

Lecture 11. Cloud feedbacks in the climate system: outstanding challenges.

Outline:

1. Background materials.

2. Paper for class discussion:

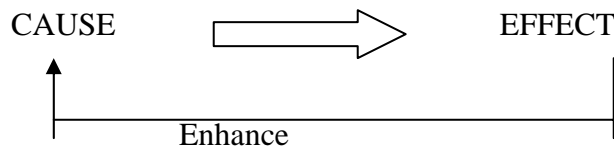
Stephens G.L., *Cloud feedbacks in the climate system: A critical review*, *Journal of Climate*, 18, 237-273, 2005.

Background materials.

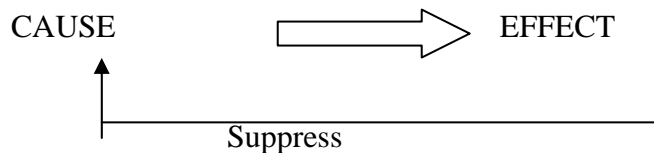
Feedback mechanisms.

A feedback mechanism is a process that results from some cause of the action, and then the results go back and influence the cause to make it produce a greater or lesser amount of the results.

Positive feedback in which the feedback reinforces the original input resulting in amplification of the output of the process.



Negative feedback effect occurs when something happens and the results make the original process produce diminished results.



The quantitative definition of feedback was first used in electrical signal control systems: Given forcing to a system ΔQ (note that we used ΔF to denote radiative forcing), if the system responds by one measure ΔT_0 , and if this response does not impact the initial forcing, the system is said to be without feedback

$$\Delta T_0 = \lambda_0 \Delta Q$$

λ_0 is defined as the no-feedback gain (or the sensitivity). It describes the system response per unit forcing. NOTE: The system does not need to be linear; but it is common to consider both the forcing and response as small perturbations, so the linear approximation holds.

If the system response also induces changes in the forcing and if the induced forcing is written as proportional to final response ΔT_{eq} by a factor of F , namely $\Delta T_{eq} F$, then F is called feedback. Thus F is the induced forcing from unit response. The total forcing to the system at the final state is $\Delta Q + \Delta T_{eq} F$. Thus we have

$$\Delta T_{eq} = \lambda_0 (\Delta Q + F \Delta T_{eq})$$

It follows

$$\Delta T_{eq} = \lambda_0 \frac{\Delta Q}{1 - \lambda_0 F}$$

This equation can also be expressed in terms of ΔT_0

$$\Delta T_{eq} = \frac{\Delta T_0}{1 - f}$$

where $f = \lambda_0 F$ is called the feedback factor.

