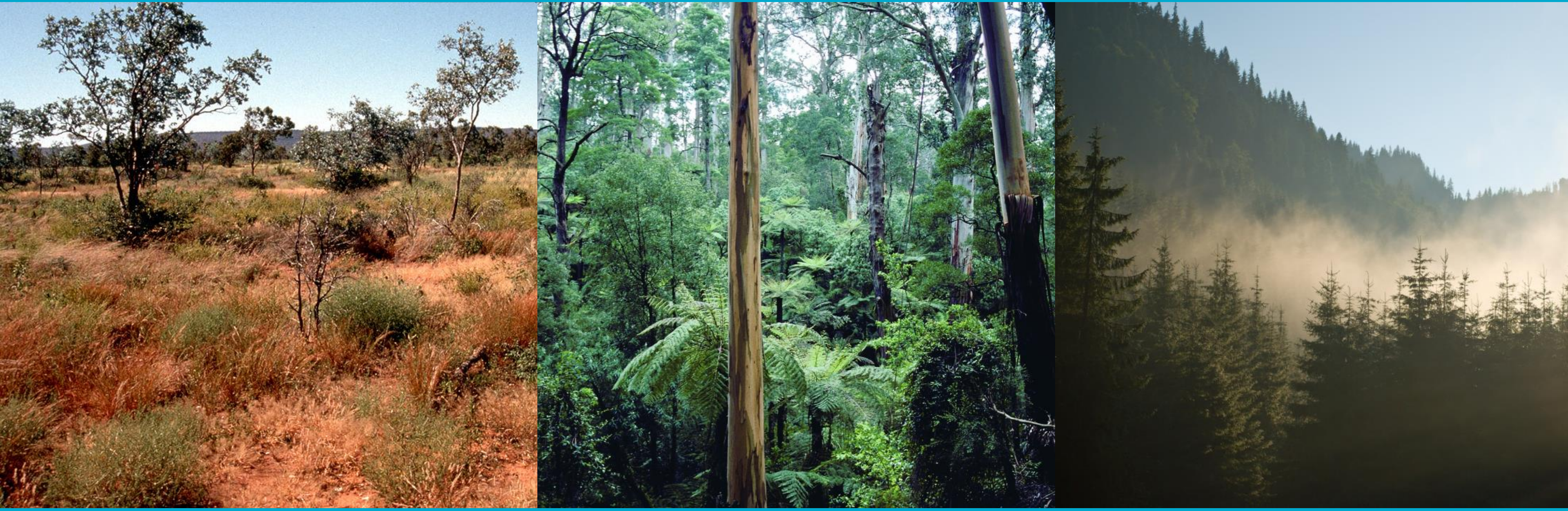
A stand-alone tree demography and landscape structure module for Earth system models

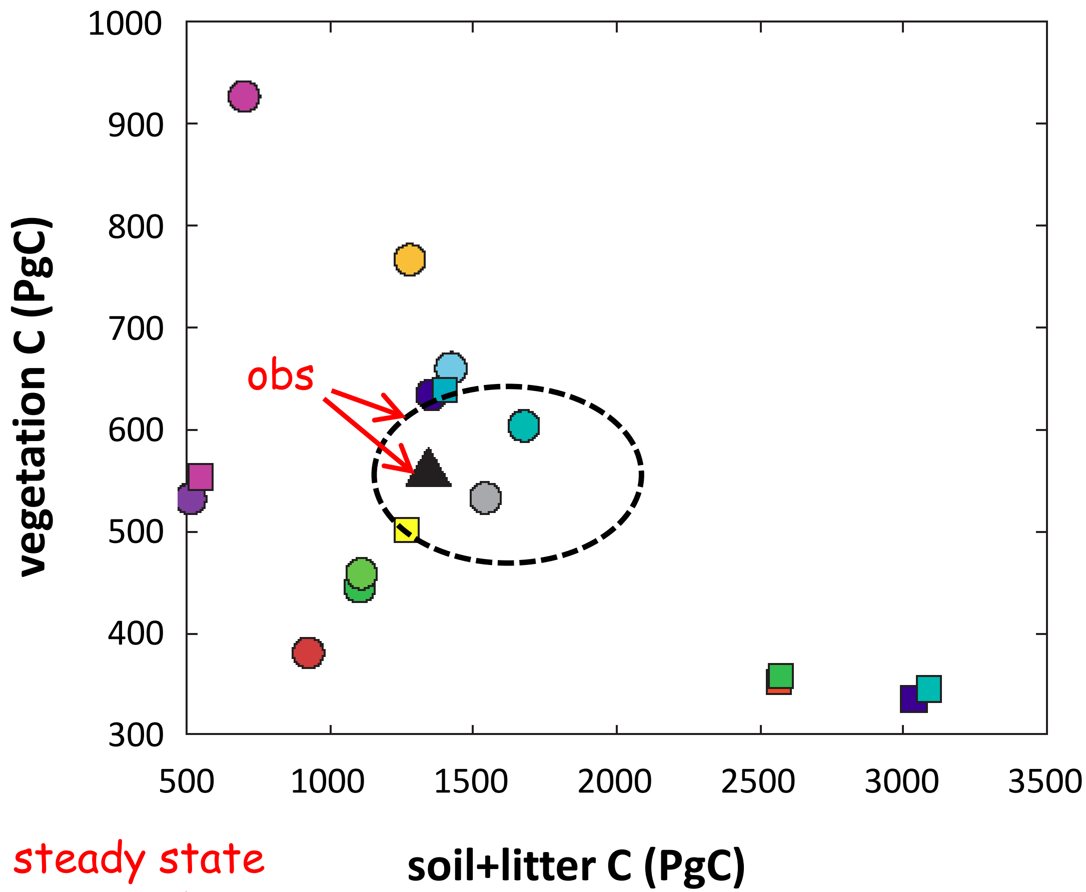
Integration with Australian savanna and global forest data



CSIRO OCEANS AND ATMOSPHERE
www.csiro.au

Vanessa Haverd, Ben Smith, Lars Nieradzik,
Peter Briggs, Cathy Trudinger, Pep Canadell

Wild Disgreement between Baseline (1986-2005) simulated terrestrial ecosystem C pools in CMIP5 carbon-climate ESMs



models disagree on steady state
by factor 3 for vegetation C,
factor 6 for soil C

Anav et al. 2013
J. Climate 26: 6801

Basic equation governing biomass pool dynamics in global C cycle models

C mass of pool ‘y’
(e.g. leaves, roots, stems)

input to litter
—strongly governs soil carbon dynamics and respiration

$$\frac{dC_y}{dt} = f_y NPP - \overbrace{\tau_y C_y}$$

fraction of NPP allocated to pool ‘y’

turnover (1/yr) of pool ‘y’

