Turbulent mixing and generation of short lived climate forcers from an Asian Mega City: The Soot and Black Carbon Conundrum

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2Tamil Nadu Pollution Control Board (TNPCB)- TN, India
3ICAS, School of Earth and Environment, University of Leeds, UK
4Mechanical Engineering, Saintgits College of Engineering- Kerala, India
Outline

- Overview
- Why are Soot and Black Carbon particles termed “short lived climate forcers”?
- SLCF from *Indian Slums* and *Vehicular Traffic*
- Linking fruits of University Research to Operational models
- Solutions
Overview - Indian cities dominate world air pollution list

Eight-Fold Levitation of Air Pollution across City during Weekend!

Cases of respiratory problems increasing in Chennai due to rising pollution levels.

"Thou knowst all, I cannot see, 
I trust I shall not live in vain"

– Oscar Wilde
What are climate forcers?
Black carbon or soot as a climate forcer...

- Soot particles are essentially elemental carbon particles with some amount of organic compounds adsorbed over them.

- Unlike carbon-dioxide (which would linger in our atmosphere for ages) soot remains in the air *for just a few weeks* – its short life span lends it the name ‘Short-lived Climate Forcer’ (SLCF).

- They are ephemeral and have insignificant falling speeds due to their light weight.

- They finally settle down under the effect of gravity or are washed away.
Soot and Black Carbon affecting Climate- Studies conducted in India

• Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX)

• Indian Ocean Experiment (INDOEX)

Main Findings:

1. Plumes of sulphates, *smoke particles*, and other anthropogenic aerosols blowing over the Indian Ocean was blocking sunlight and promoting cloud formation.

2. The amount of sunlight reaching the Earth's surface was reduced by 10%.

Atmospheric circulations associated with the ISM help in the formation of a second layer of black carbon in the upper atmosphere, which generates an upper atmospheric heating of 2 K/day.  

Rahul et al. (2014)- *Scientific Reports*
Aerosol Particle Characterisation Over Chennai

- Why is this difficult to model?
- Why is the problem so intractable?

“Current models used by Central Pollution Control Board (CPCB) under-predict concentrations by over 50-60%”

Causes of under-prediction

1. Residual Pollution not accounted for!
3. Aerosol Chemistry not incorporated into the pollution models.

Identifying the sources driving observed PM$_{2.5}$ temporal variability over Halifax, Nova Scotia, during BORTAS-B

M. D. Gibson$^1$, J. R. Pierce$^2$, D. Waugh$^3$, J. S. Kuchta$^4$, L. Chisholm$^5$, T. J. Duck$^6$, J. T. Hopper$^7$, S. Beauchamp$^8$, G. H. King$^9$, J. E. Franklin$^{10}$, W. R. Leatich$^{11}$, A. J. Wheeler$^{12}$, Z. Li$^{13}$, G. A. Gagnon$^{14}$, and P. J. Palmer$^{15}$

1 Department of Process Engineering and Applied Science, Dalhousie University, Halifax, Nova Scotia, Canada
2 Department of Physics and Atmospheric Science, Dalhousie University, Halifax, Nova Scotia, Canada
3 Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, USA
4 Environment Canada, Dartmouth, Nova Scotia, Canada
5 Environment Canada, Toronto, Ontario, Canada
6 College of Environmental Science and Engineering, Ocean University of China, Qingdao, China
7 Department of Civil and Resources Engineering, Dalhousie University, Halifax, Nova Scotia, Canada
8 School of Geosciences, University of Edinburgh, Edinburgh, UK

Poor fit between modelled and observed PM values (Gibson et al. 2013)

Application of WRF Model for Air Quality Modelling and AERMOD – A Survey

Awkash Kumar$^6$, Rashmi S. Patil$^1$, Anil Kumar Dilshit$^1$, Rakesh Kumar$^2$

1 Centre for Environmental Science and Engineering, Indian Institute of Technology, Bombay, Mumbai - 400 076, India
2 Council of Scientific and Industrial Research-National Environmental Engineering Research Institute Mumbai Zone, Mumbai - 400 076, India

Under prediction by over 50 % (Kesarkar et al. 2007)
Addressing the Problem

Our Recent research in VIT points to following course of action:

- Address why standard Air Quality models imported directly from the West are not applicable without amendment.

Preferred and Recommended Model

The Key is to quantifying **Residual Pollution**!

-Pollution Pall in Delhi

-The Times of India
What is Residual Pollution?

