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ENVIRONMENTAL PROCESSES AND CHALLENGES OF CLIMATE CHANGE

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Abstract: Brief overview of several environmental aspects are given, largely based on the IPCC AR4 climate change [1] with some updates, as well. The four key aspects tackled in this paper are (i) proof of anthropogenic origin of the recent climate changes and the global projections based on continuation of it for the 21th century; (ii) meteorological extremes and their recent and likely future tendencies; (iii) impacts of climate change in different parts of the Earth and, finally, (iv) global mean targets and possibilities of mitigation of the changes. The main conclusion is that mankind is very likely (with at least 90 % probability) contributed to the recent warming. Impacts of further changes would be significant, although variable from region to region. The so called tipping points of the climate change make it unavoidable to stop the global warming before 3 K from which 0.8 K is already behind us.
Keywords: *climate change, attribution, extreme events, impacts, mitigation*

1. PROOF OF ANTHROPOGENIC ORIGIN AND GLOBAL PROJECTION

Changes of climate can always be traced during the earth's history. But, historical changes have two common features: they were relatively slow and the processes were of natural origin in every case. In the recent century the situation has very likely been changing. Besides the natural forces, human activity has been added to the climate factors. In a few decades it can bring changes of the present climate of such extent and rate that has not been experienced in the past one hundred thousand years.

There is a broad agreement among the scientific reconstructions of mean air temperatures over the Northern Hemisphere. However, the key question of the issue is if really the mankind is the responsible for the experienced global warming.

Fig. 1 shows us the strongest argument for this statement, at least in the last 50 years. The observed series of the global mean temperature are successfully simulated by the interval of 14 global climate models reproducing the past changes under the influence of all known anthropogenic and natural climate forcing factors. But, if leaving out the anthropogenic ones, i.e. allowing just natural factors, like volcanic eruptions and solar activity to act, this simulation clearly departs from the fact.

So, the warming of the recent half century could not happen without the anthropogenic factors. This statement can be erroneous in case of two parallel strong mistakes, only. The first error, in case, would be that scientist strongly overestimates the effects of greenhouse gases in their computations, whereas the second one is that the “true” reasons of the observed warming, are not known, at all. Probability of these two mistakes is assessed by [1] as $\leq$ 10 %. Until this unlikely combination becomes proven, the only smart decision is to get prepared to further warming, as it follows from the $\geq$ 90 % likelihood of the anthropogenic origin.

Based on the success of past simulations, the climate models are also used to project the future climate (*Fig. 2*). The expected global mean temperature depends on the emission scenarios driven by the trends of population, energy resources, economic growth, equity of the regions, etc. According to these computations ([1]: Fig. 10.4 and 10.29), 1.1–6.4 K warming is expected until 2100 compared to 1980-1999. Even if the atmospheric composition remained constant, the temperature would increase by ca. 0.5 K due to oceanic thermal inertia. External uncertainties are originated by the world economy. The series of figures, including CO_2 -emission, concentration alternatives, primary effects on the radiation balance of the Earth and also effects the changes on global temperatures in case of mean and also of extreme combinations of uncertainty limits.

