Soil respiration dynamics under reduced throughfall in a dry temperate Eucalypt forest (Wombat State Forest)

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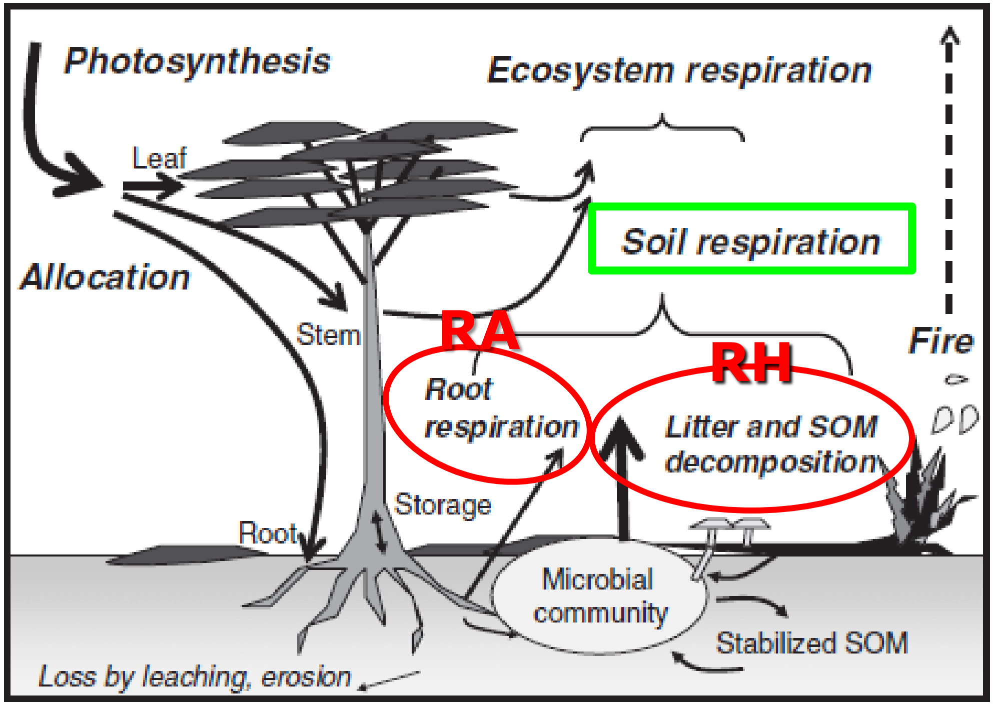
Soil respiration - Background



(Trumbore, GCB 2006)

- major CO_2 efflux of terrestrial ecosystems to the atmosphere (~ 60 $PgCyr^{-1}$) – compare → fossil fuel emissions: 7.7 $PgCyr^{-1}$
- critical role in the global (forest) carbon cycle & it's carbon sink strength
- strong dependence on
  → **soil temperature** (increase with increasing temperature)
  → **soil moisture** (decrease outside optimum range)
  → **substrate quality & quantity**
- climate change predictions for SE-Australia:
  → **increase in temperature**
  → overall **decrease in rainfall – change of rainfall pattern (intensity, frequency)**
- difficulty in predicting responses of soil respiration in forest ecosystems to changing environmental conditions
- RA and RH: different responses (sensitivity) to ennvironmental changes, e.g. soil temperature and moisture
- important to understand processes underlying soil respiration and to identify its controls thereof

Research Objectives

- Throughfall (or rainfall) manipulation experiments – minimize confounding effects of environmental drivers
- Throughfall manipulation experiments worldwide focused so far on:
  - → exclusion of throughfall
  - → responses of total soil respiration
  - → single growing season

1) seasonal variability of SR, RH and RA

2) their dependence on soil temperature and soil moisture

3) effect of a long-term throughfall reduction upon soil respiration dynamics

4) the relative contribution of RH and RA to SR patterns

in a temperate broadleaved evergreen forest.

Experimental design

- Throughfall reduction (~ 40%, TFR)
- 3 Plots as Control, 3 Plots with TFR (20 x 20 m)
- partitioning of RH and RA – **root exclusion**
- 10 chambers/ treatment/ plot

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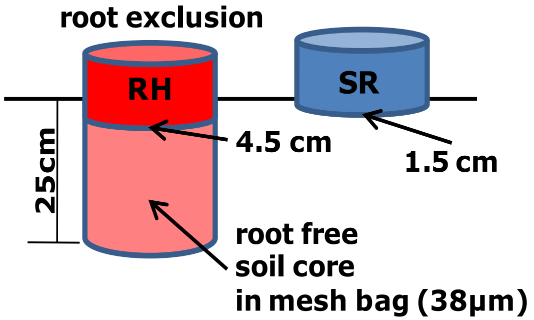
- **measured fluxes:**
  SR – Soil respiration (total)
  RH – Heterotrophic respiration
- SR – RH ⇨ **RA** – Autotrophic respiration

