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Assessment of ^{7}Be content in precipitation in a South American semi-arid environment

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HIGHLIGHTS

► ^{7}Be in precipitation was measured at a semiarid location in central Argentina.
► No atmospheric washout was observed except for one high precipitation event.
► Wet deposition of ^{7}Be was linearly correlated with precipitation.
► This relationship may be applied as a tool for assessing environmental processes.
► The latter includes natural processes as well as the impacts of human disturbance.

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ABSTRACT

There are two naturally occurring radiogenic isotopes of beryllium, ^{7}Be and ^{10}Be. These are produced when cosmic radiation interacts with oxygen and nitrogen in the atmosphere. After production, these radionuclides are input to ecosystems through wet and dry deposition. In recent years ^{7}Be and ^{10}Be have proved to be powerful tools for studying dynamic processes that occur on the surface of the earth. We measured the ^{7}Be content in precipitation at a semiarid location in central Argentina. From November 2006 to March 2009, 68 precipitation events were collected. Measured ^{7}Be content ranged from 0.7 ± 0.4 Bq L^{-1} to 3.2 ± 0.7 Bq L^{-1}, with a mean of 1.7 Bq L^{-1} $\pm$ 0.6 Bq L^{-1}. Beryllium-7 content of rainfall did not show clear relationships with amount of rainfall (mm), mean intensity (mm h^{-1}) or duration (h^{-1}), or elapsed time between events (day). The general results indicate that for the typical range of precipitation there was no atmospheric washout and that the reload of the atmosphere is not a relevant factor, but when the amount of precipitation is very high washout may occur. On the other hand, when the ^{7}Be content was measured during single rain events, a high content of this radionuclide was found to be associated with very low rainfall intensity ($\approx$3 mm h^{-1}), this suggests that rain intensity could affect the ^{7}Be content. Using all data, a good linear relationship between ^{7}Be deposition and rain magnitude was obtained ($r^2 = 0.82$, $p < 0.0001$). Because of this, the slope of this linear regression equation may be applied as a tool for tracing environmental processes that affect the surface of the earth. We can do this by directly estimating erosion/sedimentation processes using ^{7}Be or by estimating the input of ^{10}Be in the environment with the aim to evaluate land degradation phenomena.

1. Introduction

Beryllium-7 (^{7}Be) is a cosmogenic radionuclide produced in the upper atmosphere and lower stratosphere by cosmic ray spallation with nitrogen and oxygen (Lal et al., 1958). The nuclear reaction produces BeO or $Be(OH)_2$ that diffuse through the atmosphere and adsorbs electrostatically to atmospheric aerosol. The deposition of ^{7}Be on the earth's surface depends on its production rate (cosmic-ray intensity) which varies according to latitude, altitude and solar activity (Kaste et al., 2002). Factors that will influence concentration in the atmosphere include stratosphere–troposphere mixing, circulation and advection processes within the troposphere and the efficiency with which it is removed from the troposphere (Feely et al., 1989 and Kaste et al., 2002). Beryllium-7 is thought to be input to ecosystems principally by wet deposition with dry deposition contributing less than 10% (Salisbury and Cartwright, 2005; Ioannidou et al., 2005 and Wallbrink and Murray, 1994).

The relatively short half-life of ^{7}Be (53 days), along with the continuous and definable production rates, and competitiveness for cation exchange sites make it a potentially powerful tool for examining

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environmental processes; such as soil redistribution, sediment source assessment, air mass transport, and trace metal scavenging from the atmosphere (Kaste et al., 2002; Yoshimori, 2005; Steinmann et al., 1999; Daish et al., 2005; Matissoff et al., 2002; Walling et al., 1999; Blake et al., 1999; Schuller et al., 2006; Sepulveda et al., 2008). Willenbring and von Blanckenburg (2010) pointed out that knowledge of the wet deposition, seasonal variations and spatial patterns of ^{7}Be could be a useful tool along with ^{10}Be in the study of dynamic processes that occur on the surface of the earth due to the expected similar behavior of these two radionuclides.

Several studies have shown that for different regions and environments, the flux of ^{7}Be in wet deposition is dependent on precipitation volume (Kaste et al., 2002), and the seasonal deposition pattern may be closely associated with rainfall variability (Caillet et al., 2001). Studies of the correlation of ^{7}Be content, measured as activity concentration (Bq L^{-1}), in wet deposition as a function of total precipitation amount (mm) and precipitation intensity (mm h^{-1}) have been extensively studied with divergent results. Wallbrink and Murray (1994) found no significant correlation between measured activities and rainfall amount for precipitation events less than 25 mm, with values ranging from 0.02 to 5.9 Bq L^{-1}. Caillet et al. (2001) found that rainfall events of a few millimeters (<20 mm) showed the highest ^{7}Be activity concentration and that the elapsed time between events affected ^{7}Be content in rain due to the need to reload of the atmosphere with beryllium after a rain event. Through measurement of ^{7}Be in monthly precipitation samples over a seven-year period, Zhu and Olsen (2009) found that the atmospheric deposition fluxes of ^{7}Be varied seasonally, with spring and summer having 1.5 times larger fluxes than autumn and winter. Ioannidou and Papastefanou (2006) showed that precipitation intensity qualitatively characterized ^{7}Be content in rainwater with the content of rainwater being greater for events with low precipitation intensity (<5 mm h^{-1}). They also showed that for short duration events (<5 h), the ^{7}Be content of rainwater was almost five times larger for low rain intensity events relative to those of high intensity.

