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Isotopic composition of throughfall in pine plantation and native eucalyptus forest in South Australia

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SUMMARY

Knowledge of the isotopic composition in precipitation is of importance for studies using isotopic composition as hydrological tracers to investigate recharge sources of groundwater, hydrograph separation, and paleoclimate reconstruction. In catchments with vegetation cover, major water isotope inputs are throughfall instead of precipitation. Thus, it is necessary to know how much precipitation isotopic composition is altered by vegetation canopy, and how this alteration varies with different vegetation covers. However, few studies have examined these issues with continuous monitoring and for typical vegetation covers in South Australia. In this study, we investigate the stable isotopic composition of throughfall over two vegetation surfaces (pine plantation and native eucalyptus forest), with bulk precipitation and throughfall samples collected from September, 2009 to October, 2010 with an average 18-day interval, together with intra-event precipitation samples collected at a nearby location, from September, 2009 to February, 2013. We synthesized a conceptual framework for throughfall isotopic composition including the effects of intra-event selection and inter-event selection, and partial evaporation using $\delta^{18}O$ and *d*-excess. The results indicate that the selection processes, either within individual events, or between events, or both, contribute to throughfall isotopic composition over the two vegetation covers, with less important but observed effects from partial evaporation. Pine plantation site with a denser vegetation cover has experienced larger alteration in throughfall isotopic composition. The significance of the difference between throughfall and precipitation isotopic compositions for groundwater sources, hydrograph separation and paleoclimate reconstruction studies are also discussed.

1. Introduction

Knowledge of the isotopic composition of precipitation is of importance for studies using isotopic composition as hydrological tracers to investigate the origin of groundwater (e.g. Ajami et al., 2011; Clark and Fritz, 1997; Frot et al., 2007), hydrograph separation (e.g. Goller et al., 2005; Hooper and Shoemaker, 1986; Kendall and McDonnell, 1993; Wels et al., 1991), and paleoclimate reconstruction (e.g. Darling, 2004; Steinman et al., 2012). A great number of studies on precipitation isotope and its applications in hydrological processes emerged in the last few decades (e.g. Rindsberger et al., 1990; Risi et al., 2008b; 2010; Rozanski et al., 1992; 1993; Uemura et al., 2012). However, in catchments with vegetation cover, major water stable isotope inputs are throughfall instead of precipitation. Interception loss refers to a part of precipitation evaporation from vegetation during or after rainfall while throughfall refers to the remaining part of precipitation may or may not contact the canopy and falls to the ground in vegetated area (Crockford and Richardson, 2000). Thus, it is necessary to know how much precipitation isotopic composition is altered by vegetation canopy, and how this alteration varies with different vegetation covers.

It is usually thought that throughfall isotopic composition is more enriched than the bulk precipitation (Pichon et al., 1996). This is because of the isotopic fractionation during partial evaporation of canopy intercepted water. There are two models based on partial evaporation concept, Saxena (1986), Gat (2010), to predict isotopic compositions of throughfall. Saxena (1986) applied a Craig and Gordon (1965) type model to calculate isotopic composition of evaporate vapour while Gat (2010) used a Rayleigh type model to do the calculation. Because their focus is partial evaporation, certain assumption has to be made. For example, Gat (2010) gave the special solutions assuming the input isotopic signal of rain events is invariant, which is often not valid in reality.

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However, Pichon et al. (1996) pointed out that the fractionation process in partial evaporation is not the only mechanism altering throughfall isotopic composition. This is supported by the fact that both enrichment and depletion of isotopic composition of throughfall have been reported in published studies. Saxena (1986) found that throughfall ^{18}O content was higher than open rainfall for most of the 24 summer rain events in a pine forest in Sweden, but depleted throughfall was observed for a few events. In DeWalle and Swistock (1994), Brodersen et al. (2000), Kubota and Tsuboyama (2004), these two different effects were also observed. DeWalle and Swistock (1994) showed in one event under spruce, the throughfall isotope difference from precipitation can be as low as −0.65‰ and in another event that can be as high as 1.61‰ in terms of ^{18}O concentration. Similarly, Brodersen et al. (2000) showed that the difference under spruce can be as low as −1.48‰ and as high as 1.26‰. Kubota and Tsuboyama (2004) showed two events with depletion and four events with enrichment of ^{18}O in throughfall isotopic composition in comparison to that of bulk precipitation.

All these observations suggest that in addition to partial evaporation, other mechanisms should have contributed to the alteration of the throughfall isotopic composition from bulk precipitation. Because of canopy interception, part of rainfall (e.g., at the beginning or the end of the event) can be completely missing in the throughfall. If this missing part has different isotopic composition from the remaining rainfall, the throughfall isotopic composition can be different from the bulk rainfall. This mechanism is now referred to the selection process. Gat and Tzur (1967) first proposed that the selection process can affect isotopic composition when part of the event evaporates totally from the canopy. Following this concept, Saxena (1986), DeWalle and Swistock (1994), Pichon et al. (1996), Gibson et al. (2000) showed their throughfall isotopic results to support the existence of selection process. Brodersen et al. (2000) summarized that the selection process is one important process responsible for the alteration of isotopic signal by canopy. Intra-event variation of precipitation isotopic composition is the key to understand the selection process. However, none of these studies have utilized the intra-event isotopic composition to examine this process. This is probably the reason why in some other studies like Liu et al. (2008), Ikawa et al. (2011), Kato et al. (2013) the selection process is neglected. On the other hand, the selection process can also occur between events if small rainfall events are completely intercepted by canopy. This inter-event selection has not been clearly addressed in the previous studies. The isotopic amount effect, if present, is useful to examine this process.

