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Implications of Climate Science for Negotiators*

Thomas Stocker

Thomas Stocker, Climate and Environmental Physics, Physics Institute, University of Bern, Switzerland.

Abstract

The scientific assessments carried out by the Intergovernmental Panel on Climate Change have delivered robust and rigorous scientific information for the complex negotiations that should produce a binding agreement to limit climate change and its impacts and risks. Understanding climate change as a threat to key resources for the livelihood of humans and the functioning of ecosystems provides a more appropriate perspective on the scale of the problem. Model simulations suggest that today many options exist to limit climate change. However, these options are rapidly vanishing under continued carbon emissions: Temperature targets must be revised upwards by about 0.4°C every decade for constant mitigation ambitions. Mitigating climate change has the important benefit of creating favorable conditions to reach many of the Sustainable Development Goals; business-as-usual and consequent unchecked climate change will make these important universal goals unreachable.

* A shorter version is forthcoming in Barrett et al. (2015)

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1. Introduction

"*Climate change is one of the greatest challenges of our time*", This is the assertion of the parties to the United Nations Framework Convention on Climate Change [*UNFCCC*, 2009]. Confronting this challenge requires scientific information that is robust, rigorous, and transparently delivered. Since the publication of the First Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) in 1990, detailed information has been available to negotiators, decision makers and the public. The Fifth Assessment Report of the IPCC (AR5), which was completed in November 2014 with the publication of the Synthesis Report [*IPCC*, 2014c], gives a comprehensive snapshot of the knowledge science has to offer to quantify, understand, and confront this problem. The assessment is carried out on by many hundreds of scientists on a voluntary basis organized in three Working Groups. Based primarily on the peer-reviewed scientific literature it is produced through a sequence of successive drafts which are reviewed by experts worldwide. The final products of the fifth assessment cycle, including two special reports, comprise over 7500 printed pages. The wealth of the material is a resource to specialists and provides the basis from which the summary products are generated. For easier accessibility to negotiators and decision makers, so-called headline statements have been formulated that provide in a succinct and non-technical manner a complete narrative of the assessment. The four key messages from the Summary for Policymakers of the Synthesis Report are:

1. Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.

2. Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks.

3. Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term, and contribute to climate-resilient pathways for sustainable development.

4. Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales, and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives.

The power of these statements which reflect the scientific assessment lies in the fact that the member countries of the IPCC have formally approved the formulations in consensus.

The purpose of this article is to briefly introduce the reader to important insights from the physical climate science in section 2 and consider them under the perspective of threats to primary resources for human and ecosystems. Section 3 revisits projections of climate change and establishes a link to the requirements of adaptation and their limits. In section 4 cumulative carbon emissions are considered as a framework to assess the options that are available to confront climate change. Section 5 sheds light on the disappearance of these options. Future challenges and conclusions are presented in section 6.

2. Anthropogenic climate change as a threat to primary resources

Carbon dioxide concentrations in the atmosphere are now unprecedented and 30% higher than during at least the last 800,000 years, and they rise more than 100 times faster than during the past 20,000 years (Fig. 1). Similar observations hold for methane and nitrous oxide, the two other important greenhouse gases. The chemical composition of the Earth's atmosphere is now fundamentally different from that which prevailed before the industrial revolution [*Hartmann et al.*, 2013]. The large increases in the concentrations of these greenhouse gases since industrialization are caused by anthropogenic emissions stemming directly from burning fossil fuels and indirectly from deforestation, other land use change, and agricultural activities. The latest comprehensive scientific assessment Climate Change 2013: The Physical Science Basis by the Intergovernmental Panel on Climate Change documents a rapidly and profoundly changing Earth System and provides the latest scientific understanding of changes ahead of us [IPCC, 2013a], impacts and prospects for adaptation are assessed in the contributions of Working Group II [IPCC, 2014a; b], and Working Group III presents the current scientific understanding of mitigation [IPCC, 2014c].

