FUTURE AVIATION CO_2 EMISSIONS IMPACT ON CLIMATE

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Abstract. A compact Earth system model (OSCAR v2.1) is used to assess the global climate impact of aviation carbon dioxide (CO2) emissions. The impact has been quantified over the 1940–2100 period according to two aviation emissions scenarios based on the Advisory Council for Aeronautics Research in Europe (ACARE) 2050 objectives and the Quantifying the Climate Impact of Global and European Transport Systems (QUANTIFY) A1 reference scenario developed according to the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) storyline. The new calculated change in radiative forcing (RF) due to CO_2 aviation emissions for 2005 is equal to 20 mW/m^2 for ACARE 2050 and 22 mW/m^2 for QUANTIFY A1. It is lower than the previously published figure (28 mW/m^2). The revised lower CO_2 emission level used for this study and the different simple climate models used are the main reasons for the differences. In 2050, the RF increase is lower for ACARE 2050 (52 mW/m^2) than in the other study (>70 mW/m^2 for all scenarios). Conversely, the QUANTIFY A1 scenario 2050 value for RF (80 mW/m^2) is slightly above the Lee et al. values. Compared to the 2010 values, in 2050, the relative contribution of the CO_2 aviation emissions to the temperature increase (ΔT) is expected to increase by 60% (0.95%, 0.89%–1.0% 68% uncertainty range to 1.53%, 1.41%–1.62% 68% uncertainty range) in the case of the ACARE 2050 scenario and more than double (from 1.0%, 0.98%–1.1% 68% uncertainty range to 2.30%, 2.09%–2.46% 68% uncertainty range) in the QUANTIFY A1 one.

Keywords: CO_2, aviation emissions scenario, climate change, OSCAR model, compact Earth system model

INTRODUCTION

It has previously been shown that subsonic aircraft emissions perturb the radiative budget of the Earth in various ways (Sausen et al., 2005; Lee et al., 2009). Aviation emissions are estimated to contribute to 5% (2–14%, 90% likelihood range) to the anthropogenic climate forcing with a nearly threefold uncertainty due to non-CO_2 effects (Lee et al., 2010). In light of the 1.5–2°C COP21 objective, this paper aims to quantify the impact of aviation CO_2 emissions on climate from 1940 to 2050 and up to 2100 using a compact climate model with updated aviation emission scenarios and using appropriate emissions for all other sectors that will respect the Paris agreement.

DESCRIPTION OF THE MODEL

In this study, we use the OSCAR v2.1 compact Earth System model described in Gasser et al., 2016. OSCAR v2.1 is a compact coupled carbon cycle and climate model that calculates the global concentration of CO_2, CH_4, N_2O and halogenated compounds by balancing their historical anthropogenic emissions against the removal processes that define the lifetime of each gas species. As it is done in simplified climate models (Raupach, 2013), the global air surface temperature change (ΔT_AS) is calculate using a climate response function according to the following convolution:

$$\Delta T_{AS} = \lambda_T RF(t') \frac{dr_T}{dt} (t - t')dt' \qquad (1)$$

with t being the time (year), λ_T the climate sensibility (K/W.m^{-2}) of the model used and r_T the response function (year). Those two last parameters have been calibrated against the fifth phase of the Coupled Model Intercomparison Project (CMIP5) results (Taylor et al., 2013).

The various parameterization options offered by OSCAR (i.e., 12 for the oceanic cycle, 13 for the biospheric cycle, 7 for land use and 28 for the climate model) allow 3x10^4 different possible setups that can be used to calculate uncertainties using Monte Carlo methods.

