Tracking Rocket Launch and Spacecraft Re-entry Emissions Across the Space Age

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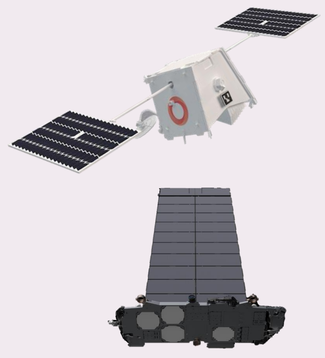
1. Rapid growth of the space industry

- There were a record **329** rocket launches in 2025, up from an average of 78 from 2000–2019.
- A record **2892** anthropogenic objects re-entered in 2025, up from an average of 570 from 2000–2019.
- This surge is driven by satellite megaconstellations such as Starlink, OneWeb, Amazon Leo, Qianfan, and Guowang.
- The number of active satellites in low Earth orbit is expected to grow from 15,400 in 2025 to >**100,000** by 2030.

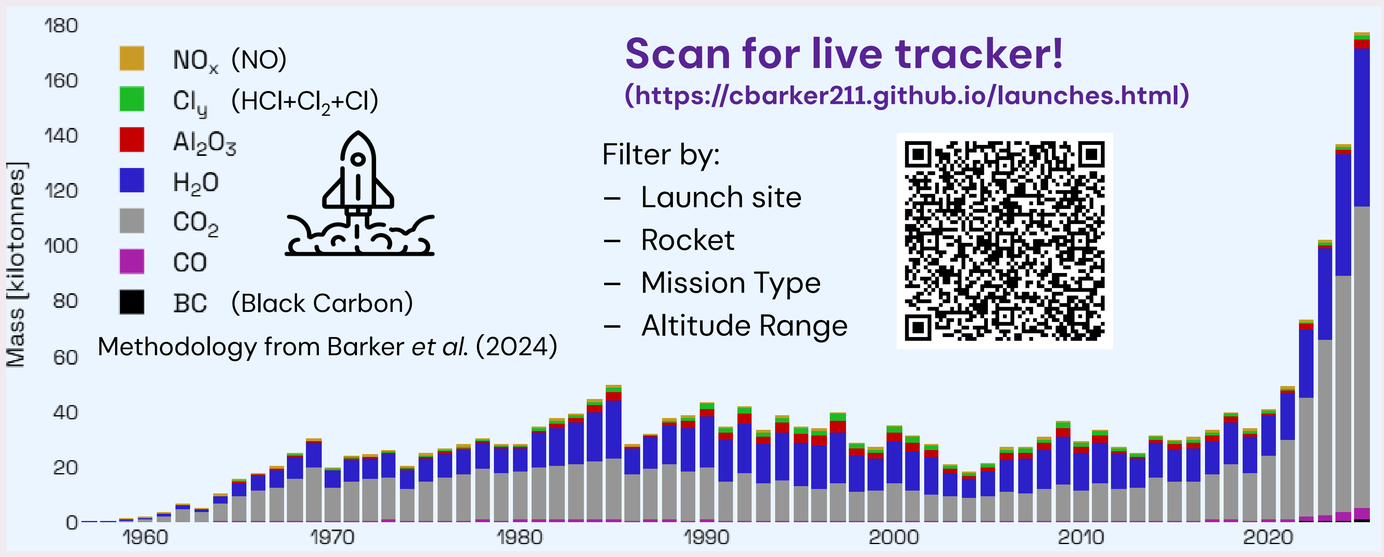


Credit SpaceX, OneWeb

2. Space industry atmospheric pollution

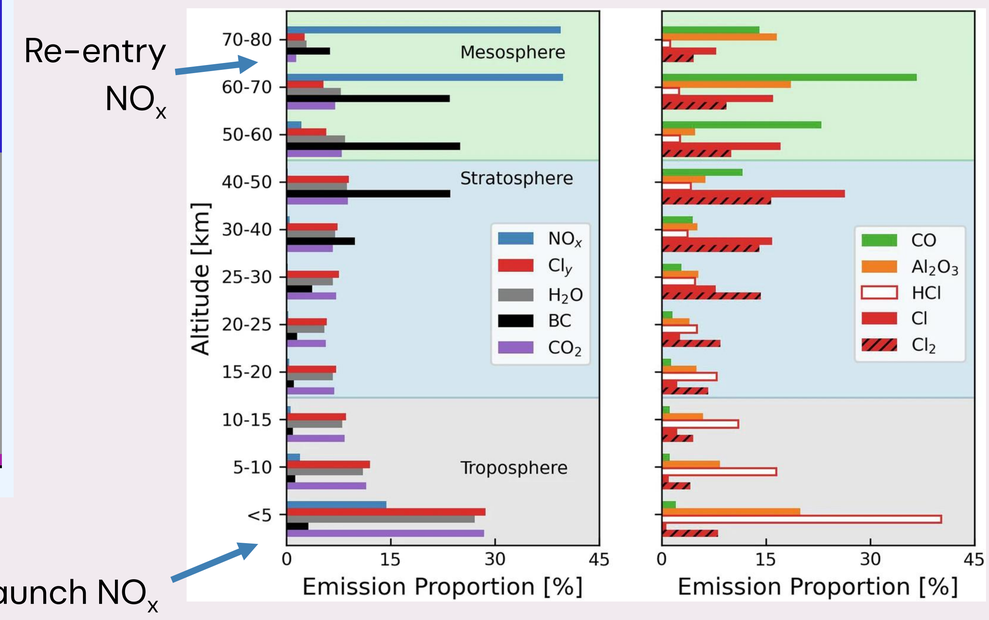
- Rocket launches and re-entries of discarded rocket bodies, payloads and debris release air pollutant emissions and CO_2 throughout the atmosphere.
- These anthropogenic events uniquely pollute above the tropopause, leading to stratospheric ozone depletion and complex climate impacts.

3. Online tracker of rocket launch emissions

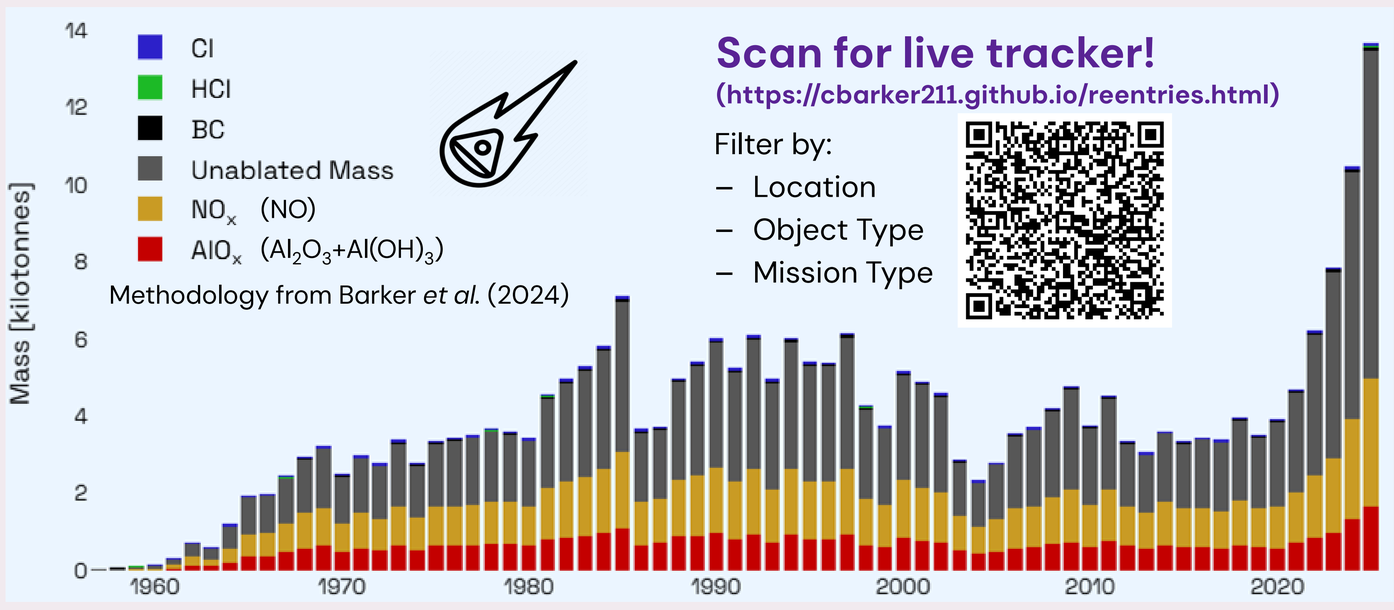


70% of space industry carbon emissions were from megaconstellations in 2025.