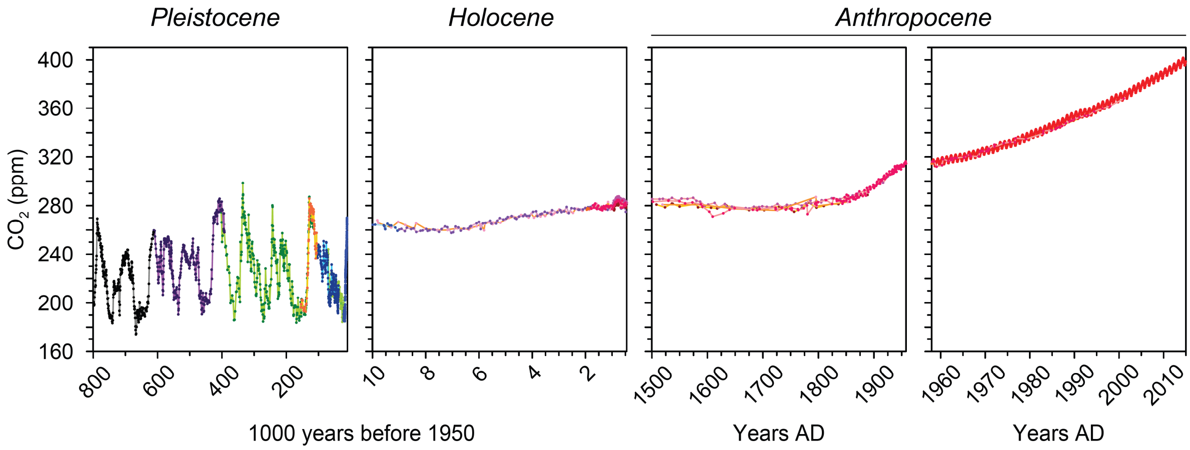

Figure 1: Atmospheric CO_2 concentrations over the past 800,000 years. Measurements of atmospheric CO_2 concentrations on air trapped in bubbles in various Antarctic ice cores (left three panels), and direct measurements at Mauna Loa since 1958 (rightmost panel). Current concentrations are far outside the natural range of variations during the glacial cycles. The stretched time scale highlights the rapid acceleration of the CO_2 increase: in the past 60 years CO_2 increased by about twice the amount it increased in the preceding 400 years, and by about four times that over the previous 10,000 years. Data from *Lüthi et al.* [2008], *Bereiter et al.* [2015] and NOAA ERSL. Figure made by B. Bereiter.

Turning back to the physical climate system, based on multiple lines of independent evidence from the atmosphere, the ocean and the cryosphere, IPCC has concluded that *warming in the climate system is unequivocal*. Since 1951 the Earth warmed by about 0.6 to 0.7°C which is the most easily accessible manifestation of a change in the global energy balance of the Earth. It resulted from positive radiative forcing since 1750 AD caused by a large warming contribution by the increase in the concentrations of the major greenhouse gases in the atmosphere (Fig. 1), and a smaller cooling contribution from aerosols. A much more convincing manifestation of the consequence of this positive radiative forcing is the detection of this extra energy in the Earth System. Since 1970, the energy conntent of the Earth Sytem has increased by about $250 \cdot 10^{21}$ J (Fig. 2). More than 90% of this stored energy is found in the ocean thanks to the unprecedented effort of the international scientific community to measure ocean temperatures on a global scale from the sea surface to a depth of about 2 km [*Roemmich et al.*, 2012]. It is somewhat paradoxical that the public is almost exclusively fixated on atmospheric temperatures, and in particular their recent decadal variability [*Boykoff*, 2014], when the ocean is a natural integrator and recorder of the warming.

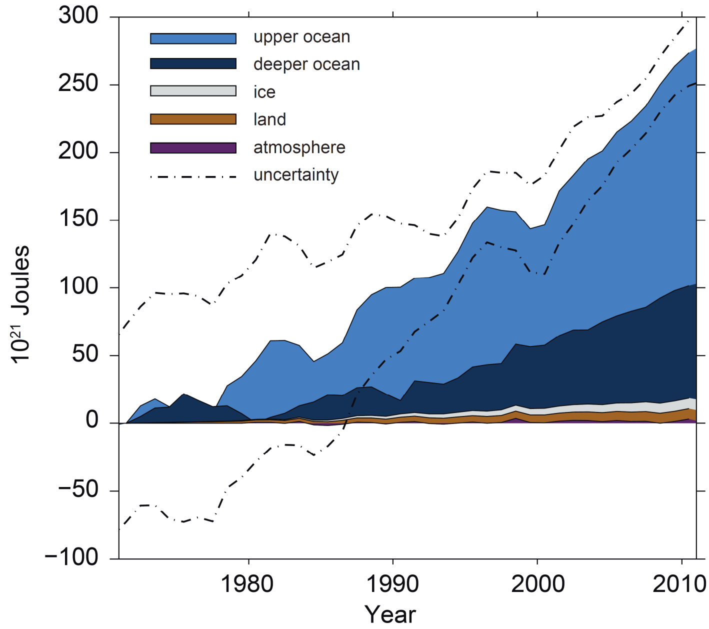

Figure 2: Heat accumulation in the Earth System. Change in the energy content of the Earth System since 1970. More than 90% of the additional energy is stored in the top 2 km of the world ocean. In contrast to identifying the warming in the atmosphere where even on the global scale decadal variations are important, the ocean is an effective integrator of the signal. Figure modified from *Stocker et al.* [2013] and *IPCC* [2014c].

