Earth System Emulation Breakout

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on behalf of the Hector team

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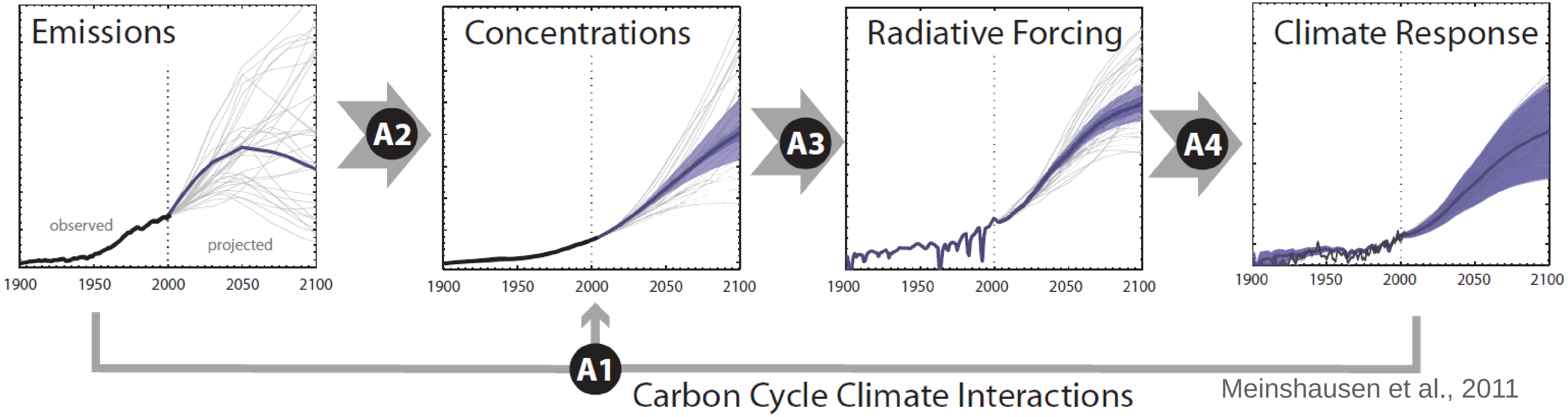
The Earth System in GCAM

The Climate System: Approach

- GCAM now uses **Hector** (no longer MAGICC) simple carbon/climate model to compute climate related outputs.
- GCAM passes emissions to the climate model
    - Fossil fuel & Industrial CO_2, Land-Use Change CO_2, CH_4, N_2O, 26 halocarbons, SO_2, CO, NO_x, NMVOCs, BC, OC
- Hector computes atmospheric CO_2 concentrations, radiative forcing (direct and indirect), temperature change, air-land/air-sea fluxes, ocean heat flux…



Meinshausen et al., 2011

Hector: Science

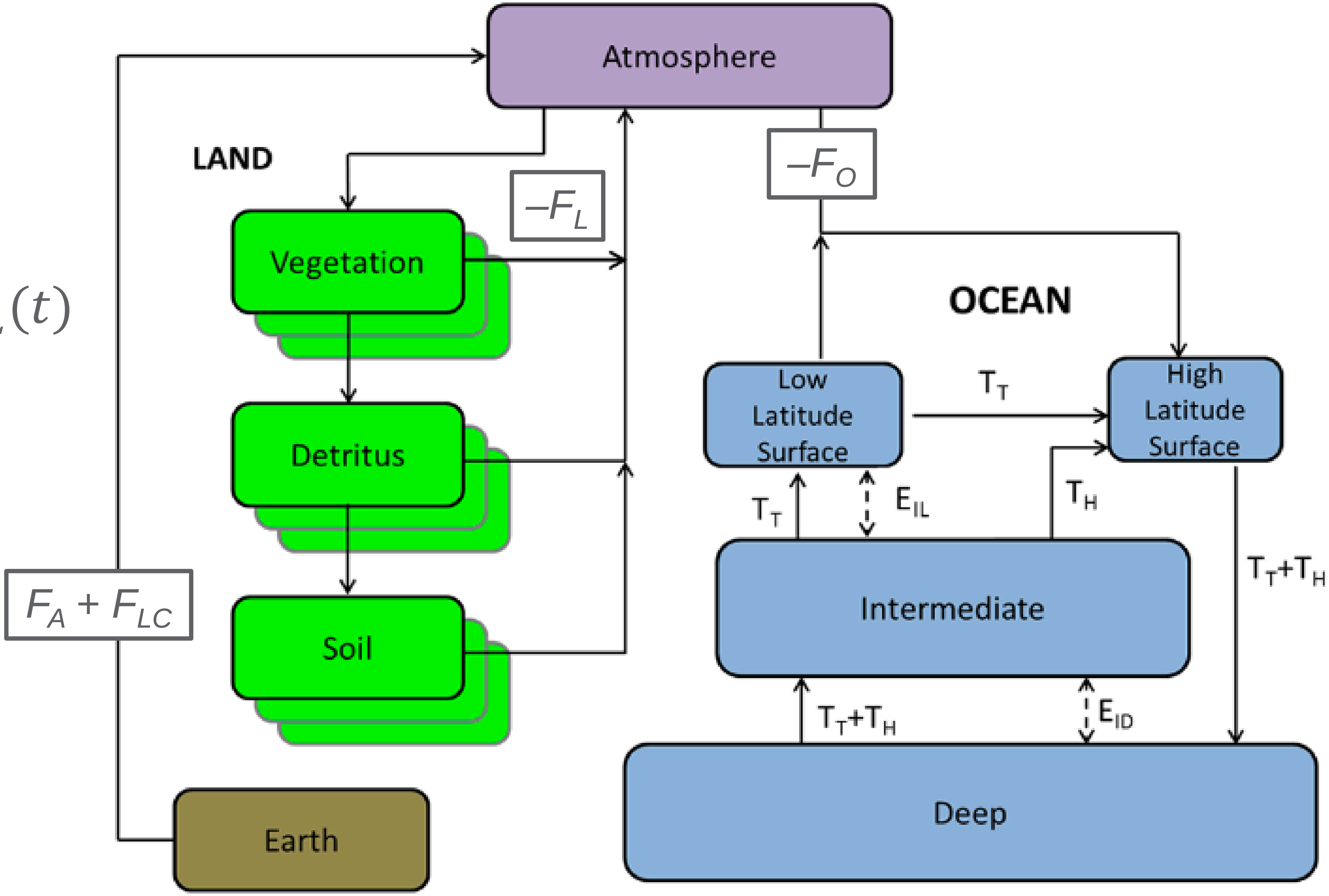
$$\Delta[CO_2]_t = F_A(t) + F_{LC}(t) - F_O(t) - F_L(t)$$

