Projections of the Transient State-Dependency of Climate Feedbacks

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Summary

Transient and state-dependent behaviour of climate feedbacks is important for accurate future projections. **However,** it is hard to track these via linear regressions of climate feedback contributions to changes in global temperature. **Hence, here** we introduce a new multivariate climate feedback framework that does take into account the transient state dependencies of climate feedback. Using the new framework, changes in **feedback processes** can be analyzed **per time scale** and **temporal evolution** can be tracked. Further, within the framework it is possible to create **transient and equilibrium projections** of (the spatial patterns of) climate feedbacks for all sort of emission scenarios. Illustrated here on CESM2.

A new climate feedback framework

In the linear regime, the response to forcing of any observable – climate feedback contributions included – can be split into M climate modes as

$$\Delta R_j(t) = \sum_{m=1}^{M} \beta_m^{[R_j]} \mathcal{M}_m^g(t)$$

where $\beta_m^{[R_j]}$ contains all observable-dependent information and $\mathcal{M}_m^g(t)$ contains all time and forcing information.

Feedback strength can then be computed per mode as

$$\lambda_j^m := \frac{\beta_m^{[R_j]}}{\beta_m^{[T]}}$$

and, for any given forcing scenario, the instantaneous feedback strength can be computed as

$$\lambda_j^{inst}(t) := \frac{\frac{d}{dt}\Delta R_j}{\frac{d}{dt}\Delta T}$$

Procedure for CESM2

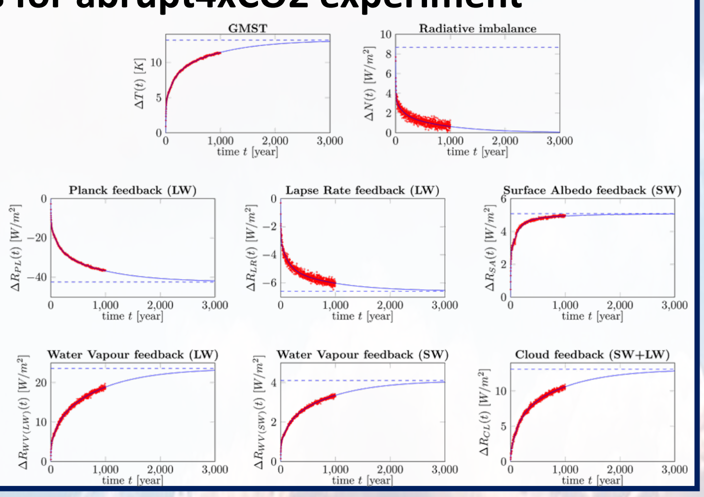
1. Compute feedback contributions $\Delta R_j(t)$ using radiative kernel approach
2. Use abrupt4xCO2 experiment to find parameters using nonlinear fitting
3. Compute feedback strengths & make projections

Remarks:

- Projections can also be made for other forcing scenarios. If applied on an ensemble of runs Linear Response Theory suggest correctness of these projections.
- Method can be easily extended to spatial patterning of feedback contributions

Fits for abrupt4xCO2 experiment

Figure 1. Evolution of several observables. Red circles denote data points from CESM2; blue lines the obtained fits. The dashed lines indicate the estimated equilibrium values (or initial forcing in the case of the radiative imbalance plot).



Projections for 1pctCO2 experiment

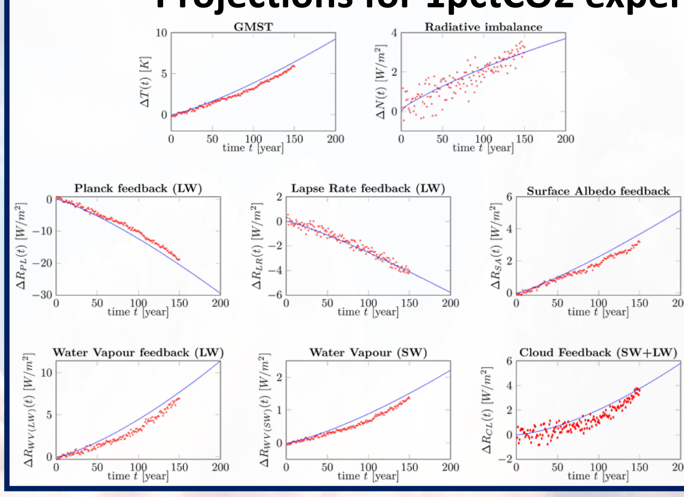


Figure 2. Projections and actual values for several observables. Red circles denote data points from CESM2; blue lines show projections based solely on data from the abrupt4xCO2 experiment.

