Climate Feedback Efficiency and Synergy

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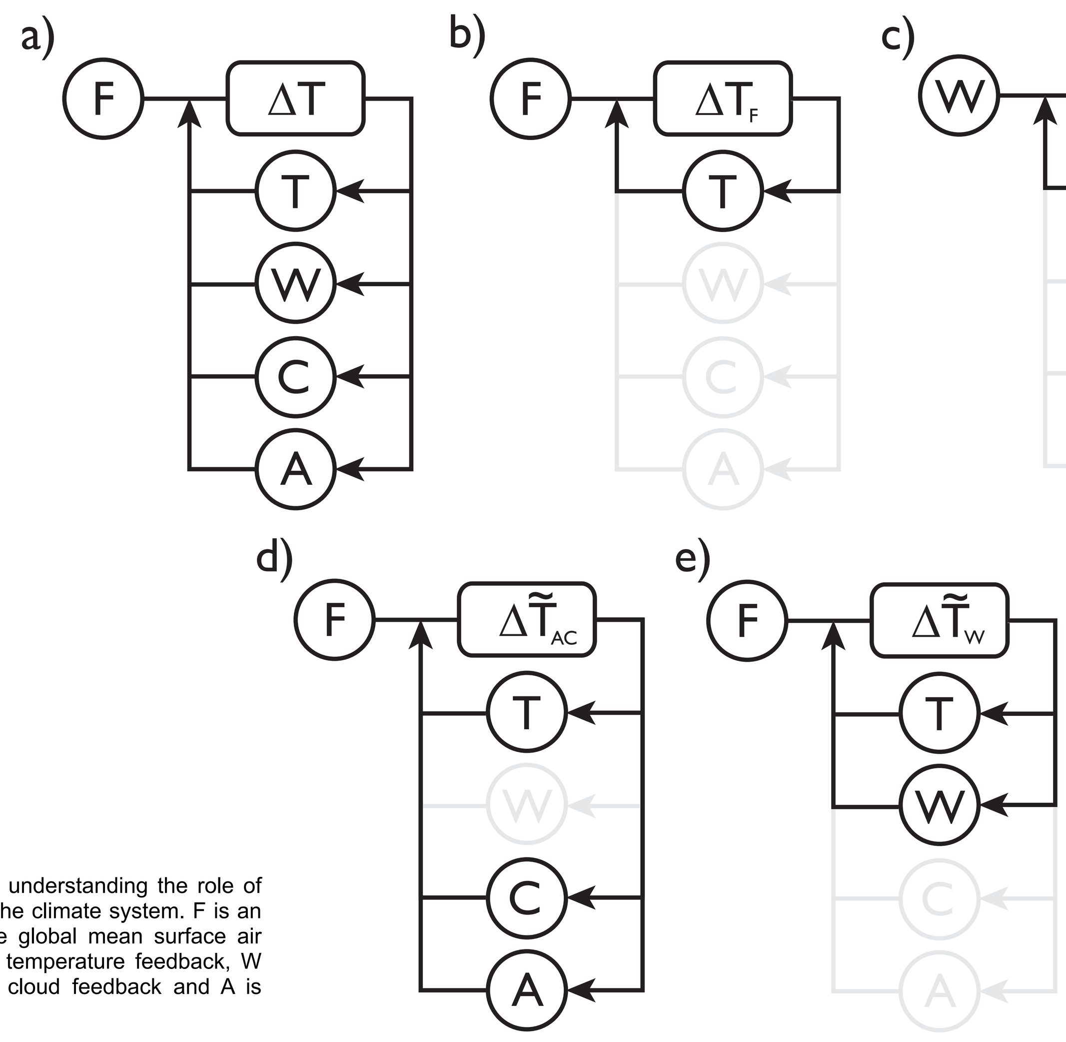
Summary

Climate change feedbacks act to either amplify or dampen forced climate change. It is often useful to think of the climate system conceptually as an energy balance box-model, whereby it is assumed that feedback mechanisms **add linearly and act independently**. Here we test these assumptions by systematically controlling the water vapor, cloud and surface albedo feedback mechanisms in a comprehensive climate model.

