The Changing Role of Dust and Open Fire PM2.5 on Africa's Air Quality and Human Health

Cornell Engineering

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INTRODUCTION

- Ambient air pollution is a major environmental and human health issue
- Exposure to PM2.5 has adverse health outcomes, even at low levels less than 5 µgm/3.
- Air pollution is responsible for about 1-in-9 deaths worldwide, or
- between 6.7 to 7 million deaths a year(Institute for Health and Metrics Evaluation(IHME).
- In 2012, about 194,000 premature deaths were recorded from fossil fuels exposure in Africa and 10 million globally.(Vohra,et al, 2021)
- Air pollution in situ data across the Africa continent relevant for policy is of poor quality or inaccessible, making efforts to track air quality difficult.
- Previous studies have focused on fossil fuels: the role of changing 'natural' aerosols from dust and wildfires has not been assessed yet.
- Humans and climate have modified dust and wildfires especially over Africa. Here we focus on natural desert dust and anthropogenic land use dust changes..

PreIndustrial, Present day and Future Dust emissions

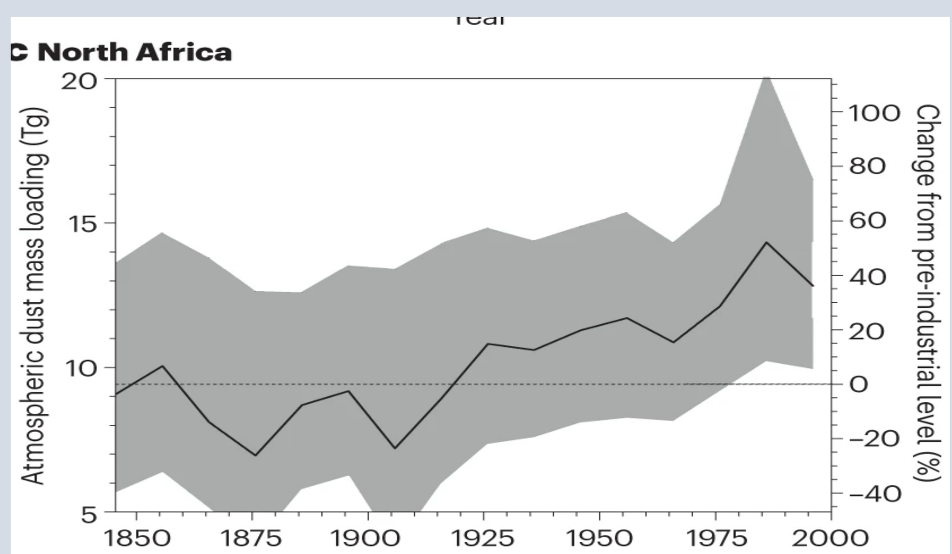

Figure 1: Paleoclimate observationally based estimates of changes in North African dust(reproduced from Kok et al,2023)

Figure 1 shows increase that the observations suggest an increase 51% from preindustrial (PI) to present day (PD) (Kok et al., 2023), and 31% from PD to future (FU) (Mahowald, 2007).

Atmospheric model description

- We used the Community Atmospheric Model(CAM6.1) , embedded within the Community Earth System Model (CESM2.1), to simulate aerosols, using a version with multiple dust tracers (Liu et al., 2016; Li et al., 2021).
- CESM has a 2.5° × 1.9° horizontal resolution and 56 vertical layers
- To isolate changes in emissions, we used the same meteorology for all emission cases based on MERRA reanalysis simulated for 2012-2017, with the first year discarded as a "spin-up period" and the mean of the last 5 years used for analysis.
- We modified the model to consider separately agricultural sources of dust, which were tuned by gridbox to have approximately the same regional proportion of agricultural dust to natural dust as Ginoux et al., 2012.
- We modified the model to allow for changes in the magnitude of the prognostic dust emissions by multiplying by factors in each grid to obtain estimated dust changes representative of three time periods: preindustrial (PI; ca. 1850 CE), present day (PD; ca. 2010 CE), and the future (FU; ca. 2100 CE) following Mahowald et al., 2010; Kok et al., 2023; and future estimates from Mahowald, 2007. (See Figure 1)
- Historical and future aerosol emissions for combustion emissions (anthropogenic and biomass burning) used Coupled Model Intercomparison Project(CMIP)
- emission datasets for the PI (1850), PD (2010) the SSP3.7 scenario (2100) (Gidden et al, 2019)

