Long term carbon and greenhouse gas exchange estimates with eddy covariance: achievements, pitfalls and questions.

Marc Aubinet
Eddy covariance for dummies

- Measures net fluxes exchanged by surface with atmosphere (H₂O, CO₂, CH₄, N₂O, BVOC,...)
- Continuous (every half hour)
- Long term (> 20 years)
- Spatially integrated (1 ha)
- Based on atmospheric turbulence
  ⇒ High frequency measurements of wind velocity and gas concentration
Why performing EC measurements?

• To obtain flux functional responses (and understand mechanisms);
• To establish budgets;
• To study the impact of extreme events;
• To study the impact of management;
• To follow flux interannual variability;
To obtain flux functional responses

CO$_2$ Fluxes response to solar radiation

Aubinet et al. 2001
To obtain flux functional responses

$\text{N}_2\text{O}$ fluxes are best phased with surface temperature:

$\Rightarrow \text{N}_2\text{O}$ emission processes occur at the very surface
To establish budgets (CO2 and Carbon)

CO₂ budget at LTO (12 Years)

-367 gC m⁻² y⁻¹

Buysse et al. 2017

Carbon budget at LTO (12 Years)

+83 gC m⁻² y⁻¹

-367 gC m⁻² y⁻¹

Buysse et al. 2017
To study the impact of extreme events

Impact of 2003 heat wave on carbon flux at European scale

Ciais et al. 2005
To study the impact of management

Impact on C sequestration of cover crops (6 Years)

Buysse et al. In prep
To follow flux interannual variability

VTO beech CO2 budget (1996 – 2016)

To be consolidated

Aubinet, not published

385 gC m\(^{-2}\) yr\(^{-1}\)

Mean

Aubinet, not published
Pitfalls and questions

Is the measurement correctly made?
Not always: Instrumental errors, breakdowns.

Is the measured flux faithful to the real exchange?
Not always: physical limitation of the method

Is the studied zone representative of the target zone?
Not always: varying footprint with climate and set up

⇒ Systematic and random errors
⇒ Uncertainties
Random errors

• Due to instruments and Stochastic nature of turbulence

• Cannot be corrected but impact decreases with the number of measurements
Uncertainties resulting from random errors

Example: Vielsalm TO
(estimated using Richardson DD method)

<table>
<thead>
<tr>
<th>Relative uncertainty</th>
<th>n</th>
<th>Mean</th>
<th>Median</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half hour</td>
<td>1</td>
<td>173 %</td>
<td>84 %</td>
<td>27 %</td>
</tr>
<tr>
<td>Day</td>
<td>48</td>
<td>54 %</td>
<td>30 %</td>
<td>11 %</td>
</tr>
<tr>
<td>Month</td>
<td>1465</td>
<td>13 %</td>
<td>10 %</td>
<td>6 %</td>
</tr>
<tr>
<td>Year</td>
<td>17520</td>
<td>4 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Y</td>
<td>175200</td>
<td>1.5 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Typically: 20 gCm$^{-2}$ for one year
Uncertainties resulting from systematic errors

- Systematic error impact *do not* decrease with measurement number!

Well identified error

Physically based correction

Proper correction procedure

No resulting uncertainty

« *We know we know* »
Uncertainties resulting from systematic errors

- Systematic error impact does not decrease with measurement number!

Well identified error

Empirical correction

Proper correction procedure

Quantifiable uncertainty

« We know we don’t know »
Uncertainties resulting from systematic errors

- Systematic error impact **do not** decrease with measurement number!

<table>
<thead>
<tr>
<th>Not identified error</th>
<th>No possible correction</th>
<th>No procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>« We don’t know we don’t know »</td>
<td>Unquantifiable uncertainty</td>
<td>Need for validation</td>
</tr>
</tbody>
</table>
Density error

- WPL correction or instantaneous molar fraction computation
- Requires exact measurement of temperature fluctuations in the IRGA volume!
We know we don’t know »

Night time error

Well identified error

Empirical correction

Proper correction procedure

Resulting uncertainty

Aubinet, not published
High frequency losses by rain cap

Not identified error (before 2016)
No possible correction

Critical for enclosed path;
Explains some correction inadequacies for closed path?

Aubinet et al. (2016)
« We don’t know we don’t know (don’t we?) »

Is a 83 gC m\(^{-2}\) y\(^{-1}\) loss realistic?
Is there an undetected systematic error?
Need for validation!
Are uncertainties critical?

- **Budgets**
  - Random errors decrease with measurement period length ⇒ not critical
  - Systematic errors don’t decrease with measurement period length ⇒ critical
Are we able to detect the vegetation sink?

Terrestrial Sink: 2.97 GtC/yr.

Vegetated surface: 11 Gha.
Forest surface: 4 Gha.

Average sink: 27 gCm$^{-2}$yr$^{-1}$ (67 gCm$^{-2}$yr$^{-1}$ if sink only in forests).

Ideally, systematic uncertainties should not exceed 27 gCm$^{-2}$yr$^{-1}$.
Are uncertainties critical?

- **Budgets**
  - Random errors decrease with measurement period length ⇒ not critical
  - Systematic errors don’t decrease with measurement period length ⇒ critical

- **Comparisons (Interannual variability, extreme events, impacts of management)**
  - Random errors significant
  - Systematic errors not critical
Conclusions

Eddy covariance already provided major insights

but

Further credibility of the method relies on continuous methodology improvement and adaptation

Improvement of existing correction procedures (night flux; frequency).

Hunt still unknown systematic errors.

Multiply validation experiments.
Thank you!