If you wait long enough ………………………

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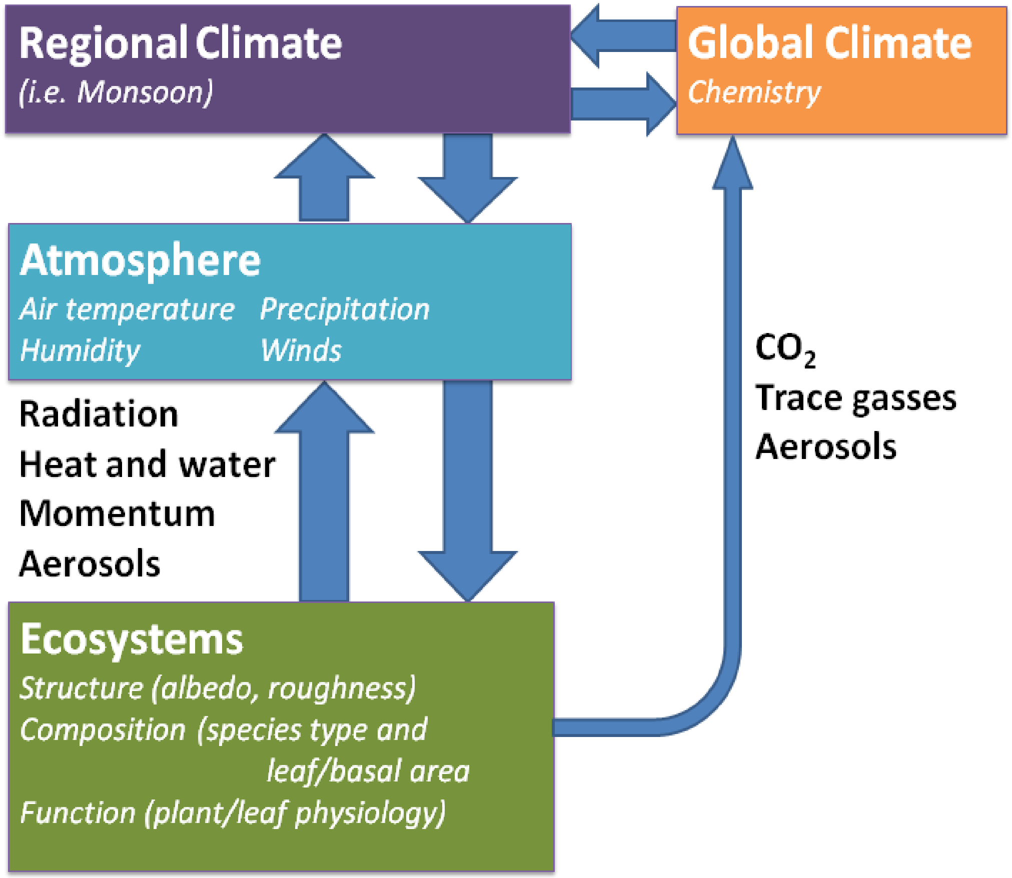
Innovation in Education

Outline

- Savanna land surface interactions
- Savannas and global change (Recap)
- Long term savanna dynamics
  - Long term changes in GPP
  - Drivers at multiple time scales
  - Attribution
  - Grass:tree dynamics
  - Woody thickening
  - Fluvial losses
- Conclusions

Importance of ecosystems in the earth system

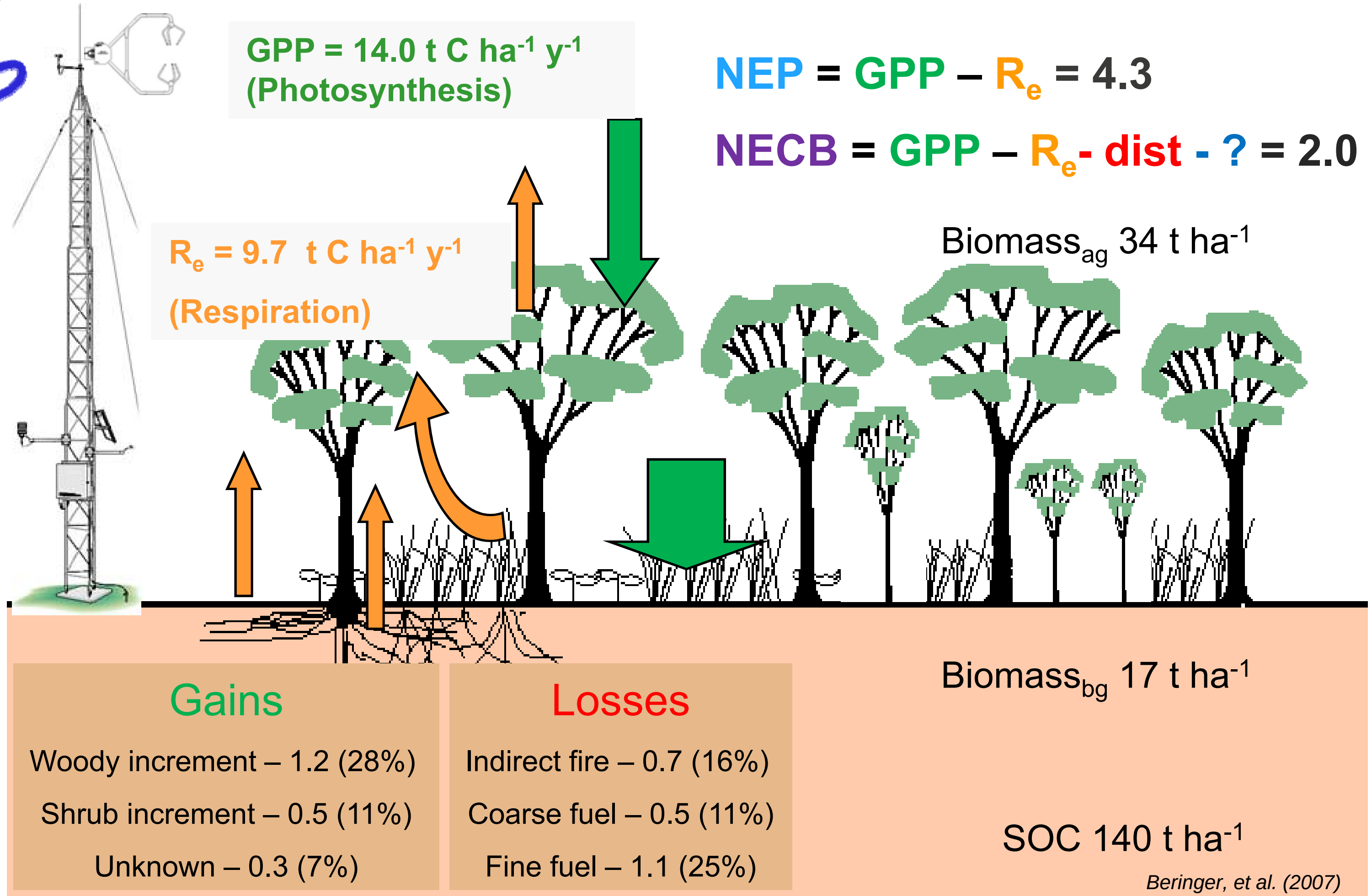
- Local ecosystem surface water and heat balance influences regional climate through **biophysics** (heat, moisture, energy).
- Regional to global coupling.
- Coupled to global climate through **biogeochemical** cycles (C, N, P, etc.).
- Changes in climate inherently influence global circulation.
- Savanna characteristics (structure, composition and function) important and affected by LULC, disturbance and long term ecology.



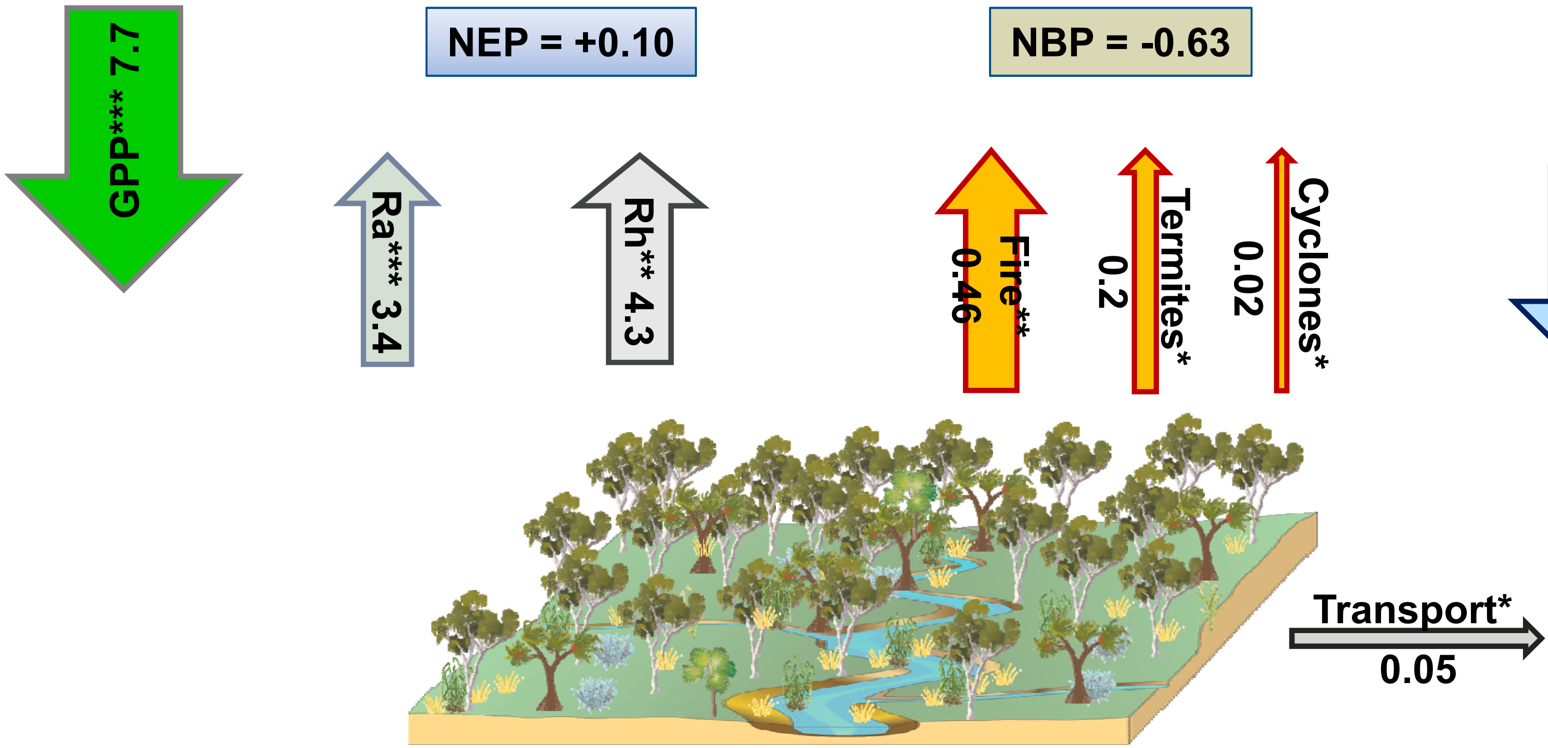
Adapted from Chapin, Beringer, et al. Science (2000)

Let's Recap

Savanna ecosystem carbon fluxes and pools



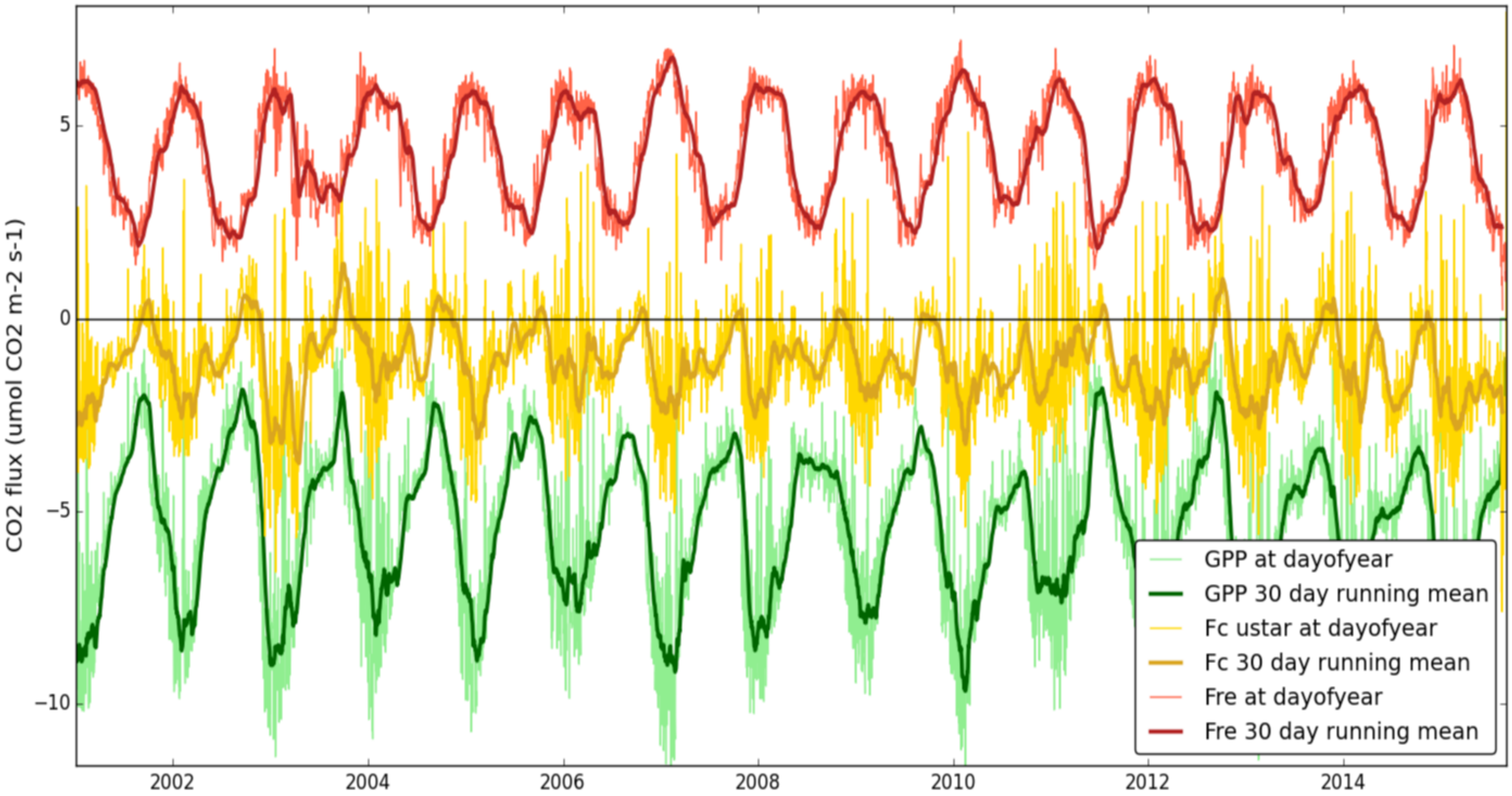
Australian Savanna Carbon and Water Balance



