CLIMATE IMPACT OF CONTRAIL AND CONTRAIL CIRRUS

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Abstract. The representation of contrail cirrus in climate models has advanced in the last years tremendously. Nevertheless, uncertainties in particular regarding the representation of contrail microphysics still remain. We extend a contrail cirrus scheme within a climate model by implementing a microphysical two-moment scheme to improve the simulation of microphysical properties of contrail cirrus. The global radiative forcing of contrail cirrus estimated for the year 2002 is close to the results of Burkhardt and Kärcher (2011). Although a higher fraction of optical visible contrails are simulated, the larger compensation of longwave and shortwave radiative forcing due to differences in the vertical overlap with natural clouds and a new radiation scheme prevent larger values of radiative forcing. The global radiative forcing of contrail cirrus for the year 2006 is estimated to be 56mW/m2. We also estimate the radiative forcing due to contrail cirrus for several aviation scenarios for the year 2050, considering the increase of air traffic volume, the shift of flight level, the climate change and the reduction of soot emissions.

Keywords: contrail cirrus, contrails in climate model, radiative forcing of contrail cirrus

INTRODUCTION

Aviation contributes around 5% to anthropogenic radiative forcing (Lee et al., 2009). Since the aviation sector increases every year by about 5% (ICAO, 2007), this effect is growing in importance. Of the aviation effects, contrail cirrus is the largest known radiative forcing component (Burkhardt and Kärcher, 2011). Contrails form in the wake of air planes if the air is cold and moist enough. Contrail cirrus comprise those line-shaped contrails and the irregularly shaped cirrus clouds arising from them. Their ice crystals scatter shortwave radiation leading to a reduction in solar radiation at the surface (shortwave cooling). On the other hand, absorption and emission of longwave radiation reduce the outgoing terrestrial radiation, because absorbed infrared radiation is emitted from the cloud tops at significantly lower temperatures than from the Earth surface (longwave warming). For contrail cirrus the warming effect dominates on average.

CONTRAIL CIRRUS IN A GLOBAL MODEL

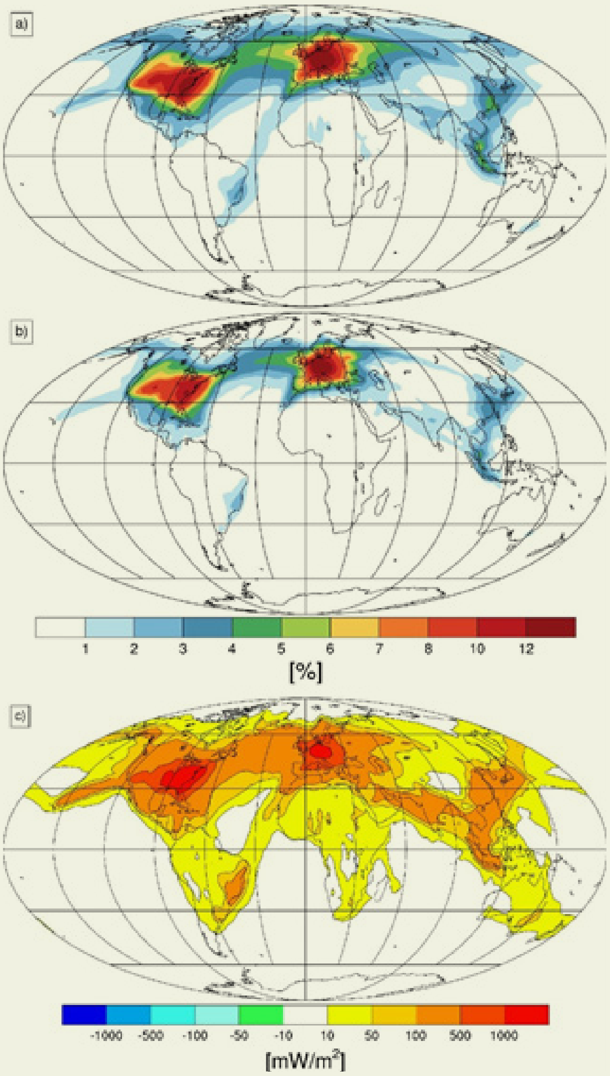
We use a contrail cirrus parameterization developed for the ECHAM5 model (Bock and Burkhardt, 2016a), which is based on the work of Burkhardt and Kärcher (2009). In these parameterizations contrail cirrus is introduced as a new cloud class in the model. Their persistence, advection, spreading, and deposition/sublimation can be estimated independently from the processes of the natural clouds. Hence, the whole life cycle of contrail cirrus is simulated. Contrail cirrus form according to the Schmidt-Appleman criterion (Schumann, 1996) and persist in ice supersaturated regions which are parameterized in the model (Burkhardt et al., 2008). The water and heat budget in the model are closed. Contrail cirrus and natural cirrus compete for available water vapor and contrails feedback on natural cirrus cloudiness due to contrail-induced changes in the temperature and moisture fields in the upper troposphere (Burkhardt and Kärcher, 2011).

For the extension of the contrail cirrus parameterization to a microphysical two-moment scheme (Bock and Burkhardt, 2016a), several processes important for the properties and life cycle of the contrails had to be introduced or improved. Besides the ice crystal number concentration, contrail cirrus volume (air volume in which contrail ice crystals are homogeneously distributed) was introduced as a new prognostic variable with turbulent diffusion and sedimentation leading to its growth. The growth of the contrail volume turned out to be a crucial process for the initial development of young contrails, limiting water vapor deposition. The latter controls the increase in contrail ice water content and ice crystal size and has therefore a strong impact on microphysical processes during the early part of the contrails' life cycle.

