Lecture *Climate Change*
Lesson 4

Temperature & Heat waves

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### Course webpage

https://www.bgc-jena.mpg.de/bgi/index.php/Lectures/HydroBioClimClimateChange

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<tr>
<th>Datum</th>
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<th>Dozent</th>
<th>Sprache</th>
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<td>Vorlesung</td>
<td>Allgemeine Einführung ins Thema, Überblick zur Vorlesung</td>
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<td>Klimawandel-Projektionen</td>
<td>Sinikka Paulus</td>
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<td>30.01.2020</td>
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Lesson 4
Temperature & Heat waves

1) Increase of mean global temperature
2) 2°C target versus other targets
3) Changes in regional & extreme temperatures
Increase of global mean temperature

Results include >30 state-of-the-art climate models

Only RCP2.6 scenario stays below 2 degree warming
Increase of global mean temperature

It is in our hands what the world will look like in 2090.
Increase of global mean temperature

Global warming might continue beyond 2100
Summary

- RCP2.6 means 2°C warming by 2100, RCP4.5 means 3°C, and RCP8.5 means 5°C, with more warming after 2100.
Lesson 4
Temperature & Heat waves

1) Increase of mean global temperature
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2°C target vs. other targets

Cumulative total anthropogenic CO₂ emissions from 1870 (GtCO₂)

Temperature anomaly relative to 1861–1880 (°C)

RCP2.6, Historical, RCP4.5, RCP6.0, RCP8.5

1% yr⁻¹ CO₂, 1% yr⁻¹ CO₂ range

IPCC (2013)
One of the most important figures in climate science.

The reason behind this relationship is that CO$_2$ stays within the atmosphere for very long time.
2°C target vs. other targets

One of the most important figures in climate science

Conclusions (1):

For temperature increase to likely (>66 %) remain below 2°C relative to preindustrial, the carbon budget is about 800 GtC

About 535 GtC have been emitted between 1870 and 2013 (IPCC 2013)

At annual emissions of about 10 GtC/yr, the remaining budget would last less than 30 years (Friedlingstein et al. 2014)
Conclusions (2):

(1) Every ton of CO$_2$ adds about the same amount of warming, no matter when and where it is emitted.

(2) Any global temperature target therefore implies a finite amount of CO$_2$ that we are allowed to emit to stay below the target, irrespective of the scenario that leads to those emissions.

(3) To stop global warming, global net emissions need to decrease to zero.

(4) Countries and generations approximately contribute to climate change in proportion to their share of the total global emissions.
Summary

- RCP2.6 means 2°C warming by 2100, RCP4.5 means 3°C, and RCP8.5 means 5°C, with more warming after 2100

- Particular emission budget associated with e.g. 2°C warming → this means that not only the emission increase must stop, but (net) emissions must end at all sometime
The 2°C target

Meinshausen et al. (2009)

The more emissions, the less likely we reach the 2°C target.
The later we start reducing emissions, the faster the reduction needs to be to reach the 2°C target.

Knutti et al. (2015)
The 2°C target

Knutti and Rogelj (2015)

Emissions in business-as-usual versus 2°C target scenarios
A scientific critique of the two-degree climate change target

Reto Knutti\textsuperscript{1*}, Joeri Rogelj\textsuperscript{1,2}, Jan Sedláček\textsuperscript{1} and Erich M. Fischer\textsuperscript{1}

The world’s governments agreed to limit global mean temperature change to below 2°C compared with pre-industrial levels in the years following the 2009 climate conference in Copenhagen. This 2°C warming target is perceived by the public as a universally accepted goal, identified by scientists as a safe limit that avoids dangerous climate change. This perception is incorrect: no scientific assessment has clearly justified or defended the 2°C target as a safe level of warming, and indeed, this is not a problem that science alone can address. We argue that global temperature is the best climate target quantity, but it is unclear what level can be considered safe. The 2°C target is useful for anchoring discussions, but has been ineffective in triggering the required emission reductions; debates on considering a lower target are strongly at odds with the current real-world level of action. These debates are moot, however, as the decisions that need to be taken now to limit warming to 1.5 or 2°C are very similar. We need to agree how to start, not where to end mitigation.
The 2°C target vs. other targets

