white ice and snow reflect it.

Carbon cycle

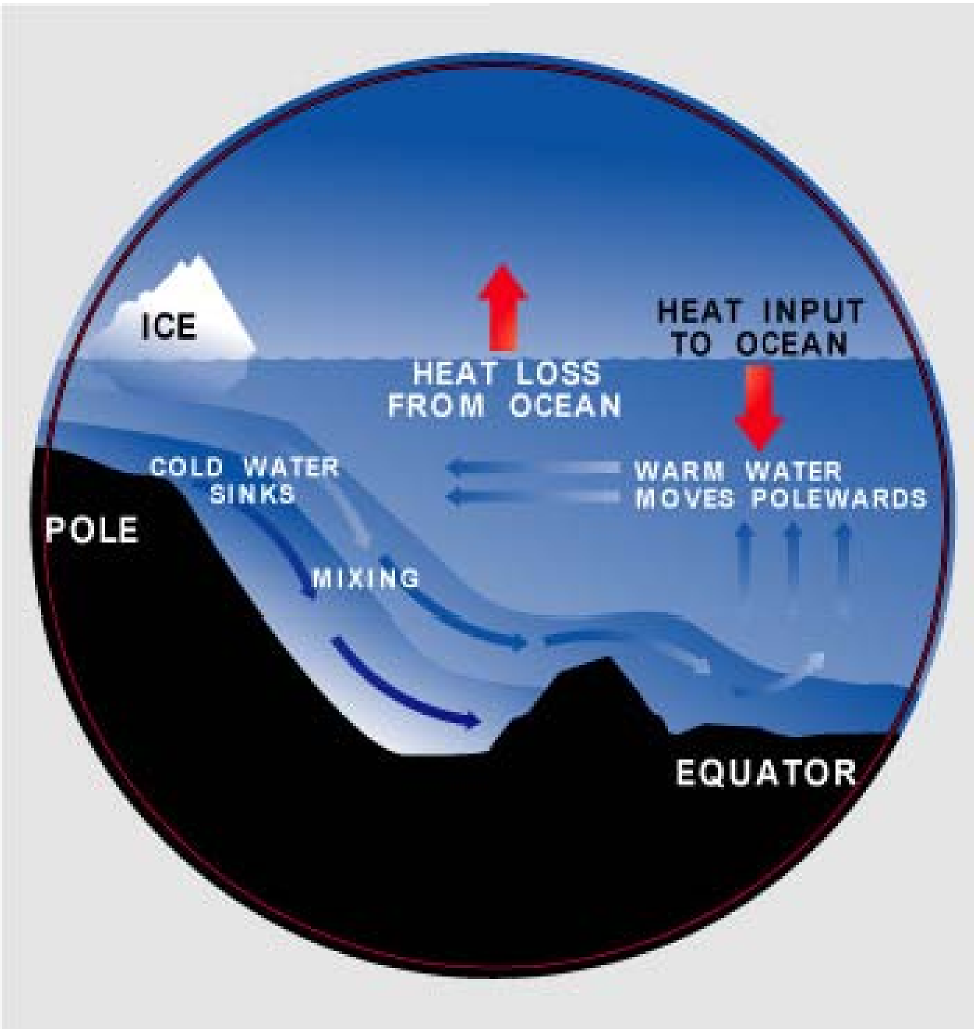


Carbon is the basis of all organic substances, from fossil fuels to human cells. On Earth, carbon is continually on the move – cycling through living things, the land, ocean, atmosphere. What happens when humans start driving the carbon cycle? We have seen that we can make a serious impact – rapidly raising the level of carbon in the atmosphere. But we really have no idea what we are doing. At the moment we don't even know what happens to all the carbon we release from burning fossil fuel. Obviously a lot of it goes into the atmosphere, but every year we loose track of between 15 and 30% (NASA). Scientists speculate that it is taken up by land vegetation, but no one really knows. This sort of uncertainty makes it doubly difficult to predict the outcome of tampering with something as complex as the carbon cycle.



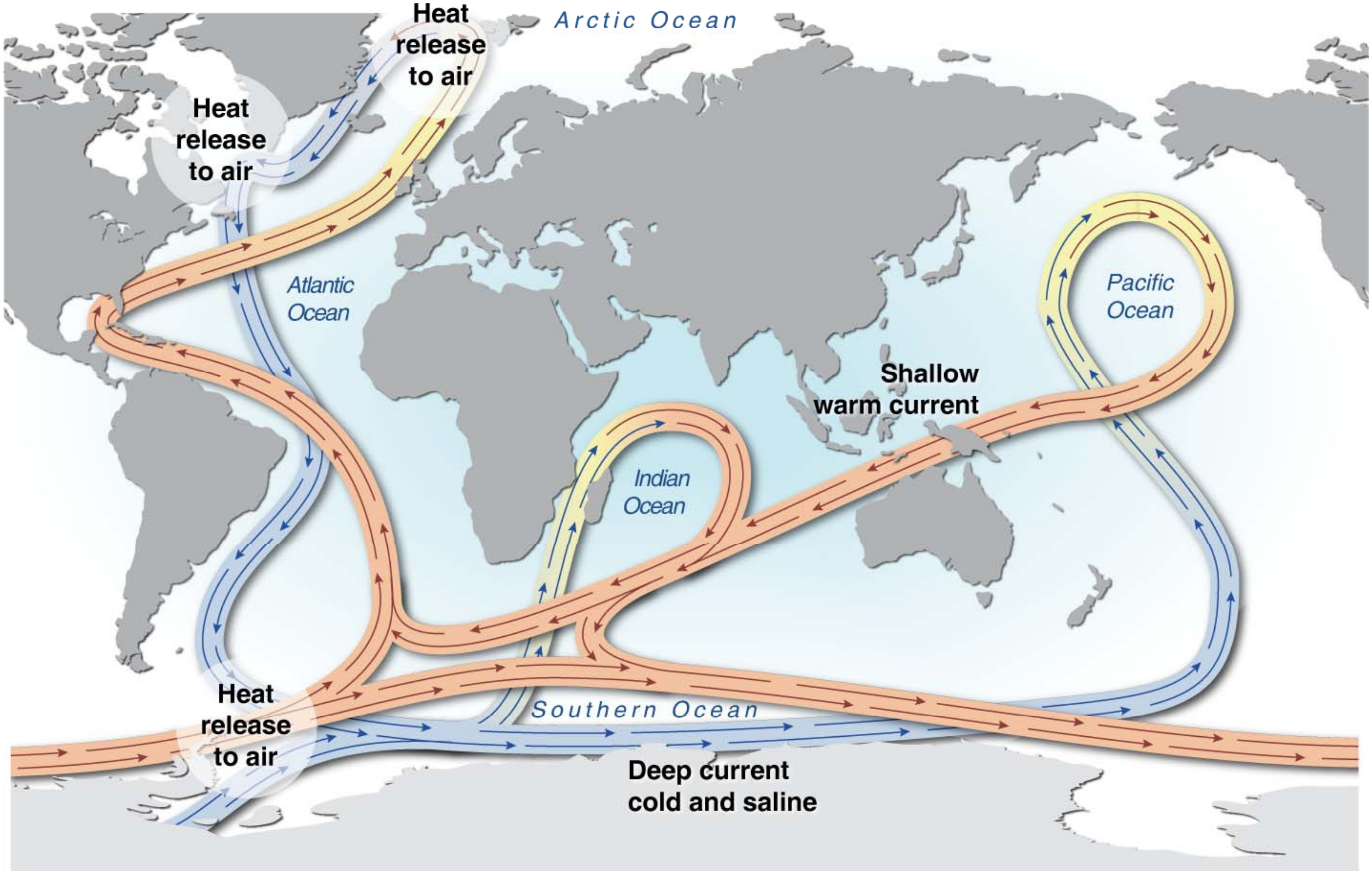
Most people have heard about climate change, they might even express a real concern about it, but how many would actually consider it a threat? Because the changes can be slow and sometimes difficult to identify within the normal variation of climatic conditions, many of us think they will not affect our lives. However, some parts of the world are already being severely affected by climatic change – both the people and the environment. And unfortunately, it appears that many developing countries bear the brunt of global warming, when the problem is mostly due to the actions of developed countries.

Ocean circulation



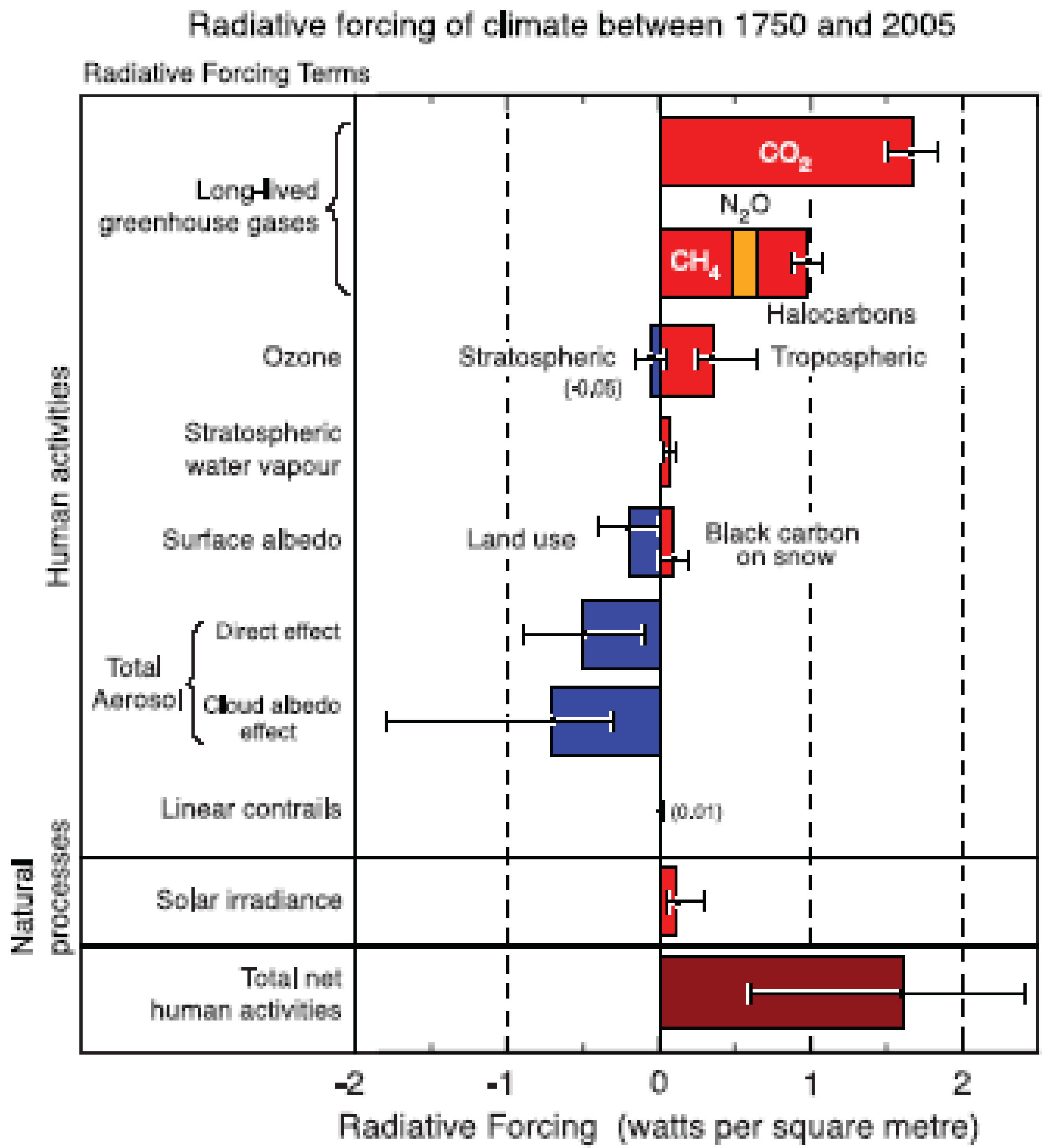
Cold water sinks at the poles and travels throughout the world's oceans. It gradually warms, becomes less dense and mixes to the surface. It then moves back towards the poles carrying heat absorbed along the way. Then the cycle continues. Without this cycle the poles would be colder and the equator would be warmer.

