Tropical forest canopies and their relationships with climate (and disturbance)

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Forest canopies are central to the importance of forest for hydrology, carbon cycles, and climate

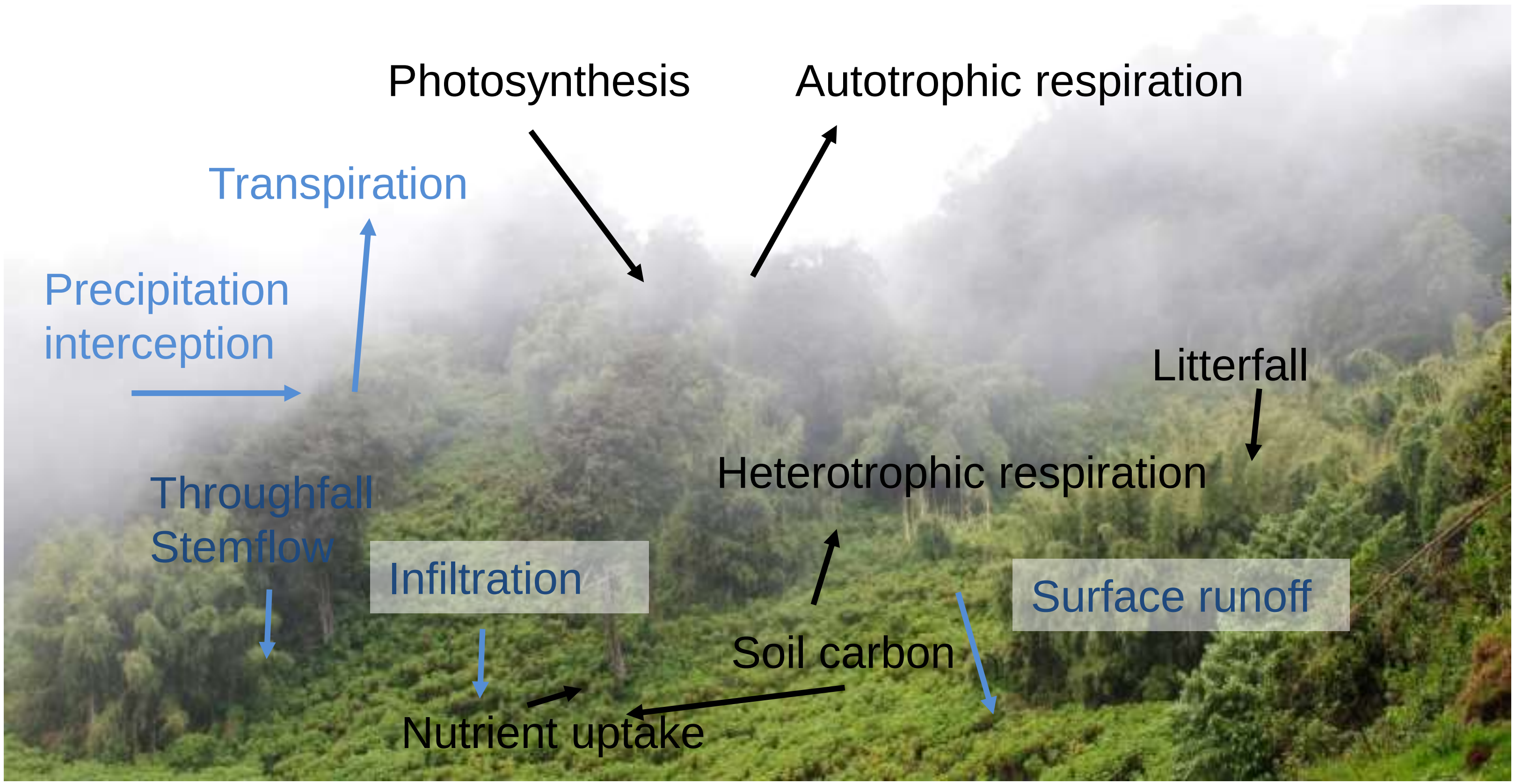

Fig. 2, From Bonan 2008. Forests in Flux. Science.

LAI & fAPAR are two of the Essential Climate Variables used for reporting to IPCC

Three essential canopy attributes:

- Leaf area index – **LAI**: leaf area per ground area [m^2/m^2]
- Fractional Vegetation Cover – **FCover**: canopy closure [%]
- Fraction of Absorbed Photosynthetically Active Radiation - **fAPAR**

Forest canopies under global change

CO_2

atmospheric CO2 concentrations will increase LAI (Kergoat et al. 2002; McGrath et al. 2010)

H_20

droughts increase tree mortality and cause canopy dieback reducing canopy leaf area up to 20 % or 30% (Nepstad et al. 2004, Meir et al. 2008)

Degradation, e.g. through (selective) logging

selective logging alters the biophysical structure of forests in the landscape, opening forest canopies and reducing LAI (Asner et al. 2004, Brando et al. 2014, Pfeifer et al. 2016).

