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Ecohydrology of Vegetated Catchments Under Climate Change

Tim McVicar, Randall Donohue, Mike Roderick*,
Tom Van Niel and Li Lingtao

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THE AUSTRALIAN NATIONAL UNIVERSITY

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Catchment responses to climate change
(E_a = actual evaporation and Q = stream flow)

	Energy-limited				Water-limited		
	E_a	Q	Vegetation cover		E_a	Q	Veg'n cover
			Tropics	High latitudes/ altitudes			
↑P	↑	↑	~	↓?	↑	↑	↑
↓E_p (*e.g.*, ↓wind, ↓R_n)	↓	↑	~	↓	↓	↑	↑
↑[CO_2]	↓	↑	~	↑?	~	~	↑

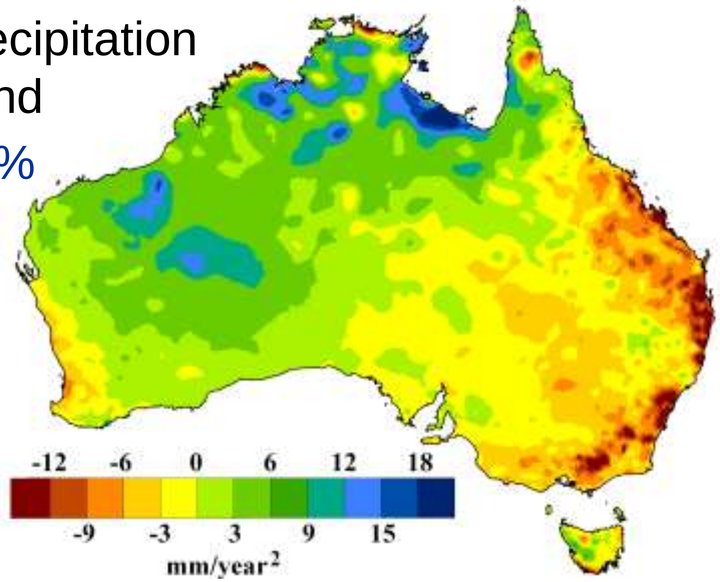
Expect a differential response to based on catchment location

Use stream flow and remotely sensed vegetation cover (and E) to assess if expectations are matched by observations

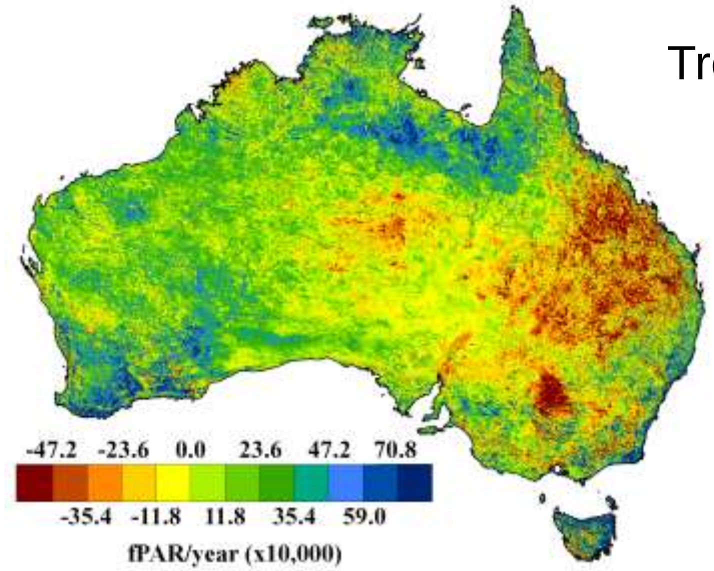
Australia-wide trends in P and fPAR 1981-2006

