FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Evaluation of FAA Climate Tools

Project 22

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ASCENT
AVIATION SUSTAINABILITY CENTER

Motivation

- This ASCENT project is part of the Aviation Climate Change Research (CCR) Consortium Effort.

- FAA simple climate tool – APMT is undergoing a new evolution to include representation of climate effects on a zonal (latitude) basis and to consider regional effects.

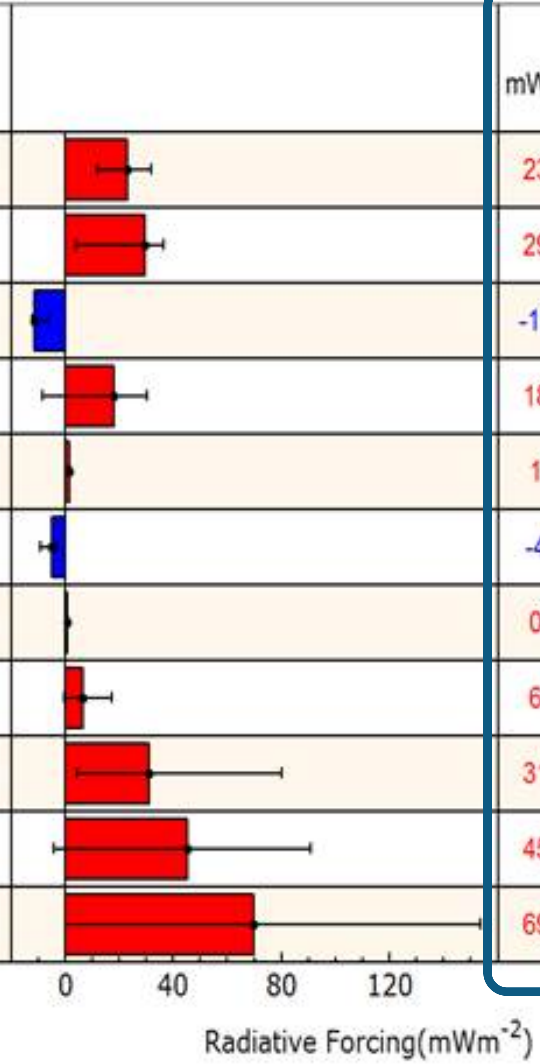
- FAA wants to establish regional analyses of aviation emissions to address policy questions and potential policymaking.

Why focus on regional effects from aviation emissions?

Previous studies:

- focused on **globally-averaged** aviation effects on climate
- **Little** information on the **spatial variability** of the effects.
- Metrics largely use global emission data whereas the impact scale of most emissions is **local to hemispheric**.

RF Terms	mWm^{-2}	RF/RF_{CO_2}	Scale	LOSU
Carbon dioxide	23.0	1.00	Global	High
Short-term ozone	29.5	1.28	Continental to hemispheric	Med -Low
Methane reduction	-11.5	-0.50	Global	Med -Low
Net NOx	18.0	0.78	Global	Med -Low
Water vapor	1.7	0.07	Hemispheric to global	Low
SO_4 aerosol direct	-4.8	-0.21	Local to global	Low
BC aerosol direct	0.8	0.03	Local to global	Low
Linear contrails	6.6	0.29	Local to continental	Low
Contrail cirrus	31.2	1.36	Local to hemispheric	Low
Total aviation w/o contrail cirrus	45.3	1.97	Global	Low
Total aviation	69.9	3.04	Global	Low



ACCRI report(2013)

Why focus on regional effects from aviation emissions?

Long-lived

Forcing agent	NH	SH	NH/SH	Global	LEE2009
CH_4	[−8.0, −12.3]	[−8.0, −12.3]	1	[−8.0, −12.3]	[−2.1, −76.2]
O_3 long	[−4.0, −4.7]	[−4.0, −4.7]	1	[−4.2, −4.5]	—
O_3 short	[10.3, 63.6]	[2.0, 24.1]	[5, 3]	[6.0, 36.5]	[8.4, 82.3]
SO_4 direct	[−5.5, −11.8]	[−0.5, −1.5]	[11, 8]	[−3.0, −7.0]	[−0.79, −29.3]
Nitrate direct	[−11.6]	[−4.2]	[3]	[−4.0, −7.5]	—
BC direct	[1.2, 1.9]	[0.1, 0.2]	[12, 10]	[0.6, 1.0]	[0.56, 20.7]
LCs				[2.9, 11.3]	[5.4, 25.6]
Contrail cirrus	[24.0, 95.0]	[0.7, 5.0]	[34, 19]	[12.4, 51.3]	[12.5, 86.7]

Short-lived

- Spatial variability is found to be **particularly important for the aviation sector**. (Lund et al., 2012)
- Forcing over **local regions** much greater than globally-averaged values, and the associated temperature change is more **heterogeneous**.

