Potential post-greenhouse gas warming?

The global climate impacts of the anthropogenic heat flux

The consumption of primary energy from sources such as fossil or nuclear fuels and the consequent **dissipation** to heat induces a direct climate warming, the so called **anthropogenic heat flux (AHF) forcing**. Here, we investigate the potential future **global temperature change** due to this anthropogenic heat flux in climate models with different complexity levels, in particular, for a civilisation with the desire for **continued growth** based on **nuclear power**.

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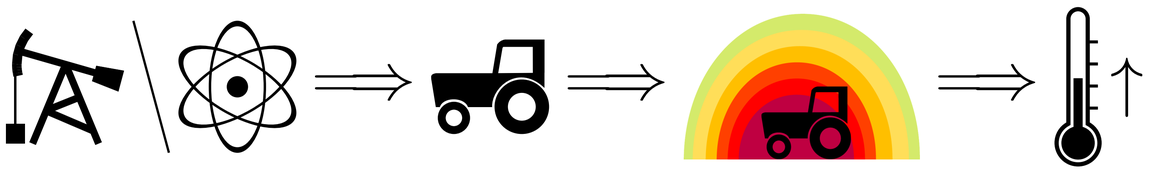
Anthropogenic Heat Flux

- During conversion and consumption by the human civilisation, nearly all primary energy eventually **dissipates to waste heat** (cf. second law of thermodynamics).
- If the consumed energy comes from **external sources**, which add **additional** energy to the natural balance, this represents a climate forcing, the **anthropogenic heat flux (AHF)**.
- On local scales, this is known as the 'Urban Heat Island effect'.
- Which energy sources contribute to the AHF?
  Nuclear, fossil fuel and, partially, geothermal and solar energy (e.g. if the solar panels decrease the local albedo).



- Currently, the AHF is negligibly small on a global scale ($\sim 2\%$ of the forcing from CO_2).
- However, an increasing number of studies investigates continental to global impacts of the AHF under certain growth scenarios (e.g. Flanner, 2009, and Chaisson, 2008).
- Here: Investigate the **global temperature response and feedbacks** to the AHF under a simple **constant growth** scenario over the next century going from **simple to intermediate complexity climate models**.

Past and Future Growth of the Anthropogenic Heat Flux

- So far, an **exponential growth** of worldwide energy production (and AHF) is observed: $\sim 2\%/yr$.
- Possible drivers for further **continuation** of the observed growth are:
  - Growth of **population**, **economy/prosperity** and energy-intensive **technology** (e.g. Bitcoin),
  - **Inertia** of the economic system (Garrett, 2014),
  - Possible use of **fusion power** for carbon-neutral electricity generation in the future.

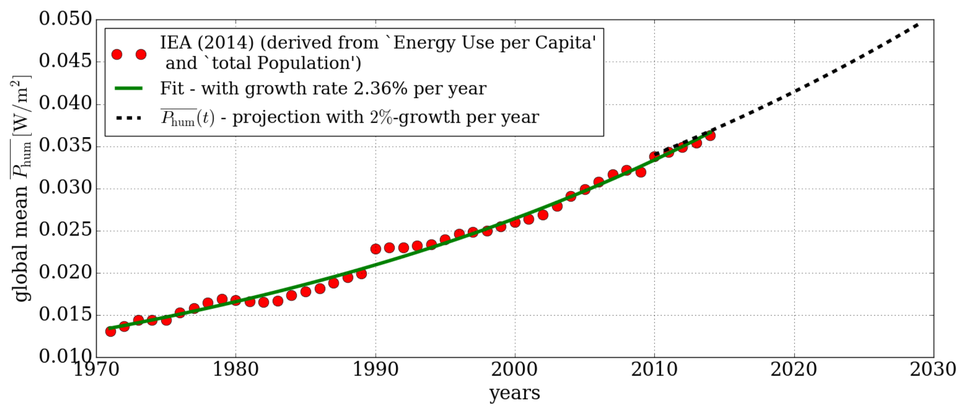


Fig. 1: Global mean energy production over the past decades (IEA, 2014) and a projection with a 2%-growth rate.

