Emissions Program Update

Presented to: REDAC Environment & Energy Subcommittee

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Primary Emissions Activities

- CO2 Emissions Aircraft Standard
- PM Emissions Engine Standard
- Air Quality Research
- Climate Research
- Surface Air Quality Impacts from Cruise Emissions

PM Emissions Engine Standard

"Conduct aircraft engine emissions measurements under varied flight conditions for subsequent analysis. Conduct testing at the exit plane, within the engine plume and in the near field. Develop sampling and measurement methodologies to support certification and standard setting."

nvPM Emissions Engine Standard

- **Goal**: Develop an international non-volatile particulate matter (nvPM) emissions engine standard
- **2 objectives to get to goal**:
- Support SAE E31 committee in the development of an Aerospace Recommended Practice (ARP) by addressing technical issues in sampling system specifications, measurement techniques, instrument calibration and operating procedures.
- Develop the international nvPM emissions engine standard via the ICAO/CAEP standard setting process.
- **Contributions from**: EPA, NASA, Transport Canada, Swiss FOCA, EU EASA, MS&T, Aerodyne, U Cambridge, NRC Canada, Swiss EMPA, Swiss ETH and many Industry Partners

PM Standard Setting Process

SAE-E31

Develop Standardized Measurement Method

Conduct engine measurements to test system performance, operability, calibration, and uncertainties.

Outcome: Aerospace Recommended Practice (ARP)

ICAO/CAEP

Develop Certification Requirement

Conduct standardized engine measurements to establish corrections for ambient conditions, engine-2-engine variation, and fuel sensitivities.

Outcome: Annex 16 vol. II update

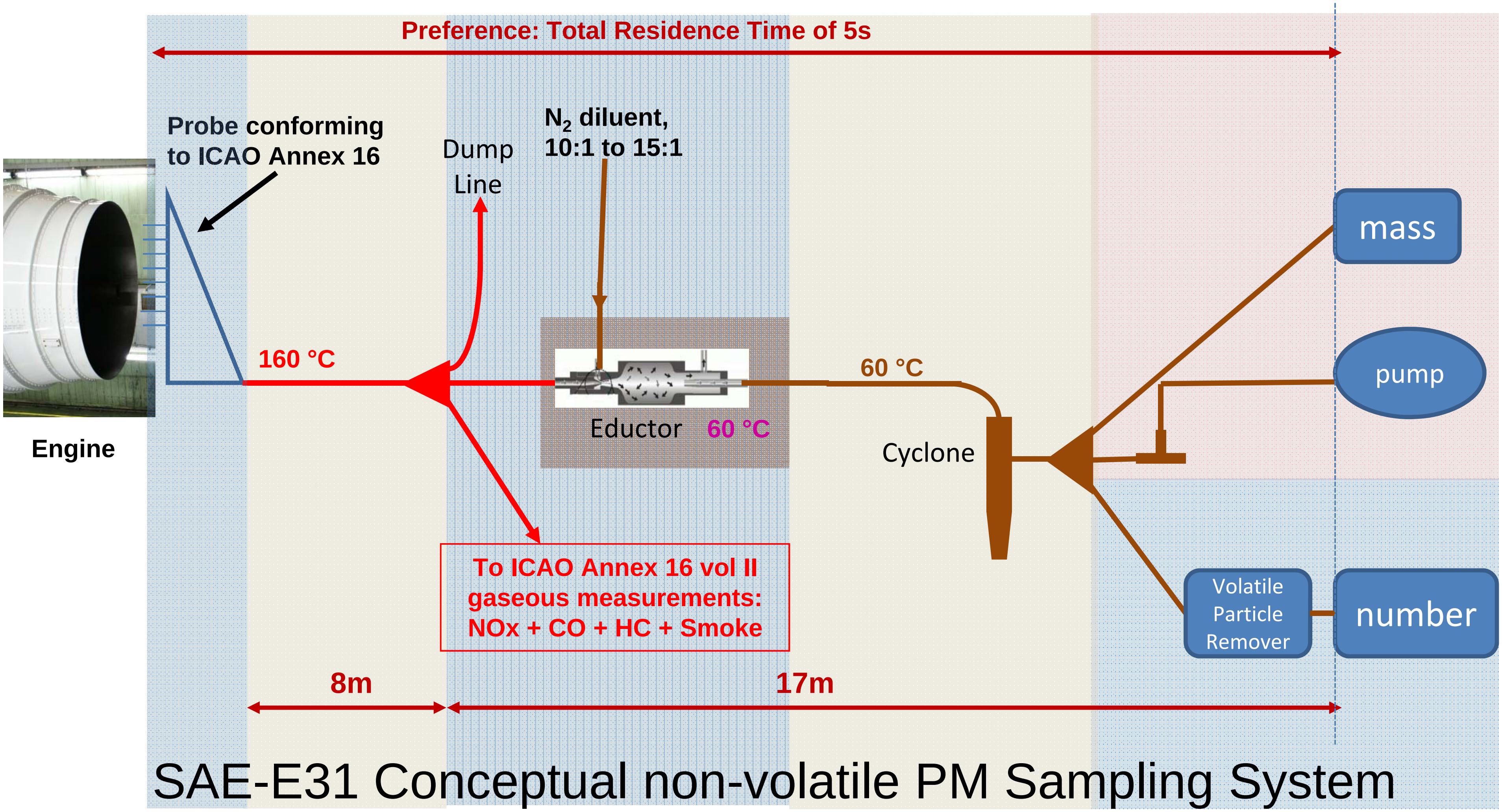
ICAO/CAEP

Develop Pass/Fail Regulatory Limit

Utilize nvPM database to determine most cost effective regulatory limit.

