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Title: Impact of 2000-2050 climate change on fine particulate matter ($PM_{2.5}$) air quality inferred from a multi-model analysis of meteorological modes

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Studies of the effect of climate change on fine particulate matter ($PM_{2.5}$) air quality using general circulation models (GCMs) have yielded inconsistent results including in the sign of the effect. This reflects uncertainty in the GCM simulations of the regional meteorological variables affecting $PM_{2.5}$. Moreover, projecting the climate change effect on $PM_{2.5}$ air quality requires an understanding of the relationships of $PM_{2.5}$ with meteorological variables, but only a few observational studies have examined such relationships and then only for small regional domains and a limited suite of species and meteorological variables.

We applied a multiple linear regression model to understand the relationships of $PM_{2.5}$ with meteorological variables in the contiguous US and from there to infer the sensitivity of $PM_{2.5}$ to climate change. We used 2004-2008 $PM_{2.5}$ observations from ~1000 sites (~200 sites for $PM_{2.5}$ components) and compared to results from the GEOS-Chem chemical transport model (CTM). All data were deseasonalized to focus on synoptic-scale correlations. We find strong positive correlations of $PM_{2.5}$ components with temperature in most of the US, except for nitrate in the Southeast where the correlation is negative. Relative humidity (RH) is generally positively correlated with sulfate and nitrate but negatively correlated with organic carbon. GEOS-Chem results indicate that most of the correlations of $PM_{2.5}$ with temperature and RH do not arise from direct dependence but from covariation with synoptic transport. We applied principal component analysis and regression to identify the dominant meteorological modes controlling $PM_{2.5}$ variability, and showed that 20-40% of the observed $PM_{2.5}$ day-to-day variability can be explained by a single dominant meteorological mode: cold frontal passages in the eastern US and maritime inflow in the West. These and other synoptic transport modes drive most of the overall correlations of $PM_{2.5}$ with temperature and RH except in the Southeast.

From 1999-2010 observations we further showed that interannual variability of annual mean $PM_{2.5}$ in most of the US is strongly correlated ($r > 0.5$) with the synoptic period T of the dominant meteorological mode as diagnosed from a spectral-autoregressive analysis, especially in the eastern US where the dominant modes represent frontal passages. We used the CMIP3 archive of data from fifteen different IPCC AR4 GCMs to obtain improved statistics of 21st-century trends in the meteorological modes driving $PM_{2.5}$ variability over the contiguous US. The GCMs all have significant skill in reproducing present-day statistics for T and we showed that this reflects their ability to simulate atmospheric baroclinicity. We then used the local $PM_{2.5}$-to-period sensitivity ($dPM_{2.5}/dT$) from the 1999-2010 observations to project $PM_{2.5}$ changes from the 2000-2050 changes in T simulated by the 15 GCMs following the SRES A1B greenhouse warming scenario. By weighted-average statistics of GCM results we project a likely 2000-2050 increase of ~0.1 $\mu g\ m^{-3}$ in annual mean $PM_{2.5}$ in the eastern US arising from less frequent frontal ventilation, and a likely decrease of ~0.3 $\mu g\ m^{-3}$ in the northwestern US due to more frequent maritime inflows and the accompanying precipitation. These circulation-driven changes, independent of changes in anthropogenic emissions and other factors, are relatively small. Potentially larger regional effects of 2000-2050 climate change on $PM_{2.5}$ may arise from changes in temperature, biogenic emissions, wildfires, and vegetation, but are still unlikely to affect annual $PM_{2.5}$ by more than 0.5 $\mu g\ m^{-3}$. Therefore, 2000-2050 climate change represents a relatively minor penalty or benefit for $PM_{2.5}$ regulatory purpose. Of more concern would be the effect of increased fires on daily $PM_{2.5}$.