Geophysical Research Abstracts
Vol. 20, EGU2018-10997, 2018
EGU General Assembly 2018

Soil water measurement from laboratory soil column to field scales using actively heated fiber optics

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A major challenge in understanding the hydrological dynamics is the modelling and measurement of soil water content (SWC) across a range of spatial and temporal scales. A range of point based sensors have advanced the measurement of SWC at defined points in space or time while remote sensing has been used to estimate SWC at continental to global scales. However, an intermediate spatial scale gap remains where we lack high resolution (both spatial and temporal) SWC data to quantify the patterns and magnitudes of hydrological dynamics and to better assess the performance of various hydrological models. The active heat pulse with fiber optic temperature sensing (AHFO) method has shown the potential to provide SWC data at sub-meter intervals along a fiber optic cable to a distance >10000 meters. This study evaluated the feasibility of AHFO to measure SWC at sub meter (spatial) and diurnal to seasonal (temporal) scales in laboratory and field. Heat pulses of three minutes duration were applied at a rate of 20 Wm-1 through a helically wrapped fiber optic cable in a sandy soil column before, during, and after irrigation in the laboratory. Heat pulses of five minutes duration were applied at a rate of 7.28 Wm-1 through eighteen fiber optic cable transects installed at three depths (0.05, 0.10 and 0.20 m) at six-hour intervals daily over nearly three months in a cropped field. A distributed temperature sensing (DTS) instrument was used to measure the cumulative temperature increase (Tcum) at locations along the cable. An indirect relationship between Tcum and SWC was developed and validated using the SWC measurements measured by the gravimetric method (laboratory) and calibrated soil water sensors in the field. Spatial and time series data were used to generate maps of SWC. Strong relationships between Tcum and SWC ($R2\geq0.90$) predicted soil water accurately; RMSE of 3 to 4 % for both laboratory and field experiment. Maps of SWC helped to identify wetting bulb formation, movement of the wetting front and changes in the dimensions (wetted radius and depth) of wetting bulbs during irrigation experiment in the laboratory. Further, AFHO method clearly identified the changes in SWC due to rainwater infiltration at diurnal to seasonal temporal scales in the field. Overall, results of this study demonstrated the feasibility of the AFHO method to measure and monitor soil water at small (laboratory soil column) to field scales at high spatial (sub-meter) and sub-hourly to seasonal temporal scales. It also showed the potential to improve water movement models using high resolution SWC measurements in the future.