Thermohaline circulation

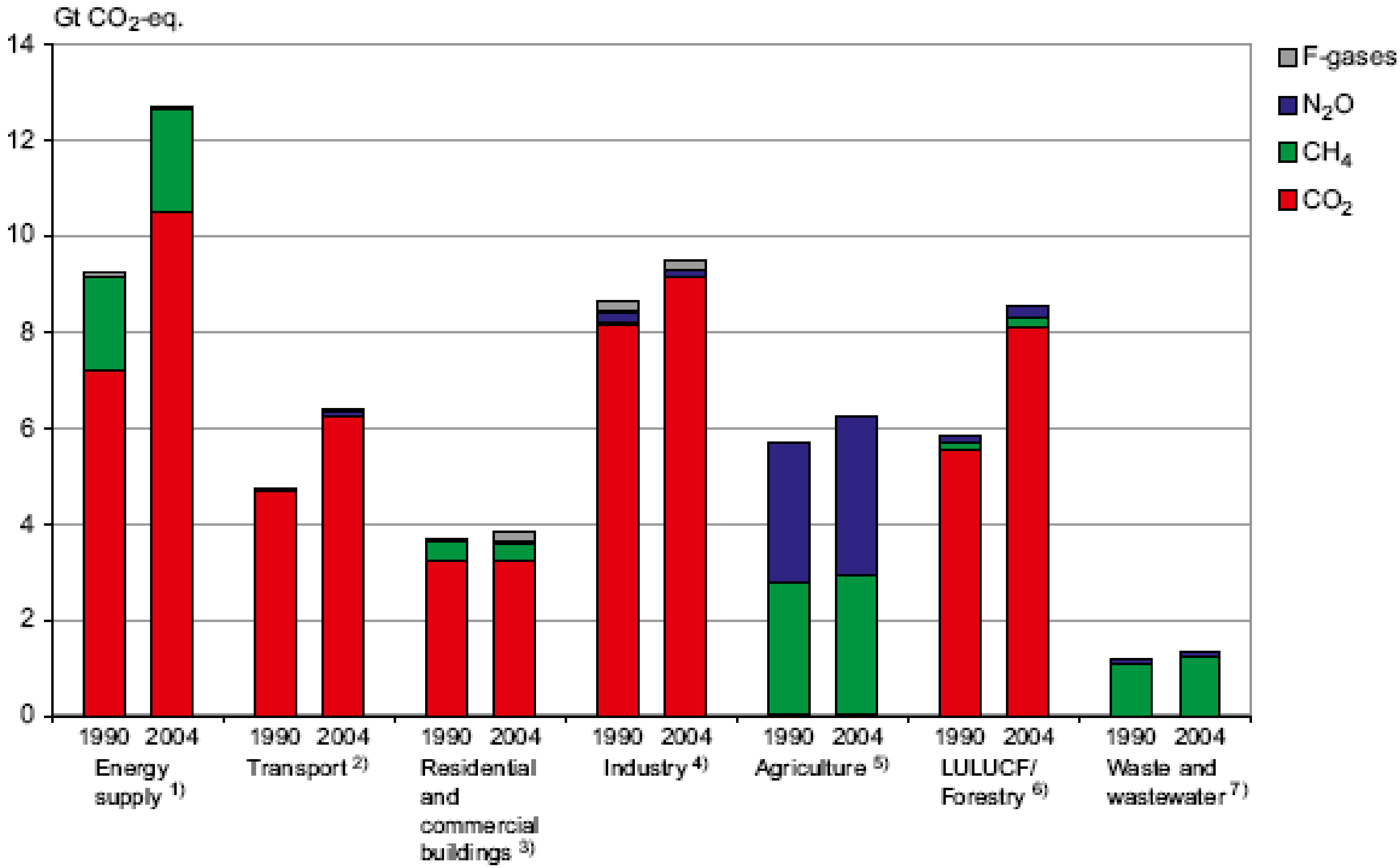


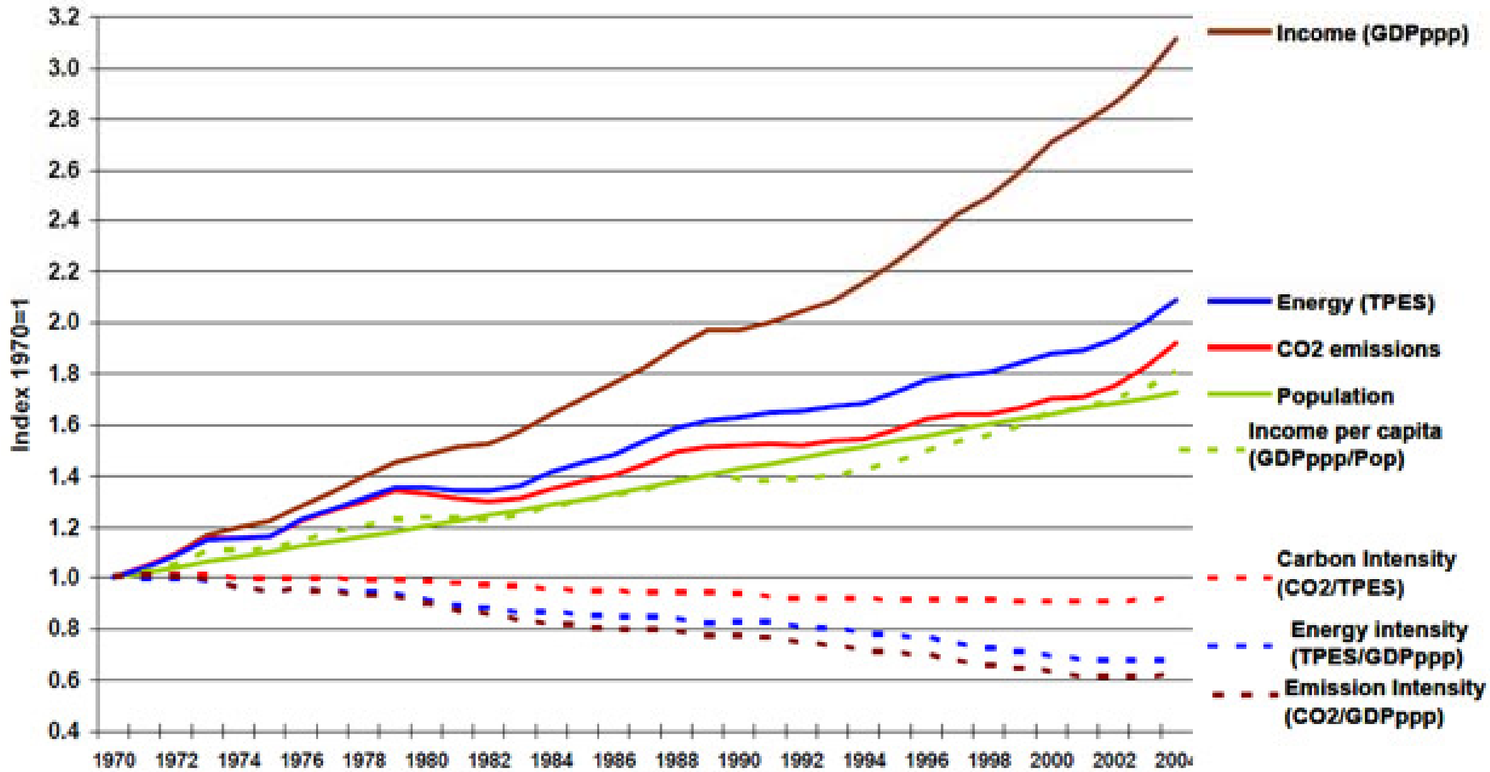
While the surface water is drived by wind, <u>density</u> difference induced by differences in temperature (thermo) and salinity (haline) generates a current in deep ocean. Global warming may have caused shutdown (or slowdown) of this ocean current (through dilution of water by melting ice in the North Atlantic) and cold temperatures in the North Altantic, leading to a new ice age.

Greenhouse gasses and their global mean radiative forcings



GHG emissions by sector in 1990 and 2004





Reasons for Global Warming

A comparison of economic development, population growth and energy usage helps understand the reasons of global warming. The recent increase in CO_2 emissions was fuelled more by economic growth than growing populations. It is not the poor masses, but the new and old rich that fuel global warming. And while energy and emission intensity have steadily decreased since the oil crisis in the 1970s, carbon intensity (carbon emission to energy consumption) has not. One conclusion could be that fixing prices for greenhouse gas emissions can help achieve emissions reduction, just like rising oil prices helped reduce energy and emissions intensity in the last decades (Graphic: IPCC).

Impact

Sensitivity of climate

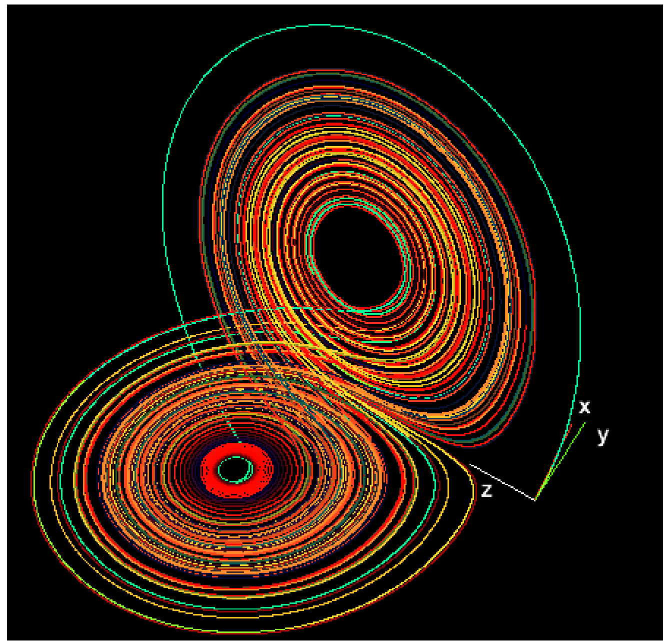
- MIT meteorologist and mathematician, **Edward Lorenz**, pioneered the theory of **chaos** – “Deterministic non-periodic flow,” *J. Atoms. Sci*., 20, 130-41(1963).

