MOZAIC

Measurement of ozone, water vapour, carbon monoxide and nitrogen oxides aboard Airbus in-service aircraft

- Long Term Observations of the Atmosphere
- Atmospheric Transport and Chemical Processes
- Budgets of Ozone and Water Vapor in the UT/LS
- Impact of Aircraft Emissions

- Quasi continuous sampling between 0 and 12 km altitude
- 2,500 flights per year
- 175,000 hours of ozone and humidity since August 1994
- Carbon monoxide and Nitrogen oxides since 2001

Scientific Background

The ozone balance in the tropopause region is governed by chemical processes involving radical chains. Hydroxyl radicals (OH) are produced from ozone photolysis followed by reaction of the $O(^1D)$ atoms with water. The OH radicals then react with carbon monoxide (CO) and to a minor part with organic compounds to hydroperoxy radicals (HO_2). The recycling pathways of HO_2 to OH depend largely on the concentration of nitrogen oxides (NO and NO_2, which are usually summarised as NOx). In the absence of NO, the radical chain leads to destruction of ozone (Fig. 1). Addition of NOx to the system leads to photochemical ozone formation until at very high levels, the reaction of NO_2 with OH becomes the dominant reaction for chain termination (Fig. 2). Removal of NOx occurs by conversion to HNO_3 and other soluble compounds, which are removed by heterogeneous processes. The accurate knowledge of the distribution of NOx is thus a prerequisite for quantifying the ozone budget in the UT and the potential influence of aircraft emissions on the ozone levels.

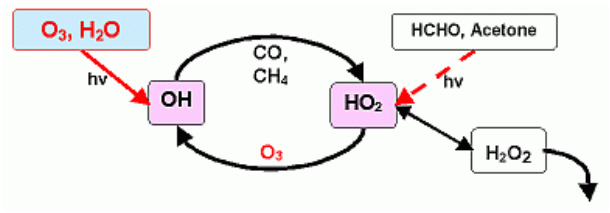


Fig. 1: Radical chemistry in absence of NOx

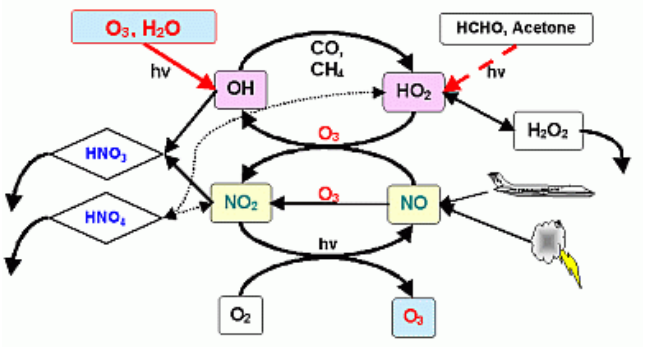
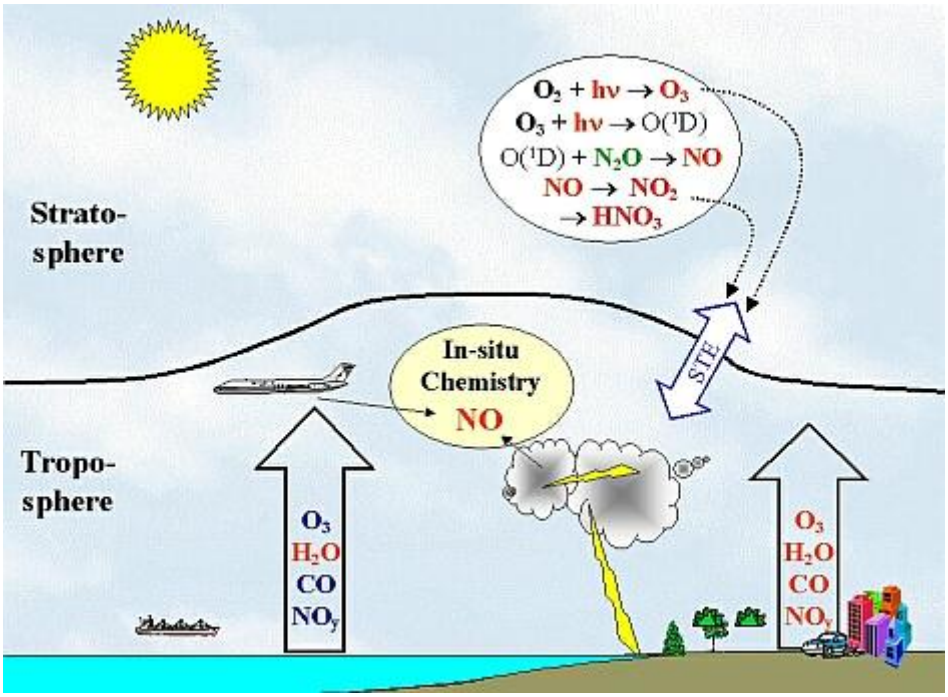


