Effects of aerosol feedback on aircraft-attributable surface O_3 and $PM_{2.5}$ concentrations using the two-way coupled WRF-CMAQ modeling system

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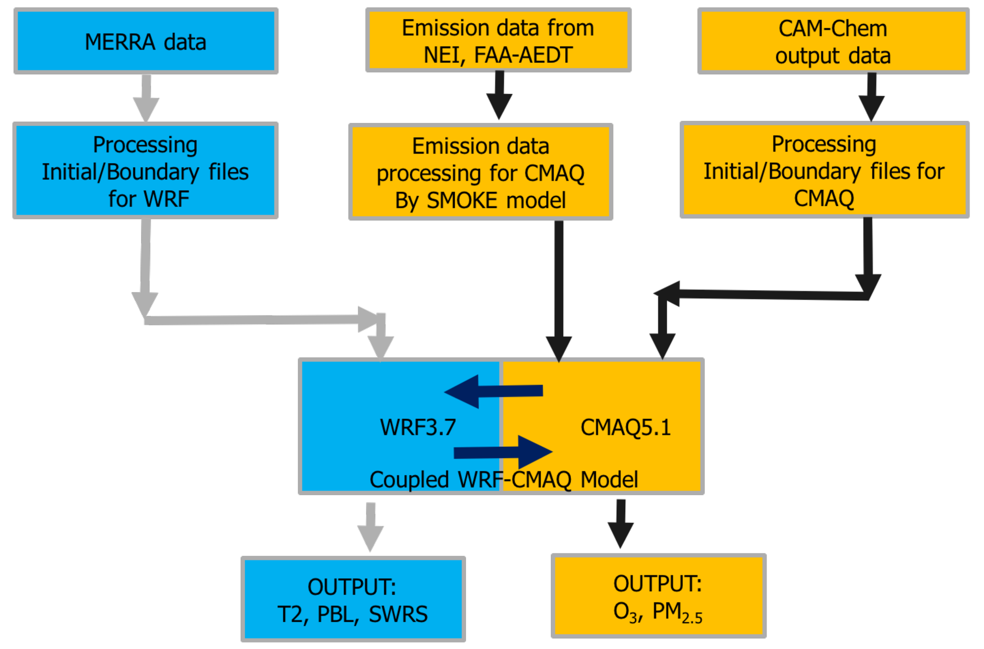
Motivation

- Aircraft emits CO, NOx, SOx , VOCs and particulate matter (PM) from which secondary pollutants such as O_3 and $PM_{2.5}$ are also produced which cause harm to human health.
- Landing and take-off (LTO) emission contributes to ~0.02% and ~0.05%[1] of surface background O_3 and $PM_{2.5}$ respectively in continental USA.
- LTO emission causes ~70-100 premature death in USA [2] and 4000 globally[3].
- Aerosol's direct feedback effect influences surface O_3, $PM_{2.5}$ and some meteorological variables.
- Limited information on using coupled meteorology-chemistry model to quantify aviation emissions' contribution to surface air quality and meteorology in a regional scale domain.
- It is important to know how aerosol's direct feedback influences the estimation of aircraft's LTO emission effects on surface O_3, $PM_{2.5}$ and meteorology by a coupled meteorology-chemistry model in a regional scale domain.

Objective

- Use the coupled meteorology-chemistry model (such as WRF-CMAQ[4] modeling system) to quantify the aircraft's LTO emission's contribution to surface O_3 , $PM_{2.5}$ and some meteorological variables (surface temperature at 2 m (T2), planetary boundary layer (PBL) height and short-wave radiation(SWR) at surface etc.).
- Understand how aerosol's direct feedback effect influences surface layer O_3, $PM_{2.5}$ and meteorology.
- Reduce aviation emission induced human health impacts and climate impacts

