Impact of megacity aerosol emissions on air quality and climate in the Met Office climate model HadGEM2

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Abstract

Megacities are a substantial source of anthropogenic pollution. This affects the air quality of hundreds of millions of people both within the cities themselves and in the wider world. The megacity pollution can also have an impact on global climate, either directly or via complex interactions within the Earth system.

The impact of megacities on particulate burden, surface concentration, deposition and resultant radiative forcing are determined using the Met Office Hadley Centre climate model (HadGEM2). The study perturbs aerosol and aerosol precursor emissions from a selection of megacities as defined by the EU MEGAPOLI project. In addition to large cities this definition includes, conurbations (e.g. Boston-New York-Washington) and highly industrialized regions (e.g. the Po valley). The specific megacities in this study are chosen to provide a global sample. From this, the differences due to the location of the megacities can be investigated. The remote responses away from megacity perturbations are considered in addition to local effects. Aerosol types investigated include sulphate, nitrate, black carbon and organic carbon.

Figure – MEGAPOLI logo

Megacity experiment

Several worldwide megacities are defined in accordance to the MEGAPOLI[(1)] present day experiment. These can be seen in Figure 1. Two experiments are performed. The first experiment is the control (CTRL) with 2005 (present day) aerosol precursor emissions.

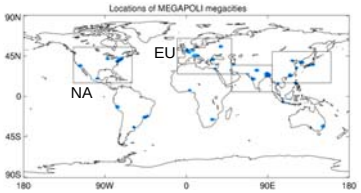

Figure 1 – Blue = Locations of megacities used. Boxes = HTAP[(2)] experiment zones. NA = North America. EU = Europe and North Africa

The second experiment is identical apart from all emissions in megacities are set to zero. By taking a difference between the two runs, the effect of global megacity emission on surface pollutant concentrations and radiative forcing can be established. Black carbon (BC), organic carbon from fossil fuels (OCFF) and sulphate (SO_4) aerosols are investigated.

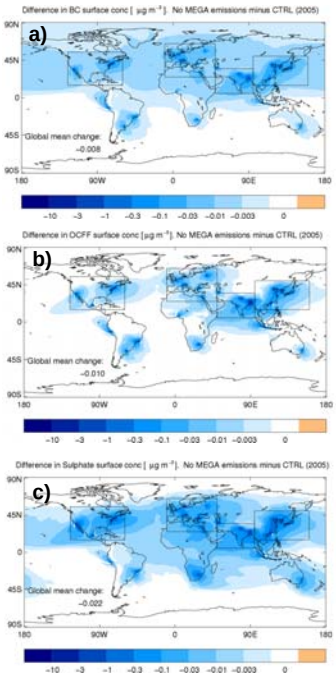

Figure 2 – Difference in aerosol surface concentration [μg m^{-3}]. No megacity run minus control run. a) BC, b) OCFF, c) Sulphate

The impact of removing megacity emissions on global surface concentration can be seen in Figure 2. The strongest impact is local to the megacity locations peaking (for all three aerosol types) at ~10 μg m^{-3}.

The impact on remote regions is in part determined from the lifetime of the particular substance in the atmosphere. In this configuration of HadGEM2, OCFF has the shortest lifetime (~5 days) and thus long range effect of the megacity removal is falling below -0.001 μg m^{-3} for most of the globe. BC has a longer lifetime (~13 days) and the influence reaches the Northern polar region (at between -0.003 and -0.01 μg m^{-3}).

Megacities contribute greatly to the surface concentration of sulphate which demonstrates the largest change of the three aerosols (-0.022 μg m^{-3} in the global mean). The megacity contribution to surface level BC and OCFF concentrations are of similar magnitude (0.008 and 0.010 μg m^{-3} respectively in the global mean).

In addition to the change in aerosol surface concentration, the change in aerosol shortwave direct effect from megacities is established. The CTRL effect can be seen in Figure 2a.

