Slide 1:

Hello and welcome to my presentation. Today I’m going to tell you about a new technique for measuring the radiocarbon signature of heterotrophic respiration in laboratory incubations of archived soil samples. First I will (hopefully) convince you that radiocarbon incubations can be a powerful technique for understanding soil carbon dynamics and why archived soils are particularly important for this. Then I will describe how our findings provide insight into the long-standing question of how air-drying and rewetting can affect the source and magnitude of soil carbon fluxes.

Slide 2:

In the mid-20th century we inadvertently began a planet-wide labeling experiment when we introduced a giant pulse of radiocarbon into the atmosphere though nuclear weapons testing. Once this practice was banned, the atmospheric label rapidly decreased as CO2 from the atmosphere was mixed into the ocean or fixed by vegetation. This pulse and subsequent decline in atmospheric radiocarbon is shown by the gray line in Figure 1.

Turning to the soil, we can see from figure 1 that the bomb-C peak arrives a few years later in the pool of rapidly cycling soil carbon (shown here in magenta), but not for decades in the more slowly cycling pool in blue.

Due to the symmetry of the bomb-C curve, as well as complexity in the distribution and exchange of carbon between “slower” and “faster” soil carbon pools, observations at a single point in time can lead to multiple model solutions. For this reason it would be great to combine measurements of the radiocarbon signature of respiration from today with that in the past—especially because the radiocarbon signature would have likely been much higher and therefore more informative.

Slide 3:

The radiocarbon signature of bulk soil carbon can be used to give us an estimate of its mean age, which is usually on the order of decades to centuries. The radiocarbon signature of heterotrophic respiration, on the other hand, is typically far younger.

The discrepancy is due to the heterogeneity of the soil carbon reservoir: once an atom of carbon enters the soil, some of it gets stuck—sorbed to clay surfaces, or occluded in a soil aggregate, for instance. In a modeling context, this effect of getting “stuck” is typically represented by a slower intrinsic decomposition rate, which is used to fractionate bulk soil into pools of “faster” or “slower” cycling carbon.

Measuring the radiocarbon signature of the respiration flux provides key information about soil carbon dynamics that we cannot get from bulk measurements alone. For example, the young age of respired carbon tells us that the majority of carbon leaving the system does not in fact get “stuck” for long, so therefore must be coming mostly from the “fast” pool.

Radiocarbon incubations are particularly powerful because they provide an integrated measure of the weighted contribution to the total flux from soil carbon pools with different intrinsic decomposition rates. This is illustrated by the box model shown in Figure 2.

Direct observation of “slow” and “fast” soil carbon is challenging. Defining soil carbon pools empirically with techniques such as density, size, or resistance to chemical attack is useful, but these methods also introduce artifacts and likely result in mixtures of pools with different age distributions.

In contrast, although they also introduce artifacts due to disturbance and potential alteration of the microbial community, laboratory soil incubations make use of the same fractionation agent as is found *in situ*: the microbial community.

Accurately interpreting radiocarbon data from soil incubations requires understanding how disturbances to the system, such as air-drying and rewetting, may alter the relative contribution of different soil carbon pools to observed fluxes.

Slide 4:

Using the model from Figure 2 on the previous slide, we can visualize how treatment effects might lead to shifts in the contribution of different soil carbon pools to respiration fluxes and how these shifts could potentially alter the observed radiocarbon signature.

Figure 3 shows a portion of the same 2-pool model curves that were shown in full on Figure 1. Delta 14C is on the y-axis, and time is on the x-axis. The filled yellow circles are observations of the radiocarbon signature of respiration under control conditions, while the open symbols represent two possible responses to a treatment such as air-drying and rewetting: either increased contribution from the “fast” pool (shown with open circles), or increased contribution from the “slow” pool (shown with open squares).

Interestingly, for this scenario, we can see from the open square symbols that increased contribution from the slow pool leads to apparent depletion in the radiocarbon signature of respiration for samples collected in 1991, but apparent enrichment in 2019, while the opposite is observed for increased fast pool contribution.

Slide 5: (RQs)

The central question of this study is this:

Can we successfully measure the radiocarbon signature of heterotrophic respiration in incubations of archived soils?

To answer this question, we identified two primary mechanisms that might affect the observed radiocarbon signature of heterotrophic respiration, air-drying and rewetting, and the duration of storage, and designed a series of experiments to test them.

Slide 6:

The diagrams on the left illustrate the differences in experimental treatments and the number of radiocarbon observations made for the three experiments conducted in this study.

The first experiment looks at the effect of air-drying in combination with the effect of storage. All of the samples for this experiment were collected in 2011 from two sites in central Germany.

The second experiment was conducted on samples collected from a subset of these same sites, but in 2019. The same air-drying treatment was imposed, but treatment samples were rewetted immediately after air-drying so there was no storage effect.

Finally, a third experiment was conducted to look at the effect of storage duration.

Samples were acquired from collaborators that had been initially incubated between 7 and 14 years earlier. Treatment incubations were then conducted on remoistened samples hewing as closely as possible to the control incubation conditions.

