A Nation-wide Assessment of Particle Number Concentrations from Commercial Aircraft Emissions in the United States

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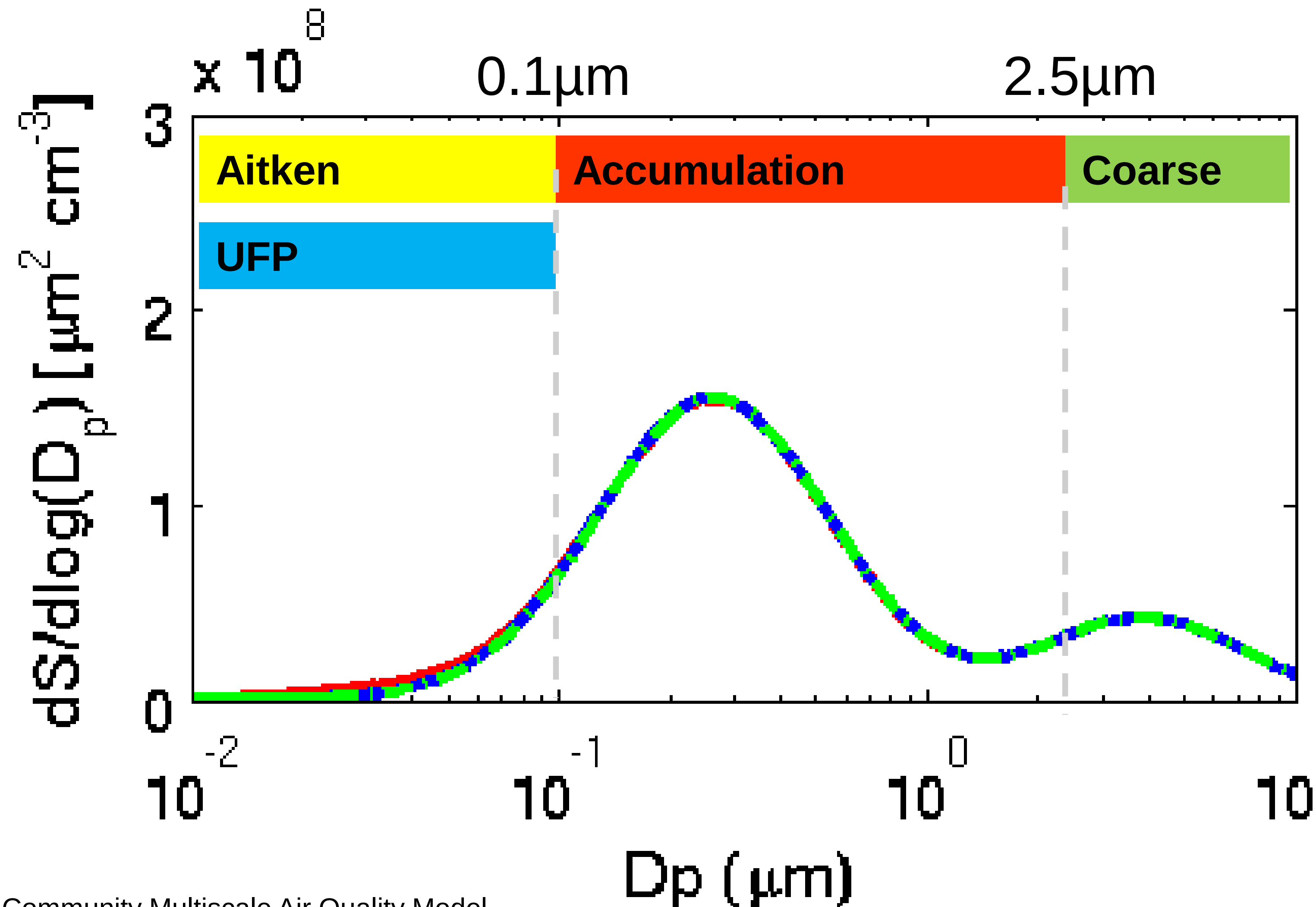
Particle modes in CMAQ