$$\frac{dx}{dt} = \sigma(y - x)$$

$$\frac{dy}{dt} = x(\rho - z) - y$$

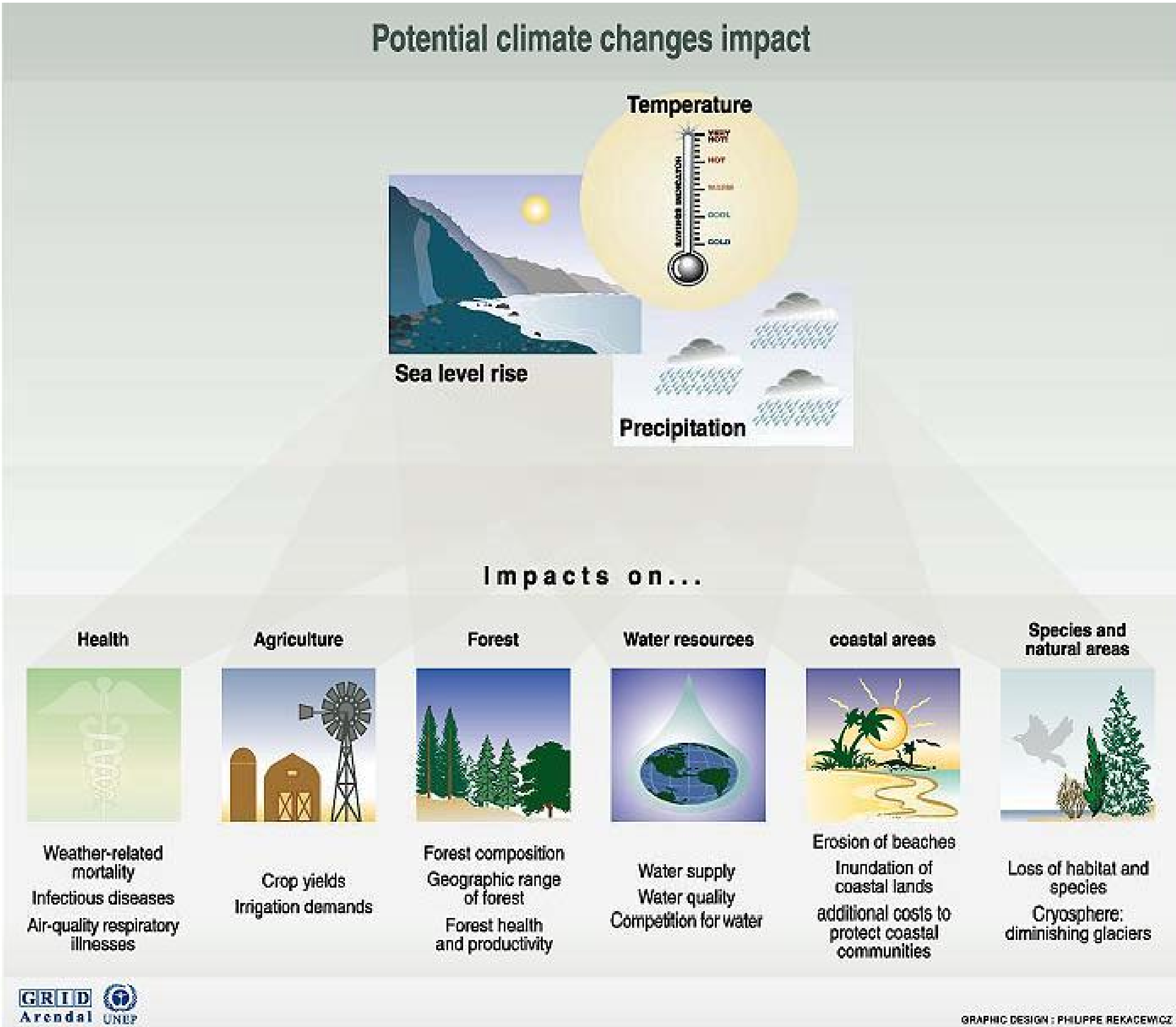
$$\frac{dz}{dt} = xy - \beta z$$

butterfly effects

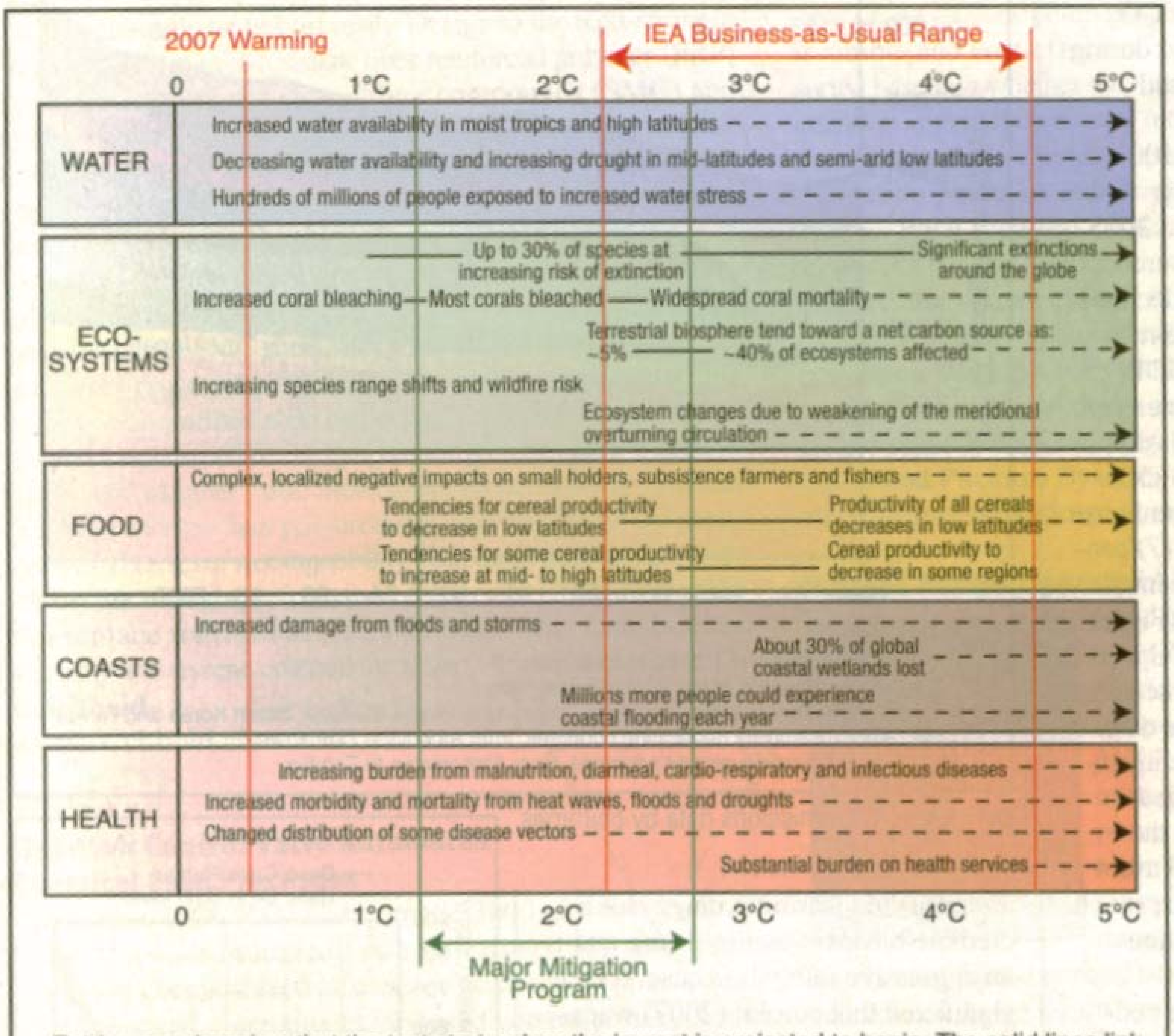


- A slight drifting of the continents, a minor shifting of ocean currents may bring ice to one land desert sands to another. “Does the flap of a butterfly’s wings in Brazil set off a tornado in Texas?” (E. Lorenz, 1979)

- Civilizations rise and fall to the pulsebeats of climate. Examples include Greenland (Erik the Red), Harapans, … etc.



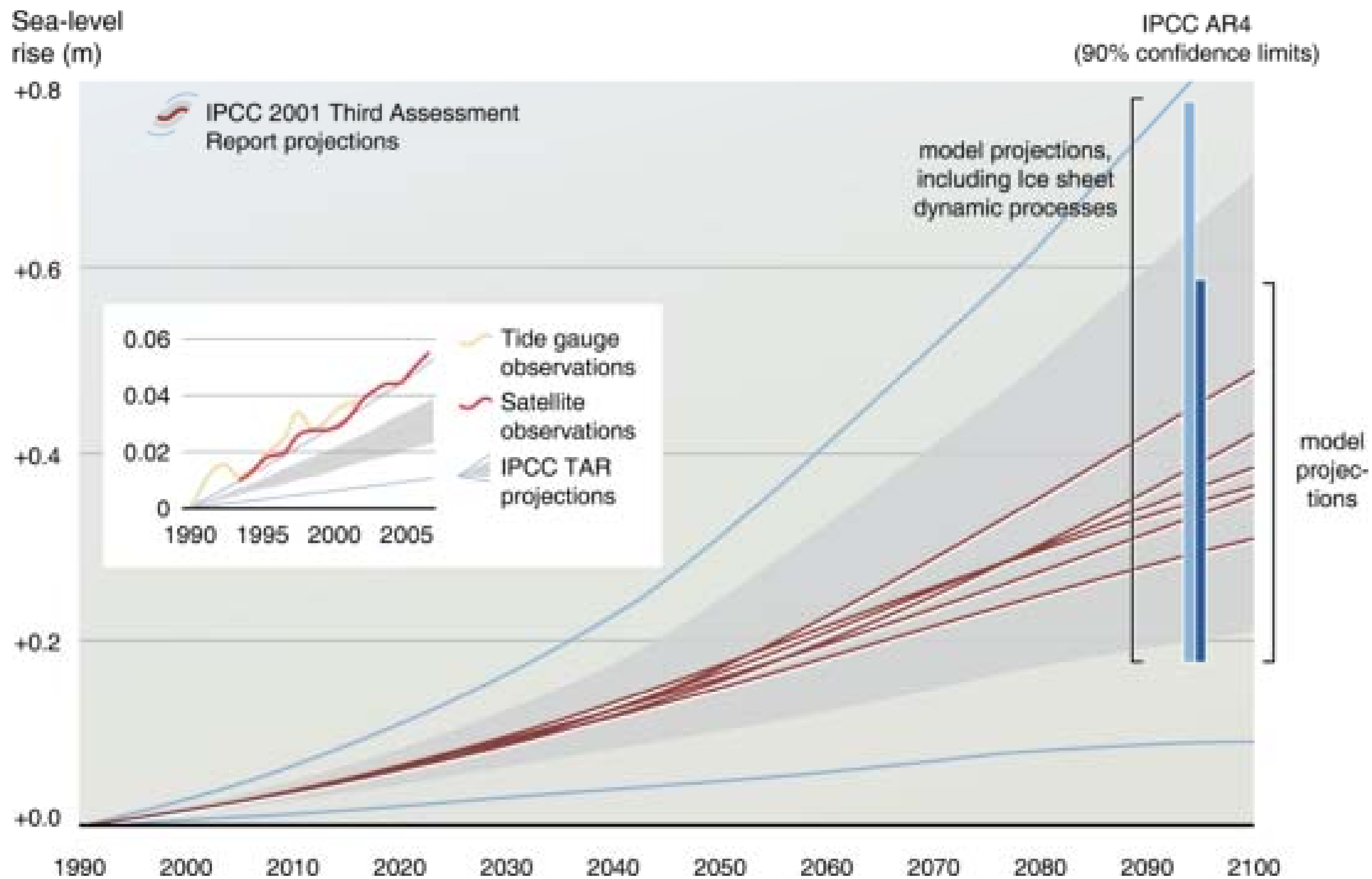
Source: United States environmental protection agency (EPA).



Entries are placed so that the text starts when the impact is projected to begin. The solid lines link related impacts, and the dashed lines indicate that the impact increases with increased warming.

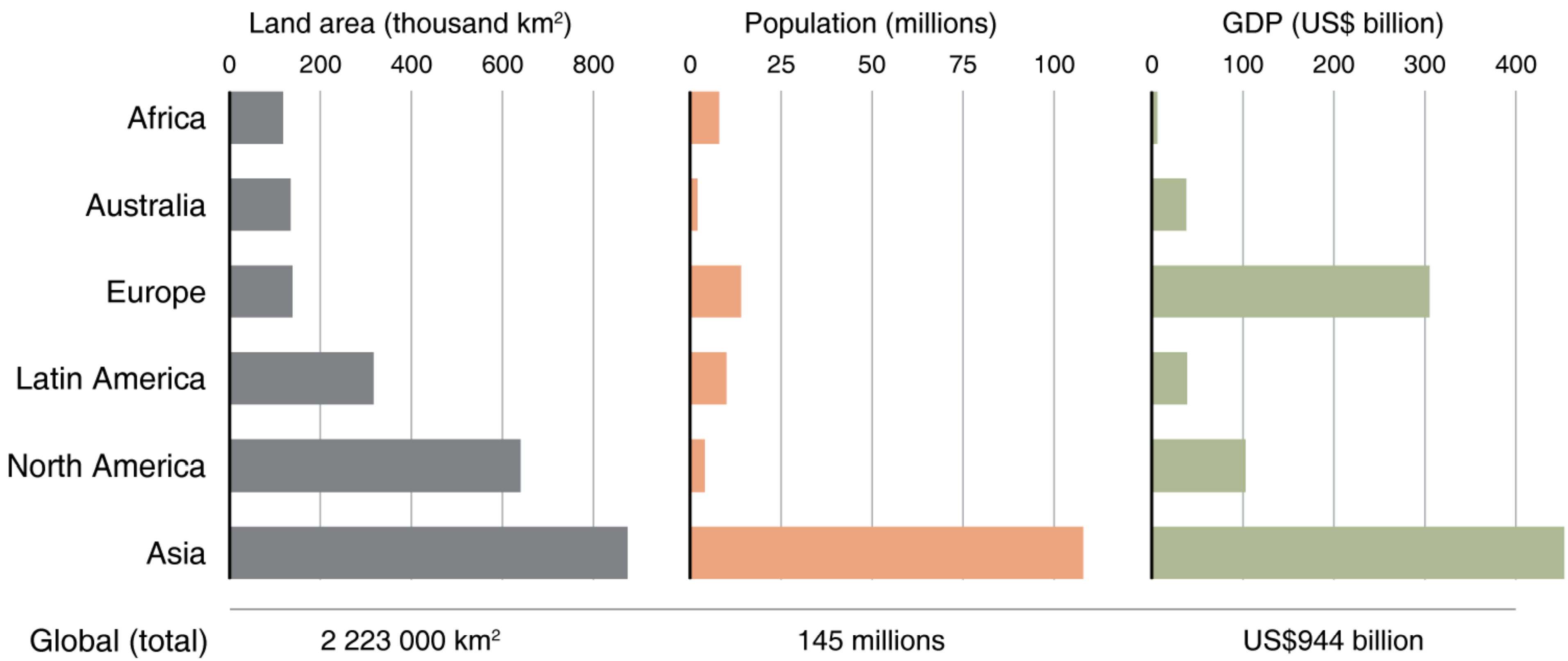
■ Figure 5. Projected impacts as a function of warming from 1990 to 2100.