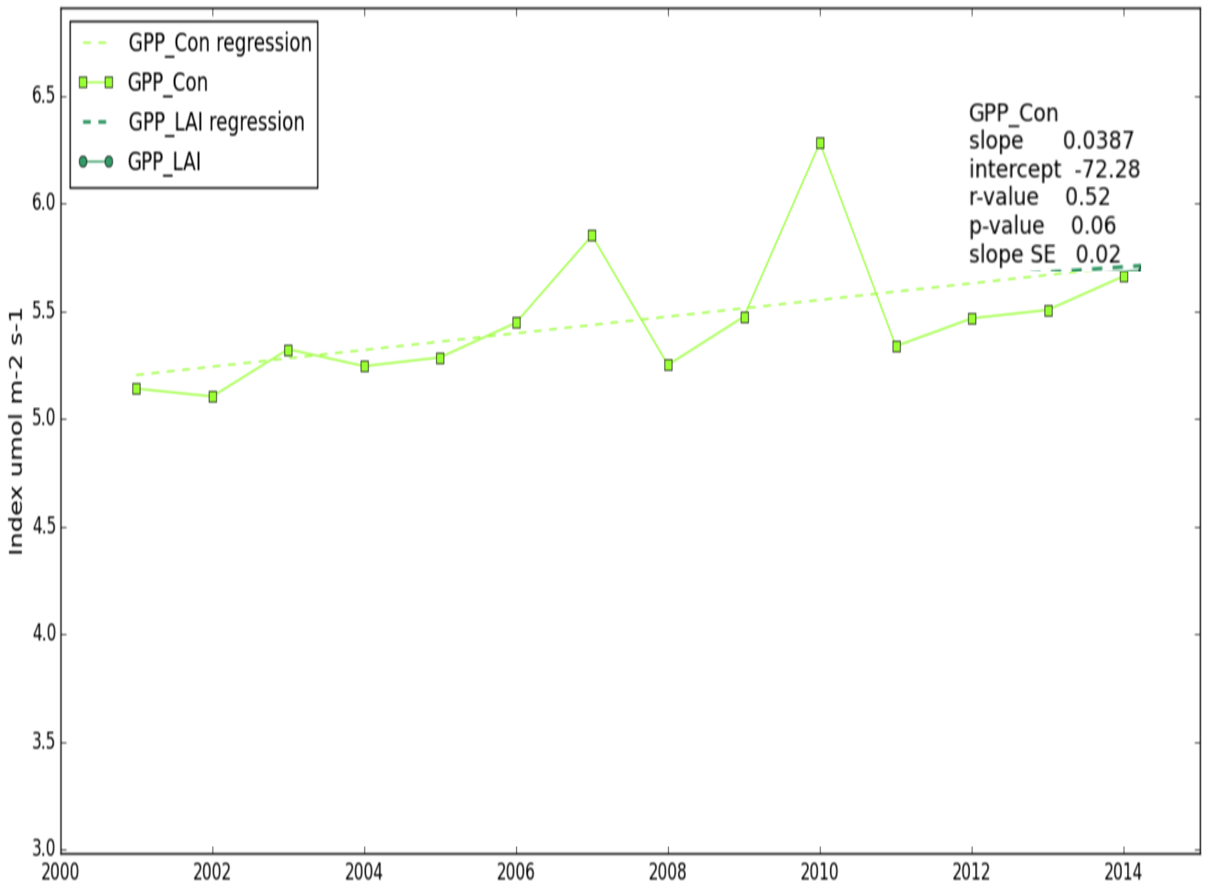
Haverd et al. (2013) Biogeosciences

Beringer et al. (2014) GCB

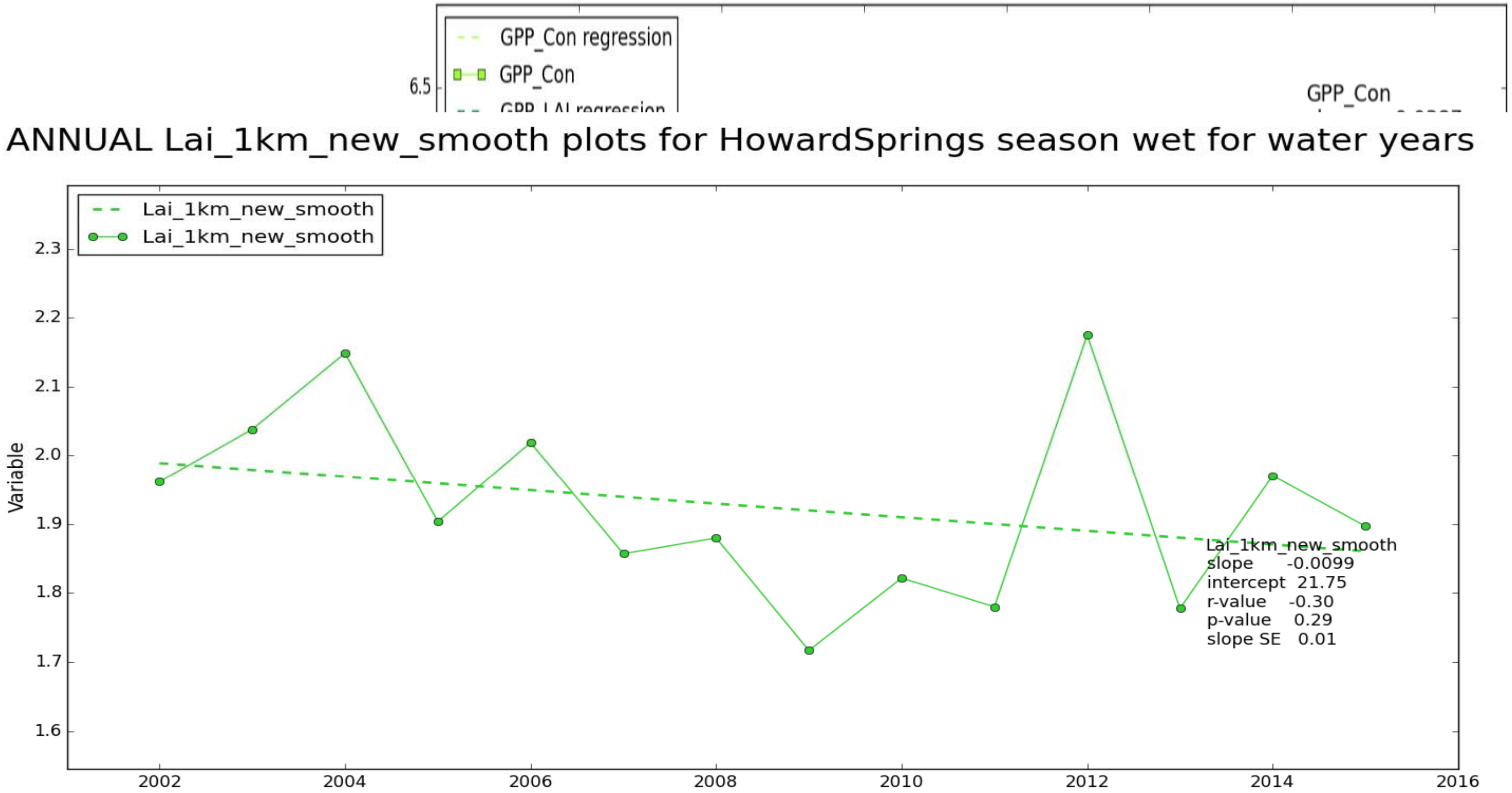
If you wait long enough…..



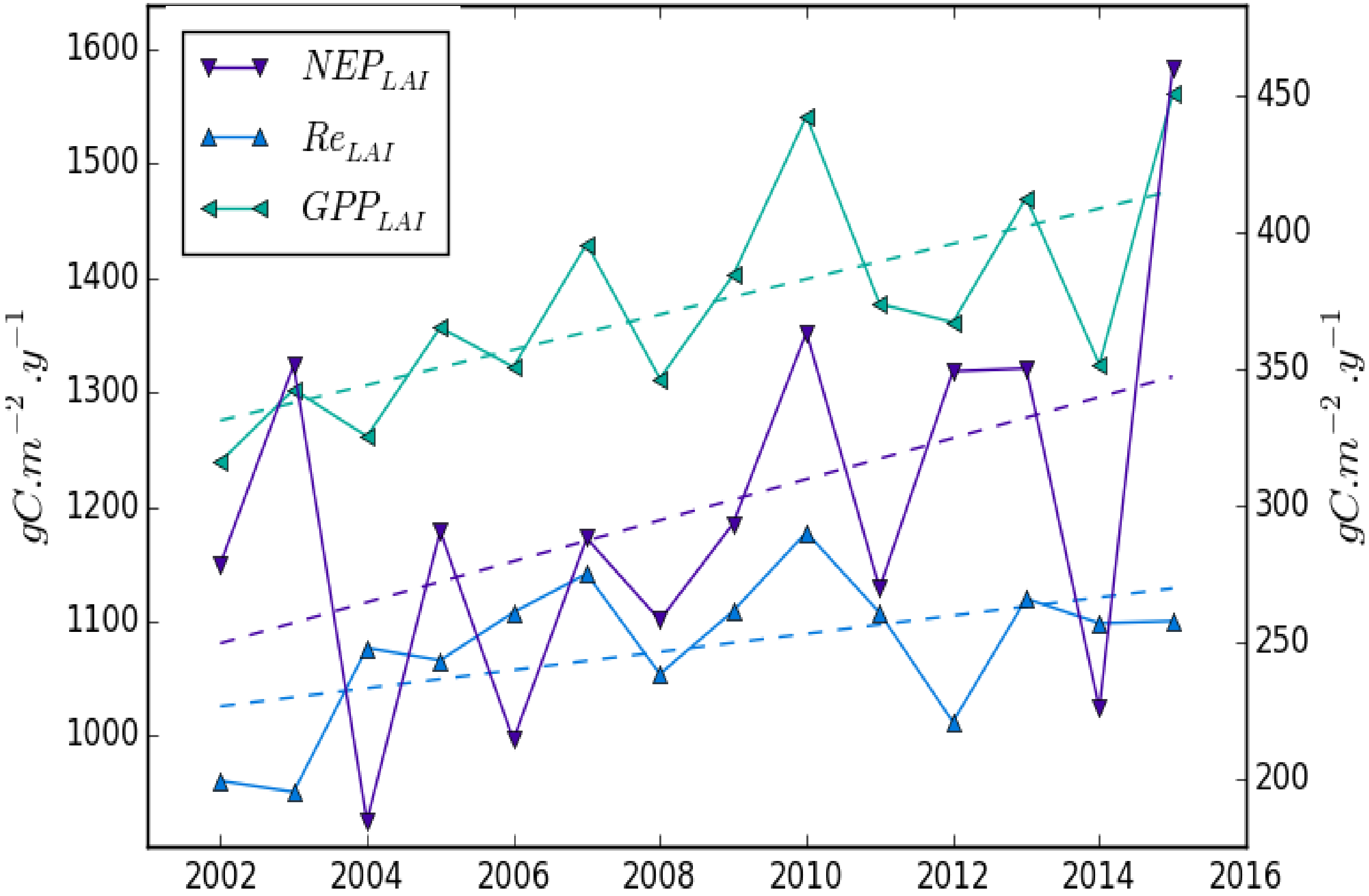
- Examine 15 'water' years.
- Significant ($p<0.10$) increase in GPP.
- What could be the driver?



- Is it LAI (trend vs variability)?



- Examine 15 'water' years
- Significant ($p<0.10$) increase in all carbon balance components when normalised by LAI.
- Rate of GPP greater than Re so NEP also increasing.
- What could be the driver?



Meteorological drivers

- Meteorological changes in moisture and CO_2 concentration.
- Growing seasons (days with soil moisture >0.1)

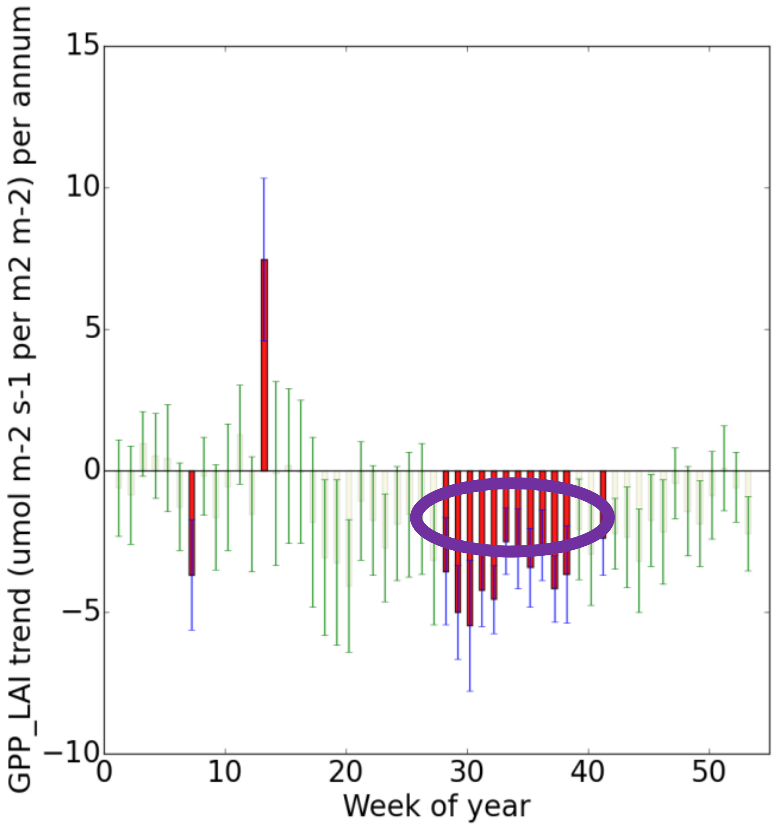
Period	F_{sd} ($MJ\ m^{-2}$)	T_{air} (^oC)	VPD (kPa)	LAI	Rainfall (mm)	SWC ($m^3\ m^{-3}$)	Growing season length (d)	$[CO_2]$ ($mg\ m^{-3}$)
All	NS	NS	NS	NS	NS	NS	6.82 (0.02)	2.66 (0.02)
Wet	NS	NS	NS	NS	28.5 (0.10)	NS	NA	
Dry	NS	NS	NS	NS	NS	NS	NA	

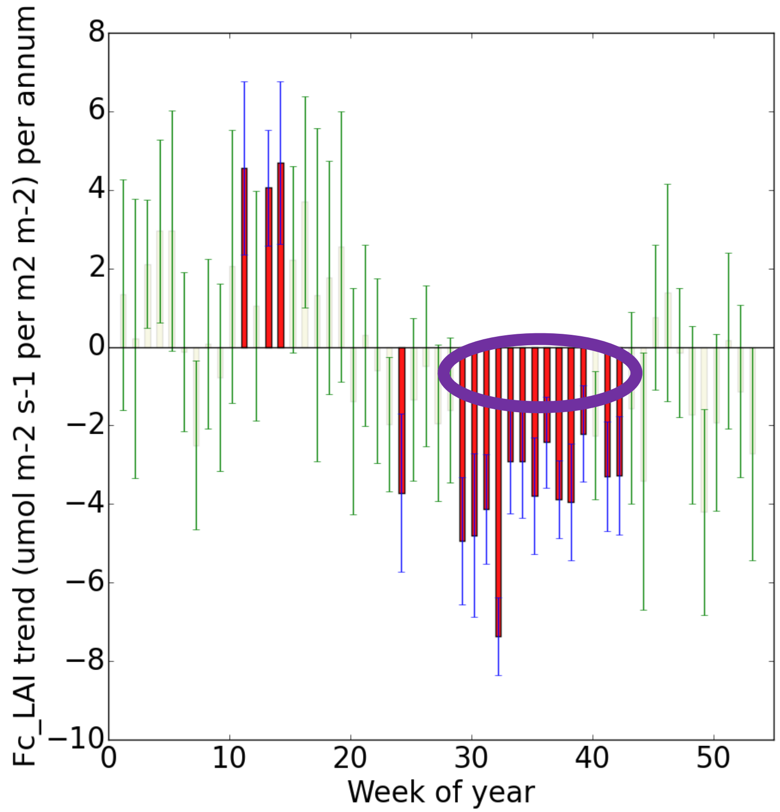
Biophysical variables

- All carbon flux components significant increasing trend.
- Also increased Fe due to greater moisture availability.
- Increase in RUE (GPP/Fsd) due to increased trend in GPP.
- IWUE NS suggesting that stomatal control not significant.
- But when? Mainly in the dry.

Period	GPP	GPP_{LAI}	F_e	F_{eLAI}	F_c	F_{cLAI}	R_e	R_{eLAI}	IWUE	$IWUE_{LAI}$	RUE	RUE_{LAI}
All	13.9 (0.01)	14.8 (0.01)	NS	0.58 (0.04)	NS	8.9 (0.08)	NS	8.4 (0.04)	NS	NS	NS	0.0034 (0.02)
Wet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Dry	23.0 (0.10)	23.5 (0.03)	NS	NS	23.5 (0.05)	23.8 (0.04)	NS	NS	NS	NS	NS	0.005 (0.10)

