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Etienne Terrenoire, Didier Hauglustaine

IMPACT OF PRESENT AND FUTURE AIRCRAFT EMISSIONS ON ATMOSPHERIC COMPOSITION AND RADIATIVE FORCING OF CLIMATE

E. Terrenoire[1] & D. Hauglustaine[2]

[1] *ONERA – DMPE – Université Paris Saclay, France, etienne.terrenoire@onera.fr*
[2] *LSCE – IPSL – Université Paris Saclay, France, didier.hauglustaine@lsce.ipsl.fr*

Abstract. Depending on the nature and the location of the emitted chemical agents, aircrafts contribute to warm or cool the climate. The chemical perturbation and the associated radiative forcing of carbon dioxide, ozone, methane, soot carbon (BC), sulphates, nitrates and organic carbon (OC) due to aircraft emissions have been calculated using five different global emission inventories using a carbon cycle compact climate change model and the climate-chemistry global model LMDz-ORCH-INCA. We found that the impact of the aviation CO_2 emissions ranges from 45 ± 2 mW/m^2 (2.5 % of the total anthropogenic warming) for an ambitious mitigation strategy scenario (Factor 2) to 78 ± 4 mW/m^2 (2.5 % of the total anthropogenic warming) for the least ambitious mitigation scenario of the study (ICAO based). Apart from CO_2, the total radiative forcing related to aviation and modifications of gases and aerosols calculated in this work is negative and varies from -2.5mW/m^2 for the present scenario REACT4C (-3.6 mW/m^2 in the case QUANTIFY_2000).

Keywords: present and future aircraft emission, short-term climate impact, global climate model

INTRODUCTION

Depending on the nature and the location of the emitted chemical agents, aircrafts contribute to warm or cool the climate. Three other major effect should be distinguished: the short-term effects (a few weeks at maximum), the long-term effects (from one year to more than 100 years) and the cloud type effects. In this paper, we will present global long-term CO_2 and short-term impacts for present and future aircraft emissions that are predominantly related to the injection of nitrogen dioxides (NO_x=NO+NO_2), water (H_2O) and non-methane hydrocarbon (NMHC) by planes. They perturb the tropospheric and lower stratospheric repartitions of ozone (O_3), methane (CH_4,) water (H_2O), sulphur dioxide (SO_2), sulphate (SO_4) and nitrate (NO_3). Other short-term effects are linked with the direct injection of aerosols such as back carbon (BC), organic carbon (OC) and sulphate (SO_4). Other effects that will be evaluated include the long-term effect link to CH_4 concentration decrease due to OH enhancement from the NO_x aircraft emissions. This paper aim to bring an updated estimation of the climate impact of those species based on leading-edge carbon cycle compact climate model and climate-chemistry global model LMDz-ORCH-INCA using multi scenarios analysis.

AIRCRAFT EMISSIONS INVENTORIES

Emission for present comes from the inventory Reducing Emissions from Aviation by Changing Trajectories for the benefit of Climate project (REACT4C) (Sovde et al., 2014).The inventory had to be adapted to our simulations as some species were not available in the original version of the database. First, for NO_x (assimilated as NO_2) and BC the data are taken directly from the original inventory. Second, for H_2O, CO and HC the data comes from the AERO2K project (Eyers et al, 2005). Third, for OC, SO_2 and SO_4, we use the mean emission factors that are reported in Lee et al. (2010). In parallel to the REACT4C inventories, another inventory representative of the 2000 emission was used. The inventory is called QUANTIFY in reference to the project of the same name. For this scenario only the fuel burn, NO_2 and BC are available. For the other species of interest (H_2O, CO, HC, OC, SO_2, SO_4), the emission factors are identical to the ones used for REACT4C. The total emissions of primary species such as NO_x, BC, SO_2 and sulphates from the QUANTIFY_2000 scenario are slightly higher than those of REACT4C (ex: 0.77 kgN/year for REACT4C_2006 against 0.84 kgN/year for QUANTIFY_2000). In QUANTIFY_2000, the species available in the original files are fuel burn, NO_2 and BC. For the other species (CO_2, H_2O, CO, HC, OC, SO_2, SO_4), the emission factors are identical to those used for the

constitution of the basic REACT4C inventory. The spatial distribution is similar for both inventories.