Brasseur et al., (2016)

Objectives

❑ Long-term objectives

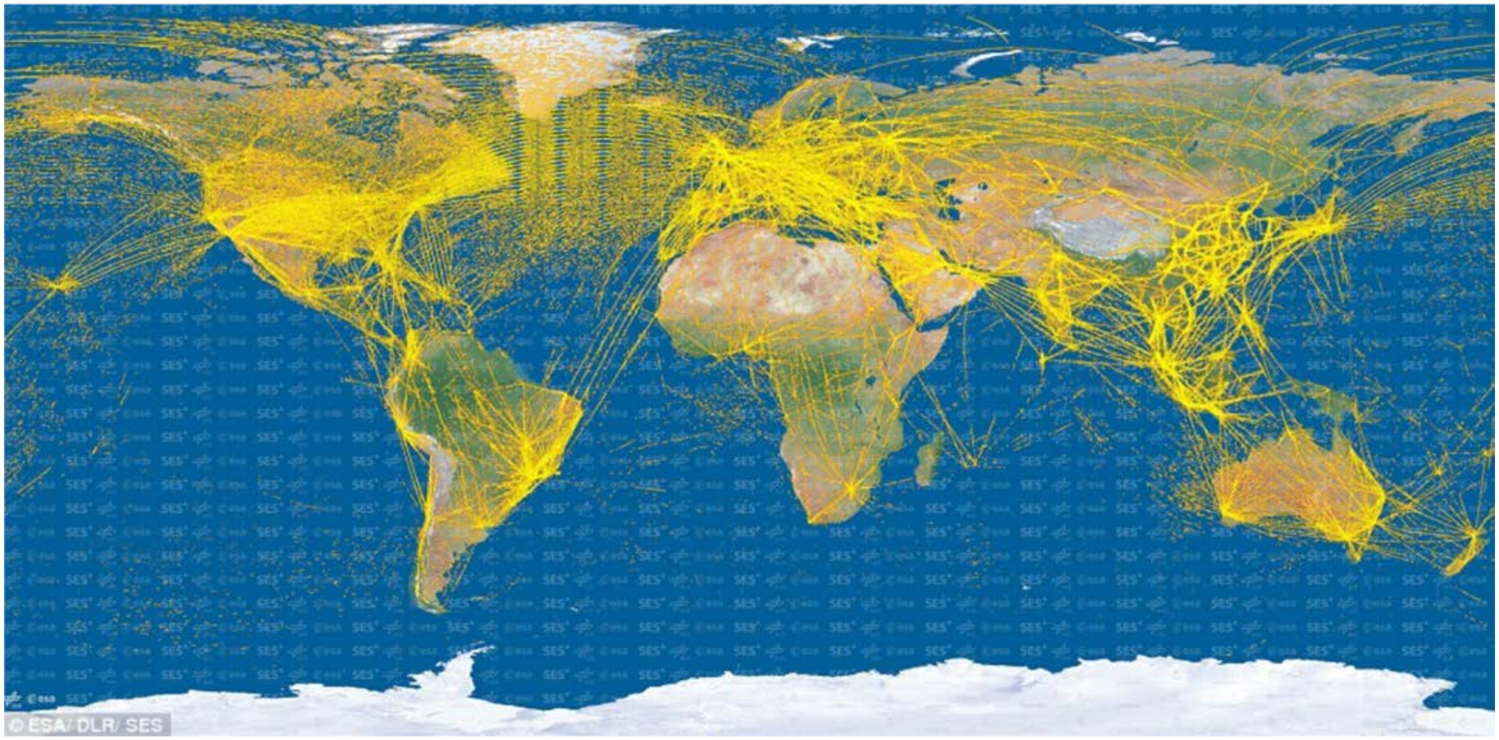
- Further enhance the overall understanding of aviation impacts on climate
- Studies to explore the regional climate impacts from aircraft emissions.
- Evaluate the capabilities, limitations, and uncertainties of climate metrics and simple models (e.g., APMT) to aid policy decisions.

