Non-monotonic feedback dependence on CO$_2$ due to a North Atlantic pattern effect

Ivan Mitevski$^1$, Yue Dong$^1$, Maria Rugenstein$^2$, Clara Orbe$^{1,3}$, Lorenzo M. Polvani$^1$

$^1$Applied Physics and Applied Mathematics, Columbia University, NYC, $^2$Department of Atmospheric Science, Colorado State University, Fort Collins, CO, $^3$NASA Goddard Institute for Space Studies, NYC

Abstract

We explore the effective climate sensitivity $S_R$ with abrupt CO$_2$ forcing experiments, spanning the range 2x, 3x, 4x, 5x, 6x, 7x, and 8xCO$_2$ using the CESM Large Ensemble model configuration (Kay et al., 2015). We find that $S_R$ is in a non-monotonic function of CO$_2$, decreasing between 3x and 4xCO$_2$ 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 nxCO$_2$ forcing experiments with a minimum at 4xCO$_2$.
- 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](image1.png)

- a) Effective Climate Sensitivity ($S_R$), b) net feedback parameter (λ) from the 150 year Gregory regression of abrupt nxCO$_2$ 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 4xCO$_2$.
- 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) a different sea surface temperature pattern.

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

![Figure 2](image2.png)

- 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 3xCO$_2$ 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 4x and 5xCO$_2$ FOM experiments with AMIP runs with same global mean surface warming as in FOM but SST pattern from 3xCO$_2$.

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

![Figure 3](image3.png)

- Figure 3: SST pattern in a) 3xCO$_2$, b) 4xCO$_2$, and c) 5xCO$_2$. The difference between 4x and 3xCO$_2$, and 5x and 4xCO$_2$ are shown in d) and e) respectively.
- Figures f-j show λ for the same CO$_2$ experiments.
- Cooling SST pattern in the North Atlantic between 3x and 4xCO$_2$ (Fig. 3d) coincides with a more negative λ (Fig. 3i) for the same region.
- Similarly, “warming” SST pattern in North Atlantic between 4x and 5xCO$_2$ (Fig. 3e) coincides with a more positive λ (Fig. 3j).

North Atlantic cooling causes λ non-monotonicity

![Figure 4](image4.png)

- Figure 4: Net feedbacks from 4xCO$_2$ AMIP runs with a) prescribed SSTs from fully coupled runs, and b) prescribed global mean SSTs from fully coupled runs and 3xCO$_2$ warming pattern. The difference is shown in c).
- Negative λ over the North Atlantic (Fig. 4a) disappears when we re-do the 4xCO$_2$ run with the same global mean warming but different SST pattern taken from 3xCO$_2$ (Fig. 4b, same as red dot at 4xCO$_2$ in Fig. 2).

LR and SW cloud feedbacks are most responsible

![Figure 5](image5.png)

- Figure 5: a-c) Net feedbacks λ, d-f) lapse rate, and g-i) shortwave cloud feedback. Left column shows 3xCO$_2$, middle shows 4xCO$_2$, and right column shows 5xCO$_2$.

AMOC collapse coincides with North Atlantic cooling

![Figure 6](image6.png)

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

Contact Information

Ivan Mitevski: im2527@columbia.edu