Evaluation of FAA Climate Tools

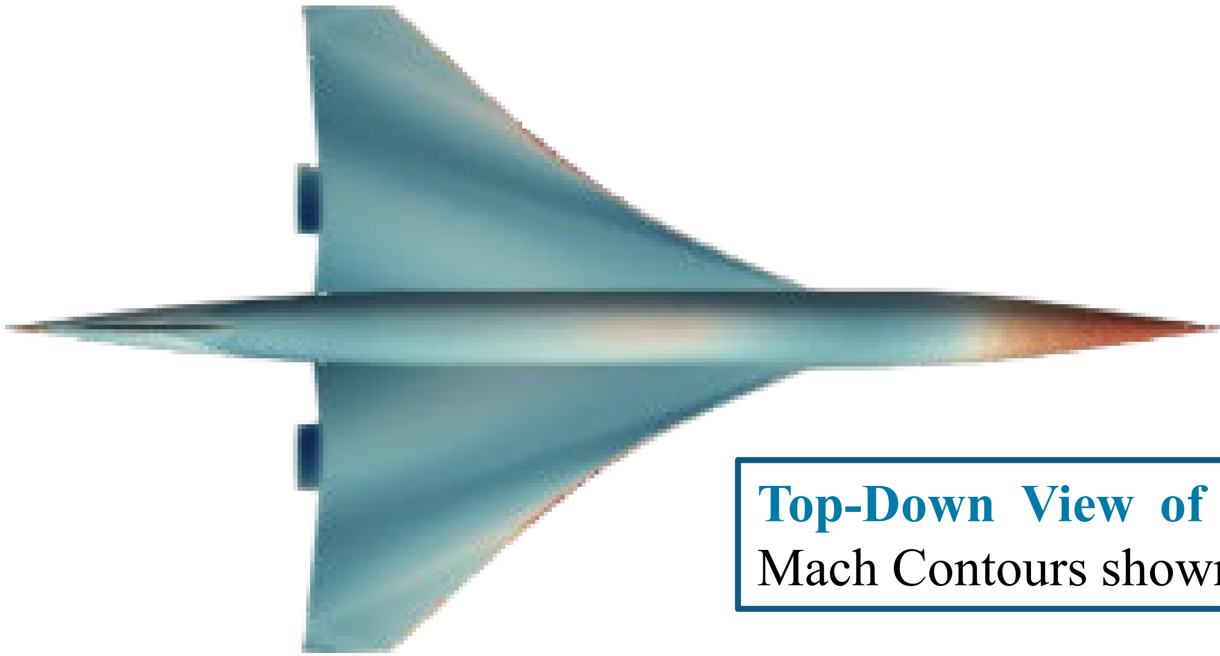
Project 22

Lead investigator: Donald Wuebbles, University of Illinois at Urbana-Champaign
Project manager: Jeetendra Upadhyay, FAA

October 24-26, 2023
Washington, DC

ASCENT
AVIATION SUSTAINABILITY CENTER

Potential Impacts on Ozone and Climate from a Proposed Fleet of Supersonic Aircraft : Intercomparison of Model Simulations



Top-Down View of the aircraft design with Mach Contours shown.

Last Time...

- **Impact analysis of three proposed supersonic transport (SST) fleet :**
  - 2 scenarios designed by MIT designated as MIT-High and MIT-Low
  - 1 scenario designed by Georgia Tech designated as GaTech

- **Model simulation :**
  - CESM2 – WACCM6 with model top ~140km with comprehensive troposphere-stratosphere-mesosphere-lower-thermosphere chemistry
  - WACCM6 run in a nudged, or specified dynamics (SD) configuration (WACCM6-SD), where the dynamics are relaxed to a free running simulation
  - Horizontal resolution $0.9^o \times 1.25^o$, 70 vertical levels
  - Troposphere, stratosphere, mesosphere and lower thermosphere (TSMLT) Chemistry package with 231 species, with 583 chemical reactions