Chem. Eng. Prog., Nov., 2007.

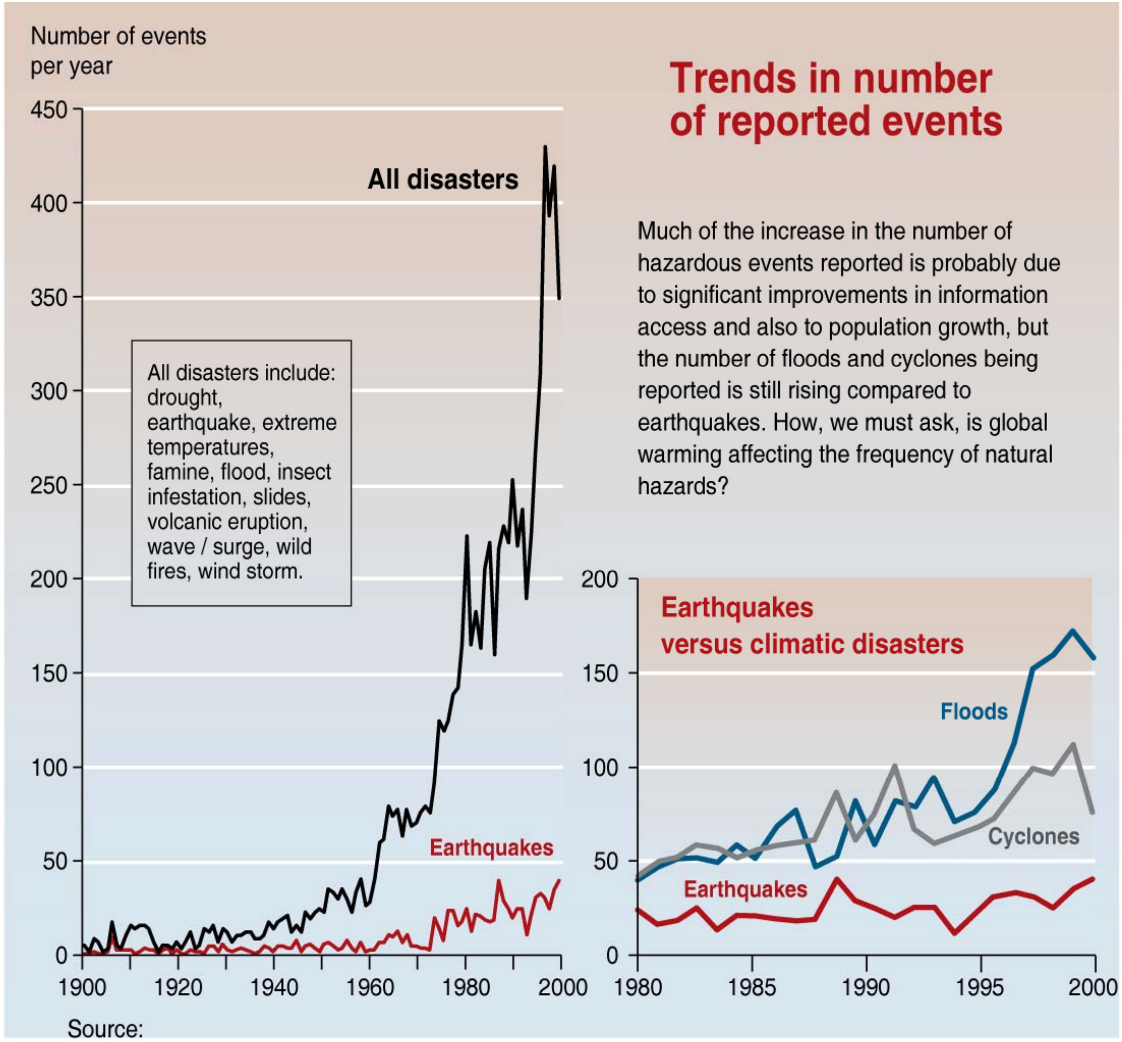


The projected range of global averaged **sea-level rise** from the IPCC 2001 Assessment Report for the period 1990 to 2100 is shown by the lines and shading. The updated AR4 IPCC projections made are shown by the bars plotted at 2095, the dark blue bar is the range of model projections (90% confidence limits) and the light blue bar has the upper range extended to allow for the potential but poorly quantified additional contribution from a dynamic response of the Greenland and Antarctic ice sheets to global warming. Note that the IPCC AR4 states that “larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea-level rise.” The inset shows the observed sea levels from tide gauges (orange) and satellites (red) are tracking along the upper bound of the IPCC 2001 projections since the start of the projections in 1990.

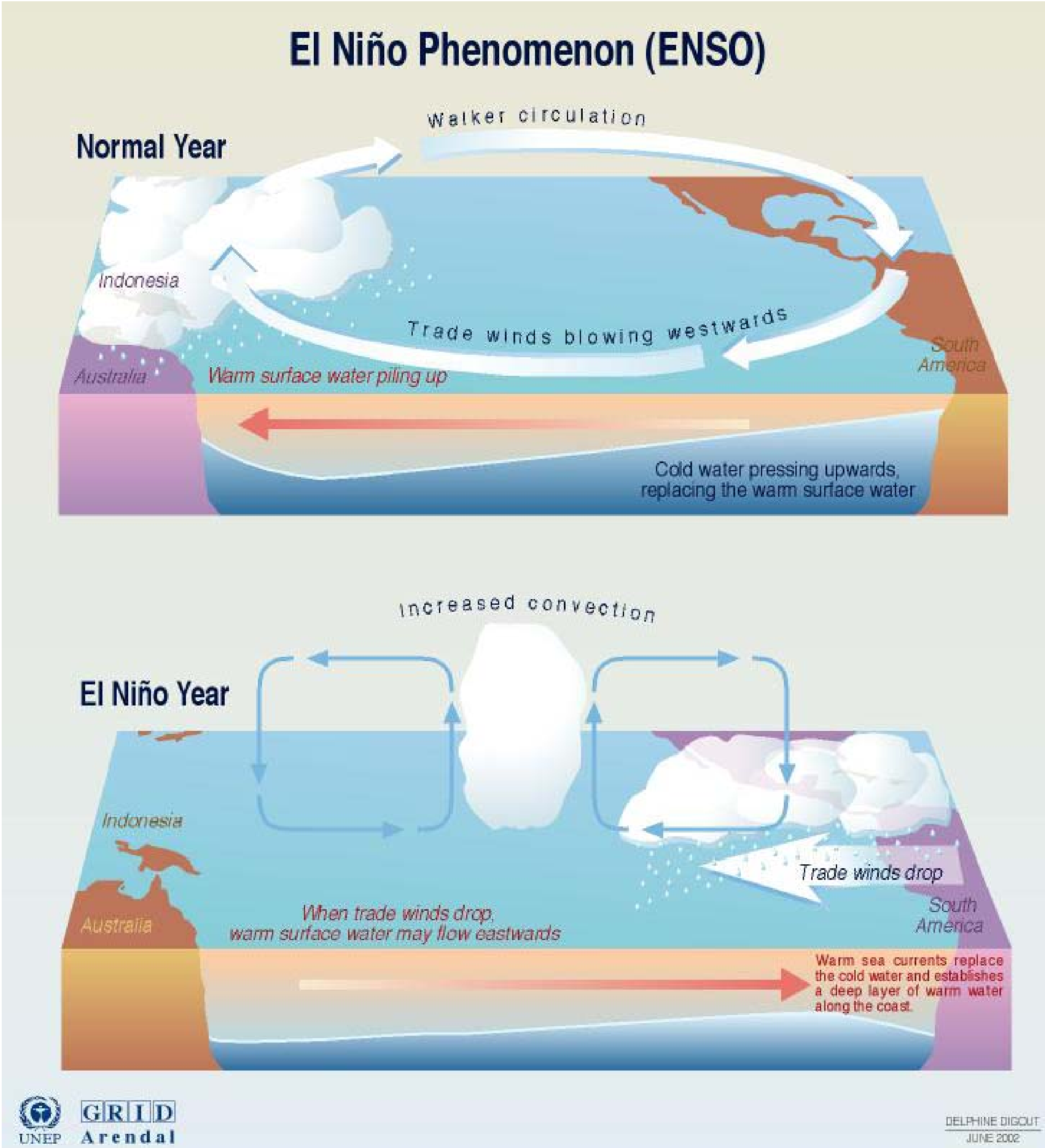
Population, area and economy affected by a 1 m sea level rise (global and regional estimates, based on today's situation)



Even for today's socio-economic conditions, both regionally and globally, large numbers of people and significant economic activity are exposed to sea-level rise. The densely populated megadeltas are especially vulnerable to sea-level rise. More than 1 million people living in the Ganges- Brahmaputra, Mekong and Nile deltas will be directly affected simply if current rates of sea-level rise continue to 2050 and there is no adaptation. More than 50 000 people are likely to be directly impacted in each of a further nine deltas, and more than 5000 in each of a further 12 deltas. Some 75 per cent of the population affected live on the Asian megadeltas and deltas, with a large proportion of the remainder living on deltas in Africa. These impacts would increase dramatically with accelerated sea-level rise.



With growing population and infrastructures the world's exposure to natural hazards is inevitably increasing. This is particularly true as the strongest population growth is located in coastal areas (with greater exposure to floods, cyclones and tidal waves). To make matters worse any land remaining available for urban growth is generally risk-prone, for instance flood plains or steep slopes subject to landslides. The statistics in this graphic reveal an exponential increase in disasters. This raises several questions. Is the increase due to a significant improvement in access to information? What part does population growth and infrastructure development play? Finally, is climate change behind the increasing frequency of natural hazards?

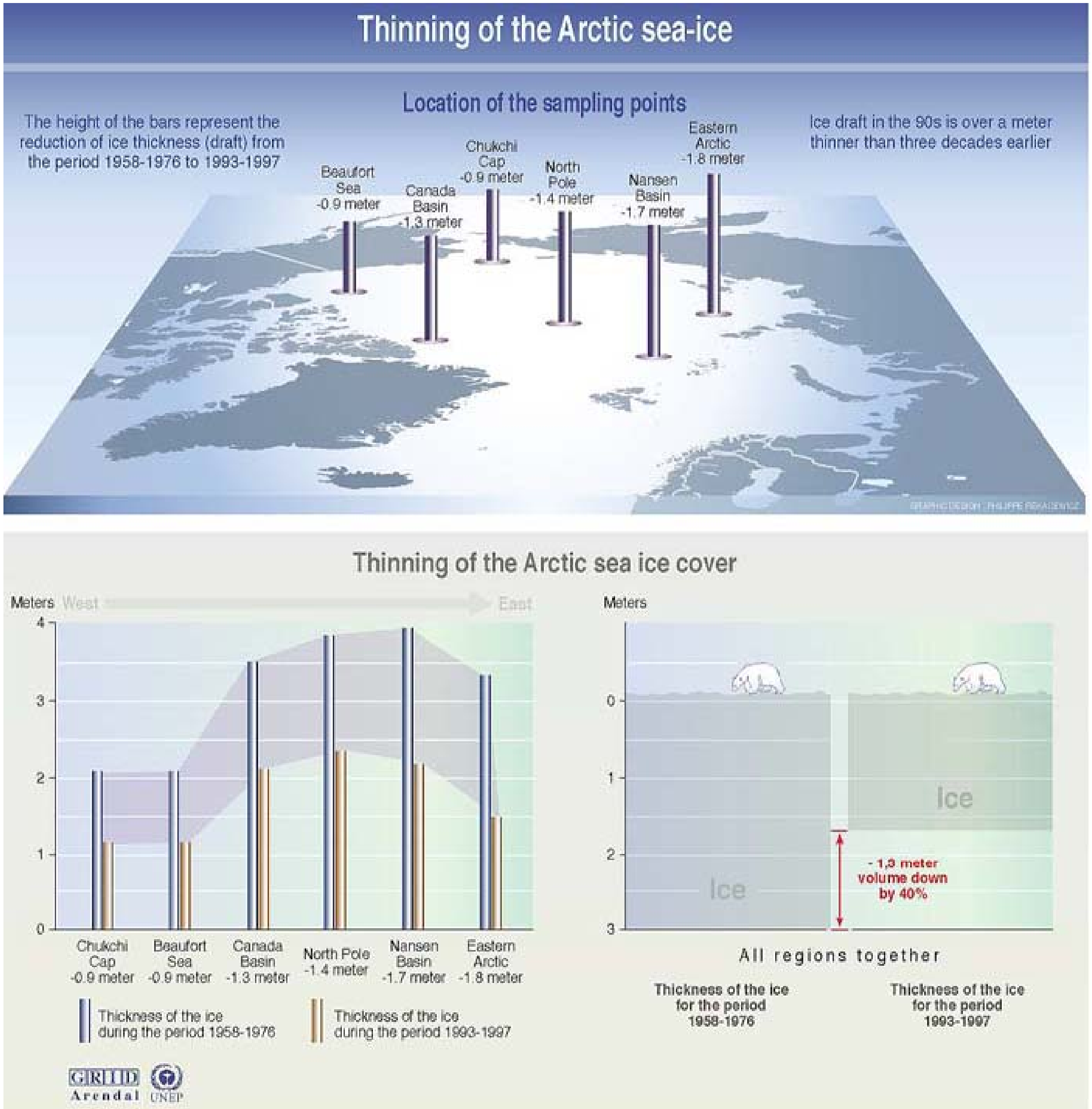


Sources: Climate Prediction Center-NCEP; NOAA.

