Megaconstellation mission emission inventory development for determining the impact on stratospheric ozone and climate

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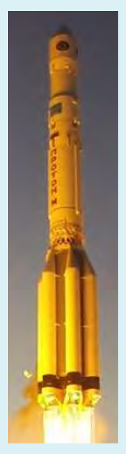
1. Satellite Megaconstellations

- Megaconstellations are driving a recent surge in rocket launches and re-entry destruction of spent satellites, with 997 megaconstellation satellites launched in 2020, rising to 1839 in 2022.
- However, the environmental impact of satellite megaconstellations remains uncharacterized and unregulated.
- We develop emission inventories of the dominant pollutants from megaconstellation and non-megaconstellation rocket launches and re-entries in 2020 to determine the impact of satellite megaconstellations on climate and stratospheric ozone.

2. Environmental Impact of Emissions

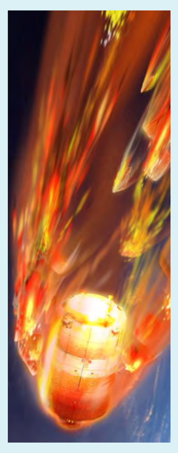
Kerosene
Falcon 9
LOX / RP1
H_2O
CO
NO_x (2°)
BC

Hydrogen
Delta IV Heavy
LH_2 / LOX
H_2O
CO
NO_x (2°)



Hypergolic
Proton-M
N_2O_4 / UDMH
H_2O
CO
NO_x (1/2°)
BC

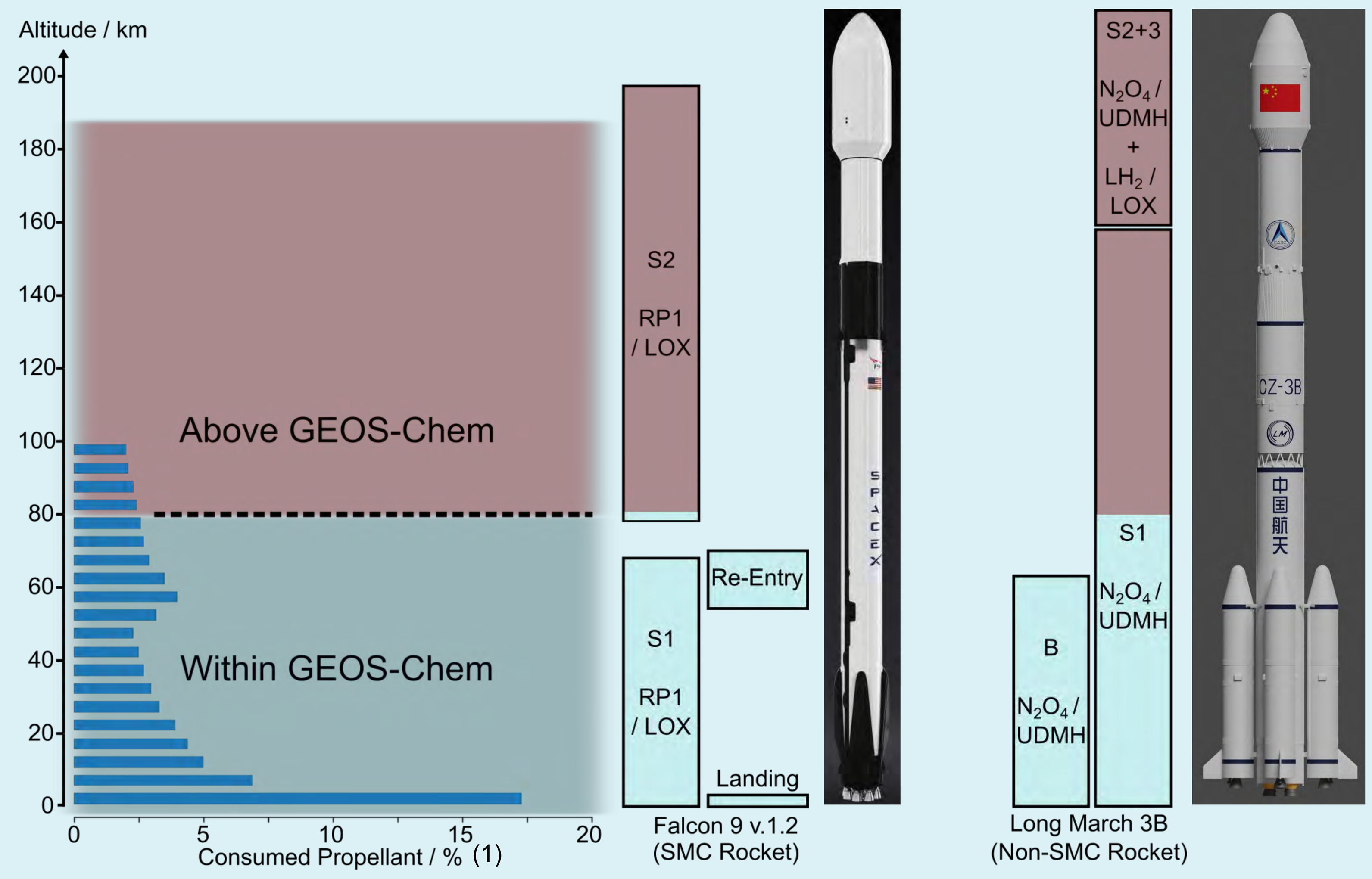
Solid
Long March 11
Al / NH_4ClO_4 / HTPB
H_2O (Water)
CO (Carbon Monoxide)
NO_x (2°) (NO+NO_2)
BC (Black Carbon)
Cl_y (Cl+Cl_2+HCl)
Al_2O_3 (Alumina)