*Left over pollution from a previous visit of the plume (transient sources)/transported from other affected areas/pall left behind due to changing wind direction.*

First pointed out by Picardo and Ghosh 2011 - *Air Pollution New Developments*

\[ v_d = r_t^{-1} = (r_a + r_b + r_c)^{-1} \text{ (cm s}^{-1}) \]  
\[ C_g(t) = C_{g0} \exp \left( -\frac{v_d t}{H_{mix}} \right) \]

A detailed study on *Asia’s Largest Lignite based Power Plant* - Neyveli Lignite Corporation (NLC) located in the Cuddalore district of Tamil Nadu in South India conducted by Picardo and Ghosh.
Wind directions over Chennai - October 2011
6 am to 8 am
12 noon to 2 pm
2 pm to 4 pm
4 pm to 6pm
6 pm to 8 pm

- One observes changing wind directions throughout the day.
- So Residual Pollution effects will be felt over time slots after the morning and evening cooking times.
Main Sources of Residual Pollution

- Smoking Auto rickshaws
- Outdated Vehicles- HCV and LCV
- Industrial Stacks
- Traditional cooking methods
Study zone- Road link and Slums
# Treatment of Transient Emissions

<table>
<thead>
<tr>
<th>Month</th>
<th>Observed Value in Vallalar Nagar TNPCB Monitoring Station in Northern Chennai 8 hrs Average PM$_{10}$ concentration in $\mu$gm$^{-3}$</th>
<th>AERMOD Model Results for Slum Emissions over North Chennai 8 hrs Average PM$_{10}$ concentration in $\mu$gm$^{-3}$</th>
<th>AERMOD Model Results for traffic Emissions over North Chennai 8 hrs Average PM$_{10}$ concentration in $\mu$gm$^{-3}$</th>
<th>Prescribed standards by CPCB for 8 hrs Average PM$_{10}$ concentration in $\mu$gm$^{-3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb-11</td>
<td>151</td>
<td>135.25-166.35</td>
<td>51.19-60.18</td>
<td>100</td>
</tr>
<tr>
<td>May-11</td>
<td>133</td>
<td>100.01-114.29</td>
<td>15.64-20.98</td>
<td>100</td>
</tr>
<tr>
<td>Aug-11</td>
<td>272</td>
<td>170.33-198.70</td>
<td>43.59-58.58</td>
<td>100</td>
</tr>
<tr>
<td>Nov-11</td>
<td>217</td>
<td>163.57-190.69</td>
<td>58.39-78.79</td>
<td>100</td>
</tr>
</tbody>
</table>

1. Even keeping slum emissions on for an entire month continuously- the numbers do not add up.

2. In reality, slum emissions peak only twice a day (Modelling studies have treated them as continuous sources)- proper treatment of transient sources necessary.
Modelling PM10 at Receptor sites

Marked contours refer to traffic pollution.
Morning slum pollution concentrations recede at the receptor.

Increase in traffic pollution concentrations at the receptor.

Marked contours refer to traffic pollution.
Morning slum pollution concentrations recede at the receptor.

Further increase in traffic pollution concentrations at the receptor.

Marked contours refer to traffic pollution.
Morning slum pollution concentrations recede at the receptor.

Increase in traffic pollution concentrations at the receptor.

Marked contours refer to traffic pollution.
Marked contours refer to traffic pollution.
Marked contours refer to traffic pollution.
Night-time slum pollution concentrations add up to the morning residual concentrations at the receptor.

Increase in traffic pollution concentrations at the receptor. *Marked contours refer to traffic pollution*
Modelled PM10 at receptor- **Kilpauk Monitoring Station Chennai**

Continued Research: Coupling University Generated Research Results To Operational Models
Coupling of Observational Research- Translation of *University research* to *Operational models*

- We address turbulence and mixing of climate forcers as they are released
  - Newer paradigms of model development in Indian city context- *cannot use European or American models verbatim.*

Dynamometer connected to the engine.

