Coupling carbon allocation with leaf and root phenology accounts for tree-grass partitioning along a savanna rainfall gradient.

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Motivation

- Vegetation dynamics of global savanna systems , which exhibit enormous spatio-temporal variability in woody and herbaceous biomass, structure and plant functional forms are poorly understood. "A single model cannot adequately represent savanna woody biomass across these regions" (Lehmann et al. 2014)*.
  - Accurate C-allocation and phenology for the main elements of savanna systems (trees and grasses) may be a key to understanding variations in tree/grass partitioning in time and space in the savanna biome worldwide.
- No existing vegetation model allows phenology to emerge as a result of allocation of assimilated carbon.
- New approach: links phenology and allocation, accounting for a temporal shift between assimilation and growth, mediated by plant carbohydrate storage

*Lehmann, C. E., Anderson, T. M., Sankaran, M., Higgins, S. I., Archibald, S., Hoffmann, W. A., Hanan, N. P., Williams, R. J., Fensham, R. J., and Felfili, J.: Savanna vegetation-fire-climate relationships differ among continents, Science, 343, 548-552, 2014.

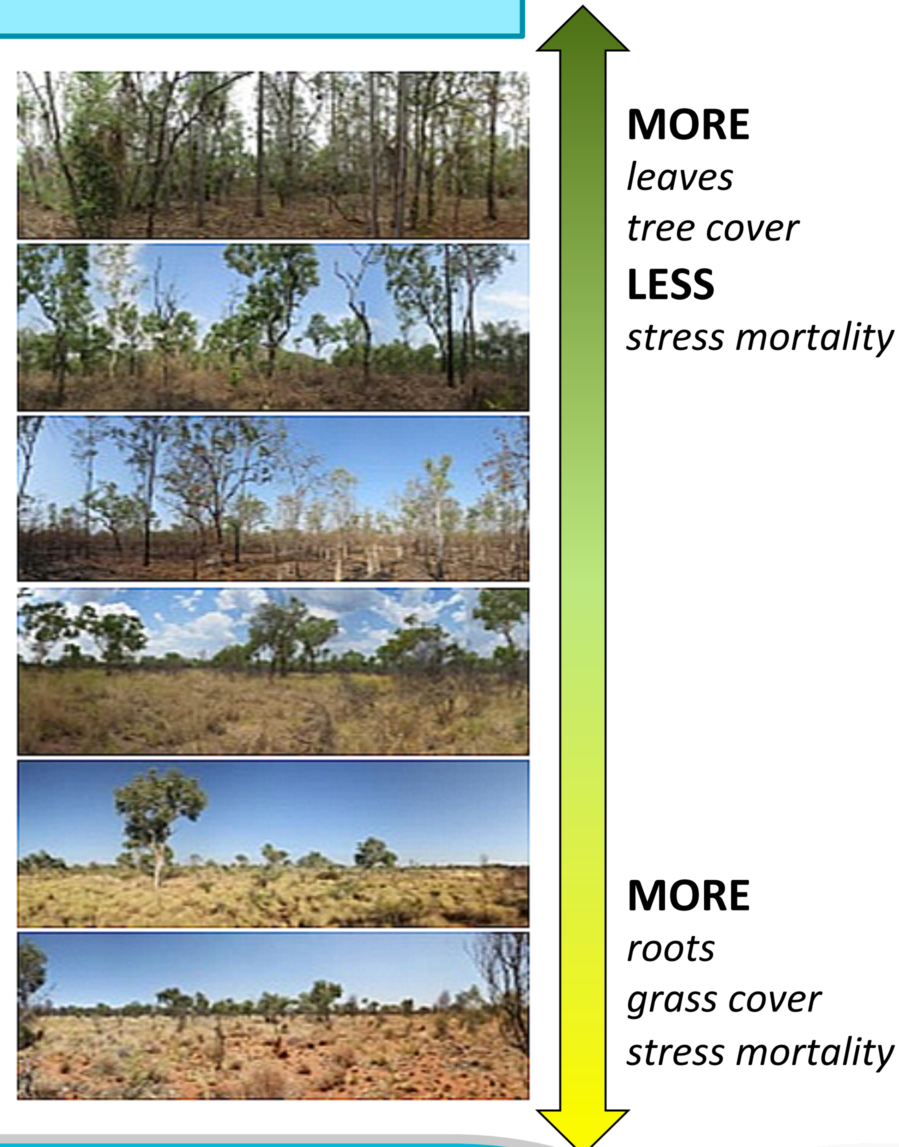
HAVANA (Hydrology, Allocation and Vegetation-dynamics Algorithm for Northern Australia) land surface model

