Assessing the appropriateness of different climate modelling approaches for the estimation of aviation NO_x climate effects

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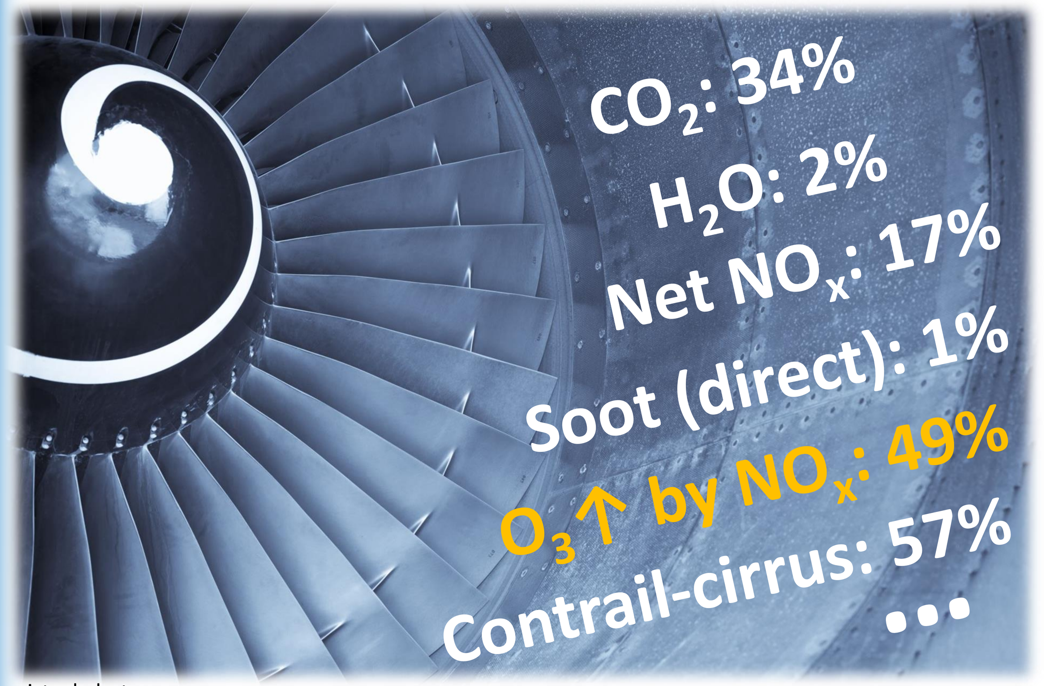
1 AVIATION AND GLOBAL WARMING



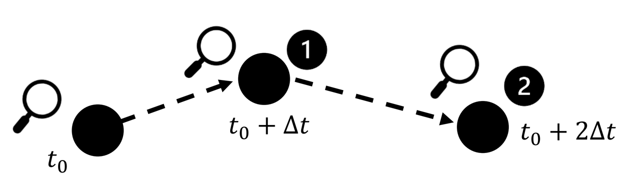
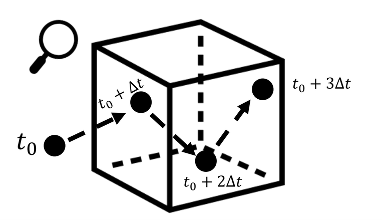
- Aviation accounts for **3-5%** of all **anthropogenic warming** [1].
- Aircraft induce **CO_2 (~33%) and non-CO_2 (~67%)** climate effects [1].
- Depending on the **modelling approach** and **question**, we can **under or overestimate** aviation's climate impact by **a factor of 6 or 7** [2].
- Our focus is on the short-term ozone (O_3) production **(~50% of total warming from aviation)** [1] induced by aviation nitrogen oxides **(NO_x)** emissions.

