Non-monotonic feedback dependence on CO_2 due to a North Atlantic pattern effect

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Abstract

We explore the effective climate sensitivity S_G with abrupt CO_2 forcing experiments, spanning the range 2×, 3×, 4×, 5×, 6×, 7×, and 8×CO_2, using the CESM Large Ensemble model configuration (Kay et al., 2015). We find that S_G is a non-monotonic function of CO_2, decreasing between 3× and 4×CO_2, and then increasing at larger CO_2. We attribute this non-monotonicity to the negative feedbacks in the North Atlantic which stem from cooling in the North Atlantic due to AMOC collapse. To isolate the importance of how the North Atlantic cooling pattern affects the net radiative feedback, we run atmosphere-only simulations of the same model with prescribed sea surface temperatures (SSTs) taken from 1) the fully coupled runs and 2) different SST patterns.

Key Points

- **We find a non-monotonic response in Effective Climate Sensitivity across a range of abrupt n×CO_2 forcing experiments with a minimum at 4×CO_2**
- **We attribute this non-monotonicity to changes in radiative feedbacks over the North Atlantic, caused by a surface cooling in that region associated with the collapse of the AMOC**

Non-monotonicity of the Effective Climate Sensitivity due to radiative feedbacks, not radiative forcing

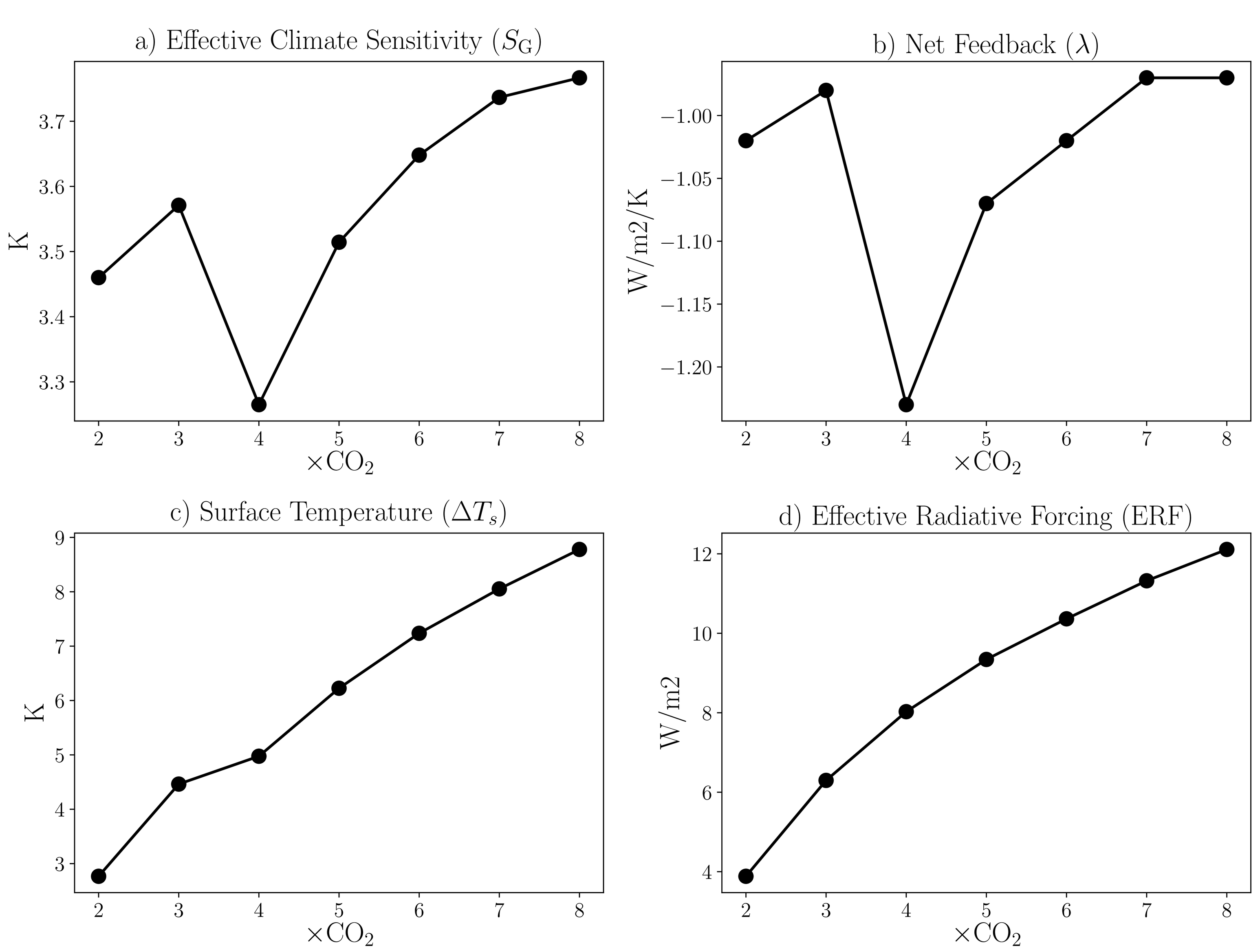

Figure 1: a) Effective Climate Sensitivity (S_G), and **b)** net feedback parameter (λ) from the 150 year Gregory regression of abrupt n×CO_2 runs. **c)** Global mean surface temperature response, and **d)** effective radiative forcing (ERF) from 30-year fixed SST runs (Forster et al., 2016).

- We find a non-monotonic response in Effective Climate Sensitivity (Fig. 1a) with a minimum at 4×CO_2
- The net feedbacks (Fig. 1b) show same non-monotonicity, and the effective radiative forcing (Fig. 1d) does not
- We **hypothesize** that either λ responds non-monotonically due to 1) increased global-mean temperature or 2) to a different sea surface temperature pattern

Non-monotonicity in λ is due to SST pattern, not global mean surface temperature increase

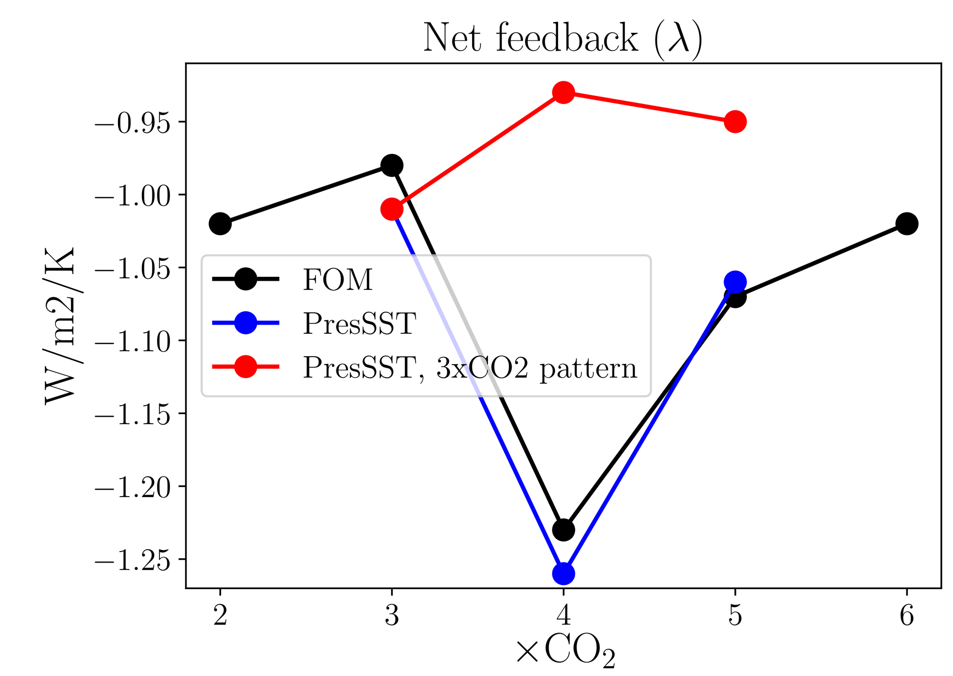

Figure 2: Net feedback parameter λ (black) from 150 year Gregory regression with fully coupled runs (FOM), AMIP runs with prescribed SSTs from fully coupled runs (blue), and AMIP runs with prescribed SSTs with 3×CO_2 warming pattern (red).