Donohue, McVicar and Roderick (2009) Global Change Biology

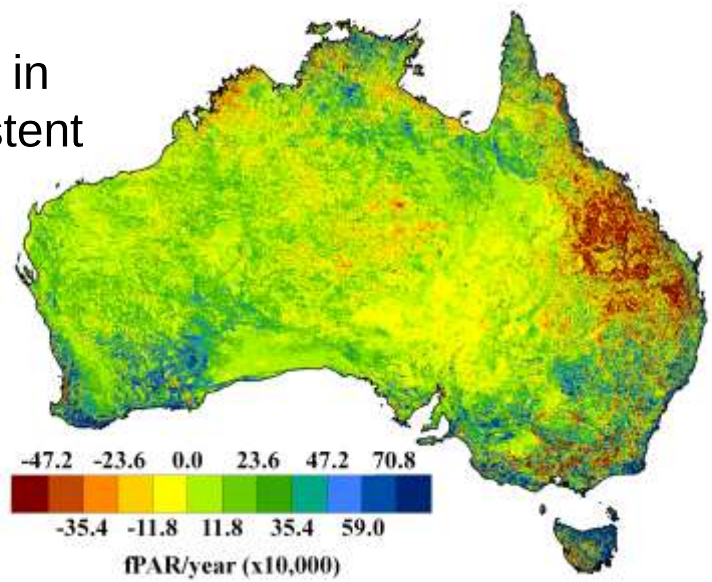
Precipitation trend
+7%



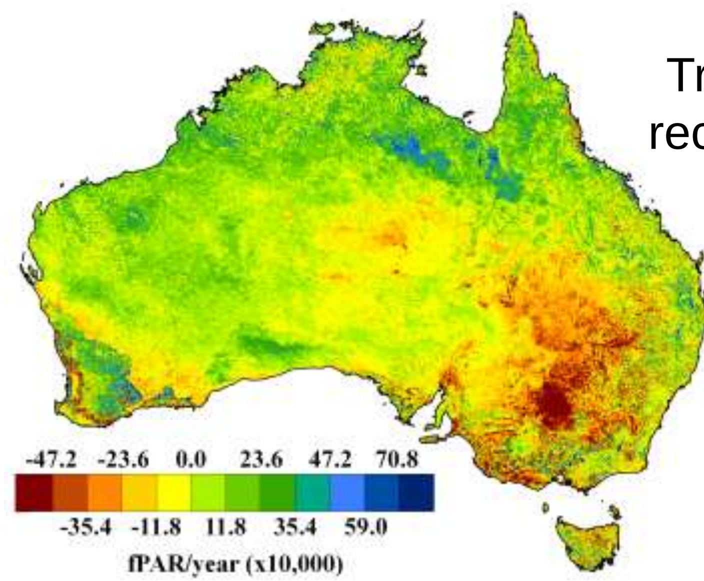
Trend in total fPAR
+8%



Trend in persistent fPAR
+21%



Trend in recurrent fPAR
-7%



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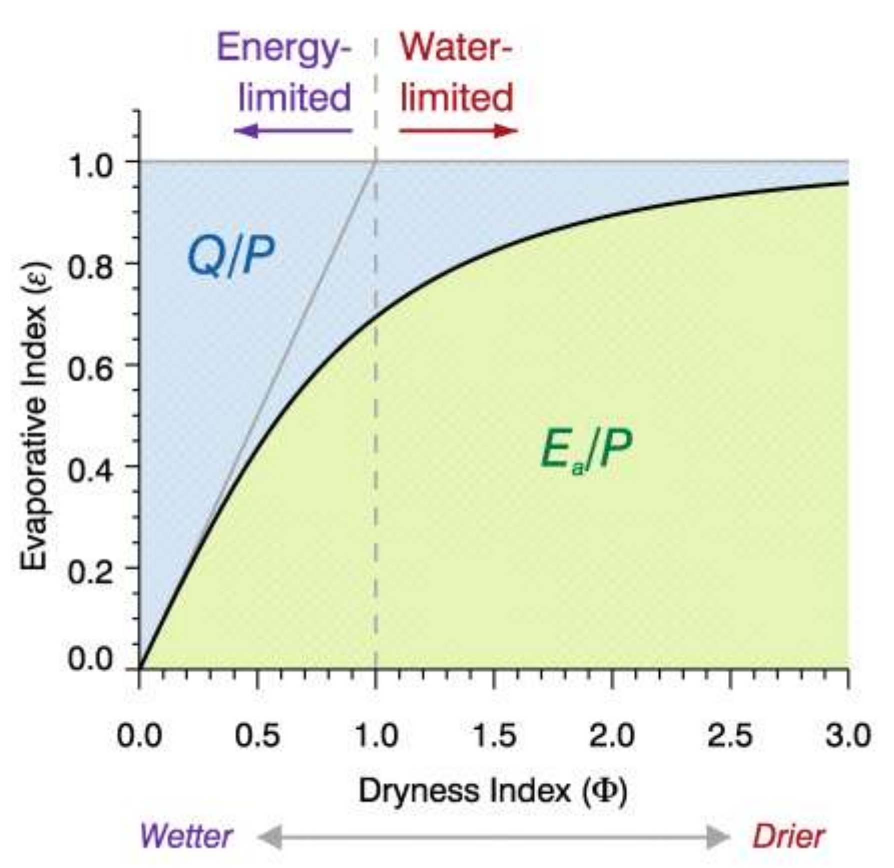
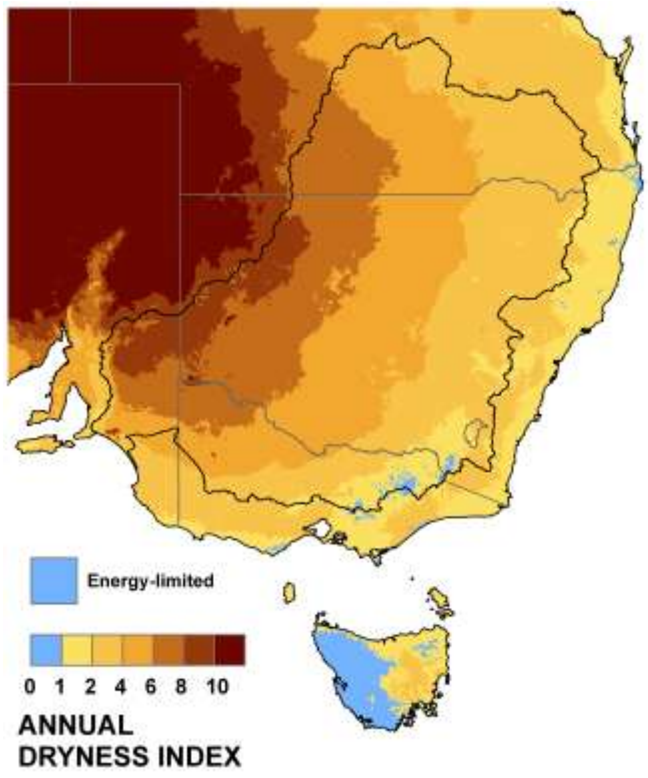
Budyko's Framework : different locations, different responses



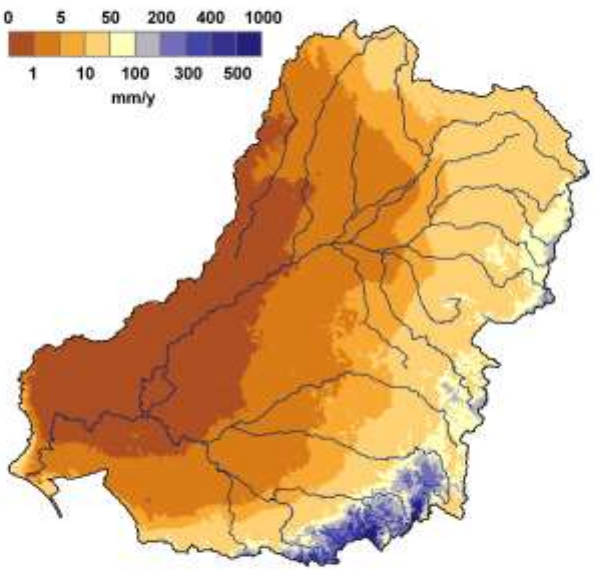


- The climatic Dryness Index (Φ) is the ratio of water demand to water supply; $\Phi = Ep / P$
- The climatic Evaporative Index (ε) is the ratio actual evaporation to precipitation; $\varepsilon = Ea / P$

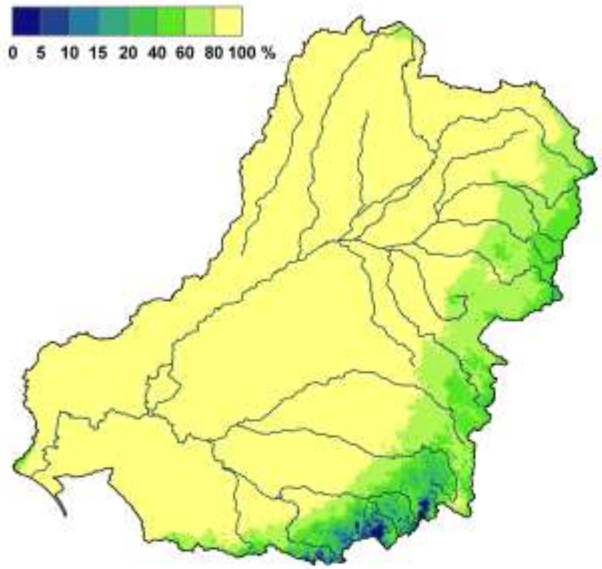
Where does the Murray-Darling Basin's runoff originate?

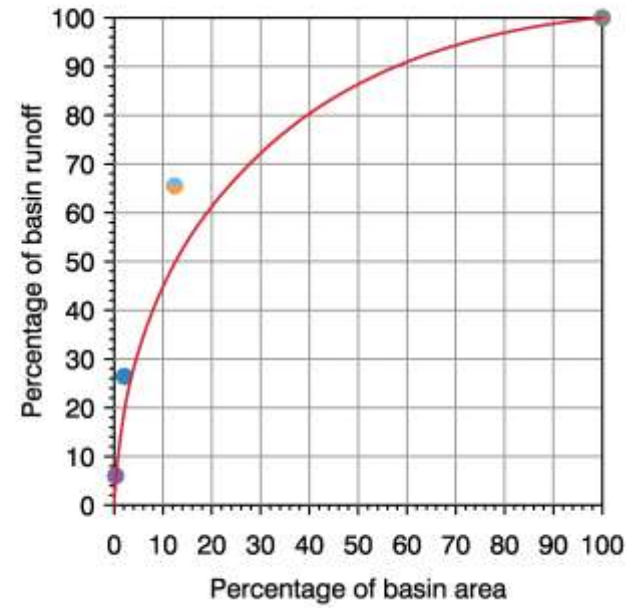
Donohue, Roderick & McVicar (2011) J Hydrology – identify runoff producing areas

Annual Runoff



Runoff proportion by area





R is modelled using Budyko's curve and assumes no change in soil water storage

10% of the land area produces ~ 45% of total runoff

20% of the land area produces ~ 60% of total runoff

Runoff sensitivity to CC using Budyko framework

Roderick and Farquhar (2011) Water Resources Research - developed method & applied in a lumped manner for the MDB. **An effective and transparent (+ repeatable) approach**

