Patterns and processes of carbon and water budgets across northern Australian landscapes: From point to region

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MONASH University
THE UNIVERSITY OF MELBOURNE
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Importance of the savanna land surface in the earth system

- Local savanna surface water and heat balance influences regional climate through **biophysics** (heat, moisture, energy)
- Regional to global coupling
- Coupled to global climate through **biogeochemical** cycles (C, N, P, etc.)
- Changes in climate inherently influence global circulation
- So savanna land surface and Carbon cycle are important

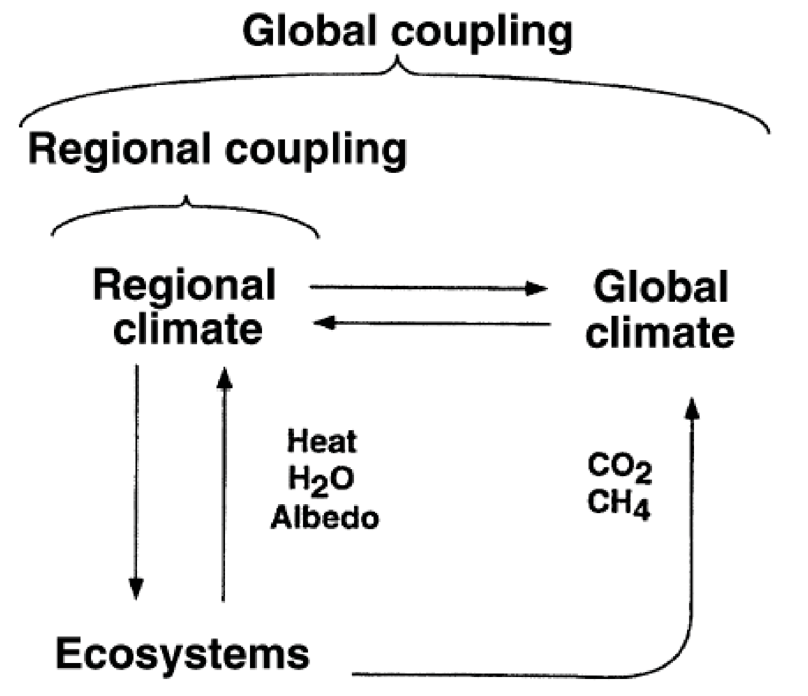


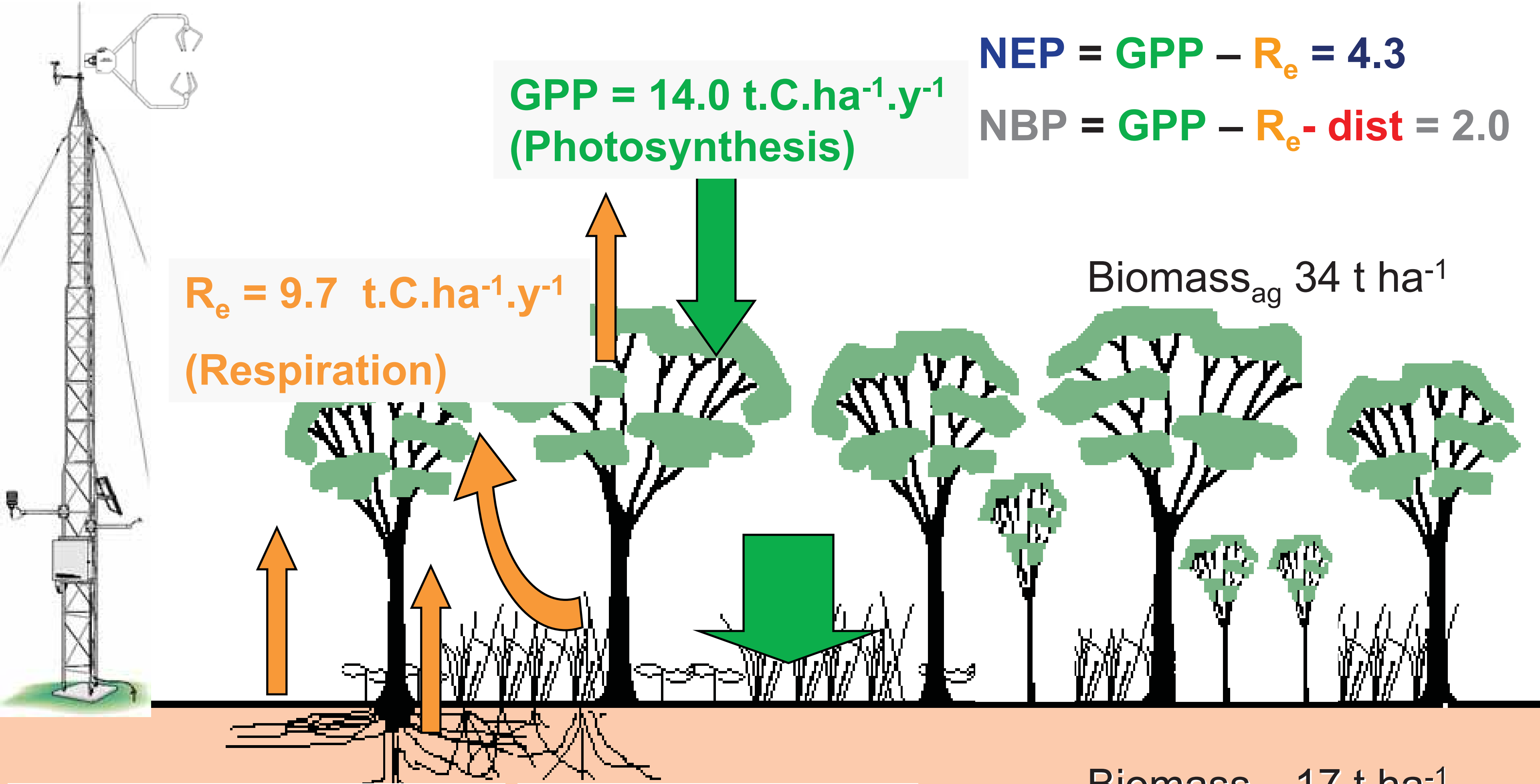
Fig. 1 The processes that couple high-latitude ecosystems to regional climate (through albedo and water/energy flux) and to global climate (through CO_2 and CH_4 flux).

Chapin, Beringer et al. Science (2000)

Savanna ecosystem carbon fluxes and pools

NEP = GPP – R_e = 4.3

NBP = GPP – R_e- dist = 2.0



SOC 140 t ha^{-1}

Gains

Woody increment – 1.2 (28%)
Shrub increment – 0.5 (11%)
Unknown – 0.3 (7%)

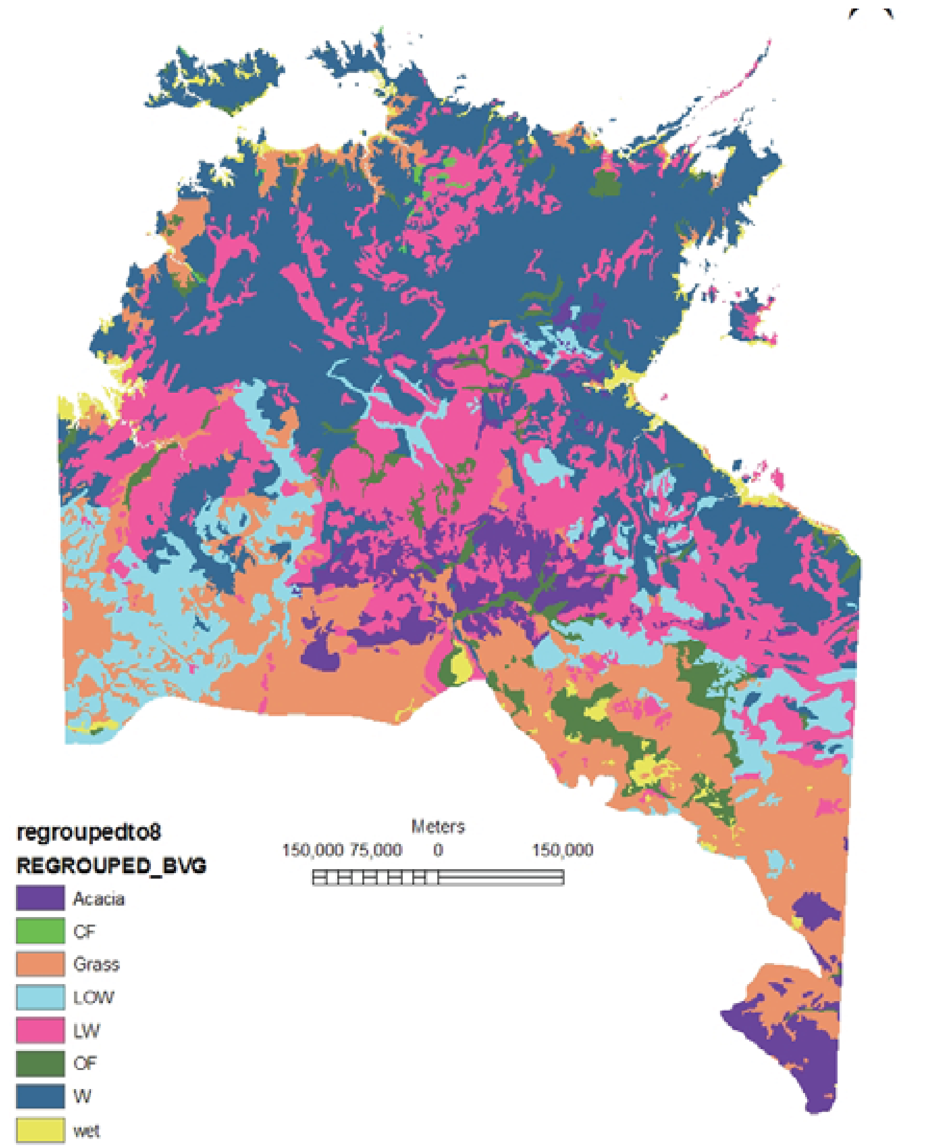
Losses

Indirect fire – 0.7 (16%)
Coarse fuel – 0.5 (11%)
Fine fuel – 1.1 (25%)

Courtesy Hutley, Chen, Beringer, et al.

Spatial variability of Land surface fluxes

- Savanna region heterogeneous vegetation
- Strong rainfall gradient
- North Australian Tropic Transect
- Issues land clearing, fire, aerosols, trace gas emissions
- Need to understand and quantify spatial variability



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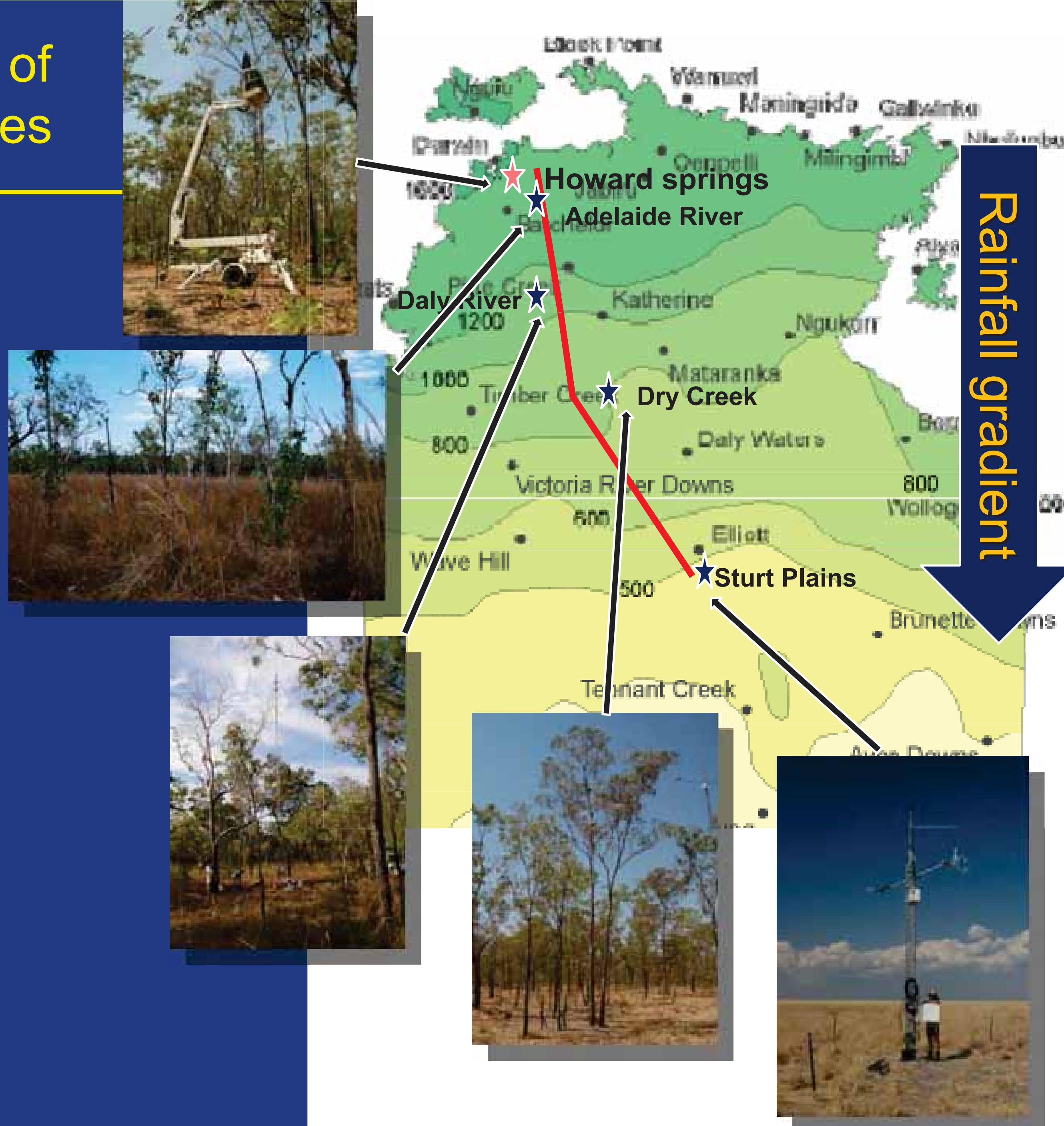


Overall Research approach

- Predict the responses of savannas to environmental change and provide options for sustainable ecosystem management at local to regional scales.
- Integrated multidisciplinary research program that will evaluate carbon and water budgets as indices of sustainable ecosystem services and health.

Observations and Processes: Flux towers, aircraft, satellite. Concentrations. Other trace gases. Land surface, land cover, vegetation properties, physical and biological variables. Transects and gradients

⇕

Models: SVAT, ecological, bioclimate, physiological, hydrological, biogeochemical. Net fluxes (comparisons tower). Response processes

Data Assimilation/Fusion: Assimilate diverse information

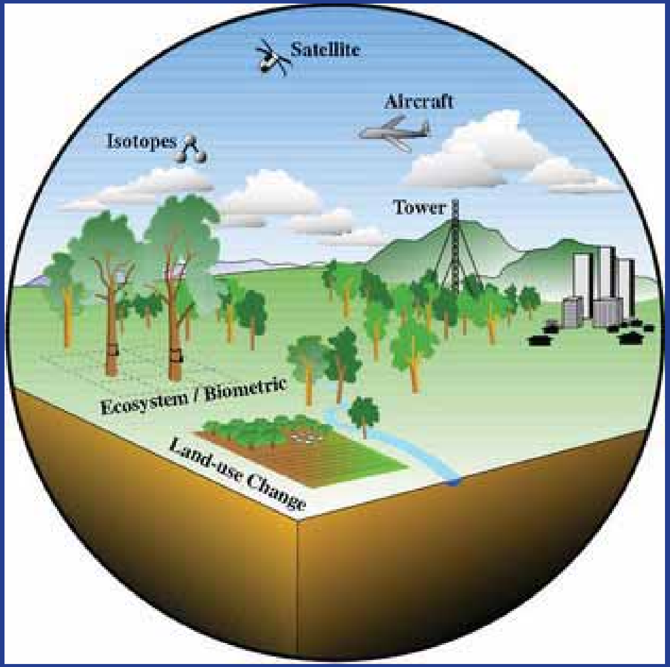
⇕ ⇕

Regional scaling: Carbon and water budgets using aircraft and regional models.

Ecosystem response to climate and human activities

⇕ ⇕

Predictive Models: Carbon and water source/sink projections, response to policy scenarios, verification of outcomes



http://www.arts.monash.edu.au/ges/research/climate/leapi/

Specific Objectives

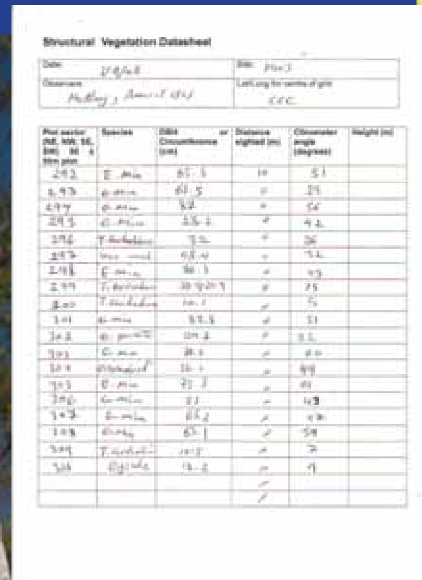
- What is the spatial variability of carbon, water and energy exchanges across important ecosystem types in the top-end and what are the key ecosystems characteristics that drive variability?
- Can fluxes of carbon, water and heat derived from different techniques be used to develop constrained estimates over the top-end
- Can a coupled mesoscale/carbon model replicate the spatial budgets
- How can we use remote sensing to inform models and regional budgets?

Measurement overview

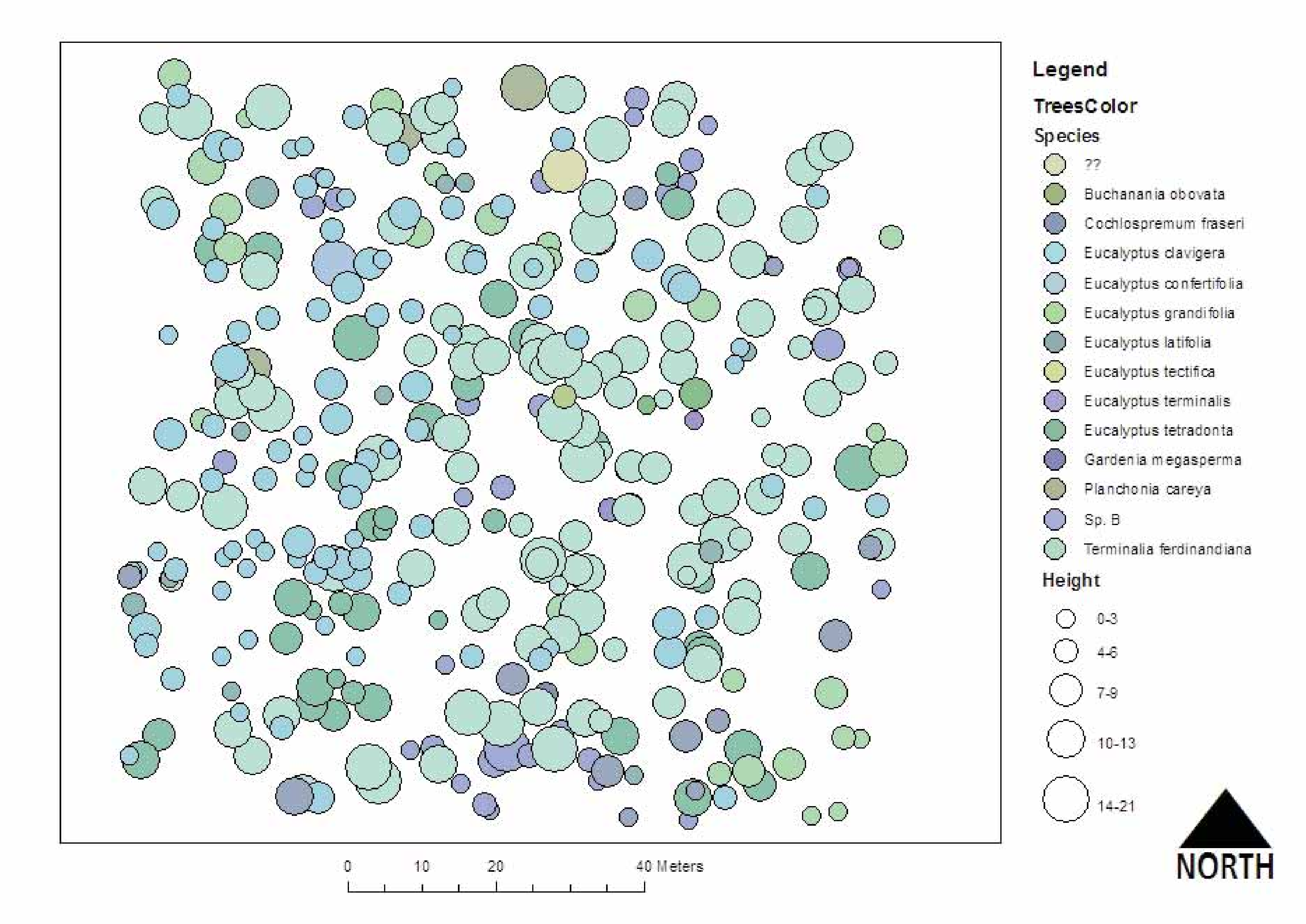
- Aircraft
  - Boundary layer
  - Flux transects (transects and grids)
  - RS transects
    - Lidar
    - Hyperspectral
    - PLMR (soil moisture)
- Ground based
  - Remote sensing (ASD, CWD, Cover, etc)
  - Structural (DBH, height, species, GPS)
  - Leaf water and leaf morphology
  - Leaf Area Index (LAI2000 and hemi photos)
  - Physiology (Aci and light use curves)
  - Soil water and physical properties
  - Biomass (live, dead, litter)
- Flux Tower Observations

Remote sensing (ASD, CWD, Cover, etc)

Structural (DBH, height, species, GPS)



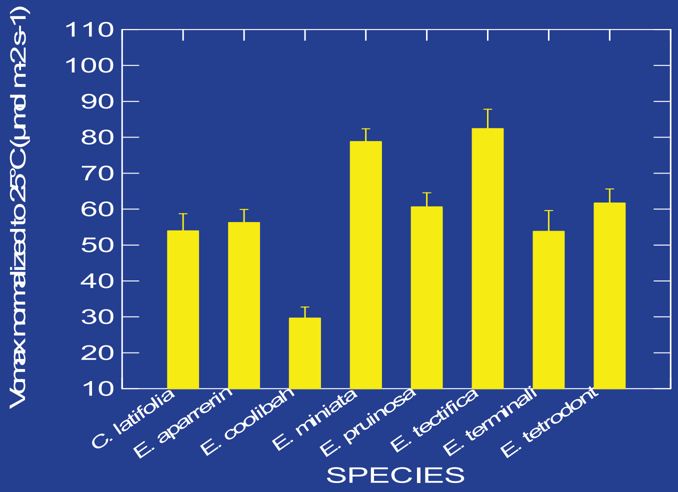
Structural (DBH, height, species, GPS)



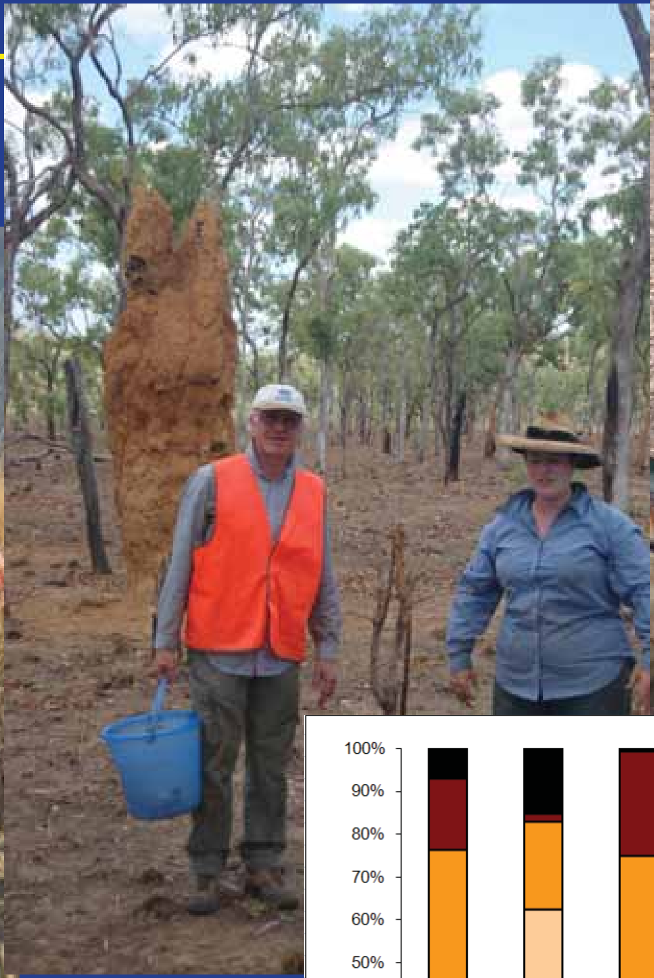
Leaf water and leaf morphology

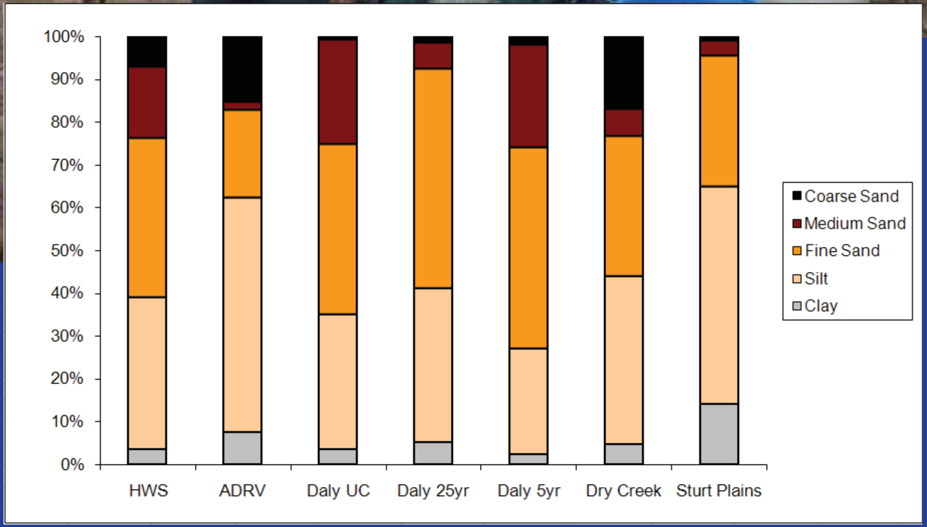
Leaf Area Index (LAI2000 and hemi photo

Physiology (Aci and light use curves)

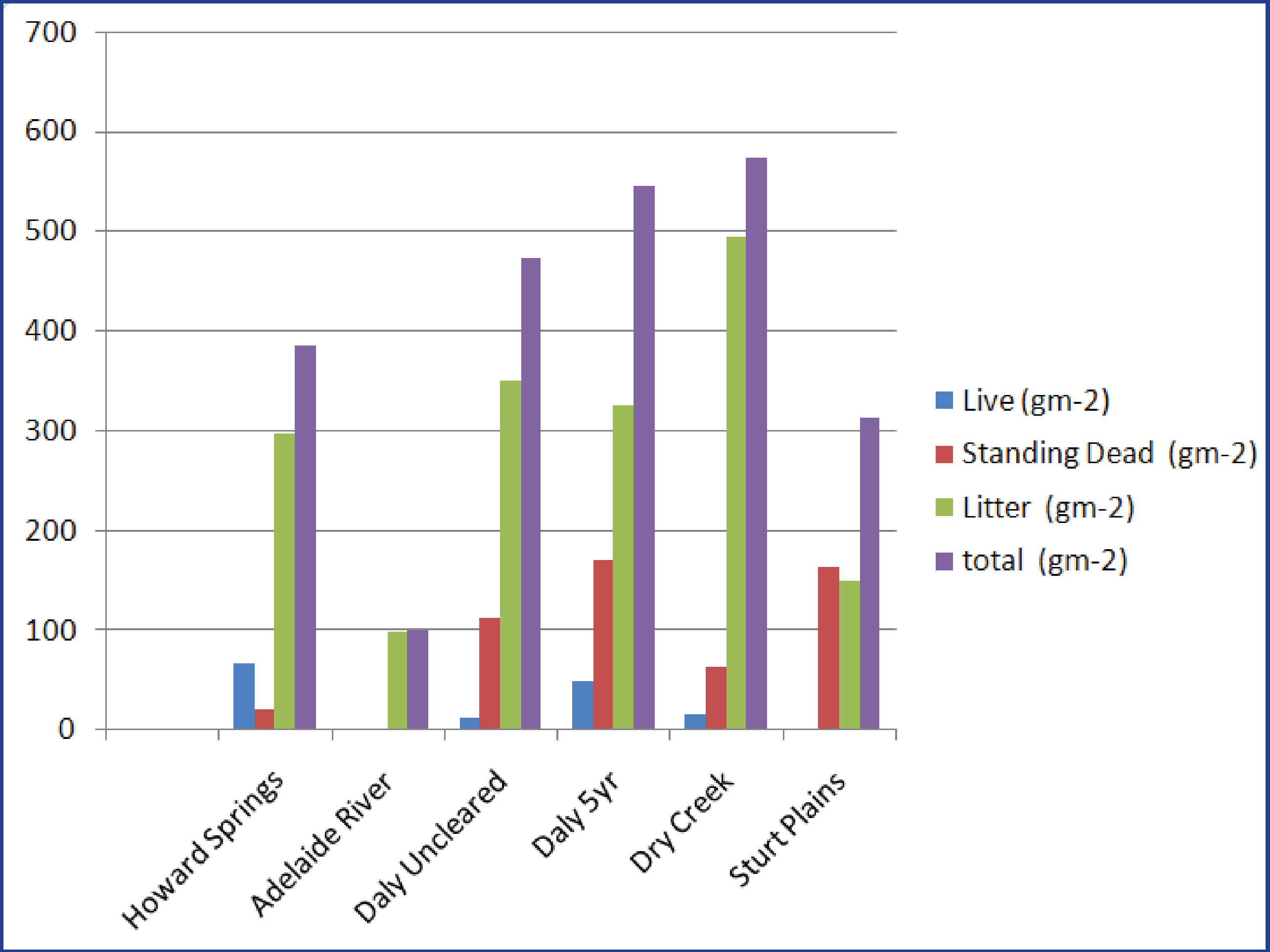


Soil water and physical properties





Biomass (live, dead, litter)



Acknowledgements

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Australian Research Council

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Flux Measurement Sites

Site	Latitude	Longitude	Comments
Howard Springs	-12.4942	131.1525	Savanna dominated by *Eucalyptus miniata* and *Erythrophleum chlorostachys*
Fogg Dam	12.559	131.307	Wetland
Adelaide River	-13.0769	131.1178	Savanna dominated by *Eucalyptus tectifica* and *Planchonia careya*
Daly Uncleared	-14.1592	131.3881	Savanna dominated by *Terminalia grandiflora* and *Eucaluptus tetradonta*
Daly 5yr	-14.1306	131.3828	Savanna 5 year old regrowth dominated by *Eucalyptus miniata* and *Eucalyptus tetradonta*
Daly 25yr	-14.0633	131.3181	Improved pasture
Dry Creek	-15.2588	132.3706	Savanna dominated by *Eucalyptus tetradonta*, *Eucalyptus terminalis* and *Eucalyptus dichromophloia*
Sturt Plains tower	-17.1508	133.3503	Tussock grassland
Sturt Plains shrubland			Shrubland dominated by *Eucalyptus pruinosa* and *Lysophylum cunninghamii*
Sturt Plains woodland	-17.1829	133.3526	dominated by *Acacia cowleana* and *Eucalyptus dichromophloia*

Howard Springs *(12.494S 131.153E)*

Site Summary: Howard Springs

Latitude: 12°29'39.12"S
Longitude: 131°09'09"E
Site dimensions: 1ha (5x5 grid of 20x20m boxes).
Description: Eucalypt open forest savanna with woollybutt, stringybark and a sorghum tall grass understory.
Species:
Eucalyptus miniata (212)
Erythrophleum chlorostachys (120)
Terminalia ferdinandiana (105)
Terminalia (61)
Eucalyptus tetradonta (53)
Eucalyptus terminalis (31)
Eucalyptus porrecta (23)
Cycad (19)
Corymbia bleeseri (18)
Eucalyptus clavigera (10)
Buchanania obovata (2)
Eucalyptus confertiflora (2)
Persosnia falcata (2)
Planchonia careya (2)
Livistona humilis (1)
Stem density: 661 stems/ha (total stems 684 stems/ha)
Basal area: 9.66 m^2/ha
Average tree height: 8.87m
LAI -
Total: 0.79
Overstorey: 0.60
Understorey: 0.19
Biomass Harvest -
mean live biomass: 66.25 gm^{-2} (standard error: 22.29)
mean standing dead biomass: 20.54 gm^{-2} (standard error: 8.34)
mean litter biomass: 297.75 gm^{-2} (standard error: 33.31)
total mean biomass: 384.54 gm^{-2} (standard error: 37.09)
Soil-
Clay: 4.10% (volume <1μm)
Silt: 37.90% (volume <1μm)
Sand: 57.93% (volume <1μm)
Sand (>1 μm): 7.45% (total weight)


Fogg Dam (12.559S 131.307E)
Daly River Uncleared
Daly River Syr
Dry Creek
Sturt Plains Woodland
Fogg Dam (wetland)
Lambells Lagoon
N
W
E
S
Image © 2006 NASA
© 2005 Google
Pointer 12°32'33.11" S 131°18'24.76" E elev 13 ft
Streaming |||||||||| 100%
Eye alt 10.02 mi




Adelaide River *(13.077S, 131.118E)*



Site Summary: Adelaide River

Latitude: 13°04’36.84”S
Longitude: 131°07’04.08”E

Site dimensions: 1ha (5x5 grid of 20x20m boxes).

Species:
Eucalyptus tectifica (114)
Planchonia careya (102)
Buchanania obovata (41)
Cochlospremum fraseri (2)
Eucalyptus clavigera (39)
Eucalyptus latifolia (31)
Sp. B (12)
Eucalyptus terminalis (11)
Eucalyptus confertifolia (4)
Terminalis ferdinandiana (2)
Eucalyptus grandifolia (1)
Eucalyptus tetradonta (1)
Gardenia megasperma (1)

Stem density: 365 stems/ha (total stems 457 stems/ha)

Basal area: 5.13 m^2/ha

Average tree height: 7.01m

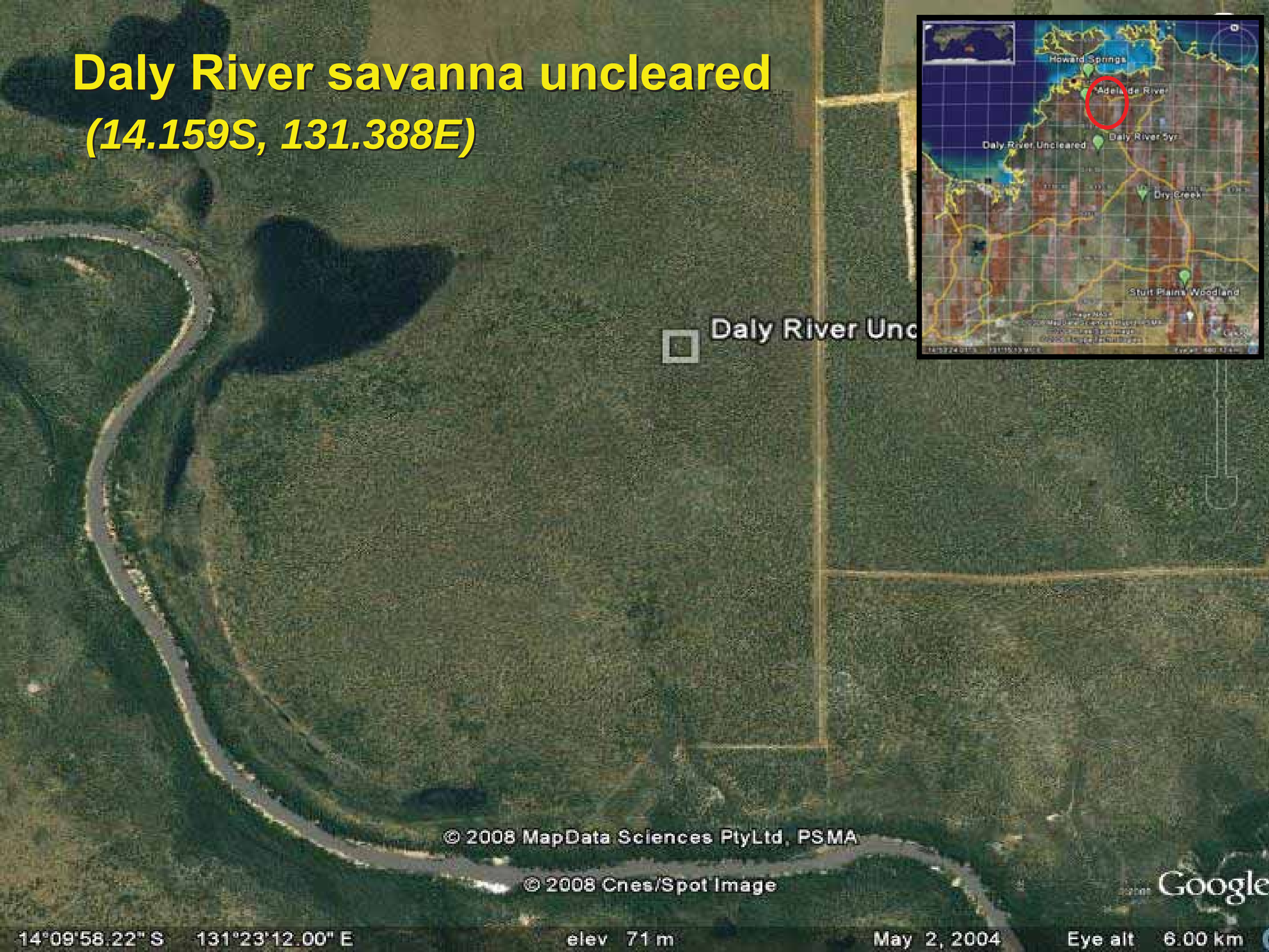
LAI-
Total: 0.75
Overstorey: 0.75

Biomass Harvest -
mean live biomass: 1.28 gm^{-2} (standard error: 0.76)
mean standing dead biomass: 0.00 gm^{-2} (standard error: 0.00)
mean litter biomass: 98.32 gm^{-2} (standard error: 42.15)
total mean biomass: 99.60 gm^{-2} (standard error: 42.11)

Soil-
Clay: 9.13% (volume <1μm)
Silt: 64.67% (volume <1μm)
Sand: 26.2% (volume <1μm)
Sand (>1 μm): 18.11% (total weight)

Daly River savanna uncleared

(14.159S, 131.388E)





Site Summary: Daly River Uncleared

Latitude: 14°09'33.12"S
Longitude: 131°23'17.16"E
Description: Eucalypt woodland/grassland savanna
Site dimensions: 1ha (5x5 grid of 20x20m boxes).
Species: *Terminalia grandiflora* (94)
Eucalyptus tetradonta (47)
Eucalyptus latifolia (18)
Erythrophleum chlorostachys (29)
Planchonia careya (14)
Eucalyptus miniata (12)
Petalostigma pubescens (8)
Petalostigma (6)
Brachychiton paradoxium (5)
Buchanania obovata (5)
Owenia vermicosa (4)
Brachychiton diversifolia (3)
Pandanus spiralus (2)
Ficus oposita (1)
Lysophylum cunninghamii (1)
Persosnia falcata (1)
Dead stems (41)
Stem density: 292 stems/ha (total stems 330 stems/ha)
Basal area: 9.38 m^2/ha
Average tree height: 8.23m
LAI- **Total:** 0.72
Overstorey: 0.41
Understorey: 0.31
Biomass Harvest - **mean live biomass:** 11.21 gm^{-2} (standard error: 4.13)
mean standing dead biomass: 113.26 gm^{-2} (standard error: 16.52)
mean litter biomass: 349.32 gm^{-2} (standard error: 32.93)
total mean biomass: 473.79 gm^{-2} (standard error: 35.06)
Soil- **Clay:** 3.63% (volume <1μm)
Silt: 31.34% (volume <1μm)
Sand: 63.46% (volume <1μm)
Sand (>1 μm): 0.79% (total weight)

Daly River savanna 5yo cleared

(14°07’50.16”S, 131°22’58.08”E)

Daly River savanna 5yo cleared

Site Summary: Daly River Uncleared

Latitude: **14°07'50.16"S**
Longitude: **131°22'58.08"E**

Site dimensions: 1ha (5x5 grid of 20x20m boxes).

