Evapotranspiration from a Deciduous Forest in a Complex Terrain and a Heterogeneous Farmland under Monsoon Climate

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1. The seasonality and controlling mechanisms of Evapotranspiration
1.1. Introduction

- Considering the rapid increase in pollution and land use change in Asia, and the consequent alterations of water cycles and drought impacts long-term measurement and analysis of ET will play a critical role to ensure sustainability in Asia.

- The number of flux measurement sites in Asia has increased to over a 100, and more multi-year observation data are now available and are used for synthetic analyses and validations for various models and satellite algorithms (e.g., HydroKorea project (ET mapping) in Korea).

- There are two flux sites, Gwangneung deciduous forest and Haenam farmland. Using both multi-year observation data we validate and improve the algorithms.

- In order to ascertain ET from two important plant functional types in Korea: (1) a deciduous forest in complex terrain and (2) a flat but heterogeneous farmland characterized by mosaic patches, we have employed the eddy covariance technique to obtain multi-year observations of turbulent flux datasets.

- The purposes of this presentation are to (1) document the seasonal and inter-annual variations of the measured ET and (2) diagnose the controlling mechanisms of ET from the two different ecosystems based on the framework of radiatively coupled Penman-Monteith combination equation.
**1.2. Materials and Methods**

<table>
<thead>
<tr>
<th>Veg. type</th>
<th>Gwangneung (GDK)</th>
<th>Haenam (HFK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous forest</td>
<td></td>
<td>Cropland</td>
</tr>
<tr>
<td>Annual mean Temp.</td>
<td>12.5 °C</td>
<td>15 °C</td>
</tr>
<tr>
<td>Annual Precip.</td>
<td>1514 mm</td>
<td>1390 mm</td>
</tr>
<tr>
<td>Study period</td>
<td>2006 ~ 2008 (3yrs)</td>
<td>2004, 2006, 2008 (3yrs)</td>
</tr>
</tbody>
</table>

**Sampling rate**: 10Hz  
**AVG time**: 30 min.  
**Planar fit rotation**  
**WPL correction**  
**Modified lookup table**
Radiativley coupled Penman-Monteith Equation

**Surface Energy Balance**

- Net radiation: $R_n$
- Sensible heat: $H$
- Latent heat: $\lambda E$

Water or ground level

The energy budget: $R_n - G = H + \lambda E$

**Aerodynamic Diffusion**

- $F_N - F_G = F_A = F_H + F_E$

- $F_H = \rho c_p (T_s - T_a) / r_{ah}$

- $F_E = \rho \lambda (Q_{sat} (T_s) - Q_a) / (r_{aE} + r_s)$

- $F_E = \frac{\varepsilon_{sa} F_A + \rho \lambda D_a g_a}{\varepsilon_{sa} + 1 + g_a / g_s}$

**Conventional PM Equation**

Stomatal feedback was ignored

**Radiatively coupled PM Eq.**

$F_N^* = (1 - a_s) F_{S\|} + e_s (F_{L\|} - \sigma T_s^4) = F_N + \rho c_p g_r (T_s - T_a)$

$g_r \approx 4 e_s \sigma T_a^3 / (\rho c_p)$  

$p = g_a / (g_a + g_r)$

$F_E = \frac{p \varepsilon_{sa} F_A^* + \rho \lambda D_a g_a}{p \varepsilon_{sa} + 1 + g_a / g_s}$

$F_E = \frac{p \varepsilon_{sa} F_A^* + \rho \lambda D_a g_a}{p \varepsilon_{sa} + 1 + g_a / g_s}$

$F_E = \frac{p \varepsilon_{sa} F_A^* + \rho \lambda D_a g_a}{p \varepsilon_{sa} + 1 + g_a / g_s}$

$F_E = F_{E(w)} \times \Omega$

Raupach (2001)
1.3.1. Results (GDK)

**GDK**

Net radiation (MJ m$^{-2}$ d$^{-1}$)

- ET (mm d$^{-1}$)
- Precipitation (mm)
- Decoupling factor ($\Omega$)

