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The shortwave to longwave ratio in contrail radiative forcing as evident in two radiation schemes used for global GCMs

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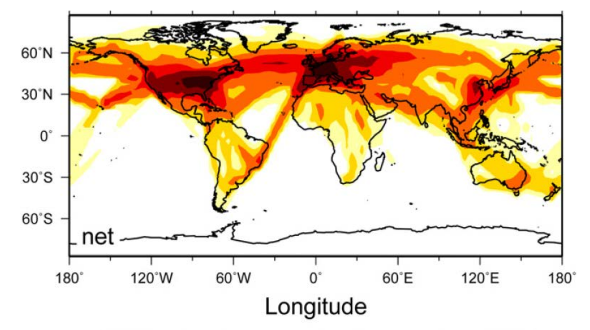
Motivation

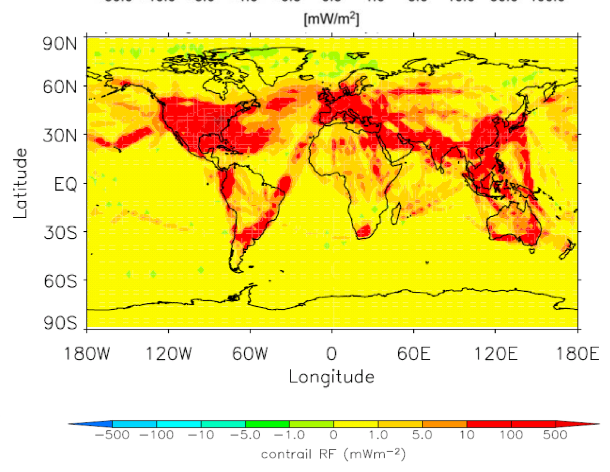
Several estimates for the radiative forcing of line-shaped contrails have been produced over the last 12 years. There are substantial differences between all these results. We show, exemplarily, two recent examples from Frömming et al. (2011, top right) and Rap et al. (2010, bottom right). Lee et al. (2009) review estimates for 2005 aviation to range between 5.4 mWm^{-2} and 25.6 mWm^{-2}.

A lack of knowledge on contrail optical properties (ice water content, crystal size, crystal habit) has usually been taken as the primary source for the uncertainty. The quality of radiative transfer schemes with respect to thin cirrus has been viewed as a matter of less concern. This may be true if global annual mean estimates of contrail radiative forcing are in the focus. However, as the interest is turning now to possible mitigation measures for contrail climate impact, it has become absolutely necessary to simulate contrail radiative forcing as correct as possible for the whole range of ambient parameters. Nighttime to daytime shift of aviation (Stuber et al., 2005) forms a prominent example.

