THIS PRESENTATION IS MEANT TO BE VIEWED AS AN INTERACTIVE WEBPAGE:

WATER FLUX PARTITIONING FOR EDDY COVARIANCE DATA

Speaker notes

- Click the arrows on the presentation or use your left/right keys to advance slides.
- Information about the slides can be found here in the Speaker notes.
- Note that some slides are interactive.
- References are links: hover over to see the citation, click to open the reference.
- Feel free to direct questions to: jnelson@bgc-jena.mpg.de
- This presentation is part of EGU 2020
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  - LAI
  - VPD
  - Dry down events
- Overview of sites used
Speaker notes

- Eddy covariance measures net or aggregate fluxes of $CO_2$, heat, and water.
- Methods have existed for over 15 years for separating net ecosystem exchange of $CO_2$ ($NEE$) into the photosynthesis part (Gross Primary Productivity, $GPP$) and the respiration part (ecosystem respiration, $R_{eco}$).
- next slide...
Eddy covariance measures net or aggregate fluxes of $CO_2$, heat, and water.

Methods have existed for over 15 years for separating net ecosystem exchange of $CO_2$ (NEE) into the photosynthesis part (Gross Primary Productivity, GPP) and the respiration part (ecosystem respiration, $R_{eco}$).

In the last few years, methods have come out to replicate the success of NEE partitioning with the water fluxes by partitioning evapotranspiration ($ET$) into transpiration ($T$) and evaporation ($E$).
• Description and application of three ET partitioning methods:
  ■ underlying water use efficiency (uWUE)
  ■ Pérez-Priego
  ■ TEA
The uWUE method relies on estimates of the underlying water use efficiency (uWUE):

\[ uWUE = \frac{GPP \cdot \sqrt{VPD}}{ET}, \]

Two uWUE variants are calculated from half-hourly data:

1. the potential uWUE \((uWUE_p)\) is calculated at an annual scale using a 95th percentile regression between \(GPP \cdot \sqrt{VPD}\) and \(ET\), representing conditions with the highest carbon gain to water loss and thus where \(T \approx ET\)

2. the apparent uWUE \((uWUE_a)\) is estimated as the linear regression slope from a daily or 8 daily window.

\(T/ET\) is then calculated as:

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**HERE IS A BRIEF OVERVIEW OF THE UWUE METHOD.**

- See the paper here.
- Navigate ↓down↓ to see a tutorial of how to apply this method to a FLUXNET2015 dataset.
- Or go directly to the →next→ method.
**introduction**

Here we will go through application of the uWUE partitioning algorithm to eddy covariance data. The script is designed to run on FLUXNET2015 (https://fluxnet.fluxdata.org/data/fluxnet2015-dataset/) .csv files directly, which ensures consistent variable names, processing and units. The tutorial will use data from the Hyytiälä forest (http://sites.fluxdata.org/FI-Hyy/) in Finland, but can be applied to any FLUXNET2015 dataset.

Some experience in Python will make things easy, but I will try to explain the process step by step so as to be accessible to all backgrounds.

**first things first**

The first step is to import all needed packages:

```python
In [15]: import xarray as xr  # labelled multi-dimensional arrays that are compatible with netcdf formats
import numpy as np  # numerical python for working with basic n-dimensional array
import warnings  # standard library for suppressing warnings
```

- An interactive tutorial can be found here:
The Pérez-Priego method utilizes a "big leaf" model, where four different parameters are fit in a five-day moving window from tower input data. A simplified version of the model is described in equations 1-4:

\[ \chi = \chi_0 \left( 1 + \beta \sqrt{V_{PD}} \right) \]

\[ g_{c,\text{max}} = G_{PP} \cdot m_{\text{max}} \cdot C_a \left( 1 - \chi \right) \]

\[ G_{PP} = g_{c} \cdot C_a \left( 1 - \chi \right) \]

\[ g_{c} \cdot T = 1.6 \cdot g_{c} \cdot V_{PD} \]

The resulting stomatal conductance \( (\chi) \) is then used to calculate transpiration (\( T \)).

- See the paper here.
- Navigate ↓down↓ to see a tutorial of how to apply this method to a FLUXNET2015 dataset.
- Or go directly to the →next← method.

