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Degree Day Feedbacks

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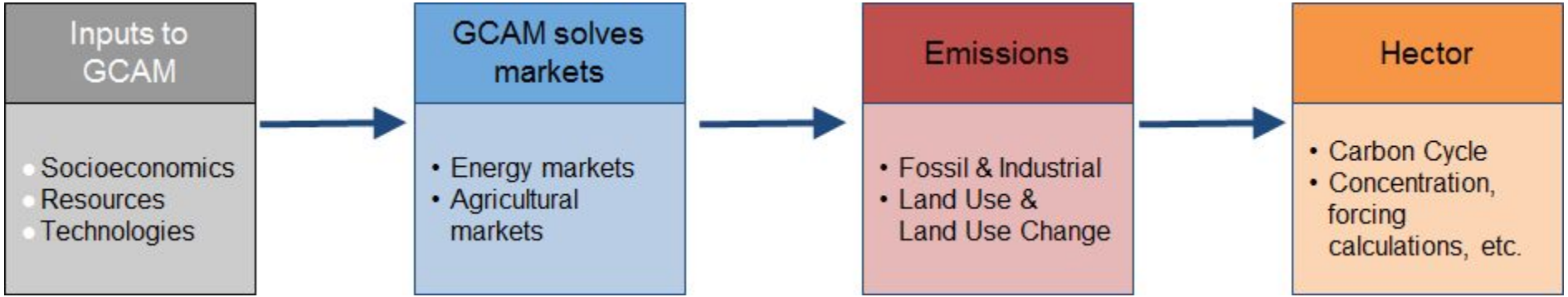
Motivation

- Human decisions influence the earth and changes in the earth influence human decision making
- The building sector is susceptible to human-earth system feedbacks due to the demand for cooling and heating which is directly related to temperature.
  - With increasing temperatures, the global demand for heating is projected to decrease, while the demand for cooling is projected to increase
  - Air conditioners release HFC gases, which have extremely high GWP
  - In the USA, heating and cooling energy accounts for about 49% of all final energy in residential buildings and 44% in commercial buildings in 2005 (Kyle et al., 2010).

GCAM Overview

- Traditionally, there is no feedback from Hector to GCAM



- Feedback capabilities are part of GCAM's new release

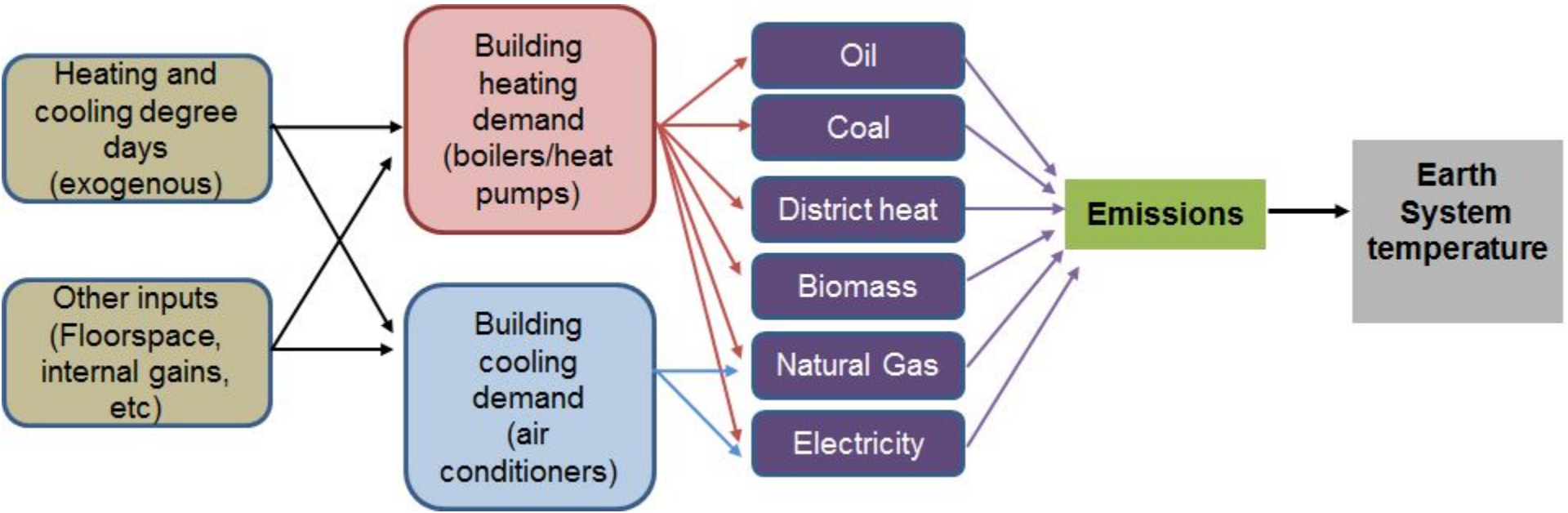
What is a degree day?

