A re-assessment of rooting depth dynamics and their influence on catchment water fluxes

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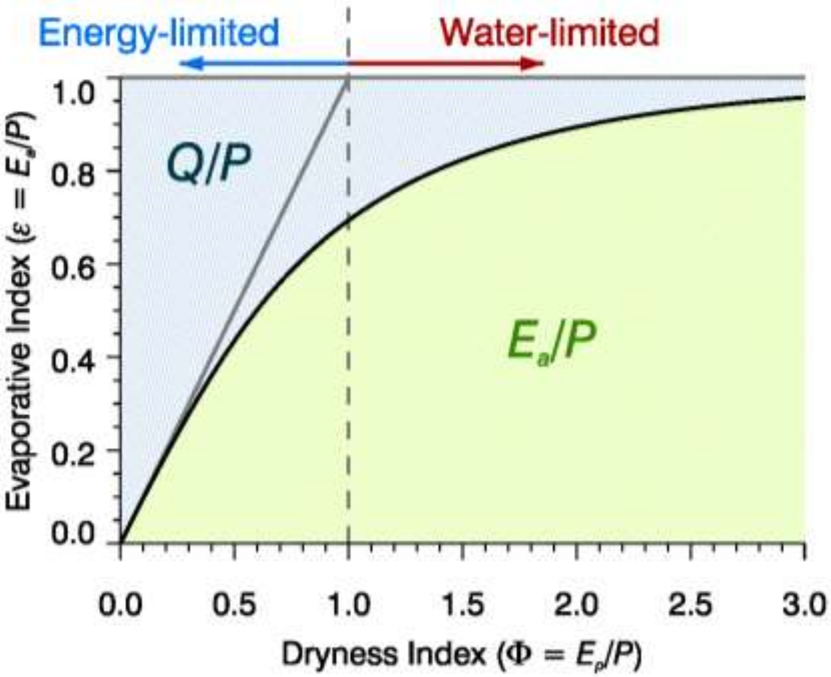
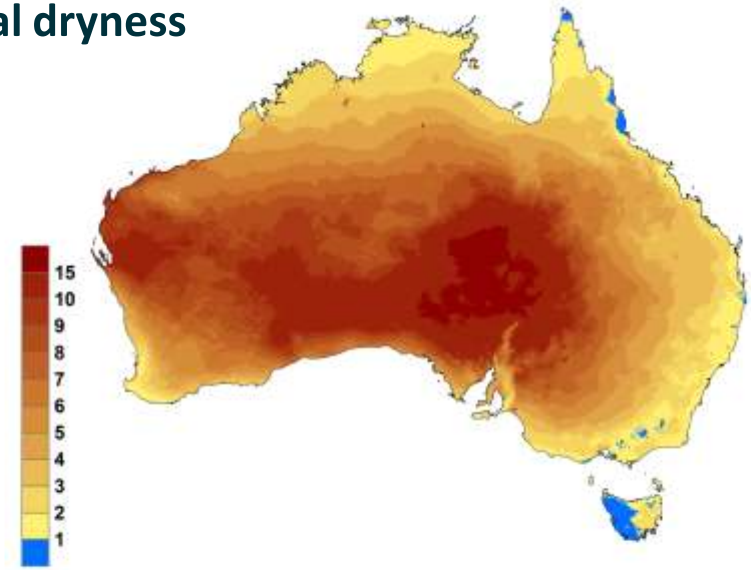
Estimating average stream flow using Budyko's model

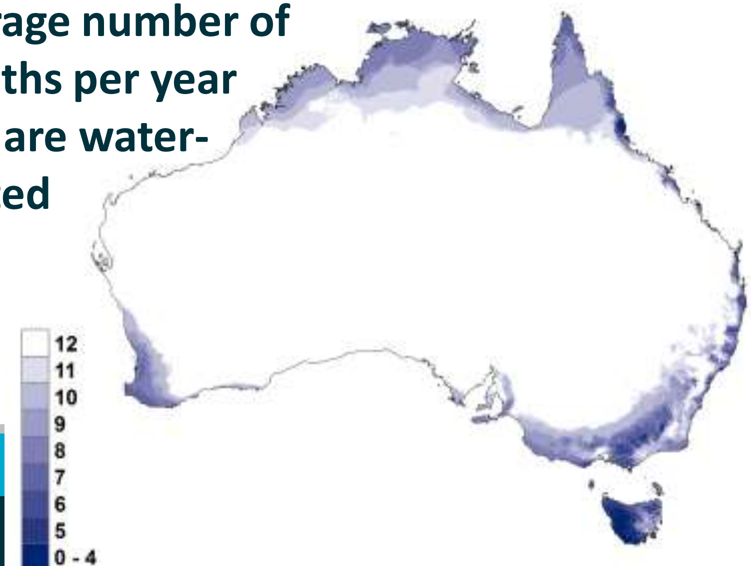


$$E_a = \left[R_s P \tanh \frac{P}{R_s} \left(1 - \cosh \frac{R_s}{P} + \sinh \frac{R_s}{P} \right) \right]^{1/2}$$

Annual dryness index



Average number of months per year that are water-limited



Note: Budyko originally framed this as water supply (P) verses energy supply (R_s). It is common to use R_s and evaporative demand (E_p) ~interchangeably.

Budyko, M.I., 1974. Climate and life. International Geophysics Series, 18. Academic, New York, 508 pp.

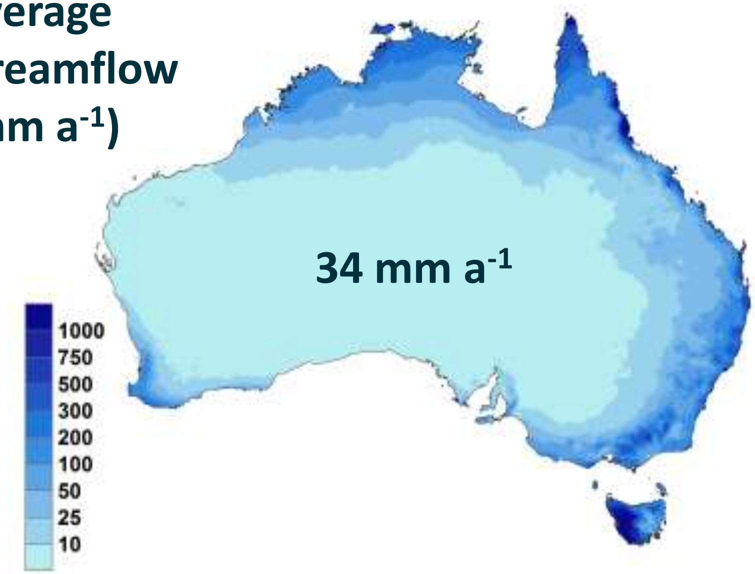
Estimating average stream flow using Choudhury's formulation

$$E_a = \frac{P R_{net}}{\left(P^n + R_{net}^{\,n}\right)^{1/n}}$$

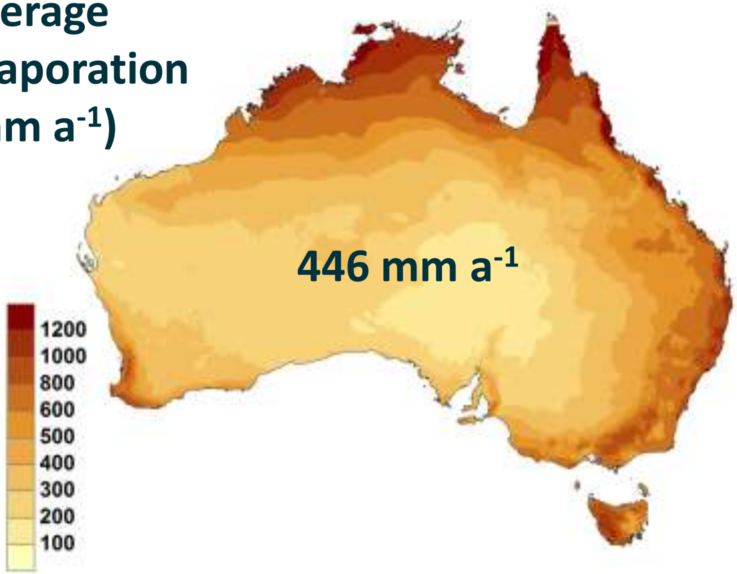
n = 1.8 for large catchments

$n \approx$ 1.9 is Budyko's curve

Average streamflow ($mm\ a^{-1}$)



Average evaporation ($mm\ a^{-1}$)

