Filling the data gap between surface based measurements and space based observations using passenger aircraft: CONTRAIL, IAGOS-CORE and IAGOS-CARIBIC: Status in March 2013

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**IAGOS** [www.iagos.org](http://www.iagos.org)
**CARIBIC** [www.caribic-atmospheric.com](http://www.caribic-atmospheric.com)
**CONTRAIL** [www.cger.nies.go.jp/contrail/](http://www.cger.nies.go.jp/contrail/)
Chemical composition and aerosol data
Where is the observational gap?
What data are needed?

Aircraft Meteorological Data Relay (AMDAR) is a World Meteorological Organization program. It supplies important meteorological data using commercial aircraft.
A coordinated global network of surface and space-based CO₂ monitoring systems are needed for long-term monitoring of atmospheric sources and sinks and to provide insight into processes controlling atmospheric CO₂.

As a first step, existing and planned CO₂ monitoring satellites could be coordinated into an ad-hoc network to improve coverage and resiliency.

I got this from Hartmut Bösch, who got it from David Crisp, JPL

AURA, ACE, ODIN, ENVISAT.....
A flight from Frankfurt to Cape Town

Meteo calculations by Peter van Velthoven KNMI

The air masses that are intercepted

Jet stream

ITCZ

Red = low altitude
Where we measure: Stratosphere or Troposphere or both?

45% > 1.0 PVU
38% > 1.5 PVU
29% > 3.0 PVU
26% > 3.5 PVU
This is for continuous data for all flights

55% undisturbed free troposphere
26% stratosphere
Balance of 19% tropopause layer

Meteorological analyses using ECMWF
Peter van Velthoven. KNMI, de Bilt, the Netherlands
One flight captures very different air masses, including surface air (Armin Rauthe Schöch MPIC)
Comprehensive Observation Network for Trace Gases by Airliner -CONTRAIL Project-
CONTRAIL development since 2005

CME: Continuous CO₂ Measuring Equipment

ASE: Automated Sampling Equipment (CO₂, CH₄, CO, N₂O, SF₆, H₂, Isotopes)

Cargo bay Boeing 747-400

747-400 (JA8917) Nov/2005-

747-400 (JA8921) Feb/2006-

777-200 (JA705J) Jun/2006-

777-200 (JA703J) Oct/2006-

777-200 (JA707J) Nov/2006-
Two Installations on the 777-200

- **CME**: Continuous CO$_2$ Measuring Equipment
- **ASE**: Automatic Air Sampling Equipment, for CO$_2$, CH$_4$, CO, N$_2$O, SF$_6$, H$_2$, isotopes
Five Boeing 777-200ER aircraft

CME

Forward Cargo Room

CME

Aft Cargo Room

ASE

777-200 (JA705J) Jun/2006-

777-200 (JA703J) Oct/2006-

777-200 (JA707J) Nov/2006-

777-200 (JA708J) Jun/2012-

777-200 (JA709J) Sep/2012-
CO$_2$ 1993 - 2011 for latitudes $30^\circ$N - $30^\circ$S
Observation of CME (~2011/10)

Flights >6,100 vertical profiles for CO$_2$ >11,500
Total 32,000,000km
Validation of Satellite Observations

Latitudinal distributions of zonal averaged GOSAT L2 XCO₂
Ver.01.10 (Hard Screening) & TCCON / Aircraft XCO₂ in Apr 2009

- GOSAT
- FTS
- Aircraft
In-service Aircraft for a Global Observing System

European Research Infrastructure

- 20 equipped long-haul a/c + 1 flying laboratory
- 230 ISI papers
- Scientific publications
- H$_2$O, O$_3$, CO, NO, NO$_x$, aerosols, clouds

Global dimension

- 16 partners from science, industry and meteorological services
- Long-term deployment (20 years)
- Near real time data provision
- Open data policy (GMES/GEO/GEOSS)

www.iagos.org
IAGOS-CORE

Permanent installations in the avionic bay of A340/A330

First flight of LH D-AIGT on 8 July 2011

Weight: 120 kg    Operation: Continuous

Near Real Time Evaluation of MACC Results
IAGOS Destinations 2013

120 profiles measured in Jan / Feb 2013 by LH and CAL at indicated airports

Lufthansa July 2011
China Airlines July 2012
Air France Spring 2013
Cathay Pacific Summer 2013
Iberia Summer 2013

http://www.iagos.fr/macc
- Lufthansa Airbus A340-600
- Instrumented container 1.6 ton
- 15 instruments
- ~100 trace species and aerosol parameters
- 4 flights per month
- CARIBIC I: 1997 – 2002
- CARIBIC II: since 2005

