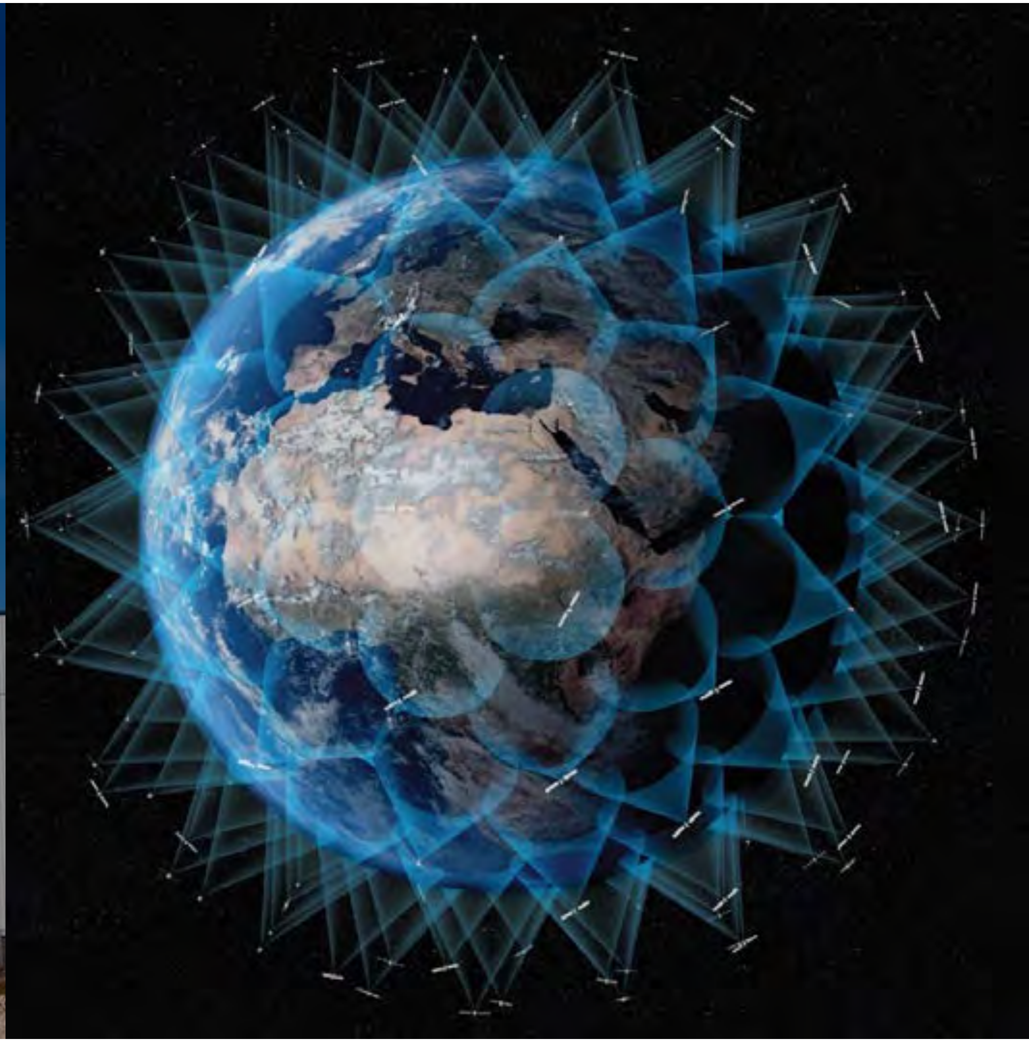
Impacts of megaconstellation satellite launches and end-of-life satellite disposal on stratospheric ozone and climate