Fig. 2: Radical chemistry in presence of NOx

The sum of NO and its atmospheric oxidation products, e.g., NO_2, NO_3, N_2O_5, HNO_3, HNO_4, PAN and other organic nitrates, as well as aerosol nitrate, is usually defined as NOy. It is a useful tracer to study atmospheric transport processes because of its invariance to homogeneous chemical conversion processes.

The global distribution of ozone and nitrogen oxides is controlled by transport from the atmospheric boundary layer, downward flux from the stratosphere. Additional production of NOx by lightning and by aircraft emissions enhance the NOx concentration and consequently influence ozone.



MOZAIC has received funding by the European Commission since 1993.

The MOZAIC Instruments on five Airbus A-340 long-range aircraft are carried free of charge by four European airlines.

The Partners:

CNRS Toulouse:
Ozone, Carbon Monoxide

FZ-Jülich:
Water Vapour,
Nitrogen Oxides

Univ. Cambridge:
Modelling

Univ. Reading:
Exchange processes

AIRBUS:
Certification, Installation

Lufthansa Technik:
Certification, Installation


Lufthansa (2 AC)

Austrian


Air France


Sabena

Facility for the Calibration of MOZAIC-Humidity Devices

1. Introduction

Within the MOZAIC project (Measurement of Ozone and Water Vapor by Airbus In Service Aircraft) the large scale distribution of tropospheric water vapor is quasi continuously measured on board five AIRBUS A340 aircraft during in-service flights [*Marenco et al., 1998*] by use of regularly calibrated humidity sensors (See Figure 1). MOZAIC is supported by EU (European Union) and sponsored by four major European airlines (Air France (1 aircraft), Austrian Airlines (1 aircraft), Lufthansa (2 aircrafts) and Sabena (1 aircraft)).

Figure 1: *Airbus A340 equipped with MOZAIC-Humidity Device. Inlet system mounted at the outside skin of the aircraft close to the cone.*

The MOZAIC-Humidity Device (MHD) is a special airborne humidity sensing device (AD-FS2), developed by Aerodata (Braunschweig, Germany) and based on the humidity and temperature transmitter HMP230 of Vaisala (Helsinkin, Finnland). As illustrated in Figure 2 the sensing element itself is a combination of a capacitive relative humidity sensor (Humicap-H, Vaisala) and a Pt100 temperature sensor which has been installed in a Rosemount housing mounted on the outside skin of the aircraft in the vicinity of the nose cone. Relative humidity and temperature are electronically measured by a transmitter unit and fed into the data acquisition system of MOZAIC aboard the A340 aircraft. Before installation in the aircraft and after about 500 hours of flight operation, each MOZAIC-Humidity Device is calibrated in the environmental calibration facility.

