Atmospheric Composition and Air Quality Group

Karn Gongda Connor Eloise Bex Eleanor Nana

Find out more about the group: https://maraisresearchgroup.co.uk/

Find out more about me: https://www.ucl.ac.uk/geography/eloise-marais

Air pollution from fossil fuel extraction, production and use and the impact on public health

Karn Vohra, Research Fellow

Quantifying the size of air pollution sources in very polluted cities in South and Southeast Asia

Gongda Lu, Research Fellow

Climate change and ozone depletion from megaconstellation mission launches and waste

Connor Barker, Research Fellow

Addressing knowledge gaps of the under-appreciated upper troposphere with NASA aircraft observations

Nana Wei, PhD

Making innovative use of satellite observations to address data gaps in tropospheric atmospheric composition

Bex Horner, PhD

Measuring atmospheric composition and air quality in Central London

Eleanor Gershenson-Smith, PhD

Other Group Activities

- ❑ Organize and host international meetings at UCL
- ❑ Past research into UK agriculture and the impact on public health
- ❑ Training to share research with the media (Sky, BBC, Channel 4, The Guardian, Time, and so on)
- ❑ Training to present research to other scientists at conferences
- ❑ Routine, structured research group meetings
- ❑ Weekly / fortnightly structured supervisory meetings
- ❑ Research-relevant information on frequently updated internal wiki
- ❑ Training in open science (code, data, talks, papers)
- ❑ Training in lead author and co-author of high-impact papers (write → implement feedback → submit → respond to reviewers)

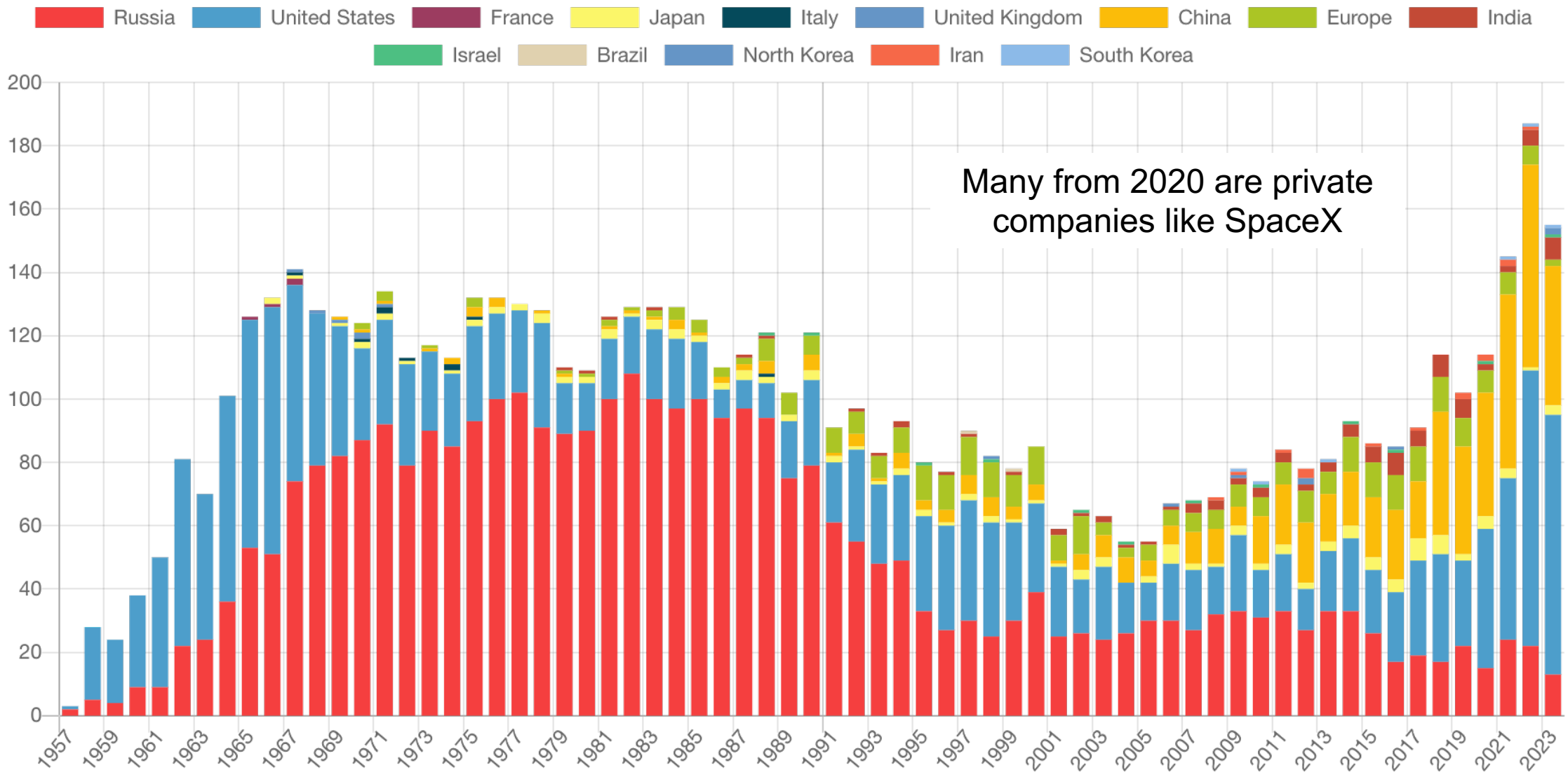
Any questions about my group?

What to do to make an informed decision about your PhD?

