An integrated modeled and measurement-based assessment of particle number concentrations from a major US airport

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Particle number concentration (PNC) at downwind of airport

PNC at LAX Airport

- Measurements show particle number concentration (PNC) increases 4 to 5 fold at 8-10 km downwind of LAX\(^1\) and 1.33 to 2.33 fold at 4-5 km downwind of BOS\(^2\) airport.

- Dispersion modeling of PNC will be helpful to better quantify LTO attributable PNC increase at nearby spatial locations.

- Dispersion modeling with multi-component chemistry and aerosol microphysics can give aircraft attributable PNC at high resolution spatial locations.

Motivation and objective

- Estimation of aircraft’s landing and take-off (LTO) attributable PNC near surrounding areas of airport is important for health effect study.

- It is important to know how PNC changes by emission, nucleation, coagulation, deposition and advection by aircraft’s LTO emission.

Objective: Estimation of aircraft’s LTO attributable PNC at high resolution spatial locations surrounding Boston Logan International Airport (BOS) by the Second-order Closure Integrated Puff model with chemistry (SCICHEM³) dispersion model by:

- Single component simulation without chemistry and aerosol microphysics
- Multi-component simulation with chemistry and aerosol microphysics

Then compare results with Boston University's PNC measurements.

Methods: SCICHEM dispersion model

- Model domain:
  - Ymin=300 km, Ymax=420 km, Xmin=4619 km, Xmax=4785 km (UTM)
- Emissions: 959 segmented area emission sources at the ground
- Simulation day and duration: July 13, 2017, 6 hours
Modeling domain and emission sources

- **Receptor Domain-1**: 200m x 200m
- **Receptor Domain-2**: 2km x 2km
- **BU measurement stations**
- **Emission segment points in LTO path**
- **Boston airport**

[Map with markers and links]

https://mapmakerapp.com

http://www.gpsvisualizer.com
Boston University Measurement Set-up

- 6 Monitor sites along the runway 4R/4L
- Measured High-quality UFP at 1 Hertz
- Measurement period: April- September 2017
- Measured at three sites simultaneously for one week at a time, rotating among six locations

### PNC (#/cc) distribution at monitor sites at 6 stations

<table>
<thead>
<tr>
<th>Sample Size (days)</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
<th>Site 4</th>
<th>Site 5</th>
<th>Site 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>67</td>
<td>71</td>
<td>57</td>
<td>61</td>
<td>57</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>2nd Floor</td>
<td>Ground</td>
<td>2nd Floor</td>
<td>Ground</td>
<td>Ground</td>
<td>Ground</td>
</tr>
<tr>
<td>Nearest Runway</td>
<td>4R</td>
<td>4R</td>
<td>4R</td>
<td>4R</td>
<td>4R</td>
<td>4R</td>
</tr>
<tr>
<td>Distance to Runway (km)</td>
<td>4.0</td>
<td>4.9</td>
<td>10.8</td>
<td>6.7</td>
<td>8.2</td>
<td>16.6</td>
</tr>
<tr>
<td>0.1st PCTL</td>
<td>800</td>
<td>1,100</td>
<td>1,600</td>
<td>2,500</td>
<td>2,000</td>
<td>1,800</td>
</tr>
<tr>
<td>1st PCTL</td>
<td>1,000</td>
<td>2,900</td>
<td>2,500</td>
<td>5,100</td>
<td>2,900</td>
<td>2,500</td>
</tr>
<tr>
<td>5th PCTL</td>
<td>4,300</td>
<td>5,800</td>
<td>4,300</td>
<td>8,200</td>
<td>5,700</td>
<td>4,300</td>
</tr>
<tr>
<td>50th PCTL</td>
<td>14,100</td>
<td>16,600</td>
<td>11,600</td>
<td>20,600</td>
<td>17,100</td>
<td>12,000</td>
</tr>
<tr>
<td>95th PCTL</td>
<td>55,600</td>
<td>63,000</td>
<td>28,000</td>
<td>67,900</td>
<td>47,100</td>
<td>31,400</td>
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<tr>
<td>99th PCTL</td>
<td>116,800</td>
<td>119,200</td>
<td>47,400</td>
<td>103,200</td>
<td>70,700</td>
<td>50,500</td>
</tr>
<tr>
<td>99.9th PCTL</td>
<td>180,200</td>
<td>206,600</td>
<td>87,500</td>
<td>150,800</td>
<td>96,500</td>
<td>95,800</td>
</tr>
</tbody>
</table>
Details of a Single Emission Segment