Outcome: Annex 16 vol. II update

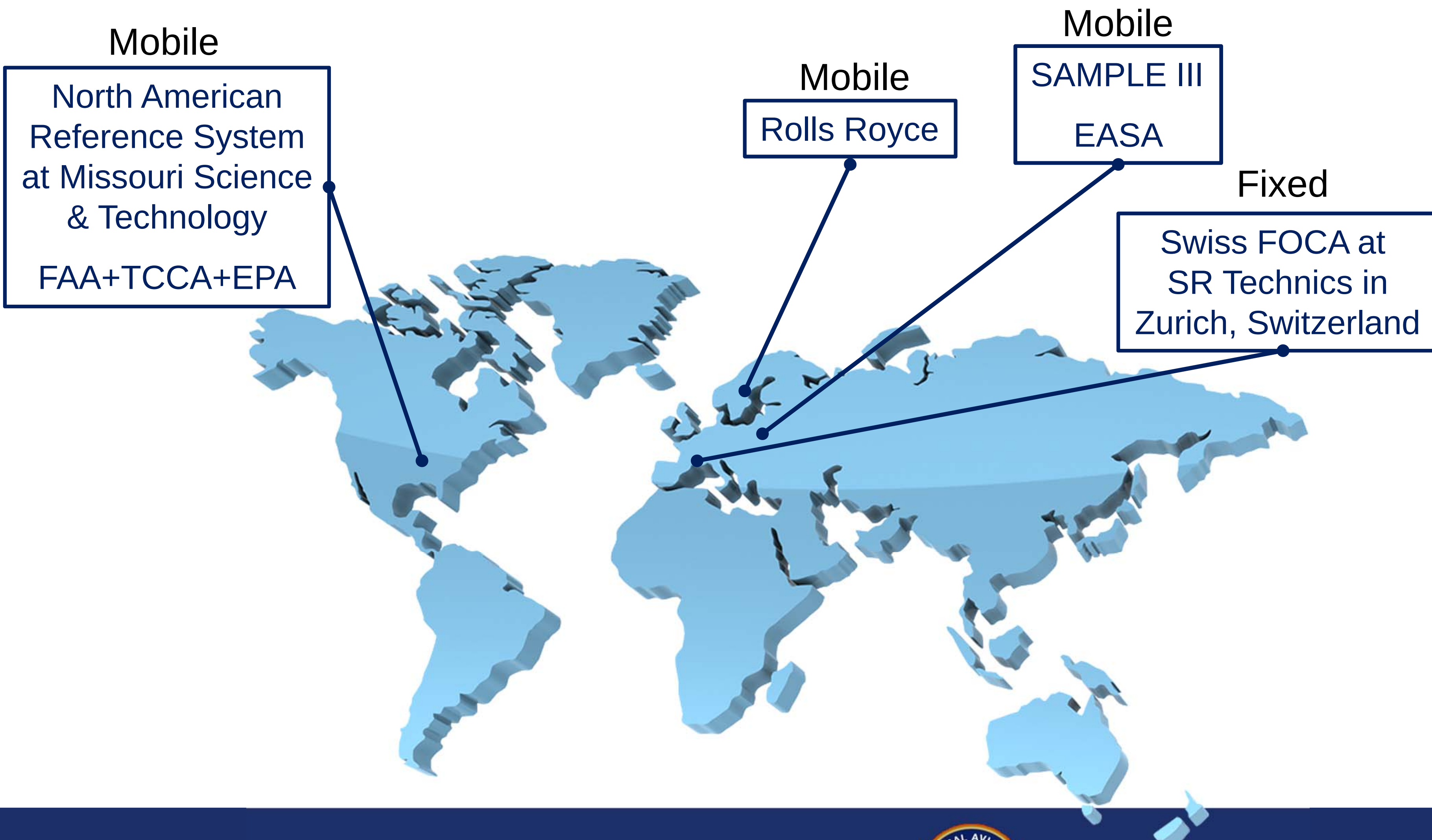
What is the standardized sampling method?



SAE-E31 Conceptual non-volatile PM Sampling System

AIR6241 published Nov 2013

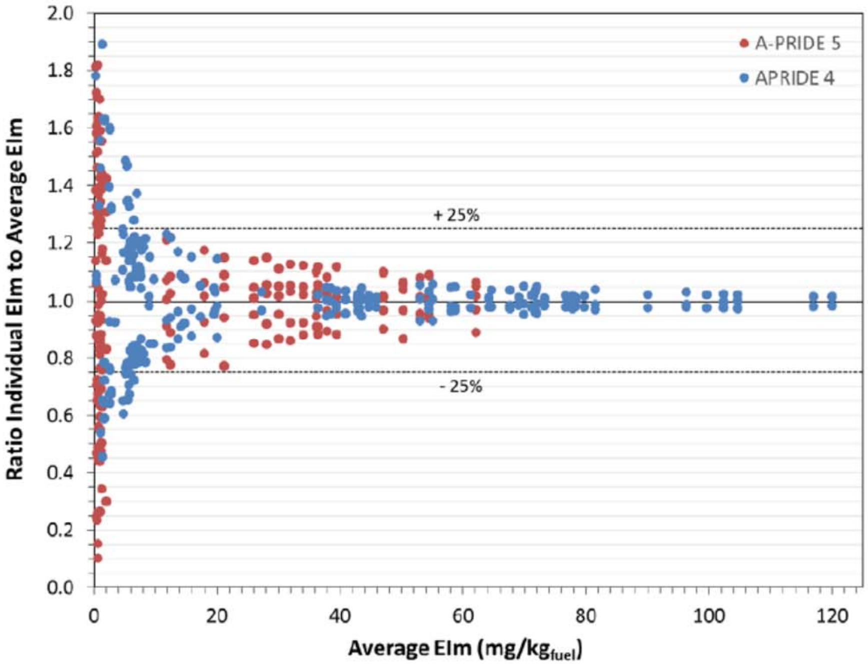
AIR6241 Compliant Systems

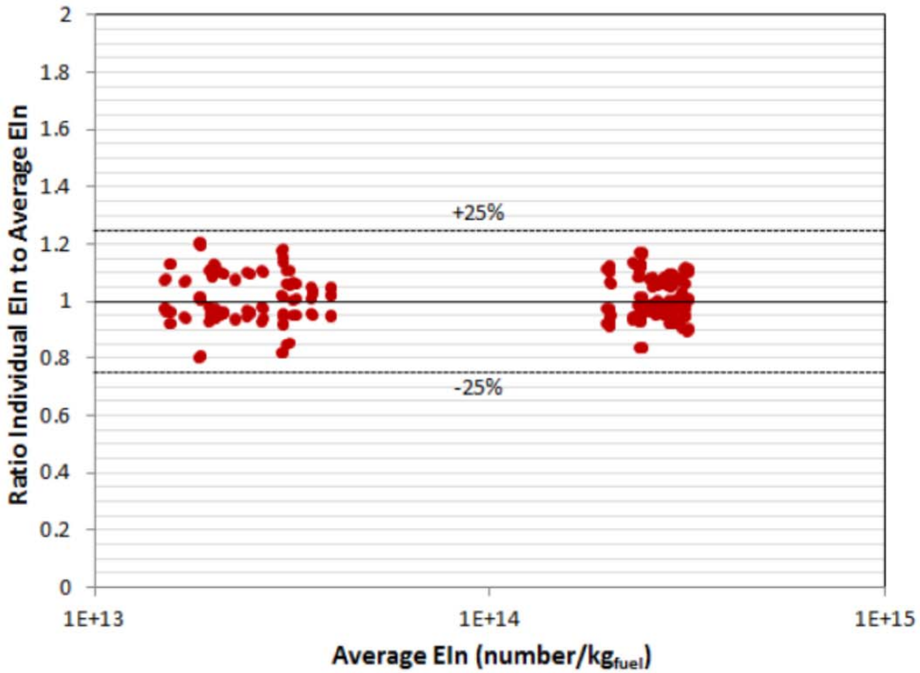


Measurement Campaigns

- Alternative Aviation Fuels EXperiment II – Mar 2011: Palmdale, CA
- "APRIDE 4" SR Technics Campaign – Dec 2011: Zurich, Switzerland
- "APRIDE 5" SR Technics Campaign – Nov 2012: Zurich, Switzerland
- Williams International Campaign – May 2013: Walled Lake, MI
- Pratt & Whitney Engine Certification – March 2014: East Hartford, CT
- **Honeywell Campaign – June 2014: Phoenix, Arizona**
- **GE Ambient Conditions Campaign – TBD 2014: Peebles, OH**
- **"APRIDE 6" SR Technics Campaign – TBD 2014: Zurich, Switzerland**
- **GE Engine-2-Engine Variation Campaign – TBD 2015: Peebles, OH**
- **Rolls Royce Indiana – TBD 2015: Indianapolis, IN**
- **NASA Glenn N+2 Combustor Rig – TBD 2015: Cleveland, OH**

Measurement Uncertainties





Preliminary Results. Not final.