F_A : Fossil fuel emissions

F_{LC}: Land-use change emissions

F_O: Atm. → ocean flux

F_L: Atm. → land flux



Hartin et al. 2015 *GMD*

Terrestrial Carbon cycle

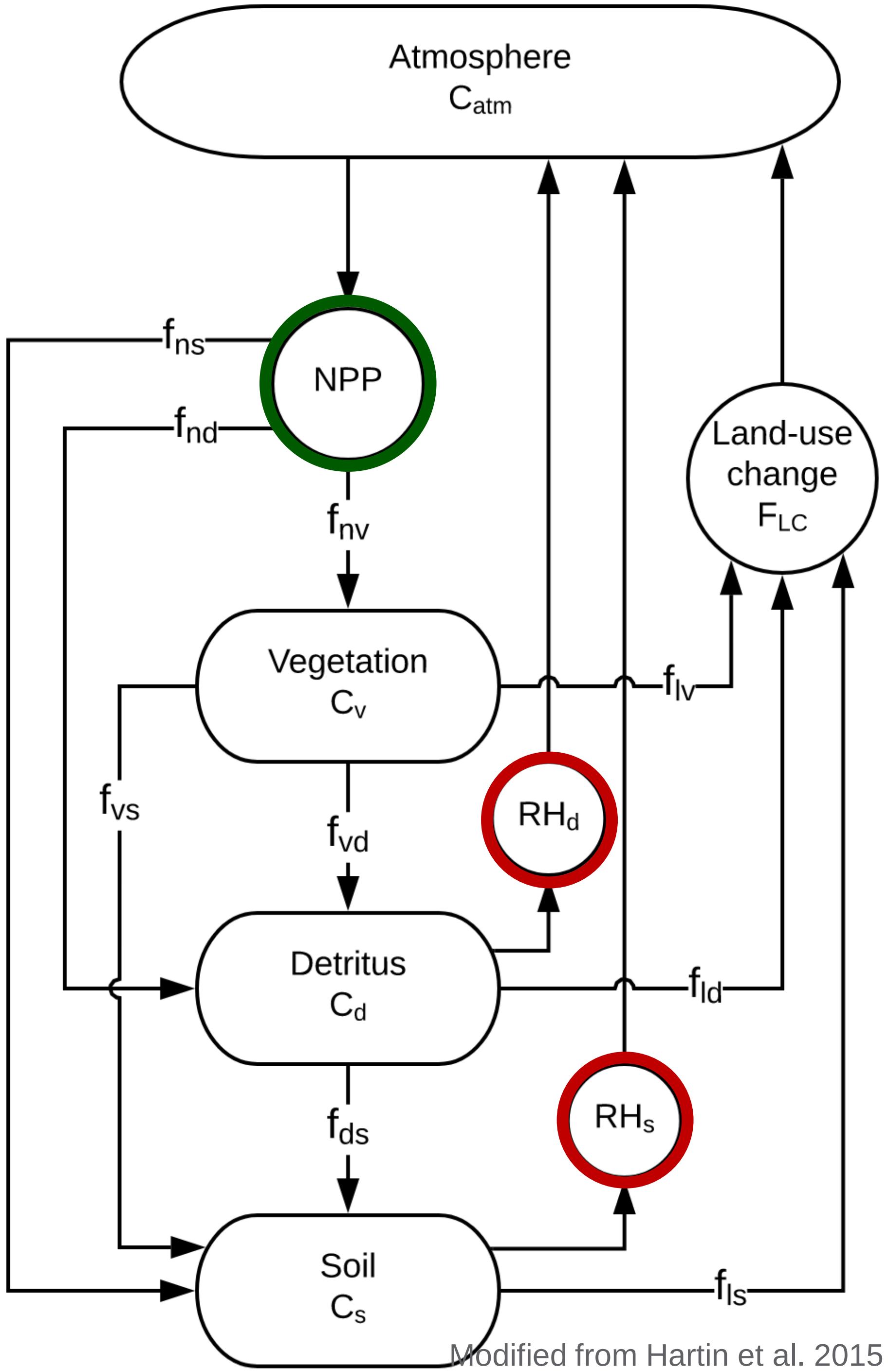
NPP: Net primary productivity (photosynthesis – plant respiration) increases with atmospheric CO_2 concentration according to parameter β:

