BIOGEOGRAPHY: SCIENTIFIC PERSPECTIVES, CONSERVATION AND CLIMATE CHANGE

Adaptation of the Types of Bioclimatic Regimes (TBR) method to the island of El Hierro (Canary Islands)

Damián Caballero Fernández[1]

[1]Universitat de Barcelona, Barcelona, Spain
E-mail: damian.caballero@ub.edu

Montserrat Salvà-Catarineu[2]

[2]Universitat de Barcelona, Barcelona, Spain
E-mail: salva@ub.edu

revista GeoUSP espaço e tempo

ISSN 2179-0892
Volume 28 • n° 3 (2024)
e230590

How to cite this article: CABALLERO FERNÁNDEZ, D.; SALVÀ-CATARINEU, M. Adaptation of the Types of Bioclimatic Regimes (TBR) method to the island of El Hierro (Canary Islands). **Geousp**, v. 28, n. 3, e230590. 2024. https://doi.org/10.11606/issn.2179-0892.geousp.2024.230590en

Adaptation of the Types of Bioclimatic Regimes (TBR) method to the island of El Hierro (Canary Islands)

ABSTRACT

Types of Bioclimatic Regimes (TBR) is a global bioclimatic classification methodology that integrates thermo-pluviometric and edaphic data. Since 2022, the BIOCLIM package in RStudio has facilitated the application of this classification across various fields of study. In this study, the TBR method is tested on El Hierro, a volcanic island with complex geographical features and high biodiversity, to evaluate its applicability at large scale. The Universal Kriging (UK) method was employed for the spatial interpolation of maps. Additionally, for the bioclimatic subtypes map (TBRs), a multiple linear regression model adjusted using Ordinary Least Squares (OLS) and a residual correction using Ordinary Kriging (OK) were applied. The evaluation of the interpolations demonstrates good precision, although with limitations in the higher and more inaccessible areas of the island. The results provide an updated, detailed, and adjusted bioclimatic map, which is crucial in the context of the climate emergency.

Keywords: TBR. BIOCLIM. Bioclimatic classifications. Universal Kriging. Canary Islands.

Adaptación del método de Tipos de Regímenes Bioclimáticos (TRB) a la isla de El Hierro (Canarias)

RESUMEN

Los Tipos de Regímenes Bioclimáticos (TRB) es una metodología de clasificación bioclimática global que integra datos termo-pluviométricos y edáficos. Desde 2022, el paquete BIOCLIM en RStudio permite aplicar esta clasificación a diversas áreas de estudio. Este estudio prueba el método TRB en El Hierro, una isla volcánica con características geográficas complejas y gran biodiversidad, para evaluar su aplicabilidad a escalas grandes. Se utilizó el método Kriging Universal (KU) para la interpolación espacial de los mapas, y para el mapa de subtipos bioclimáticos (sTRB), se aplicó también un modelo de regresión lineal múltiple ajustado mediante mínimos cuadrados ordinarios (MCO) y una corrección de residuos con Kriging Ordinario (KO). La evaluación de las interpolaciones muestra buena precisión, aunque con limitaciones en las áreas más elevadas e inaccesibles de la isla. Los resultados ofrecen un mapa bioclimático actualizado, ajustado y detallado, crucial en el contexto de la emergencia climática.

Palabras clave: TRB. BIOCLIM. Clasificaciones bioclimáticas. Kriging Universal. Canarias.

Adaptação do método de Tipos de Regimes Bioclimáticos (TRB) à ilha de El Hierro (Canárias)

RESUMO

Os tipos de regimes bioclimáticos (TRB) são uma metodologia de classificação bioclimática global que integra dados termo-pluviométricos e edáficos. Desde 2022, o pacote BIOCLIM no RStudio permite aplicar essa classificação a diversas áreas de estudo. Este estudo testa o método TRB em El Hierro, uma ilha vulcânica com características geográficas complexas e grande biodiversidade, para avaliar sua aplicabilidade em escalas grandes. O método Kriging Universal (KU) foi utilizado para a interpolação espacial dos mapas, e para o mapa de subtipos bioclimáticos (sTRB), também foi aplicado um modelo de regressão linear múltipla ajustado por

meio de mínimos quadrados ordinários (MCO) e uma correção de resíduos com Kriging Ordinário (KO). A avaliação das interpolacões mostra boa precisão, embora com limitações nas áreas mais elevadas e inacessíveis da ilha. Os resultados oferecem um mapa bioclimático atualizado, ajustado e detalhado, crucial no contexto da emergência climática.
Palavras-chave: TRB. BIOCLIM. Classificações bioclimáticas. Kriging Universal. Canárias.

INTRODUCTION

Bioclimatic classifications enable the categorization, synthesis, and description of the climates of different territories and their biological characteristics (Pham et al., 2023). These classifications are fundamental to phytoclimatology, a branch of biogeography that studies the relationships between vegetation distribution and climate. Over the years, numerous studies have attempted to propose globally valid phytoclimatic classifications (Rivas Martínez; Rivas Sáenz; Penas, 2002; Cui et al., 2021; Serrano Notivoli; Longares; Cámara Artigas, 2022). These classifications are based on climatic parameters proposed by authors such as Thornthwaite (1933, 1948), Köppen and Geiger (1936), and Montero de Burgos and González Rebollar (1974), or on nomenclatures and ecological limits derived from researchers such as Drude (1890), Clements (1909), and, specifically for Spain, Huguet del Villar (1929).

One of the most widely recognized global bioclimatic classifications is that proposed by Rivas-Martínez (1995) and Rivas-Martínez et al. (2002). This system is based on a set of bioclimatic indices, such as the continentality index or the ombrothermic index, and thermal magnitudes, such as the mean annual temperature. The objective of these calculations is to categorize the planet based on the interaction between temperature and precipitation. Rivas-Martínez et al. (2002) managed to identify five major macrobioclimates (tropical, Mediterranean, temperate, boreal, and polar), as well as 27 more detailed bioclimates, which are further subdivided into thermo-types (temperature-based) and ombrotypes (moisture-based). This combination of indices provides insights into the distribution and types of vegetation that can thrive in each region of the world.