CMAQ: Community Multiscale Air Quality Model

Ultra fine particle (UFP) ≅ Aitken mode

Current CMAQ uses uniform PSD in all emission sectors

	Original				Updated		
mode	Mass fraction		D_{gv} (m m)	s_g	Mass fraction	D_{gv} (m m)	s_g
Aitken	EC/OC/NCOM	0.001	0.030	1.7	0.10	0.060	1.7
	Other	0.000					
accumulation	EC/OC/NCOM	0.999	0.300	2.0	0.90	0.280	1.7
	Other	1.000					

Nolte et al., 2015 GMD

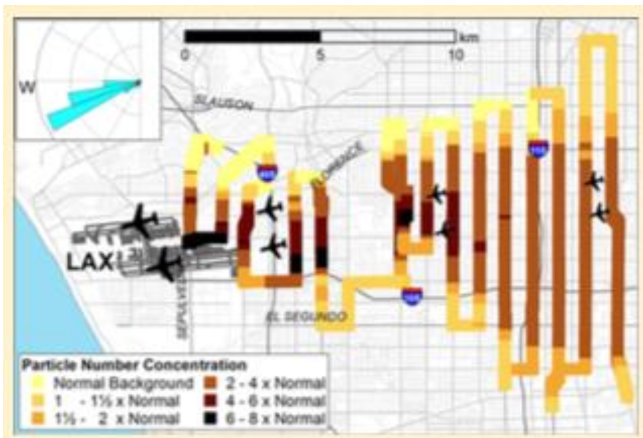
However, this uniform setting of PSD from emissions might not be appropriate for all sources

See Winijkul et al., 2015, Atmos Environ and Murphy et al, 2017, AAAR

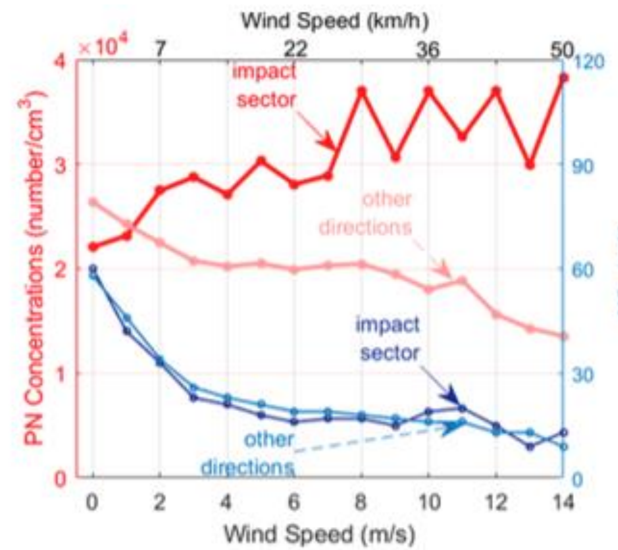
PSD: Particle Size Distribution

Number concentrations of ultrafine particles from LTO emissions

LAX



BOS



Hudda et al., 2014, 2016

Recent studies indicate that number concentrations of ultrafine particle significantly increase due to LTO activity in LAX, BOS, AMST, Rome

4- to 5-fold increase to 8-10 km downwind in LAX

1.33- to 2-fold increase to 4-7.3 km downwind in BOS

Motivation


CREDIT: FLICKR/DSLEETER_2000

PSD of aircraft emissions

Non-volatile PM (nvPM): PEC

Volatile PM (vPM): PSO4, POC

Reference	Species	Method	UFP GMD (nm)	Accumulation GMD (nm)	GSD
Petzold et al., 1999	Black Carbon	Cruise tail Plume	25-35 UFP	150-160	1.55-1.87
Kinsey et al., 2010 APEX 1-3	Total number	Surface Plume	10-35 UFP		1.2-2.3
Herndon et al., 2008 ES&T	Total number	Surface Plume			
Keuken et al., 2015 AE	Total number	Surface Plume			
Wey et al., 2006 APEX	Total number	Surface Plume	15-40 UFP		
Peck et al., 2012 JEGTP	Soot and volatile	Surface Plume with dilution	15 Nucleation 35 soot		
Onasch et al., 2009	Soot and volatile	Surface Plume	20	100	
AEDT preparation guide*	NA		5-20 UFP vPM 40 UFP nvPM		
Our study	Total		20 UFP vPM 40 UFP nvPM	150	1.5-1.6

*based on *Herndon et al., 2005, AST; Lobo et al., 2007, JPP; Timko et al., 2010, JEGTP*

Emission split factor of Aitken:Accumulation from aircraft emission = 91.8 : 8.2 %.
What is the effect of this new split on $PM_{2.5}$ mass and number near airports in the US?