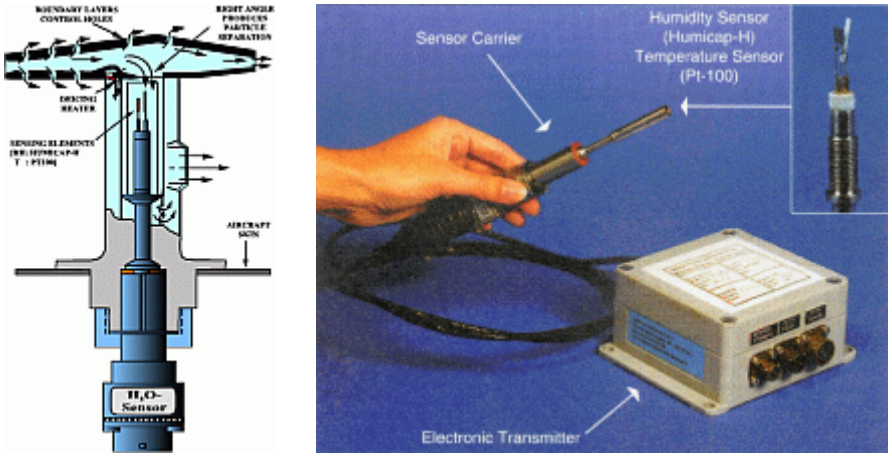


Figure 2: *Left panel: Cross section of the airborne MOZAIC humidity sensor mounted in air sampling housing (Rosemount, Model 102 BX). Right panel: MOZAIC Humidity Device (MHD) to be installed in a Rosemount housing mounted on the outside skin of the Airbus A340 aircraft (see Figure 1).*

2. Calibration of MHD

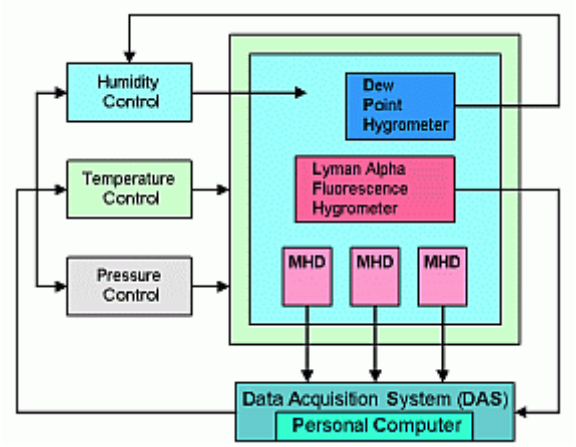


Figure 3: *Scheme of the set up for the calibration of humidity sensing devices in the environmental simulation chamber*

Caused by the high aircraft cruising speed of about Mach 0.8 and the strong speed reduction in the inlet part of the housing the sampled air is subject to adiabatic compression. The conversion of kinetic energy of the sampled air leads to a substantial temperature increase of about 25°C at cruise altitude (10-12 km) such that the relative humidity measured at the sensing element is much lower than the actual relative humidity of the ambient air. This effect necessitates the careful and individual calibration of each flown MOZAIC Humidity Device (=MHD) against a water vapor reference instrument, Lyman alpha Fluorescense Hygrometer (LFH), in the environmental simulation facility at Jülich before and after one month of flight operation. Up to three MHDs can be calibrated simultaneously during a simulation run (See Figure 3). They are positioned just at the outlet of the air flow duct of the LFH (see Figure 4).

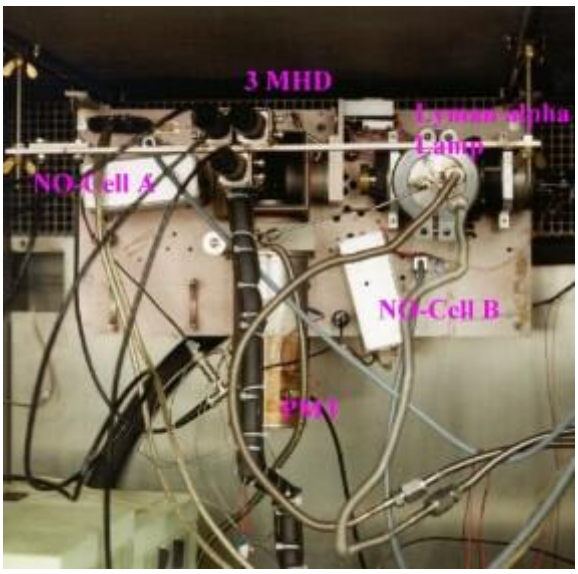


Figure 4: *Three MOZAIC-Humidity Devices (MHD) installed at the outlet of the air sampling duct of the Lyman (α) Fluorescence Hygrometer (LFH) in the environmental simulation chamber just prior to a calibration run.*

A typical calibration run of the chamber is shown in Figure 5. Calibration is executed at three air temperatures, -40°C, -30°C, and -20°C, the prevailing temperatures at which the humidity sensors are operating in the Rosemount housing. The pressure at -40°C and -30°C is set to 180 hPa and for -20°C changed to 400 hPa. At each temperature three different humidity levels are set by adjustment of the wall temperature to the corresponding dew point temperature while optional moistened air is added to compensate for the water deficiency effect. The relatively slowly varying parts of the humidity steps are used to calibrate the MHDs with the LFH as reference.

