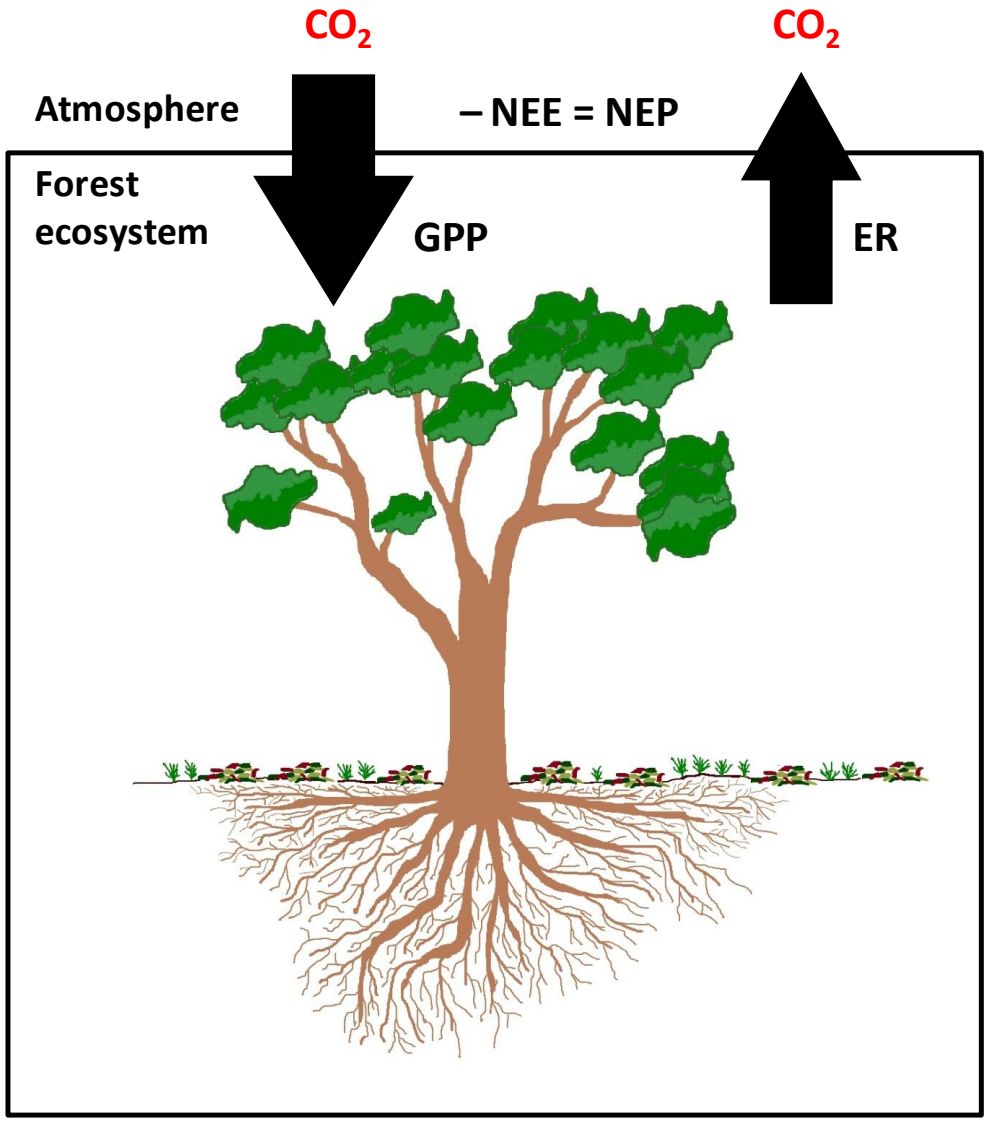
# Temporal variability in the relative contribution of soil respiration to ecosystem respiration

Nina Hinko-Najera,
Steve Livesley, Stefan Arndt

OzFlux - July 2016

# The carbon balance of forest ecosystems

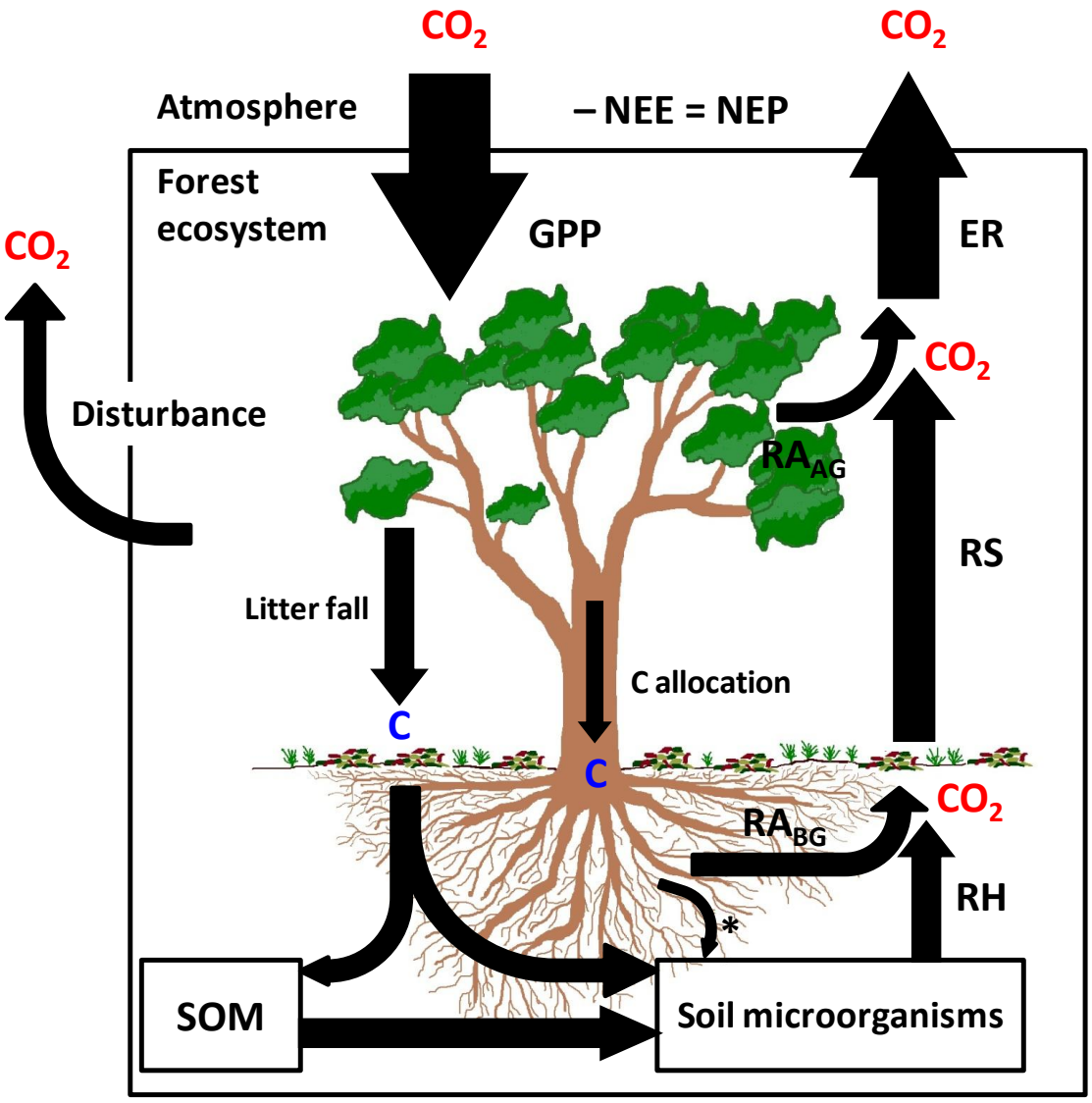



- Forests important carbon sinks of anthropogenic derived atmospheric $CO_2$ *(1)*
- Uncertainty regarding future trends and strength of sink
- High inter-annual variability in the sink strength – strong dependence on changes in climate *(2)*
- Unknown sensitivity of soil carbon decomposition to global warming *(3)*
- Critical to assess and improve understanding of processes controlling the carbon balance of terrestrial ecosystems

