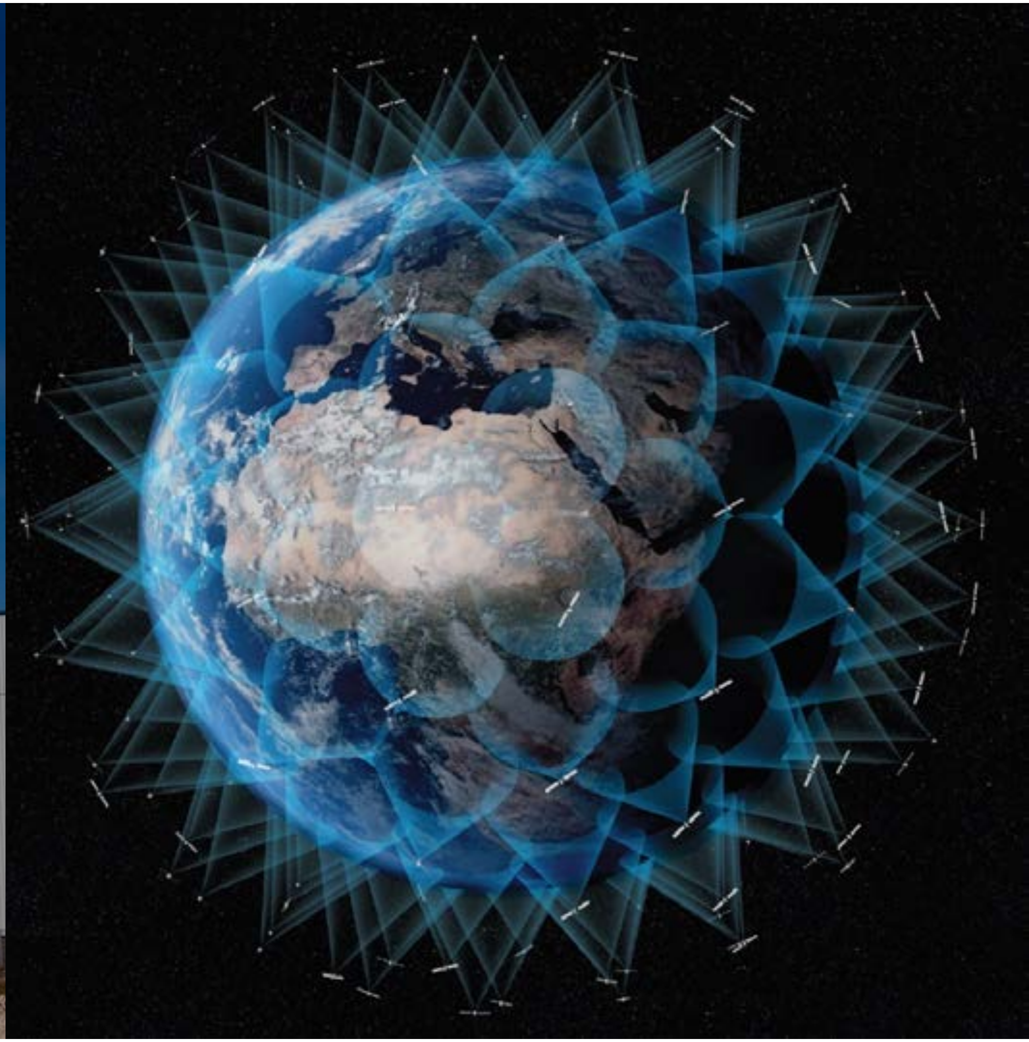
Impacts of megaconstellation satellite launches and end-of-life satellite disposal on stratospheric ozone and climate

