# How Does an Improved Representation of Convection Affect Future Air Quality in the Community Earth System Model?

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## Introduction

In 21st Century climate simulations, fine particulate matter (PM2.5) which is hazardous to human health, is projected to decrease as aerosol emissions are reduced. However, future projections of climate which simulate anthropogenically emitted greenhouse gas emissions, such as RCP8.5, also produce changes in global precipitation frequency with warming, which can influence the removal of aerosol.

In order to isolate the effect of precipitation on aerosol removal (wet deposition), our previous work has simulated future climates with aerosol emissions cycled at present-day levels in the Community Atmosphere Model (CAM6), and found meteorological changes which contribute to worsening air quality.[1] However, since present-day precipitation frequency is not well represented in conventional models, the impact of this change may be better captured by Earth system models with convective parameterizations replaced by high-resolution cloud resolving models (i.e., superparameterization). Multiscale modeling techniques like superparameterization use explicit calculations of aerosol processes at the cloud scale (also called ECPP; or the Explicit Cloud Parameterized Pollutant approach). While conventional models produce light rain events too frequently, superparameterized convection better represents the frequency and intensity of rain events, and match high resolution satellite observations.[2]

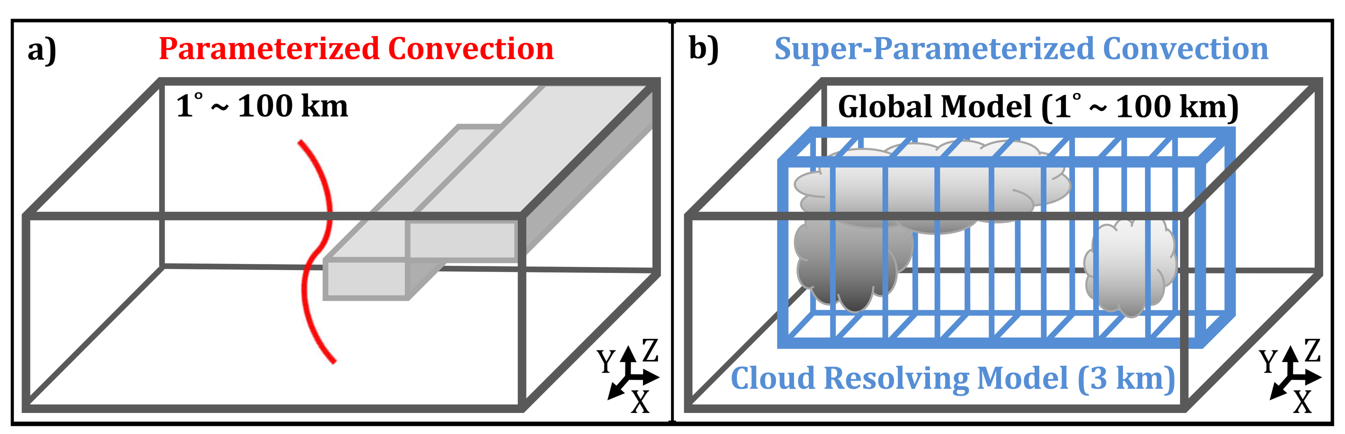


**Figure 1**. Super-parameterization is a technique in Earth system model development which allows us to examine sub-grid scale (4km) cloud processes.

We find that when compared to conventional parameterized convection, resolved convection with superparameterization shows major increases in aerosol burden particularly over tropical continents, and decreases in wet day frequency. Additionally, we identify regions of worsening air quality as defined by the World Health Organization for long-term changes and extreme events (>25 μg/m$^3$ for a 24-hour period). These results highlight the need to continually reassess aerosol emissions regulations in response to changes in the climate system.