A database for the tropics to obtain a benchmark for climate dependencies of tropical canopy structure

Hypothesis 1: Tropical forest canopy attributes differ among continents reflecting regional differences in water availability, temperature and radiation (Nemani et al. 2003)

Assumption:

- forests adapt to local climate leading to an equilibrium in canopy structure variables (Kergoat et al. 2002)

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Hypothesis 2: Protected forests yield significantly higher LAI, fAPAR and FCover compared to unprotected forests.

Assumption:

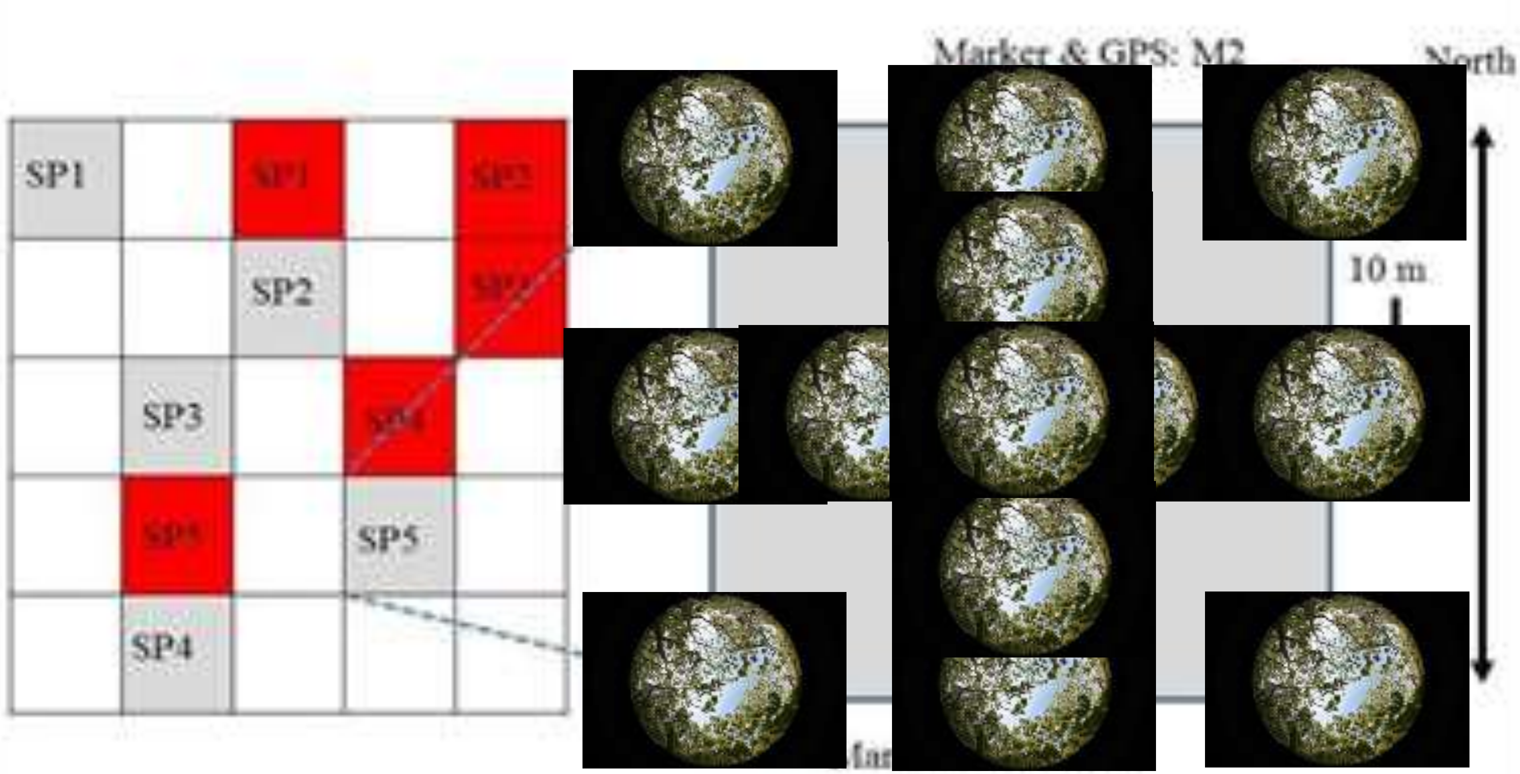
- anthropogenic disturbance has already modulated climate dependencies of tropical forest canopies

What did we measure?

Hemispherical upward looking images of the forest canopy:
≥ 8 per plot (sample location)

How did we measure it?

