The contribution of photo-degradation to the ecosystem carbon budget of a semi-arid Corymbia-*hummock savanna*

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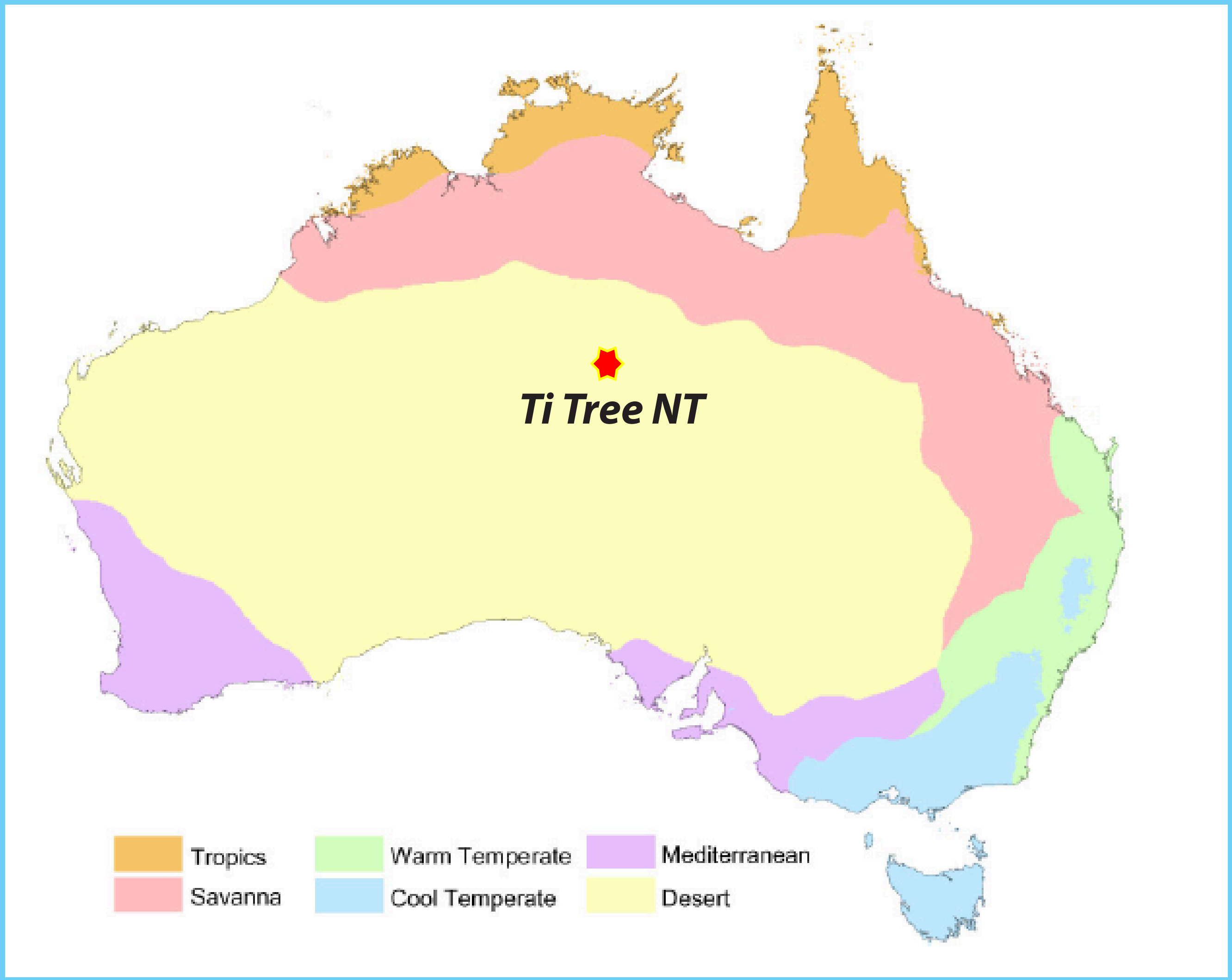
Australian arid zone



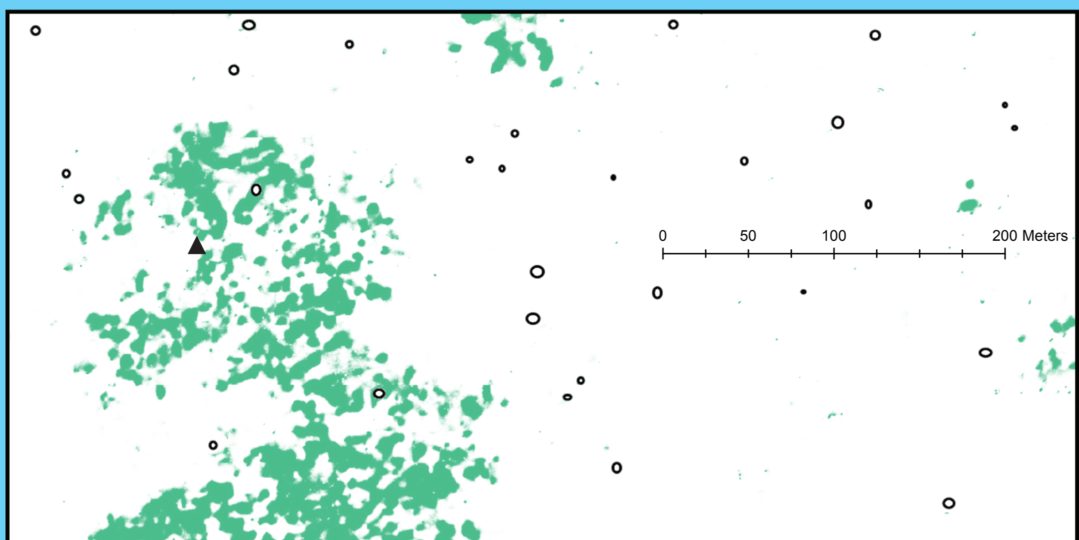
[Haverd et al. 2013]

70% of continental land area is semi-arid [Eamus et al. 2006]

Two-thirds of net primary production from grasses and crops [Haverd et al. 2013]

Ti Tree East

Corymbia *open savanna—hummock grass*



Established July 2012

Flat with negligible runoff
- **sandy soil:**
  - **reduced local redistribution**
  - **weaker hardpan where it occurs**

Triangle: tower

Green shading: Mulga

Open circles: *Corymbia* trees

Woody vegetation cover:
- **Mulga: 6%**
- ***Corymbia*: 0.4%**

Empty space:
- **tussock grass in Mulga patch**
- **hummock grass elsewhere**

Hummock grass (Spinifex)
T. schinzii

20–25% of continental land area [Bowman et al. 2008]

Deep-rooted (10s of metres) [Reid et al. 2008, Nano & Clarke 2010]

C_4 photosynthesis:

- **negligible photorespiration, no practical thermal limit & large water-, light-**
  - **and nutrient-use efficiencies** [Ehleringer & Percy 1983, Ehleringer et al. 1991, 1997, Ehleringer & Monson 1993, Barron-Gafford et al. 2012, Taylor et al. 2014]

Drought tolerant anatomy (leaf rolling with interior stomata) [Grigg et al. 2008]

Pyrophytic [Nicholas et al. 2011]

Ecosystem carbon budget
Definitions

NEE = ER – GPP (assume abiotic decomposition, geological processes, etc are negligible)

ER_{night}: nocturnal thermal-response curves [Reichstein et al. 2005]

ER_{dark}: light-response curves [Lasslop et al. 2010, Stoy et al. 2006]

Increasingly seeing comparison of the two (day & night) [Baldocchi and Sturtevant 2015]

Soil respiration = heterotrophic respiration + rhizosphere respiration (autotrophic)

Light-response functions

Autotrophic (leaf), heterotrophic + autotrophic (ecosystem)

