Effects of extreme weather cycles on ecosystem photosynthesis, respiration and evapotranspiration in semi-arid central Australia

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Precipitation
Climatology

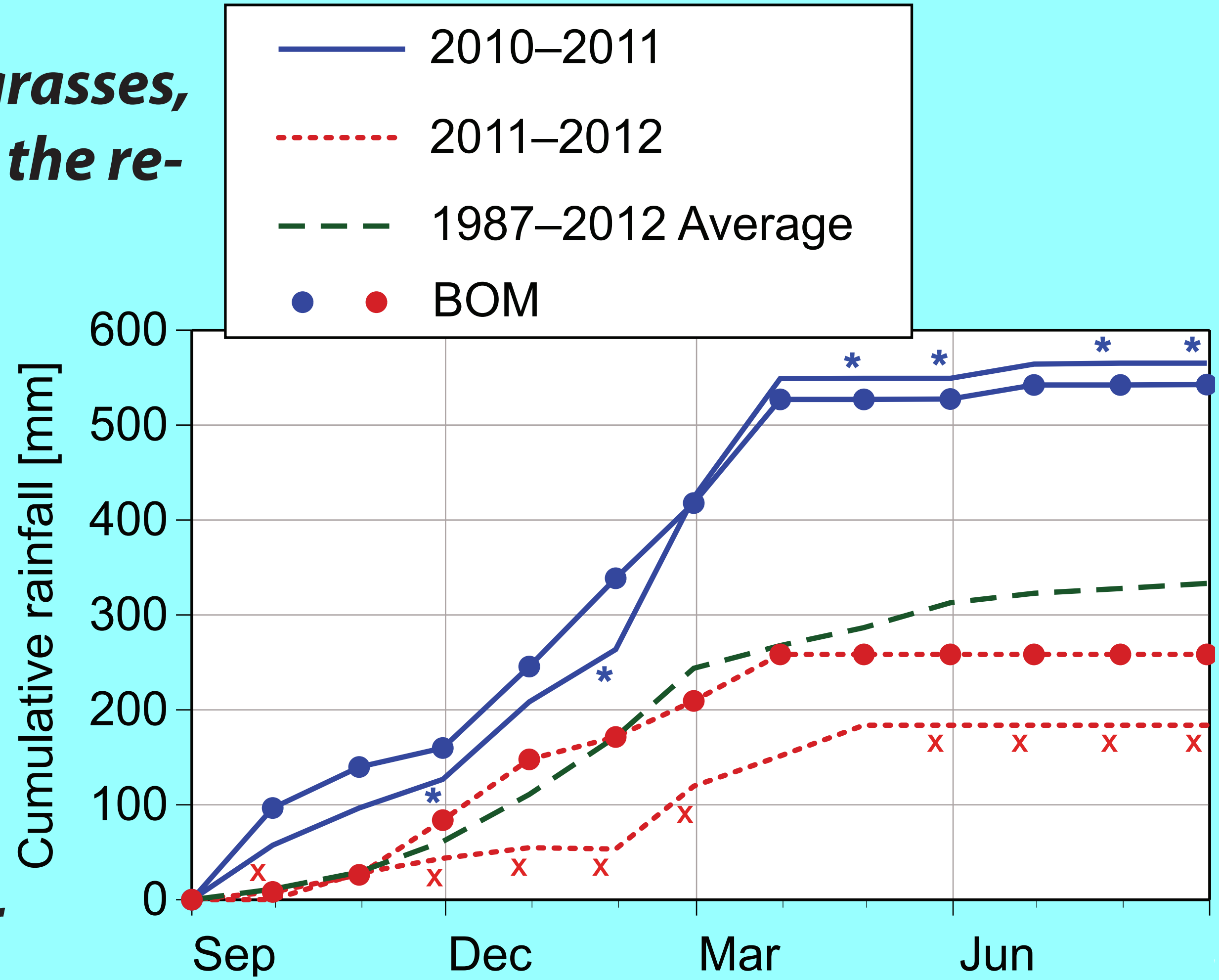
- Mean: 318 mm yr^{-1} (http://www.bom.gov.au)
    - Semi-arid
- Median: 298 mm yr^{-1}
  - Summer (DJF): 72%
  - Monsoon season (Nov–Apr): 86%
    - Just inside the monsoon tropics (Bowman et al. 2010)
- Minimum: 100 mm yr^{-1}, 2009
- Minimum: 750 mm yr^{-1}, 2010

- Long-term at Alice Springs airport:
  - Record: 2010–2011, 1408 mm $(2\ yr)^{-1}$; 50–100 yr recurrence interval (Papalexiou & Koutsoyiannis 2013)
    - Interaction: Australian low and the monsoon depression (Kong & Zhao 2010)
  - Chance of either system being strong in a given year is small (Berry et al. 2011)

- Hypothesis: the Mulga ecosystem was expected to range from a strong sink (wet) to a strong source (dry) (Huxman et al., 2004; Baldocchi, 2008; Wohlfahrt et al., 2008; Yan et al., 2011)

Precipitation
Extremes

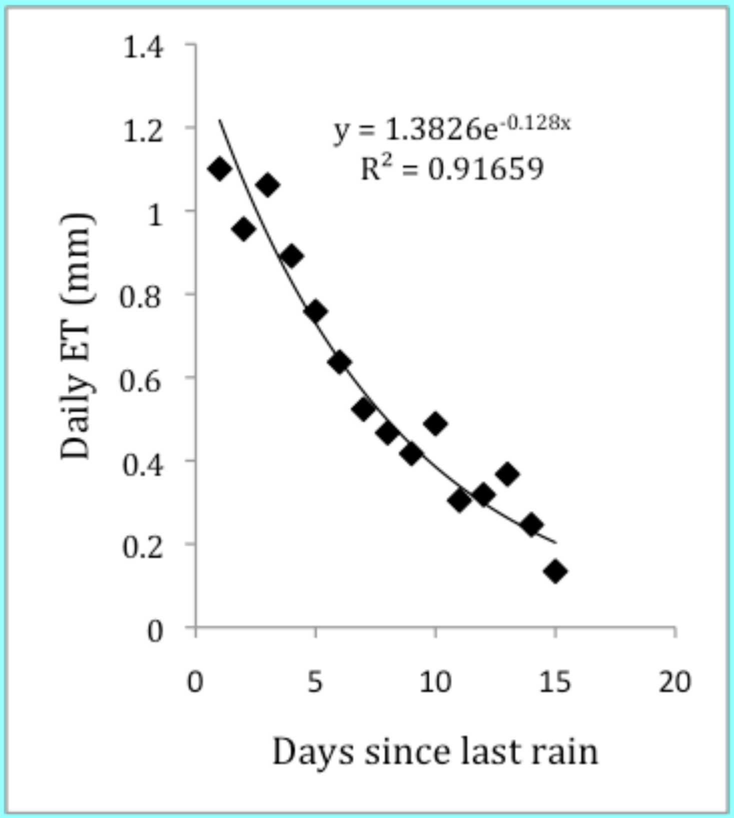
- ***First year: > 200 mm above the long-term average** (http://www.bom.gov.au: Territory Grape Farm 1987–2012)*
- ***Second year: > 100 mm below normal***
- ***Extraordinary explosion in grasses, forbs and fauna throughout the region, 2010–Apr 2011***
- ***Rainfall concluded by April 2011, after which months of below-average precipitation were common***
- ***May–Aug 2012: record period without rainfall***
- ***Spatial heterogeneity larger in second year***