Basal Area: 177 cm^2
Chamber V: 4.8 L



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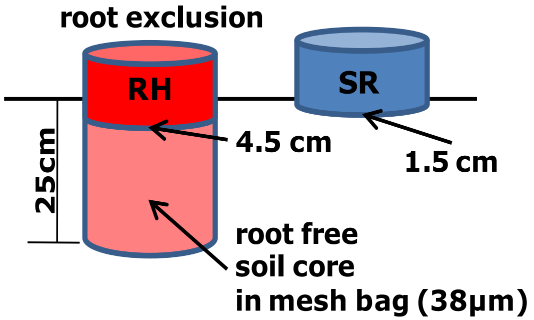
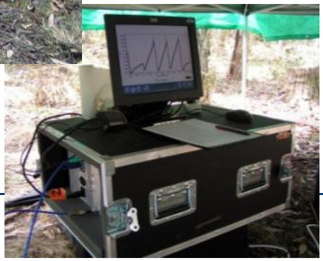
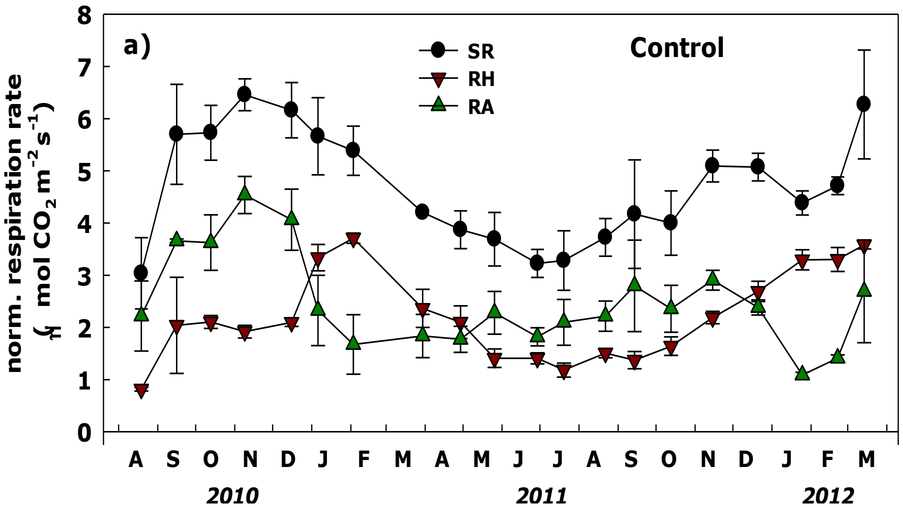


- monthly measurements of CO_2 (CH_4, water vapour) with dynamic closed chambers linked to a Fast Greenhouse Gas Analyser (FGGA, LGR)
- corresponding measurements of soil moisture and soil temperature during soil respiration measurements & automated measurements



Component fluxes – Control plot



mean $\mu mol CO_2 m^{-2} s^{-1}$

SR: 4.69 ± 0.24

RH: 2.20 ± 0.19

RA: 2.49 ± 0.20

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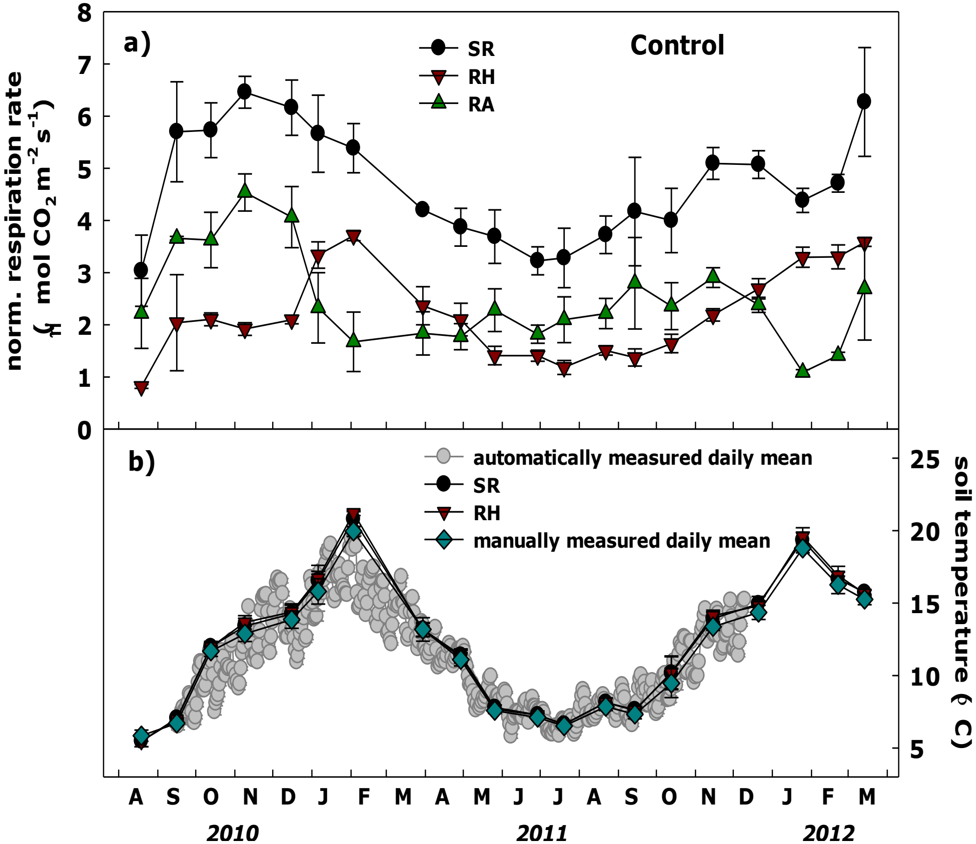

