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Net primary production in South African grasslands: relationship to rainfall, soil type and history

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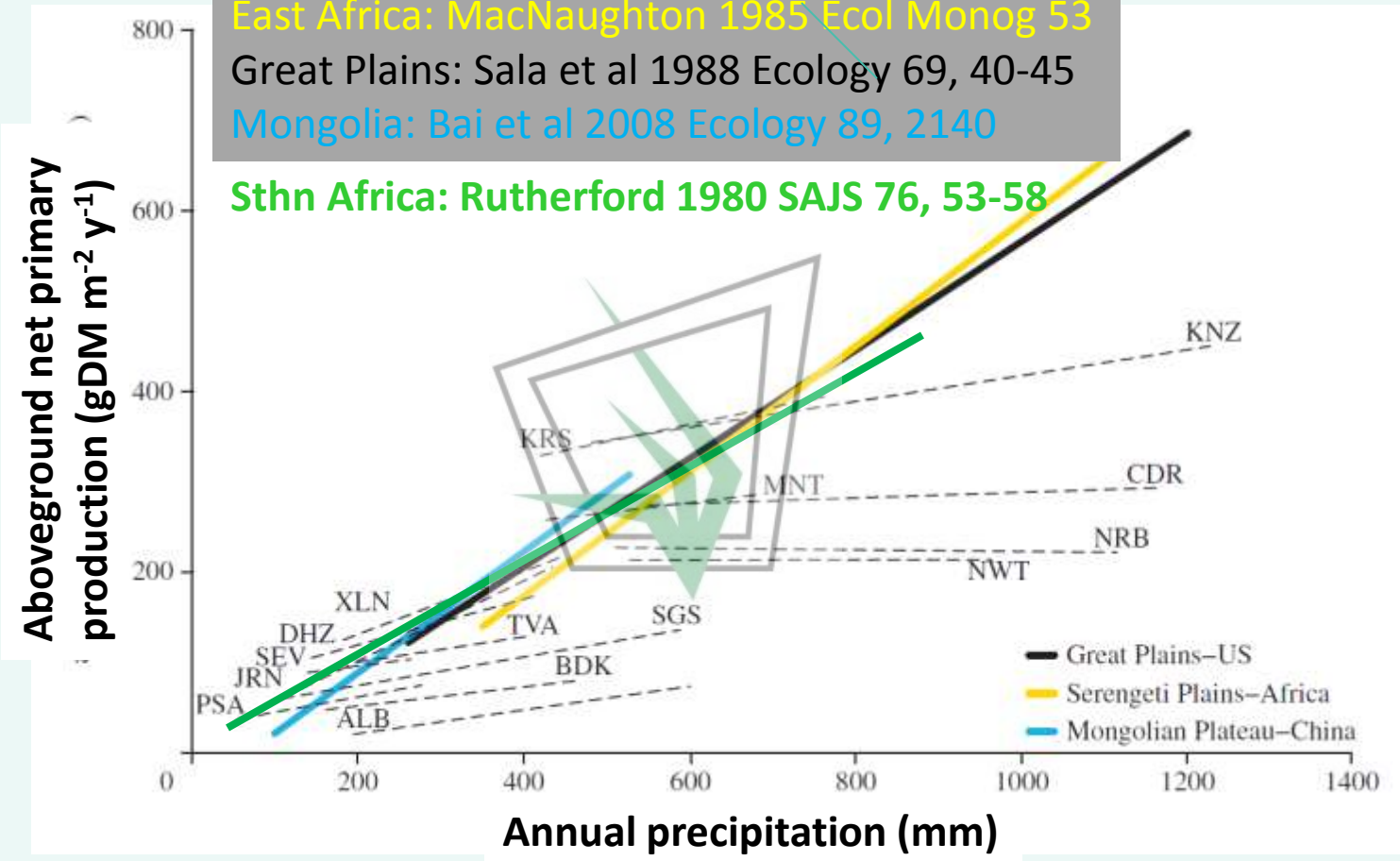
The primary productivity-rainfall relation in grasslands

The spatial relation (across-sites) has a higher slope than the temporal relation (within-site)
Temporal relations also explain less variance (10-75%) than the spatial (48-94%) relations

East Africa: MacNaughton 1985 Ecol Monog 53
Great Plains: Sala et al 1988 Ecology 69, 40-45
Mongolia: Bai et al 2008 Ecology 89, 2140