Species:
Eucalyptus miniata (162)
Eucalyptus tetradonta (113)
Petalostigma pubescens (49)
Terminalia grandiflora (28)
Planchonia careya (24)
Denhamia obscura (16)
Buchanania obovata (4)
Erythrophleum chlorostachys (2)
Ficus oposita (2)
Persosnia falcata (1)
Terminalia ferdinandiana (1)
Dead stems (4)

Stem density: 410 stems/ha (total stems 992 stems/ha)
Basal area: 1.26 m^2/ha
Average tree height: 3.31 m

LAI-
Total: 0.34
Overstorey: 0.30
Understorey: 0.05

Biomass Harvest -
mean live biomass: 49.33 gm^{-2} (standard error: 18.35)
mean standing dead biomass: 171.09 gm^{-2} (standard error: 59.25)
mean litter biomass: 325.19 gm^{-2} (standard error: 39.94)
total mean biomass: 545.61 gm^{-2} (standard error: 99.02)

Soil-
Clay: 2.7% (volume <1µm)
Silt: 27.57% (volume <1µm)
Sand: 78.9% (volume <1µm)
Sand (>1 µm): 2.03% (total weight)

Daly 25 yr cleared

Dry Creek

(15°15’31.62” , 132°22’14.04”E)

Site Summary: Dry Creek

Latitude: 15°15'31.62"S
Longitude: 132°22'14.04"E

Site dimensions: 1ha (5x5 grid of 20x20m boxes).

Species:
Eucalyptus tetradonta (182)
Eucalyptus terminalis (177)
Eucalyptus dichromophloia (125)
Eucalyptus miniata (41)
Sp. A (16)
Gardenia megasperma (11)
Planchonia careya (16)
Acacia cowleana (8)
Sp. B (2)
Sp. C (1)
Dead stems (3)

Stem density: 582 stems/ha (total stems 709 stems/ha)
Basal area: 5.42 m^2/ha
Average tree height: 6.12 m

LAI-
Total: 0.52
Overstorey: 0.48
Understorey: 0.04

Biomass Harvest -
mean live biomass: 14.9 gm^{-2} (standard error: 7.24)
mean standing dead biomass: 64.03 gm^{-2} (standard error: 14.52)
mean litter biomass: 494.62 gm^{-2} (standard error: 61.17)
total mean biomass: 573.55 gm^{-2} (standard error: 66.65)

Soil-
Clay: 5.74% (volume <1μm)
Silt: 47.42% (volume <1μm)
Sand: 46.83% (volume <1μm)
Sand (>1 μm): 20.31% (total weight)



Sturt Plains Grassland Tower

(17°09’2.76”S, 133°21’1.14”E)

Sturt Plains Grassland Tower

Site Summary: Sturt Plains Grassland Tower

Latitude: 17°09’2.76”S
Longitude: 133°21’1.14”E

Site dimensions: no grid

Species: Mitchell grass (genus *Astrebla*)

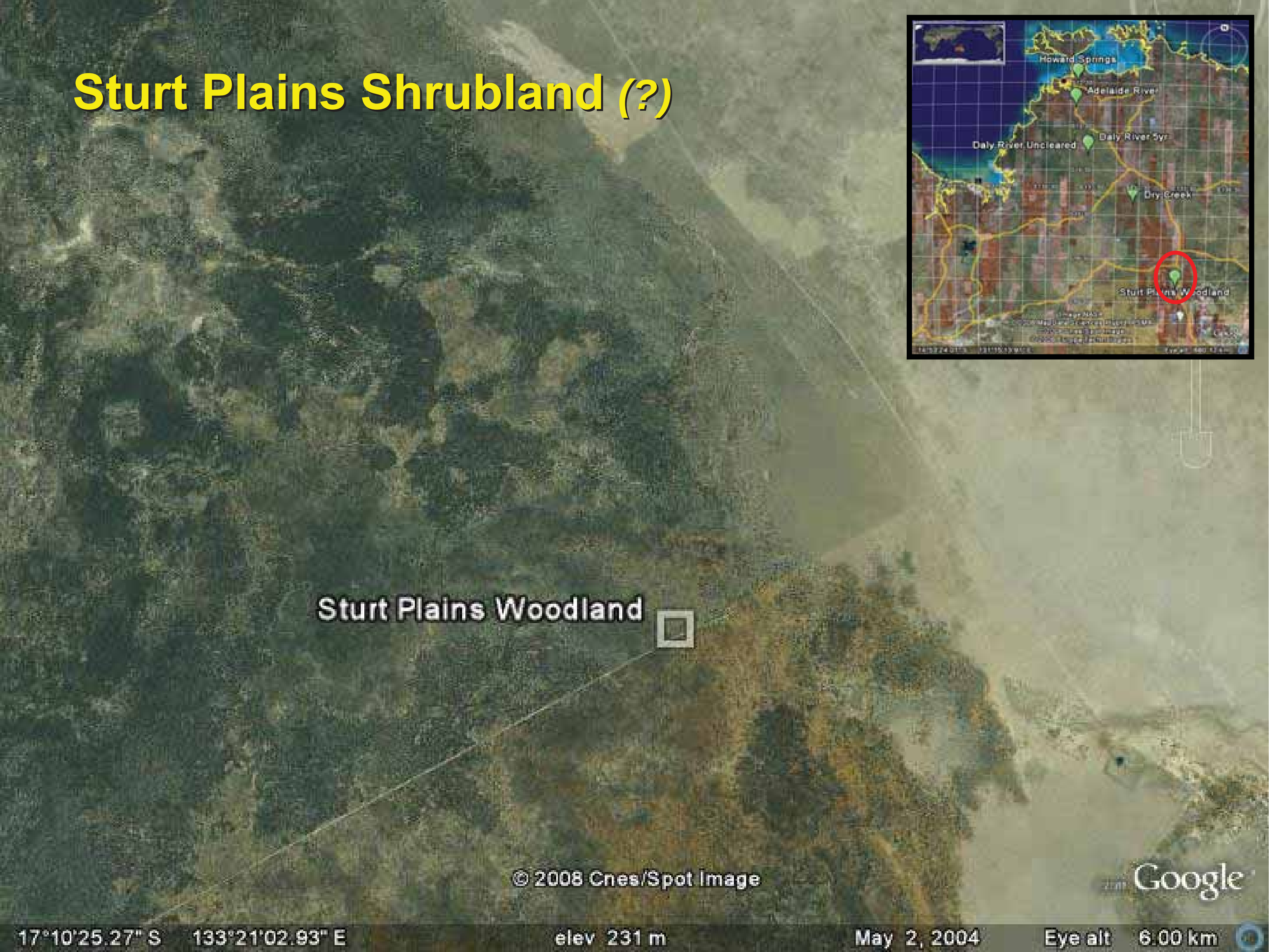
Biomass Harvest -

mean live biomass: 0.00 gm^{-2} (standard error: 0.00)
mean standing dead biomass: 163.42 gm^{-2} (standard error: 16.73)
mean litter biomass: 148.99 gm^{-2} (standard error: 21.32)
total mean biomass: 312.40 gm^{-2} (standard error: 30.80)

Soil-

Clay: 14.47% (volume <1μm)
Silt: 51.23% (volume <1μm)
Sand: 34.30% (volume <1μm)
Sand (>1 μm): 1.02% (total weight)

Sturt Plains Shrubland *(?)*




Sturt Plains Shrubland

Site Summary: Sturt Plains Shrubland

Latitude:
Longitude:

Site dimensions: 4/25 ha (2x2 grid of 20x20m boxes).

Species:
Eucalyptus pruinosa (14)
Lysophylum cunninghamii (10)
Acacia holicericia (3)
Acacia lysopholia (3)
L. Bush (3)
Wrightia saligna (2)
Ghostgum (1)
Dead stems (22)

Stem density: 362.5 stems/ha (total stems 1625 stems/ha)

Basal area: 4.86 m^2/ha

Average tree height: 3.74 m

Sturt Plains Woodland

(17°10’58.53”S, 133°21’09.39”E)

Site Summary: Sturt Plains Woodland

Latitude: 17°10’58.53”S
Longitude: 133°21’09.39”E

Site dimensions: 4/25 ha (2x2 grid of 20x20m boxes).

Species:
Acacia cowleana (27)
Eucalyptus dichromophloia (18)
Eucalyptus ferruginia (15)
Eucalyptus chlorostachys (6)
Lysophylum cunninghamii (4)

Stem density: 427.5 stems/ha (total stems 675 stems/ha)

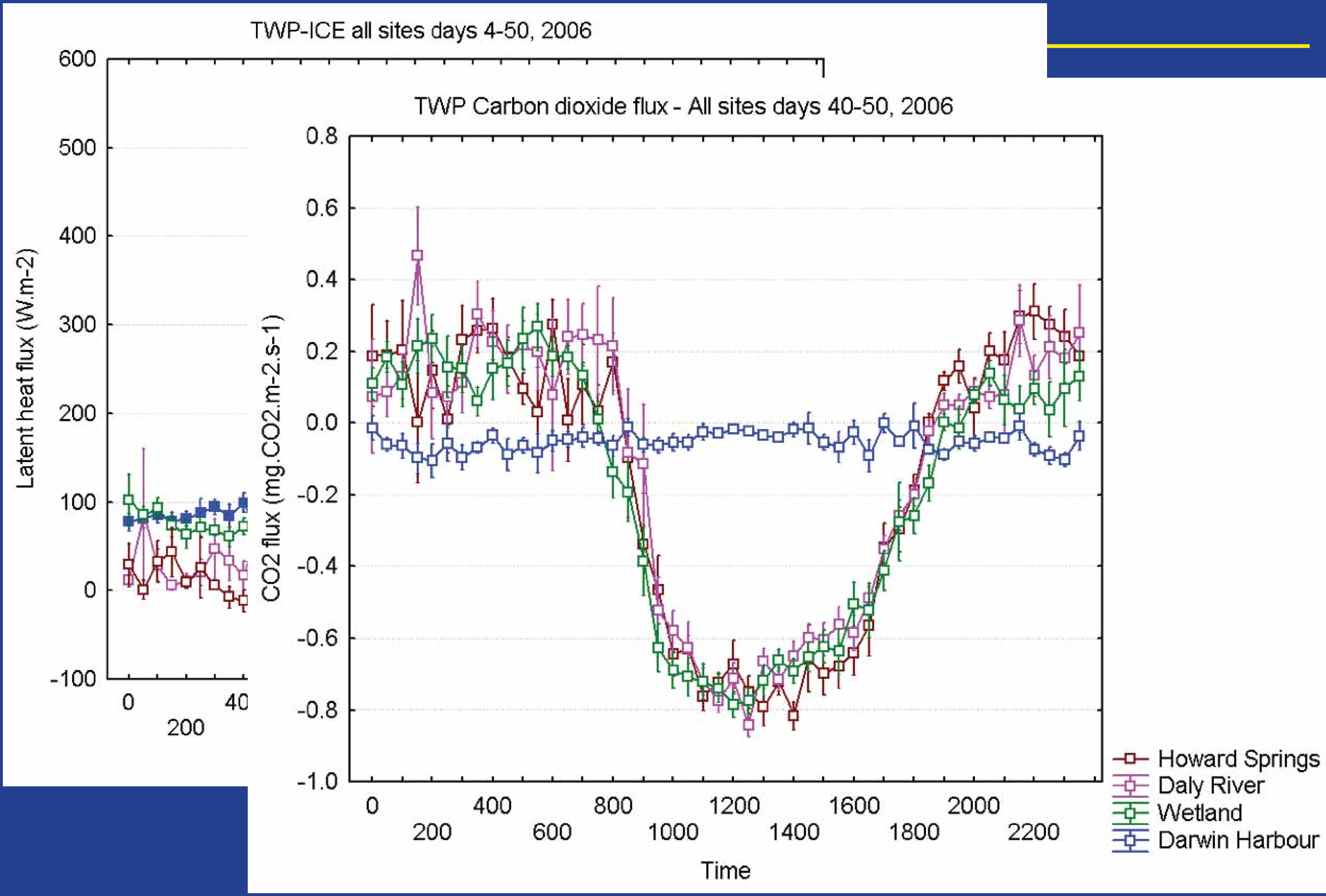
Basal area: 5.19 m^2/ha

Average tree height: 5.87 m

Sturt Plains - Woodland

Darwin Harbor *(12.499S 130.886E)*

Preliminary data

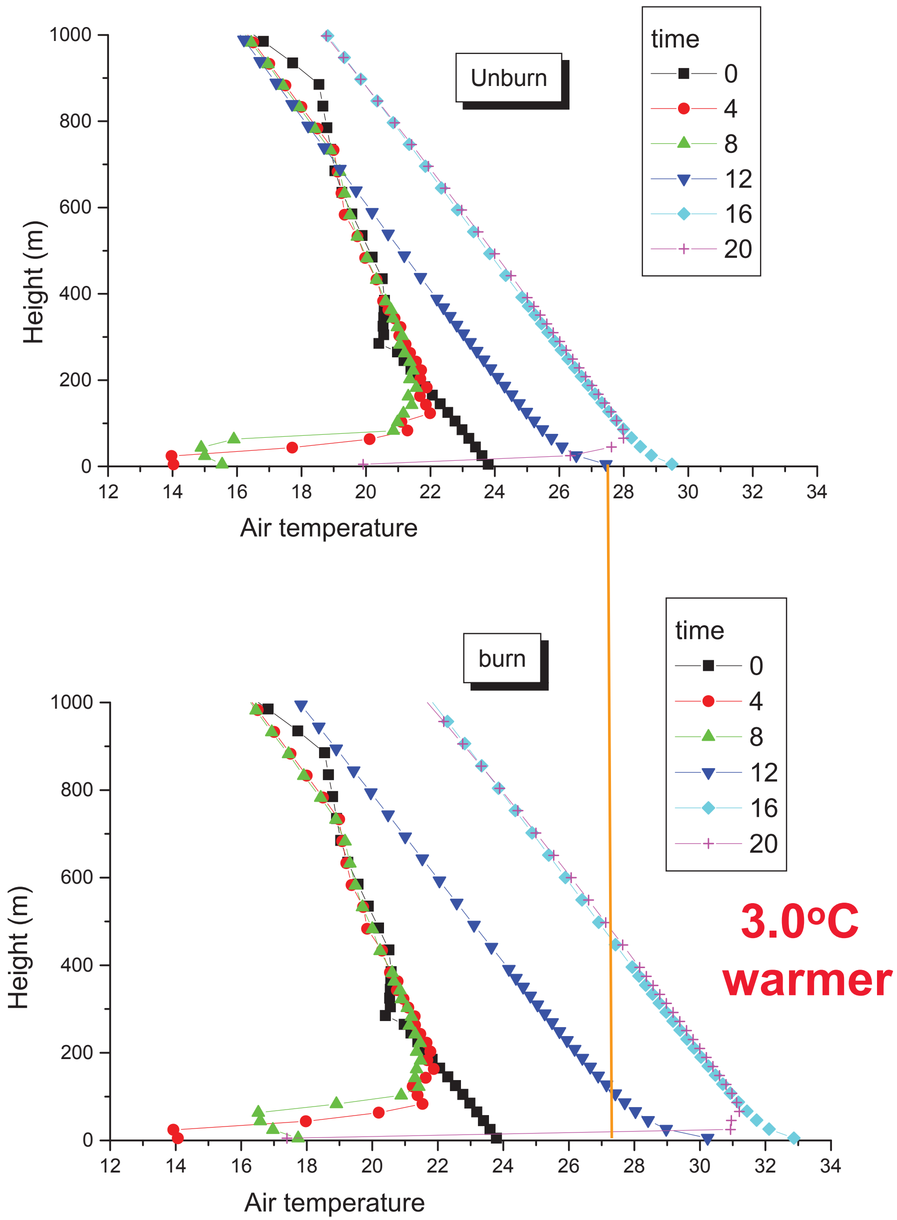


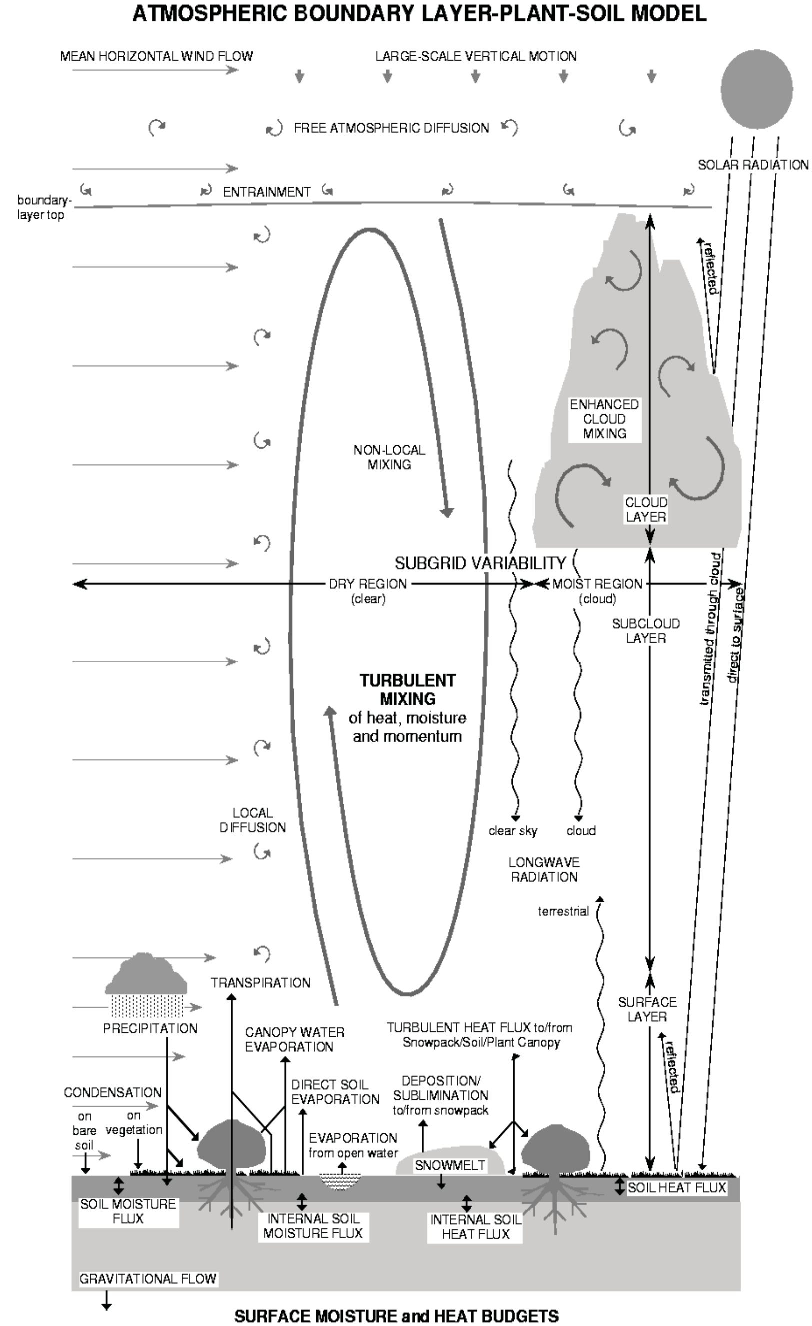
Ongoing Projects

- Tropical savanna carbon budgets
- GPP and role of smoke aerosols
- Daly River Catchment water balance
- Flux inhomogeneity (Fluxtower, aircraft, etc.)
- Remote sensing (carbon and water)
- Ecosystem/Land surface modeling (CABLE, ACASA, LPJ)
- Regional carbon/water modeling
- Isotopes
- Trace gas measurements (auto chambers / EC)

- Opportunities for collaboration? (SMOZ, FRE and savanna fire emissions etc?)

OSU Boundary Layer Model





Mahrt and Ek

http://blg.coas.oregonstate.edu/1.d.model/

Influence of landscape scale fires on the region

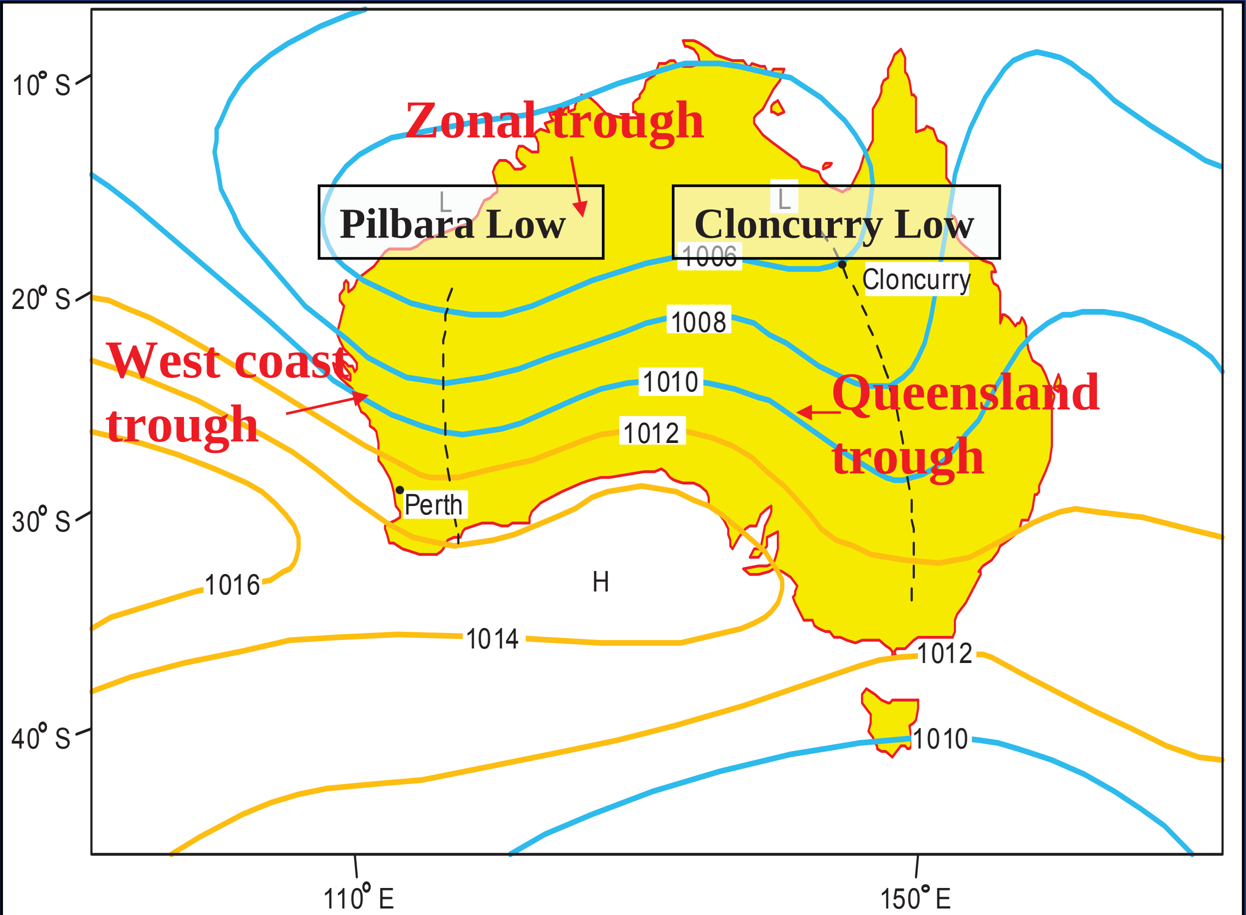


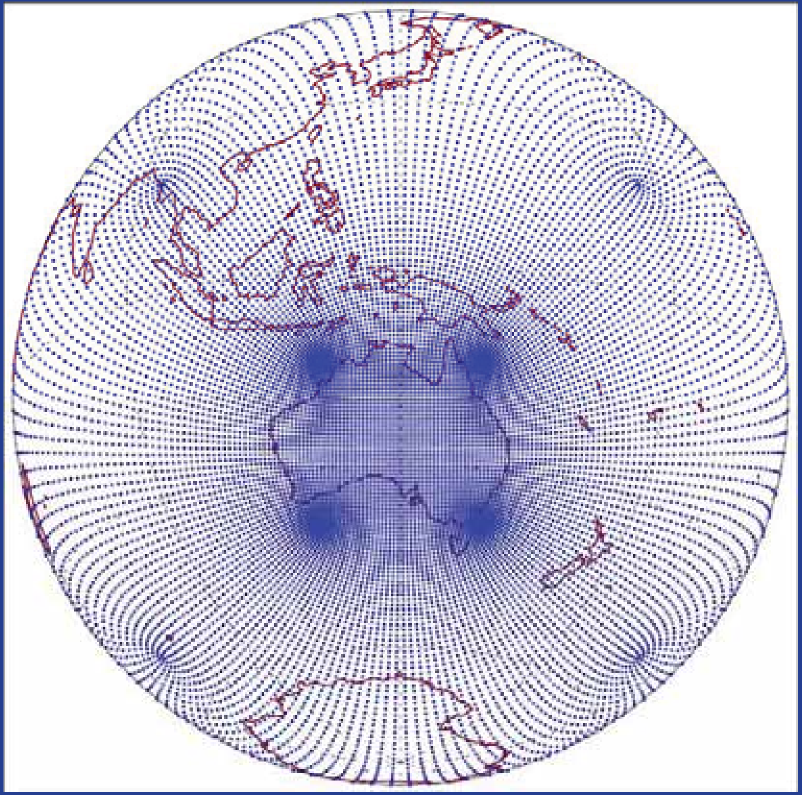
Figure 7.32 Ten-year average of the January 0000 UTC mean sea-level pressure field across Australia. The positions of the east and west coast troughs are indicated (after Fandry & Leslie 1984).

Sturman and Tapper (2005)

- Given fires cover 30% of landscape could this influence regional climate
- Heat-lows and linking of the troughs drives ITCZ onto continent
- Fire on large scales could have an influence

Global climate modelling

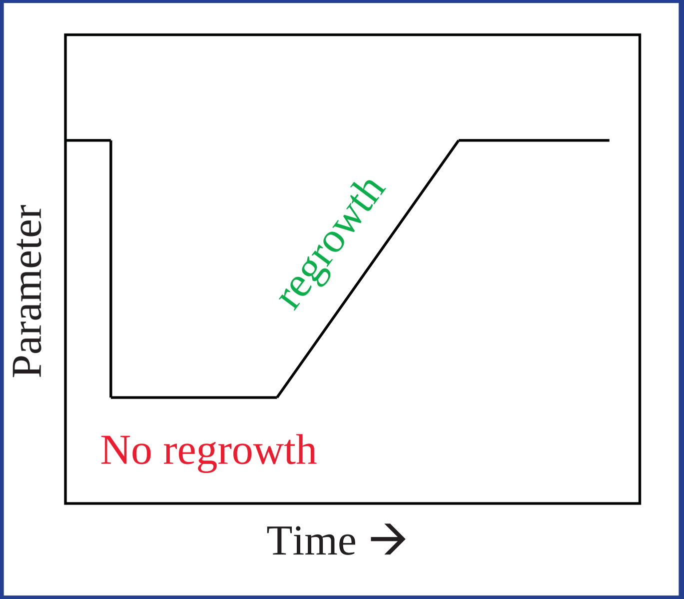
- CCAM: Conformal cubic atmosphere model, CSIRO
- 60 km spatial resolution over Australia
- Far-field nudging: winds, sea surface temperature
- Implemented fire and regrowth scheme
- Ran model from 1979-1999



Görgen K., et al. (2006)

C-CAM Fire / Re-Growth Scheme

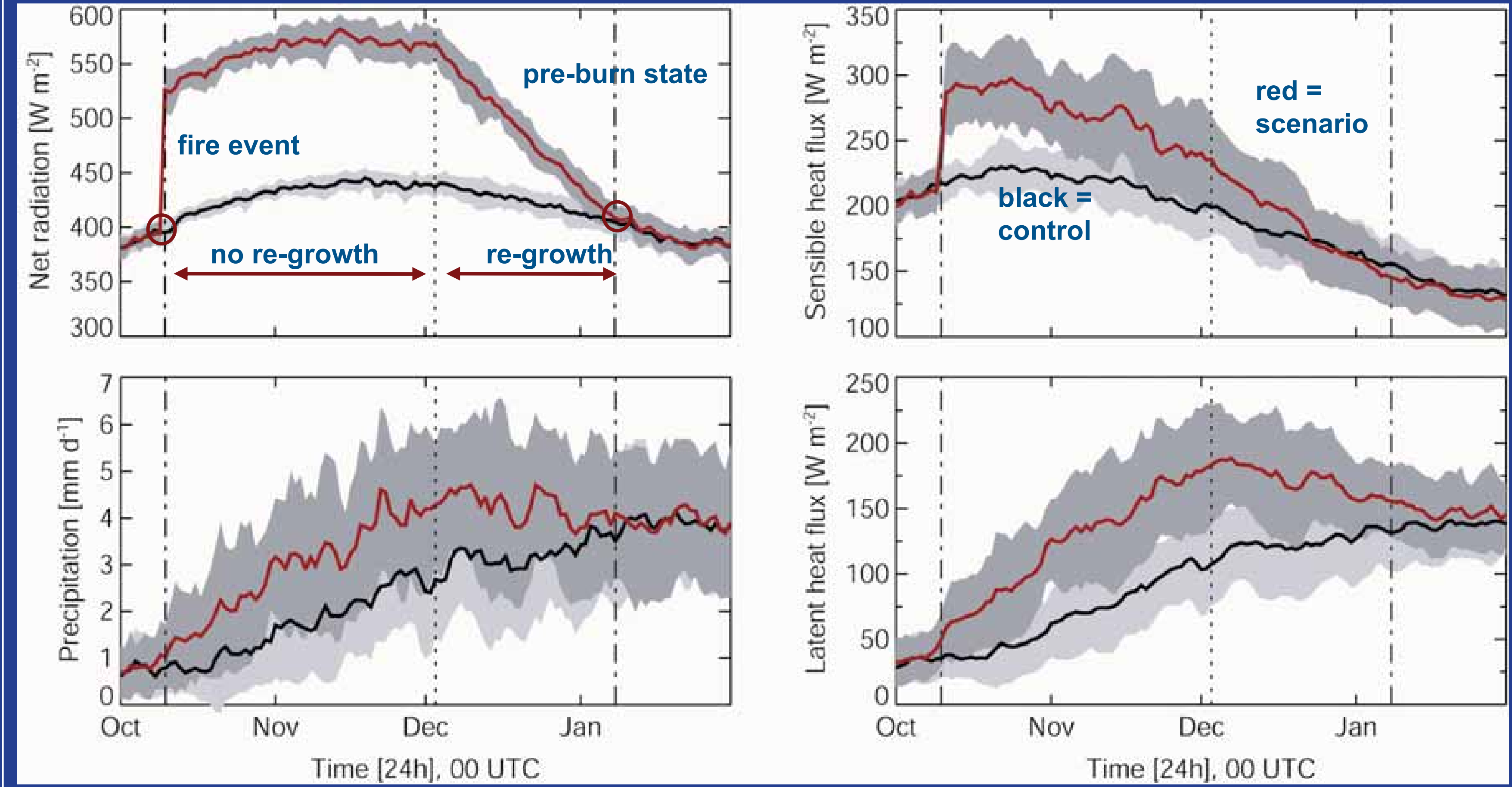
- Fire / re-growth implementation: abrupt changes in pre- scribed temporal evolution of vegetation properties by forcing perturbations
  Intensity, area, timing, length of re-growth period
- C-CAM variables modified by fire intensity
  Leaf area index, albedo, roughness length, vegetation coverage
- Re-growth described via non-linear function, back to vegetation state in seasonal cycle without fires
- Constrained setup
  - Fire event (80% area burnt and 80% intensity, 2 months no-regrowth, 1 month regrowth)
  - No fire-vegetation feedbacks
  - Constant forcing perturbations and yearly fires per experiment



Climatological Impacts Single Scenario, Regional Impacts

Longterm (1979 to 1999) means, averaged over fire-affected area

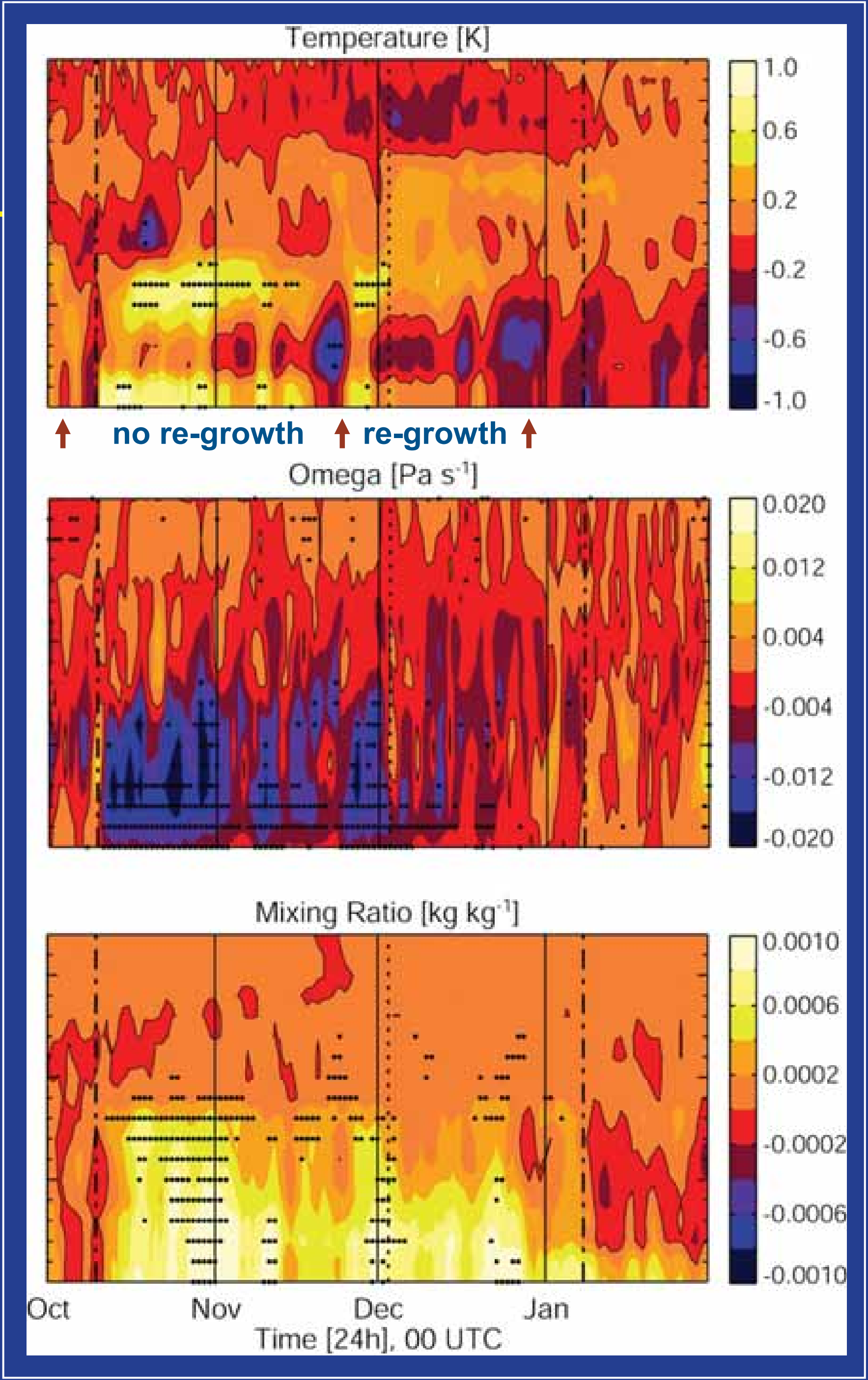
Scenario: intensity=80%, area=80%, timing=10 October, re-growth length=90 d



(Görgen et al. 2006)

