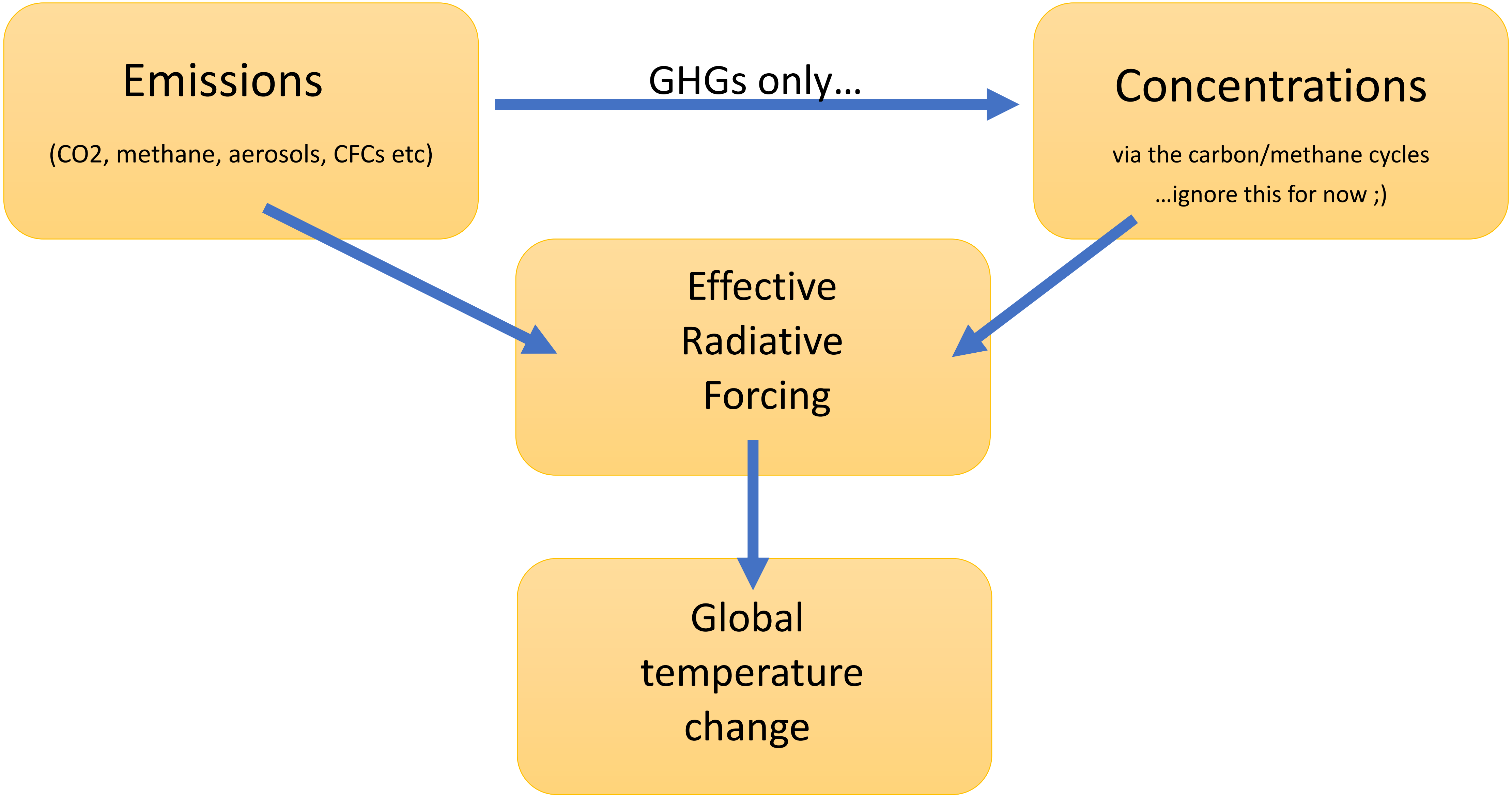
FaIR overview

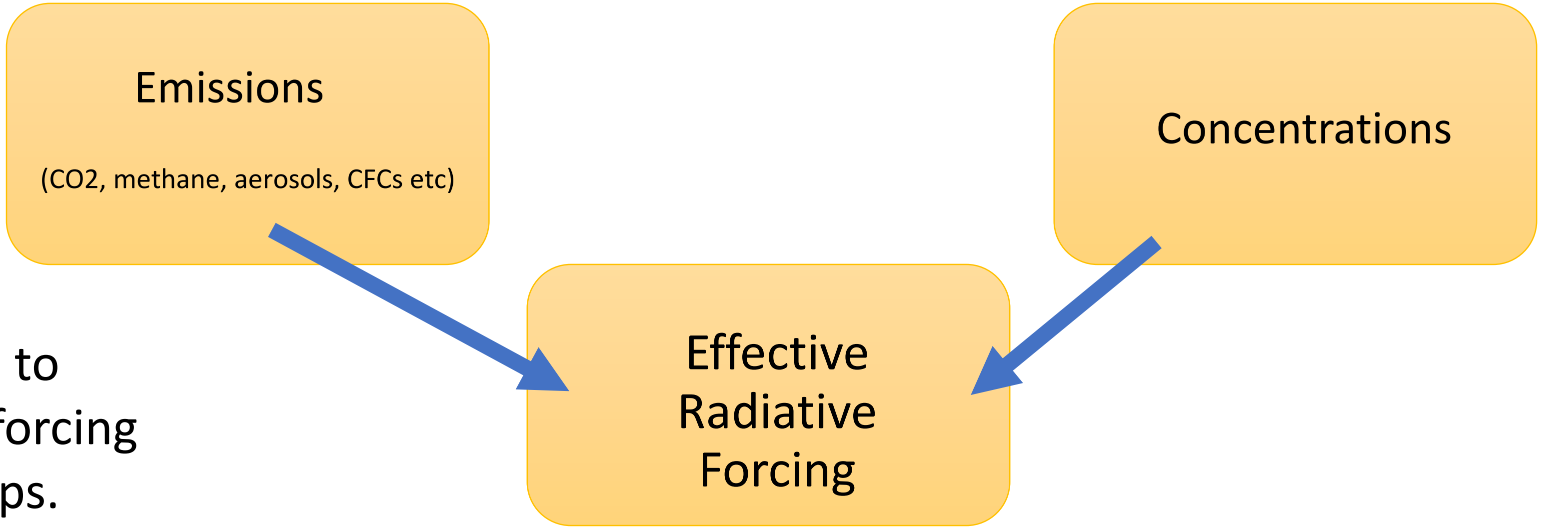
- **F.a.I.R.** ~ **F**inite **A**mplitude **I**mpulse-**R**esponse model
- A simple, Python-based climate model which is idealized enough to run in a few seconds on your laptop but can also be used to explore interesting climate behaviour!
- General idea is, specify some input emissions, and the model gives you GHG concentrations, effective radiative forcing and temperature change. ☺
- We're going to try and use this model to explore:
  - The different responses of climate to greenhouse gases and aerosols
  - …and the role of feedbacks and uncertainty in the historical response.

(Smith et al., GMD, 2018)

FaIR schematic



Radiative Forcing



- For some well-mixed GHGs, it's possible to relate their concentrations to radiative forcing using simple, semi-empirical relationships.

- For aerosols, it's much more complicated(*) and few closed analytical expressions exist.