1. Water vapor and surface albedo feedbacks **add linearly** resulting in temperature changes in close agreement with theory. **The cloud feedback is particularly inefficient in causing climate change**, resulting in less than half the predicted temperature change.

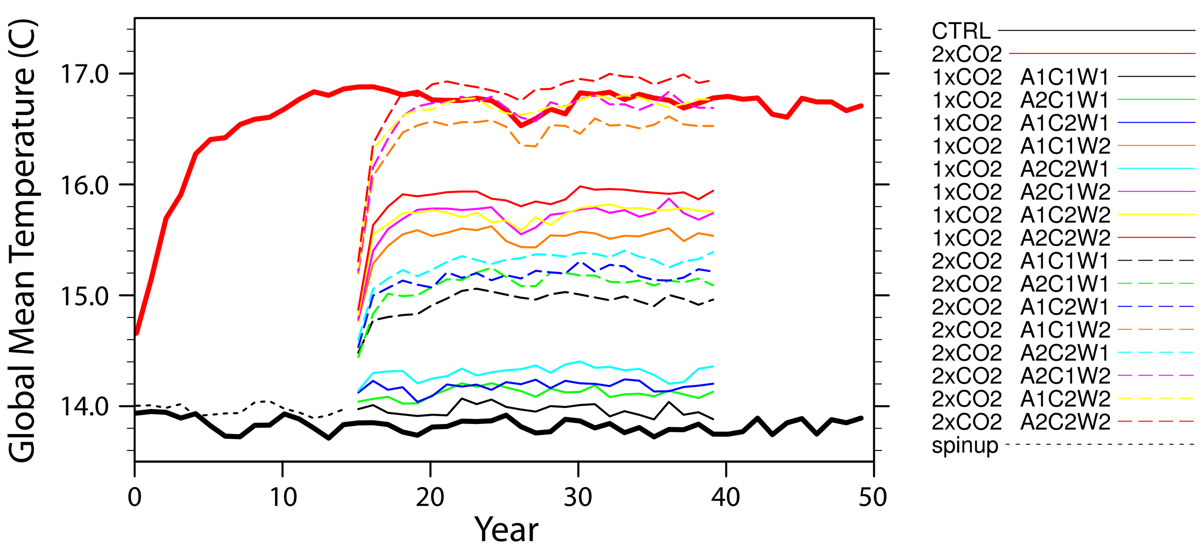
2. There are **positive synergies** between the cloud and water vapor feedbacks, while surface albedo feedback **interacts negatively** with the other two feedbacks.



Conceptual framework for understanding the role of feedback mechanisms in the climate system. F is an external forcing, ΔT is the global mean surface air temperature change, T is temperature feedback, W water vapor feedback, C cloud feedback and A is surface albedo feedback.