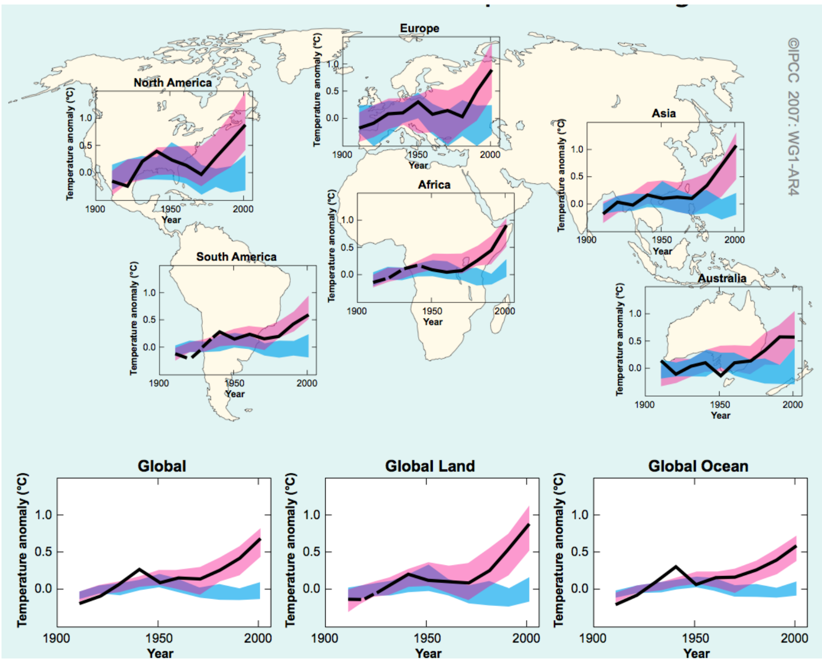


Figure 1: Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models. Decadal averages of observations are shown for the period 1906–2005 (black line) plotted against the centre of the decade and relative to the corresponding average for 1901–1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5–95% range for 19 simulations from 5 climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5–95% range for 58 simulations by 14 climate models using both natural and anthropogenic factors ([1]: FAQ 9.2, Figure 1).

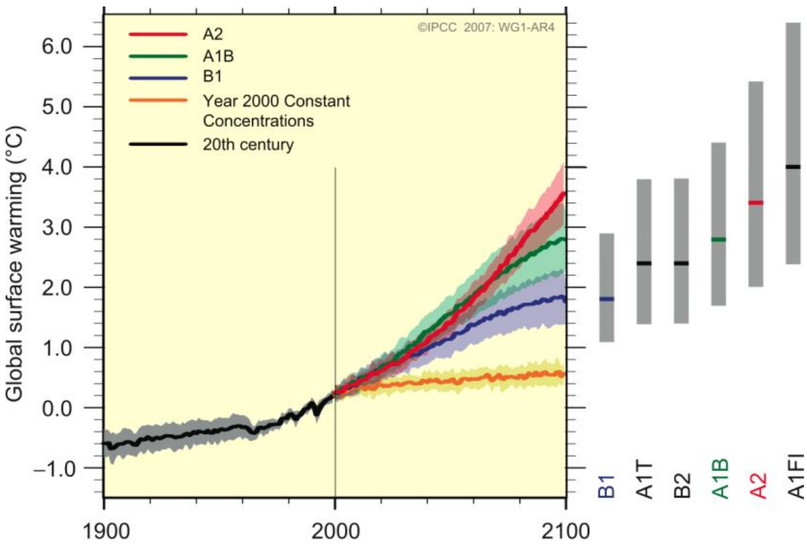


Figure 2: Projections of the global average temperature. The solid lanes show the establishment of the global mean surface temperature. Lane before 2000 are the observed values with their uncertainty, also forming the reference period in 1980–1999. In the inner Figure, A2, A1B and B1 shows the future according to the scenarios. The columns to the right from this display indicate the uncertainty of the model estimates, i.e. deviation from the mean by +60 % and -40 %. ([1]: Fig. SPM 5)

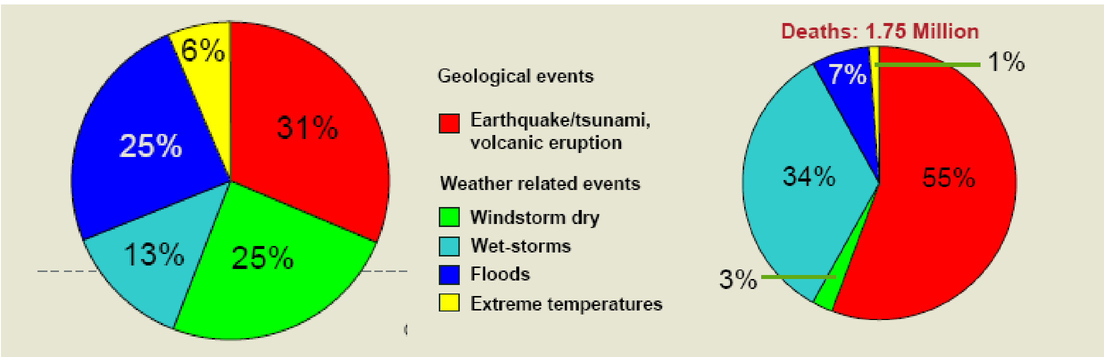
2. WEATHER AND CLIMATE EXTREMES

Meteorological extremes are events that are rare within its statistical reference distribution at a particular place. Definitions of “rare” vary, but an extreme weather event would normally be rarer than the 10th or 90th percentile. Characteristics of what is called “extreme” may vary from place to place. Society as a whole has likely become more sensitive to extreme weather, since population and infrastructure continues to grow in areas that are vulnerable to the weather and climate extremes.

The *impacts* of extreme events cover wide ranges. Nearly all sectors of the economy are facing such impacts. The disadvantageous impacts of extreme meteorological events include: floods, excess inland water inundations, droughts, rainstorms, hails, heat waves, increasing UV radiation, early and late frosts, snow jams, wind storms, forest and bush fires, appearance of new pathogens and pests.