    - *Question: Why could this be? What's different about aerosols?

$$\mathcal{F}_{\mathrm{CO_2}}(t) = \frac{\mathcal{F}_{\mathrm{2xCO_2}}}{\ln(2)} \ln\left(\frac{[\mathrm{CO_2}]_t}{[\mathrm{CO_2}]_{\mathrm{PI}}}\right)$$

$$\mathcal{F}_{\mathrm{SO_2}}(t) = -\alpha\left[\mathrm{SO_2}\right]_t - \beta \ln\left(\frac{\left[\mathrm{SO_2}\right]_{\mathrm{ant}}}{\left[\mathrm{SO_2}\right]_{\mathrm{nat}}} + 1\right)$$

$$\mathcal{F}_{\mathrm{CH_4}}(t) \sim \sqrt{[\mathrm{CH_4}]_t - [\mathrm{CH_4}]_{\mathrm{PI}}}$$

$$\mathcal{F}_{\mathrm{N_2O}}(t) \sim \sqrt{[\mathrm{N_2O}]_t - [\mathrm{N_2O}]_{\mathrm{PI}}}$$

Radiative forcing of Aerosol Radiation Interactions

A highly simplified model of (global mean) “direct” aerosol forcing:

Molecular weight factor

Anthropogenic SO_2 source

Lifetime

Sulfate yield

Mass extinction

$$\overline{RF}_{ari} = -\alpha\overline{Q}_a = -\eta\left(\frac{C_r E_r K T_* \frac{3}{2} Y}{\Omega}\right)\overline{Q}_a$$