## Simulations

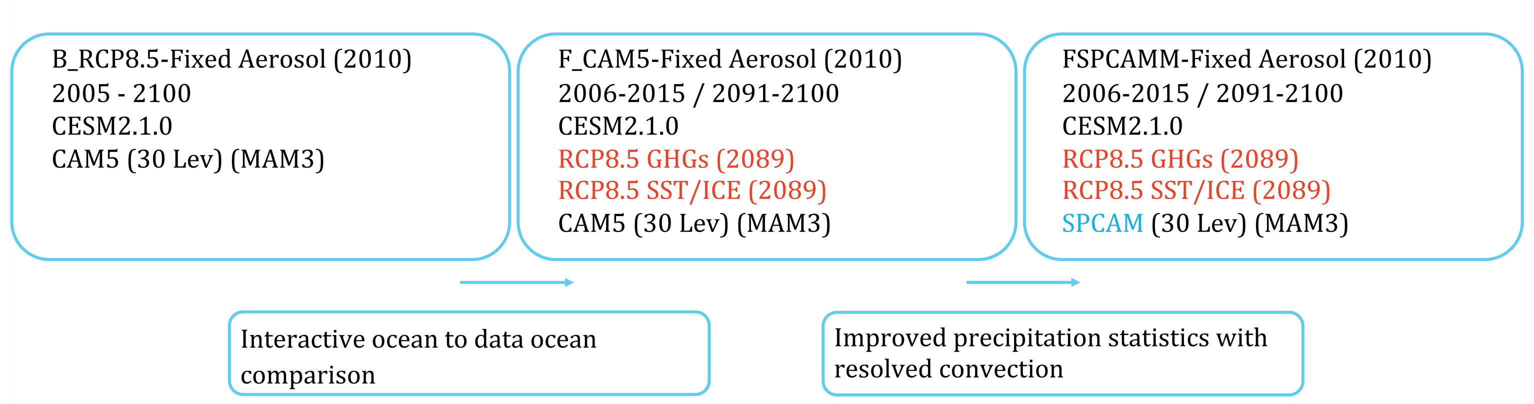


**Figure 2**. Experiment design for "fixed emissions" aerosol simulations in CESM2.1.0

We used the Community Earth System Model (CESM2.1.0) in conjunction with the Representative Concentration Pathway (RCP8.5) to provide a baseline of atmospheric behavior driven by a high greenhouse gas (GHG) emissions scenario from 2005 to 2100. To represent convection at smaller scales, we use a superparameterized atmosphere model (SPCAM), with SST/ICE and GHG emissions driven by the RCP8.5 simulation. As a bridge between the interactive ocean simulation and FSPCAMM, we created a simulation with both GHGs and SST/ICE derived from RCP8.5, and named it FCAM5.