Regional Impacts

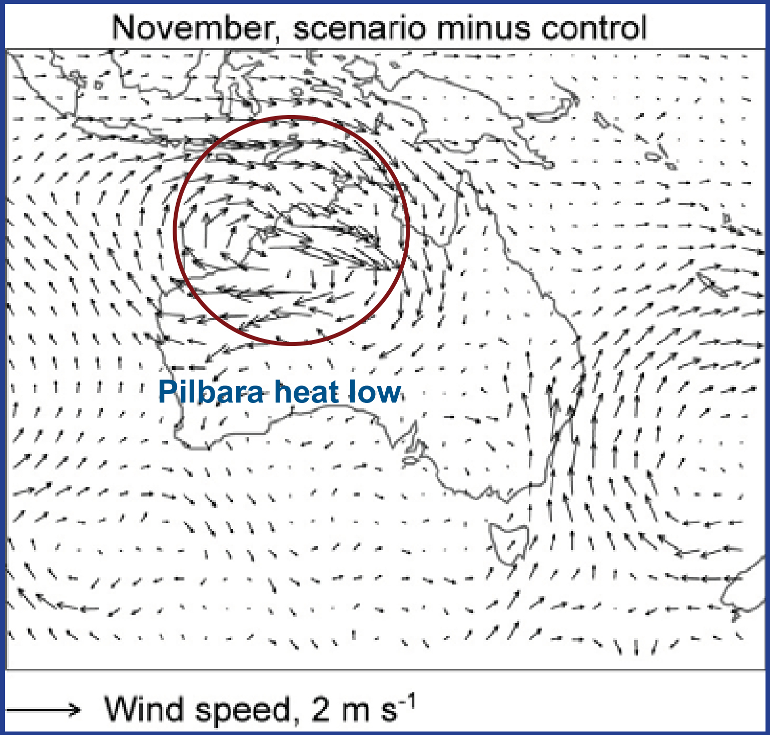
- Main impacts
  - Overall intensification of boundary layer processes
  - Increased sensible and latent heat fluxes
  - Stronger convection
  - Increased precipitation, which in a positive feedback loop further enhances this process



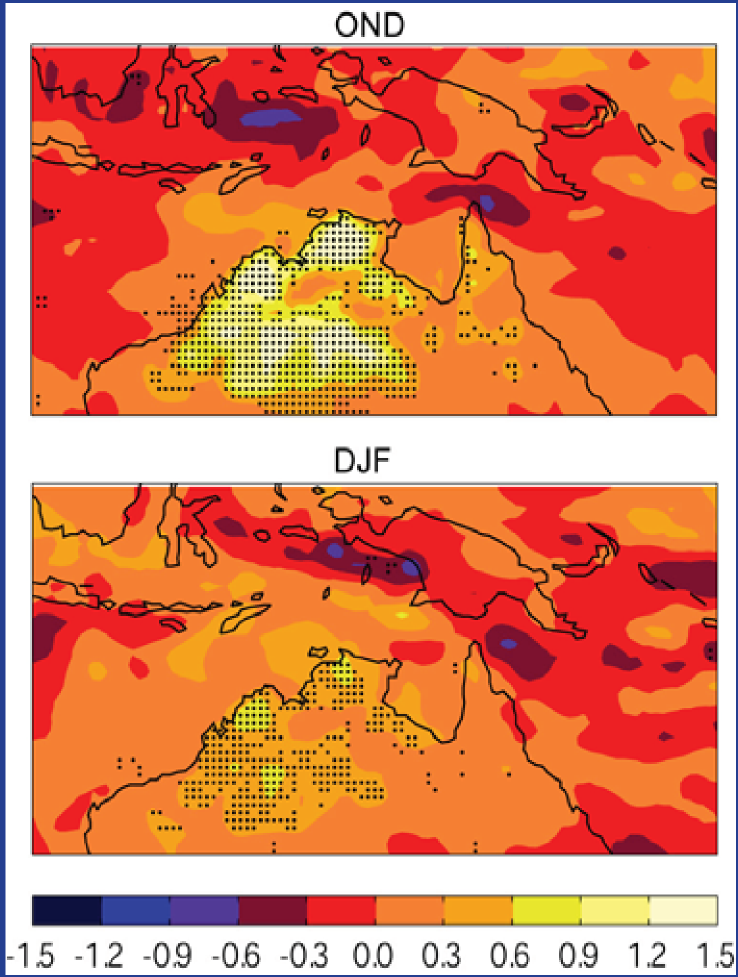
Scenario minus control, vertical profiles of longterm means

Continent-Wide Impacts

Scenario minus control, longterm 850 hPa wind fields



Scenario minus control, longterm mean precipitation [mm d^{-1}]



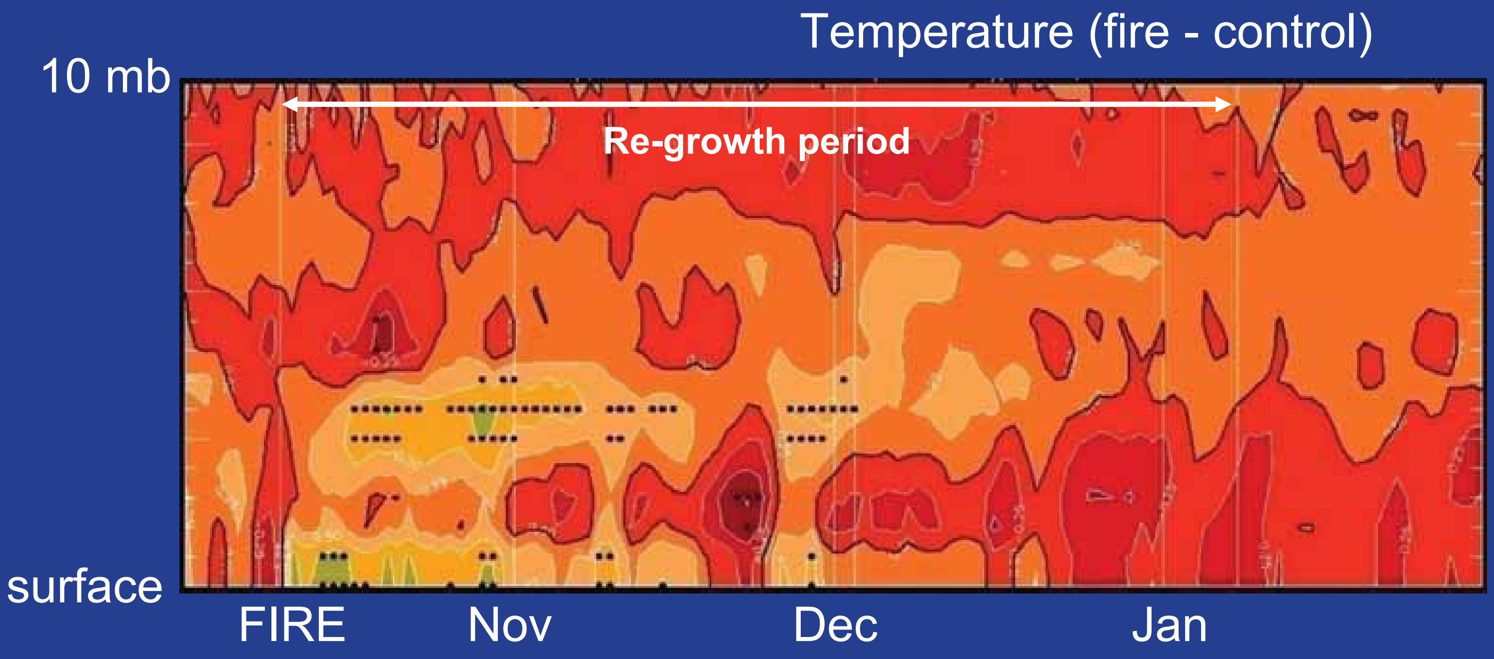
- Intensification of heat low
- Significant precip. increase

Conclusions

- Step change in albedo, energy and carbon fluxes after fire
- Demonstrated influence on Boundary Layer
- Burning on large scales may influence regional climate by strengthening heat low and strengthening the monsoon
- Next sensitivity study to look at 90 realizations of the same run varying parameters.
- Generate reduced statistical model
- Part of the equation for sustainable fire management practices

Fire / re-growth sensitivity test

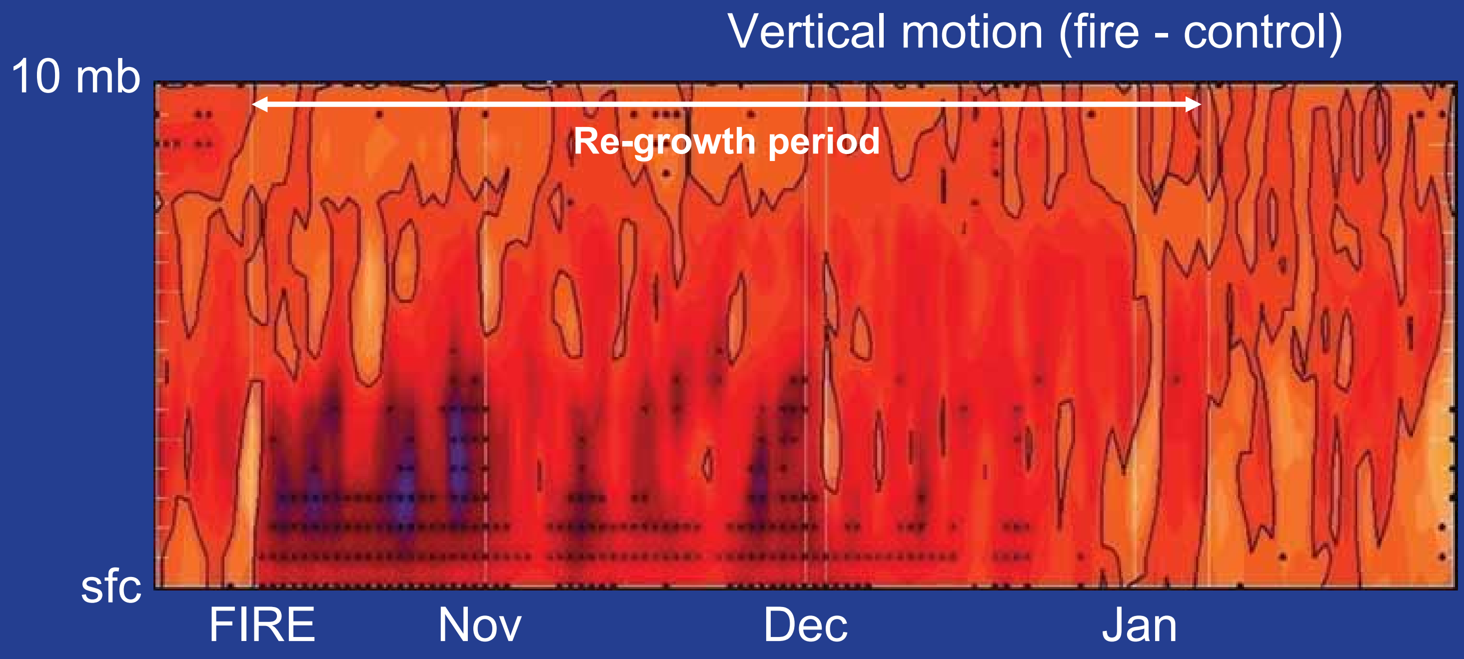
Boundary layer penetration of impacts
(1979-1999 means, dots indicate significant at 90%)



Görgen K., et al. (2006)

Fire / re-growth sensitivity test

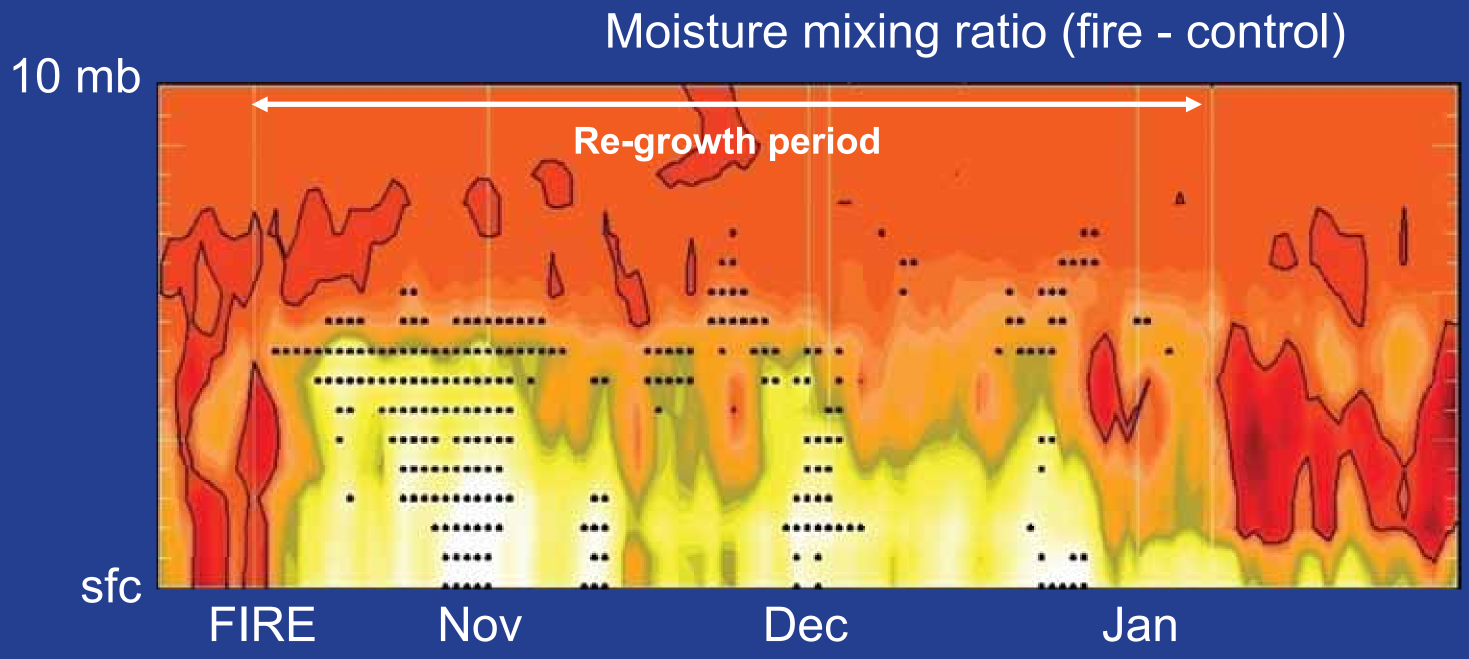
Boundary layer penetration of impacts
(1979-1999 means, dots indicate significant at 90%)



Görgen K., et al. (2006)

Fire / re-growth sensitivity test

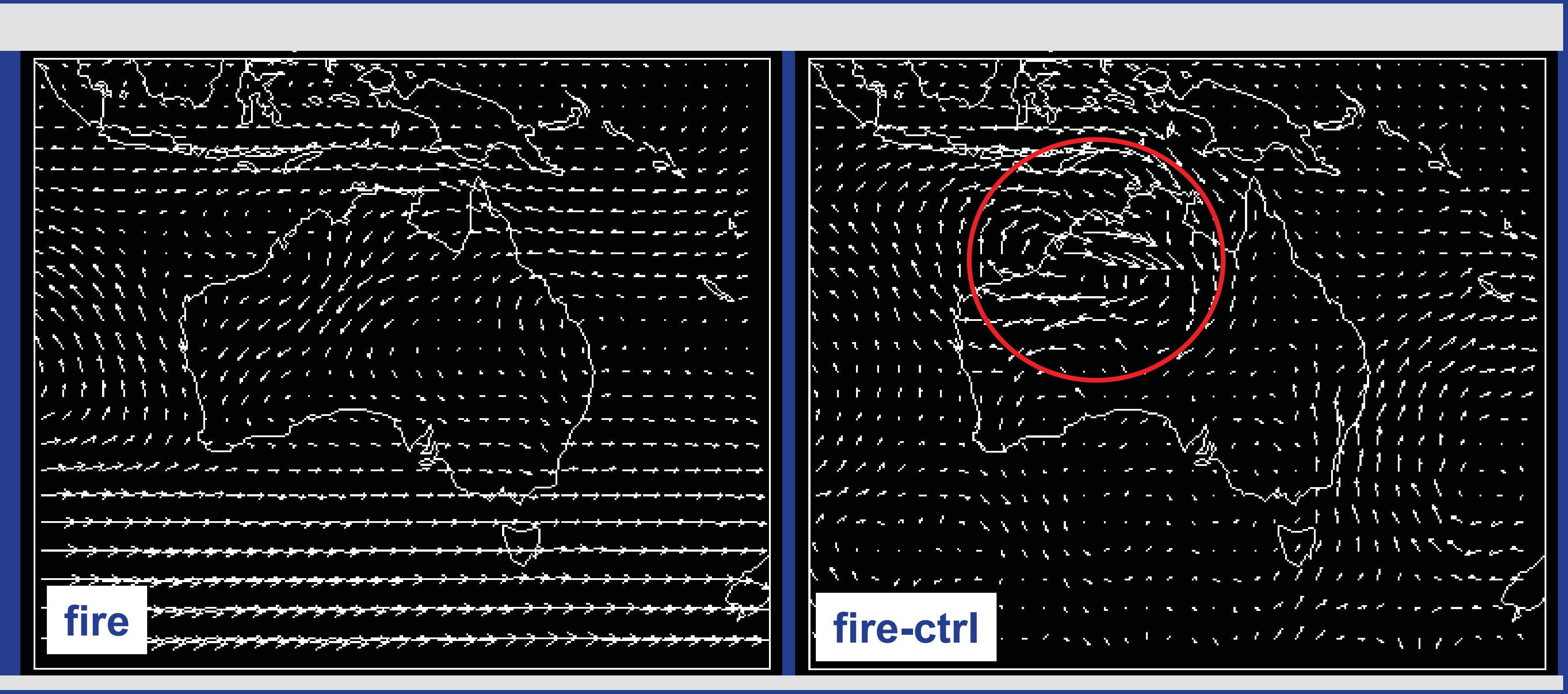
Boundary layer penetration of impacts
(1979-1999 means, dots indicate significant at 90%)



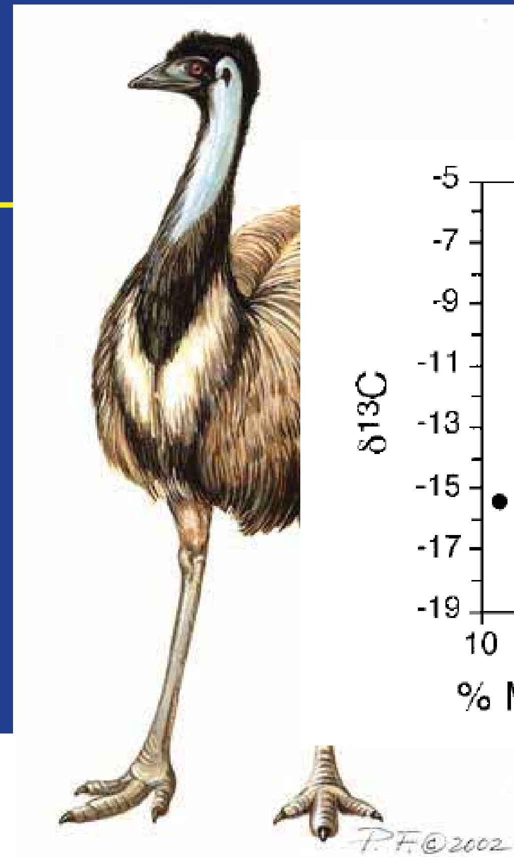
Görgen K., et al. (2006)

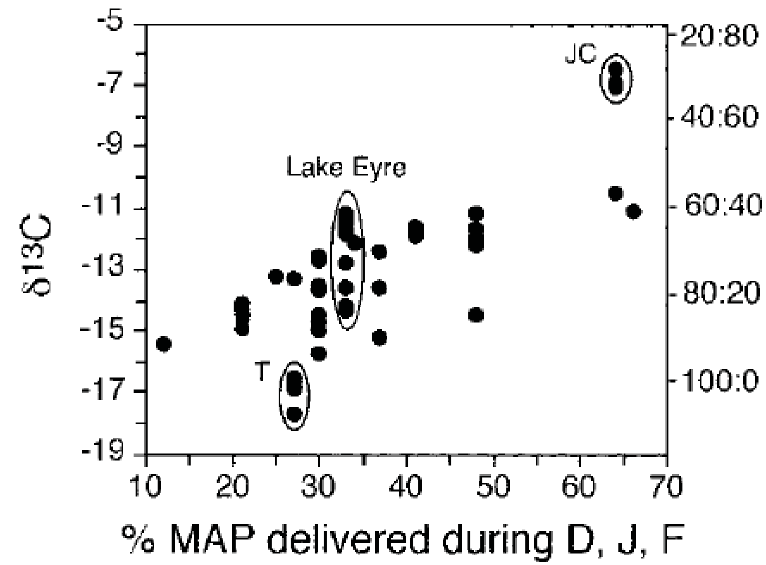
Fire / re-growth sensitivity test

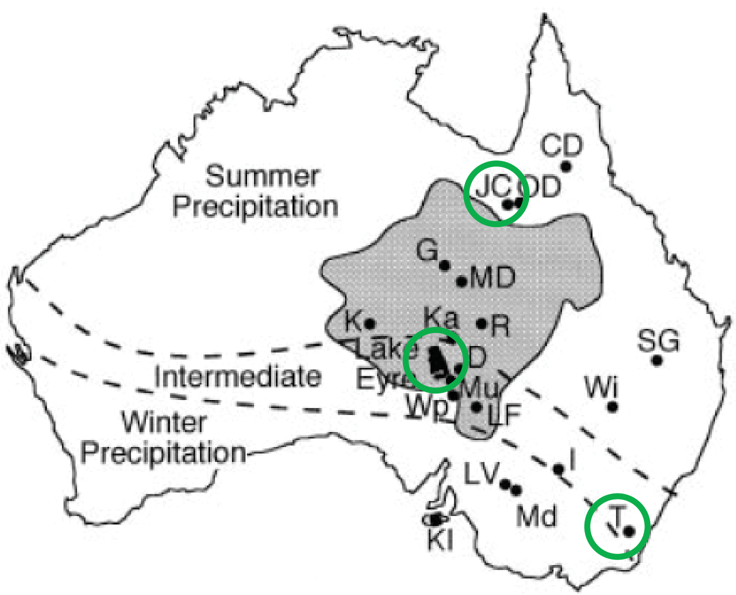
Circulation shift in November (850 mb): strongest easterlies and ITCZ shifted south



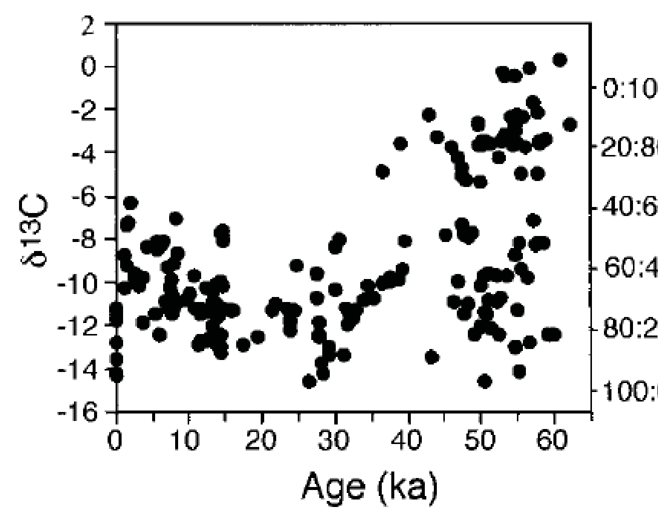
Görgen K., et al. (2006)


P.F.©2002


JC
Lake Eyre
T
δ13C
% MAP delivered during D, J, F
-5
-7
-9
-11
-13
-15
-17
-19
10
20
30
40
50
60
70
20:80
40:60
60:40
80:20
100:0


CD
JC
DD
Summer Precipitation
G
MD
K
Ka
R
Lake Eyre
D
SG
Intermediate
Mu
Wi
Wp
LF
Winter Precipitation
I
LV
Md
T
KI


1
2
3
4
5

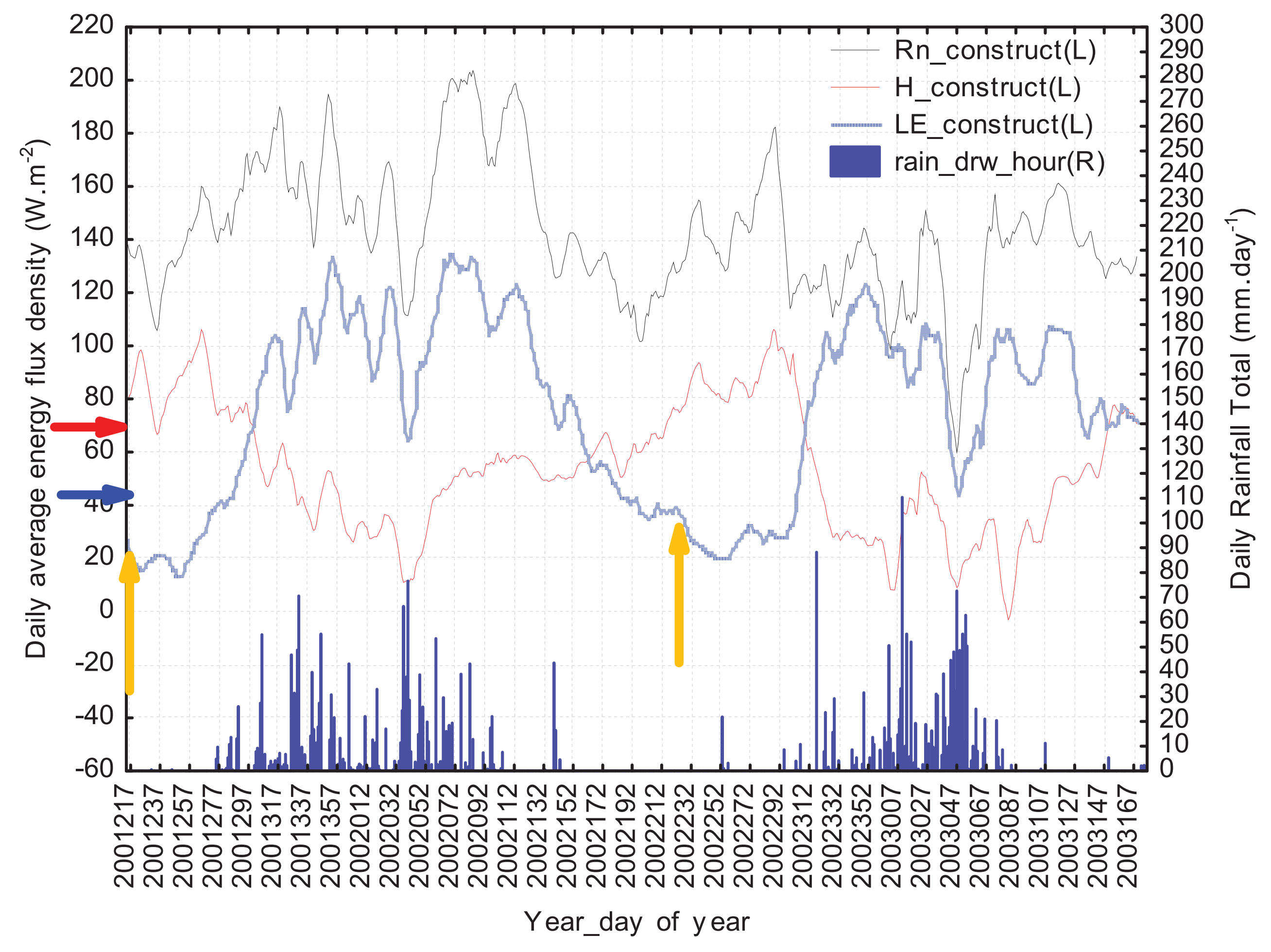

δ13C
Age (ka)
2
0
-2
-4
-6
-8
-10
-12
-14
-16
0
10
20
30
40
50
60
0:100
20:80
40:60
60:40
80:20
100:0

Annual Energy Fluxes

Year 2001-2002
Rainfall 1699 $mm.year^{-1}$
Total ET 978 $mm.year^{-1}$

Year 2002-2003
Rainfall 1486.8 $mm.year^{-1}$
Total ET 892 $mm.year^{-1}$

- Step change in fluxes following fire
- Strong seasonal changes



References

- Johnson, B.J. et al., 1999. 65 000 years of vegetation change in Central Australia and the Australian Summer Monsoon. Science, 248: 1150-1152.
- Beringer, J. et al., 2003. Fire impacts on surface heat, moisture and carbon fluxes from a tropical savanna in north Australia. International Journal of Wildland Fire, 12: 333-340.

Net Biome Productivity

- Measurements indicate net sink of -0.7 and -2.6 $tC.ha^{-1}.yr^{-1}$ for each annual period.
- But fire results in emission of ~+1.5 and +2.9 $tC.ha^{-1}.yr^{-1}$ based on fuel loads
- NEP for year including fire ~ +0.8 and + 0.3 $tC.ha^{-1}.yr^{-1}$.
- True NBP ?

Summary results

	2001-2002	2002-2003	Inventory	Eamus et al.
Re	+16.1	+15.6	+17	
GPP	-16.8	-18.0	-20.8	
NEP	-0.7 *	-2.6 *	-3.8	-2.8
Fire losses	+1.5	+2.9	~+1.5	
NEP-fire	+0.8	+0.3	-2.3	
NBP				

-0.6

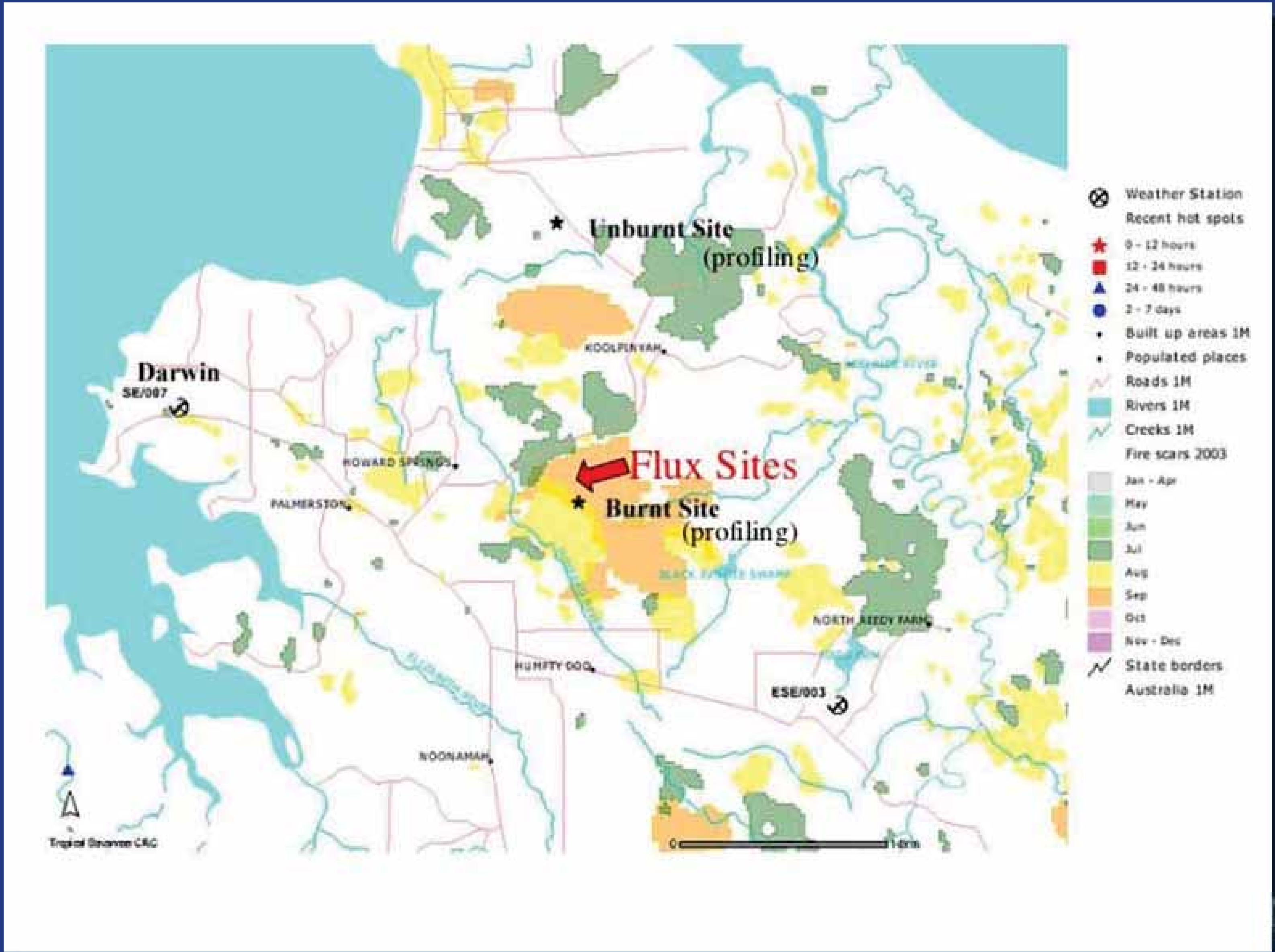
* Includes impacts of a fire event in that year excluding emissions

Future work

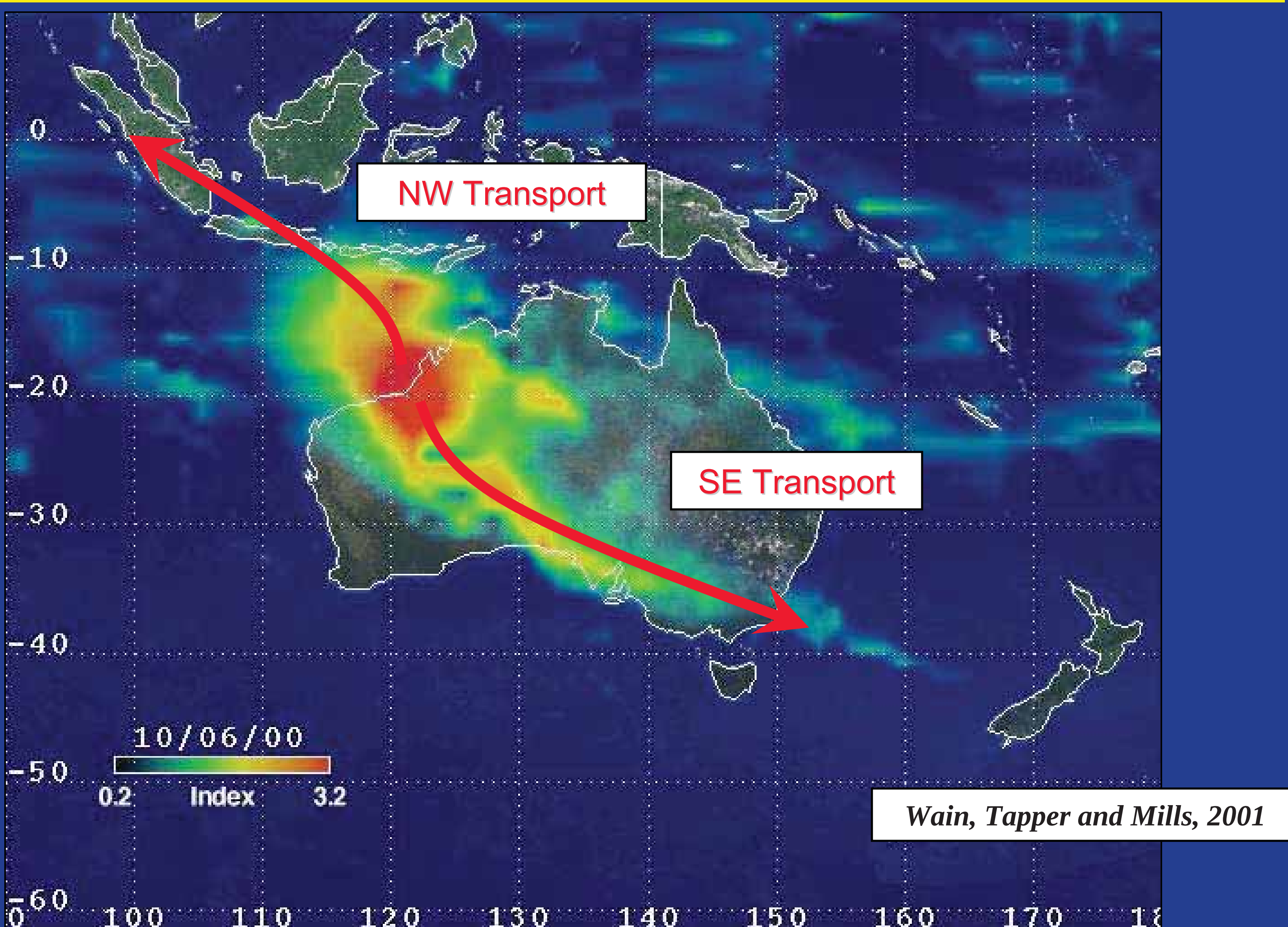
Alterations in savanna energy exchange following fire are likely to have important impacts on atmospheric circulation and water balance

- Heating contrasts between burned and unburned areas could generate local scale circulations and convection.
- On landscape scales this may modify patterns of precipitation and potentially affect the strength of the Australian monsoon.
- Boundary layer profiles and mesoscale climate modelling will be employed to address these questions.

Location of study site



Regional Transport – TOMS Aerosol Loading in Australian Region, 6 October 2000



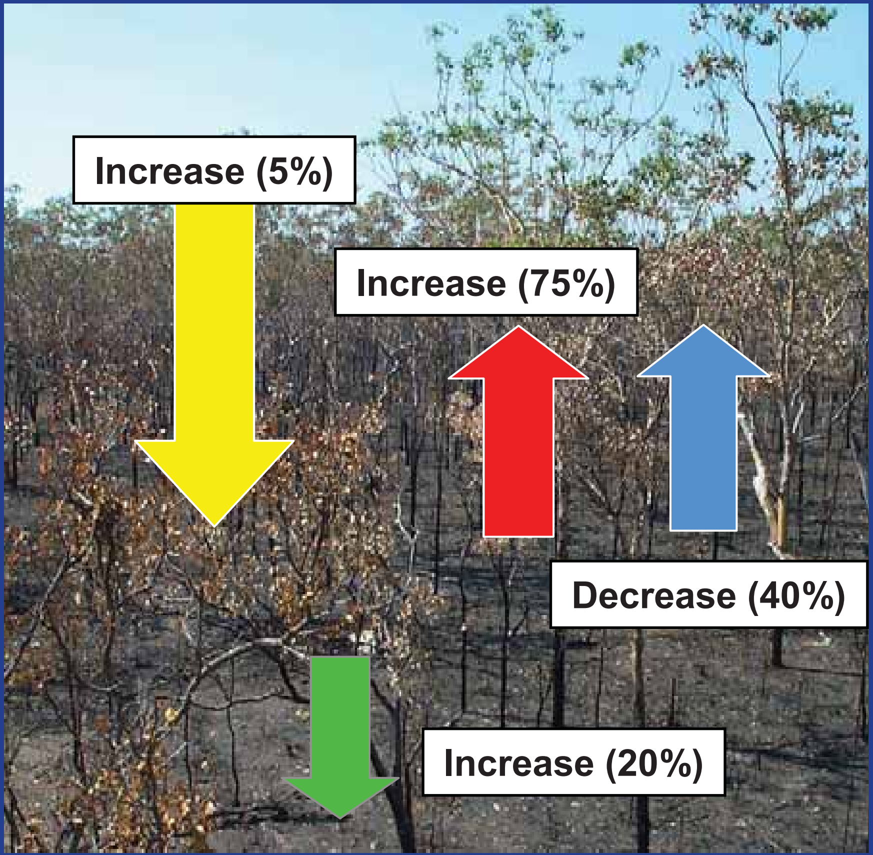
Biophysical ecosystem changes

•Changes in energy balance follow fire.