- phenology
- stress (and background) mortality
- disturbance frequency and impact

CSIRO

PNAS

Carbon residence time dominates uncertainty in terrestrial vegetation responses to future climate and atmospheric CO_2

Andrew D. Friend[a,1], Wolfgang Lucht[b,c], Tim T. Rademacher[a], Rozenn Keribin[a], Richard Betts[d], Patricia Cadule[e], Philippe Ciais[f], Douglas B. Clark[g], Rutger Dankers[d], Pete D. Falloon[d], Akihiko Ito[h], Ron Kahana[d], Axel Kleidon[i], Mark R. Lomas[j], Kazuya Nishina[h], Sebastian Ostberg[b], Ryan Pavlick[i], Philippe Peylin[f], Sibyll Schaphoff[b], Nicolas Vuichard[f], Lila Warszawski[b], Andy Wiltshire[d], and F. Ian Woodward[j]

Friend et al., 2014
PNAS, 111: 3280

- Vegetation responses predicted by 7 GVMs to CMIP5 future climate projections

- “A change in research priorities away from production and toward structural dynamics and demographic processes is recommended.”

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Our Goal: Vegetation dynamics approach for ESMs that is:

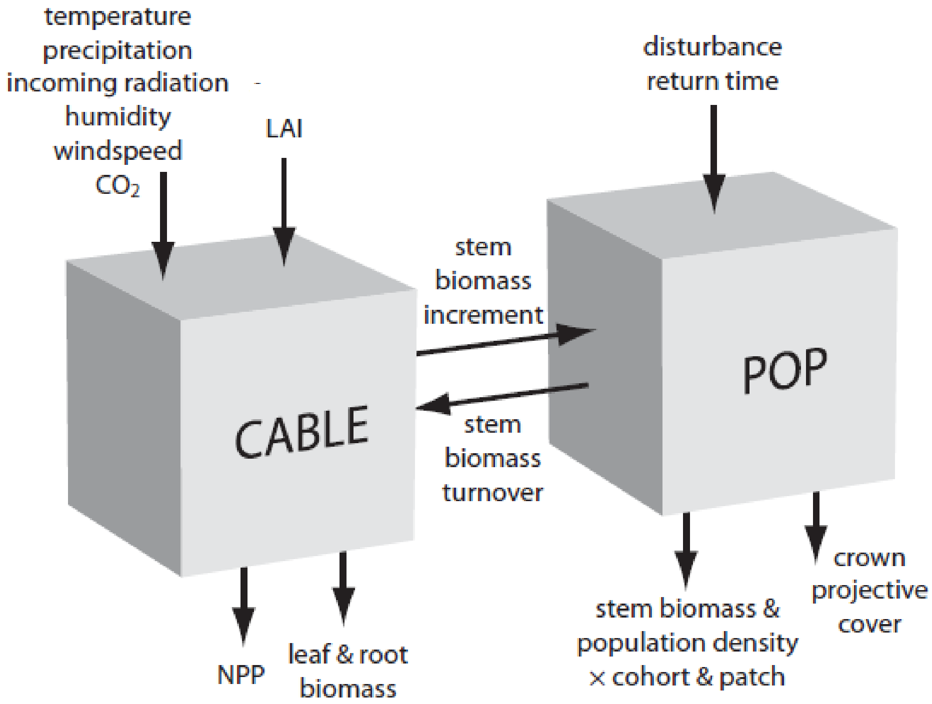
- **ecologically defensible,** separates individual and population growth
- **modular**, coupled to, not integrated within, existing ESM land surface model
- **deterministic**
- **computationally efficient**

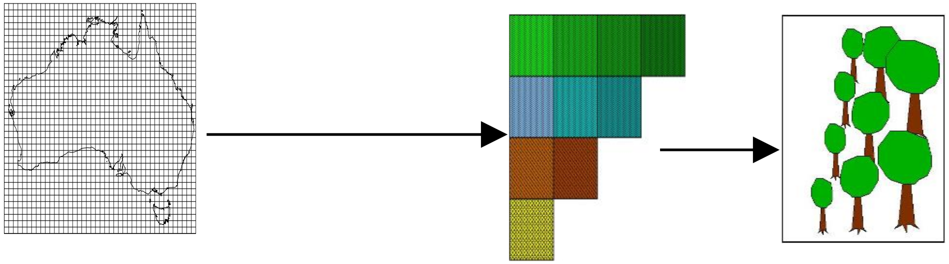
Proposed new approach: Populations-order-physiology (POP)

- Forcing by whole-ecosystem stem biomass increment from host LSM
- Simulate recruitment, allometric growth and mortality of age-size cohorts of generic trees in local stands (patches)
- Partition total stem biomass increment among stands and cohorts as a declining proportion of current size
- Mortality influenced by declining growth efficiency under crowding and with increased size
- Upscaling to landscape (grid cell) by interpolation among stands of different age-since-disturbance
- Two disturbance types:
    - catastrophic (e.g. Cyclone)
    - partial (e.g. wildfire)

Proposed new approach: Populations-order-physiology (POP)

