Using the Interhemispheric Asymmetry of Warming to Constrain ECS

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Motivation

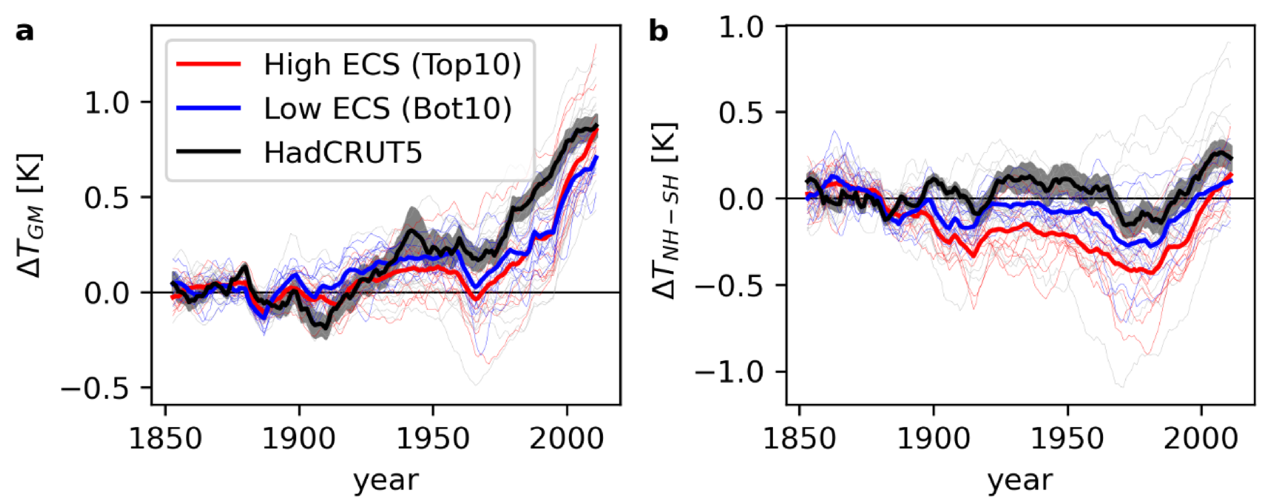


Fig. 1. The a) global-mean and b) the NH-SH temperature anomaly of the historical simulation (CMIP6 models, blue for low ECS models and red for high ECS models) and observation (HadCRUT5, black).

Can ΔT_{NH-SH} provide additional constrain on climate sensitivity ?

1. Compensation between aerosol forcing and climate feedback exists in generations of climate models. (A large portion of historical record of global-mean temperature change is useless to constrain the ECS. Fig. 1a).
2. Aerosols are mostly emitted in NH in the past and cause more cooling in high ECS models (Fig. 1b).

Method (Emergent Constraint + Weight Function)

- Two-variable linear model:

$$ECS = \alpha\, \Delta T_{GM} + \beta\, \Delta T_{NH-SH} + \gamma + N(0, \sigma)$$

ΔT_{GM} and ΔT_{NH-SH} are trends in different time window.

Q: How to deal with the time-sensitive results?

- Create the weights with the cross-validation error (σ=std. of CMIP6 ECS)

$$w[t] = \prod_{i=1,\ldots,41} N(0, \sigma, x = CV\_error[i])$$

- Weighted sum of all constrained pdf of ECS:

$$\mathrm{P_{ECS}} = \frac{\sum w[t] * p_{ECS}[t]}{\sum w[t]}$$

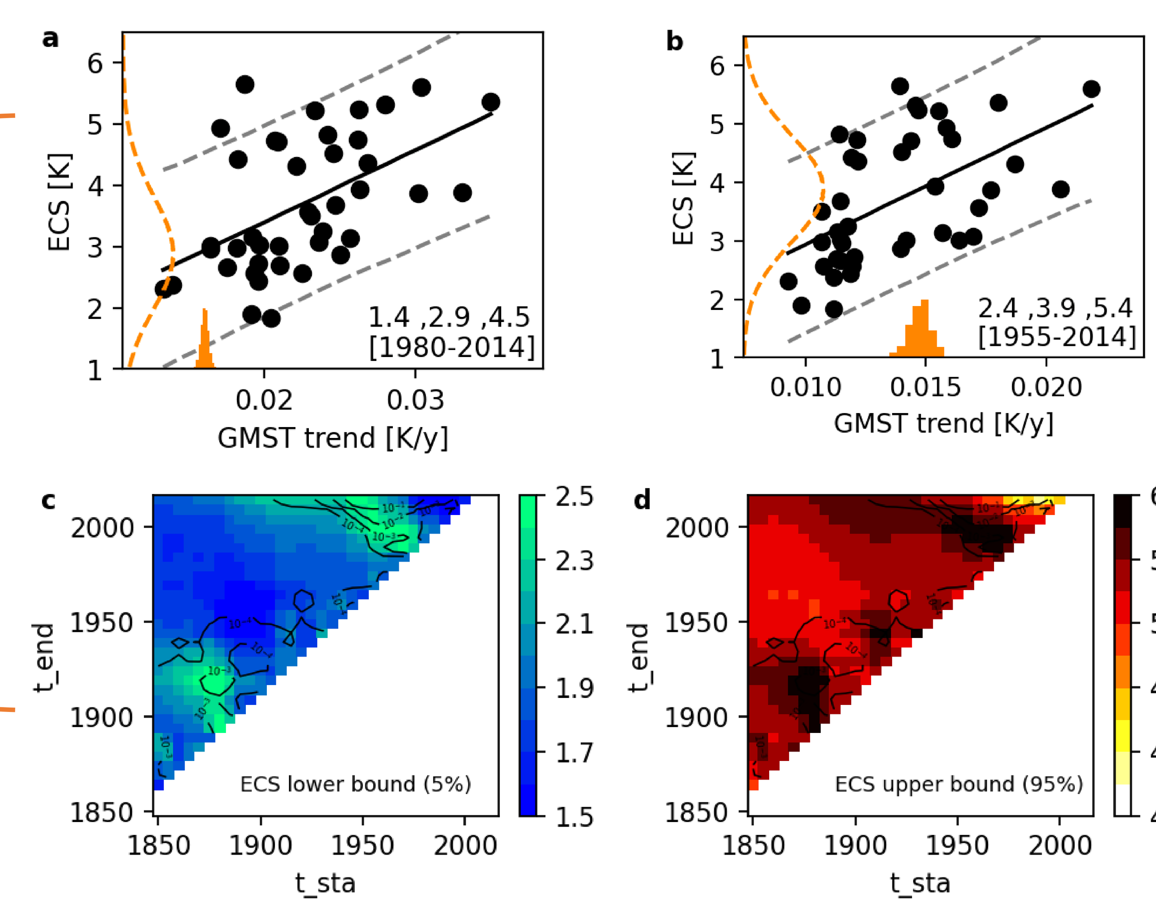


Fig. 2. Constrain the ECS with global-mean warming trend in a) 1980-2014 and b) 1955-2014. The sensitivity of the constrained ECS c) lower bound and d) upped bound to time selection.

Results: Use GCM to constrain ECS (CMIP6)

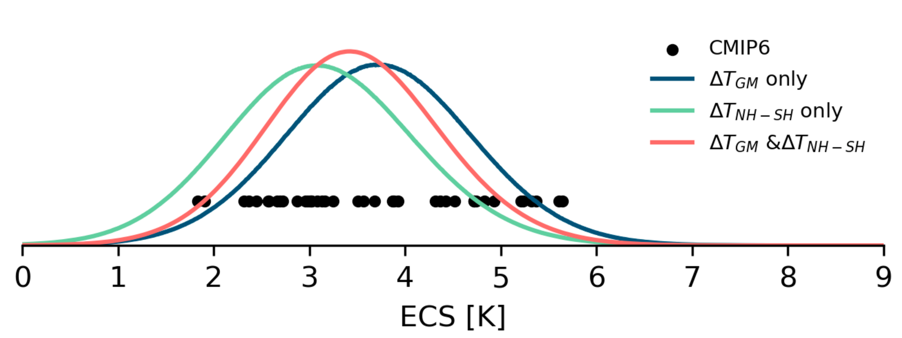


Fig. 3. The distribution of the constrained ECS with ΔT_{GM}, ΔT_{NH-SH} and both. Black dots represent the ECS of 41 climate models in CMIP6.

	5%	17%	50%	83%	95%
CMIP6	2.32	2.64	3.51	4.85	5.37
ΔT_{GM} **only**	2.11	2.79	3.72	4.66	5.35
ΔT_{NH-SH} **only**	1.50	2.17	3.10	4.05	4.77
ΔT_{GM} **&** ΔT_{NH-SH}	1.95	2.58	3.44	4.33	5.00
IPCC AR6	2.0	2.5	3.0	4.0	5.0
Nijsse et al. (2020)	1.52		2.6		4.03

Table 1. The median, likely and very likely range of the ECS before and after constraint. The results are compared with values from other studies.

