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 Managers: Jeetendra Upadhyay, Mohammed Majeed, FAA

Fall Advisory Board Meeting
September 26 - 27, 2017
Alexandria, VA

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

Real-world atmospheric process includes feedback of chemistry on meteorology, which some models do not capture

- Chemistry Transport Model (CTM) vs. Climate Response Model (CRM)

- 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 emissions-attributable health impacts are 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
  - Adapt air quality modeling tools to estimate AQ impacts due to aviation emissions NAS-wide to facilitate year-to-year reporting and scenario analysis
  - Develop implementation of advanced sensitivity tools in CMAQ (such as the Decoupled-Direct Method [DDM]) to allow for individual airport-related AQ and health impact characterization, informing a more dynamic modeling tool
  - Assess/quantify changes in aviation-attributable concentrations due to changes in assumptions aircraft-emitted $PM_{2.5}$ size distributions
  - Develop tools that use consistent set of meteorological inputs for emissions, and air quality models

Outcomes and Practical Applications

- Outcomes
  - Provide tools that combined will:
    - Enable the assessment of exposure and mortality/morbidity risk due to aviation-attributable $PM_{2.5}$ and ozone
    - Allow for the assessment of a wide range of aircraft emissions scenarios, including differential growth rates and emissions indices
    - Account for changes in non-aviation emissions and allow for assessing sensitivity to meteorology
    - Refined and consistent modeling framework across scales
    - Provide NAS-wide and airport-by-airport results
- Practical applications
  - Tools for policy-makers considering various potential aviation policy scenarios
  - Improved understanding of aviation impacts in terms of air quality and public health
  - Updated metrics to track aviation air quality impacts

Approach (1 of 2)

- CMAQ-WRF-SMOKE modeling system
  - Upgrade to latest versions of the model with improved science
- WRF downscaled from NASA's MERRA Reanalysis dataset
- New higher resolution application for the entire U.S.
  - 12x12-km instead of 36x36-km in prior work
  - Over 10x increase in computational resources
- EPA's NEI for 2011 and 2014 for non-aviation sources
- FAA's AEDT chorded inventories for 2011 and 2015
- Initial and background conditions from climatological averages and Northern hemispheric-scale CMAQ applications for consistency

Approach (2 of 2)

- Assess airport contributions to hypothetical non-attainment
- Using 2005 modeling platform, but upgraded to using CMAQ V5.0.2 with Decoupled Direct Method (DDM)
  - Compute both 1st and 2nd order O_3 and $PM_{2.5}$ sensitivities to precursors
- Identify airports in the U.S. based upon following criteria
  - Currently in attainment for all criteria pollutants
  - Falls in at least “Small” size category per FAA VALE classification
    - (> 0.05% of total enplanements)
  - In geographically diverse regions with broadly varying climatological conditions (temperature and precipitation)
  - Serves a major metropolitan area with at least 1M people
- Initial list of 17 airports, screened to choose 5 airports
  - Seattle Tacoma, WA (SEA), Raleigh-Durham, NC (RDU), Boston Logan, MA (BOS), Kansas City, KS (MCI), Tucson, AZ (TUS)

Schedule and Status

- NAS-wide analyses **[Ongoing]**
  - With revised AEDT inputs, implement new higher resolution framework for 2011, 2015
- Airport-specific analyses
  - Develop 1st order sensitivities for 66 airports [**Completed**]
  - Develop 2nd order sensitivities [**Completed]**
  - Develop non-linearity ratios **[Ongoing]**
- Create tools and approach for processing High Fidelity Weather for use in AEDT **[Completed]**
- Assess impacts of changes in $PM_{2.5}$ size distributions
  - Annual simulations [**Completed]**
- Develop new AEDT generalized gridding tool **[Completed]**
- Perform monitor-model comparisons of UFP from Boston Logan airport **[Not yet started]**

