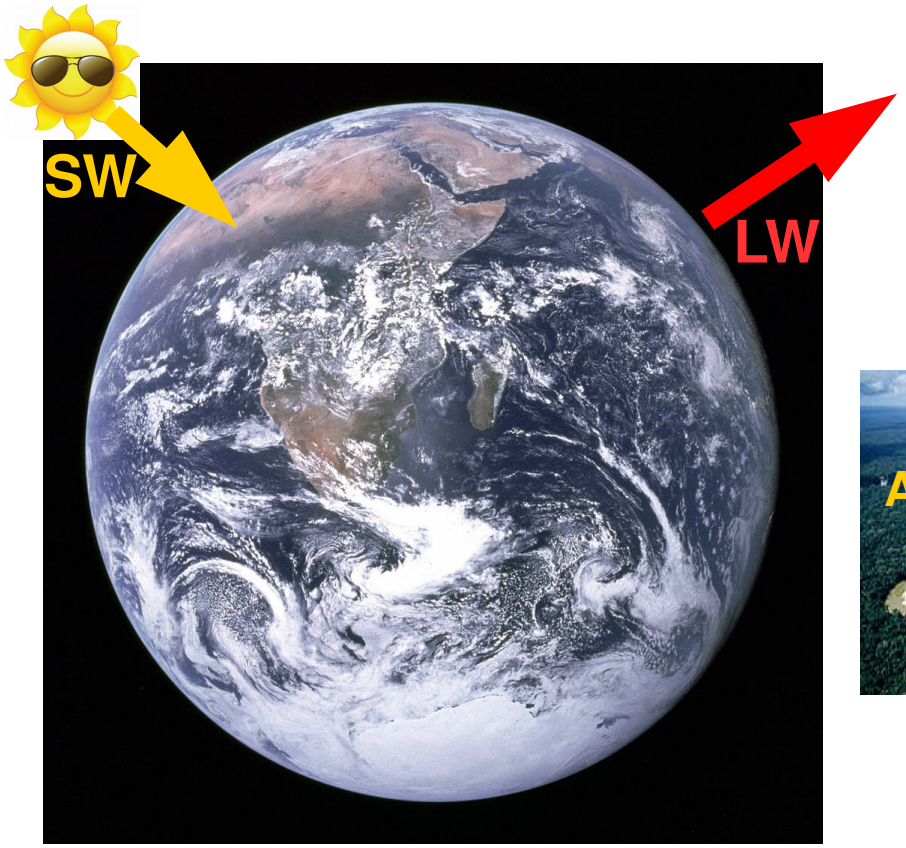
IP project: CDICE climate emulator

- **IP project embedded in real world science (CDICE, see next slides)**
- **CDICE provides context and examples, besides 'simple' examples**
- **8 tasks (not all mandatory!) illustrate some aspects of python**

3 Task by Task

Simulating the ‘blue marble’: ‘climate’ + ‘socio-economics’



Earth from 45’000 km distance, image by Apollo 17, December 7, 1972. Image credit: NASA

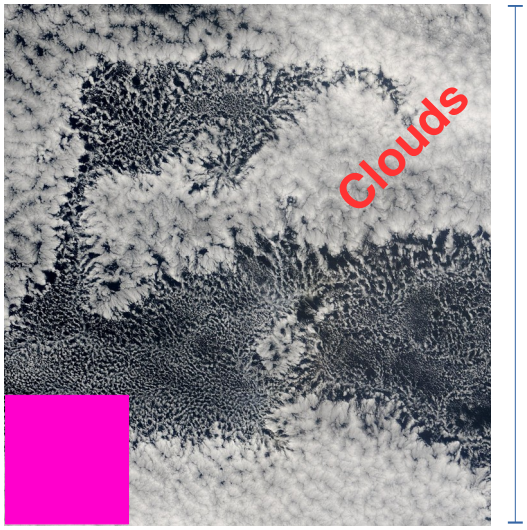


Image credit: Raimond Spekking

Simple Climate Models / Climate Emulators (SCMs / CEs)

