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High precision radiocarbon concentrations in tree rings from Northeastern Mexico: A new record with annual resolution for dating the recent past

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A R T I C L E I N F O

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A B S T R A C T

We present a new record of atmospheric $\Delta^{14}C$ from 1926–2002 AD constructed from annual measurements of dendrochronologically dated tree rings from Nuevo Leon in Northeast (NE) Mexico. The results are very similar to the Northern Hemisphere Zone 2 compilation, indicating that this location provides a suitable record of background atmospheric $\Delta^{14}C$. Closer examination of the atmospheric bomb peak years (1962–1965 AD), however reveals subtle differences from the Zone 2 compilation that may reflect transport of ^{14}C-depleted air from the south during the summer season influenced not only by the northward migration of the Intertropical Convergence Zone but also by the North American Monsoon system and tropical storms and hurricanes over the Gulf of Mexico. These differences decrease after 1965 indicating that Northern Hemisphere atmospheric mixing had largely occurred by this point. Examination of the pre-bomb peak period reveals a steady decrease in $F^{14}C$ associated with fossil fuel derived CO_2 emissions from 1922–1950 AD. The NE Mexico record is enriched in ^{14}C relative to a record from the Pacific Northwest during this period, potentially reflecting a greater impact of fossil fuel emissions and/or release of aged CO_2 from Pacific upwelling in this region. This record from NE Mexico represents the longest such record from North America and will contribute to improved characterization of the spatial and temporal variability of atmospheric $\Delta^{14}C$ in the Northern Hemisphere.

1. Introduction

In the mid-20th century, above-ground nuclear weapons testing caused a rapid increase in atmospheric ^{14}C concentrations, nearly doubling it by 1963–1964 when the Limited Test Ban Treaty was ratified. At this time, the signatories ceased atmospheric weapons testing and the production of bomb radiocarbon stopped. The majority of atmospheric weapons tests were conducted in the Northern Hemisphere (NH), and most of the bomb-produced ^{14}C was carried into the lower stratosphere by nuclear fireballs (Glasstone and Dolan, 1977). The excess ^{14}C was quickly oxidized to $^{14}CO_2$ and entered the troposphere during mid-to high-latitude winter and spring stratospheric/tropospheric mixing, creating a gradient of $\Delta^{14}CO_2$ both between hemispheres and within the NH (Randerson et al., 2002). This bomb radiocarbon began to mix through the surface carbon reservoirs, diluting atmospheric $\Delta^{14}CO_2$ due to CO_2 exchange between the atmosphere and the terrestrial biosphere and the oceans, resulting in a pulse-shaped variation with a quasi-exponential decrease since the mid-1960s. Studies tracing the movement of bomb ^{14}C through the Earth system have yielded key information about C exchange and C turnover times in reservoirs of the global carbon cycle.

The timing of the so-called "bomb peak" is often used for chronological control in recent geological and biological archives including calcite speleothems (e.g. Genty et al., 1998, Genty and Massault, 1999; Hua et al., 2012), sediments (e.g. Blaauw et al., 2010), plants (e.g. English et al., 2010), and trees lacking annual rings (e.g. Biondi and Fessenden, 1999). It is also used in forensic applications (Buchholz, 2009), to provide dates to verify the legality and authenticity of recent

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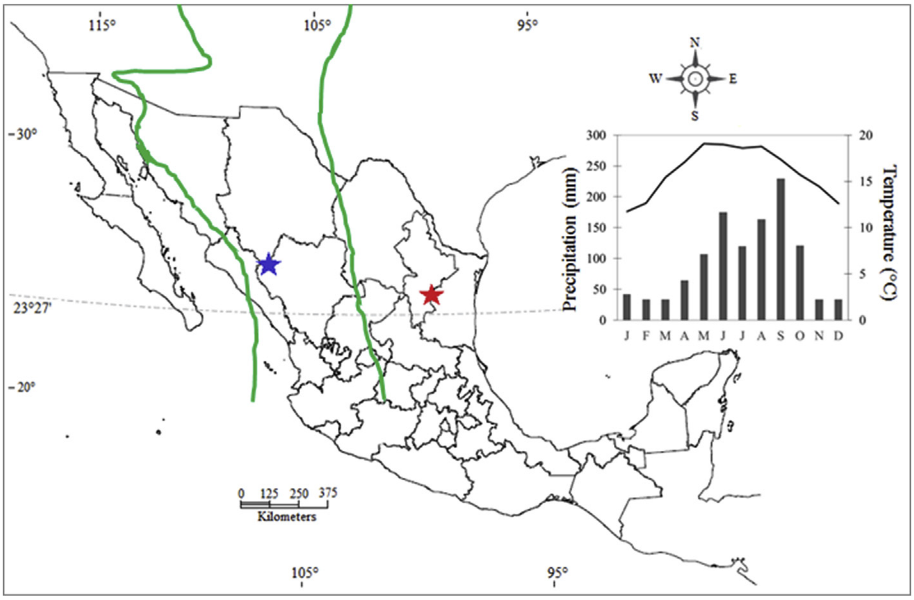

