How old is the carbon that forests respire? Seasonal patterns in soil and ecosystem $^{14}\text{CO}_2$ from a hardwood forest in Northern Wisconsin.

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Introduction

Radiocarbon ($^{14}$C) is often substantially more abundant in soil $\text{CO}_2$ than in the atmosphere or plant respiration, making it a potential tracer for detecting soil contributions to whole forest respiration.

We conducted a coupled soil-atmosphere study of $^{14}\text{CO}_2$ dynamics at a deciduous forest in Northern Wisconsin, to assess whether soil emissions can be detected in atmospheric $^{14}\text{CO}_2$ abundance.

Questions:
1) How does soil-respired $^{14}$C-$\text{CO}_2$ vary seasonally at Willow Creek Ameriflux site? With environmental drivers?
2) Can signals from soil respiration be detected in canopy $^{14}\text{CO}_2$ using mixing equations?
3) How do whole-forest emissions impact $^{14}\text{CO}_2$ far above the canopy, at a nearby tall tower? (LEF, Park Falls, WI)

Approach

We monitored $\text{CO}_2$ fluxes and $^{14}\text{CO}_2$ abundance in 2011 & 2012, at three nested spatial scales.

1. Soil plots at Willow Creek (~$4 \text{ m}^2$ footprint)

   - Four plot array, including one trenched (no live roots)
   - Subsurface $\text{CO}_2/^{14}\text{CO}_2$
   - Temp, Moisture
   - Surface fluxes (hourly)

2. Willow Creek Eddy Covariance Tower
   (30 m agl, 1 to 10 km$^2$ footprint)

   - 14CO2 samples collected by NOAA-ESRL, analyzed at CAMS-LNL

3. LEF, Park Falls (450 m agl)
   ($^{14}\text{CO}_2$ samples)

Soil $^{14}\text{CO}_2$ Dynamics

1. **In situ** $^{14}\text{CO}_2$ in bulk soils was intermediate between the atmosphere and a trenched (heterotrophic) soil plot, reflecting contemporary $^1$C respired by roots.

   - Bulk soil: Increasing root contributions through summer decreases $^{14}\text{CO}_2$
   - Partitioned heterotrophic sources through time and by depth. Root incubations (not shown) were used for autotrophic end-member; and trenched plot $^{14}\text{CO}_2$ for heterotrophic end-member.

2. $^{14}\text{CO}_2$ dynamics through 2012 growing season seemed driven primarily by relative levels of root activity.

   - Mid-summer $^{14}\text{CO}_2$ concentration $= -60$ ppm

3. **In situ** $^{14}\text{CO}_2$ was enriched in $^{14}\text{CO}_2$ compared to lab incubations, because of high relative respiration rates in shallow subsurface where substrates are enriched $^{14}$C.

   - Even in the trenched plot without roots, $^{14}\text{CO}_2$ was contemporary throughout profile, and much higher than $^{14}\text{CO}_2$ produced by soils incubated in lab.

Can we detect soil $^{14}\text{CO}_2$ in whole-forest emissions?

4. Compared to background atmosphere (LEF), WCR CO$_2$ is enriched in $^{14}\text{C}$, consistent with soil emissions

5. Two nocturnal canopy profiles in 2012 produced Keeling intercepts similar to soil $^{14}\text{CO}_2$

Can we detect soil $^{14}\text{CO}_2$ in regional emissions?

6. Many tall towers have shown lower $^{14}\text{CO}_2$ than free troposphere, related to fossil fuel emissions, but LEF has $^{14}$C enrichment during summer.

Conclusions and Future Directions

1. Soil $^{14}\text{CO}_2$ was distinct from the atmosphere. It was produced mainly from shallow substrates enriched in bomb-$^{14}$C, and showed seasonal variation primarily related to root activity.

2. $^{14}$C enrichment above the forest canopy indicates soil contributions, but estimates of bomb HC in canopy-level emissions were quite variable.

3. Summer $^{14}$C enrichment at LEF may be partially related to elevated soil activity during summer.

4. Ongoing soil analysis includes modeling to assess the expected sensitivity of soil $^{14}\text{CO}_2$ to changes in SOM turnover.

5. Ongoing atmospheric work includes footprint analysis to constrain potential sources of summer $^{14}\text{CO}_2$ at LEF.