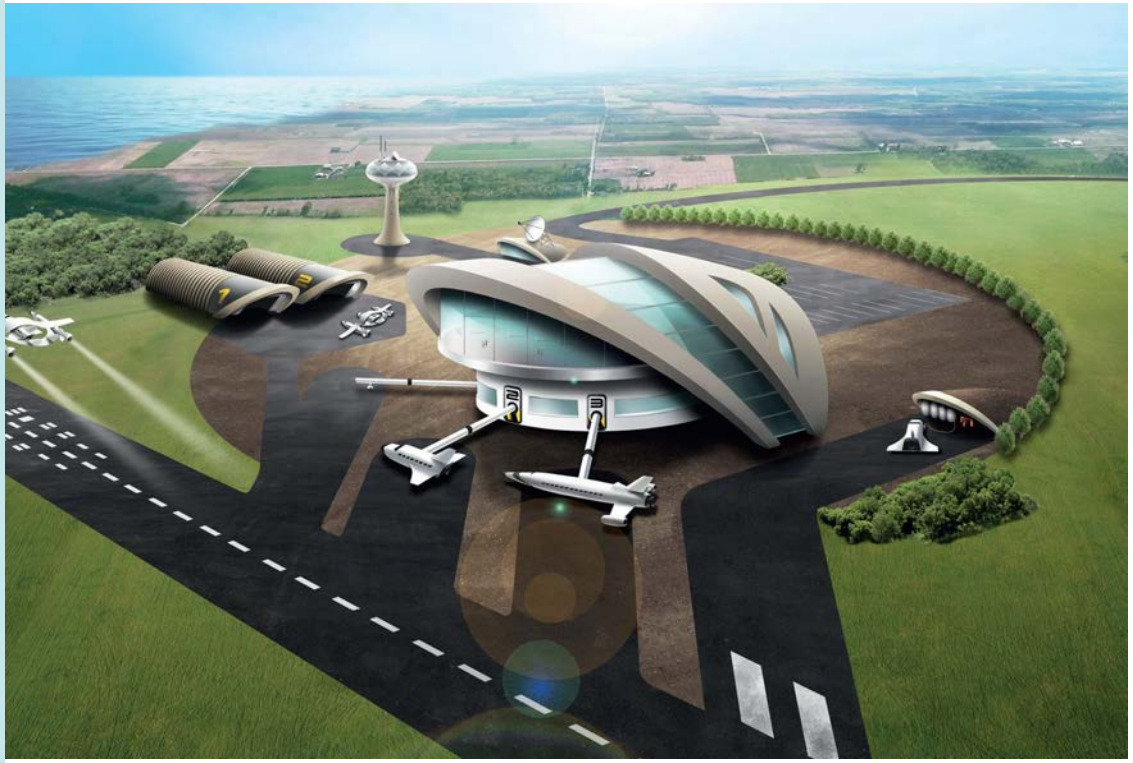
Environmental Effects of the Space Sector: Rockets and waste

More diverse space sector than the first space race

Number of rocket launches per country in each year



Even the UK has joined the race



Dramatic increase in objects in space

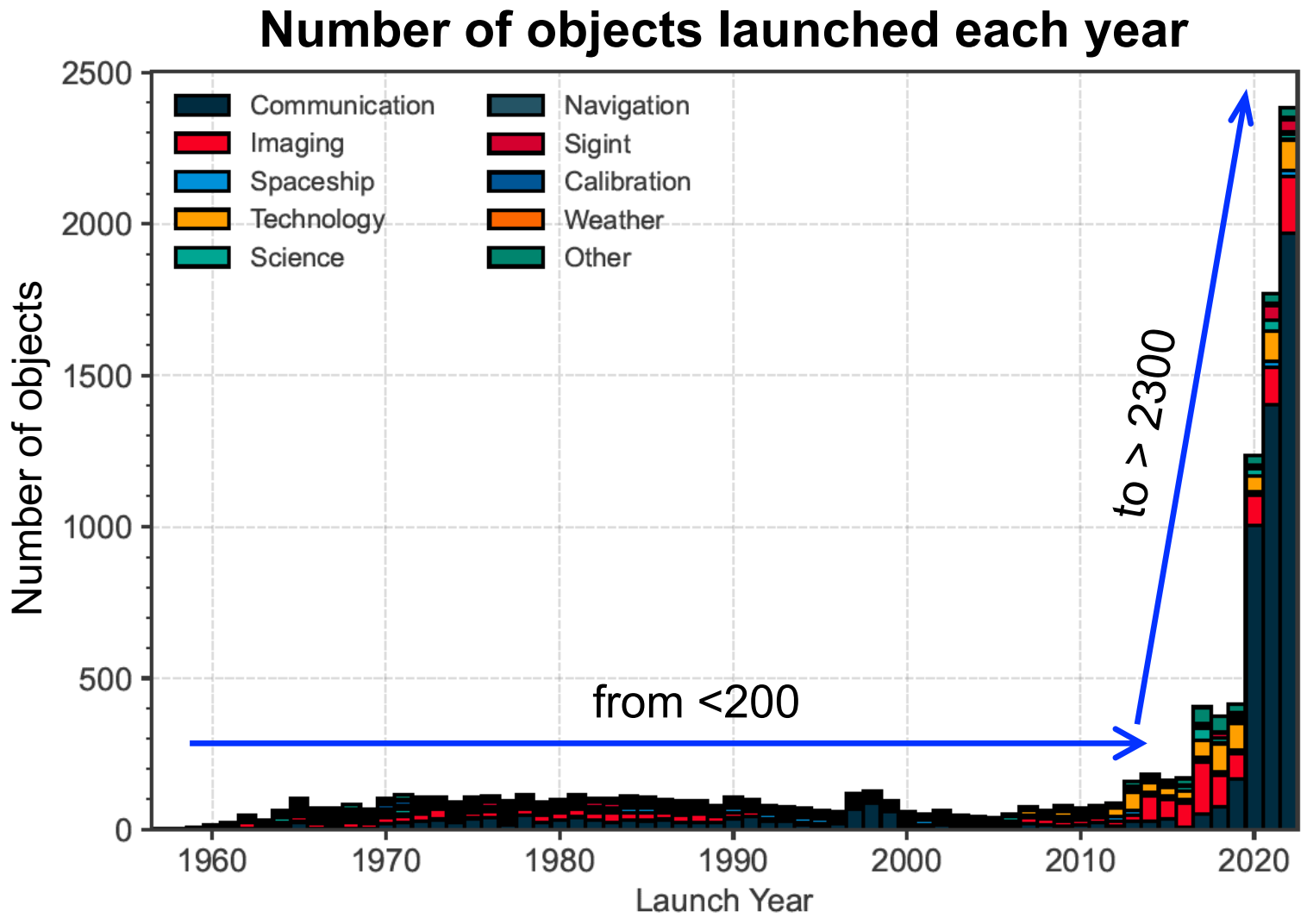


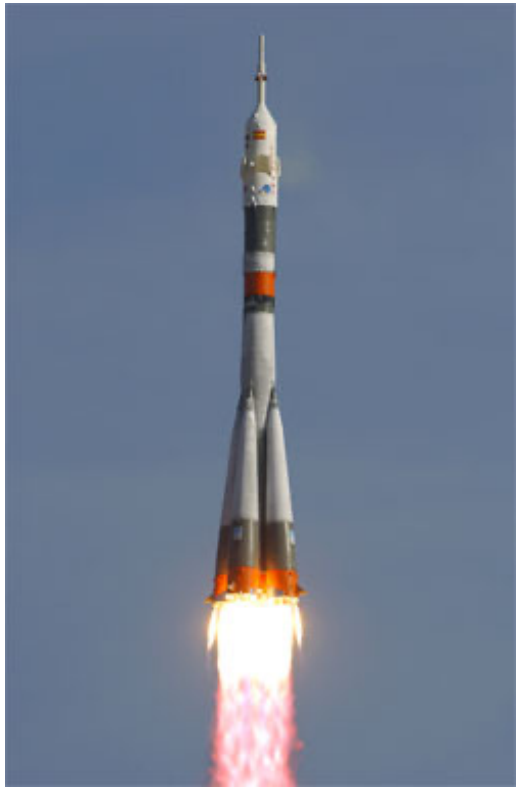
Image from ESA's Annual Space Environment Report, 2023

