A numerical approach for picking win-win strategies for air pollution in megacities

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Introduction

Fine particulate matter ($PM_{2.5}$) and surface ozone (O_3) are both major air pollutants. Current mitigation strategies in Asian megacities (e.g., Beijing and Delhi) usually focus on $PM_{2.5}$ and overlook O_3. Co-reduction of NOx with $PM_{2.5}$ may increase O_3 in megacities which are in a VOC-limited regime, as is happening in Beijing (Li et al., 2018). In addition to negative health effects, O_3 also causes large negative impacts on the biosphere and agriculture (Ghude et al., 2014). Comprehensive studies of mitigation strategy with respect to the dual targets of $PM_{2.5}$ and O_3 are urgently needed prior to policy actions. Here, we use Delhi, one of the megacities with poorest air quality in the world, as an example to demonstrate an ensembled numerical approach for mitigation strategy consultation. We use Gaussian process emulation (Ryan et al., 2018), which provides a computationally efficient surrogate for a regional air quality model (WRF-Chem), to facilitate global sensitivity analysis and generate emission-sector-wise response surfaces. Our results suggest a short-term solution that requires less policy effort and a long-term strategy aimed at reducing $PM_{2.5}$ in Delhi whilst minimizing O_3 risks.

Method

We set up a WRF-Chem simulation framework with three nested domains that cover South Asia, the Indo Gangetic Plain and the National Capital Region of Delhi (NCR). Model results during a pre-monsoon period in 2015 (peak O_3 season, 2-15 May) agree reasonably well with surface observations of $PM_{2.5}$ and O_3. A Gaussian process emulator is generated based on 20 training simulations with variations (0-200%) in four emission sectors, which include traffic in Delhi (TRA, including road dust), domestic in Delhi (DOM), power and industry in Delhi (OTH) and total emissions in the NCR region but outside Delhi (NCR). The emulation can reproduce the WRF-Chem results of $PM_{2.5}$ and O_3 (R2=0.99) with much greater computational efficiency. We then perform global sensitivity analysis based on 10,000 iterations of the emulator and identify TRA and NCR as the two major sectors contributing to $PM_{2.5}$ and O_3. Furthermore, we perform 120,000 emulator runs and generate sector-wise response surfaces to formulate optimal mitigation strategy.

Result

Our results (Fig. 1) caution that while control of TRA alone (e.g., by 50%) could lead to a ~25% increase of O3 during the pre-monsoon season, although achieve a ~20% reduction of PM2.5 in Delhi. Joint control with NCR region is suggested to further reduce PM2.5 whilst minimizing the O3 risk. A short-term solution in Delhi alone would be control of DOM, which moderately reduces PM2.5 and avoids O3 increase.

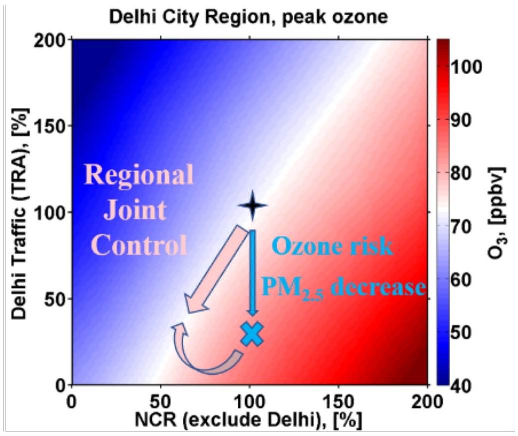

Figure 1. Mitigation strategy for Delhi air quality.

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