The strongest natural fluctuation of climate on interannual time-scales is the El Niño-Southern Oscillation (ENSO) phenomenon, and ENSO-like fluctuations also dominate decadal time-scales (sometimes referred to as the Pacific decadal oscillation). ENSO originates in the tropical Pacific but affects climate conditions globally. The importance of changes in ENSO as the climate changes, and its potential role in possible abrupt shifts have only recently been appreciated.

Technically, ENSO is generated by ocean-atmosphere interactions internal to the tropical Pacific and overlying atmosphere. Positive temperature anomalies in the eastern equatorial Pacific (characteristic of an El Niño event) reduce the normally large sea surface temperature difference across the tropical Pacific. As a consequence, the trade winds weaken, the Southern Oscillation index (defined as the sea level pressure difference between Tahiti and Darwin) becomes anomalously negative, and sea level falls in the west and rises in the east by as much as 25 cm, as warm waters extend eastward along the equator. At the same time, these weakened trade winds reduce the upwelling of cold water in the eastern equatorial Pacific, thereby strengthening the initial positive temperature anomaly. The weakened trades also cause negative off-equatorial thermocline depth anomalies in the central and western Pacific.

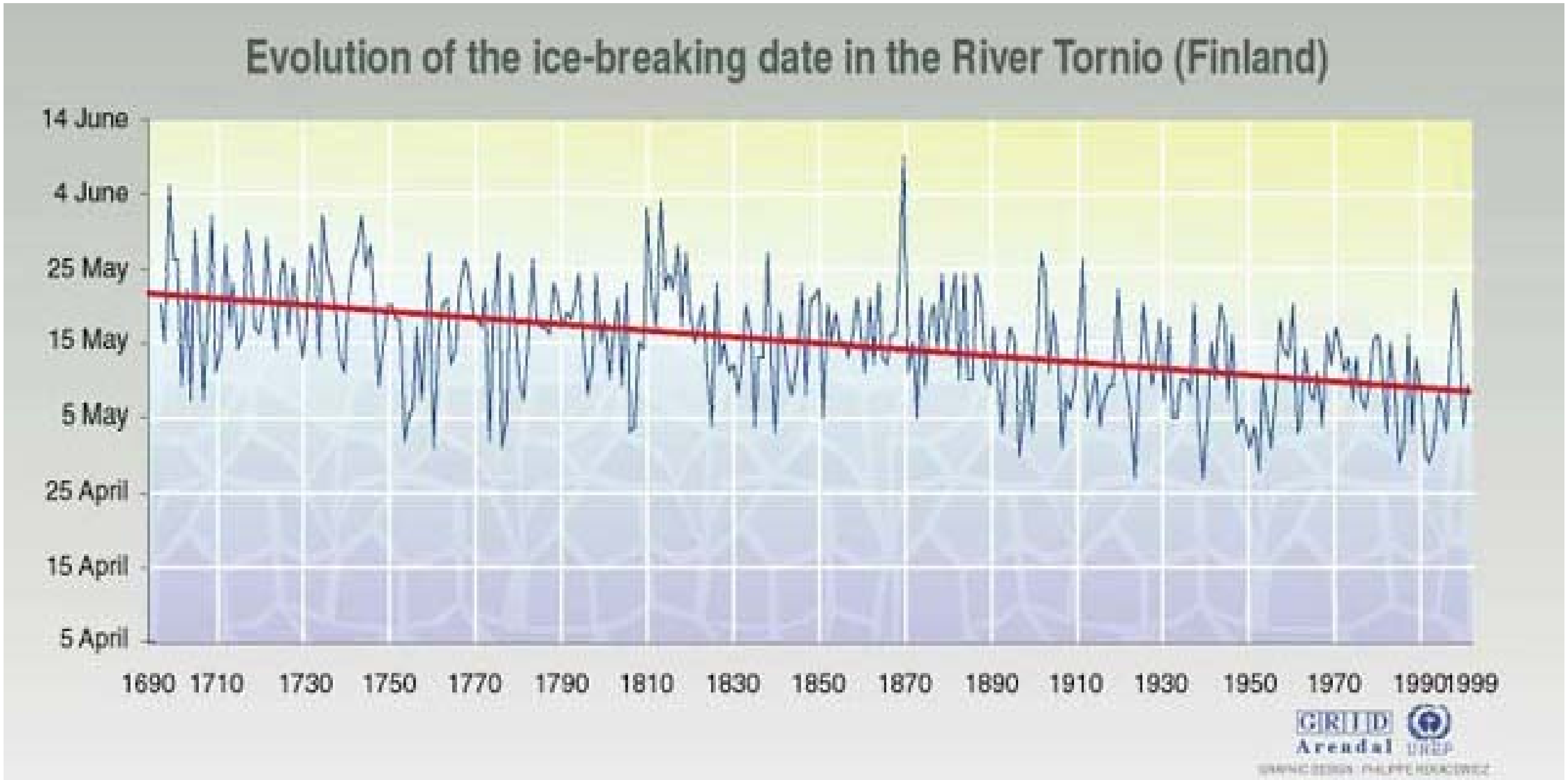
These anomalies spread westward to Indonesia, where they are reflected and propagate eastward along the equator. Thus some time after their generation, these negative anomalies cause the temperature anomaly in the east to decrease and change again. The combination of the tropical air-sea instability and the delayed negative feedback due to sub-surface ocean dynamics can give rise to oscillations. Beyond influencing tropical climate, ENSO seems to have a global influence: during and following El Niño, the global mean surface temperature increases as the ocean transfers heat to the atmosphere.



Note: comparison of sea-ice draft data acquired on submarine cruises betwen 1993 and 1997 with data from 1958-1976 indicates that mean ice draft at the end of the melt season has decreased by 1,3 m (from 3,1 m to 1,8 m). Value is down by 40%

Sources: D.A. Rothrock, Y.Yu and G.A. Maykut, Thinning of the Arctic sea-ice cover, University of Washington, Seattle, 1999.

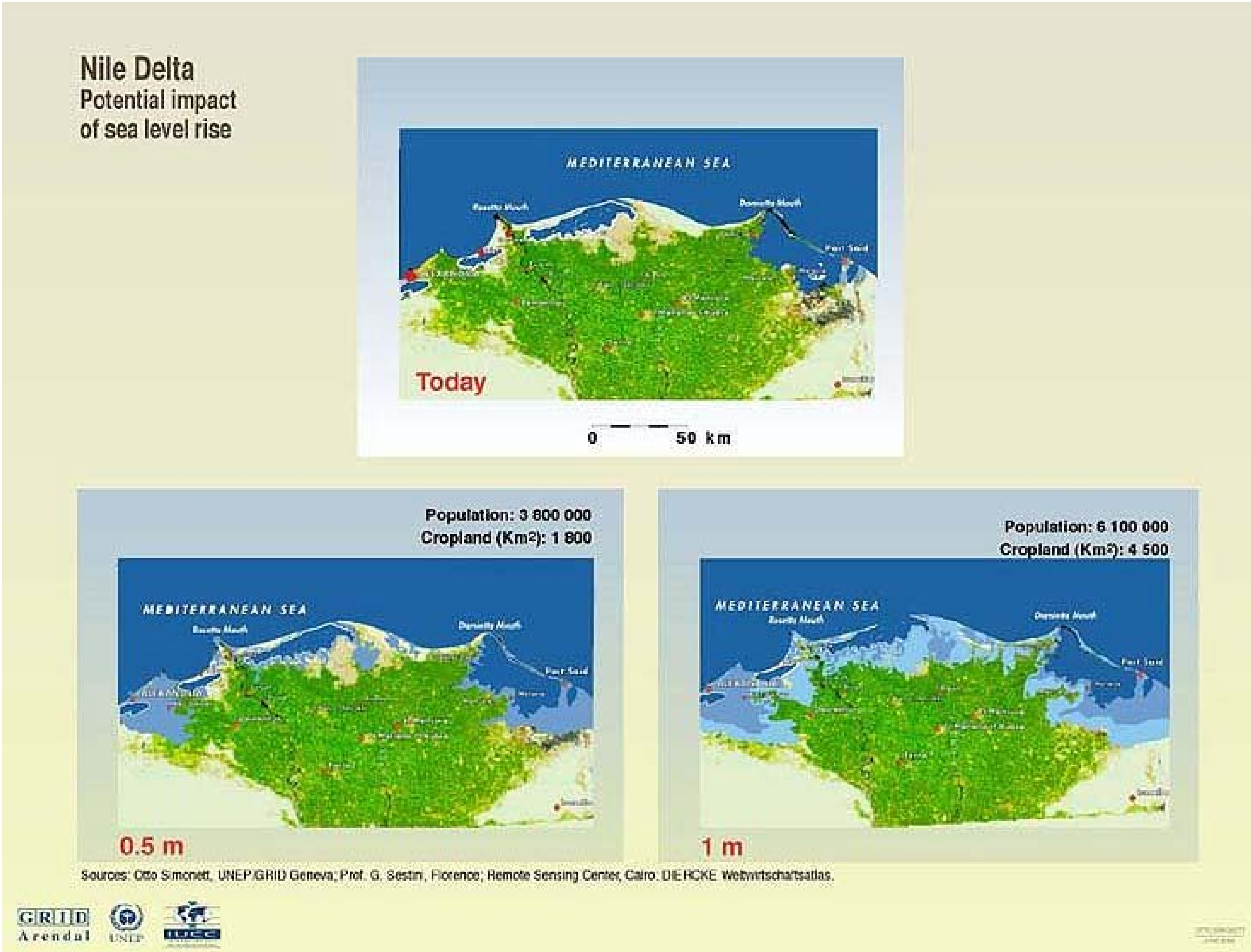
Sea-ice draft is the thickness of the part of the ice that is submerged under the sea. Comparison of sea-ice draft data acquired on submarine cruises between 1993 and 1997 with similar data acquired between 1958 and 1976 indicates that the mean ice draft at the end of the melt season has decreased by about 1.3 m in most of the deep water portion of the Arctic Ocean, from 3.1 m in 1958-1976 to 1.8 m in the 1990s. In summary: ice draft in the 1990s is over a meter thinner than two to four decades earlier. The main draft has decreased from over 3 meters to under 2 meters, and the volume is down by some 40%.



Source: Trends in the finnish Environment 1997, fig. 1.7, updated in February 2000.

