After rain comes sunshine

canopy and forest floor interception

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Outline

• What is interception?
  • Definition
  • Types of interception

• Interception measurements
  • Canopy interception
  • Forest floor interception

• Site descriptions

• Some results on:
  • Evaporation
  • Storage capacity

• Spatial and temporal variability of interception

• Effect of throughfall patterns on soil moisture patterns

• Scales
  • Temporal upscaling: Budyko framework
  • Spatial upscaling: energy balance
What is interception?
What is interception?

- Temporarily **storage of rainfall** on any surface, and the successive **evaporation** from this storage, resulting in a reduction of infiltration.

\[ I = \frac{dS}{dt} + E \]

process = storage + flux
Focus of my study
Measurements & Experimental sites
Canopy interception
Canopy interception measurements

- Throughfall
- Stemflow
Forest floor interception
Forest floor interception measurements

\[ \frac{dS_{upper}}{dt} + E = P - \frac{dS_{lower}}{dt} \]  

(Gerrits et al., 2007 HESS)
Site descriptions:

**HUEWELERBACH:**
- Beech

**WESTERBORK:**
- Grass/Mosses

**DELFT:**
- Cedar needles

**HARARE**
- MSASA

**ESTERBORK:**
- Grass/Mosses
Some results: canopy beech

Summer: 15%
Winter: 7%
Some results: forest floor beech

Summer & winter: 22% of throughfall
Results interception evaporation

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Season</th>
<th>Canopy</th>
<th>Forest floor</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beech (huewelerbach)</strong></td>
<td>Summer</td>
<td>15%</td>
<td>19% (22% of Tf)</td>
<td>34%</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>7%</td>
<td>20% (22% of Tf)</td>
<td>27%</td>
</tr>
<tr>
<td><strong>Moss/grass (westerbork)</strong></td>
<td>Summer</td>
<td>-</td>
<td>25%</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>-</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td><strong>Cedar (botanical garden)</strong></td>
<td>Summer</td>
<td>-</td>
<td>20% of Tf</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Winter</td>
<td>-</td>
<td>16% of Tf</td>
<td>-</td>
</tr>
</tbody>
</table>
Interception as a threshold process

storage capacity
Results Storage capacity: Beech (Huewelerbach)

Canopy

Forest floor
Results interception storage

- Beech canopy
- Beech floor
- Moss/Grass floor
- Cedar floor

[mm]

- Summer
- Winter
Spatial and temporal variability of interception

Huewelerbach beech forest

Throughfall [mm]

P = 33 mm
Semi-variogram

\[
\gamma(h) = \frac{\sum n(h) \left( \tilde{N}_{x,y} - \tilde{N}_{x,y+h} \right)^2}{2n(h)}
\]

(Keim et al, 2005 JoH)

Spatial correlation:

- highest in winter (7.4m) and summer (6.7m)
- lowest in the transition seasons (5.9m)
Persistence throughfall

wet

dry
Effect of throughfall patterns on soil moisture patterns

Approach

► Measuring, but:
  • difficult to synthesize (site specific, single case)
  • “Need to consider interactions between controls on hydrologic response” (Buttle [2006])

► Virtual experiments
  "Numerical experiments driven by collective field intelligence”
  (Weiler & McDonnell [2004])
What do we have/know?

- Lots of experience on Panola hillslope behaviour and modelling (Freer, Tromp-van Meerveld, Weiler, McDonnell, ...)
  - Existing HYDRUS 3D model

- Spatial throughfall data of beech forest in Luxembourg (Huewelerbach)
Mapping throughfall pattern on Panola hillslope

Hot spot with TF > P
Panola storm 6-7 March 1996
Soil moisture patterns

dry state  wet state
Semivariogram analysis

a) throughfall pattern

- Correlation length: 5 m

b) mean water content pattern (layer 5-10)

- Correlation length: 5 - 21 m

c) bedrock irregularity pattern

- Correlation length: 21 m
Geo-statistical hydrograph
Interplay between throughfall and bedrock pattern on soil moisture

