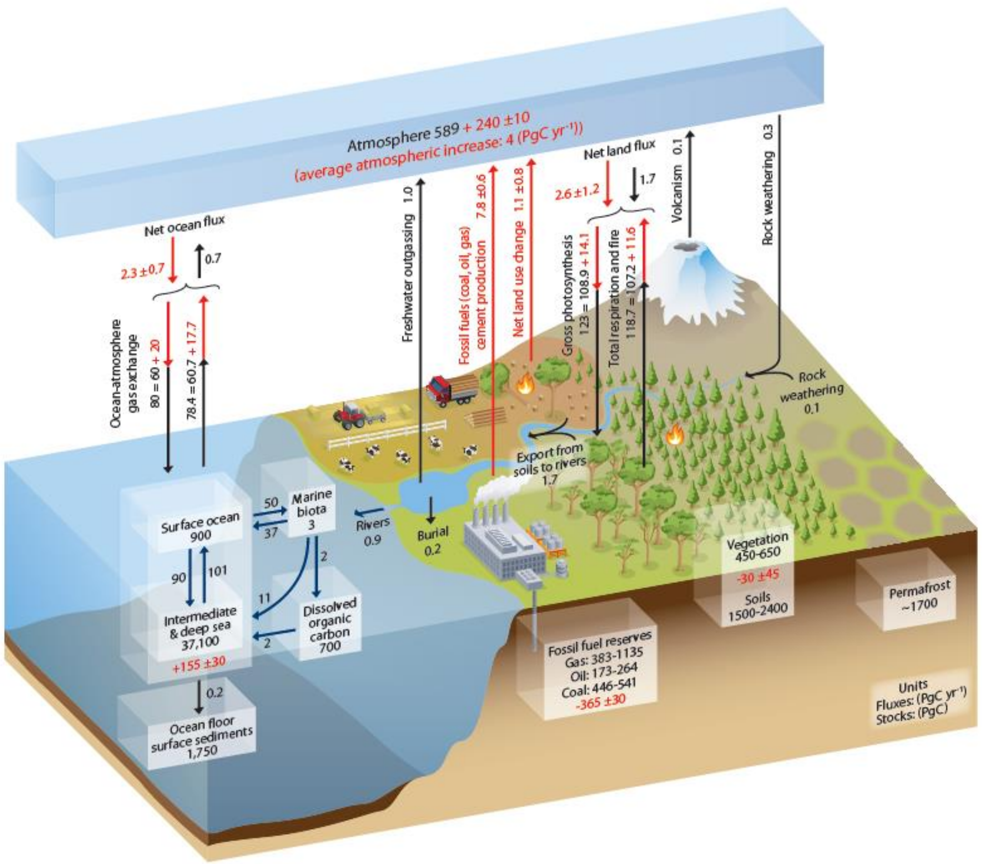
ECOSYSTEM RESPIRATION

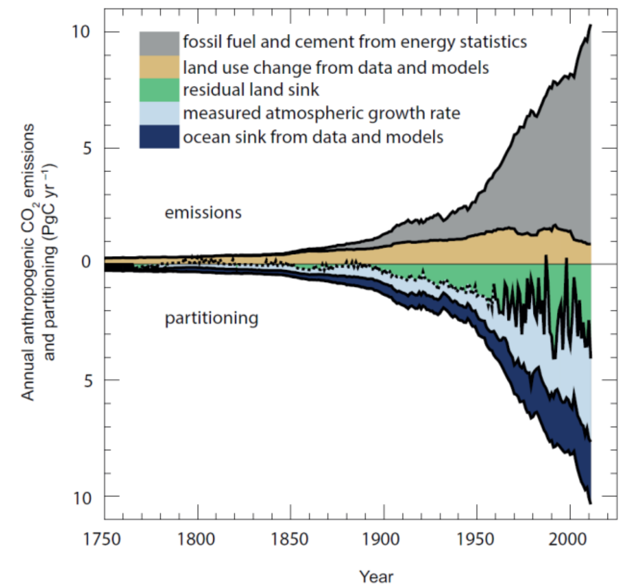
An unknown quantity?

Outline

- Motivations
- A brief outline of the problem
- Some site results
- Ways forward

