

The impact of space launches on global climate and stratospheric ozone

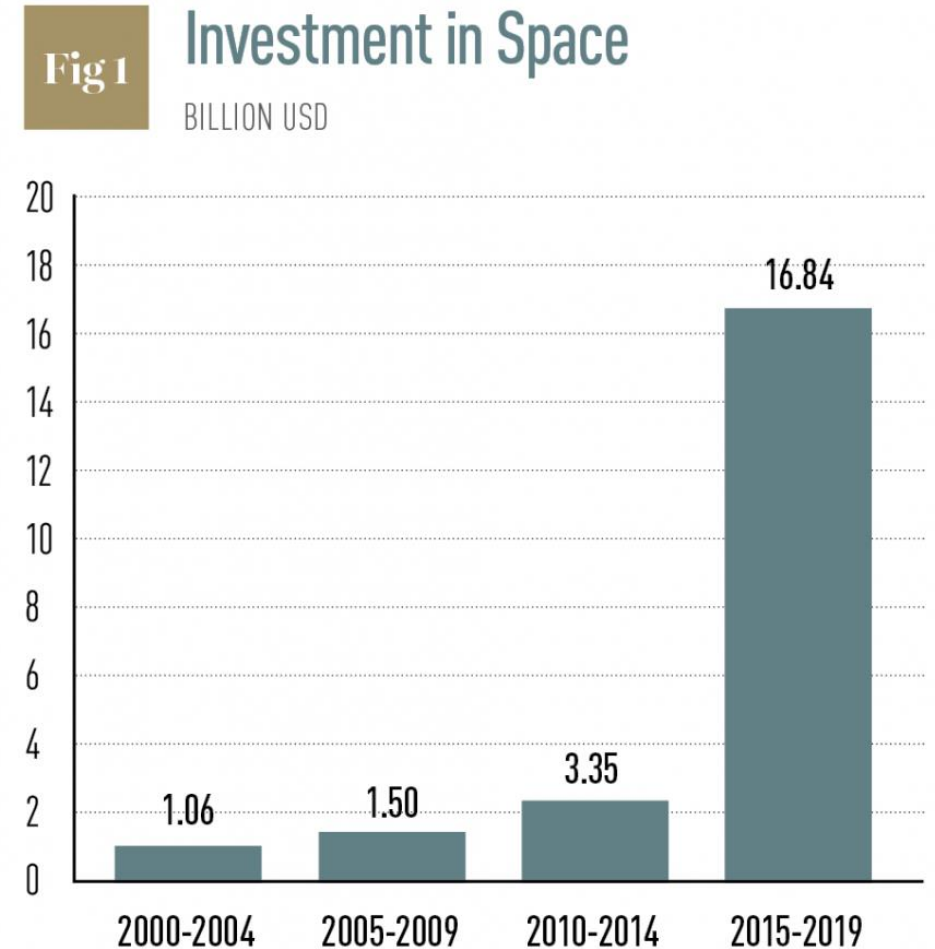
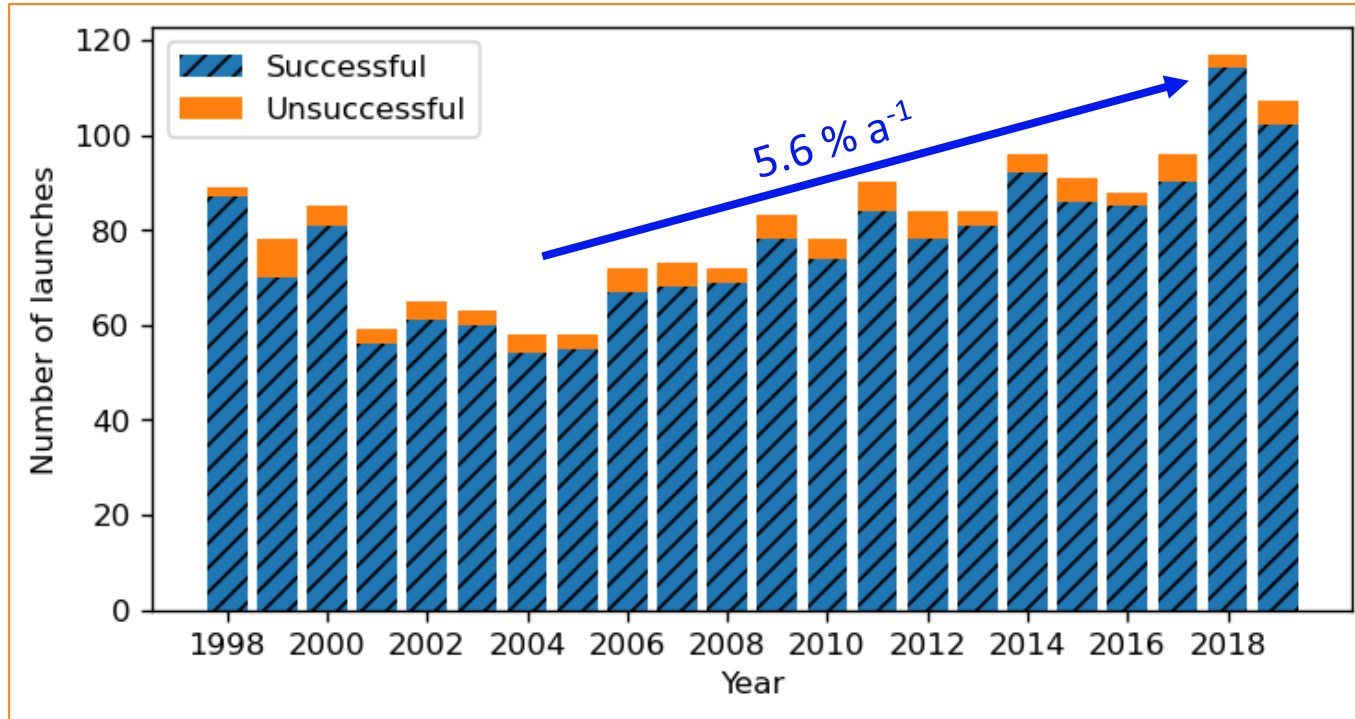
Dr Robert Ryan – UCL Physical Geography Seminar, Jan 20, 2022