*adapted from Chapin et al. 2006, 2011*

*(1) Pan et al., 2011; (2) e.g. Heimann and Reichstein, 2008, Reichstein at al., 2013, Ciais et al., 2013, Ahlström et al, 2015; Poulter et al. 2014, Ahlström et al, 2015 (3) Conant et al., 2011, Davidson and Janssens, 2006*

# Ecosystem Respiration




**NEP = (-NEE) = GPP – ER**

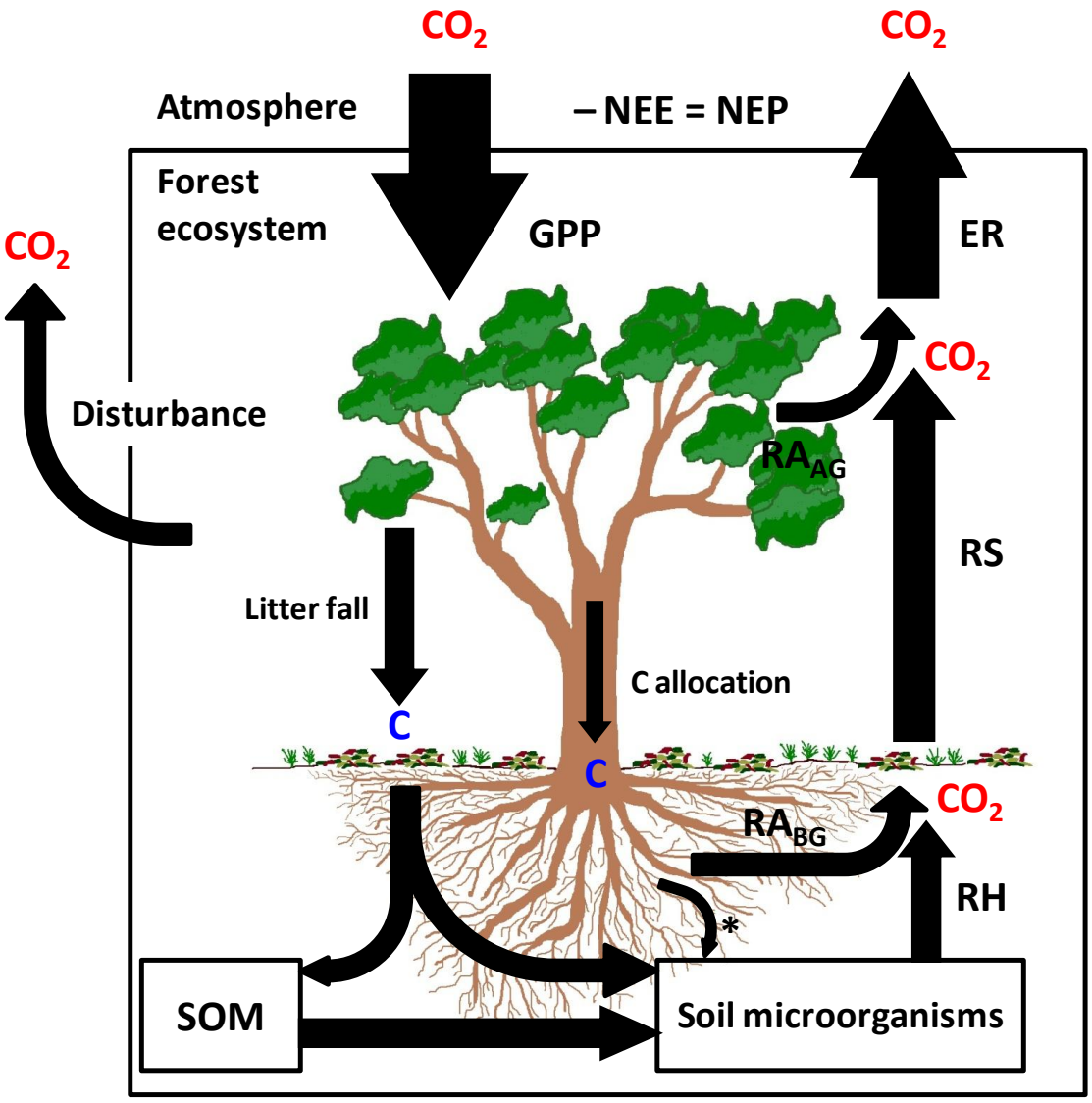
**GPP** – gross primary production (photosynthesis)

**ER – ecosystem respiration:**

- **RH – heterotrophic respiration**
  - → microbial decomposition of litter and soil organic matter (SOM)
- **RA – total autotrophic respiration:**
  - **$RA_{AG}$** – aboveground respiration
  - **$RA_{BG}$** – belowground respiration:
    - → living roots and closely associated microbes & symbionts (mycorrhiza) in the rhizosphere

