Impact of aircraft NO_x and aerosol emissions on atmospheric composition: a model intercomparison

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Introduction: Aviation impacts climate with both CO_2 and non-CO_2 effects. The latter have been recently evaluated as twice the CO_2 effects regarding their effective radiative forcing (ERF) in 2018, with uncertainties 8 times more important (Lee et al., 2021). The ACACIA EU project (Advancing the Science for Aviation and Climate) aims to improve the knowledge on non-CO_2 effects from subsonic aviation on climate. Among the aircraft emissions, the nitrogen oxides (NO_x) show both warming and cooling effects through photochemical processes on gases and aerosols. Its net ERF notably depends on the NO_x and methane background and still shows important uncertainties (Skowron et al., 2021; Terrenoire et al, 2022).

Modeling experiment: Impact of NO_x and aerosol emissions on atmospheric composition and climate

- Tools: 6 global chemistry-climate models
→ EMAC, LMDZ-INCA, MOZART-3, Oslo-CTM3, UKESM1, GEOS-Chem
- Simulations setup:
→ Chemistry: gaseous and aerosol phases, troposphere and stratosphere
→ Nudged horizontal winds, without any feedback from chemistry to dynamics

- Aircraft emissions inventories:
  - Present-day: CEDS (Hoesly et al., 2018)
  - Future: several socioeconomic scenarios (Gidden et al., 2019)
  - Emissions files corrected (Thor et al., 2023)
- Main perturbation test: ***Standard*** run minus ***No aircraft*** run