High Volume Sampler (HVS) Placed near the engine exhaust.
Soot and Black carbon measurement

1. AVL Smoke Meter-415SE

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Details</th>
<th>Particulars</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equipment name</td>
<td>AVL Smoke Meter-415SE</td>
</tr>
<tr>
<td>2</td>
<td>Measurement Range</td>
<td>0 to 10 FSN</td>
</tr>
<tr>
<td>3</td>
<td>Sample Flow rate</td>
<td>10 litre per minute</td>
</tr>
<tr>
<td>4</td>
<td>Filter Paper</td>
<td>PTFE Membrane Filter paper</td>
</tr>
</tbody>
</table>

2. High Volume Sampler

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Details</th>
<th>Particulars</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equipment name</td>
<td>Particulate Sampler (Aerovironment- FPS 9000)</td>
</tr>
<tr>
<td>2</td>
<td>Particle Collection Range</td>
<td>Less than 10µm</td>
</tr>
<tr>
<td>3</td>
<td>Flow rate</td>
<td>1.5 litre per minute</td>
</tr>
<tr>
<td>4</td>
<td>Filter Paper</td>
<td>Glass Micro Fibre Filter, Size 20.3 x 25.4 cm</td>
</tr>
</tbody>
</table>
Experiment Configuration and Observations - Soot and Black Carbon Deposition

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Load</td>
<td>25 N-m</td>
</tr>
<tr>
<td>Speed</td>
<td>2250 rpm</td>
</tr>
<tr>
<td>Smoke</td>
<td>11.41 mg.m⁻³</td>
</tr>
<tr>
<td>FSN (Smoke Number)</td>
<td>0.712</td>
</tr>
</tbody>
</table>

**PTFE Membrane filter**

**Glass micro-fibre filter**

**Observations**
1. We observe submicron size- it ensures *low Stokesian settling velocities*.
2. These add to Residual Pollution Loads when there is a change in wind direction.
3. When aged in Sulphur-rich environment, they become CCN.
Purpose of Experimental Analysis

We are trying to attack the problem - It’s only possible if we model turbulent transport and dispersion as these particles are released.

Objectives:

1. To obtain Particle Size Distribution (PSD)- Chennai is home to dysfunctional gasoline/diesel operated vehicles emitting copious amounts of soot and black carbon into the atmosphere.

Results pertain to a single engine. How do the numbers add up for Chennai?
### Statistics of Vehicles plying in Chennai -
**A continuous source**

<table>
<thead>
<tr>
<th>SI. No</th>
<th>Category of Vehicles</th>
<th>$X_i$ (PM 10)</th>
<th>$T_n$ (No. of Veh. /24)</th>
<th>$T$ (Det. Fac.) (0-5)</th>
<th>$L$ (km)</th>
<th>$R_i$</th>
<th>Pollution Load (g km$^{-1}$day$^{-1}$)</th>
<th>Pollution Load (g km$^{-1}$s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Heavy vehicles (Bus, etc.)</td>
<td>0.56</td>
<td>2434.04</td>
<td>1.35</td>
<td>1</td>
<td>1</td>
<td>1840</td>
<td>0.021</td>
</tr>
<tr>
<td>2</td>
<td>Heavy Vehicles (Trucks/Tractors/Goods vehicles)</td>
<td>0.28</td>
<td>4320.42</td>
<td>1.59</td>
<td>1</td>
<td>1</td>
<td>1923</td>
<td>0.022</td>
</tr>
<tr>
<td>3</td>
<td>Light vehicles (Cars/Taxis, etc.)</td>
<td>0.08</td>
<td>3103.40</td>
<td>1.28</td>
<td>1</td>
<td>1</td>
<td>318</td>
<td>0.004</td>
</tr>
<tr>
<td>4</td>
<td>Three wheeler (Tempo, Auto-Rickshaw)</td>
<td>0.05</td>
<td>11014.03</td>
<td>1.7</td>
<td>1</td>
<td>1</td>
<td>936</td>
<td>0.011</td>
</tr>
<tr>
<td>5</td>
<td>Two-wheelers (Motorcycle, Scooter, moped)</td>
<td>0.02</td>
<td>24401.25</td>
<td>1.3</td>
<td>1</td>
<td>1</td>
<td>634</td>
<td>0.007</td>
</tr>
</tbody>
</table>
Sprinklers not a solution!

Anti-smog guns fails CPCB's test to control pollution in Delhi, board declares machine ineffective!

New Delhi: The Delhi government's experiment with anti-smog guns to control pollution has failed the test of Central Pollution Control Board (CPCB), which on Thursday declared the machine ineffective in open areas and on fine particles.
Remedial Measures

- **Green** Facades (On the Air Cleansing Efficiency of an Extended Green Wall: A CFD Analysis of Mechanistic Details of Transport Processes- *Journal of Theoretical Biology* [Joshi and Ghosh 2014])

Green Facade draped with *V. elaeagnifolia*

*How much will settle under gravity and how much will be lifted up by updraft?*

Contours of SO2 concentration on a passage way cross-section at $t = 13$ h  
*Without the facade*

Contours of SO2 concentration on a passage way cross-section at $t = 13$ h  
*With the facade*
Remedial Measures


Strong updrafts lift these particles aloft for cloud processing - formation of CCN.

