Lecture *Climate Change*
Lesson 2

Projections of Climate Change

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Many thanks for registering for this course through Friedolin!
## Course webpage

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

### Wintersemester 2019/2020

- **NEUER RAUM:** Fürstengraben 1, Seminarraum 162
- **Zeit:** Donnerstags 10:15-12:00 Uhr
- **Erster Termin:** Donnerstag 17. Oktober 2019, 10:15-12:00 Uhr
- **Bewertung:** Nach aktiver Teilnahme an den Vorlesungen und Übungen wird ein Zertifikat ausgestellt zur Bestätigung der erfolgreichen Vorlesungsteilnahme.
- **Kontakt:** Rene Orth [renee.orth@bgc-jena.mpg.de], Tel. 03641 576250

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Lesson 2

Projections of Climate Change

“Prediction is very difficult, especially about the future”

Niels Bohr
Lesson 2
Projections of Climate Change

If You Cannot Predict the Weather Next Month, How Can You Predict Climate for the Coming Decade?

• Weather forecasts try to provide day-to-day predictions of the state of the atmosphere for a specific point in time

• Climate predictions provide probabilities of long term changes in averages of climate variables, climate predictions aim to reflect only general trends and not detailed further evolution of weather
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Projections of Climate Change

1) Representative concentration pathways (RCPs)
2) Emissions corresponding to RCPs
3) Societal development corresponding to RCPs
4) Climate change corresponding to RCPs
Lesson 2
Projections of Climate Change

1) Representative concentration pathways (RCPs)
2) Emissions corresponding to RCPs
3) Societal development corresponding to RCPs
4) Climate change corresponding to RCPs
Why are emission projections needed?
Why are emission projections needed?

Future greenhouse gas emissions are unknown but essential.
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Future greenhouse gas emissions are unknown but essential

emissions depend on numerous (interacting) drivers such as population, economy, air pollution, land use, energy sources, ...
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Future greenhouse gas emissions are *unknown but essential*

- emissions depend on numerous (interacting) drivers such as population, economy, air pollution, land use, energy sources, ...
- crucial for climate development
Why are emission projections needed?

Future greenhouse gas emissions are *unknown* but *essential*.

Emissions depend on numerous (interacting) drivers such as population, economy, air pollution, land use, energy sources, ...

Solution: Projections!

Projections describe several possible pathways (scenarios) which arise from different possible developments of drivers.
Why are emission projections needed?

Future greenhouse gas emissions are *unknown but essential*

emissions depend on numerous (interacting) drivers such as population, economy, air pollution, land use, energy sources, ...

crucial for climate development

Solution: Projections!
Projections describe several possible pathways (scenarios) which arise from different possible developments of drivers

Note:
Projections are not a prediction which describes one likely pathway
Representative concentration pathways (RCPs)

Emission scenarios are possible future developments which make it possible to model future climate and corresponding impacts.
Representative concentration pathways (RCPs)

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4 pathways selected based on frequent use in literature

Emission scenarios describe possible future greenhouse gas concentration developments
Representative concentration pathways (RCPs)

Emission scenarios are possible future developments which make it possible to model future climate and corresponding impacts.

4 pathways selected based on frequent use in literature. Emission scenarios describe possible future greenhouse gas concentration developments.

There are RCP2.6, RCP4.5, RCP6.0, RCP8.5. The numbers describe the assumed radiative forcing (= additional long-wave radiation reaching the surface) in 2100.
Representative concentration pathways (RCPs)

At first, radiative forcing pathways are defined. Then, the associated climate change and plausible emissions are inferred.
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Representative concentration pathways (RCPs)

At first, radiative forcing pathways are defined. Then, the **associated climate change** and **plausible emissions** are inferred.

RCPs help to coordinate research, make results comparable, and to save money. The occurrence probability of each particular RCP scenario is low.

IPCC (2013)
Summary

- Representative concentration pathways describe possible future developments of the radiative forcing
Summary

- Representative concentration pathways describe possible future developments of the radiative forcing.
- None of the pathways might turn out true, still they are useful for comparable climate change modelling.
Lesson 2
Projections of Climate Change

1) Representative concentration pathways (RCPs)

2) Emissions corresponding to RCPs

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4) Climate change corresponding to RCPs
Emissions corresponding to RCPs

**CO₂ emissions**
- RCP8.5
- RCP6.0
- RCP4.5
- RCP2.6
- Historical

**CO₂ concentration**
- RCP8.5
- RCP6.0
- RCP4.5
- RCP2.6

2013 level

IPCC (2013)
Emissions corresponding to RCPs

Strong diversity across scenarios
RCP2.6 assumed negative emissions at end of century

IPCC (2013)
Emissions corresponding to RCPs

There are more greenhouse gases than just CO$_2$!
Emissions corresponding to RCPs

There are more greenhouse gases than just \( \text{CO}_2 \)!

(a) \( \text{CO}_2 \) emissions

(b) \( \text{CH}_4 \) emissions

(c) \( \text{N}_2\text{O} \) emissions

(d) \( \text{SO}_2 \) emissions

(e) \( \text{CO}_2\text{-eq concentration (ppm)} \)

- Historical emissions
- WGIII scenarios categorized by 2100
  - CO\(_2\)-eq concentration (ppm), 5 to 95%
    - >1000
    - 720–1000
    - 580–720
    - 530–580
    - 480–530
    - 430–480

- RCP scenarios
  - RCP8.5
  - RCP6.0
  - RCP4.5
  - RCP2.6

- Full range of the WGIII AR5 scenario database in 2100

IPCC (2013)
Emissions corresponding to RCPs

There are more greenhouse gases than just CO$_2$!

