The Contribution of Aviation NO_x Emissions to Climate Change

Volker Grewe*, Sigrun Matthes, Katrin Dahlmann

Institut für Physik der Atmosphäre, DLR-Oberpfaffenofen
*also at TU-Delft; Faculty of Aerospace Engineering

IOP Publishing Environ. Res. Lett. 14 (2019) 121003 https://doi.org/10.1088/1748-9326/ab5dd7

Environmental Research Letters

CrossMark

OPEN ACCESS

PUBLISHED
19 December 2019

PERSPECTIVE

The contribution of aviation NO_x emissions to climate change: are we ignoring methodological flaws?

Volker Grewe[1,2], Sigrun Matthes[1] and Katrin Dahlmann[1]

[1] Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany
[2] Delft University of Technology, Aerospace Engineering, section Aircraft Noise and Climate Effects, Delft, The Netherlands

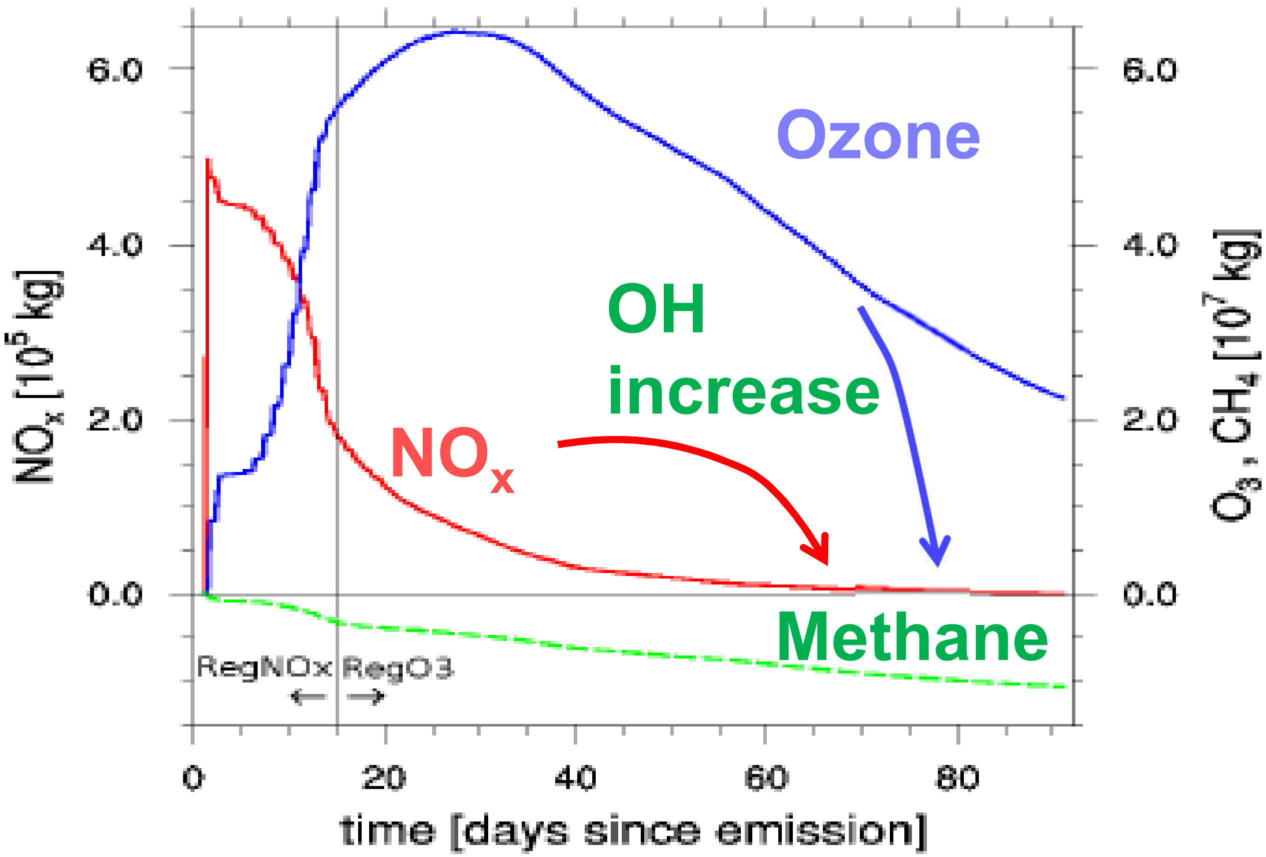
Keywords: aviation NO_x emissions, aviation climate impact, atmospheric chemistry

