A simple model of the climate system

Background

By using the concepts of radiative forcings, climate feedbacks and ocean heat uptake we can make a conceptual model that make use of the above three concepts to demonstrate how temperature changes are influenced by the three parameters.

Mathematically it contains two equations: One for the upper ocean and one for the deep ocean. The two are connected through a heat transfer parameter γ which transfer heat from the upper to the deeper ocean.

The upper ocean is given as:

$$c_{mix}\frac{d\Delta T_s}{dt} = \Delta Q + \lambda \Delta T_s + \gamma(\Delta T_s - \Delta T_o)$$

where ΔT_s (K) is the temperature change in the upper ocean, ΔQ (W/m^2) is the radiative forcing, λ (K/(W/m^2) is the sum of the feedback factors (see week two article on feedbacks), ΔT_o is the deep ocean temperature change and γ the heat transfer parameter that transfer heat from the upper to the deeper ocean. $c_{mix}$is the effective heat capacity of the upper ocean that will respond quite fast to the radiative forcing (a few decades) due to efficient wind induced mixing.

The upper to deep ocean heat transfer parameter (γ) can be approximated by assuming that the transport of energy from the upper to deep ocean is equal the ocean heat uptake efficiency (as the mixed layer equilibrate within a few decades to a new radiative forcing, this assumption means that our model should be ok for timescales longer than a few decades).

The deep ocean can only change its temperature by receiving more or less heat from the upper ocean:

$$c_{deep}\frac{d\Delta T_o}{dt} = -\gamma(\Delta T_s - \Delta T_o)$$

c_{deep} is the effective heat capacity of the deep ocean (note that is this simplification we have assumed that the effective heat capacity will not change with time

In the model we neglect land areas. Thus, ΔT_s should be seen as being representative for near surface ocean temperature changes.

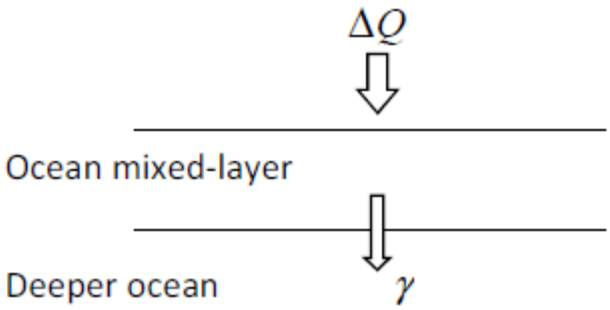

Figure: Schematic of the simple model forced with a given radiative forcing (ΔQ) and where the transport of heat into the deeper ocean is given by a heat transfer parameter γ.

In order to use the model we will need values for the radiative forcing (ΔQ), the feedbacks (λ) and the upper to deep ocean heat transfer parameter (γ).

Note that this model is only applicable to a transient climate, not a climate in equilibrium. Setting γ to zero and assuming equilibrium ($d\Delta T_o/dt$ is zero) the model reduces to the equilibrium temperature response given in the feedback article in week 2.

$$\Delta T_{eq} = -\frac{1}{\lambda}\Delta Q$$

Model parameters

- <u>**Radiative forcing:**</u> *Radiative forcing is described in week 1.*

The model needs specified radiative forcings (ΔQ) as input. For the historical case the model may take into account radiative forcing from:

- ✓ Well mixed greenhouse gasses
- ✓ Man-made aerosols (this is the sum of all direct and indirect effects).
- ✓ The sun
- ✓ Volcanoes
- ✓ Landuse

$$\Delta Q = \Delta Q_{ghg} + \Delta Q_{solar} + \Delta Q_{volc} + \Delta Q_{landuse} + \Delta Q_{man-aero} \qquad \left[\frac{\mathrm{W}}{\mathrm{m}^2}\right]$$

All values are taken from IPCC AR5 WG1 Annex II: *Climate System Scenario Tables Table AII.1.2.*