Why simple climate models? Because they are cheap, thus can be used

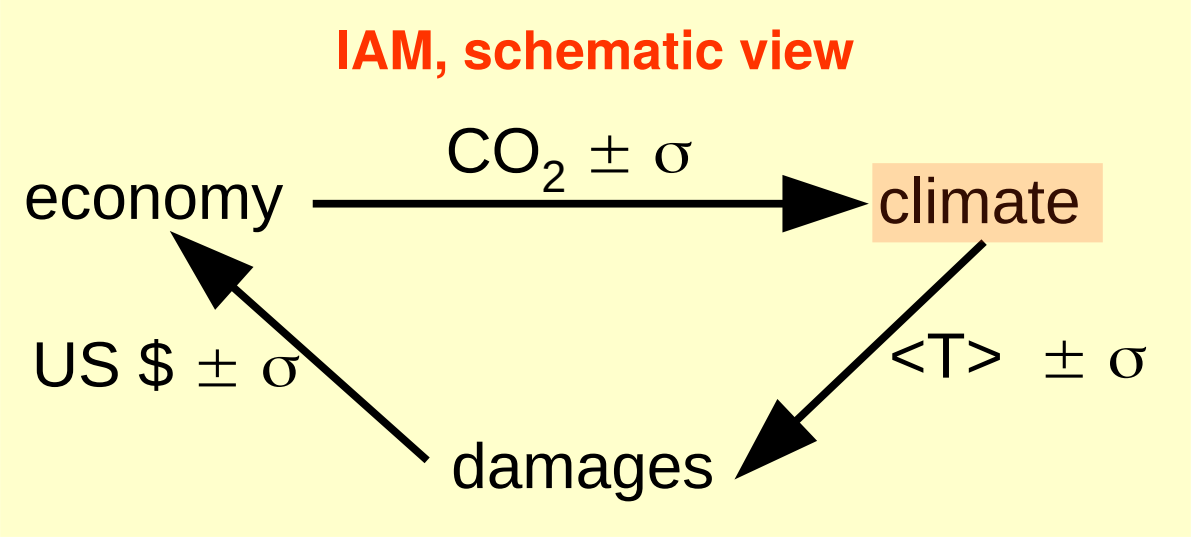
→ to explore climate over millions of years (paleo-climate)

→ **as part of IAMs (Integrated Assessment Models) to**

→ explore socio-economic story lines ('what if...', key for IPCC, see later)

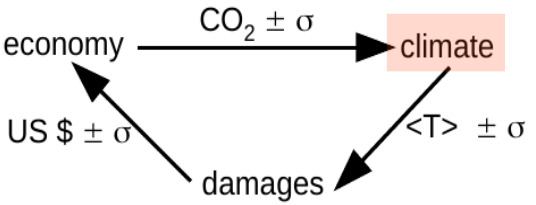
→ **explore social costs of carbon (carbon tax, econ-models…)**

→ CO2 emissions from econ → CO2 concentrations → global warming

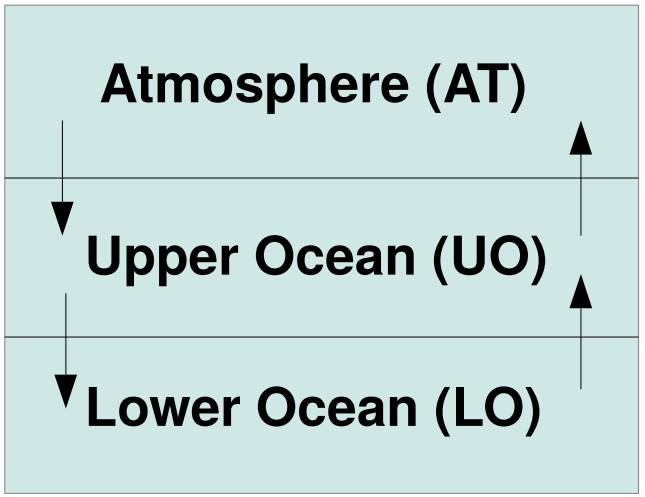


CDICE – the simple climate model in DICE

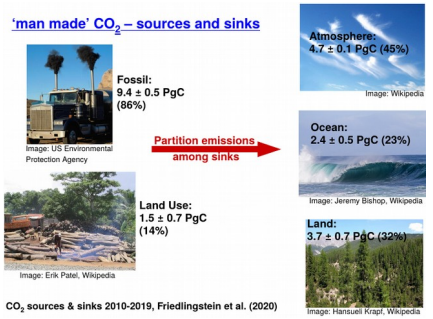
[https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3885021]