*adapted from Chapin et al. 2006, 2011*

# Soil Respiration




**RS – soil respiration**:

→ **combined flux of $RA_{BG}$ and RH**

- **Carbon source:**

  **$RA_{BG}$** → allocation of recently assimilated photosynthates belowground and root exudates *(1)*

  **RH** → fresh litterfall, root turnover and existing soil organic matter (SOM)

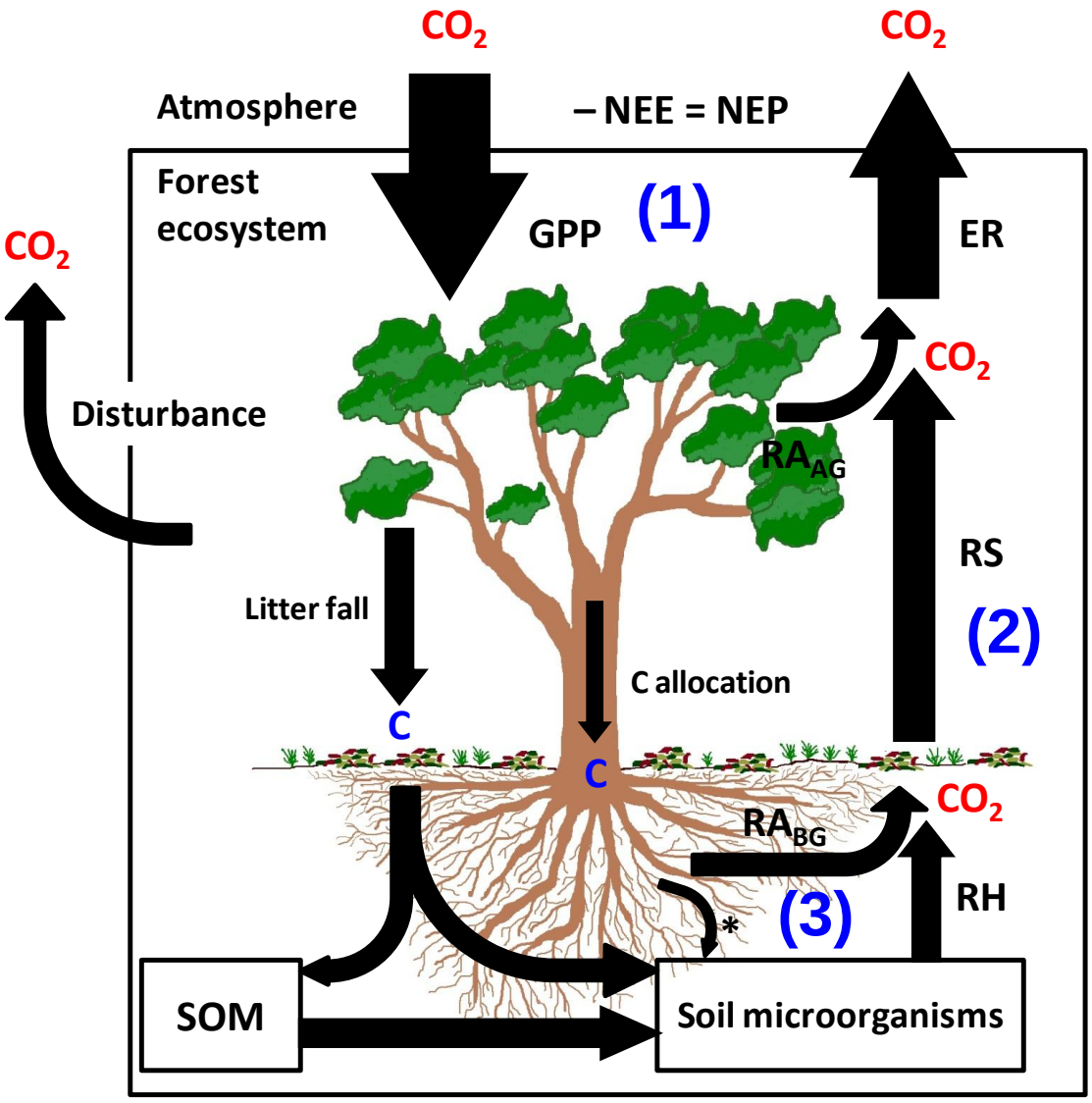
- Relative annual contribution of RH to RS around 40 – 50% ; strong seasonal variability (10 – 90%) in forest ecosystems *(2)*

- RS can contribute 30 to 80% to ER; ~ 70% of ER in temperate forests *(3)*

*adapted from Chapin et al. 2006, 2011*

*(1) Ekblad & Högberg, 2001; Högberg et al., 2001; Kuzyakov & Larionova, 2005; (2) Bond-Lamberty et al., 2004; Hanson et al., 2000; Subke et al., 2006; (3) Davidson et al., 2006; Janssens et al. 2001*

# Research rationale




**Australia's perspective:**

- limited published data available on forest ecosystem carbon dynamics including respiration processes
- Dry temperate eucalypt forests ?
- No published long-term data of RS from high temporal measurements in Australian forest ecosystems

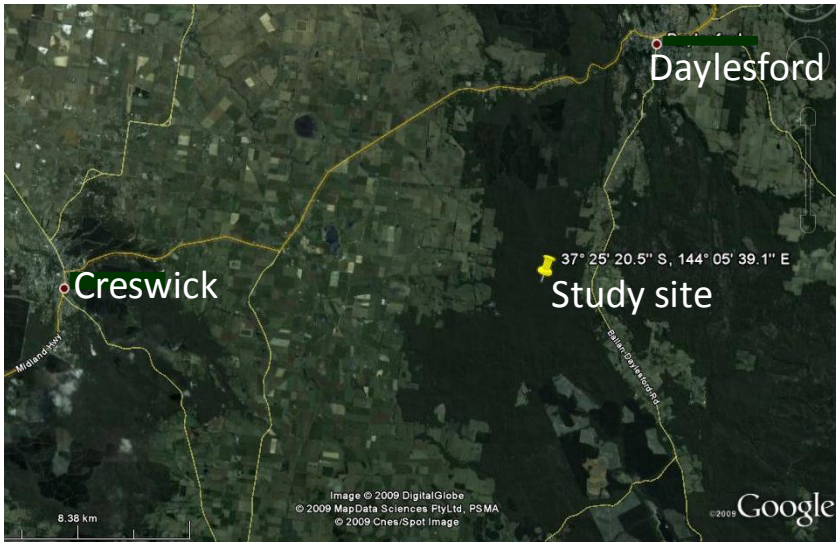
- **Understanding temporal dynamics of processes controlling NEE with focus on soil respiration processes in a dry temperate eucalypt forest**

**(4)** Relative contribution of the various component fluxes to the ER and the overall NEE

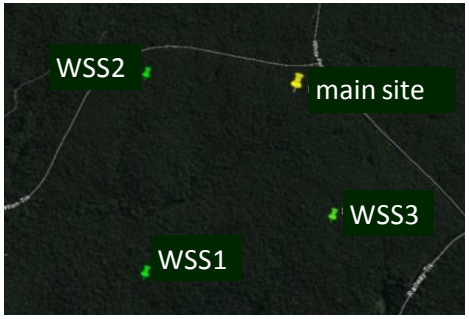
*adapted from Chapin et al. 2006, 2011*

*(1) Ekblad & Högberg, 2001; Högberg et al., 2001; Kuzyakov & Larionova, 2005; (2) Bond-Lamberty et al., 2004; Hanson et al., 2000; Subke et al., 2006; (3) Davidson et al., 2006; Janssens et al. 2001*

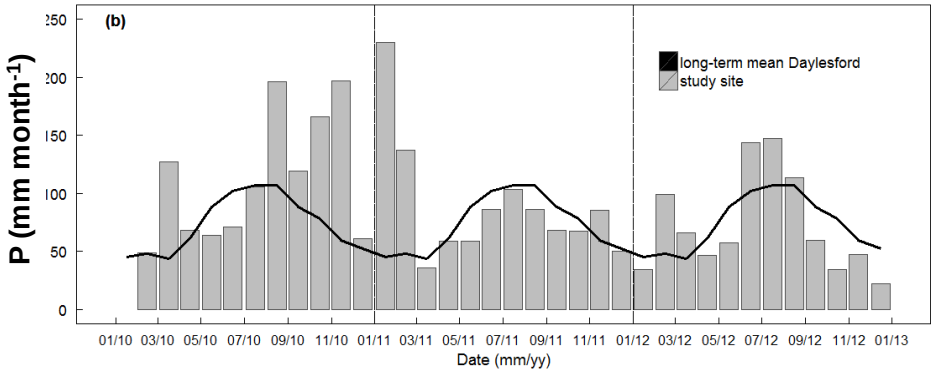
# Study site – Wombat State Forest




- ~ 25 yr secondary regrowth forest, canopy height ~ 22 m
- *E. obliqua* (messmate stringybark),
  *E. radiata* (narrow-leafed peppermint),
  *E. rubida* (candlebark gum)
- Climate: cool temperate to Mediterranean
- Main long-term research site with automated & continuous measurements, operating since Jan 2010
- 3 sites within proximity with manual & periodic (monthly) measurements