GCE2

Connor Barker
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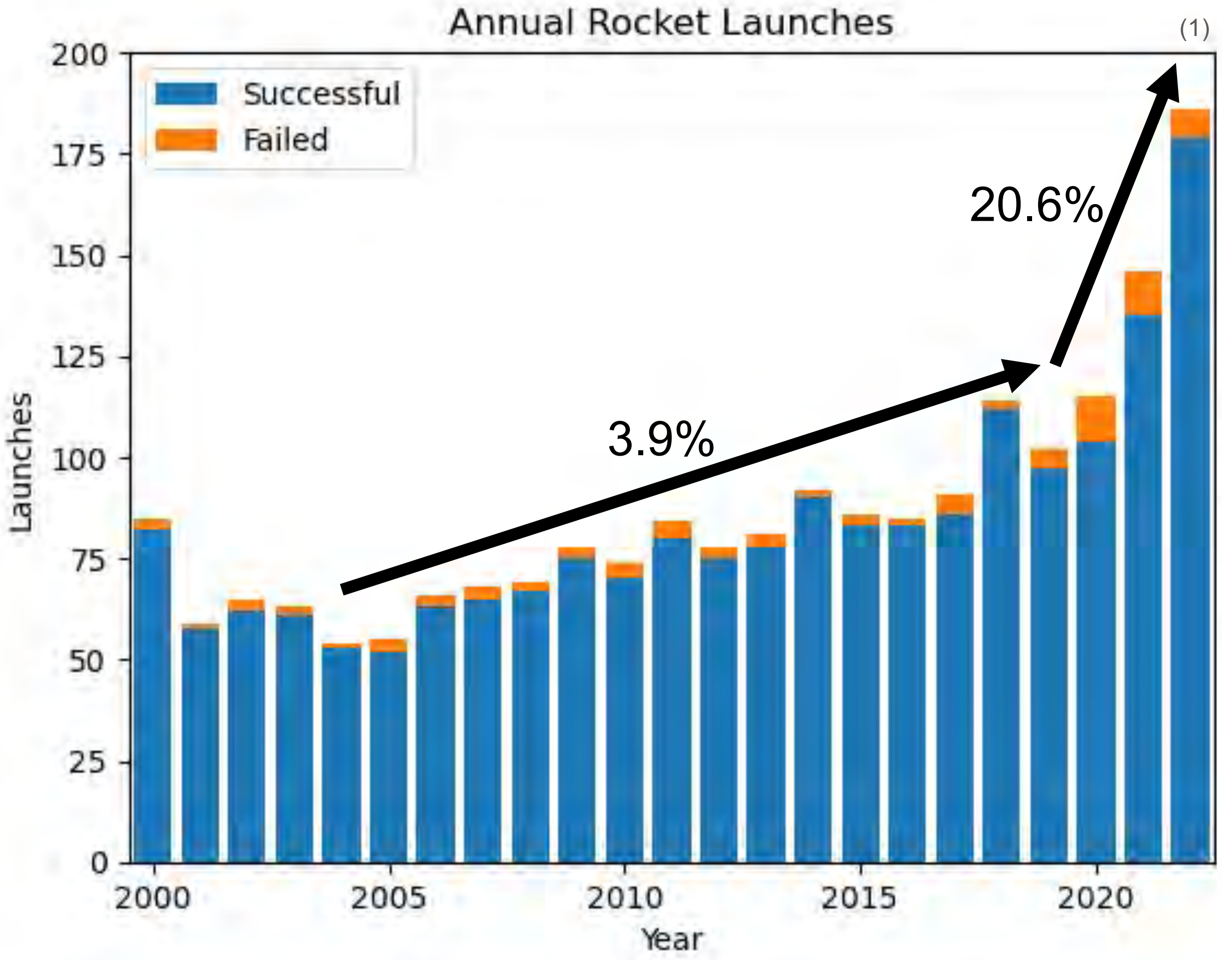
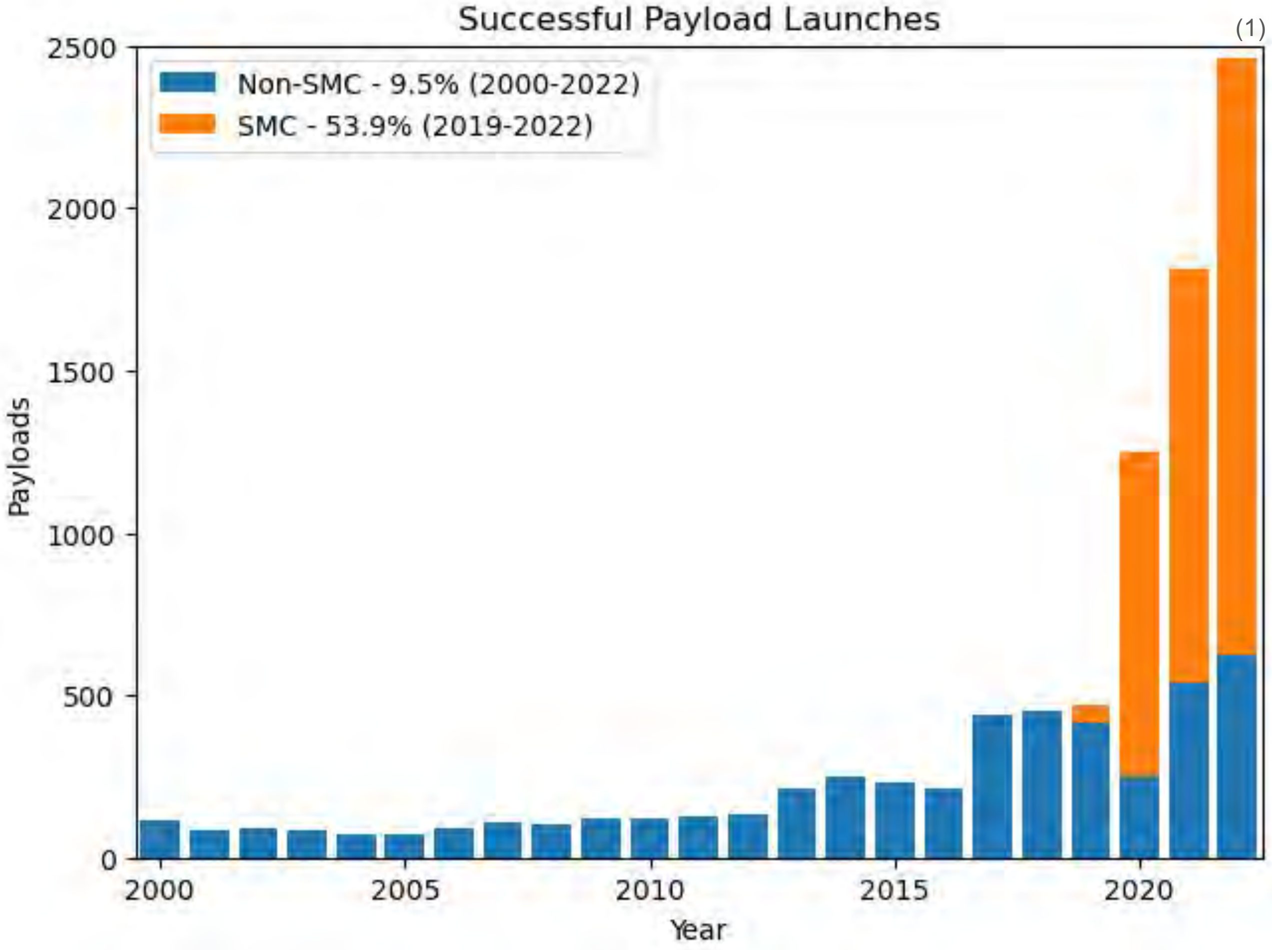
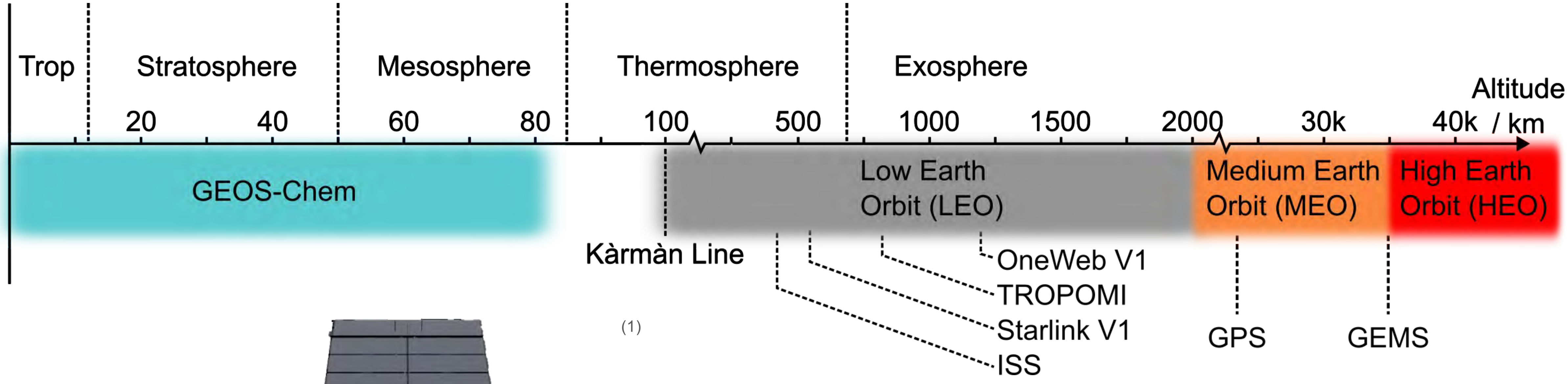
15th August 2023

