SMHI

CRESCENDO

Colin Jones

SMHI/University of Leeds

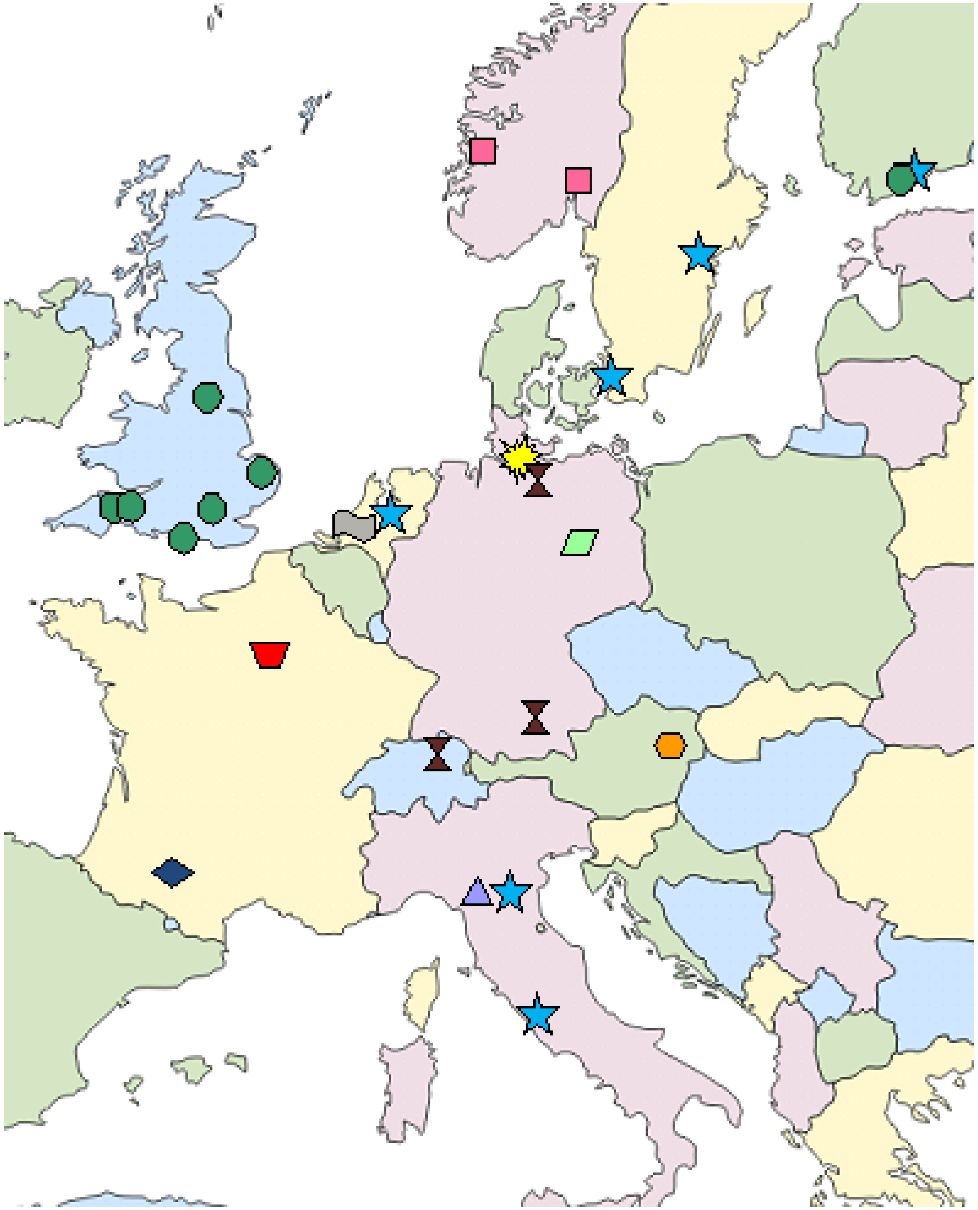
CRESCENDO

SMHI

- CRESCENDO is a European Union Horizon 2020 research project that works to further develop mathematical/computer models used to understand and predict the **future evolution of the Earth´s climate** (over the coming ~ 10 to 100 years).
- **Earth System Models** (ESMs) developed by CRESCENDO´s scientists are cutting-edge tools used to study the response of the global environment to past (observed) and future (scenarios) of human greenhouse gas emissions.
- There are 7 ESMs from different parts of Europe involved in CRESCENDO.
- CRESCENDO is also committed towards engaging with **society** through **communication and outreach** activities.