AVIATION EMISSION SCENARIOS

In the frame of the "IMPACT *de l'aviation sur le climat présent et future*" French project funded by the Direction Générale de l'Aviation Civile (DGAC), two emission scenario named ACARE 2050 and QUANTIFY A1 have been used to model the global radiative forcing and temperature increase triggered by CO_2 aviation emissions. Fig. 1 shows the temporal evolution of the aviation CO_2 emissions for five different scenarios over the 1940 -2050 period: three QUANTIFY scenarios (A1, B1 B1-ACARE), an ACARE 2050 scenario and neutral grow one. QUANTIFY A1 is linked to a world of rapid economic growth while ACARE 2050 is more representative of a "green" scenario such as the B1 scenario (2050 values rather close). Hence, for this paper, the QUANTIFY A1 (business as usual) and the ACARE 2050 (optimistic) scenario are used in order to show the rather large range of possible future impacts.

ACARE 2050 is a future emission scenario developed in agreement with the ACARE 2050 CO2 emission reduction objective (ACARE, 2011). The objective is to reach a 75% CO_2 reduction per kg fuel/km/passenger in 2050 in reference to the 2000 value. From 1940 to 1999, the emission data are taken from Sausen and Schumann, 2000. A linear interpolation is used to calculate the value between 1995 and 2005 using the 2005 value from the System for Assessing Aviation's Global Emission (SAGE) (Kim et al., 2007). Then, according to the EU-ACARE 2050 objectives, the 2005 base value is extended using a traffic growth coefficient of 4.6% yr^{-1} associated with an efficiency gain of 2.7% yr^{-1} until 2050. The ACARE 2050 scenario is an optimistic scenario with CO^2 emissions increasing at a slow rate between 2010 (653 Mt) and 2020 (777 Mt) up to 1280 Mt in 2050. The QUANTIFY A1 scenario is taken as described in Owen et al., 2010. For this scenario, the CO^2 emissions from planes are higher than in the ACARE 2050 case and increase from 870 Mt in 2010 to 1063 Mt in 2020 to reach a maximum of 2418 Mt in 2050.

The historical non-aviation CO2 emissions for the 1940 - 2010 period come from the Carbon Dioxide Information Analysis Center (CDIAC) (Boden et al., 2013). As the main objective of the study is to quantify the impact of the aviation sector on future climate in a 1.5 -2 °C temperature increase projection (i.e. COP21 Paris agreement), RCP2.6 is used for emissions from other sectors (i.e. energy, industry, agriculture). Indeed, among the four RCPs assessed by the IPCC, RCP2.6 is the one that aims to limit global warming to less than 2 °C above preindustrial levels (Van Vuuren., 2011).

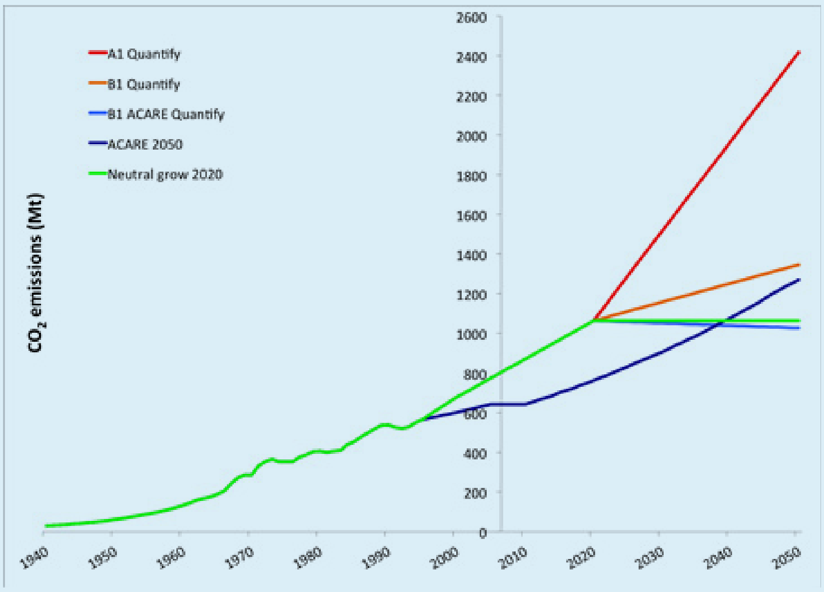

Figure 1. Past and future CO_2 aviation emissions (Mt) using the QUANTIFY A1, ACARE 2050 and other scenarios over the 1940 - 2050 period.