- Metric that indicates requirements for building heating and cooling
- Signify difference from a base temperature, in this study 18.3°C (65°F)
- Annual degree days are the summation of temperature difference over time and capture both the extremity and duration of difference between outdoor temperatures and a reference temperature

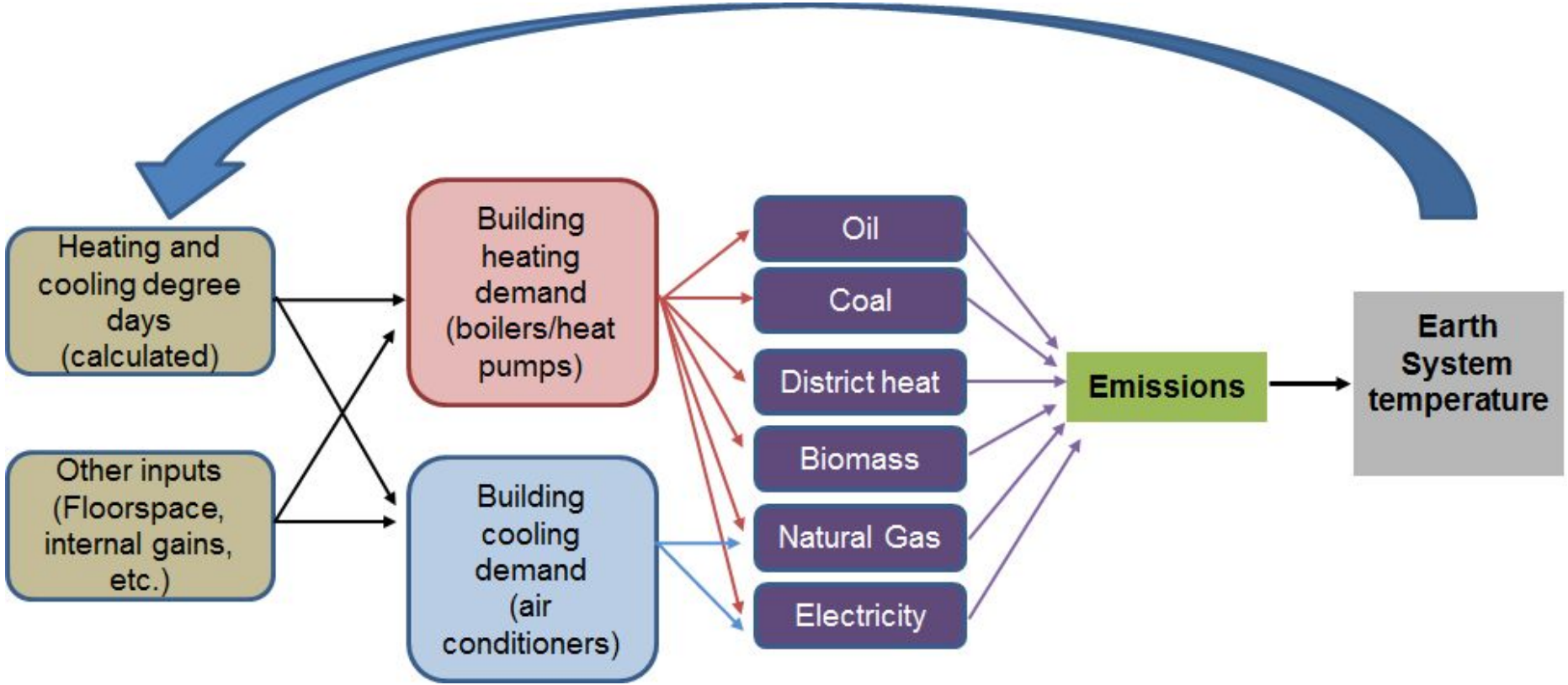
$$CDD = \begin{cases} T_S - T_B, & \text{if } T_S > T_B \\ 0, & \text{if } T_S \leq T_B \end{cases} \qquad HDD = \begin{cases} T_B - T_S, & \text{if } T_S < T_B \\ 0, & \text{if } T_S \geq T_B \end{cases}$$

$$T_S = \text{Surface Temperature}$$
$$T_B = \text{BaseTemperature}$$

Building heating and cooling: GCAM



Building heating and cooling: GCAM



Statistical relationship

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- In order to calculate feedback of temperature on HDD/CDD, need to develop a statistical relationship

