FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Development of Aviation Air Quality Tools for Airport-Specific Impact Assessment
Project 19

Lead Investigator: S. Arunachalam, University of North Carolina at Chapel Hill

Project Manager: Jeetendra Upadhyay

Spring Advisory Board Meeting
April 18 – 19, 2019
Atlanta, GA

ASCENT
AVIATION SUSTAINABILITY CENTER

Motivation

Previous PARTNER work showed that aviation-attributable health impacts due to $PM_{2.5}$ will be ~6x in 2025 compared to 2005

- Woody et al, 2011, Levy et al, 2012

Recent measurement campaigns at several airports have shown significant levels of Ultrafine Particulate Matter (UFP) due to aircraft LTO operations at LAX, Boston, Amsterdam, Rome, Tianjin, etc.

- Hudda et al 2014, 2016; Staffogia et al, 2016; Ren et al, 2016

- FAA's Aspirational Goal: Achieve an absolute reduction in aviation emissions induced "significant health impacts"
- For ICAO's Committee on Aviation Environmental Protection (CAEP) tools to assess global aviation-attributable health impacts needed

➢ In both cases, science-based tools are required to report year-over-year changes in health impacts

➢ Need to identify airport-specific trends in adverse health impacts for developing mitigation strategies

Objectives

- Long term
  - Develop tools for AQ and health impacts reporting and analyzing potential aviation policy scenarios for FAA and ICAO CAEP
- Near term
  - T1: Adapt modeling tools to estimate AQ impacts due to aviation emissions NAS-wide to facilitate year-to-year reporting and scenario analysis
  - T2: Assess/quantify modeled aviation-attributable UFP, and compare with new measurements from field campaign at Boston Logan airport
  - T3: Develop new modeling framework for dispersion modeling of aircraft sources during LTO cycles

Schedule and Status

- Task 1: NAS-wide and Airport-specific analyses
  - With revised AEDT inputs, implement new higher resolution framework for 2011, 2015 **[Ongoing]**
  - Assess impacts of changes in $PM_{2.5}$ size distributions [**Completed]**
- Task 2: Perform monitor-model comparisons of UFP from Boston Logan airport
  - Using SCICHEM **[Ongoing]**
  - Using CMAQ **[Just getting started]**
- Task 3: Develop new framework for dispersion modeling **[Just getting started]**

Task 1 Objective

Develop NAS-wide modeling platform for the years 2011 and 2015 at fine resolution of 12x12 km

- CMAQ model configuration
  - 2011: CMAQv5.1 with CB05 chemistry at 12x12 km resolution
  - 2015: CMAQv5.2.1 with CB6 chemistry at 12x12 km resolution
- New higher resolution application for the entire U.S.
  - 12x12-km instead of 36x36-km in prior work
  - Over 10x increase in computational resources
- Results compared across 3 years: 2005, 2011, and 2015

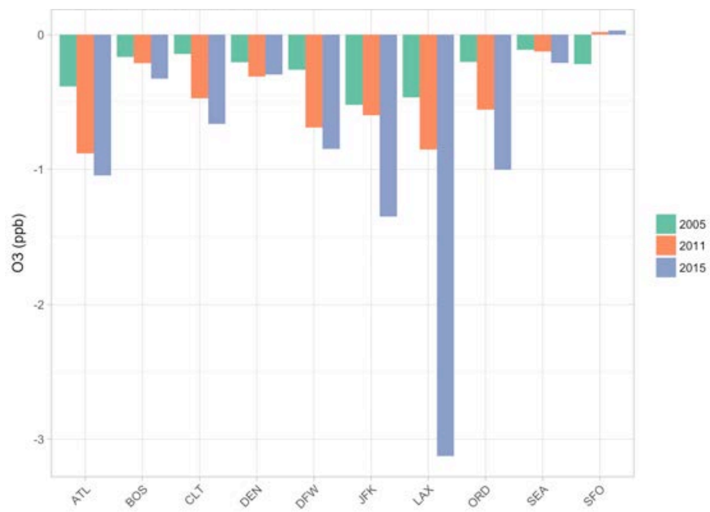
Accomplishments from last meeting:

- In-depth analyses to interpret increases and decreases in air quality impacts at individual airports

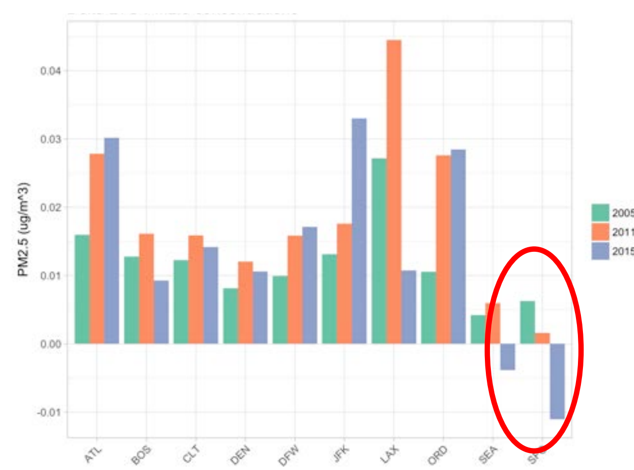
Task 1 Results

Concentrations at airport-containing grid cells

O_3



$PM_{2.5}$



- Increases in NO_X emissions over the model years results in a larger O_3 titration effect at airport-containing grid cells
- $PM_{2.5}$ increases seen in most airport grid-locations

Air Quality Modeling Platform Differences

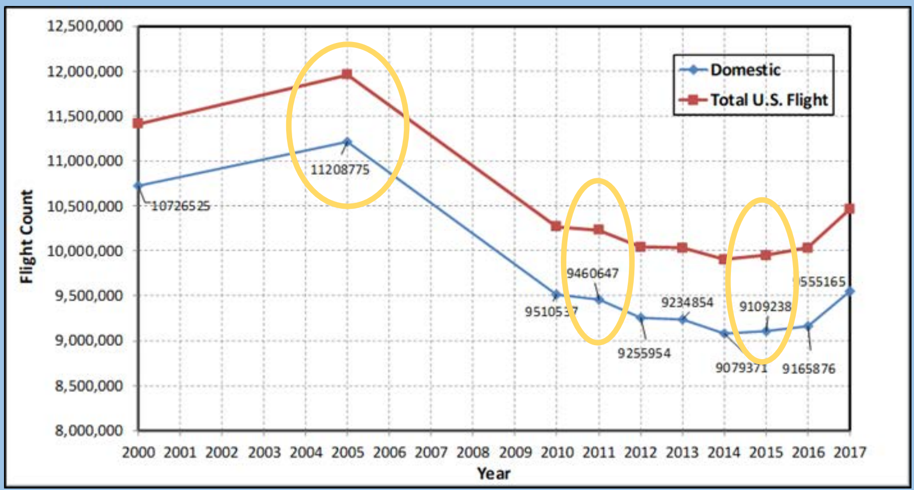
Air Quality Results

*Only used for comparison in health impacts portion of dynamic evaluation

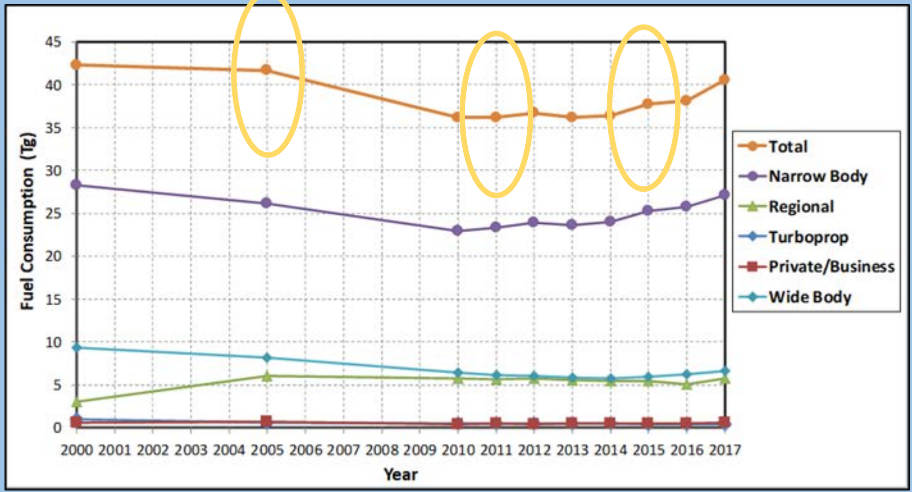
[1] Levy et al. 2012
[2] Woody et al. 2011

NAS-wide Aviation Emissions Trends

Flight Count



Fuel Burn



U.S. aviation trends indicate a sharp decrease in flight count and fuel consumption after 2005, with a gradual increase after 2014