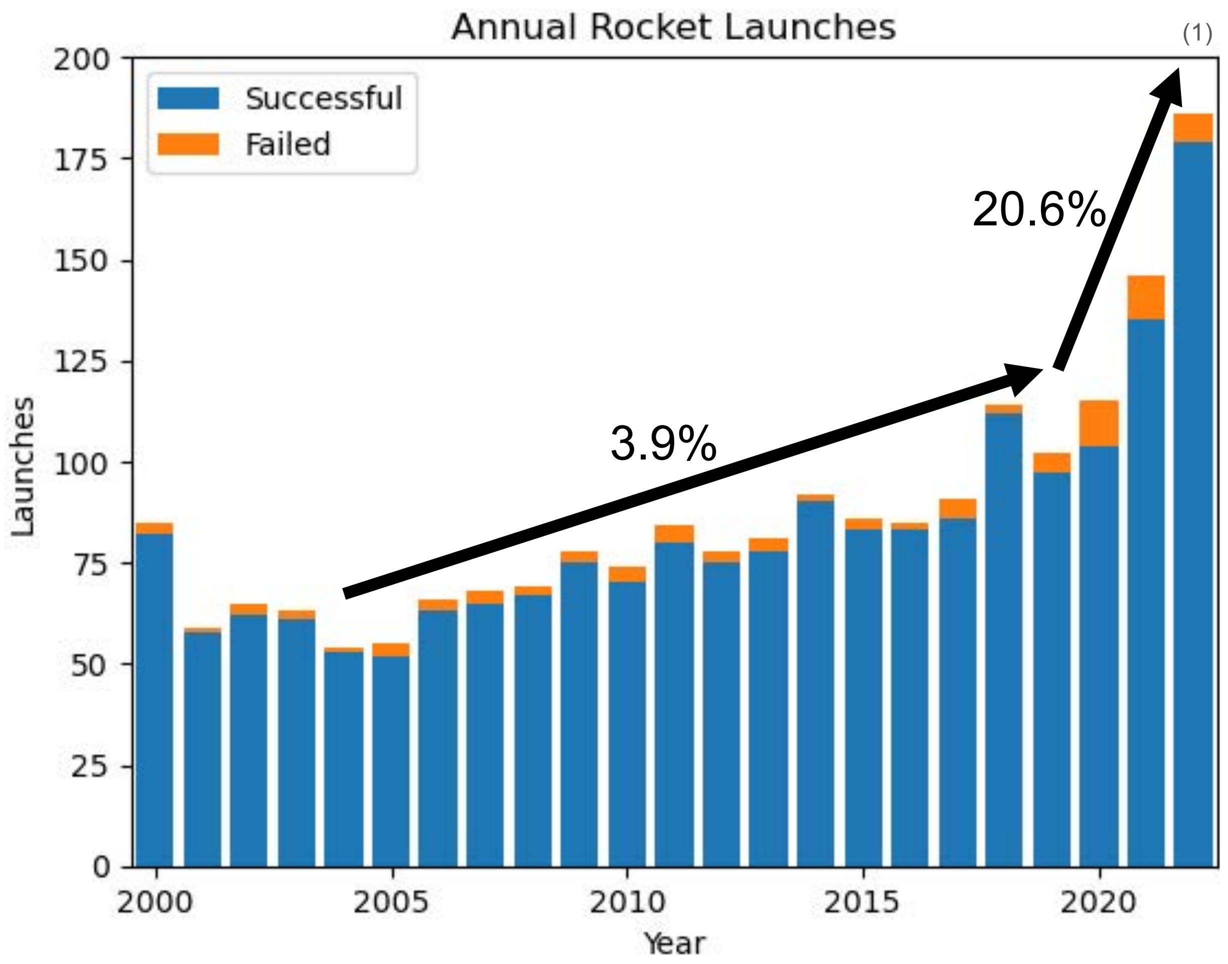


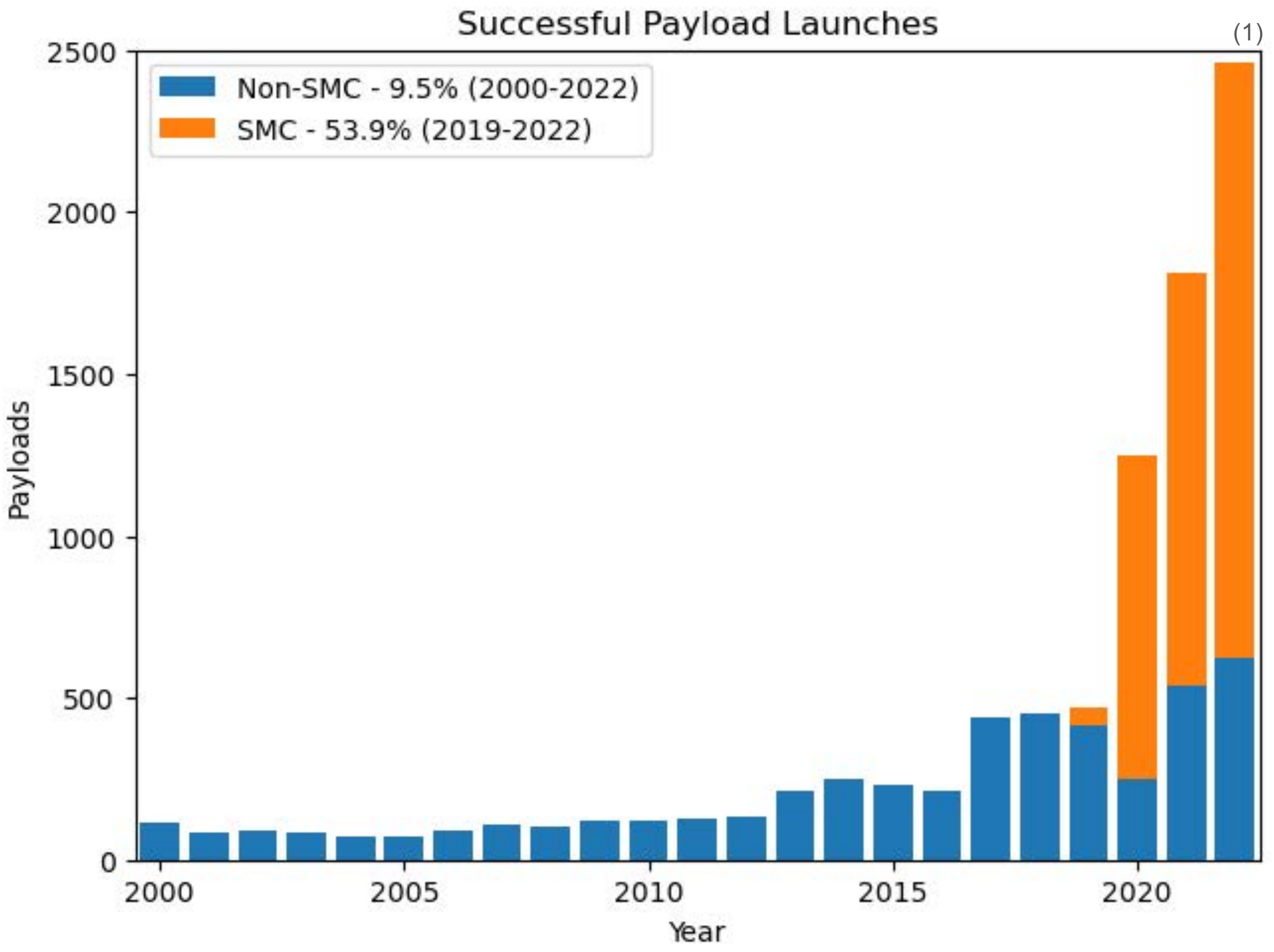
GCE2

Connor Barker
connor.barker@ucl.ac.uk

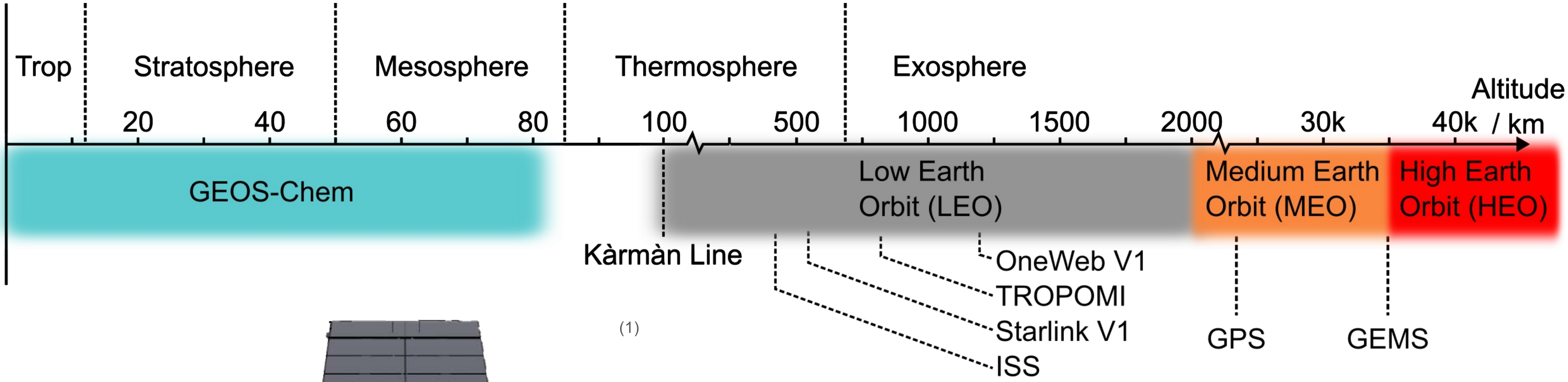
15th August 2023

A Rapidly Expanding Space Sector

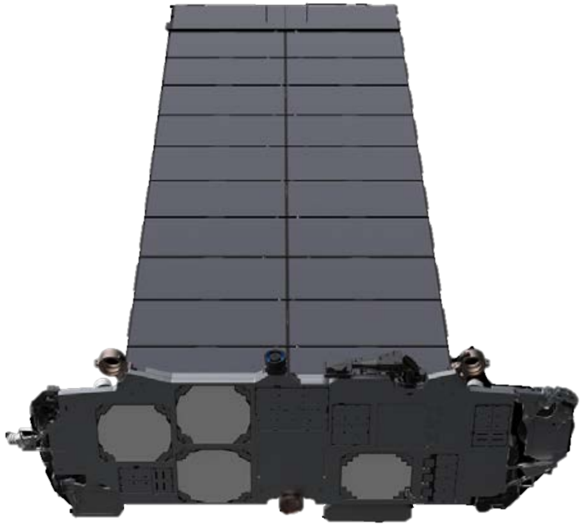




Satellite Megaconstellations (SMC)



(1)



Starlink (3)

OneWeb (4)

There are 9 planned satellite megaconstellations (N>500).
This equates to over 60,000 extra satellites in LEO!