UCL

The modern space launch industry

- Are launch rates about to accelerate, and what will the environmental consequences be?



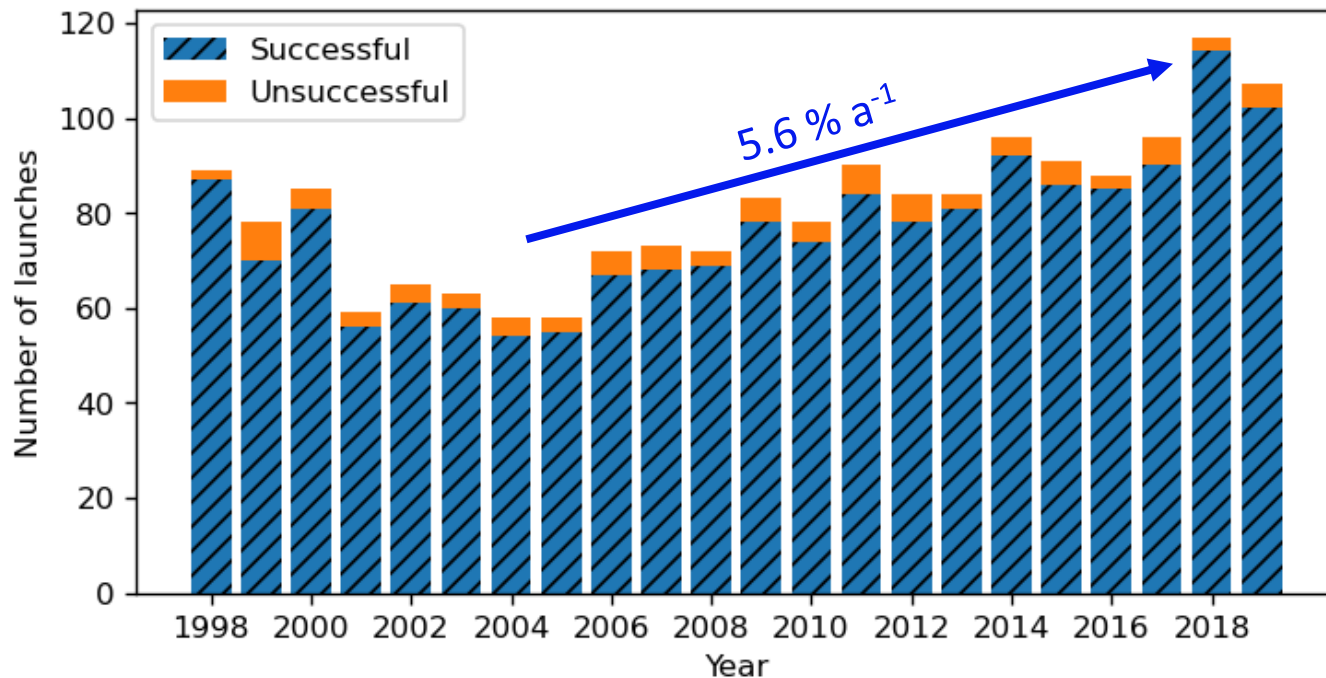
Source: Tauri Group via worldfinance.com

The modern space launch industry

- Are launch rates about to accelerate, and what will the environmental consequences be?