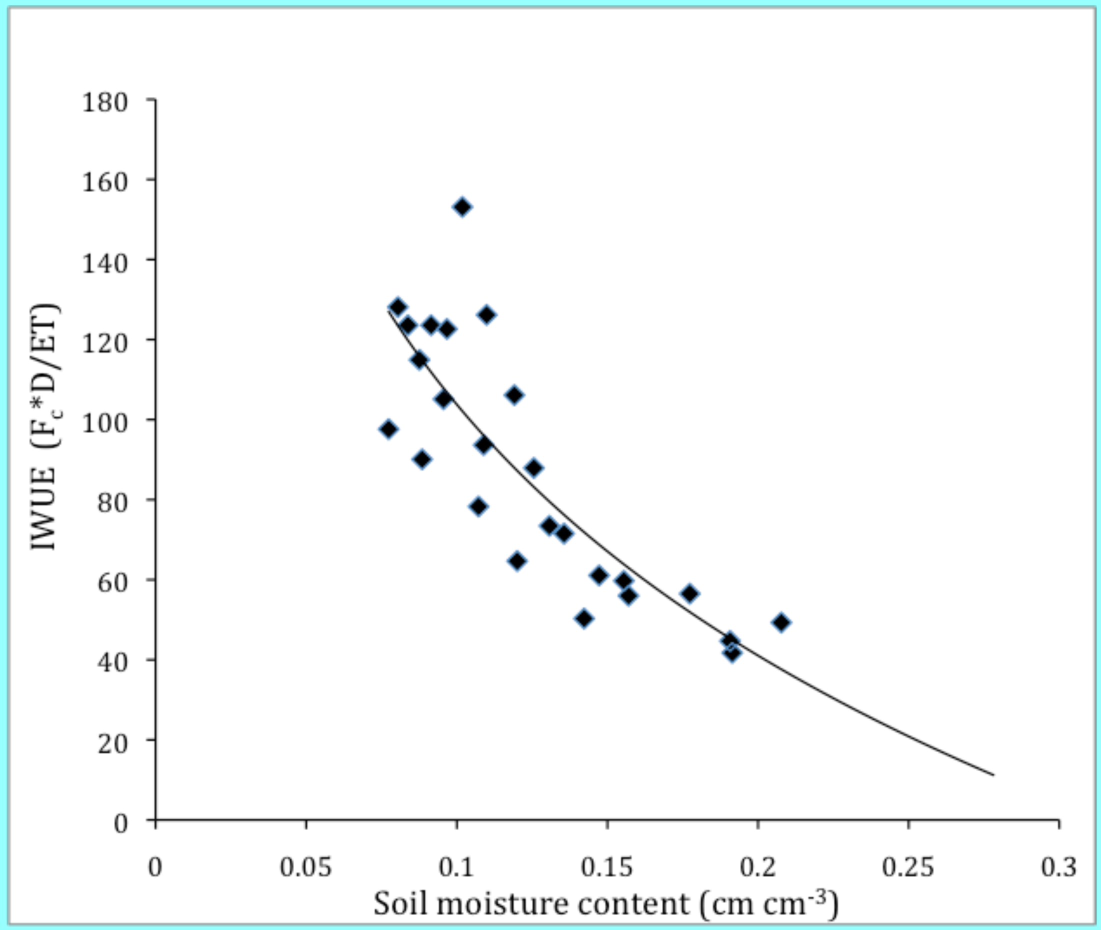


Cleverly et al., J. Geophys. Res.

Pulse–Response, first year
Evapotranspiration and soil moisture

- **Rapid decline in soil moisture after rainfall**
- **Exponential decline of ET following rainfall**
- **Exponential increase in inherent water use efficiency as soil dries**
- **Better fit between IWUE* and soil moisture during wet season**

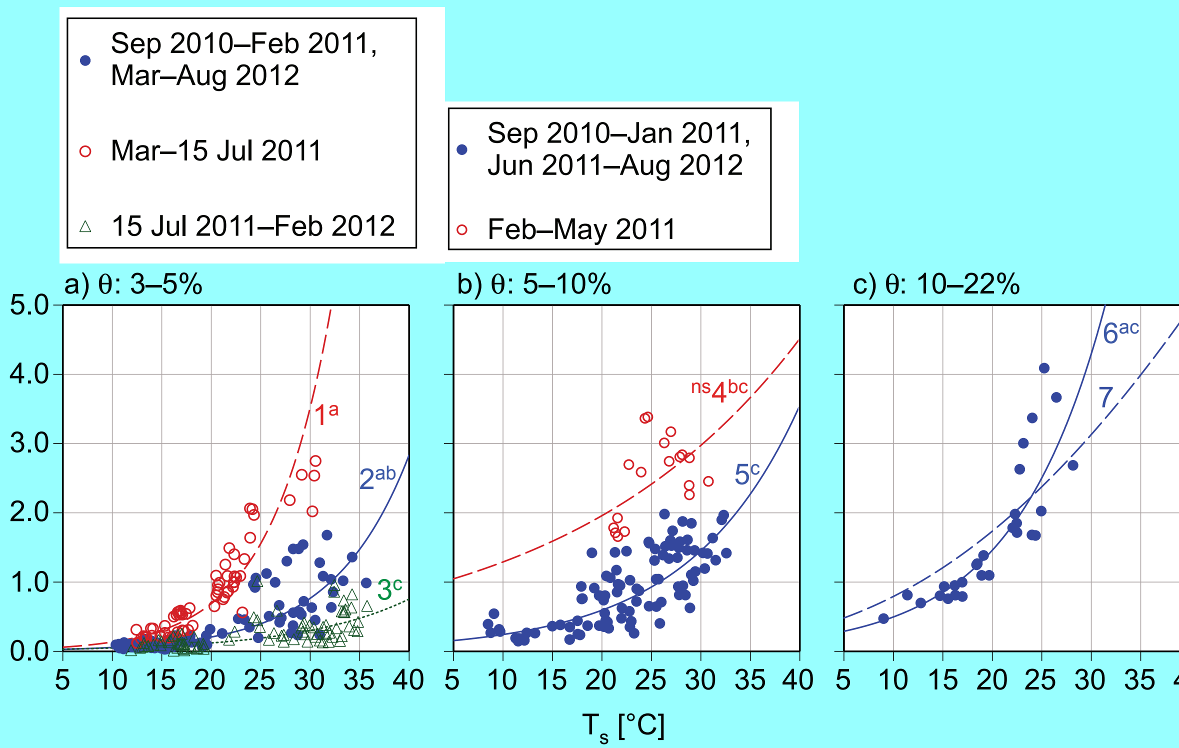




Eamus et al., 2013 Agric. Forest Meteor.

Nocturnal Respiration Responses
Soil moisture & substrate availability

- ***Mar–15 Jul 2011: Very large thermal sensitivity of nocturnal respiration***
  - ***Coincides with cessation of wet period and***
    - ***senescence of understorey growth (Eamus et al. 2013)***
    - ***limited leaf water stress in Mulga (–1.8 MPa) (Eamus et al. 2013)***
- ***Weak thermal sensitivity during dry periods***
- ***Small sample size when soil was very wet resulted in no significant differences between moisture classes***