1) Systematically controlling feedbacks

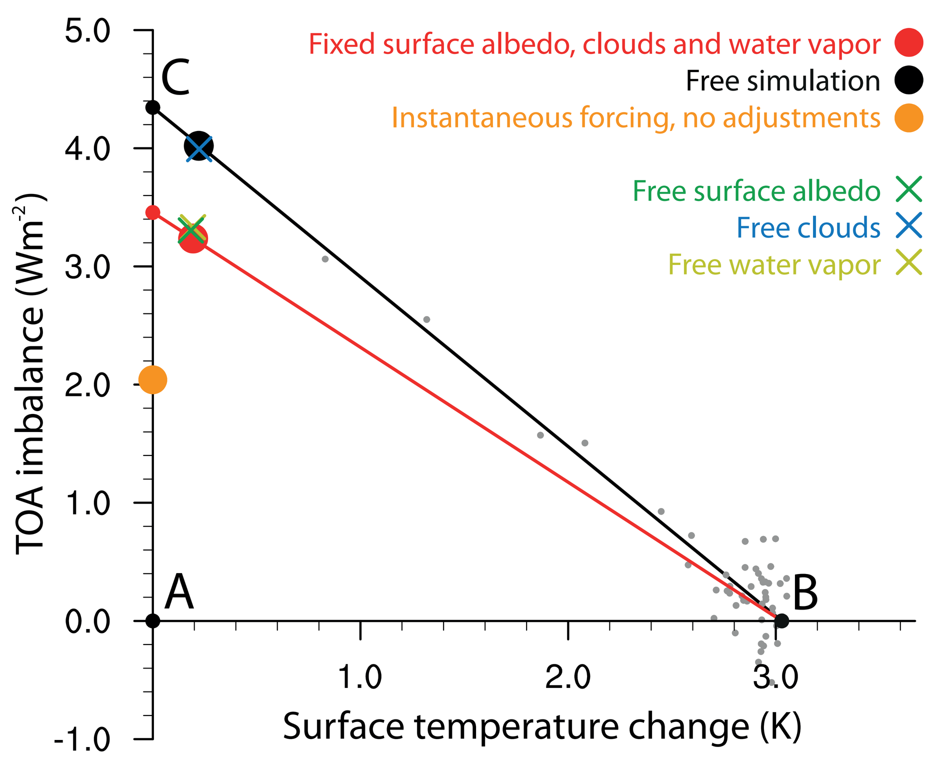
A feedback mechanism is controlled in ECHAM6 by first writing out e.g. the water vapor (W) fields at every radiation call (2-hourly), and then reading them in again in another simulation. The same is done for clouds (C) and surface albedo (A). Temperature feedback (T) is always free. The three different feedbacks are read from different years. The stored fields are applied only in the radiation call: That is, **the model retains its own hydrological and energy cycles.**



Examples of temperature evolution from mixed-layer ocean simulations. Thick lines are from the standard model, while the thin lines are simulations with imposed feedbacks, The naming scheme indicates whether the relevant fields are read from the CTRL (1) or 2xCO2 (2) simulations.

