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Calculation of the CO_2 storage term in an urban environment: results and guidelines from Central London

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2: University of Reading

Acknowledgements: NERC ClearfLo (Clean Air for London) Project
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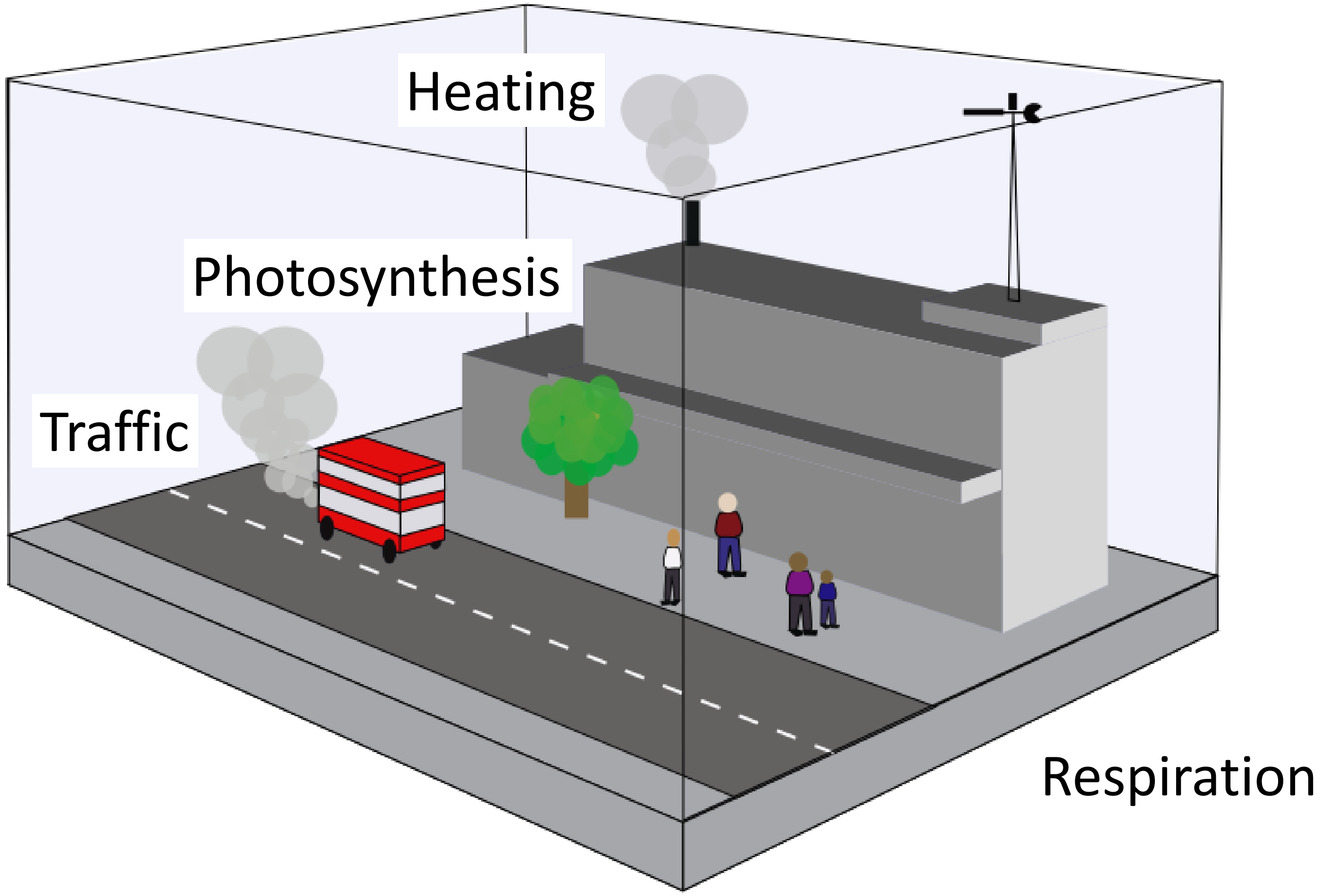
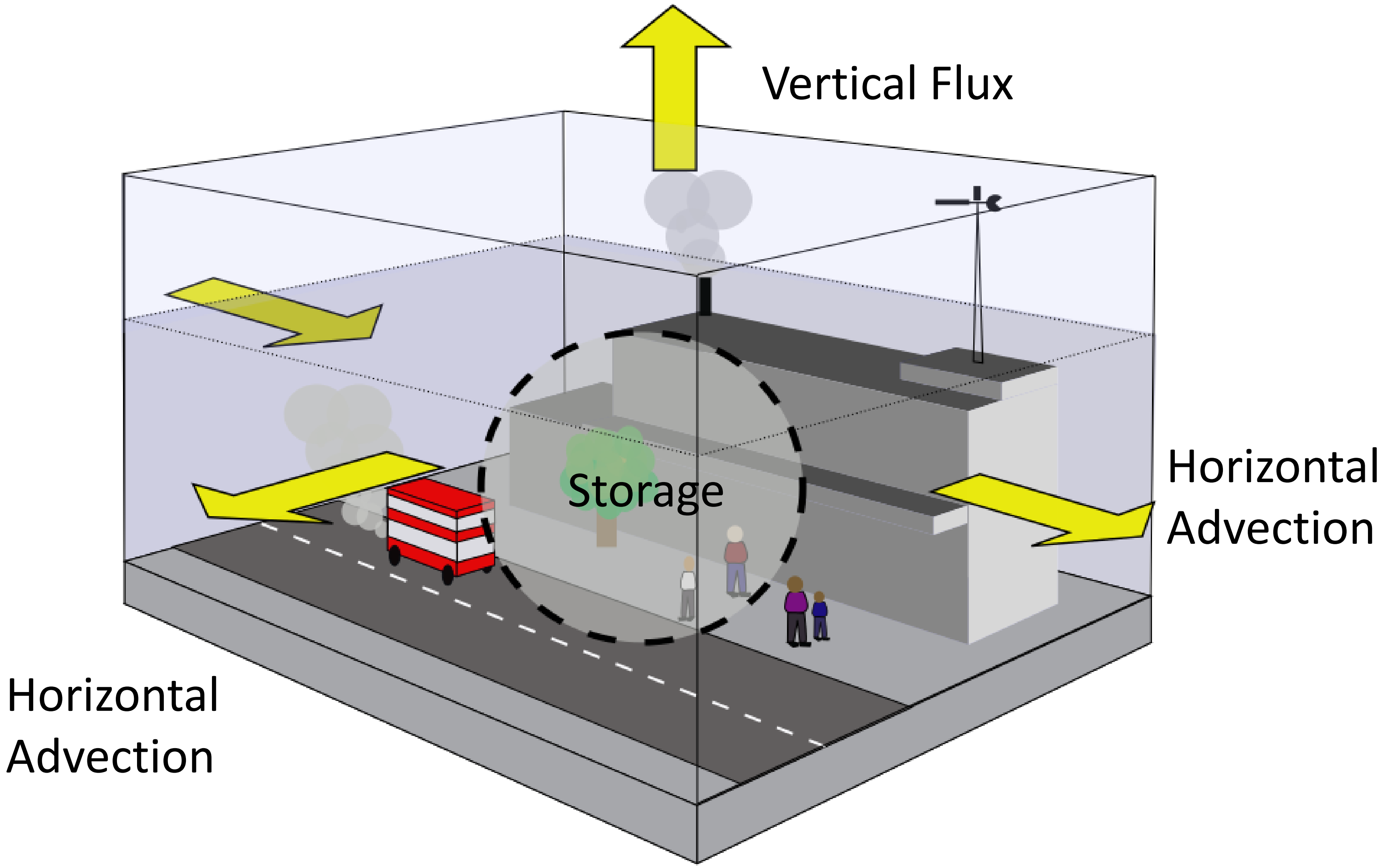
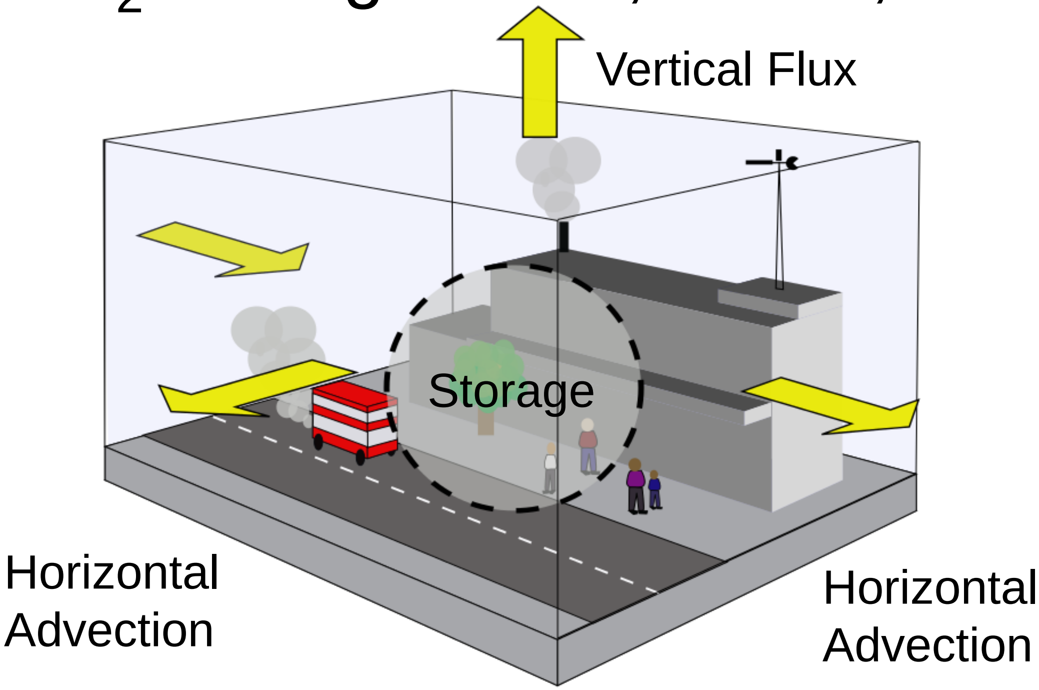
Net Emissions = Heating + Traffic + Respiration - Photosynthesis

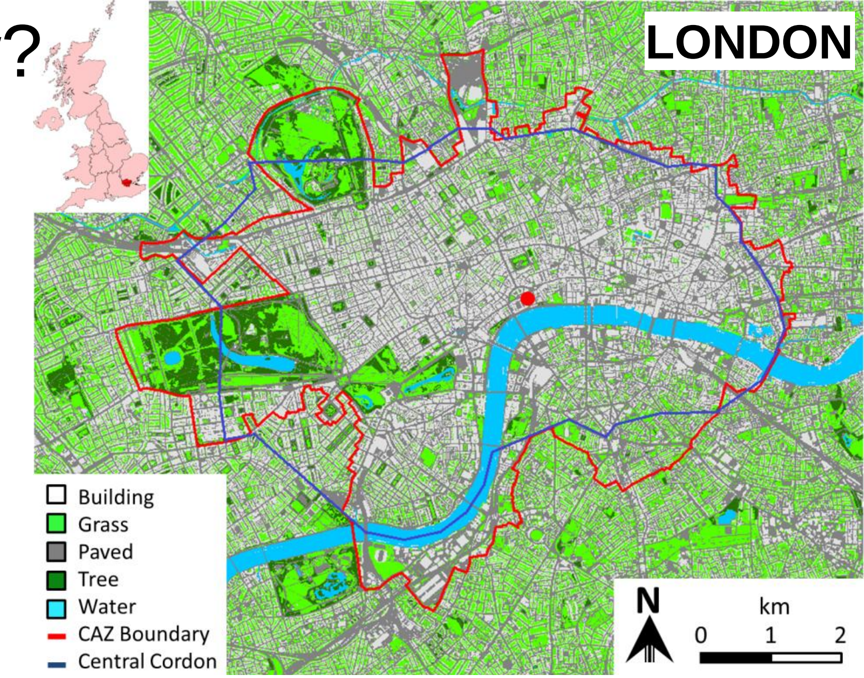


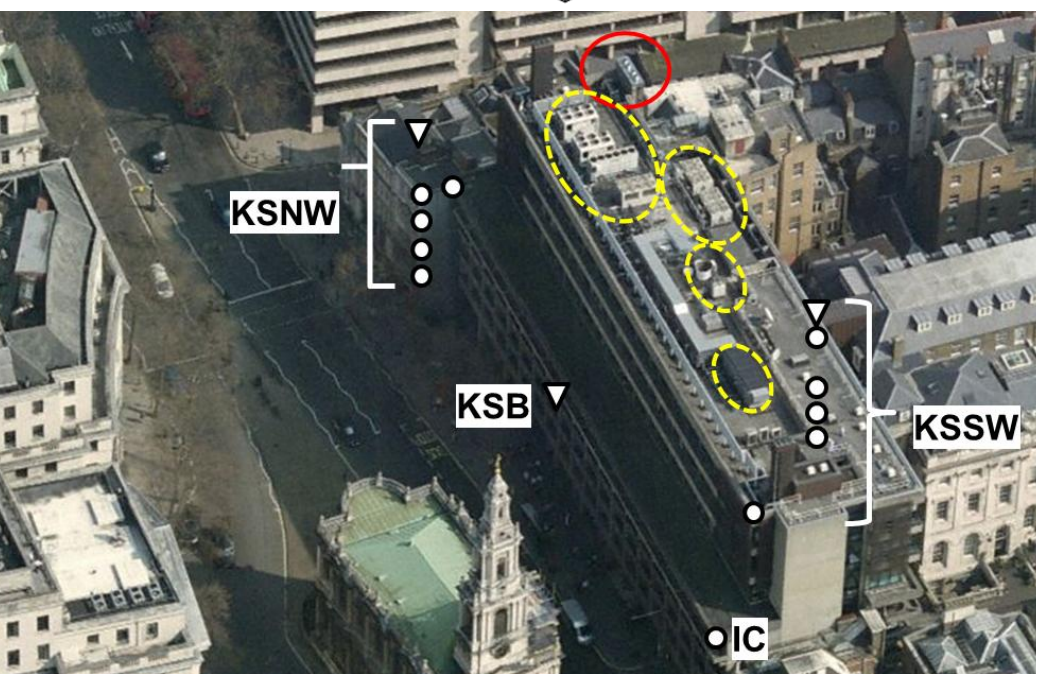
Net Emissions = Flux + ~~Storage~~ + ~~Advection~~