Air pollutant emissions from rocket launches

Solid

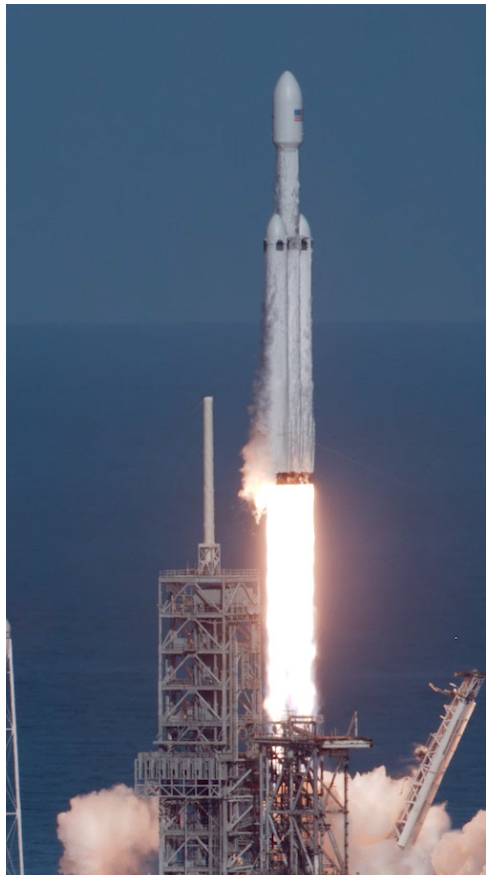
NO_x
HCl+Cl
Al_2O_3
H_2O
BC

Hypergolic



NO_x
H_2O
BC

Kerosene



NO_x
H_2O
BC

Cryogenic

NO_x
H_2O

Air pollutant emissions from rocket launches

Solid

NO_x
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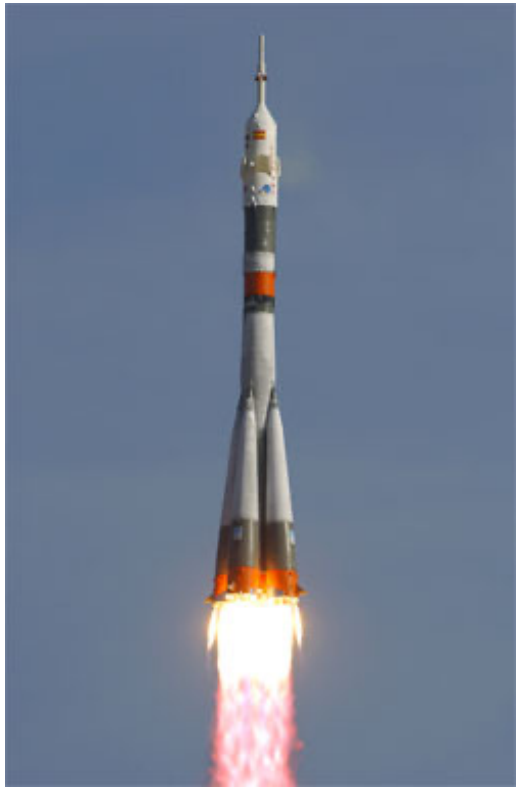

NO_x
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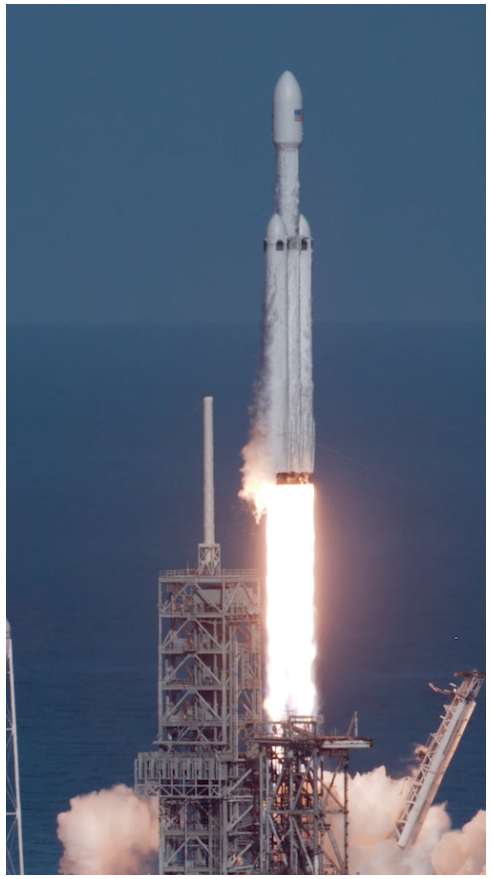
Kerosene



NO_x
H_2O
BC

Cryogenic

NO_x
H_2O

Climate concern

Black carbon or soot particles here on Earth

Air pollutant emissions from rocket launches

Solid

NO_x
HCl+Cl
Al_2O_3
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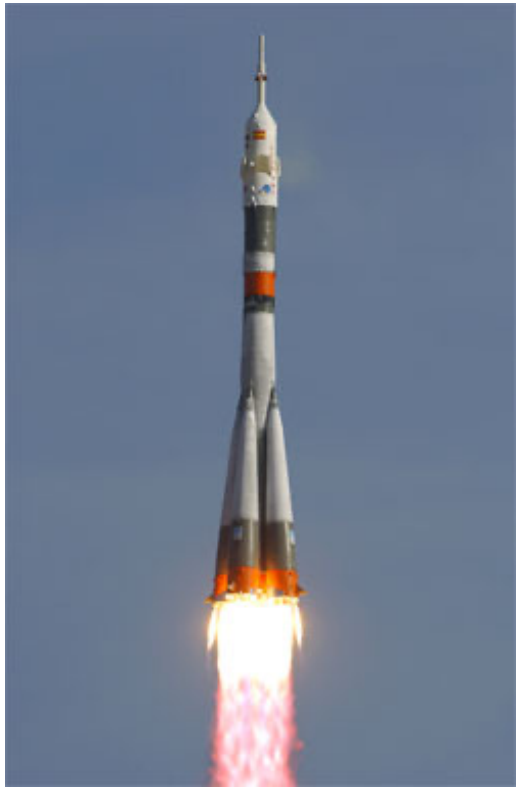
BC

