Airborne microplastic radiative effects: a sensitivity study

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Introduction

- Airborne microplastics can alter the passage of radiation through the atmosphere and consequently impact the climate if concentrations become large enough.
- Direct interactions between atmospheric aerosols and radiation (such as absorption and scattering) comprise the direct radiative effect.
- Radiative forcing due to an aerosol is calculated as the change in outgoing radiation at the top of the atmosphere between states with and without the aerosol.
- Revell et al. (2021) made the first assessments of the direct radiative effect of pristine airborne microplastics. They found weak radiative forcing of +0.044±0.399 mW m^{-2}.
- In that work, confining the microplastic distribution to the bottom 2 km of the atmosphere amplified the radiative forcing to -0.746±0.553 mW m^{-2}, hinting at its sensitivity to the vertical profile.
- Subsequent work has provided more information on the physical and optical properties of airborne microplastics, as well as their distribution throughout the atmosphere.
- Using new optical property data and emissions datasets, we extend the work of Revell et al. (2021) to investigate the sensitivity of the microplastic radiative forcing to these factors.

Acknowledgements

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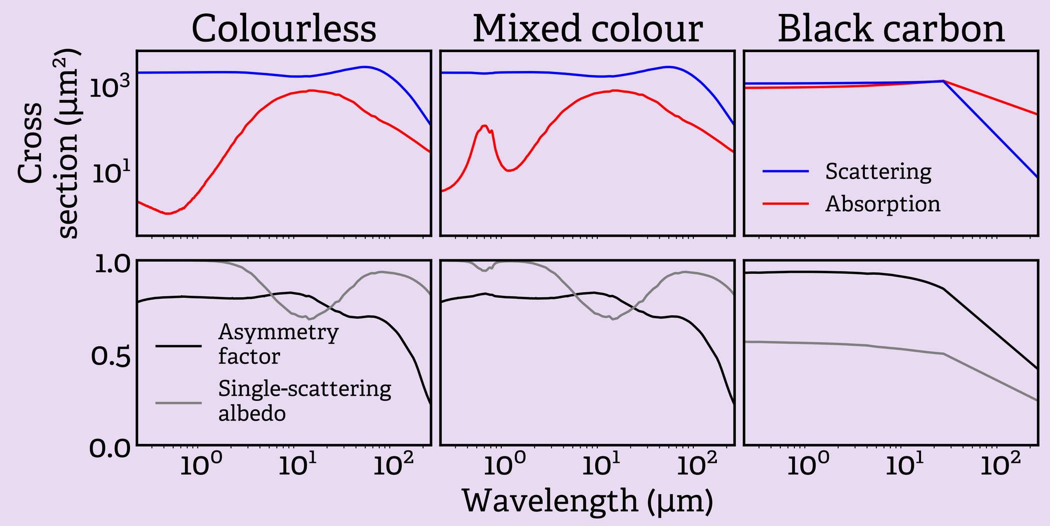
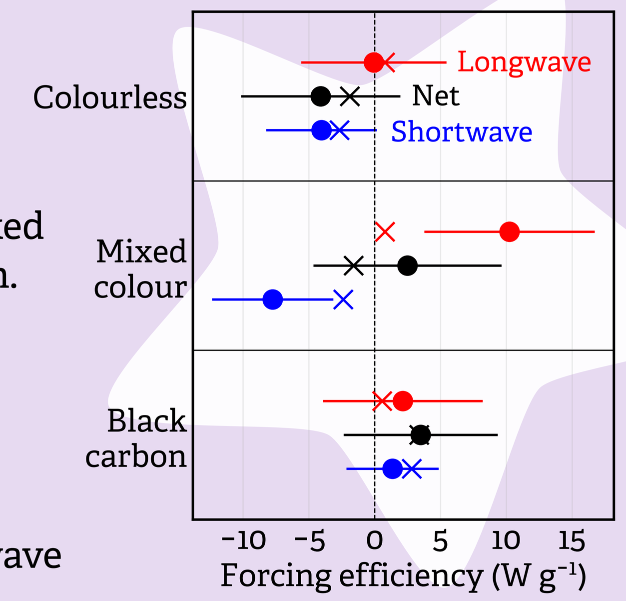
Microplastic colour



