Vegetation dynamics in drylands: simulations and observations

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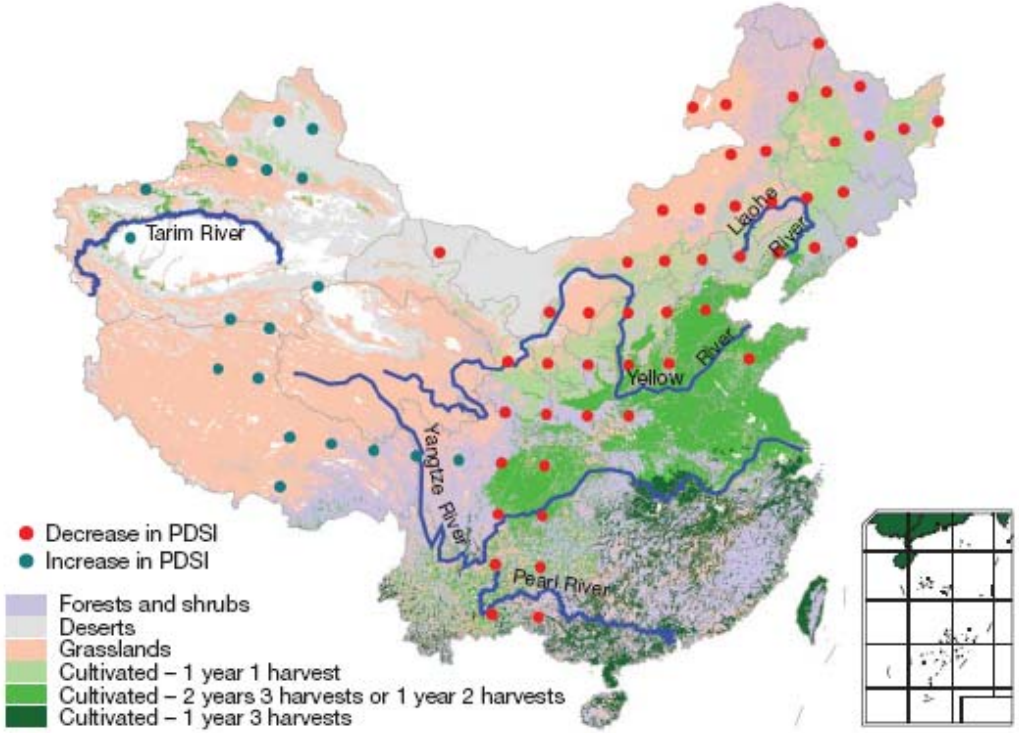
- Simulation and observation
- Tree growth and forest NPP
- Savanna vegetation dynamics

Scientific questions in drylands

Threatens from drought

The impacts of climate change on water resources and agriculture in China



Piao et al., 2010 Vol 467|2 September 2010|

Hundreds of thousands fled the 1930s US Dust Bowl; more drought-spurred migrations are expected.

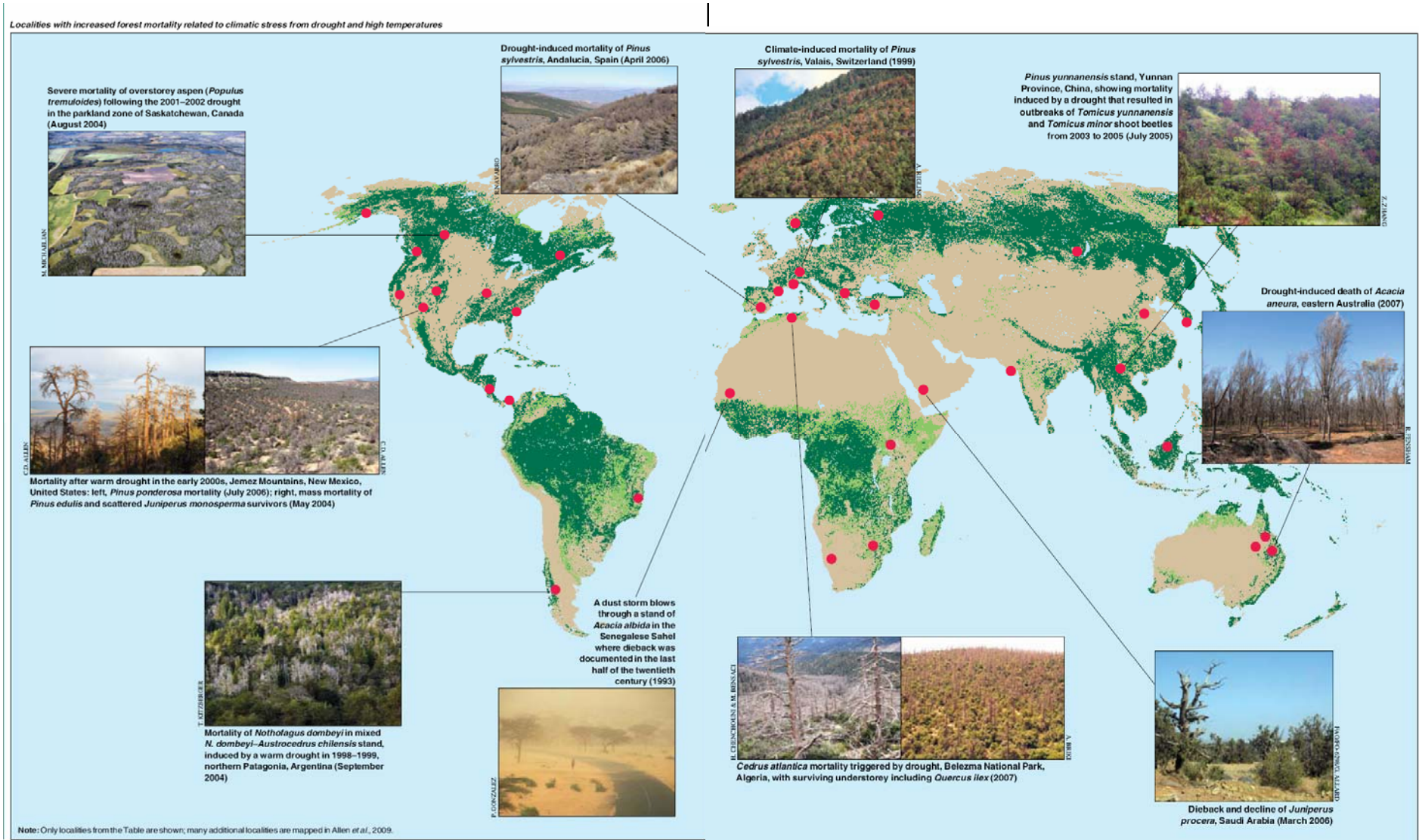
The next dust bowl

Drought is the most pressing problem caused by climate change. It receives too little attention, says **Joseph Romm**.

| NATURE | VOL 478 | 27 OCTOBER 2011

Scientific questions in drylands

Growth and die-off



Scientific questions in drylands

Carbon and water

Trading Water for Carbon with Biological Carbon Sequestration

Robert B. Jackson,[1*] Esteban G. Jobbágy,[1,2] Roni Avissar,[3] Somnath Baidya Roy,[3] Damian J. Barrett,[4] Charles W. Cook,[1] Kathleen A. Farley,[1] David C. le Maitre,[5] Bruce A. McCarl,[6] Brian C. Murray[7]

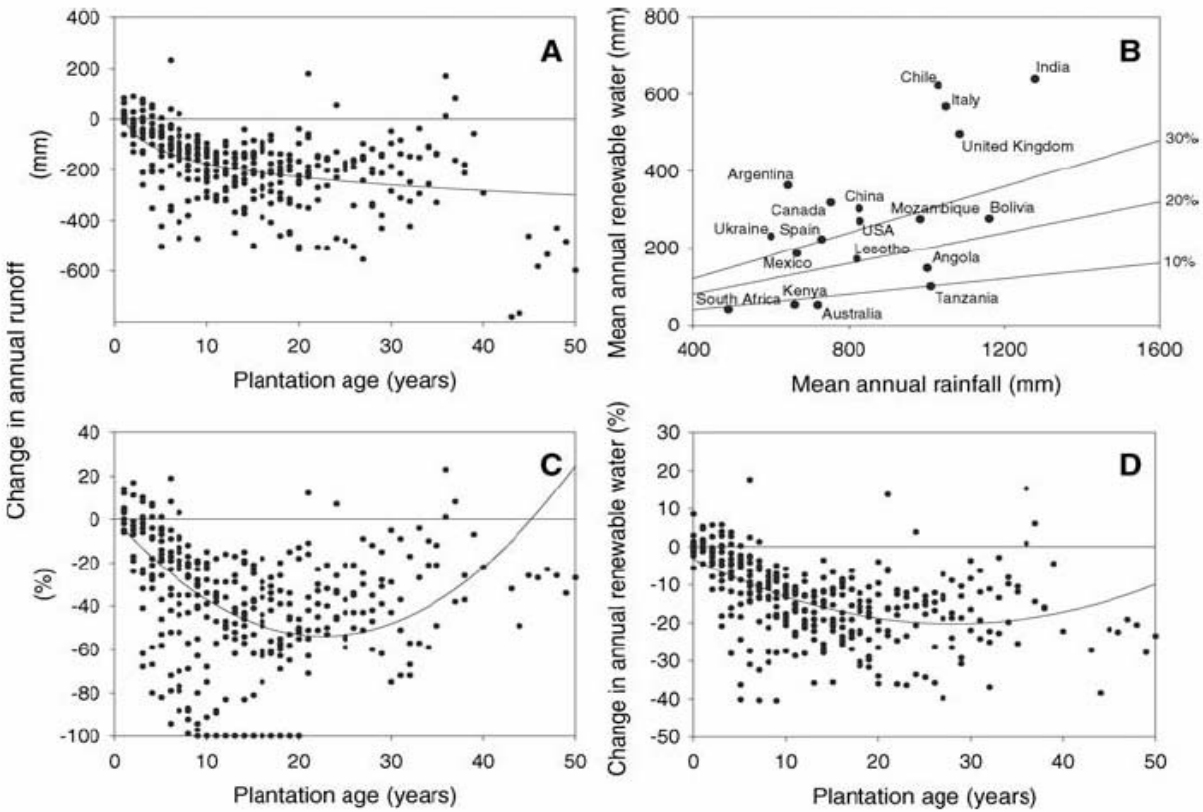


Fig. 1. Changes in stream flow and annual renewable water as a function of plantation age, and the relative abundance of renewable water by country. Changes in stream flow in mm (A) and proportion (%) (C) as a function of plantation age. (D) Changes in annual renewable water (annual stream flow in mm divided by annual precipitation). (B) Average renewable freshwater (mm) versus mean annual precipitation (mm) by nation. The lines define 10%, 20%, and 30% renewable water as a percentage of MAP. See (*13*).

