The impact of air traffic on tropospheric composition
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ABSTRACT

Aircraft emissions establish a major contribution to the pollution of the upper troposphere and lower stratosphere in particular in corridors with increased flight densities. As an example, the North Atlantic corridor should be mentioned. Using current estimates of aircraft emissions a mesoscale chemical transport model has been applied to assess the impact of air traffic in this corridor on the tropopause region through the simulation of episodes. The results indicate that it is important to develop realistic emission scenarios for such simulations. Nevertheless, simplified scenarios can be used to investigate interactive processes of tracer transport and chemical transformation and thus to establish a more reliable basis for the assessment of global climate effects.

INTRODUCTION

The observation of a gradual increase of the ozone concentration near the tropopause and an expected growth of air traffic during the next decade have caused serious concern about possible negative effects of airplane exhaust regarding atmospheric composition and global climate trend. Though fossil fuel consumption by aircraft is only a small fraction of total consumption (about 6%) and NOx production by aviation amounts to an even smaller fraction (around 3%) of total anthropogenic NOx emissions pollution through subsonic flights occurs in a quite vulnerable height range of the atmosphere, namely around the tropopause (Schumann [11], Hoinka et al. [7]). About 30% of the total NOx input to these regions seems to be caused by airtraffic whereas 70% is due to up- and downward mass-transport from lower tropospheric and upper stratospheric levels, respectively, and to lightning (Ehhalt et al. [4]). Other emissions like those of CO2 and water vapour also occur, but the major effect on atmospheric composition can obviously be ascribed to NOx leading to an increase in net ozone production (e.g. Beck et al. [1]).

Many details of the processes controlling the impact of subsonic air traffic emissions on the upper troposphere and lower stratosphere still lack
complete understanding. Uncertainties exist in the estimates of emission rates as a function of latitude, longitude, height and time. A critical parameter for the assessment of airplane exhaust efficiency is the cruising time above and below the tropopause (Hoinka et al. [7]) because significant differences exist in chemical transformation and transport behaviour in the lower stratosphere and upper troposphere. An important part of relevant transport processes occurs in the larger mesoscale. As an example, tropopause folding is mentioned. The mesoscale is relatively unexplored in the context of air traffic emission effects, whereas more emphasis is put on the investigation of plume chemistry and mixing on the one hand and global scale effects on the other hand. This study is intended as a contribution to filling the existing gap. A transport model has been applied to study regional meso–scale chemical features of the impact of subsonic aircraft emissions.

REGIONAL ASPECTS
An appreciable fraction of the cruising time is spent over limited areas (e.g. McInnes and Walker [8]). The North Atlantic flight corridor and Europe represent such areas. They have been selected as target regions for a series of air traffic pollution simulations on the larger meso–scale. The goal is a better understanding of the interaction of complex chemistry and tropopause dynamics, for instance the scavenging of airplane exhaust through tropopause folding events. It is important to note that a considerable fraction of emissions from aviation is found in a latitude belt (about 40–60°N) where tropopause folds and cut–off lows are a frequent phenomena and strongly contribute to stratosphere–troposphere exchange. This also affects the dispersion of polluted air in the flight corridors and shows that the distribution of emissions cannot only be treated as a function of cruising heights and times.

MODEL DESCRIPTION
The European Acid Deposition (EURAD) model is a system of submodels to treat transport, chemical transformation and deposition of pollutants in the meso–scale (Ebel et al. [3]). The model is applied to episodic studies in the order of several days. A new version of this model has been extended to 10 hPa to include all flight altitudes (Elbern et al. [5]). By doing this the number of vertical layers increased from 15 to 29. Because most airplanes cruise in the upper troposphere or lower stratosphere the vertical resolution was improved especially in the tropopause region. More about the model is found in [2], [6], [9] and [12].

SIMULATIONS OF AIRCRAFT EXHAUST IMPACT
For the episode from October 11 to 21, 1993 passive tracer studies and studies of reactive species following trajectories were performed concer-
ning the trans-Atlantic airtraffic and its effect on the composition of the atmosphere. The meteorological situation is characterized by a high pressure system with its center over Greenland and a trough developing over the central Atlantic.

**Figure 1**: Distribution of passive tracers 12 hours (left panel) and 36 hours (right panel) after release along a mean transatlantic flight path. Upper part: horizontal distribution in the 200 hPa level. Lower part: E–W cross sections along the lines displayed in the corresponding upper panels. For further explanations see text.