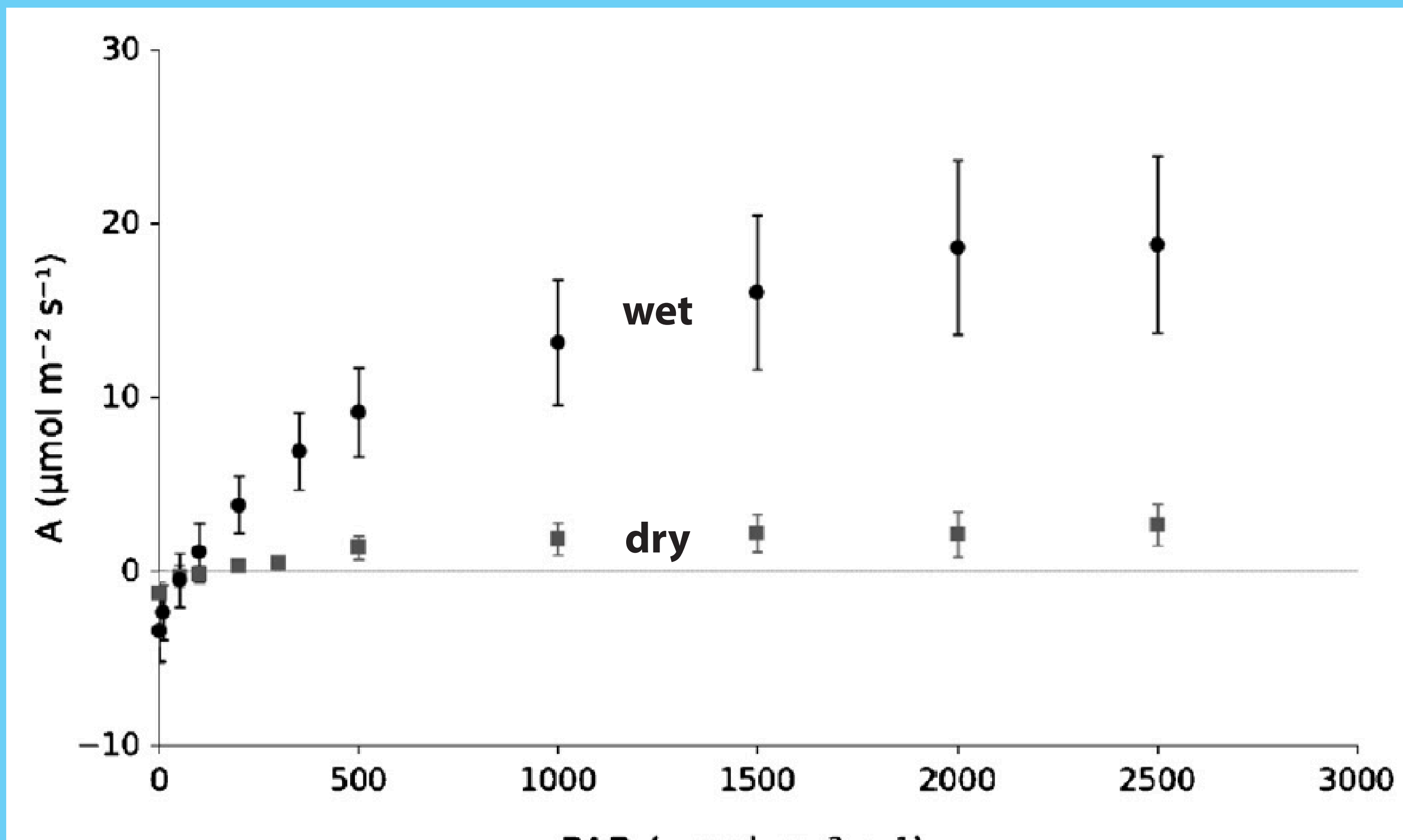
A: net photosynthetic assimilation

A = gross photosynthesis – photorespiration – dark respiration [Wohlfahrt 2015]

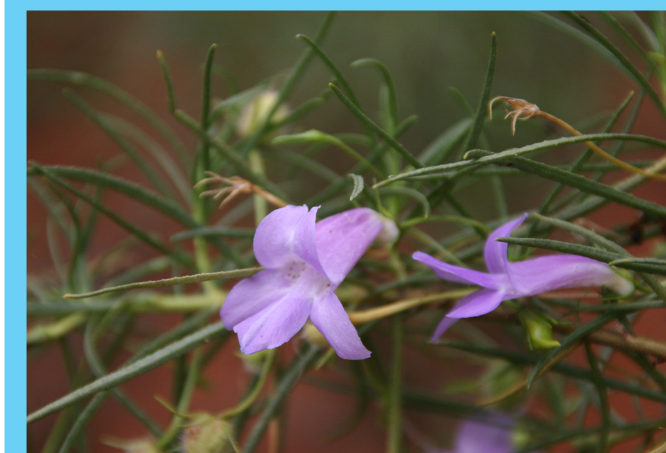
Dark respiration: intercept of the photosynthetic light-response function

Maximal photosynthetic rate under light saturation is very sensitive to moisture in Mulga

Ecosystem GPP = gross photosynthesis – photorespiration [Wohlfahrt 2015]



[Eamus et al. 2013]



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relax assumption of negligible abiotic decomposition:

NEE = (ER + abiotic decomposition) – GPP

NEP = –(NEE – abiotic decomposition) = GPP – ER [Chapin et al. 2006]

Soil respiration = heterotrophic respiration + rhizosphere respiration (autotrophic)

Abiotic decomposition

Photo-degradation

- Photo-degradation breaks down lignin, biotic decomposition does not [Austin and Ballare 2010]
- Abiotic decomposition depends on aridity and leaf chemistry in semi-arid areas [Brandt et al. 2007]
- Photo-oxidation is one of several mechanisms responsible for photo-degradation [Lee et al. 2012]
- Abiotic decomposition is important in arid and semi-arid areas with open canopies and large amounts of standing dead matter [Rutledge et al. 2010]
- *Triodia* leaf lignin content: 8.5–15.0% of oven dry weight from wet to dry seasons, respectively [Islam and Adams 1999]

"Current global change projections suggest that the importance of abiotic decomposition processes to the global C cycle may increase in the future." [Lee et al. 2012]