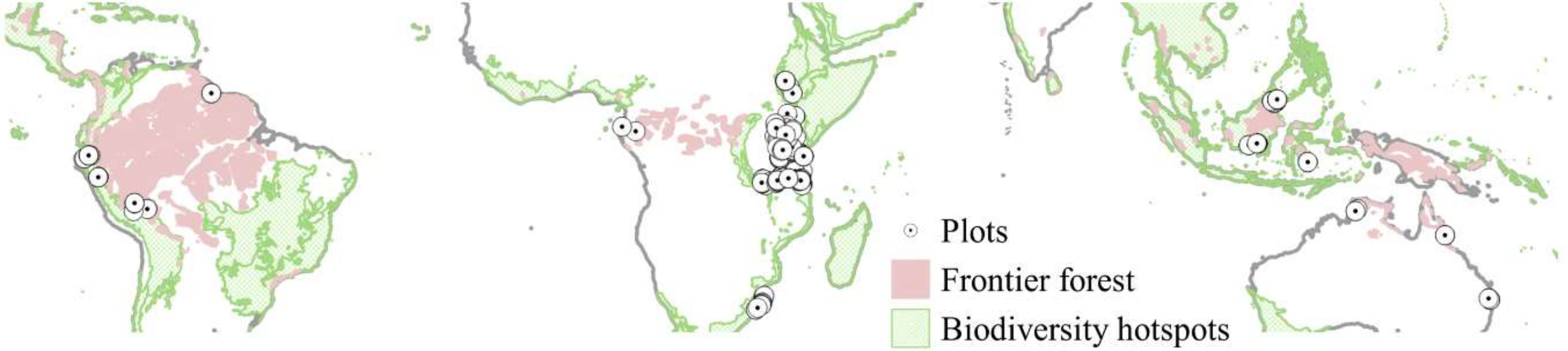
Sampling design following Validation of Land European Remote Sensing Instruments (http://w3.avignon.inra.fr/valeri/)



Where did we measure?

n = 887 plots   natural forest/woodland (not intensively managed for timber in recent times)

Africa, n = 516; America, n = 94;
Asia, n = 250; Australasia, n = 27



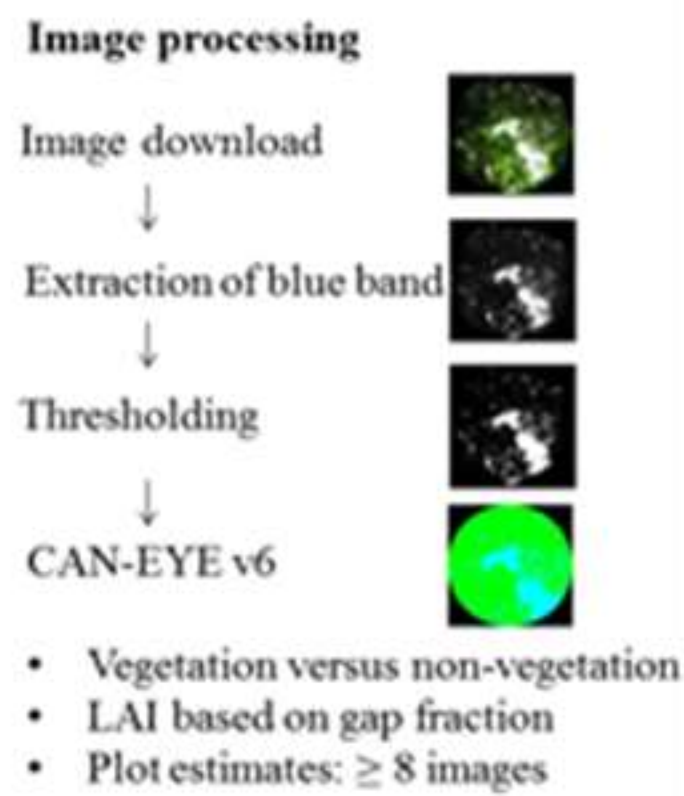
https://globallai.wordpress.com/

What did we do with the images?