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

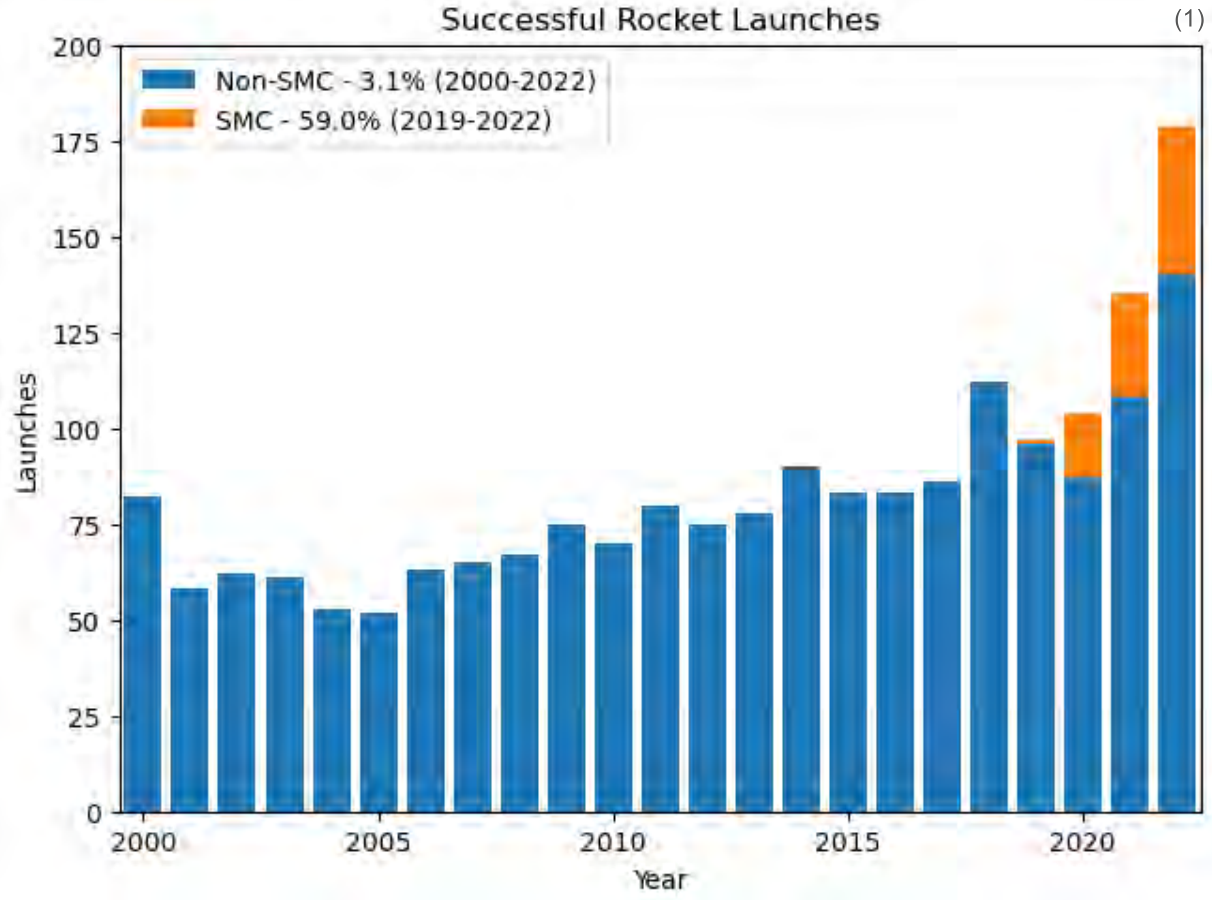
→

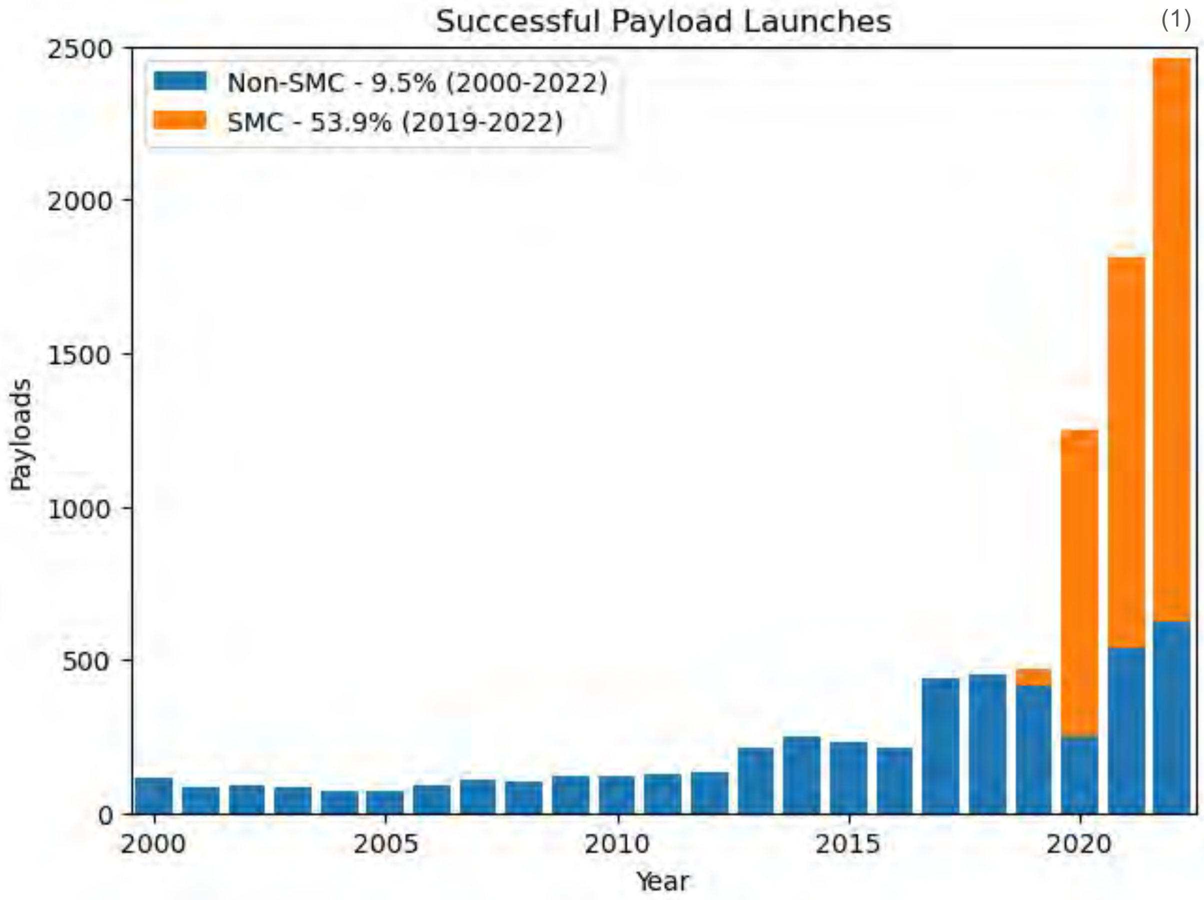
+ RRTMG

10-year simulations (2020-2029)

