High temporal resolution $^{13}$C tracing to link xylem–phloem pathways of carbon in oak trees

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Tree’s C and hydraulic cycle

• Photosynthesis assimilates CO₂ to form sugar.

• Sugar is transported to above- & belowground organs to support C sinks.

• CO₂ is released back to the atmosphere through plant respiration and soil respiration.
Fate of respired CO$_2$

- Living cells of plant (e.g. parenchyma) respire CO$_2$ which is released to the atmosphere from the bark.

- Internal transport of dissolved CO$_2$ has been often ignored.
Upward and downward transport of C

- Results in underestimation of belowground respiration
- Potential re-fixation in leaves and green bark
- Unaccounted local source of C
Motivations of the research

Observe upward and downward movement and dynamics of C in trees, connecting above and belowground tissue.

Trace the fate of phloem transported sugar and xylem transported CO$_2$ in high temporal resolution.

Observe potential mixing of C in xylem and phloem through lateral transport and CO$_2$ re-fixation.
Methods: Xylem–phloem dual-labeling

- We used two types of pulse labeling to trace C in young oak trees (*Quercus rubra*; *n* = 3):
  - **Canopy $^{13}$CO$_2$ labeling** (*n* = 3) and **xylem $^{13}$CO$_2$ infusion labeling** (*n* = 4)

- The goal is to trace detect **phloem transported CO$_2$** and **xylem transported CO$_2$** in respiration and biomass.

- We also aimed to detect connectivity between the two pools of C (transfer between the two)

- Experiment was conducted in Innsbruck University Botanical garden during 2015 and 2016 by Jasper Bloemen
Methods: Canopy $^{13}$CO$_2$ labeling

- Labeling chamber
- Isotope-ratio infrared spectroscopy
- 99% $^{13}$CO$_2$
- High resolution time-series data
Methods: Xylem $^{13}\text{CO}_2$ infusion labeling

- $^{13}\text{CO}_2$ gas was dissolved in DI water amended with KCl
- Infused water was carried upward on xylem stream.
• Label follows a decay due to depletion of label

• Short mean residency time for xylem infused $^{13}$CO$_2$ (5 - 16 h)

• Xylem infused $^{13}$CO$_2$ remained in CO$_2$ efflux several days after labeling
Residuals of **canopy labeled tree**

- Residual of fitted model shows diurnal pattern of **excess $^{13}$CO$_2$ efflux**, primarily driven by dynamics of respiration.

- **Isotopic composition** (atom fraction) of CO$_2$ efflux doesn’t show a clear diurnal pattern.
Residuals of xylem labeled tree

- Residual of fitted model shows increased daytime excess $^{13}$CO$_2$ efflux from the stem.

- Isotopic composition (atom fraction) of stem efflux also show a diurnal pattern.
Potential mechanisms of diurnal $^{13}$C dynamics in xylem labeled trees

- Increased degassification of infused CO$_2$ due to increased temperature or stem CO$_2$ concentration driven by respiration.
- Incorporation of infused CO$_2$ in respiratory substrate.
- Effects from diurnal change in sap flow
Xylem infused $^{13}\text{CO}_2$ were found in stem phloem at various height.

Strong $^{13}\text{C}$ signal in petiole and veins suggests recycling of xylem transported $\text{CO}_2$ as a source of sugar.
\( ^{13}C \) labels found in biomass after **canopy labeling**

Lateral transport of C from phloem to xylem was observed after canopy labeling.
Conclusion

• Soluble sugar from phloem were laterally transported to inner xylem within a few days.

• CO₂ transported upward through xylem had relatively short residency time, but was re-assimilated as soluble sugar.

• Pathway of xylem transported CO₂ and phloem transported sugar is linked, connecting two of the C pools within a few days.