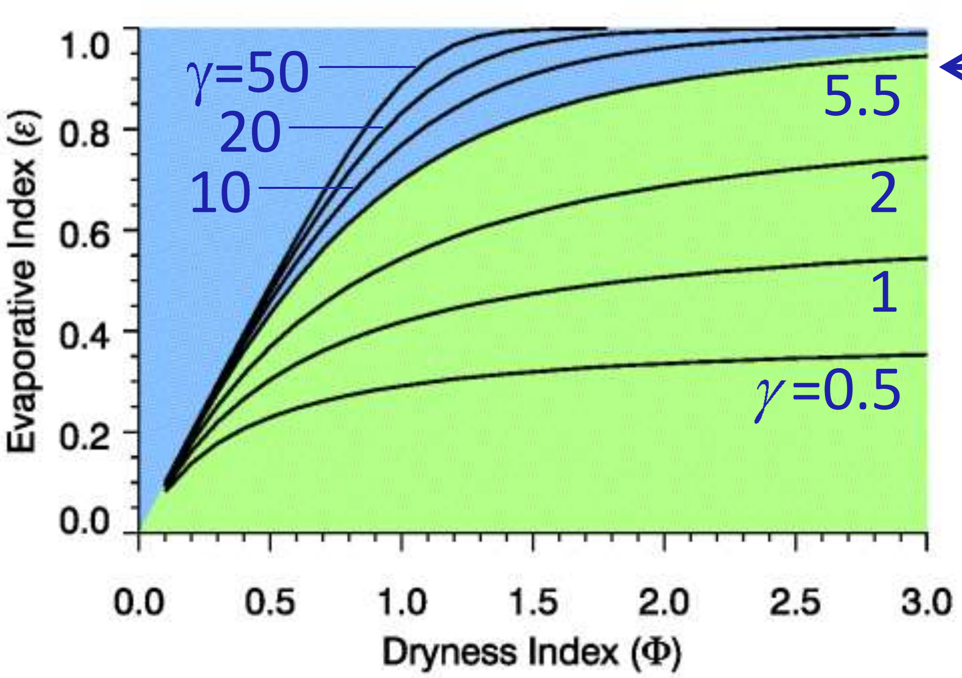


Choudhury, B.J., 1999. Evaluation of an empirical equation for annual evaporation using field observations and results from a biophysical model. Journal of Hydrology, 216(1/2), pp 99-110

Porporato *et al*'s supply/storage relation

$$\gamma = \frac{\kappa Z}{\alpha}$$

κ = relative soil water holding capacity (mm/mm)
Z = max. storage depth (mm)
α = storm depth (mm)



Budyko's curve is where the storage depth is ~5.5 times the mean supply depth

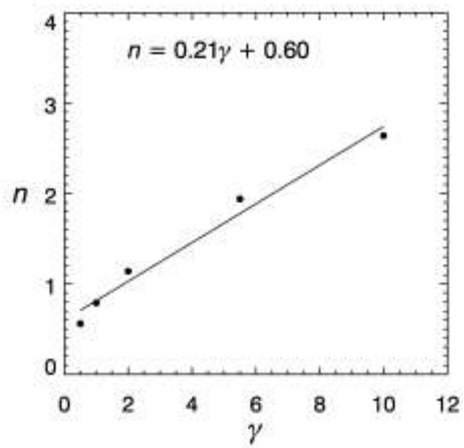
Z is the extraction (rooting) depth = vegetation!

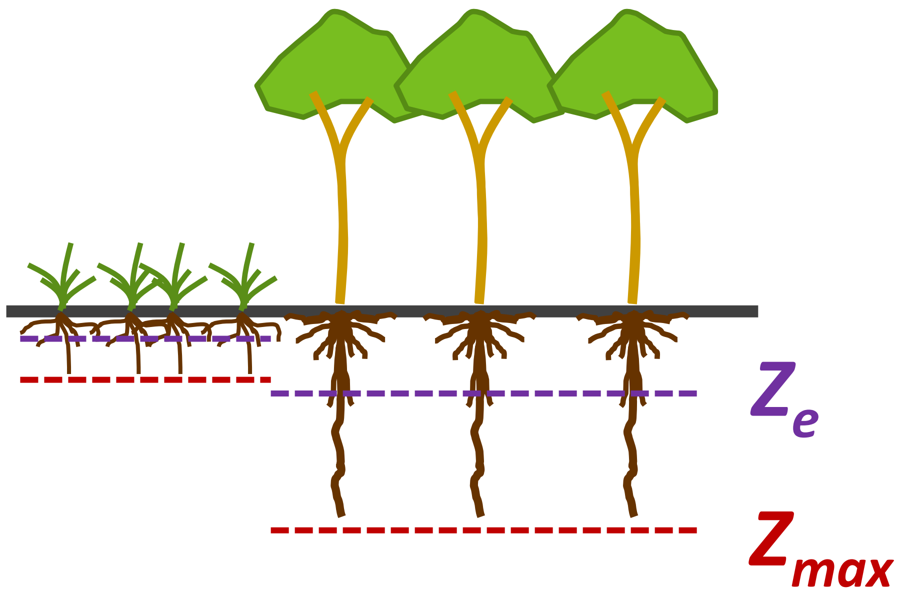
Porporato, A., Daly, E. and Rodriguez-Iturbe, I., 2004. Soil water balance and ecosystem response to climate change. Am Nat, 164(5), pp 625-632

The Budyko–Choudhury–Porporato (BCP) model

$$E_a = \frac{PE_p}{{P^n + E_p{}^n}^{\,1/n}}$$

$$n \approx 0.21\frac{\kappa Z_e}{\alpha} + 0.6$$





Donohue, R.J., Roderick, M.L. and McVicar, T.R., 2012. Roots, storms and soil pores: incorporating key ecohydrological processes into Budyko's hydrological model. Journal of Hydrology, 436-437, pp 35-50.

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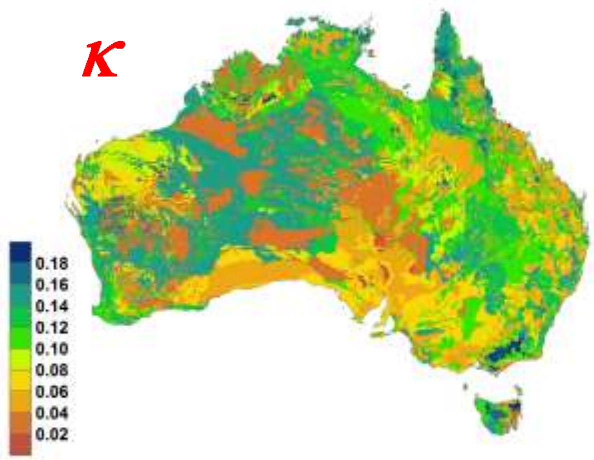

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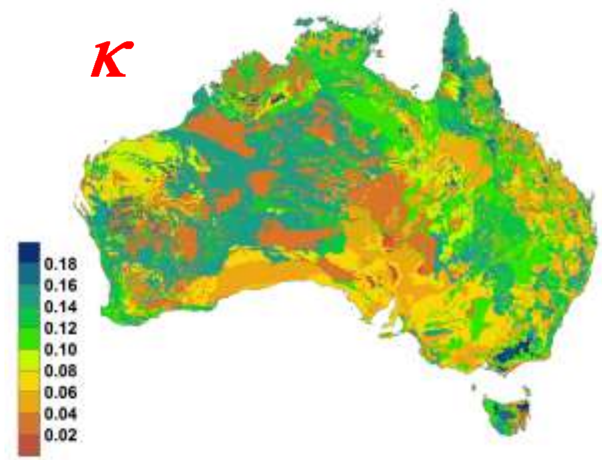
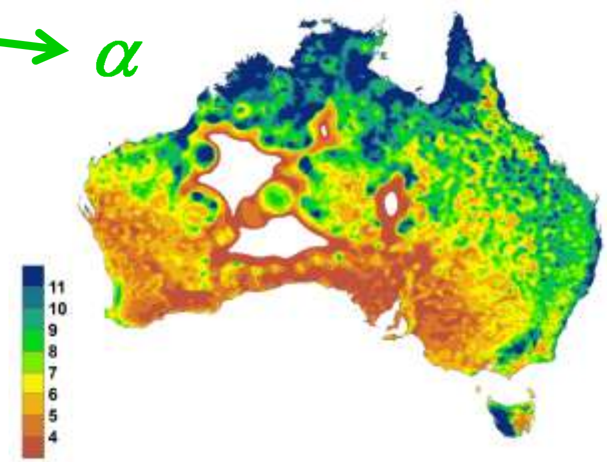
κ