SpaceX launches world's first 'amateur astronaut' crew to orbit Earth

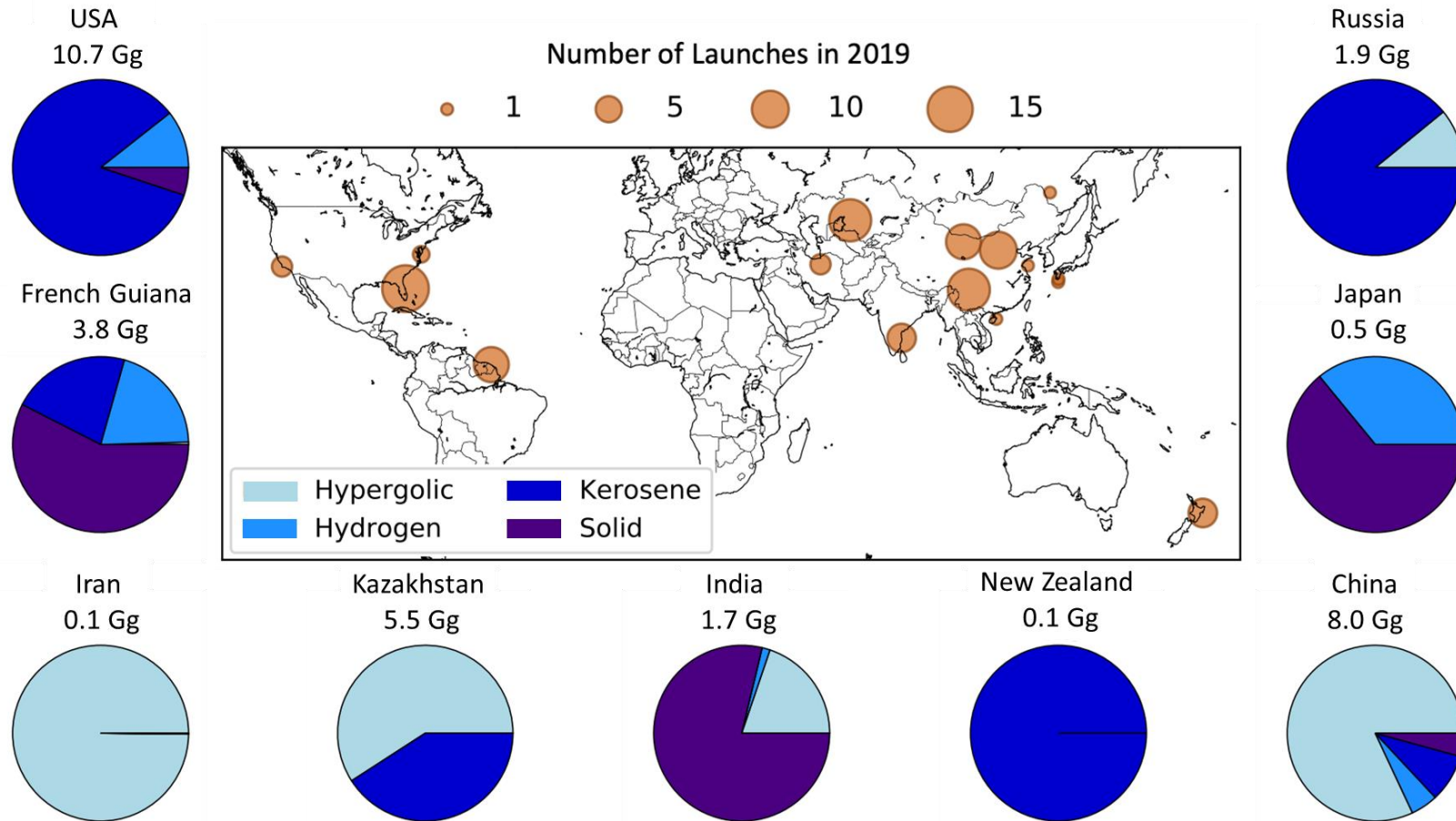
Launch marks biggest advancement so far in space tourism as Elon Musk's company conducts first chartered passenger flight