- Proper treatment of concentrated ionic solution droplets (*Models neglect these effects*).
- Detailed Mass Transfer Processing

Model Improvements strategies:

1. Quantifying how Residual Pollution is brought to cloud bases through strong updrafts.
2. How cities pollution help age the particle to form partially soluble sites.
3. Growth and activation of such particles in Cloud Condensation Nuclei
4. Ascertaining optimal updraft speeds, RH, Temp to promote high auto-conversion rates.
The microstructures of some common aerosols

- **Leaf debris (biomass)**
- **Soot - chains of spherules of 10 nm dia**
- **Sea Salt (SEM image)**
- **Sodium chloride 80 microns**
- **Ammonium sulphate 80 microns**
Aerosol Particles as CCN: Complexities and Challenges

1. Atmospheric aerosol particles- hydrophobic, water-insoluble, possess hydrophilic sites.

2. Some water-soluble component- biomass aerosol internally mixed with sulphate aerosol.

3. Soluble gases- dissolve into a growing solution droplet prior to activation in cloud- this can decrease the critical super-saturation for activation.

4. In-cloud oxidation of SO₂.
The great Indian haze revisited: aerosol distribution effects on microphysical and optical properties of warm clouds over peninsular India

R. Ghanti¹ and S. Ghosh¹,²

Figure 1. Schematic showing the diversity of spatial scales, vortices and particle number concentrations in cloud microphysical calculations. The numbers within brackets refer to radius in microns, number per litre and terminal velocity of droplets in cm s⁻¹, respectively.
Science Questions to be answered

1. What are the regimes when the effect of microscale vortices on cloud droplet growth is important?

2. This research shows that this effect is pervasive ONLY in multi-component aerosol mixtures. (Rap et al. 2009)

3. Multi-component mixtures perturb the Aerosol-CDNC relationships over certain regimes.

4. It remains to be examined quantitatively the further perturbing effect of enhanced settling rates
This problem has historically been reduced to finding the relationship between aerosol number concentration and cloud droplet number concentration. Empirical relationships are often used.
Mixed aerosols perturbs the CDN relationship

(\( \text{CDN} = N_0 (1 - \exp[-AN_a]) \)) with the coefficients \( N_0 \) and \( A \) (375 and \(-0.0025\) (Jones et al. 1994); \( N_a \) being the aerosol number concentration).
Integrating biomass, sulphate and sea-salt aerosol responses into a microphysical chemical parcel model: implications for climate studies

BY S. GHOSH*, M. H. SMITH AND A. RAP

School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK

Table 2. Input aerosol spectral properties.

<table>
<thead>
<tr>
<th>spectral properties</th>
<th>median radius, $\bar{\sigma}$ (nm)</th>
<th>s.d., $\sigma$</th>
<th>density, $\rho$ (kg m$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pure ammonium sulphate</td>
<td>95</td>
<td>1.4</td>
<td>1769</td>
</tr>
<tr>
<td>biomass smoke</td>
<td>120</td>
<td>1.3</td>
<td>1350</td>
</tr>
<tr>
<td>sea salt (film mode)</td>
<td>100</td>
<td>1.9</td>
<td>2165</td>
</tr>
<tr>
<td>sea salt (jet mode)</td>
<td>1000</td>
<td>2.0</td>
<td>2165</td>
</tr>
</tbody>
</table>

Fig. 1. Dry aerosol spectra for (a) AS and BOB (* and + represents the data observed by Jayaraman (2001) and Murugavel et al. (2008) respectively) and (b) Indian Ocean (represents the data observed by Murugavel et al., 2001). There were no observational data points for salt distributions for BOB and IO-wind-speed dependent estimates are shown.
New insights: Interaction of small cloud droplets grown from aerosol particles over the Bay of Bengal with micro-scale vortices in cumulus clouds.

Length scales associated with cyclonic and normal convective activity: Retrieved form MODIS.

