Assessing Air Quality Impacts of Airport Emissions from Local to Regional Scales

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Outline

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- Context of Health Risk due to Aircraft Emissions compared to other Sectors
- Aircraft Emissions – Spatio-temporal Profiles
- Air Quality Studies
  - Regional-Scale Studies at Select Airports
    - Atlanta, Chicago and Providence
  - Future Year Assessment
    - US-wide impacts
  - Airport-Specific Impacts using Sensitivity Modeling
    - NAS-wide vs. Top 99 airports in the U.S.
    - Illustration for NYC Top 3 airports
  - UFP due to Aircraft
  - Local-Scale Dispersion Studies
    - Los Angeles International Source Apportionment Study
- Conclusion

Health Risks Due to Air Pollution

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Risk Factors by Burden of Disease

Ranking legend: 1–5, 6–10, 11–15, 16–20, 21–25, 26–30, 31–35, 36–40, >40

Risk factor	Global	High-income Asia Pacific	Western Europe	Australasia	High-income North America	Central Europe	Southern Latin America	Eastern Europe	East Asia	Tropical Latin America	Central Latin America	Southeast Asia	Central Asia	Andean Latin America	North Africa and Middle East	Caribbean	South Asia	Oceania	Southern sub-Saharan Africa	Eastern sub-Saharan Africa	Central sub-Saharan Africa	Western sub-Saharan Africa
High blood pressure	1	1	2	3	3	1	2	2	1	1	4	1	1	2	1	1	3	5	2	5	5	6
Tobacco smoking, including second-hand smoke	2	2	1	2	1	2	3	3	2	4	5	2	2	5	3	3	2	3	5	7	12	10
Household air pollution from solid fuels	3	42	..	..	..	14	23	20	5	18	11	3	12	7	25	8	1	4	7	2	2	2
Diet low in fruits	4	4	7	6	6	5	6	5	3	6	7	4	4	10	6	7	5	9	8	8	11	13
Alcohol use	5	5	6	9	7	4	4	1	8	2	2	6	5	1	18	9	10	7	1	6	10	5
High body-mass index	6	8	3	1	2	3	1	4	9	3	1	9	3	3	2	2	17	2	3	14	18	15
High fasting plasma glucose	7	7	5	5	4	7	5	10	7	5	3	5	7	6	4	4	7	1	6	10	13	11
Childhood underweight	8	39	38	37	39	38	38	38	38	32	23	13	25	18	20	14	4	8	9	1	1	1
Ambient particulate matter pollution	9	9	11	26	14	12	24	14	4	27	19	11	10	24	7	19	6	32	25	16	14	7
Physical inactivity and low physical activity	10	3	4	4	5	6	7	7	10	8	6	8	9	8	5	6	11	6	11	15	15	16

	GBD (2010)		GBD (2015)	
	Risk Ranking	Premature Mortalities	Risk Ranking	Premature Mortalities
Ambient Ozone	39	152K	34	254K
Ambient PM	9	3.2M	5	4.2M

Lim et al, Lancet 2012, Cohen et al Lancet, 2017

Health Risk by Sector in U.S.

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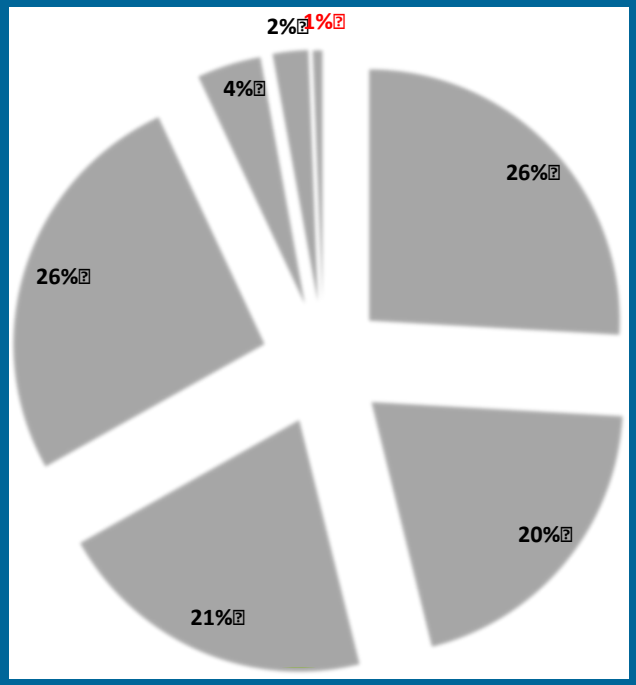
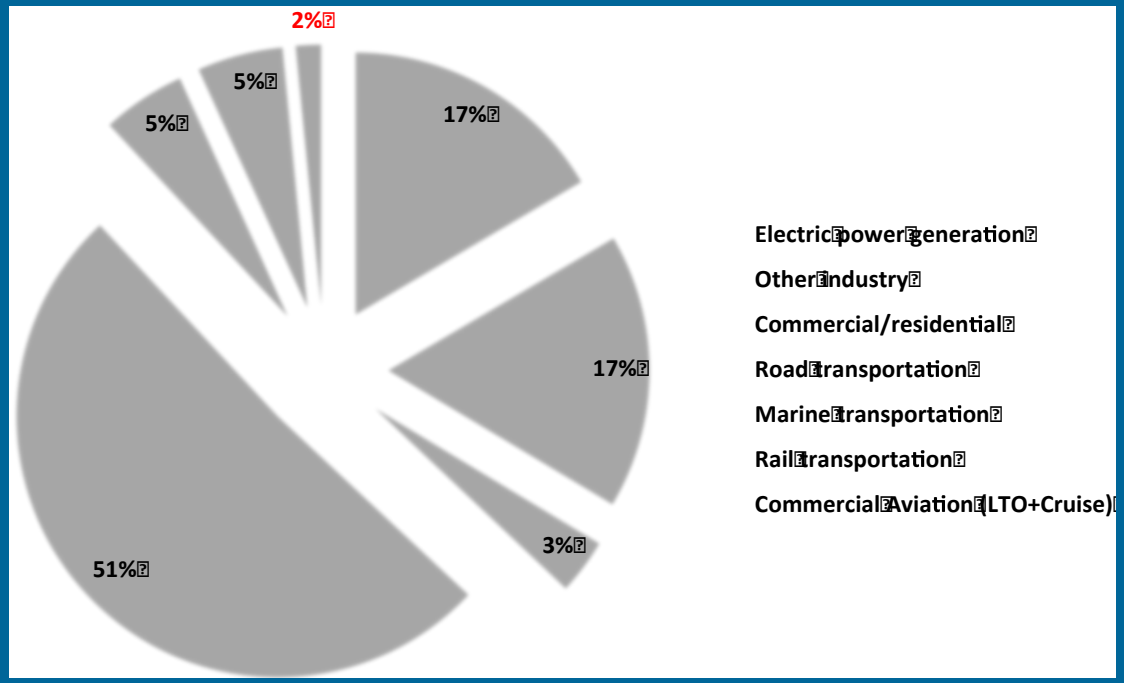
Premature Mortality Counts

$PM_{2.5}$
200K [95% CI 89K – 367K]

O_3
10.1K [95% CI -1.3K – 3.7K]

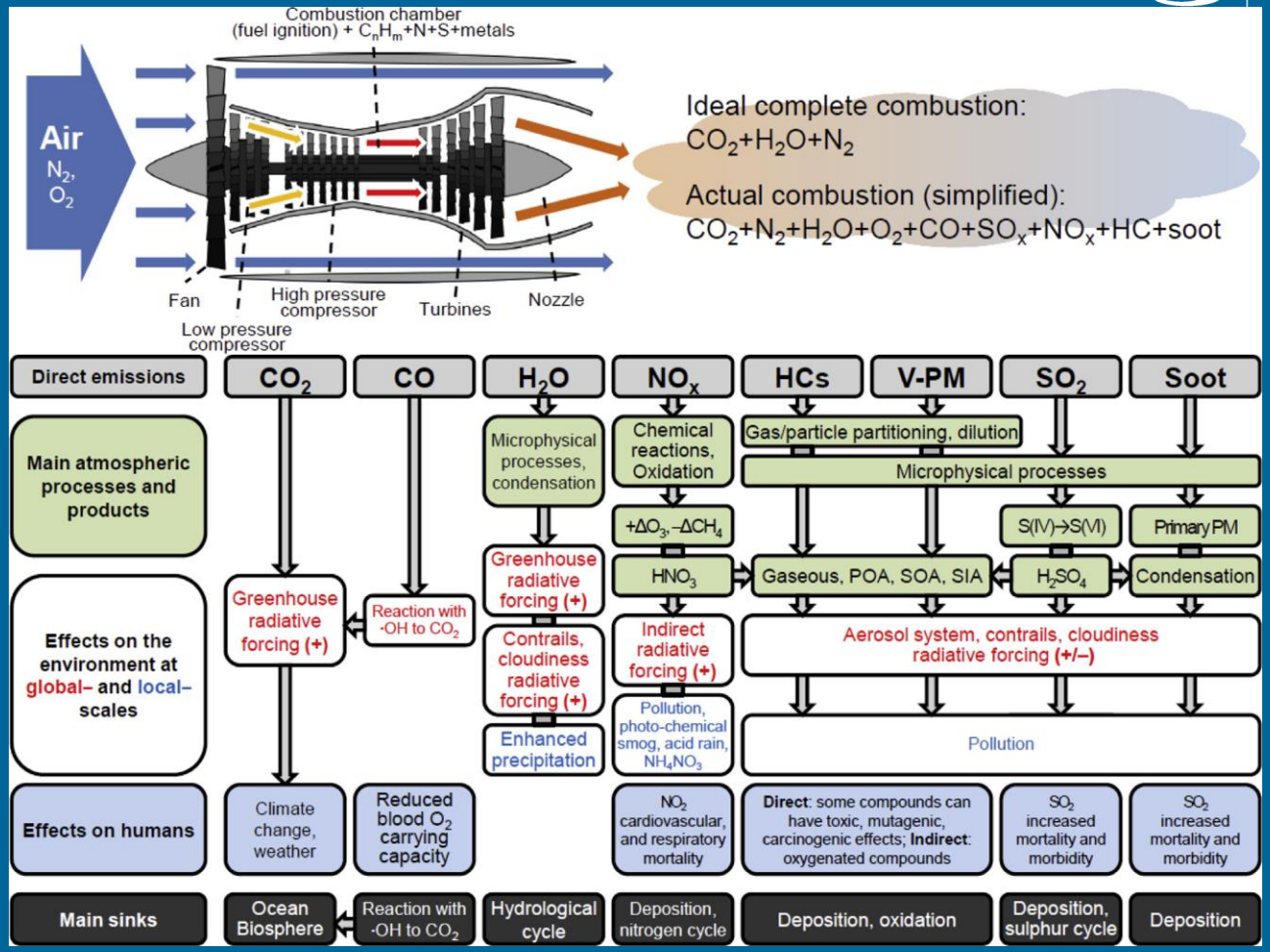




Caiazzo et al, AE 2013
Yim et al, AE 2013

Transportation sectors contribution is ~33% for $PM_{2.5}$ and 63% for O_3
Aircraft contribute about 2% for O_3 and 1% for $PM_{2.5}$ in the U.S.