Sthn Africa: Rutherford 1980 SAJS 76, 53-58



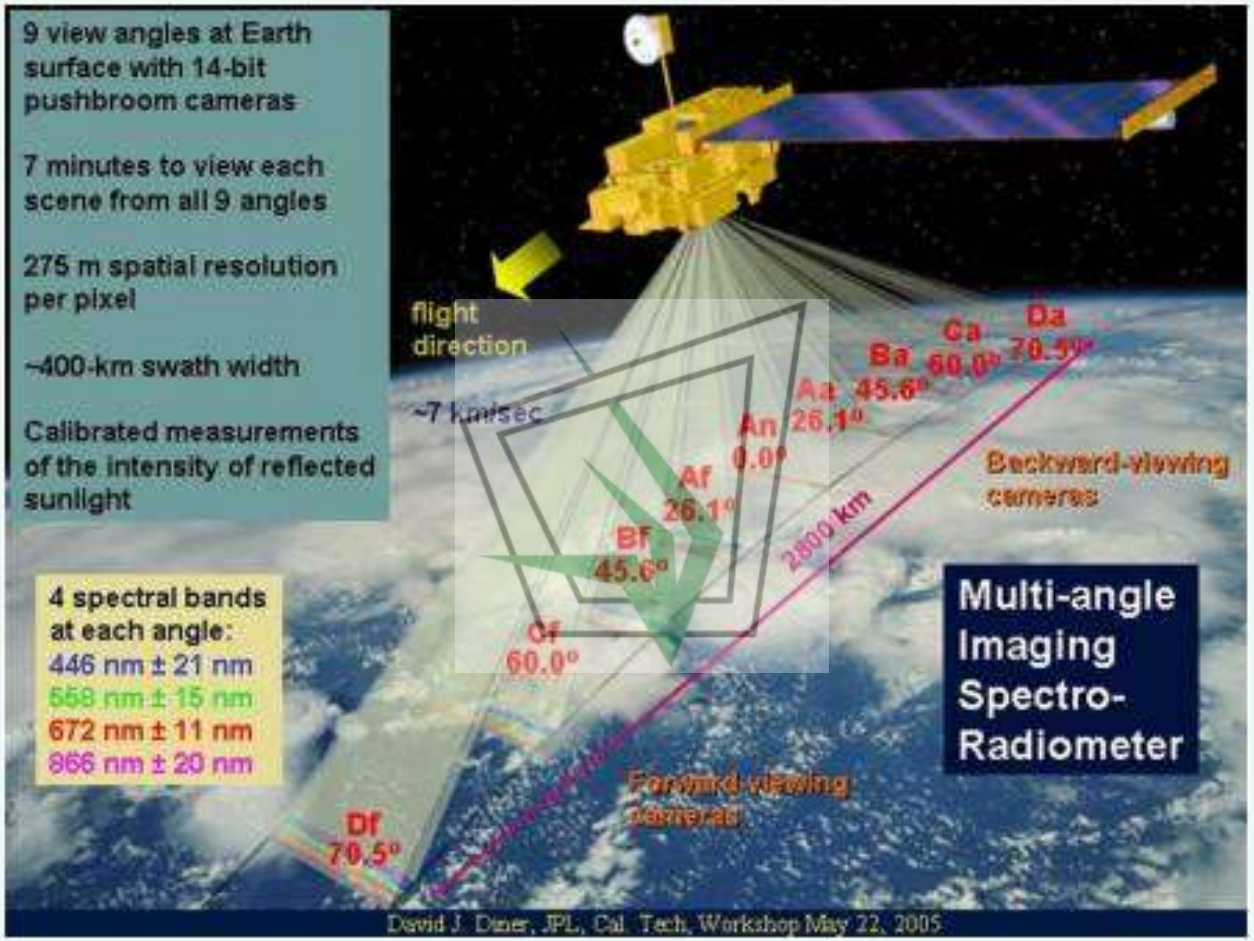
Key references

Sala et al 2012 Phil Trans Roy Soc B 367, 3135-3142
Knapp&Smith 2001 Science 291
Huxman et al 2004. Nature, 429, 651.

Prior research has found…

- About 1/3 of Sub-Saharan Africa shows a significant positive relation between NDVI and rainfall (Camberlin et al 2007 RSE *106*,199-216)
- Most grasslands show a dependence not only on current season rainfall, but on past rainfall (Sala, et al 2012. Phil Trans Roy Soc B: 367: 3135–3144)

MISR FAPAR: a powerful tool



Verstraete, M., Hunt, L., Scholes, R., Clerici, M., Pinty, B., Nelson, D., 2012. Generating 275-m resolution land surface products from the multi-angle imaging spectroradiometer data. 3980 IEEE Transactions on Geoscience and Remote Sensing 50 (10).