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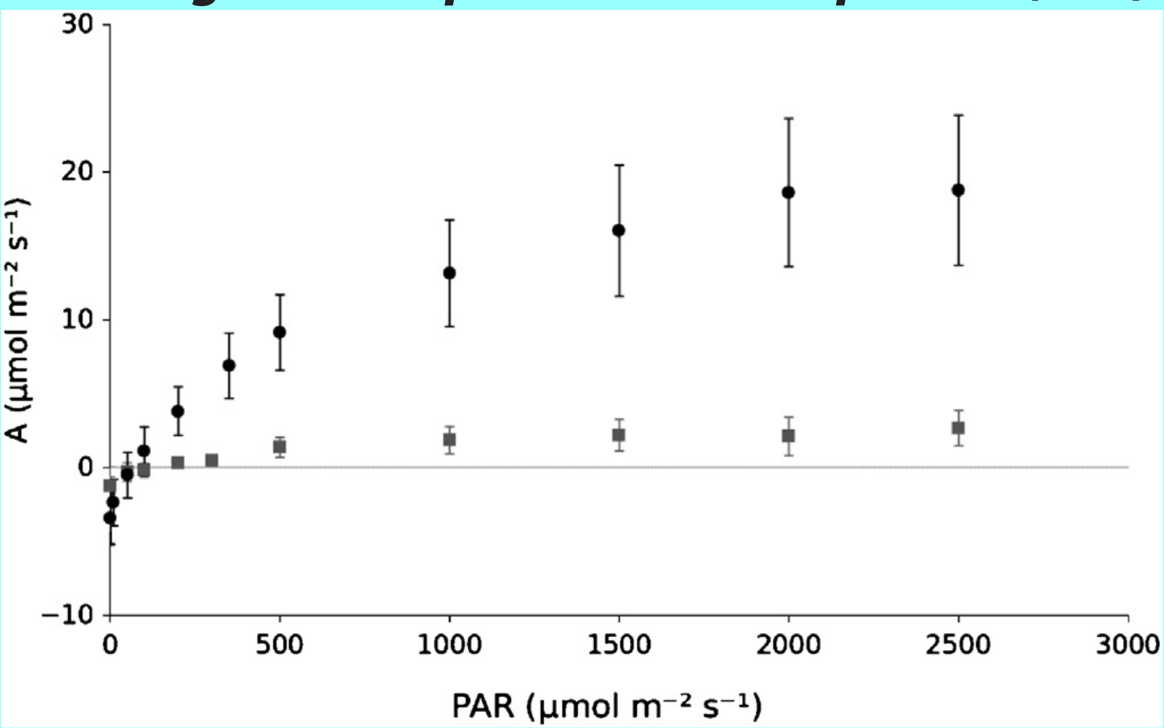
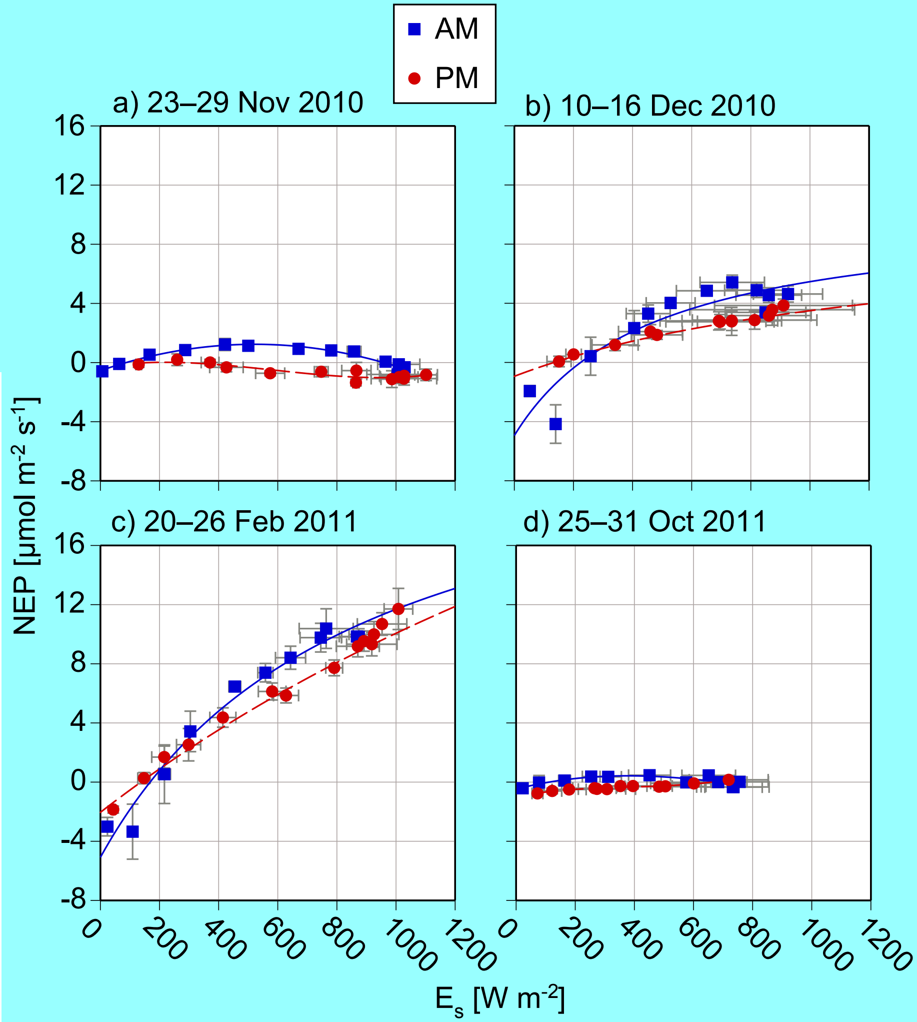
Net Photosynthesis
Seasonal sensitivity

- **Mulga:**
  - *steep quantum yield (initial slope of light response function)*
  - *near-zero midday assimilation in dry*
- **Ecosystem:**
  - *morning net assimilation, midday net respiration*
  - *Assimilation fails to saturate in full sun-light at the peak of GPP responses (Feb)*



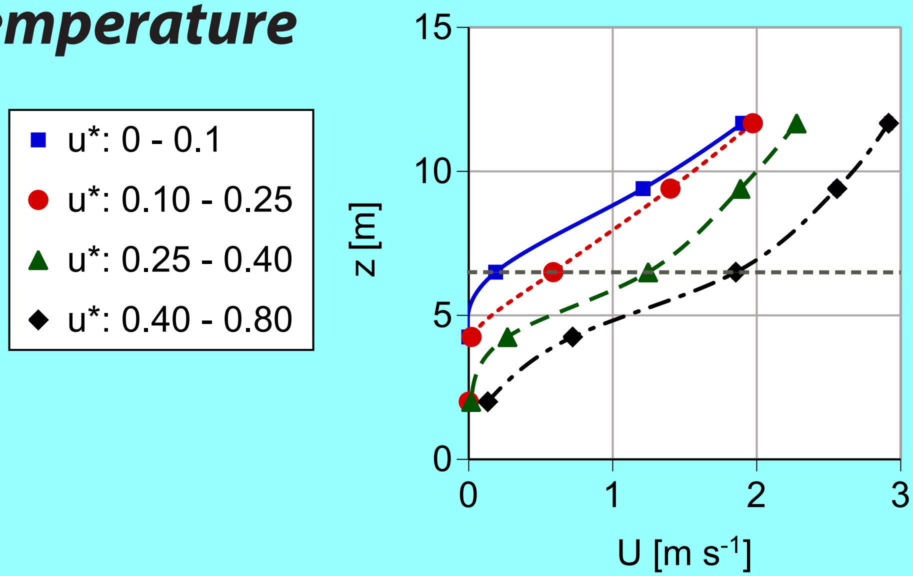
Eamus et al., 2013 Agric. Forest Meteor.

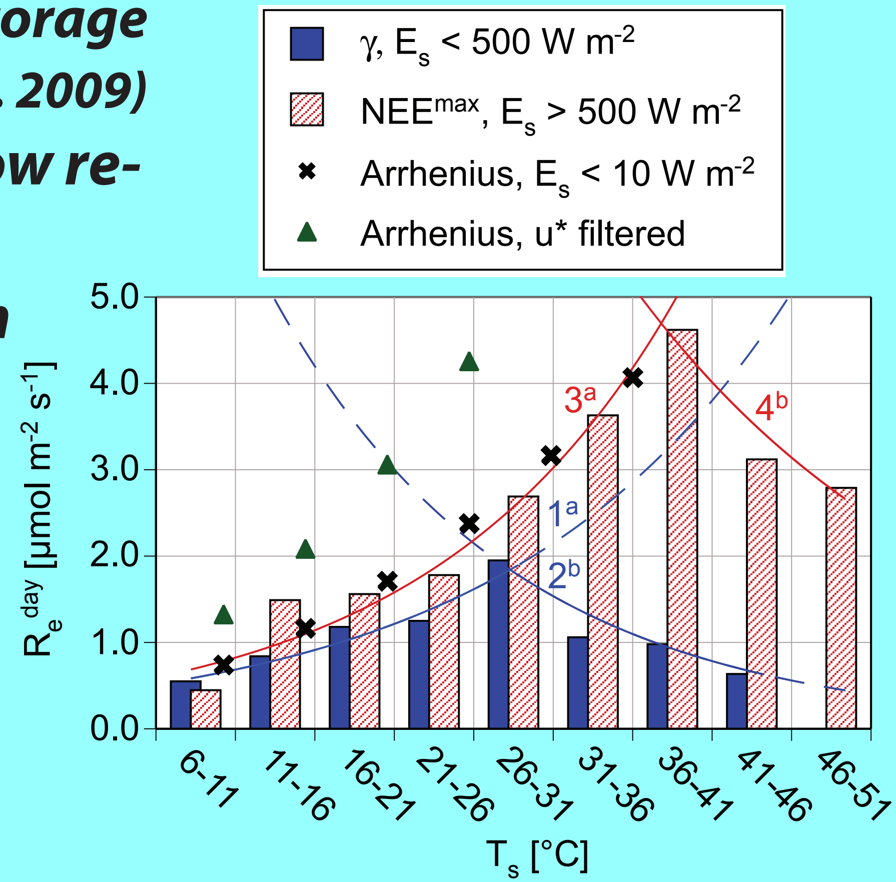


Cleverly et al., J. Geophys. Res.