nvPM Status

- **SAE E31 working to transition from AIR6241 to an ARP in 2015**
- **Continue to make engine measurements towards assembling nvPM database**
- **ICAO/CAEP standard setting process evaluating what can be accomplished by**
  - Feb 2016 (CAEP10 meeting)
  - Feb 2019 (CAEP11 meeting)

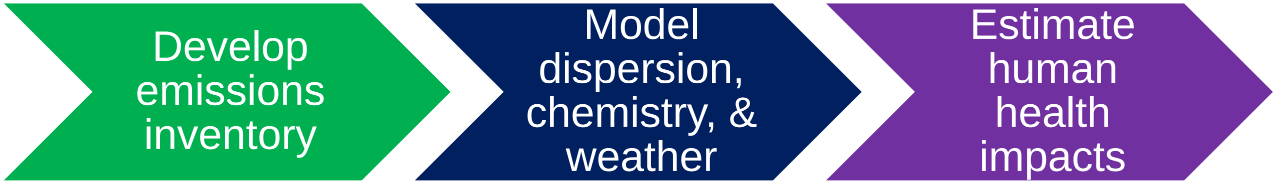
Air Quality Research

"Develop analytical methods and emissions indices from measurement data to model aviation emissions for use in environmental modeling for all phases of flight."

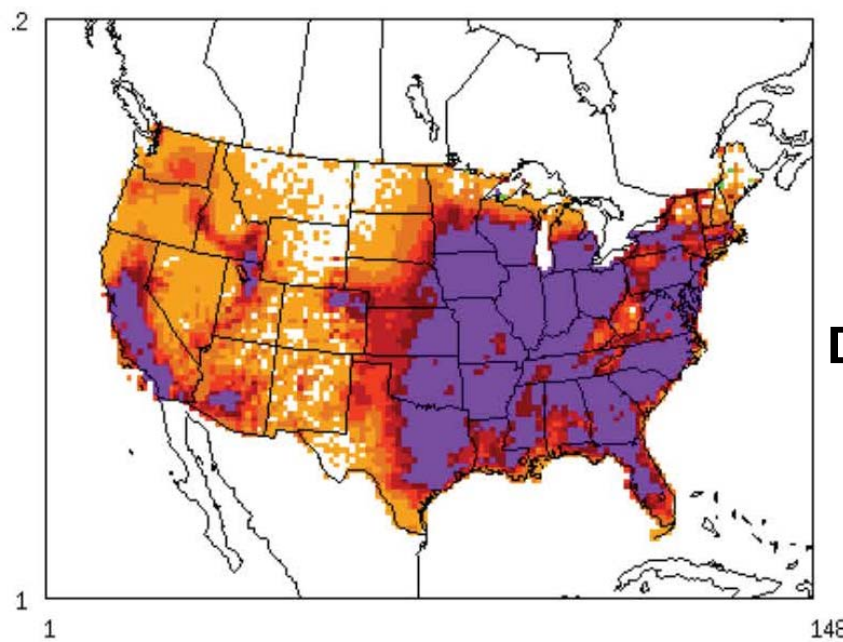
Air Quality Research

- **Research Question :**
  - Can we reduce significant health impacts by 50% in 2018 vs. 2005 base?
  - Destination 2025 aspirational goal
- **Quantify health impacts consistently using inventories (AEDT) + impacts model (APMT-AQ)**
- **Build upon earlier research (P11&P16) for reporting in a regulatory framework:**
  - NAS-wide Community Multi-scale Air Quality Model (CMAQ)
  - Defined "significant health impacts" in this context and quantify consistently

Air Quality Modeling Approach

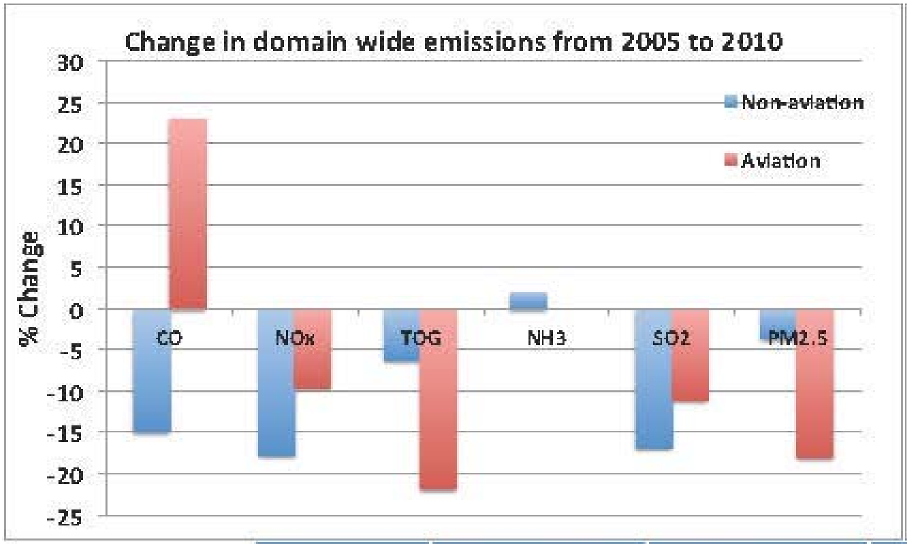


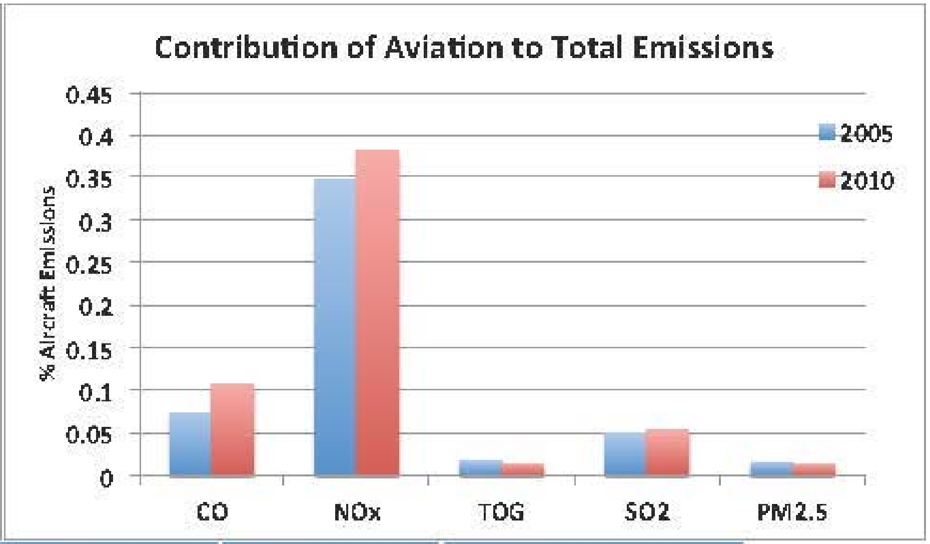
- PARTNER-45 NAS-wide CMAQ Model
- Modern Era Retrospective Re-Analysis (MERRA) weather
- State-of-the-art Air Quality modeling practices
- Landing Take Off (LTO) only