→

Δ Strat. [O_3]
Radiative Forcing





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

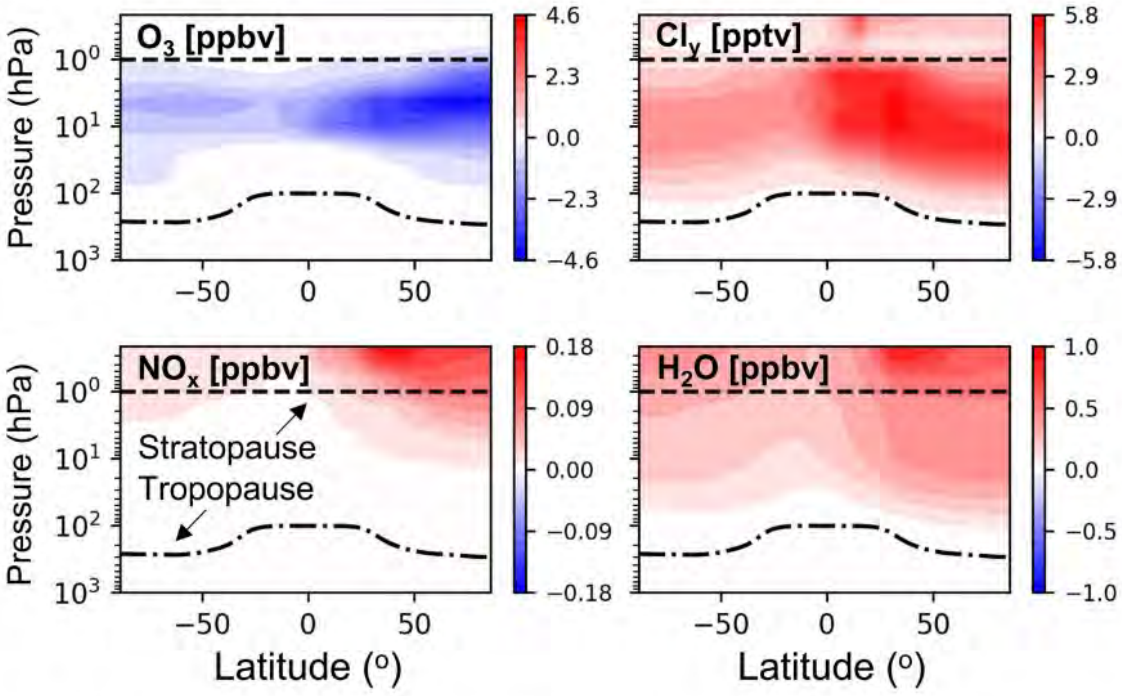


Figure 3. The effect of a decade of sustained growth in rocket and re-entry burn emissions on atmospheric composition.

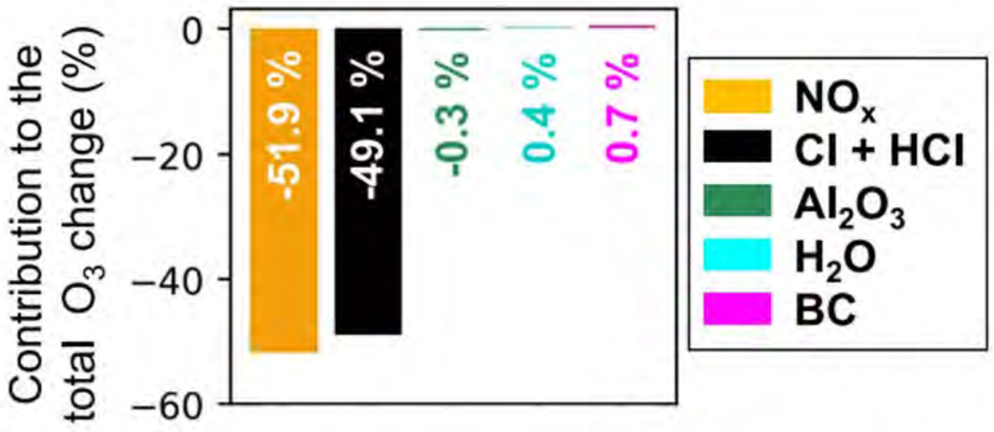


Figure 5. Contribution of individual pollutants to stratospheric O_3 depletion.

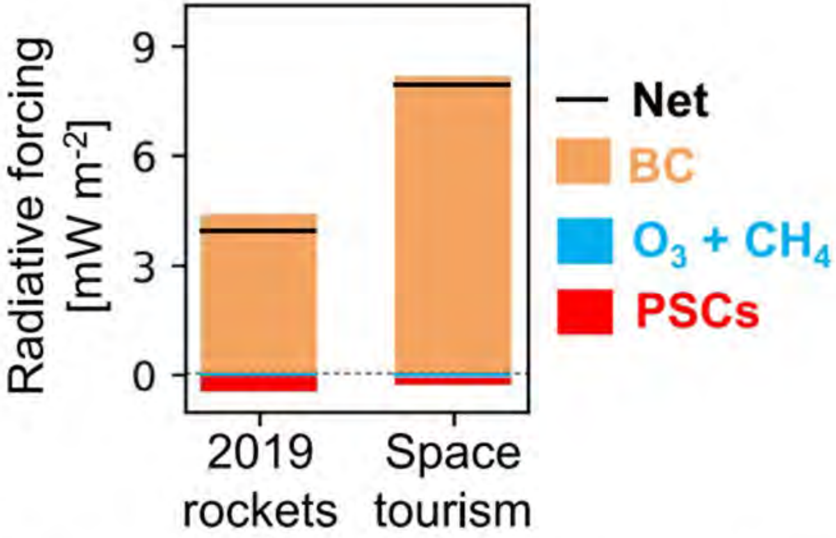
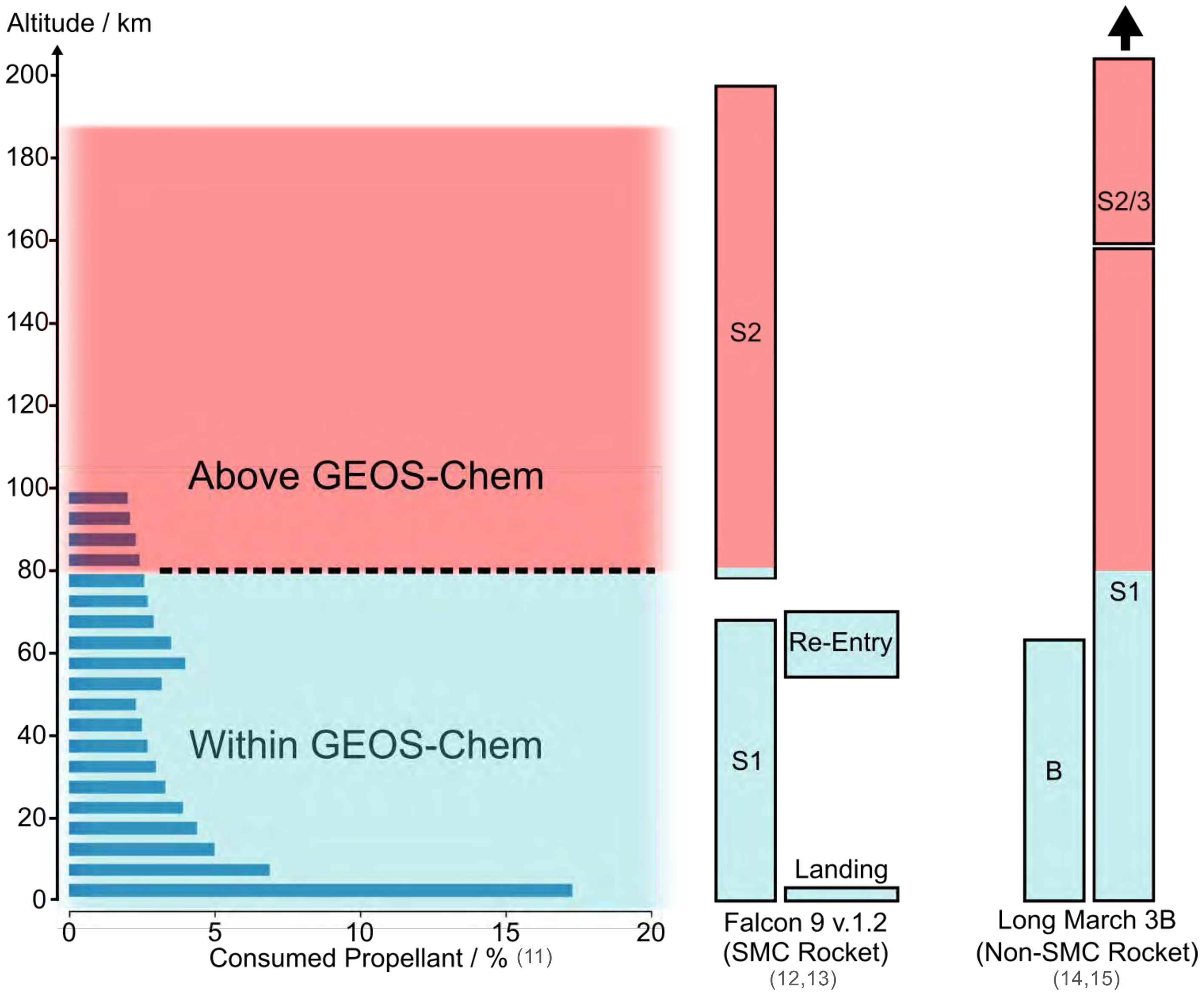