1) CO_2 emissions →

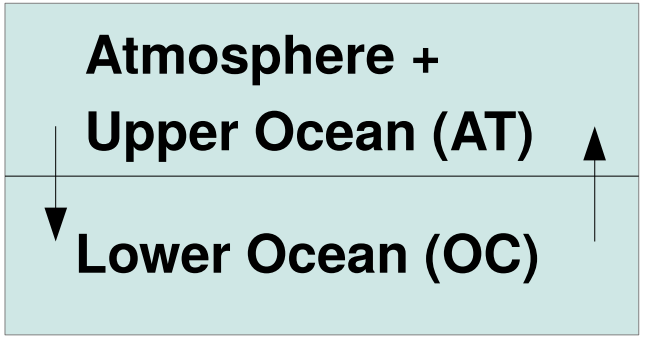


→ CO_2 concentrations (atmosphere)



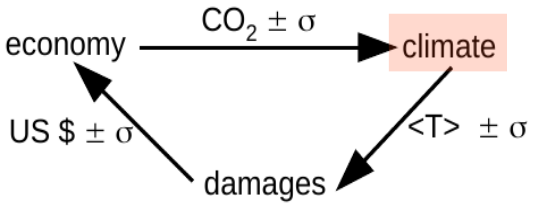
2) CO_2 concentrations → $F_t = F_{2XCO2}\frac{\log(M_t^{AT}/M_{EQ}^{AT})}{\log(2)} + F_t^{EX}$ **→ forcing**

3) forcing →



→ temperature T (global mean)

CDICE – the simple climate modle in DICE

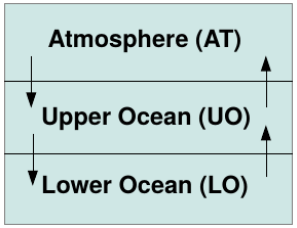


Carbon Cycle: 4 free parameters → calibration
Forcing: 1 free function (F^{EX}) → choice
Temperature: 4 free parameters → calibration

1) CO_2 emissions →

$$M_{t+1} = (I + \Delta_t \cdot B) \cdot M_t + \Delta_t \cdot E_t$$

→ CO_2 concentrations (masses)



$$M_t = (M_t^{AT}, M_t^{UO}, M_t^{LO}) \qquad B = \begin{pmatrix} b_{11} & b_{21} & b_{31} \\ b_{12} & b_{22} & b_{32} \\ b_{13} & b_{23} & b_{33} \end{pmatrix}$$

$$\begin{aligned} b_{11} &= -b_{12}, \\ b_{21} &= b_{12} \cdot r_1, \\ b_{22} &= -b_{21} - b_{23}, \\ b_{32} &= b_{23} \cdot r_2, \\ b_{33} &= -b_{32}. \end{aligned}$$

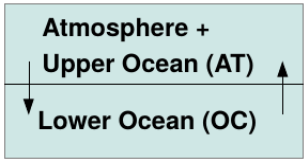
$$r_1 = \frac{M_{EQ}^{AT}}{M_{EQ}^{UO}} \qquad r_2 = \frac{M_{EQ}^{UO}}{M_{EQ}^{LO}}$$

2) CO_2 concentrations →

$$F_t = F_{2XCO2} \frac{\log(M_t^{AT}/M_{EQ}^{AT})}{\log(2)} + F_t^{EX}$$

→ forcing

3) forcing →



$$T_{t+1}^{AT} = T_t^{AT} + \Delta_t \cdot c_1 \left(F_t - \lambda T_t^{AT} - c_3 \left(T_t^{AT} - T_t^{OC} \right) \right)$$