α



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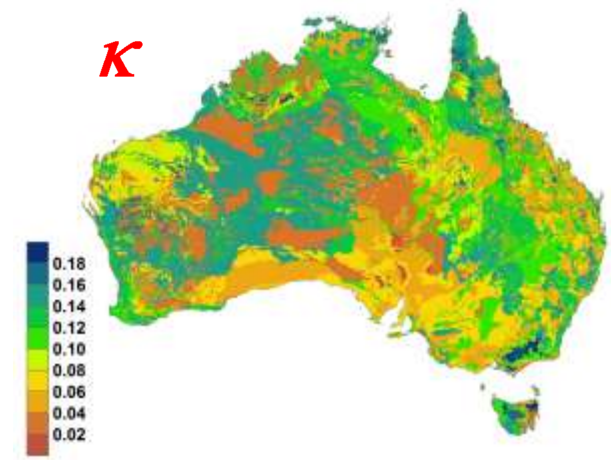
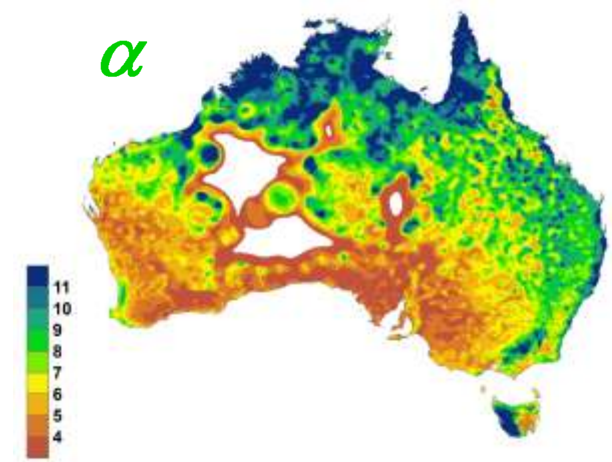
Z_e

κ



α



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For a given vegetation type, what determines rooting depth?

Broad generalisations suggest that, under water-limited conditions...

Precipitation amount

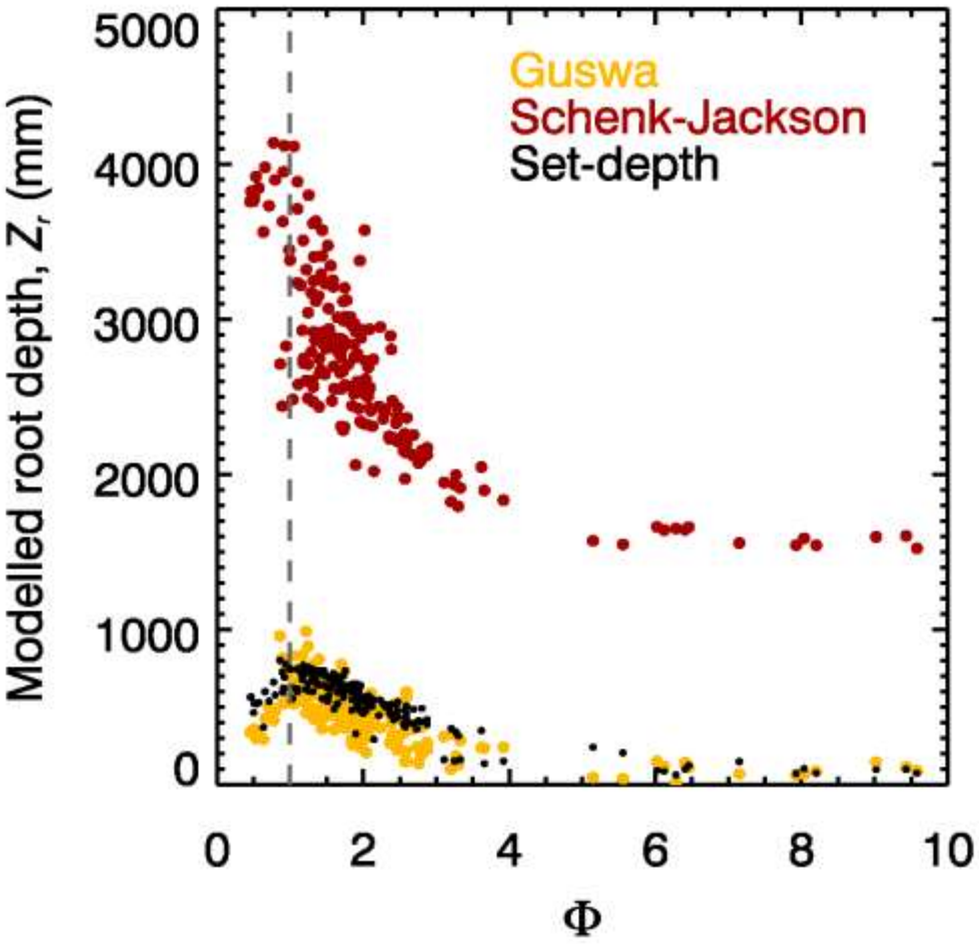
...the higher the rainfall, the deeper the rooting depth (Schenk and Jackson, 2002)

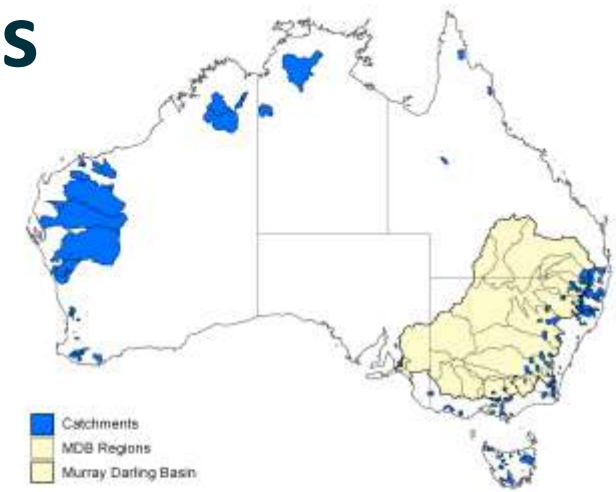
Precipitation intensity/seasonality

...the higher the rainfall intensity and/or seasonality under a given annual rainfall, the deeper roots become in order to maintain the same transpiration rate (Laio et al., 2002; Milly, 1994a; Porporato et al., 2004; Schenk and Jackson, 2002).

Models of rooting depth typically capture only the first of these generalisations.......

Existing rooting depth models





Existing rooting depth models

Schenck-Jackson – empirical model (Z_{max})

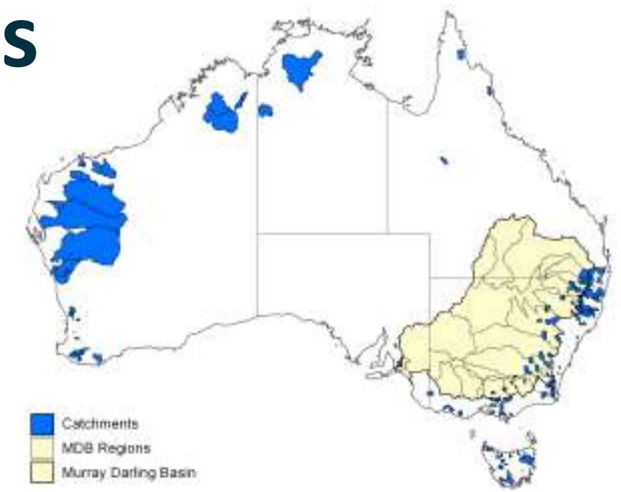
Schenk, H.J. and Jackson, R.B., 2002. J Ecol, 90, pp 480-494

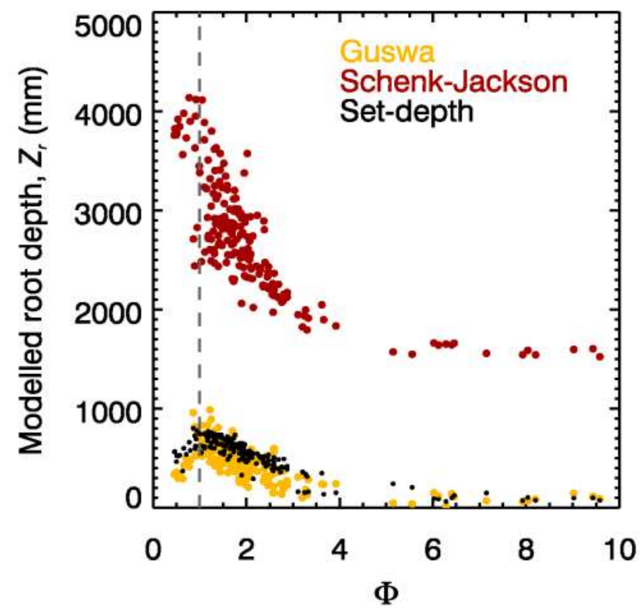
Perennial grasses

$$Z_{max} = -2.662 + 0.392 \log P + 0.543 \log E_p$$

Trees

$$Z_{max} = 4.967 - 0.086 \log P + 1.323 \log E_p$$





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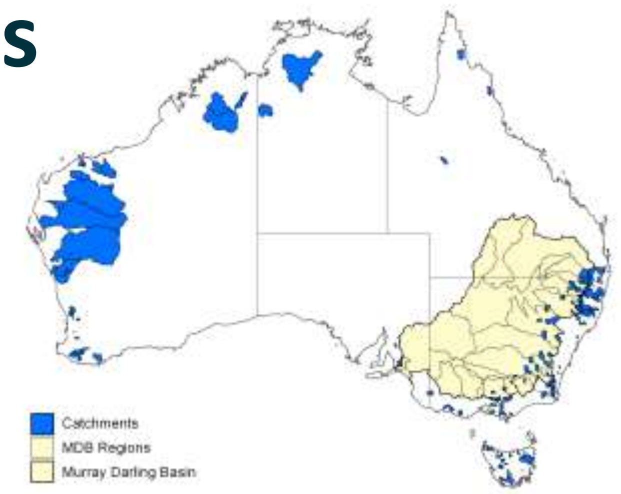


