Using triple oxygen measurements of lacustrine carbonates to constrain the Miocene topography of the Dinaric Alps

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Motivation

- The Dinaric Alps formed as a result of the collision between the Adria microplate with Eurasia during ongoing closure of the Tethys Ocean[1,2].
- However, there remain a number of questions regarding the mechanisms that created the high topography of this region.
- We take advantage of a series of lacustrine basins known as the Dinaride Lake System (DLS) that formed during the Early to Middle Miocene to contrain paleo-elevations of the Dinaric Alps using stable isotope paleoaltimetry.
- We collected authigenic lacustrine carbonate samples from six basins in Croatia and Bosnia and Herzegovina that span the range from sea-level to high-elevation (~1200 m) and measured these samples for $\delta^{18}O$. In addition, we also collected stream samples that span the range to constrain modern change in $\delta^{18}O$ acorss the Dinaric Alps.
- Stable-isotope paleoaltimetry is based on the concept that, as moist air parcels are forced upwards by orography, ^{18}O is preferentially removed by the resulting precipitation, resulting in lower $\delta^{18}O$ at higher-elevations and in the lee of ranges[3,4].
- Because lacustrine carbonate $\delta^{18}O$ is frequently impacted by evaporation, we analyzed a subset of our samples for $\Delta^{17}O$, which is sensitive to the degree of evaporation.

Study area

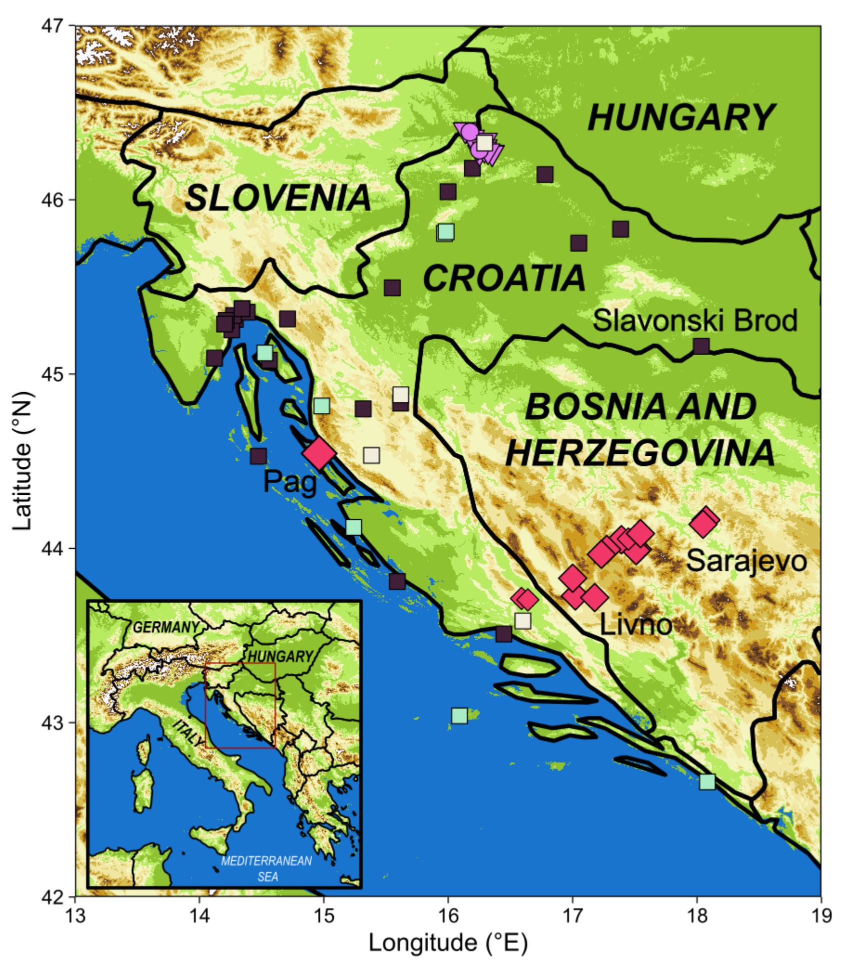
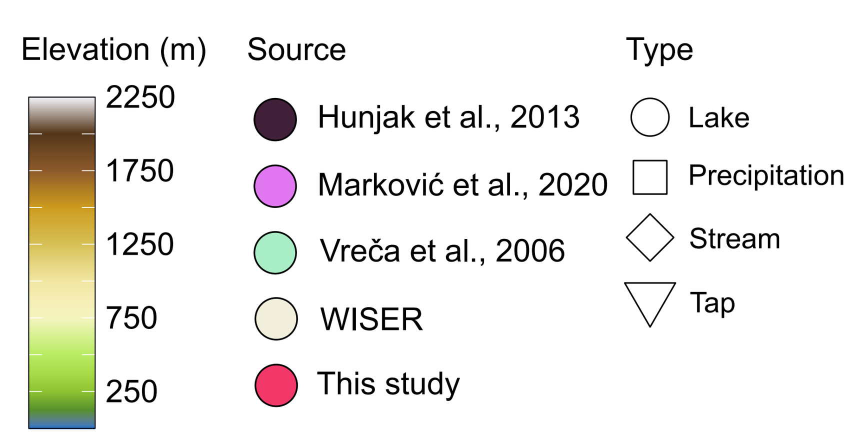