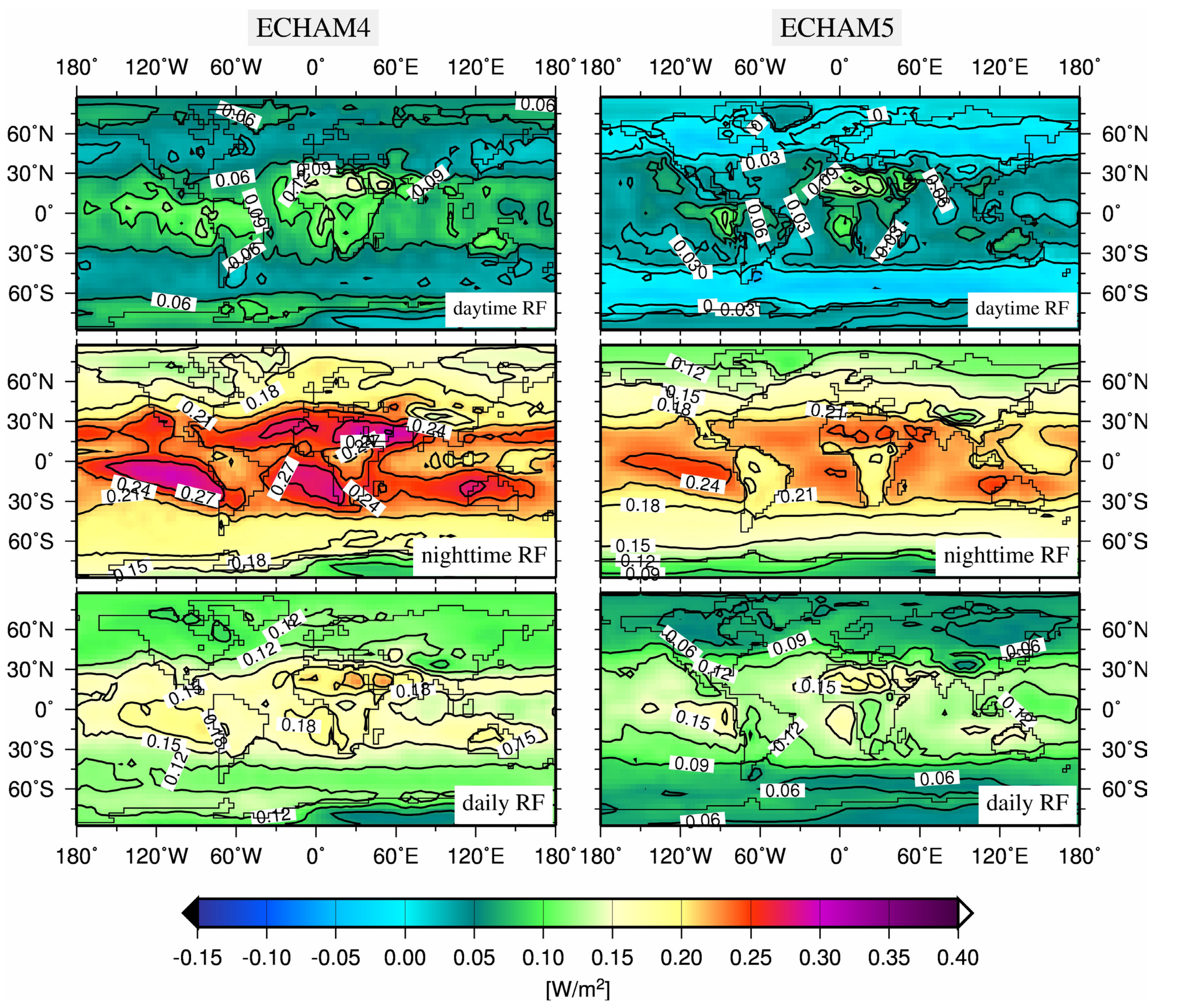
3D-climate models are optimally suited to provide a representation of the required variety of ambient parameters for a climatological estimate of contrail radiative forcing. However, especially these models' radiation schemes are often simplified because of computational efficiency.

Here we test two radiation schemes: One (ECHAM4) has frequently been used for providing contrail climate impact estimates (e.g., Marquart et al., 2003; Frömming et al., 2011). The other (ECHAM5, also part of EMAC) will be used for future work, e.g., within the REACT-4C EU project.





Annual Mean Radiative Forcing at Day and Night



	coverage	RF_{sw}	RF_{lw}	RF_{net}
Daytime mean *ECHAM4*	1.00	*–0.157*	*+0.221*	*+0.065*
ECHAM5		**–0.167**	**+0.194**	**+0.027**
Nighttime mean *ECHAM4*	1.00	*0.*	*+0.216*	*+0.216*
ECHAM5		**0.**	**+0.189**	**+0.189**
Daily (24h) mean *ECHAM4*	1.00	*–0.078*	*+0.219*	*+0.141*
ECHAM5		**–0.084**	**+0.192**	**+0.108**
	[%]	[W/m²]	[W/m²]	[W/m²]

Shortwave RF increases in ECHAM5 relative to ECHAM4, while longwave RF decreases. This results in a substantially reduced net RF in ECHAM5 for daytime and daily means.