Last Time…

Emissions Scenarios

		GaTech	MIT - High	MIT - Low
Design choice	Mach number	2.2	1.6	1.6
	Pax. capacity	55	100	100
	Max. range, nmi	4,500	3,500	3,500
Cruise ceiling, km		21	17	17
Fuel per 100 seat-km, kg/100 seat-km		19	7.15	7.08
Total fuel burn, Tg		122	43.1	9.6
Fleet average $EINO_x$, g/kg		14.7	9.0	9.2
Total NOx, Gg (TgNO2 equivalent)		1797.6	389.8	87.8
Total black carbon, Gg		6116.1	1355.4	299.7

Last Time…

- Brief summary of Result from UIUC / WACCM Simulation

	GaTech	MIT - High	MIT - Low
Total fuel burn (Tg)	122	43.1	9.6
Reduction of Total Global Ozone column (%)	0.74	0.33	0.06
Total Stratospheric Adjusted Radiative Forcing (mW/m^2)	45.4	14.7	4.4

This Time…

Model Intercomparison:

Comparing Ozone and Climate Effects for MIT-High and GaTech SST Scenarios using UIUC/WACCM and MIT/GeosChem Simulations

Contrasting Simulation Frameworks

	UIUC / WACCM	MIT / GeosChem
Simulation Design	CESM2-WACCM6-SD	Global CTM Geos-Chem v11
Horizontal Resolution	0.9° latitude × 1.25° longitude	4° latitude × 5° longitude
Vertical Resolution	70 non uniform vertical level with model top at 140km	72 non uniform vertical later with model top at 80km
Background atmosphere	CMIP6, SSP2-4.5, 2035 background atmosphere 12-year simulation from 2025-2036 with/without SST	MERRA reanalysis data
Radiative Forcing Module	PORT model (radiative transfer code offline); Calculates both instantaneous and stratospheric adjusted RF	RRTMG radiative transfer model embedded in GEOS-Chem Online calculation of RF due to water vapor and methane
Chemistry package	TSMLT	Geos-Chem UCX
Water Vapor Treatment	Simulated explicitly in SD-WACCM, trend validated with Satellite data. Source in middle atmosphere: direct entry from troposphere at tropical tropopause, and methane oxidation in upper stratosphere and mesosphere Gradual increase of 0.33ppmv per decade from change is stratospheric cold point temperature	Water vapor entering tropical tropopause($\pm 30^{o}$) cold point vary sinusoidally, between 3.0-4.8ppmv with an offset of 155days from the start of the year Average trend +0.0020%(+8.0 x 10^{5}ppmv) per year in the tropics at 20km altitude

Results

- Intercomparison of Ozone Impacts
- Intercomparison of Climate Impacts

Results: Intercomparison of Ozone Impact

Similarities →

- ✓ Total ozone depletion occurs for the entire year
- ✓ Maximum Ozone Reduction in NH
- ✓ Peaks over the Tropical region