Figure 1. Study area in the Dinaric Alps. We collected 31 stream water samples across the Dinarides in the summer of 2022. Sites ranged from the coast of Croatia to the high elevation intermontane region of Bosnia and Herzegovina. In addition, we compiled 734 samples of published[5,6,7] groundwater, lake, precipitation, and stream data. Inset map shows the location of the study area (red square) in relation to central and southern Europe.



Modern $\delta^{18}O$ gradient

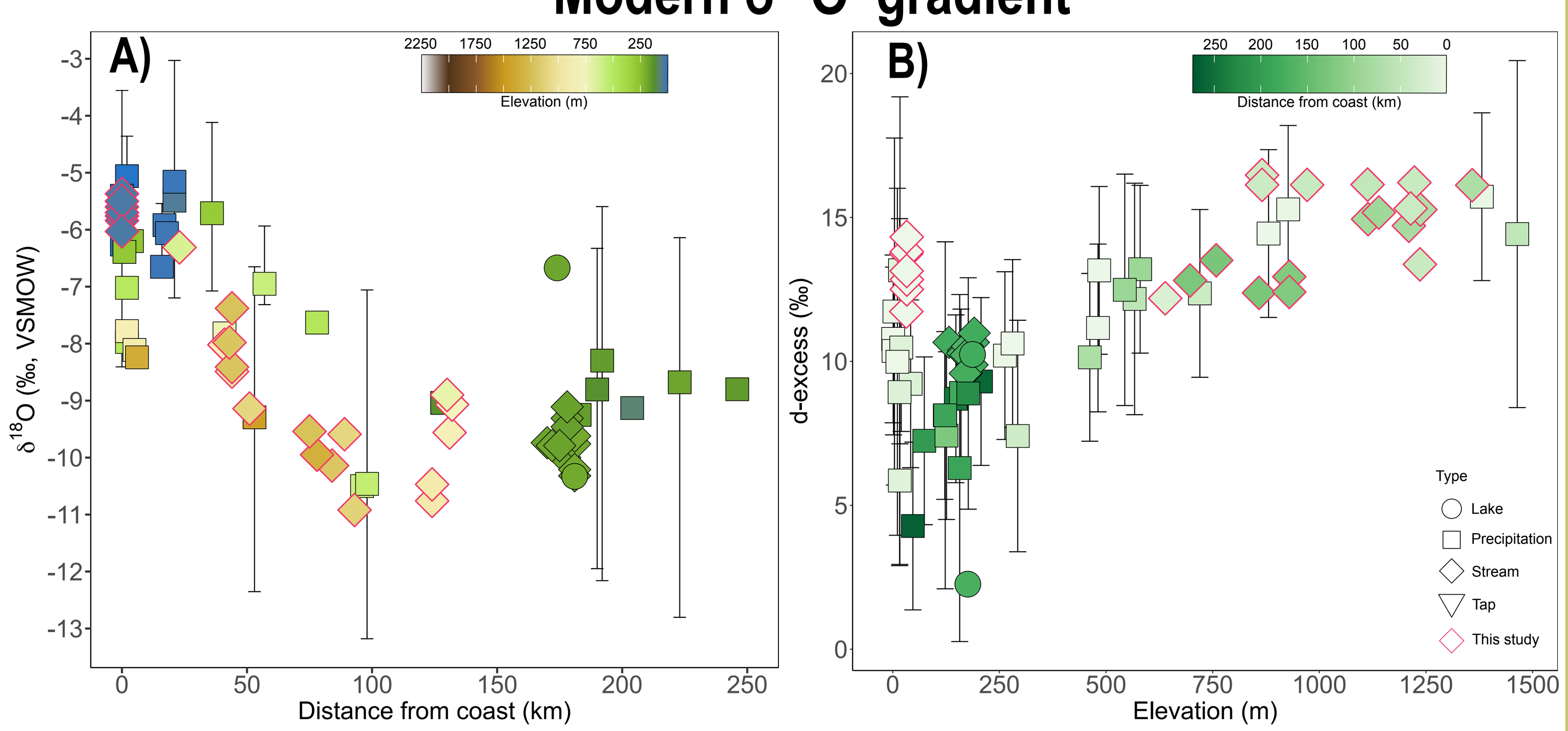


Figure 2. A) Modern $\delta^{18}O$ gradient and elevation (m) of the Dinaric Alps plotted against distance from coast (km). $\delta^{18}O$ decreases inland. Higher $\delta^{18}O$ values are observed at the coast, while lower $\delta^{18}O$ values are seen at the crest of the range. **B)** d-excess plotted against mean basin elevation (m). In both panels, error bars on mean precipitation samples from Vreča et al. (2006) represent the mean winter and summer values. Points are colored by mean basin elevation (m).