Vertical distribution of space industry emissions in 2022

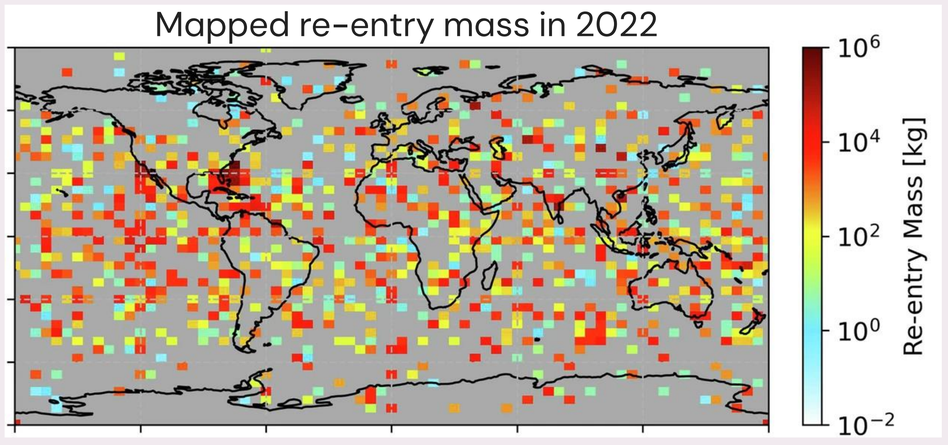


4. Online tracker of spacecraft re-entry emissions



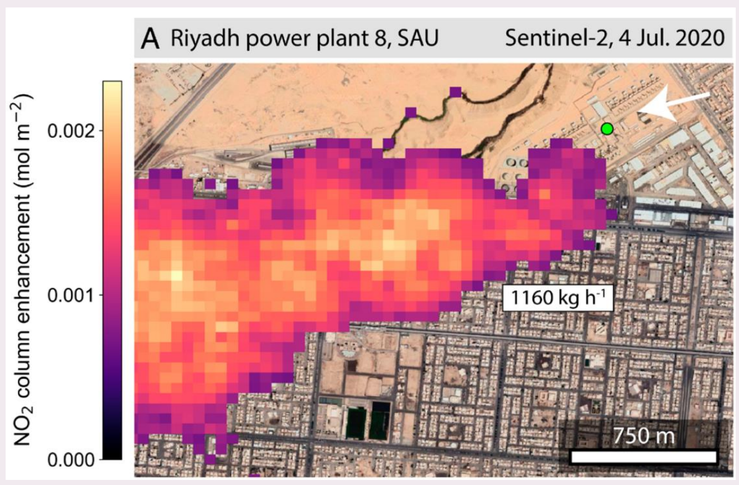
Megaconstellations represent **~50%** of re-entry NO_x and AlO_x emissions in 2025.

Re-entry mass is clustered around the equator and at launch sites



We calculate hourly, 3D emission estimates up the mesopause, allowing for direct input into atmospheric models.

5. Quantifying NO_2 plumes using remote sensing



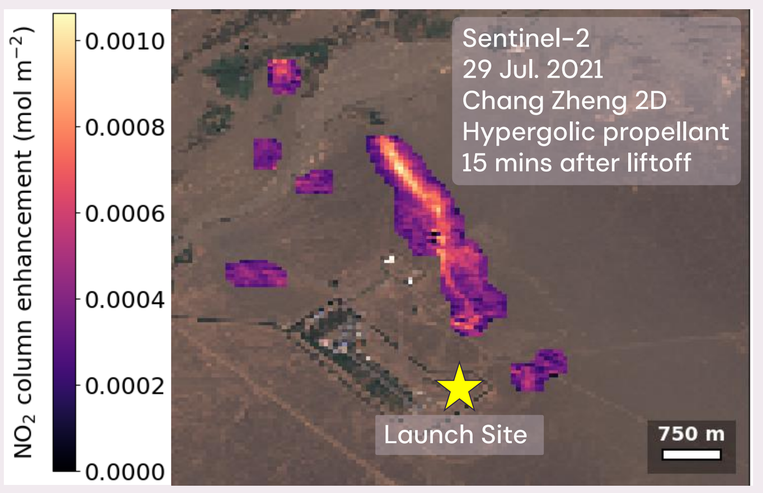
Varon *et al.* (2024)

- Broadband sensors (Sentinel-2, Landsat) are used to detect plume NO_2 at high resolutions (10–60m).
- The NO_2 signal is obtained by comparing scenes with and without the source.

Challenges include transient launches (weak point source signal), and retrievals complicated by co-emitted aerosol and H_2O.

6. Detection of rocket pollution using Sentinel-2

Jiuquan Satellite Launch Center, Northwest China



- The Chang Zheng 2D rocket is ~2.2 times smaller than Falcon 9.
- Hypergolic propellant combustion releases 1° (fuel burn) and 2° (afterburning) NO_x.
- The signal is 2x weaker than found for power plant NO_2.

7. Future Work

1. Improve the retrieval using matched cluster filtering.
2. Calculate total NO_x emissions using integrated mass enhancement.
3. Mine other satellite data for launch-coincident overpasses using other multispectral (Landsat 8–9, GOES-R) and hyperspectral instruments (EMIT, PACE).

8. References

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