- The AMIP runs with prescribed SSTs (blue in Fig. 2) can fully reproduce λ from the fully coupled runs (black)
- We get rid of the non-monotonicity (red in Fig. 2) when we repeat the 4× and 5×CO_2 FOM experiments with AMIP runs with same global mean surface warming as in FOM but SST pattern from 3×CO_2

Cooling SST pattern in North Atlantic coincides with λ non-monotonicity

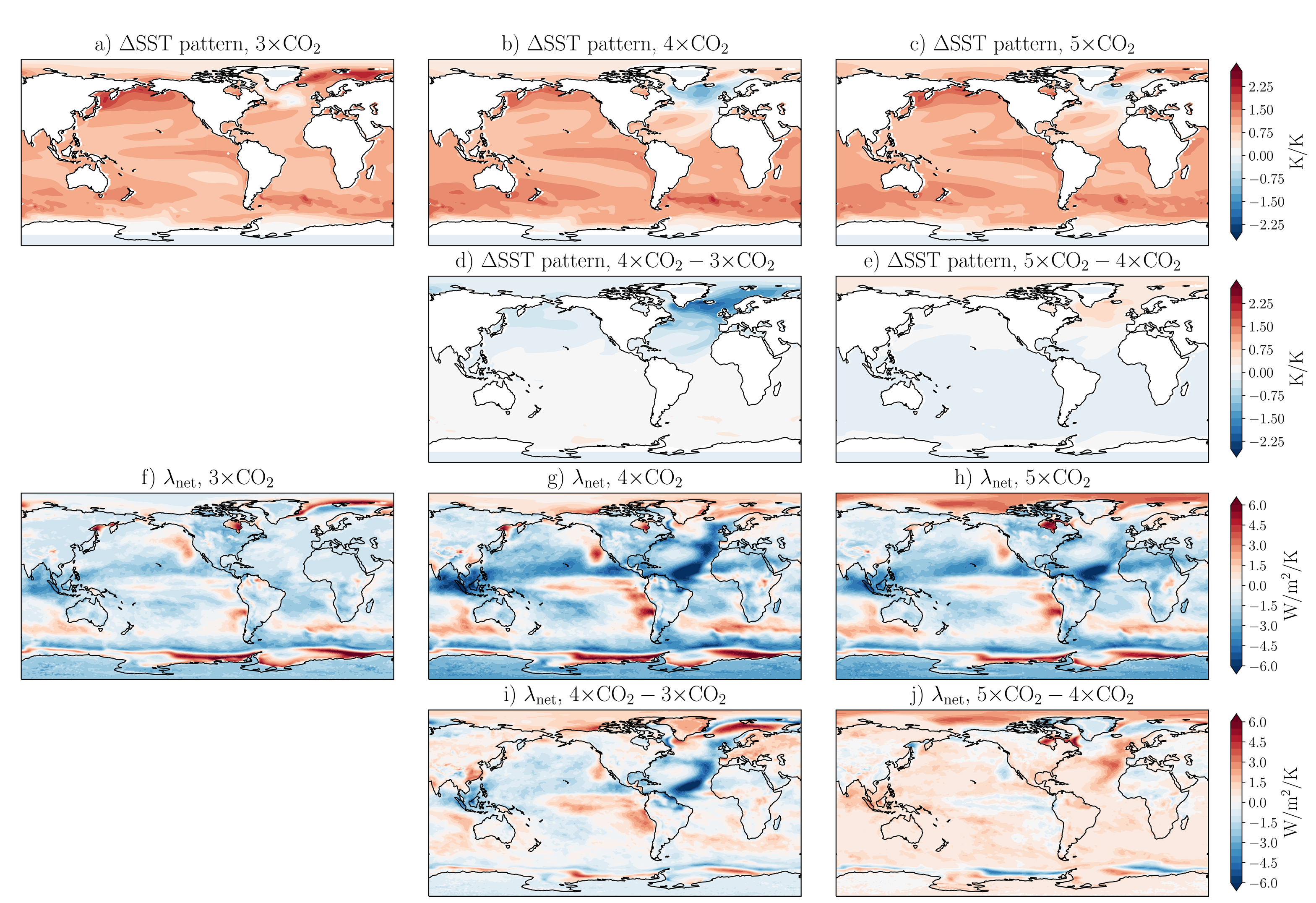

Figure 3: SST pattern in **a)** 3×CO_2, **b)** 4×CO_2, and **c)** 5×CO_2. The difference between 4× and 3×CO_2, and 5× and 4×CO_2 are show in **d)** and **e)**, respectively. Figures **f-j)** show λ for the same CO_2 experiments.