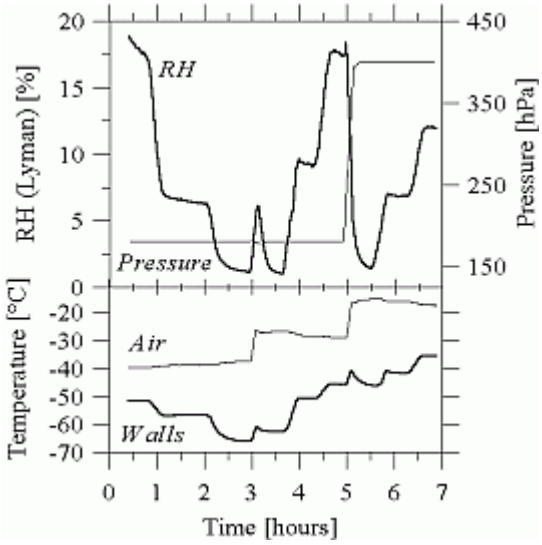


Figure 5: *Water vapor calibration run in the environmental simulation chamber as function of simulation time. Shown are RH, measured by Lyman-Alpha fluorescence hygrometer, pressure, air temperature, and temperature of the chamber walls.*

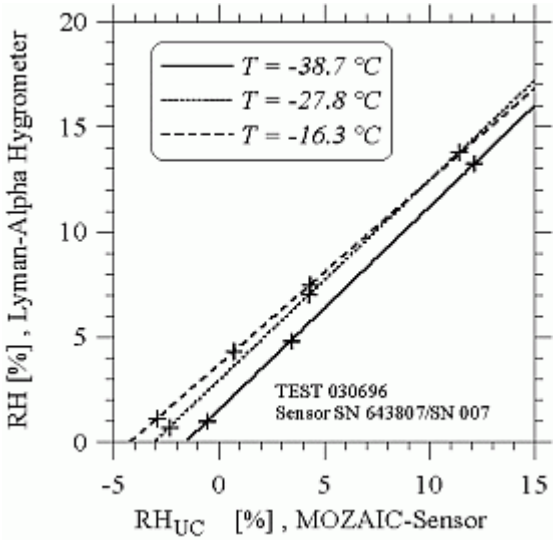


Figure 6: *The calibration of a MOZAIC humidity sensor in the environmental simulation chamber results in three linear calibration curves at three different temperatures.*

An example of the results of a calibration of a MHD at three temperature levels is shown in Figure 6.

All calibrations revealed that the relative humidity of a calibrated sensor (RH_C) for a constant temperature can be expressed by a linear relation

$$\mathbf{RH_c = a + b \cdot RH_{uc}} \qquad [1]$$

where RH_{UC} is the uncalibrated output from an individual sensor, and a and b are coefficients that result from the calibration procedure. Each calibration is executed at three temperatures, -20°C, -30°C, and 40°C, resulting in three pairs of calibration coefficients a and b.The mean of the pre- and post-flight calibration coefficients of each flight period are used to evaluate the measurements. Typical time periods between pre- and post flight calibration runs are determined by the frequency of the main aircraft servicing intervalls and are roughly 500 flight hours apart. The differences between both sets of these calibration coefficients give the main contribution to the uncertainty of the measurement [*Helten et al.*, 1998].

A more detailed evaluation of the calibration and performance of the MOZAIC humidity measurements is reported by *Helten et al.* [1998, 1999].

References

Helten, M., H.G.J. Smit, W. Sträter, D. Kley, P. Nedelec, M. Zöger, and R. Busen, Calibration and Performance of Automatic Compact Intrumentation for the Measurement of Relative Humidity from Passenger Aircraft*. J. Geophys. Res. 103,* 25643 - 25652, 1998.

