Impacts of long-term air pollution on trees through analysis of tree ring chemistry

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Introduction and Objectives

Anthropogenic atmospheric additions such as carbon dioxide can have positive impacts on plants. Other pollutants have negative impacts such as sulfur dioxide and ozone (Li et al., 2010). However, the net combined effects from air pollutants in natural environments are not well understood. Recent models indicate that positive effects from nitrogen may offset negative effects from ozone (Felzer et al., 2007). In agreement, a recent tree-ring study in the eastern U.S. found sulfur dioxide to be the primary pollutant impacting tree physiology (Li et al., 2010).

In this study, we will examine changes in wood chemistry over the last ~100 years to provide insight into overall effects of human activity on tree growth.

Our objectives are to:

1. Analyze long-term effects of pollutant exposure on plant growth and health
2. Determine the relative importance of common pollutants

Study Sites and Methods

This study will analyze changes in tree-ring chemistry from four sites in the Chicago, IL area (Fig. 1). A minimum of four *Quercus alba* or *Quercus bicolor* individuals from each site were sampled in 2011. Four cores were taken from each sampled tree. *Quercus* tree, have been previously shown to be appropriate species for tree-ring chemical analysis.

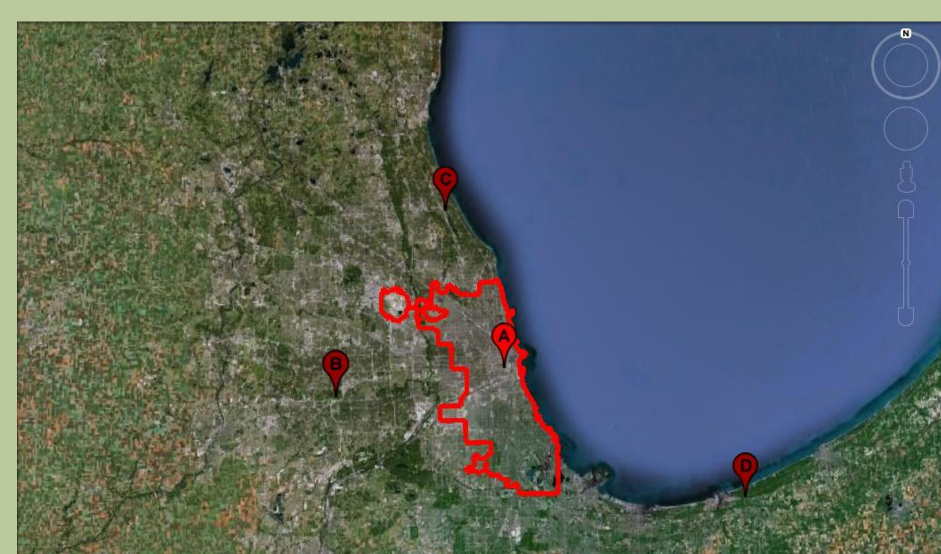

Figure 1: The study area near Chicago, IL (red border).

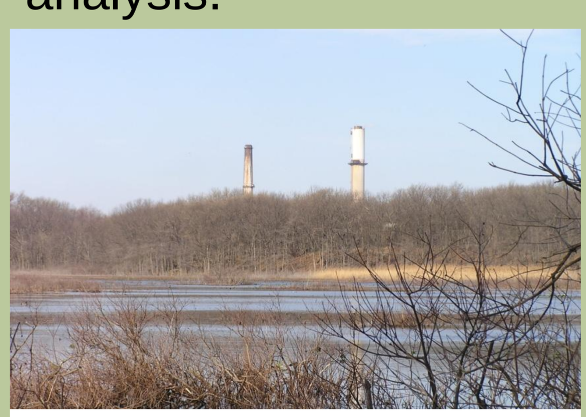

Figure 2: Sampling location at Indiana Dunes National Lakeshore.

Sample sites include (A) the campus of UIC near downtown, (B) Morton Arboretum, (C) Chicago Botanic Garden (CBG) and (D) Indiana Dunes National Lakeshore (INDL) where sampled trees are <1 km from a power plant. All trees are >100 years old (except at the UIC site).

One core per tree is for dating and ring width analysis. Two cores are pooled in annual segments for isotope analysis. The fourth core has been reserved for future trace element and anatomical analysis.

Tree rings and stable carbon isotope theory

Temperate trees produce annual rings of growth that can be identified (Fig. 3). By counting back from the year of sampling, an exact year of growth is known for each ring. Each year can be chemically analyzed to gain insight into environmental conditions for that year.

Figure 3: *Q. alba* rings. Large cells are spring vessel cells.

