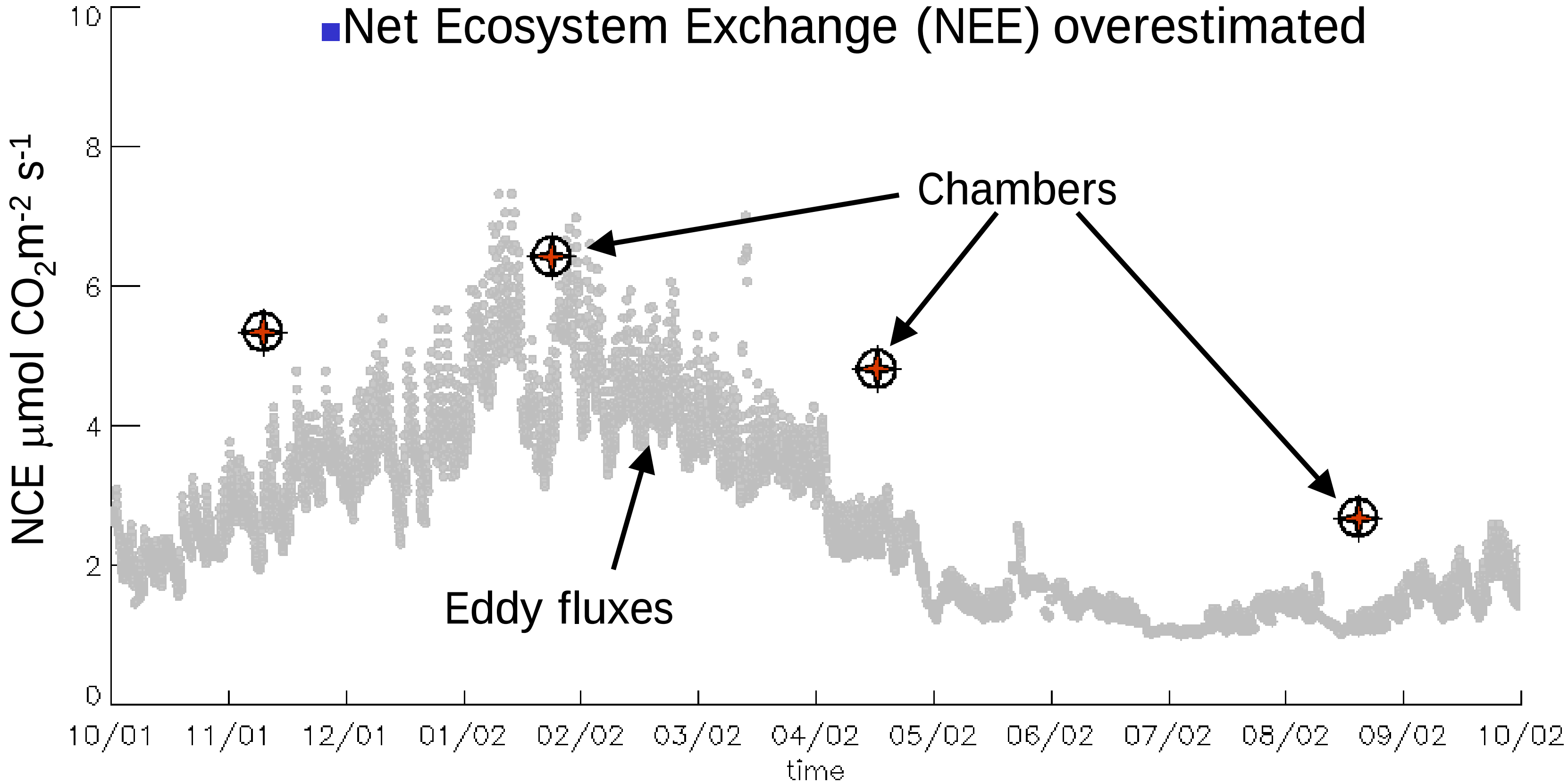
Lecture 7: Nocturnal fluxes

- Nocturnal advection experiment
  - Measuring nocturnal drainage flows of CO_2 below a forest canopy
- Nocturnal CO_2 fluxes
  - u_* correction
  - van Gorsel method
- An advection experiment
- Summary

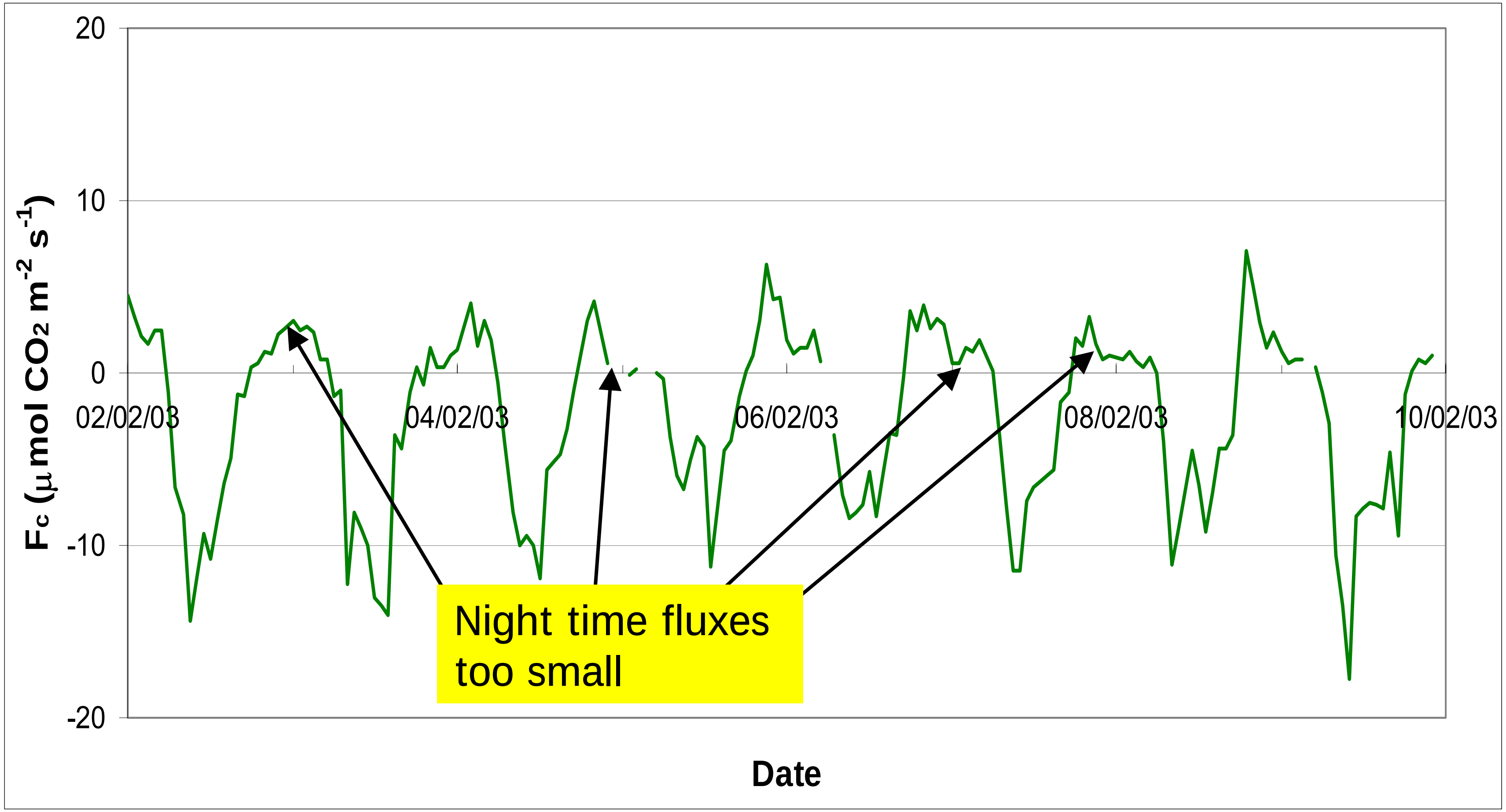
Eddy fluxes vs chamber measurements

Van Gorsel et al. (2006)

- Comparisons consistently show:
- Nocturnal Carbon Exchange (NCE) underestimated
- Net Ecosystem Exchange (NEE) overestimated