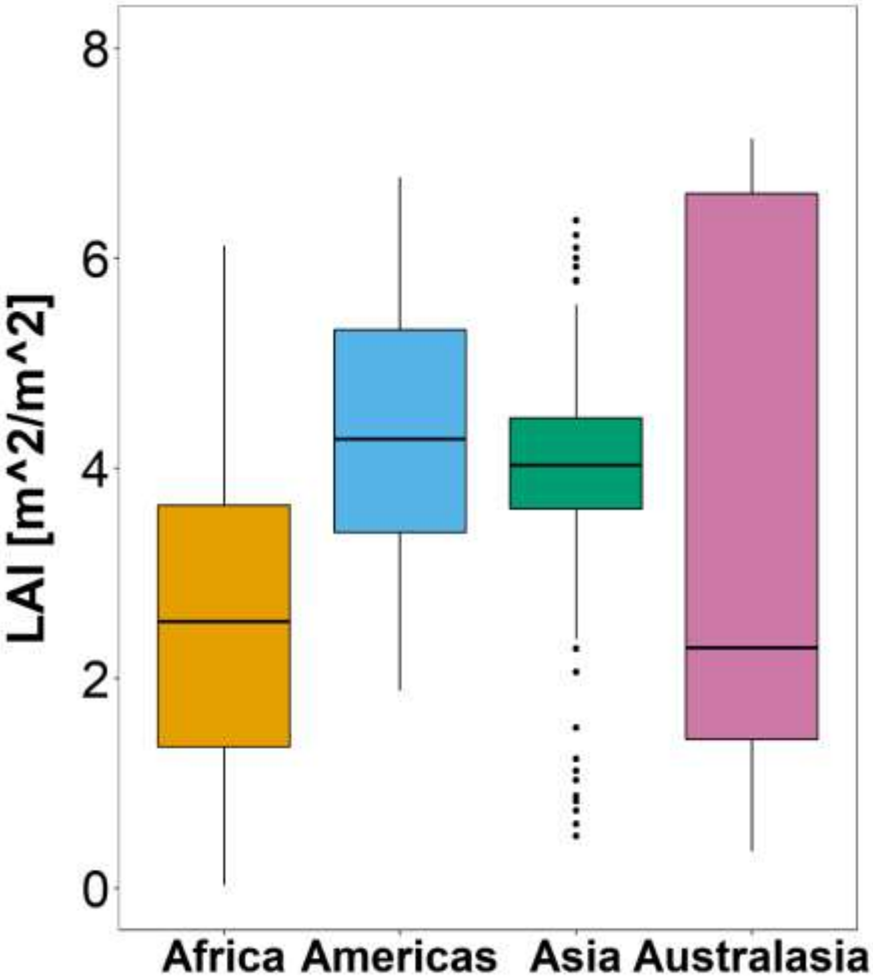
Hemispherical images - Processing

CAN-EYE

LAI & fAPAR per plot
FCover per image



The forests and their canopies



LAI (as well as FCover and fAPAR) were significantly lower in African forests compared to forests elsewhere (Wilcoxon rank sum test $P < 0.001$)

The forests in Africa

Seasonal Aacacia woodlands

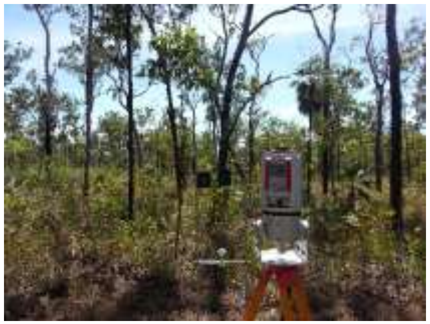
Riverine forests

Humid highland forests

Semi-deciduous forests

The forests elsewhere

South East Asia



Dry to wet Eucalypt

Australia

South America

Manu NP
(c)http://www.amazon-rainforest-tours.org

Podocarpus NP, Ecuador
(c) www.alamy.com

The climate predictors and confounding factors

Worldclim version 2 datasets (Fick & Hijmans 2017)

- mean minimum temperature of the coldest month (Bio6)
- mean annual rainfall (Bio12)
- the coefficient of variation in annual rainfall (Bio15)
- an annual moisture index (computed, Platts et al. 2010)
- maximum water deficit (computed, Platts et al. 2010)

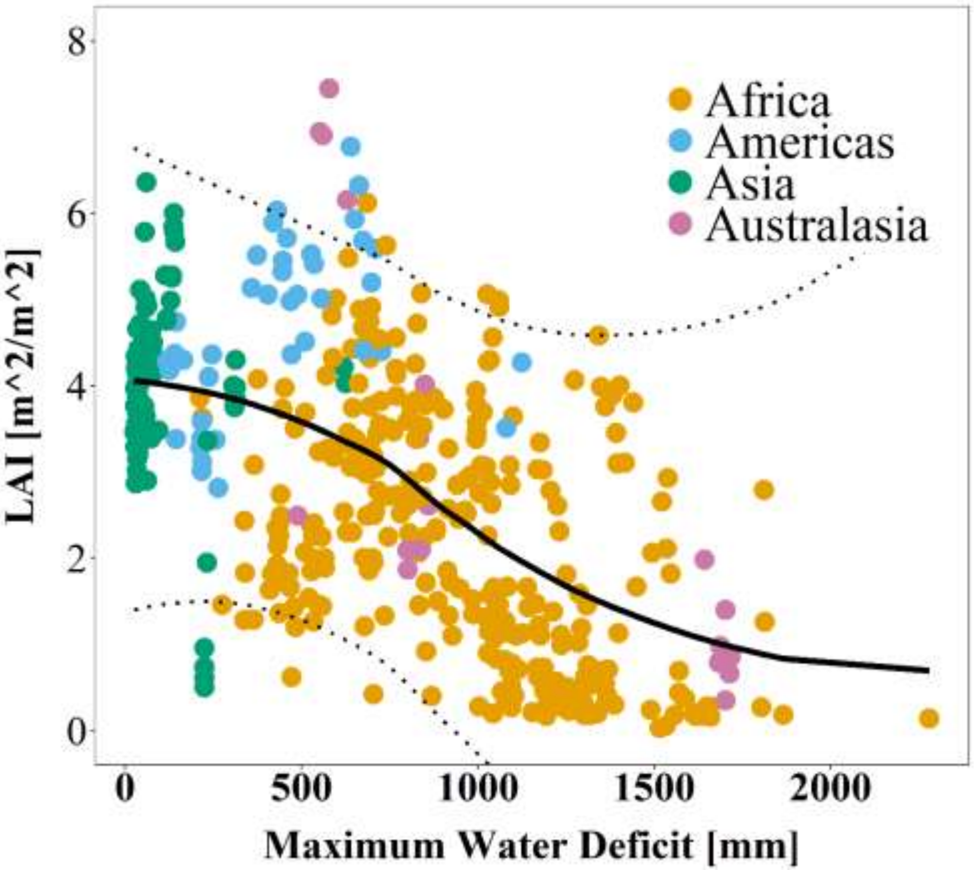
Confounding variables

- human population density in 2015 (Worldpop)
- human population pressure (computed, Platts unpubl.)
- topography: minimum elevation, slope (SRTM)
- protected/not protected (WDPA 2010)

For details see Pfeifer et al. Submitted. *Forest Ecosystems*.