If there is more than one process that can induce changes in the forcing, then

$$\Delta T_{eq} = \lambda_0 (\Delta Q + \sum_i F_i \Delta T_{eq})$$

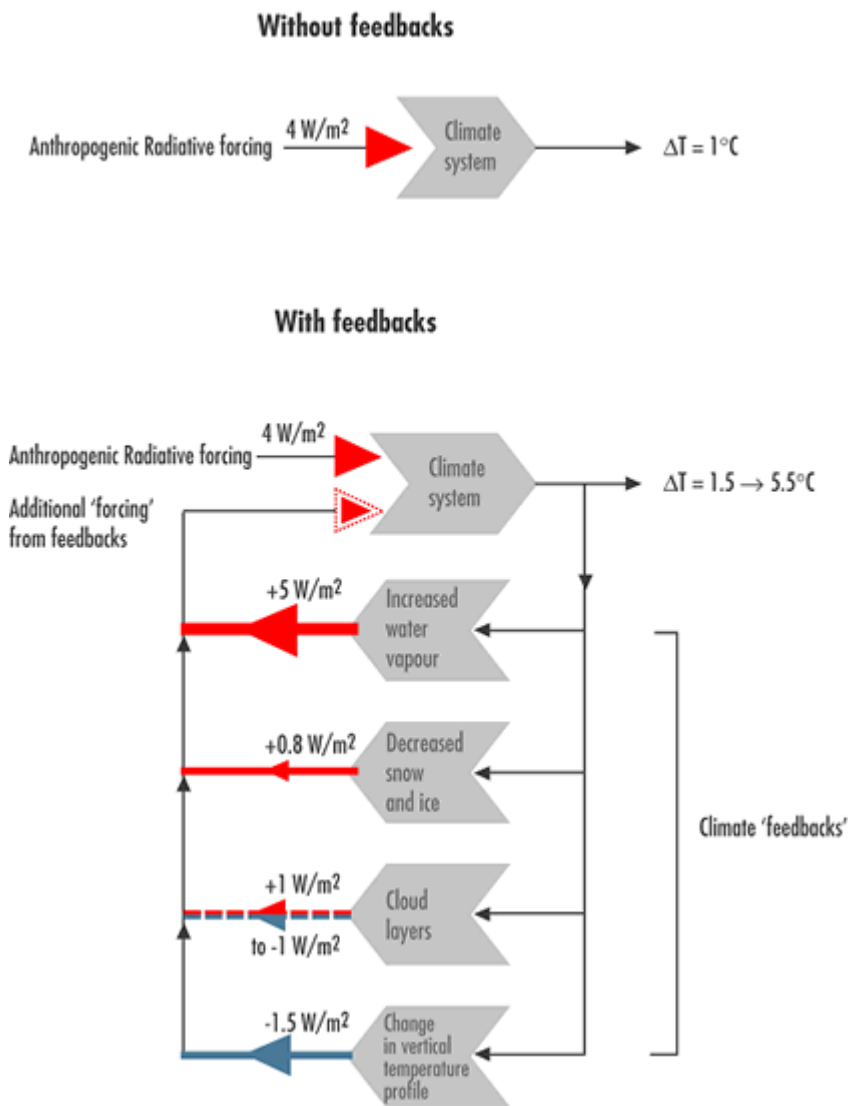
$$\Delta T_{eq} = \frac{\Delta T_0}{1 - \sum_i f_i}$$

where $f_i = \lambda_0 F_i$

While feedbacks and feedback factors are additive, the system response to additional feedback is not.

Influence of Climate feedbacks on radiative forcing in climate models

Schematic showing the influence of climate feedbacks on the amount and sign of radiative forcing driving a climate model. The arrows are indicative of the magnitude and sign of individual feedbacks, as determined from the climate model. The dominant positive feedback is due to water vapor. This climate model gives a positive cloud feedback, but this varies greatly between climate models. The range in surface temperature changes indicated results from the varying effect of all feedbacks, but particularly of clouds.

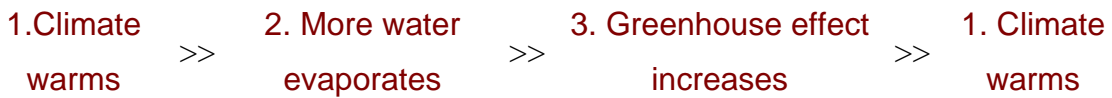


Radiation feedbacks in the Earth’s climate system:

- ✓ Water vapor feedback
- ✓ Cloud feedback
- ✓ Ice-Albedo feedback

Water vapor feedback.

“Simple” analysis of water vapor feedback:



$$f = \lambda_0 \frac{\partial F}{\partial W_v} \frac{dW_v}{dT_o}$$

where

f is the feedback factor, λ_0 is the gain of the system with no feedback,

W_v is the vertically-integrated amount of water vapor

$$\frac{\partial F}{\partial W_v} > 0 \quad \text{and} \quad \frac{dW_v}{dT_o} > 0 \quad \Longrightarrow \quad \text{positive feedback}$$

Does it always positive?

Tropics

Lindzen’s hypothesis (“adaptive IR iris hypothesis”):

The tropical water vapor feedback is negative

Mechanism: rising global surface temperatures will lead to deeper, more vigorous tropical convection, giving rise to a drier upper troposphere with fewer cirrus cloud cover.

Lindzen, R.S., Chou, M.-D. and Hou, A.Y. 2001. Does the earth have an adaptive infrared iris? Bulletin of the American Meteorological Society 82: 417-432.

