Welcome to the third issue, which sees MOZAIC now gathering data at a rapid rate. It is also time to say goodbye to Georg Poschmann of Airbus Industrie, recently retired. Georg has been involved with MOZAIC since it was conceived about 5 years ago and he has nurtured that idea to fruition. Without Georg there would be no MOZAIC (and no MOZAIC Newsletter - but whether that is a good thing or a bad thing is up to you, dear reader, to decide). So, Georg, a sincere thanks - and may you have a long and happy retirement.

In place of Georg we have now Rainer Von Wrede (Al's Manager, Environment), and we wish him the very best of luck.

**LATEST MOZAIC NEWS**

With all 5 aircraft now flying, the number of flights has reached over 2200. It is nice to see, in the Report of the Fourth WMO Meeting of Experts on the Quality Assurance / Science Activities of the Global Atmospheric Watch programme - "The Working Group was highly impressed with the ongoing MOZAIC project...". It is also worth noting that NASA is interested in making measurements from commercial airliners.

**ATMOSPHERIC MEASUREMENTS FROMOVER 2200 A340 FLIGHTS AVAILABLE**

**Special news**

Many congratulations to Paul CRUTZEN - our colleague in MOZAIC - on his NOBEL PRIZE, shared with Mario Molina and Sherwood Rowland for work on explaining the chemistry of the ozone layer.

Professor Crutzen was one of the speakers at the Airbus Industrie seminar (in July 1990) and contributed to formulating the ideas of MOZAIC and using the first A340 for atmospheric research.

**MOZAIC meeting**

A meeting at Laboratoire d'Aérologie / CNRS in Toulouse in early October discussed a wide range of topics including an update on the status of data collection & processing, the state of the database and presentations of some ozone & water measurements.

The strategy and plans for data interpretation and for modelling were also aired. A draft protocol on data availability was discussed; it aims to encourage, in a way acceptable to the European Commission, rapid dissemination of our results whilst at the same time allowing those science groups directly involved the opportunity to explore and utilise the data.

Future plans for MOZAIC were also an important subject. Although the Commission had been unable to support our proposal for "MOZAIC II" in the current round of funding, the project was considered highly enough to be put on the reserve list. Progress now depends on decisions in the Commission and the availability of funds.

**ICAO matters**

Regulators of aircraft noise & emissions are preparing for the meeting of ICAO's Committee on Aviation Environmental Protection in December. The Committee meets infrequently - about every five years - and recommends noise/emission standards to national governments. At its last meeting, CAEP made the NOx standard more stringent by 20%. Since then a number of working groups have been examining whether further stringency increases are needed and feasible from a technical and economic point of view.

At present, it seems too early to assess the effect of aircraft emissions at high altitude but this will be a topic of great interest in the next few years - and it is projects like MOZAIC that will ensure that the debate is an informed one.
EC matters
The Commission has established five "task forces" to spearhead efforts on joint projects of industrial interest. One of the forces is the Aeronautical Task Force. It will set research priorities, ensure effective co-ordination of available resources (in particular those of the Fourth Framework) and encourage the use of additional financial resources. The task forces work programmes are currently being developed. The aeronautics group is covering issues such as "the Environmentally Friendly Aircraft" and "the More Efficient Aircraft". Its activities will stimulate interest and action in the examination of the aviation/environment relationship.

(C. Hume - AI/BAe, Bristol, UK)

MOZAIC FIRST YEAR MEASUREMENTS
Monthly Vertical Profiles Available Over Various Continents

Figure 1

MOZAIC STATUS

Between April 1994 and March 1995, the five MOZAIC aircraft were delivered to the MOZAIC programme participating airlines : two for Air France, two for Lufthansa and one for Austrian Airlines. By November 22nd 1995, the MOZAIC systems installed on these five aircraft have recorded 2254 flights, which includes mainly long range flights (e.g. Vienna-Tokyo, Frankfurt - San Francisco), but also short range flights (e.g. Rio de Janeiro - Sao Paulo, Dallas - Houston). These 2254 flights represent some 20000 flight hours.