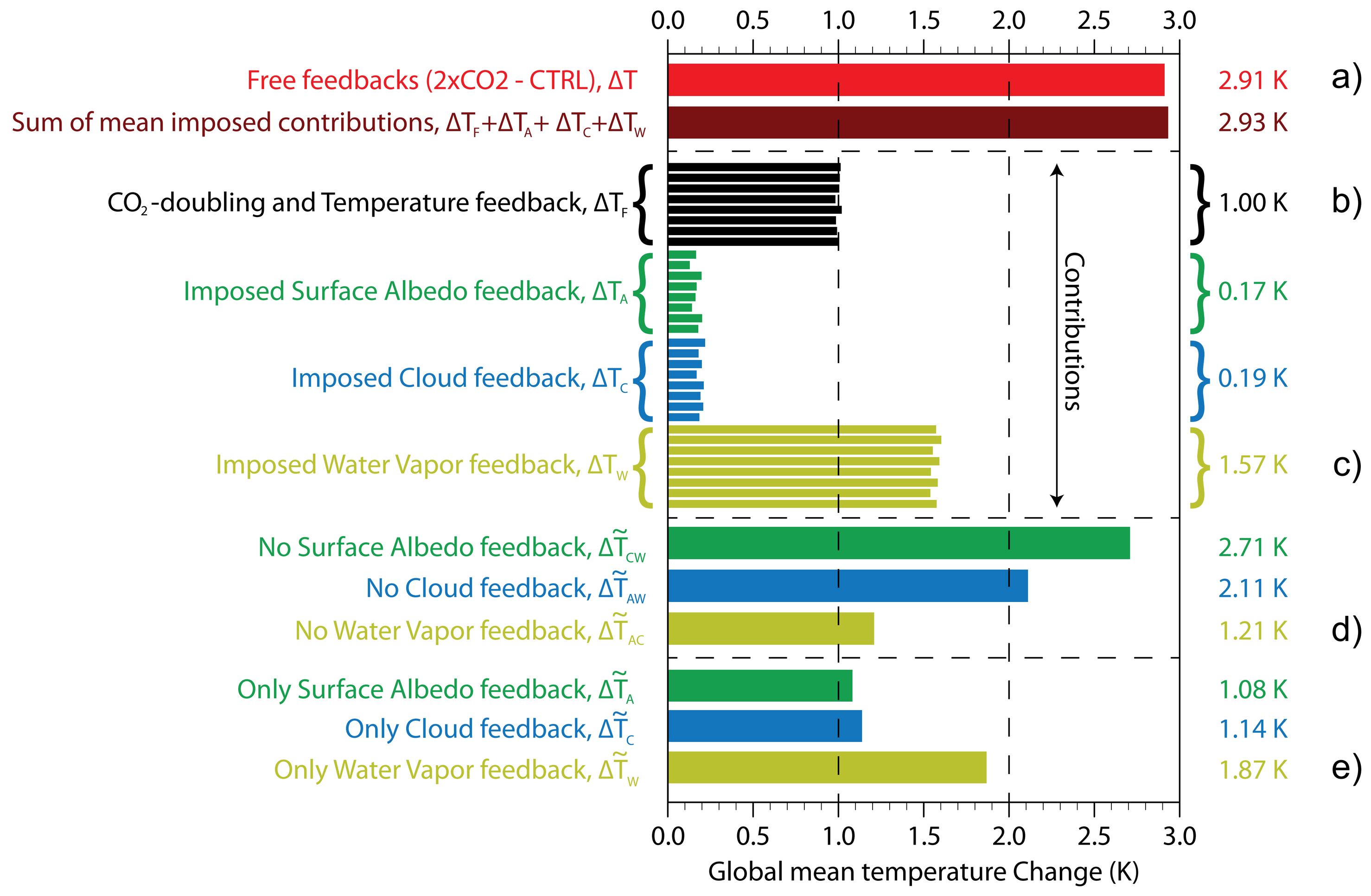
2) Forcing, feedback and response

The climate sensitivity to an instantaneous doubling of CO2 is the distance between A and B. The forcing can be considered the distance between A and C, while the slope between C and B is the total climate system feedback. From this point view the forcing is 4.40 Wm-2. However, the simulation with fixed feedbacks (red) indicates that fast adjustments due mainly to clouds contribute to forcing. Therefore, *for our purposes*, the relevant forcing from a doubling of CO2 is 3.45 Wm-2.



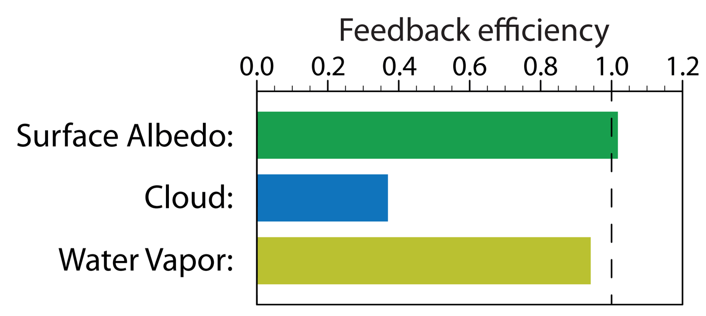
Response to instantaneous doubling of CO2 with ECHAM 6.0 coupled to a mixed-layer ocean. Small grey dots are individual years. The large dots correspond to the difference from two 20-year long runs with fixed SST and sea ice, where CO2 is is set to 1xCO2 and 2xCO2 (atmospheric adjustment).