As it is seen in *Fig. 3*, weather extremes play a sorrowful important role among the natural disasters in global and in European comparison, especially concerning the economical losses.

a.)



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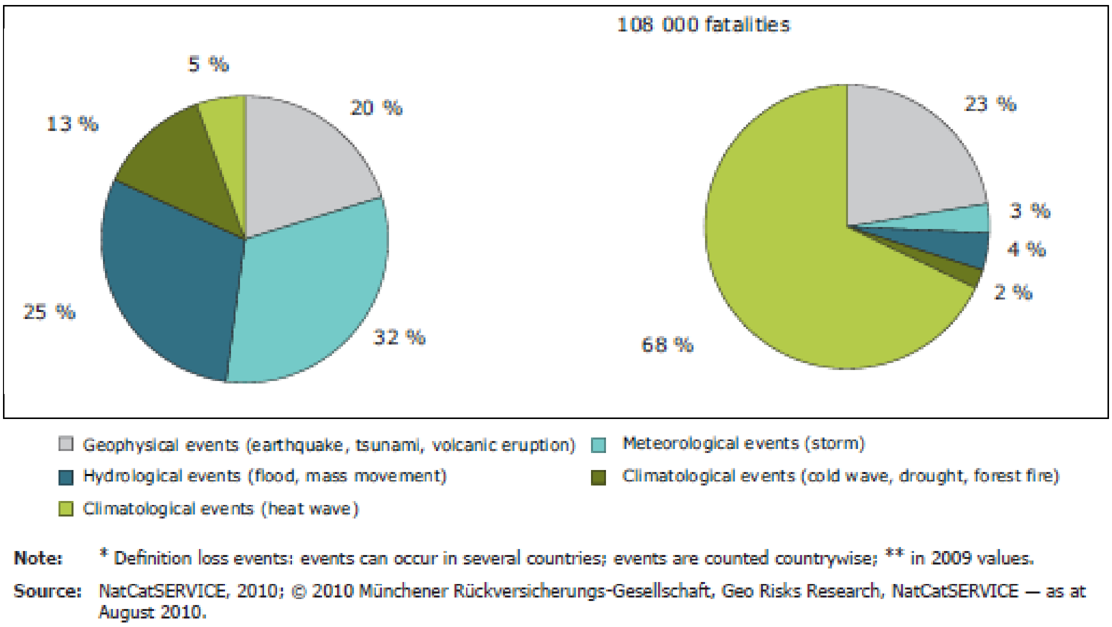

Figure 3: *Percentage distribution of economical loss (left) and number of fatalities (right) caused by natural disasters a.) Global mean in 1950-2005 [2]; b.) Europe-mean (EU+5 countries) 1980-2009 [3].*

2.1 Time and space scales of extremes

Specific concern at the middle latitudes are caused by thunderstorms, tornadoes, hail, dust storms and smoke, fog and fire weather. These small-scale severe weather phenomena, that are sparse in space and time, may have important impacts on societies, such as loss of life and property damage. Their temporal scales range from minutes to a few days at any location and typically cover spatial scales from hundreds of meters to hundreds of kilometres. These extremes are accompanied with further hydro-meteorological hazards, like floods, debris and mudslides, storm surges, wind, rain and other severe storms, blizzards, lightning. For example, mudslides disrupt electric, water, sewer and gas lines. They wash out roads and create health problems when sewage or flood water spills down hillsides, often contaminating drinking water. Power lines and fallen tree limbs can be dangerous and can cause electric shock. Alternate heat sources used improperly can lead to death or illness from fire or carbon monoxide poisoning.

Atmospheric objects exhibit fairly arranged space and time scales. Either drawing the meteorological extremes in the space (x-axis) and time (y-axis) system of coordinates (*Fig. 4*), we observe a diagonal distribution of the objects of both drawings. This means, small scale objects are generally short lived, whereas large-scale objects spend more time in the atmosphere.

On the other hand it also means that there are no fast developing extremes which cover large areas and also we do not experience long-term individual extremes or objects which threaten just small areas. Fig 6.3a provides a comprehensive list of meteorological extremes.