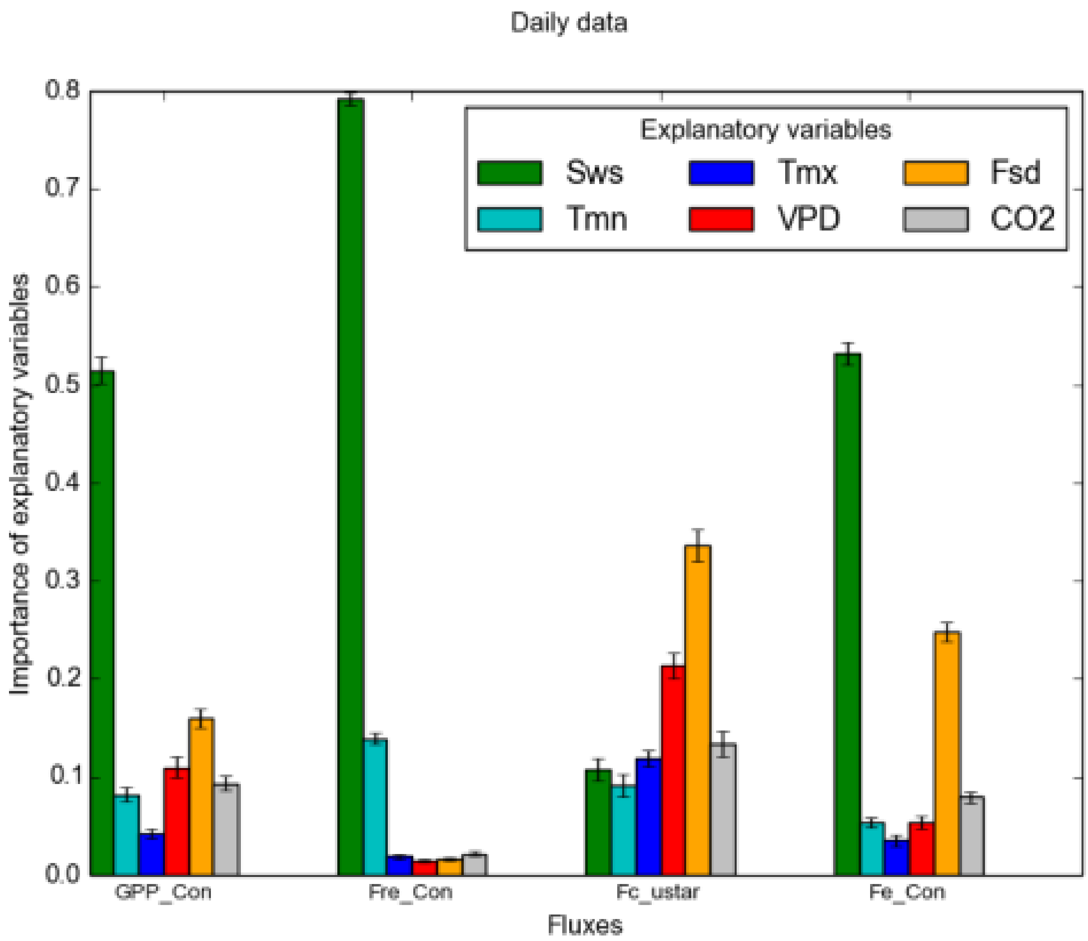
Seasonal attribution



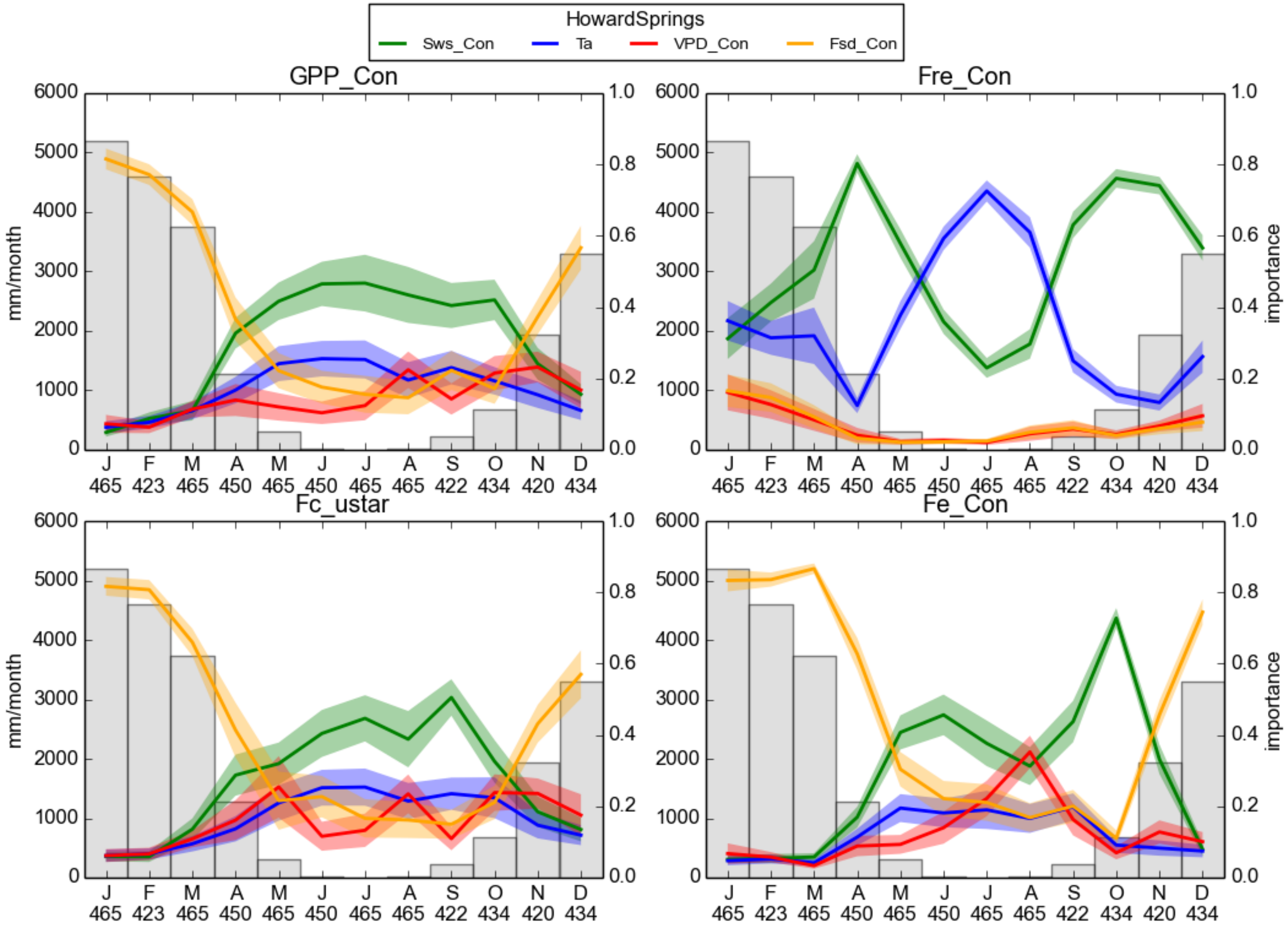


Driver importance

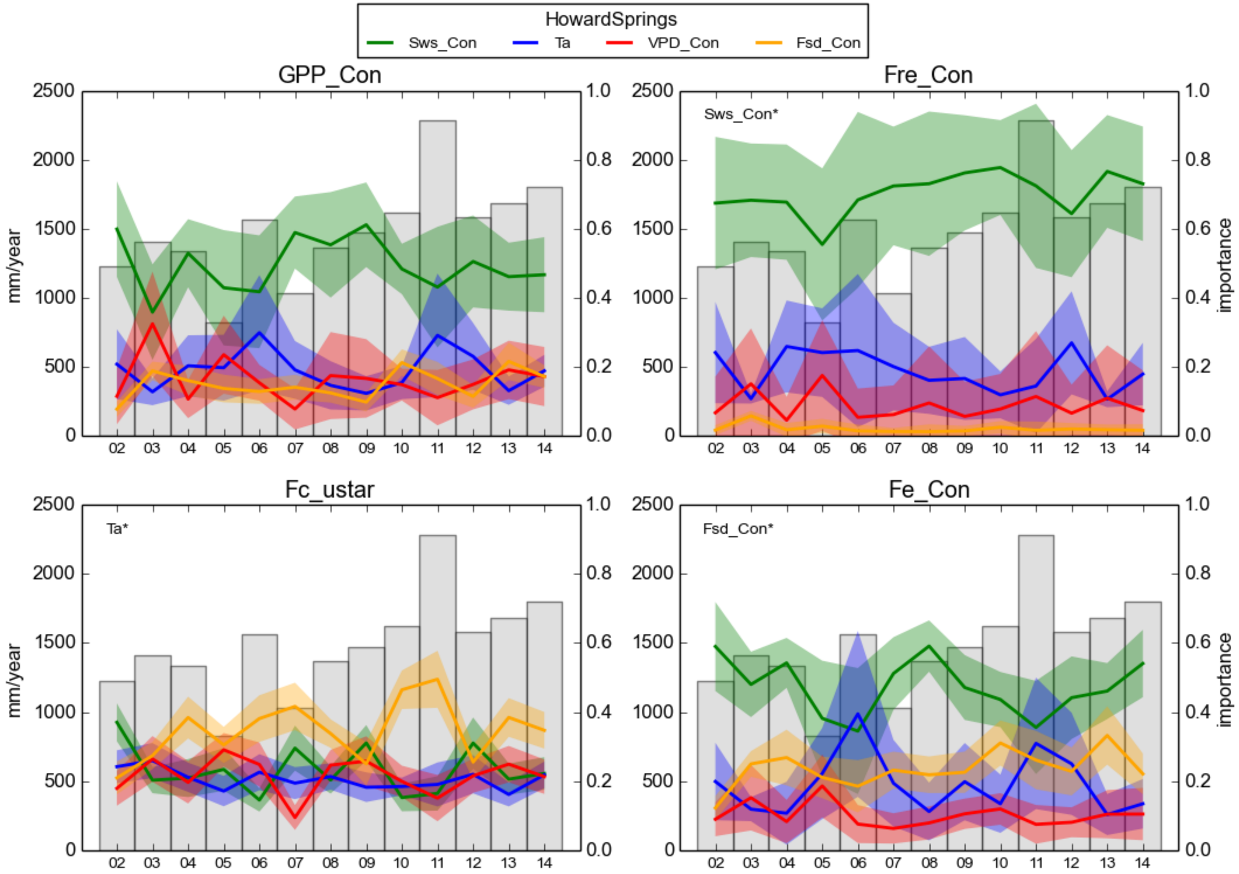
- Random Forest ensemble learning approach used for examining drivers.
- 15 years of flux data
- Typically performed given period at certain frequency (i.e. daily data and all year).
- Usual suspects….



- New application at monthly bins over year for seasonal.
- Changing dynamics of importance of drivers seasonally.
- For example, Fsd most important in driving GPP in wet but soil moisture in the dry.



- New application at annual bins for IAV and trends.
- Are there any changes in the importance of drivers of 15 years?
- Increasing trend of importance of soil moisture in driving Fre.
- Increasing trend of importance of Ta in driving Fc.
- Increasing trend of importance of Fsd in driving Fe.



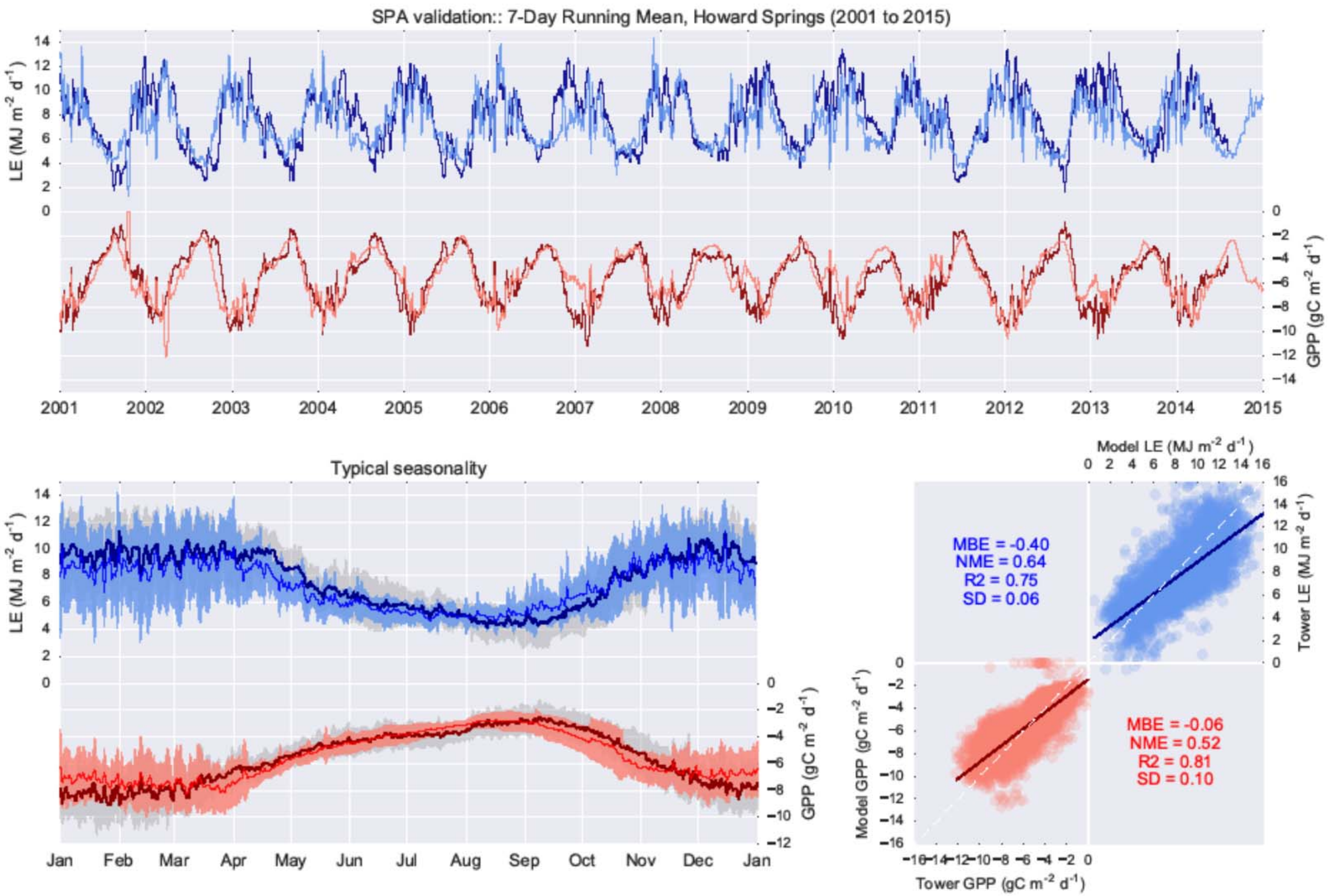
Model Attribution (Whitley)

- Trends and drivers somewhat unsatisfactory.
- Could not separate which drivers CAUSE the trend.
- Use process based LSM (SPA) tuned to HWS for attribution.
- Model experiments using (1) the locally measured meteorology and (2) a de-trended and repeated climatology.

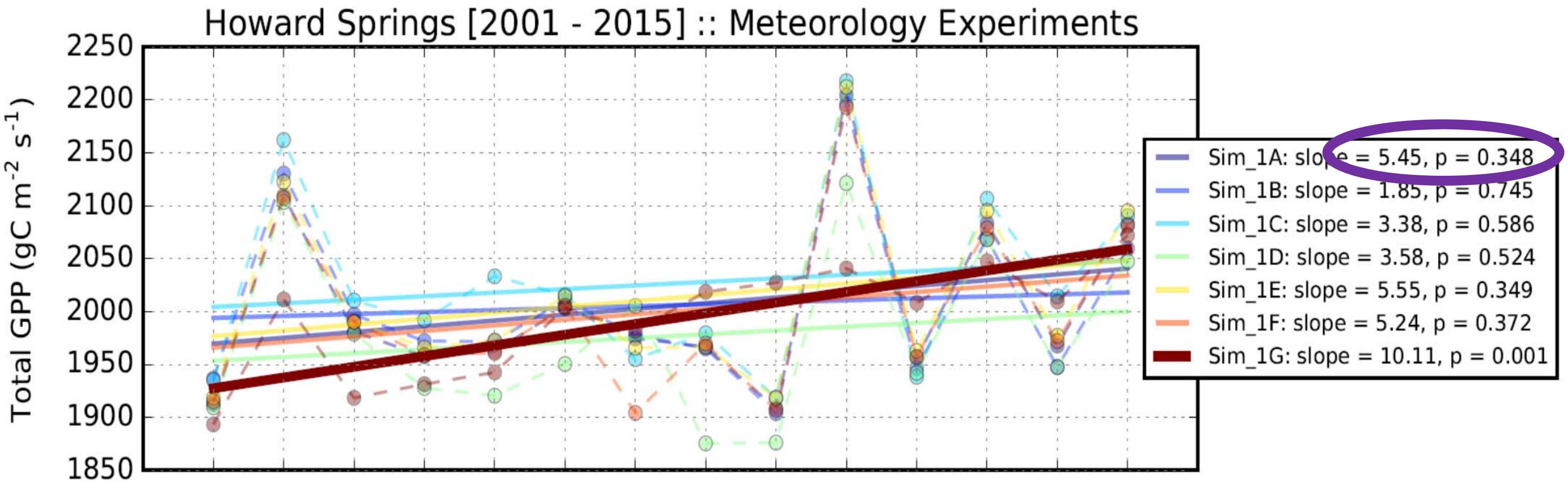
Model Experiment Series 2 // Constrained Inputs

Simulation Label	$[CO_2]$	T_a	PPT	R_s	VPD	LAI
A	clim	clim	clim	clim	clim	clim
B	**met**	clim	clim	clim	clim	clim
C	clim	**met**	clim	clim	clim	clim
D	clim	clim	**met**	clim	clim	clim
E	clim	clim	clim	**met**	clim	clim
F	clim	clim	clim	clim	**met**	clim
G	clim	clim	clim	clim	clim	**met**