Figures provided by FAA

NAS-wide LTO Emissions for Prior Platform and Current Platform

LTO aircraft emissions		Prior Platform		Current Platform		
Species		**2005**	**2025**	**2005**	**2011**	**2015**
NO_X	ktons yr^{-1}	92.2	198.6	83.6	70.1	82.8
	% change from 2005		115%		-16%	-1%
	% of Total Emissions			1.1% (7,600)	1.3% (5,392)	1.6% (5,175)
SO_2	ktons yr^{-1}	7.9	16.7	7.4	6.0	6.8
	% change from 2005		111%		-19%	-8%
	% of Total Emissions			0.04% (18,500)	0.07% (8,571)	0.12% (5,667)
PEC	ktons yr^{-1}	0.33	0.58	0.28	0.18	0.20
	% change from 2005		76%		-36%	-29%
	% of Total Emissions			0.04% (700)	0.03% (600)	0.03% (667)
TOG	ktons yr^{-1}	14.8	26.4	14.3	10.1	13.5
	% change from 2005		78%		-29%	-6%
	% of Total Emissions			0.03% (47,667)	0.06% (16,833)	0.05% (27,000)

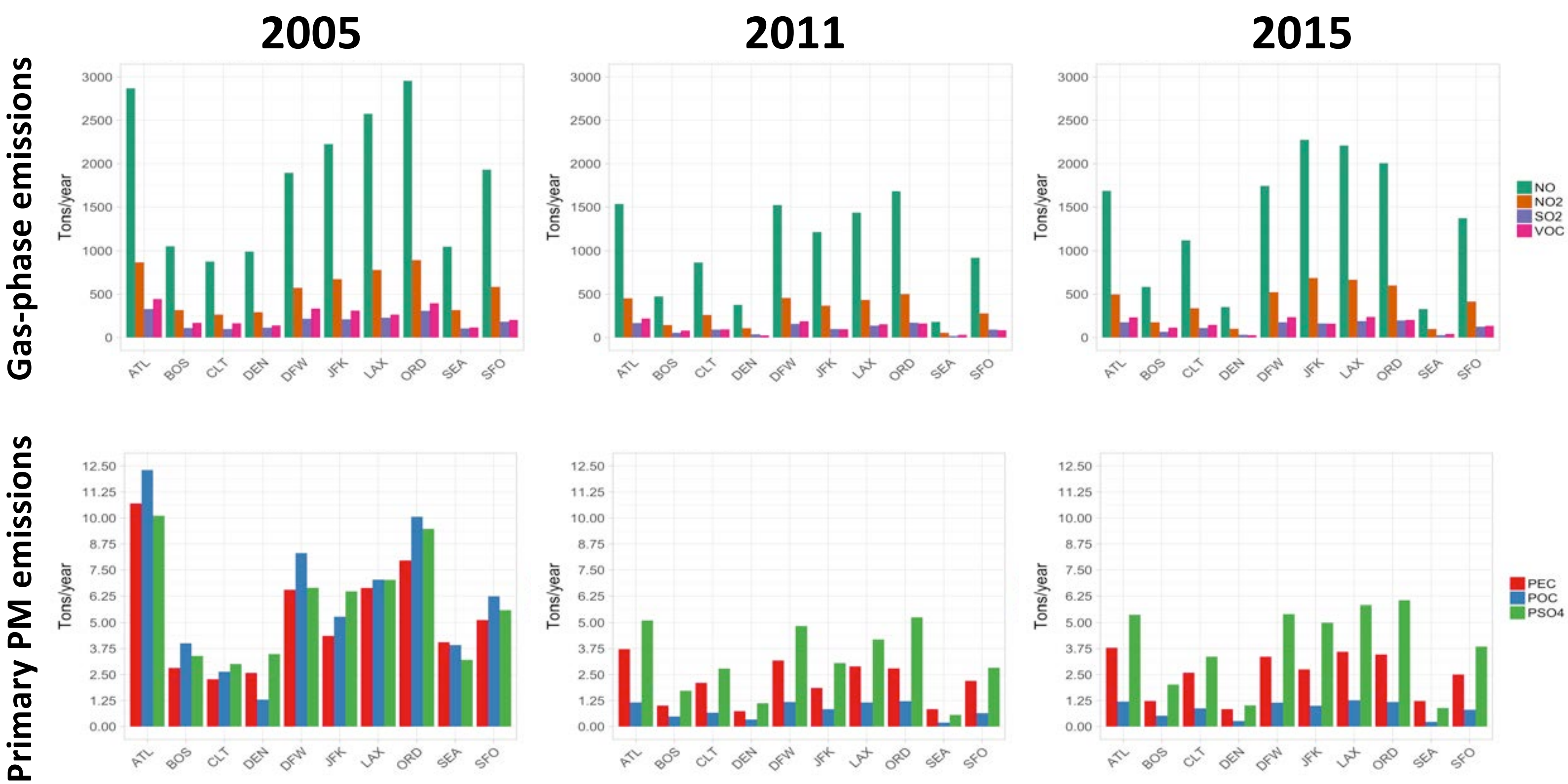
Prior platform with EDMS inventory has higher emissions than all AEDT inventories in current platform

Prior platform 2025 estimates represents 2.27 times higher activity than 2005

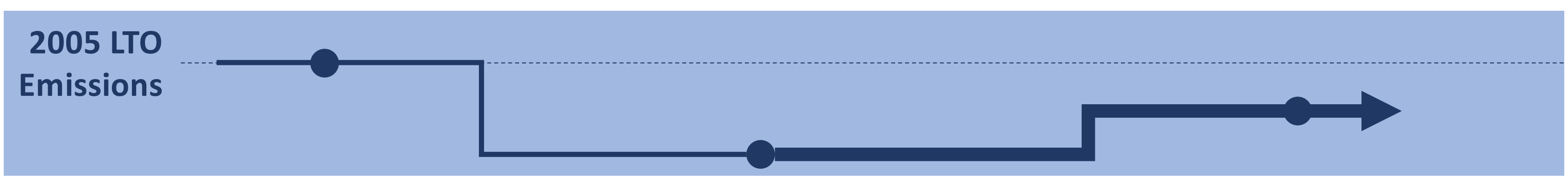
2005 AEDT inventory has higher emissions than 2011 and 2015 AEDT inventories, with 2011 having the lowest of the three

2015 AEDT inventory makes up the largest percent of total emissions during its year for NO_X and SO_2 emissions

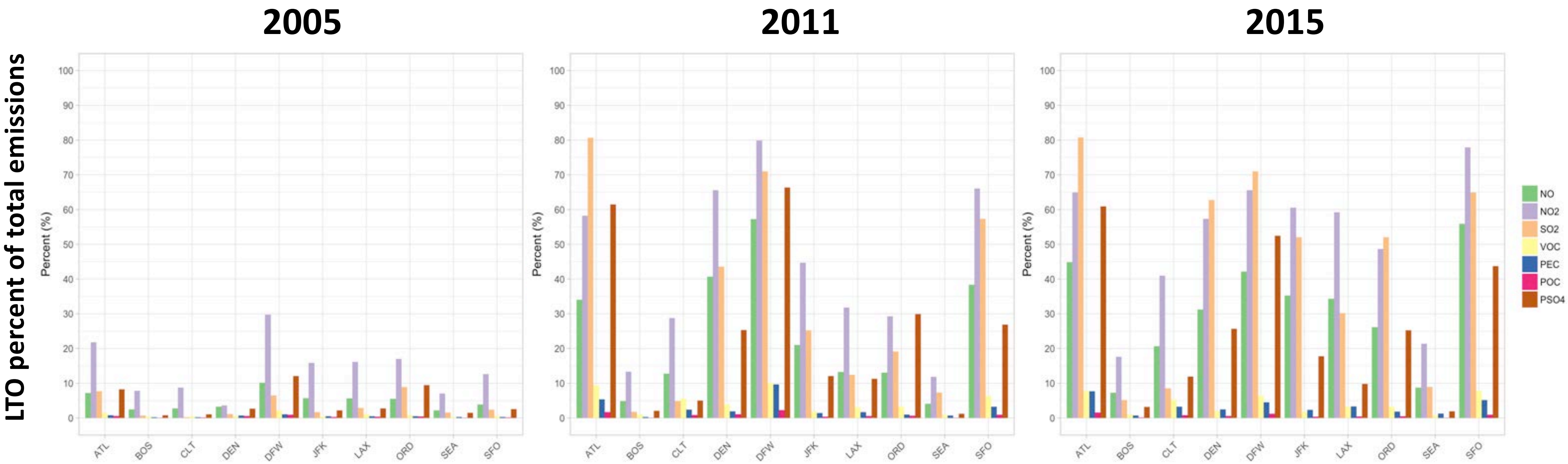
LTO Emissions at the Airport-Containing Grid Cell

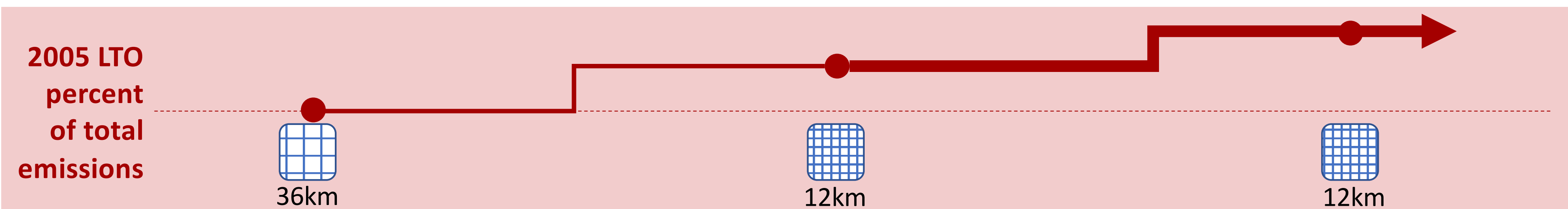


Airport-specific trends follow NAS-wide trends as 2005 LTO emissions are the largest and 2011 LTO emissions are the smallest