Key Features

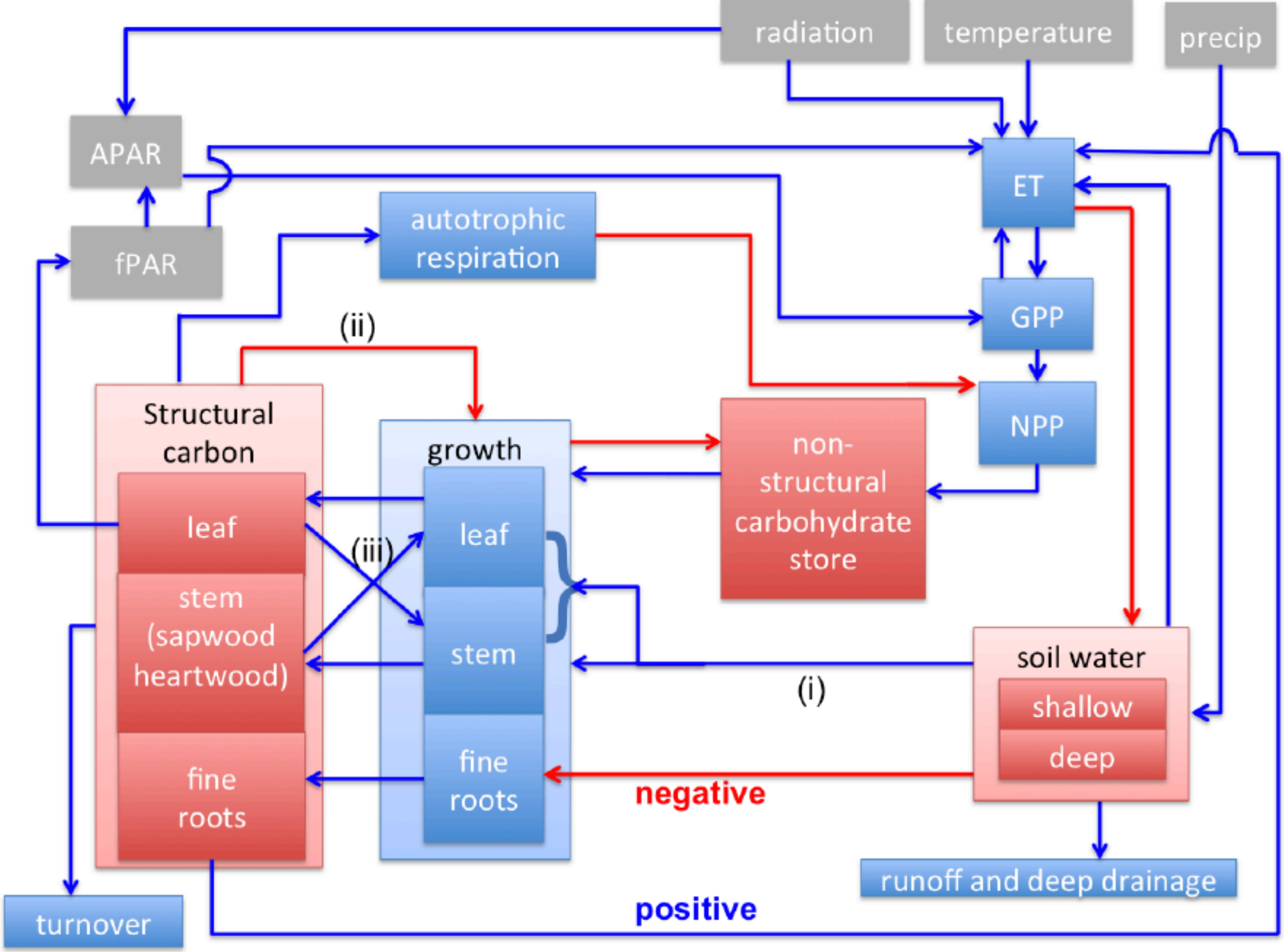
- Root/shoot C-allocation optimises NPP based on resource limitation
- Growth decoupled from production
- Storage to buffer stress
- Tree-grass competition
- Emergent leaf and root phenology

Structure → Function feedbacks

- Mortality → biomass turnover
- Sapwood area → leaf/wood C-allocation (pipe model)
- Sapwood biomass → autotrophic respiration
- Clumping index → light interception

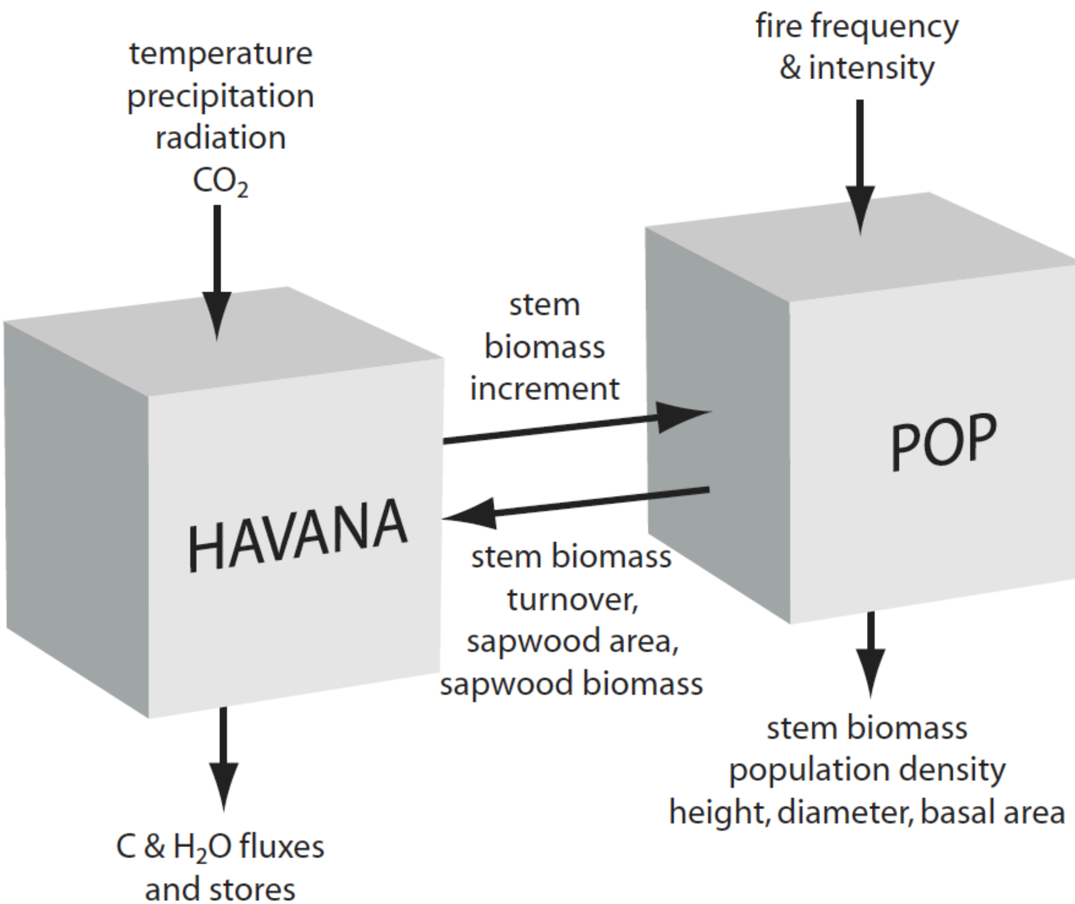


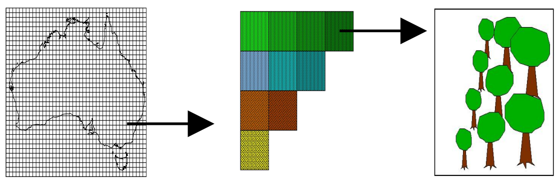
Haverd, V. *et al.* Coupling carbon allocation with leaf and root phenology predicts tree-grass partitioning along a savanna rainfall gradient. *Biogeosciences Discuss.* **12**, 16313-16357, (2015)