Aircraft Exhaust

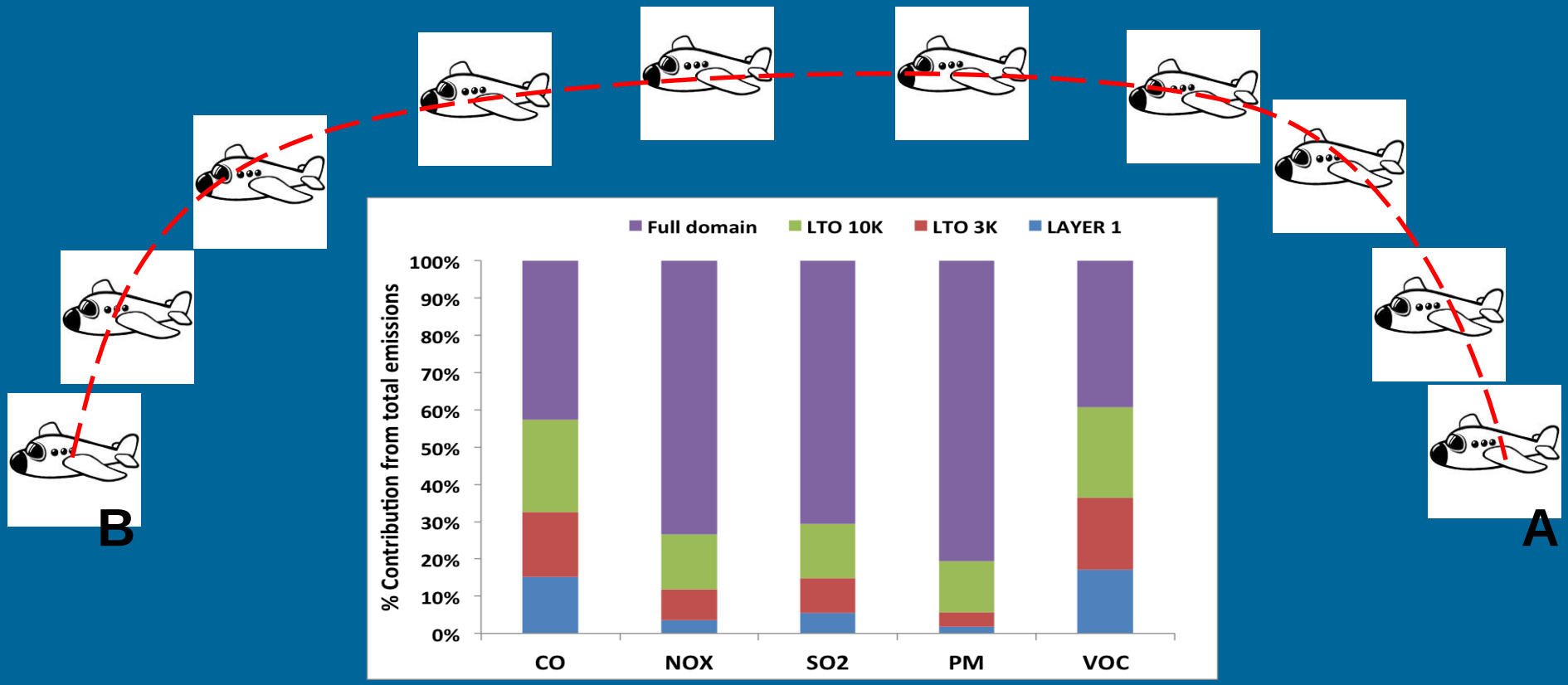


Key Air Pollutants

CO, NO_2, SO_2, O_3, Lead, $PM_{2.5}$, UFP, Air Toxics

Adapted from Masiol et al, 2014

FAA's Emissions Model
EDMS -> AEDT



- Only landing and take-off (below 3000 ft) includes climb out, approach, taxi, and idle
- Estimated from Aviation Environmental Design Tool (AEDT) based on the aircraft locations
- NOx, SO2, VOC, CO + 3 directly emitted components of $PM_{2.5}$

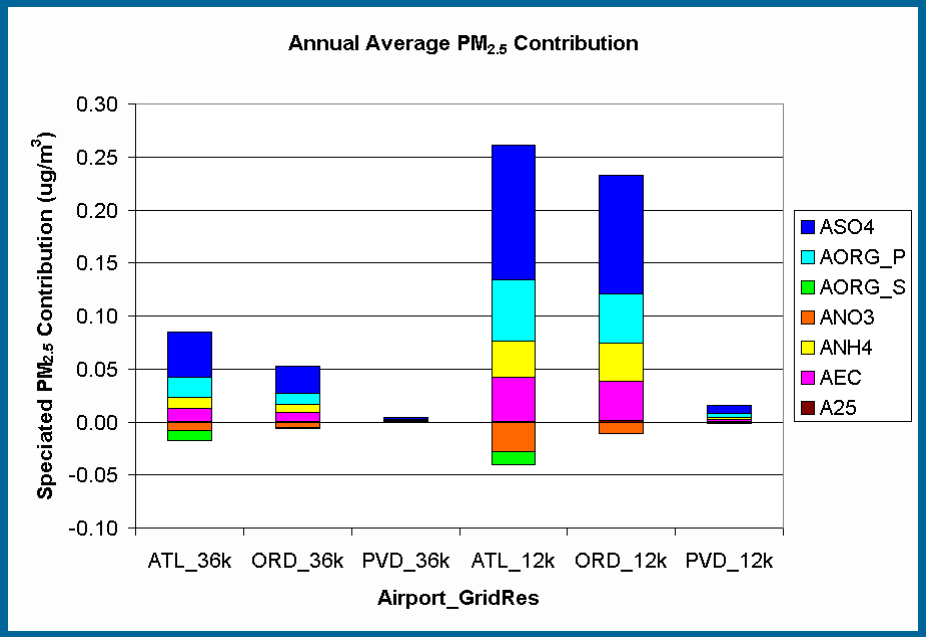
EDMS: Emissions Dispersion Modeling System

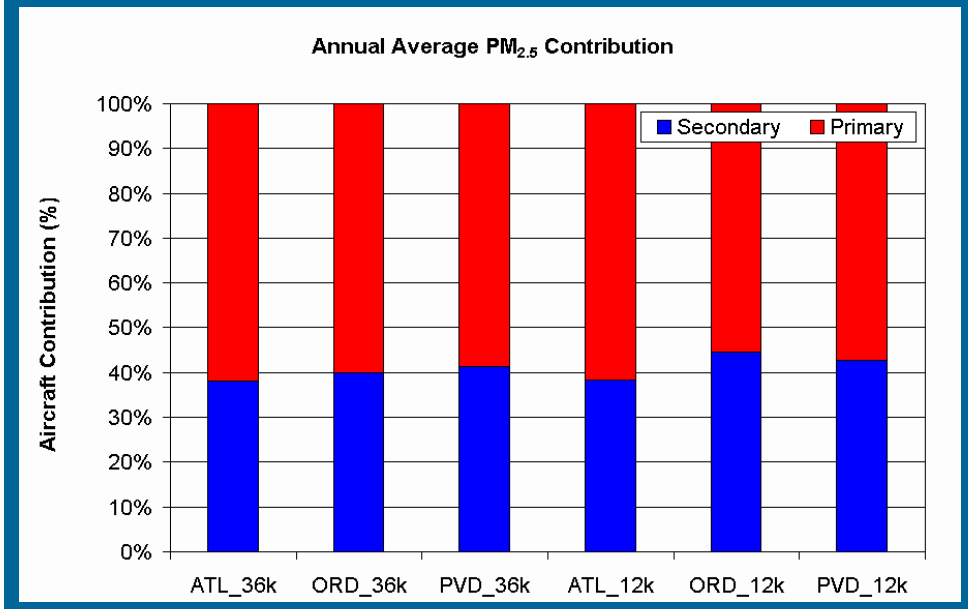
AEDT: Aviation Environmental Design Tool

Wilkerson et al, ACP 2010

Baek et al, 2012

$PM_{2.5}$ formed from LTO emissions at 3 U.S. airports
Atlanta, Chicago, Providence

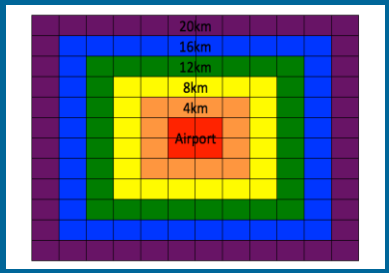


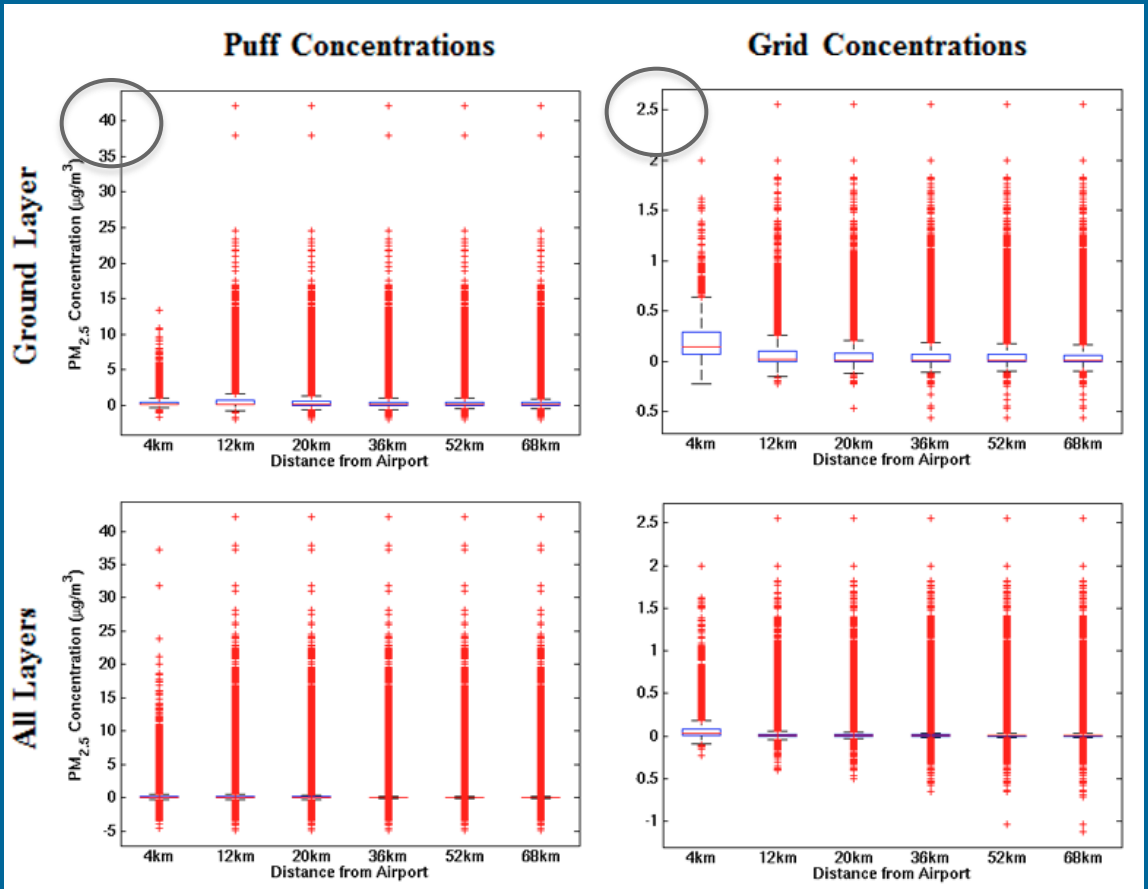


- **Focus on Grid-cell containing airport**
- **Up to 40% of $PM_{2.5}$ is due to secondary contribution**