Second, the representation of water deposition was improved as compared to the earlier one-moment microphysical scheme (Burkhardt and Kärcher, 2009), limiting the amount of deposited water to an estimate of the diffusional growth of ice crystals dependent on the ice crystal number concentration and ice crystal size. This is, in particular, important in the later stages of the contrail cirrus life cycle but also in areas below the flight level which are dominated by sedimentation. Due to the improved representation of microphysical processes, the temporal evolution of contrail cirrus optical depth, τ, can be resolved more realistically.

RADIATIVE FORCING OF CONTRAIL CIRRUS

Prescribing different air traffic inventories for specific basis years, we simulate contrail cirrus coverage, microphysical properties, and radiative forcing (Bock and Burkhardt, 2016b). We use the simulation for the year 2002 using the AERO2k inventory for a comparison with the results from Burkhardt and Kärcher (2011). The coverage of contrail cirrus with solar optical depth > 0.02 amounts to 0.61%, considerably higher than that estimated by Burkhardt and Kärcher (2011). Such optically thick contrail cirrus contribute 84% to the total contrail cirrus coverage. The main reason for this discrepancy is the fact that contrail cirrus optical depth is large due to the large number of small ice crystals. This could not be resolved with the old contrail cirrus scheme comprising the microphysical one-moment scheme. Our estimate of global radiative forcing due to contrail cirrus is 35mW/m^2, for the year 2002, similar to the 39mW/m^2 of Burkhardt and Kärcher (2011). This is surprising given that coverage due to contrail cirrus with optical depth larger 0.02 is increased by a factor of about 2.7 in the new model, suggesting a larger radiative forcing. The decrease in radiative forcing relative to the contrail cirrus coverage can be explained by a decrease in the vertical overlap of contrail cirrus with natural clouds and by the larger compensation of longwave and shortwave radiative forcing, associated with the new radiation scheme.

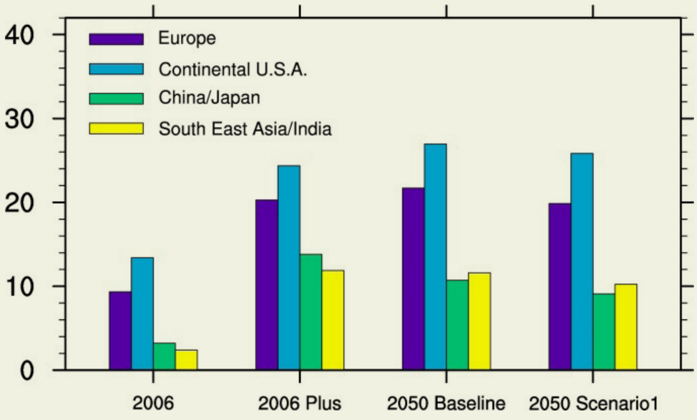


The simulated radiative forcing for 2006 using the AEDT inventory is 56mW/m^2 (Fig. 1). This strong increase by a factor of about 1.6 relative to the estimate for 2002, using the AERO2k inventory, corresponds to the strong increase of flight distance by a factor of 1.8 from the AERO2k inventory for the year 2002 to the AEDT inventory for the year 2006. It should be noted that the increase in flight distance is attributable not only to the increase in air traffic but also to the use of slant flight distance instead of track flight distance and to differences in the data and methods used in producing the inventory. Estimating radiative forcing for 2006 prescribing track distance, we find that about one third of the increase in contrail cirrus radiative forcing may be attributable to the fact that we now use slant distance. The other two thirds could be explained by the increase of flight distance, especially at main air traffic altitudes, and the better representations of flight distance in the newer AEDT inventory. We found that in an area where the representation of flight distance is strongly changed due to the superior data and methods used in the new inventory, that is, in the northern Pacific flight track, contrail cirrus radiative forcing changed only slightly.

FUTURE SCENARIOS FOR 2050

We estimate the effect of a change in air traffic for the year 2050 with our contrail cirrus parameterization (microphysical 2-moment scheme) within ECHAM5. We perform simulations for four scenarios developed at the Volpe National Transportation Centre using the U.S. Federal Aviation Administration (FAA) Aviation Environmental Design Tool (AEDT) (Roof et al., 2007; Barret et al., 2010). This contains a base case for the year 2006 and three future 2050 scenarios. The 2050 baseline scenario describes the increase in air traffic volume, whereas the second 2050 scenario additionally considers the improvement in fuel efficiency. The complete usage of renewable alternative fuel is included in the third 2050 scenario. Therefore, the separate impacts of increases in air traffic volume, the climate change, the improved fuel efficiency and soot reductions when using alternative fuels are investigated. Also regional aspects are shown.

We estimate a strong increase of radiative forcing from 2006 to 2050 due to the larger air traffic volume and the shift of air traffic towards higher altitudes, even though climate change and a reduction in soot emissions act to reduce the climate impact. The relative increase in air traffic is strongest in the tropics and has therefor a particularly large impact on the global contrail cirrus radiative forcing. The shift of future air traffic into higher altitudes intensifies this trend in the tropics. Nevertheless, the Continental U.S.A. and Europe contribute most to the global radiative forcing due to contrail cirrus also for the 2050 scenarios (Fig. 2). We consider in our simulations the climate change until 2050 following the RCP 6.0., which leads to a warming of the upper troposphere and therefore a lower frequency of ice supersaturation. Climate change appears to limit contrail cirrus radiative forcing in the tropics and leads to a slight increase in the USA and Europe. An improvement in fuel efficiency leads to a higher critical temperature for contrail formation, as a result of which the region where contrail could form increases. Nevertheless this has a negligible effect on the global radiative forcing of contrail cirrus. The reduction of soot emissions changes the microphysical properties of contrail cirrus and leads to a decrease in optical thickness and climate impact of contrail cirrus.



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