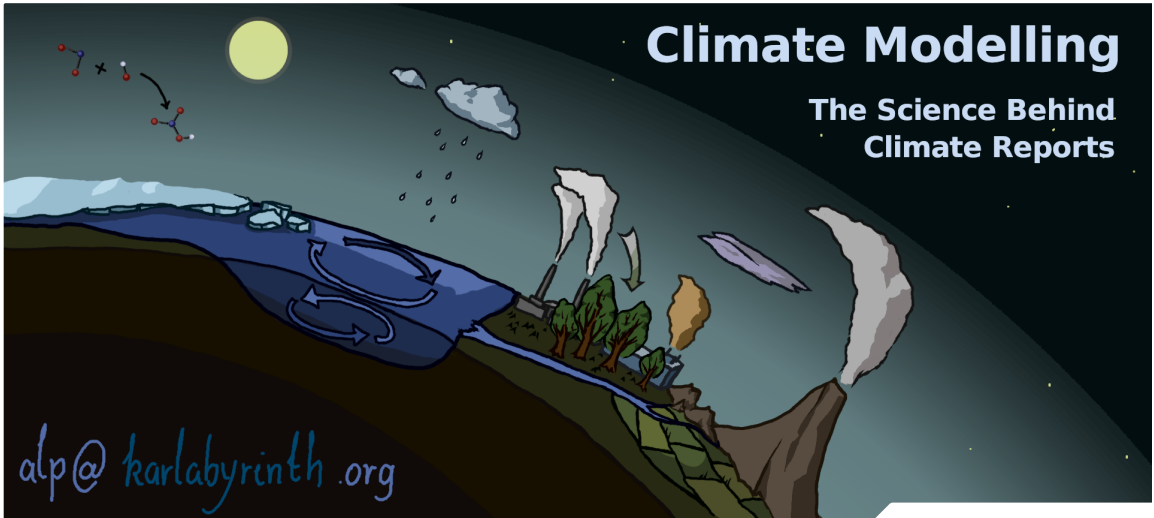
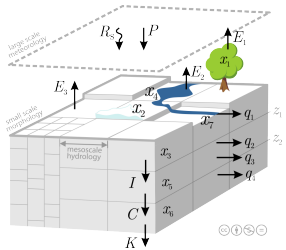
UFZ HELMHOLTZ Centre for Environmental Research



Shortly About Myself

karlabyrinth (Maren Kaluza)



mesoscale Hydrologic Model (mHM)

Weather is the physical state of the atmosphere at a given time

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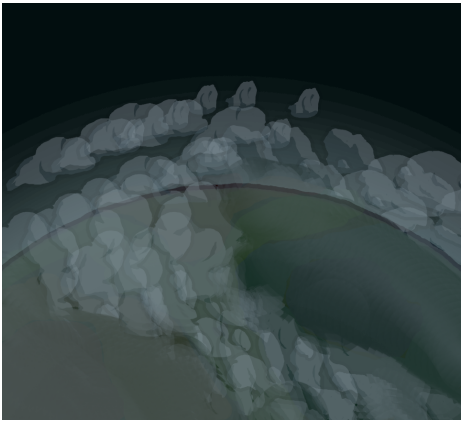
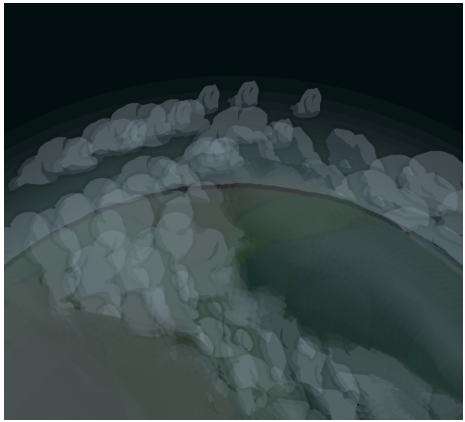
Climate is averaged weather (often 30 years)



While we are not able to predict weather at a specific date in a decade, why does it still make sense to propose general trends?



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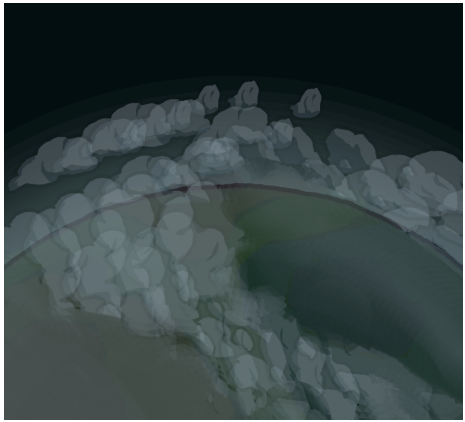
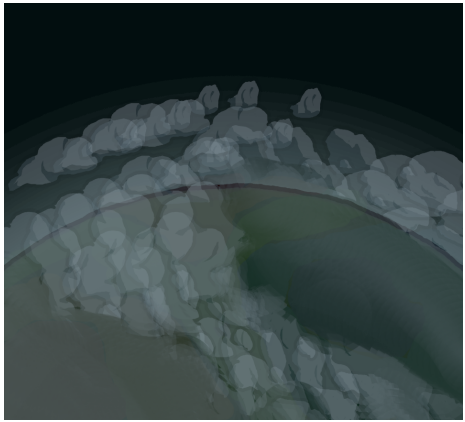
Average cloud coverage $\Rightarrow$ Average reflection



While we are not able to predict weather at a specific date in a decade, why does it still make sense to propose general trends?

Average cloud coverage $\Rightarrow$ Average reflection

Average precipitation/temperature $\Rightarrow$ vegetation $\Rightarrow$ influences carbon cycle $\Rightarrow$ warming/cooling $\Rightarrow$ ice coverage $\Rightarrow$ reflection ...



Definition (AR5)

A climate model is a numerical representation of the climate system.

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AR5:
IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the* ***Fifth Assessment Report*** *of the* ***Intergovernmental Panel on Climate Change*** [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley(eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

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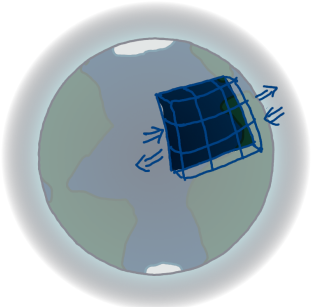

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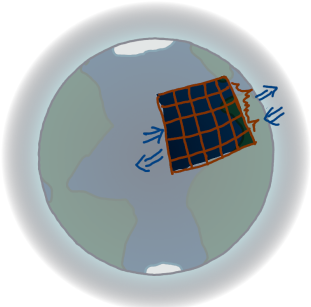
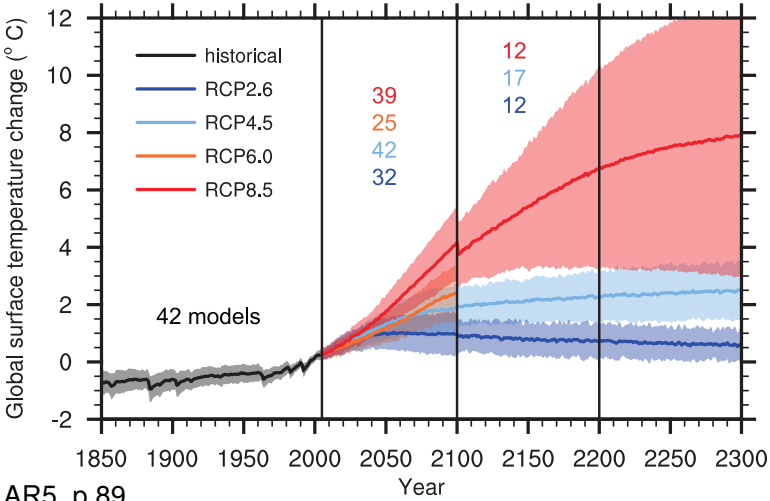
Impact Model: Not a climate model, higher time and space resolution, for simulating extreme weather events like floods



IPCC Reports

A typical image people show when adressing climate change



AR5, p.89

- Numbers, Uncertainties

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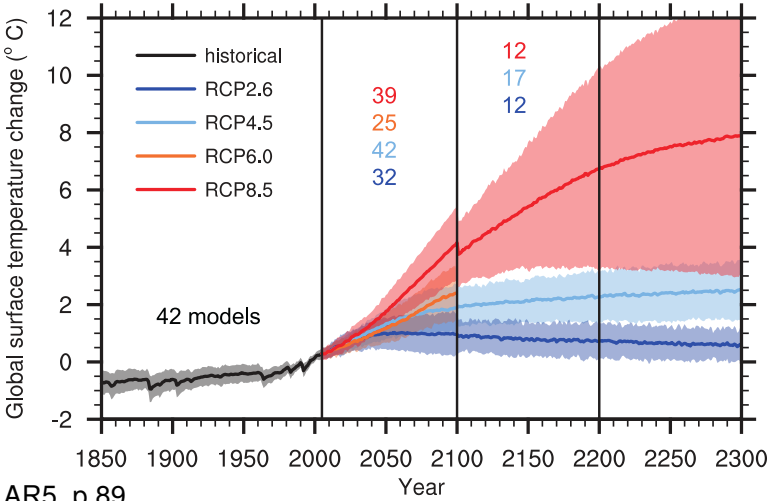

AR5, p.89

- Numbers, Uncertainties
- Representative Concentration Pathways (RCP)

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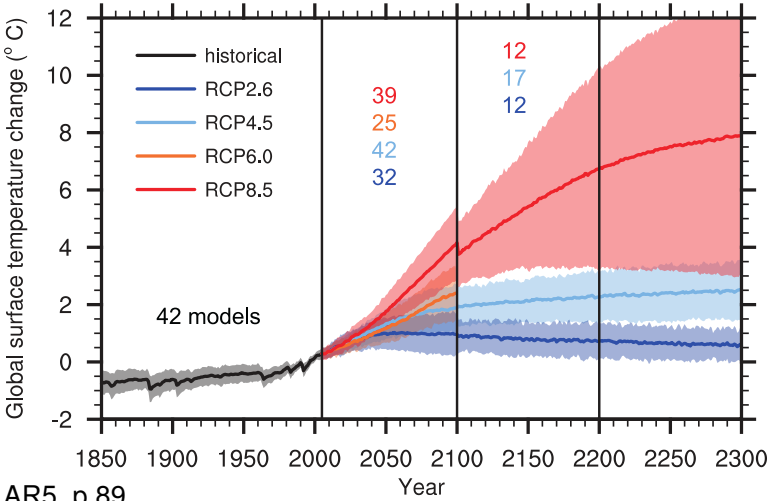

AR5, p.89

- Numbers, Uncertainties
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IPCC Reports

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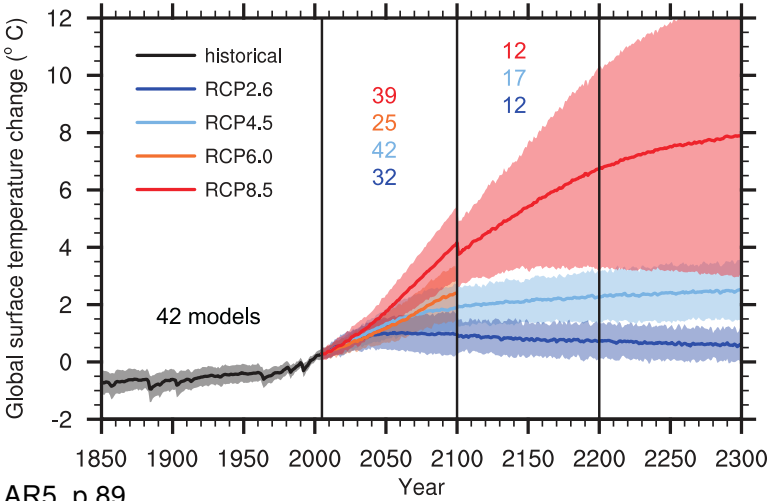

AR5, p.89

- Numbers, Uncertainties
- Representative Concentration Pathways (RCP)
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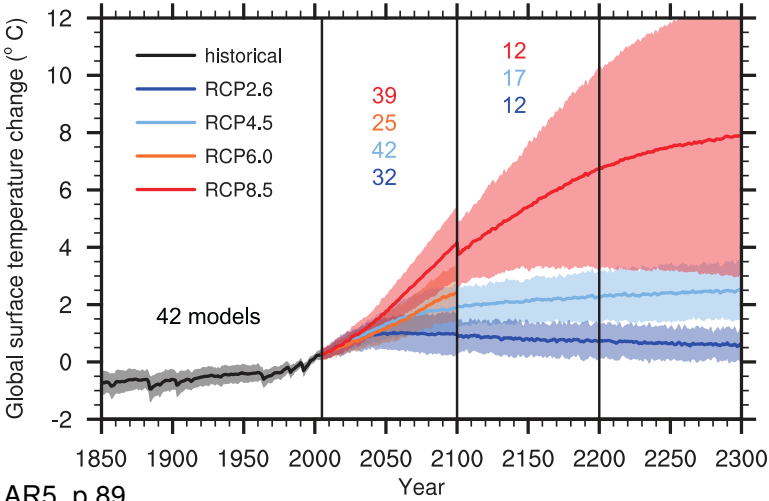
- Is it proven? Is there *scientific evidence*?