•Energy balance helps determine overlying boundary layer and climate

$$Q^* = Q_G + Q_H + Q_E$$

- Q^* = Net radiation
- Q_G = Ground heat flux
- Q_H = Sensible heat flux
- Q_E = Latent heat flux



Effects of Fire:

- ~~Carbon dioxide~~ released through biomass burning
- Decreased albedo
- Scorching of the leaves
- Trees shut down and do not photosynthesise

Emissions from N.T. biomass burning in 1992

29.5×10^6 tonnes of biomass consumed; emissions were:-

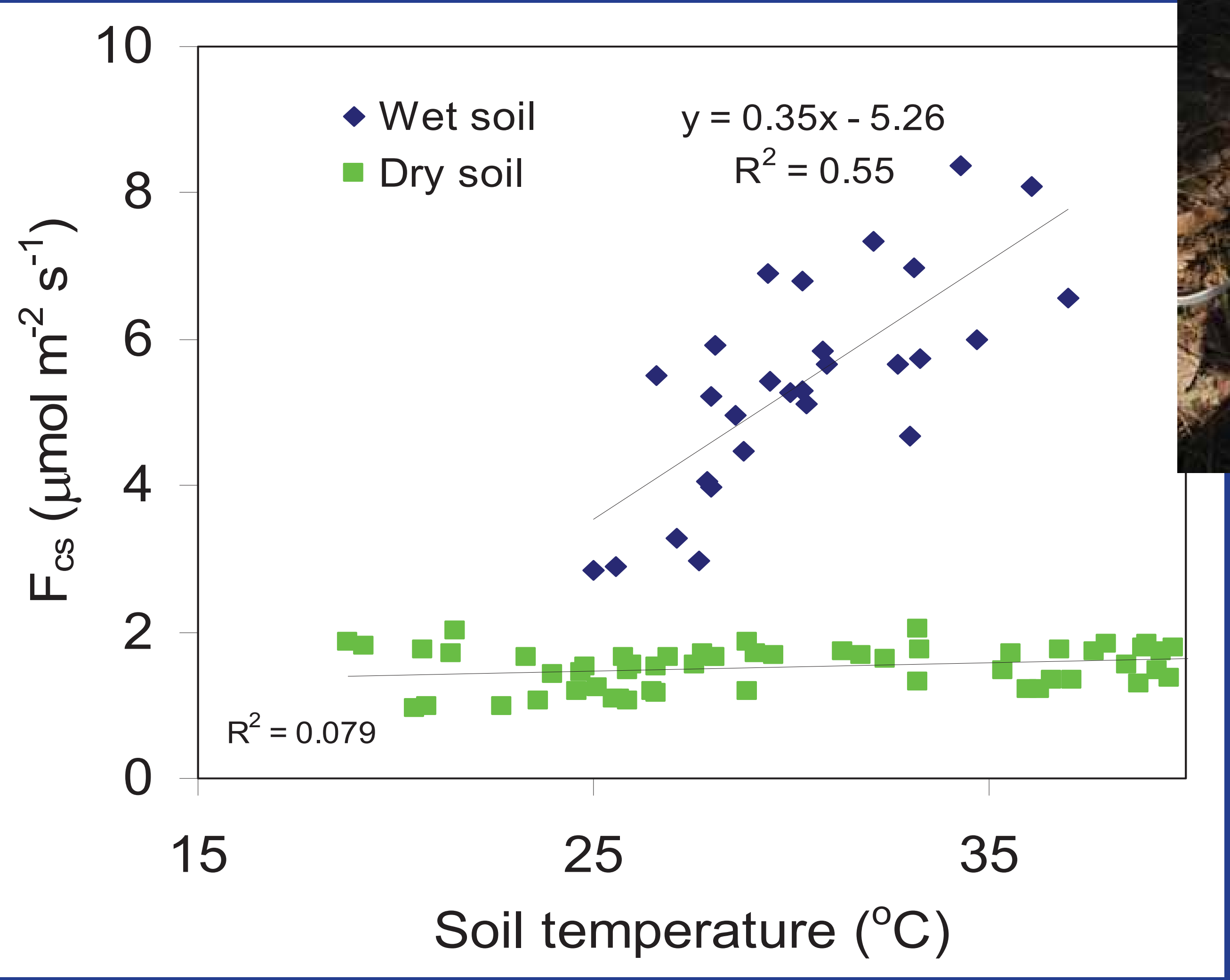
- 11.3 Tg carbon as carbon dioxide
- 1.02 Tg carbon as carbon monoxide
- 0.005 Tg carbon as particulate matter
- 0.026 Tg nitrogen as nitrous oxides

[NB. 1 Tg (teragram) = 10^{12} grams]

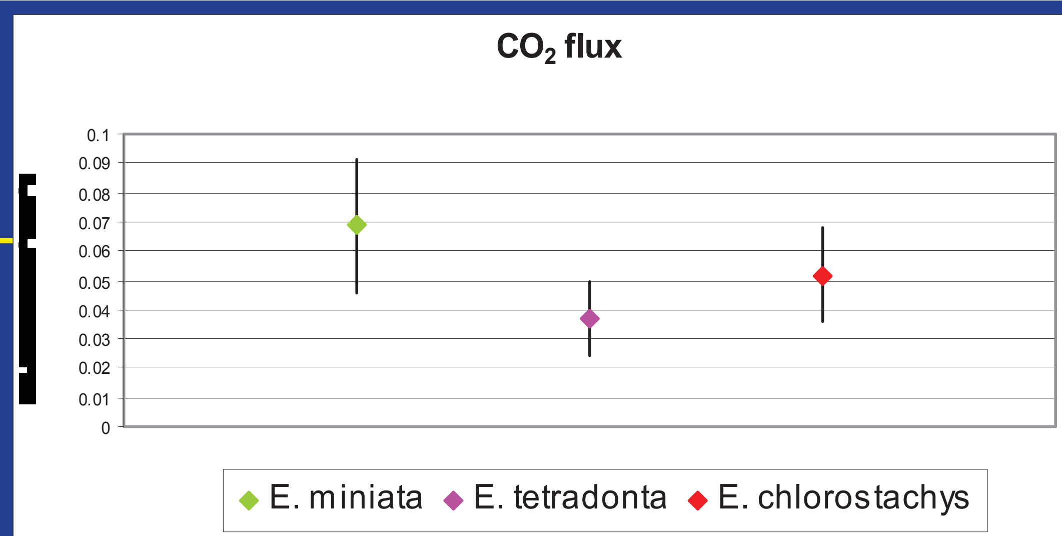
(Beringer, Packham and Tapper, 1995)

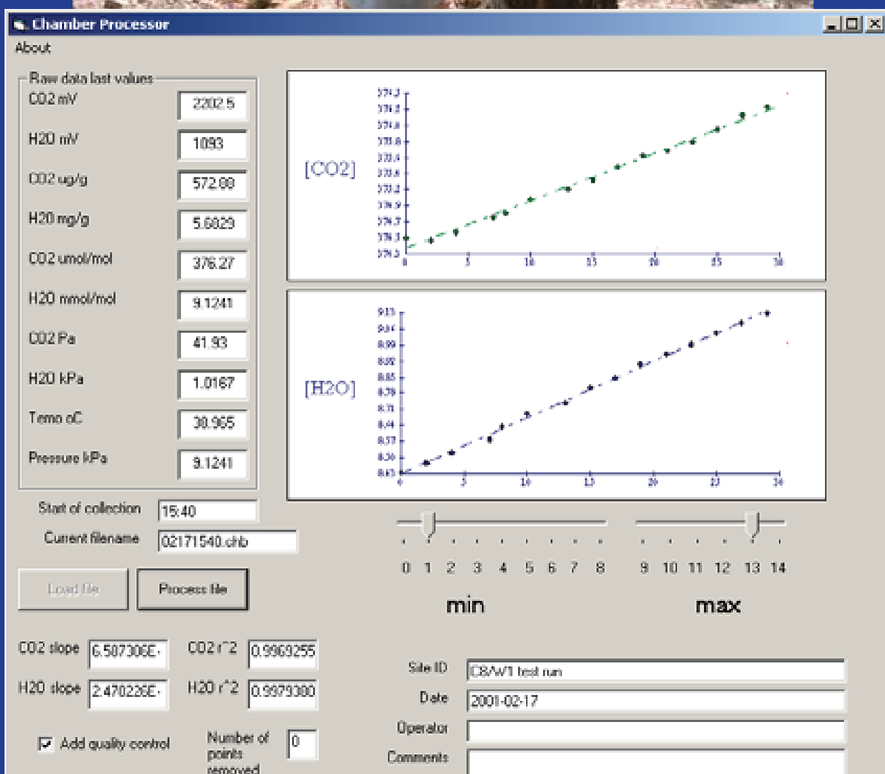

02.10.03 Week 6 of study.
Howard springs, Gun Point, NT
Magnetic Termite mounds in the
NT facing North-South.
Picture M.Grundmann

Soil respiration

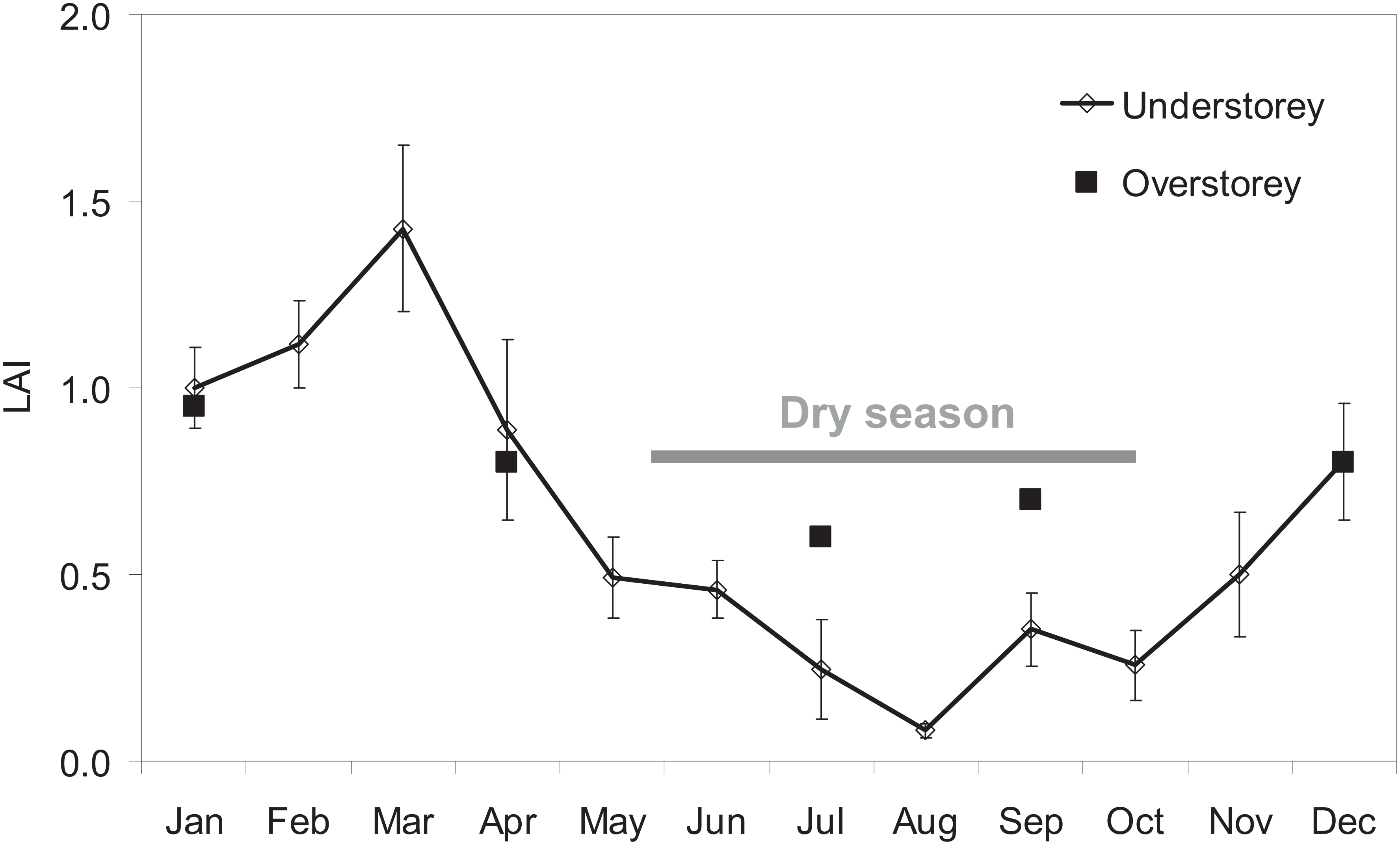


Stem respiration

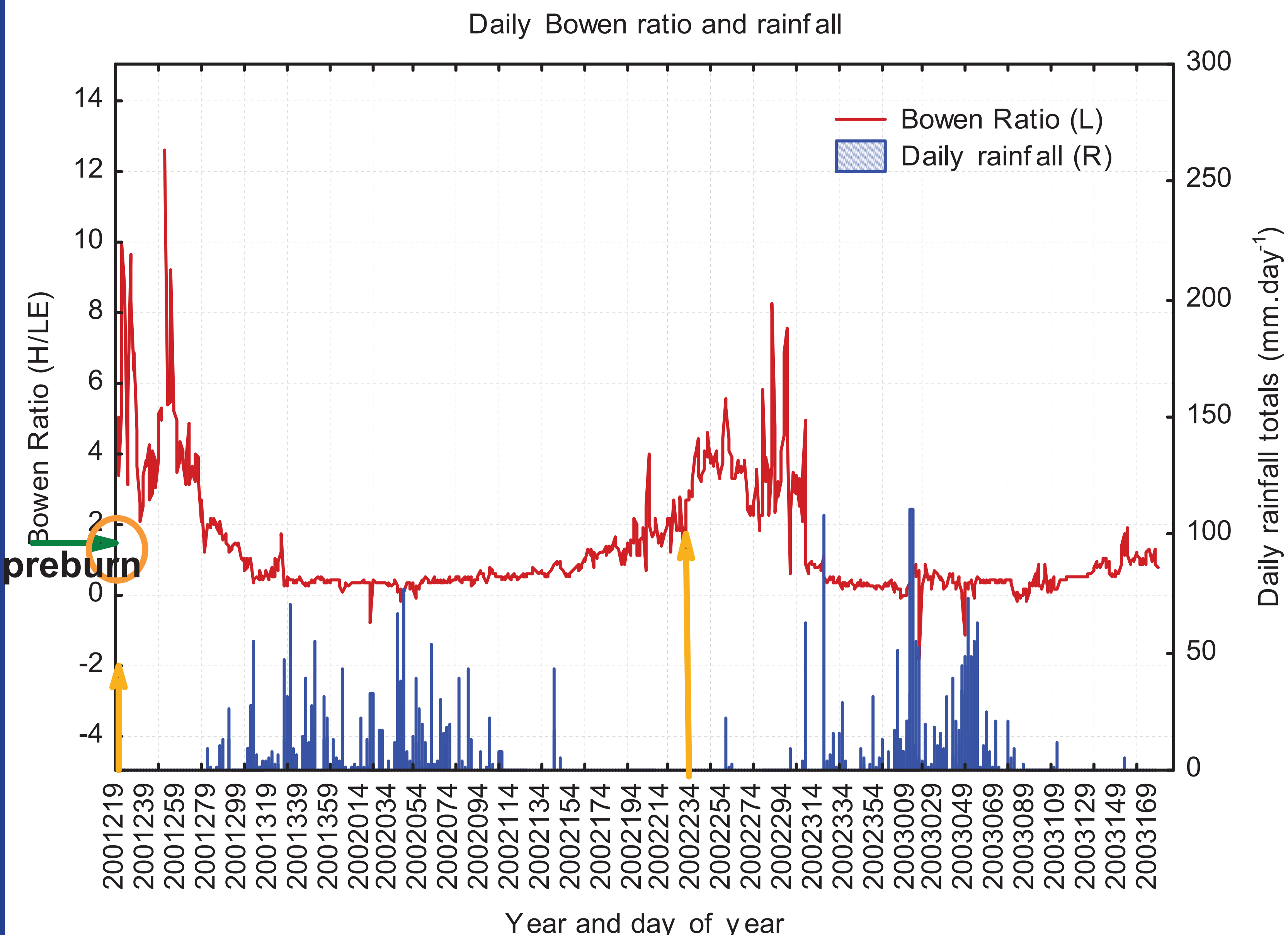




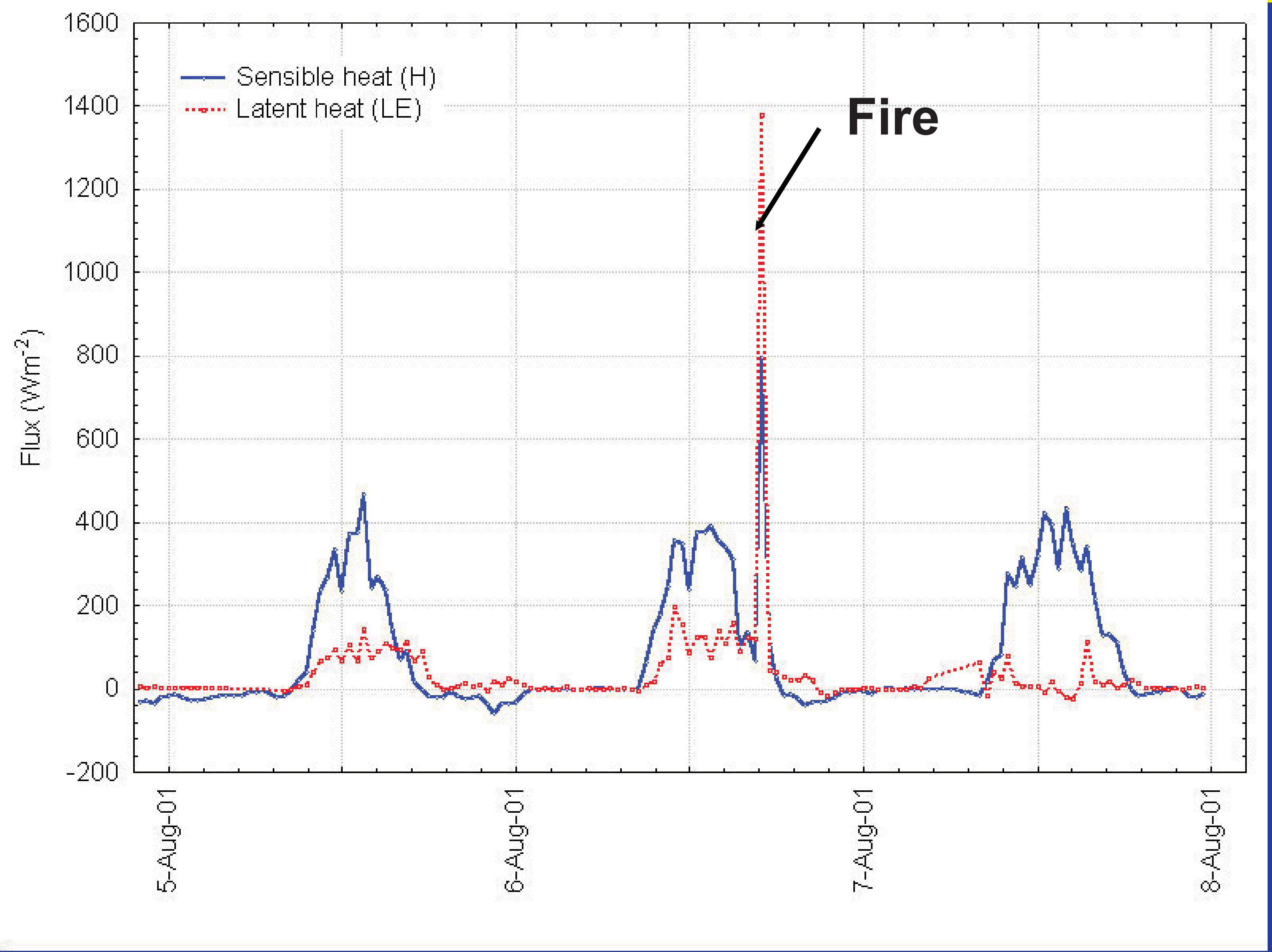
Seasonality – Leaf Area Index

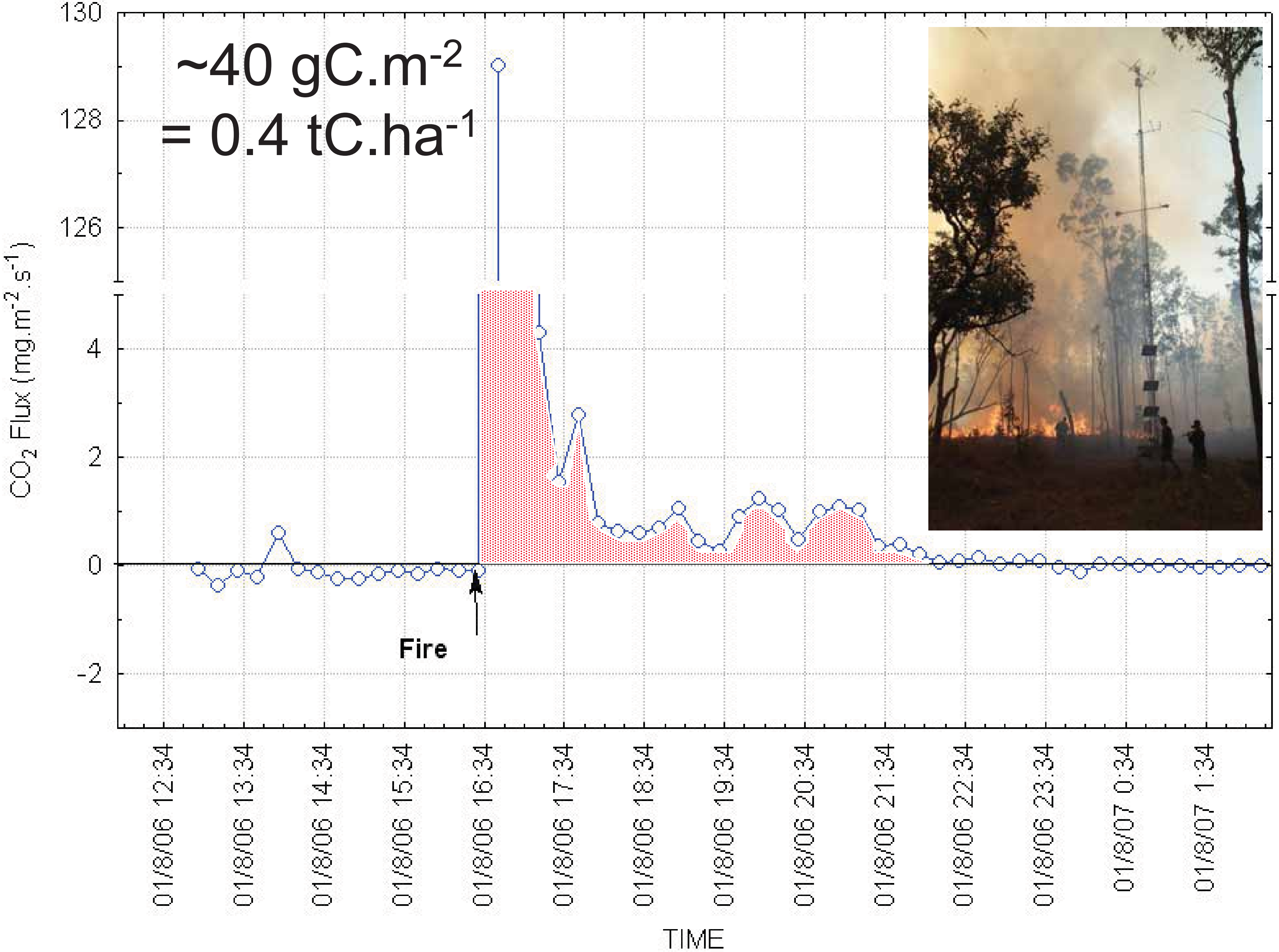


Annual Bowen Ratio

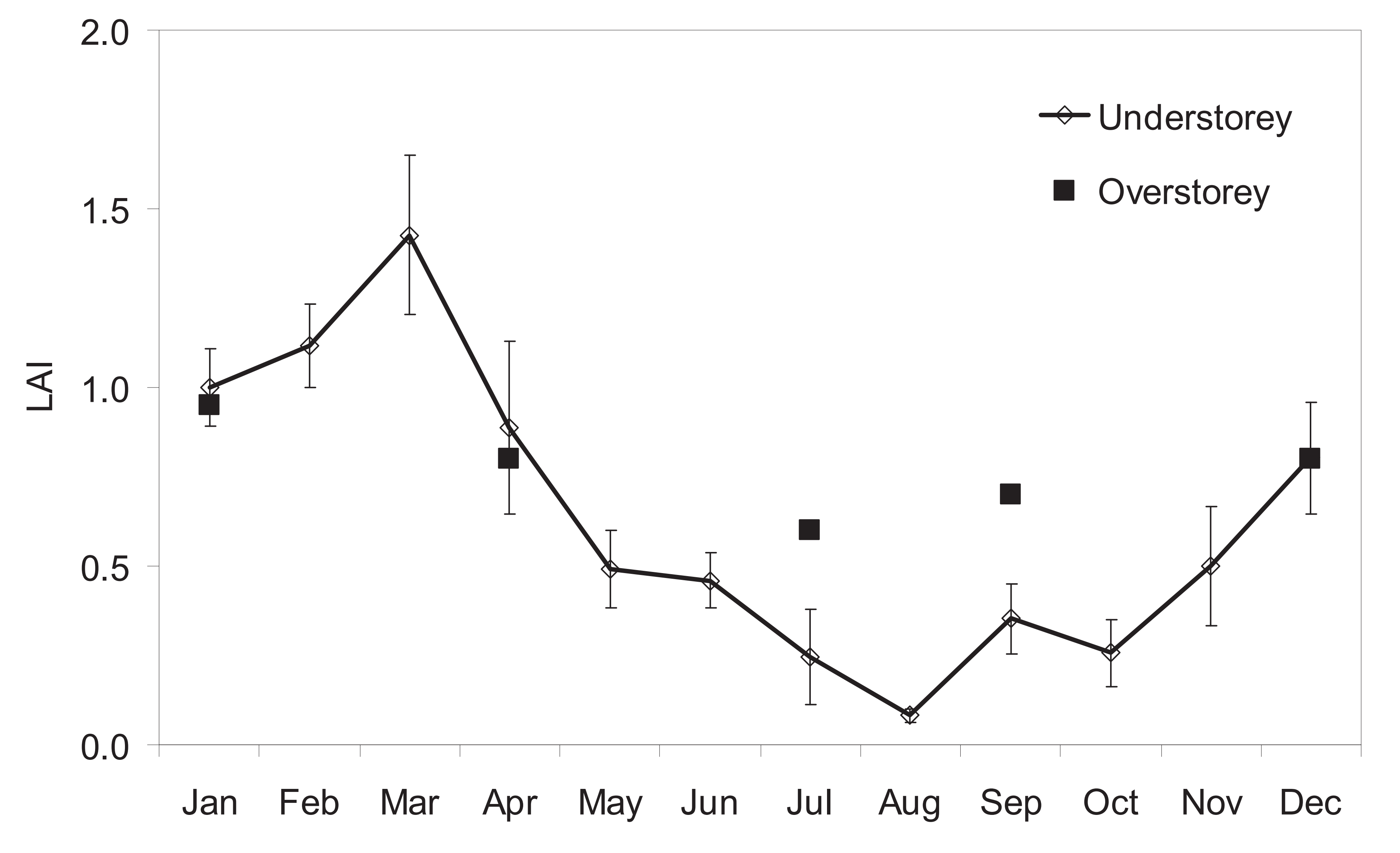


Heat and Moisture Fluxes before and after the burn




~40 gC.m-2
= 0.4 tC.ha-1
CO2 Flux (mg.m-2.s-1)
130
128
126
4
2
0
-2
Fire
01/8/06 12:34
01/8/06 13:34
01/8/06 14:34
01/8/06 15:34
01/8/06 16:34
01/8/06 17:34
01/8/06 18:34
01/8/06 19:34
01/8/06 20:34
01/8/06 21:34
01/8/06 22:34
01/8/06 23:34
01/8/07 0:34
01/8/07 1:34
TIME

Seasonality – Leaf Area Index

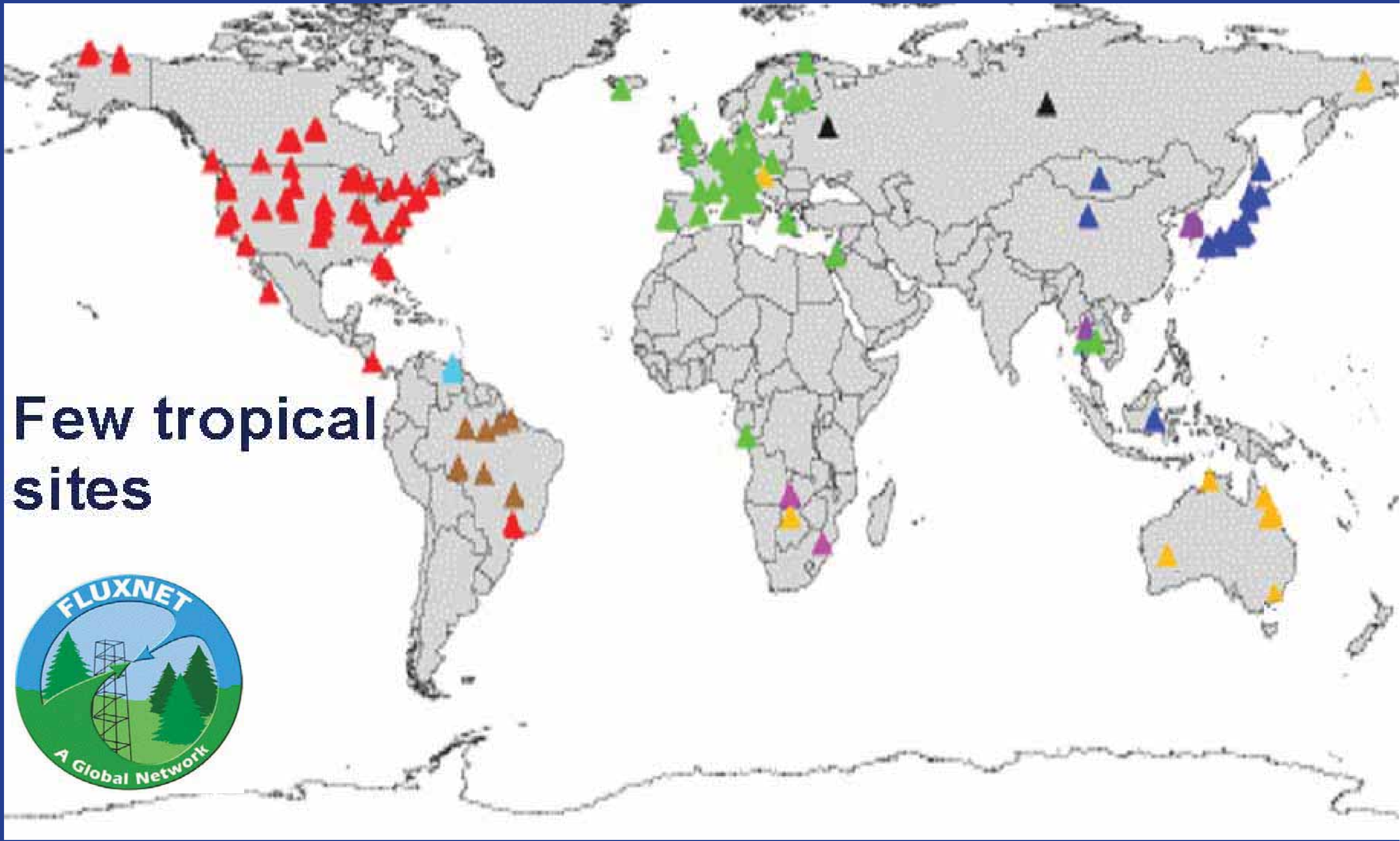


Hypothesis 3

Future climate change will alter the north Australian fire regime, with consequent feedbacks to vegetation and climate

The climate associated with a projected doubling of CO_2 will lead to a more extreme fire regime for northern Australia and a likely increase in area burnt each fire season. This will lead to dynamic changes in vegetation and climate in a series of complicated feedbacks.

