Recent findings on the effects of aerosols on the climate

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Conclusions

• Anthropogenic aerosols currently mask at least 0.5°C of global warming

• Aerosol climate impacts (temperature, precipitation and extremes) are regionally heterogeneous, and follow different patterns than those from greenhouse gases – and from emissions emission patterns

• Sulfate aerosols (from SO2 emissions) are the main temperature driver – …with aerosol-cloud interactions representing a major source of uncertainty

• Black carbon (BC) has a lower climate impact (and radiative forcing) than previously thought – …with emission estimates representing a major source of uncertainty

• Organic carbon (OC) emissions are moderately cooling – …with emission estimates and brown carbon (BrC) representing major sources of uncertainty

• Aerosols (very likely) affect precipitation, globally (ITCZ, surface cooling, atmospheric stability) and regionally (monsoon patterns, mediterranean and South African drying)

• Present and future air quality measures will affect the climate, but it’s far from clear just how and how much
The climate impact of aerosols (here: BC)

Breaking it down:

\[ \text{Em} \times \text{LT} \times \text{MAC} \times \text{RFE} = \text{RF} \]

\[ \text{AAOD} \times \text{RFE} = \text{RF} \]

\[ \text{RF} \rightarrow \text{dT}, \text{dP} \]

- \text{Em} = \text{Emissions}
- \text{LT} = \text{Lifetime / residence time}
- \text{MAC} = \text{Mass absorption coefficient}
- \text{RFE} = \text{Radiative forcing efficiency}
- \text{AAOD} = \text{Aerosol absorption optical depth}
- \text{RF} = \text{Radiative forcing}
- \text{dT} = \text{Surface temperature change}
- \text{dP} = \text{Precipitation change}

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Hoesly et al. 2018 / Myhre et al. 2013 / Stjern et al. 2017 / IPCC AR5 WG1
The climate impact of present day emissions of anthropogenic aerosols

Tug-of-war between aerosol cooling and greenhouse gas warming
Surface temperature and precipitation have, since preindustrial times, been affected by both greenhouse gases and aerosols. Model simulations comparing the periods 1985 to 2005 and 1880 to 1900 show that across the global land area, aerosols have limited the impacts of greenhouse gas warming. The regional patterns are more complex for precipitation. Data from (4).

(a) Surface temperature change (K)

(e) Precipitation change (mm day⁻¹)
Aerosol impacts follow a different pattern to GHG, due – partly – to long range transport.
Sulfate

- Emissions: Relatively well characterized
- Climate impact: Uncertain, due to aerosol-cloud-interactions
- Several groups working to unify model estimates with observational estimates

Gryspeerdt et al. 2018 PNAS
McCoy et al. 2017 JGRA
Malavelle et al. 2017 Nature
Organic aerosol

• Broad term (primary organic aerosols, secondary organics, broad range of sources, chemistry and transport, lack of observations…)
• Thorough multi-model inter- and observational comparison: Tsigaridis et al. 2014 ACP
• Recent topic: Brown Carbon Prevalent, also in upper troposphere:

![Graph showing scattering and BrC vs. high/low altitude](image)

• However, BrC only weakly modifies global negative RF from OA in most studies. SOA scattering dominates POA, due to altitude. (Lund et al. 2018, ACPD)
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Emissions keep increasing

\[ \text{Em} \times \text{LT} \times \text{MAC} \times \text{RFE} = \text{RF} \rightarrow \text{dT}, \text{dP} \]

SPEW (Bond et al., 2007), J08 (Junker and Liousse, 2008), ACCMIP and MACCity for the Atmospheric Chemistry and Climate Model Intercomparison Project (Lamarque et al., 2010; Granier et al., 2011), CMIP6 (Coupled Model Intercomparison Project Phase 6) (Hoesly et al., 2017), PKU-BC (Wang et al., 2014), K17 for (Klimont et al, 2017), GFED2 (Global Fire Emissions Database version 2) (van der Werf et al., 2006), GFED3 (van der Werf et al., 2006), GFED4 (Randerson et al., 2015), GICC (Le programme Gestion et Impacts du Changement climatique) (Mieville et al., 2010) and RETRO (REanalysis of the TROpospheric chemical composition over the past 40 years) (Schultz et al., 2008). For the PKU-BC inventory, annual BC emissions and uncertainties are shown as median values (red line) and inter-quartile ranges (shaded area) from a Monte Carlo simulation.

NB: Cohen and Wang 2014, Kalman filter estimate, $17.8 \pm 5.6 \text{Tg/yr}$,

Many thanks to prof. Rong Wang for this compilation.
Forcing efficiency: (D)RF is not temperature
ERF = direct RF + rapid adjustments

\[ \text{Em} \times \text{LT} \times \text{MAC} \times \text{RFE} = \text{RF} \rightarrow dT, dP \]
Temperature response...  
...seems moderate

\[ \text{Em} \times \text{LT} \times \text{MAC} \times \text{RFE} = \text{RF} \rightarrow dT, dP \]

+ Baker 2015, ACP
Precipitation impact?
Rapid adjustments and weak temperature response make BC mess up global modelling!

Em × LT × MAC × RFE = RF → dT, dP


Mediterranean: See Tao et al. 2018, ACPD
Regional response: See Liu 2018, JCLIM
Regional effects of anthropogenic aerosols

- ITCZ shift
- Asian Monsoon slowdown
- Southern African and Mediterranean drying
- ...
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Something funny…

Aerosol optical depth

MODIS Terra

OMI

MISR