radiation
temperature
precip
APAR
fPAR
autotrophic respiration
ET
GPP
NPP
(ii)
Structural carbon
leaf
stem (sapwood heartwood)
fine roots
growth
leaf
stem
fine roots
(iii)
non-structural carbohydrate store
soil water
shallow
deep
(i)
negative
positive
runoff and deep drainage
turnover

HAVANA – POP Coupling

POP is a module for tree demography and disturbance-mediated landscape heterogeneity.*





Grid-cell (tile) represented by patches distinguished by time since last disturbance

Recruitment, Growth, Mortality in each patch

*Haverd et al. 2013
Geophysical Research Letters
40: 5234-5239

Dynamic Storage: the difference between NPP and growth

- Change in Storage (zero in long term)

$$\int_{t-t_{av}}^{t} \frac{dC_{storage}}{dt} dt = \int_{t-t_{av}}^{t} F_{C,NPP} \, dt - \int_{t-t_{av}}^{t} F_{C,\mathrm{Growth}} \, dt$$

Long term change in Storage (non-structural carbohydrate)

Long term NPP

Long term growth

Logistic Growth

$$F_{C,Growth} = \beta_{growth}\left(\overline{F_{C,NPP}} + \Delta C_{storage}\right) f(w)\left(1 - \frac{C_L + C_R}{C_{max}}\right)$$

Maximum Growth Rate

Function of Soil Moisture

Deviation From Carrying Capacity

Dynamic Allocation: growth allocated to pool with highest marginal gain in NPP

- C dynamics controlled by allocation of growth , and first-order decay, e.g.

$$\frac{dC_{\mathrm{L}}}{dt} = \alpha_L F_{C,Growth} - k_L C_L$$

- Carbon allocation coefficients vary in time to maximise the total carbon gain, i.e. the long-term integral of $F_{C,NPP}$
- Allocation coefficients have "bang-bang" character
    - at each instant *t*, an allocation coefficient of one is assigned to the pool for which the marginal return on invested growth is largest while all the other pools receive zero allocation