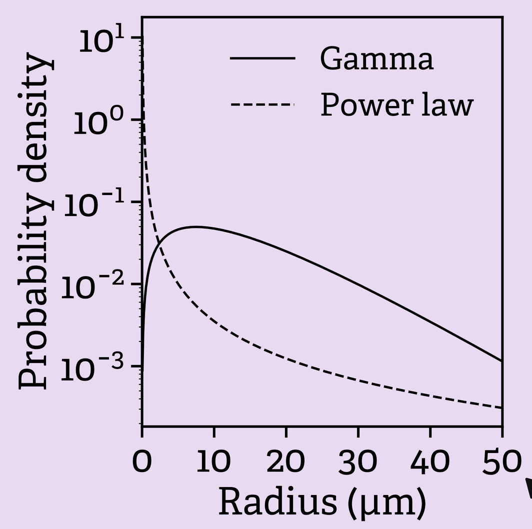
- Revell et al. (2021) considered colourless microplastics.
- We consider an average of four dyes ('mixed colour') absorbing in the visible spectrum. This produces a small decrease in the cooling shortwave forcing.
- We also consider a mixture of colourless plastic and black carbon (20%wt). This is much more strongly absorbing of shortwave radiation, producing a **net warming**.



Crosses denote instantaneous radiative forcings (IRFs); **dots and bars denote effective radiative forcings** (ERFs) and their 5 to 95% confidence intervals.

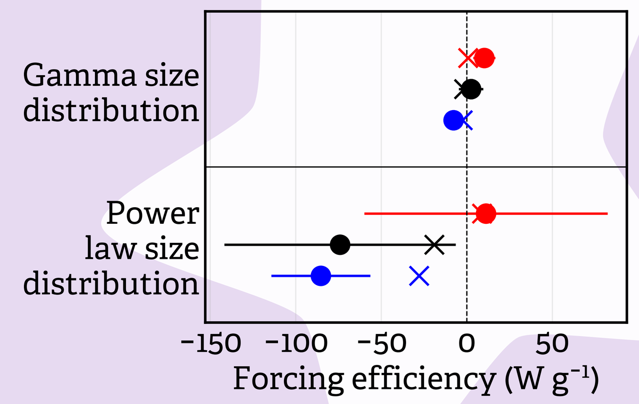
We plot the radiative forcing efficiency, which is the radiative forcing (W m^{-2}) normalised by the column microplastic mass burden (g m^{-2}) to ensure comparability between scenarios.

Microplastic size distribution

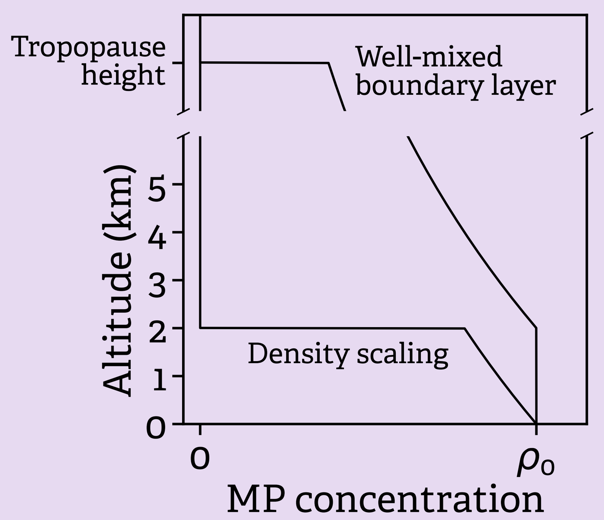


We consider particles 1–100 µm in diameter.

- Revell et al. (2021) considered a gamma size distribution.
- Leusch et al. (2023) show that a power law gives an accurate fit to the size distribution across environmental compartments.
- The power law size distribution results in ~10 times more particles for the same mass of plastic, and a consequent **~12 times increase** in the forcing efficiency.