Arunachalam et al, AE 2011

Hybrid Modeling with CMAQ and SCIPUFF (Atlanta Airport)

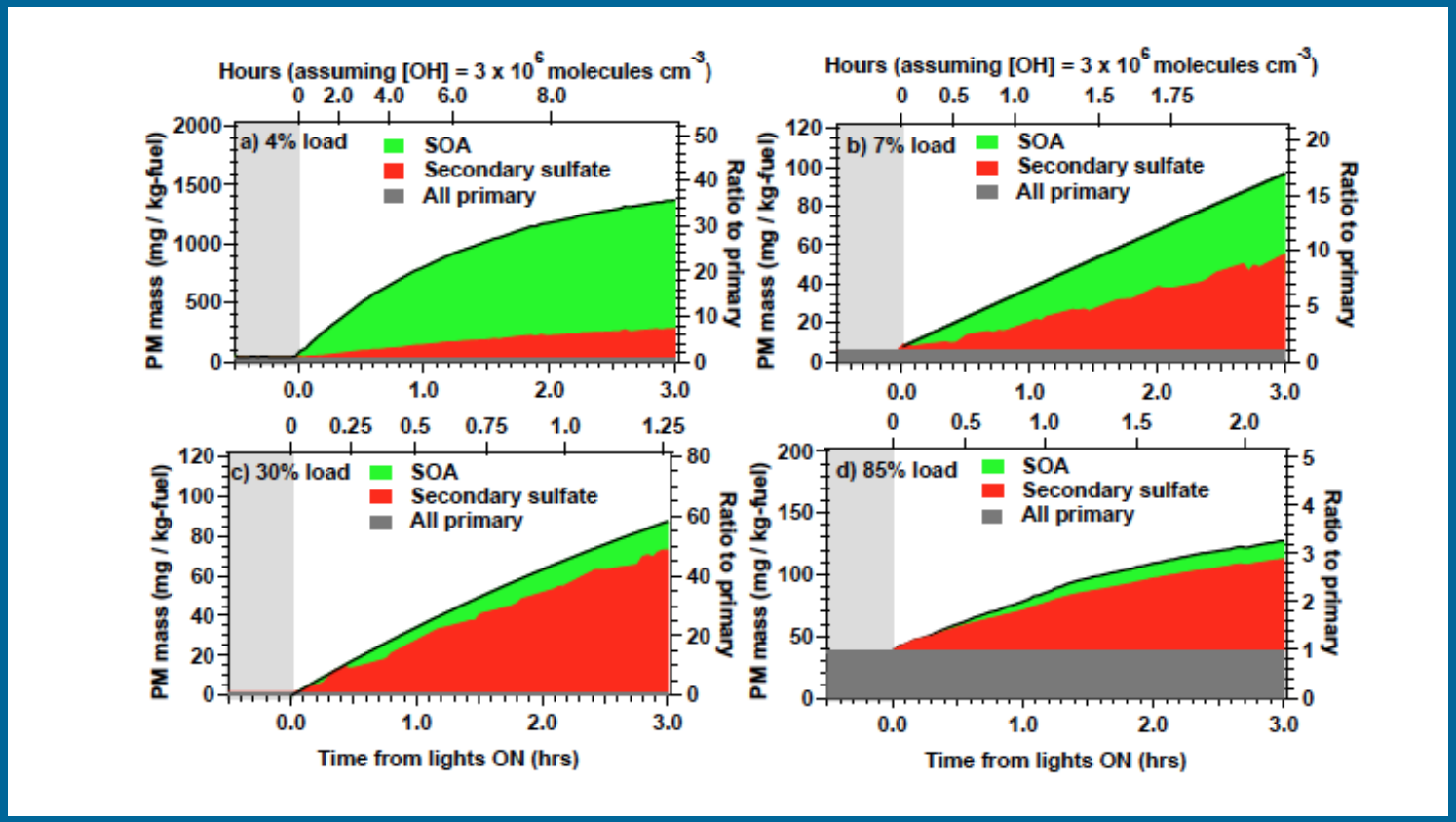




- Maximum puff conc > 10x grid conc, vary between 6.1 – 42.1 μg/m^3
- Use of a subgrid-scale treatment may be less important if one seeks to understand only median impacts, but provides insight in revealing potential max impacts masked by grid-scale modeling

Rissman et al, ACP, 2013

SOA due to Aircraft



- Measured changes in PM mass at different loads (4% idle; 7% taxi, 30% landing and 85% takeoff)
- Traditional SOA model underpredicts total SOA by ~60% at 4% load, and ~40% at 85% load

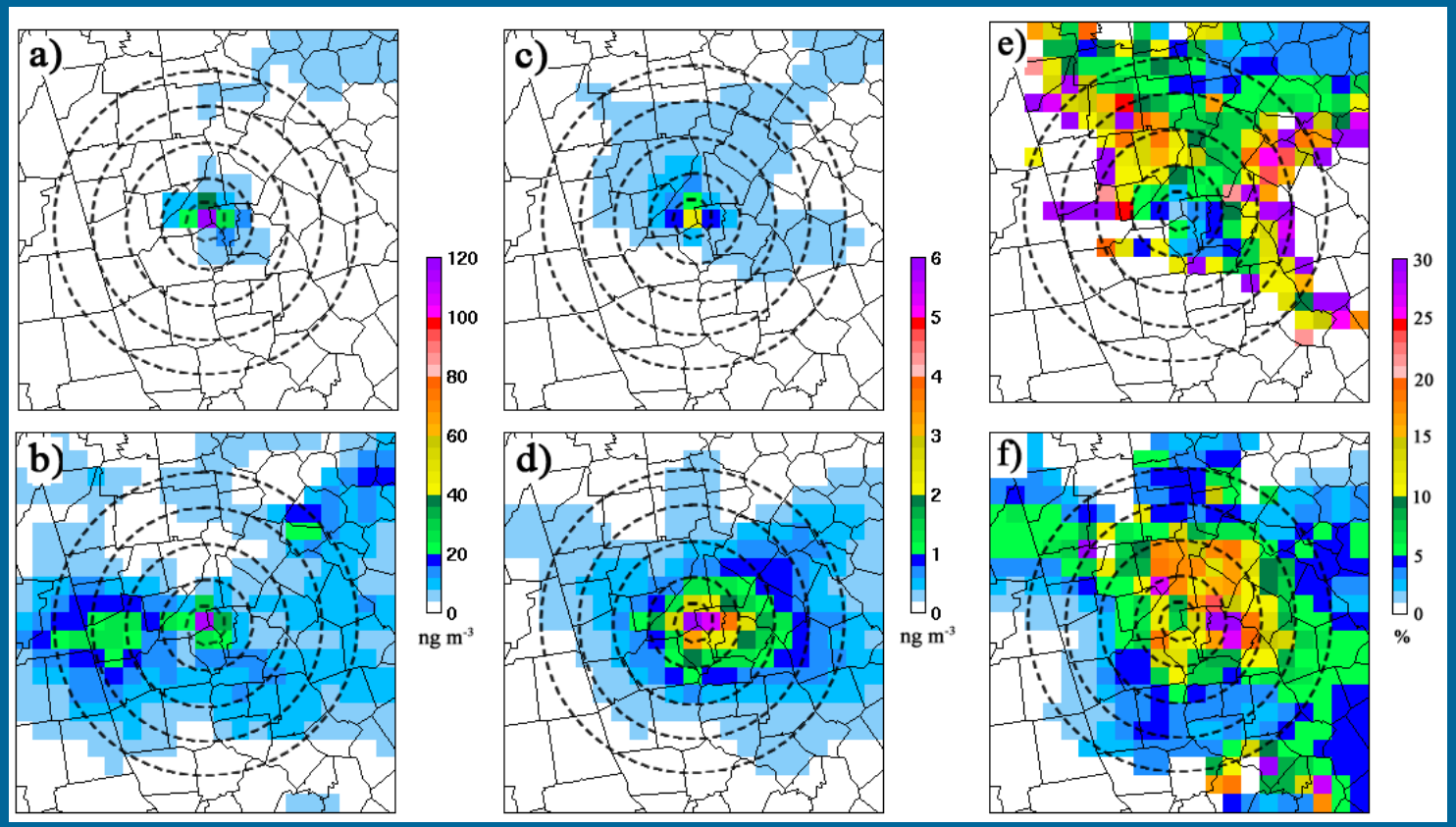
Miracolo et al, ACP 2011

Non-traditional SOA Contributions to $PM_{2.5}$ at ATL

$PM_{2.5}$ NTSOA $NTSOA/PM_{2.5}*100$

Jan

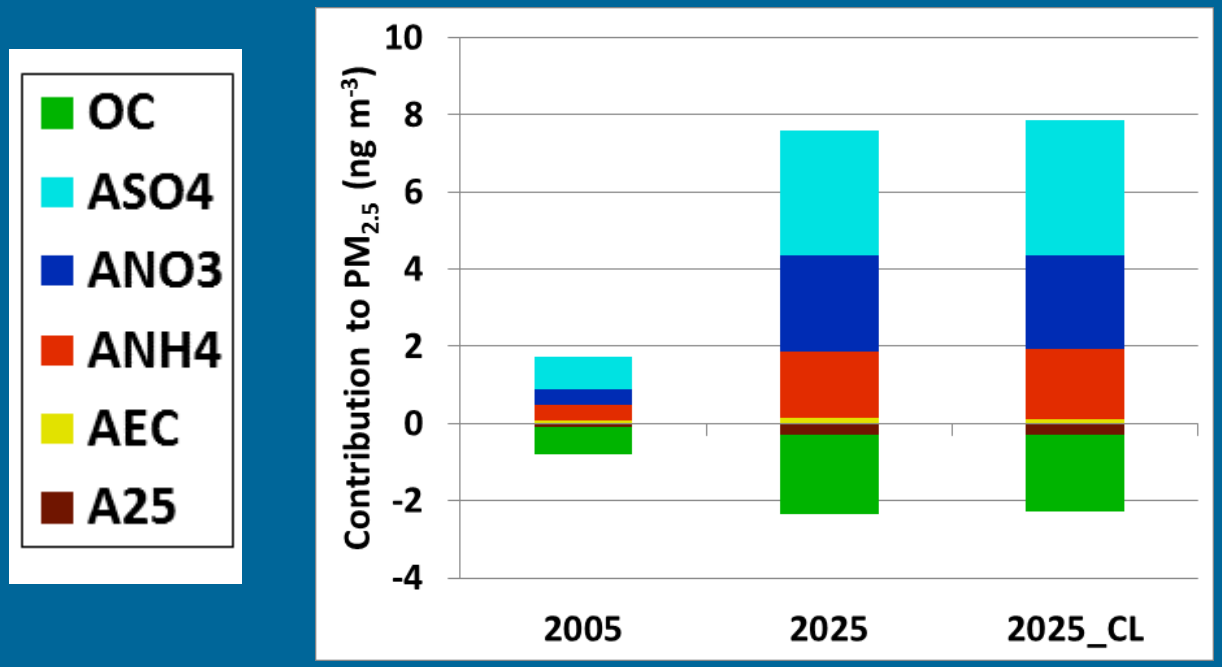
Jul



Woody et al, ACP 2015

- NTSOA formed from oxidation of S/IVOCs, typically not accounted for in AQMs
  - NTSOA contributed 1.7 – 7.4% at ATL; ~6x higher than aircraft TSOA
  - NTSOA comprised up to 30% of aviation-attributable $PM_{2.5}$ downwind of ATL