Methodology



Coupled two-way WRF-CMAQ modeling system

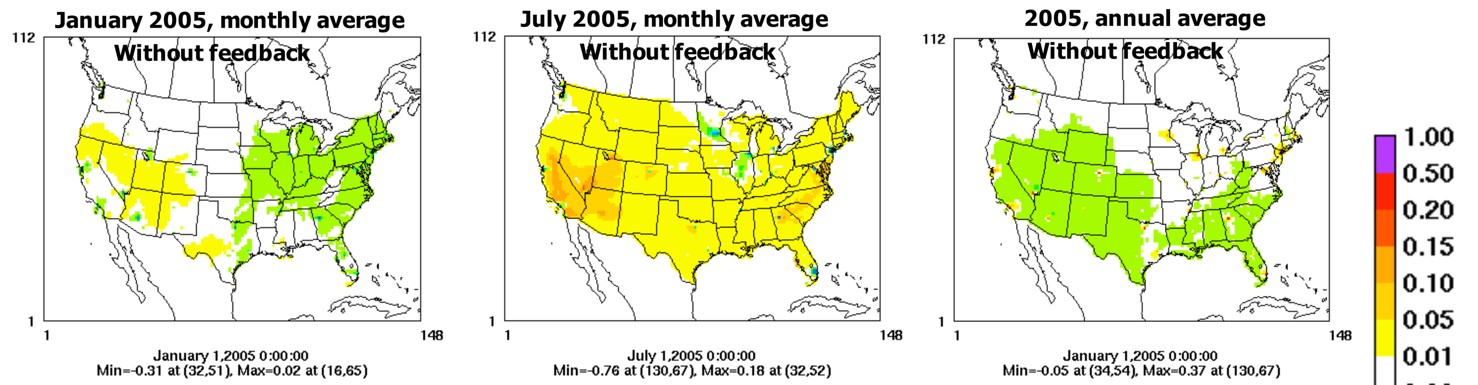
Four sensitivity simulation cases

Case number	Case description
1	Without aircraft emissions without aerosol feedback
2	Without aircraft emissions with aerosol feedback
3	With aircraft emissions without aerosol feedback
4	With aircraft emissions with aerosol feedback

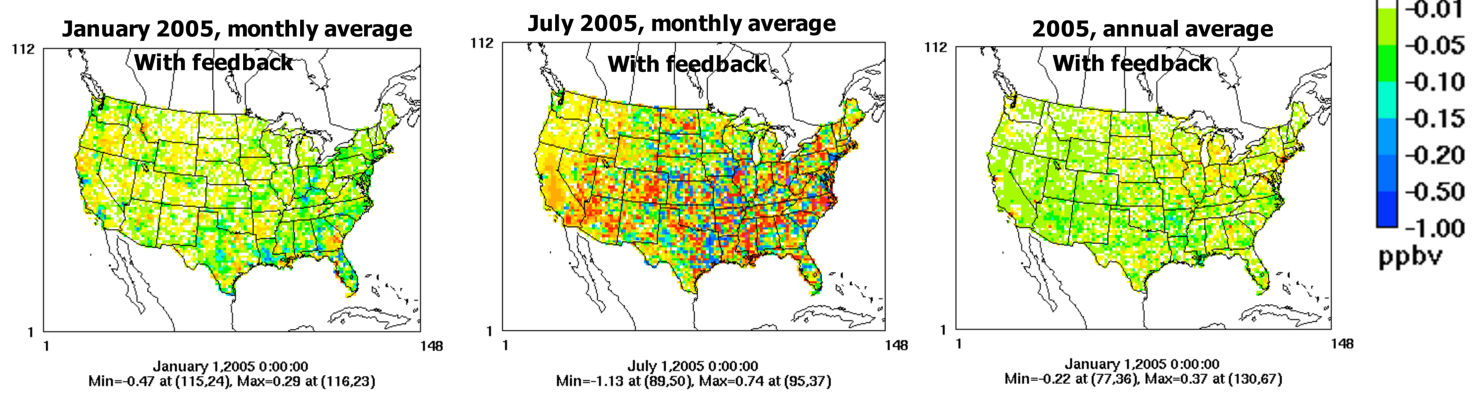
Model configuration

Name	Description
Model version used	Coupled WRFv3.7-CMAQv5.1
Simulation period	2005 (1 year) with 6 months spin-up
Domain	Continental US (CONUS)
Spatial grid size	36x36 km^2
Number of sigma vertical layers	35 (with top layer at 50 hPa)
Input meteorological data	NASA Modern Era Reanalysis for Research and Applications (MERRA; http://disc.sci.gsfc.nasa.gov/mdisc/ overview/index.shtml)
Planetary boundary layer scheme	Asymmetrical Convective Model version 2 (ACM2)
Cloud microphysics scheme	Morrison 2-moment scheme
Land surface model	Pleim-Xiu
Cumulus parameterization	Version 2 of Kain–Fritsch scheme (KF2)
Land use	USGS 24
Gas–phase chemistry	Carbon Bond 05
Aerosol chemistry	Aero6
Short wave radiation scheme	RRTMG
Long wave radiation scheme	None
Emission	2005 NEI and FAA-AEDT processed by SMOKE