$$NPP(t) \sim f(NPP(0), [CO_2]_t \mid \beta)$$

RH: Heterotrophic respiration (respiration by microbes) from soil and detritus increases with atmospheric temperature according to parameter Q_{10}:

$$RH_x \sim f(T_{atm} | Q_{10,x})$$

At each time step, **C gain from NPP** and **C loss from decomposition and land-use change (LC)** are **distributed between vegetation, soil, and detritus pools** according to fractionation parameters f_{ab}



Modified from Hartin et al. 2015 *GMD*

Ocean Carbon cycle

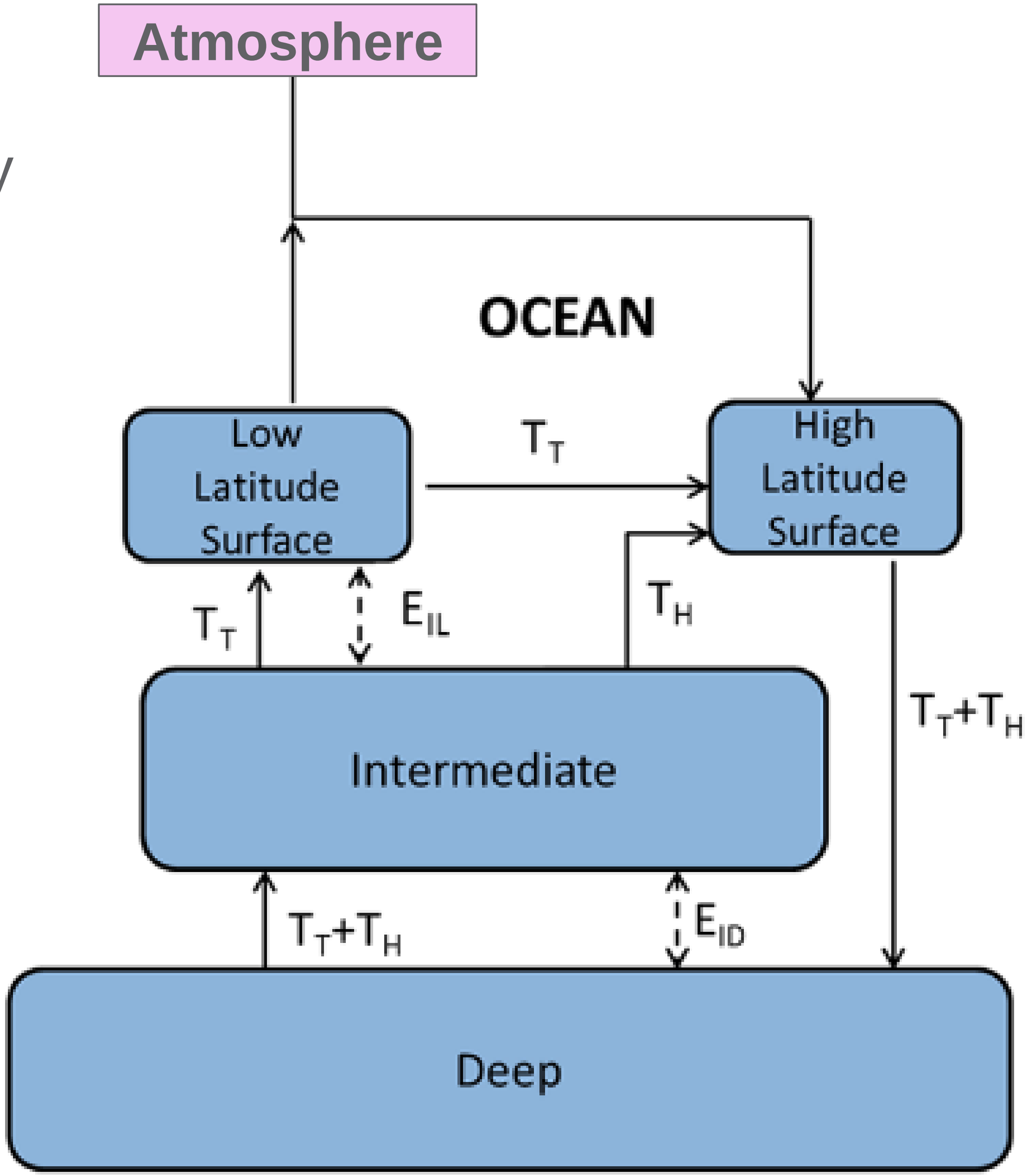
Surface boxes exchange CO_2 with the atmosphere based on the CO_2 gas transfer velocity (*k*), the solubility of CO_2 (α), and the ocean-atmosphere gradient of CO_2 partial pressure.