Environmental Impacts of Satellite Launches

Kerosene

(5)

Falcon 9

- H_2O
- CO
- NO_x (2°)
- BC

Hydrogen

(6)

Delta IV Heavy

- H_2O
- CO
- NO_x (2°)

Hypergolic

(7)

Proton-M

- H_2O
- CO
- NO_x (2°)
- BC
- NO_x (1°)

Solid

(8)

LM(CZ) -11

- H_2O
- CO
- NO_x (2°)
- BC
- Cl_y
- Al_2O_3

(9)

Rocket / Satellite

- NO_x (2°)
- Al_2O_3

Future megaconstellations have the potential to contribute to large increases in emissions to all layers of the atmosphere.

Radiative Forcing

Strat. [O_3] Depletion

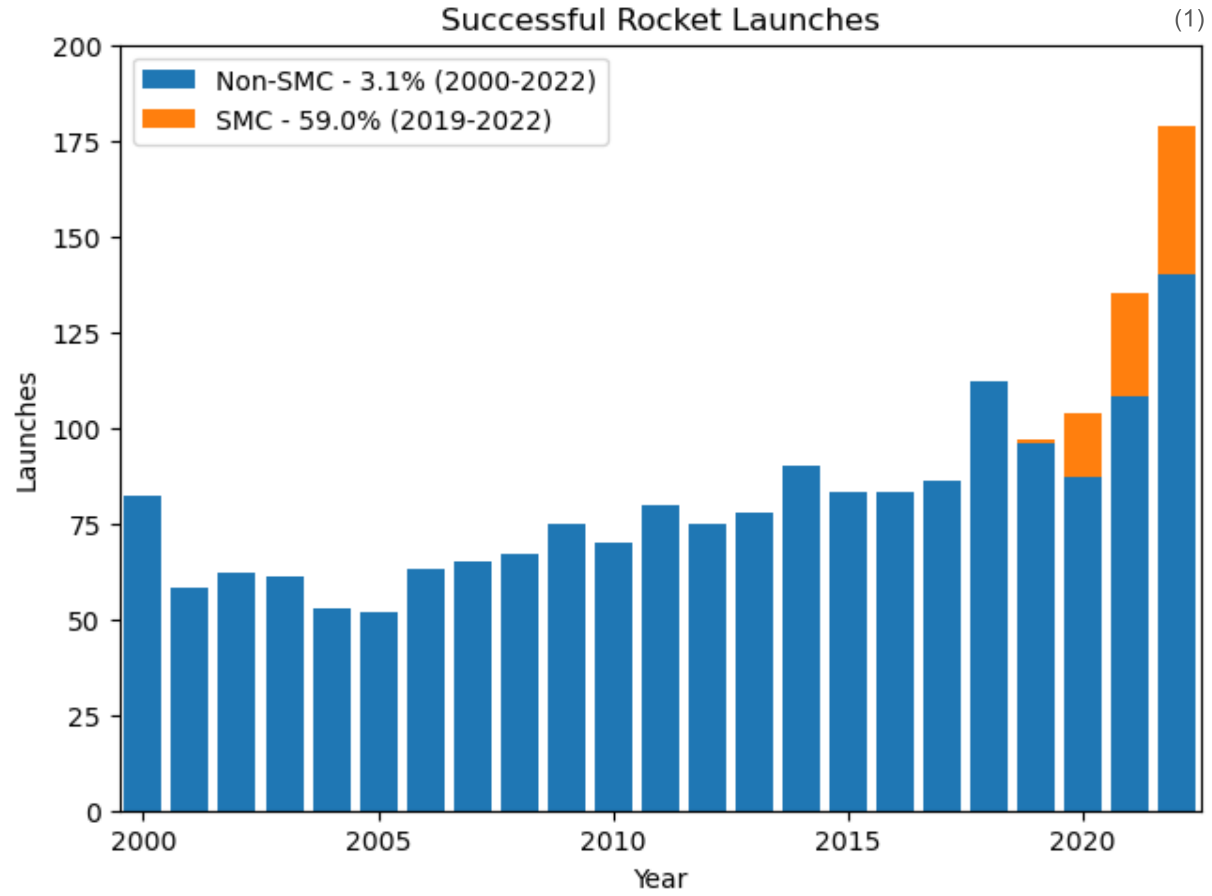
GEOS-Chem Megaconstellation Study

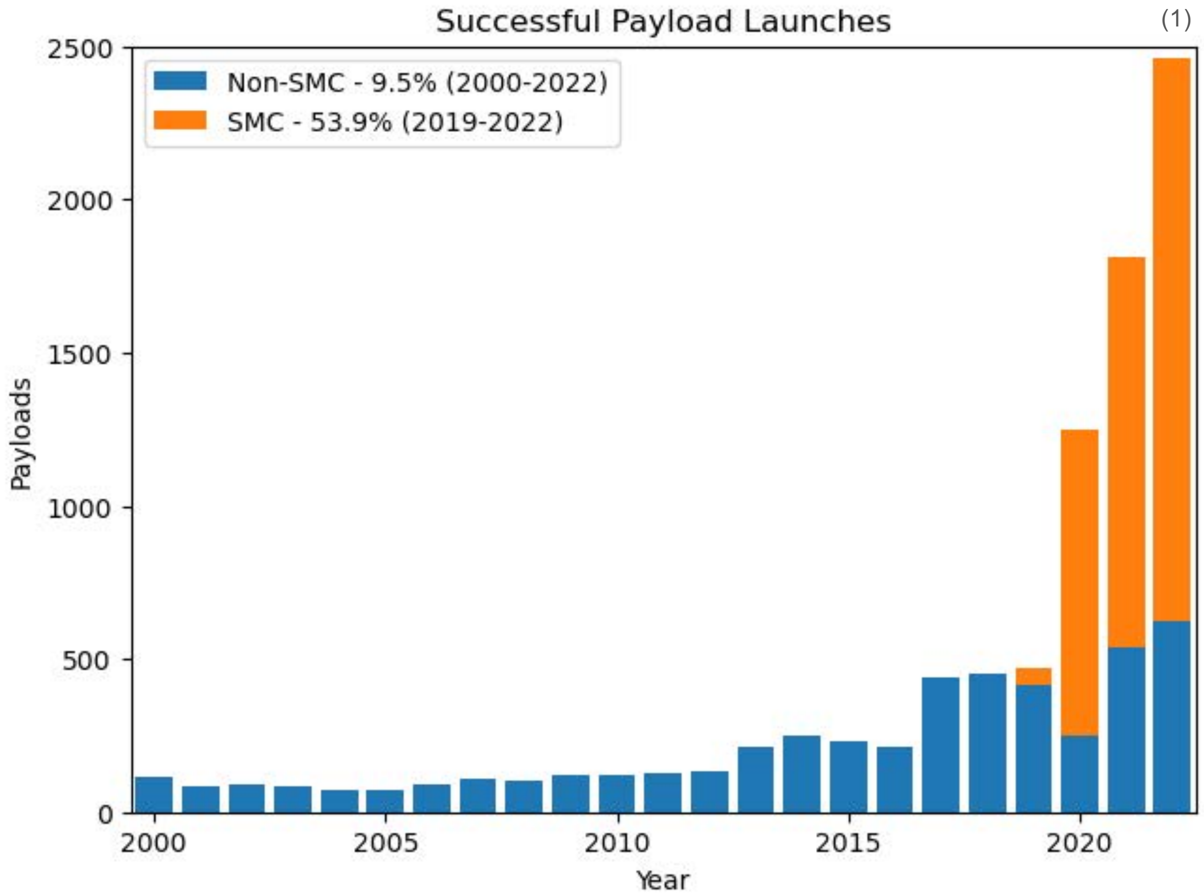
Bottom-up Emission Inventory

GEOS-Chem + RRTMG

10-year simulations (2020-2029)

