Eddy covariance measurements of CO$_2$ fluxes from Mexico City

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Outline:

- Introduction
- The eddy covariance method
- \( \text{CO}_2 \) flux measurements at the CENICA site in April 2003
- \( \text{CO}_2 \) Flux measurements at the SIMAT site in March 2006
- Comparison of the fluxes measured in Mexico City with fluxes measured in other cities of the world
- Conclusions
- Acknowledgements
CO₂ emissions from urban environments are a major concern because CO₂ is a significant contributor to global warming. Urban areas are acknowledged to be major sources of anthropogenic CO₂, and according to recent estimates, 50% of the world’s population live in urban areas.

Direct measurements of CO₂ emissions that include all emissions sources in urban areas are necessary to improve our understanding of the role cities play in global change, in particular megacities of developing countries.
Emission = \((activity\ unit) \times (emission\ factor)\)

\[
\frac{kg\ of\ CO_2}{m^3\ of\ burned\ fuel}
\]

\[
\frac{kg\ of\ CO_2}{ton\ of\ cement}
\]

\[
\frac{kg\ of\ CO_2}{(#\ of\ inhabitants)(km^2)}
\]

\[
\frac{kg\ of\ CO_2}{(#\ of\ workers)}
\]

\[
\frac{kg\ of\ CO_2}{(traveled\ km)}
\]
Population: ~ 19 million
Vehicular fleet: > 3.5 million cars (~9 years old)
Industries and services: > 53,000
Direct emissions measurements

- Tracer ratio point sources
- Micrometeorological techniques
  - Stack measurements
  - Emission profiles of different sources
- Remote sensing
- Tunnel studies
- Vehicle chasing
Emissions from different sources are blended by the turbulence generated in the Roughness Sub-Layer, producing a net exchange flux in the Constant Flux-Layer, at which height the instruments must be mounted.
The flux of a trace gas ($F_\chi$) is calculated as the covariance between the instantaneous deviation of the vertical wind velocity ($w'$) and the instantaneous deviation of the trace gas concentration ($c_\chi'$) for time periods between 30 min. and an hour.

\[
F_\chi = \frac{1}{N} \sum_{i=1}^{N} w'(t_i)c'(t_i)
\]

- Fast response sensors
- Fast response data acquisition systems
Vertical wind speed (m s\(^{-1}\))

Concentration (g m\(^{-3}\))

\[
\begin{align*}
\bar{w} &= w_i - \bar{w} \\
c' &= c_i - \bar{c}
\end{align*}
\]

\[
F_x = \bar{w}'c' = \left(\frac{m}{s}\right)\left(\frac{g}{m^{-3}}\right) = \left(\frac{g}{m^2 s}\right)
\]
MCMA-2003 Field Campaign
(April 7 to 29, 2003)

Dimensions are in meters.
Diurnal profile of CO$_2$ flux

$\overline{F_{\text{CO}_2}} = 0.41 \text{ mg m}^{-2} \text{ s}^{-1}$

In both figures the grey shadow represent ±1 standard deviation from the total averages.

Diurnal profile of CO$_2$ concentration

$[\text{CO}_2] = 388 \text{ ppm}$
The orange contour indicates the fraction of the flux measured equal to 80%.
Fluxes as a function of the vehicular activity

Diurnal profile of CO$_2$ fluxes and plots of traffic counts for intersection (I$_{2-3}$)

CO$_2$ emission fraction per type of vehicle as a function of the hour of the day for intersection (I$_{2-3}$)
MILAGRO
MCMA-2006
March 6 to 30, 2006

SIMAT site
Diurnal profile of CO₂ flux

In both figures the grey shadow represent ±1 standard deviation from the total averages.

-3.11 ppm (21-6 h)

6.27 ppm (6-21 h)

61% (6-10 h)

48% (6-21 h)

[CO₂] = 409 ppm

F₉O₂ = 0.51 mg m⁻² s⁻¹

Diurnal profile of CO₂ concentration
In both figures the grey shadow represents ±1 standard deviation from the total averages.

### Ambient concentrations

### Fluxes

- **25.3%**(6-21 h)
- **-1.2%**(21-6 h)

- **22 ppm**
URBAN CO₂ FLUX MEASUREMENTS

North America:
- Vancouver
- Mexico City
- Denver
- Baltimore
- Chicago
- Roseville

Europe:
- Edinburgh
- Copenhagen
- Roma
- Toulouse
- Marseille
- Lodz
- Berlin
- Basel
- Essen

Asia and Australia:
- Beijing
- Tokyo
- Melbourne

More information about urban flux measurements are available at the URBAN FLUXNET website:
http://www.urban-climate.org
**CO₂ fluxes in Mexico City vs CO₂ fluxes in other cities**

**Tokyo**
- Residential district: 11.07 kg m⁻² year⁻¹

**Copenhagen**
- Urban average: 12.9 kg m⁻² year⁻¹

**Mexico City**
- Residential district: 12.8 kg m⁻² year⁻¹
- Residential & commercial district with heavy traffic: 16.2 kg m⁻² year⁻¹

**Edinburgh**
- City Center: 36.1 kg m⁻² year⁻¹

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*Moriwaki & Kanda, 2004*
**Soegaard & Møller-Jensen, 2003*
$Nemitz et al., 2002$
#Velasco et al., 2005
Conclusions

• The urban surface of Mexico City is a net source of CO$_2$.

• CO$_2$ fluxes showed clear diurnal patterns and a strong correlation to vehicular traffic.

• The effects of CO$_2$ uptake by urban vegetation during the daytime do not appear to be significant for the two measured sites.

• The annual average flux measured for Mexico City (12.9 kg m$^{-2}$) is similar to annual fluxes reported for developed urban areas, such as Tokyo, Copenhagen and Vancouver.

• The differences between the two measured sites in 2003 and 2006 are due to differences in vehicular traffic and landuse and not due to an increment in the CO$_2$ emissions in Mexico City.
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Additional slides
Heterogeneous area:

- The spatial variability of surface cover and roughness is high.
- Diverse emission sources (motor vehicles, industrial processes, food cooking, etc.).
Validity for the eddy covariance system:

Criterion 1: Statistical characteristics of the raw instantaneous measurements (e.g. wind speed not to exceed 25 m s\(^{-1}\))

Criterion 2: **Stationarity test:** the average flux from 6 continuous subperiods of 5 min is within 60% of the flux obtained from a 30 min average.

Criterion 3: **Spectra and cospectra analysis:** the flux system is fully capable of measuring turbulence fluxes if the spectra and cospectra at high frequencies show the expected behavior in the inertial subrange, range where the net energy coming from the energy-containing eddies is in equilibrium with the net energy cascading to smaller scales where it is dissipated.
The shape and details of the CO$_2$ and $T$ spectra and cospectra correspond closely over the entire range of frequencies measured.

The -5/3 slope indicates the theoretical slope in the inertial subrange.
In 56% of the periods, the flux difference was less than 30%, which indicates periods that meet and exceed the stationarity criteria. In 18% of the periods, the flux difference was between 30 and 60%, which means that these periods have an acceptable quality.
References of urban measurements of CO₂ fluxes by EC