Aviation attributable $PM_{2.5}$ contributions – Current and Future - U.S. Wide activity



- Future year 2025 $PM_{2.5}$ impacts due to aircraft activity growth is 5.5x that of 2005 (using 2005 climate)
- Most of this growth is due to increase in "Free ammonia" in 2025 (8% ↑ in background NH_3 and 35% ↓ in background NO_x emissions)
- Incorporating change in climate increases this to 5.9x (~7% additional contribution)

Woody et al, AE 2011

Future Year AQ Impacts of Growth in Aviation from 2005 to 2025

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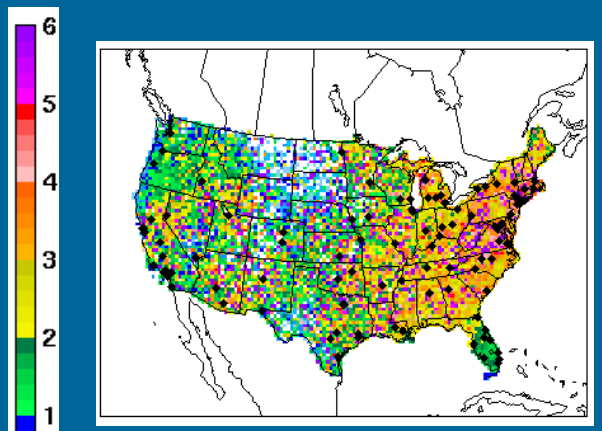
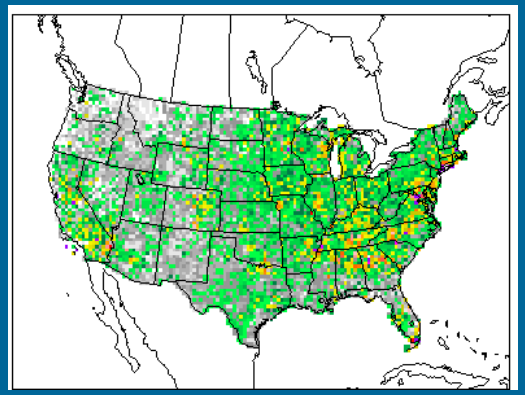
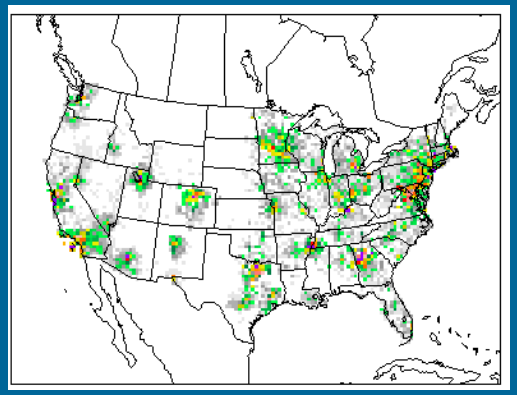


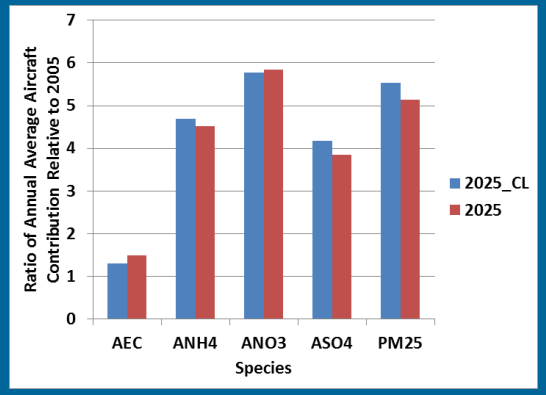
Annual Average $PM_{2.5}$



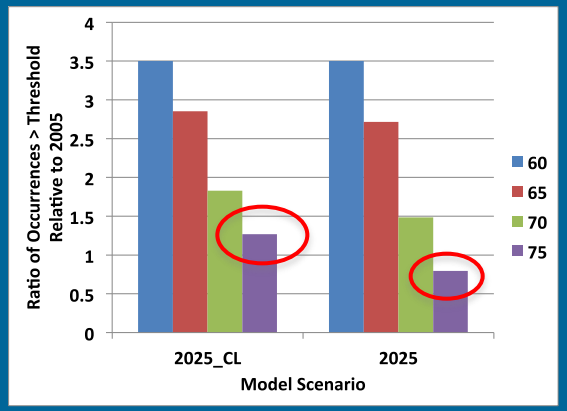
98th Percentile DMax O_3

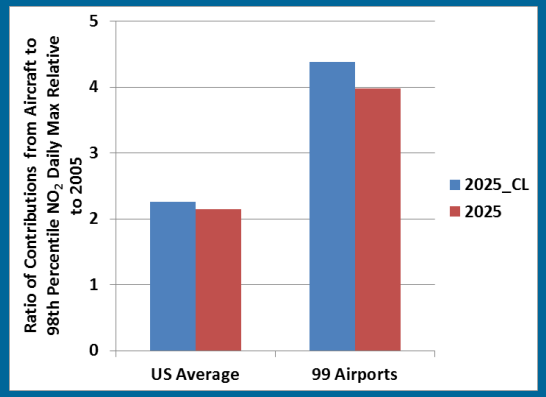


98th Percentile DMax NO_2



Arunachalam et al, 2015

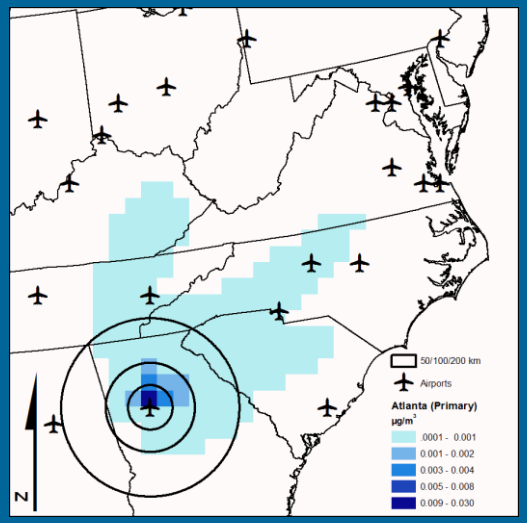


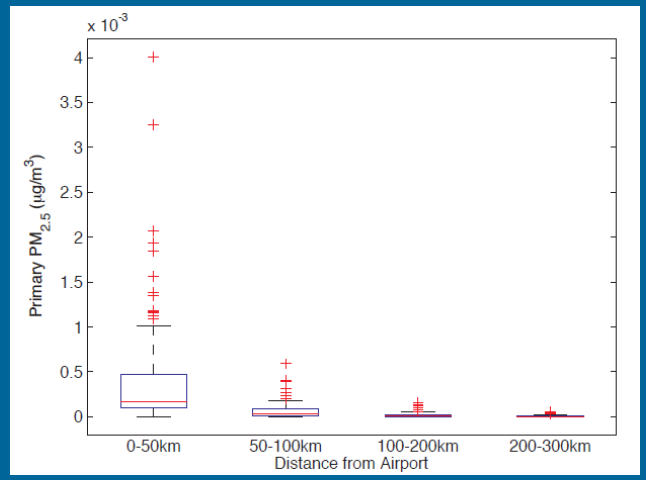


- Aviation emissions cause a ~6x increase in future year $PM_{2.5}$ impacts, mostly from secondary components
- # Grid-cells exceeding O_3 NAAQS (75 ppb) see a 60% ↑ in future year due to change in climate
- Aircraft emissions increase future year NO_2 exceedances by 6x in some major urban areas

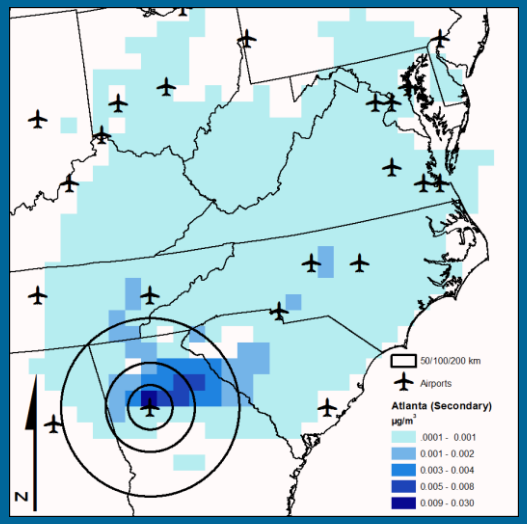
Primary and Secondary $PM_{2.5}$ Impacts at Downwind Distances of Airport

