MIT LABORATORY FOR
AVIATION AND
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Changes in aircraft emissions impacts due to non-linear, subgrid-scale plume processes

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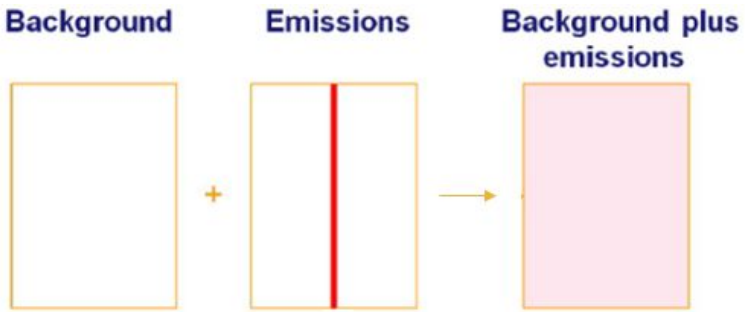
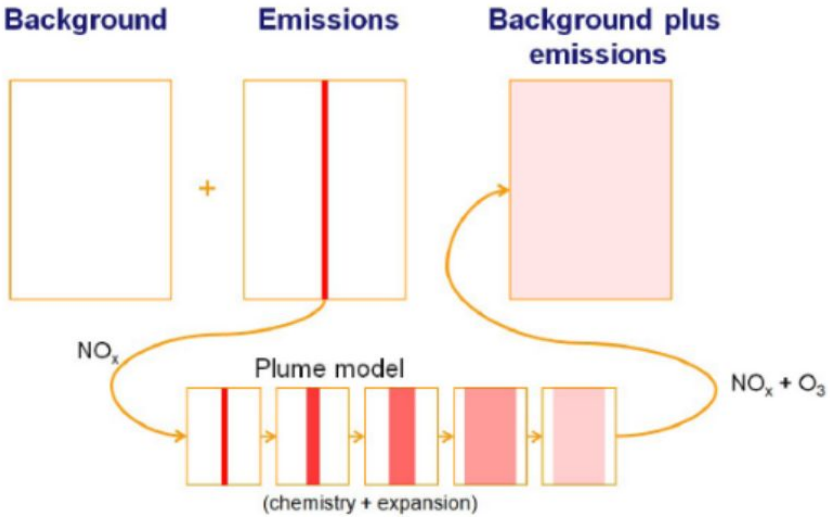
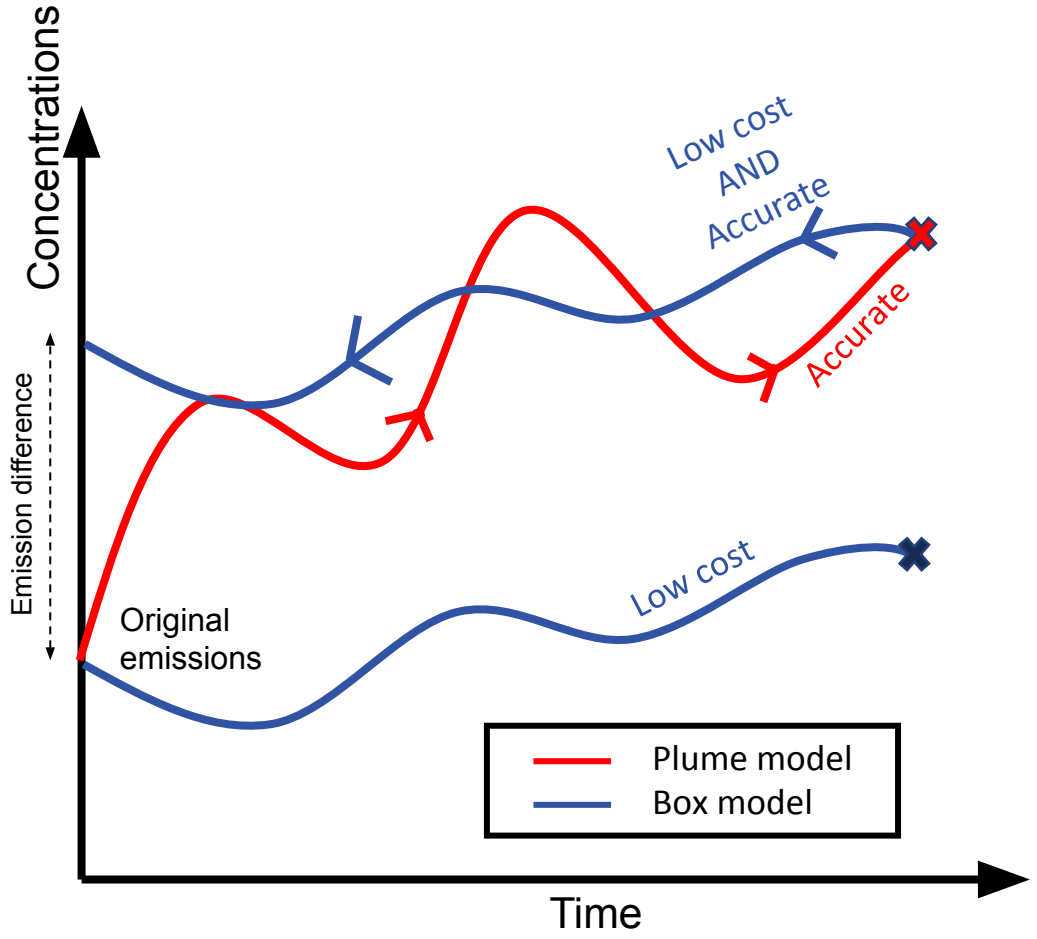
Models