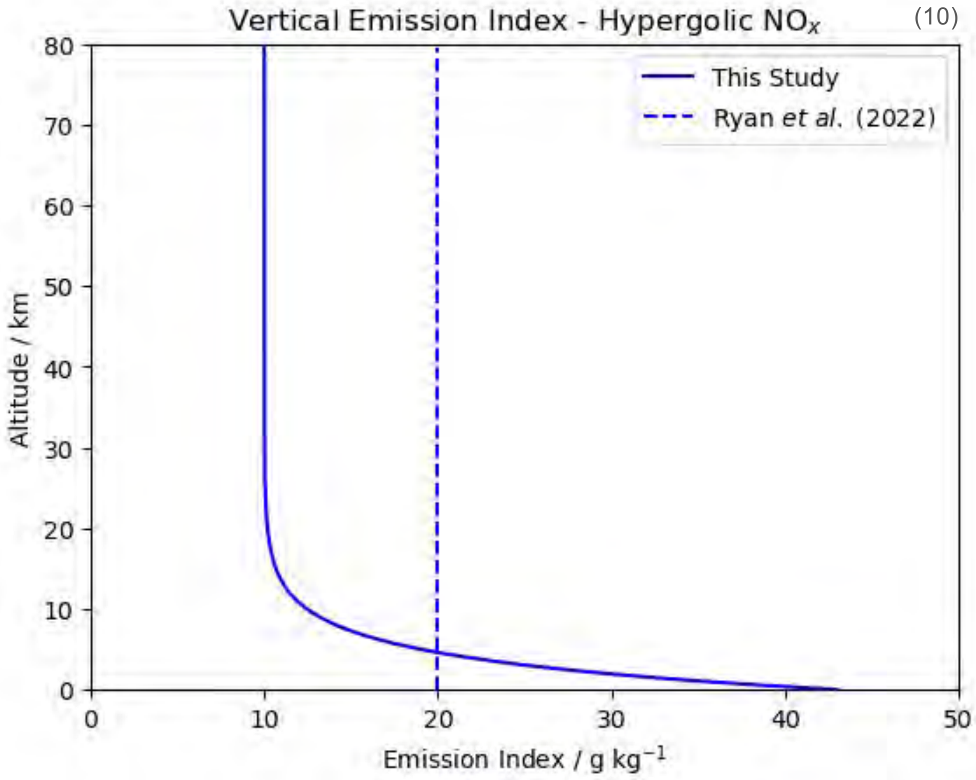
Figure 6. Effect of rocket launch and re-entry emissions on global climate forcing.

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

Event Altitudes and Propellant Distribution

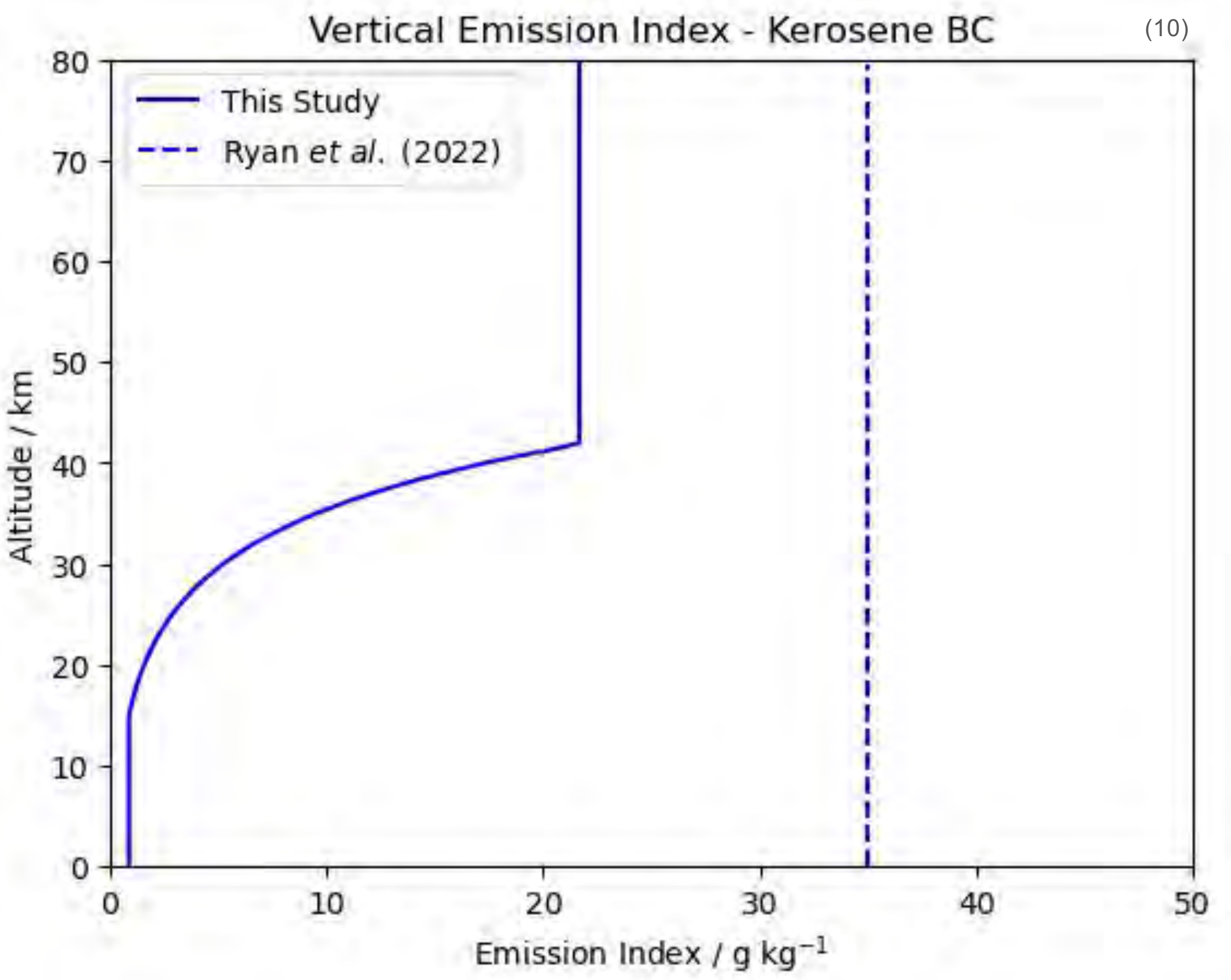
$$Mass\ Emissions(g) = Propellant\ consumed\ (kg) \times Emission\ Index\ (g\ kg^{-1})$$