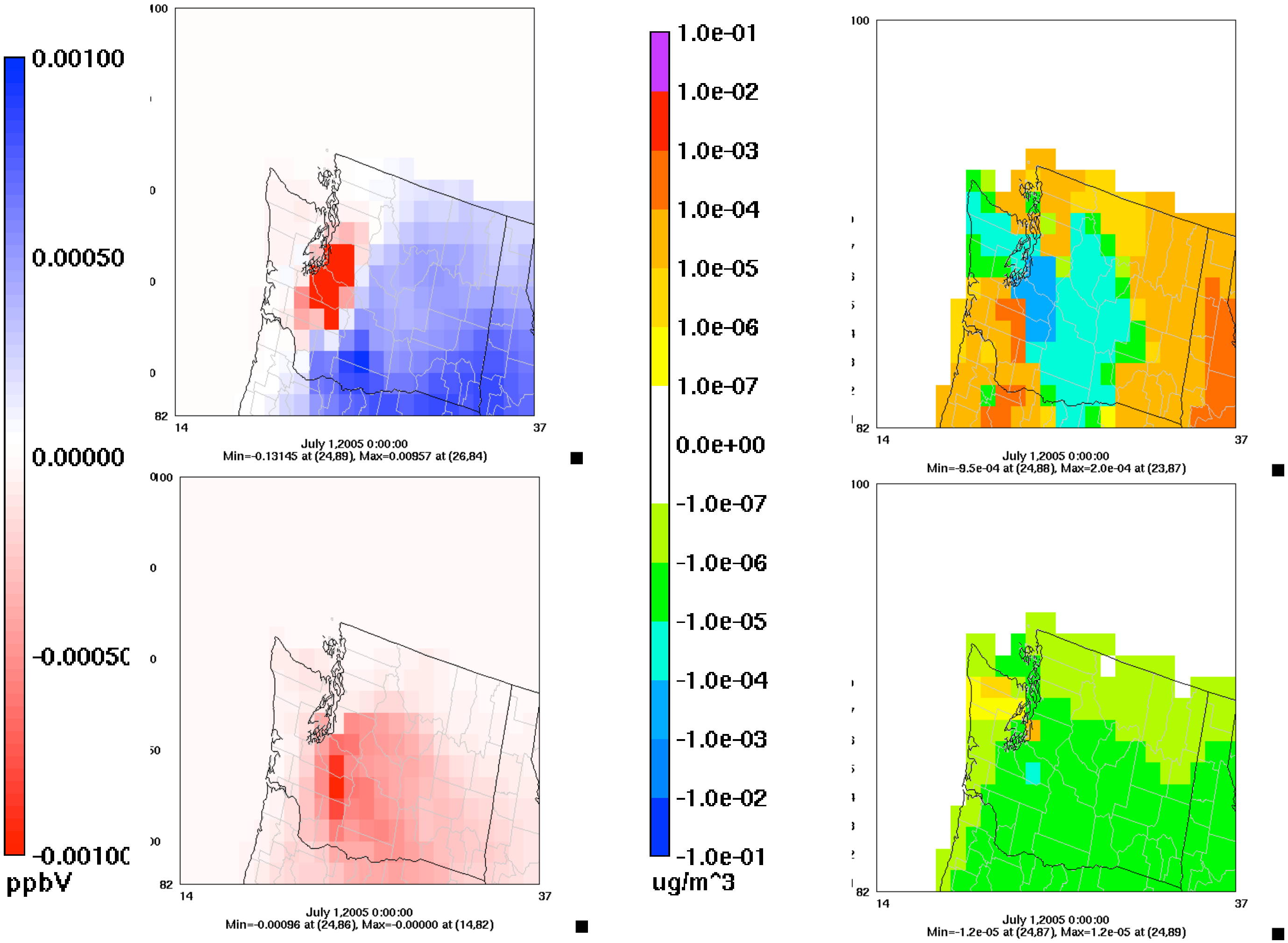
Characteristics of 5 Chosen Airports

Airport	Code	Enplanements	Population	Average Annual Min Temp (degF)	Average Annual Max Temp (degF)	Average Annual Precip (in) 2005 - 2009
Boston	BOS	15.6 M	4.8 M	37 – 43	59 – 68	51 – 80
Kansas	MCI	5.0 M	2.1 M	43 – 48	59 – 68	36 – 50
Raleigh-Durham	RDU	4.7 M	1.3 M	48 – 55	68 – 77	36 – 50
Seattle-Tacoma	SEA	17.9 M	3.8 M	43 – 48	68 – 77	36 – 50
Tucson	TUS	1.6 M	1.0 M	48 – 55	77 – 86	0 – 20

CMAQ-DDM Sensitivities for O_3 and $PM_{2.5}$ to NO_x Emissions from Seattle

1st Order O_3

2nd Order O_3



1st Order $PM_{2.5}$

2nd Order $PM_{2.5}$

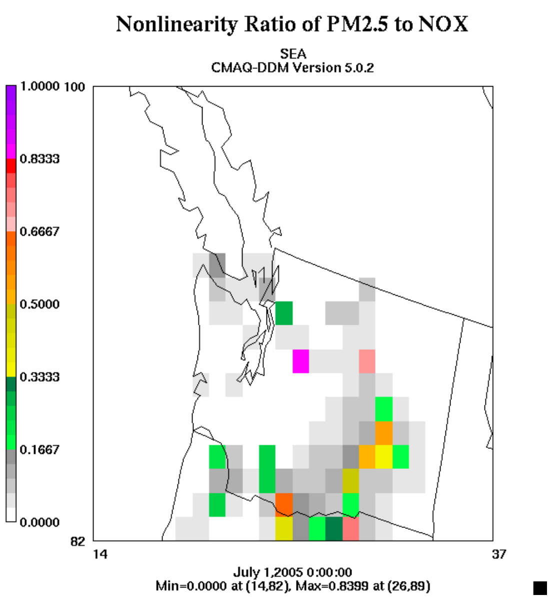
1st Order O_3 and $PM_{2.5}$ sensitivities show localized decreases and downwind increases
2nd Order sensitivities are generally smaller, showing the effects of non-linearities