Objectives

Goal

To investigate the changes of PM characteristics in the atmosphere due to PSD changes from aircraft emissions near major airports in the U.S.

Objectives

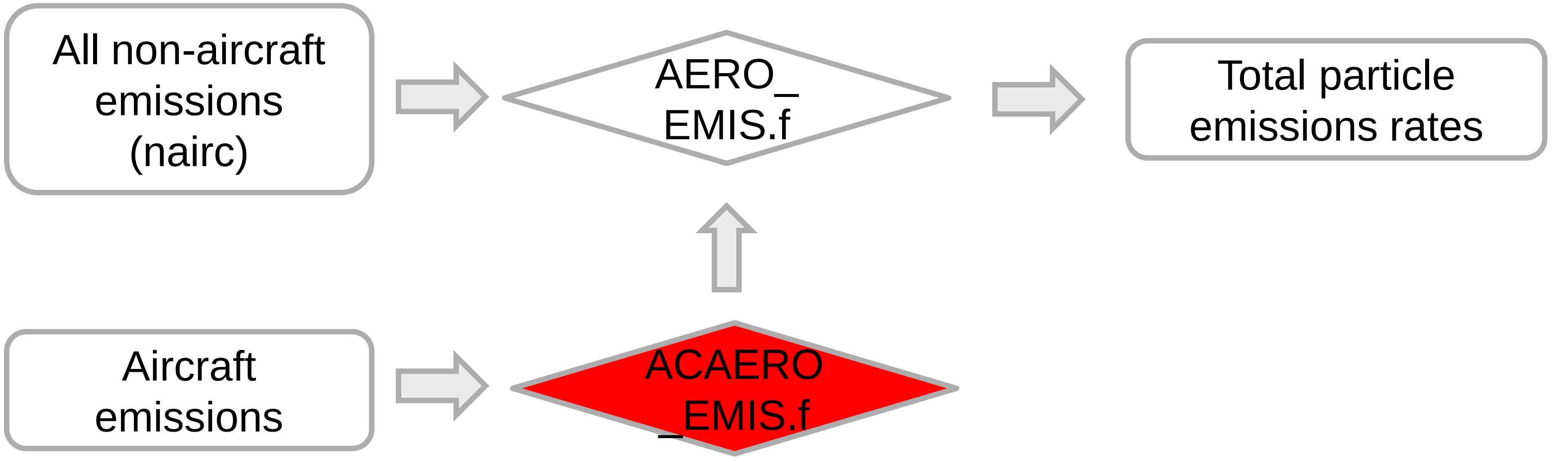
- To quantify changes in Aitken mode number concentrations and $PM_{2.5}$ mass
- To investigate changes in deposition, heterogeneous chemistry, and partitioning of gas-aerosols
- To determine shifts in output PSD and chemical composition

Impacts

New knowledge on aircraft attributable PM in the context of recent field measurement campaigns

Approach

WRF-SMOKE-CMAQ 36 km 2005



- Develop a new module: ACAERO_EMIS
  - Read particle emissions from a specific source sector (i.e. aircraft emissions) separately
  - Re-assign different emission split factors, GMD and GSD for different species
- Merge with emissions from all other sources to create CMAQ-ready inputs
- Model three CMAQ scenarios
  - Nonaircraft emissions, base, sensitivities