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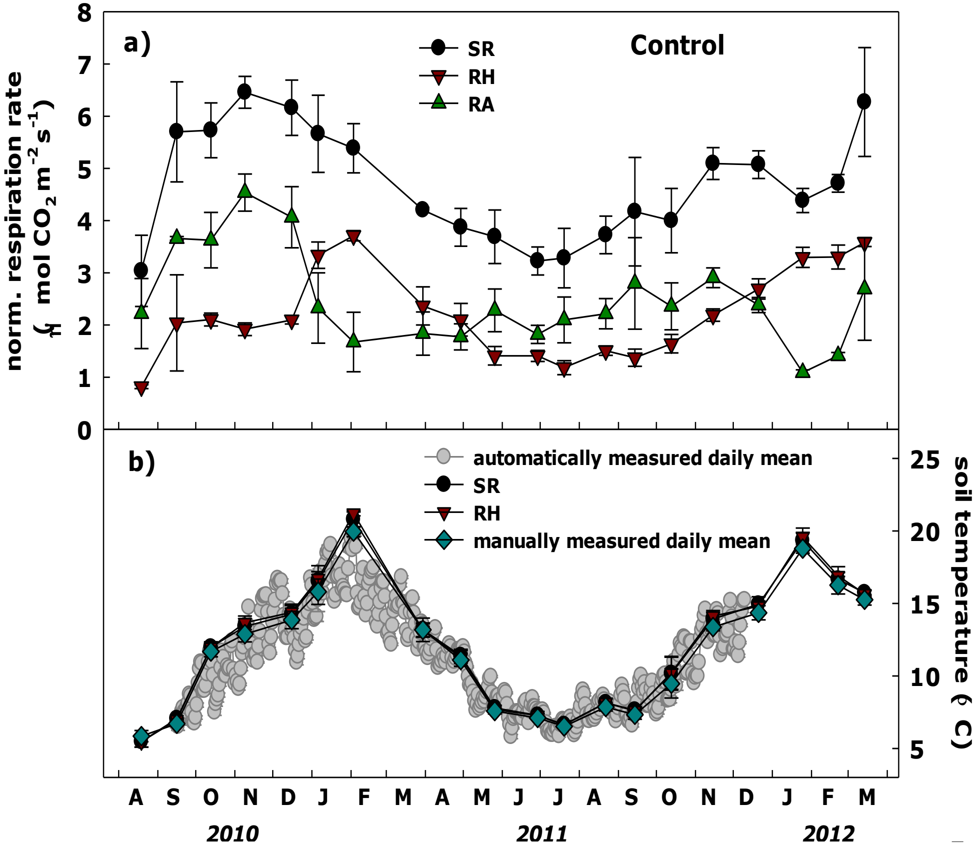

