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Effects of three-dimensional photons transport on the radiative forcing of realistic contrails

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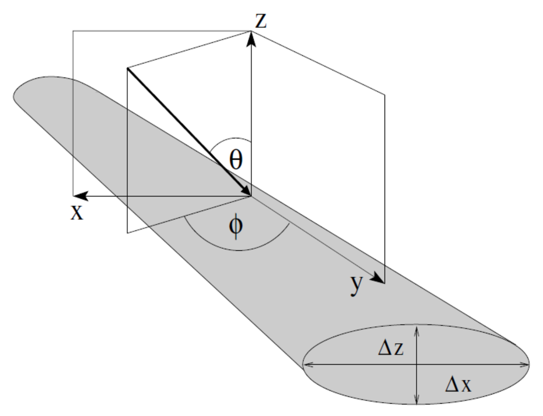
Motivation

Estimates of the global radiative forcing (RF) of line-shaped contrails and contrail-cirrus exhibit a high level of uncertainty. In most cases, 1D radiative models have been used to determine the RF on a global scale. Here, we quantify the effect of neglecting the 3D radiative effects of realistic contrails. For the investigation of the 3D effects of more realistic contrails the microphysical input was provided by simulations of a 2D contrail-to-cirrus LES (large-eddy simulation) model. Two contrail evolutions from 20 min up to 6 h in an environment with either high or no vertical wind shear were studied. This study revealed that the 3D effects show a high variability under realistic conditions since they depend strongly on the optical properties (optical depth, effective radius) and the evolutionary state (aspect ratio, optical depth) of the contrails. The differences are especially large for low elevations of the sun and contrails spreading in a sheared environment. The small 3D effects in the shortwave and longwave add up in the net RF. Thus, the effect of horizontal photon transport in contrails, especially for larger SZAs, is not negligible. A parameterization of the 3D effects in climate models would therefore need to consider both geometry and microphysics of the contrail.

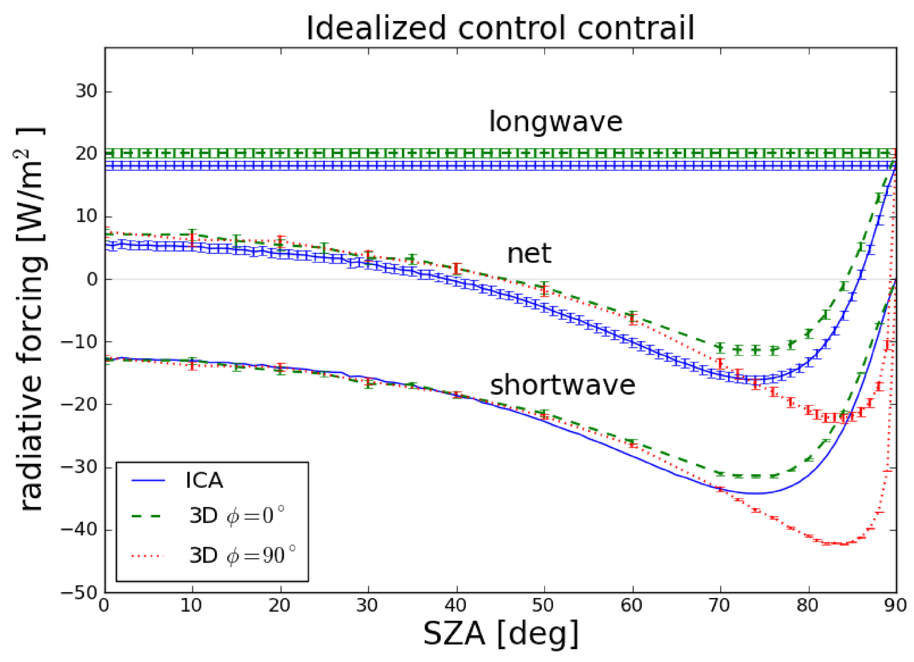
Idealized Contrail



Idealized elliptical contrail like in Gounou and Hogan (2007):
400 x 800 m, mean optical depth: 0.4 at 550 nm, solid hexagonal ice columns.