Objectives

❑ Near term objective

FAA would like to have estimates of regional temperature change due to global aviation emissions

Determine ΔT over United States, Europe, and East Asia



Outcomes and Practical Applications

- **Outcomes**
  - Biweekly telecons with FAA
  - Quarterly reports to FAA
  - Annual report summarizing progress
  - Presentations and participation in CCR and ASCENT meetings, AGU and other conference
- **Practical applications**
  - Extend the understanding of aviation effects on climate and evaluating a simplified model to address policy questions
  - Analyses are useful to the FAA, to ICAO, and to the aviation industry

Approach

Regional analyses of climate effect for aviation emissions

- State-of-the art modeling capabilities (CAM version of CESM: CAM-Chem5)
- Conduct simulations with different emissions as well as their combinations, from aviation emissions to explore the gas and particle separate and combined effects on regional climate.
- Derive temperature response over four latitude bands using CICERO approach, and explore possible way to derive temperature change over regions.

Previous Accomplishments and Contributions

Our previous analysis (reported at last ASCENT meeting):

Calculated the radiative forcing over latitude bands and regions induced from global aviation emissions.

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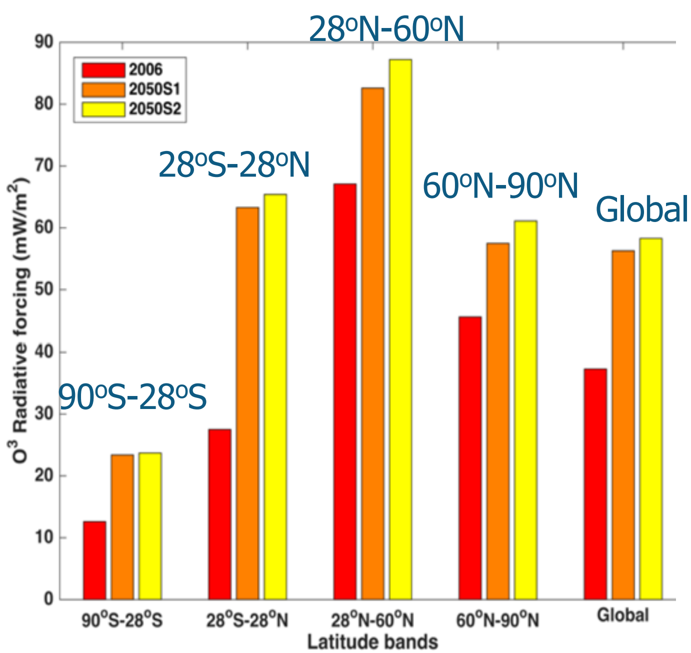
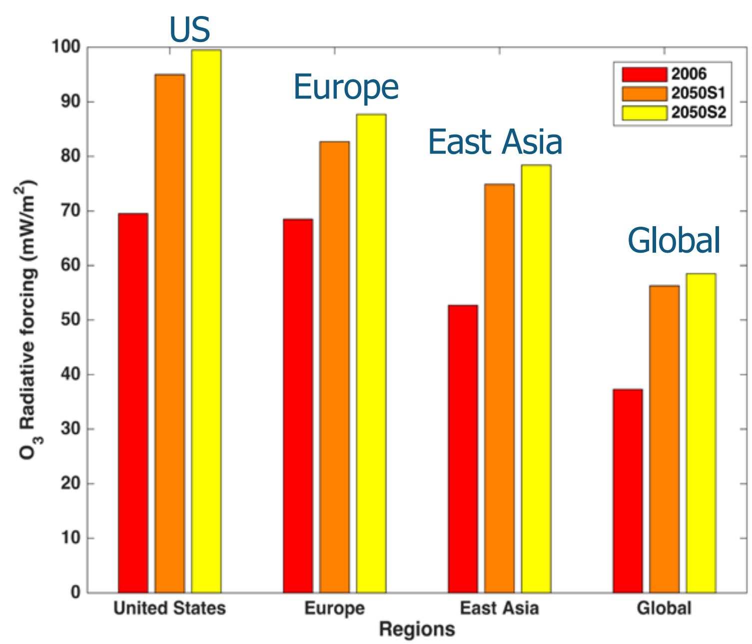
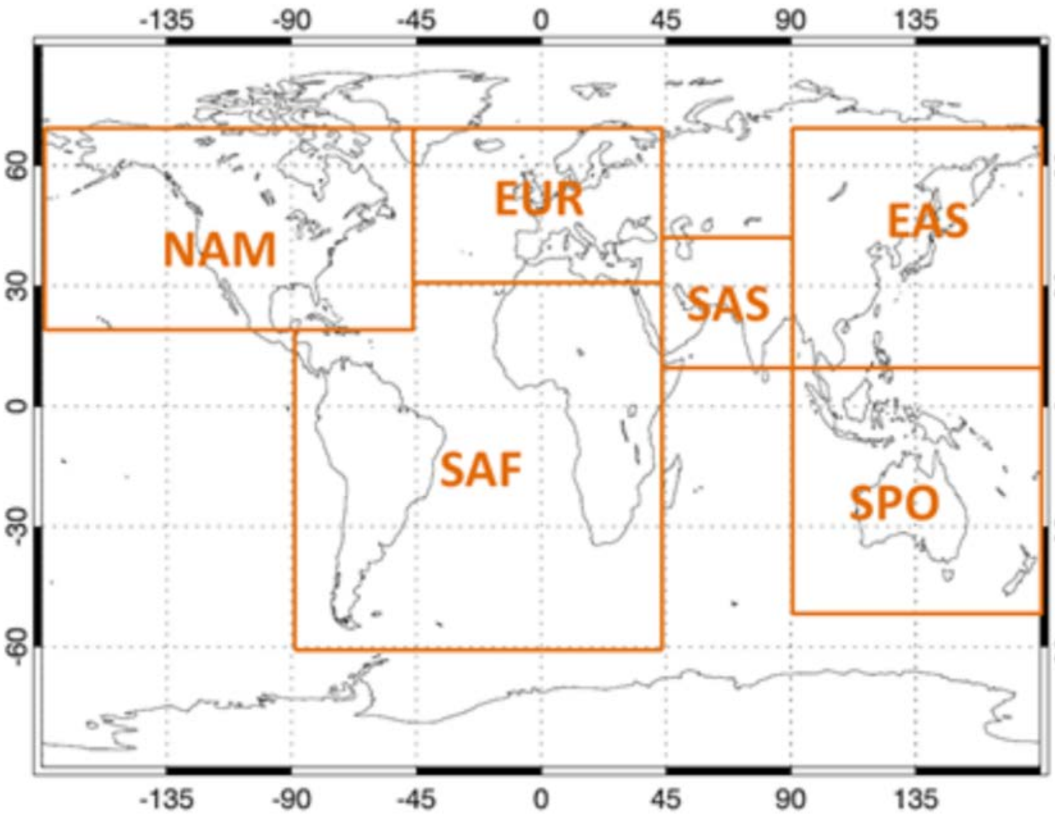




O_3

CICERO Approach

CICERO took such analyses one step further by calculating the latitudinal band temperature change accounting for localized regional sources



NAM = North America, EUR = Europe, SAS = South Asia and Middle East, EAS = East Asia, SAF = South America and Africa, SPO = South Pacific Ocean

Six source regions

- **CICERO approach calculates the temperature change over four latitude bands due to six emission source regions**

  ΔT over
  - 90^{o}S – 28^{o}S,
  - 28^{o}S – 28^{o}N,
  - 28^{o}N – 60^{o}N,
  - 60^{o}N – 90^{o}N

Lund et al., 2017

CICERO Approach

- Uses regional climate sensitivity (RCS) and impulse response functions as bridges from forcing to response.
- Considerations in using CICERO approach to calculate temperature change over regions
  - Our model simulations can determine regional RF
  - RCS is important to determine the amount of temperature response induced from RF
  - To get temperature change over regions, RCS over corresponding regions are needed
  - Make assumptions based on RCS over latitude bands to get RCS over interested regions

