Evaluating conditional sampling strategies for trace-gas flux measurements in urban environments

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In contrast to forests and agricultural surfaces, micrometeorological measurements of turbulent trace-gas exchange between urban surfaces and the atmosphere are rare. There are a small number of experiments limited to the study of turbulent CO_2-exchange in urban environments. However, no attempts have been made to directly monitor the turbulent exchange processes of the large variety of other relevant trace-gases in urban environments using eddy-covariance.

Most trace-gases are not measurable in-situ with the high frequency and resolution needed for eddy covariance. Conditional sampling techniques like Relaxed Eddy Accumulation (REA) or Disjunct Eddy Covariance (DEC) have been developed in the last 15 years in order to operate slower gas-analyzers. Unfortunately, they introduce new uncertainties by their parametrization and/or by a lower statistical significance.

Selected urban flux monitoring towers

View from tower	Site / Land-use	Height	Instrumentation
	**Baltimore - Cub Hill** Vegetated suburban	40 m z/h = 1.8	Sonic (Young 81000) Closed Path (Li7000)
	**Tokyo - Kugahara** Dense urban	29 m z/h = 4.0	Sonic (Metek USA-1) Open Path (Li7500)
	**Basel - Klingelbergstrasse** Dense urban	38 m z/h = 1.9	Sonic (Gill HS) Open Path (Li7500)
	**Berlin - Steglitzer Kreisel** Regional / urban	119 m z/h = 8.0	Sonic (Metek USA-1) Open Path (Li7500)

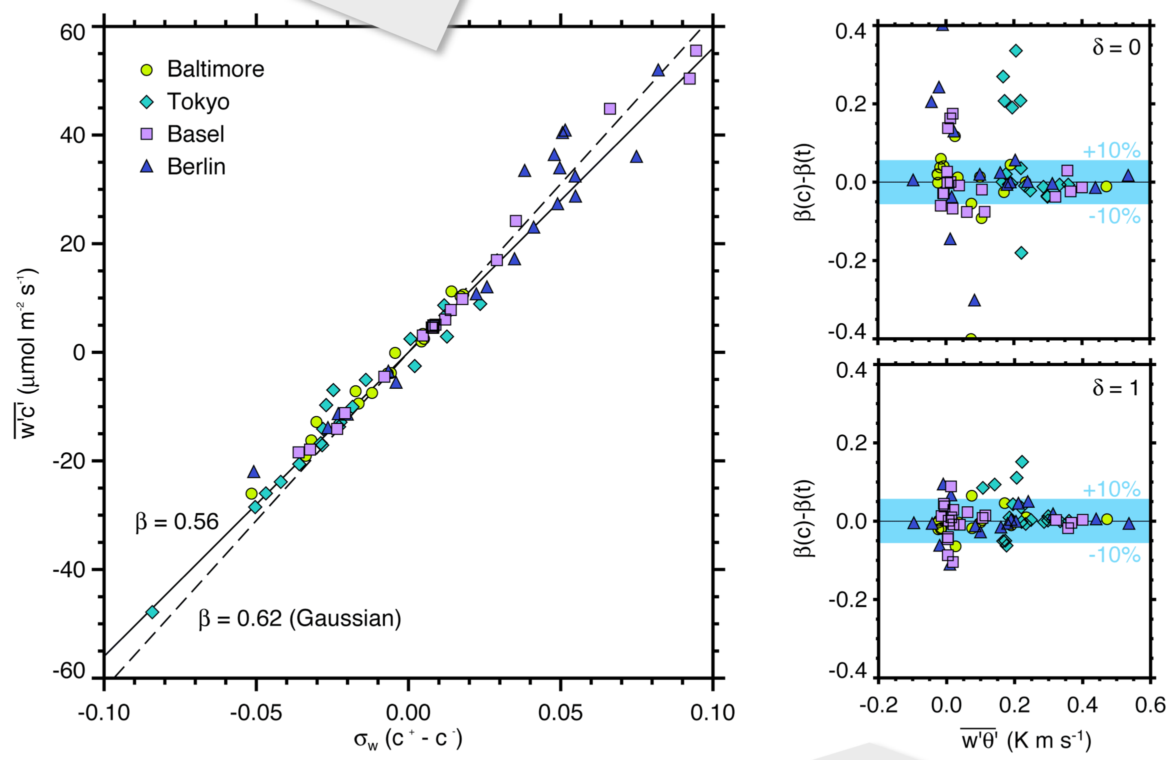
To test these conditional sampling techniques in urban turbulence, they were simulated with 80 hourly runs from four existing urban CO_2-data-sets (Baltimore, Tokyo, Basel and Berlin). Here CO_2-exchange is used as a surrogate for any trace-gas. It was directly measured using high-frequency analyzers at all sites. The data-sets also include temperature, H_2O and wind fluctuations at 8 to 20 Hz.

