Modelling photochemical impacts of haze pollution in a Chinese Megacity

RMetS Air Pollution in Megacities: 20\textsuperscript{th} March 2019

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Air pollution in Beijing

- Global megacity with population of approximately 21 million people
- Rapid economic growth and industrialisation over the last 30 years
- Haze events are becoming more frequent with high loadings of fine particulate matter (PM$_{2.5}$)
- PM$_{2.5}$ is harmful to human health but can also severely reduce visibility.

Diagram:
- Scattered light
- Reduced incoming radiation
- Aerosol

(Lancaster University logo)
Impacts of haze on photolysis

- Photolysis is a key driver of oxidant photochemistry through effect on species such as $O_3$ and $NO_2$
- HONO photolysis important source of OH in urban environments
- Aerosols in haze can impact photolysis rates
- Implications for both local and regional atmospheric chemistry. E.g. Secondary aerosol formation
FAST–JX photolysis scheme

- Simulates the multiple scattering of aerosol and cloud layers in the atmosphere
- Simulates photolysis rates for 18 wavelength bins covering both the troposphere and stratosphere
- Can be driven in stand-alone mode with observations/re-analysis data
- Is also integrated into a number of atmospheric models and fully coupled to model chemistry schemes (E.g. UKCA).
Simulation of photolysis rates in Beijing – modifications to FAST - JX

- Modified to include NO$_2$ absorption
- Scattering phase functions updated based on campaign measurements
- Account for effects of coating on absorption by Black Carbon (BC)
- Driven using cloud data from ECMWF ERA5 reanalysis data
APHH campaigns: Nov-Dec 2016 & May-June 2017

• Aerosol composition and size monitored throughout both campaigns

• Lidar extinction by aerosol to show vertical distribution of aerosol layers

• Co-located PAX instrument to measure total aerosol extinction at the surface

• SP2 instrument to measure BC properties including core and coating size
Measured aerosol extinction during both campaigns.

Summer
How do we estimate vertical profiles of each aerosol species?

Example image

$SO_4^{2-}$?

$NO_3^-$?

$Cl^-$?

$BC$?

$OA$?

Use optimisation factoring in hygroscopic growth
Which aerosols contribute the most to AOD?

- Haze days: PM$_{2.5}$ > 75 µgm$^{-3}$ (AQI 100)
- SO$_4$ and BC dominate winter haze
- Organic aerosol dominate summer haze
- Largest AOD tend to be higher altitudes in summer – regional transport?
How well does FAST-JX capture haze events over Beijing?

![Graphs showing diurnal mean for summer and winter.](image)
Which aerosols have the largest impact on photolysis rates?

- Absorbers dominate towards the surface, scatterers higher up.
- Effect from absorbers more pronounced through column in winter.
- Absolute changes in $J$ rates higher in the summer.
Impacts on mean diurnal JO$_3$ and NO$_2$ profiles

- Impacts of all aerosols versus clear sky conditions
- Largest reductions in JO$_3$ of 33.7% in winter
- Largest reductions in JNO$_2$ of 66% in summer
Haze impacts versus cloud impacts

- In winter aerosol impacts dominate <1km.
- Aerosol and cloud have similar effects at surface in summer.
- In summer aerosol effects dominate >3km.
- Absolute changes in J rates higher in summer!
Potential photochemical impacts using a simple box model

• Simple VOC oxidation scheme based around generic reaction set

• Aerosols result in potential reductions of ~12% in surface $O_3$ concentrations (0.0 to 3.0% for OH)

• What are the implications for oxidants if PM controls implemented?
Summary

- Severe haze pollution episodes occur in both winter and summer resulting in up to 34% reduction in JO$_3$ (winter) and 66% reduction in JNO$_2$ (Summer).
- Largest magnitude reductions are seen during summer months – despite PM in general being lower.
- Absorbing species dominate response of photolysis rates in winter and scatterers dominate in the summer.
- During both campaigns in severe haze pollution aerosol effects dominate over clouds (when present).
- Severe haze potentially reduces surface O$_3$ and OH concentrations by up to ~12% and 3% respectively.
- What are potential feedbacks of PM removal on photochemistry?
Thank You!

Questions?