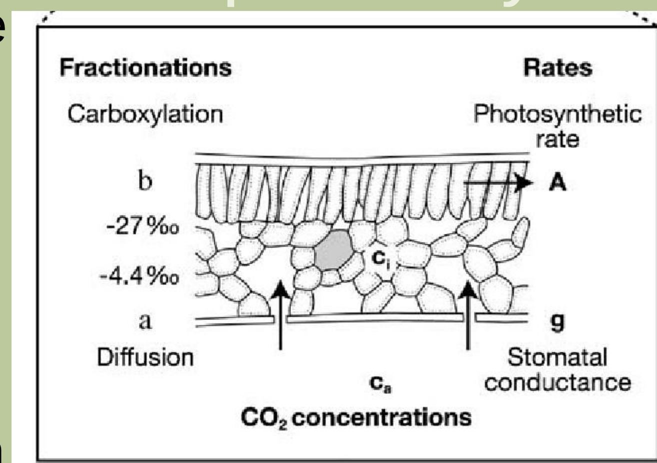

Figure 4: Factors affecting leaf $\delta^{13}C$ (from McCarroll and Loader 2004).

$$\Delta (‰) = \delta^{13}C_a - \delta^{13}C_{wood} \quad (1)$$

$$\Delta (‰) \approx a + (b-a) * Ci/Ca \quad (2)$$

$$A/g_{H_2O} = (c_a - c_i)/1.6 \quad (3)$$

The carbon isotope composition of wood is affected by environmental variables that change either Assimilation (A) or stomatal conductance (g) (Eq. 2, 3).

Increased atmospheric CO_2 affects $\delta^{13}C$ directly while phytotoxic pollutants, including SO_2 and O_3 reduce stomatal conductance, also impacting $\delta^{13}C$.