1. Using the information from the whole time series (compare to a single time frame) of ΔT_{GM} doesn't help much on constraining ECS.
2. Compared with the ΔT_{GM}, the ΔT_{NH-SH} argues for lower ECS values.
3. Using both, we have a constrained ECS range that is close to the one in IPCC AR6 report.
4. The same analysis for TCR shows that its best estimate is 1.9K (IPCC AR6: 1.8K) and the very likely range is 1.3-2.5K (IPCC AR6: 1.2-2.4K).

Box-model (NH, SH and Deep Ocean)

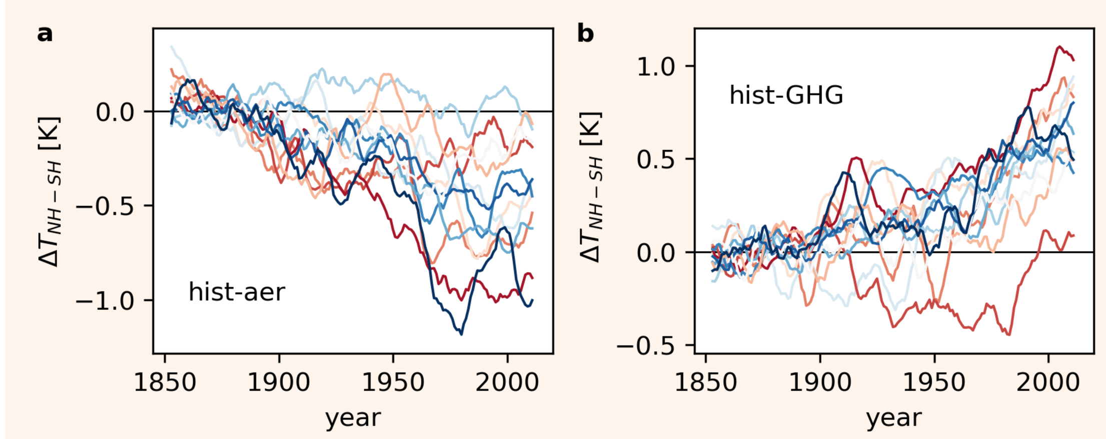


Fig. 4. Time series of IAST in hist- aer, hist- GHG. Only 12 models are available for now. They are colored from blue to red to represent low to high ECS models.

1. There are no enough model results in CMIP6 to thoroughly discuss the connection between aerosol, climate feedback and ΔT_{NH-SH}.
2. A 3-box model is developed to learn the GCM behavior and perform a large ensemble of exploratory experiment.

Learn from GCMs and run with realistic forcing

1. Learn (fit) all the dynamical parameter of the 41 climate models in CMIP6 from theirs abrupt-4xCO2 experiment. (Fit Method: HMCMC, ML-PINN [https://github.com/ChenggongWang/3bcm_with_PINN])
2. Kick 3-box model with realistic historical forcing from AR6 report . DOI 10.5281/zenodo.5705391
3. Explore how ΔT_{NH-SH} response to aerosol forcing by adjusting its strength and distribution.

$$C_n \frac{dT_n}{dt} = F_n + \lambda_n T_n - \epsilon_n \gamma_n (T_n - T_d) - Q(T_n - T_s) \qquad \text{NH}$$

$$C_s \frac{dT_s}{dt} = F_s + \lambda_s T_s - \epsilon_s \gamma_s (T_s - T_d) + Q(T_n - T_s) \qquad \text{SH}$$

$$C_d \frac{dT_d}{dt} = \gamma_s (T_s - T_d) + \gamma_n (T_n - T_d) \qquad \text{Deep Ocean}$$

feedbacks λ, heat capacities C, ocean heat uptake efficiency γ and efficacy ϵ

What are the role of the interhemispheric asymmetrical aerosol forcing ?