PM2.5 concentrations

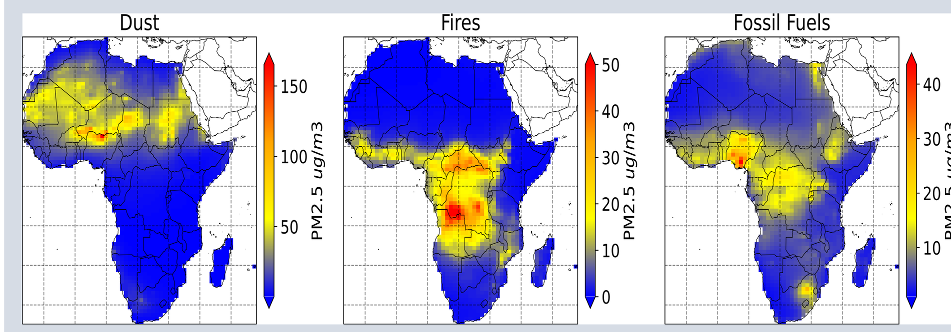

Fig .2. Annua present day(PD)l Dust, fire, and Fossil fuel PM2.5l(ug/m^3) over continental Africa

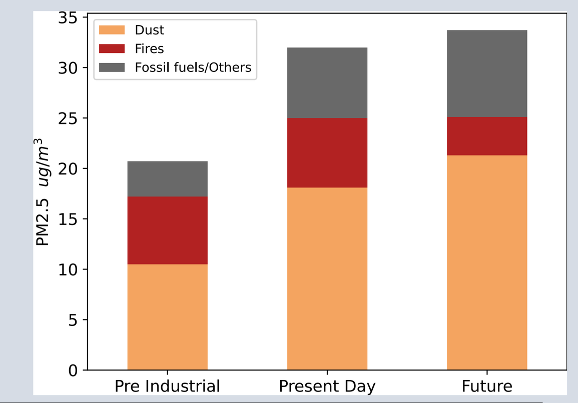

Fig.3. Annual mean concentrations of speciated PM2.5(ug/m^3) averaged over continental Africa

- Modeled dust concentrations averaged over continental Africa dominate aerosol concentrations.
- The dominant sources of PM2.5 in PD over the African continent are "natural" dust from North Africa and biomass burning from Central Africa.
- Annual mean continental average concentration levels of PM2.5 exceeds World Health Organization guidelines (5 ug/m3) even in preindustrial period.
- PD and FU total PM2.5 rose by 54% and 63%, respectively relative to PI.
- In Present day , dust PM2.5 has increased by 73 % from PI and in the future under the SSP3.7 scenario, it is expected to increase by 100% more relative to PI, representing the largest increases over Africa.
- Concentrations of PM2.5 from combustion sources (anthropogenic plus biomass burning) have also increased in PD by 100% from PI and in future expected to increase to 23% relative to PD and 100% more relative to PI

Mortality Estimation; Health Impact Function

Mortality estimation is calculated using the health impact function that relate changes in pollutant concentrations to changes in mortality.

$$\Delta mort = M_b * pop * AF$$

$$AF = \frac{RR-1}{RR}$$

$$RR = EXP^{\beta \Delta X}$$

- RR is the relative risk obtained from epidemiological studies
- AF is the attributable fraction which is the fraction of the disease burden attributable to the risk factor
- β is the concentration response factor (log estimate of the the estimated slope of the log-linear relation between concentration and mortality)

ΔX is the change in concentration

- Mort is the changes in mortality due to exposure to PM2.5
- Pop is the population in 2020 (to isolate changes in emissions, population does not change in emission scenarios)
- Mb is the country/continent specific baseline mortality rate (IHME,2019).

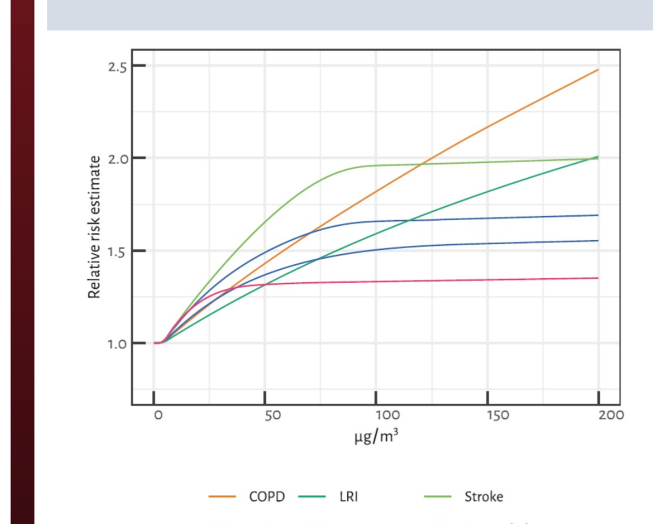

Fig.4, Relative risk estimates using the Global burden of Disease(GBD) 2019 MR-BRT method and a theoretical minimum risk exposure level of a distribution between 2·4 and 5·9 µg/m3. RR estimates are provided by GBD by age groups and cause specific for diseases such as diabetes, Chronic Obstructive pulmonary Disease,(COPD) Lower Respiratory Infections(LRI). Adapted from (Sutherland et al,2022)

