The isotope composition of vapor and flux and the coupling of SW model and C-G model in a temperate forest
Outline

Part 1
Background
Site and observation

Isotopes distribution and environmental factor

Part 2
Vapor isotopes: $\delta_v$ and $d_v$
Flux isotopes: $\delta_{ET}/\delta_E$ and $d_{ET}/d_E$

SW model & C-G model

Part 3
Method
Partition of evapotranspiration
Calculated $\delta_{ET}$ and $\delta_E$

Part 4
Summary
Background

• The isotopic composition of atmospheric vapor is a good tracer for environmental change and vapor source, and has been used wildly in Ecology, hydrology, atmospheric chemistry and other research.

• There are many processes that could influence the isotopic composition of water vapor, including canopy transpiration and the evaporation, while the contribution of E & T to vapor isotopes and it’s isotopic composition has not been presented clearly until now.

• C-G model has already been proofed that it could perfectly simulated the isotopic composition of evaporation in open water (eg. Lake); while the application on terrestrial ecosystem is more complex and lack of comparation between simulated with observed value.

• The coupling of SW model and C-G model could help to calculate the isotopic composition of soil evaporation and canopy transpiration in steady state.
Late May - late August. DOY 148-233.

Stand height: 22m 100 years old

Red maple, Aspen, white ash

Figure 1. The site location and experiment setup.

Environment Canada’s Borden Forest Research Station

(Santos et al., 2012)
R: heavier isotoper/lighter isotoper

$\delta^{18}$O and $\delta$D of H$_2$O (‰):

$$\delta = \left( \frac{R_{\text{Sampling}}}{R_{\text{VSMOW}}} - 1 \right) \times 1000$$

$$d_{\text{excess}} = \delta \text{D} - 8 \delta^{18} \text{O}$$

Flux isotope ratio

$$R_{ET} = R_d \frac{x_{16} - x_{16}}{x_{18} - x_{18}} \times \frac{x_{18} - x_{18}}{x_{16} - x_{16}}$$
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Summary
2.1 The vapor isotope and environmental factors

Figure 2. Mean diurnal cycles from May-August of vapor isotopes and main meteorological factors.

Figure 3. The relationship between $d_v$ and (a) RH, (b) vapor mixing ratio w.
Table 1. Linear correlation between afternoon value of $d_v$ and enviromental factors during May-August

<table>
<thead>
<tr>
<th></th>
<th>Mean value</th>
<th>Half hourly</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>m</td>
<td>b</td>
</tr>
<tr>
<td>Above C</td>
<td>-1.24</td>
<td>38.15</td>
</tr>
<tr>
<td>Under C (mmol/mol)</td>
<td>-1.04</td>
<td>33.76</td>
</tr>
<tr>
<td>All</td>
<td>-1.21</td>
<td>37.37</td>
</tr>
<tr>
<td>Above C (RHw, %)</td>
<td>-0.36</td>
<td>42.13</td>
</tr>
<tr>
<td>Under C</td>
<td>-0.39</td>
<td>43.20</td>
</tr>
<tr>
<td>All</td>
<td>-0.37</td>
<td>42.71</td>
</tr>
<tr>
<td>Above C (Ft/Fe, mmol/m²s)</td>
<td>2.51</td>
<td>8.48</td>
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<tr>
<td>Under C</td>
<td>392.25</td>
<td>5.89</td>
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<tr>
<td>All</td>
<td>2.14</td>
<td>11.37</td>
</tr>
<tr>
<td>Above C (Tsc, °C)</td>
<td>-1.29</td>
<td>45.29</td>
</tr>
<tr>
<td>Under C</td>
<td>-1.45</td>
<td>44.64</td>
</tr>
<tr>
<td>All</td>
<td>-1.39</td>
<td>46.34</td>
</tr>
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</table>
3.2 The flux isotope and meteorological factors

Table 2. Linear correlation between afternoon means of $d_{ET}$ and meteorological factors during May-August

<table>
<thead>
<tr>
<th></th>
<th>m</th>
<th>b</th>
<th>R</th>
<th>P</th>
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</thead>
<tbody>
<tr>
<td>$d_{ET}$</td>
<td>22.3</td>
<td>-1440</td>
<td>0.32</td>
<td>0.01</td>
</tr>
<tr>
<td>$d_E$</td>
<td>\</td>
<td>\</td>
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<tr>
<td>$d_{ET}$</td>
<td>-79.6</td>
<td>1720</td>
<td>-0.30</td>
<td>0.02</td>
</tr>
<tr>
<td>$d_E$</td>
<td>\</td>
<td>\</td>
<td>\</td>
<td>\</td>
</tr>
</tbody>
</table>