Model Domain

Comparison of Aviation and Non-aviation for 2005 and 2010



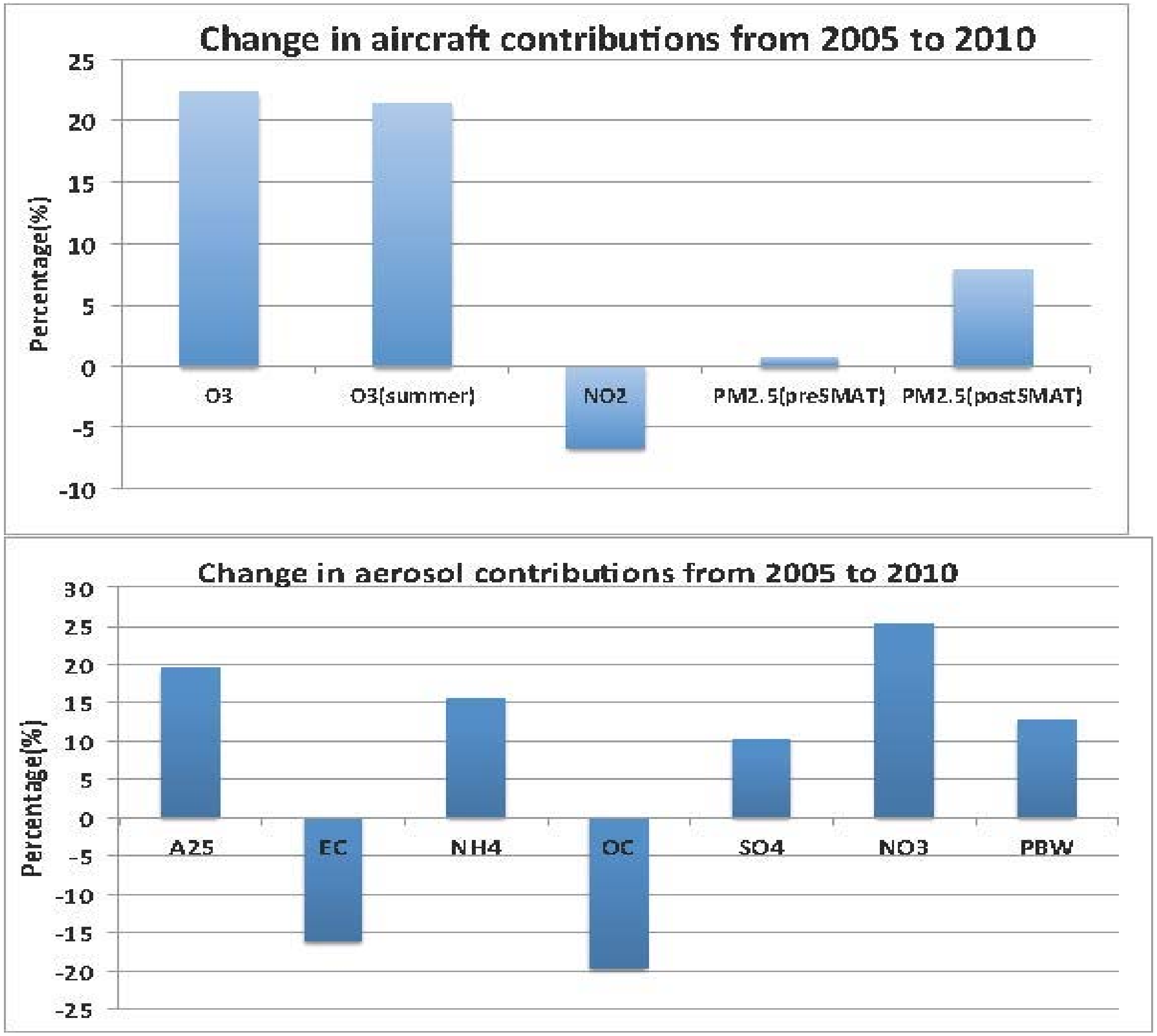


Aircraft

Year	CO (tons/yr)	NOx (tons/yr)	PM2.5 (tons/yr)	SO2 (tons/yr)	TOG (tons/yr)
2005	68,346	83,749	668	7,410	14,897
2010	84,050	75,784	548	6,589	11,638

Total

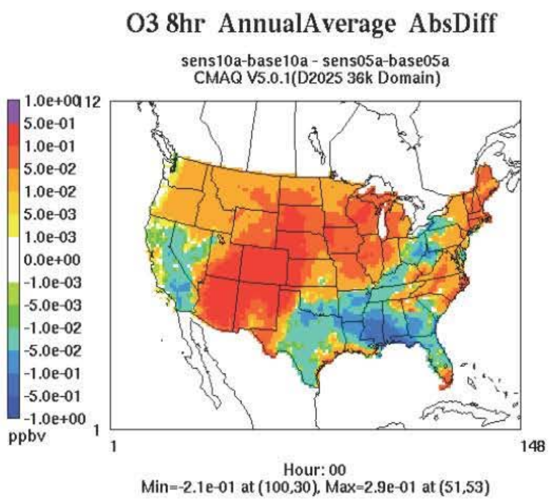
Year	CO (tons/yr)	NOx (tons/yr)	PM2.5 (tons/yr)	SO2 (tons/yr)	TOG (tons/yr)	NH3 (tons/yr)
2005	92,413,964	24,143,854	4,302,222	14,961,497	87,011,068	3,762,115
2010	78,655,559	19,867,915	4,146,395	12,440,968	81,601,131	3,834,789

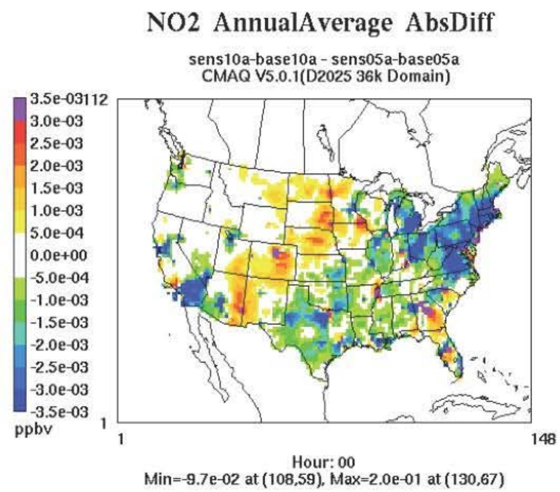


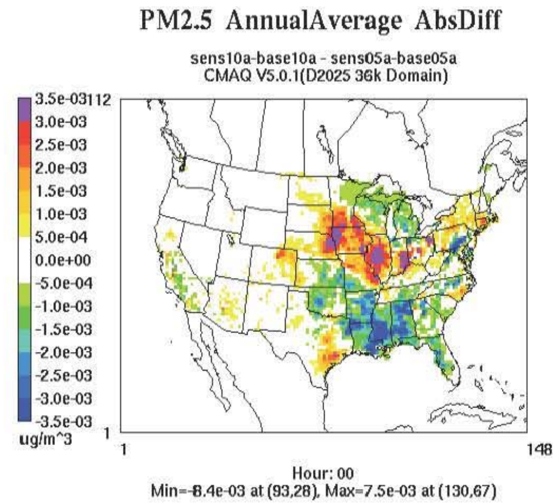
O3 = ozone
NO2 = nitrogen dioxide
PM2.5 = particulate matter
A25 = remaining unspeciated anthropogenic aerosols
EC = elemental carbon
NH4 = ammonium
OC = organic carbon
SO4 = sulfate
NO3 = nitrate
PBW = particle-bound water

Domain-wide AQ impacts in 2010 vs. 2005 --> O_3: 22.3%, $PM_{2.5}$: 7.9% and NO_2 : -7%