CRESCENDO: 25 institutes, ~100 researchers from 10 countries

SMHI



Earth System Model ***(Contributing partners)***

- CNRM-ESM *(MF-CNRM)*
- CMCC-ESM *(CMCC)*
- EC-Earth *(ENEA, FMI, CNR, KNMI, SMHI, ULUND)*
- IPSL-ESM *(CNRS-IPSL)*
- MPI-ESM *(MPG)*
- NorESM *(UiB, METNO)*
- UKESM *(MOHC, NOC, UNEXE, UEA, UNIVLEEDS, UREAD, FMI)*

Integrated Assessment Model ***(Contributing partners)***

- IMAGE *(PBL)*
- MESSAGE/GLOBIOM *(IIASA)*
- REMIND/MAgPIE *(PIK)*

Partners expert in ESMVal Tool and Emergent Constraints

- *DLR, ETH, UHAM*, *LMU*

Develops and uses

Global Climate Models

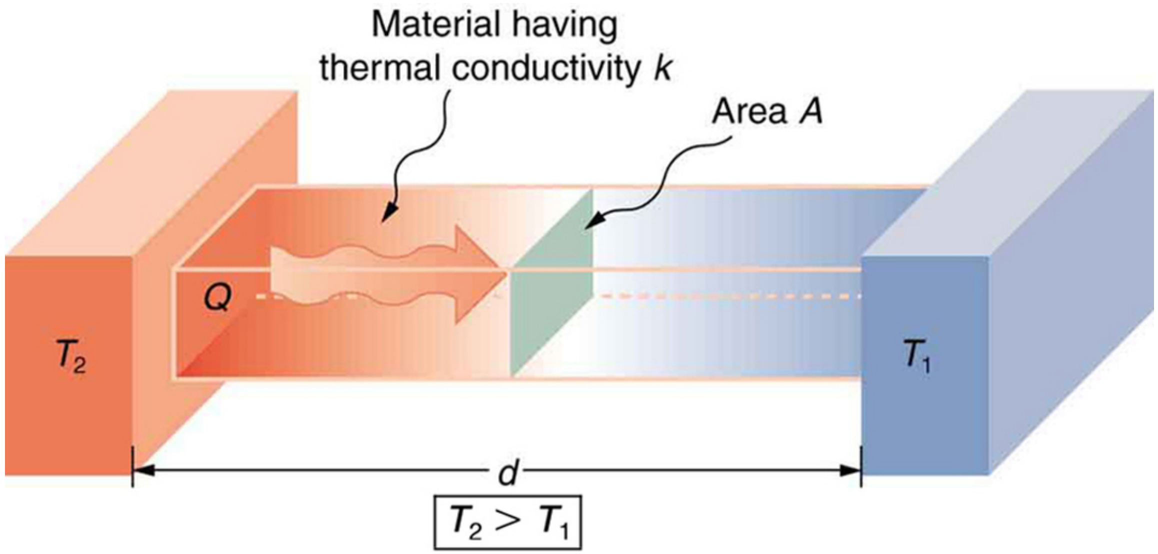
OR

Earth system models

What is a model ?

A mathematical representation of something in the real world
that allows us to understand and predict the behaviour of that part
when it is subject to different external and internal forcing agents

A model to predict the diffusion of heat through a material with a thermal conductivity = *k*