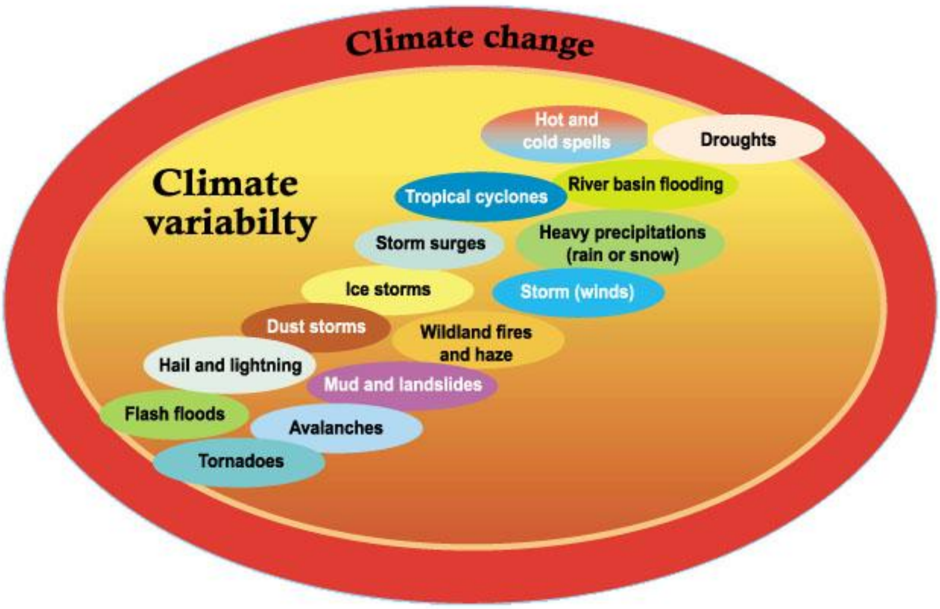

Figure 4: Characteristic space (horizontal) and time (vertical) scales of a.) weather and climate extremes. Source: [4]

Mean frequency of several weather extremes is displayed in frequency maps e.g. by [5]. These maps indicate that majority of extremes belong to more than one climate belt. *Fig. 5* also supports this fact, representing the strongest meteorological extremes of the recent 2001-2010 decade. Except the tropical cyclones, the other four types of extremities belong to various latitudes. Both hot and cold long-term temperature extremes and positive or negative anomalies of water balance exhibit fairly wide spatial coverage. Another experience from this Figure is, that putting all kinds of extremities together, practically all continents experienced one or the other types of serious extremes.

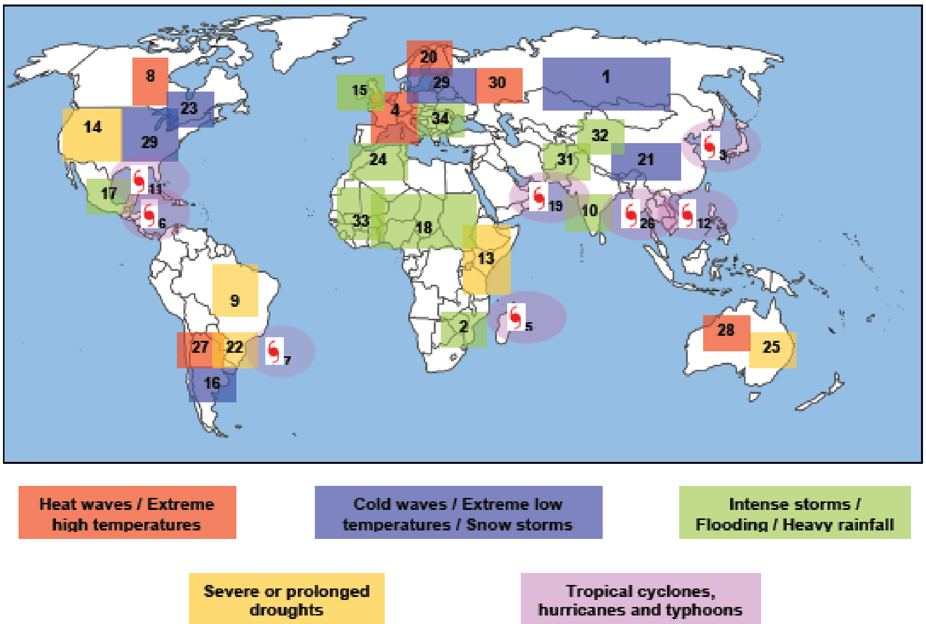

Figure 5: Distribution of various extreme events over the world in 2001-2010 [6]. The map indicates that, one, or the other one of them may occur practically everywhere.

2.2 What is seen from the data?

The IPCC (2007, see *Table 1*) displayed a table on the major extreme events, indicating the 20th century tendencies, likelihood of human contribution in the observed trend and likelihood of the future trends. Recently, the IPCC SREX report [7]. reviewed the changes in extreme events.

