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Impact on flight trajectory characteristics when avoiding the formation of persistent contrails for transatlantic flights

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ABSTRACT

This paper studies the impacts on flight trajectories, such as lateral and vertical changes, when avoiding the formation of persistent contrails for transatlantic flights. A sophisticated Earth-System Model (EMAC) coupled with a flight routing submodel (AirTraf) and a contrail submodel (CONTRAIL) is used to optimize flight trajectories concerning the flight time and the flight distance through contrail forming regions (contrail distance). All the trajectories are calculated taking into account the effects of the actual and local meteorological parameters, e.g., wind, temperature, relative humidity, etc. A full-year simulation has been conducted based on a daily flight schedule of 103 transatlantic flights. The trade-off between the flight time and contrail distance shows a large daily variability, meaning for the same increase in flight time, the reduction in contrail distance varies from 20% to 80% depending on the daily meteorological situation. The results confirm that the overall changes in flight trajectories follow a seasonal cycle corresponding to the nature of the potential contrail coverage. In non-summer seasons, the southward and upward shifts of the trajectories are favorable to avoid the contrail formation. In summer, the northward and upward shifts are preferred. A partial mitigation strategy for up to 40% reduction in contrail distance can be achieved throughout all the seasons with a negligible increase in flight time (less than 2%), which represents a reasonable trade-off between flight time increase and contrail avoidance.

1. Introduction

Scientific understanding reveals the unequivocal evidence of climate change due to anthropogenic activities since the mid-20th century (Solomon et al., 2007), and aviation shares 3–5% of the anthropogenic causes to climate change. Nevertheless, the demand for air transportation is anticipated to grow at 4.4% per annum in the next 20 years (Airbus, 2017). In facing the continuing expansion of air traffic, the goal of developing eco-efficient aviation becomes increasingly challenging.

Aircraft emit gases such as carbon dioxides (CO_2), nitrogen oxides (NO_x), water vapor, sulphur oxides (SO_x), and aerosols. The atmospheric feedback to these species, especially non-CO_2 emissions, involves complex physical processes acting on different spatial and temporal scales (Lee et al., 2010). The resulting climate impact differs not only by quantity and by type of emissions but also by altitude, geographical location, time and the local weather conditions. Such complexities make it difficult to reduce the climate

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Nomenclature

Abbreviations

ARMOGA	Adaptive Range Multi-objective Genetic Algorithm
BADA	Base of Aircraft Data
PCC	potential contrail coverage
PCCDist	contrail distance [km]
CPs	control points
DJF	December, January and February
DR	distance ratio
EMAC	ECHAM5/MESSy atmospheric chemistry
JJA	June, July and August
MAM	March, April and May
RF	radiative forcing
SAC	Schmidt-Appleman Criterion
SON	September, October and November

Symbols

c_p	specific heat at constant pressure [J/kg/K]
$\Delta\lambda_{airport}$	longitude distance for a given airport pair[km]
α	weight factor
K	coefficient [seconds/km (contrails)]
n	number of waypoints
t	flight time [minute]

Subscripts

dist_opt	maximal contrail distance reduction scenario
t_opt	time optimal scenario
tot	total value

impact of aviation systematically, yet offers mitigation options beyond the sole reduction of emissions, e.g., the optimization of flight trajectories avoiding climate-sensitive regions (Matthes et al., 2017; Rosenow et al., 2017; Lim et al., 2017).

Studies in Lee et al. (2009) and Grewe et al. (2017) show that CO_2 emissions share significantly less than 50% of the total aviation radiative forcing (RF) if non-CO_2 effects from NO_x, water vapor, direct aerosol, contrails and the induced cirrus (contrail-cirrus) are included. Fig. 1 (Grewe et al., 2017) (an update of the Fig. 4 in Lee et al. (2009) shows that the contrail cirrus is the largest individual contributor to the total aviation RF with some uncertainties at the current level of understanding. Due to insufficient knowledge about the aviation induced cirrus, it was not possible to quote a likelihood range with a certain confidence level for the RF of the total contrail cirrus, therefore, only a possible range was given. An identical conclusion is also given in a recent IPCC (Intergovernmental Panel on Climate Change) report (Solomon et al., 2007).

The formation of persistent contrails depends on the environmental conditions and aircraft/engine technologies. The Schmidt-Appleman Criterion (SAC) (Schmidt, 1941; Appleman, 1953) tells that the straightforward technological measure to reduce contrail formation would be reducing the H_2O emission index, increasing the fuel specific heat capacity, or decreasing the propulsion efficiency. Most of them are undesirable for the fuel efficiency of an aircraft. Nevertheless, the technological measures may change the

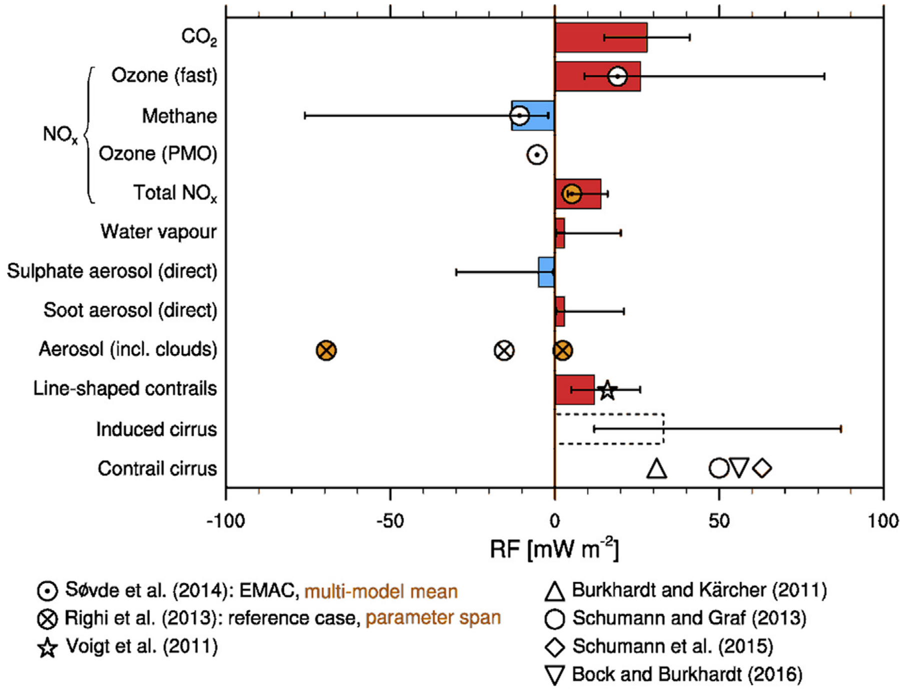

Fig. 1. Aviation induced RF from different components (Grewe et al., 2017; Burkhardt and Kärcher, 2011; Søvde et al., 2014; Voigt et al., 2011; Schumann and Graf, 2013; Bock and Burkhardt, 2016; Righi et al., 2013; Schumann et al., 2015). Error bars represent the 90% likelihood range for each estimate.