Global Warming without Global Mean Precipitation Increase?

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Global Hydrological Cycle

Higher surface temperature → increased evaporation → more precipitation?

Yes ☐

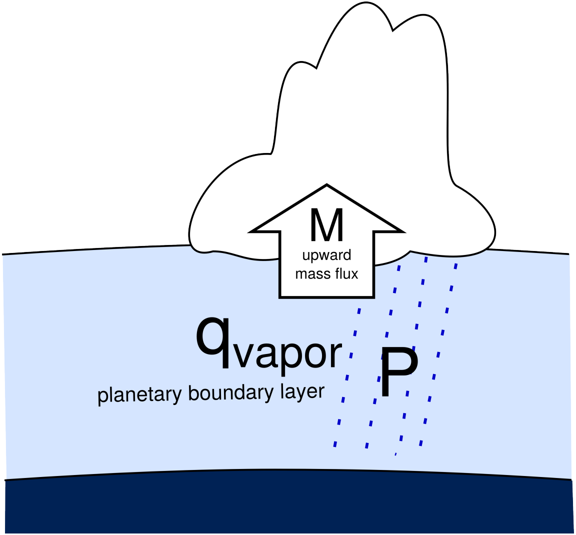
No ☐

Global Hydrological Cycle

for CO_2 increase global models yield

- $\sim$7% increase water vapor mixing ratio per kelvin temperature increase (in agreement with expectation according to Clausius-Clapeyron relation)
- $\sim$2% increase in surface precipitation per kelvin temperature increase ("muted response")

Global Hydrological Cycle



Global Hydrological Cycle

$$P = Mq$$

- P: precipitation
- M: upward mass flux out of the boundary layer
- q: water vapor mixing ratio in the boundary layer

Global Hydrological Cycle

for CO_2 increase global models yield

- $\sim$7% increase in water vapor mixing ratio per Kelvin temperature increase (in agreement with expectation according to Clausius-Clapeyron relation)
- $\sim$2% increase in surface precipitation per Kelvin temperature increase ("muted response")
- overall circulation slowdown

Global Tropospheric Heat Budget

if sensible heat flux is assumed to remain constant:

$$\Delta R_n = L\Delta P$$

perturbation radiative cooling (ΔR_n)

precipitation perturbation ($L\Delta P$)

- precipitation change limited by capability of the tropsphere to radiate away heat

Response to CO_2 increase

- CO_2 absorbs terrestrial radiation
- makes it harder to radiate away heat directly
- expect slowdown of subsiding branch of Hadley ciculation
- adding CO_2 at fixed surface temperature leads to precipitation decrease
- found out long ago in some of the very early atmosphere-only model runs

Response to CO_2 increase

- CO_2 radiative effect dampens precipitation response to surface warming

Response to Aerosols

- aersols mainly scatter and/or absorb solar radiation
- expect weaker damping
- expect larger hydrological sensitivity

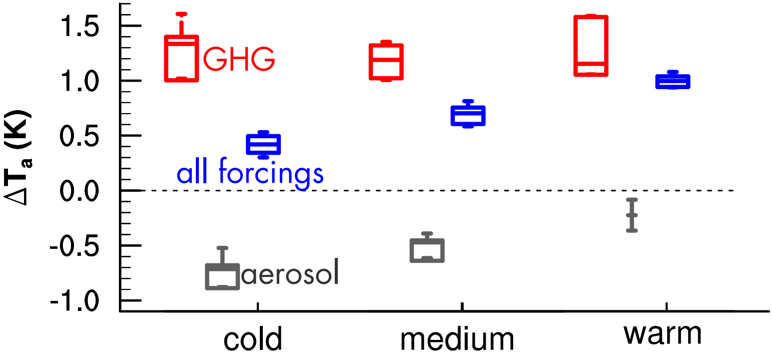
Coupled Climate Model Data

Coupled **M**odel **I**ntercomparision **P**roject, Phase **5** (CMIP5)

- single-forcing runs from 15 models:
  - only greenhouse anthropogenic gases (historicalGHG, 46 runs)
  - only anthropogenic aerosols (historicalAero, 28 runs, only 8 models)
- all forcings (historical, 71 runs)