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



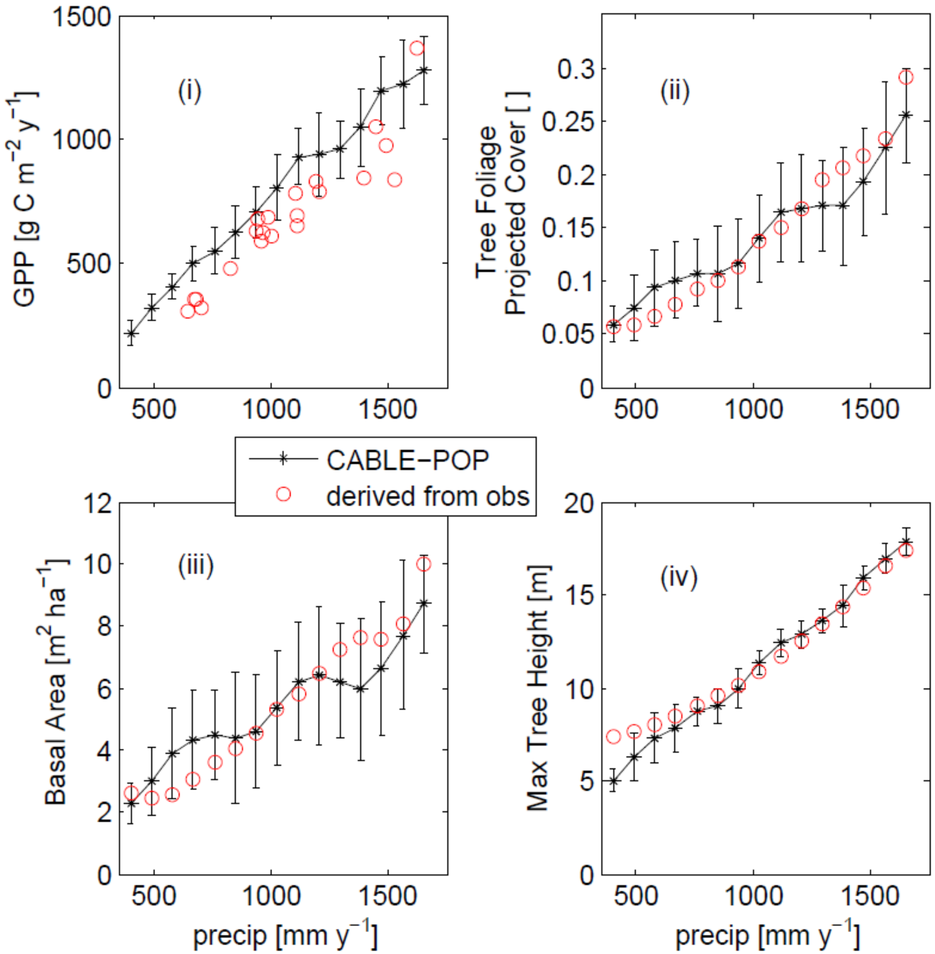


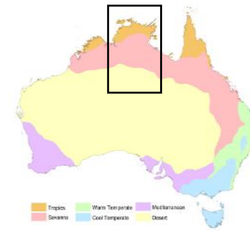
Grid-cells

patches (disturbance)

cohorts (recruitment, growth, mortality)

Case Study 1: Vegetation Structure along the North Australian Tropical Transect*





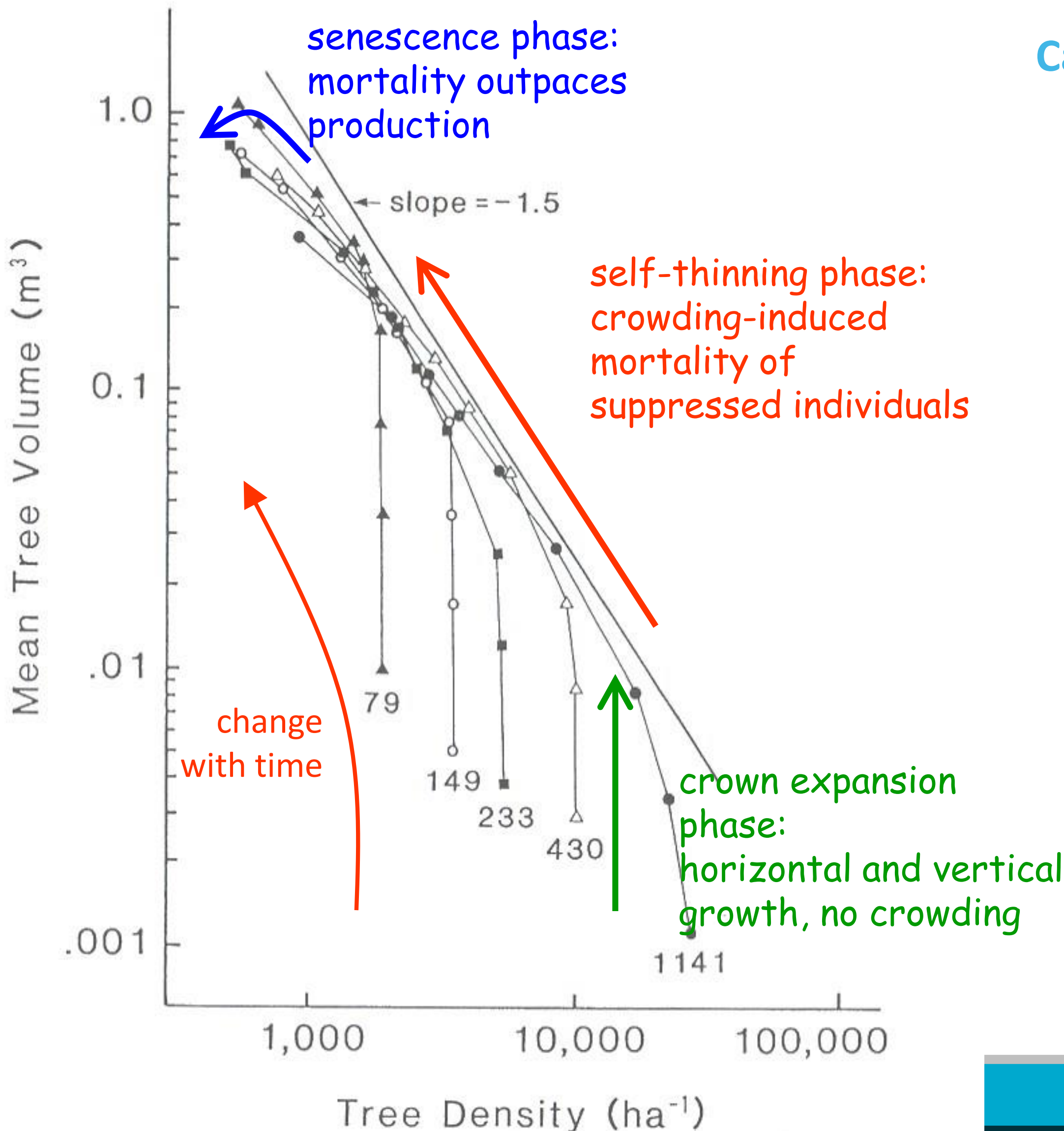
Observation-based estimates:

GPP: Kanniah et al. 2011. Agr. For. Meteor. 151: 1429

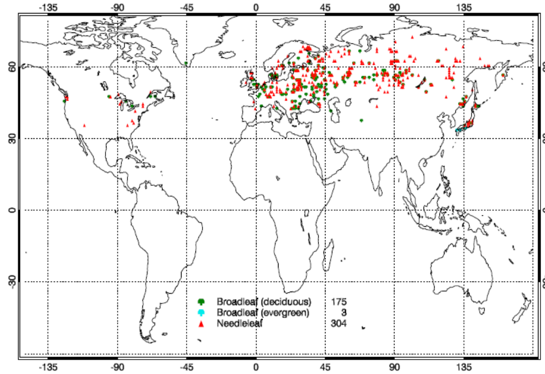
Forest structure: Williams et al. 1996. Aust. J. Biogeogr. 23: 747