METHODOLOGY

Using the compact Earth System Model (ESM) OSCARv2.2 (Gasser et al., 2017), we quantify the climate impact of present and future (up to 2100) civil aviation carbon dioxide (CO_2) emissions using eight aviation scenarios ranging from 386 Mt CO_2/year (Factor 2 scenario) to 2338 Mt CO_2/year (ICAO/CAEP scenario) in 2050. This approach allow quantifying the uncertainty due to the difficulty to estimate the future mitigation effort. The influence of other emission sectors is evaluated using two background Representative Concentrations Pathways (RCP2.6 and RCP6.0).
For the short-term species, a new version of the LMDz-INCA (LMDz version 5, INCA version 4) have been used. This new version has 39 vertical levels and extends up to 80 km in altitude. The vertical resolution has been improve around the cruise altitude of planes (<1 km). CNRS-LIVE has used the LMDz-INCA global chemistry-aerosol-climate model coupling on-line with the LMDz (Laboratoire de Météorologie Dynamique, version 5) General Circulation Model (Hourdin et al., 2006) and the INCA (INteraction with Chemistry and Aerosols, version 4) model (Hauglustaine et al., 2004). INCA initially included a state-of-the-art CH_4-NO_x-CO-NMHC-O_3 tropospheric photochemistry (Hauglustaine et al., 2004). The tropospheric photochemistry and aerosols scheme used in this model version is described through a total of 123 tracers including 22 tracers to represent aerosols. The model includes 234 homogeneous chemical reactions, 43 photolytic reactions and 30 heterogeneous reactions. Please refer to Hauglustaine et al. (2004) and Folberth et al. (2006) for the list of reactions included in the tropospheric chemistry scheme. The gas-phase version of the model has been extensively compared to observations in the lower-troposphere and in the upper-troposphere. For aerosols, the INCA model simulates the distribution of aerosols with anthropogenic sources such as sulfates, nitrates, black carbon, particulate organic matter, as well as natural aerosols such as sea-salt and dust.

RESULTS

In 2050, on a climate trajectory in line with the Paris Agreement limiting the global warming below 2 °C (RCP2.6), we found that the impact of the aviation CO_2 emissions ranges from 45 ± 2 mW/m^2 (2.5 % of the total anthropogenic warming) for an ambitious mitigation strategy scenario (Factor 2) to 78 ± 4 mW/m^2 (2.5 % of the total anthropogenic warming) for the least ambitious mitigation scenario of the study (ICAO based) (Terrenoire et al., 2019). Figure 1 summarizes the radiative forcing calculated for the different scenarios for the short-term species (Terrenoire et al., in preparation). The increase of ozone in the troposphere is responsible for a positive radiative forcing of 15.8 mW/m^2 for the present reference scenario REACT4C_2006. In the case of methane we calculate a negative forcing of about -15 mW/m^2 for different simulations by aviation. These two steady-state forcings associated with nitrogen oxides (ozone and methane) largely offset each other. The forcing of methane can in fact be broken down into four distinct forcings: a direct forcing and three indirect forcing. Indirect forcings were recalculated with the LMDZ-OR-INCA model. On the one hand, the increase in OH directly disrupts the methane well in the atmosphere. The increase in this photochemical loss results in a decrease in methane and a direct radiative forcing at equilibrium of -10.7 mW/m^2 for the present. Concentrations of several types of particles will also be disrupted by aviation-related emissions. Direct emissions of soot carbon (BC) by aviation induce a positive radiative forcing of 0.46 mW/m^2 in the present case for the REACT4C inventory. In the future, this forcing reaches 1.88 mW/m^2. Sulfates that are reflective particles will be influenced by SO_2 emissions but also by direct SO4 emissions. The negative forcing associated with these particles dominates the effect of the other particles (-3.9 mW/m^2). The distribution of nitrates is indirectly affected by aviation by the variation of the content in sulphates and the NO_x disturbance. These particles are responsible for a

positive forcing (0.07 mW /m^2). A slight negative forcing is associated with the emission of organic carbon by aviation. In total the particles are responsible for a negative forcing largely dominated by sulphates ranging from -3.4 mW/m^2 in this case REACT4C. Apart from CO_2 and streaks, the total radiative forcing related to aviation and modifications of gases and aerosols calculated in this work is negative and varies from -2.5 mW/m^2 for the present scenario REACT4C (-3.6 mW/m^2 in the case QUANTIFY_2000).