<table>
<thead>
<tr>
<th>symbol</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a_1, a_2, a_3, \beta )</td>
<td>fit model parameters</td>
</tr>
<tr>
<td>( TA )</td>
<td>ambient air temperature</td>
</tr>
<tr>
<td>( VPD )</td>
<td>vapor pressure deficit</td>
</tr>
<tr>
<td>( PPFD )</td>
<td>photosynthetic photon flux density</td>
</tr>
<tr>
<td>( GPP_{max} )</td>
<td>ninetieth percentile of GPP in 5 day window</td>
</tr>
<tr>
<td>( C_a )</td>
<td>ambient ( CO_2 ) mixing ratio</td>
</tr>
<tr>
<td>( \chi )</td>
<td>Internal to ambient ( CO_2 ) concentration</td>
</tr>
<tr>
<td>( \chi_0 )</td>
<td>Long-term effective ( \chi )</td>
</tr>
<tr>
<td>( g_c )</td>
<td>canopy stomatal conductance</td>
</tr>
</tbody>
</table>
**introduction**

Here we will go through application of the Pérez-Priego partitioning algorithm to eddy covariance data. The script is designed to run on FLUXNET2015 (https://fluxnet.fluxdata.org/data/fluxnet2015-dataset/) .csv files directly, which ensures consistent variable names, processing and units. The tutorial will use data from the Hyytiälä forest (http://sites.fluxdata.org/FI-Hyy/) in Finland, but can be applied to any FLUXNET2015 dataset.

Some experience in R will make things easy, but I will try to explain the process step by step so as to be accessible to all backgrounds.

This example has been adapted from the original example:

https://github.com/oscarperezpriego/ETpartitioning/blob/master/inst/main_ETpartitioning.r

(first things first)

The first step is to import all needed packages:

```r
library(ETpartitioning)  # The package containing the partitioning code
library(FME)              # Package for parameter optimization
library(bigleaf)
```

An interactive tutorial can be found here:
The TEA method utilizes a version of Random Forest (RF), to predict water use efficiency \( WUE = \frac{GPP}{ET} \). The model is trained on the ecosystem water use efficiency (\( WUE_{eco} = \frac{GPP}{ET} \)) during periods in the growing season and when surfaces are likely to be dry, i.e. where \( E/ET \) should be minimal. The RF, trained on \( WUE_{eco} \) from the filtered periods, then predicts \( WUE \) (now \( \frac{GPP}{T} \)) for the full time series.

\[
WUE_{eco} = \frac{GPP}{ET}
\]

\[
WUE = \frac{GPP}{T}
\]

Click on a point of \( T/ET \) from the plot above to see the predicted WUE from TEA in the plot to the left.

**HERE IS A BRIEF OVERVIEW OF THE TEA METHOD.**

- See the paper here.
- Navigate ↓down↓ to see a tutorial of how to apply this method to a FLUXNET2015 dataset.
- Or go directly to the →next→ method.
introduction

Here we will go through application of the TEA algorithm to eddy covariance data. The script is designed to run on FLUXNET2015 (https://fluxnet.fluxdata.org/data/fluxnet2015-dataset/) .csv files directly, which ensures consistent variable names, processing and units. The tutorial will use data from the Hytylä forest (http://sites.fluxdata.org/FI-Hyy/) in Finland, but can be applied to any FLUXNET2015 dataset.

Some experience in Python will make things easy, but I will try to explain the process step by step so as to be accessible to all backgrounds.

resource usage

Note that processing large dataset can take some time and memory use. This script only processes six years worth of data. Processing the original 18 year dataset with one processor takes approximately 10 minutes and 0.75 GiB of RAM. If you have access to a multi-core processor, the speed can be increased considerably. Here are the maximum memory usage and run times when using different number of processors on my laptop:

<table>
<thead>
<tr>
<th>processors</th>
<th>max memory</th>
<th>time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5 GiB</td>
<td>2min 18s</td>
</tr>
<tr>
<td>2</td>
<td>0.6 GiB</td>
<td>1min 32s</td>
</tr>
<tr>
<td>4</td>
<td>0.6 GiB</td>
<td>0min 50s</td>
</tr>
<tr>
<td>8</td>
<td>0.6 GiB</td>
<td>0min 41s</td>
</tr>
</tbody>
</table>

Setting the number of processors is explained later in the tutorial.