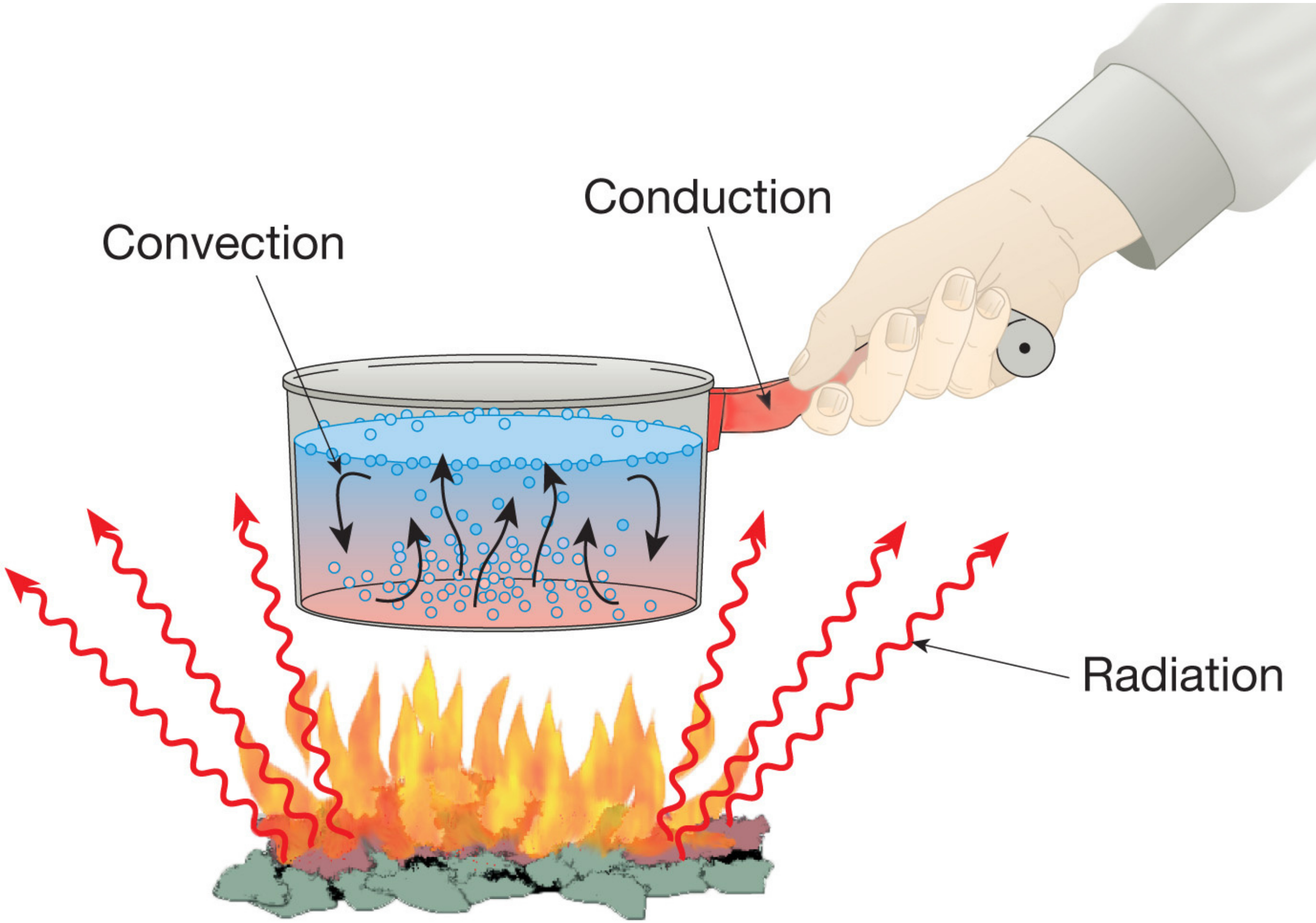
$$\frac{\partial T}{\partial t} = \kappa \nabla^2 T + f$$