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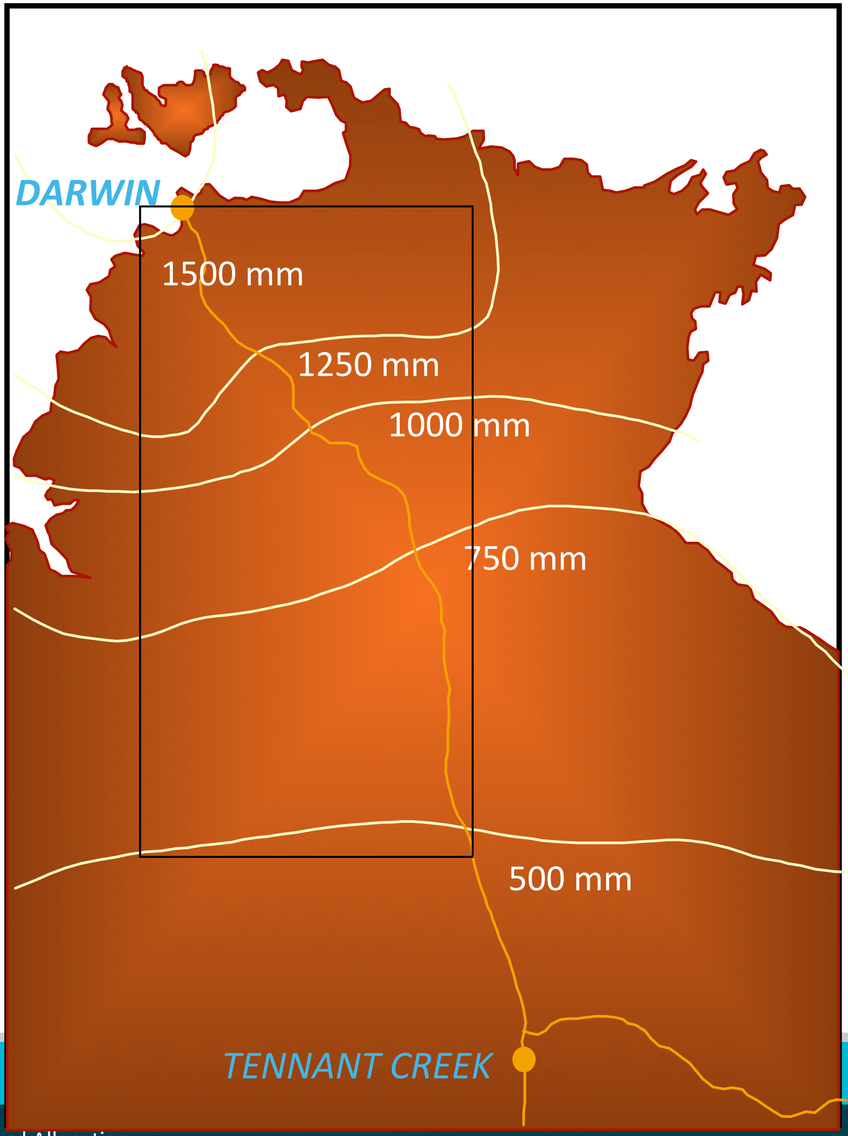
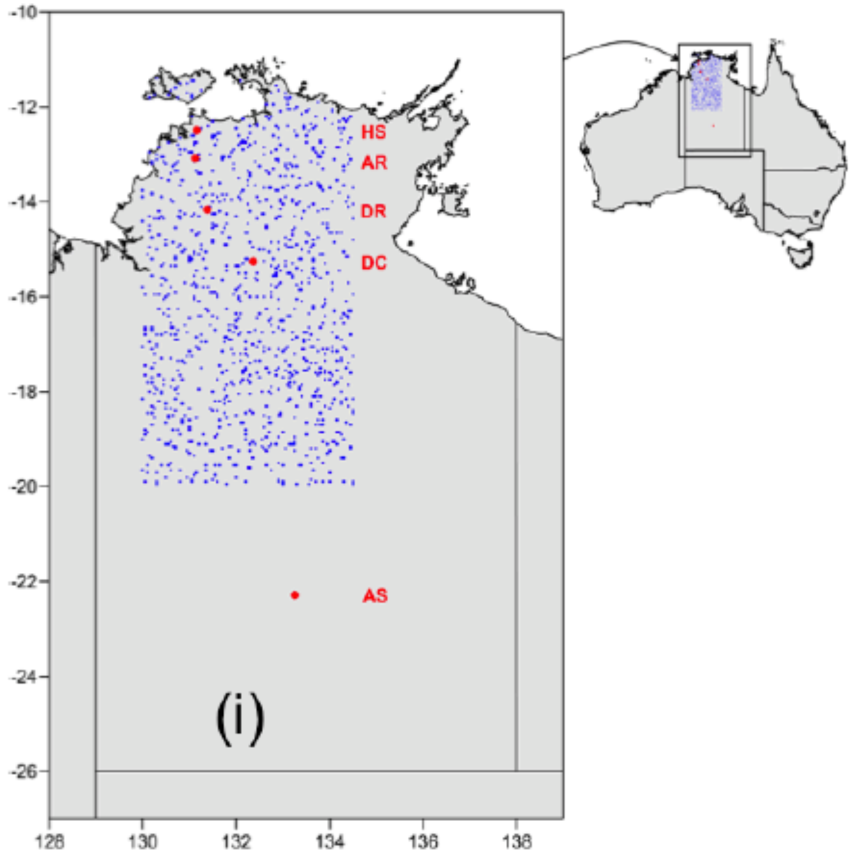
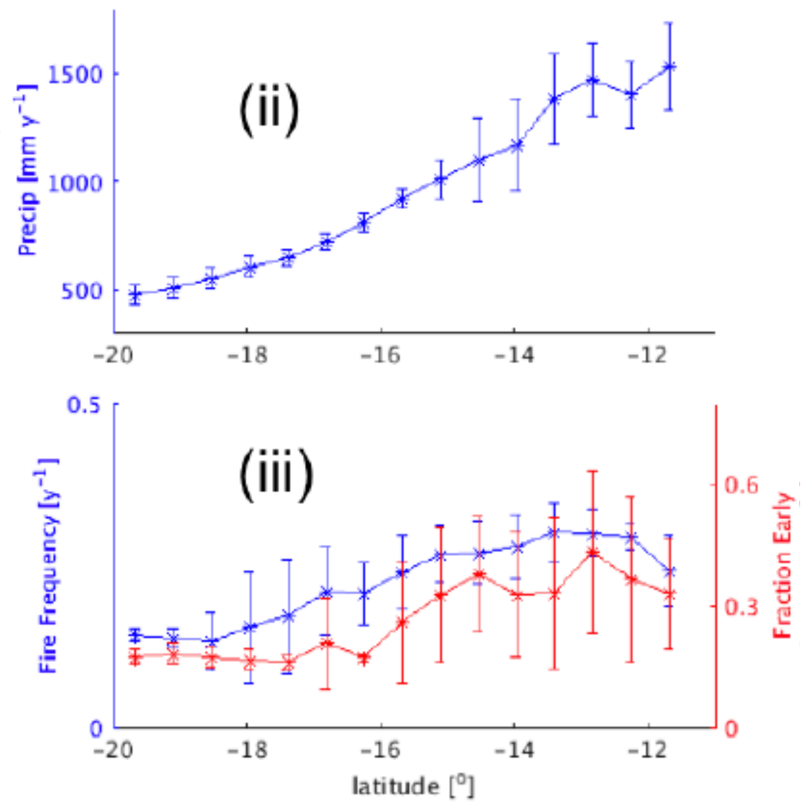
Study Area: Northern Australian Tropical Transect