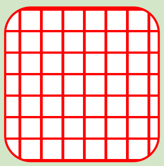
LTO Emissions as a Percent of Total Emissions at Airport-containing Grid Cell



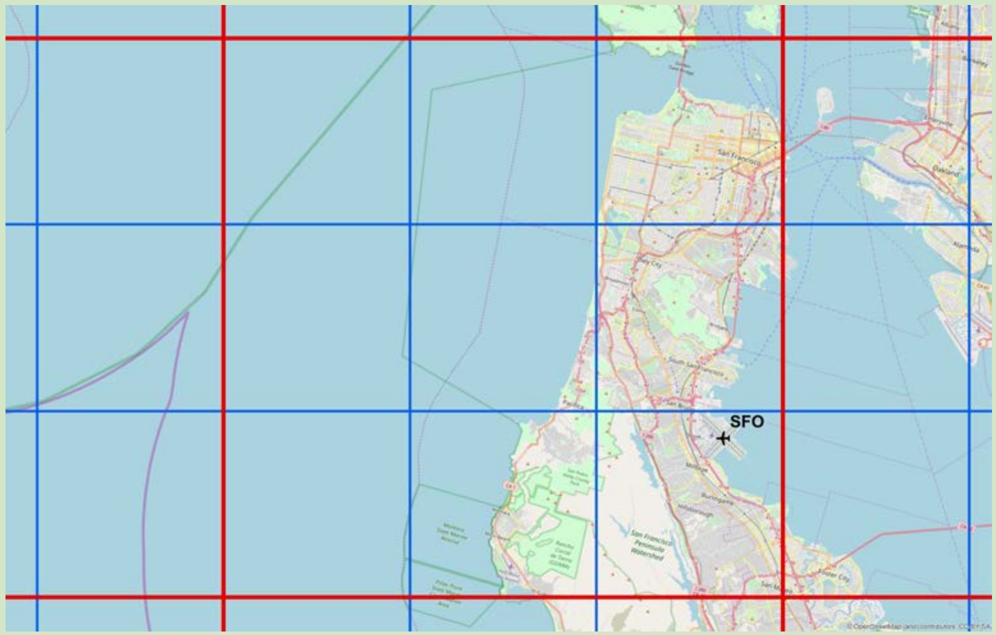


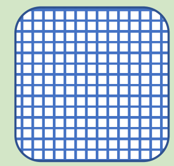
LTO emissions as a percent of total emissions are highly dependent on grid cell size, 2005 percentages in a 36km grid cell are much smaller than 2011/2015 percentages in 12km grid cells

Difference Between Grid Cell Resolution



36km





12km

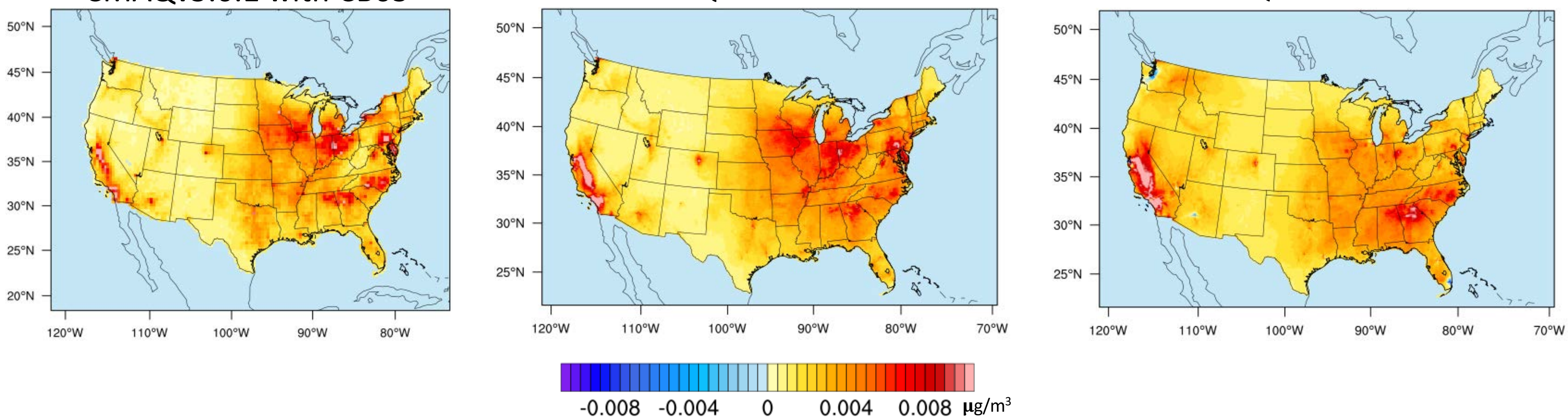
36km grid cell resolution contains much more of the surrounding area which can dilute aircraft emissions' impacts in the airport-containing grid cell

Domain-wide Aviation Attributable $PM_{2.5}$

2005 CMAQv5.0.1 with CB05

2011 CMAQv5.1 with CB05

2015 CMAQv5.2.1 with CB6



	2005	2011	2015
Domain-wide average ($\mu g/m^3$)	0.0023	0.0026	0.0027
Percent of total $PM_{2.5}$	0.03%	0.05%	0.04%

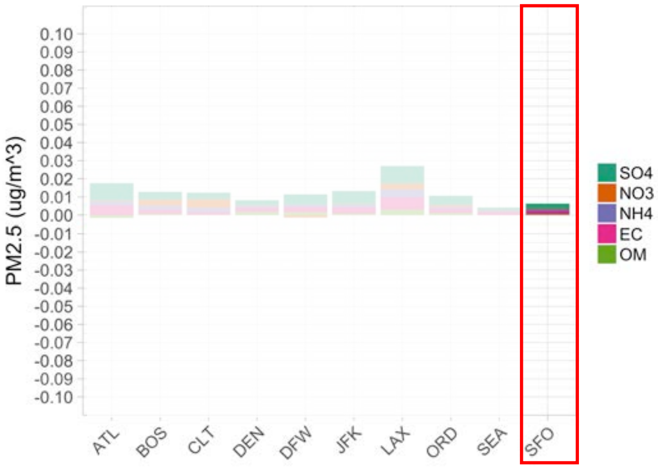
Domain-wide average aviation attributable $PM_{2.5}$ increases each year

Aviation attributable $PM_{2.5}$ as a percent of total $PM_{2.5}$ is highest in 2011