Decomposition implies prior accumulation of GPP

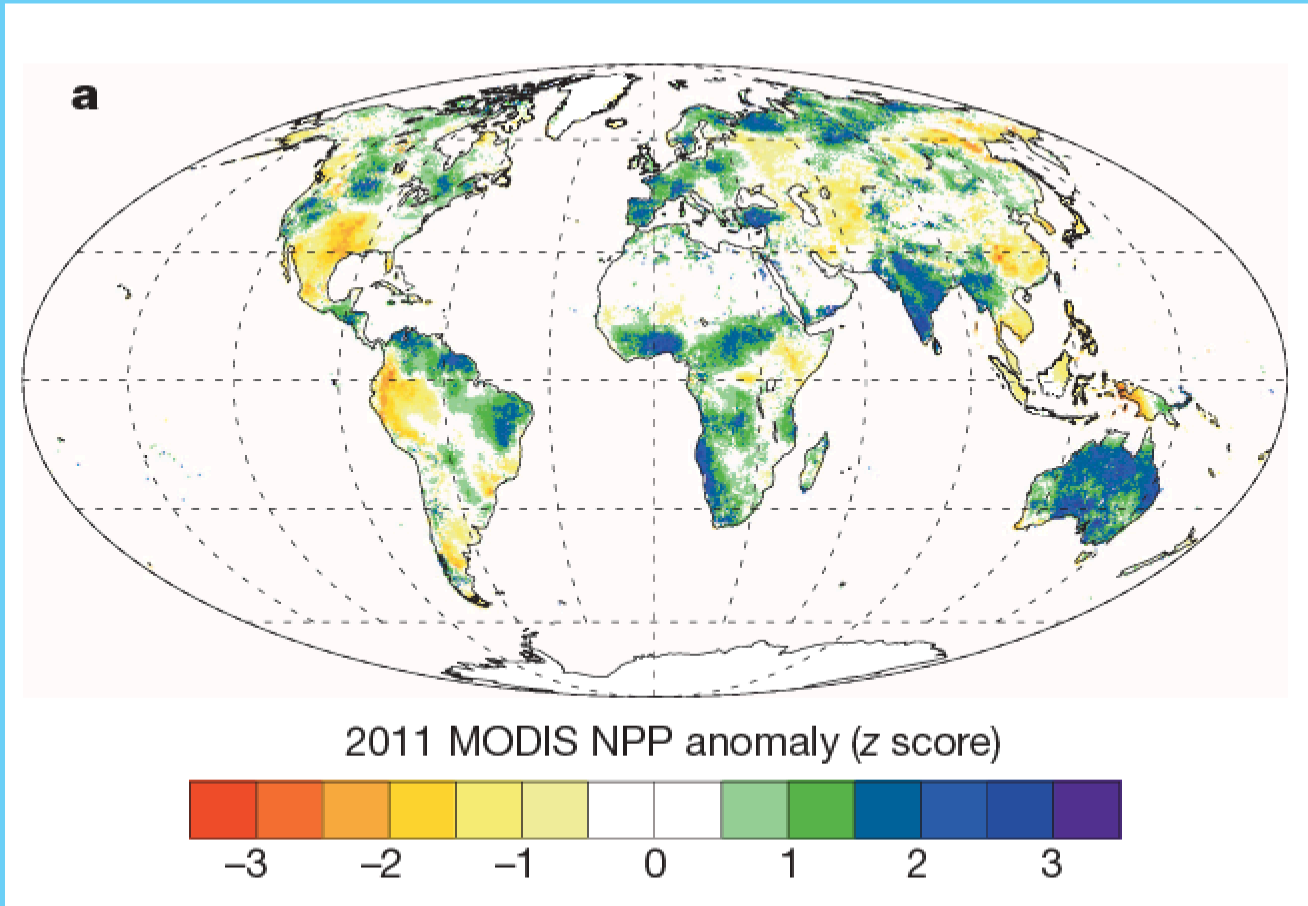
2011 global land C sink anomaly

Extraordinary C sink identified in semi-arid regions of the Southern Hemisphere, 57% attributed to Australian semi-arid regions [Poulter et al. 2014]

Larger increase in GPP than in ER (largely autotrophic) [Cleverly et al. 2013]

Intrinsic response of Australian vegetation to rainfall variability [Haverd et al. 2016]

Mad Max lost to Africa, flooding in QLD **[Cleverly and Eamus 2016 The Conversation]**



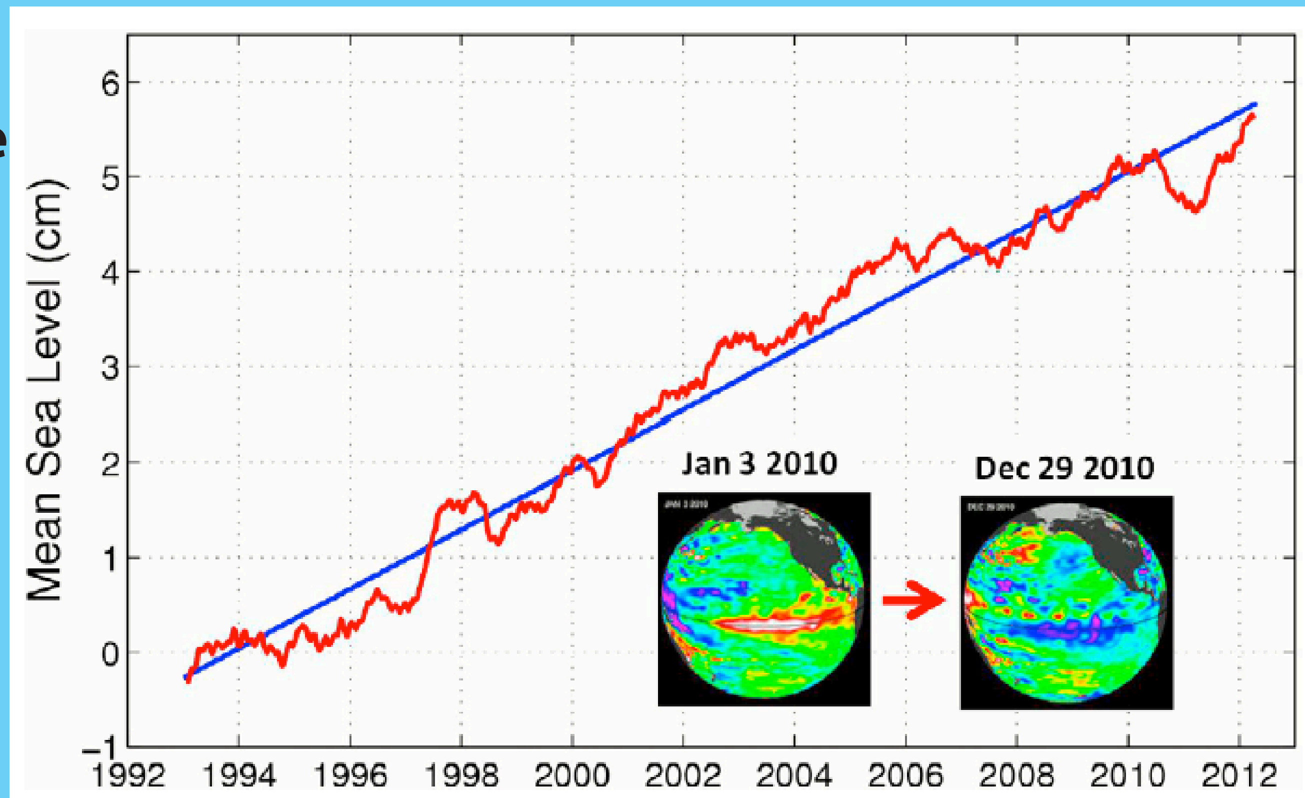
[Poulter et al. 2014]

Global anomalies: ocean level decline
2010–2011

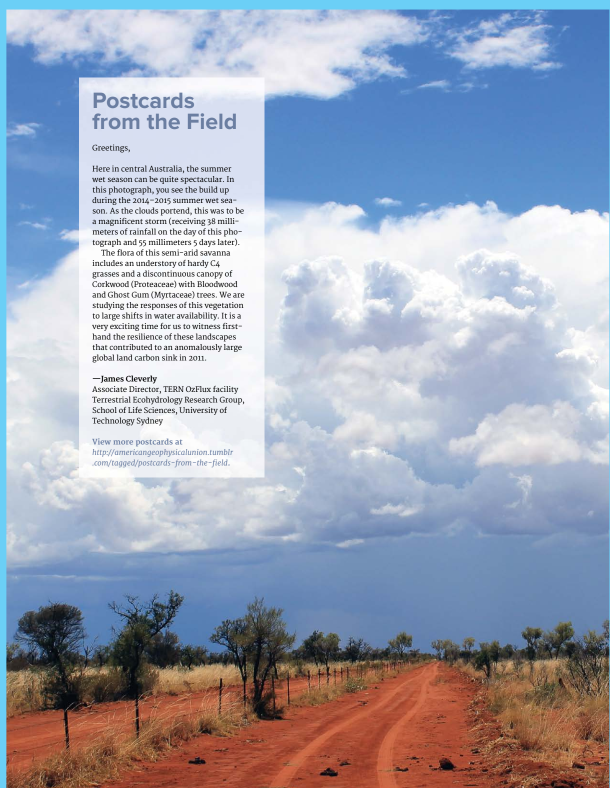
Strongest sustained La Niña in over 90 years (since 1917) [Boening et al. 2012]

5 mm drop in ocean level [Boening et al. 2012]

Increase in total continental water mass through 2012 [Fasullo et al. 2013]
— water anomaly persisted due to drought responses of vegetation following the end of the wet [Cleverly et al. 2016 AgForMet]



[Boening et al. 2012]



[Cleverly 2016, EOS Postcards from the Field]

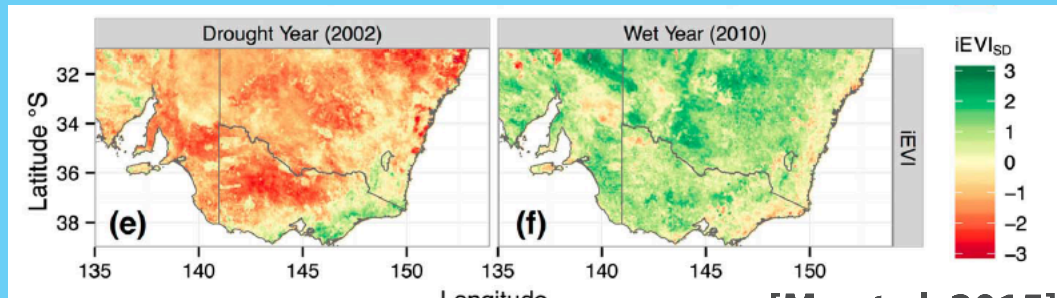
A history of droughts and flooding rains