23 DECEMBER 2005 VOL 310 SCIENCE

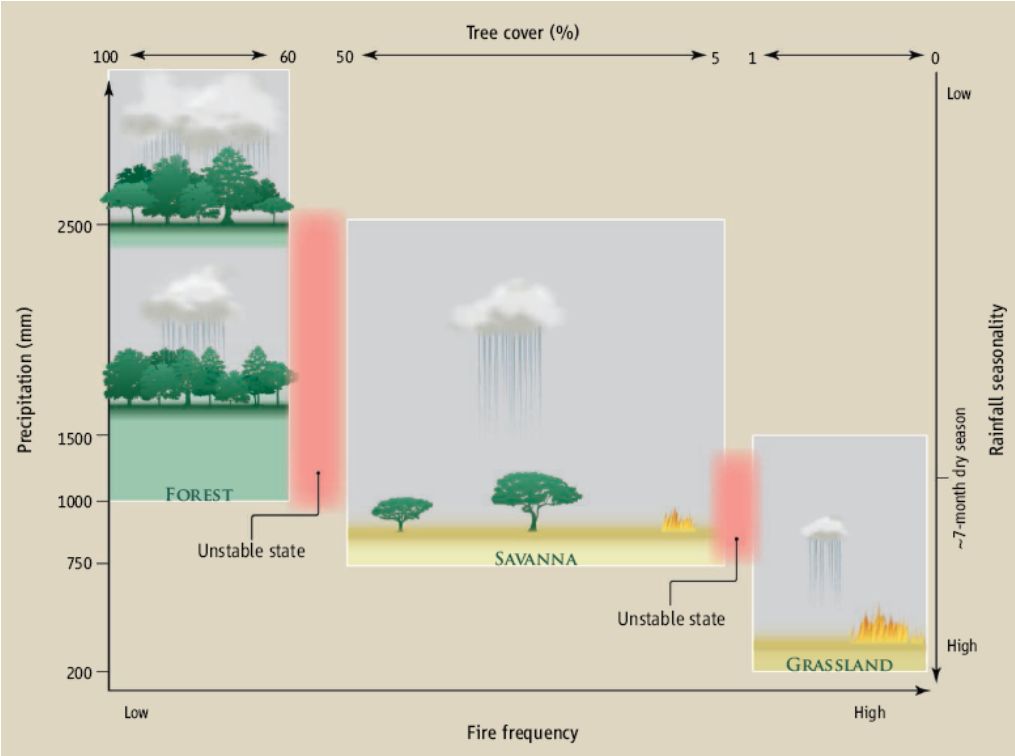
Scientific questions in drylands

Tree and grass

ECOLOGY

Grass Trumps Trees with Fire

Audrey L. Mayer and Azad Henareh Khalyani

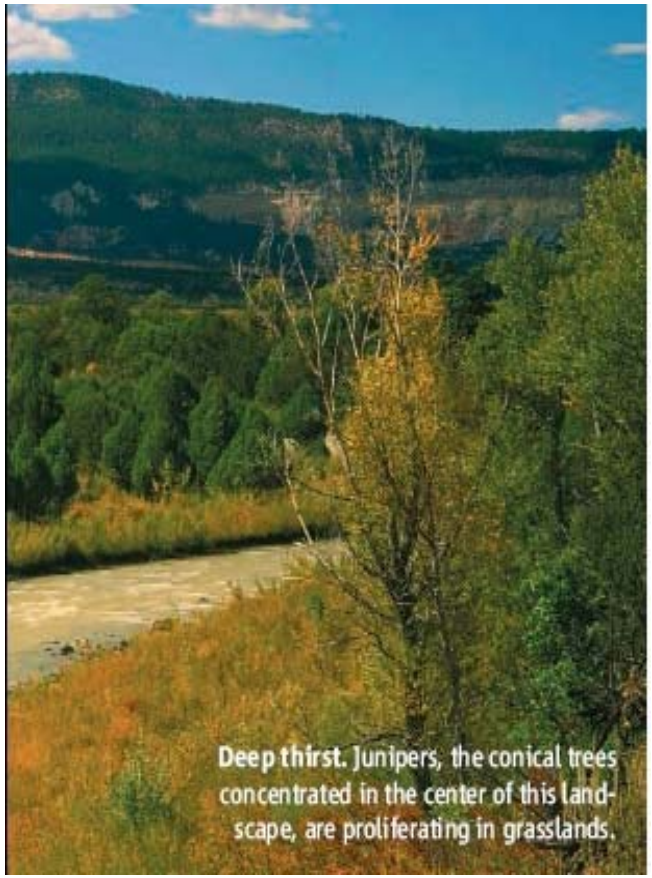


14 OCTOBER 2011 VOL 334 SCIENCE

ECOLOGY

When Juniper and Woody Plants Invade, Water May Retreat

Dense plants are taking over grasslands in many areas; researchers in the U.S. Southwest are studying how they tap into water supplies—and how to keep them in check



Deep thirst. Junipers, the conical trees concentrated in the center of this landscape, are proliferating in grasslands.

12 DECEMBER 2008 VOL 322 SCIENCE

Simulation and observation

- Model simulation: The interacting climate, soil and fire effects are difficult to isolate or experimentally. manipulate in order to evaluate their impacts at spatial and temporal scales appropriate for assessing ecosystem dynamics.
- Field observation: To parameterize the model and to validate the simulation results, we need observation data
- Combined model simulation and field observation make future prediction possible.

Tree growth and forest NPP

Vertically distributed ecosystems on the Tianshan Mts.

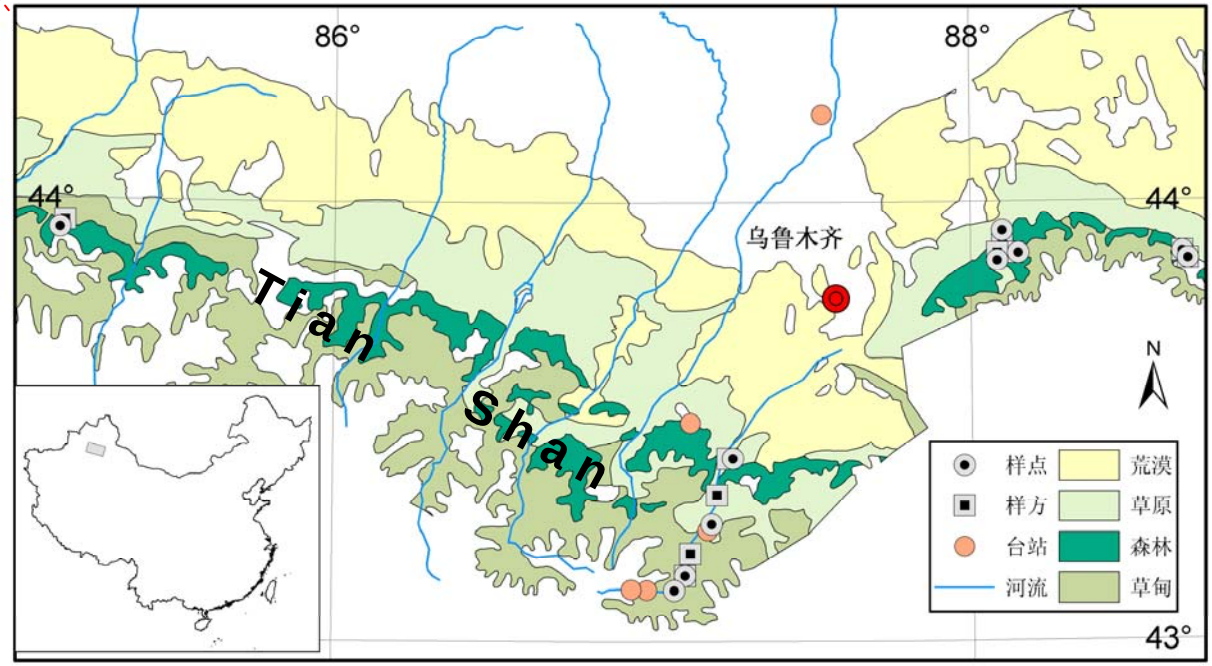
H<1100 m: Desert

H=1100-1600 m: Desert steppe

H=1600-2100 m: Steppe

H=2800-3400 m: Forest

H=2800-3400 m: Alpine Meadow



Tree growth and forest NPP

Scientific questions

- Growth of trees on temperate arid mountainous areas is constrained by temperature, precipitation, and CO_2 concentration; therefore, the interactions among them could be much more complicated than in ecosystems limited by a single factor. In what manner, and to what degree, the effect of CO_2 concentration rising is offset by shortage of available water or low temperature in the temperate arid mountains remains unclear.