Table 1: *Recent trends, assessment of human influence on them, and projections of extreme weather events for which there is an observed 20th century trend. ([1]: Tab. SPM-2)*

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

One of these recent results is seen in *Fig. 6*. It indicates that whereas duration of warm spells increases all over Europe, observed changes the winter cold events (though not extremes), the so called frost days exhibited a rather patchy structure over the continent with some places of even more frequent frost days, despite the overall tendency of warming. This can likely be explained by more anti-cyclonic situations in winter, as it was reported by [8] and reflected by the IPCC AR4 Report [1].

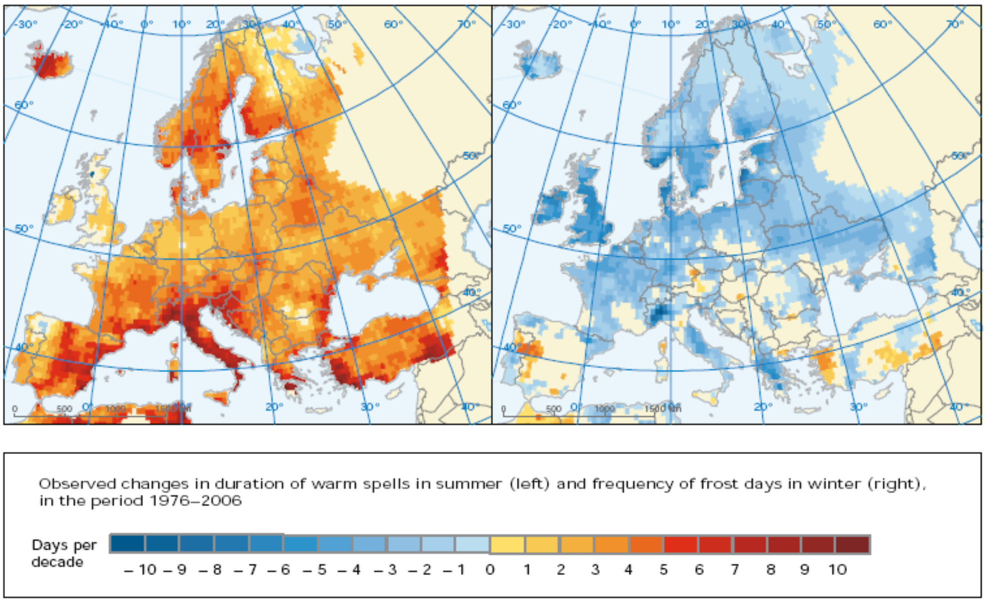

Figure 6: Observed changes (days/10 years) in duration of warm spells in summer and in frequency of frost days (T_{max}<0°C) in winter in the warming-up 1976-2006 time period in Europe ([9]: Map 5.6).

3. IMPACTS OF CLIMATE CHANGE

Most of the living world characteristics, as well as many features of the social and economic life have been developed basically in alignment with the climate of the environment. Hence, changes of climate may lead to significant impacts in the various geographical latitudes.

The oceanic and coastal areas mainly suffer from the consequences of sea-level rise which generally outweigh the other effects. The effects of sea-level rise include: erosion of beaches and coastal margins; land-use changes; pressure on natural wetlands; changes in frequency and severity of flooding; damage to port facilities and coastal structures; and damage to water management systems.

For the high latitude regions the following effects were considered to be the most important: changes of the pack ice conditions; increased cloudiness and precipitation; and slow disappearance of the permafrost. These changes affect such factors as marine transportation, energy development, marine fisheries, agriculture, human settlement, northern ecosystems, and security issues.

In the mid-latitude regions, the effects of climatic change on agriculture, water resources and soils were considered, but it was concluded that the main effect would be on unmanaged ecosystems. It is understandably, that the forest vegetation can not follow the fast shift of climate belts.

Climatic changes would probably worsen the current critical problems of the semi-arid tropics and the major effects could be expected on food availability; water availability; fuel-wood availability; human settlement and unmanaged ecosystems. The major effects of climatic changes on the humid tropical regions would result from rising water levels along coasts and rivers and the changing spatio-temporal distribution of temperature and precipitation. Thus, the most vulnerable regions of the humid tropics would be the coastal and riverine regions, and the upland regions of infertile soils.

