COMUNICACIONES
REPORTS
COMUNICAÇÕES

EXPLORING CLIMATE VARIABILITY IN THE MATAQUITO RIVER BASIN OF THE MAULE REGION, CHILE: A SPECTRAL ANALYSIS APPROACH

Juan José Garcés-Gálvez, Alejandra Geraldi and Marcos Medina-Tapia

SUMMARY

The ecosystem services of freshwater provision and climate regulation depend on climate variability, so it is critical to understand climate variability to analyze the interaction between the natural and social systems. The Mataquito River basin, located in the Maule Region of Chile, transitions from mountainous terrain to coastal areas, giving rise to diverse landscapes, industrial activities, and microclimatic conditions. This work aimed to analyze the climatic variability in the Mataquito River Basin by applying spectral analysis techniques. The work method consists of three stages: (i) downloading and consolidation of meteorological data series; (ii) application of Fast Fourier Transform (FFT) and Wavelet techniques; and (iii) analysis of seasonal, annual, interannual, and decadal climate variability scales. The results indicate that there are seasonal, annual, and interannual variations. Finally, the lowest frequencies of the precipitation and temperature spectrum reflect phenomena with a typical duration of 3 to 7 years, coinciding with the duration of the El Niño-Southern Oscillation (ENSO) phenomenon.

Introduction

Ecosystems are regulated by independent factors (climate, material, topography, biota, weather, human activities) and by interactive factors (resource supply, microenvironment, disturbance regime, and types of organisms), with their stability and resilience depending on forces and interactions between negative stabilizing feedback and positive amplifying feedback (Chapin *et al*., 2011). Human reliance on ecosystem services underlines the need to understand the dynamics of these regulating and driving forces. The climatic variables of most excellent and most significant interest for the study of impacts are those that develop at the lowest levels of the atmosphere (Universidad de Chile, 2006). Indeed, understanding climate variability is fundamental to analyzing the interaction of the natural system and the social system, and interpreting the effects on activities, resources, population health, infrastructure, and services (Ferrelli *et al*., 2017). To understand the behavior of climate variables, the occurrence and intensity of their variations must be analyzed, depending on their location could be subject to diurnal, annual, or decadal temporal variations.

Harmonic analysis allows us to know and represent the fluctuations of meteorological data series, depending on their frequency domain. This type of technique allows us to see separately the contributions of processes that vary at different speeds to a time series (Wilks, 2020). Among this type of techniques, the Fourier

KEYWORDS / Chile / Climate Variability / Fast Fourier Transform / Maule / Time Series / Wavelets /

Received: 12/11/2023. Modified: 05/07/2024. Accepted: 05/09/2024.

Juan José Garcés-Gálvez. Doctoral student in Geography, Universidad Nacional del Sur (UNS), Argentina. Lecturer, Department of Geospatial and Environmental Engineering, Universidad de Santiago de Chile (USACH), Chile. e-mail: juan.garces@usach.cl.

Alejandra Geraldi. PhD in Geography, UNS, Argentina. Post-doctorate at the Department of Geoinformatics, Hydrology and Modeling, Friedrich-Schiller-University Jena, Germany. Independent Researcher at CONICET. Associate Professor at the Department of Geography and Tourism, UNS, Argentina. e-mail: ageraldi@criba.edu.ar.

Marcos Medina-Tapia (Corresponding author). Doctor in Transportation Engineering and Infrastructures, Universidad Politécnica de Cataluña (UPC), Spain. Assistant Professor, Department of Geospatial and Environmental Engineering, Universidad de Santiago de Chile (USACH), Chile. Address: Avenida Libertador Bernardo O'Higgins nº 3363, Estación Central, Santiago, Chile. e-mail: marcos.medina@usach.cl.