Over most of the globe, the aerosols largely reflect shortwave radiation. This is not the case in the polar regions however. This is largely due to black carbon aerosol absorbing radiation that would otherwise be reflected by the bright surface underneath. When the megacities are removed and the result is subtracted from the control (Figure 2b), a positive effect can be seen local to the megacities. This occurs as the aerosol is no longer available to reflect sunlight, increasing the amount reaching the surface. A negative effect can be seen over remote areas and highly reflective areas (e.g. Sahara). This is due to the longer lifetime of BC in HadGEM2 compared to the more reflective aerosols.

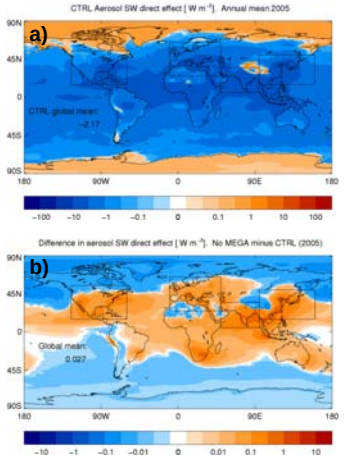

Figure 3 – a) Control direct aerosol shortwave forcing. b) Difference in forcing. No megacity run minus control run [W m^{-2}]

Sulphate and Nitrate in HadGEM2

An additional study investigates interactions between SO_2, NOx and NH_3 and the resultant impact on surface concentrations of sulphate and nitrate. The study consists of a control (CTRL), 3 experiments where each of SO_2, NOx and NH_3 emissions are in turn reduced to 80% in the North America (NA) region (Figure 1) and 3 similar experiments with reductions in Europe (EU). Regions are defined according to HTAP[(1)]. The experiment minus CTRL values can be found in Table 1. Values are multiplied by minus 5 to give "total" contribution (i.e 20% to 100%).

SO_2 emissions from NA enhance the EU sulphate surface concentration. The same emissions reduce EU nitrate concentrations as less nitrate is created over NA and thus transported nitrate is reduced. Locally produced SO_2 accounts for the bulk of the EU background SO_4 concentration.

NA NOx emissions contribute to EU nitrate surface concentrations. NOx emissions also enhance EU sulphate at the surface. This is due to the effect of NOx on oxidants (e.g. hydrogen peroxide). When the NOx is advected over low NOx regions oxidant levels are increased resulting in increased oxidation of SO_2. EU NOx is the largest contributor to local nitrate concentrations. Most of the EU sector is high in NOx, thus adding more NOx reduces available oxidants, this outweighs the effect of the North African low NOx part of the sector.

	EU SULPHATE	EU NITRATE
CTRL	2.327	1.632
NA SO2	0.030 (1.2%)	-0.004 (-0.2%)
NA NOx	0.012 (0.5%)	0.021 (1.3%)
NA NH3	--- ---	0.008 (0.5%)
EU SO2	1.899 (81.6%)	-0.151 (-9.3%)
EU NOx	-0.057 (-2.4%)	0.763 (46.8%)
EU NH3	--- ---	2.016 (123.5%)

Table 1 – Area averaged surface concentrations of sulphate [μg $[SO_4]$ m^{-3}] and nitrate [μg $[NO_3]$ m^{-3}]. Top = Control. Next is contribution of precursor from the stated region (see Figure 1)

In HadGEM2, NH_3 affects the partitioning of sulphate, but not the total. NA NH_3 emissions have a small effect on the EU nitrate concentrations. Local EU NH_3 appears to "super contribute". This shows that nitrate is ammonia limited over the EU sector.

Nitrate is currently in the process of being introduced into the megacity experiments.

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References and links:

(1) MEGAPOLI Website (http://megapoli.dmi.dk)

(2) HTAP – Hemispheric Transport of Air Pollution (http://aqm.jrc.ec.europa.eu/HTAP/)