Moisture sources across the Dinarides

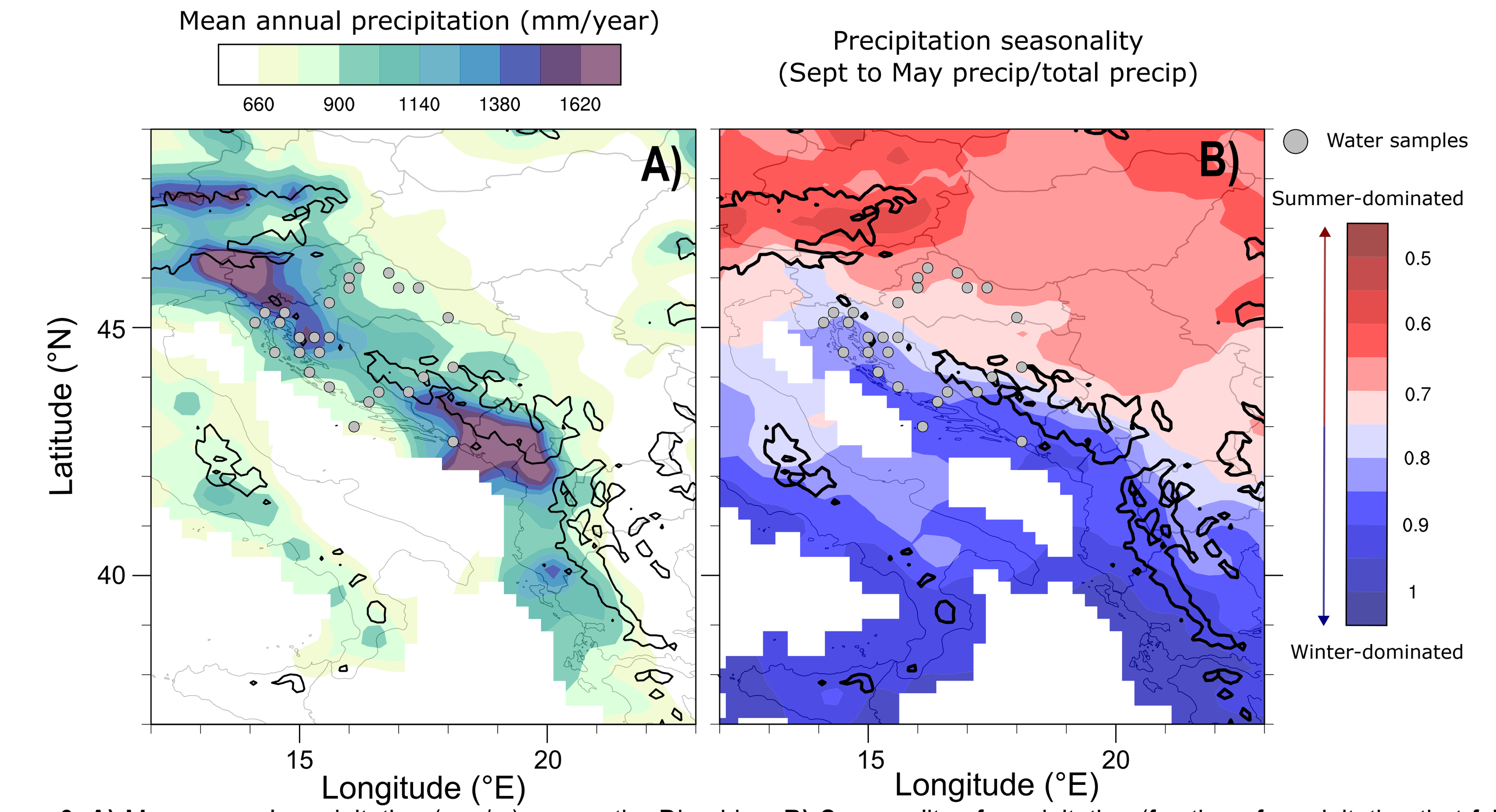


Figure 3. A) Mean annual precipitation (mm/yr) across the Dinarides. **B)** Seasonality of precipitation (fraction of precipitation that falls between September and May over the total precipitation. Red colors represent summer-dominated (JJA) moisture. Black line is the 1000 m contour line.

