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

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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 GCMSs.

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

\[ N = (1 - \alpha)S(t) + G(t) - \varepsilon f(T_u) + \varepsilon \]

1. Albedo (\( \alpha \)), long-wave emissivity (\( \varepsilon \)) 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

\[ E = CT_u; \quad \dot{E} = N + \dot{C}T_u \]

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

Iironically, 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

\[ F_{\text{pat, dyn}} = C_u \frac{K}{|\lambda|} \tanh \left( \frac{K}{2} (t - t_0) + \arctanh(Z) \right) \]

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

The hyperbolic tangent factor strengthens the feedback prior to

\[ t = t_0 + \frac{2}{K} \arctanh |Z| = t_{\text{rev}} \]

Afterwards, it weakens the feedback, leading to the bending and mimicking the change in ocean circulation.

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

**Figure 2.** Timescale \( t_{\text{rev}} \) in the CMIP ensembles.

**Figure 3.** Behaviour of the radiative feedback in the CMIP ensemble.

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