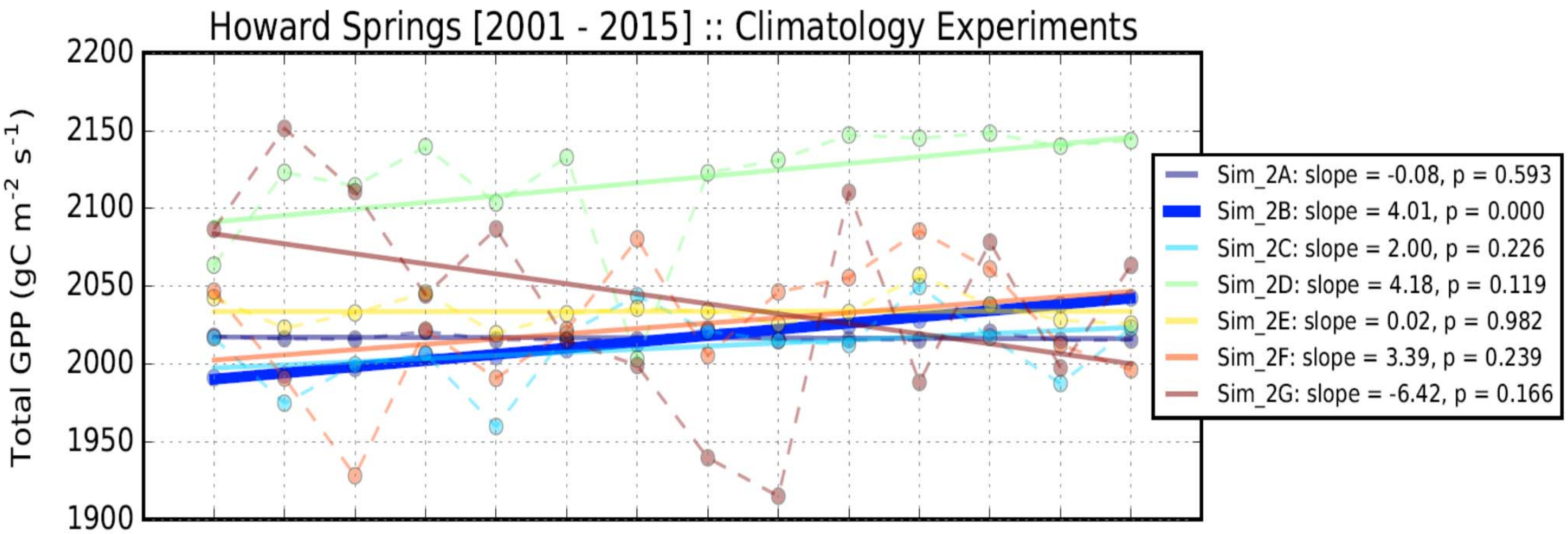
- Excellent model performance



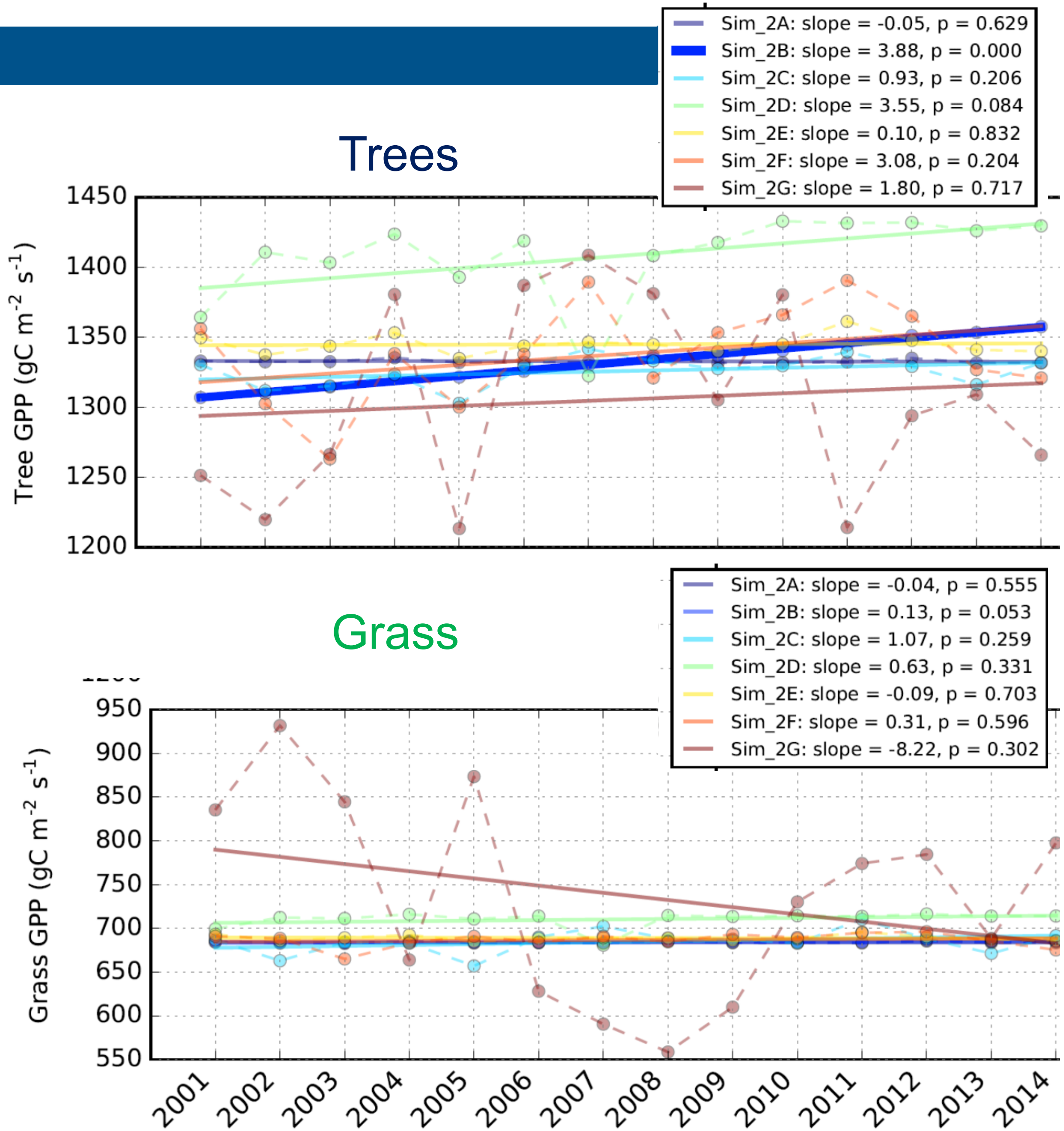
- Simulation with all drivers varying (baseline) you may expect to show same trend of GPP as observations. Yes but not significant. Actually slope here 5.45 gC m^{-2} yr^{-1} compares to observed of 13.9 gC m^{-2} yr^{-1}



- Simulation allowing one variable to change at a time shows only significant driver is [CO_2].
- Slope here 4.01 gC m^{-2} yr^{-1} compares to model baseline of 5.45 gC m^{-2} yr^{-1} (74%) but likely interacting effects. Precip has positive correlation (almost nearly significant) with modelled GPP.

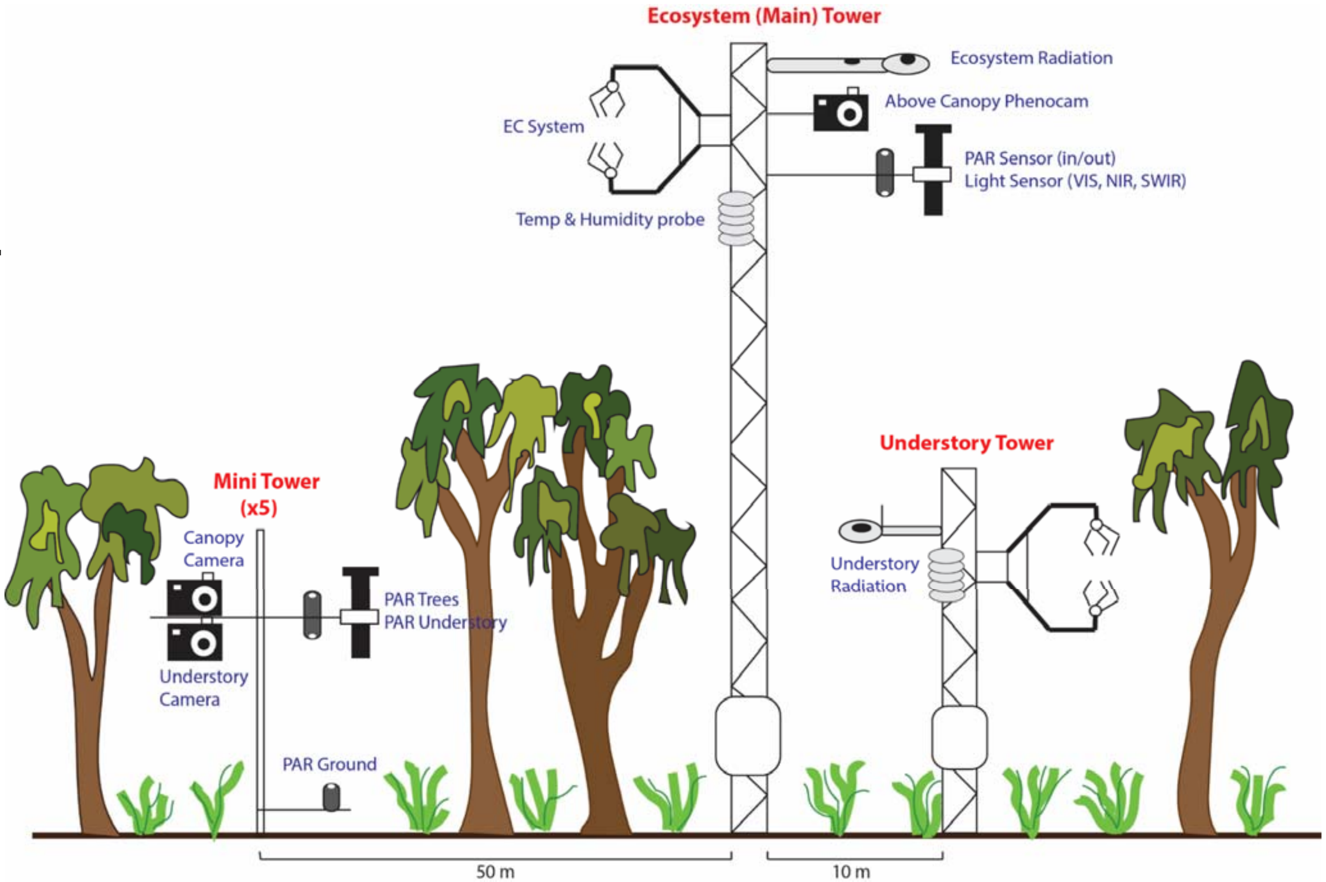


- SPA simulates trees and grass separately so can examine which one is responding.
- Grass almost nothing significant. CO_2 slight positive correlation ($p<0.10$)
- Trees have stronger relationship with [CO_2] and greater slope (3.8 c/w 0.13).
- Suggests that a good portion (~74%) of the observed trend in GPP attributed to CO_2 fertilisation by trees



Partitioning grasses and trees (Moore)

Understand tree and grass dynamics (short and long term) using understorey EC and phenocam information.



Moore, et al. (2016a)

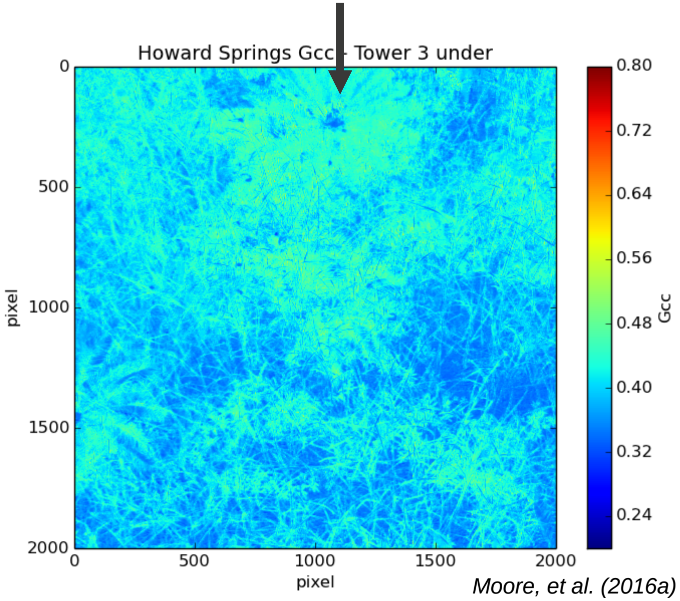
Mini Tower Instrumentation:

- 5 x upward facing cameras
- 5 x downward facing cameras
- 15 PAR sensors
- 10 4-chanel light sensors

Moore, et al. (2016a)

Image Analysis

- Every digital image contains RGB digital number (DN) information relating to pixel colour
- Choose a ROI to analyse for each image



Moore, et al. (2016a)

- Green Chromatic Coordinate

$$Gcc = G_{DN} /(G_{DN}+R_{DN}+B_{DN})$$

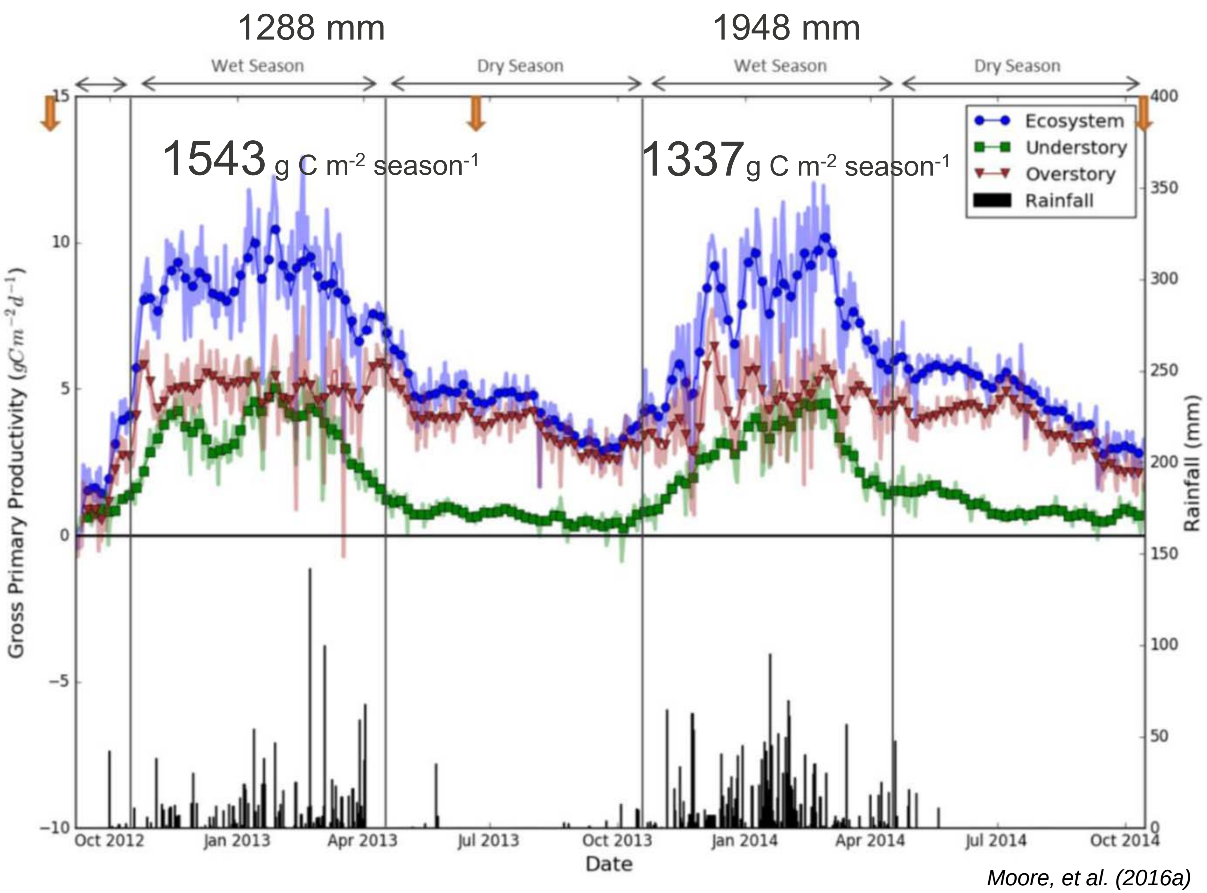
- Excess Green

$$ExG = 2G_{DN} – (R_{DN}+B_{DN})$$

- QA/QC images

Understorey contribution

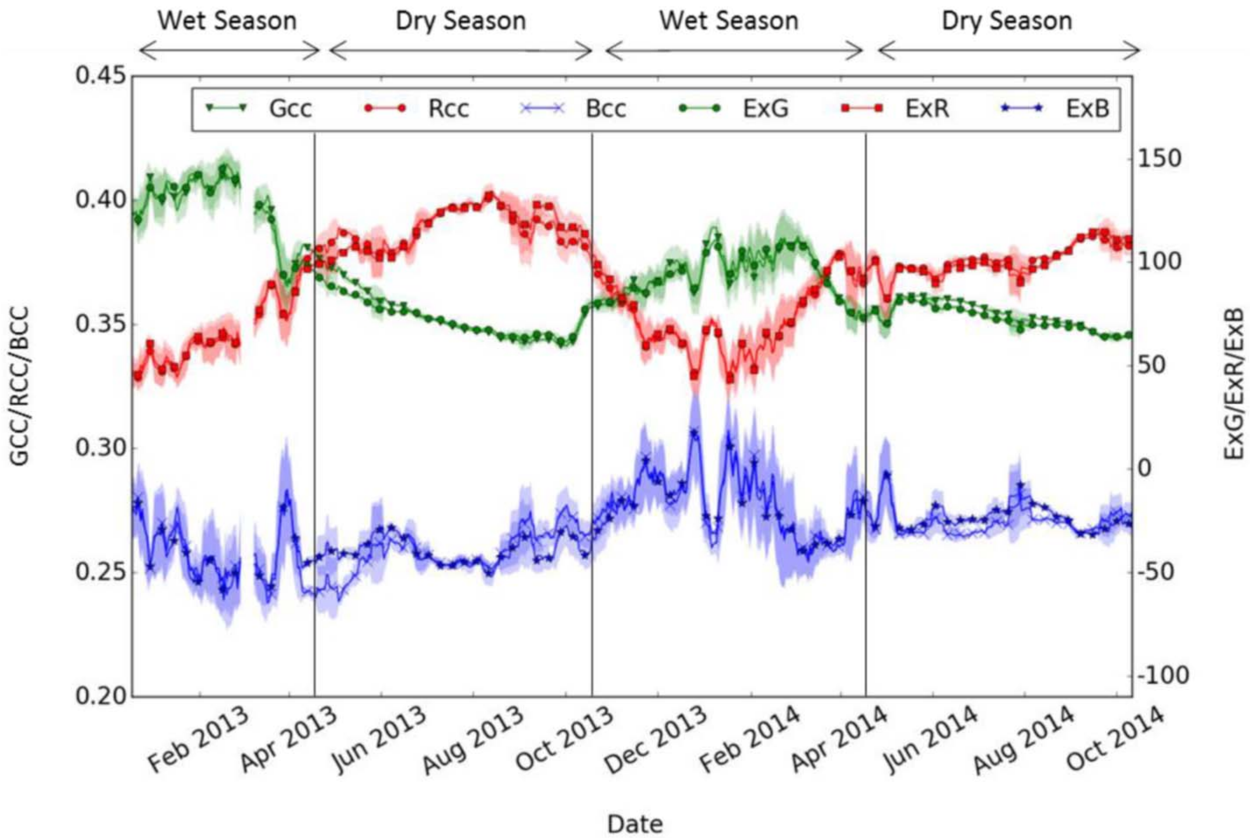
- The total gross primary productivity (GPP) was 2267 (± 80 SE) gC m^{-2} y^{-1} (understory 32 %).
- Understory strongly seasonal, most GPP in the wet season (40 % of total ecosystem in the wet season and 18 % in the dry).
- Two contrasting 'water' years. Drier year had higher productivity.
- But higher GPP during the dry season in the wet year.