Helten, M., H.G.J. Smit, D. Kley, J. Ovarlez, H. Schlager, R. Baumann, U. Schumann, P. Nedelec, A. Marenco, In-flight intercomparison of MOZAIC and POLINAT water vapor Measurements, *J. Geophys. Res., 104,* 26,087-26,096, 1999.

Marenco, A., V. Thouret, P. Nedelec, H.G.J. Smit, M. Helten, D. Kley, F. Karcher, P. Simon, K. Law, J. Pyle, G. Poschmann, R. von Wrede, C. Hume, and T. Cook, Measurement of ozone and water vapor by AIRBUS in-service aircraft: The MOZAIC airborne program, an overview, *J. Geophys. Res., 103*, 25,631-25,642, 1998.

NOy-Instrument

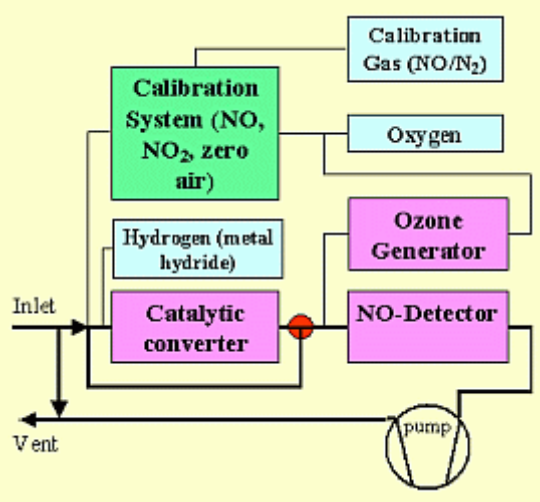
A small, fully automatic instrument for the measurement of total odd-nitrogen (NOy) was developed at FZJ and was installed in 2001 aboard an A-340 long-range aircraft of the Deutsche Lufthansa. The NOy -instrument is installed in the avionic bay below the cockpit next to the special flange which carries the air inlets for the MOZAIC instruments. An avionic oxygen cylinder is mounted under the instrument.

Measurement principle

NOy is defined as the sum of NO and its atmospheric oxidation products, e.g., NO_2, NO_3, N_2O_5, HNO_3, HNO_4, PAN, and aerosol nitrate. The different NOy-compounds are first reduced by traces of hydrogen on a hot gold surface (reaction 1) to NO, which is then detected and quantified by the chemiluminescence upon reaction with ozone (2a,b). The ozone is generated in-situ from ultra pure oxygen in an electrical discharge.

$$\begin{aligned} &(1) && NO_y + H_2 \rightarrow NO \quad (Au, 300°C) \\ &(2a) && NO + O_3 \rightarrow NO_2^* \\ &(2b) && NO_2^* \rightarrow NO_2 + h\nu \end{aligned}$$

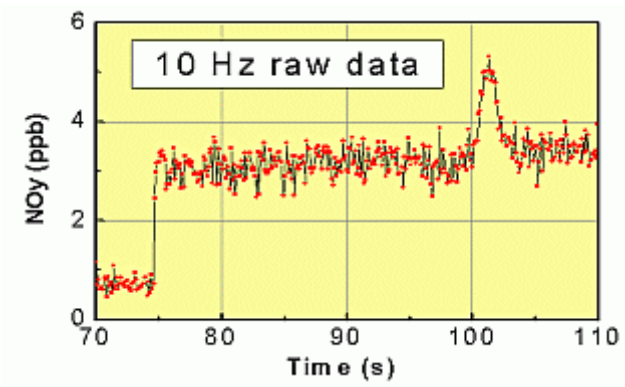
An important aspect for unattended long-term operation is to prevent contamination, e.g. by kerosin vapour, whenever the aircraft is on ground. Just before landing, the instrument is therefore put automatically in the stand-by mode. The pump is then disabled and the inlet is back-flushed with oxygen. The measurement is enabled again after take-off. Once a month, the NOy-instrument is exchanged, serviced and certified for re-installation. Operation is fully automatic by means of a PC-104 system with special software. Sensitivity and conversion efficiency are determined in-situ by automatic calibration.



Principle of the NOy-Instrument.