The increase of atmospheric CO_2 concentrations has further, far-reaching consequences: it acidifies the entire world ocean [*Orr et al.*, 2005]. This global-scale change does not generally receive adequate attention by policymakers, negotiators and the public. However, it is now recognized as one of the most profound and long-lasting changes that humans are inflicting on the Earth System. This is due to the fact that much of the emitted CO_2 remains in the atmosphere for many millennia owing to the buffering effect of the ocean water with respect to CO_2. Consequences of ocean acidification, compounded with the world-wide warming, are little known, but they will affect marine ecosystems on a world-wide scale with growing risks for marine life [*Gattuso et al.*, 2015].

The warming also increases sea level directly and indirectly. The thermal expansing of the warming water, and the melting of the glaciers on land, and the loss of mass from Greenland and Antarctica, all together contribute to the rapid increase of sea level [*Church et al.*, 2013].

Numerous other changes have been detected over the past 50 years in all components of the Earth System. Among these observations are reductions in the Arctic sea ice cover in both extent and thickness, melting of the Greenland and Antarctic ice sheets, shrinking of glaciers worldwide, changes in the global water cycle, increases in the occurrence and strengths of extreme events such as the doubling in the frequency of heat waves. The warming and many of the consequent changes are caused by the increase in greenhouse gas concentrations and other substances in the atmosphere. This conclusion arises from the combination of global model simulations and observations which permits the attribution of the observed changes to various drivers and causes [*Bindoff et al.*, 2013]. Recognizing this robust scientific evidence, IPCC concludes in AR5: *Human influence on the climate system is clear*. This surprisingly blunt and simple statement is the succinct summary of thousands of scientific studies that were considered in the latest assessment and represents approved language by the member states of the IPCC.

The importance of these physical changes and their consequent impacts around the globe becomes, however, prominently evident to negotiators and the public if we understand them as changes to key resources available to humans. The primary resources for human subsistence are land, food and water. They are all directly threatened by climate change:

- The resource of land is diminished by a rising level of the sea;
- The resource of food on land is challenged by changes in fundamental ecosystem conditions such as mean temperature and precipitation and their seasonal expression;
- The resource of food from the ocean is threatened by the compound effect of warming and acidification;
- The resource of water is impacted in many regions of the world due to changes in precipitation and evaporation on a global scale with a tendency to exacerbate existing stresses such as drought or flooding.

It is against this backdrop that we must consider Article 2 of the UN Framework Convention on Climate Change [*UNFCCC*, 1992] which reads:

> The ultimate objective of this Convention [...] is to achieve [...] stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within 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.

It is against this backdrop that we must consider Article 2 of the UN Framework Convention on Climate Change [*UNFCCC*, 1992] which stipulates that "*dangerous anthropogenic interference with the climate system*" must be prevented. The notion "dangerous" has been notoriously difficult to describe and constrain, for it cannot be determined or quantified by science. Undisputedly, there is an inherent and evident danger associated with changes in resources. Social systems enjoyed a long period to develop and optimize under resource availability within relatively bounded variability ranges. If the mean supply of resources or if its variability leave this range of tested and experienced resilience, the finely equilibrated network of systems is seriously perturbed.

3. Climate change projections and the threat of adaptation limits

The long-term character of climate change projections over many decades is often difficult to comprehend for the policymakers and the public. How can scientists estimate future changes in the Earth System, when there is an inherent limit of predictability of weather of currently about 10 days? A simple analogy from classical physics may clarify this ever recurring question. Consider a container of water that is put on a heating plate. We know the physical dimensions of the container, the amount of water, and the power of the heating plate. No one would doubt that we can deliver a fairly accurate estimate of the mean temperature of the water after, say, five minutes of heating at a selected level or power. What we will not be able to tell the cook is at what moment a water vapor bubble will form at the bottom of the container and rise to the surface. Fortunately, the cook will likely not be interested to know. Our inability to provide this information is owing to the turbulence of the fluid and the chaotic processes associated with convection when heat is supplied to the fluid from below [*Lorenz*, 1963]. The existence of internal chaotic processes, however, does not prevent us from quite accurately estimating the mean temperature using energy balance, and with some extra effort one may also calculate the statistics of bubble formation at the bottom of the container as a function of time.

This is an appropriate analogy to the climate change predictability problem. The example illustrates why we are confident to provide rather robust estimates on the future state of the Earth System even though we are unable to quantify the complete internal dynamics at every point in time. To estimate the future temperature of the water in the container, the power we select for the heating plate is the key information. To estimate climate change, it is the greenhouse gas emission scenario.