Δ Strat. [O_3]
Radiative Forcing





Space Tourism Study - Ryan et al. (2022) [10]

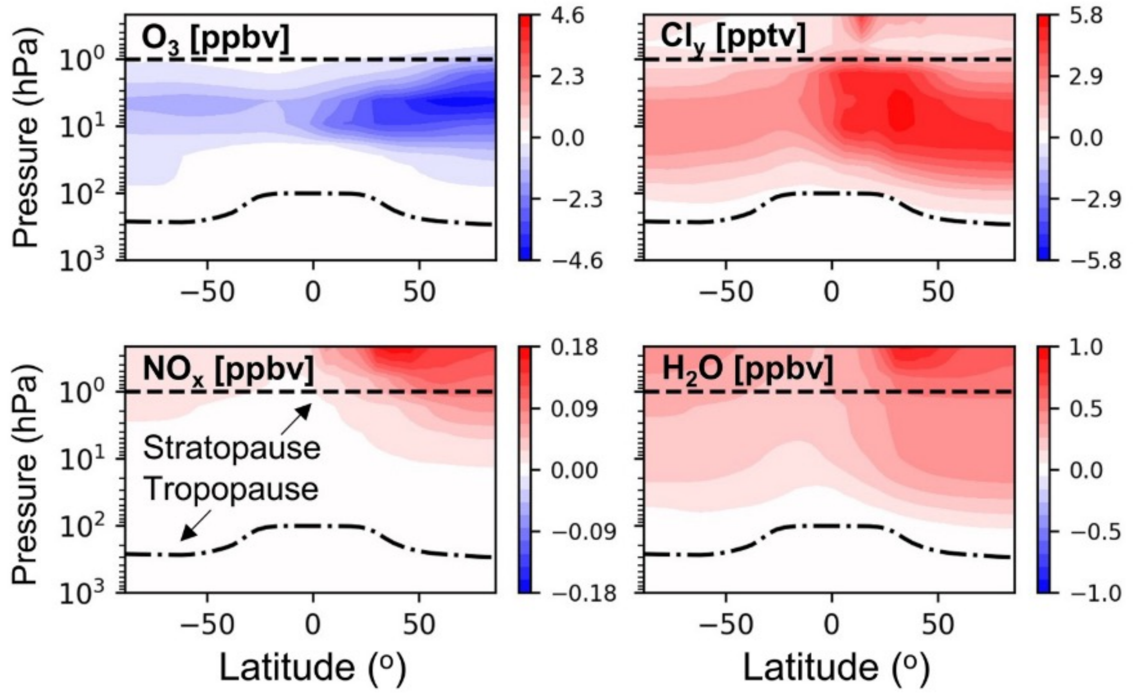


Figure 3. The effect of a decade of sustained growth in rocket and re-entry burn emissions on atmospheric composition.

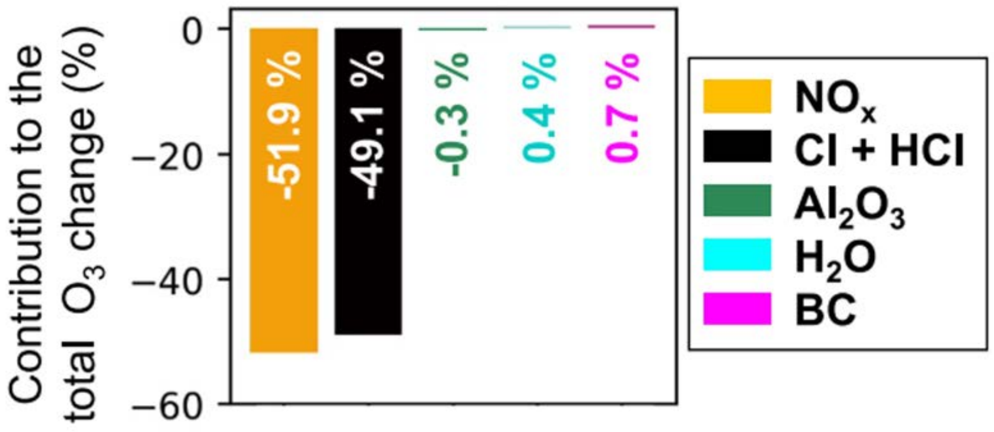


Figure 5. Contribution of individual pollutants to stratospheric O$_3$ depletion.

Space tourism contributes only 0.02% of global BC emissions, but 6% of the warming – 475x greater climate forcing efficiency!