Choudhury formulation

$$R = P - \frac{PE_p}{\left(P^n + E_p{}^n\right)^{1/n}}$$

Essentially

$$R = f(P, E_p, n)$$

Sensitivity of Runoff

$$dR = \frac{\partial R}{\partial P} dP + \frac{\partial R}{\partial E_p} dE_p + \frac{\partial R}{\partial n} dn$$

Influence of 3 terms

$$\frac{\partial R}{\partial P} = 1 - \frac{E}{P}\left(\frac{E_p{}^n}{P^n + E_p{}^n}\right)$$

$$\frac{\partial R}{\partial E_p} = \frac{-E}{E_p}\left(\frac{P^n}{P^n + E_p{}^n}\right)$$

$$\frac{\partial R}{\partial n} = \frac{-E}{n}\left(\frac{\ln(P^n + E_p{}^n)}{n} - \frac{P^n \ln P + E_p{}^n \ln E_p}{P^n + E_p{}^n}\right)$$

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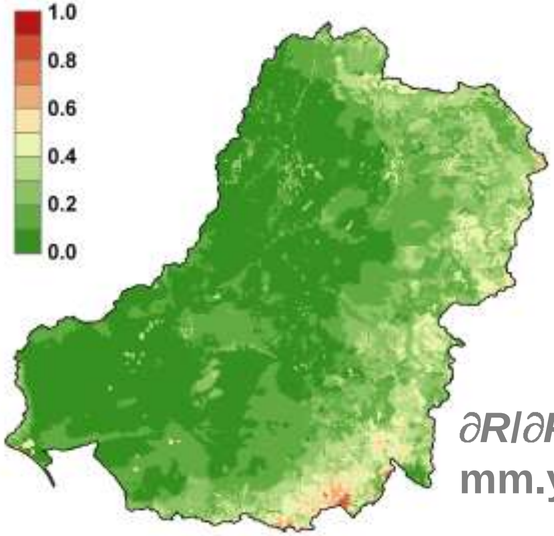
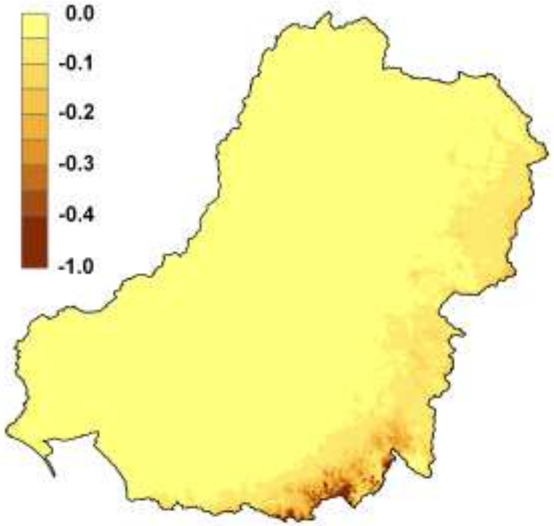
Runoff sensitivity to CC using Budyko framework in the MDB

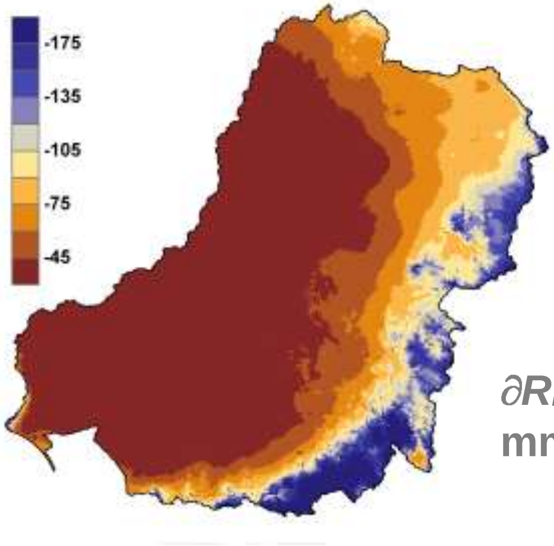
Donohue, Roderick & McVicar (2011) J Hydrology – spatially apply the sensitivity approach to Budyko framework the MDB



