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Dirty air offsets some inequality

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Atmospheric aerosols have probably masked a significant portion of the greenhouse-gas-induced warming so far. Research now shows that this also may have masked some of the world's increasing economic inequality.

The term 'air pollution' may evoke images of acid rain, smokestacks or blackened lungs, but what about economic inequality? Clean air and sustainable development are closely interlinked, and although air pollution is not formulated as an explicit target, it is central to several of the UN Sustainable Development Goals, such as good health, zero hunger and healthy ecosystems. Air pollution also disproportionately affects poor populations in middle- and low-income

countries, hence contributing negatively to global equality[1]. However, the latter may not always be the case. Writing in *Nature Climate Change*, Yixuan Zheng and co-authors[2] suggest that the climate impact of aerosols, a key component of air pollution, has had an overlooked impact on national economies. They estimate that surface cooling from anthropogenic aerosols has caused regionally opposing economic impacts that may have partially offset increases in global economic inequality.

AQ1

AQ2

AQ3

Among the numerous expected consequences of global warming is an impact on economic output through temperature-mediated changes in productivity. Previous work suggests that warming unevenly affects country-level economic development, harming economies in warmer climates but benefiting those in colder regions[3]. But greenhouse gases (GHGs) are not the only thing affecting climate. Aerosols, tiny particles suspended in the air, exert a powerful influence on climate by interacting with solar radiation and clouds. And despite uncertainty in aerosol-climate interactions, the net effect of anthropogenic aerosol emissions is understood to be a global cooling that has counteracted a notable fraction of GHG warming since pre-industrial times[4]. With the uneven relationship between temperature change and economic development in mind, Zheng and colleagues investigate whether this aerosol-induced cooling has had a positive effect on less wealthy economies in hotter regions and a negative effect on high-income economies of the Northern Hemisphere.

To answer this, the authors perform simulations with the fully coupled Community Earth System Model (CESM), creating scenarios with and without historical emissions of aerosols and their precursors. The resulting aerosol-induced change in surface temperature is then combined with empirical macroeconomic relationships between temperature and gross domestic product (GDP) in order to translate impacts to monetary terms at the country level. The authors find statistically significant cooling due to aerosols over all major populated regions, often delaying the onset of warming by decades compared with a world with only GHG emissions. Of the 197 countries studied, the authors find that 109 are very likely to have experienced positive economic impacts from this aerosol-induced cooling, and these countries encompass roughly 21% of global GDP and 59% of global population. Negative economic impacts were found for 30 countries that represent 21% of GDP and 8% of population. Geographically, almost all regions with reductions in GDP were located north of 45° N whereas benefits were mostly experienced by regions in the south, in contrast to the general~~more heterogeneous~~ distribution of high- and lower-

income countries across the globe . I've tried with a suggestion to maintain my original intent, which was to highlight the opposite north-south pattern in aerosol-induced damages and level of economic development. I think the addition of "more heterogeneous" led to that point becoming less clear.

Two factors are critical for confidence in these results: first, the ability with which the climate model used can represent observed temperature at the country level, and second, the accuracy of the response functions used to estimate the real-world response of economic productivity to changes in temperature at these scales. However, several sensitivity calculations using alternative response functions and temperature datasets consistently show the same north–south pattern: countries that have the highest probability of benefiting economically from aerosol cooling are concentrated in the tropics and subtropics, whereas economic damage primarily occurs in higher-income countries at high northern latitudes.