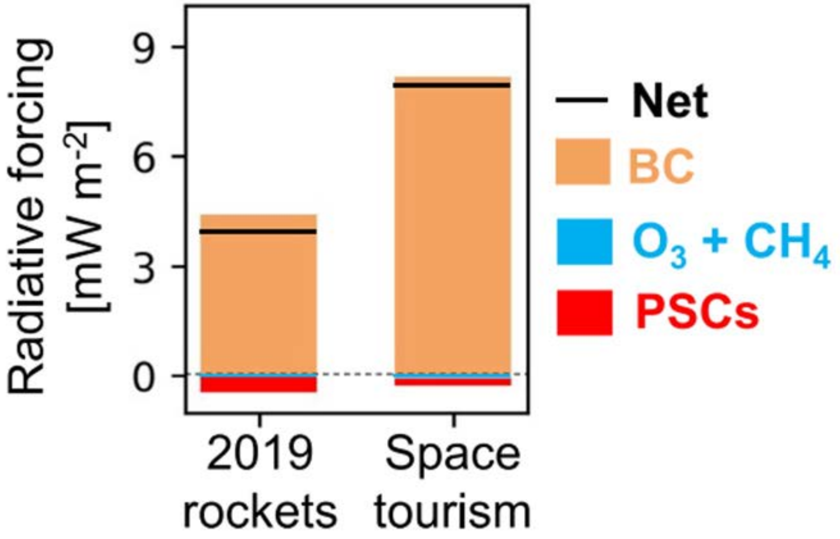
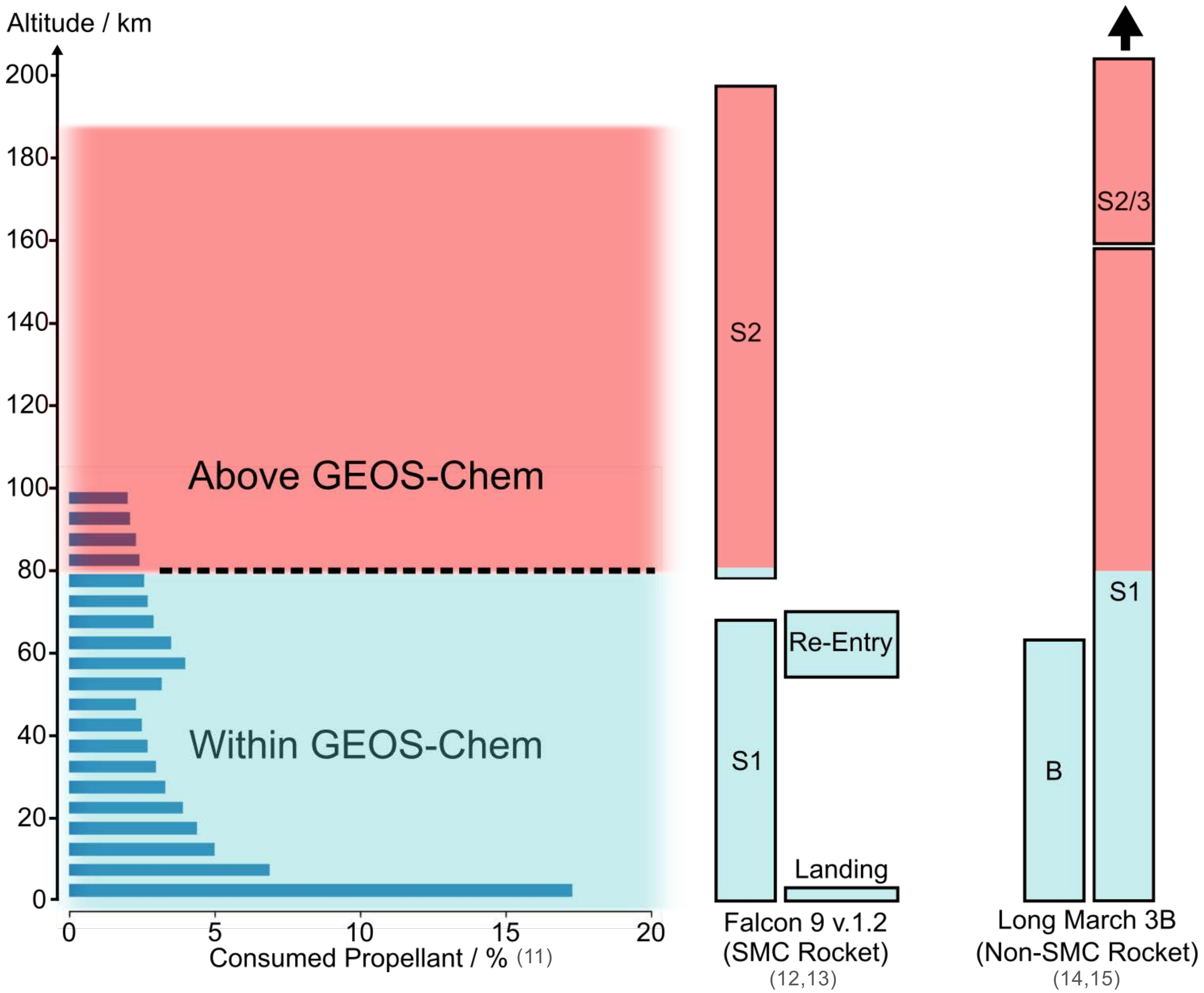
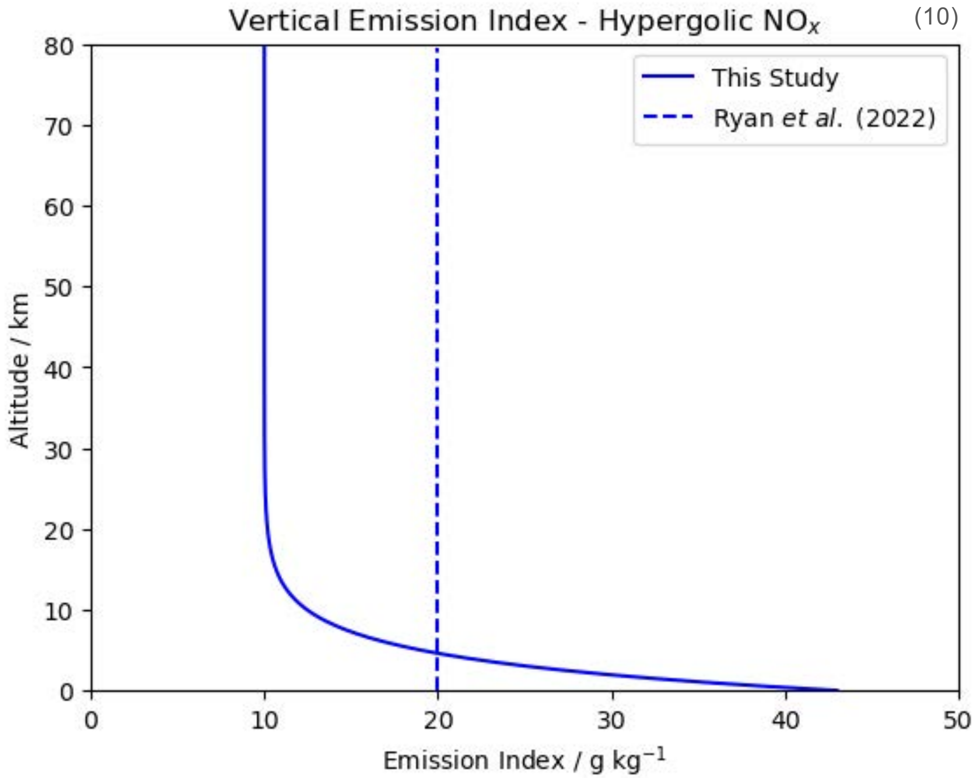


Figure 6. Effect of rocket launch and re-entry emissions on global climate forcing.

Event Altitudes and Propellant Distribution

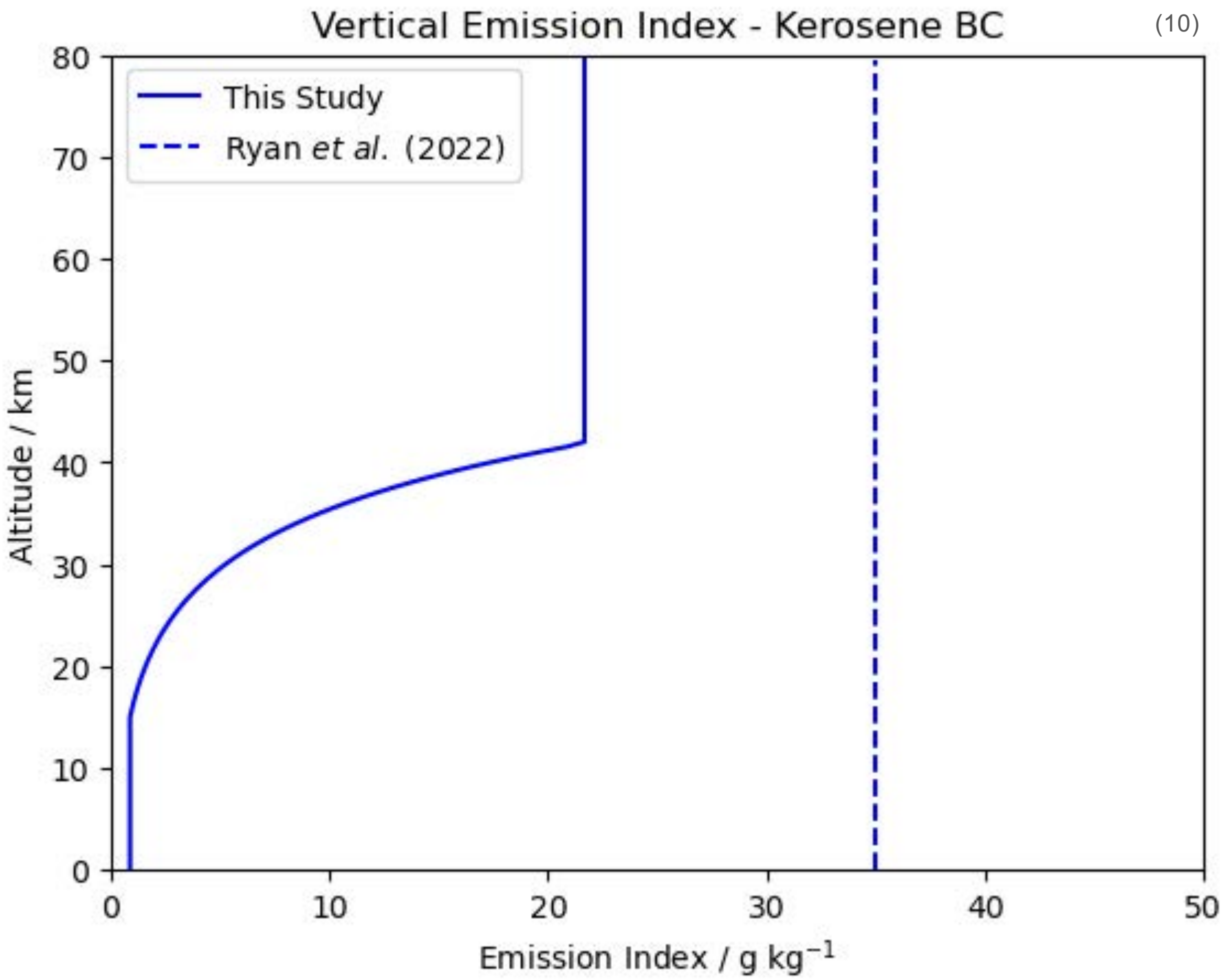
$$Mass\ Emissions(g) = Propellant\ consumed\ (kg) \times Emission\ Index\ (g\ kg^{-1})$$