Eddy covariance sites - FluxNet



Few tropical sites

Conclusions

- Fire is an integral part of Tropical Australia
- Emissions from fire contributes to the enhanced greenhouse
- Fire alters the heat and moisture balance
- This may in turn influence local to regional climate
- Changes in the carbon balance are also important

NT Savannas - NBP estimate

- Assume NEP 1.5 t ha^{-1} y^{-1}
- Area 400 000 km^2
- Savanna sink strength 60 Mt C y^{-1}
- Fire emission
  - – low fire year (9 Mt C y^{-1}) Beringer et al. (1995)
  - – high fire year (20 Mt C y^{-1})
- Fire consumes between 15-35% sequestered C
- Approximation only

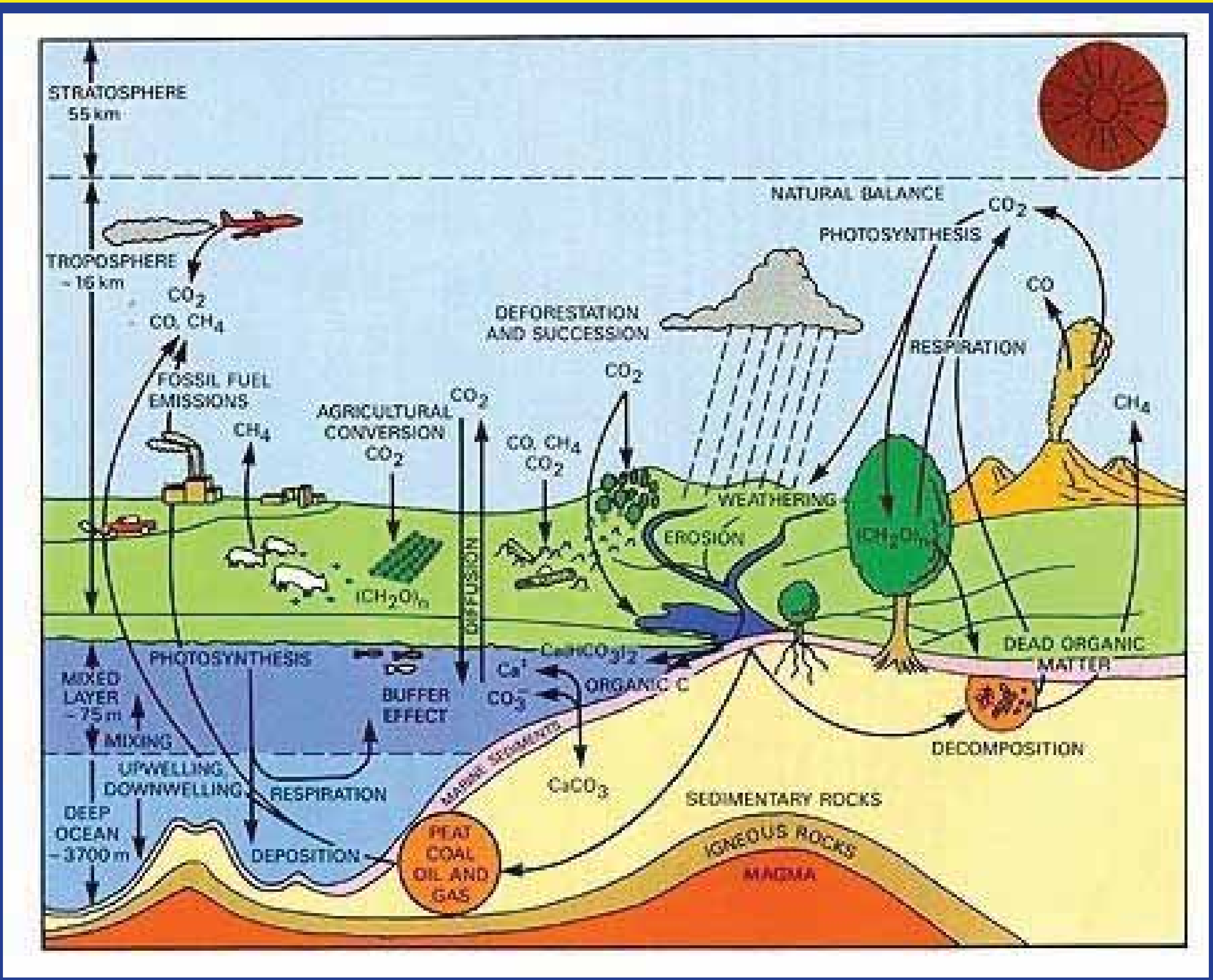
Partition Savanna NEP

- Grasses 45% of annual NEP estimate
- Grass ‘carbon neutral’ over 2-3 y period
- **What is woody sink strength ?**

NEP (t ha^{-1} y^{-1})	Wet	Dry	Late Dry	Annual
Tree	0.48	0.65	0.40	1.53
Understorey	1.13	0.16	0.00	1.29
Total	1.61	0.81	0.40	2.82

NT Savannas - NBP estimate for tree component

- Assume 0.75 t ha y-1 all Eucalypt savanna
- Area 400 000 km^2
- Tree carbon sink strength 30 Mt C y^{-1}
- Equivalent to fire emissions
  - Biomass consumed
    - 29.5 Mt y^{-1} (Beringer et al. 1995)
    - 23 Mt y^{-1} (Russell-Smith et al., submitted)



STRATOSPHERE
55 km
TROPOSPHERE
~16 km
CO_2
CO, CH_4
FOSSIL FUEL
EMISSIONS
CH_4
AGRICULTURAL
CONVERSION
CO_2
$(CH_2O)_n$
CO_2
DIFFUSION
DEFORESTATION
AND SUCCESSION
CO_2
CO, CH_4
CO_2
NATURAL BALANCE
CO_2
PHOTOSYNTHESIS
CO
RESPIRATION
CH_4
WEATHERING
EROSION
$(CH_2O)_n$
DEAD ORGANIC
MATTER
DECOMPOSITION
MIXED
LAYER
~75 m
MIXING
UPWELLING
DOWNWELLING
DEEP
OCEAN
~3700 m
PHOTOSYNTHESIS
BUFFER
EFFECT
RESPIRATION
DEPOSITION
$Ca(HCO_3)_2$
Ca^+
CO_3^-
ORGANIC C
$CaCO_3$
MARINE SEDIMENTS
PEAT
COAL
OIL AND
GAS
SEDIMENTARY ROCKS
IGNEOUS ROCKS
MAGMA

Community	*NEP* *(t C ha^{-1} y^{-1})*	*Ref*
Tropical savanna (NT)	**2.8**	**Eamus et al. (2001)**
Sahelian savanna	0.32	Hanan et al. 1998
Amazonian forest (mature)	1	Grace et al. 1996
Amazonian forest (young)	5.5	Malhi et al. 1998
Temperate deciduous forest	2-5	Goulden et al. 1996 Greco and Baldocchi 1996

Vegetation and the carbon cycle

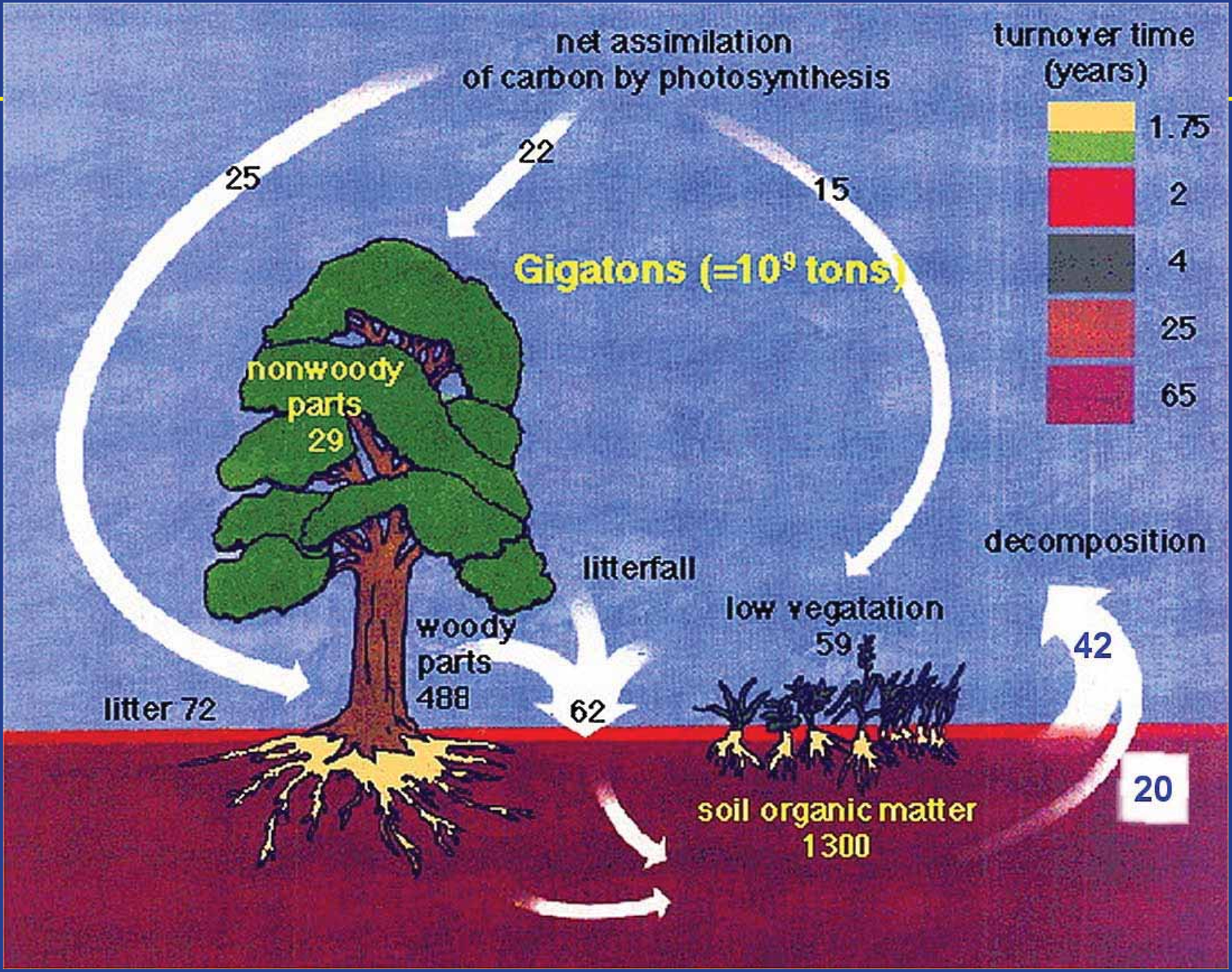
Carbon cycle - fluxes and pools

- GPP - Gross primary productivity
  - carbon assimilated via photosynthesis
- NPP - Net primary production
  - fraction of GPP allocated to growth minus respiration from vegetation (R_a)
- NEP - Net ecosystem production
  - losses from soil respiration (R_h)
- NBP - Net biome production
  - losses from disturbance

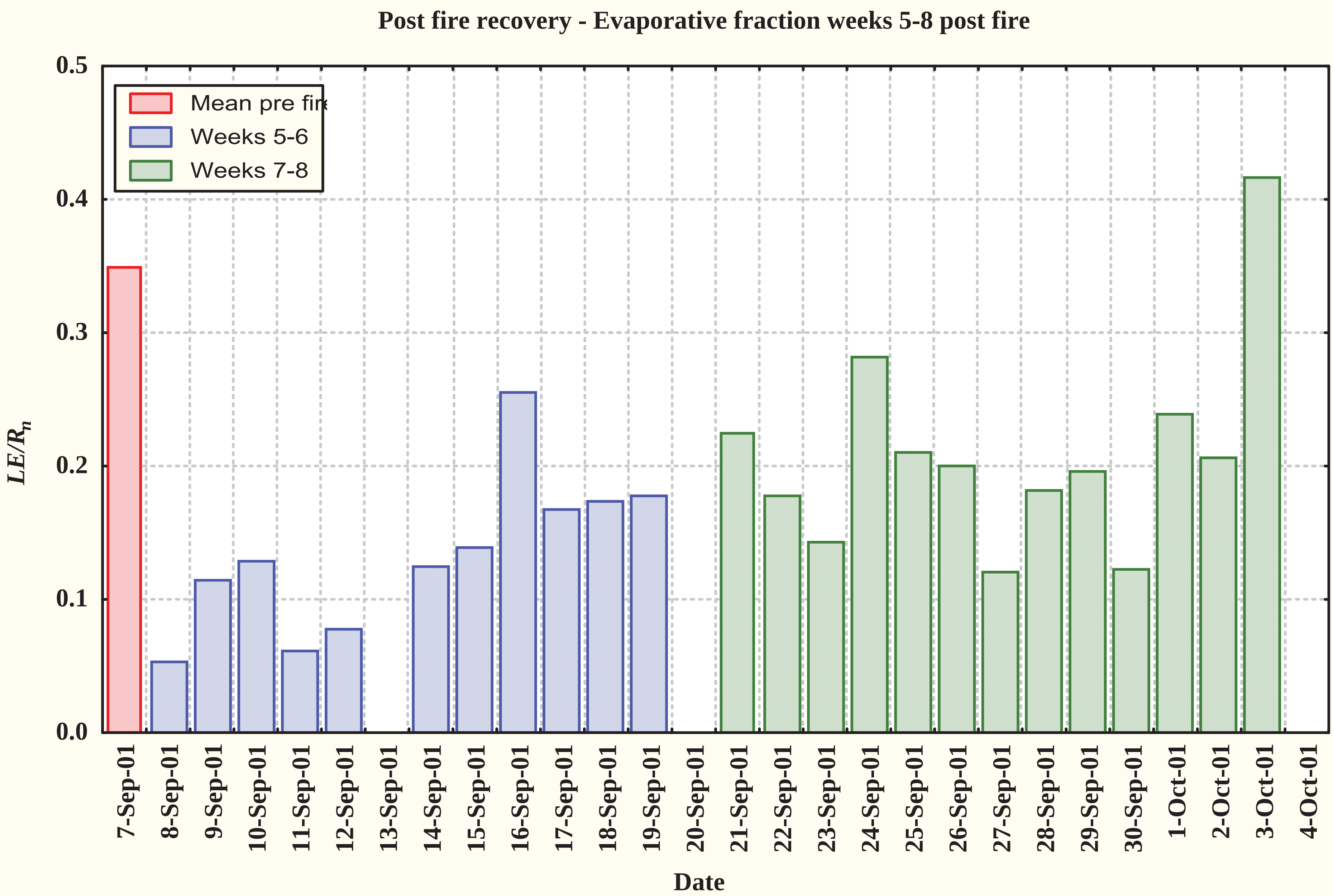
Savanna carbon cycle

Tree and grass components

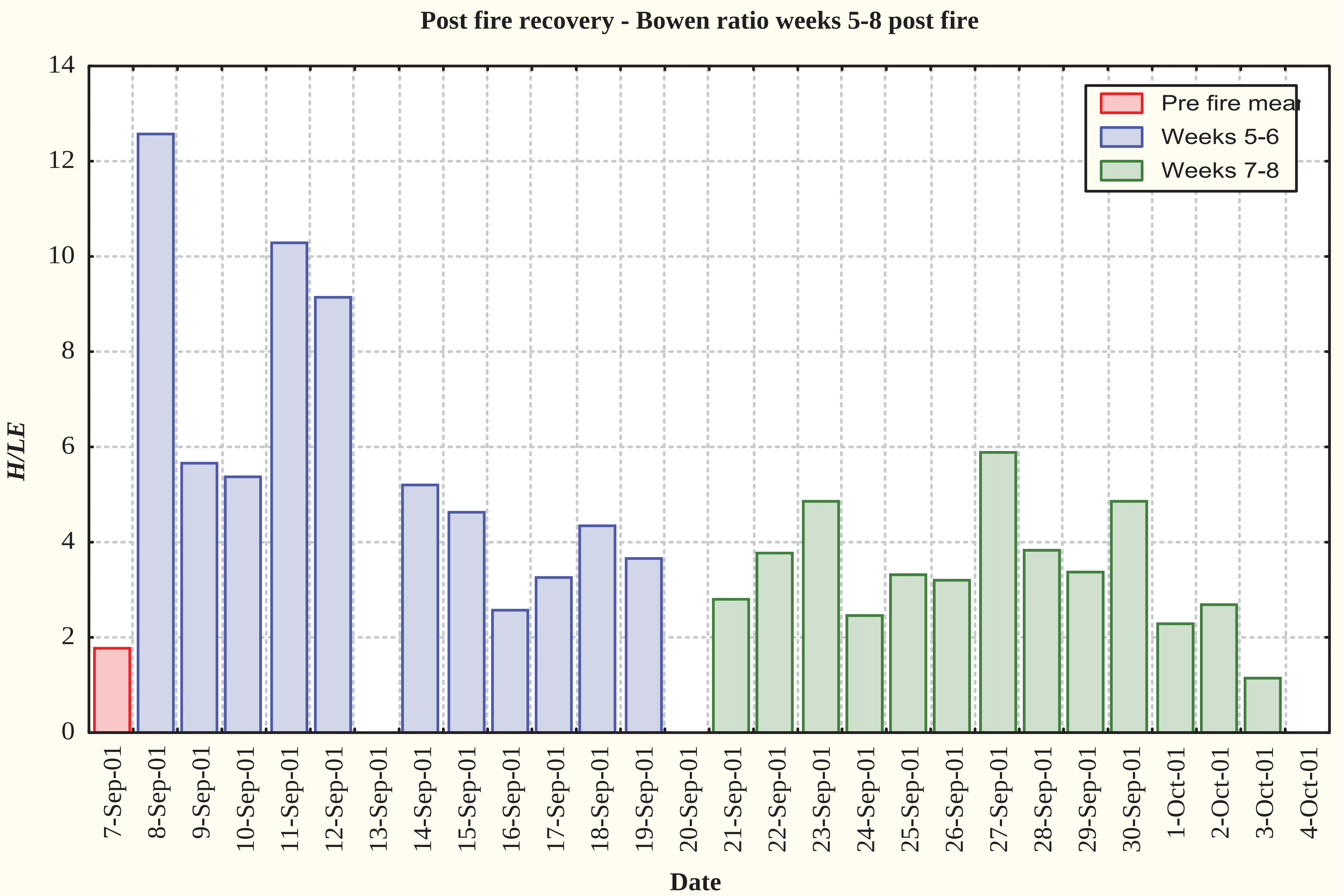
- Tree
  - C3
  - Long lived
  - long term carbon pool
- Grass
  - C4
  - Short lived
  - short term carbon pool

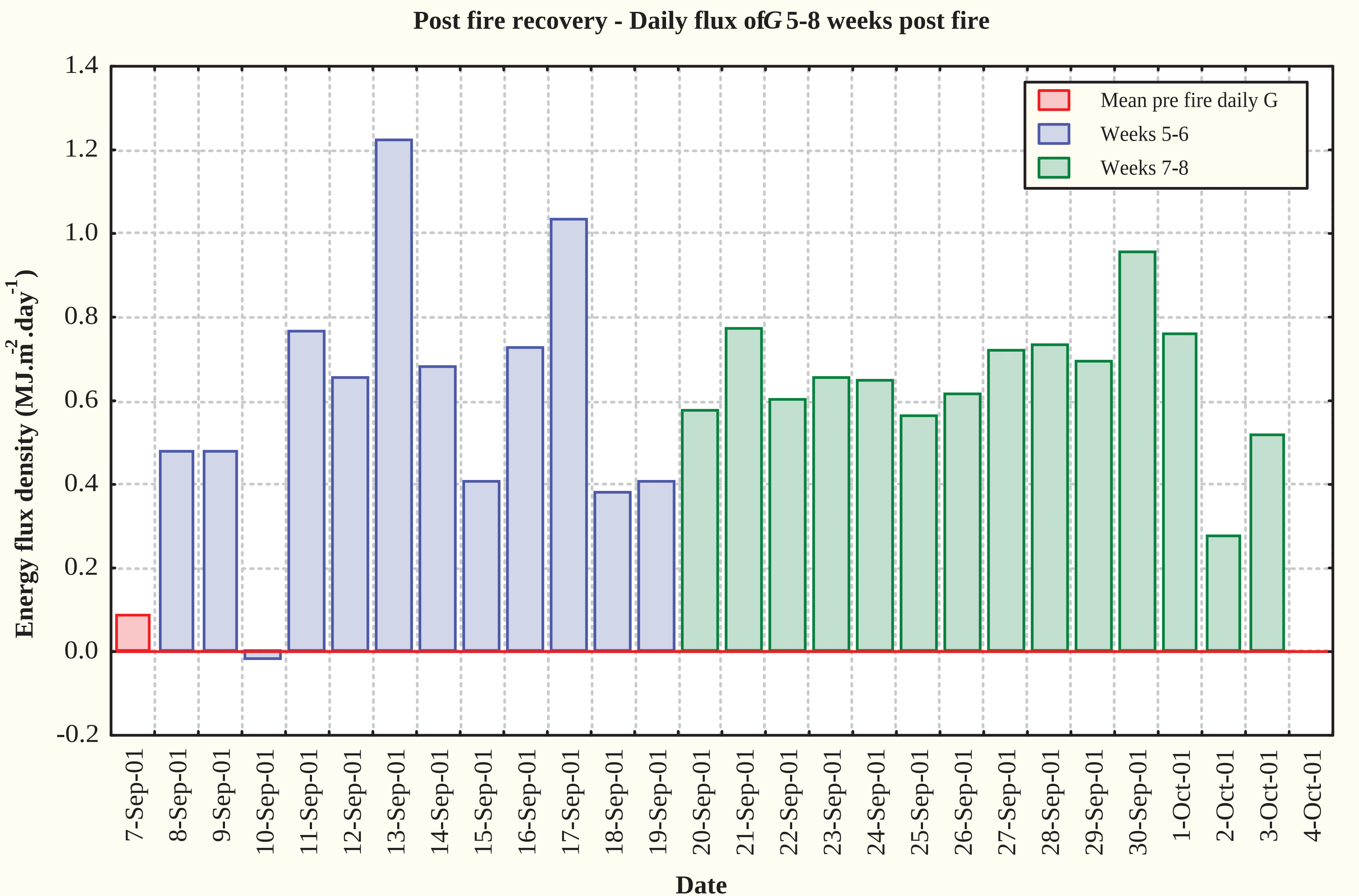

net assimilation
of carbon by photosynthesis
turnover time
(years)
1.75
2
4
25
65
25
22
15
Gigatons (=10⁹ tons)
nonwoody
parts
29
decomposition
litterfall
low vegatation
59
woody
parts
488
42
litter 72
62
20
soil organic matter
1300

Ef and br site a

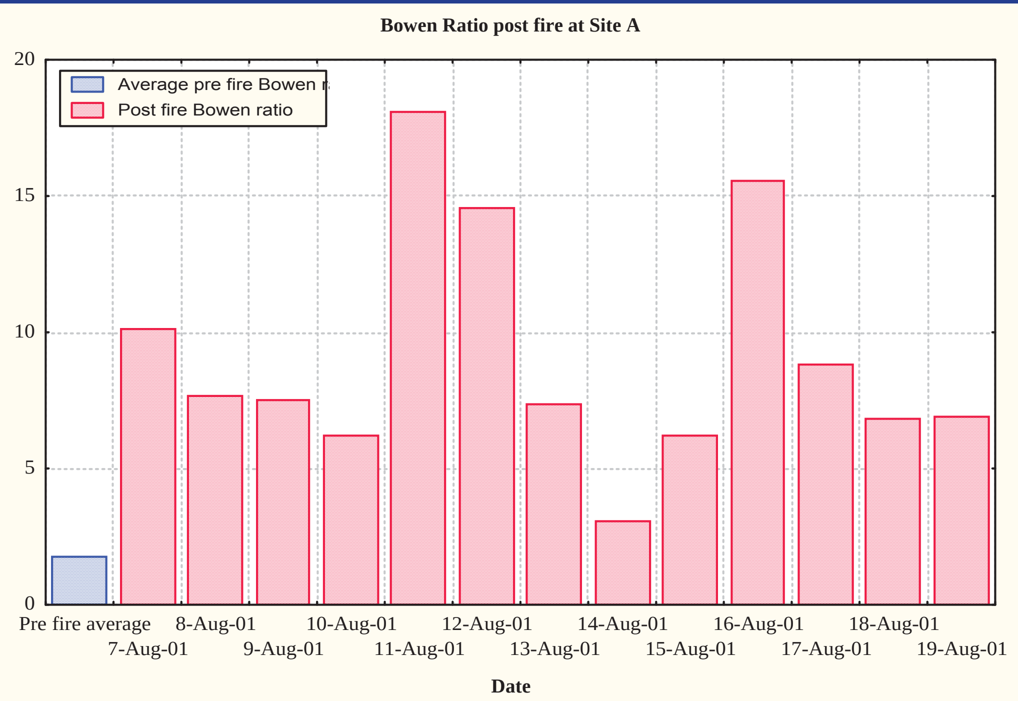


Ef and br site a

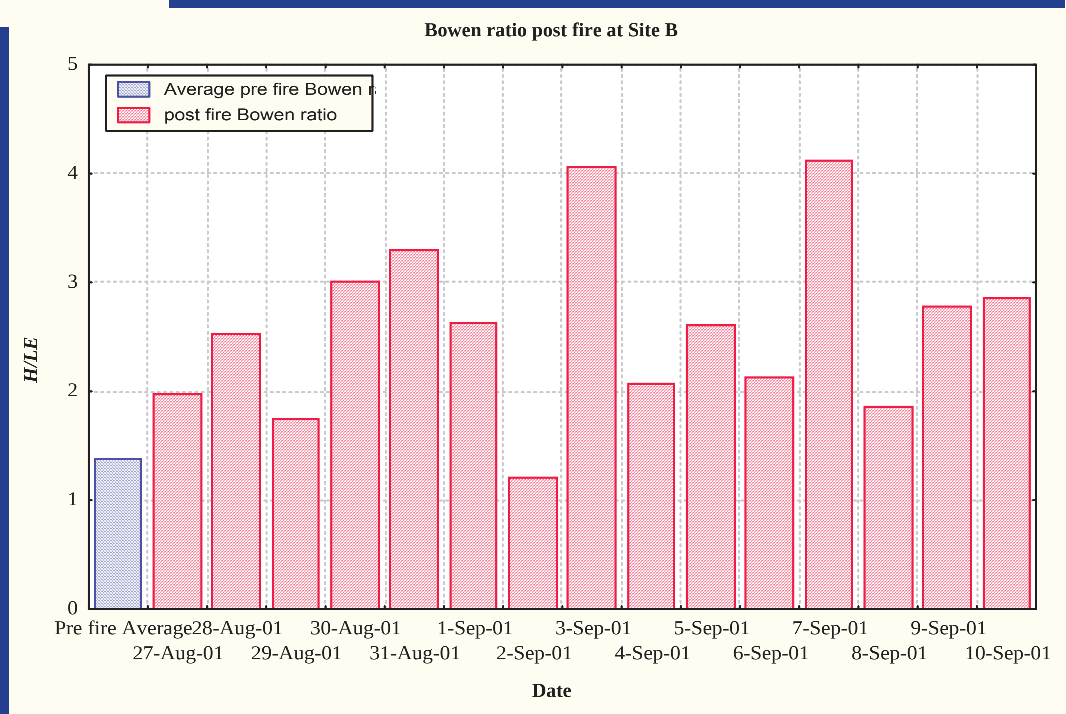




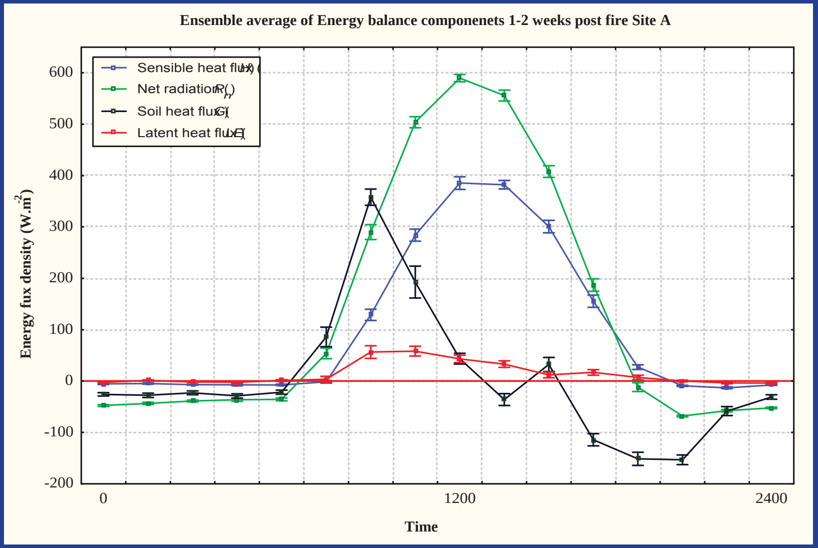
Post fire recovery - Daily flux of G 5-8 weeks post fire
Mean pre fire daily G
Weeks 5-6
Weeks 7-8
Energy flux density (MJ.m-2.day-1)
Date
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
7-Sep-01
8-Sep-01
9-Sep-01
10-Sep-01
11-Sep-01
12-Sep-01
13-Sep-01
14-Sep-01
15-Sep-01
16-Sep-01
17-Sep-01
18-Sep-01
19-Sep-01
20-Sep-01
21-Sep-01
22-Sep-01
23-Sep-01
24-Sep-01
25-Sep-01
26-Sep-01
27-Sep-01
28-Sep-01
29-Sep-01
30-Sep-01
1-Oct-01
2-Oct-01
3-Oct-01
4-Oct-01



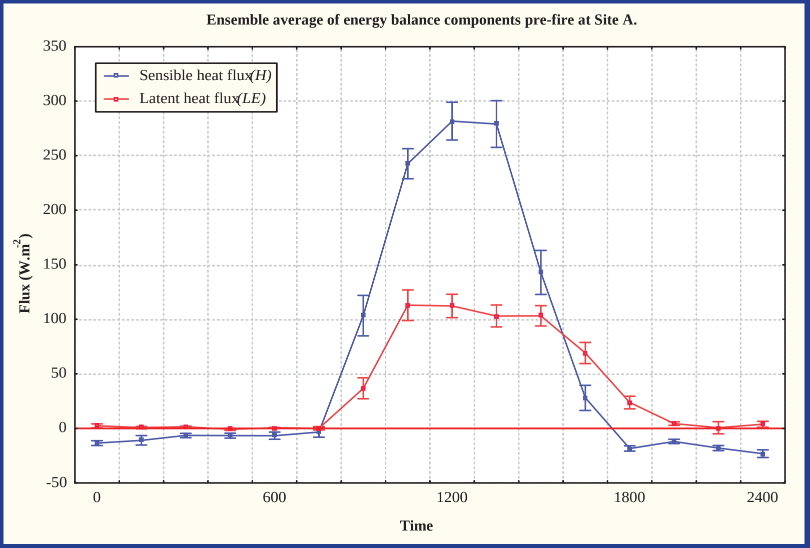
Bowen Ratio post fire at Site A
Average pre fire Bowen r
Post fire Bowen ratio
20
15
10
5
0
Pre fire average
7-Aug-01
8-Aug-01
9-Aug-01
10-Aug-01
11-Aug-01
12-Aug-01
13-Aug-01
14-Aug-01
15-Aug-01
16-Aug-01
17-Aug-01
18-Aug-01
19-Aug-01
Date



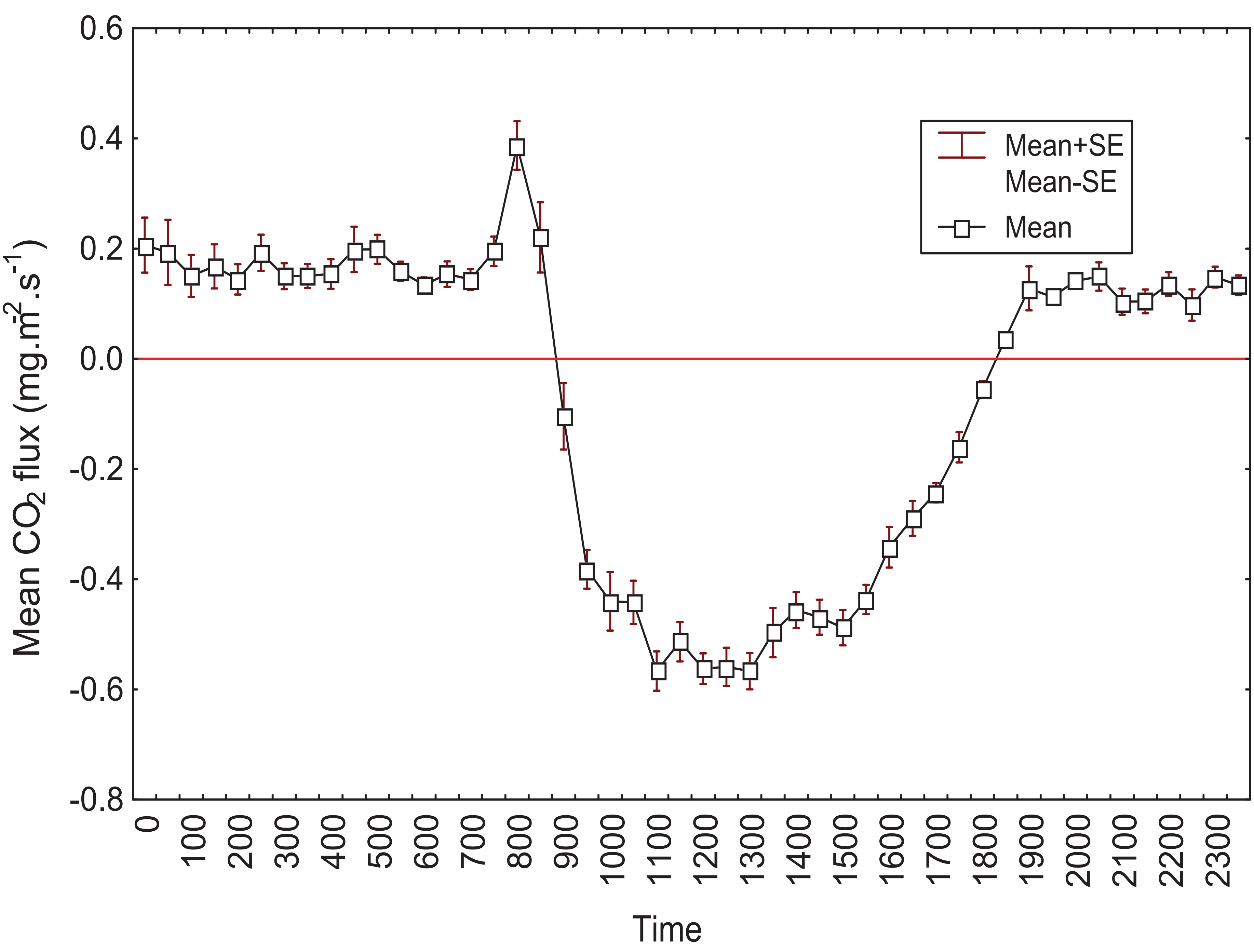
Bowen ratio post fire at Site B
Average pre fire Bowen r
post fire Bowen ratio
H/LE
5
4
3
2
1
0
Pre fire Average
27-Aug-01
28-Aug-01
29-Aug-01
30-Aug-01
31-Aug-01
1-Sep-01
2-Sep-01
3-Sep-01
4-Sep-01
5-Sep-01
6-Sep-01
7-Sep-01
8-Sep-01
9-Sep-01
10-Sep-01
Date



Ensemble average of Energy balance componenets 1-2 weeks post fire Site A
Sensible heat flux (H)
Net radiation (Rn)
Soil heat flux (G)
Latent heat flux (LE)
Energy flux density (W.m-2)
600
500
400
300
200
100
0
-100
-200
0
1200
2400
Time



Ensemble average of energy balance components pre-fire at Site A.
Sensible heat flux (H)
Latent heat flux (LE)
Flux (W.m-2)
350
300
250
200
150
100
50
0
-50
0
600
1200
1800
2400
Time

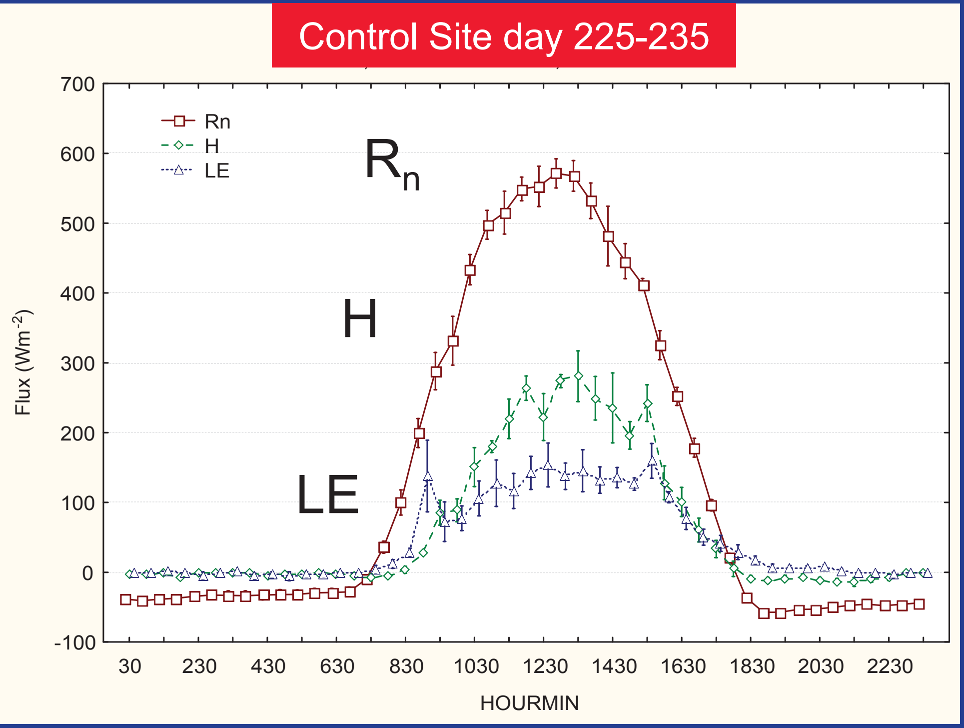


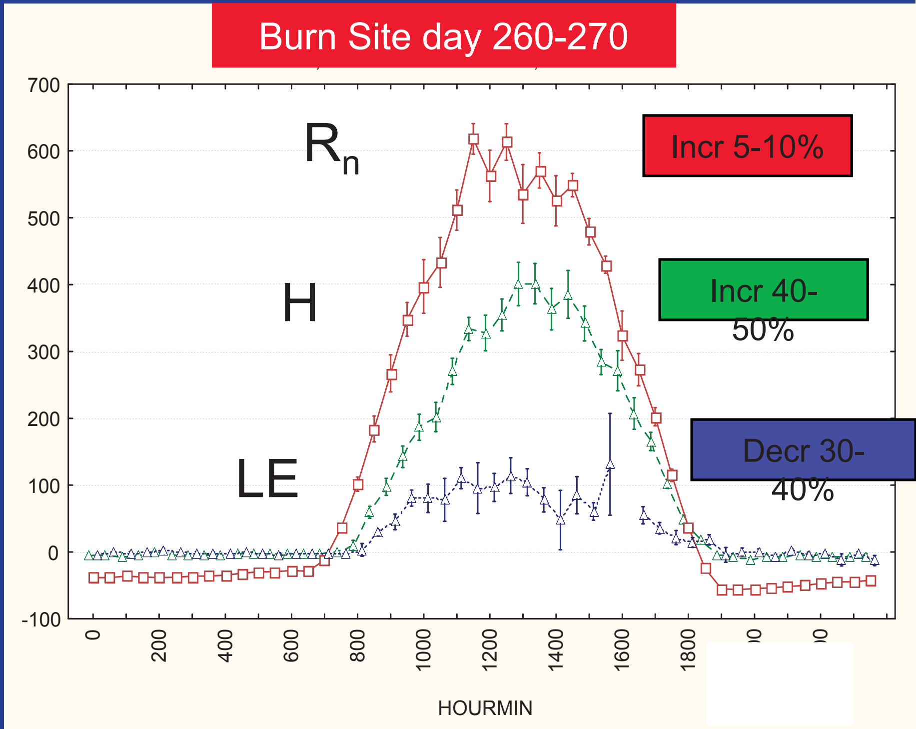
Mean CO_2 flux ($mg.m^{-2}.s^{-1}$)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
Time
Mean+SE
Mean-SE
Mean

Table 5.2 Char height, scorch height, and corresponding fire intensity, using the relationship of Williams et al. (1997) as in figures 4.4 and 4.5. Remaining biomass following each fire is also given

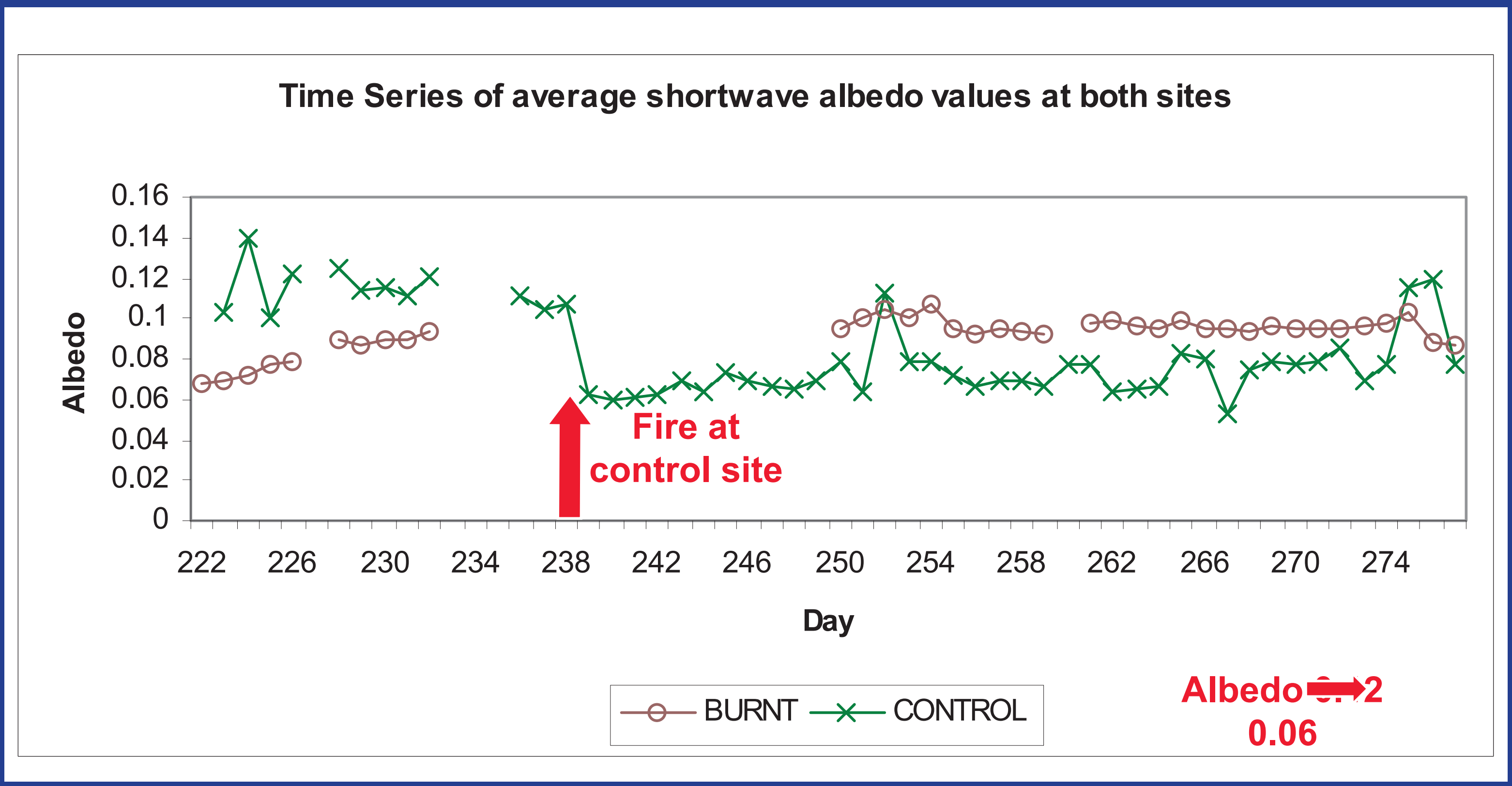
	Site A	Site B
Leaf char height (m)	2.01 ± 0.10	0.45 ± 0.03
Leaf scorch height (m)	13.5 ± 1.5	2.50 ± 0.45
Average intensity (kW.m^{-1})	**3563 ± 637**	**607 ± 60**
Total/grass fuel load	**6.4/1.6**	
Remaining Biomass (t.ha^{-1})	0.95 ± 0.28	1.1 ± 0.19