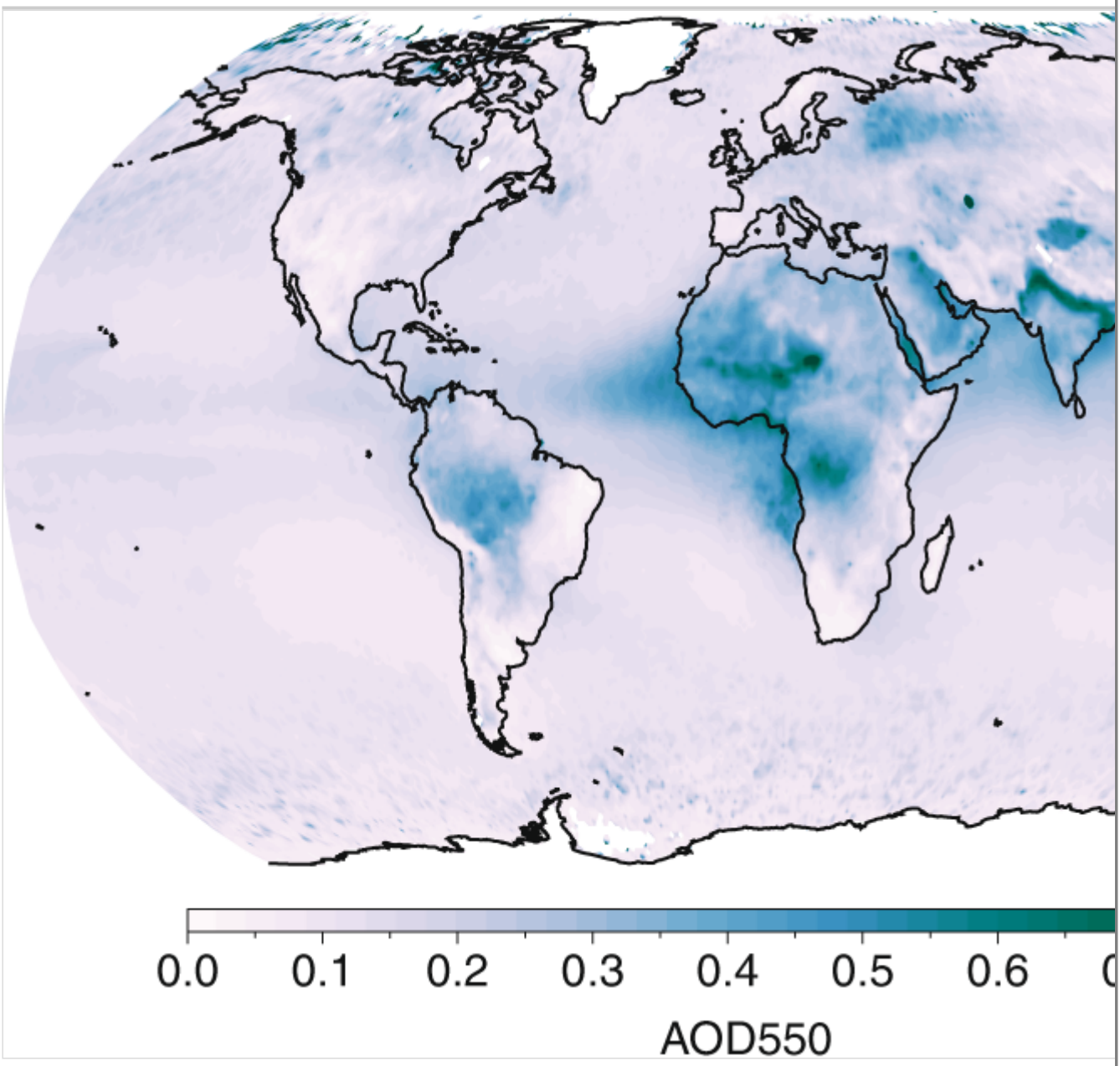
The authors do not compare their estimated GDP changes with environmental damages from air pollution but note that the latter very probably overwhelm any economic benefits from aerosol cooling. An additional important caveat is that the damage function methodology used to estimate how temperature affects GDP only considered temperature within the same year, so the cumulative impacts of cooling and warming in previous years are likely to be larger. Socioeconomic and climatic trends, as well as year-to-year variability, make it difficult to extrapolate results beyond this qualitative understanding. Further work is therefore needed to quantify the full effect over the historical period. Nevertheless, a key implication of the study is that we need a better understanding of the many ways that air pollution affects society, and at detailed geographical resolution Fig. 1.

Fig. 1

Anthropogenic aerosols in the climate system.

Annual mean aerosol optical depth at 550 nm (AOD550) from MODIS-Aqua for 2010 (left); and a schematic illustration of cause-and-effect chain relating emissions to damages (right). Anthropogenic aerosols like those shown on the left interact with clouds and radiation to cause net surface cooling, and tracing the ultimate economic impacts of emissions can be an uncertain exercise but is highly policy-relevant, as illustrated here. Zheng and colleagues[2] estimate that aerosol-induced cooling has economically benefited developing countries in warmer climates and harmed high-latitude developed countries. This implies that aerosol emissions have partially offset the increases to economic inequality that would

have occurred in their absence. Left panel, data from NASA Giovanni database (https://giovanni.gsfc.nasa.gov/giovanni/); right panel adapted from ref. [7].



AQ4

In contrast to GHGs, aerosol perturbations are highly heterogeneous in space and time, with impacts that may occur rapidly but are still associated with high scientific uncertainty[5]. What is clear is that aerosols play a key role in shaping the present climate, and that even a localized perturbation can have global implications[6]. How this translates into societal impacts at a regional scale, however, remains poorly quantified. And, as demonstrated by Zheng and co-authors, the socioeconomic responses and sensitivities can be similarly heterogeneous. Aerosol emissions are now evolving rapidly in the main source regions, a development that may continue over the coming decades[5]. Quantifying the associated risks for society is therefore a critical challenge for

the scientific community. The work by Zheng and colleagues highlights the need to move beyond changes in physical climate quantities and toward a more comprehensive treatment of societal responses when considering the implications of emissions mitigation and climate change adaptation policies.

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