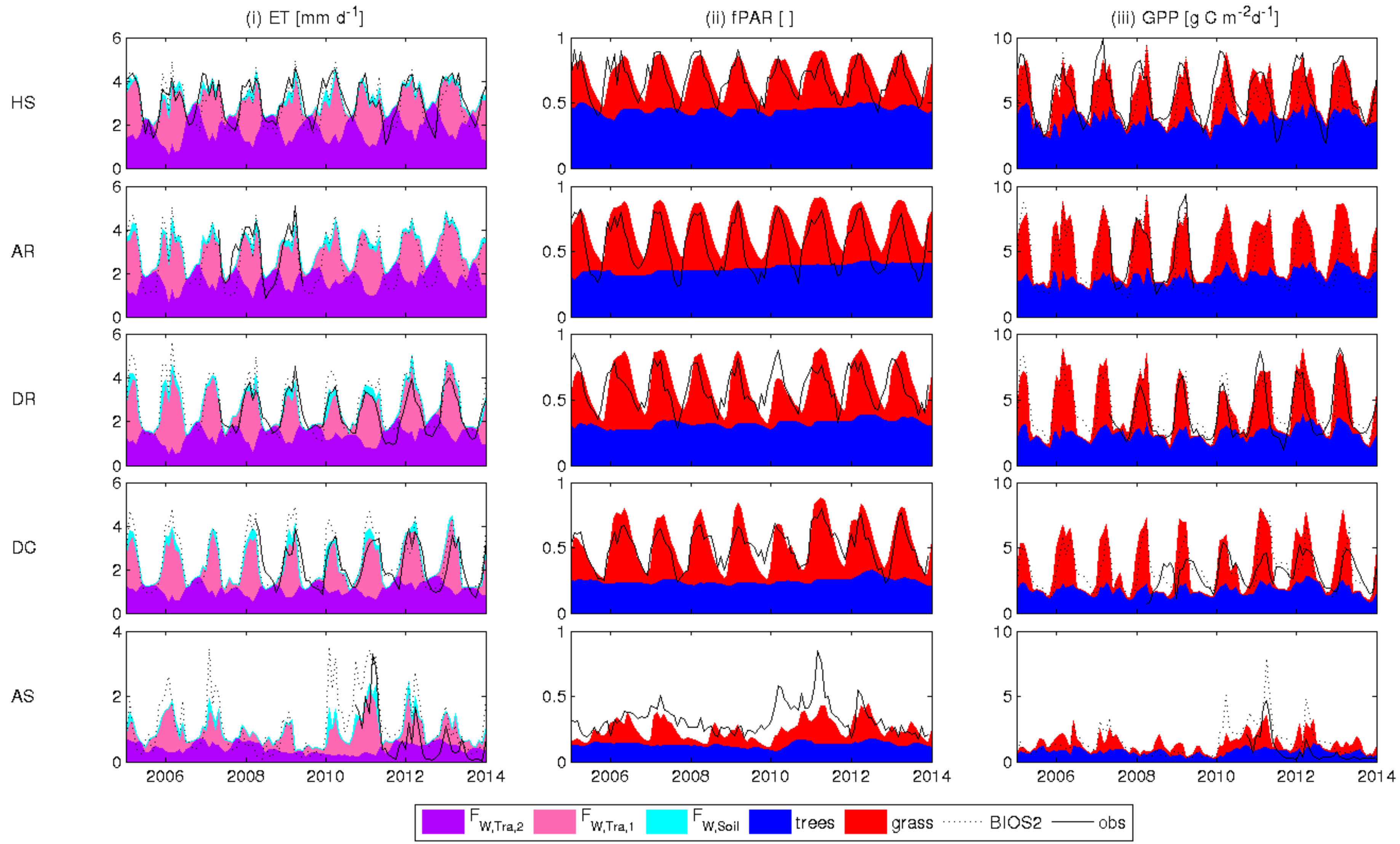
Photos: Adam Liedloff

Sampling the Northern Australian Tropical Transect

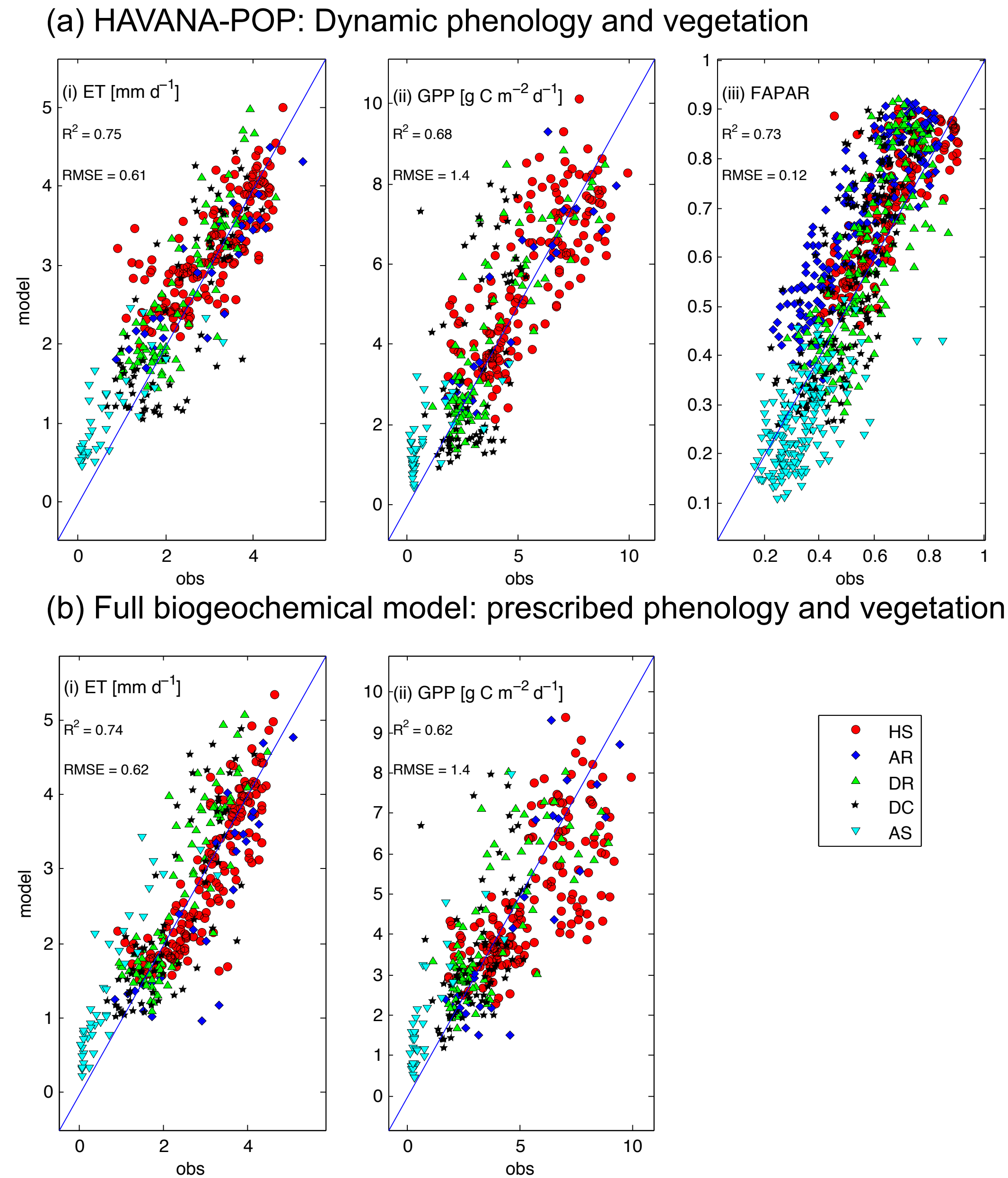




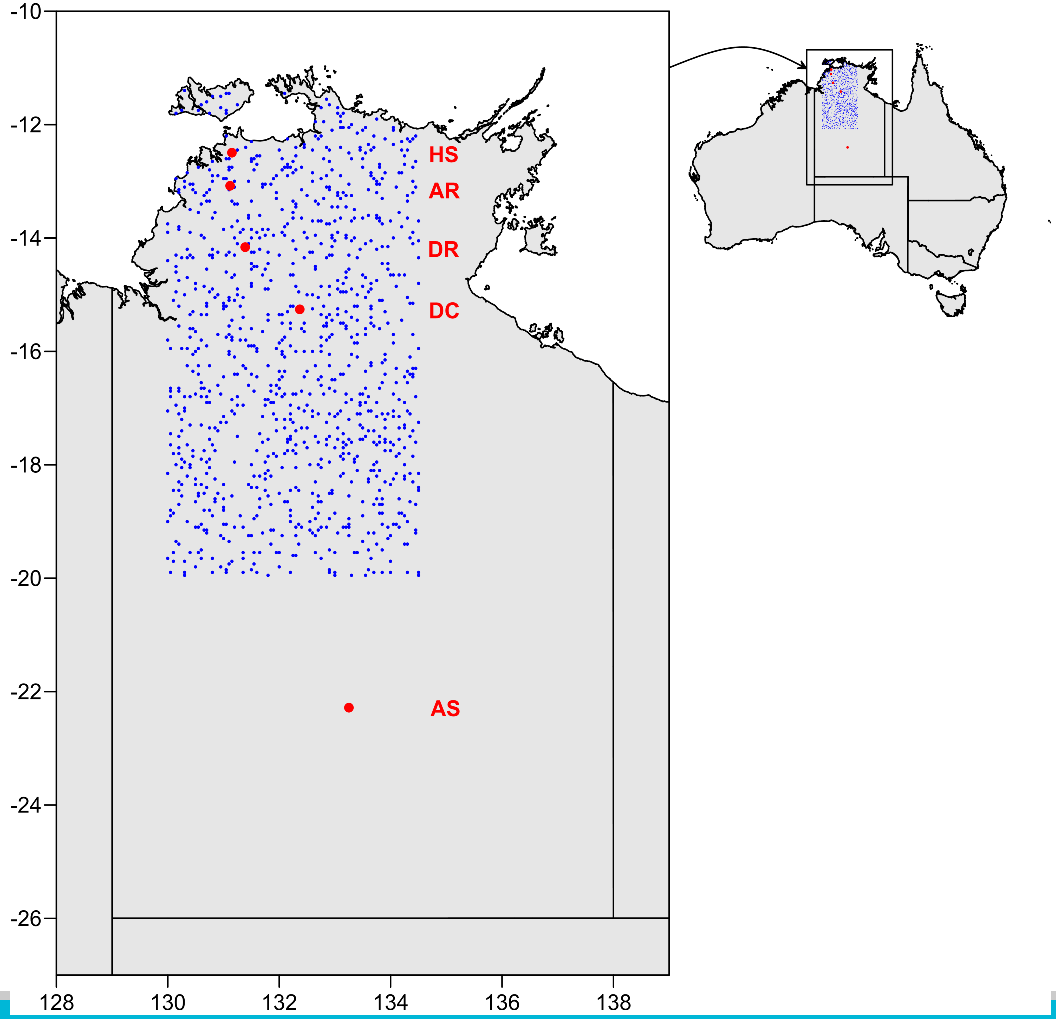