Approach

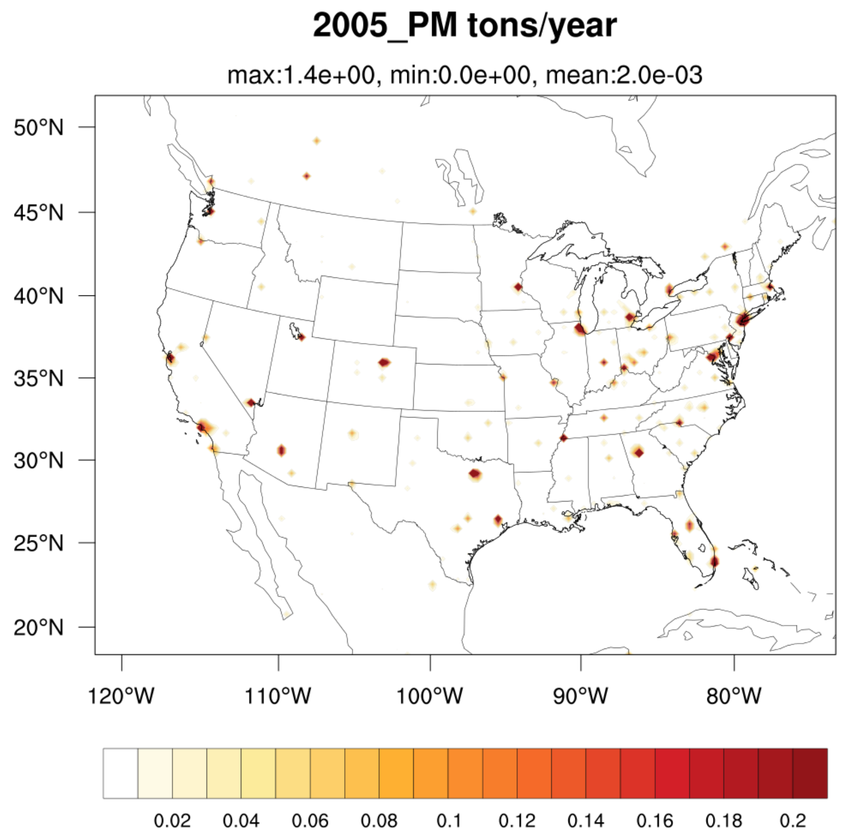
annual scenarios

Blue indicates the difference between background and base scenarios
Red indicates the difference between base and sensitivity scenarios
Base – nairc : aircraft contribution [Traditional]
Sens – nairc : aircraft contribution [New]
Sens – base : PSD change in aircraft emissions [IMPACT]
nvPM: PEC, vPM: PSO4, POC

	Emission split factor	GMD (nm)	GSD	Emission data
non-aircraft (no-airc)	***EC/OC/NCOM*** UFP: 0.1 Accumulation: 99.9 ***OTHER*** UFP: 0 Accumulation: 1	***EC/OC/NCOM*** UFP: 30 Accumulation: 300 ***OTHER*** Accumulation: 300	***EC/OC/NCOM*** UFP: 1.7 Accumulation: 2.0 ***OTHER*** Accumulation: 2.0	All emissions without aircraft emissions
Base (base)	***nvPM*** UFP: 0.1 Accumulation: 99.9 ***vPM*** UFP: 0.1 Accumulation: 99.9	***nvPM*** UFP: 30 Accumulation: 300 ***vPM*** UFP: 30 Accumulation: 300	***nvPM*** UFP: 1.7 Accumulation: 2.0 ***vPM*** UFP: 1.7 Accumulation: 2.0	All emissions and aircraft emissions in separate files
Sensitivity (sens, same as vPM_UFP_20nm-sens_6 in Table 2)	***nvPM*** UFP: 91.8 Accumulation: 8.2 ***vPM*** UFP: 91.8 Accumulation: 8.2	***nvPM*** UFP: 40 Accumulation: 150 ***vPM*** UFP: 20 Accumulation: 150	***nvPM*** UFP: 1.6 Accumulation: 1.87 ***vPM*** UFP: 1.5 Accumulation: 1.87	All emissions and aircraft emissions in separate files

- CMAQ v5.0.2 simulations (CB05_tump with AE06) for annual 2005 with 2-week spin-up
- Post-process CMAQ outputs to assess monthly, seasonal and annual patterns

Annual aircraft emission rates in North America



species	2005 emissions tons	% of total emissions
SO_2	7,217	0.05
NOx	83,248	0.35
PM	638	<0.05
CO	62,669	<0.05
TOG	13,841	<0.05