CARIBIC flight routes
May 2005 – Feb 2013 (300 flights)
<table>
<thead>
<tr>
<th>Objectives</th>
<th>Uses</th>
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| **IAGOS-CORE** | • Changes in the Tropopause Region  
  – high spatial and temporal resolution of in-situ observations  
  – ozone background and trend  
  – water vapour background and trend  
• Validation of Atmospheric Models and Satellite Retrievals  
  – tropospheric profiles of $\text{H}_2\text{O}$, $\text{O}_3$, $\text{CO}$, $\text{NO}_x$, aerosol, $\text{CO}_2$, $\text{CH}_4$  
• Global Air Quality  
  – influence of developing regions  
  – long-range transport of air pollutants  
  – biomass burning, climate change, ...  
• International Transfer Standards  
  – same systems everywhere  
  – regular Quality Assurance |
| • To equip 20 aircraft with scientific instruments for:  
  – atmospheric chemical composition ($\text{H}_2\text{O}$, $\text{O}_3$, $\text{CO}$, $\text{NO}_x$, $\text{NO}_y$, $\text{CO}_2$, $\text{CH}_4$)  
  – aerosol number conc. and size  
  – cloud particle number conc. and size  
• Long-term deployment (20 yrs)  
• Global coverage  
• Open data policy (GMES/GEO/GEOSS)  
• Near real time data provision  
| • Changes in the Tropopause Region  
  – high spatial and temporal resolution of in-situ observations  
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  – water vapour background and trend  
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• Global Air Quality  
  – influence of developing regions  
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  – biomass burning, climate change, ...  
• International Transfer Standards  
  – same systems everywhere  
  – regular Quality Assurance |
| **IAGOS-CARIBIC** |  
• To deploy and extend the CARIBIC measurement container  
  Remote sensing HONO, BrO, $\text{SO}_2$, large number of species, air sampling 116, $\text{NO}_2$, $\text{Hg}$, VOCs, Halocarbons, $\text{N}_2\text{O}$, $\text{SF}_6$, aerosol elemental composition, $\text{H}_2$ isotopes, $\text{SO}_2$  
|
IAGOS-CORE Instrumentation

**Package 1 (CNRS)**
- O$_3$, CO (CNRS)
- H$_2$O (FZJ)
- BCP (UMAN)
- RTTU (MF)

**Programs**
- **Option 1**
  - Package 2a (FZJ)
    - NOy

- **Option 2**
  - Package 2b (FZJ)
    - NOx

- **Option 3**
  - Package 2c (FZJ)
    - Aerosol

- **Option 4**
  - Package 2d (MPG)
    - CO$_2$, CH$_4$

**Parameter** | **MOZAIC** | **IAGOS**
---|---|---
Ozone | 1994 | 2011
Water Vapour | 1994 | 2011
Carbon Monoxide | 2002 | 2011
Odd Nitrogen (NO$_y$) | 2001 | 2011
Nitrogen Oxides (NO$_x$) | 2011 | 2011
Carbon Dioxide | 2013 | 2011
Methane | 2013 | 2011
Aerosol | 2013/2014 | 2011
Cloud Particles |  | 2011
IAGOS-CORE Data QA/QC

- Use of proven technology (field campaigns, intercomparison studies)
- One lab responsible for each type of instrument on all a/c
- Calibration against reference instruments during maintenance
- In-flight calibration ($O_3$, CO, NO$_x$, GHGs)
- Comparison of measurements from different IAGOS aircraft during regular flights (consistency)
- IAGOS Partners are strongly involved in international QA/QC activities:
  - GAW WCC for $O_3$ sondes and for NO$_x$
  - GAW SAG Aerosol, GAW SAG Reactive gases
  - TROPOS (Leipzig): GAW WCC for Aerosols
  - MPI-BGC (Jena): ICOS Central Facility for GHG analysis, GAW SAG GHG
- IAGOS data contribute to harmonisation of global networks through data assimilation by, e.g., MACC, GMES, GEOSS
- Data QA/QC efforts supported by EU FP7 project IGAS (started 2013)
### Key Findings from IAGOS precursors