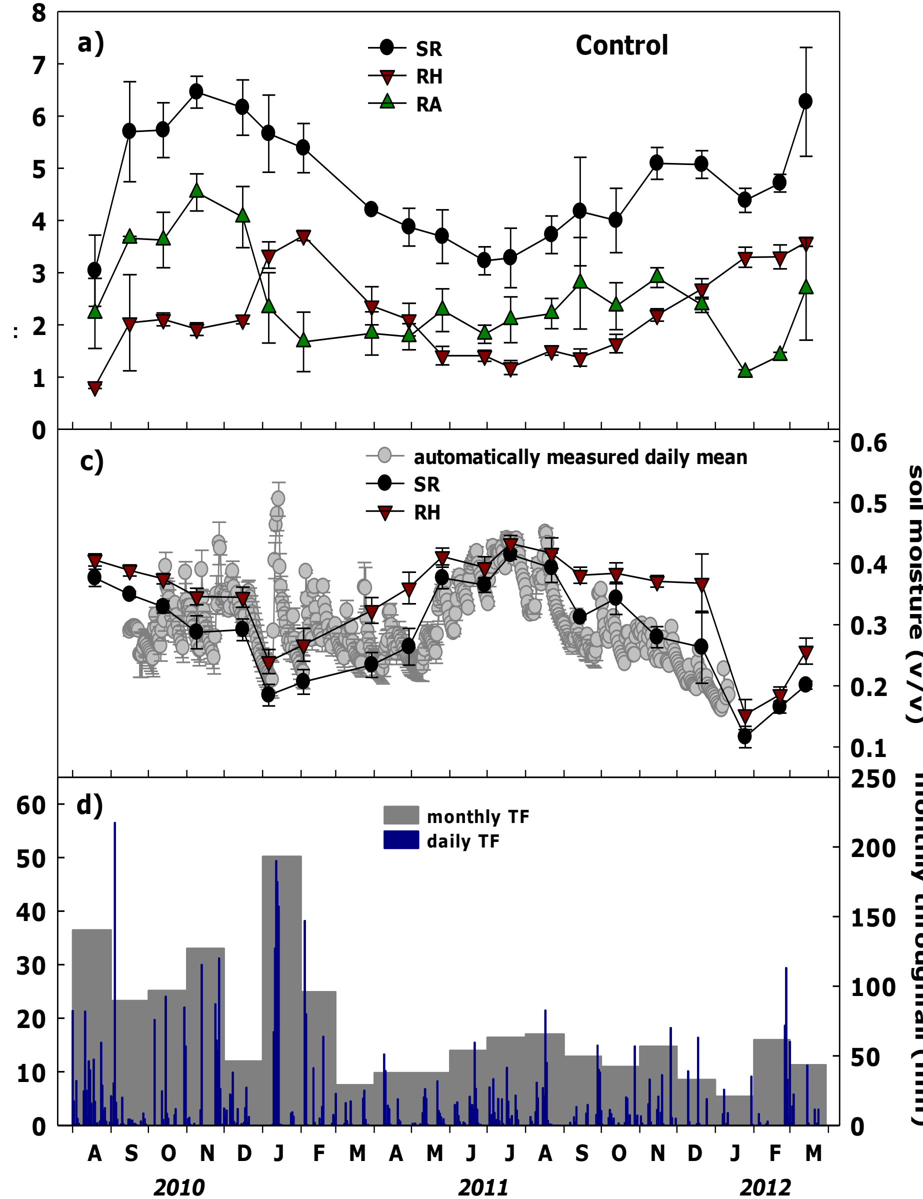

mean µmol$CO_2$$m^{-2}s^{-1}$

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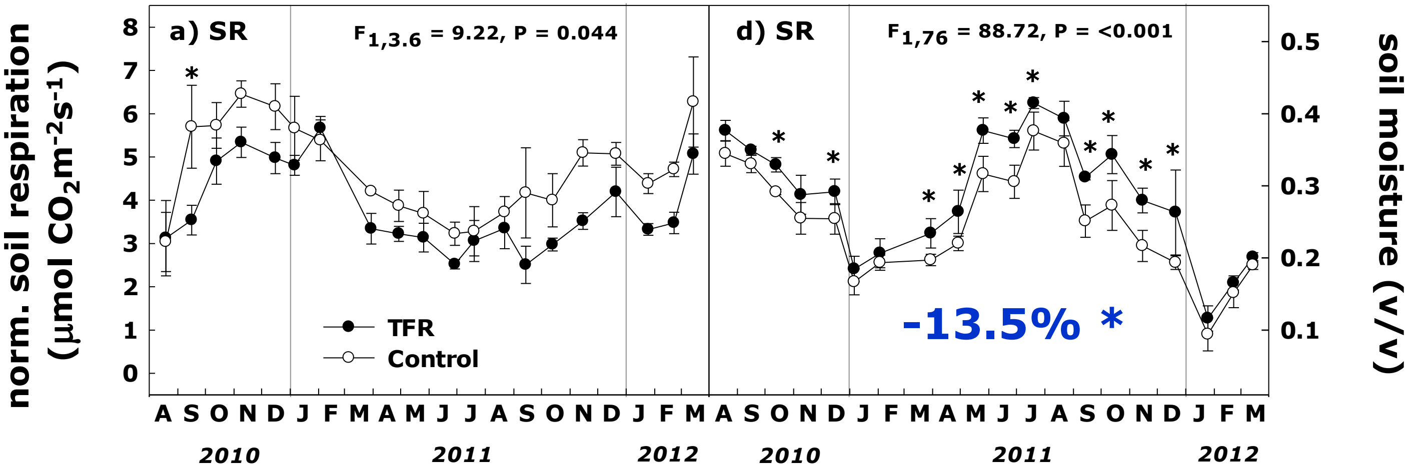
annual rainfall (mm)	
142 yr	871
1997-2009	760
2010	1250
2011	1059