Airport-specific Aviation Attributable $PM_{2.5}$

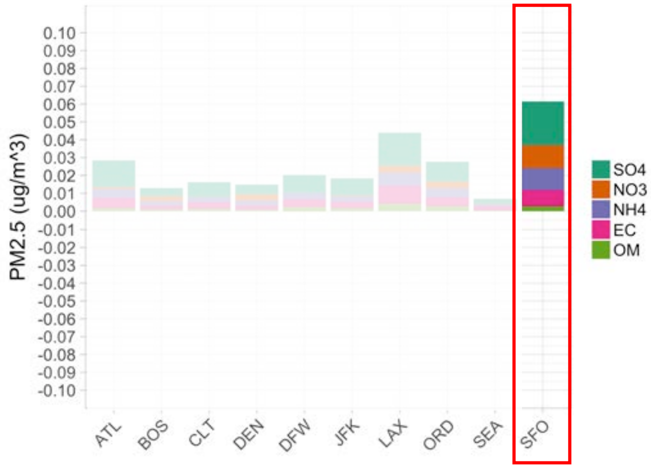
2005

CMAQv5.0.1 with CB05



2011

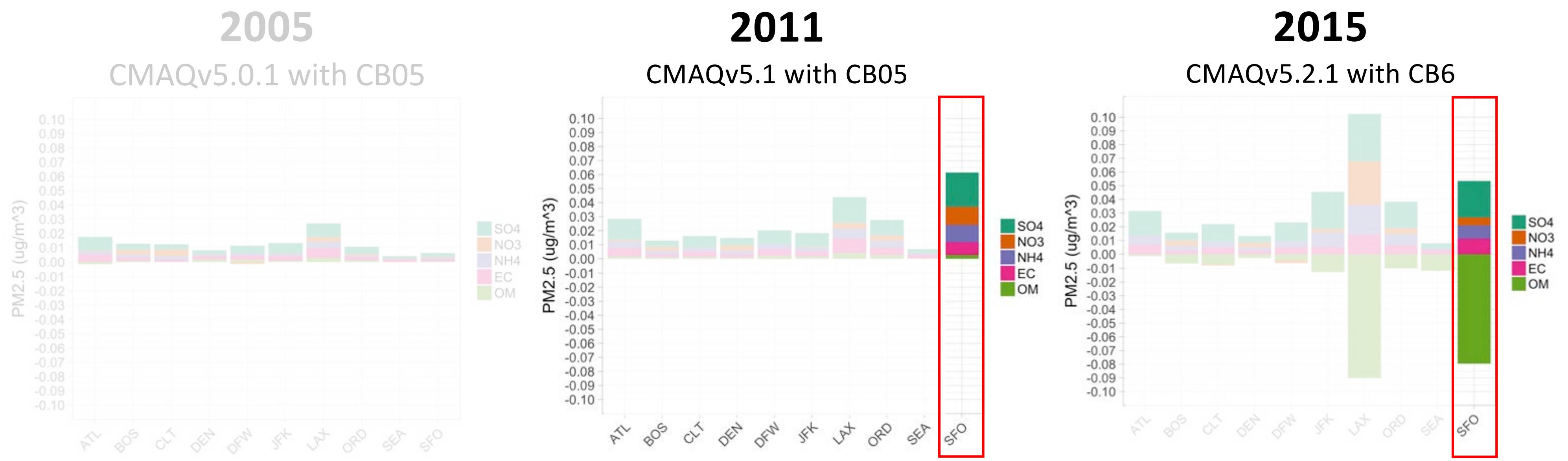
CMAQv5.1 with CB05



2015

CMAQv5.2.1 with CB6

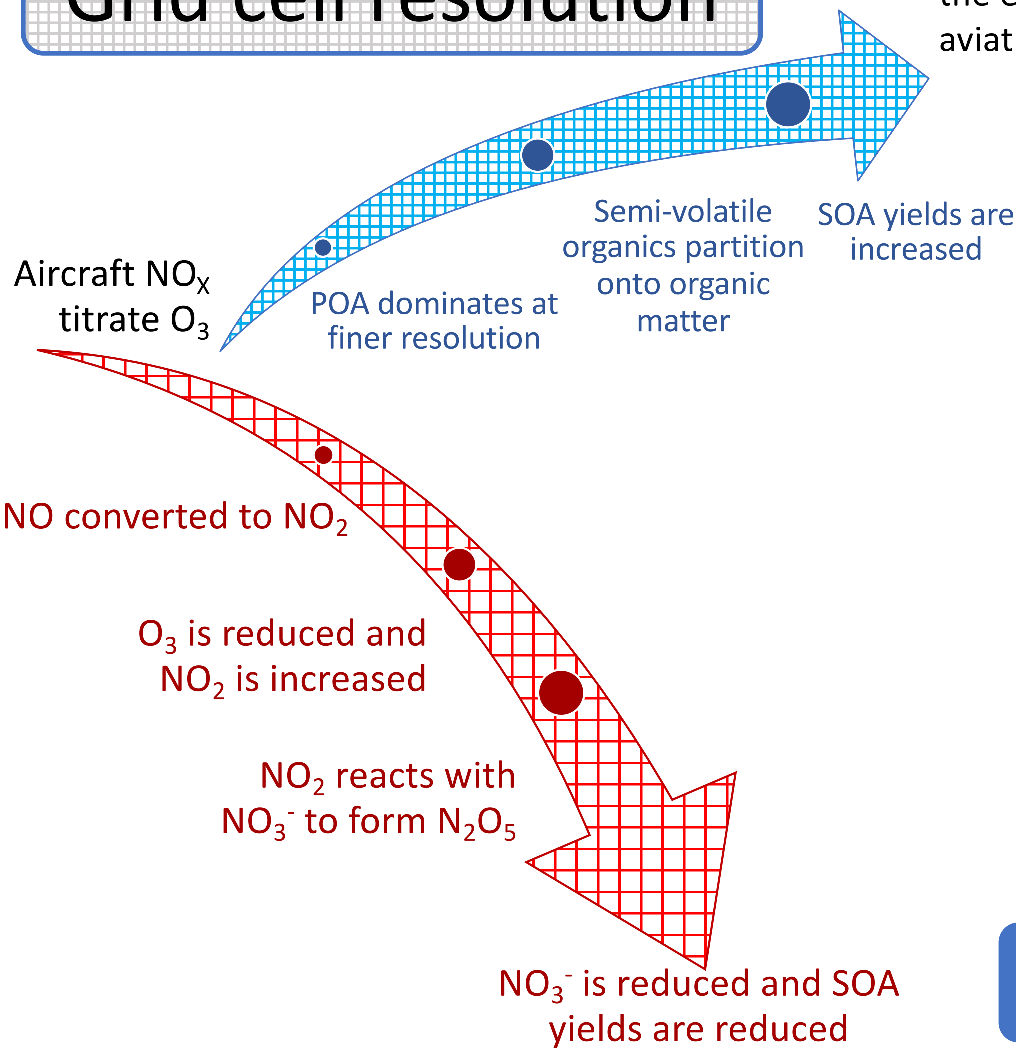
Airport-specific Aviation Attributable $PM_{2.5}$



Differences in aviation-attributable $PM_{2.5}$ at the airport-containing grid cell level can be explained by:

- Grid cell resolution
- Gas-phase chemical mechanism
- Aerosol treatment in model

Grid cell resolution



Two studies (Woody et al. 2013, Arunachalam et al. 2011) looked at the effect of three grid cell resolutions (36km, 12km, and 4km) on aviation-attributable $PM_{2.5}$

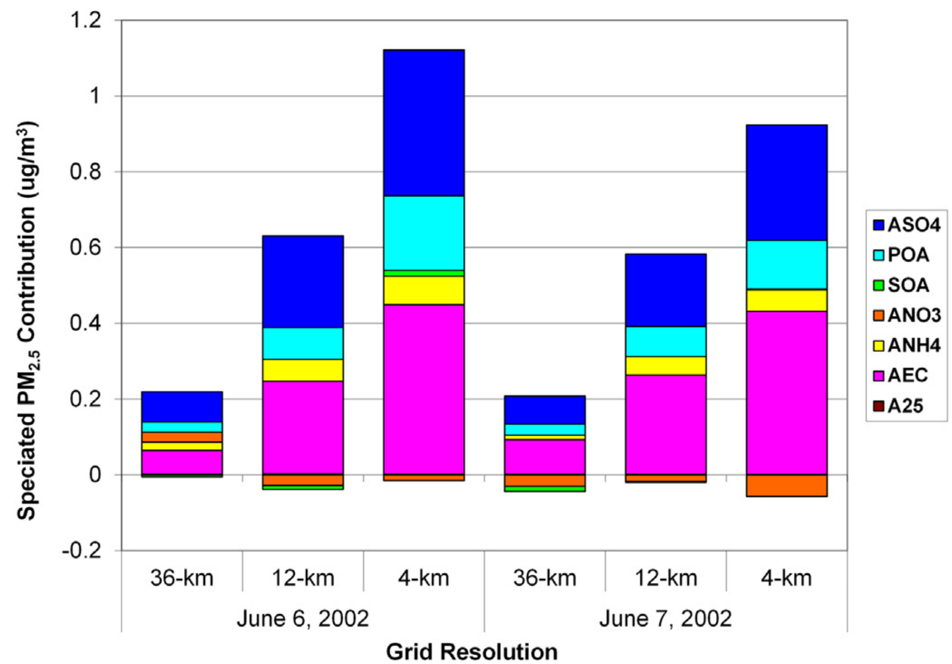


Fig. 3. Modeled speciated daily average speciated $PM_{2.5}$ contributions by mass from aircraft emissions at the grid cell containing the ATL airport on June 6 and 7, 2002 for sulfate (ASO4), primary organics (POA), secondary organics (SOA), nitrate (ANO3), ammonium (ANH4), elemental carbon (AEC), and crustal (A25) aerosols.

Coarser grid cell resolutions suppress rate of secondary organic aerosol (SOA) formation

Gas-phase chemical mechanism

Aircraft TOG is converted to VOC which is speciated according to FAA/EPA 2009 Profile

Species	Description	CB05	CB6	Impact on SOA formation
ALD2	•Acetaldehyde	✈	✈	
ALDX	•Propionaldehyde and higher aldehydes	✈	✈	
ETH	•Ethene	✈	✈	
ETHA	•Ethane	✈	✈	
FORM	•Formaldehyde	✈	✈	
IOLE	•Internal olefin carbon bond (R-C=C-R)	✈	✈	
MEOH	•Methanol	✈	✈	
OLE	•Terminal olefin carbon bond (R-C=C)	✈	✈	
PAR	•Paraffin carbon bond (C-C)	✈	✈	
TOL	•Toluene and other monoalkyl aromatics	✈	✈	
XYL/XYLMN	•Xylene	✈	✈	
ACET	•Acetone		✈	Photolyzes and can be a source of radicals
BENZ	•Benzene		✈	Precursor to glyoxal which is an SOA precursor
ETHY	•Ethyne		✈	Reacts slowly with OH, tends to accumulate at regional scales, precursor to glyoxal
NAPH	•Naphthalene		✈	Same reaction products and rates as xylene
PRPA	•Propane		✈	Precursor to acetone
SOAALK	•Precursor to alkane SOA		✈	Lumped SOA tracer species that accounts for SOA formed from alkanes

An illustrative point regarding model specific gas-phase and aerosol-phase chemistry[a]

Model specific details in CMAQv4.6

- Anthropogenic SOA precursors undergo oxidation *only* with OH
- Biogenic SOA precursors undergo oxidation with OH, NO_3^-, O_3, and odd oxygen
- Change in OH radicals has greater influence on anthropogenic SOA
- High and low-NO_X pathways only for anthropogenic SOA