The (one-dimensional) Energy Balance Model

- In equilibrium: (Averaged) Outgoing Radiation = Incoming Energy (Solar + AHF)

$$0 = \frac{S(\theta)}{4} \cdot \left(1 - \begin{cases} 0.6 \text{ Northern ice} \\ 0.3 \text{ no ice} \\ 0.6 \text{ Southern ice} \end{cases}\right) - \tau\sigma T(\theta)^4 + D \cdot \frac{1}{cos(\theta)} \cdot \frac{\partial}{\partial\theta} cos(\theta) \frac{\partial}{\partial\theta} T(\theta) + P_{\rm hum}(\theta)$$

$$0 = \text{Solar} \cdot (1 - \text{Albedo}) - \text{OLR} + \text{Meridional Transport} + \text{AHF}$$

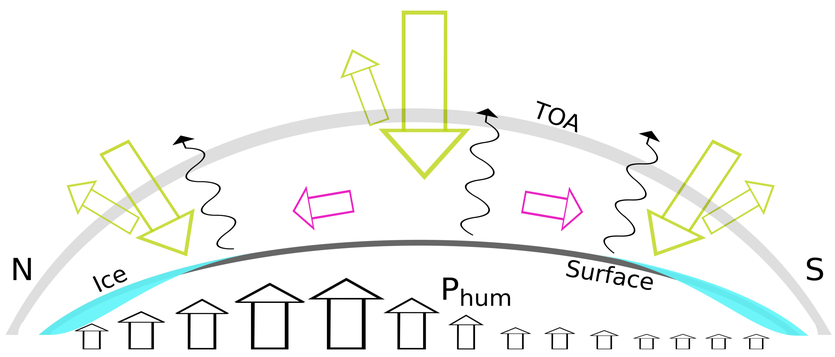


Fig. 2: Sketch of the one-dimensional Energy Balance Model with latitude-dependent solar radiation, outgoing longwave radiation, equator-to-pole heat exchange (modelled as diffusion) and the additional forcing from the AHF concentrated in the Northern Hemisphere.

- Results:
  - Today: $\overline{P_{\rm hum}} \approx 0.034\,{\rm W/m^2} \rightarrow \overline{\Delta T} \approx 0.010\,{\rm K}$
  - In $\sim$100 years (with constant 2%-growth): $\overline{P_{\rm hum}} \approx 0.34\,{\rm W/m^2} \rightarrow \overline{\Delta T} \approx 0.096 - 0.219\,{\rm K}$
- In many model configurations the increase of the AHF in the Northern Hemisphere leads to a **loss of Arctic ice**.
- $\overline{\Delta T}$ amplified through the **ice-albedo feedback**.

An Earth System Model of Intermediate Complexity

CLIMBER-3α: Earth System model that combines a general circulation ocean model with a dynamic sea-ice module and a statistical-dynamical atmosphere (Montoya et al., 2005).

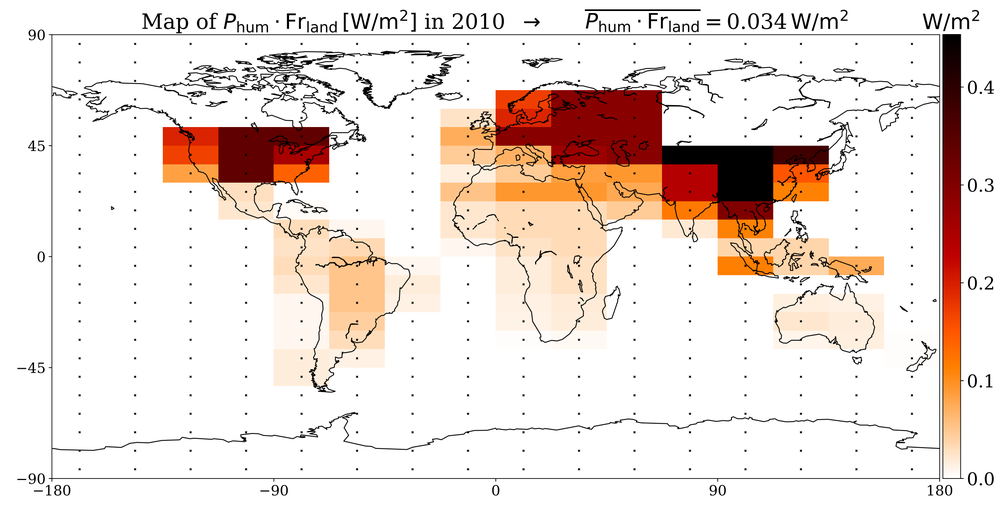


Fig. 3: Heterogeneous AHF forcing $P_{\rm hum}$ in $\rm W/m^2$ at the surface layer of the atmosphere according to the energy production data from IEA (2014) weighted by the land fraction ${\rm Fr}_{\rm land}$ of each cell.