O_3 perturbation by aircraft's LTO emission with & without feedback

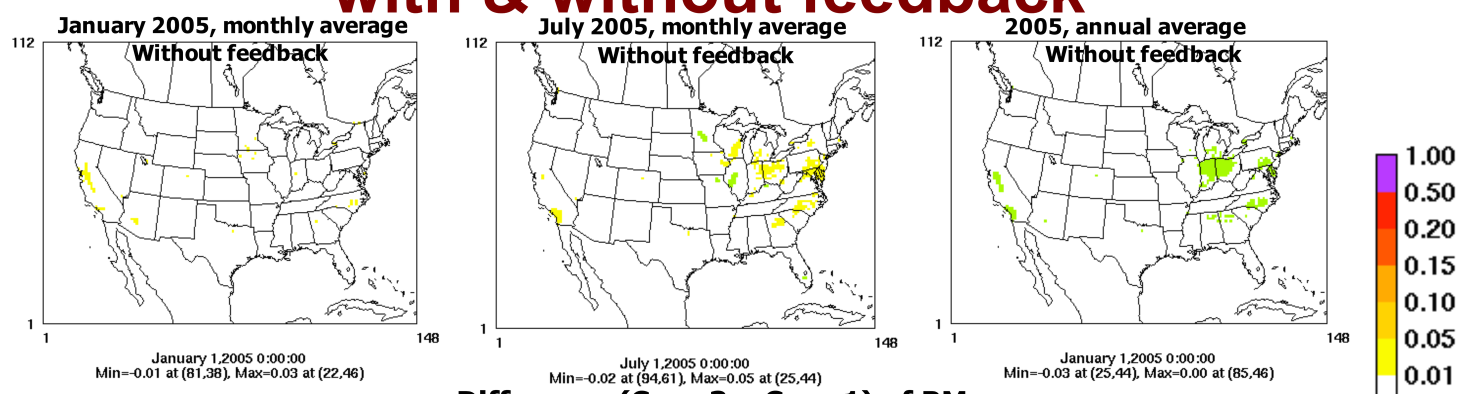


Difference (Case 3 – Case 1) of O_3

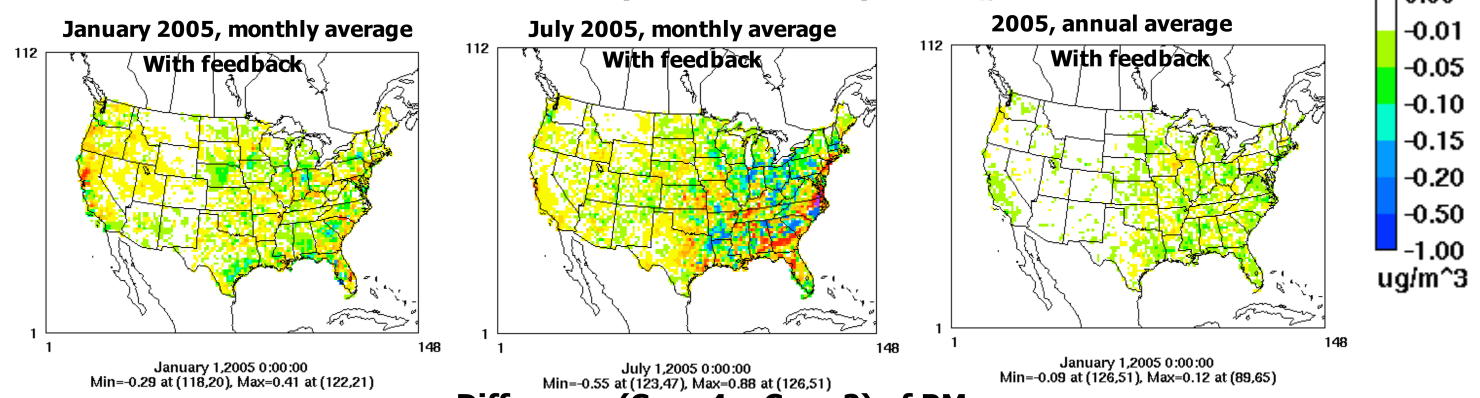


Difference (Case 4 – Case 2) of O_3

