How can aircraft measurements tell us about the source/sink distribution of greenhouse gases?

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Unique Value of In-situ Aircraft Sampling

The ability to probe tracers both in the vertical and the horizontal at multiple scales, enabling:

• Determination of spatial variability of tracers (CO$_2$ as example here)

• Direct constraint of regional-scale fluxes from airmass-following experiments

• Model testing: diagnosis of errors in atmospheric modelling (e.g., PBL ht, wind vectors, convection)

• Validation of space-borne sensors
COBRA (CO$_2$ Budget & Rectification Airborne Study)

What have we learned from intensive atmospheric sampling field programmes of CO$_2$?


*Tellus (2006), 58B, 331–343

Fig. 1. Flight tracks from the CO$_2$ Budget and Rectification Airborne (COBRA) study from three different years: August 2000, May–June of 2003, and May–August of 2004. The aircraft altitude above sea-level is shown in grayscale.

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COBRA (CO₂ Budget & Rectification Airborne Study)

University of North Dakota Citation
(COBRA-2000, 2003)

University of Wyoming King Air
(COBRA-2004)
COBRA Participants:

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Dave Hollinger: \textit{(University of New Hampshire)}

Ken Davis: \textit{(Pennsylvania State University)}

Scott Denning, Marek Uliasz: \textit{(Colorado State University)}

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• Determination of spatial variability of CO₂ and other tracers

• Direct constraint of regional-scale fluxes from airmass-following experiments

• Model testing: diagnosis of errors in atmospheric modelling (e.g., PBL ht, wind vectors, convection)

• Validation of space-borne sensors


June 27~28th, 2003

CO$_2$ Large-scale Distribution [ppmv]

CO Large-scale Distribution [ppbv]
For spatially heterogeneous field of CO$_2$ concentration over land, there is can be large differences between an observation at a point location and the gridcell-averaged value. ("representation error")
Representation Error derived from Spatial simulation for $CO_2$, based on Variogram

error dependent on grid size (hor. resolution) and spatial variability of tracer

Representation error: Stdev($CO_2$) within each subgrid of size $\Delta x \Delta y$
Representation error: continent vs ocean

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Planning and Analysis of “Air-Following” Experiments

Objective: test method for providing tight atmospheric constraint on fluxes in targeted regions

Planning and Analysis of “Air-Following” Experiments

Receptor: Howland, Maine
(June 11th 2004, 2200UT)

Planning and Analysis of "Air-Following" Experiments

Upwind/Late Morning CO₂ Observations
(June 11th 2004, 1600UT)

Planning and Analysis of “Air-Following” Experiments

Downwind/Afternoon CO₂ Observations
(June 11th 2004, 2200UT)

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Atmosphere Serving as an Integrator. But need to know how big box is! (mixed-layer height)

Mixed-layer height controls size of box over which fluxes are diluted

Fig. 18.15 of *Meteorology Today*, by C. Donald Ahrens
Atmosphere Serving as an Integrator. But need to know how big box is! (mixed-layer height)

Fig. 2. (A to C) Observed Northern Hemisphere average profiles compared with predictions of the 12 T3L2 models over the same seasonal intervals as in Fig. 1. Gray lines indicate the observed average vertical CO₂ gradients (center) and uncertainties (width) from Fig. 1 (25). The model output was processed in the same way as the observations at each site before averaging (25). Symbols indicate 1- and 4-km values used for calculating the vertical gradients shown in Fig. 3. The horizontal axis in (B) is zoomed by a factor of 2 relative to those in (A) and (C).

Weak Northern and Strong Tropical Land Carbon Uptake from Vertical Profiles of Atmospheric CO₂
Mixed-Layer Biases

Normalized Gross Error (NGE)

$$NGE = \frac{\text{mean(model)} - \text{mean(obs)}}{\text{mean(obs)}}$$

WRF mesoscale model fields compared against radiosonde data.
Aircrafts yield rich datasets with which to test models.
• Determination of spatial variability of CO$_2$ and other tracers

• Direct constraint of regional-scale fluxes from airmass-following experiments

• Model testing: diagnosis of errors in atmospheric modelling (e.g., PBL ht, wind vectors, convection)

• **Validation of space-borne sensors**
Aircraft measurements can help probe troposphere and contribute to validation efforts.

(results from Thomas Kurosu, Harvard-Smithsonian Center for Astrophysics)
Column CO$_2$ Measurements from Satellites?

CO$_2$ vertical profiles measured by aircraft (COBRA field campaign)

Column amount would be insensitive to mixed-layer height

Even better: if we could separate out column into at least two pieces of information
1) within mixed-layer
2) free troposphere
Comparisons to Column CO₂

Figure 6. Integrated profiles by the DC-8 (triangles) and King Air (circles) compared to FTS retrievals from the two CO₂ bands, CO₂ 6228 cm⁻¹ band retrievals are solid; CO₂ 6348 cm⁻¹ band retrievals are shaded. Each integrated aircraft profile has been divided by the dry surface pressure, yielding the familiar units of ppmv. The relationship between integrated profile and FTS column-average CO₂ VMR is linear for each band. A linear fit with intercept 0 gives slopes of 1.0216 for the CO₂ 6228 cm⁻¹ band and 1.0240 for the CO₂ 6348 cm⁻¹ band. The top plot shows the difference between the FTS measurements and the fitted line.

Conclusions and Future Steps

• Aircraft observations provide unique information on the spatial variability of tracers

• Airmass-following experiments yield constraints on regional fluxes for targeted areas: e.g., boreal forest fires, carbon loss in pine beetle-infested forests, methane release in Arctic

• The high-resolution atmospheric observations are valuable for improving models

• Aircraft data help in satellite validation efforts

=> Aircraft sampling is an important complement and addition to satellite observations!