Dynamics of the Global Energy Budget with a time dependant Climate Feedback Parameter

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The 0-dimensional linearised energy balance model (EBM) introduced by Budyko (1968) allows us to study the response of the climate system to a radiative forcing such that an increase of atmospheric CO2. This EBM reads: CdTs/dt = N = F - λ Ts, where C is the ocean heat capacity, Ts is the global surface temperature, N is the Earth Energy Imbalance and λ is the constant climate feedback parameter.

However, recent studies show that a constant climate feedback parameter cannot represent accurately the long term dynamics of the climate response, notably due to the dependence of λ on the pattern of warming (Armour et al. 2013).

Here, we introduce the time dependence of λ in a simple energy balance model and develop the consequences on climate sensitivity.

Theoretical framework

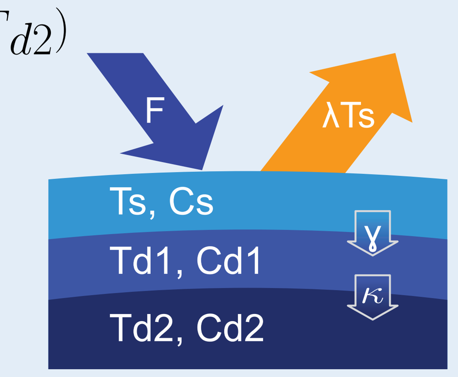
1. Energy Balance Model

$$C_s \frac{dT_s}{dt} = F - \lambda T_s - \gamma\,(T_s - T_{d1}) \quad (1)$$

$$C_{d1} \frac{dT_{d1}}{dt} = \gamma\,(T_s - T_{d1}) - \kappa\,(T_{d1} - T_{d2}) \quad (2)$$

$$C_{d2} \frac{dT_{d2}}{dt} = \kappa\,(T_{d1} - T_{d2}) \quad (3)$$

Three layers energy balance model, adapted from Geoffroy et al. (2013)



2. Hypotheses

- The climate system is a forced dynamical system. We assume the existence of steady states variables: T_{s0}, F_0 and λ_0.
- When δF is applied, the system deviates from its steady state and tends to reach a new equilibrium.
- The perturbation theory allows us to study this new dynamical system system. **We hypothesise that our study is in the scope of the pertubation theory.**

3. Applying perturbation theory

We apply perturbation theory to the surface equation to derive the perturbed anomaly system.

With a constant λ_0

$$C_s \frac{d}{dt}(\delta T_s) = \delta F - \lambda_0\,\delta T_s - \gamma\,(\delta T_s - \delta T_{d1})$$

With forced variation of λ

$$C_s \frac{d}{dt}(\delta T_s) = \delta F - \lambda_0\,\delta T_s - \delta\lambda(t) T_{s0} - \gamma\,(\delta T_s - \delta T_{d1})$$

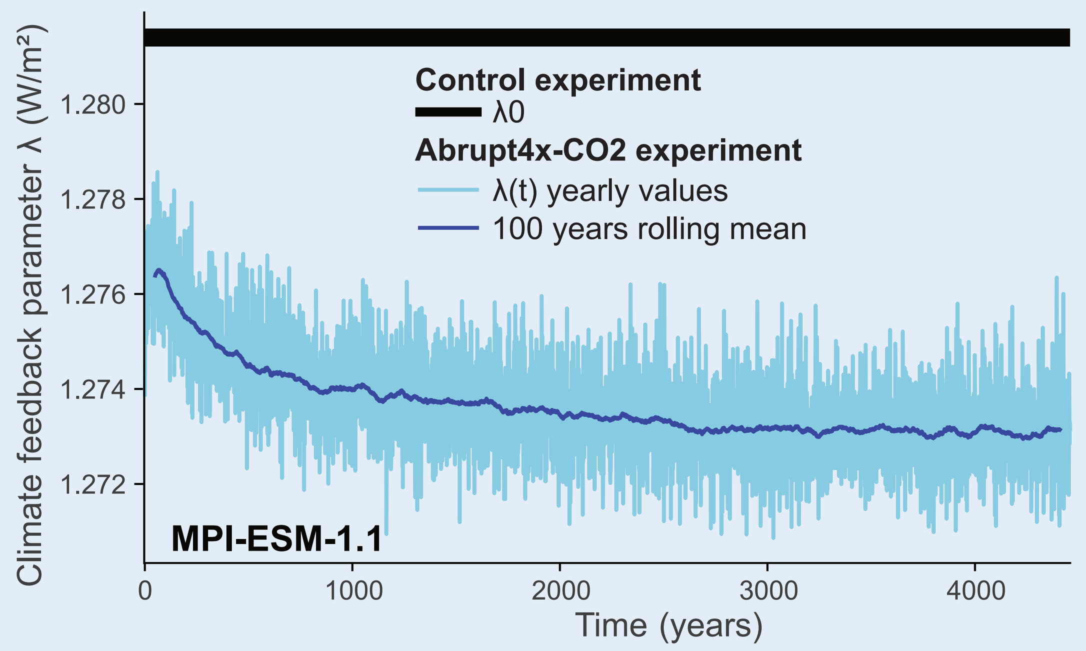
Assuming a variable λ leads to the emergence of a new term in the anomaly energy budget

