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An easy and effective way to diagnose equilibrium climate sensitivity

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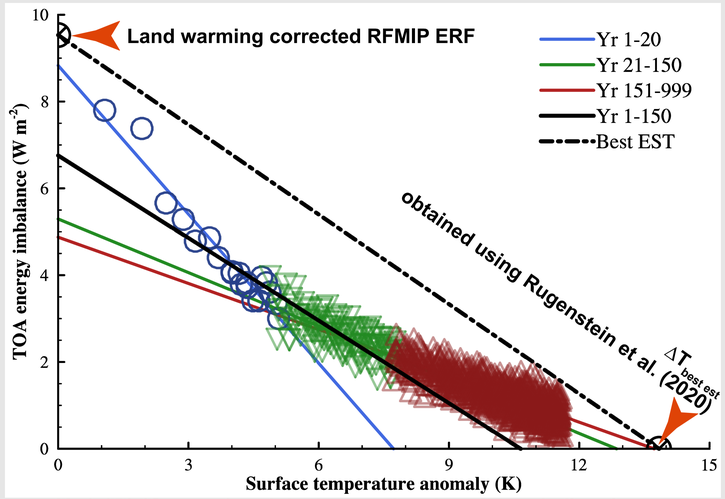
1. Current thoughts on the underestimated ECS from the Gregory method

Quoting a great summary in Dong et al. (2021):

"*In practice, ECS is often extrapolated from a linear regression of ΔN against ΔT for the first 150 years of abrupt-4xCO2 simulations (Gregory et al., 2004). This extrapolation generally underestimates the true ECS due to changes in radiative feedbacks as climate equilibrates (Dunne et al., 2020; Rugenstein et al., 2020), owing to time-evolving surface warming patterns (e.g., Andrews et al., 2015; Armour et al., 2013; Dong et al., 2020), and nonlinear state dependence of radiative feedbacks (e.g., Bloch-Johnson et al., 2015, 2021; Caballero & Huber, 2013).*"

Is this time-dependent radiative feedback really the reason for the underestimated ECS from the Gregory method?
I'm afraid we don't think so!

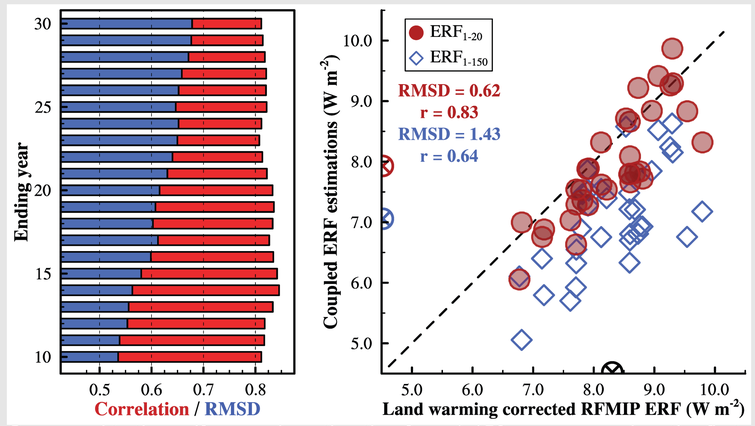
2. Why? A schematic plot with CESM2 results



Yr 1-150 (Gregory) and the best estimation share similar slopes.

In this case, the reason for the underestimated ECS from Gregory method really is the underestimated ERF. Hence, $ECS_{Modified} = -ERF_{1-20}/2\lambda_{1-150}$

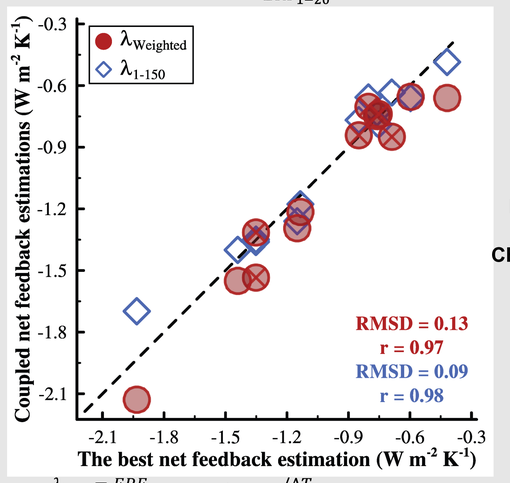
3. Effective radiative forcing evaluations



Compared to the uniform underestimation from 1-150 year regression, the first 20 year regression provides ERF much closer to the best estimations from RFMIP and has acceptable correlation and RMSD.

4. Net feedback evaluations

$$\lambda_{Weighted} = \frac{\lambda_{1-20}Damp_{1-20} + \lambda_{21-150}Damp_{21-150} + \lambda_{151-}Damp_{151-}}{ERF_{1-20}};$$



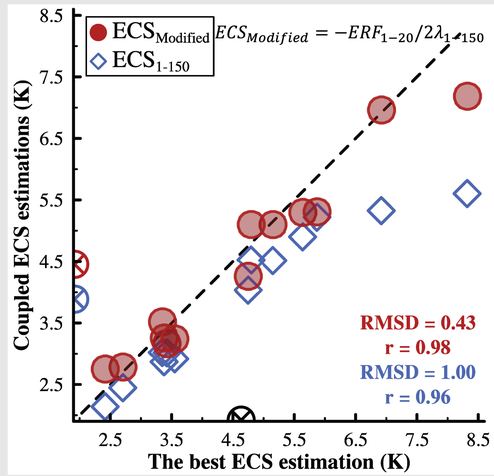
LongRunMIP models
+
CESM2 & IPSL-CM6A-LR

$\lambda_{best} = ERF_{best:\ RFMIP/ERF_{1-20}}/\Delta T_{best:2\times ECS_{Rugenstein}}$

The 150-yr feedback estimations are well matched with the best (equilibrium) net feedback estimation.

The equilibrium net feedback is the weighted sum of feedbacks at different periods.

5. Equilibrium climate sensitivity evaluations

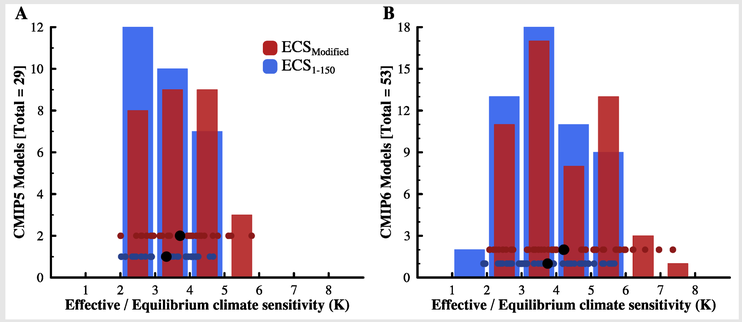


LongRunMIP models
+
CESM2 & IPSL-CM6A-LR

Rugenstein et al. (2020)

The modified Gregory method provides pretty good ECS estimations, especially for those high ECS models.

6. Revisit ECS of CMIP5 and CMIP6



7. Take-home points $ECS_{Modified} = -ERF_{1-20}/2\lambda_{1-150}$

a. The underestimated ECS from Gregory method is mainly due to its underestimation of ERF, since the feedback estimations from Gregory method are well matched with the equilibrium net feedback estimation;
b. The contribution from higher ERF in CMIP6 to the higher ECS in CMIP6 is underestimated.