Schedule and Status

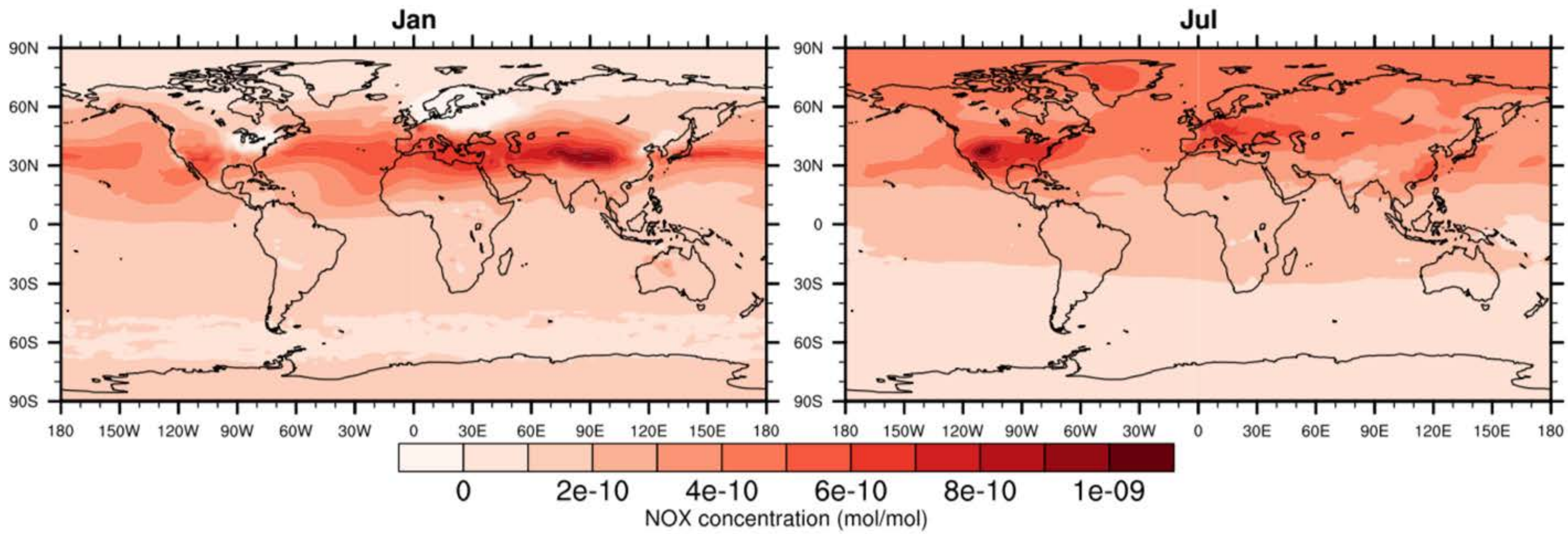
CCR / ASCENT Projects (Mar 2018 to Oct 2018):

- ✓ Evaluation of the regional climate effects based on different latitudinal bands and regions (ongoing)
- ✓ For regional studies, new modeling studies using CAM5-Chem to calculate the regional forcing effects of NOx and aerosols emissions (ongoing)
- ✓ Calculate temperature response over latitude bands and regions based on model output and CICERO approach (ongoing)
- ✓ Conduct simulations on new version CESM2 (CAM6-chem) (In process)

Recent Accomplishments and Contributions

Simulations of the climate effects induced by regionally important aviation emission species (NOx, SO_4 and BC)