Diurnal Energy Fluxes Control and Burn Site

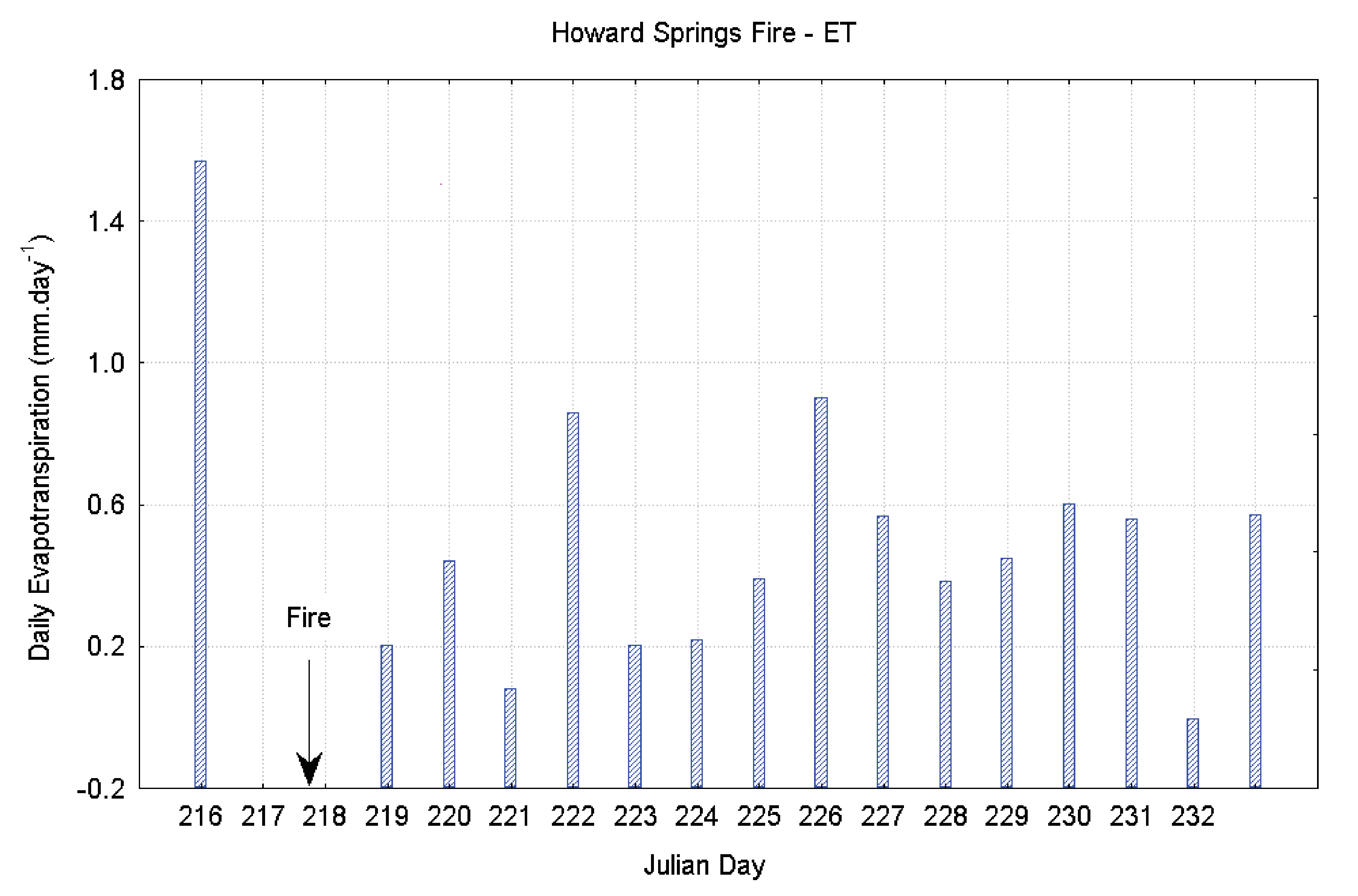




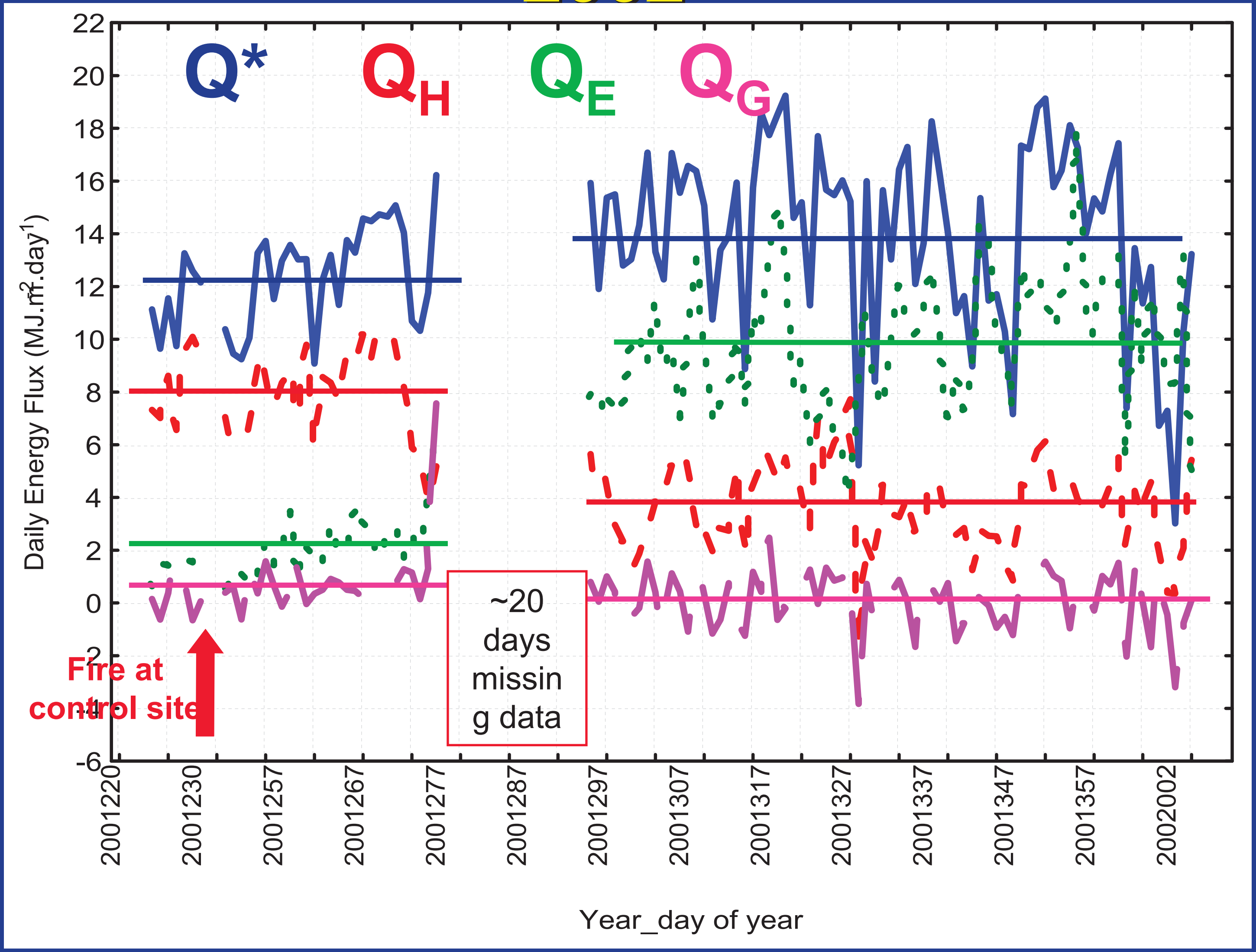
Daily Albedo at Burn and Control (Burn2) Site, August – September 2001



Evapotranspiration Before and After the Fire at the Burn Site



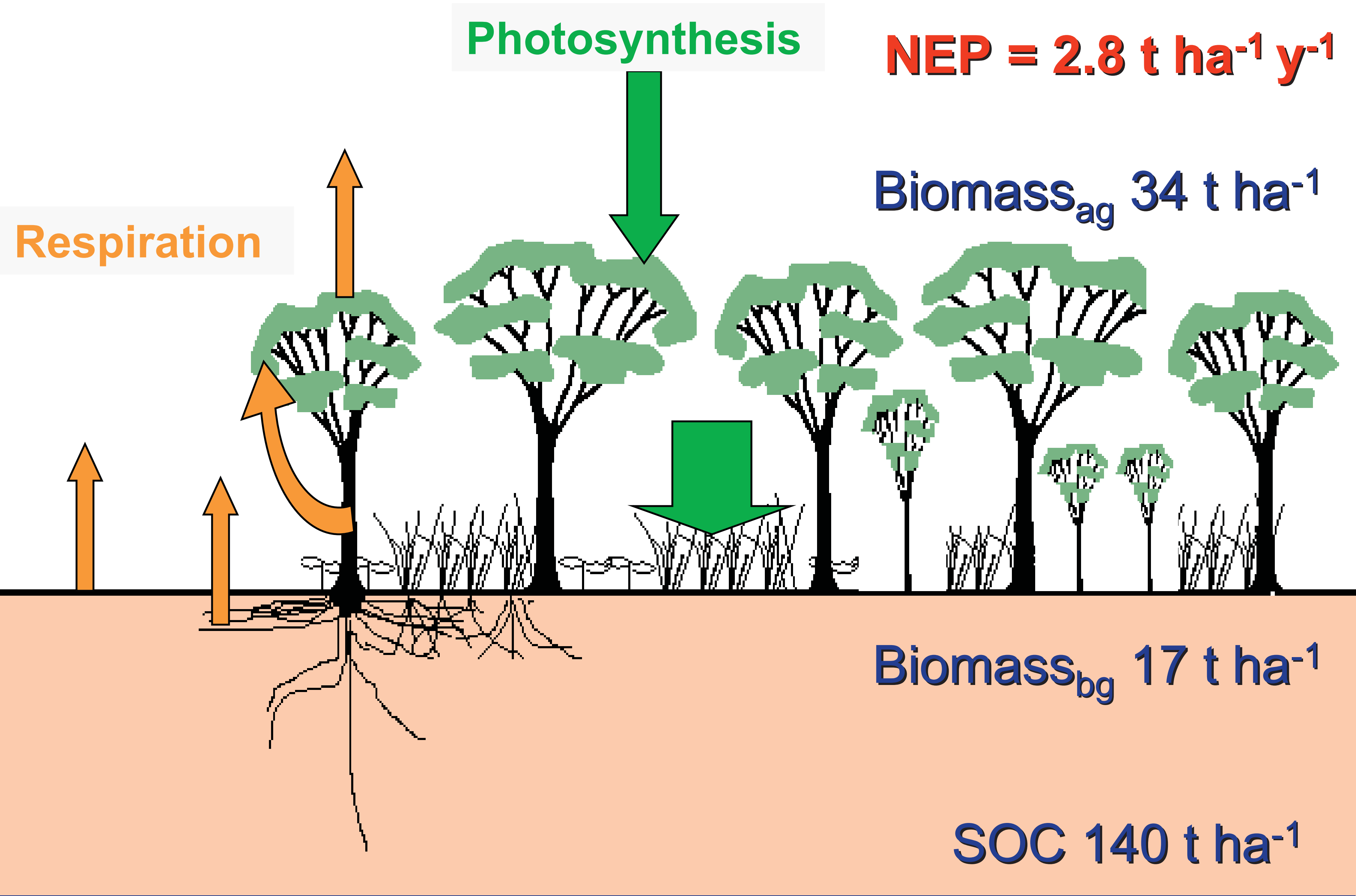
Energy Flux Time Series for the Control (Burn2) Site, August 2001 – January 2002

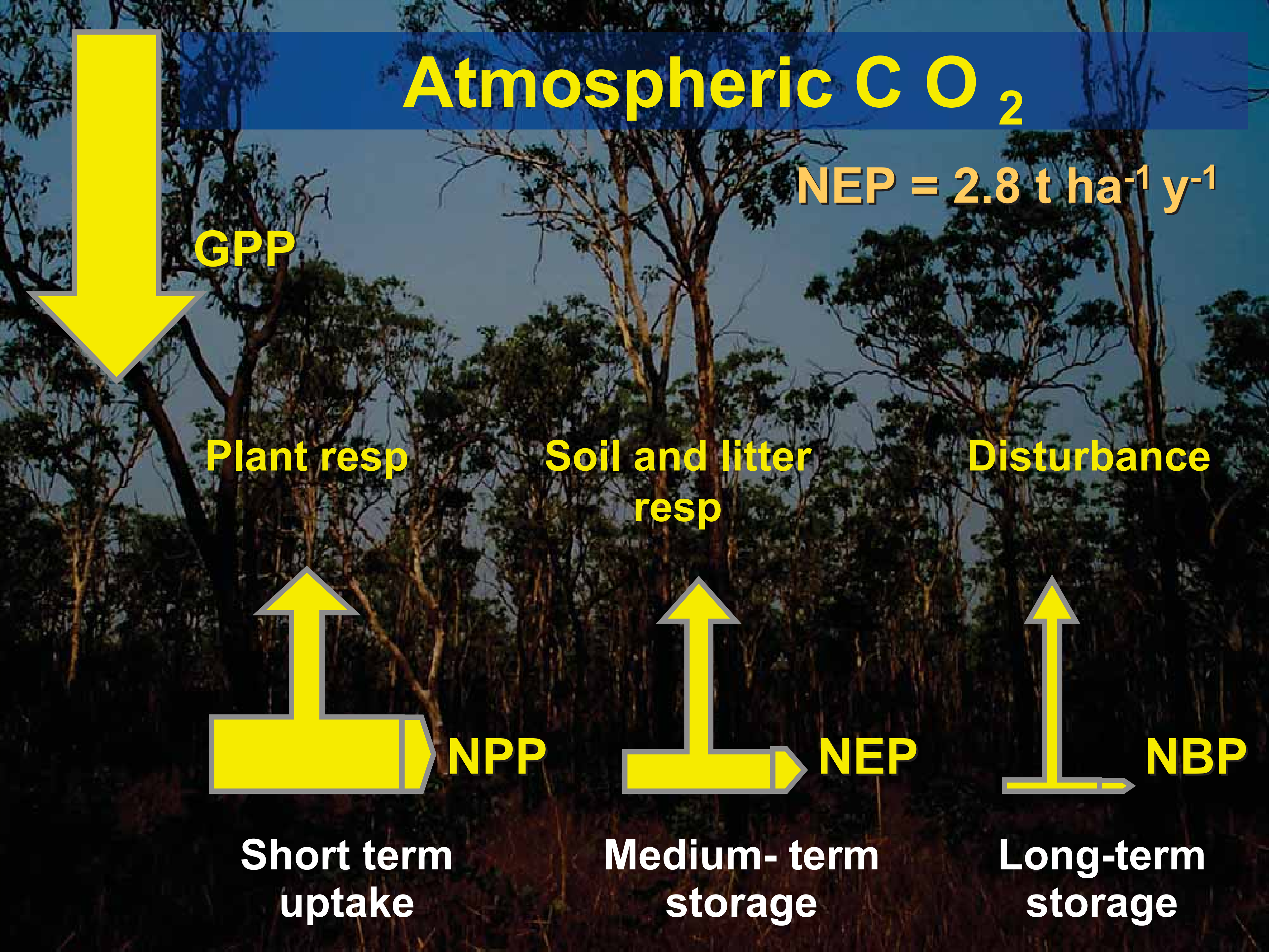


Concluding Comments

- Fire and fire scars have massive impacts in the Australian tropics where ~30% of the area burns each year
- We have already documented some of the direct impacts of fire scars on heat, moisture and (as you will see) CO_2 fluxes to the atmosphere
- These impacts on heat and moisture may in turn influence local to regional-scale climate – this is an important area for future research
- Future collaboration in this area is planned with NTU, CRCTS, NCAR, U. of Colorado (PAOS). Potential funding from ARC, NSF and NCAR

Savanna carbon fluxes and pools

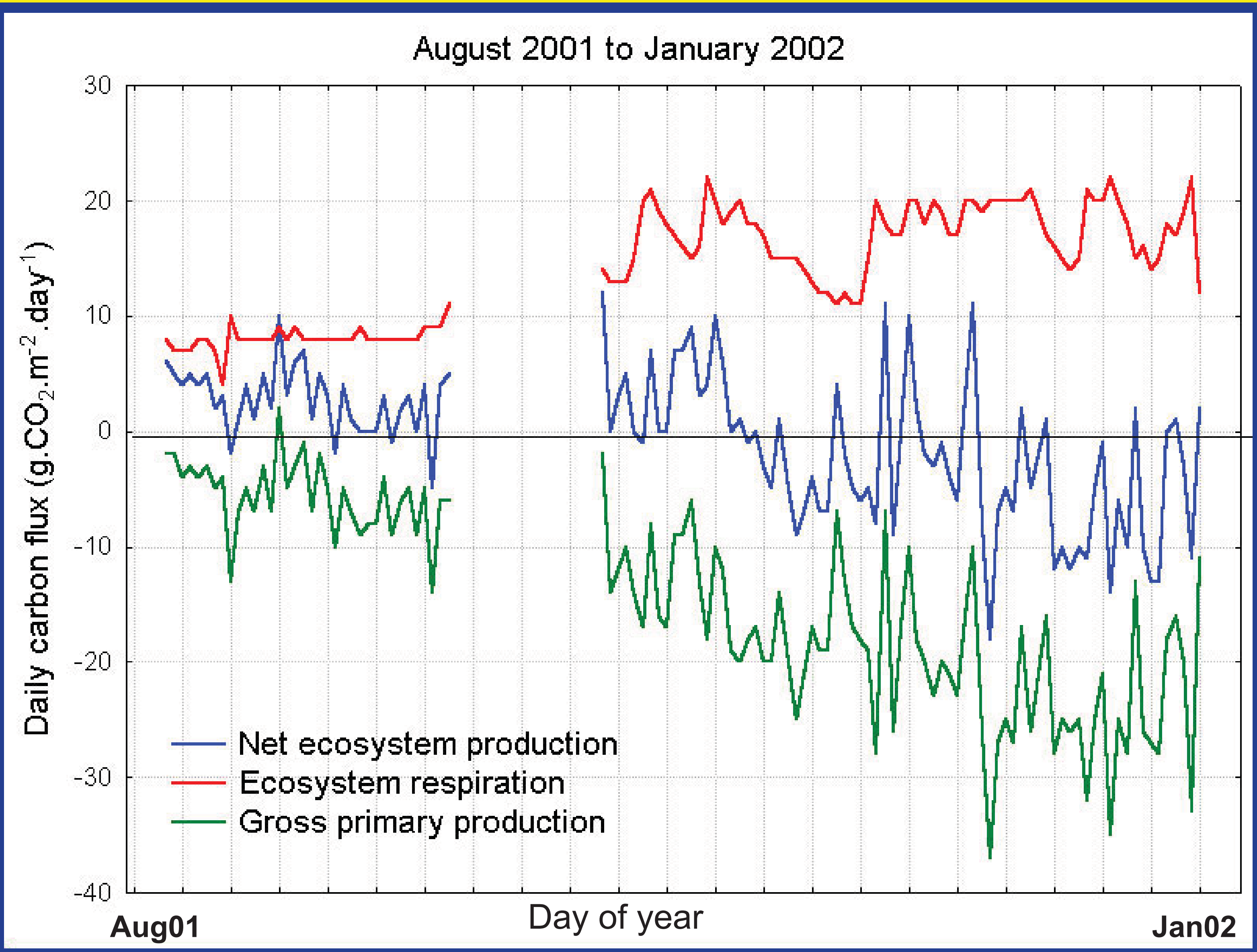


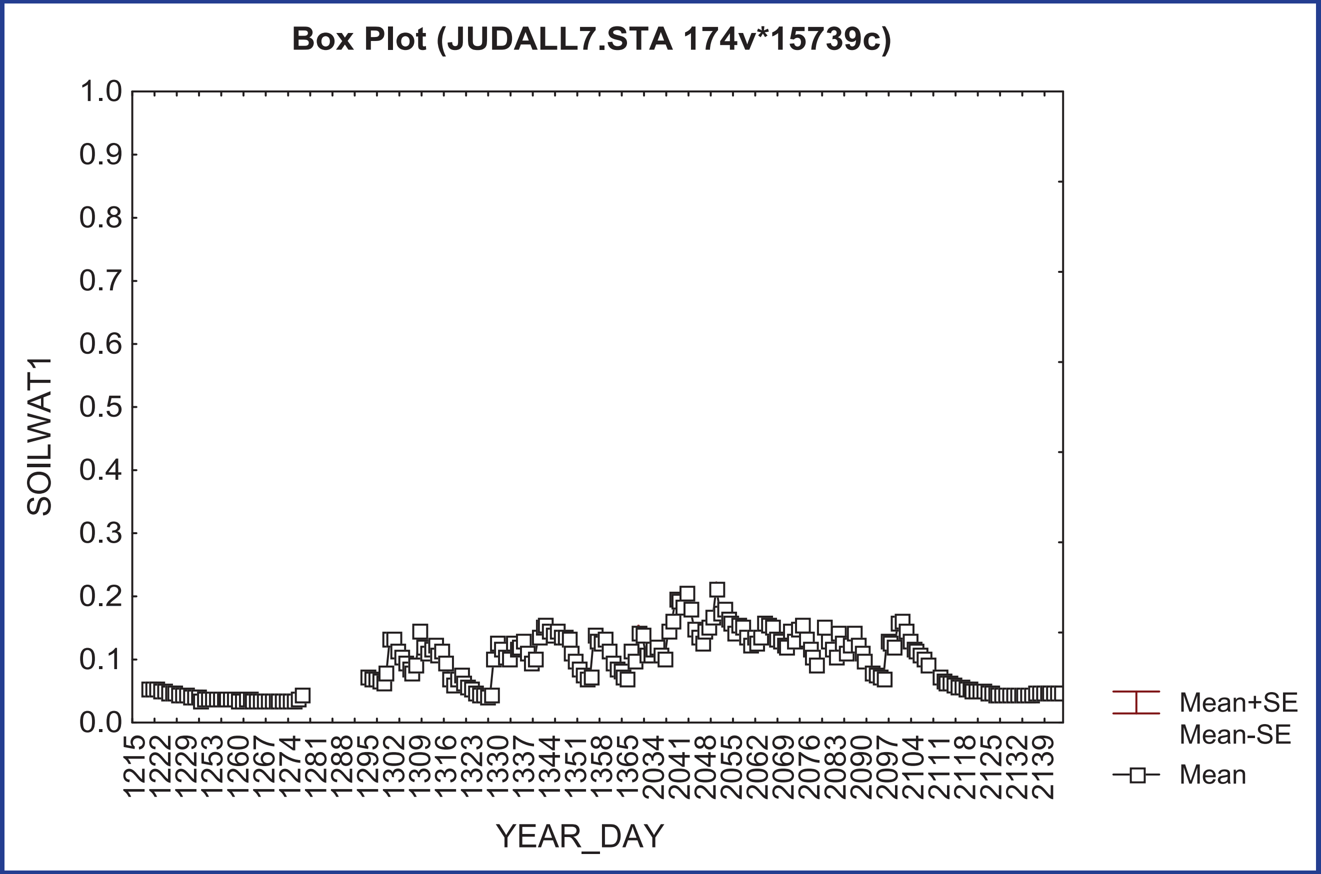

Atmospheric C O 2
NEP = 2.8 t ha-1 y-1
GPP
Plant resp
Soil and litter resp
Disturbance
NPP
NEP
NBP
Short term uptake
Medium- term storage
Long-term storage

Net Biome Productivity

- Net biome productivity (NBP) is net ecosystem productivity (NEP) but accounting for disturbance (FIRE!).
- Initial emissions and long term recovery are important

Longer term carbon balance





Box Plot (JUDALL7.STA 174v*15739c)
SOILWAT1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1215
1222
1229
1253
1260
1267
1274
1281
1288
1295
1302
1309
1316
1323
1330
1337
1344
1351
1358
1365
2034
2041
2048
2055
2062
2069
2076
2083
2090
2097
2104
2111
2118
2125
2132
2139
YEAR_DAY
Mean+SE
Mean-SE
Mean

Effects of Fire:

- Carbon dioxide released through biomass burning
- Decreased albedo
- Scorching of the leaves
- Trees shut down and don't photosynthesise

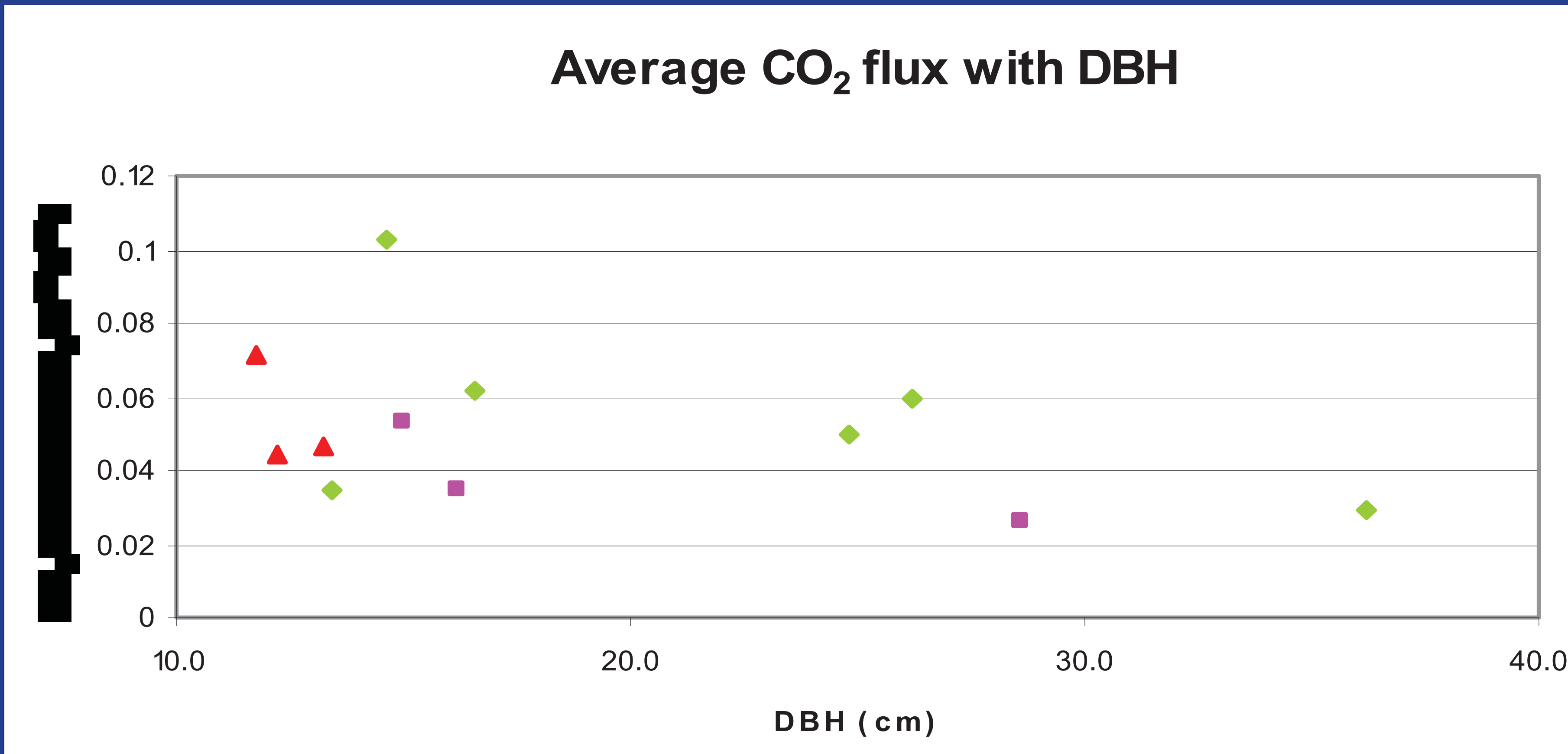


FIGURE : CO_2 flux with DBH. Red diamonds represent *Erythrophloem chlorostachys*, green diamonds represent *Eucalyptus miniata*, and purple diamonds represent *Eucalyptus tetradonta*.

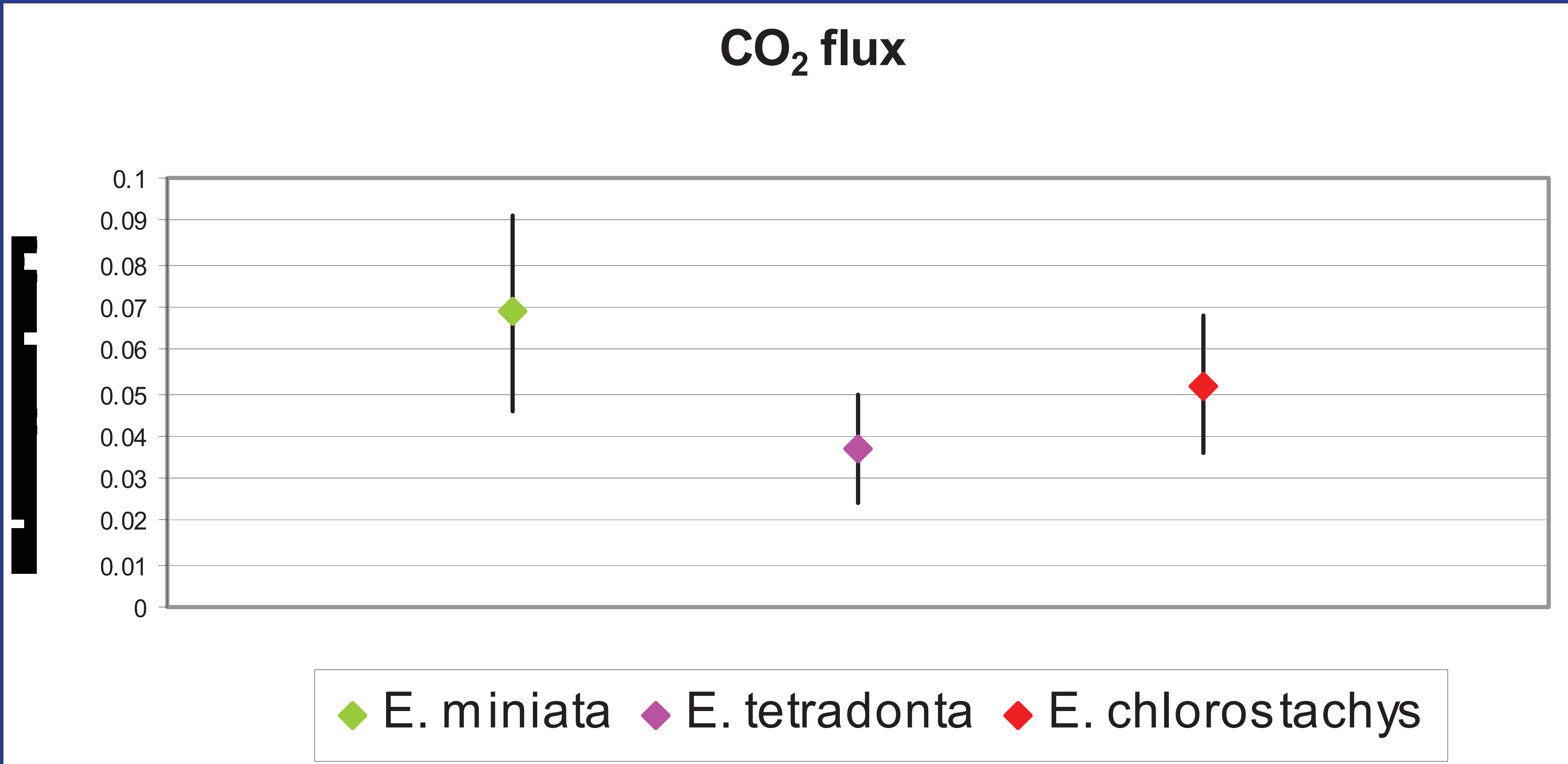


FIGURE 5.18: Comparison of average rates of respiration from each of *Eucalyptus miniata*, *Eucalyptus tetradonta* ar *Erythrophloem chlorostachys*. Standard error for each species was ± 0.022683, 0.012342 and 0.016029 reading left to right.