Preliminary Results

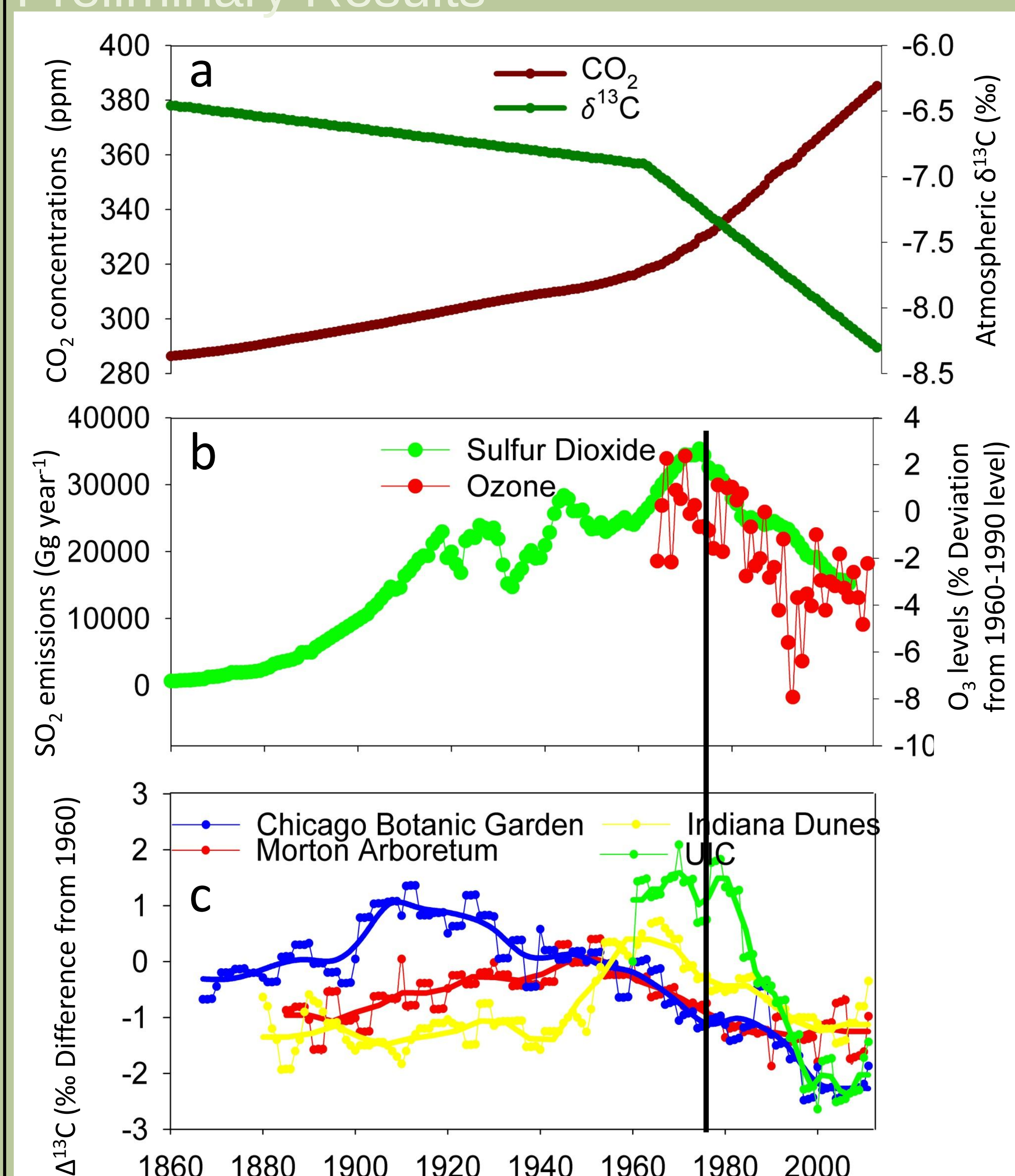

Figure 5: Changes in atmospheric trace gases since 1860 and preliminary results. (a) Atmospheric CO_2 concentrations and changes in $\delta^{13}C$ from fossil fuel emissions. (b) Modeled emissions of SO_2 and measured concentrations of O_3 in North America. (c) Preliminary tree-ring $\delta^{13}C$ results. Black lines indicates 1973, when emissions of several pollutants decreased due to the Clean Air Act.

Burning of fossil fuels has elevated atmospheric CO2 concentrations and changed the isotopic composition of the atmosphere (Fig. 5a). All results (Fig. 5c) are reported in $\Delta^{13}C$ form (see eq. 1, above) to remove any effect from changes in atmospheric $\delta^{13}C$ on wood $\delta^{13}C$.

Both sulfur dioxide (SO2) and ozone (O3) concentrations in North America have been decreasing since the Clean Air act in the early1970's (vertical black line Fig. 5). Nitrogen deposition has increased in the Midwest since mid-1900's.

Increased wood $\Delta^{13}C$ values (Fig. 5c) indicated exposure to environmental stress. Preliminary results show large variation between our four sites. Only at UIC and INDL does release from stress potentially coincide with reduced emissions from the clean air act. These two sites are down-wind from Chicago emissions and potentially exposed to higher pollutant loads. At CBG and Morton Arboretum, increases in CO_2 and N-deposition may drive changes in $\Delta^{13}C$. Other wood chemistry data will help confirm these results (see Future work section).

Future Work

Changes in carbon isotope composition do not provide enough information to determine which specific industrial pollutants induce changes in tree physiology.

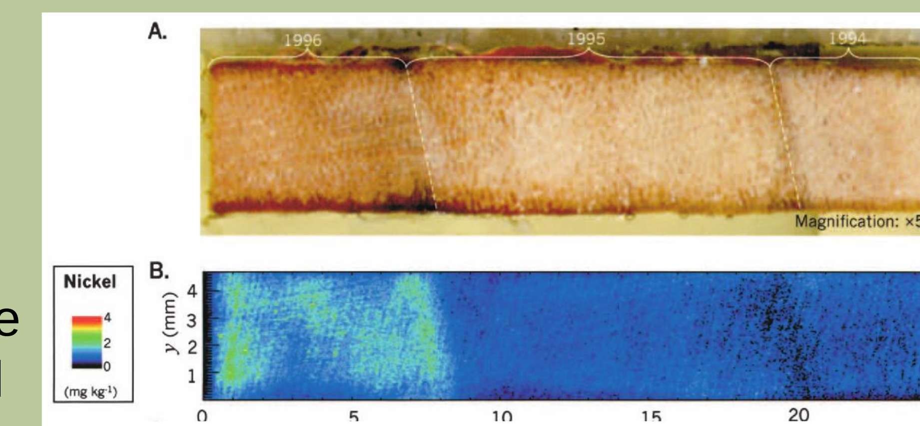

Figure 6: An example of using tree-rings to detect changes in trace element concentrations (from Punshon et al., 2005).

Further tree-ring analyses will provide additional information:

Oxygen isotopic composition – Unlike carbon, O isotopes are only affected by changes in g (eq. 3). Combing C and O isotopic composition can determine if assimilation or stomatal conductance is affected.

Nitrogen isotopic composition – Provides information to quantify changes induced by N-deposition

Trace element concentrations (Fig. 6) – Acid deposition (SO_2) decreases soil pH leading to changing cation availability which is recorded through changes in wood cation concentration.

Together, these analyses will help quantify the impacts of industrial activity on tree growth.

Implications

As human activities have both positive and negative impacts, studies in natural environments can provide unique information on the net impacts of human activities on ecosystems.

A recent tree-ring study found that ~2.5‰ change in $\delta^{13}C$ led to >60% growth enhancement since 1970 in eastern PA (Li et al., 2010 Chemical Geology). Thus, studies such as this have implications for carbon storage with forest recovery due to environmental legislation, such as the Clean Air Act.

References

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Acknowledgements

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