Scaling from sulfate to total forcing

Effective clear-sky fraction

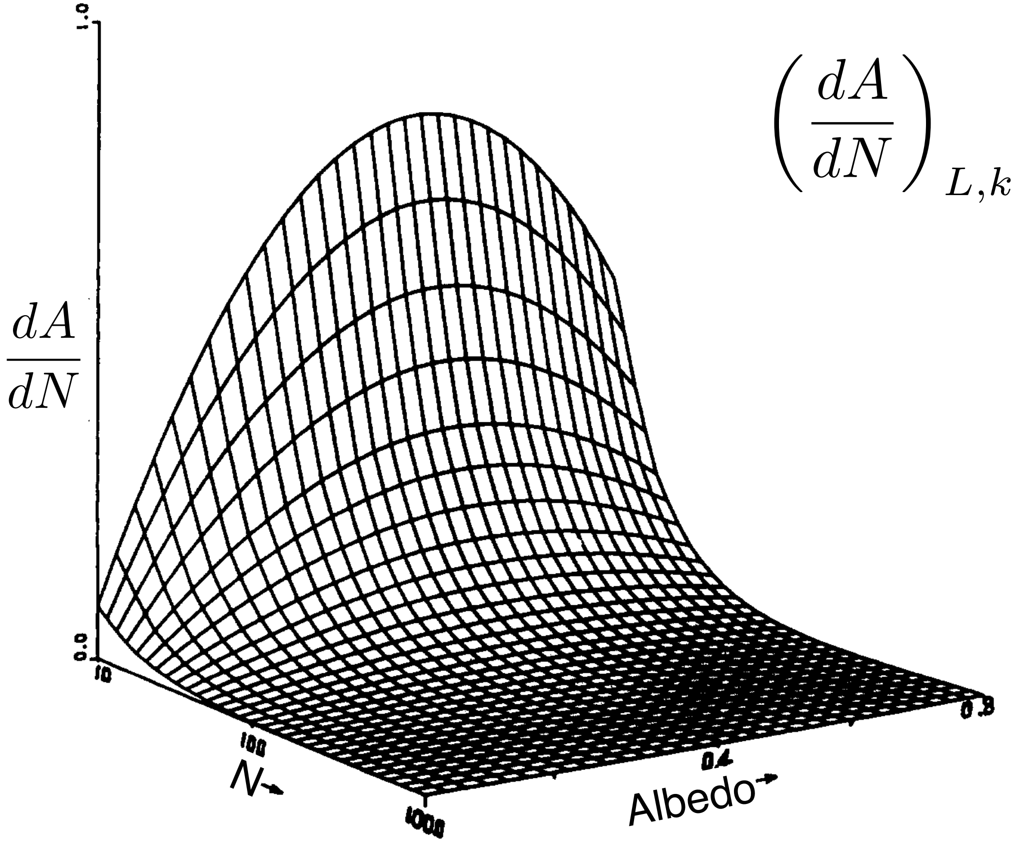
Forcing efficiency

Earth’s surface area

(Stevens et al., J.Clim., 2015; note numerous strong assumptions)

Radiative forcing of Aerosol Cloud Interactions

Cloud Albedo Effect (Twomey 1977, 1991)



$$\left(\frac{dA}{dN}\right)_{L,k,h} = \frac{A(1-A)}{3N}$$

Important

This assumes constant:

- liquid water content (L)
- cloud depth h
- droplet spectrum shape (k)

Albedo susceptibility of clouds for range of albedos and cloud droplet numbers

(As derived by Johannes Quaas, adapted from Twomey, 1991)

Radiative forcing of Aerosol Cloud Interactions

A highly simplified model of (global mean) "indirect" aerosol forcing:

$$\overline{RF}_{aci} = -\beta \ln\left(\frac{\overline{Q}_a}{\overline{Q}_n} + 1\right) = -CE\left(\frac{\overline{\delta N}}{\overline{N}}\right)$$

Anthropogenic SO_2 source

Effective liquid cloud fraction

Anthropogenic aerosol induced change

Scaling factor

Natural aerosol source

Cloud radiative forcing efficiency

Cloud droplet concentration

(Stevens et al., J.Clim., 2015; note numerous strong assumptions)