Values for climate feedback strength per mode

	Mode 1	Mode 2	Mode 3	Equilibrium
τ_m	4.5 (± 0.1)	127 (± 3.8)	889 (± 50)	—
λ_m	−1.28 (± 0.08)	−0.38 (± 0.03)	−0.37 (± 0.02)	−0.66 (± 0.03)
Planck (LW)	−3.16 (± 0.02)	−3.24 (± 0.02)	−3.23 (± 0.01)	−3.21 (± 0.05)
Lapse Rate (LW)	−0.73 (± 0.03)	−0.50 (± 0.03)	−0.32 (± 0.03)	−0.50 (± 0.01)
Surface Albedo (SW)	+0.62 (± 0.04)	+0.56 (± 0.02)	+0.08 (± 0.10)	+0.39 (± 0.01)
Water Vapour (LW)	+0.97 (± 0.03)	+1.38 (± 0.02)	+2.71 (± 0.01)	+1.79 (± 0.04)
Water Vapour (SW)	+0.21 (± 0.09)	+0.26 (± 0.05)	+0.43 (± 0.02)	+0.31 (± 0.01)
Clouds (SW + LW)	+0.27 (± 0.36)	+1.19 (± 0.02)	+1.43 (± 0.01)	+1.00 (± 0.03)
sum	−1.82 (± 0.37)	−0.36 (± 0.07)	+1.09 (± 0.11)	−0.22 (± 0.08)
residue	+0.54 (± 0.38)	−0.02 (± 0.08)	−1.46 (± 0.11)	−0.43 (± 0.08)

Table 1. τ_m denotes the time scale in years; the other values have units $Wm^{-2}K^{-1}$. Plusminus values indicate 95% confidence intervals based on the fitted parameters.

Evolution of feedback strength over time

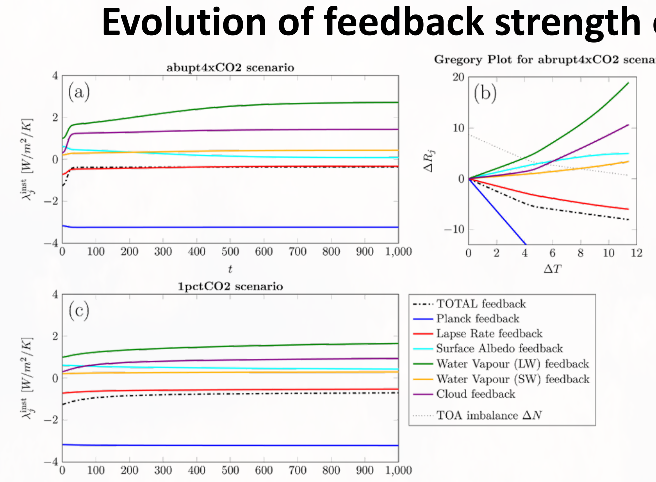


Figure 3. Instantaneous feedback strengths for (a) abrupt4xCO2 and (c) 1pctCO2 experiments, and (b) Gregory plot for climate feedback contributions against warming in the abrupt4xCO2 experiment. The 1pctCO2 panel shows feedback strengths for continued 1% yearly CO2 increase.

Estimated equilibrium spatial distribution

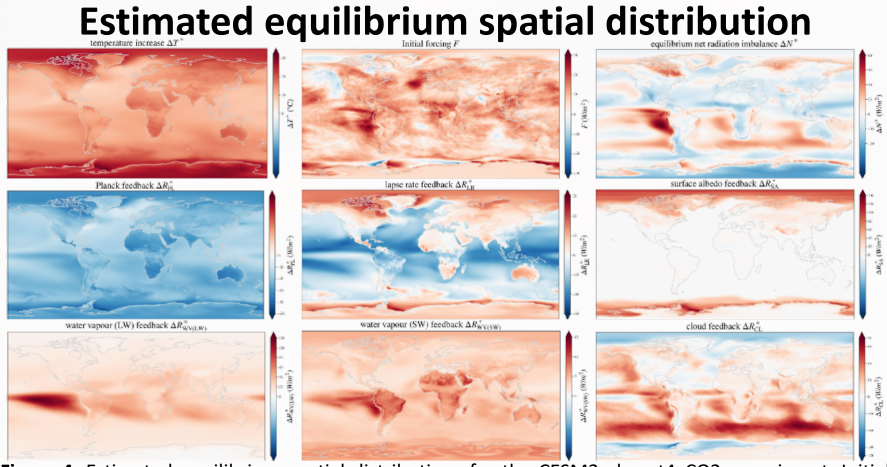


Figure 4. Estimated equilibrium spatial distributions for the CESM2 abrupt4xCO2 experiment. Initial forcing is derived directly from data; the other estimates are derived via the fitted spatial modes.

Discussion

- Long-term evolution and state-depency of climate feedbacks can be captured
- Multivariate climate projections can be made, even for other forcing scenarios
- Results on CESM2 align with previous research for the faster modes
- Results for mode 3 consider longer time scales than normally and show a larger increase in mainly water vapour and cloud feedbacks
- It seems a feedback might be overlooked that is relevant on long time scales

Co-financed by the Connecting Europe Facility of the European Union

TiPES — TIPPING POINTS IN THE EARTH SYSTEM

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Paper link (code is available!)