In Search of the Compensation Point: Leaf-Level Exchange of Nitrogen Oxides and Ozone for Selected Tree Species at a North America Temperate Forest

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Introduction

- Nitric oxide (NO), nitrogen dioxide (NO2), and ozone (O3) are atmospheric trace gas species that play important roles in tropospheric oxidation chemistry and secondary organic aerosol formation, affecting air quality and climate.
- In forested areas, interactions of these trace gases within and above the canopy, from soil to leaf to atmosphere, occur through sink processes that result in canopy-scale bi-directional exchange of these species in the atmosphere, influencing both net and budget of these components.
- Many previous studies since the late 1980's have shown both foliar level uptake and emission of NO, i.e. NO and NO2. For each of these compounds there may exist a certain ambient concentration at which the net flux in and out of the leaf is zero. This particular ambient trace gas concentration is termed the compensation point.
- However, recent studies using improved instrumentation have cast doubt on leaf-level emission and the existence of a compensation point, or if it exists, it is much lower than previously determined.
- But in a model analysis of the NOx flux to the atmosphere based on ground-level observations at the University of Michigan Biological Station (UMBS), a compensation point was newly invoked to achieve reasonable agreement between the simulated and measured results.

Objectives

We return to the UMBS study site and conduct branch enclosure experiments on the dominant tree species in the forest to investigate if indeed such compensation points exist for NO and NO2. The results of this study will be incorporated into an updated forest canopy exchange model to improve the analysis and understanding of the dynamics and the biosphere-atmosphere bi-directional exchange of these trace gases.

Study Site and Methods

The study site (red pin on the map, Location: 45.56°-84.71°) is a northern hardwood forest at UMBS, in the northern part of the Lower Peninsula of Michigan, surrounded by the Great Lakes. The four dominant tree species used in this study, white pine (Pinus strobus), bigtooth aspen (Populus grandidentata), red maple (Acer rubrum), and red oak (Quercus rubra), together cover over 90% of the basal and leaf area of the forest.

Chamber experiment: Two identical Teflar bags filled with air and sensor wires are used to form a branch enclosure and a blank reference enclosure. The enclosures are typically side-by-side make-up of the canopy with mixed sun and shade light exposure. Ambient air is drawn free of NO, O3 and O2 through both enclosures at ~ 37 L m2 h. Temperature sensor wires. “Umbilical” cord bundle consisting of tubing for carrying air flow and the branch enclosure (right).

Trace gas flux in the branch enclosure

Each enclosure is purged with only the scrubbed air for ~ 12 hours or more after the initial setup. During the experiments, the mixing ratios of the introduced trace gases are kept below or at a level comparable to that of the ambient at the time of the measurements.

Trace gas maximum mixing ratio at the enclosure inlet

<table>
<thead>
<tr>
<th>NO2</th>
<th>O3</th>
</tr>
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<tbody>
<tr>
<td>1000 ppm</td>
<td>200 ppm</td>
</tr>
<tr>
<td>NO</td>
<td>5 ppm</td>
</tr>
</tbody>
</table>

Most of the time, NO2 and O3 are absorbed by the foliage (e.g. Fig. 1).

Results

- The flux of the trace gas is calculated as follows:

\[ F_x = \frac{1}{C_2 - C_1} \]

where \( F_x \) is the flux of trace gas X, C1, the purge air inflow rate, A, the leaf area in the enclosure, and C2 and C1, the trace gas concentration at the inlet and orifice of the enclosure, respectively.
- Although the ambient to leaf gas flux is driven by the ambient leaf gas concentration gradient, the data in Figure 1 show that other factors also affect the air to leaf deposition.

For each enclosure and tree species, the flux varies with the concentration in the enclosure and time of day:

- The fluxes of NO2 and O3 increase with their concentrations in the enclosure as shown in Figure 2.
- The fluxes are also larger during the day time than at nighttime, with generally the largest value around noon to mid-afternoon. Fluxes at night is very small in comparison, hardly any variability with concentration in case of the red maple enclosure. However, white pine, the only coniferous tree in this study, is an exception.
- If the compensation point is determined by the location where the line from the linear fit of flux vs. concentration crosses the zero flux point, a range instead of a single point may result due to the variability of fluxes throughout the time of the day.

A significant part of the leaf-level uptake of NO2 and O3 depends on the stomatal conductance:

- Since the trace gas uptake has a clear diurnal pattern, it is reasonable to consider the uptake is correlated with leaf stomatal conductance.
- The CO2 assimilation rate by the plant material, CO2 concentration and the relative humidity in the enclosure can be used as proxy for the stomatal conductance as:

\[ g = \frac{F_{CO2}}{B} \frac{RH}{[CO2]} \]

where g is the stomatal conductance, \( F_{CO2} \) and [CO2] are the assimilation rate and concentration of CO2 and RH is the relative humidity.

In Figure 4 is the flux normalized to the concentration plotted against the proxy of stomatal conductance. Only daytime data are included based on the assumption that at nighttime, the stomata are closed.
- The foliar trace gas uptake during daytime depends on the stomatal conductance, with the red oak and the red maple showing relatively strong correlation while the aspen and white pine correlate to a less degree.

Conclusions

- There is essentially no foliar uptake of NO at the range of the input NO concentration, which is comparable to the level at this relatively remote research site. Because of the very low NO concentration and the limited number of data in this experiment, we currently we cannot distinguish whether this NO is from fossil emission or possible photochemistry of other nitrogen oxides, such as HONO, which may have been deposited on the leaf surface.

References

For selected prior reports on measuring leaf-level trace gas exchange, see:


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