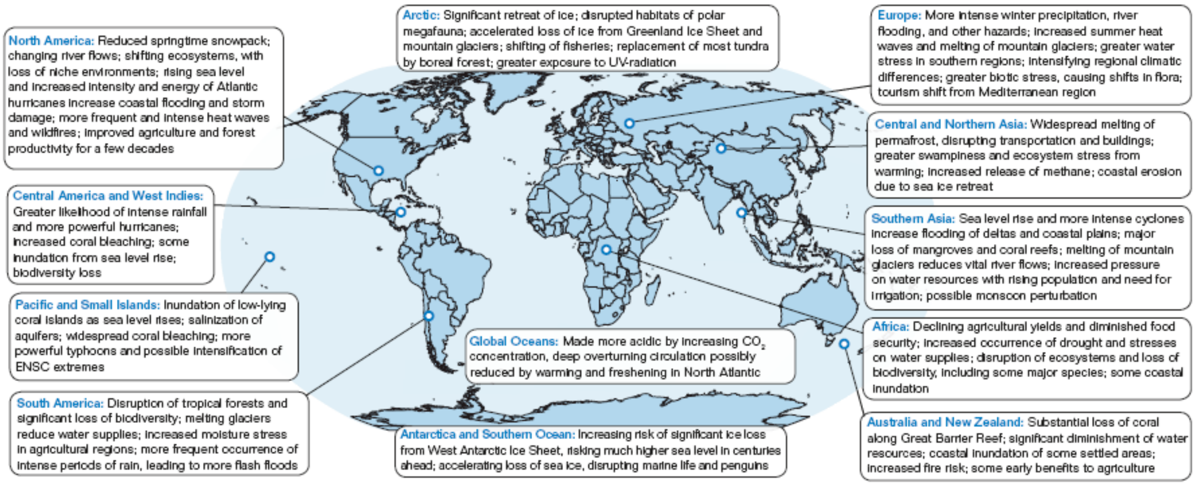

Fig. 7: *Significant impacts of climate change that likely occur in the Globe in the 21st century [10].*

Fig. 7 presents a general overview of the most sensitive sectors of the environment and economy concerning effects of the global warming. There are vast areas and sectors everywhere indicated to be endangered by the changes.

One could thing that for the present cold poles of the continents the general warming can only be advantageous. But, as it is seen in *Fig. 8* this is not the case. The permafrost areas which hold huge building in the common belief that they remain solid are threatened by collapse of the existing structures as the permafrost becomes melting. From the beginning of the 20th century to 2005 the area of permafrost decreased by 3 million square kilometres, which is 7 % of the initial area.

Climate change leads to a sequence of side-effects, some of which compromise the quality of air, water, and soil. Increasing air temperatures lead, e.g., to higher metabolic rates in soils with resulting emissions and changing water chemistry. Other sources will release more volatile components, etc. As a result, precursor concentrations increase in the atmosphere, and water quality experiences serious changes due to an altered soil hydrology and chemical interactions.

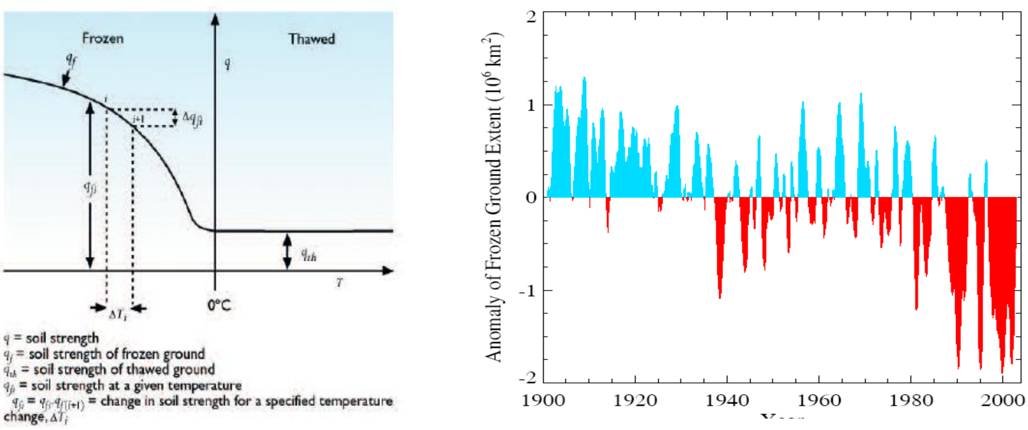

Figure 8: Melting the permafrost areas. Left figure: the schematic function of the weight holding capacity of the soil in connection with the soil temperature. It is seen that even in moderately frozen conditions the soil can keep much less weight on its surface than in strongly frozen conditions. Right figure: the global trend of melting.

