# Quantitative assessment of tree trunk inclination and topographic conditions using multi-temporal point cloud data in a hilly catchment

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Recent advances in the measurement approaches using terrestrial laser scanning (TLS) have enabled quantitative evaluation of forest environments with three-dimensional (3D) point cloud data. Several issues, including estimation of biomass, light transmission through canopies, and hierarchical structures of forests, have been investigated by point cloud analysis. However, the 3D structures of individual trees, as well as the relationships among such vegetation characteristics and topographic conditions, remain to be further examined. In this study, we examine the inclination of tree trunks, as a representative shape parameter of forest vegetation, in a small hilly watershed using 3D point cloud data. The effects of topographic conditions on the vegetation shape are further investigated. We use multiple time series of point cloud data obtained by TLS in 2005 and 2016, which enable us to detect decadal changes in the vegetation and topography in the study site. Spatial distribution of the tree inclinations shows topographic controls on the vegetation shape: for instance, more inclined trees are found around the valley bottom where slopes tend to be steep due to the channel incision. Comparisons of the multi-temporal point cloud data reveal the changes in both vegetation shape and topography. In particular, gradual erosion and deposition of sediments on the order of decimeters to meters are found to have occurred around the valley bottom following the occurrence of the debris flow in 2005. In the last decade, the sediment accumulation was domant in gentle reaches along the channel, while the erosion occurred on the steep side slopes. Such the change in topography seems to have affected the tree trunk inclinations, probably due to the soil creep toward the steepest descent of the catchment slopes. Also, it is suggested that the tree crown have grown asymmetrically toward the sunlight that is more available in the forest gap around the valley bottom, leading the tree trunk more inclined toward the gap due to its unbalanced weight. This kind of analysis will also contribute to the disaster prevention issues in mountainous or hilly areas with forests.

キーワード：樹木の幹の傾き、地形、TLS
Keywords: tree trunk inclination, topographic , TLS