Diurnal Respiration Responses
Temperature & irradiance

- ***GPP = NEP + R_e***
- ***Extroplation of nocturnal respiration (Arrhenius)***
  - ***u* filter leads to substantial over-estimation of R_e and GPP***
    - ***consistent with double-counting of de-storage fluxes (Aubinet 2008)***
  - ***very close agreement between nocturnal R_e and light response estimates of R_e***
    - ***close agreement between nocturnal + storage fluxes and LRF estimates (van Gorsel et al. 2009)***
- ***Low-light and high-light LRFs match below respective temperature optima***
- ***Soil moisture limitations imposed at high temperature***



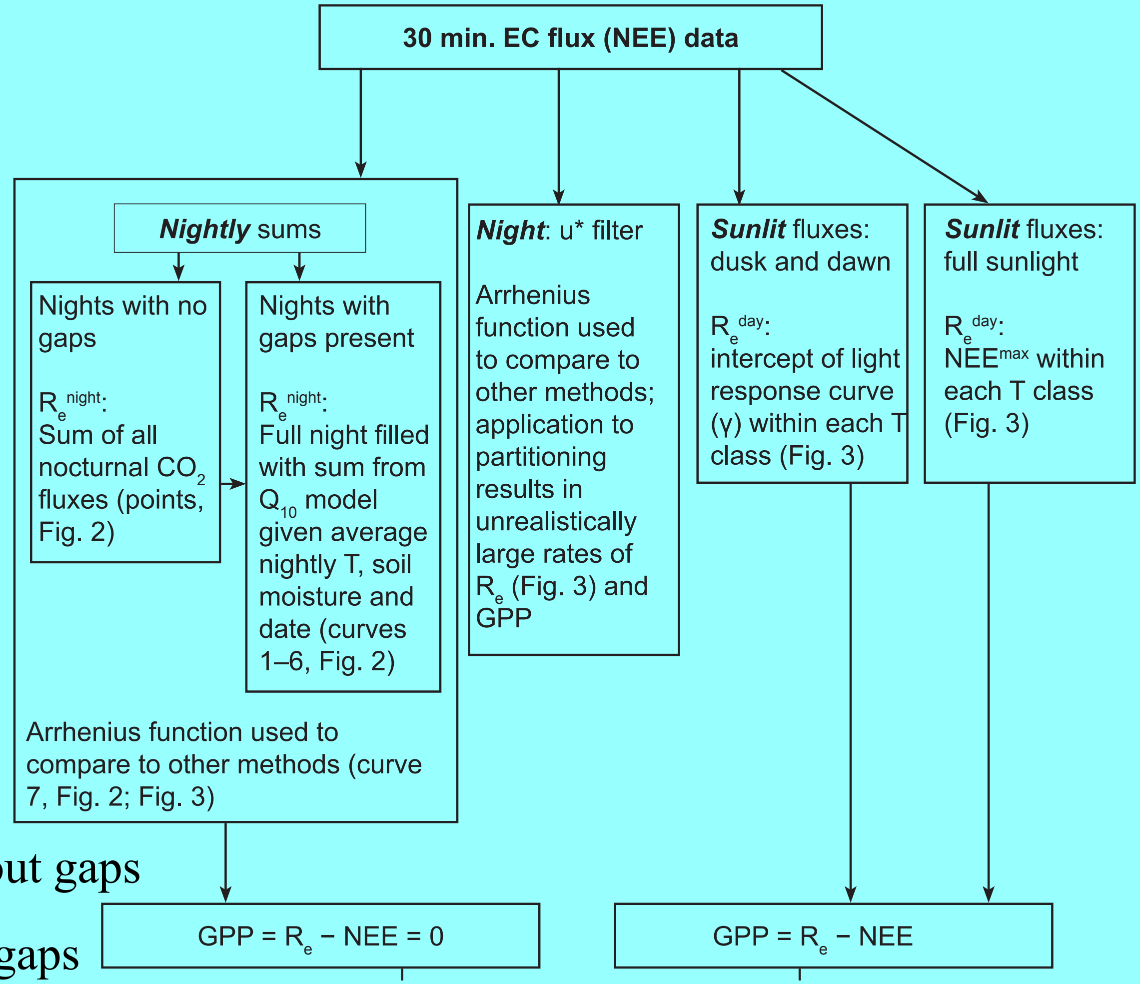


Cleverly et al., J. Geophys. Res.

Partitioning NEE

Gross primary production and ecosystem respiration

- ***Nocturnal R_e:***
  - ***u* filter: unrealistically large R_e***
    - ***not used for partitioning***
- ***Diurnal R_e:***
  - ***High light:***
    - ***Midday positive NEE can be larger than intercept (Scott et al. 2010)***



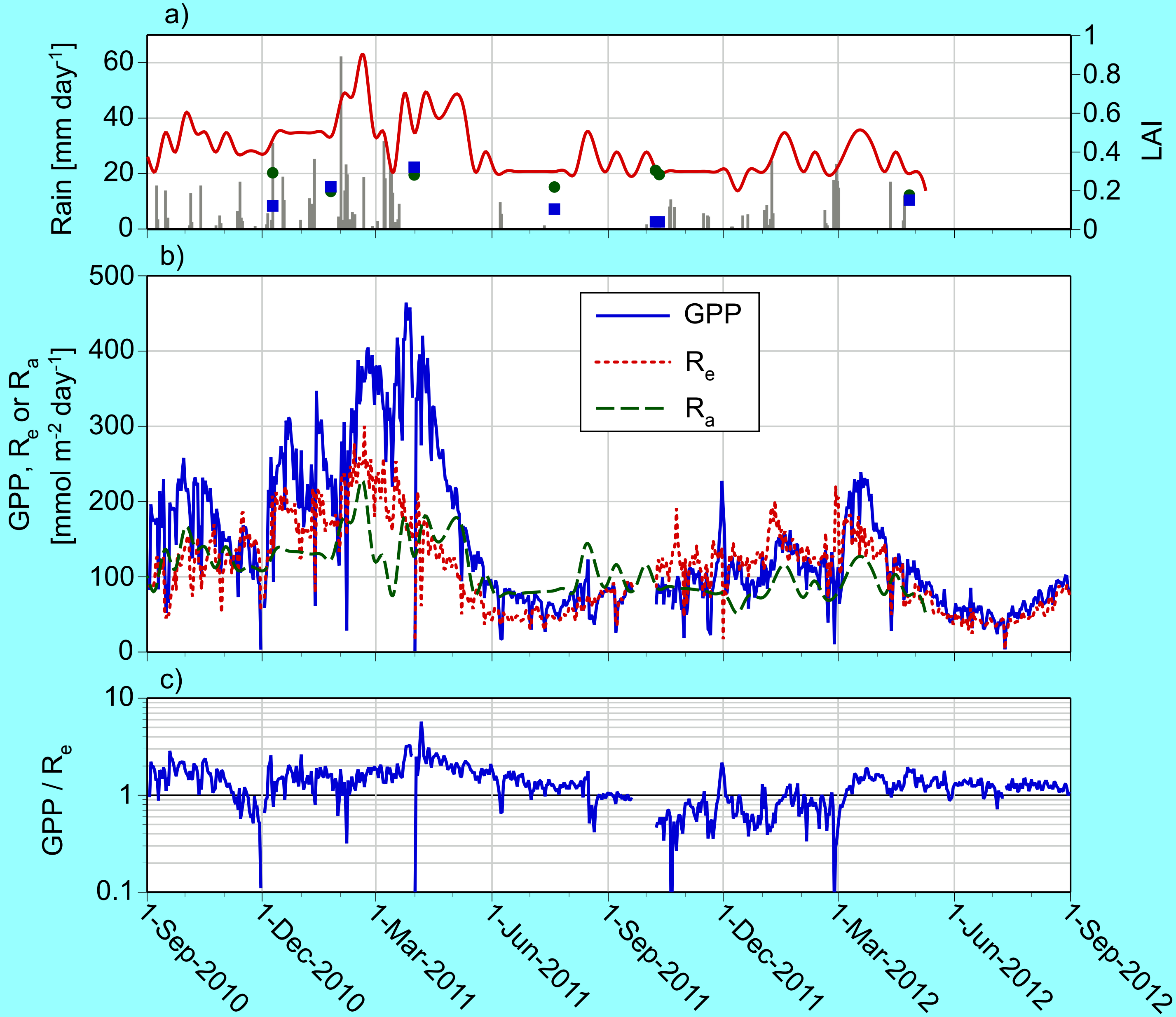
$$
R_e = \begin{cases}
R_e^{night} = \sum NEE & \text{night: without gaps} \\
R_e^{night} = a \exp\left(bT_s\right)_{(\theta,\text{date})} & \text{night: with gaps} \\
R_e^{day} = \gamma_{(T)} & \text{sunlit: } 10\ \text{W m}^{-2} < E_s < 500\ \text{W m}^{-2} \\
R_e^{day} = \gamma_{(T)}\Big|_{GPP=0} = NEE^{max}_{(T)} & \text{sunlit: } E_s > 500\ \text{W m}^{-2}
\end{cases}
$$