EDMS area emission segment details:
Segment name = B04R02AC
Release height (m) = 877.45
Length of X side of the area (m) = 20.0
Length of Y side of the area (m) = 800.00
Angle = 19.67 (clockwise from North)
Emission of CO at 01 EST (g/m²-s) = 1.04E-11

Equivalent point emission details:
Segment name = B04R02AC
Release height (m) = 877.45
Equivalent Dia (m) = 71.3 (surface area equiv.)
Emission of CO at 01 EST (g/s) = 1.67e-007

- Area emission has advantages as it does not need stack dia, temp. and velocity
- Area emission has been used in single-component run, and point emission will also be explored in multi-component run
Wind profile on simulation day:
July 13, 2017

North-easterly wind will bring plume to BU measurement stations.
Hence, simulation day is chosen July 13, 2017 because it has North-easterly and Northerly wind over BOS airport.
Emission of CO from Boston Airport at 6 hours

- Emissions were from EDMS’s Feb 19, 2015 emission data which was time shifted to simulation day July 13, 2017.
- Each dot represents an area-emission-source segment.
- Emissions start increasing 0600 EST.
- Aircraft’s LTO attributable CO can be seen on the map.
- Plume travels along the wind (North-easterly and Northerly wind)
- The simulation is computationally demanding: 6 hours computation time for 1 hour simulation
- Number of puffs increases ~140k to 386k in 6 hours

Neglecting nucleation and coagulation, PNC of the $i^{th}$ mode can be approximated using the volume (mass) concentration of aerosol species in the post process by this equation (Binkowski 2003):

$$N_i = \frac{M_{3,i}}{D_{g,i}^3 \exp(\frac{g}{2} \ln^2 \sigma_{g,i})} \quad (1)$$

Where $N_i =$ Particle number concentration of $i^{th}$ mode (#/cm$^3$)

$M_{3,i} =$ 3rd Aerosol moment (Total volume concentration) of $i^{th}$ mode (cm$^3$/cm$^3$)

$D_{g,i} =$ Geometric mean diameter of $i^{th}$ mode (cm)

$\sigma_{g,i} =$ Geometric standard deviation of $i^{th}$ mode

$D_{g,i}$ and $\sigma_{g,i}$ will be used in Eq. 1 based on the near source observation (Whitby 1978)$^5$

<table>
<thead>
<tr>
<th></th>
<th>Aitken</th>
<th>Accumulation</th>
<th>Coarse</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{g,i} (\mu m)$</td>
<td>0.03</td>
<td>0.3</td>
<td>6</td>
</tr>
<tr>
<td>$\sigma_{g,i}$</td>
<td>1.7</td>
<td>2</td>
<td>2.2</td>
</tr>
</tbody>
</table>

SCICHEM’s single component run gives $M_{3,i}$ which will give $N_i$


Simulated Airport ground emission attributable PNC at 6 hours without chemistry

PNC_I = Aitken mode PNC (ASO4_I + AORG_I + AEC_I which is 91.8% of total PM emission

Domain maximum PNC in plume were ~1400 #/cm³ at 0300 EST

Inclusion of nucleation will increase the number
Multicomponent-run: Modeling PNC in SCICHEM: by detailed moment model

- Particles are assumed to follow a log-normal size distribution having 3 modes:
  - Aitken mode: particle diameter from 0 to 0.1 μm
  - Accumulation mode: particle diameter from 0.1 μm to 2.5 μm
  - Coarse mode: particle diameter greater than 2.5 μm

- Moment-based algorithm of Binkowski and Roselle (2003) will be used in SCICHEM model to estimate PNC

- SCICHEM will track the 0th (number concentration), 2nd (surface area concentration), and 3rd (volume concentration) moments of all three distinct population modes (Aitken, Accumulation and Coarse modes) 4.

Summary

- Aircraft’s LTO attributable Particle number concentration (PNC) for Aitken model particles and CO have been simulated in a 2 km x 2 km domain around BOS airport by SCICHEM model.

- PNC and CO concentrations increases along the plume trajectory

- Most pollutant comes from the terminal at the ground

- Airport ground emission attributable maximum Aitken mode PNC were found to be ~1400 #/cm³ during a 6 hour period in night time without chemistry and aerosol microphysics at a grid point in a 2x2km domain towards the wind direction.

Future work

- Estimation of PNC by detailed aerosol microphysics (nucleation and coagulation) and multi-component chemistry
- Compare source-based dispersion model results with BU's regression model that will be developed for PNC at BU for BOS airport
- Improve point source treatment
Acknowledgements

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Thank You
Reference