EXPLORANDO LA VARIABILIDAD CLIMÁTICA EN LA CUENCA DEL RÍO MATAQUITO DE LA REGIÓN DEL MAULE, CHILE: UN ENFOQUE DE ANÁLISIS ESPECTRAL

Juan José Garcés-Gálvez, Alejandra Geraldi y Marcos Medina-Tapia

RESUMEN

Los servicios ecosistémicos de provisión de agua dulce y regulación del clima dependen de la variabilidad climática, por lo que es fundamental comprender la variabilidad climática para analizar la interacción entre los sistemas naturales y sociales. La cuenca del río Mataquito, ubicada en la Región del Maule en Chile, presenta transiciones de terreno montañoso a zonas costeras, dando lugar a diversos paisajes, actividades industriales y condiciones microclimáticas. Este trabajo tuvo como objetivo analizar la variabilidad climática en la cuenca del río Mataquito mediante la aplicación de técnicas de análisis espectral. El método de trabajo consta de tres etapas: (i) descarga y consolidación de las series de datos meteorológicos; (ii) aplicación de las técnicas de Transformada Rápida de Fourier (FFT) y Wavelet; y (iii) análisis de las escalas de variabilidad climática estacional, anual, interanual y decadal. Los resultados indican que existen variaciones estacionales, anuales e interanuales. Por último, las frecuencias más bajas del espectro de precipitaciones y temperaturas reflejan fenómenos con una duración típica de 3 a 7 años, coincidiendo con la duración del fenómeno El Niño-Oscilación Austral (ENOS).

EXPLORANDO A VARIABILIDADE CLIMÁTICA NA BACIA DO RIO MATAQUITO DA REGIÃO DE MAULE, CHILE: UMA ABORDAGEM DE ANÁLISE ESPECTRA

Juan José Garcés-Gálvez, Alejandra Geraldi e Marcos Medina-Tapia

RESUMO

Os serviços ecossistêmicos de abastecimento de água doce e regulação climática dependem da variabilidade climática, portanto, é fundamental entender a variabilidade climática para analisar a interação entre os sistemas naturais e sociais. A bacia do rio Mataquito, localizada na região de Maule, no Chile, passa de um terrenos montanhosos e áreas costeiras, dando origem a diversas paisagens, atividades industriais e condições microclimáticas. Este trabalho teve como objetivo analisar a variabilidade climática na Bacia do Rio Mataquito aplicando técnicas de análise espectral. O método de trabalho consiste em três etapas: (i) download e consolidação de séries de dados meteorológicos; (ii) aplicação das técnicas de Transformada Rápida de Fourier (FFT) e Wavelet; e (iii) análise das escalas de variabilidade climática sazonal, anual, interanual e decadal. Os resultados indicam que há variações sazonais, anuais e interanuais. Por fim, as frequências mais baixas do espectro de precipitação e temperatura refletem fenômenos com duração típica de 3 a 7 anos, coincidindo com a duração do fenômeno El Niño-Oscilação Sul (ENSO).

---

transform stands out, which transforms the characteristics of a series in the frequency domain; thus, the series spectrum shows the contributions of the oscillations of a time series at various frequencies (Wilks, 2020). Also, allow the analysis of periodicities in the entire time-frequency domain (Berman, 2011).

The Mataquito River basin, located in the Maule Region of Chile, extends from latitude 34º50' in the north to latitude 35º30' in the south, and is characterized by its development from mountain range to coast, whose natural characteristics originate diverse landscapes, industrial activities, and microclimatic conditions, presenting a warm, sub-humid and coastal Mediterranean climate that benefits the existence and diversity of native vegetation, forest plantations, and agricultural development (Biblioteca del Congreso Nacional de Chile, 2020). Due to its, broad longitudinal development, this work aims to analyze the climatic variability in the Mataquito river basin by applying spectral analysis techniques. For this purpose, data were collected from meteorological stations located in the foothills, valley, and coast, to applying using two spectral analysis techniques to use two spectral analysis techniques to analyze climatic variability.

The following sections present the study area, materials, and methods. The findings show the variability of temperatures and precipitation in the Mataquito River basin. Finally, the paper presents the research's conclusions.

Materials and Methods

The following subsections detail the study area, data, and methods used.