Reentries
Payload/Rocket
Al / Other Metals
NO_x (2°)
Al_2O_3

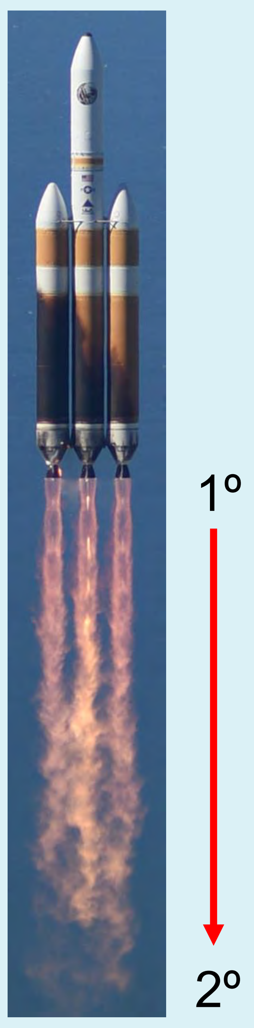
- We compile information on 44 rockets (propellant type/mass, stage mass), 115 launches (time, geolocation, rocket) and 807 re-entries (time, geolocation, mass, ablation) in 2020.
- The emissions are distributed hourly at a resolution of 4° x 5°, over 47 vertical layers from 0-80 km, for simulation in the GEOS-Chem chemical transport model. Al_2O_3 and BC emissions are added as radiative species.

