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Title: Distributed Temperature Sensing (DTS) to Characterize Soil Moisture and Heat Dynamics of a Vegetated Hillslope in Mill Haft, Staffordshire, UK.

Monitoring the coupled water and heat dynamics in the soil vadose zone is crucial to the eco-hydrological characterization of any ecosystem.
As multiple concurrent atmospheric and underground forcing affect such dynamics, consequently water and heat movements evolve across a wide range of scales in complex spatiotemporal patterns and as such are often difficult to identify.
Existing monitoring techniques have limitations in providing precise measurements of key indicators such as soil temperature and moisture content over large areas, especially at high spatial and temporal resolution.
Point sensors (e.g. time/frequency domain reflectometry-based probes) can be extremely precise, but by definition only over a limited spatial scale.
Remote techniques (e.g. satellites, cosmic rays probes, ground penetrating radar), that can cover much larger spatial extents usually provide averaged measurements with only limited temporal resolution and shallow penetration depths.

Optical fibre based distributed temperature sensing (DTS) provides precise temperature monitoring along a multi kilometres optical cable, with sampling resolutions as fine as few centimetres and measurement times of several seconds.
Once the optical cable is set in the soil, distributed soil temperature profiles are directly measured.
Soil thermal diffusivity and moisture measurements can be obtained utilising both passive and active DTS techniques.
Passive techniques require soil temperatures at multiple depths; values of soil thermal diffusivity and moisture content are inferred by measuring amplitude attenuation and phase shift of the diurnal forcing at the soil surface. In contrast active techniques rely on sending a heat pulse along the optical cable (usually by flowing electrical current through metal elements embedded in the cable structure). Differences in heating and cooling along the cable are directly related to different thermal diffusivities, and soil moisture regimes.

In July, 2015 Silixa Ltd., a leading manufacturer of Distributed Temperature Sensing instruments (http://silixa.com/technology/), along with the University of Birmingham (UoB) and the Birmingham Institute of FOrest Research (BIFOR), launched an ambitious monitoring campaign as part of the ground-breaking Free Air Carbon dioxide Enrichment (FACE) experiment (http://www.birmingham.ac.uk/research/activity/bifor/face/index.aspx).

Three loops of 480 m of optical cable were buried in the soil at different depths (0.05m, 0.25m and 0.40m), along an inclined and recently vegetated field (Figure 1, a, b) at the southern border of the Mill Haft woodland, Staffordshire (UK) (Figure 2). A temporary measurement station for both active and passive DTS has been located at the bottom of the hillslope (Figure 3).

This deployment aims at:

i) Using both passive and active DTS measurements to:
   a. monitoring long-term evolution of soil temperature and moisture
   b. tracing water and heat movements in this complex vadose zone

ii) Associating soil heat and water dynamics to:
   a. sporadic events (e.g. rainfalls, irrigation)
   b. soil features (e.g. inclination, vegetation)
   c. periodic atmospheric forcing (diurnal, seasonal, annual)

iii) Allowing critical improvements to:
   a. irrigation techniques
   b. calibration and validation of numerical models
   c. upscaling of point sensor and/or downscaling of remote sensor measurements.

The first tests with the active DTS technique were performed in August and October, 2015. These measurements yielded promising results.
The optical cable heating is clearly visible at the different depths and shows evident spatial patterns (Figure 4).
However, as the trenched soil has not yet recovered a natural compaction, the results are still preliminary and indicative of the current soil conditions.
New measurements are scheduled for February and March, 2016, and the temporary monitoring station is expected to become permanent by April, 2016.
The innovative set-up and the first results of the measurements have been presented at several international conferences:

European Geophysical Union (EGU) general assembly (Vienna, April 2015):
http://meetingorganizer.copernicus.org/EGU2015/EGU2015-13958.pdf

International Association of Hydrogeology (IAH) AQUA meeting (Rome, Italy, September 2015):
https://www.aqua2015.com/author.php?id=667

American Geophysical Union (AGU) fall meeting (San Francisco, US, December 2015:
https://agu.confex.com/agu/fm15/meetingapp.cgi/Person/27004

Furthermore, given the high scientific relevance of the measurements performed, publications in peer-reviewed journals of eco-hydrology are also expected.

Figure 1: Experimental arrangement.

Optical cable deployment required the digging of a 0.1 m thick, 0.4 m deep soil trench for the 480 m loop, in between rows of young growing trees. View from the bottom of the hillslope. The temporary monitoring station is under the green tent (b).

