Observational constraints on climate sensitivity derived from the 1971-2017 global energy budget

Jonathan Chenal, Benoit Meyssignac, Aurélien Ribes, Robin Guillaume-Castel

LEGOS, Université de Toulouse - **ENPC**

jonathan.chenal@legos.obs-mip.fr – jonathanchenal@yahoo.fr

Earth Energy Budget

On a global scale, the Earth Energy budget can be written with the **forcing/feedback framework**, assuming a linear radiative response with surface temperature:

$$N = F + \lambda T$$

The **equilibrium climate sensitivity (ECS)** is the equilibrium surface temperature increase induced by an abrupt doubling in atmospheric CO_2.

$$ECS = -\frac{F_{2\times}}{\lambda}$$

ECS is reached only at equilibrium: it cannot be directly measured in the real world and requires extremely long runs to be simulated.

Effective Climate sensitivity

In practice the climate sensitivity is derived from the transient regime and is called effective climate sensitivity (effCS).

$$effCS = -F_{2\times}\frac{T}{N-F}$$

histeffCS	CO_2effCS
from the historical energy budget	from 150yr of abrupt $2xCO_2$

CO2effCs is a precise estimate of the ECS (although biased by ~17%).

The aim of this study is to derive an observational constraint on CO_2effCS

The Pattern Effect

The radiative response of the Earth depends on the geographic pattern in surface air temperature.
(Sherwood et al. 2020; Gregory et al. 2020)

This effect is called the pattern effect. It arises from:

- Mix of radiative forcings
- Lag-dependent responses to forcings
- Unforced variability.

The pattern effect leads to apparent time variations in λ and thus:

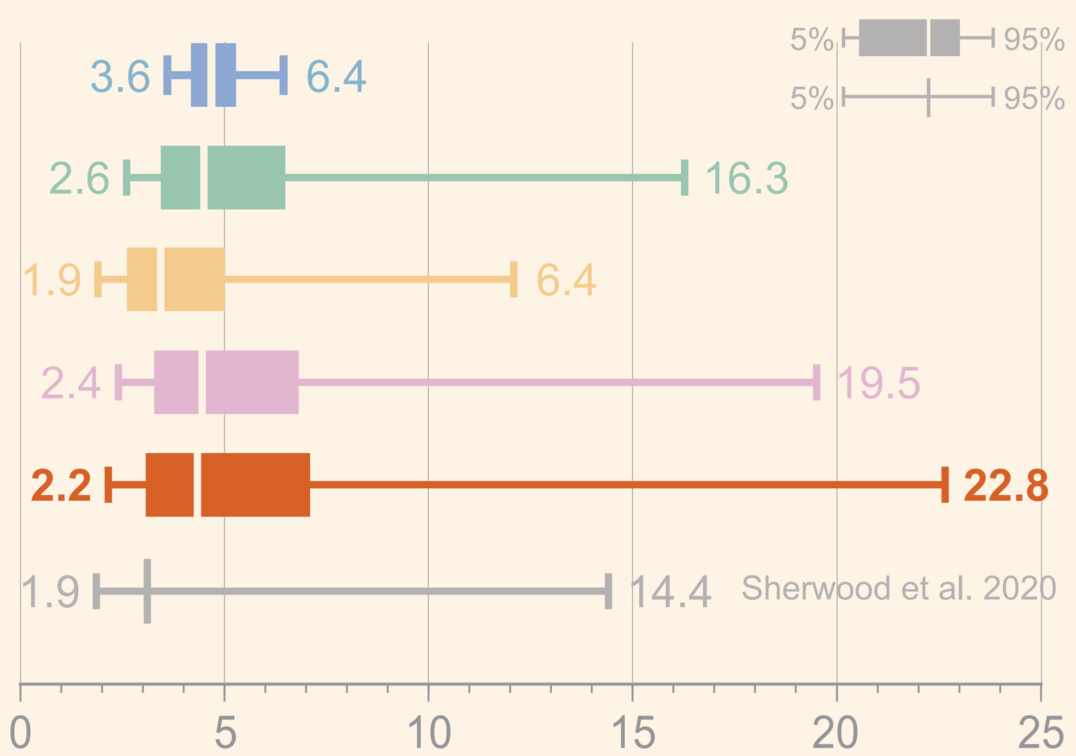
$$histeffCS \neq CO_2effCS$$

Observational constraints on CO2effCS

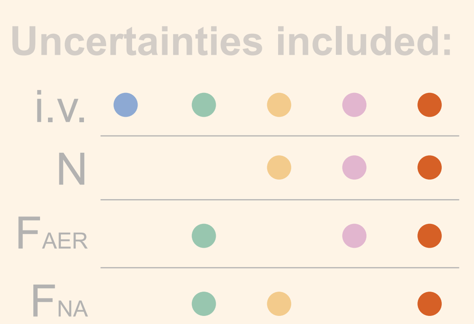
- Compute histeffCS using a regression on observations of the energy budget from 1971-2017:
  - **F non aerosol** (F_{NA}) from Sherwood et al. 2020
  - **F aerosol** (F_{AER}) from Bellouin et al. 2020
  - **T** from the Cowtan and Way 2014 corrected for the surface bias due to satellite data (Richardson et al. 2016)
  - **N** from Ocean heat content estimates derived from optimal interpolation of ocean in situ data (Ishii et al. 2017, Cheng et al. 2017)
- Include all sources of observational uncertainty
- Quantify the pattern effect from CMIP6:
  - Internal variability **i.v.** in λ
  - A distance between histeffCS and CO_2effCS

Main results

histeffCS and associated uncertainties

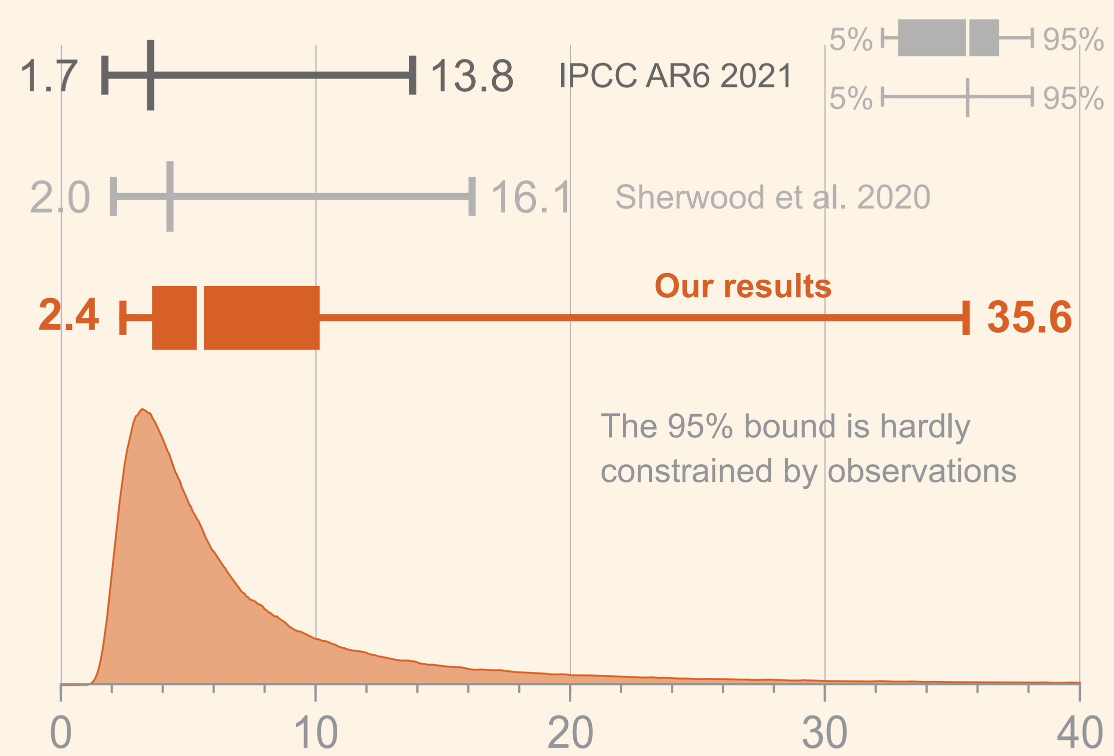


Historical effective climate sensitivity (histeffCS) (K)



