Revisiting the Role of the Water-Vapor and Lapse-Rate Feedbacks in the Arctic Amplification of Climate Change

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Abstract

The **processes that contribute to** the **Arctic amplification** of global warming are often described in the context of climate feedbacks. Previous studies have used a **traditional feedback analysis** framework to partition the regional surface warming into contributions from each feedback process. However, this partitioning can be complicated by interactions in the climate system. Here we focus **instead** on the physically intuitive approach of **inactivating individual feedback processes** during forced warming and evaluating the resulting change in the surface temperature field: a **feedback locking analysis**. We investigate this using a moist energy balance model. We find that when warming is attributed to each feedback process by comparing how the climate would change if the process were not active, the **water-vapor feedback is the primary reason that the Arctic region warms more than the tropics, and the lapse-rate feedback has a neutral effect on Arctic amplification** by cooling the Arctic and the tropics by approximately equivalent amounts. These results are **strikingly different from** previous **traditional feedback analyses**, which identified the lapse-rate feedback as the largest contributor to Arctic amplification, with the water-vapor feedback being the main opposing factor by warming the tropics more than the Arctic region. This highlights the importance of comparing different approaches of analyzing how feedbacks contribute to warming in order to build a better understanding of how feedbacks influence climate changes.

1. Introduction

• Recent studies have identified the lapse-rate feedback as the main contributor to Arctic amplification, with the water-vapor feedback being the largest factor opposing Arctic amplification (Pithan and Mauritsen 2014; Stuecker et al. 2018; Goosse et al. 2018).

• These studies adopt a traditional feedback analysis framework that partitions regional temperature changes into warming contributions from each feedback, as described in Sec. 2 below. Such a result is shown in Fig. 1a.

2. Attributing warming to individual feedback

• The sum of spatially-varying individual feedbacks is the total feedback:

$$\underbrace{\lambda(\phi)}_{\phi \text{ is latitude}} = \underbrace{\lambda_0}_{\text{global-mean Planck}} + \underbrace{\sum_i \lambda_i(\phi)}_{\text{individual feedbacks}}$$

• The TOA energy budget is written as

$$0 = \lambda(\phi) \underbrace{T(\phi)}_{\text{surface temp}} + \underbrace{F(\phi)}_{\text{rad forcing + OHU + AHT}}$$

• The **traditional feedback analysis** partitions total warming as

$$T(\phi) = \underbrace{\frac{F(\phi)}{-\lambda_0}}_{\text{warming with no feedbacks}} + \underbrace{\sum_i T_{i*}}_{\text{warming contributions from each feedback}}$$

with warming contributions

$$T_{i*}(\phi) \equiv \lambda_i(\phi)\frac{T(\phi)}{-\lambda_0}$$

• We perform a feedback locking analysis using a moist energy balance model (**MEBM**). This MEBM has been shown to reproduce 90% of the variance in surface temperature in CMIP5 GCMs (Bonan et al. 2018).

• The MEBM takes as inputs the total feedback $\lambda(\phi)$ and the radiative forcing and OHU components of $F(\phi)$, which are diagnosed from GCMs, and it gives the AHT and warming as outputs.

• We lock each feedback i in the MEBM by replacing $\lambda(\phi)$ with $\lambda(\phi) - \lambda_i(\phi)$ and computing the resulting AHT and warming, $F_{-i}(\phi)$ and $T_{-i}(\phi)$.