Based on a new set of emissions scenarios, comprehensive climate models project the changes in the climate system during the 21st century and beyond [*Edenhofer et al.*, 2015]. Global surface temperature will increase in all scenarios and by the end of the 21st century will *likely* exceed 1.5°C relative to 1850 to 1900 for all but the lowest emission scenario. This low emission scenario assumes effective policy intervention which would result in aggressive emissions reductions of about 50% by the mid 21st century and complete decarbonization thereafter. Conversely, a business-as-usual scenario would project global mean temperature increases exceeding 4.5°C relative to 1850 to 1900 with profound changes in all components of the climate system. Sea level would rise between 0.52 to 0.98 m by 2100, relative to 1986-2005, with a rate of 8 to 16 mm per year, caused by increased ocean warming and loss of mass from glaciers and ice sheets. In this scenario a nearly ice-free Arctic Ocean in September is *likely* before mid-century. Furthermore, the contrast between wet and dry regions, and between wet and dry seasons will increase. Climate change will also affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere. Further uptake of carbon by the ocean will increase ocean acidification.

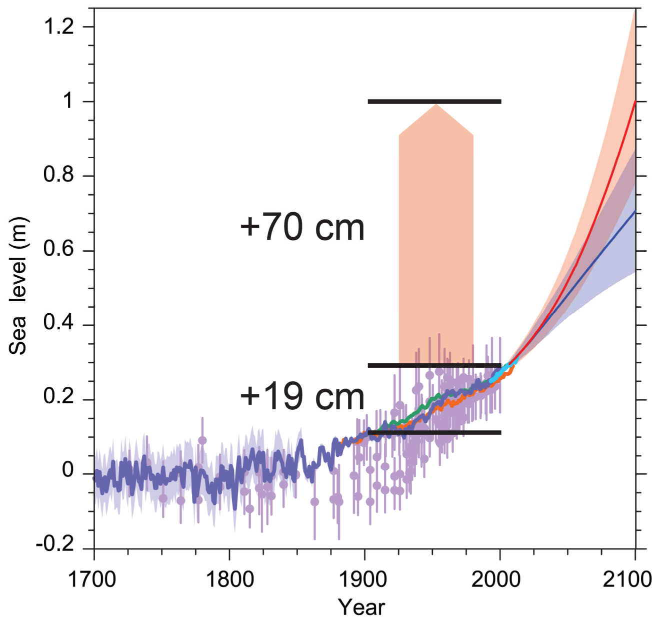

Figure 3: The scale of committed adaptation to sea level rise. Compilation of paleo sea level data (purple), tide gauge data (blue, red and green), altimeter data (light blue) and central estimates and likely ranges for projections of global mean sea level rise from the combination of CMIP5 and process-based models for RCP2.6 (blue) and RCP8.5 (red) scenarios, all relative to pre-industrial values. During the past 100 years adaptation to 19 cm rise was required, much less than the 70 cm, estimated for 2100 under a business-as-usual scenario. Modified from *Stocker et al.* [2013].

Considering these changes, a key question for policymakers and negotiators concerns the capability of adaptation. We illustrate this with projected sea level rise (Fig. 3). So far, adaptation happened to a sea level rise of 19 cm since the beginning of the 20th century, noting that complete adaptation to this change was not necessary since many coastal infrastructures have only been built in the course of the 20th century. Comparing this with the committed adaptation under a business-as-usual scenario, another 70 cm, and considering mature infrastructure and established coastal settlements that must adapt, this indicates the dramatic challenges ahead. The mitigation scenario (RCP2.6) still requires adaptation to sea level rise but at about half this amount. Note that successful adaptation to 21st century conditions will be not sufficient because sea level will continue to rise long beyond 2100. Many regions are likely to encounter their limits of adaptation capacity already in the 21st century [*Klein et al.*, 2014]. As for sea level, adaptation limits also exist for ecosystems on land and in the ocean [*Burrows et al.*, 2011].

The limits of adaptation that we may reach in the course of the 21st century depend on our choices, decisions, and actions today. Limits of adaptation form part of the more fundamental insight that the Earth System offers habitability only within restricted boundaries, the so-called planetary boundaries [*Rockström et al.*, 2009]. If these boundaries change through human activity, or if we push the state of the Earth System beyond these boundaries, the well-functioning of the world as we know it today, is seriously threatened.

4. Current options to address the problem

In AR5 various emission scenarios have been developed for a hierarchy of climate and Earth System models to project the changes in the Earth System [*IPCC*, 2013a], assess the impacts and risks [*IPCC*, 2014a], and to inform about technological options, and economic and societal requirements [*IPCC*, 2014b]. This palette of results, communicated through the four "Representative Concentration Pathways", the RCP scenarios, suggest that we have a full choice of options. Indeed, today there exists a choice between a profoundly altered Earth System in which the availability of the two primary resources for human communities and ecosystems will be different. Land area will diminish through further sea level rise with severe and pervasive impacts on coastal settlements, and changes in the global water cycle will accentuate the differences between dry and wet areas with particularly severe effects on regions that are already now challenged by droughts. Or, alternatively, an Earth System with limited changes and in which adaptation still appears feasible in many regions.