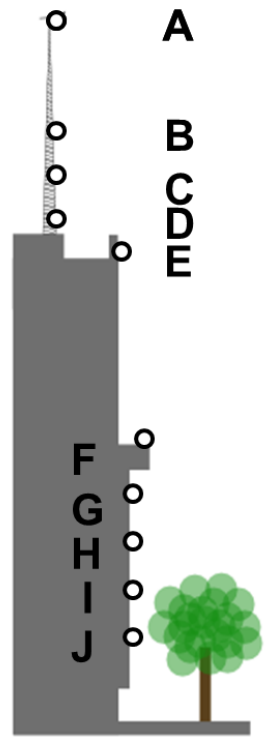


CO_2 Storage: what, where, how?









$$\Delta C_S = \int_0^{z_h} \frac{\partial \bar{c}}{\partial t} dz \approx \sum_{i=1}^{h} \left[\frac{\Delta c(z_i)}{\Delta t} \right] \Delta z_i$$

Δz_i ↕ ← $\Delta c(z_i)$

10:55 10:45

Calculating CO_2 storage: workflow

Installation

- Ease of access for maintenance
- Power/internet connection
- **Required spatial density**

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Measurements

- Frequency of calibration
- **Time resolution of measurements**

↓

Processing

- De-spiking procedures e.g. IMAS*
- Drift adjustment
- **Spatial and temporal interpolation**

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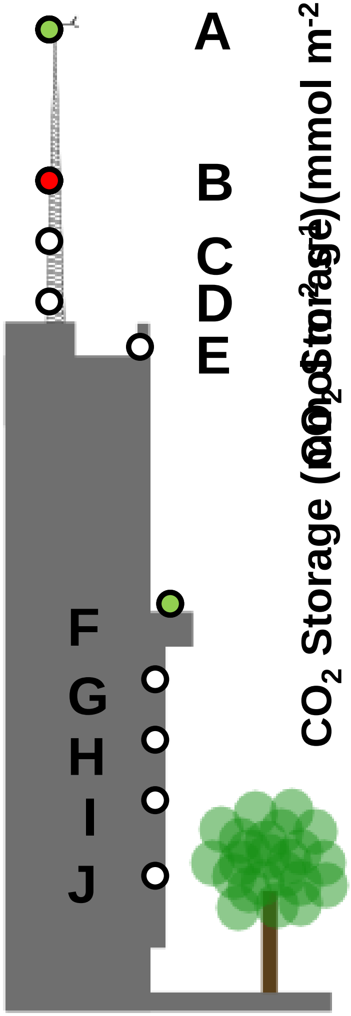
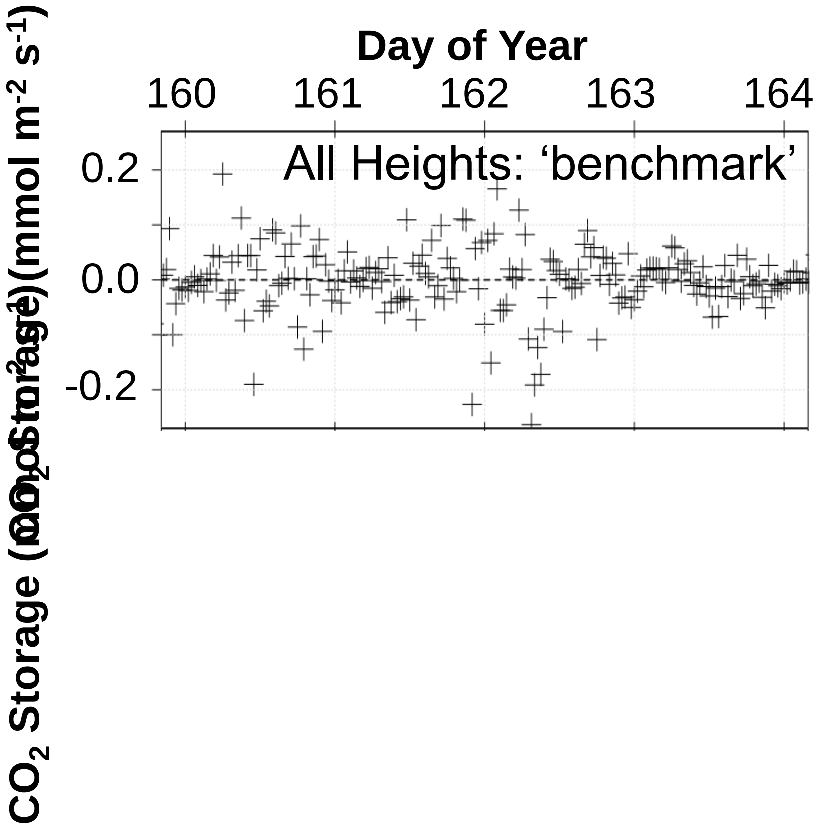
Quality Assessment

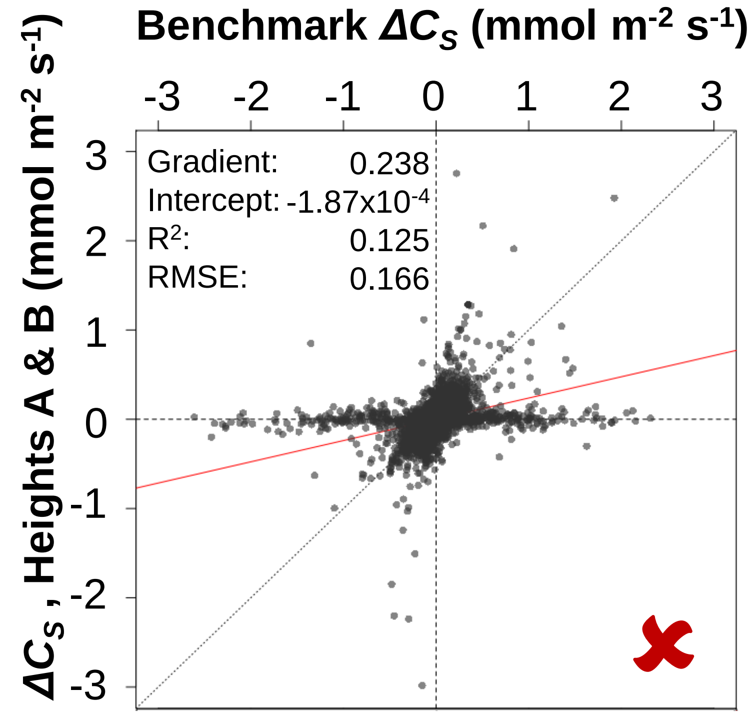
- Compare to co-located measurements (continuous or intermittent)
- **Energy (co)spectra**

* Kotthaus and Grimmond (2012)

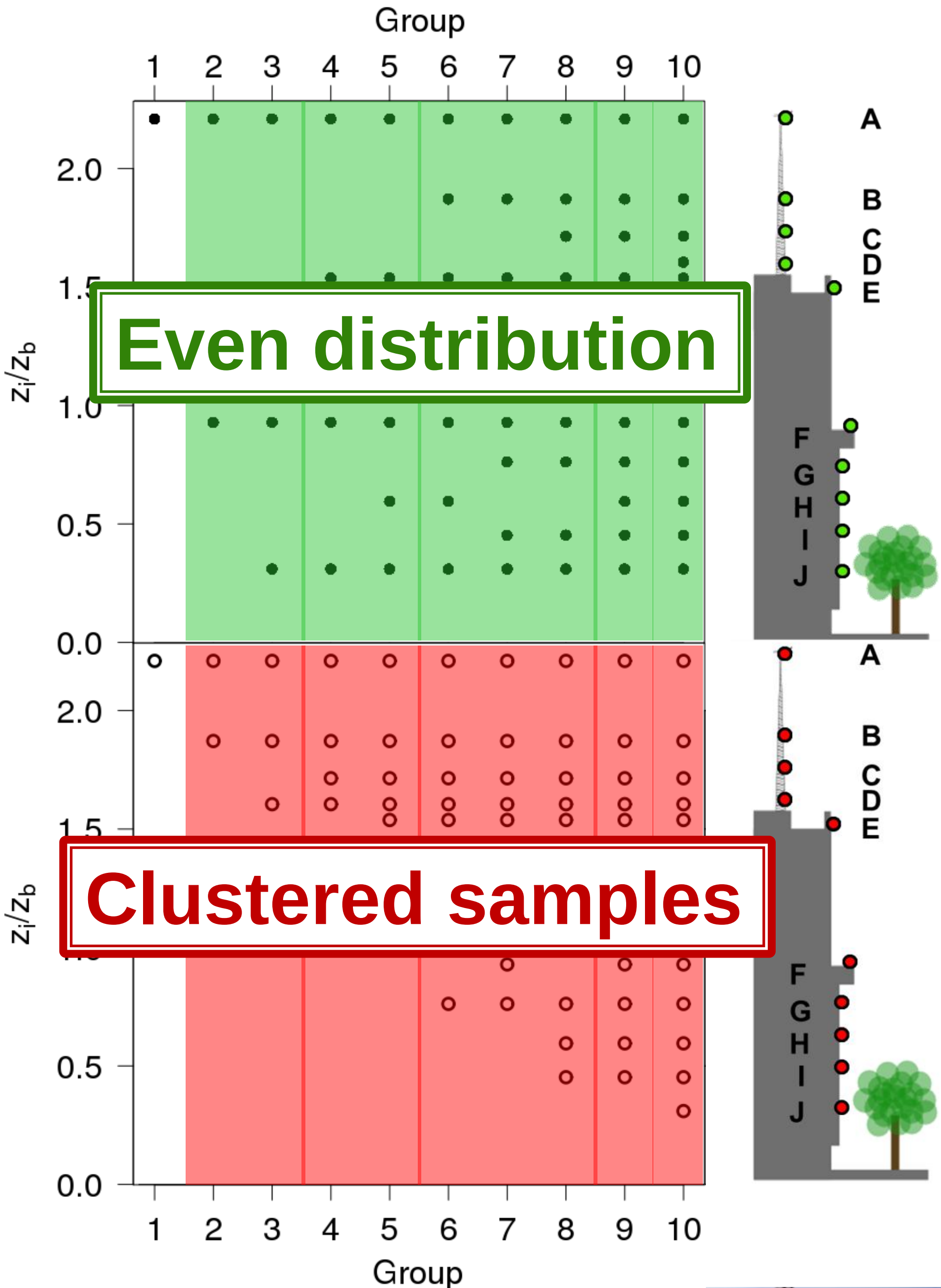
CO_2 Storage: Spatial Resolution of Measurements