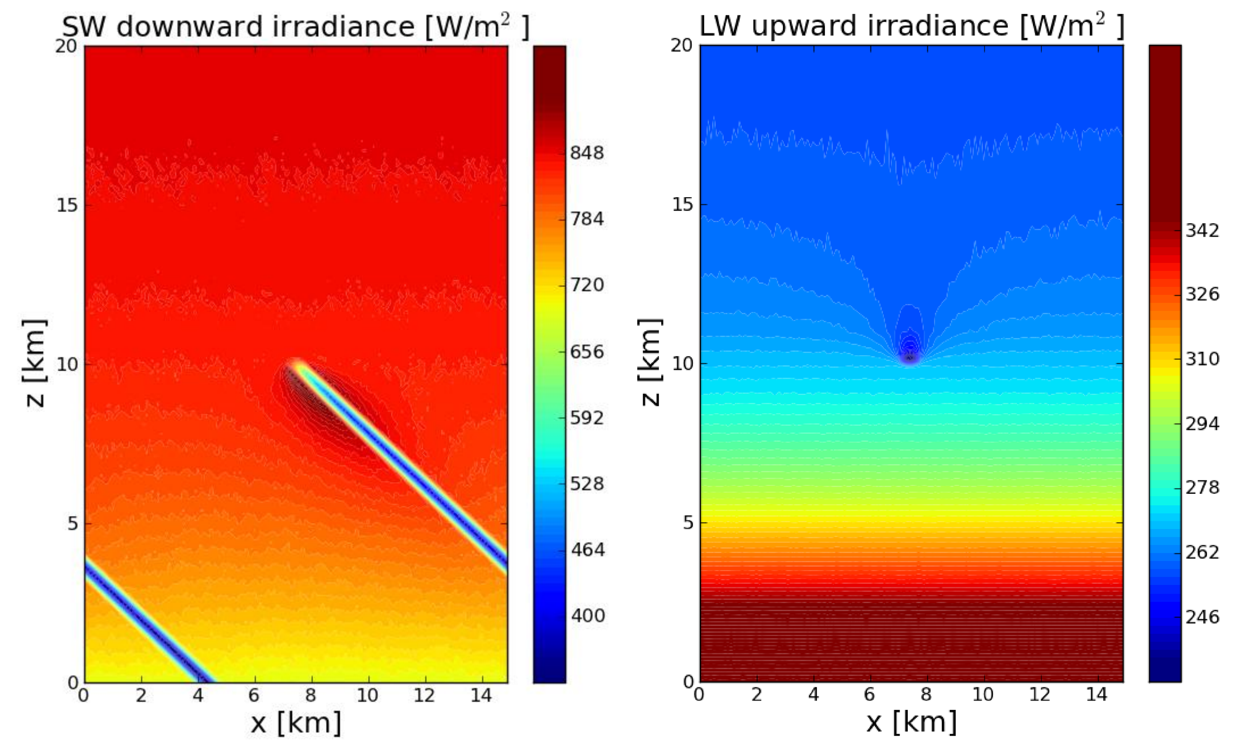
The position of the sun is determined by the **solar zenith angle (SZA)** ϴ and the **solar azimuth angle** ϕ.
(ϕ=270 East, ϕ=90 West, ϕ=0 South)

3D Effects of Idealized Contrail



Calculating the **3D effect (= difference in RF between 3D calculation and 1D approximation)** on contrail RF with the 3D radiative transfer model MYSTIC produced comparable results with Gounou and Hogan (2007). The **3D effect** was of the order of **10%** in the **longwave and shortwave**. The net 3D effect however can be much larger, since the shortwave and longwave RF largely cancel during the day.