- (a) CO$_2$ emissions
- (b) CH$_4$ emissions
- (c) N$_2$O emissions
- (d) SO$_2$ emissions

Complex interplay of all greenhouse gases

IPCC (2013)
Emissions corresponding to RCPs

Comparing past emission scenarios
Emissions corresponding to RCPs

Comparing past emission scenarios

IPCC (2013)
Emissions corresponding to RCPs

Comparing past emission scenarios

IPCC (2013)
Emissions corresponding to RCPs

Comparing past emission scenarios

\( \text{CO}_2 \) scenarios consistent
Repeated overestimation of methane emissions
Summary

- Representative concentration pathways describe possible future developments of the radiative forcing.
- None of the pathways might turn out true, still they are useful for comparable climate change modelling.
- RCPs cover wide range of emission scenarios.
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1) Representative concentration pathways (RCPs)
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Societal development corresponding to RCPs
Societal development corresponding to RCPs

Van Vuuren et al. (2011)
More people or more GDP not always associated with more projected emissions
Societal development corresponding to RCPs

IPCC (2013)
Societal development corresponding to RCPs

Energy use and energy source matter

IPCC (2013)
Societal development corresponding to RCPs

IPCC (2013)
Societal development corresponding to RCPs

Also agriculture and forestry play an important role
Summary

- Representative concentration pathways describe possible future developments of the radiative forcing.
- None of the pathways might turn out true, still they are useful for comparable climate change modelling.
- RCPs cover a wide range of emission scenarios.
- Different (combinations of) societal developments can impact the radiative forcing as projected by the RCPs.
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Projections of Climate Change

1) Representative concentration pathways (RCPs)
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Climate change corresponding to RCPs
Uncertainties arise from:
- Internal variability
- Differences between scenarios
- Differences between models

Climate change corresponding to RCPs

Uncertainty in Global decadal mean ANN temperature

Fraction of total variance [%]

Year

IPCC (2013)
Climate change corresponding to RCPs

Global mean temperature near-term projections relative to 1986–2005

- Observations
- Historical (41 models)
- RCP 2.6 (32 models)
- RCP 4.5 (41 models)
- RCP 6.0 (25 models)
- RCP 8.5 (39 models)
Climate change corresponding to RCPs

Large inter-annual variability
Differences between models, but all agree on warming
Figure 1 | Range of future climate outcomes. **a**, December-January-February (DJF) temperature trends during 2005-2060. Top panel shows the average of the 40 model runs (all values are statistically significantly different from zero at the 5% confidence level); middle and bottom panels show the model runs with the largest and smallest trends for the contiguous United States as a whole, respectively. **b**, DJF temperature anomaly time series for selected cities (marked by open circles in the left panels), the contiguous United States and the globe (land areas only). Black curves show observed records from 1910 to 2008 (minus the long-term mean); red and blue curves show model projections for 2005-2060 from the realizations with the largest and smallest future trends, respectively, for each location or region. Dashed red and blue lines show the best-fit linear trends to the red and blue curves, respectively. For visual clarity, the model projections are matched to observations averaged over their common period of record 2005-2008. Thus, projected values at the end of the simulation (2060) should be regarded in relative terms (see Supplementary Information). **c**, Distribution of projected DJF temperature trends (2005-2060) across the 40 ensemble members at the locations shown in panel **b**.  

Deser et al. (2012)
Natural variability influences climate change trends

Figure 1 | Range of future climate outcomes. a. December-January-February (DJF) temperature trends during 2005-2060. Top panel shows the average of the 40 model runs (all values are statistically significantly different from zero at the 5% confidence level); middle and bottom panels show the model runs with the largest and smallest trends for the contiguous United States as a whole, respectively. b. DJF temperature anomaly time series for selected cities (marked by open circles in the left panels), the contiguous United States and the globe (land areas only). Black curves show observed records from 1910 to 2008 (minus the long-term mean); red and blue curves show model projections for 2005-2060 from the realizations with the largest and smallest future trends, respectively, for each location or region. Dashed red and blue lines show the best-fit linear trends to the red and blue curves, respectively. For visual clarity, the model projections are matched to observations averaged over their common period of record 2005-2008. Thus, projected values at the end of the simulation (2060) should be regarded in relative terms (see Supplementary Information). c. Distribution of projected DJF temperature trends (2005-2060) across the 40 ensemble members at the locations shown in panel b.

- Deser et al. (2012)
Development of climate models
Development of climate models

A national strategy for advancing climate modelling, nap.edu
Development of climate models

Climate models are becoming Earth system models...
Development of climate models

- KIT, gauss-centre.eu
Development of climate models

Global climate models few years ago

Highest resolution among global climate models now

Weather forecast resolution few years ago

KIT, gauss-centre.eu
Development of climate models

Global climate models few years ago

Highest resolution among global climate models now

Weather forecast resolution few years ago

Increasing resolution possible thanks to advancing computer power

With higher resolution, more physical processes can be explicitly represented instead of approximating them
Summary

- Representative concentration pathways describe possible future developments of the radiative forcing.
- None of the pathways might turn out true, still they are useful for comparable climate change modelling.
- RCPs cover a wide range of emission scenarios.
- Different (combinations of) societal developments can impact the radiative forcing as projected by the RCPs.
- Natural variability and differences between models influence projected short-term temperature trends.
- Differences between RCPs influence long-term temperature trends.
- Significant advances in climate model development in recent decades.