This system is widely used and has often been adapted at the national level (Mesquita; Sousa, 2009; Pesaresi et al., 2014) or at regional level (Pham et al., 2023; Massarelli; Campanale, 2023). In the Canary Islands, it is the most commonly applied bioclimatic classification method, with notable bioclimatic categorizations of all the islands by Del Arco Aguilar et al. (2006) and Del Arco Aguilar and Rodríguez Delgado (2018). Del Arco Aguilar, Acebes and Pérez de Paz (1996) and Del Arco Aguilar et al. (1999, 2002, 2006, 2009) have also adapted this global classification system to individual islands, such as La Gomera, Tenerife, Gran Canaria, and even El Hierro.

The Type of Bioclimatic Regime (TBR) method, proposed by Cámara Artigas, Díaz del Olmo and Martínez Batlle (2020), aims to establish a rigorous, and multi-scale global classification. The main innovation is in the combination of thermo-pluviometric and edaphic variables of the territory, which significantly improves the bioclimatic classification. The TBR is based on the calculation of three key components: the water balance, which determines the ability of the environment to support vegetation, the bioclimatic balance, which identifies periods of active plant growth and periods of inactivity, and the bioclimatic intensities, which provide insights into plant growth and development. These balances are calculated based on classical classifications, such as those by Montero de Burgos and González Rebollar (1974) and Thornthwaite (1933, 1948).

The aim of this study is to adapt the TBR classifications to the geospatial characteristics of El Hierro, utilizing data from 17 thermal stations and 26 rainfall stations distributed across the island to test the model at a detailed scale.

METHOD

Study area

El Hierro (268 km²), the youngest and westernmost island of the Canary archipelago, is located between the coordinates 27°38’-27°50’N and 17°53’-18°09’W (Figure 1). Renowned for its exceptional diversity of landscapes, geology and bioclimates (Carracedo et al., 1997) and is home to the largest extent of *Juniperus canariensis* in the entire Canary Islands (Salvà Catarineu et al., 2016).

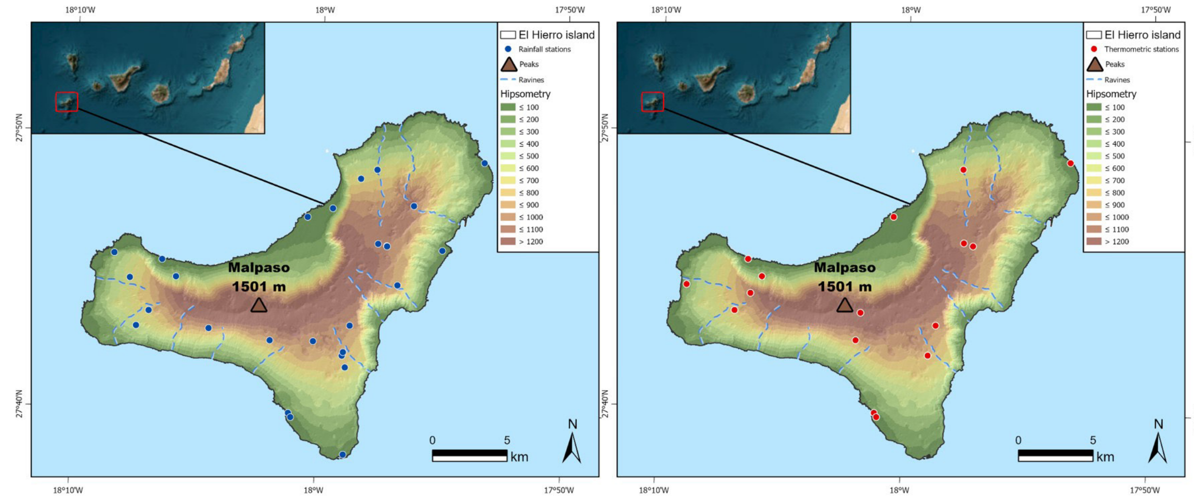

Figure 1 – Location of El Hierro Island and the employed thermo-pluviometric stations. **Source:** Own elaboration with data from GRAFCAN and AEMET.

The climate of El Hierro is influenced by the thermodynamic factors associated with the mid-latitudes, such as the jet stream and the Azores High (Dorta Antequera, 2007; Del Arco Aguilar; Rodríguez Delgado, 2018). In addition, local geographic factors shape the climate types across the archipelago. The varying orientation and altitude of El Hierro give rise to a wide range of climatic conditions, from desert and steppe to Mediterranean and oceanic climates (Mayer Suárez; Luque Söllheim; García Hernández, 2022; Luque Söllheim; Mayer Suarez; García Hernández, 2024).

The climate regime is characterized by atmospheric stability, dominated by the trade winds and a pronounced temperature inversion, which is responsible for the formation of low-level stratiform clouds on the northern slopes of the island. During late autumn, winter, and early spring, the Azores High shifts southward and westward, permitting the occasional passage of fronts and low-pressure systems (Morales Matos; Pérez González, 2000).

These climatic conditions are reflected in the vegetation, which varies depending on the altitude and orientation of the island. Succulent plant communities, such as the tabaibal-cardonal, dominate the coastal areas. Between 200 and 700 meters above sea level, the thermophilic forest, characterized by the iconic Canary Island juniper, can be found. The laurel forest begins at an altitude of around 600 meters on the northern slopes, while the Canary Island pine occurs at an altitude of over 700 meters on the southern slopes (Aeschimann, 2021).

The soils of the island are typically shallow and formed on recent parent materials. They are characterized by high infiltration rates and limited water retention capacity (Padrón Padrón et al., 1990; Padrón Padrón, 1993).

Data used and cartographic layers

For this study, data from 26 rainfall stations and 17 temperature stations (Figure 2) were used. The data were provided by the Spanish State Meteorological Agency (AEMET). These stations were selected to ensure a balanced geographic distribution across the island and to guarantee the quality of the records during the study period.

Field capacity values for each station, which are essential for bioclimatic calculations, were obtained from the study by Padrón Padrón et al. (1990) that assessed the island's soils.

In order to improve the accuracy of the spatial interpolations in an area characterized by geospatial variability, a Digital Terrain Model (DTM) and a smoothed slope map, both provided by Cartografía de Canarias S.A. (GRAFCAN) at an original resolution of 25x25 meters, were incorporated as topographic layers. These layers were subsequently resampled to a 100x100 meter resolution.

All climate and bioclimatic maps were generated using ArcGIS Pro (version 2.5.0).