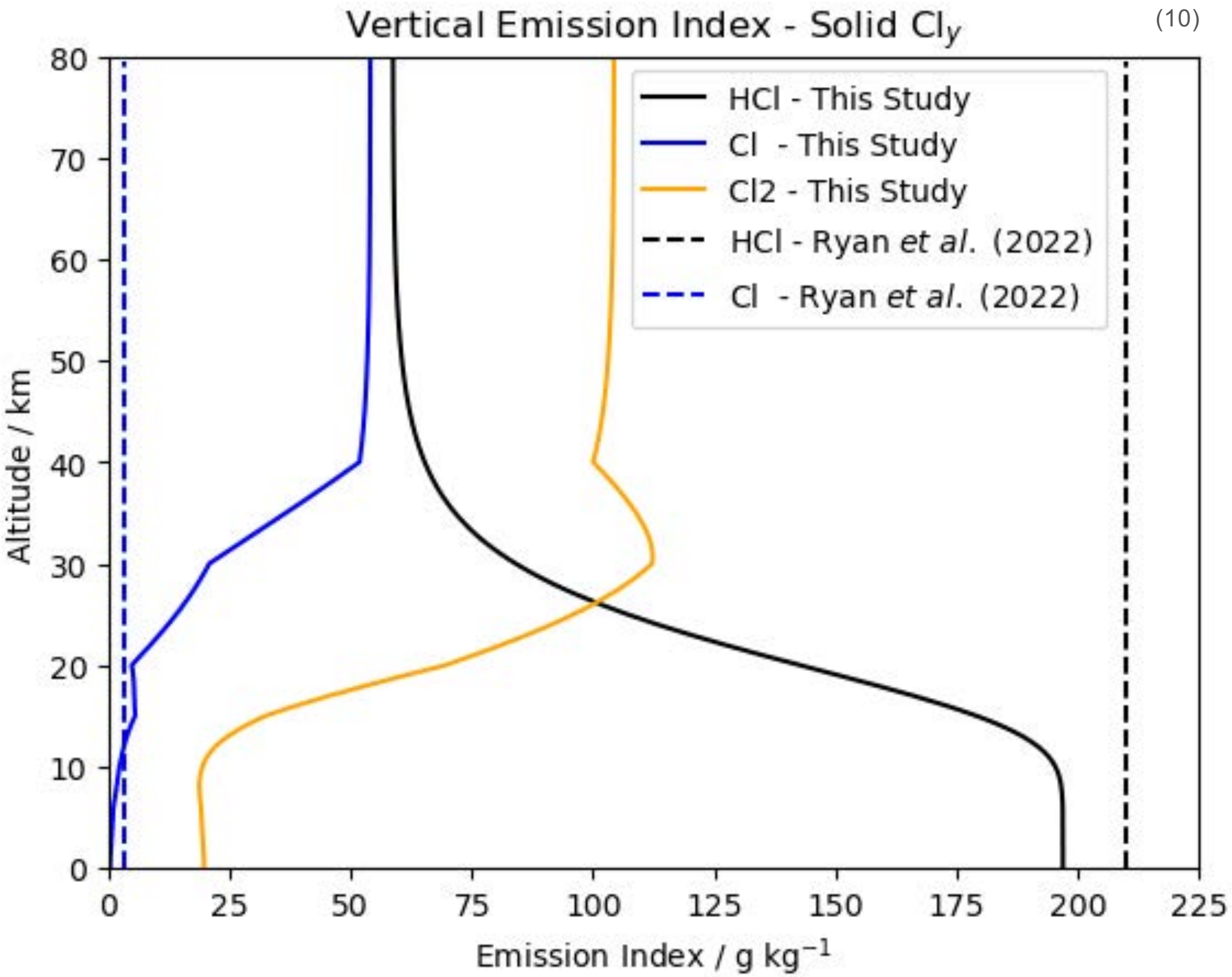


Altitude-dependent emission indices are required to accurately model rocket exhaust emissions.

Altitude-Dependent Emission Indices



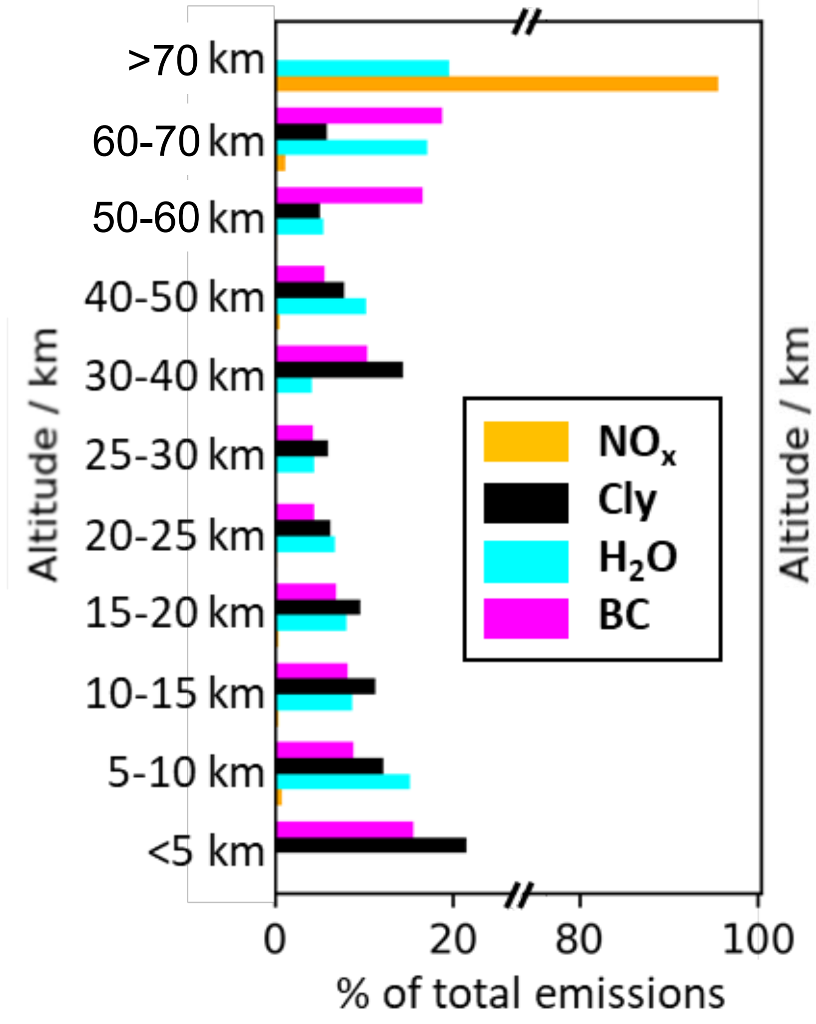
[10]