3) Temperature responses with free and locked feedbacks

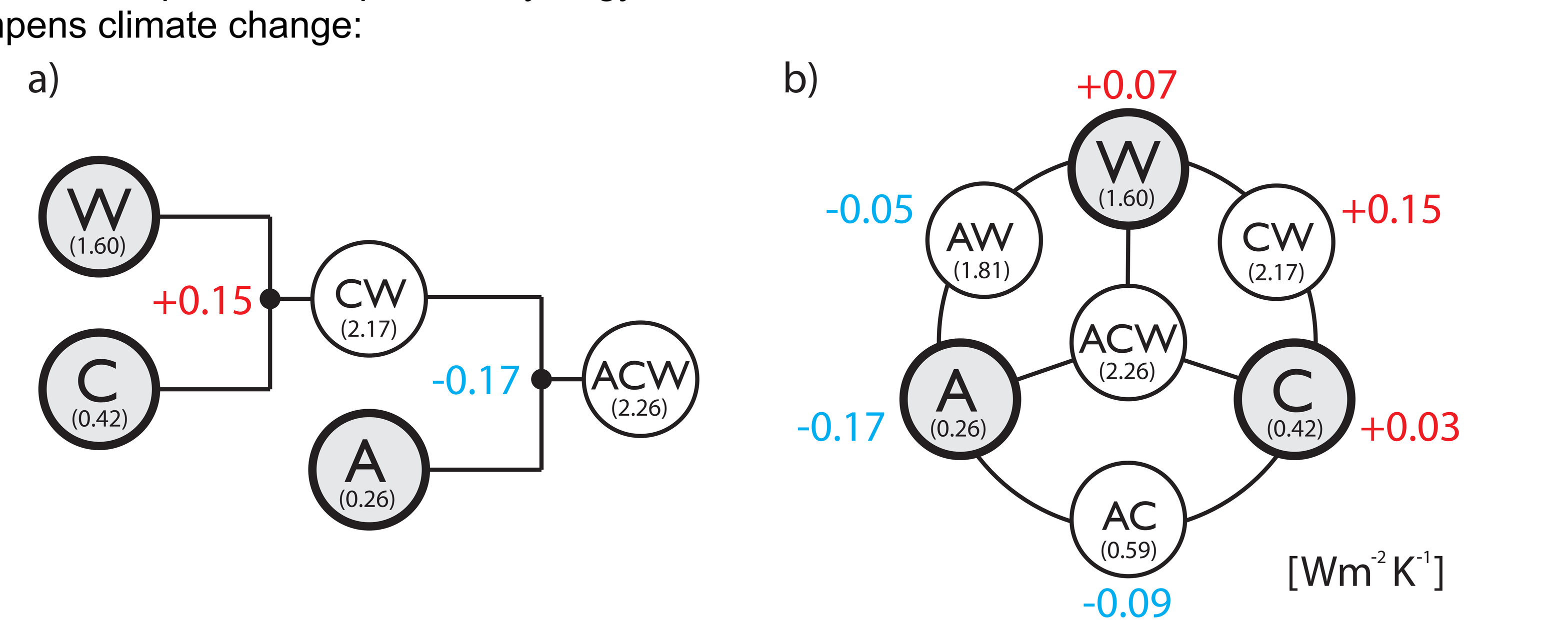


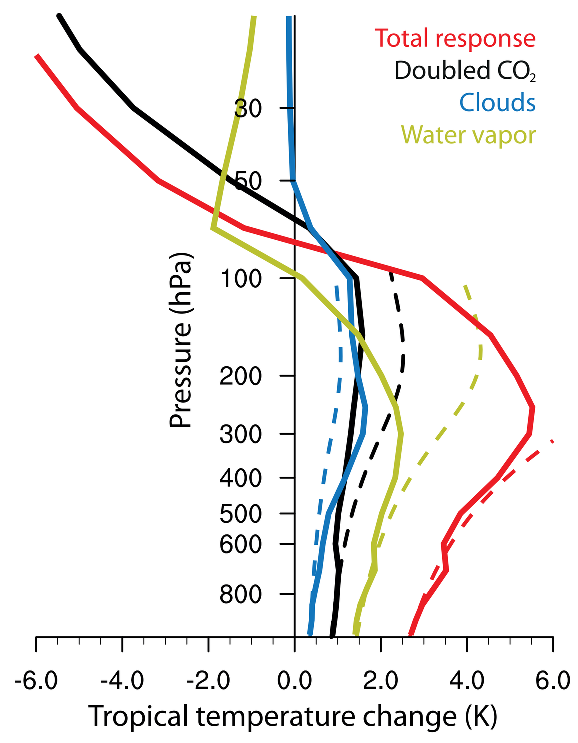
4) Feedback efficiency and synergy

With a bit of algebra it is possible to derive effective feedback factors from the temperature responses shown above, while knowing the forcing. If the feedbacks add linearly there should be a ratio of **unity** to diagnosed feedback factors. This is the case of surface albedo and water vapor feedbacks, while the **cloud feedback mechanism is inefficient** at causing surface temperature change.



A positive synergy exists when the combined system is more than the sum of its parts. Clouds and water vapor exhibit positive synergy, while interactions with the surface albedo feedback dampens climate change:



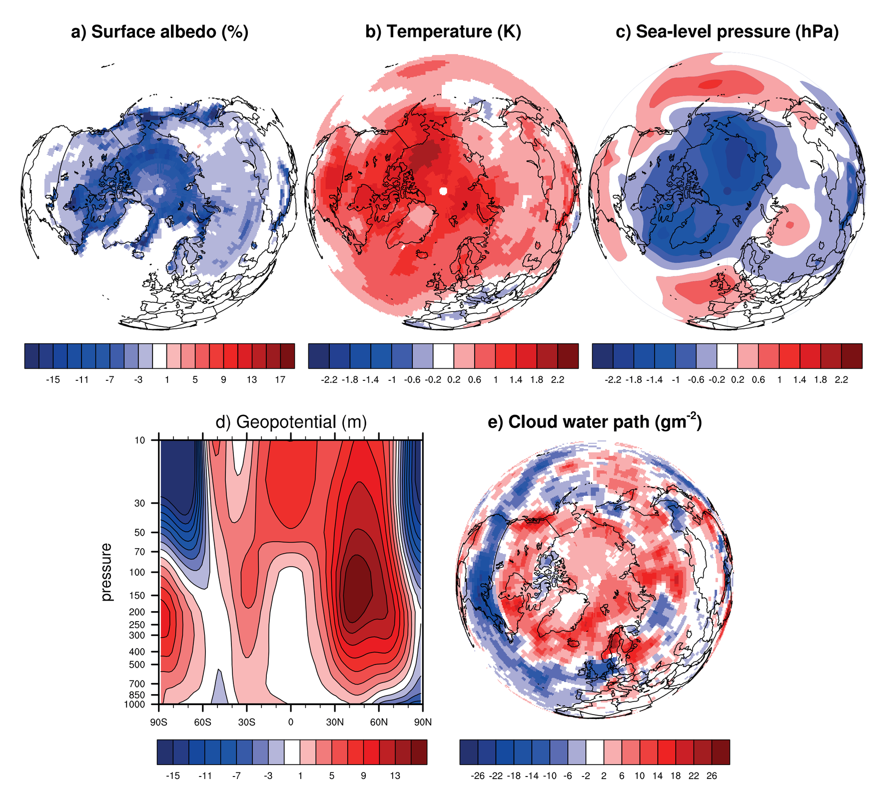


Clouds (solid blue) induce faster than moist-adiabatic (dashed blue) warming throughout the Tropical troposphere (left, 30S to 30N):

1. This warming aloft induces a negative lapse-rate feedback explaining the weak feedback efficiency.
2. At the same time, more warming aloft permits more water vapor which could explain the positive synergy between the cloud and water vapor feedbacks.

Impacts of reduced surface albedo:

1. Reduced surface albedo alters the atmospheric circulation leading to thickening clouds, thereby dampening the warming.
2. Albedo-induced warming is predominantly close to surface, where the associated water vapor increase has little or no effect on TOA radiation.



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