Impact of Climate Change on Fine Particulate Matter (PM$_{2.5}$) Air Quality Inferred from a Multi-model Analysis of Meteorological Modes

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AMS Conference on Atmospheric Biogeosciences
Jun 1, 2012
Fine Particulate Matter (PM$_{2.5}$): Composition, Sources and Sinks

**emissions**
- Fossil fuel
- Agriculture
- Vegetation

**precursor gases**
- $\text{SO}_2$
- $\text{NO}_x$
- $\text{NH}_3$

**chemistry (oxidation, condensation)**

**volatile organic compound (VOC)**

**PM$_{2.5}$ components**
- Sulfate
- Nitrate
- Ammonium
- Organic carbon
- Black carbon

**removal processes**
- Transport (ventilation)
- Scavenging

(combustion, wildfires)
GCM-CTM studies show ±0.1-1 µg m⁻³ effect of climate change on PM₂.₅ with no consistency even in sign of effect.

Reflects uncertainty of GCMs in simulating regional climate, and use of single GCM realizations in GCM-CTM studies which is not sufficient due to complex meteorological dependence.
Dominant Meteorological Modes for Daily PM$_{2.5}$ Variability

- **Principal component analysis (PCA)** of 8 meteorological variables to identify dominant meteorological mode that drives day-to-day PM$_{2.5}$ variability by region:

  \[ PC(t) = \alpha_T T(t) + \alpha_{precip} \text{precip}(t) + \alpha_{SLP} \text{SLP}(t) + \ldots \]

Transport modes for PM$_{2.5}$:

- Eastern US: **mid-latitude cyclone and cold front passage**
- Pacific coast: **synoptic-scale maritime inflow**

[Tai et al., 2012]
Identify dominant meteorological mode for interannual PM$_{2.5}$ variability whose mean period $T$ (~5-10 days) is most strongly correlated with annual mean PM$_{2.5}$.

Midwest: local $d$PM$_{2.5}$/dT = ~1 µg m$^{-3}$ d$^{-1}$

Anomaly of annual mean PM$_{2.5}$ and period of dominant meteorological mode (cyclone passage) for US Midwest

[Tai et al., 2012]
Multi-model Projection of Synoptic Period and PM$_{2.5}$

Climatological observation of $d$PM$_{2.5}/dT$

Weighted average 2000-2050 change in $T$
(15 IPCC AR4 GCMs)

Resulting 2000-2050 change in PM$_{2.5}$

[Tai et al., in prep]
Likely increase of \(~0.1 \, \mu g \, m^{-3}\) in eastern US due to more stagnant atmosphere; likely decrease of \(~0.3 \, \mu g \, m^{-3}\) in Northwest due to more frequent maritime inflows

Uncertain in other regions

[Tai et al., in prep]
Overall assessment of PM$_{2.5}$ response to climate change

- Overall climate effect on annual PM$_{2.5}$ unlikely to exceed ±0.5 µg m$^{-3}$
- Effect of fires on daily PM$_{2.5}$ in the West may be more prominent issue