The climate dependencies of tropical canopies

LAI ~ MWD*Protection+(1+MWD|Continent)



a measure of dry season water stress

Defined across consecutive months in which rainfall < PET (i.e. an accumulation in the shortfall of rain)

Marginal R^2 of MWD on LAI: 15%, on FCover 28%, and on fAPAR 28%.

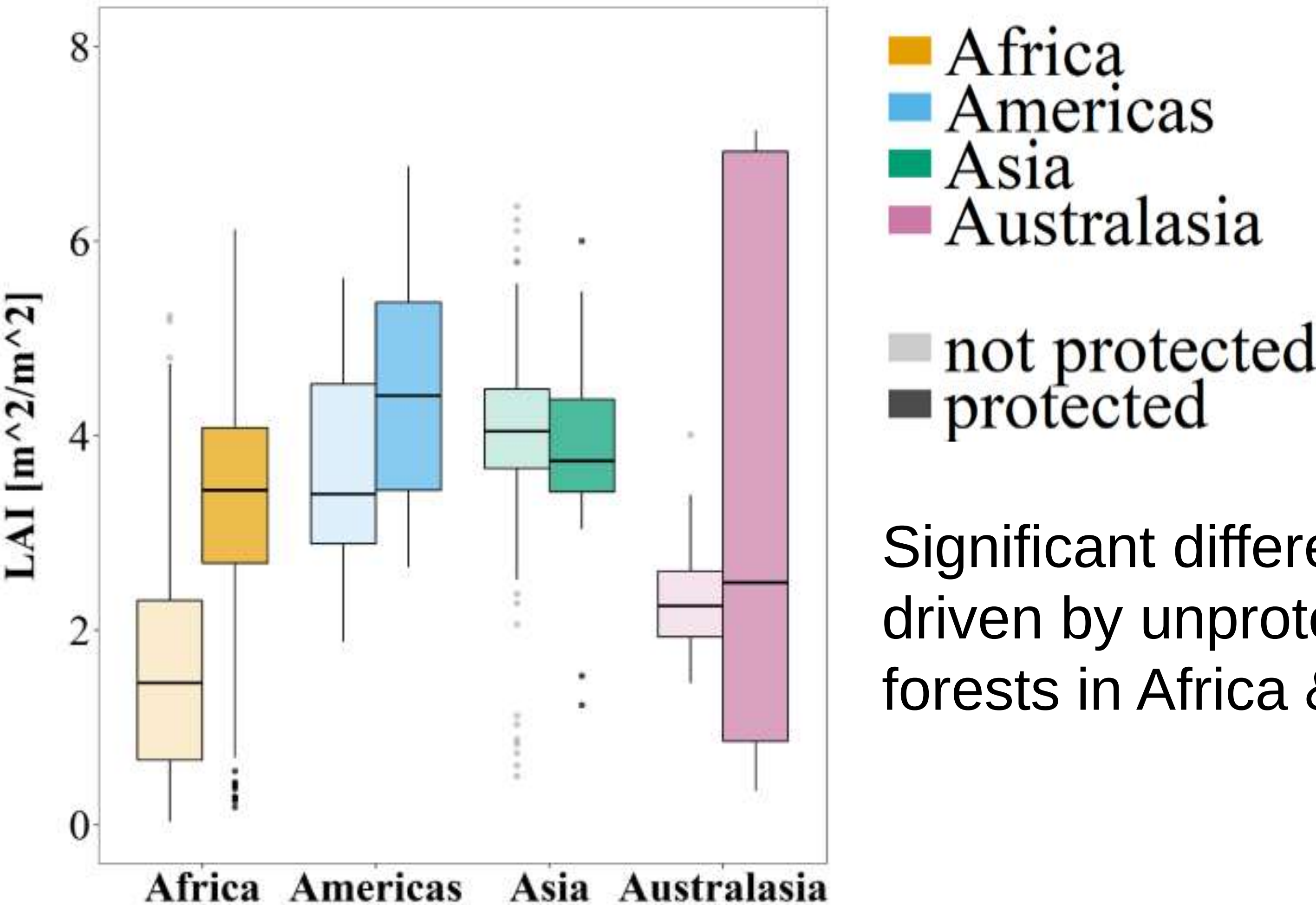
Conditional R^2: 76% (LAI) and 64% (for both FCover and fAPAR)

So, for our hypothesis 1

Long-term water stress correlates with plant canopy architecture

- The maximum water deficit in a region - which forest stands experience and thus evolve to adapt to (Kergoat et al. 2002) - had the strongest negative impact on canopy structure variation across plots and continents
- MWD lowered canopy attributes with the slope of this effect being steeper for Australasian plots