Climate Feedback Parameter time series

With N = F - λ Ts, we can write

$$\lambda(t) = \frac{F_0 + \delta F - N(t)}{T_{s0} + \delta T_s(t)}$$

Which gives a times series of the climate feedback parameter.

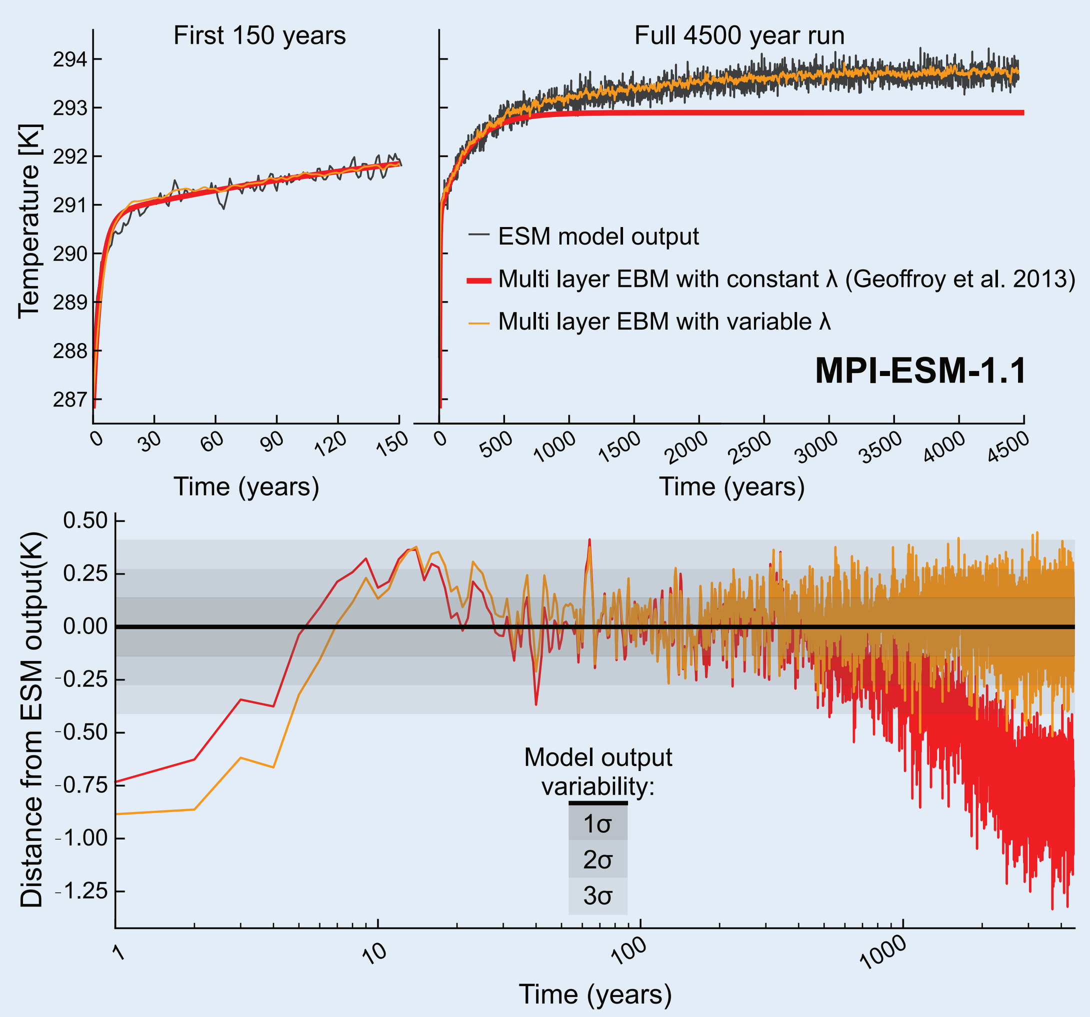


We verify $\delta\lambda \ll \lambda_0$

which validates the perturbation theory hypothesis.