$$F_i(t) = k\alpha(pCO_{2,i} - pCO_{2,atm})$$

An **ocean chemistry submodel** relates total C in each ocean box to the dissolved organic C (DIC) used for these calculations.

A **simplified model of global ocean circulation** moves water (and dissolved C therein) between ocean boxes, according to the following empirical parameters:

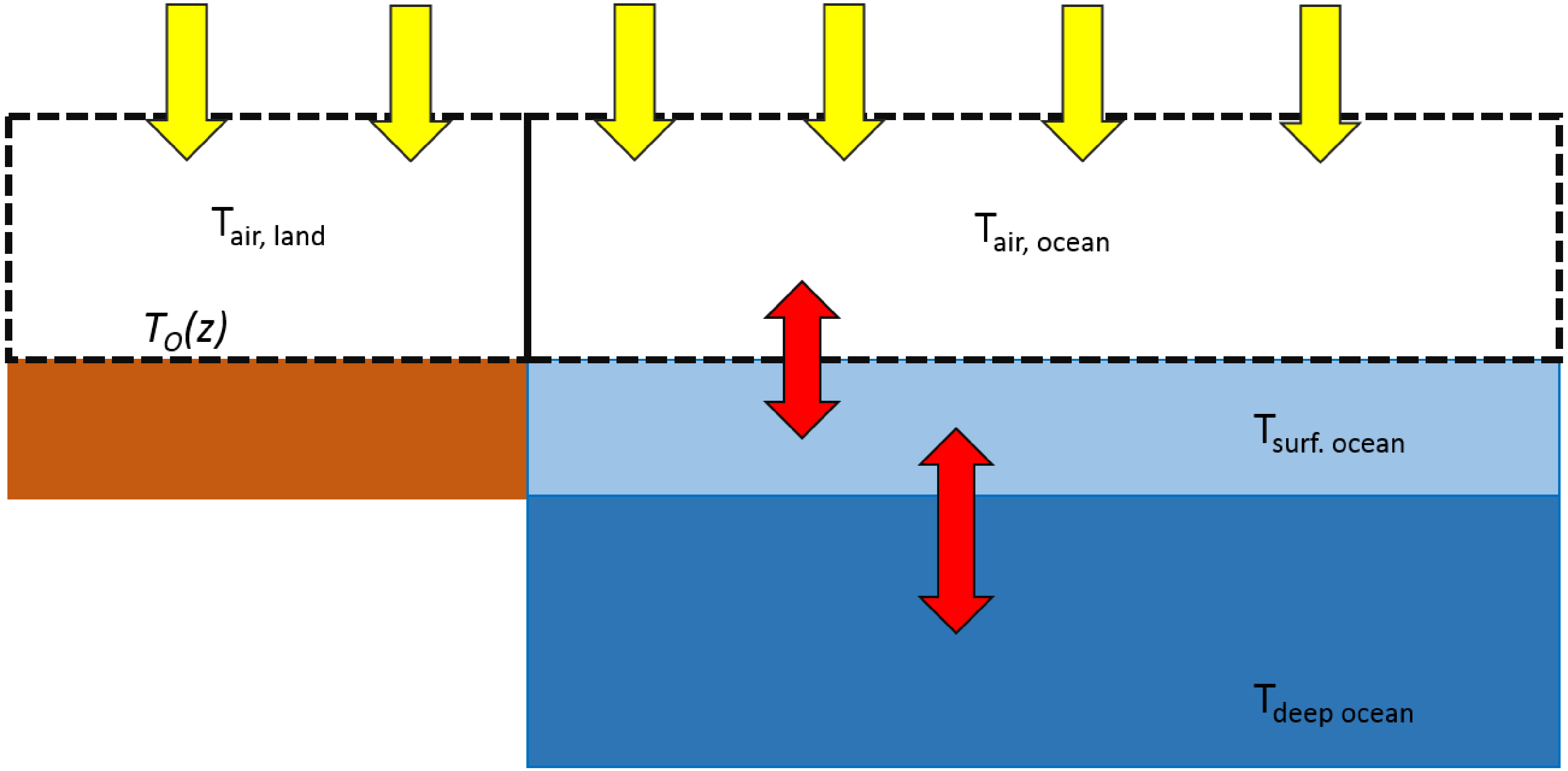
T_T : Thermohaline circulation
T_H : High-latitude circulation
E_{ID} : Water mass exchange – intermediate to deep
E_{LI} : Water mass exchange – low-latitude to intermediate