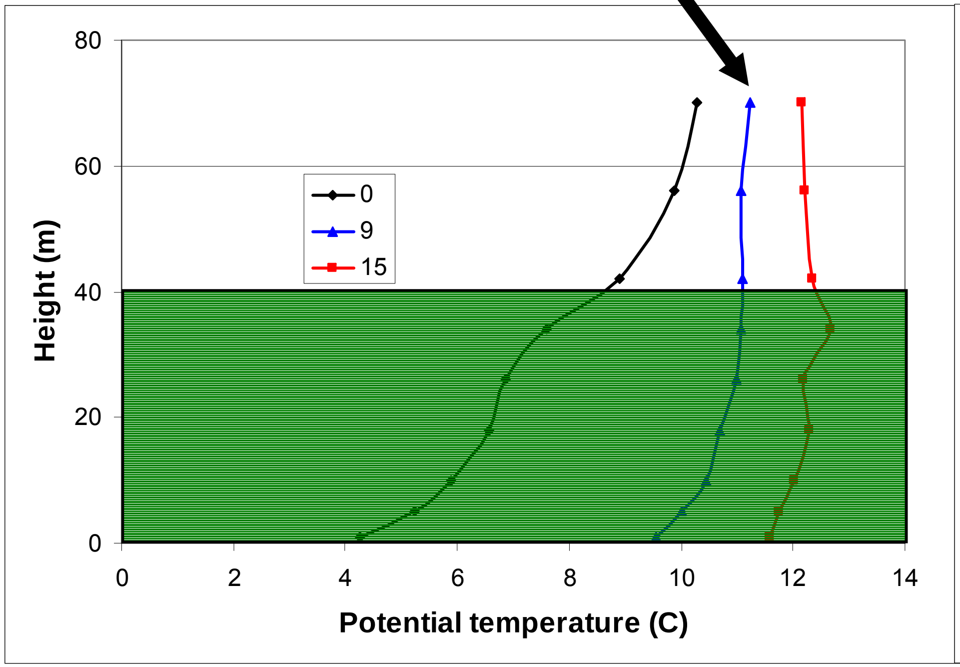
CO_2 fluxes at Tumbarumba

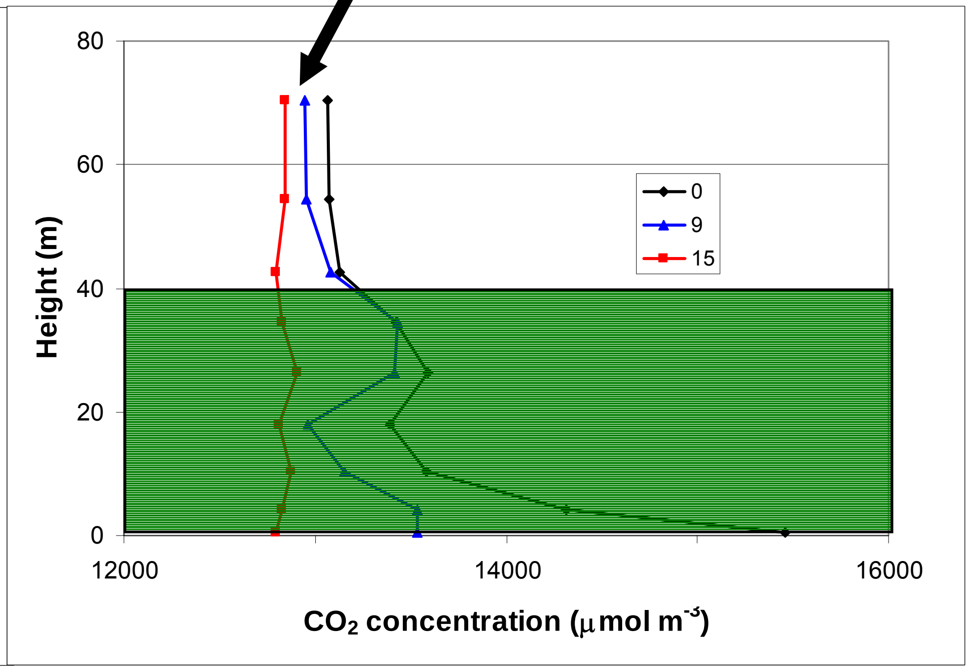


T & CO_2 profiles

Variation in θ day to night

Variation in CO_2 day to night

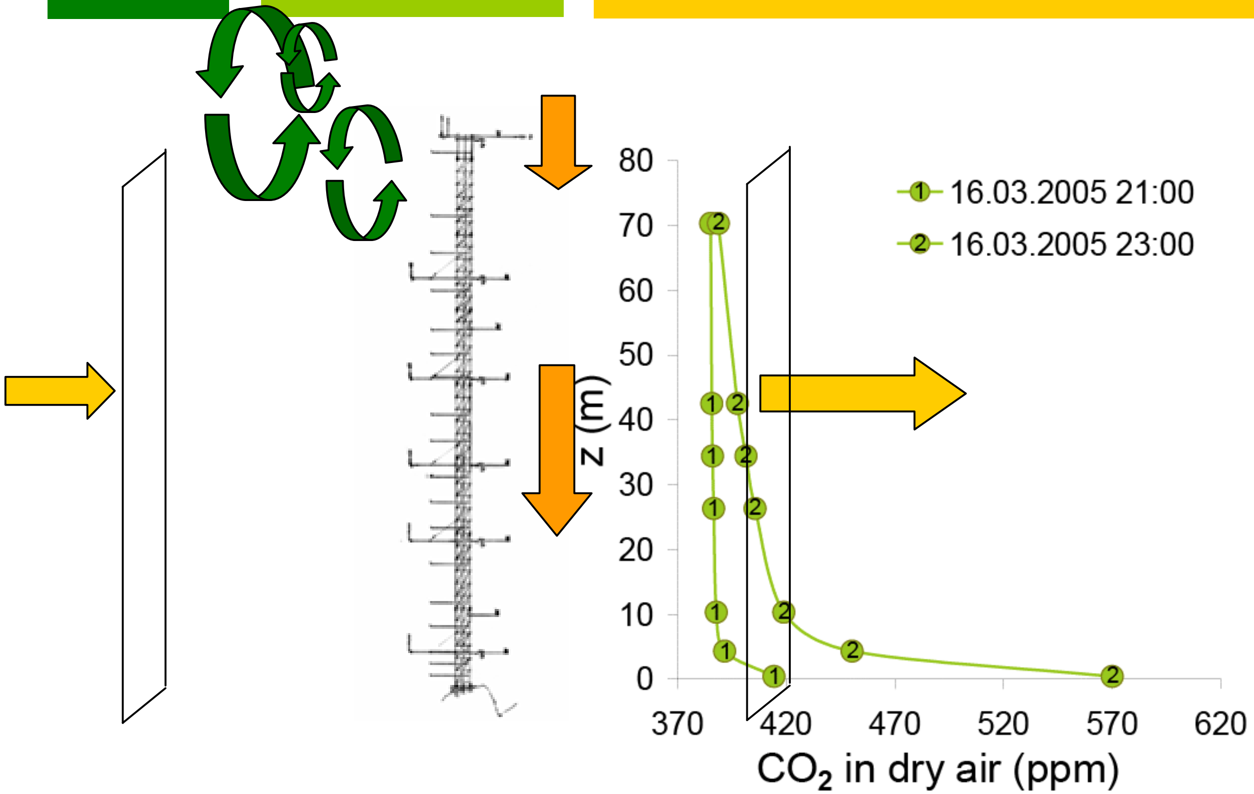




Measurements on a single tower

Van Gorsel et al. (2006)

$$R = \overline{w'c'}(h_r) + \int_0^{h_r} \frac{\partial \overline{c}(z)}{\partial t} dz + \int_0^{h_r} \left(\overline{u}(z)\frac{\partial \overline{c}(z)}{\partial x} + \overline{v}(z)\frac{\partial \overline{c}(z)}{\partial y} \right) dz + \int_0^{h_r} \overline{w}(z)\frac{\partial \overline{c}(z)}{\partial z} dz$$



Neglect advection

Van Gorsel et al. (2006)

$$R = \overline{w'c'}(h_r) + \int_0^{h_r} \frac{\partial \overline{c}(z)}{\partial t} dz + \int_0^{h_r} \left(\overline{u}(z) \frac{\partial \overline{c}(z)}{\partial x} + \overline{v}(z) \frac{\partial \overline{c}(z)}{\partial y} \right) dz + \int_0^{h_r} \overline{w}(z) \frac{\partial \overline{c}(z)}{\partial z} dz$$

- Horizontal & vertical advection not measured
  - Assume horizontally homogeneous, flat terrain

Eddy flux + change in storage

Van Gorsel et al. (2006)

$$R = \overline{w'c'}(h_r) + \int_0^{h_r} \frac{\partial \overline{c}(z)}{\partial t} dz$$

- Horizontal & vertical advection not measured
  - Assume horizontally homogeneous, flat terrain
- Strong turbulence
  - No change in storage

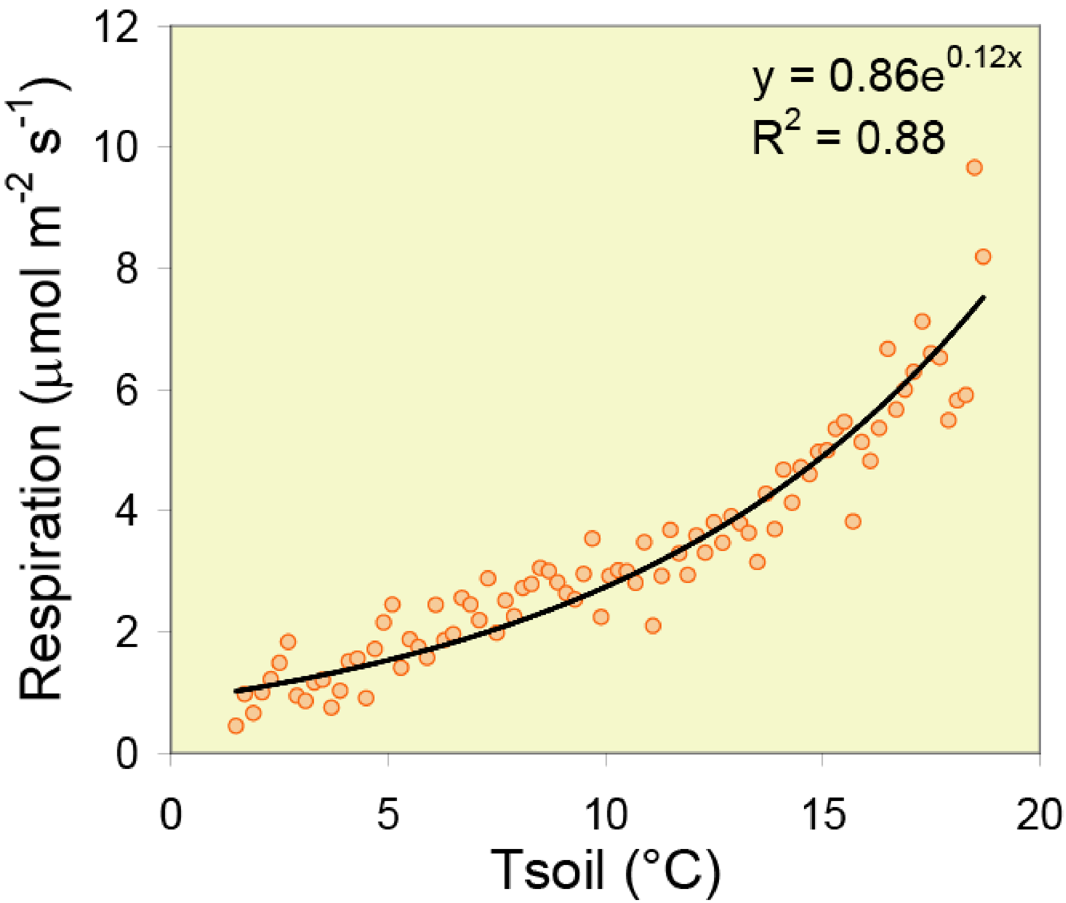
Eddy fluxes, ‘strong’ turbulence

Van Gorsel et al. (2006)