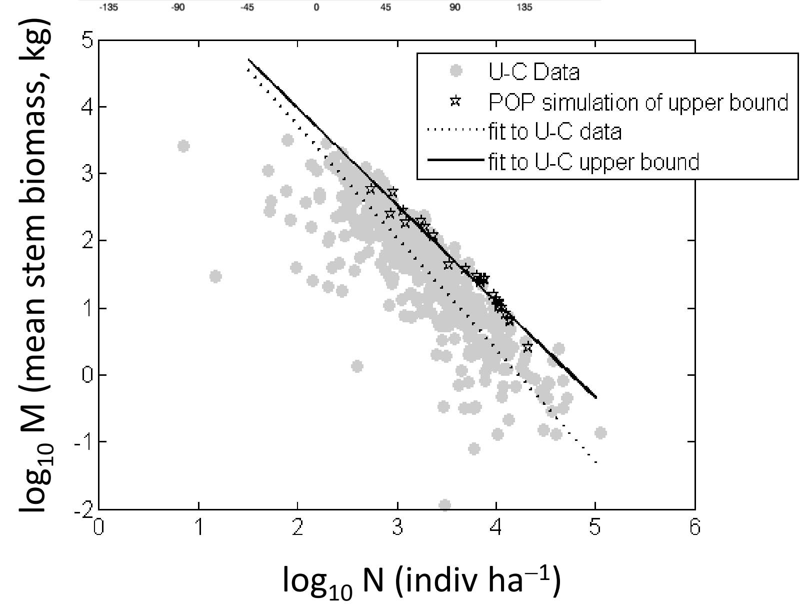
*Haverd et al. 2013, *Geophys. Res. Lett.* 40: 5234-5239

Case Study 2: demographic and structure-function relationships for temperate and boreal forest ecosystems



Calibration of POP crowding mortality*

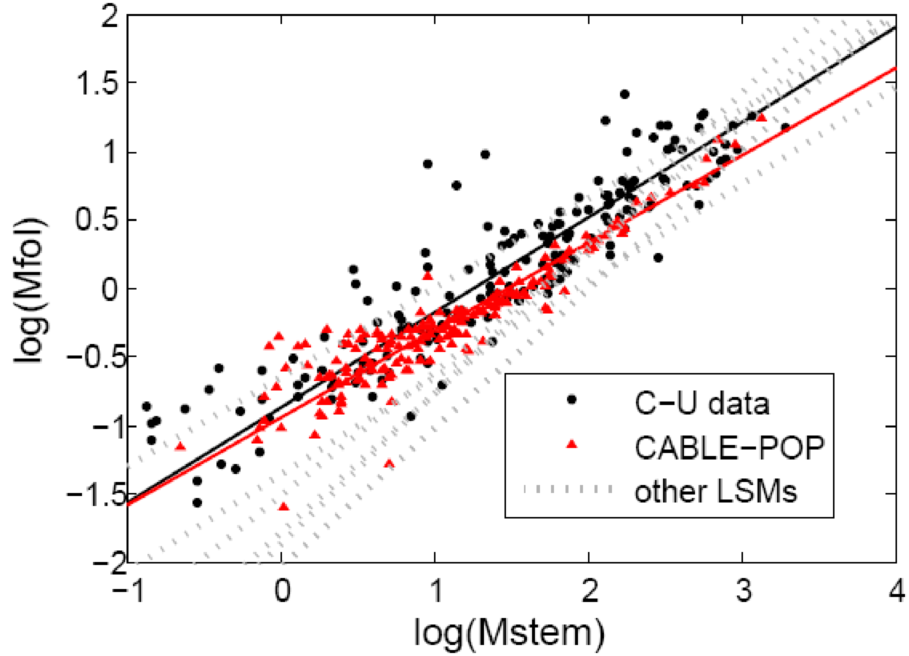




*Haverd et al., 2014 Biogeosciences **11**: 4039-4055

POP reproduces observation-based leaf-stem allometry relation*

"Function"



"Structure"

Curve fits for other LSMs:
Wolf et al. 2011 Global Biogeochem Cycles 25

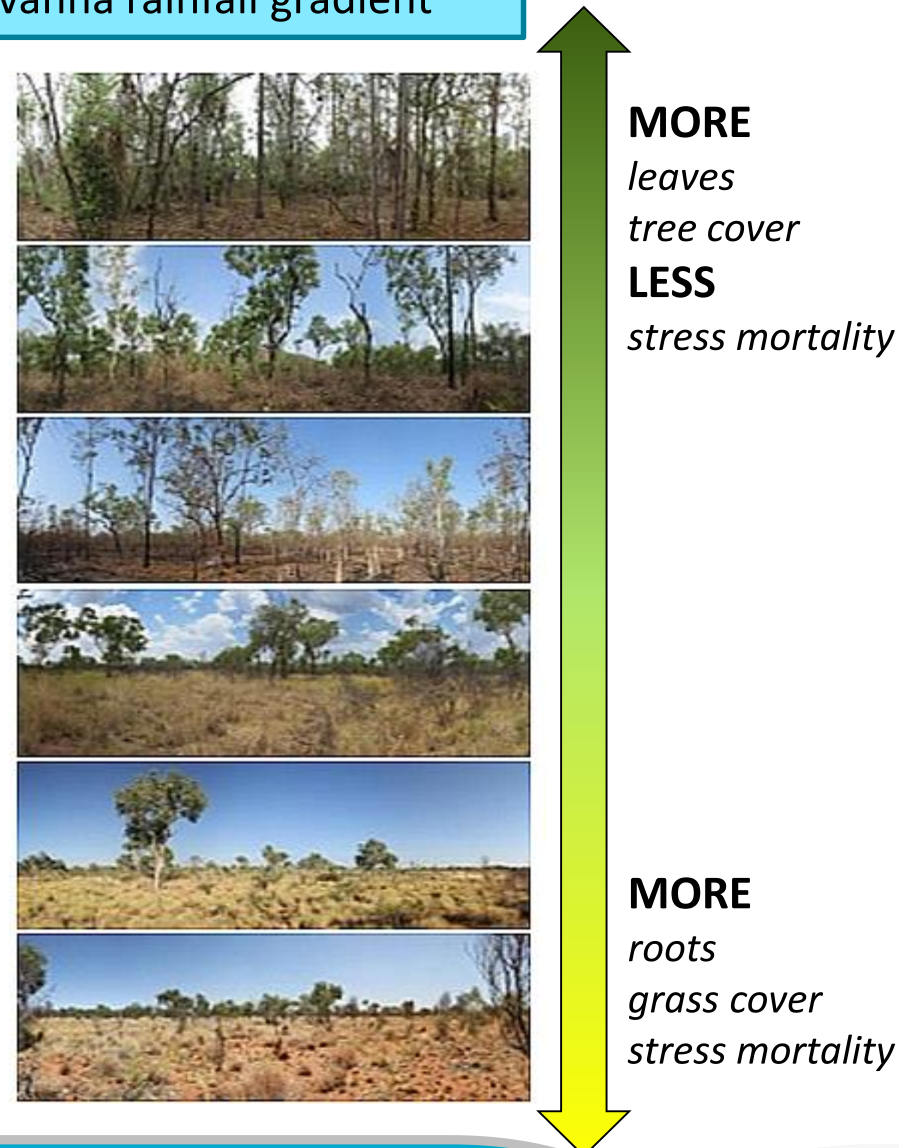
Case Study 3: Coupling carbon allocation with leaf and root phenology accounts for tree-grass partitioning along a savanna rainfall gradient*