Typhoon Changma

7-day running mean
1.3.1. Results (HFK)
1.3.2. Discussions
1.4. Summary

- The annual ET was on average 373 mm (25% of annual precipitation) at the deciduous forest site and 614 mm (45% of the annual precipitation) at the farmland site.
- ET from both sites showed mid-season depressions mainly due to reduced available energy associated with summer monsoon and typhoons.
- The annual ET at both sites changed little from year to year despite the inter-annual variations in precipitation.
- The ET from the HFK site was equally contributed by both equilibrium ET and imposed ET, whereas the GDK site was to some extent more influenced by imposed ET (hence, air saturation deficit and surface conductance).
2. On estimating wet canopy evaporation from deciduous forest
2.1. Introduction

• The proportion of ET in Gwangneung deciduous forest is estimated approximately 25% of the total annual precipitation (typically 1500 mm), which is considered to be rather low, compared to those reported in other studies conducted in Monsoon Asia (shimizu et al., 2003; Kosugi et al., 2007).

• For the estimation of the annual ET, about 20% of the data was gap-filled following the standard gap-filling method of KoFlux (Hong et al., 2009).

• Main causes of these gaps were (1) malfunction of open-path eddy covariance (EC) system due to precipitation and (2) inadequate environmental conditions for the eddy covariance ET measurement.

• We argue that these gap-filled ET data may have been precipitation-biased (i.e., underestimated) due to the failure of taking the contribution of wet canopy evaporation ($E_{WC}$) into account.

• The overarching questions in this presentation are (1) What are the durations of wet and dry canopy on an annual basis at the GDK site? (2) How well does the open-path EC system measure ET under wet canopy conditions? (3) Can we reliably replace the missing $E_{WC}$ data by the modeled $E_{WC}$ using land surface models (LSM)? (4) How much is the relative contribution of $E_{WC}$ to the annual ET at the GDK site?
2.2. Materials and Methods

- Measurement
- Gwangneung Super site (GDK)
- Vegetation type: Deciduous forest
- Study Period: 2007.9 ~ 2008.8
- Wetness Sensor - 4 levels (0, 10, 15, 20m)

- Modelling
- $E_{we}$ algorithm in VIC LSM
- The parameters are measured by LAI-2000.

\[ E_{we} = \sigma_f E_p \left( \frac{W_c}{S} \right)^n \]
\[ \frac{\partial W_c}{\partial t} = \sigma_f P - D - E_{we} \]
\[ S(mm) = 0.2LAI \]

$L$ indicates the layer thickness in meters.

$Liang et al., (1994)$

$E_{we}$: wet canopy evaporation
$\sigma_f$: vegetation fraction
$E_p$: potential evaporation
$W_c$: canopy water content
$S$: maximum canopy capacity
$P$: precipitation
$D$: drip
2.3.1. Open-Path EC system in the precipitation

The total gaps of the ET measurement due to precipitation was about 41 days in 2007-2008 (about 84% of total period of wet canopy ≈ 50 days).
2.3.2. Validation of Wet Canopy Evaporation Algorithm

The result of $E_{WC}$ algorithm agreed reasonably well with observation.
2.3.3. Comparison of $\lambda E_{WC}$: Modified Lookup Table vs. VIC LSM Algorithm

During the daytime, $\lambda E_{WC}$ from the two methods produced similar magnitudes and patterns. During the nighttime, $\lambda E_{WC}$ estimated by VIC LSM was more realistic due to the consideration of the available energy from the advection of sensible heat.
2.3.4. Quantification of $E_{WC}$ and its Contribution to Total ET

Based on the modified lookup table, the annual EWC was 48 mm (13% of the annual ET), whereas VIC LSM produced 114 mm (31% of the annual ET).
2.4. Summary

- (1) On an annual basis, the duration of wet canopy at the GDK site was 48.6 days.

- (2) For only 16% of such wet conditions, $E_{WC}$ data were measured by the open-path EC system, resulting in 84% being gap-filled.

- (3) We can estimate the reliable modeled $E_{WC}$ using LSMs for replacement the missing $E_{WC}$ data. $E_{WC}$ algorithm in LSM can be used for gap-filling method.

- (4) The annual $E_{WC}$ ranges from 48 mm (based on the gap-filled data with modified lookup table) to 114 mm (with $E_{WC}$ estimated by VIC LSM).

- (5) The contribution of $E_{WC}$ was significant (13~32% of ET) and should be considered carefully in the current gap-filling methods.