Hypergolic



NO_x
H_2O
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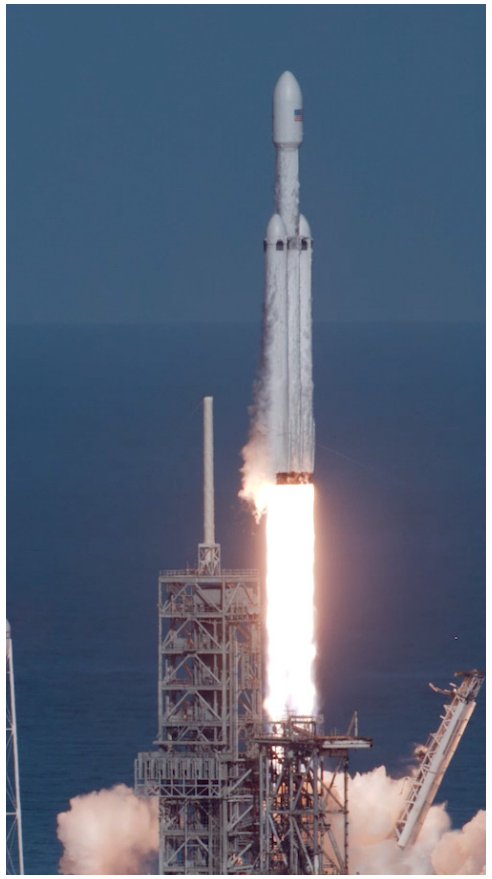
Kerosene



NO_x
H_2O
BC

Cryogenic

NO_x
H_2O

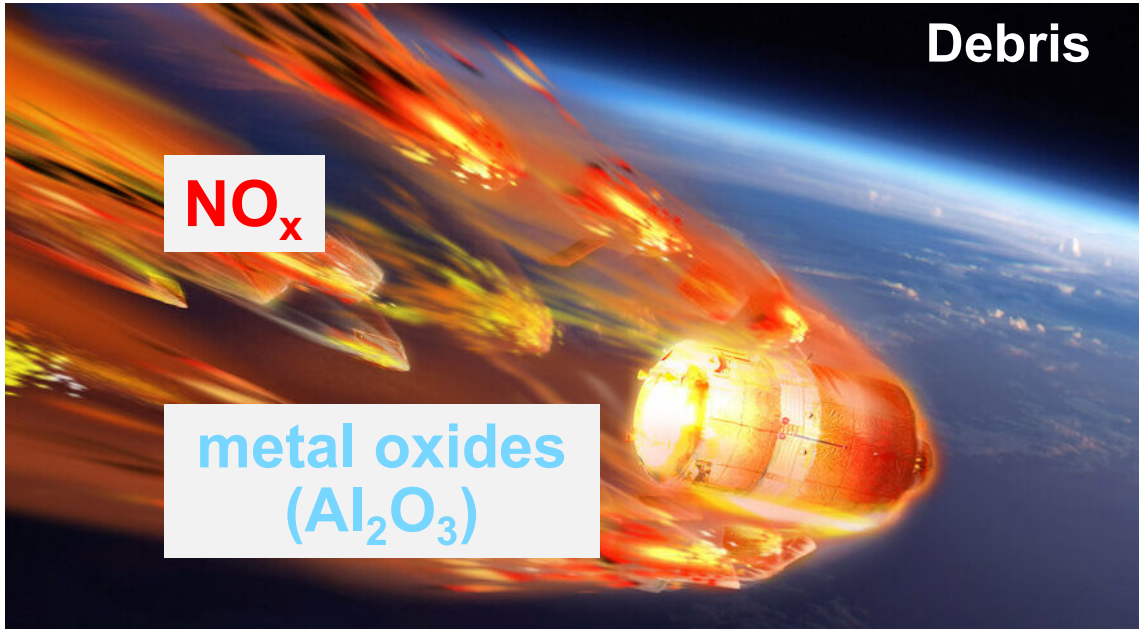
Direct ozone depletion

Air pollutant emissions from re-entry

Natural:

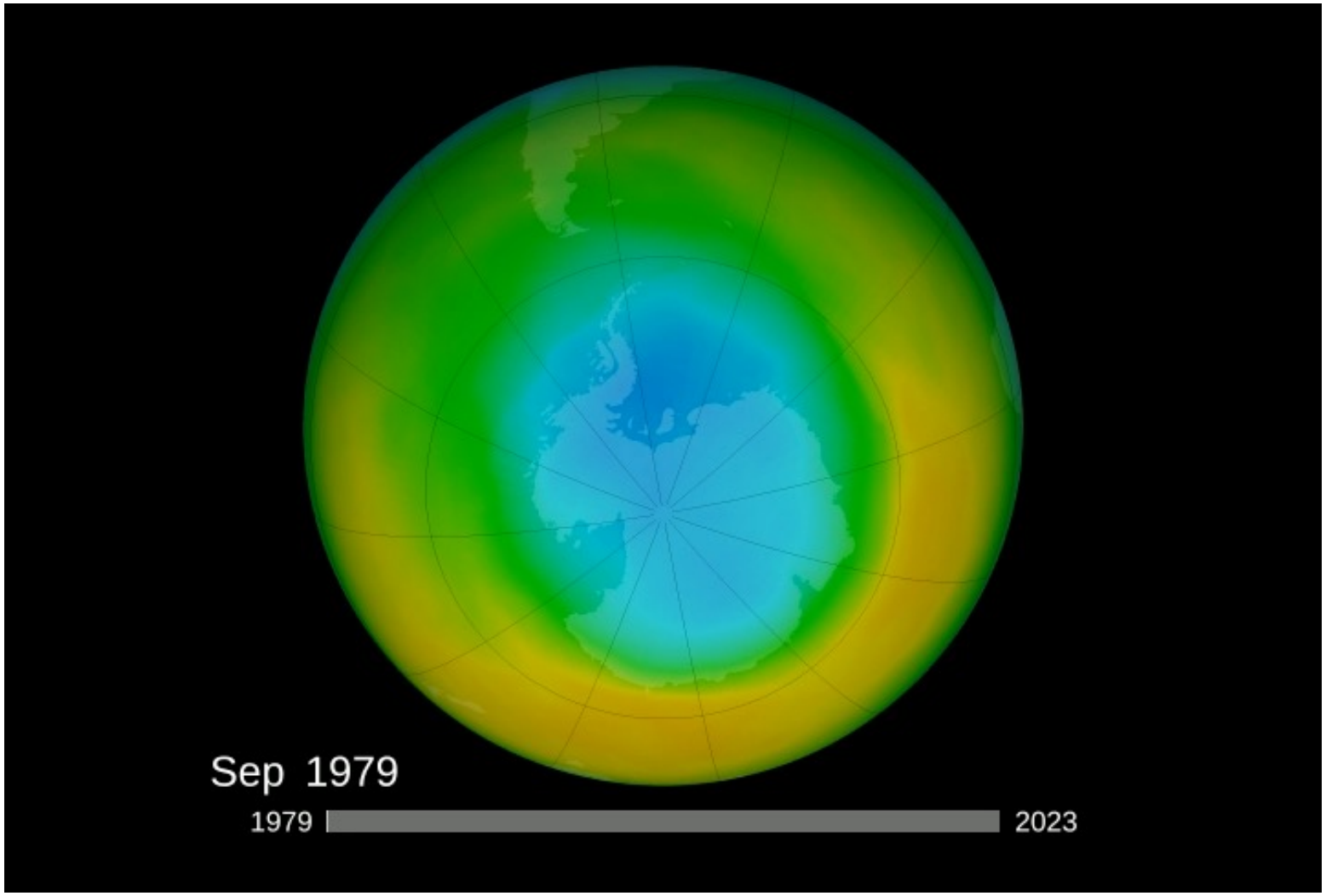
2-40 Gg NO_x per year

Artificial:



Current “sustainable” way of cleaning up space is re-entry vaporization of waste

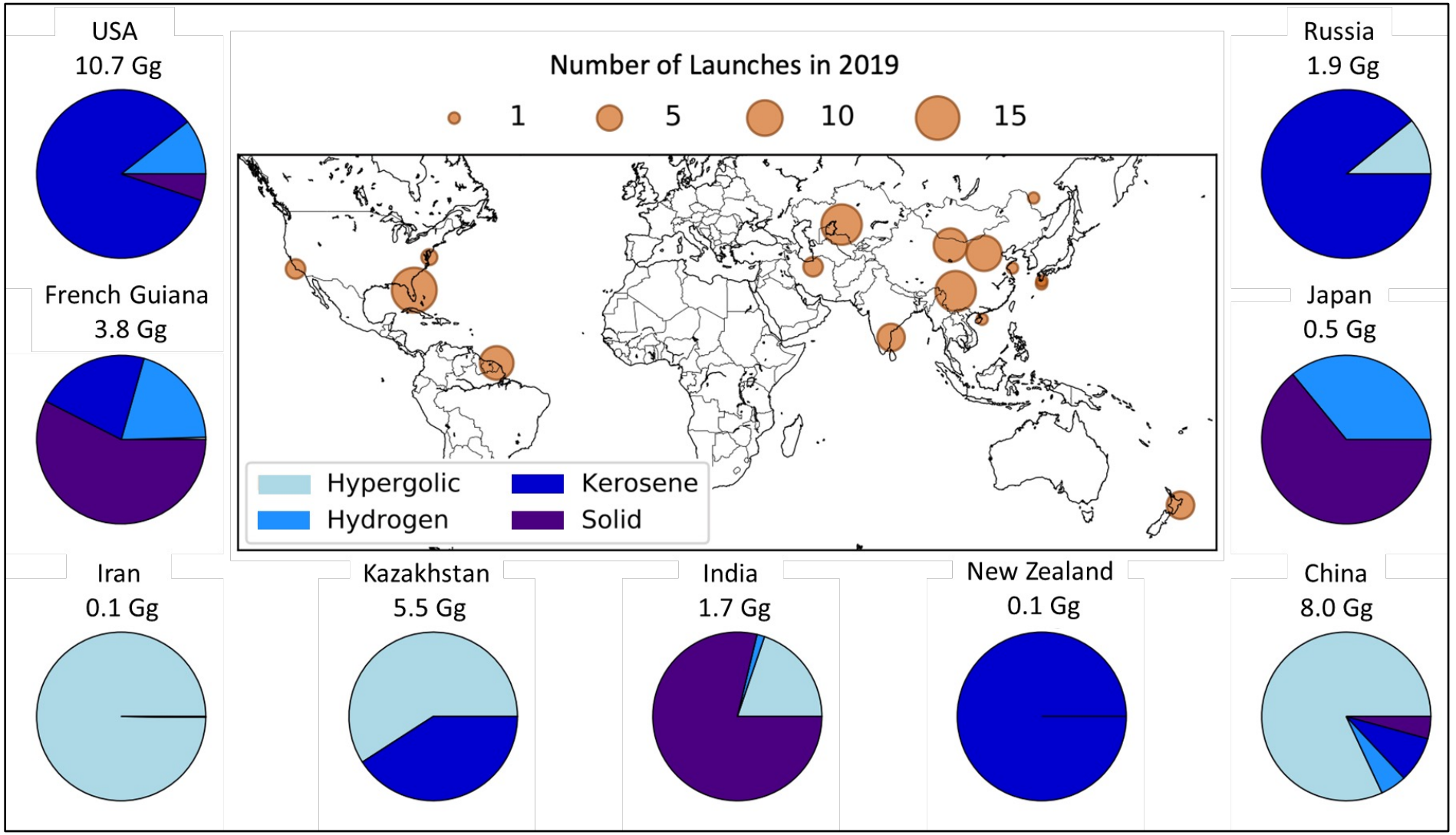
The Protective Ozone Layer



MONTREAL PROTOCOL 1989

https://ozonewatch.gsfc.nasa.gov/

Calculate and map a single year of emissions



Annual Emissions:

- H_2O: 11 Gg
- BC: 0.5 Gg
- Al_2O_3: 2 Gg
- HCl: 1 Gg
- Launch NO_x: 0.2 Gg
- Re-entry NO_x: 2 Gg

Gg = kilotonnes

~100 successful launches in 2019

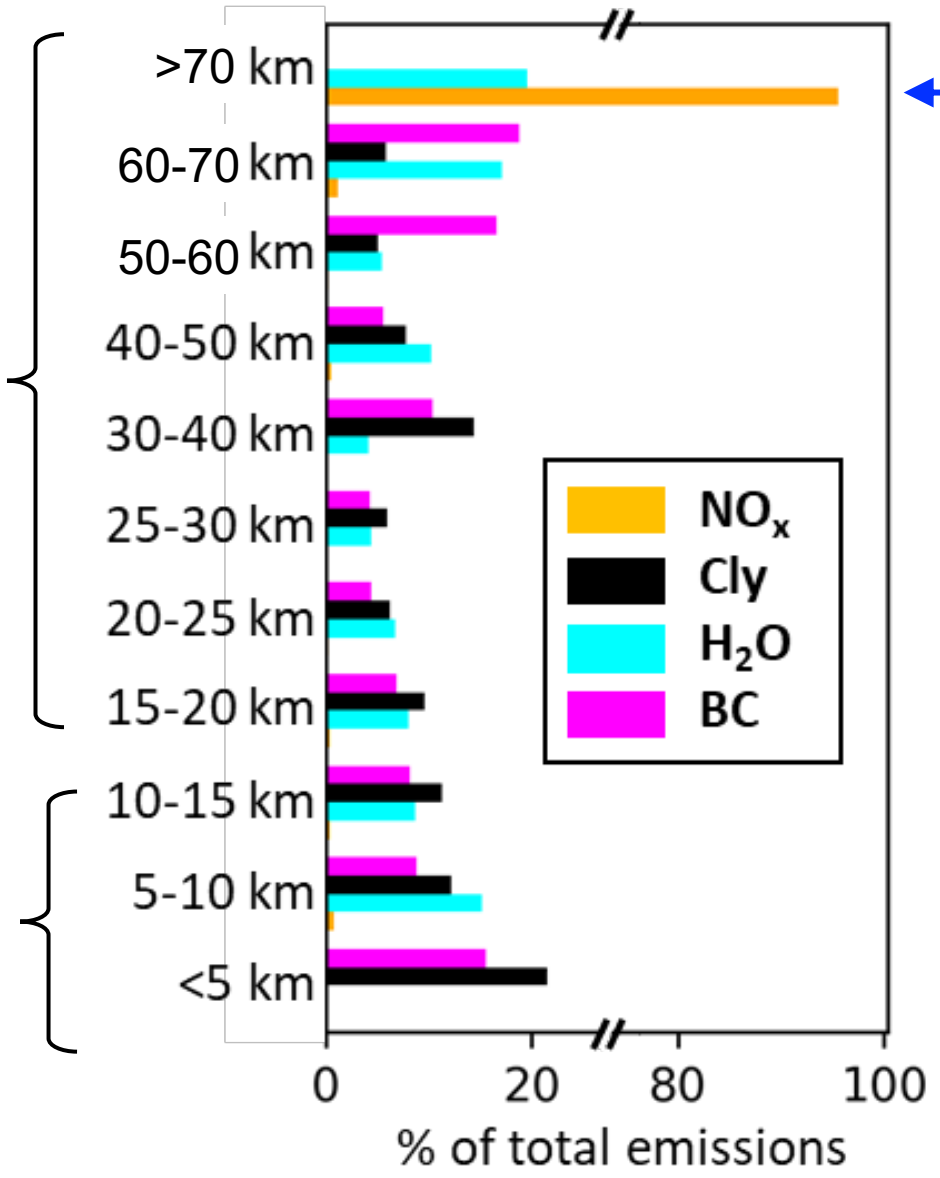
Reaches 135 in 2021. 186 in 2022. Already 159 in 2023

Incorporate these in a Chemical Transport Model

GEOS-Chem extends to **80 km**

Stratosphere & mesosphere:
lifetime >2 years
(*gravitational settling*)

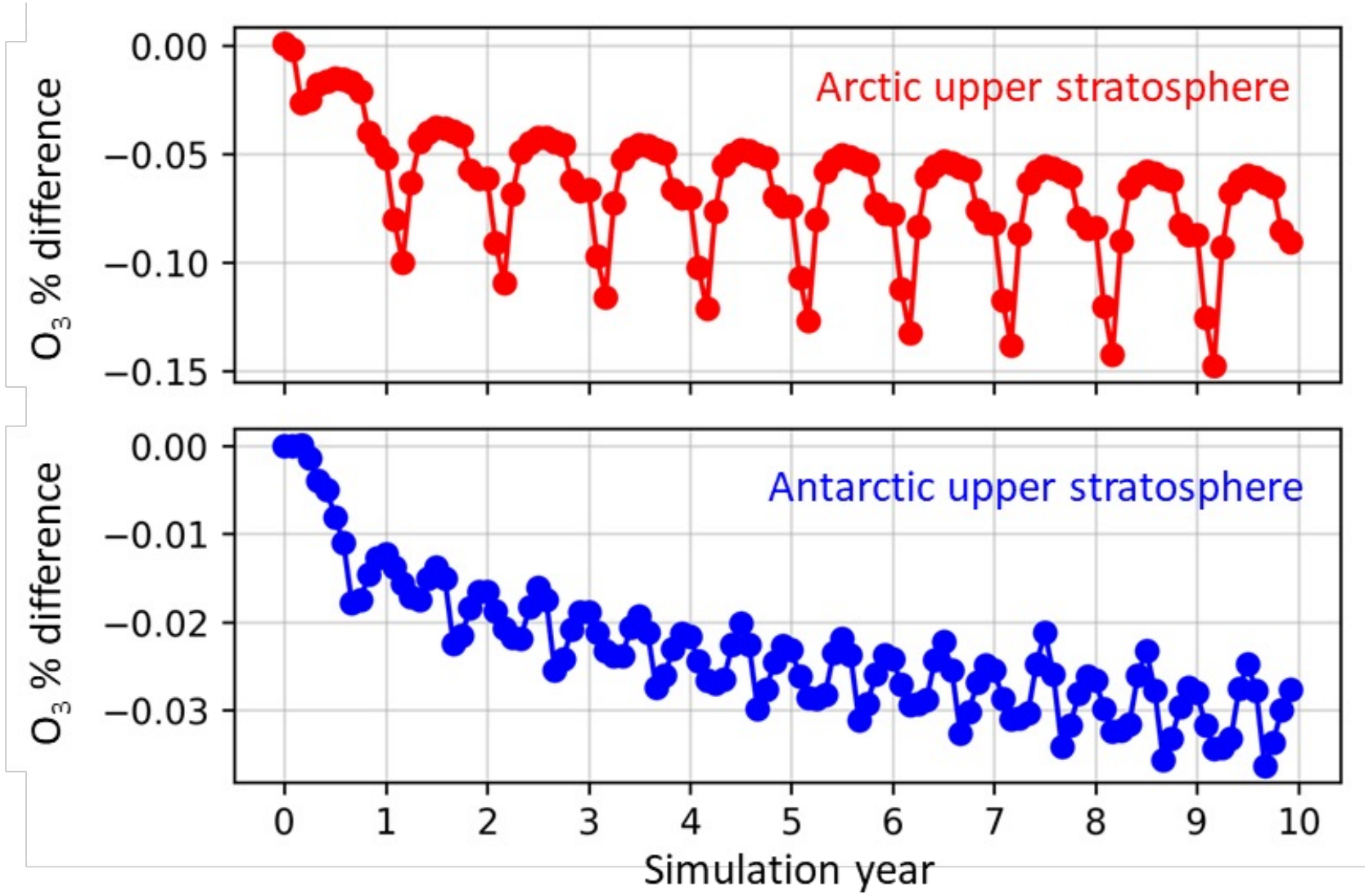
Troposphere:
lifetime weeks to months
(*wet and dry deposition, subsidence, chemical losses*)



