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Small slope tilts caused by meteorological effects and vital processes of trees on a wooded slope in Hidegvíz Valley, Hungary

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ABSTRACT

Long-term measurements were carried out to investigate the relationship between ground tilts and variations of meteorological (temperature, precipitation) and hydrological (soil moisture content) parameters in the area of the Sopron Mountains, on a wooded slope of the Hidegvíz Valley, Hungary. The connection between surface tilts and the vital processes of the trees was also studied on the basis of the reference evapotranspiration calculated for the study area. Long- and short-term variations were separated. A long-term ground temperature change of 1 °C caused a 4 µrad tilt in the SE direction. Short-term temperature effects can be neglected. The fluctuation of temperature around the freezing point caused tilts of about 10 µrad °C^{-1}. The soil water content variation had the largest effect on the ground tilt (0.5 µrad mm^{-1}). Its contribution to the total ground tilt in the investigated period was about 70 µrad (65% of the total tilt of 107 µrad) toward the SSE. The contribution of the wind speed to the ground tilt was about 20 µrad m s^{-1} toward the SSE depending on the water content of the soil. The wind did not cause a permanent ground tilt. The magnitude of the daily tilt variations in the active growing period of trees, from March to October, is 1–2 µrad while in the dormant period (with no canopy) the tilt variations were less than 0.4 µrad. The admittances between the evapotranspiration and the ground tilts were 0.3–0.5 µrad mm^{-1} and 0.1–0.2 µrad mm^{-1} in the active and dormant period of the trees, respectively. These small effects superimposed on each other can significantly contribute to slope failures. The results of this study provide information which can be useful in the modelling of landslide movements and for the mitigation of landslide hazards.

1. Introduction

The investigation of the causes of landslide movements has a long history. In order to develop early warning systems and prevent landslides, complex observation methods based on new highly sensitive multi-sensor systems (e.g., geophysical, hydrological, meteorological, geodetic and geotechnical) were developed and widely adopted. The new geodetic terrestrial and satellite techniques (e.g. Rott et al., 1999; Hooper et al., 2005; Glabsch et al., 2009; Herrera et al., 2009; Rödelsperger et al., 2010; Thuro et al., 2010; Cigna et al., 2011; Herrera et al., 2011) complemented by continuously measuring borehole tiltmeters and extensometers (e.g. Kümpel, 1983; Corominas et al., 2000; Mentes, 2003; García et al., 2010; Moore et al., 2010; Mentes, 2012) make the detection of movements possible from large to small scales.

In spite of the highly sensitive measuring techniques, most studies have focused on the investigation of seasonal, meteorological, hydrological effects (e.g. Coe et al., 2003) and the water balance (e.g. Carey and Woo, 2001) of the landslide area on the basis of geodetic measurements. Only few studies examined the small ground movements due to the variation of hydrological and meteorological parameters (e.g. Schulz et al., 2009; García et al., 2010; Uchimura et al., 2010; Grøneng et al., 2011; Leung and Ng, 2012; Mentes and Bódis, 2012) by means of continuous tilt and displacement measurements.

Vegetation also plays a very important role in the stability of slopes prone to mass movements (Greenway, 1987; Van De Wiel and Darby, 2007; Hubble et al., 2010). The relationships between vegetation and geomorphology are summarized by Marston (2010). Most publications deal with the effect of vegetation on soil erosion (e.g. Micheli and Kirchner, 2002; Zheng, 2006; Pizzuto et al., 2010) and with the hydro-geomorphological processes affected by forest harvesting and clear cutting (Imaizumi et al., 2008; Bathurst et al., 2010). Many authors investigated the mechanical and hydrologic effects of the root networks of vegetation on slope stability (e.g. Terwilliger, 1990; Nilaweera and Nutalaya, 1999; Simon and Collison, 2002; Pollen, 2007; Pollen-Bankhead and Simon, 2010) by field monitoring, laboratory and computer modelling to quantify the different effects and their relationships. Ground movements due to life processes of vegetation were investigated by Rebscher et al. (1995) and Rebscher (1996). They monitored ground movements using borehole tiltmeters close to a large horse chestnut tree while the sap flow in the tree was recorded. The pore pressure variations of the ground due to transpiration of trees

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cause ground motions which can be recorded by highly sensitive borehole tiltmeters (Kümpel, 1983, 1986; Kümpel et al., 1996; Fabian and Kümpel, 2003; Mentes, 2003). Liang et al. (2011) studied the soil water dynamics around a tree on a hillslope but a complete investigation of the effect of trees has not been carried out till now, according to our knowledge. To fill this gap, we conducted continuous tilt measurements and meteorological/hydrological measurements (e.g. soil and air temperature, rainfall, wind speed, solar radiation, soil moisture in different depths and water balance of trees) on a wooded hillslope in the Sopron Mountains. In this paper the methods of the measurements, data processing and analysis are described and the relationships of micro-tilt with meteorological, hydrological data and vital processes of the trees are investigated to study the effect of trees on hillslope stability.

2. Test site

Our investigations were carried out on a wooded slope in the Sopron Mountains (Hidegvíz Valley) where researchers of the Institute of Environmental and Earth Sciences of the University of West Hungary have measured different meteorological and hydrological parameters for years to study the life processes of trees. The Sopron Mountains belong to the Eastern Alps and are composed of crystalline rocks consisting of medium-grade crystalline schist and subordinate low-grade muscovite gneiss and leucophyllite covered by Neogene sediments (Haas, 2001) and brown forest soil. The orientation of the slope is NNW–SSE. The slope angle is about 15° but several landslides occurred in the past. The location and the digital terrain model (DTM) of the test site are shown in Figs. 1, and 2 shows the photos of the test site and the measuring tower.