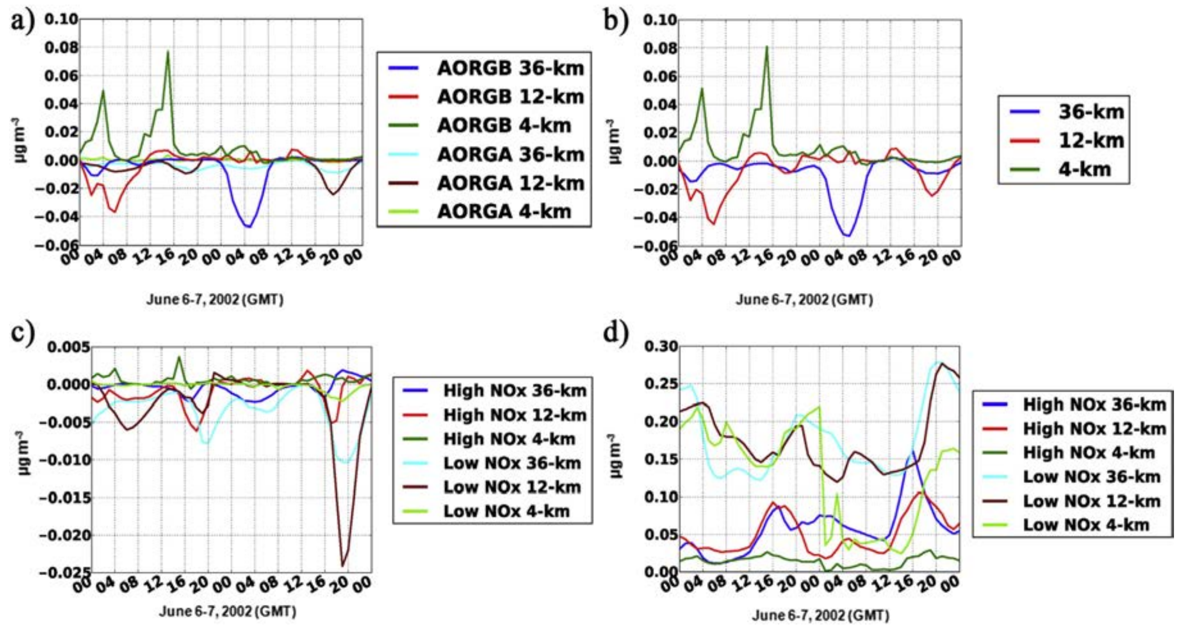


Fig. 6. Changes in (a) anthropogenic (AORGA), biogenic (AORGB), and (b) total SOA concentrations due to aircraft emissions at ATL. Changes in anthropogenic SOA concentrations formed from low and high-NO_x pathways at ATL (c) due to aircraft emissions and (d) due to emissions from all sources.

As the CMAQ model develops, the chemical and physical processes evolve to capture the most up-to-date science

[a]Woody et al. 2013

Aerosol treatment in model

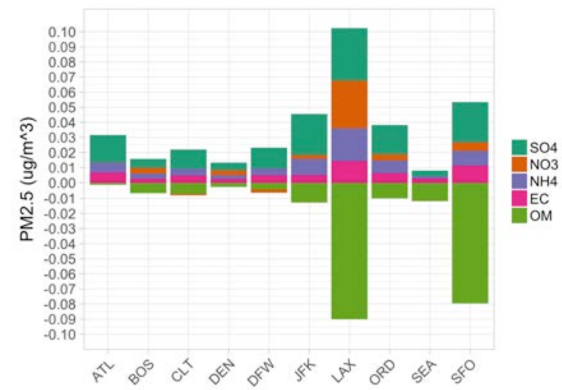
2011

CMAQv5.1 with CB05

LTO aircraft emissions **positively** contribute to OM (organic aerosol) portion of $PM_{2.5}$

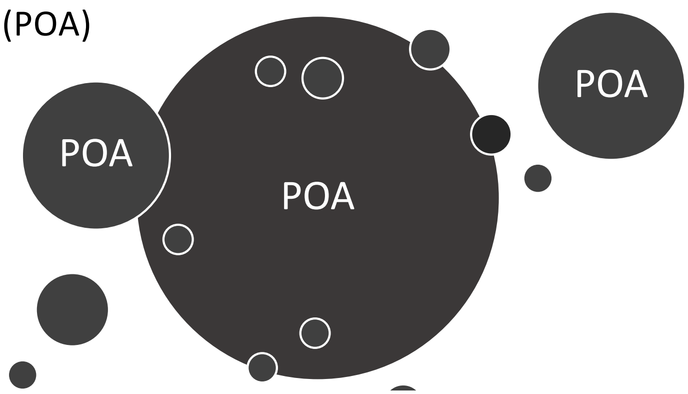
2015

CMAQv5.2.1 with CB6

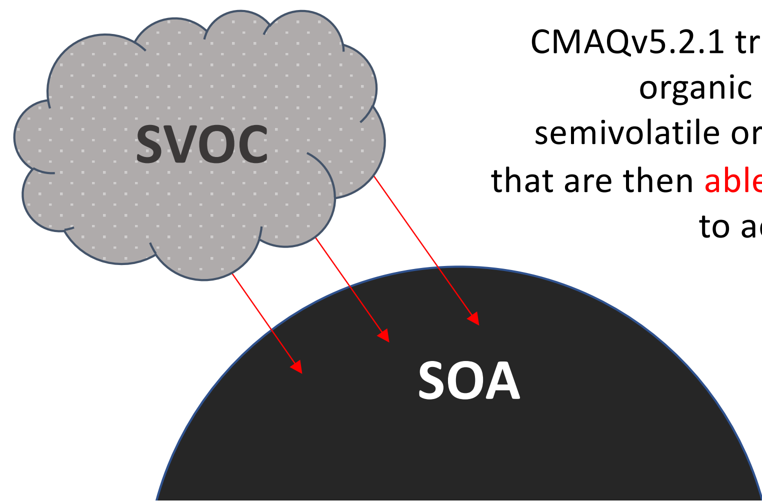


LTO aircraft emissions **negatively** contribute to OM (organic aerosol) portion of $PM_{2.5}$

CMAQv5.1 treats primary organic emissions as primary organic aerosol (POA)



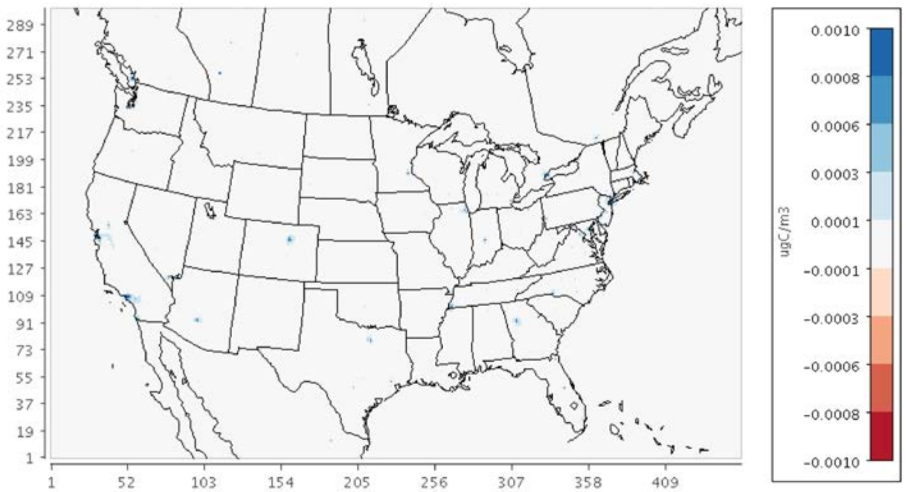
CMAQv5.2.1 treats primary organic emissions as semivolatile organic vapors that are then able to partition to aerosol phase