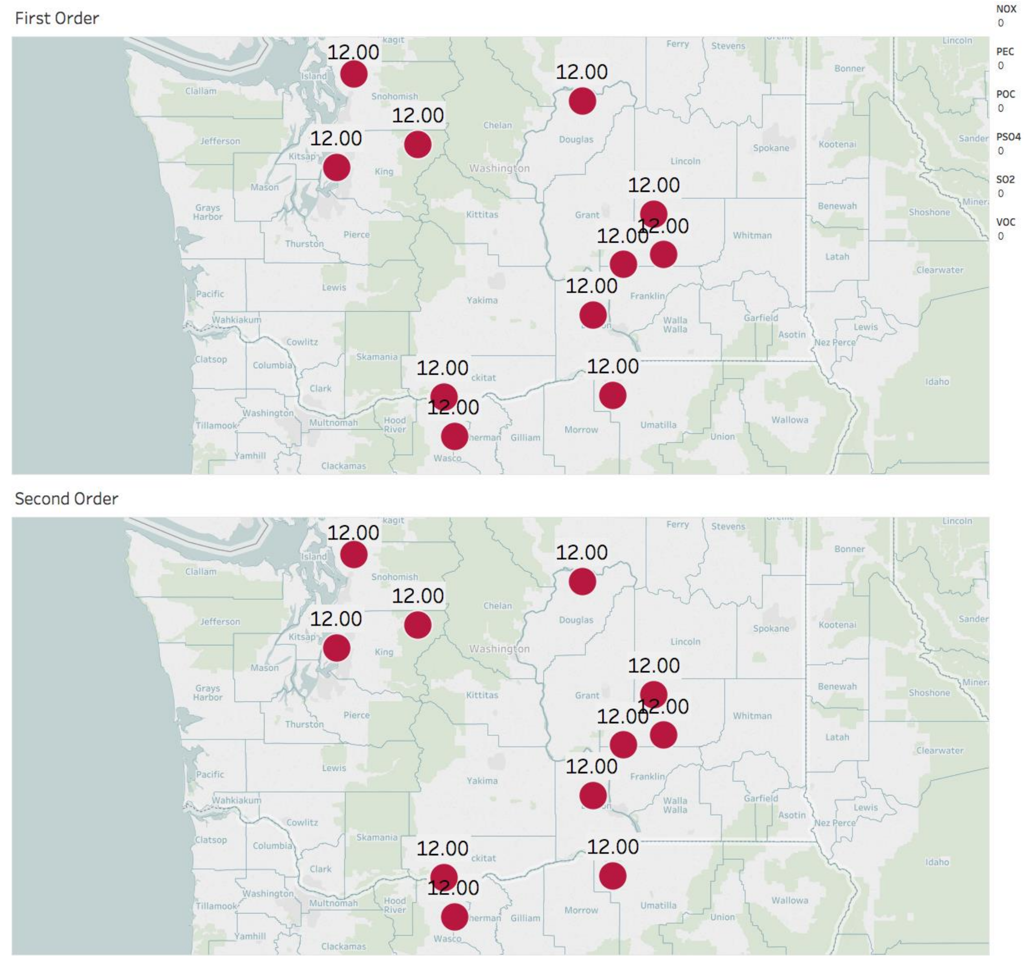
CMAQ-DDM Sensitivities and Non-linearity analysis @ Seattle

- Use non-linearity ratio:

$$R_{O_3} = \frac{|0.5S^{(2)}|}{|S^{(1)}| + |0.5S^{(2)}|}$$

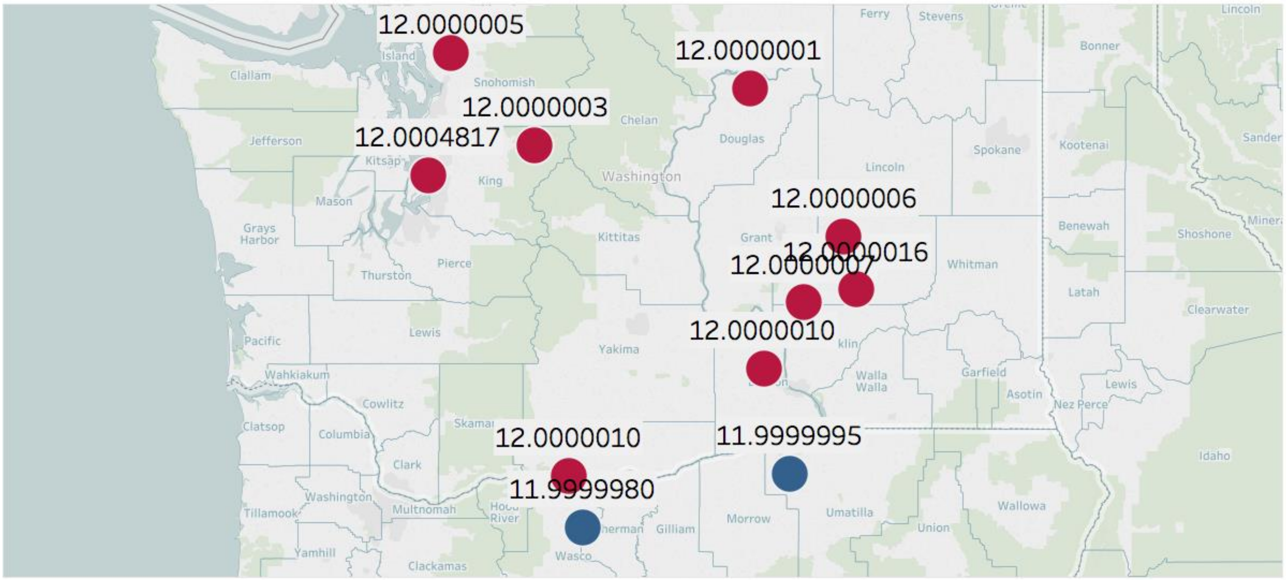
  - R_{O3} ranges from 0 – 1





Interactive Tool for Assessing Impacts due to Changes in Emissions

First Order



NOX
-0.518759380

PEC
0

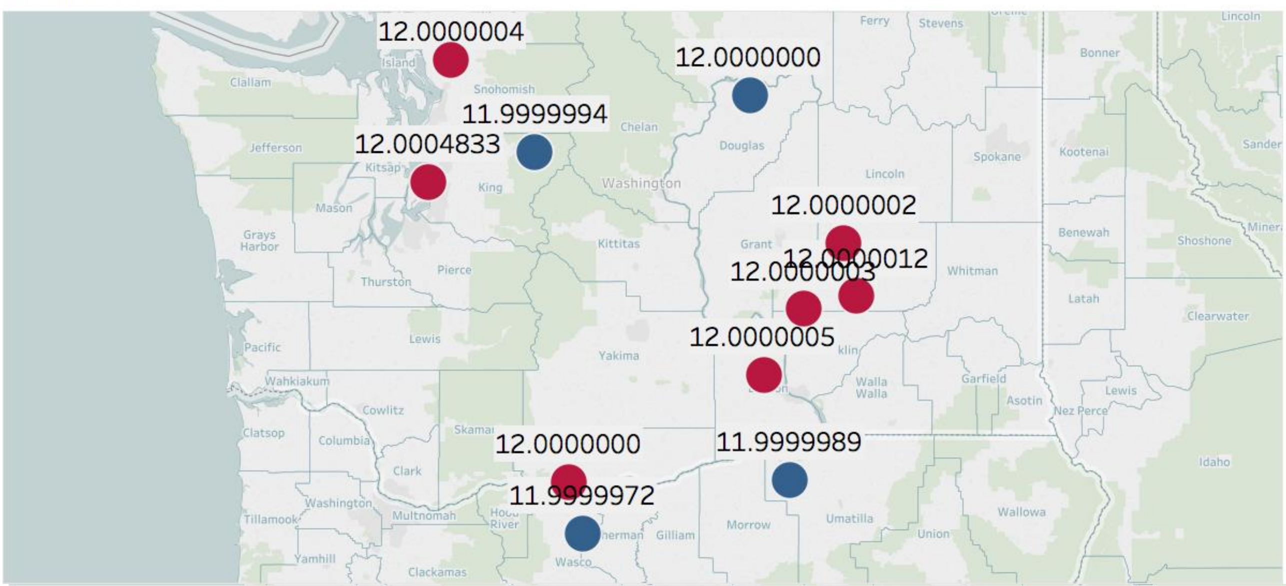
POC
0

PSO4
0

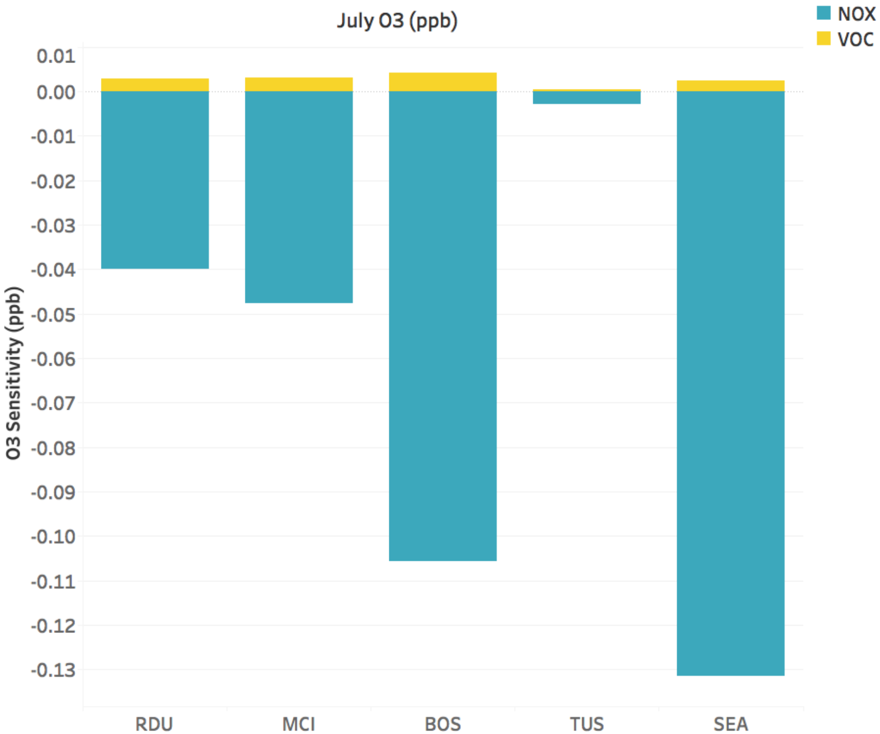
SO2
0

VOC
0

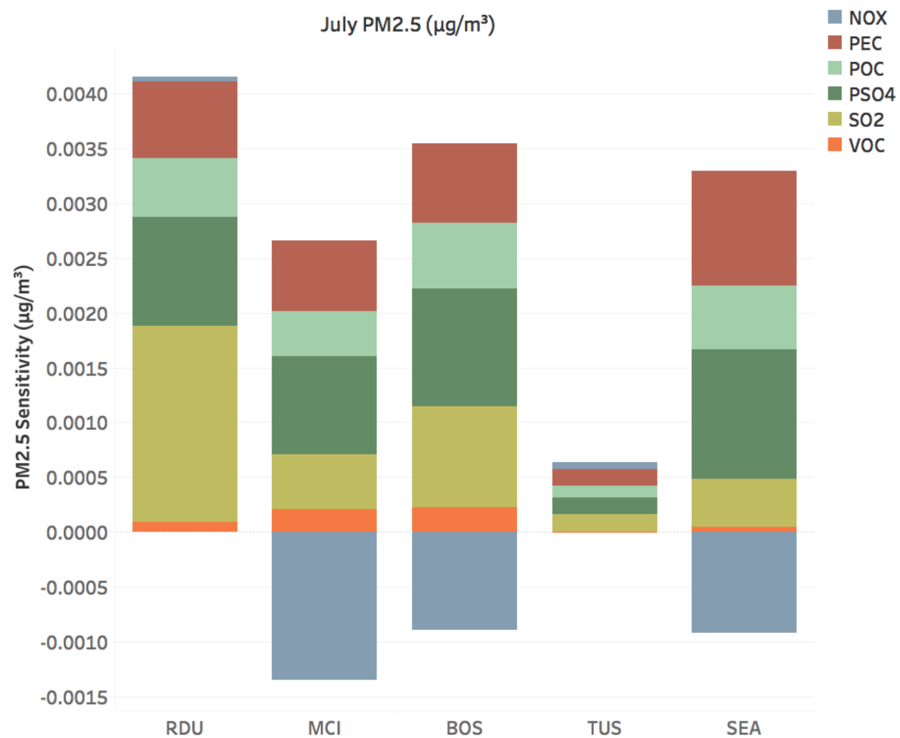
Second Order



O_3 and $PM_{2.5}$ Sensitivities for 5 Clean Airports during July



July O3 sensitivities disaggregated by precursor species at grid cell containing airport