• The **feedback locking analysis** attributes the warming from each feedback as

$$T_i \equiv T - T_{-i}$$

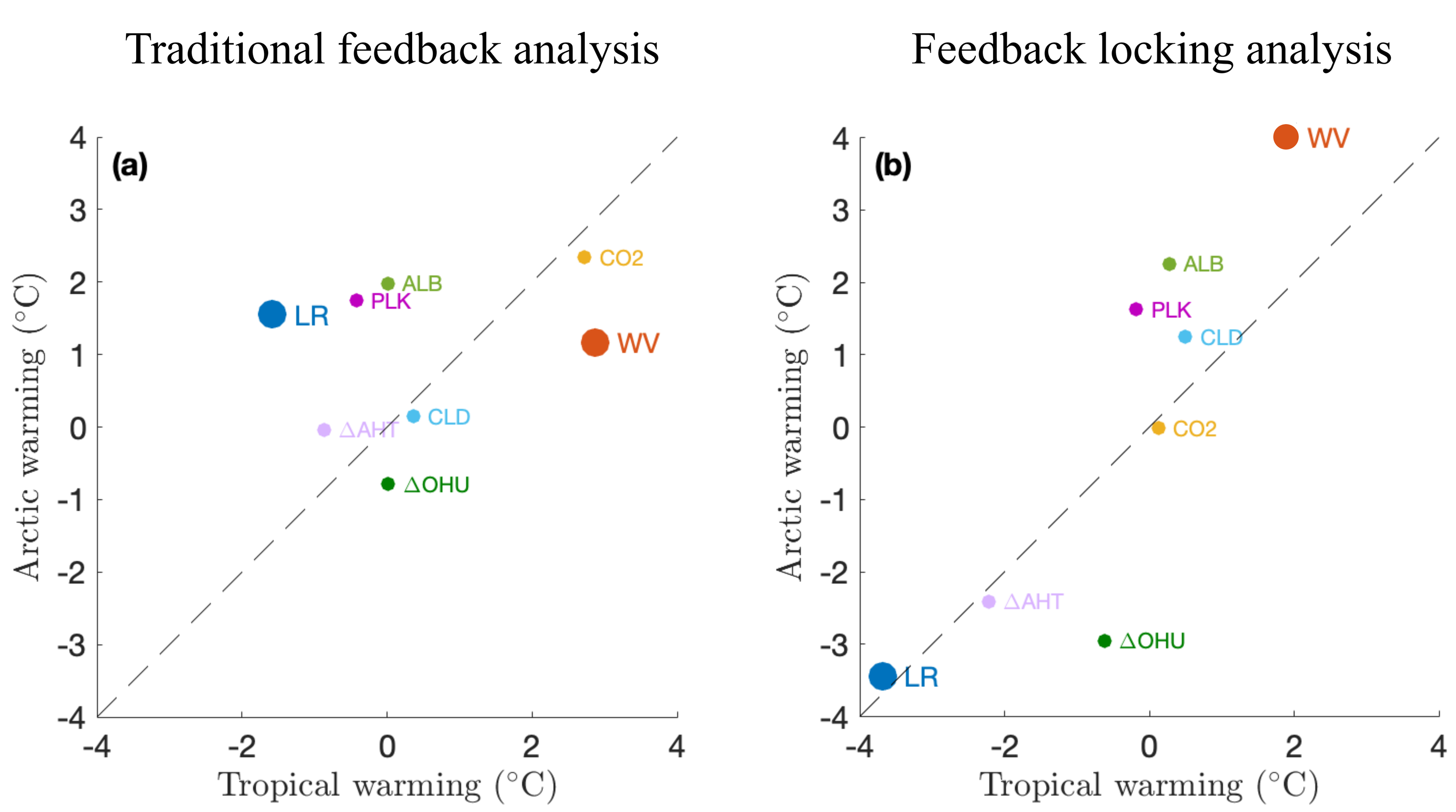

Fig. 1. Contributions of each feedback to Arctic amplification. (a) Traditional feedback analysis, as in previous studies. (b) Feedback locking analysis, which is investigated in the present study.

3. Lapse-rate and water-vapor feedbacks

• The results in Fig. 1 show striking differences between the two approaches, especially for the water-vapor and lapse-rate feedbacks.

• The **water-vapor feedback** is the **largest factor opposing Arctic amplification** in the **traditional feedback analysis** (i.e., it is the point farthest in the downward right direction from the dashed line in Fig. 1a). In the **feedback locking analysis**, by contrast, it is the **largest contributor to Arctic amplification** (the point farthest in the upward left direction from the dashed line in Fig. 1b).