$\partial R/\partial P$
$mm.y^{-1}/mm.y^{-1}$

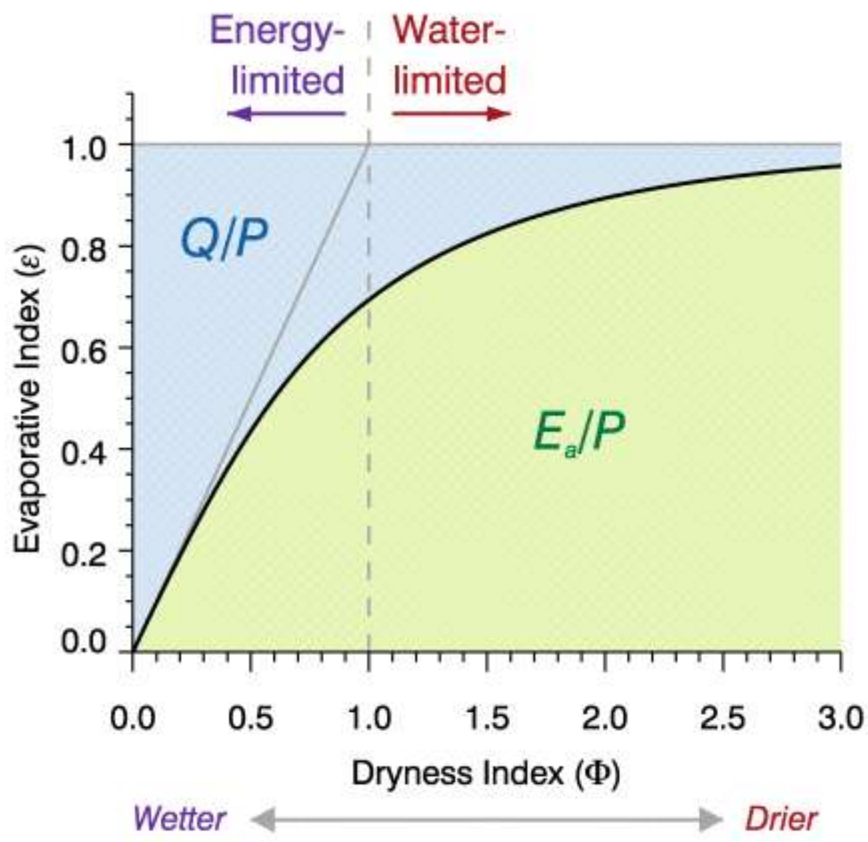


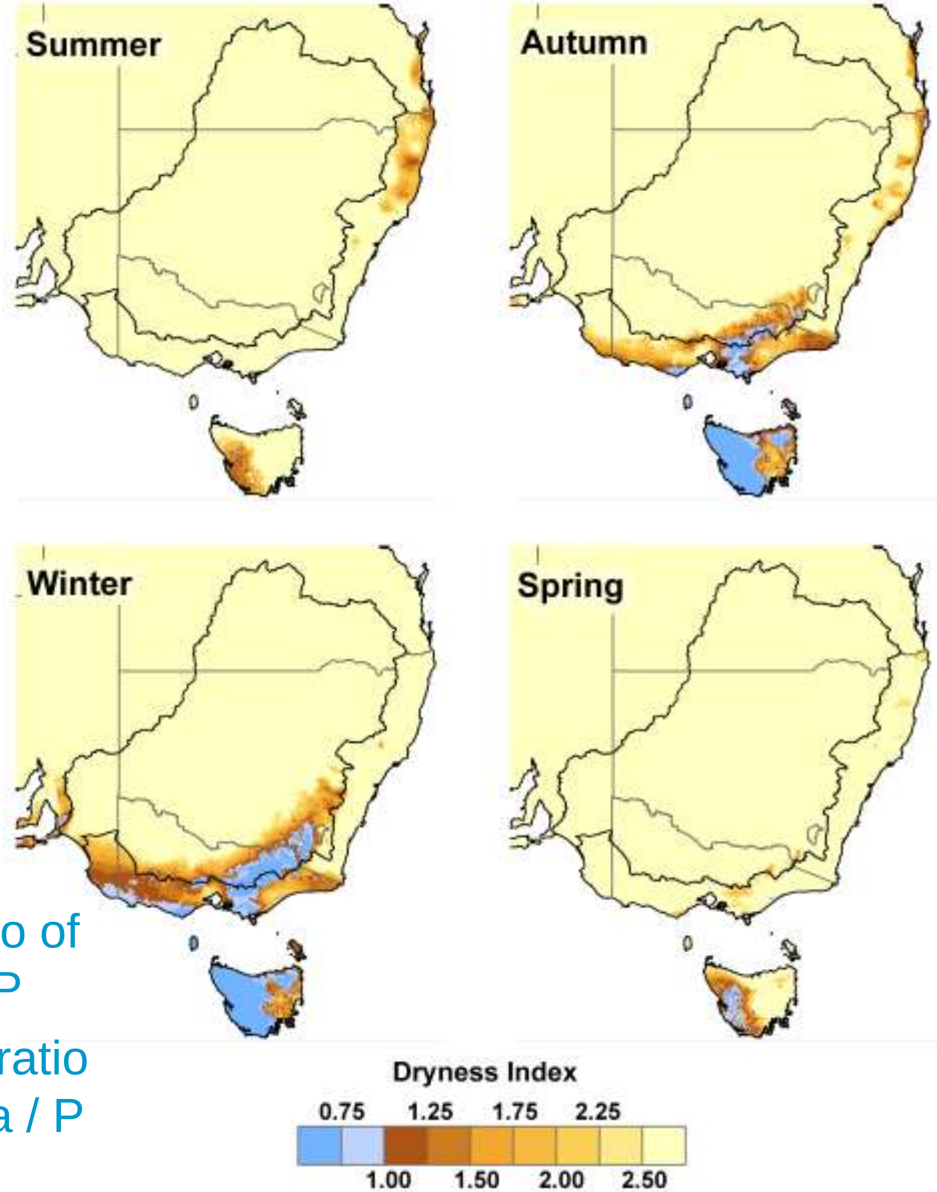
$\partial R/\partial E_p$
$mm.y^{-1}/mm.y^{-1}$



$\partial R/\partial n$
$mm.y^{-1}$

Budyko's Framework : different locations + different times, leads to different responses





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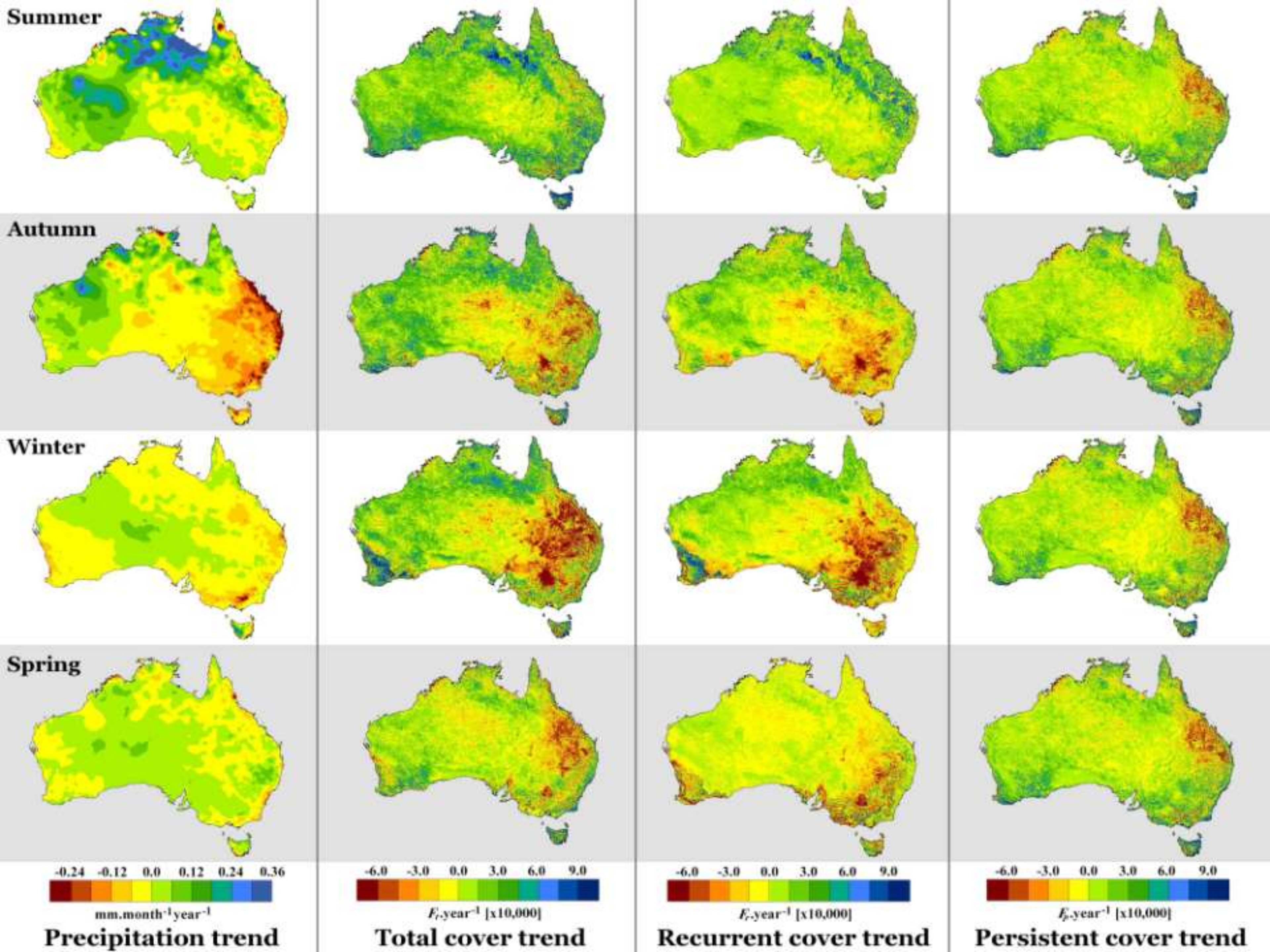
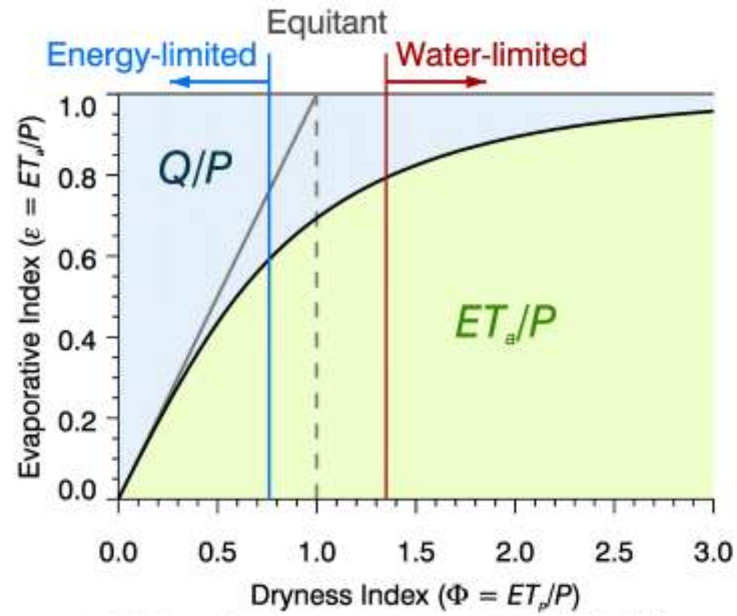