2 CLIMATE EFFECTS ESTIMATION METHODS

Table 1: the calculation methods – source contribution or perturbation

	Source Contribution (Tagging)	Perturbation
What is it?	**Tags or labels** pollutants by tracking them across chemical reactions to **attribute** them to **specific sources [3]**. Calculates the **contribution** of a source.	Finds the **difference** in pollutant concentrations **from 2 simulations**: one with all emissions and a second with changed emissions [3]. Calculates the **impact** by varying the emission strength.
When to use it?	Estimate **share** of O_3 **contributed** by NO_x **from a sector** (e.g. aviation) to the total O_3 budget.	Find the **impact** on O_3 concentration from **changing** aviation NO_x emissions, i.e., for assessing mitigation options.

Read more!

	Lagrangian tagging: follow air parcels	**Eulerian tagging:** observe a control volume
		
Advantages	Visualization of transport paths. 1 simulation = 28 independent emission scenarios (efficient).	More realistic (non-linear) and detailed chemistry available, which is more suitable for NO_x-O_3.
Disadvantages	Linearized reaction rates (NO_x-O_3 chemistry is non-linear). Simplified chemistry along trajectories.	More computationally intensive. Unable to visualize detailed transport patterns.

4 RESULTS

Comparing NO_x-induced scaled O_3 production

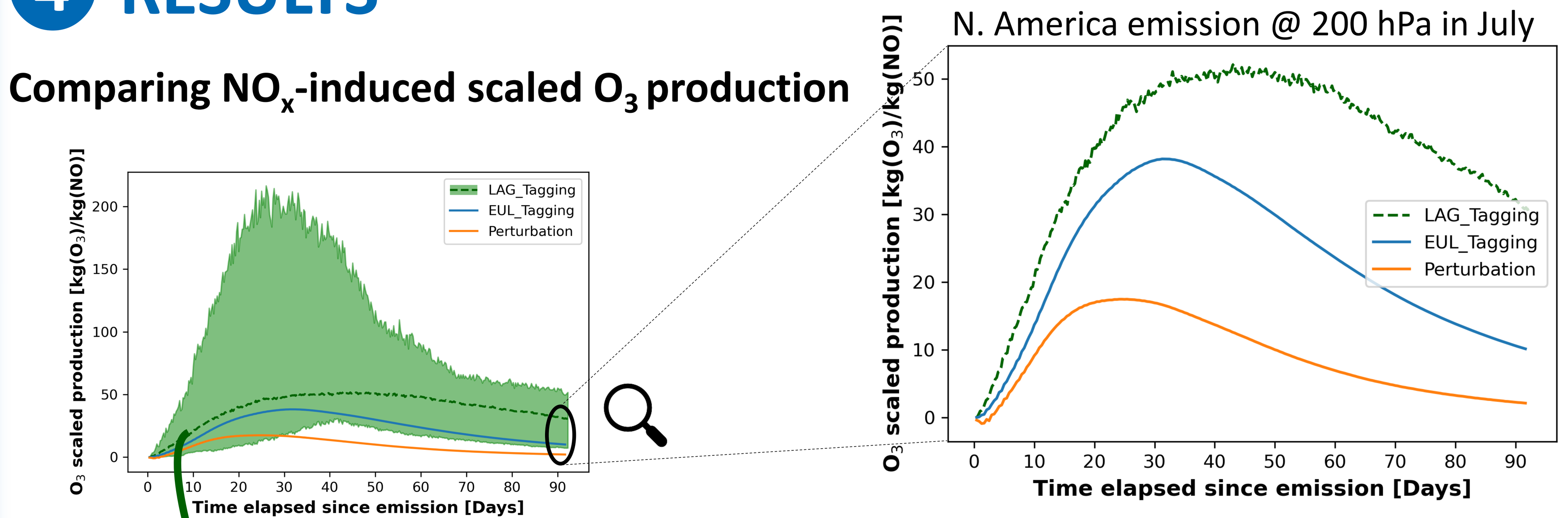


Figure 2: scaled O_3 production for **Lagrangian (LAG) tagging**, **Eulerian (EUL) tagging** and **perturbation (PERT) approaches**

The dotted green line is an **average** of all O_3 curves from the **28 emission points (Figure 1)** from **1 Lagrangian simulation**. The shaded area similarly represents the minimum and maximum range of variation of O_3 production from these scenarios (Figure 3).