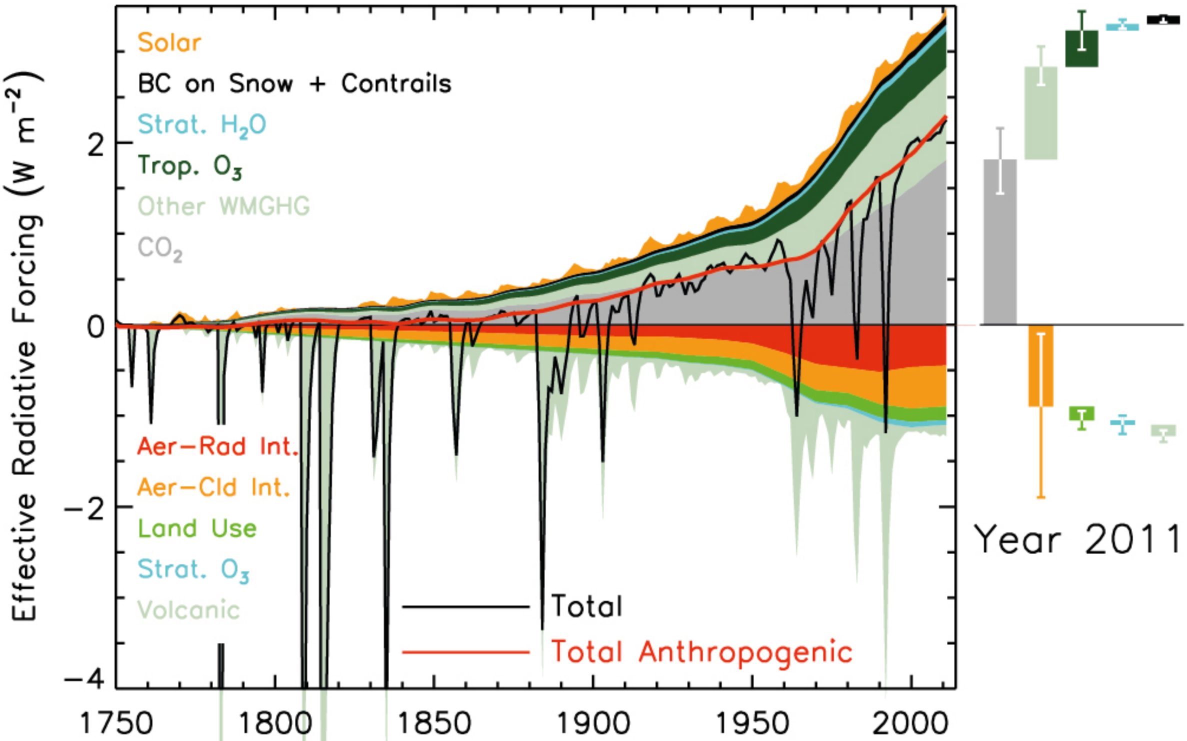

Figure: The Historical effective radiative forcing, taken from *IPCC AR5 WGI Chapter 8, figure 8.18*.

- **<u>Feedback Parameters:</u>** *The climate feedbacks are described in week 2.*

Taking into account the main radiative feedbacks the feedback parameter can be written as the sum of feedbacks due to Stefan-Boltzman's law (λ_{Planck}), the temperature lapse rate (λ_{lapse}), water vapour ($\lambda_{water\ vap}$), clouds (λ_{cloud}), surface reflectivity (albedo) (λ_{albedo}) and other possible feedbacks (λ_{other}).

$$\lambda = \lambda_{Planck} + \lambda_{lapse} + \lambda_{water\ vap.} + \lambda_{cloud} + \lambda_{albedo} + \lambda_{other}$$

Model	Planck	Lapse rate	Water vapor	Surface albedo	Clouds
	Feedback Factors				
CNRM	-3.21	-0.89	1.83	0.31	0.79
GFDL CM2_0	-3.2	-0.85	1.87	0.33	0.67
GFDL CM2_1	-3.24	-1.12	1.97	0.21	0.81
GISS AOM	-3.25	-1.27	2.14	0.27	-
GISS EH	-3.26	-1.12	1.99	0.07	-
GISS ER	-3.24	-1.05	1.86	0.15	0.65
INMCM3	-3.18	-0.51	1.56	0.32	0.35
IPSL	-3.24	-0.84	1.83	0.22	1.06
MIROC MEDRES	-3.2	-0.75	1.64	0.31	1.09
MRI	-3.21	-0.65	1.85	0.27	0.24
MPI ECHAM5	-3.22	-1.03	1.9	0.29	1.18
NCAR CCSM3	-3.17	-0.54	1.6	0.34	0.14
NCAR PCM1	-3.13	-0.41	1.48	0.34	0.18
UKMO HADCM3	-3.2	-0.74	1.67	0.22	1.08
AVERAGE	**-3.21**	**-0.84**	**1.80**	**0.26**	**0.69**

Table: Strength of individual feedback parameters [W/(m^{2}K)] from different state of the art climate models. Values are taken from Soden and Held (2006).

- **<u>Ocean heat uptake efficiency coefficient:</u>** *The ocean heat uptake is described in week 3.*

The ocean heat uptake efficiency coefficients are taken from Dufresne and Bony (2008).

Model	Heat uptake efficiency
CNRM	-0.80
GFDL CM2_0	-0.53
GFDL CM2_1	-0.81
GISS ER	-0.92
INMCM3	-0.56
IPSL	-0.79
MIROC MEDRES	-0.77
MRI	-0.61
MPI ECHAM5	-0.57
NCAR CCSM3	-0.70
NCAR PCM1	-0.62
UKMO HADCM3	-0.59
AVERAGE	**-0.69**