NATURE | VOL 429 | 10 JUNE 2004 | www.nature.com/nature

letters to nature

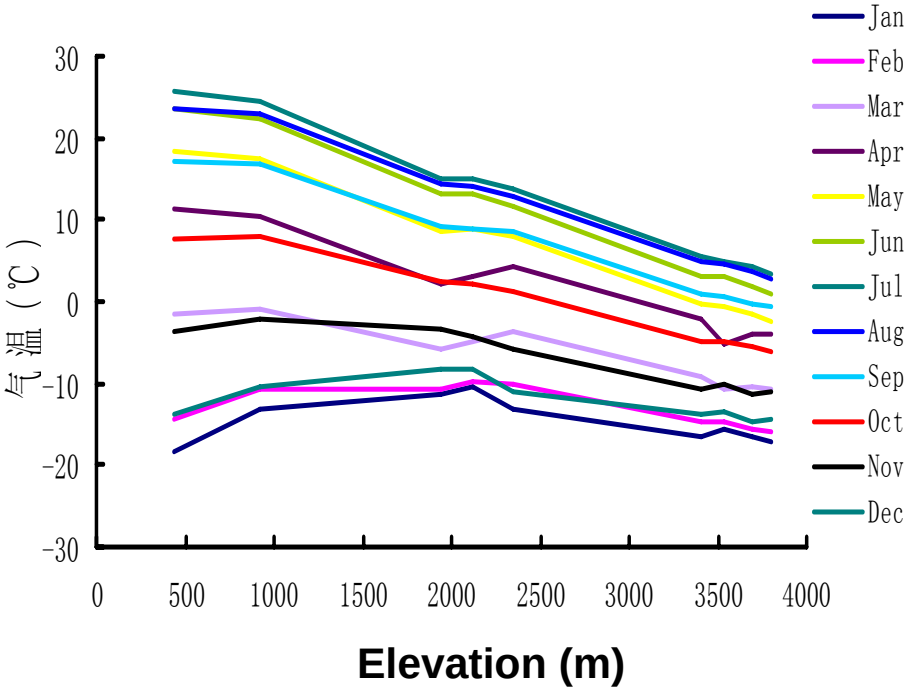
Convergence across biomes to a common rain-use efficiency

Travis E. Huxman[1*], Melinda D. Smith[2,3*], Philip A. Fay[4], Alan K. Knapp[5], M. Rebecca Shaw[6], Michael E. Loik[7], Stanley D. Smith[8], David T. Tissue[9], John C. Zak[9], Jake F. Weltzin[10], William T. Pockman[11], Osvaldo E. Sala[12], Brent M. Haddad[7], John Harte[13], George W. Koch[14], Susan Schwinning[15], Eric E. Small[16] & David G. Williams[17]

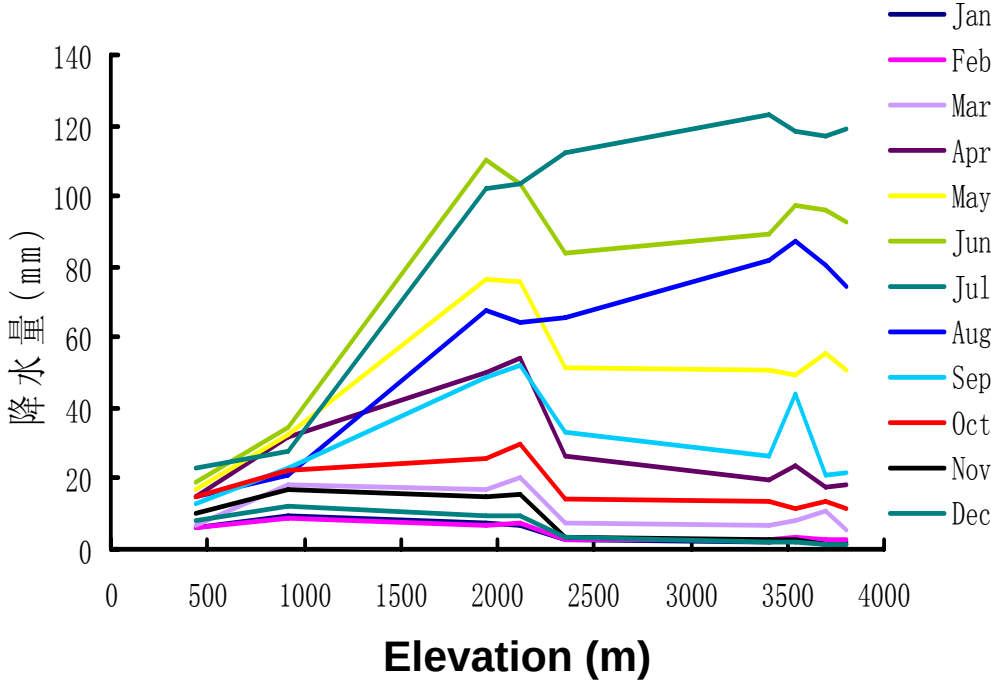
Tree growth and forest NPP

Vertical climate features

Monthly temperature



Monthly precipitation



Tree growth and forest NPP

Vertical vegetation belts

Tree growth and forest NPP

Tree-ring samples

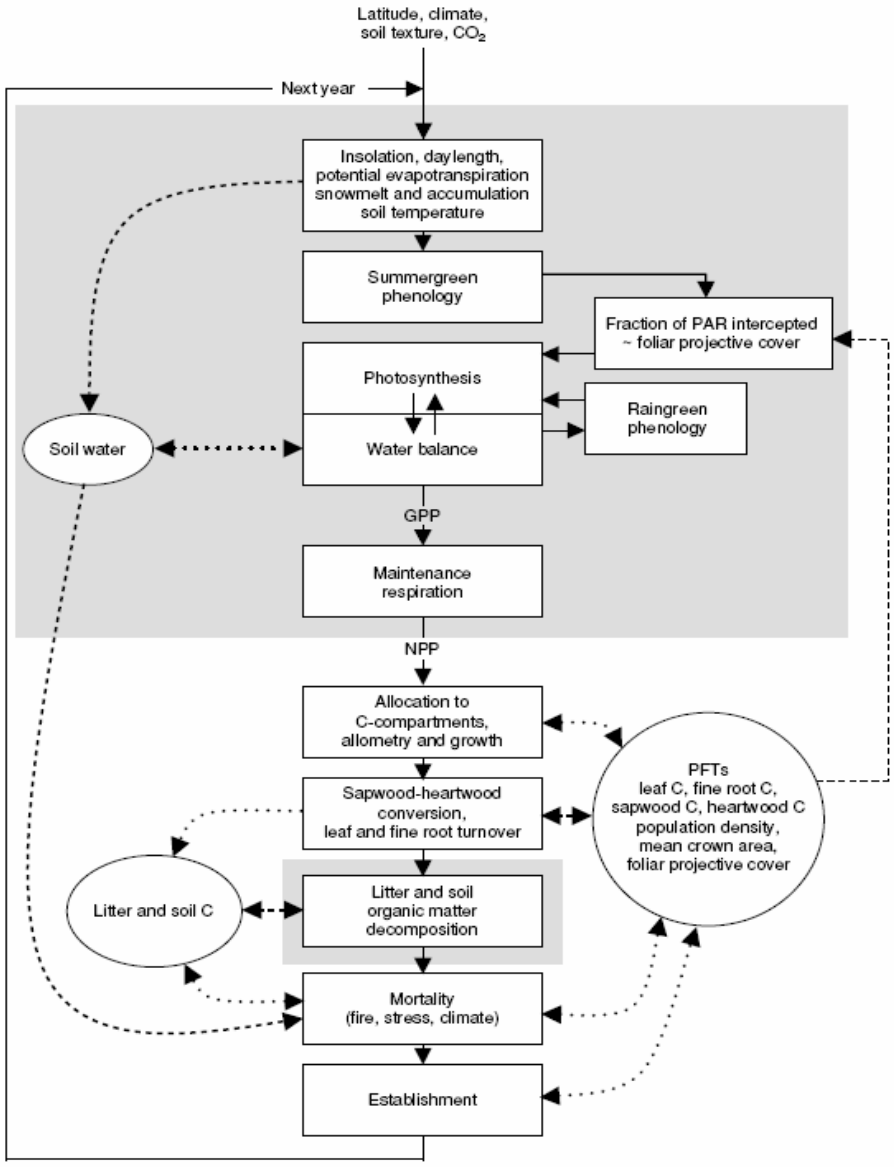
- Individual trees: We sampled climate-sensitive isolated trees, at least 20 individuals in one site. Totally 11 sites in an elevation gradient are sampled

- 11 plots with size of 25 × 25 m^2 were selected from interior forest belt in three river basins. 40~70 individuals were sampled for each plot. Two rings, one in NS and the other in EW directions, were cored for each tree within the plot.
- $B = 0.06014 \times \ln d^{2.5393}$
- $NPP = + \Delta B + D + G$

Tree growth and forest NPP

LPJ-DGVM Simulation

- LPJ: A process-based dynamic global vegetation model (DGVM).
- Historical climate data from 1901-2003 as input
- Three scenarios: 1) constant CO_2 concentration (317.2 ppm in 1961) since 1961; 2) doubling CO_2 concentration (634.4 ppm) since 1961; 3) ambient annual CO_2 concentration