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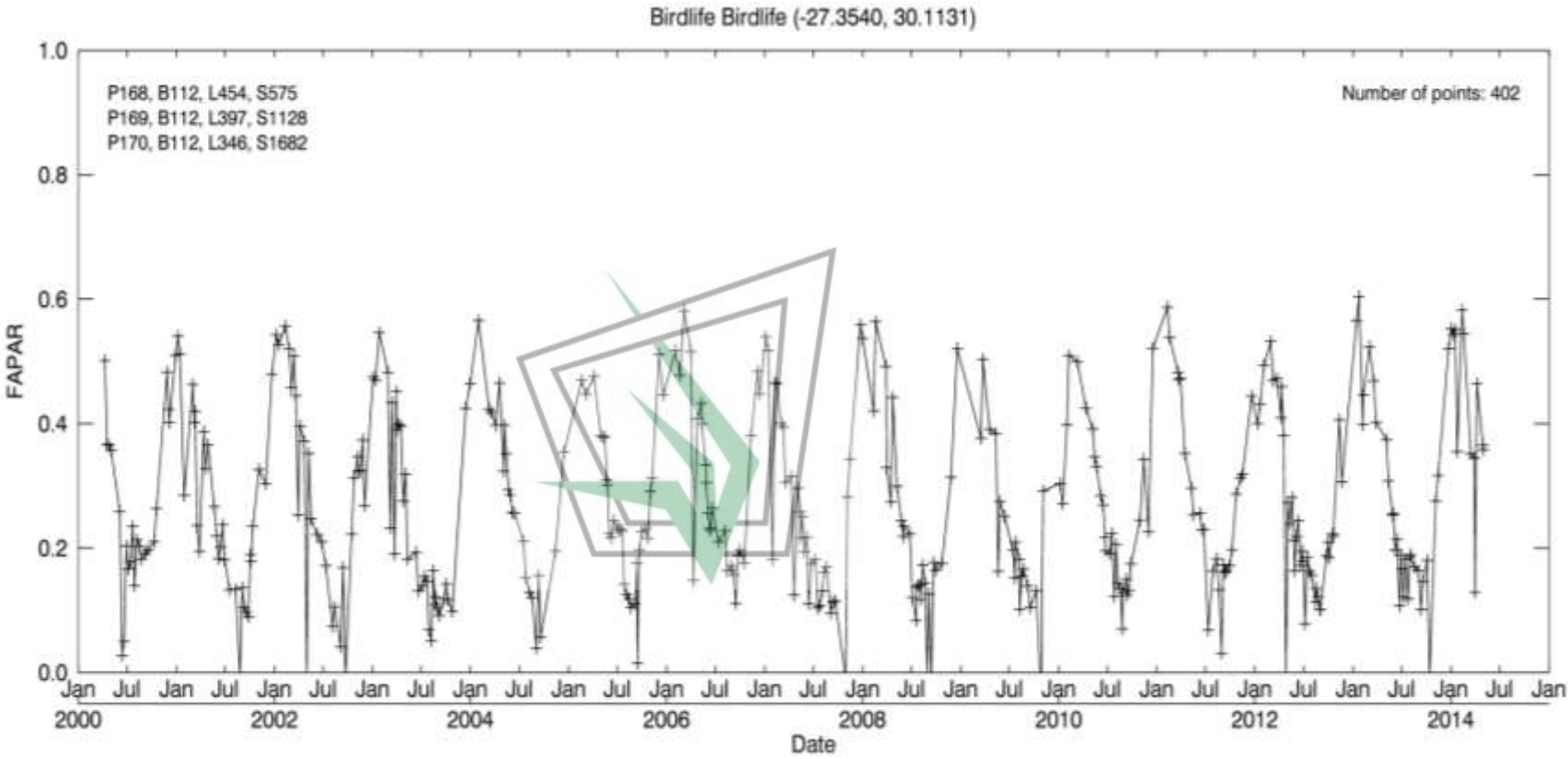
The swath is narrow but there is overlap between adjacent paths
You get three views every 8 days, about half cloud-obscured

Example: Wakkerstroom

15 years of FAPAR every ~ 8 days



Moyo, M 2018 The Phenology of the Enkangala Grasslands. MSc thesis, Wits

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Why is FAPAR better than NDVI?

- There is a direct mechanistic relationship between FAPAR and GPP. The relationship is often good for NDVI, but indirect and always empirical
- NDVI has mathematic properties which lead to problems at both low and high extremes, as well as on reddish soils
- The S:N ratio of FAPAR is better than for NDVI; and inversion-based FAPAR estimates come with an uncertainty estimate.

FAPAR and productivity

GPP = APAR*ε (ε for C4 grasses ~ 1.85 gC/MJ)

Also:

APAR = PAR*FAPAR

PAR, South Africa,growing season ~ 6.8 MJ/m^2/day (~0.45*↓SW)

NPP~ 0.5 GPP, AGNPP ~ 0.5 NPP

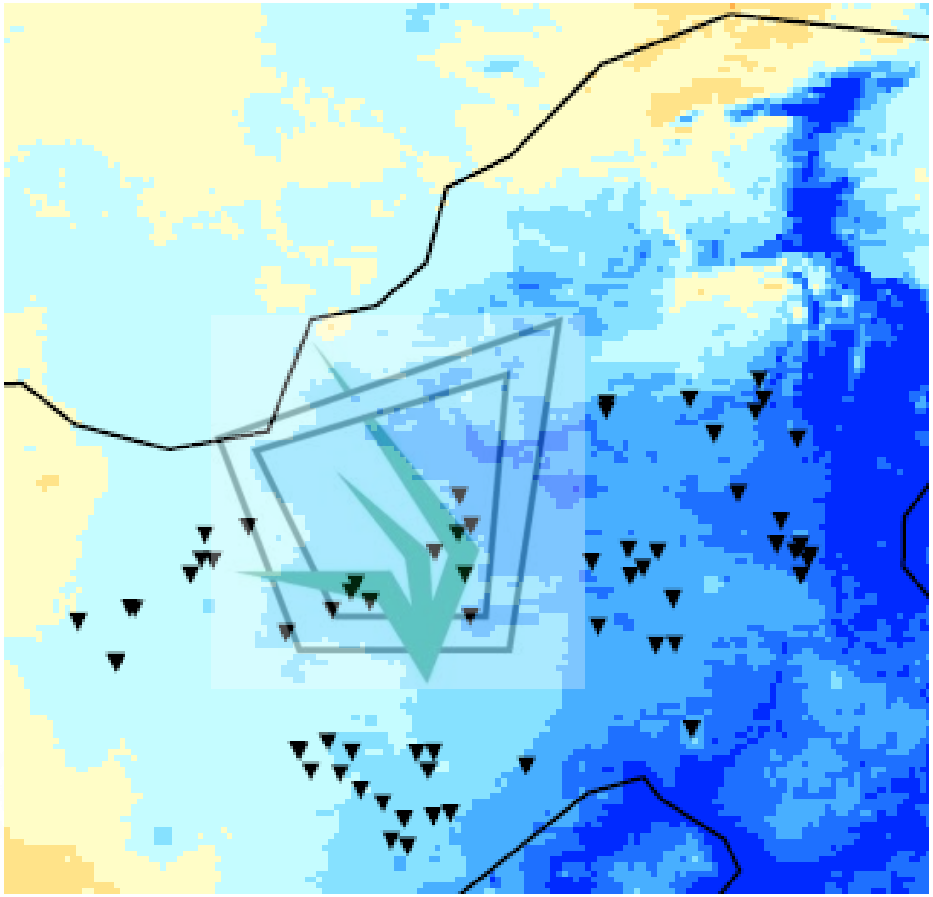
Thus:

AGNPP (gC/m^2)~180*6.8*1.85*0.5*0.5*FAPAR

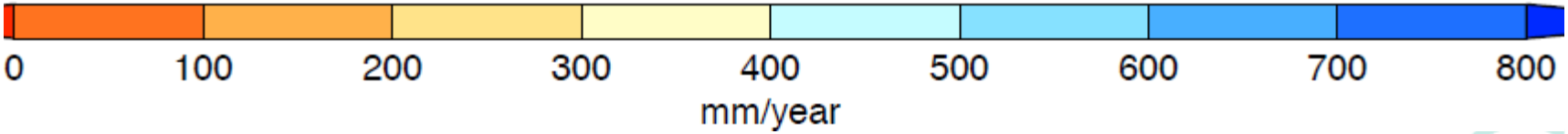
~ 566*seasonally-averaged FAPAR

60 Sample locations in the grassland biome

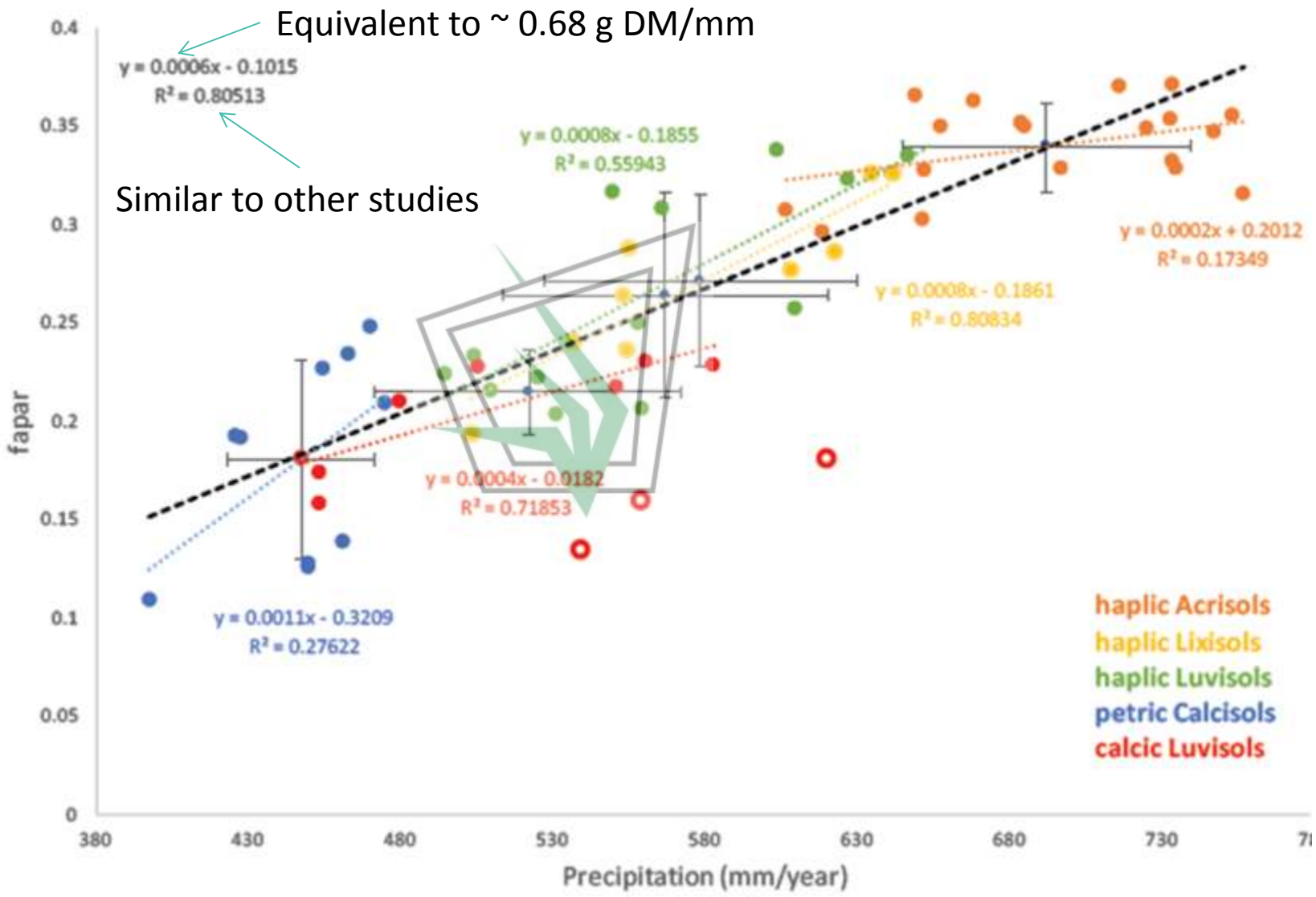
visually controlled with high-res images to be level, un-degraded grasslands