Climate and bioclimatic data processing and analysis

Data processing and analysis were conducted in several stages. Given the poor quality of the thermo-pluviometric records on the island, it was necessary to reconstruct climatic data for the most recent climatic normal (1991-2020). This reconstruction involved selecting stations with high correlations to maximize the amount of complete data. For this purpose, the software CLIMATOL (version 4.1.1) was used. Additionally, CLIMATOL was also employed to verify data quality and homogeneity, and to fill in missing data gaps (Guijarro, 2024).

Subsequently, a bioclimatic classification of the weather stations was performed using the BIOCLIM package in RStudio (Serrano-Notivoli; Longares; Cámara Artigas, 2022). The TBR method (Cámara Artigas; Díaz del Olmo; Martínez Batlle, 2020) was applied, taking into account the mean monthly temperature, mean monthly precipitation, latitude and field capacity. Below is an example of the necessary parameters incorporated to calculate bioclimatic subtypes for each station:

Weather station: El Hierro-aeropuerto

wb < − watbal(t = c(19.03,18.80, 19.13, 19.66, 20.69, 22.06, 23.12, 24.12, 24.42, 23.70, 21.84, 20.21),

p = c(27.47,24.92, 20.20,14.25, 2.57, 1.48, 0.20, 1.17, 3.46, 17.60, 30.74, 41.28),

lat = 27.75,

CC = 150)

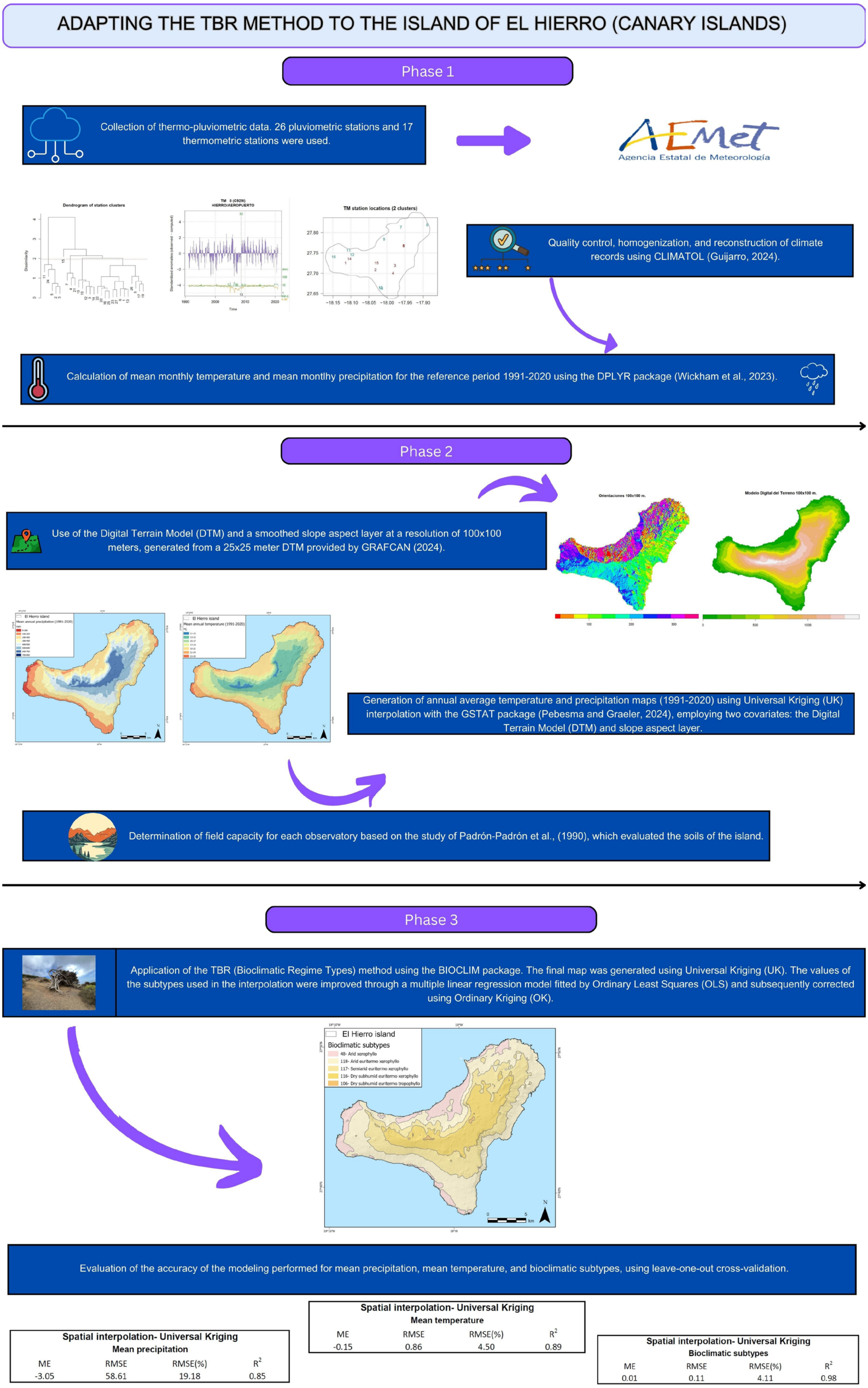

Figure 2 – Schematic summary of the employed method. **Source:** Own elaboration

Universal Kriging (UK) was chosen for the spatial interpolation using RStudio (version 2023.12.1+402) and the GSTAT package (Pebesma; Graeler, 2024). UK was considered the most suitable method due to the strong spatial variations observed on the island of El Hierro. UK accounts for both local variability and spatial trends related to the terrain, enabling a more accurate representation of the island's complex characteristics (Chazarra Bernabé, 2014; Santra; Kumar; Panwar, 2017). Furthermore, this technique is particularly advantageous given the number of stations employed.

However, while the final TBRs map was also generated using UK, the predictions employed for that interpolation were based on the values of the subtypes improved through a combination of techniques. Initially, a multiple linear regression model adjusted with the Ordinary Least Squares (OLS) method was used, where the subtypes were reconverted to numerical variables as the dependent variable. Subsequently, an Ordinary Kriging model was applied to fit the OLS residuals. This procedure was executed using geoprocessing tools such as Ordinary Least Squares and Kriging in ArcGIS Pro.

