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

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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:

\[ \text{EffCS} = -\frac{F}{N - \lambda T} \]

The equilibrium climate sensitivity (ECS) is the equilibrium surface temperature increase induced by an abrupt doubling in atmospheric CO₂.

\[ \text{ECS} = -\frac{F}{N - \lambda T} \]

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):

\[ \text{effCS} = -\frac{F_{2x}}{N - \lambda T} \]

The observed 1971-2017 Earth energy budget is inconsistent with a CO₂ effCS lower than 2.4°C

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 aim of this study is to derive an observational constraint on CO₂ effCS.

The Pattern Effect Workshop

LEGOS, Université de Toulouse - ENPC

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 CO₂ effCS of 5.5 K with a 5-95% interval of 2.4-35.6 K
2. CO₂ effCS 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 uncertainty are 1. the aerosol forcing and 2. the earth energy balance estimate from the ocean heat content

Main results

Observational constraints on CO₂ effCS

- Compute histeffCS using a regression on observations of the energy budget from 1971-2017:
  - F non aerosol (F_{non}) from Sherwood et al. 2020
  - F aerosol (F_{aerosol}) from Ballmann et al. 2020
  - T from the Cowtan and Way 2014 corrected for the surface bias due to satellite data (Knighton et al. 2016)
  - N from Ocean heat content estimates derived from optimal interpolation of ocean in situ data (Shi et al. 2017; Cheng et al. 2017)

- Include all sources of observational uncertainty
- Quantify the pattern effect from CMIP6:
  - Internal variability i.e. A
  - A distance between histeffCS and CO₂ effCS

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)

CO₂ effCS estimates:
- 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

Comparison with previous estimates

Our lower bound estimate is 1.2 K above Lewis and Curry (2018) and 0.4 K above Sherwood et al. (2020)

The difference with Sherwood et al. is explained by the high ocean heat uptake of +0.2 W/m² they use as the reference state in 1860

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

Historical effective climate sensitivity (histeffCS) (K)

<table>
<thead>
<tr>
<th>histeffCS</th>
<th>associated uncertainties</th>
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<tbody>
<tr>
<td>3.6</td>
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<tr>
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<tr>
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</tr>
<tr>
<td>2.9</td>
<td>6.4</td>
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<tr>
<td>14.4</td>
<td>Sherwood et al. 2020</td>
</tr>
</tbody>
</table>

Historical effective climate sensitivity (histeffCS) (K)

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

1.9

Effective climate sensitivity to CO₂ (CO₂ effCS) derived from state of the art observational datasets (K)

<table>
<thead>
<tr>
<th>CO₂ effCS</th>
<th>13.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>16.1</td>
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<tr>
<td>2.4</td>
<td>35.6</td>
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Effective climate sensitivity to CO₂ (CO₂ effCS) derived from state of the art observational datasets (K)

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Comparison with previous studies

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References