Summer
Autumn
Winter
Spring
-0.24 -0.12 0.0 0.12 0.24 0.36
mm.month⁻¹year⁻¹
Precipitation trend
-6.0 -3.0 0.0 3.0 6.0 9.0
F_t.year⁻¹ [x10,000]
Total cover trend
-6.0 -3.0 0.0 3.0 6.0 9.0
F_r.year⁻¹ [x10,000]
Recurrent cover trend
-6.0 -3.0 0.0 3.0 6.0 9.0
F_p.year⁻¹ [x10,000]
Persistent cover trend

Extending Budyko Framework: (Randall introduced BCP y/day)

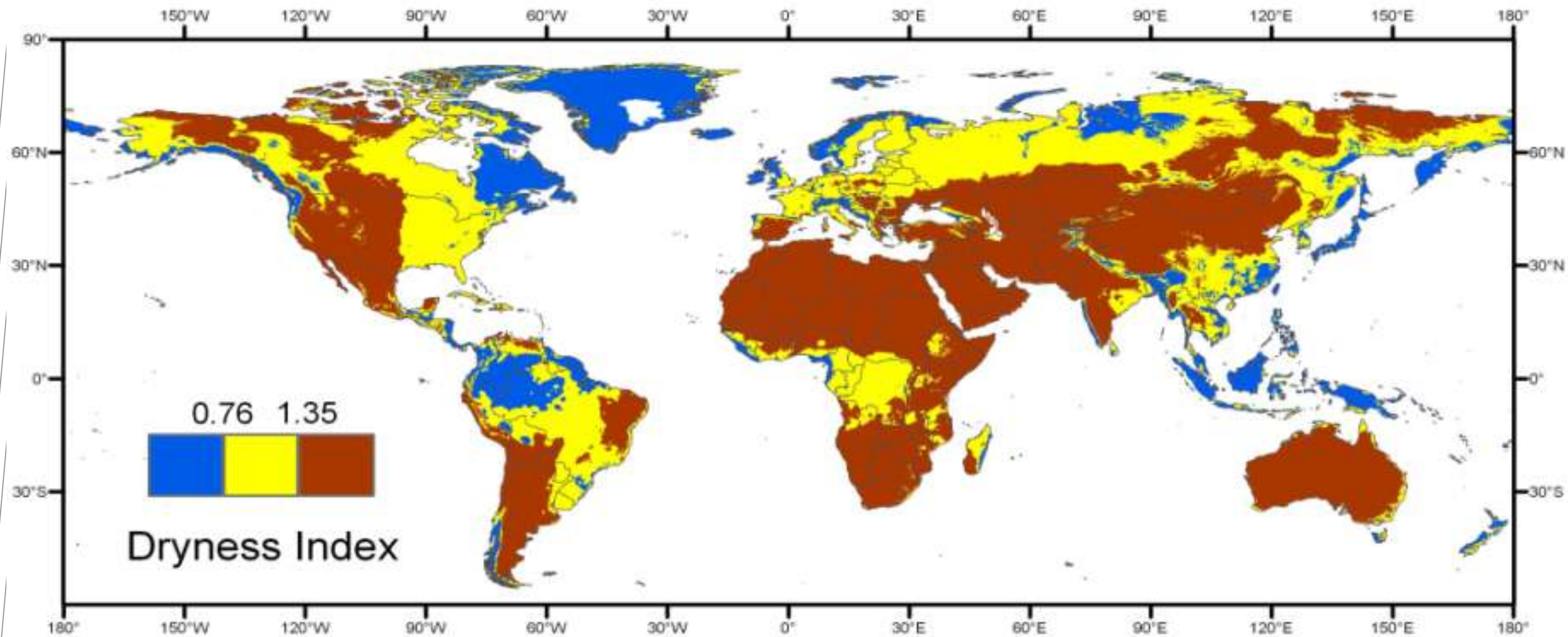


Account for importance of seasonal dynamics:

1) Precip and ETp

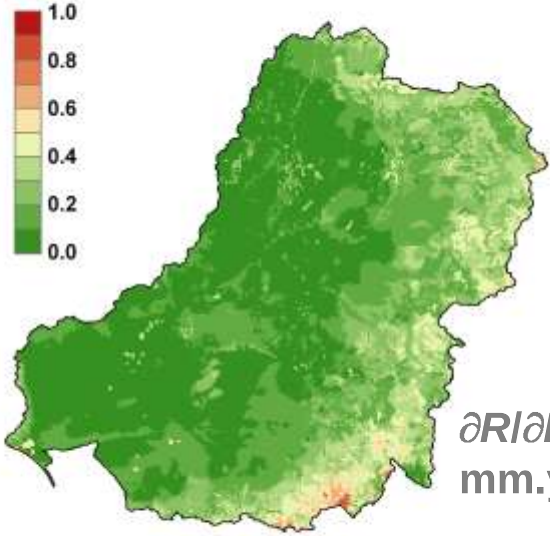
2) Vegetation activity (roots and phenology)

3) Storage (both soil and GW)



Runoff sensitivity in the MDB using the BCP model

Donohue, Roderick & McVicar (2012) J Hydrology – developed BCP model (& inputs) and spatially assessed sensitivity of runoff to changes in inputs