These options, however, have an expiration date: with continuous greenhouse gas emissions, growing at a rate of about 1.8% per year as during the past 40 years, options are gradually vanishing. AR5 now equips the negotiators with an instrument that links the climate change risk assessment with the requirements for climate change limitation. This is the key result from the Synthesis Report [*IPCC*, 2014c]. A key new element is the near-linear relationship between global mean surface warming by the late 21st century and the total cumulative emissions of CO_2 since industrialization [*IPCC*, 2013b]. The larger cumulative emissions are, the higher the peak temperature in the 21st century will be. The important point is that the warming is recognized as a function of all effected emissions bringing in an important and hitherto missing historical perspective of the origin of the future warming.

Figure 4 illustrates this highly policy relevant result. Risks associated with climate change increase at specific rates with the warming (panel a). Therefore, a risk limit that may be established through the political negotiation process, translates into an amount of allowable cumulative emissions (panel b), i.e., a limited carbon budget. The metric here is temperature, but it is clear from Article 2 of the UNFCCC, that temperature alone does not comprehensively address the declared goal. For example, any risks caused by ocean acidification would be ignored if temperature were the sole indicator of change. Likewise, long-term consequences of sea level rise do not scale with the warming in the 21st century. The agreement to limit climate change and its impacts and risks implies not to overspend the carbon budget, and hence emissions must be reduced. These reductions are quantified in panel c for the time horizon 2050. The carbon budget is also clear about the fact that complete net decarbonization must be achieved beyond 2050, if the warming is to be kept below an agreed target.