$PM_{2.5}$ perturbation by aircraft's LTO emission with & without feedback

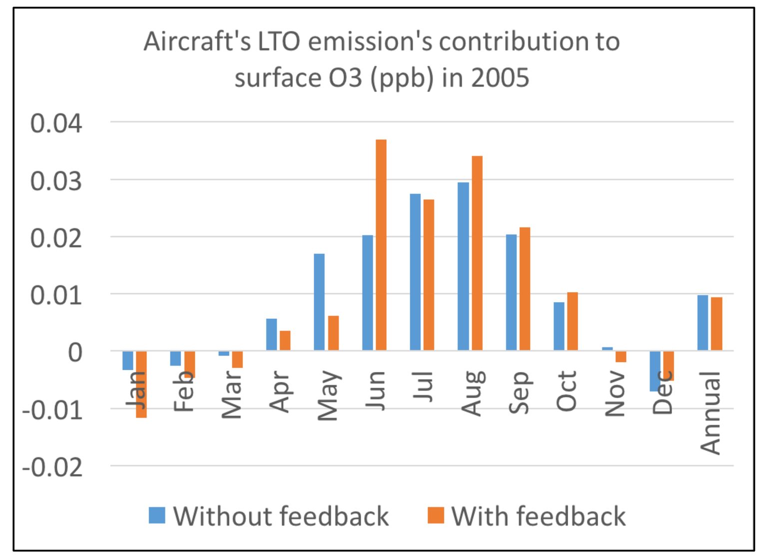


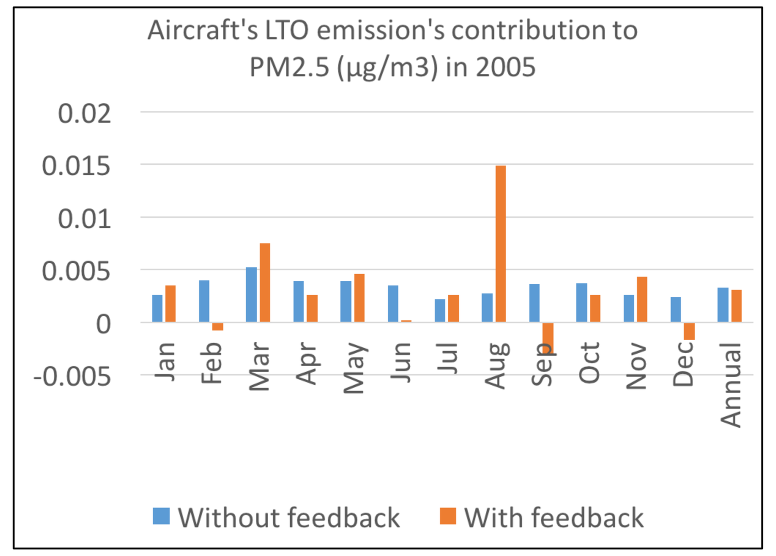
Difference (Case 3 – Case 1) of $PM_{2.5}$