$$\nabla^2 T = \partial^2_{xx} T + \partial^2_{yy} T + \partial^2_{zz} T$$

CRESCENDO

SMHI

A model to predict how rapidly a pan of water will boil



CRESCENDO

SMHI

A model to predict plant growth

CRESCENDO

SMHI

A model to predict plant growth : External/Internal forcing agents

CRESCENDO

SMHI

A model to predict plant growth : External/Internal forcing agents

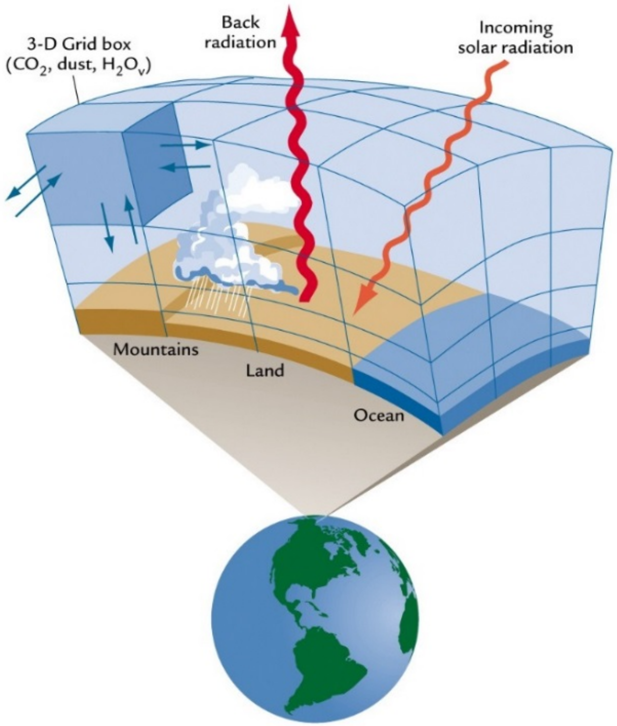
CRESCENDO

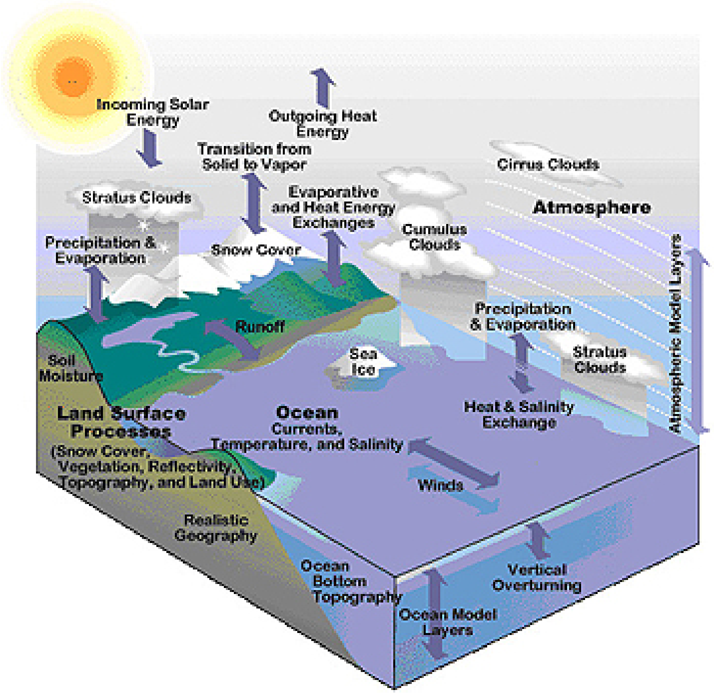
SMHI

A model to predict plant growth : External/Internal forcing agents

Global Climate Models try to represent all the coupled **physical and dynamical** components of the climate system: **ocean, atmosphere, land, sea-ice** including interactions between them

e.g. radiation, clouds, precipitation, winds, convection, ocean currents, ocean heat uptake, sea-ice, soil physics, snow processes etc etc: all coupled to each other





Global Climate Models are used to estimate the future climate response to a range of plausible Scenarios **of atmospheric CO_2 concentrations** derived from (simple) socio-economic models

Navier-Stokes Equations
3 – dimensional – unsteady

Glenn Research Center

Coordinates: (x,y,z)

Velocity Components: (u,v,w)

Time : t

Density: ρ

Total Energy: Et

Pressure: p

Stress: τ

Heat Flux: q

Reynolds Number: Re

Prandtl Number: Pr

Continuity:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0$$

X – Momentum:

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u^2)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = -\frac{\partial p}{\partial x} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z}\right]$$

Y – Momentum:

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho v^2)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = -\frac{\partial p}{\partial y} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z}\right]$$

Z – Momentum

$$\frac{\partial(\rho w)}{\partial t} + \frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \frac{1}{Re_r}\left[\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}\right]$$

Energy:

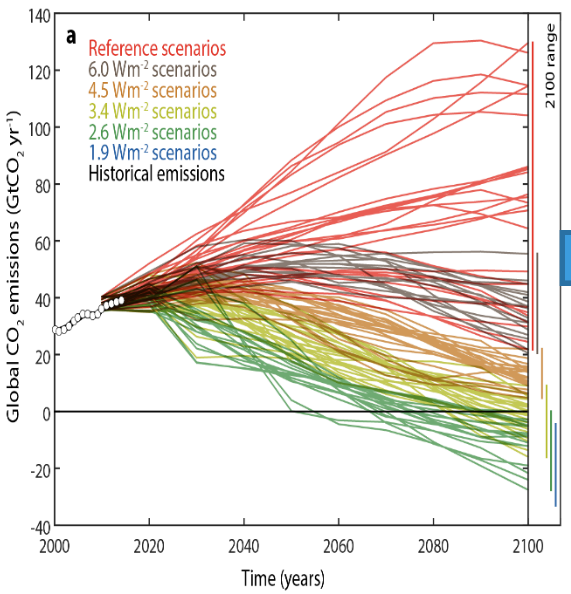
$$\frac{\partial(E_T)}{\partial t} + \frac{\partial(uE_T)}{\partial x} + \frac{\partial(vE_T)}{\partial y} + \frac{\partial(wE_T)}{\partial z} = -\frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} - \frac{1}{Re_r Pr_r}\left[\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} + \frac{\partial q_z}{\partial z}\right]$$

$$+ \frac{1}{Re_r}\left[\frac{\partial}{\partial x}(u\,\tau_{xx} + v\,\tau_{xy} + w\,\tau_{xz}) + \frac{\partial}{\partial y}(u\,\tau_{xy} + v\,\tau_{yy} + w\,\tau_{yz}) + \frac{\partial}{\partial z}(u\,\tau_{xz} + v\,\tau_{yz} + w\,\tau_{zz})\right]$$

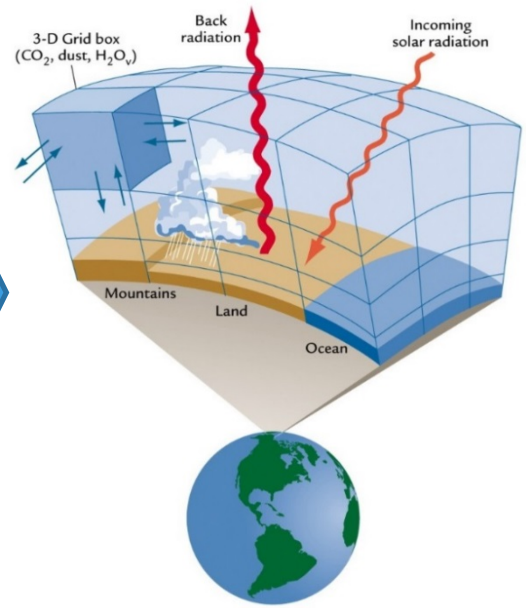
Making future climate projections with GCMs

The typical chain of events

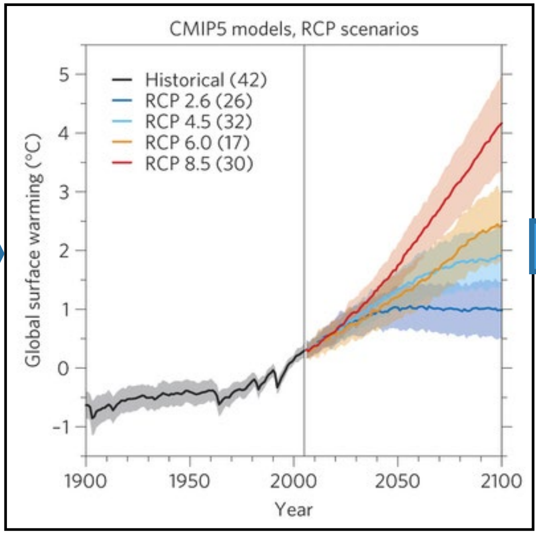
A range of plausible future human emissions of GHGs, land-use & other pollutants



Are used to run a set of GCMs over the coming ~100 years



Climate change projections from these models are used to inform governments and to assess the impacts of climate change



Climate Change Impact Models

Navier–Stokes equations *(general)*

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right) = -\nabla p + \nabla\cdot\mathbf{T} + \mathbf{f}$$