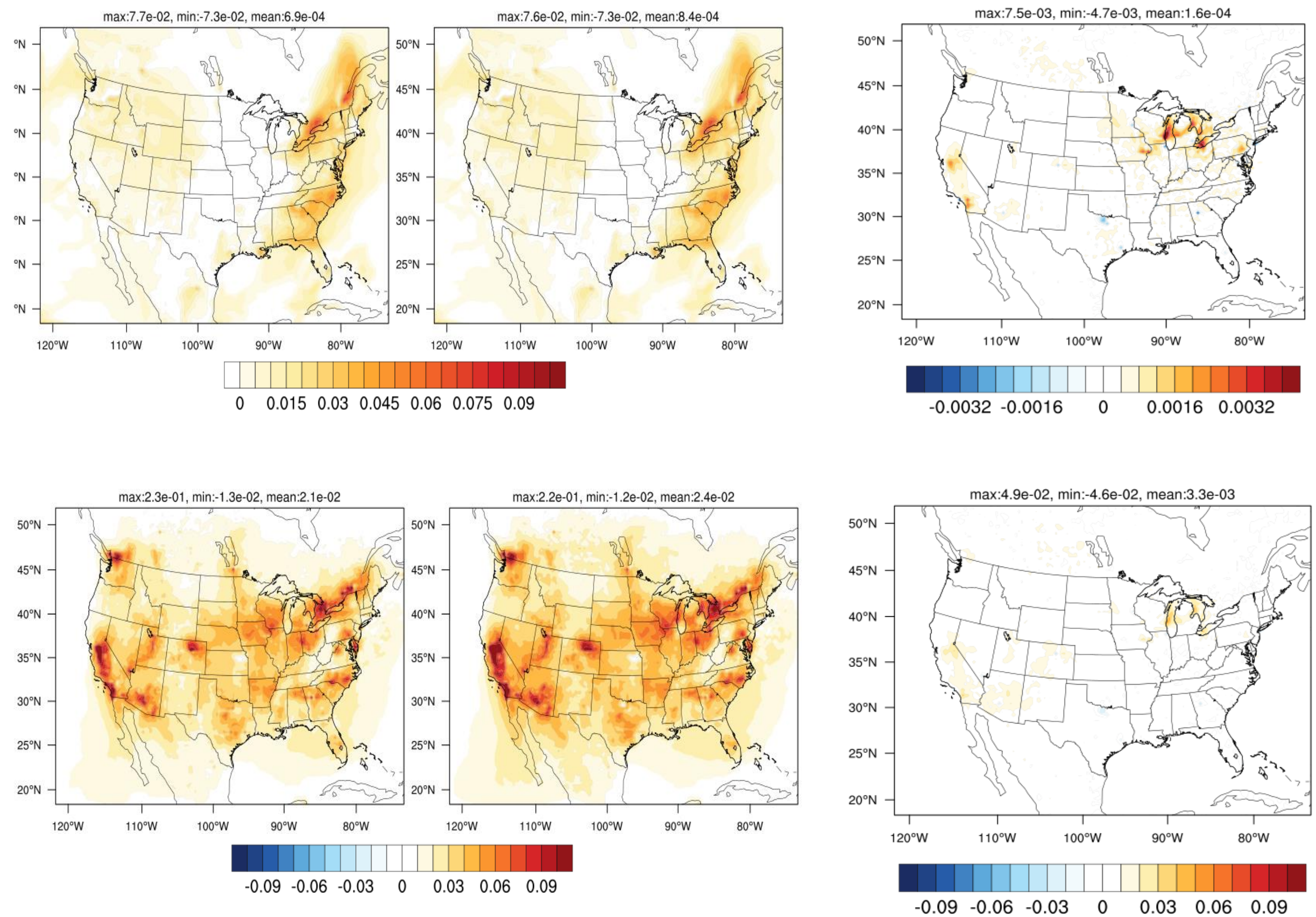
B

A

- **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 $PM_{2.5}$

Aircraft-attributable $PM_{2.5}$ Impacts

	Traditional	New	New-Traditional
$PM_{2.5}$ [μg/m^3]			
$PM_{2.5}$[%]			