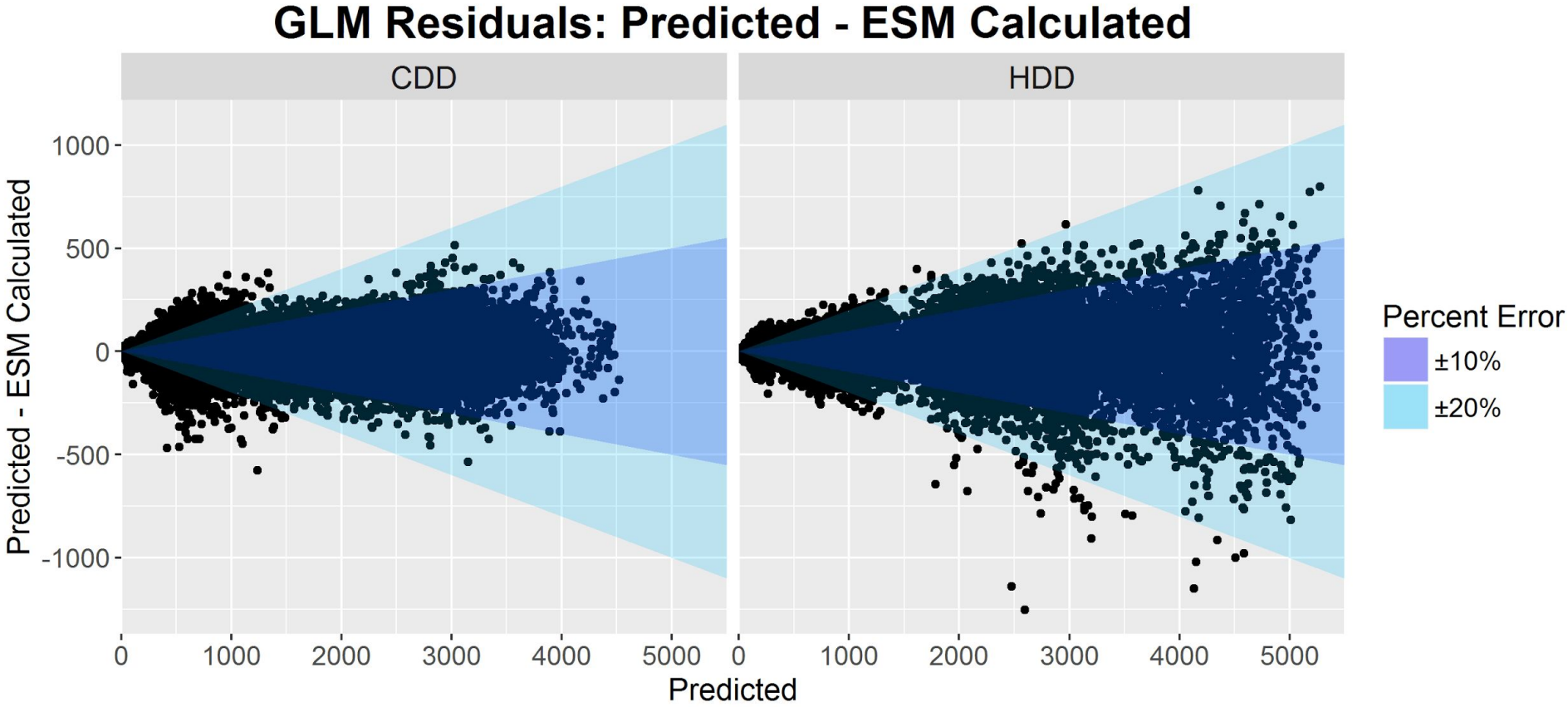
- Our method:
  - Gridded daily average temperature data from CMIP5 models
  - Calculated annual HDD/CDD within each grid cell, then population-weighted to GCAM region
  - For each ESM, developed 2 generalized linear models to relate HDD/CDD to global temperature and average regional latitude
  - Used a Poisson error distribution (treated as count data)

1) $\ln N_C = \beta_1 T + \beta_2 T L_r + \beta_3^r T^2 + \beta_4^r$

2) $\ln N_H = \alpha_1 T + \alpha_2 T L_r + \alpha_3^r T^2 + \alpha_4^r$

N_C = Number of CDD
N_H = Number of HDD
T = Global mean temperature
L_r = Average latitude

