Hydrological Measurements

Miriam Coenders

5. Measuring Evaporation
Measuring evaporation
Evaporation is ...

\[ E = E_o + E_t + E_s + E_i \]

- \( E \) = total evaporation
- \( E_o \) = open water evaporation
- \( E_t \) = transpiration
- \( E_s \) = soil evaporation
- \( E_i \) = interception evaporation
Potential vs Actual

- Potential:
  - No water stress
  - Atmospheric demand for moisture

- Actual:
  - Reality
  - Net result of atmospheric demand for moisture from a surface and the ability of the surface to supply moisture
# Evaporation measurements

<table>
<thead>
<tr>
<th>Measurement</th>
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Potential evaporation measurements
Class A-pan
Penman (-Monteith)

\[ \lambda E = \frac{\Delta (R_n - G) + \rho_{\text{air}} c_p \text{vpd} / r_a}{\Delta + \gamma (1 + r_s / r_a)} \]

= 0 for Penman (no vegetation)
Radiation \[ R_n = (R_{s,in} - R_{s,out}) - (R_{l,in} - R_{l,out}) \]

http://thegreendove.com/2010/05/radiation-flying/
Radiation – Net radiation

\[ R_N = (1-r)R_C - R_B \]

<table>
<thead>
<tr>
<th>Location</th>
<th>( R_C )</th>
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<tbody>
<tr>
<td>The Netherlands</td>
<td>( 0.20 + 0.48 \frac{n}{N}R_A )</td>
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<tr>
<td>Average climate</td>
<td>( 0.25 + 0.50 \frac{n}{N}R_A )</td>
</tr>
<tr>
<td>New Delhi</td>
<td>( 0.31 + 0.60 \frac{n}{N}R_A )</td>
</tr>
<tr>
<td>Singapore</td>
<td>( 0.21 + 0.48 \frac{n}{N}R_A )</td>
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</table>

\[ R_B = \sigma \left(273 + t_a\right)^4 \left(0.47 - 0.21 \sqrt{e_a}\right) \left(0.2 + 0.8 \frac{n}{N}\right) \]
Radiation – Net radiation
Radiation – Short wave radiation

The absorber (1) absorbs radiation (2). The radiation is converted into heat. The heat flux to the heat sink (4) is measured by the thermopile (3).

Hukseflux LP02 (Pyranometer)

**LP02 SPECIFICATIONS**

- ISO classification: second class
- Spectral range: 305 to 2800 nm
- Sensitivity (nominal): 15 μV/ Wm⁻²
- Temperature range: -40 to +80 °C
- Range: 0 to 2000 Wm⁻²
- Temperature dependence: < 0.1%/°C
- Calibration traceability: WRR

[Source Unknown]

Radiation – Long wave radiation

Kipp & Zonen CGR3 Pyrgeometer

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<tr>
<th>Parameter</th>
<th>Specification</th>
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<tr>
<td>Spectral Range</td>
<td>4.5 to 42 µm (50% points)</td>
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<tr>
<td>Sensitivity (nominal)</td>
<td>5 to 7 µV/W/m²</td>
</tr>
<tr>
<td>Response time (63 %)</td>
<td>&lt; 6 s</td>
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<tr>
<td>Response Time (99 %)</td>
<td>&lt;18 s</td>
</tr>
<tr>
<td>Temperature Dependence of Sensitivity (−20 to +50 °C)</td>
<td>-10 to +40 °C ±5 %</td>
</tr>
<tr>
<td>Field of View</td>
<td>150°</td>
</tr>
<tr>
<td>Irradiance</td>
<td>-250 to +250 W/m² (net irradiance)</td>
</tr>
<tr>
<td>Non stability change / year</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Temperature sensor</td>
<td>Thermistor (YSI 44031)</td>
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</table>
Radiation – Remote sensing

Meteosat incoming radiation

Source Unknown
Soil heat flux
Vapor Pressure Deficit ($e_s - e_a$)

\[ e_s (t) = 0.61 \exp \left( \frac{17.3t}{237 + t} \right) \]

\[
h = \frac{e_a (t)}{e_s (t)} \]

- Temperature
- Humidity:
  - Psychrometer
  - Humidity sensor
VPD - Psychrometer

\[ e_s(t) = 0.61 \exp \left( \frac{17.3t}{237 + t} \right) \]

\[ e_a(t_a) = e_s(t_w) - \gamma(t_a - t_w) \]
VPD - Humidity
Aerodynamic resistance

\[ r_a = \frac{245}{(0.54u_2 + 0.5)} \times \frac{1}{86400} \]
Summary Penman

- Net radiation
- Ground heat flux (G=0 on daily time scale)
- Temperature
- Humidity
- Wind
Actual evaporation measurements

- Lysimeter
- Scintillometer
- Eddy correlation
- Bowen ratio
- Water balance

Measurement scales:
- 1m²
- 10 ha
- 500 ha
- 10,000 ha
Lysimeters
Lysimeters
Lysimeters
Bowen ratio

\[ R_n = \rho \lambda E + H + G \]

\[ \beta = \frac{H}{\rho \lambda E} = \gamma \frac{T_2 - T_1}{e_2 - e_1} \]

Arid: \( \beta >> 1 \)
Humid: \( \beta << 1 \)

\[ E = \frac{R_n}{\rho \lambda (1 + \beta)} \]
Bowen ratio instruments were placed in the field to collect evapotranspiration data. Inset, plates were placed just below the soil surface in the plant row, bed shoulder and center of the furrow to measure soil heat flux.

Source Unknown
Bowen ratio with DTS
Eddy covariance
Principle eddy covariance

Wind

+ Concentration

Temperature (H)
Humidity (λE)

Eddy covariance

http://www.campbellsci.com
Eddy covariance

In no wind, or cross wind; the ultrasonic pulse moves at the same speed in each direction.

Source Unknown
Scintillometer

Transmitter

Turbulent Atmosphere

Receiver
Scintillometer

LAS and XLAS transmitter part

LAS – Receiver and Transmitter
The LAS 150 measures the amount of intensity fluctuations ('scintillations')

- The amount of fluctuations is related to the vertical transport of sensible heat ($H$) by turbulent *eddies* in the atmosphere.
- E is derived from the surface energy balance equation

$$Q^* = H + L_vE + G$$
Measurements of ET fluxes

Source Unknown
Water balance

\[ \frac{dS}{dt} = P - E - Q \]
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