For experiments 1 and 2 we incubated samples from an equal number of forest and grassland sites, as we hypothesized that the soil carbon stabilization mechanisms, and therefore the treatment response, may vary between these ecosystems. Unfortunately we could not find any previously incubated grassland samples for experiment 3.

Slide 8:

Now for some results. In figure 4 we can see that respiration rates in experiments 1 and 2 responded strongly to both the air-drying and air-drying + storage treatments.

In the top panel we can see that the treatment effect of air-drying plus storage treatment was stronger in grassland samples than in forests, but this pattern was not observed in the 2019 samples for the air-drying treatment alone.

These results match what has been observed in many other incubation studies: air-dried soils show a large burst in respiration immediately following rewetting, but then return to similar basal respiration rates as in control samples that were not exposed to the air-drying treatment.

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Despite the strong treatment effects on respiration rates shown in the previous slides, the differences in respiration rates between the pre-incubation period and the equilibrium respiration period did not lead to difference in radiocarbon.

Indeed, the radiocarbon signature of the pre-incubation period was not significantly different from that of the equilibrium respiration period, and neither treatment nor land use had a significant effect on this relationship.

As you can see by the greater spread of data along the x-axis, pre-incubation 14C was more variable across samples than was equilibrium respiration 14C.

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Now let’s look at the treatment effects on the 14C of equilibrium respiration over time. As you can see, the respiration signature is 14C enriched in both control and treatment samples relative to the atmosphere, reflecting the contribution of older, bomb-C-enriched carbon to the respiration flux.

For samples collected in 2011, the air-dry + storage treatment led to depletion in 14C relative to the controls for forest samples, but had the opposite effect in grassland samples.

In contrast, the air-dry treatment alone led to enrichment in both forest and grassland soils for the samples collected in 2019.

We hypothesize that the switch in the direction of trend for the forest samples between 2011 and 2019 is due to a crossing of the slow and fast soil carbon pool curves (as we saw earlier in figure 2). In contrast, the slow and fast curves had likely already crossed by 2011 for the grassland samples. This makes sense, since respired C in grassland control samples is closer to the atmosphere, suggesting a faster transit time in this system. If this interpretation is correct, both the air-drying and air-drying + storage treatments lead to slight increases in the contribution of the more slowly cycling soil carbon pool to respiration, as compared to control samples.

Slide 11:

Here we see the results from all three experiments. Note that the black points in this plot are data from experiments 1 and 2.

∆14C of equilibrium respiration from treatment samples is on the y-axis, while that of control samples is on the x-axis.

The solid line shows a 1:1 relationship, while the dashed and dotted lines represent differences of 20 and 40 per mille, respectively. Over the past twenty years atmospheric ∆14C has decreased at a nearly linear rate of 4 per mille per year, meaning that a 20 and 40 per mille offsets represent differences of approximately 5 and 10 years, respectively.

Treatment differences for forest samples are within 20 per mille for the majority of samples, while differences are within 40 per mille for grassland samples.

The Oak Ridge samples—magenta triangles—are an exception. These samples were part of a labeling experiment, and thus represent an extreme case where almost all of the label is stored entirely in the fastest cycling soil C pool. In line with our interpretation of the natural abundance samples, an increase in the contribution of the slow pool to respiration following air-drying and rewetting would lead to a correspondingly greater drop in the radiocarbon signature of respired CO2 for these samples, which is what we observe.

Slide 12:

Here we see the duration of storage plotted on the x-axis, and the difference in delta 14C between control and treatment samples on the y-axis.

The labeled Oak Ridge samples in magenta do appear to show a slight increasing trend, suggesting losses of highly enriched recently fixed carbon over the duration of storage.

However, the remaining natural abundance do not appear to show a trend in with increasing storage duration, but this relatively sparse dataset does not really allow for conclusive testing of the storage duration effect.

Slide 13:

In summary:

1. Air-drying and rewetting significantly affects 14C of respired CO2 in laboratory incubations, and **the effect is stronger in grasslands than in forests**
2. Although we observed the characteristic pulse of CO2 following rewetting, the **14C of respired CO2 in the pre-incubation period was not significantly different than the 14C of respired CO2 in the equilibrium respiration period.**
3. In line with point 2, **the amount of C respired was not significantly related to the difference in 14C of respired CO2** between control and treatment samples
4. Duration of storage does not seem to have a substantial effect on the 14C of respired CO2, but more data are needed to prove this conclusively.

Slide 14:

Conclusions:

* Incubation of soils following air-drying and rewetting mobilizes a different fraction of soil carbon than would otherwise be accessible to the microbial community, affecting the relative contribution of older versus younger carbon pools to observed heterotrophic respiration
* Differences in 14C of respired CO2 observed in this study suggest that incubations of air-dried and rewet soils can shift the apparent transit time of soil carbon by 5 to 10 years relative to estimates from incubations of soils that have not undergone air-drying
* Overall, we believe the radiocarbon incubation technique for archived soils is promising approach for improving soil carbon models