Supplementary material for this article is available online

DLR

Well established relation between NO_x-ozone-methane (typical situation)

(e.g. Fuglestvedt et al 1999)



$O_3 + H_2O \rightarrow 2\ OH$
$NO + HO_2 \rightarrow NO_2 + OH$

Methane Loss
$CH_4 + OH \rightarrow CH_3 + H_2O$

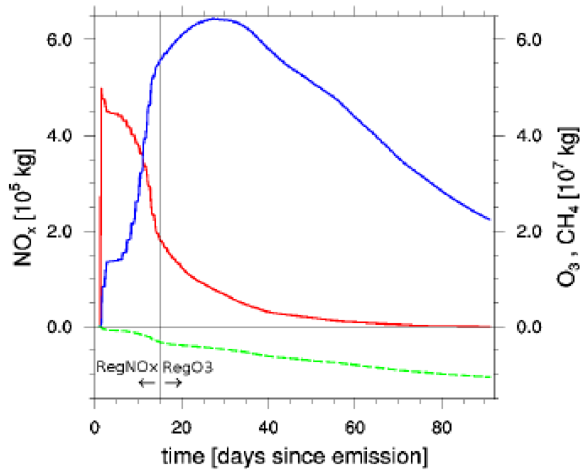
Less Background Ozone Production = Primary Mode Ozone
PMO

Less Stratospheric Water Vapour
SWV

Different timescales for NO_x, ozone, and methane
Grewe et al. (2017)

Overview on aviation NO_x "News"

- **Well Established Chemical-Physical Processes:**
  - Tropospheric chemistry: NO_x-O_3-OH-CH_4
  - Feedback: Primary Mode Ozone PMO
  - Feedback: Stratospheric Water Vapour (SWV)



- **Revised Methane Radiative Forcing Estimate**
  - Inclusion of short-wave radiation effects (Etminan et al 2016)

$$[a_3\overline{M} + b_3\overline{N} + 0.043]\left(\sqrt{M} - \sqrt{M_0}\right)$$

$c_2 = -4.9 \times 10^{-6} Wm^{-2} ppb^{-1}$
$a_3 = -1.3 \times 10^{-6} Wm^{-2} ppb^{-1}$
$b_3 = -8.2 \times 10^{-6} Wm^{-2} ppb^{-1}$

- **Methodological Flaws** (Grewe et al. 2019)
  - Steady-State assumption in the methane calculation
  - Ozone-Contribution calculation

IOP Publishing Environ. Res. Lett. 14 (2019) 121003 https://doi.org/10.1088/1748-9326/ab5dd7

Environmental Research Letters

PERSPECTIVE

The contribution of aviation NO_x emissions to climate change: are we ignoring methodological flaws?

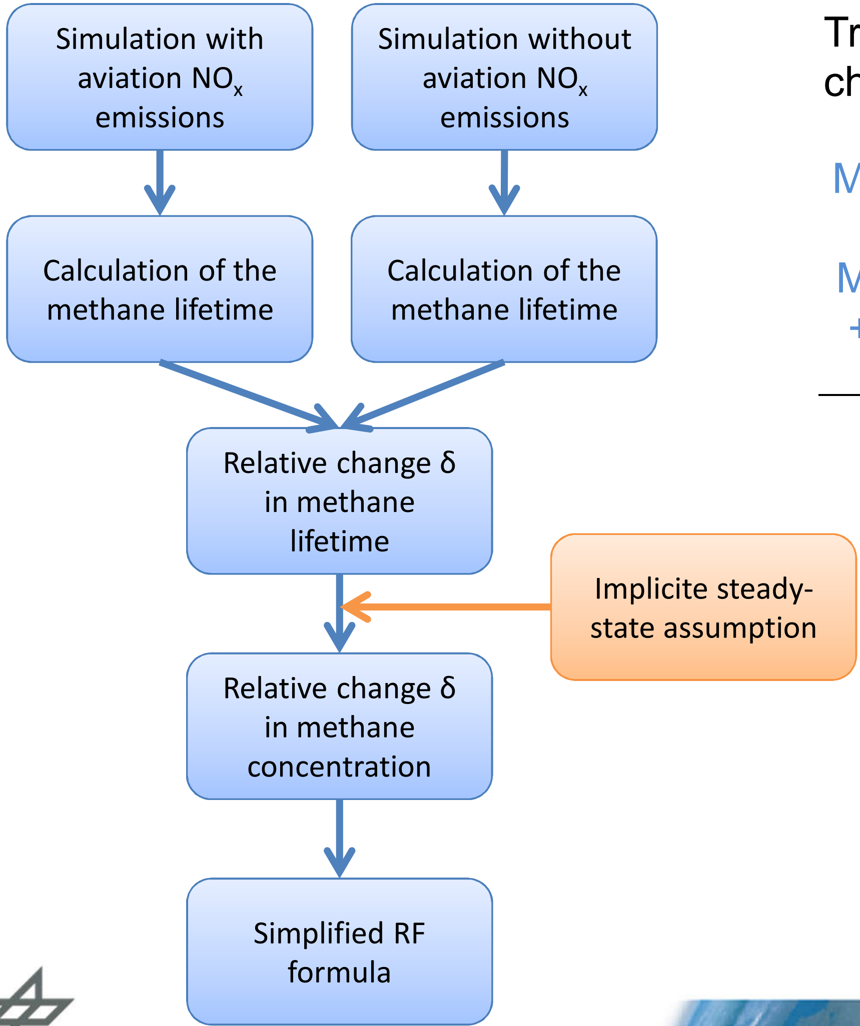
CrossMark
OPEN ACCESS
PUBLISHED
19 December 2019