Schenck-Jackson – empirical model (Z_{max})

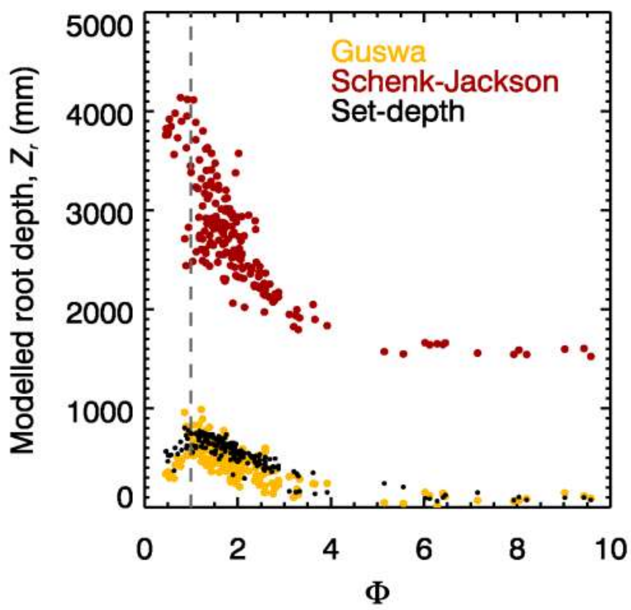
Schenk, H.J. and Jackson, R.B., 2002. J Ecol, 90, pp 480-494

Guswa – estimates the marginal carbon cost and benefit of deeper roots (Z_e)

Guswa, A.J., 2008. Water Resour. Res., 44(2).

Z_e is estimated, for a vegetation type, as a function of

- ϕ = dryness index
- κ = relative soil water holding capacity
- α = storm depth
- γ_r = mean root respiration rate
- f_s = growing season length
- SRL = specific root length
- RLD = root length density
- WUE = water use efficiency (of photosynth)



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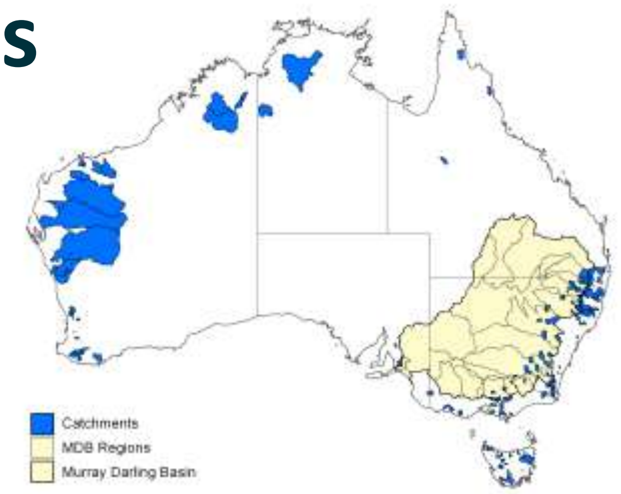
Existing rooting depth models



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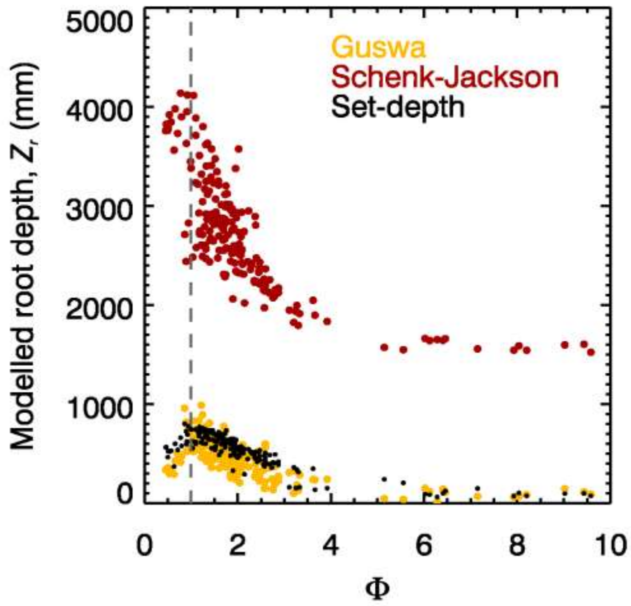
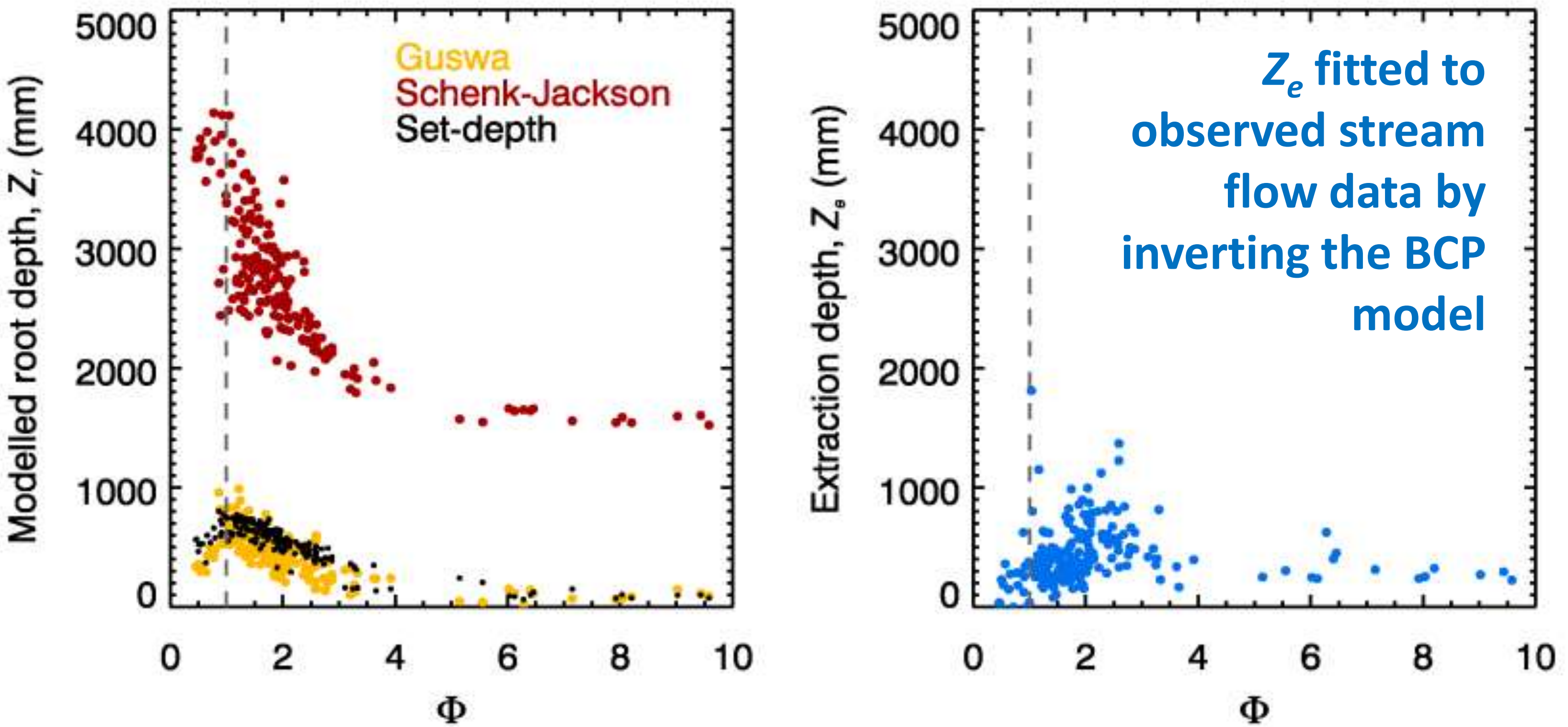
'Set-depth' – a constant rooting depth apportioned by remotely sensed fractional vegetation cover:

$$Z_e = 900F_{tree} + 600F_{grass}$$

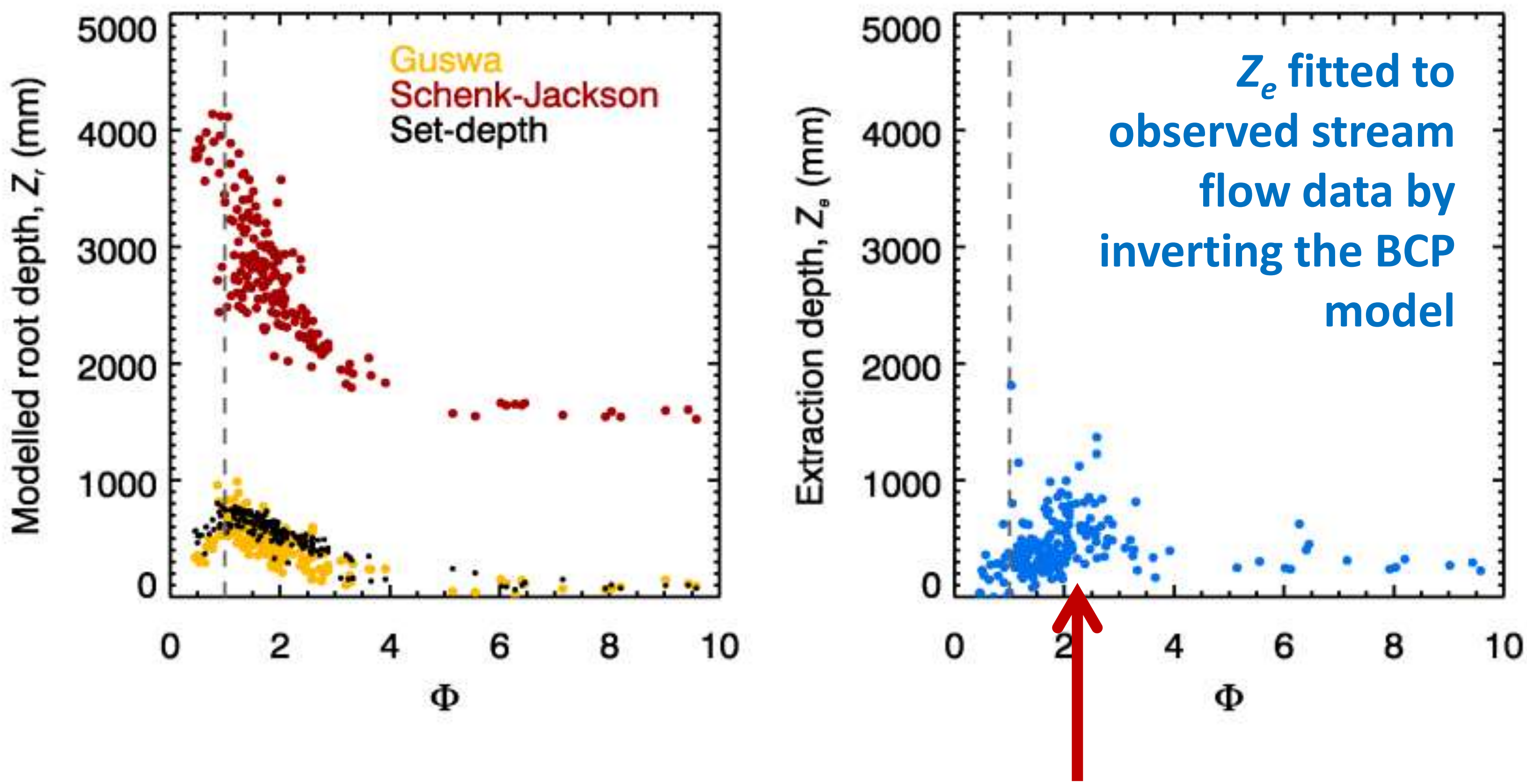


All of these models are run at the annual average time-step

Existing rooting depth models

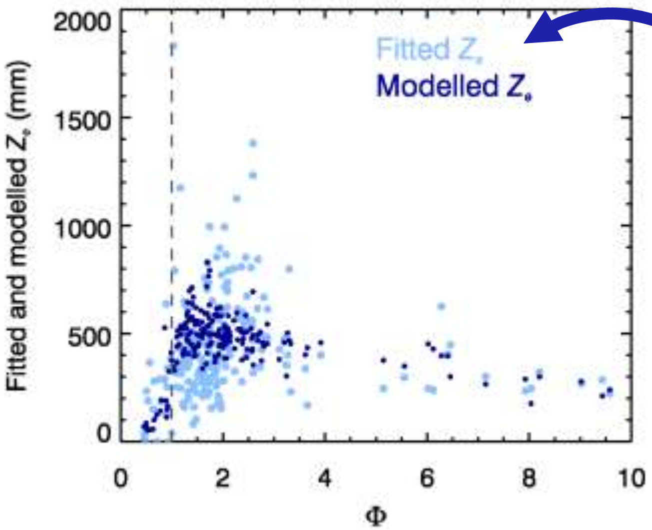


Existing rooting depth models

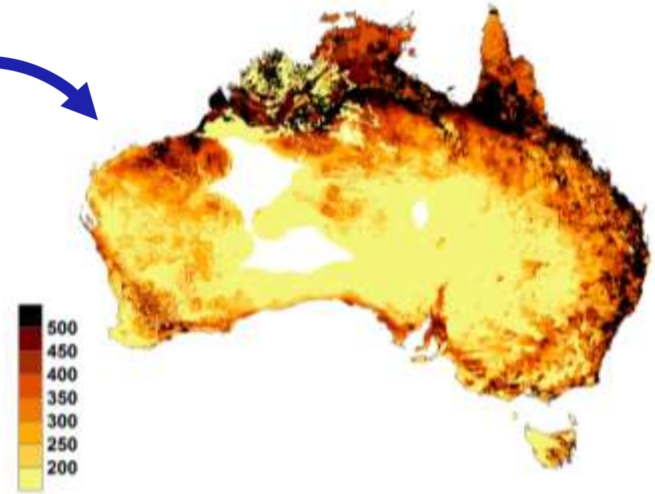


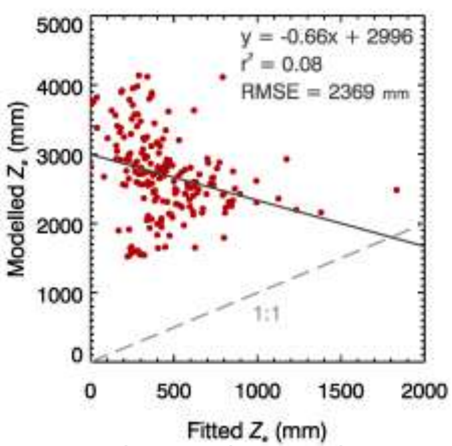
The effects of climate seasonality!