Differences ↓

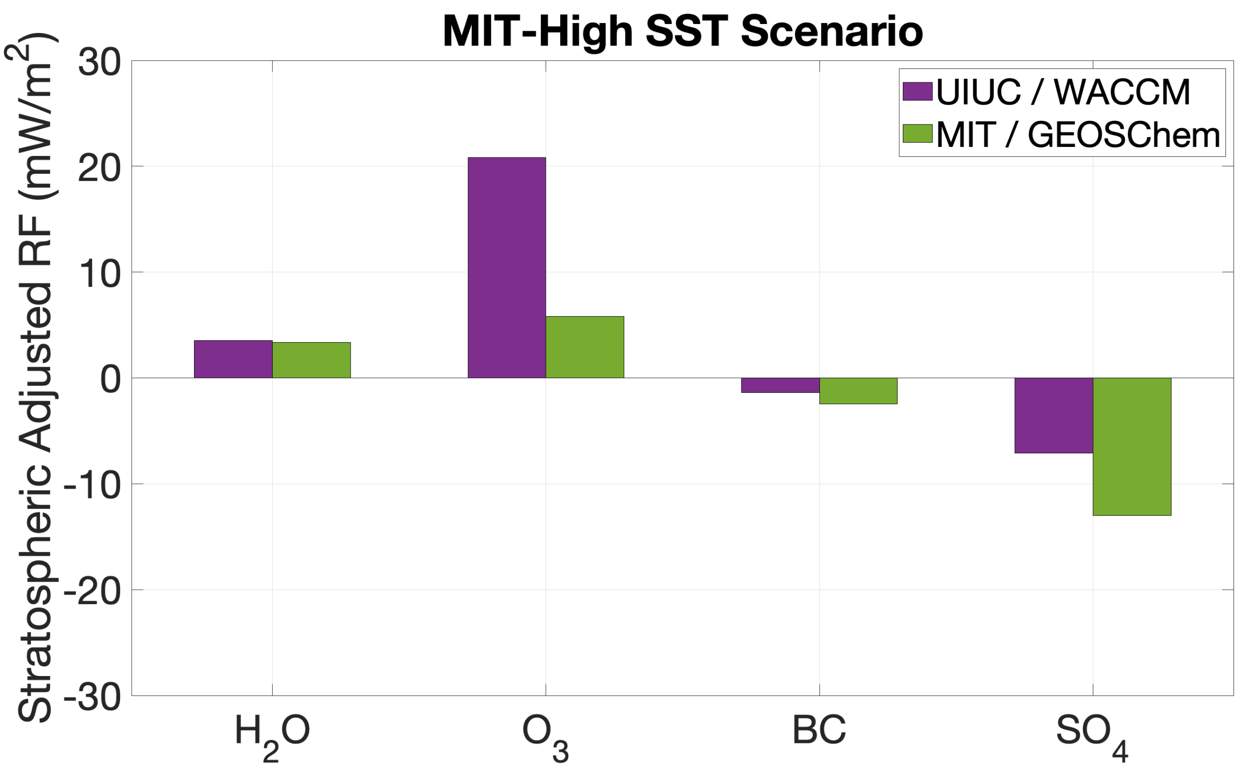
		UIUC / WACCM	MIT / GeosChem
MIT-High	**Global Ozone Column Reduction (%)**	0.33	0.13
	Maximum Ozone reduction: Seasonal Average (%)	0.11	0.57
	Maximum Ozone reduction NH (%)	0.42	0.88
GaTech	**Global Ozone Column (%)**	0.74	6.72
	Maximum Ozone reduction: Seasonal Average (%)	5	18.40
	Maximum Ozone reduction NH (%)	1.4	39.71

Intercomparison Ozone Response: Summary

- Ozone Response is directly related to the emissions assumed especially for the emissions of NO_x, H_2O, BC and SO_2
- The difference can be attributed to the different stratospheric water vapor treatment and methane feedback between the two models
- Fraction of SST emission is lower in SH compared to NH, atmospheric transport results in significant ozone loss in SH
- Since a large fraction of emission is happening around the tropics, the resultant ozone loss is also high in this region