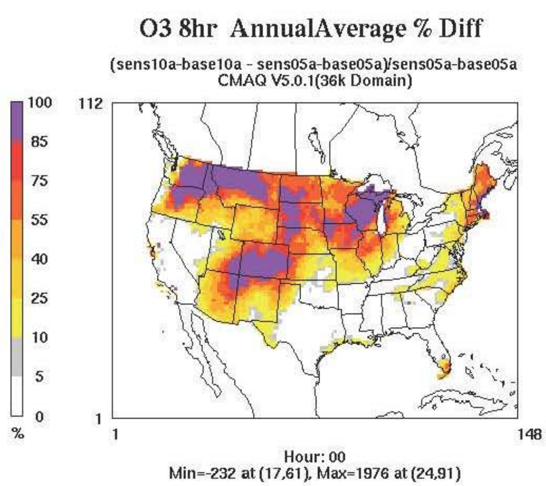
Incremental Contributions due to Aircraft: 2010 - 2005

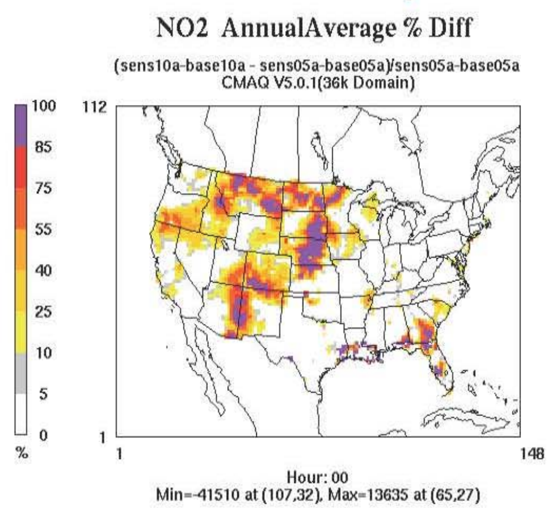


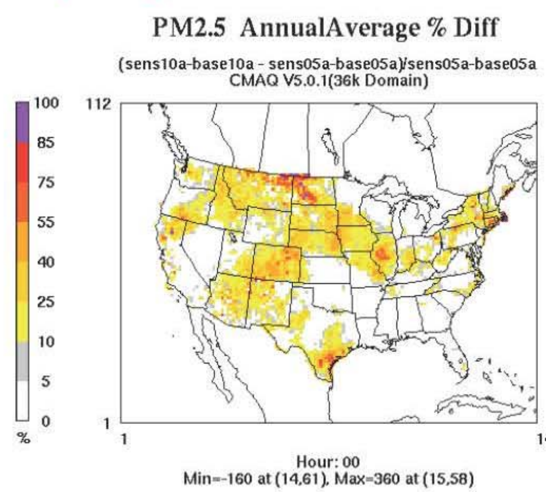




Incremental Contributions due to Aircraft: (2010 – 2005)*100/2005

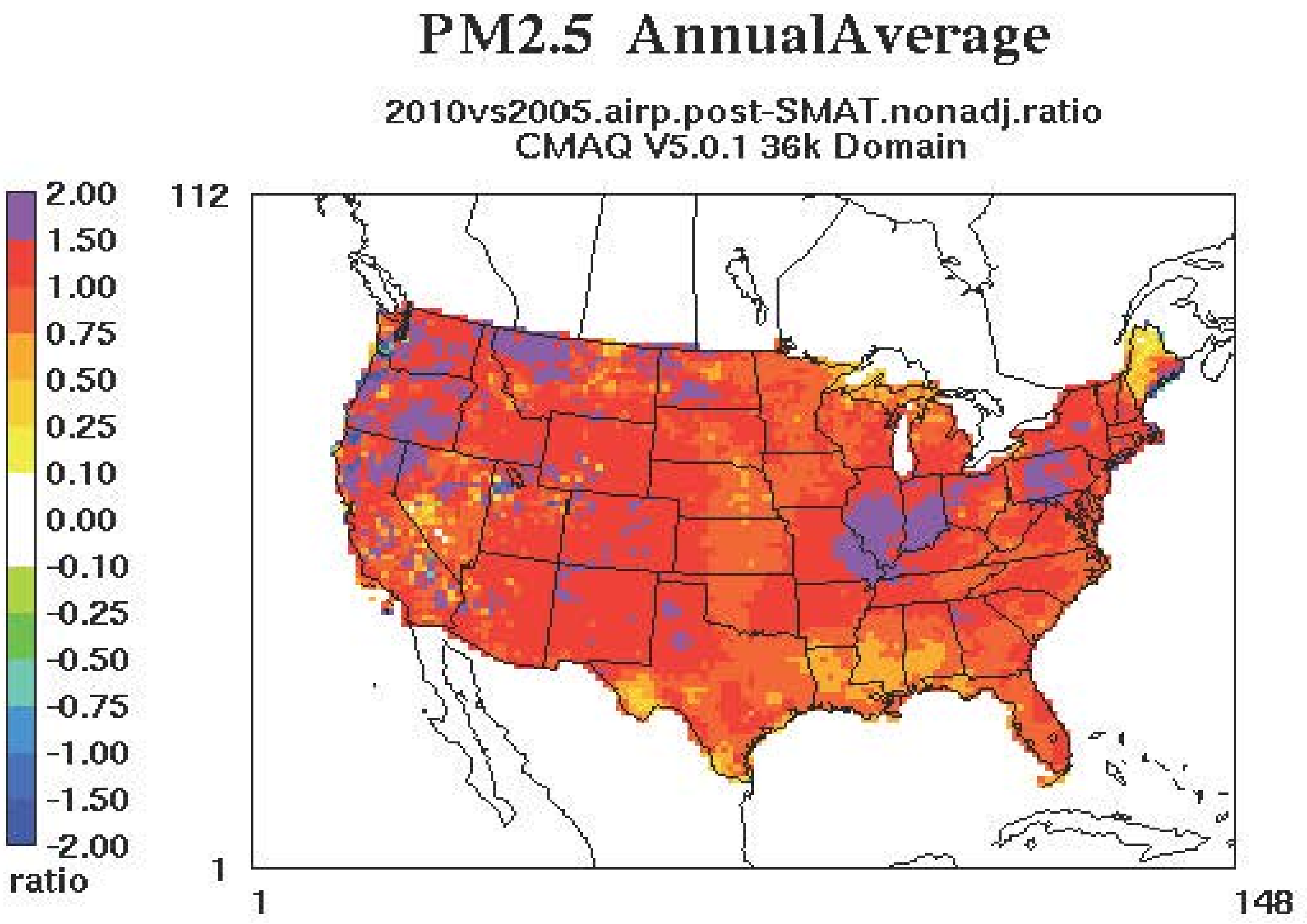






Exposure, Health Impacts and Valuation

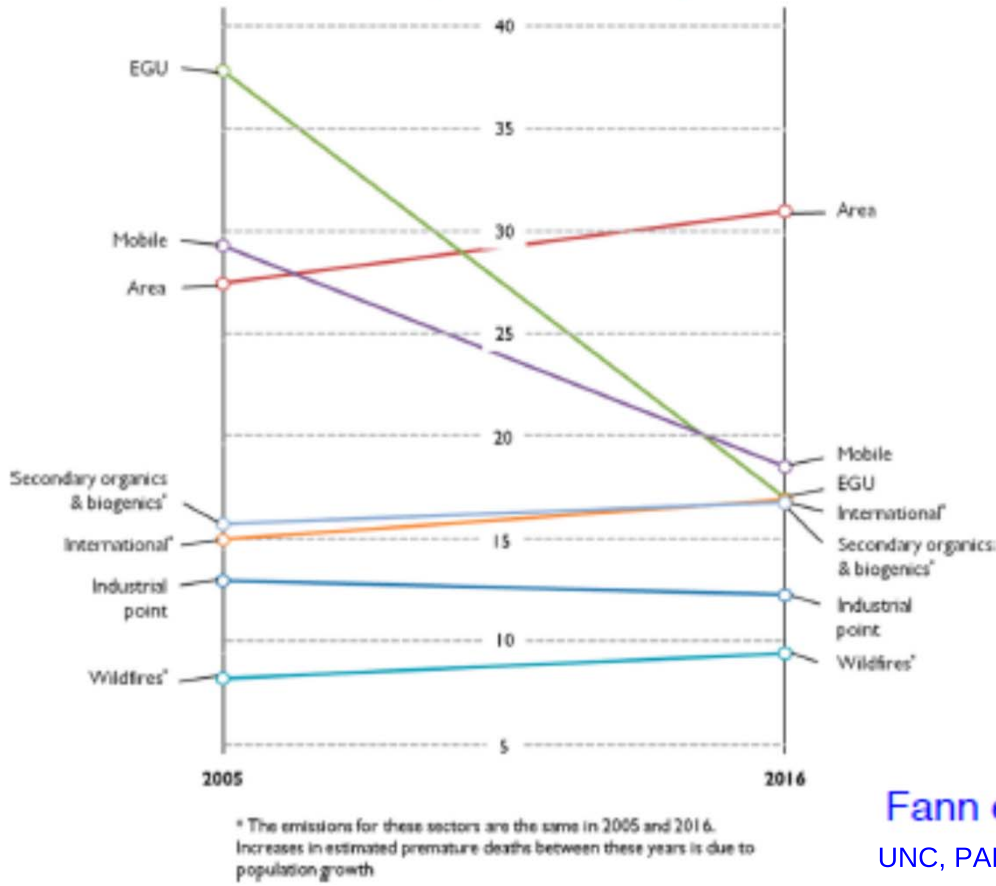
- **Use Concentration Response Functions (CRFs) suitable for regulatory reporting**
  - Mortality
  - Hospitalization (Respiratory and Cardiopulmonary)
  - Non-fatal myocardial infarctions
- **Valuation of impacts due to significant health outcomes (i.e. top contributing factors)**
- **Make consistent across AEE's operational tools**