- Change hillslope attributes: 36 simulations

<table>
<thead>
<tr>
<th>Storm size, $R$</th>
<th>Topography</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slope angle, $A$</td>
</tr>
<tr>
<td>32 mm</td>
<td>6.5°</td>
</tr>
<tr>
<td>63 mm *</td>
<td>13° *</td>
</tr>
<tr>
<td>82 mm</td>
<td>26°</td>
</tr>
<tr>
<td></td>
<td>40°</td>
</tr>
</tbody>
</table>

* = base case scenario
Interplay between throughfall and bedrock pattern on soil moisture

c) Range 2nd peak [m]

soil depth [m]

1.84
1.22
0.62

slope angle [°]

26 13 6.5 32 63 82

storm depth [mm]

bedrock

throughfall

http://www.miriamcoenders.nl
Temporal up scaling

Analytical derivation of the Budyko curve based on rainfall characteristics and a simple evaporation model

Budyko curve framework

\[ \frac{E_{a}}{P_a} \rightarrow \frac{E_p}{P_a} \]

Water limited

\[ \rightarrow \text{aridity} \left( \frac{E_p}{P_a} \right) \]
What did we learn from the field experiments?

- Interception is largely determined by the rainfall sequence
- Interception is a threshold process
- Interception is limited by the potential evaporation

On daily time scale:

\[ E_{\text{int}} = \min (P, D, E_p) \]
Approach

- Both interception and transpiration can be modelled as threshold processes
  - Interception: daily
  - Transpiration: monthly
- Evaporation = Interception + Transpiration
Approach

Daily

Monthly

Annual

transpiration

interception

f(Pd)

f(Pm)

f(Pn)
Example derivation: 
*monthly interception*

\[ f_{i,d}(P_d) = \frac{1}{\beta} \exp\left( -\frac{P_d}{\beta} \right) \]

\[ \beta = \frac{P_m}{\text{E}(n_{r,d} | n_m)} \]

*(De Groen et al, 2006 WRR)*
Example Harare

\[ \mathbb{E}(n_{r,d} \mid n_m) = n_m \frac{p_{01}}{1 - p_{11} + p_{01}} \]

\[ \mathbb{E}(n_{r,d} \mid n_m) = \text{constant} \]
Results of the analytical Budyko curve with $A$ according to Table 3

$\rightarrow E_a/P_a$  

$\rightarrow$ aridity $(E_p/P_a)$
Required parameters

Daily

- interception
  - $D_{\text{int}}$

Monthly

- transpiration
  - $f(P_d)$
- interception
  - $f(P_m)$

Annual

- transpiration
  - $D_{\text{tra}}$
- interception
  - $f(P_n)$

soil moisture ‘carry-over factor’
Energy balance measurements

the challenge of spatial up scaling...

Energy balance measurements of forest floor interception in the Huwelerbach catchment, Luxembourg
(in preparation)
Challenge:
From plot to basin scale

Possible solution direction:

- Developments in Remote Sensing products:
  - Radiation
  - Rainfall
  - Surface Temperature
  - NDVI
  - ...

ër ENERGY BALANCE
Challenge: From plot to basin scale

On the plot scale:
Find relation between the water and the energy balance

Measured @ plot

WATER BALANCE

ENERGY BALANCE

Remote Sensing

Measured @ plot

http://www.miriamcoenders.nl
Energy balance: the parameters

\[
\text{RH} + \text{temp} + \text{wind} \quad \sim 5 \text{ m}
\]

\[
\text{RH} + \text{temp} + 2 \times R_S \quad \sim 10 \text{ m}
\]

R_L \downarrow (http://landsaf.meteo.pt)
Energy balance: the model

\[ C_v \frac{dT_{sk}}{dt} = R_N - H - \lambda E - G \]

\[ H = f(T_{sk}, T_{10}, g_a) \]

\[ \lambda E = f(q_{sk}^*, q_{10}, g_a) \]

\[ G = f(T_{sk}, T_l) \]