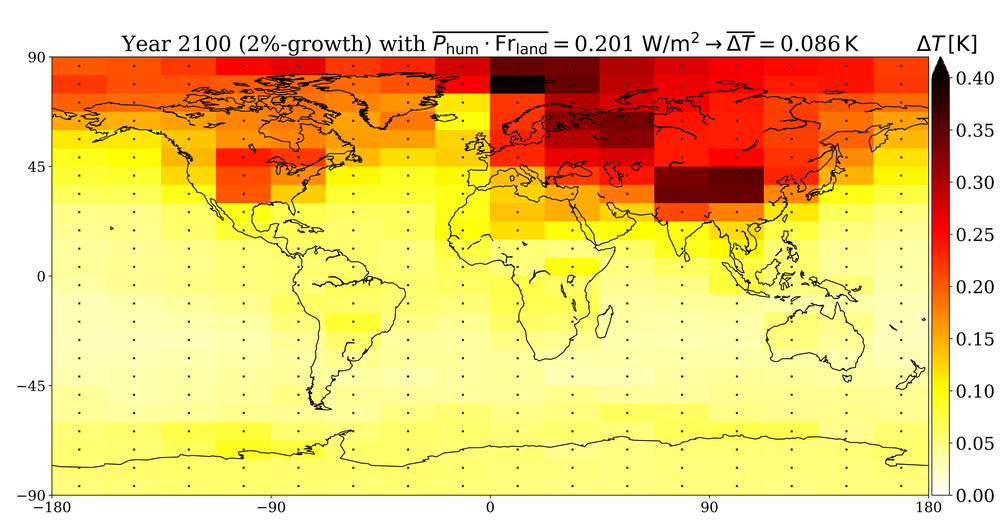


Fig. 4: Corresponding temperature change in 2100 (with constant 2%-growth per year).

- Strongly **localised temperature responses**.
- But, again, significantly **amplified ΔT in the Arctic**. In particular, areas surrounding the North Atlantic (e.g. Spitzbergen) are strongly impacted, which indicates changes in the ocean circulation.
- Global mean (transient) temperature change in $\sim$100 years (with constant 2%-growth):
  $\overline{P_{\rm hum}} \approx 0.34\,{\rm W/m^2} \rightarrow \overline{\Delta T} \approx 0.127\,K$.

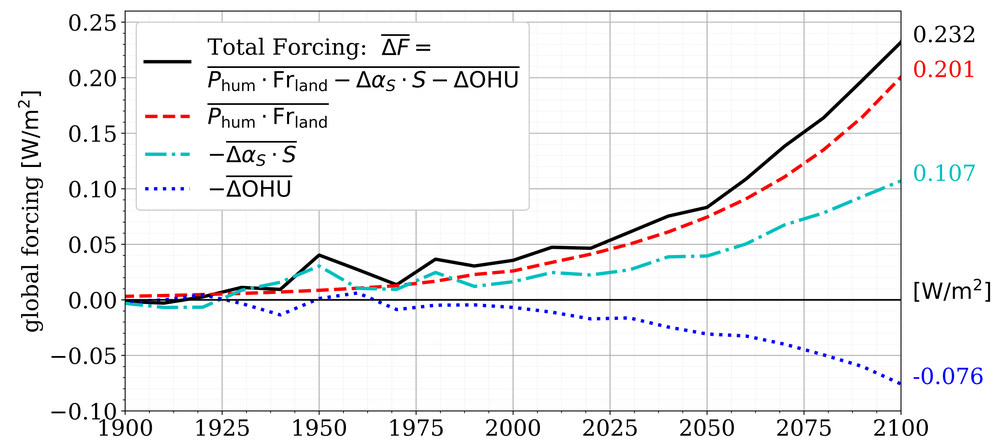


Fig. 5: The forcing from the AHF (with 2%-growth assumption), an approximation of the ice-albedo feedback (via the latitudinal average of the albedo change $\Delta\alpha_S$ and the solar radiation S), and the changes in the forcing from the ocean heat uptake over the next decades.

- Stronger **ocean heat uptake** nearly equalises the positive **ice-albedo feedback**.
- Both feedbacks (ocean heat uptake as well as ice-albedo) depend on the **location** of the heat emission, in particular on the **latitude** and some features of the surrounding cells like **ocean fraction** and **circulation patterns**.

References

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