Fig. 1. Map of Mexico showing location of sampling site in NE Mexico (red star) and sampling site of previous record from NW Mexico (blue star, Beramendi-Orosco et al., 2010). Green lines represent the region influenced by the North American monsoon system (adapted from Comrie and Glenn, 1998). Graph of mean temperature (line) and precipitation (bars) from the nearest meteorological stations for the 1951–2010 period. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

organic materials such as pearls (Krzemnicki, 2013), fine art (Caforio et al., 2014), ivory (Uno et al., 2013) and wine (Fahrni et al., 2015). The zonal compilations of atmospheric $\Delta^{14}C$ presented by Hua et al. (2013) are one of the most widely used bomb peak datasets in chronological and geochemical studies. Based on published measurements of atmospheric $\Delta^{14}CO_2$ and $\Delta^{14}C$ of dendrochronologically dated tree rings, Hua et al. (2013) delineate 5 zones that have distinctly different tropospheric $\Delta^{14}CO_2$ variation over the 20th century. The NH is separated into three zones: NH zone 1 spanning from the pole to the Ferrell-Hadley cell boundary defined as 40°N, NH zone 2 from 40°N to the mean position of the summer Inter Tropical Convergence Zone (ITCZ), and NH zone 3 covering the remainder of the NH to the equator. These compilations are derived from the mean of measurements from clean air sites within the defined zone pre-1973, whereas post-1973 are derived from all measurements within the whole hemisphere, based on the assumption that sufficient mixing had occurred within the NH such that no significant gradient persisted, with values from the different zones overlapping within 1σ uncertainties (Hua et al., 2013).

The compilation for the NH zone 2 includes only one record from the North American continent, covering the 1950–1955 period derived from a tree-ring sequence collected in southern Arizona (32°26′N, 110°47′W), and for the years of the sharp atmospheric ^{14}C increase of the 1960 decade, there is a lack of data in the NH zone 2 curve. A tree ring reconstruction of the second half of 20th century ^{14}C in Northwestern (NW) Mexico (Beramendi-Orosco et al., 2010) showed ^{14}C values significantly depleted for the bomb peak years as compared to the NH zone 2 values, with the 1964.5 value being closer to the NH zone 3 (values within the ± 2σ interval). This result suggests that the ^{14}C distribution during the growing season (May to October) in NW Mexico is influenced by the North American monsoon, which carries ^{14}C-depleted air from the southwest, as the sampling site for that tree is located inside the region dominated by the monsoon system (Comrie and Glenn, 1998).

Pre-bomb period records derived from tree rings show a decreasing trend since the late 19th century as a result of the Suess effect, with different magnitudes depending on the local and regional fossil CO_2 emissions (Tans et al., 1979; Stuiver and Quay, 1981). Even though this phenomenon has been observed in several tree ring-derived ^{14}C records, the AD 1890–1950 period of the IntCal calibration curve includes only two records with annual resolution and two with quinquennial resolution from temperate latitudes (Reimer et al., 2013). Thus, it becomes relevant to generate more high resolution ^{14}C data for the recent past to improve the potential of radiocarbon for dating samples from this period.

To gain a better understanding of the influence of the North American monsoon on atmospheric $^{14}CO_2$ for Eastern North America during the bomb-peak years, and to strengthen the early 20th century portion of the IntCal curve, we present the results of new annual-resolution ^{14}C measurements of tree cellulose from a clean air site in Northeastern (NE) Mexico, outside the region influenced by the monsoon, covering the period 1926–2002 AD.

2. Methods

2.1. Sample description

A cross section of a Douglas Fir (*Pseudotsuga menziesii*) was collected in April 2003 from Peña Nevada (23°49′00″ N, 99°50′48″ W, 3200 m asl, Fig. 1), located in the Sierra Madre Oriental (SMO), Nuevo León, Mexico. The sampling site is in a montane forest ecosystem with vegetation dominated by conifer species such as *Pinus culminicola*, *Abies vejarii*, *Pinus rudis*, *Pinus ayacahuite* and *Pseudotsuga menziesii* (Villanueva-Diaz et al., 2007). The climate is temperate sub-humid with a mean annual temperature of 15 °C (ranging from 6 to 27 °C for the period 1951–2010) and mean annual precipitation of 1220 mm, mainly during the summer months with peaks in June and September (Magaña et al., 1999; CONAGUA, 2016). This bimodal precipitation regime is dominated by the north Atlantic subtropical anticyclone and is partly associated with tropical storms and hurricanes over the Caribbean/Atlantic basin, outside the influence area of the North American monsoon system (Comrie and Glenn, 1998). A complete dendrochronology for the area, previously reported by Villanueva-Diaz et al. (2007), was used to accurately date the sequence, with the first year of tree growth dating to 1921.

2.2. Radiocarbon analysis

Rings were sampled annually with a blade and split into smaller pieces to facilitate fast pretreatment. Samples were pretreated to isolate holocellulose via the methods described in Southon and Magana (2010). Briefly, aliquots of shaved wood were treated with a standard acid-base-acid treatment, followed by a bleaching treatment to isolate hollocellulose. All samples were treated in individual 13 mm glass test tubes. Following pretreatment, samples were converted to CO_2 via

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