Impact on gaseous species

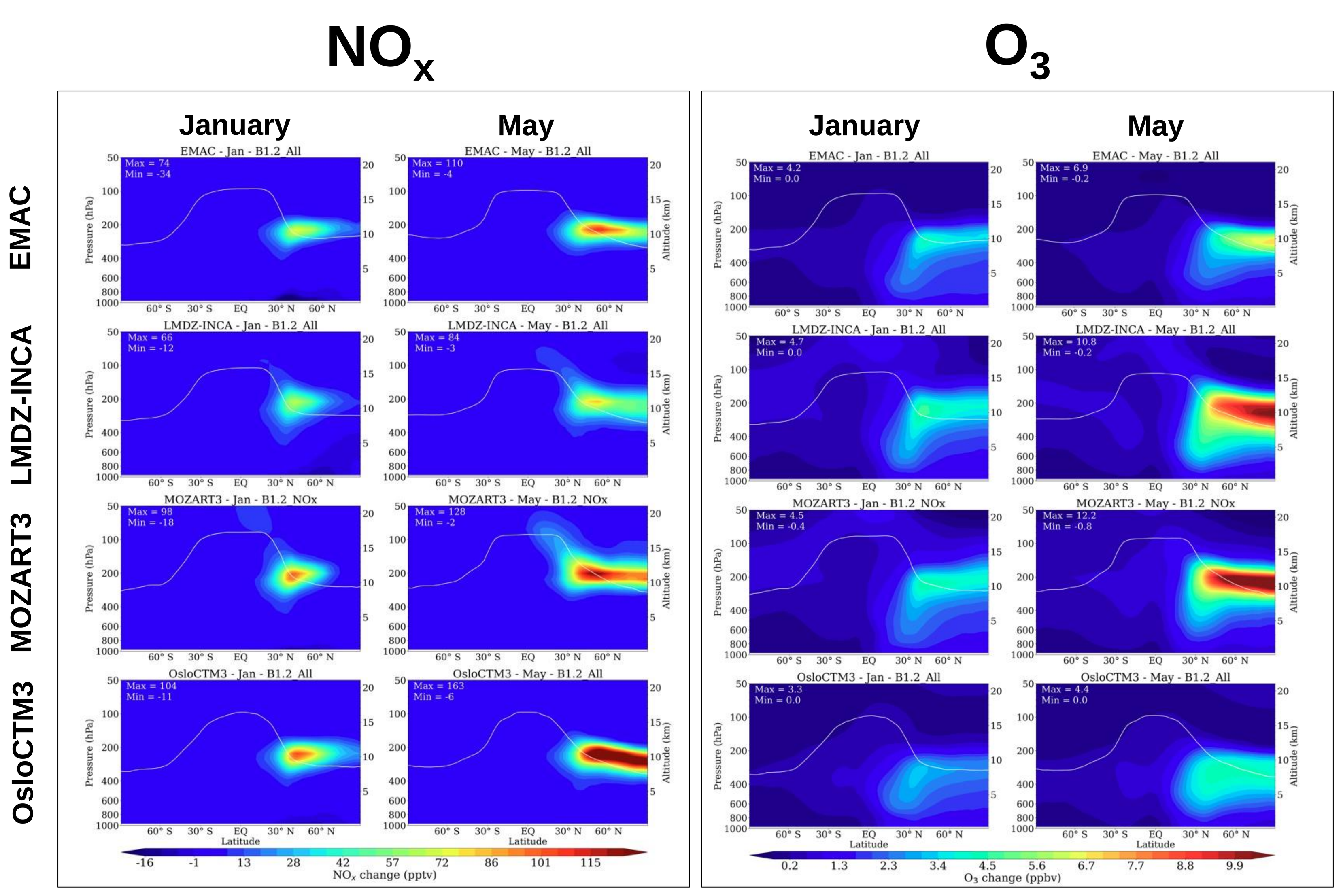

Figure 1: *Zonal cross sections of the impact of aircraft emissions on gaseous species (nitrogen oxides and ozone) from 4 models, averaged over 2014 – 2018.*

Similarities
- Maximum response above the tropopause
- January: response rather confined at mid-latitudes
- May:
  - Northward spread
  - Subsidence effects on ozone

Differences
- NO_x magnitude: up to a factor 2
→ due to nitrogen species partitioning
→ but responses rather similar for NO_y
- Ozone magnitude: maximum ranging from 3.3 to 4.7 ppb in January, and from 4.4 to 12.2 ppb in May

Table 1: *Backgrounds of NO_x in the UTLS and methane lifetime (TCH_4), with the global perturbation of ozone, methane lifetime and OH concentration normalized to the annual NO_x emission rate (ENO_x).*

	Unit	EMAC	LMDZ-INCA	MOZART3	OsloCTM3
NO_X background (150 – 300 hPa)	10^{-2} TgN	6.8	3.4	4.6	6.9
$\Delta O_3/ENO_x$	DU $(TgN/a)^{-1}$	0.51	0.76	0.73	0.61
Background CH_4 lifetime (TCH_4)	year	7.8	8.1	8.4	7.6
$\Delta TCH_4/ENO_x$	% $(TgN/a)^{-1}$	-1.3	-1.6	-1.2	-1.2
ΔOH	10^5 cm^{-3}	0.18	0.27	0.18	0.19

- Stronger ozone response with a lesser NO_x background at the cruise altitudes
- Methane lifetime sensitivity ranging between -1.2 and -1.6 % per TgN/a