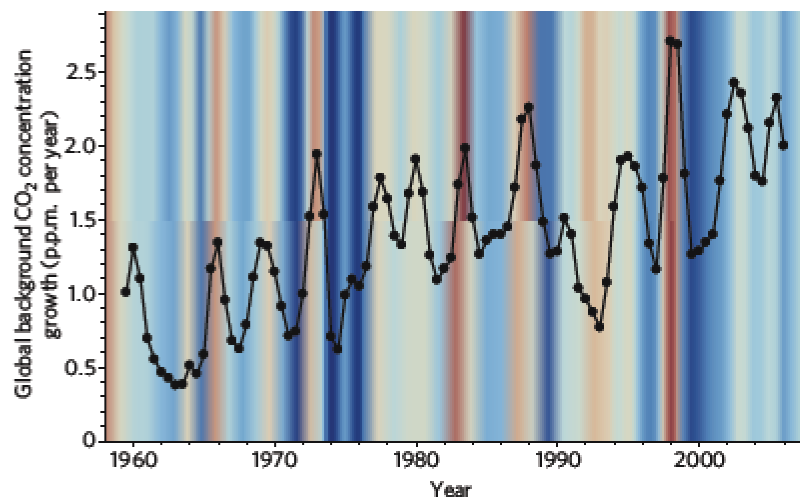
Motivation – Major: Global Carbon Cycle





- Gross photosynthesis = 123
- Respiration = 118.7
- To hydrosphere = 1.7

} Net ecosystem sink = 2.6 GtC

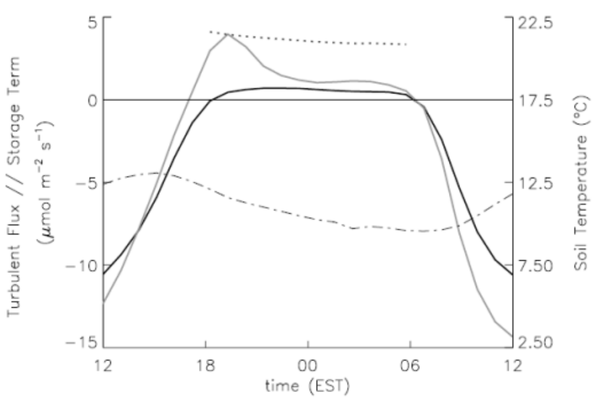


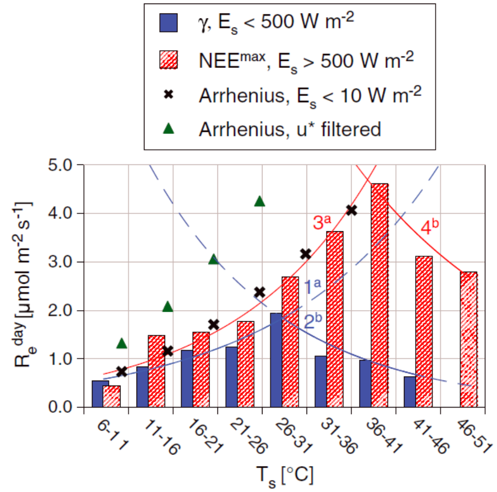
Motivation – minor: multi-site respiration paper

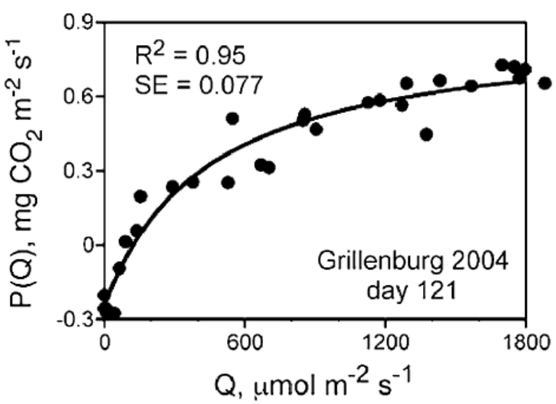
- ## Respiration is key:
  - Derived from nocturnal NEE measurements – biggest potential source of selective systematic (*i.e.* bias) error
  - Large effect on cumulative C exchange estimates at daily and longer time scales
  - Large effect on partitioning

- ## Cross-site methodological consistency is important, but not at the expense of accuracy:
  - Use same techniques where possible, different techniques where necessary

- ## Methodology:
  - Site selection
  - QC: we may consider additional statistical criteria (e.g. CARBOEurope criteria: stationarity, integral turbulence characteristics, wind direction)
  - Measure all possible components of the surface mass balance (*i.e.* turbulent flux and storage)
  - Apply corrections / exclude data to account for unmeasured components (*i.e.* advection and storage terms)
  - Fill gaps
  - Quantify uncertainties (where possible)
  - Independent validation







What we measure when we measure C balance

$$F_c = \rho\overline{w'\chi'_c} + \int_0^t \frac{\delta\overline{\chi_c}}{\delta t}\,dz + \int_0^t \left[\rho\bar{u}\frac{\delta\bar{\chi}_{c,x}}{\delta x} + \rho\bar{v}\frac{\delta\bar{\chi}_{c,y}}{\delta y}\right]dz + \int_0^t \left[\rho\bar{w}\frac{\delta\bar{\chi}_{c,z}}{\delta z}\right]dz$$