Study area

Figure 1 shows the location of the Mataquito River basin in the context of the Maule Region, the river basin in the context of Maule Region; the area has a strong agroforestry vocation, in addition to a recent mining pressure due to its metallic and non-metallic potential (Aguilera, 2019). The Mataquito River has a mixed regime, with its main tributaries being the Teno and Lontué Rivers. It boasts a hydrographic basin covering an area of 6,200km². Within this region, the transition from mountainous terrain to coastal areas highlights the distinctive relief features of the country mountain range, intermediate depression, coastal mountain range, and coastal plains-presenting a warm, sub-humid, and coastal Mediterranean climate that benefits the existence and diversity of native vegetation, forest plantations and agricultural development (Biblioteca del Congreso Nacional de Chile, 2020). The population is distributed mainly in the central valley - intermediate depression - in urban centers and numerous small towns in rural areas. The delimitation of the study area responds to the hydrographic basins; it is important to note that the

basins do not entirely coincide with the regional political-administrative limits.

The region's warm, sub-humid, coastal Mediterranean climate benefits the existence and diversity of native vegetation, forest plantations, and agricultural development (Biblioteca del Congreso Nacional de Chile, 2020; Servicio Nacional de Geología y Minería, 2020). These characteristics configure different ecosystem services in which the regulation services are relevant in the study area and contribute to the maintenance and control of the climate due to the presence of the Mataquito River in the north of the region.

Materials

The data used in this study were collected from meteorological stations strategically located in various geographical areas, including the foothills, valleys, and coastal regions. These stations provide comprehensive coverage of meteorological variables across diverse terrains, enabling a thorough analysis of climate variability in the study area. Their location is shown in Figure 1, and their characterization is presented in Table I. The Chilean Meteorological Directorate (DMC) and the General Water Directorate (DGA) manage the meteorological stations. The variables recorded correspond to daily accumulated precipitation (mm) and daily average atmospheric temperature (°C). At the Licantén station, there are no temperature records. Data for the year 2023 has records up to October 12.

Method

For the analysis of climate variability in the meteorological stations of interest, the following steps were applied: i) the download and consolidation of the meteorological data series, for this purpose the meteorological data from each station were organized and consolidated; ii) the application of spectral analysis techniques, for each data series, the Fast Fourier Transform (FFT) and Wavelet were applied through programming in R language; and, iii) the analysis of seasonal, annual, interannual and decadal climate variability scales (Ferrelli *et al*., 2017). Spectral analysis techniques have been applied in a wide variety of studies to detect the recurrence of phenomena, such as the environmental and social consequences of climate in a region to guide territorial planning policies (Ferrelli *et al*., 2017); the influence of climate on carbon exchange in primary forests (Wharton *et al*., 2016); remote forcings and their influence on the air, water, and sediment temperature of a tidal flat (Beigt *et al*., 2009); and in the analysis of the influence of the leading climate drivers on drought events (Araneda-Cabrera *et al*., 2021).