Statistical relationship



GCAM Scenarios

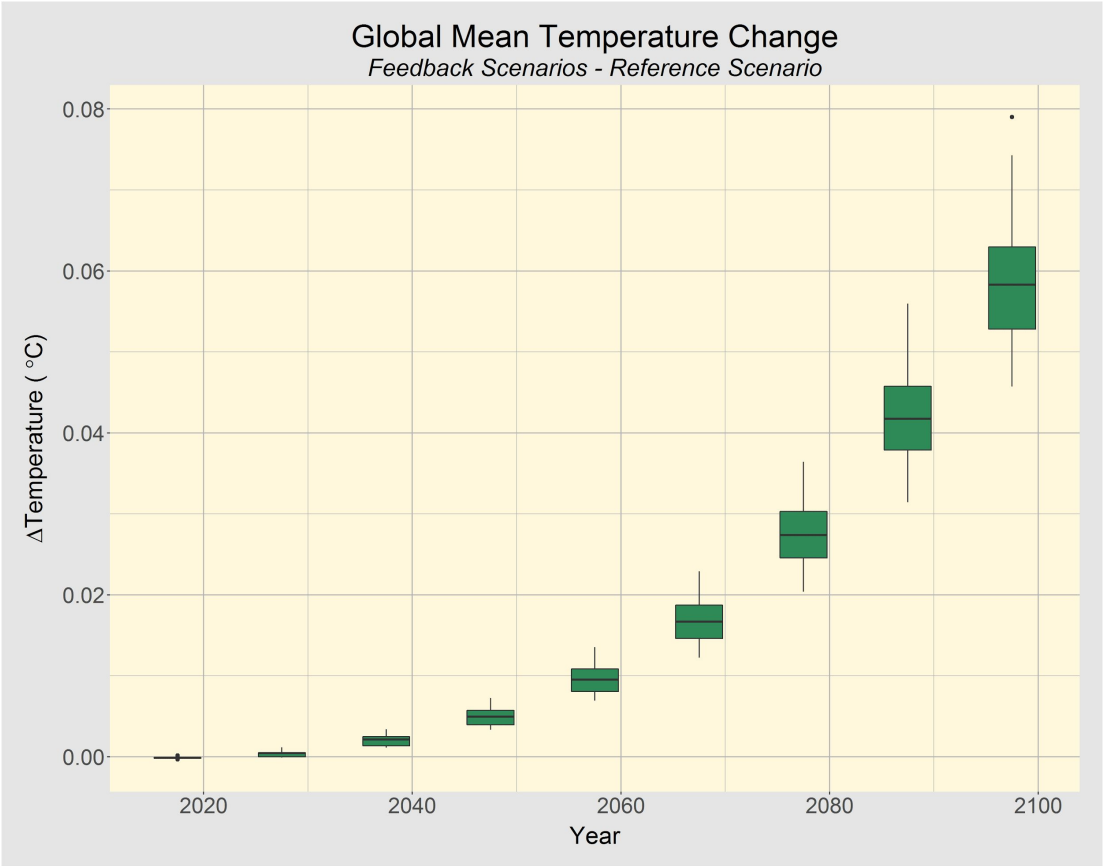
- 14 GCAM Scenarios run:
  - 1 reference/no-feedback run
  - 13 feedback runs, based on feedback equations from ESM

- No changes from standard reference run in GCAM, apart from inclusion of feedbacks

ACCESS1-0	CanESM2
CESM1-CAM5	CCSM4
CMCC-CMS	CNRM-CM5
GFDL-CM3	HadGEM2-ES
inmcm4	IPSL-CM5A-MR
MIROC-ESM	MPI-ESM-MR
NorESM1-M	