IPCC Reports
The Questions



AR5, p.89

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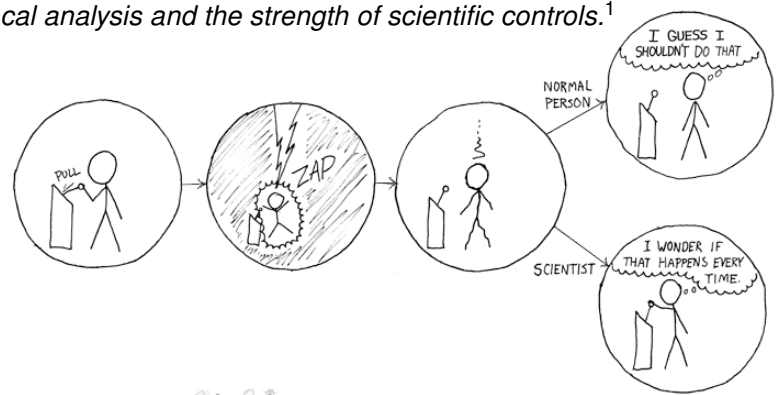
IPCC Reports

Is it proven? Is there *scientific evidence*

The strength of scientific evidence is generally based on the results of statistical analysis and the strength of scientific controls.[1]



[1] wikipedia, Scientific Evidence, 24th Nov 2019

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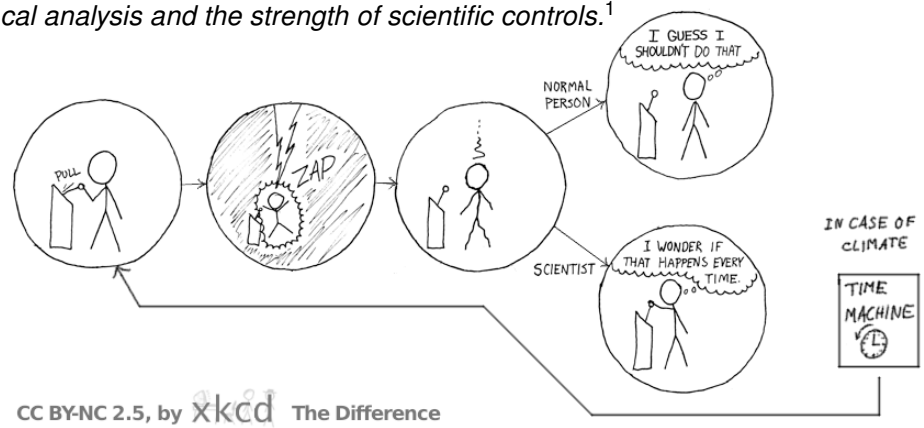

[1] wikipedia, Scientific Evidence, 24th Nov 2019

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Is it proven? Is there *scientific evidence*

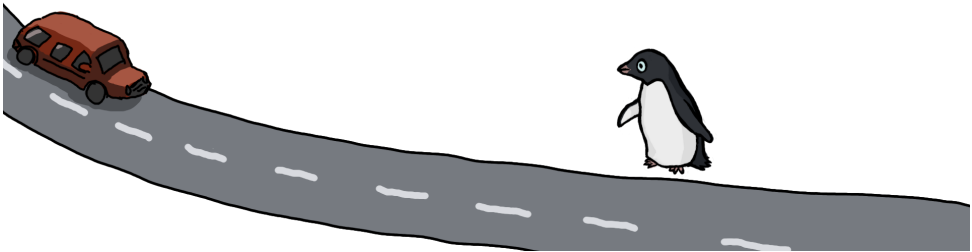
> *Human beings are now carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future.*

– Roger Revelle, 1957

IPCC Reports

Is it proven? Is there *scientific evidence*

Would you cross the road?



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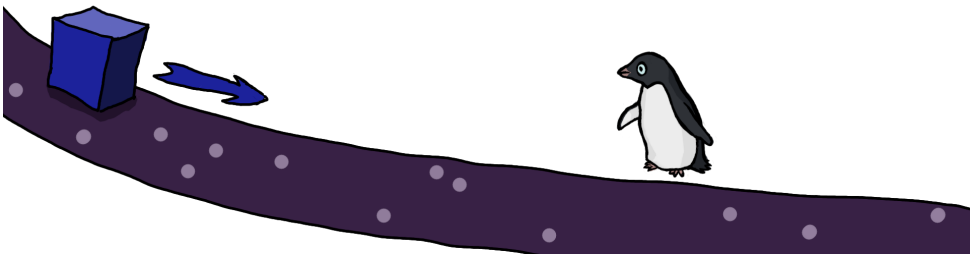

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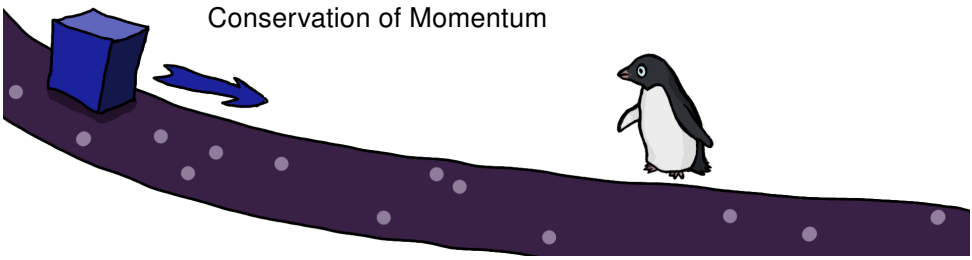
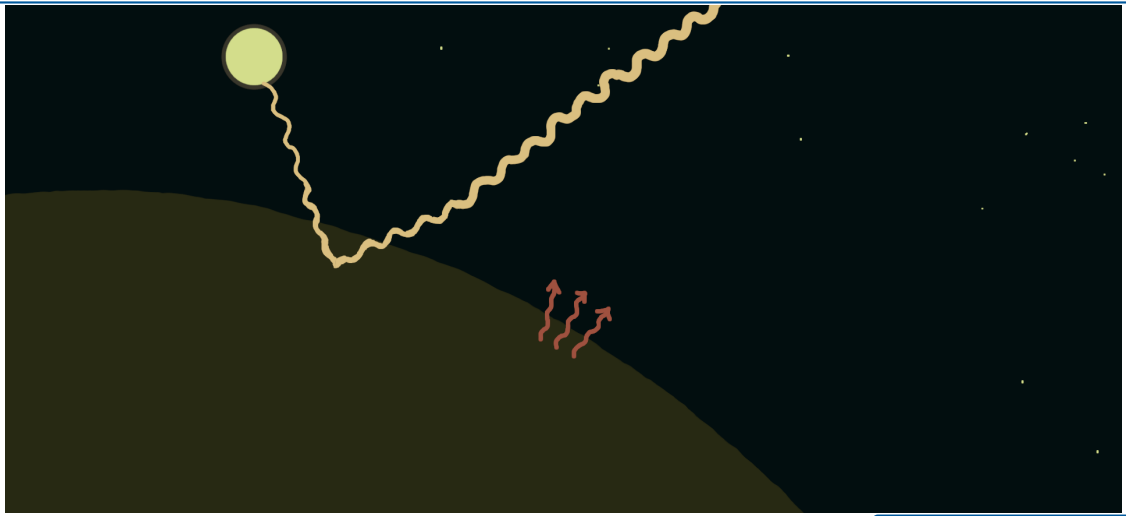
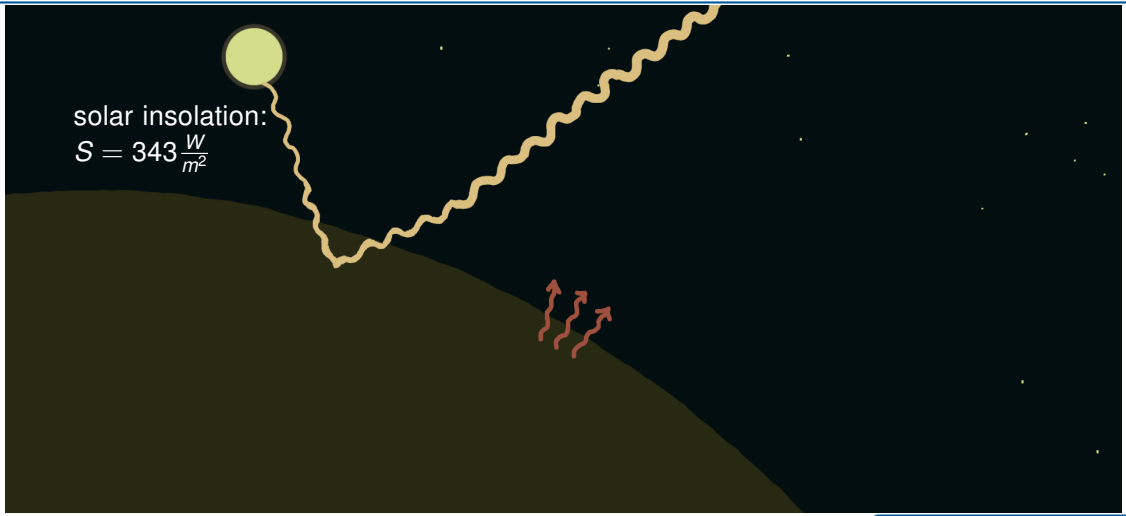
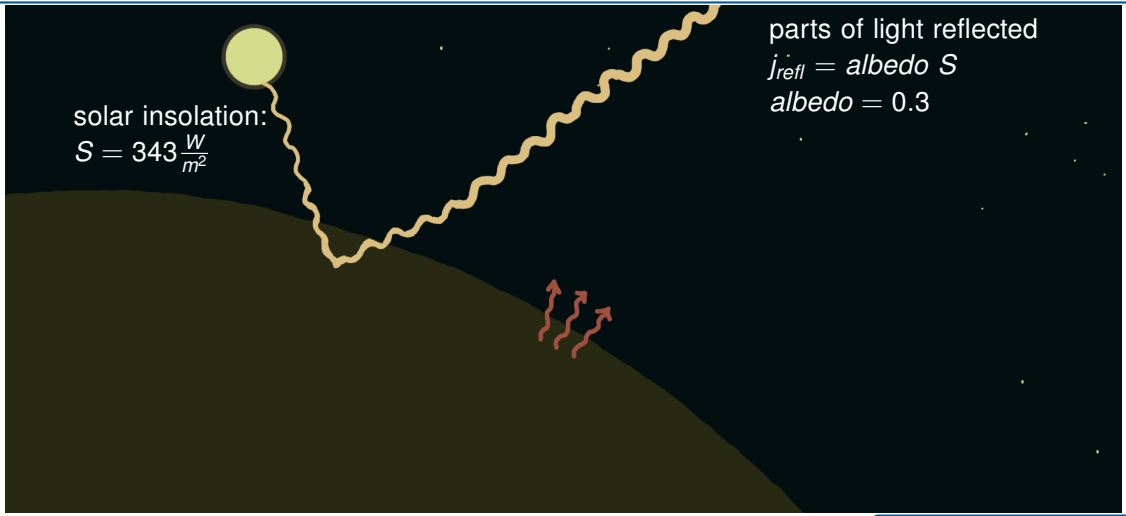