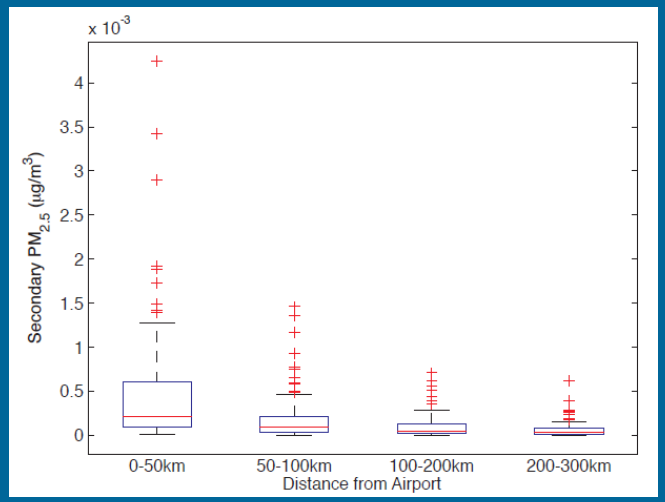
Primary $PM_{2.5}$





Secondary $PM_{2.5}$



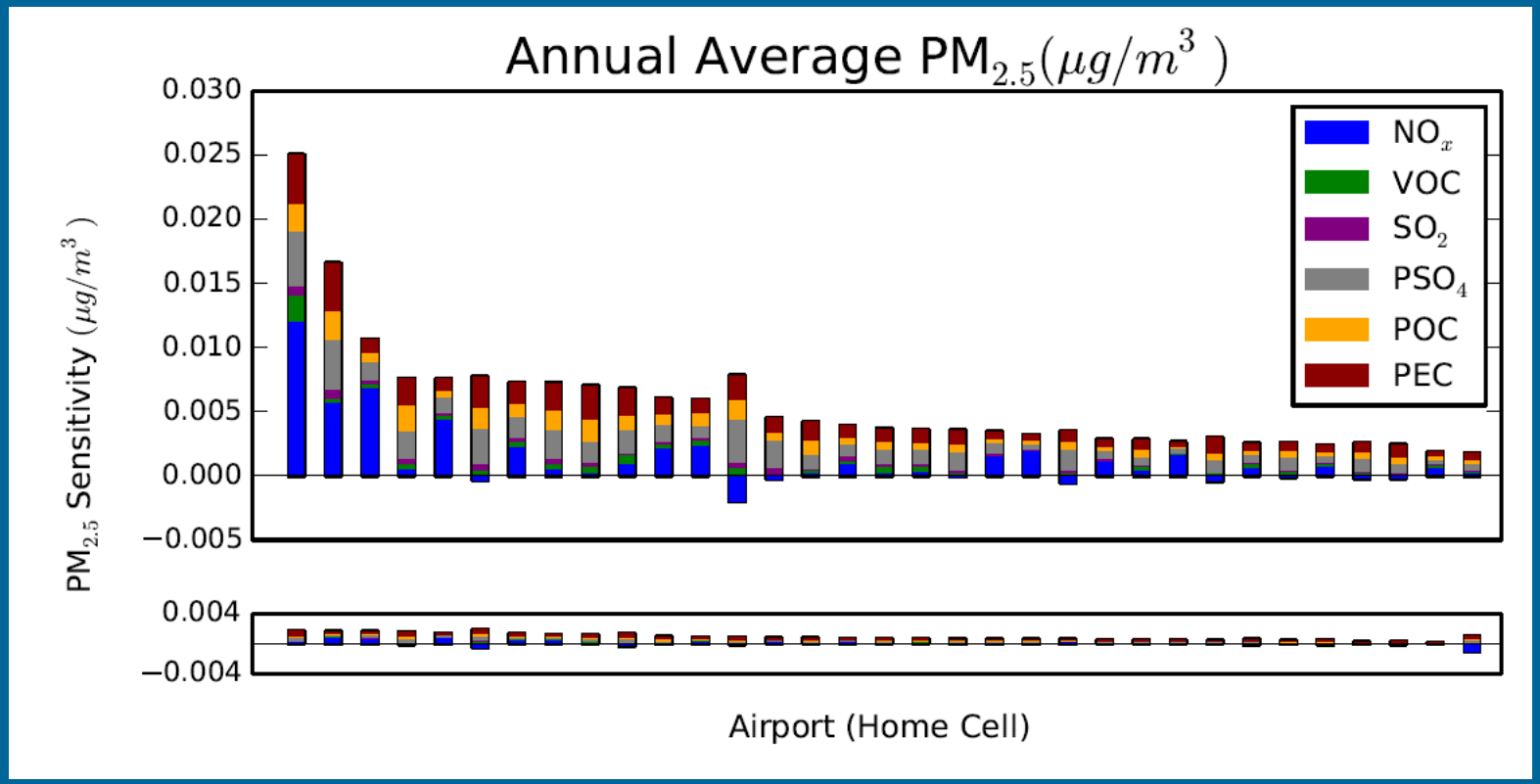


Boone et al, 2015

Atlanta Airport **Top 99 U.S. Airports**

- Radial analysis of $PM_{2.5}$ from CMAQ-DDM Simulations of 99 U.S. Airports

Speciated individual airport $PM_{2.5}$ sensitivities at home grid cell

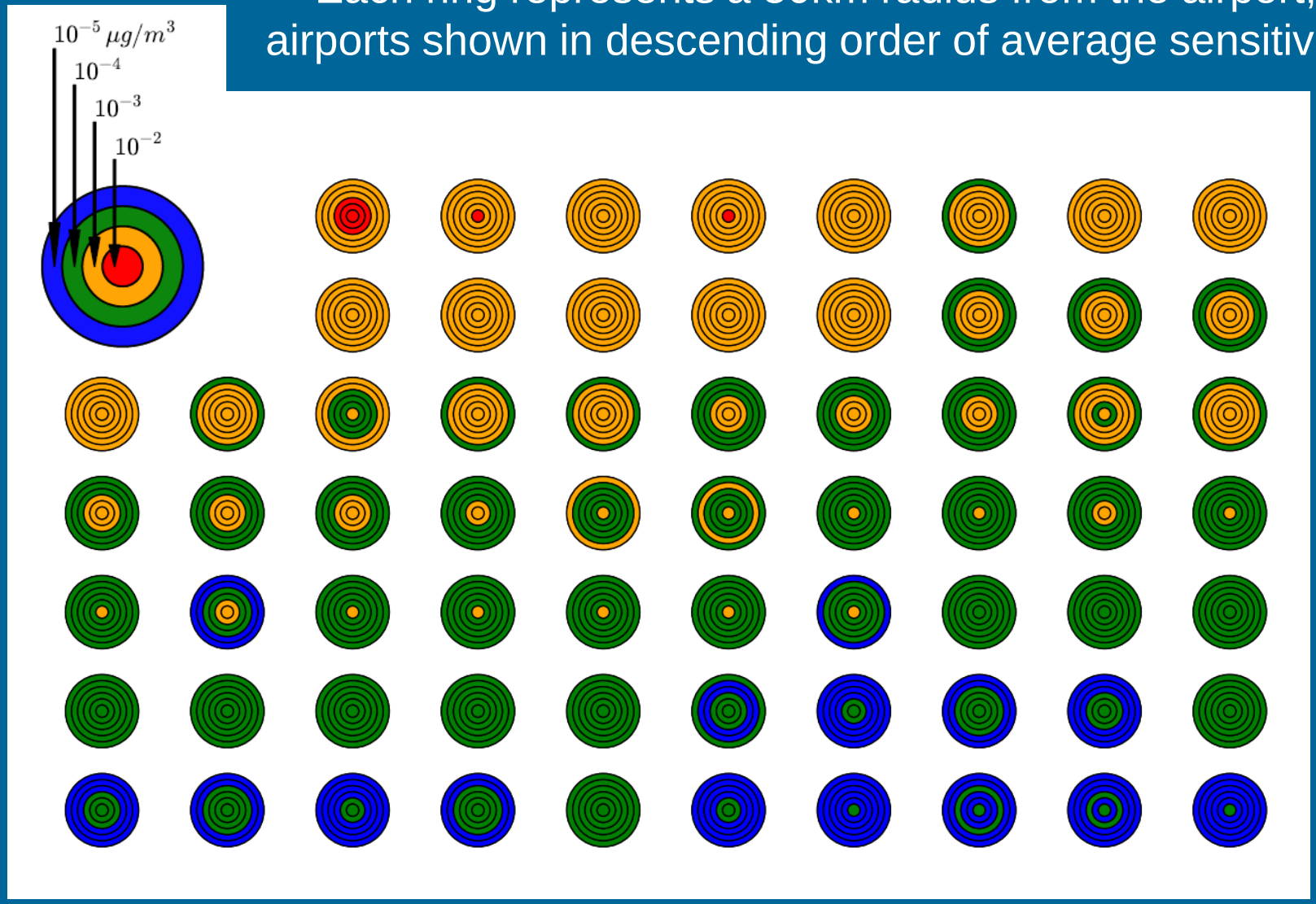


When sensitivity of $PM_{2.5}$ is disaggregated by precursor, the amount of $PM_{2.5}$ species produced by each tagged input can be seen. Airports shown in descending order of home-cell $PM_{2.5}$ sensitivity.

Boone et al, 2015

U.S. airports $PM_{2.5}$ sensitivity by radius

Each ring represents a 50km radius from the airport; airports shown in descending order of average sensitivity.



Boone et al, 2015

Relative contribution at airport grid cell

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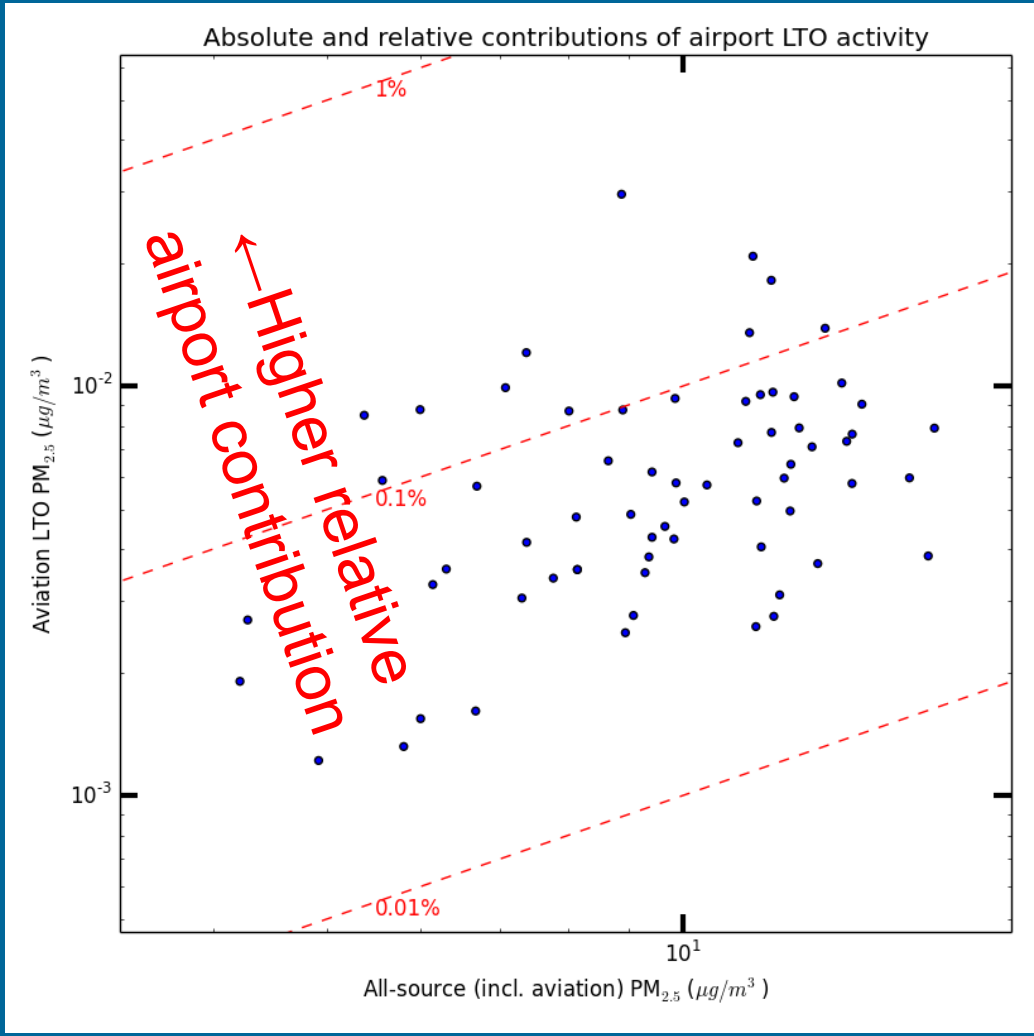
Higher airport contribution ($\log_{10}$)→