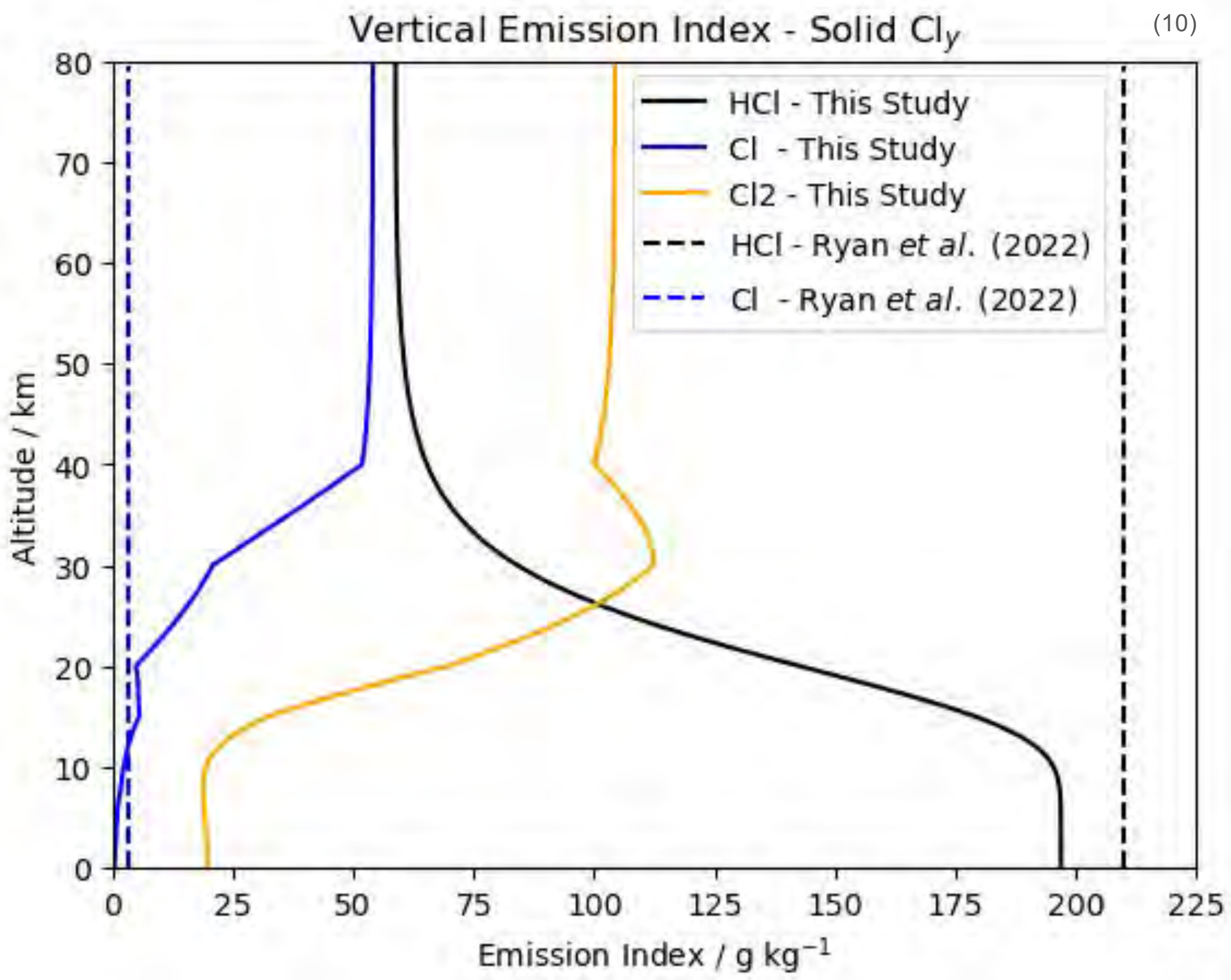




Altitude-dependent emission indices are required to accurately model rocket exhaust emissions.