De Ridder and Schayes, 1997 (Am. Meteo. Soc.)
Results... Winter... Summer

Winter

$R_{S,c}$ ↓
$R_{L,o}$ ↓

RH (z=10)
T (z=10)
coverage

u (z=10)
P net

accum. P net

Ei,f (modelled)
Ei,f (observed)

Obs: 18 mm (21%)
Mod: 12 mm (13%)
Winter

Simulated accum. $E_{i,f}$ [mm]

Observed accum. $E_{i,f}$ [mm]

Simulated $E_{i,f}$ [mm/d]

Observed $E_{i,f}$ [mm/d]


03/03/08
08/03/08
13/03/08
18/03/08
23/03/08
28/03/08
02/04/08

Simulated $E_{i,f}$ [mm/d]

Observed $E_{i,f}$ [mm/d]

$0.5\,1\,1.5\,2\,2.5$

$0\,1\,2\,3\,4\,5\,6\,7\,8\,9\,10\,11\,12\,13\,14\,15\,16\,17\,18$

Accum. $P_{net}$ [mm]

$P_{net}$ [mm/5 min]

$0\,20\,40\,60\,80$

$0\,0.5\,1\,1.5\,2$

$03/03/08 08/03/08 13/03/08 18/03/08 23/03/08 28/03/08 02/04/08$

Accum. $P_{net}$

$E_{i,f}$ (modelled)

$E_{i,f}$ (observed)

$0.5\,1\,1.5\,2\,2.5$

$0\,1\,2\,3\,4\,5\,6\,7\,8\,9\,10\,11\,12\,13\,14\,15\,16\,17\,18$

03/03/08 08/03/08 13/03/08 18/03/08 23/03/08 28/03/08 02/04/08

$\lambda E$ [W/m$^2$]

$P_{net}$ [mm/5 min]

$0\,200\,400$

$0\,0.5\,1\,1.5\,2\,2.5$

$03/03/08 08/03/08 13/03/08 18/03/08 23/03/08 28/03/08 02/04/08$
Summer

30-May-2010 until 06-Jul-2010

$R_{s.c}$ [W/m$^2$]

$R_{L}\delta$ [W/m$^2$]

$R_{L}$ [W/m$^2$]

$RH (z=10)$

$T (z=10)$

coverage

$u (z=10)$

$P_{net}$ [mm/6 min]

$P_{net}$ [mm/6 min]

accum. $P_{net}$

$E_{L}$ (modelled)

$E_{L}$ (observed)

Obs: 5 mm (18%)

Mod: 5 mm (19%)
Conclusions energy balance

• Energy balance model shows reasonable results, however:
  • Extreme weather conditions (snow, thunder)
  • Temperature sensitivity of observations

• Future:
  • Including canopy and coupling
  • Using more RS products
  • Upscaling
Conclusions

Roles of interception in the hydrological cycle
Conclusions: roles of interception

• **Interception as rainfall reducer**

Dependent on:
• Available storage
• **Precipitation characteristics**
• Potential evaporation

<table>
<thead>
<tr>
<th>Species</th>
<th>Location</th>
<th>Season</th>
<th>$P$</th>
<th>$E_{i,c}$</th>
<th>$E_{i,f}$</th>
<th>$E_i$</th>
</tr>
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<tr>
<td>Beech</td>
<td>Huewelerbach</td>
<td>Summer</td>
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<td>-</td>
<td>- (16% of $T_f$)</td>
<td>-</td>
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</table>
Conclusions: roles of interception

- **Interception as a spatial redistributor**
  - Occurrence of `hotspots` (season dependent)
  - Spatial correlation in winter and summer higher than in the transition seasons
  - Effect on soil moisture patterns (especially with large storms and gentle slopes)
Conclusions: roles of interception

- **Interception as a temporal redistributor**
  - `Interception cascade`

*canopy*

*understorey*

*forest floor*
Further research studies

- Occurrence of hotspots
- Effect on soil moisture patterns
- Energy balance
- Separating evaporation flux (isotopes)

- Interception in urban areas