VALIDATION

To evaluate the quality of the UK interpolations, Leave-One-Out Cross-Validation (LOOCV) was implemented using the GSTAT package in RStudio (Pebesma; Graeler, 2024). This method, a widely accepted approach for assessing model performance, was utilized to estimate prediction errors (Vehtari; Gelman; Gabry, 2017; Geroldinger et al., 2023).

Consequently, the mean error was calculated (Equation 1):

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left(y_i - \widehat{y_i}\right) \tag{1}$$

The root mean squared error, in absolute terms and as a percentage (Equation 2):

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}(yi - \widehat{y_i})^2} \tag{2}$$

And the coefficient of determination (Mokari et al., 2022) (Equation 3):

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(yi - \widehat{y_i})^2}{\sum_{i=1}^{n}(yi - \overline{y})^2} \tag{3}$$

Subsequently, the results were compared with findings from other comparable climate or bioclimatic studies (Luque Söllheim; Mayer Suárez; García Hernández, 2024).

RESULTS

Thermo-pluviometric maps

Detailed thermo-pluviometric maps of El Hierro were produced (Figures 3 and 4). The mean precipitation recorded on the island during the last climate normal shows a significant altitudinal increase. The highest precipitation, close to or exceeding 700 mm, occurring in the elevated areas. The areas with higher values are located in the northeast of the island, a territory affected by both orographic and horizontal precipitation. In contrast, the areas with the lowest precipitation are located in the south and southwest, where accumulated values are less than 100 mm. This can be explained by the fact that this is an area located in the lee of the prevailing trade winds, in an area where a rain shadow occurs. Additionally, their lower altitude limits the ability of these areas to benefit from precipitation generated by the altitudinal gradient (Mayer Suárez; Marzol Jaén, 2013).

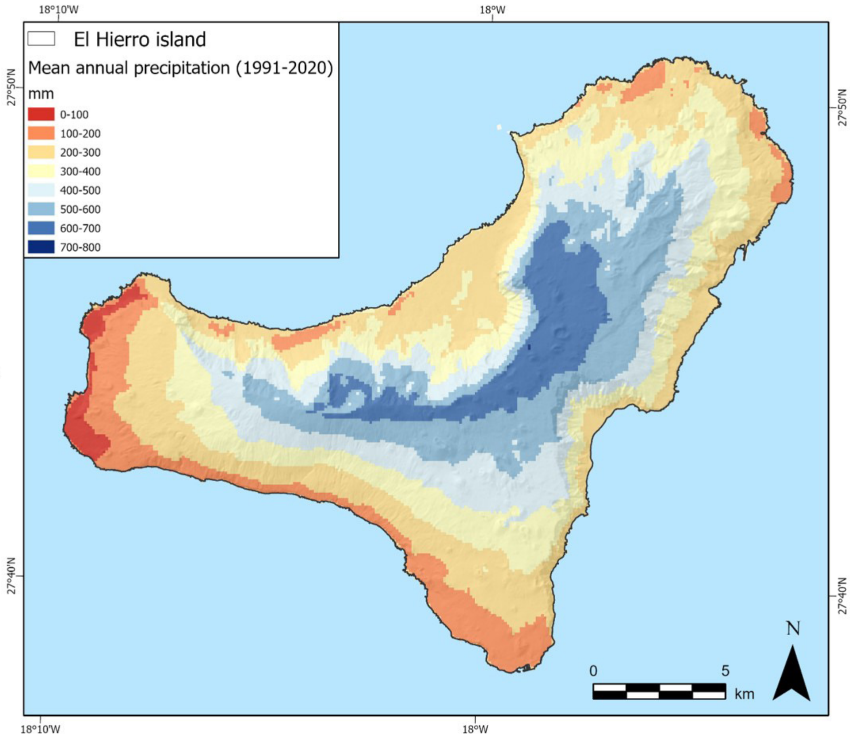

Figure 3 – Mean annual precipitation on the island of El Hierro (1991-2020). **Source:** Own elaboration based on AEMET data.

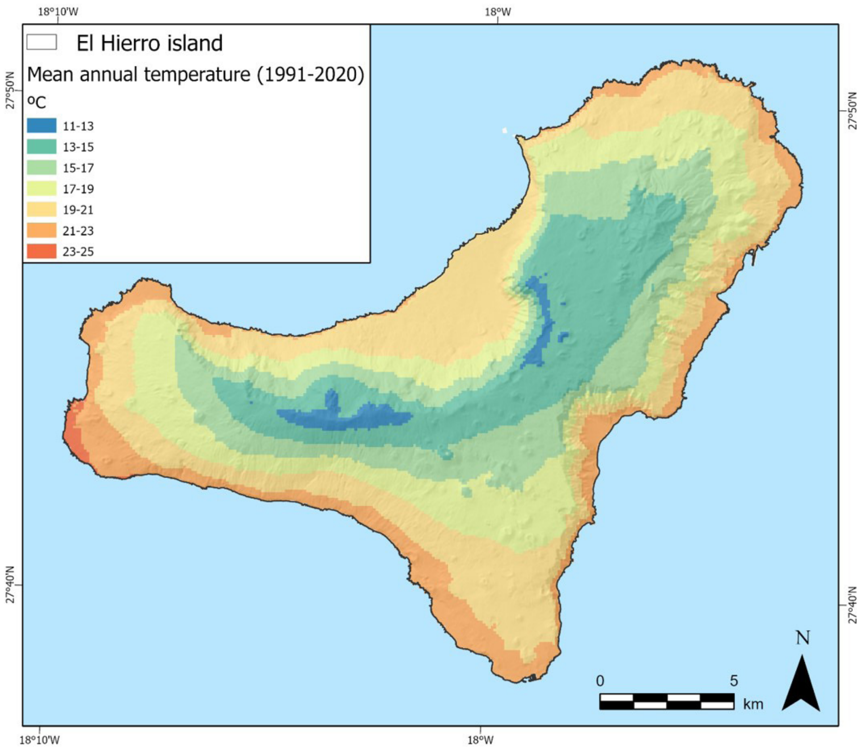

Figure 4 – Mean annual temperature on the island of El Hierro (1991-2020). **Source:** Own elaboration based on AEMET data

The mean temperatures on the island are notably mild, which is due to its subtropical location and latitude (Figure 4). As the altitude increases, the temperature decreases, with the highest mean temperatures (over 20 °C) being recorded in the coastal areas, while in the higher regions the mean temperatures are more continental European (between 11 °C and 13 °C). Exceptionally, in the southwest of the territory, temperatures reach or exceed 23 °C, areas where insolation is higher and there are very few cloudy days (Marzol Jaén; Máyer Suárez, 2012). Although this temperature magnitude might be considered anomalous, it has been corroborated by the findings presented in the Climate Atlas of the Canary Islands (Luque Söllheim; Mayer Suárez; García Hernández, 2024).