## Fewer Rainy Days

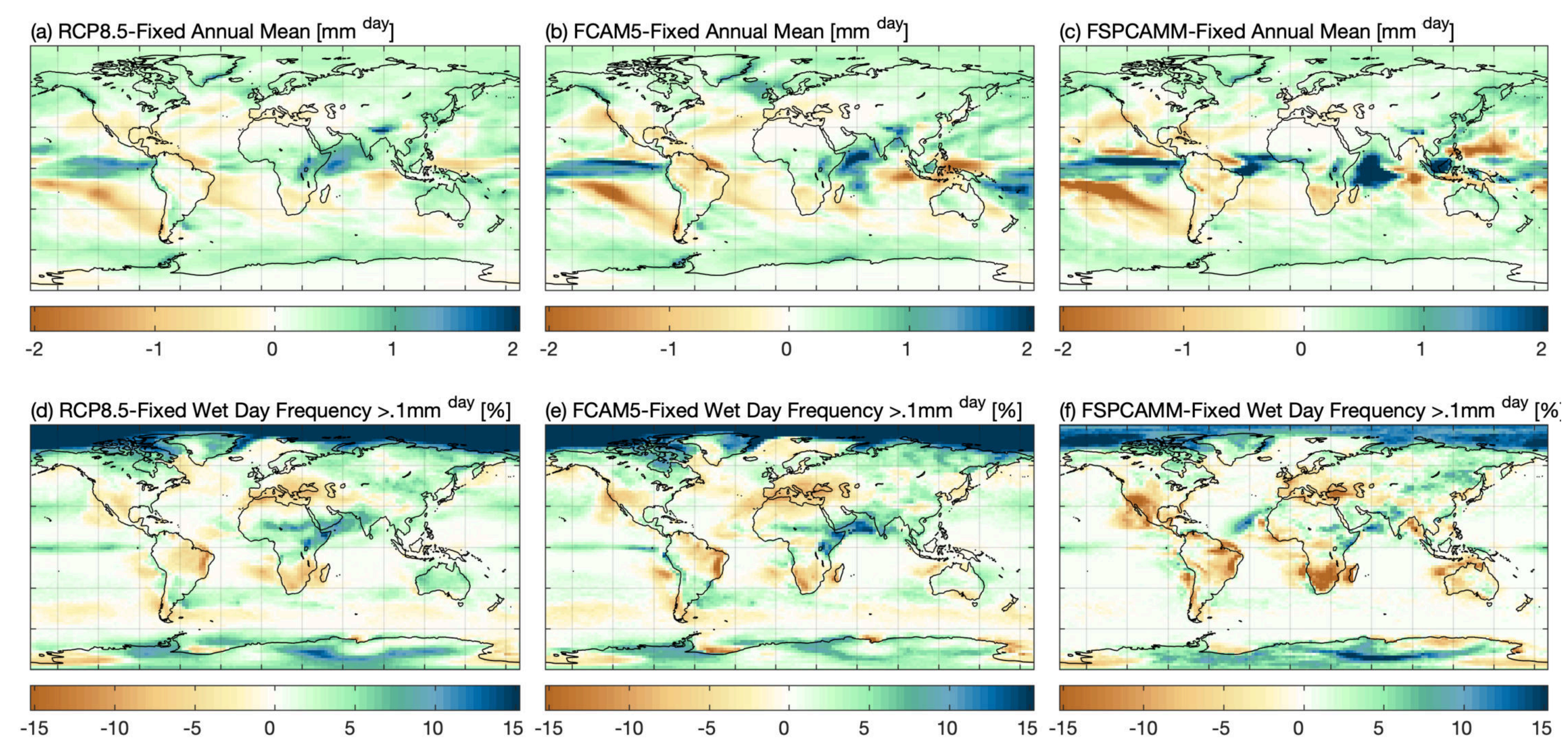


**Figure 3.** Precipitation Changes from 2010-2100 in simulations where aerosol emissions are cycled at present day levels, shown in annual average (a,b,c) [mm/day] and by frequency of rainy days (d,e,f) [% of days with >.1 mm of precipitation].

- Precipitation average and frequency decreases are intensified in FSPCAMM over continents
- While FSPCAMM shows an average increase of precipitation over the oceans, when compared to CAM5 simulations, FSPCAMM produces fewer rainy days globally.

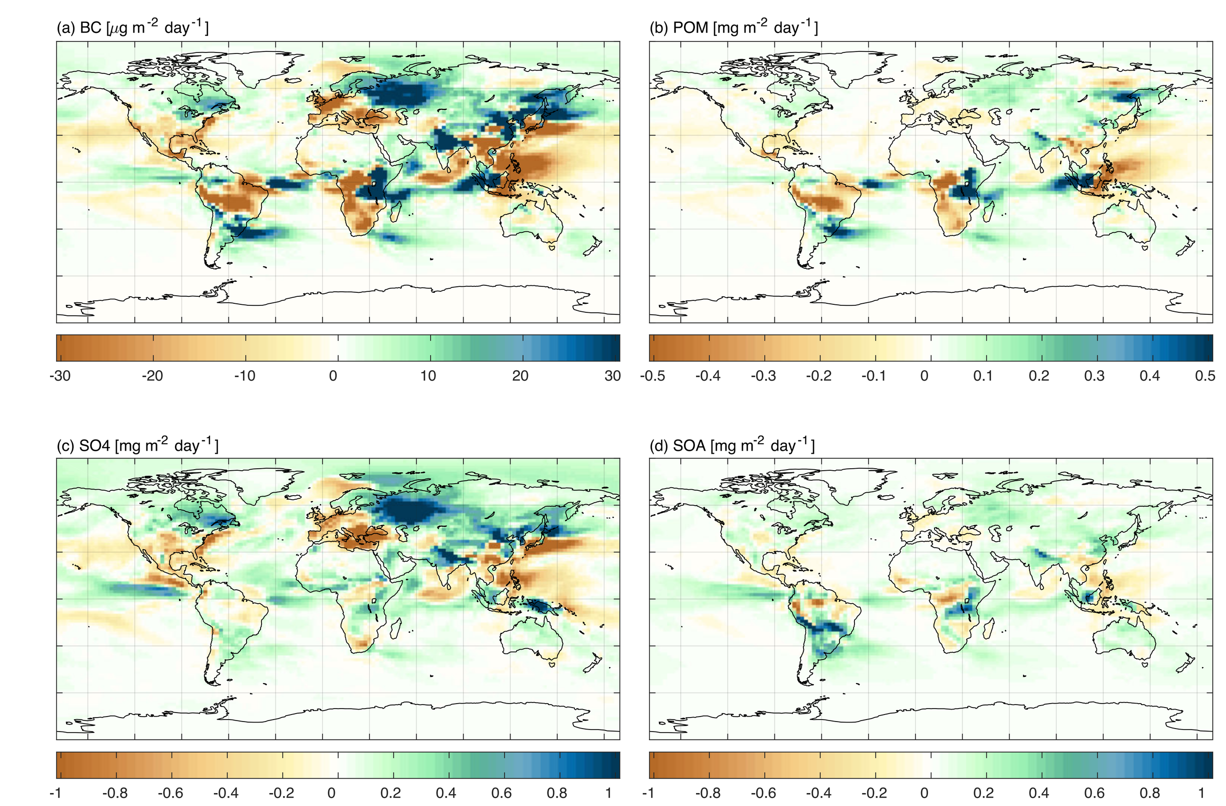

**Figure 4.** Changes from 2010-2100 in wet deposition of aerosol species for FSPCAMM. Black Carbon (a)shown in [μm/m$^2$/day], POM (b), $SO_4$ (c), and SOA (d) are shown in units of [mg/m$^2$/day]