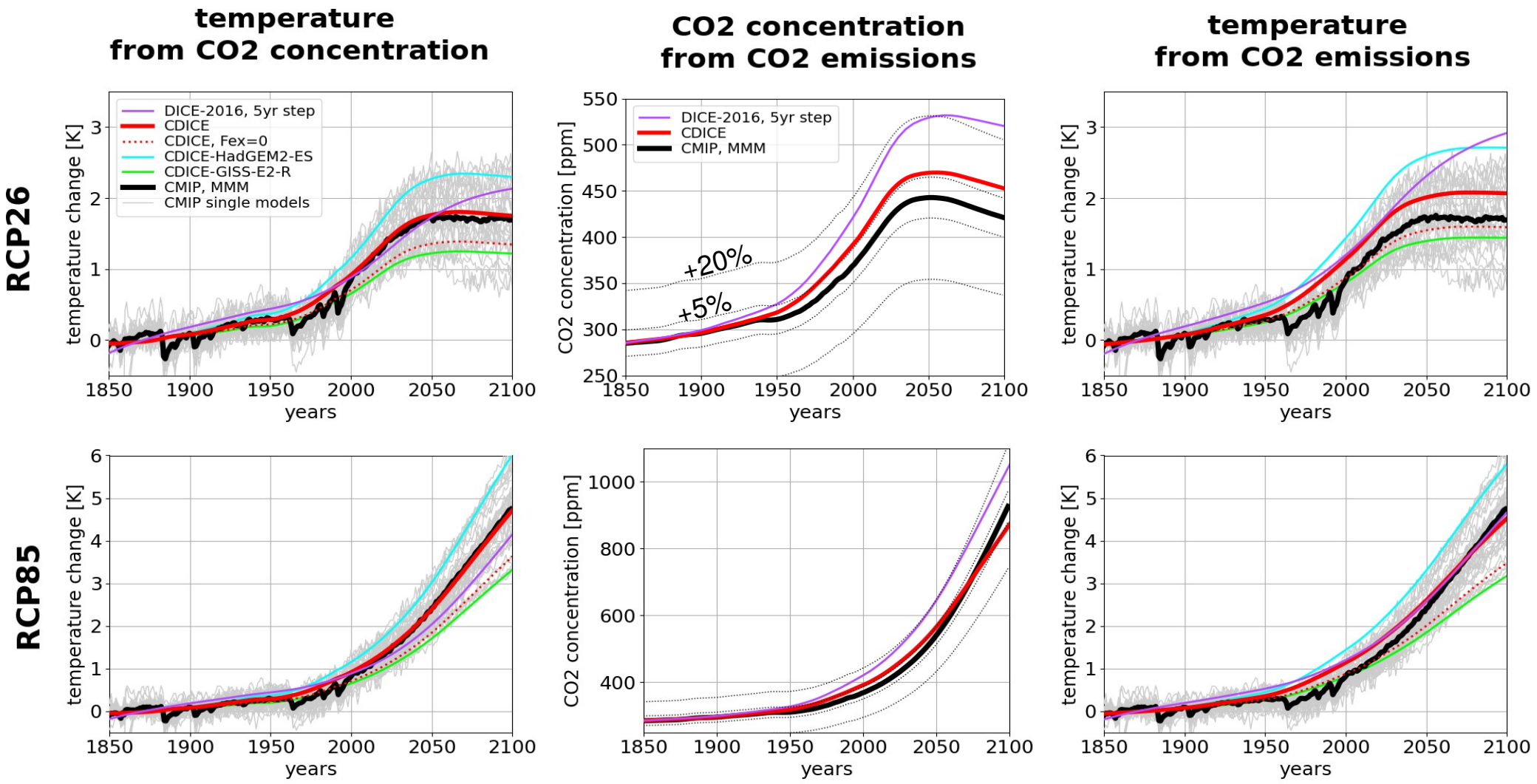
$$T_{t+1}^{OC} = T_t^{OC} + \Delta_t \cdot c_4 \left(T_t^{AT} - T_t^{OC} \right)$$