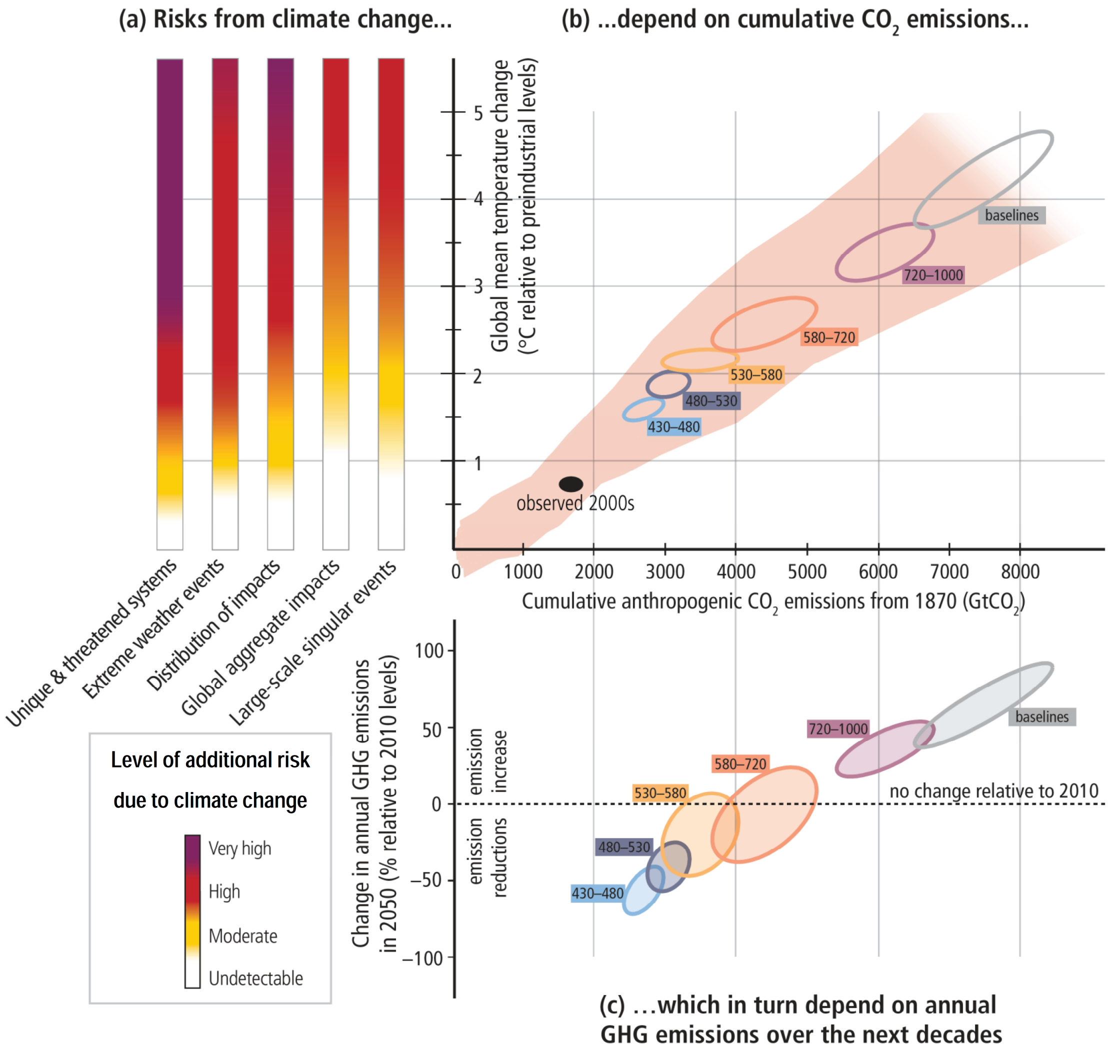

Figure 4: The most policy-relevant findings from the synthesis of the three working group assessments. Panel a) identifies five key climate change related risks whose levels increase with rising temperatures. Due to the near-linear relationship between cumulative anthropogenic CO_2 emissions and warming (panel b), the risk level is tied to a total amount of emitted CO_2. Based on the emissions up to now, requirements of emission reductions by 2050 can be estimated (panel c). For example, to have a chance of more than 66% to limit the risks to those expected for a warming of no more than 2°C, emissions need to be reduced by 40 to 70% relative to 2010 levels. Uncertainty estimates are indicated by the colored wedge (panel b) and the ellipses (panels b and c). Modified from *IPCC* [2014c].

The Working Group I assessment finds that in order to have a fair chance to keep global mean warming below 2°C, the total amount of carbon emitted in the atmosphere since the late mid-19th century is about 1000 billion tons of carbon[1] of which by 2014 already 545 billion tons have been emitted. Compatible with this target, therefore only 455 billion tons of carbon can be emitted in the future. If the effects of additional greenhouse gases, such as methane and nitrous oxide coming from food production, are taken into account, this amount reduces to only 245 billion tons of carbon. This is equivalent to less than 25 years of year-2014 emissions. While this estimate is simplistic, it illustrates the fact that options have an expiration date that is imminent.

The temperature target agreed by the parties to the UNFCCC [*United Nations Framework Convention on Climate Change*, 2010] is not a guarantee to fulfill Article 2 of the convention comprehensively. Adaptation and food production, as well as poverty eradication through sustainable development all call for a more encompassing approach. One step towards this is the definition of additional climate targets as proposed recently by *Steinacher et al.* [2013]. Using an Earth System model of reduced complexity, the Bern3D model, various sets of combined climate targets were defined and the compatible cumulative carbon emissions were determined probabilistically. The set of climate targets comprised both physical and carbon-cycle related quantities, i.e. in addition to the global mean temperature limit, also limits on sea level rise, ocean acidification and in loss of primary production on land. The detailed calculations showed that levels of comparable ambition in the individual targets result in an overall smaller budget if all targets are to be met: the reduction of the budget by 30% is substantial (Fig. 5).

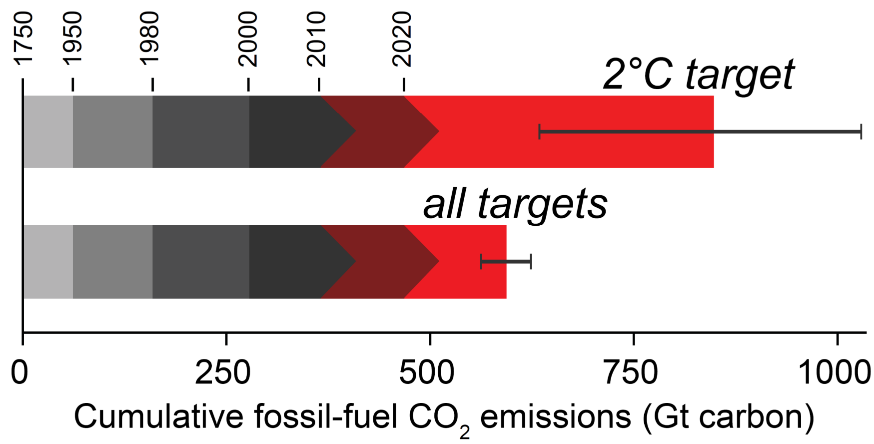

Figure 5: Effect of multiple climate targets on cumulative emissions. Cumulative fossil-fuel emissions, i.e., excluding past and future land use changes, that are compatible with a single temperature target (upper bar) are significantly larger than those consistent with a set of policy-relevant climate targets addressing more comprehensively Article 2 of the UNFCCC. The likely range (66%) of the probabilistic estimates are indicated by the uncertainty bars. Figure made by M. Steinacher, based on *Steinacher et al.* [2013].

[1] Note that WGI reports emission reductions in Gigatons of Carbon (GtC). WGIII reports emissions in 1 Gigatons of Carbon Dioxide ($GtCO_2$). 1GtC = 3.667 $GtCO_2$. Also note that uncertainty estimates are comprehensively given in the reports of Working Group I and III.