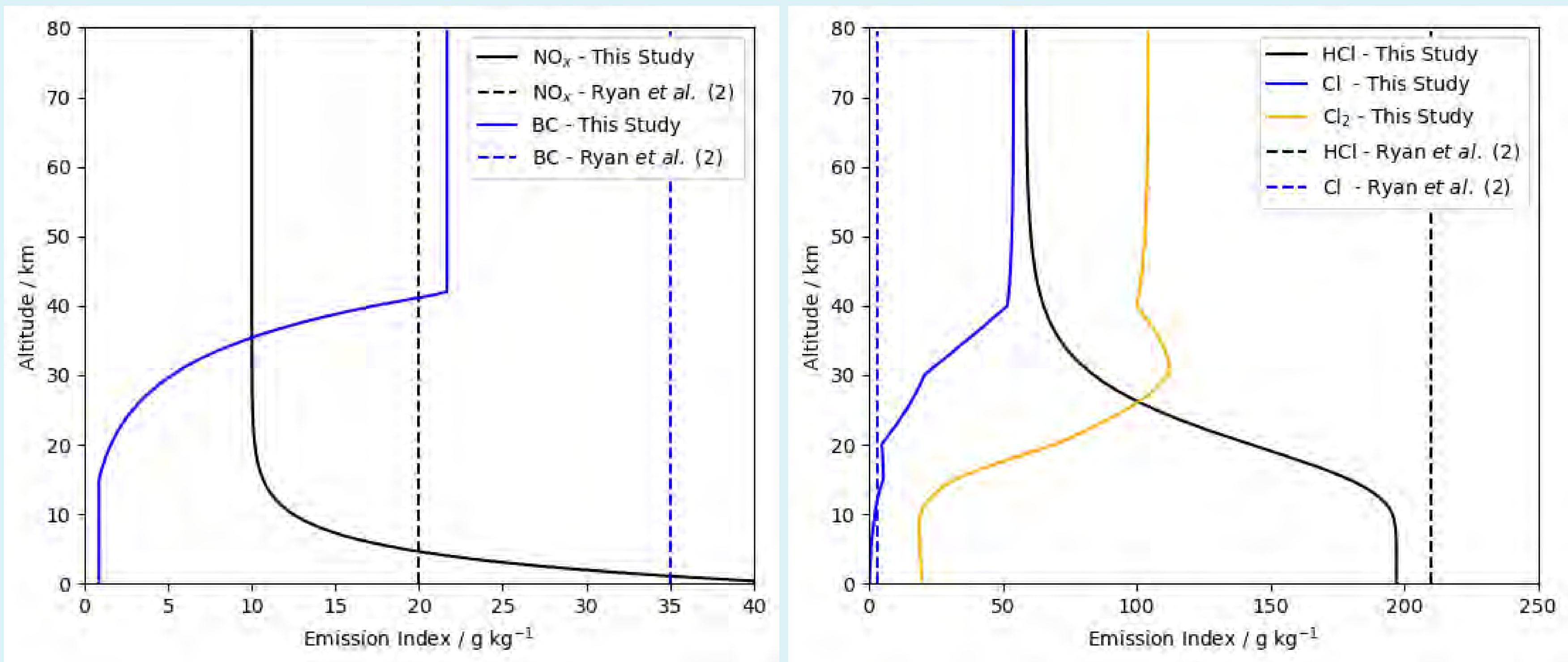
3. Vertical Propellant Consumption



- The altitude range of each rocket stage propellant burn varies between launch vehicle and mission.
- The mass of propellant consumed in each vertical layer is calculated by combining:
  a) Literature estimates of the propellant consumption [1].
  b) Specific launch profiles for each rocket.
- Overall, 79% of the rocket launch emissions are calculated to occur within the GEOS-Chem limits.