**2010:** 1254 mm **2011:** 1070 mm **2012:** 872 mm



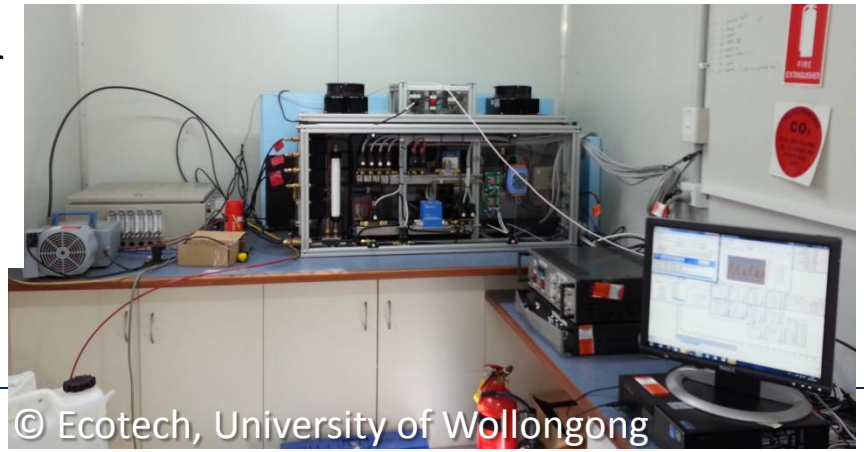
# Main research site

**NEE measurements and ER estimation:**

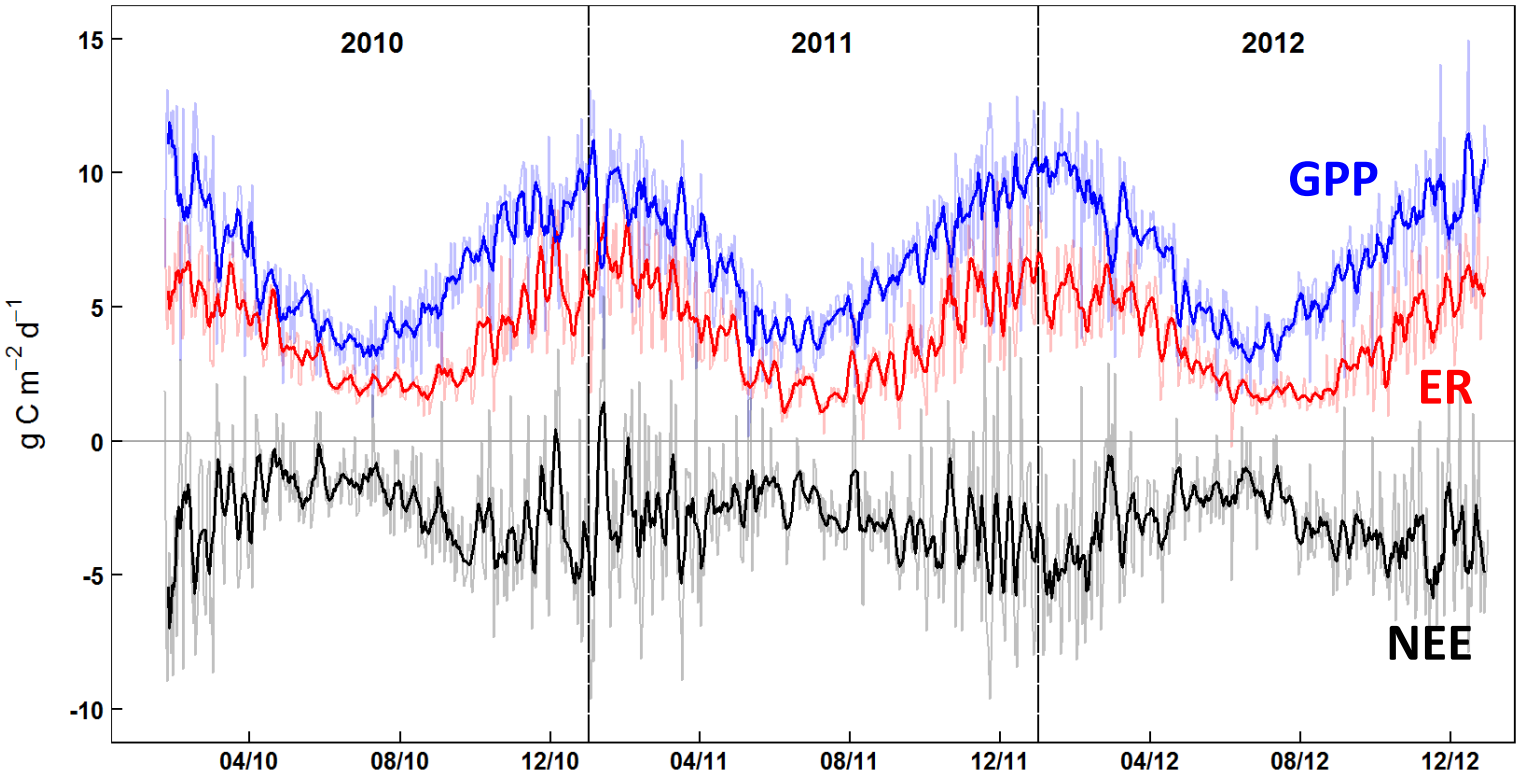
- 35 m high Eddy Covariance (EC) – tower
- Remote area power system, remote internet connection
- QA/QC and gap filling following OzFlux standard protocol [(1)] and "Dynamic Integrated Gap filling and partitioning for OzFlux" (DINGO) routine

**Continuous soil respiration measurements**

- 6 automated soil respiration chambers
- FTIR (*Fourier Transform Infra Red*) trace gas analyser
- Chamber cycle from 1.5 hours (15 min closure) to 3 hours (30 min closure)