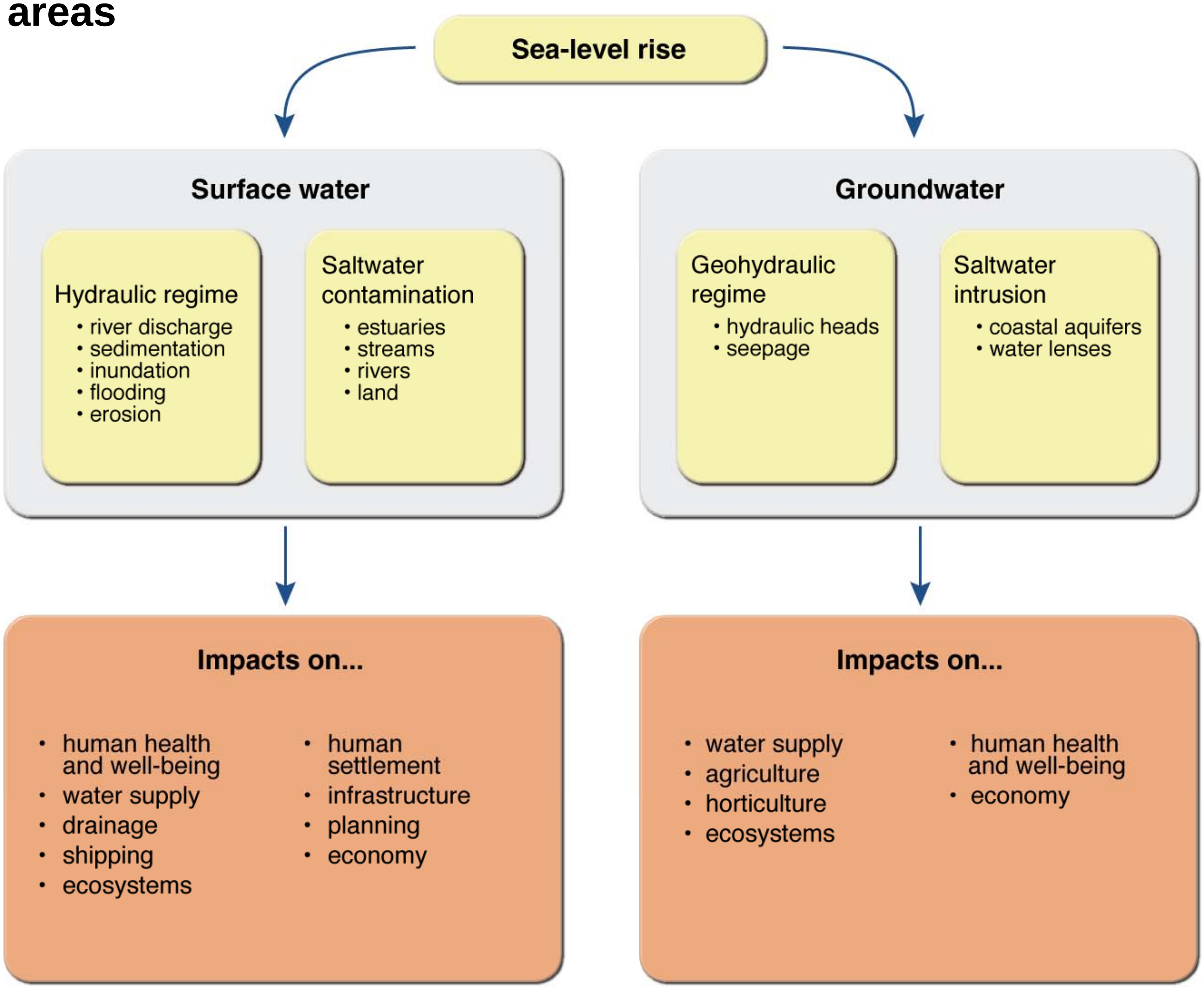
The icebreaking date for the Tornio River in Finland has been recorded since 1693. With the increased greenhouse effect, impacts on the cryosphere are likely. One impact will be less ice on rivers and lakes. Freeze-up dates will be delayed, and break-up will begin earlier. The period of river-ice could be shortened by up to a month. Many rivers within the temperate regions could become ice-free or develop only intermittent or partial ice coverage.

Nile Delta: Potential Impact of Sea Level Rise

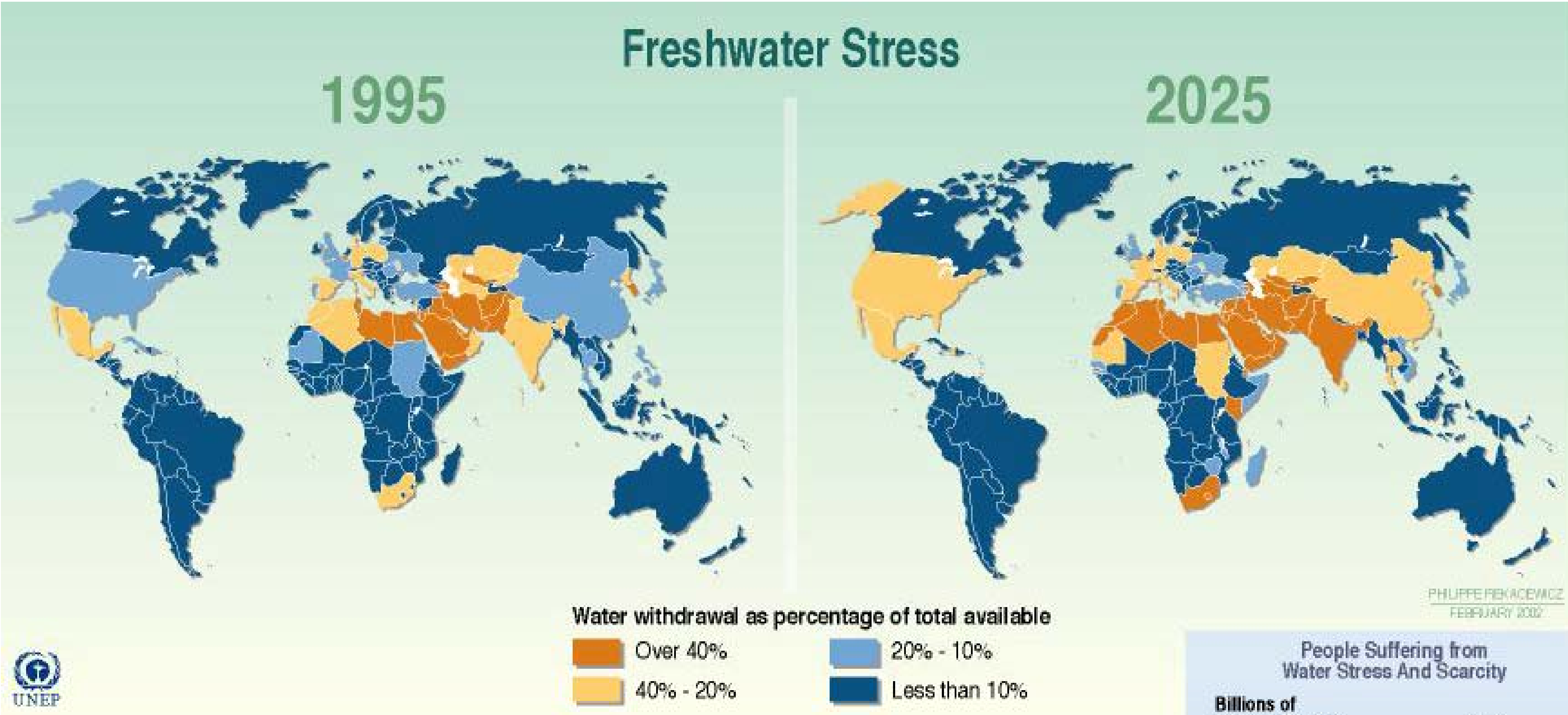


The potential impacts of sea level rise on the Nile Delta are expected to include a decline in water quality that would affect freshwater fish, the flooding of agricultural land and damage to infrastructure. This graphic shows the Nile Delta region as it is today (2002), the area as it would appear with a 0.5 m sea level rise, and the area as it would appear with a 1.0 m sea level rise.

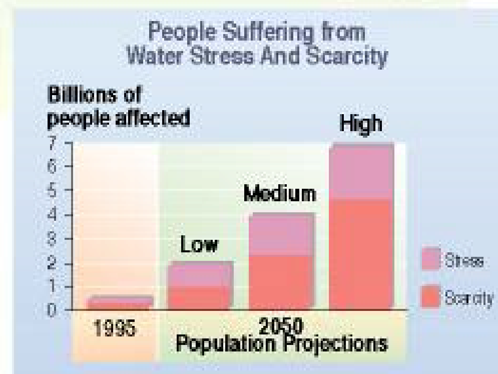
Effects of sea-level rise on water resources of small islands and low-lying coastal areas



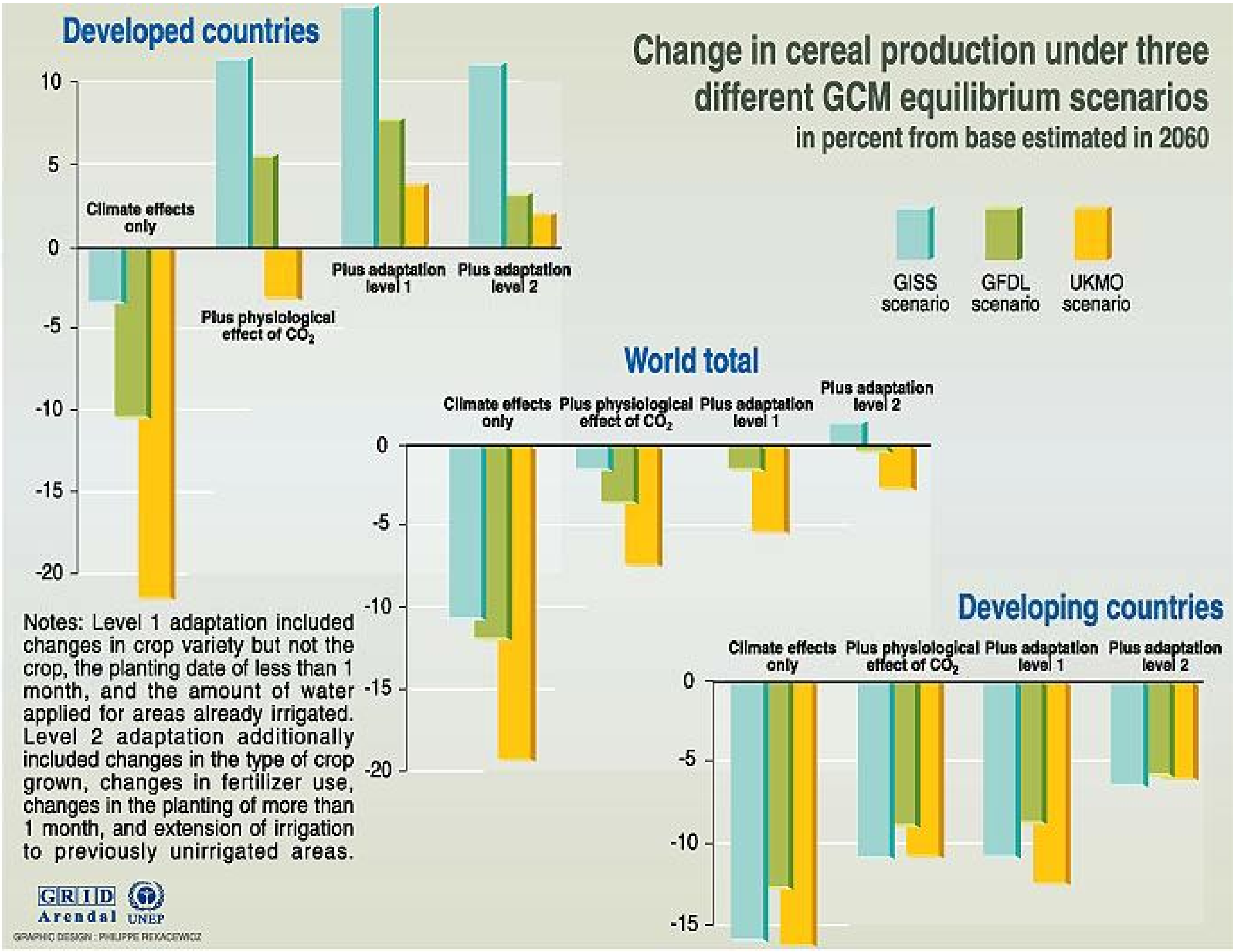
The water resources of small islands and low-lying coastal areas are very susceptible to sea-level rise. This figure illustrates the direct impacts on the water resources sector, as well as the plethora of higher-order impacts which affect not only that sector but most, if not all, other sectors including health, transport and agriculture.



Source: World Meteorological Organisation (WMO), Geneva, 1996; Global Environment Outlook 2000 (GEO), UNEP, Earthscan, London, 1999.

