A comparison of carbon storage and exchange in two subalpine grasslands

Ian McHugh
Context and objectives

- Part of HCFEF project under Bushfire CRC
- Montane / subalpine / alpine ecosystems vulnerable to climate change because of: 1) rate of climate change; 2) sensitivity to change; 3) inability to migrate (‘Islands in the sky’)
- How is the carbon cycle, and thus carbon storage, likely to be affected?

1. Quantify soil and vegetation carbon reservoirs
   - Field sampling / laboratory analysis of soils and vegetation
2. Quantify annual net ecosystem exchange (NEE)
   - Eddy covariance technique / auxiliary chamber measurements
3. Investigate drivers of variation in NEE between sites
   - Partition GPP and $R_e$ and quantify biotic and abiotic factors
Two climatologically contrasting subalpine grasslands...

Dargo:
S37° 08.003’
E147 10.258’
1518mASL
• South-easterly aspect
• Exposed midslope

Nimmo:
S36° 12.953’
E148 33.165’
1326mASL
• South-easterly aspect
• Valley floor
### Climate

**Temperature (°C)**

<table>
<thead>
<tr>
<th></th>
<th>Dargo</th>
<th>Nimmo</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>14.4</td>
<td>15.7</td>
</tr>
<tr>
<td>July</td>
<td>-0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Annual</td>
<td>6.8</td>
<td>7.7</td>
</tr>
</tbody>
</table>

**Precipitation (mm)**

<table>
<thead>
<tr>
<th></th>
<th>Dargo</th>
<th>Nimmo</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>1084</td>
<td>996</td>
</tr>
<tr>
<td>2008</td>
<td>812</td>
<td>970</td>
</tr>
</tbody>
</table>
## Data quality assurance

<table>
<thead>
<tr>
<th>Automatic rejection</th>
<th>Conditional rejection</th>
<th>Statistical rejection</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Precipitation</td>
<td>Based on combined quality flags (see Foken and Wichura, 1996; Aubinet, 2000; Foken et al. 2004) of:</td>
<td>Outlier identification based on median of absolute deviation from differences between neighbouring points (see Papale, 2006); applied iteratively.</td>
</tr>
<tr>
<td>• Plausible range limits</td>
<td>1. Time series stationarity</td>
<td></td>
</tr>
<tr>
<td>• Instrument diagnostics</td>
<td>2. Integral turbulence</td>
<td></td>
</tr>
<tr>
<td>• Missing data &gt;30%</td>
<td>3. Wind direction</td>
<td></td>
</tr>
<tr>
<td>• Momentum +ve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• $F_c$ and LE if $H$ false</td>
<td>Class 1-3 data highest quality (used for parameterisations); 4-6 acceptable; 6-8 conditional on other criteria; &gt;8 rejected.</td>
<td></td>
</tr>
<tr>
<td>• $F_c$ if LE false</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Low $u^*$ correction with objective threshold determination technique (Reichstein et al., 2005)
- Low temperature semi-empirical LI7500 correction (Burba et al., 2008)
Data imputation: artificial neural nets

- Multi-layer perceptrons
- Trained annually
- SOS cost function
- Test and train datasets
- Early stopping procedure

<table>
<thead>
<tr>
<th>Target</th>
<th>Input</th>
</tr>
</thead>
</table>
| NEE    | 1. Incoming photosynthetically active radiation (PAR)  
2. Reflected PAR  
3. Air temperature (2m)  
4. Soil temperature (0-0.1m)  
5. Vapour pressure deficit  
6. Volumetric soil moisture content (0-0.1m) |
\[ R_e = f \overline{T_s} \cdot f(VWC) \]

Temperature response: Lloyd & Taylor (1994) modified Arrhenius function

\[ f \overline{T_s} = R_{ref} e^{E_o \left( \frac{1}{T_{ref} - T_0} - \frac{1}{T_s - T_0} \right)} \]

- \( R_{ref} \): reference respiration
- \( E_o \): activation energy
- \( T_{ref} \): reference temperature (283.15K)
- \( T_0 \): zero \( R_e \) temperature (227.13K)

Soil moisture response: generic sigmoid function (see Richardson et al. 2007)

\[ f(VWC) = \frac{1}{1 + e^{\Theta_1 - \Theta_2 VWC}} \]

- \( \Theta_1 \): sigmoid shape parameters
- \( \Theta_2 \): sigmoid shape parameters
GPP estimation

Light response: modified Michaelis-Menten (1913) rectangular hyperbolic function (Falge et al., 2001)

\[
GPP = \frac{\alpha Q}{1 - Q/2000 + \alpha Q/A_{\text{opt}}}
\]

• \(\alpha\) quantum efficiency (\(\mu\text{mol CO}_2 / \mu\text{mol photons}\))
• \(Q\) photosynthetic photon flux density (\(\mu\text{mol photons m}^{-2} \text{ s}^{-1}\))
• \(A_{\text{opt}}\) GPP @ \(Q = 2000\mu\text{mol photons m}^{-2} \text{ s}^{-1}\)
Data validation

Systematic error checks:
1. Energy balance closure
2. Comparison of nocturnal and light use curve-derived $R_e$
3. Comparison of eddy covariance and chamber-based $R_e$
Carbon storage

Soil organic C density ± SE (kgC m⁻²)

<table>
<thead>
<tr>
<th></th>
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<th>Nimmo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19.12±0.39</td>
<td>13.34±0.35</td>
</tr>
</tbody>
</table>