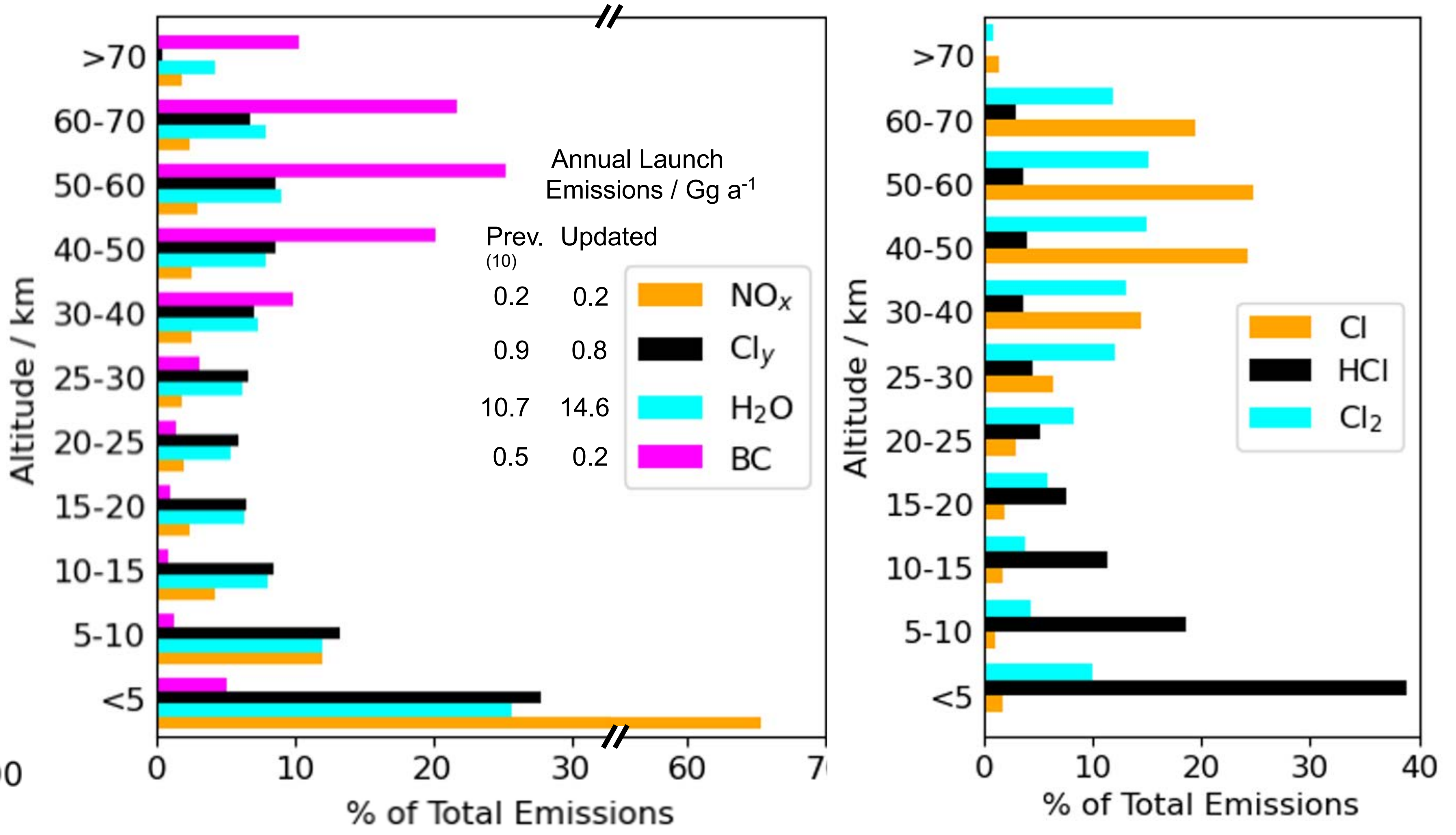
[10]

Updated Vertical Emission Profiles

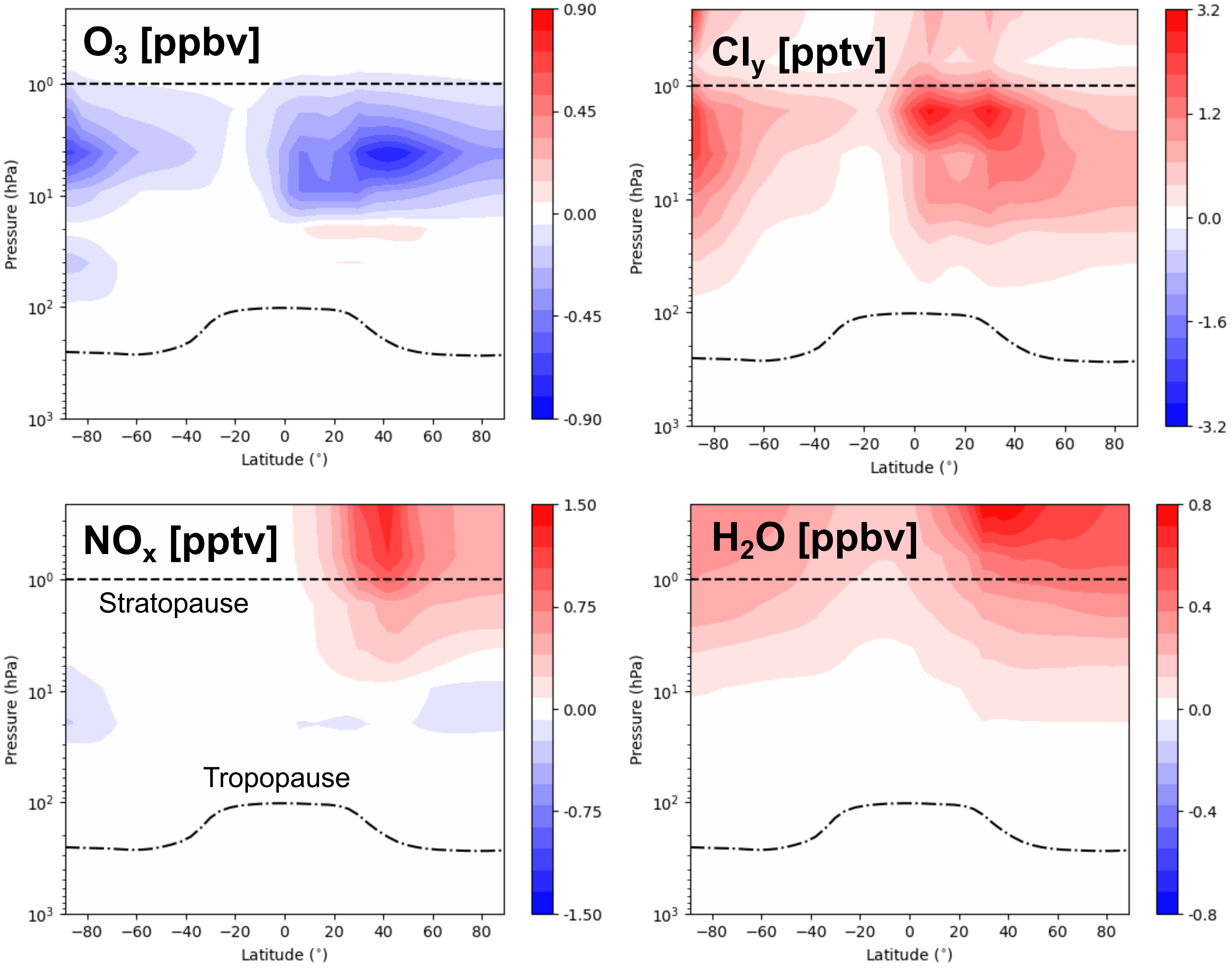
Ryan *et al.* (2022) [10]