Figure 1 shows the MOZAIC geographical coverage for the period July 1994 - July 1995. For the five continents covered by MOZAIC aircraft, this graph presents the number of vertical profiles (ascents or descents) recorded every month on each continent : between 300 and 400 per month now, 2 vertical profiles per flight.

In 1994, the MOZAIC programme covered mainly Europe, North America and South America. The Austrian Airlines aircraft operations - started end of March 1995 - gives now a better coverage of Asia and Africa, while South America is less covered, due to the airlines redistribution of their A340 flights to North America and Asia.

The two Air France aircraft, based in Paris, are flying to North America (Washington, Miami ...), South America (Sao Paulo, Rio de Janeiro, Caracas...) and Asia (Bangkok, Seoul, Osaka...). They also make local flights in South America and in Asia. The two Lufthansa aircraft operate mainly from Europe (Frankfurt or Köln) to North America (New York, Miami, Dallas, San Francisco, Houston...) and being New York. The Austrian Airlines aircraft is flying mainly from Vienna to Asia (Tokyo, Peking) and Africa (Johannesburg).

The 15 main towns covered by MOZAIC from July 1994 to October 1995 are listed on Table 1. For each town, the number of flights corresponds to flights departing or arriving from/to this town. Three of these main towns are located in Europe, where MOZAIC aircraft are based (Frankfurt, Paris, Vienna), while seven are located in North America, three in South America and two in Asia. Johannesburg, in Africa, can now be added to the MOZAIC main towns (53 flights) after the Austrian Airlines aircraft delivery in March 1995.

(P. Nédélec - CHIMAIR / Toulouse, France)
MOZAIC EXTREME VARIATIONS

Very high ozone concentrations were found in stratospheric air sampled by MOZAIC aircraft over the north-Atlantic, during winter 1995. The highest levels were recorded in February 1995 when ozone mixing ratios greater than 1100 ppb were found at about 11.5 km altitude.

A typical ozone variation is shown in Figure 2 for a transatlantic flight (Frankfurt - New York, on 13/02/1995); it shows that above 9 km altitude - that is to say more than 90% of the time - the aircraft was flying in stratospheric air with ozone concentrations higher than 200 ppb and very low humidity. The ozone maximum (>500-600 ppb) lasted most of the time during several hours and is associated with a lower altitude tropopause or cut-off layer.

When looking at the ozone maxima observed on all transatlantic flights available for February 1995 (see Figure 3), it can be seen that such high values are found during the whole month and increase with altitude: 500-600 ppb at 10.5 km and 600-1100 ppb at 11.5 km altitude.

It is well known that the tropopause altitude is lowest in winter, corresponding also to a shift of the polar front southward. Thus, subsonic aircraft flying over the north-Atlantic are spending much more time in stratospheric air in this period. That is confirmed by the climatology of ozone obtained from MOZAIC data over a one year cycle.

To study the impact of engine exhaust on atmospheric ozone, it is fundamental to have an accurate description of the environment in which the pollutant (NOx,H2O) release occurs. Secondary ozone formation could be expected for an injection in tropospheric air (low ozone, high water vapour). But a quite different effect would be obtained when making these emissions in stratospheric air containing 1000 ppb of O3 and a few ppm of H2O. Ozone destruction will probably occur then, and the question arises of how could these NOx releases in lower stratospheric air affect also the upper layers, if they be transported to higher altitudes by vertical mixing.

The evaluation of subsonic aircraft impact is not possible without a sound validation of the 3D models used. This stresses again the value of experimental programmes like MOZAIC for such a purpose.

(A. Marenco - INSU/CNRS Toulouse, France)

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Table 1 - Main towns covered by MOZAIC programme

<table>
<thead>
<tr>
<th>Town</th>
<th>Number of Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRANKFURT</td>
<td>943</td>
</tr>
<tr>
<td>PARIS</td>
<td>666</td>
</tr>
<tr>
<td>NEW YORK</td>
<td>485</td>
</tr>
<tr>
<td>VIENNA</td>
<td>203</td>
</tr>
<tr>
<td>WASHINGTON</td>
<td>174</td>
</tr>
<tr>
<td>MIAMI</td>
<td>171</td>
</tr>
<tr>
<td>BANGKOK</td>
<td>164</td>
</tr>
<tr>
<td>SAO PAULO</td>
<td>128</td>
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<tr>
<td>CARACAS</td>
<td>124</td>
</tr>
<tr>
<td>HOUSTON</td>
<td>122</td>
</tr>
<tr>
<td>RIO DE JANEIRO</td>
<td>97</td>
</tr>
<tr>
<td>DALLAS</td>
<td>96</td>
</tr>
<tr>
<td>SAN FRANCISCO</td>
<td>84</td>
</tr>
<tr>
<td>TOKYO</td>
<td>79</td>
</tr>
<tr>
<td>BOSTON</td>
<td>79</td>
</tr>
</tbody>
</table>

