Theses on the magnitude of ERFaer
Submission for the Ringberg workshop, 26 February to 2 March 2018

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3 December 2017

Reference state

Using the IPCC-recommended reference year of 1750 makes quantifying aerosol radiative forcing an impossible task because we will never know what aerosols were like in 1750 or any other year before the satellite aerosol retrieval era started in 1979. But the forcing-response-feedback framework allows us to make other choices, for example a reference state where aerosols and cloud condensation nuclei are only due to natural processes, without anthropogenic contributions. Present-day natural aerosols are good candidates to characterise such a reference state because we have observations of their distributions. In most regions, natural aerosol changes due to anthropogenic climate change (wind speed, soil moisture, vegetation cover, …) are likely small. That could be tested with observations over the past 30 years.

The anthropogenic fraction of present-day aerosol optical depth, f_{anth}, is uncertain but at least we have the observations to try and estimate it. Bellouin et al. (2013) use the MACC reanalysis of atmospheric composition and AeroCom models to find f_{anth} = 40%. Kinne et al. (2013) use AERONET retrievals to scale AeroCom models to find f_{anth} = 48%. I know the Bellouin et al. (2013) dataset best and think it overestimates f_{anth} because fine-mode biogenic aerosols from land and oceanic sources, and lightning-induced fires, are likely to be mis-categorised as being anthropogenic. So, I would put the range for f_{anth} at 25-50%.

In the following I define aerosol radiative forcing with respect to present-day natural aerosols.

RFari and RFaci

The ranges for aerosol radiative forcing, rapid adjustments excluded, in the CAMS Climate Forcing (which I lead so I am biased) are RFari = −1.0 to −0.5 W m^{-2} and RFaci = −1.0 to 0.0 W m^{-2}. Uncertainties in RFari are dominated by uncertainties in anthropogenic fraction and total aerosol optical depth. Anthropogenic absorption, both in cloud-free and cloudy sky, is only a second order uncertainty, on a global average. The RFaci range is based on satellite constraints of cloud albedo responses to aerosol changes developed in Johannes Quaas' group, and I believe the range we currently have is a good measure of total uncertainty.

However, the anthropogenic fraction from which those numbers are derived is probably at the high end, so I would shift those ranges towards weaker forcings, RFari = −0.8 to −0.4 W m^{-2} and RFaci = −0.7 to 0.0 W m^{-2}. My range for RFari+aci is then −1.5 to −0.4 W m^{-2}.

Rapid adjustments

Finding signatures of rapid adjustments in cloud fraction and liquid water path (LWP) in observations and even large eddy modelling is difficult. That fact strikes me as being incompatible with rapid adjustments exerting a large radiative forcing. Peters et al. (2014) suggest that natural variability is large enough to mask very strong radiative forcings. That would be bad news: if we cannot detect an impact on the average, the next best move is to look at the tails of the cloud fraction and LWP distributions. But there, aerosol-driven changes are probably small because cloud evolution is driven by other factors (available moisture, accretion, …). In any case, responses derived from satellite retrievals of stratocumulus clouds show cases where LWP increases, decreases, or does not change (Christensen and Stephens 2011; Toll et al. 2017). That means the universal increase in LWP simulated by global models is wrong, so we cannot use those models to get a best estimate and range of rapid adjustments.

For cloud fraction changes, the upper bound of −0.5 W m^{-2} obtained from satellite retrievals by Gryspeerdt et al. (2016) is a good starting point. It is likely too strong because it relies on the MACC anthropogenic fraction and because it is likely that meteorologically-driven covariances between aerosols and cloud fraction remain. For LWP responses, the satellite studies cited above suggest a response centred on zero in the stratocumulus regime. Looking at extratropical cyclones, McCoy et al. (2017) say that aerosol may increase LWP of the veil clouds that follow the cold front, but not of the thicker frontal clouds. I am unconvinced that aerosols invigorate convective clouds, as observations are equally consistent with a shift of both cloud base and top to higher altitudes.

For semi-direct effects, PDRMIP results (Stjern et al. 2017) suggests compensations between changes in cloud properties and surface energy budget. There may also be a positive radiative forcing on longwave radiation because the aerosol layer is warmer. But the chain of responses needs to be linear to interpret the PDRMIP simulations, which required artificially large increases in aerosol emissions to yield detectable responses. In addition, I would not place more confidence in modelled semi-direct than in second indirect effects.

For ice clouds, I also believe that strong aerosol-driven changes in cloud fraction or ice water path would have already been detected, but I leave the door open to surprises.

All considered, I would place a range of −0.5 to 0 W m^{-2} for the sum of all rapid adjustments.

My overall range for ERFari+aci would then be −2.0 to −0.4 W m^{-2}, but values stronger than −1.0 W m^{-2} require that all processes, including rapid adjustments, exert sizeable radiative forcings.

References

Bellouin, N., et al. Estimates of aerosol radiative forcing from the MACC re-analysis. Atmos. Chem. Phys., 13 (4), 2045-2062, doi: 10.5194/acp-13-2045-2013, 2013.

Christensen, M. W., and G. L. Stephens. Microphysical and macrophysical responses of marine stratocumulus polluted by underlying ships, J. Geophys. Res., doi:10.1029/2010JD014638, 2011.

Kinne, S., et al. MAC-v1: A new global aerosol climatology for climate studies, J. Adv. Model. Earth Syst., doi:10.1002/jame.20035, 2013.

McCoy, D. T., et al. The aerosol-cyclone indirect effect in observations and high-resolution simulations, Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-649, 2017.

Peters, K., et al. Processes limiting the emergence of detectable aerosol indirect effects on tropical warm clouds in global aerosol-climate model and satellite data, Tellus B, doi:10.3402/tellusb.v66.24054, 2014.

Stjern, C. W., et al. Rapid adjustments cause weak surface temperature response to increased black carbon concentrations. J. Geophys. Res., doi:10.1002/2017JD027326, 2017.

Toll, V., et al. Volcano and ship tracks indicate excessive aerosol-induced cloud water increases in a climate model. Geophys. Res. Lett., accepted, 2017.