5. While negotiations continue, climate mitigation and adaptation options disappear at an accelerating pace

The passing of time caused by the complexity of the negotiations is particularly detrimental to the ultimate goal of the UNFCCC to stabilize greenhouse gas concentrations in the atmosphere. That goal was agreed in 1992 and entered into force already in 1994. Since 1994 alone, over 20% of the budget of cumulative carbon emissions compatible with the 2°C target, or 42% of the then remaining budget, have been consumed by now. The starting time of the global emissions reduction pathway is crucial. To illustrate this, we consider idealized carbon emission pathways [*Stocker*, 2013]. They are so simple that they lend themselves to an analytical evaluation. Three pathways with different starting times of a global mitigation scheme and all compatible with the 2°C target are shown in Fig. 6. It is evident that the delay of mitigation increases ambitions for mitigation rapidly: when started now, emissions must drop at a constant rate of 4.4% per year, while starting 15 years later, that rate has grown to over 25% per year, a decarbonization rate that is economically impossible [*den Elzen et al.*, 2007].

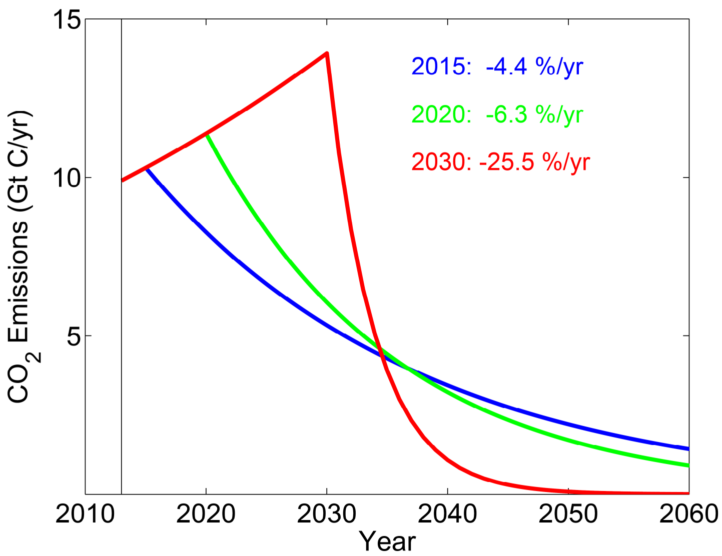

Figure 6: Idealized exponential emission pathways compatible with a 2°C target. The pathways consist of a period of continued emission growth of 2 % per year, approximately the current long-term rate, and a subsequent sustained reduction starting at various times in the future. Based on *Stocker* [2013].

A different way to look at the problem is to ask for the required emission reduction rate given an agreed temperature target and a starting year of mitigation. Delaying mitigation for too long means "hitting the wall" and entering the "Area of Unachievability" as shown in Fig. 7. The red boundary line evidences the accelerated permanent loss of climate target options when the allowable carbon budget is exhausted.

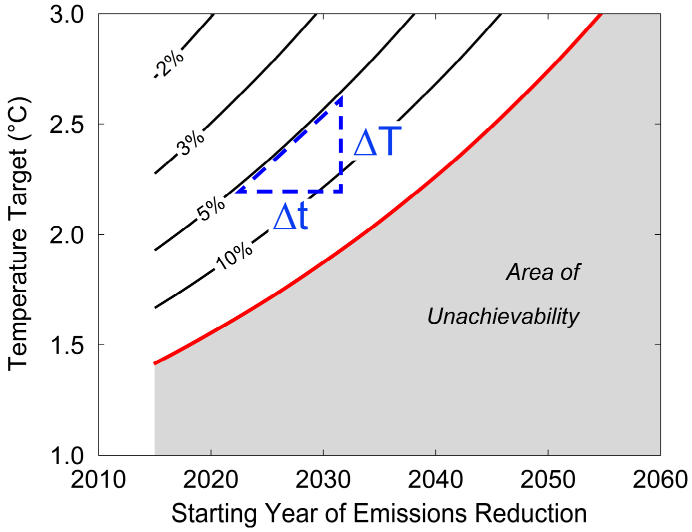

Figure 7: The closing door of climate targets. Required emission reduction rates (contours, in % per year) which keep the warming below 2°C. The area of unachievability highlights the finite time for which temperature targets remain options. The slope of the contours defines the Mitigation Delay Sensitivity MDS=ΔT/Δt, a new policy-relevant metric of the Earth System. Based on *Stocker* [2013].