A seasonal implementation of Guswa's model

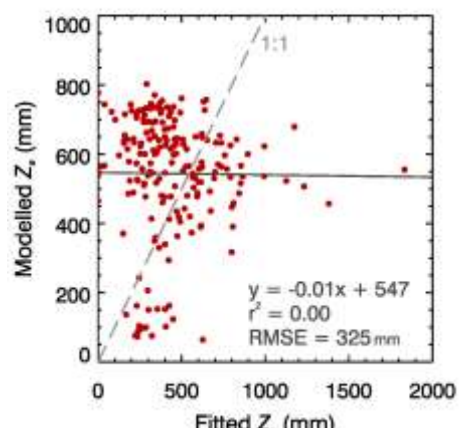


Guswa run at a LT monthly time-step to get an annual Z_e

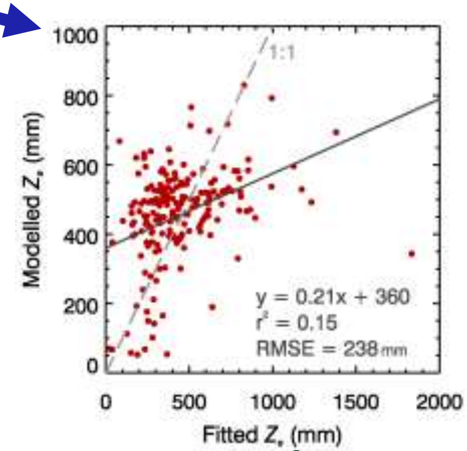




Schenck-Jackson



Guswa/set-depth



Seasonal Guswa

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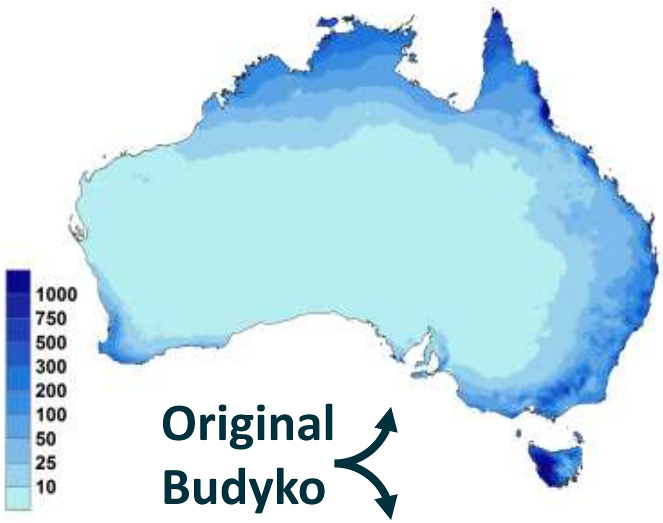
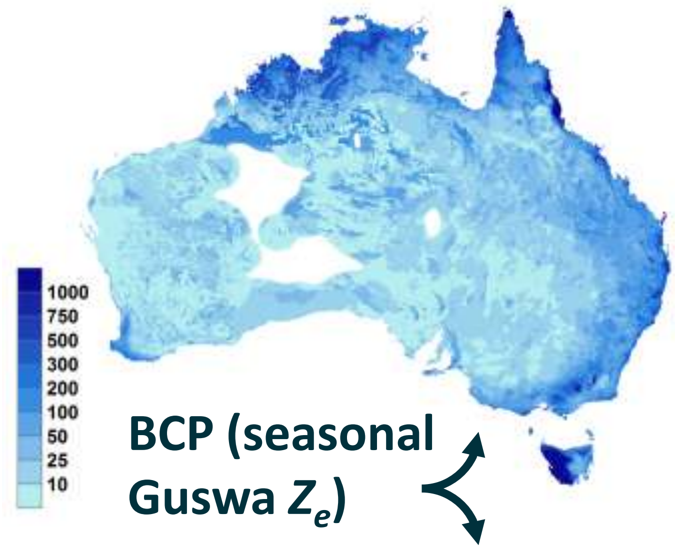
Stream flow estimated using the BCP model

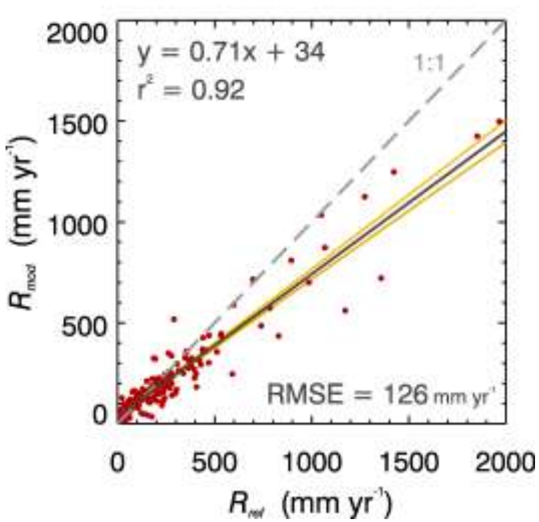


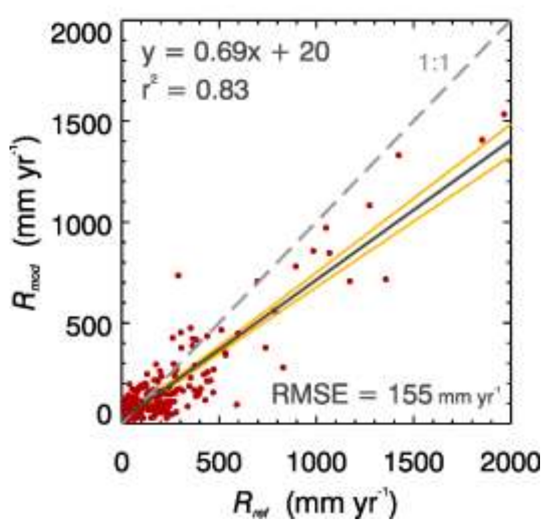


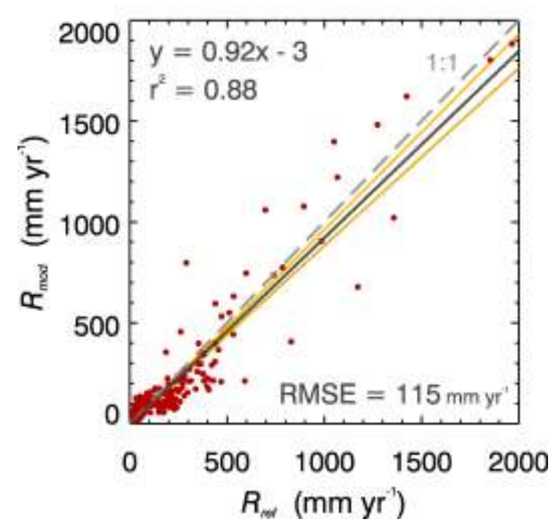
Original Budyko

BCP (original Guswa Z_e)

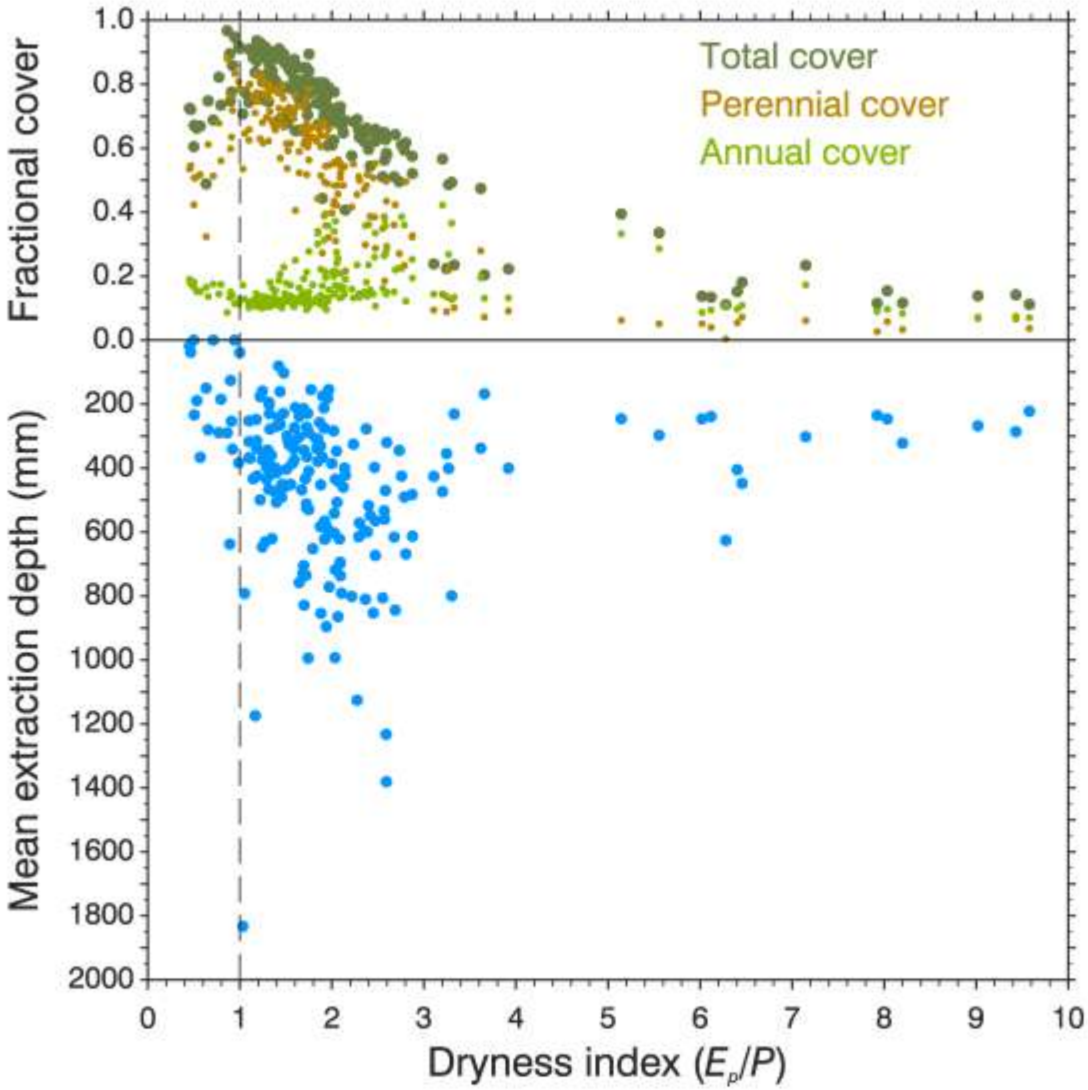
BCP (seasonal Guswa Z_e)