Eucalyptus miniata

Erythrophloem chlorostachys

Eucalyptus tetradonta

TABLE 5.1: Flux rates from each collar group

Collar group	Mean CO_2 flux (mg CO_2 m^{-2} s^{-1})	Standard error
Control (C)	0.051242	0.004865
Wet (W)	0.124797	0.015560
Saturated (S)	0.102987	0.012404

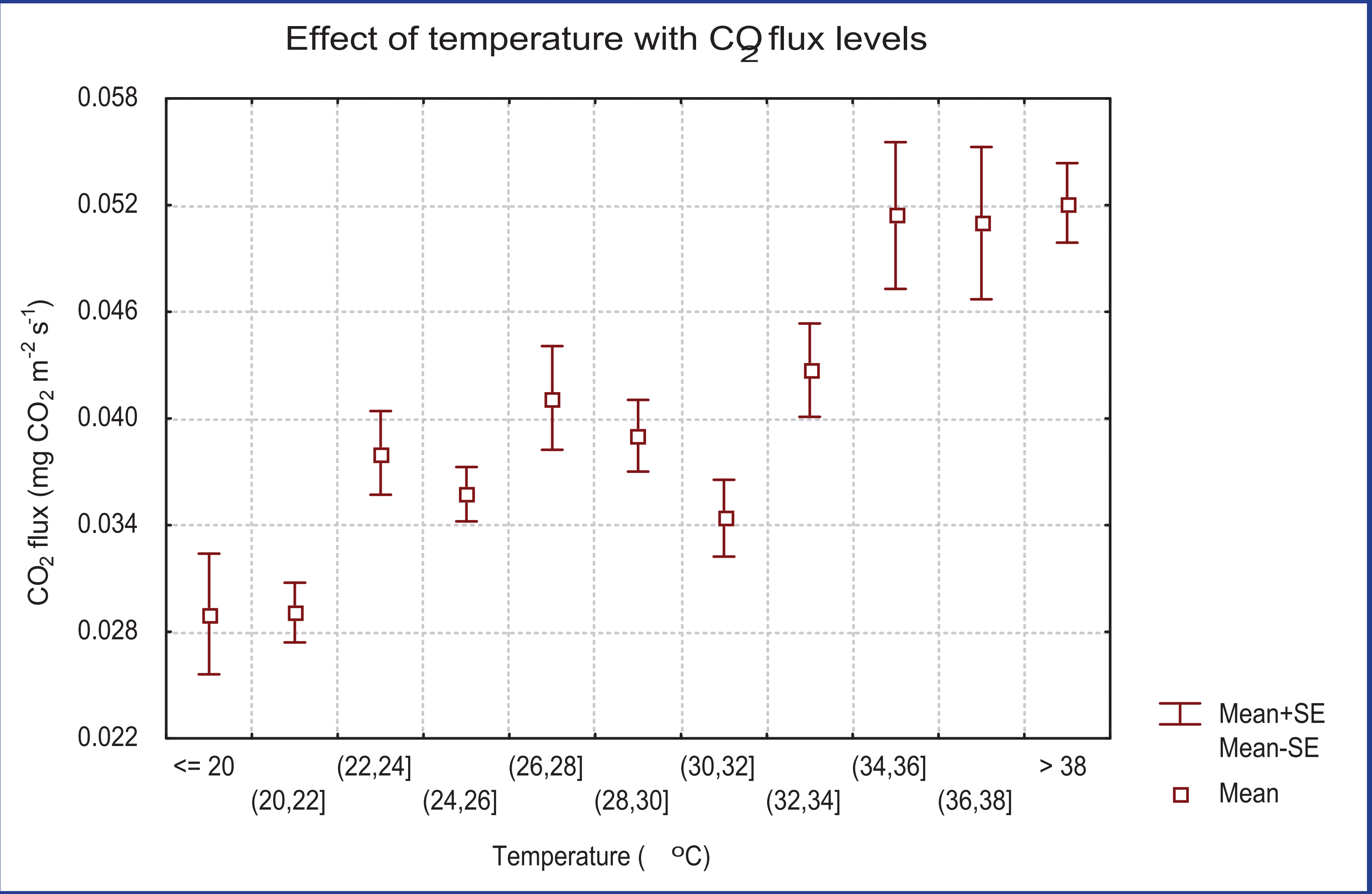


FIGURE 5.19: Effect of temperature on CO_2 flux from *Eucalyptus miniata*, *Eucalyptus tetradonta* and *Erythrophloem chlorostachys*

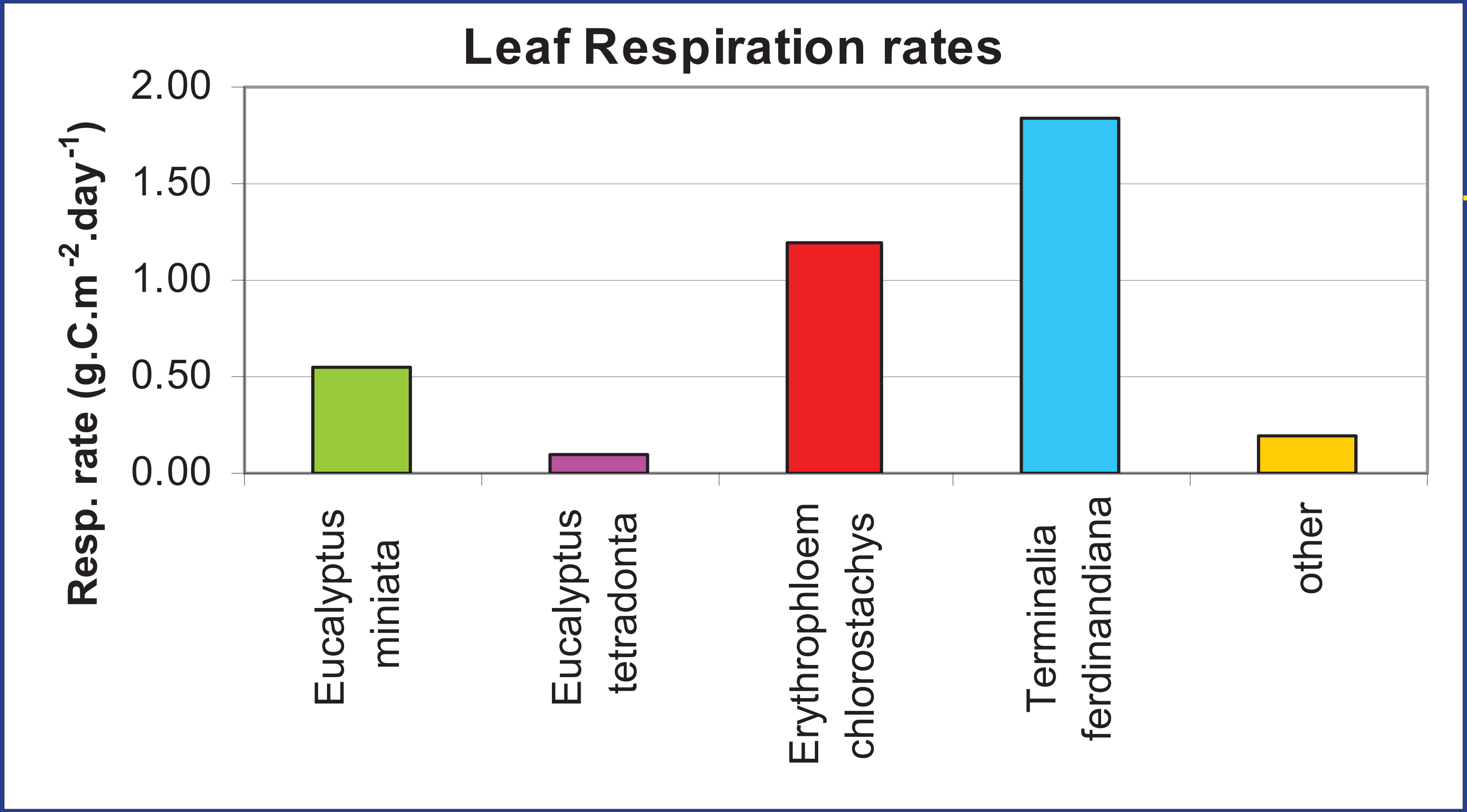


FIGURE 5.24: Leaf respiration rates by species groupings

TABLE 5.4: Comparison of quantification of respiration components of the northern Australian wet-dry tropical savanna

	Chen *et al.* (2002b)	**This investigation**
	g C m^{-2} day^{-1}	g C m^{-2} day^{-1}
Soil	2.3	1.2
Stem	0.11	0.3
Leaf	0.38	7.7
Total	**2.8**	**9.2**

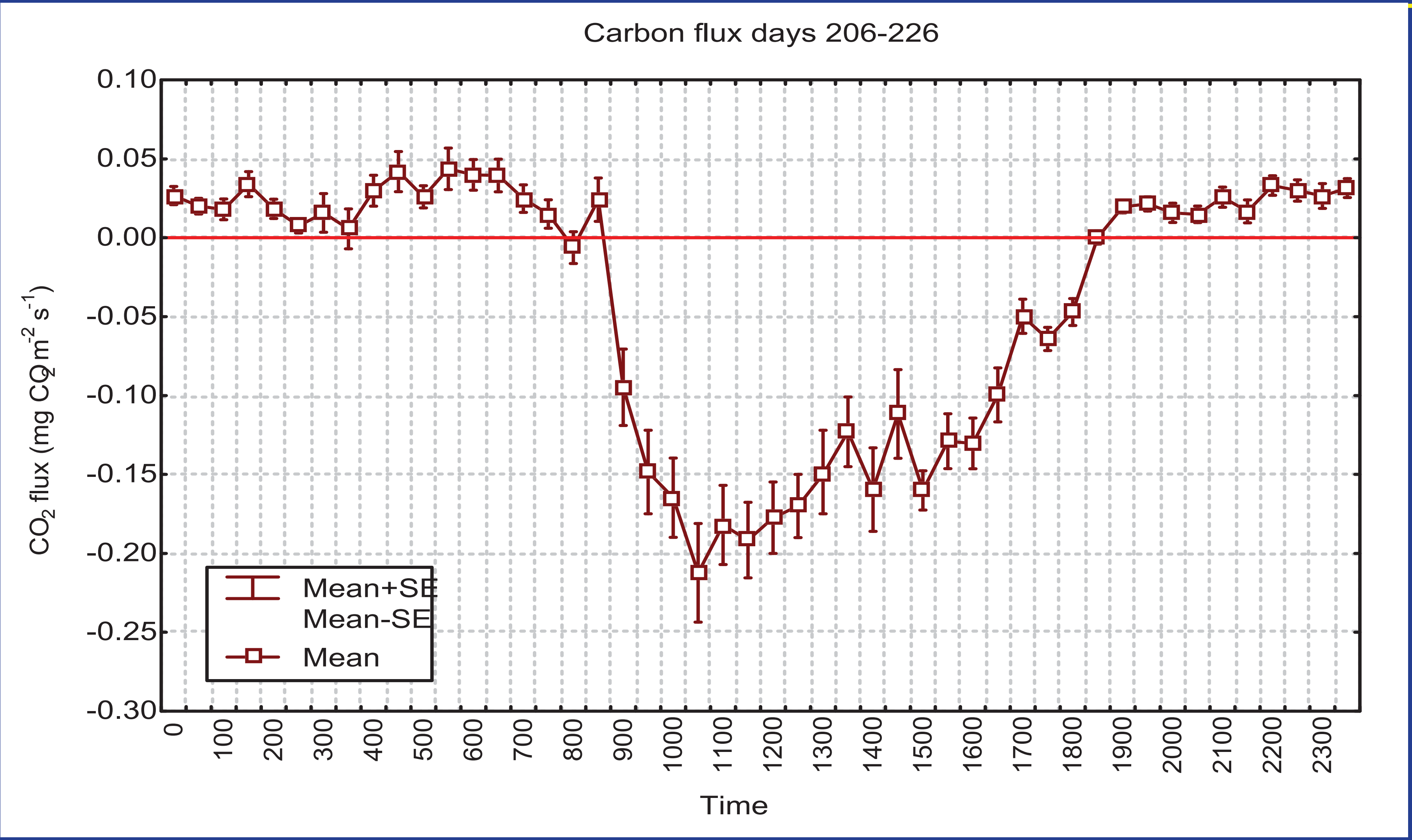


FIGURE 5.28: Uncorrected ecosystem carbon flux for the study site

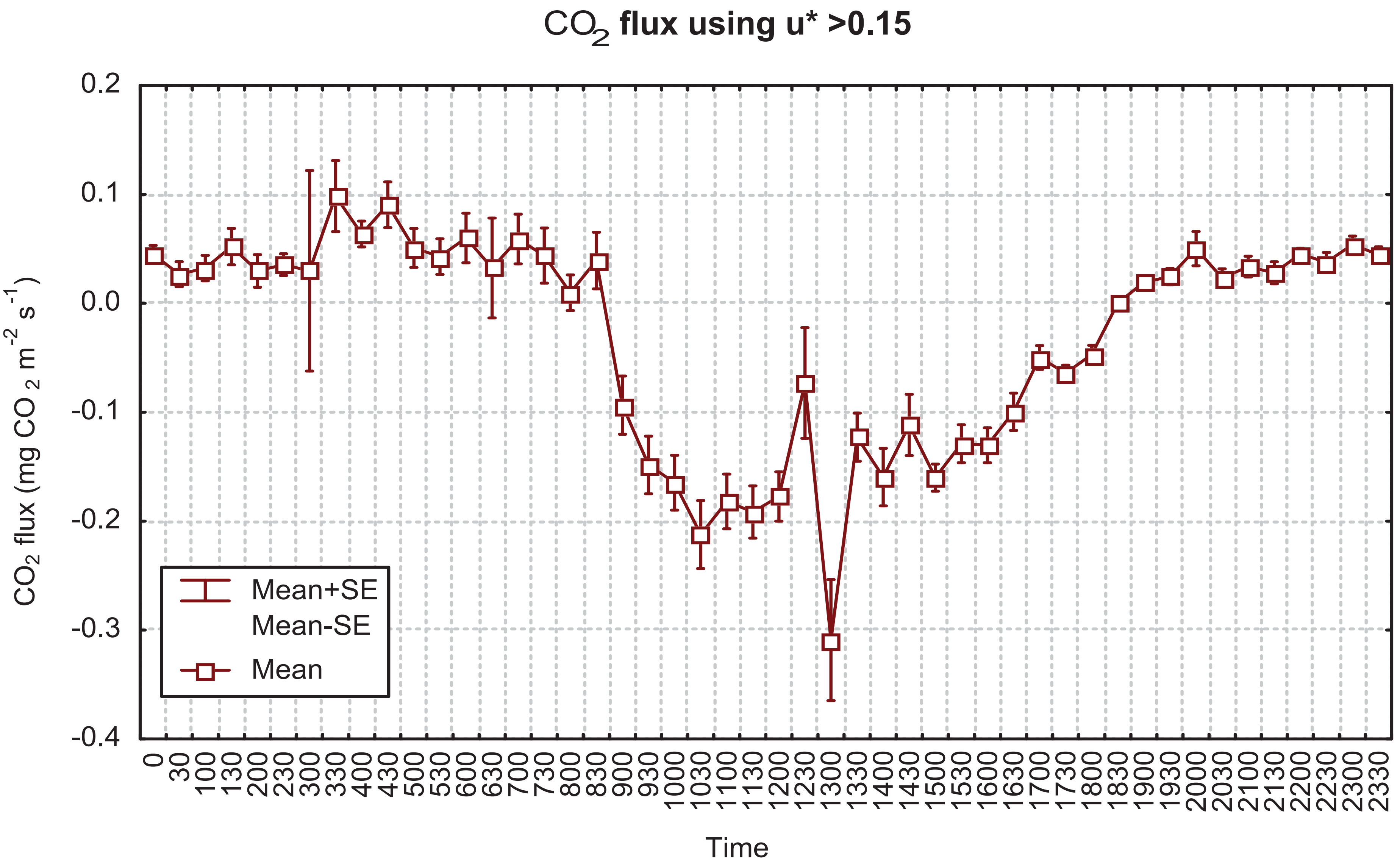
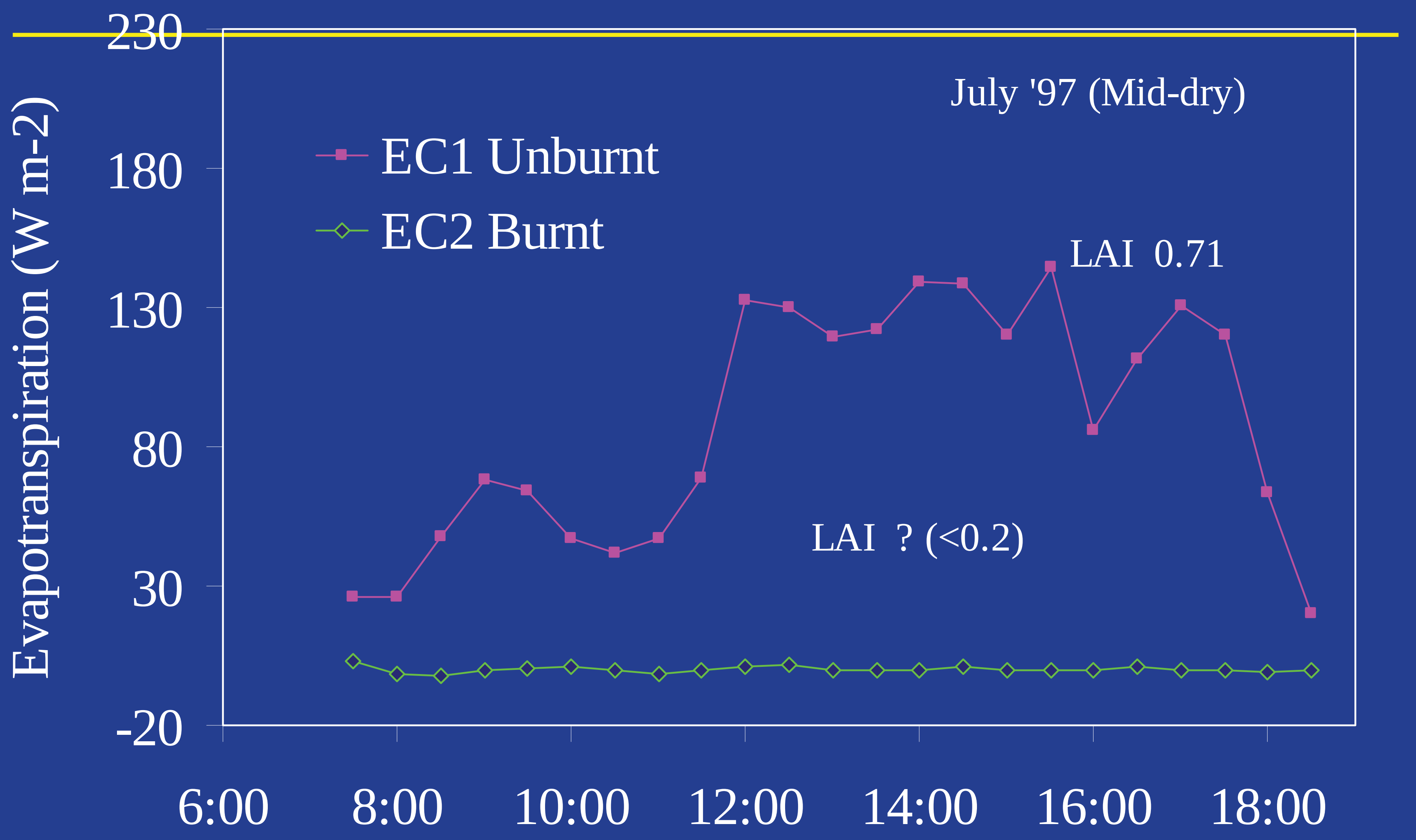


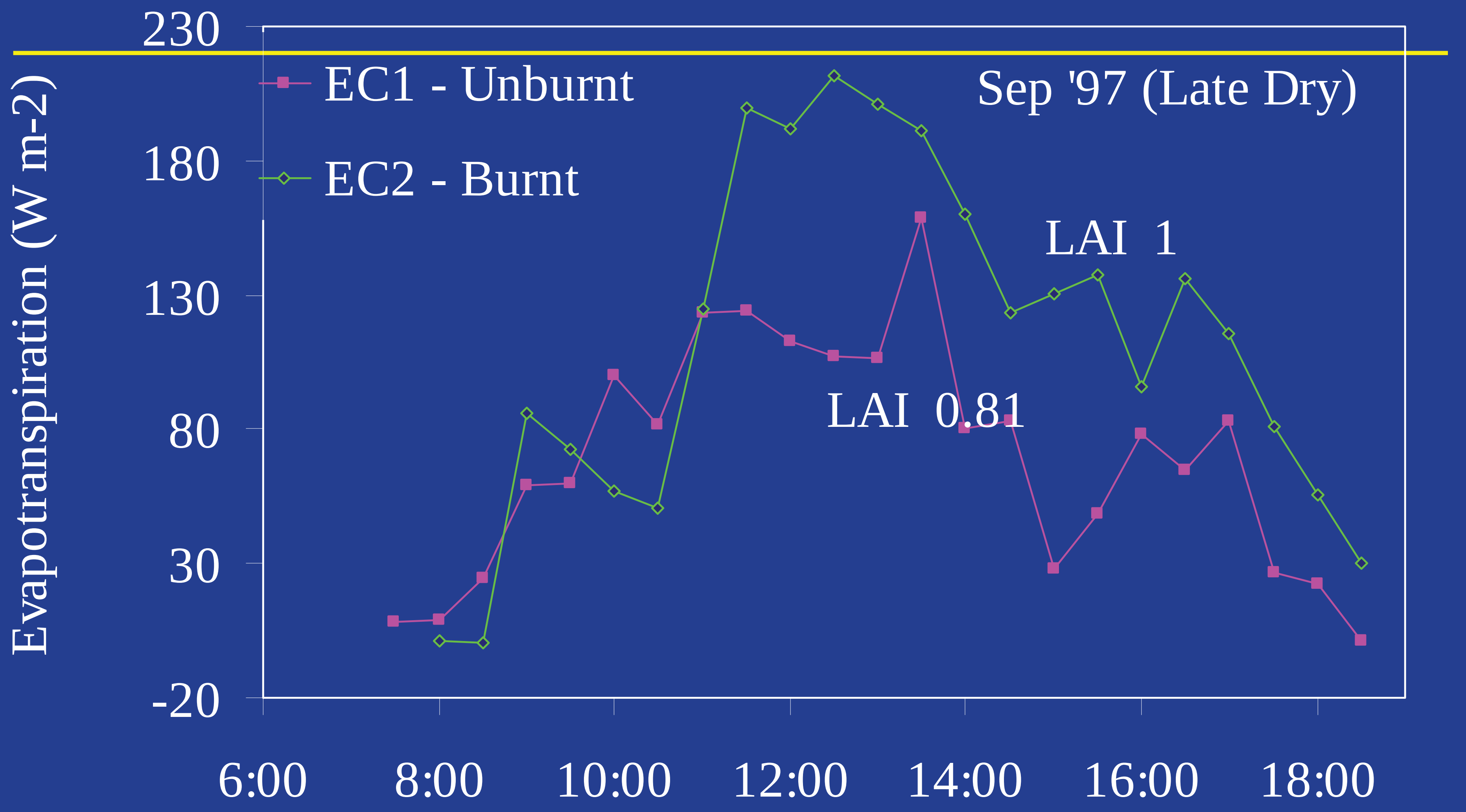
FIGURE 5.29: Ecosystem CO_2 flux using u* >0.15 correction

TABLE 5.6: Comparison of different methods to measure ecosystem respiration

Technique used to measure ecosystem flux	**Result of technique**
Nighttime eddy covariance (raw)	0.94 g C m^{-2} day^{-1}
Nighttime eddy covariance (corrected with u* >0.15)	1.4 g C m^{-2} day^{-1}
Net ecosystem respiration using observations and estimates (this study)	9.2 g C m^{-2} day^{-1}
Net ecosystem respiration in the dry season Chen *et al*. (2002b) results	2.8 g C m^{-2} day^{-1}



Evapotranspiration (W m-2)
230
180
130
80
30
-20
July '97 (Mid-dry)
EC1 Unburnt
EC2 Burnt
LAI 0.71
LAI ? (<0.2)
6:00
8:00
10:00
12:00
14:00
16:00
18:00



Evapotranspiration (W m-2)
230
180
130
80
30
-20
EC1 - Unburnt
EC2 - Burnt
Sep '97 (Late Dry)
LAI 1
LAI 0.81
6:00
8:00
10:00
12:00
14:00
16:00
18:00

Within-catchment variability

- Two tower sites established (EC1, EC2)
- EC2 fire induced flushing

Mean ET Sep '97

EC1	**1.24 mm**	**LAI 0.8**
EC2	**1.55 mm**	**LAI 1.0**

- 20% site difference in LAI
- 20% site difference in ET

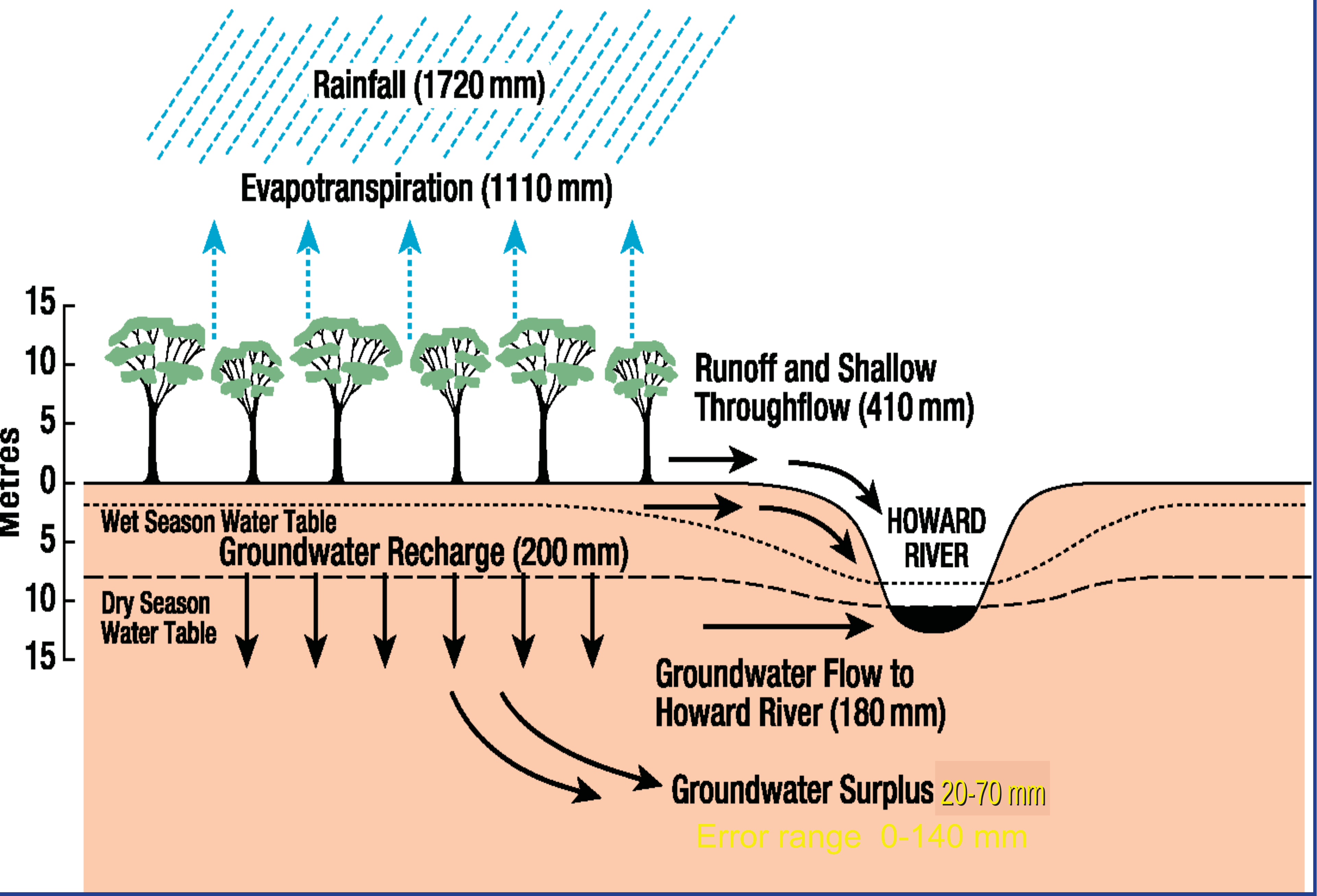
Within Catchment Variation Conclusions

- Spatial and temporal variation of surface fluxes may be significant
- Determined by seasonal variation in LAI and soil water - therefore predictable
- Fire effects significant
- LAI and soil water dynamics
  – Part of on-going research activities in P1.2

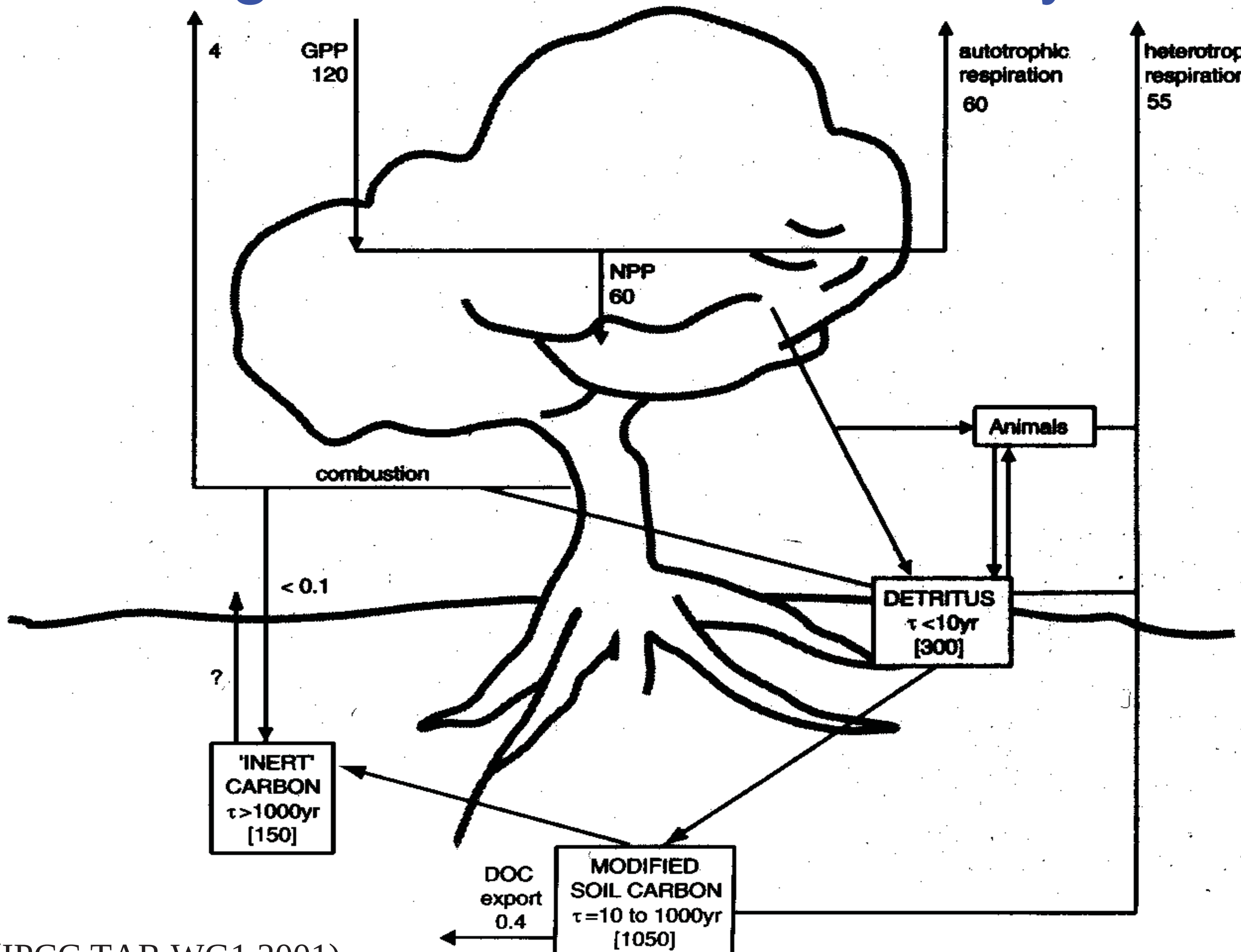
Tropical savanna of northern Australia

Semi-arid savanna of northern Australia

EUCALYPT SAVANNA WATER BALANCE



Vegetation and the carbon cycle



(IPCC TAR WG1 2001)

Impacts of clearing Australia's native vegetat

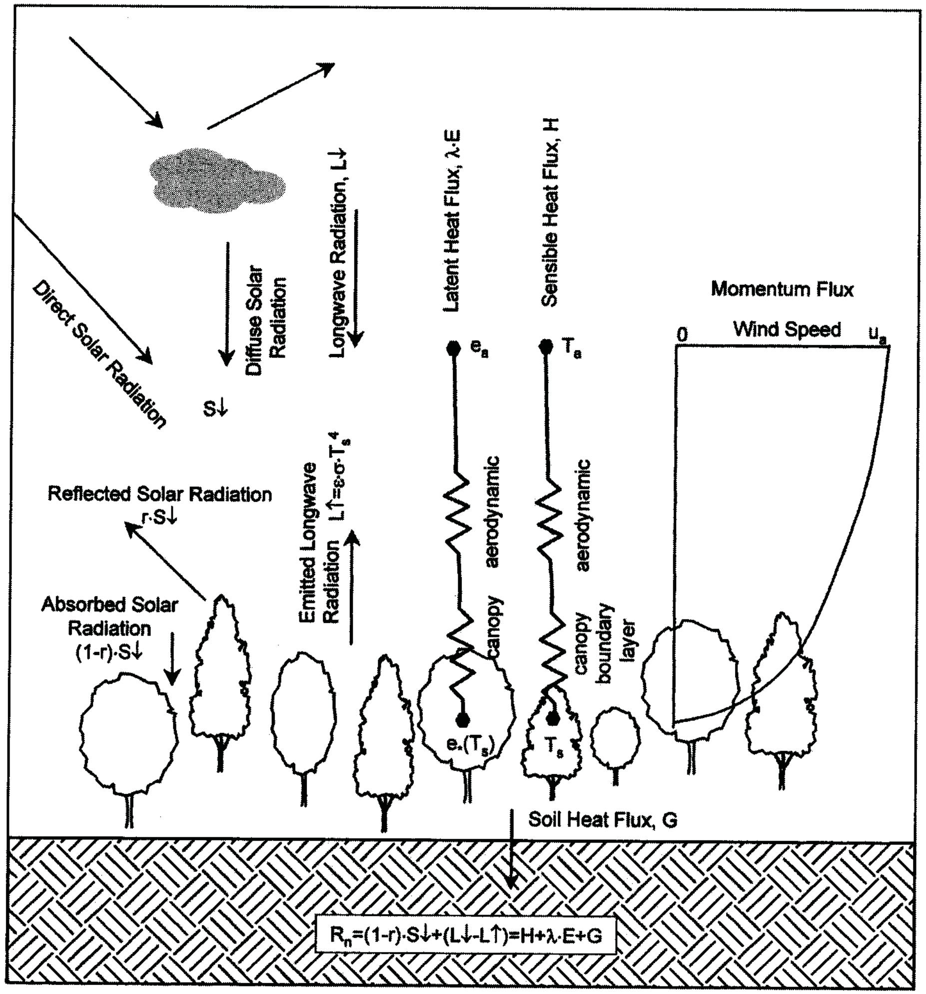


Figure 7.9. Energy balance and momentum transfer for a forest.

Vegetation and the energy cycle

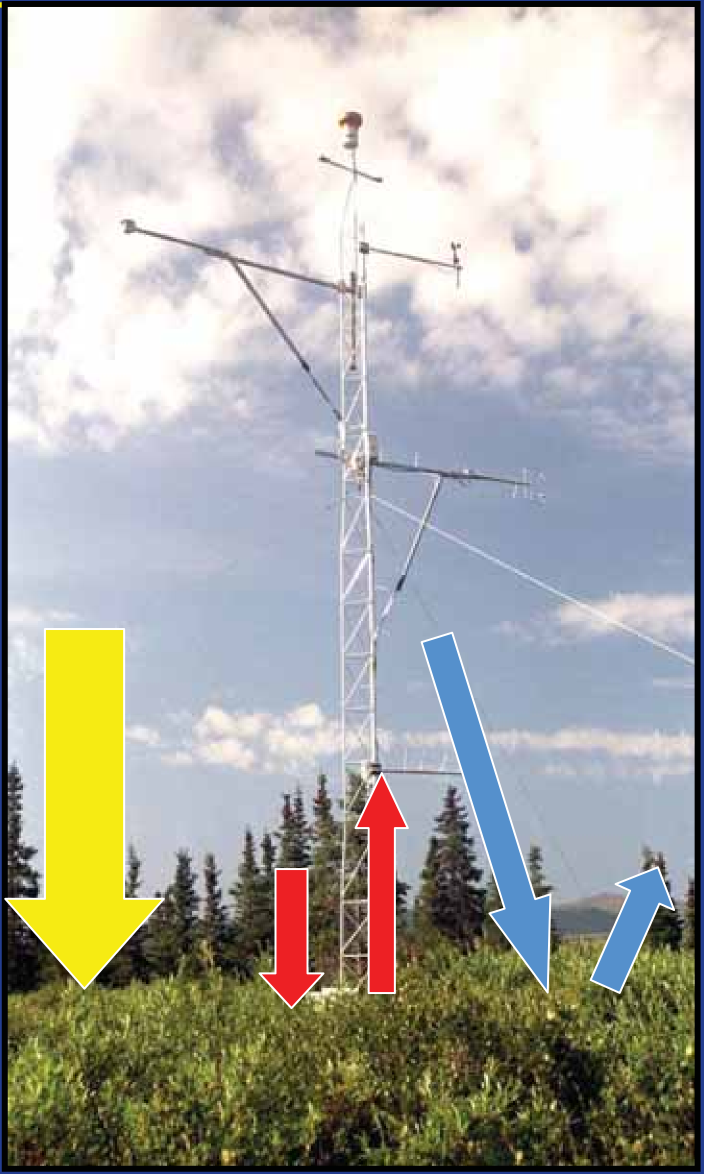
Radiation balance

$$Q^* = (L_{down} - L_{up}) + (K_{down} - K_{up})$$

Albedo (α) = K_{up}/K_{down}

Forest α = 0.1

Grass α = 0.2

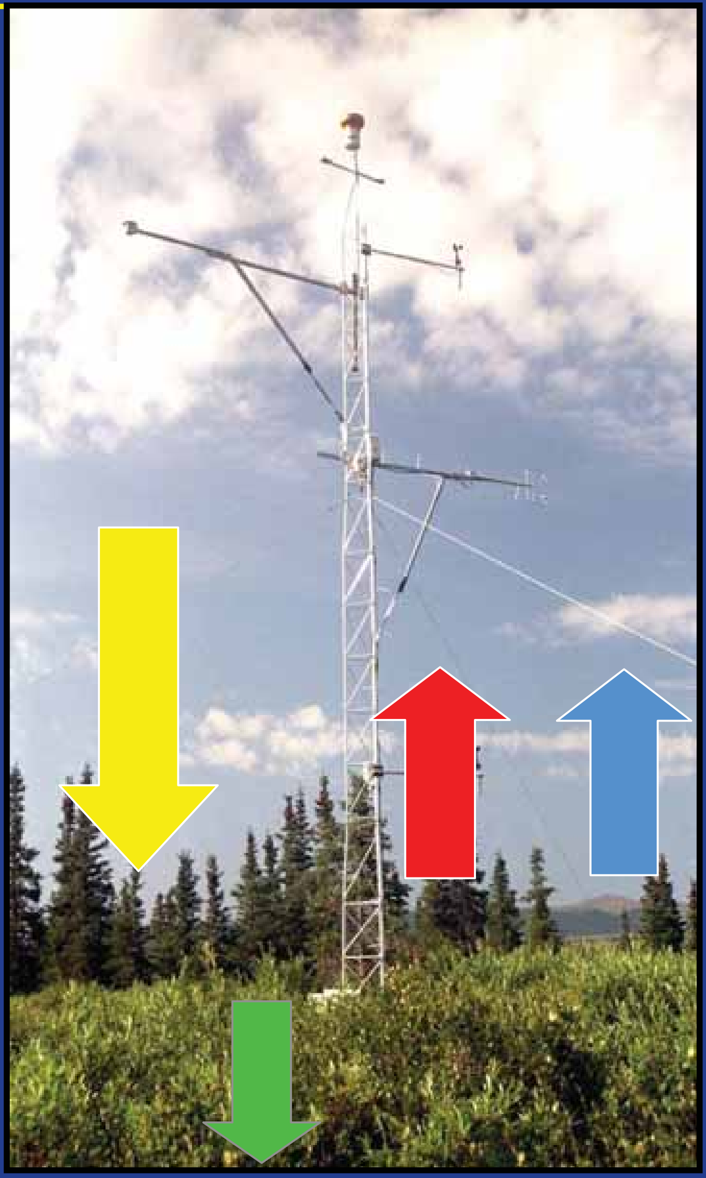


Vegetation and the energy cycle

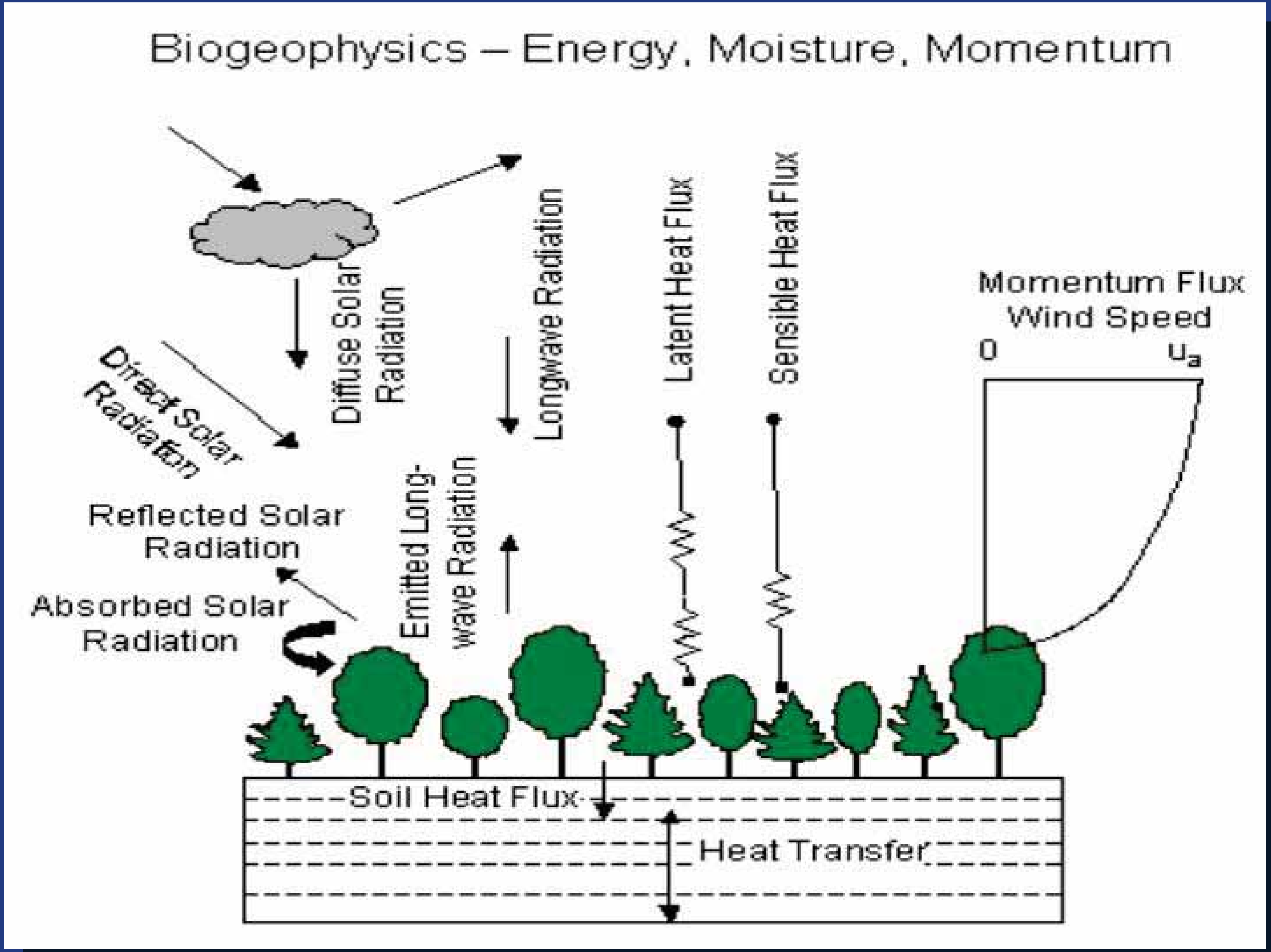
Net radiation drives exchanges of energy at the surface and is described by an energy balance:

$$Q^* = Q_G + Q_H + Q_E$$

- Q^* = Net radiation
- Q_G = Ground heat flux
- Q_H = Sensible heat flux
- Q_E = Latent heat flux