IPCC Reports
Basic Physics




solar insolation:
$S = 343 \frac{W}{m^2}$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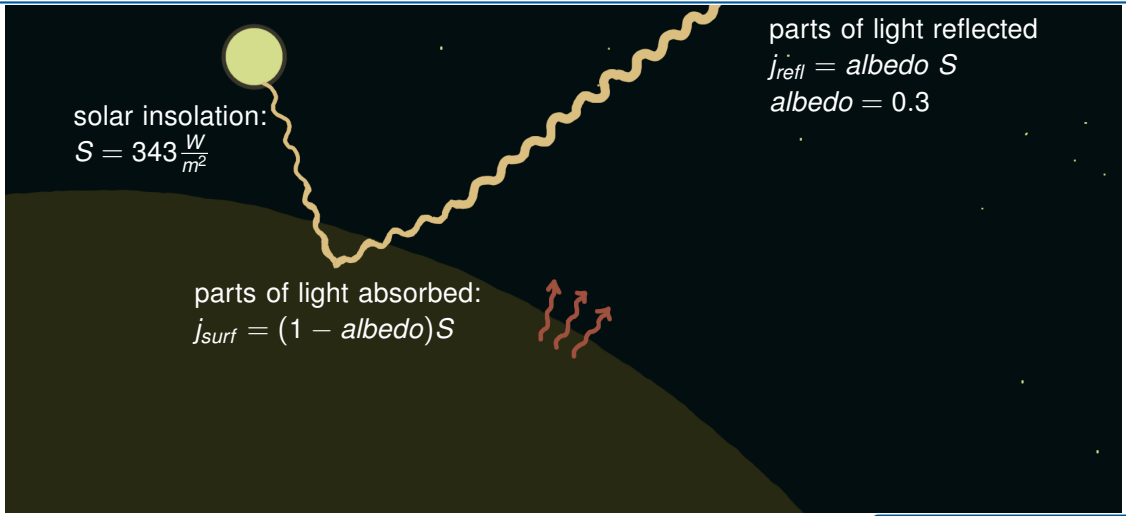
parts of light reflected
$j_{refl} = albedo\ S$
$albedo = 0.3$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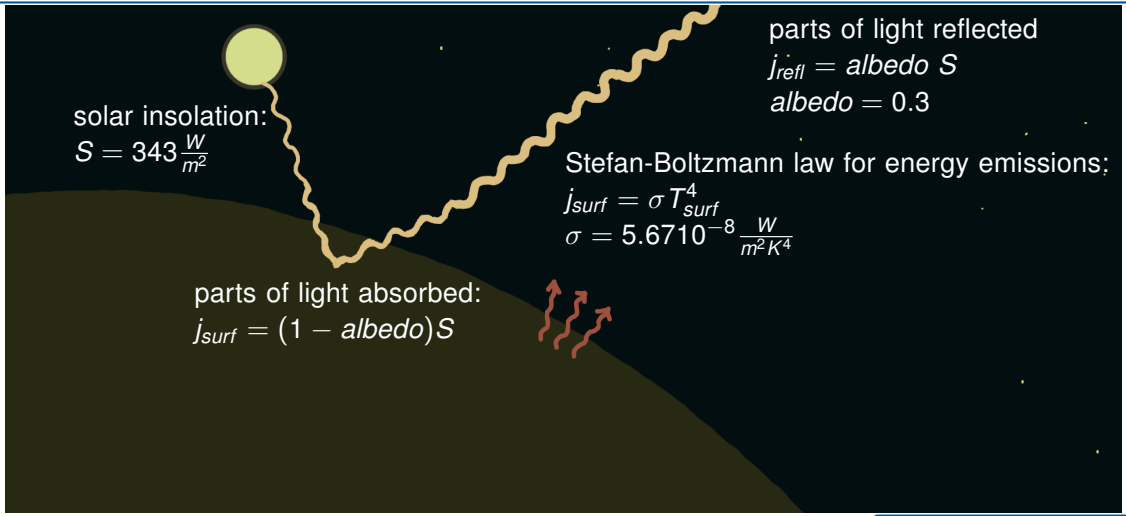
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solar insolation:
$S = 343 \frac{W}{m^2}$
Stefan-Boltzmann law for energy emissions:
$j_{surf} = \sigma T_{surf}^4$
$\sigma = 5.6710^{-8} \frac{W}{m^2 K^4}$
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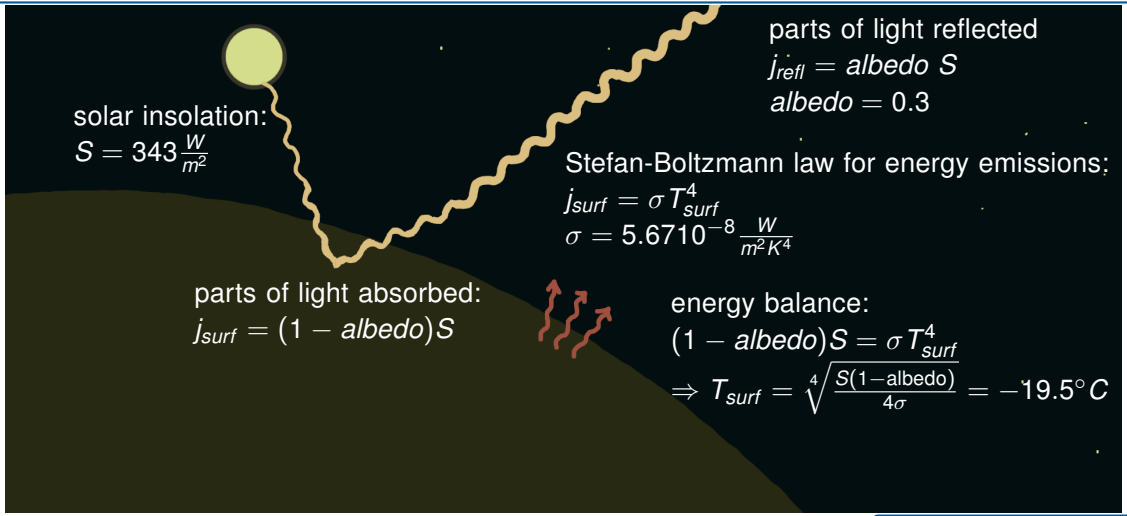
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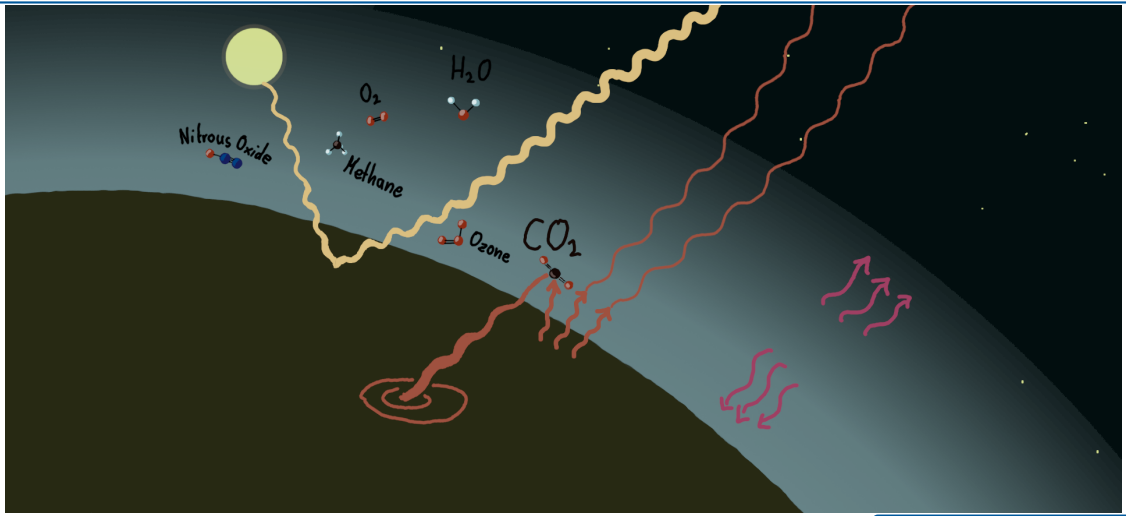
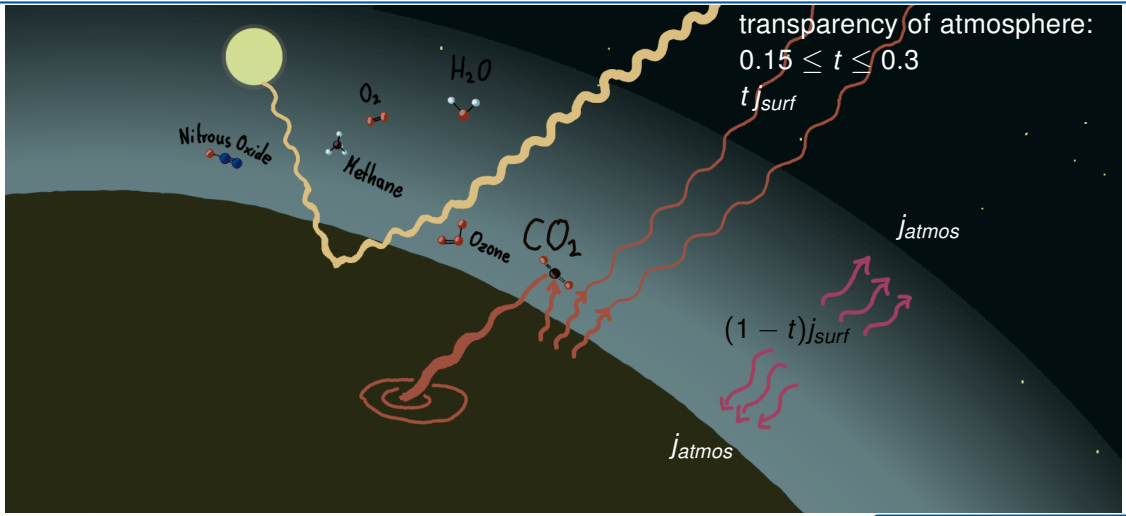
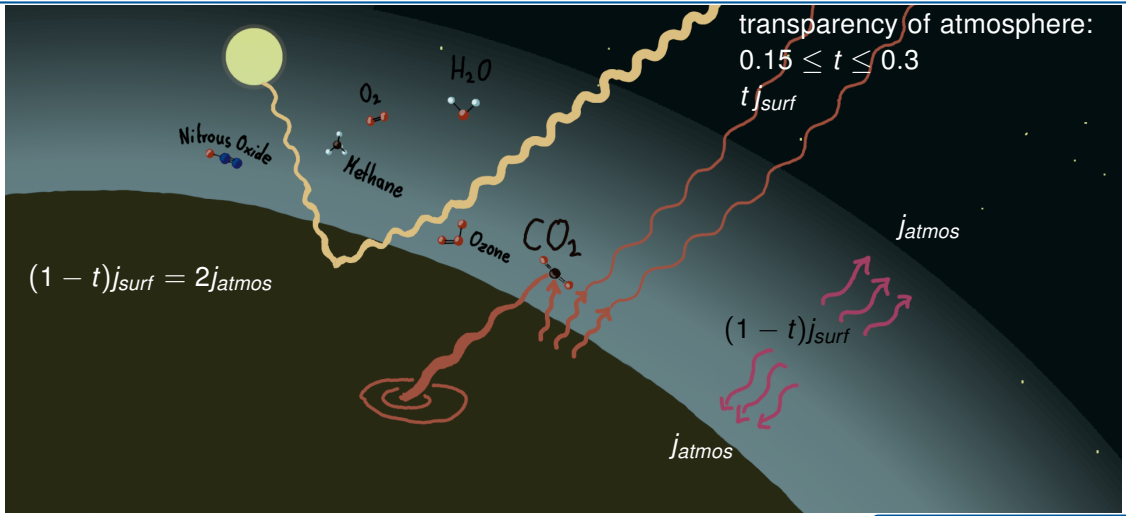
energy balance:
$(1 - albedo)S = \sigma T_{surf}^4$
$\Rightarrow T_{surf} = \sqrt[4]{\frac{S(1-\text{albedo})}{4\sigma}} = -19.5°C$