Instant dilution approach	Aircraft plume model
Neglects the coupling between mixing with ambient air and chemistry. Model is **low-cost**.	**Solves for any plume process** and couples them using an operator splitting method. Computationally **expensive**.





State of the art: Model comparison



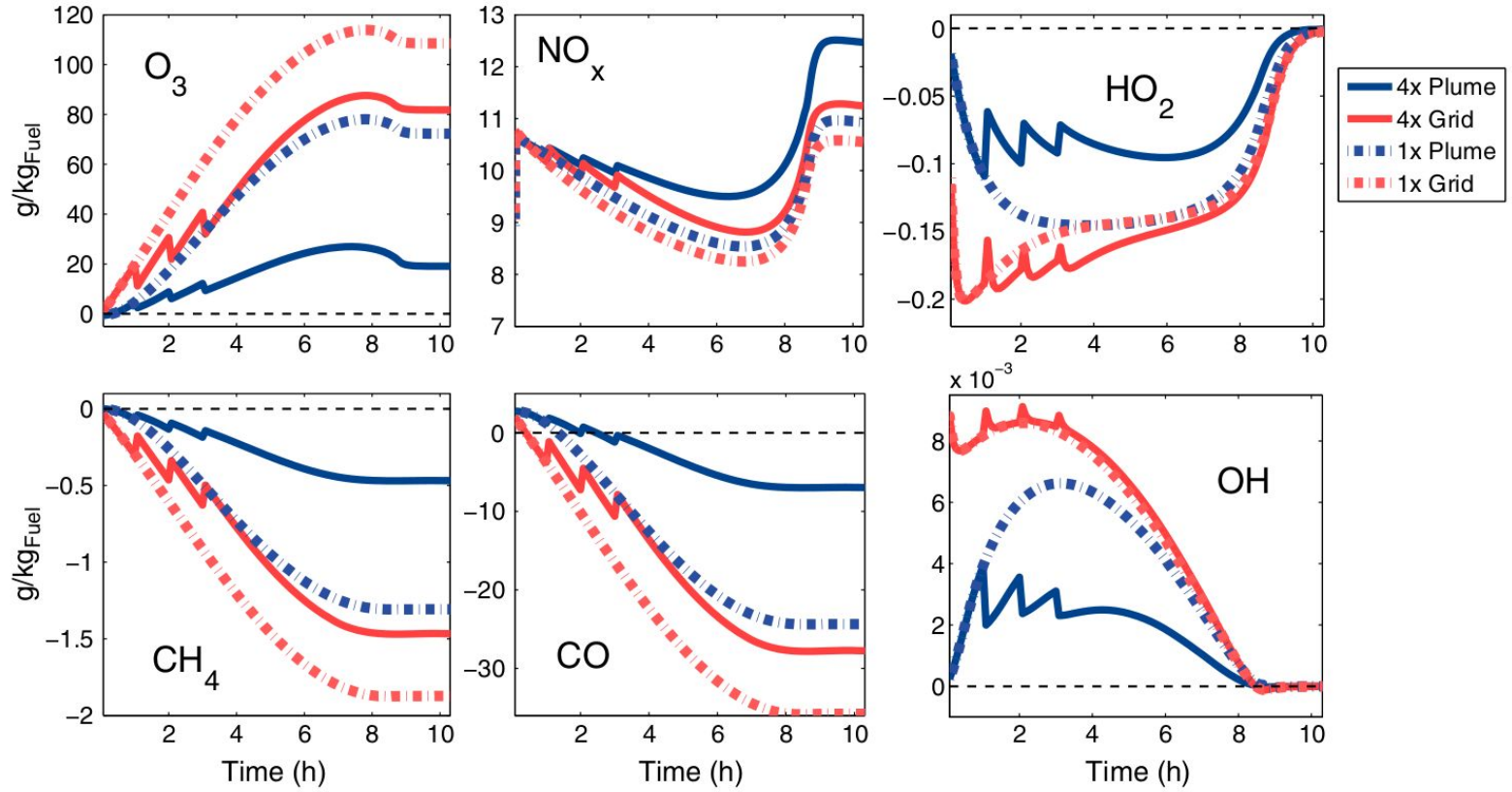
Summary

Build a look-up table to benefit from:

- The **numerical accuracy of the plume model**
- The **low cost of the instant dilution approach**

More accurate way to assess aviation's environmental impact.

State of the art: Previous research



Previous research:

- **Urban-scale processing** of emissions (Cohen et al., 2011)
- Impact of **ship NO_x emissions** leading to the **PARANOX** module in GEOS-Chem (Vinken et al., 2011; Holmes et al., 2014)
- Effects of a plume-scale **treatment of aircraft emissions** (Cameron et al., 2013)

(1) Cohen, Jason Blake, Ronald G. Prinn, and Chien Wang. "The impact of detailed urban-scale processing on the composition, distribution, and radiative forcing of anthropogenic aerosols." *Geophysical Research Letters* 38.10 (2011).

(2) Vinken, Geert CM, et al. "Accounting for non-linear chemistry of ship plumes in the GEOS-Chem global chemistry transport model." *Atmospheric Chemistry and Physics* 11.22 (2011): 11707-11722.

(3) Holmes, C. D., M. J. Prather, and G. C. M. Vinken. "The climate impact of ship NO x emissions: an improved estimate accounting for plume chemistry." *Atmospheric Chemistry and Physics* 14.13 (2014): 6801-6812.

(4) Cameron, Mary A., et al. "Effects of plume-scale versus grid-scale treatment of aircraft exhaust photochemistry." *Geophysical Research Letters* 40.21 (2013): 5815-5820.

