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Developing inventories of by-products from satellite megaconstellation launches and disposal to determine the influence on stratospheric ozone and climate

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There are close to 6000 megaconstellation satellites in low-Earth orbit comprising 65% of all satellites orbiting Earth. The growth in satellite megaconstellations has driven surges in rocket launches and re-entry destruction of spent satellites. This has contributed to large increases in emissions of pollutants that are very effective at depleting stratospheric ozone and altering climate, due to direct injection of pollutants into the upper layers of the atmosphere where turnover rates are very slow. An additional 540,000 megaconstellation satellites are proposed, yet the environmental impacts of emissions from current and future satellite megaconstellations remain uncharacterized and unregulated. Here we calculate emissions of the dominant pollutants from megaconstellation and non-megaconstellation rocket launches and re-entries from 2020 to 2022 to determine the effect on climate and stratospheric ozone. Pollutants include black carbon (BC), nitrogen oxides ($NO_x \equiv NO+NO_2$), water vapour (H_2O), carbon monoxide (CO), alumina aerosol (Al_2O_3) and chlorine species ($Cl_y \equiv HCl+Cl_2+Cl$) from rocket launches and nitrogen oxides ($NO_x \equiv NO$) and alumina aerosol (Al_2O_3) from re-entries. Launch emissions are calculated by determining the vertical distribution of propellant consumption for each rocket stage and calculating and applying vertically resolved propellant specific emission indices that account for additional oxidation in the hot rocket plume and changes in atmospheric composition with altitude. To quantify the re-entry emissions, the mass of re-entering objects is compiled for all objects (spacecraft, rocket stages, fairings, and components) re-entering Earth's atmosphere in 2020-2022. Many objects, accounting for 12-16% of re-entry mass, are not geolocated, so the longitude and latitude of re-entry is bounded by the reported orbital inclination. Object class and object reusability are used to define the chemical composition and mass ablation profile of each re-entering object. We find that total propellant consumed has nearly doubled from ~38 Gg in 2020 to ~67 Gg in 2022 and re-entry mass has increased from ~3.3 Gg in 2020 to ~5.6 Gg in 2022. Megaconstellation re-entries accounted for 8-12% of the Al_2O_3 and NO_x re-entry emissions in 2020-2022, due to increased megaconstellation launches and short (~2 years) lifespan of most (85%) megaconstellation satellites. Anthropogenic re-entry emissions of NO_x (~4.2 Gg) and Al_2O_3 (~0.96 Gg) in 2022 equal a third of the natural meteoritic injection of NO_x and surpass the natural injection by 7 times for Al_2O_3. The annual emissions for 2020-2022 will be used to predict the rise in emissions up to 2029 from megaconstellation and non-megaconstellation rocket launches and object re-entries for input to the 3D atmospheric chemistry transport model GEOS-Chem coupled to a radiative transfer model to simulate stratospheric ozone depletion and radiative forcing attributable to a decade of satellite megaconstellation emissions.

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