In order to measure the speed of climate target loss, the new metric MDS (mitigation delay sensitivity) is defined [*Allen and Stocker*, 2014]. MDS corresponds to the slope of the contour lines in Fig. 7 and hence describes the amount of temperature target (ΔT) that is lost per unit time (Δt), keeping ambition constant. As such, this is a very policy-relevant quantity because it informs directly about the urgency for the implementation of mitigation measures provided a target should remain achievable. MDS can be determined also for other policy-relevant quantities such as sea level rise or measures of ocean acidification [*Pfister and Stocker*, 2015].

	global mean surface temperature trend		**thermosteric sea level rise**
year	°C per decade	year	mm per decade
1880-2012	0.06	1901-1990	37
1951-2012	0.12	1971-2010	8
1998-2012	0.05	1993-2010	11
MDS	**0.4**	**MDS**	**100**

Table 1: Mitigation delay sensitivity (MDS) as a policy-relevant metric for the urgency of the problem. Comparison between observed rates of change of global mean temperature and thermosteric sea level rise and their respective rates of target loss , the MDS, under continuing emission growth, based on idealized scenarios. From *Pfister and Stocker* [2015].

Simulations with the Bern3D model permit estimates of MDS for global mean temperature and thermosteric sea level rise [*Pfister and Stocker*, 2015]. Central estimates of MDS for temperature are about 0.4°C per decade and about 100 mm per decade for thermosteric sea level rise. It is instructive to compare these numbers to various observed rates of change as illustrated in Tab. 1.

In other words, in about 10 years the 2.5°C target will become as ambitious at the 2°C today. A given climate target therefore disappears at a rate that is 2 to 6 times faster than the observed warming during the past few decades. Due to the slow response of sea level to the forcing, sea level mitigation delay sensitivities are 9 to 25 times larger than current observed rates. Observed warming and sea level rise therefore create a false impression about the urgency of the problem.

6. Future challenges and conclusions

For the physical sciences, I see several areas where an increased effort is required to strengthen the information to negotiators:

- Better understanding and quantification of changes to the hydrological cycle, in particular precipitation and its seasonal distribution;
- Statistics of extreme events and their response to climate change;
- Evolution of the patterns, intensity, and frequency of natural modes of variability, foremost El Niño-Southern Oscillation and monsoon systems;
- Enhanced regionality of information by linking global-scale and regional models with downscaling approaches, with the goal to provide useful model information for impact and risk studies ;
- Improved knowledge and quantification of climate system feedbacks such as cloud-aerosol, ocean-sea ice-atmospheric dynamics, and ocean-ice sheets;
- Improved knowledge and quantification of climate-biogeochemical cycle feedbacks, in particular the climate-carbon cycle feedback;
- Better constraints on fundamental metrics of the coupled Earth System such as equilibrium climate sensitivity, transient climate response, transient climate response to cumulative carbon emissions, and mitigation delay sensitivity;
- Enhanced model capability and physical understanding of the dynamics of large ice sheets and their interaction with the bed and the adjacent ocean, in order to better assess potential instabilities;
- Better understanding of changes in atmospheric and oceanic circulations in response to changing greenhouse gas concentrations and areosol distributions.

Many countries have started to develop climate services under the auspices of the World Meteorological Organization. It will be crucial to involve the scientific community in this effort. Without a close contact to the latest scientific developments, climate services will not be able to deliver useful information in conditions of continual Earth System changes. It is also abundantly evident, that without a much enlarged base of observational networks, progress will be impossible.

For example, climate and regional model evaluation and improvement critically depend on the availability of high-quality observations. If they are not available and freely accessible, the further development of important tools for decision making will be hampered and progress will stagnate.

Information from the physical science will remain crucial for reaching robust, science based decisions. With the progress in the above areas, a basis will be laid to establish much stronger links between the physical science and the impact and risk science. This combined information will be in high demand by negotiators and decision makers. However, without strengthening the disciplinary pillars of the elements, the cross-cutting topics will not be supplied with the necessary scientific substance in the long run.

One of the largest challenges for negotiators is the limited time that is available to realistically achieve the 2°C target. As discussed in the contributions on the architecture and governance parts of this e-book, while solutions are being sought, agreements being formulated, and legal frameworks being negotiated, global carbon emissions continue to grow. With every decade, about 0.4°C of a temperature target are lost given a constant level of ambition. Once the carbon budget for a specific target is consumed, that target is lost permanently, barring global-scale negative emissions which will be unavailable in the near future. This implies that at some stage, climate change targets will need to be corrected upward. If this is happening, how would we deal with such a failure of global stewardship?

Taking a broader perspective, we should recognize that addressing climate change is a sheer necessity if we want to achieve the Sustainable Development Goals (SDGs). Effective climate change mitigation is a good start on the pathway towards the SDGDs and will accelerate reaching many of them. Business-as-usual, on the other hand, certainly makes the SGDGs unachievable. Addressing climate change, -therefore, must be an integral part of a strategy to reach the Sustainable Development Goals.

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