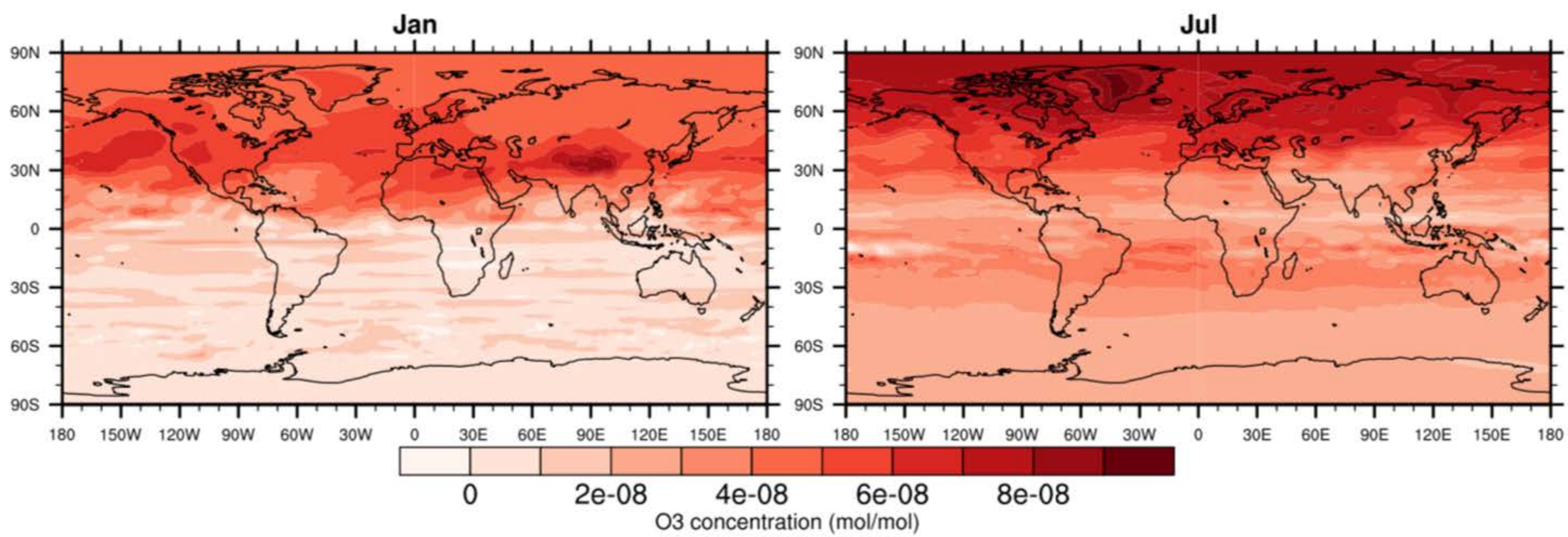
NOx perturbation simulation



- Perturbations of the NOx concentration in January and July based on 2006 aviation NOx emission

Recent Accomplishments and Contributions

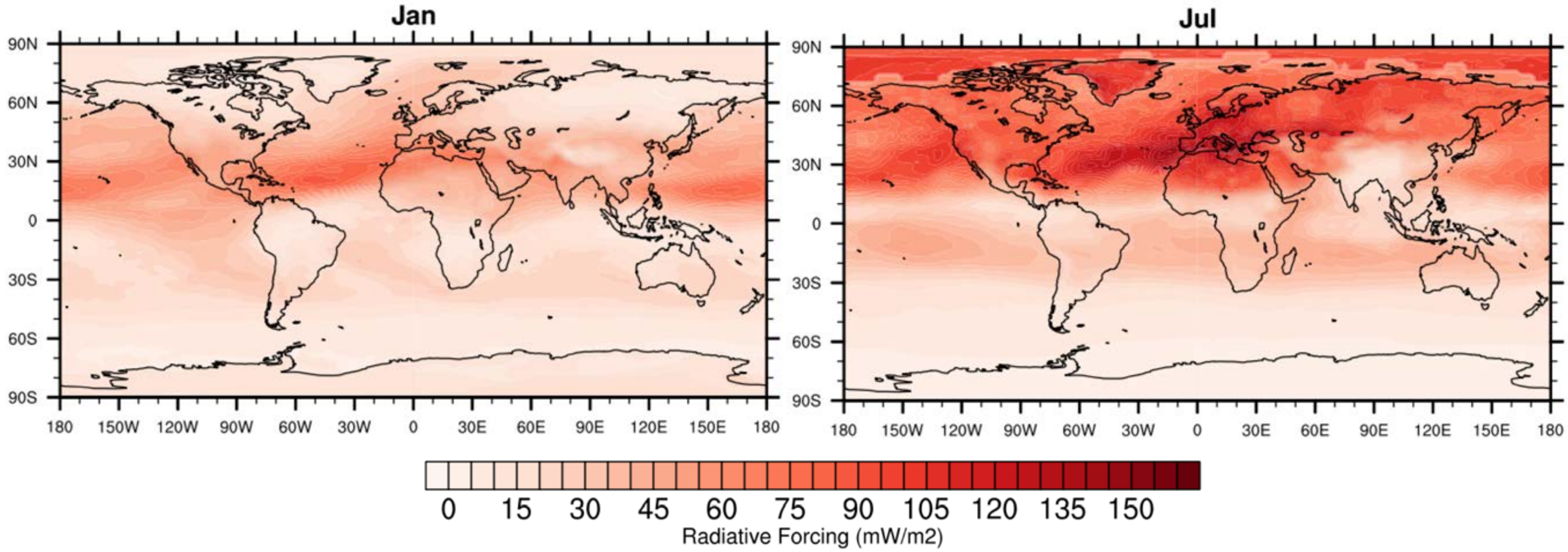
Perturbations of the O_3 concentration in January and July based on 2006 aviation NOx emission



