Reviewer 3

This manuscript presents a data visualisation method designed to help users quickly grasp trends in air pollution and understand its impacts on human health over several decades. Communicating air quality levels, including their causes and implications for health, is often challenging. This tool has the potential to simplify and enhance such communication. The final graphs are certainly helpful, as they integrate a lot of information in a clear and understandable manner. It could be especially valuable for policymakers, NGOs, and the general public to raise awareness and support informed decision-making. Using WHO Guidelines as a benchmark is a strong point and provides a credible standard for comparison.

We thank the reviewer for the thorough review, and these encouraging comments.

However, I have some concerns and suggestions that the authors may wish to consider to significantly enhance the manuscript's clarity, robustness, and utility.

General: Is the project focused solely on PM2.5? While PM2.5 is a key pollutant, referring more generally to "air quality" without including other pollutants (e.g., NO_2, O_3) may be misleading. This is particularly important when comparing across European countries, where long-range transport rather than local emissions can heavily influence PM2.5 levels. If the project is to extend beyond PM2.5, what needs to be done to make it easily applicable to other pollutants?

This is an important point. This project focuses on particulate matter (PM2.5) due to its significant health impacts; the Global Burden of Disease study estimates PM2.5 contributes to ~4 million premature deaths a year, compared to 350,000 for Ozone. Similarly the Disability-Adjusted Life Years estimated for NO_2 is lower than that for PM2.5 or Ozone. PM2.5 is the pollutant of most concern for air quality and health, thus it is the focus of this first attempt to present global historical air quality data in an engaging way.

Due to the very high public health burden, particulate matter air pollution has received significant press attention over the past decade and it is now a fairly well-understood concept and a widely recognised problem, thus images that focus solely on PM2.5 are an effective entry point for broader engagement on air quality issues. NGOs and policy makers will also be aware of the term.

To avoid confusion, every image has the words "Air Pollution (PM2.5) Concentrations" on it and we have a section on the website giving a background on PM2.5 (https://airqualitystripes.info/faq/).

We agree that it would be interesting to also consider other air pollutants and we plan to do this in the future, but this requires a substantial amount of work, not just to combine present day observations (which are less widely available for O_3 and NO_2) and historical model data, but also to consider how to present the data. The different pollutants differ substantially in terms of sources, atmospheric behaviour, and trends (NO_2 often reflects local emissions and shows sharper spatial and temporal gradients, while O_3 has a more complex, non-linear relationship with precursors) and they all have very different historical profiles. This complexity means that simply combining the concentrations of all pollutants in a single image would obscure or "smear out" the clear trends that are visible in PM2.5, making the images less engaging and the message and interpretation more complex. Future work will consider how to address this.

Added text in Intro:

We focus on the air pollutant PM2.5 because its health impact surpasses that of other pollutants due to its ability to penetrate vital organs and disrupt physiological processes (Schraufnagel et al., 2019b))

Specific per section:

Section 1.1: L34–35: How does onshore flow affect PM2.5 levels? Does it lead to an increase due to sea salt or a decrease due to dilution? This should be clarified for the reader who is not so familiar with this topic.

Thanks for this suggestion. We have now re-written this section to include more detail and to clarify this point.

Previous Version

PM2.5 concentrations are influenced by factors such as industrial and agricultural activity, urbanization, air quality regulation, geographic location and meteorological conditions. In some places natural (or semi-natural) sources of PM2.5 such as mineral dust or black carbon from wildfires strongly influence concentrations (Reddington et al., 2014; Zhang et al., 2016; Graham et al., 2021; Pai et al., 2022), while other urban locations are affected by strong onshore winds which can influence concentrations (Pillai et al., 2002; Dall'Osto et al., 2010). PM2.5 has an atmospheric lifetime of a few weeks, allowing pollution to travel between nearby cities and countries, causing transboundary air pollution issues (Zhang et al., 2017; Chen et al., 2022). However, this relatively short lifetime means that concentrations respond quickly to effective clean air legislation (e.g. Silver et al. 2020).

New Version

The concentration of PM2.5 at any given location is governed by the balance between the magnitude of source terms (including direct emissions, secondary formation, and transport from other regions) and removal processes (such as deposition and atmospheric dispersion). Sources of PM2.5 are diverse and include combustion from vehicles, residential heating, industry, power generation, and agriculture, as well as secondary aerosol formation from gaseous precursors like SO_2, NO_x, and VOCs. Natural and semi-natural sources - such as mineral dust, sea salt, volcanic emissions, and black carbon from wildfires - can also contribute substantially to PM2.5 levels (Reddington et al., 2014; Zhang et al., 2016; Graham et al., 2021; Pai et al., 2022).

Meteorological conditions strongly modulate both source and removal terms. Temperature inversions, for instance, can suppress vertical mixing and trap pollutants near the surface, resulting in acute pollution episodes. Cities situated in valleys or at the foot of mountain ranges can experience higher concentrations due to restricted air movement (limiting the dispersion of pollutants), while some coastal cities are influenced by strong onshore winds that transport pollutants away (Pillai et al., 2002; Dall'Osto et al., 2010). Furthermore, PM2.5 also displays quite significant seasonal trends due to seasonal changes in meteorology and emission patterns.