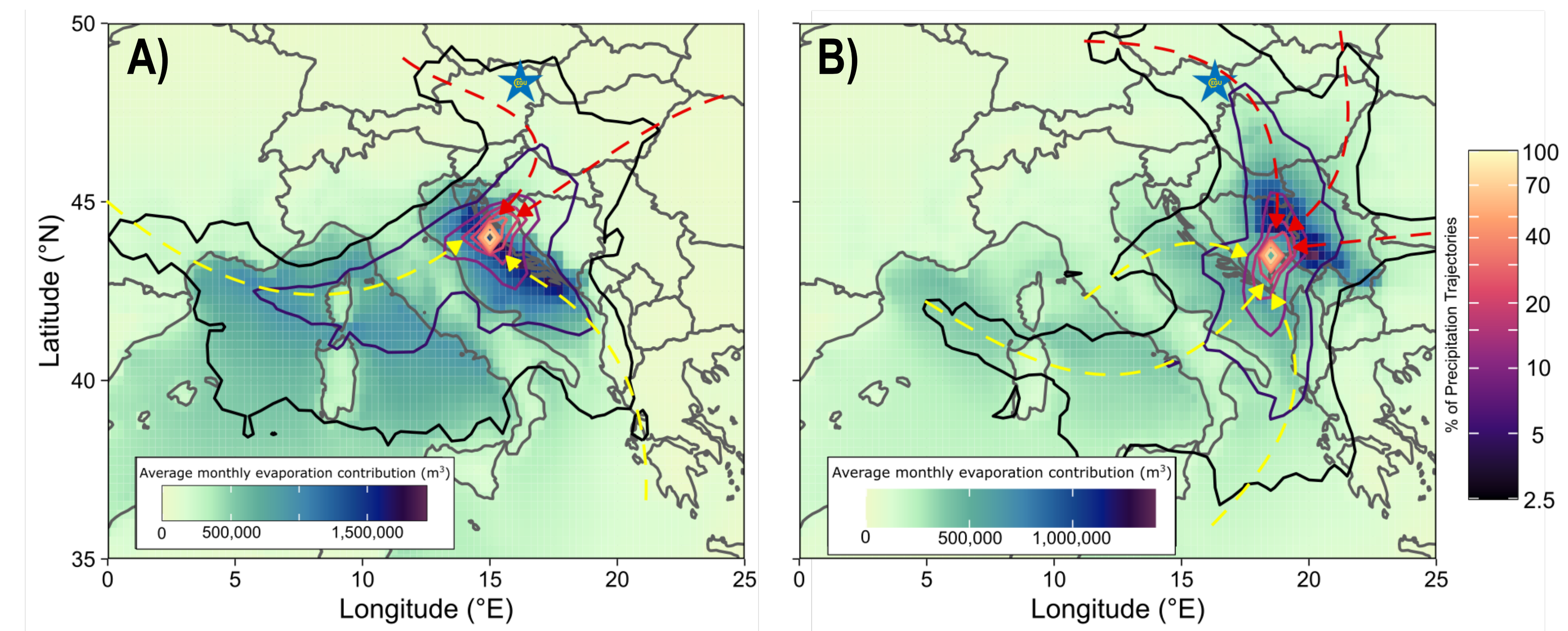


Figure 4. Hybrid Single-Particle Lagrangian Trajectory Model (HYSPLIT)[8] model trajectories for precipitation-producing air parcels. Arrows represent the observed trajectories. Yellow arrows represent trajectories originating from the Mediterranean Sea. Red arrows are continental trajectories. Colored density contours show the fraction of precipitation trajectories. Since HYSPLIT only tracks air parcels we ran a Water Accounting Model (WAM)[9,10] to specifically track moisture on the windward **(A)** and leeward **(B)** sides of the Dinarides.

