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Isotopic characteristics of precipitation in Slovenia and Croatia: Comparison of continental and maritime stations

Polona Vreča [a,*], Ines Krajcar Bronić [b], Nada Horvatinčić [b], Jadranka Barešić [b]

[a] *Jožef Stefan Institute, Department of Environmental Sciences, Jamova 39, SI – 1000 Ljubljana, Slovenia*
[b] *Rudjer Bošković Institute, Bijenička 54, HR – 10000 Zagreb, Croatia*

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Summary The stable isotopic composition of hydrogen and oxygen (δ^2H and δ^{18}O) and tritium activity (^{3}H) were monitored in monthly precipitation at two continental stations (Ljubljana, Zagreb) and six stations along the eastern Adriatic coasts of Slovenia and Croatia in the period 2001–2003. Mean air temperatures and amount of precipitation were also recorded.

Distinct differences in both meteorological and isotopic data between the continental and maritime stations were observed. Seasonal variations in δ^{18}O are smaller at the maritime stations than at the continental ones due to smaller seasonal temperature variations. A good correlation between δ^{18}O and δ^2H was obtained for each station, and the local meteoric water lines are close to the Global Meteoric Water Line, with a decreasing trend of slope for the south-Adriatic stations. Good correlations between δ^{18}O in monthly precipitation and mean monthly air temperature were observed at all stations. The slope of δ^{18}O vs. T varied between 0.37‰ °C^{-1} and 0.15‰ °C^{-1}. Mean ^{3}H activity and seasonal variation of ^{3}H activity are smaller at maritime stations than at continental ones. Additionally, ^{3}H activity decreases in the NW–SE direction of the Adriatic coast.

The study of spatial variations over this relatively small area rich in geographical and climatic diversities showed the complexity of the isotopic composition of precipitation and the isotopic data obtained for eight stations, most of them in the karstic area along the Adriatic coast, and gave valuable information for regional hydrological investigations and modelling of isotope variability over the Mediterranean basin.

* Corresponding author. Tel.: +386 1 5885304; fax: +386 1 5885346.
E-mail address: polona.vreca@ijs.si (P. Vreča).

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Introduction

The stable isotopes oxygen-18 (^{18}O) and deuterium (^{2}H) and the radioactive isotope tritium (^{3}H) are rare components of the water molecule. However, they offer a broad range of possibilities for studying processes within the water cycle and thus became an important tool not only in isotope hydrology, routinely applied in studies of the origin and dynamics of surface and groundwaters, but also in studies related to atmospheric circulation and paleoclimatic investigations (Araguas-Araguas et al., 2000, and references therein). Understanding the formation of precipitation and its isotopic composition ($\delta^{18}O$, $\delta^{2}H$ and ^{3}H activity), as well as a knowledge of temporal and spatial variations in the amount and mode of precipitation and in its isotopic composition, are important for basin-wide balance studies. The Global Network of Isotopes in Precipitation (GNIP) is a database that contains data on $\delta^{2}H$, $\delta^{18}O$ and ^{3}H activity, and relevant meteorological data on a monthly basis, and is thus extremely valuable for modelling climatic changes, as well as in hydrological and hydrogeological investigations (IAEA, 2006). However, the need for a much more refined understanding of isotope variations was indicated in climatic studies and therefore the IAEA initiated a programme of collecting new data at a higher spatial density and temporal frequency in the Mediterranean basin, including the eastern Adriatic coast (Gourcy et al., 2004; IAEA, 2005).

The Adriatic Sea is an elongated basin (NW—SE direction) located in the northern part of the Central Mediterranean, enclosed between the Italian and Balkan peninsulae (Raicich, 1996). Because of its geographical position, the Adriatic Sea experiences the influence of air masses of different origin, causing noticeable spatial and seasonal variability of the meteorological parameters over the basin. Precipitation is higher along the eastern coast in all seasons due to orography and exposure to wetter southerly winds.