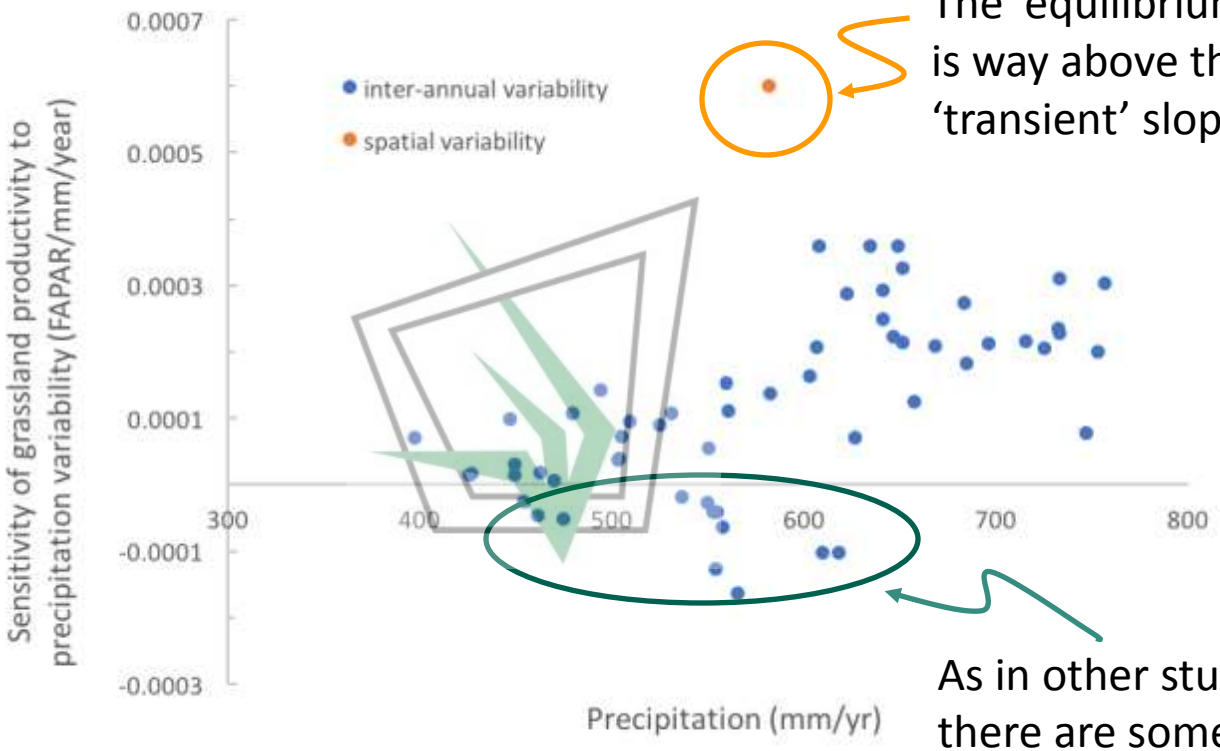
Overlaid on CHIRPS rainfall (Funk et al)