The protection status of forest matters



Significant differences driven by unprotected forests in Africa & Australia

And, for our hypothesis 2

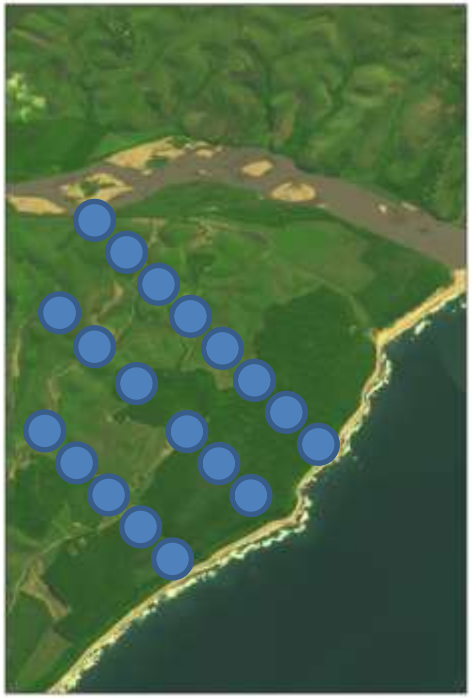
Protection matters, human pressure not

- Our data confirm the additional positive impacts of forest protection and terrain topography on forest canopy leaf area and closure

Linear mixed effects models, multi-model averaging

LAI		**fAPAR**		**FCover**	
Protection :	+	Protection:	+	Protection:	+
Min Temp:	+	Elevation:	-	Min Temp:	+
MWD:	-	MWD:	-	MWD:	-
Prot:MWD:	+	Prot:MWD:	+	Prot:MWD:	+
		Slope:	+	LatLong:	-

Where from here?



Use an approach grounded in fragmentation ecology to predict biodiversity turnover (Pfeifer et al. Accepted. Nature) & livelihood / food security implications in forest – agricultural landscapes

Thank you

Forest-regulated biodiversity underpinning livelihood security in tropical forest-agricultural landscapes

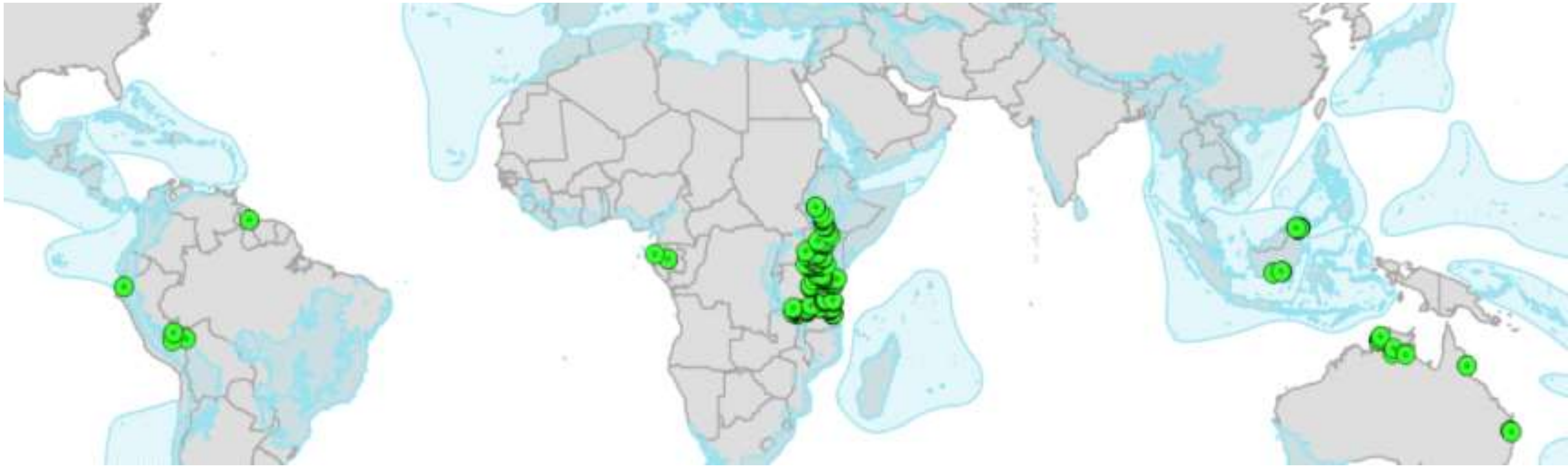
- Fieldwork: forest quality, land use mapping, crop quality, insects & birds
- Upscaling using remote sensing
- Development of trophic network models: simple models and DNA metabarcoding

Pilot study on forest / crop quality mapping in Mozambique funded through Royal Society

Pfeifer et al. 2012 Rem Sens Environ, 2014 Rem Sens

General upscaling algorithms? the Global LAI project

https://globallai.wordpress.com/



Recent global analysis: different approaches to measure canopy structure, focus on temperate regions and managed vegetation types