Passive tracer studies
Both pressure systems are strongly influencing the trans–Atlantic flightroutes and the distribution of the aircraft exhausts which is studied by simu-
Computer Simulation

Lating passive tracer transport. In lack of the actual flight routes which are individually fitted to the wind system we assume flight routes according to their mean distribution (McInnes and Walker [8]). Along these routes passive tracers are assumed to be emitted during October 13 in approximately 200 hPa height. Then the emissions are stopped to avoid accumulation. Fig. 1 shows their redistribution by the actual wind system in four sketches. The upper panels show the horizontal tracer redistribution in the 200 hPa level 12 hours and 36 hours after the start of the simulation, respectively. On the lower part, the corresponding vertical distribution is displayed in E–W cuts for October 13 and October 14 along the lines marked by A—B in the upper part. The horizontal cuts show that the predominant jet system captures the tracers so that they are quickly disposed. After 36 hours the distribution of the tracers covers the whole model domain and even details of the predominant wind system are revealed. The bold line in the vertical cross section shows the tropopause. Following this line the emissions move downward with stratospheric air where they may be mixed into the troposphere by eddy diffusion.

Trajectory studies

Trajectory studies have been conducted to study the fate of aircraft emissions in airparcels transported away from a flight path. Chemical box calculations have been carried out. They show that $NO_x$ emissions from air traffic lead to a general increase of the concentration with differences larger during the night than during the day. Of course, box calculations have to be regarded as a first approximation to more realistic calculations taking into account, e.g., entrainment of ambient air. Nevertheless, they are helpful to identify major impacts due to aircraft emissions. An example of the calculations is exhibited in Fig. 2. As regards the small amounts of concentration changes it should be noted that they are derived from a single flight and that the total effect of a larger number of cruises in a flight corridor is certainly significant. A model experiment for a more realistic scenario is discussed in the next section.

Line source simulation

A run with the 29 level three-dimensional version of CTM2 was performed for a different episode (April 1986) above central and western Europe. As in the trajectory studies we chose the 200 hPa level as flight altitude. Since no detailed emission scenarios are available the source is treated as a E–W line source above Europe. The emissions are estimated according to Weyrauther et al. [13], height class 30–35, without water. We further assumed permanent emissions. The impact of aircraft pollutants on the chemical composition of the atmosphere at 200 hPa is examined by comparing simulations with and without airtraffic. Again the main effects are observed in dynamically active areas (Fig. 3). In those areas where the emissions are advected $NO_2$ is removed (left frames) while $O_3$ values increase (right frames). Increasing $NO_2$ concentrations are found during night–time (upper
left frame) as \( NO \) is emitted and oxidated while \( NO_2 \) cannot be photolyzed. In these areas of increasing \( NO_2 \) ozone is removed by the oxidation of \( NO \). Instead ozone accumulates in areas with originally high values. The resulting distributions show the influence of both dynamics and chemical transformation: When the run with emissions is compared to the base case (without emissions) the main differences appear along the corridor and in dynamically active areas. Obviously the emitted species can change the atmospheric composition even far away from the region where they are released.

![Graph](https://via.placeholder.com/150)

**Figure 2:** Influence of aircraft emissions on \( O_3 \) (upper frame) and \( NO_2 \) (bottom frame) calculated with a box model without entrainment. The solid line shows the calculated concentrations without emissions, the dotted curve is obtained when emissions are included. The temperature of the box (coarse dashed line) and the pressure level of the box along the trajectory (fine dashed line) are also displayed.
CONCLUSIONS

Emissions caused by air traffic may significantly affect the composition of the tropopause region on a regional scale. The primary pollutant of major concern is $NO_x$. Mesoscale models with sufficient resolution enable a rather detailed treatment of aircraft emissions in their early phase of diffusion in the atmosphere and accompanying chemical transformation. Simulations with the EURAD model have revealed the important role which mesoscale circulation disturbances are playing for the diffusion process. Yet realistic episode simulations also require detailed emission models with regard to spatial structures and temporal changes. Such data are not yet available. Regarding the fundamental importance mesoscale aircraft pollutant studies have for the assessment of the impact of air traffic on the atmosphere appropriate mesoscale emission scenarios have to be generated as soon as possible. An additional reason for spending more efforts on this topic is the fact that such scenarios are also needed for the interpretation of airborne measurements aiming at the experimental evaluation of air traffic impact on atmospheric composition.

Extrapolations of mesoscale effects to the global scale seem to be possible in some cases, e.g. for the influence of stratosphere–troposphere exchange (Elbern et al. [5]). Of course, global models are more conveniently applied in this context. They have also been applied to the evaluation of the effect of water vapour emission on radiative processes. Water vapour was not considered in this study which was mainly aiming towards the treatment of chemically reactive emissions. Future mesoscale studies are planned which will also concentrate on $H_2O$ emissions and their possible perturbations of diabatic processes affecting the vertical mixing of air traffic pollutants in the upper troposphere on the mesoscale.

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Figure 3: Influence of permanent aircraft emissions along a line in E–W direction on $O_3$ (right) and $NO_x$ (left) at 200 hPa at night (upper panels) and day (bottom).

REFERENCES