The major sources of uncertaintiy in histeffCS are first the aerosol forcing and then the ocean heat content

CO2effCS



Effective climate sensitivity to CO_2 (CO_2effCS) derived from state of the art observationnal datasets (K)

The observed 1971-2017 Earth energy budget is inconsistent with a CO2effCS lower than 2.4°C

Comparison with previous studies

The two most recent studies estimating climate sensitivity from observational data are **Lewis and Curry (2018)** and **Sherwood et al. (2020)**

CO_2effCS estimates:	5%	Med.	95%
Lewis & Curry (2018)	1.2	1.7	2.7
Sherwood et al. (2020)	2.0	4.3	16.1
Chenal et al. (2022)	2.4	5.5	35.6

L&C18 use the IPCC AR5 gaussian aerosol forcing and do not correct for the **pattern effect**

Both L&C18 and S20 use a state difference method with N(~1860) = +0.2 W/m² but it is an uncertain value (probably < 0?). The regression approach removes this dependence

The higher bound difference between our estimate and S20 is unsignificant

Summary

Approach

1. Regression on **observational data** from 1971 to 2017
2. Include all sources of **observational uncertainty**
3. Quantify and include the **pattern effect**

Results

1. We find an CO_2effCS of **5.5 K** with a 5-95% interval of 2.4-35.6 K
2. **CO2effCS below 2.4 K is inconsistent with the observed energy budget**
3. The upper bound is not constrained by observations
4. The main observational sources of uncertainy are 1. the **aerosol forcing** and 2. **the earth energy balance** estimate from the ocean heat content

Comparison with previous estimates

1. Our lower bound estimate is **1.2 K** above Lewis and Curry (2018) and **0.4 K** above Sherwood et al. (2020)
2. The difference with Sherwood et al. is explained by the high ocean heat uptake of +0.2W/m² they use as the reference state in 1860
3. The further difference with Lewis and Curry is explained by the fact that, in addition, they ignore the pattern effect and use gaussian aerosol forcing from AR5

References

Bellouin et al. (2020). Bounding global aerosol radiative forcing of climate change. Reviews of Geophysics, 58(1), e2019RG000660.
Chenal et al. (2022). Observational constraint on the climate sensitivity to atmospheric CO2 concentrations changes derived from the 1971-2017 global energy budget, J. Clim., in press.
Cheng et al. (2017). Improved estimates of ocean heat content from 1960 to 2015. Science Advances, 3(3), e1601545.
Cowtan & Way (2014). Coverage bias in the HadCRUT4 temperature series and its impact on recent temperature trends. Quarterly Journal of the Royal Meteorological Society, 140(683), 1935-1944.
Forster at al. (2021). The Earth's energy budget, climate feedbacks, and climate sensitivity. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press. In Press
Gregory et al. (2020). How accurately can the climate sensitivity to CO2 be estimated from historical climate change?. Climate Dynamics, 54(1), 129-157.
IPCC (2014). Climate change 2014 : synthesis report. Contribution of working groups I, II, III to the Fifth assessment report of Intergovernmental Panel on Climate Change, C. W. Team, R. K. Pachauri, and L. A. Meyer, Eds., IPCC, Geneva, Switzerland.
Ishii et al. (2017). Accuracy of global upper ocean heat content estimation expected from present observational data sets. Sola, 13, 163-167.
Lewis and Curry (2018). The impact of recent forcing and ocean heat uptake data on estimates of climate sensitivity. Journal of Climate, 31(15), 6051-6071.
Richardson at al. (2021). Reconciled climate response estimates from climate models and the energy budget of Earth. Nature Climate Change, 6(10), 931-935.
Sherwood at al. (2020). An assessment of Earth's climate sensitivity using multiple lines of evidence. Reviews of Geophysics, 58(4), e2019RG000678.

The Pattern Effect Workshop
Boulder, CO, USA
RGC 2022