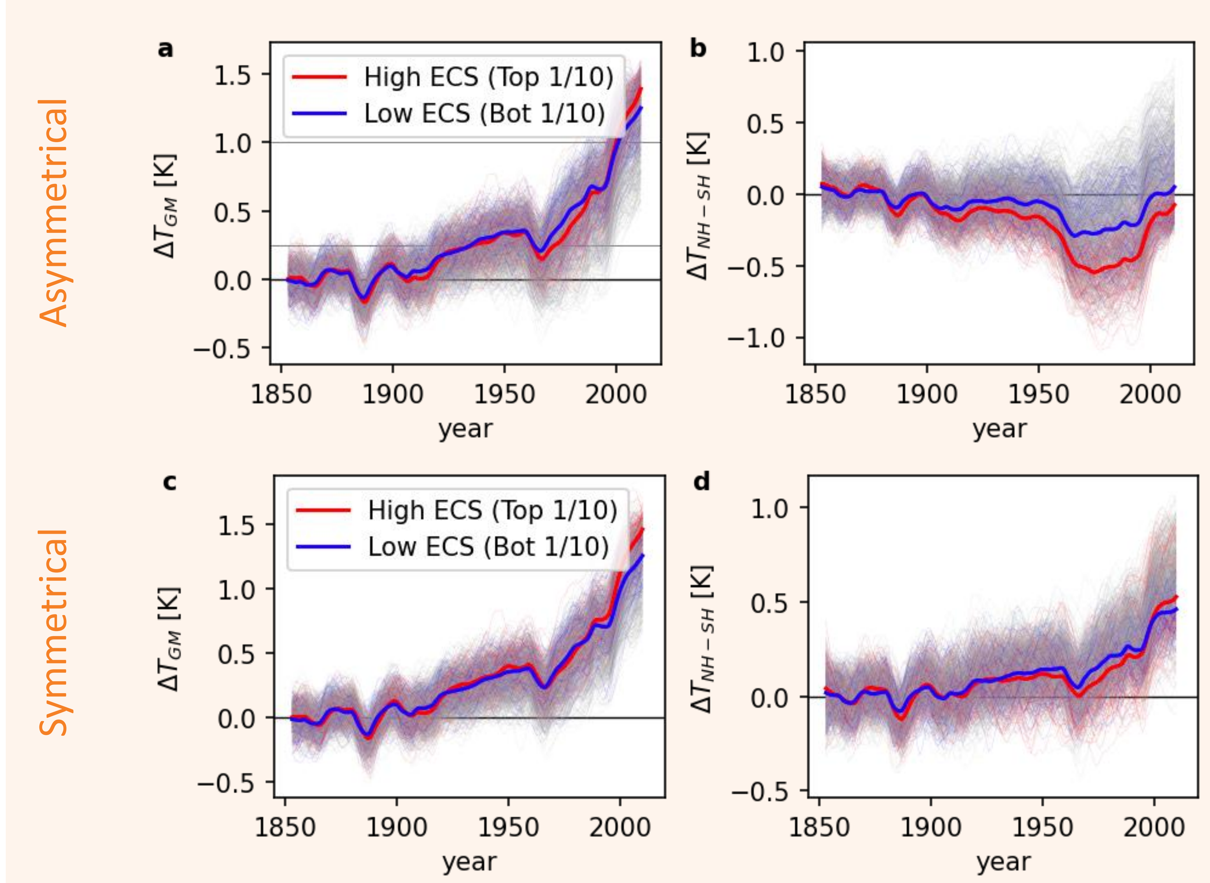
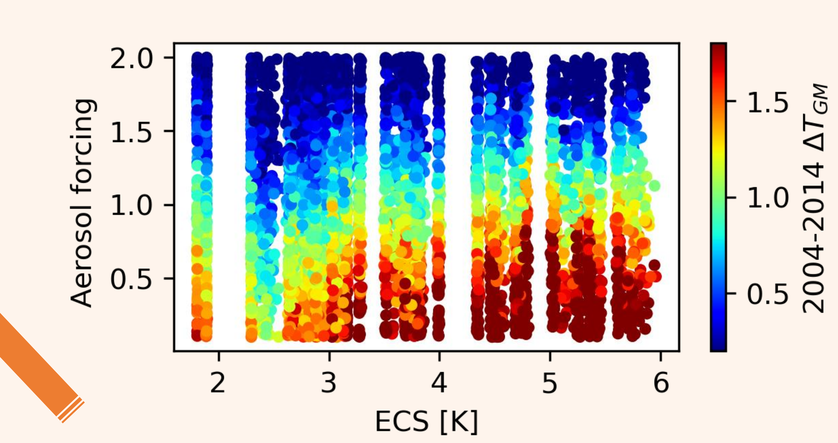


Fig. 5. Large ensembles (1000) of 3-box model with interhemispheric asymmetrical (top row) and symmetrical (bottom row) aerosol forcing. Time series of a) ΔT_{GM} and b) ΔT_{NH-SH} for box models with aerosol forcing only in NH. c) and d) show the models with uniform aerosol forcing in NH and SH. Like in Fig. 1, we color the highest and lowest (top/bottom one tenth) ECS models with red and blue lines (thick lines are the ensemble mean).

1. Randomly match the dynamical parameter and aerosol forcing strength to produce a large ensemble of climate models. ~5000 models
2. Tune the model by selecting those with reasonable warming (within range of CMIP6). ~1000 models



3. Run the same 1000 models but with symmetrical aerosol forcing.

Symmetrical aerosol forcing almost kills the connection between ΔT_{NH-SH} and ECS.
Asymmetrical aerosol forcing is why the ΔT_{NH-SH} can provide additional constraint on ECS.

Manuscript to be submitted.

Key References:
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