Cleverly et al., J. Geophys. Res.

Carbon responses

Gross primary production and ecosystem respiration

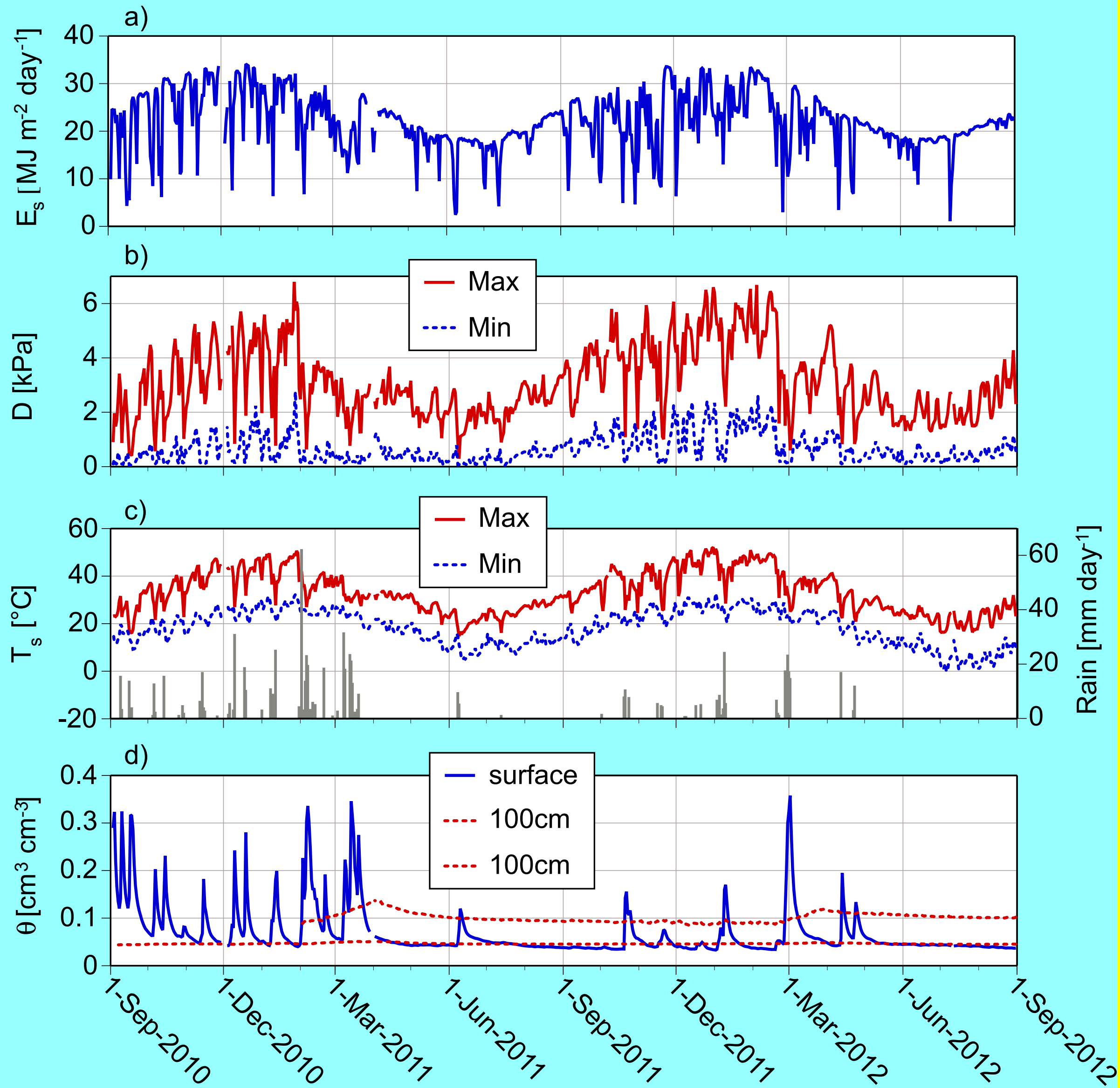
- ***Large GPP:***
  - ***33–66 mol m^{-2} yr^{-1}***
- ***Small–moderate R_e:***
  - ***34–45 mol m^{-2} yr^{-1}***
  - ***closely matches LAI***
  - ***decomposition pulse during understorey senescence***
- ***Wet year: carbon sink***
- ***Dry year: carbon neutral***
- ***Hypothesis: rejected (thus far)***



Cleverly et al., J. Geophys. Res.

Storm pulses
Rainfall and soil moisture

- ***Multi-day storm ensembles:***
  - ***storm period: 2–5 days***
    - ***low temperature***
    - ***little irradiance***
    - ***small vapour pressure deficit***
    - ***large surface soil moisture content***
  - ***inter-storm period: 5–10 days***



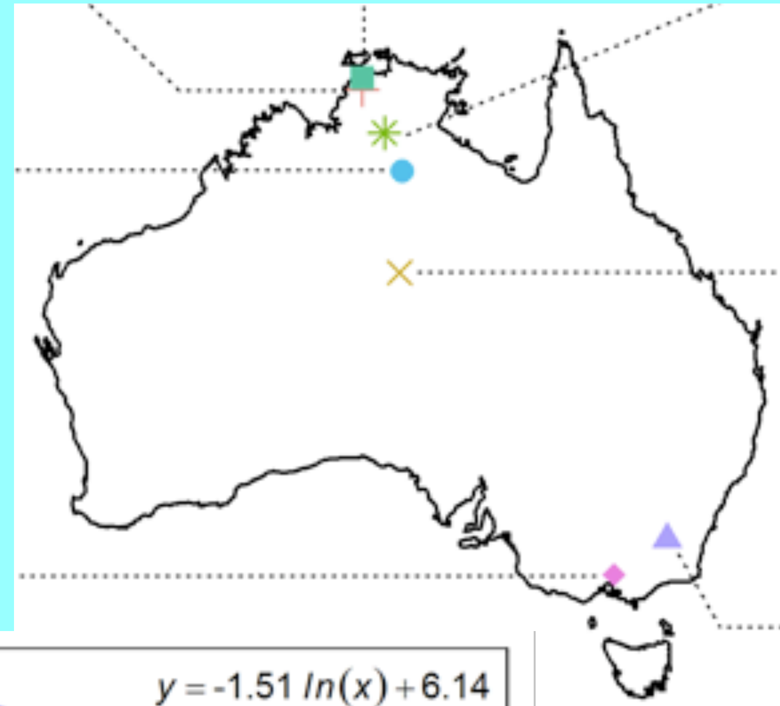
Cleverly et al., J. Geophys. Res.