$$R = \overline{w'c'}(h_r)$$

$$R = f\,(T_{soil})$$

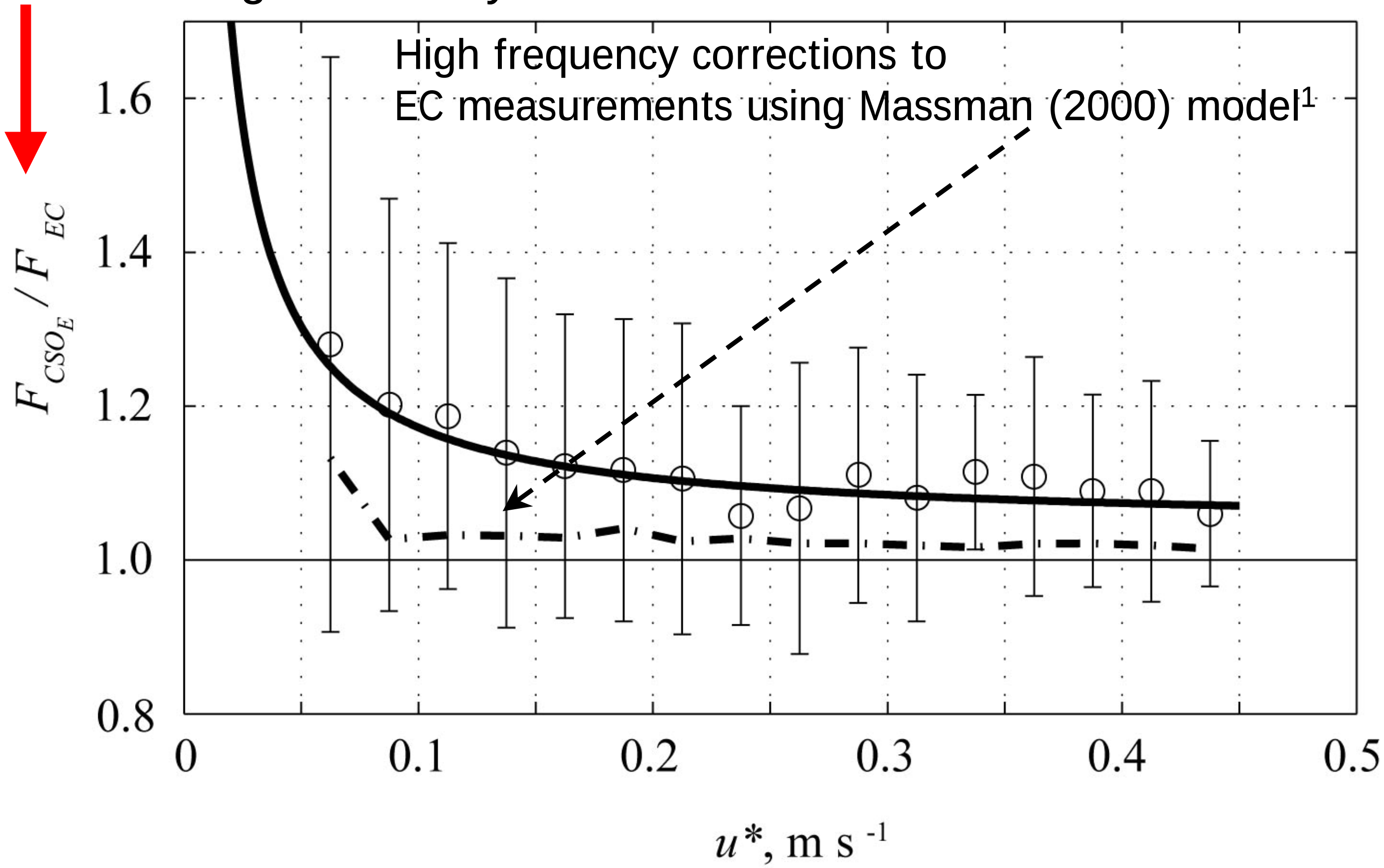
$$u_* > 0.25\,\mathrm{m\,s^{-1}}$$



CO_2 Fluxes above the Canopy

Courtesy Prof. G. Katul, Duke University

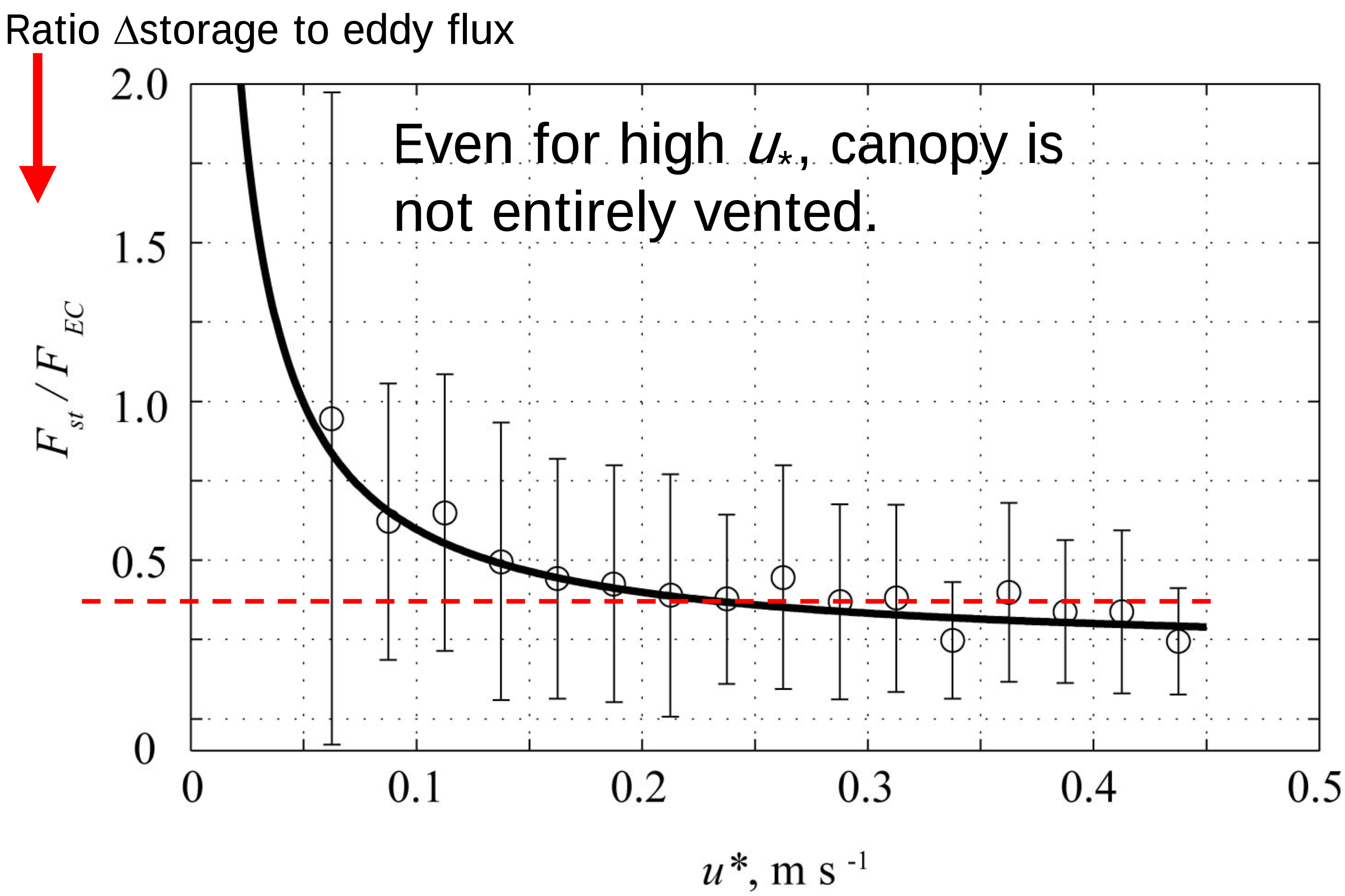
Ratio biological to eddy flux



[1]Massman, W. J. (2000), A simple method for estimating frequency response corrections for eddy covariance systems, Agricultural and Forest Meteorology, 104, 185-198

Storage Flux vs Canopy Flux

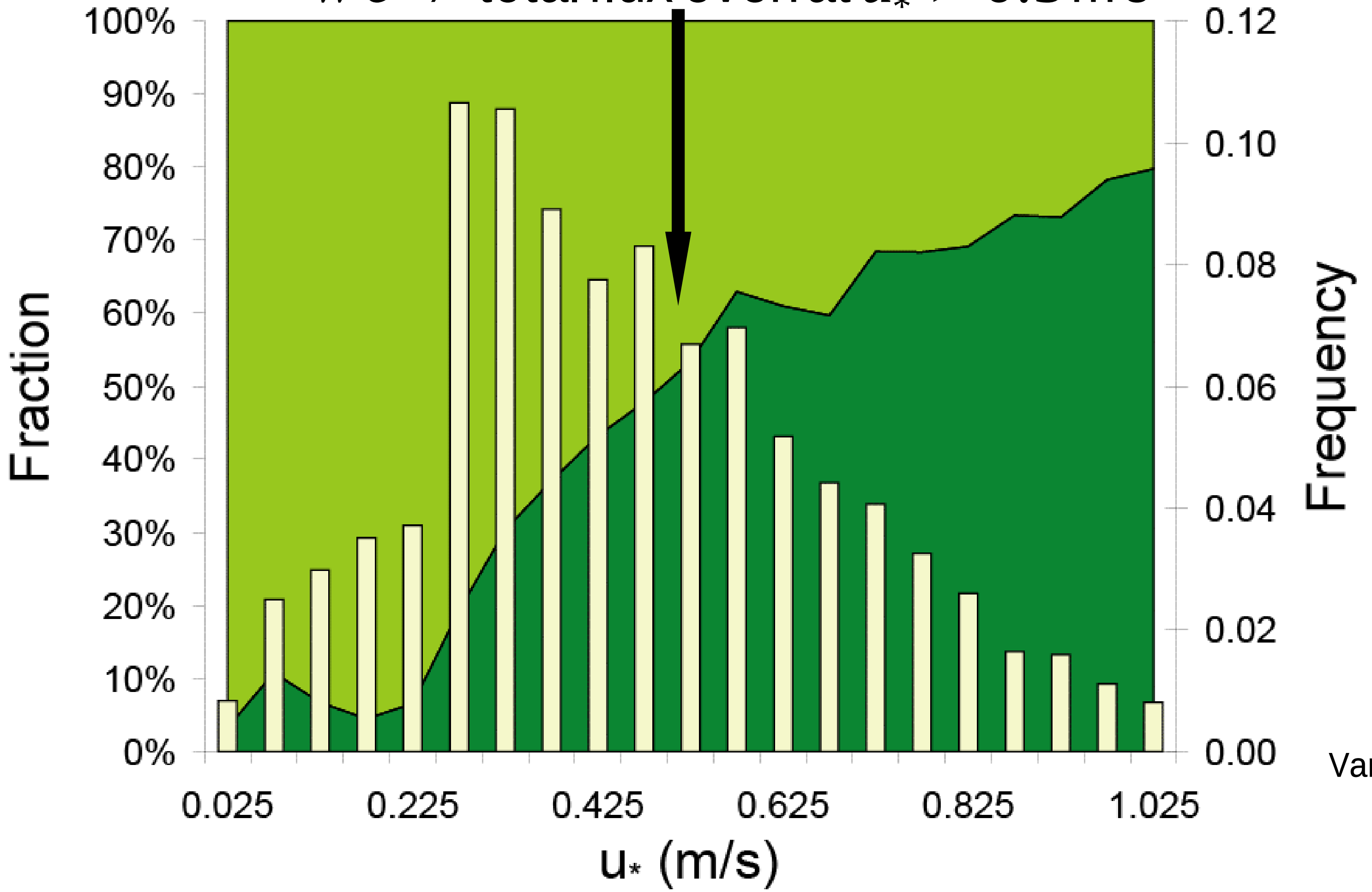
Courtesy Prof. G. Katul, Duke University



