Electronic supplementary material to

Machine Learning Analysis for Predicting Spatial Distribution and key influencers of Stable Isotope Patterns in European Precipitation

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1. Data Sources

Monthly precipitation stable isotope values were acquired from the European stations of the Global Network of Isotopes in Precipitation (n=271) extended by additional monthly data from 214 stations from regional networks and individual records distributed across the continent.

The detailed list of data sources is the following:

Networks:

- GNIP (Global Network of Isotopes in Precipitation (IAEA, 2019), online: https://nucleus.iaea.org/wiser/)
- ANIP (Austrian Network of Isotopes in Precipitation (Kralik et al., 2003), online: https://wasser.umweltbundesamt.at/h2odb/),
- SLONIP (Slovenian Network of Isotopes in Precipitation (Vreča et al., 2022), online: https://slonip.ijs.si/),
- PAPIN (Pan-Arctic Precipitation Isotope Network),

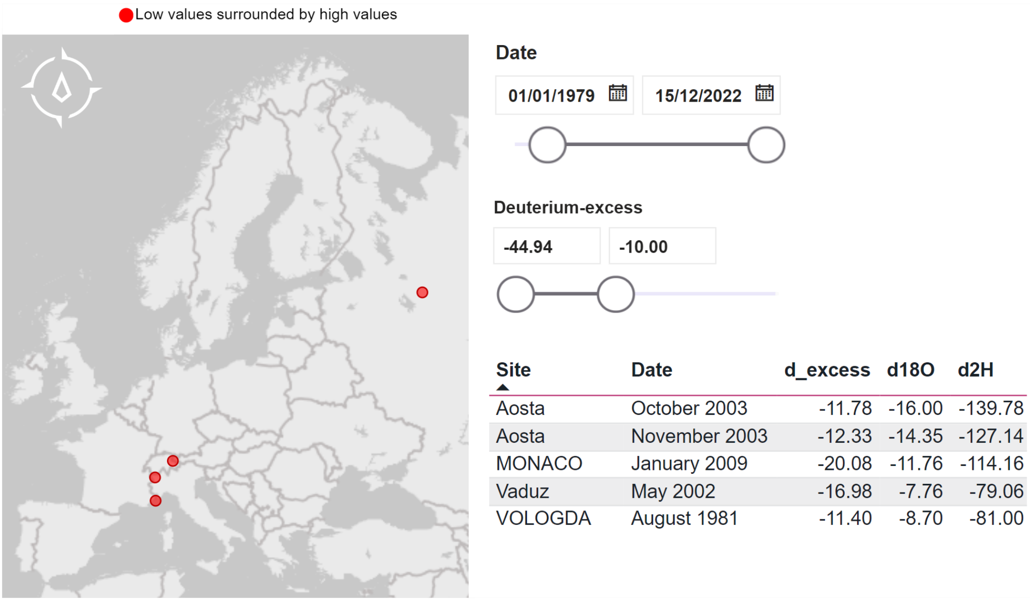
- RO_MD (Precipitation Stable Isotope network for Romania and Moldova (Aurel Perșoiu unpublished))
- Precipitation Isotope network of the University of Bern (Markus Leuenberger unpublished)

Station groups and individual records:

- Cyprus (Christofi et al., 2020)
- Italy (Cervi et al., 2017; Longinelli et al., 2006; Longinelli és Selmo, 2003; Longinelli et al., 2008; Natali et al., 2021; Natali et al., 2023; Natali et al., 2022)
- Montenegro (Živković et al., 2020)
- Poland (Rozanski és Dulinski, 1988)
- Hungary (Czuppon et al., 2021; Fórizs et al., 2020; Kern et al., 2020; Schöll-Barna, 2011; Vodila et al., 2011)
- Croatia (Krajcar Bronić et al., 2020a; Krajcar Bronić et al., 2020b; Marković et al., 2020; Paar et al., 2019)
- Crimea (Dublyansky et al., 2018)
- Corsica (Frederic Huneau unpublished)

2. Filtering outliers using Local Moran’s I statistics and Deuterium-excess

For data preprocessing, local Moran statistics and deuterium-excess were considered in a way similar to (Erdélyi et al., 2023). In the screening process five obvious outliers were found (Fig. S1).

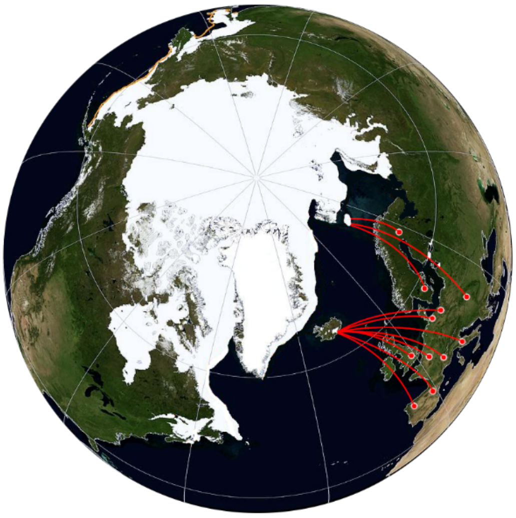


Site	Date	d_excess	d18O	d2H
Aosta	October 2003	-11.78	-16.00	-139.78
Aosta	November 2003	-12.33	-14.35	-127.14
MONACO	January 2009	-20.08	-11.76	-114.16
Vaduz	May 2002	-16.98	-7.76	-79.06
VOLOGDA	August 1981	-11.40	-8.70	-81.00

Figure S1: Local Moran’s I statistics and deuterium-excess values. When a monthly measurement drops to the area of the Local Moran’s I scatterplot that called “Low values surrounded by high values” and its deuterium-excess value is below -10; it can be visible in the map, marked with red circles, and its deuterium-excess value shown in the table, $\delta^{18}O$ and $\delta^{2}H$ values are also added.

3. Distance from the Arctic Sea Ice

We get the exact locations of the monthly Arctic Sea Ice using the data provided by the National Snow and Ice Data Center (DATA SET ID: G02135, DOI: 10.7265/N5K072F8). It is a source for consistent, up-to-date sea ice extent and concentration images, in GeoTIFF format, from November 1978 to the present in EPSG:4326 projection. Our target variable is the nearest distance value between the training and test points to the Arctic Ice. For calculation, we used the `RANN` package `nn2` function in `R` that is based on the `ANN` C++ library, which supports data structures and algorithms for both exact and approximate nearest neighbour searching in arbitrarily high dimensions. After the `nn2` calculated the distances between each training & test location to each Arctic Sea Ice covered cell, the minimum value for each training & test location had been extracted and used as predictor for the machine learning models (Fig. S2).



Credit: NSIDC/NASA Earth Observatory I

Figure S2: Blue Marble image from NASA shows Arctic Sea Ice in February 2022. The red points representing some training station location in Europe. The red lines representing the distance between each training point to the nearest location covered with Arctic Ice.

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