Phytomass components ± SE (gC m⁻²)

<table>
<thead>
<tr>
<th></th>
<th>Dargo</th>
<th>Nimmo</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGP</td>
<td>441.8±52.1</td>
<td>231.5±36.4</td>
</tr>
<tr>
<td>BGP</td>
<td>317.3±35.1</td>
<td>207.7±19.6</td>
</tr>
<tr>
<td>Total</td>
<td>759.2±55.5</td>
<td>439.3±40.1</td>
</tr>
</tbody>
</table>
Net ecosystem exchange (NEE)
## Annual NEE

<table>
<thead>
<tr>
<th>Year</th>
<th>Dargo</th>
<th>Nimmo</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>-76.6 ± 14.9</td>
<td>-172.8 ± 23.8</td>
</tr>
<tr>
<td>2008</td>
<td>-83.8 ± 11.9</td>
<td>-322.7 ± 28.2</td>
</tr>
</tbody>
</table>

**NEE±95%CI (gC m$^{-2}$)**

![Graph showing cumulative NEE (gC m$^{-2}$) for Dargo and Nimmo in 2007 and 2008.](graph.png)
Dargo

2007

\[ R_e = 1064.0 \pm 10.7 \text{gC m}^{-2} \text{a}^{-1} \]
\[ \text{NEE} = -76.6 \pm 14.9 \text{gC m}^{-2} \text{a}^{-1} \]
\[ \text{GPP} = -1140.6 \pm 10.7 \text{gC m}^{-2} \text{a}^{-1} \]

2008

\[ R_e = 1184.4 \pm 11.9 \text{gC m}^{-2} \text{a}^{-1} \]
\[ \text{NEE} = -83.8 \pm 11.9 \text{gC m}^{-2} \text{a}^{-1} \]
\[ \text{GPP} = -1268.2 \pm 11.9 \text{gC m}^{-2} \text{a}^{-1} \]
Nimmo

\[ R_e = 1127.1 \pm 15.8 \text{gC m}^{-2} \text{a}^{-1} \]

\[ NEE = -172.8 \pm 23.8 \text{gC m}^{-2} \text{a}^{-1} \]

\[ GPP = -1299.9 \pm 15.8 \text{gC m}^{-2} \text{a}^{-1} \]

\[ R_e = 1174.9 \pm 16.5 \text{gC m}^{-2} \text{a}^{-1} \]

\[ NEE = -322.7 \pm 28.2 \text{gC m}^{-2} \text{a}^{-1} \]

\[ GPP = -1497.6 \pm 16.5 \text{gC m}^{-2} \text{a}^{-1} \]
Global context

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Annual NEE (gC m⁻²)</th>
<th>Dargo</th>
<th>Nimmo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasslands</td>
<td>+400 to -800</td>
<td>91.5 ≤ 93.3 ≤ 95.1 (85.0)</td>
<td>84.5 ≤ 86.7 ≤ 89.0</td>
</tr>
<tr>
<td>Alpine grasslands</td>
<td>+112 to -282</td>
<td>91.7 ≤ 93.4 ≤ 95.1 (82.3)</td>
<td>76.5 ≤ 78.5 ≤ 80.4</td>
</tr>
</tbody>
</table>

Yi et al. (2011)

Baldocchi (2008)

Re:GPP = 77%
Causes of NEE differences...

1. $R_e$

2. Abiotic  Biotic  Abiotic  Biotic

   - $T$
   - VWC

   - $E_0$
   - $R_{ref}$

   - $K$
   - VPD
   - VWC
   - $T$

   - $\alpha$
   - $A_{max}$
$R_e$ response

<table>
<thead>
<tr>
<th></th>
<th>$E_0$</th>
<th>$R_{ref}$</th>
<th>$\theta_1$</th>
<th>$\theta_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dargo</td>
<td>0.1581</td>
<td>221.01</td>
<td>1.595</td>
<td>17.94</td>
</tr>
<tr>
<td>Nimmo</td>
<td>0.1435</td>
<td>237.6</td>
<td>1.178</td>
<td>18.55</td>
</tr>
</tbody>
</table>
$R_e$ and GPP
Summing up...

- **Intersite NEE differences (Dargo < Nimmo)**
  - $R_e$ (Dargo $\approx$ Nimmo)
  - GPP (Dargo $<$ Nimmo)
    - Abiotic factors (dominant)
      - 1) Snow season length ($K \downarrow$); 2) air temperature
    - Biotic factors (secondary)
      - $A_{\text{opt,Dargo}} < A_{\text{opt,Nimmo}}$; $\alpha_{\text{Dargo}} \approx \alpha_{\text{Nimmo}}$

- **Interannual NEE differences (2008 $>$ 2007)**
  - $R_e$ (2008 $>$ 2007)
    - Abiotic factors (dominant)
      - 1) Soil moisture; 2) soil temperature
    - Biotic factors (secondary)
      - $R_{\text{ref,2008}} > R_{\text{ref,2007}}$; $E_{0,2008} \approx E_{0,2007}$
  - GPP (2008 $>$ 2007)
    - Abiotic factors (dominant)
      - Soil moisture (Nimmo); Snow season length ($K \downarrow$) and soil moisture (Dargo)
Thank you for your attention!

... and thanks to

JB, P. Isaac
Mike Kemp
Mark Adams, Rob Simpson