Variations of Ozone concentrations in Stratospheric air over the North Atlantic, during February 1995

Figure 3 - (Source: A. Marenco CNRS/Toulouse, France)
WATER VAPOUR IN THE ATMOSPHERE

Introduction
Fundamental deficiencies exist in the present understanding of moist atmospheric processes and the role of water vapour in the global hydrologic cycle, climate and atmospheric chemistry. Inadequate knowledge of the distribution of atmospheric water vapour and its transport is a major impediment to progress in achieving a better understanding of the major processes involved in climate and chemistry of the atmosphere. In order to make reliable predictions of the potential climatic change on global and regional scales caused by increasing greenhouse gases like carbon dioxide (CO₂), chlorofluorocarbons (CFCs), ozone (O₃) - from various sources including aircraft - etc., it is of fundamental importance to understand the present climate and to describe it in a proper way.

The role of water vapour in atmospheric processes
Water vapour plays a crucial role in our atmosphere. The importance of atmospheric water vapour can be separated into three fundamental aspects, namely: water vapour is the engine of atmospheric dynamics, water vapour is the predominant greenhouse gas and, as chemical substance, water vapour is strongly involved in atmospheric chemistry.

Water vapour as engine of atmospheric dynamics:
Water vapour plays a large role in the energetic of the atmosphere. The release or uptake of large amounts of latent heat due to moist processes, like condensation or evaporation, respectively makes water vapour the principal medium for direct energy exchange among major components of the atmosphere. For example, the release of large amounts of latent heat, due to the condensation of water vapour in convective (especially cumulonimbus) clouds, provides the mechanism to transport mass and energy from the surface into the middle/upper troposphere. Water vapour thus acts as the engine of atmospheric dynamics and therefore it plays an important role in the general circulation of the atmosphere. Knowledge of the distribution of water vapour and its transport is essential to understand the processes which govern atmospheric dynamics.

Water vapour and the greenhouse effect:
Water vapour is the predominant greenhouse gas. In a cloudless atmosphere, water vapour contributes approximately 90% to the cloud free greenhouse effect. The impact of increasing greenhouse gases - like CO₂, CFCs, O₃ etc. - on climatic changes depends strongly on the radiative feedback of water vapour and particularly that of clouds.

Conventional climate models show that, for a doubling of the CO₂ concentration, a temperature increase of 2-5°C is expected; only 1/3 part of this is a direct effect of CO₂, but 2/3 is caused by the positive feedback of water vapour. However, the consequent increase of water vapour in response to climate warming is not well understood. Particularly there are fundamental deficiencies in the understanding of the physics of clouds and their radiative properties. Clouds can have a positive as well as a negative contribution to the greenhouse effect. The positive contribution is due to the absorption of infra-red radiation coming from the Earth's surface. The negative contribution is caused by the fact that clouds reflect partly the direct solar radiation back into space. The net effect of clouds on the climate is very poorly understood. Knowledge of the distribution of water vapour, particularly in the upper part of the troposphere, is thereby a prerequisite.

Water vapour and atmospheric chemistry:
Water vapour as chemical substance plays a key role in chemical processes in the atmosphere. In the gas phase, water vapour is directly involved in the primary production of hydroxyl radicals from the UV-photosynthesis of ozone by solar radiation in the presence of water vapour. These radicals are of crucial importance for the self-cleaning effect of the atmosphere due to their reaction with most of the atmospheric trace gases like carbon monoxide (CO), hydrocarbons (HCs), nitrogen oxides (NOₓ) etc. In addition, these radical reactions also initiate a chain of chemical reactions which have a strong influence on the photochemical fate of ozone. Further, water vapour is strongly involved in heterogeneous chemical reactions at the surfaces of aerosols or cloud droplets, which can be important removal mechanisms for trace gases like sulfur dioxide (SO₂) or nitrogen oxides (NOₓ).