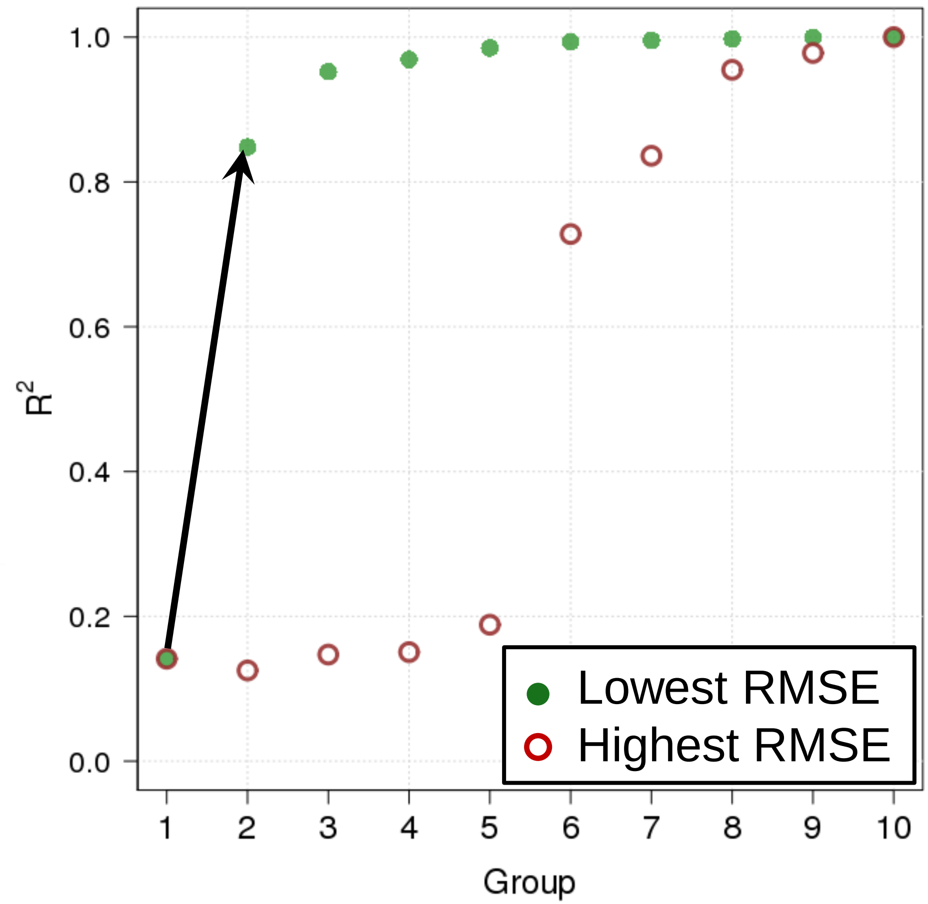






Data collected by Li840
2012/150 – 2013/153



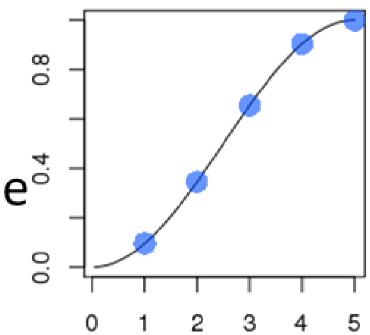


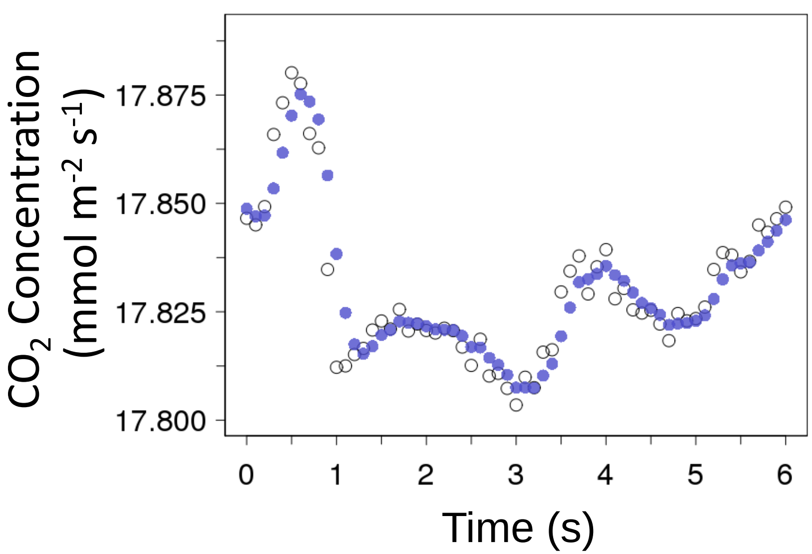
Only need 2 measurements

Time resolution of measurements

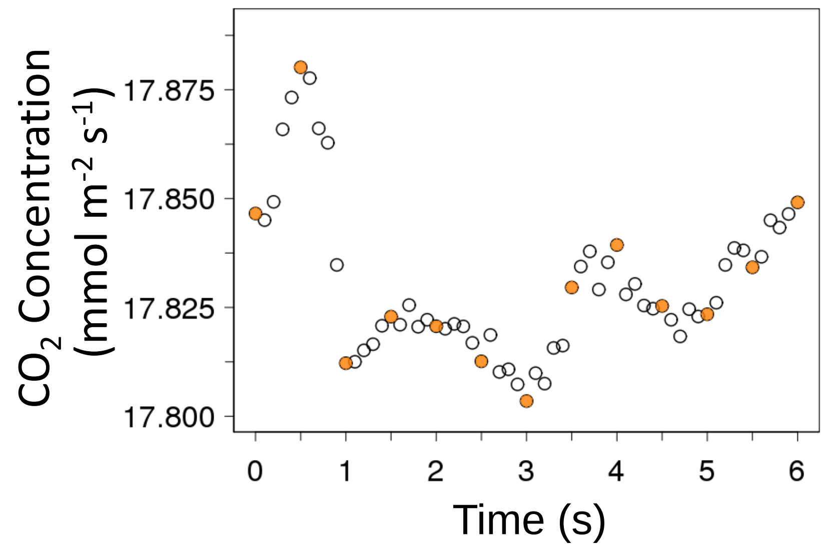
Sensor response time

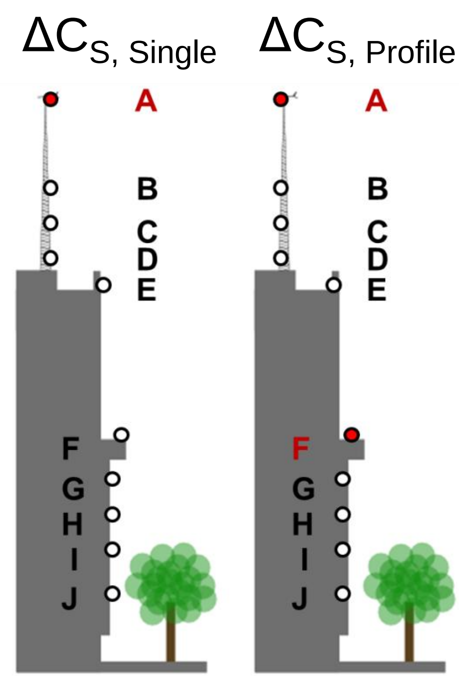
Smoothed by modified cosine

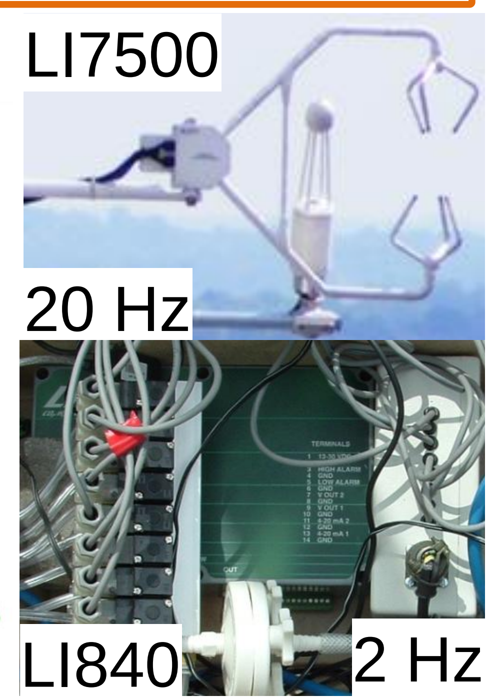


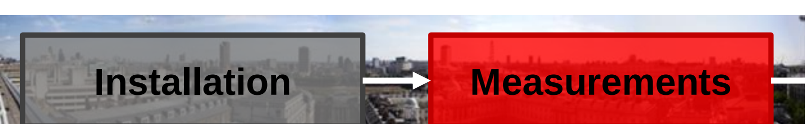


Sensor sampling interval





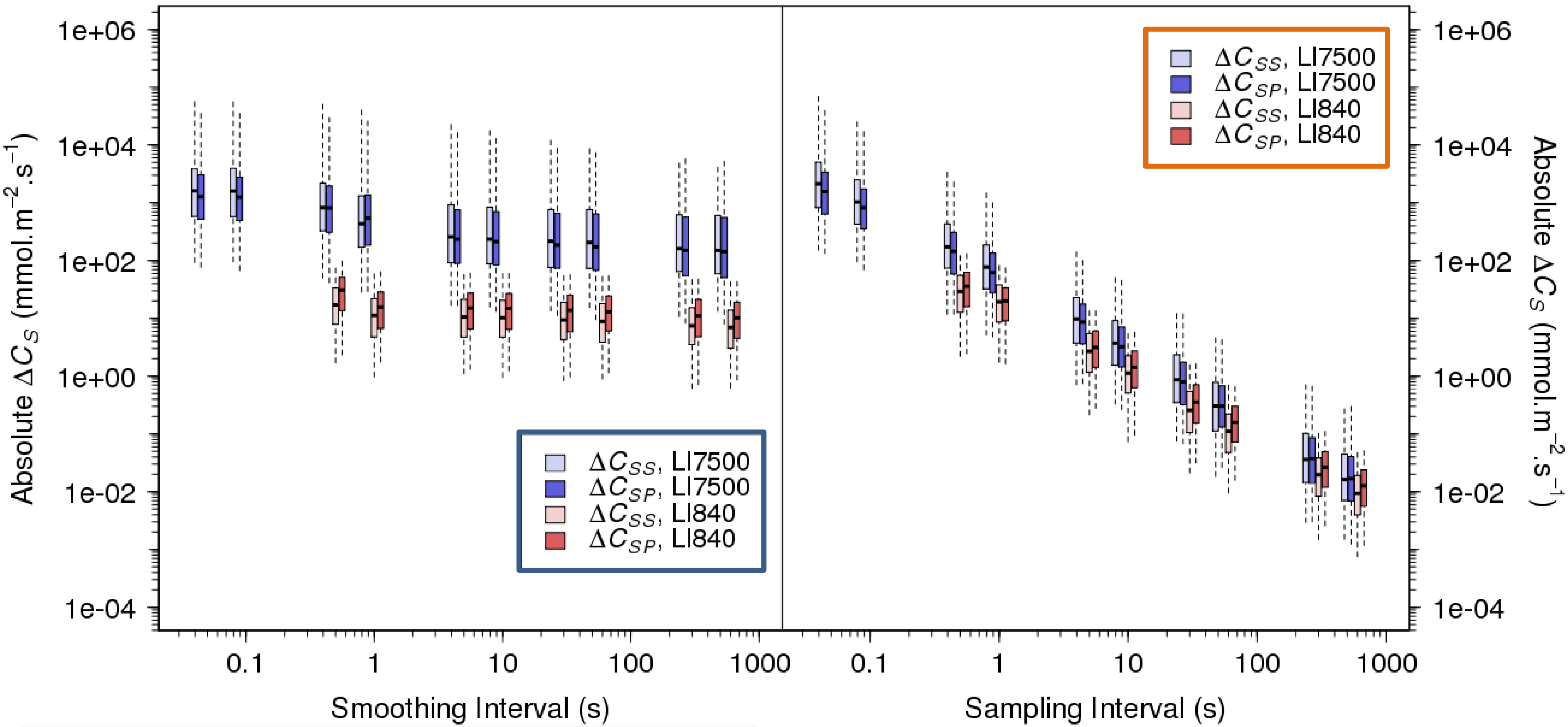




Time resolution of measurements

LI7500 and LI840, Heights A and F, 2014/013 – 2014/043

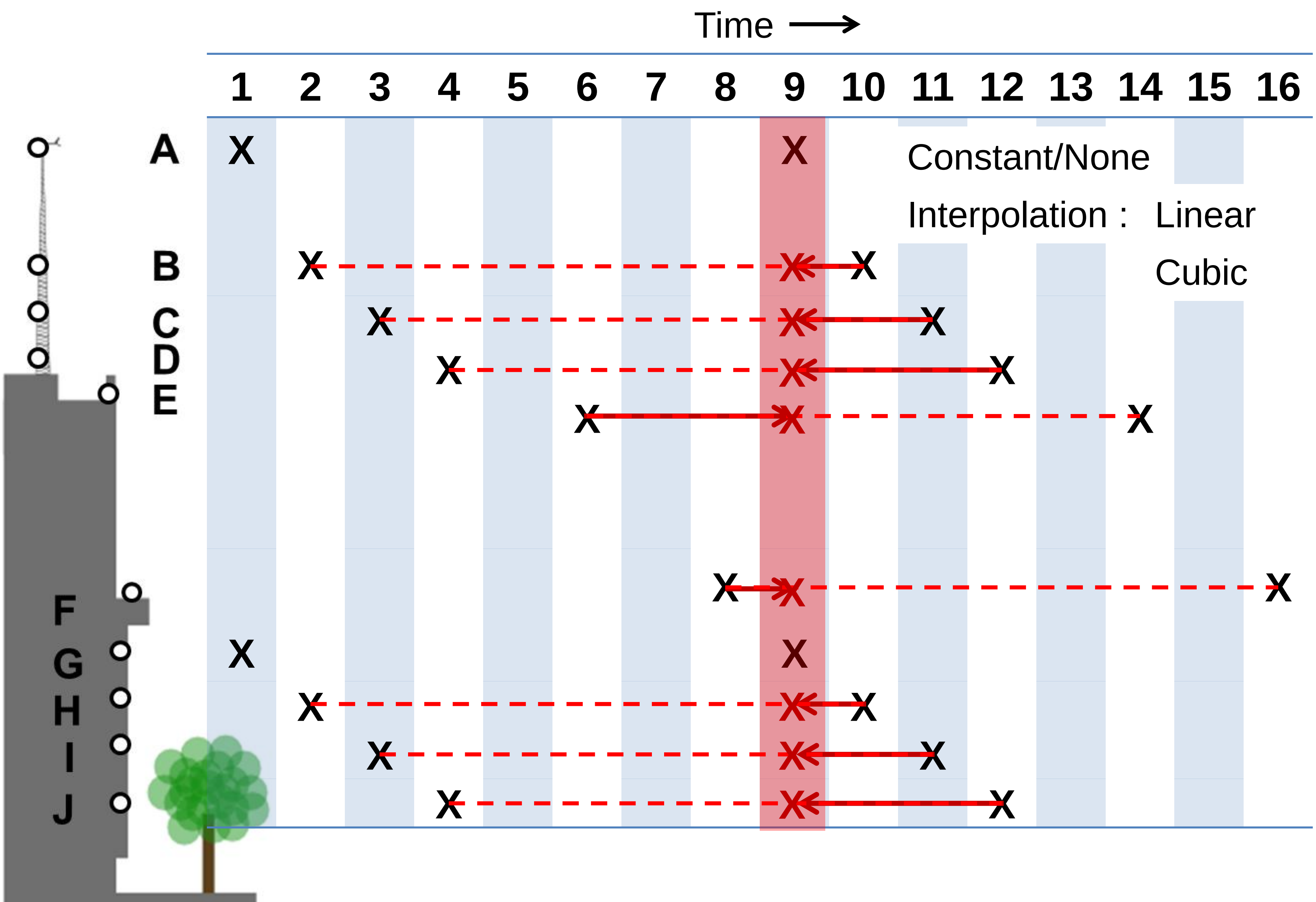
ΔC_{SS}: data from single height
ΔC_{SP}: data from vertical profile



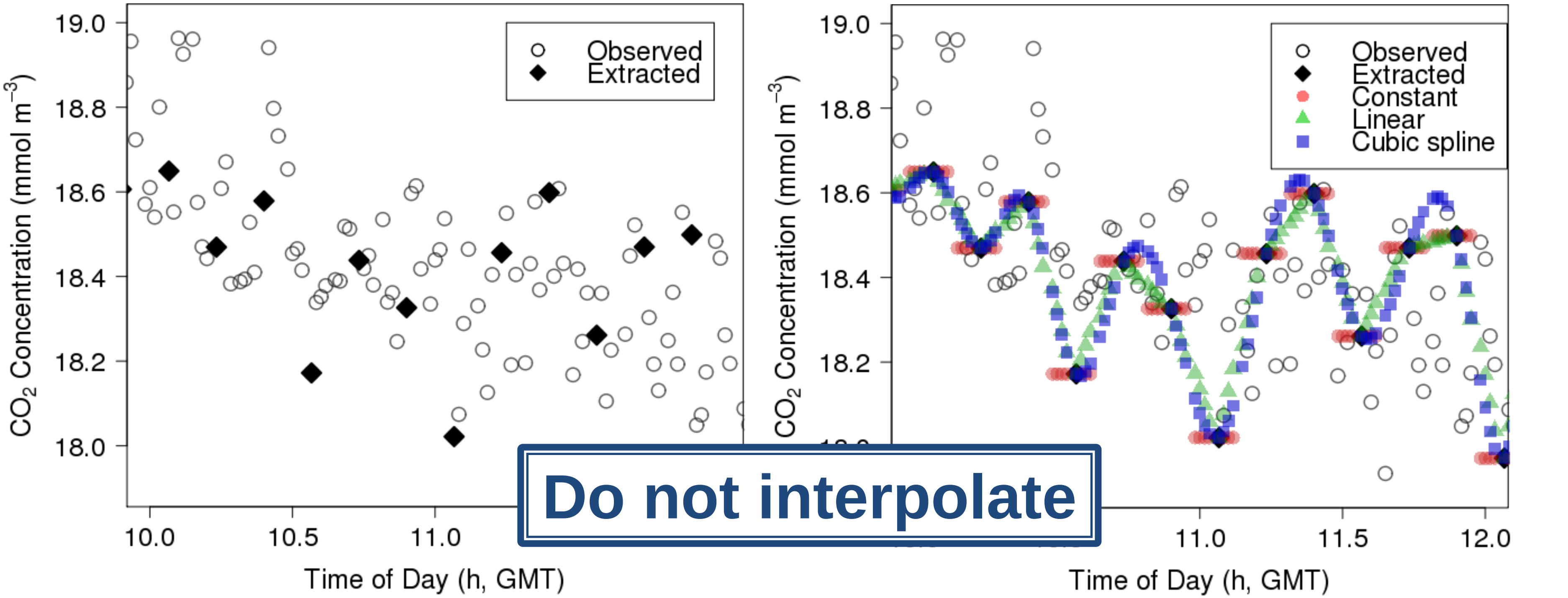
- Aim for response time < 0.1 s
- Little difference between response times > 1 s

$$\log_{10}\left(\overline{|\Delta C_S|}\right) = a \log_{10}(t_s) + b$$

