

Rocket launch tropospheric NO_x emission: Impact on ozone and methane concentrations and launch location sensitivity

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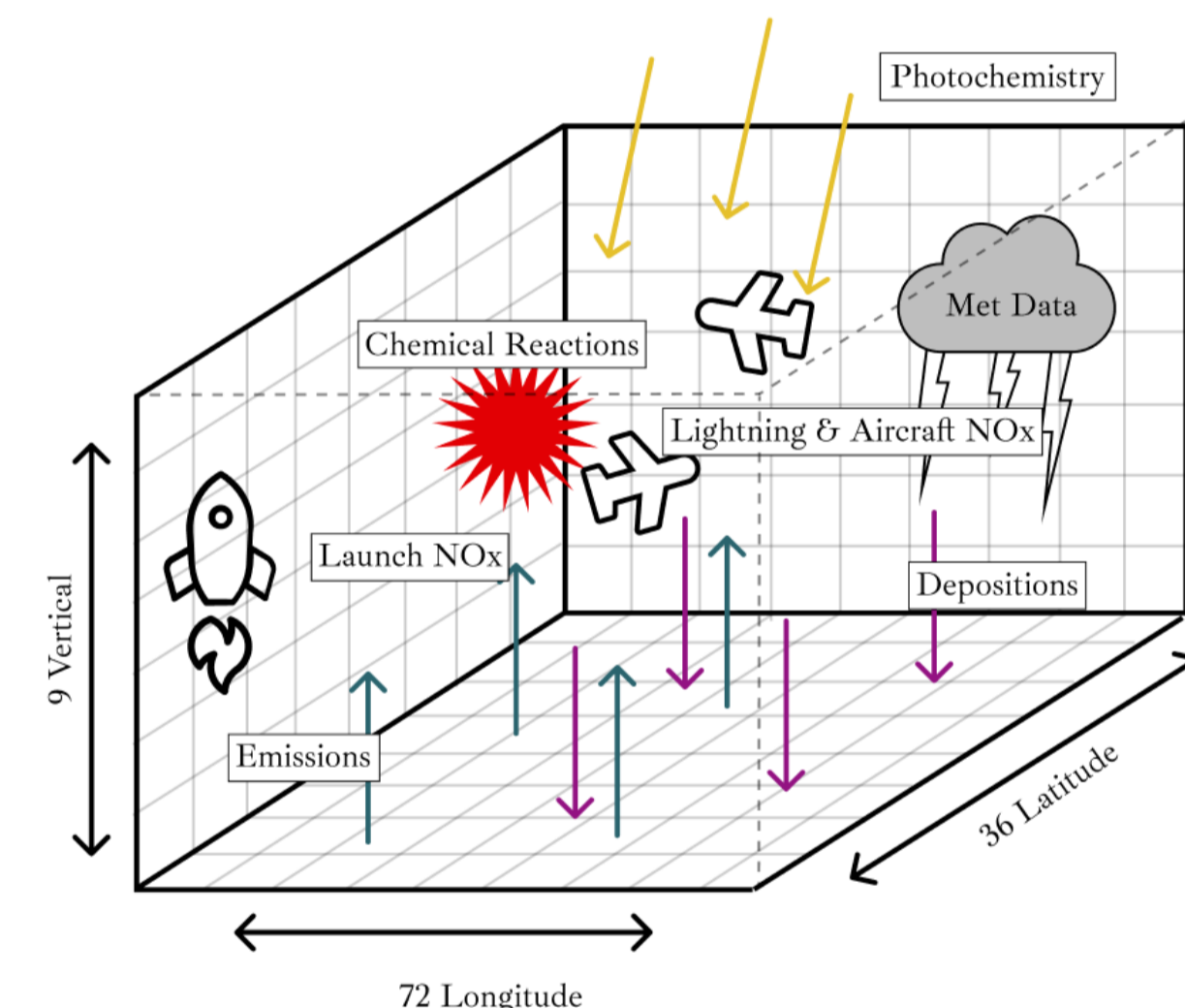
Introduction

- ▶ Rocket launches occur globally with increasing frequency and prevalence.
- ▶ Reliance on combustion for thrust generation currently offers no clear pathway to a zero-emissions alternative.
- ▶ The direct impacts of rocket emissions in the troposphere are understudied, with previous work focusing more heavily on full-atmosphere models.
- ▶ This study focuses on the tropospheric warming effects of ozone and methane.
- ▶ Rocket-generated column emissions are unique among anthropogenic sources in the troposphere and therefore require further investigation.
- ▶ The latitude and longitude dependence of launch locations may inform climate-optimised future launch site selection.
- ▶ The STOCHEM-CRI CTM was run on BluePebble HPC Cluster (University of Bristol), producing 38 five-year simulations for comparison.



