The varying Earth's radiative feedback connected to the ocean energy uptake: a theoretical perspective from conceptual frameworks

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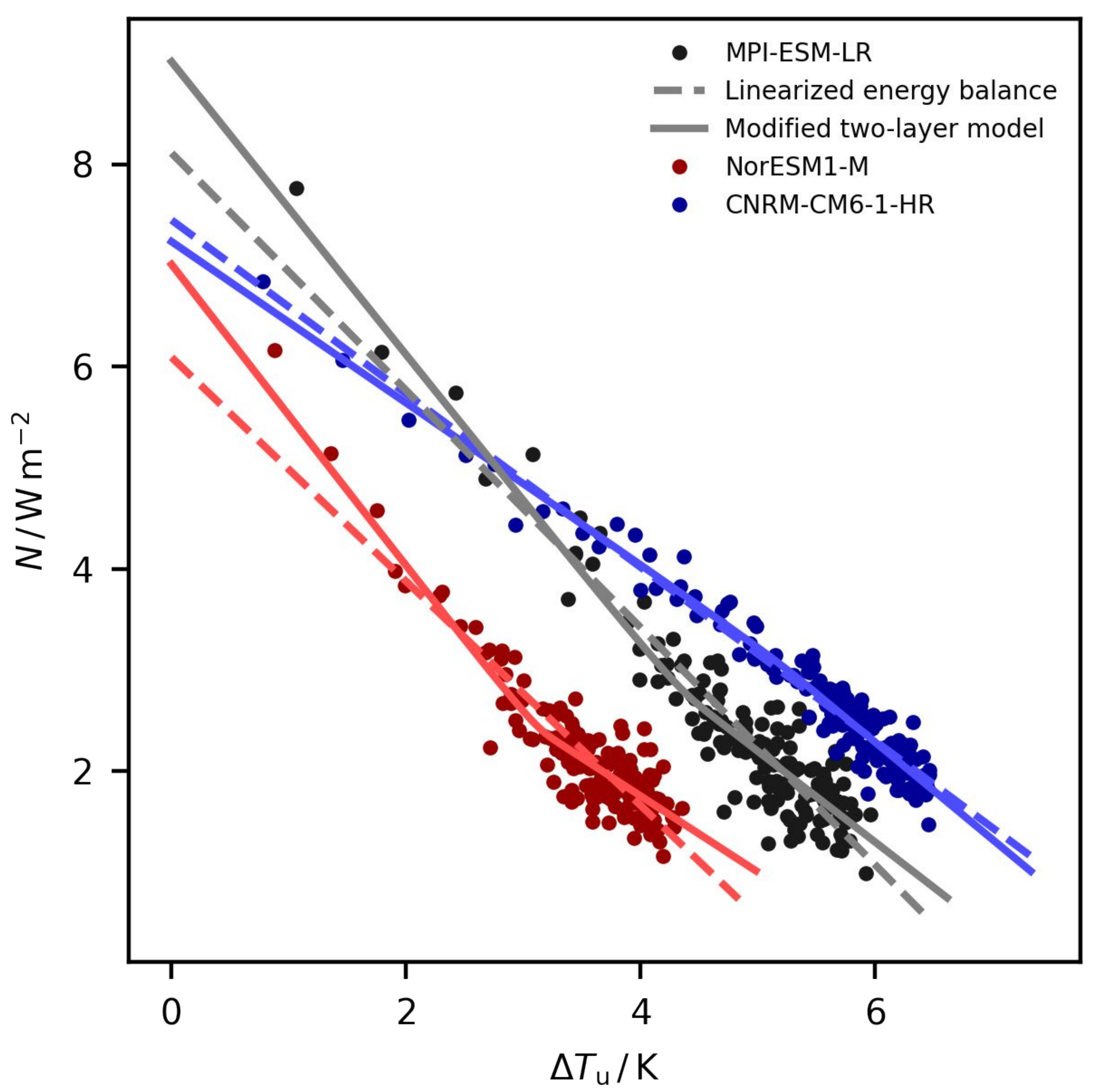

Figure 1. NT-diagrams for three models with different pattern effects.

The effect of the evolving warming pattern is a departure from a linearity in NT-diagrams. Radiative feedbacks are now time-varying.