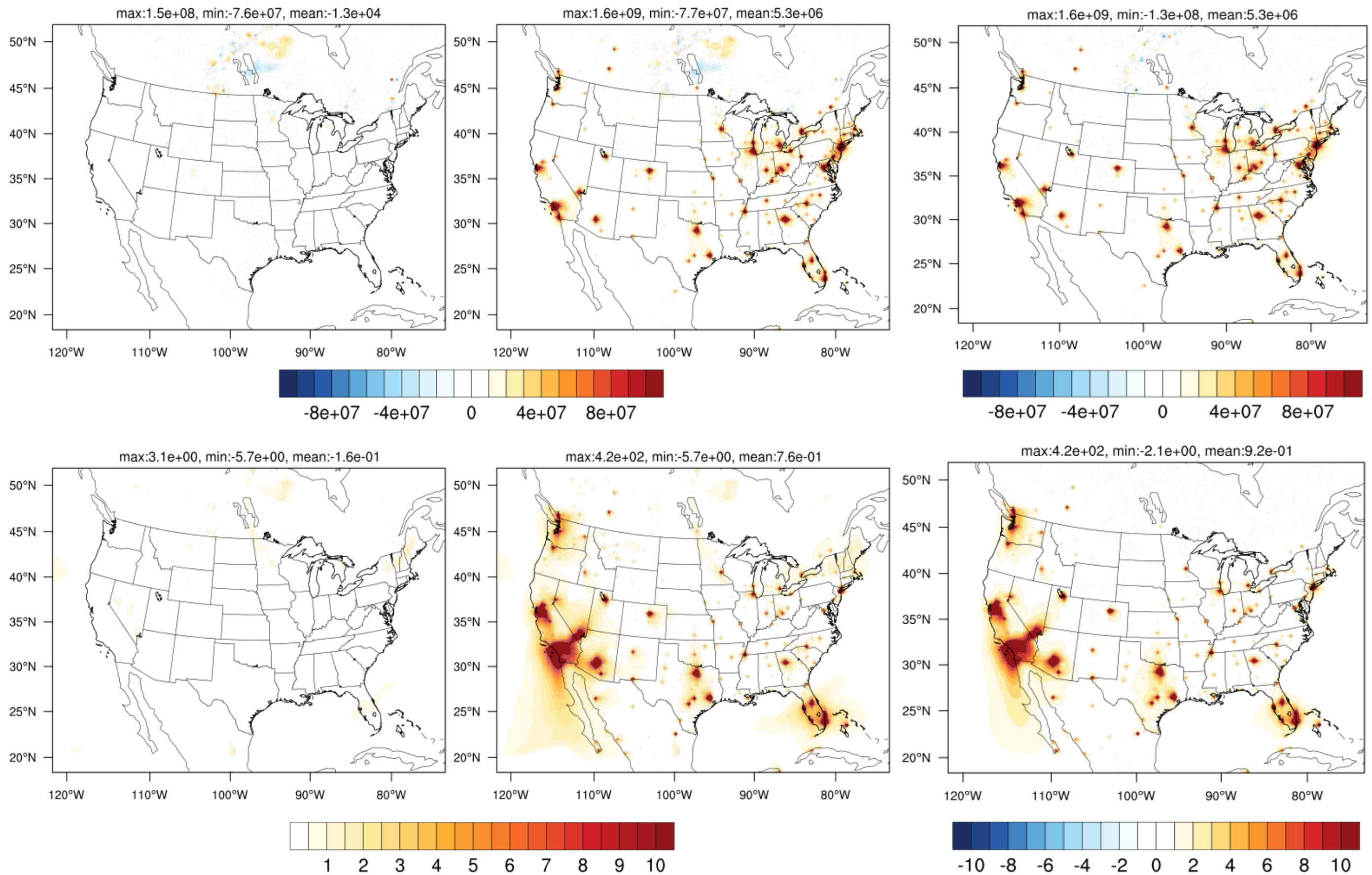
Mass concentrations change < 5% from changing of aircraft PSD, the results are similar to previous studies (*Nolte et al., 2015 and Elleman and Covert (2010*)