# NEE, ER and GPP estimates 2010 – 2012

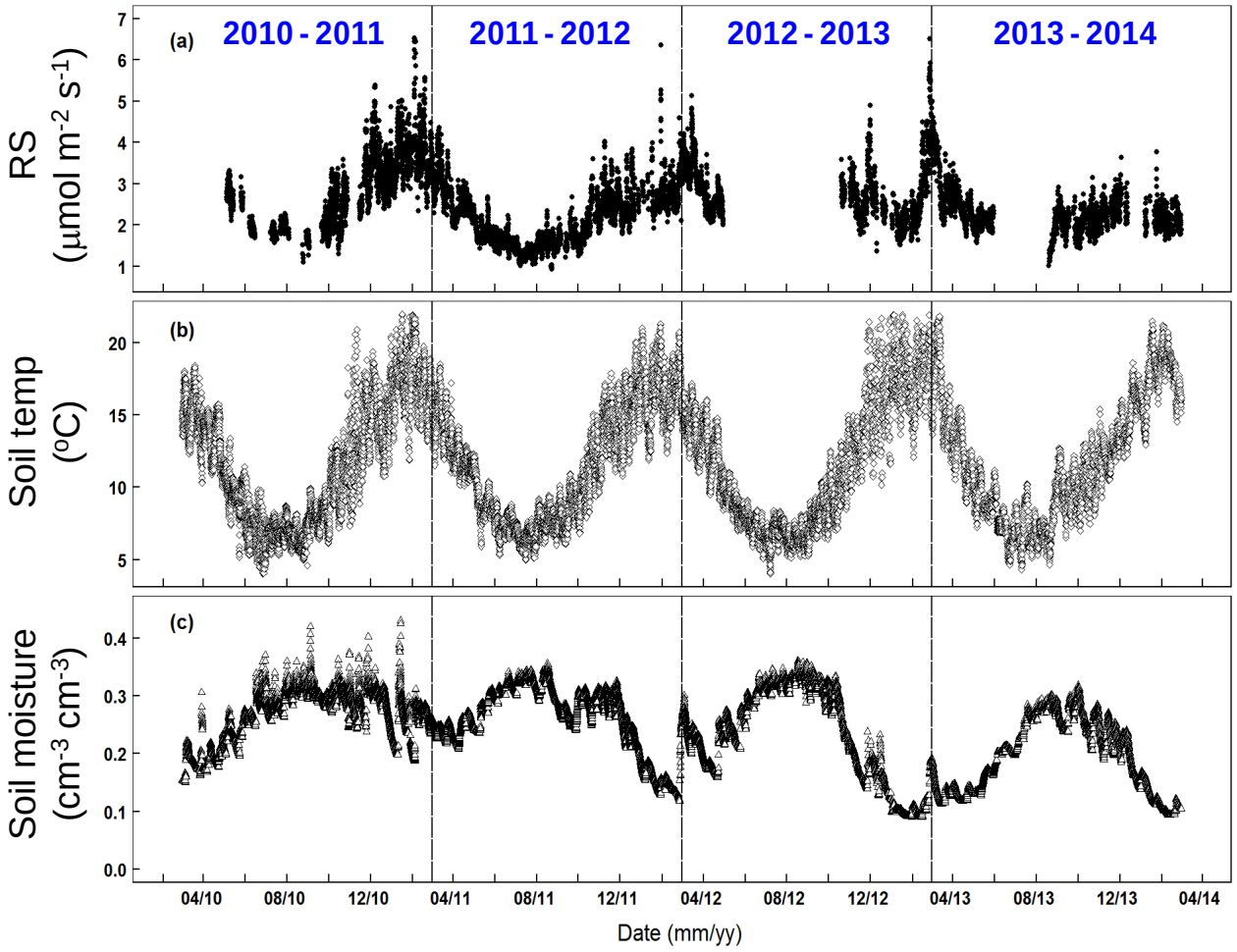



| Year | NEE (g C m$^{-2}$) | ER (g C m$^{-2}$) | GPP (g C m$^{-2}$) |
|---|---|---|---|
| 2010 | -976 *a* | 1475 | 2451 |
| 2011 | -1053 *ab* | 1502 | 2555 |
| 2012 | -1158 *b* | 1399 | 2557 |
| CV (%) | 8.6 ** | 3.6 *ns* | 2.4 *ns* |

- large and constant carbon sink throughout study period (mean ER/GPP ratio = 0.58)
- Gross $CO_2$ ecosystem fluxes: pronounced seasonality, no inter-annual variability

*(Hinko-Najera et al., 2016, BGD)*

# Automated soil respiration measurements

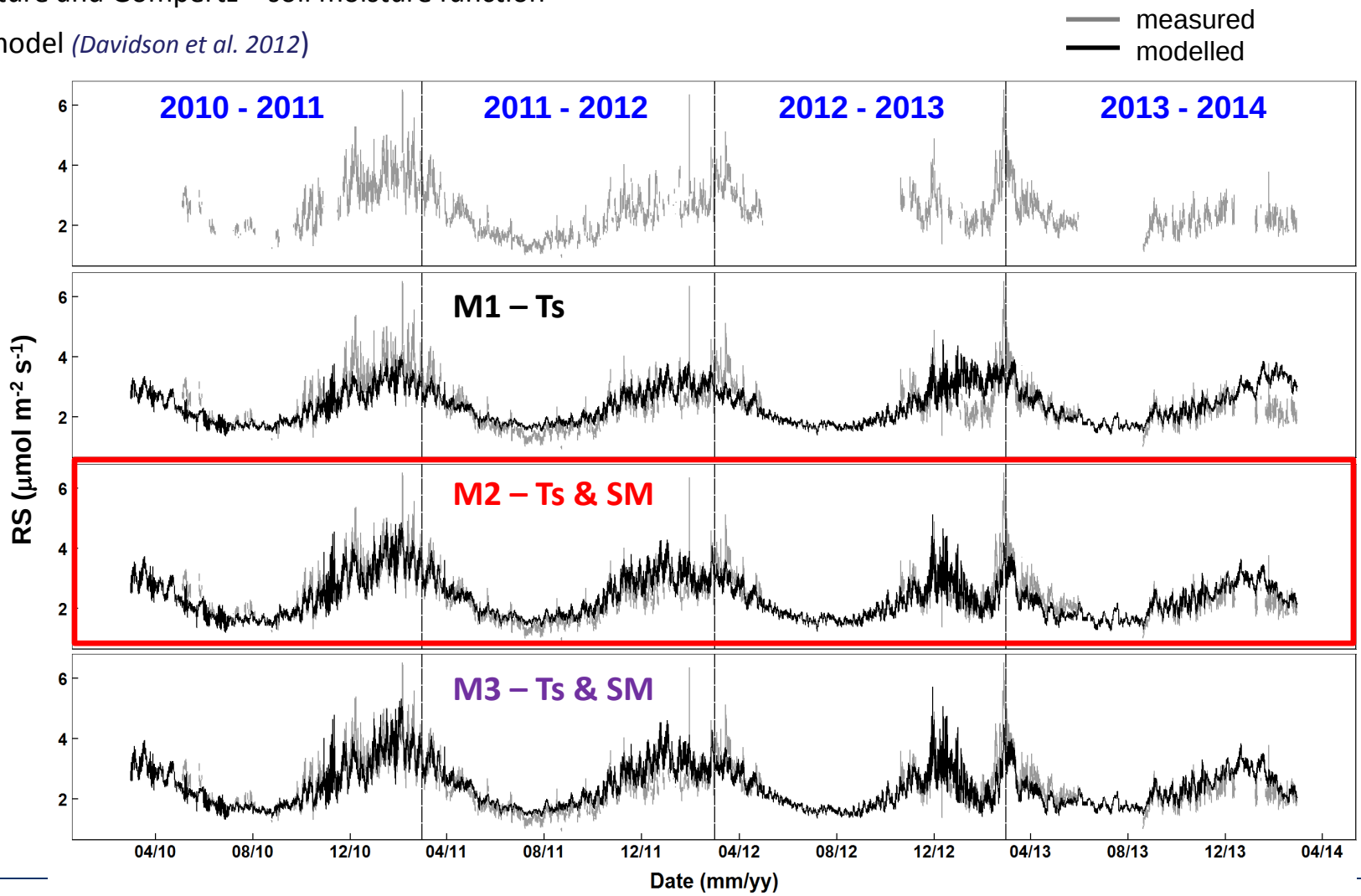



- Seasonal variability primarily driven by soil temperature (> 73%) when soil moisture not limiting
- RS decreased below soil moisture threshold (19 vol%), primarily during summer months

*(Hinko-Najera et al., submitted to SBB)*

# Modelling soil respiration

- **M1:** Temperature function *(Lloyd and Taylor, 1994)*
- **M2:** Temperature and Gompertz – soil moisture function
- **M3:** DAMM model *(Davidson et al. 2012)*