The extended two-layer model used a perturbed coupling between the upper and deep ocean which provides the bending as in GCMs[1,2]

$$N = F + \lambda \Delta T_{\mathrm{u}} + (H - H')$$
$$H - H' = (1 - \hat{\varepsilon})\gamma(\Delta T_{\mathrm{u}} - \Delta T_{\mathrm{d}})$$

The leading interpretation, however, considers it as part of the radiative response, considering it a patch for a broken model.

Problem: From a non-linear planetary energy budget this interpretation is lacking

$$N = (1-\alpha)S(t) + G(t) - \epsilon\sigma(fT_{\mathrm{u}})^4$$

1. Albedo (α), long-wave emissivity (ϵ) and the emission temperature scaling factor (f) depend on an oceanic hidden variable...
2. ...or are functions of the pattern but here we see the global effect

***Solution**: The total change in energy E has a component from a varying effective thermal capacity*

$$E = CT_{\mathrm{u}};\ \dot{E} = N + \dot{C}T_{\mathrm{u}}$$

The changing ocean circulation:

- redistributes the ocean energy, changing the uptake.
- changes also the SSTs from below through deep water formation and upwelling. The radiative feedbacks respond to this change.
- Parts of this mechanism have been revealed in recent studies[3,4,5].

Globally, it looks like a change in the effective thermal capacity.

Ironically, the traces are also in the extended two-layer model. Solving analytically the model, there is an explicit expression of the time-varying radiative feedback. The time-varying term is proportional to the ratio of the deep to the upper layer energy content

$$\mathcal{F}_{\mathrm{pat,\,dyn}} = C_{\mathrm{u}}\frac{\kappa}{|\lambda|}\tanh\left[\frac{\kappa}{2}(t - t_0) + \mathrm{arctanh}(Z)\right]$$

where, the coefficients are functions of the thermal and radiative parameters.

The hyperbolic tangent factor strengthens the feedback prior to $t = t_0 + \frac{2}{\kappa}\mathrm{arctanh}\,|Z| = t_{\mathrm{rev}}$. Afterwards, it weakens the feedback, leading to the bending and mimicking the change in ocean circulation.

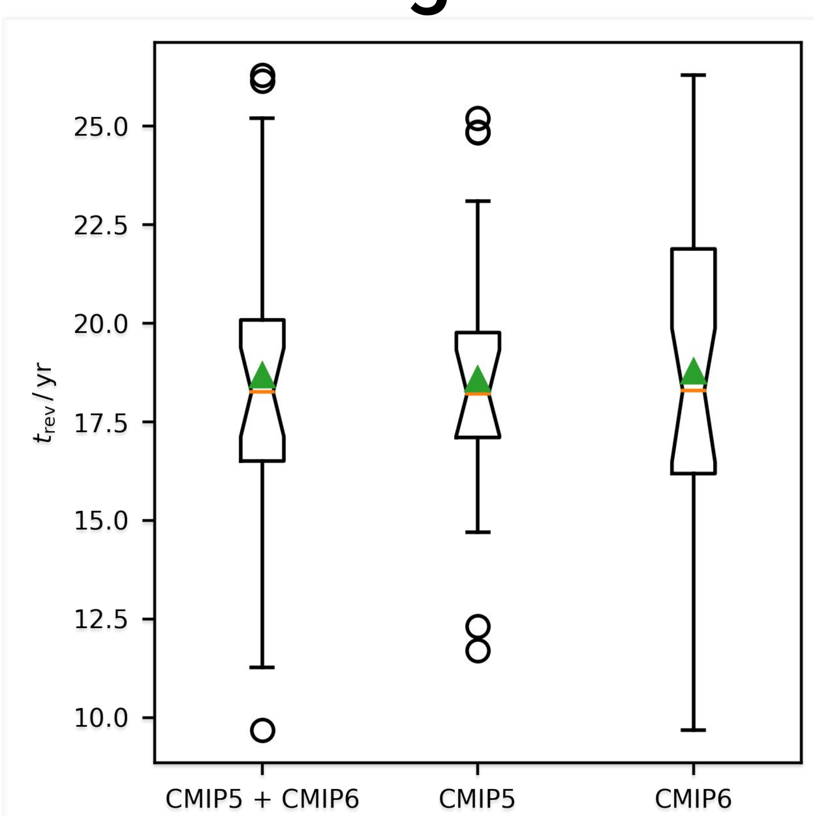

Figure 2. Timescale t_{rev} in the CMIP ensembles.