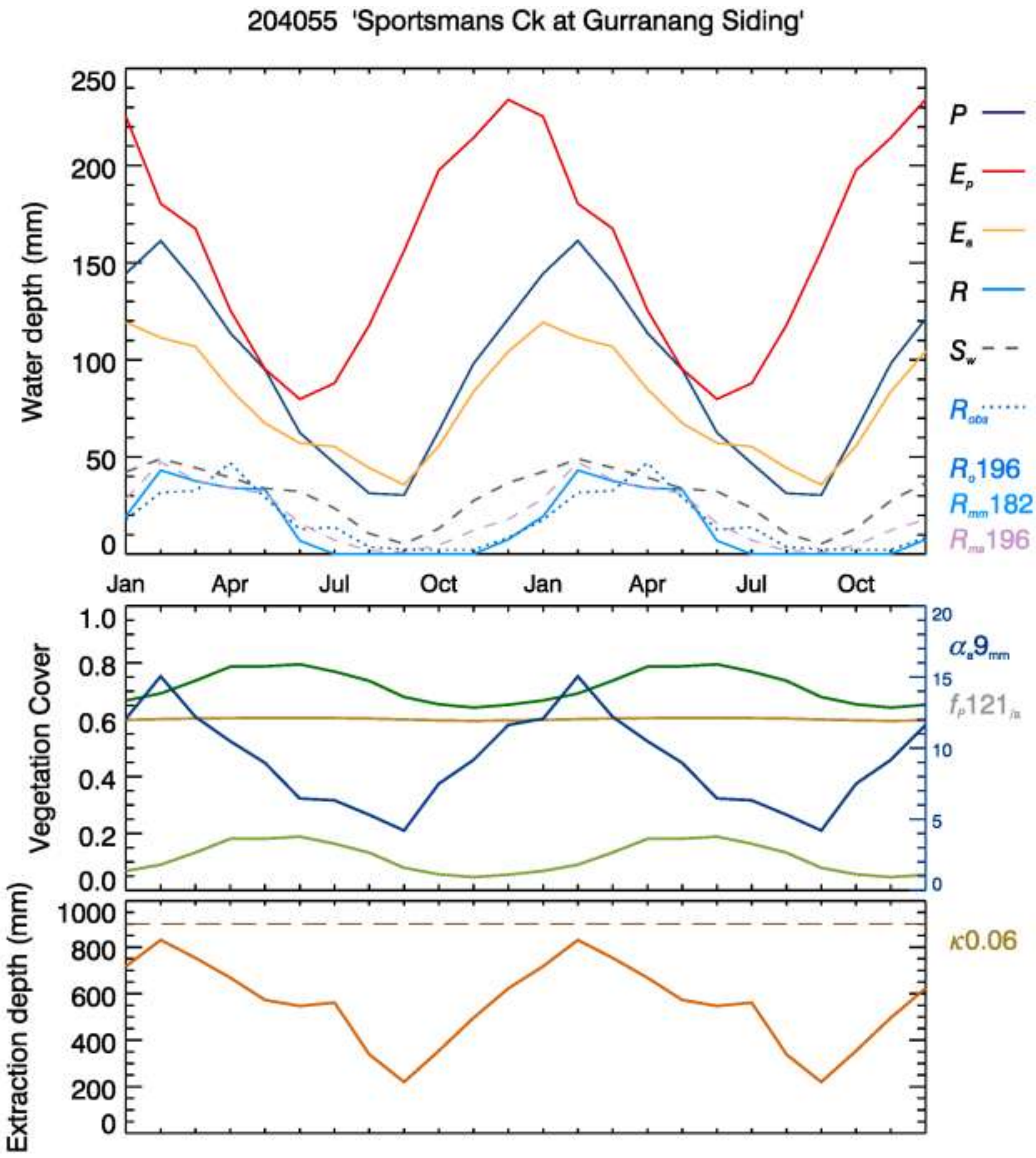




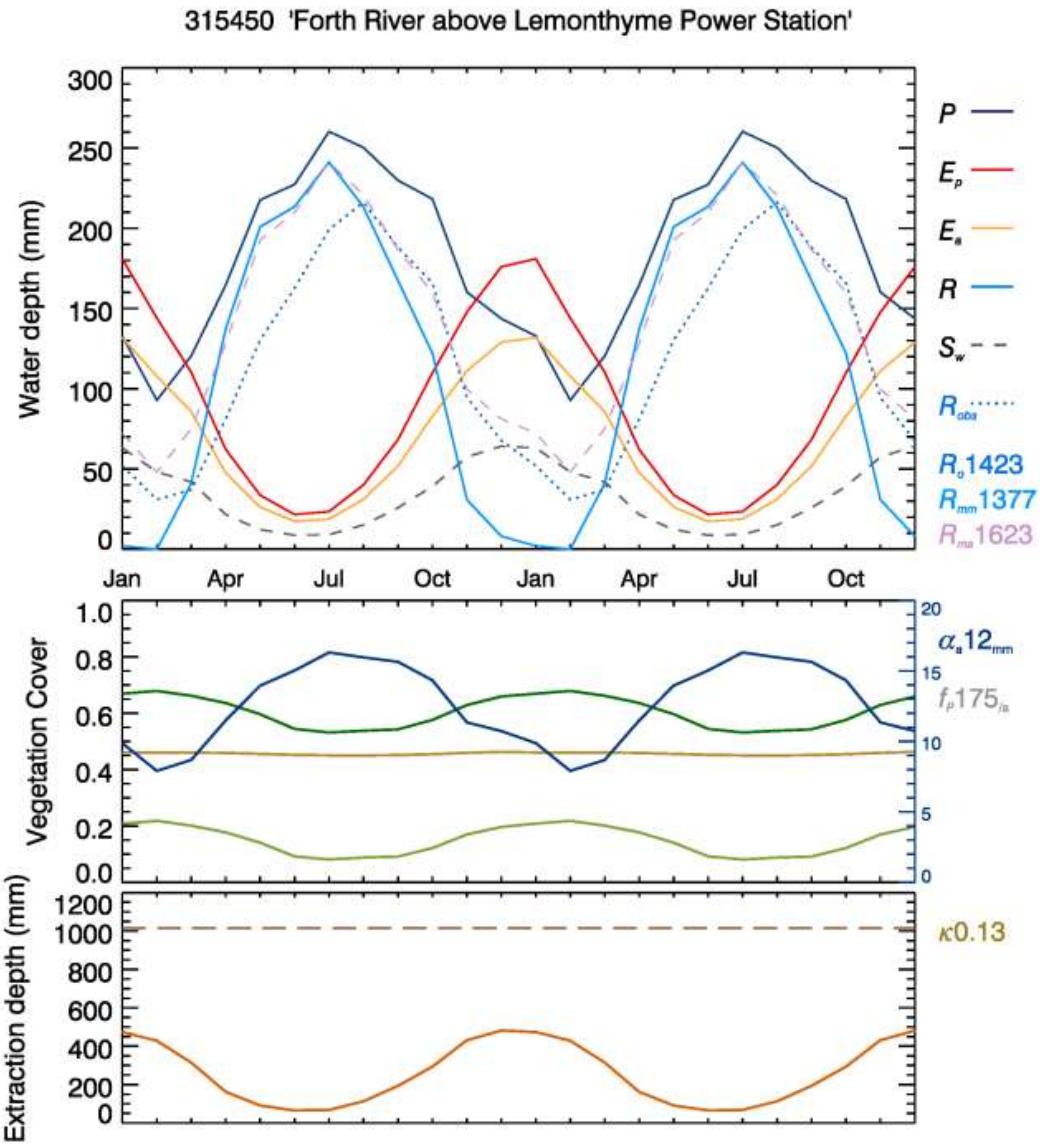


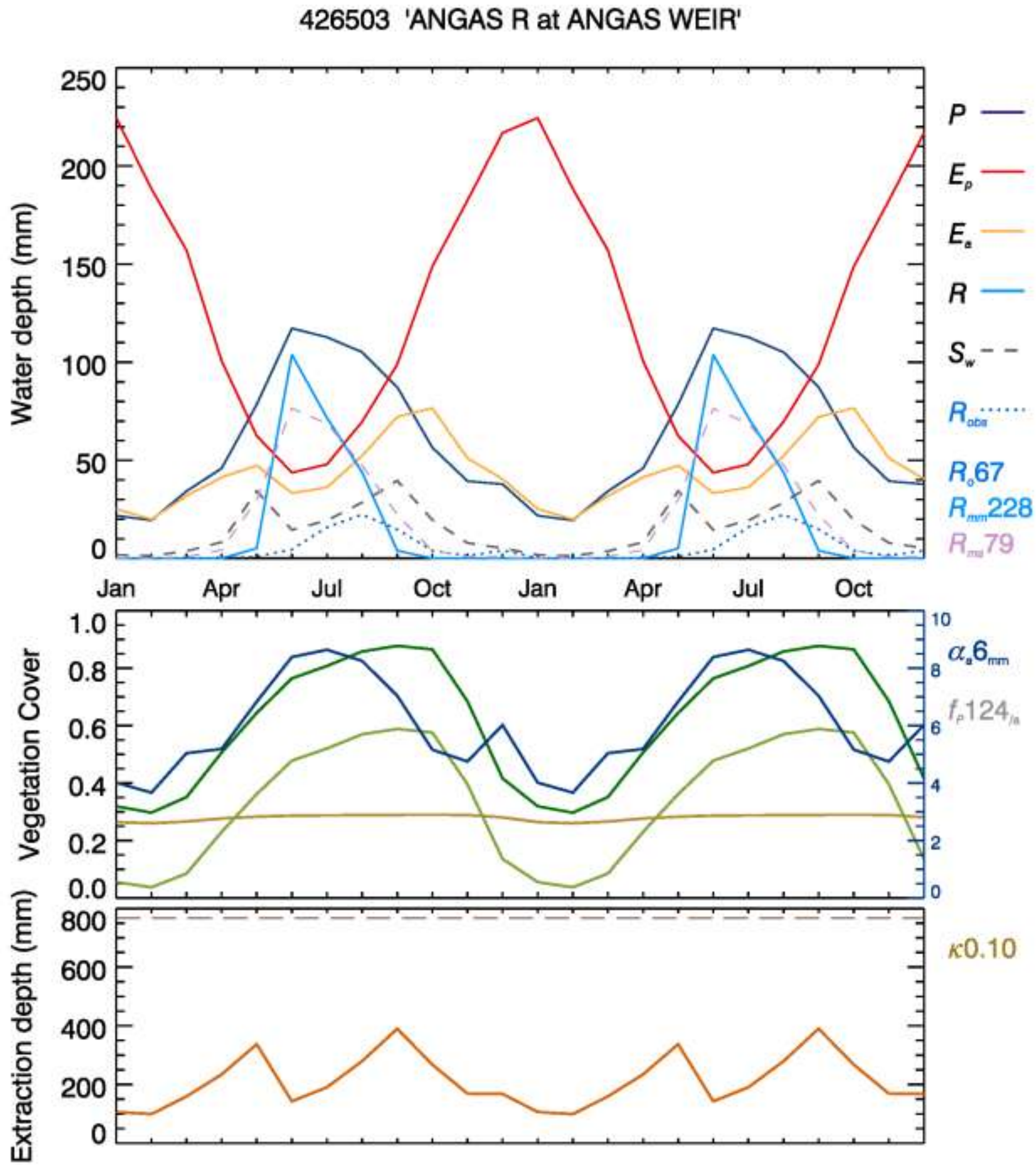
Implications for the carbon cycle



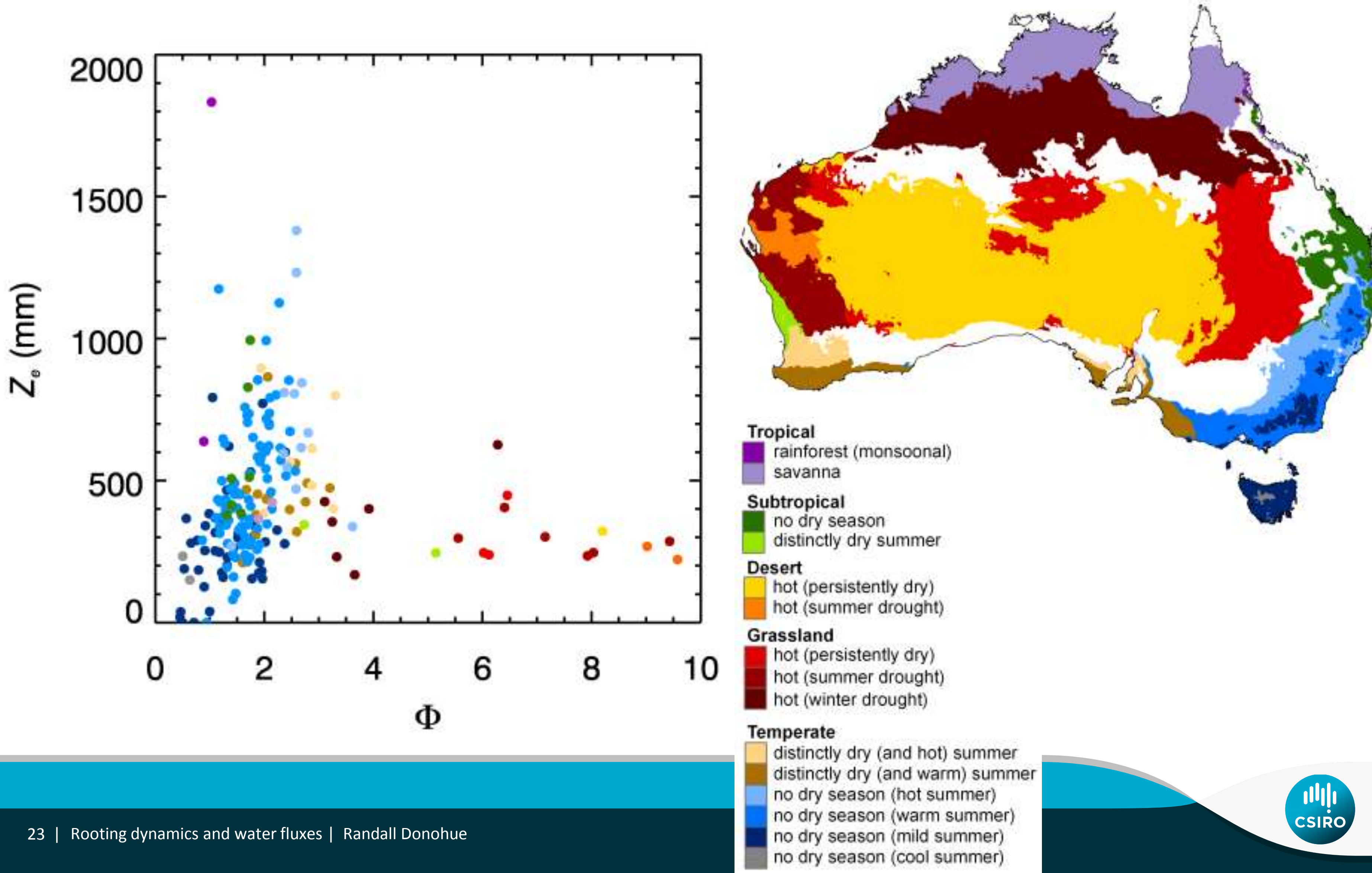


204055 'Sportsmans Ck at Gurranang Siding'
Water depth (mm)
250
200
150
100
50
0
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
P
E_p
E_a
R
S_w
R_{obs}
R_o196
R_{mm}182
R_{ma}196
Vegetation Cover
1.0
0.8
0.6
0.4
0.2
0.0
20
15
10
5
0
$\alpha_a 9_{mm}$
$f_p 121_{/a}$
Extraction depth (mm)
1000
800
600
400
200
0
κ0.06


315450 'Forth River above Lemonthyme Power Station'
Water depth (mm)
300
250
200
150
100
50
0
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
P
E_p
E_a
R
S_w
R_{obs}
R_o1423
R_{mm}1377
R_{ma}1623
Vegetation Cover
1.0
0.8
0.6
0.4
0.2
0.0
20
15
10
5
0
$\alpha_a 12_{mm}$
$f_p 175_{/a}$
Extraction depth (mm)
1200
1000
800
600
400
200
0
κ0.13


426503 'ANGAS R at ANGAS WEIR'
Water depth (mm)
250
200
150
100
50
0
Jan
Apr
Jul
Oct
Jan
Apr
Jul
Oct
P
E_p
E_a
R
S_w
R_{obs}
R_o67
R_{mm}228
R_{ms}79
Vegetation Cover
1.0
0.8
0.6
0.4
0.2
0.0
10
8
6
4
2
0
$\alpha_a 6_{mm}$
$f_P 124_{/a}$
Extraction depth (mm)
800
600
400
200
0
κ0.10

Koppen climatic classes and fitted rooting depth



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