# DLR Inventory of Global Emissions by Launchers 2024

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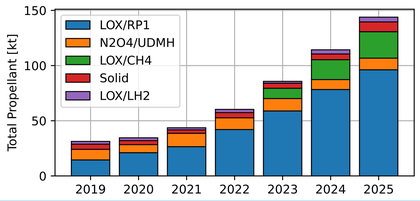
## Motivation

### Atmospheric impact of launches

- Launches release **gases and particles** across multiple atmospheric layers
- Atmospheric impact might be larger due to **high altitude emissions**
- Emissions have more than **quadrupled since 2019**



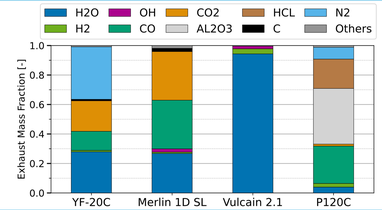

### Emission models as foundation

Reliable impact assessment requires consistent quantification of emissions in terms of magnitude, composition, and spatial distribution, which is the goal of this inventory.

## Innovations

### Rocket science to model emissions

- **Validated models** for aerodynamics, masses, and engines of each launcher
- Mission-specific 3D modelling of **each launch trajectory** with booster returns
- Modelling of all **main and secondary exhaust flows**




### Integrated modelling framework

The full emission chain is modelled, linking launcher design, trajectory simulation, and engine emissions to a global, three-dimensional emission inventory.

## 1. Launcher

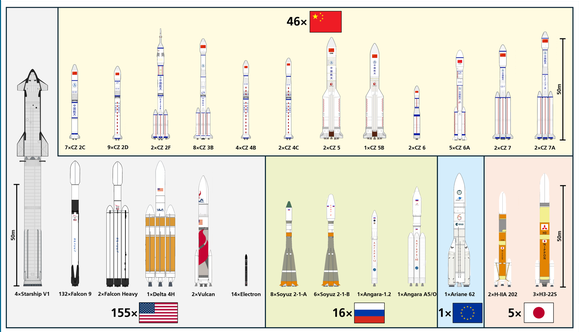



**Figure 1: Launch vehicles included in the IGEL 2024 emission inventory, with launch counts for 2024; all vehicles are shown to scale. Sketches courtesy of Spaceflight Archive [1].**

- Selection of launchers based on total propellant consumption
- Creation of **detailed aerodynamic, mass, and engine models** using DLR launcher design tools
- **Validation** of models **with launch telemetry** and payload performance

➢ **25** detailed launcher models that cover **95.6%** of the total propellant burned in 2024

## 2. Trajectories

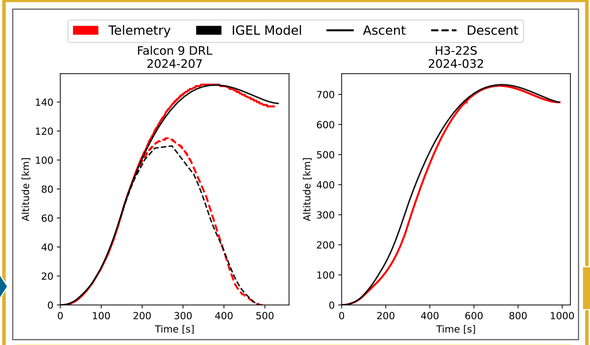



**Figure 2: Altitude–time profile comparison between modelled IGEL launches and real telemetry [2-5].**

- **Mission-specific input data** including insertion orbits and launch-site azimuth constraints
- 3D **trajectory optimization for all launches**, including reusable booster returns
- **Realistic flight behaviour** through launcher-specific constraints and control schemes

➢ **223** ascent and **134** descent trajectories providing the spatial propellant-use-profiles

## 3. Emissions

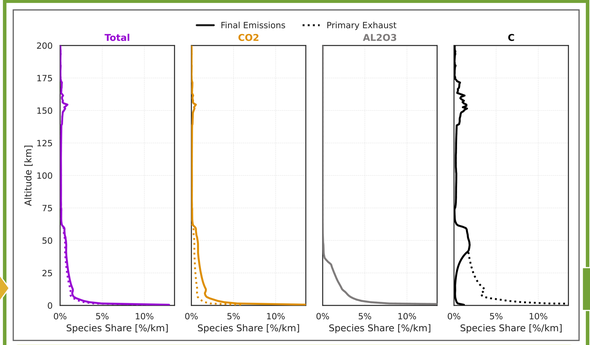



**Figure 3: Altitude profiles of primary exhaust and final emissions for selected species, each expressed relative to the total final emissions of that species.**