Re-entry

Cl_y: family of chlorinated compounds

Stratospheric ozone depletion due to rockets and re-entry



Oscillatory pattern takes 2-3 years to establish

Seasonality tracks sunlight chemistry

50:50 contribution from re-entry NO_x and rocket launch chlorine

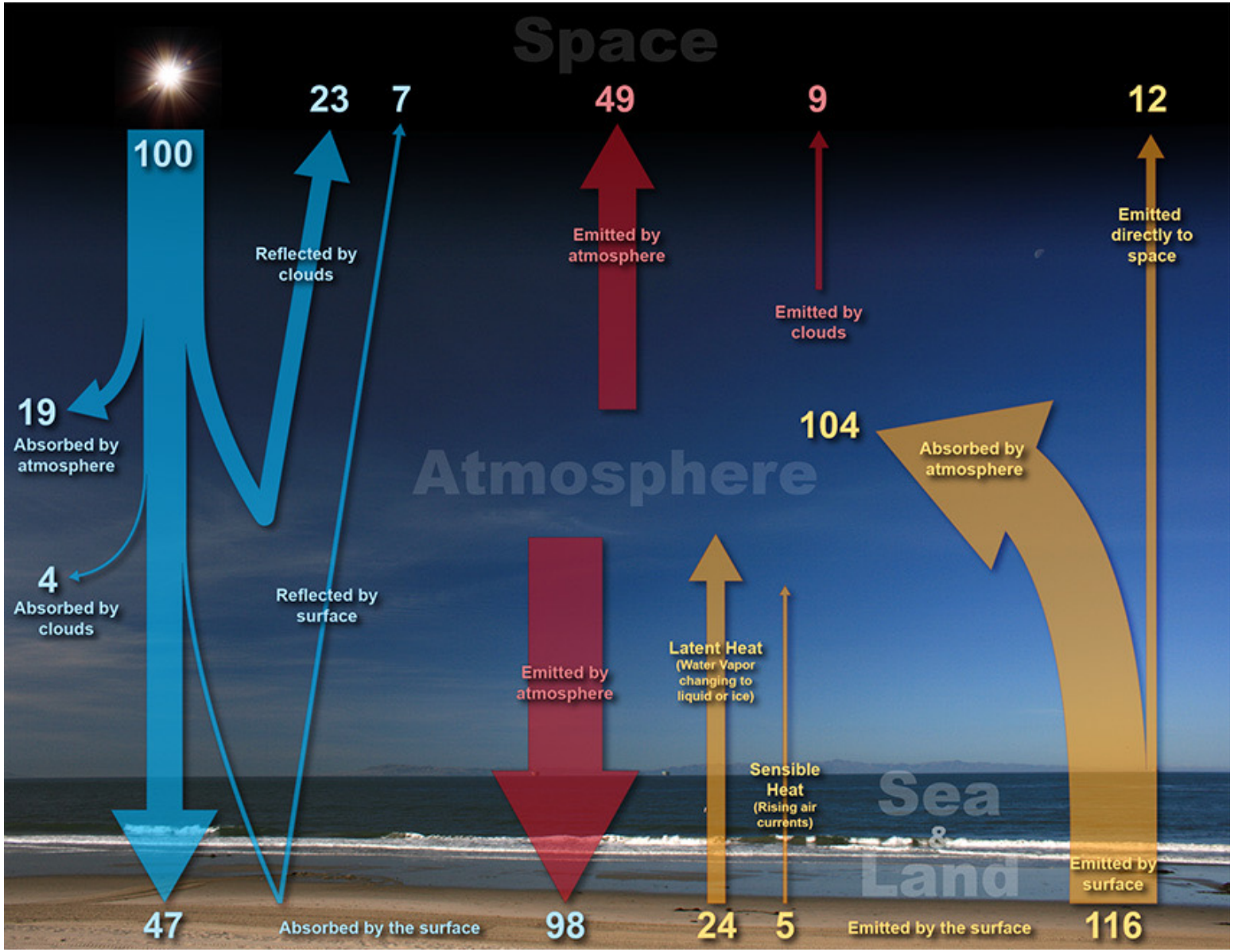
Peak decline in spring is **0.15% in the NH** and **0.04% in the SH**

Springtime Arctic upper stratospheric ozone depletion reaches **~0.15%** after a decade of launches

This is ~10% of upper stratospheric ozone recovery attributed to Montreal Protocol ban on ODS