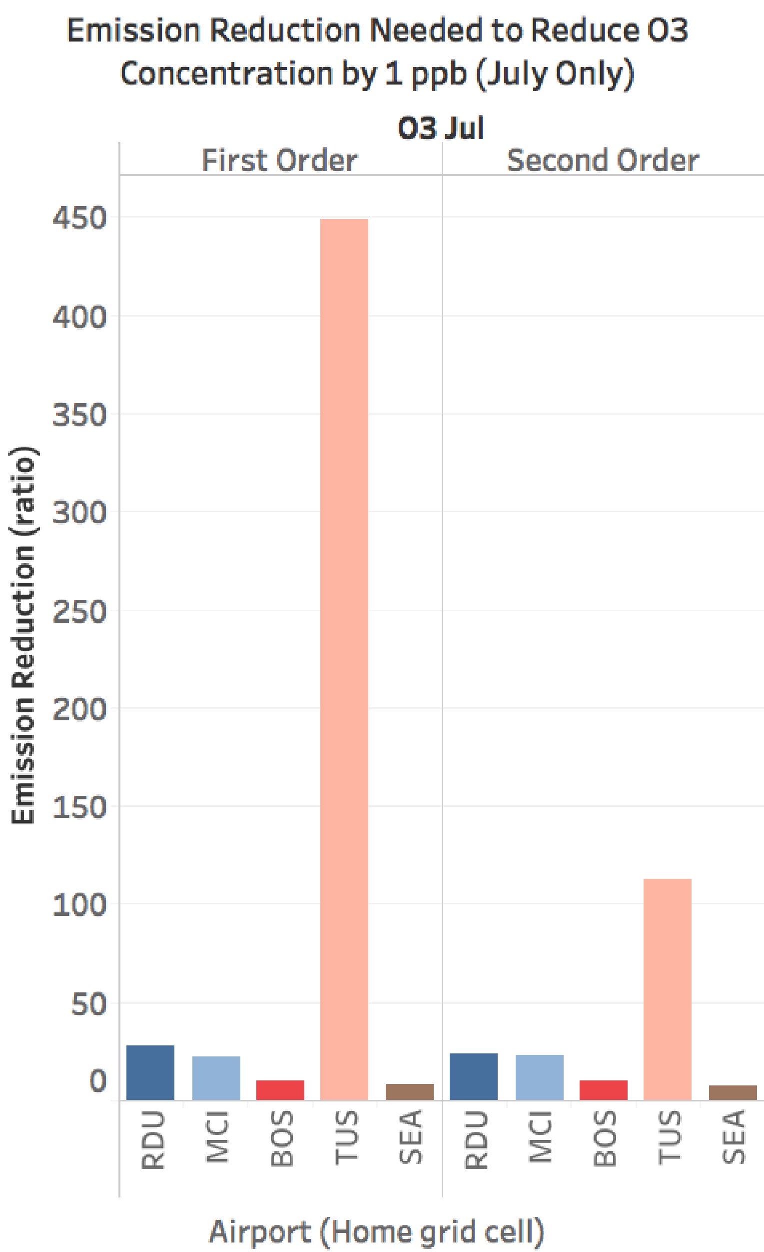
July PM2.5 sensitivities disaggregated by precursor species at grid cell containing airport