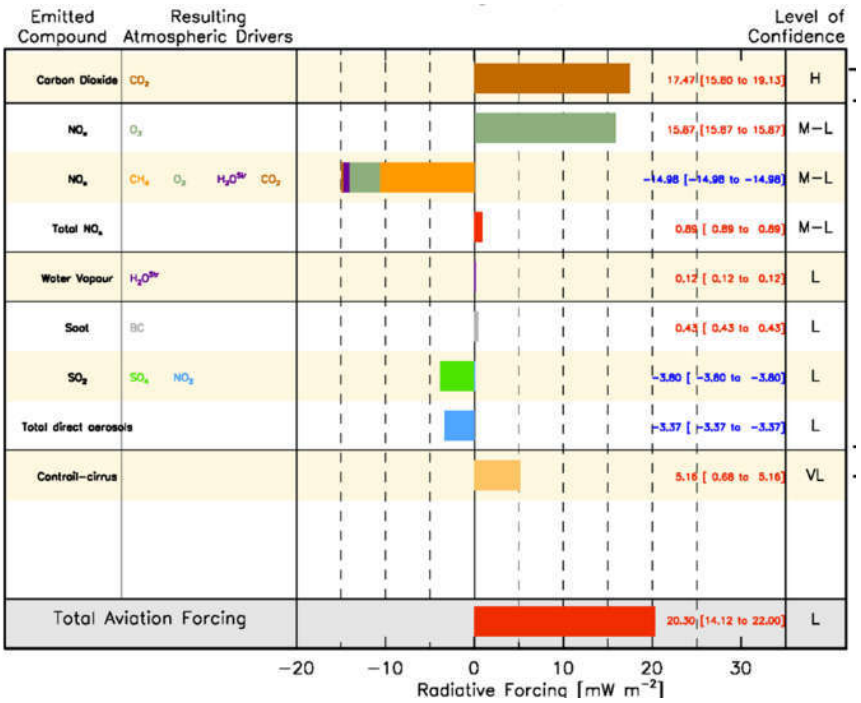

Figure 1: Radiative forcings of climate associated with aircraft emissions REACT4C emission inventory (2006).

CONCLUSION

The chemical perturbation and the associated radiative forcing of carbon dioxide, ozone, methane, soot carbon (BC), sulphates, nitrates and organic carbon (OC) due to aircraft emissions have been calculated using five different global emission inventories using a carbon cycle compact climate change model and the climate-chemistry global model LMDz-ORCH-INCA. We found that the impact of the aviation CO_2 emissions ranges from 45 ± 2 mW/m^2 (2.5 % of the total anthropogenic warming) for an ambitious mitigation strategy scenario (Factor 2) to 78 ± 4 mW/m^2 (2.5 % of the total anthropogenic warming) for the least ambitious mitigation scenario of the study (ICAO based). The increase of ozone in the troposphere is responsible for a positive radiative forcing of 15.8 mW/m^2 for the present reference scenario REACT4C_2006. In the case of methane, we calculate a negative forcing of about -15 mW/m^2. In total, the particles are responsible for a negative forcing largely dominated by sulphates ranging from -3.4 mW/m^2 in this case REACT4C to -10.6 mW/m^2 in 2050. Apart from CO_2 and streaks, the total radiative forcing related to aviation and modifications of gases and aerosols calculated in this work is negative and varies from -2.5mW/m^2 for the present scenario REACT4C (-3.6 mW/m^2 in the case QUANTIFY_2000).

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