The STOCHEM-CRI Model

- ▶ STOCHEM-CRI is a global Lagrangian chemistry transport model, originally developed by the UK Met Office in 1998 [1].
- ▶ It includes a comprehensive tropospheric chemistry scheme for simulating global distributions of O₃, NO_x, and CH₄.
- ▶ The model uses a horizontal resolution of 5° latitude × 5° longitude, with nine equally spaced vertical layers extending from the surface to 100 mb.
- ▶ The model was later expanded to represent the atmospheric chemistry of O₃, NO_x, carbon monoxide (CO), CH₄, and a range of organic compounds using the Common Representative Intermediates (CRI) chemical mechanism [2].



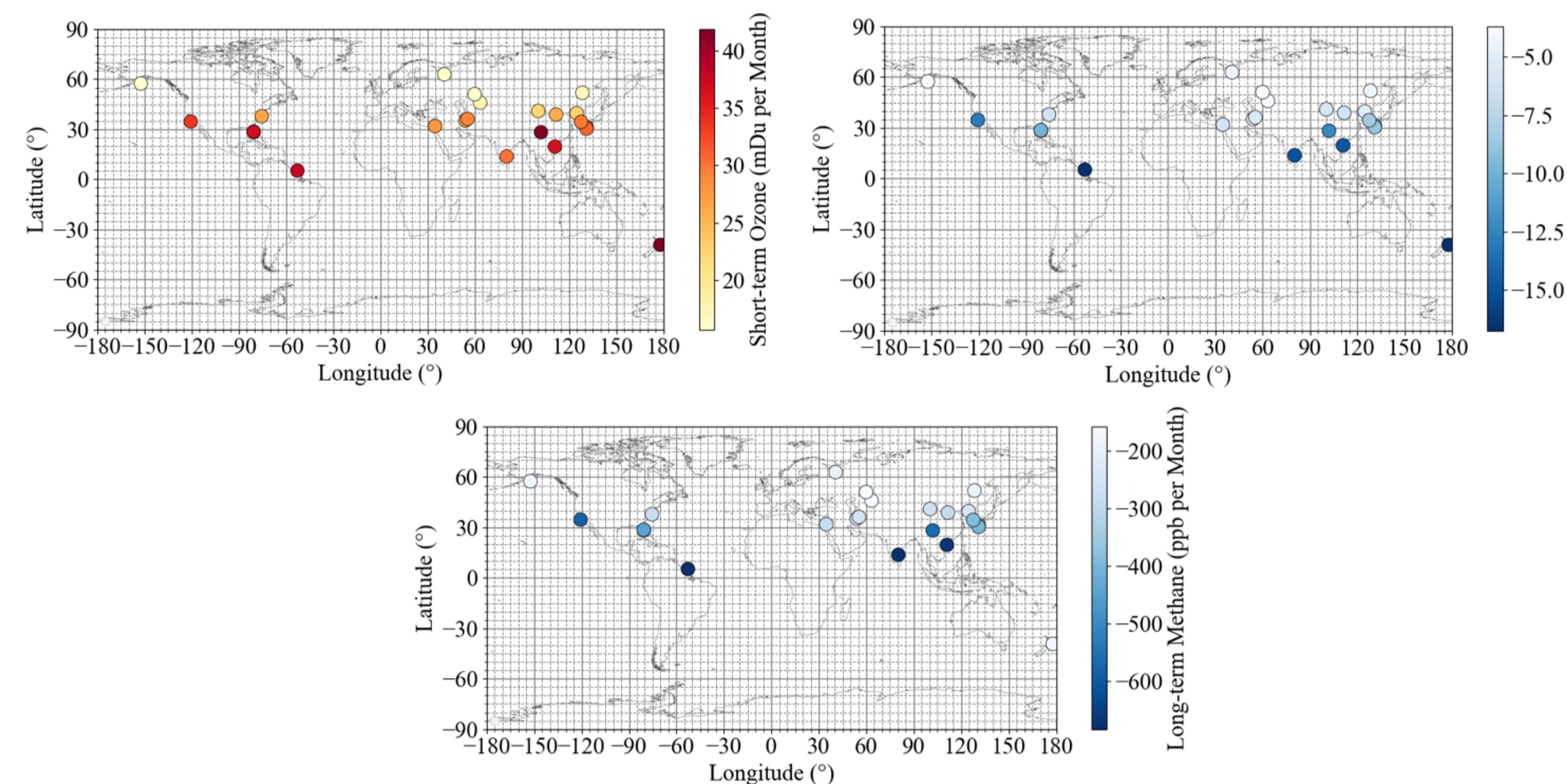
Experimental Overview

- ▶ Rocket launches were simulated in the model using representative pulses of NO_x across a range of magnitudes and locations.
- ▶ Emissions were distributed equally across all nine vertical levels of a 5° × 5° model column.