I — II — III — IV — V

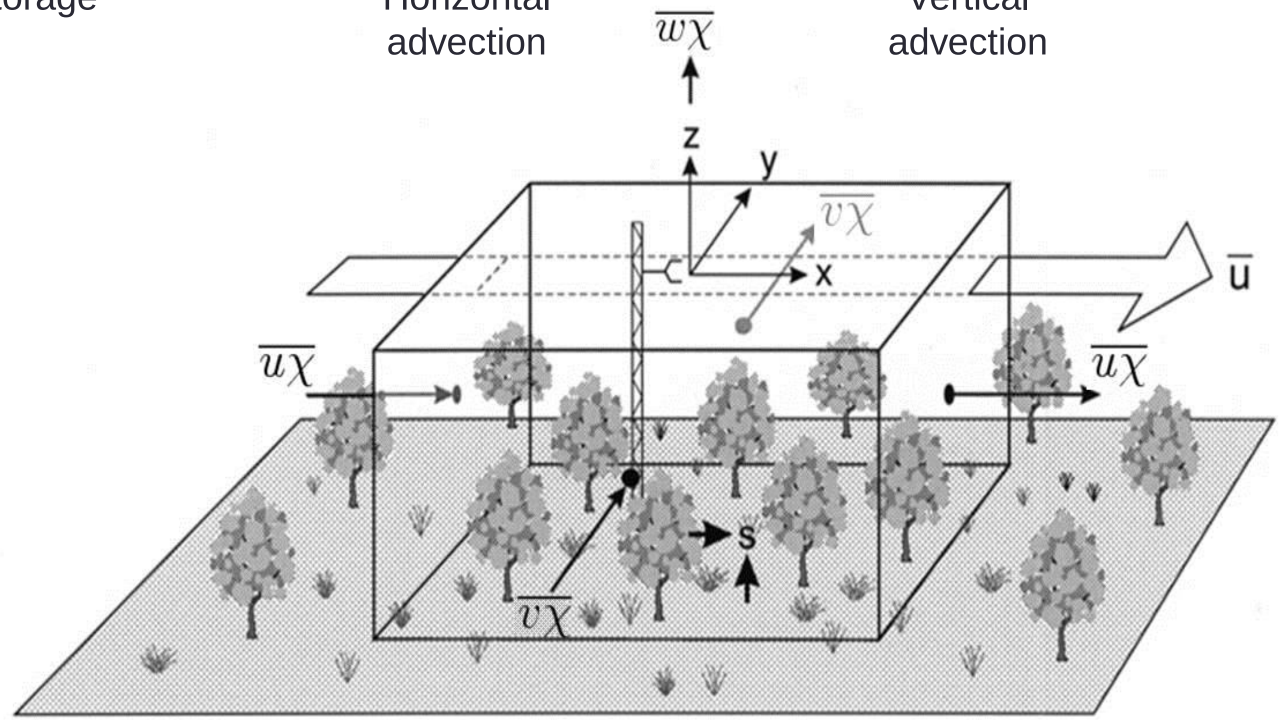
Surface source/sink

Turbulent transfer

Storage

Horizontal advection

Vertical advection

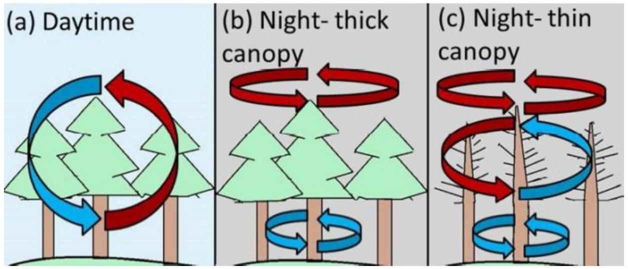


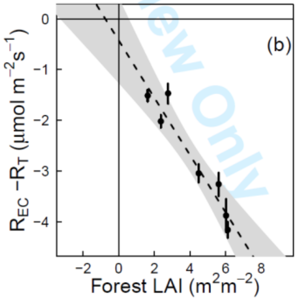
At most we measure terms I and II

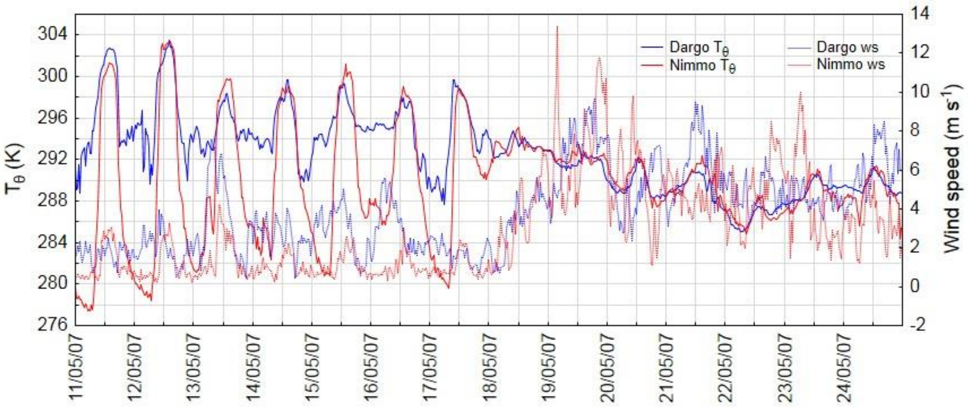
Assumed that under well-developed turbulence, advection terms small

The nocturnal problem

- Vegetation height
- Vegetation density
- Topographic complexity
- Nocturnal stability
- Advection

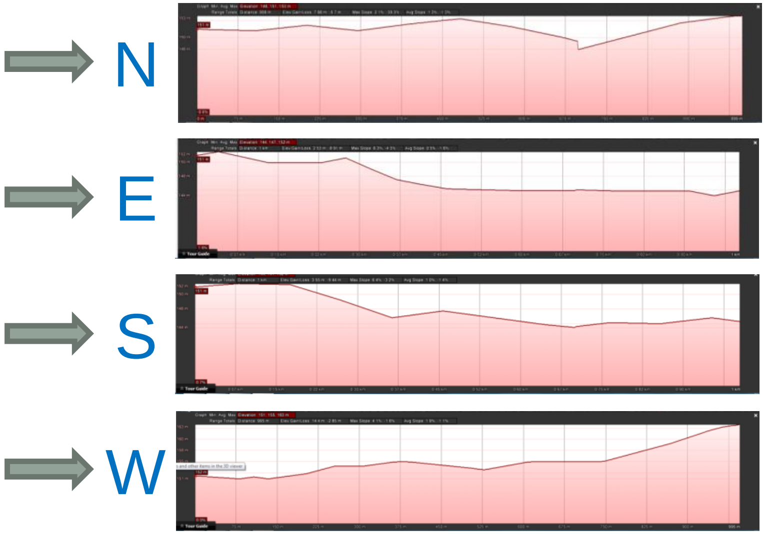






Whroo Conservation Area

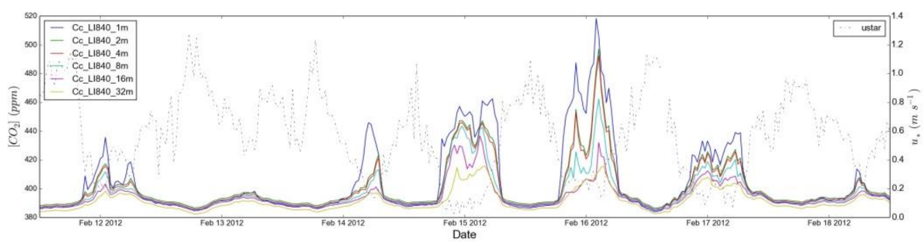
Over-storey LAI (m^2 m^{-2})	Canopy height ±SD (m)	ABG biomass C (t Ha^{-1})	BG biomass C	Litter C	Soil C 0-0.05m	Soil C 0.05-0.3m	Total C
0.95-1.2	15.3±6.2	37.75	10.74	5.80	1.34	0.35	55.98

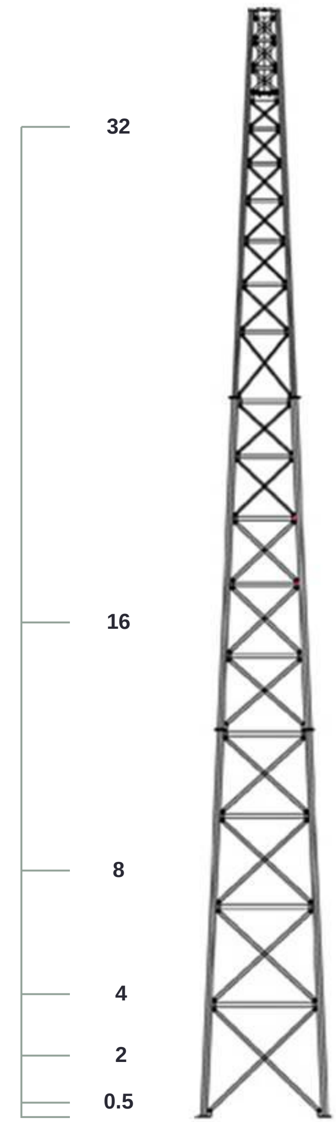


Measurement of storage term

- Storage term is the difference between instantaneous concentration profiles at the tower measured at the beginning and end of the averaging period
- Estimates strongly affected by random spikes in [CO_2] due to wind gusts, so averages used instead
- Measured at several heights within control volume (generally a logarithmic arrangement)
- Vertical integration assumes linearity of $\delta C / \delta z$
- Lack of *spatial* averaging means inevitable trade-off between noise and high frequency attenuation – Finnigan (2006):