Bioclimatic subtypes map

The TBR method, adapted for El Hierro, has enabled the identification of up to five bioclimatic subtypes (Figure 5).

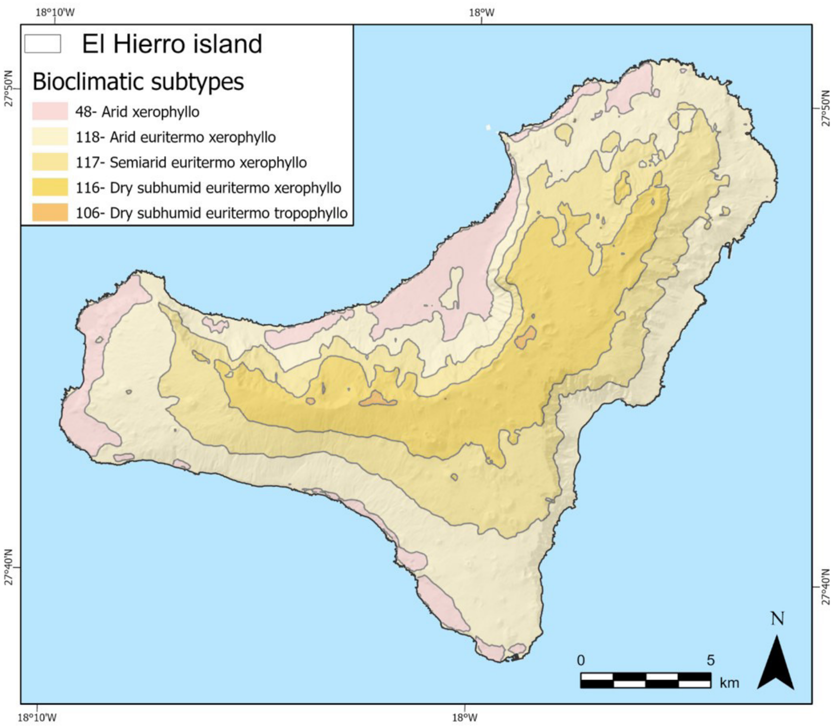

Figure 5 – Bioclimatic classification of El Hierro Island. **Source:** Own elaboration based on AEMET data.

According to this method, the thermal regime (tropical) is present in a large part of the coastal areas of the territory, covering up to 11.55% of the total island (Table 1). This is due to its thermal behavior, with mean temperatures above 18 °C during all months of the year. In these areas, arid xerophilous spaces predominate, with a vegetative standstill of 5-8 months due to insufficient water availability.

As we move inland and ascend in altitude, euritermo (subtropical) subtypes predominate, characterized by mean monthly temperatures between 7.5 °C to 18 °C. While there is no thermal standstill, although water stress becomes significant again, with periods ranging from 5 to 8 months. In these areas, arid xerophilous spaces predominate, the most common subtype on the island (39.51%), as well as semi-arid or dry sub-humid areas.

Table 1 – Area (km²) and proportion of each bioclimatic subtype on El Hierro.

Subtype	Area in Km²	Percent %	Most representative potential vegetation
48- Arid xerophyllo	30.98	11.55	Tabaibal-Cardonal
118- Arid euritermo xerophyllo	105.89	39.51	El Hierro juniper woodland
117- Semiarid euritermo xerophyllo	75.33	28.10	Juniper-pine woodland- Dry montane cloud forest
116- Dry subhumid euritermo xerophyllo	54.87	20.47	El Hierro pine- cloud forest
106- Dry subhumid euritermo tropophyllo	1.21	0.45	High-altitude fayal-brezal

Source: Own elaboration.

In some scattered areas in the highest parts of the island, with a prevalence of 0.45%, a tropophilous subtype is identified, characterized by a more limited water stress of 1 to 4 months. This subtype is typically found in the Canary Islands at altitudes around 1,400 meters above sea level, particularly in islands with greater elevations, such as La Palma. However, this subtype has been obtained through interpolation and has not been validated as the highest areas of the island lack stations with quality and quantity records.

DISCUSSION

The results demonstrate that, despite its small size (268 km²), the island of El Hierro showcases a remarkable range of bioclimates.

The climate maps produced were compared with those in the Climate Atlas of the Canary Islands, as both studies employed similar methodologies. The main difference between the two lies in the interpolation method; the Atlas uses MLR and incorporates more topographic covariates such as latitude, longitude, and distance to the sea. However, the present study utilized a larger number of stations from the island of El Hierro. The validation showed a significant agreement between the results of the Atlas and those of the present study, both in terms of magnitude and thermo-pluviometric distribution (Luque Söllheim; Máyer Suarez; García Hernández, 2024).

Adapting the TBR method to the island has allowed us to verify that El Hierro has confirmed that the island exhibits a greater number and diversity of bioclimatic subtypes than those identified in previous studies applying TBR at a 1 km spatial resolution (Cámara Artigas; Díaz del Olmo; Martínez Batlle, 2020). This study shows that a finer resolution, together with interpolation techniques better suited to the island context and the integration of topographic variables that influence the distribution of subtypes, leads to better results. The results are also consistent with previous research using other methods to characterize the island biogeographically (Del Arco Aguilar; Acebes; Pérez de Paz, 1996; Del Arco Aguilar et al., 1999; Stierstorfer, 2005).

The results obtained using the UK interpolation method show very accurate results (Table 2), comparable to interpolation performances applied to insular areas (Garzón Machado; Otto; Del Arco Aguilar, 2014).

For temperature data, validation results are even more precise across all calculations performed, as temperature values exhibit less contrast than precipitation (Table 3).

Table 2 – Cross-validation results of the UK interpolation for mean precipitation.

Spatial interpolation- Universal Kriging	
Mean precipitation	
Mean error	3.05
Root mean squared error	58.61
Root mean squared error in %	19.18
Coefficient of determination (R^2)	0.85

Table 3 – Cross-validation results of the UK interpolation for mean temperature.