The Guardian, 15/9/2021

SpaceX makes history with first all-civilian crew launched into orbit - video

Compiling a rocket launch dataset

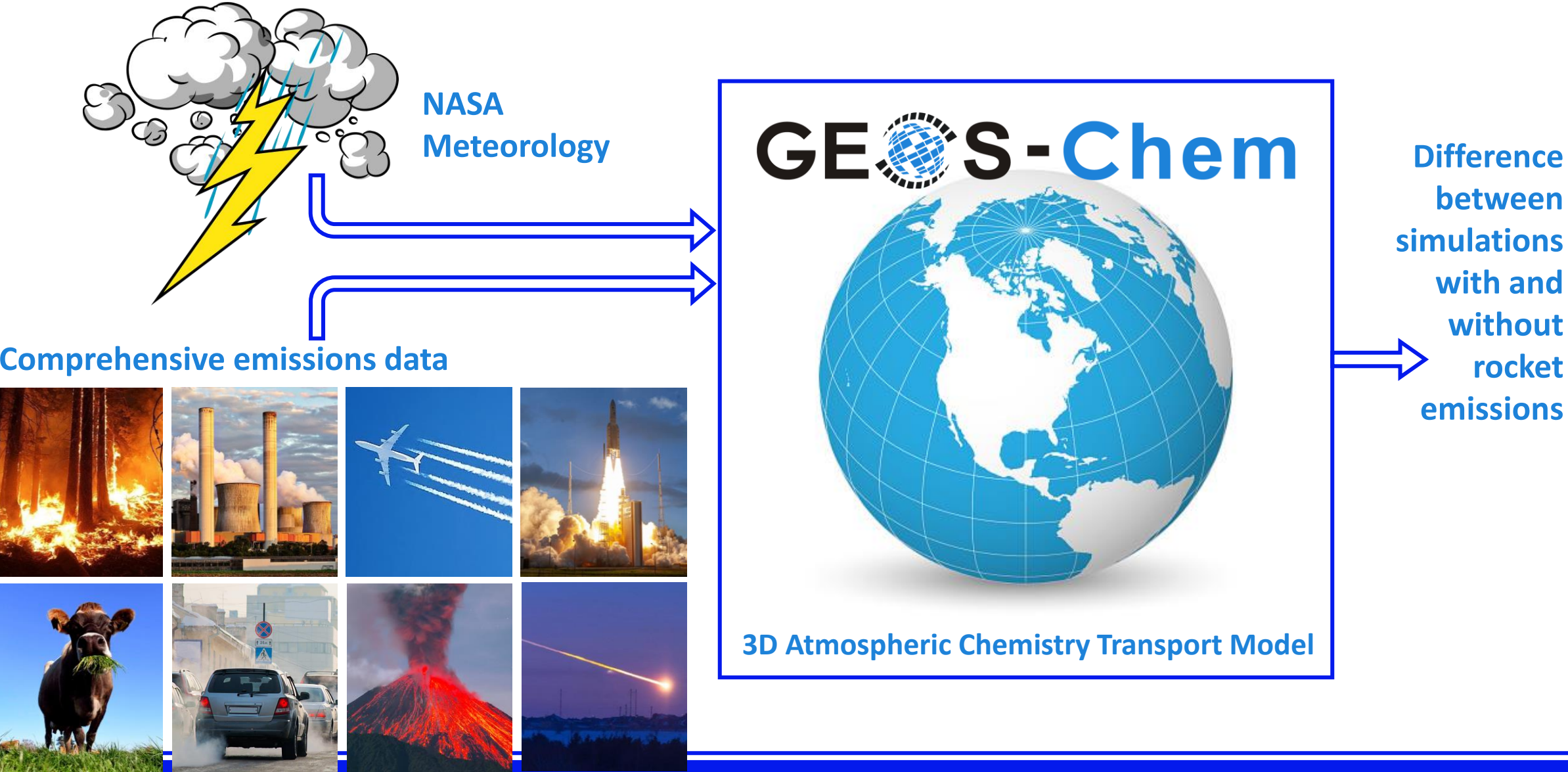


Fuel type	Emissions
Kerosene	NO _x , H ₂ O, soot
Hypergolic fuel	NO _x , H ₂ O, soot
Liquid hydrogen	NO _x , water
Solid fuel	NO _x , H ₂ O, Alumina, Chlorine
Re-entering components	NO _x

* Ozone depletion

* Atmospheric warming

Simulating ozone and radiative forcing changes



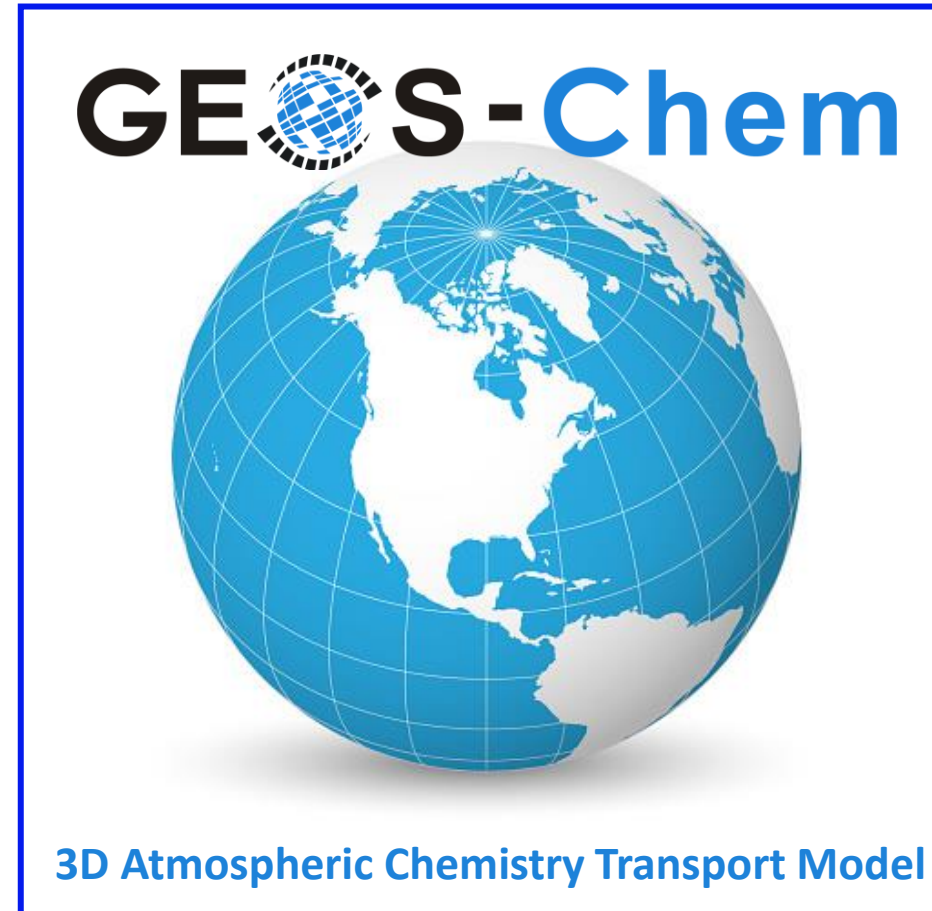
Simulating ozone and radiative forcing changes