PM2.5 AnnualAverage
2010vs2005.airp.post-SMAT.nonadj.ratio
CMAQ V5.0.1 36k Domain
2.00
1.50
1.00
0.75
0.50
0.25
0.10
0.00
-0.10
-0.25
-0.50
-0.75
-1.00
-1.50
-2.00
ratio
112
1
1
148

Health Risk by Sector in the U.S.

Study 1: Premature Mortality Counts due to O_3 and $PM_{2.5}$

(in thousands)



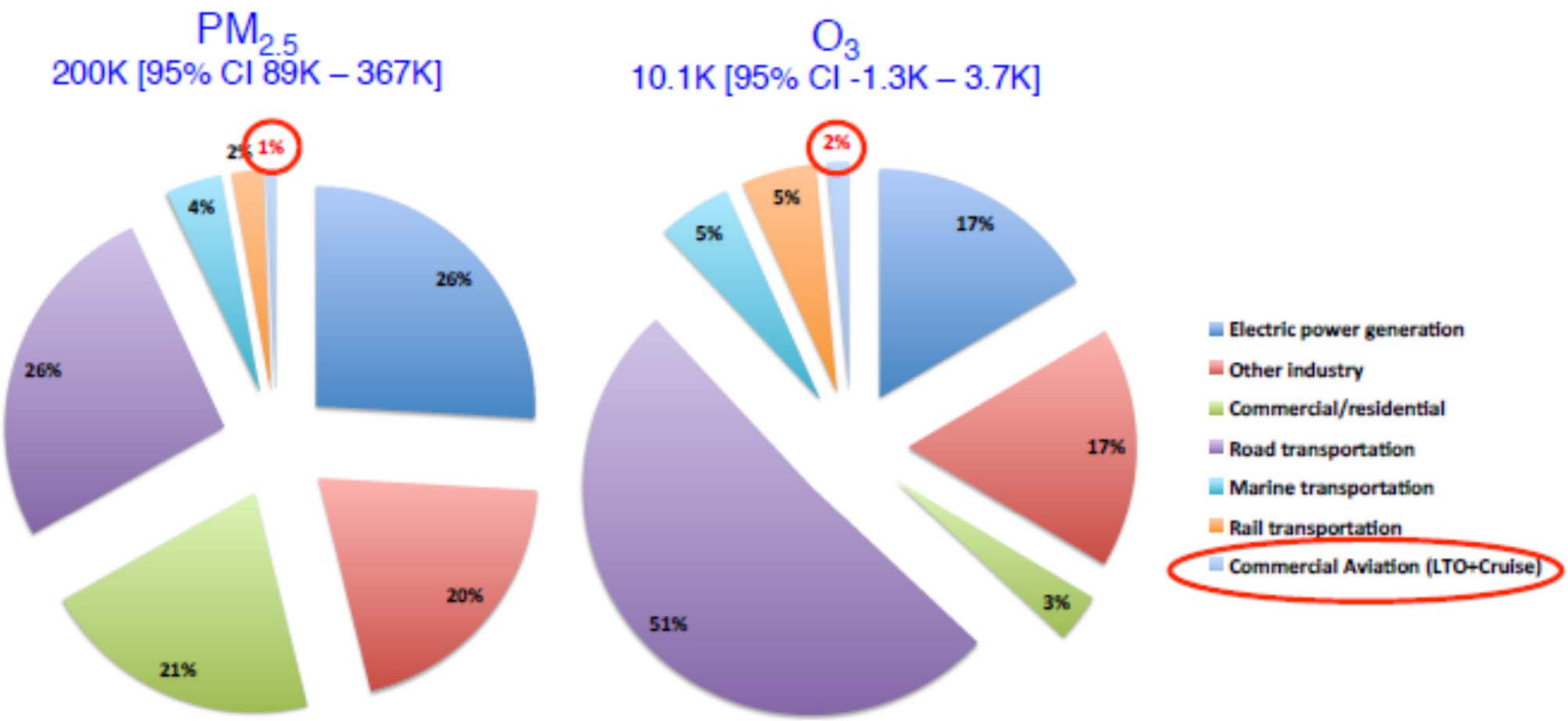
In total, combustion-related emissions from all sources in 2005 cause ~145,000 premature mortality due to PM2.5

Fann et al, EST 2013

UNC, PARTNER/ASCENT University

Health Risk by Sector in the U.S.

Study 2: Premature Mortality Counts



This study estimates 35% higher total premature mortality due to PM2.5.

Transportation sectors contribution is 33% vs. 20% by Fann et al.