Spatial interpolation- Universal Kriging	
Mean temperature	
Mean error	-0.15
Root mean squared error	0.86
Root mean squared error in %	4.50
Coefficient of determination (R^2)	0.89

Regarding subtypes, cross-validation prediction results were improved (Table 4) through a three-step prediction process: Ordinary Least Squares (OLS) was initially applied, followed by Ordinary Kriging (OK) to correct residuals, and finally, the final interpolation was obtained using Universal Kriging (UK):

Table 4 – Cross-validation results of UK interpolation for bioclimatic subtypes.

Spatial interpolation- Universal Kriging	
Bioclimatic subtypes	
Mean error	-0.01
Root mean squared error	0.11
Root mean squared error in %	4.11
Coefficient of determination (R^2)	0.98

Previous studies conducted in the Iberian Peninsula and the Canary Islands have highlighted the suitability of UK for climate data, particularly in complex terrains such as islands (Izquierdo; Márquez, 2006, 2007; Caballero; Giraldo; Mateu, 2013; Cantet, 2017). Furthermore, the combination of a Multiple Linear Regression (MLR) with Ordinary Kriging (OK) has been recommended for bioclimatic mapping (Garzón Machado; Otto; Del Arco Aguilar, 2014).

By producing a detailed map of subtypes, this study allows for a more accurate identification of areas in El Hierro affected by horizontal precipitation. Crypto-precipitation, formed by the condensation of fog water on vegetation, should be further explored in bioclimatic studies (Stierstorfer, 2005; Aeschimann, 2021). Unfortunately, it has not yet been possible to estimate the additional precipitation generated by this phenomenon on El Hierro (Caballero Fernández, 2024), although estimates are available for other islands such as Tenerife (Marzol Jaén; Sánchez Megía, 2008).

While direct measurements are lacking, we have identified areas with a higher propensity for this type of precipitation, concentrated in the higher elevations of the northeastern part of the island (Figure 6).

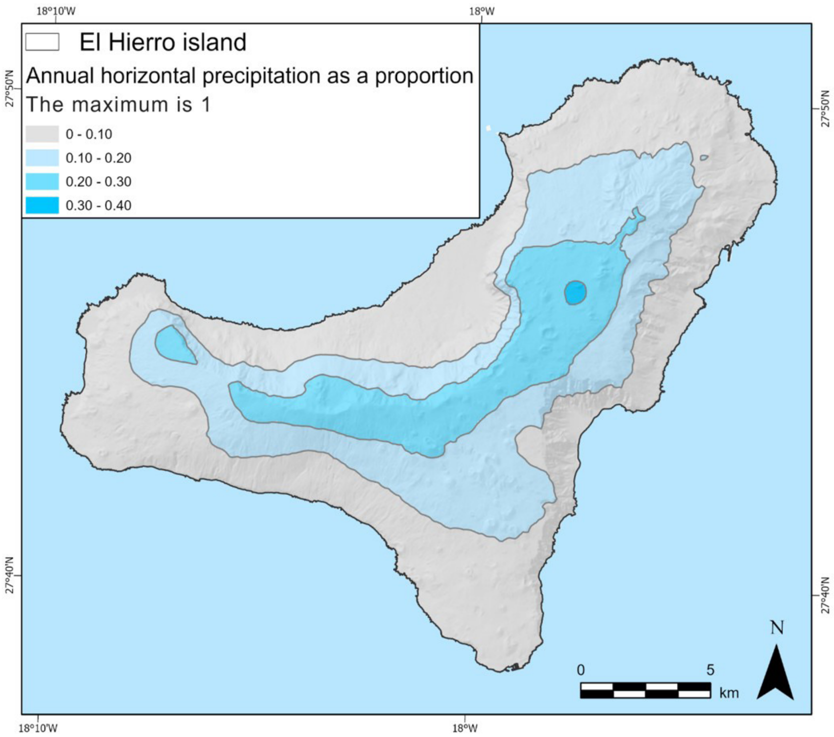

Figure 6 – Areas with higher susceptibility to horizontal precipitation. **Source:** Own elaboration.

In future research, it would be valuable to adapt the methodology of Rivas-Martínez et al. (2002) to the island, utilizing more recent climate records from a larger network of stations, and incorporating additional maps into the analysis.

CONCLUSION

The findings of this study underscore the remarkable climatic diversity of El Hierro Island. Despite its compact size, the island displays pronounced geospatial contrasts.

Using climate data from the most recent climate normal period (1991-2020) and applying the TBR method, our results indicate that a tropical arid regime, characterized by mean monthly temperatures above 18 °C and a vegetation dormancy period of 5-8 months, is already present in a substantial portion of the territory, covering approximately 11% of the surface. These findings suggest that bioclimatic regimes typical of lower latitudes are becoming increasingly prevalent in the Canary Islands.

A remarkable result is the identification of a less arid tropophilous subtype in scattered areas of the island's higher elevations, covering approximately 0.45% of the surface. Although further validation is needed, this subtype has previously only been documented on higher-altitude islands, such as La Palma. Additionally, a dry subhumid euritermo xerophyllo subtype, which had not been previously calculated for El Hierro, was identified, covering around 20% of the island. This latter subtype was observed at some of the weather stations used in this study.

The projected increase in aridity, the altitudinal shift in subtypes and the encroachment of increasingly tropical features pose a significant threat to emblematic ecosystems, especially thermophilic forests, which are highly vulnerable to prolonged water scarcity. These forests are concentrated in the two most common subtypes on the island: arid euritermo xerophyllo (39%) and semi-arid (28%).

Universal Kriging (UK) interpolation has proven to be an effective tool for adapting the TBR method, enhancing predictions by incorporating external topographic variables, particularly in an insular environment with abrupt changes. This spatial interpolation technique has enabled the generation of high-quality detailed maps, contributing to the improvement and updating of previously scarce bioclimatic studies on the island.

This study aims to highlight the value of the TBR method in a small-sized territory, allowing for detailed scale analyses, particularly in islands hosting unique and fragile ecosystems. This method can aid in the improved management and understanding of such environments in the face of global change.

REFERENCES

AESCHIMANN, D. **Flore et végétation sur l'île d'El Hierro**: canaries. Bussigny: Rossolis, 2021.