- Without increasing emissions, the lower frequency of rain events in Europe, southern Africa, South America, and the south-western United States, leads to less wet deposition in those regions.
- Wet deposition for $SO_4$ is complicated by aqueous production.

## Increase in Particulate Matter in the Atmosphere

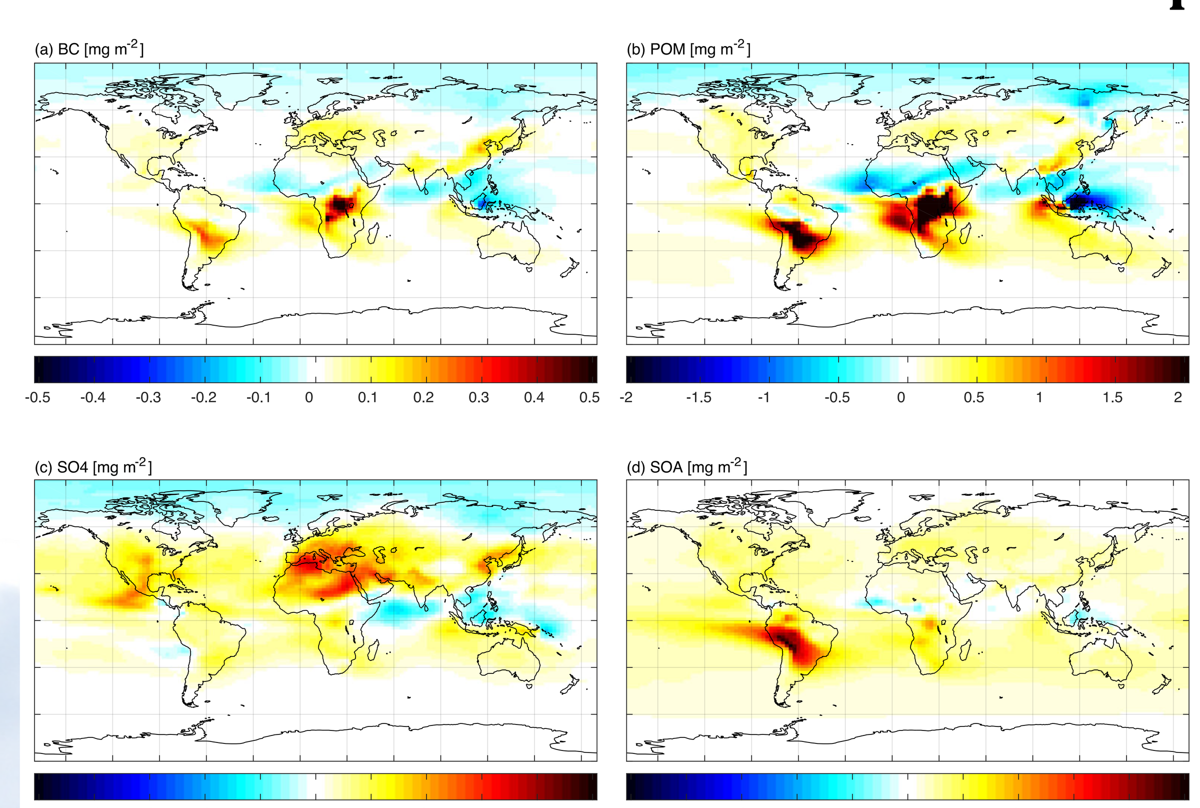

**Figure 5.** Changes from 2010-2100 in annual mean burden of aerosol species for FSPCAMM [mg/m$^2$].

- Despite fixed emissions, increases in column burden are found in BC/POM over continental tropics, and SO4/SOA globally.