'… this [time averaging] procedure underestimates the storage by at least ***50%*** *in most conditions with larger errors occurring when the integral time scale of the turbulence is much smaller than the averaging time.'*





Objective u* threshold determination

Change point detection (adapted from Barr et al., 2013):

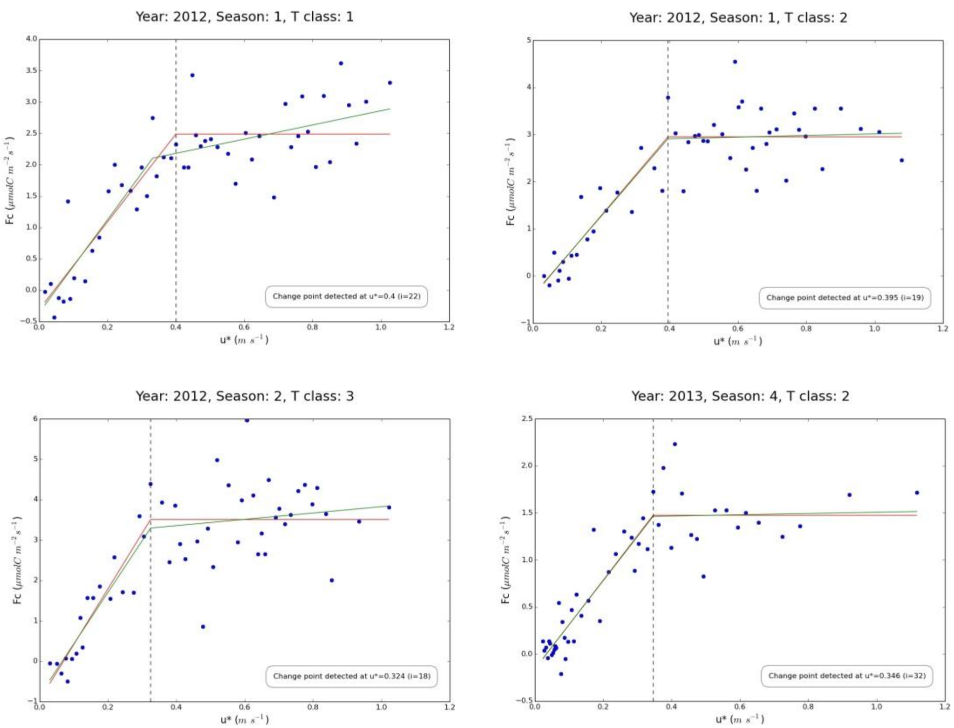
1. Stratify nocturnal NEE into fixed length periods; stratify periods into temperature classes by quantile; bin average NEE within temperature classes ordered by ↑u*
2. Identify unknown change points (c) using two-phase linear regression
3. Test all possible change points in range $2 \leq c \leq n-1$; select c that minimises SSE
4. Calculate f score to test two-phase regression performance against null model
5. Bootstrap data to yield distribution of change points; mean is best threshold estimate
6. Propagate variance to test effect on cumulative NEP of underlying threshold uncertainty (in progress)

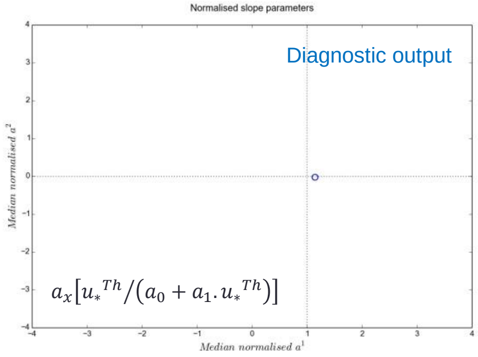
Diagnostic model:

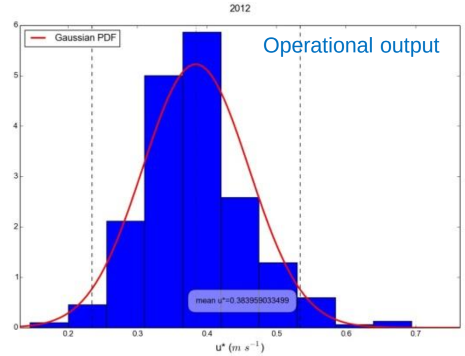
$$y_i = \begin{cases} a_0 + a_1 x_i + \varepsilon, & 1 \leq i \leq c \\ a_0 + a_1 x_c + a_2(x_i - x_c) + \varepsilon, & c < i \leq n \end{cases}$$

Operational model:

$$y_i = \begin{cases} b_0 + b_1 x_i + \varepsilon, & 1 \leq i \leq c \\ b_0 + b_1 x_c + \varepsilon, & c < i \leq n \end{cases}$$





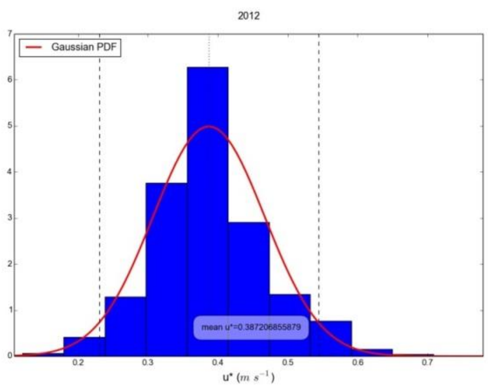


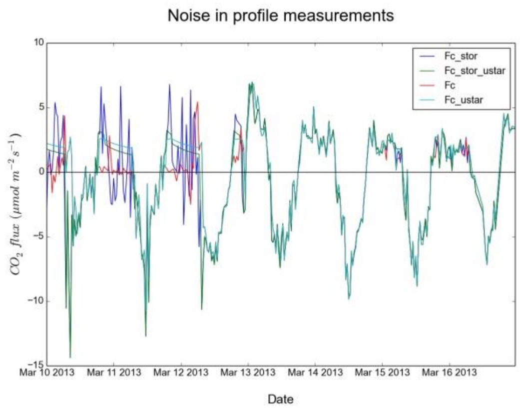
Effects of storage on u* threshold determination