Caiazzo et al, AE 2013
Yim et al, AE 2013
MIT, PARTNER/ASCENT University

Preliminary Results

Do not Cite or Quote

Mortality

Pollutant	2005	2010	2010 with 2005 population	% change 2005 - 2010	% change 2005 - 2010 (emissions only)
O_3	89	110	99	18%	11%
Ammonium nitrate	40	51	49	28%	22%
Ammonium sulfate	130	160	150	23%	17%
EC	7.9	8.3	7.9	4%	0%
OC	26	24	22	-8%	-14%
Crustal	-1.2	-1.6	-1.5	36%	30%
Total $PM_{2.5}$	200	240	230	19%	13%
Total impacts	290	350	330	19%	13%

Preliminary Results

Do not Cite or Quote

Monetized Outcomes (Millions – 2010 Dollars)

Pollutant/ Outcome	2005	2010	2010 with 2005 population
$PM_{2.5}$ Mortality	$1,500	$2,100	$2,000
Ozone Mortality	$680	$930	$880
$PM_{2.5}$ Respiratory Hospital Admissions	$0.38	$0.57	$0.51
Ozone Respiratory Hospital Admissions	$5.9	$8.7	$7.9
$PM_{2.5}$ Cardiovascular Hospital Admissions	$0.58	$0.87	$0.8
$PM_{2.5}$ non-fatal Myocardial Infarctions	$0.77	$1.2	$1.0
Total	$2,200	$3,100	$2,900

Mortality dominates cost…

Project Description

- Develop and adapt the adjoint model (global **GEOS-Chem** adjoint model and its US nested model) for Aviation Scenario Analyses.
- Forward approach requires two simulations to assess one policy scenario (background scenario vs policy scenario). To perform **N+1** number of simulations for **N** number of policy scenarios
- The adjoint approach is a computationally efficient way of calculating sensitivities (partial derivatives) of few outputs to many inputs, requires only **one** simulation of both forward and adjoint models for **N** number of policy scenarios

Status

- **Global Adjoint Development Complete**
  - Evaluation and comparison with the forward model in progress due to recent code change
  - Global and CAEP air quality analyses

- **Nested NAS Adjoint Implementation Complete**
  - Evaluation with nested forward model in Progress
  - Evaluation with CMAQ-based tool
  - Will replace RSMv3 within APMT-Impacts AQ tool

Climate Research

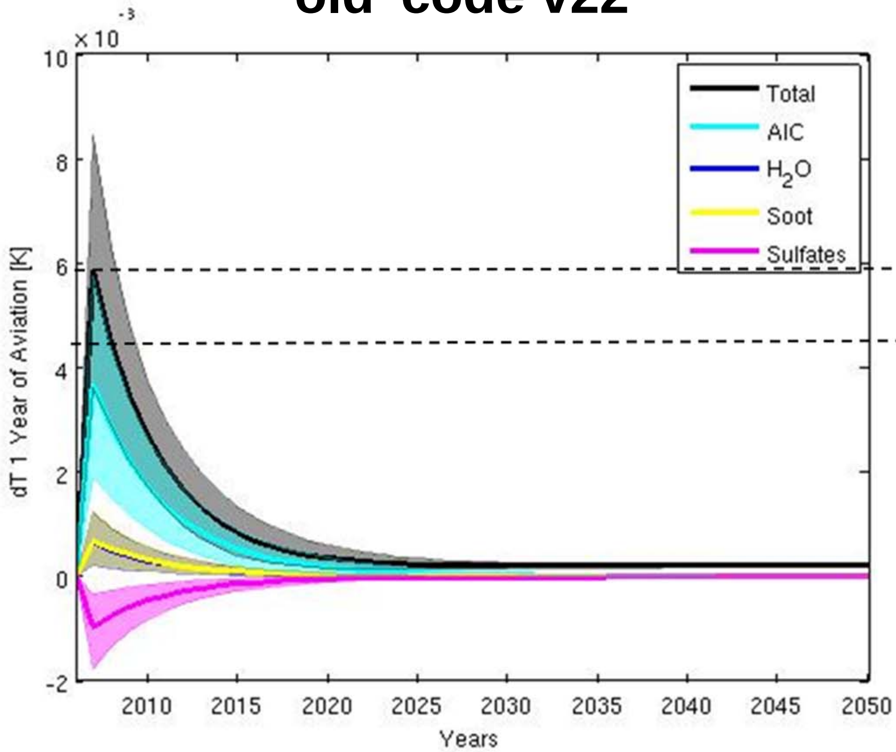
"Assess the uncertainties in our understanding of aviation's influence on local, regional, and global air quality and climate change and develop means to reduce these uncertainties."

ACCRI is Completed

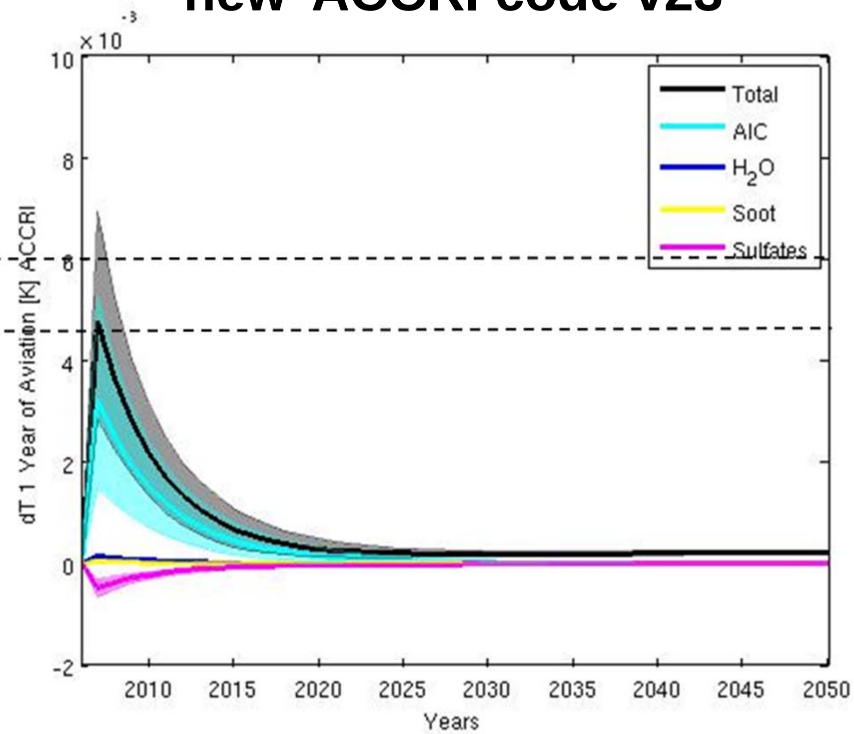
RF(mWm^{-2})	LEE2009			ACCRI		
	Mean	Lower bound	Upper bound	Mean	Min.	Max.
CO_2	28.0	15.2	40.8	23.0	12.0	32.0
O_3-short	26.3	8.4	82.3	29.5	4.0	36.5
CH_4	-12.5	-76.2	-2.1	-11.5	-12.3	-6.0
Water	2.8	0.39	20.3	1.7	1.3	2.0
SO4	-4.8	-29.3	-0.79	-4.8	-9.0	-3.0
BC	3.4	0.56	20.7	0.8	0.0	1.2
Contrail	11.8	5.4	25.6	6.6	-0.3	17.5
Contrail cirrus	33.0	12.5	86.7	31.2	4.4	80.0
Total excl. Cirrus	55.0	23.0	87.0	45.3	2.0	73.9
Total	78.0	38.0	139.0	69.9	6.7	136.4

ACCRI summary article is being drafted for publication.