Relaxed Eddy Accumulation (REA)

An updraft and a downdraft reservoir are conditionally filled with air based on the instantaneous value of vertical wind w. The reservoirs are later probed by slow gas analyzers and the measured trace-gas concentration difference between the two reservoirs (c^+-c^-) is related to the flux $\overline{w'c'}$, using the coefficient β and σ_w [1]:

$$\overline{w'c'} = \beta\, \sigma_w\, (c^+ - c^-)$$

β-coefficient: β has recieved much attention in literature [2-4]. For the surface layer, values around 0.56 are reported. The strongly non-Gaussian turbulence driving the exchange above rough surfaces and the non-uniformity of sources in urban areas call for a reevaluation of its value in urban environments. However, the current urban datasets in general do not suggest a strong departure. Regression slopes at all sites range between 0.50 and 0.60. The dense built-up sites (Basel, Berlin) are even closer to the Gaussian prediction [5], but show larger scatter.

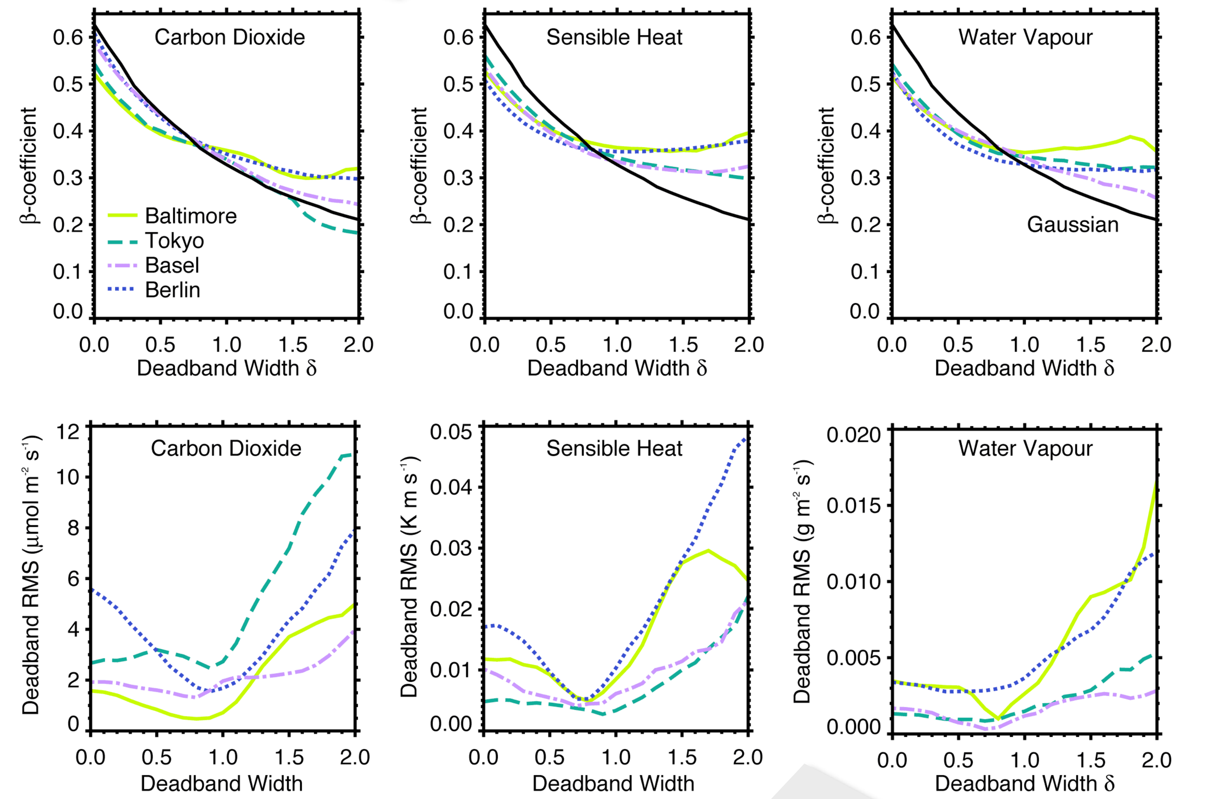