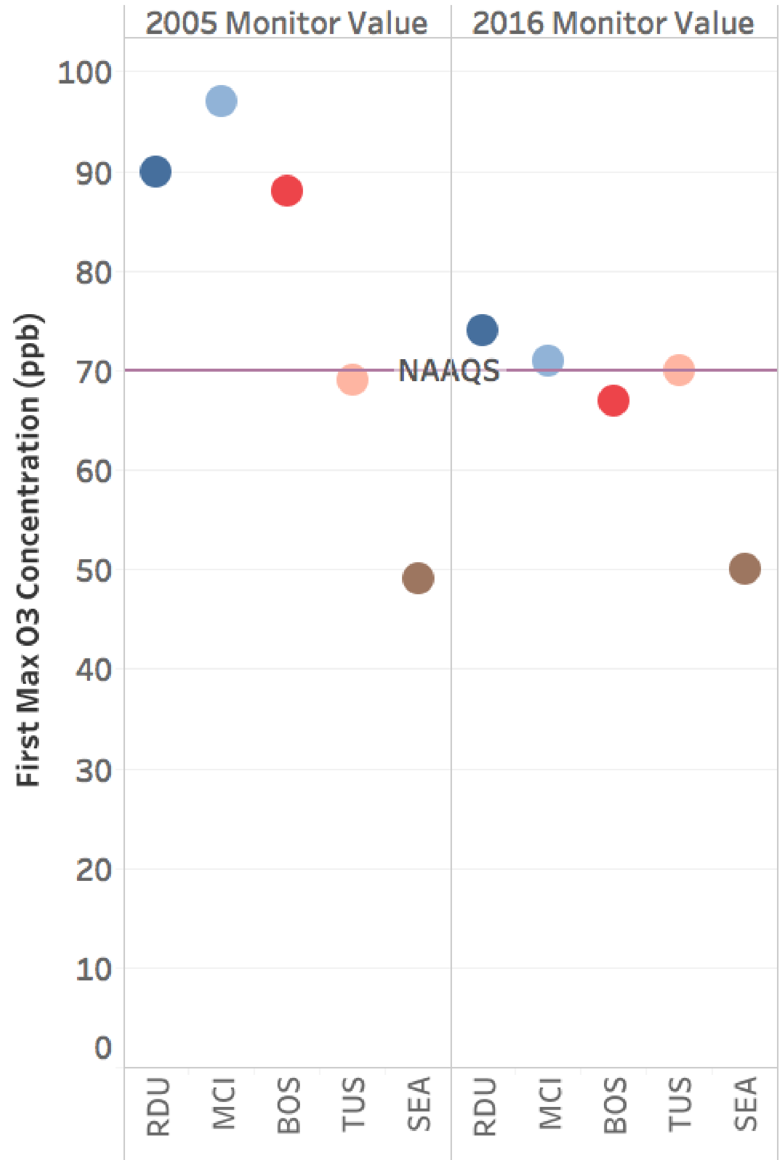
Focus on airport grid-cell

O_3 sensitivities to aircraft emissions are always negative due to NO_x titration effects

$PM_{2.5}$ sensitivities are more complex, and DDM allows attribution to individual precursors; But max magnitudes are < 0.005 µg/m³

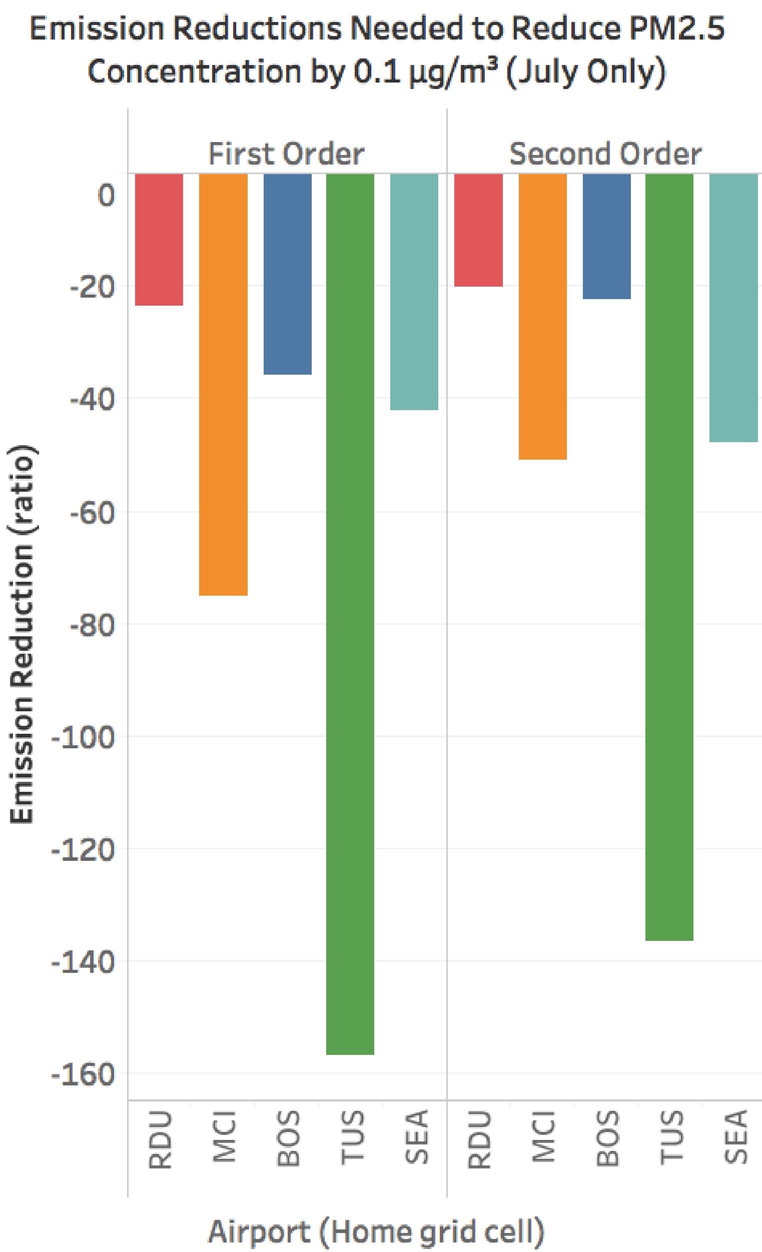
O_3 Nonattainment Analyses for 5 Clean Airports

