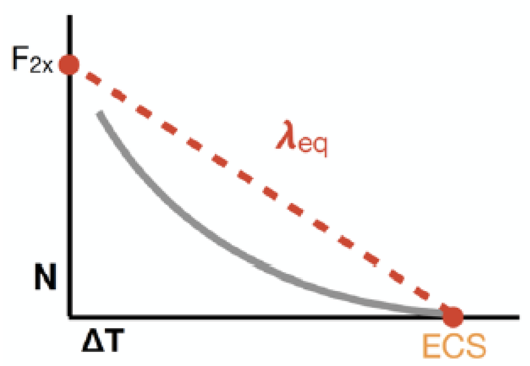
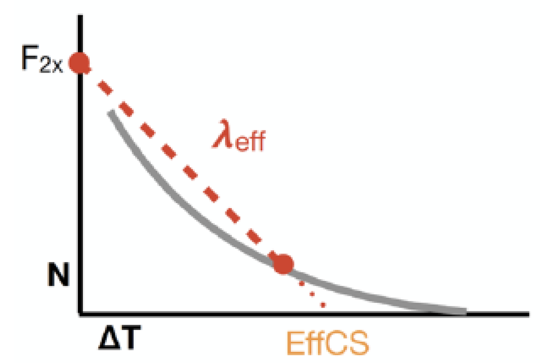
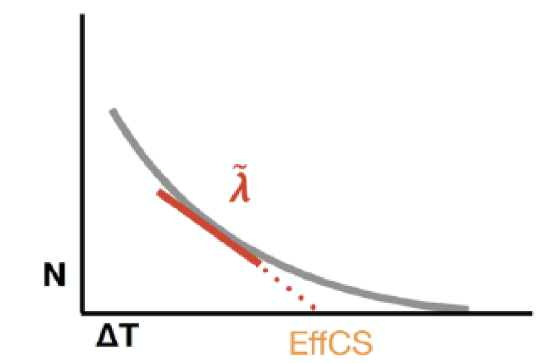
Three Flavors of Radiative Feedbacks and Thoughts on the Relevance of the Southern Ocean

Maria Rugenstein, Colorado State University

Three Flavors of Radiative Feedbacks I

Pattern effect and feedback temperature dependence render feedbacks non-constant – how should we define and calculate them?

Equilibrium feedback parameter	**Effective feedback parameter**	**Differential feedback parameter**
$\lambda_{\text{eq}} = -F_{2\times}/\text{ECS}$ Difference between two equilibrated states	$\lambda_{\text{eff}} = \Delta R/\Delta T$, with $R = F - N$ Change w.r.t. a steady state	$\widetilde{\lambda} = \delta R/\delta T$ or $\widetilde{\lambda} = \delta N/\delta T$ Covariance of R (or N) and T w.r.t. a selected state
		
Dependent on the two endpoint states	**Dependent on two states (starting and current)**	**Dependent on warming within the concerned period**
• Satisfies $N = F + \lambda_{\text{eff}}\,\Delta T$ at $N = 0$, thus $\text{ECS} = -F_{2\times}/\lambda_{\text{eq}}$ • Time-invariant; not impacted by internal variability → Studying $\mathcal{O}(\Delta T^2)$, i.e. nonlinearities → Comparing equilibrated models and paleo-proxies	• Satisfies $N = F + \lambda_{\text{eff}}\,\Delta T$, $\text{EffCS} = -F_{2\times}/\lambda_{\text{eff}} \neq \text{ECS}$ • Can be impacted by internal variability and pattern effect, depending on period → Estimate EffCS from the historical period, the paleo record, and non-equilibrated climate model simulations	• $N \neq F + \widetilde{\lambda}\Delta T$; $\text{ECS} \neq -F_{2\times}/\widetilde{\lambda}$ • Can be dominated by internal variability if δR or δT small → Understanding causes of temporal changes in λ → Estimate EffCS from satellite or other short observations