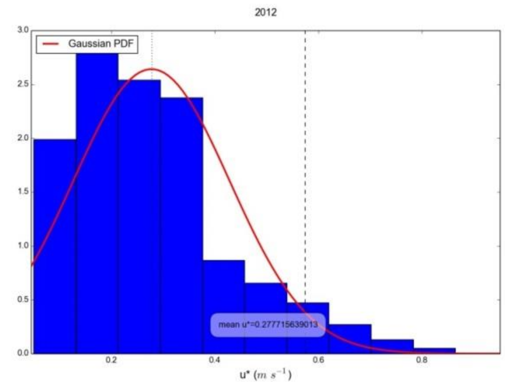
The reasoning underlying the test for u* threshold is that non-turbulent terms contribute substantially to the mass balance below some ecosystem-specific level (depending on canopy height and density); if this reasoning is sound, threshold should also be identifiable in profile measurements

Ideally, we could test whether advection is occurring by searching for u* threshold *after* summing turbulent and storage terms. If advection is negligible then u* threshold should be absent. However:

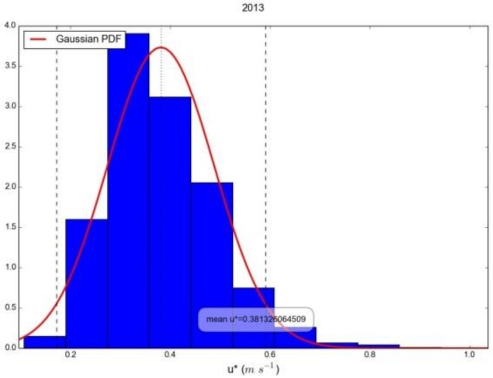
- Profile measurements underestimate true storage within control volume, so dependency may remain
- Profile measurements are noisy - ustar threshold may be obscured rather than absent

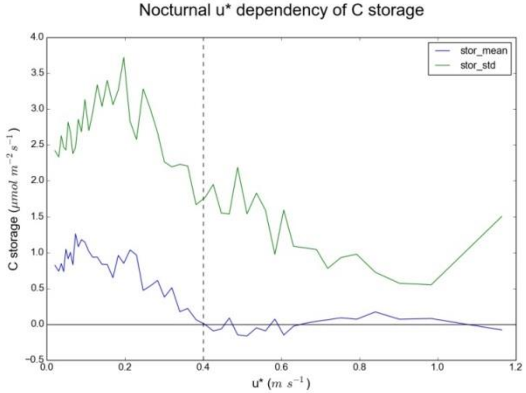


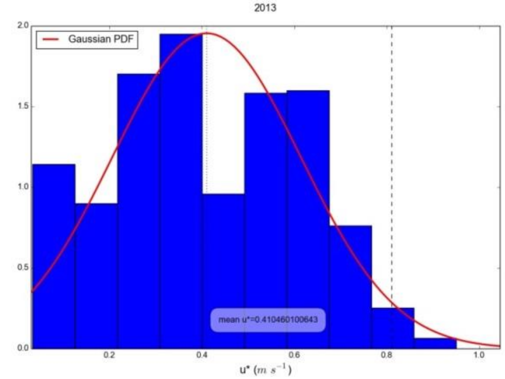




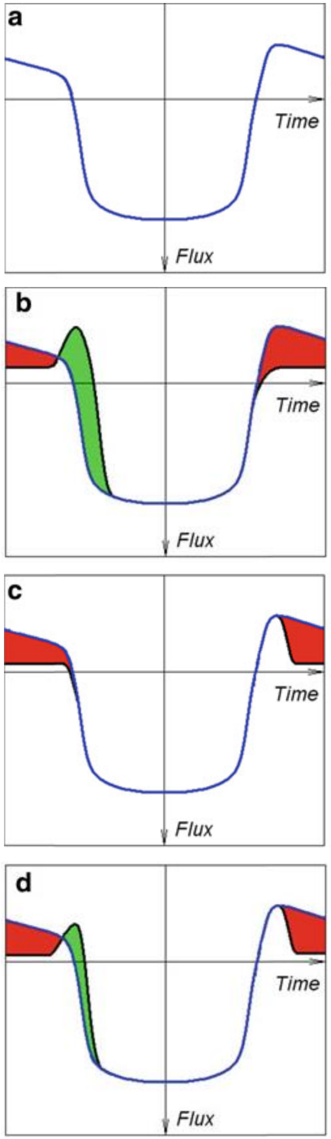
F_c $\qquad$ F_c + storage



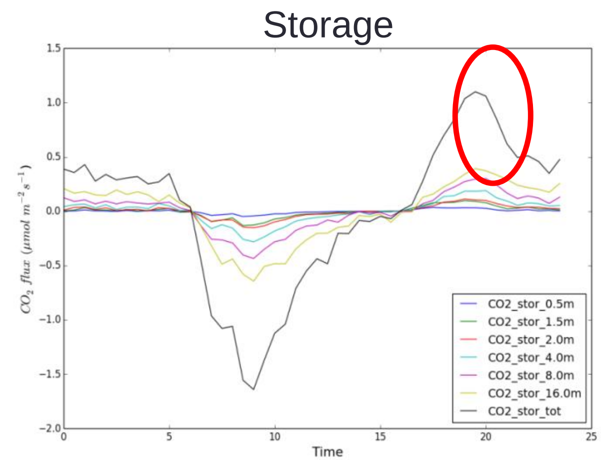


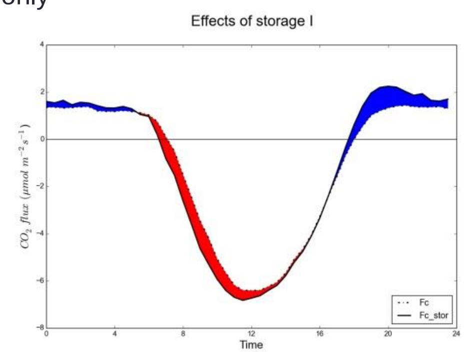


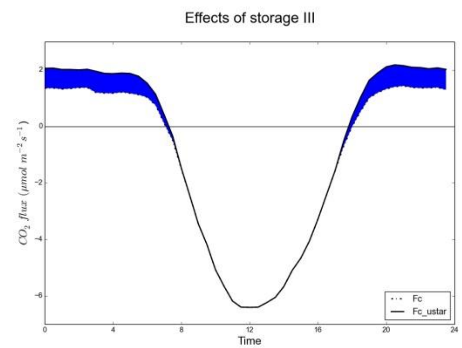
Effects of storage on diurnal carbon balance