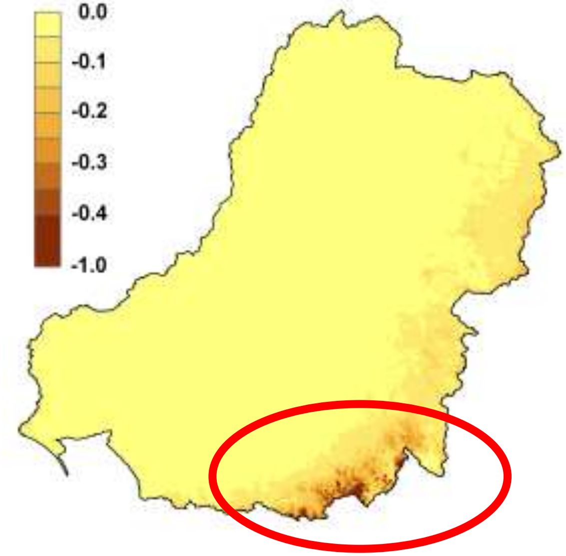


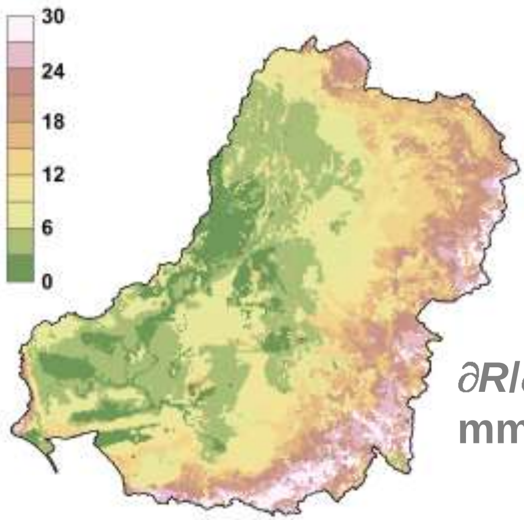
$\partial R/\partial P$

$mm.y^{-1}/mm.y^{-1}$

$\partial R/\partial E_p$

$mm.y^{-1}/mm.y^{-1}$



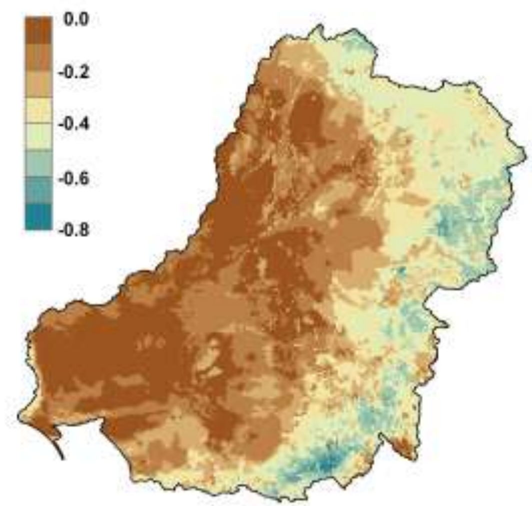


$\partial R/\partial \alpha$

$mm.y^{-1}/mm$

$\partial R/\partial Z_r$

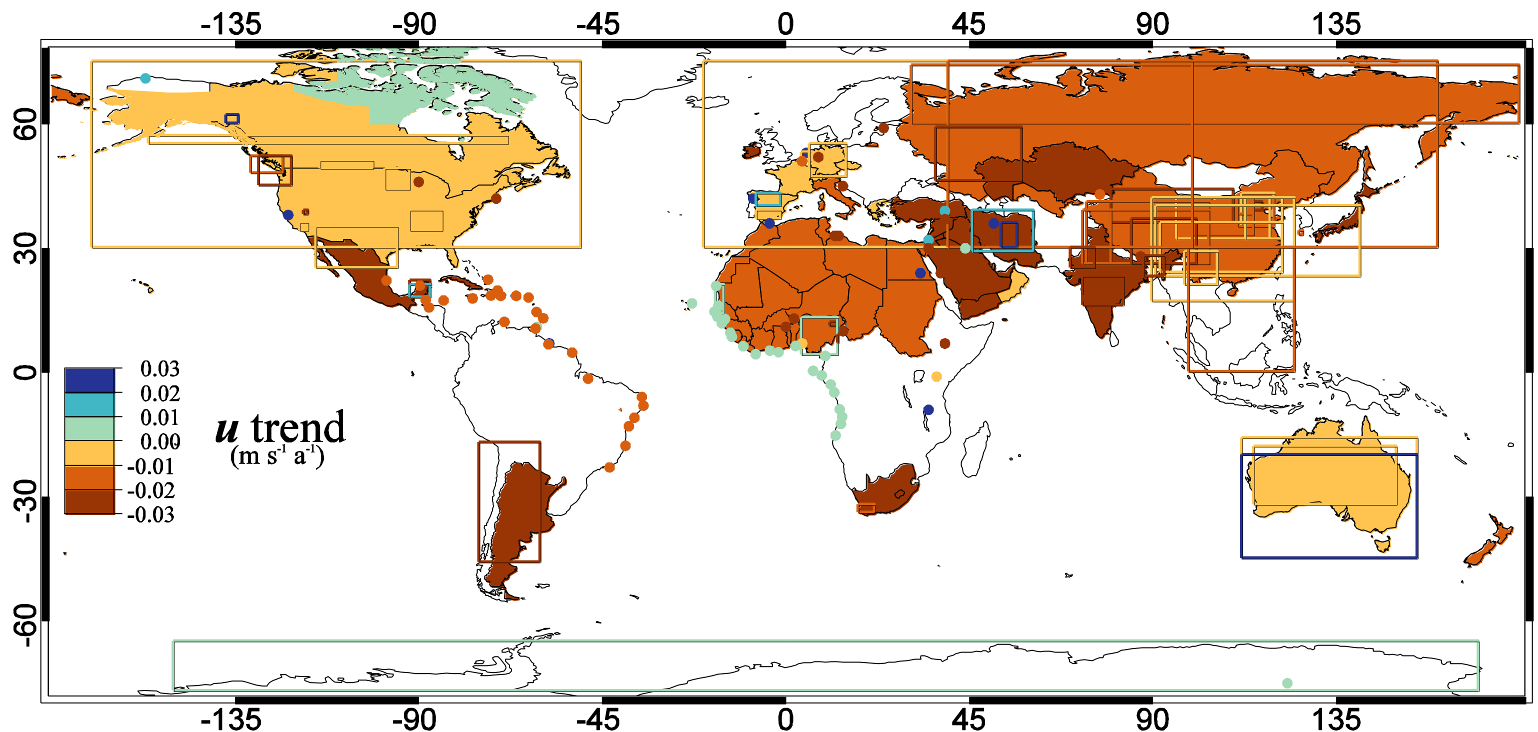
$mm.y^{-1}/mm$



Observed Global Trends in Near-Surface Wind Speed

McVicar, Roderick, Donohue et al. (2012) J of Hydrology

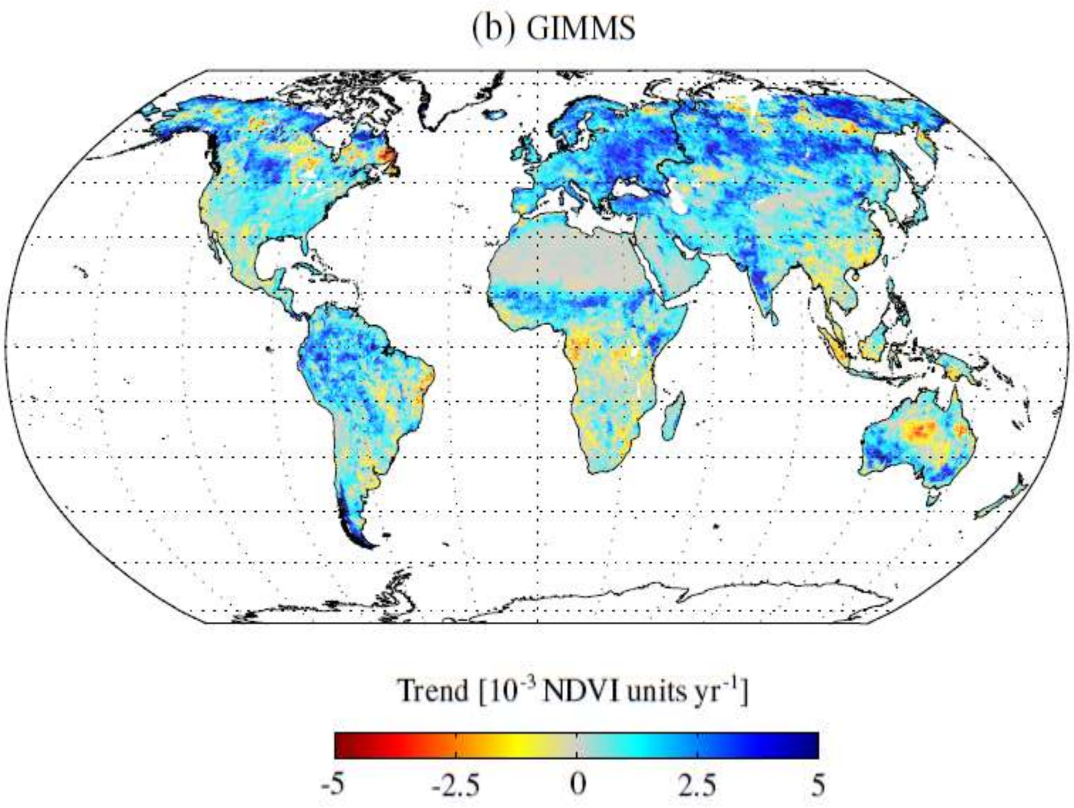
- Penman (1948) combined the radiative and aerodynamic components
- To date CC related evaporative trends had strong focus on Ta, Rad and Precip
- From 148 regional studies average wind speed trend = ~-0.014 m s^{-1} a^{-1}
- Assuming a linear trend this is a -0.7 m s^{-1} decline over the last 50 years
- Trend of ET_a depends on limit to ET_a (P in WL areas, P and ET_p in EL areas)