Extremes of dry and wet

Variability in global carbon cycle associated with source/sink dynamics in semi-arid environments [Ahlström et al. 2015]

Large resilience in Australian semi-arid ecosystems [Cleverly et al. 2016 AgForMet, Ma et al. 2015]

Reduction of global productivity due to the millennium drought in Southern Hemisphere/Australia [Zhao and Running 2010]

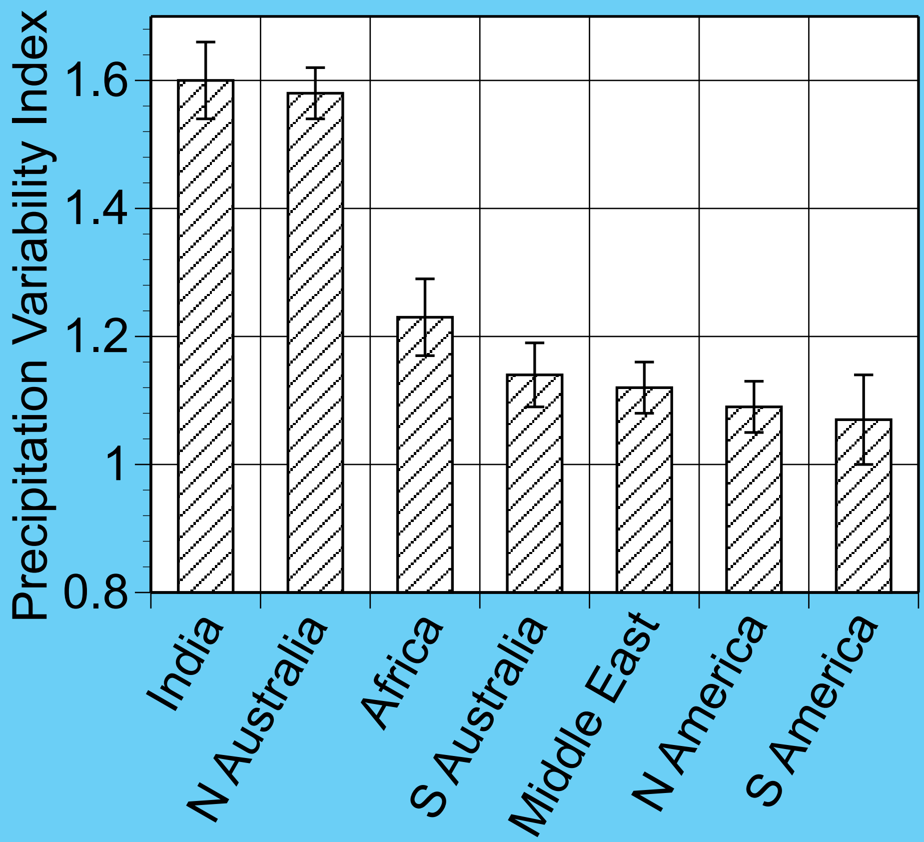


[Ma et al. 2015]

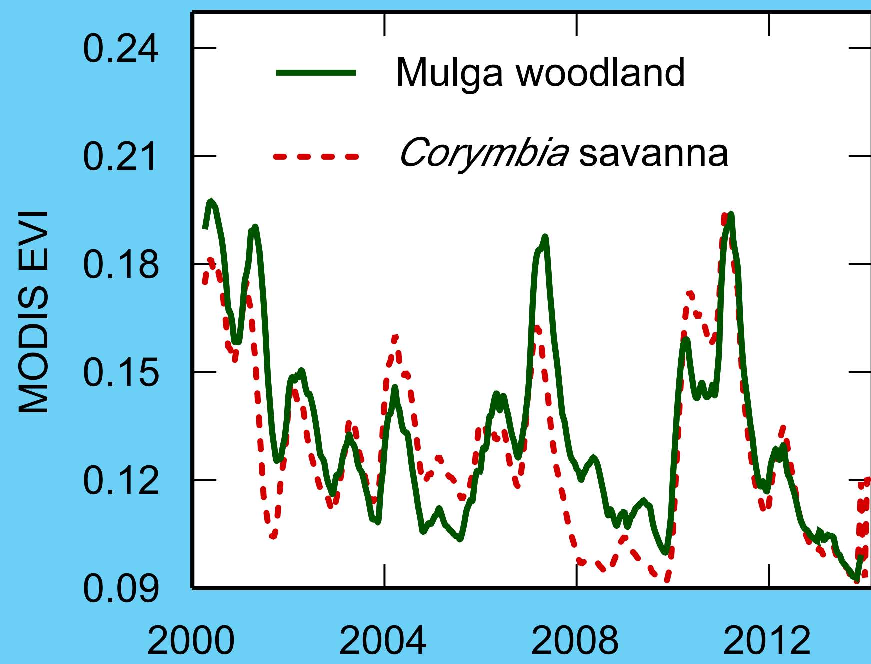
[Rammig & Mahecha 2015]

Extraordinary variation between wet and dry

Semi-arid regions of the Indian Ocean rim



[Van Etten 2009]



[Cleverly et al. 2016 AgForMet]

Semi-arid environments prone to variations between a large carbon sinks during wet periods and a large carbon source during dry [Wohlfahrt et al. 2008, Hastings et al. 2005]

Extraordinary variability in rainfall around the Indian Ocean rim is associated with large fluctuations in productivity of the dominant vegetation in semi-arid regions

How is climate responsible for these patterns?

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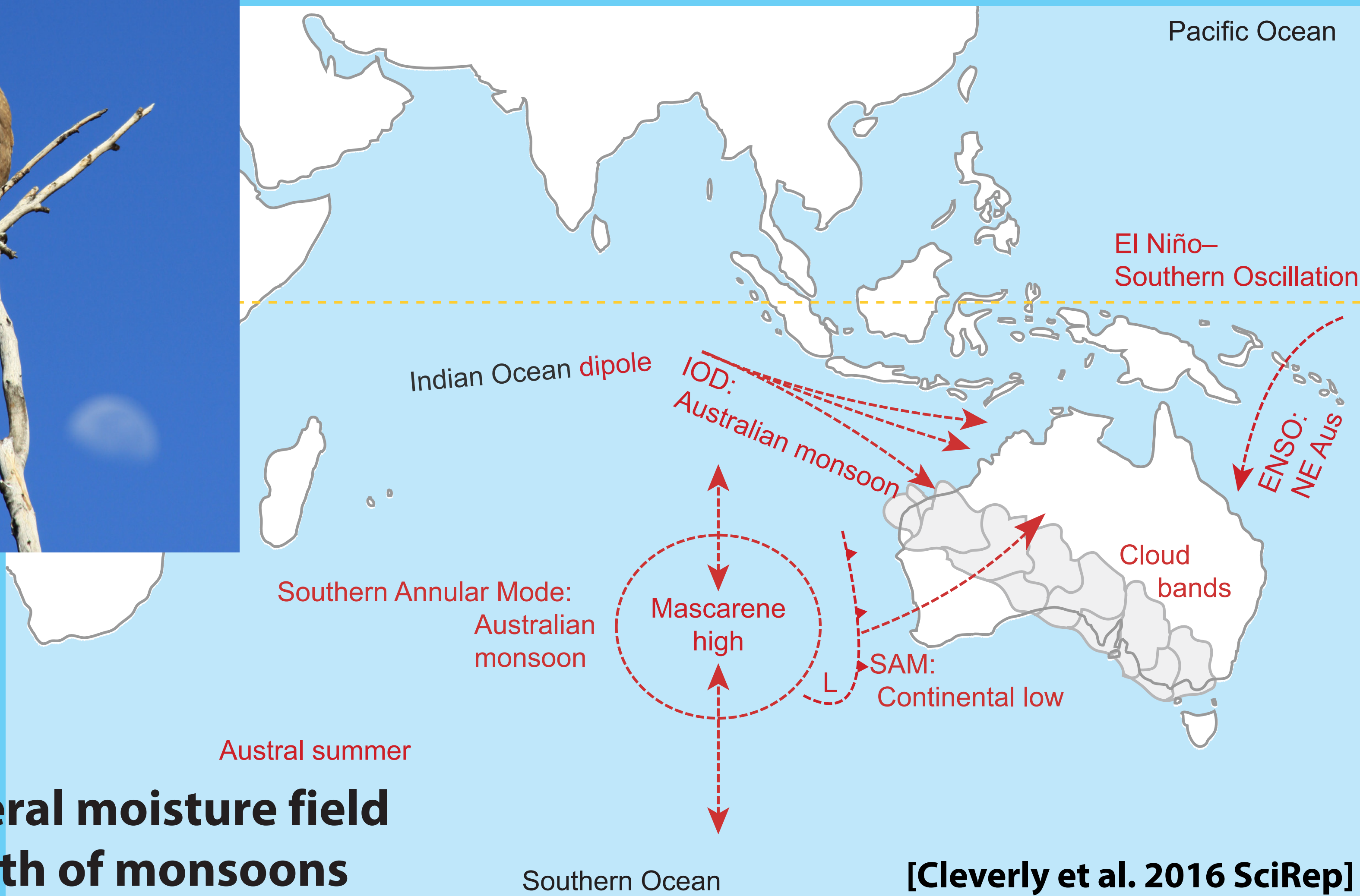
Climate interactions bring extreme weather
1999–2013