Experiment 1:

- Inventory of 2019 rocket emissions added to GEOS-Chem
- We allowed the emissions to grow and accumulate in the atmosphere for 10 years, at $5.6 \% \text{ year}^{-1}$

Experiment 2:

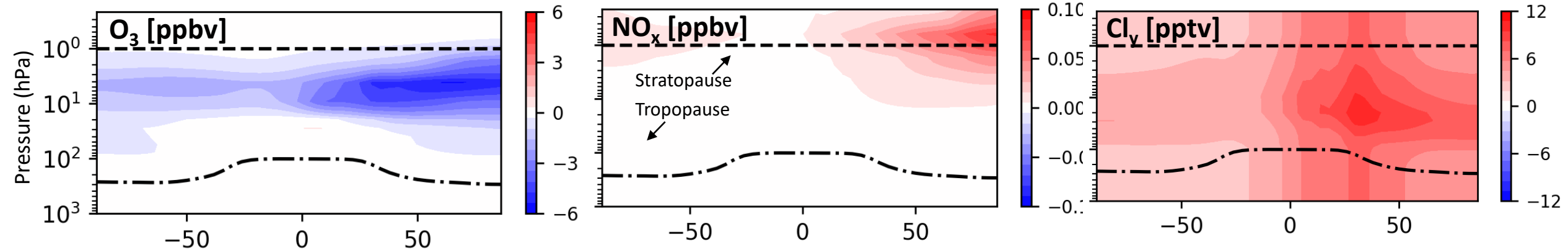
- Speculative daily and weekly space tourism launches added to Experiment 1, based on billionaires' advertised plans
- We allowed the emissions to grow and accumulate in the atmosphere for 3 years, the time it takes for stratospheric emissions to stabilise.



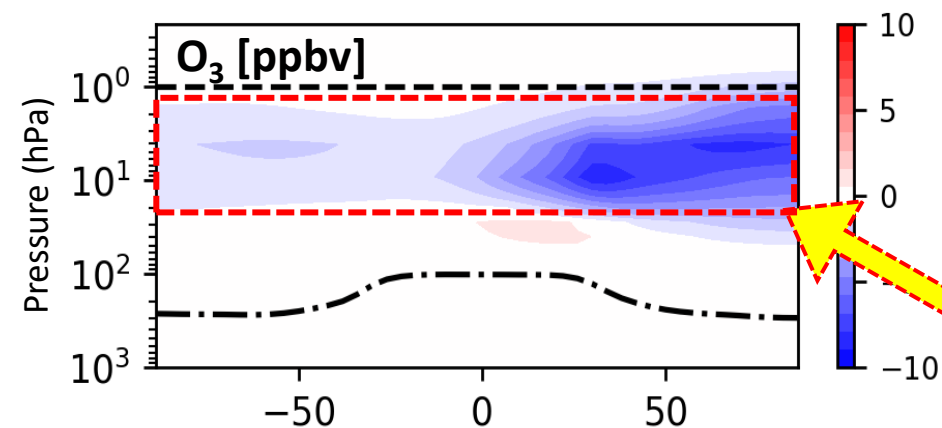
Difference
between
simulations
with and
without
rocket
emissions