Additional structure → function (POP → LSM) feedbacks

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

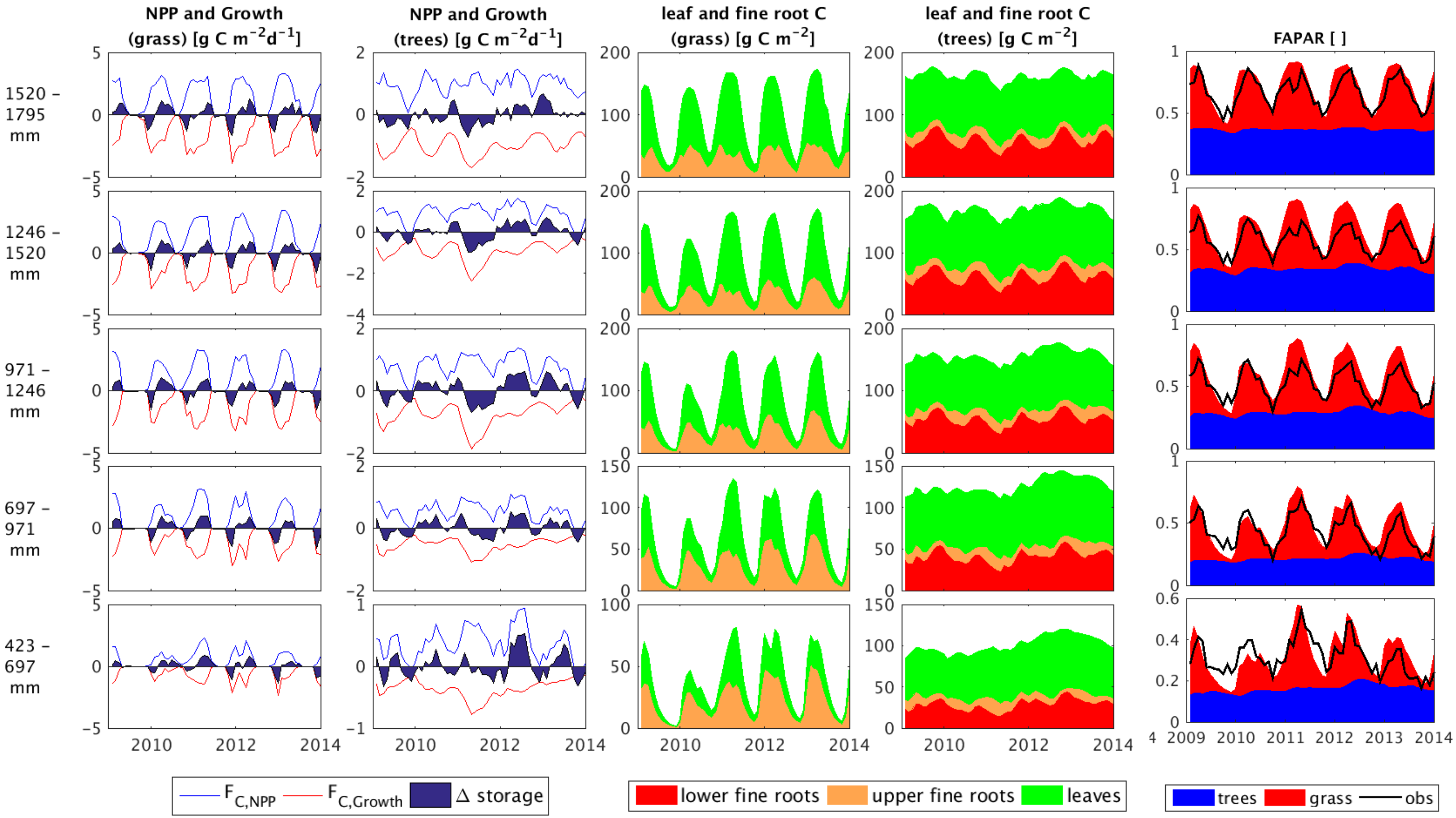
HAVANA (Hydrology, Allocation and Vegetation-dynamics Algorithm for Northern Australia) land surface model

