Climate sensitivity with a time-dependent climate feedback parameter

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Summary

Going back from the initial equations by Budyko and Sellers in 1969, we re-develop the energy balance model of the Earth accounting for the time dependence of λ **(A)**. Our framework allows us to evaluate λ(t) **(B)** and provides a new expression of the climate sensitivity **(C)**.

1. The radiative response of the Earth now has an **explicit** and **quantifiable** dependence on the pattern of warming
$$T_{ss}\delta\lambda(p) + \lambda_{ss}\delta T$$

2. λ varies by **~0.01 $Wm^{-2}K^{-1}$** but its impact on the radiative response is important

3. The climate sensitivity is a sum of **two terms**:
   - one accounting for the radiative response with a **constant temperature pattern**
   - one accounting for the **pattern effect**

4. The pattern effect :
   - increases the ECS in **all models** by up to **100%**
   - explains most of the intermodel spread in ECS

Coming soon ...

Meyssignac et al. (2022): Dynamics of the global energy budget with a time dependent climate feedback parameter: a unified framework. *Submitted to J. Climate*

Guillaume-Castel and Meyssignac: Application to climate sensitivity, *to be submitted*

Meyssignac et al.: Application to runaway warming, *in prep*

A. Theoretical framework

- The Earth energy budget is: $N = F + R$
- If no perturbation for a long time: steady state with a mean temperature T_{ss} and a pattern of temperature p_{ss}: $N_{ss} = F_{ss} + R_{ss} = 0$
- Now a perturbation δF breaks the balance (e.g. CO2 emissions)

Hypotheses:
1. The radiative response depends on the mean temperature T and on the pattern of temperature p
2. δF is small and will induce small variations of T and p

- We can use a first order Taylor expansion to linearize the response dR to δF around T_{ss} and p_{ss}:

$$dR = \left.\frac{\partial R}{\partial T}\right|_{T_{ss},p_{ss}} dT + \left.\frac{\partial R}{\partial p}\right|_{T_{ss},p_{ss}} dp$$

Hypothesis:
1. The radiative response is linear with the **total** surface temperature: Budyko (1969), Sellers (1969)
$$R = A + \lambda(p)T$$

- We identify: $\left.\frac{\partial R}{\partial T}\right|_{T_{ss},p_{ss}} = \lambda(p_{ss})$ $\quad\left.\frac{\partial R}{\partial p}\right|_{T_{ss},p_{ss}} = T_{ss}$

The resulting energy balance model with a time dependent climate feedback parameter is:

$$N = \delta F + \lambda_{ss}\delta T + T_{ss}\delta\lambda(p)$$

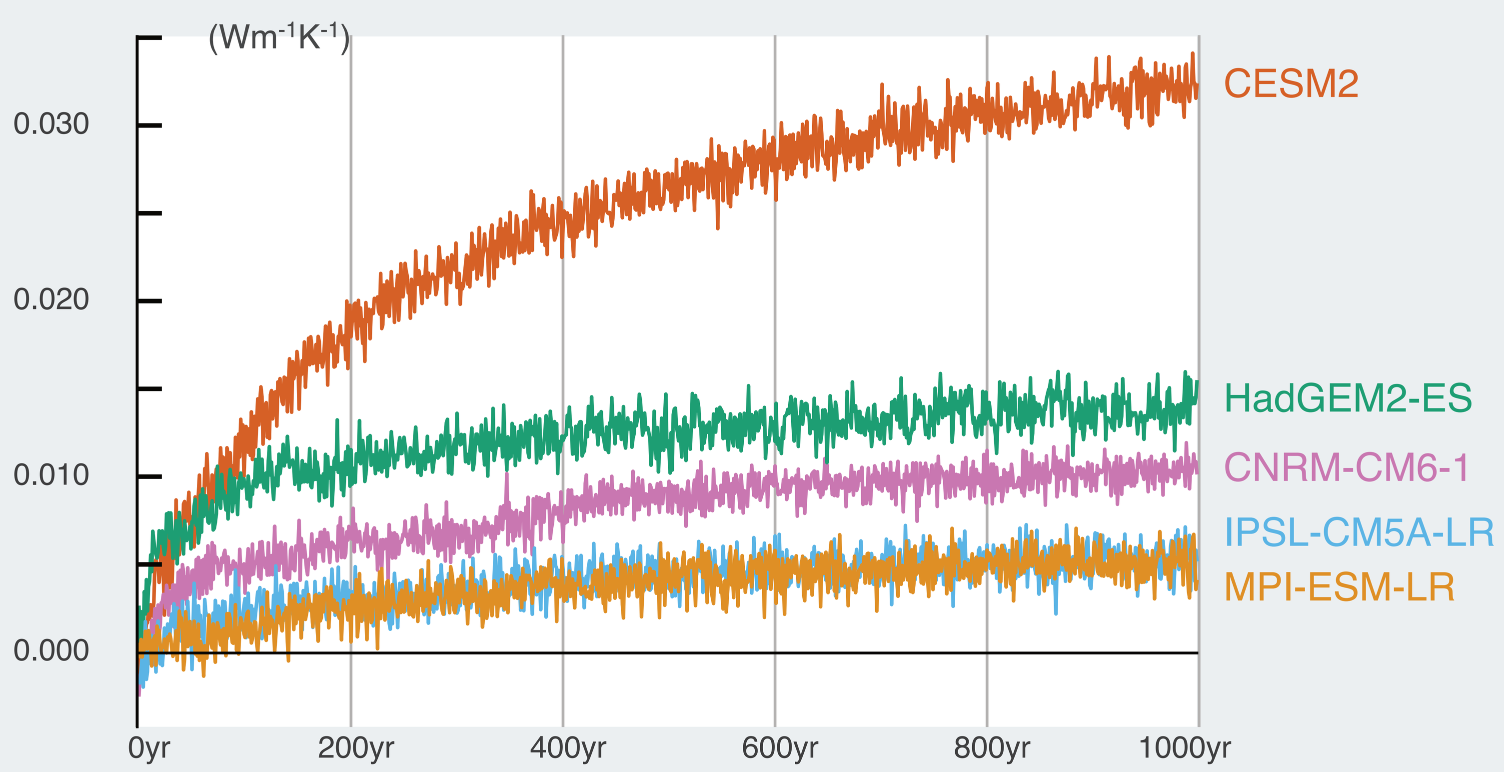
Which is different from the classical approach: $N = \delta F + \lambda(p)\delta T$

B. Evaluation of λ(t)

Following our EBM, we evaluate $\delta\lambda = \dfrac{N - \delta F - \lambda_{ss}\delta T}{T_{ss}}$

T_{ss}	λ_{ss}
Mean temperature of the control run	Difference between runs with same pattern but different mean T: amip and amip-p4K $\lambda_{ss} = \dfrac{N_{amip-p4K} - N_{amip}}{T_{amip-p4K} - T_{amip}}$
286.4 ± 0.7 K	-1.34 ± 0.19 $Wm^{-1}K^{-1}$