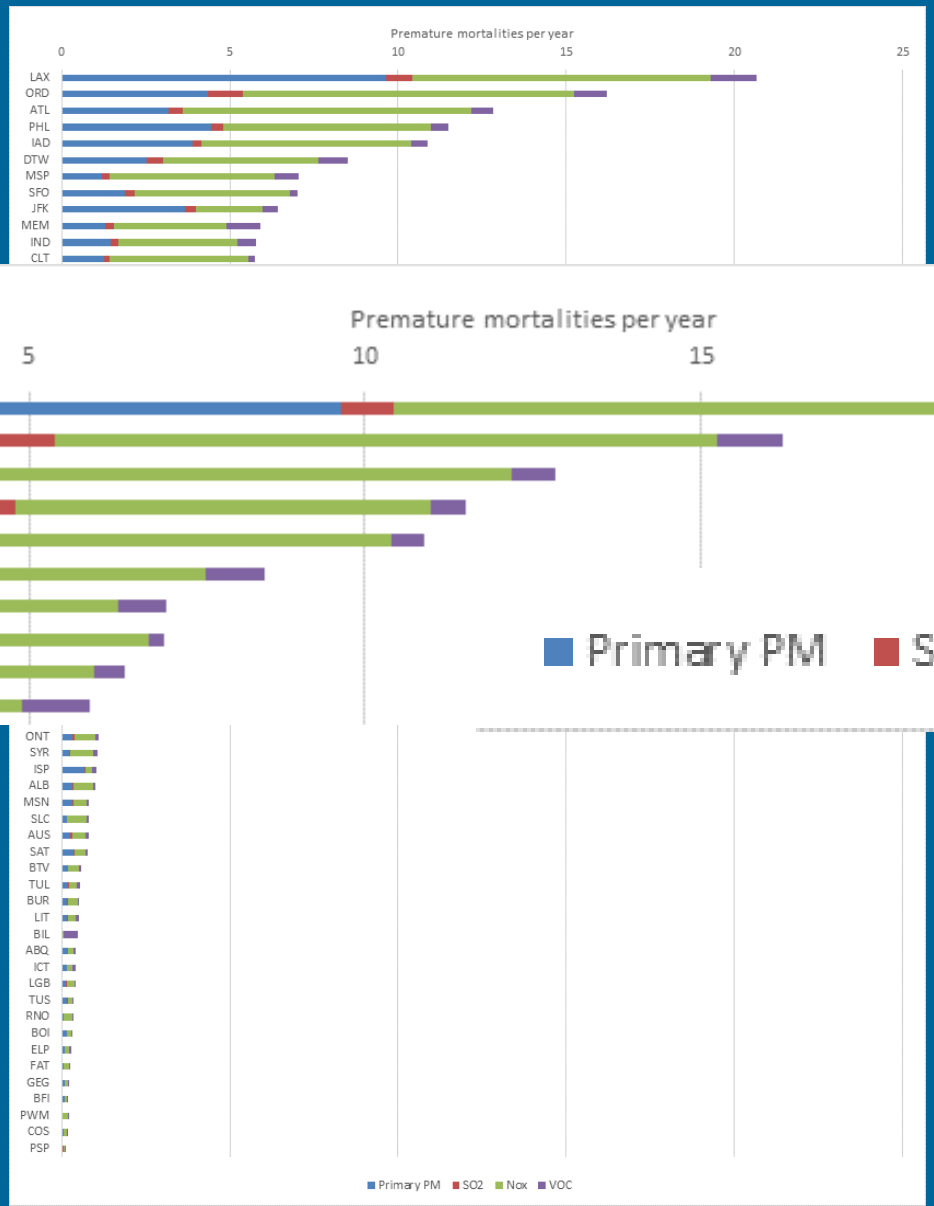


Boone et al, 2015

Higher total aerosol concentration ($\log_{10}$)→

- Several airports contribute > 0.1% of total $PM_{2.5}$ in the vicinity of airport

Airport-specific premature mortalities



Penn et al, Environ. Res. 2017

Sensitivities of O_3 and $PM_{2.5}$ due to Precursors from NYC airports - EWR, JFK and LGA

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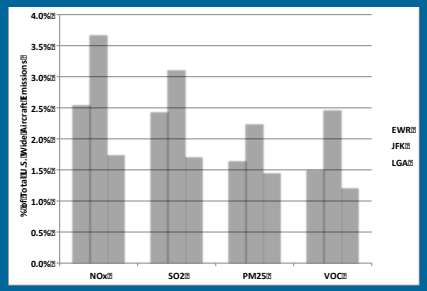
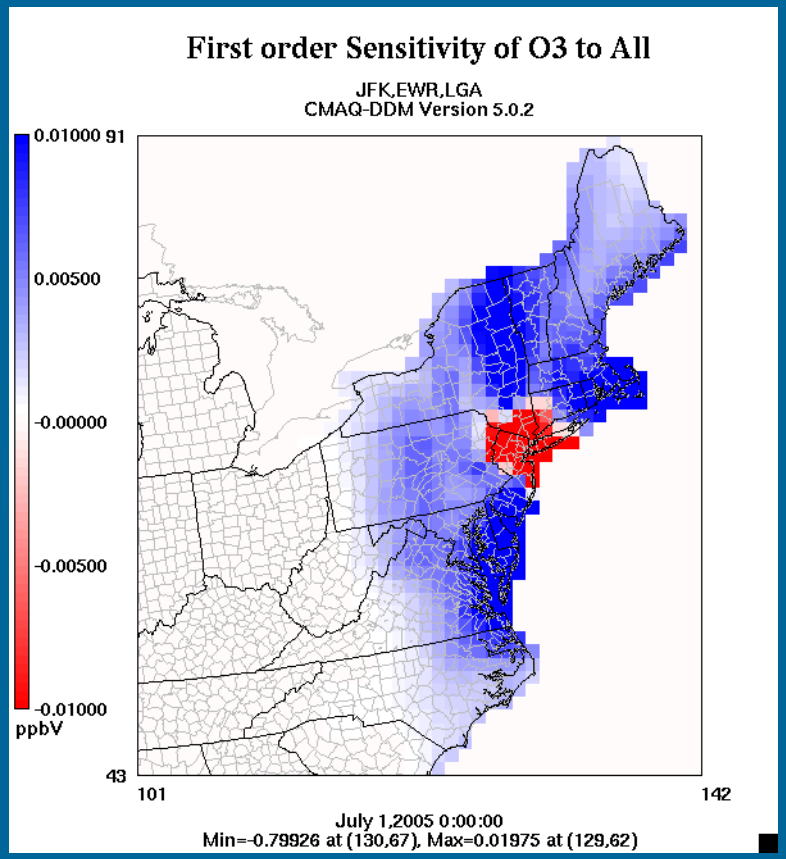
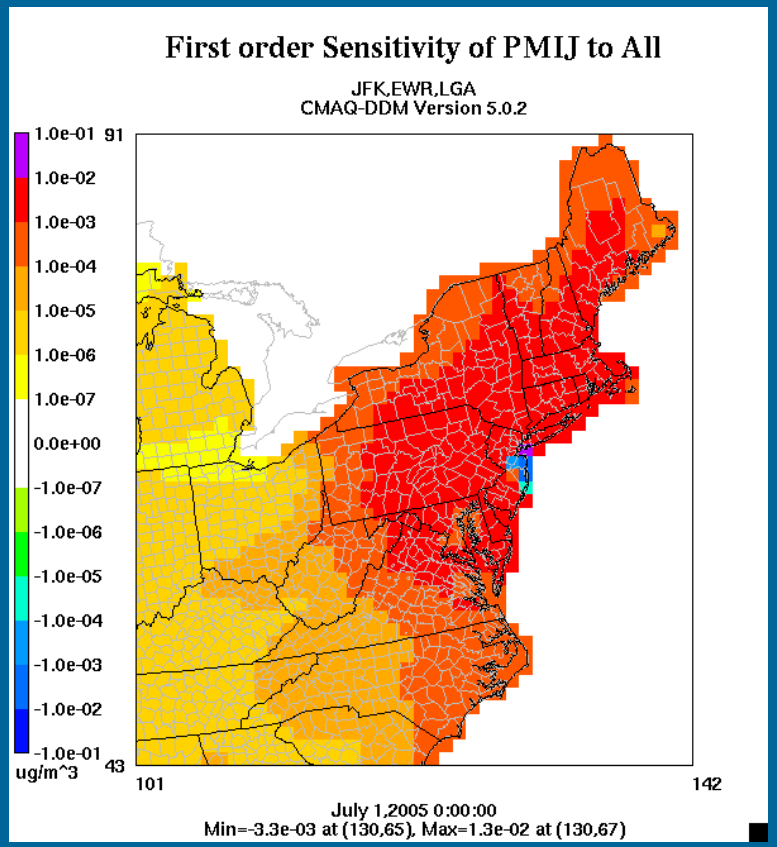