Hartin et al. 2015 *GMD*

Incorporated a diffusive ocean energy balance model into Hector - DOECLIM

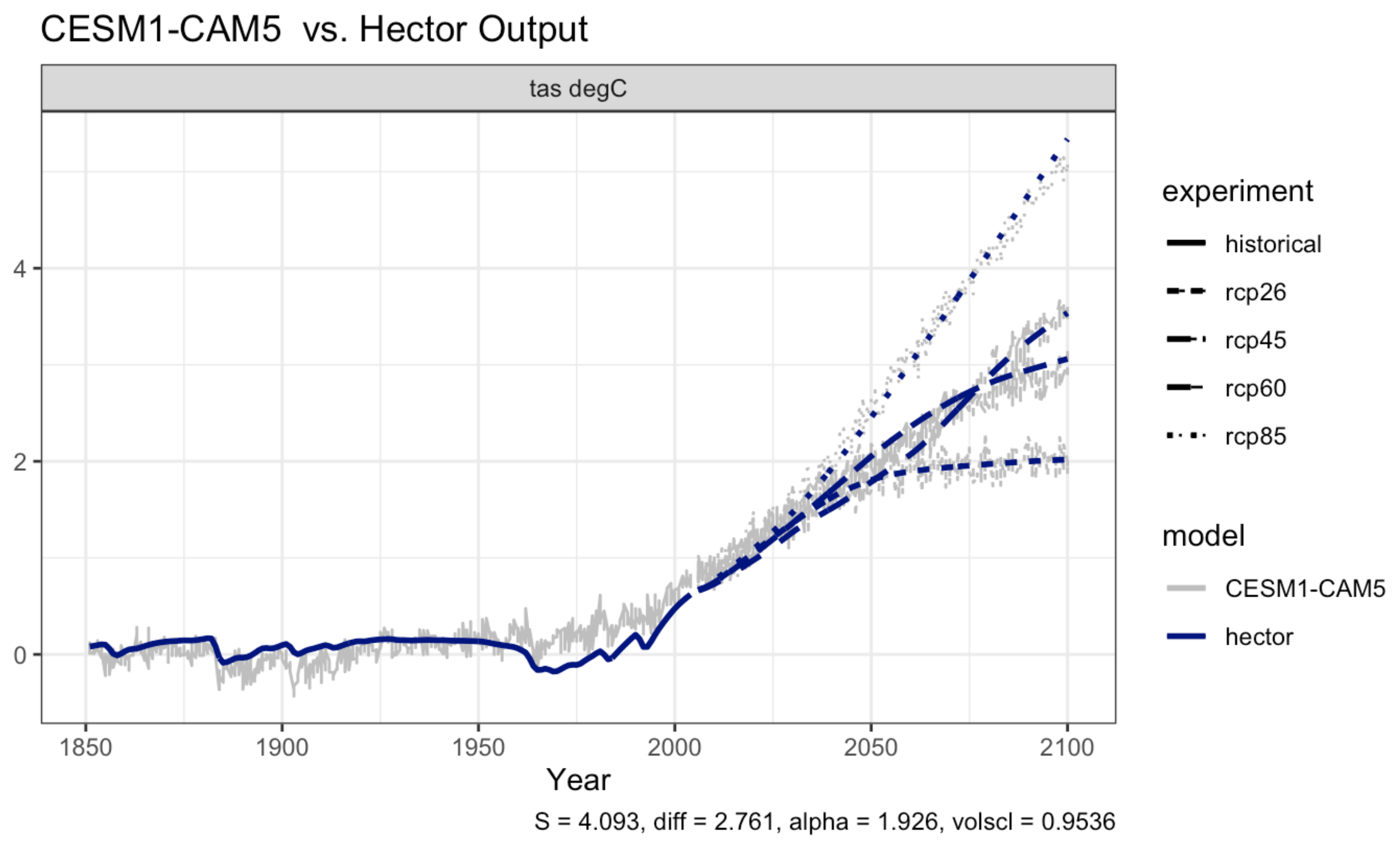
Hector outputs:
Air temperature over land
Air temperature over ocean
Ocean surface temperature
Global Mean Temperature
Ocean heat uptake/flux