Tree growth and forest NPP

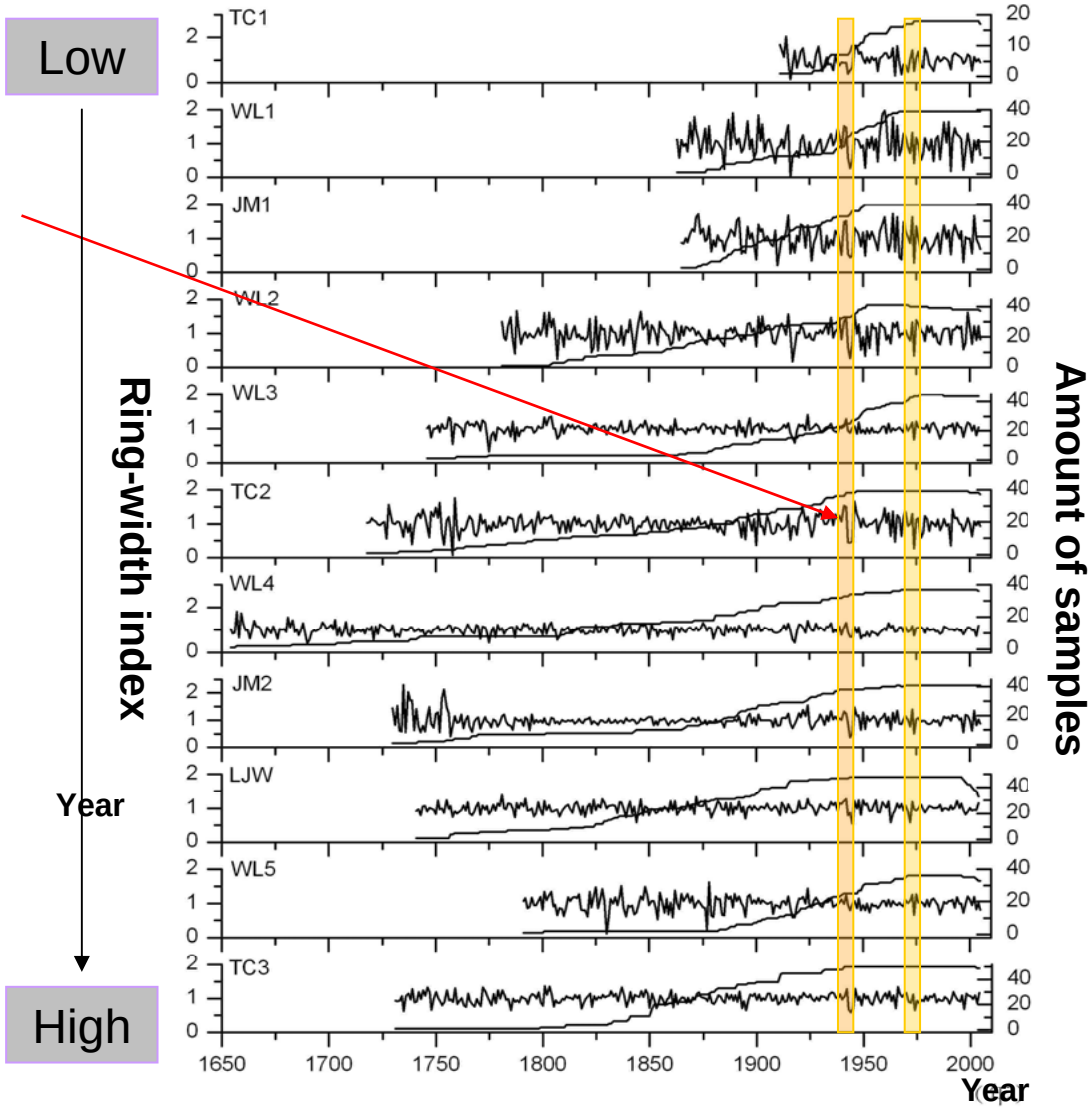
Remote sensing image interpretation

- NDVI data sets used in this study were produced by the Global Inventory Monitoring and Modeling Studies (GIMMS) group using the AVHRR/NOAA series satellites, at a spatial resolution of 8*8 km^2 and 10-day interval, for the period from 1982 to 2000
- The horizontal extent of each vertical biome occupies 1~3 pixels perpendicularly in the 8 km-resolution NDVI data sets. Only those pixels fully covered by a definite biome were selected for calculation. At least 40 pixels for each biome were obtained. Each pixel contains 19 years of NDVI data, constituting a time series with 19 values. If the trend line has a slope >0, it indicates an increasing trend. If it passes the t-test with significant level of 0.05, it means a significant increasing trend

Tree growth and forest NPP

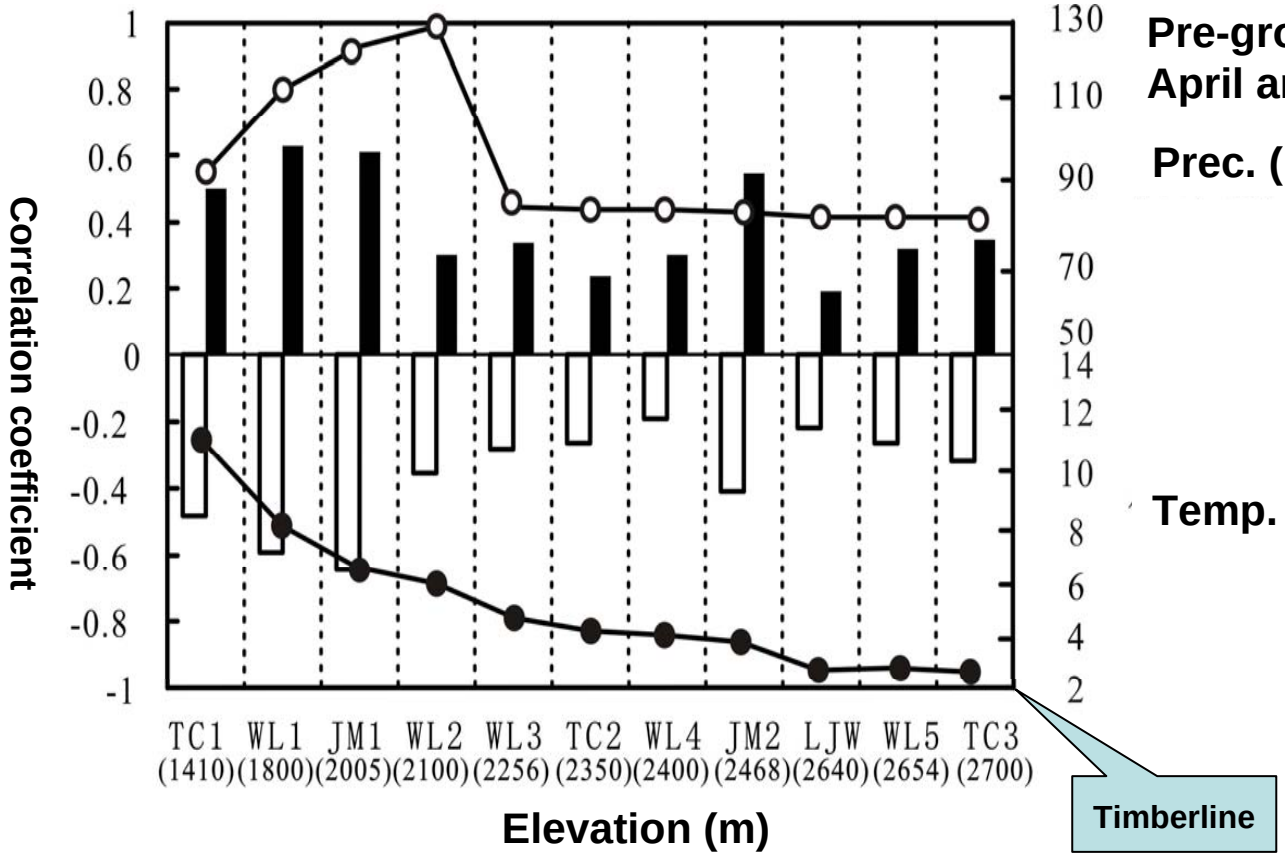
Patterns of ring-width change with elevation

- Common narrow rings
- Variations of ring-width decrease with elevation



Tree growth and forest NPP

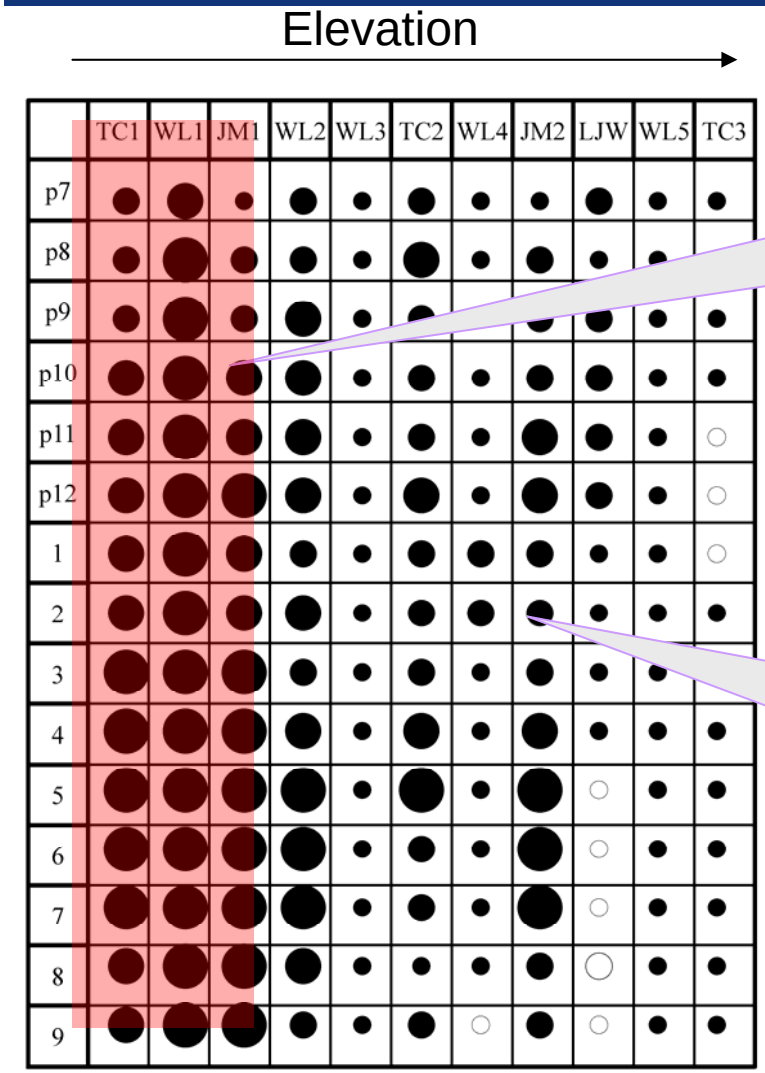
Drought-forced individual tree growth



- Opposite roles from temperature and precipitation forces
- No evident change when approaching the timberline

