Relationship between decadal climate variability and climate sensitivity

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Abstract

Relationships between climate variability and climate sensitivity are to be expected where the damping of a climatic anomaly is due to a change in the energy balance of the planet, such that the Fluctuation-Dissipation theorem heuristically applies [Leith, 1975]. A recent attempt to relate Equilibrium Climate Sensitivity (ECS) to global temperature variability over the historical period suggested a surprisingly tight emergent constraint on ECS [Cox et al., 2018]. However, the sensitivity-variability relationship in that study was partially hidden by anthropogenic forcing over the historical period. Here we examine instead CMIP5 control runs. These runs have no external forcing and therefore provide a much cleaner test of proposed links between internal variability and sensitivity. It has been noted before that there is a positive correlation between decadal temperature variability and climate sensitivity across climate models [Colman & Power, 2018]. Questions remained however as to how robust this relationship is across different model ensembles, what mechanisms are responsible for it, and whether it can be used as an emergent constraint on climate sensitivity. We examine the relationship between decadal variability and ECS using models of varying complexity, including CMIP5 control runs and a range of conceptual energy balance models for which analytical solutions are presented. Based on these results, a general mechanism becomes apparent and the shape of the relationship is determined to be more quadratic than linear. The nonlinearity has implications for using this relationship as an emergent constraint, where an incorrect assumption of linearity might lead to biased estimates. A further surprising implication of the study is that a slowdown in global warming does not necessarily imply that climate sensitivity is lower than previously estimated. Models with a higher sensitivity, but which broadly reproduce the long-term record of global warming, are actually more likely to have slow-down periods than models with lower sensitivity.

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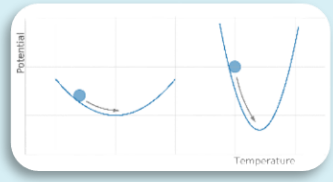
Background

- Major question in climate science to determine "safe climate" is finding out climate sensitivity: How much does the earth warm under doubling of CO_2?
- But: safe climate also depends on climate variability. Here we examine them together.
- Decadal variability chosen as scale relevant to humans.

Why more sensitive systems have more variability



Sketch of a system of a high sensitivity (left) versus low sensitivity (right). Giving the left-hand system a small perturbation will lead to a big temperature change and a slow recovery rate.

Common model of Earth's temperature: Hasselmann model:

$$C\frac{dT}{dt} = -\lambda T + Q$$

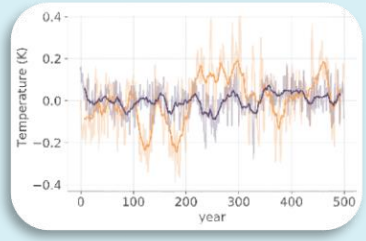
Here C is the heat capacity, T temperature anomaly, $\frac{1}{\lambda}$ proportional to Equilibrium Climate Sensitivity (ECS) and Q internal noise (forcing) and external forcing.

Methods

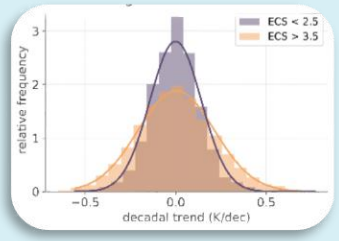
1. Use the control simulations of the CMIP5 model ensemble:
   (Control because of long record)
2. Compute all temperature trends of 10 years
3. Compute the standard deviation and fit a normal distribution
4. Combine this information with the background information of historical simulations and projections.

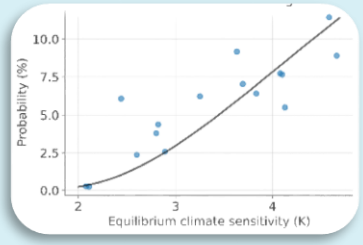
Results

Comparison of Global Mean Surface Temperatures (GMST) timeseries for control simulation. The orange is the HadGEM2-ES model with ECS = 4.6 K, while the purple is the GISS-E2-R model with ECS = 2.1 K. The high sensitivity has a larger typical decadal trend.

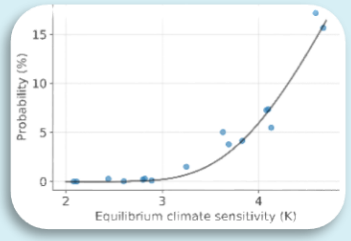


Histogram of decadal trends found in a set of climate models. Again, the high sensitive models show higher decadal variability. Overall, the Pearson's r between ECS and the standard deviation of decadal trends is 0.82.





Probability of a decade without warming. Here a background warming independent of ECS was assumed, which corresponds to a model ensemble that is tuned to match historical warming. Using a ECS-dependent background warming, the relationship becomes weaker. Each dot corresponds to one member of the CMIP5 ensemble.



Chance of a hyperwarming decade in the RCP8.5 scenario. Hyperwarming is defined here as >10 times the mean warming rate over the 20th century.

Possibility that one decade of 21st century warming equals entire 20th century's.

Discussion

Assumptions include:

- Internal noise generation (Q) independent of ECS
- Ocean internal variability not dominant
- Year-to-year variation in λ small and has same regulating mechanism as long-term climate sensitivity.[1]

Relation to historical measurements

- Historical measurements of decadal variability are consistent with ECS around 2.2 – 3.8 K, comparable to earlier work using variability. [2]

Conclusions

- Under RCP8.5 and with high climate sensitivity: 1 in 12 decades will be decades of hyperwarming. Virtually impossible in a low ECS world.

Cooling decade begin 21st century more likely in high ECS climate.

- Reducing uncertainty in climate sensitivity is critical for building resilience to climate variability.

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