Hector emulates the CMIP5 median and individual models*

* CMIP6 near future

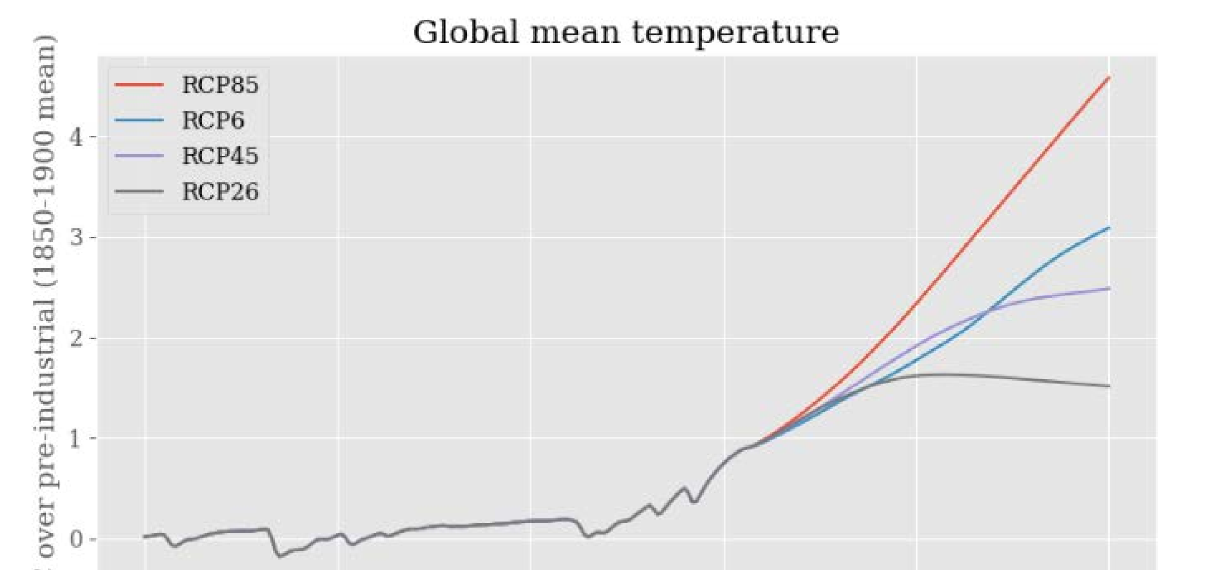
Hector Outputs:
Atmospheric CO_2
Concentrations of GHGs
Radiative Forcing – total and individual
Global Mean Temperature
Ocean Surface Temperature
Net Primary Production
Heterotrophic Respiration
Ocean Acidification



Dorheim et al., submitted JAMES

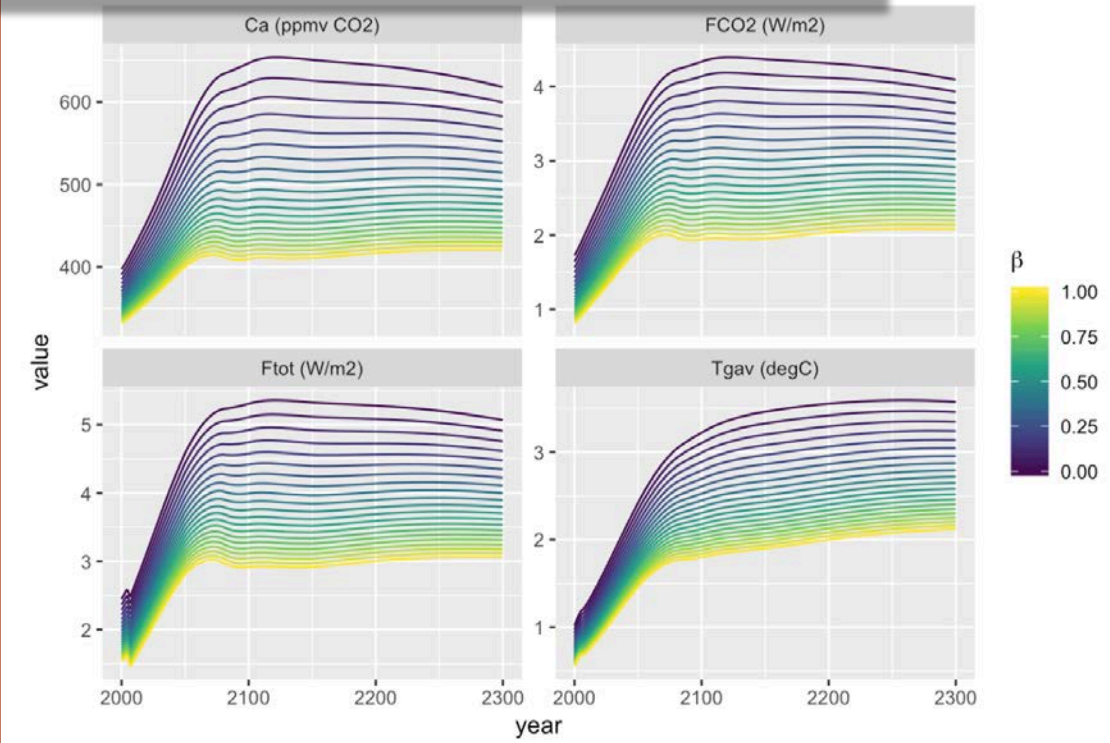
User Friendly Applications - pyhector and rhector

```python
import pyhector
from pyhector import rcp26, rcp45, rcp60, rcp85

import matplotlib.pyplot as plt

for rcp in [rcp26, rcp45, rcp60, rcp85]:
    output = pyhector.run(rcp, {"core": {"endDate": 2100}})
    temp = output["temperature.Tgav"]
    # Adjust to 1850 - 1900 reference period
    temp = temp.loc[1850:] - temp.loc[1850:1900].mean()
    temp.plot(label=rcp.name.split("_")[0])
plt.title("Global mean temperature")
plt.ylabel("°C over pre-industrial (1850-1900 mean)")
plt.legend(loc="best")
plt.show()
```