- Cooling SST pattern in the North Atlantic between 3× and 4×CO_2 (Fig. 3d) coincides with a more negative λ (Fig. 3i) for the same region
- Similarly, "warming" SST pattern in North Atlantic between 4× and 5×CO_2 (Fig. 3e) coincides with a more positive λ (Fig. 3j)

North Atlantic cooling causes λ non-monotonicity

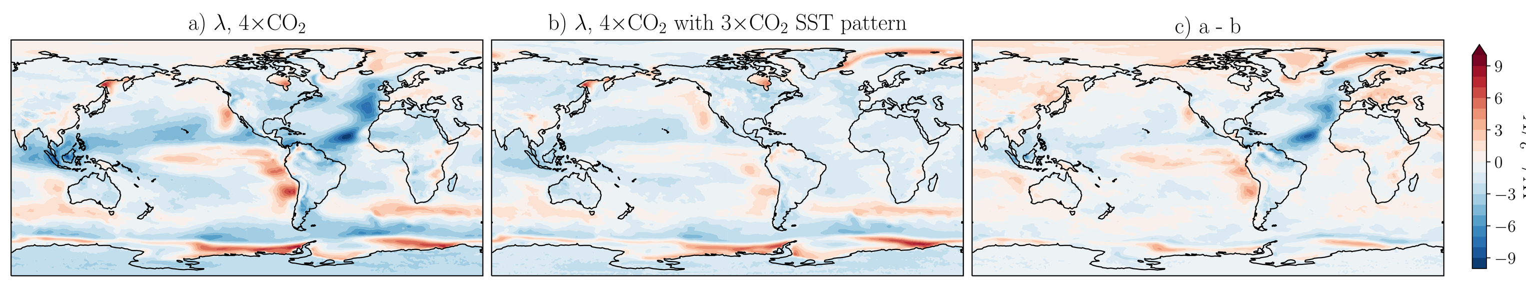

Figure 4: Net feedbacks from 4×CO_2 AMIP runs with **a)** prescribed SSTs from fully coupled runs, and **b)** prescribed global mean SSTs from fully coupled runs and 3×CO_2 warming pattern. The difference is shown in **c)**.

- Negative λ over the North Atlantic (Fig. 4a) disappears when we re-do the 4×CO_2 run with the same global mean warming but different SST pattern taken from 3×CO_2 (Fig. 4b, same as red dot at 4×CO_2 in Fig. 2)