- •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

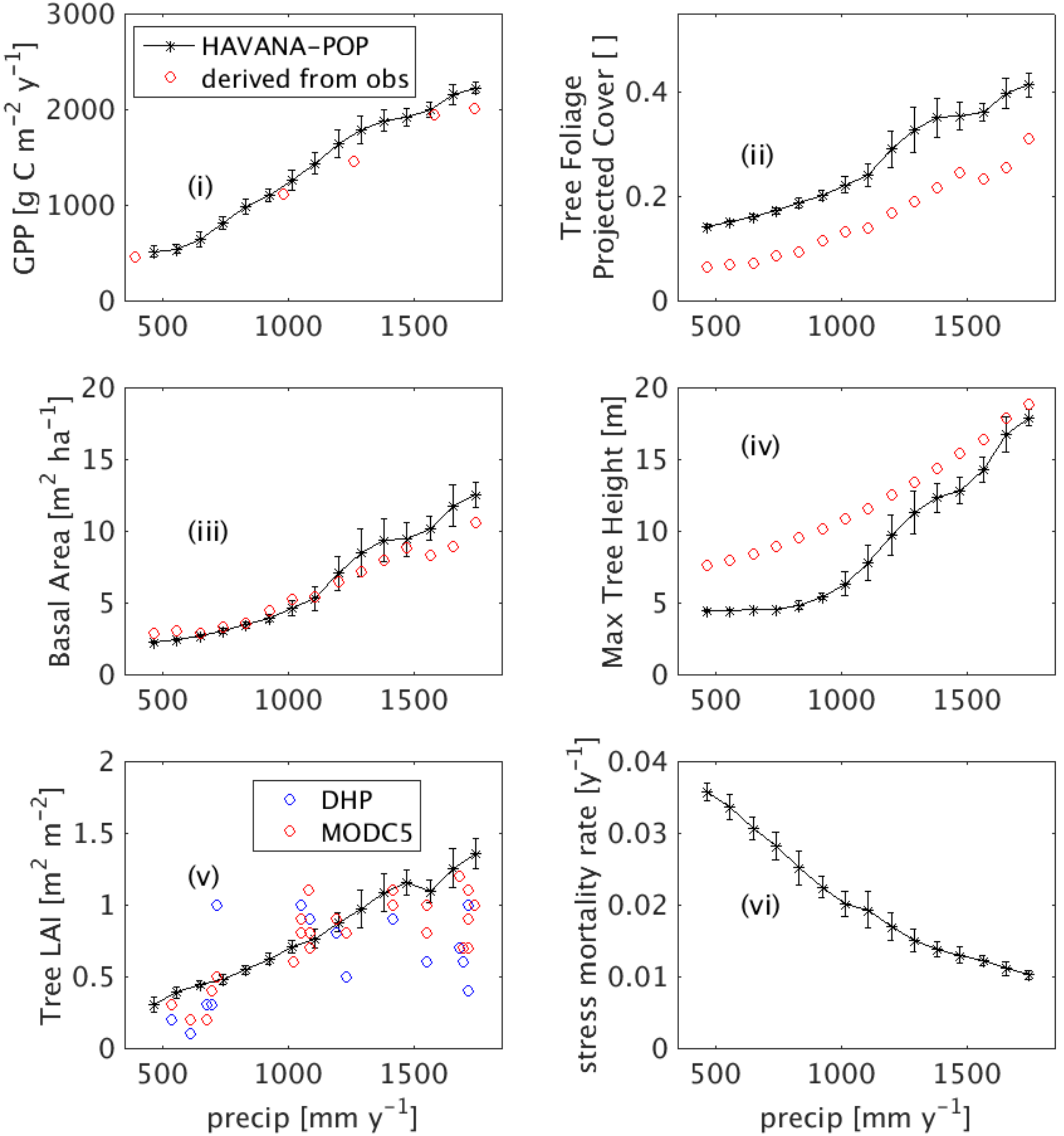


*Haverd et al. 2015, in prep

HAVANA-POP productivity, growth and phenology predictions along the NATT



HAVANA-POP vegetation structure, productivity and mortality along the NATT*



Observation-based estimates:

GPP: OzFlux

Forest structure: Williams et al. 1996. Aust. J. Biogeogr. 23: 747

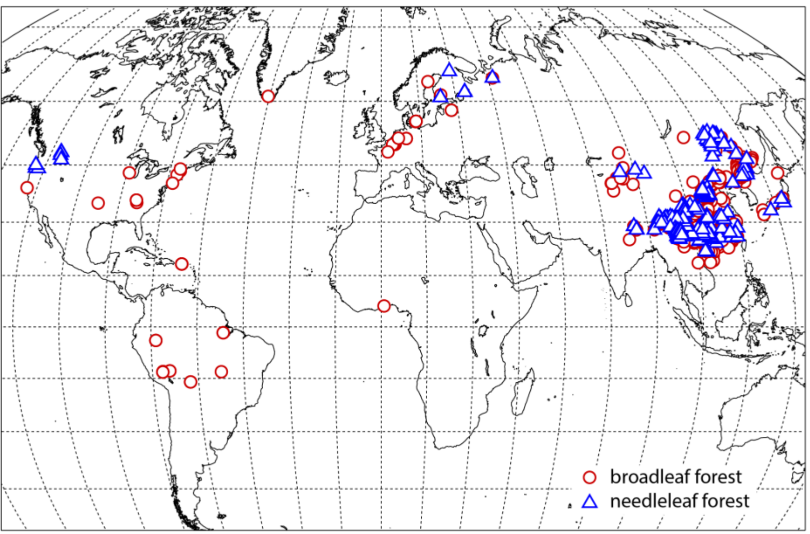
Case Study 4: Age effects on Net Primary Production

ARTICLE

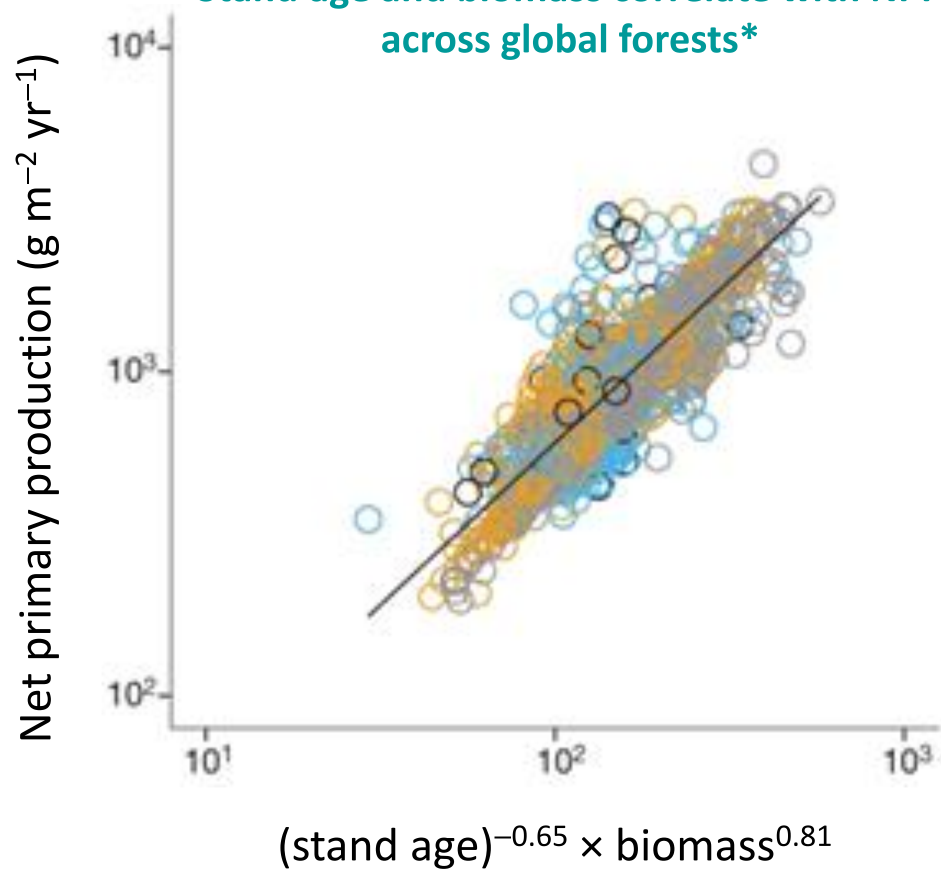
doi:10.1038/nature13470

Convergence of terrestrial plant production across global climate gradients

Sean T. Michaletz[1], Dongliang Cheng[2], Andrew J. Kerkhoff[3] & Brian J. Enquist[1,4,5,6]