Interpolation in time



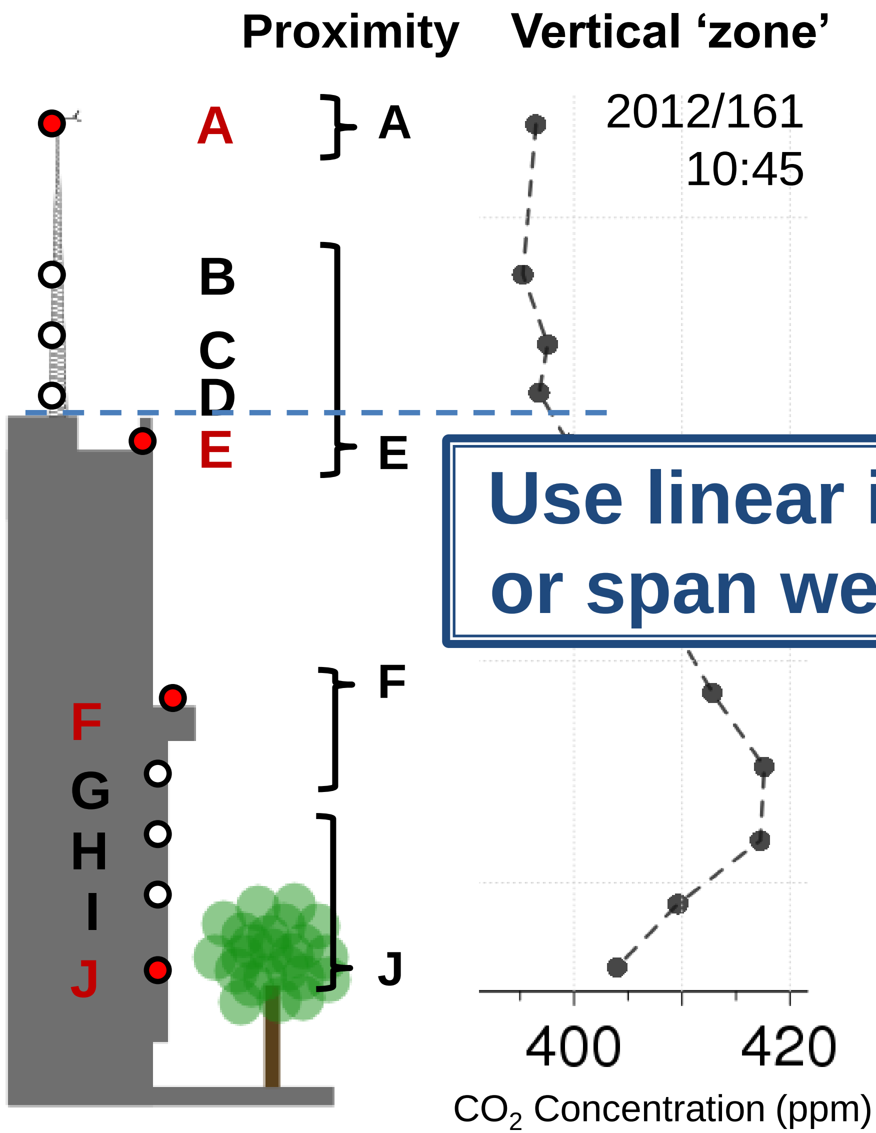
Interpolation in time: 2013/160 – 2013/365



Do not interpolate

	Interpolation Method	R^2	Slope	Intercept	RMSE	DoF x10^3
CO_2 Concentration (mmol m^{-3})	None	0.987	0.993	0.131	0.151	181
	Linear	0.989	0.992	0.146	0.140	210
	Cubic	0.987	0.992	0.136	0.151	210
CO_2 Storage (mmol m^{-2} s^{-1})	None	0	0	0.022	7.73	26
	Linear	0.030	0.945	-0.002	5.34	209
	Cubic	0.011	0.601	-0.001	5.39	209

Interpolation in Space: 2013/160 – 2013/365



Interpolation Method	Sample Location	R^2	Intercept (ppm)	Slope	RMSE (ppm)	DoF x10³
None (proximity)	B (E)	0.82	64.3	0.84	10.4	41
	C (E)	0.82	50.9	0.87	10.9	41
	D (E)	0.85	50.3	0.87	10.0	41
	G (F)	0.86	3.2	1.00	10.7	38
	H (J)	0.91	28.9	0.93	7.9	38
	I (J)	0.90	30.0	0.93	8.4	38

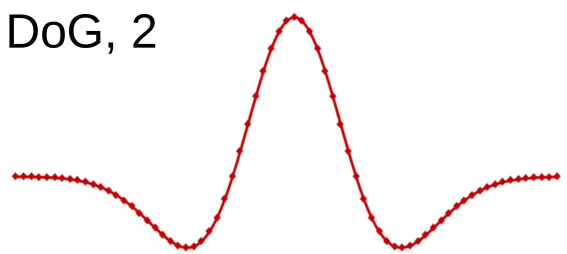
Use linear interpolation or span weight by zone