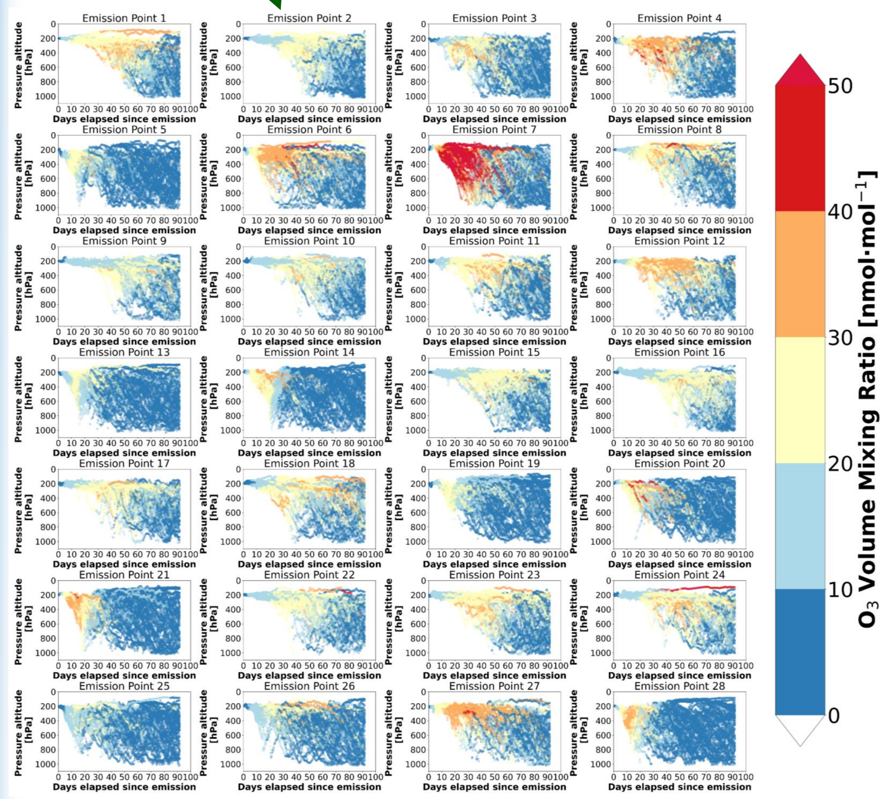


Figure 3: vertical transport of NO_x-induced O_3 by **air parcels started at 28 points** in N. America (Figure 1) for a 200 hPa NO emission **(Lagrangian Tagging)**

How do we **compare** the total O_3 produced in each of the **3 approaches**? With an **area ratio**!

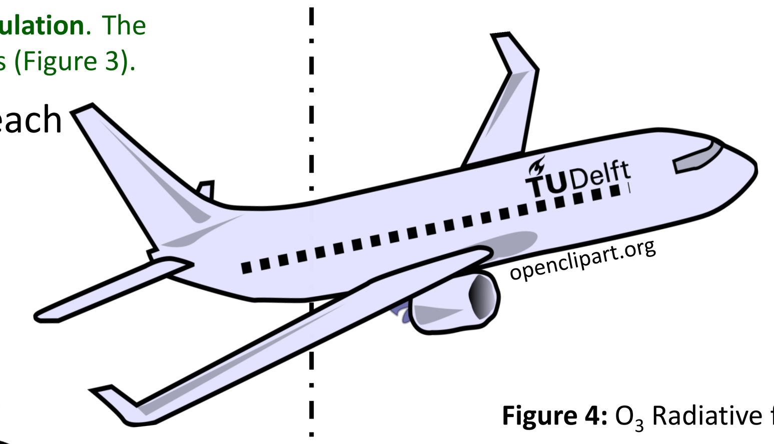
$$A_{app1,app2} = \frac{\int_0^T (O_3)_{app1}(t)dt}{\int_0^T (O_3)_{app2}(t)dt}$$

T is the total simulation time in days and "app" is "approach".

$$A_{LAGRANGIAN,EULERIAN} = 1.7$$
$$A_{EULERIAN,PERTURBATION} = 2.6$$

Therefore, to find the **contribution of aviation NO_x** to atmospheric O_3, the **ideal method** is the **Eulerian tagging** approach.