• The **lapse-rate feedback** is the **largest contributor** to **Arctic amplification** in the **traditional feedback analysis** (Fig. 1a), warming the Arctic while cooling the tropics. By contrast, it has an **approximately neutral effect** in the **feedback locking analysis** (Fig. 1b), because it cools the tropics and the Arctic by similar amounts.

4. Decomposition of feedback locking result

• It can be readily shown using the formalism above that the warming attributed to each feedback in the feedback locking analysis can be decomposed as

$$\underbrace{T_i}_{\text{feedback locking result}} = \underbrace{T_{i*}}_{\text{individual warming contribution}} + \underbrace{\frac{\sum_{j\neq i}\lambda_j T_i}{-\lambda_0}}_{\text{feedback interactions}} + \underbrace{\frac{F - F_{-i}}{-\lambda_0}}_{\text{AHT interactions}}$$

• This shows that **the inclusion of a given feedback causes warming** (T_i) that can be **decomposed** into contributions from

- the individual warming contribution **result from** the **traditional feedback analysis**, which is the product of the regional value of the feedback and the regional warming (normalized by the global-mean Planck feedback),
- the **feedback interactions**, whereby the warming that occurs due to feedback i being activated is amplified by each of the other feedbacks, and
- the **AHT interactions**, whereby the AHT changes when feedback i is activated due to the change in the regional warming pattern.

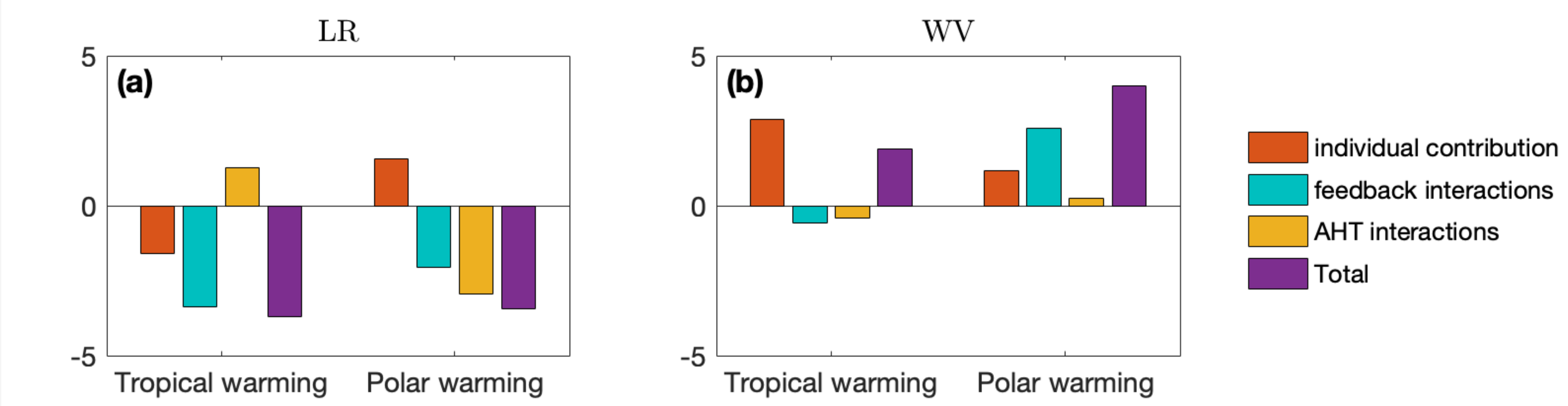

Fig. 2. Decomposition of warming in the feedback locking analysis. (a) Lapse-rate feedback. (b) Water-vapor feedback.

5. Summary

• Previous studies have used **traditional feedback analyses** to investigate the contribution of each climate feedback process to the **Arctic amplification** of global warming.

• Here we **instead** adopted a **feedback locking approach**, in which the warming is computed with an MEBM when each feedback process is turned off. This is arguably more **physically intuitive** in that it assesses how much warming would occur in the absence of a given climate feedback process.

• We find that adopting a feedback locking approach **substantially changes** the level of warming attributed to each feedback process.

See publication at https://t.ly/r25tr for further details.

References Cited

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