TERENO NETWORKS

Soil moisture monitoring in German observatories

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Identified high risk regions

Network of TERENO Observatories
Budget: ~20 Mio. €
Start: 2008

MULTI-SCALE AND MULTI-COMPARTMENT MONITORING CONCEPT
Some soil moisture data also transferred to ISMN
TERENO RUR

- 12 Cosmic ray soil moisture stations including SMT100
- 2 High density soil moisture networks
  - Grassland site Rollesbroich
  - Forest site Wüstebach
SOILNET

Subsurface wireless sensor network

Advantages:

- Low visibility
- Protection against vandalism, animals etc.
- Protection against temperature changes
- No interference with agricultural practices (grassland)
SOILNET

Subsurface wireless sensor network

Zigbee standard, a LoRa standard is under development
SOILNET

Router and coordinator

Sensor network Rollesbroich

Coordinator with GSM modem

sector antennas

router
## SOILNET

### Sensor examples

<table>
<thead>
<tr>
<th>Name</th>
<th>Variable</th>
<th>Interface</th>
<th>Company</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMT100</td>
<td>Soil moisture, soil temperature</td>
<td>SDI-12</td>
<td>truebner.de</td>
</tr>
<tr>
<td>MPS-6</td>
<td>Water potential</td>
<td>SDI-12</td>
<td>decagon.com</td>
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<tr>
<td>GS3</td>
<td>Soil moisture, soil temperature, el. conductivity</td>
<td>SDI-12</td>
<td>decagon.com</td>
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<tr>
<td>5TE</td>
<td>Soil moisture, soil temperature, el. conductivity</td>
<td>SDI-12</td>
<td>decagon.com</td>
</tr>
<tr>
<td>CTD-10</td>
<td>Water level, temperature, el. conductivity</td>
<td>SDI-12</td>
<td>decagon.com</td>
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<tr>
<td>RT-1</td>
<td>Soil temperature</td>
<td>SDI-12</td>
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<td>EC-5</td>
<td>Soil moisture</td>
<td>analogue</td>
<td>decagon.com</td>
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<tr>
<td>RG2501</td>
<td>Precipitation</td>
<td>pulse</td>
<td>omega.com</td>
</tr>
</tbody>
</table>
SOILNET CALIBRATION
Fist step: Relationship between sensor output and permittivity

M1: Air (ε=1)
M2: Dry sand (ε=3)
M3: (2-Isopropanol, ε ~ 18.1)
M4: (2-Isopropanol, ε ~ 26.3)
M5: (2-Isopropanol, ε ~ 34.8)
SOILNET CALIBRATION

First step: Relationship between sensor output and permittivity

\[ K_a = \gamma + \frac{1}{\alpha + \frac{\beta}{(18000 - \text{counts})/5000}} \]

Universal model

Sensor specific calibration

\[ \Delta \text{Counts} = 150, \quad \text{STD} = 47 \]
\[ \Delta \text{Counts} = 259, \quad \text{STD} = 42 \]
\[ \Delta \text{Counts} = 226, \quad \text{STD} = 56 \]
\[ \Delta \text{Counts} = 129, \quad \text{STD} = 58 \]
\[ \Delta \text{Counts} = 154, \quad \text{STD} = 42 \]
SOILNET CALIBRATION

Second step: Relationship between SWC and permittivity

- Empirical models (e.g. Topp et al., 1980) -> not universal

\[ \Theta_v = -5.3 \cdot 10^{-2} + K_c \cdot 2.92 \cdot 10^{-2} - K_c^2 \cdot 5.5 \cdot 10^{-4} + K_c^3 \cdot 4.3 \cdot 10^{-6} \]

\( \Theta_v \): Volumetric soil water content
\( K_c \): Measured apparent soil permittivity

- Physically based models:
  - Three component model CRIM (Roth et al., 1990)

\[ \theta = 100 \cdot \frac{K_a^{\beta} - (1 - \eta) \cdot K_s^{\beta} - \eta K_{air}^{\beta}}{K_w(T)^{\beta} - K_{air}^{\beta}} \]

\( K_a \): Apparent permittivity
\( K_s \), \( K_w \), \( K_{air} \): Relative permittivities of the solid, water, and air phases
\( \eta \): Porosity
\( \beta \): Shape factor
SOILNET CALIBRATION

Soil-specific calibration

CRIM Model:

\[ \theta = \frac{K_a^\beta - (1 - \eta) \cdot K_s^\beta - \eta K_{air}^\beta}{K_w(T)^\beta - K_{air}^\beta} \]

\[ \text{RMSE}=2.9 \text{ Vol.\%} \]

Rosenbaum et al. (2012)
THE WÜSTEBACH NETWORK

Forest hydrology research (27ha)

Test site Wüstebach

- 150 Sensor units
- 18 Router units
- 900 Soil moisture sensors
- 300 Temperature sensors

455 days: ~10 Mio. hourly measurements!

Bogena et al. (2010)
THE WÜSTEBACH NETWORK

Spatial variability vs. mean soil moisture

- Highest soil moisture variability as well as scatter is observed in 5 cm.
- SD peaks in the intermediate soil moisture range.
THE WÜSTEBACH NETWORK

A clear-cut experiment

Before

<table>
<thead>
<tr>
<th>SM</th>
<th>Reference area</th>
<th>Clear-cut area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>39.5 (7.6)</td>
<td>43.6 (7.2)</td>
</tr>
<tr>
<td>After</td>
<td>38.6 (6.9)</td>
<td>51.2 (4.9)</td>
</tr>
</tbody>
</table>

Wiekenkamp et al., 2016
THE ROLLESBROICH NETWORK

Grassland hydrology (40ha)

- 200 Sensor units
- 18 Router units
- 1200 Soil moisture sensors
- 300 Temperature sensors

Long-term L-band radiometer measurements
AIRBORNE CAMPAIGNS

L-band SAR (DLR F-SAR) and radiometer measurements (PLMR2)
CONCLUSIONS AND OUTLOOK

- To get closest to real spatiotemporal variability of soil moisture with in situ sensors, wireless sensor networks have some advantages
- SoilNet applications since 9 years mainly for soil water dynamics research
- SoilNet is restricted to small catchments
- SoilNetLoRa makes monitoring of larger catchments possible (e.g. 100 km²)
- 2 step SM sensor calibration is TERENO standard
- TERENO Rur observatory (ag site Selhausen) will be location of a test campaign for the ESA Copernicus L-band SAR candidate mission