Stratospheric ozone depletion

10 YEARS GROWTH OF EMISSIONS ON 2019 LEVELS



3 YEARS OF SPACE TOURISM



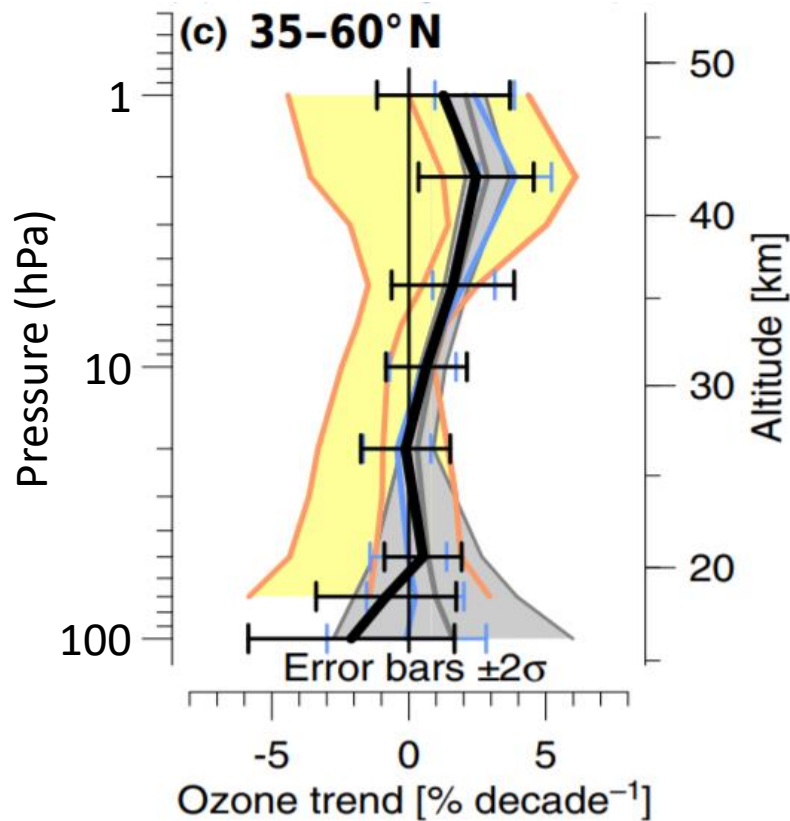
- Mean stratospheric O_3 depletion is $< 0.02\%$
- In the upper stratosphere, the mean O_3 depletion is 0.16%
- After 3 years of space tourism, upper strat. O_3 depletion reaches 0.28%

Seems like a small effect... what's the big deal?

