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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 water and heat patterns in soils is important for understanding how an ecosystem functions. Such patterns are formed by the interaction of atmospheric (e.g. air temperature) and underground (e.g. soil type) factors, and are often difficult to identify in detail.

Existing monitoring techniques have difficulties in providing precise measurements of soil temperature and moisture over large areas, especially at high resolutions. Point sensors can be extremely precise, but by definition are limited to a single point. Remote sensing techniques (e.g. satellites) can cover much larger spatial extents, but their temporal resolution is limited.

Optical fibre-based distributed temperature sensing (DTS) provides precise temperature monitoring along an optical cable several km long, with sampling resolutions as fine as a few centimetres and the capacity to repeat measurements every few seconds.

Once the optical cable is set in the soil, distributed soil temperature and moisture profiles are directly measured using either passive or active techniques.

Passive techniques require soil temperatures at multiple depths; values of soil thermal diffusivity and moisture content are inferred from daily temperature cycles.

In contrast, active techniques rely on sending a heat pulse along the optical cable (usually by 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/BIFoR).

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 is located at the bottom of the hillslope (Figure 3).

This deployment has the following aims:

i) Using both passive and active DTS measurements to:
   a. monitor long-term evolution of soil temperature and moisture
   b. trace 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 fully from compaction incurred during installatiom, the results are still preliminary.

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).

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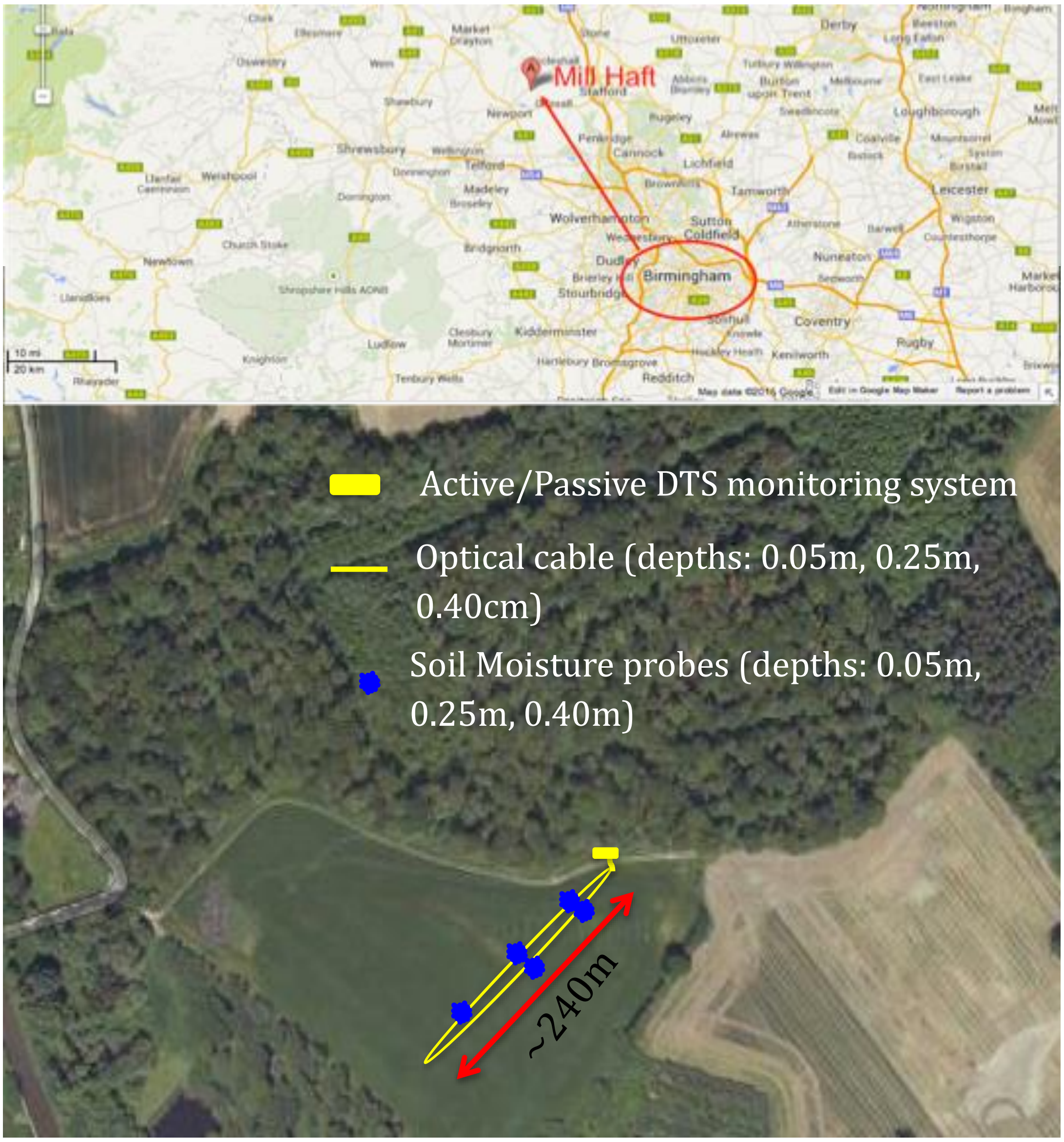

Figure 2: Site and deployment location.

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.

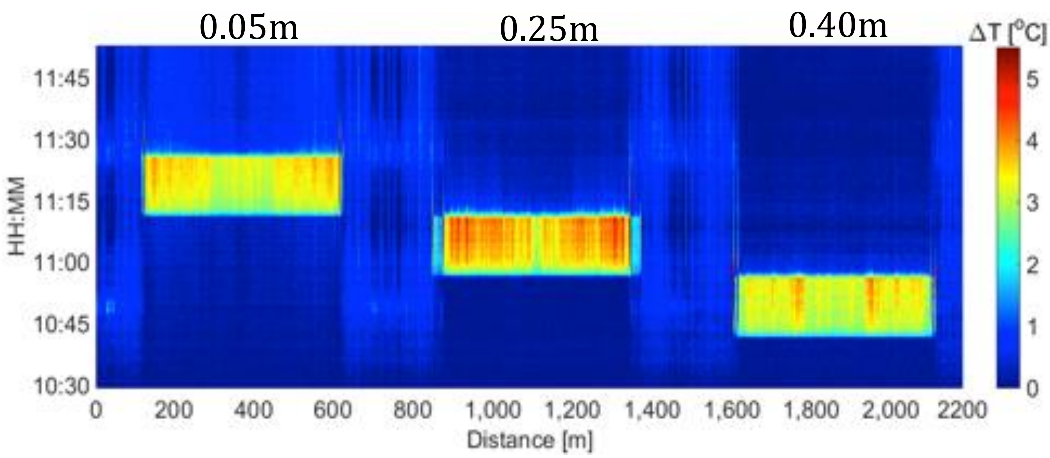

Figure 4: Example of DTS measurements during an active experiment.

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.