Change in storage, eddy flux & u_*

- Assume no advection

$\overline{w'c'} \neq$ total flux even at $u_* > 0.5\,\mathrm{m\,s^{-1}}$



$$\int_0^{h_r} \frac{\partial \overline{c}(z)}{\partial t} dz$$

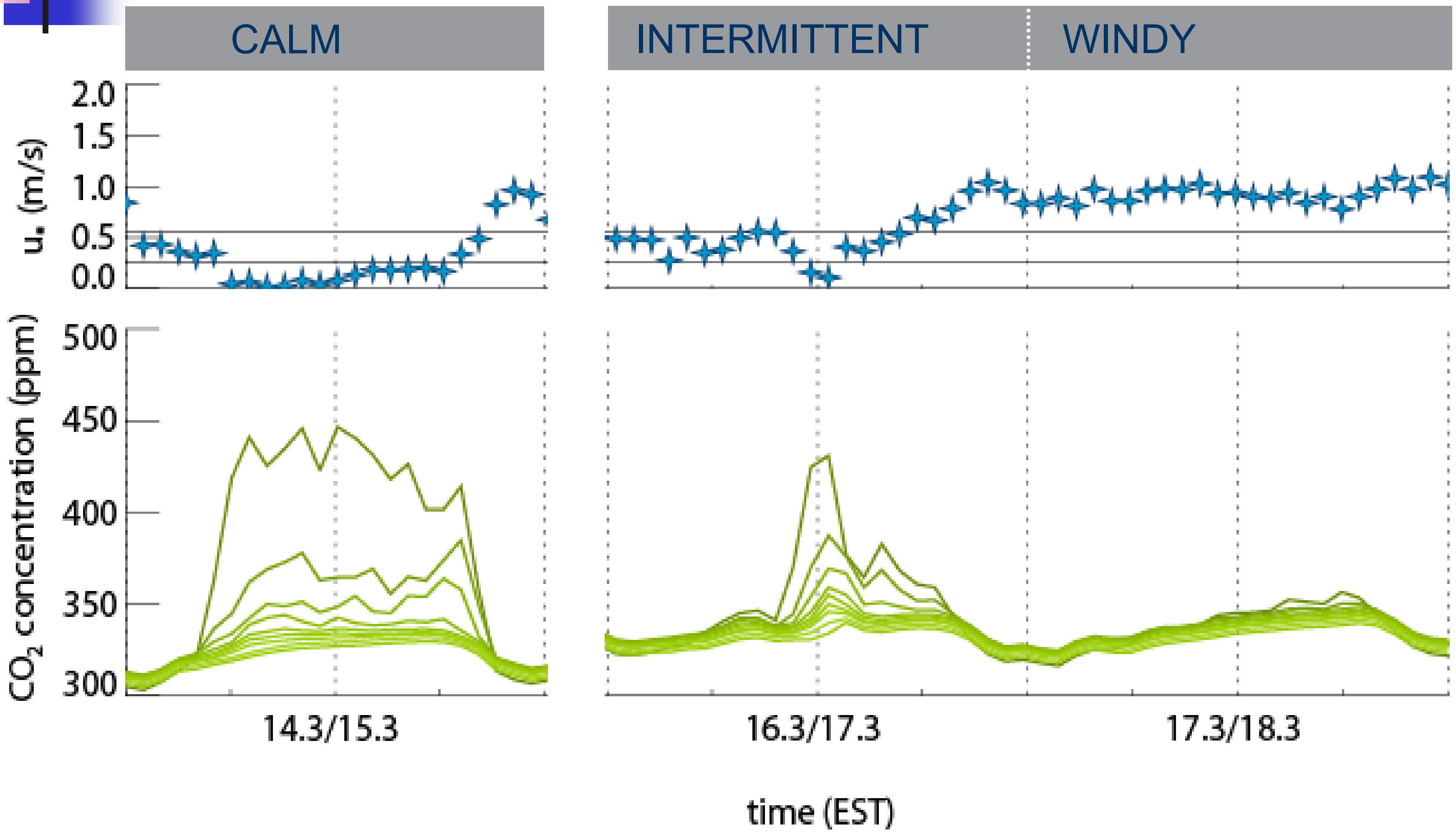
$$\overline{w'c'}(h_r)$$

Frequency (u_*)

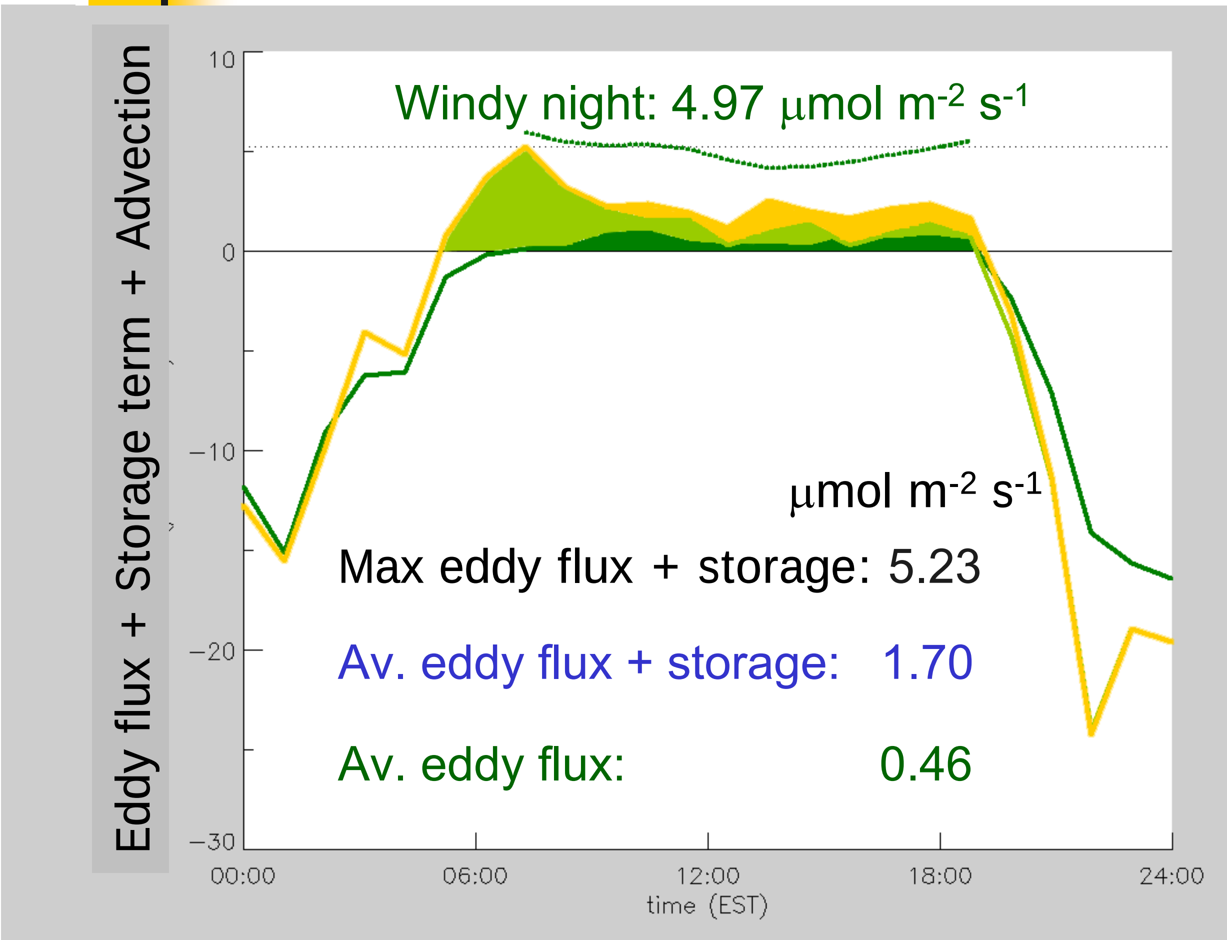
Van Gorsel et al. (2006)

CO_2 concentration time series

Van Gorsel et al. (2006)



Eddy flux + Storage term + Advection



Total night time NCE

Chamber (Soil + Leaf + Wood)
5.18 μmol m^{-2} s^{-1}

$$\overline{w'c'}(h_r)$$

$$\overline{w'c'}(h_r)+\int_0^{h_r}\frac{\partial\overline{c}(z)}{\partial t}dz$$