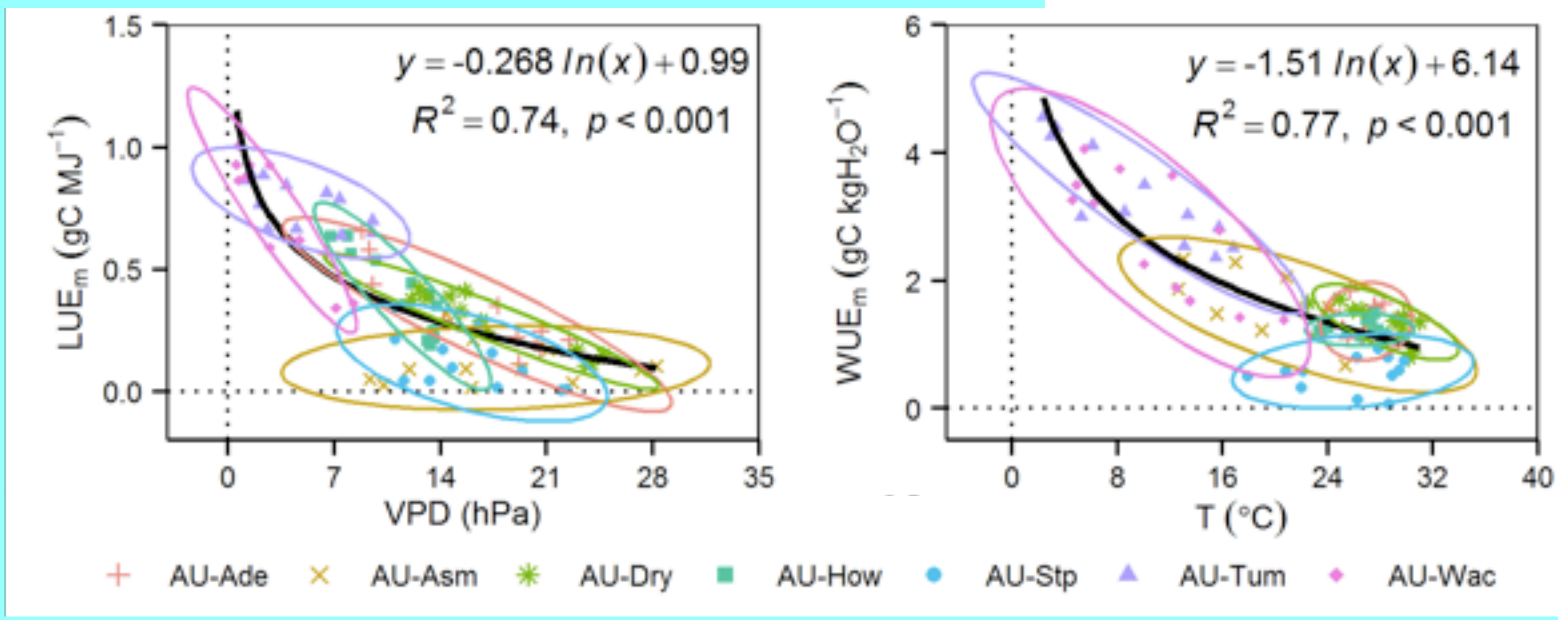
Light & water use efficiency
OzFlux transect

$$LUE = \frac{\sum_i^n GPP_i}{\sum_i^n 0.5\left(F_{sd}\right)_i}$$

$$WUE = \frac{\sum_i^n GPP_i}{\sum_i^n ET_i}$$

- ***Convergence on negative exponential across sites***
- ***Alice Springs:***
  - ***Large range in VPD and T_a***
  - ***No LUE response to VPD***
  - ***Large WUE response to VPD***

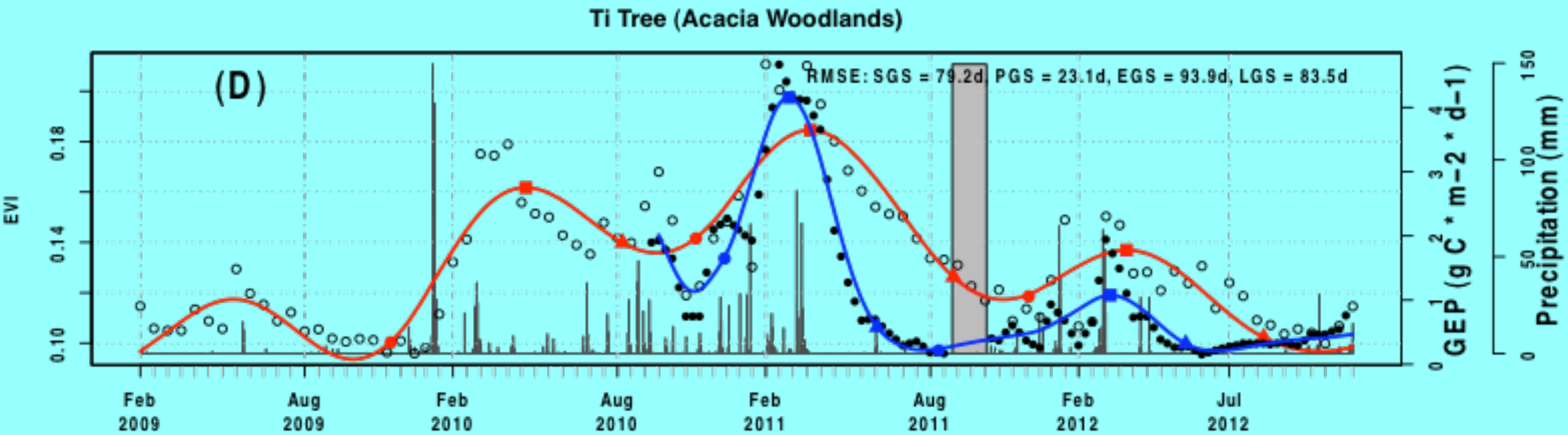




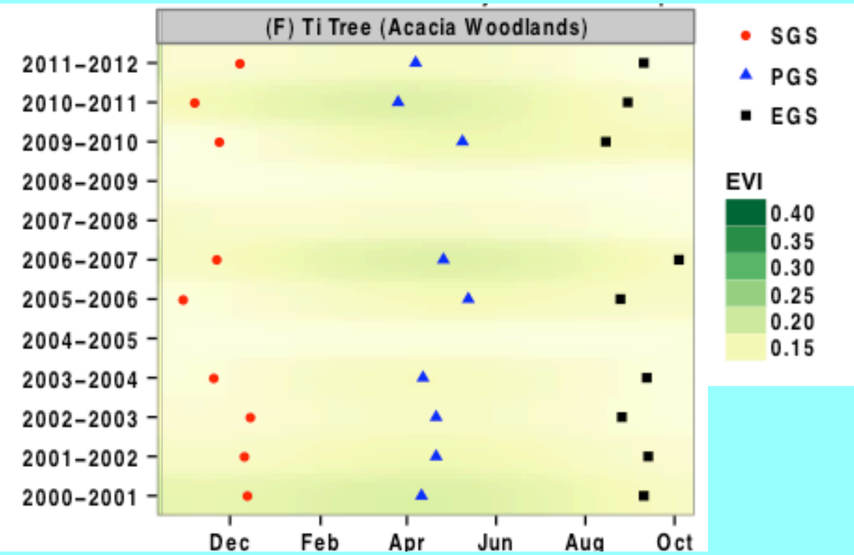
Shi et al., in preparation

Phenology responses

Gross ecosystem photosynthesis & EVI



- *Large variability in seasonal phenology*
  - *No detectable growing season during dry years*
  - *Nearly full-year growing season during extraordinarily wet years*
  - *Start-of-growing season and End-of-growing season vary*