- If the **Lagrangian tagging approach** were used, aviation's O_3 production would be **overestimated by a factor of 1.7**, given its simplified chemistry along the trajectories.
- If the **perturbation approach** were used, we would **underestimate** aviation's O_3 contribution by a **factor of almost 3.**



Comparing NO_x-induced O_3 radiative forcing (RF) fields

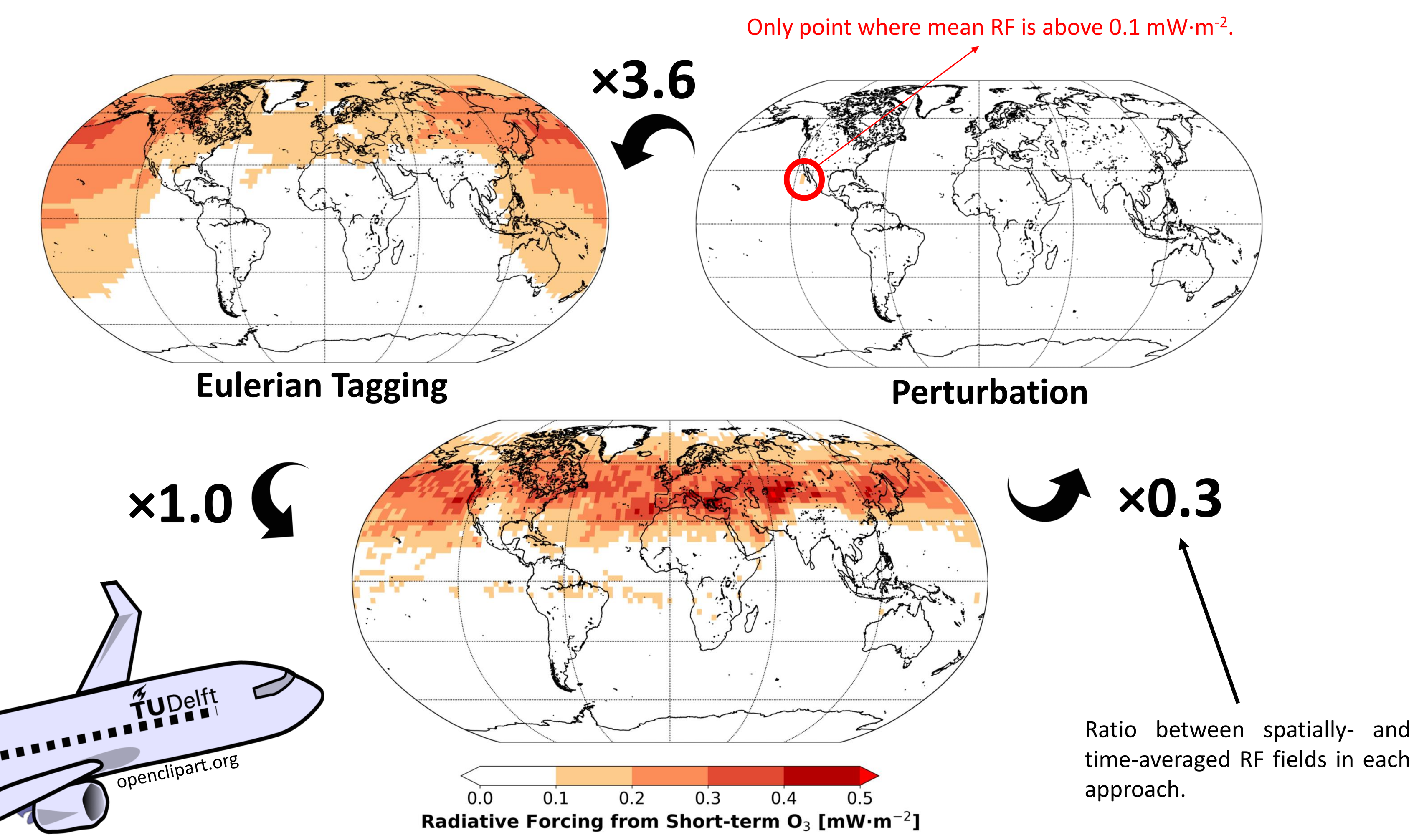


Figure 4: O_3 Radiative forcing fields for **Lagrangian (LAG) tagging**, **Eulerian (EUL) tagging** and **perturbation (PERT)** approaches

Side note: how does NO_x-induced O_3 RF vary with emission altitude?