Moore, et al. (2016a)

Phenocam indices

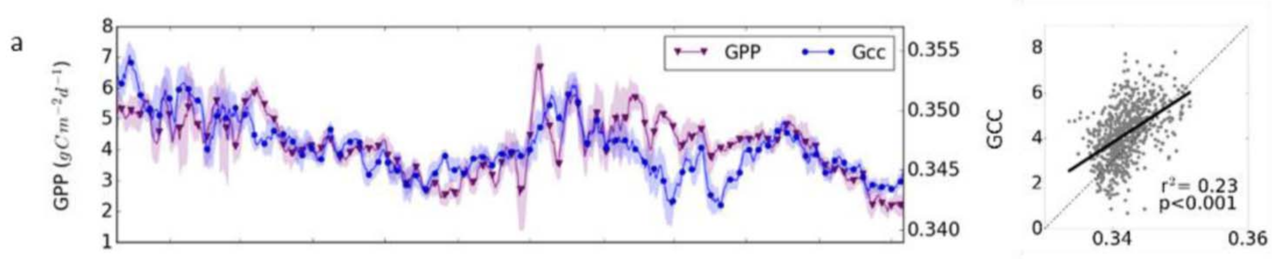
- Phenocam indices GCC and ExG captured the temporal dynamics of grass and trees phenology



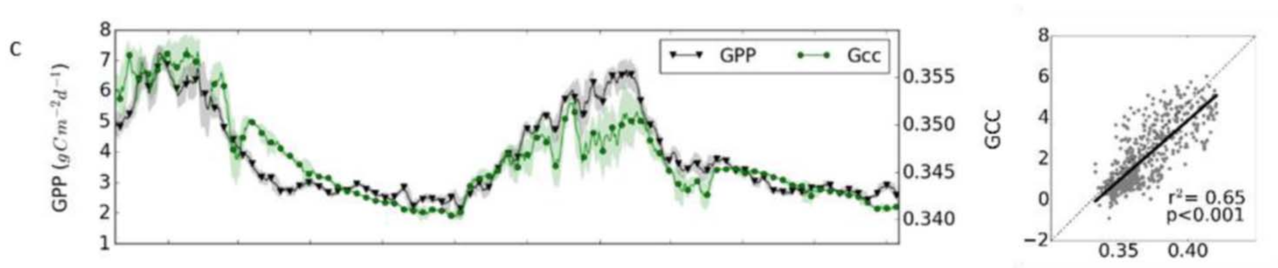
Moore, et al. (2016b)

- GCC and ExG were well correlated with tower GPP for understory (r^2 = 0.65 to 0.72) and overstory (r^2 = 0.09 to 0.23).
- EVI well correlated with GPP at whole canopy scale (r^2 = 0.73).

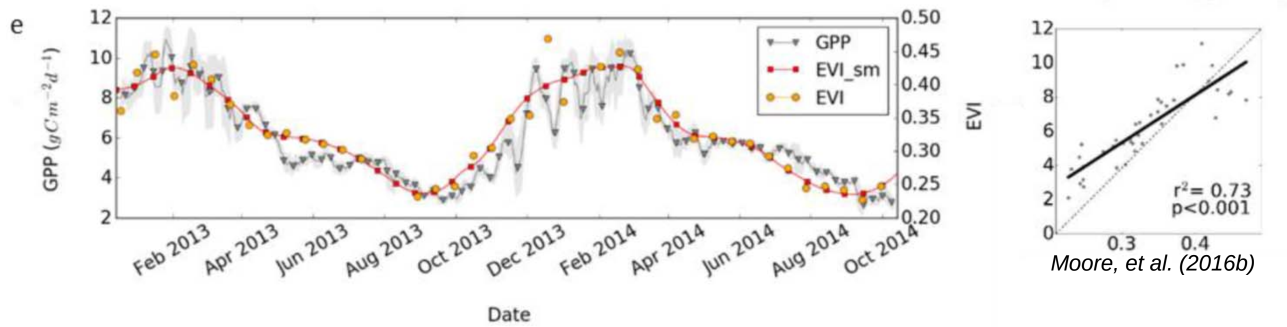
Overstorey



Understorey



Ecosystem



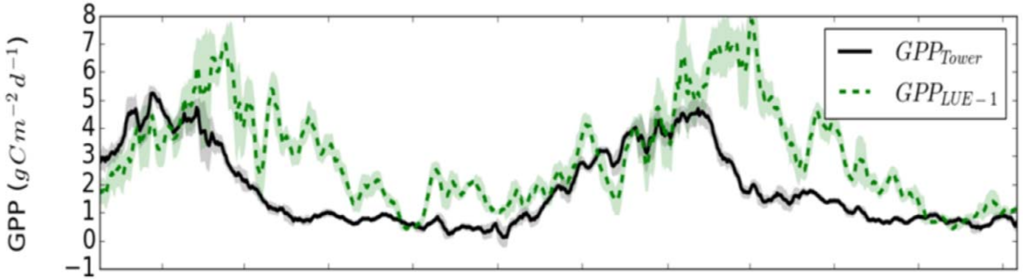
Moore, et al. (2016b)

- Previous studies shown MODIS GPP performs poorly for savannas.
- The MODIS enhanced vegetation index (EVI) correlated well with GPP at the ecosystem scale (r^2 = 0.72).
- We used GCC and EVI to parameterise a LUE model (MODIS).

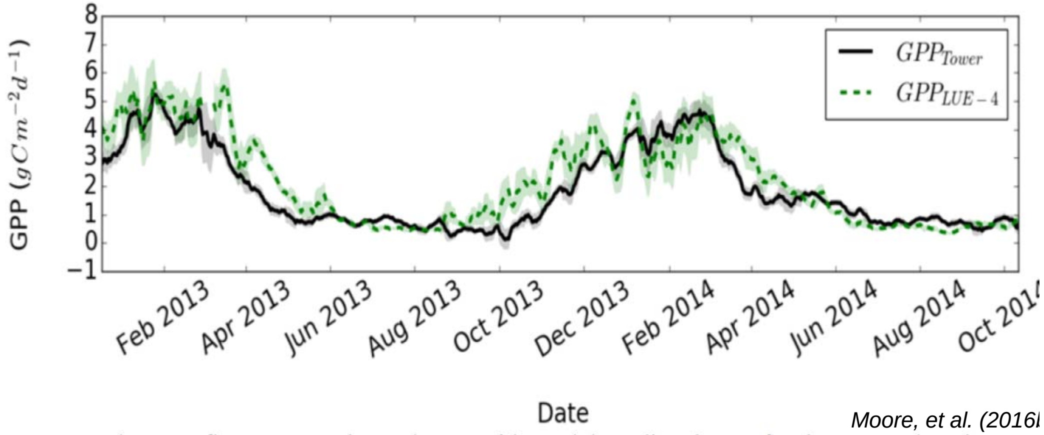
$$GPP = APAR \times LUE_p \times T_{MIN}scalar \times VPDscalar$$

- GCC and EF improved prediction of GPP greatly compared to 'off the shelf' especially for understorey (r^2 0.57 to 0.85 and lower RMSE). Less pronounced for overstorey.

Understorey MODIS LUE model standard



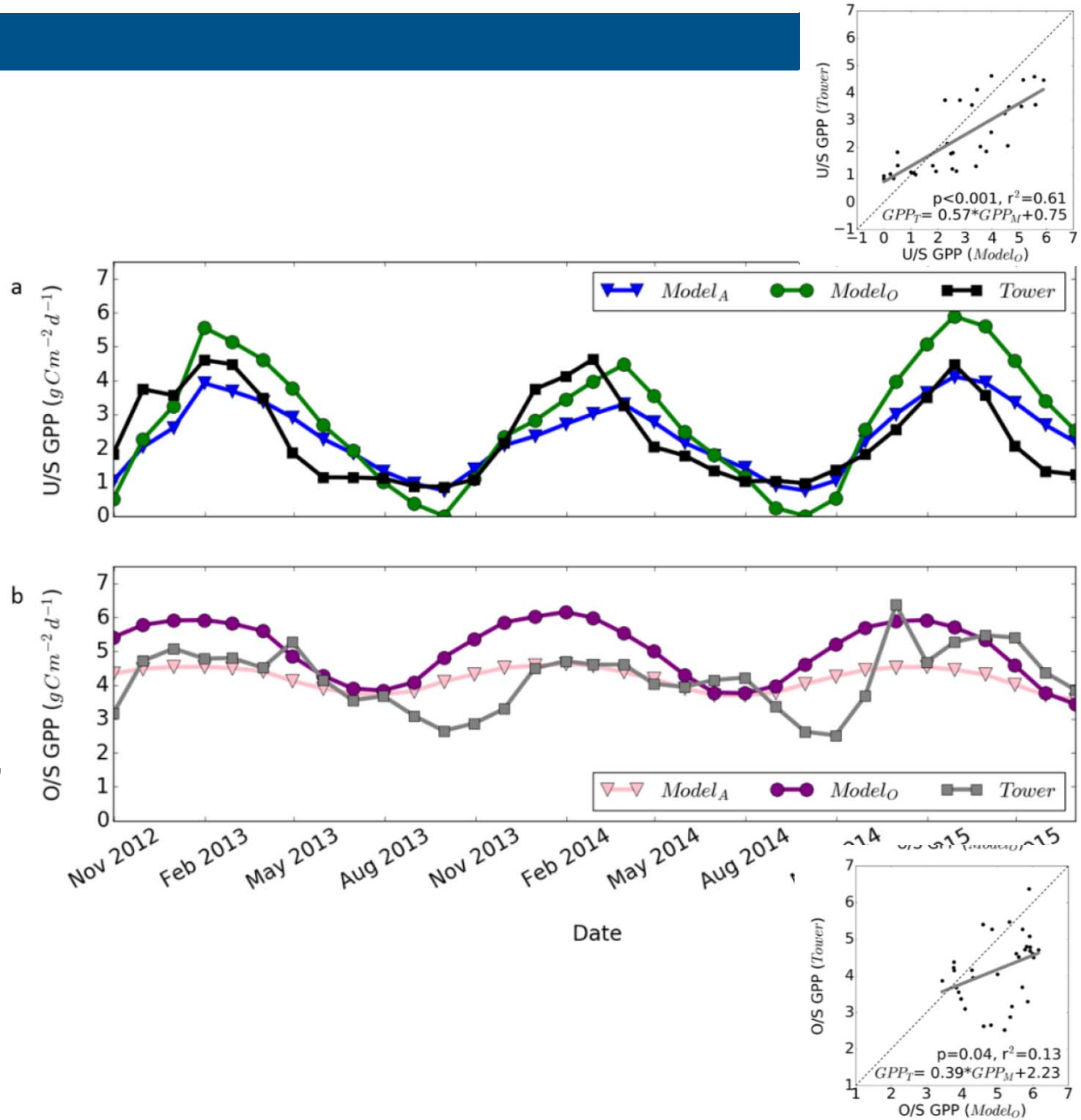
Understorey MODIS LUE model with GCC and EF



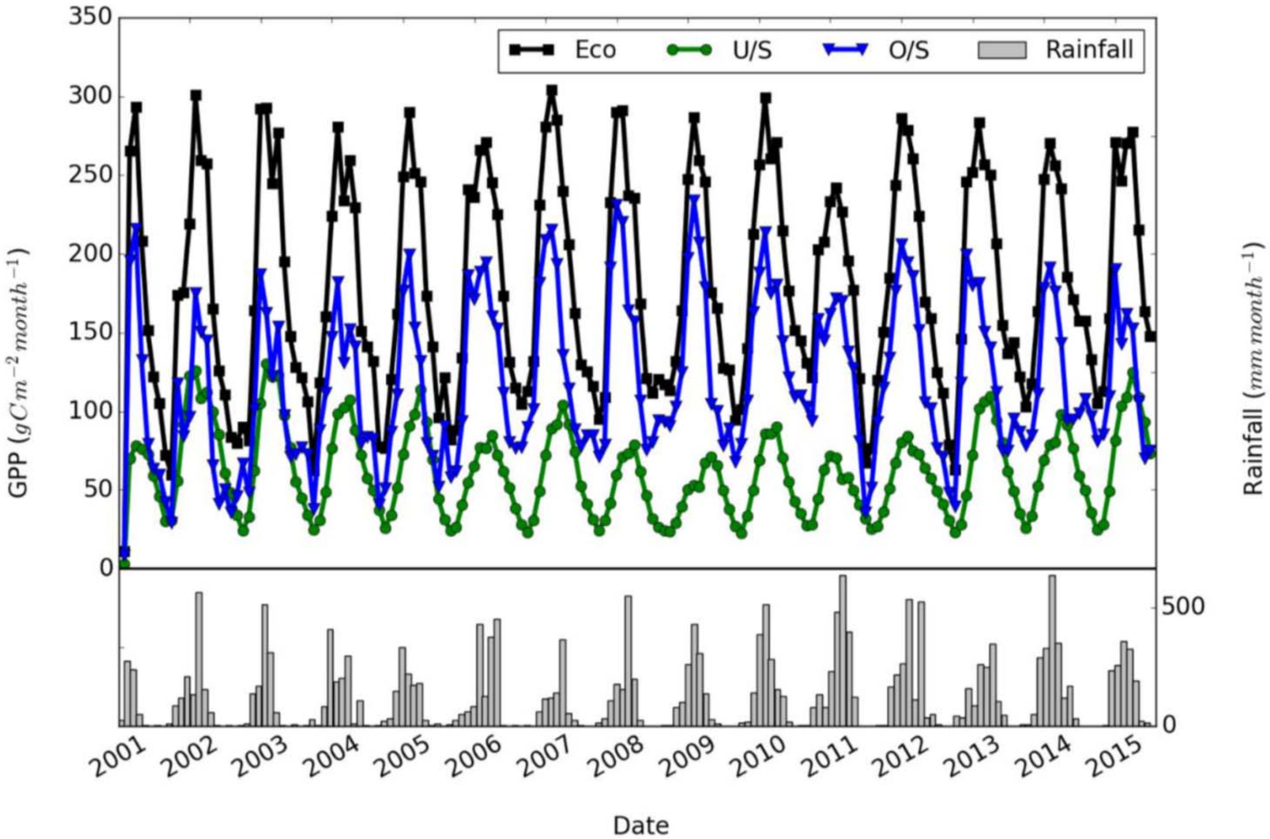
Moore, et al. (2016

Australian Savannas

- Can we used RS to extend tree/grass dynamics back in time?
- New models (Donohue DIFFUSE model) have attempted to derive time-varying grass, tree, bare soil fractions.
- Use 3 years of understorey flux data.
- Original Donohue model needs ‘adjusting’ partly as it assumes zero GPP in dry.
- Adjusted u/s model performs OK (r^2=0.61).



