Civil Aviation Monitors Air Quality and Climate

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Vertical profiles of trace gases in the troposphere are paramount for monitoring and predicting changes in air quality on local, regional, and global scales. These data are necessary to calibrate the global chemical transport models that assess the influence of long-range and hemispheric transport of pollutants on local background concentrations or their contribution to the violation of air quality standards.

The profiles can also provide the boundary conditions for regional air quality models that provide guidance for legislative and regulatory issues, as well as 3-D observations for model evaluation. While remote sensing from space has a broad global coverage, it is biased by clear weather and provides very little information about vertical gradients which are critical to evaluating model boundary layer parameterizations and regional flux estimates derived from inverse calculations.[1,2,3] On the other hand, observations from ground-based networks often suffer from limited spatial representativeness due to local influences. The theme reports on atmospheric chemistry[4] and on the global carbon cycle[5] of the Integrated Global Observing Strategy (IGOS) emphasize the need for regular aircraft measurements as an essential complement to ground-based and satellite observations.

History

The use of in-service aircraft for in situ observation of the atmosphere has a long tradition beginning in the 1970s when NASA implemented the Global Atmospheric Sampling Program[6] (http://gcmd.nasa.gov/records/GCMD_NCAR_DS 368.0.html). In 1993, the idea was revived with the European MOZAIC project (http://mozaic.aero.obs-mip.fr), in which airborne systems for ozone and water vapor were installed on five A340 aircraft[7] with carbon monoxide (CO) and total reactive nitrogen (NO_y) added in 2001. More than 25,000 flights have been completed since 1994 (see Figure 1), and three of the aircraft (2 Lufthansa, 1 Air Namibia) are still in service.[8]

At the same time, the Japan Airlines (JAL) project was initiated to regularly collect air samples for measurements of greenhouse gases on flights between Tokyo and Australia.[9] CONTRAIL (www.jal-foundation.or.jp/shintaikikansokue/Contrail_index(E).htm), the follow up JAL project, was started in 2005 with enhanced sampling capabilities and included in-situ measurements for carbon dioxide (CO_2) on five aircraft.[10] In parallel, the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory has been using small aircraft to measure greenhouse gases, carbon isotopes, halocarbons and hydrocarbons between 500 and 8000 m altitude, using automated flask sampling over North America. The program started in 1992 and has been expanded to over 16 sites which are sampled between one and eight times per month and by in situ profiling of aerosol.

By the late 1990s, NOXAR provided the first regular measurements of nitrogen oxides from a passenger aircraft operated by Swiss Air.[11]

The European project CARIBIC (civil aircraft for the regular investigation of the atmosphere based on an instrument container; www.caribic-atmospheric.com) took a different approach by monthly deploying an instrumented cargo container aboard an LTU Boeing 767 and later a Lufthansa A340-600.[12] The large set of measurements comprises those mentioned as well as hydrocarbons, halocarbons, and isotopic composition. A sophisticated inlet system allows accurate measurements of aerosols and allows remote sensing by differential absorption spectroscopy.

The Value

MOZAIC has provided novel information on the distributions of H_2O, ozone (O_3,) CO and NO_y in the upper troposphere and lower stratosphere (UT/LS) as well as vertical profiles down to the surface. The data have been exploited by investigators from research institutions worldwide, resulting in 13 PhD theses and more than 135 peer-reviewed publications.[8] Research topics include the seasonal, geographical, and interannual variation of the trace gases in relation to their sources and atmospheric dynamics, the evaluation of global chemical transport models, and the evaluation of satellite retrievals. Key findings concern the persistent layering of the atmosphere, the large fraction of ice supersaturation in the UT and the strong influence of biomass burning over some regions on the concentrations of CO and NOy in the UT/LS, which are usually not captured by global models.

The combination of MOZAIC data with data from surface stations has been shown relevant for understanding the processes governing the distribution of ozone and its precursors in the boundary layer. For example, the MOZAIC profiles over Frankfurt allowed accurate definition of the ozone and carbon monoxide anomalies within the boundary layer during the summer 2003 heat wave (Figure 3). The ozone pollution peaks at 1 km altitude with concentrations over 90 ppb, largely exceeding the standard deviation of the 1994–2004 climatology. Plumes of CO (> 200 ppb), originating from wildfires over Portugal, were captured above 5 km altitude at the beginning of the heat wave, and likely contributed to the pollution near the surface at the end of the heat wave.

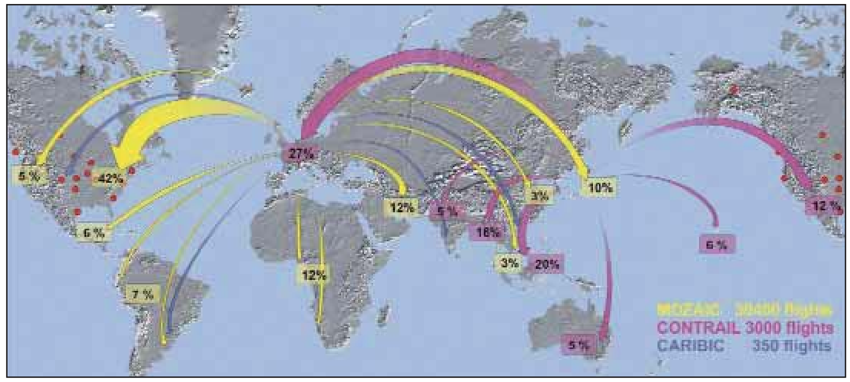


Figure 1. Flight routes of MOZAIC, CARIBIC and CONTRAIL, and locations of the NOAA aircraft network.