Global Climate Models

to

Earth system models

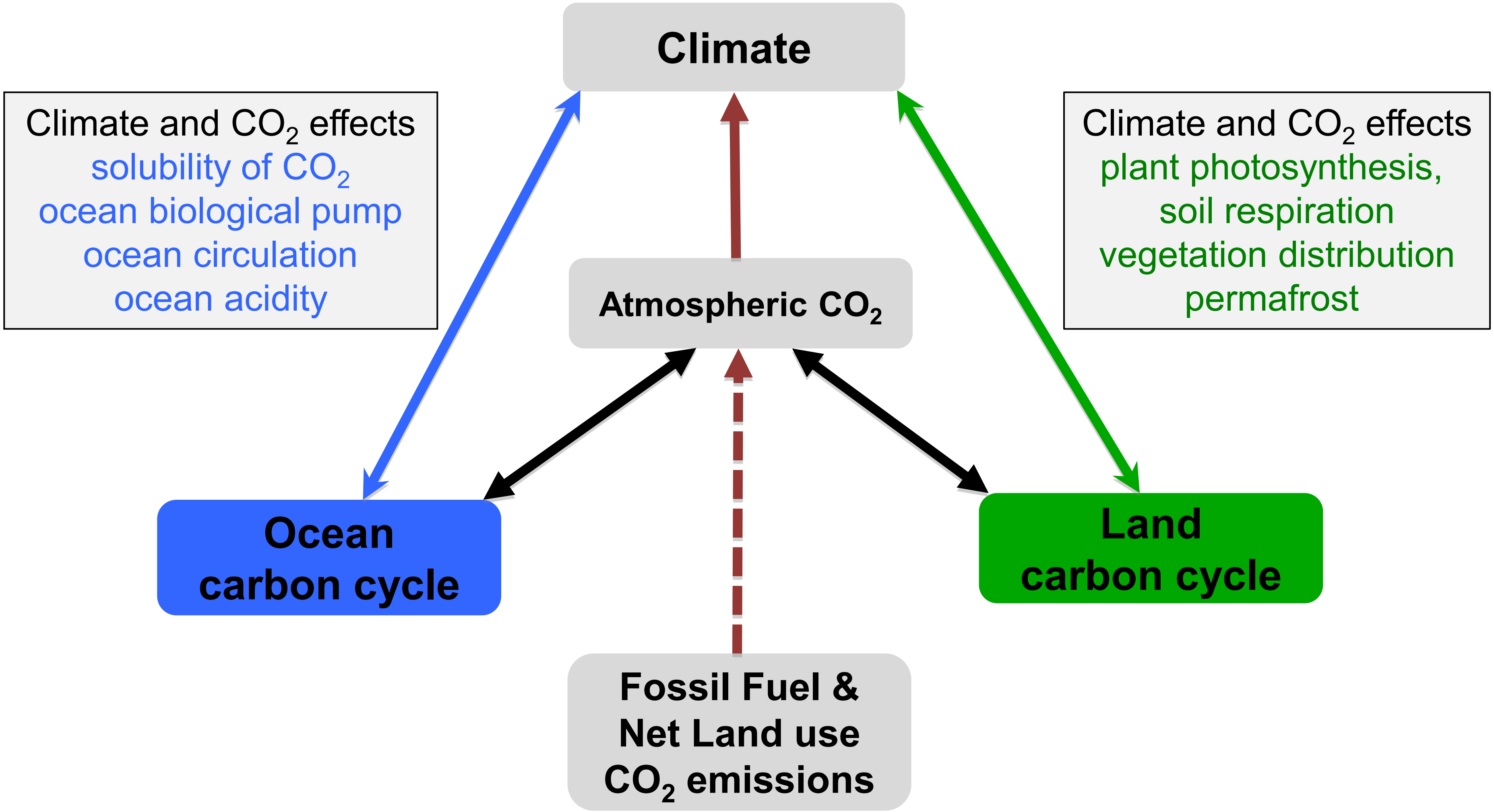
Only ~50% of the CO_2 emitted by human activities stays in the atmosphere