https://github.com/openclimatedata/pyhector

```r
run_with_beta <- function(value) {
  setvar(core, NA, BETA(), value, "(unitless)")
  reset(core)
  run(core)
  result <- fetchvars(core, 2000:2300)
  result[["beta"]] <- value
  result[["variable_unit"]] <- with(result, {
    sprintf("%s (%s)", variable, units)
  })
  result
}

mapped <- Map(run_with_beta, seq(0, 1, 0.05))
sensitivity_beta <- Reduce(rbind, mapped)
```



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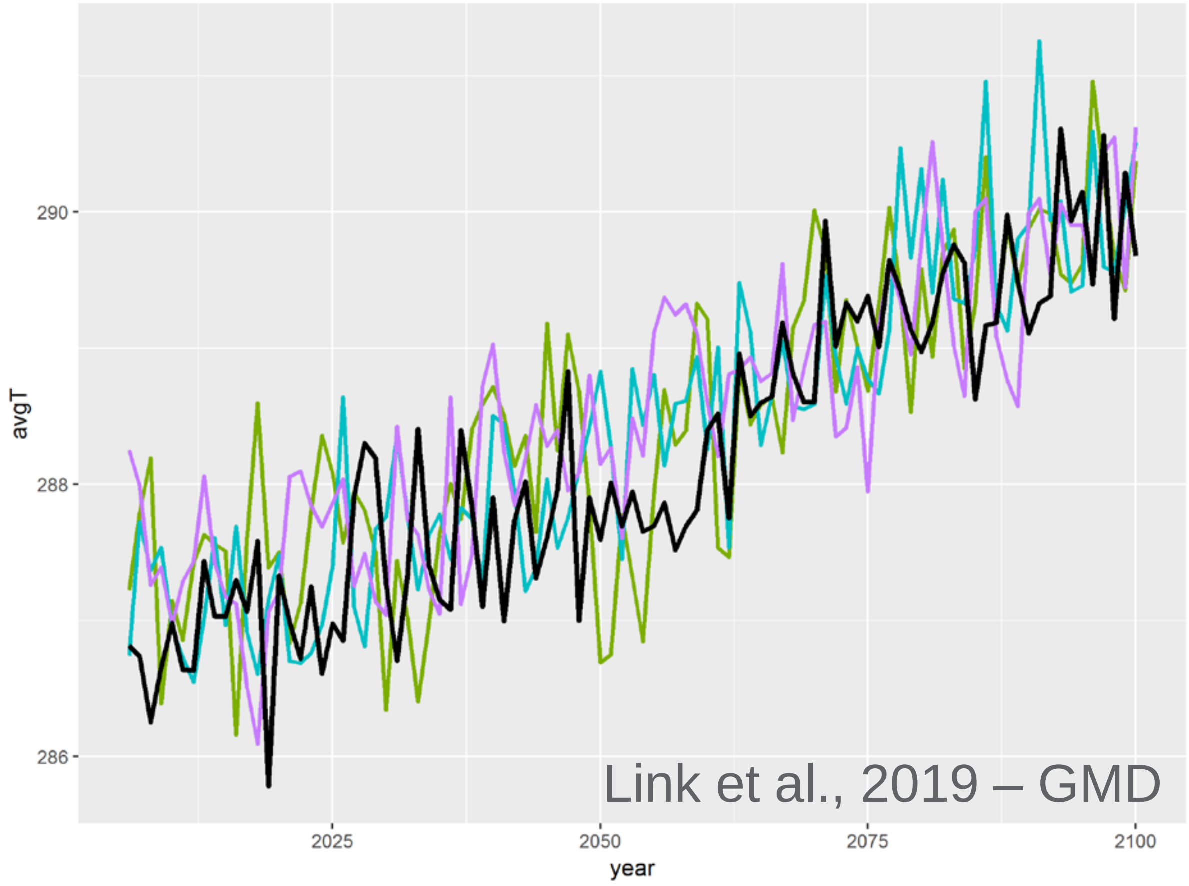
Regional Climate Emulation

- Impact studies require emulation that includes short-term variability and extremes.

