Climate Dynamics
Summer Semester 2019

UNIVERSITÄT LEIPZIG

Homework 8
Due 26 June 2019

Problem 1 Feedback parameter

The radiative forcing F, top-of-atmosphere energy imbalance ΔR, and surface temperature change ΔT_s are approximately linearly related through the climate feedback parameter:

$$\Delta R = \lambda \Delta T_s + F \tag{1}$$

One way to diagnose the feedback strength in models is to apply an abrupt GHG forcing at $t = 0$, then let the model run to a state approaching a new equilibrium. Often, $4 \times CO_2$ is used so that the forcing is strong compared to internal variability. See Gregory et al. (2004).

The files in `/home_local/jmuelmenstaedt/gregory/` contain the near-surface air temperature (tas) and the TOA incident shortwave (rsdt), outgoing shortwave (rsut), and outgoing longwave (rlut) radiative fluxes for the preindustrial control climate (piControl) and for an abrupt $4 \times CO_2$ run in the MPI–ESM model.

(a) Using the radiative fluxes provided, calculate an annual-mean, global-mean ΔR for each year of the abrupt $4 \times CO_2$ simulation. Plot ΔR as a function of ΔT_s. *Note: when calculating the global mean, remember that not all grid boxes have the same area.*

(b) Does the climate system reach a new equilibrium? If not, why not?

(c) Fit a straight line to the ΔT_s–ΔR plot. Determine the values of effective radiative forcing (ERF), feedback parameter, and the equilibrium temperature change.

(d) Assuming that the radiative forcing is logarithmic in CO_2 concentration, what is the equilibrium climate sensitivity (ECS) of this model? *Note: by convention, ECS is the equilibrium ΔT_s resulting from doubled CO_2 concentration.*

Problem 2 The importance of using TOA forcings

When analyzing forcing mechanisms, it is important to consider their effect on the climate system as a whole, which is why we look at their effect on the TOA energy balance. Otherwise, things can get confusing quickly, as these two problems illustrate.

(a) "Absorbing aerosols prevent a fraction of the incident solar radiation from reaching the surface. Therefore, they exert a cooling effect on the surface temperature, which corresponds to a negative radiative forcing." This argument is incorrect in at least two ways. What are they?

(b) "Increasing the atmospheric GHG concentration causes the atmosphere to emit more downwelling thermal radiation to the surface at a given atmospheric temperature. For the climate system to return to equilibrium, the surface energy budget must come back into balance. This requires the climate system to cool, so the GHG forcing is negative." This argument has at least two flaws. What are they?

Problem 3 Forcing by power consumption

Whenever we consume power, that power eventually becomes waste heat. Most of this waste heat is a positive contribution to the energy budget of the climate, which will lead to an increase in the equilibrium surface temperature.

(a) A small fraction of our power consumption does not enter the climate system as waste heat; why not?

(b) At what per-capita power consumption does the waste heat produce the same forcing as a doubling of the CO_2 concentration (≈ 4 W m^{-2})? For reference, most wealthy countries consume between 4 and 10 kW per capita.

(c) The heat released by burning 1 kg of coal is about 30 MJ. If the CO_2 released in the process enters the present-day atmosphere (≈ 400 ppmv CO_2), how long will it take until the increased radiative forcing exceeds 30 MJ?