IPCC Reports
Basic Physics




transparency of atmosphere:
$0.15 \leq t \leq 0.3$
$t\, j_{surf}$
H_2O
O_2
Nitrous Oxide
Methane
Ozone
CO_2
j_{atmos}
$(1-t)j_{surf}$
j_{atmos}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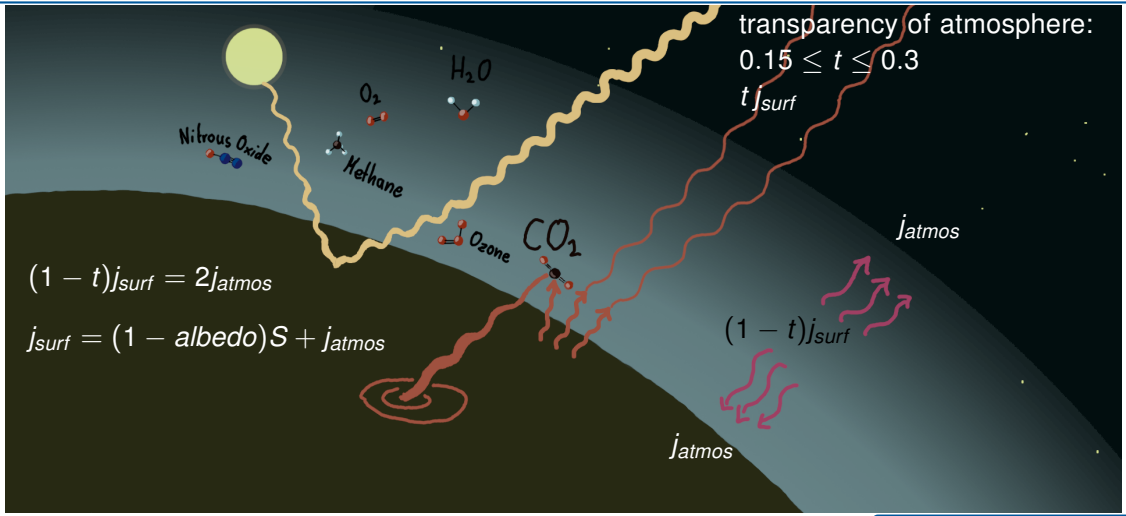
$t\, j_{surf}$
H_2O
O_2
Nitrous Oxide
Methane
Ozone
CO_2
j_{atmos}
$(1-t)j_{surf} = 2j_{atmos}$
$(1-t)j_{surf}$
j_{atmos}

IPCC Reports
Basic Physics



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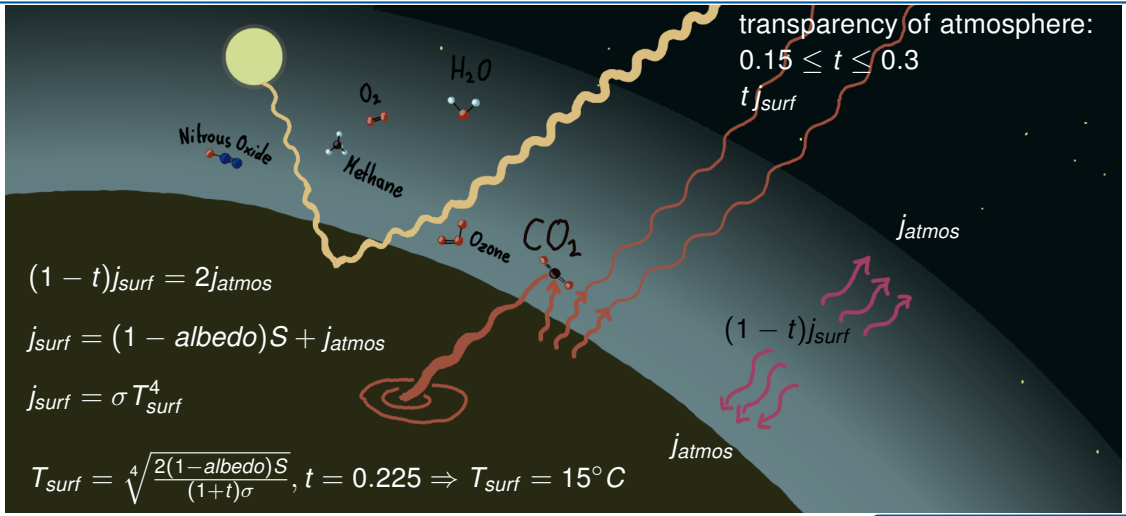

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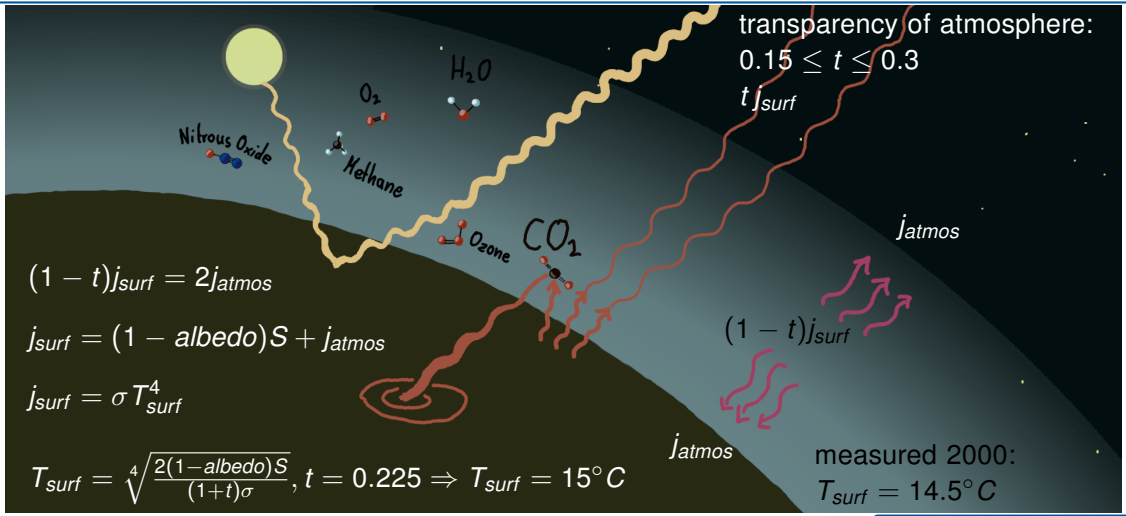

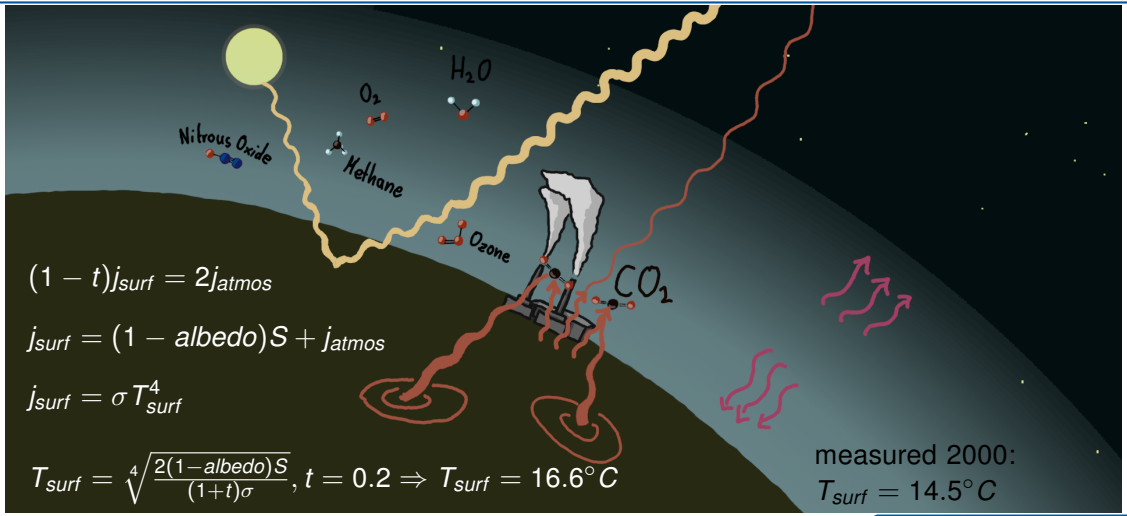
H_2O
O_2
Nitrous Oxide
Methane
Ozone
CO_2
$(1-t)j_{surf} = 2j_{atmos}$
$j_{surf} = (1-albedo)S + j_{atmos}$
$j_{surf} = \sigma T_{surf}^4$
$T_{surf} = \sqrt[4]{\frac{2(1-albedo)S}{(1+t)\sigma}}, t = 0.2 \Rightarrow T_{surf} = 16.6°C$
measured 2000:
$T_{surf} = 14.5°C$

Latitude.	Carbonic Acid = 0·67.					Carbonic Acid = 1·5.					Carbonic Acid = 2·0.					Carbonic Acid = 2·5.					Carbonic Acid = 3·0.				
	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.
70	−2·9	−3·0	−3·4	−3·1	−3·1	3·3	3·4	3·8	3·6	3·52	6·0	6·1	6·0	6·1	6·05	7·9	8·0	7·9	8·0	7·95	9·1	9·3	9·4	9·4	9·3
60	−3·0	−3·2	−3·4	−3·3	−3·22	3·4	3·7	3·6	3·8	3·62	6·1	6·1	5·8	6·1	6·02	8·0	8·0	7·6	7·9	7·87	9·3	9·5	8·9	9·5	9·3
50	−3·2	−3·3	−3·3	−3·4	−3·3	3·7	3·8	3·4	3·7	3·65	6·1	6·1	5·5	6·0	5·92	8·0	7·9	7·0	7·9	7·7	9·5	9·4	8·6	9·2	9·17
40	−3·4	−3·4	−3·2	−3·3	−3·32	3·7	3·6	3·3	3·5	3·52	6·0	5·8	5·4	5·6	5·7	7·9	7·6	6·9	7·3	7·42	9·3	9·0	8·2	8·8	8·82
30	−3·3	−3·2	−3·1	−3·1	−3·17	3·5	3·3	3·2	3·5	3·47	5·6	5·4	5·0	5·2	5·3	7·2	7·0	6·6	6·7	6·87	8·7	8·3	7·5	7·9	8·1
20	−3·1	−3·1	−3·0	−3·1	−3·07	3·5	3·2	3·1	3·2	3·25	5·2	5·0	4·9	5·0	5·02	6·7	6·6	6·3	6·6	6·52	7·9	7·5	7·2	7·5	7·52
10	−3·1	−3·0	−3·0	−3·0	−3·02	3·2	3·2	3·1	3·1	3·15	5·0	5·0	4·9	4·9	4·95	6·6	6·4	6·3	6·4	6·42	7·4	7·3	7·2	7·3	7·3
0	−3·0	−3·0	−3·1	−3·0	−3·02	3·1	3·1	3·2	3·2	3·15	4·9	4·9	5·0	5·0	4·95	6·4	6·4	6·6	6·6	6·5	7·3	7·3	7·4	7·4	7·35
−10	−3·1	−3·1	−3·2	−3·1	−3·12	3·2	3·2	3·2	3·2	3·2	5·0	5·0	5·2	5·1	5·07	6·6	6·6	6·7	6·7	6·62	7·4	7·5	8·0	7·6	7·62
−20	−3·1	−3·2	−3·3	−3·2	−3·2	3·2	3·2	3·4	3·3	3·27	5·2	5·3	5·5	5·4	5·33	6·7	6·8	7·0	7·0	6·87	7·9	8·1	8·6	8·3	8·22
−30	−3·3	−3·3	−3·4	−3·4	−3·35	3·4	3·5	3·7	3·5	3·52	5·5	5·6	5·8	5·6	5·62	7·0	7·2	7·7	7·4	7·32	8·6	8·7	9·1	8·8	8·8
−40	−3·4	−3·4	−3·3	−3·4	−3·37	3·6	3·7	3·8	3·7	3·7	5·8	6·0	6·0	6·0	5·95	7·7	7·9	7·9	7·9	7·85	9·1	9·2	9·4	9·3	9·25
−50	−3·2	−3·3	—	—	—	3·8	3·7	—	—	—	6·0	6·1	—	—	—	7·9	8·0	—	—	—	9·4	9·5	—	—	—
−60																									

Percentage of additional CO_2

Carbonic Acid = 2·0.

average Temperature rise in Dec. in Leipzig

6·1

Arrhenius 1896: $\Rightarrow$ 4-6° C

Current Models: $\Rightarrow$ 2-4° C

Svante Arrhenius, *On the influence of carbonic acid in the air upon the temperature of the ground*, The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science 5, 237–276 (1896)

A climate model represents physical laws. Where do uncertainties come from?

