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Sulphate-forced Atlantic Multidecadal Variability in HadGEM3-GC3.1

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Introduction

The Atlantic Multidecadal Variability (AMV) is a major mode of variability with significant climate impacts around the world (1). The relative role of internal variability vs external forcing in driving the AMV remains a topic of lively debate. Recent studies have suggested that external forcing, such as varying levels of sulphate aerosol emissions, through industrial activity, have caused the observed variations in North Atlantic sea surface temperature (SST) (2, 3). However, how this happens is not well understood, partly because of the difficulty in disentangling different processes in the historical simulations.

In this study, we performed an idealised single-forcing experiment to isolate and understand the processes linking North American and European sulphate aerosol emissions to North Atlantic multidecadal variability.

1). Experimental Design

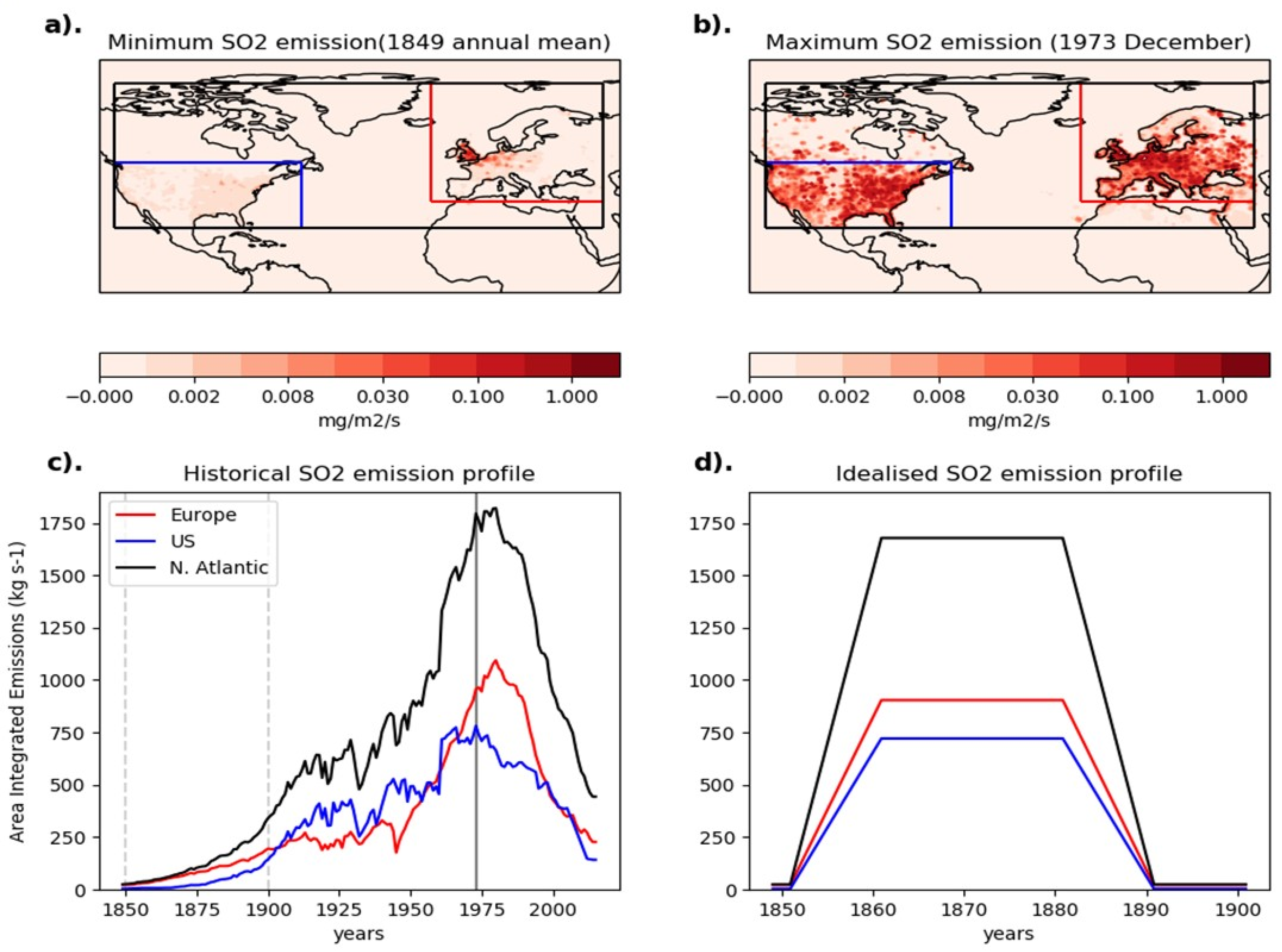

*Figure 1: Panels **a)** and **b)** Shows the regional distribution of the applied sulphate-aerosol emissions. The minimum emission is based on the 1849 annual mean (**a**) and the maximum emission is based on the 1973 annual mean (**b**) of the historical emissions . Panel **c)** shows the time series of historical sulphate emissions across 3 different regions: Europe (red), North America (blue), N. Atlantic (black). Regional boxes are shown in **a)** and **b)**. Panel **d)** shows the time series of the idealised sulphate emission applied in the single-forcing experiment.*

- The model used is the HadGEM3-GC3.1-MM, from the UK Met Office. This model has horizontal resolution of 0.25° in the ocean and ~60km in the atmosphere.
- 4 ensemble members were used in this experiment. The initial conditions were chosen to sample a range of AMV and IPO phases.
- We have chosen to only include North American and European emissions to simplify the situation, because they vary relatively coherently and likely impact the N. Atlantic in a similar way, as oppose to Asian aerosol emissions.
- The idealised emission ramps up from a minimum (based on 1849) to a maximum (based on 1973) over 10 years. This is followed by 20 years of constant maximum emissions, then 10 years ramp-down and finally, 10 years of minimum emissions (fig. 1d).

References

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2. Booth, B., et al., *Nature*, **484**, 228–232 (2012)
3. Undorf, S., et al., *Geophysical Research Letters*, 45, 11,930– 11,940 (2018)

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2). Evolution of key variables