HAVANA-POP: Results for Flux Tower Sites



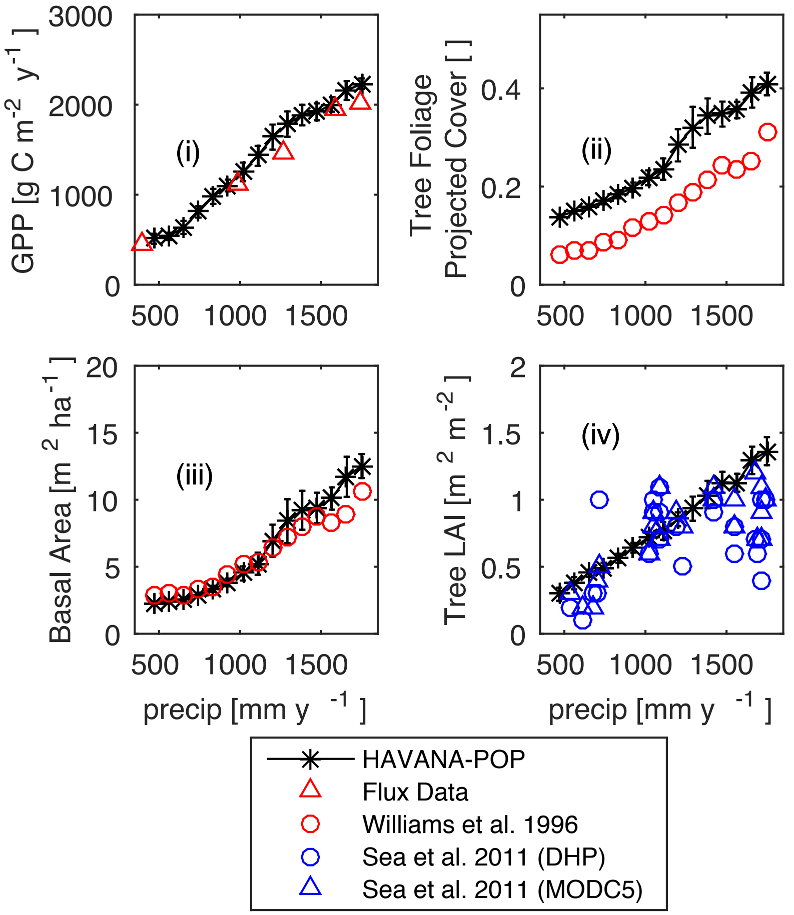
HAVANA-POP: Evaluation against Flux Data and Remotely-Sensed Vegetation Cover (monthly)