Basics of Climate-Vegetation Interaction



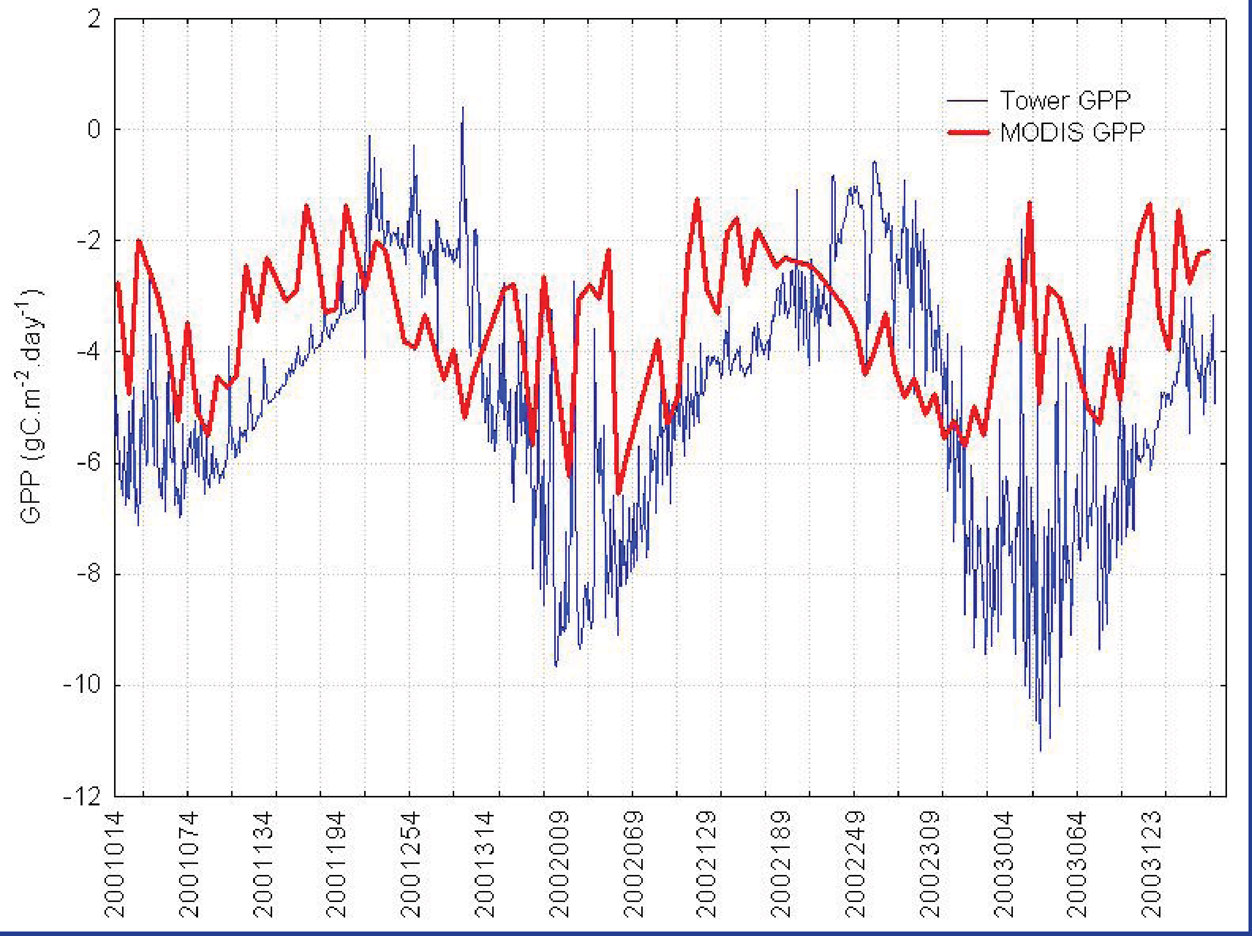
Savanna fluxes

MODIS satellite products to derive GPP and give spatial variations

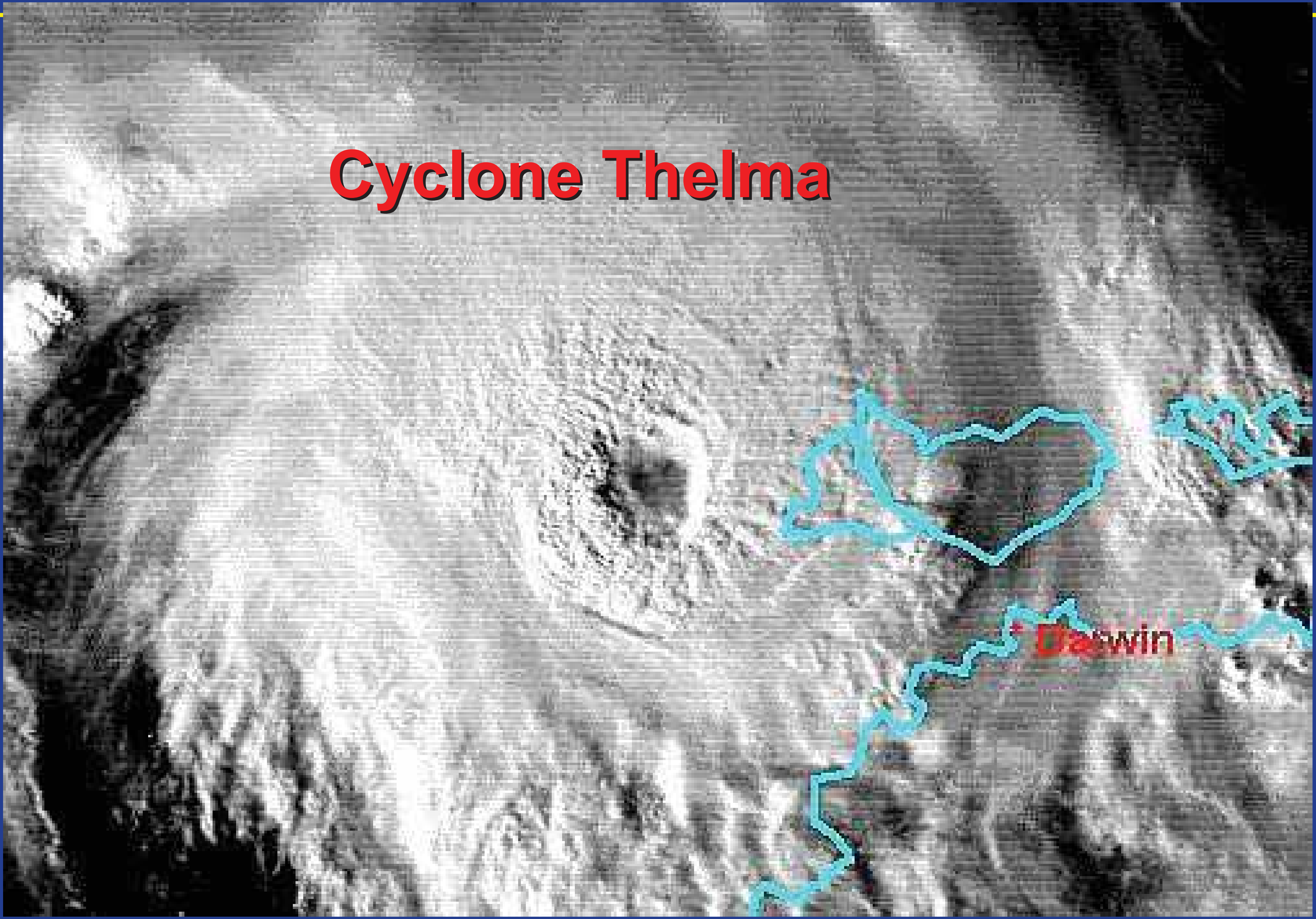
Tower Pixel

6 = Closed Shrublands
8 = Woody Savannas
9 = Savannas

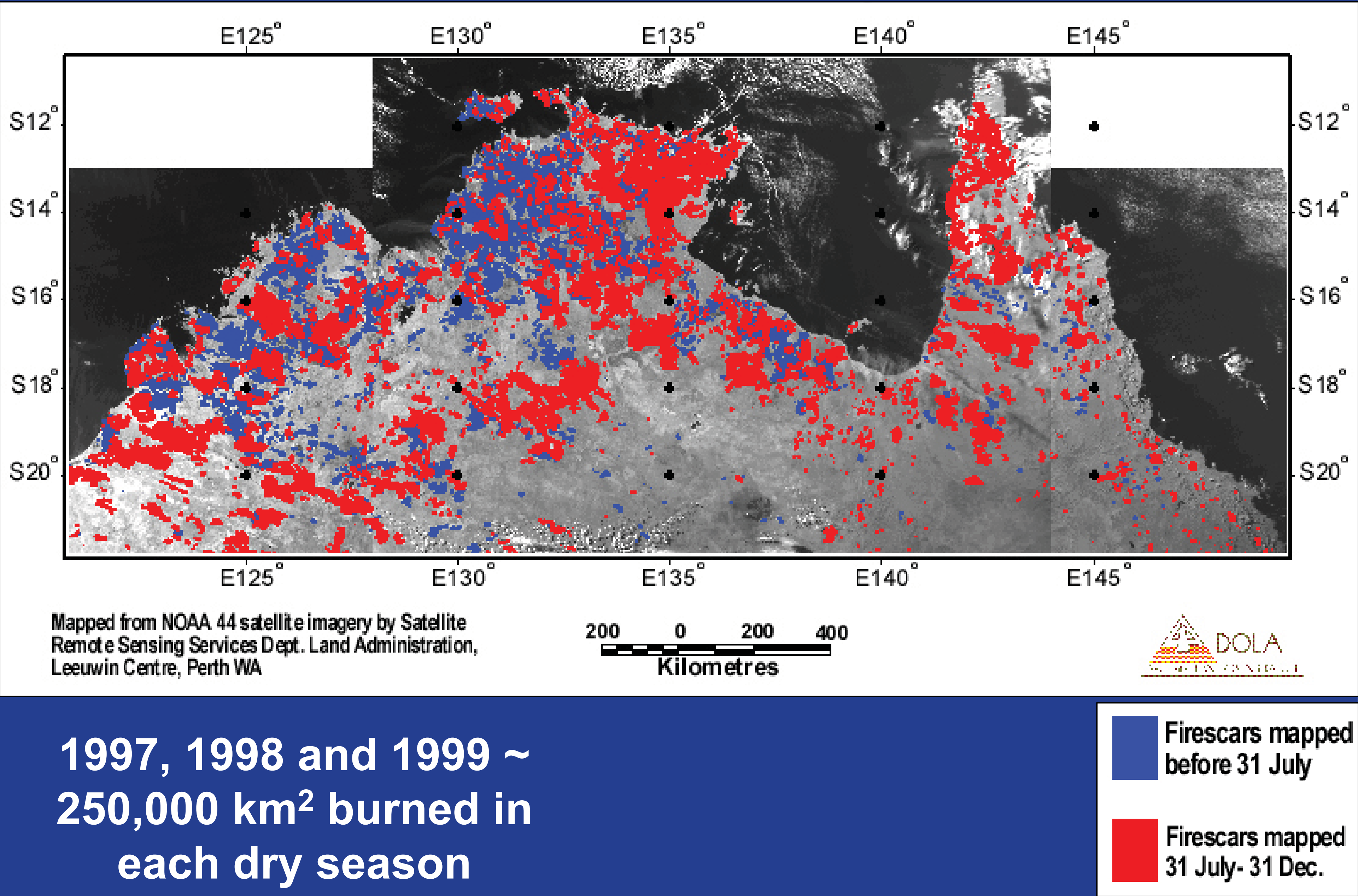
9	8	8	8	8	8	8
8	8	8	6	8	8	8
8	9	8	8	8	9	8
8	8	8	8	9	8	8
8	8	8	8	8	9	8
8	8	8	8	9	8	9
8	8	8	8	8	8	9



Wet-dry tropics - Monsoon driven

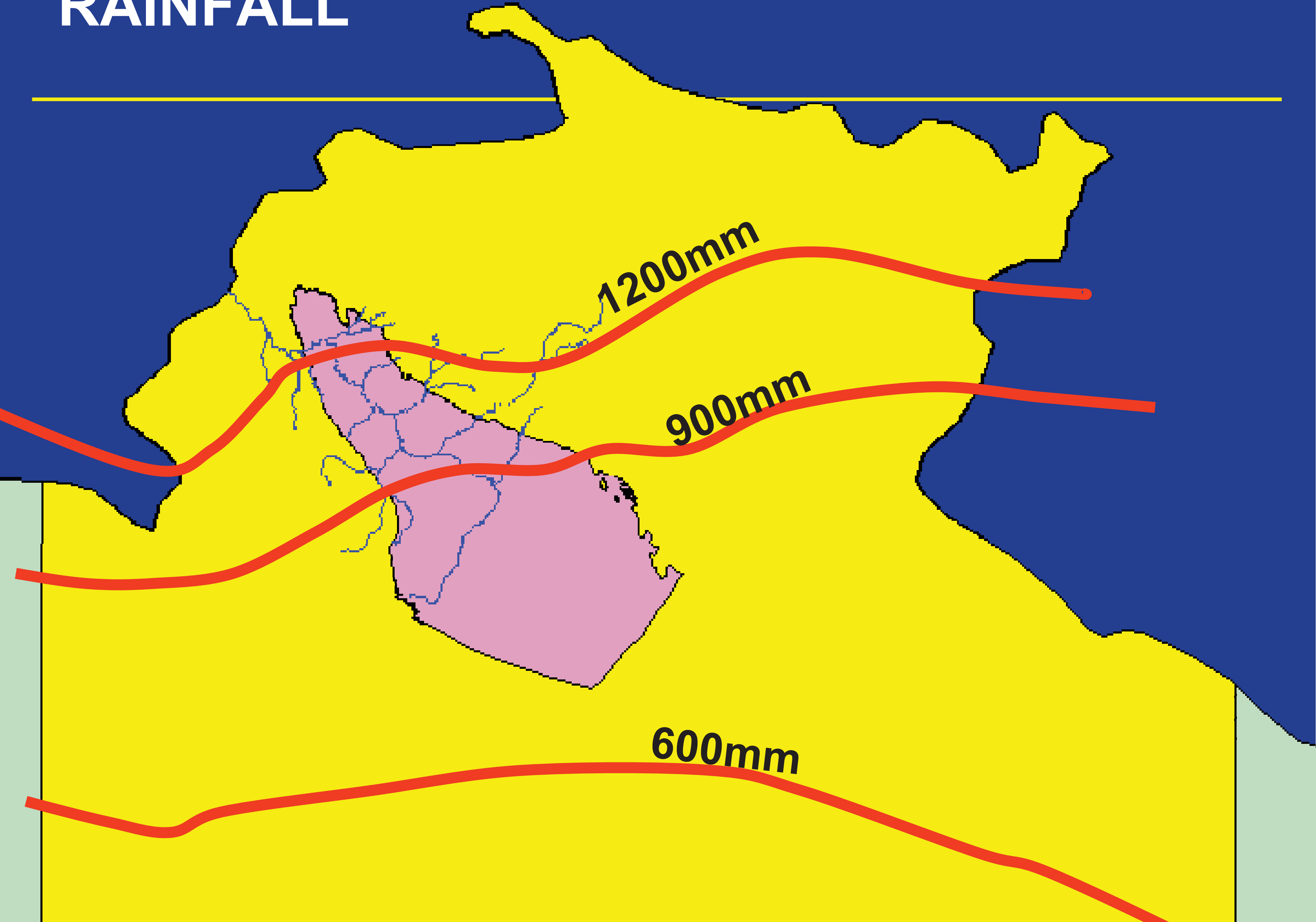


Fire Scars Mapped in 1999

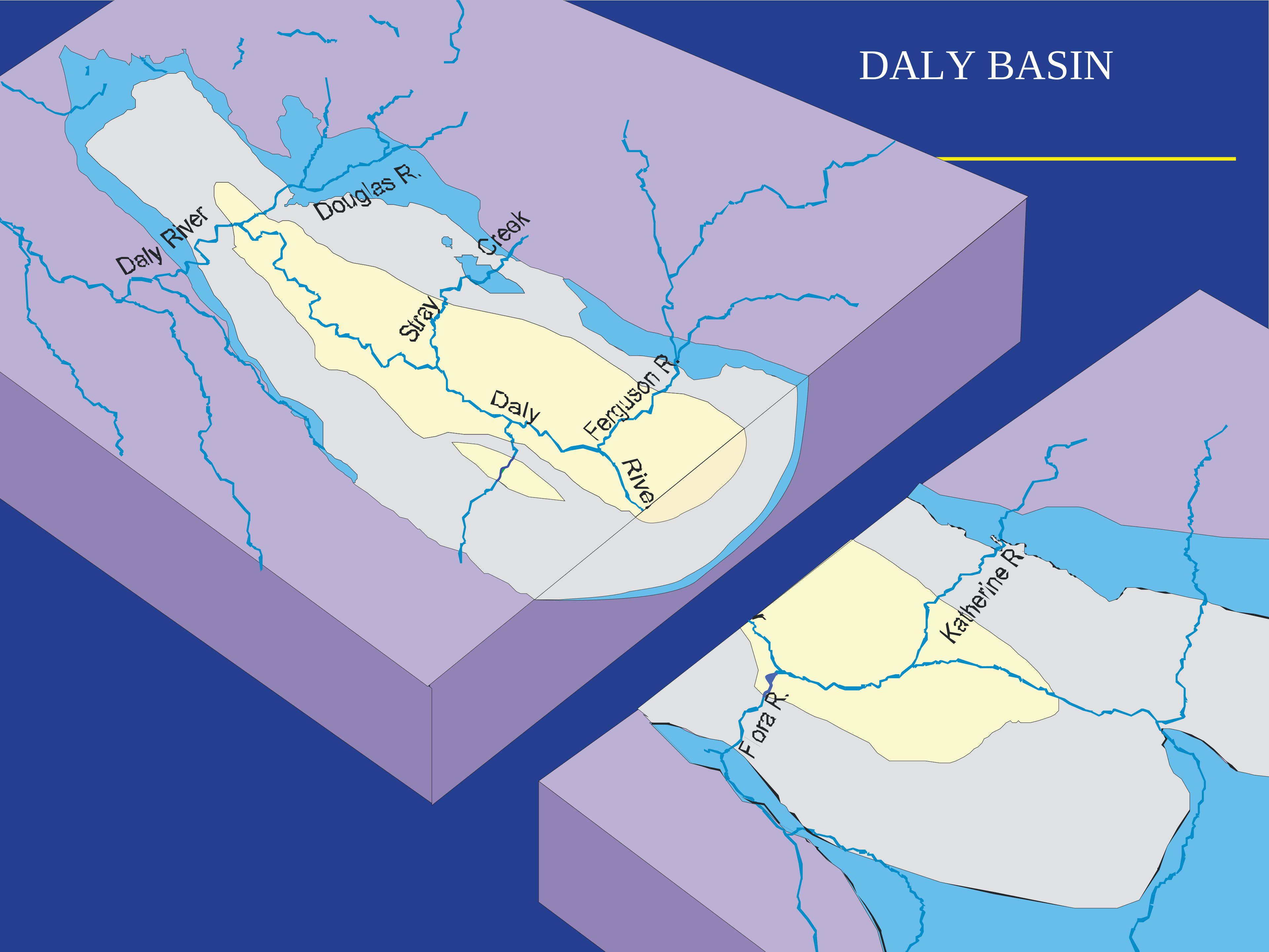


1997, 1998 and 1999 ~ 250,000 km² burned in each dry season

RAINFALL



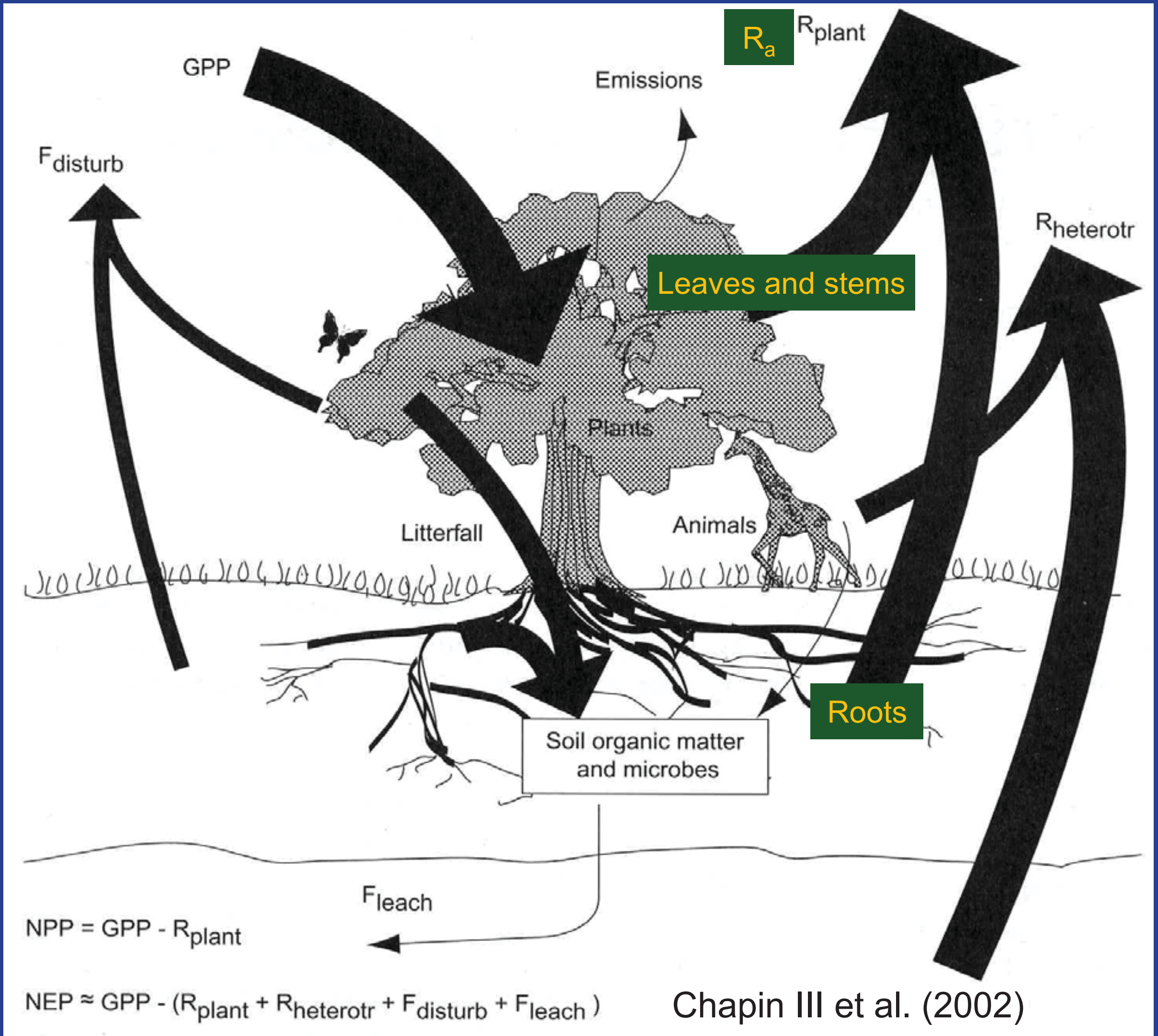
DALY BASIN



Daly River
Douglas R.
Creek
Stray
Daly
Ferguson R.
Rive
Katherine R.
Fora R.

Net ecosystem production

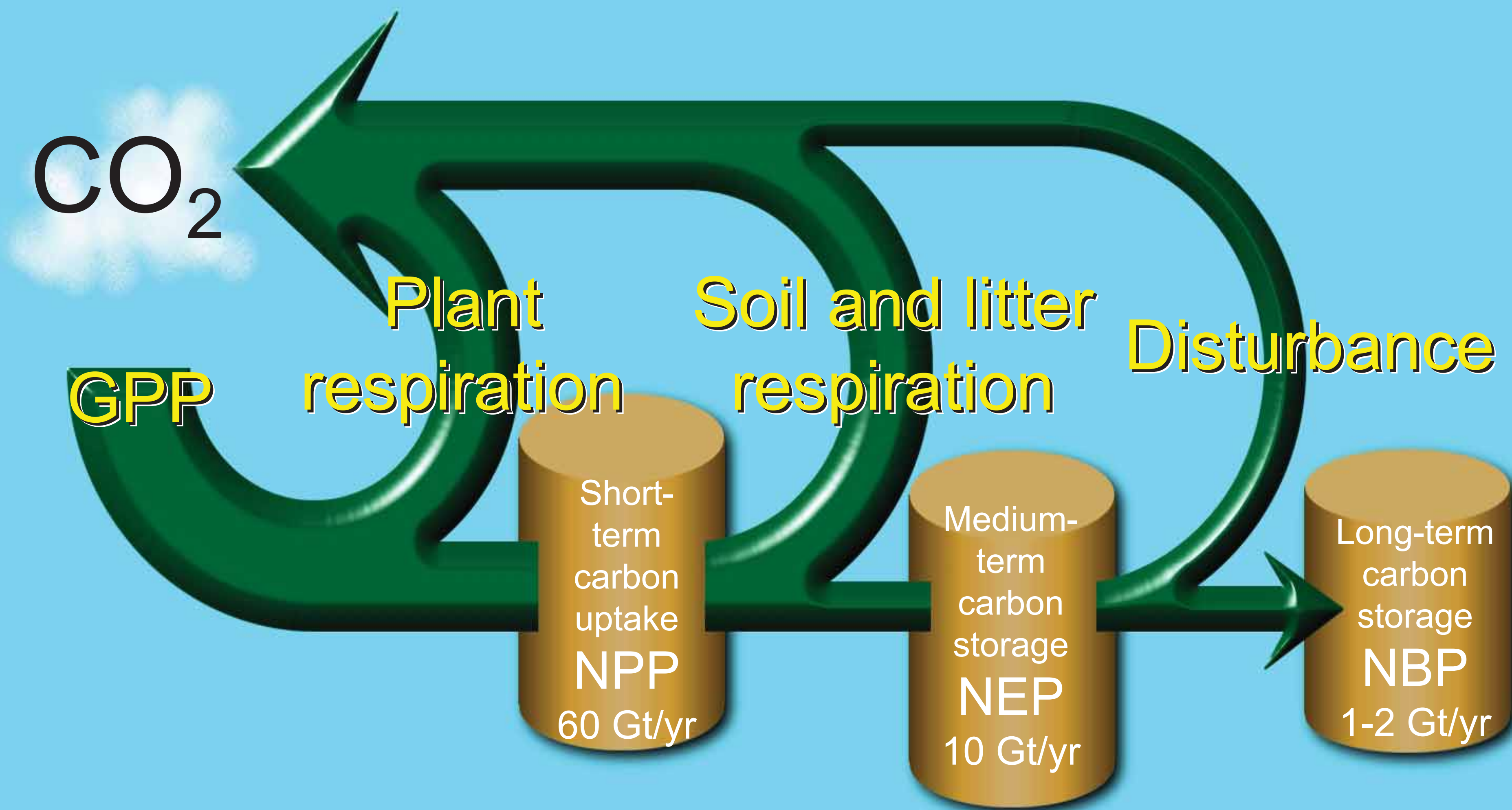
- Net ecosystem production (NEP) = GPP – R_a - R_h



Chapin III et al. (2002)

Net Biome Production

- Disturbance results in increases C losses
- Defined as Net Biome Productivity (NBP)
  - $NBP = GPP – R_a – R_h$ - disturbance



IGBP 1998

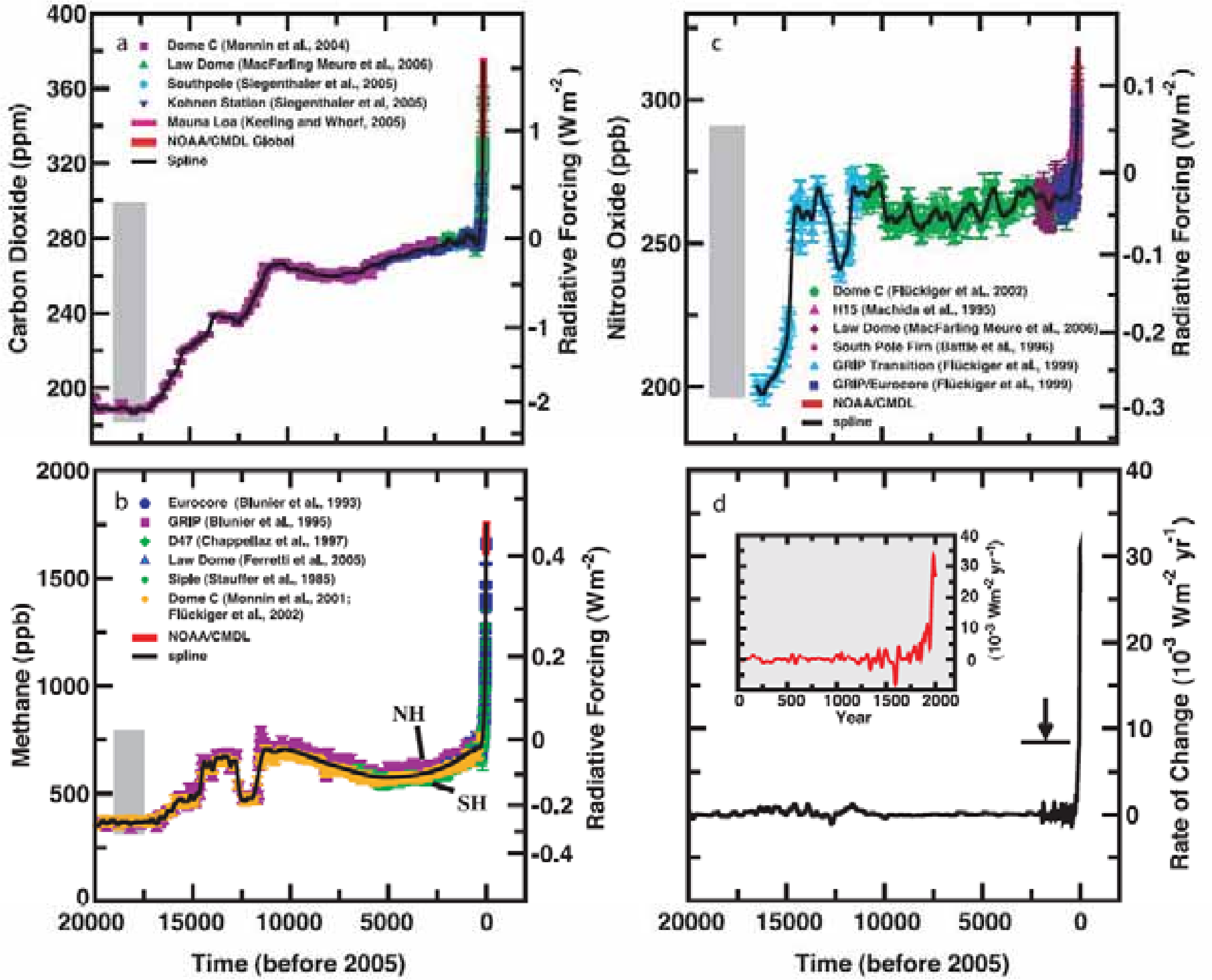
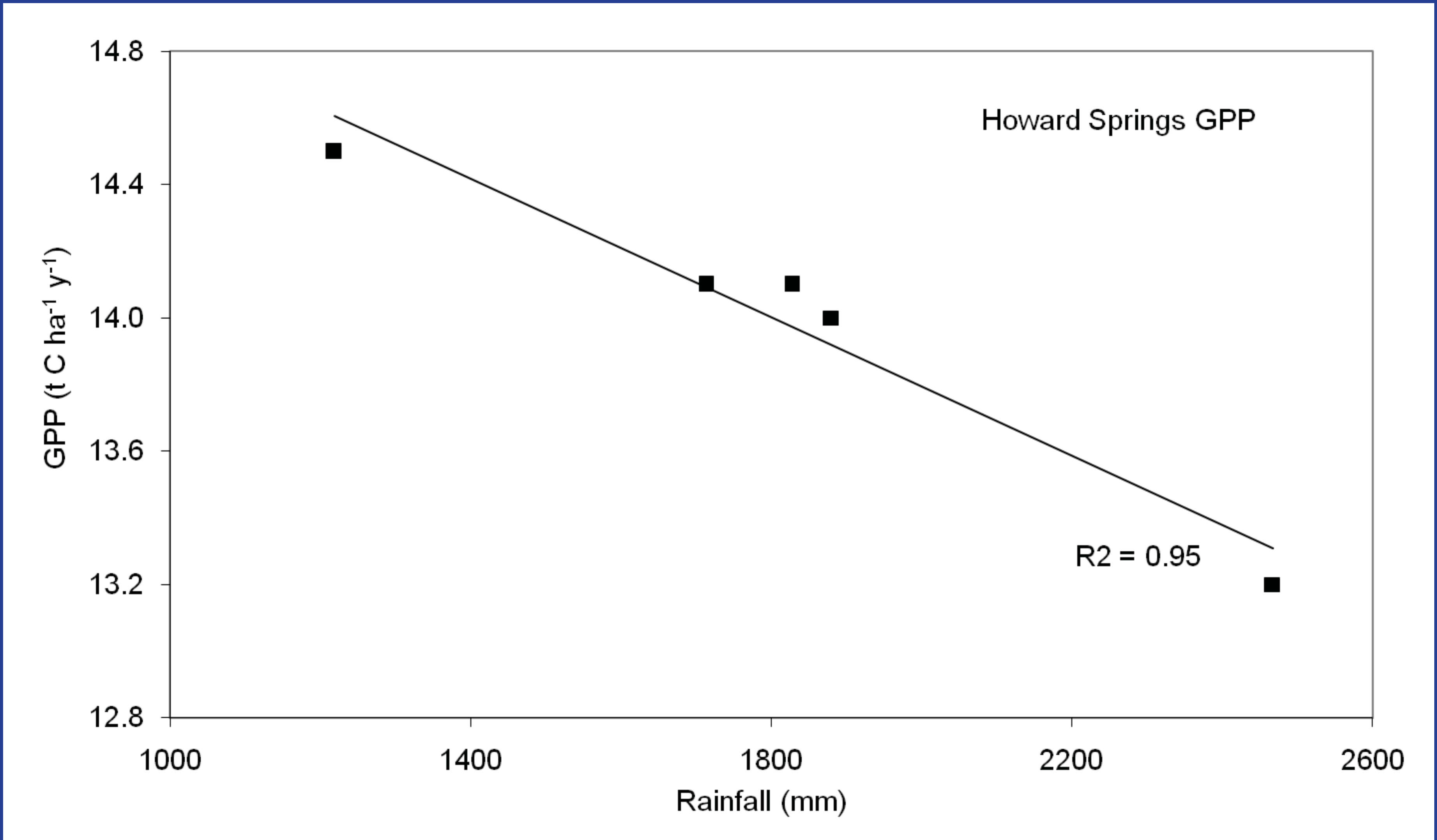


Figure 6.4. *The concentrations and radiative forcing by (a) CO_2, (b) CH_4 and (c) nitrous oxide (N_2O), and (d) the rate of change in their combined radiative forcing over the last 20 kyr reconstructed from antarctic and Greenland ice and firn data (symbols) and direct atmospheric measurements (red and magenta lines). The grey bars show the reconstructed ranges of natural variability for the past 650 kyr (Siegenthaler et al., 2005a; Spahni et al., 2005). Radiative forcing was computed with the simplified expressions of Chapter 2 (Myhre et al., 1998). The rate of change in radiative forcing (black line) was computed from spline fits (Enting, 1987) of the concentration data (black lines in panels a to c). The width of the age distribution of the bubbles in ice varies from about 20 years for sites with a high accumulation of snow such as Law Dome, Antarctica, to about 200 years for low-accumulation sites such as Dome C, Antarctica. The Law Dome ice and firn data, covering the past two millennia, and recent instrumental data have been splined with a cut-off period of 40 years, with the resulting rate of change in radiative forcing shown by the inset in (d). The arrow shows the peak in the rate of change in radiative forcing after the anthropogenic signals of CO_2, CH_4 and N_2O have been smoothed with a model describing the enclosure process of air in ice (Spahni et al., 2003) applied for conditions at the low accumulation Dome C site for the last glacial transition. The CO_2 data are from Etheridge et al. (1996); Monnin et al. (2001); Monnin et al. (2004); Siegenthaler et al. (2005b; South Pole); Siegenthaler et al. (2005a; Kohnen Station); and MacFarling Meure et al. (2006). The CH_4 data are from Stauffer et al. (1985); Steele et al. (1992); Blunier et al. (1993); Dlugokencky et al. (1994); Blunier et al. (1995); Chappellaz et al. (1997); Monnin et al. (2001); Flückiger et al. (2002); and Ferretti et al. (2005). The N_2O data are from Machida et al. (1995); Battle et al. (1996); Flückiger et al. (1999, 2002); and MacFarling Meure et al. (2006). Atmospheric data are from the National Oceanic and Atmospheric Administration's global air sampling network, representing global average concentrations (dry air mole fraction; Steele et al., 1992; Dlugokencky et al., 1994; Tans and Conway, 2005), and from Mauna Loa, Hawaii (Keeling and Whorf, 2005). The globally averaged data are available from http://www.cmdl.noaa.gov/.*


Howard Springs GPP
R2 = 0.95
GPP (t C ha-1 y-1)
14.8
14.4
14.0
13.6
13.2
12.8
1000
1400
1800
2200
2600
Rainfall (mm)