Specification of the NOy-Instrument

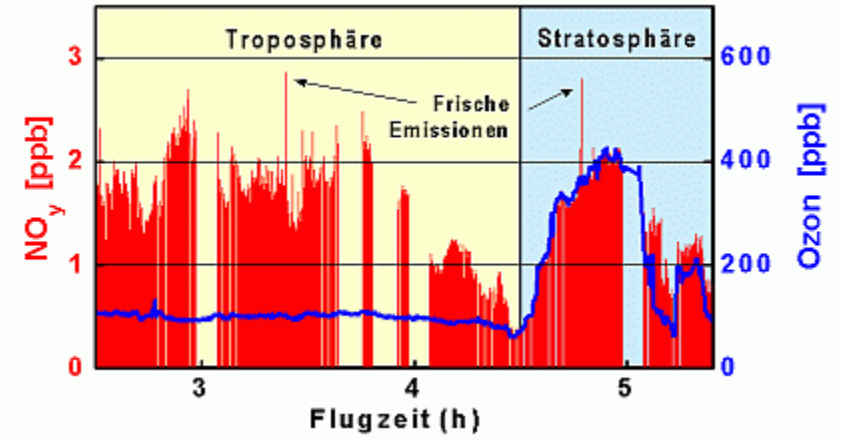
Total weight	50 kg
Power consumption	300 VA
Flow Rate	100 Nml/min
Sensitivity	500 cps/ppb
Time resolution	10 Hz
Precision (2 ppb, 10 Hz)	< 10 %
Detection Limit (4s, 2σ)	± 50 ppt



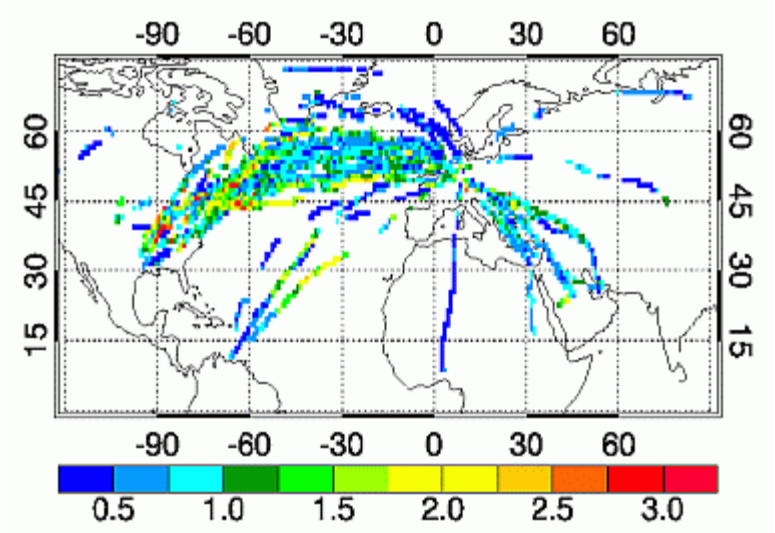
The high time resolution of 0.1 s (corresponding to a distance of 30 m at cruise level) allows to identify aircraft emissions and other recent sources in the raw data.

Results of NOy Measurements

Time series of ozone and NOy (4s averages) during a flight from Boston to Frankfurt. In the lower stratosphere, a good correlation exists between NOy and O_3 (R^2 > 0.9; O_3/NOy ca. 200), in good agreement with results from campaigns with research aircraft. The data gaps are due to automatic calibrations.



The NOy mixing ratio in the upper troposphere is usually below 2 ppb. The significantly higher values over the eastern part of the USA and downwind of the North American continent highlight the importance of convective transport from the atmospheric boundary layer for the chemical composition of the upper troposphere. Because of the much better representativeness compared to episodic campaigns with research aircraft of the MOZAIC data (more than 250 successful flights in the first year of operation), the new measurements provide an important contribution to a better quantification of the NOy budget in the upper troposphere.



Climatology of NOy in the upper troposphere (z > 8km, O_3 < 100 ppb) compiled from the MOZAIC-data beteen April '01 and Feb '02. The color scale gives the mixing ratio in ppb (10^{-9}). The individual measurements were averaged on a 1°x1° grid.