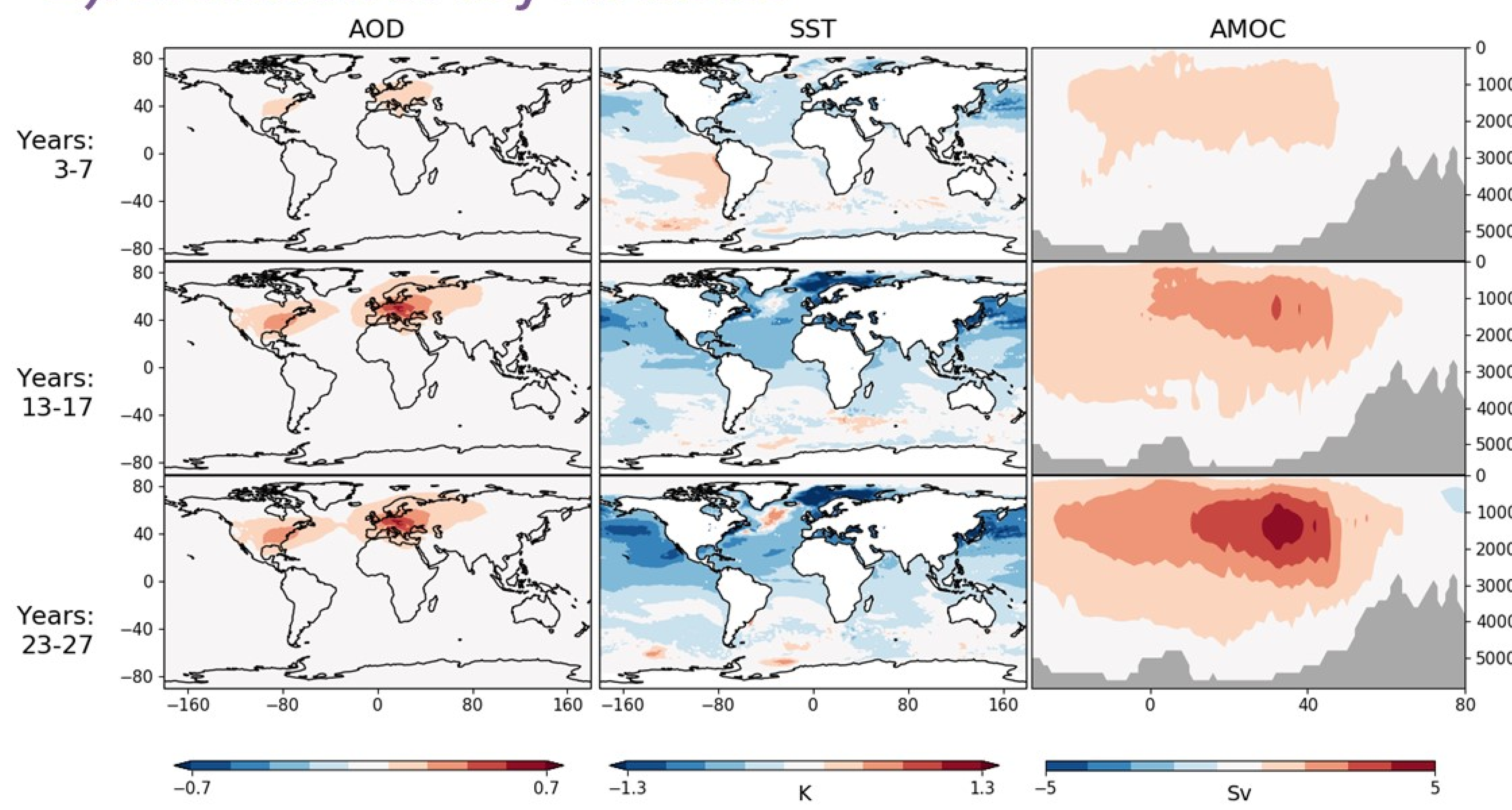

Figure 2: Evolution of aerosol optical depth (AOD), SST, and AMOC strength, for the first 27 years of the experiment. All variables are anomalies taken with respect the pre-industrial control. All variables are smoothed by a 5-year running mean.

- The AOD panels show that some sulphate aerosols are advected from their source regions to over the N. Atlantic ocean and over the Western Eurasian continent.
- The aerosol caused widespread cooling across the whole Northern hemisphere. This cooling is especially intense in the Nordic and Barents Sea.
- Evolution of subpolar N. Atlantic SST is different to the rest of the N. hemisphere. Although the subpolar N. At. is initially cool, it becomes anomalously warm by year 23-27, despite aerosol emissions are at the maximum and the rest of the N. hemisphere is still anomalously cool. This warming is due to the massive strengthening (up to 5Sv) of the AMOC as a response to the aerosol forcing.