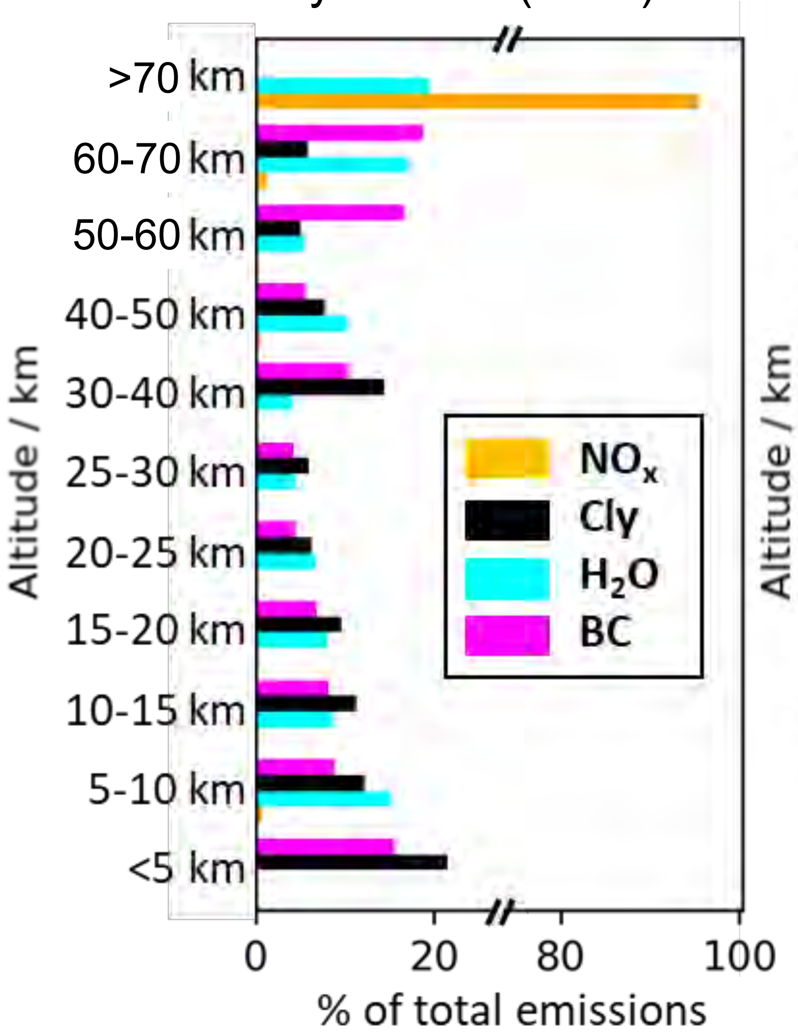
Altitude-Dependent Emission Indices



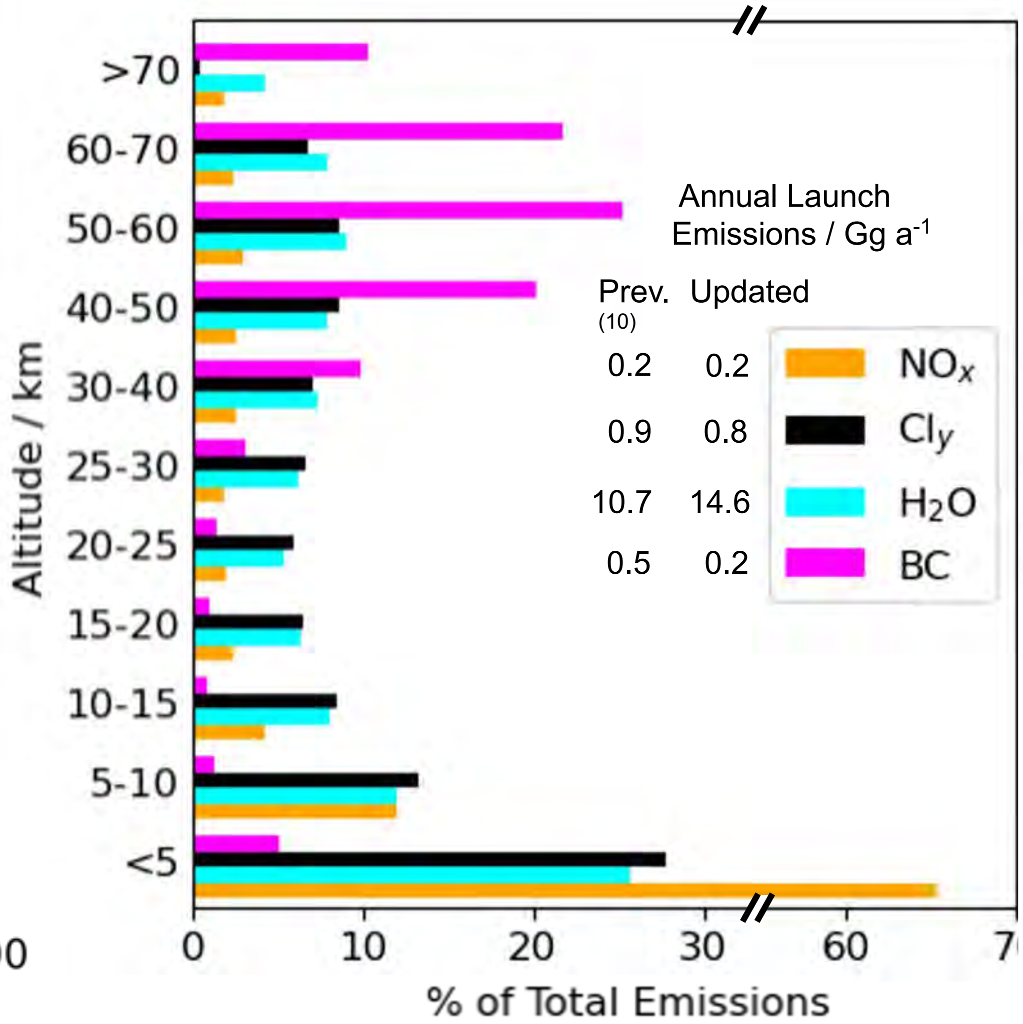


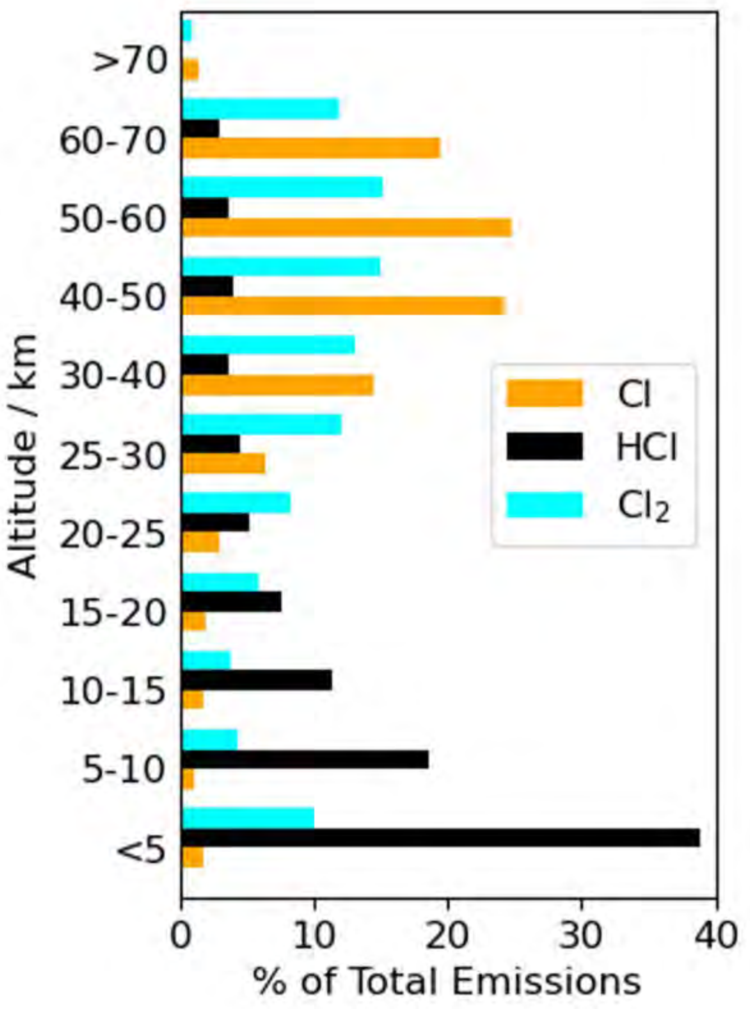
Updated Vertical Emission Profiles

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

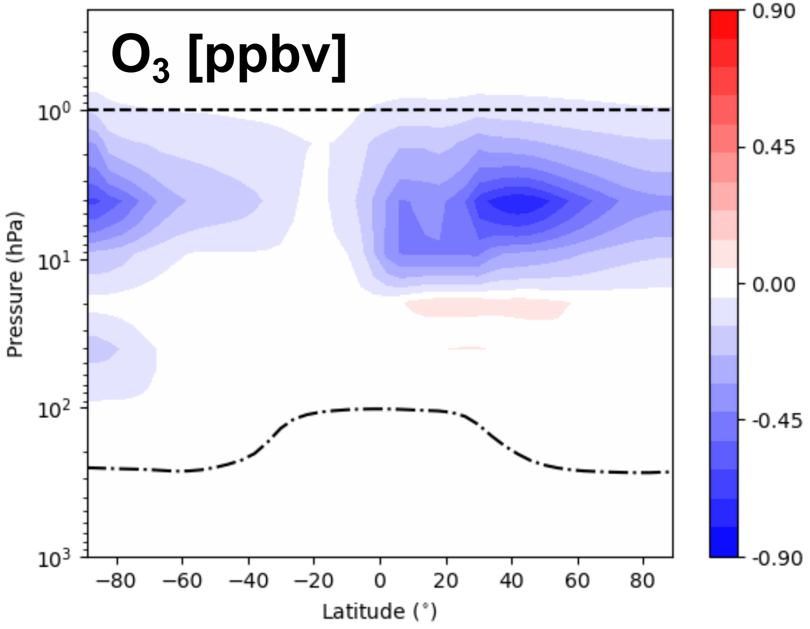


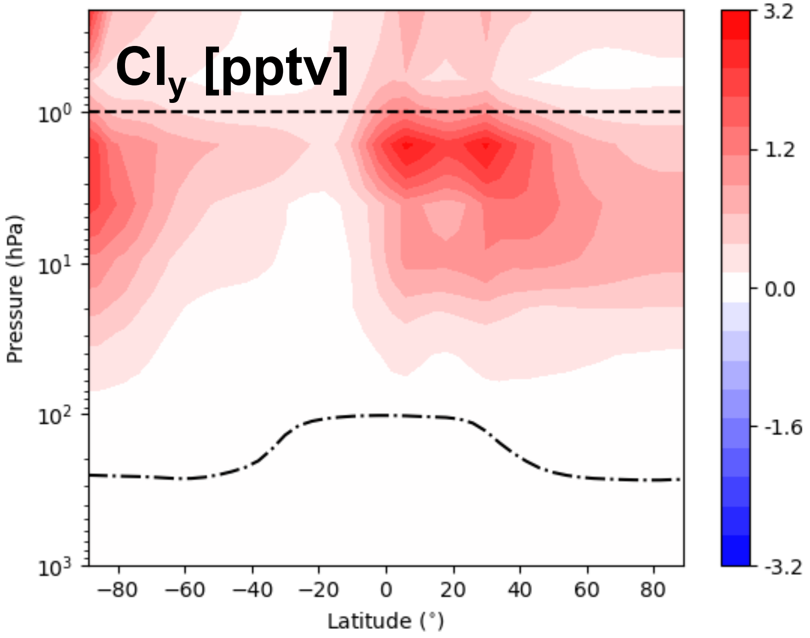
Updated Vertical Profiles