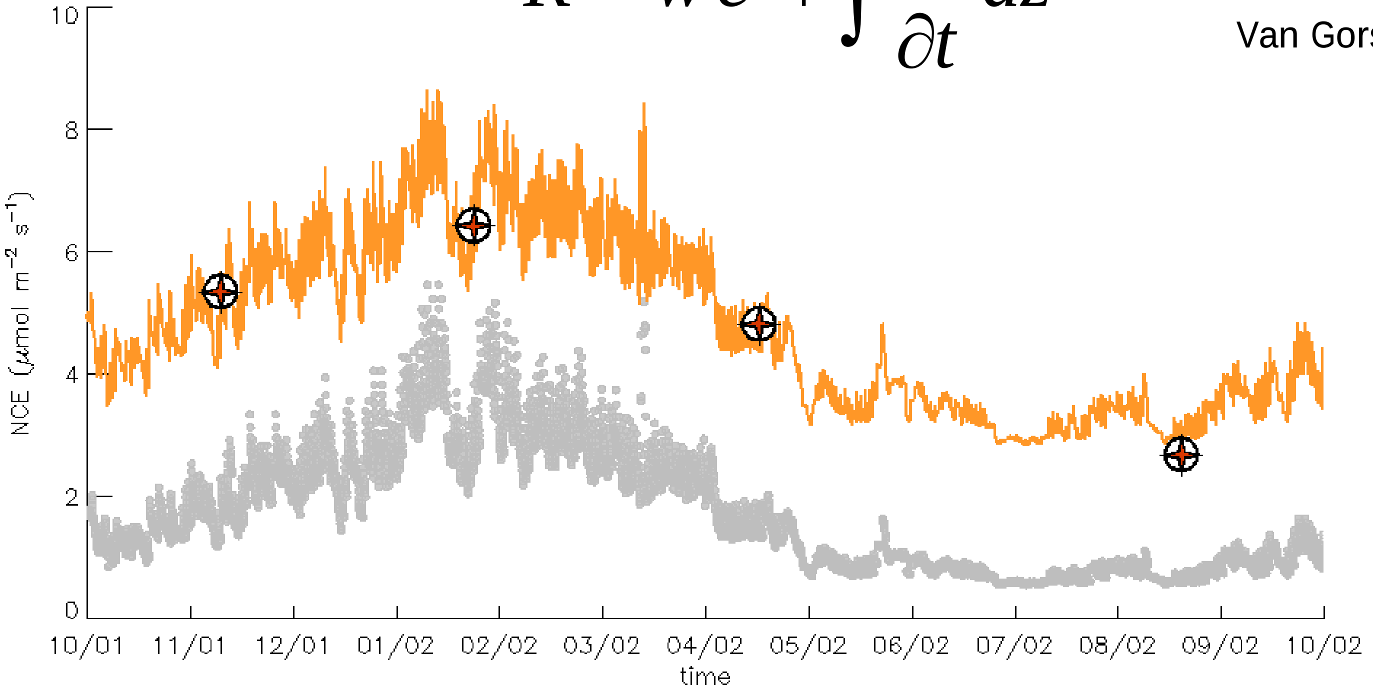
$$\overline{w'c'}(h_r)+\int_0^{h_r}\frac{\partial\overline{c}(z)}{\partial t}dz+\int_0^{h_r}\left(\overline{u}(z)\frac{\partial\overline{c}(z)}{\partial x}+\overline{v}(z)\frac{\partial\overline{c}(z)}{\partial y}\right)dz$$

Van Gorsel et al. (2006)

Revised NCE using nightly maximum

$$R = \overline{w'c'} + \int \overline{\frac{\partial c}{\partial t}} dz$$

Van Gorsel et al. (2006)



Summary

Applying a relationship between T_{soil} and R_{max} Improves estimate of NCE when eddy flux flux and storage terms are measured but advection is not.

An advection experiment

- Measure all terms in mass balance of a 50 x 50 x 6 m control volume on forest floor at Tumbarumba

Advection experiment
- mass balance on a control volume

$$\overline{F}_0 = \overline{c}_d \overline{w'\chi_c'}\Big|_h + \overline{c}_d \int_0^h \overline{w} \frac{\partial \overline{\chi}_c}{\partial z} dz$$

Eddy flux at ***h*** + vertical advection

$$+ \frac{\overline{c}_d}{\Delta t}\left[\int_0^h \chi_c dz \Big|_{t+\Delta t} - \int_0^h \chi_c dz \Big|_t \right]$$

Change in storage

$$+ \frac{\overline{c}_d}{L}\left[\int_0^h \overline{u}_h \overline{\chi}_{c\,yz}(z) dz \Big|_L - \int_0^h \overline{u}_h \overline{\chi}_{c\,yz}(z) dz \Big|_0 \right]$$

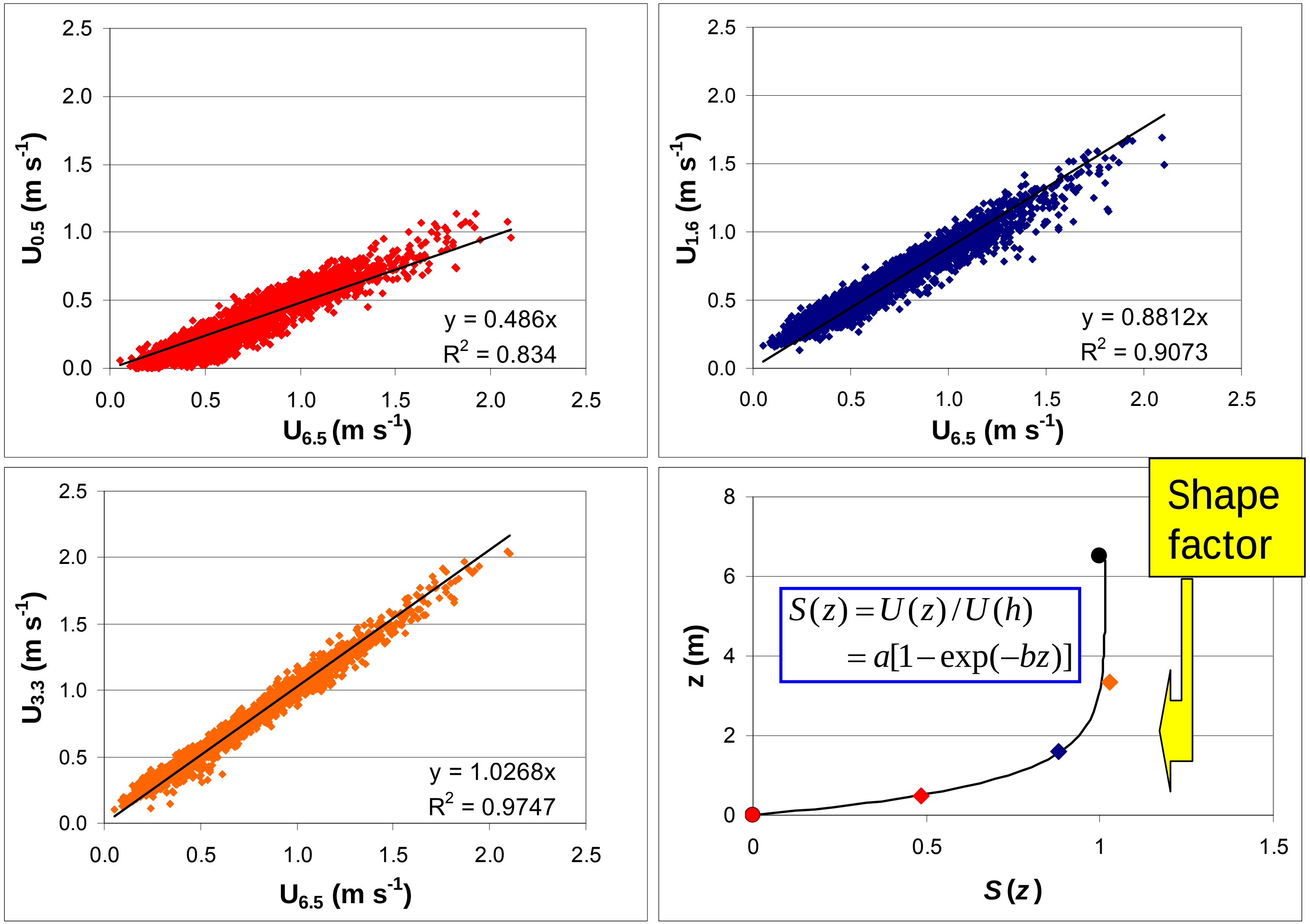
Advection *x* direction

$$+ \frac{\overline{c}_d}{L}\left[\int_0^h \overline{v}_h \overline{\chi}_{c\,xz}(z) dz \Big|_L - \int_0^h \overline{v}_h \overline{\chi}_{c\,xz}(z) dz \Big|_0 \right]$$

Advection *y* direction

Define normalized wind profiles:

$$S(z) = u(z)/u_h = v(z)/v_h$$



Horizontal advection: shape & sample weighting factors

$$S(z) = u(z)/u_h = v(z)/v_h$$

Shape factor

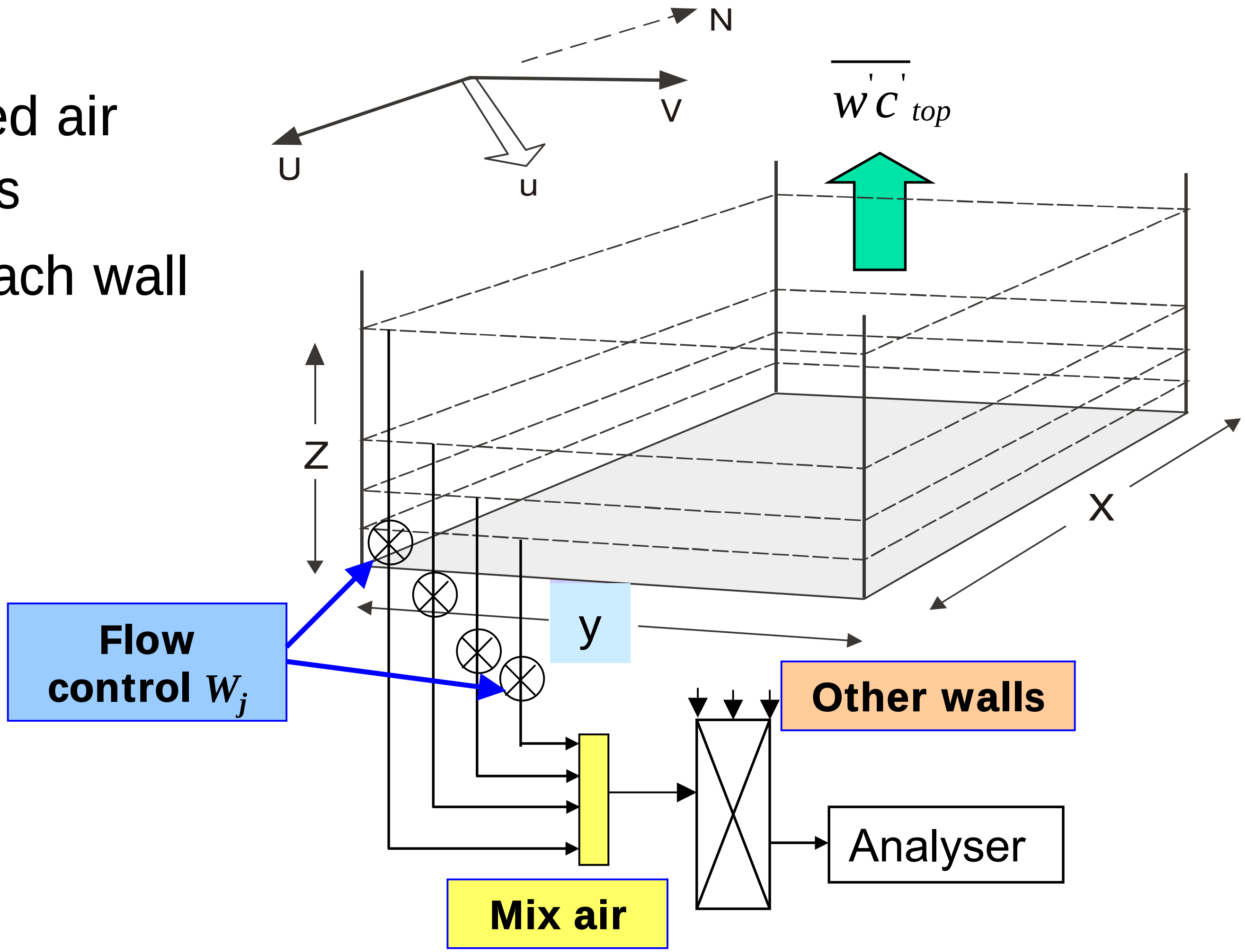
$$W_j = S(z)\Delta z$$

Weighting factor

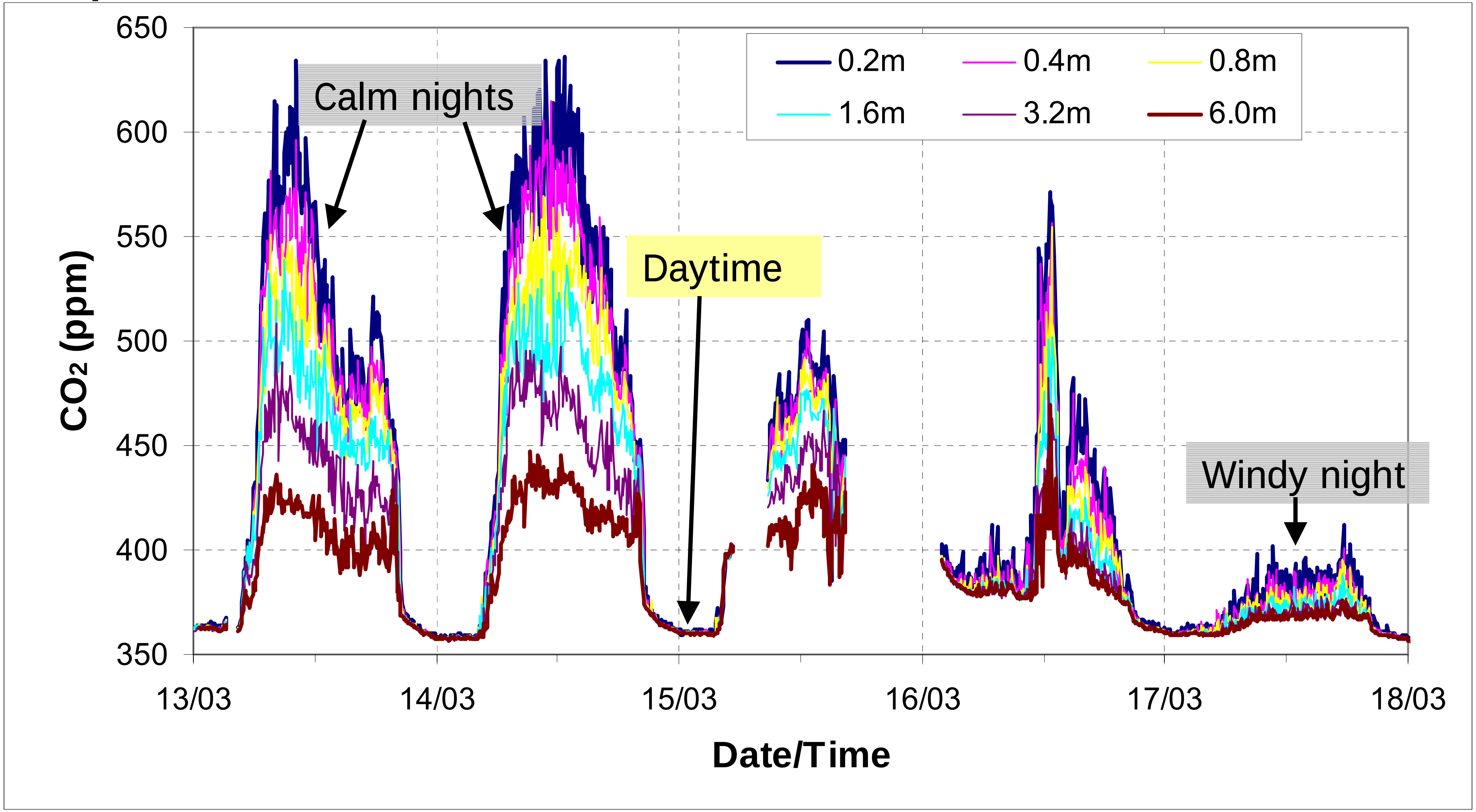
$$F_{adv,hor} = \frac{\overline{c_d}\,\overline{u_h}}{L}\left[\sum_{j=1}^{6} W_j \overline{\chi_{c\ yz,j}}\Big|_L - \sum_{j=1}^{6} W_j \overline{\chi_{c\ yz,j}}\Big|_0\right] + \frac{\overline{c_d}\,\overline{v_h}}{L}\left[\sum_{j=1}^{6} W_j \overline{\chi_{c\ xz,j}}\Big|_L - \sum_{j=1}^{6} W_j \overline{\chi_{c\ xz,j}}\Big|_0\right]$$