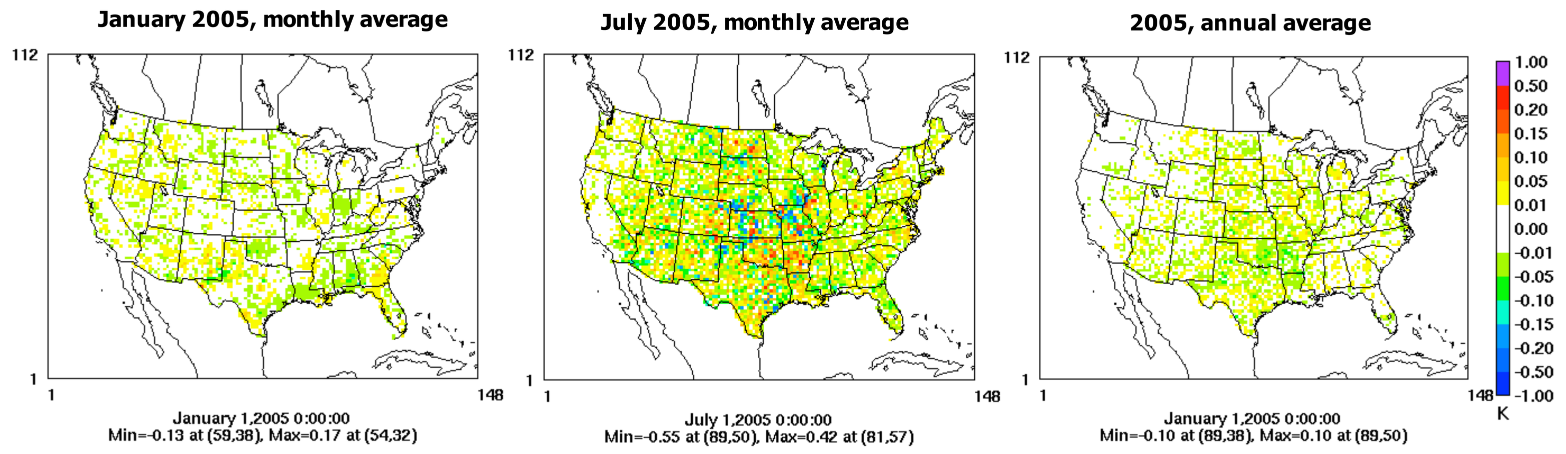
Difference (Case 4 – Case 2) of $PM_{2.5}$

Domain average of O_3 and $PM_{2.5}$ perturbation by aircraft's LTO emission with & without aerosol feedback