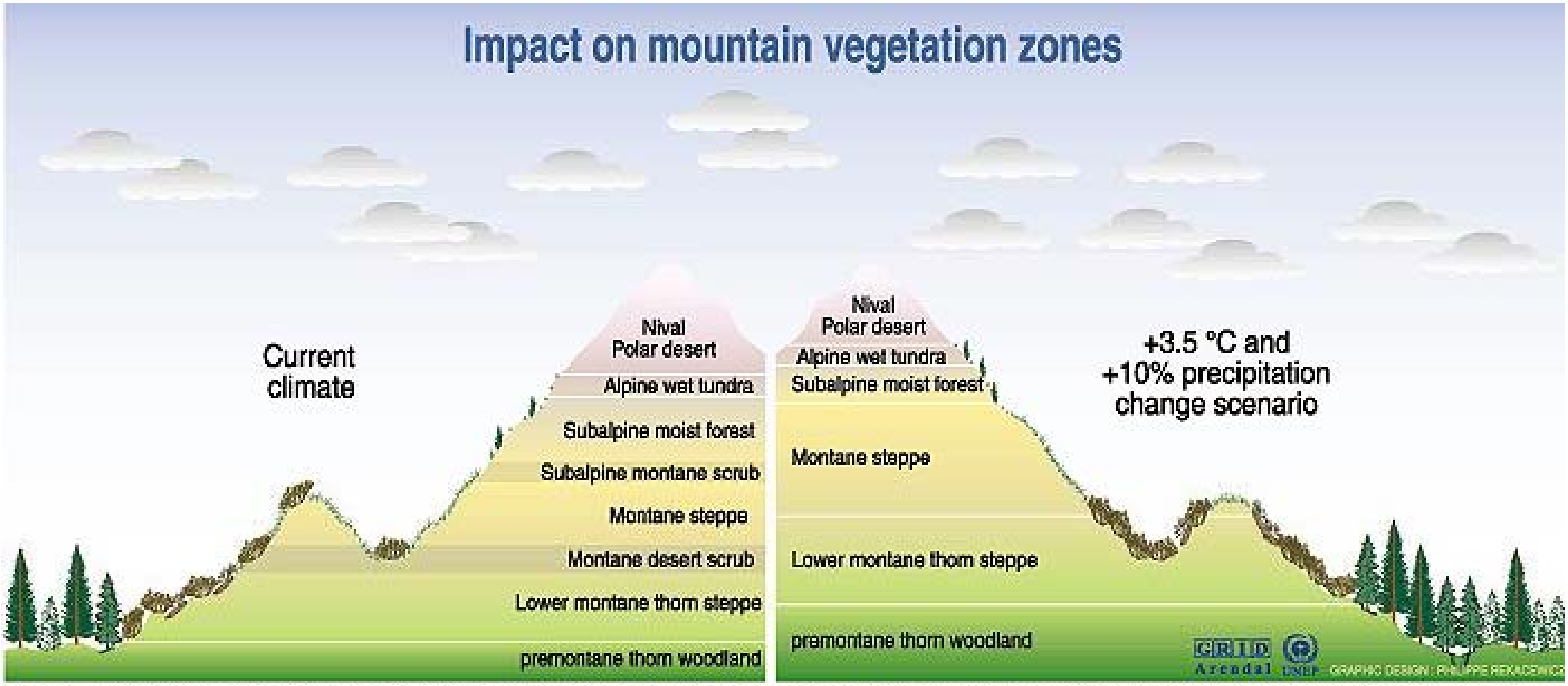


This graphic shows the amount of water withdrawal as a percentage of the total available supply, at the national level in 1995 and in 2025 (projected amounts). Overall, the percentages are expected to rise substantially by 2025. This resource also includes a graphic showing the number of people suffering from water stress and water scarcity worldwide in 1995, compared to projected rates for the year 2050. As the population continues to rise, the number of people affected by water stress and water scarcity is expected to rise sharply.



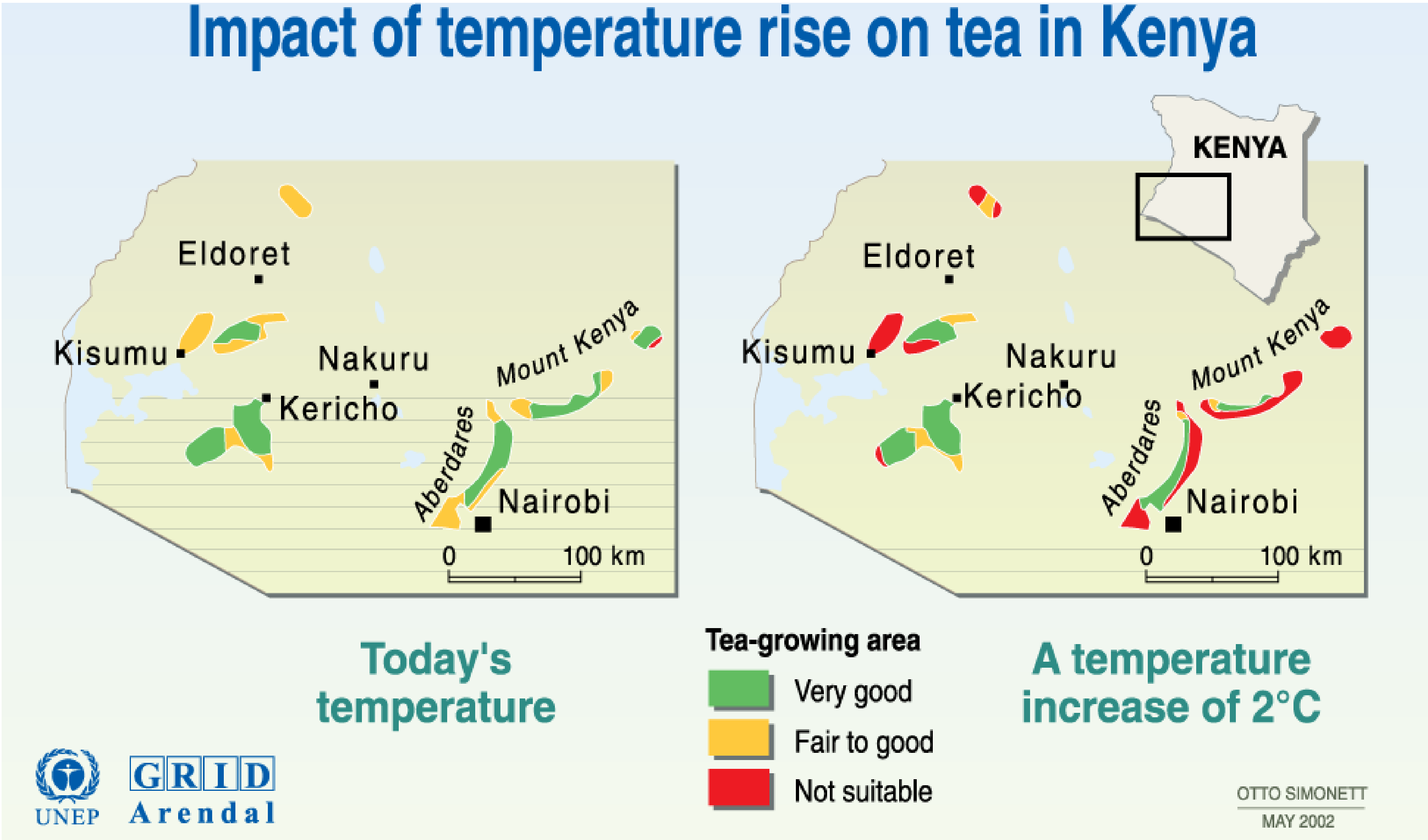
Source: Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

The figure shows change in cereals production under three different GCM equilibrium scenarios (percent from base estimated in 2060). While there are still uncertainties about whether climate change will cause global agricultural production to increase or decrease, changes in the aggregate level of production are expected to be small or moderate. The result of the studies that have been conducted so far vary depending on such variables as the trade models and market assumptions that are used.For example, the difference between agricultural impacts in developed and developing countries can be reinforced by markets and depending on the trade model used, agricultural exporters may gain even though their supplies fall as a result of higher world prices. The figure also illustrates how trade and adaptation capability can interact. Developing country production levels fell more as compared with those of developed countries under adaptation level 1 because their estimated capability to adapt was less than in developed countries. The situation reverses under adaptation level 2.



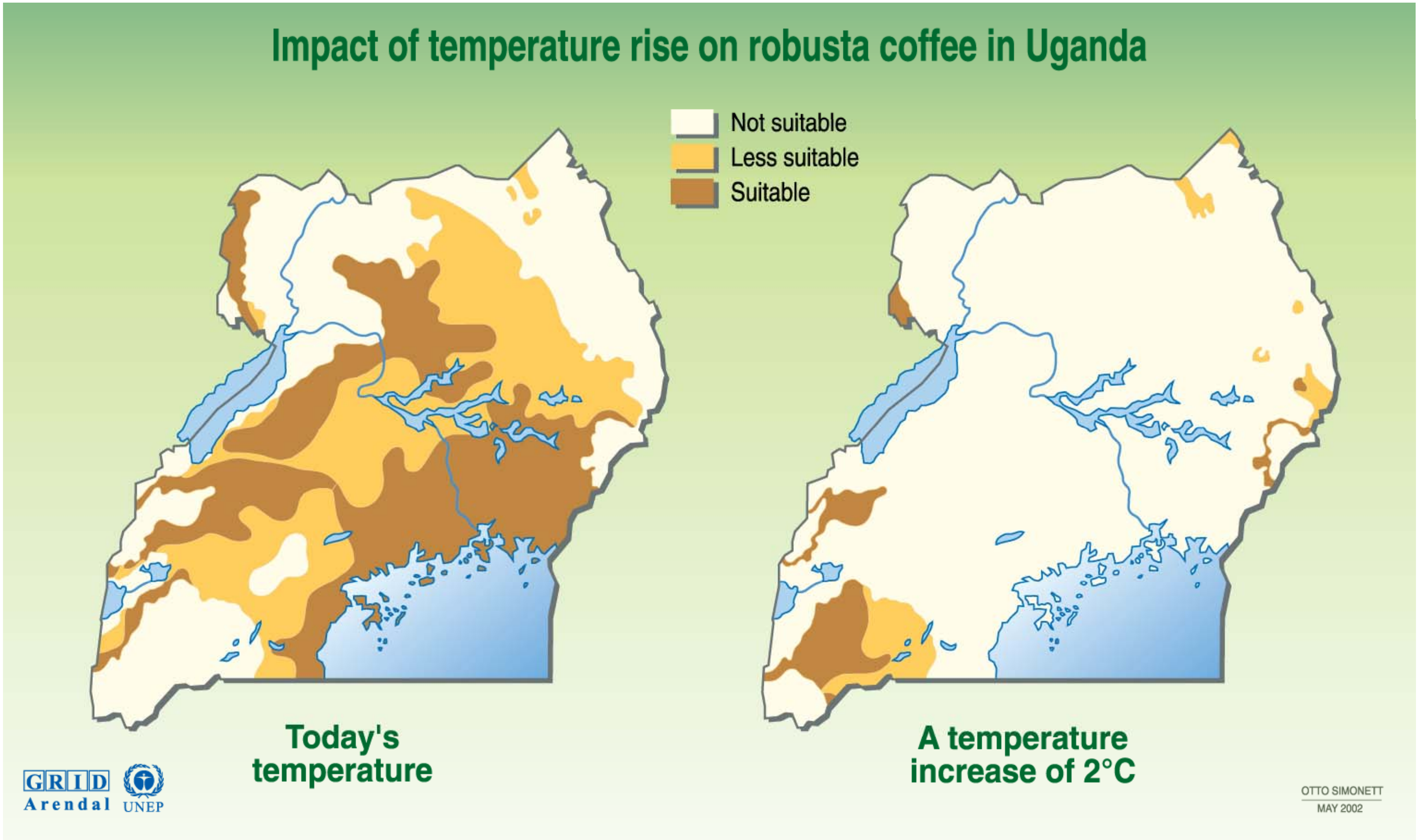
Sources: Martin Beniston, Mountain environments in changing climates, Routledge, London, 1994; Climate change 1995, Impacts, adaptations and migration of climate change, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change (IPCC), UNEP and WMO, Cambridge press university, 1996.