Tree growth and forest NPP

Limitation by soil moisture

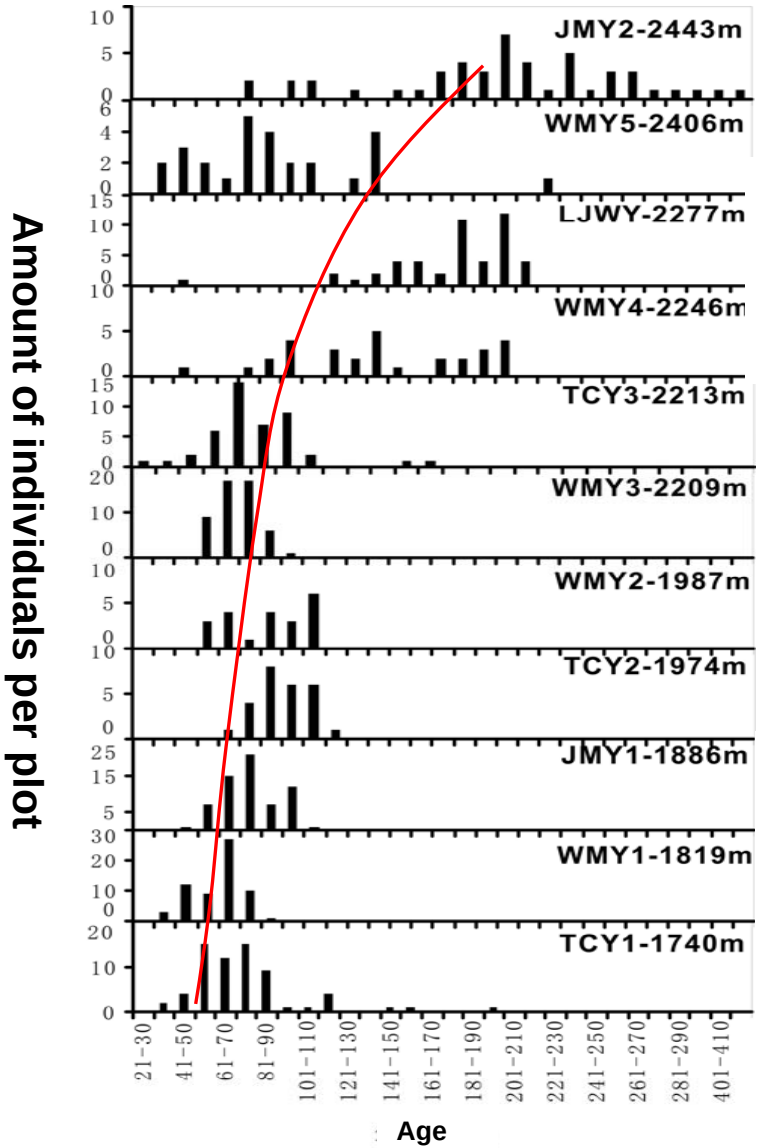


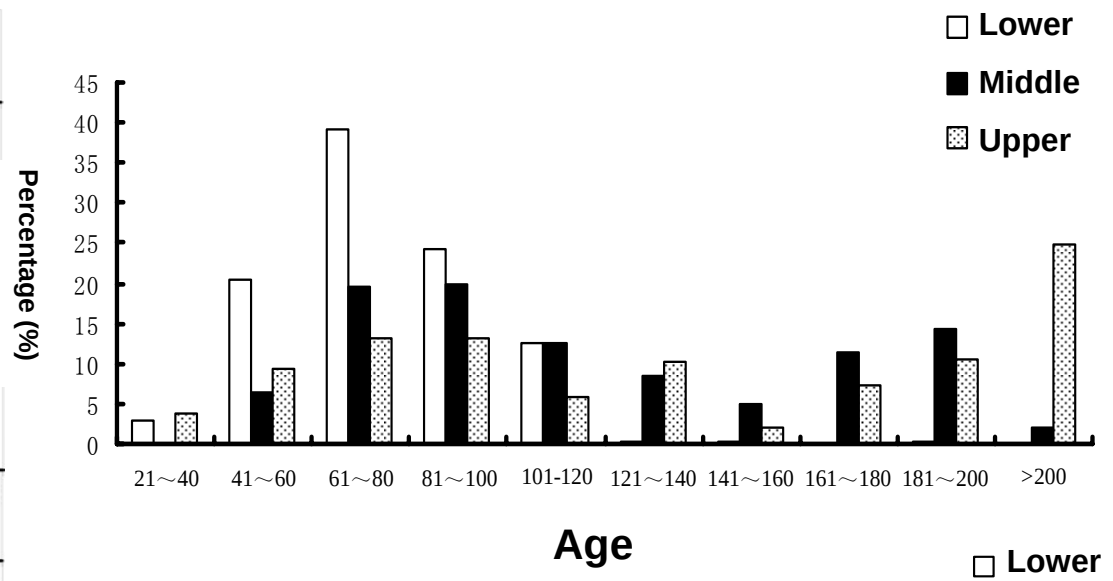
High sensitivity of tree growth to soil moisture on the lower forest zone over the whole growing season

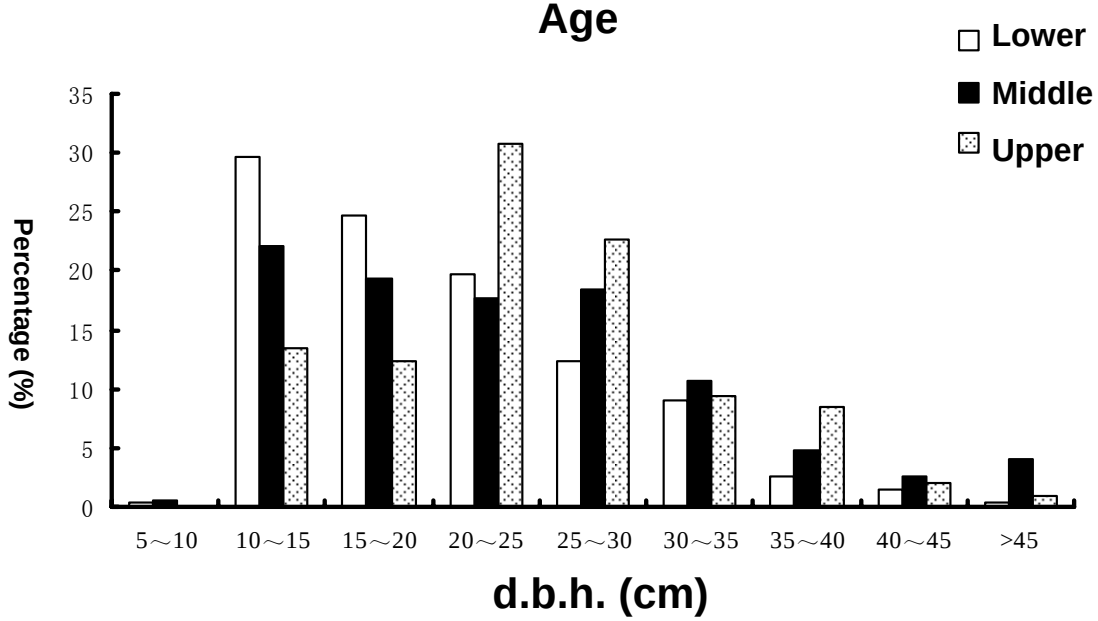
Decrease of tree growth sensitivity to soil moisture on the middle and upper forest zone