Health impact function combined annual average $PM_{2.5}$ concentrations, population counts, baseline mortality rates, and epidemiologically derived concentration response functions relating $PM_{2.5}$ concentrations and health outcomes.

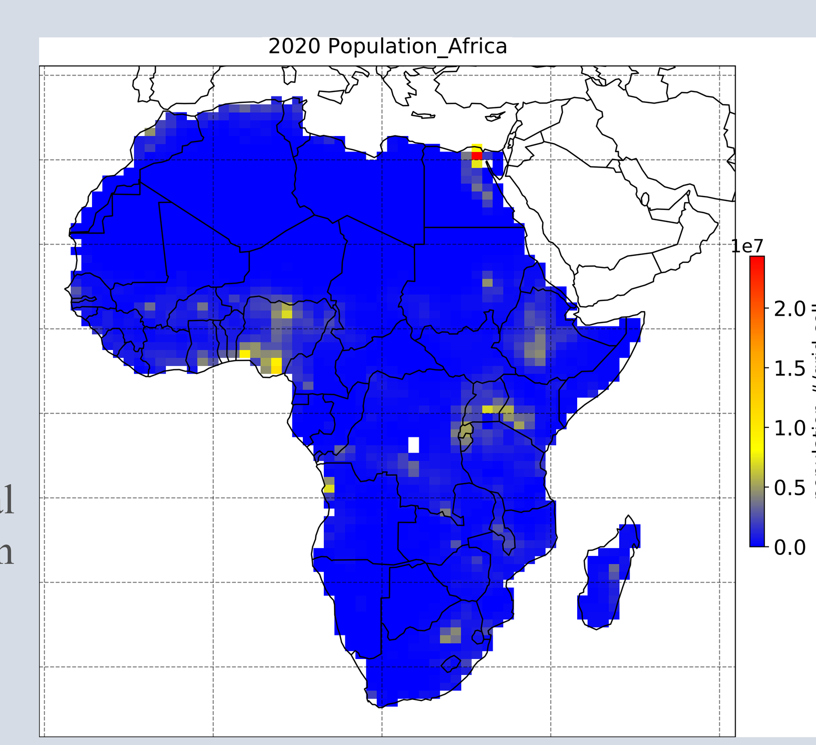

Figure 5. Population count for 2020 over Africa used for all calculations (Gridded population of the world (gpw), v4.)

PM2.5 related Mortality

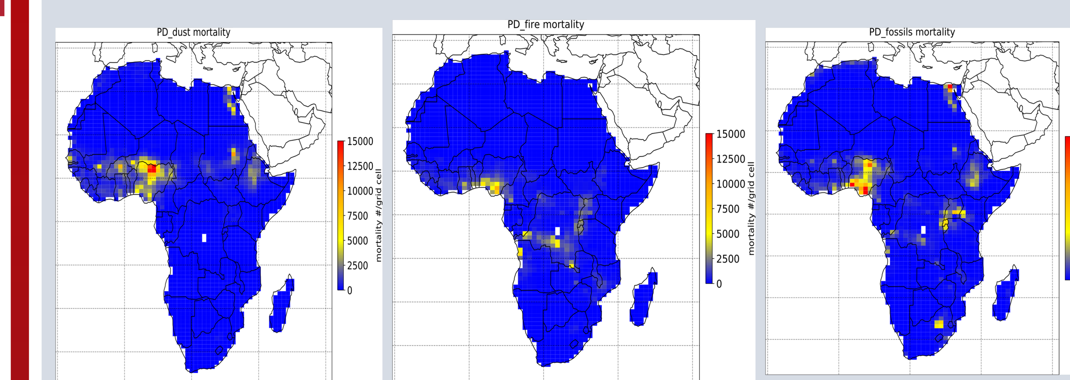

Fig. 6. Number of excess premature deaths from Dust , Fire and fossils PM2.5 exposure per gridbox. Mortality was calculated using the health impact function which relates changes in pollutant concentration to changes in mortality