PM2.5 has an atmospheric lifetime of approximately a few weeks, allowing pollution to be transported to nearby cities and countries, causing transboundary air pollution issues (Zhang et al., 2017; Chen et al., 2022). However, this relatively short lifetime

means that concentrations respond quickly to effective clean air legislation (e.g. Silver et al. 2020).

L37: The statement about the "short lifetime" of PM2.5 could be expanded. What is the typical lifetime? Why is this relevant? Providing a brief explanation would enhance the reader's understanding.

Thanks for this comment. We agree and we have expanded the description of the lifetime of PM2.5 and why it is relevant for air quality studies.

Previous Version

PM2.5 has an atmospheric lifetime of a few weeks, allowing pollution to travel between nearby cities and countries, causing transboundary air pollution issues (Zhang et al., 2017; Chen et al., 2022). However, this relatively short lifetime means that concentrations respond quickly to effective clean air legislation (e.g. Silver et al. 2020).

New Version

PM2.5 has an atmospheric lifetime of **approximately** a few weeks, allowing pollution to be transported to nearby cities and countries, causing transboundary air pollution issues (Zhang et al., 2017; Chen et al., 2022). **At the same time, it means that PM2.5 concentrations can respond relatively quickly - on the order of days to weeks - to effective emissions controls and clean air legislation (e.g., Silver et al., 2020), making policy interventions both impactful and measurable over short timescales.**

Section 2.1: While it is understandable that the authors use climate simulations to support their visualisations, it is important to acknowledge that most climate models are not optimised for air quality assessment, particularly in urban contexts. The manuscript notes that many CMIP6 models do not include key physical and chemical processes relevant to PM2.5, which is a significant limitation, especially given the focus on urban environments and long-range transport that affects cities' background concentrations.

Thanks for this comment, we have added more detail on and references to the model (see below).

The authors are commended for applying bias correction, which is essential in this context. However, more detail on the model's spatial resolution is needed. Climate models generally operate on coarse grids, which may not capture city-level variations in PM2.5.

The plots show annual mean concentrations of PM2.5 over a historical timescale; using the bias correction approach gives us a higher resolution, observationally constrained baseline for the present day (1998 onwards) we then apply the longer term trends (from the model) to this corrected baseline. Thus while the model data is on a coarse grid, because the satellite data is at a higher resolution (0.1 degree), the historical concentrations are informed by the higher resolution data.

Model and satellite resolution has been added to the text

L49: Was UKESM1 selected because it includes relevant particulate matter processes? If so, this should be clearly stated. If not, the rationale for choosing this model should be explained.

Thanks for highlighting this lack of clarity, we have updated the text.

Previous version

Only some CMIP6 models include interactive particulate matter and chemical processes; we used PM2.5 data from UKESM1 (UK Earth System Model, version 1, Sellar (2020)).

New version

Only some CMIP6 models include interactive particulate matter and chemical processes; we used PM2.5 data from one of these models, UKESM1 (UK Earth System Model, version 1, Sellar et al. 2020). This model uses a two-moment aerosol microphysics scheme for the main types of particulate matter (sulfate, black carbon, organic carbon, sea salt) and a sectional (bin) scheme for mineral dust (Mulcahy et al., 2020). At present, UKESM does not treat nitrate aerosol. Model simulations were at N96 spatial resolution (1.875° longitude × 1.25° latitude). This model has been widely used for air quality studies (Reddington et al., 2023; Turnock et al., 2020, 2023; Allen et al., 2021; Butt et al., 2017). CMIP6 data are freely available (Earth System Grid Federation, 2024).

Also added resolution of the satellite: "0.1 degree resolution"

Section 3.1: L75: Is there a reference or source for the colour theory used in the visualisation? If so, it should be included.

Added reference to: Building Science Graphics: An Illustrated Guide to Communicating Science through Diagrams and Visualizations by Jen Christiansen

L97: How many individuals participated in the informal testing phase, and what kind of feedback was collected? More information on the methodology would strengthen the section.

Previous Version

However, the project aimed to create accessible and engaging images for a wide audience. To achieve this, draft images were shown to colleagues, friends, and family during an informal testing phase.

New Version

However, the project aimed to create accessible and engaging images for a wide audience. **To achieve this, different versions of draft images were shown to 15 to 20 individuals, including colleagues (air quality researchers, public engagement specialists and researchers in different fields), friends, and family, during an informal testing phase. Feedback was gathered on aspects such as clarity, visual appeal, colour interpretation, and perceived message.**

L104: What daily values were used to extrapolate the ranges for the remaining categories? Were these values consistent across all cities? If not, the differences should be clearly indicated, as this affects interpretation.

We've added a description on the mapping values to our Air Quality Stripes Zenodo repository https://zenodo.org/records/15363039. The values were consistent across all cities, so any given PM2.5 concentration always maps to the same indicative category.

Added: **To enable direct visual comparison the mapping from PM2.5 concentration to the indicative label is the same for every city, for more details see Pringle (2025)**