Using the fact that tropospheric concentrations of water vapour strongly decrease with altitude, water vapour can be used as an indicator for ascending (wet) or descending (dry) air masses in order to trace back the origin of tropospheric ozone. Particularly in the vicinity of the tropopause, water vapour in combination with the simultaneously measured ozone and the calculated potential vorticity can be used to investigate the exchange processes between stratosphere and troposphere and hence identify the origin of upper tropospheric ozone.

Figure 4 - Relative humidity sensor to be installed on the outside skin of the aircraft. (photograph from K. Klatte - KFA/Jülich)

- Sensor Carrier
- Humidity Sensor (Humicap-H)
- Temperature Sensor (Pt-100)
- Electronic Transmitter
MOZAIC AND WATER VAPOUR

Deficit of water vapour measurements

As explained in more detail in the previous section, water vapour plays a crucial role in our atmosphere. Therefore, adequate knowledge of the global distribution of water vapour is needed to investigate and to define the processes determining the meteorology, chemistry and climate of the atmosphere. At this moment very little is known about the global distribution of water vapour, particularly in the upper troposphere. Up to now, obtaining measurements of middle/upper tropospheric water vapour on various time and spatial scales has been difficult due to the fact that:

- Standard meteorological humidity sensors are not reliable above 500 mbar, so that their accuracy and precision are not well known;

- Satellite instruments cannot look down through uppermost cirrus clouds or they have a bad vertical resolution and accuracy in the troposphere;

- Accurate water vapour measurements in the middle/upper troposphere are only obtained during a small number of dedicated aircraft or balloon sounding campaigns.

There is an urgent need for measured data of the spatial and temporal distribution of middle/upper tropospheric water vapour in both hemispheres. The MOZAIC programme will contribute to relieving this shortage of measured water vapour data. At present, automatic water vapour measurements are made from aboard five A340-aircraft during normal commercial "in-service" flights. Water vapour measurements, made during MOZAIC flights at a cruise altitude of 9-12 km, provide a quasi global climatology of the large scale distribution of upper tropospheric water vapour. Additional climatologies of the vertical distribution of water vapour are obtained in the vicinity of airports during ascents and descents of the aircraft.

An important aspect within the MOZAIC programme is the question of the relevance of the emission of water vapour and, particularly, particles by highflying aircraft to the formation of contrails - which are ice clouds (cirrus clouds) - and their influence on the chemistry and greenhouse effect in the upper troposphere. At the present, the fate of these contrails and their impact on atmospheric chemistry and climate is very poorly understood. The MOZAIC water vapour measurements provide a data base to study the aircraft contrails in more details.

Water vapour sensing instruments aboard Airbus A340

Within the MOZAIC project, we have
started to measure the large scale distribution of tropospheric water vapour by use of regularly calibrated humidity sensors aboard the five Airbus A340 aircraft during "in-service" flights. A special airborne humidity sensing device (AD-FS2), developed by Aerodata (Braunschweig, Germany) and based on the humidity and temperature transmitter HMP 230 of Vaisala (Helsinki, Finland), is used for measuring relative humidity and temperature of the atmosphere. As illustrated in Figure 4 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 (Model 102 BX), mounted on the outside skin of the aircraft. Relative humidity and total temperature are electronically measured by a transmitter unit and fed into the data acquisition system of MOZAIC aboard the A340 aircraft.

**Pre- and post flight calibration of the Humicap water vapour sensors**

Before installation in the A340 and after about 500 hours of flight operation, each water vapour sensing unit is calibrated in the environmental simulation chamber in Jülich. This temperature and pressure controlled vacuum chamber (Figure 5) with a test room volume of 500 liter (80x80x80 cm) can simulate pressure (10-1000 hPa) and temperature (-70°C to +30°C) similar to atmospheric conditions during flight operation. The chamber has been modified in order to simulate water vapour concentrations in typical tropospheric conditions up to an altitude of 12-15 km. Frost point as well as dry temperature of the air inside the test room can be controlled down to -70°C.