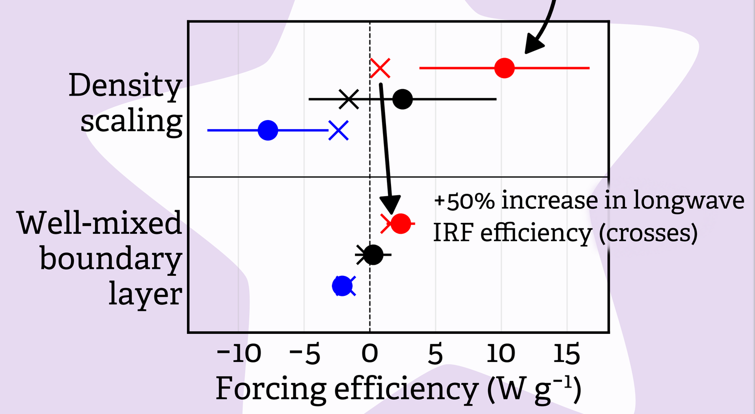


Microplastic vertical spatial distribution

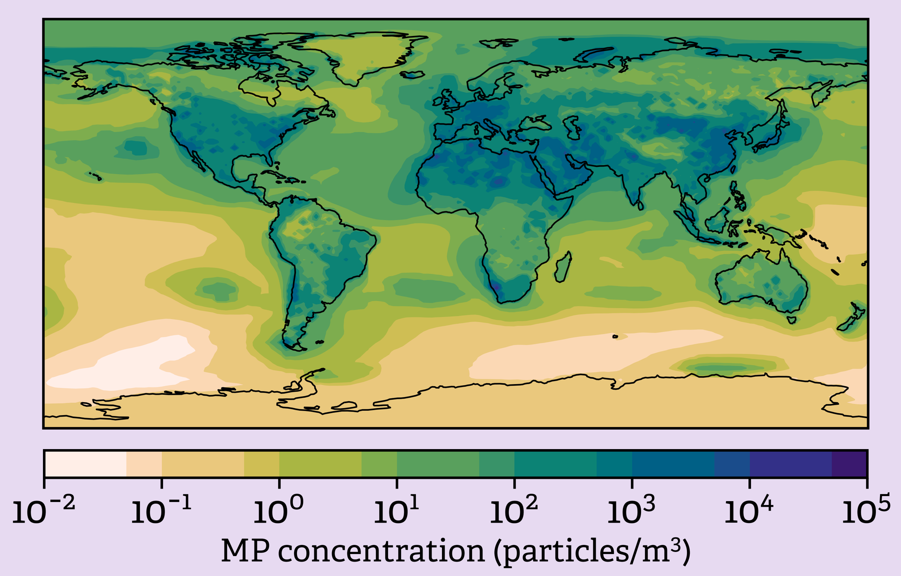


- Revell et al. (2021) considered a vertical distribution that scaled proportionately to air density ('Density scaling' here).
- We consider a distribution uniform in the bottom 2 km and extending up to the tropopause (the 'Well-mixed boundary layer').
- The higher vertical extent results in a stronger longwave warming effect due to a lower emission temperature.
- The greater plastic mass also produces a stronger forcing, hence a greater signal to noise ratio and a smaller uncertainty.

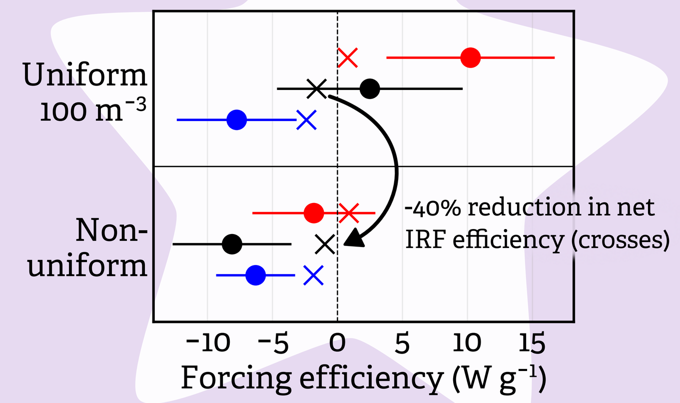
Wide confidence intervals in the ERF estimates result from noise produced by model internal variability, which is large in comparison to the weak radiative forcing.