4. Vertical Emission Indices



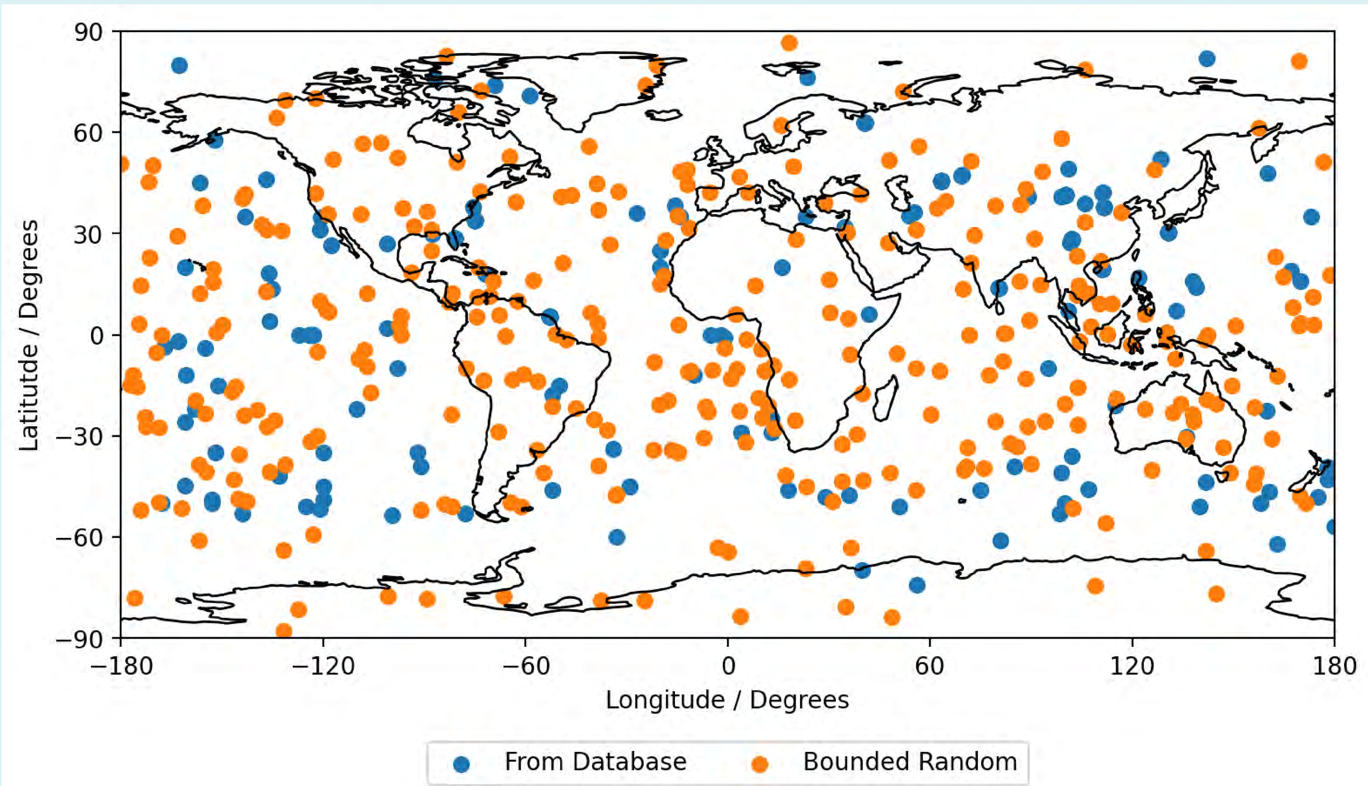


$$\textit{Mass Emissions } (g) = \textit{Propellant consumed } (kg) \times \textit{Emission Index } (g\ kg^{-1})$$

- 1º emission indices include propellant burning emissions only.
- 2º emission indices (included here) also account for additional oxidation in the hot rocket plume and changes in atmospheric composition with altitude.

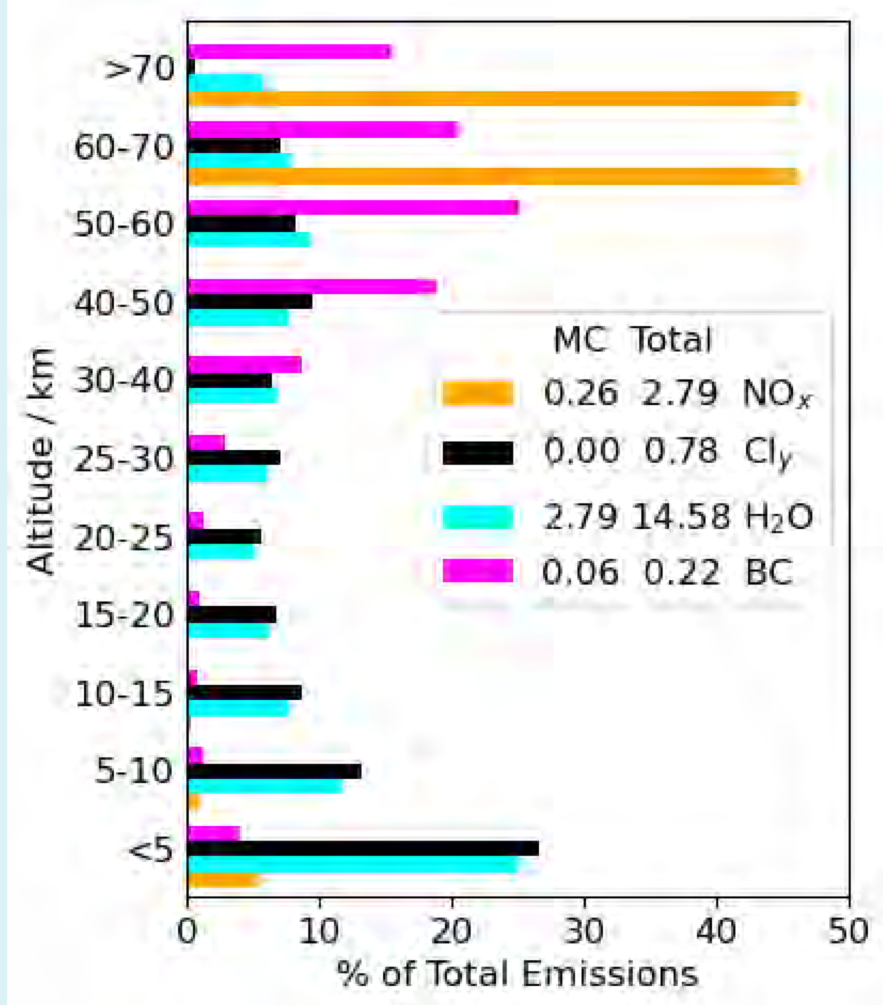
5. Object Re-entries

- Data is compiled from online repositories for all payloads, components, and rocket bodies re-entering from above 50 km in 2020.
- Chemical composition, mass ablation profiles and object reusability are used to determine the mass of Al_2O_3 released into the upper atmosphere.
- Where geolocation data is not available, coordinates are randomly assigned with latitude bounded by the orbital inclination.