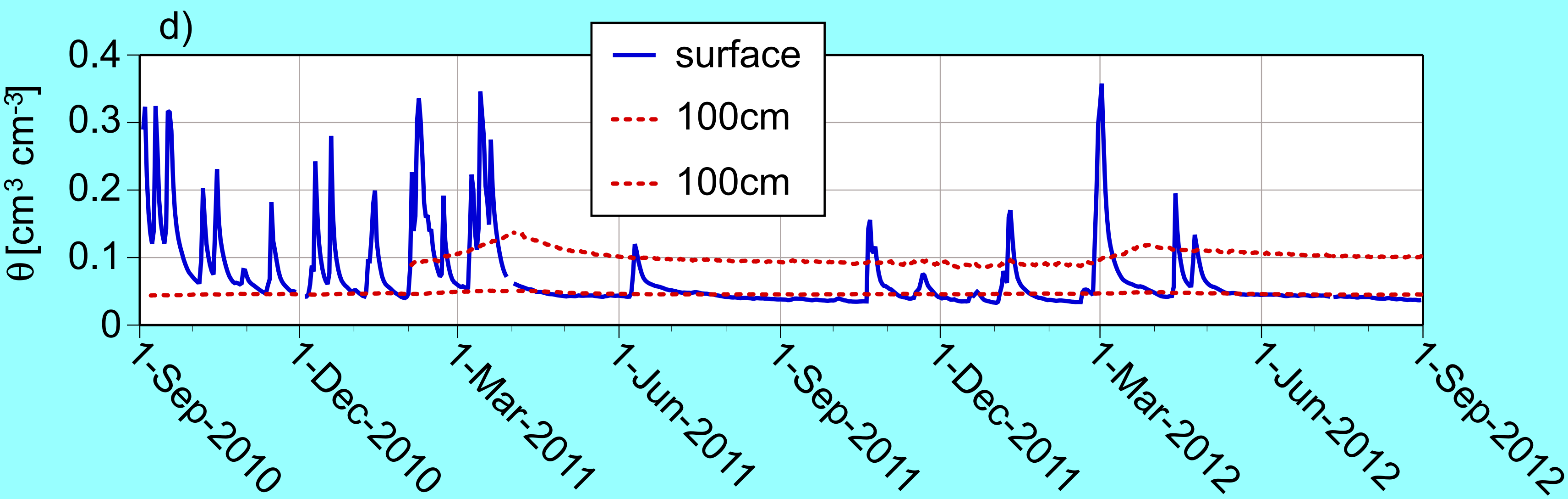


Ma et al., Remote Sensing Environ.

Soil

Heavily weathered red kandosol

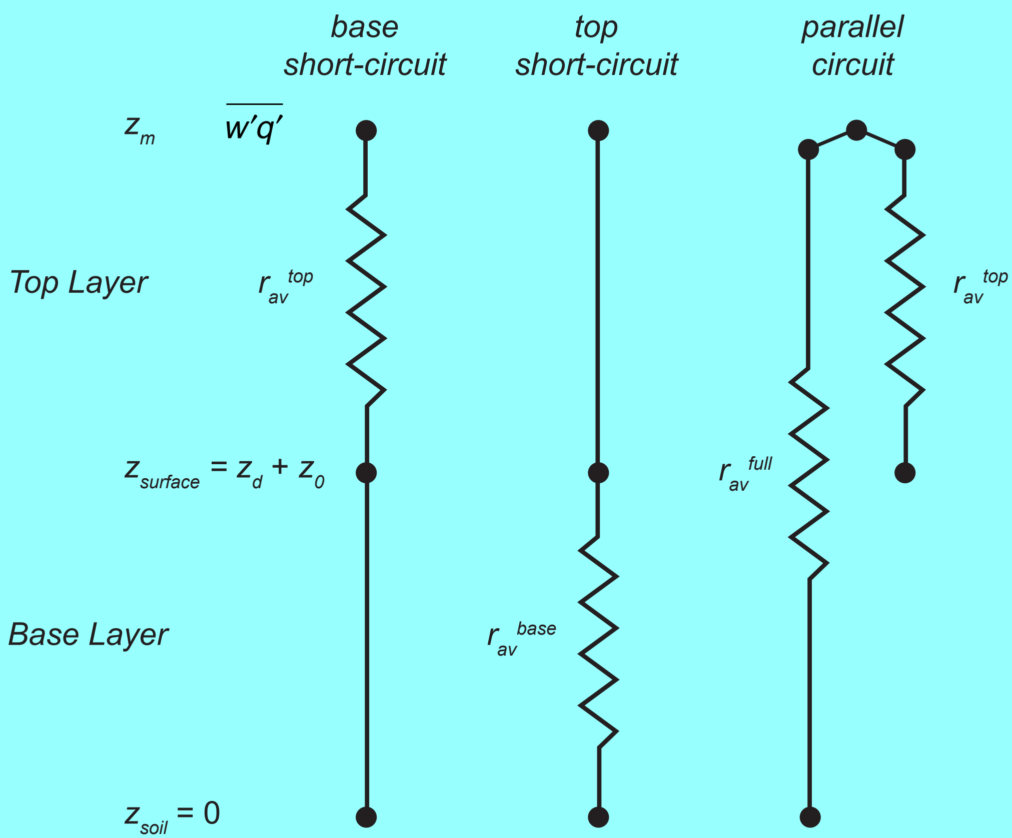
- ***Typical of large areas of semi-arid Australia; large potential for drainage** (Schmidt et al. 2010, Morton et al. 2011)*
- ***Sandy loam (74/11/15% sand/silt/clay)***
- ***Hardpan commonly formed in the top metre (possibly deeper)** (Morton et al. 2011)*
- ***Soil organic matter:***
  - ***1.1% at surface, 0.7% at 0.1 m depth, 0.5% in hardpan***
- ***Surface bulk density: 1.69 ± 0.02 g cm^{-3}***



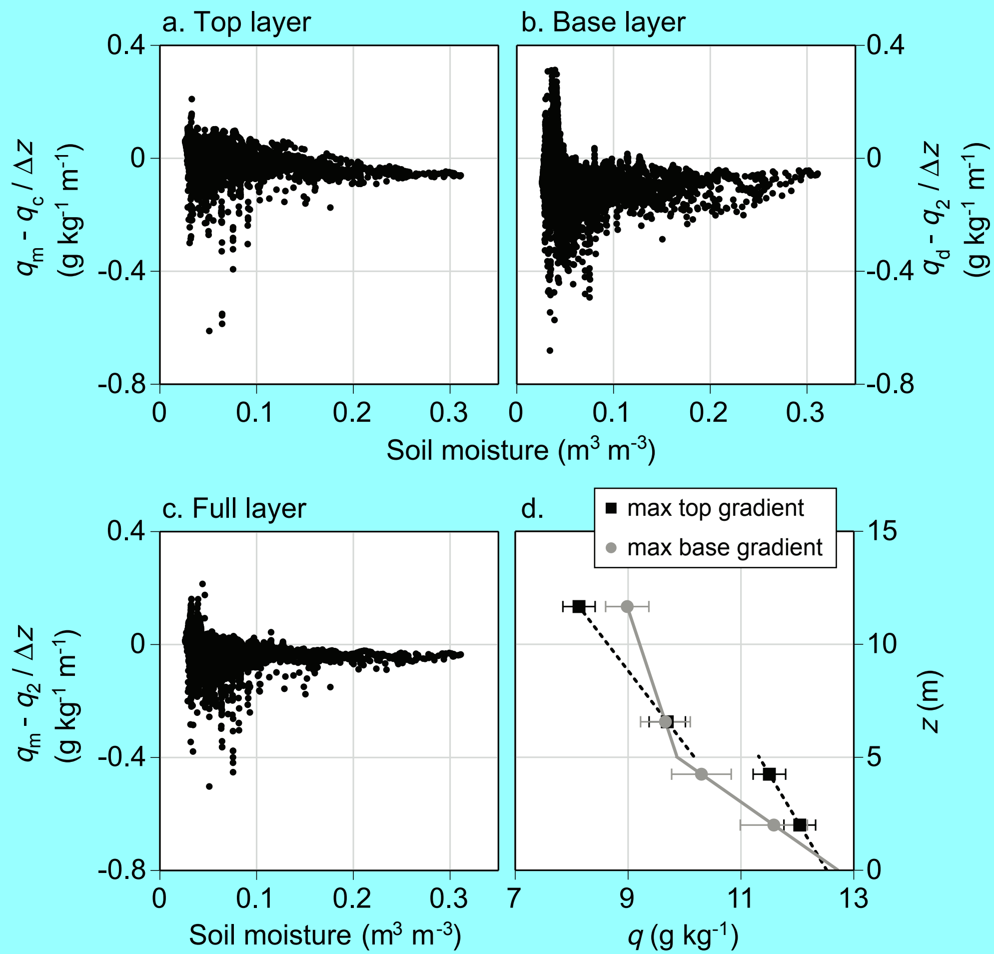
Cleverly et al., J. Geophys. Res.