Observed Global Trends in Near-Surface Wind Speed

Most plausible drivers of near-surface wind speed trends are:

i. increased roughness (Vautard et al., (2010) NGS);
ii. widening of the Hadley cell (Seidel et al., (2010) NGS); and
iii. increased aerosols (Jacobson and Kaufman (2006) GRL)



1982-1999
AVHRR NDVI trends
Beck et al (2011) RSE

GIMMS best able to track trends in 1424 Landsat pairs located worldwide

Observed Global Trends in E_{pan}

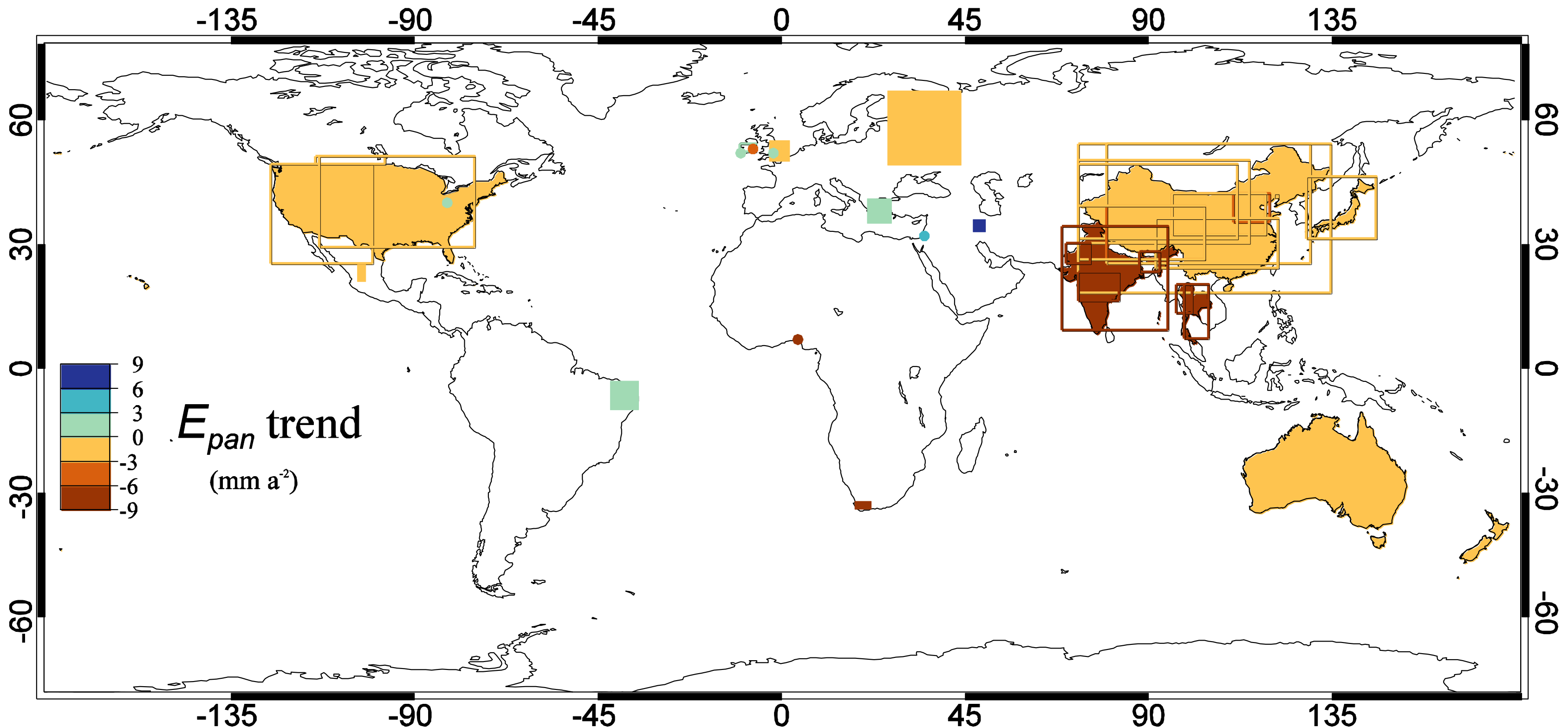
McVicar, Roderick, Donohue et al., (2012) J of Hydrology

Globally 58 E_{pan} studies reviewed with average trend = -3.2 mm a^{-2}

Only Class A pan studies = -3.8 mm a^{-2} (n =37)

Studies using more than 10 Class A pans = -2.6 mm a^{-2} (n =24)

Meteorological data forced modelled E_{pan} trends in line with observed E_{pan} trends in both N and S hemispheres; based on Roderick et al., (2007) GRL

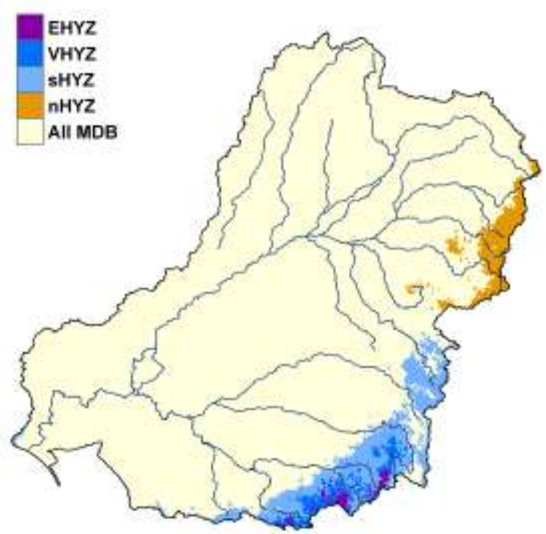


Climate Non-Stationarity: E_p Penman Trends (1981-2006)