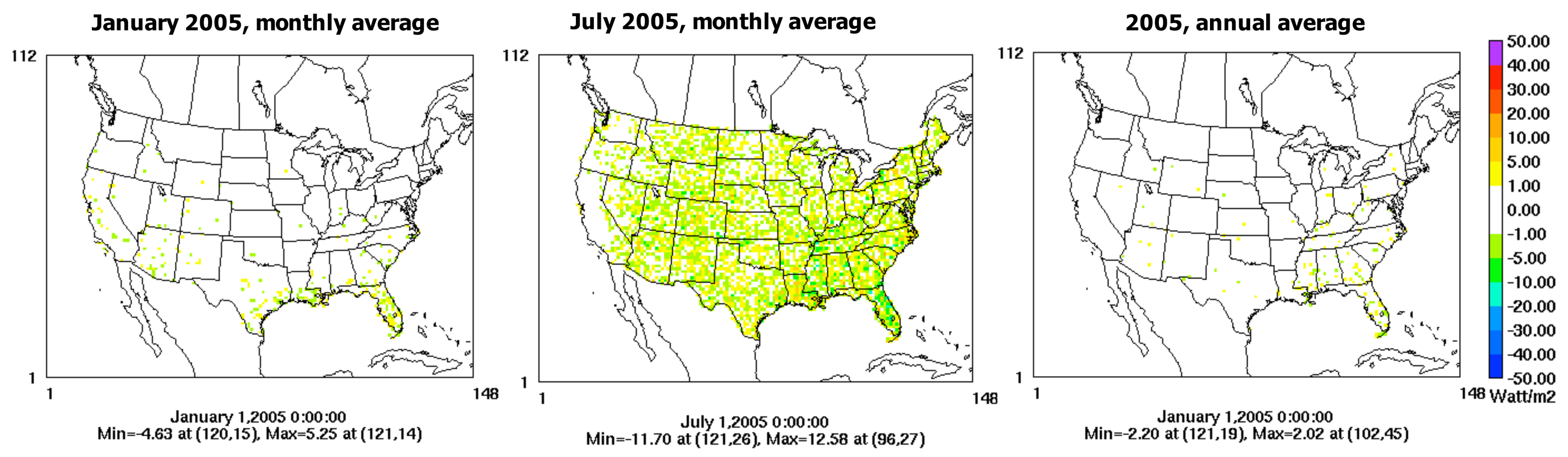




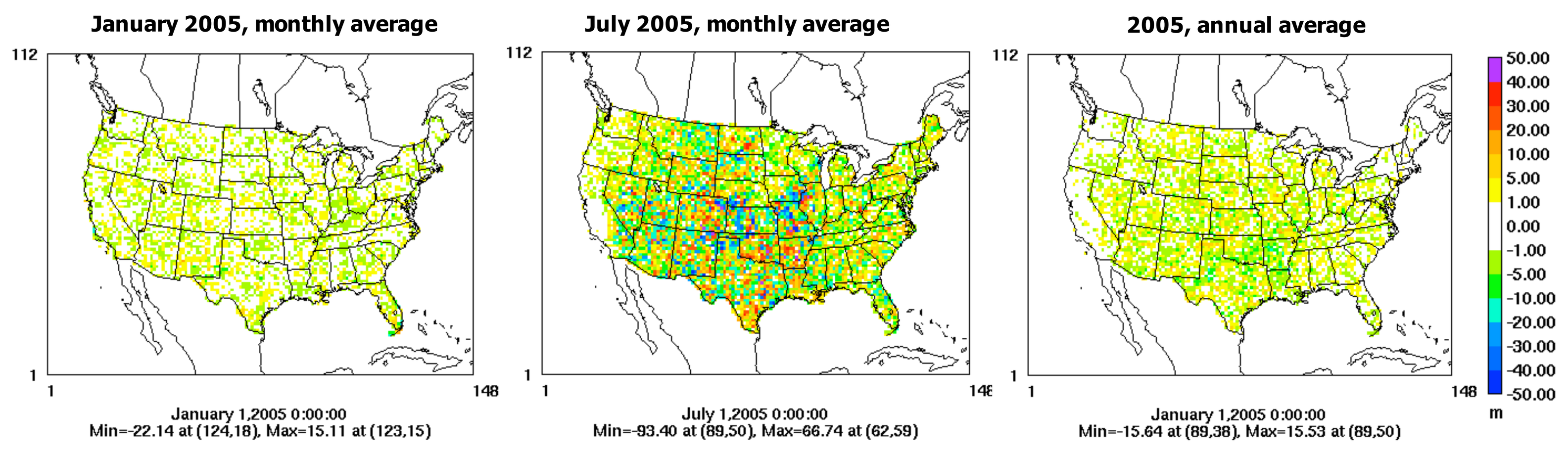
T2, SWR, PBL perturbation by aircraft's LTO emission when aerosol feedback was considered