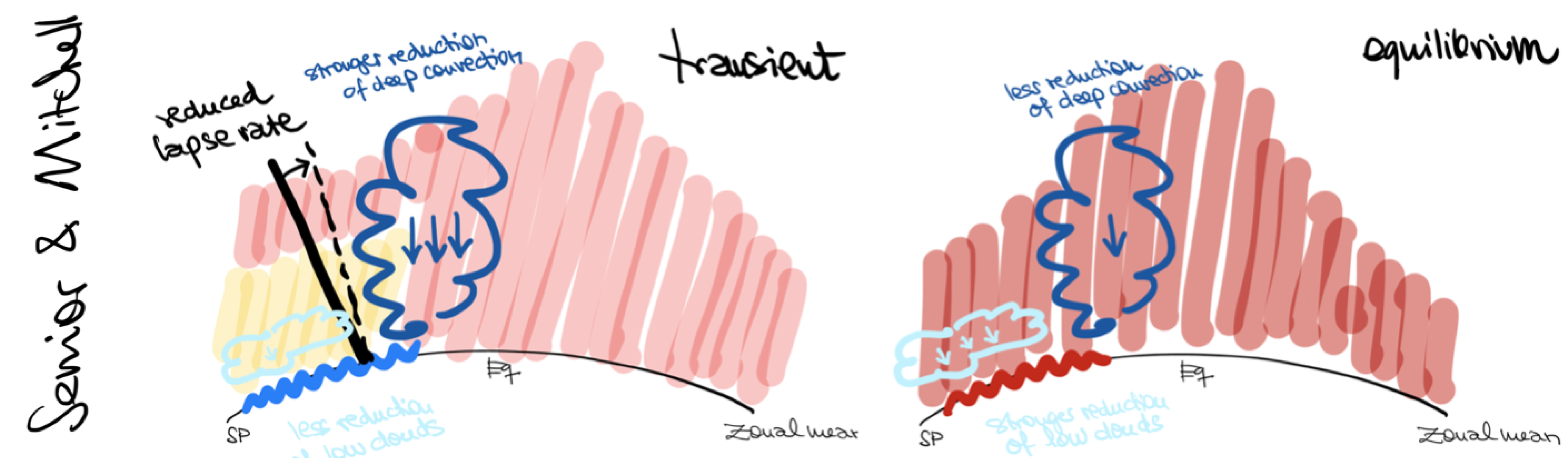
Equilibrium climate sensitivity (ECS)	**Effective climate sensitivity (EffCS)**
Equilibrated temperature to doubled CO_2 above pre-ind. levels	Extrapolation of (linear) fit to time-evolving ΔT and R (or N)
+ Clear and concise definition – Conceptually blurs into Earth System Sensitivity with slow, non-Charney feedbacks – Requires long simulations or paleo-proxies equilibrated w.r.t. Charney feedbacks and ocean heat uptake	+ Correlates with a model's effective and differential feedback magnitude + Used widely for short simulations and historical observations – Not well defined – Measures various degrees of equilibration, depending on input – Difficult to compare to ECS and EffCS computed with other definitions of time-frames due to missing standards on timescales, fitting methods, quantification of internal variability and F

Note. For simplicity, all values and notation in the table refer to a doubling of CO_2, and thus, $F_{2\times}$ and ECS. "Gregory plots" illustrate a step-forcing response of a climate model in gray, the feedback parameter in red, and the climate sensitivity in orange. Noteworthy properties of the definitions are denoted with bullet points, common applications with arrows, advantages with a plus, and disadvantages with a minus.

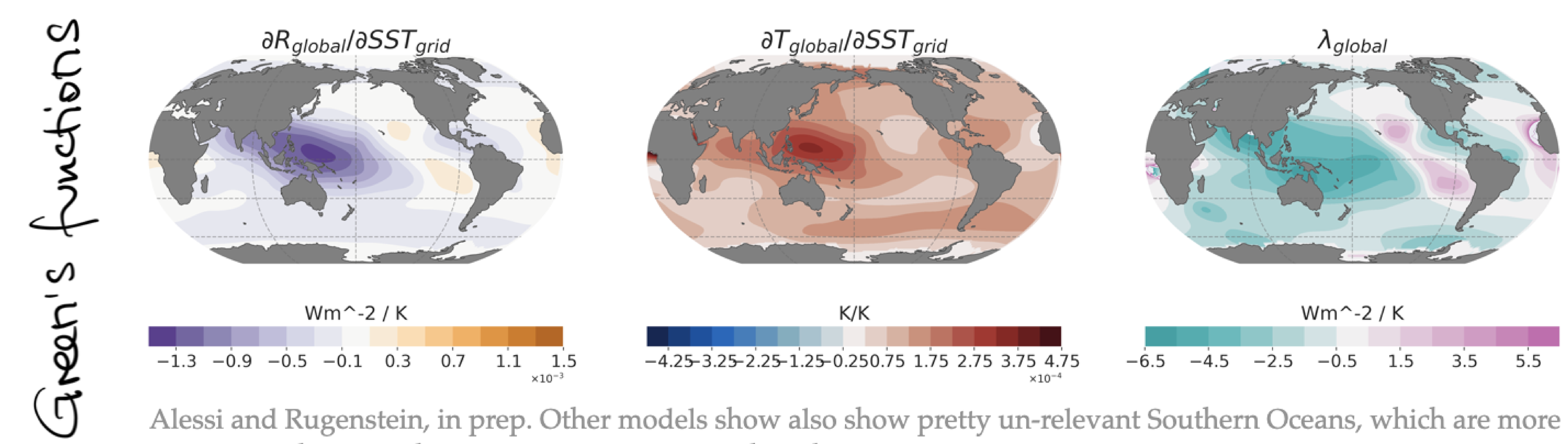
- The definitions represent different properties of how the climate system responds to forcing. They are not right or wrong but are often compared as if they represented the same thing.
- Methods to estimate climate sensitivity use different definitions and this reflects in the estimate. Different feedback definitions can result in ECS differences of several degrees (see figures on the right). This is published in Rugenstein and Armour 2021, GRL.
- **Defining the pattern effect as** $\Delta\lambda = \lambda_{\text{reference}} - \lambda_{\text{period of interest}}$ potentially attributes a difference between feedback definitions to the pattern effect. We didn't discuss this in the paper! Thoughts welcome. I suggest $\lambda_{\text{reference}} = \lambda_{\text{homogeneous}=\text{Cess}}$ instead of $\lambda_{\text{reference}} = \lambda_{\text{4xCO2 150yr}}$.