The net RF at daytime is generally positive for ECHAM4, but may turn negative for ECHAM5 between about 40° and 65° latitude.

The 24-h averaged net RF remains positive everywhere for both radiative schemes, but the latitudinal structure is somewhat different.

Conclusions

•GCM borne radiation schemes yield radiative forcing results for thin cirrus that are in the range of respective calculations with more sophisticated radiative transfer models.

•Yet, different GCM radiation schemes give substantially different estimates, even for prescribed coverage and optical properties. Making a decision on the superiority of one scheme is not straightforward.

•Results of the "Myhre benchmark", e.g. with respect to the sw to lw compensation, usually give a good first impression how the schemes will perform for "real" contrails with varying optical depth.

•One has to keep in mind, however, that for "real" contrails uncertainties and variability of their optical properties (ice water content, crystal habit) will add on top of the uncertainty range showing up in our results.

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Frömming, C., et al. (2011): Sensitivity of contrail coverage and contrail radiative forcing to selected key parameters. Atmos. Environ 45, 1483-1490.
Lee, D.S., et al. (2009): Aviation and global climate change in the 21st century. Atmos. Environ. 43, 3520-3537.
Marquart, S., et al. (2003): Future development of contrail cover, optical depth and radiative forcing, J. Clim. 16, 2890-2904
Myhre, G., et al. (2002): Intercomparison of radiative forcing calculations of stratospheric water vapour and contrails. Meteorol. Z. 18, 585-596.
Rap, A., et al. (2010): Parameterisation of contrails in the UK Met Office climate model. J. Geophys. Res. 115, D10205.
Stuber, N., et al. (2005): The importance of the diurnal cycle of air traffic for contrail radiative forcing. Nature 441, 864-867.
Schumann, U. (2012): A contrail cirrus prediction model. Geosci. Model Dev., 5, 543-580.

The Radiation Schemes

ECHAM4 (Roeckner et al., 1996)

•Shortwave (sw) part: Fouquart and Bonnel (1980), 2 spectral bands

•Longwave (lw) part: Morcrette and Fouquart (1985), 6 spectral bands, no scattering by clouds (usually –but not here!– a posteriori corrected for global mean radiative forcing, according to Marquart and Mayer, 2002)

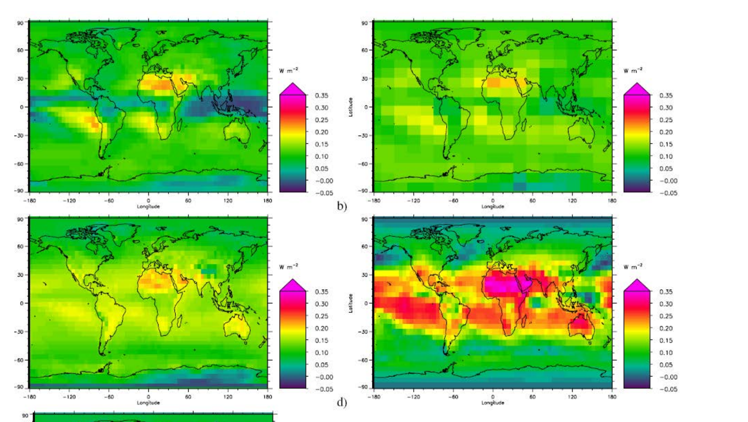
ECHAM5 (Roeckner et al., 2003); also used in EMAC (Jöckel et al., 2006)

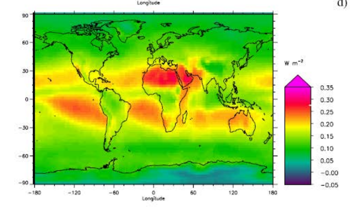
•Sw part: Fouquart and Bonnel (1980), 4 spectral bands, effective thickness approach to correct for non-homogeneous clouds