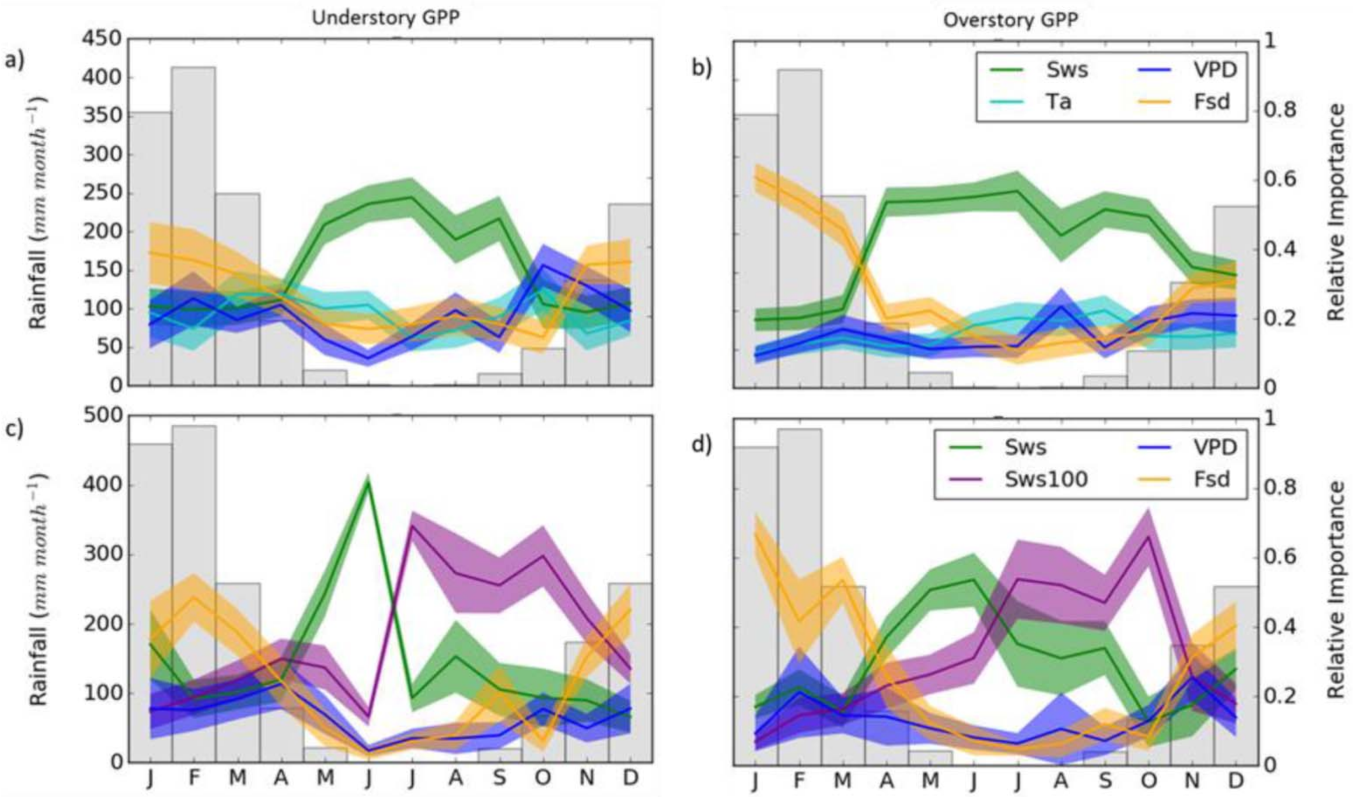
- Use the diffuse model changes in tree vs. grass fraction AND 15 years flux tower ecosystem GPP to extend tree grass productivity back to 2001.



Moore, et al. (2016c)

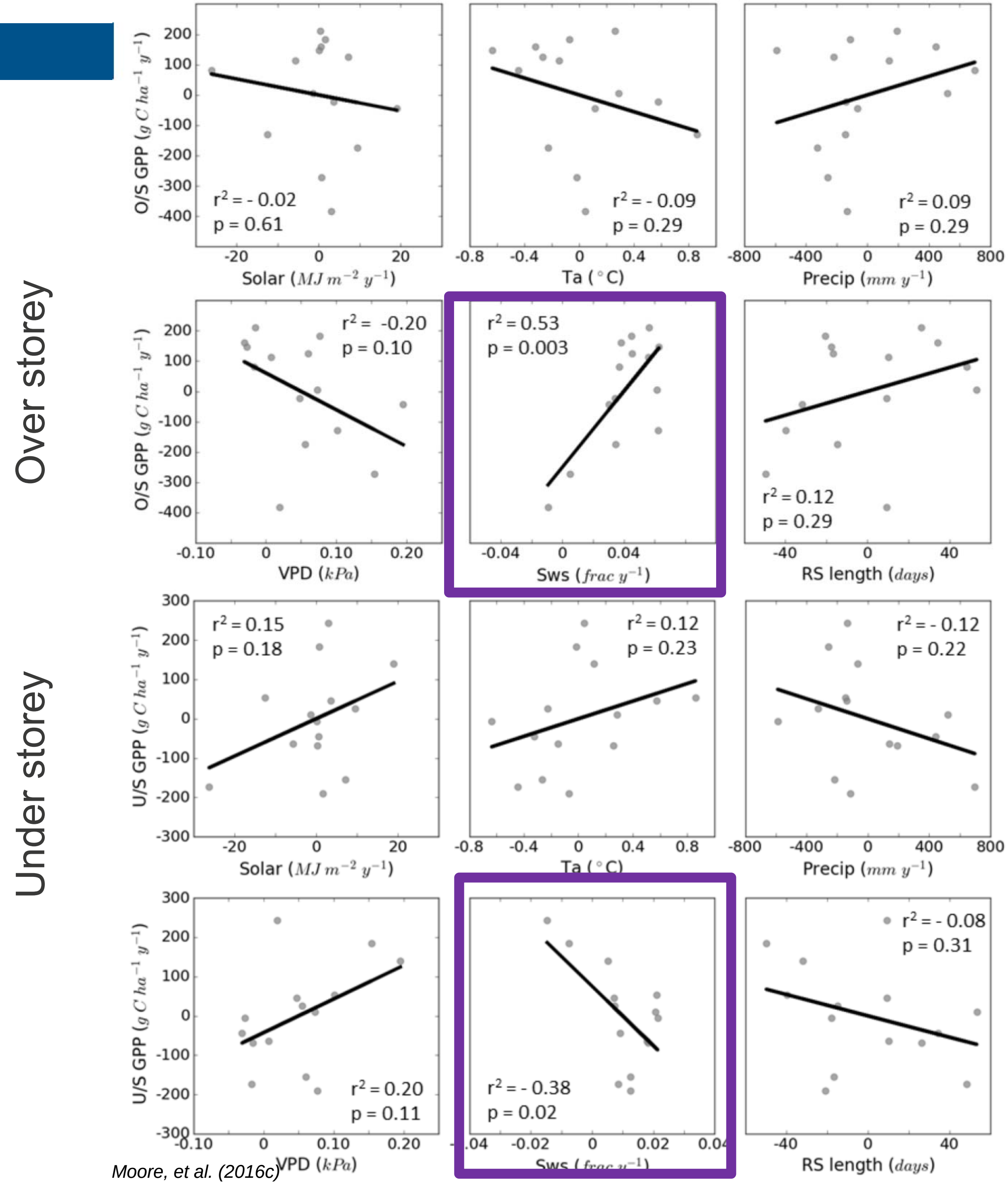
Tree/grass drivers

- What are the drivers of the tree and grass productivity and are they different?
- Using available flux data and random forest to examine short term (seasonal) importance's of drivers.
- Deeper soil moisture more important for trees.



Moore, et al. (2016c)

- What are the long term drivers of the tree and grass productivity?
- Examine anomalies of GPP and climate drivers.
- Soil moisture anomalies +VE correlated with GPP anomalies for o/s but –VE for u/s.



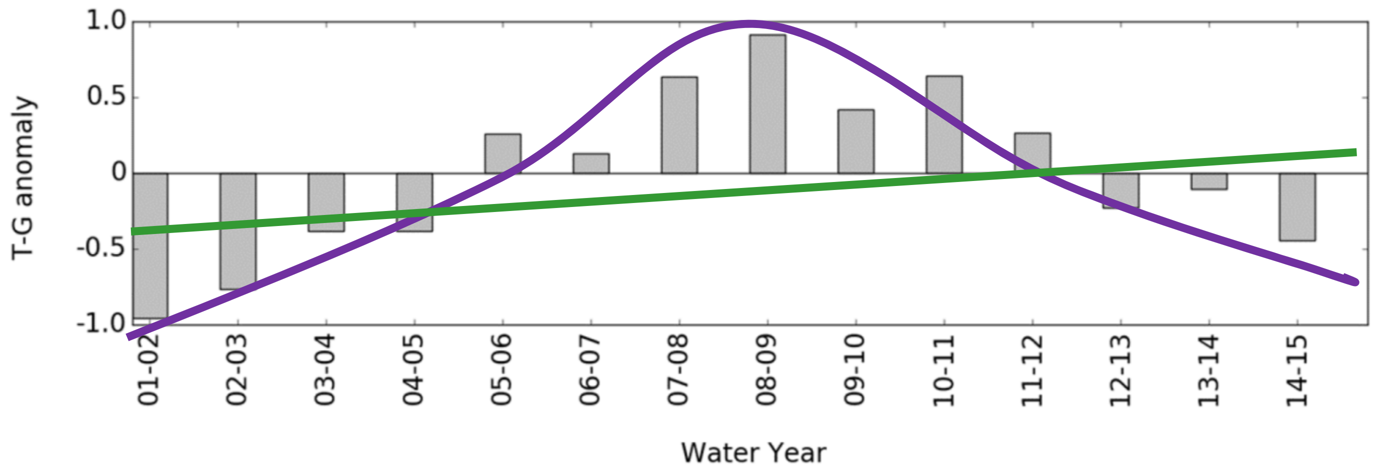
Moore, et al. (2016c)

Tree:grass ratios

- Has there been any trend in tree:grass ratio?

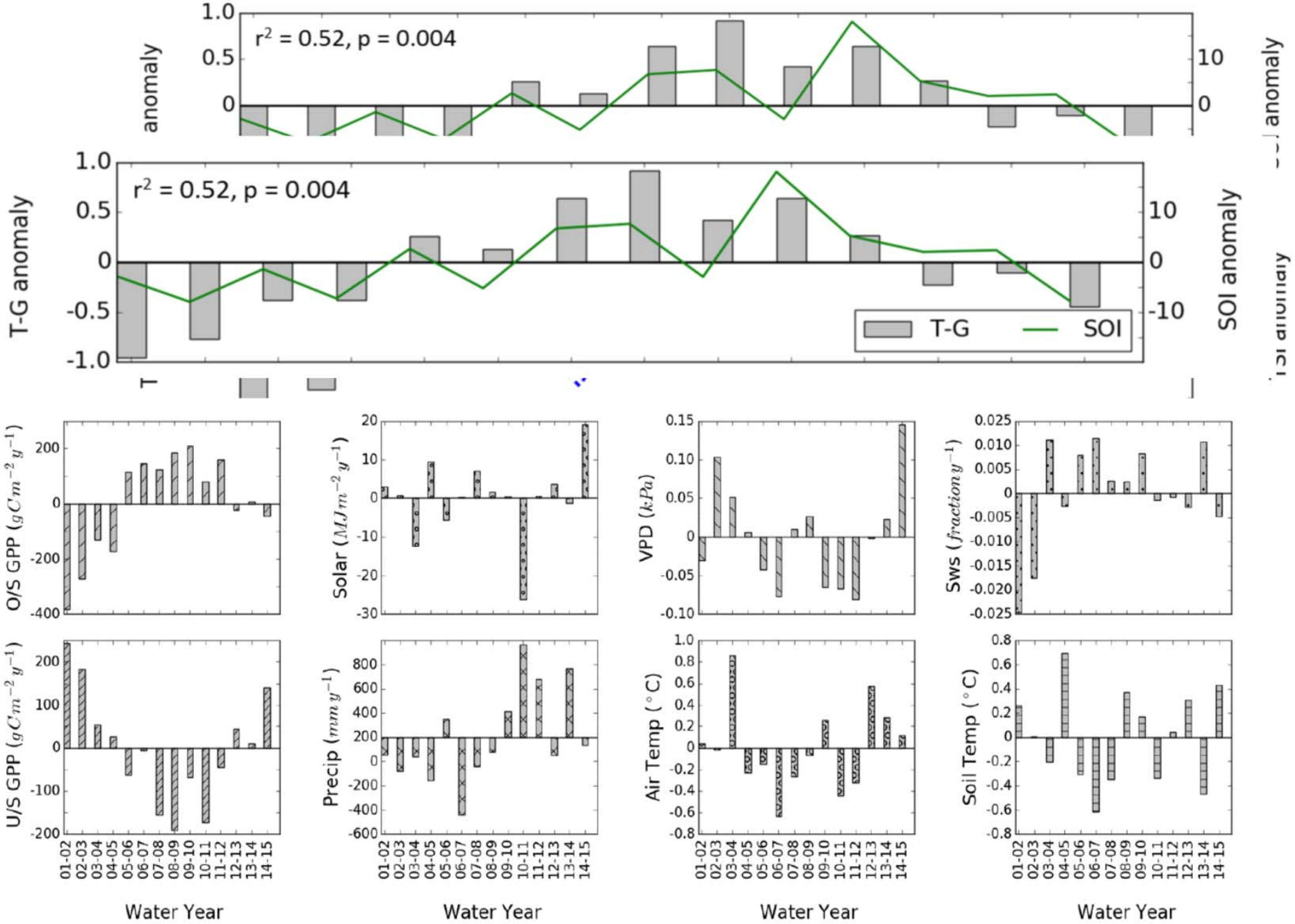
- Periodic cycle (decadal)?

- What could drive this?



Moore, et al. (2016c)

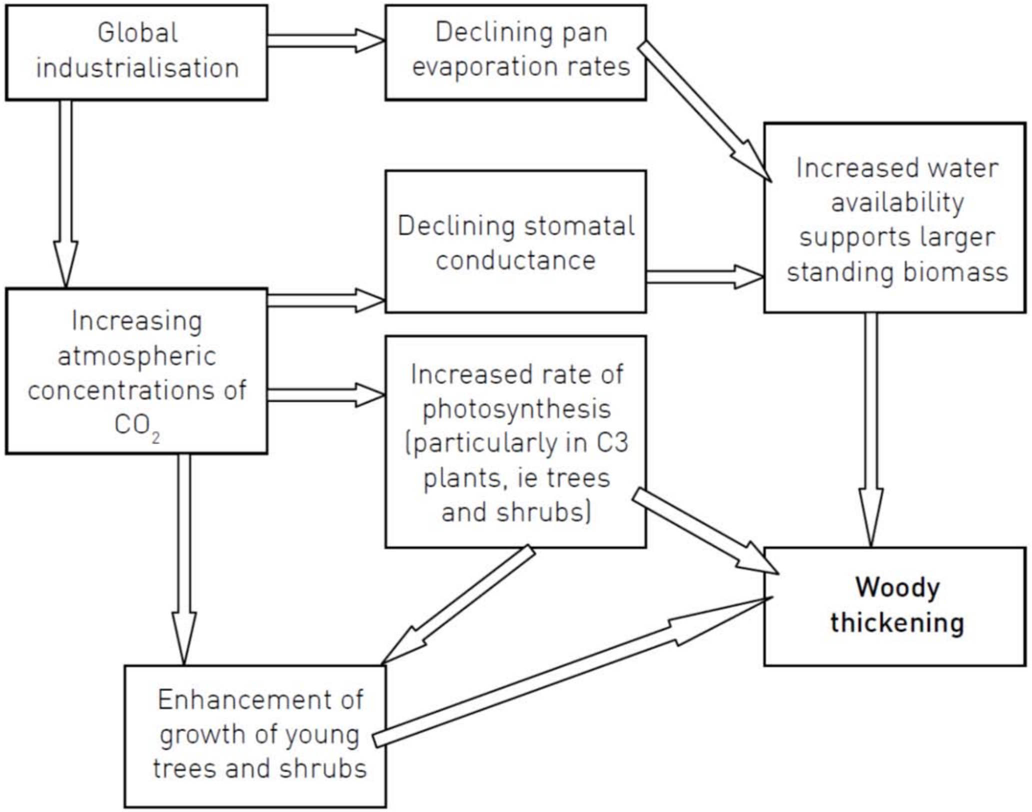
- Correlated with known modes of climate variability for the region (Rogers and Beringer 2016)
- Significant (p=0.004 and r^2=0.52) correlation onl with SOI.
- What is the mechanism?
- Evidence of woody thickening?



Moore, et al. (2016c)

Woody thickening

- Woody thickening defined as increasing density of trees and woody shrubs.
- Any or all of these mechanisms could be operating at HWS.
- How do we detect woody thickening (carbon increment and change in demographics)?



Conceptual model describing the role of climate change in woody thickening.