- **Figure 4** (Lagrangian) shows the **variation of RF from O_3** for N. America during January and July.
- The **RF is larger during a July emission** given the added **O_3 production** from photolysis.
- **Emitting higher**, into the **stratosphere** at 200 hPa, may lead to **smaller RF** from the induced **destruction of O_3** by NO_x.

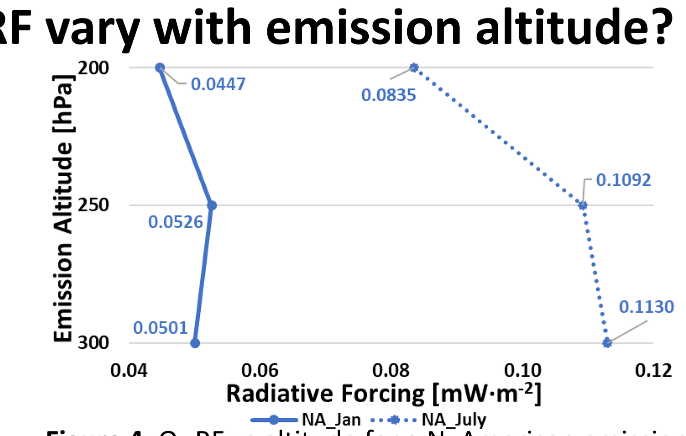
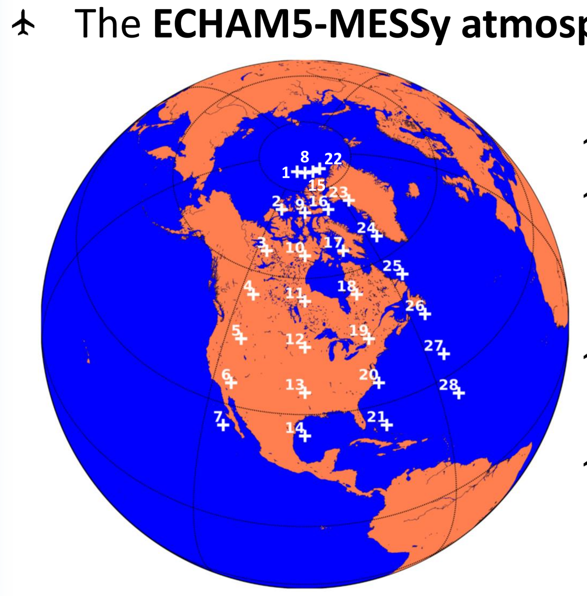


Figure 4: O_3 RF vs altitude for a N. American emission

3 THE SIMULATION SETUP

- The **ECHAM5-MESSy atmospheric chemistry model (EMAC)** was used.



- **28** emission points in **North America**.
- **Model resolution** (T42L41):
  - 64 latitudes, 128 longitudes **(2.8° × 2.8° grid)**
  - 41 vertical levels **(from the surface to 5 hPa)**
- At each of the 28 points, **$5×10^5$ kg of NO** is emitted at **3 altitudes**: 200, 250 and 300 hPa.
- Emissions occurred in **January and July of 2014**.

Figure 1: the 28 emission points in North America (read more about the setup in [4])

5 CONCLUSIONS

- The **ideal method** used to estimate aviation's climate impact **depends on our research question**.
- If an **inadequate method** is used, we could **significantly over or underestimate the climate effect**, even by more than **a factor of 4**.
- The **linearized Lagrangian sub-model** used may benefit from a **correction factor of ~1.8** for more accuracy.

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