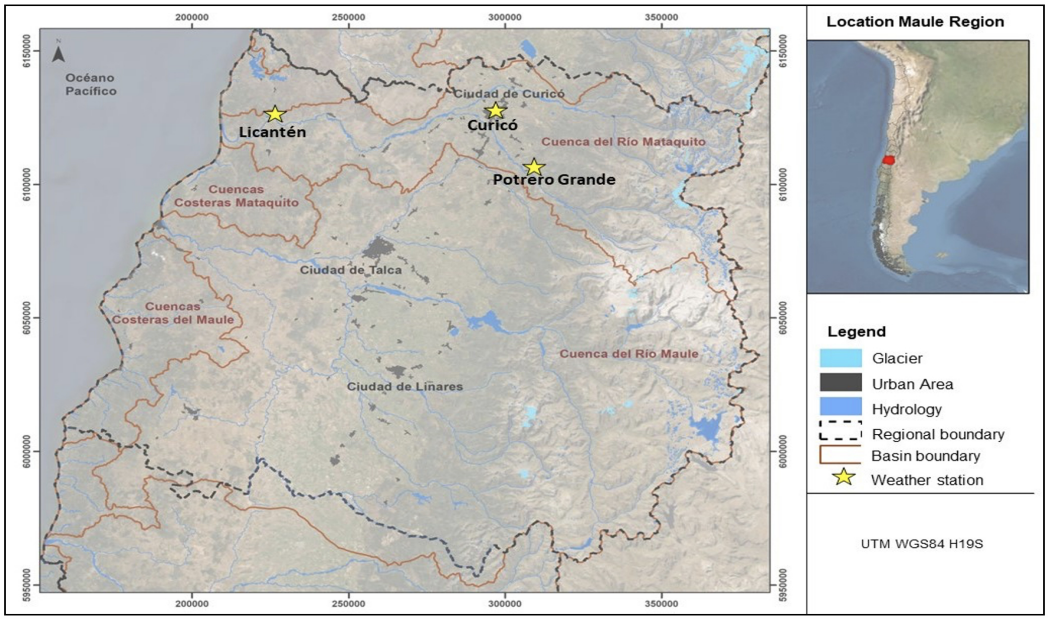

Figure 1. River basin - northern sector - The study area and the location of the Mataquito River basin - northern sector - are in the context of the Maule Region of Chile. Source: Own elaboration.

Results and Discussion

The following subsections present the variability of temperatures and precipitation in the Mataquito River basin. In the case of the periodogram plots (Fast Fourier Transform (FFT)), the peak values indicate the typical length of the pseudocycles that can be associated with a phenomenon or event. In contrast, the Wavelet plots highlight the variation of the phenomena in the series of years in greater intensity.

Atmospheric temperature

The highest intensity of the temperature spectral signal is

TABLE I
METEOROLOGICAL STATIONS RIVER BASIN IS LOCATED IN THE MATAQUITO RIVER BASIN

ID	Station	Sector	Manager	Height (msl)	Coordinates		Daily accumulated precipitation (mm)		Average daily temperature (°C)	
					°S	°O	Average	Period	Average	Period
1	Potrero Grande	Cordillera	DGA	445	35.2	71.1	2.9	1971-2023	12.8	1975-1993
2	Curicó	Valle	DMC	225	34.9	71.2	1.8	1958-2023|	13.7	1964-2001
3	Licantén	Costa	DGA	20	35.0	72.0	1.7	2001-2023	ND	ND

ND: No Data. Source: Own elaboration based on data declared by station managers.

seen in the annual cycle (365 days). There is also an interseasonal variation around 180 days, a seasonal variation around 90 days, and an interannual variation (~1000 days). There is no marked synoptic variation. Regarding periodicity, it is appreciated that, in the case of the station located in the valley (Curicó), there was a slight shift of the annual component in 1972 and 1996, coinciding with the interannual variation close to (≈1000 days); while in the station in the foothills (Potrero Grande) there was a similar shift of the annual component in 1984 (Figure 2). The change is reflected in an anomaly in the time series of the station in the mountain range, but not in the time series of the station in the valley.

Precipitation

The highest intensity of the precipitation spectral signal is seen in the annual cycle (365 days). There is also an interseasonal variation around 180 days, an interannual variation (~1000 days) and synoptic variation (<30 days). The synoptic variations are more clearly observed at the stations along the coast (Licantén) and the mountain range (Potrero Grande). Additionally, they exhibit a very pronounced intensity in the indicated variations. Regarding periodicity, in addition to the annual pattern, it can be seen that: a) in the case of the station located in the valley, there are events with high intensity with a period of 3 to 10 years; b) in the case of the coast, an event with a period of 3 years in 2008; c) in the case of the mountain range, there are high intensities in a dispersed manner, but there is a phenomenon with a period of every 3 years (Figure 3).