A Lyman alpha fluorescence hygrometer (Figure 5) serves as reference instrument for the calibration of the water vapour sensors, using a combination of fluorescence and absorption measurement of ambient water concentration. Three sensor units can be calibrated simultaneously during a one day calibration run in the simulation chamber.

The calibrations have shown that the humidity sensor used within MOZAIC is a reliable instrument to measure relative humidity from the surface up to the upper troposphere. An example of the results of a pre- and post-flight calibration of a sensor operated aboard aboard an A340 aircraft is given in Figure 6. The simulated relative humidities (0-15 %) and temperatures (-20 to -40°C) are typical in-flight conditions to which the sensor is exposed in the Rosemount housing during operation in the middle and upper troposphere. The pre- and post-flight calibration curves obtained at different sensor temperatures are in good agreement with each other. All measured calibration curves of the Humicap water vapour sensor are linear, whereby at lower temperatures the slope is slightly decreasing while concurrently an increasing negative offset is observed at lower temperatures. However, the pre- and post-flight calibrations show a good response, good reproducibility and an accuracy of about ± (5-10) % on the scale of true air relative humidity. Most of the flown sensors show similar results with a good stability of the pre- and post-flight curves.

**Water vapour measurements: first results**

At the KFA-Jülich the raw data of water vapour and temperature measurements, made from aboard the MOZAIC A340 aircraft, are further processed using the individual results of the pre- and post-flight calibration of each unit. In addition the data are validated, filtered for erratic values and evaluated.

An example of the results at cruise altitude of an intercontinental flight between Boston (USA) and Frankfurt (Germany) is presented in Figure 7. A striking feature is that the measured relative humidity shows, some times, values larger than 100 %: this is not an artifact but is mostly likely caused by the evaporation of hydrometeors due to adiabatic heating of the sampled airflow in the sensor housing. This means that the sensor in its present configuration is measuring also partly total water content which makes it suitable as an indicator for the presence of hydrometeors (clouds) in general and particularly for the presence of aircraft contrails. This over-saturation effect is a typical feature which had been observed more often in the aircraft corridors between Europe and USA. These observations will be subject for further investigations.

Figure 8 shows an example of an intercontinental flight between Rio de Janeiro (Brasil) and Paris (France). This typical result of a north-south transatlantic flight shows enhanced, almost saturated, water vapour in the vicinity of the equator which is caused by strong tropical (deep) convection. This deep convective activity moistens the upper troposphere and carries ozone deficient near-surface air into the upper troposphere. Outside the convective region, the trade wind region, the upper tropospheric water vapour concentrations are low due to general
Figure 7 - Longitudinal distribution of relative humidity, ozone concentration and air temperature measured during a flight on 20 October 1994, at a cruise altitude of about 35000 feet.

Figure 8 - Latitudinal distribution of relative humidity, ozone concentration and air temperature measured during a flight on 20 August 1994, at a cruise altitude of about 37000 feet.

Subsidence of the air. This effect is also observed by the coexisting enhanced ozone values. The dynamics in the tropical/extra-tropical regions are important processes involved in climate and chemistry of the atmosphere. Upper tropospheric water vapour is thereby a crucial factor determining climatic and chemical processes.

At present, we have started to set up an inventory of water vapour data measured within MOZAIC in order to obtain climatologies of large scale distributions of upper tropospheric water vapour in the aircraft corridors as well as climatologies of the vertical distributions of tropospheric water vapour in the vicinity of the different airports located on the continents, like Europe, North and South America and Asia. These measured climatologies serve as base to investigate spatial and seasonal variations of tropospheric water vapour in more detail. The climatologies will be analysed paying particular attention to the poorly understood feature of the formation and presence of aircraft contrails and their impact on atmospheric climate and chemistry. The climatologies of water vapour will serve as an essential base for the validation and improvement of numerical model simulations of physical and chemical processes in the atmosphere in order to have a better understanding of the impact of aircraft on our atmospheric system.

(H.G.J. Smit and M. Helten - KFA Jülich/ICG-2, Germany)
MOZAIC Flights: % in main directions (January - August 1995)

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