‘old’ code v22



‘new’ ACCRI code v23



ACCRI focused on reducing uncertainties related to short-lived climate forcers (SLCF). Using APMT-Impacts Climate, the reduction in uncertainty in SLCF alone could improve the estimate of the total yearly impact of aviation by 15%.

Improve APMT-I Climate Tool

- **Regional Climate Analysis Capabilities**
  - APMT-Impacts Climate provides average global temperature change and average global impact
  - Want to understand spatial variation of impact

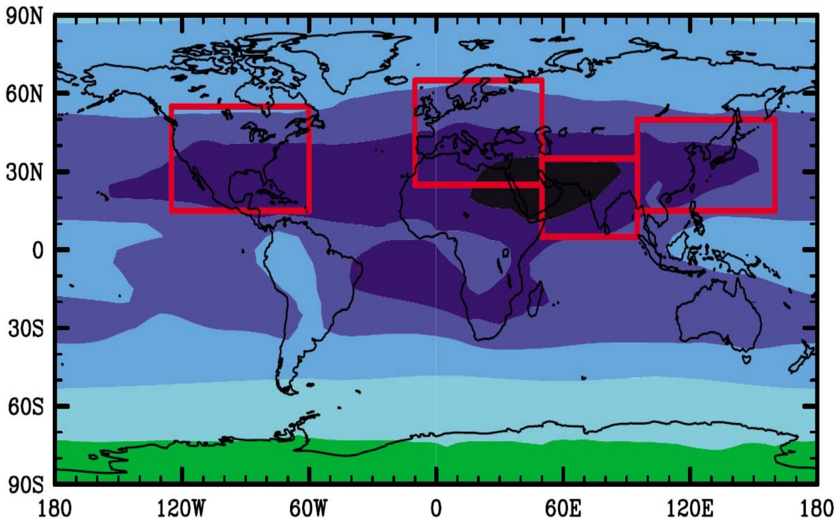
- **Examining two different approaches**
  - MIT Integrated Global System Model (ISGM)
  - CICERO zonal climate model

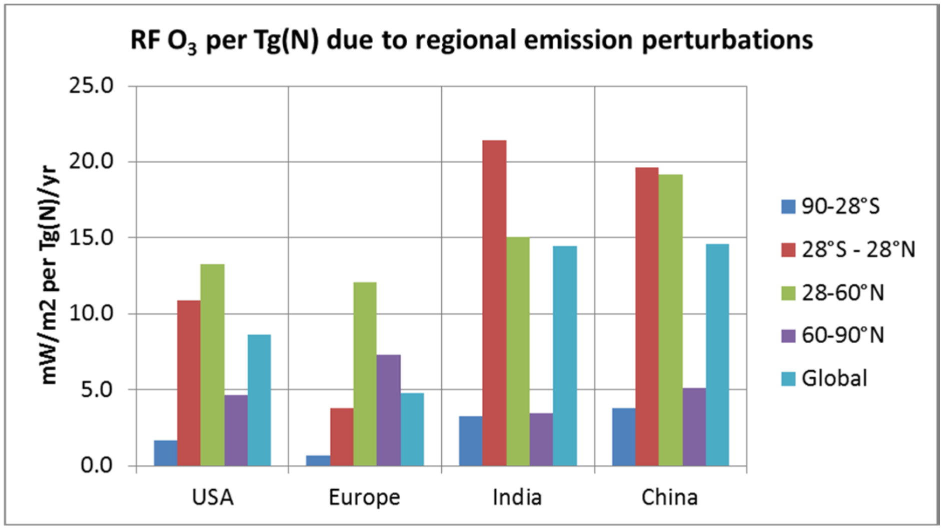
Method 1 – Regional Climate Impacts

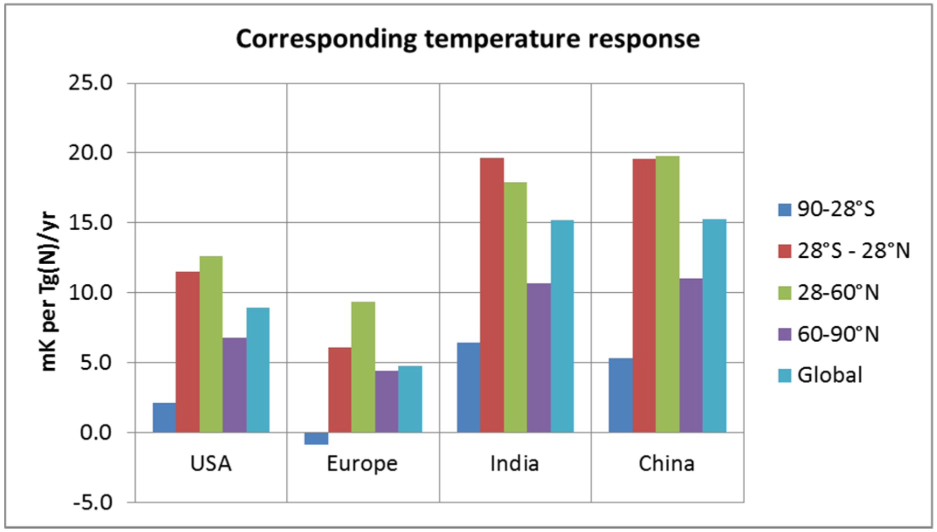
- **Integrated Global System Model (IGSM)**
  - Used to compare the environmental impact due to different aviation growth rates
  - Evaluate the interaction with varying background emission levels as a result of fluctuations in other sectors
  - Can distinguish the impacts of geospatial differences in emissions
  - Assess zonal climate response and impacts

Method 2 – Regional Climate Impacts

- Regional Emissions to Regional Temperature Change







•Data from Köhler et al. (2013), courtesy of Gabi Rädel for illustration.

Surface Air Quality Impacts from Cruise Emissions

"Conduct air quality monitoring and atmospheric measurement campaigns and source apportionment studies to develop improved methods to assess relative and absolute impact of aviation emissions on surface air quality."

Global Premature Mortalities due to Aviation Emissions

- **A Tale of 3 Studies…**
  - 10,000 per year
    - Barrett et al. (2010)
  - 620 per year
    - Jacobsen et al. (2012)
  - 810 per year
    - Yim et al. (2012)
- **that use different assumptions and models…**

FAA-Sponsored Global Research

- **1 Integrated Study… Surface AQ Impacts from Cruise Emissions**
  - 6 different models
  - Harmonized approach
    - Background concentrations
    - Grid size resolutions
    - Vertical resolutions
    - With & without feedback
    - Number of chemical reactions
    - Health impact data

ASCENT
EMISSIONS RESEARCH

ASCENT FY14 NOI Requests…

- **Particulate Matter Emission Measurements**
- **Air Quality Research**
- **Climate Research**
  - NASA's ACCESS II + Transport Canada + DLR
  - Contrail Observational Data Set
  - Microphysical Modeling
  - Regional Climate Model Development
- **Research in Support of Standard Setting**
  - Aircraft CO_2 Emissions Standard
  - Engine PM Emissions Standard

Questions?

- **We are very busy…**

- **CO_2 Emissions Aircraft Standard**
- **PM Emissions Engine Standard**
- **Air Quality Research**
- **Climate Research**
- **Surface Air Quality Impacts from Cruise Emissions**