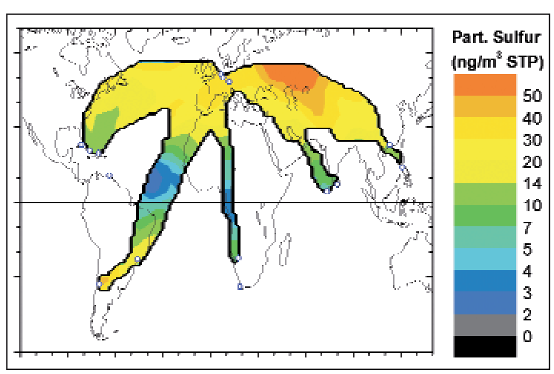
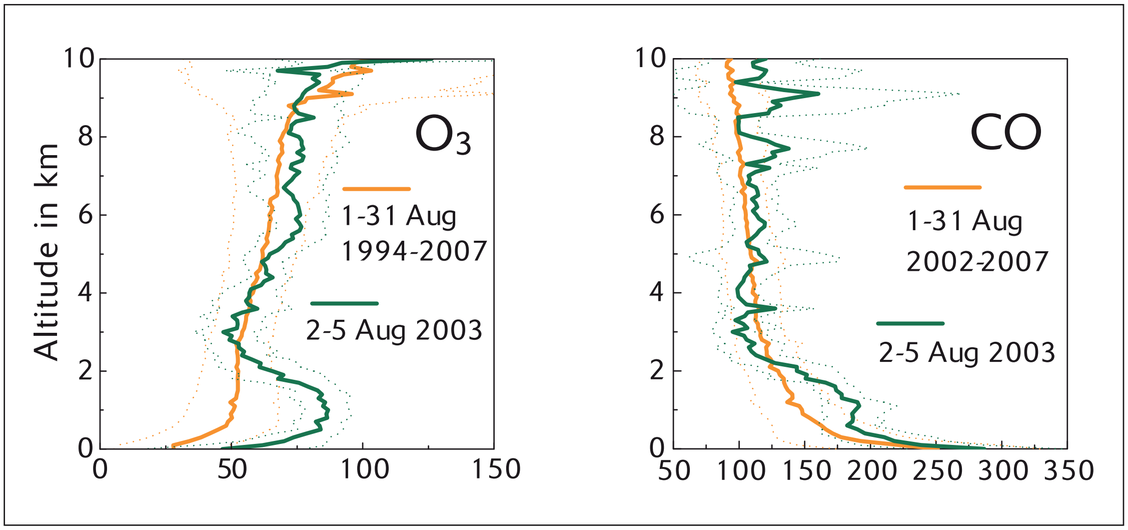


Figure 2. Distribution of sulphate aerosol derived from CARIBIC at cruise altitude (courtesy of Bengt Martinsson, University of Lund).

Figure 3. *Vertical profiles of ozone (left) and carbon monoxide (right) from MOZAIC data on August 2-5, 2003 (green lines) as compared to the climatological profile (1994–2004, red lines) Average profiles solid, standard deviation dashed.*[13]



MOZAIC data were also crucial for the discovery of a large region of high ozone concentrations in the upper troposphere above the southern U.S. that recurs every summer. When these data were merged with data from research aircraft, ozonesondes, and transport models the resulting picture showed that much of the ozone enhancement was due to unexpectedly large ozone production from lightning oxides of nitrogen (NO_x) emissions.[14]

Outlook

After ten years of successful operation, owed to the strong support from the international scientific community, the MOZAIC community decided in 2003 to tackle the challenge of expanding towards a sustainable infrastructure with enhanced measurement capabilities. The first step in the development of the new infrastructure IAGOS (In-service Aircraft for a Global Observing System; www.iagos.org), funded by the European Commission under the 6th and 7th Framework Programme, is the redesign of the heavy MOZAIC rack into a compact package with aeronautic certification for retrofitting on civil aircraft, the development of new instruments for NO_x, H_2O, aerosol, cloud particles, CO_2 and methane, and the provision for real-time data transmission into the meteorological network.[15] Within IAGOS, CARIBIC has joined MOZAIC and also aims at a long-term operation.

Figure 4. *MOZAIC instrument for autonomous NOy measurements in the avionic compartment of an Airbus A340. The new IAGOS equipment will be installed in the same location. (Photo by Udo Kröner, Lufthansa).*

Summary

Routine aircraft observations are providing valuable information on atmospheric composition that improve the understanding of global and regional air quality, as well as the potential impact of greenhouse gasses on climate change. The comparability of measurements from an airborne monitoring network, where data collected from all over the world come from a few identical systems with identical quality assurance procedures, is inherently better than that from many stations operated by different institutions using different instrumentation. In this sense, routine aircraft could even provide a standard for harmonization of different networks.

IAGOS builds on previous European initiatives with novel technological developments and a strong emphasis to expand the network to the Pacific, North America, and into the Southern Hemisphere. The success relies heavily on the willingness of airlines to support the operation. Several airlines, including Lufthansa, Air France, China Airlines, Cathay Pacific, Iberia, and South African Airlines, have already expressed their interest in participating in the new IAGOS infrastructure. Discussions are also underway with scientists to enable a partnership with IAGOS in the U.S., in addition to expanding the NOAA network of small aircraft. Major efforts are still required, however, to secure the financial support for the initial investments and the operation of the IAGOS systems. This requires a mutual approach for securing a sustainable funding stream in the frame of international observing strategies such as GEOSS and its European component GMES. **em**

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