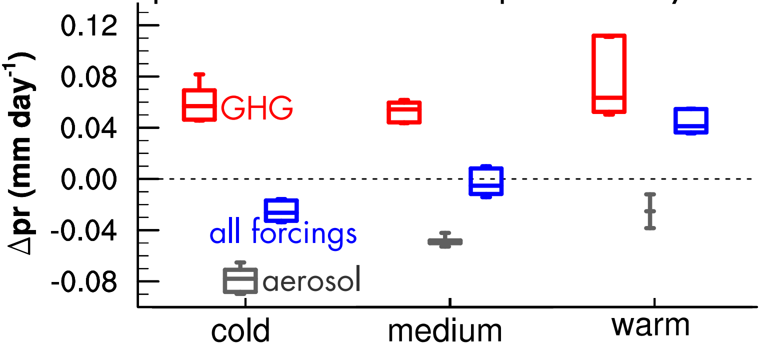
Surface Temperature Change

- CMIP5 pre-industrial to near present day



Precipitation Change

- CMIP5 pre-industrial to near present day



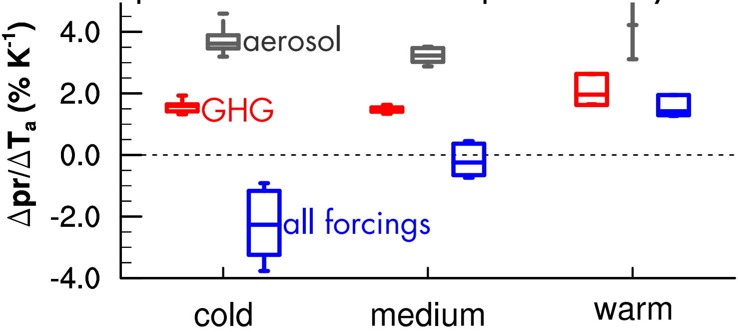
Hydrological Sensitivity

$$hs = \frac{\delta P(in\,\%)}{\delta T}$$

- percentage change of precipitation per K warming or cooling

Hydrological Sensitivity

- CMIP5 pre-industrial to near present day



Hydrological Sensitivity - Result

- only GHG: $1.7 \pm 0.4\% K^{-1}$
- only Aerosol: $3.6 \pm 0.5\% K^{-1}$

Hydrological Sensitivity - Result

- hydrological sensitivity for aerosol is roughly twice as large as that for GHG
- similar to the one for temperature surface increase only
- but still smaller than the 7%K^{-1} vapor increase (consistent with water vapor radiative feedback)

Strange Formula

since $\Delta T = \Delta T_G + \Delta T_A$ and $\Delta P = \Delta P_G + \Delta P_A$:

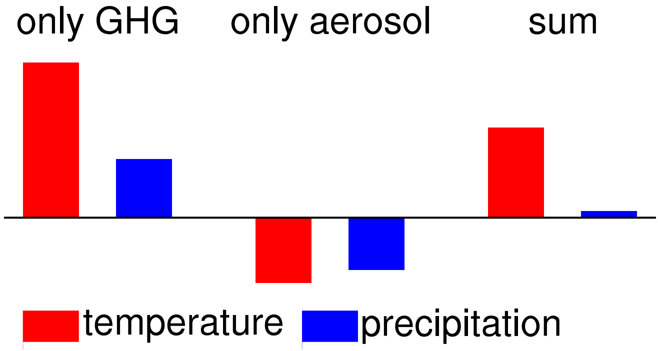
$$\frac{\delta P}{\delta T} = \frac{\Delta P_G + \Delta P_A}{\Delta T_G + \Delta T_A}$$

and thus:

$$\Delta P = \frac{\delta P}{\delta T}\Delta T = \left(\frac{\delta P}{\delta T}\right)_G \Delta T_G + \left(\frac{\delta P}{\delta T}\right)_A \Delta T_A$$