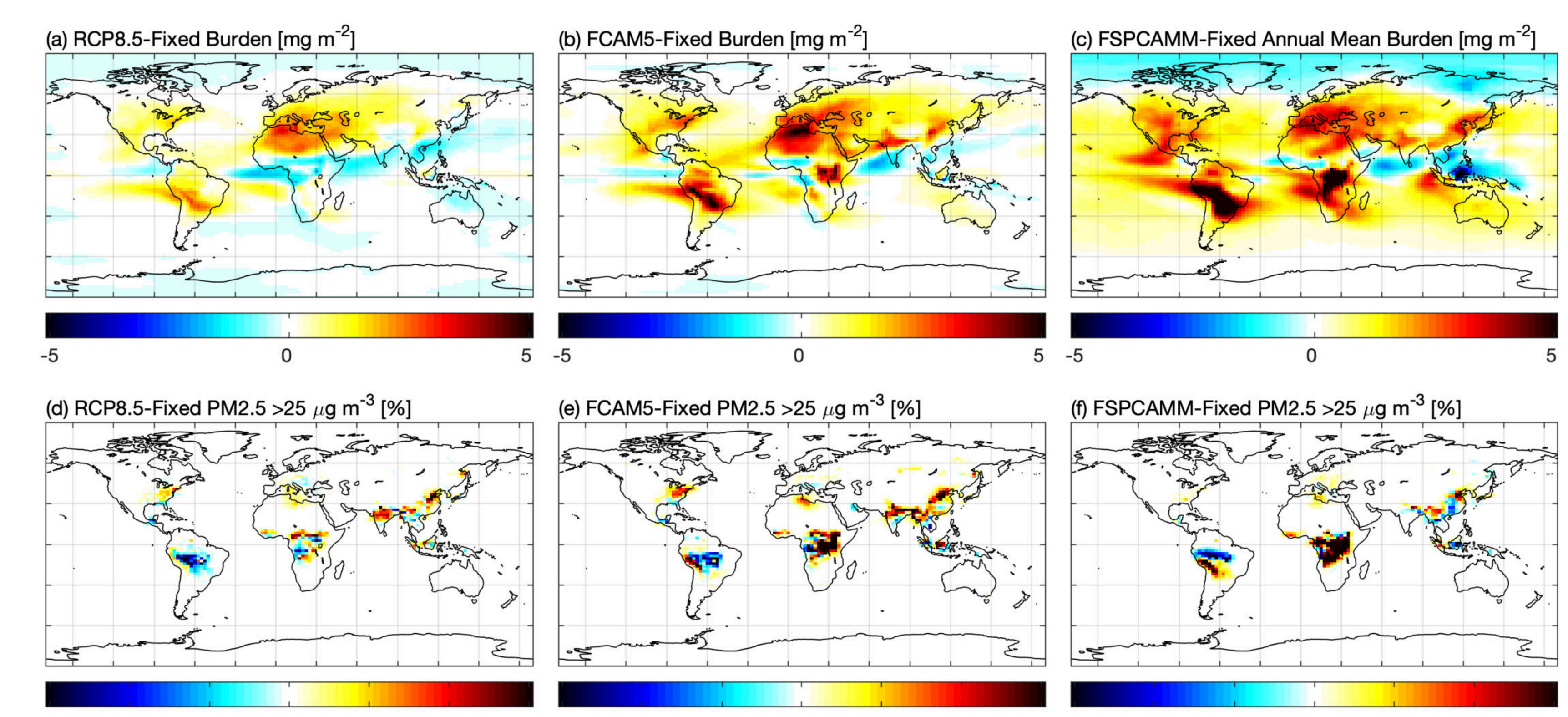


**Figure 6.** Mean changes from 2010-2100 in four species of aerosol (BC, POM, SO4, ,SOA) for FSPCAMM. Column burden (a,b,c) shown in [mg/m$^2$] and days which exceed daily recommendations of maximum exposure to surface PM2.5 (c,d,e) are shown in [% ].

- Compared with CAM5, FSPCAMM shows a global intensification of aerosol burden.
- Despite burden major increase, the percentage of poor air quality days changes slightly.

## Key Takeaways

- Harmful atmospheric pollutants are shown to intensify over continents, even when emissions are fixed at present-day rates.
- While climate models are projecting more precipitation on average globally, the frequency of rain events that would scavenge aerosol particles decreases over continents. In simulations where convection is resolved at finer scales, this effects strengthens.
- Future work will investigate consecutive dry days in order to understand potential further deterioration of air quality in these simulations.

## References and Acknowledgements

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[1]Banks, A., Kooperman, G., Xu, Y. (2021). Meteorological Influences on PM2.5 in Future Climates: Species Level Analysis in the Community Earth System Model v2. Earth's Future (*Accepted*)

[2]Kooperman, G., Pritchard, et. al. (2016). Robust effects of cloud superparameterization on simulated daily rainfall intensity statistics across multiple versions of the Community Earth System Model. https://doi.org/10.1002/2014MS000335

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