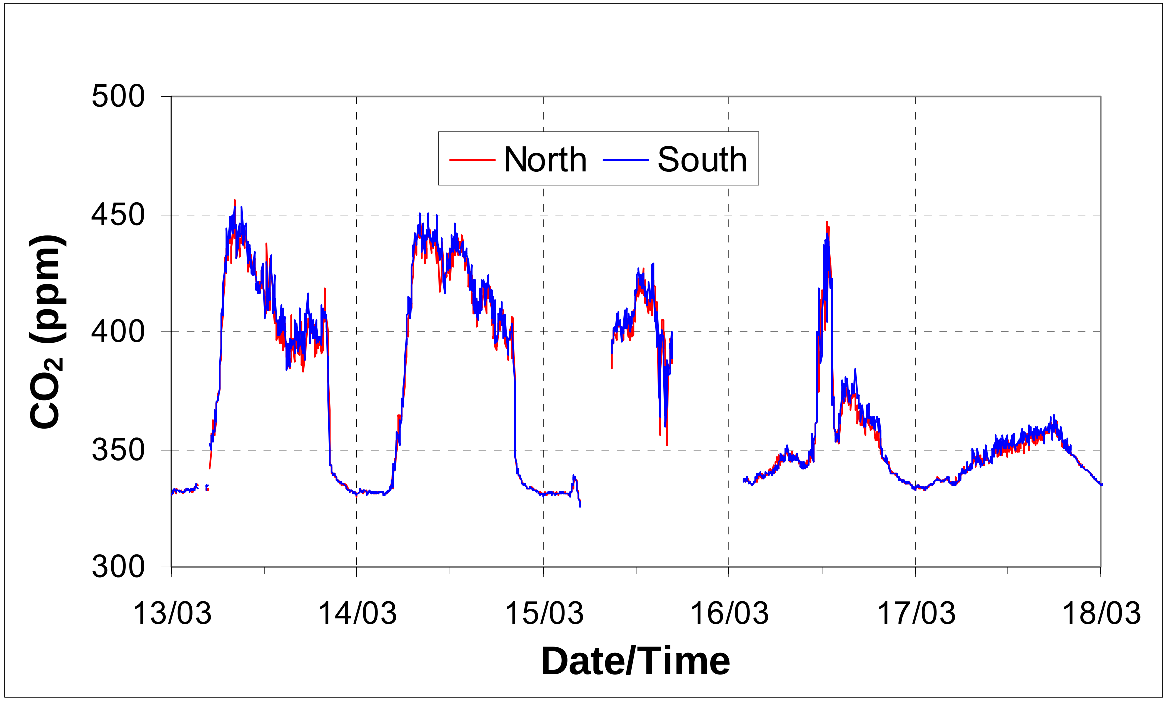
Air sampling - W_j

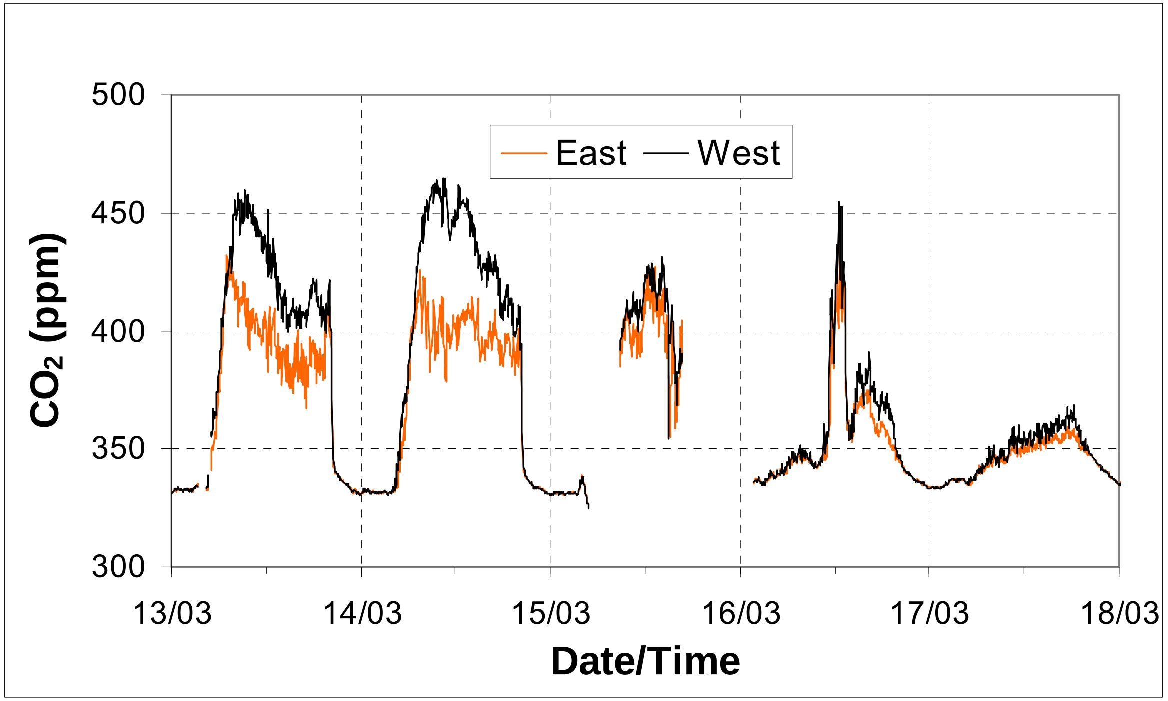
- Mix flow-weighted air (W_j) from 6 levels
- Pump air from each wall to gas analyzer



CO_2 profiles- central mast of CV





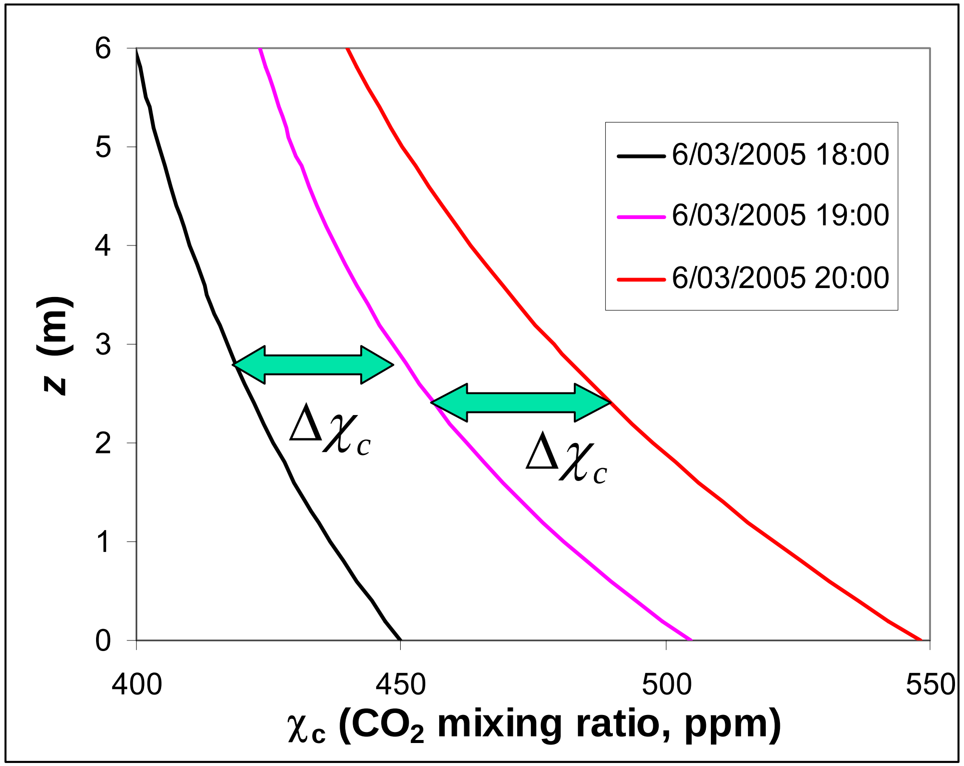


Weighted concentrations on 4 walls of CV

$$\sum_{j=1}^{6} W_j \overline{\chi_{c,j}}$$

CO_2 profiles – change in storage term

$$F_{\Delta storage} = \frac{\overline{c}_d}{\Delta t}\left[\int_0^h \chi_c dz \Big|_{t=\Delta t} - \int_0^h \chi_c dz \Big|_{t=0} \right]$$



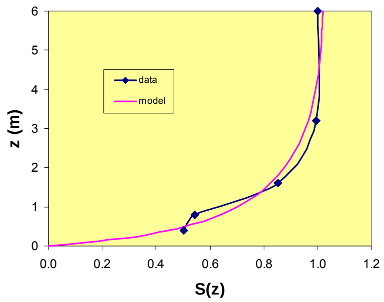
Vertical advection

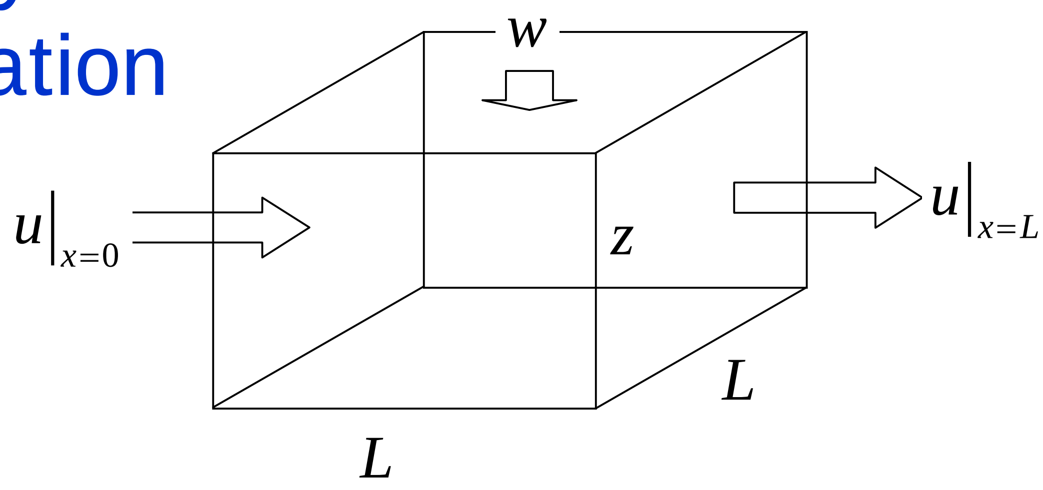
Product rule of integration

$$\int_0^h \left(\overline{w} \frac{\partial \overline{\chi_c}}{\partial z} \right) dz = \overline{w}(h)\overline{\chi_c}(h) - \int_0^h \left(\overline{\chi}_c \frac{\partial \overline{w}}{\partial z} \right) dz$$

- Need
  - Vertical velocity profile
  - CO_2 mixing ratio profiles

Vertical velocity: continuity equation





$$\overline{w}(z) = \frac{-1}{L}\Delta\left[\int_0^z \overline{u}(\varsigma)d\varsigma\right] - \frac{-1}{L}\Delta\left[\int_0^z \overline{v}(\varsigma)d\varsigma\right]$$

$$\overline{w}(z) = \frac{-1}{L}\left[\Delta u_h + \Delta v_h\right]\int_0^z S(\varsigma)d\varsigma$$

$$\frac{d\overline{w}}{dz} = \frac{-1}{L}\left[\Delta u_h + \Delta v_h\right]S(z)$$

Vertical advection

$$\int_0^h \left(\overline{w} \frac{\partial \overline{\chi_c}}{\partial z} \right) dz = \overline{w}(h)\overline{\chi_c}(h) - \int_0^h \left(\overline{\chi}_c \frac{\partial \overline{w}}{\partial z} \right) dz$$

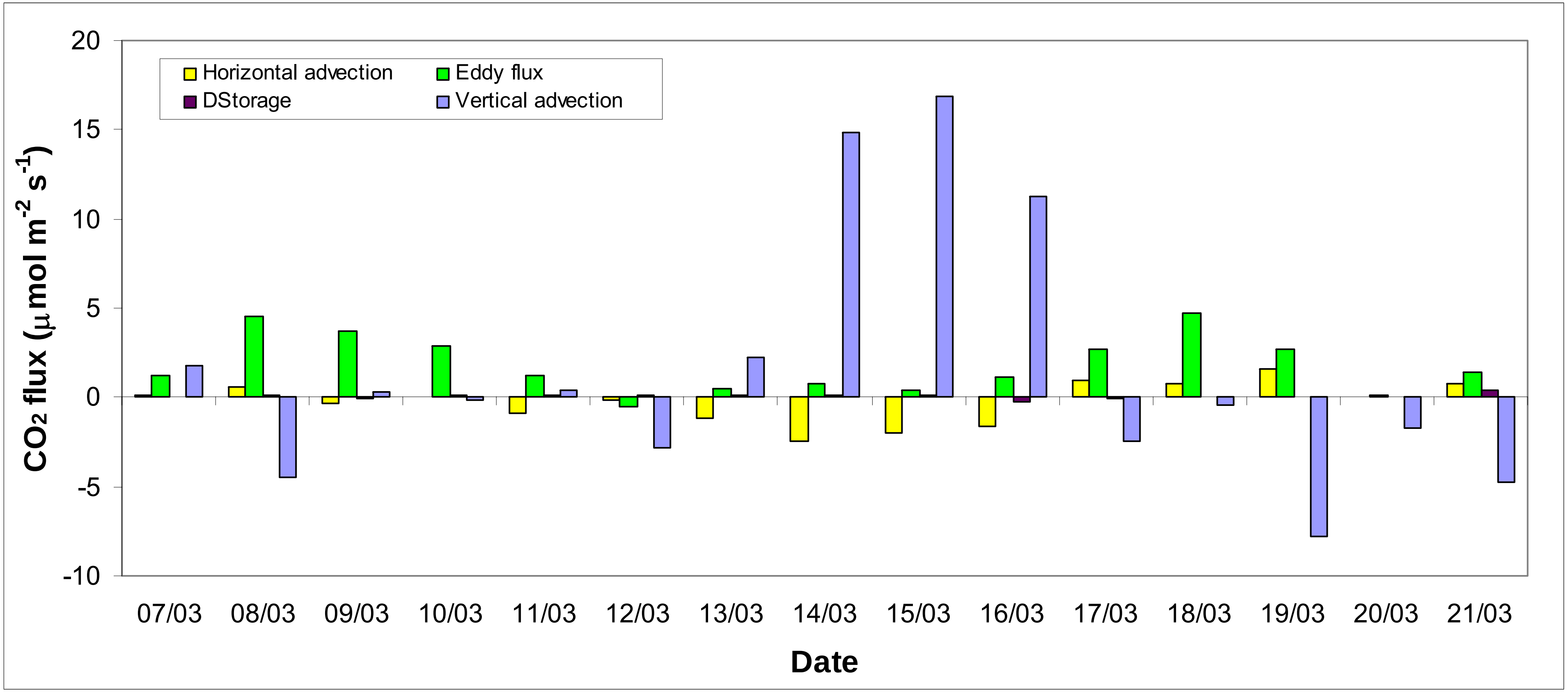
$$= \overline{w}(h) \left[\overline{\chi}_c(h) - \frac{\int_0^h \overline{\chi}_c(z) S(z) dz}{\int_0^h S(z) dz} \right]$$