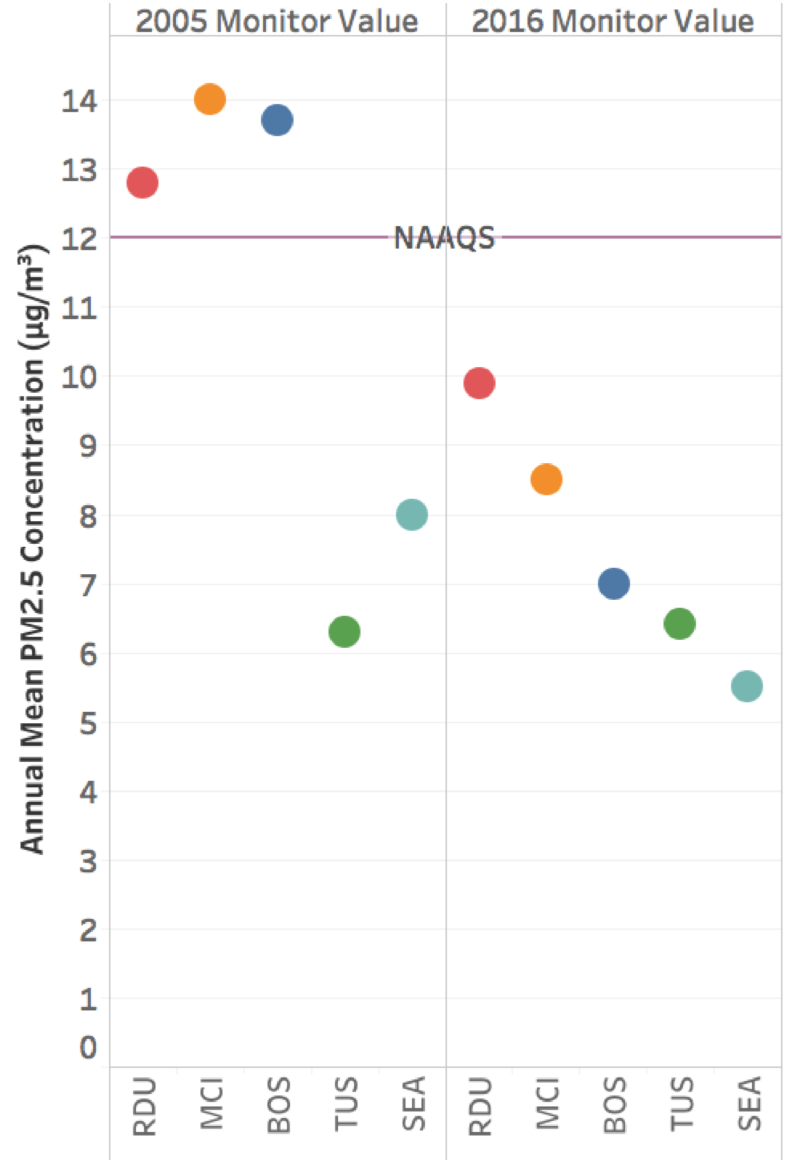




Observed values for O3 concentrations at selected monitors for the years 2005 and 2016.

$PM_{2.5}$ Nonattainment Analyses for 5 Clean Airports





Observed values for PM2.5 concentrations at selected monitors for the years 2005 and 2016.

Generalized AEDT Gridding Tool (1 of 3)

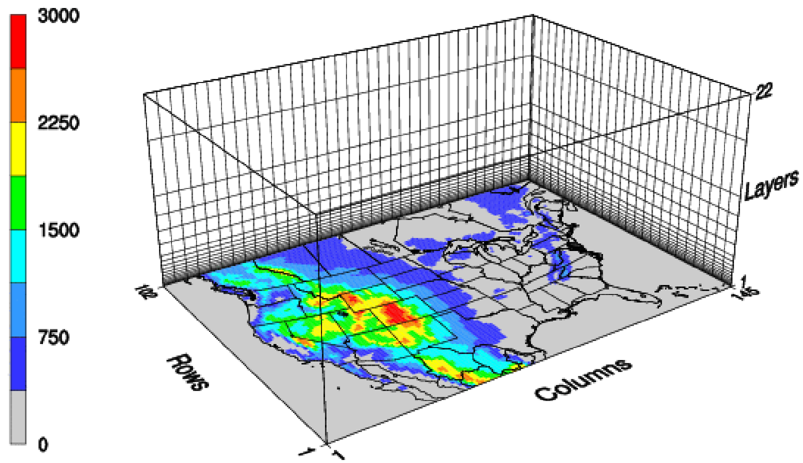
- Current approach for gridding:
  1. Run AEDT to create SQL *.bak file
  2. Use SQL code to create flat files with chorded segment data of global aircraft activity
  3. Individual air quality modeling groups develop custom code to grid AEDT outputs to their model native resolution
- Above approach has led to inconsistent practices, and often reinventing the wheel by each user of AEDT data
- Need for consistent and scalable tool to be applied across multiple models and groups

Generalized AEDT Gridding Tool (2 of 3)

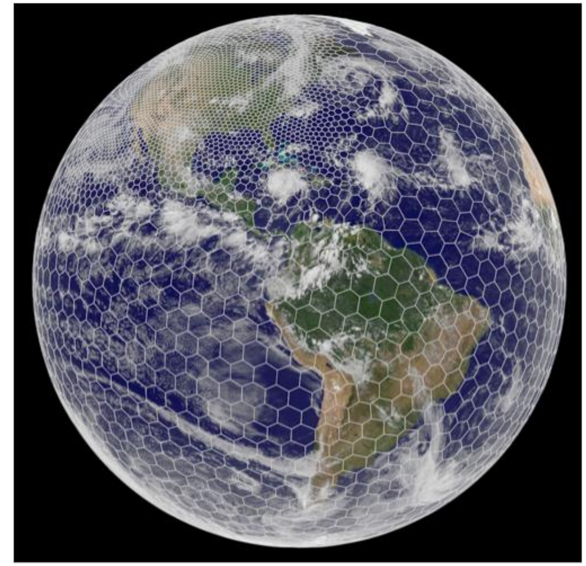
- Need for new tool with following requirements:
  - Support multiple air quality models at regional and global scales
    - E.g. CMAQ, CAMx, GEOS-Chem, CAM-Chem, MOZART, etc.
  - Support uniform (structured) and non-uniform (unstructured) grids
    - E.g. CMAQ-like and MPAS-like

    MPAS = Model for Prediction Across Scales, the new 5th generation modeling system to model from global to urban scales in one system
  - Support user-defined time resolutions consistent with input meteorology
    - E.g. hourly to daily to monthly
  - Support multiple map projections
    - E.g., Lat/Lon, Mercator, Lambert Conformal, Polar Stereographic, etc.
  - Support various chemical mechanisms
  - Support direct access of SQL file from Windows
- Started from previously developed AEDTProc developed by UNC to incorporate above features

Generalized AEDT Gridding Tool (3 of 3)