3D Effects of Idealized Contrail

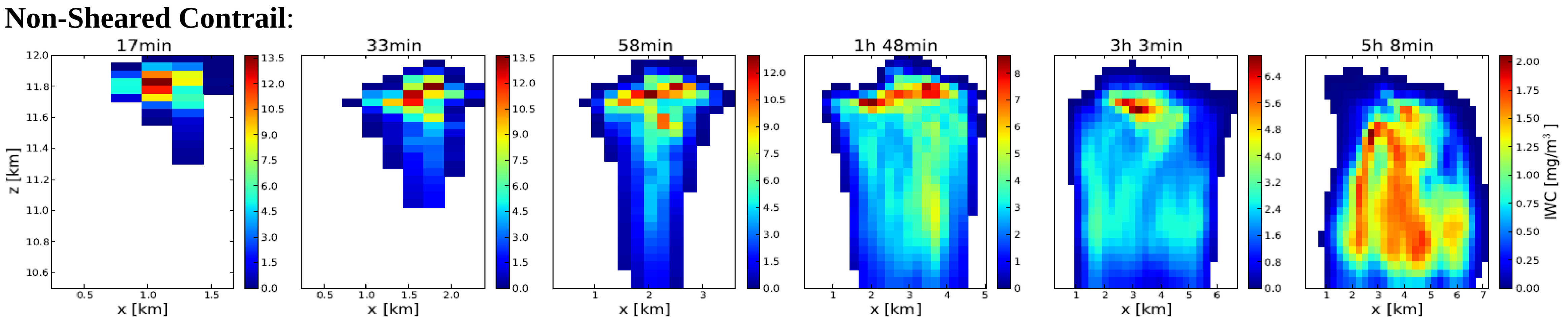


MYSTIC (Mayer 2009) calculation of the **shortwave downward** (left) and **longwave upward** (right) irradiances influenced by the idealized contrail. Solar zenith 50 and azimuth angle 90 (West).