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Initial Conditions: how is the current state of the climate system

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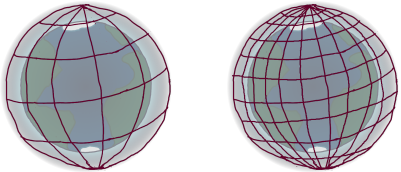
Initial Conditions: how is the current state of the climate system

Resolution: temporal and spatial step length



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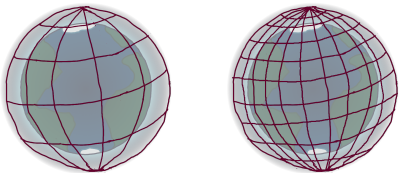


Initial Conditions: how is the current state of the climate system

Resolution: temporal and spatial step length

Truncation: computational limits

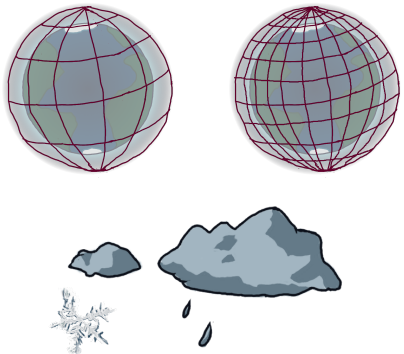
A climate model represents physical laws. Where do uncertainties come from?

Initial Conditions: how is the current state of the climate system

Resolution: temporal and spatial step length

Truncation: computational limits

Lack of Understanding: for example clouds



Why is there no such thing as the one best climate model?

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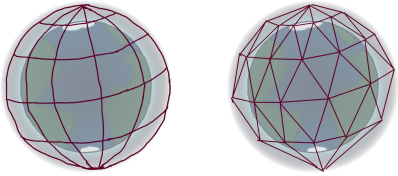
Dynamic Core: including the method for differential equations, such as the grid



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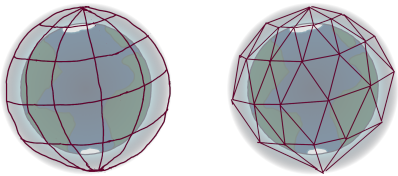

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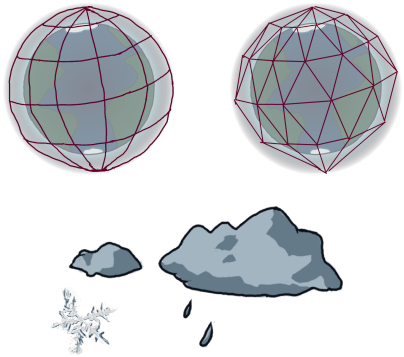

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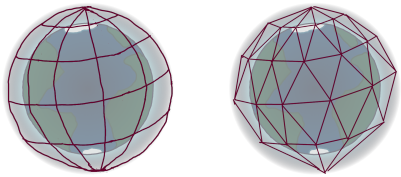

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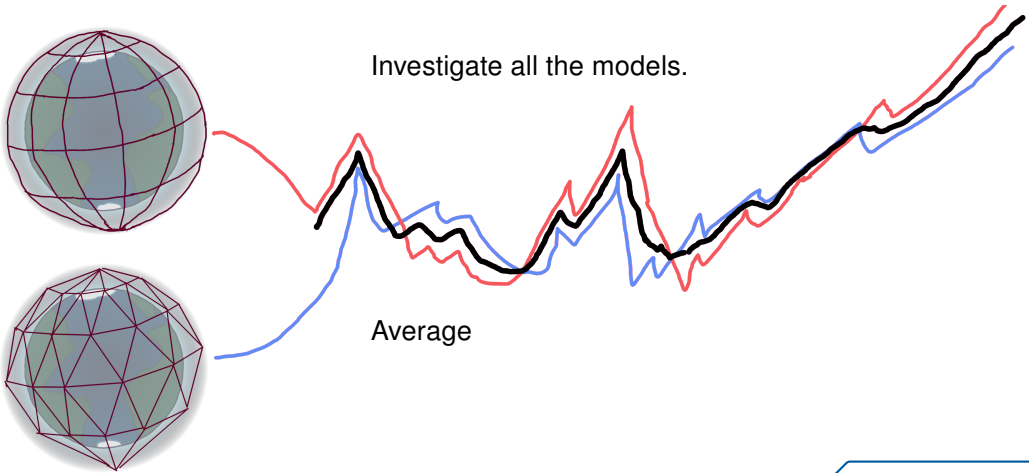
Schemes: different formulations of physical processes

Truncation: how to limit due to computational power

Solution:



Coordinated GCMs

The specific conditions are defined via the *Coupled model intercomparison project phase 4/5/6 (CMIP4/CMIP5/CMIP6)*

- map shows research centers which took part in CMIP6

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- map shows research centers which took part in CMIP6
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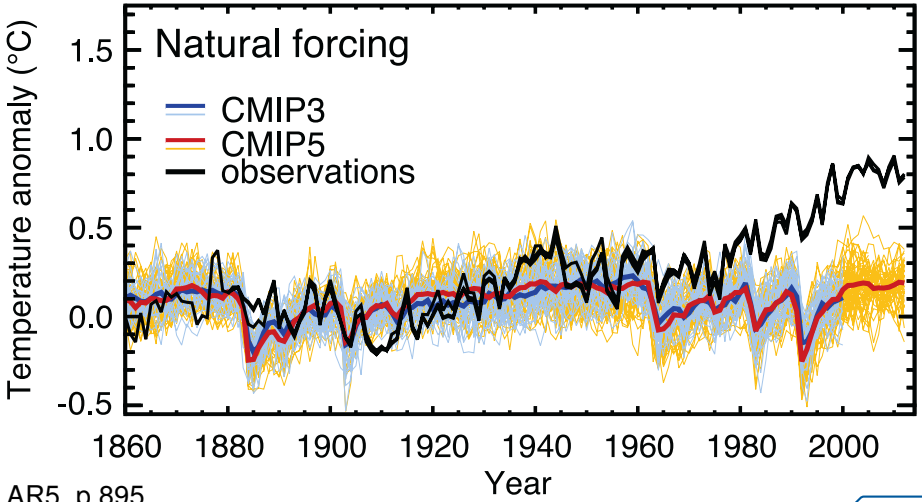
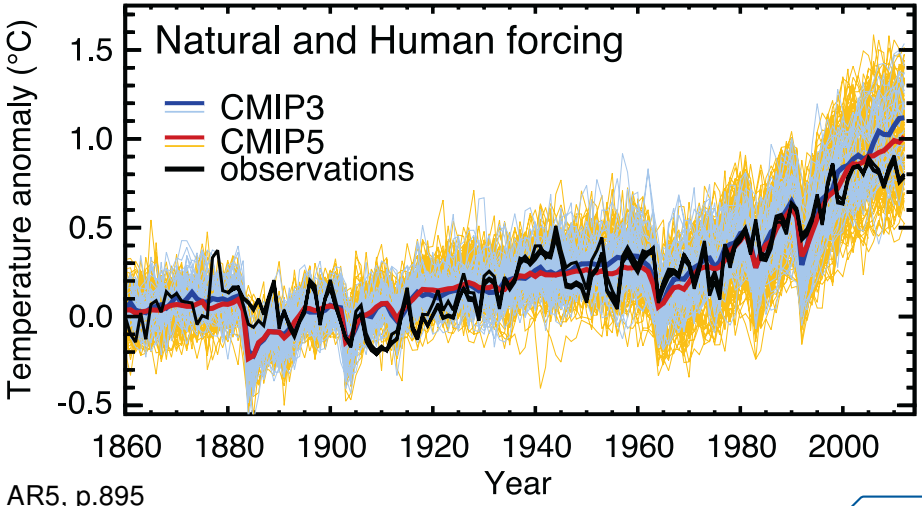
- institutions need to produce variables for a set of defined experiments and a historical simulation (1850 to present)


Natural forcing
CMIP3
CMIP5
observations
Temperature anomaly (°C)
1.5
1.0
0.5
0.0
-0.5
1860
1880
1900
1920
1940
1960
1980
2000
Year

AR5, p.895


Natural and Human forcing
CMIP3
CMIP5
observations
Temperature anomaly (°C)
1.5
1.0
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-0.5
1860
1880
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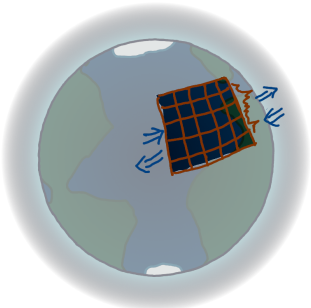
AR5, p.895

Other Coordinated MIPs

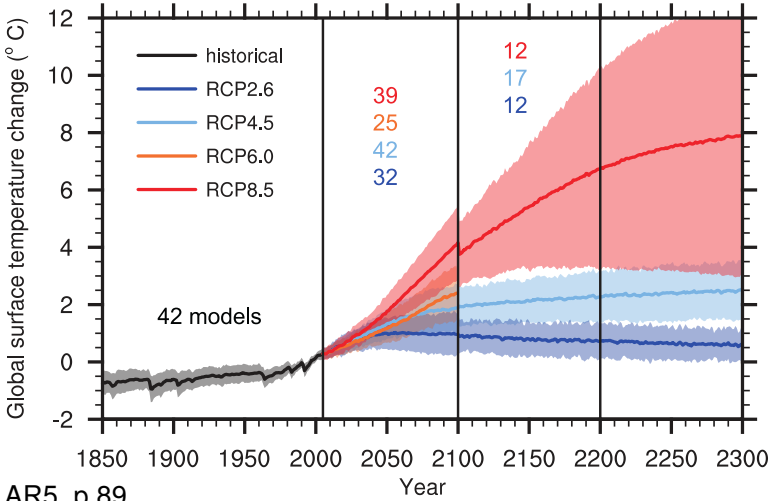
There are many more specific *model intercomparison projects (MIP)* where the scientific focus is on a sub-topic e.g. for land surface.

Not Coordinated Within IPCC

This is a glimpse on the coordinated research for IPCC/CMIP reports, you can always do research outside that framework, go to a journal and publish your findings there.