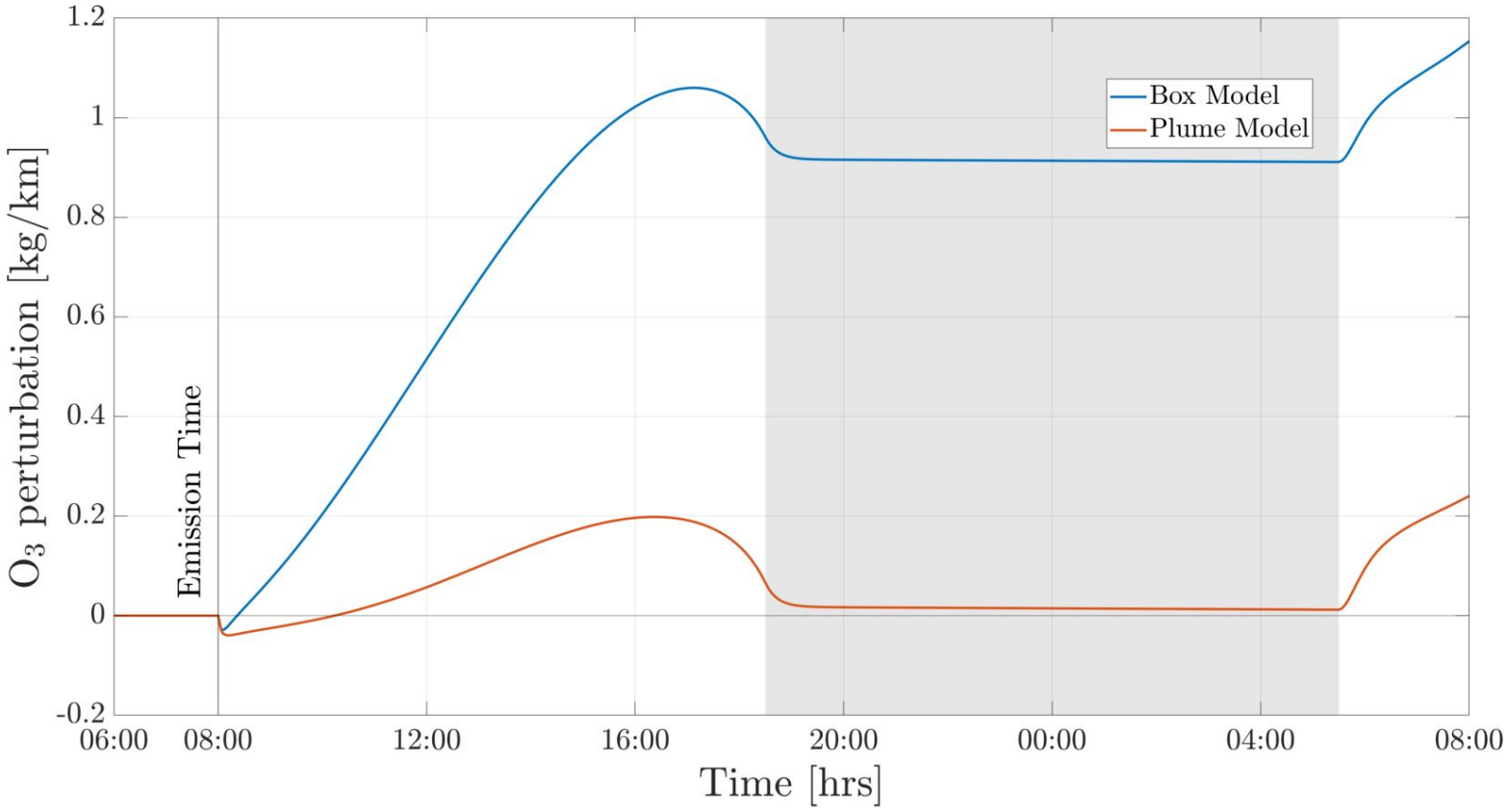
Model results – Overview

Box model:

Release of nitrogen oxides into a hydrogen oxides (HO_x)-rich environment leads to **enhanced ozone production.**

Plume model:

Emissions released in a small volume leading to **early ozone depletion through NO titration**. Lower amount of produced ozone because early plume phases are **HO_x-limited**.