Macinnis-Ng and Eamus (2009)

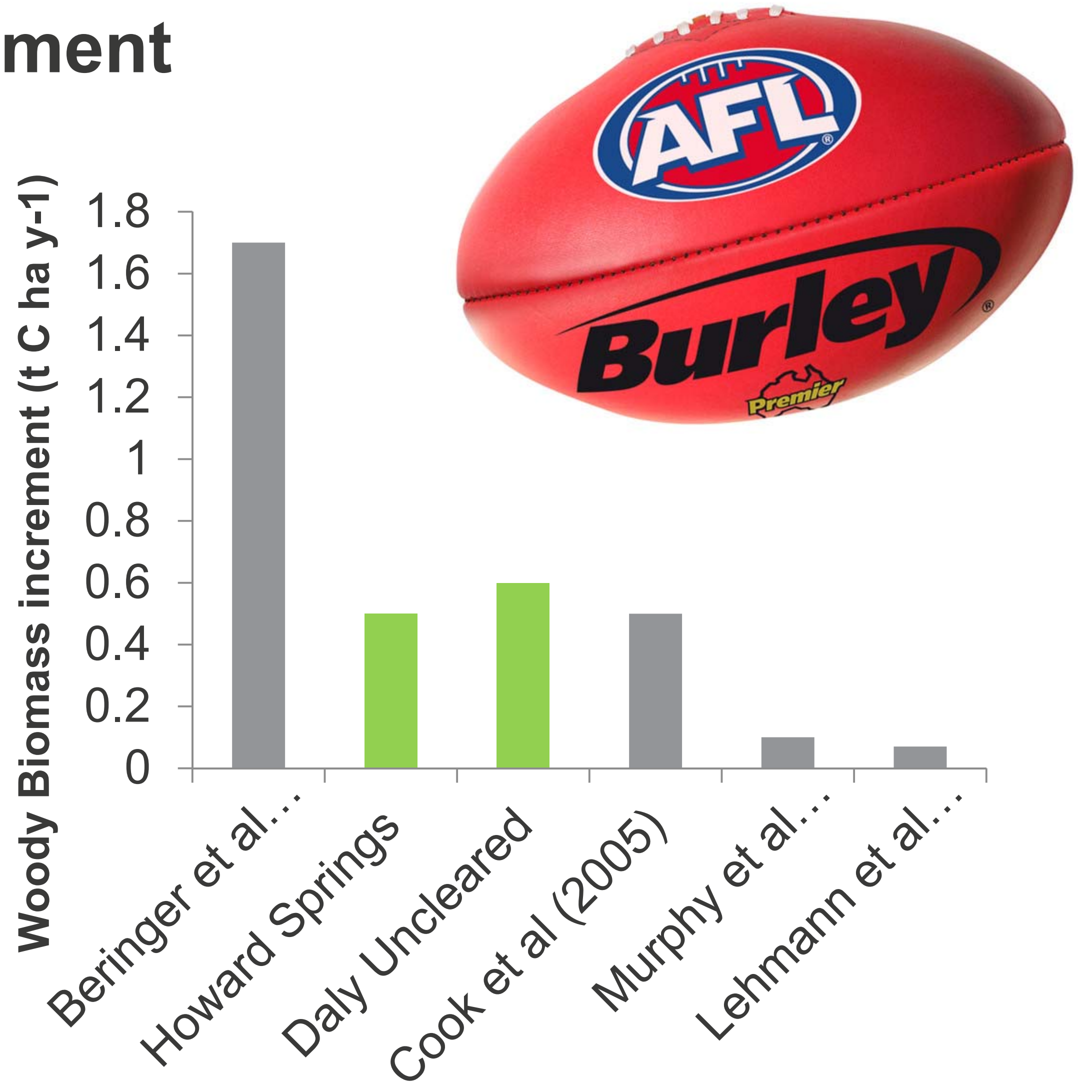
Methods - tree increment (Rudge)

- Used historic (2008) 1 ha veg survey plots
- Measured DBH, height, floristics
- Used existing allometry to calculate biomass increment over time (2008-2014)

Rudge, et al. (2016)

Results - tree increment

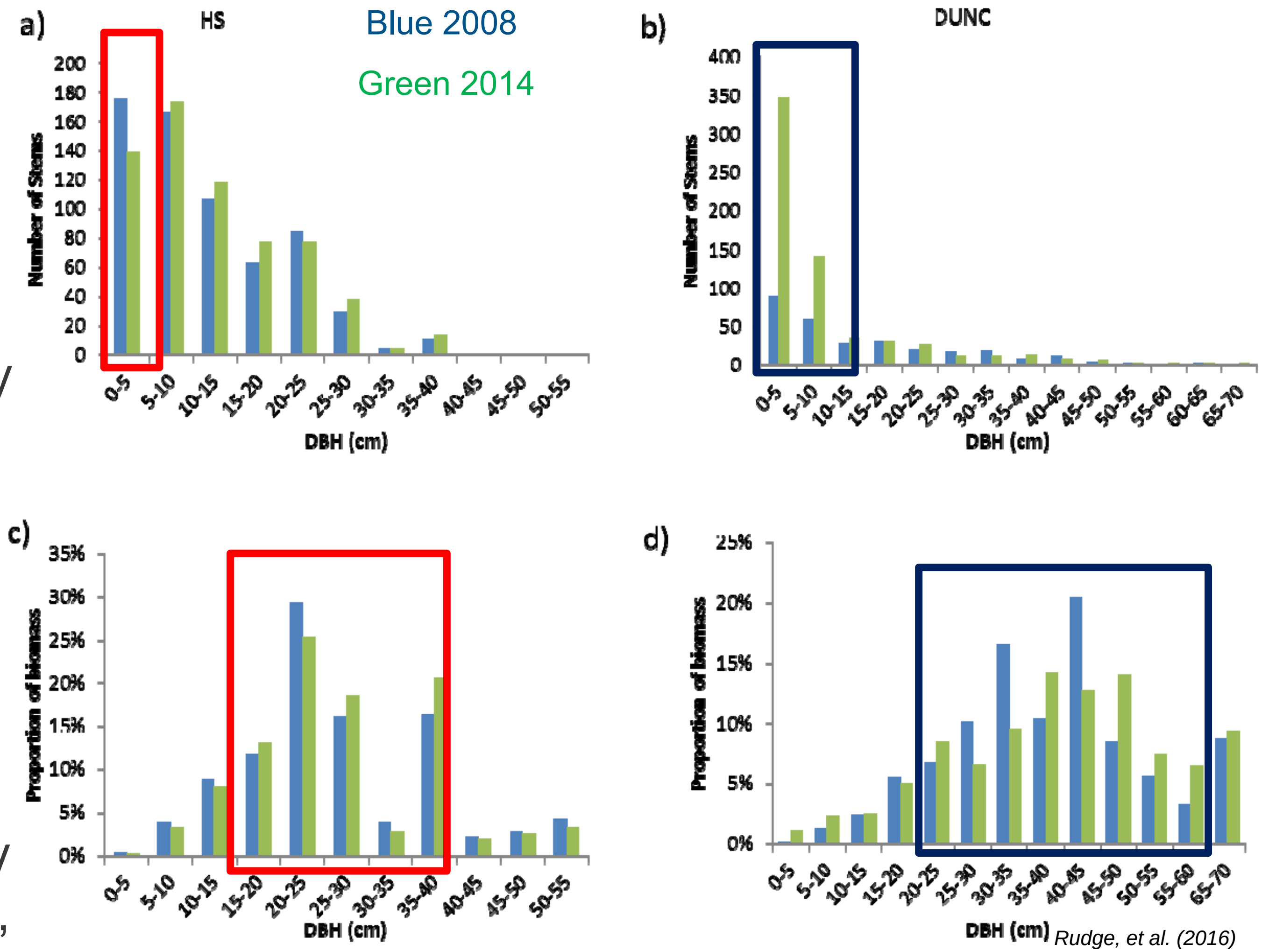
- Tree sink
  - HS 0.5 t C ha^{-1} y^{-1}
  - DU 0.6 t C ha^{-1} y^{-1}
- Increment dominated by large trees
- Doesn't explain EC derived sink



Rudge, et al. (2016)

Demographics

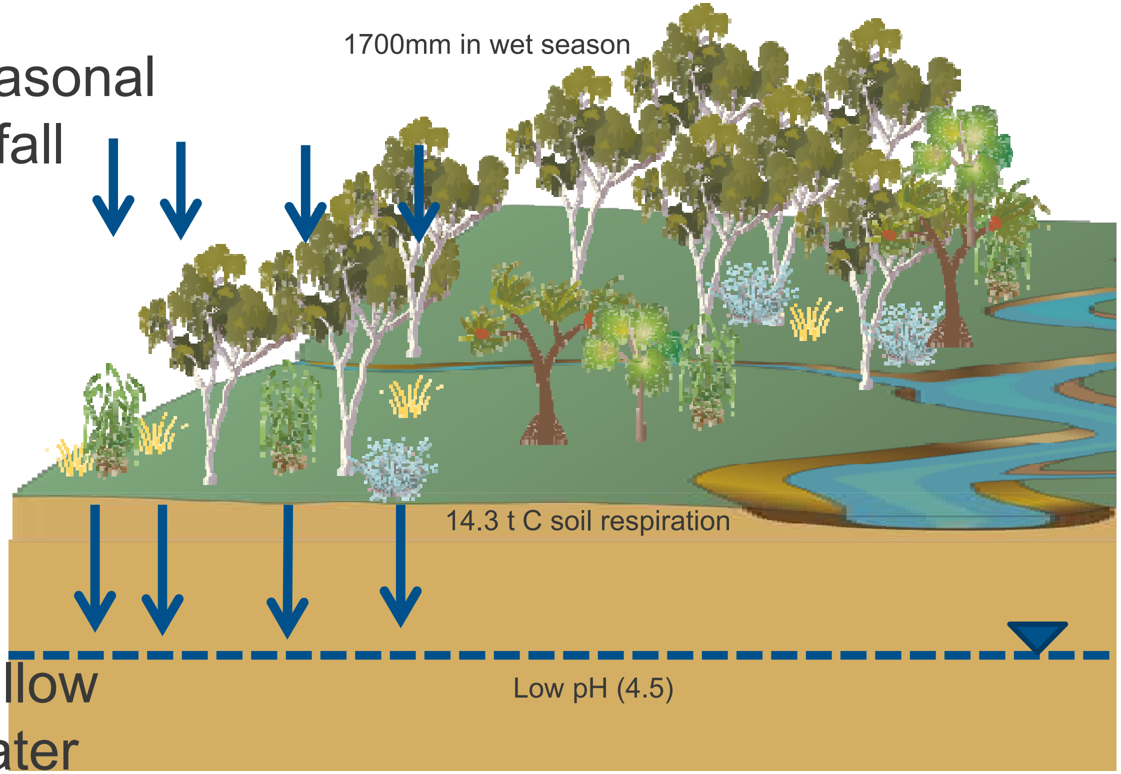
- HWS biomass increment in mid canopy.
- If anything a decrease in the smallest size class at HWS (not woody thickening).
- Daly River strong woody thickening but woody increment in larger size classes.
- Disturbance history (Cyclones, grazing, fire).



Rudge, et al. (2016)

Lateral C flow Australian savanna?

High, seasonal Rainfall

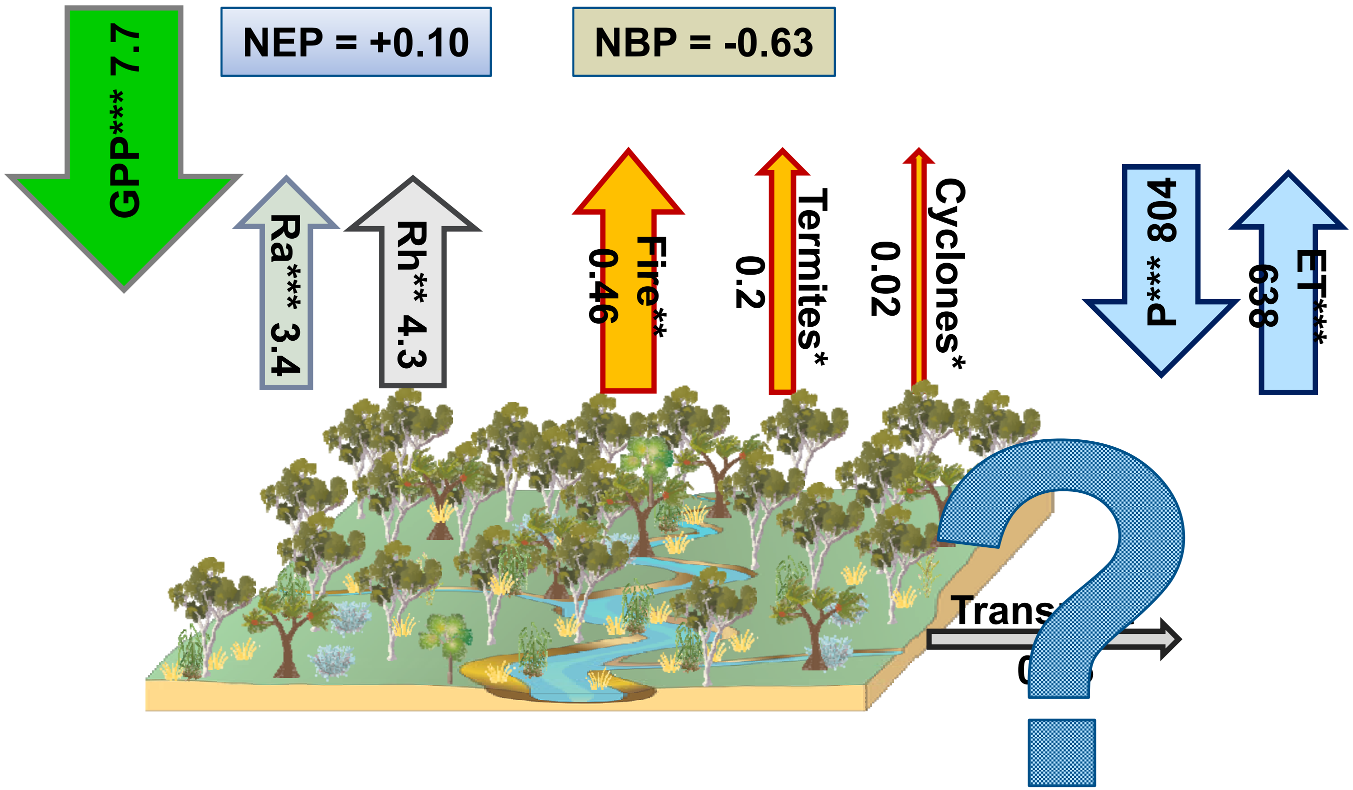


High soil respiration

Acidic shallow groundwater

Rudge, et al. (2016)

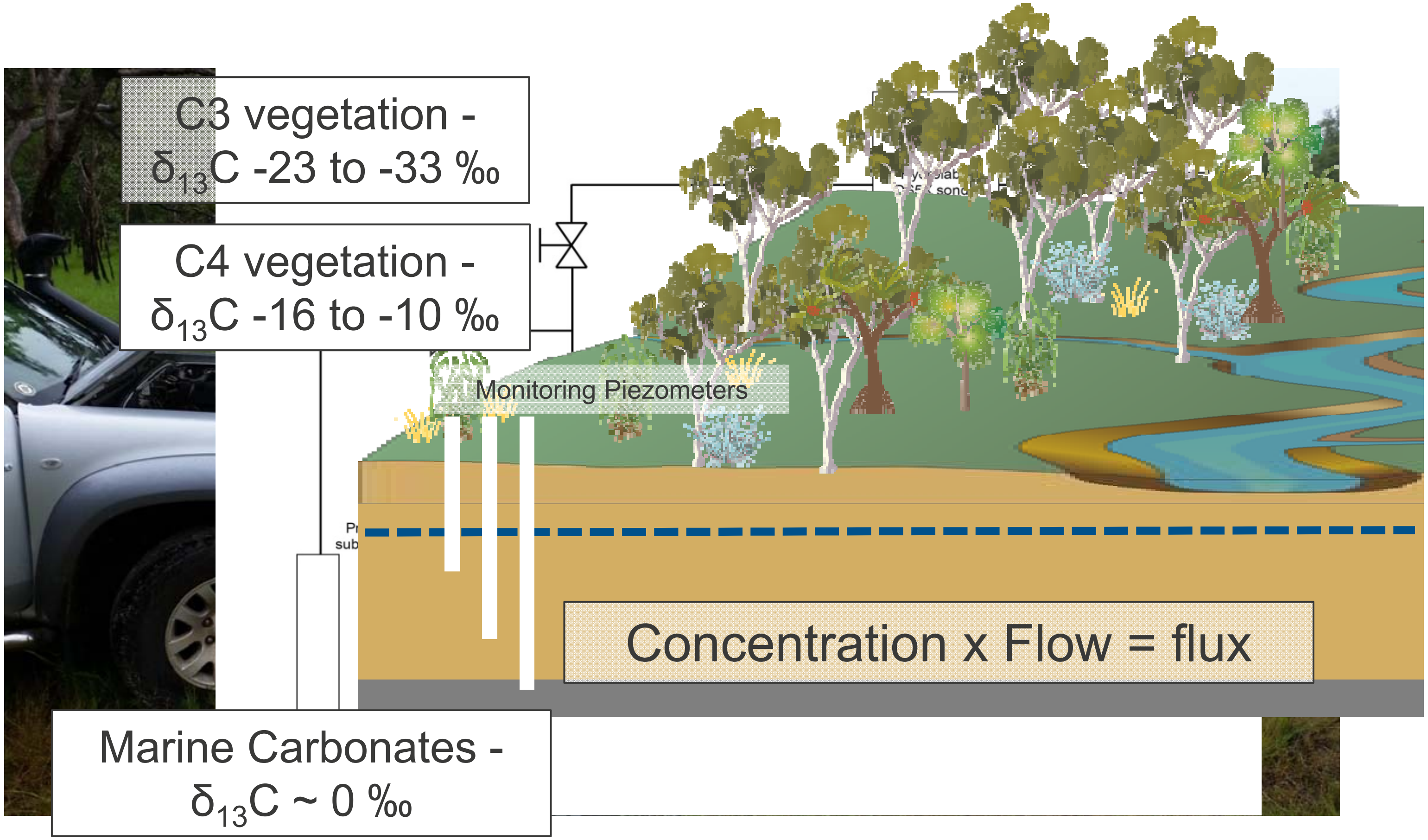
Australian Savanna Carbon and Water Balance