→ temperature T (global mean)

CDICE – Benchmark IPCC AR5 / CMIP5, RCP26 & RCP85

Global mean temperature, 1850 to 2100, RCP 26 / 85 (low / high emission scenario)

CDICE is in line with complex climate models as in IPCC AR5 / **CMIP5**



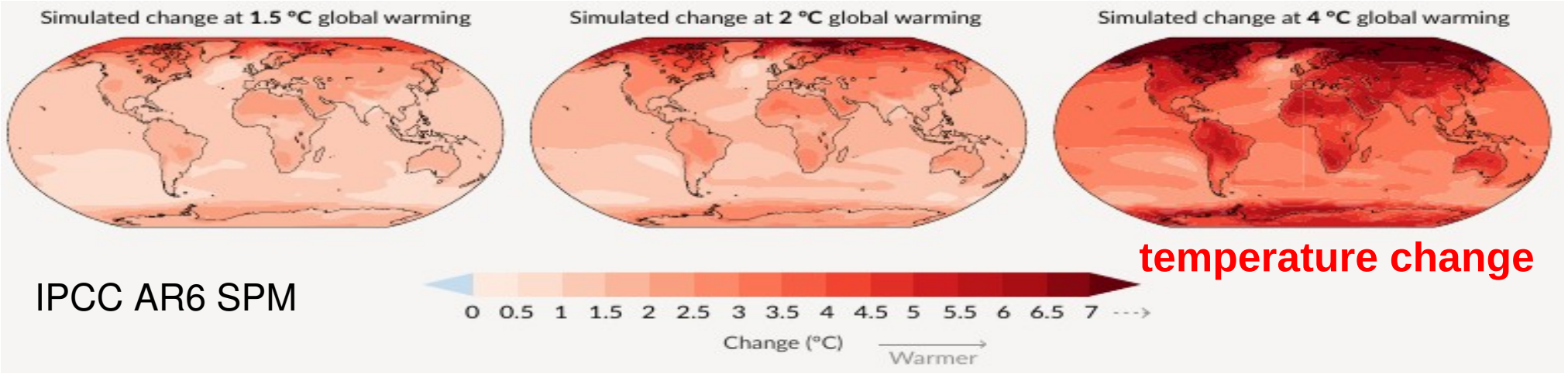
CDICE – regional temperature change / pattern scaling

Land warms more strongly than ocean

High latitudes warm more strongly than low latitudes

Cities warm more strongly than country side (heat island effect)

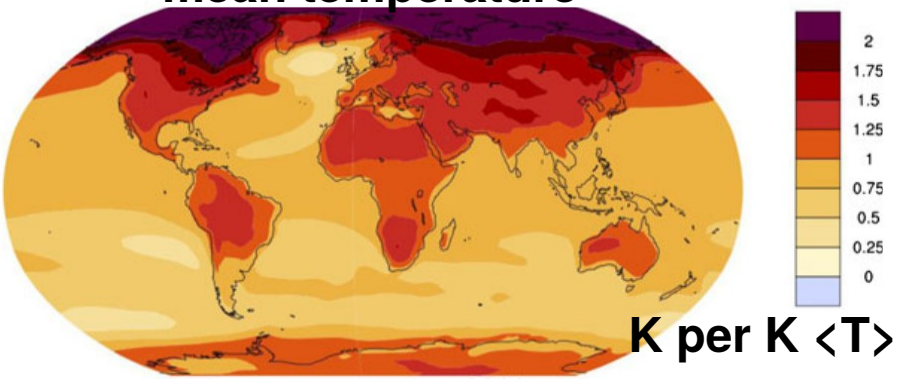
(Differences in warming winter / summer / day / night / max / min)