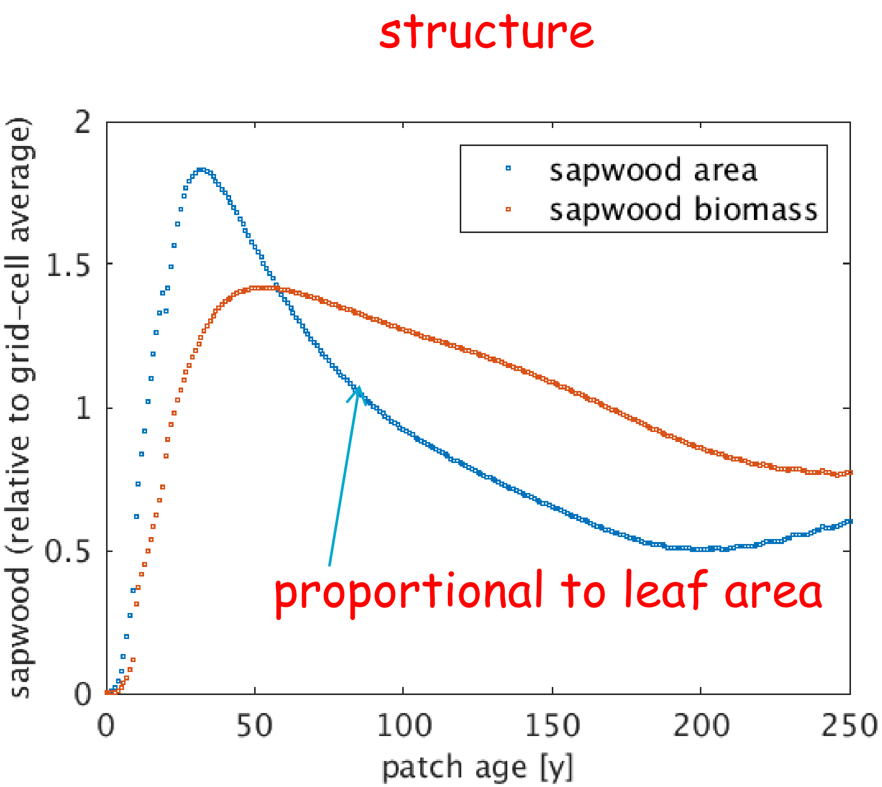
Stand age and biomass correlate with NPP across global forests*

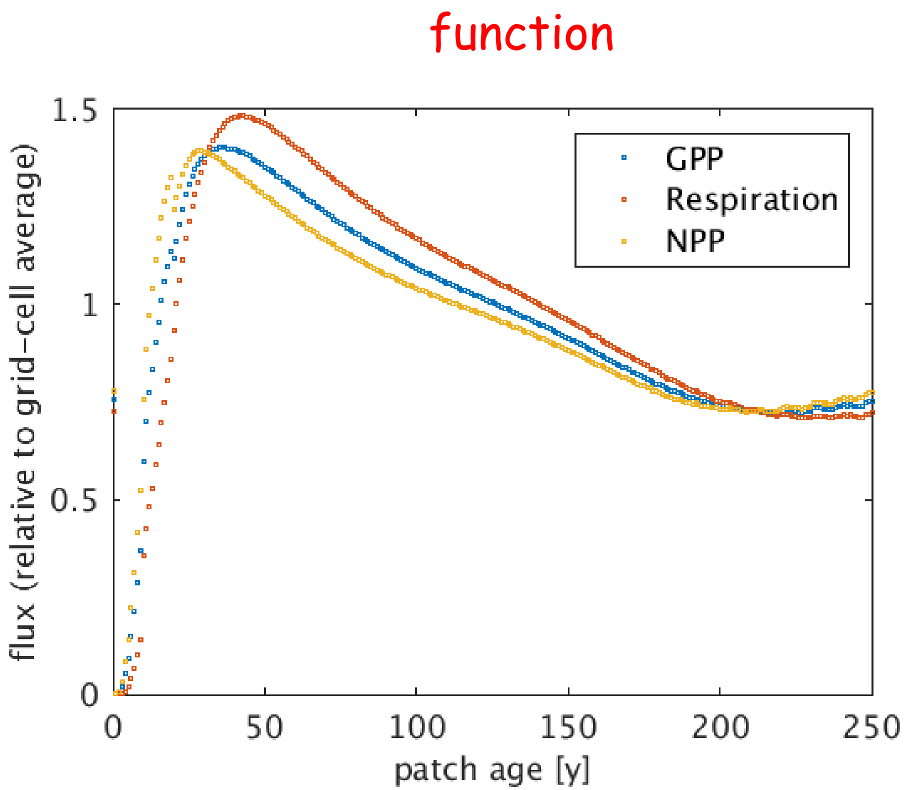


"Climate controls NPP via biomass and age"