Senior and Mitchell 2000's contradicts the Green's function's perspective

Senior and Mitchell 2000 propose the pattern effect is mostly due to *local* lapse-rate-caused-cloud-feedback changes in the Southern Ocean region. SST-TOA Green's functions make the Southern Ocean seem having a very weak local response, compared to the Tropics. Were Senior and Mitchell 2000 wrong (flux adjusted model, ancient cloud parameterizations, ...?)? Does the Green's function approach by construction miss local Southern Ocean feedbacks? Hypothesis: The spatial cross-terms are relevant and the GF underestimates important local feedbacks. The Senior and Mitchell process needs a warmer free tropospheric temperature *as well as* an initially relatively cool Southern Ocean, which slowly warms up.



Sketch of processes proposed by Senior and Mitchell 2000: Southern Ocean heat uptake forces regional feedbacks



Alessi and Rugenstein, in prep. Other models show also show pretty un-relevant Southern Oceans, which are more efficient in changing the Equatorial West Pacific than the local TOA radiative fluxes.

Three Flavors of Radiative Feedbacks II

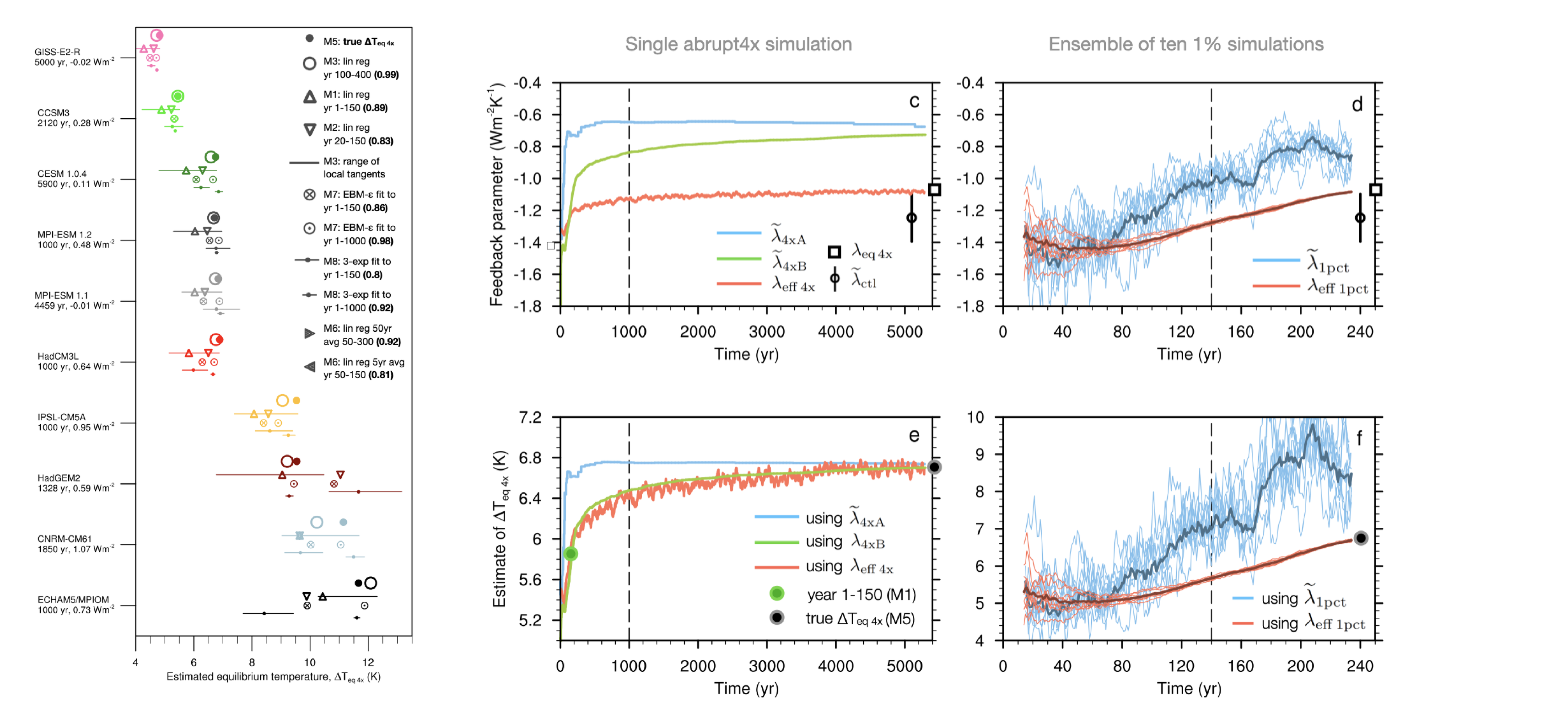


Figure 1:(left) ECS estimation methods using different feedback definitions result in different estimates, especially if the overall sensitivity is high. (right) Values of different feedback definitions and their ECS estimate through time.