Aviation-attributable POA

2011

CMAQv5.1 with CB05



2015

CMAQv5.2.1 with CB6

APOCI + APOCJ → APOCIJ

Aerosol calculations in the models

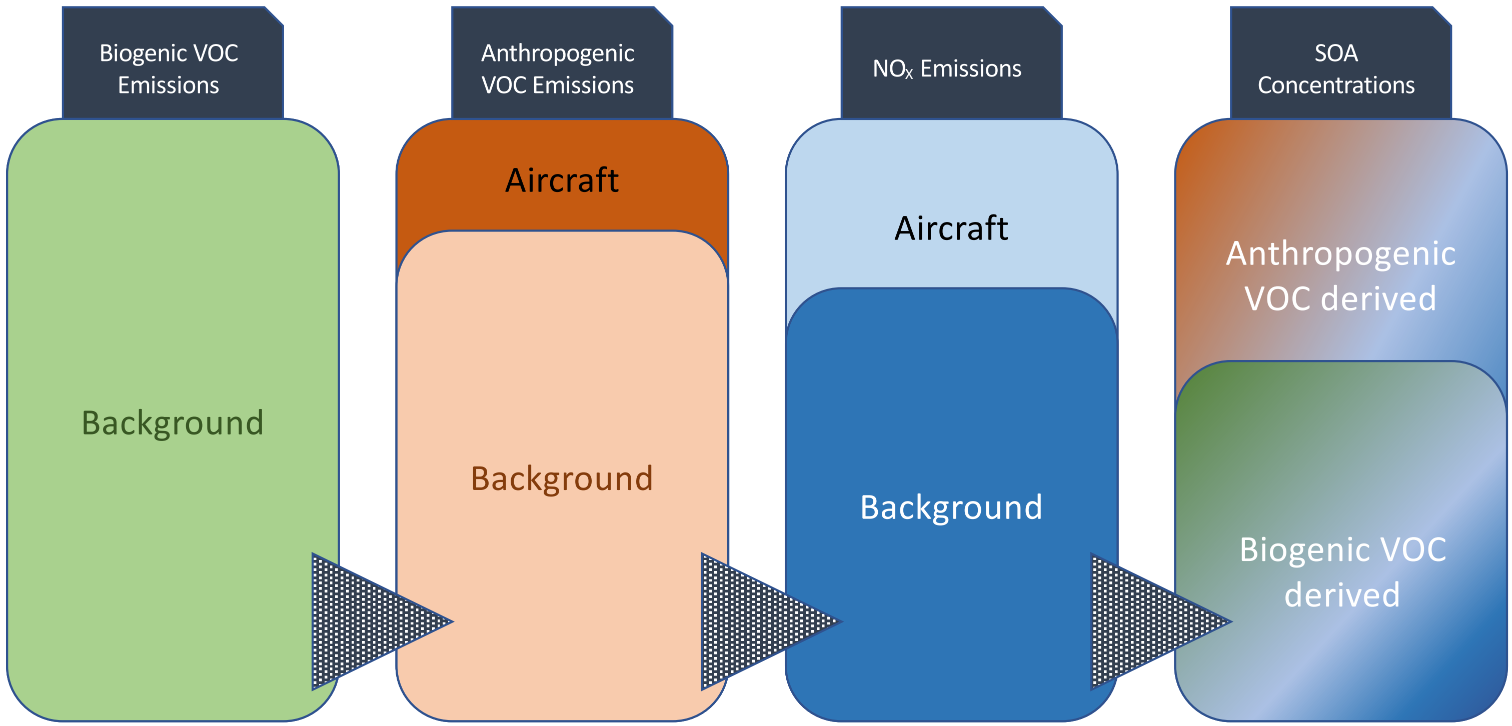
APOCI+APOCJ → APOCIJ

ALVPO1J/1.39+ASVPO1J/1.32+ASVPO2J/1.26+ASVPO3J/1.21
+AIVPO1J/1.17+ALVPO1I/1.39+ASVPO1I/1.32+ASVPO2I/1.26

LTO emissions **positively** contribute to POA in the 2011 CMAQv5.1 simulation

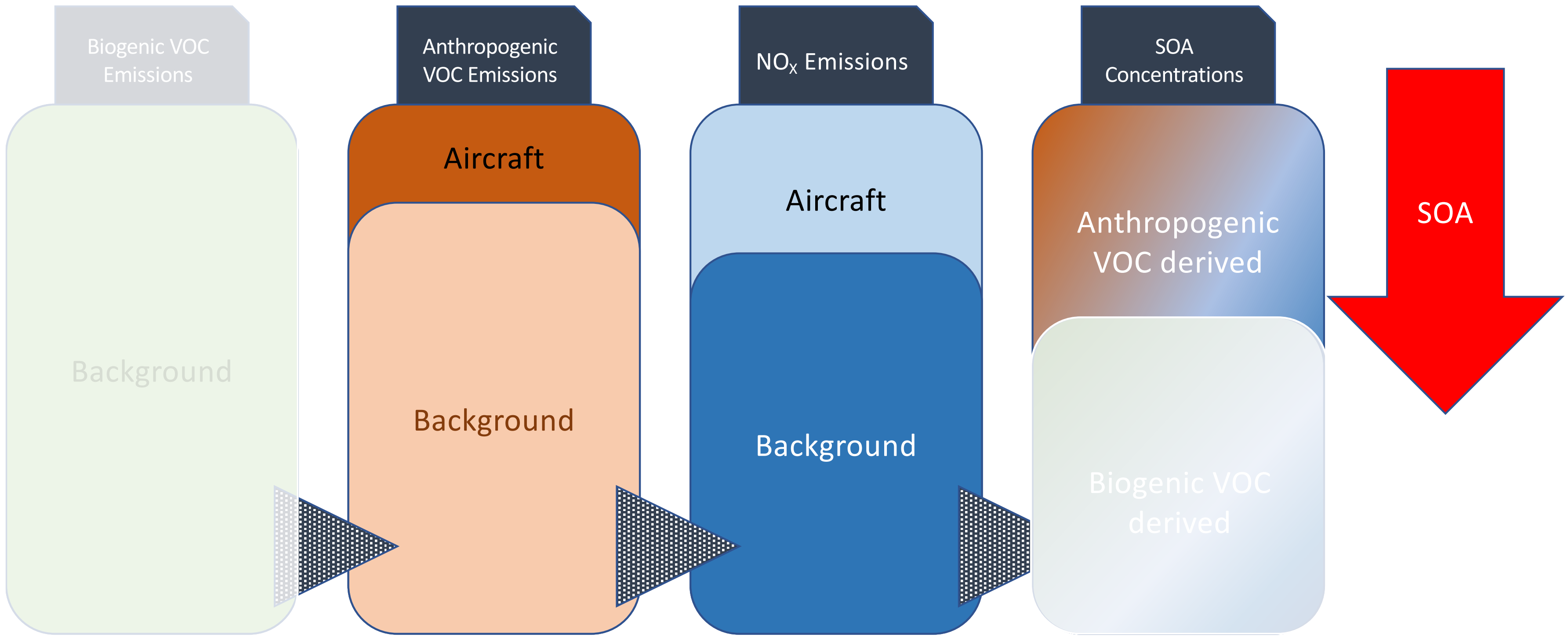
LTO emissions **negatively** contribute to POA in the 2015 CMAQv5.2.1 simulation

Biogenic and Anthropogenic VOC-derived SOA



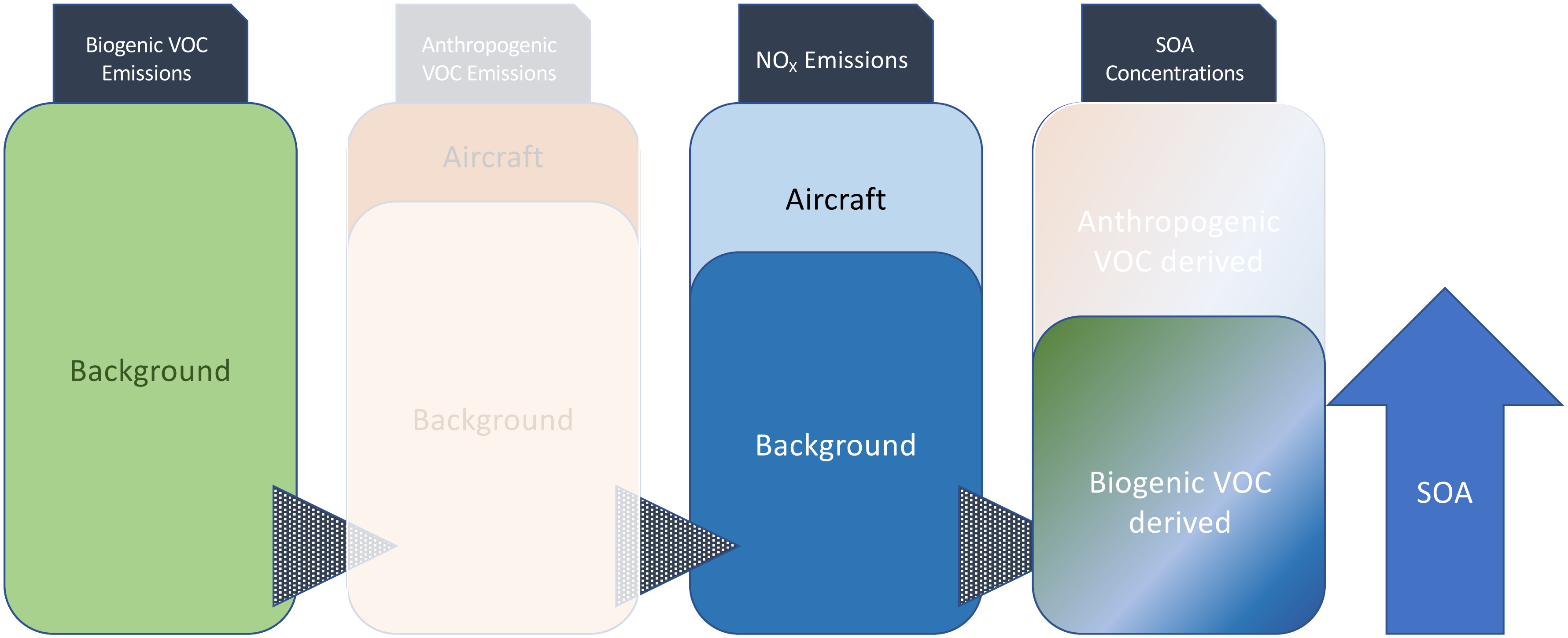
SOA formation differs under high/low-NO_X conditions