- Conversion of propellant-use-profiles into **engine-specific** primary emissions
- Engine-specific emission indices including **main and secondary exhaust flows** for **37 engines**
- **Altitude-dependent post-combustion** using empirical parameterizations (James [6], Barker [7])

➢ **223** three-dimensional final emission profiles totalling **131 Gg** across **39** species

## 4. Global Inventory

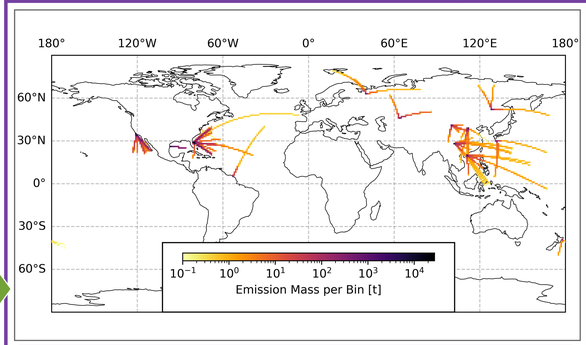



**Figure 4: Global distribution of total emission mass integrated over all altitudes from all species across the 223 launches included in IGEL 2024.**

- Aggregation of **individual launches** into a time-resolved, 3D emission inventory for 2024
- Conversion into **model-ready NetCDF dataset**
- Provision of a configurable inventory generator for custom spatial and temporal resolutions

➢ **2024 global launcher emission inventory for direct use in atmospheric chemistry models**

## Outlook

### Future Plans

- **Publication is under way** and will include the global inventory, launch-wise distributions, and engine-specific EIs
- Future versions will include **additional years**, **post-combustion** models, and **dispersion** models

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### Atmospheric impact modelling

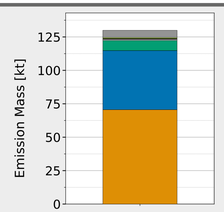
Within the S3D-BETTER project, IGEL 2024 will be used in climate chemistry models to contribute to the quantification of the impact of launch emissions.

## Take Home

**223 launches** and **>95%** of global launch emissions in 2024

Emissions based on the full chain of **launcher, trajectory,** and **engine models**

**Model-ready,** time-resolved, three-dimensional **dataset** for global chemistry climate studies




**131,000t of emissions in 2024**

- 70580t CO2
- 44210t H2O
- 7570t CO
- 810t AL2O3
- 700t C
- 690t NO
- 5400t Others

**Acronyms:**

| | |
|---|---|
| **DLR** | German Aerospace Center |
| **IGEL** | Inventory of Global Emissions by Launchers |
| **SL** | Sea-Level |
| **RP1** | Rocket Propellant 1 (highly refined kerosene) |

**References:**

**[1]** SpaceflightArchives. Orbital launch attempts of 2024, Available: https://www.reddit.com/r/SpaceXLounge/comments/1iarntp/orbital_launch_attempts_of_2024/ , 2025.
**[2]** The Launch Pad (2024): LIFTOFF! SpaceX Starlink 6-69 Launch. YouTube. , Available: r https://www.youtube.com/watch?v=iEmUO8Kpaok
**[3]** European Space Agency (2024): Ariane 6 first flight (Official broadcast). YouTube , Available: https://www.youtube.com/watch?v=B0oFpOJaIYc
**[4]** The Launch Pad (2024): REPLAY! Japan H3 Return To Flight. YouTube, Available: https://www.youtube.com/watch?v=6vHLDSjxv-s
**[5]** ArianeSpace (2016): Flight VS15 – Galileo Sat 13-14 | Soyuz Launch | Arianespace. YouTube, Available: https://www.youtube.com/watch?v=_7GM9psXJqs
**[6]** Michael M. James; Shane V. Lympany; Alexandria R. Salton; Matthew F. Calton; Blue Ridge Research and Consulting; LLC et al. (2021): Commercial Space Vehicle Emissions Modeling.
**[7]** Barker, Connor R.; Marais, Eloise A.; McDowell, Jonathan C. (2024): Global 3D rocket launch and re-entry air pollutant and CO2 emissions at the onset of the megaconstellation era.