Tree growth and forest NPP

Age structure with elevation

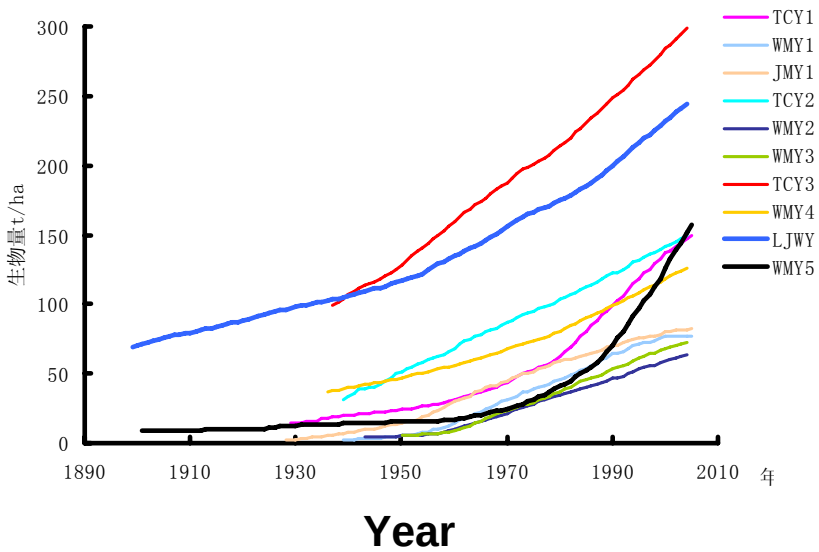




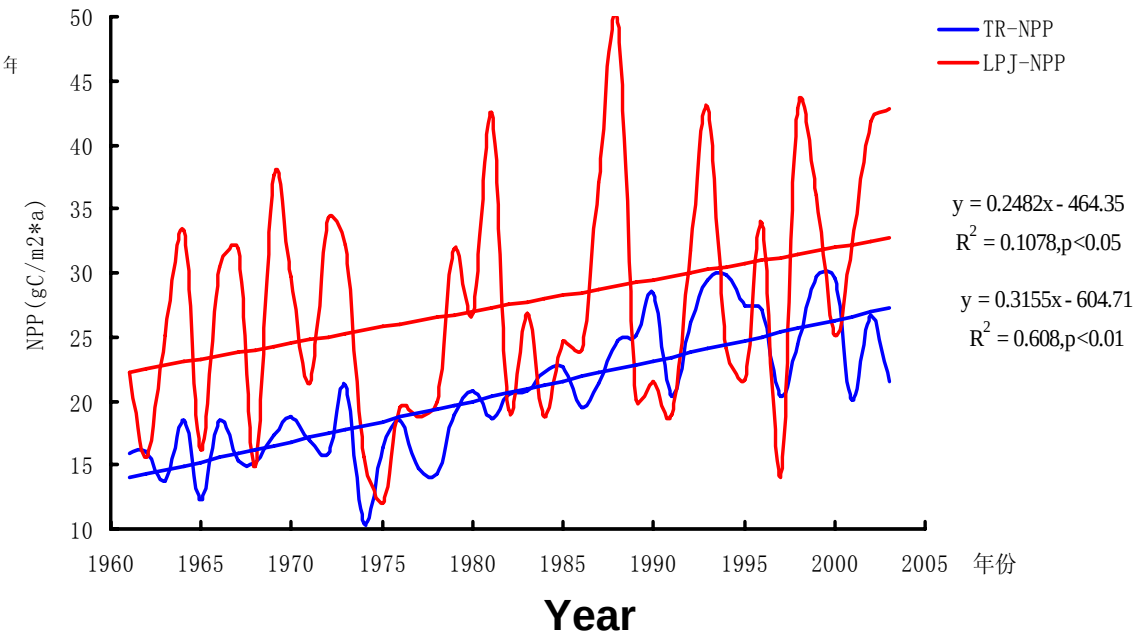


Tree growth and forest NPP

Increased forest biomass and NPP during the last 40 years

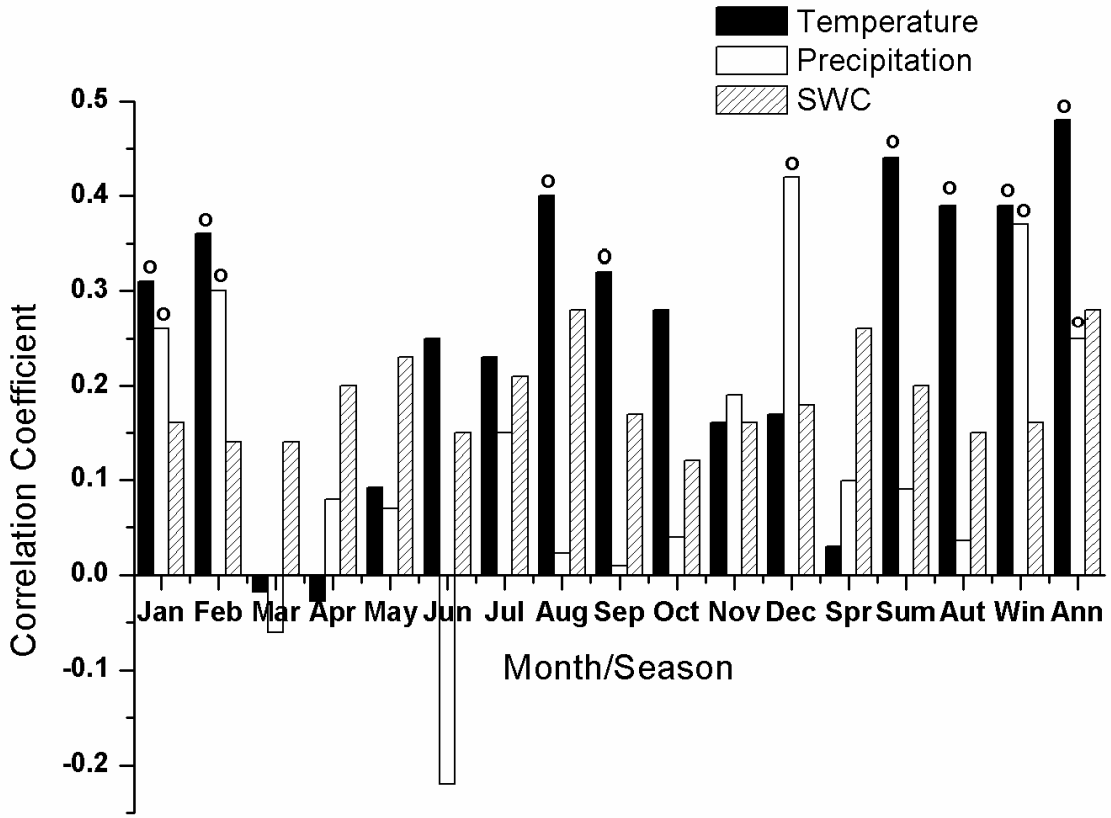


- Increase of forest biomass in all plots
- Consistent increase trend between tree-ring estimated NPP and LPJ-simulated NPP



Tree growth and forest NPP

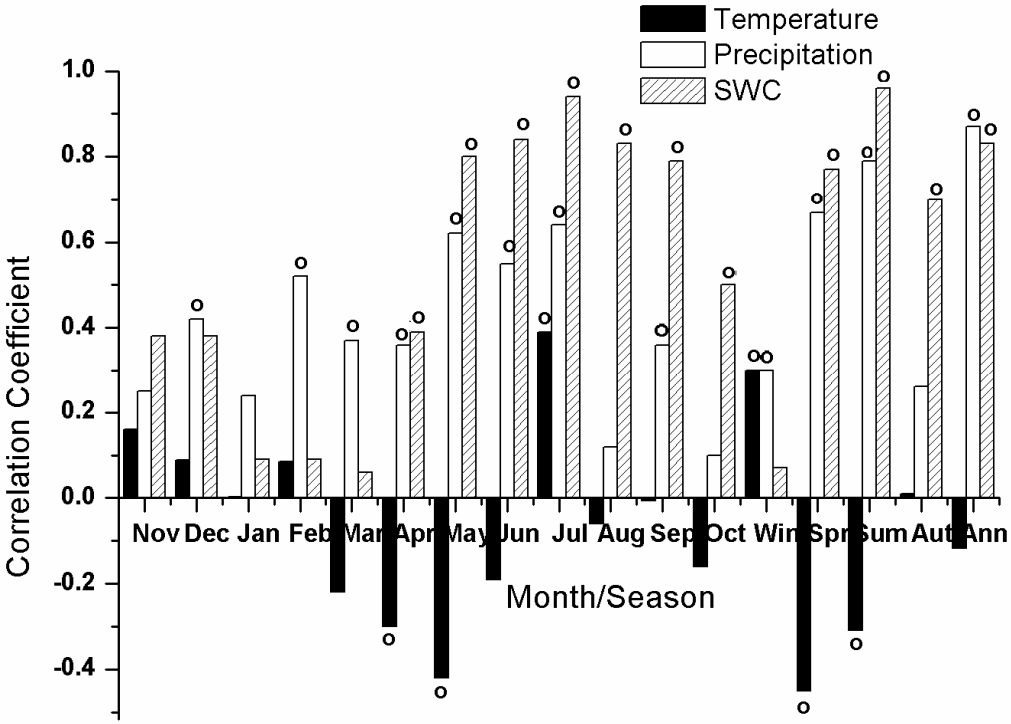
Climate trend during the last 40 years



- Common significant increasing trend in precipitation and temperature was found only in winter.
- Soil moisture shows insignificant increase in all the months and seasons.

Tree growth and forest NPP

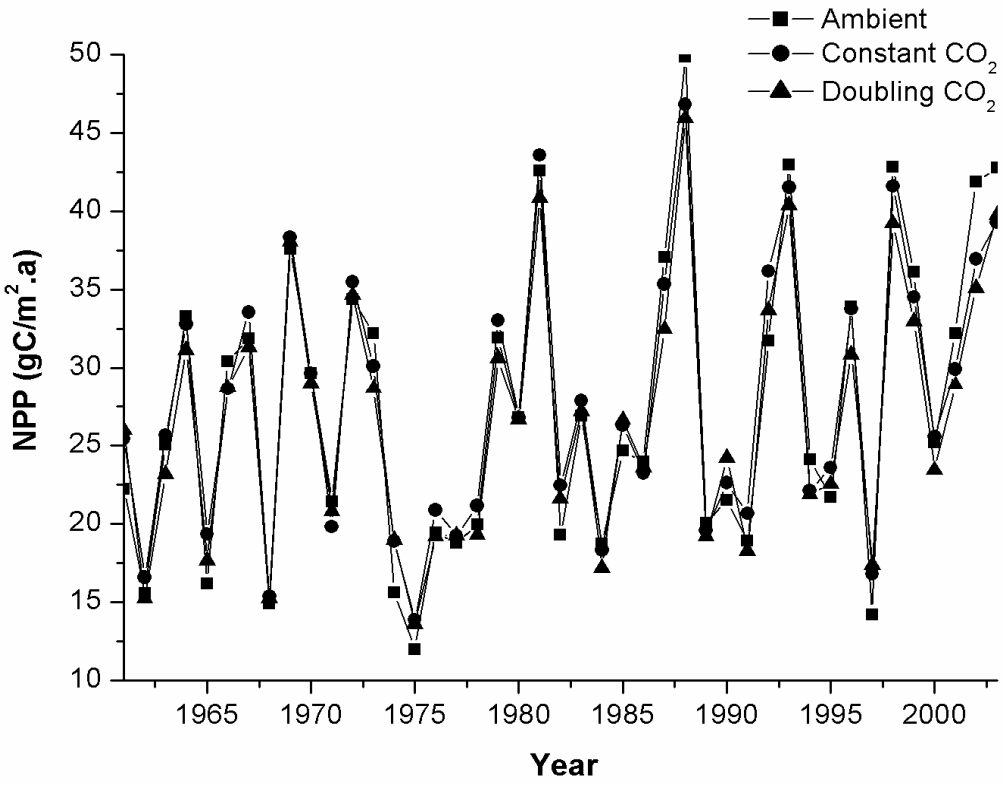
Drought-forced forest NPP increase



- The most evident correlation was found for soil moisture
- Soil moisture in the non-growing season, particularly in January to March, show no significant correlation with annual NPP, implying a time-lag between winter precipitation increasing and tree-growth enhancement