Variety of impacts with 2°C warming, intensifying (non-linearly) with additional warming

IPCC (2013)
The 2°C target vs. other targets

More warming = more (severe) impacts, 2°C is arbitrary threshold
The 2°C target vs. other targets

<table>
<thead>
<tr>
<th>CO₂ eq Concentrations in 2100 [ppm CO₂ eq]</th>
<th>Subcategories</th>
<th>Relative position of the RCPs $^5$</th>
<th>Cumulative CO₂ emissions $^1$ [GtCO₂]</th>
<th>Change in CO₂ eq emissions compared to 2010 in [%]$^6$</th>
<th>2100 Temperature change [°C]$^7$</th>
<th>Temperature change (relative to 1850–1900)$^8$</th>
<th>Likelihood of staying below temperature level over the 21st century$^9$</th>
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<tr>
<td>Category label (concentration range)$^3$</td>
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<td></td>
<td>2011–2050</td>
<td>2011–2100</td>
<td>2050</td>
<td>2100</td>
<td>1.5°C</td>
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<td>&lt; 430</td>
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<td>Likely</td>
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<td>450 (430–480)</td>
<td>Total range$^1,10$</td>
<td>RCP2.6</td>
<td>550–1300</td>
<td>630–1180</td>
<td>−72 to −41</td>
<td>−118 to −78</td>
<td>More unlikely than likely</td>
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<td>No overshoot of 530 ppm CO₂ eq</td>
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<td>860–1180</td>
<td>960–1430</td>
<td>−57 to −42</td>
<td>−107 to −73</td>
<td>More likely than likely</td>
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<td>Overshoot of 530 ppm CO₂ eq</td>
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<td>1130–1530</td>
<td>990–1550</td>
<td>−55 to −25</td>
<td>−114 to −90</td>
<td>About as likely as not</td>
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<tr>
<td>500 (480–530)</td>
<td>Total range$^1,10$</td>
<td>RCP4.5</td>
<td>1070–1460</td>
<td>1240–2240</td>
<td>−47 to −19</td>
<td>−81 to −59</td>
<td>More unlikely than likely</td>
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<td>No overshoot of 580 ppm CO₂ eq</td>
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<td>1420–1750</td>
<td>1170–2100</td>
<td>−16 to 7</td>
<td>−183 to −86</td>
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<td></td>
<td>Overshoot of 580 ppm CO₂ eq</td>
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<td></td>
<td></td>
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<td>Likely</td>
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<tr>
<td>550 (530–580)</td>
<td>Total range$^1,10$</td>
<td>RCP4.5</td>
<td>1260–1640</td>
<td>1870–2440</td>
<td>−38 to 24</td>
<td>−134 to −50</td>
<td>More likely than likely</td>
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<tr>
<td></td>
<td>Total range$^1,10$</td>
<td>RCP4.5</td>
<td>1310–1750</td>
<td>2570–3340</td>
<td>−11 to 17</td>
<td>−54 to −21</td>
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<td>580–650</td>
<td>Total range</td>
<td>RCP6.0</td>
<td>1570–1940</td>
<td>3620–4990</td>
<td>18 to 54</td>
<td>−7 to 72</td>
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<tr>
<td>(650–720)</td>
<td>Total range</td>
<td>RCP8.5</td>
<td>1840–2310</td>
<td>5350–7010</td>
<td>52 to 95</td>
<td>74 to 178</td>
<td>More likely than likely</td>
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with RCP2.6 we could reach the 2°C target with RCP4.5 we could reach the 3°C target with RCP6.0 we could reach the 4°C target
Summary

- RCP2.6 means 2°C warming by 2100, RCP4.5 means 3°C, and RCP8.5 means 5°C, with more warming after 2100

- Particular emission budget associated with e.g. 2°C warming → this means that not only the emission increase must stop, but (net) emissions must end at all sometime