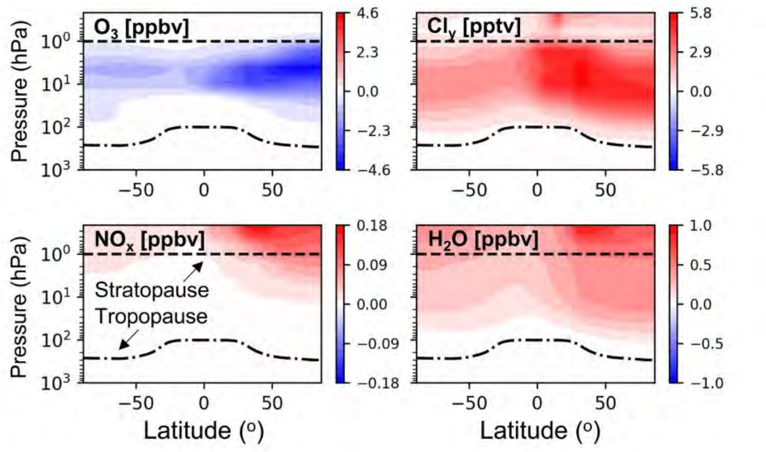




GEOS-Chem Simulations







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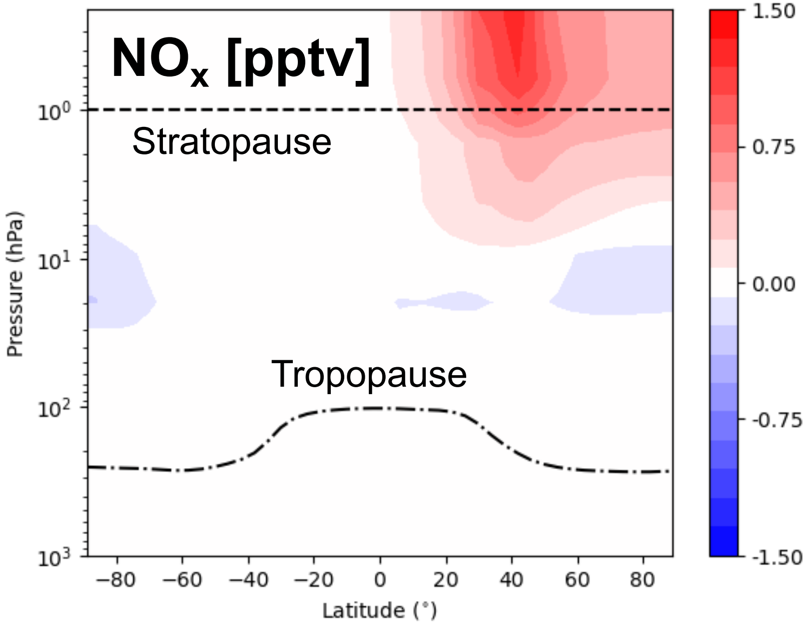

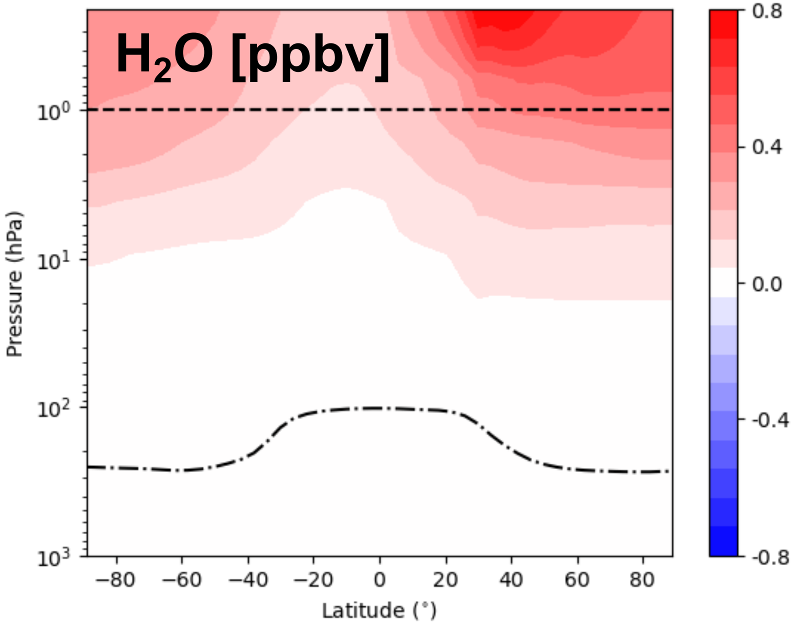

Preliminary GEOS-Chem simulations demonstrate similar trends to 2019 study.

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.

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