Difference (Case 4 – Case 2) of T2

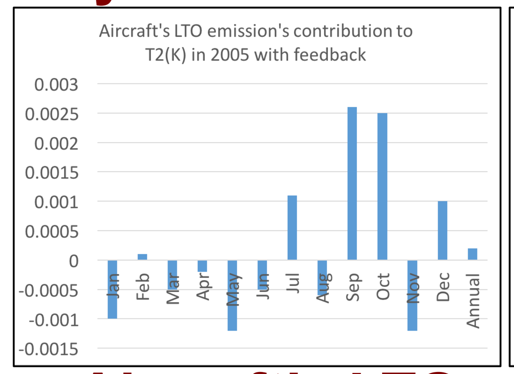


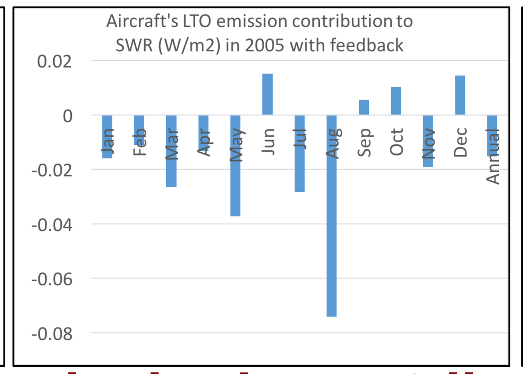
Difference (Case 4 – Case 2) of SWR

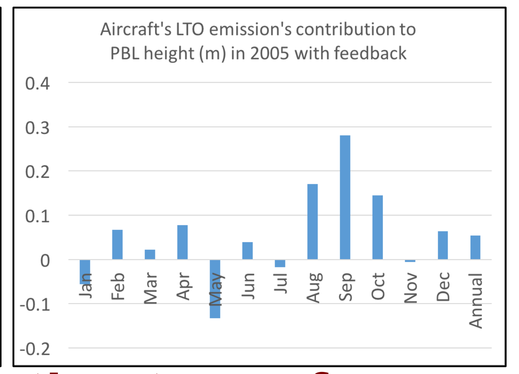


Difference (Case 4 – Case 2) of PBL height

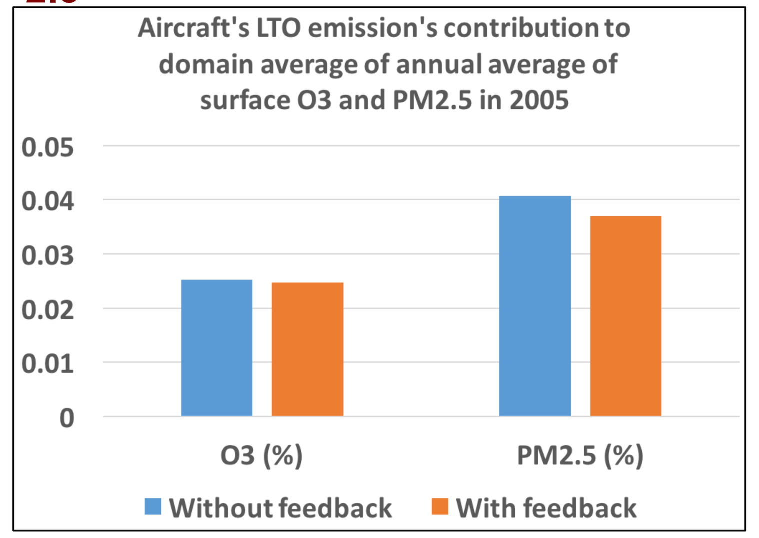
Perturbation of domain average of T2, SWR and PBL by aircraft's LTO emission due to aerosol feedback







Aircraft's LTO emission's contribution to surface O_3 and $PM_{2.5}$ with & without aerosol feedback



Summary

- Coupled WRF3.7-CMAQ5.1 model was used to determine aviation contribution of LTO emissions of all US airports to both air quality and meteorology
- Aircraft's LTO emissions' contribution to domain average of annual average of total concentration of O_3 and $PM_{2.5}$ were 0.0252% and 0.040% respectively without aerosol feedback and 0.0247% (3% lower than without feedback) and 0.037% (6% lower than without feedback) respectively with aerosol feedback .
- When aerosol feedback effect was considered, perturbation of domain average of annual average of meteorological variables: temperature at 2 m (T2), short-wave radiation (SWR) at ground and PBL height by aircraft's LTO emission were +0.0002 K, -0.015 W/m^2 and +0.054 m respectively.
- Minimum and maximum perturbation of daily average across the entire domain in 2005 of O_3 and $PM_{2.5}$ at surface by aircraft's LTO emission respectively were :
  - Without feedback: ΔO_3: –0.028 ppb on Mar 11, 2005 and +0.057 ppb on May 7, 2005, $\Delta PM_{2.5}$: –0.009 µg/m^3 on Sep 8, 2005 and +0.007 µg/m^3 on Nov 1, 2005.
  - With feedback: ΔO_3: –0.538 ppb on Aug 30, 2005 and +0.115 ppb on June 23, 2005, $\Delta PM_{2.5}$: –0.027 µg/m^3 on Sep 16, 2005 and +0.051 µg/m^3 on Aug 6, 2005.

Future work

- To study the effects of aerosol feedback on aircraft's cruise emissions' contribution to both vertical profile of O_3 ,$PM_{2.5}$, temperature and also the surface O_3 and $PM_{2.5}$ impacts and surface temperature

Acknowledgement: This work was funded by FAA under the Air Transportation Center of Excellence for Alternative Jet Fuels and Environment (AJFE) Cooperative Agreement 13-C-AJFE-UNC. Any opinions, finding, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the FAA. Authors are thankful to David Wong of EPA, Vennam Lakshmi of IE-UNC and Mark Reed of ITS Research Computing of UNC.

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