- ▶ A location sensitivity study was conducted to assess how launch latitude and longitude affect ozone and methane concentrations for an emission pulse.
- ▶ A linearity study was conducted to evaluate the linear relationship between larger representative pulses and the smaller emissions associated with an individual launch.
- ▶ A step-versus-pulse experiment was conducted to compare the effects of a monthly emission pulse with those of continuous emissions sustained over five years.



Location Sensitivity

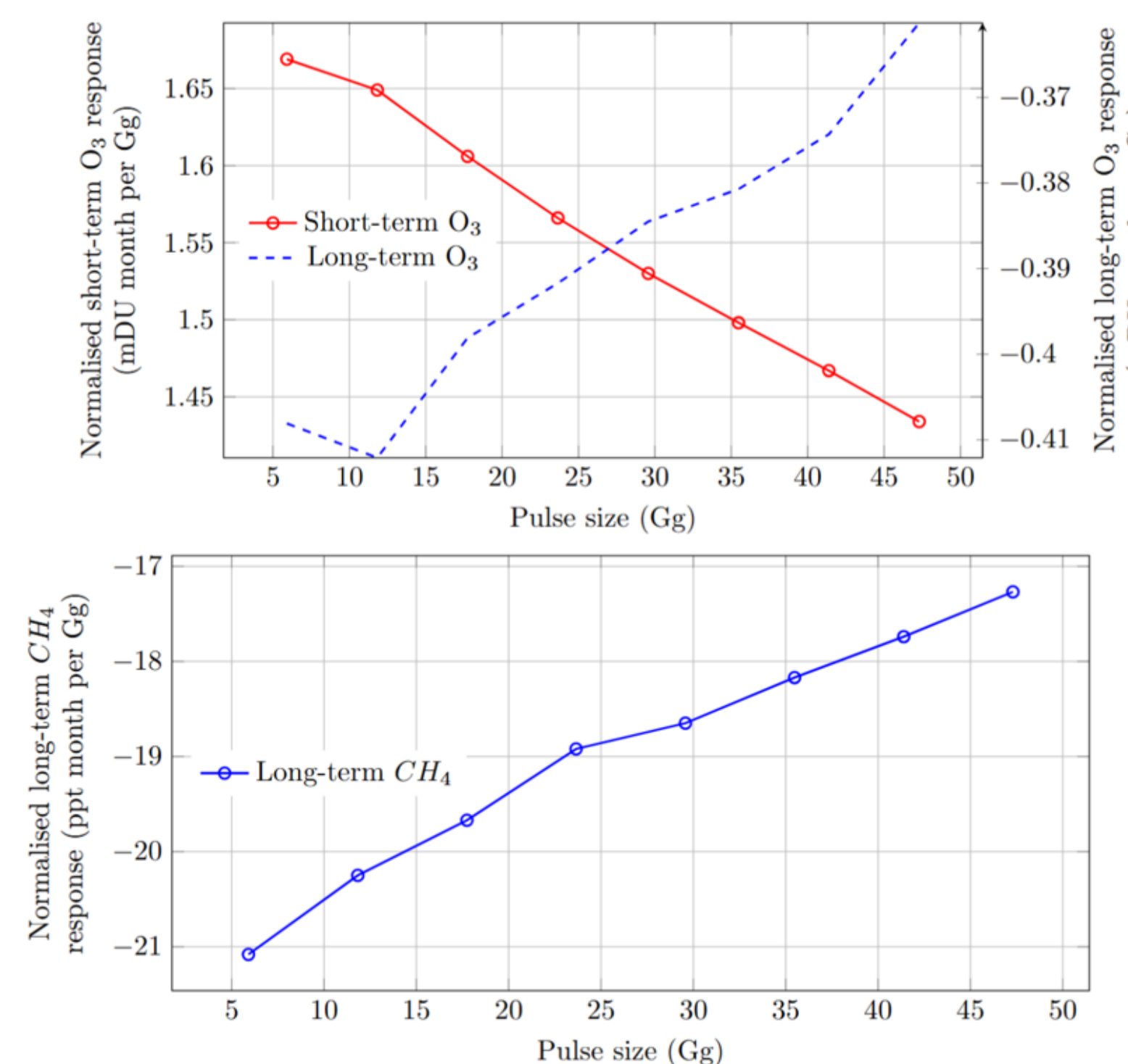
- ▶ Twenty-three launch sites were modelled using 23.65 Gg NO_x pulses distributed across 5° × 5° atmospheric columns.
- ▶ Short-term ozone, long-term ozone, and methane concentration responses are presented graphically.
- ▶ Ozone exhibits a change in response magnitude over time, which is used to distinguish short- and long-term ozone impacts.
- ▶ Long-term impacts were extrapolated from the five-year simulations to a 100-year time horizon.