Microplastic horizontal spatial distribution

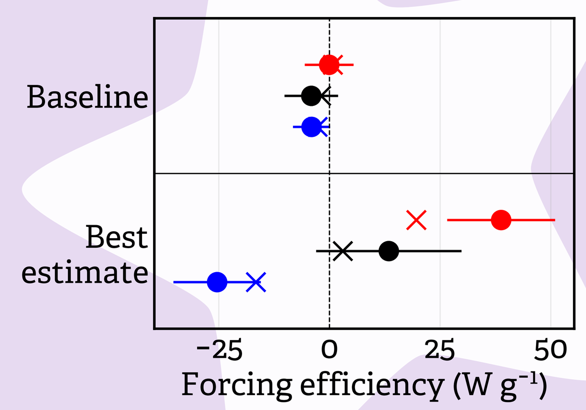


- Revell et al. (2021) considered a uniform surface concentration of 100 MPs m^{-3}.
- Using an updated version of the emissions inventory of Evangeliou et al. (2022), we derive the surface concentrations shown to the left.
- Microplastics produce a warming effect over high albedo surfaces and a cooling effect over low albedo surfaces. The reduction of microplastic concentrations over low albedo open ocean slightly reduces the net cooling effect.



"Best estimate" case

- Taking the most likely real-world value for each of these parameters – mixed colour particles, a size distribution given by a power law, a vertical distribution with a mixed boundary layer, and a non-uniform horizontal distribution – we calculate a "best estimate" radiative forcing.
- This is contrasted with our "baseline" case – colourless plastic, particle sizes given by a gamma distribution, a vertical distribution scaled like air density and cut off at 2km, and a uniform horizontal distribution of 100 MPs m^{-3}.
- Like the case of plastic mixed with black carbon and unlike every other case, our "best estimate" result yields a **net warming radiative forcing** of +22.8±50.4 mW m^{-2}.



Methods

Effective radiative forcing (ERF) and **instantaneous radiative forcing** (IRF) are two metrics of radiative forcing that differ in whether they include the radiative effects of rapid atmospheric adjustments (e.g. changes to temperature or water vapour profiles). ERF includes such effects, IRF does not.

We estimate ERFs using simulations with the **Hadley Centre Global Environment Model version 3–Global Atmosphere model 7.1** (**HadGEM3-GA7.1**). This is an atmosphere-only model, which we run for a 21 year period from 1 Sep 1988 for each simulation, and discard the first year as spin-up. Microplastic optical properties are provided to the model via the EasyAerosol system, which provides absorption and scattering properties of aerosols to the model via ancillary files. Microplastic transport is not simulated.

ERFs are calculated as the change in annual global-mean outgoing radiation at the top of the atmosphere between each simulation and a control simulation with no microplastics. We assume each 20-year time series of radiative forcings is *t*-distributed, and from this distribution derive the mean ERF and 5 to 95% confidence interval.

IRFs are estimated using the **Suite of Community Radiative Transfer codes based on Edwards and Slingo** (**SOCRATES**; which is also used internally in the HadGEM3-GA7.1). We supply the radiative transfer model with annual-mean atmospheric profiles and surface albedo derived from ERA5 reanalysis.

The non-uniform surface concentration dataset was derived from the emissions inventory of Evangeliou et al. (2022), with subsequent updates to better account for the distribution of microplastics in surface waters per Isobe et al. (2021). This emissions dataset was used to drive a 10-year simulation of the UKESM1.1 with an in-development extension to the aerosol scheme to simulate microplastics (McErlich et al., 2025). Average surface microplastic concentrations were taken from this simulation and rescaled to a global average of 100 MPs m^{-3}.

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