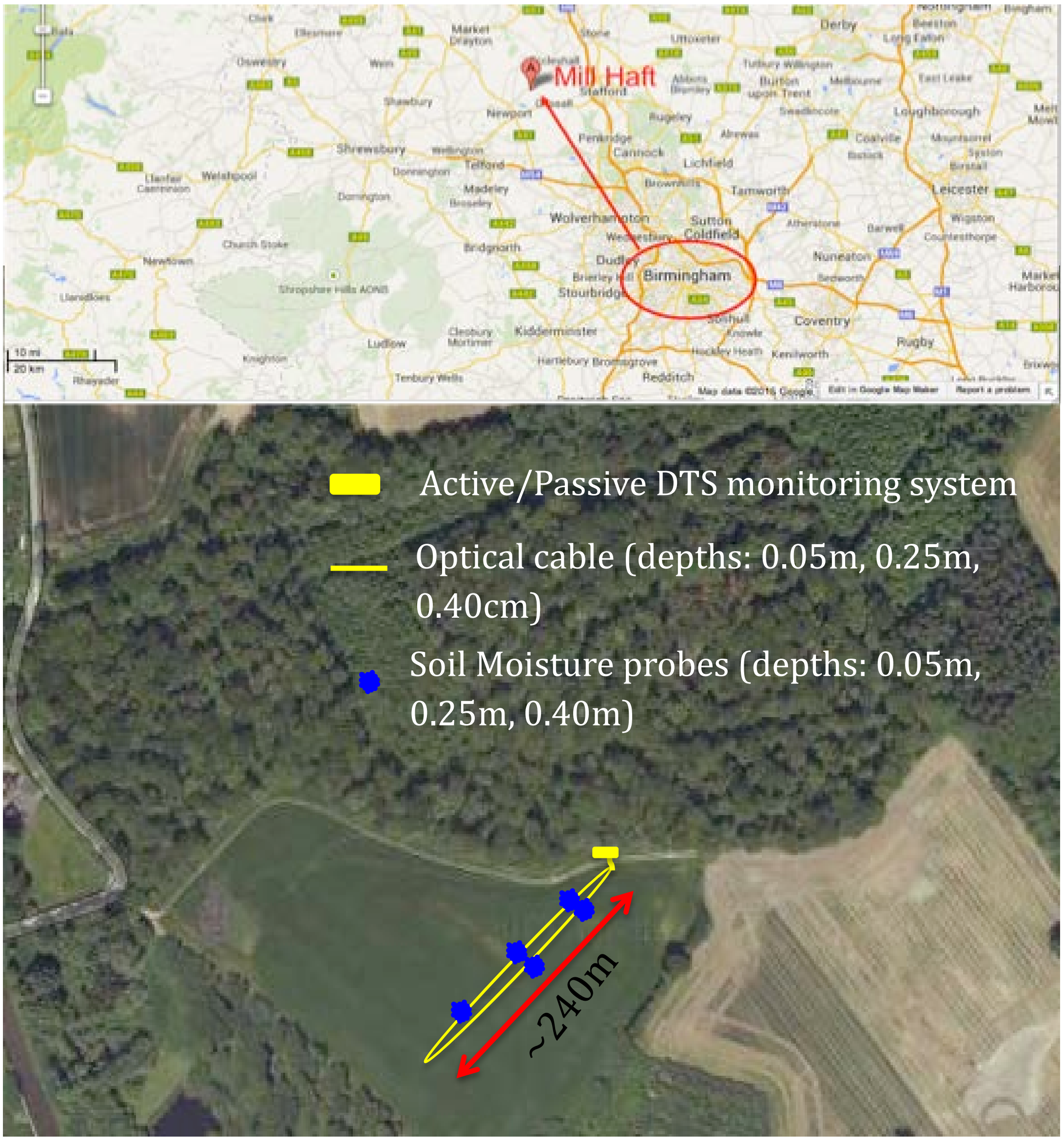

Figure 2: Site and deployment location.

Mill Haft woodland in Staffordshire (North West of Birmingham, UK), is the site hosting the FACE experiment. The hillslope is located at the southern border of the woodland. Independent soil moisture and temperature measurements using point sensors are performed simultaneously in five locations along the optical cable path (blue dots).

Figure 3: Active and passive DTS monitoring system for soil heat and moisture dynamics.

The left enclosure controls the heat pulses to the optical cable for active DTS. The connections to the DTS instrument (not shown) are enclosed in the black box in the middle of the coils of spare optical cable. The switches in the right enclosure control the cable to which the heat is applied.

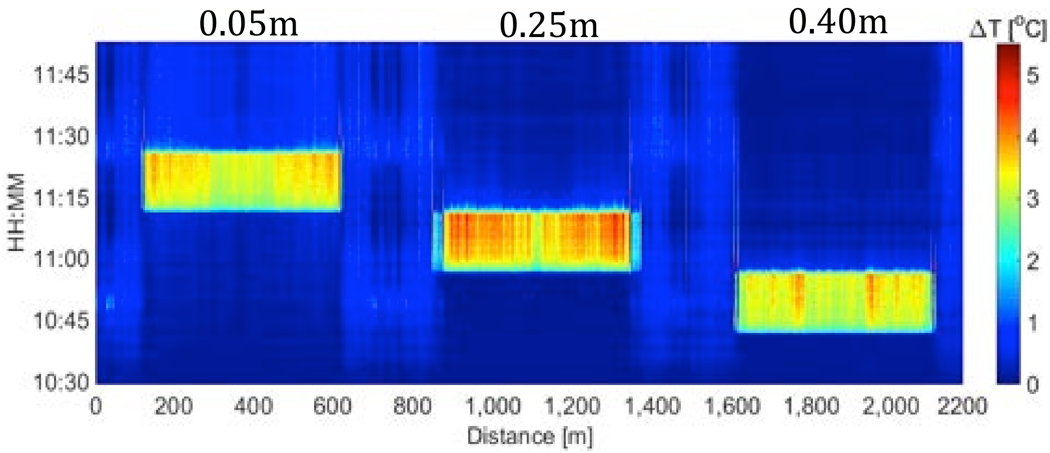

Figure 4: Example of DTS measurements during an active experiment.

Optical cable at the different depths was heated in sequence for 15 minutes. The spatial differences in temperature within each of the three loops, mark out areas of different thermal diffusivity and, therefore, soil moisture content.