Inescapable variation
Effects of a non-homogeneous flux tower footprint on seasonal carbon fluxes in a temperate forest

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Fig. 1: Forest distribution in Australia. (Australia’s State of the Forest Report, 2008)
Site characteristics

- Evergreen eucalypt forest
- Mixed species (*Eucalyptus rubida*, *E. obliqua*, *E. radiata*)
- History of selective harvesting, burns etc.
- Variable tree heights (South: 15 m North: 25 m)
- Patchy understorey, mainly grasses and ferns
- Flux tower instrumentation at 30 m
Observation – large variability in NEE

Ecosystem dynamics:
- Forest is a carbon sink in all seasons
- Large seasonal variation of NEE
- Important for annual NEE sums, also for respiration and GPP

Fig. 2. Daily NEE, GPP and Respiration from 2010 to 2014.
What can cause such interannual variations in NEE?

climatic drivers?

Terrain?

surface characteristics?
Terrain overview

- Ridge oriented N-S
- Descending NW-SE and NE-SW
- Wind channelled along the orientation of slopes (typically NW/SE)

- Slopes are moderate
- Gullies towards NW, SW and S
- Flat terrain E of tower
Vegetation and wetness within footprint

Fig. 5. Topographic wetness index (TWI) variation within flux tower footprint.

- Topography formed drainage basins
- Large range of wetness within flux footprint → patchy understory
- Drier towards N and W & wetter towards E and SW

Fig. 6. Overstory leaf area index (LAI) variation within flux tower footprint.

- LAI ranges from 1.5 to 2 m²/m²
- Lower LAI towards NW of tower, greater LAI towards SE of tower
Wind direction 2013 and 2014

Fig. 7. Wind rose for 2013. Typically hotter and drier air

Fig. 8. Wind rose for 2014. Typically wetter and moister air

Similar wind roses for both years
Daytime fluxes 2013 and 2014

N wind direction reduced sink capacity
SE wind direction larger sink capacity

Fig. 9. Day-time carbon flux ($F_c$) for 2013.
Fig. 10. Day-time carbon flux ($F_c$) for 2014.

$(\text{mmol m}^{-2} \text{s}^{-1})$
Large contribution of NW-wind direction with reduced sink capacity

Large contribution of SE-wind direction with increased sink capacity

More variation in N wind directions, generally stronger uptake than 2013

Predominantly SE-wind direction with largely increased sink capacity

Fig. 11. Carbon flux during summer 2013 under optimal light conditions (incoming radiation >800 W m\(^{-2}\))

Fig. 12. Carbon flux during summer 2014 under optimal light conditions (incoming radiation >800 W m\(^{-2}\))
Distinct wind speed and wind direction combinations result in CO$_2$ uptake hotspots

- Location and intensity of hotspots varies with season
- Consistencies per sector:
  - NE: very minor contribution
  - SE: hotspot noticeable in every season, strongest in summer
  - SW & NW: varying intensity with season
Yearly variation of summer hotspots

Distinct wind speed and wind direction combinations result in CO$_2$ uptake hotspots

- Location and intensity of hotspots varies with year
- 2010: hotspot extends further North
- 2011: hotspot split
- 2012 and 2014: hotspot very distinct
- 2013: hotspot intensity is weak
Role of footprint:

- Forest is C sink in all wind sectors
- Large range of C uptake between all sectors
- Hotspot location and extent reflected in wind sector contribution:
  - 2010 & 2011: northward shift = increased contribution of NE sector
  - 2013: weak hotspot = reduced sink
  - 2012 & 2014: strong hotspot = strong sink

Ecosystem dynamics:

- Large seasonal variation of NEE
- Large range of annual sums
Role of footprint:

- % contribution varies with sector
  - SE sector contributes ~35%
- largest differences in summer months
  - SE sector contributes ~50%
- continental scale climate patterns largely modified sectoral contributions (La Niña in 2010-2011)
steps:

1) determine the average wind pattern from all observation years for each wind sector and sum the occurrences when fluxes originated from each sector, then divided by the number of observation years
   ➢ *standardized frequency contribution for each sector*

2) determine the average carbon flux from each sector during each year
   ➢ *preserves natural variability within each sector and year*

3) re-calculate the cumulative carbon uptake for each sector and each year based on the average wind patterns that were standardized over the study period, i.e. we multiplied the sector-specific results from step 1) with average fluxes from step 2)
   ➢ *footprint coverage now equal for each year*

4) integrate across all sectors in each year
   ➢ *result: remaining annual variability of CO2 fluxes can be linked more accurately to variations in ecophysiological drivers*
### Footprint adjustment (%)

<table>
<thead>
<tr>
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### Footprint adjustment (g C m\(^{-2}\) yr\(^{-1}\))

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### Annual budgets (g C m\(^{-2}\) yr\(^{-1}\))

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What can cause such interannual variations in NEE?

**climatic drivers?**
- Hot and dry air from N
- Colder and wetter air from S

**Terrain?**
- Channels northerly winds into NW direction
- Channels southerly winds into SE direction

**surface characteristics?**
- Higher LAI in the SE direction
- Lower LAI in the NW direction
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