β-coefficient determined from proxy-parameter. A common approach is the determination of β from simultaneously measured sensible heat flux, assuming similarity between $\beta(\theta)$ and $\beta(c)$. Unfortunately, the urban-datasets show strong dissimilarities between sensible heat and CO_2-exchange. Introducing a deadband of width δ=1 (see next column) results in smaller departures (bottom).

The REA-Deadband

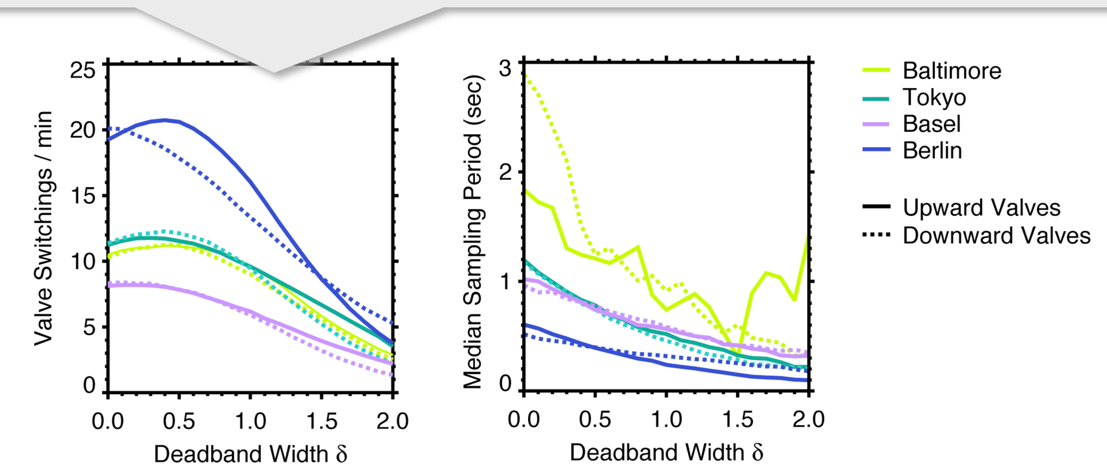
Practically, a deadband of width $\pm\delta\, \sigma_w$ is excluded from analysis in order to reduce valve switching around the zero-crossing of w and to increase the concentration differences in the two reservoirs.

β-coefficient as a function of deadband width: Dissimilarities between the fluxes of CO_2, sensible heat and H_2O are reflected by different β-coefficients. Runs with a wide deadband show significant departures between the different scalars and sites. The theoretical β-coefficient as a function of δ for a Gaussian distribution is drawn in black.



Errors related to deadband width: The current simulation suggests that deadband widths up to δ=1 do not reduce the reliability of the parameterized flux. Higher δ even lower the overall RMS in some cases by removing the disorganized around the zero-crossing below. However, above δ=1 statistical significance becomes increasingly lower.