Time series of δλ



$$\delta\lambda \ll \lambda_{ss}$$ ✓

C. Application to climate sensitivity

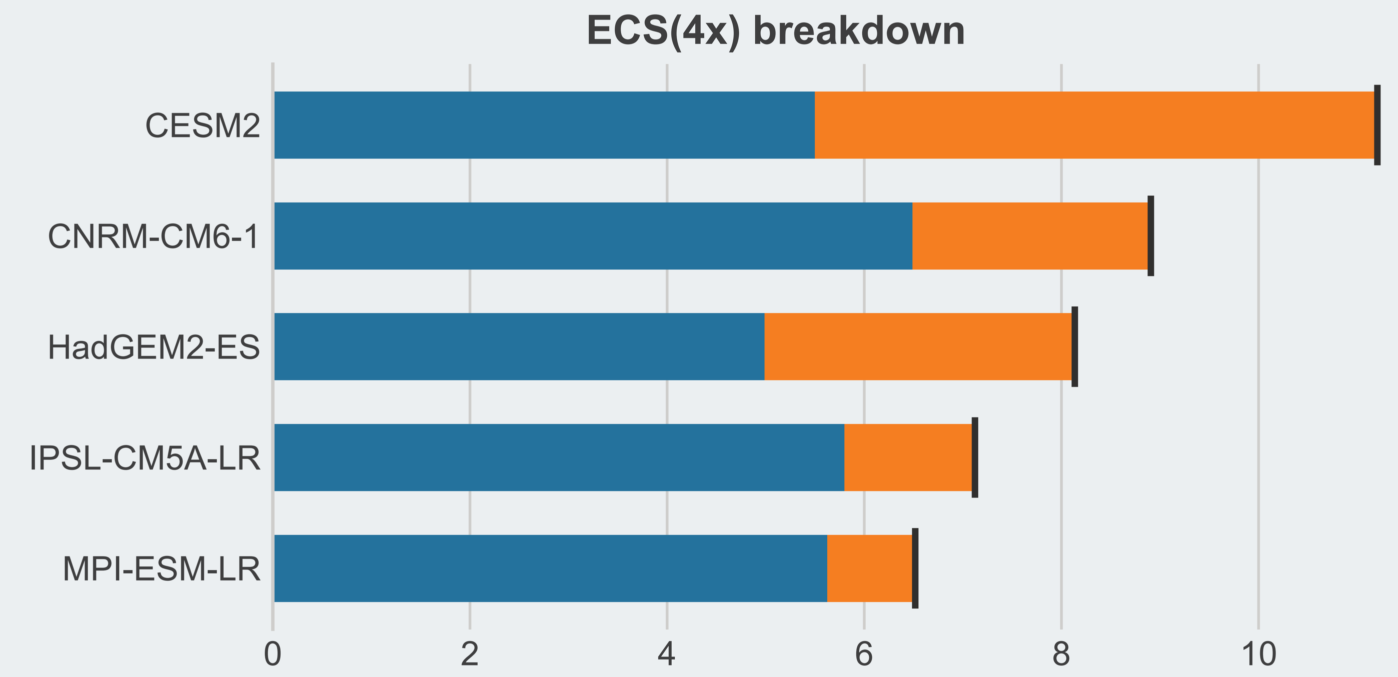
The equilibrium climate sensitivity is given at steady state by:

$$ECS = -\frac{\delta F(2\times CO_2)}{\lambda_{ss}} - \delta\lambda(p_\infty)\frac{T_{ss}}{\lambda_{ss}}$$

Different from the classical approach where $ECS = -\dfrac{\delta F(2\times CO_2)}{\lambda(p_\infty)}$

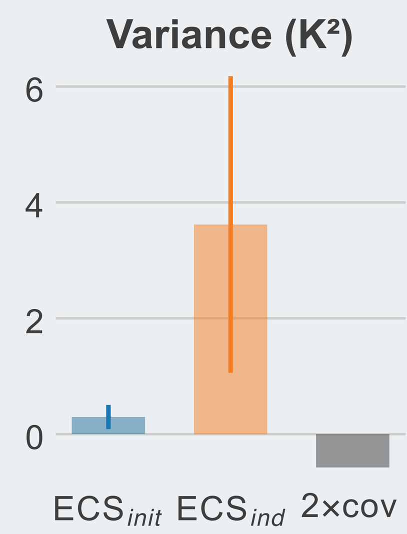
Initial ECS: Climate response if the pattern of temperature did not change

Pattern-induced ECS: Additional climate response induced by the changing temperature pattern



In all models, the pattern effect increases the ECS by 23 to 103%

The spread in ECS is mostly driven by the spread in the pattern effect



Workshop on Mathematics and Theoretical Physics for Climate Dynamics
Mini school on Climate Sensitivity
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