Effect of reduced throughfall

SR

-19.0% *



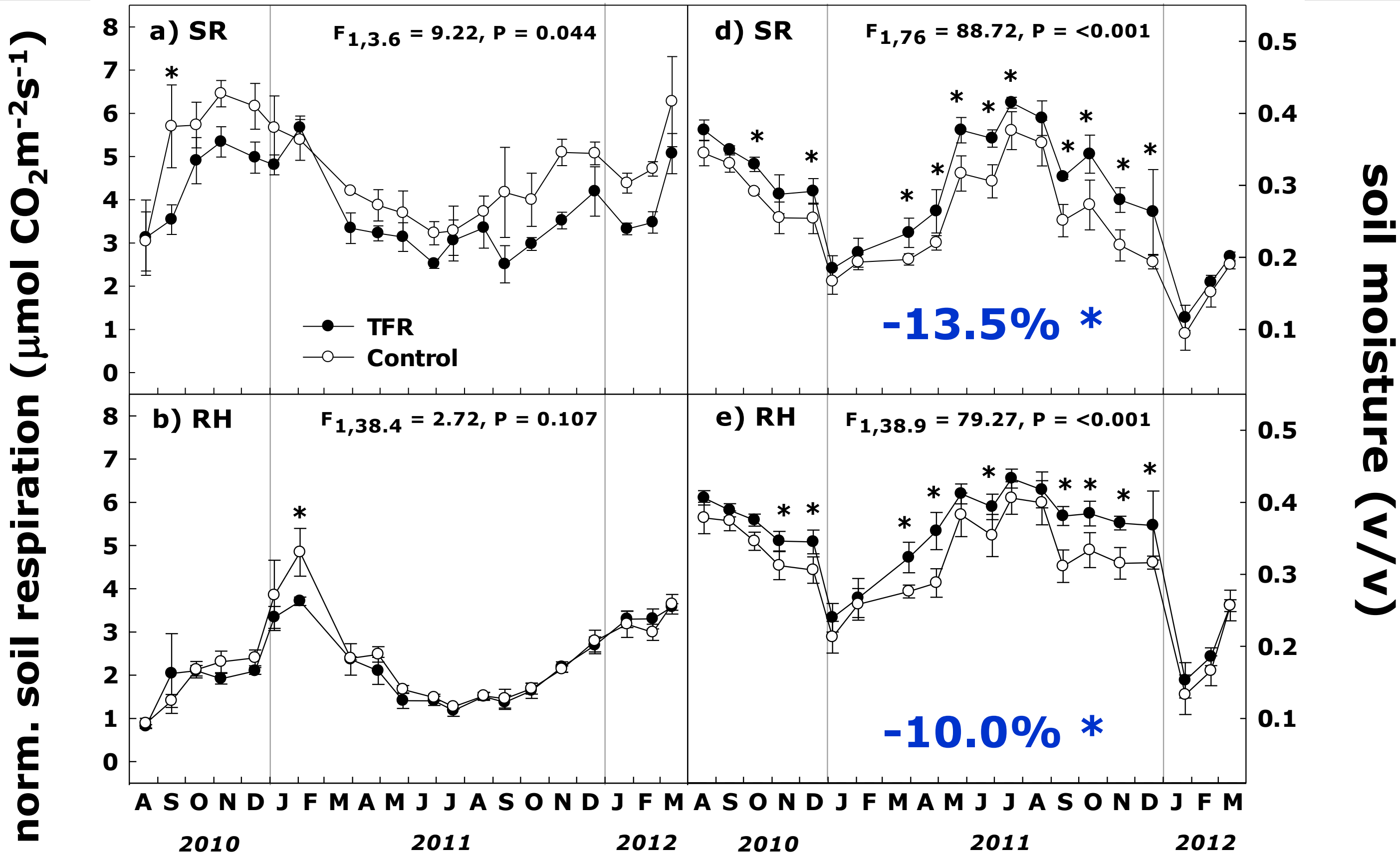
Effect of reduced throughfall

SR

-19.0% *

RH

+ 5.5 %



Effect of reduced throughfall

SR

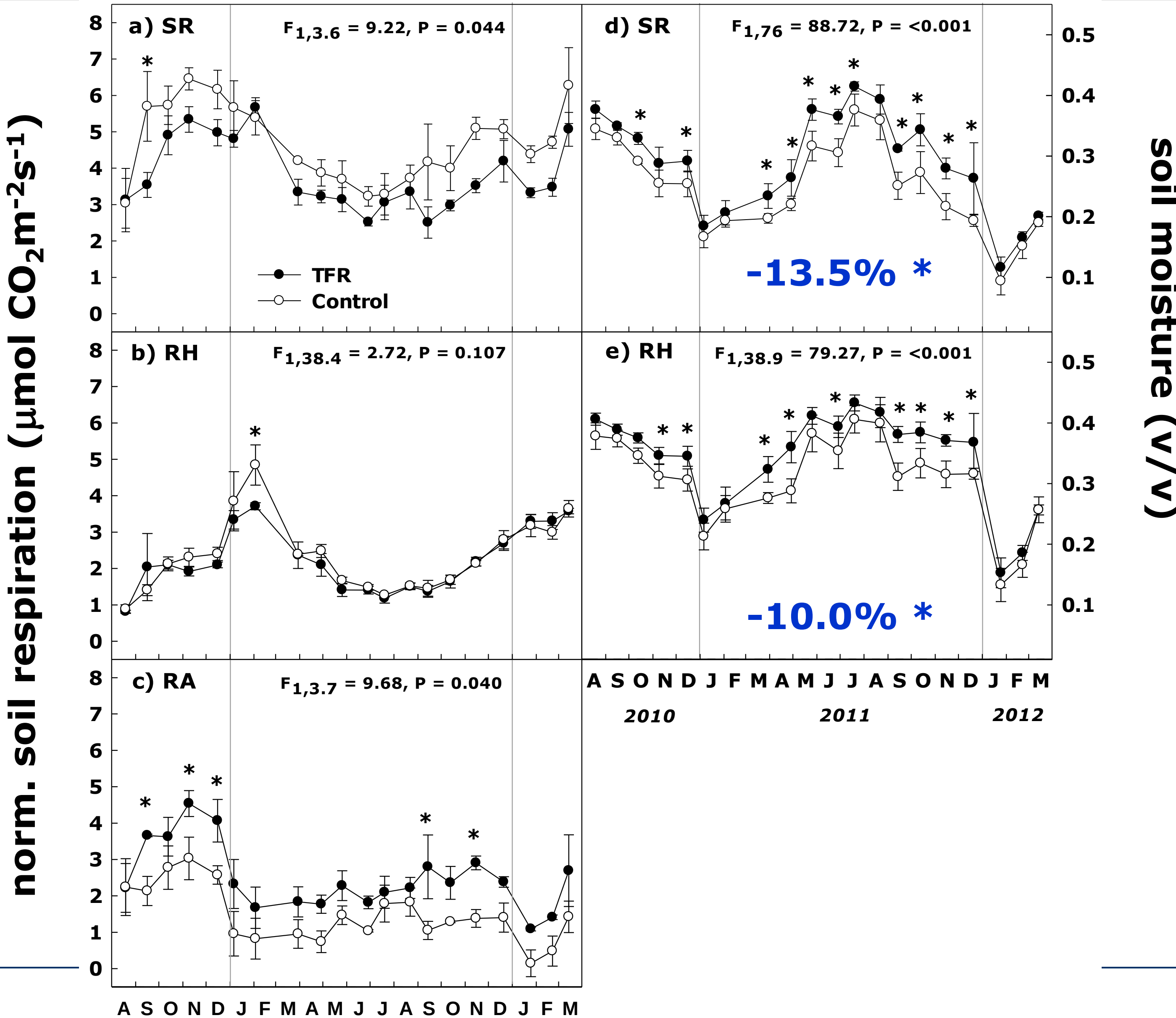
-19.0% *

RH

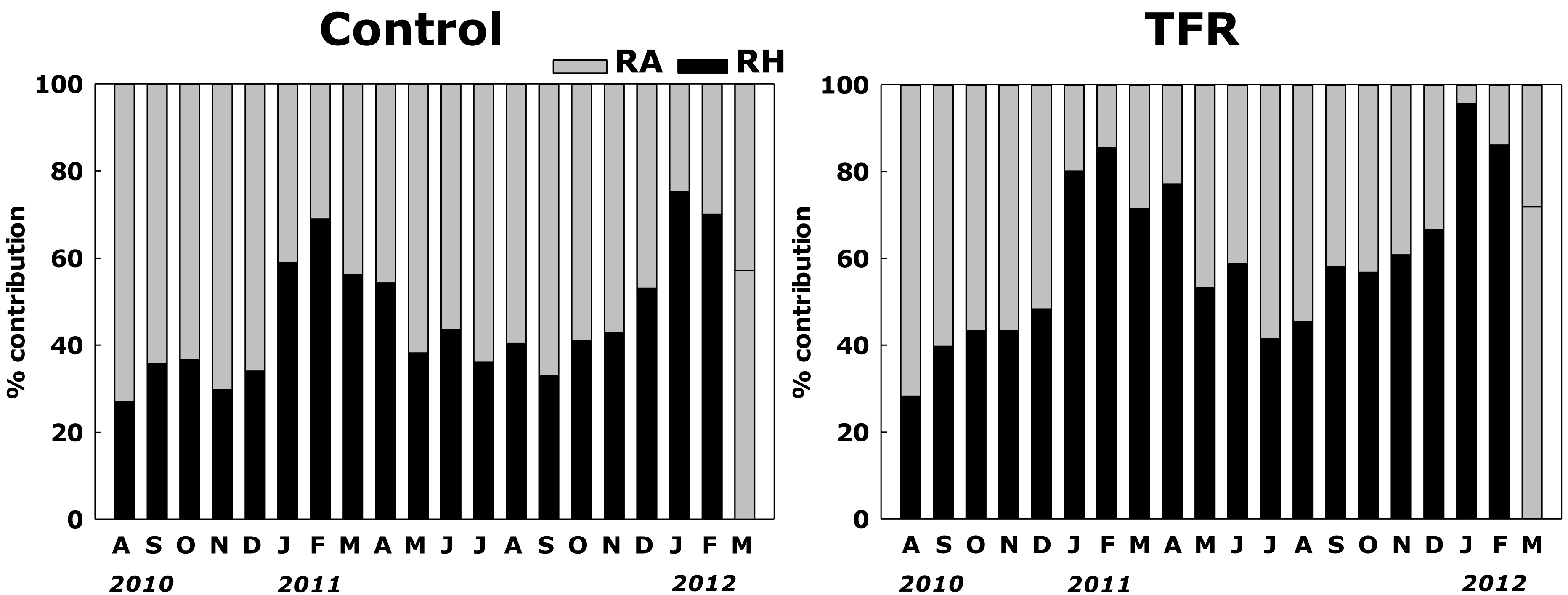
+ 5.5 %

RA

-40.7% *



Relative contribution of RH and RA



mean relative contribution of RH to SR:

47% (27-75%) in the Control

61% (28-96%) in TFR

Temperature sensitivity

Lloyd & Taylor (1994):

$$R = R_{ref} * e^{E*(1/(T_{ref}-T_0)-1/(T_s-T_0))}$$

Q_{10} function:

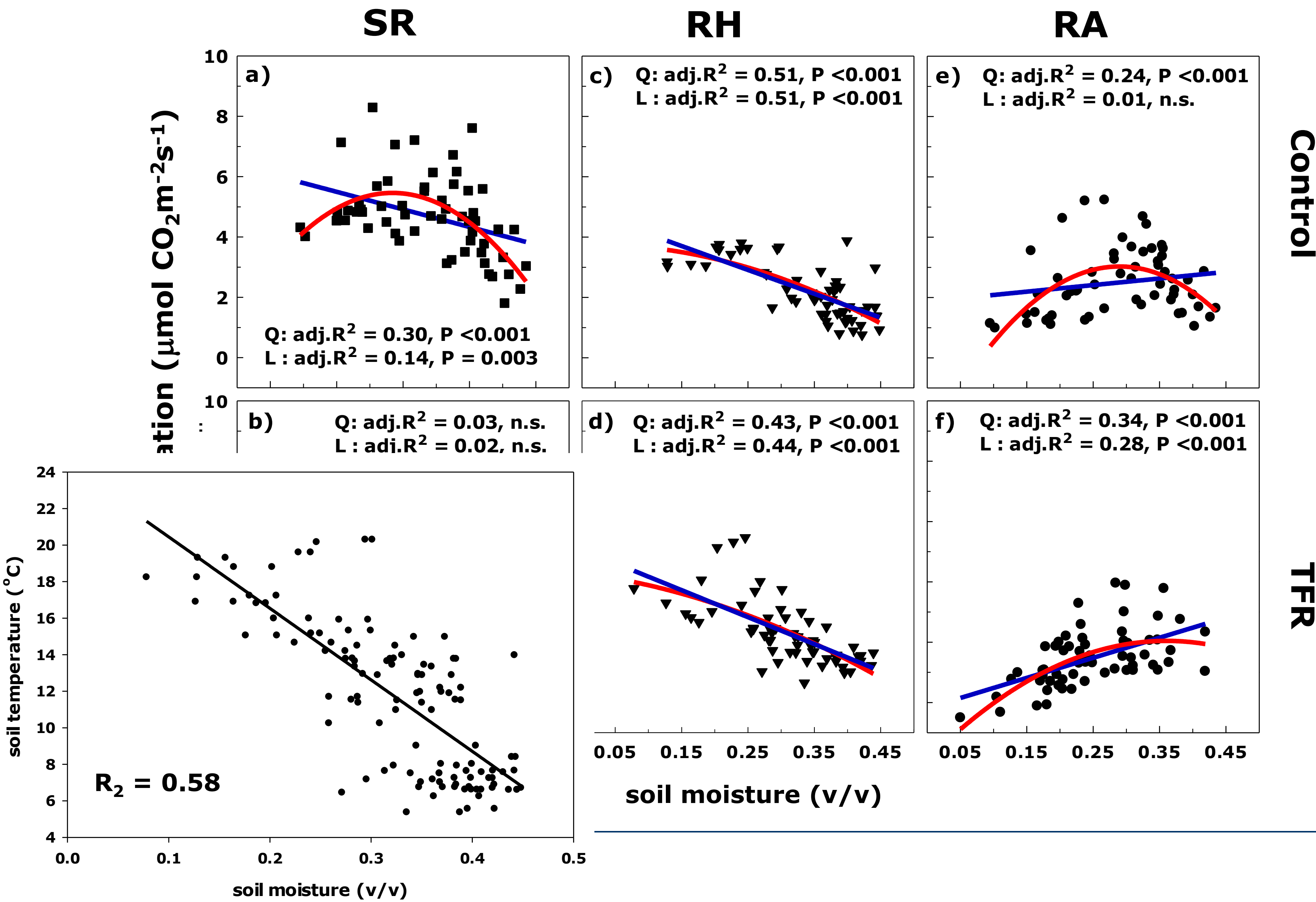
$$R = R_{ref} * Q_{10}^{((T_s-T_{ref})/10)}$$

T_{ref} :10° C

		a) ***Lloyd & Taylor***				b) ***Q_{10} function***				
		Rref	***E***	***R^2***	***P***	***Rref***	***Q_{10}***	***R^2***	***P***	***n***
Control	**SR**	4.45 ± 0.18	105.51 ± 25.95	0.24	***	4.43 ± 0.18	1.34 ± 0.10	0.22	***	58
	RH	1.84 ± 0.08	279.08 ± 24.90	0.72	***	1.83 ± 0.08	2.16 ± 0.15	0.71	***	58
	RA	2.52 ± 0.16	-40.16 ± 46.89	0.01	*n.s.*	2.53 ± 0.16	0.87 ± 0.12	0.02	***	58
TFR	**SR**	3.54 ± 0.12	130.66 ± 25.58	0.32	***	3.51 ± 0.13	1.47 ± 0.11	0.31	***	60
	RH	1.88 ± 0.07	306.25 ± 24.61	0.75	***	1.86 ± 0.07	2.42 ± 0.17	0.74	***	60
	RA	1.60 ± 0.12	-54.71 ± 61.50	0.02	*n.s.*	1.61 ± 0.12	0.83 ± 0.16	0.02	***	60

significance level: *** <0.001, ** <0.01, * <0.5, n.s. not significant

Soil moisture dependency



Soil moisture dependency

	Control							TFR						
	SR		**RH**		**RA**			**SR**		**RH**		**RA**		
	adj.R^2	P	adj.R^2	P	adj.R^2	P	n	adj.R^2	P	adj.R^2	P	adj.R^2	P	n
Summer months	0.18	*n.s.*	0.25[1]	*	0.36	**	17	0.35	**	0.01	*n.s.*	0.70	***	18
All months except summer	0.26[1]	***	0.37[1]	***	0.13[2]	*	41	0.00	*n.s.*	0.36[1]	***	0.11[2]	*	42

[1] negative correlation; [2] best fit quadratic regression; significance level: *** <0.001, ** <0.01, * <0.5, n.s. not significant

- soil moisture alone did not explain the strong decrease of RA during summer months in the Control
- changes in RA often occur concurrently with changes in fine root and aboveground plant growth – possible reduced fine root growth
- no correlation between GPP, VPD or PAR and soil respiration fluxes in the Control
- likely plant internal carbon allocation → 'phenological programming' (Joslin et al. 2001, Mission et al., 2006; Hendrick and Pregitzer 1996)

