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Original paper

Meteoric isotopic gradient on the windward side of theSierra Madre Oriental area, Veracruz – Mexico

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Resumen

Se caracterizó la composición isotópica $\delta^{18}O$ ‰ y δD‰, del agua meteórica en el flanco oriental de la Faja Volcánica Transmexicana, sobre un transecto de 90 km que parte de nivel de mar hasta 4220 msnm. Las muestras de lluvia fueron colectadas, durante los años 2007 a 2012, en temporada de lluvia (mayo a Octubre). Se obtuvo una Línea Meteórica Local (LML) bajo una regresión lineal la cual queda descrita por $\delta D = 7.4\ \delta^{18}O + 7.3$, $R^2 = 0.99$. Esta línea tiende a separarse de la Línea Meteórica Mundial (LMM) donde la precipitación ocurre a altitudes mayores a 3000 msnm, debido a un enriquecimiento en Deuterio. El resultado obtenido en esta investigación fue comparado con los datos isotópicos, colectados en el Puerto de Veracruz, extraídos de la base de datos de la Red Mundial de Isótopos en Precipitación. El gradiente altitudinal de $\delta^{18}O$, es descrito por una regresión lineal $\delta^{18}O = -2.1$ (Z km) - 5.56, $R^2 = 0.86$, la cual implica un gradiente vertical de -0.21 ‰/ 100m. Finalmente, el registro isotópico en agua meteórica durante los años de observación en esta investigación muestra un enriquecimiento en $\delta^{18}O$ y δD a una altitud aproximada de 1400 msnm, probablemente influenciado por la topografía y/o relacionado por efectos isotópicos de tormentas tropicales, típicas de estas latitudes. Esta caracterización aumentará la comprensión de importantes procesos hidrológicos y proporcionará la base para futuras investigaciones hidrológicas.

Palabras clave: Isótopos estables, gradiente isotópico, Veracruz México, composición isotópica, precipitación.

Abstract

The isotopic composition ($\delta^{18}O$, δD‰) of precipitation in the windward side of the Sierra Madre Oriental on the eastern flank of the Mexican Volcanic Belt was characterized along a 90 km transect from sea level up to an altitude of 4220 meters. Rain samples were collected during the rainy season (May through October) from 2007 through 2012. The Local Meteoric Water Line (LMWL), determined with linear regression of isotope results, is $\delta D = 7.44\ \delta^{18}O + 7.3$, $R^2 = 0.99$. This line departs from the Global Meteoric Water Line (GMWL) for precipitation at altitudes greater than 3000 masl due to deuterium enrichment processes. The results obtained in this research were compared with isotopic data of the Global Network of Isotopes Precipitation (GNIP) data base from the port of Veracruz. The altitude (Z) gradient of $\delta^{18}O$ was also determined by the linear regression of precipitation data, resulting in the relation $\delta^{18}O = -2.1Z - 5.56$, $R^2 = 0.86$, where Z is altitude in kilometers. This implies a $\delta^{18}O$ vertical gradient of -0.21 ‰/ 100 m, which falls within the normal range described in the literature for tropical areas. Finally, the isotopic record of meteoric waters during the years of observation shows anomalous enrichment in $\delta^{18}O$ and δD at an altitude of about 1400 m, probably influenced by the local topography and/or an isotope effect related to tropical storms typical of this latitude. This characterization will increase the understanding of important hydrological processes and will provide a foundation for future hydrological research.

Key words: Stable isotopes, isotopic gradient, Veracruz, México, isotopic composition, precipitation.