4. MITIGATION OF CLIMATE CHANGE

Climate faces changes that are unprecedented in the history of mankind with great probability as the consequence of human activity. The risk of climate change accompanied by the regular increase of mean ground surface temperature becomes greater and greater. Rise of sea-level in the warmer climate, alteration of the extension of polar ice covers, displacement of the climate zones, as well as more adverse precipitation supply, that may occur in many regions of the Earth are warning that the present day generation should take steps to avoid the risk of climate change or to mitigate it, at least.

4.1 The minimum goal: to avoid jump-like climate changes

Considering the extremity in global scale, we should establish that there are so called tipping points [11], where our climate may exhibit irreversible changes (*Table 2*) Melting of the West Antarctic ice sheet, slow-dawn of the Atlantic thermohaline circulation and the El Nino – Southern Oscillation may turn into a new state after 3 K of global warming. The Greenland ice-sheet starts melting after 1-2 K, the Arctic summer ice melts already.

To avoid the 3 K warming the mankind must start decreasing its greenhouse gas emission by 2020, the latest. This can be established by considering the so called policy-scenarios with the conclusion that the concentration should be stopped at 445-490 or 495-535 ppm equivalent CO_2 concentrations. (This is a value when all greenhouse gases express the same forcing, as the CO_2 in the given concentration.) Since this is a very complex question, majority of the mitigation requests consider 2 K for the maximum allowed warming for the future.

Table 2: Selected tipping-points of climate that should be avoided by sharp reduction of greenhouse gas emission from ca. 2020, to avoid the last three jumps [11].

Tipping element	Feature of system, *F* (direction of change)	Control parameter(s), ρ	Critical value(s),† ρ_{crit}	Global warming†‡	Transition timescale,† *T*	Key impacts
Arctic summer sea-ice	Areal extent (−)	Local ΔT_{air}, ocean heat transport	Unidentified§	+0.5–2°C	≈10 yr (rapid)	Amplified warming, ecosystem change
Greenland ice sheet (GIS)	Ice volume (−)	Local ΔT_{air}	+≈3°C	+1–2°C	>300 yr (slow)	Sea level +2–7 m
West Antarctic ice sheet (WAIS)	Ice volume (−)	Local ΔT_{air}, or less ΔT_{ocean}	+≈5–8°C	+3–5°C	>300 yr (slow)	Sea level +5 m
Atlantic thermohaline circulation (THC)	Overturning (−)	Freshwater input to N Atlantic	+0.1–0.5 Sv	+3–5°C	≈100 yr (gradual)	Regional cooling, sea level, ITCZ shift
El Niño–Southern Oscillation (ENSO)	Amplitude (+)	Thermocline depth, sharpness in EEP	Unidentified§	+3–6°C	≈100 yr (gradual)	Drought in SE Asia and elsewhere

4.2 Possibilities of mitigation

Emission of CO_2 is a product of four general components, each of them concentrating several scientific and technological challenges. They are the number of people on the Earth *(Pop);* the average well being of humans (*GDP/capita)*; the mean energy required to create one USD *(TPES/GDP)* and the mean CO_2 emission required to produce a unit amount of energy *(CO2/TPES)*:

$$CO2 = Pop \times (GDP/capita) \times (TPES/GDP) \times (CO2/TPES)$$

As it is seen in *Fig. 9*, the product of the first two components are increasing much faster than the already ongoing decrease of the third and fourth components. Though, it is also interesting, that the latter two components started to decrease far before climate-, or environmental awareness, just in consequence of the technological development.

Finally, *Figure 10* indicates the relative importance of the possible tools to decrease greenhouse gas emission. From above downward, they are renewable energy sources, nuclear energy, carbon sequestration, forest sinks and non-carbon dioxide greenhouse gases. As we can see, no single solution exists, i.e. all tools are needed to achieve the stabilization!