- ▶ Ozone shows a latitudinal dependence, with lower magnitudes in the Northern Hemisphere and higher magnitudes in the Southern Hemisphere.
- ▶ Methane shows an equatorial dependence in response magnitude.
- ▶ Additional low-latitude simulations would help confirm these relationships.

Linearity Study

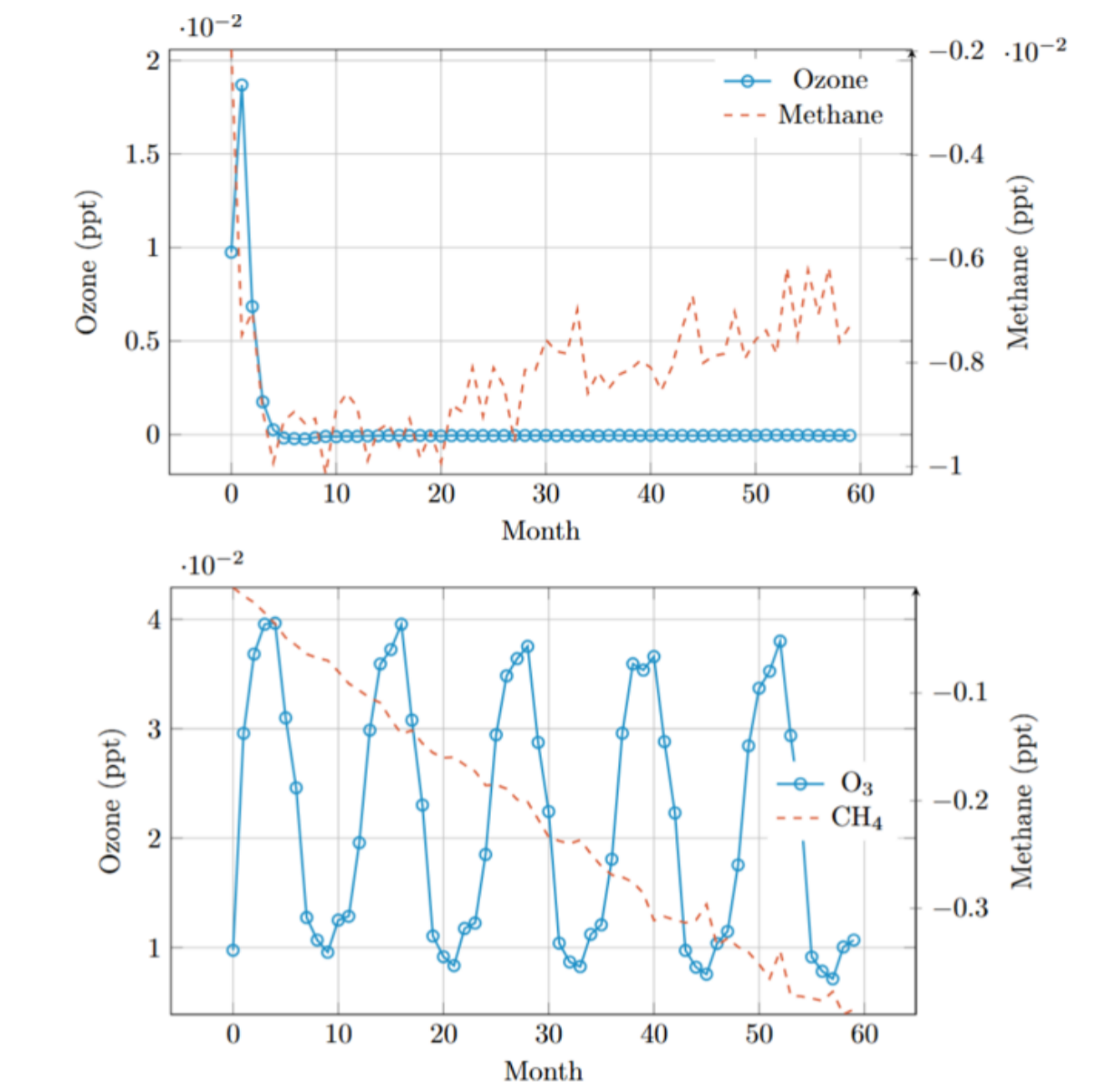
- ▶ A range of pulse sizes, from 5.915 Gg to 47.3 Gg, was simulated at the Cape Canaveral launch site.
- ▶ Short-term O₃, long-term O₃, and methane responses for each pulse were normalised by pulse size and plotted.



- ▶ The responses were considered linear, as changes with pulse size remained within ±10% despite large variations in pulse magnitude.

Step vs Pulse Experiments

- ▶ Additional step-change emissions at Cape Canaveral, ranging from 5.915 Gg to 47.3 Gg, were simulated over full five-year runs.
- ▶ Step-to-pulse response ratios were calculated as 0.62 for ozone and 0.80 for methane.
- ▶ Pulse responses were evaluated as net changes, while step responses were taken as the mean of the final simulation year.
- ▶ Pulse experiments showed rapid ozone recovery and slower methane recovery, with ozone stabilising below baseline levels.
- ▶ Step experiments showed a seasonal dependence in ozone response and a continuous change in methane.
- ▶ The overestimation observed in pulse experiments is likely an artefact of the month-long emission timescale, as modelled emissions are not truly instantaneous.



Conclusions

- ▶ In this study, the computational CTM STOCHEM-CRI was used to model the effects of rocket launch emissions on tropospheric ozone and methane.
- ▶ A clear latitudinal dependence was identified, with the magnitude of the response strongly dependent on launch location across the 23 modelled launch sites.
- ▶ Both short-term and long-term effects were observed, with their total magnitudes beginning to offset one another.
- ▶ However, this apparent cancellation can obscure the strongly localised short-term warming associated with peak ozone production, while the longer-term cooling effects occur on a global scale over much longer timescales.
- ▶ These results were contextualised through a linearity study and step-versus-pulse comparison, highlighting both the applicability of the approach for future work and the limitations of the model.

References

- [1] W.J. Collins et al. Tropospheric Ozone in a Global-Scale Three-Dimensional Lagrangian Model and Its Response to NO_x Emission Control. *Journal of Atmospheric Chemistry*, 1997.
- [2] M.E. Jenkin et al. Common Representative Intermediates (CRI) Mechanism for VOC Degradation, Part 1: Gas phase mechanism development. *Atmospheric Environment*, 2008.

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