Haverd et al. (2013) Biogeosciences

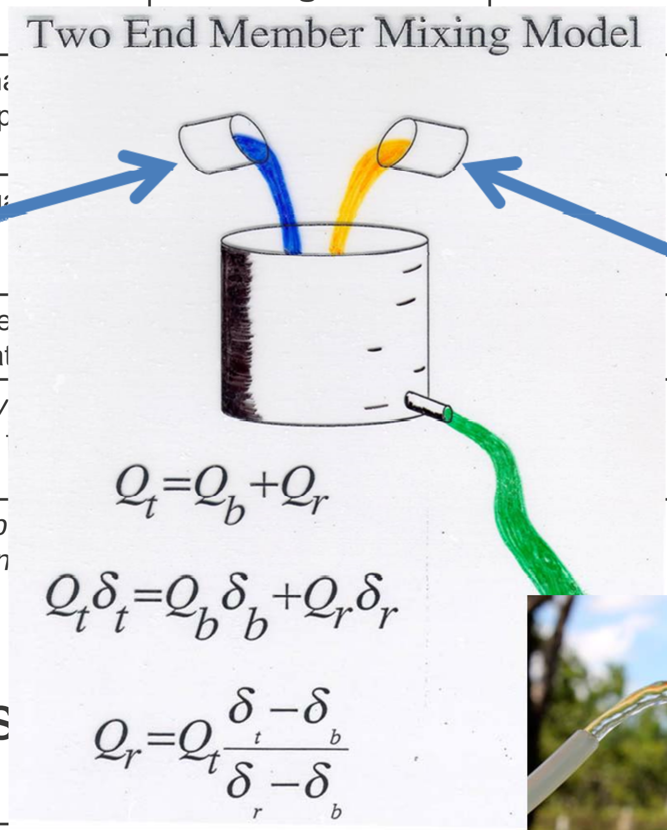
Beringer et al. (2014) GCB

Methods – quantifying the magnitude of fluvial loss



Rudge, et al. (2016)

Mixing model – partitioning C sources



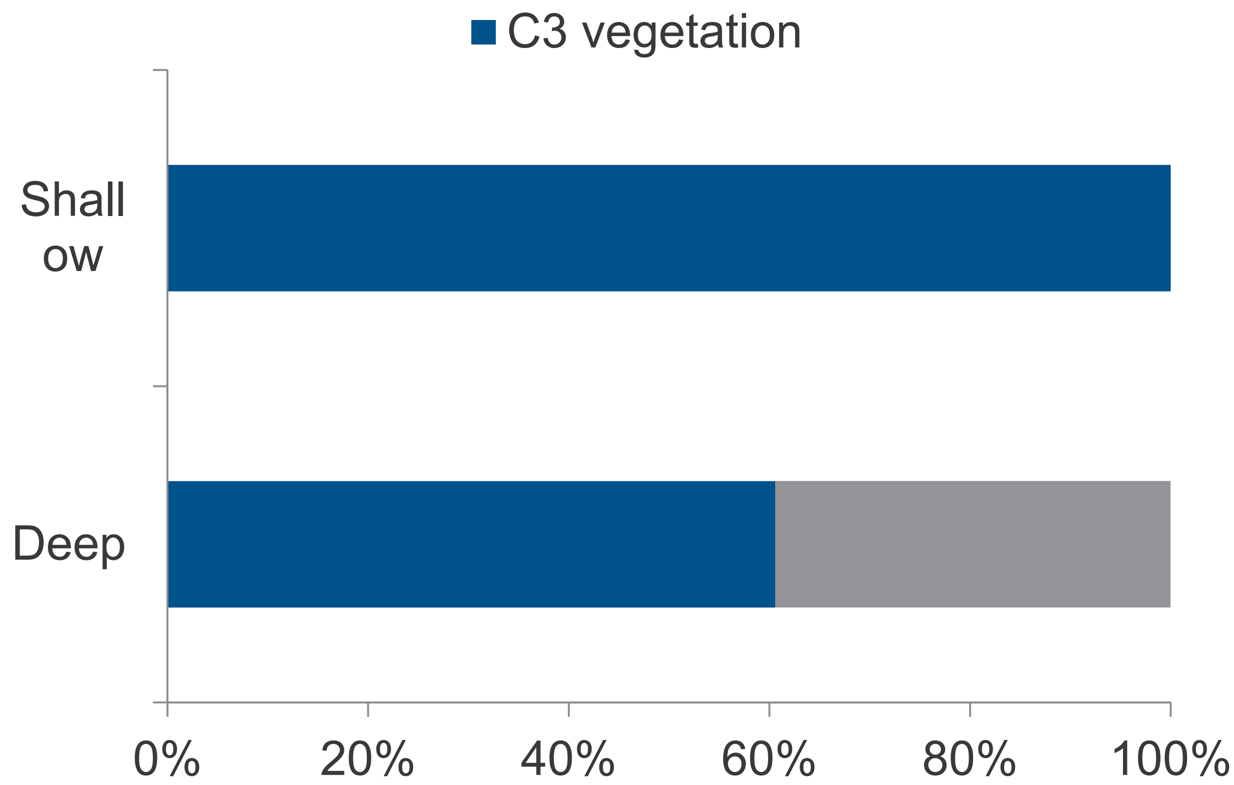
End Members

	source	Average value	Site	
Geological carbonates	Koolpinyah dolomite	-3.4 (-4.4 to -2.5)	River Catchment	dy

snobear.colorado.edu

Rudge, et al. (2016)

Mixing model – partitioning C sources



Rudge, et al. (2016)

Summary

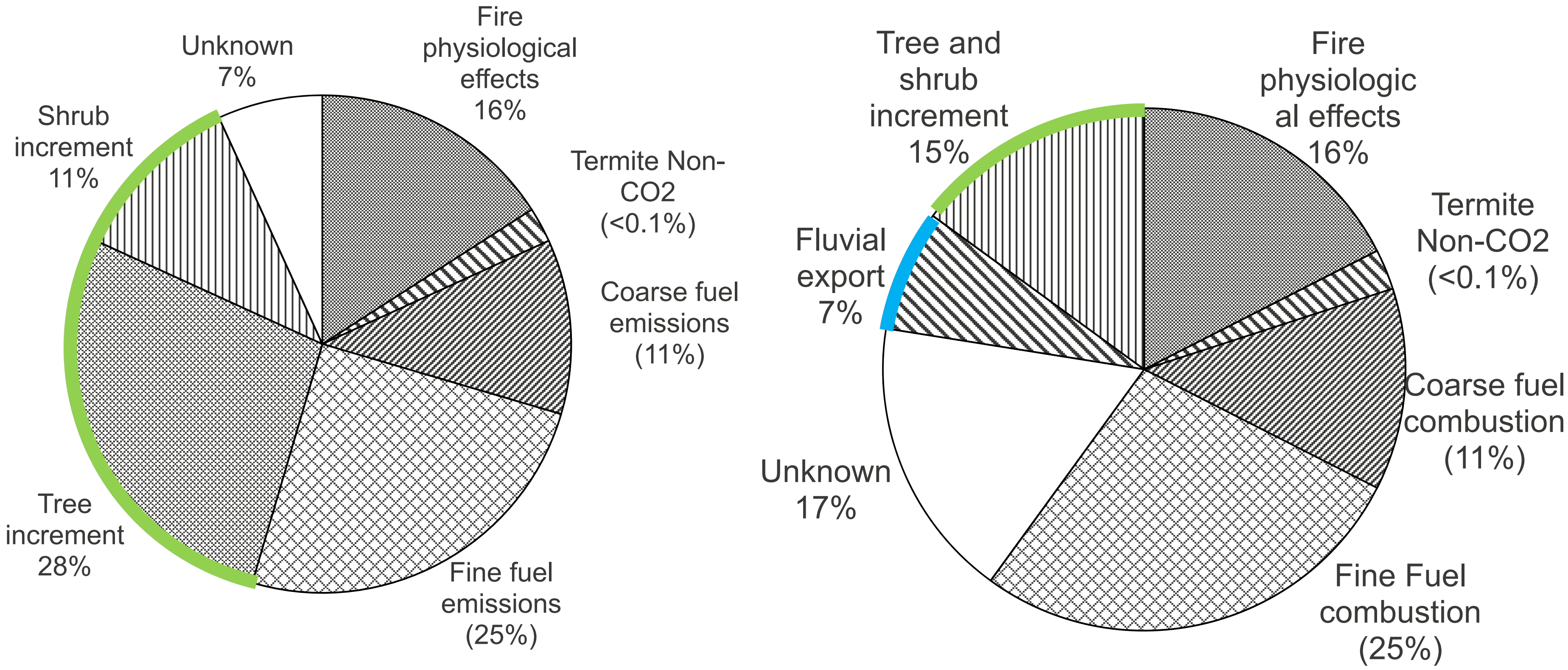
1) **Magnitude of tree sink** – What is the long term tree increment at the high rainfall EC sites (Howard Springs and Daly Uncleared)? → 0.5 and 0.6 $t\ C\ ha^{-1}\ y^{-1}$

2) **Magnitude of fluvial loss** - what is the annual loss of savanna carbon through groundwater transport in the Howard Springs catchment? → 0.3 - 0.45 $t\ C\ ha^{-1}\ y^{-1}$

Fluvial transport is of similar magnitude to the tree sink

Rudge, et al. (2016)

Redrawing the Howard River catchment C budget

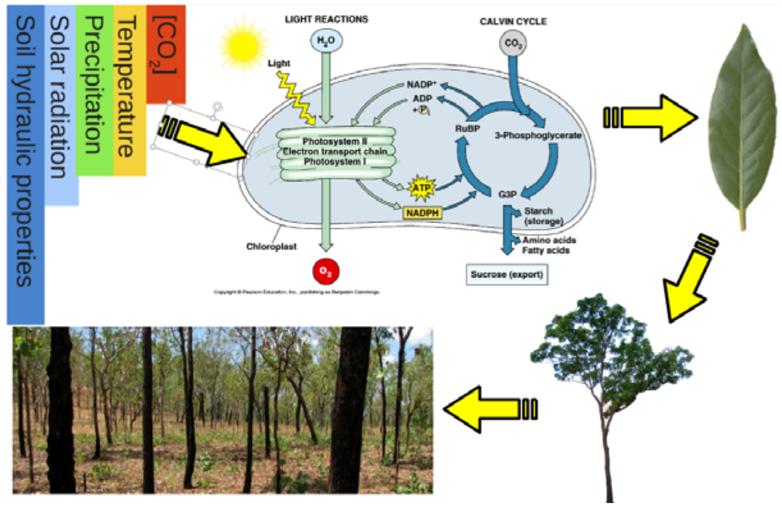


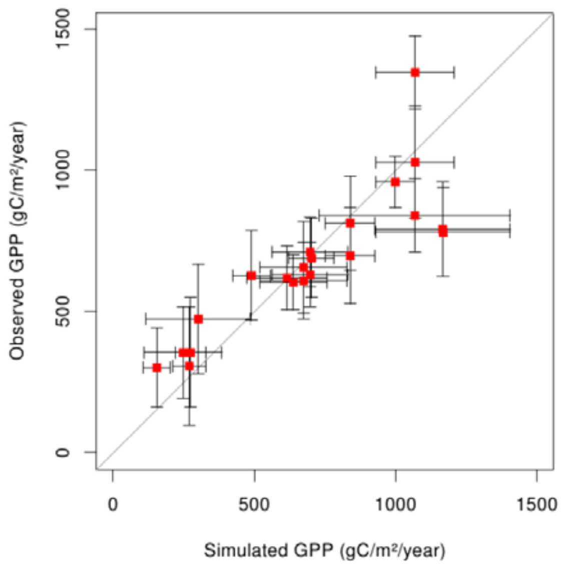
Beringer *et al*, 2007

This Study

Future Environmental Change

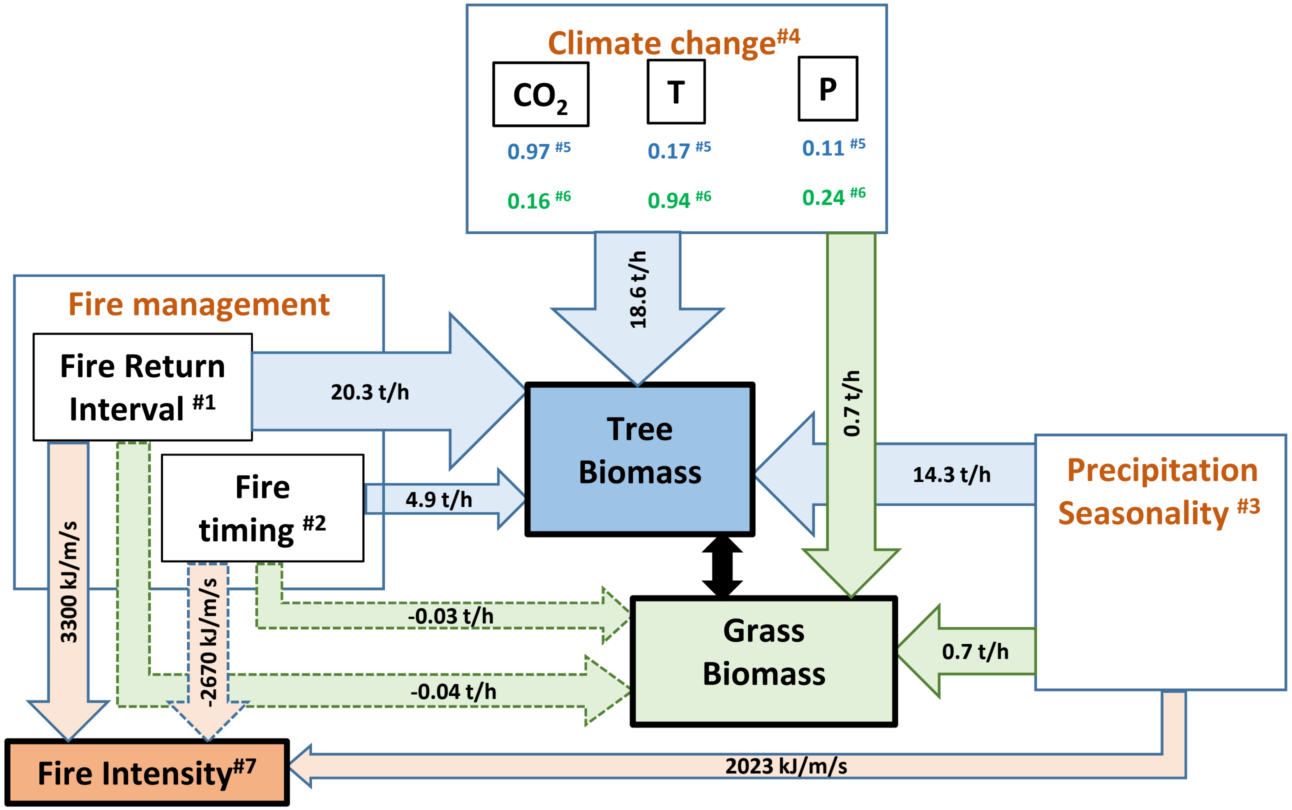
- Bio-physical model
- Individual-based approach
- Vegetation responds to climate
- → based on leaf-level physiology
- → process-based allocation
- → process-based phenology
- Simulates light and root competition
- Fire and herbivore impacts depend on tree height
- Four vegetation types: C_3 and C_4 grasses, fire-tolerant and fire-sensitive tree
- Validated using flux tower GPP and tree basal area data from NATT





Scheiter and Higgins (2009) GCB

Future Environmental Change



Beringer, et al. (2014)

Conclusions

- Long term increase in carbon fluxes over 15 yrs at Howard. Variability reduced by normalising by LAI.
- Increased rates correlated with precipitation and soil moisture. “Just add water”
- Model attribution showed atmospheric CO_2 concentration a major driver. The “Hawaii factor”.
- Short term drivers sun and water. The “Bali factor”
- Differential response of trees versus grass with tree:grass ratio related to ENSO. The “Tahiti factor”.
- Substantial C loss through lateral transport.
- No noticeable woody thickening at Howard Springs but consistent carbon accumulation (woody increment) due to disturbance history. The “Tracey factor”

References

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