•Lw part: RRTM (Mlawer et al., 1997), 16 spectral bands, correlated-k method

Fouquart, Y., and Bonnel, B. (1980): Computations of solar heating of the earth's atmosphere: a new parameterisation. Beitr. Phys. Atmos., 53, 35-62.
Jöckel, P., et al. (2006): The atmospheric chemistry general circulation model ECHAM5/MESSy1: consistent simulation of ozone from the surface to the mesosphere. Atmos. Chem. Phys. 6, 5067-5104.
Marquart, S., and Mayer B. (2002): Towards a reliable GCM estimation of contrail radiative forcing. Geophys. Res. Lett., 29 (08).
Mlawer, E.J., et al. (1997): Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k-model for the longwave, J. Geophys. Res., 102, 16663-16682.
Morcrette, J.-J., and Fouquart, Y. (1985): On systemaric errors in parametrized calculations of longwave radiative transfer, Q. J. R. Meteorol Soc., 111, 691-708.
Roeckner, E., et al. (1996): The atmospheric general circulation model ECHAM-4: model description and simulation of present-day climate. MPI für Meteorologie Report No. 218, 90pp.
Roeckner, E., et al. (2003): The atmospheric general circulation model ECHAM5, Part I: model description. MPI für Meteorologie Report No.349, 127pp.

The "Myhre Benchmark Test" to Evaluate the Performance of Radiation Schemes for Thin Cirrus (Contrails)





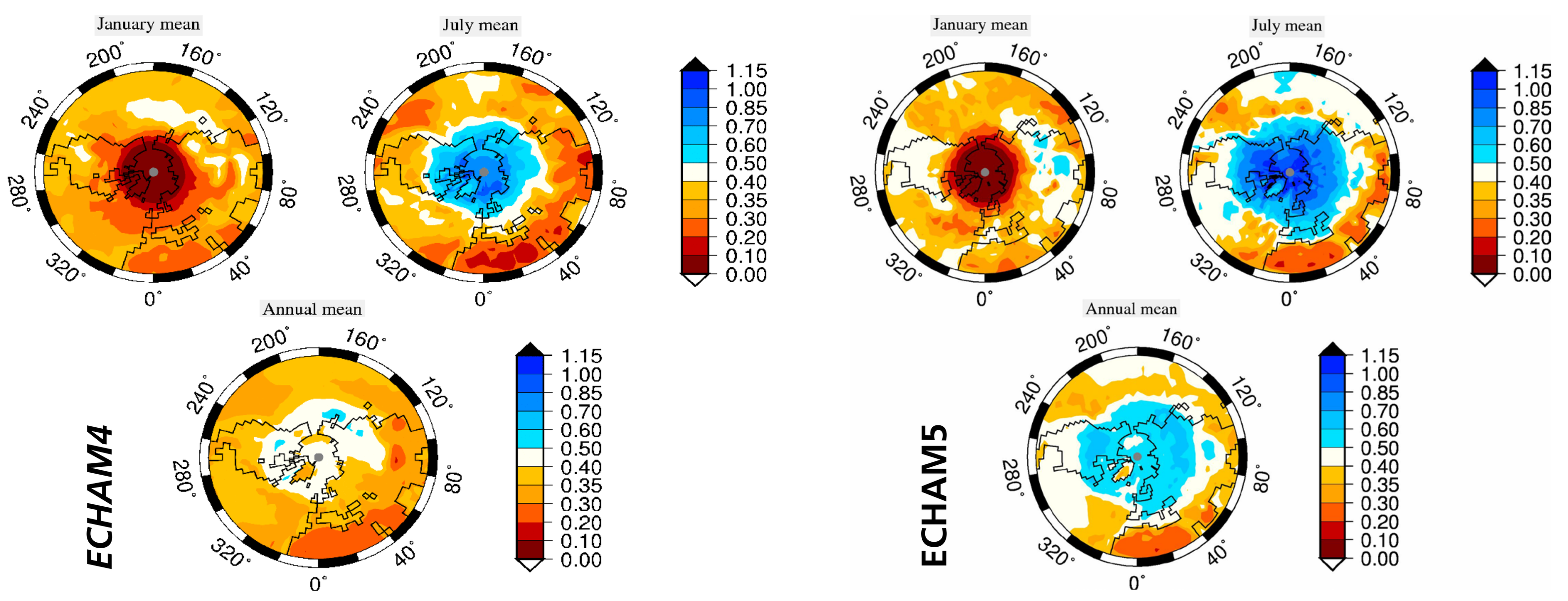
Annual mean radiative forcing simulated by five radiative transfer schemes (top: UiO, UoR (Fu); middle: UW (Fu), CNRM; bottom: UoL(E-S), references see Myhre et al. 2009). These are all-sky simulations, i.e., the effect of natural background clouds is included.