^{17}O excess

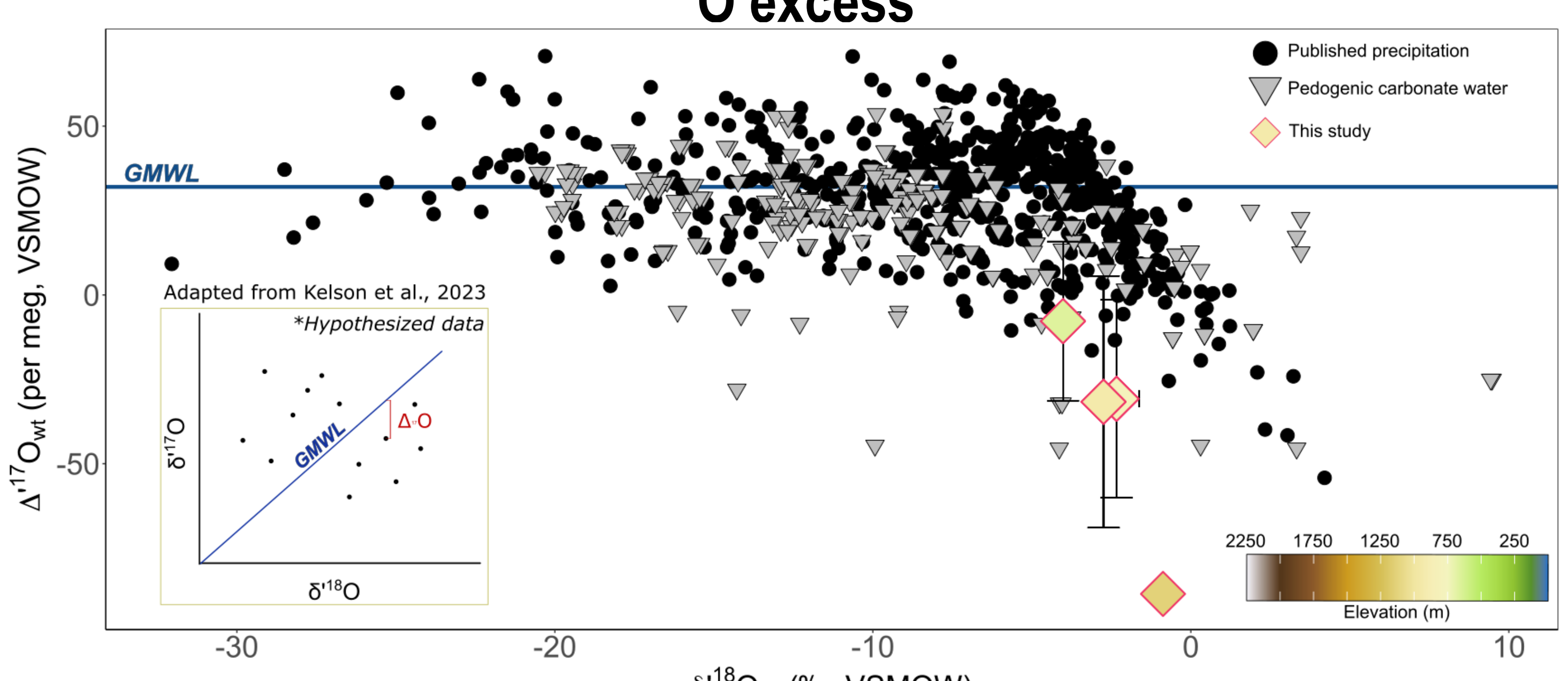


Figure 5. Initial $\Delta'^{17}O$ data of carbonates from high-elevation, intermontane basins plotted along with published soil carbonate waters and precipitation. The basins analyzed are evaporatively-enriched. ^{17}O is the least abundant of oxygen's stable isotopes and methods that use $\delta^{17}O$ are relatively new. There have been recent studies done using triple oxygen (^{16}O, ^{17}O, and ^{18}O) to calculate the unevaporated $\delta^{18}O$ of cherts[11] and soil carbonates[12]. We first analyze sample for the $\delta'^{17}O$ value of the carbonate to calculate the $\Delta'^{17}O$ of the waters that formed the carbonate. Inset plot shows how $\Delta'^{17}O$ is the ^{17}O excess as normalized to the $\delta^{18}O$-$\delta^{17}O$ meteoric water line (GMWL). Evaporation causes higher $\delta^{18}O$ values, but lower $\Delta'^{17}O$ values. We can use this relationship and trace back to isolate the effect of evaporation and reconstruct the unevaporated $\delta^{18}O$[13].