Atmospheric humidity gradients

Penman-Monteith ET



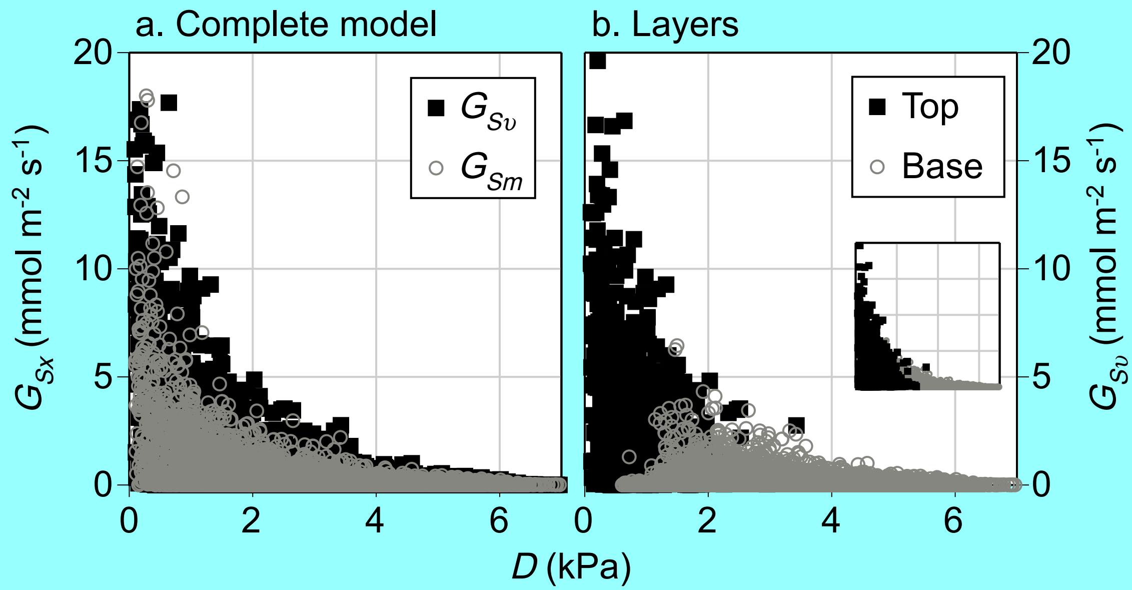
$$r_{av} = \begin{cases} r_{av}^{top} = -\dfrac{q_m - q_{surface}}{\overline{w'q'}} & r_{av}^{base} \le 0 \text{ (i.e., } q_{surface} - q_{soil} \ge 0) \\ r_{av}^{base} = -\dfrac{q_{surface} - q_{soil}}{\overline{w'q'}} & r_{av}^{top} \le 0 \text{ (i.e., } q_m - q_{surface} \ge 0) \\ r_{av}^{full} \,\|\, r_{av}^{top} = \dfrac{r_{av}^{full} r_{av}^{top}}{r_{av}^{full} + r_{av}^{top}} & r_{av}^{top}, r_{av}^{base} > 0 \end{cases}$$

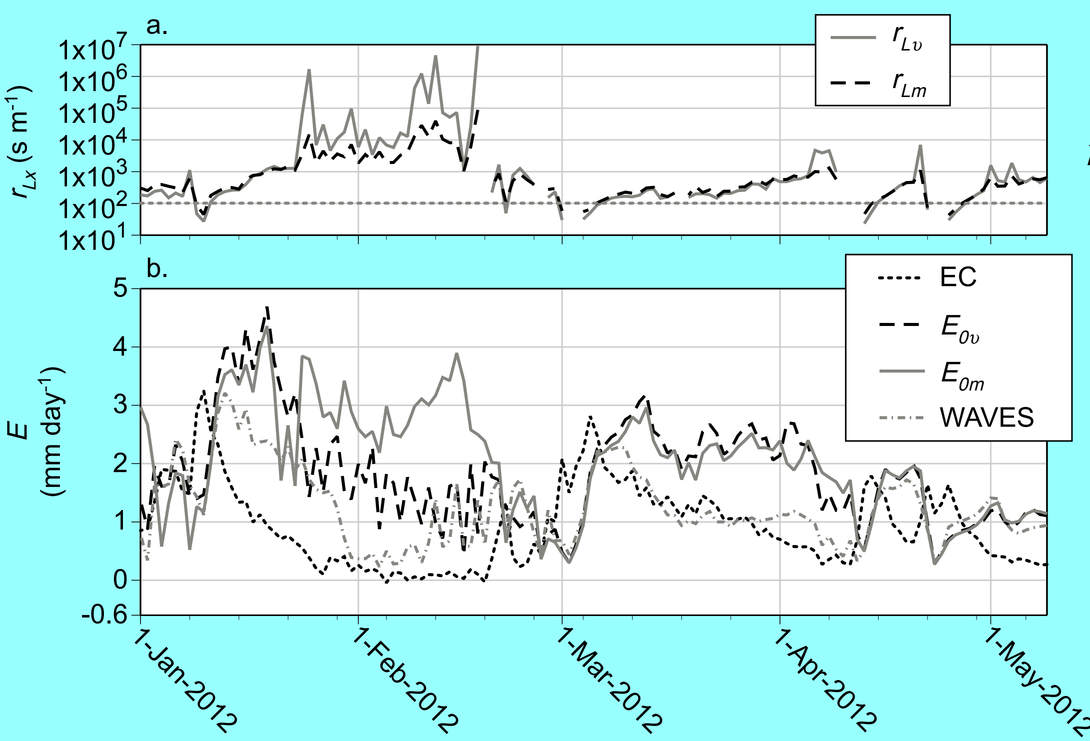


Cleverly et al., J. Hydrometeorol.

Penman-Monteith Inversion
C_E & C_D

- ***Improved conductance response to vapour pressure deficit***
- ***Smaller error during summer***
- ***Separation between layers based upon D***





$$r_{am} = \left(UC_D\right)^{-1} \approx \frac{\ln\left[\left(z_m - z_d\right)/z_{0m}\right]\ln\left[\left(z_m - z_d\right)/z_{0v}\right]}{k^2 U}$$

$$r_{av} = \left(UC_E\right)^{-1} = -\frac{q_a - q_0}{\overline{w'q'}}$$ ***(Brutseart 1982, Stull 1988)***

$$G_{Sx}^{-1} = r_{ax}\left\{\left[\left(\frac{\Delta Q_A + \rho_a c_P D r_{ax}^{-1}}{\lambda \overline{w'q'}} - \Delta\right)\gamma^{-1}\right] - 1\right\}$$

Cleverly et al., J. Hydrometeorol.


Thank you

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