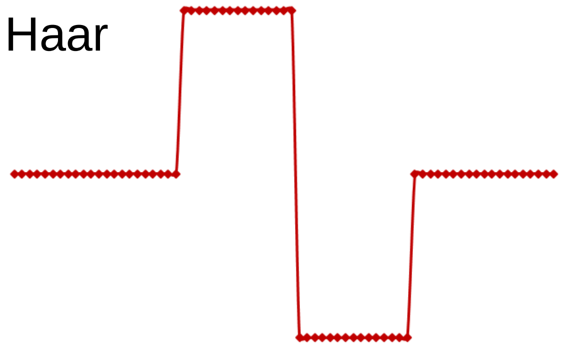
Choice of method for frequency analysis

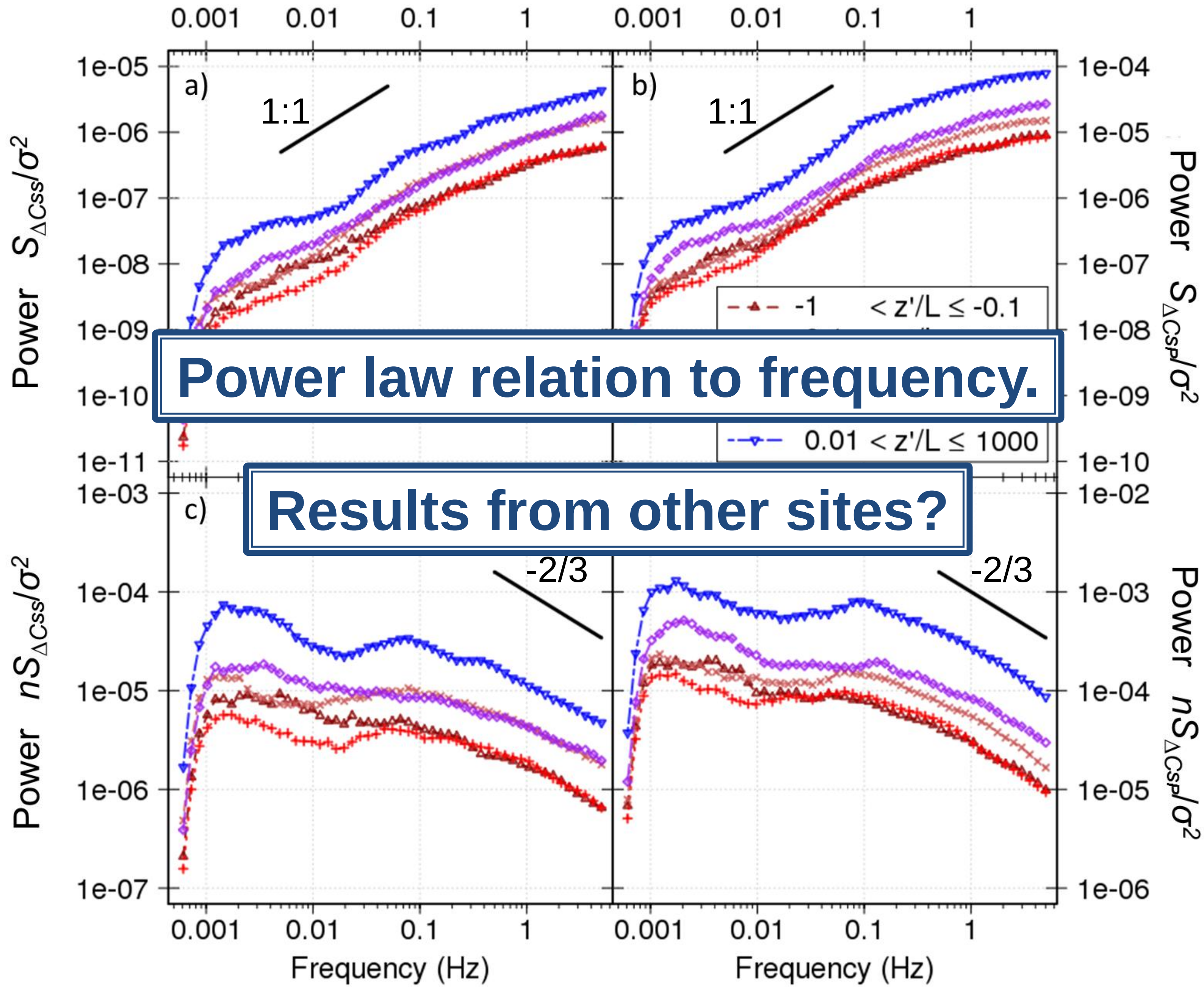
Criteria	Fourier Analysis	Lomb-Scargle Periodogram	Wavelet Analysis
Automatable	✓	✓	✓
Tolerant to gaps/errors	✗	✓	~
Quick to run	✓	✗	✓

<u>Admissibility Conditions</u>

- Mean of 0
- Localised in both time and frequency space



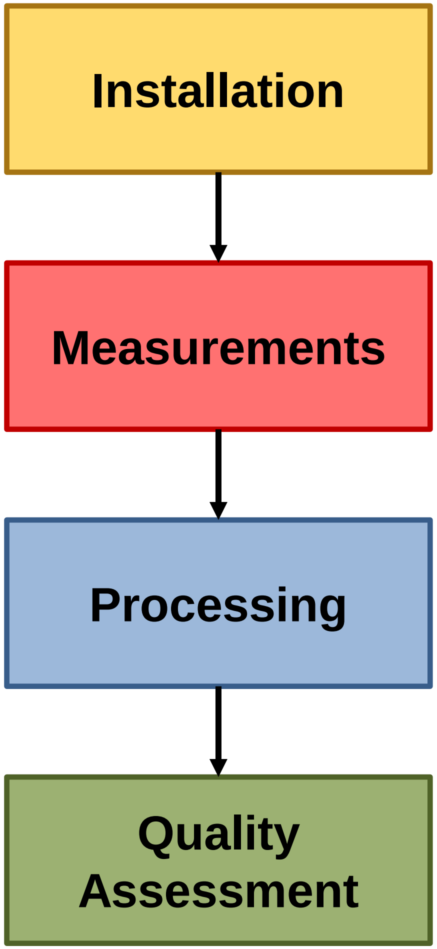




Power law relation to frequency.

Results from other sites?

Conclusions



- Urban CO_2 profile very different from rural
- At least one measurement within the street canyon is required

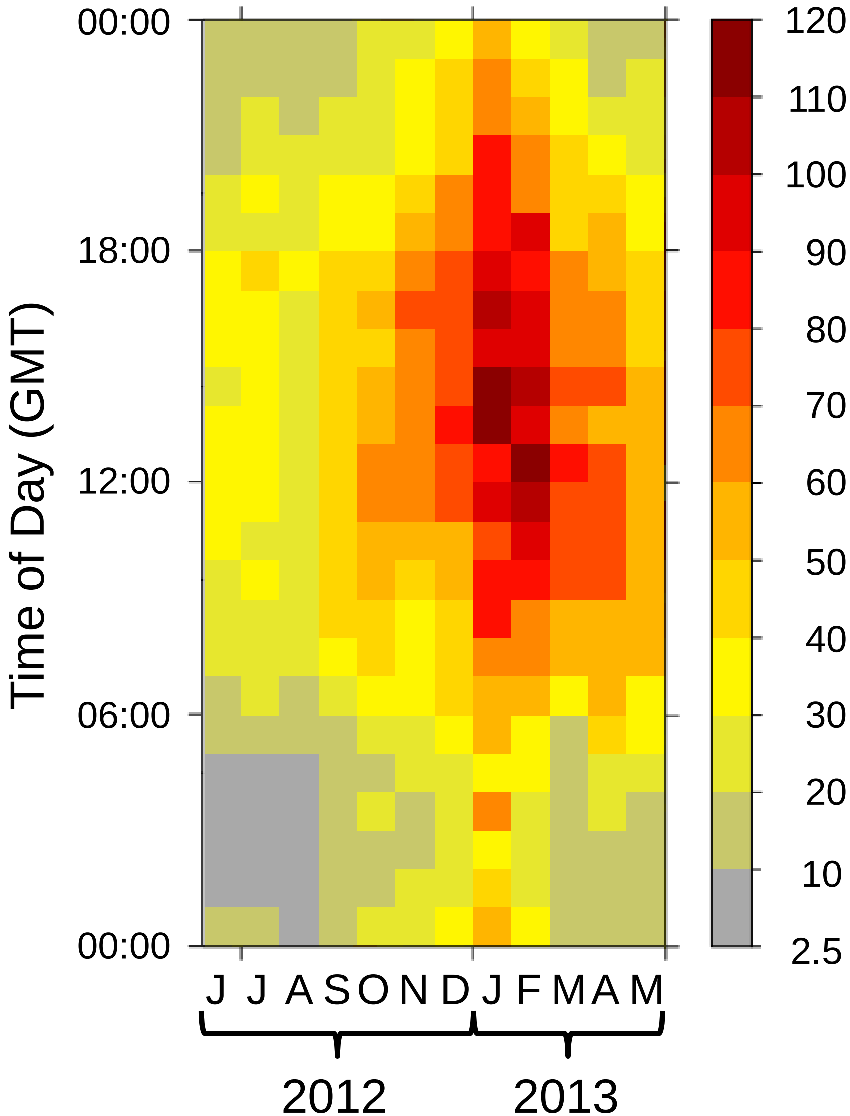
- Sensor response time should be < 0.1 s
- CO_2 storage magnitude declines with sampling frequency

- If characteristic shape of vertical profile known, span weight by ‘zone’
- If not, interpolate linearly or span to midpoints

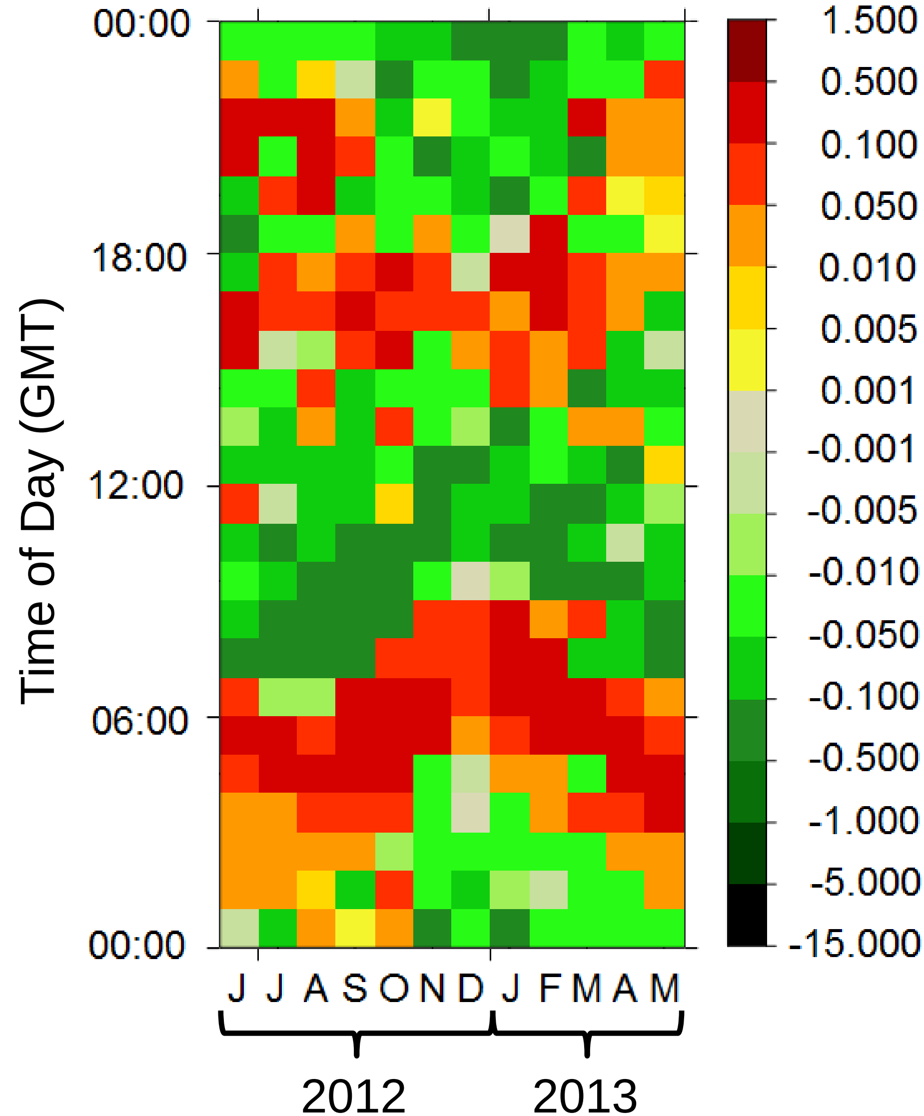
- CO_2 storage has a power law relation to frequency

<u>Results:</u> Vertical flux and CO_2 storage June 2012 to May 2013

Vertical CO_2 Flux ($\mu mol\ m^{-2}\ s^{-1}$)