ENSO: general moisture field

IOD: strength of monsoons

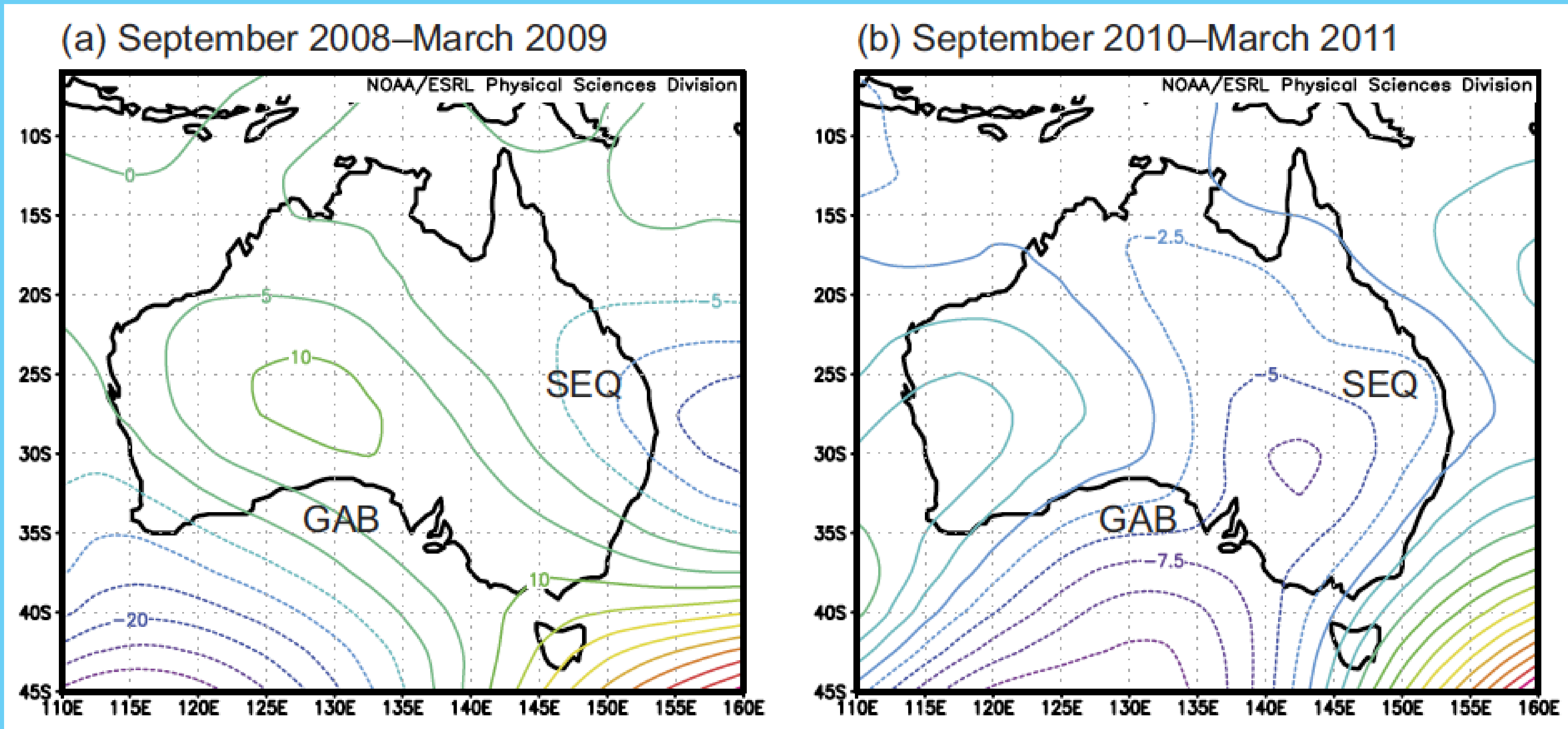
SAM: location of monsoon landfall; interaction with continental low [Kong and Zhao 2010]

Individually related to rainfall occurrence, not amount [Pui et al. 2012]

Three climate modes periodically combine to create weather extremes (1999–2013)
[Cleverly et al. 2016 SciRep]

Meteorological patterns during climate synchronisation

500 hPa geopotential height

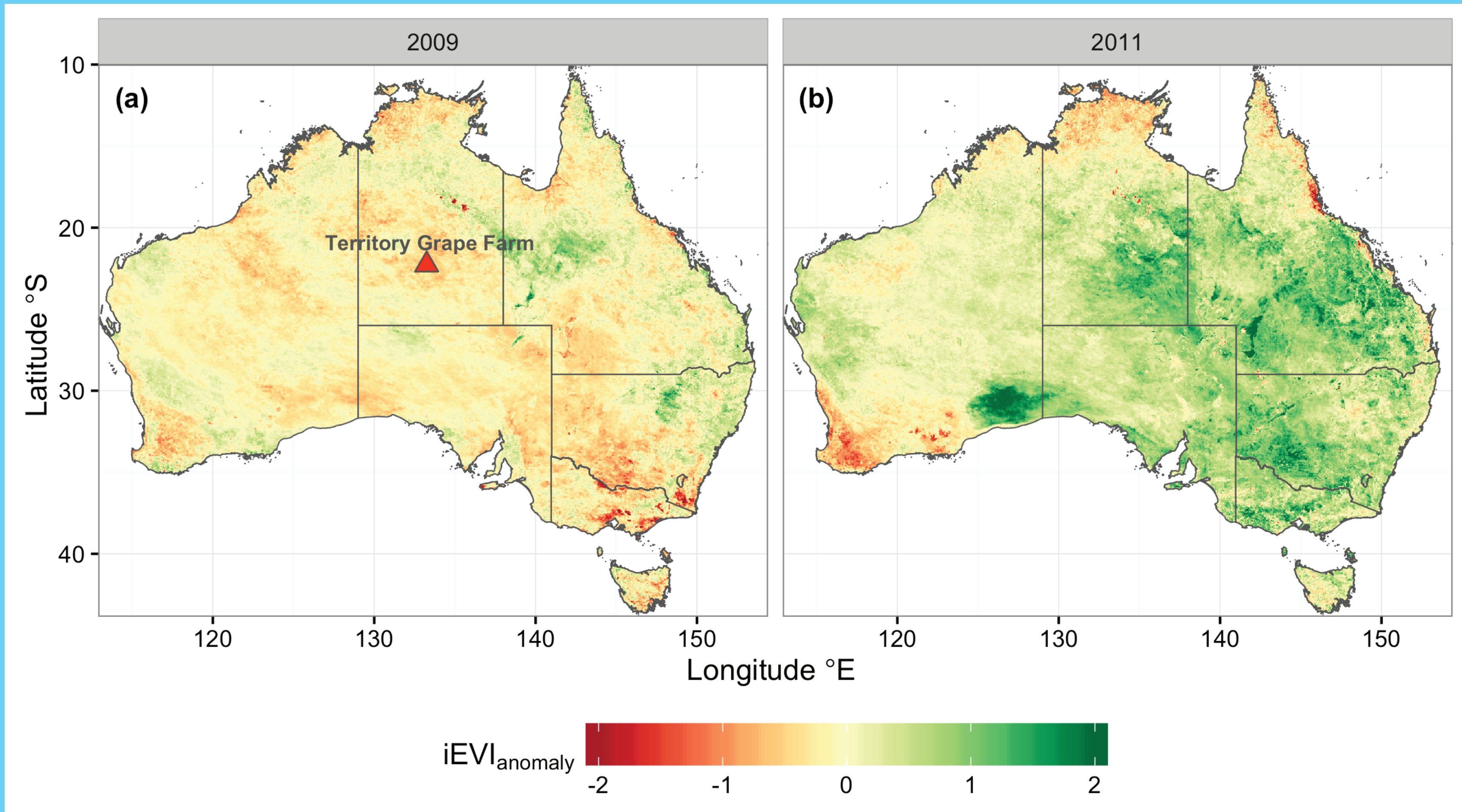


[Cleverly et al. 2016 SciRep]