Tree growth and forest NPP

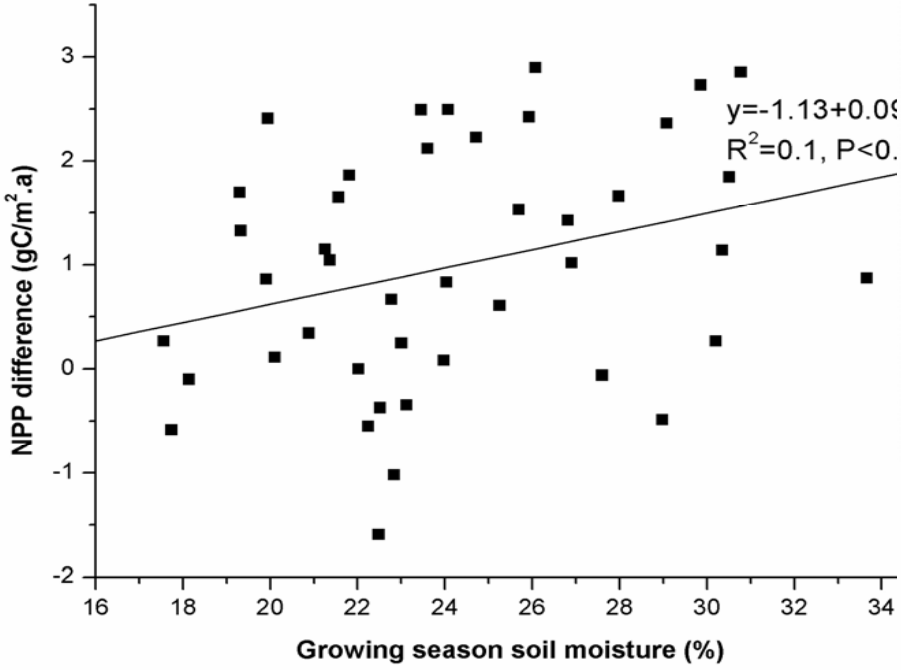
CO_2 –forced forest NPP dynamics

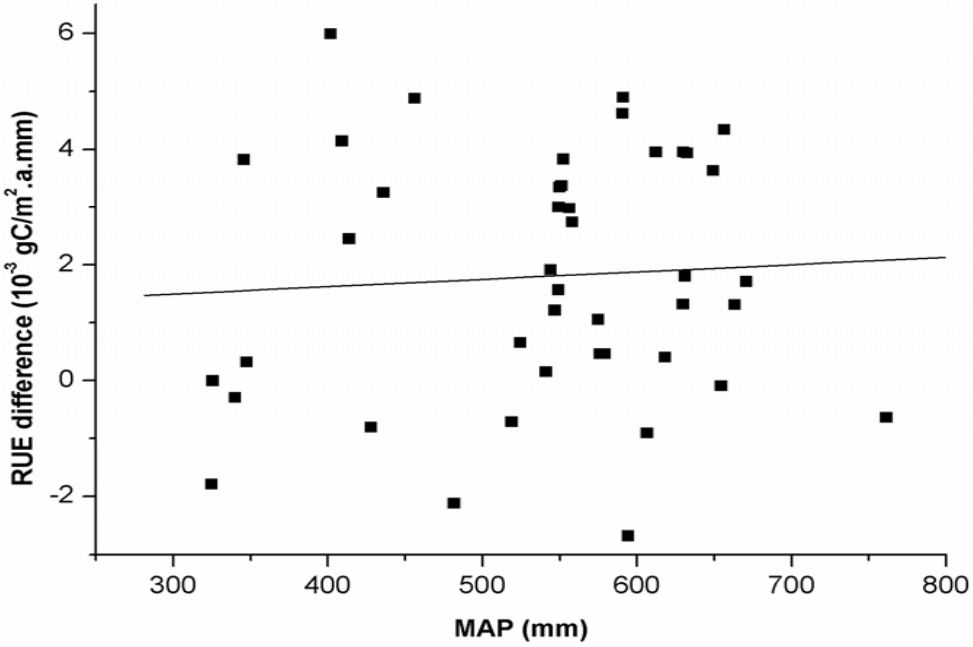


- The three CO_2 concentration scenarios produce consistent interannual variations in forest NPP

Tree growth and forest NPP

Synergetic effect between water and CO_2





- The NPP difference between doubling CO_2 and constant CO_2 scenarios is linearly related with the growing-season soil moisture, indicating a soil moisture associated CO_2 fertilization
- The doubling CO_2 concentration scenario has higher water use efficiencies than the constant CO_2 concentration scenario for most MAPs. Their difference insignificantly increases with MAP

Tree growth and forest NPP

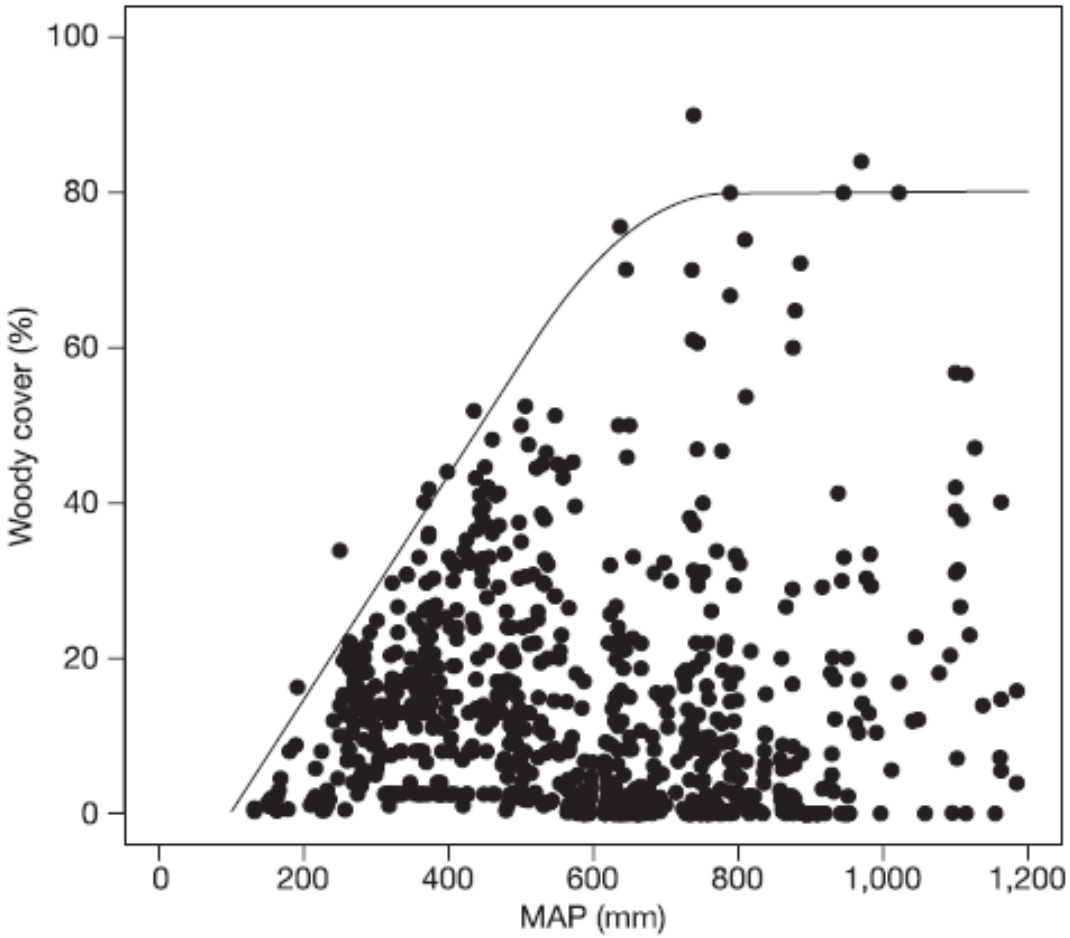
Summary

- Different from the boreal forest in high latitudes, we highlight the role of non-growing season (winter) temperature on spring soil moisture for the temperate arid mountainous forest
- Both winter temperature and precipitation contribute to growing season soil moisture; however, the role of temperature and precipitation are opposite in spring and summer due to their different roles on soil moisture
- Our study further implies a synergetic effect between water and CO_2 on carbon fixation in temperate arid mountainous forest. High CO_2 concentration improves water use efficiency and further enhances carbon fixation, which was simply ascribed to CO_2 fertilization

Savanna vegetation dynamics

Scientific question

- It was suggested that the two-layer root distribution determines tree-grass coexistence in the Savanna (Walter, 1972).
- How does root distribution contribute to savanna vegetation patterns and dynamics?



NATURE|Vol 438|8 December 2005

Sakharan et al., 2005)

Savanna vegetation dynamics

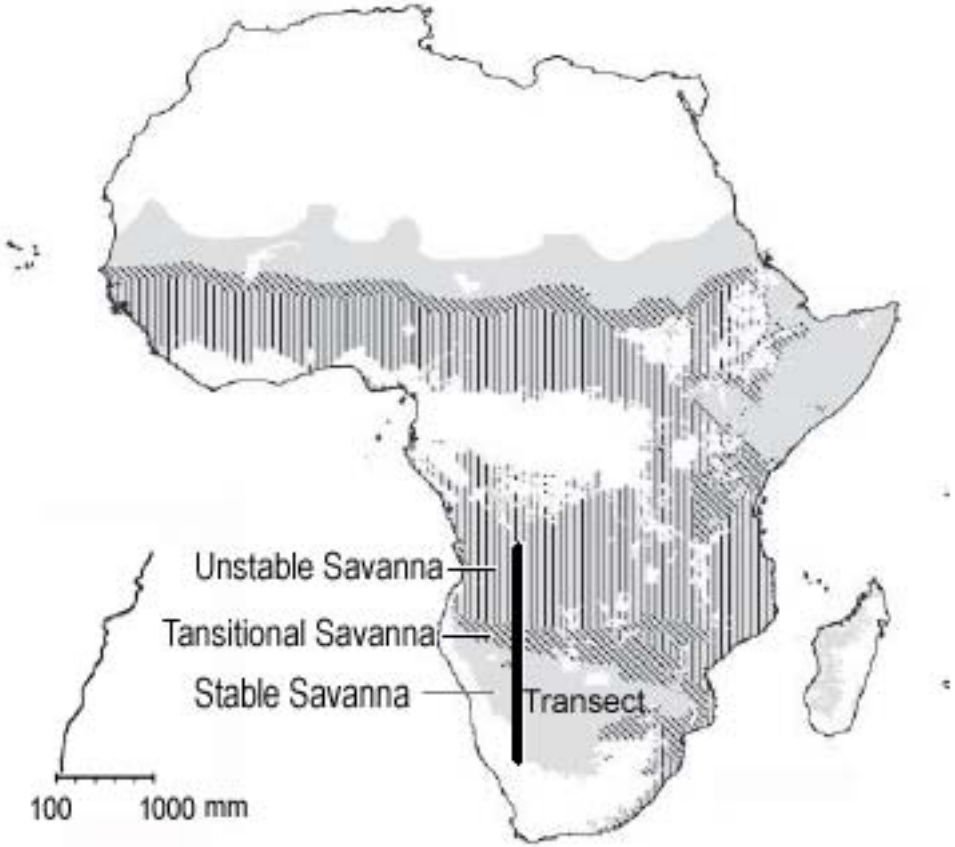
Simulation experiments

Root Distribution		Two-layer separate	Even distribution	Mixed distribution	Topsoil only	Subsoil only
PFTs	TrBE	0	0.5	0.85	1	0
	TrBR	0	0.5	0.7	1	0
	TeNE	0	0.5	0.7	1	0
	TeBE	0	0.5	0.7	1	0
	TeBS	0	0.5	0.8	1	0
	C3	1	0.5	0.9	1	0
	C4	1	0.5	0.9	1	0