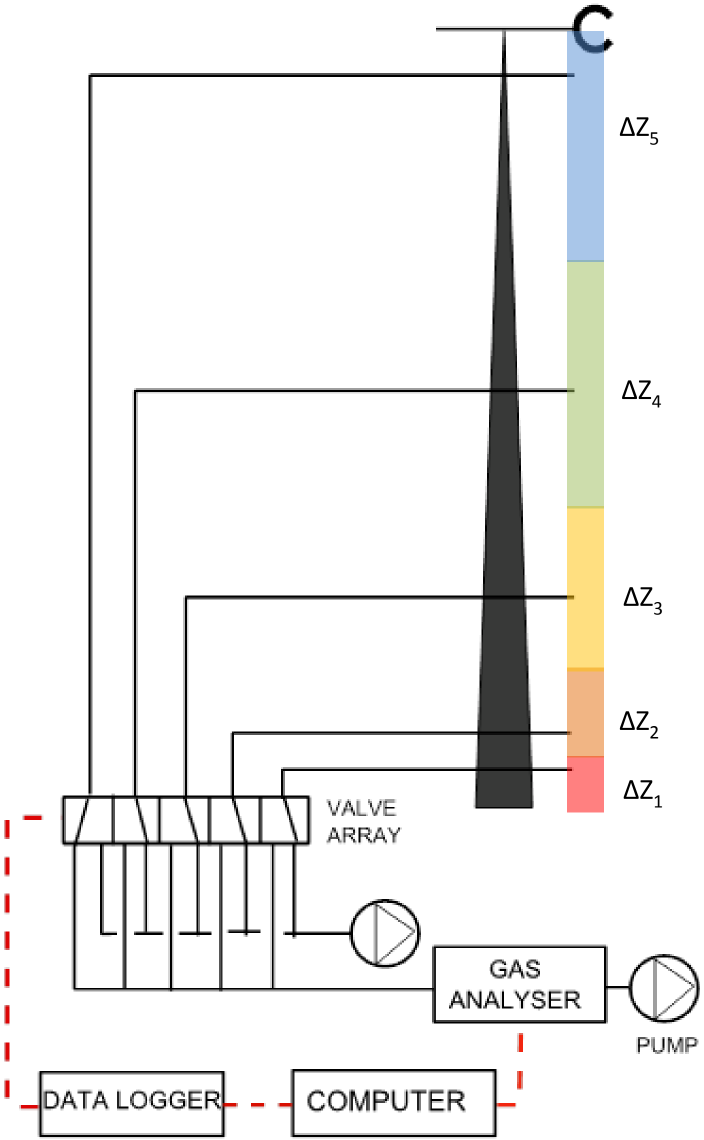


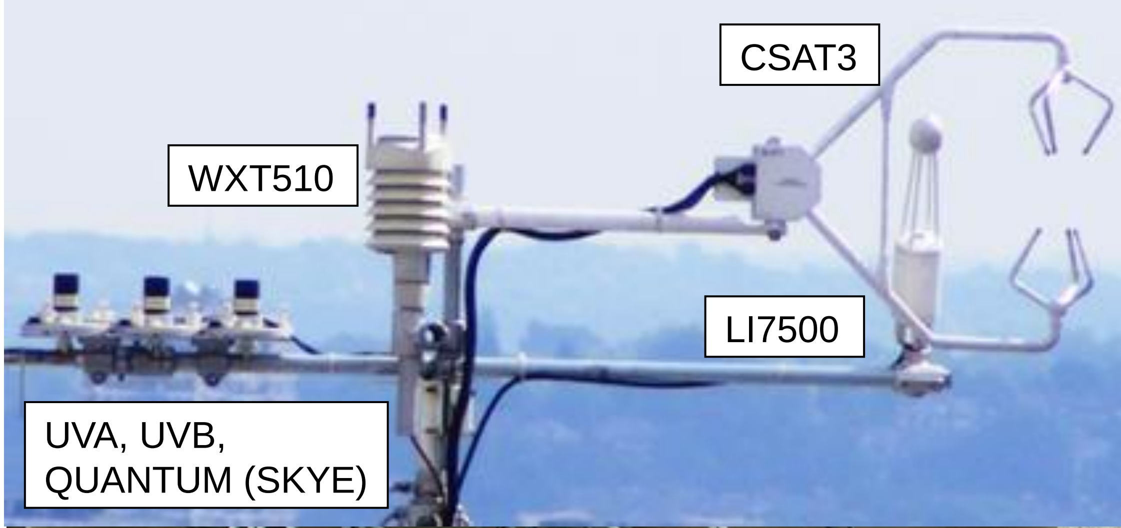
$\Delta C_{S,\ Profile}$ ($\mu mol\ m^{-2}\ s^{-1}$)

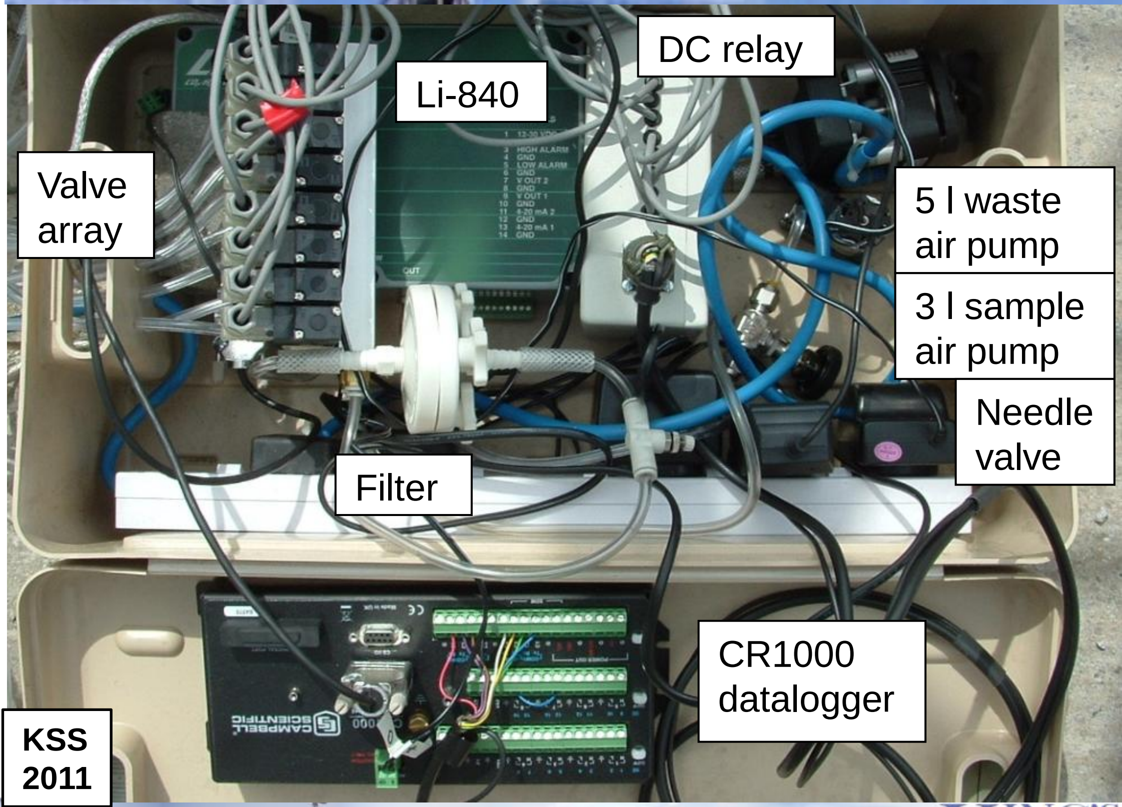


<u>References:</u> Kotthaus, S. and Grimmond, C.S.B. (2012) Identification of micro-scale anthropogenic CO_2, heat and moisture sources – processing eddy covariance fluxes for a dense urban environment. *Atmospheric Environment,* 57, 301-316.