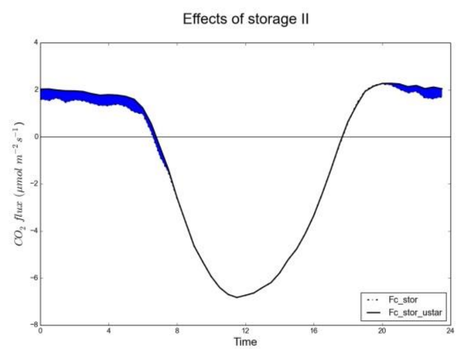


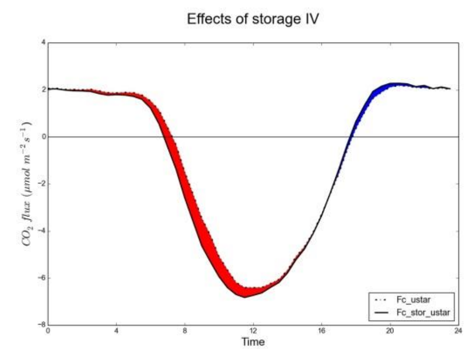
- Storage term increases nocturnally respiratory efflux *and* daytime photosynthetic influx by similar amounts
- Storage term alone increases nocturnal respiratory efflux, but substantial further increases when u* filter applied to turbulent flux + storage
- u* filter applied to turbulent flux alone greatly increases nocturnal respiratory efflux
- Estimates of nocturnal respiration are virtually identical for u* filtered storage-inclusive and exclusive data
- Early evening peak and rapid storage decline indicates possible advective losses
- Late evening rates of decline similar for u* / storage-corrected versus storage-corrected only









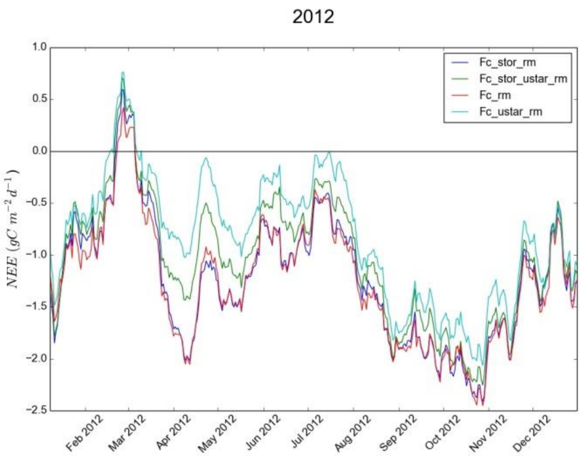


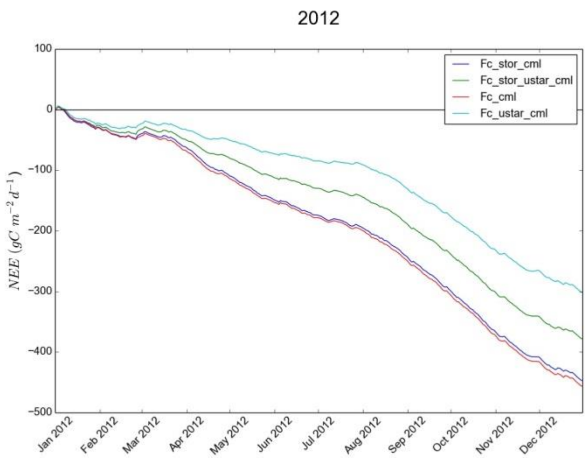
a) Idealised flux
b) Effect of neglecting storage
c) Effect of neglecting advection
d) Effect of neglecting storage and advection

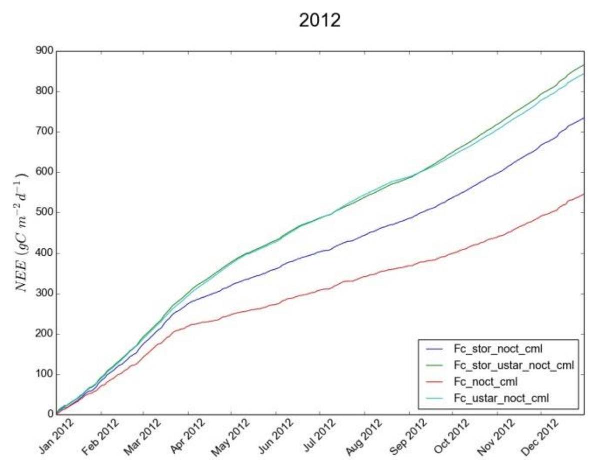
Effects of storage on annual carbon balance

- Failure to correct for underestimation of nocturnal respiratory efflux overestimates C sink by 1.5t Ha^{-1}
- Application of u* threshold to nocturnal turbulent C flux estimates alone produces similar results to addition of storage term
- Storage does not completely account for underestimation of nocturnal NEE at low u* - this may be due to: i) underestimation of storage, or; ii) neglect of advection
- Storage sums to approximately zero over 24 hours, thus there is little difference between annual NEP for uncorrected and storage-corrected flux measurements
- Daytime differences in NEE between storage-corrected and non-storage corrected fluxes results in difference of 0.7-0.8t Ha^{-1}
- Storage is also likely to be underestimated during the day

	2012	2013
NEP (tC ha^{-1})	4.56	4.45
NEP_stor	4.47	4.66
NEP_stor_u*	3.78	4.01
NEP_u*	3.02	3.19