Anthropogenic VOC-derived SOA



Anthropogenic VOC-derived SOA yield is suppressed under high-NO_X conditions

Biogenic VOC-derived SOA

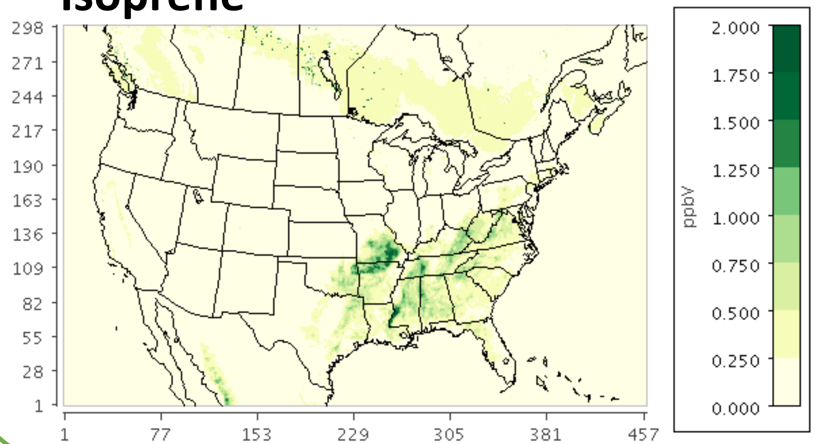


Biogenic VOC-derived SOA yield is enhanced under high-NO_X conditions

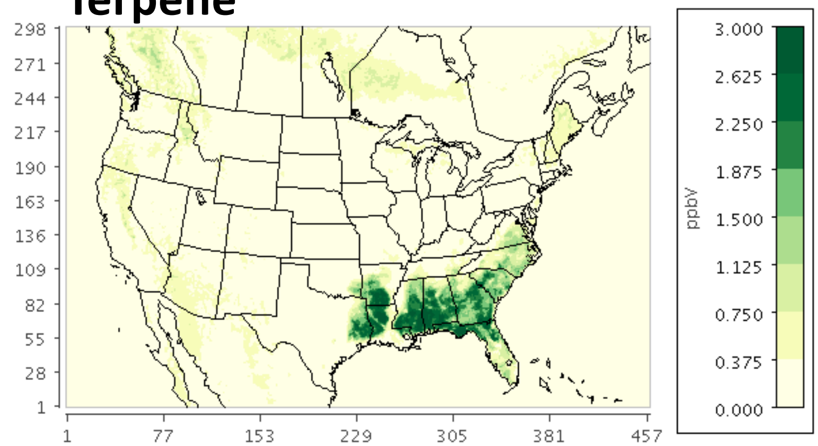
Examples of Biogenic and Anthropogenic VOCs