**MOZAIC and CARIBIC**

<table>
<thead>
<tr>
<th>Compound</th>
<th>Findings</th>
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<tr>
<td>H₂O</td>
<td>Large abundance of ice supersaturated regions in the UT (Gierens et al., An. Geo., 1999; Luo et al., J. Climate, 2008)</td>
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<td></td>
<td>Observed water isotopes identify transport pathways from the UT to the lowermost stratosphere (Christner et al., to be submitted to GRL)</td>
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<td>CO</td>
<td>Extremely high values in the UTLS due to Biomass Burning (Nedelec et al., GRL, 2005)</td>
</tr>
<tr>
<td>NOₓ</td>
<td>High values in the UTLS due to convection and lightning (Thomas et al., to be submitted to ACP)</td>
</tr>
<tr>
<td>HOₓ</td>
<td>HOₓ production rate from acetone photolysis accounts to 30-70% of HOₓ from O₃ photolysis (Neumaier et al., to be submitted to ACP)</td>
</tr>
</tbody>
</table>
Building Climatologies, e.g. $\text{H}_2\text{O}$

**MOZAIC (green)**
Climatological data from routine observation

**SPURT (black)**
Data from dedicated research aircraft campaign

→ Need for routine long-term observations like performed in IAGOS
  - seasonal, interannual variations
  - data not available from satellite
  - extremely valuable for model evaluation

Meridional Profile of $\delta D(H_2O)$

First „almost representative“ meridional in-situ profile of HDO/H$_2$O measured on CARIBIC.

Good agreement with satellite and research a/c data.

Enriched H$_2$O in tropics due to convection and ice lofting.

Rayleigh profile indicates slow (equilibrium) transport and agrees with data at mid-latitudes, but underestimates HDO in tropics.

Meridional cross-section of HDO/H$_2$O (in permil, relative to Standard-Mean-Ocean-Water SMOW) measured at 10-12 km altitude, as probability density function (blue) and mean values (red line)

Christner et al., to be submitted to GRL
High NO$_y$ in the UT

MOZAIC:
High NO$_y$ in UT in spring and summer
Max observed values $> 2.5$ ppb
Model prediction $< 1$ ppb
Sources: Convection and lightning

Thomas et al., to be submitted to ACP
OH yield from acetone photolysis

UTLS measurement of HO\textsubscript{x} precursors (O\textsubscript{3}, H\textsubscript{2}O, acetone)

CARIBIC : Largest UTLS in-situ dataset of acetone

\[ \Rightarrow \text{HO}_x \text{ production rate from acetone photolysis accounts to 30-70\% of O}_3 \text{ photolysis} \]

Neumaier et al., to be submitted to ACP
IAGOS Roadmap for Implementation

2006 - IAGOS identified in the roadmap of the European Strategy Forum on Research Infrastructures (ESFRI). EU supports IAGOS in its design phase and preparatory phase

2010 - CARIBIC container revised and certified
       - Instruments on 3 MOZAIC aircraft back to operation

July 2011 - IAGOS package installed in a Lufthansa Airbus A340

July 2012 - IAGOS package installed in a China Airbus Airlines A340

2013 - greenhouse gas package (CO₂, CH₄, H₂O) certified
       - aerosol package (number conc., size distr.) certified
       - IAGOS-STC on Air France and Iberia A340
       - IAGOS-STC on Cathay Pacific A330
       - US-Airline under negotiation

=> 5 IAGOS aircraft, plus CARIBIC, plus 3 MOZAIC aircraft by 2013

STC: Supplemental Type Certificate (approval by EASA)
Conclusions about passenger aircraft use

There is a proven 15-20 yr track record for all three passenger aircraft observing systems: CONTRAIL, MOZAIC, CARIBIC. The latter is based on a very different approach.

These passenger aircraft systems have given detailed consistent data over large parts of the globe, including vertical profiles. They can be operated over many decades. Such is important from the GAW perspective. Use of data as witnessed by publications shows a healthy growth.

IAGOS which merges MOZAIC and CARIBIC into IAGOS-CORE and IAGOS-CARIBIC not merely combines the 2 systems as an observational infrastructure but provides real time data and furthermore renders the resulting observing system truly global by operating from different continents.