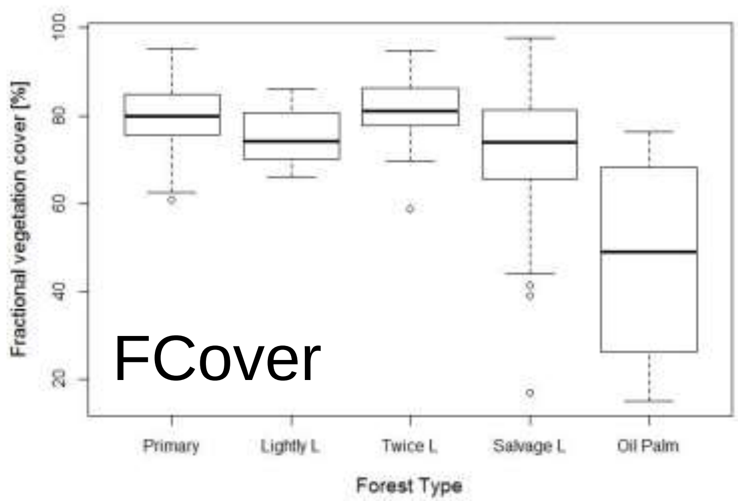
Data extracted from Iio et al. 2014 GEB.
Table: extract of data collected between -30 degrees and +30 degrees and from natural woody biomes (n = 306)

Methods used in the field to estimate LAI	Africa	Asia	Australia	N America	S & C America
Direct methods	10	37	36	11	41
Indirect optical with clumping	4	12	24	18	2
Indirect optical no clumping	4	30	4	3	55
Other methods	0	0	3	0	12
Total n of plots	18	79	67	32	110
Mean LAI ± SD	4.6 ± 3.3	5.9 ± 2.7	1.3 ± 1.5	3.3 ± 2.0	5.5 ± 2.9

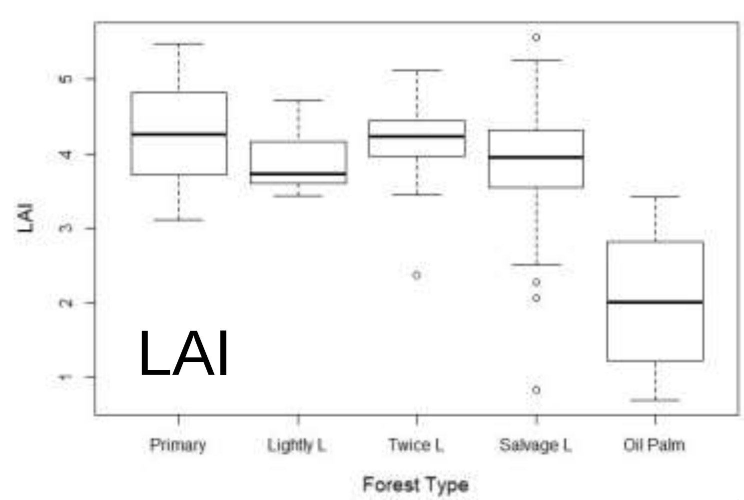
Canopy recovery after logging can be quick

Amazon ~ one-half of the canopy opening caused by logging is closed within one year of regrowth following timber harvests (Asner et al. 2004)

Borneo Recovery > 10 years after logging (Pfeifer et al. 2016)