Figure 4. Mean diurnal cycles of isotopic flux ratios in the temperate forest.
Figure 5. Schematic representation of the major processes and the $d$ in these processes
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Summary
3.1 Method

\[ T_a, T_{sk}, RH, VPD, u, C_s, Sm, R_n, G, PAR_i, GPP, S... \]

\[ r_{ss} = b_1 \times (\theta_s / \theta)^{b_2} + b_3 \]
\[ r_{sc} = \frac{1}{g_0 + a_i f(\theta) P_h \bar{h}_s / C_s} \times 1.6 \]
\[ f(\theta) = \frac{\theta - \theta_s}{\theta_r - \theta_s} \]

\[ r_a, r_{ac}, r_{as} \]

\[ \lambda ET = E_c + E_s = C_c PM_c + C_s PM_s \]
\[ PM_c = \frac{\Delta R + (\rho C_p D - \Delta r_{ac} R_s) / (r_{aa} + r_{ac})}{\Delta + \gamma \left[ 1 + r_{sc} / (r_{aa} + r_{ac}) \right]} \]
\[ PM_s = \frac{\Delta R + [\rho C_p D - \Delta r_{as} (R - R_s)] / (r_{aa} + r_{as})}{\Delta + \gamma \left[ 1 + r_{ss} / (r_{aa} + r_{as}) \right]} \]
\[ C_c = \frac{1}{1 + \rho_a \rho_c / [\rho_s (\rho_a + \rho_c)]} \]
\[ C_s = \frac{1}{1 + \rho_a \rho_s / [\rho_c (\rho_a + \rho_s)]} \]

\[ r_a, r_{ac}, r_{as}, r_{sc}, r_{ss} \]

\[ \delta_E = \frac{\delta_s / \alpha_{eq} - h_s \delta_v - \varepsilon_{eq} - (1 - h_s) \varepsilon_k}{(1 - h_s) + (1 - h_s) (\varepsilon_k / 1000)} \]
\[ \alpha_{eq} = f(T_{sk}) \quad \varepsilon_{eq} = (1 - 1/\alpha_{eq}) \times 1000 (\%) \]
\[ \varepsilon_{k,s}^0 = \frac{32 r_{ss}}{r_a + r_{as} + r_{ss}} \]
\[ \varepsilon_{k,c}^0 = \frac{21 r_{ac} + 32 r_c}{r_a + r_{ac} + r_c} \]

\[ r_{ss} \] was estimated as a function of soil water content (Lin and Sun, 1983);
\[ r_{sc} \] is simulated by the modified Ball–Berry model (Wang and Leuning, 1998);
The 3 aerodynamic resistances: \( r_a, r_{ac}, r_{as} \) is calculated same approach as Shuttleworth and Wallace (1985).
3.2 Partition of evapotranspiration

The energy closure equation: \( y = 0.87x - 13.63 \)

Figure 6. ET simulation on 30-min scale.

Figure 7. Time series of ET measurements (dots) and simulation (line).

Figure 8. Time series of ET components.

The energy closure equation: 
\[ y = 0.98x - 0.13, \quad R^2 = 0.73 \]
\[ p < 0.001, \quad n = 1947 \]
3.3 Simulated $\delta_E$

Figure 9. Time series of $\delta^{18}O_E$ and $\delta D_E$ measurements (dots) and simulation (line) by C-G model.
Figure 10. Time series of simulated $\delta^{18}O_E$ by C-G model in the temperate forest.

Figure 11. Effect of relative humidity ($h_{ss}$) on soil evaporation $\delta^{18}O_E$ in the temperate forest.
Figure 12. Time series of $\delta^{18}$O$_{ET}$ and $\delta$D$_{ET}$ measurements (dots) and simulation (line) by C-G model in the temperate forest.
Figure 13. Mean diurnal cycles of simulated isotopic flux ratios in the temperate forest.

Figure 14. Effect of relative humidity (RH<sub>s</sub>) on canopy transpiration δ<sup>18</sup>O<sub>ET</sub>/δD<sub>ET</sub> and d<sub>ET</sub> in the temperate forest.
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1. $\delta^{18}O_v$ and $\delta D_v$ near the ground in this forest present a ‘W’ diurnal distribution while a ‘U’ type for $\delta^{18}O_v$ over canopy with a light rise up during afternoon.

2. The water vapor content in atmosphere is the main factor that driven $\delta_v$ and $d_v$ variation, which could been proved by the mean diurnal cycle and linear correlation of RH and vapor mixing ratio.

3. Observed $\delta^{18}O_{ET}$ showed a two peak pattern in daytime, in which time the $\delta D_{ET}$ and $d_{ET}$ decreased gradually, there is no obvious variation for isotope of evaporation.

4. The SW model is well played on the simulation of ET, but the $F_e/F_{et}$ is almost zero in this study.

5. C-G model simulated poorly in this study, both for $\delta_{ET}$ and $\delta_E$, a mean reason is RH, which bias much as greater than 90%.
Thank you for your attention!