**$R^2$ = 0.53**
ME = 0.53
MAE = 15.7 %
RSME = 21.7 %

**$R^2$ = 0.72**
ME = 0.72
MAE = 13.0 %
RSME = 16.9 %

**$R^2$ = 0.70**
ME = 0.70
MAE = 13.2 %
RSME = 17.4 %

*(Hinko-Najera et al., submitted to SBB)*

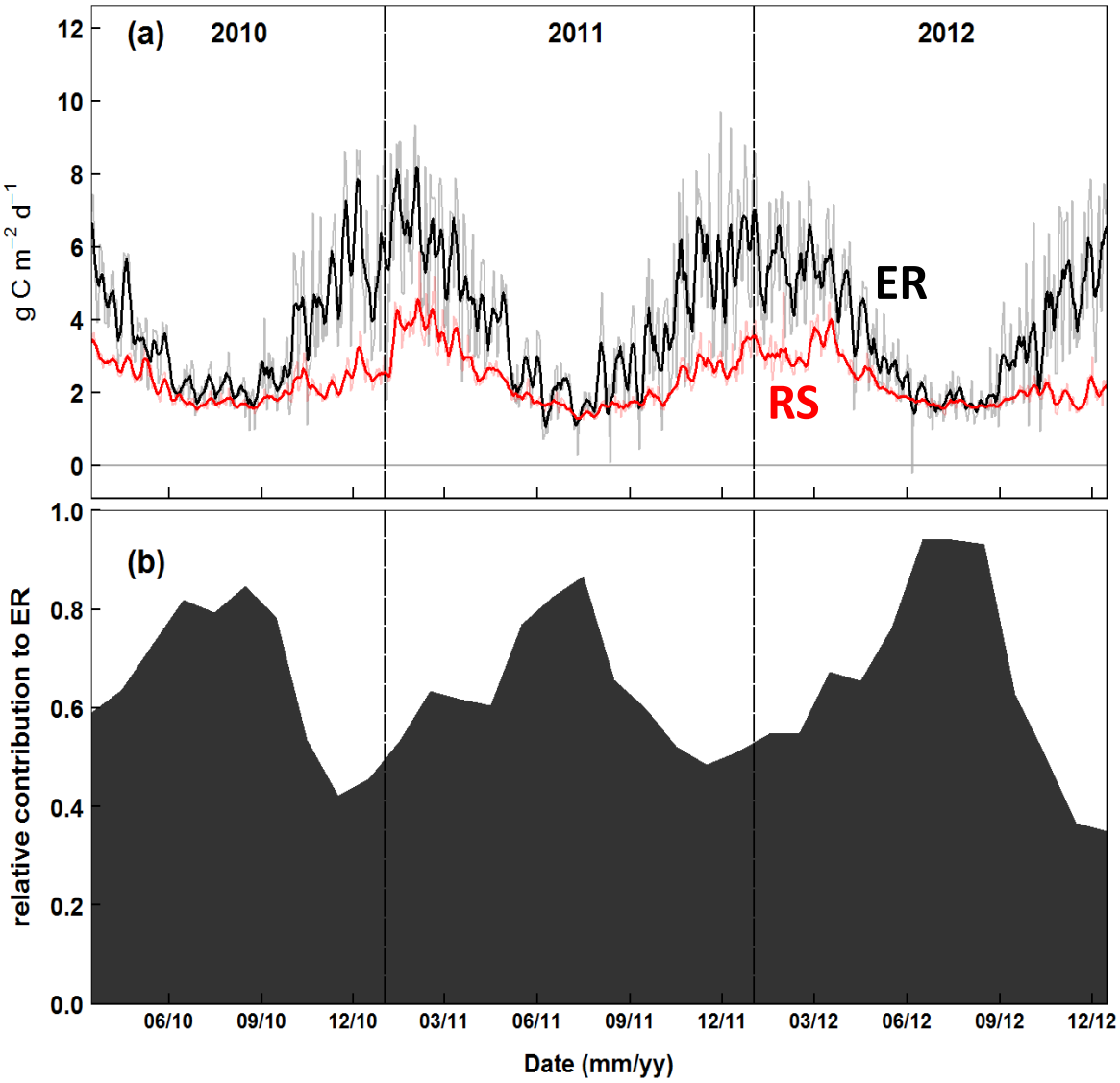
# Soil respiration – annual estimates

| data selection | variables | 2010-11 | 2011-12 | 2012-13 | 2013-14 | CV (%) |
|---|---|---|---|---|---|---|
| **Total** | **RS (g C $m^{-2}$)** | **908** | **858** | **762** | **849** | 7 |
| | Precipitation (mm) | 1519 | 838 | 815 | 743 | 37 |
| | $T_{air}$ (°C) | 11.1 ± 1.3 | 11.4 ± 1.1 | 11.7 ± 1.3 | 12.1 ± 1.3 | 4 |
| | $T_{soil}$ (°C) | 11.9 ± 1.2 | 11.8 ± 1.1 | 12.0 ± 1.2 | 12.2 ± 1.2 | 1 |
| | SM ($cm^{-3}$ $cm^{-3}$) | 0.26 ± 0.01 | 0.26 ± 0.02 | 0.22 ± 0.02 | 0.19 ± 0.02 | 15 |
| **Summer** | **RS (g C $m^{-2}$)** | **304** | **274** | **186** | **242** | 20 |
| | Precipitation (mm) | 431 | 182 | 102 | 52 | 88 |
| | $T_{air}$ (°C) | 15.8 ± 0.9 | 16.1 ± 0.9 | 17.0 ± 1.0 | 17.7 ± 1.1 | 5 |
| | $T_{soil}$ (°C) | 16.6 ± 0.8 | 16.2 ± 0.5 | 17.4 ± 0.6 | 16.9 ± 0.9 | 3 |
| | SM ($cm^{-3}$ $cm^{-3}$) | 0.27 ± 0.01 | 0.18 ± 0.03 | 0.12 ± 0.02 | 0.14 ± 0.03 | 36 |
| **Summer excluded** | **RS (g C $m^{-2}$)** | **604** | **584** | **576** | **606** | 2 |
| | Precipitation (mm) | 1088 | 656 | 713 | 691 | 26 |
| | $T_{air}$ (°C) | 9.3 ± 1.2 | 9.6 ± 1.0 | 9.4 ± 1.1 | 10.3 ± 1.1 | 5 |
| | $T_{soil}$ (°C) | 10.1 ± 1.1 | 10.0 ± 1.0 | 9.7 ± 1.0 | 10.2 ± 1.0 | 2 |
| | SM ($cm^{-3}$ $cm^{-3}$) | 0.26 ± 0.02 | 0.28 ± 0.01 | 0.26 ± 0.02 | 0.21 ± 0.02 | 12 |

- Inter-annual variation of RS reflected inter-annual variability in rainfall distribution and subsequent changes in soil moisture patterns, highest during summer months when changes in soil moisture and rainfall were greatest

*(Hinko-Najera et al., submitted to SBB)*

# Relative contribution of RS to ER

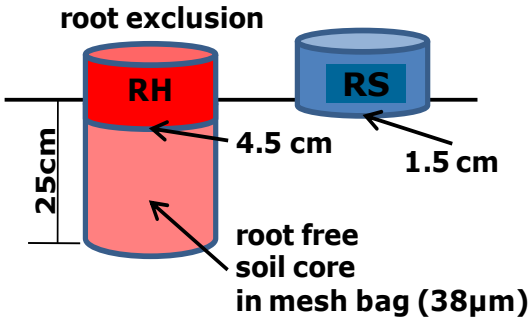



- No inter-annual variability → mean **RS/ER ratio = 0.65**
- Strong seasonal variability (0.35 – 0.94)
- Low RS/ER ratio in spring and summer → greater indicated contribution of $RA_{ab}$ to ER → high GPP & strong influence of plant internal carbon allocation in aboveground plant tissues
- High RS/ER ratio in autumn → likely decomposition of litter fall accumulated through summer (↑ RS) and/or a decrease in air temperature (↓ $RA_{AG}$)