Disturbance



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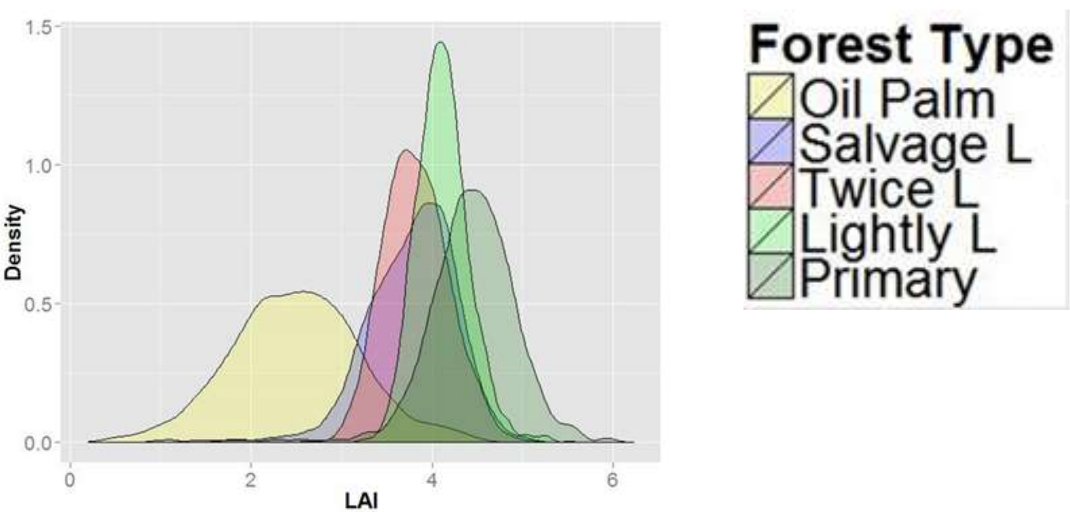
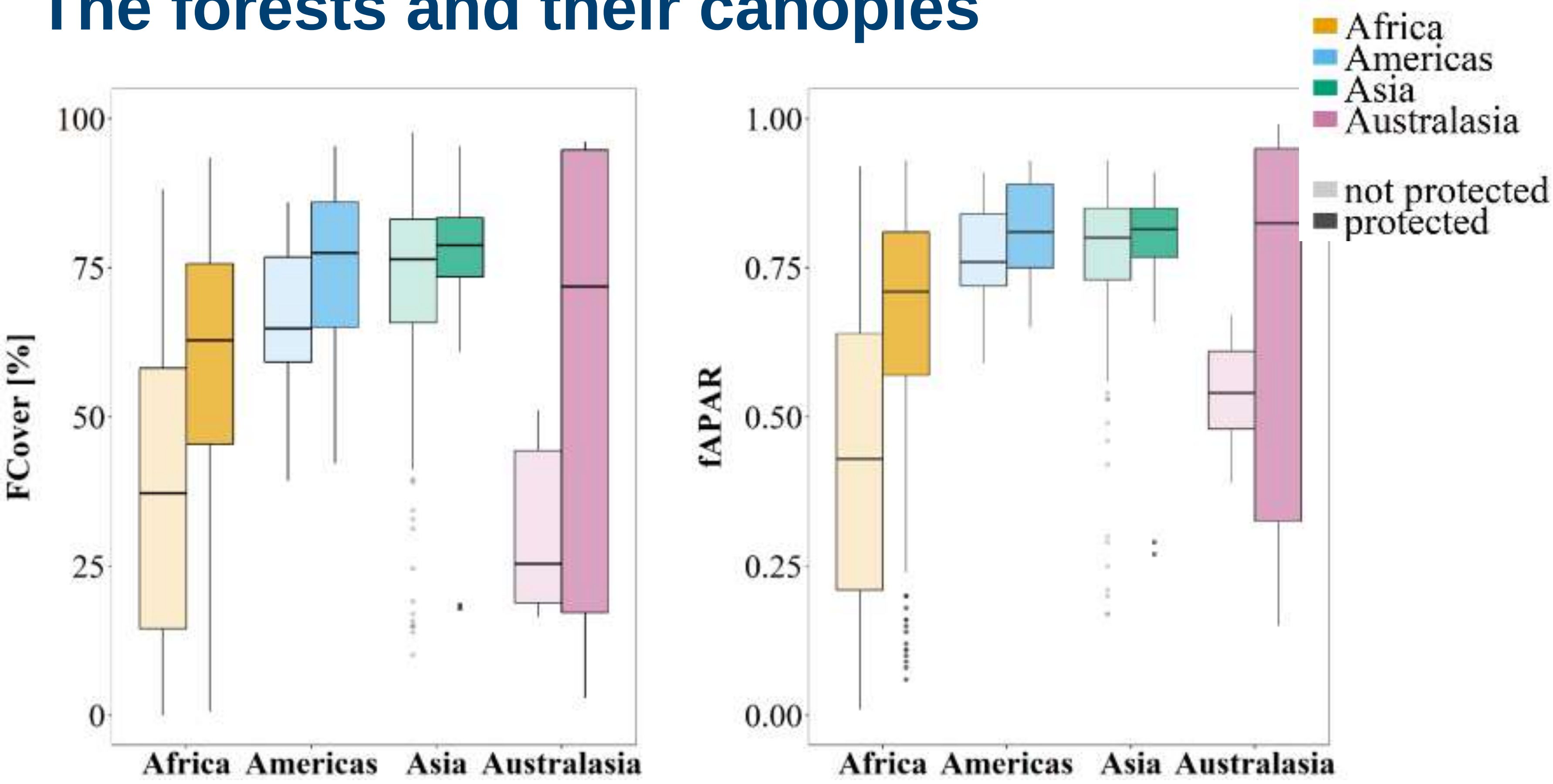
Borneo

Recovery > 10 years after logging (Pfeifer et al. 2016)



Up-scaled maps using passive sensor data: LAI and FCover are still reduced in logged compared to primary forest stands & much lower in oil palm stands.

The forests and their canopies



A) LAI (bounded between 0 and 10), Linear mixed effects model	
Global model	MWD * Protection + Poppress * Protection + MinT * Protection + Slope * Protection + LatLong + (1 + MWD|Continent)
N final models	2
Model importance and sign of coefficient estimates (conditional model-average)	Intercept: + 0.342 **Protection** = 1: 1, + 0.117 MinT: 1, + 0.036 MWD: 0.72, - 0.073 **Protection:MWD**: 0.72, + 0.046

Akora 2002 Reviews of Geophysics

LAI & fAPAR are central to prescribing vegetation dynamics in ecological models

Phenology

$$\mathrm{LAI}_T = 0 \qquad \text{if } T_{0.5} < T_{\mathrm{on/off}}$$

$$\mathrm{LAI}_T = \mathrm{LAI}_{\max}\left[1 - \left(\frac{T_{\max} - T_{0.5}}{T_{\max} - T_{\mathrm{on/off}}}\right)^2\right] \qquad \text{if } T_{\mathrm{on/off}} < T_{0.5} < T_{\max}$$

$$\mathrm{LAI}_T = \mathrm{LAI}_{\max} \qquad \text{if } T_{0.5} < T_{\max}$$

Akora 2002 Reviews of Geophysics

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Photosynthesis

Light Use Efficiency method:

LUE = NPP / APAR with APAR = PAR x **fAPAR**

Carbon Assimilation method:

$GPP = c_{max} f_1(PAR)\ f_2(\mathbf{LAI})\ f_3(c_{a,}\ g_s)\ f_4(N)$