CABALLERO, W.; GIRALDO, R.; MATEU, J. A universal kriging approach for spatial functional data. **Stochastic Environmental Research and Risk Assessment**, Heidelberg, v. 27, n. 7, p. 1553-1563, 2013. DOI: http://doi.org/10.1007/s00477-013-0691-4.

CABALLERO FERNÁNDEZ, D. Estimation of horizontal precipitation on the island of El Hierro (Canary Islands). *In*: INTERNATIONAL GEOGRAPHICAL CONGRESS, 35., 2024, Dublin, Ireland. **Proceedings [...]**. Dublin: Geographical Society of Ireland, 2024.

CÁMARA ARTIGAS, R.; DÍAZ DEL OLMO, F; MARTÍNEZ BATLLE, J. R. TBRs, a methodology for the multi-scalar cartographic analysis of the distribution of plant formations. **Boletín de la Asociación de Geógrafos Españoles**, España, n. 85, p. 1-38, 2020.

CANTET, P. Mapping the mean monthly precipitation of a small island using kriging with external drifts. **Theoretical and Applied Climatology**, Vienna, v. 127, n. 1-2, p. 31-44, 2017. DOI: http://doi.org/10.1007/s00704-015-1610-z.

CARRACEDO, J. C. *et al*. **Excursion guidebook.** Geology of the island of El Hierro, Canary islands: stratigraphy, volcanology and structure. Gran Canaria: Estación Volcanológica de Canarias (Consejo Superior de Investigaciones Científicas) and the Depto. Física-geología, 1997.

CHAZARRA BERNABÉ, A. **Interpolación espacial de la temperatura mínima diaria mediante Krigeado universal.** Oviedo: Asociación Meteorológica Española, 2014.

CLEMENTS, F. E. **Greek and Latin in biological nomenclature**. Lincoln: University of Nebraska, 1909.

CUI, D. *et al*. A 1 km global dataset of historical (1979-2013) and future (2020-2100) Köppen-Geiger climate classification and bioclimatic variables. **Earth System Science Data**, Göttingen, v. 13, n. 11, p. 5087-5114, 2021. DOI: http://doi.org/10.5194/essd-13-5087-2021.

DEL ARCO AGUILAR, M. J.; ACEBES, J. R.; PÉREZ DE PAZ, P. L. Bioclimatology and climatophilous vegetation of the Island of Hierro (Canary Islands). **Phytocoenologia**, Stuttgart, v. 26, n. 4, p. 445-479, 1996. DOI: http://doi.org/10.1127/phyto/26/1996/445.

DEL ARCO AGUILAR, M. J. *et al*. Bioclimatology and climatophilous vegetation of Hierro (part 2) and La Palma (Canary Islands). **Phytocoenologia**, Stuttgart, v. 29, n. 2, p. 253-290, 1999.

DEL ARCO AGUILAR M. J. *et al*. Bioclimatology and climatophilous vegetation of Gran Canaria (Canary Islands). **Annales Botanici Fennici**, Helsinki, v. 39, n. 1, p. 15-41, 2002.

DEL ARCO AGUILAR, M. J. *et al*. Bioclimatology and climatophilous vegetation of Tenerife (Canary Islands). **Annales Botanici Fennici**, Helsinki, v. 43, n. 3, p. 167-192, 2006.

DEL ARCO AGUILAR, M. J. *et al*. Bioclimatology and climatophilous vegetation of Gomera (Canary Islands). **Annales Botanici Fennici**, Helsinki, v. 46, n. 3, p. 161-191, 2009.

DEL ARCO AGUILAR, M. J.; RODRÍGUEZ DELGADO, O. **Vegetation of the Canary Islands.** Cham: Springer. 2018. DOI: http://doi.org/10.1007/978-3-319-77255-4.

DORTA ANTEQUERA, P. J. Catálogo de riesgos climáticos en Canarias: amenazas y vulnerabilidad. **Geographicalia**, Zaragoza, n. 51, p. 133-160, 2007. DOI: http://doi.org/10.26754/ojs_geoph/geoph.2007511118.

DRUDE, O. **Handbuch der pflanzengeographie**. Sttuttgart: Verlag Von J. Engerlhorn, 1890. v. 7.

GARZÓN MACHADO, V.; OTTO, R.; DEL ARCO AGUILAR, M. J. Bioclimatic and vegetation mapping of a topographically complex oceanic island applying different interpolation techniques. **International Journal of Biometeorology**, Berlin, v. 58, n. 5, p. 887-899, 2014. PMid:23686111.

GEROLDINGER, A. *et al*. Leave-one-out cross-validation, penalization, and differential bias of some prediction model performance measures: a simulation study. **Diagnostic and Prognostic Research**, London, v. 7, n. 1, p. 9, 2023. DOI: http://doi.org/10.1186/s41512-023-00146-0. PMid:37127679.

GUIJARRO, J. A. **User's guide of the climatol R Package (version 4.1.1)**. 2024. Disponible en: https://climatol.eu. Accedido en: 1 Oct 2024.

HUGUET DEL VILLAR, E. **Geobotánica**. Barcelona: Labor, 1929.

IZQUIERDO, T.; MÁRQUEZ, A. Comparación de métodos de interpolación para la realización de mapas de precipitación para el acuífero de Icod-Cañadas. **GEOGACETA**, Salamanca, n. 40, p. 307-310, 2006.

IZQUIERDO, T.; MÁRQUEZ, A. Estudio comparativo de diferentes métodos de interpolación para la realización de mapas de precipitación en la isla de La Gomera (Islas Canarias): evaluación de la incorporación de la altura. **GEOGACETA**, Salamanca, n. 42, p. 131-134, 2007.

KÖPPEN, W; GEIGER, R. Das geographische system de klimate. *In*: KÖPPEN, W.; GEIGER, R. (ed.).**Handbuch der klimatologie**. Berlin: Verlag Gebrüder Borntrager, 1936.

LUQUE SÖLLHEIM, Á. L.; MÁYER SUAREZ, P.; GARCÍA HERNÁNDEZ, F. The digital climate atlas of the Canary Islands: a tool to improve knowledge of climate and temperature and precipitation trends in the Atlantic islands. **Climate Services**, Amsterdam, v. 34, p. 100487, 2024. DOI: http://doi.org/10.1016/j.cliser.2024.100487.