Volker Grewe[1,2], Sigrun Matthes[1] and Katrin Dahlmann[1]
[1] Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany
[2] Delft University of Technology, Aerospace Engineering, section Aircraft Noise and Climate Effects, Delft, The Netherlands

Keywords: aviation NO_x emissions, aviation climate impact, atmospheric chemistry
Supplementary material for this article is available online

DLR

Implicite steady-state assumption for methane



Transient development of methane considering a relative change in the methane lifetime: δ

Methane Background

$$\frac{d}{dt}\mathrm{C}^{\mathrm{CH_4}} = \mathrm{Prod}(t) - \tau_{\mathrm{CH_4}}^{-1} \times \mathrm{C}^{\mathrm{CH_4}} \quad (1)$$

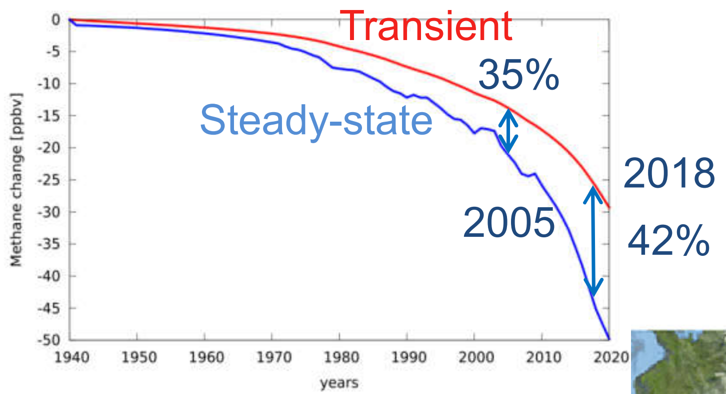
Methane Background + Aviation

$$\frac{d}{dt}\tilde{\mathrm{C}}^{\mathrm{CH_4}} = \mathrm{Prod}(t) - \tau_{\mathrm{CH_4}}^{-1} \times (1+\delta(t))^{-1} \times \tilde{\mathrm{C}}^{\mathrm{CH_4}} \quad (2)$$

Grewe and Stenke (2008)

