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Machine learning analysis for predicting spatial distribution and key influencers of stable isotope patterns in European precipitation

Dániel Erdélyi[1,2], Zoltán Kern[1], István Gábor Hatvani[1], Polona Vreča[3], Klara Žagar[3], Frederic Huneau[4], Aurel Perşoiu[5,6], Markus Leuenberger[7,8], Sonja Lojen[3], Oliver Kracht[9], Astrid Harjung[9], Pekka Rossi[10], Kaisa-Riikka Mustonen[11], and Jeffrey Welker[11,12,13]

[1]Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Siences, Budapest, Hungary (danderdelyi@gmail.com, zoltan.kern@gmail.com, hatvaniig@gmail.com)
[2]Department of Geology, Eötvös Loránd University, Budapest, Hungary (danderdelyi@gmail.com)
[3]Jožef Stefan Institute, Department of Environmental Sciences, Ljubljana, Slovenia (polona.vreca@ijs.si, klara.nagode@ijs.si, sonja.lojen@ijs.si)
[4]Laboratoire d'Hydrogéologie CNRS UMR 6134 SPE, University of Corsica, Corte, France (huneau@univ-corse.fr)
[5]Emil Racoviță Institute of Speleology, Romanian Academy, Cluj-Napoca, Romania (aurel.persoiu@gmail.com)
[6]Stable Isotope Laboratory, Ștefan cel Mare University, Suceava, Romania (aurel.persoiu@gmail.com)
[7]Climate and Environmental Physics, University of Bern, Bern, Switzerland (leuenberger@climate.unibe.ch)
[8]Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland (leuenberger@climate.unibe.ch)
[9]International Atomic Energy Agency, Department of Nuclear Sciences and Applications, Vienna, Austria (o.kracht@iaea.org, a.harjung@iaea.org)
[10]Water Resources and Environmental Engineering Research Unit, University of Oulu, Oulu, Finland (pekka.rossi@oulu.fi)
[11]Ecology and Genetics Research Unit, University of Oulu, Oulu, Finland (kaisa-eiikka.mustonen@oulu.fi, jeffrey.welker@oulu.fi)
[12]Department of Biological Sciences, University of Alaska, Anchorage, United States (jmwelker@alaska.edu)
[13]Ecology and Genetics Research Unit, University of the Arctic, Rovaniemi, Finland (jmwelker@alaska.edu)

Natural abundance variations in stable isotope ratios of hydrogen and oxygen are important environmental tracers with a significant range of applications (e.g., the exploration of the present water cycle, paleoclimate reconstructions, ecology, and food authenticity). These applications and research themes are often based on spatially explicit predictions of precipitation isotopic variations obtained from point sample collections and measurements through various interpolation techniques. The derivation of spatially continuous and georeferenced isotope databases, known as isotopic landscapes (isoscapes), has been considered most effective through regression kriging for precipitation beginning in the early 2000s. However, the number of interpolation methods used in geostatistics has increased rapidly in recent decades, with new machine learning algorithms becoming increasingly important and proving more successful than conventional methods for certain isotopic parameters. In the present research we present a monthly 10 x 10 km European isoscape based on state-of-the art hybrid machine learning method that combines LASSO Regression and Random Forest (Zhang et al., 2019) for spatial predictions for 1973-2022. Data were retrieved from the IAEA/WMO Global Network of Isotopes in Precipitation (no. of stations: 329) and other national datasets from about 10 countries (no. of stations: ~150).

A pilot study (for 2008-2017; Erdélyi et al. 2023) indicated the highest prediction error for the northern premises. This suggested the incorporation of sea ice as an additional predictor, since a Pan-Arctic precipitation stable isotope study pointed out that sea ice cover change is a key driver of oceanic moisture sources (Mellat et al., 2021). Results indicate an overwhelming importance of minimum temperature with the variable representing sea ice cover, ranking among the least influential parameters. The analysis fails to consider moisture source effects, transport distances, and secondary processes of recycling associated with evaporation and transpiration from landscapes across Europe. These results provide a more refined prediction due to the higher station density compared to previous models and thanks to the hybrid model, a more accurate prediction of monthly precipitation stable isotope compositions is expected for the critical areas including the latitudinal margins as well as the mountainous zones.

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