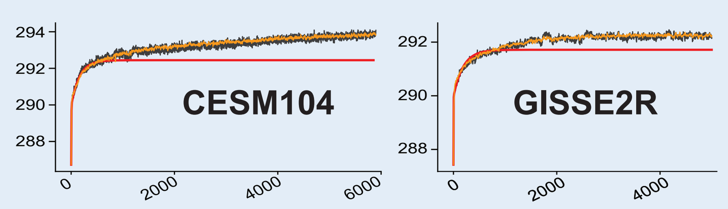
With such a climate feedback parameter, we expect to reproduce the dynamics of the global surface temperature in the model with the numerical integration of the system.

Numerical integration



We reproduce the dynamics of the global average surface temperature in the MPI-ESM1.1 abrupt4x-CO2 run from the longrunMIP experiment (Rugenstein et al. 2019) **at all time scales.**

How about other models?



Consequences on climate sensitivity

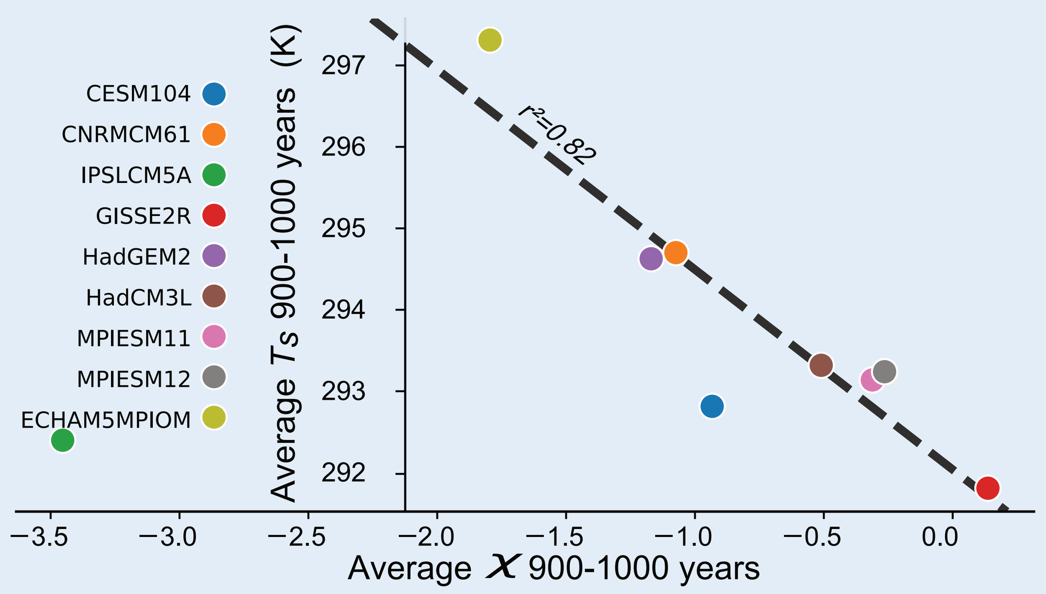
Getting λ from N = F-λTs and developping the new EBM to equilibrium leads to a new expression of the climate sensitivity:

$$S = S_0\,(1 - \chi)$$

$$\chi = \frac{F_0\,\delta\lambda}{\lambda_0\,\delta F} \qquad S_0 = \frac{\delta F}{\lambda_0}$$

Where χ is the **climate susceptibility** to forcing

- Explicit dependance on the initial climate state
- Explicit dependence on λ variations



The intermodel spread in climate sensitivity in the LongRunMIP experiment is due to different variations of λ among models.

Conclusions

1. A simple theory is developed to account for the time dependency of λ in the global energy budget.
2. The resulting differential equation accurately reproduces the response of the climate under abrupt changes in CO2 concentrations **at all time scales** as simulated in a mulitmillenia earth system model.
3. Analysis of the asymptotic form of the differential equation yields a new expression of the climate sensitivity which explicitely depends on the temporal variations of the climate feedback parameter.
4. We find that **the spread in climate sensitivity among climate models of the LongRunMip experiment is essentially due to different temporal changes in λ** (and thus different pattern effect) among models.

References

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