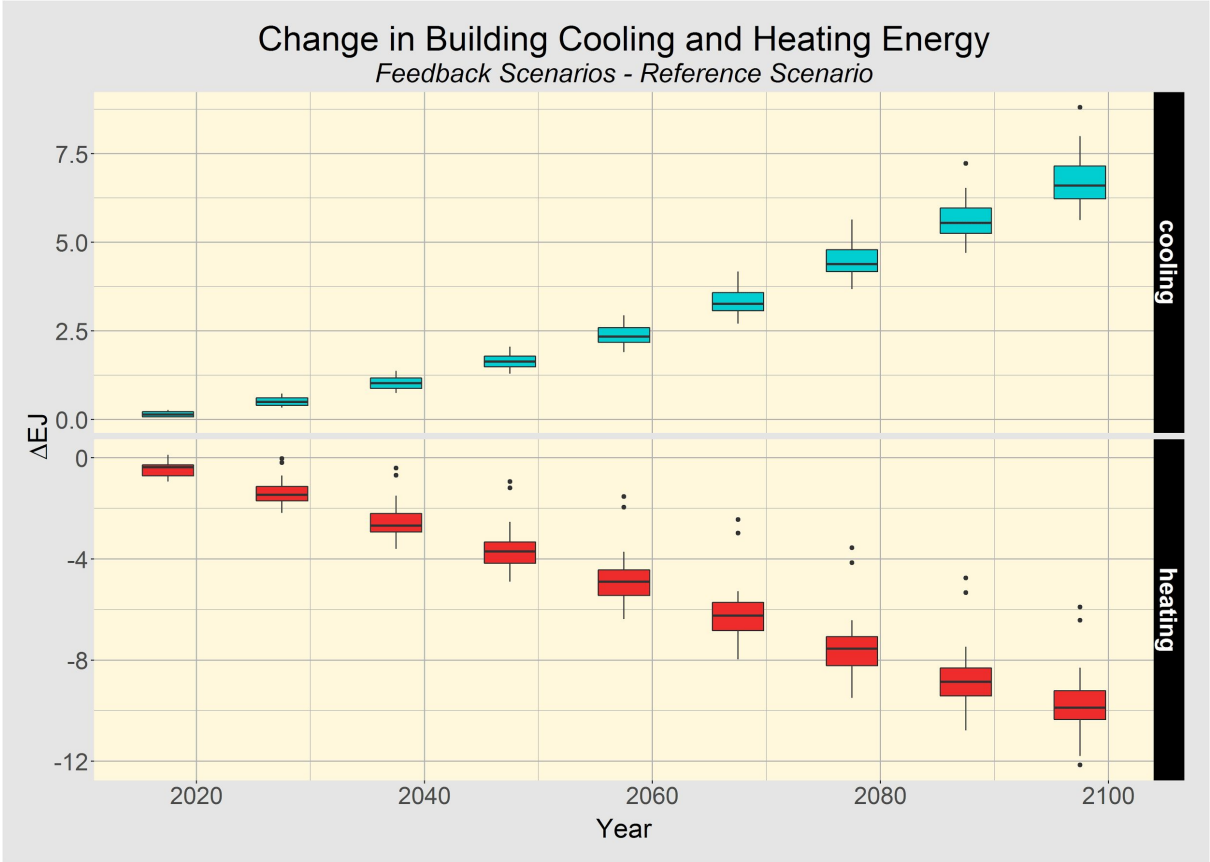
Results: Global Mean Temperature Change

- Global temperature increases across all feedback scenarios



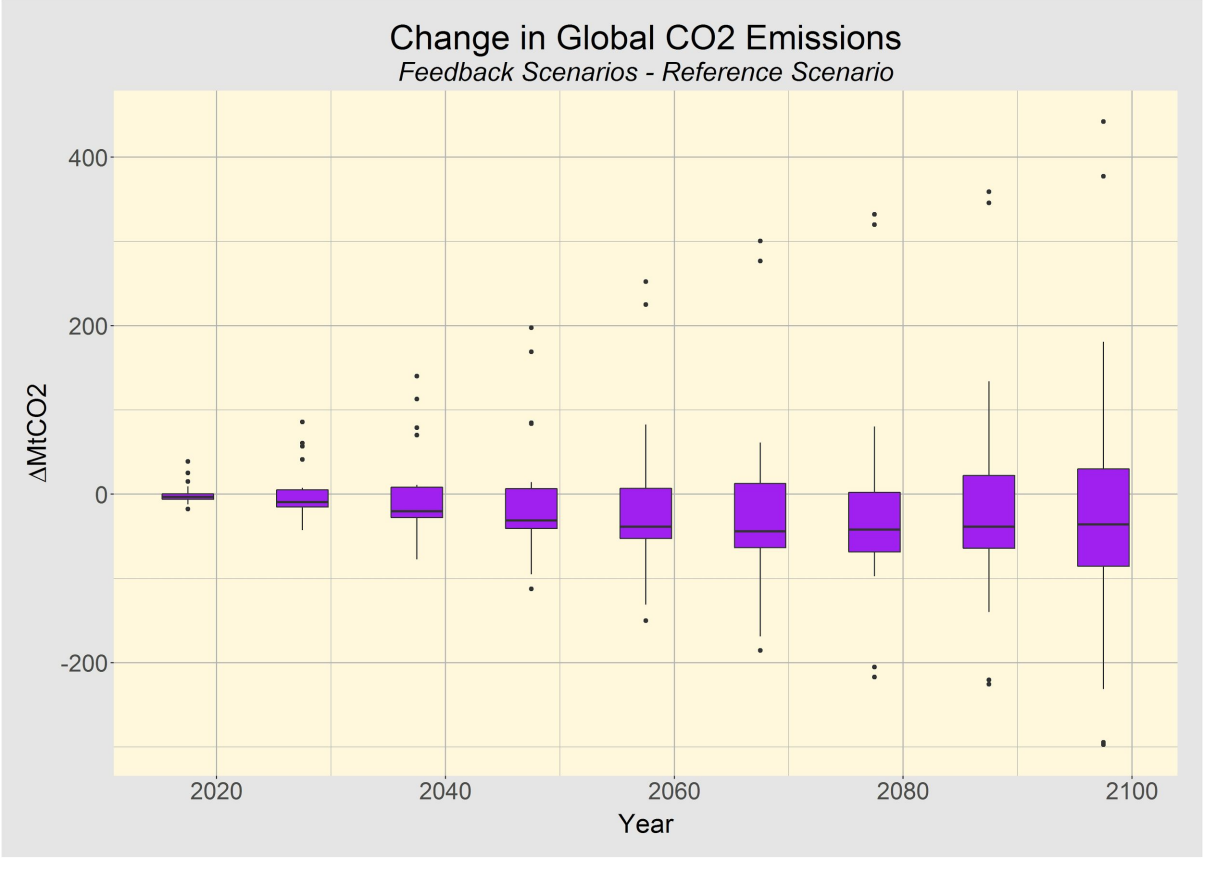
Results: Building Energy Consumption

- Global building energy consumption decreases across all feedback scenarios