RESULTS

OSCAR v2.1 was used to model the temporal evolution of different global climate change indicators such as the CO_2 atmospheric concentration, the global radiative forcing (RF) and the air surface temperature (T) under the influence of two CO_2 aviation emissions scenarios. RF and T are relative to their preindustrial level and are denoted ΔRF and ΔT, respectively. The results with (red lines) and without (blue lines) airplane emissions are shown on Fig. 2 for ΔRF and ΔT using the QUANTIFY A1 (top) and the ACARE 2050 scenarios (down). The relative contribution (%) is shown in green.

When using the QUANTIFY A1 scenario, the RF absolute contribution of aviation increases from 22 mW/m^2 (20–23 mW/m^2, 68% uncertainty range) in 2005 to a maximum of 80 mW/m^2 (73–85 mW/m^2, 68% uncertainty range) in 2050. Due to the fact that non-aviation emissions decrease massively from 2020 (RCP2.6), the relative contribution of the aviation sector to the RF increase is doubled between 2020 (1.30% 1.23–1.36%, 68% uncertainty range) and 2050 (2.77 %, 2.52–2.94%, 68% uncertainty range). OSCAR modelled a temperature increase of 11mK (8-13 mK, 68% uncertainty range) in 2005 up to 42 mK (33–46 mK, 68% uncertainty range) in 2050. The relative contribution to the temperature increase shows a maximum of 2.3% (2.09–2.46 %, 68% uncertainty range) in 2050.

The ACARE 2050 scenario shows the benefit of decreasing the CO_2 emissions from planes in term of RF and temperature. Indeed, in 2050, the RF from planes is reduced to 52 mW/m^2 (47–57 mW/m^2, 68% uncertainty range) while the temperature increase is maximal in 2050 with 28 mK (22–33 mK, 68% uncertainty range) of increase. Such as for the QUANTIFY A1 scenario, the aviation transport sector contributes to slightly more than 1% of the global RF and T increase in 2020. Although, an increase of RF and T due to the CO_2 aviation emissions is encountered after 2020, the relative contributions of CO_2 airplane emissions stay, however, lower by about 1% for RF and 0.77 % for T in 2050 (1.77%, 1.63–1.86%, 68% uncertainty range for RF and 1.53%, 1.41–1.62%, 68% uncertainty range for T) compared to the values calculated using the QUANTIFY A1 scenario.

