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Soil temperature dynamics at the catchment scale

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ABSTRACT

Temperature has a large impact on soil biogeochemical functioning. While this is well recognised there is a lack of data on the variability of soil temperature at the hillslope and catchment scale. Here we examine soil temperature for a series of nested catchments in the east of New South Wales, Australia over a twelve year period. Temperature characteristics between the three catchments were shown to be quite similar, falling into a 1 °C band. Across each catchment, the larger catchments of Krui (590km^2) and Merriwa (808km^2) had a larger varibaility in temperature range (3.4°C and 4.9 °C repectively) compared to the much smaller Stanley (175 ha) sub-catchment (1.8 °C), indicating that larger catchments will generally have larger variability in soil temperatures. The larger catchments also had a lapse rate of approximately 1 °C per 100 m elevation. Seasonal trends in soil temperature variability were observed to be quite similar between the two larger catchments, with soil temperature exhibiting greater variability for both catchments within the warmer months of the year. The similarity in soil temperature trends between Krui and Merriwa over the year is attributed to their similar size, climate, soils, and north–south orientation. All three catchments had a narrower range of temperatures during the cooler months, when Krui and Merriwa have a similar range to the soil temperatures of Stanley. The variability in soil temperature across the Stanley catchment is relatively stable throughout the year. This was attributed to its smaller size. In terms of quantifying catchment scale soil temperature from a single point, weather station sites that were located closer to the geographic centre of the catchment were shown to be less likely to over or under-estimate the average soil temperature of the catchment. The use of point-scale air temperature as a surrogate for predicting catchment soil temperature was suitable when corrections were applied. The importance of soil temperature to many ecological processes, in particular vegetation growth and soil biological activity, and therefore the soil carbon cycle and soil carbon sequestration, highlights the significance of this research.

1. Introduction

Soil temperature plays an important role in many of the biogeochemical processes that are integral to plant growth and is closely linked to other climate variables such as soil moisture, snow cover, and thawing and freezing processes (Oelke and Zhang, 2004). Soil temperature is a key variable in the growth and decomposition of above and below ground biomass (Abramoff and Finzi, 2015; Munir et al., 2015; Wang et al., 2013; Xu et al., 2013), changing the length of the growing season, plant productivity and N uptake (Luo et al., 2009; Rustad et al., 2001). The diversity and distribution of plant species, particularly in alpine regions has also been linked to soil temperature variation (Mark et al., 2001; Pickering and Green, 2009). Changes in soil temperature can have an important bearing on climate change via the exchange of carbon between the terrestrial and atmospheric carbon pools (Post, 2002) as it impacts on the composition and activity of soil microbial communities (Wu et al., 2015), soil/root respiration processes and the rate of decomposition of organic matter in the soil column (Boone et al., 1998; Kirschbaum, 1995; Raich and Schlesinger, 1992; Schlesinger and Andrews, 2000; Wildung et al., 1975).

Despite the pivotal nature of this variable long term records of soil temperature are still relatively rare (some examples include (Bai et al., 2013; Changnon, 1999; García-Suárez and Butler, 2006; Qian et al., 2011) and consequently carbon turnover models such as RothC (Coleman et al., 1997) utilise more readily available air temperature data as a surrogate; however this approach may not necessarily reflect the true soil temperature dynamics (Wells et al., 2013). Of the limited number of soil temperature data sets available only a small fraction focus on high spatial resolution soil temperature data particularly at the hill-slope and catchment level scale (Liang et al., 2014; Martinez et al., 2007; Wundram et al., 2010). As a result our ability to understand and model temperature sensitive ecological/climatological processes at the catchment scale is limited (Martinez et al., 2007).

A small number of studies however have begun to address this knowledge gap. Wundram et al. (2010), for example examined soil temperature variability at multiple spatial scales in an alpine region and concluded that micro-topographic site conditions dominated thermal changes along altitudinal gradients and consequently the authors

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argue that the use of mean temperature values to characterise temperature sensitive processes in alpine regions is questionable. In a more recent study Liang et al. (2014), proposed a simple framework for estimating distributed soil temperatures in mountainous regions using discrete air temperature measurements which produced root mean square errors of between 2.1 to 2.9 °C and predicted daily and monthly soil temperature variability well.

Possibly because of the limited amount of data available, little work has been undertaken on the relationship between soil temperature and local topographic, soil and vegetation characteristics. Such relationships are likely to be important in determining soil temperature distribution at the catchment and hillslope spatial scales. A number of topographical, meteorological, physical and soil surface characteristic factors have been identified that impact soil temperatures, including elevation, slope of the soil surface, soil surface orientation relative to the path of the sun, the degree of shadowing experienced by the site from nearby raised landforms, soil type, soil texture, relative humidity, soil moisture levels as well as the nature and abundance of local vegetation (Bai et al., 2010; Dubayah, 1994; Liang et al., 2014; Zhou et al., 2007). Vegetation cover and litter affect soil temperature by intercepting solar radiation, acting as a buffer for soil temperature changes (Liang et al., 2014; Wang et al., 2010). A study by (Song et al., 2013) showed that vegetation height and density was inversely proportional to soil temperature, which was attributed to the increased reflectance of vegetation, and decreased absorption of solar radiation by the underlying soil. Successional vegetation, such as found in abandoned agricultural lands, also play a role in offsetting net ecological production through reducing soil temperature by shading (Emanuel et al., 2006; Wang et al., 2010). Despite this progress in identifying and examining the factors driving soil temperature, a considerable knowledge gap remains as to the relative importance of these factors.