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Introduction

The isotopic characterization of local rainfall in water-resource studies is very important, considering that such precipitation typically represents the primary source of recharge to groundwater systems. This isotopic signature can subsequently be used to trace groundwater flow within the aquifer. On the basis of 400 stable isotopic (δ^2H and δ^{18}O) samples of water (rivers, rain and snow) at different geographical locations, the linear relationship δ^2H (δD) = 8δ^{18}O + 10 was defined by Craig (1961) as the Global Meteoric Water Line (GMWL). Dansgaard (1964), using data from GNIP (Global Network of Isotopes in Precipitation, 2012), found that isotopic ratios of monthly precipitation recorded at stations located in the northern continental hemisphere complied with the GMWL. Significant deviations from the GMWL line, however, were observed relative to other continents and islands. These deviations were attributed to differences in the local weather conditions and in the processes controlling precipitation. The analysis of the GNIP data for the periods 1960-1978 and 1960-1987 were reported by Yurtsever and Gat (1981) and Rozanski *et al*. (1993), respectively. Using the same methodology described by previous authors, the IAEA (International Atomic Energy Agency, 2005) processed data from 1961 to 2000 and found that the arithmetic mean of the isotopic ratios in precipitation recorded from 410 stations distributed globally are well-described by the equation: δD = 8.07 (± 0.02) δ^{18}O + 9.9(± 0.1), R^2 = 0.98. The deuterium excess can be described globally as d_{ex} δ^2H - 8δ^{18}O.The weighted averages of long-term precipitation for the same period (1961-2000) were calculated by GNIP from a subset of measurements during years for which more than 70% of precipitation during that year was analyzed for a given isotope (with a minimum requirement of at least one full year of data). The weighted average correlation is δD= 8.14 (± 0.02) δ^{18}O +10.9 (± 0.2), R^2 = 0.98.

There are several widely documented effects that control the spatial variation of the isotopic composition in the meteoric waters including altitude, latitude, continental, amount and season (Clark and Fritz, 1997). Of these, altitude (topography) is considered the most important factor. It has been shown that on the windward side of the mountains, the δ^{18}O and δD ratios of rain decrease (become isotopically depleted) with increasing altitude. This is mainly due to the combination of two factors: (1) rainfall becomes progressively depleted by the loss of isotopically heavy isotopes as rain events progress in a topographically up gradient direction and, (2) the temperature is lower and thus the condensate becomes isotopically enriched because of fractionation (Clark and Fritz, 1997). Other hydrologic factors may affect the stable isotopic signature of precipitation at windward tropical forests. Vogelmann (1973) showed that evapotranspiration in a cloud forest of eastern Mexico was subsequently recycled as fog precipitation, which could affect its isotopic content. This process of fog interception was quantified in a cloud forest of Puerto Rico (Holwerda *et al*., 2010), accounting for about 10% of the total precipitation.

The objective of this study is the isotopic characterization of precipitation on the windward (Atlantic) side of the Sierra Madre Oriental in the State of Veracruz, the most populated part of the State of Veracruz. The main scope of this work is the spatial and temporal isotopic characterization of meteoric waters and their possible relationship with dominant isotopic effects in our study area. Because the isotopic meteoric line varies with region, it was important to determine a local meteoric water line. Local conditions can also be described by the vertical isotopic gradient and the deuterium excess (d_{ex}), which can be used assess the difference between local conditions in Veracruz compared with to the global meteoric water line δD = 8 δ^{18}O + 10 (Craig, 1961). In this research, we show the isotopic relationship between δ^{18}O‰ and δD‰ measured in the cumulative rainfall as a time series based on samples was collected during six rainy seasons (2007-2012). Importantly we evaluate the isotopic gradient along a topographic transect from sea level to an altitude of over 4000 m. This characterization will increase the understanding of important hydrological processes and will provide a foundation for future hydrological research.

Study area

The 2000 km^2 study area is located in the central part of the state of Veracruz, Mexico, between 2110000 and 2180000 UTM coordinates north latitude (Figure 1). Its shape is elongated in an orientation northwest to south east (approximately 90 km long) and narrower from northeast to southwest (approximately 20 km wide). It is bounded on the east by the Gulf of Mexico and to the west by the Sierra Madre Oriental. The topographic relief is variable and characterized by two main areas: a lower and flatter area located along the coast, and a higher and steeper area located along the Sierra Madre Oriental (Tejeda *et al*., 1989; Barradas *et al*., 2004).The altitudinal gradient is extremely large rising from sea level at the