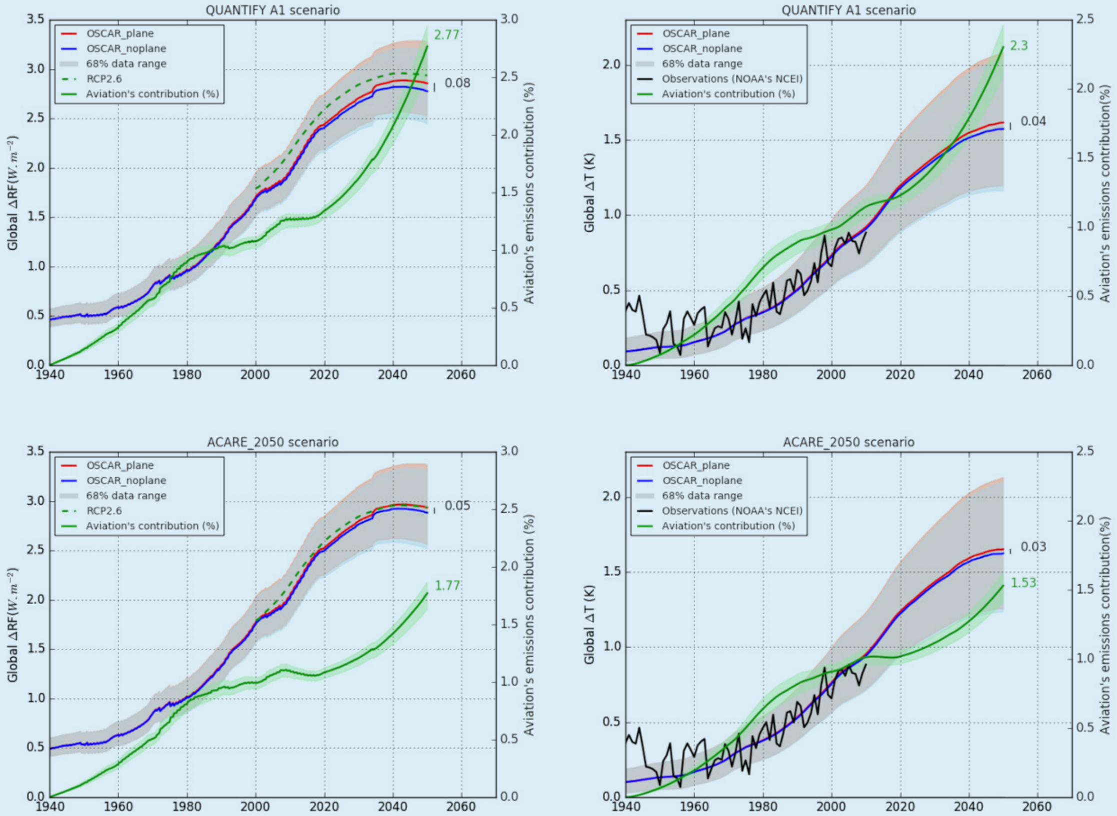

Figure 2. Temporal evolution (1940 - 2050) of the ΔRF (W/m^2) and ΔT (K) for the QUANTIFY A1 (top) and ACARE 2050 scenarios (down).

CONCLUSIONS AND DISCUSSION

A long-term simulation of the CO_2 aviation impact on climate was done using the compact coupled carbon cycle and climate model OSCAR v2.1 over the 1940 - 2050 period in the 1.5-2°C context (e.g. RCP2.6) using two emission scenarios. The emissions are based on referenced historical data (1940-1999) and on the QUANTIFY A1 CO_2 aviation emissions scenario and ACARE 2050 objectives (2000-2050) for the future. The calculated RF value for 2005 (20 mW/m^2 for ACARE 2050 and 22 mW/m^2 for QUANTIFY A1) is lower than the reference value from Lee et al., 2009 (28 mW/m^2). The revised lower CO^2 emission level used for this study and the different simple climate models used are the main reasons for the differences. In 2050, the RF increase is lower for ACARE 2050 (52 mW/m^2) than in the other study (>70 mW/m^2 according to the scenario). However, the QUANTIFY A1 scenario value for RF due to aviation (80 mW/m^2) is slightly above the Lee et al.

values. In 2050, the two RF values calculated using the ACARE 2050 and QUANTIFY A1 emission scenarios span a range of possible values in the future (2050). Compared to the 2010 values, in 2050, the relative contribution of the CO2 aviation emissions to the temperature increase (ΔT) is expected to increase by 60% (0.95%, 0.89%–1.0% 68% uncertainty range to 1.53%, 1.41%–1.62% 68% uncertainty range) in the case of the ACARE 2050 scenario and more than double (from 1.0%, 0.98%–1.1% 68% uncertainty range to 2.30%, 2.09%–2.46% 68% uncertainty range) in the QUANTIFY A1 one. Therefore, in the context of limiting global warming to below 2°C, the aviation is projected to have a stronger impact on climate in the near future, especially, if no significant effort is done to mitigate the emission from this sector (e.g. QUANTIFY A1 scenario).

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