IPCC Reports
Sources Of The Graphs



AR5, p.89

- Numbers, Uncertainties
- Representative Concentration Pathways (RCP)
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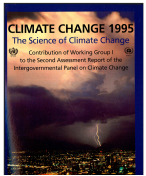
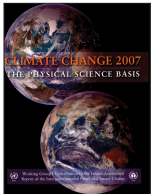
IPCC Reports
Sources Of The Graphs

fifth Assessment Report (AR5 2013)

IPCC Reports
Sources Of The Graphs

A history of IPCC reports





first Assessment Report (FAR 1990)

second Assessment Report (SAR 1995)

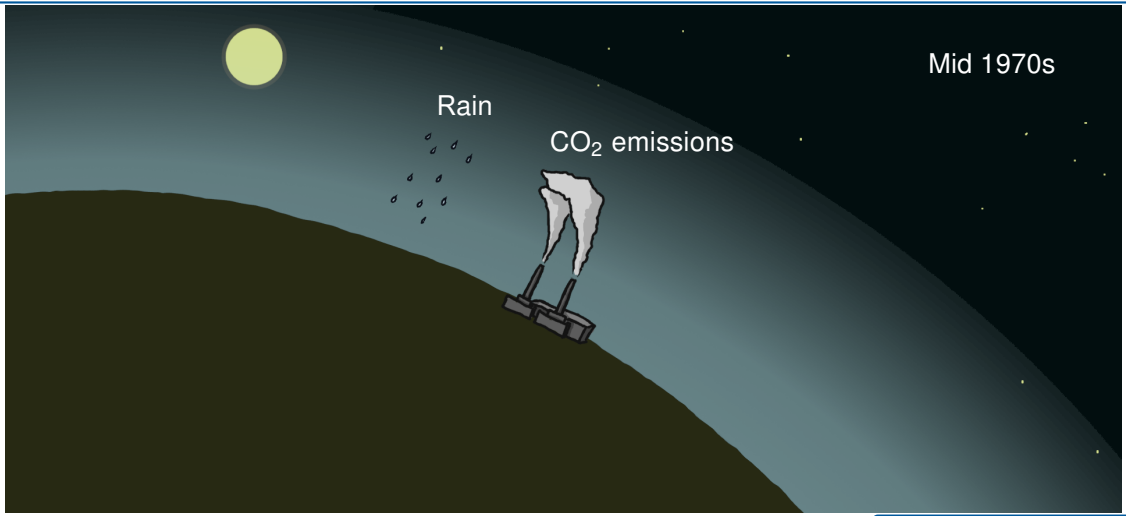
third Assessment Report (TAR 2001)

fourth Assessment Report (AR4 2007)

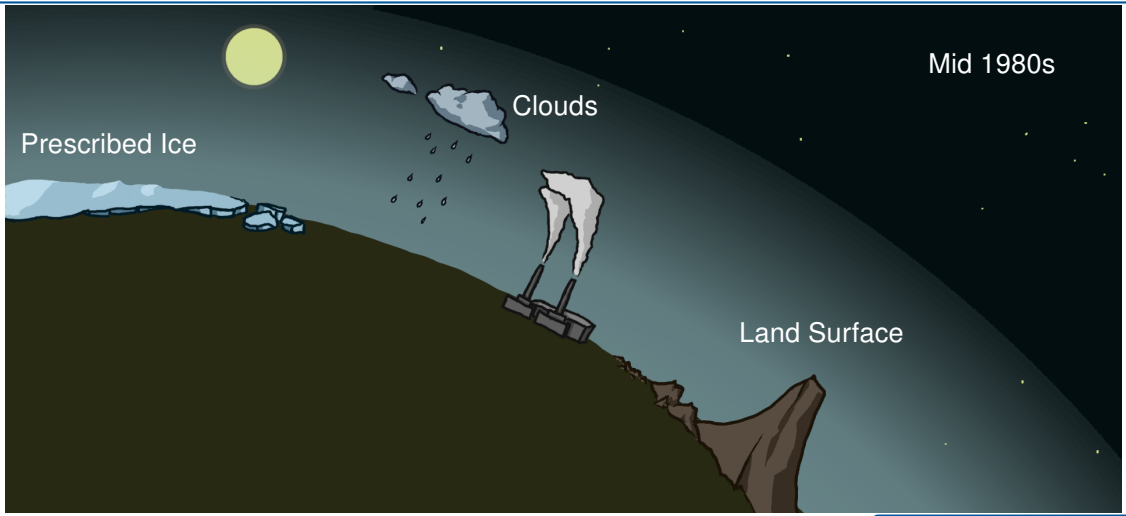
fifth Assessment Report (AR5 2013)

The IPCC consists of several working groups, including Working Group I-III, providing the *Assessment Reports*:

WG I	Scientific aspects of the climate system and climate change.
WG II	Vulnerability of socio-economic and natural systems to climate change, consequences, and adaptation options.
WG III	Options for limiting greenhouse gas emissions and otherwise mitigating climate change.


Mid 1970s
Rain
CO_2 emissions

IPCC Reports
Sources Of The Graphs



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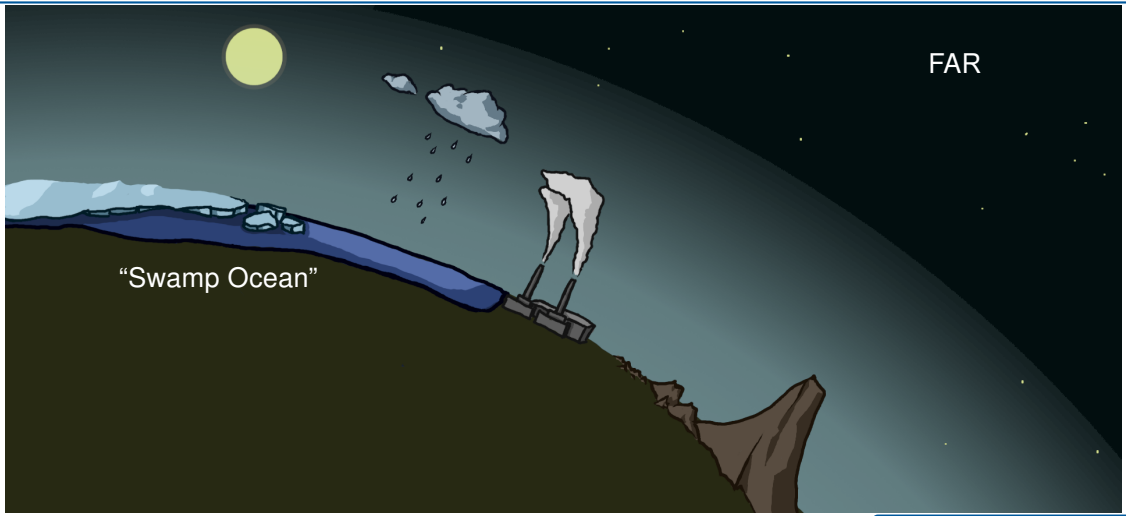

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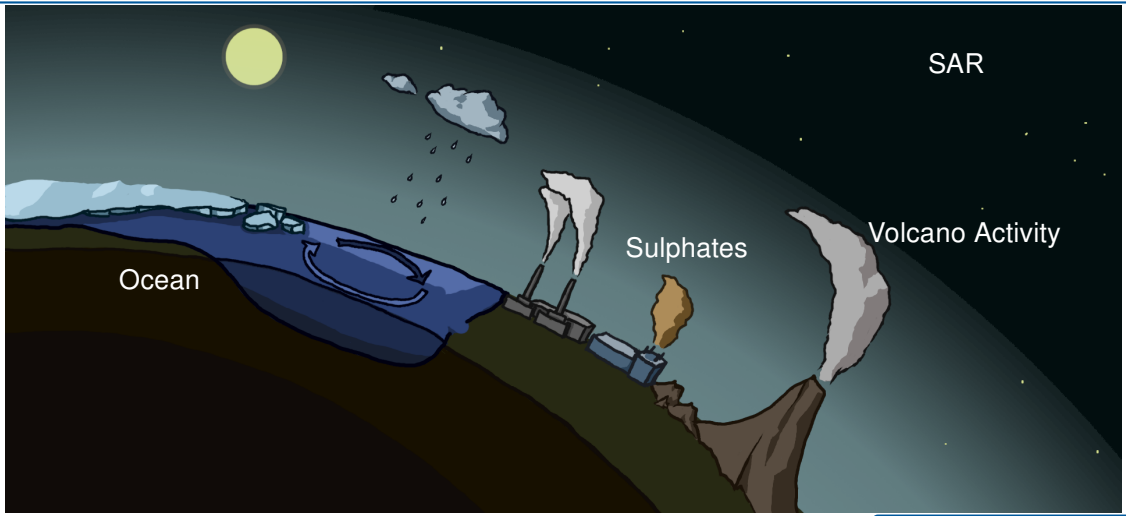

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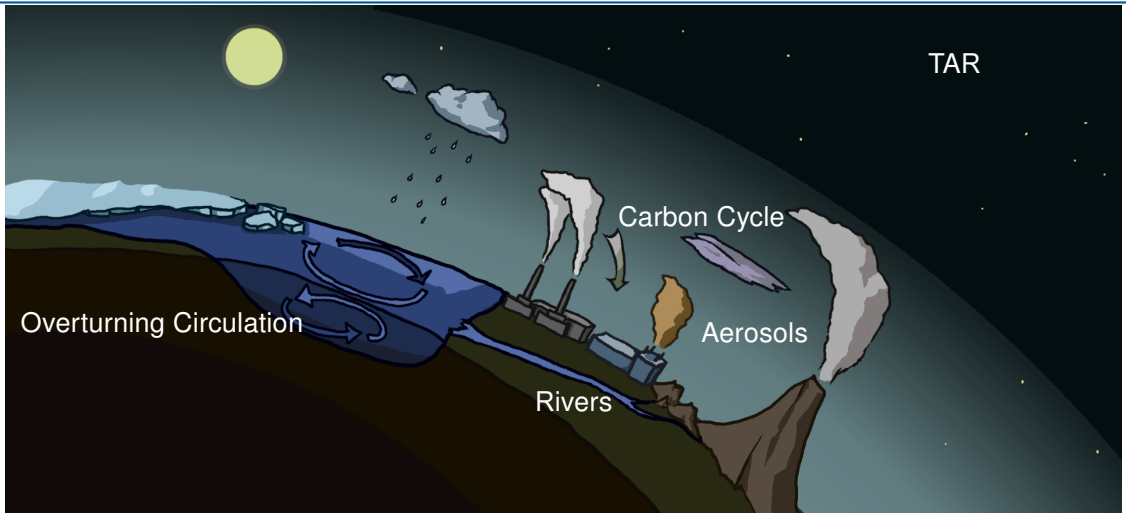

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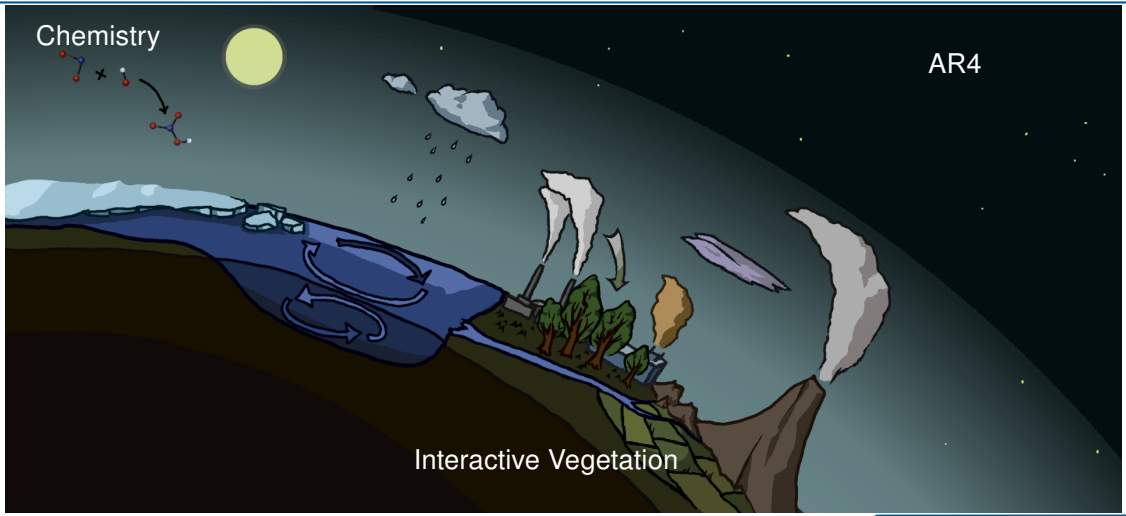