The cross-site FAPAR vs rainfall relation for South African grasslands



Slope of temporal vs spatial correlations



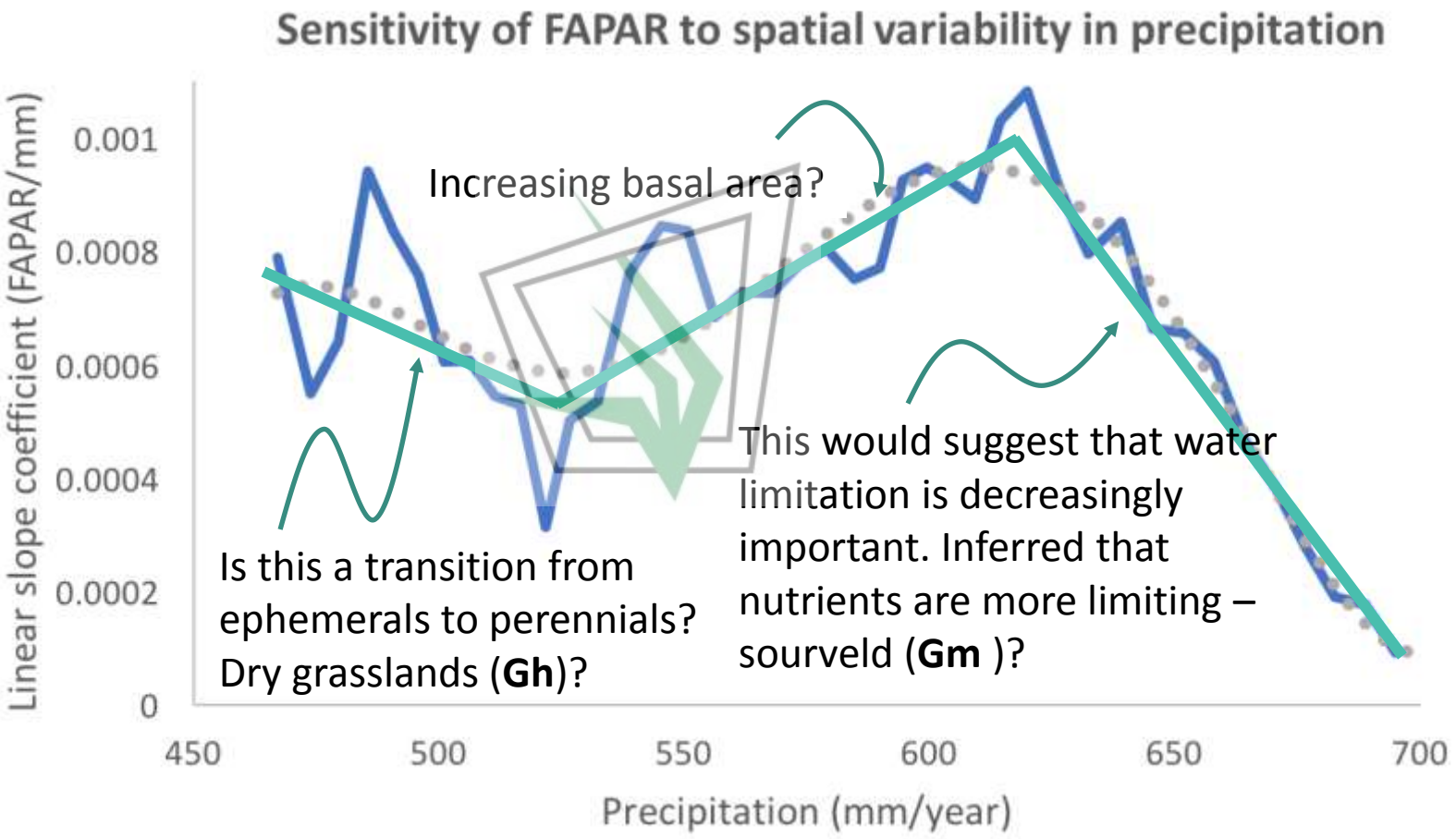
The 'equilibrium' slope is way above the 'transient' slopes

As in other studies, there are some sites where the relation is negative

This is suggested to be a result of pulse-press dynamics
Schwinning et al 2004. Oecologia 141: 191–193 and 211-220

There is a slope change above 625 mm

And perhaps another at 520?

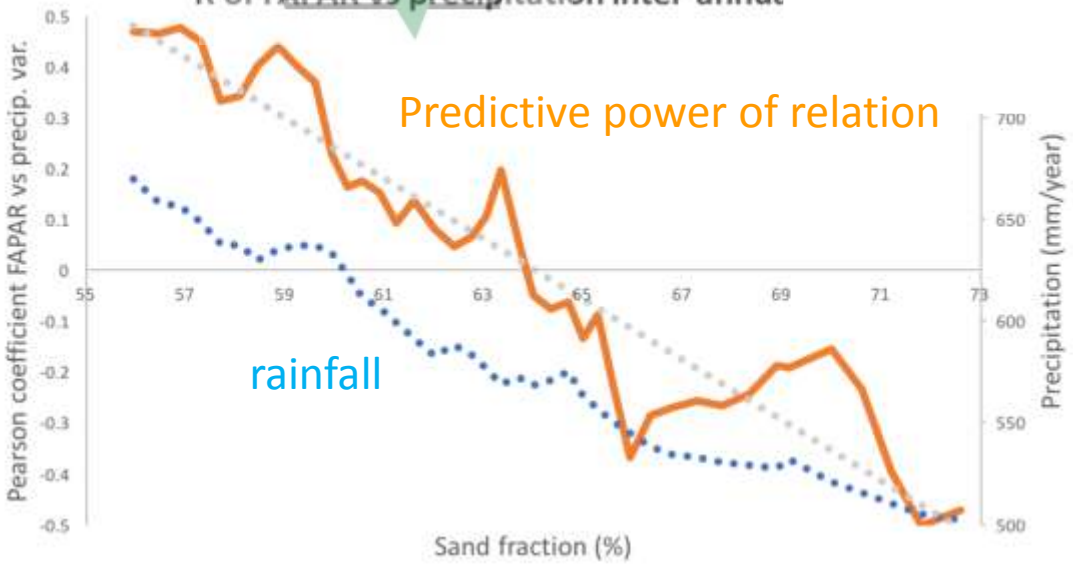


Rainfall is the main controller of FAPAR

soil features also matter, but they are covariant with rain

	FAPAR	precip	stdev. pre-cip	CEC	OC	BD	clay	sand	silt	rock depth	prob. regosols	pH
FAPAR	1.00											
precip	0.90	1.00										
stdev. precip	0.085	0.32	1.00									
CEC	0.38	0.35	-0.05	1.00								
OC	0.85	0.88	0.125	0.40	1.00							
BD	-0.56	-0.59	-0.21	-0.57	-0.61	1.00						
clay	0.73	0.75	0.03	0.65	0.82	-0.77	1.00					
sand	0.75	-0.75	-0.07	-0.27	-0.71	0.51	-0.64	1.00				
silt	0.40	0.39	0.07	-0.15	0.28	-0.06	0.05	-0.80	1.00			
rock depth	-0.47	-0.47	-0.12	-0.33	-0.28	-0.36	-0.34	0.35	-0.19	1.00		
prob. regosols	-0.04	-0.04	-0.18	0.02	-0.02	0.09	-0.10	0.02	0.05	-0.21	1.00	
pH	0.89	-0.88	-0.18	-0.22	-0.81	0.47	-0.59	0.77	-0.54	0.53	-0.01	1.00