Can we expect micro-scale vortices?
How turbulence enhances coalescence of settling particles with applications to rain in clouds

By S. Ghosh¹, J. Dávila², J. C. R. Hunt³, A. Srdic⁵, H. J. S. Fernando⁵ and P. R. Jonas⁶

• From Ghosh et al. (2005), it can be inferred that the small inertial particles with density equal to \( \beta(>1) \) times that of the fluid, are ‘centrifuged’ out of the micro-scale vortices and eddies in turbulence.
• This process enhances the average sedimentation rate \( (V_T) \) of particles lying below a critical radius (~ 20 um) by about 80%.
• Thus, current forecasting models - which assume particle collision in still air – predict significantly lower precipitation rates.
• With this new insight, storm water drainage design can now be modified to accommodate the effect of turbulence enhancements on precipitation rates.
Recent literature on the effect of turbulence on cloud settling rates

1. Falkovich et al. 2002. Acceleration of rain initiation by cloud by cloud turbulent. doi:10.1038/nature00983


Figure 2. Mechanisms of particles falling near vortices: (a) typical trajectories of settling particles A, B, C moving around a vortex with strength $\Gamma$ and radius $R_v$ with increasing fall speed $V_{TO}$. Here, $\Delta l_v$ is the distance between vortices; (b) average settling velocity ratio $V_T/V_{TO}$ versus the particle Froude number $F_p$ and particle radius ratio $a/a_{cr}$;
Figure 3. Collision mechanisms: (a) colliding droplets settling in still air in the absence of vortices with larger and smaller radii \( \tilde{a}, \hat{a} \). Note the vertical collision distance \( l_\infty \); (b) colliding droplets descending near an isolated vortex. Note the curved collision line with length \( l_c \); the large droplet collides with a smaller droplet both released at \( t=0 \), if they start on the curved collision line;
Figure 4. (a) Colliding droplet pairs with radii 20 and 25 μm descending near an isolated vortex with circulation $\Gamma = 1.5 \times 10^{-4}$ m$^2$ s$^{-1}$ and radius $R_v = 1.5$ mm calculated from the Dávila & Hunt (2001) theory. Note the absence of collisions. (b) Colliding droplet pairs with radii 5 and 10 μm descending near an isolated vortex with circulation $\Gamma = 1.5 \times 10^{-4}$ m$^2$ s$^{-1}$ and radius $R_v = 1.5$ mm calculated from the Dávila & Hunt (2001) theory. Note the presence of multiple collisions.
Estimation of critical cloud droplet radius where micro-scale vortices impact settling rates

\[ V_{TO} \approx g(\beta - 1) \frac{a^2}{(9\nu/2)}, \quad (2.2) \]
\[ \tau_p = \frac{(2/9)(\beta - 1) a^2}{\nu}, \quad (2.3) \]

From 2.2 and 2.3

\[ \Gamma (R) \sim V_{TO}^2 \tau_p \sim \frac{a^6 g^2 (\beta - 1)^3}{(9/2)^3 \nu^3}. \quad (3.2) \]

At the micro-scales where \( R = R_k \), the circulation

\[ \Gamma = \Gamma_k \sim U_k R_k \sim (\epsilon \nu)^{1/4} (\nu^3/\epsilon)^{1/4} \sim \nu. \quad (3.3) \]

\[ a_{cr} \sim \nu^{2/3} g^{-1/3} (\beta - 1)^{-1/2}. \quad (3.5) \]

In air \( a_{cr} \sim 20 \mu m \), and in water, for \( \beta = 2 \), \( a_{cr} \sim 100 \mu m \).

IMP: This critical radius is independent of the turbulent kinetic energy dissipation rate
Estimating new fall velocity: effect of micro-scale vortices

- Droplets in cloud turbulence

\[ P_{ij} = E(\hat{a}_i, \hat{a}_j)\pi(\hat{a}_i + \hat{a}_j)^2(V_{Ti} - V_{Tj}). \]

<table>
<thead>
<tr>
<th>Enhanced Velocities (ms(^{-1}))</th>
<th>Stokesian Velocities (ms(^{-1}))</th>
<th>Radii (um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.14E+00</td>
<td>3.40E-01</td>
<td>5.28E+00</td>
</tr>
<tr>
<td>2.70E+00</td>
<td>4.27E-01</td>
<td>5.93E+00</td>
</tr>
<tr>
<td>3.40E+00</td>
<td>5.37E-01</td>
<td>6.66E+00</td>
</tr>
<tr>
<td>4.28E+00</td>
<td>6.76E-01</td>
<td>7.47E+00</td>
</tr>
<tr>
<td>5.40E+00</td>
<td>8.51E-01</td>
<td>8.39E+00</td>
</tr>
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<td>6.80E+00</td>
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<td>2.11E+01</td>
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<td>4.32E+01</td>
<td>6.55E+00</td>
<td>2.37E+01</td>
</tr>
<tr>
<td>5.44E+01</td>
<td>8.15E+00</td>
<td>2.66E+01</td>
</tr>
</tbody>
</table>