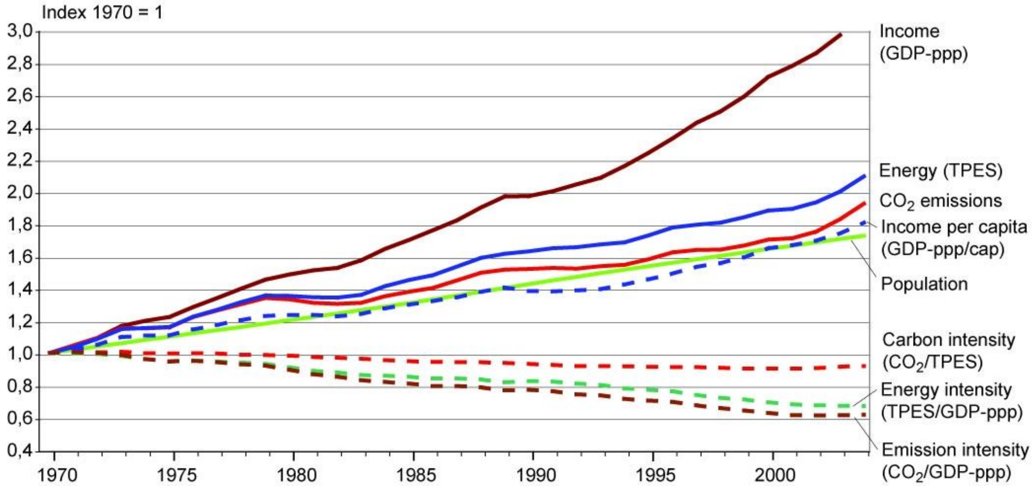

Figure 9: Intensity of energy use and CO_2 emission, 1970-2004. ([12], 2007: Fig. 1.5)

Options for reducing the CO_2 emissions include: a reduction of fossil fuel use through increased end-use energy efficiency; replacement of fossil fuel combustion with alternative energy sources; a reversal of the current deforestation trend; a shift of the fossil fuel mix from high- to low-CO_2 emitting fuels; and disposal of CO_2 in the deep ocean.

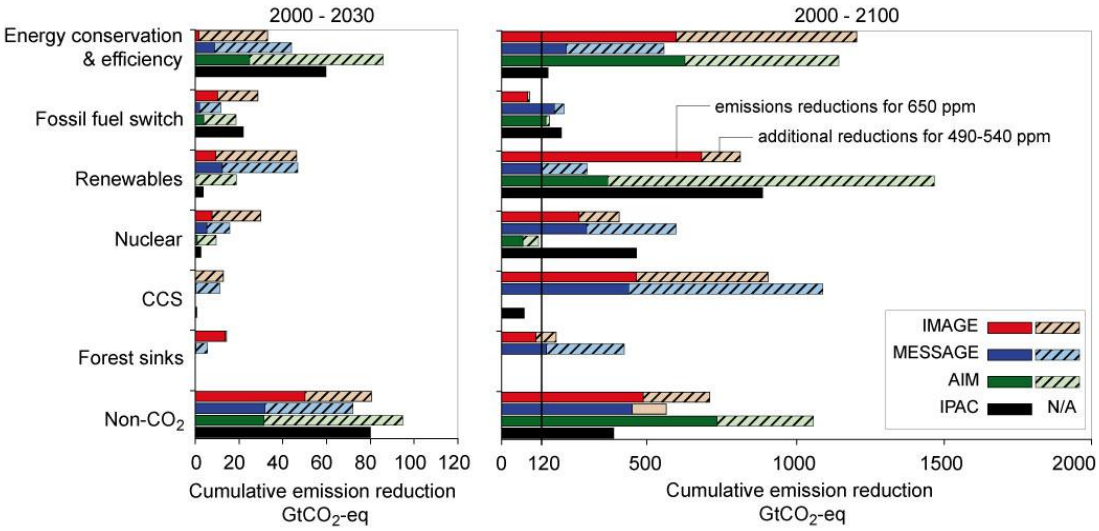

Figure 10: Cumulative emissions reductions for alternative mitigation measures for 2000 to 2030 (left panel) and for 2000-2100 (right panel). The Figure shows illustrative scenarios from four different economical models aiming at the stabilization at 490-540 ppm CO_2-eq and levels of 650 ppm CO_2-eq, respectively. Dark bars denote reductions for a target of 650 ppm CO_2-eq and light bars the additional reductions to achieve 490-540 ppm CO_2-eq. CCS includes carbon capture and storage from biomass. Forest sinks include reducing emissions from deforestation. ([12]: Fig 3.23)

In shorter range, until 2030, energy conservation and efficiency is the strongest potential component of the mitigation, together with the various possibilities of reducing the non-CO_2 greenhouse gases. Renewable energy sources take the third place in the comparison. The fossil fuel switch means larger proportion of using natural gas than coal in the future, since natural gas, and also oil, produces less carbon-dioxide emission for providing the same amount of energy than coal. This is due to unification of hydrogen and oxygen, providing a part of energy without CO_2 emission.

For the longer term by 2100 the importance of non-CO_2 GHG reduction and fossil fuel switch is decreasing with parallel forwarding of the renewables and the CCS technologies (i.e. CO_2-sequestration into the lithosphere). The relatively minor role of strengthening the forest sinks and application nuclear energy reflects parallel environmental considerations, too.

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