Equipment

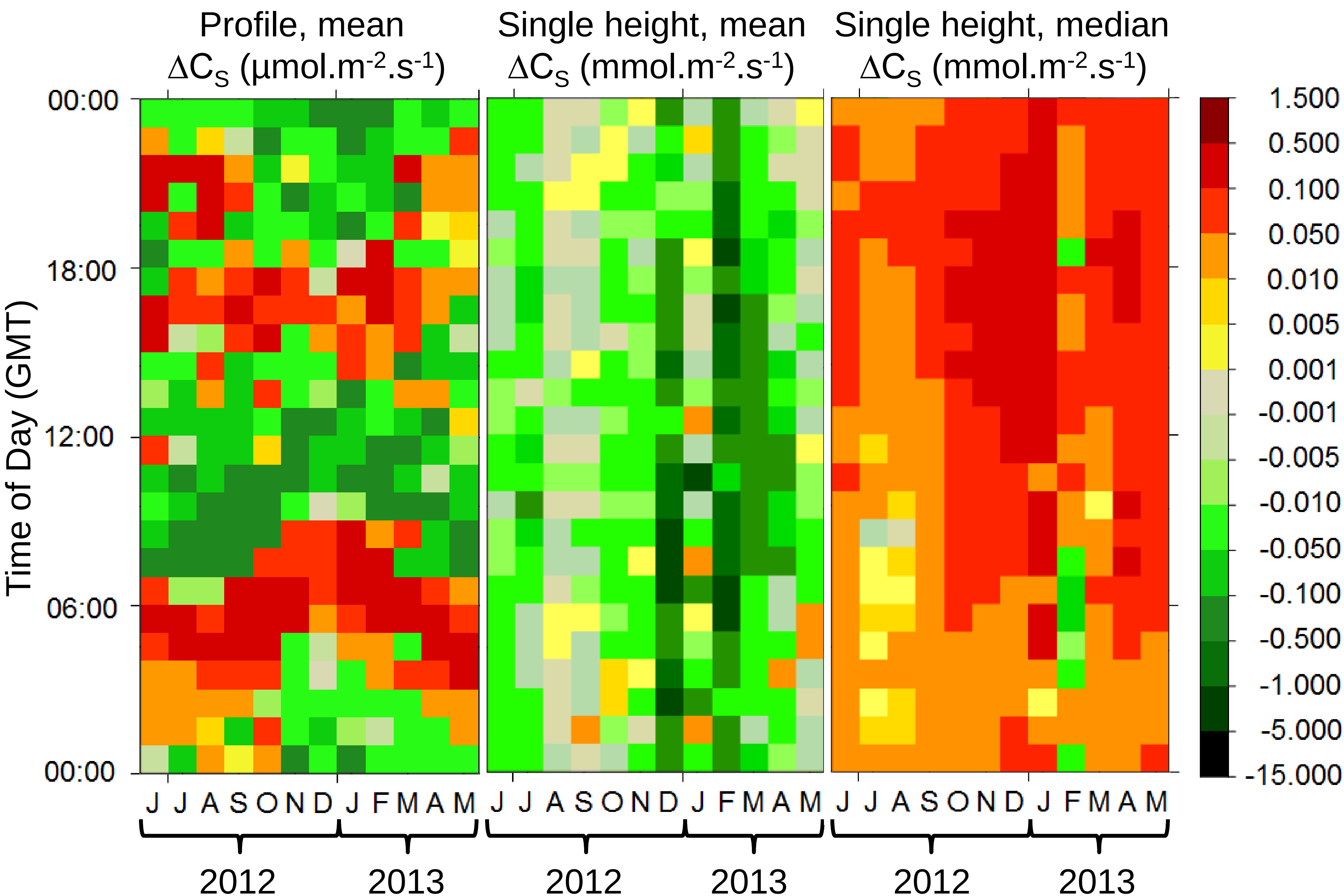






KSS 2011

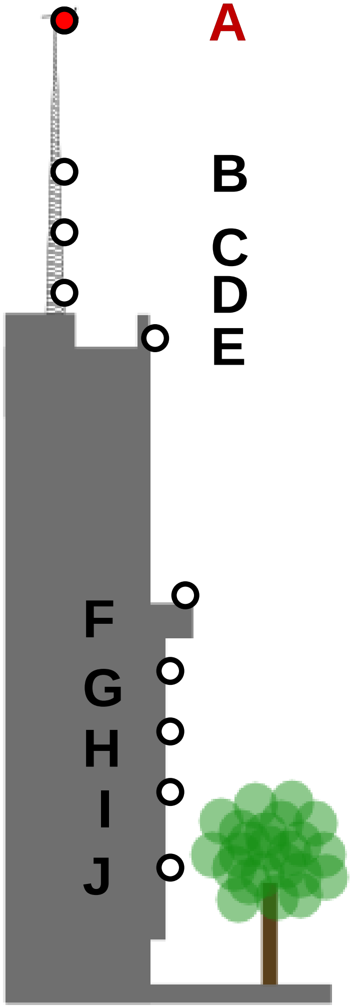
CO_2 Storage: 2012/159-2013/150

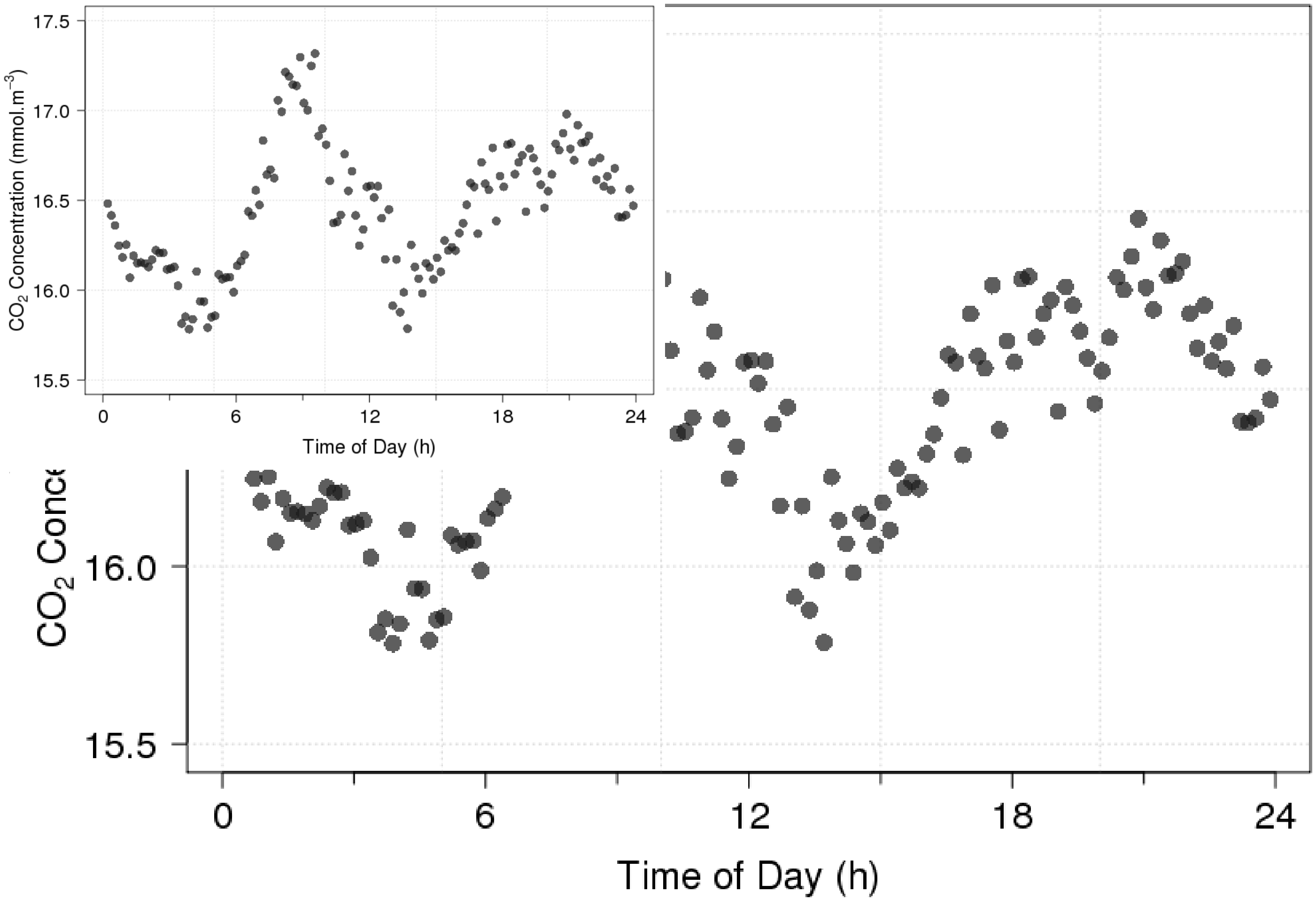


CO_2 Storage

$$\Delta C_S = \int_0^{z_h} \frac{\partial \bar{c}}{\partial t}\, dz \approx \sum_{i=1}^{h} \left[\frac{\Delta c(z_i)}{\Delta t} \right] \Delta z_i$$

Monday 3rd December 2012 (2012/338)





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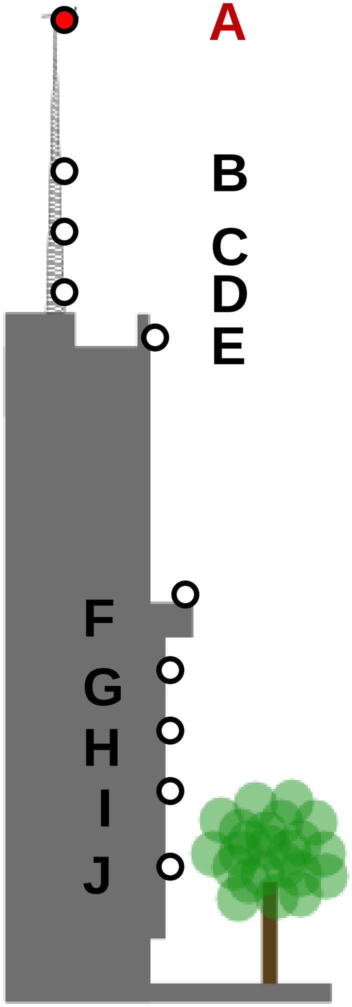

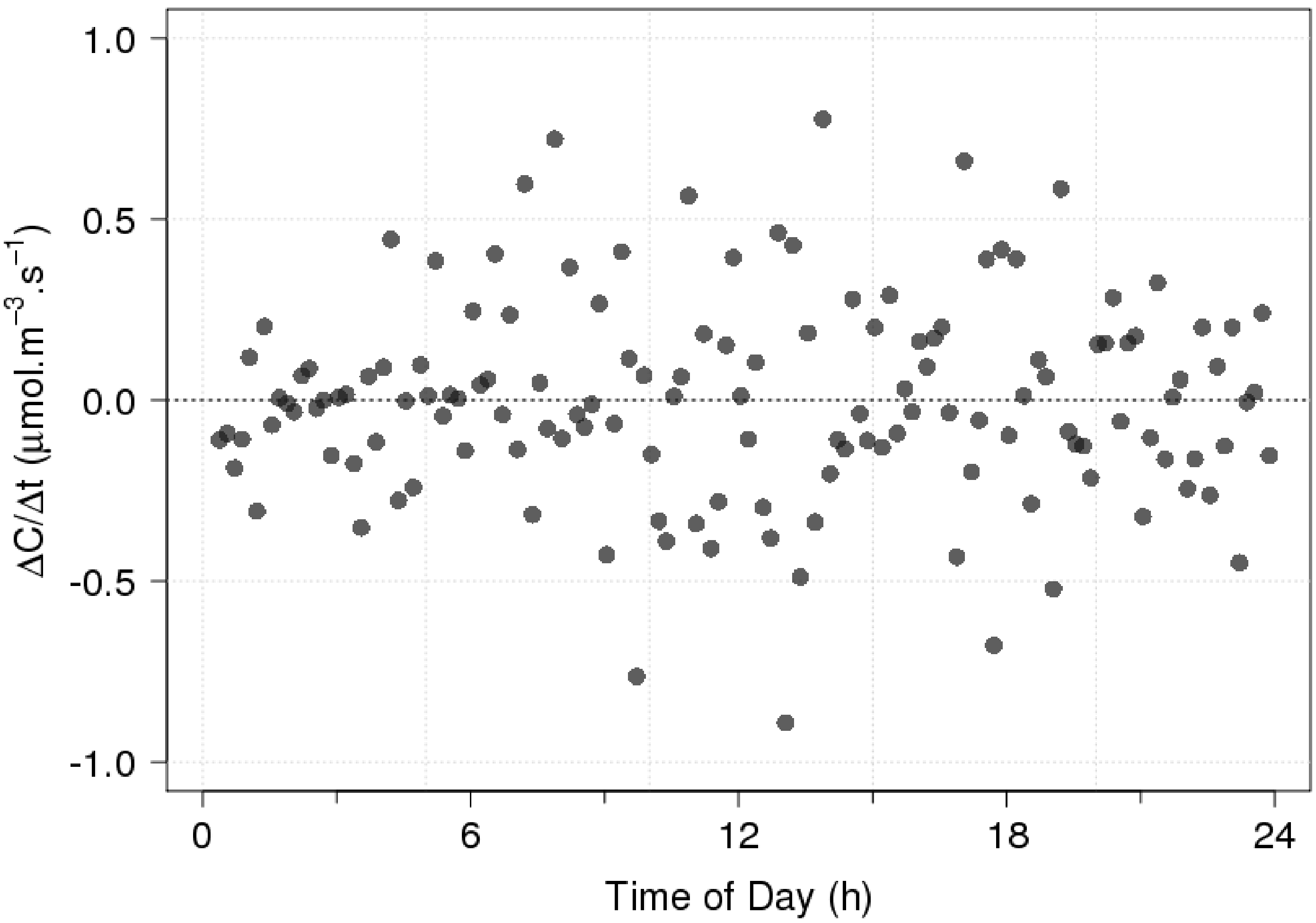

CO_2 Storage

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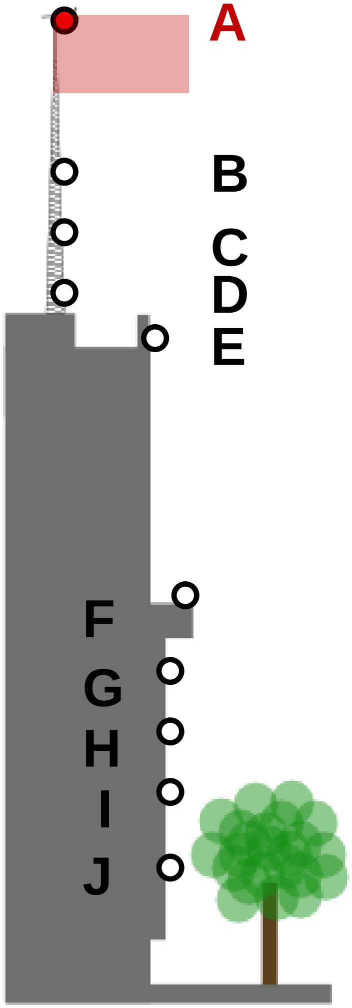

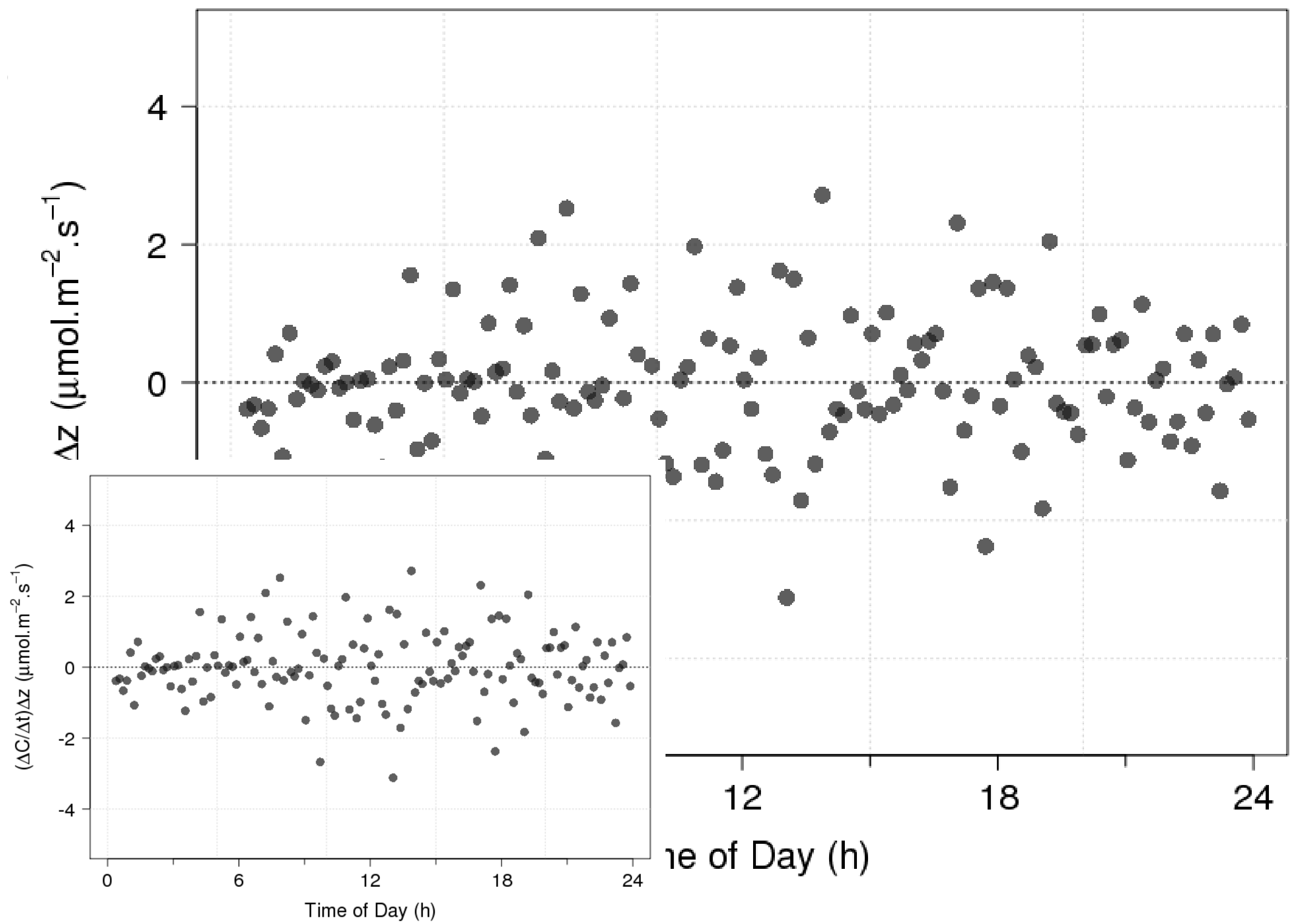

CO_2 Storage

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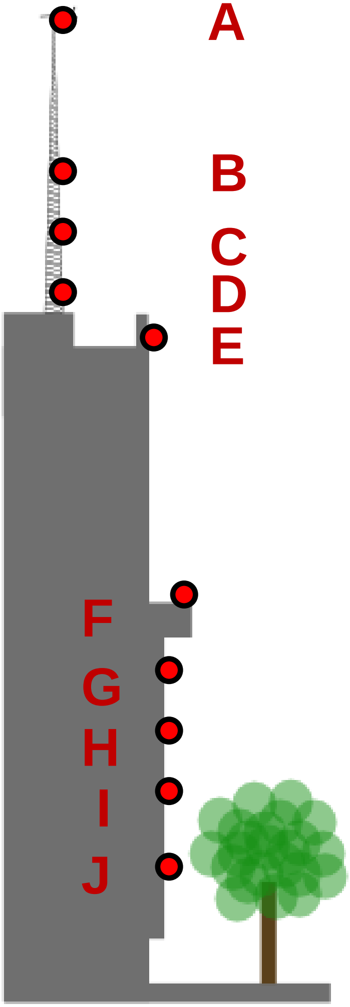