This study, which forms a part of an ongoing investigation by the authors on soil carbon dynamics, erosion and hydrological processes occurring at the catchment and hillslope scale, examines the spatial variability of root zone (150 mm deep) soil temperatures over neighbouring catchments and nested catchments from records accumulated over a 12 year period. The aim of such an examination is four fold:

1) Quantify the levels of variability of soil temperatures at the catchment and sub-catchment scale.
2) Develop a better understanding of the relative impact of local factors (topological, insolation, and soil moisture) on soil temperatures at these spatial scales.
3) Determine the limitations in using single point scale measurements of soil temperature to represent catchment averages.
4) Question the appropriateness of using nearby meteorological station air temperature data as a surrogate for soil temperature data.

2. Study site

This study examines soil temperatures obtained in two nested catchments (the 590 km^2 Krui River catchment and the 170 ha Stanley sub-catchment) and a neighbouring paired catchment (the 808 km^2 Merriwa River catchment) located in the Upper Hunter Valley, New South Wales (Fig. 1). Soil and air temperature data recorded at the Scone Soil Conservation Service (SCS) research centre (Bureau of Meteorology (BOM) site No. 61089) located approximately 35 km east of the Goulburn River catchment is also included in this study. This site is the closest to the main study area with a long term record of soil temperature data.

The study area is bounded to the north by the Liverpool Ranges, where topography is rugged, while the landscape to the south is hilly to undulating (Story et al., 1963). The catchments are underlain with Tertiary basalt of the Liverpool Range beds and forms part of the Merriwa Plateau (Story et al., 1963). The site is located in the temperate zone of eastern Australia. Climate in the region is dominated by a continental influence, although topography, elevation and proximity to the ocean are also considered important (Kovac and Lawrie, 1991). Monthly rainfall data for the region are 50–60 mm in summer and 30–40 mm in winter, where winter rainfall is least variable, and rainfall in late summer–autumn is most variable (Kovac and Lawrie, 1991). Annual average rainfall is highest in the north near the

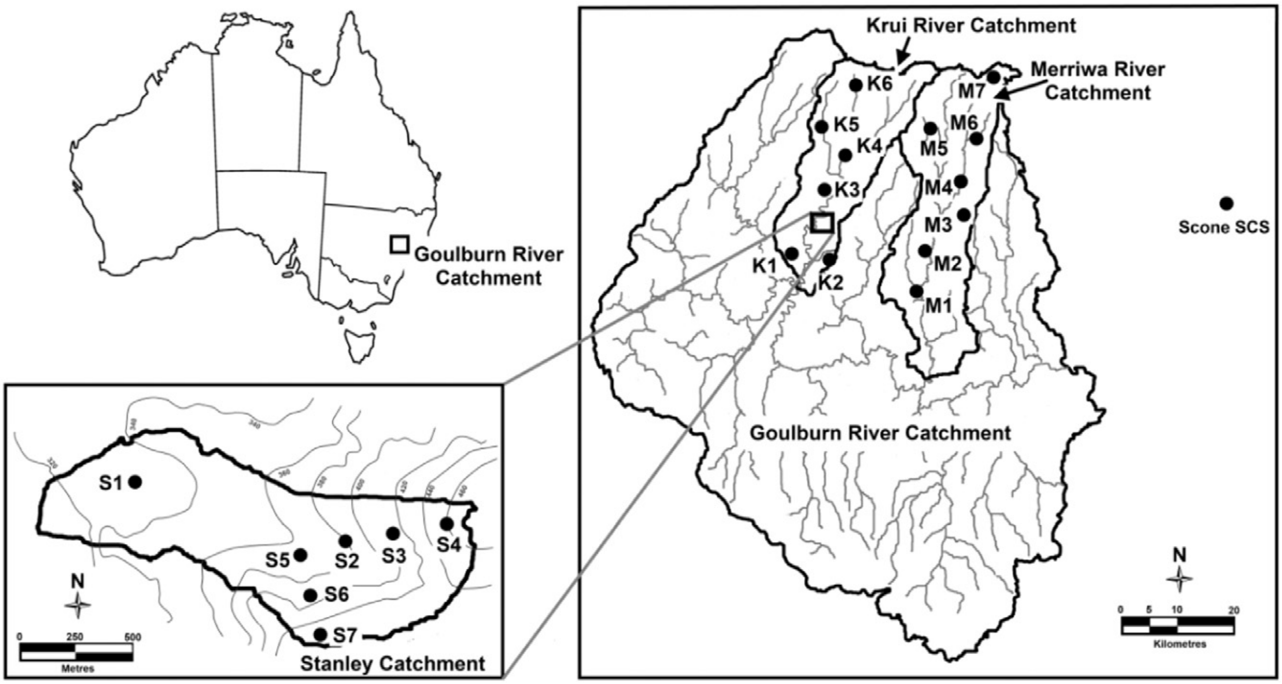

Fig. 1. Distribution of soil temperature monitoring sites and weather stations used in this study.