Impact on aerosol species

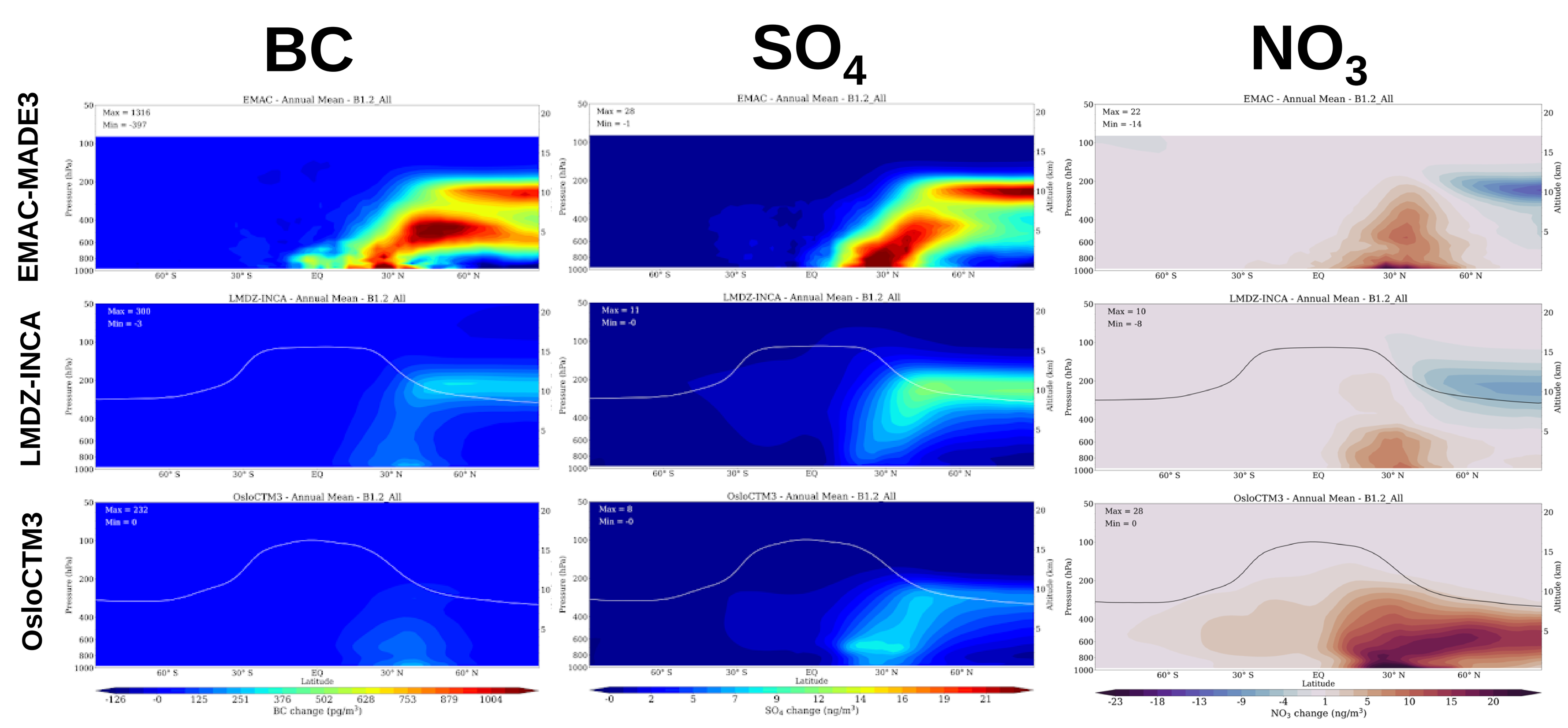

Figure 2: *Zonal cross sections of the annual impact of aircraft emissions on aerosol species (black carbon, sulfate and nitrate) from 3 models. The aerosol output from the EMAC-MADE3 model (Righi et al., 2023) have been generated independently from the current protocol, and includes a coupling between aerosols and dynamics.*

Similarities:
- 3 models: impact at the surface, and nitrate (NO_3) increased in the troposphere
- EMAC-MADE3 and LMDZ-INCA: impact in the UTLS, with an increase in sulfate (SO_4) as a product from sulfur dioxide (SO_2) emissions, and from the NO_x-induced OH increases

→ less NH_3 available for the formation of ammonium nitrate (NH_4NO_3), because NH_3 reacts more efficiently with SO_4 → less NO_3 in the UTLS

Differences:
Magnitude of the responses in the UTLS (different modal distributions)

Conclusions

- Encouraging similarities amongst the models
- Some intermodel differences still to be understood

→ Need of further experimentations:
  → With the same reaction rates through the models
  → With more similar parameterizations: scavenging, lightning, aerosol bins, heterogeneous reactions...

Next step: 3 papers to submit

- Current study to be completed: incoming outputs from 2 models
- Assessment using the IAGOS data
- Present-day and future radiative forcings based on these simulations

References

- Terrenoire et al.: Impact of present and future aircraft NO_x and aerosol emissions on atmospheric composition and associated direct radiative forcing of climate, Atmos. Chem. Phys. (2022). doi:10.5194/acp-22-11987-2022
- Skowron et al.: Greater fuel efficiency is potentially preferable to reducing NO_x emissions for aviation's climate impacts. *Nat Commun* **12,** 564 (2021). doi:10.1038/s41467-020-20771-3
- Lee et al.: The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018, *Atmos. Environ.* (2021). doi:10.1016/j.atmosenv.2020.117834