Efficacies of various forcing components contributing to aircraft climate impact

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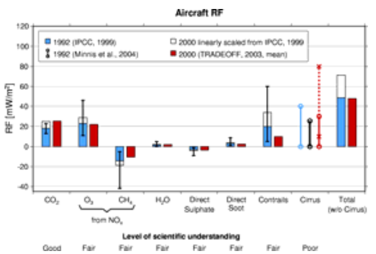
Linearity and Additivity of Forcing and Response

Traditionally, the global climate impact of individual emission sectors, as well as specific components contributing to the total effect of some sector, have been inter-compared in terms of radiative forcing (example from Sausen et al., 2005, in the column diagram below). In doing so it is implicitly assumed that the radiative forcings of the perturbations add linearly, that the climate response scales linearly with the radiative forcing, and that all radiative forcing have the same **efficacy**. All assumptions need to be checked, particularly if



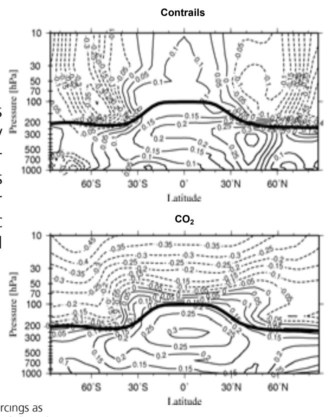
- perturbations are heavily scaled to yield a statistical significant signal in climate change simulations with 3-d GCMs or to apply the regression-based radiative forcing definition of Gregory et al. (2004)
- some perturbations display a distinctly non-homogeneous distribution, in which case it is doubtful if forcing and response are linked by the same climate sensitivity parameter for all components contributing to the total effect

Distinctive Efficacies of Non-CO2 Aviation Forcings

$$\Delta T_{sfc}^{(i)} = \lambda^{(i)} \bullet RF^{(i)} = r^{(i)} \bullet \lambda^{(CO2)} \bullet RF^{(i)}$$

$$r^{(i)} = \lambda^{(i)} / \lambda^{(CO2)} \neq 1$$

Previous equilibrium climate change simulations have suggested the possibility of a significantly different climate sensitivity parameter (**λ**) for non-CO_2 aviation perturbations, with efficacies (r, Hansen et al., 2005) up to 40% smaller or larger than in the reference case. A systematic approach using but one well-defined GCM framework has been lacking, however.



	CO_2	O_3	CH_4	H_2O	contrails
λ	0.73	1.00	0.86	0.83	0.43
r	1.00	1.37	1.18	1.14	0.59

Efficacies of aviation forcings as compiled by Ponater et al. (2006) from various models.

Basic Climate Sensitivity and Efficacy values

Perturbation	ΔT_{surf}	RF_{adj}	λ_{adj}	r	r	RF_{greg}	λ_{greg}	r_{greg}	r_{greg}
CO2 (1 W/m²)	0.703	1.010	0.696	1	**0.96**	0.96	0.790	1	**1.01**
CO2 (doubling)	2.748	3.792	0.724		**1**	3.62	0.782		**1**
CO2 (tripling)	4.572	6.160	0.742		**1.02**	5.62	0.842		**1.08**
Sol (1 W/m²)	0.671	1.016	0.660	0.95	**0.91**	1.08	0.640	0.81	**0.82**
Sol (+2%)	3.285	4.591	0.716		**0.99**	4.52	0.781		**1.00**
CH4 (1 W/m²)	0.760	1.053	0.722	1.04	**1.00**	1.26	0.636	0.81	**0.81**
CH4 (+8.6ppmv)	1.576	2.213	0.712		**0.98**	2.06	0.860		**1.10**
Contrails (80, τ =0.4)	0.385	0.833	0.462		**0.64**	0.47*	0.771*		**0.99***
*from **8** spin-up simulations	[K]	[Wm⁻²]	[K/ Wm⁻²]			[Wm⁻²]	[K/ Wm⁻²]		

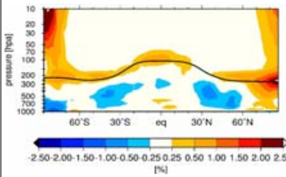
For conventional forcings the notion of a universal climate sensitivity parameter within a certain model framework is confirmed to a large extent by the common (IPCC) RF calculation method.

If the regression method is applied, even contrail efficacy is near 1, but the uncertainty of the RF_{greg} and λ_{greg} values becomes so large that ensembles of spinup simulations are needed.