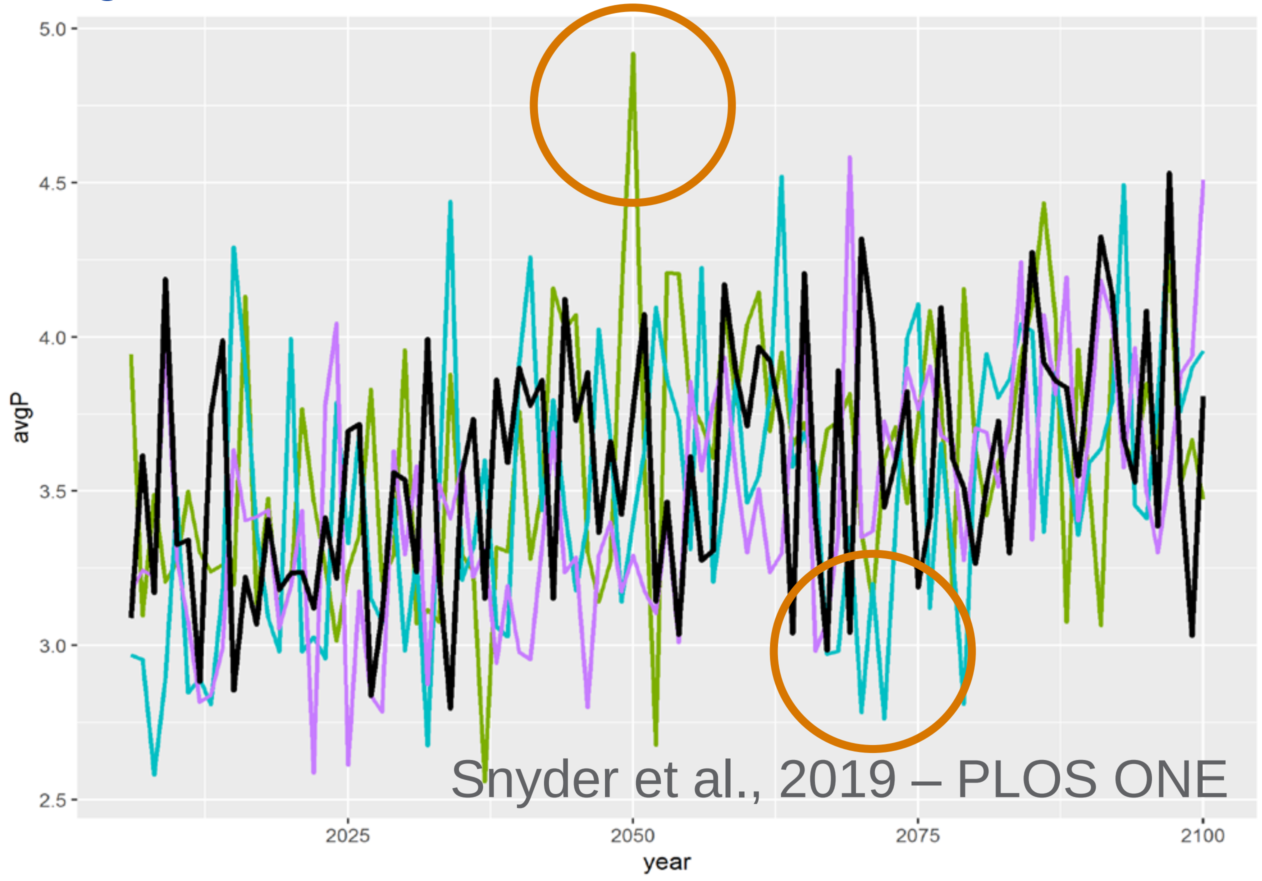
Temperature (K)

www.github.com/JGCRI/fldgen



Link et al., 2019 – GMD

Precipitation (mm/day)



Snyder et al., 2019 – PLOS ONE

Future Directions and Model Improvements

- Multiple biome capability
  - Permafrost
- Sea-level rise
  - BRICK (Wong et al., 2017)
- Subannual temperature and precipitation
  - Machine learning techniques
- Albedo changes
- Emulating CMIP6 models

Next up:

- R demo ~ 5 mins
- Online interface demo ~ 5 mins
- Open Discussion
  - What is the community currently using SCMs for?
  - What capabilities would make life easier?
  - Temporal and spatial resolutions?

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Thank you