Time evolution of liquid-water mass for Phailin spectra (modal radius 15 um) [5 minutes difference]
Time evolution of liquid-water mass for Normal day aerosol spectra with high convective activity (modal radius 12 um) [10 minutes difference]
Real Time Applications: Streamlining Cloud Seeding: VIT-JNTU Collaboration

Variation of Volume of Seeded and Unseeded clouds on August 11, 2008

Geographical area of the country: 322 M. ha, about 60% of total area
- USSR: 10%
- U.K: 29%
- U.S: 20%
- Pak: 26%
- China: 10%

Cultivable Area: 188 M. ha

Cropped land at present: 144 M. ha

Present area under irrigation: 78 M. ha

Likely irrigated area by the year 2025 to meet food production: 100 M. ha

Total utilizable Water Resources: 114 M. ha.m

Present utilisation: 55 M. ha.m

Water required by the year 2025: 105 M. ha.m

<table>
<thead>
<tr>
<th>S.No</th>
<th>Particles Size (Microns)</th>
<th>% of Total</th>
<th>Particles Size (Microns)</th>
<th>% of Total</th>
<th>Particles Size (Microns)</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2</td>
<td>41.60%</td>
<td>0.1</td>
<td>41.60%</td>
<td>0.8</td>
<td>25.50%</td>
</tr>
<tr>
<td>2</td>
<td>0.4</td>
<td>33.30%</td>
<td>0.3</td>
<td>33.30%</td>
<td>1</td>
<td>12.50%</td>
</tr>
<tr>
<td>3</td>
<td>0.6</td>
<td>16.60%</td>
<td>0.5</td>
<td>16.60%</td>
<td>0.2</td>
<td>14.60%</td>
</tr>
<tr>
<td>4</td>
<td>0.8</td>
<td>8.30%</td>
<td>0.7</td>
<td>8.30%</td>
<td>0.4</td>
<td>10.20%</td>
</tr>
</tbody>
</table>

Variation of Volume of Seeded and Unseeded clouds on August 11, 2008

CaCl
Seeding of Target Cloud 136/147
The 2008 seeding operations undertaken by JNTU, Hyderabad indeed augmented precipitation over rain shadow districts of the region – but the success rate was limited to 18% incurring costs to the tune of several hundred thousand US dollars. It is shown for the first time ever, how microphysical process modelling prior to the launch of seeding operations help in a better release strategy. The study recommends that flares be released a few tens of meters below the cloud base, allowing them to disperse and dilute, and prior to them being lifted up by prevailing updrafts.
Improved mass accommodation calculations: implications

• Ghosh et al. (2018)
Fig. 1 Schematic representation of the processes involved. In stage 1, dry aerosol spectral data and updraft speeds are fed to the CPM. In stage 2, aerosol particles grow into activated cloud droplets through a detailed configuration of the CPM using dynamical variables from a WRF-ARW run. In stage 3, the cloud droplets grow into rain droplets through a stochastic coalescence model. α is the mass accommodation coefficient.
Fig. 7 Cloud base heights obtained from supersaturation profiles using the CPM. Standard diffusivity values (labelled P & K (Pruppacher and Klett 1998)) and for $\alpha = 1$ yields a cloud base height of 1226 m. Using the corrected values for $D^*_v$ and $\alpha$ yields a cloud base at 1161 m for all three modes.

Fig. 13 Uptake rates (s$^{-1}$) for water vapor diffusing into cloud hydrometeors—liquid droplets and ice crystals for Chapala's cloud structure. Rate constants in ice crystals for $r = 30$ μm and $\alpha_{ref} = 0.013$.
Concluding Remarks

1. Particle retention times for residual pollution are long- of the order of 12 hours. A slow ascent rate of an updraft eddy will ensure sufficient diffusional mass transport.

2. Green facades are known to work well in cleansing Residual Pollution. ([Ghosh and Joshi 2014](#))

3. Vernonia *elaeagnifolia*—easy to maintain—adds aesthetic appeal.

4. Since the median size is biased towards the sub-micron range, anti smog guns failed. Artificial injection of liquid droplets through carefully controlled experiments can bias the growth to exceed 20 um radii. This will foster rapid onset of stochastic coalescence ([Proc. Royal Met. Soc. Ghosh](#))
Thank You