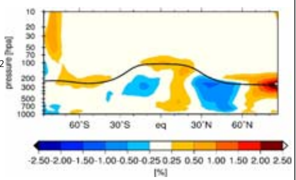
Feedback of Natural Clouds under Contrail Forcing

Perturbation	ΔT_{surf}	RF_{adj}	λ_{adj}	ΔswCRF	ΔlwCRF	ΔCRF
CO2 (1 W/m²)	0.703	1.010	0.696	−0.659	+0.532	−0.127
Contrails (80, τ =0.4) – C2	0.385	0.833	0.462	−0.296	−0.058	−0.354
Contrails (100, τ =0.3) – C3	0.297	0.694	0.423	−0.262	−0.111	−0.373
Contrails (100, τ =0.4) – C4	0.383	0.928	0.413	−0.365	−0.110	−0.475
	[K]	[Wm⁻²]	[K/ Wm⁻²]			

The cloud radiative feedback under a moderate global warming is usually negative in the GCM framework used here, but it appears to be more negative for contrails than for the reference CO_2 case. An additional negative cloud feedback (natural cirrus reduction in the region of contrail abundance, figures below) evidently contributes to the reduced climate sensitivity of contrails.



Response of natural cloud cover in the CO_2 (left) and in the contrail (right) simulation



Conclusions

- Indications of anomalous efficacies for aviation forcings do exist, but confirming support from other model frameworks is urgently required.
- Radiative forcing scales linearly through a wide range of values and adds almost perfectly even after moderate scaling.
- Deeper understanding of feedbacks for non-CO_2 perturbations is necessary to allow proper interpretation of results.
- There are promising indications that component efficacies may be linearly combined.

Aviation Ozone, Water Vapour, and Contrails

Perturbation	ΔT_{surf}	RF_{adj}	λ_{adj}	r
CO2 (1 W/m²)	0.703	1.010	0.696	
CO2 (doubling)	2.748	3.792	0.724	**1**
Ozone_avia (30) – O1	-	0.540 (28)	-	**-**
Ozone_avia (40) – O2	-	0.704 (37)	-	**-**
Ozone_avia (50) – O3	0.617	0.862 (44)	0.712	**0.98**
Ozone_avia (100) – O4	1.167	1.593 (82)	0.733	**1.01**
Contrails (80, τ =0.3) – C1	-	0.609	-	**-**
Contrails (80, τ =0.4) – C2	0.385	0.833	0.462	**0.65**
Contrails (100, τ =0.3) – C3	0.297	0.694	0.423	**0.59**
Contrails (100, τ =0.4) – C4	0.383	0.928	0.413	**0.57**
WatVap_avia (750) – H1	0.223	0.442 (553)	0.505	**0.70**
WatVap_avia (1000) – H2	0.273	0.555 (694)	0.492	**0.68**
WatVap_avia[SCENIC] (20) – HS	0.428	0.585 (17)	0.731	**1.01**
O1 + C1	0.683	1.122 (98%)	0.609	**0.84**
O2 + C3	0.854	1.409 (100%)	0.606	**0.84**
O3 + C2	-	1.667 (98%)	-	**-**
O1 + H1	0.609	0.983 (100%)	0.620	**0.86**
O2 + HS	0.994	1.294 (100%)	0.768	**1.06**
C1 + H1	0.494	1.037 (98%)	0.476	**0.68**
C2 + HS	0.716	1.201 (100%)	0.596	**0.82**
C1 + O1 + H1	0.935	1.577 (99%)	0.593	**0.82**
	[K]	[Wm⁻²]	[K/ Wm⁻²]	

- The efficacy of contrails appears to be significantly lower than 1 (~0.6).
- The efficacy of aviation water vapour appears to be significantly lower than 1 (~0.7).
- Indications of an anomalous efficacy for aviation ozone and water vapour from supersonics are weak.

$RF(a \bullet \Delta O_3^{(i)}) = a \bullet RF(\Delta O_3^{(i)})$? Linearity of aviation forcings is restricted to moderate scaling.

$RF(\sum \Delta O_3^{(i)}) = \sum RF(\Delta O_3^{(i)})$? Additivity of aviation forcings is nearly perfect.

Linearity of the Response: Joint Efficacies ?

$$\Delta T_{sfc} = \sum \Delta T_{sfc}^{(i)} \Leftrightarrow r_{comb} = \sum(RF^{(i)} \bullet r^{(i)}) / \sum(RF^{(i)}) \quad ?$$

In case that characteristic efficacies for individual forcing components can be established, the response appears to be sufficiently additive to calculate joint efficacies by linear combination. An attempt to define an overall efficacy for a whole transport sector (in this case aviation) could thus be worthwhile.

Perturbation	r_{comb}	r
CO2	-	**1**
Ozone_avia (O)	-	**1.0**
WatVap_avia (H)	-	**0.7**
Contrails (C)	-	**0.6**
O1 + C1	0.81	**0.84**
O2 + C3	0.80	**0.84**
O1 + H1	0.86	**0.86**
C1 + H1	0.65	**0.68**
C2 + HS	0.79	**0.82**
O1+ C1 + H1	0.78	**0.82**

References

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