- 44% median increase in energy for building cooling compared to reference in 2100
- 33% median decrease in energy for building heating compared to reference in 2100



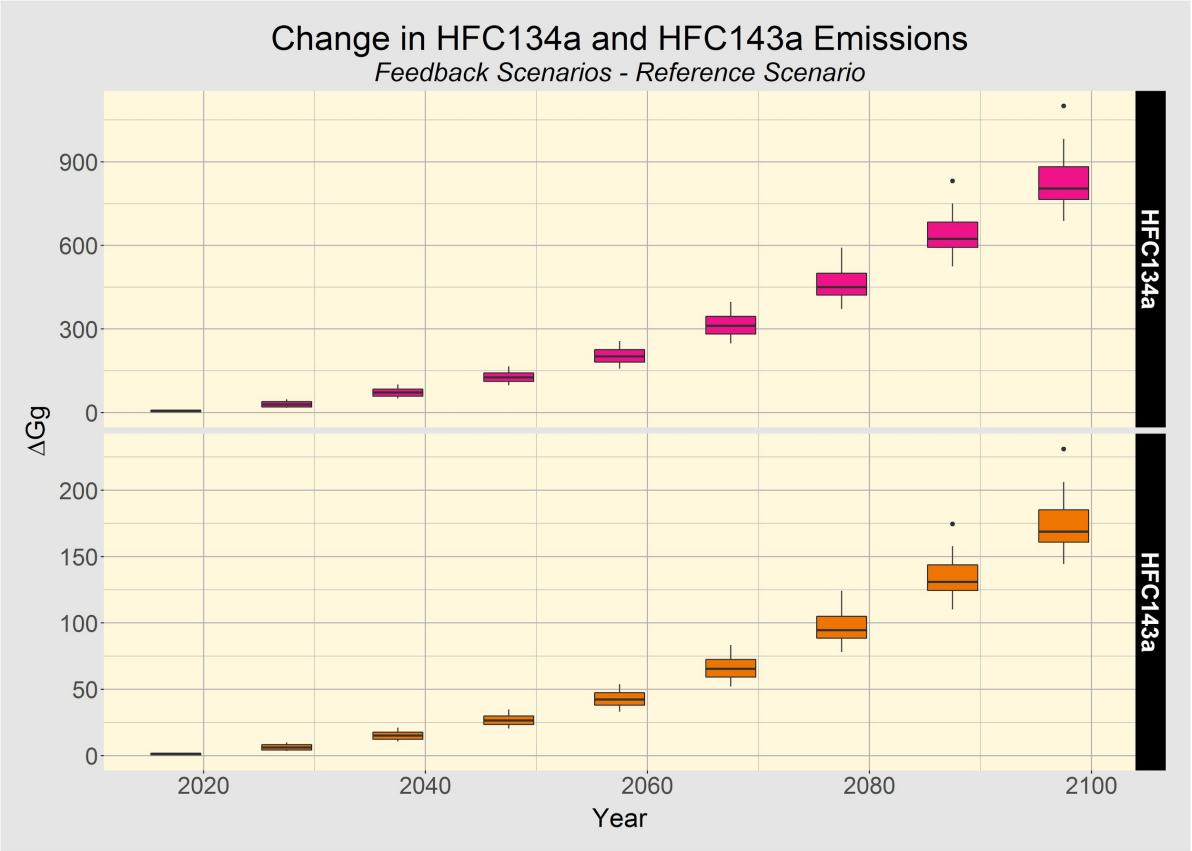
Results: CO2 emissions

- Change in building energy composition does not have much impact on CO2 emissions