Biogenic

Isoprene

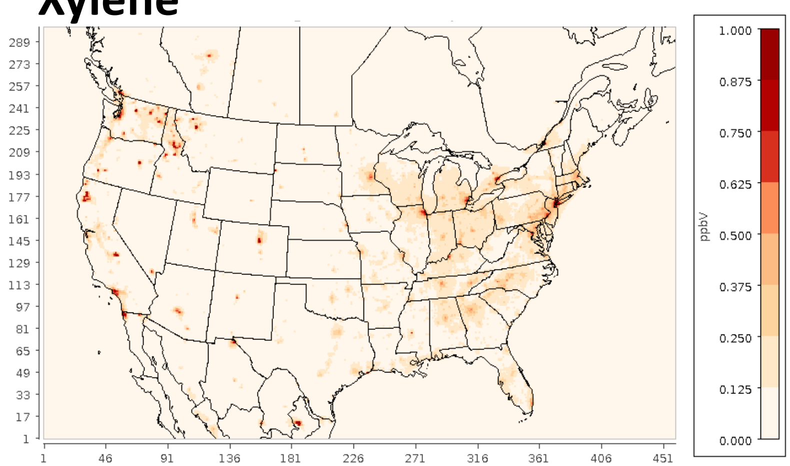


Terpene

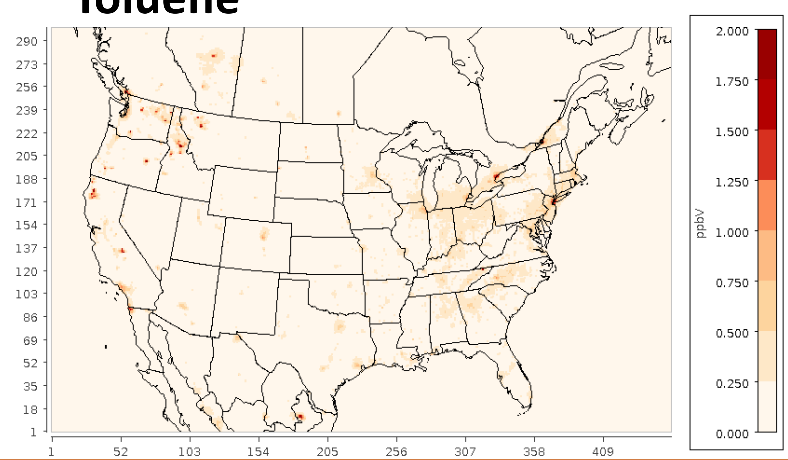


Anthropogenic

Xylene



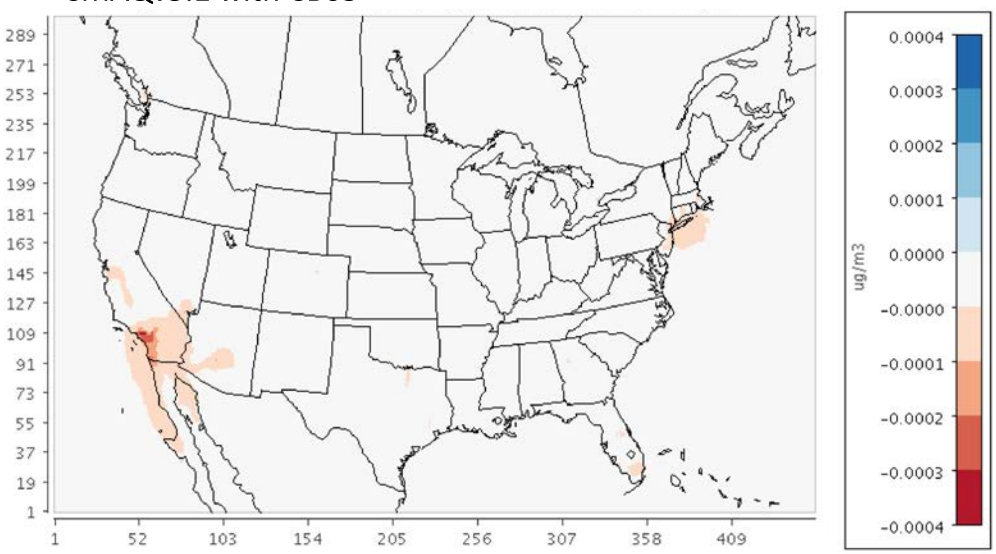
Toluene



Aviation-attributable anthropogenic-VOC derived SOA

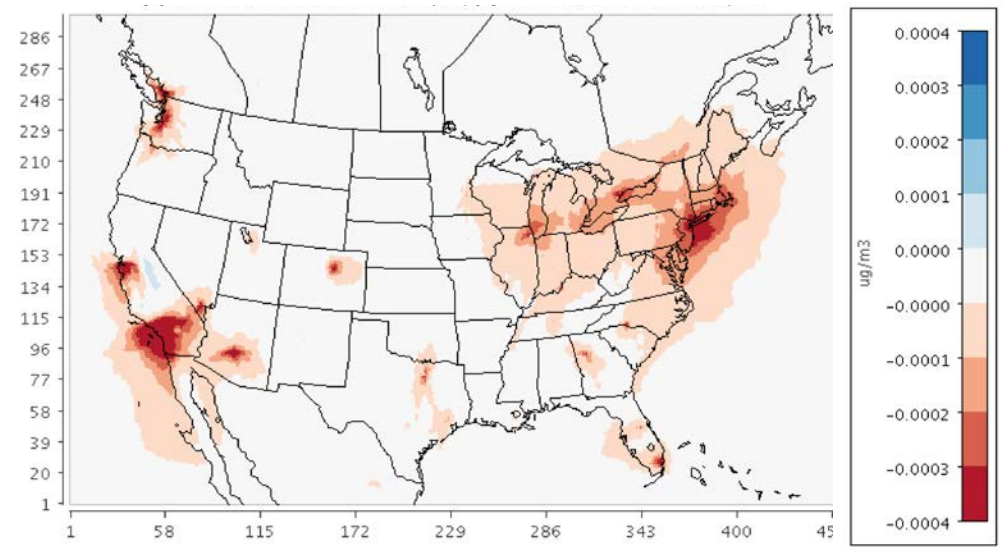
2011

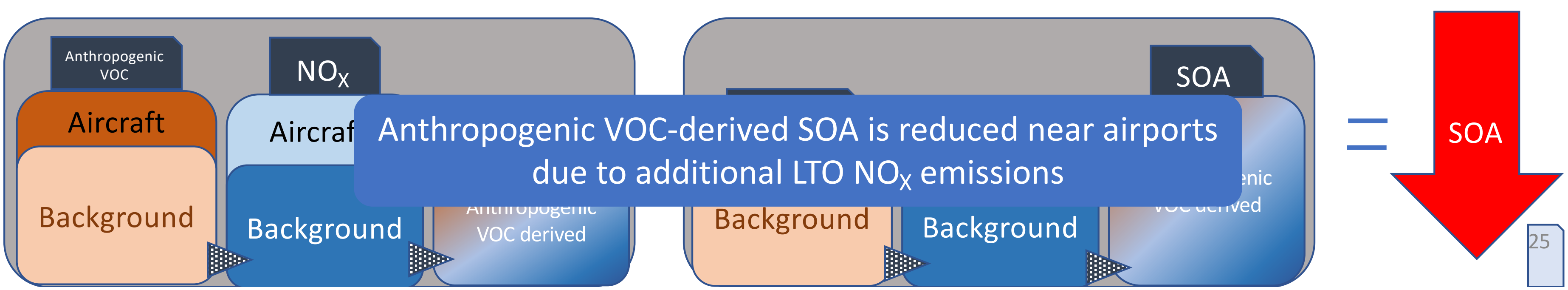
CMAQv5.1 with CB05



2015

CMAQv5.2.1 with CB6



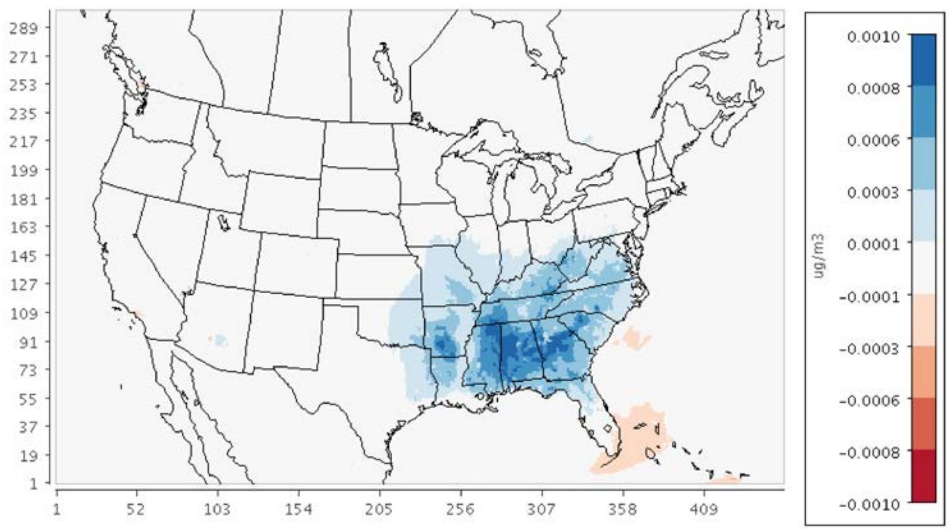


Anthropogenic VOC-derived SOA is reduced near airports due to additional LTO NO_X emissions

Aviation-attributable biogenic-VOC derived SOA

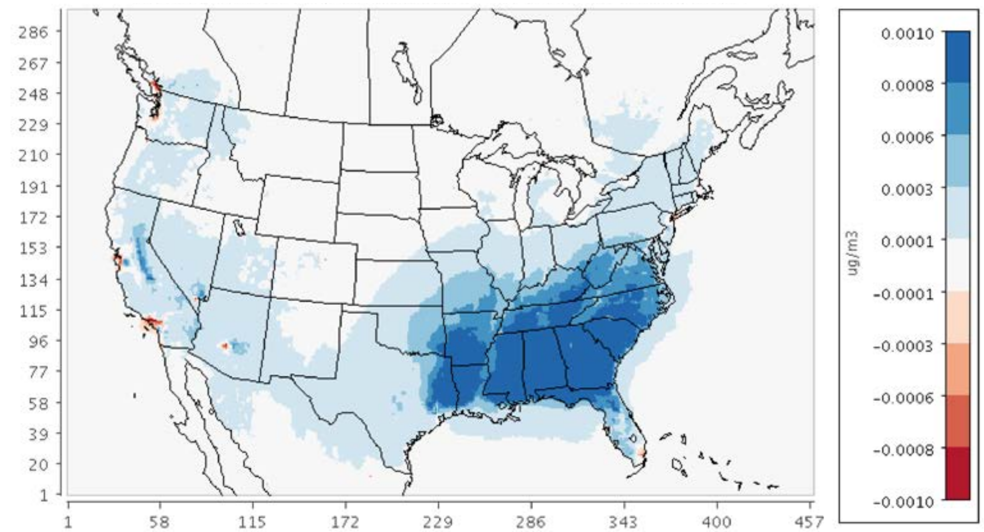
2011

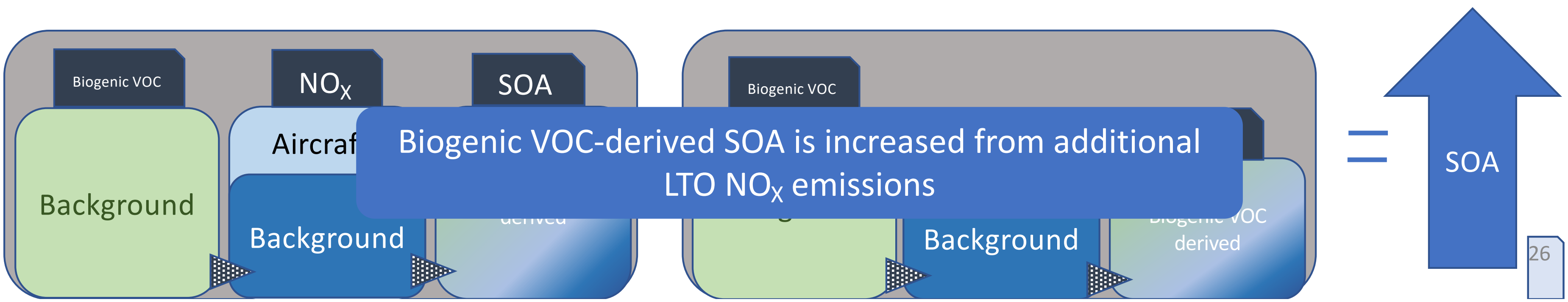
CMAQv5.1 with CB05



2015

CMAQv5.2.1 with CB6





Biogenic VOC-derived SOA is increased from additional LTO NO_X emissions

Task 2: UFP Study at Boston Logan

Objective

- Develop high resolution model application for Boston Logan and compare with UFP measurements from field study at Logan

Approach

- Phase 1: Develop SCICHEM application
  - Presented at last meeting
  - Several limitations found with SCICHEM, and being wrapped up
- Phase 2:
  - Create new Logan LTO inventory using AEDT
  - Create WRF-SMOKE-CMAQ modeling application @12/4/1-km
    - Use updated CMAQ with new nucleation mode for aerosols, and new aircraft-specific module for accurate particle size distribution for aircraft emissions
  - Perform model-monitor comparisons

Task 3: New Dispersion Modeling Framework

- Objective
  - Demonstrate that a robust, improved pollutant dispersion model for aircraft can be developed for U.S. regulatory compliance purposes
- Known limitations
  - Several studies have shown limitations with AERMOD – the current local scale dispersion model used for airport-level assessments
  - Problems identified in issues related to:
    - Source representation: area vs. volume
    - Lack of plume rise for hot buoyant plumes
    - Limited treatment of chemistry, etc.
- Next steps
  - Perform comprehensive literature review including various modeling approaches – line, puff, line-puff, etc. – in existing models
  - Review current approaches for developing airport-level emissions inventories in AEDT/AERMOD
  - Develop initial design of new framework for new modeling approach
    - Include itemized list of research tasks needed to develop framework

Summary

- Summary statement
  - Modeled impacts of LTO emissions on the formation of $PM_{2.5}$ shows a modest 17% increase in domain-wide $PM_{2.5}$ from 2005 to 2015
  - Impacts at the airport-containing grid cell level are primarily determined by modeled grid cell resolution, gas-phase chemical mechanism, and aerosol treatment within the model
- Next steps
  - Finalize comparisons of current year-over-year trajectory with previous trajectory from 2005 to 2025
  - Start high resolution model application for Boston Logan with enhanced modeling system for model-measurement assessment
  - Start review of dispersion model limitations to develop new framework

Interfaces and Communications

- External
  - Multiple presentations at Annual CMAS Conference, and UC Davis Aviation Noise and Emissions Symposium
  - Additional presentations:
    - NC-BREATHE Conference, April 2019
  - National Aviation University, Kyiv, Ukraine

- Within ASCENT
  - ASCENT NOI 18 (BU)

Contributors

- UNC: S. Arunachalam, C. Arter, M. Chowdhury, B.H. Baek, D. Yang
- BU: Jonathan Levy, Kevin Lane and team
- U.S. DOT Volpe Center for AEDT inventories
- U.S. EPA: Alison Eyth for NEI inventories