LR and SW cloud feedbacks are most responsible

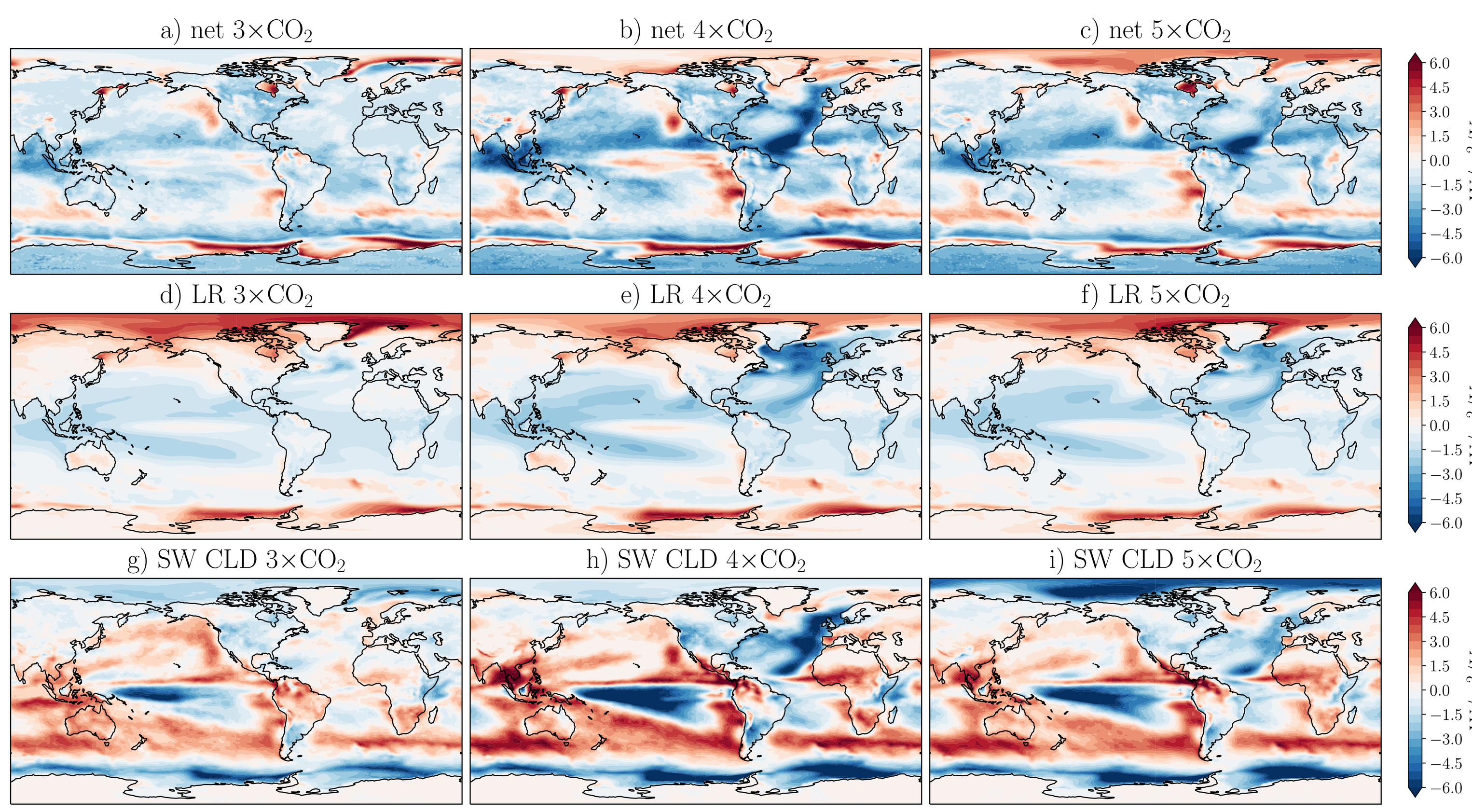

Figure 5: a-c) Net feedbacks λ, **d-f)** lapse rate, and **g-i)** shortwave cloud feedback. Left column shows 3×CO_2, middle shows 4×CO_2, and right column shows 5×CO_2.

AMOC collapse coincides with North Atlantic cooling

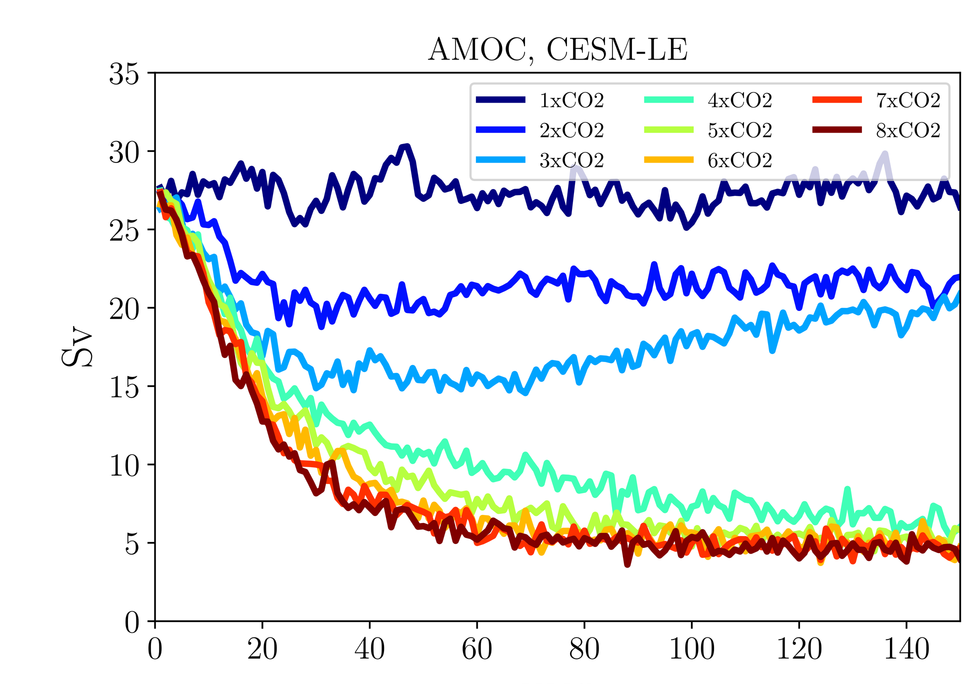

Figure 6: The evolution of the Atlantic Meridional Overturning Circulation.

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