Couple the model to a radiative transfer model

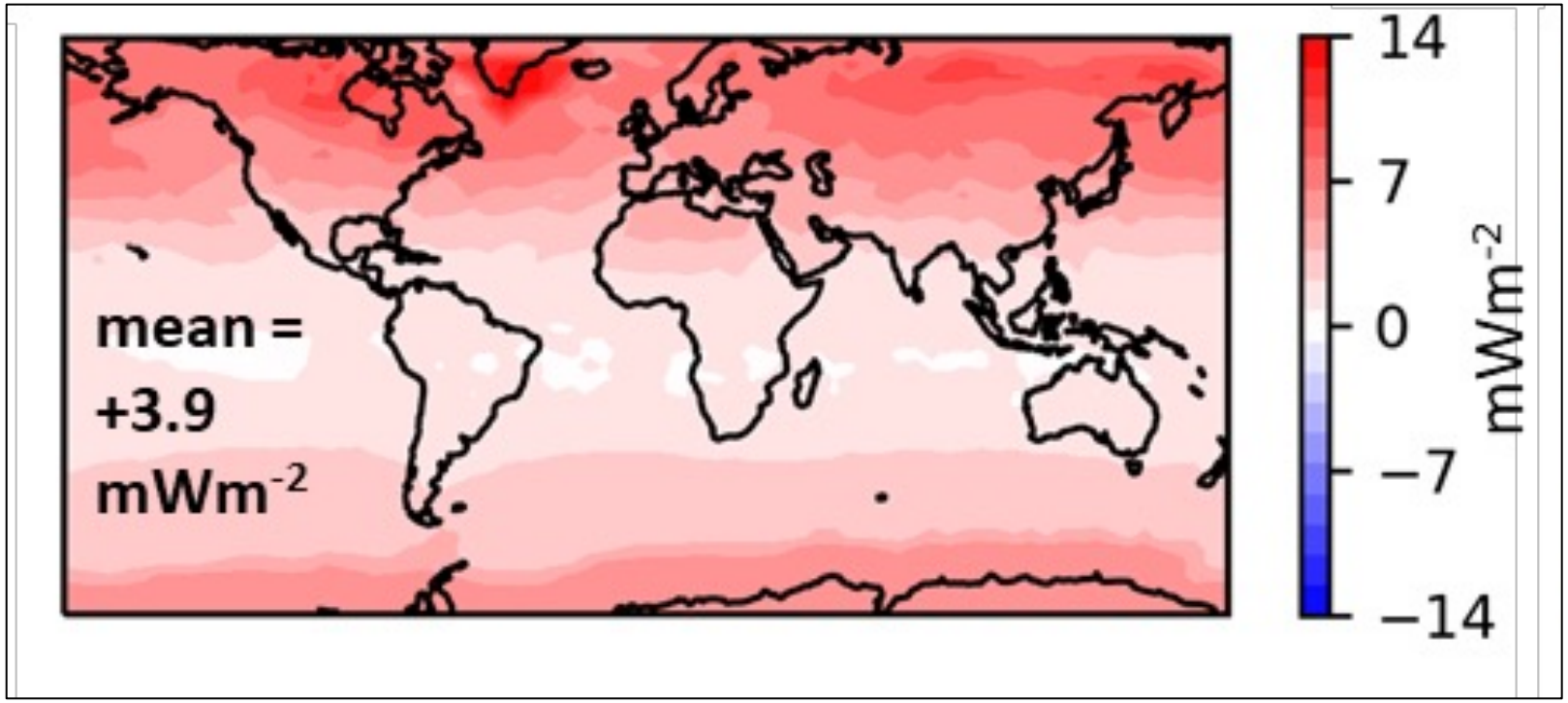
Values are % or arbitrary



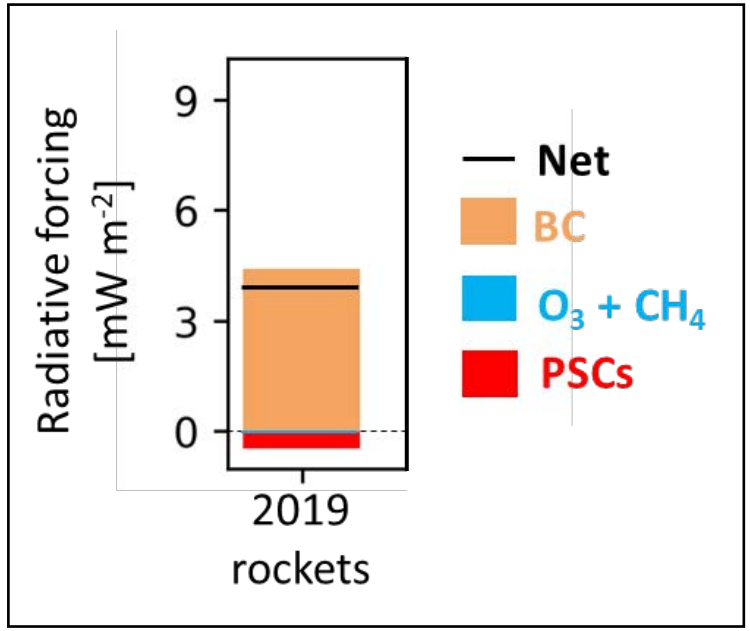
https://www.noaa.gov/

Radiative forcing due to black carbon (soot) emissions

After 10 years of emissions assuming modest growth



Mostly due to BC



Rockets ~3% of BC radiative forcing from all anthropogenic sources, but only 0.01% of emissions.

BC from rockets **400-500 times greater radiative effect** than BC from Earth-bound sources

SpaceX Starship mission plan is 3 launches per day, so 10-fold increase in annual launches

Are rocket pollution emissions cause for concern?

Number of rockets launched likely to surpass 200 this year, but this is still far less than the millions of passenger flights each year. **So, should we care?**

How do rocket emissions of NO_x from a SpaceX Falcon 9 kerosene-fuelled rocket stack up against NO_x emissions from the most polluted city (Dhaka) and the highest-capacity power plant in the UK.

Step 1: Find the data.

Google search “UCL Eloise Marais”, click on my UCL profile, scroll down to “Lab/Research Group Website” in the right panel below my picture, click on the Education then Teaching tab and select the PDF slides below the “NERC DTP Induction 2023-2024 heading” to download this presentation.

UK Point source emissions in 2021: https://naei.beis.gov.uk/data/map-uk-das?pollutant_id=6

Dhaka, Bangladesh: https://maraisresearchgroup.co.uk/Presentations/GLu-GCE2-talk.pdf

Rocket kerosene emission factors: Table 1 of Ryan et al. (2022) (https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2021EF002612)

SpaceX Falcon 9 rocket propellant mass: https://doi.org/10.5522/04/17032349

Step 2: Put the data on the same scale (same units).

Step 3: Compare.