In addition to D and ^{18}O concentration, the secondary isotopic variable – deuterium excess which defined as $D = \delta^2H - 8 \cdot \delta^{18}O$ (Dansgaard, 1964), is helpful to distinguish the selection processes from partial evaporation. Such useful information has been applied in only a few throughfall studies. Using both $\delta^{18}O$ and *d*-excess to develop an operational framework will be useful to examine different processes responsible for the alteration of throughfall isotopic composition.

The objectives of this study are (i) to examine the isotopic composition of throughfall in two typical vegetation surfaces, pine plantation and native eucalyptus forest, in South Australia; (ii) to understand the mechanisms leading to alteration of precipitation isotopic composition due to vegetation cover using a synthesized conceptual framework; (iii) to evaluate the significance of throughfall isotopic variations in the studies of groundwater recharge sources, hydrograph separation and paleoclimate reconstruction.

2. Study area

The study was conducted in Kuitpo Forest (138.68°E, 35.18°S, 335 m a.s.l.), 20 km east of Gulf St. Vincent and 30 km south of the central business district of Adelaide, South Australia (Fig. 1). The study area is characterized with a Mediterranean type climate, being cold and humid in winter and hot and dry in summer. Long-term average annual precipitation (1971–2000) is 830 mm dominated by winter rain events, and monthly mean temperature (1975–1995) ranges from 8 °C to 19.5 °C (http://www.bom.gov.au/climate/data/). Three sites were selected including one bulk precipitation sampling site in open field (hereafter referred to as O site) and two throughfall sampling sites (Fig. 1). One throughfall site is at a sampling plot under planted trees (hereafter referred to as P site). Another throughfall site is at a sampling plot under native eucalyptus trees (hereafter referred to as N site). The tree species at P site is *Pinus radiata* and at N site are *Eucalyptus camaldulensis*, *Eucalyptus leucoxylon* and *Eucalyptus baxteri*. More details of the study area can be found in Deng et al. (2013).

3. Methods

3.1. Field work

In the open field, four identical funnel collectors were placed to sample bulk precipitation. In each vegetation site, twenty collectors were placed randomly in a plot of 20×20 m^2. Each collector was made of 15 cm diameter funnel connected to a bottle of 1.5 L capacity. The funnel had coarse filters to stop leaf litter from falling into the bottle. The collector was held up in a plastic tube 55 cm above the ground to avoid dirt splashing into the funnels. To prevent water evaporation, each sampling bottle was filled with around 1 cm thick of liquid paraffin (Ajax Finechem Pty. Ltd., Adelaide) before being placed in the field. From September 29, 2009 to October 26, 2010, 17 batches of bulk precipitation and throughfall samples were collected. In every batch, 44 samples were collected with a roughly 18-day interval depending on the event rainfall amount during the sampling period. For batch 10, overflow occurred.

Understanding of intra-event variation of isotopic composition is a good start to understanding the isotopic composition of throughfall, thus more than 300 (34 events) intra-event rainwater samples were collected using automated sequential samplers at two sites: the Flinders University campus (elevation, 160 m a.s.l.) in Adelaide, and Bridgewater (elevation, 435 m a.s.l.) in the Mount Lofty Ranges (Fig. 1) from 4 Sep. 2009 to 28 Feb. 2013. 289 samples (28 events) were collected on campus and the rest were collected at Bridgewater. Each sample was prescribed to collect a maximum of 2 mm, whereas a few were set to collect 1 mm during an event. Monthly rain isotope data collected at Global Network of Isotopes in Precipitation (GNIP) Adelaide site (#9467500, 34.97°S, 138.58°E, and 45 m above sea level) was also used for this study. The GNIP site monthly data covers a period between 1962 and 1984.

3.2. Isotopic analysis

Water samples were filtered with 0.45 μm filter paper (GN-6 Metrice Grid, Pall 186 Corporation) and kept in a cold room (4 °C) before isotope analysis. Both ^{18}O and deuterium analysis of all samples were performed at Flinders Analytical Laboratory using L2130-i Cavity Ring-Down Spectroscopy (CRDS) Isotopic Water Analyzer (Picarro Inc., Santa Clara, CA, USA). Delta notation is used to express the stable isotope ratios of hydrogen and oxygen in precipitation and throughfall samples:

$$\delta\ (\%) = \left(\frac{R_{\text{sample}}}{R_{\text{standard}}} - 1\right) \times 1000 \quad (1)$$

where R_{sample} and R_{standard} represent the D/H or $^{18}O/^{16}O$ abundance ratios in sample and standard, respectively, and the standard refers to the Vienna Standard Mean Ocean Water (VSMOW). Precision