- NOx-induced O_3 production are mainly over Northern Hemisphere

Recent Accomplishments and Contributions

Radiative forcing (mWm−2) from O_3 in January and July due to 2006 aviation NOx emissions



- Strong regional and seasonal variability
- Forcing mainly over emission regions
- July has larger forcing

Recent Accomplishments and Contributions

Radiative forcing (mWm–2) of O_3 over latitude bands and regions compared with global values for 2006

Radiative forcing (mW/m2)	90ºS-28ºS	28ºS-28ºN	28ºN-60ºN	60ºN-90ºN	Global
O_3	12.6	27.5	67.1	45.6	37.3

Radiative forcing (mW/m2)	United States	Europe	East Asia	Global
O_3	69.5	68.5	52.7	37.3

Summary

Findings

- Model simulations underway for studying regional effects.
- Analyses and evaluation of CICERO approach partially done.

Next steps

- Complete modeling studies using new CAM6-Chem to calculate the forcing effects of aviation for both 2006 and 2050.
- Derive regional temperature change based on model simulated forcing due to global aviation emissions.

Key challenges/barriers

- CESM2 recently released; will rerun all simulations on this new version.

References

Brasseur, G. P., A. Gettelman, M. Jacobson, P. Minnis, J. Penner, R. Prinn, H. B. Selkirk, N. Unger, H.-W. Wong, D. J. Wuebbles, P. Yang, R. Halthore and S. D. Jacob, 2013: *Aviation Climate Change Research Initiative (ACCRI) Phase II Report*. Federal Aviation Administration, Washington, D. C.

Chen, C.-C., and Gettelman, A.: Simulated 2050 aviation radiative forcing from contrails and aerosols, *Atmos. Chem. Phys.*, 16, 7317- 7333, doi:10.5194/acp-16-7317-2016, 2016.

Khodayari, A., S. Times, S. C. Olsen, D. Phoenix, and D. J. Wuebbles, J.-F. Lamarque, and C.-C. Chen, 2015: Aviation 2006 NOx-Induced effects on atmospheric ozone and HOx in Community Earth System Model (CESM). *Atmos. Chem. Phys.,* 113, 135-139, doi:10.1016/j.atmosenv.2015.04.070.

Lund, M. T., Berntsen, T., Fuglestvedt, J. S., Ponater, M., & Shine, K. P. (2012). How much information is lost by using global-mean climate metrics? an example using the transport sector. *Climatic Change*, *113*(3-4), 949-963.

Zhang and Wuebbles, 2016: Evaluation of FAA Climate Tools: APMT. Federal Aviation Administration report.

Zhang and Wuebbles, 2017: Evaluation of FAA Climate Tools: APMT. Federal Aviation Administration report.

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Supplementary

CICERO Approach

$$ARTP_{i,r,m}(H) = \sum_l \frac{RF_{i,l,r}}{E_{i,r}} \cdot RCS_{i,l,m} \cdot IRF(H)$$

$\boldsymbol{ARTP_{i,r,m}(H)}$: absolute regional temperature change of species *i* in latitude band m at time *H* following a pulse emission in region *r*.

$\boldsymbol{RF_{i,l,r}}$: the radiative forcing in latitude band *l* caused by one year of emissions $E_{i,r}$ of species *i* in region *r*.

$\boldsymbol{E_{i,r}}$: emissions of species *i* in region *r*.

$\boldsymbol{RCS_{i,l,m}}$: regional climate sensitivity, the regional response in latitude band *m* due to a radiative forcing in latitude band *l* caused by a change in species *i*

$\boldsymbol{IRF(H)}$: temporal temperature response to an instantaneous unit pulse of RF