Aircraft-attributable UFP Impacts

Traditional | New | New-Traditional

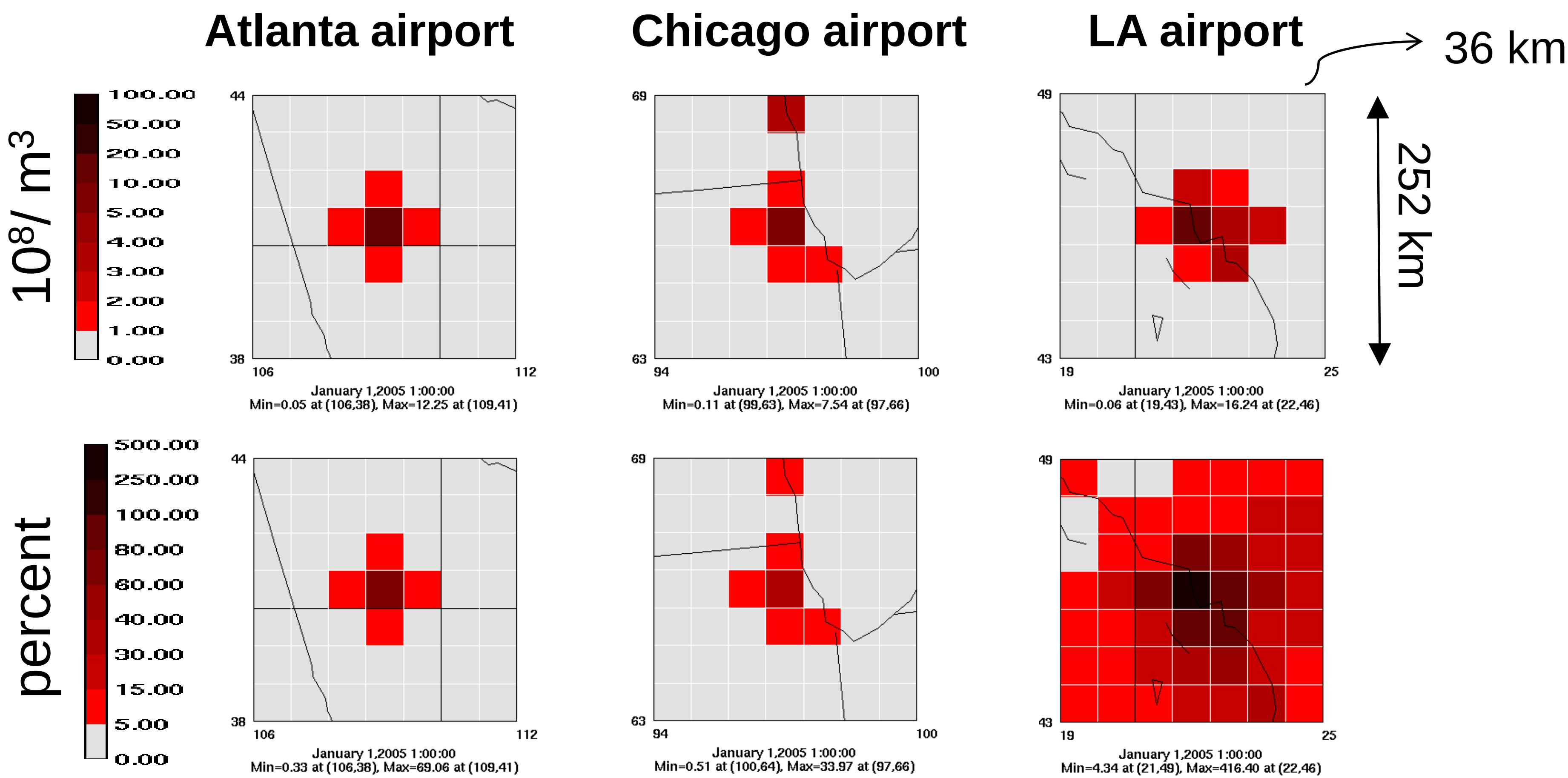
UFP number concentration [#/m^3]

UFP number concentration [%]



Number concentration in accumulation mode does not change much

Aircraft-attributable $PM_{2.5}$ Impacts – Effect of New Approach at airports



Airports are located in the center

UFP number concentrations significantly increase in airport grid-cells
Increases of UFP number concentrations in these three airports vary, and this is due to different physical and chemical processes

Conclusions

- Aircraft contribution of ambient $PM_{2.5}$ mass can be up to ~0.0023 μg m^{-3} in airports
- Changes in PSD of aircraft emissions based upon aircraft engine measurements show new information on AQ impacts of aviation
  - In airports, $PM_{2.5}$ mass decrease (up to 25%) and UFP number concentrations increase (up to 5x)
  - Overall $PM_{2.5}$ mass slightly increase (0.00016 μg m^{-3}) domain-wide

Implications and Future work

- CMAQ modeled estimates using our new approach show some consistency with recent measurements
- Impacts of particle size changes on CMAQ chemistry
- Additional processes such as secondary organic aerosol new particle formation from vapors

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