Results: Intercomparison of Radiative Forcing

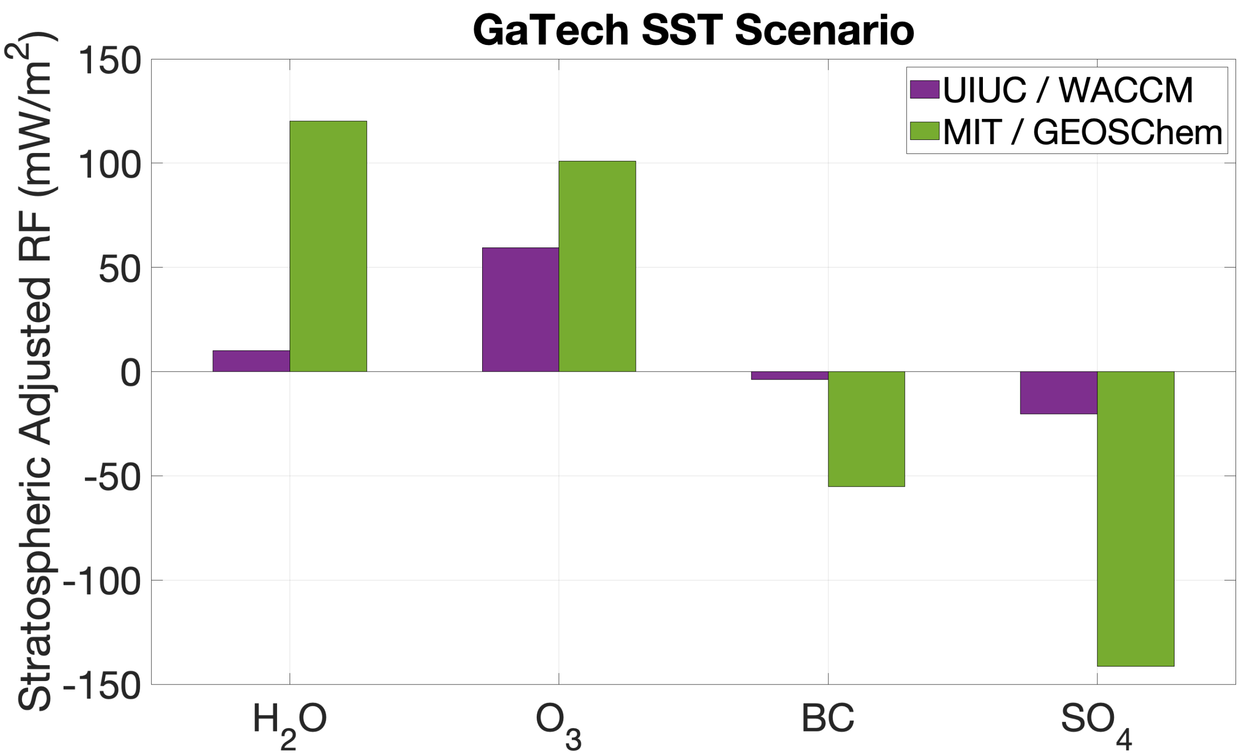
Annual and global average change in stratospheric-adjusted RF at the tropopause for supersonic aircraft induced changes in concentrations and distributions of Ozone, H_2O, BC and Sulfate



	UIUC / WACCM	MIT / GeosChem
Total Fuel Burn (Tg)	43.1	
Total RF (mW/m²)	15.9	6.3

Results: Intercomparison of Radiative Forcing

Annual and global average change in stratospheric-adjusted RF at the tropopause for supersonic aircraft induced changes in concentrations and distributions of Ozone, H_2O, BC and Sulfate



	UIUC / WACCM	MIT / GeosChem
Total Fuel Burn (Tg)	122	
Total RF (mW/m²)	45.4	24.5

Intercomparison of Radiative Forcing: Summary

- Radiative forcing impacts from SST emission is associated with its emissions of CO_2, H_2O, NO_x, SO_2, and BC
- Contribution to global climate change from stratospheric ozone and water vapor perturbations is likely larger than that from CO_2 emission
- Radiative perturbation of above the tropopause, in the stratosphere is not rapidly transported to the Troposphere
- The different treatment of water vapor resulting in difference of loss of Ozone is the likely contributor of the difference in RF

Summary

- Model Intercomparison of SST fleets are examined for environmental effects from their emissions.
- MIT-high scenario fuel burn 43.1 Tg/year (0.39 Tg NOx/year).
- GaTech scenario fuel burn 122 Tg/year (1.9 Tg NOx/year).
- UIUC / WACCM and MIT / Geoschem both shows similar response to ozone and climate impacts for each of the SST scenarios
- The variations in the magnitude of their responses can be attributed to differences in the models' underlying physics, particularly in how they handle water vapor in the stratosphere.
- We are currently conducting further investigations to understand these differences in more detail.

Analyses for ICAO ISG

Underway in 2023

- Task Group on Contrail Impacts / Aviation Induced Cloudiness (David Lee and Steven Barrett, co-chairs)
- Task Group on Supersonic Climate, Air Quality and Noise Impacts (Don Wuebbles and Seb Eastham, co-chairs)
- Review paper "Contrails and Contrail Cirrus: Modeling Their Effects on the Earth's Climate"

Completed in 2022:

- Jacob, S. D., Lee, D. S., Wuebbles, D. J., Fuglesvedt, J. S., Johansson, D., Fahey, D. W., Hauglustaine, D., Sausen, R., van Velthoven, P. J. F., & Barrett, S. R. H. (2022). ***Allowed emission of carbon dioxide for limiting global mean temperature increases to 1.5 or 2°C***.
- Hauglustaine, D. R., Miake-Lye, C., Arunachalam, S., Barrett, S. R. H., Fahey, D. W., Fuglestvedt, J. S., Madden, P., Skowron, A., van Velthoven, P., & Wuebbles, D. J. (2022). ***Assessment of the impact of airport emissions on local levels of*** NO_x ***and human health; impacts of cruise emissions of*** NO_x ***on human health; impacts of cruise*** NO_x ***on climate***.
- Wuebbles, D. J., Baughcum, S., Barrett, S., Catalano, F., Fahey, D. W., Madden, P., Rhodes, D., Skowron, A., & Sparrow, V. (2022). ***Understanding the potential environmental impacts from supersonic aircraft: An update***.

Acknowledgements

Special thanks to

Jeet Upadhyay (FAA), Seb Estham, Lucas Oh (MIT) and Jun Zhang (UCAR) for many helpful discussions.

Participants

Project Postdocs: Swarnali Sanyal

Dharmendra Singh

ASCENT Project 022
Evaluation of FAA Climate Tools

University of Illinois at Urbana-Champaign

PI: Dr. Donald Wuebbles
PM: Dr. Jeetendra Upadhyay and Swarnali Sanyal
Cost Share Partner: University of Illinois / DLR

Objective:

- Further enhance the overall understanding of aviation impacts on climate and environment
- Support and analyses to assist ICAO Impacts Science Group.
- Evaluate capabilities, limitations, and uncertainties of climate metrics and simple models (e.g., APMT) to aid policy decisions.

Motivation

- Science-based evaluation of analytical tools used by the FAA;
- Development of ideas and concepts for the next generation treatment of aviation effects on the Earth system;
- Updated evaluation and analyses of the science of aviation effects on atmospheric composition and climate;
- Evaluation of potential environmental effects from assumed fleets of supersonic commercial and business jet aircraft
- Address policy questions and consideration of potential policymaking.

Project Benefits:

- Science-based evaluation of analytical tools used by the FAA;
- Advancing consideration of aviation effects on the Earth system;
- Enhanced understanding of aviation effects on atmospheric composition;
- The evaluation of potential environmental effects from assumed fleets of supersonic commercial and business jet aircraft;
- Addressing policy questions and consideration of potential policymaking quantifying regional climate impacts.

Research Approach:

Analyses of atmospheric composition changes and climate effects from aviation emissions

- State-of-the art climate-chemistry modeling capabilities (we are using the greatly extended Whole Atmosphere Community Climate Model (WACCM) version of NCAR's Community Earth System Model) – ground to 140 km with comprehensive atmospheric chemistry.
- Conduct simulations with different emissions scenarios as well as sensitivity studies for different parameters (e.g., fuel burn, NOx) for supersonic and subsonic aircraft fleets.

Analyses to assist ICAO Impacts Science Group

- Scientific studies and report preparations for ICAO on aviation emissions related topics.

Major Accomplishments (to date):

- Completed evaluation and published paper of atmospheric chemistry and climate impacts for emissions from SST fleet aircraft proposed by Ga. Tech.
- Completed analyses of MIT SST emissions scenarios.
- Comparison of UIUC/WACCM and MIT/Geoschem simulations
- Working on new reports for ICAO through ISG
- Biweekly telecons with FAA; Quarterly and annual reports
- Presentations and participation in CCR and ASCENT meetings, ICAO, AGU and other conferences.

Future Work / Schedule:

- Publish joint journal paper with MIT for study of their projected supersonic fleets.
- Complete ICAO studies.
- Coordinate with MIT on further APMT-IC, e.g., for supersonic impacts (ASCENT Project 58).

This research was funded by the U.S. Federal Aviation Administration Office of Environment and Energy through ASCENT, the FAA Center of Excellence for Alternative Jet Fuels and the Environment, project A22 through FAA Award Number 13-C-AJFE-UI-029 under the supervision of Daniel Jacob. Any opinions, findings, conclusions or recommendations expressed in this this material are those of the authors and do not necessarily reflect the views of the FAA.