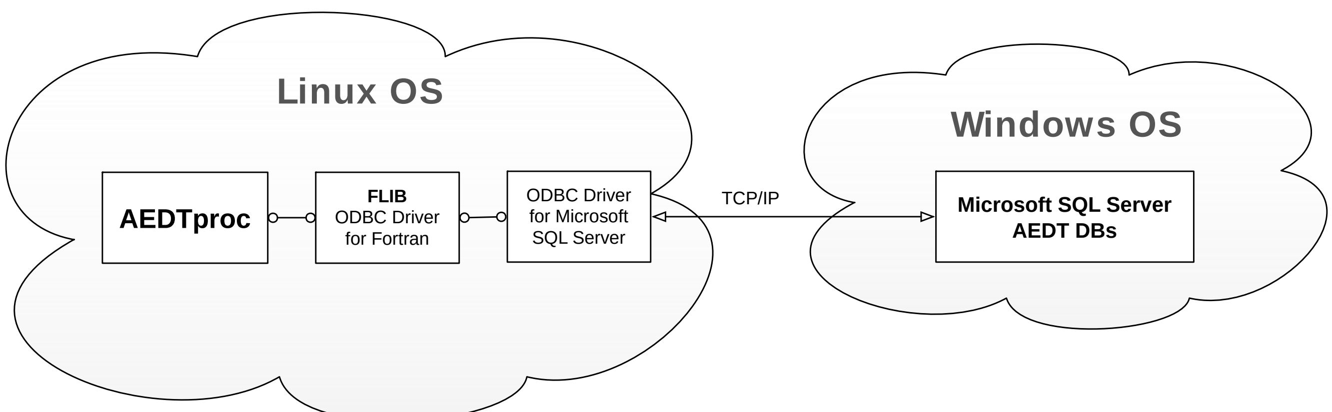
Source: Arunachalam et al



Source: NCAR

Structured Grid

Unstructured Grid



Tool Architecture

Interfaces and Communications

- External
  - Multiple presentations at Annual CMAS Conference, 2016 and 2017 (upcoming) in Chapel Hill
  - Additional presentations:
    - ITM Conference, October 2016
    - ISES Conference, October 2016
    - ANERS Conference, April 2017
    - AAAR Conference, October 2017 (upcoming)
    - ISES Conference, October 2017 (upcoming)
  - National Aviation University, Kyiv, Ukraine
- Within ASCENT
  - ASCENT NOI 18 (BU) and 20 (MIT)
  - ACCRI, Post-ACCRI Activities

Summary

- Summary statement
  - New higher resolution modeling platform being developed for the U.S. with latest models and inputs
  - CMAQ-DDM based sensitivities provide novel approach to look at potential contribution of airport emissions to nonattainment
  - Key tools developed for promoting consistency across models and scales such as AEDT-Gridder, AEDT for MERRA and WRF

- Next steps
  - Use consistent meteorology (MERRA) in both AEDT and CMAQ for the same application to assess potential benefits of higher fidelity weather inputs
  - Assess NAS-wide AQ impacts using new high resolution application
  - Extrapolate nonattainment analyses to associated fuel burn

- Key challenges/barriers
  - Dispersion modeling capabilities need to be enhanced

References

- Appel, K. W., et al: Description and evaluation of the Community Multiscale Air Quality (CMAQ) modeling system version 5.1, *Geosci. Model Dev*., 10, 1703-1732, 2017.
- Levy JI, et al. Current and future particulate matter-related mortality risks in the United States from aviation emissions during landing and takeoff. *Risk Anal* 32: 237-249, 2012.
- Napelenok, S., D. Cohan, Y. Hu, A. Russell, 2006: Decoupled direct 3D sensitivity analysis for particulate matter (DDM-3D/PM). *Atmos. Environ*., 40, 6112-6121.
- Nolte, C. G., et al. Evaluation of the CMAQ model v5.0 against size-resolved measurements of inorganic particle composition across sites in North America, *Geosci. Model Dev*., 8, 2877-2892, 2015.
- Rienecker, et al: 2011: MERRA - NASA's Modern-Era Retrospective Analysis for Research and Applications. *J. Climate*, 24, 3624-3648, doi:10.1175/JCLI-D-11-00015.1.
- Woody, M., et al. An Assessment of Aviation Contribution to Current and Future Fine Particulate Matter in the United States, *Atmos. Environ., 45 (20):*3424-3433, 2011.
- Zhang, W., Capps, S. L., Hu, Y., Nenes, A., Napelenok, S. L., and Russell, A. G.: Development of the high-order decoupled direct method in three dimensions for particulate matter: enabling advanced sensitivity analysis in air quality models, *Geosci. Model Dev*., 5, 355–368, doi:10.5194/gmd-5-355-2012, 2012.

Contributors

- UNC: S. Arunachalam, C. Arter, B.H. Baek, J.H. Bowden, M. Chowdhury, C.J. Coats, J. Huang, C. Seppanen
- U.S. DOT Volpe Center

Acronyms

- AEDT: Aviation Environmental Design Tool
- AEDTProc: AEDT Processor
- CAMChem: Community Atmospheric Model with Chemistry
- CMAQ: Community Multiscale Air Quality Model
- DDM: Decoupled Direct Method
- EC/OC/NCOM: Elemental Carbon / Organic Carbon / NonCarbon Organic Matter
- MERRA: Modern Era Retrospective Analysis for Research and Applications
- NEI: National Emissions Inventory
- SMOKE: Sparse Matrix Operator Kernel Emissions
- VALE: Voluntary Airport Low Emissions Program
- WRF: Weather Research Forecast Model
- vPM: Volatile Particulate Matter
- nvPM: NonVolatile Particulate Matter