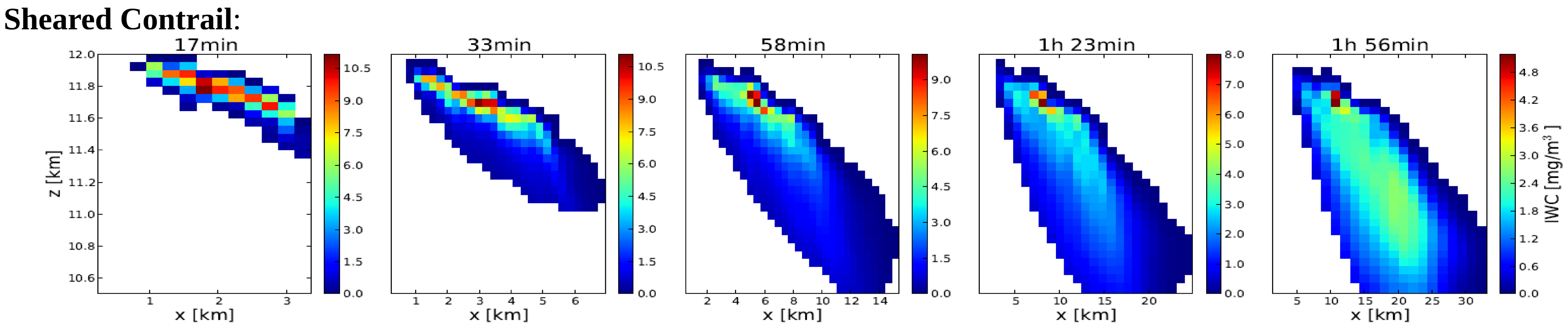
Realistic Contrails

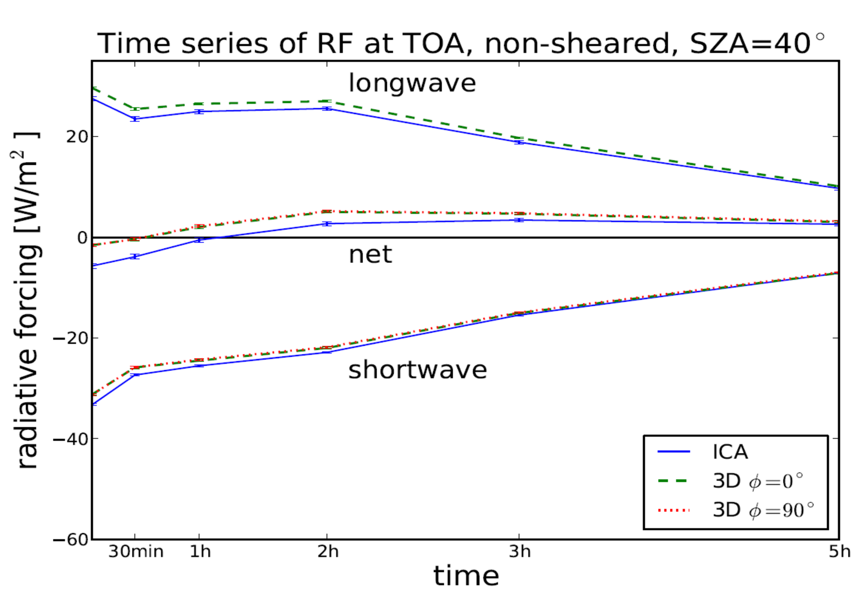
The microphysical properties (ice water content (IWC), effective ice particle radius) are produced by a **2D LES model**, used for the simulation of persistent contrails (Unterstrasser and Gierens, 2010a).
Cross section of **IWC-distribution** for selected time steps of the spreading contrail:

Non-Sheared Contrail:



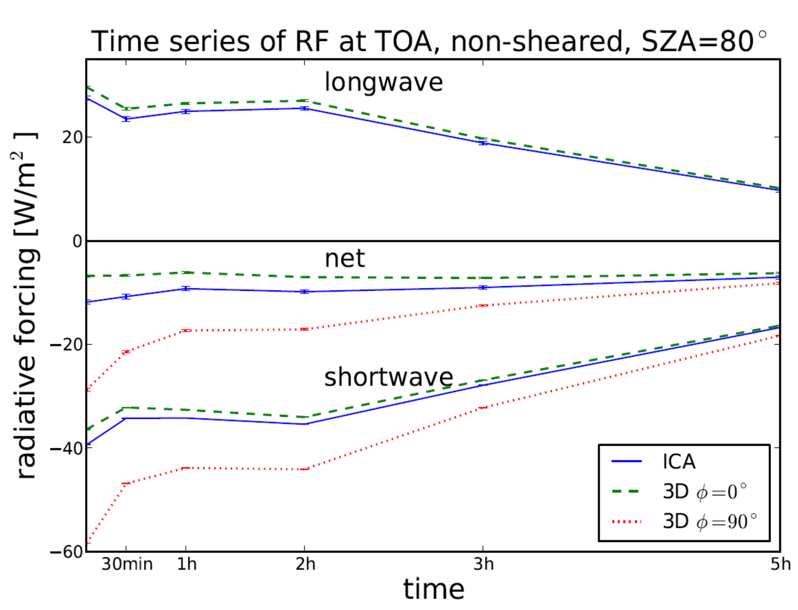
Sheared Contrail:





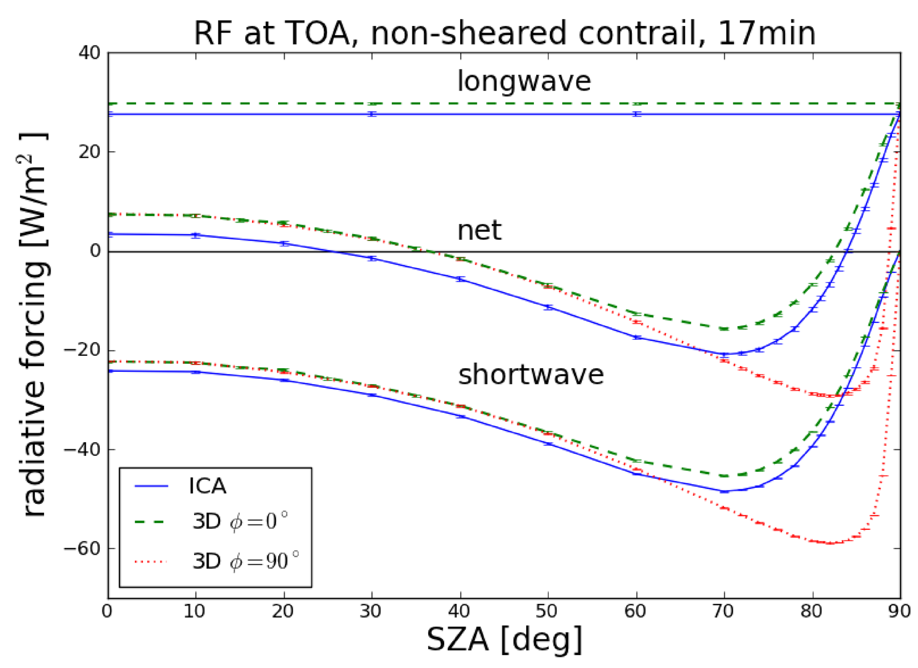
3D Effects

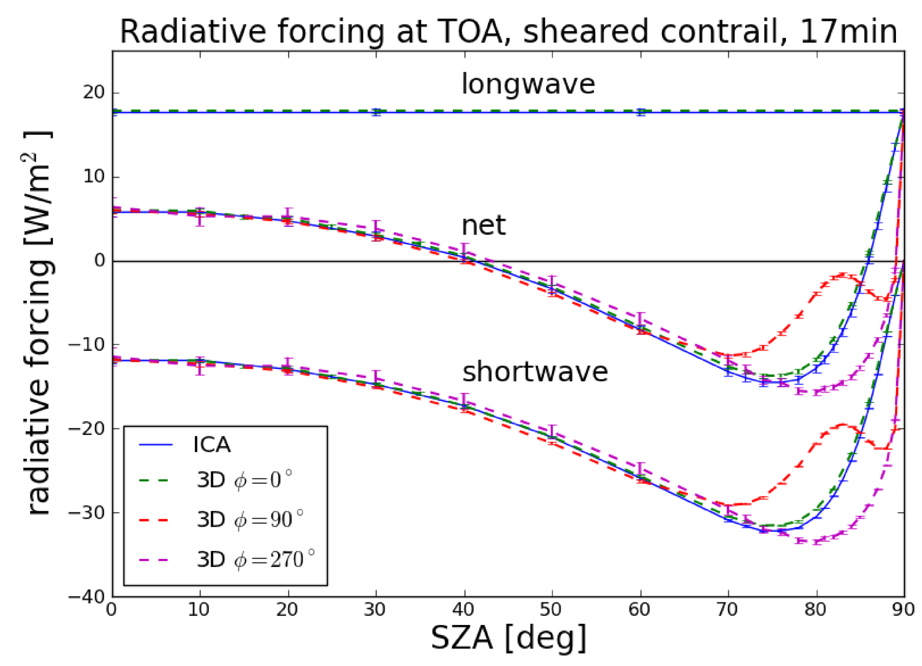
For ageing contrails, the **3D effects** remain significant, yet **decrease** as the mean optical depth of the spreading contrail diminishes.
Interestingly, the **net RF changes sign** over the contrail's life cycle for selected SZAs.



3D Effects of Realistic Contrails

In general, 3D effects are largest for low elevations of the sun and for sun and contrail perpendicular to each other.





For small SZAs the **3D effect** is **more pronounced** in the case of the **non-sheared contrail** (top) (8.1% SW, 7.6% LW, 122% net). The **local maximum** in the **SW RF of the sheared contrail** (bottom) with the sun in the East (ϕ=270) is caused by its **tilted geometry**.

Forster, L. and C. Emde, and S. Unterstrasser, and B. Mayer, 2012: Effects of Three-Dimensional Photon Transport on the Radiative Forcing of Realistic Contrails. J. Atmos. Sci., 2 doi: 10.1175/JAS-D-11-0206.1, in press.
Gounou, A. and R. J. Hogan, 2007: A sensitivity study of the effect of horizontal photontransport on the radiative forcing of contrails. J. Atmos. Sci., 64, 1706-1716.
B. Mayer, 2009: Radiative transfer in the cloudy atmosphere. European Physical Journal Conferences., 1:75-99.
Unterstrasser, S. and K. Gierens, 2010a: Numerical simulations of contrail-to-cirrus transition - part 1: An extensive parametric study. Atmos. Chem. Phys., 10 (4), 2017-2036.

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