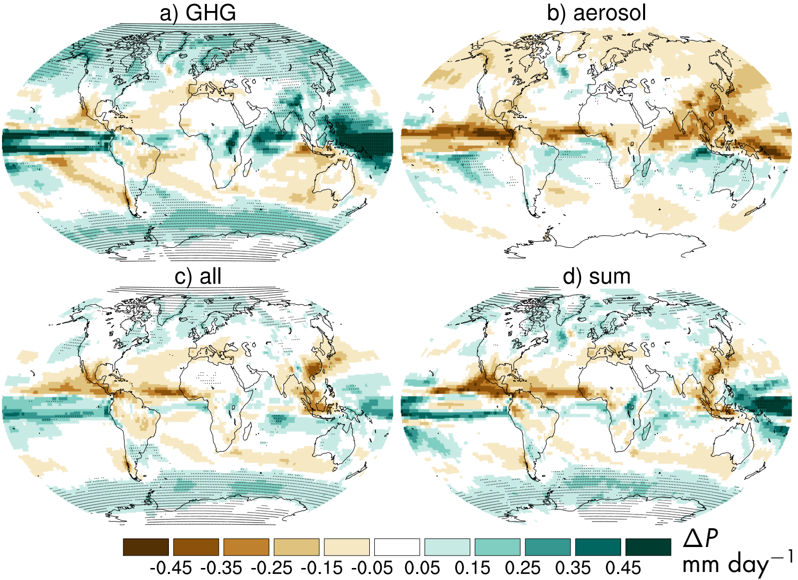
where $\left(\frac{\delta P}{\delta T}\right)_G$ and $\left(\frac{\delta P}{\delta T}\right)_A$ are the hydrological sensitivities from the single forcing experiments.

Schematic: changes pre-industrial to recent past

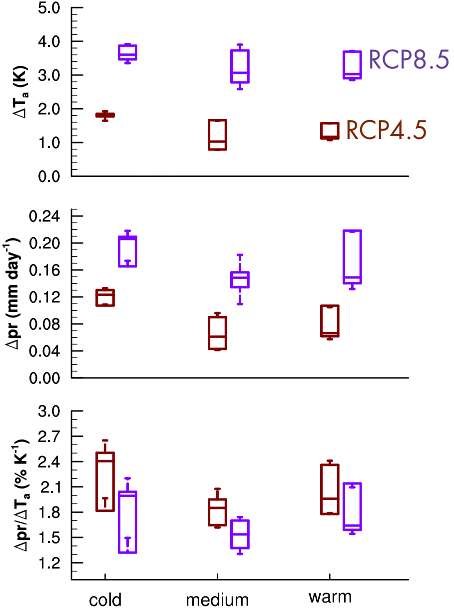


based on CMIP5 models with a realistic 20th century warming

But: effects do not cancel regionally!

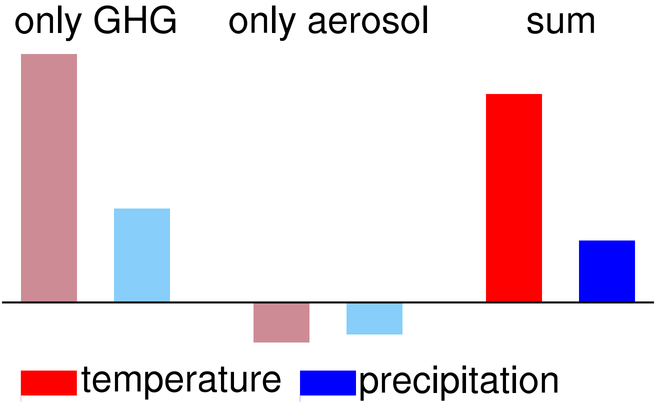


Future?



5.0
4.0
3.0
2.0
1.0
0.0
ΔT_a (K)
RCP8.5
RCP4.5
0.24
0.20
0.16
0.12
0.08
0.04
0.00
Δpr (mm day^{-1})
3.0
2.7
2.4
2.1
1.8
1.5
1.2
$\Delta pr/\Delta T_a$ (% K^{-1})
cold
medium
warm

Schematic: future changes



light colors: informed guess

Summary

- robust response of the hydrological cycle to aerosol cooling
- models with realistic 20th century warming show almost vanishingly small precipitation increase
- as future will be dominated by CO_2 warming clear signal will emerge

- thank you!

Reference: M. Salzmann, Global warming without global mean precipitation increase?. Sci. Adv. 2, e1501572, doi:10.1126/sciadv.1501572, 2016.