TEA

An interactive tutorial can be found here:
<table>
<thead>
<tr>
<th>Method</th>
<th>Equation</th>
<th>Assumptions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>uWUE</td>
<td>$T \propto GPP \cdot \sqrt{VPD}$</td>
<td>$T \approx ET$ during some periods</td>
<td>easiest to calculate</td>
</tr>
<tr>
<td>Pérez-Priego</td>
<td>big leaf model with optimality</td>
<td>no $T \approx ET$ assumption</td>
<td>expensive parameter estimation</td>
</tr>
<tr>
<td>TEA</td>
<td>models WUE via machine learning</td>
<td>$T \approx ET$ during some periods</td>
<td></td>
</tr>
</tbody>
</table>

The table above summarizes some key aspects of the three methods related to:
- core functionality
- whether the method assumes $T \approx ET$ during some periods
- unique aspects of the method
Comparison of the partitioning methods to:
- Canopy T estimates from SAPFLUXNET
- LAI
- VPD
- Dry down events
Comparison of sap flow based estimates of transpiration ($T_{SF}$) against estimated transpiration (T) and measured evapotranspiration (ET) from eddy covariance (EC). Note the three different sizes of markers in the correlation plots (corr(EC,SF)), where the largest markers represent the mean correlation, the smallest markers represent the correlations from each available year, and the medium sized markers represent the selected year shown (time series in the left column of sub-figures).

Sap flow data from SAPFLUXNET

Figure from: Nelson, et al (2020). Ecosystem transpiration and evaporation: insights from three water flux partitioning methods across FLUXNET sites. Manuscript submitted for publication
Daily T/ET from each EC based method as a function of MODIS LAI. For each PFT, the associated relationship derived from Wei et al (2017) is shown in black, which was derived from site level T/ET estimates. Points show the distribution within the given LAI bin, truncated to the 25th and 75th percentiles. PFTs were grouped to match those found in Wei, Z. et al (2017) and are slightly different compared to subsequent figures.

Relationship of both WUE (top row) and T/ET (bottom row) to VPD at daily scale across 124 sites. Lines indicate the median value from one hPa wide bins. Only days with a mean temperature above 5° C, at least 1 mm, day$^{-1}$ of ET, and where all three partitioning methods could be applied were included.

Percentage of evaporation ($E/ET$) estimated using the TEA, uWUE, and Pérez-Priego methods for progressive days after rain (rainy days defined as receiving > 0.1 mm in one day). Upper and lower panels show daily aggregated and diurnal cycles of $E/ET$, respectively. Diurnal cycles are estimated as the median for each half hour, with the interquartile range shown as shading. Only days with a mean temperature above 5° C, at least 1 mm, day$^{-1}$ of ET, and where all partitioning methods could be applied for all half hours in a day were included.

Figure from: Nelson, et al (2020). Ecosystem transpiration and evaporation: insights from three water flux partitioning methods across FLUXNET sites. Manuscript submitted for publication
<table>
<thead>
<tr>
<th>#</th>
<th>Site ID</th>
<th>Site Name</th>
<th>Citation</th>
<th>Dataset</th>
<th>PI</th>
<th>TEA T/ET (%)</th>
<th>uWUE T/ET (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>AR-SLu</td>
<td>San Luis</td>
<td>10.18140/FLX/14401</td>
<td>FLUXNET 2015</td>
<td>Gabriela Posse</td>
<td>56.7</td>
<td>22.4</td>
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<tr>
<td>1</td>
<td>AT-Neu</td>
<td>Neustift</td>
<td>10.18140/FLX/14401</td>
<td>FLUXNET 2015</td>
<td>Georg Wohlfahrt</td>
<td>78</td>
<td>51.2</td>
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<tr>
<td>2</td>
<td>AU-ASM</td>
<td>Alice Springs</td>
<td>10.18140/FLX/14401</td>
<td>FLUXNET 2015</td>
<td>Derek Eamus</td>
<td>51.4</td>
<td>26.2</td>
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<tr>
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<td>AU-Cpr</td>
<td>Calperum</td>
<td>10.18140/FLX/14401</td>
<td>FLUXNET 2015</td>
<td>Georgia Koerber</td>
<td>62.4</td>
<td>38.8</td>
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<tr>
<td>4</td>
<td>AU-Cum</td>
<td>Cumberland Plain</td>
<td>10.18140/FLX/14401</td>
<td>FLUXNET 2015</td>
<td>Elise Pendall</td>
<td>64.4</td>
<td>40.3</td>
</tr>
<tr>
<td>5</td>
<td>AU-DaP</td>
<td>Daly River Savanna</td>
<td>10.18140/FLX/14401</td>
<td>FLUXNET 2015</td>
<td>Jason Beringer</td>
<td>75.2</td>
<td>52.1</td>
</tr>
</tbody>
</table>

**OVERVIEW OF FLUXNET SITES USED HERE**

- Hover over points on the map to see more information.
Many thanks to my co-authors:


And all the FLUXNET/SAPFLUXNET PIs and support personnel.