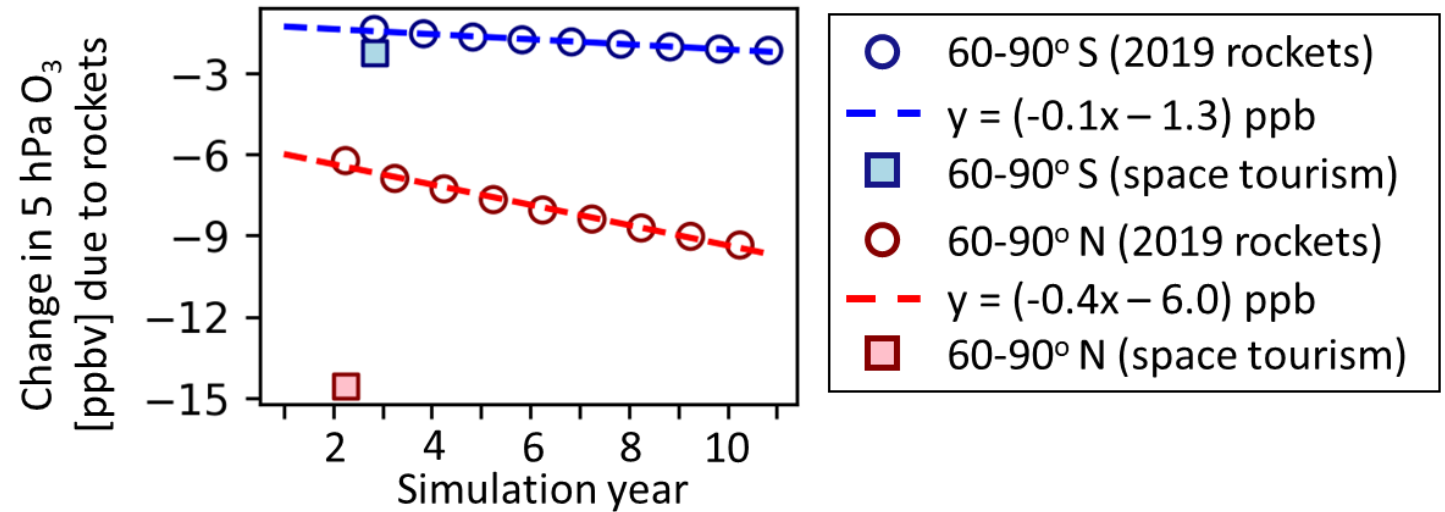
Stratospheric ozone depletion

Steinbrecht et al., 2017

7 satellite merged dataset,
Ozone trend 2000-2016



- The spring recovery trend in the Arctic upper stratosphere is 81 ppb dec⁻¹

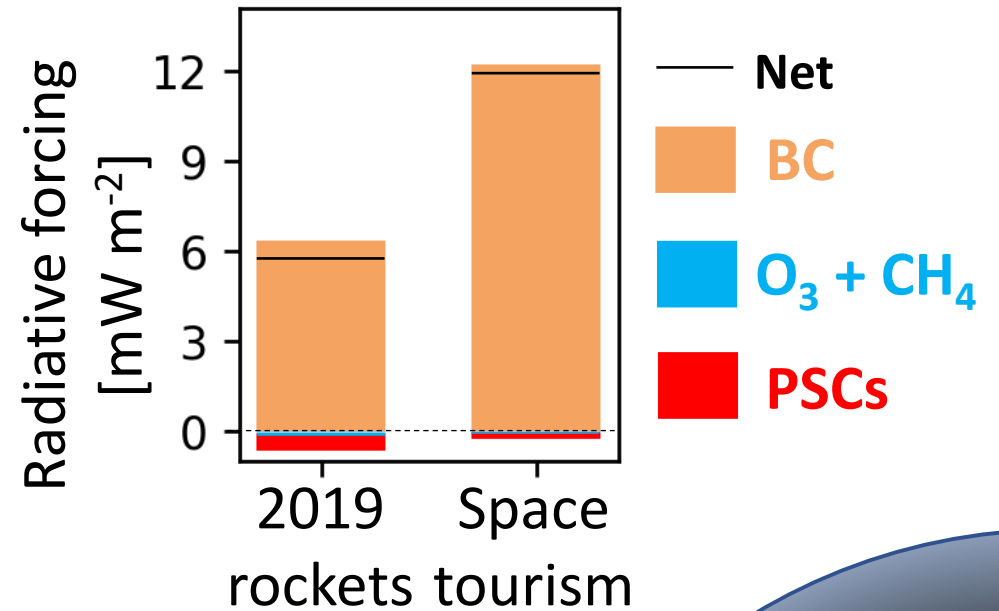
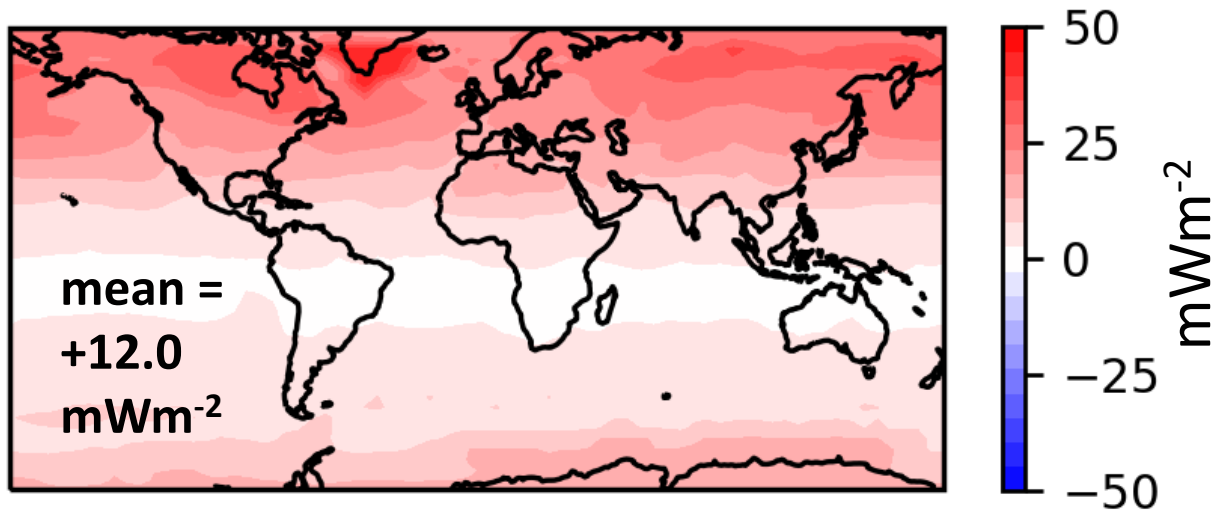


- We find springtime Arctic O₃ loss at 5 hPa is 10 ppb dec⁻¹
- This increases this to 18 ppb dec⁻¹ with space tourism.

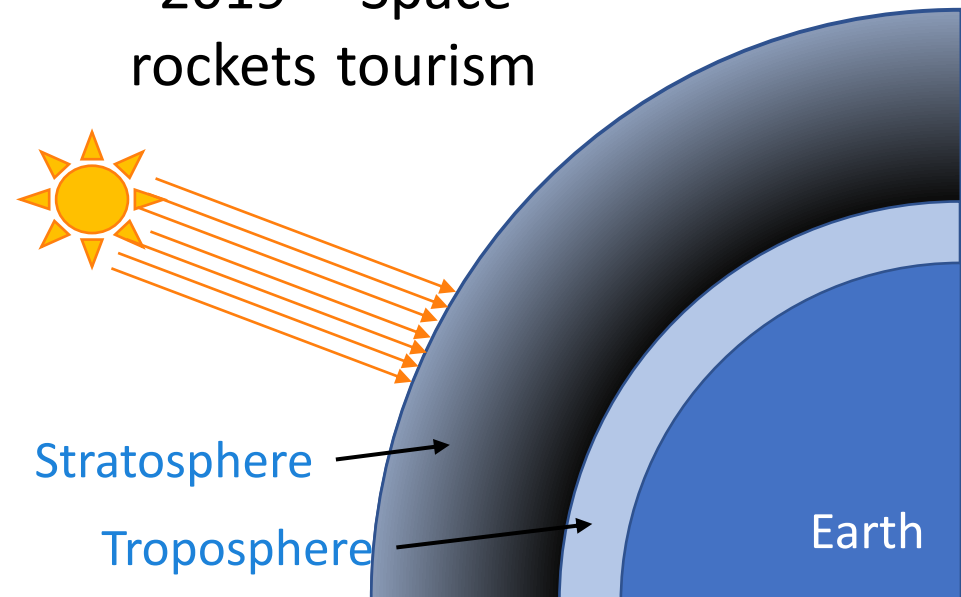
Potential to undermine 20 % of the post-Montreal Protocol gains