*Michaletz et al. 2014
Nature 512: 39-44

Age effects on Net Primary Production in POP

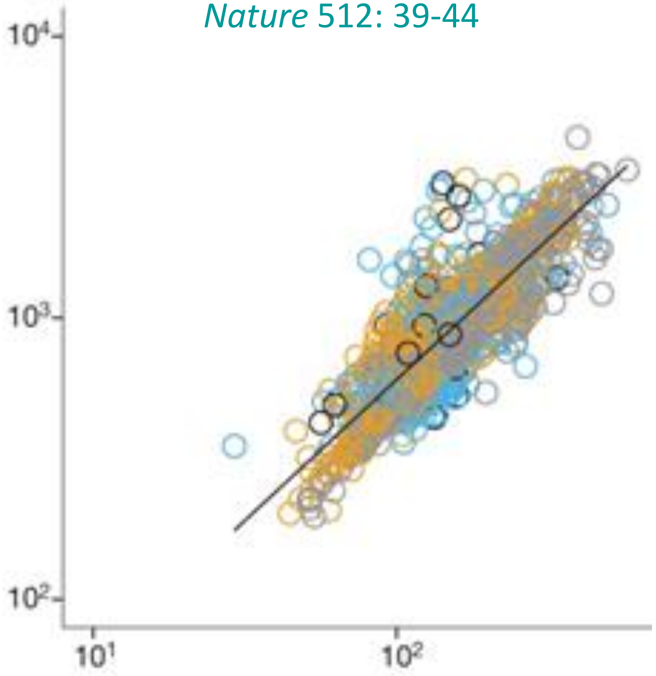


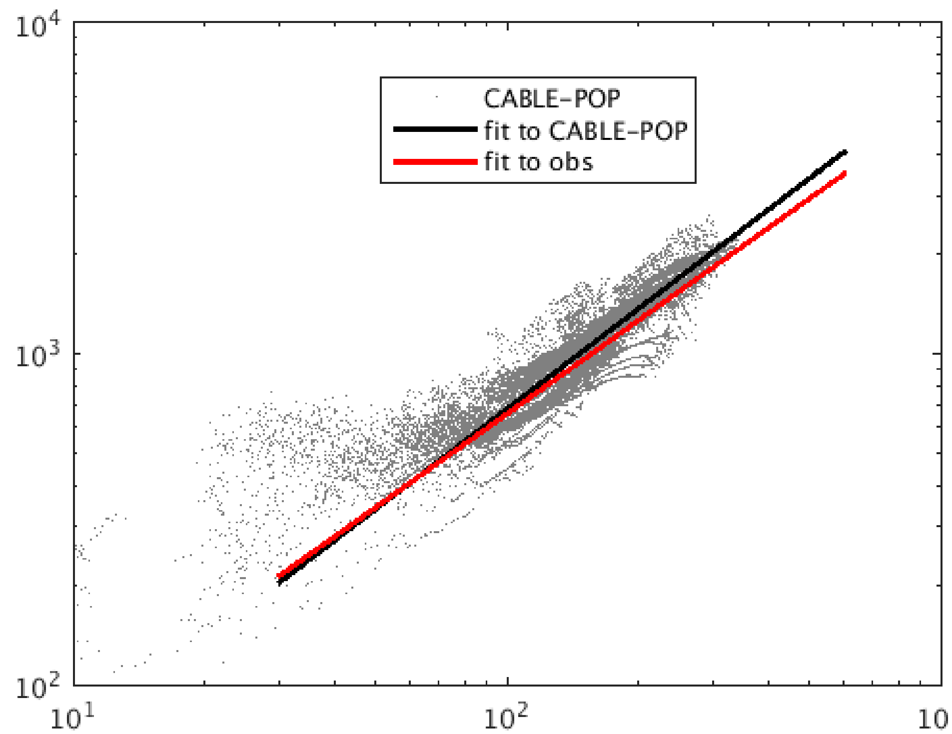


Climate controls NPP via biomass and age*

*Michaletz et al. 2014
Nature 512: 39-44

Net primary production ($g\ m^{-2}\ yr^{-1}$)

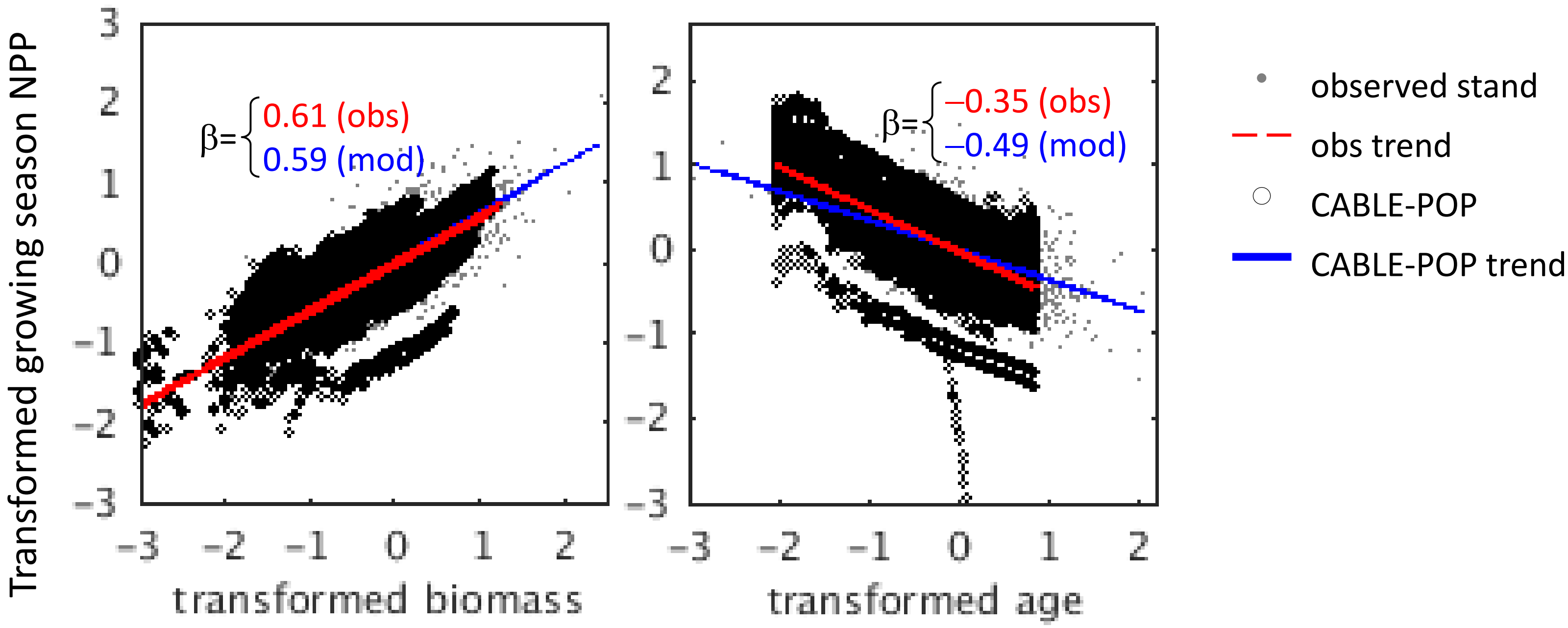




$(\text{stand age})^{-0.65} \times \text{biomass}^{0.81}$

Stand age and biomass correlate with NPP across global forests*

Partial regression plots



Transformed biomass

Transformed age

*Michaletz et al. 2014. *Nature* 512: 39-44

Conclusion

- Structural dynamics need to be included in ESMs
  - Biomass turnover
  - Plant function and biophysical coupling to the atmosphere
- There is a need for change and a solution available (code available online):

  Haverd, V., Smith, B., Nieradzik, L. P., and Briggs, P. R.: A stand-alone tree demography and landscape structure module for Earth system models: integration with inventory data from temperate and boreal forests, Biogeosciences, 11, 4039-4055, doi:10.5194/bg-11-4039-2014, 2014.