Miocene $\delta^{18}O$ gradient

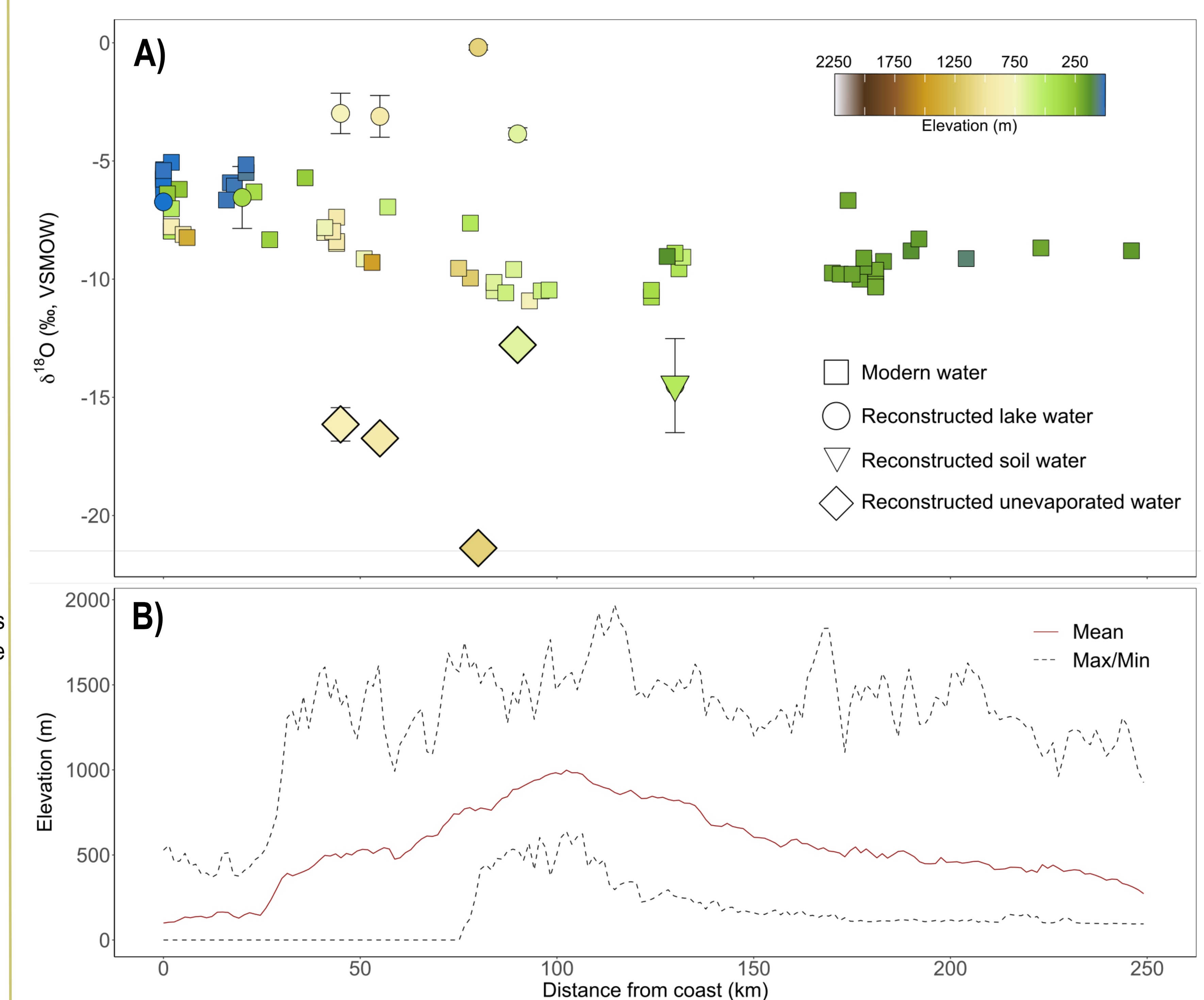


Figure 4. A) Oxygen gradient of modern waters, Miocene-age waters that formed the lacustrine and paleosol carbonates, and the reconstructed/unevaporated carbonate waters. Lacustrine carbonates have shown to be affected by evaporation, which preferentially removes ^{16}O from the lake thus creating higher $\delta^{18}O$ values[14]. For this reason, evaporation leads to the underestimation of past elevation. In order to account and correct for evaporation, we analyzed a subset of carbonates for $\Delta^{17}O$ (Fig. 5). Using our $\Delta^{17}O$ data and a model of lake evaporation[13], we reconstruct the unevaporated meteoric water $\delta^{18}O$. **B)** Elevation profile of modern Dinaric Alps topography across a 250 km transect.

Discussion

- High $\delta^{18}O$ values at the coast and lower $\delta^{18}O$ values at the crest of the range are a result of Rayleigh distillation in which a parcel of air carrying moisture is forced upwards by mountains, ^{18}O is preferentially removed by the resulting precipitation and becomes more depleted in ^{18}O[15, 16].
- Lake carbonates are affected by evaporation due to long residence times[14].

Conclusions and future work

- Modern $\delta^{18}O$ gradient shows a strong influence of Mediterranean moisture influencing streams in Croatia and Bosnia and Herzegovina.
- Miocene $\delta^{18}O$ gradient shows carbonates in this area were evaporatively enriched at the time of formation.
- Evaporation causes an underestimation of past topography, which creates a need for methods in order to isolate this effect.
- Initial $\Delta'^{17}O$ results suggest the Dinaric Alps had a higher elevation 15-17 Ma than they do today.
- Ongoing extension within the Dinaric Alps due to slab rollback may be responsible for lowering of topography.
- We will analyze the carbonates collected from the coast for ^{17}O to get a gradient of our full transect.

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References