On the study site, beech (Fagus sylvatica) is the predominant species (95%) accompanied by chestnut oak (Quercus petraea) and hornbeam (Carpinus betulus). The trees are 53 years old on average and their greatest height is about 18 m. The soil is covered by dry fallen leaves and parched grass and the sparse undergrowth is Dentaria enneaphyllos, Galium sylvaticum and Primula vulgaris (see Fig. 2a).

3. Methodology

3.1. Measurement of meteorological and hydrological parameters

Meteorological and hydrological measurements on the test site have been carried out since 1995. The aim of the measurements is twofold: 1) studying the life processes of trees, and 2) investigating the micro-meteorological changes and the water balance of the soil due to the life processes of trees are investigated. The meteorological parameters at different heights from the surface are measured on an iron tower 30 m high and the soil temperature and moisture at different depths on the area are also measured. The parameters are:

- direction and velocity of the wind: at heights of 2, 14, 19, 23 and 30 m;
- air temperature and humidity: at heights of 2, 14, 19, 23 and 30 m;
- total solar radiation: at heights of 2, 23 and 30 m;
- precipitation: at a height of 20 m;
- soil temperature: at heights of 0.05, 0 m and at depths of: 0.05, 0.1, 0.2, 0.5, 1 m;
- soil moisture content: at depths of 0.1, 0.2, 0.3, 0.4, 0.6, 1 m.

The direction and velocity of the wind were measured by a WAV151 wind vane and by WAA151 anemometers manufactured by VAISALA Inc. (VAISALA, 2002). The temperature and relative humidity of the air were measured by a temperature and relative humidity probe, model HMP45C (Campbell Scientific Corp., 2010). The measurement of the total radiation was carried out by CNR1 net radiometers (Campbell Scientific Inc., 2000). The precipitation was measured by a Lambrecht precipitation sensor of type 15188 (www.lambrecht.net); the soil

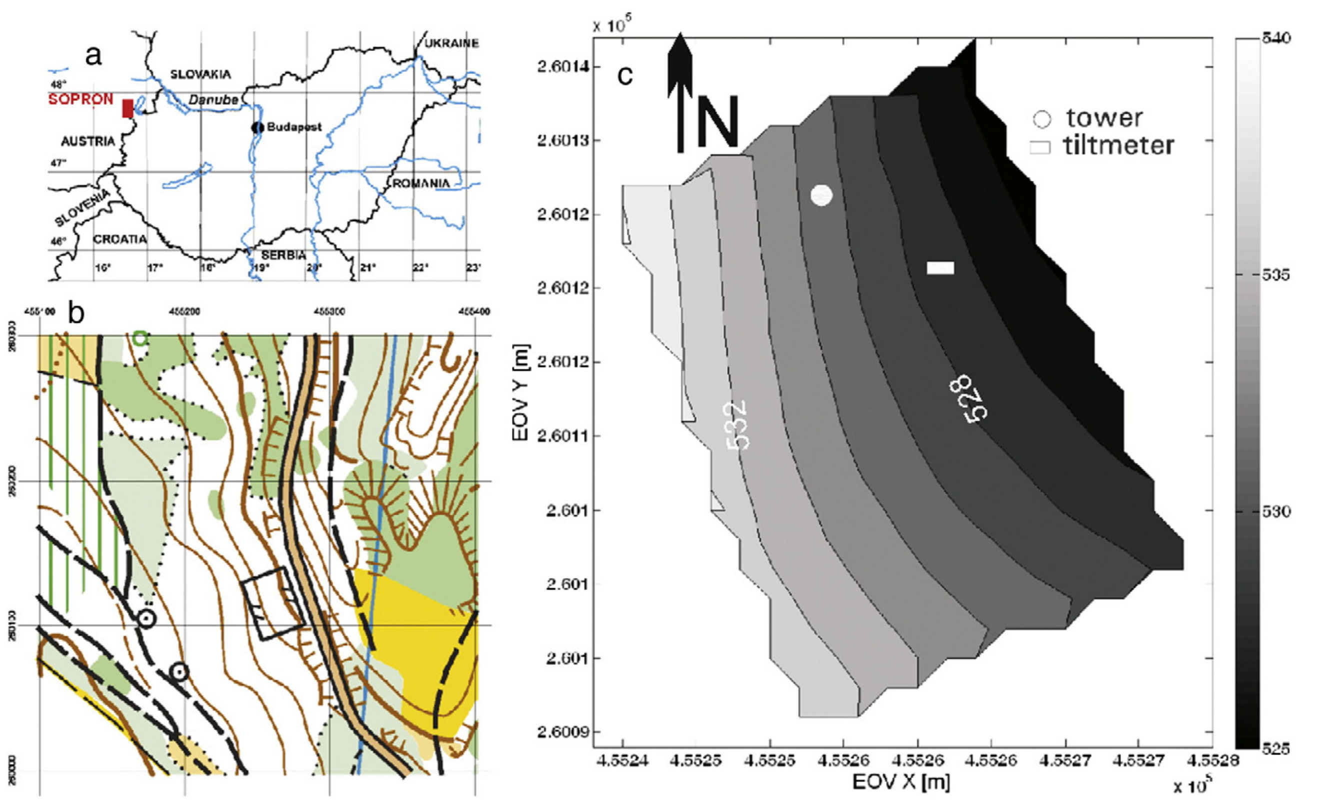

Fig. 1. Hidegvíz-valley test site. a) Location in Hungary (SOPRON); b) Topographic map of the test site and its surroundings (the black square denotes the study area); c) Digital terrain model of the study area. In subfigures b) and c) the coordinates are given in the local coordinate system of Hungary (EOV).