Dry: weakened monsoon depression (IOD) deflected northward (SAM), El Niño

Wet: strong monsoon depression (IOD) deflected onto the continent (SAM), La Niña

Ecosystem responses to climate extremes
Spatial coordination of climate, weather and productivity



[Cleverly et al. 2016 SciRep]

Widespread failure of photosynthetic production in drier-than-average year, except in a narrow path along geopotential contours toward south-east QLD

Widespread green leaf production during the 2011 land carbon sink anomaly with equivalent spatial patterns to climate (two slides previous) and weather (previous slide)

Research questions

Aim: to investigate fluctuations in the carbon budget of a semi-arid very open *Corymbia-Triodia* savanna in response to reductions in precipitation subsequent to the 2011 land C sink anomaly.

- **Did the productivity pulse persist following 2011?**
- **How did the legacy of the grass biomass produced in the land C anomaly affect the carbon budget?**

Hypotheses

Two hypotheses:

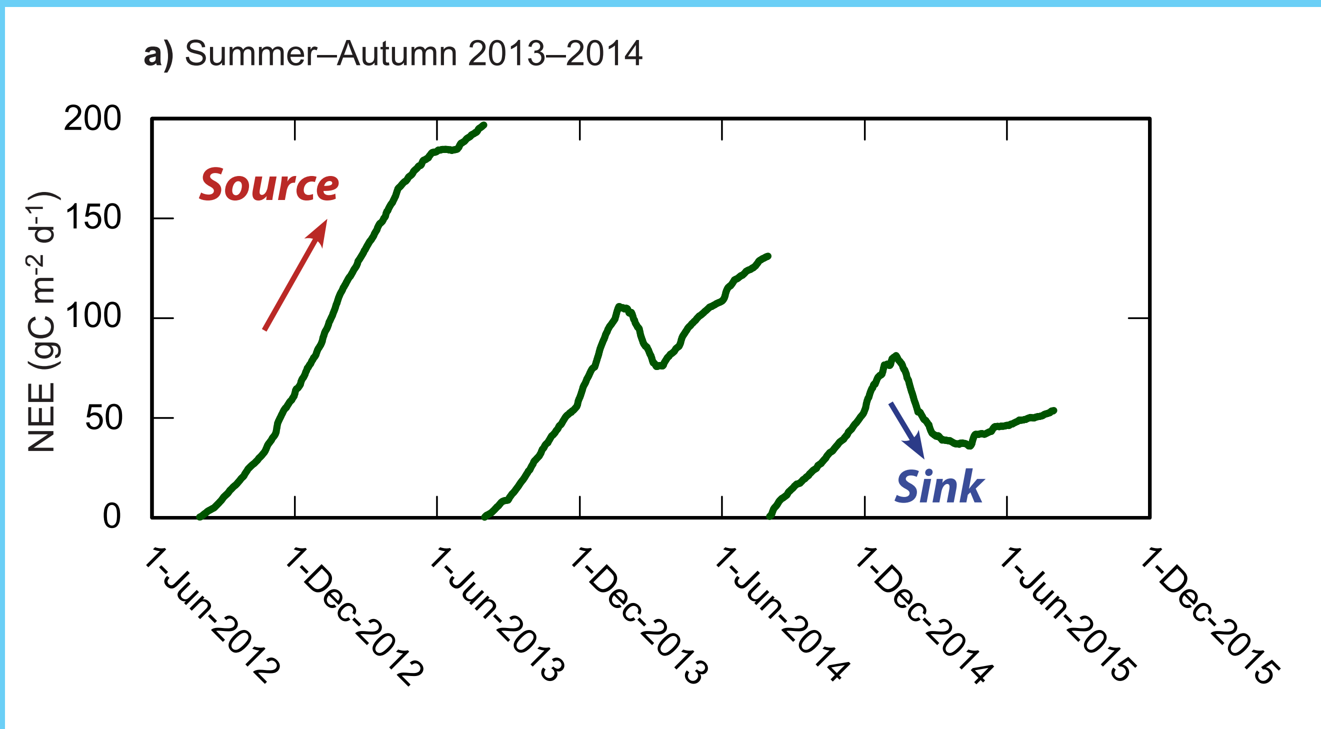
- **Abiotic decomposition was expected to be a major component of the carbon budget, declining with time since the land C sink anomaly; and**
- **Responses of ecosystem productivity to light will follow a predominately C_4 pattern due to the dominant cover of Spinifex (> 90%)**