Kaste et al. (2011) pointed out that, in order to evaluate the potential of ^{7}Be as a tracer in arid and semi-arid environments, it is necessary to know the seasonal and spatial depositional variability and quantify the relationship between precipitation and surface inventories. Walling et al. (2009) proposed a new model to enable the use of ^{7}Be measurements to evaluate soil redistribution rates on a time scale larger than a single rain event; and emphasized that for the applications of this model the ^{7}Be content in rainfall needs to be known.

In a previous work we analyzed the deposition of ^{7}Be by the precipitations, and developed a model for predicting ^{7}Be content in soil (Juri Ayub et al., 2009). This was a first step in a project investigating the use of ^{7}Be for assessing soil redistribution studies in the framework of the IAEA ARCAL RLA 5/0/51 project: “Using Environmental Radionuclides as Indicators of Land Degradation in Latin American, Caribbean and Antarctic Ecosystems”. The aim of this paper is to evaluate, in a more exhaustive way, the temporal variability in ^{7}Be content of rainfall with respect to the characteristics of precipitation events using data from 68 samples collected from November 2006 to March 2009. In order to evaluate the effect of rainfall intensity on ^{7}Be content, three rain events were studied in detail to determine changes in activity concentration during the events.

2. Materials and methods

2.1. Study area

The study site was located in central Argentina (S 33°11′; W 66°18′), 15 km north of San Luis City (Province of San Luis); the altitude of the sampling site is 709 m above sea level (Supplementary material). The average annual temperature is 17 °C, while in summer (December–March) the mean temperature is 23 °C. Annual rainfall ranges from 600 mm to 800 mm. In this region, rainfall varies seasonally, with a dry season (from May to October) and a rainy season (from November to April). Rains in the dry season are scarce and sporadic (Fig. 1).

2.2. Sampling procedures

Rainwater was collected using two types of collectors: Type I and Type II. Type I collector consisted of a plastic collector of 0.16 cm^{2} surface area and 10 L capacity to facilitate capture of an entire precipitation event. Type II collector was constructed of galvanized steel with a surface area of 0.5 m^{2}. This collector allowed us to collect manually 500 mL of rainwater for each mm of rainfall. The two collectors were placed on a stand 1 m above the ground in order to avoid soil contamination. These were deployed when precipitation began and removed when it ended. After each event collection these were thoroughly rinsed with distilled water.

From the total amount of water collected in Type I collector, a sample of 500 mL was taken. Rainwater samples (collector Types I and II) were filtered and transferred to plastic bottles without further treatment.

The amount of precipitation was measured with a standard rain gauge (Hellmann type, TFA). When Type II collector was used, the elapsed time between collections of each millimeter of rain was recorded with a stopwatch.

2.3. ^{7}Be activity analysis

Beryllium-7 activity concentration (^{7}Be content) in rainwater was determined by measuring gamma emission at 477.6 keV. Gamma-ray measurements were performed using a 1.033 kg high-purity germanium detector built by Princeton Gamma-Tech. The cryostat, made from electroformed high-purity copper, and the related ultralow-background technology were developed by the collaboration of the Pacific Northwest Laboratory and the University of South Carolina (Brodzinski et al., 1990). Background count rate was 0.0005 counts/s/keV at the region of interest (475 to 480 keV). The detector was positioned at the center of a *castle* (≈1 m^{3}) made from lead bricks to provide shielding against radioactive background; the shield has a total mass of ≈12 t.

For gamma counting, 400 mL of each rainwater sample was placed in plastic Marinelli beakers. Counting periods were typically one day. With this geometrical configuration, an absolute photo-peak detection

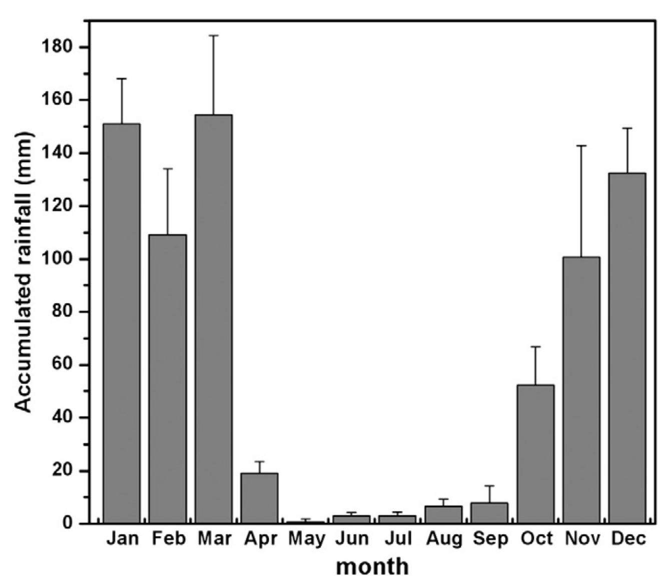

Fig. 1. Mean monthly accumulated rainfall amount in the studied zone. Mean values were obtained averaging the last four years. Bars indicate the standard error.