Vertical velocity at top of CV

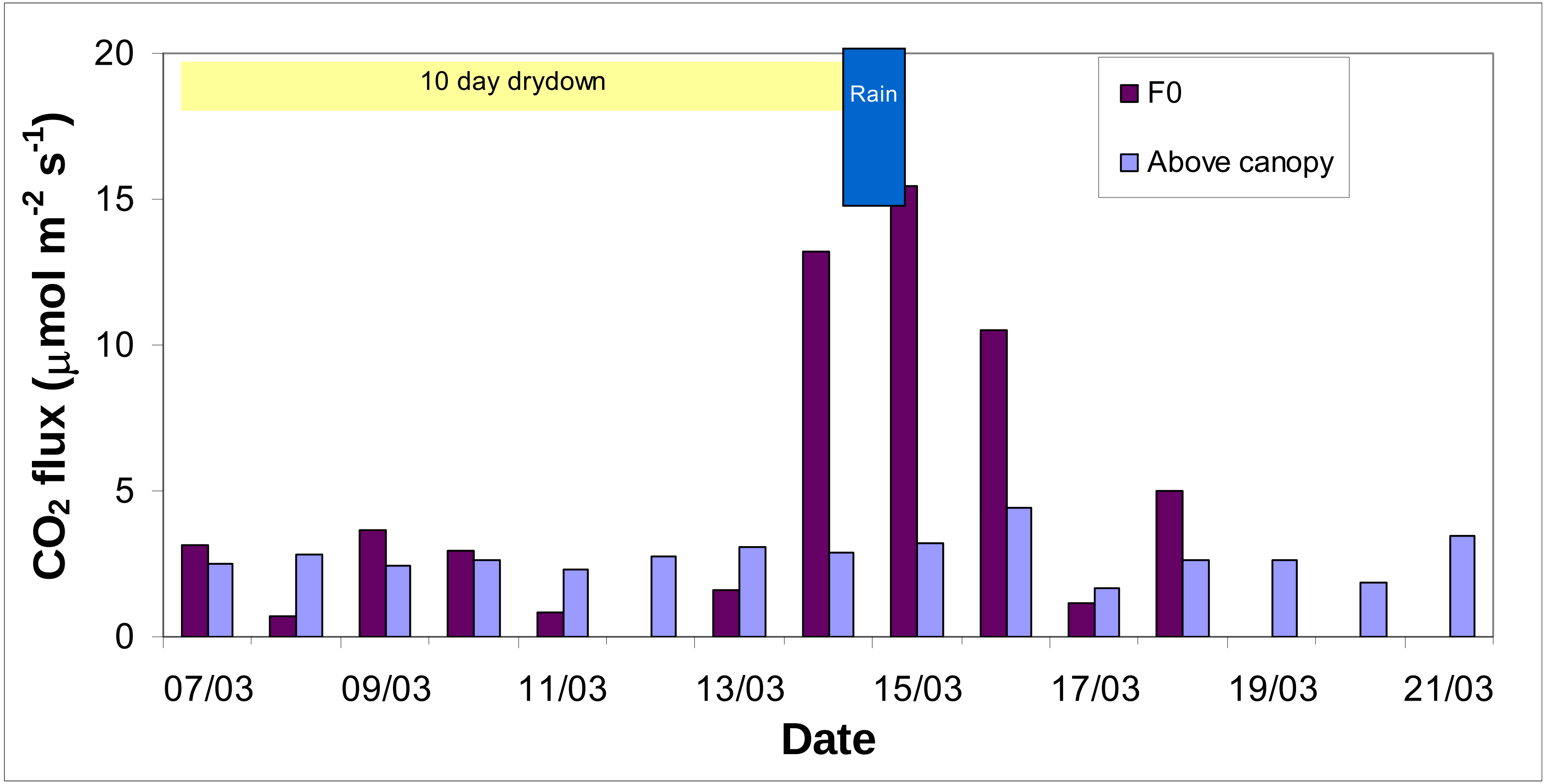
Mixing ratio at top of CV

Shape-factor weighted mixing ratio within CV

Night time CO_2 flux components

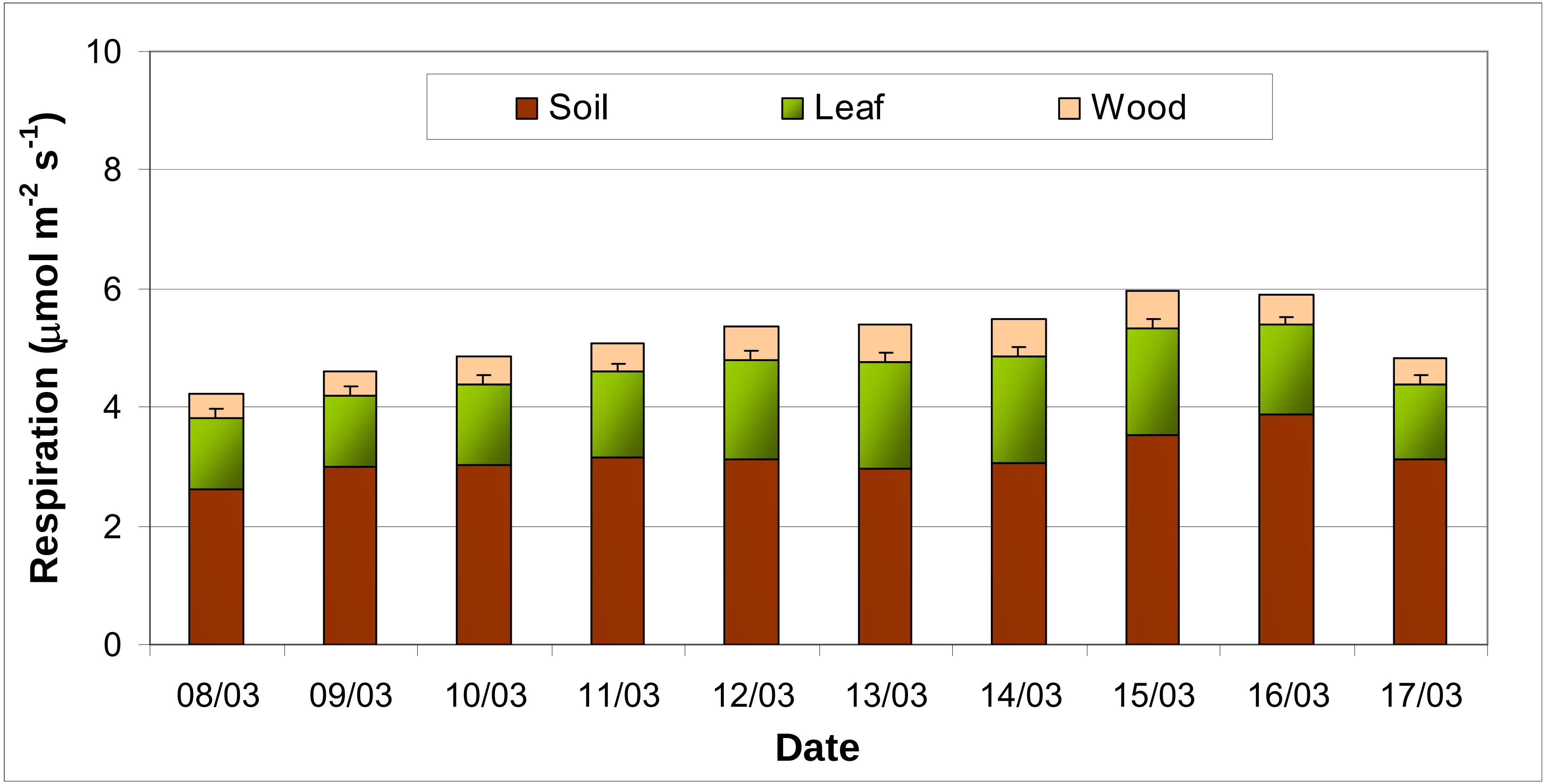


Total night time CO_2 flux



Soil + Leaf + Wood respiration Chamber measurements

Courtesy of Dr Heather Keith, CSIRO



Night time averages: 8 - 17 March

	Main mast[1] ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	Mass balance[2] ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	Soil + Leaf respiration[3] ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)
Mean	2.83	3.18	4.65
s.e of mean	0.22	1.82	0.15

[1]Eddy flux @70 m + ΔStorage

[2]Full mass balance on control volume below canopy

[3]Soil + leaf + wood respiration from biometric measurements

Summary

- Drainage flows cause horizontal and vertical advection at night
- Average eddy flux + change in storage underestimates NCE because advection not measured
- Δstorage, horizontal advection & eddy fluxes same order of magnitude at night
- Horizontal advection can be positive or negative
- Vertical velocity can be estimated using continuity equation
- Vertical advection large, variable, ± sign & dominates night time mass balance calculations
- u_* threshold method produces unreliable NCE estimates
- Van Gorsel method using max{eddy flux + ΔStorage} recommended