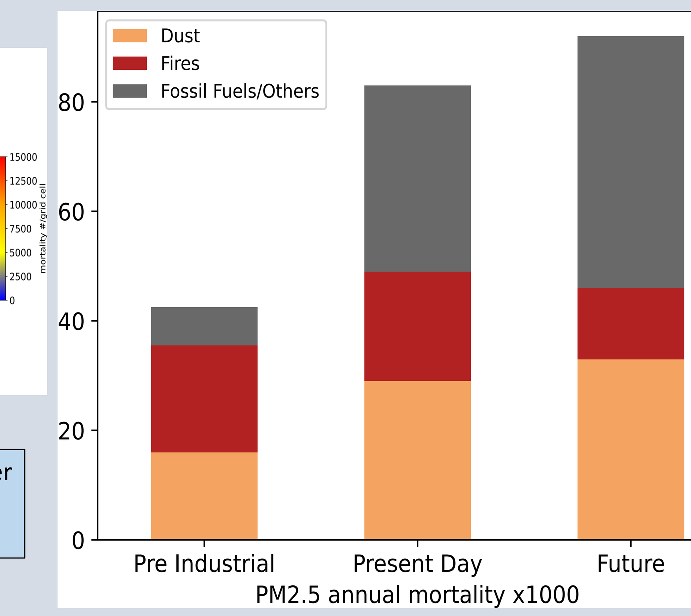

Fig.7. Number of excess premature mortality from speciated PM25 since pre industrial times

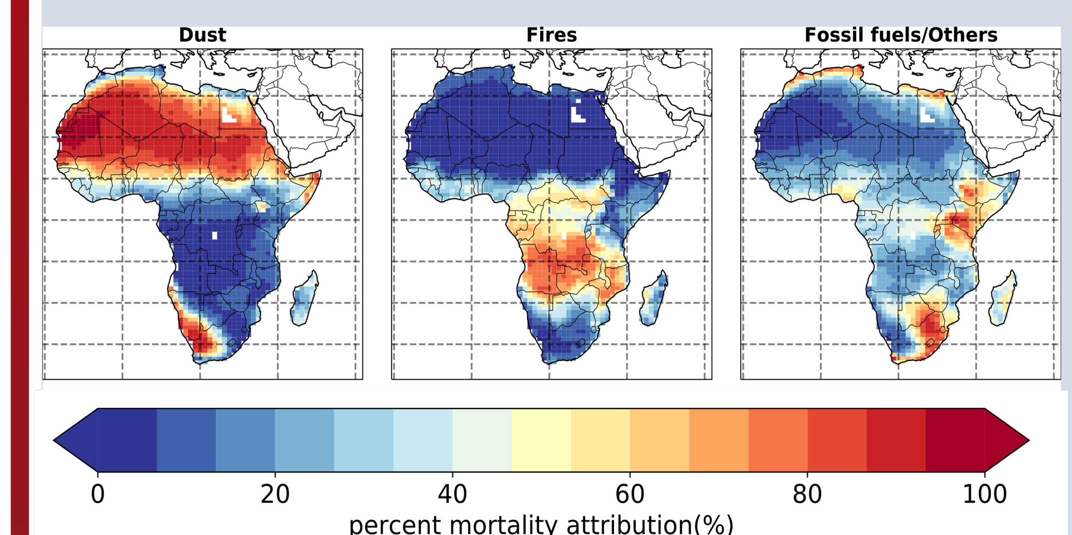

Fig.8 Present Day Excess premature mortality attribution from Dust, Fires and fossil fuel concentrations

Because of the distribution of population, mortality over Africa is dominated by combustion emissions even though dust aerosols dominant over the region.

Conclusions

- We calculate about 86,000 people dying per year from PM2.5 in Africa, which is within the range of the literature (e.g Vohra,et al, 2021, Mortality from fossil fuels)
- We also estimate about 30,000 deaths from PD dust PM2.5 and about 20,000 from fire PM2.5.
- Concentrations of fire at continental Africa have changed substantially since preindustrial times and in future expected to decrease under SSP370. Fires accounted for 40% mortality for PI, 25% for PD and 19% for FU.
- Concentrations of dust dominant at the continental scale have changed substantially since preindustrial times. Because of lower population in these dust dominated regions these do not affect health as much as combustion but are still important. It accounted for 36% mortality for PI, 35% for PD and 36% for FU.
- **Future work**: 1) Compare model estimates of PM25 concentrations to limited available observations in Africa.

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