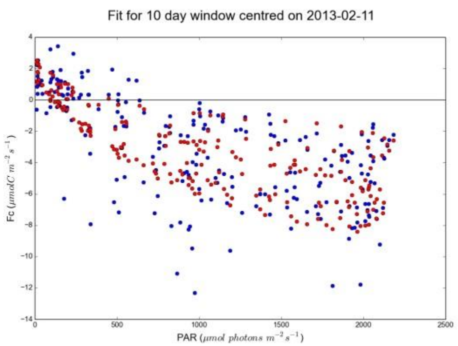
Models

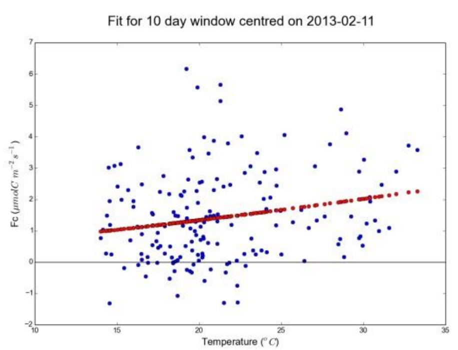
- Artificial neural nets (with appropriate safeguards) are gold standard for gap filling – approach noise limit, but:
  1. Unreliable for longer gaps when drivers are changing rapidly
  2. Are a black box – don't yield parameters that can be physiologically interpreted
  3. Cannot be reliably extrapolated to data outside training domain (*e.g.* nocturnal to daytime respiration)
- We need empirical approaches that are adaptable to Australian conditions!

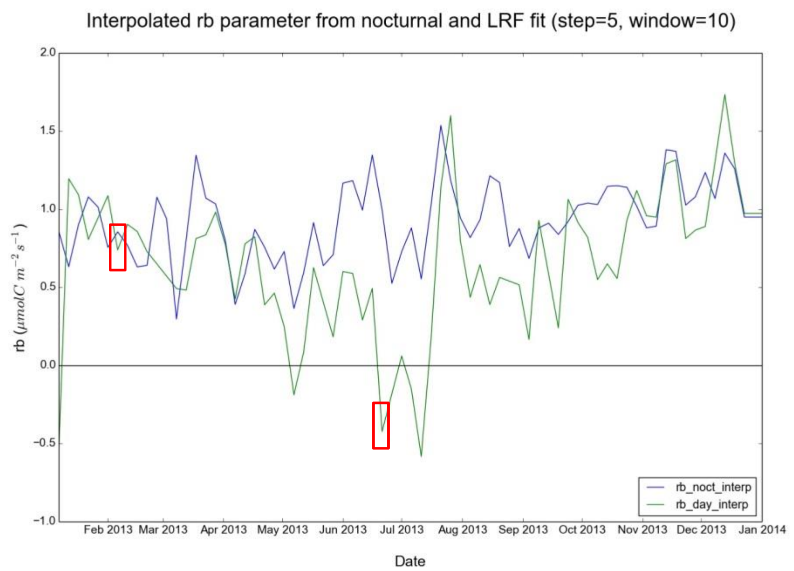
$$NEE = \frac{\alpha Q}{(1 - [Q/2000] + [\alpha Q/\beta])} + Re$$

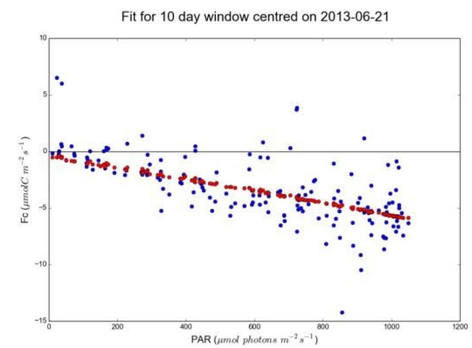
$$Re = rb\ e^{\left(E_o\left[\frac{1}{T_{ref}-T_0} - \frac{1}{T_{air}-T_0}\right]\right)}$$

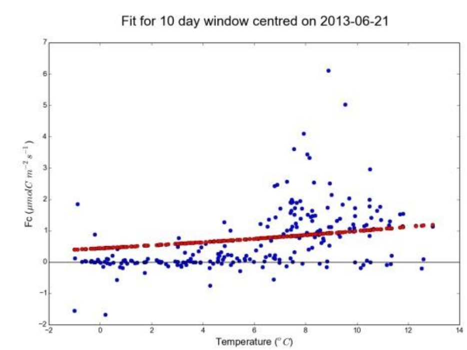
$$\beta = \begin{Bmatrix} \beta_0 e^{(-k[VPD-VPD_0])}, VPD > VPD_0 \\ \beta_0, \qquad VPD < VPD_0 \end{Bmatrix}$$











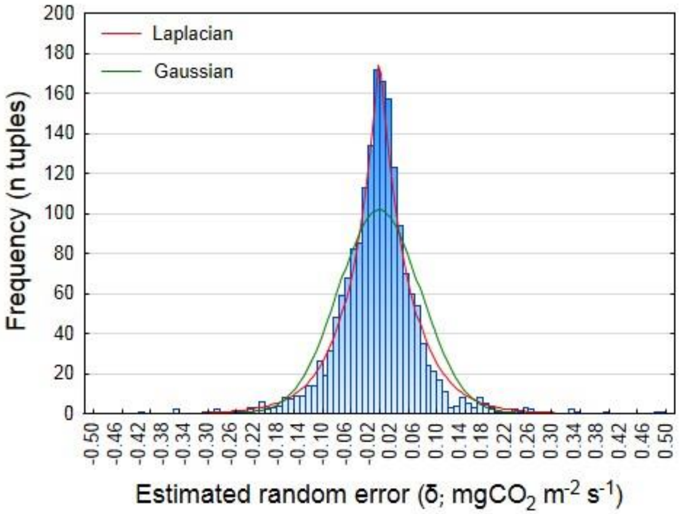
Uncertainty calculation and propagation

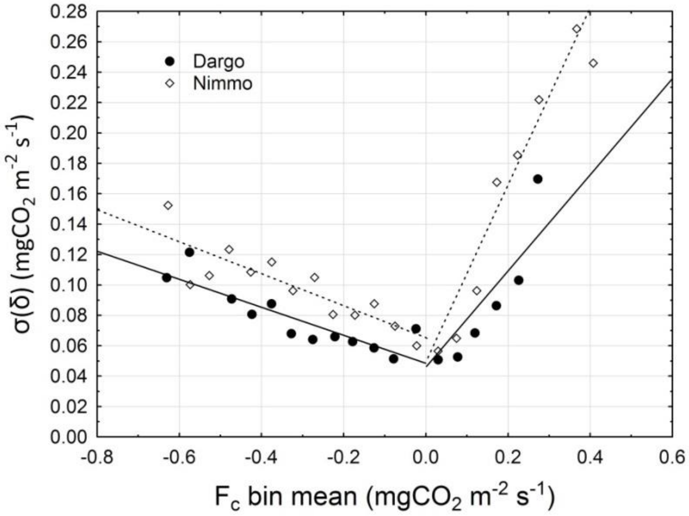
Key uncertainties:

- Systematic measurement error
  - Nocturnal respiration underestimation is arguably most important of 'known' uncertainties because it is *selectively* systematic
  - We can use the 95%CI of the distribution of u* thresholds derived from change point detection to estimate upper and lower uncertainty bounds for cumulative estimates
  - Some potential problems with this: for example, u* generally seasonally variable, so filtering may create seasonal biases (fewer points increases effects of noise)
- Random error
  - Relatively minor in cumulative estimates (*e.g.* generally <30gC a^{-1}) but does *not* sum to zero!
  - Can be (over!) estimated using daily differencing procedure
  - More important with respect to its effect on model estimates
- Model error
  - Uncertainty arises due to inevitable simplification of real processes – some proportion of variance in signal explained by missing / unknown drivers
  - Can be estimated using Monte-Carlo simulation (using observed-model error distribution)
  - Also arises due to the effects of random error on model optimisation – specifically, random error distribution and variance both violate assumption of least squares; optimisation cost functions should therefore be non-least squares. Richardson et al:

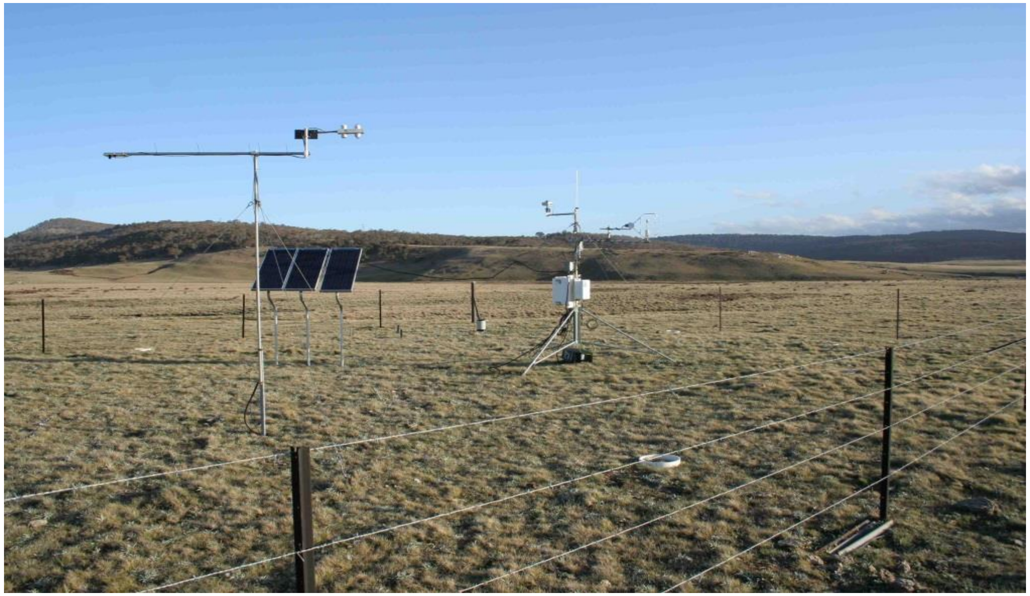
'Using the absolute deviation criterion reduces the estimated annual sum of respiration by about 10% (70–145 g C m^{-2} y^{-1}) compared to OLS; this is comparable in magnitude but opposite in sign to the effect of filtering nighttime data using a range of plausible u_* thresholds.'

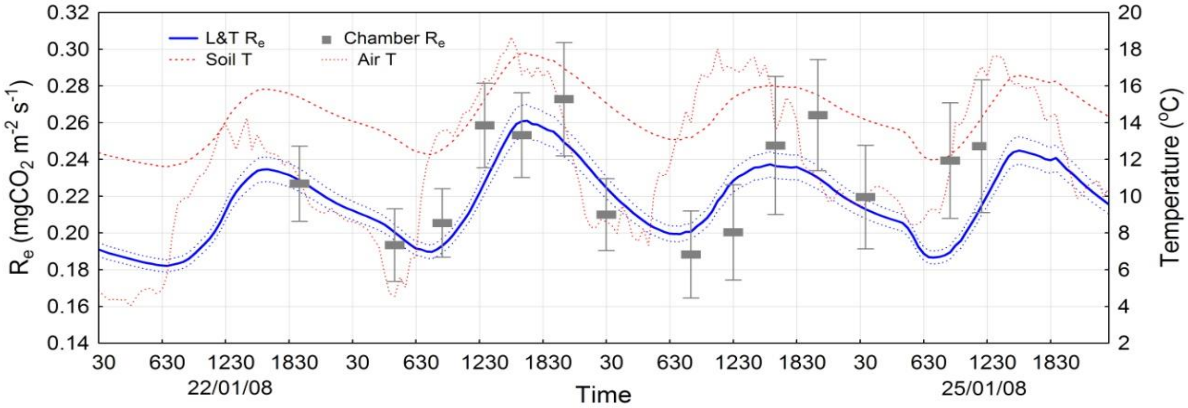
$$\frac{|obs - pred|}{\sigma(\delta)}$$





Independent validation





Conclusions and further work

- u* correction appears to be effective for Whroo site
- Can possibly be generalised to sites with open canopies, but validation required
- Storage term appears to be underestimated nocturnally
- Storage term relatively unimportant nocturnally
- Storage term has large effect on annual sums due to effect on daytime uptake

Next steps:

- Complete error propagation algorithms
- Network-wide chamber-based validation campaigns?

Among the primary purposes of the Fluxnet are to *'… underpin the interpretation of regional CO_2 source-sink patterns, CO_2 flux responses to forcings, and predictions of the future terrestrial [carbon] balance,'* (Friend et al., 2007, p610) and thus to act as *'… a canary in the coalmine with respect to quantifying how the terrestrial biosphere's metabolism is responding to global change'* (Baldocchi, 2007, p547).