3). Regional SST changes

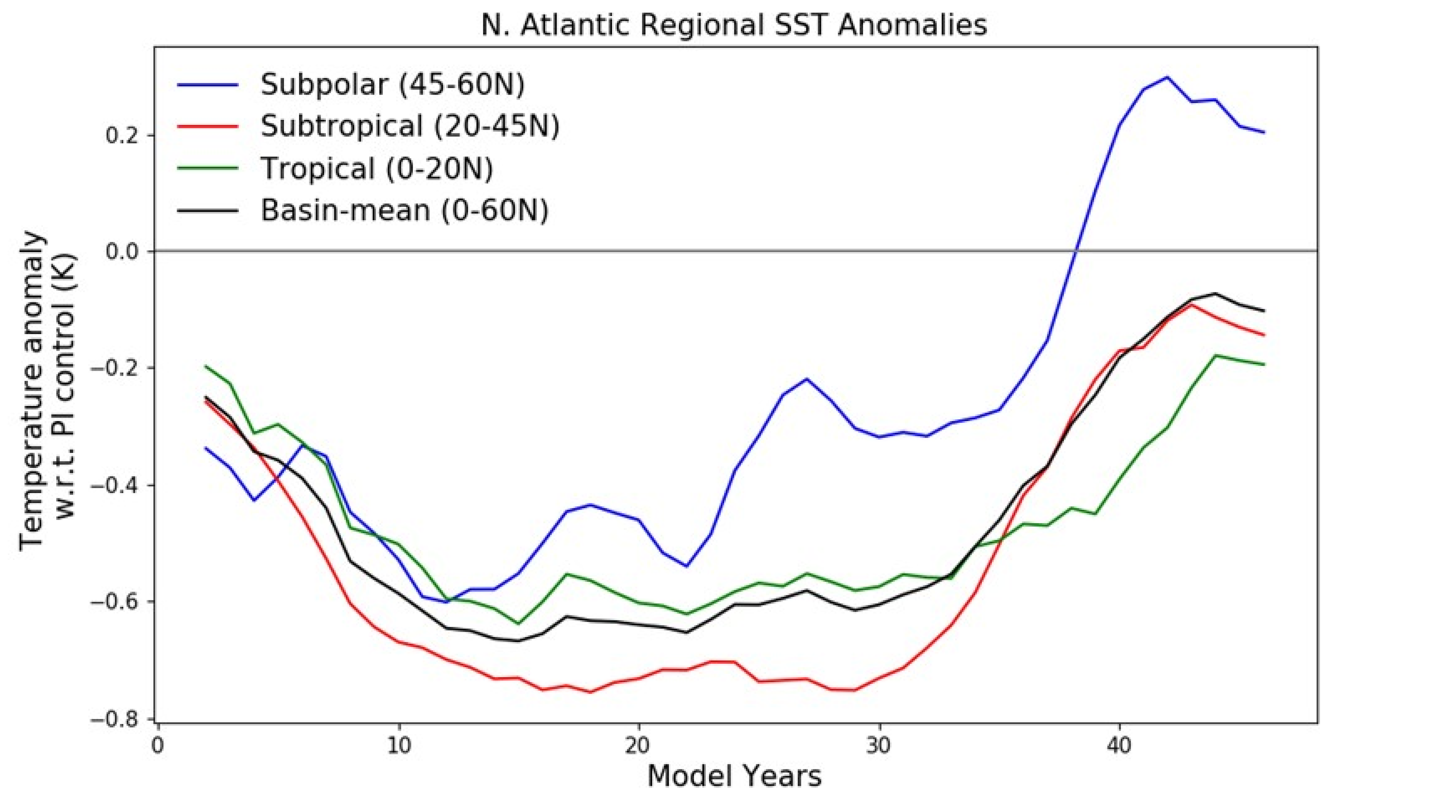

Figure 3: Time series of N. At. SST anomalies at different latitudes smoothed by a 5-year running mean. The subpolar region (45N:60N, 7.5W:75W) is shown in blue, subtropical region (20-45N) in red, tropical region (20N-45N) in green and the basin mean(0N-60N) in black.

- Difference in the evolution of N. At. SST in different regions can be seen clearly in Fig. 3. In the subtropical and tropical N. Atlantic, the SST anomalies resemble the inverse of the applied aerosol. Suggesting that the fast aerosol-forced cooling dominates in these regions.
- The subpolar region also cools initially, but a delayed warming trend develops by year 10, which then results in temperature higher than the initial state by year 40.

Summary

- We have applied an idealised emission of sulphate aerosols to understand how anthropogenic aerosols can influence North Atlantic multidecadal variability.
- The tropical and subtropical SST is dominated by a fast cooling response to aerosol forcing.
- The subpolar SST initially cools, but a delayed warming trend then dominates due to an aerosol-forced AMOC strengthening.
- These results highlight that externally-forced ocean circulation changes is an important part of the overall N. Atlantic variability.