Slovenia and Croatia are situated along the eastern Adriatic coast. The coastal region is very narrow and divided from the continental region by the karstic Dinaric Mountains. The NW part of Slovenia belongs to the Alps, while the peripheral part of the Pannonian Plain reaches the N of Croatia and NE of Slovenia.

There are four major air masses influencing the weather in Slovenia (Pučnik, 1980) and Croatia: (1) maritime polar air masses, which originate in the Northern Atlantic and North Sea; (2) maritime tropical air masses, which originate predominantly in the Azores; (3) continental tropical air masses, originating from northern Africa and Asia Minor; (4) continental polar air masses, which originate in Scandinavia, Finland, Russia, and the Pannonian Plain. Both maritime air masses are generally moist, containing considerable amounts of water vapour, while continental air masses are usually drier. Furthermore, the characteristic geographical diversity influences the climate in Slovenia and Croatia considerably. Consequently, there is a mixture of (1) a continental climate that influences the major part of Slovenia and the northern part of Croatia, (2) an Alpine climate that influences the NW part of Slovenia, as well as a colder mountain-type of continental climate in the mountainous part of Croatia, and (3) along the Adriatic coast the Mediterranean climate prevails, which transforms to sub-Mediterranean in the N Adriatic.

Two stations in the continental regions, Ljubljana in Slovenia and Zagreb in Croatia, are stations of the GNIP network and have long-term isotopic records (IAEA, 2006). In the period 2001—2003 the network was extended along the Adriatic coast (IAEA, 2005) where no data on the isotopic composition of precipitation previously existed.

The main purposes of our investigation were therefore (1) to determine the monthly variability of isotopic composition in precipitation along the eastern Adriatic coast, (2) to correlate these variations with the general meteorological parameters, and (3) to compare the results obtained with the long-term data at two continental stations.

Sampling sites

Monthly sampling of precipitation was performed at three stations in Slovenia (Ljubljana, Portorož — Airport, Kozina) and five stations in Croatia (Zagreb — Grič, Zavižan — Mt. Velebit, Zadar, Komiža — Vis Island, Dubrovnik) (Fig. 1) from September 2000 to December 2003. However, only data for the complete years 2001—2003 were taken for further analysis. In the N-Adriatic sampling was performed at the additional station of Malinska on Krk Island for 1 year (Horvatinčić et al., 2005). Table 1 gives the main station characteristics, as well as mean annual meteorological data for the observation period 2001—2003. Monthly mean air temperatures (T) and precipitation amounts were obtained from the Environmental Agency of the Republic of Slovenia and from the Meteorological and Hydrological Service of the Republic of Croatia.

Isotope analyses

The stable isotopic composition of water samples was measured on a Varian MAT 250 mass spectrometer at the Jožef Stefan Institute. The oxygen isotopic composition ($\delta^{18}O$) was measured by means of the water—CO_2 equilibration technique (Epstein and Mayeda, 1953), and the isotopic

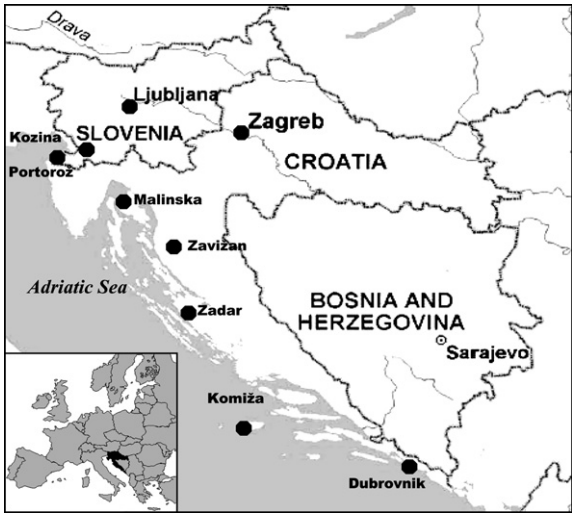

Figure 1 Map of Slovenia and Croatia indicating the sampling stations.