IPCC Reports
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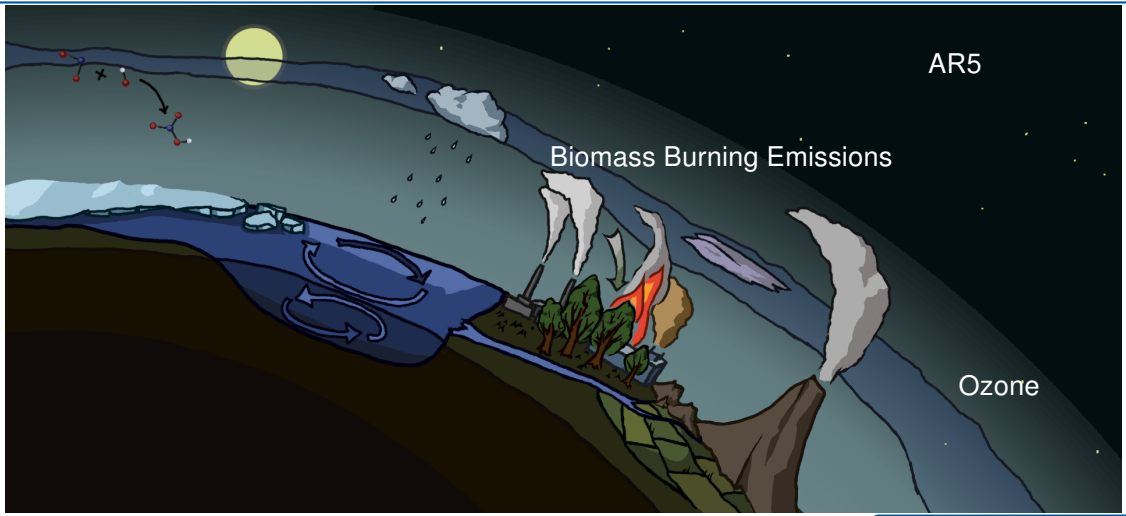

Vilhelm Bjerknes, 1904 governing equations could be solved to obtain future states of the atmosphere. He envisioned to split the task with many people

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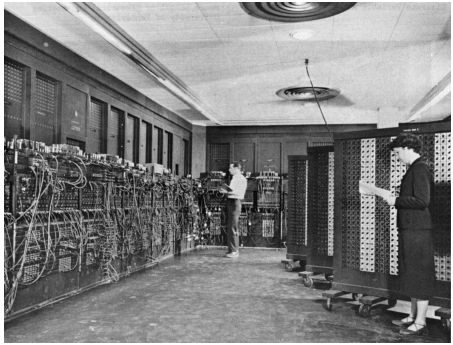
ENIAC, 1950 first successful weather model run on the computer called ENIAC (Neumann)



ENIAC

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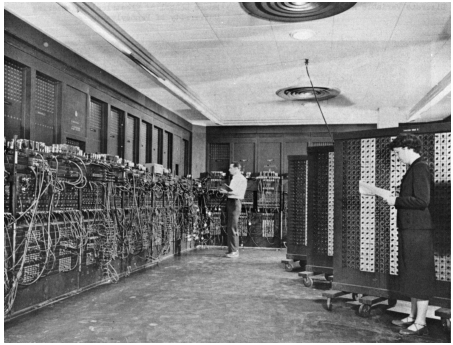
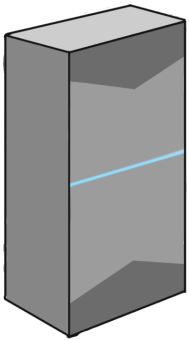
1955 weather predictions were run twice a day on an IBM 701



ENIAC

Today: For example JUWELS (Jülich Wizard For European Leadership Science):



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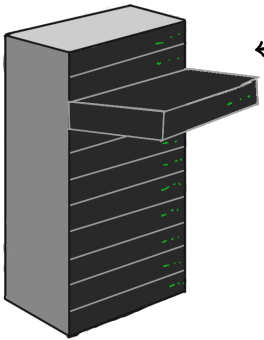

standard nodes:
2x 24 cores, 2.7 GHz
12x 8 GB, 2666 MHz

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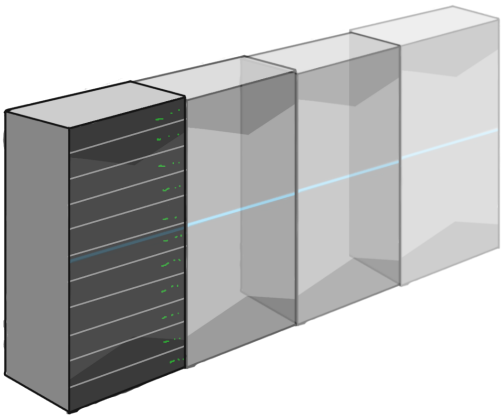

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2271 standard nodes
240 large mem nodes
56 accellerated nodes

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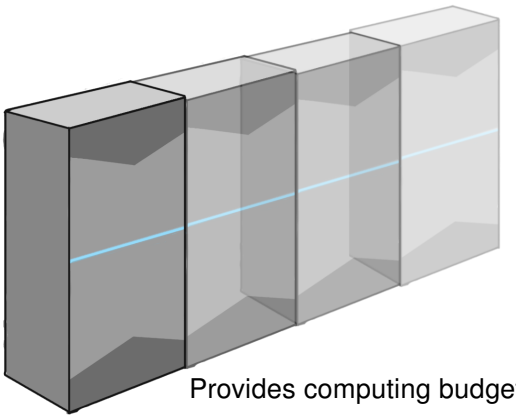

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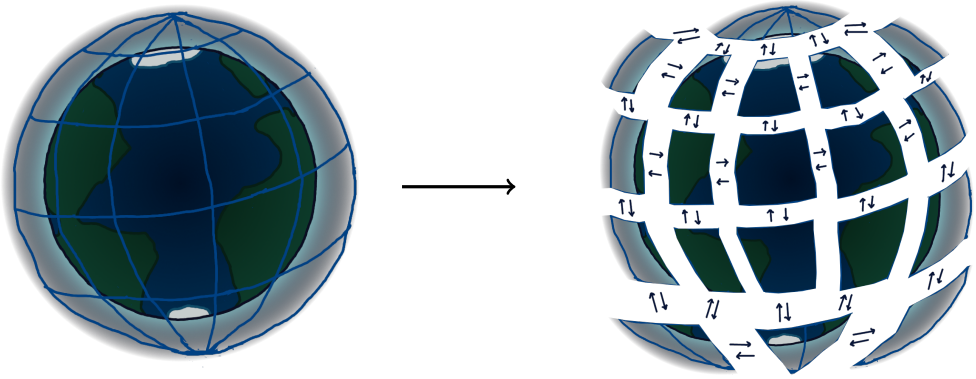
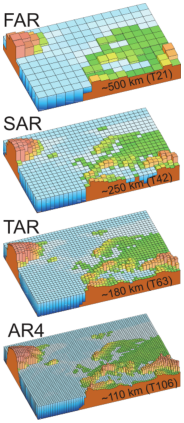
ESM Advanced Earth System Modelling Capacity

Provides computing budget for the *Advaced Earth System Modelling Capacity*

IPCC Reports
Parallelization



IPCC Reports
Sources Of The Graphs



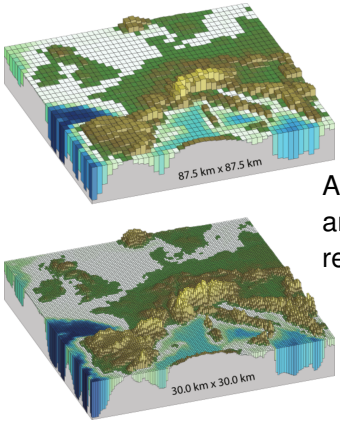
FAR: ∼ 500km

SAR: ∼ 250km

TAR: ∼ 180km

AR4: ∼ 120km

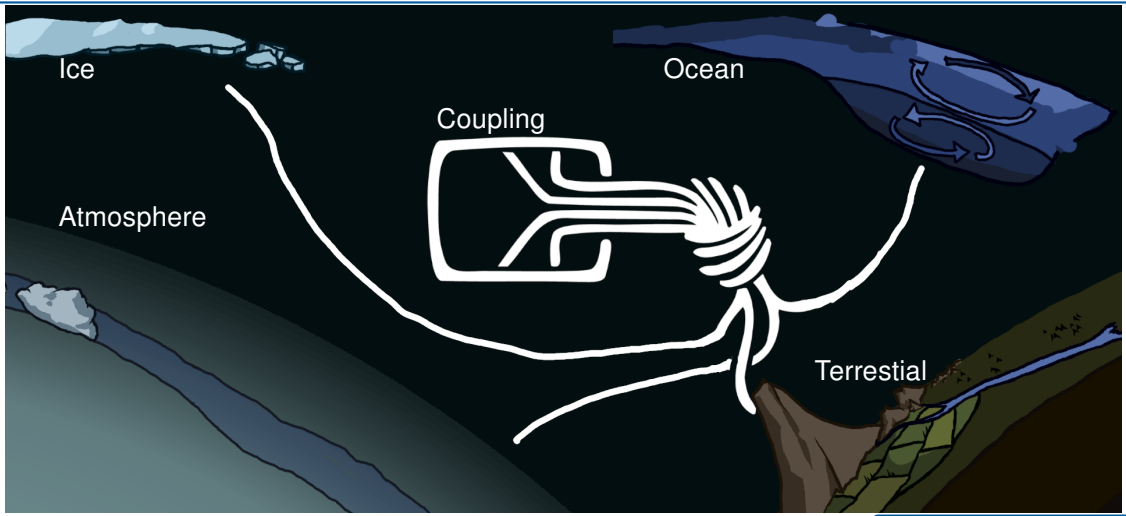
AR4, p.113



AR5: higher (87.5km) and very high (30km) resolution models tested

AR5, p.145

IPCC Reports
Sources Of The Graphs



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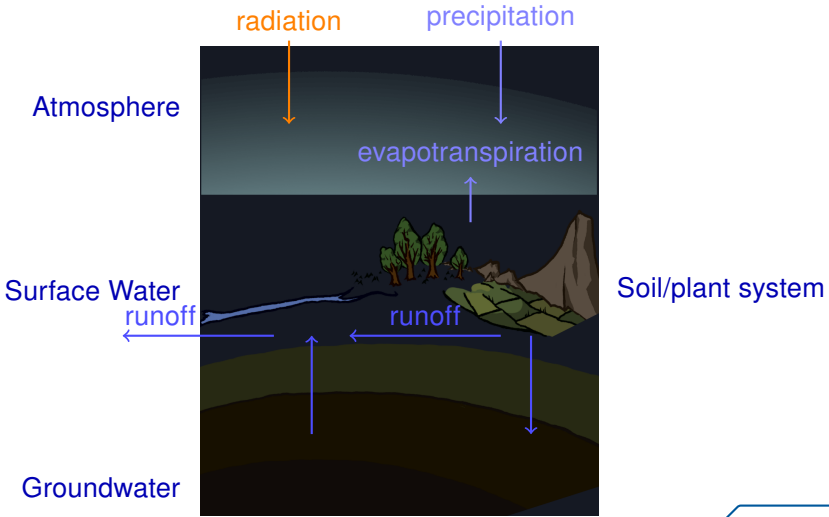
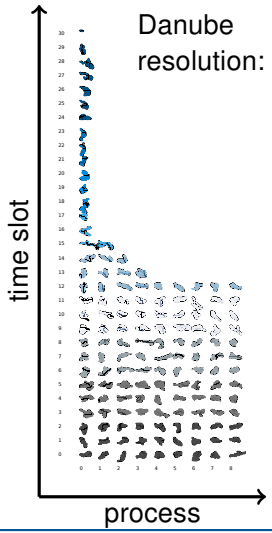
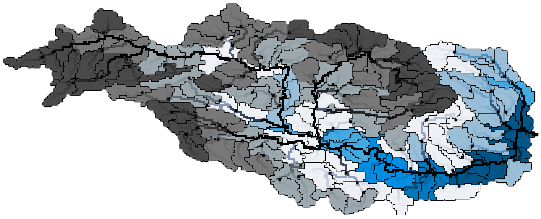
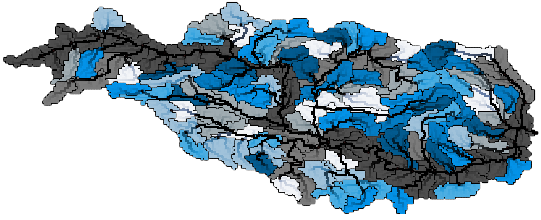