Many quantities scale with global mean temperature change

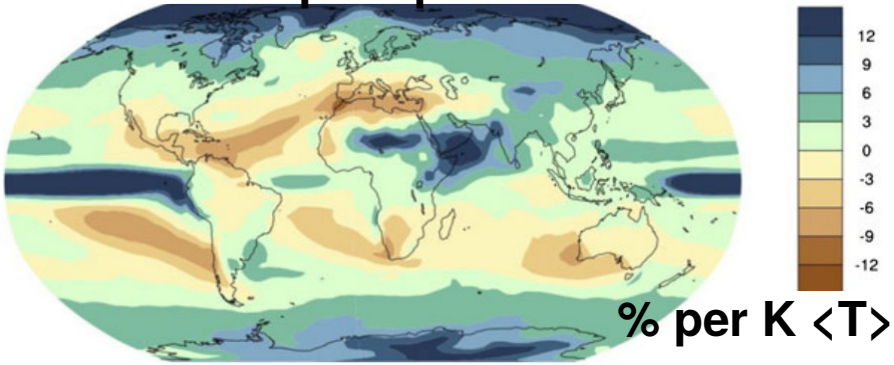
change patterns per Kelvin global mean warming

mean temperature



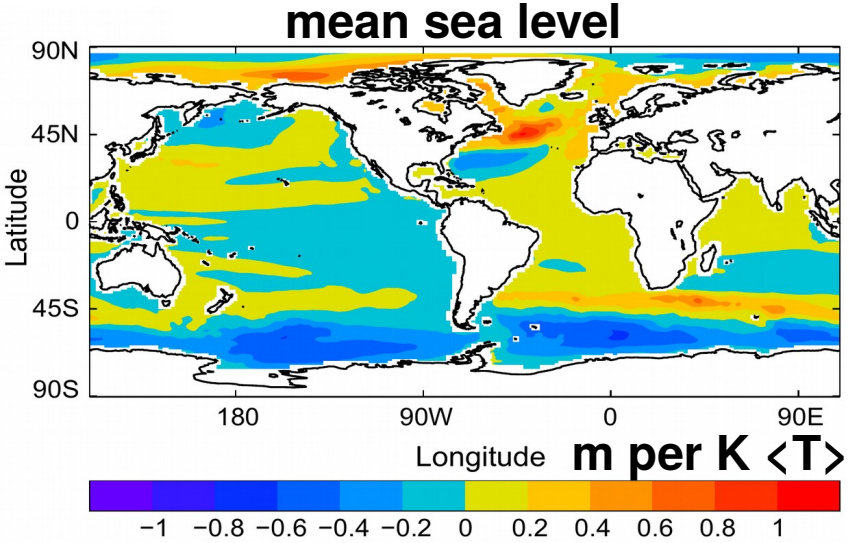
K per K <T>

mean precipitation



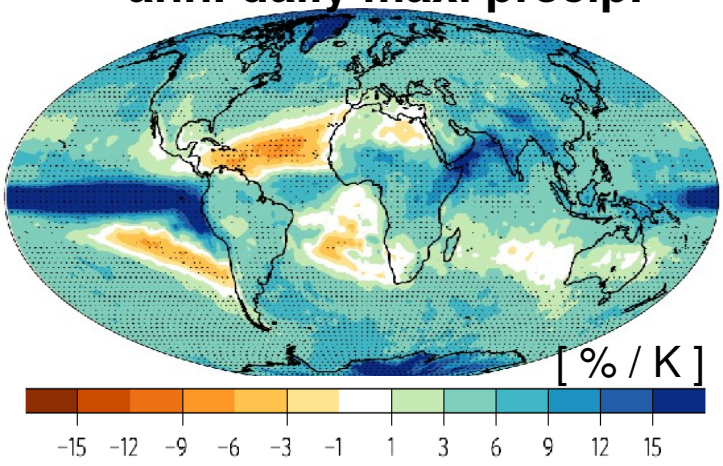
% per K <T>

mean sea level



m per K <T>

ann. daily max. precip.



[% / K]

[Tebaldi & Arblaster (2014); Bilbao et al. (2015); Pfahl et al. (2017)]