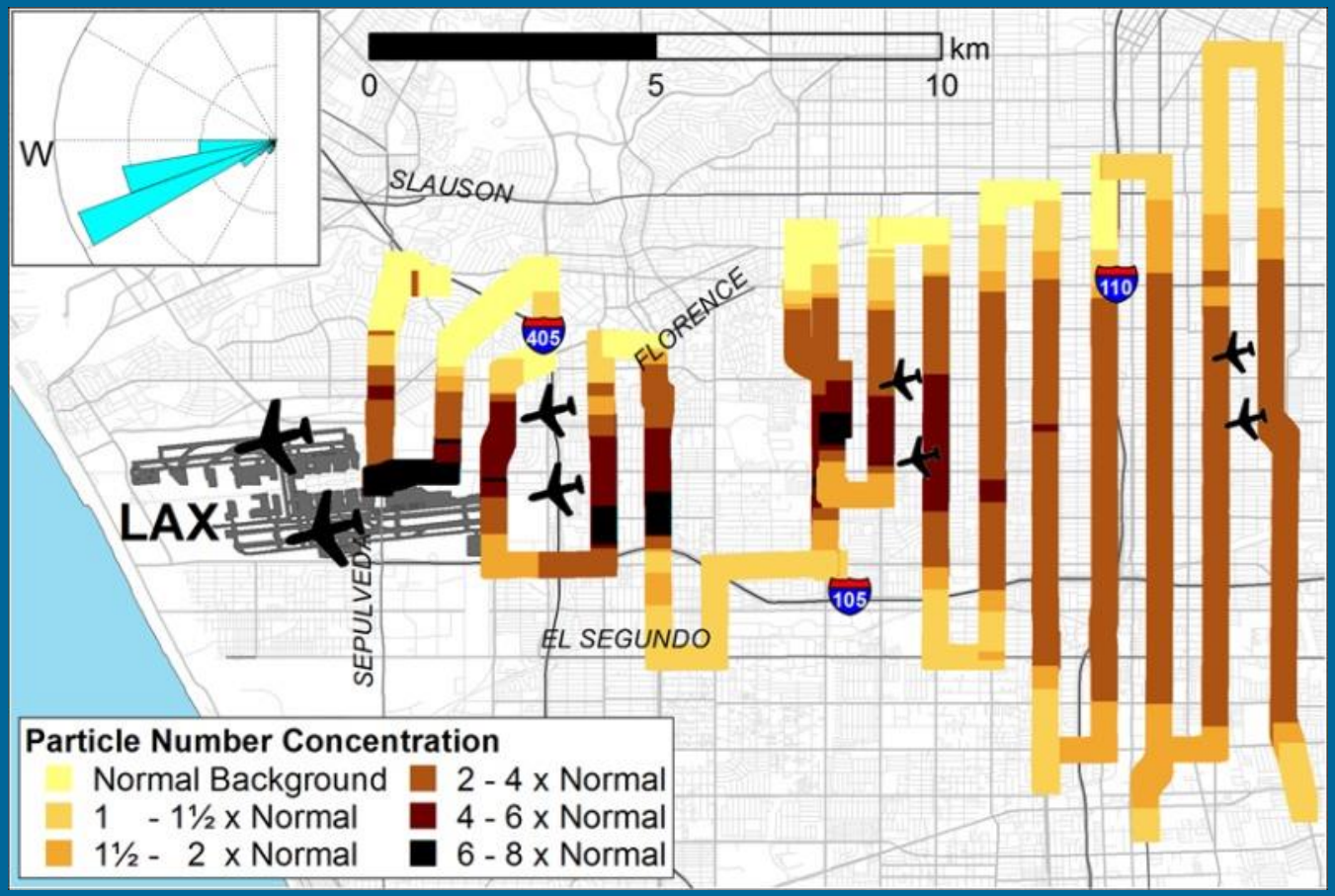


O_3



$PM_{2.5}$

UFP at Los Angeles International (LAX) Airport



Recent studies indicate that number concentrations of ultrafine particle significantly increase due to LTO activity in LAX, BOS, AMST, Rome (Hudda et al., 2016; Hudda and Fruin, 2016; Keuken et al., 2015; Riley et al., 2016; Stafoggia et al., 2016)

Hudda et al., ES&T 2014

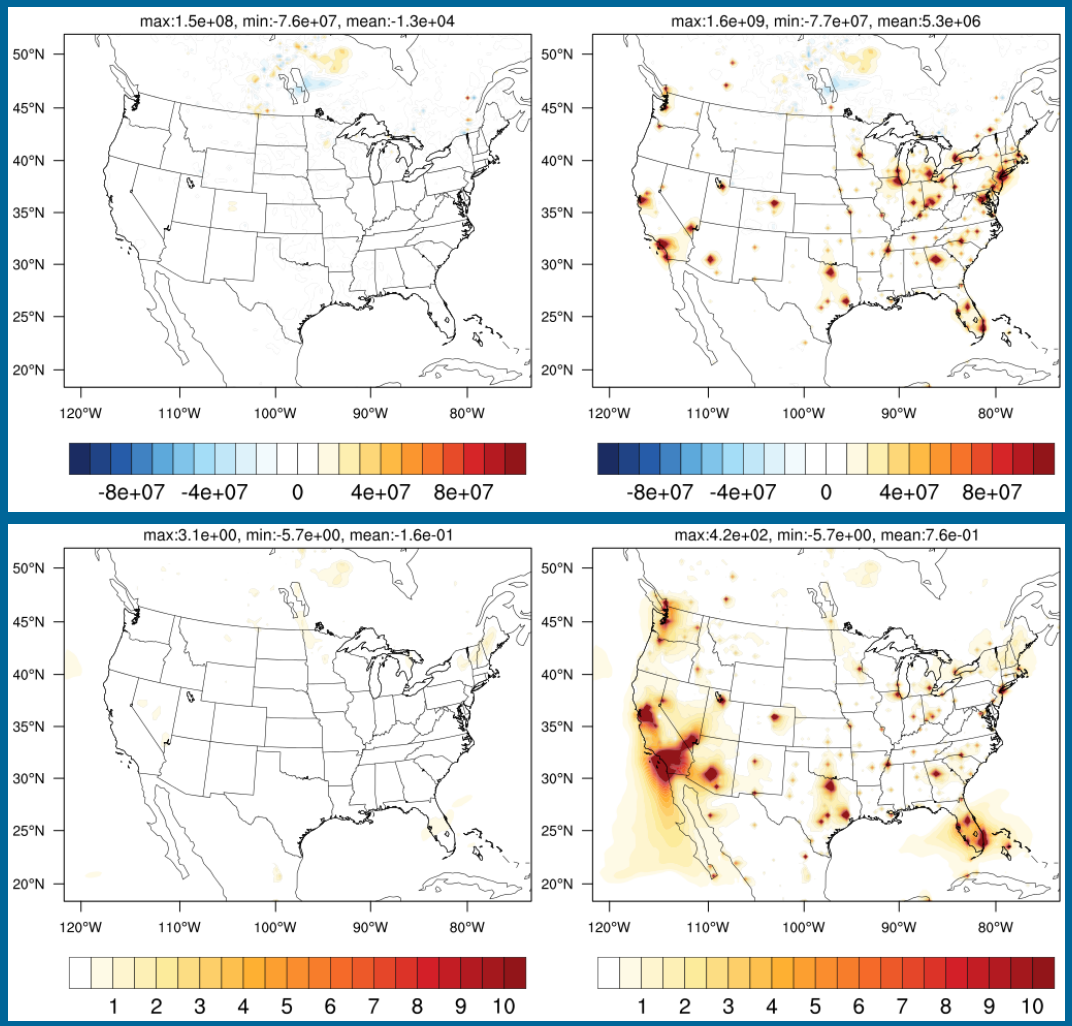
Aircraft-attributable UFP Impacts

Impact of new CMAQ module to treat aircraft emissions using size characteristics from engine measurements

Traditional **New**

UFP number concentration [#/m³]

UFP number concentration [%]



Huang et al, In Prep

In airport grid-cells, $PM_{2.5}$ mass ↓ by upto ~25%, whereas particle number concentration (of UFP) by ↑ upto ~5x at large airports

LAX Airport Source Apportionment Study

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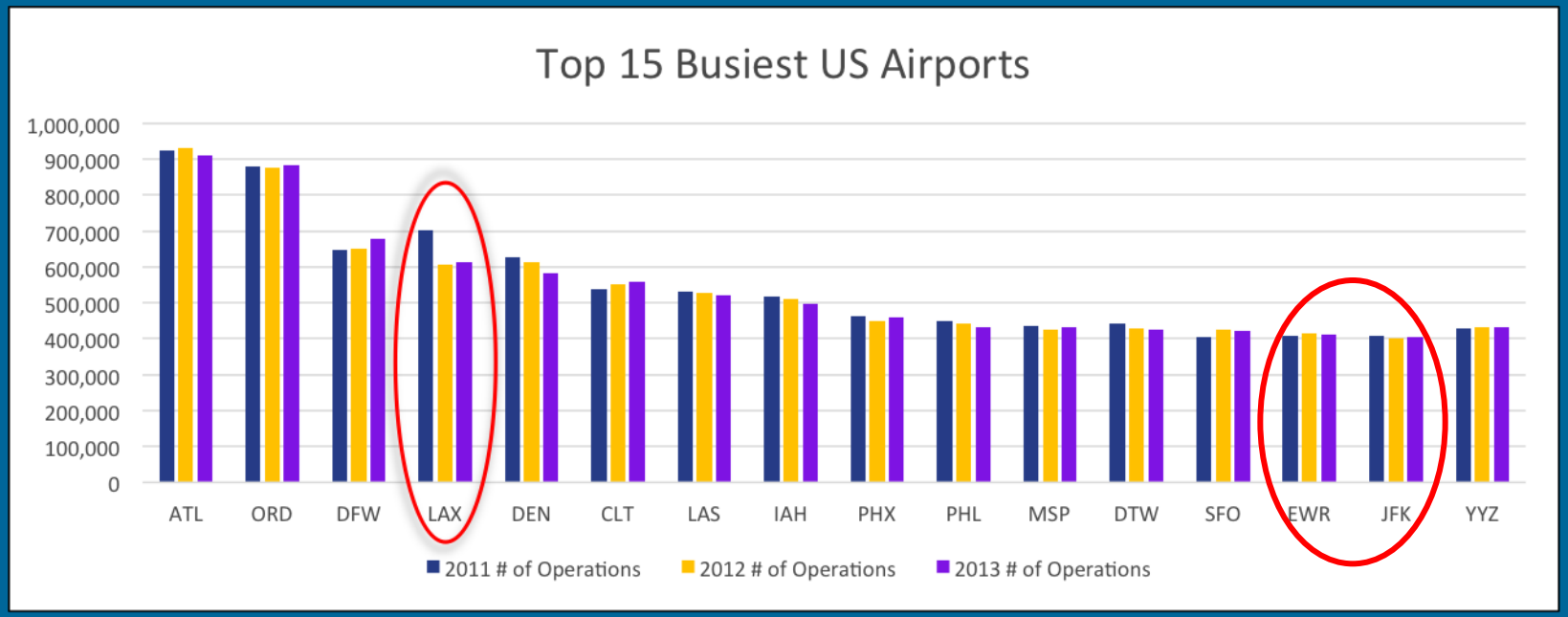
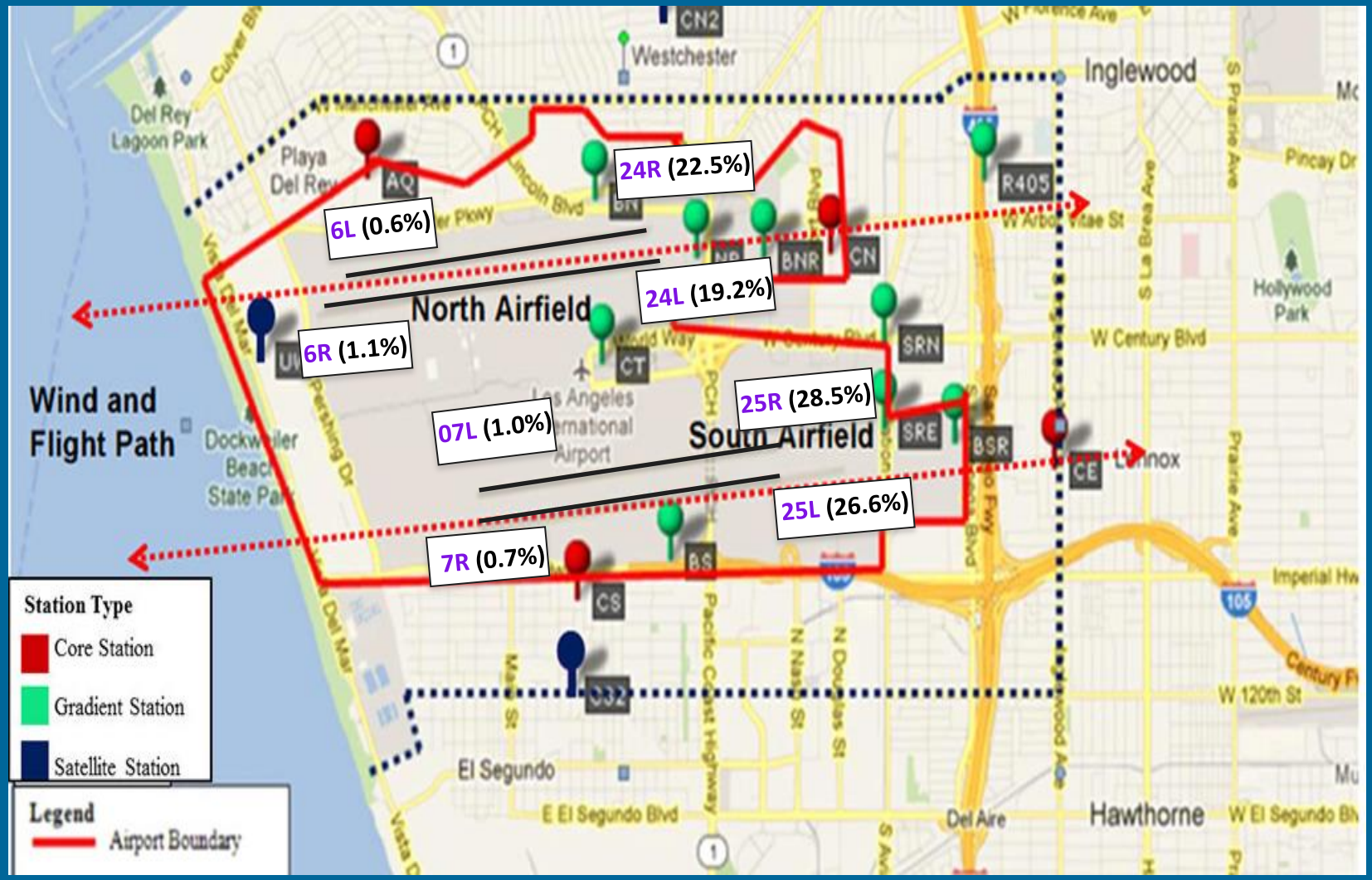
- Los Angeles International (LAX) chosen because
  - LAX is one of the top 5 airports in the U.S.
  - Los Angeles World Airport (LAWA) conducted the Air Quality Source Apportionment Study (AQSAS) Phase III
  - Intensive field campaign during two seasons
    - Winter (January 31 – March 13, 2012)
    - Summer (July 18 – August 12, 2012)
    - Over 400 compounds measured at 17 locations
    - 4 “core”, 4 “satellite” and 9 “gradient”