Net ecosystem exchange
CO_2 efflux

Corymbia **savanna: strong carbon source 2012–2013: 200 gC m^{-2} y^{-1}**

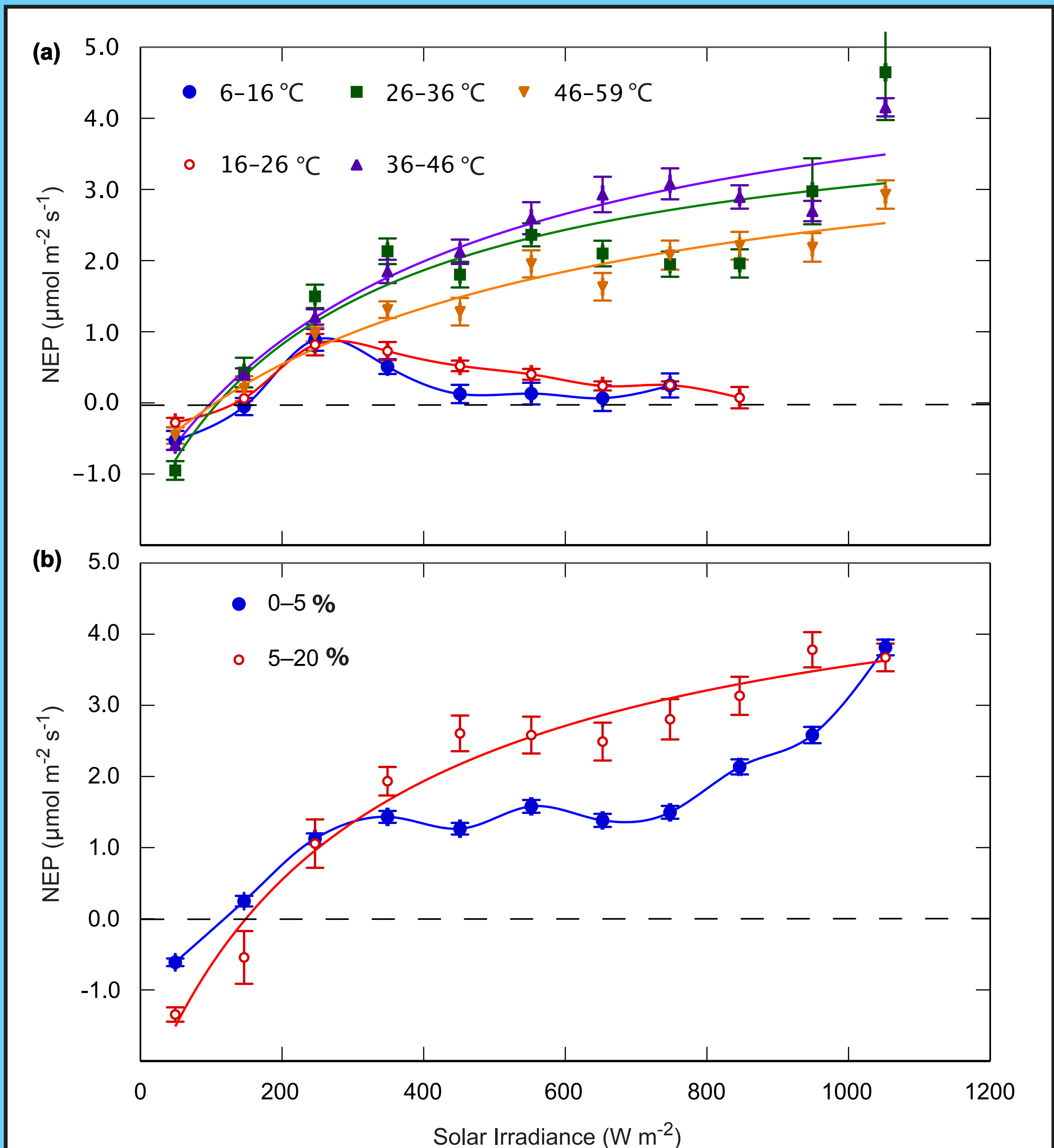
Declining NEE with time

Legacy of land C anomaly



Light-response functions (Corymbia *savanna)*

Carbon sink



Sink: minority of cases (small sample size)

Smaller maximal rates than in the Mulga woodland during land C sink anomaly [cf. Cleverly et al. 2013]

Curves show consistent deviations from standard leaf photosynthetic curves, implying that CO_2 efflux might respond to light

Deviations from standard curves more prevalent at low temperature (6–26 °C) and low soil moisture content (< 5%)

Daily patterns

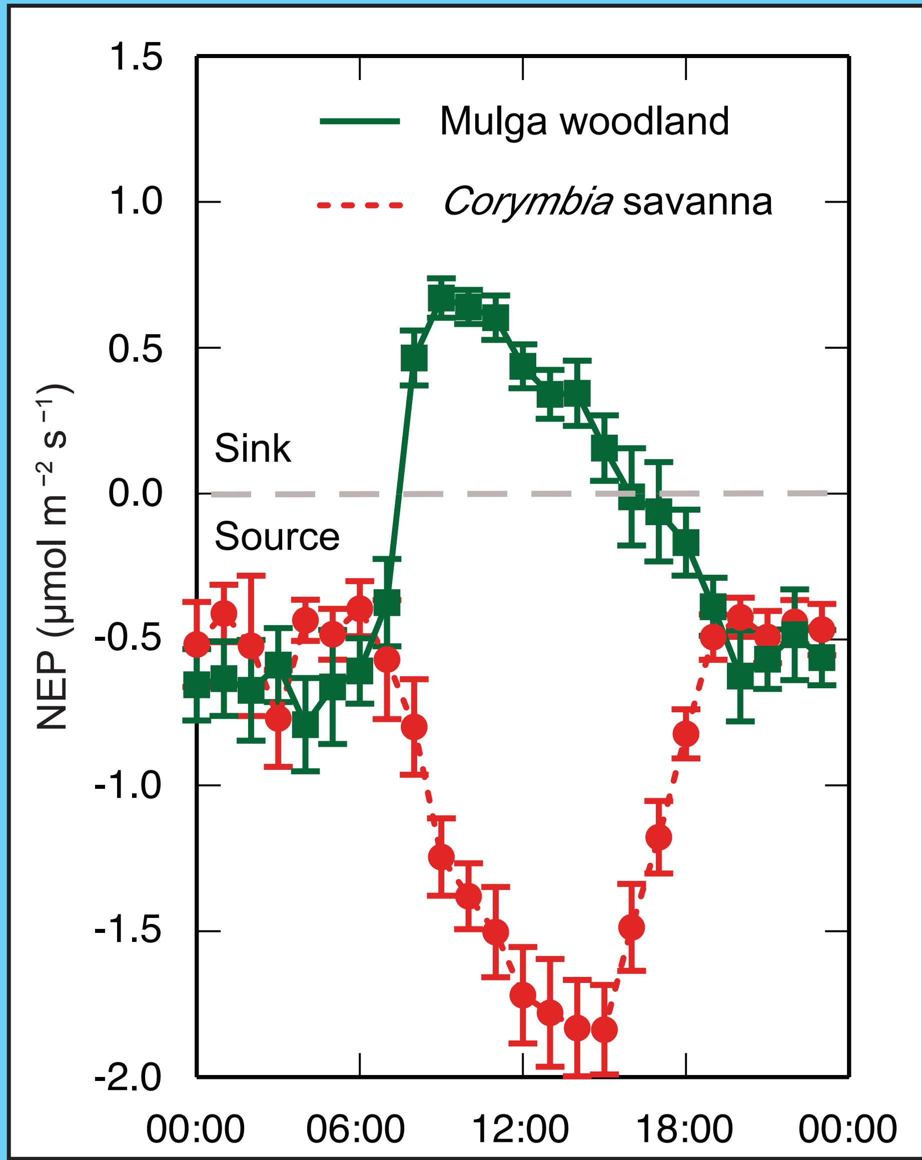
January 2013, both sites net carbon source

Mulga woodland most productive in the morning hours, when temperature and vapour pressure deficit are low

Both ecosystem have the same rate of nocturnal respiration

CO_2 efflux increases in the *Corymbia* savanna as a function of light intensity

Photo-degradation: abiotic decomposition of leaf litter that is enhanced by sunlight



[Cleverly et al. 2016 AgForMet]

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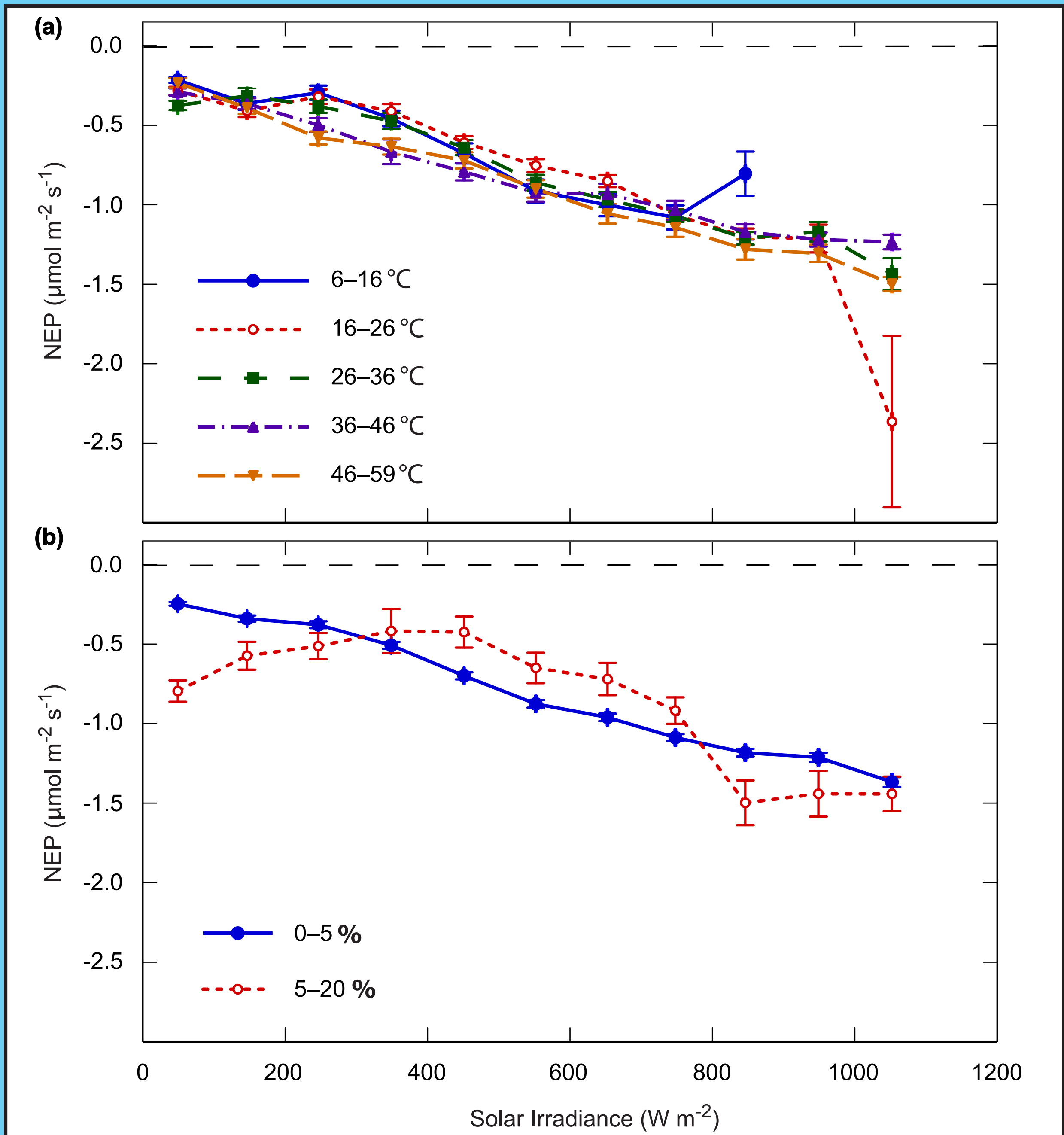
Carbon source