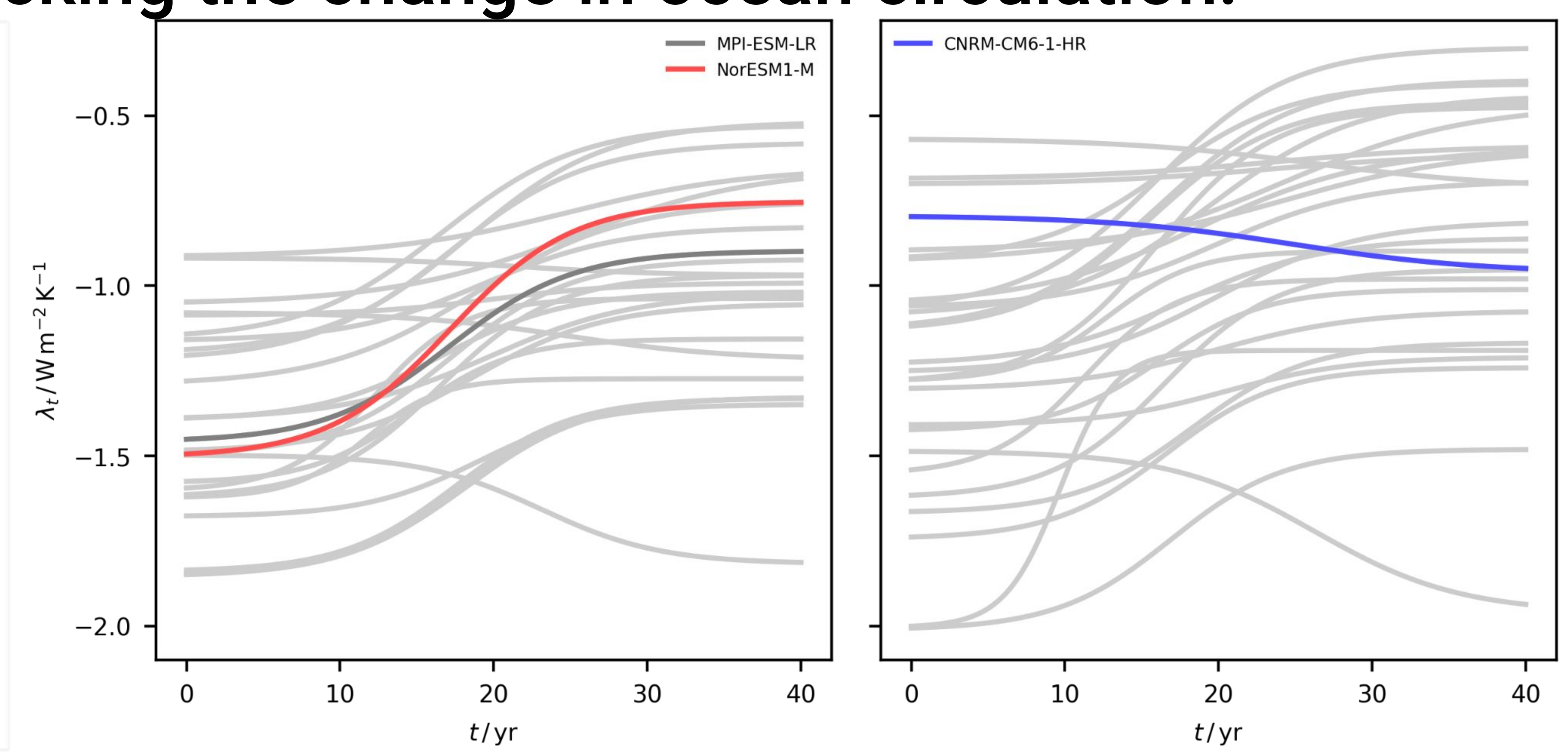

Figure 3. Behaviour of the radiative feedback in the CMIP ensemble. Left, CMIP5. Right, CMIP6.

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