Global warming caused by soot emissions

Net radiative forcing (Space tourism)



- Rocket soot makes up ~0.0002 % of global soot emissions but produces nearly **10 % of the total soot warming**

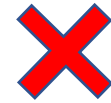
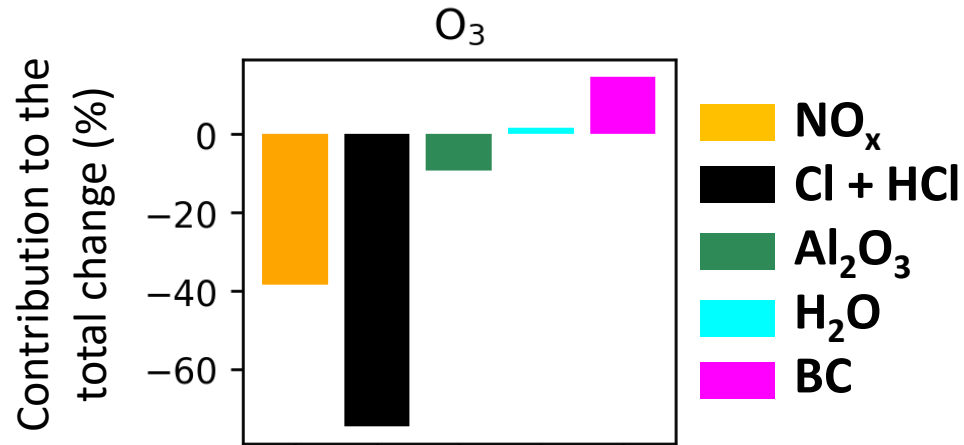


Are there any 'clean' rocket fuels?



Solid fuels:

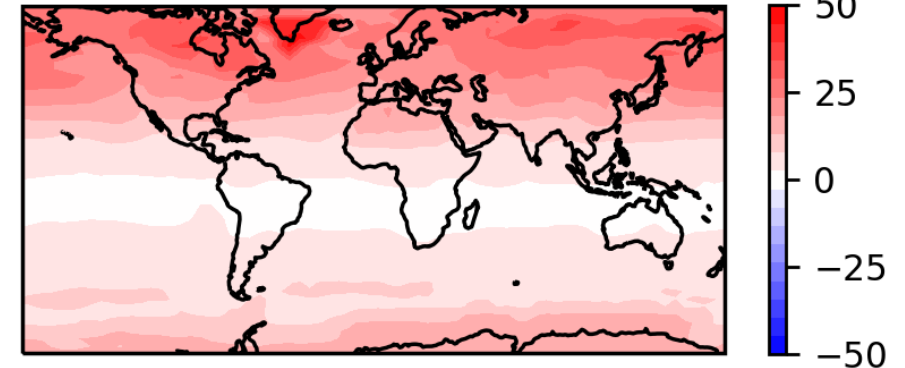
Rocket chlorine emissions (Cl + HCl) cause the most ozone depletion



Hypergolic and kerosene-based fuels:

Hydrocarbon based fuel emissions are the cause of positive radiative forcing

Black carbon mean forcing: 12.2
mW m⁻²



Liquid hydrogen fuel

No BC or chlorine, but ubiquitous NO_x (including re-entry NO_x), which plays an important O₃ depletion role

Summary

We added an emissions inventory of pollutants from rocket launches to GEOS-Chem

- Contemporary emissions and emissions growth scenario
- Speculative space tourism emissions

Chlorine and nitrogen oxides are responsible for ozone depletion

- Small global average impact
- Strongest O₃ depletion in the upper stratosphere
- Potential to undermine ~20 % of gains made post-Montreal Protocol, in this part of the atmosphere

Black carbon (soot) is responsible for enhanced radiative forcing

- Due to the altitude of emission, rocket soot is extremely efficient (1000 times other sources!) at warming the atmosphere.

Outlook for the space industry

SpaceX launches 49 Starlink internet satellites, lands rocket at sea

By Mike Wall published 1 day ago

It was the 10th launch and landing for this particular Falcon 9 rocket first stage.

space.com

“Starlink satellites are photo-bombing astronomical images”

*NASA is going back to the moon
... with the largest rocket booster ever
manufactured, and it burns hydrocarbon-
based fuel*

NASA's Artemis 1 moon mission readies for 'wet dress rehearsal'

By Elizabeth Howell published about 18 hours ago

A simulated launch and core stage testing are all part of getting ready for a round-the-moon trip.

space.com

Forbes

Dec 31, 2021, 04:43pm EST | 1,822 views

5 Space Tourism Experiences You Can Book In 2022

- Are launch rates about to accelerate, and what will the environmental consequences be?

Yes

Potentially serious climate and ozone impacts