Updated Vertical Profiles



GEOS-Chem Simulations



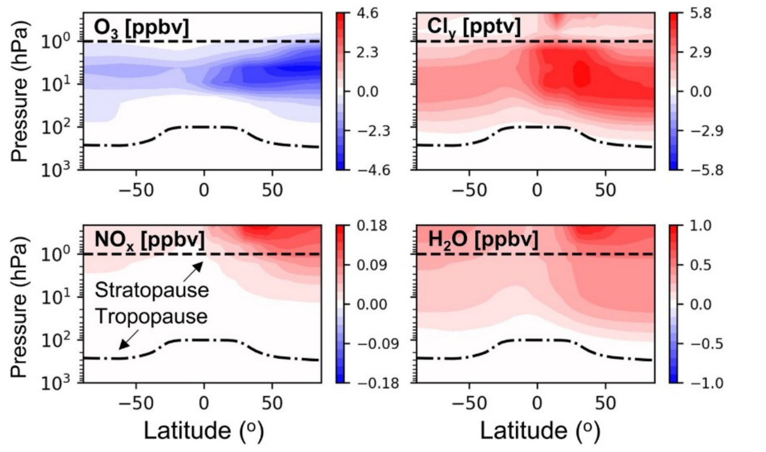


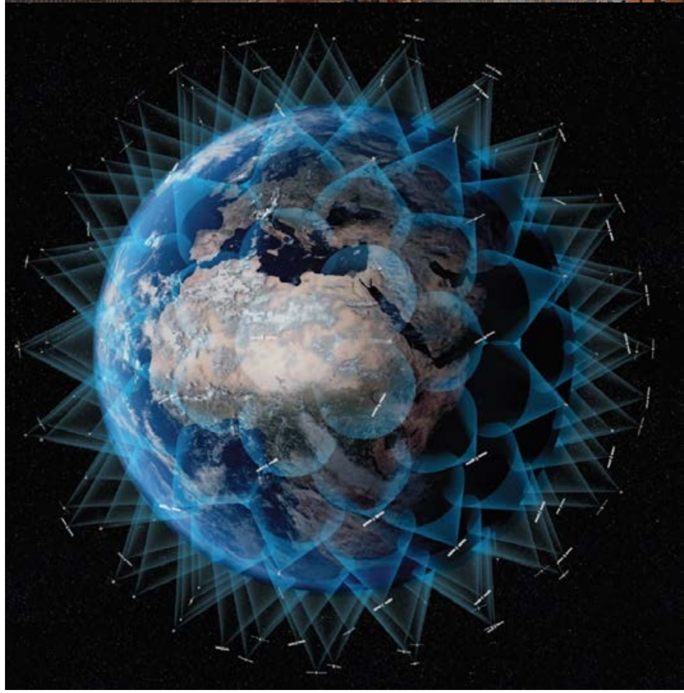
Figure 3. The effect of a decade of sustained growth in rocket and re-entry burn emissions on atmospheric composition.

Preliminary GEOS-Chem simulations demonstrate similar trends to 2019 study.

Global stratospheric ozone loss is minimal so far, however re-entry NO_x and Al_2O_3 have not yet been added.

Conclusion and Next Steps

- Separate emission inventories for SMC and non-SMC rocket launches have been compiled for 2020.
  - Propellant masses, propellant types, and primary emission indices were compiled for all 43 rockets and 7 major emission species.
  - Rocket-configuration specific altitude profiles were used to accurately determine the altitude bins of all emissions.
  - Altitude-dependent secondary emission indices were calculated to account for complex afterburning reactions.
- Preliminary results of 2020 launch emissions demonstrate minimal stratospheric ozone loss, however re-entry NO_x and Al_2O_3 are yet to be added.
- Next steps:
  - Add 2020 re-entries to emission inventory.
  - Improve Al_2O_3 chemistry by adding a trimodal size distribution and including radiative effects.
  - Include emissions occurring above GEOS-Chem limits.
  - Adjust and test modified hydrophobic/hydrophilic ratio for black carbon from launch emissions.



References

1. ESA Database and Information System Characterising Objects in Space
2. ESA's Annual Space Environment Report 2022
3. SpaceX, "How Starlink Works", Accessed 11/08/23, https://www.starlink.com/technology
4. OneWeb, Accessed 11/08/23, https://oneweb.net/themes/oneweb/assets/images/homepage/satellite.png
5. SpaceX, Accessed 11/08/23, https://spaceflightnow.com/2020/11/29/photos-falcon-9-launches-and-lands-at-vandenberg-air-force-base/
6. United Launch Alliance, Accessed 11/08/23, https://www.flickr.com/photos/ulalaunch/sets/72157718439516256/
7. Sputnik News, Accessed 11/08/23, https://english.almayadeen.net/news/technology/russian-proton-m-rocket-launched-into-space-with-satellite:
8. CALT, Accessed 11/08/23, https://spaceflightnow.com/2018/04/26/long-march-11-rocket-delivers-five-commercial-satellites-to-orbit/
9. ESA, Accessed 11/08/23, https://www.esa.int/ESA_Multimedia/Images/2014/07/Artist_s_view_of_ATV-5_reentry
10. Ryan, R. G., Marais, E. A., Balhatchet, C. J., & Eastham, S. D. (2022). Impact of rocket launch and space debris air pollutant emissions on stratospheric ozone and global climate. Earth's Future, 10, e2021EF002612. https://doi.org/10.1029/2021EF002612
11. Ross, M.N. and Sheaffer, P.M. (2014), Radiative forcing caused by rocket engine emissions. Earth's Future, 2: 177-196. https://doi.org/10.1002/2013EF000160
12. SpaceX, Accessed 13/08/23, https://www.spacex.com/launches/
13. Kim Y, Lee H-J, Roh T-S. Analysis of Propellant Weight under Re-Entry Conditions for a Reusable Launch Vehicle Using Retropropulsion. Energies. 2021; 14(11):3210. https://doi.org/10.3390/en14113210
14. Arianespace, Accessed 13/08/23, https://www.arianespace.com/mission/soyuz-flight-vs25/
15. International Launch Services, Accessed 13/08/23, https://www.mach5lowdown.com/wp-content/uploads/PUG/Angara-Mission-Planners-Guide-Rev-0-2002-12.pdf