Source: majority of cases (large sample size)

Very little resemblance to photo-synthetic light-response functions

Linear enhancement of CO_2 efflux by light, no distinction by temperature — Photo-degradation

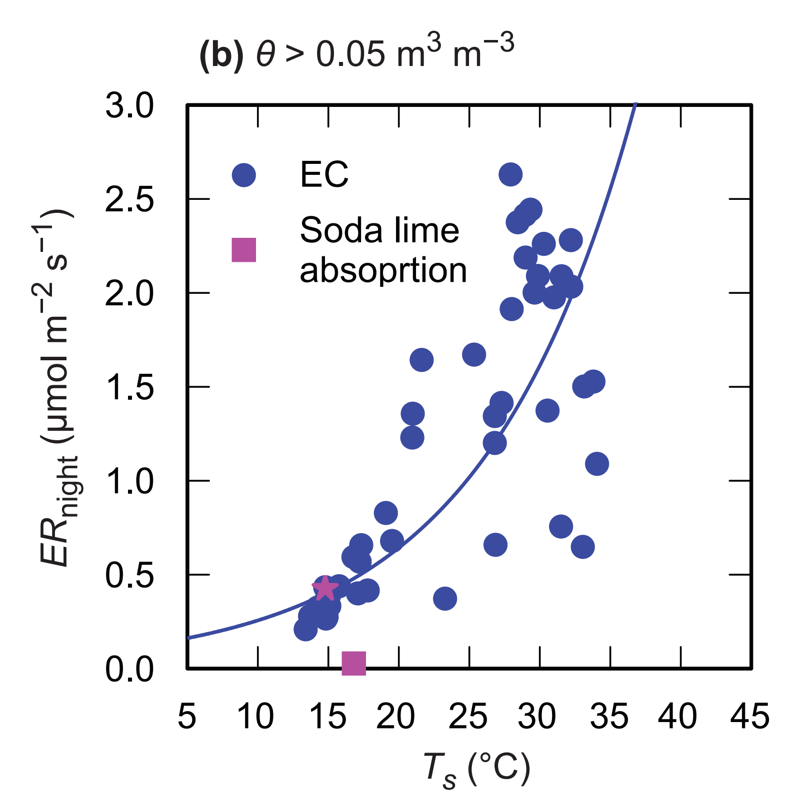
Carbon budgets in the presence of photo-degradation

When ER < NEE, GPP = NEE – ER < 0

Spurious GPP losses to the atmosphere from nocturnal thermal-response functions (ER_{night}) or light-response functions (ER_{dark})

Short-circuit of soil carbon cycle (CO_2 lost directly to the atmosphere, bypassing the soil): very low soil organic matter/soil organic carbon [Austin and Vivanco 2006]

Static respiration chambers (soda lime) [Monteith et al. 1964, Janssens et al. 2000, Keith et al. 2006]



Can we partition photo-degradation from NEE?

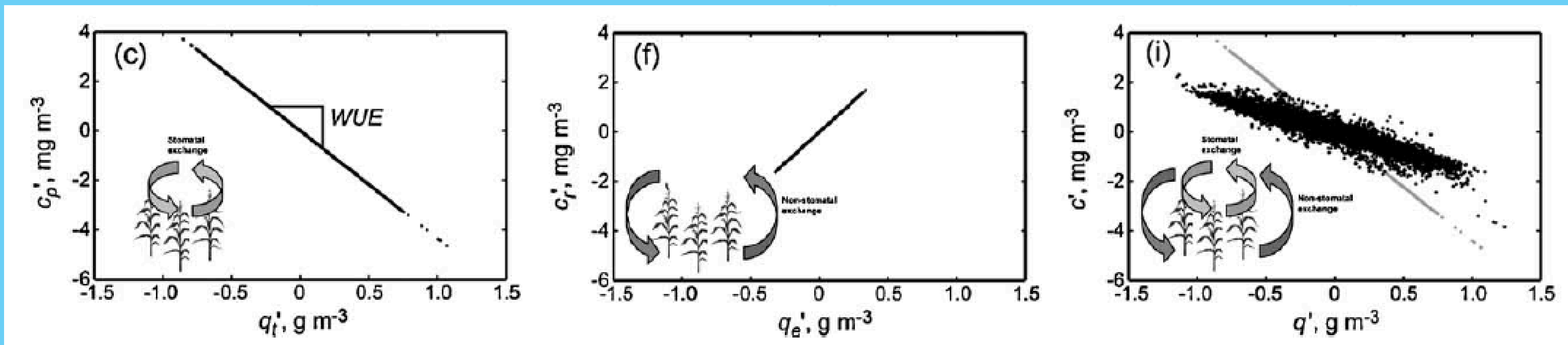
I certainly hope so, but it appears to be tricky (avoid getting stung?)

Correlation analysis: **[Scanlon and Sahu 2008, Scanlon and Kustas 2010, Palatella et al. 2014]**

Stomatal exchange: Photosynthesis and transpiration

Non-stomatal exchange: CO_2 efflux and evaporation

Partition NEE and ET simultaneously from eddy covariance data



$$WUE = \frac{\overline{w'c'}}{\overline{w'q'}} \cdot \frac{\dfrac{-2WUE^{-2}\sigma^2_{c_P'} \pm \sqrt{4WUE^{-4}\sigma^4_{c_P'} - 4WUE^{-2}\rho^{-2}_{c_P',c_R'}\sigma^2_{c_P'}\left(\sigma^2_{c_P'}WUE^{-2} - \sigma^2_q\right)}}{2WUE^{-2}\rho^{-2}_{c_P',c_R'}\sigma^2_{c_P'}} + 1}{\dfrac{-2\sigma^2_{c_P'} \pm \sqrt{4\sigma^4_{c_P'} - 4\sigma^2_{c_P'}\rho^{-2}_{c_P',c_R'}\left(\sigma^2_{c_P'} - \sigma^2_c\right)}}{2\sigma^2_{c_P'}\rho^{-2}_{c_P',c_R'}} + 1}$$

$$\text{where } WUE = \frac{\overline{w'c_P'}}{\overline{w'q_T'}}$$

$$\rightarrow \sigma^2_{c_P'} = f\left(\rho_{c_P',c_R'}\right)$$

Conclusions

H1: Carbon source legacy of the 2011 C sink anomaly:

Tentatively verified, the carbon source legacy in the *Corymbia* savanna was dominated by photo-degradation, although effective partitioning of NEE is required to quantitatively confirm or reject H1.

H2: Patterns of ecosystem photosynthetic light-response functions (C_3 and C_4):

Mostly verified, but with a critical exception due to photo-degradation. The presence of photo-degradation as a strong source of CO_2 efflux dominated the light-response functions as a result of the carbon source legacy in H1.

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Co-authors: OzFlux Special Issue, to be re-submitted upon solution of conditional correlation


Thank you
Questions?
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