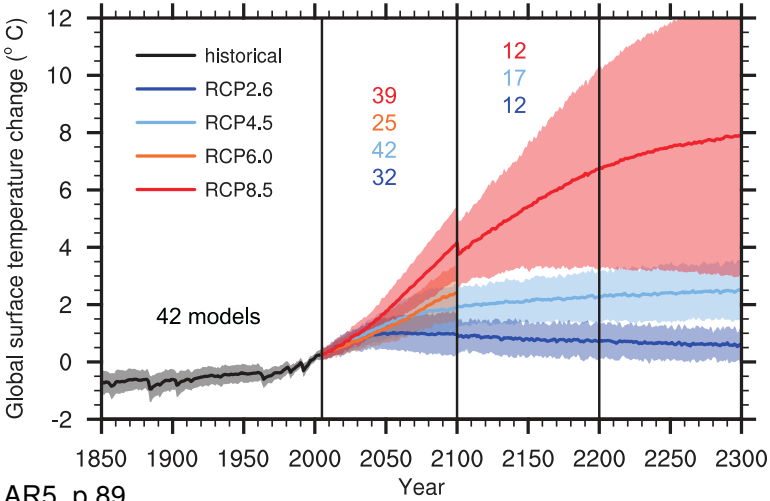
Danube
resolution: ∼ 5km





IPCC Reports

Representative Concentration Pathways (RCP)



AR5, p.89

- Numbers, Uncertainties
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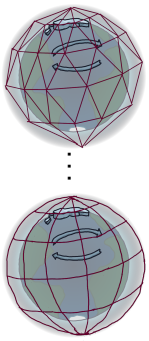
WG I generally tests a selection of (coupled) *Climate Models* matching specific conditions and investigates the output assuming different emission *scenarios*.



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IPCC Reports

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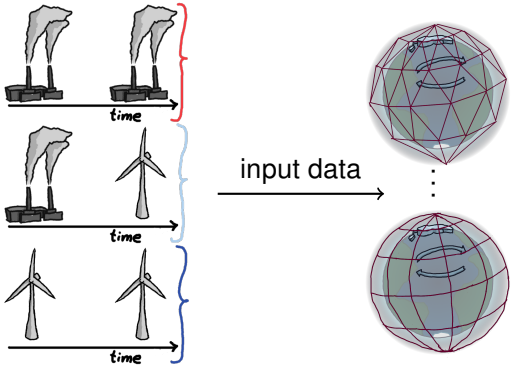

scenarios

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IPCC Reports

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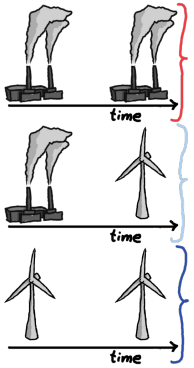

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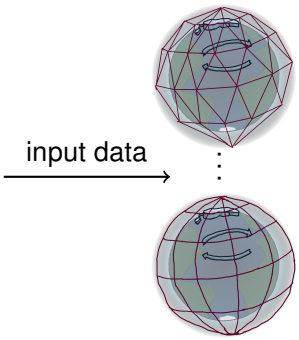
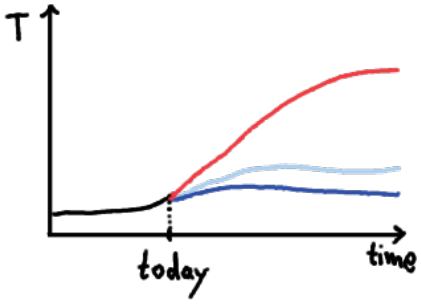


(coupled) Climate Models



Model Output

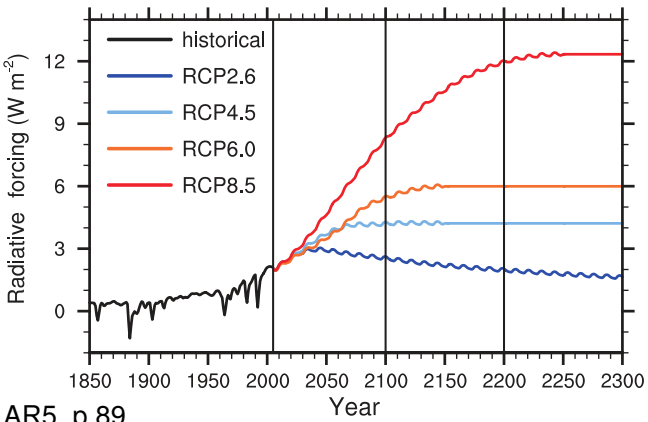
WG I generally tests a selection of (coupled) *Climate Models* matching specific conditions and investigates the output assuming different emission *scenarios*.

Representative Concentration Pathways (RCPs)

Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover (Moss et al., 2008).

AR5, p.89

Representative Concentration Pathways (RCPs)



AR5, p.89

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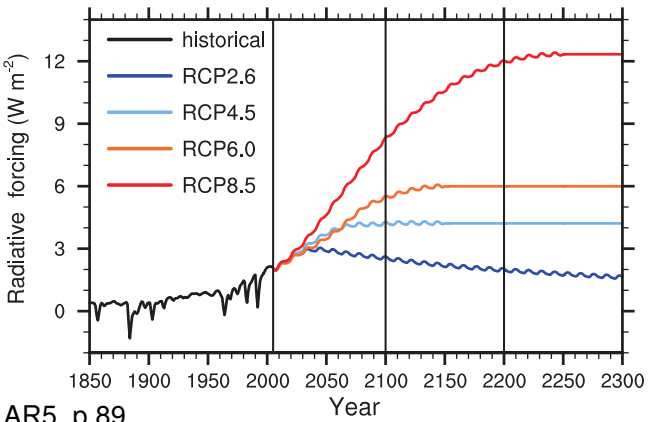
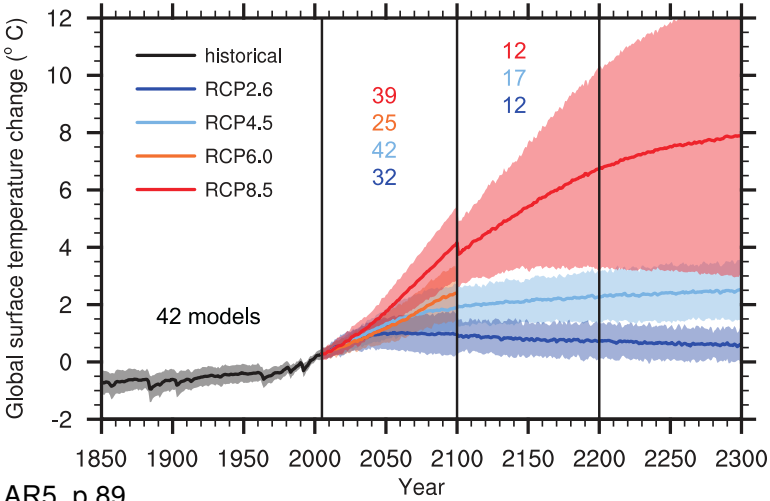


AR5, p.89

The data for the RCP scenarios is coordinated by *input4MIPS (input datasets for Model Intercomparison Projects)*. Most of it is freely available https://esgf-node.llnl.gov/projects/input4mips

IPCC Reports
Numbers, Uncertainties



AR5, p.89

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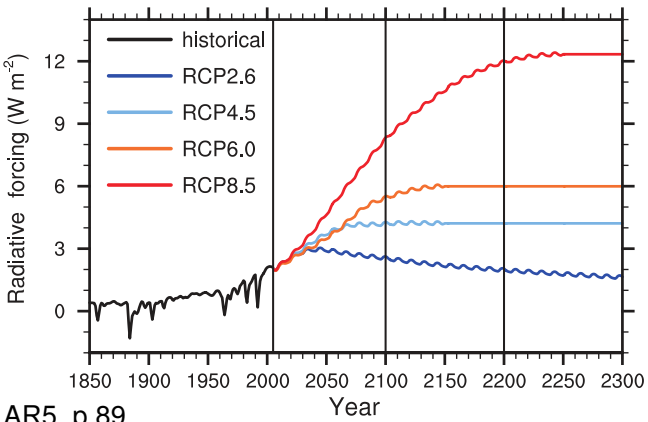
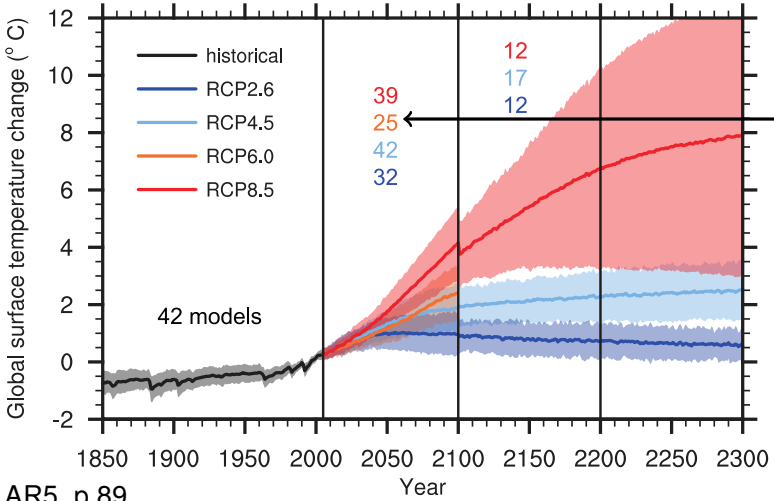


AR5, p.89

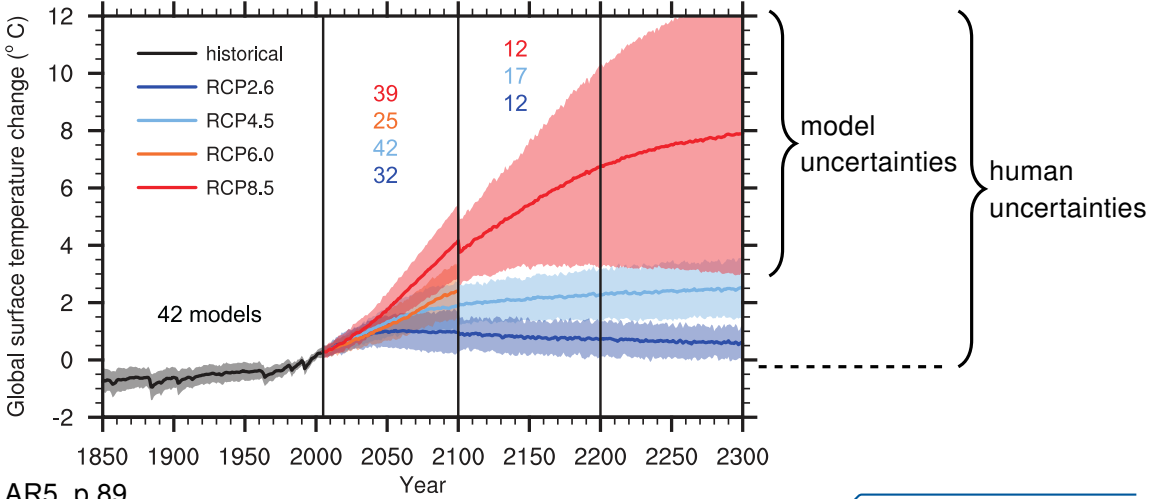
The numbers behind RCP refer to the radiative forcing at the end of the modelling period 2100.



number of models used for this scenario in this time period

AR5, p.89

IPCC Reports
Numbers, Uncertainties



AR5, p.89

Example: Install An Impact Model To Your Local PC (Linux)

dependencies: a fortran compiler, make, cmake, netcdf-fortran

clone repository: `git clone https://git.ufz.de/mhm/mhm.git`

build directory: `cd mhm ; mkdir build ; cd build`

create a makefile: `cmake ..`

build the executable: `make`

run the model with test domains: `cd .. ; build/mhm`

git.ufz.de/mhm/mhm

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