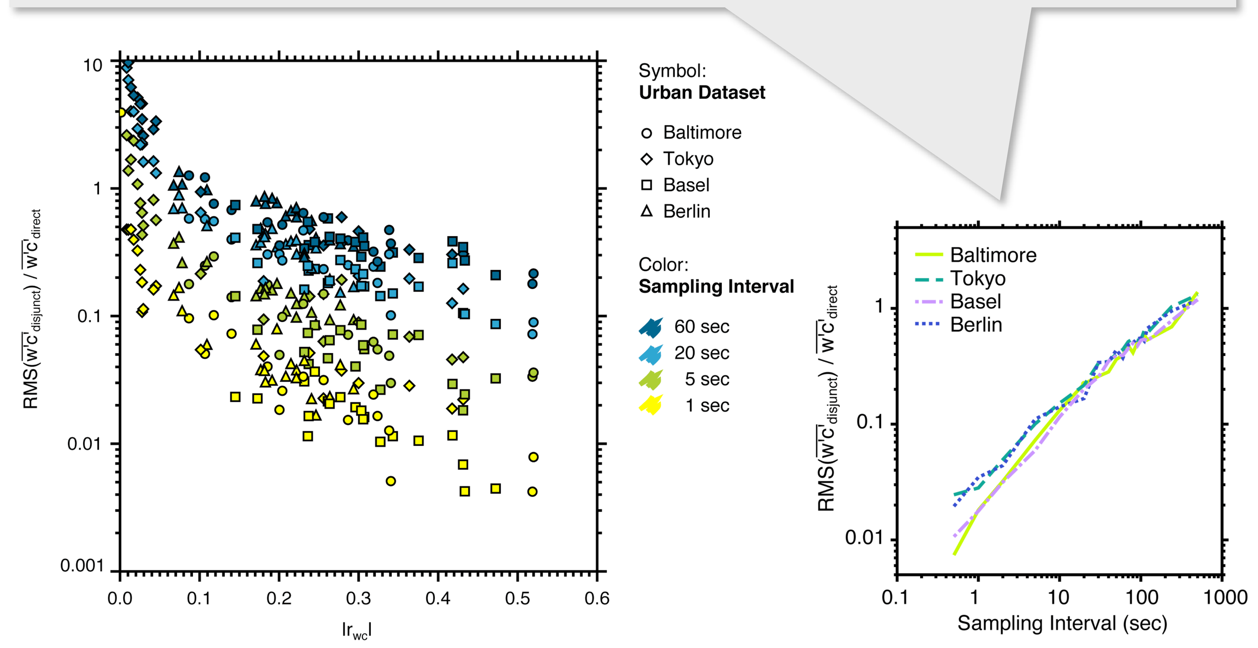
Valves performance: From a practical point of view, it is best to reduce valve switching rates but also to increase the average sampling period. Obviously, a higher δ lowers the valve switching rate but it also lowers the average sampling period. In any instrumental realization there will be always a trade-off between a high concentration difference, a good statistical significance and a low valve switching rate.



Disjunct Eddy Covariance (DEC)

Instead of a continuous measurement of w and trace-gas concentration c, a drastically reduced subset is used to calculate the trace-gas flux. In fix sampling intervals, air is sucked very fast into reservoirs (< 0.1 sec) and analyzed during a longer sampling interval. The flux is reconstructed with the small number of measured c' and simultaneously measured w' [6]. DEC is a direct method. Above urban surfaces, fluxes are typically associated with large coherent structures occupying only small time fractions. Therefore, also DEC has to be carefully simulated with urban CO_2-data before measurement systems will be deployed in cities.

Statistical error of the DEC: With increasing sampling interval, the statistical significance of the DEC is lowered. The RMS was calculated for each run and a variety of equally spaced sampling intervals by simulating a large number of realizations using different offsets relative to the first measurement.



Correlation coefficient: It is no surprise that not only narrow sampling intervals (resulting in more sampling points), but also a high correlation coefficient $r_{wc} = \overline{w'c'}/(\sigma_w\, \sigma_c)$ raise the quality of the DEC flux estimation.

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