MARZOL JAÉN, M. V.; SÁNCHEZ MEGÍA, J. L. **El potencial hídrico de los *stratocumulus* subtropicales**: el caso de Canarias y Marruecos. Zaragoza: Asociación Meteorológica Española, 2008.

MARZOL JAÉN, M. V.; MÁYER SUÁREZ, P. Algunas reflexiones acerca del clima de las Islas Canarias. **Nimbus: Revista de Climatología, Meteorología y Paisaje**, Almería, n. 29-30, p. 399-416, 2012.

MASSARELLI, C.; CAMPANALE, C. Climatic, bioclimatic, and pedological influences on the vegetation classification of "Bosco dell'Incoronata" in Southern Italy. **Rendiconti Lincei. Scienze Fisiche e Naturali**, Rome, v. 34, n. 2, p. 537-552, 2023. DOI: http://doi.org/10.1007/s12210-023-01146-4.

MAYER SUÁREZ, P.; LUQUE SÖLLHEIM, Á.L.; GARCÍA HERNÁNDEZ, F. **Atlas climático interactivo de Canarias de alta resolución espacial**: fuentes de datos, metodología y resultados. Canarias: Grupo de Geografía Física y Medio Ambiente de la ULPGC, Grafcan, SA y Consejería de Transición Ecológica Lucha contra el Cambio Climático y Planificación Territorial del Gobierno autónomo de Canarias, 2022.

MAYER SUÁREZ, P.; MARZOL JAÉN, V. **Análisis de la pluviosidad en las Islas Canarias mediante la elaboración de gradientes**. Palma de Mallorca: Universitat de les Illes Balears, 2013. p. 145-154.

MESQUITA, S.; SOUSA, A. J. Bioclimatic mapping using geostatistical approaches: Application to mainland Portugal. **International Journal of Climatology**, Chichester, v. 29, n. 14, p. 2156-2170, 2009. DOI: http://doi.org/10.1002/joc.1837.

MONTERO DE BURGOS, J. L.; GONZÁLEZ REBOLLAR, J. L. **Diagramas bioclimáticos**. Madri: Instituto Nacional para la Conservación de la Naturaleza (ICONA), 1974.

MOKARI, E. *et al*. Estimation of daily reference evapotranspiration with limited climatic data using machine learning approaches across different climate zones in New Mexico. **Theoretical and Applied Climatology**, Vienna, v. 147, n. 1-2, p. 575-587, 2022. DOI: http://doi.org/10.1007/s00704-021-03855-y.

MORALES MATOS, G.; PÉREZ GONZÁLEZ, M. **Gran atlas temático de Canarias**. Tenerife: Interinsular Canaria, 2000.

PADRÓN PADRÓN, P. A. *et al*. Evaluación de los suelos de la isla de El Hierro como recurso natural. I. Distribución ambiental. **Vieraea**, Santa Cruz de Tenerife, n. 19, p. 349-364. 1990.

PADRÓN PADRÓN, P. A. **Estudio edafoambiental de la isla de el hierro**. 1993. Tesis (Doctoral en Ciencias del Suelo) – Universidad de la Laguna, San Cristobal de la Laguna, 1993.

PEBESMA, E.; GRAELER, B. **Package "gstat"**. 2024. Disponible en: https://cran.r-project.org/web/packages/gstat/index.html. Accedido en: 2 Oct 2024.

PESARESI, S. *et al*. Bioclimate of Italy: application of the worldwide bioclimatic classification system. **Journal of Maps**, London, v. 10, n. 4, p. 538-553, 2014. DOI: http://doi.org/10.1080/17445647.2014.891472.

PHAM, T. M. *et al*. Application of the Worldwide Bioclimatic Classification System to determine bioclimatic features and potential natural vegetation distribution in Van Chan district, Vietnam. **Tropical Ecology**, Dehradun, v. 64, n. 4, p. 765-780, 2023. DOI: http://doi.org/10.1007/s42965-023-00300-1.

RIVAS MARTÍNEZ, S. Clasificación bioclimática de la Tierra. **Folia Botanica Matriensis**, Budapeste, n. 16, p. 29, 1995.

RIVAS MARTÍNEZ, S.; RIVAS SÁENZ, S.; PENAS, A. **Worldwide bioclimatic classification system**. Kerkwerve: Backhuys Pub, 2002.

SALVÀ CATARINEU, M. *et al*. On the detection of thermohygrometric differences of Juniperus turbinata habitat between north and south faces in the island of El Hierro (Canary Islands). *In*: EGU GENERAL ASSEMBLY CONFERENCE, 2016, Vienna, Austria. **Abstracts [...]**. Vienna: EGUsphere, 2016. v. 18.

SANTRA, P.; KUMAR, M.; PANWAR, N. Digital soil mapping of sand content in arid western India through geostatistical approaches. **Geoderma Regional**, Amsterdam, v. 9, p. 56-72, 2017. DOI: http://doi.org/10.1016/j.geodrs.2017.03.003.

SERRANO-NOTIVOLI, R.; LONGARES, L. A.; CÁMARA ARTIGAS, R. bioclim: an R package for bioclimatic classifications via adaptive water balance. **Ecological Informatics**, Amsterdam, v. 71, p. 101810, 2022. DOI: http://doi.org/10.1016/j.ecoinf.2022.101810.

STIERSTORFER, C. **The vascular plant vegetation in the forest belt of El Hierro (Canary Islands)**. Berlin: J. Cramer, 2005.

THORNTHWAITE, C. W. The climates of the earth. **Geographical Review**, Hoboken, v. 23, n. 3, p. 433-440, 1933. DOI: http://doi.org/10.2307/209629.

THORNTHWAITE, C. W. An approach toward a rational classification of climate. **Geographical Review**, Hoboken, v. 38, n. 1, p. 55-59, 1948. DOI: http://doi.org/10.2307/210739.

VEHTARI, A.; GELMAN, A.; GABRY, J. Practical Bayesian model evaluation using leave-one-out cross-validation and WAIC. **Statistics and Computing**, Amsterdam, v. 27, n. 5, p. 1413-1432, 2017. DOI: http://doi.org/10.1007/s11222-016-9696-4.

Author's contribution

Both authors contributed equally to this work.

Article editor

Gustavo Schacht, Sueli Angelo Furlan and Karine Vargas

Received: Oct. 15 2024
Accepted: Nov. 5 2024