(2) – (1)
Methane Change due to aviation

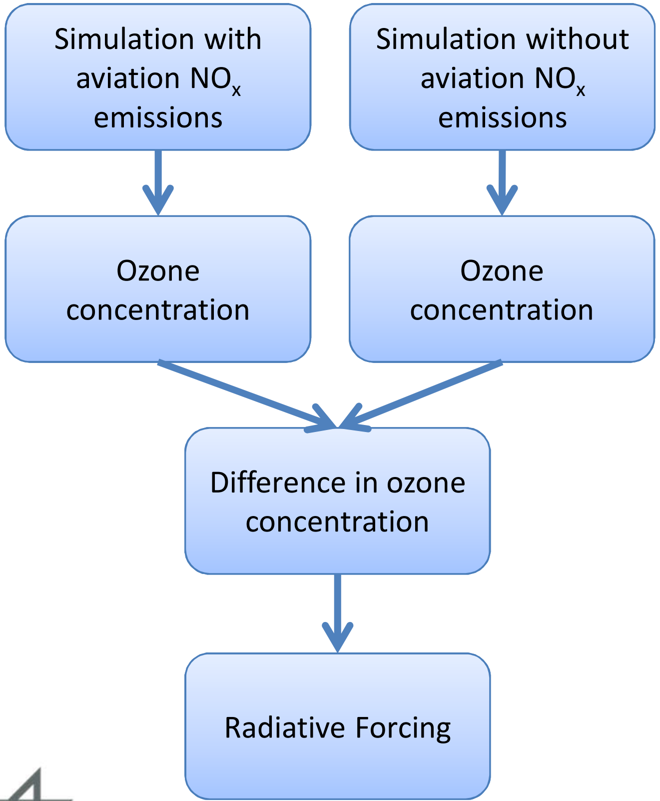
$$\frac{d}{dt}\Delta C^{\mathrm{CH_4}} = \underbrace{\frac{\delta}{1+\delta}\tau_{\mathrm{CH_4}}^{-1} C^{\mathrm{CH_4}}}_{\text{Depletion of background methane}} - \underbrace{\frac{1}{1+\delta}\tau_{\mathrm{CH_4}}^{-1} \Delta C^{\mathrm{CH_4}}}_{\text{Lifetime of aviation methane changes}}, \quad (3)$$



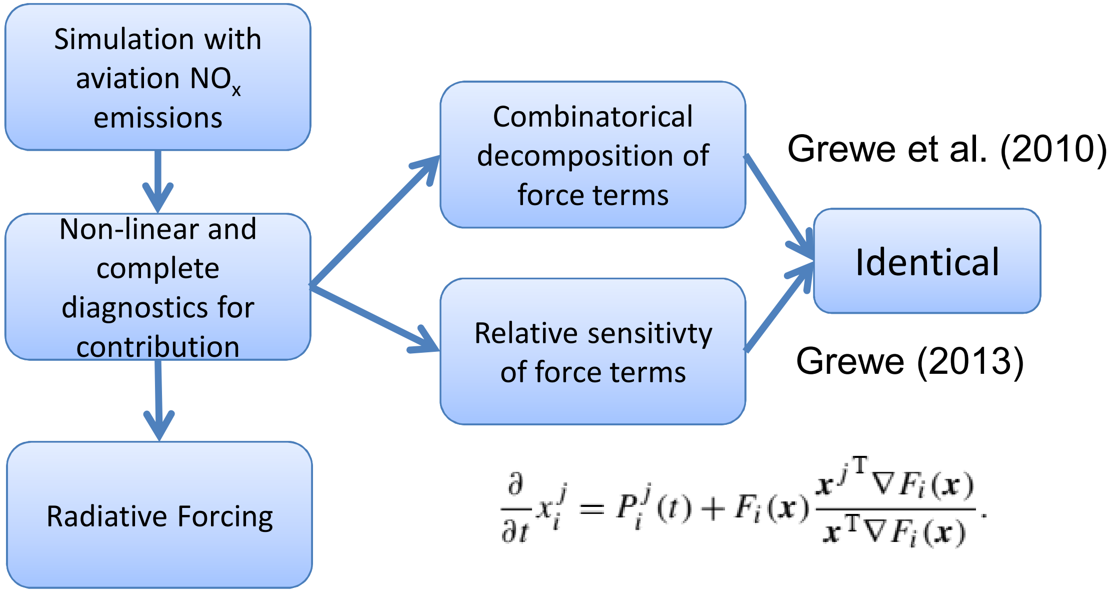
This effect has been picked up by Lee et al. 2020; they found 21% difference for 2018.

Ozone Contribution Calculation

Perturbation approach
Sensitivity approach
Incremental approach



Contribution approach
Source apportionment method



$$\frac{\partial}{\partial t} x_i^j = P_i^j(t) + F_i(\boldsymbol{x}) \frac{\boldsymbol{x}^{j\,\mathrm{T}} \nabla F_i(\boldsymbol{x})}{\boldsymbol{x}^{\mathrm{T}} \nabla F_i(\boldsymbol{x})}.$$

DLR

Ozone Contribution Calculation – References and Results

However, this study demonstrates that when the relationship between emissions and concentrations is nonlinear, sensitivity approaches are not suitable to retrieve source contributions

Clappier et al (2017)

The simplest approach based on increments (incremental approach) is often not suitable to support air quality planning.