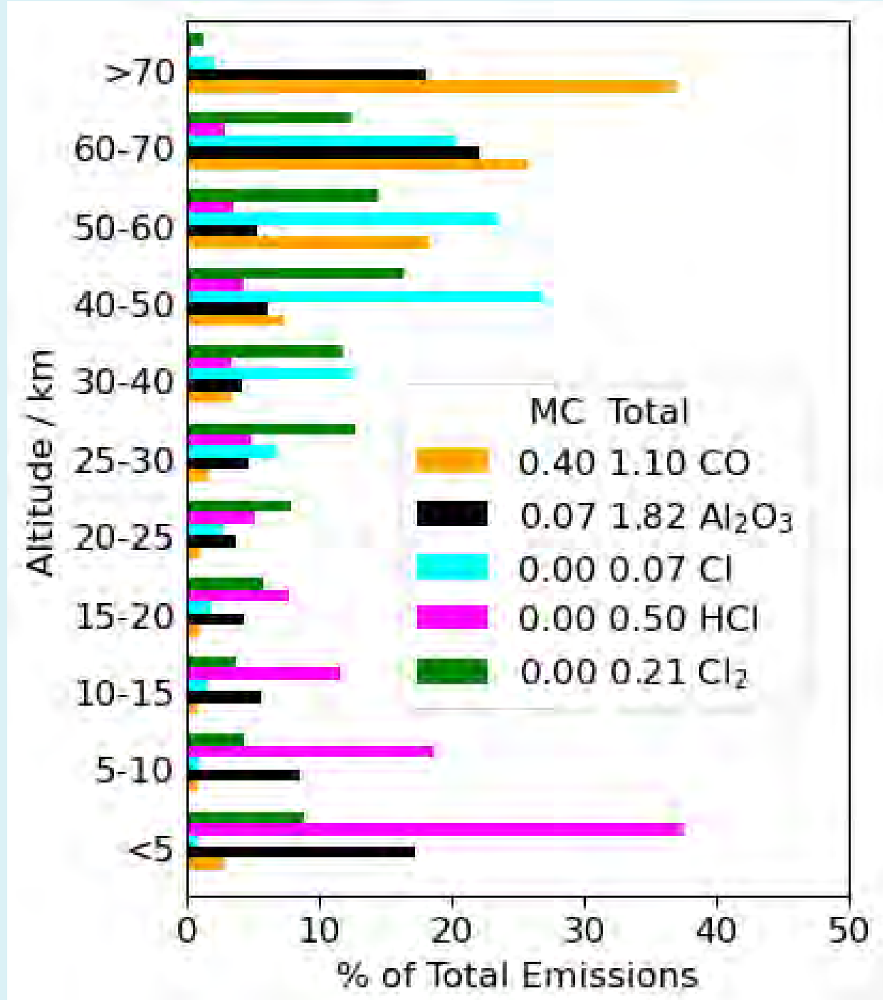


esa DISCOSweb API (2.0.0)
Jonathan's Space Home Page
AEROSPACE

6. Final Emission Distributions



- Total propellant mass consumption (37.2 Gg) has increased by 16% relative to 2019.
- Propellant mass consumption from megaconstellations (MC) was 8.3 Gg in 2020.



- Calculated 2020 re-entry Al_2O_3 deposited to the mesosphere (0.64 Gg) is more than twice the reported natural contribution from meteorites.
- The short lifetime of megaconstellation satellites (2-5 years), and increasing payload launch rate is likely to increase future megaconstellation emissions.

6. Summary and Next Steps

- Separate emission inventories for SMC and non-SMC rocket launch and satellite re-entry emissions compiled for 2020.
- Launch emissions are calculated using rocket-specific launch profiles and altitude-dependent chemistry.
- Re-entry emissions of Al_2O_3 are calculated using object ablation and object composition data.

Next steps

- Calculate 2021/2022 emissions.
- Add gravitational settling of emissions above 80 km.
- Use GEOS-Chem to simulate the impact of a decade (2020-2029) of megaconstellation emissions on stratospheric ozone and climate.

7. References

- 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
- 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
- Satellite/rocket images obtained from Wikipedia, SpaceX, OneWeb, United Launch Alliance, Sputnik News, CALT, ESA.

This work was funded by the European Research Council