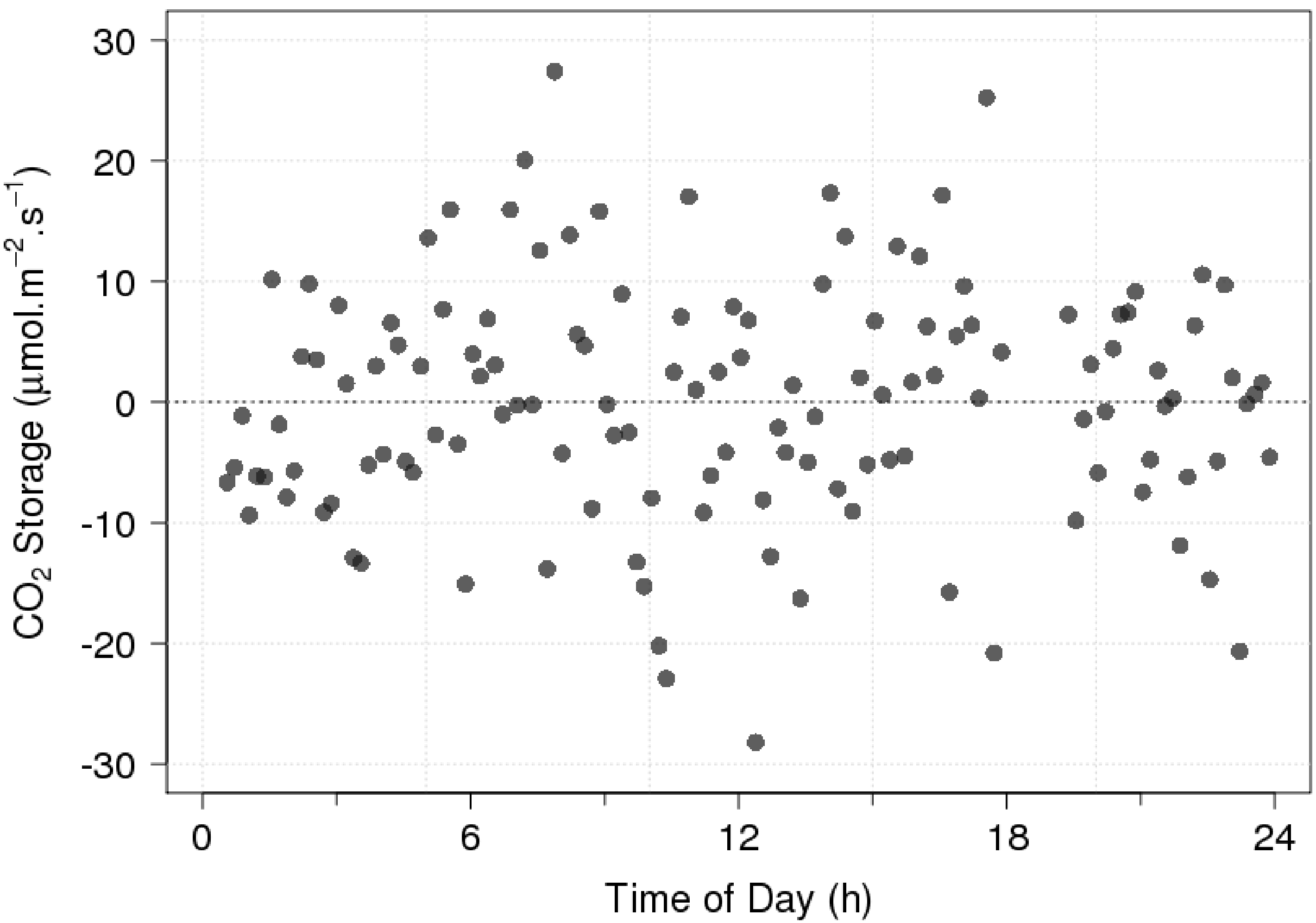

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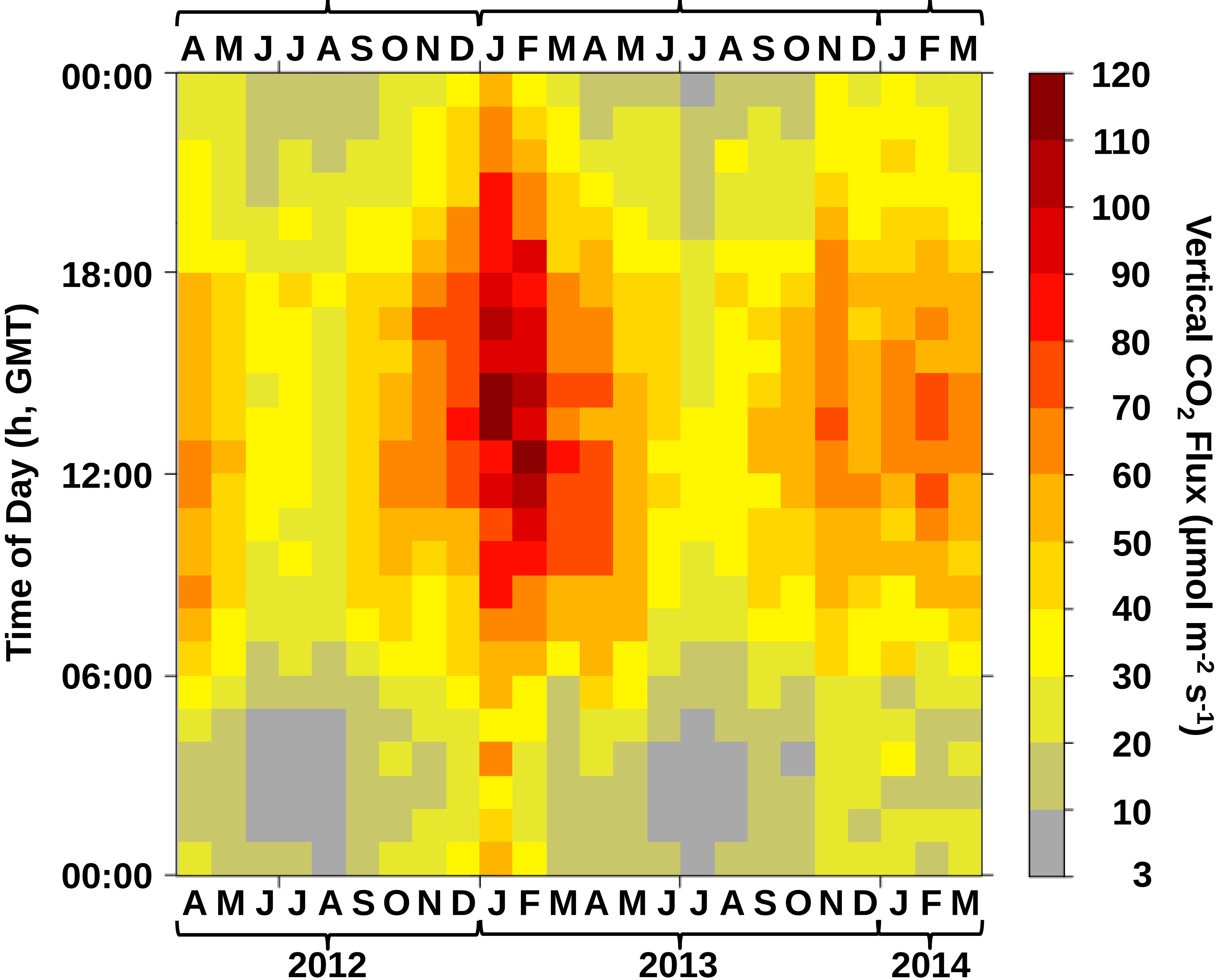
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Time of Day (h, GMT)
2012
2013
2014
120
110
100
90
80
70
60
50
40
30
20
10
3
Vertical CO_2 Flux (µmol m^{-2} s^{-1})


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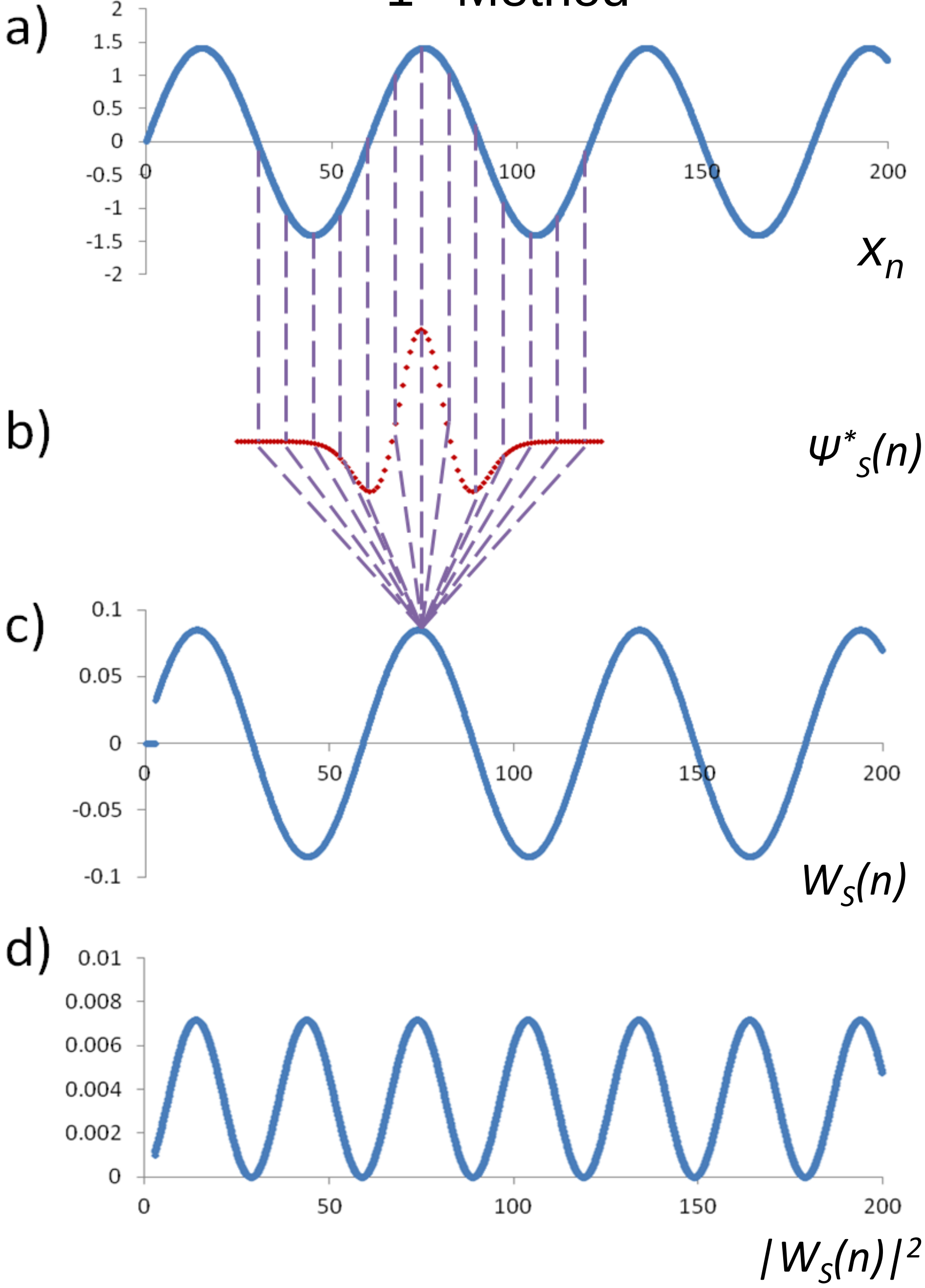
Wavelet Transform

1st Method



2nd Method

$$W_S(n) = x_n \otimes \psi_S(n)$$
$$= x_n \times \psi^*_S(n)$$

Convolution theorem:

$$F\{f \otimes g\} = F\{f\}.F\{g\}$$
$$f \otimes g = F^{-1}\{F\{f\}.F\{g\}\}$$

$$\hat{x}_k = \frac{1}{N}\sum_{n=0}^{N-1} x_n e^{-2\pi i k n/N}$$

$$W_n(s) = \sum_{n=0}^{N-1} \hat{x}_k \hat{\psi}^*(s w_k) e^{i w k n \delta t}$$

Torrence and Compo, 1998