Savanna vegetation dynamics

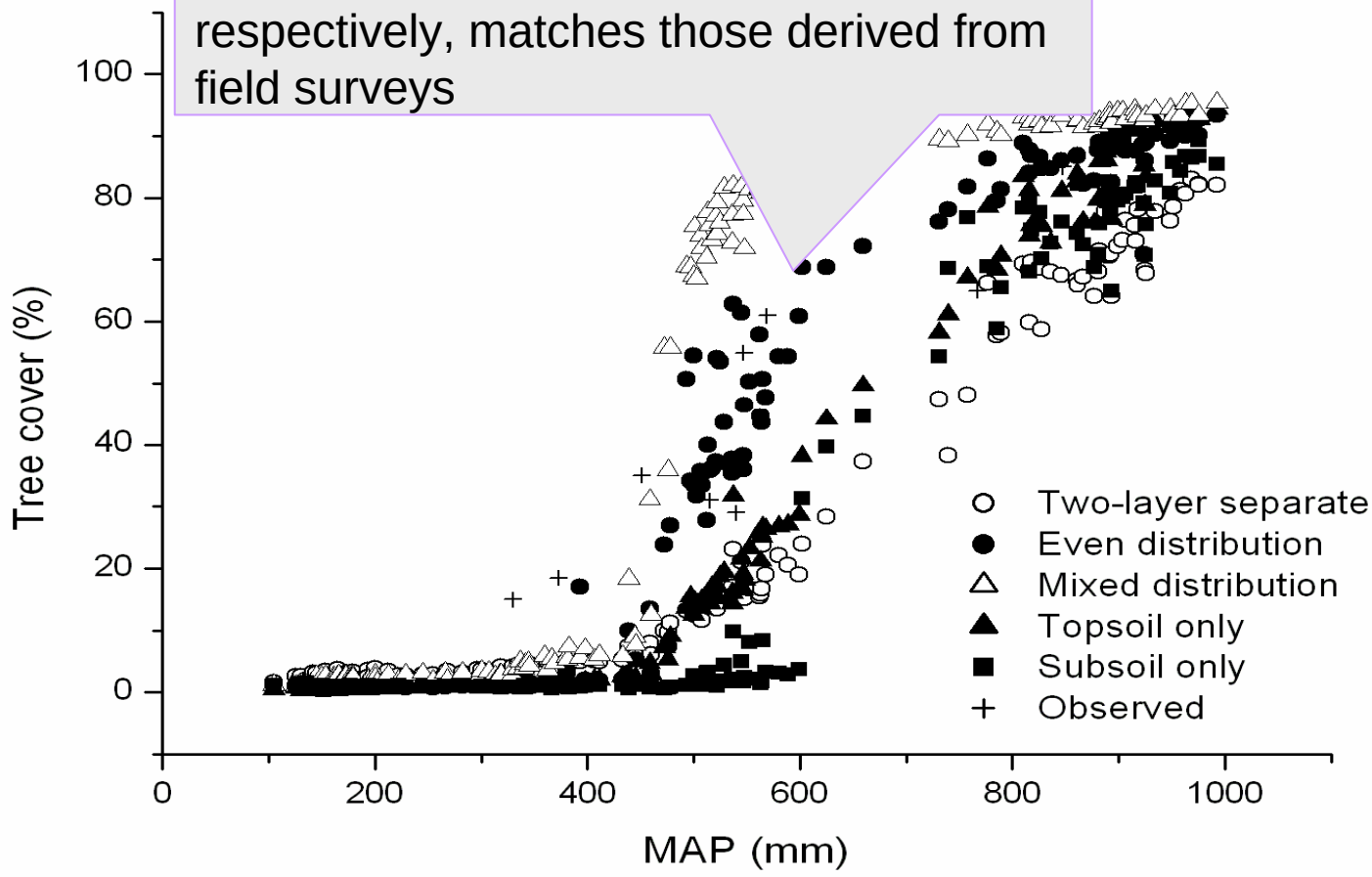
Simulated transect

The Karahari Transect



Simulated and observed tree covers

a half-half fine root distribution for both trees and grasses in topsoil and subsoil respectively, matches those derived from field surveys

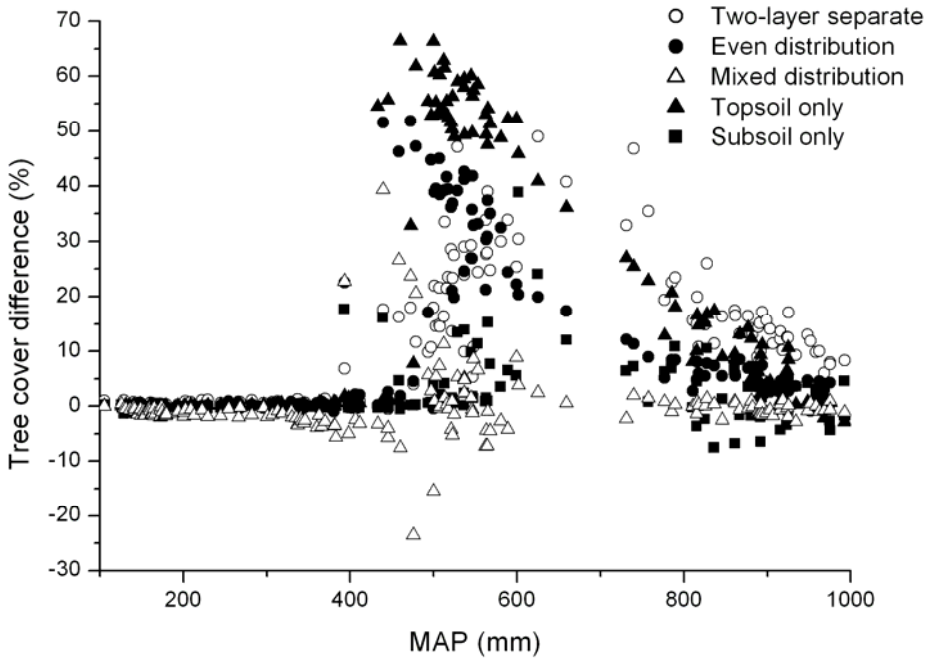


Savanna vegetation dynamics

Tree-cover differences between fire-on and -off

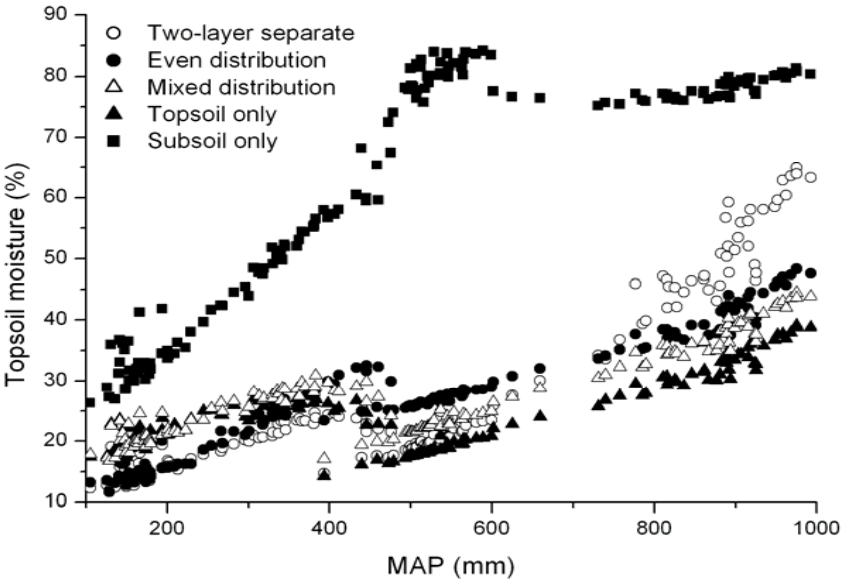
- The highest correlation coefficient between simulated soil moisture and the Palmer Drought Severity Index (PDSI) occurs in the mixed root distribution, followed by the even root distribution

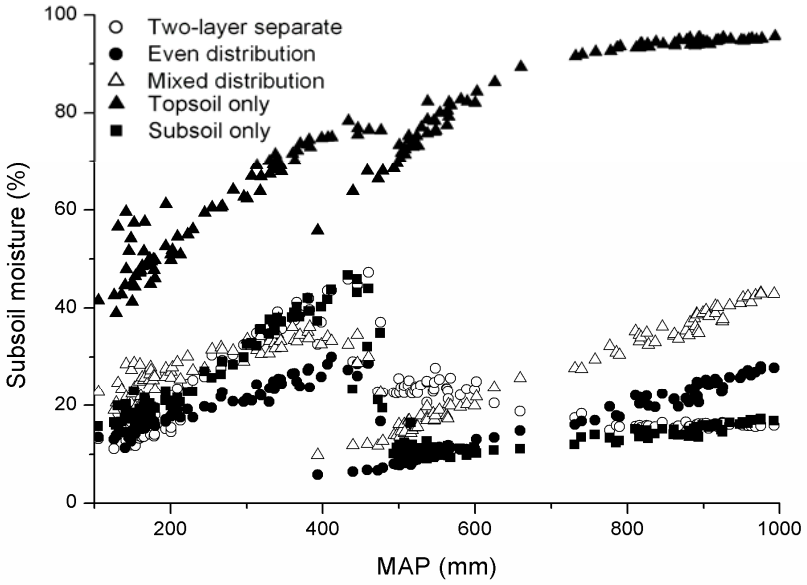
- The mixed root distribution assuming most of roots of both trees and grasses in the topsoil shows unexplainable fire disturbance on tree cover.



Simulated topsoil moisture with MAP

- The evenly distributed fine roots sustain water uptake from both topsoil and subsoil





Summary

- The evenly distributed fine roots sustain water uptake from both topsoil and subsoil, which most likely contributes to a stable savanna.
- Mediation of fire on tree cover changes is different under the five simulated root distributions, implying a possible linkage between the root distribution and fire disturbance, whose mechanism needs further investigation.

Thank you for your attention!

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