# Partitioning of soil respiration

**Experimental design**

- August 2010 – March 2012
- 3 Control plots (20 x 20 m)
- partitioning of RH and $RA_{BG}$ – **root exclusion**
- 10 chambers/ treatment/ plot



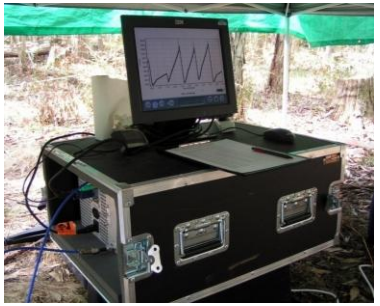

- **Measured fluxes:**

  **RS** – soil respiration (total)

  **RH** – heterotrophic respiration

- RS – RH ⇨ **$RA_{BG}$** – autotrophic respiration

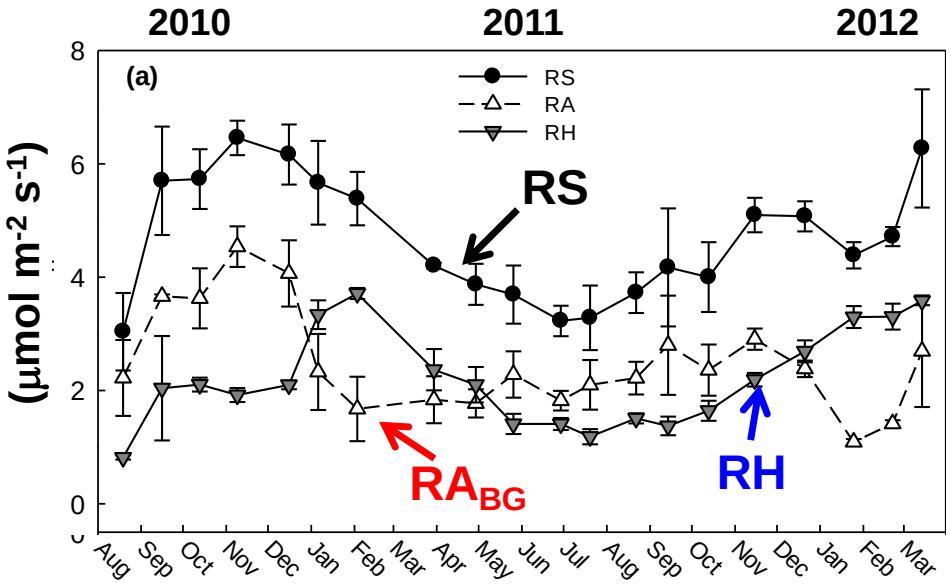
- Monthly measurements of $CO_2$ with closed dynamic chambers (CDC) linked to a Fast Greenhouse Gas Analyser (FGGA, Los Gatos Research)

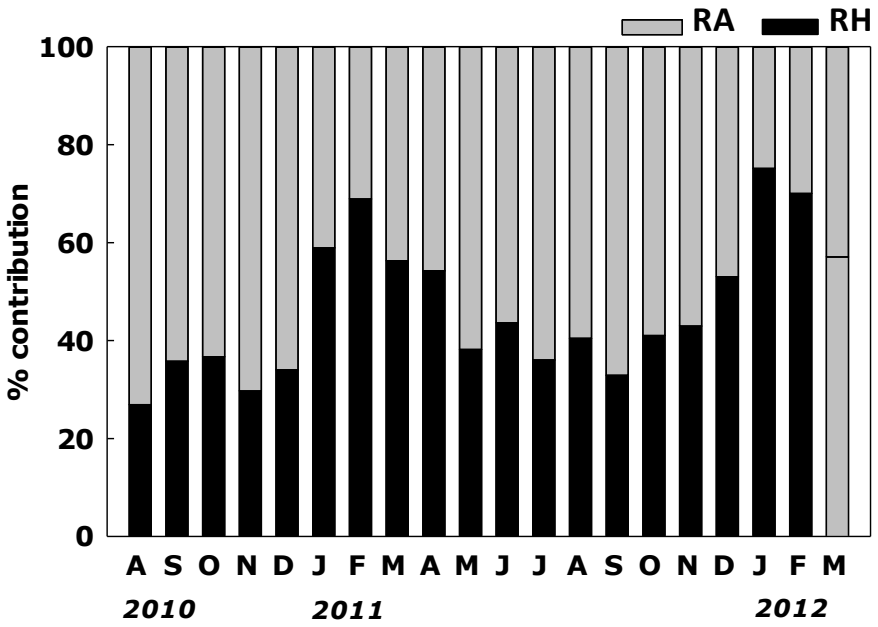


- Concurrent measurements of soil moisture and soil temperature per chamber & automated measurements within plot