Aircraft LTO Activity at LAX and monitoring locations



http://www.lawa.org/airQualityStudy.aspx?id=7716

Emissions from Aircraft sources compared to Airport-wide sources at LAX

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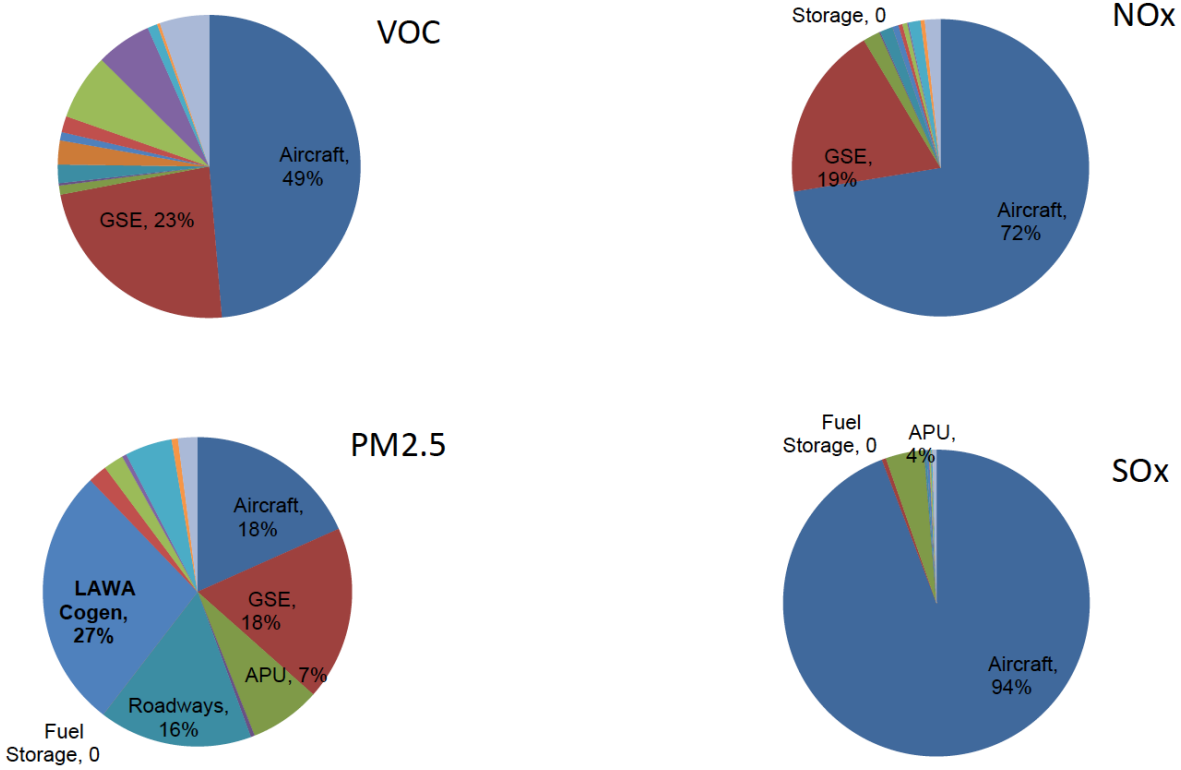
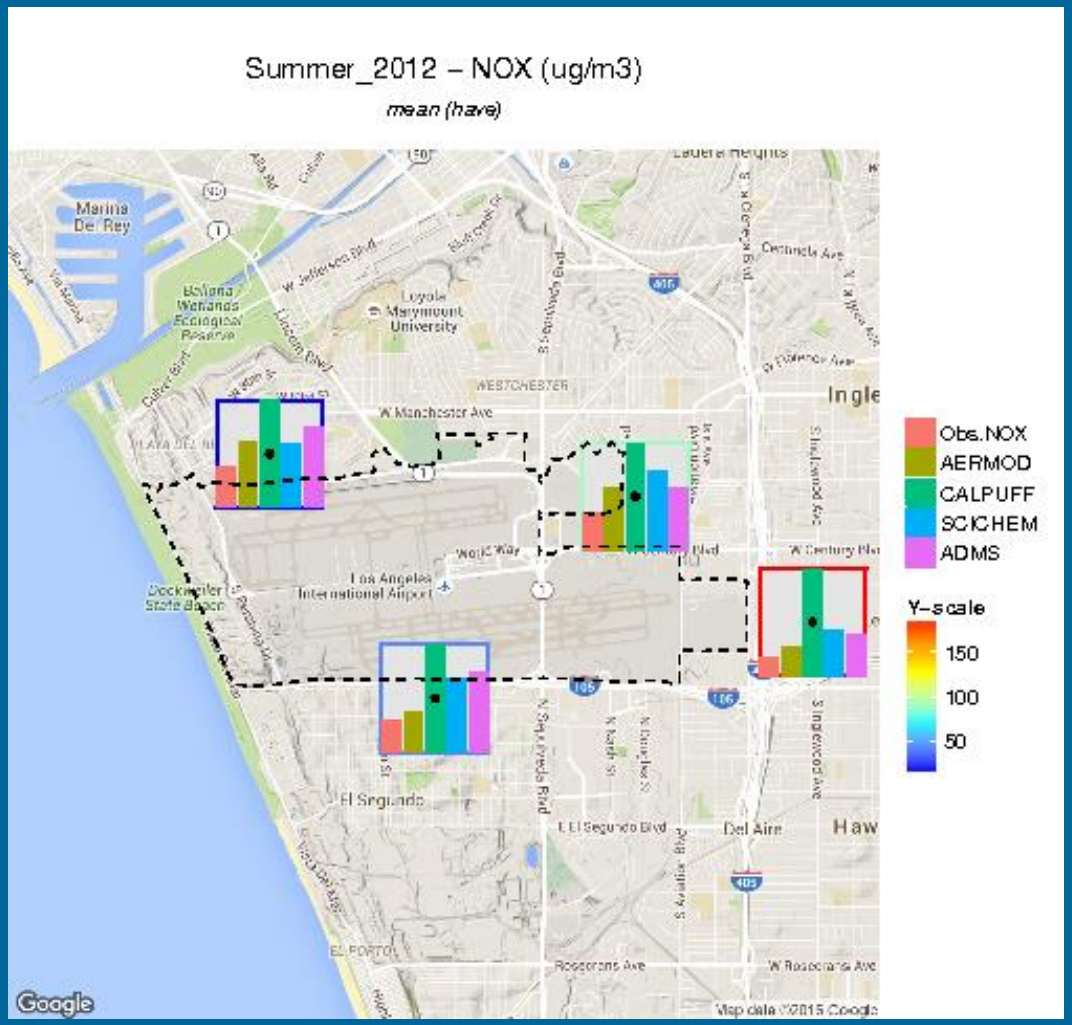


Aircraft and GSE dominate NO_x

Aircraft dominate SO_x

$PM_{2.5}$ is from several sources

Mean NO_x during Summer



AERMOD and SCICHEM predicted means are closer to observations, while ADMS and CALPUFF tend to overpredict

Arunachalam et al, ACRP Report 179, In Press

Summary Points (1 of 2)

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- Health impacts from $PM_{2.5}$ dominate compared to other pollutants (O_3, air toxics) (Levy et al., 2008)
- Secondary $PM_{2.5}$ dominates at downwind distances (~200-300 km from airport), while primary components dominate in near field (Arunachalam et al, 2011)
- Future year AQ impacts of aviation growth in U.S. dominated by nitrate aerosol, largely due to increase in background free ammonia (Woody et al, 2011)
- Future year aviation-related health impacts in U.S. would increase by 6.1x from 2005 to 2025 (2.1x due to emissions, 1.3x to population, and 2.3x to background) (Levy et al, 2012)
- Incorporating for change in climate adds another ~7%, which we attribute as “climate penalty” (Arunachalam et al, 2015)
- Hybrid modeling approach assists with assessing local and regional AQ impacts of aviation (Rissman et al, 2013)

Summary Points (2 of 2)

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- NTSOA contributions can be upto ~30% of total $PM_{2.5}$ due to airport emissions (Woody et al, 2015)
  - Recently gained knowledge on SOA (TSOA + NTSOA) shifts both magnitude and composition of aviation-attributable $PM_{2.5}$
- Stringent revisions to health-based standards will likely exacerbate aviation-related contributions to exceedances in non-attainment areas
- CMAQ-DDM based sensitivity approach provides potentially powerful framework to explore attainment/non-attainment issues
- Additional work needed to
  - Reduce uncertainties in aircraft emissions of nvPM, and precursors of volPM [Stettler et al, 2013; Penn et al, AE 2015]
  - Characterize UFP impacts (Mass vs. Number on a size-resolved basis)
  - Enhance local-scale dispersion models to represent aircraft sources adequately for accurate local-scale impact assessment

Acknowledgements

- Sponsors
  - FAA/NASA/DOD/DOE/EPA/Transport Canada under PARTNER and ASCENT Centers of Excellence
  - Los Angeles World Authority (LAWA)
  - Transportation Research Board
  - NASA ROA: NNH10ZEA001N NextGen CTD2
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- Other UNC-IE Staff: BH Baek, Jared Bowden, Mohammad Omary, Alex Valencia
- Boston University: Jon Levy