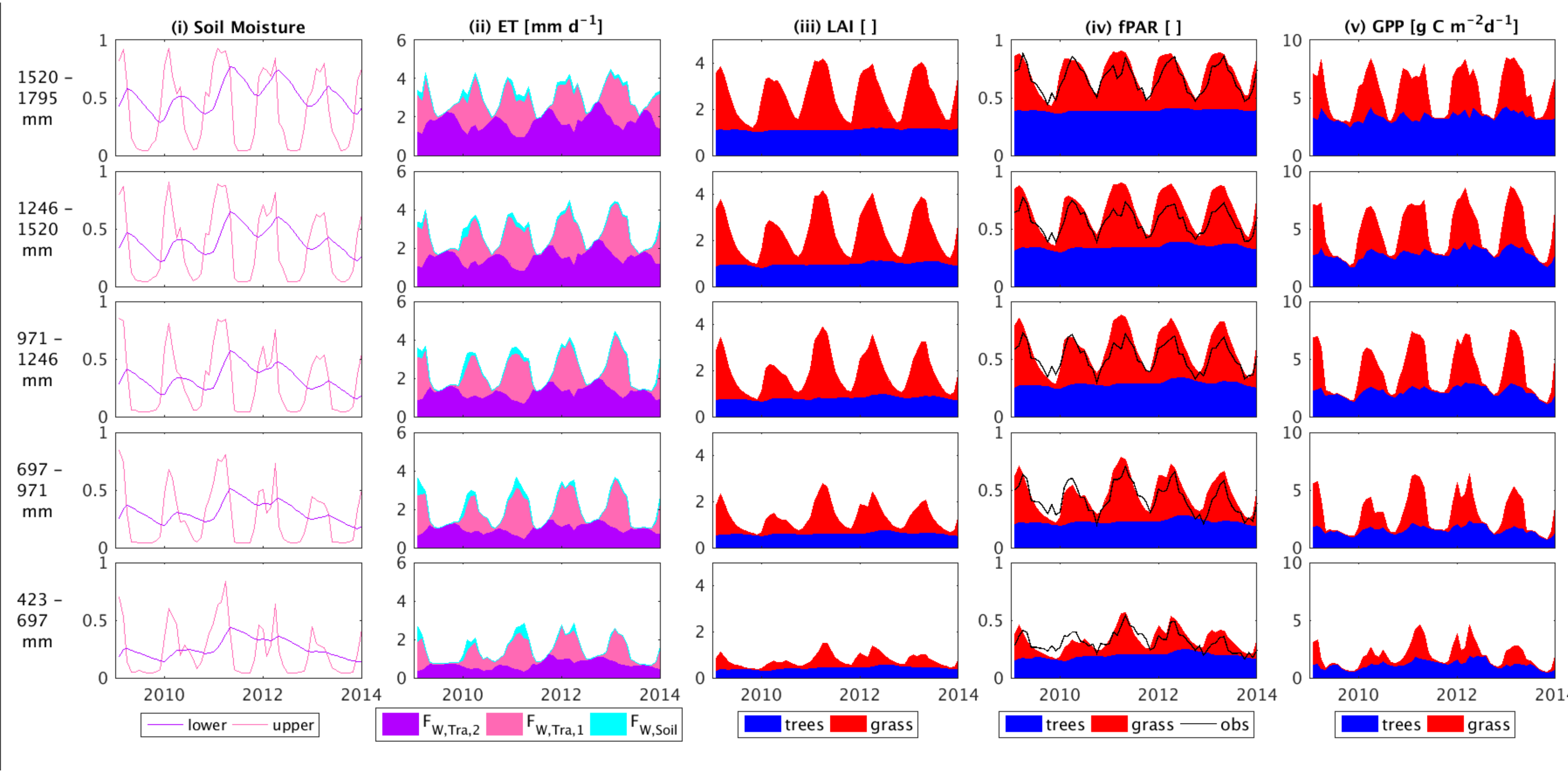
Sampling the Northern Australian Tropical Transect



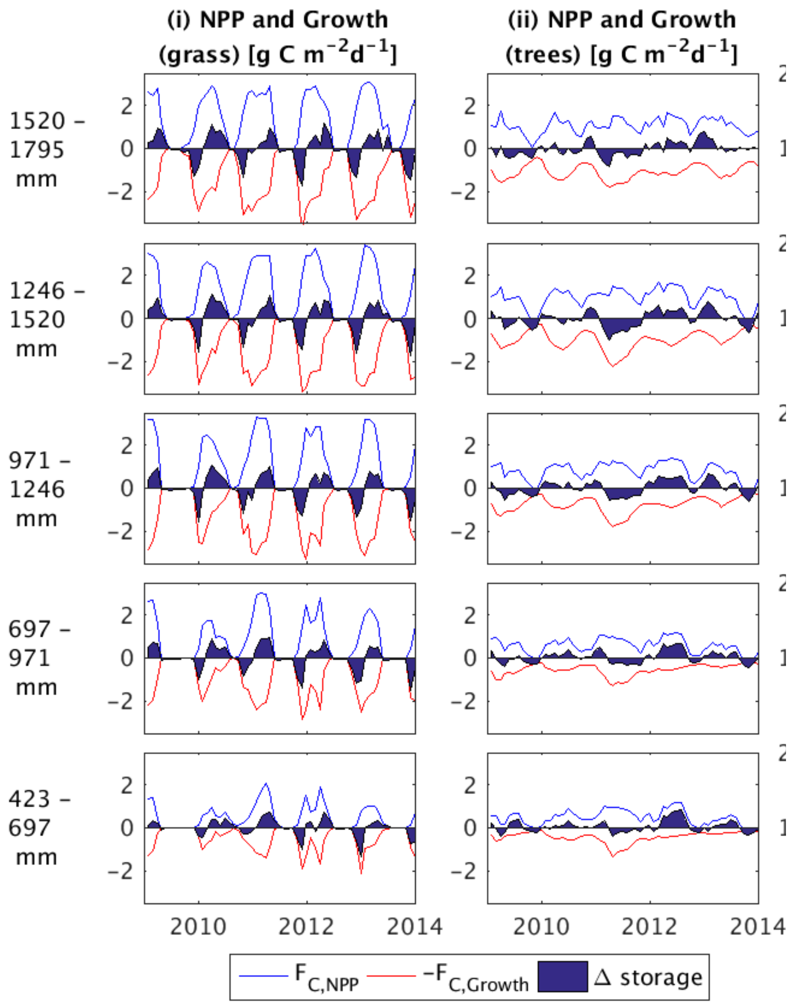
Variation of Structure and Function Along the NATT