R of FAPAR vs precipitation inter-annual variability ation mean



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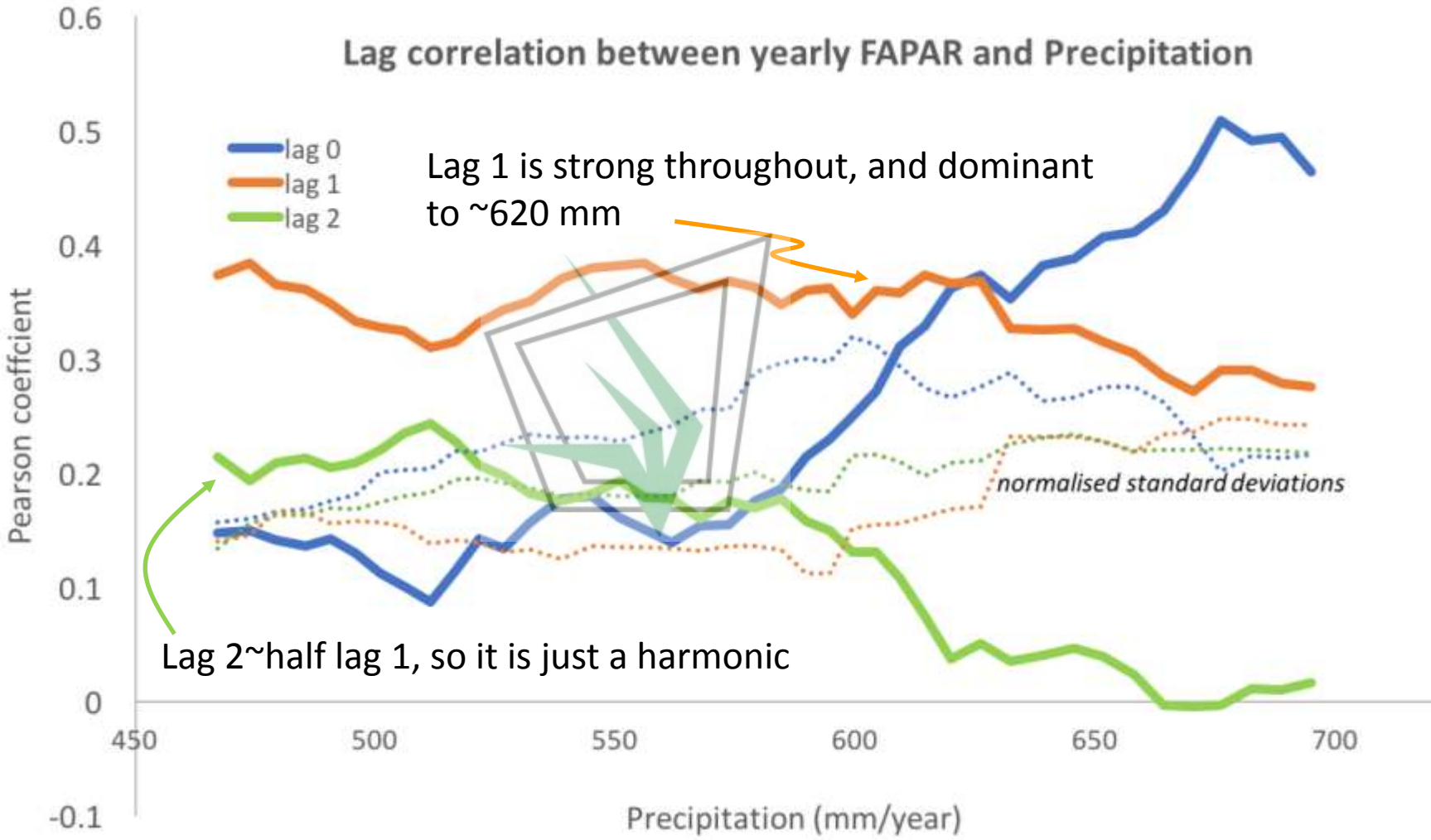
The memory of grasslands

How does production in year t depend on $rainfall_t$, $rainfall_{t-1}$ and $rainfall_{t-2}$?



Lag 0 grows in predictive power above 570 mm, Lag -1 dominates to 625 mm
Lag -2 is about half as important as lag -1, but falls off above 580 mm

