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Intraday monitoring of granitic exfoliation sheets with LiDAR and thermal imaging (Yosemite Valley, California, USA)

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Rockfall activity in Yosemite Valley is often linked to the presence of exfoliation sheets associated with other structures such as faults, joints or geological contacts. Daily and seasonal temperature variations or freeze-thaw cycles may strongly promote crack propagation along discontinuities, ultimately leading to rockfalls (Stock et al., 2013). However, little is known concerning the impact of thermal variations on rock face deformation, despite its occurrence at all times of year. To understand the influence of daily temperature fluctuations on the behavior of exfoliation joints (i.e. fractures separating exfoliation sheets), we carried out two different experiments in October 2015: (a) We first monitored a sub-vertical granodiorite flake (19 m by 4 m by 0.1 m ; Collins and Stock, 2014) for 24 consecutive hours using LiDAR and infrared thermal sensors; (b) We monitored a rock cliff (60 m by 45 m) composed of tens of exfoliation sheets located on the southeast face of El Capitan (an ∼1000-m-tall cliff located in western Yosemite Valley) for several hours (from 05:30 pm to 01:30 am) to investigate the diurnal cooling effect on rocks of different lithologies.

To calibrate the raw apparent temperature measured by the thermal imager (FLIR T660 infrared camera), we fixed pieces of reflective paper (aluminum foil) and black duct tape on both monitored cliffs to measure the reflected temperature and the emissivity of the different rocks. In addition, ambient temperature and relative humidity readings were performed for each acquisition. We then compared the calibrated temperatures to the values registered by resistance temperature detectors (Pt100 sensors), also attached to the rock. Finally, we compared the millimeter scale deformations observed with LiDAR to the values measured by manual crackmeters (standard analog comparators with springs) installed beforehand in the fractures.

For the first experiment (24-hour monitoring), a series of measurements were carried out: (a) thermal pictures were collected every 20 minutes, (b) LiDAR scans (4 mm point spacing) were collected every hour and (c) the measurements provided by the crackmeters and thermoresistances were recorded every two hours. The thermal images were then draped on the LiDAR triangular meshes to quantify the lateral propagation of temperature during the warming and cooling periods. Results show that the flake edge is cooler than the surrounding areas and that this part undergoes the most significant daily temperature variations. Furthermore, the comparison of point clouds allowed observing and quantifying one full contraction-expansion cycle of the monitored exfoliation sheet, confirming the observations of Collins and Stock, 2014. The maximum deformation (17.5 mm in total) occurred between 04:00 am and 03:00 pm, when temperatures were respectively minimum (16 °C) and maximum (28 °C); this deformation value is consistent with those measured by the crackmeters.

Regarding the second experiment, we collected a series of thermal images and LiDAR scans with the same time interval (20 minutes) but with a lower spatial resolution (point spacing of about 7 mm). Here, we also observed that the edge of exfoliation sheets were cooler in this test, and not dependent on the length of the analyzed flakes (from a few tens of cm to several m).

Our experiment indicates that the infrared thermography can be used to remotely detect exfoliations sheets in the cliff at short distances (within 100 m), and to generate a 3D map of partially detached unstable rocky compartments. For some flakes, we locally observed a decrease of temperature of a few °C in surface, suggesting the presence of rock bridges. Finally, our thermal comparisons show that the cooling amplitude varies depending on lithologies: the cooling is more important for dark rocks (e.g., diorites) than for light-coloured rocks (e.g., granites) which reflect more incident radiation.