Donohue, McVicar and Roderick (2010) J Hydrology

Area	Total	Trends of Penman potential evapotranspiration (mm yr^{-2})				
	(mm yr^{-1})	Total	Due to $\mathbf{R_n}$	Due to u	Due to e_a	Due to T_a
EHYZ	1248	**-0.5**	**-0.3**	**-1.1**	**-0.5**	**+1.4**
VHYZ	1379	**-0.1**	**-0.5**	**-0.7**	**-0.5**	**+1.6**
sHYZ	1502	**-0.3**	**-0.6**	**-1.2**	**-0.4**	**+1.9**
nHYZ	1739	+2.0	+0.9	-0.7	-0.1	+1.9
MDB	1977	+0.4	-1.7	-0.9	+0.7	+2.3
All Aus	2340	-0.8	-0.6	-1.3	-0.4	+1.5

These southern water yielding zones provide 50% of MDB Q



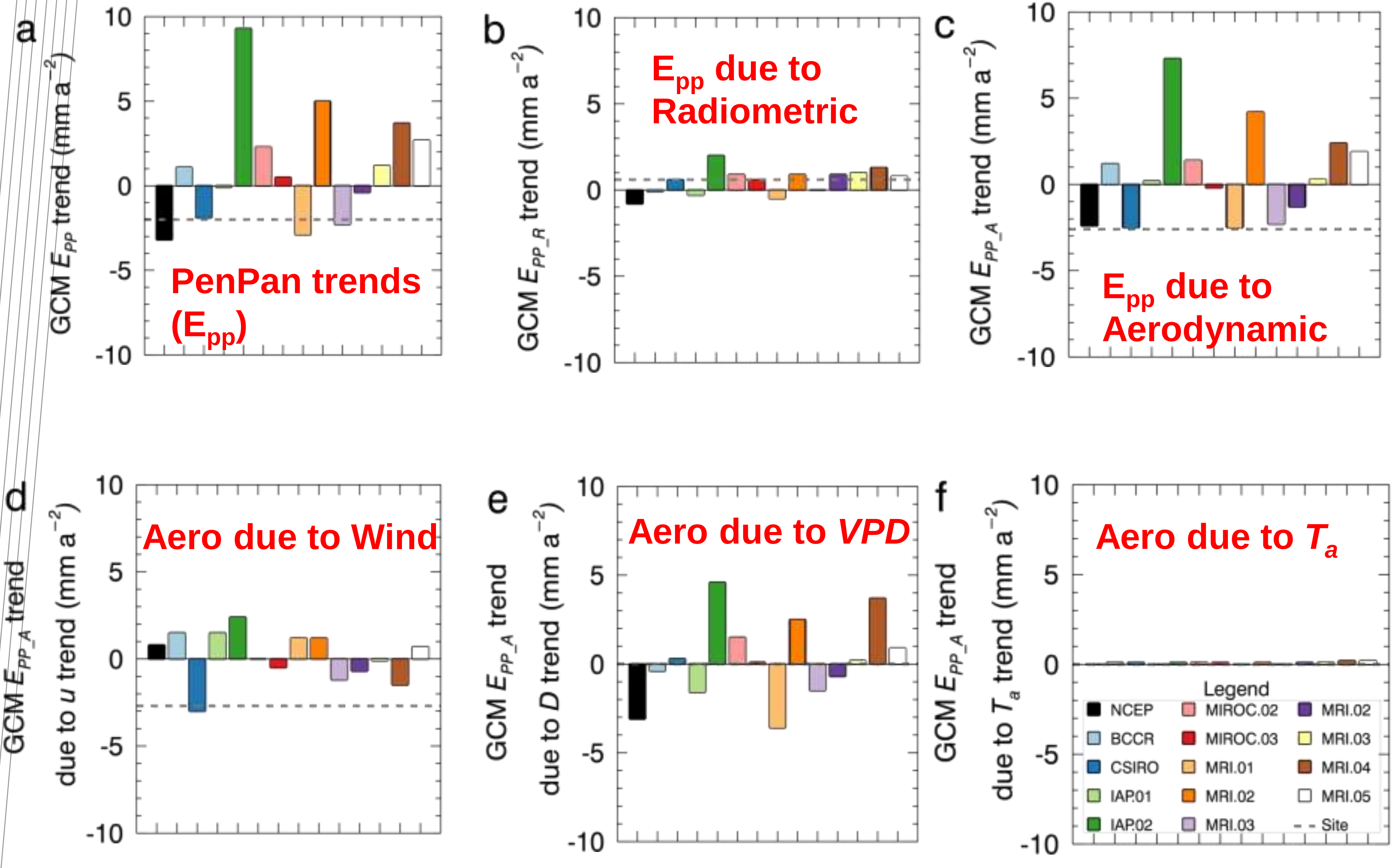
Different response to a changing climate depending on the location of the catchment / study area

There is not one rule for all locations for all time periods (responses change in space and time)

Facing climate change not only global warming

Class A pan Evaporation : Attribution of the trends

Roderick et al (2007) GRL PenPan site data; Johnson and Sharma (2010) J HydroMet GCM data



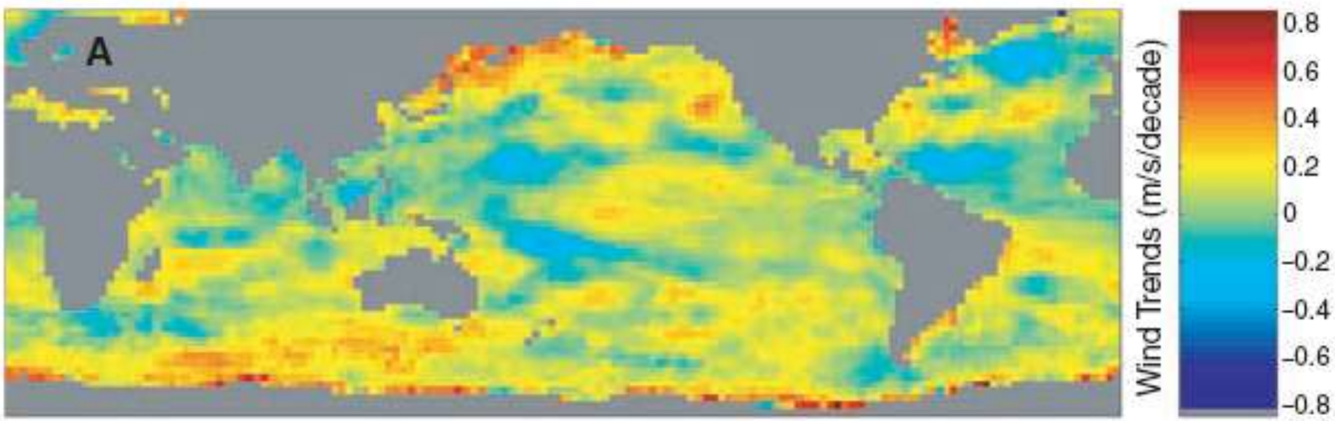
Ta ↑; Relative Humidity ~ Constant; Specific Humidity (q) ↑

q = g H_2O / kg wet air and the mixing ratio = g H_2O / kg dry air

With much of the land-surface being EL, where is the water the coming from?

Intensification of the global hydrological cycle (Huntington 2006 J Hydrology) and are there greater rates of evaporation over oceans due to increased heat storage and wind speeds over the oceans?

Wentz et al (2007) Science: 1987-2006, average trend + 0.008 m s^{-1} a^{-1}



SSM/I Wind Trend Map

CSIRO Land and Water

Dr Tim McVicar
Principal Research Scientist

Phone: +61 2 6246 5741
Email: tim.mcvicar@csiro.au
Web: www.clw.csiro.au/research/sensing/remote/
www.csiro.au/people/Tim.McVicar.html

Thank you