The figure shows a comparison of current vegetation zones at a hypothetical dry temperate mountain site with simulated vegetation zones under a climate-warming scenario. Mountains cover about 20% of the Earth's continents and serve as an important water source for most major rivers. Paleologic records indicate that climate warming in the past has caused vegetation zones to shift to higher elevations, resulting in the loss of some species and ecosystems. Simulated scenarios for temperate-climate mountain sites suggest that continued warming could have similar consequences. Species and ecosystems with limited climatic ranges could disappear and, in most mountain regions, the extent and volume of glaciers and the extent of permafrost and seasonal snow cover will be reduced. Along with possible changes in precipitation this would affect soil stability and socio-economic activities such as agriculture, tourism, hydropower and logging. Resources for indigenous populations and recreational activities would also be disrupted.



Source: Otto Simonett, *Potential impacts of global warming*, GRID-Geneva, case studies on climate change. Geneva, 1989.

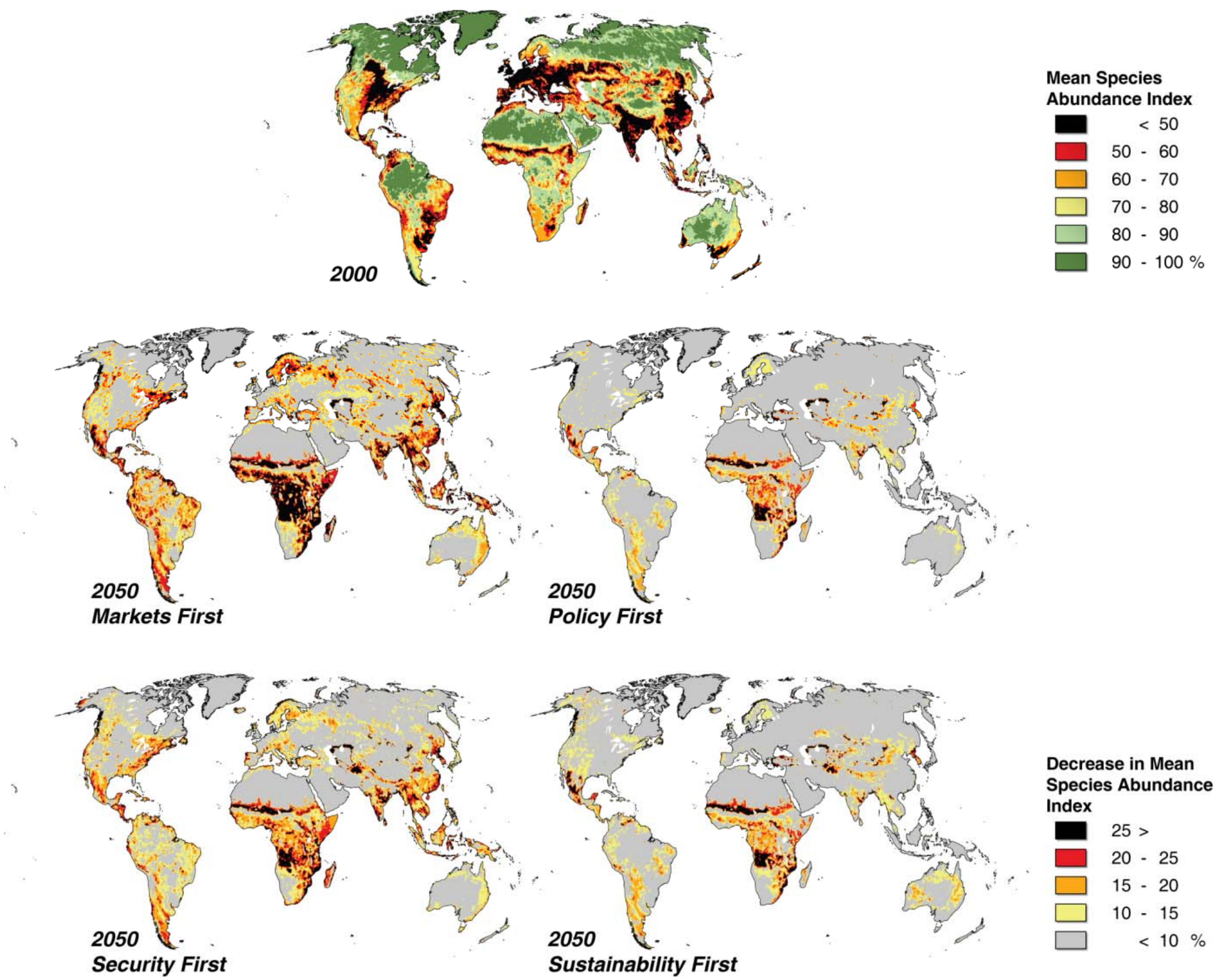
Increasing temperatures will likely affect major crops such as tea in Kenya. Major impacts on food production will come from changes in temperature, moisture levels, ultraviolet (UV) radiation, CO2 levels, and pests and diseases. This graphic shows the current locations of tea-growing areas in Kenya, and how some of these areas are expected to become less suitable for tea-growing if there is a temperature rise of 2 degrees Celsius.



Source: Otto Simonett, Potential impacts of global warming, GRID-Geneva, case studies on climatic change. Geneva, 1989.

Developing countries, whose economies often rely heavily on one or two agricultural products, are especially vulnerable to climate change. This graphic shows that with an increase of only 2 degrees Celsius, there would be a dramatic decrease in the amount of land suitable for growing Robusta coffee in Uganda.

Biodiversity loss: state and scenarios 2000 and 2050



These projections of biodiversity loss from 2000 to 2050 were produced by the GLOBIO consortium for UNEP's Global Environment Outlook 4. Across the GEO scenarios and regions, global biodiversity continues to be threatened, with strong implications for ecosystem services and human well-being. All regions continue to experience declines in terrestrial biodiversity in each of the scenarios. The greatest losses are seen in Markets First, followed by Security First, Policy First and Sustainability First for most regions. Africa, and Latin America and the Caribbean experience the greatest losses of terrestrial biodiversity by 2050 in all four scenarios, followed by Asia and the Pacific. The differences among the regions are largely a result of broad-scale land-use changes, especially increases in pastureland and areas dedicated to biofuel production. The overall changes in terrestrial biodiversity though, are influenced by a number of other factors, including infrastructure development, pollution and climate change, as well as public policy and conflict. For the full report, please see http://www.unep.org/geo/geo4

Disease	Vector	Population at risk (million)[1]	Number of people currently infected or new cases per year	Present distribution	Likelihood of altered distribution
Malaria	Mosquito	2,400[2]	300-500 million	Tropics and Subtropics	Highly likely
Schistosomiasis	Water snail	600	200 million	Tropics and Subtropics	Very likely
Lymphatic Filariasis	Mosquito	1 094[3]	117 million	Tropics and Subtropics	Likely
African Trypanosomiasis (Sleeping sickness)	Tsetse fly	55[4]	250 000 to 300 000 cases per year	Tropical Africa	Likely
Dracunculiasis (Guinea worm)	Crustacean (Copepod)	100[5]	100 000 per year	South Asia, Arabian Peninsula, Central-West Africa	Unknown
Leishmaniasis	Phlebotomine sand fly	350	12 million infected, 500 000 new cases per year[6]	Asia, Southern Europe Africa, Americas	Likely
Onchocerciasis (River blindness)	Black fly	123	17.5 million	Africa, Latin America	Very likely
American Trypanosomiasis (Chagas disease)	Triatomine bug	100[7]	18 million	Central and South America	Likely
Dengue	Mosquito	1,800	10-30 million per year	All Tropical countries	Very likely
Yellow Fever	Mosquito	450	more than 5 000 cases per year	Tropical South America Africa	Likely

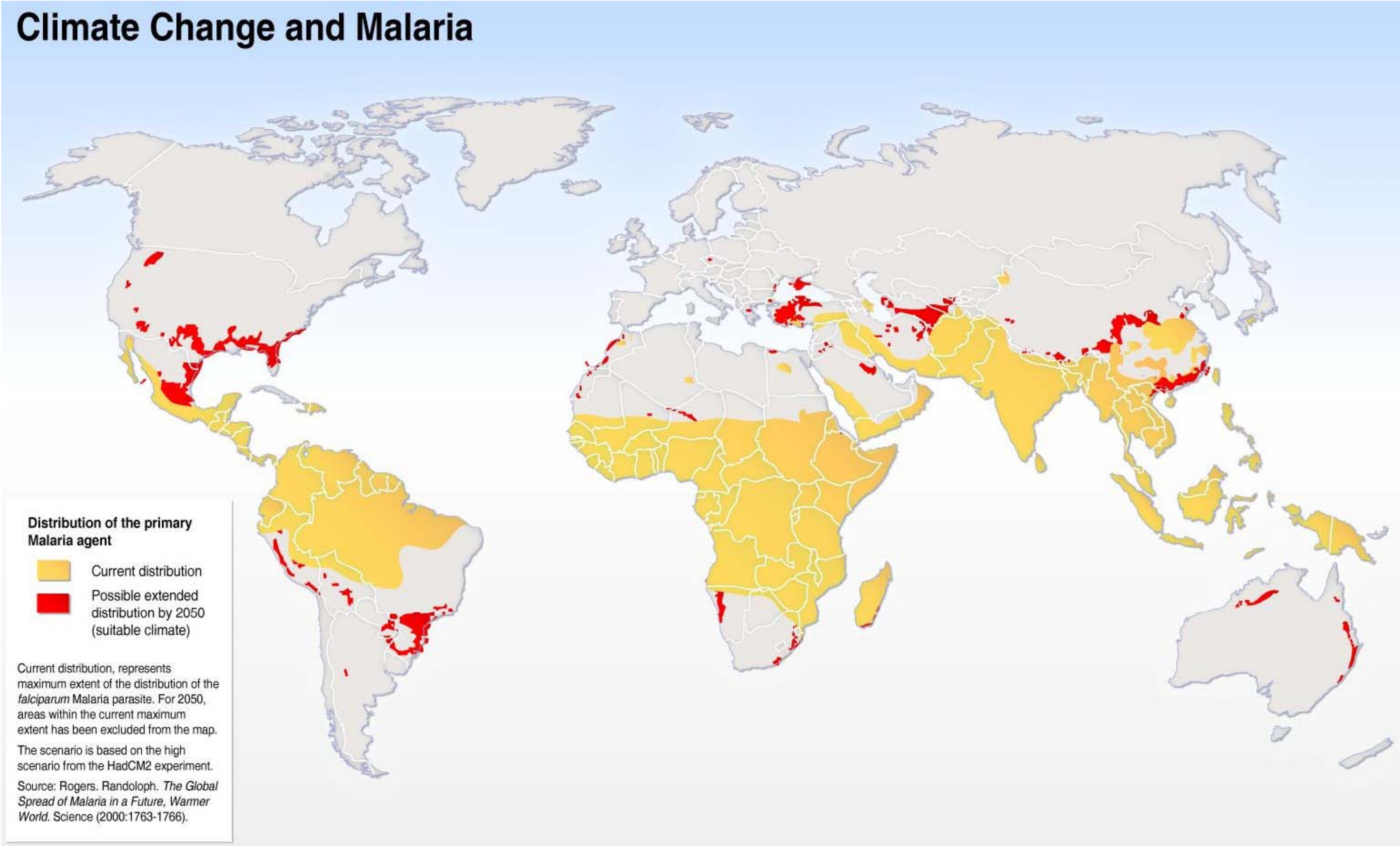
1. Top three entries are population-prorated projections, based on 1989 estimates.
2. WHO, 1994.
3. Michael and Bundy, 1995.
4. WHO, 1994.
5. Ranque, personal communication.
6. Annual incidence of visceral leishmaniasis; annual incidence of cutaneous leishmaniasis is 1-1.5 million cases/yr (PAHO, 1994).
7. WHO, 1995.

Highly likely / Very likely / Likely / Unknown

GRID Arendal UNEP
GRAPHIC DESIGN : PHILIPPE REKACEWICZ

Source: Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

Climate change and altered weather patters would affect the range (both altitude and latitude), intensity, and seasonality of many major tropical vector-borne and other infectious diseases - such as malaria and dengue fever.



With climate conditions changing in the future, due to increased concentrations of carbon dioxide in the atmosphere, conditions for pests also change. The primary Malaria agent, the falciparum malaria parasite, will be able to spread into new areas, as displayed in this map, by 2050 using the Hadley CM2 high scenario. Other areas, not displayed in the map, will be uninhabitable by the parasite, and thus free of the pest.