*(Hinko-Najera et al., 2015)*

# Relative contribution of $RA_{BG}$ and RH to RS

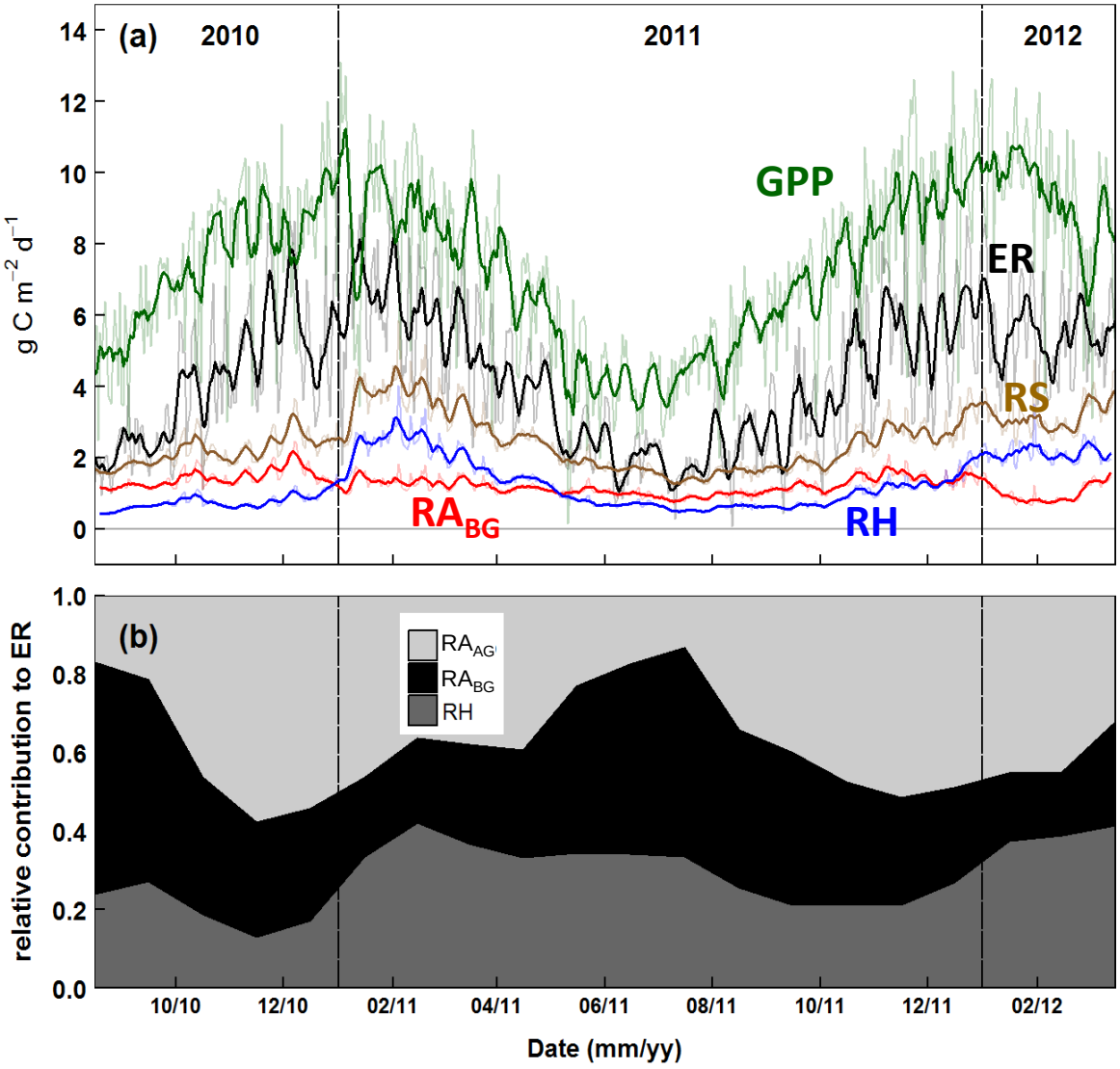



- Seasonality of RS – result of distinct seasonal patterns of RH and $RA_{BG}$
- Strong decrease in $RA_{BG}$ during summer: reduced fine root growth? - low soil moisture & plant internal carbon allocation
- **Mean relative contribution of $RA_{BG}$ to RS: 53% (25 – 73%), lowest in summer, highest in spring/winter**

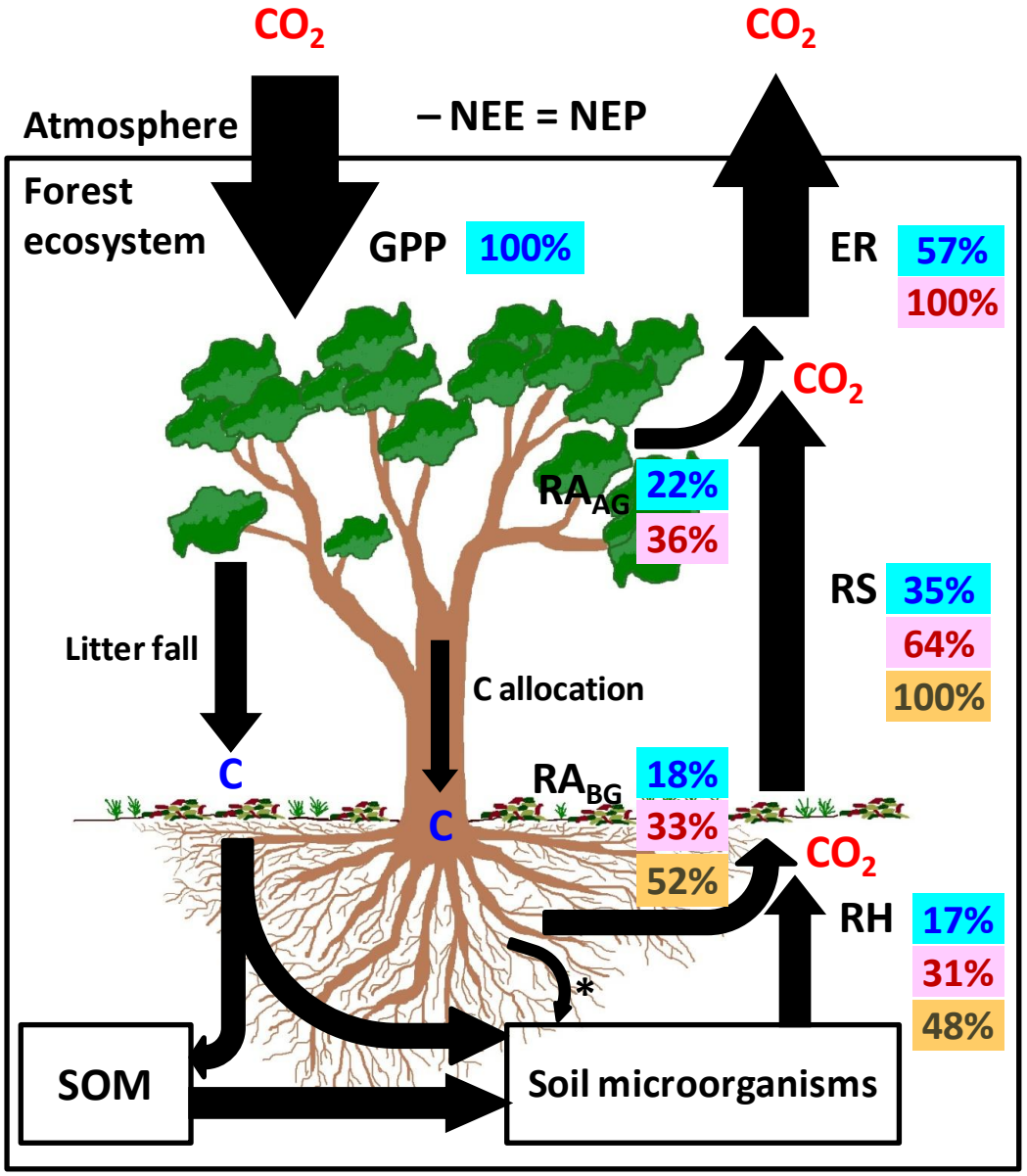
*(Hinko-Najera et al., 2015)*

# Relative contribution of $RA_{BG}$ and RH to ER




- Total autotrophic respiration – combined belowground ($RA_{BG}$) & aboveground ($RA_{AG}$) autotrophic respiration – dominates ER (71%)
- overall forest carbon loss mainly driven by processes involving carbon substrates with likely relatively short residence times
- relatively small contribution of microbial decomposition of older SOM

# Annual relative contribution of component fluxes to ER and NEE for 2011




- RS is the largest efflux of $CO_2$ from dry temperate eucalypt forest to atmosphere
- $RA_{AG} > RA_{BG} > RH$
- High CUE (carbon use efficiency): GPP/NPP – ratio = 0.6

# Conclusion

- Importance to directly measure/ estimate component fluxes that contribute to overall NEE
- strong & continuous net carbon sink
- RS main carbon efflux from the forest but overall ER is dominated by autotrophic respiration processes during high rainfall years
- Rather fast carbon cycling rate through this forest ecosystem $\rightarrow$ potentially higher vulnerability of forest carbon sink to climate change and variability
- Strong influence of seasonal plant internal carbon allocation patterns on carbon ecosystem fluxes
- Dynamic nature in the relative contribution of various components of ER $\rightarrow$ consideration in process-based models
- Provide empirical data for process-based models $\rightarrow$ help to reduce uncertainties in ecosystem feedback predictions to climate change

# THANK YOU!

**I'd like to thank:**

**Benedikt Fest, UoM**
**Julio Najera, UoM**

**Peter Isaac, Eva van Gorsel, CSIRO**
**Jason Beringer, UWA; Darren Hocking, Ian McHugh, Monash University**

**David Griffith, Graham Kettlewell, University of Wollongong**





**contact: n.hinko.najera@gmail.com**