Outcome

- strong seasonality – SR result of distinct seasonal patterns of RH and RA
- spring flush in SR due to strong increase in RA - increased growth after decade long drought periods
- strong decrease in RA during summer – possible reduced fine root growth - low soil moisture & plant internal carbon allocation
- interannual variability in soil respiration fluxes – different rainfall pattern
- RH strongly dependent on soil temperature , no dependence on soil moisture
- RA no apparent temperature sensitivity, partly dependent on soil moisture
- Throughfall reduction (40%) → greatest effect on RA (-41%) – summer & spring 2011
  → no effect on RH
  → reduction in SR (-19%) – spring & summer 2011
  ⇒ possible reduction in fine root growth
- main relative determinant of SR:
  RA in Control (53%) and RH under reduced throughfall (61%)

Conclusion

- long-term throughfall manipulation experiments important to address seasonal and interannual variability in rainfall and responses of soil respiration processes
- in combination with partitioning of soil respiration into its component fluxes - strength to improve process based forest ecosystem models and to make more realistic predictions that include consideration of climate change carbon cycle feedbacks.
- Reduction in rainfall will lead to overall decrease of soil respiration in temperate broadleaved evergreen forests but the magnitude influenced by seasonal and interannual climate variability which can only be overcome by long-term climate manipulation experiments.
- Ultimate effect of climate change on the forest's carbon balance - dependence on direct response of plant productivity and indirectly due to its influence upon soil respiration dynamics.

Thanks to:

Julio Najera

Anne-Sophie Leclercq

Pierrick Pigot

Pierre Du-Buit

Xin Kun

Laurie Beroule

Mathilde Lepee

Maja Dietrich

OzFlux

POSTERA CRESCAM LAUDE

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TERN Terrestrial Ecosystem Research Network

State Government Victoria Department of Sustainability and Environment

AUSTRALIA Australian Government Australian Research Council

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Supplementary – GPP, VPD, PAR

- often strong & significant relationships between RH and /or TSR with GPP, VPD, PAR or Tair
- but Autocorrelation with soil temperature:
  Tair (R = 0.96)
  PAR (R = 0.86)
  VPD (R = 0.85)
  GPP (R = 0.84).
- confounded by strong relationships between soil respiration rates and soil temperature

monthly averages

	variables	TSR	RH	RA
	Tair	0.34 **	0.78 **	*n.s.*
	PAR	0.45 **	0.59 **	*n.s.*
	GPP	0.51 **	0.59 **	*n.s.*
	VPD	0.22 *	0.55 **	*n.s.*

daily averages

time lag (days)	variables	TSR	RH	RA
0	Tair	0.21 **	0.66 **	*n.s.*
	PAR	0.14 **	0.38 **	*n.s.*
	GPP	0.17 **	0.31 **	*n.s.*
	VPD	0.09 *	0.35 **	*n.s.*
1	Tair	0.26 **	0.62 **	*n.s.*
	PAR	0.17 **	0.32 **	*n.s.*
	GPP	0.18 **	0.27 **	*n.s.*
	VPD	0.12 **	0.33 **	*n.s.*
3	Tair	0.13 **	0.47 **	*n.s.*
	PAR	0.28 **	0.33 **	*n.s.*
	GPP	0.32 **	0.33 **	*n.s.*
	VPD	0.07 *	0.21 **	*n.s.*
5	Tair	*n.s.*	0.38 **	0.09 *
	PAR	0.21 **	0.51 **	*n.s.*
	GPP	0.31 **	0.52 **	*n.s.*
	VPD	*n.s.*	0.18 **	*n.s.*
7	Tair	0.12 **	0.48 **	*n.s.*
	PAR.tot	0.22 **	0.46 **	*n.s.*
	GPP	0.32 **	0.44 **	*n.s.*
	VPD	*n.s.*	0.22 **	*n.s.*

monthly averages: n=20, daily averages: n=58

Supplementary – site characteristics

Table 1 Main site characteristics of the Wombat State Forest, Victoria, Australia

Main species	Eucalyptus (*E .obliqua* , *E.rubida* , *E.radiata*)
Longitude	144° 05' E
Latitude	37° 25' S
Elevation (m)	706
Total Area (ha)	70000
Mean annual temperature (°C)	12.1 ± 0.1
Mean annual rainfall (142 yrs, mm)	871 ± 16
2011 annual rainfall (mm)	1059
soil characteristics	
Soil type	podzolic, silty clays overlying clays
Soil depth (cm)	50cm
Root depth (>80% of root biomass, cm)	0-30 cm
pH	4.83 ± 0.02
EC (mS cm^{-1})	0.064 ± 0.002
C/N	30.9 ± 0.5
Bulk density (0-10 cm, kg m^{-3})	0.94 ± 0.02
% sand	45.4 ± 1.8
% silt	27.9 ± 1.9
% clay	26.7 ± 0.4
stand characteristics	
Litterfall (g m^{-2} yr^{-1})	1120 ± 52
Litterdecomposition (g g^{-1} yr^{-1})	0.75 ± 0.02
Tree density (ha^{-1})	1316*
Tree dbh (cm)	18.6*
Tree height (m)	15*
LAI (leaf area index m^2 m^{-2})	1.81*

where applicable: mean of n = 3 ± 1SE; * Moore (2011)