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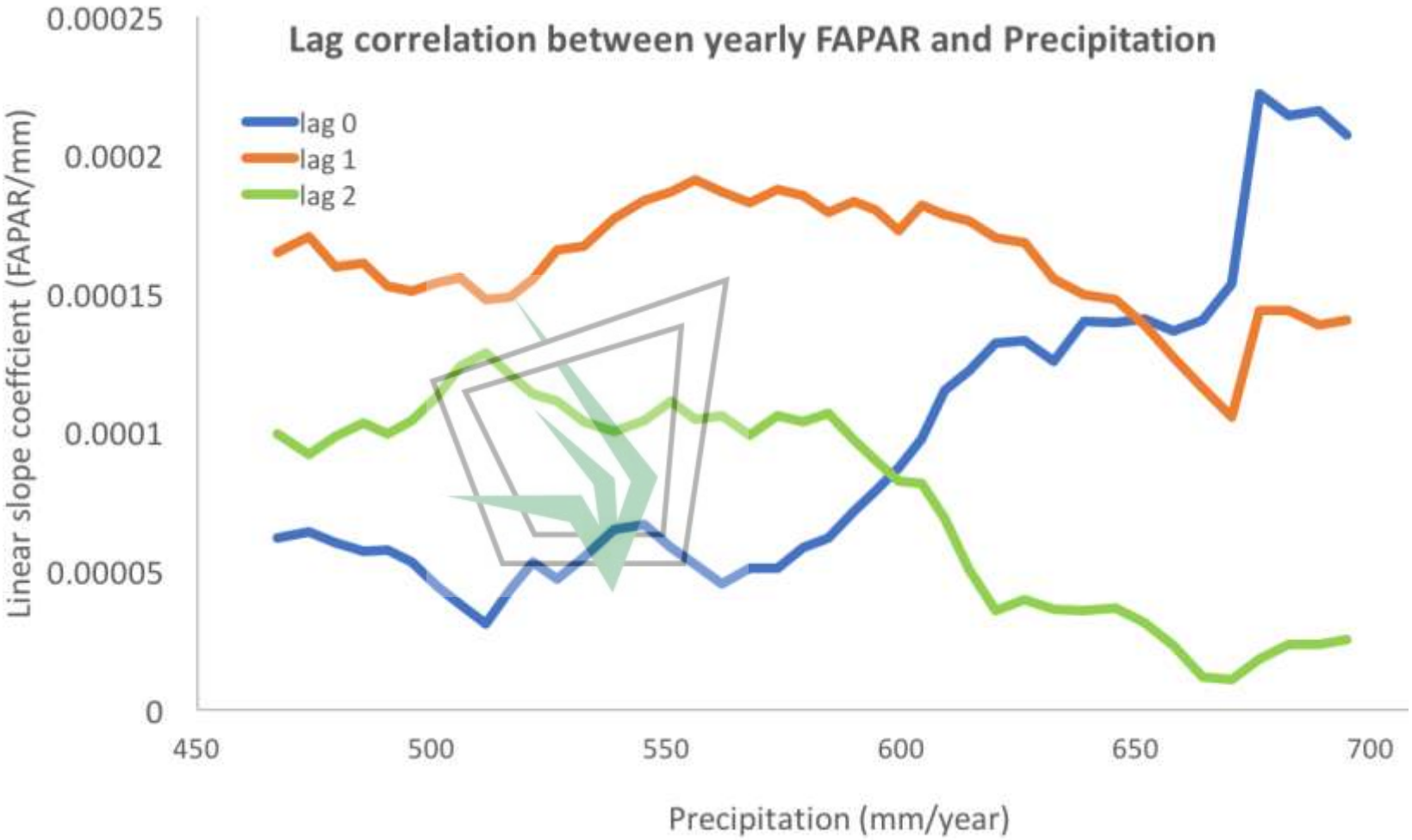
What about sensitivity to past rainfall?



Slope coefficients are **positive** throughout, suggesting carryover of reserves from previous years (tillers? carbohydrates?) rather than depletions or damages
Trends in relation to MAP in complete contrast to Sala et al 2015.

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Contrasting hypotheses regarding memory

- The 'basal area effect'
  - A good rainfall year, or an un-degraded state, allows a higher basal area which leads to higher rain use efficiency (Weigand et al 2004)
- The 'nitrogen pool depletion' effect
  - A higher rainfall year depletes the soil available nitrogen in the subsequent year (Schwinnin&Sala 2004)
- The fire effect
  - In the year following a fire, higher grassland production is observed,
    - Is it due to reduction in self-shading, or stimulation of the nitrogen cycle?

Schwinning & Sala, O. E. (2004). Hierarchy of responses to resource pulses in arid and semi-arid ecosystems. Oecologia, 141, 211-220.
Wiegand, T., Snyman, H.A., Kellner, K. and Paruelo, J.M., 2004. Do grasslands have a memory: modeling phytomass production of a semiarid South African grassland. Ecosystems, 7:243-258.
Briggs, J. M., & Knapp, A. K. (1995). Interannual variability in primary production in tallgrass prairie: climate, soil moisture, topographic position, and fire as determinants of aboveground biomass. Am J of Botany, 82, 1024-1030.

Next directions

- **Can we construct a predictive model good enough to detect degradation above the interannual noise?**
  - Annual models typically explain~70% of variance; monthly models~80%, and daily models~ 90%
- **Is there a robust *functional* way of classifying South African grasslands which can also be spatially mapped at useful resolution?**
  - The distinct splits at 620 mm and possibly 520 mm suggest there may be.

Sala, Gherardi & Peters, D.P., 2015. Climatic Change, 131(2), pp.213-227.

In summary…

1. Long-term, consistent, physically-based remotely-sensed observations allow fundamental grassland ecology questions to be addressed

2. NPP at un-degraded sites is highly predictable from rainfall in the present and previous year. Deviations from this expectation to be detected and attributed

3. There seems to be a distinct functional shift in southern African grasslands just above 600 mm MAP.

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