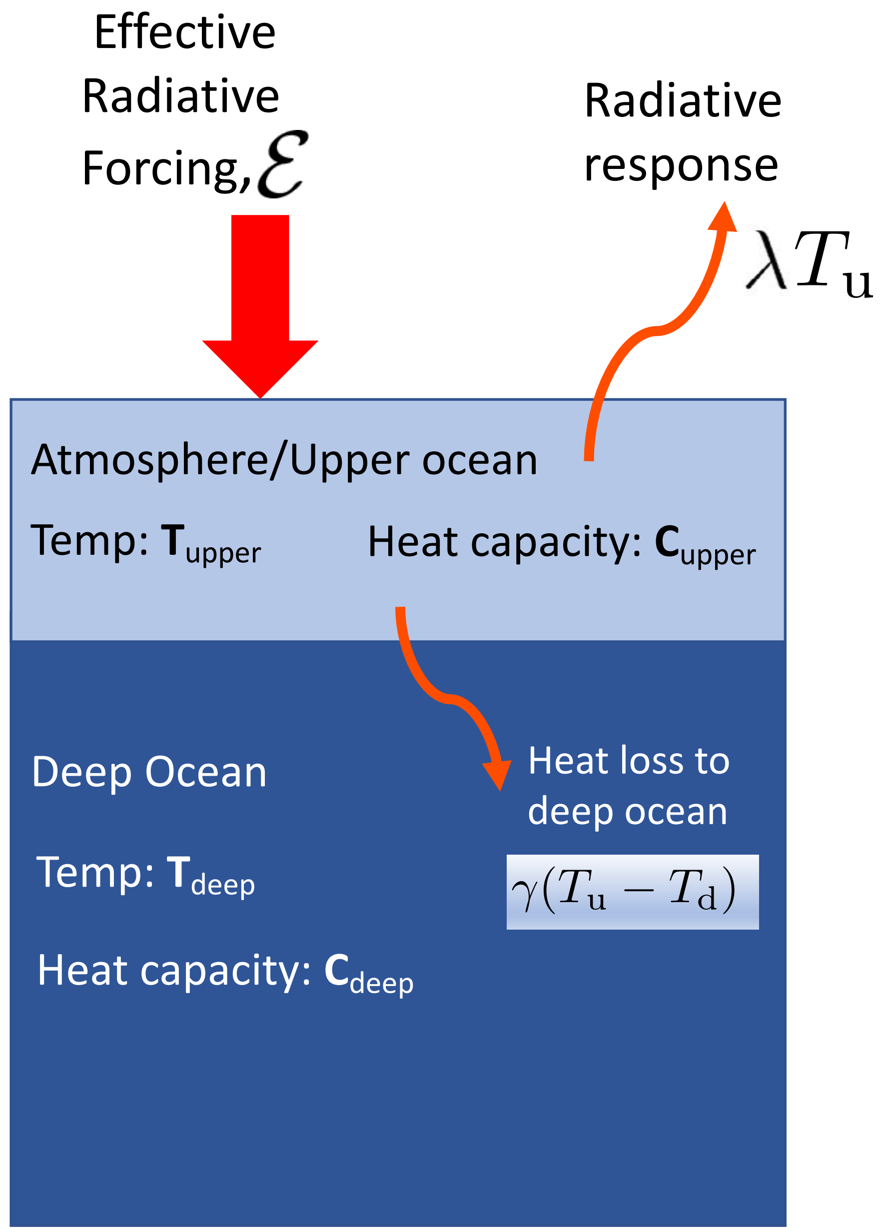
From Radiative Forcing --> Temperature

- **FaIR** uses a *two-layer* “energy balance model” to represent the combined atmosphere-ocean system and its response to forcing.

$$\overbrace{C_{\mathrm{u}}\frac{dT_{\mathrm{u}}}{dt} = \mathcal{E}}^{\text{External forcing warms the surface-layer}} - \overbrace{\lambda T_{\mathrm{u}}}^{\text{Surface layer responds to forcing}} - \underbrace{\gamma(T_{\mathrm{u}} - T_{\mathrm{d}})}$$

$$C_d\frac{dT_{\mathrm{d}}}{dt} = \gamma(T_{\mathrm{u}} - T_{\mathrm{d}})$$

Deep ocean warms due to heating from above, acts as a “heat sink”.



(Geoffroy et al., J.Clim, 2013)

Aims:

- Next, we're going to fire up the FaIR model and use it to investigate
  - The response of climate to CO_2 emissions
  - How this differs when we instead consider anthropogenic aerosol.
  - How these two forcings, coupled with climate feedbacks, give us the historical temperature record we observe!