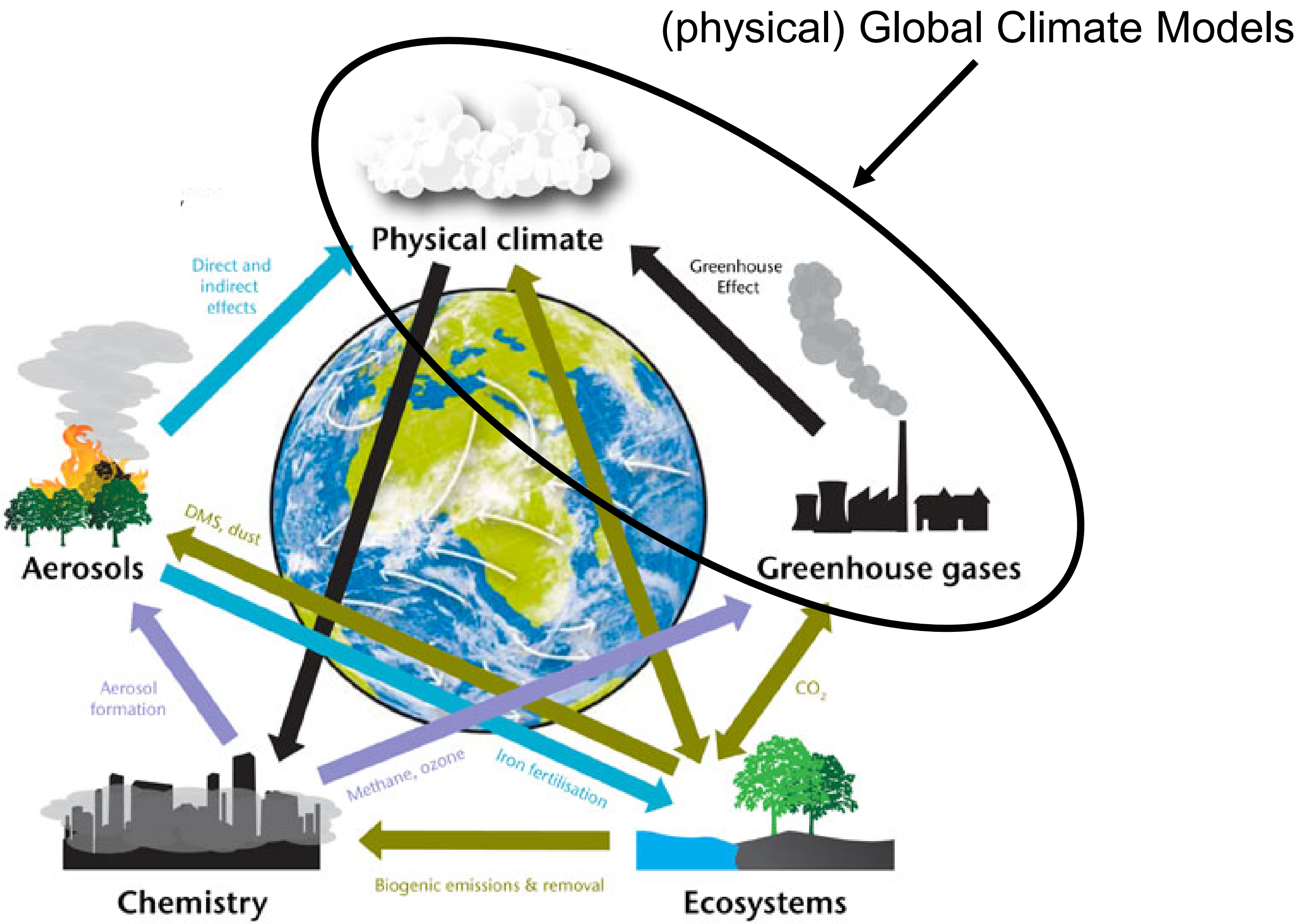
The other ~50% is absorbed by the terrestrial biosphere and the global oceans

This is a strong negative feedback on climate warming resulting from CO_2 emissions

If the efficiency of these sinks changes in the future a larger/smaller fraction of CO_2 may stay in the atmosphere amplifying/decreasing warming per unit of emitted CO_2

Feedbacks involving a warming climate, increasing CO_2 concentrations and the Earth's carbon cycle: Earth system models must accurately represent such feedbacks




(physical) Global Climate Models
Physical climate
Direct and indirect effects
Greenhouse Effect
Aerosols
Greenhouse gases
DMS, dust
Aerosol formation
CO_2
Methane, ozone
Iron fertilisation
Biogenic emissions & removal
Chemistry
Ecosystems

Earth system models