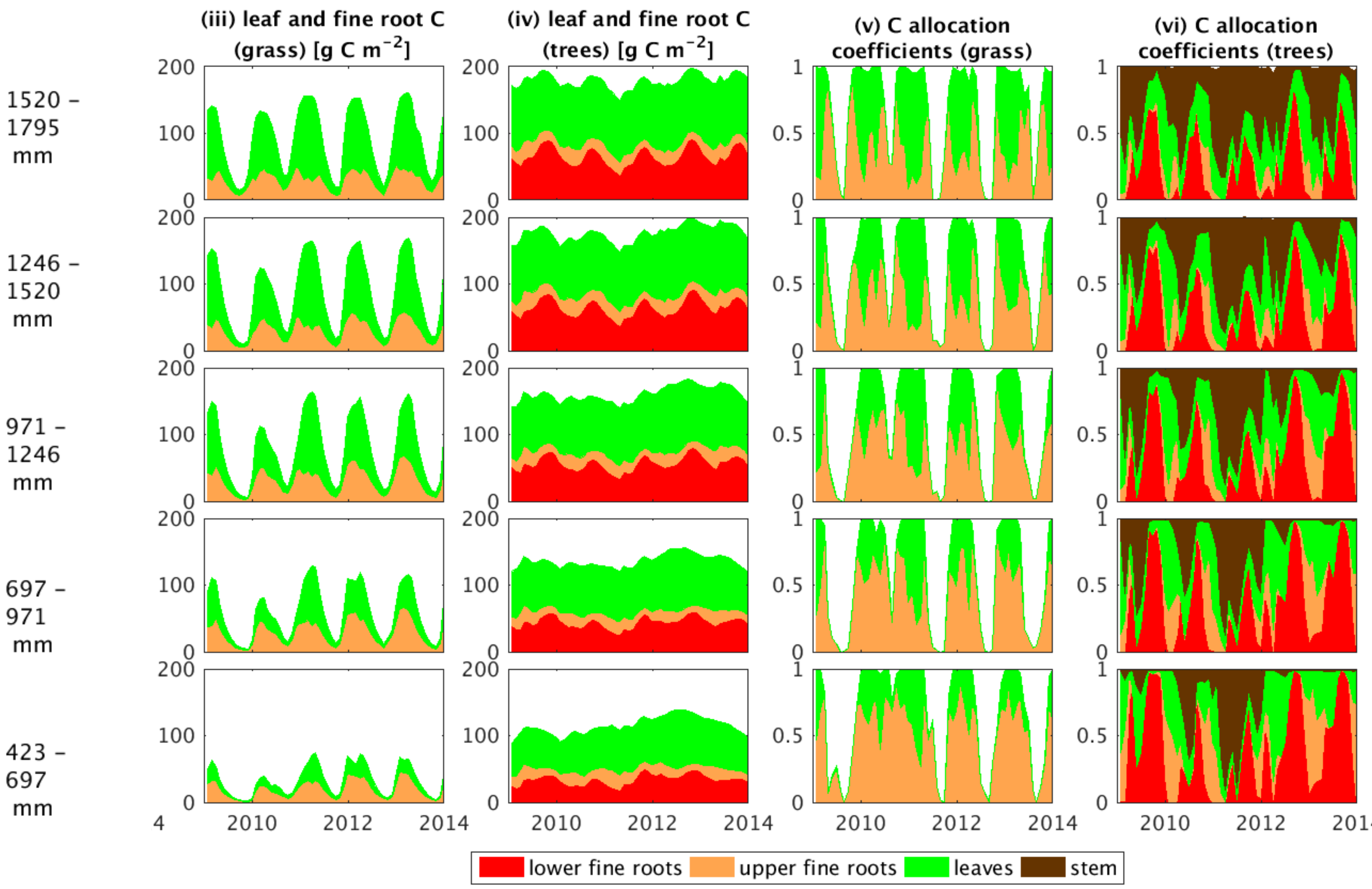
Model Dynamics: Soil Moisture, GPP, LAI



Model Dynamics: NPP, Growth and Storage



Model Dynamics: Allocation and C Pools



Determinant of Woody Vegetation Cover: Resource limitation or Disturbance ?

- HAVANA-POP : 68-84% biomass turnover is attributable to resource-limitation, and the remainder to disturbance.

- Agrees with review by Murphy et al. 2015 “Fire impacts controlling Eucalyptus and Corymbia woody cover have been exaggerated in north Australian savanna, with intraspecific competition for limited water and nutrient resources a far stronger driver of cover”*

- Contrasts with African savannas where woody carrying capacity is limited by rainfall but savannas held below carrying capacity by grazing and fire.**

*Murphy, B. P., Liedloff, A. C., and Cook, G. D.: Does fire limit tree biomass in Australian savannas?, International Journal of Wildland Fire, 24, 1, 2015.

**Sankaran, M., Hanan, N. P., Scholes, R. J., Ratnam, J., Augustine, D. J., Cade, B. S., Gignoux, J., Higgins, S. I., Le Roux, X., and Ludwig, F.: Determinants of woody cover in African savannas, Nature, 438, 846-849, 2005.

Conclusion

- HAVANA-POP predicts tree/grass partitioning along the NATT.
- Predictions emerge from complex feed-backs between plant function and structure, and not from imposed hypotheses about the controls on tree-grass coexistence

Future Directions

- Implementation of Coupled Phenology/Allocation into CABLE-POP-BLAZE
- Apply to global Savannas