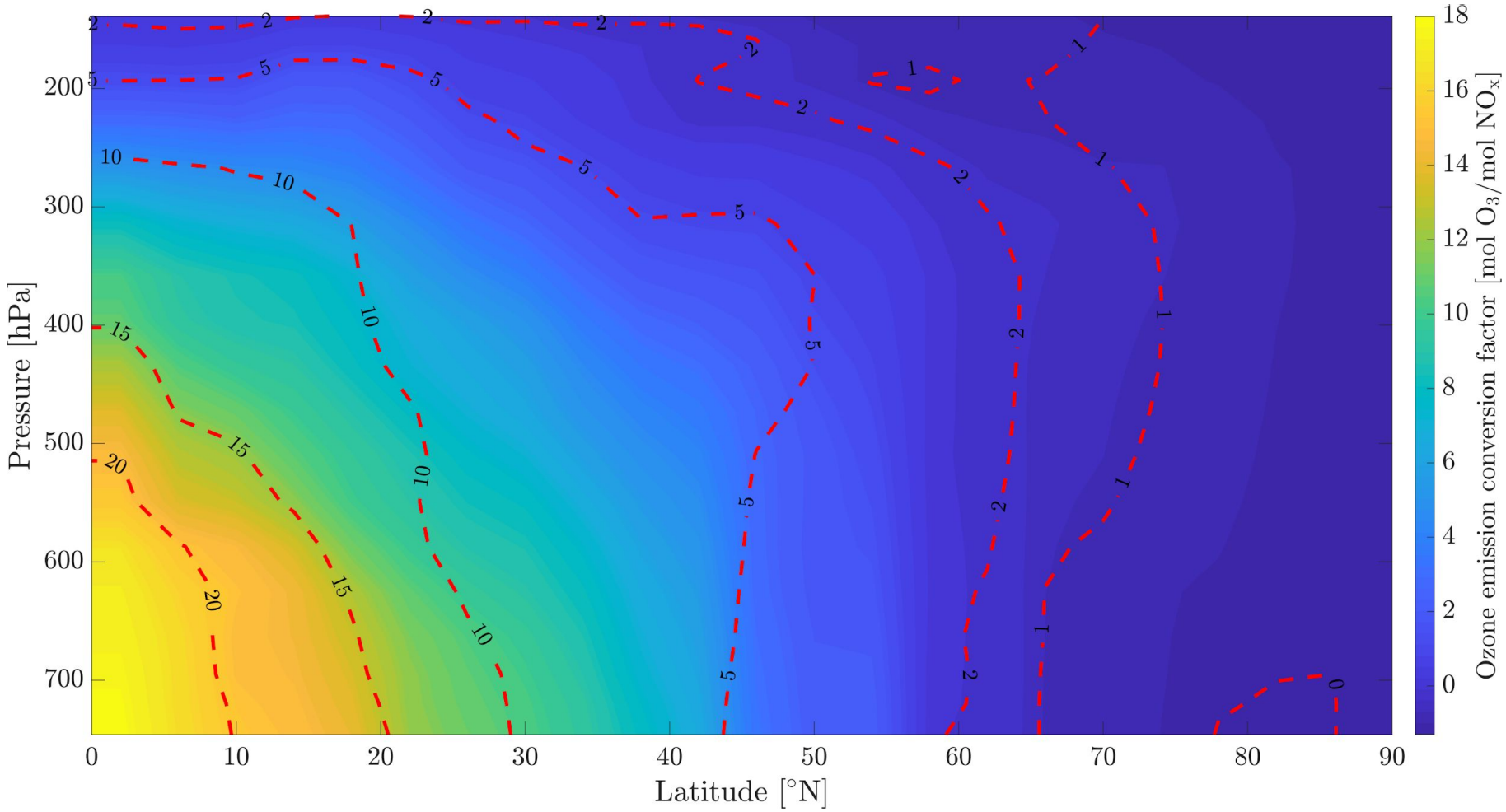
Model sensitivities – Parameter sweep

Emission conversion factor

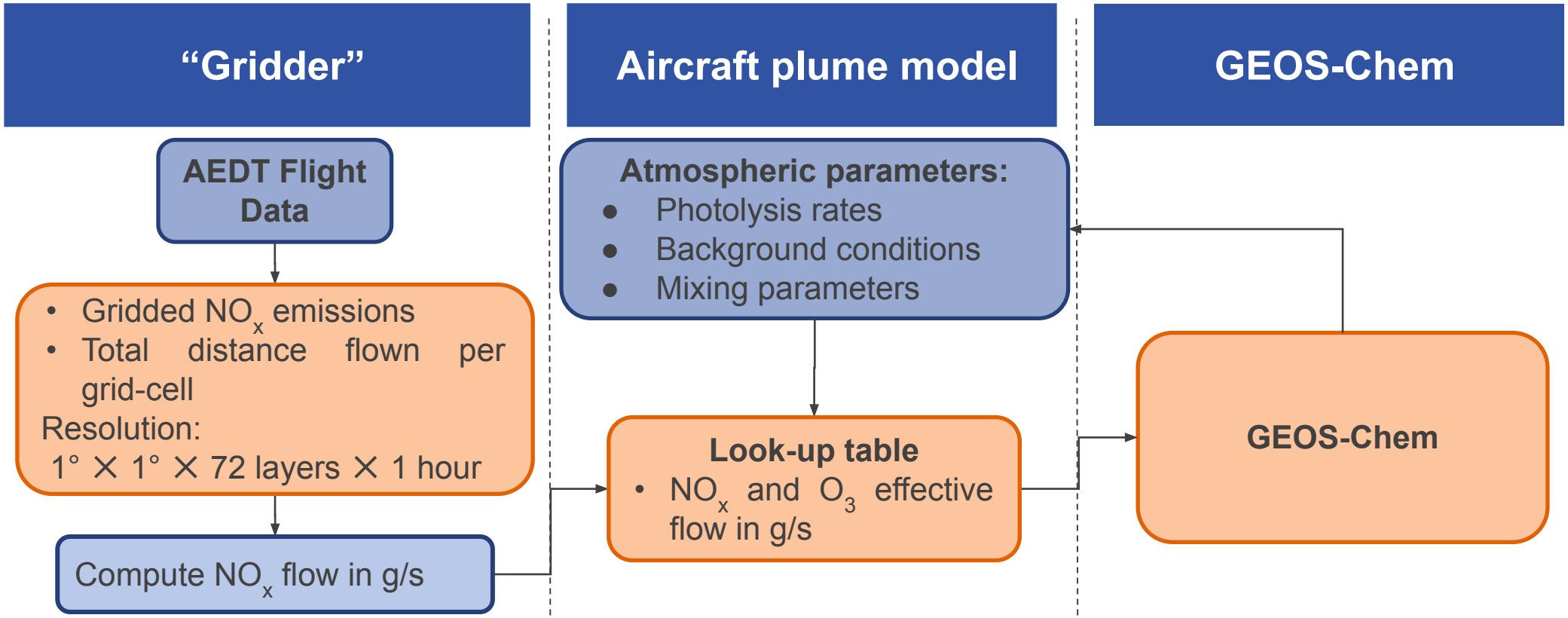
$$\mathrm{ECF}_X(t) = \frac{\Delta X(t)}{E_{NO_y}}$$

Key findings

- The plume model predicts a **decreasing OPE from the equator to the North Pole**
- The results of the box model **underestimate the fraction of remaining NO_x at high altitudes** and overestimate at lower altitudes.



Methods


"Gridder"
Aircraft plume model
GEOS-Chem
AEDT Flight Data
• Gridded NO_x emissions
• Total distance flown per grid-cell
Resolution:
1° × 1° × 72 layers × 1 hour
Compute NO_x flow in g/s
Atmospheric parameters:
• Photolysis rates
• Background conditions
• Mixing parameters
Look-up table
• NO_x and O_3 effective flow in g/s
GEOS-Chem

Findings

What my research shows:

1. **Instant dilution of aircraft emissions** into coarse grid cells **overestimates ozone production and NO_x conversion rates**.

2. Results between the instant dilution approach and the plume model **differ by up to 200% after 24 hours** at cruise altitudes.

3. **Any microphysical process** (contrail formation, background aerosols) **is neglected in the instant dilution approach**. Heterogeneous chemistry on aerosols has a significant impact on the NO_x partitioning (greater HNO_3 production rate through depletion of converted/ambient N_2O_5).

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