U.S. contributions:

- contributions to CMIP5 from modeling groups at NOAA, NASA, NCAR
- analysis software: NCL (UCAR/NCAR/CISL/TDD)
- software for data distribution (ESG) from PCMDI/DOE

ongoing mission by NASA and JAXA with other international collaborators: Global Precipitation Measurement (GPM) mission

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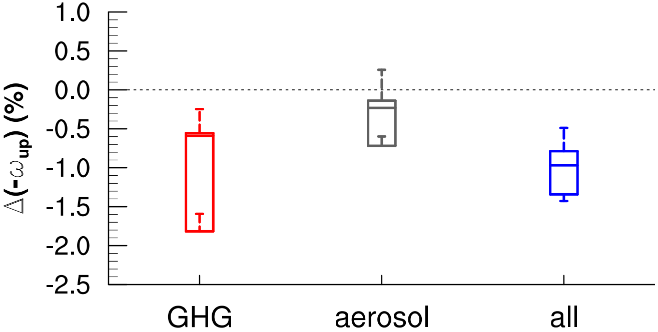
Global mean circulation



Global Tropospheric Heat Budget

$$LW_{emi} = SW_{abs} + LW_{abs} + LHF + SHF$$

- LW_{emi} ↑ emission of terrestrial radiation
- SW_{abs} ↑ absorption of solar radiation
- LW_{abs} ↑ absorption of terrestrial radiation
- LHF ↑ latent heat flux
- SHF ↑ sensible heat flux

Global Tropospheric Heat Budget

net radiation balanced by LHF and SHF

$$R_{net} = LW_{emi} - SW_{abs} - LW_{abs} = LHF + SHF$$

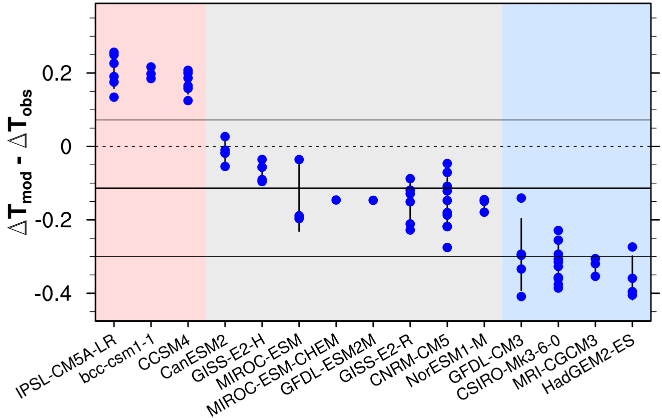
or since globally $LHF = LP$:

$$R_{net} = LP + SHF$$

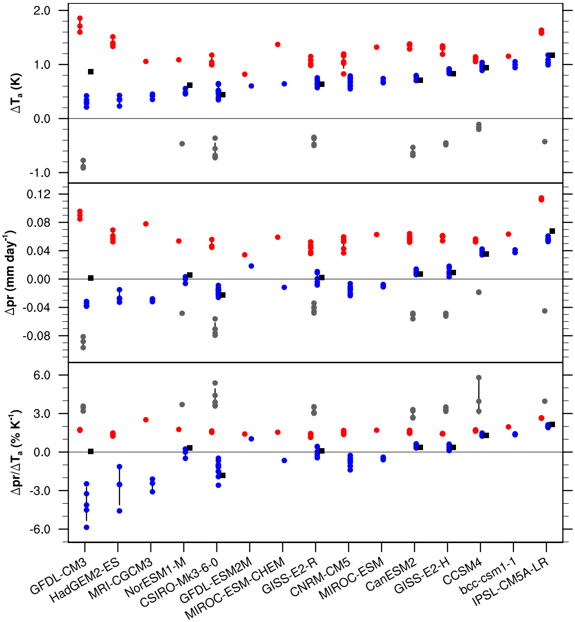
where

- L latent heat of evaporation
- P precipitation

Model classification



Additivity



2.0
1.0
0.0
-1.0
ΔTa (K)
0.12
0.08
0.04
0.00
-0.04
-0.08
Δpr (mm day-1)
6.0
3.0
0.0
-3.0
-6.0
Δpr/ΔTa (% K-1)
GFDL-CM3
HadGEM2-ES
MRI-CGCM3
NorESM1-M
CSIRO-Mk3-6-0
GFDL-ESM2M
MIROC-ESM-CHEM
GISS-E2-R
CNRM-CM5
MIROC-ESM
CanESM2
GISS-E2-H
CCSM4
bcc-csm1-1
IPSL-CM5A-LR