- 2°C target useful for anchoring discussions, but dangerous and/or irreversible climate change can also occur with less warming
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1) Increase of mean global temperature
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Changes in regional & extreme temperatures

- **Temperature variance important for occurrence of extremes**

(a) Increase in mean:
- Fewer cold extremes
- More hot extremes

(b) Increase in variance:
- More cold extremes
- More hot extremes

(c) Increase in mean and variance:
- More/Fewer cold extremes
- More hot extremes

**Temperature variance important for occurrence of extremes**

IPCC (2013)
Changes in regional & extreme temperatures

Stronger temperature changes in extremes than in the mean

ΔT_{mean} until 2100, RCP8.5

ΔT_{min} 2100, RCP8.5

ΔT_{max} 2100, RCP8.5

Seneviratne et al. (2016)
Changes in regional & extreme temperatures

Amplified increase of selected regional extreme temperatures compared with global mean temperature
Changes in regional & extreme temperatures

Amplified increase of selected regional extreme temperatures compared with global mean temperature

Seneviratne et al. (2016)
Changes in regional & extreme temperatures

Temperature increase differs
- across Europe
- across seasons
- across means & extremes
Summary

- RCP2.6 means 2°C warming by 2100, RCP4.5 means 3°C, and RCP8.5 means 5°C, with more warming after 2100
- Particular emission budget associated with e.g. 2°C warming → this means that not only the emission increase must stop, but (net) emissions must end at all sometime
- 2°C target useful for anchoring discussions, but dangerous and/or irreversible climate change can also occur with less warming
- Global warming is not uniform; significant differences across regions and mean vs. extreme temperature increases
Changes in regional & extreme temperatures

Regionally differing temperature increases between different scenarios

IPCC (2013)
Changes in regional & extreme temperatures

Increased greenhouse gas concentrations lead to cooling of stratosphere

Less long-wave radiation from surface reaches higher altitudes
Long-term implications

5.8.3 Next Glacial Inception

Since orbital forcing can be accurately calculated for the future (see Section 5.2.1), efforts can be made to predict the onset of the next glacial period. However, the glaciation threshold depends not only on insolation but also on the atmospheric CO$_2$ concentration (Archer and Ganopolski, 2005). Models of different complexity have been used to investigate the response to orbital forcing in the future for a range of atmospheric CO$_2$ levels. These results consistently show that a glacial inception is not expected to happen within the next approximate 50 kyr if either atmospheric CO$_2$ concentration remains above 300 ppm or cumulative carbon emissions exceed 1000 PgC (Loutre and Berger, 2000; Archer and Ganopolski, 2005; Cochelin et al., 2006). Only if atmospheric CO$_2$ content was below the pre-industrial level would a glaciation be possible under present orbital configuration (Loutre and Berger, 2000; Cochelin et al., 2006; Kutzbach et al., 2011; Vettoretti and Peltier, 2011; Tzedakis et al., 2012a). Simulations with climate–carbon cycle models show multi-millennial lifetime of the anthropogenic CO$_2$ in the atmosphere (see Box 6.1). Even for the lowest RCP 2.6 scenario, atmospheric CO$_2$ concentrations will exceed 300 ppm until the year 3000. It is therefore virtually certain that orbital forcing will not trigger a glacial inception before the end of the next millennium.

As a consequence of human emissions, no ice age for the next 50’000 years

IPCC (2013)
Summary

- RCP2.6 means 2°C warming by 2100, RCP4.5 means 3°C, and RCP8.5 means 5°C, with more warming after 2100.
- Particular emission budget associated with e.g. 2°C warming → this means that not only the emission increase must stop, but (net) emissions must end at all sometime.
- 2°C target useful for anchoring discussions, but dangerous and/or irreversible climate change can also occur with less warming.
- Global warming is not uniform; significant differences across regions and mean vs. extreme temperature increases.
- Anthropogenic greenhouse gas emissions lead to cooling of higher atmosphere, and prevent/shift next ice age.