Thunis et al (2019)

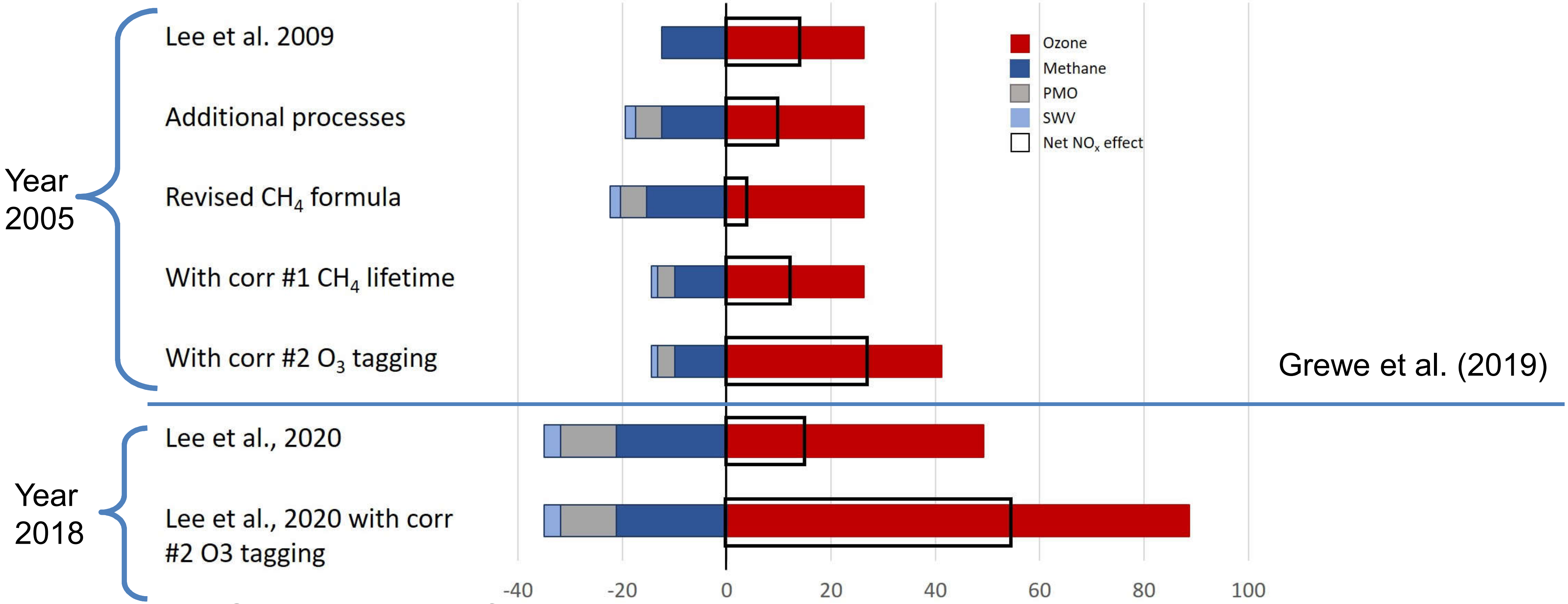
Note, that the sensitivity method, based on its concept, is inappropriate for source attribution,

Grewe et al (2010)

Perturbation approach underestimates contribution by a factor of

- 2-4 for biomass burning (Emmons et al. 2016)
- ~2 for surface traffic (Mertens et al. 2018)
- ~1.8 for aviation (Dahlmann et al. 2011)

Intercomparison with Lee et al. (2020)



Contribution of aviation to climate change:

Lee et al. 2020
Aviation: 3.5%

→

Lee et al. 2020 + O_3 source attribution
Aviation: 4.5%

DLR

Summary of the climate impact of aviation NO_x emissions Year 2005

Radiative forcing of Aviation NO_x emission in 2005 in mW/m^2	Lee et al. 2009	Additional processes (PMO, SWV)	Revised methane RF formula	correction in methods	
				#1 Methane lifetime (GS, 2008; Myhre et al, 2011)	#2 Ozone contribution method (Dahlmann et al 2011)
Ozone	26.3	26.3	26.3	26.3	41.2
Methane	-12.5	-12.5	-15.4	-10.0	-10.0
PMO		-5.0	-5.0	-3.3	-3.3
SWV		-1.9	-1.9	-1.2	-1.2
Total NO_x-RF	13.8	6.9	4.0	11.8	26.7

Grewe, Matthes, Dahlmann, 2019

DLR