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Observations of soil moisture from thermal infrared data

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Soil moisture is one of the most important parameter affecting surface stability in soil slopes. In unsaturated soils effective stresses and shear strength are directly related to water content, and even pre-failure deformations are largely controlled by this parameter. Different experimental techniques are commonly employed to measure soil moisture in the unstable horizon and its relation with rainfall and snow (sampling and laboratory measurements, tensiometers, capacitance sensors, TDR). However, most of the available methods are suitable to acquire discrete data points which can be difficult to interpolate in the spatial domain. Recent advances in remote sensing have shown that soil moisture can be measured by satellite observations such as passive microwave emissivities, active microwave scatterometer data, and infrared estimates of the diurnal amplitude of the surface skin temperature. Hydrologic analyses at the basin scale (evaporation estimates, rainfall-runoff modelling) are greatly benefiting from this new technology, but this is not the case of slope stability studies at small scale. In fact, the spatial resolution of remotely sensed data (tens of meters) is usually too coarse to capture the small-scale variations of soil moisture that characterise surface slope instabilities.

This work presents experimental results on the use of thermal infrared visual camera for mapping soil moisture in unstable slopes. Two field tests and several laboratory tests in controlled conditions were performed to evaluate the relationship between thermal infrared-signature and water content of the soil surface. The camera is a NEC Thermo Tracer TH9100Pro, which has a spectral range of 8 to 14 μm, a resolution of about 0.04 ˚C, and a focusing range from 30 cm to infinity. The pixel size of the thermal image is about 1.2 mm at ad distance of 1 m and 1.2 cm at a distance of 10 m.

In the laboratory, six samples of fine calcareous sand were prepared at different water content (from dry to fully saturated), with both the grains and the water at the same temperature (20 ˚C). The samples were then brought outside, where the air temperature was about 5 ˚C, and recorded with the thermal camera. During the cooling process we captured one thermal image every 1 minute, until all the samples reached approximately the same temperature. The soil water content of the whole sample and of the surface skin was measured immediately before and after the test. In the field, two tests were conducted in the crown area of two complex earthflows (Silla and Firenzuola landslides, Northern Apennines, Bologna, Italy). In both sites, we placed the camera at an average distance of 80-100 m from the headscarp in order to monitor a crown sector 30-50 m wide with a pixel resolution of about 5 cm. The tests lasted from 2 PM to 1 AM and one thermal image every 10 minutes was captured. At the end of the tests, we collected 20 cylindrical samples of soils (diameter=5 cm; height= 5 cm) and 20 remoulded samples of the soil skin to measure the water content. Sampling locations were carefully detected in the digital images by pixel coordinates.

Test results show that thermal infrared data are closely related to soil moisture. The tightness of this correlation was already evident during the tests. In the laboratory, wet samples were significantly warmer than dry samples since they were cooling much more slowly due to the smaller heat capacity. In the field, wet areas were cooler because they took longer to be warmed by the sun. Plot of the measured water content against the recorded temperature in the corresponding pixel gives a statistically significant relationship between the two parameters. More extensive tests are required with different soils and in different site conditions, but these preliminary experiments suggest that thermal infrared images can be useful to map areas characterised by different soil moisture even at a large scale.