The benchmark framework introduced by Myhre et al. (2009) has been designed to test the performance of radiation schemes for thin cirrus. The optical properties are chosen similar to those of contrails.

A 1% cirrus increase is prescribed all over the globe at 10 to 11 km (200 hPa) altitude. The optical depth is 0.3. The single scattering albedo is 1.0 in the solar spectrum and 0.6 in the thermal spectrum. The asymmetry parameter is prescribed as 0.8 without any dependence on wavelength.

However, there are some differences between individual model setups independent from the radiation scheme, as each model uses clouds, water vapour, surface albedo and few other parameters from its reference (simulated or prescribed) climatologic background.

Compensation between Shortwave and Longwave Forcing (Dependence on Latitude and Season)



In the ECHAM4 radiation scheme the amount of the daily mean shortwave forcing is smaller compared to the longwave forcing at almost all latitudes and seasons (left). The compensation is most effective at polar latitudes in summer (up to 80%).

In the ECHAM5 radiation scheme the compensation is generally more efficient (everywhere and in all seasons) but only at polar latitudes in summer the shortwave forcing component may dominate the longwave one (right) at very few locations.

Compensation is obviously different over (dark) water and (bright) ice, although this effect is partially masked by the presence of natural background clouds. Mind that those are different in ECHAM4 and ECHAM5!

Compensation between Longwave and Shortwave Forcing (Annual Global Mean)

	RF_{net}	RF_{sw}	RF_{lw}	Sw/Lw ratio
*ECHAM4**	*+0.141*	*–0.078*	*+0.219*	***36%***
ECHAM5	**+0.108**	**–0.084**	**+0.192**	**44%**
UiO**	+0.097	–0.105	+0.202	52%
UoR (Fu)**	+0.124	–0.079	+0.203	39%
UW (Fu)**	+0.148	–0.082	+0.229	36%
CNRM**	+0.190	–0.150	+0.340	44%
UoL (Edwards/Slingo)**	+0.157	–0.119	+0.276	43%
CoCiP#	+0.096	–0.117	+0.212	55%
	[Wm^{-2}]	[Wm^{-2}]	[Wm^{-2}]	

*see Frömming et al. (2011)
**see Myhre et al. (2009)
#see Schumann (2012)

Both ECHAM4 and ECHAM5 produce relatively low cirrus forcing amounts (ECHAM5 lowest for the lw, ECHAM4 for the shortwave), yet they are not outliers in the benchmark testing range. The net forcing is even in good agreement with the other (mostly more sophisticated) radiative transfer models.

ECHAM4 produces the lowest degree of lw to sw forcing compensation, while ECHAM5 lies near the average of the other models in this respect.

The compensation in ECHAM4 would be even lower (~25%), if RF_{lw} were corrected a posteriori for the absence of longwave scattering in that scheme (see above and further discussion in Frömming et al., 2011).

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