Results: HFC emissions

- Median 41% increase in 2100 compared to reference scenario
- Hydrofluorocarbons (HFCs) are used as coolants across the world
- HFCs typically have much longer lifetimes and stronger radiative forcing properties than CO_2, leading to much greater GWPs



Results: Regional Building Energy Consumption

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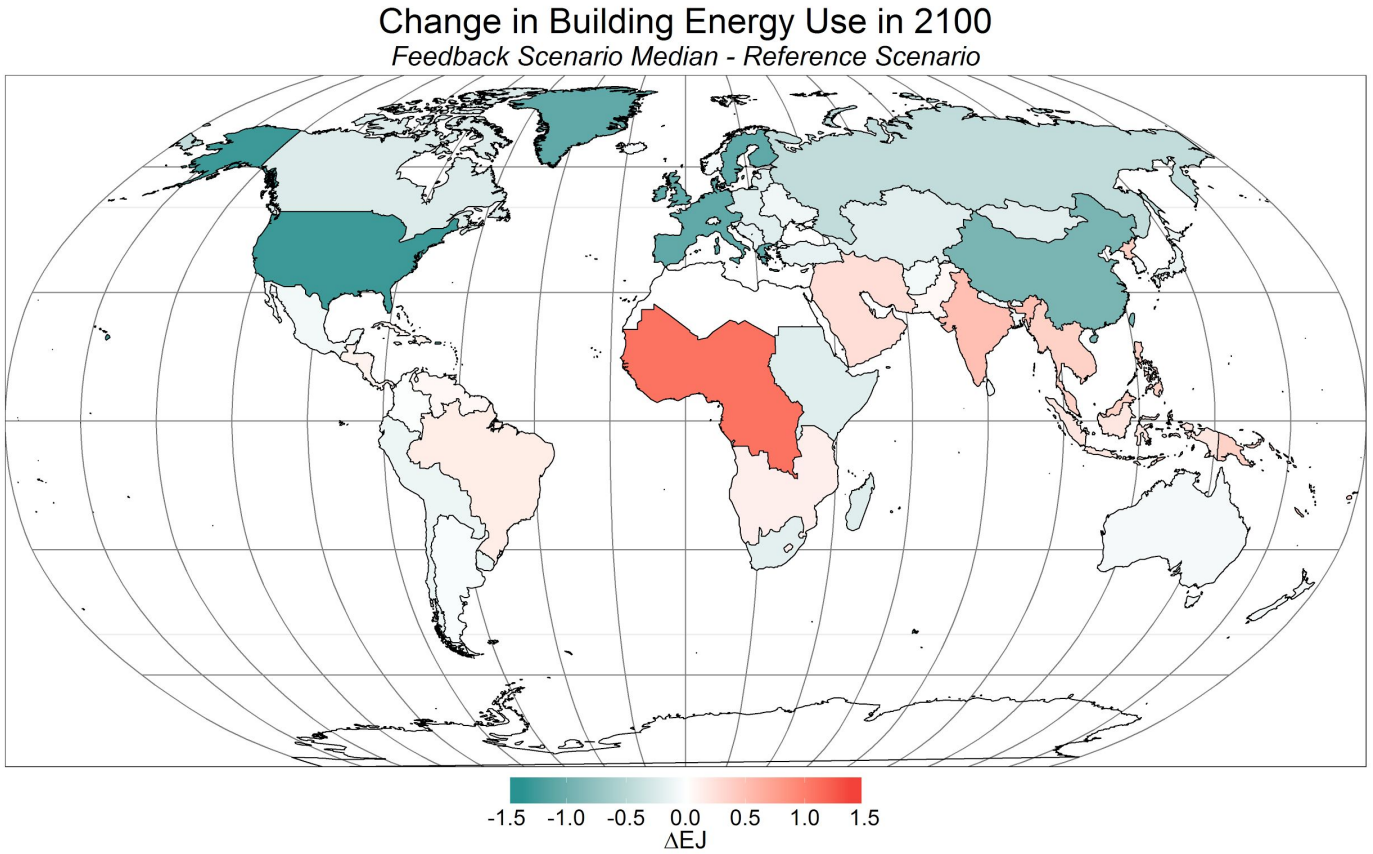
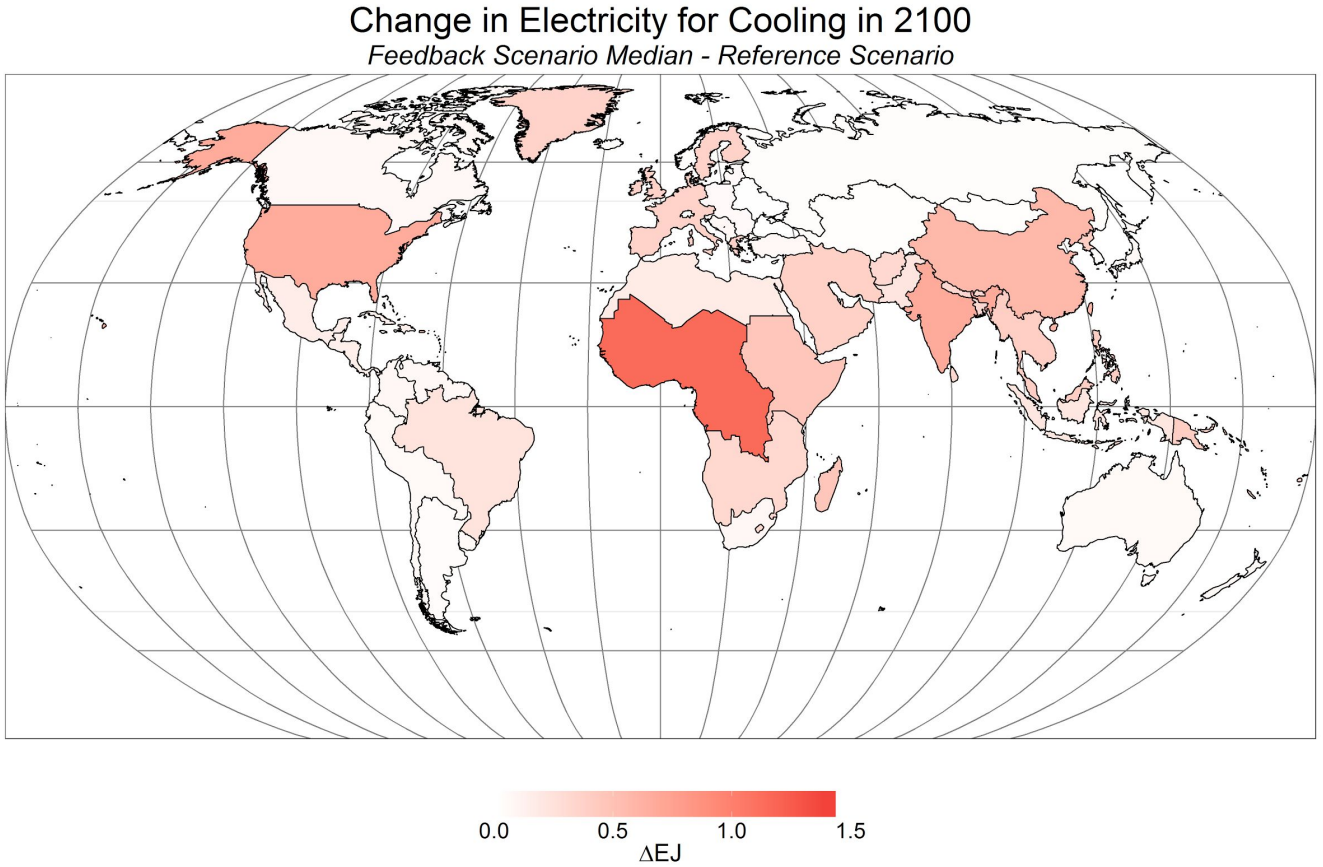
- Brazil: 3.6%
- Indonesia: 3.6%
- Western Africa: 3.5%
- India: 1.9%

- USA: -5.1%
- Canada: -7.6%
- Russia: -8.4%
- South Africa: -8.9%



Results: Regional Consumption of Electricity for Cooling

- Western Africa: 33%
- India: 32%
- USA: 61%
- China: 60%



Future Directions...

- Implications of this work:
  - Feedbacks have impact and can be captured in the new release of GCAM
  - Highlighting an easy application of feedbacks
- Future directions - feedbacks between the earth system and
  - Agriculture
  - Water
- GCAM's reference socioeconomic assumptions were used – feedback may be more impactful under scenarios with more growth in low-latitude regions
- Compare to non-constant HDD/CDD