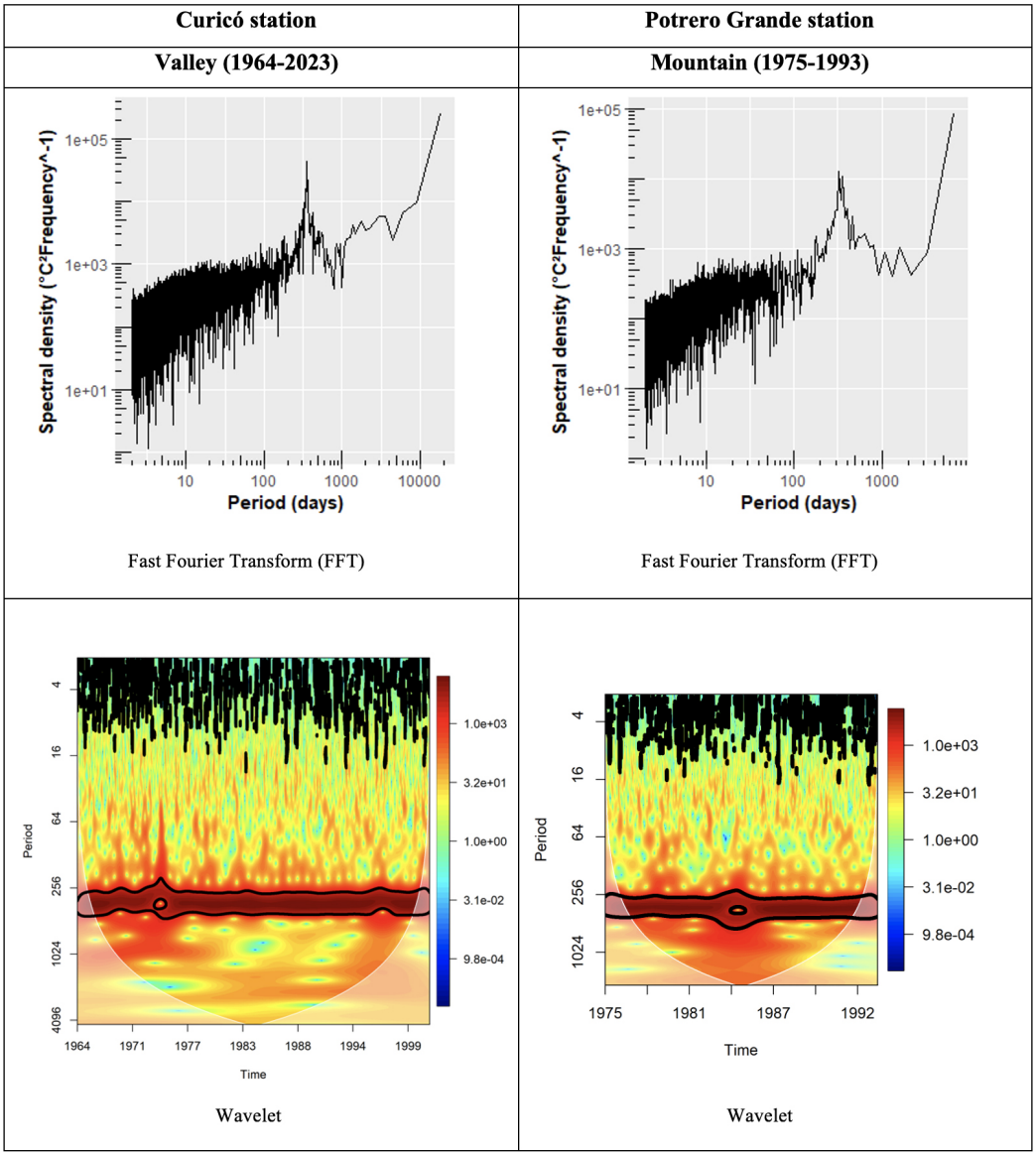

Figure 2. Spectral density of daily temperature using Fast Fourier Transform (FFT) and Wavelet, Curicó Station, and Potrero Grande Station. Source: Own elaboration.

Conclusions

The climatic variability in the Mataquito River basin, in terms of temperature, the valley and foothill stations register intensities that coincide with the annual (365 days), seasonal (~90 days), and interannual (~1000 days) components. In the case of both stations, the lowest frequencies of the spectrum reflect phenomena with a typical duration of 3 to 7 years, coinciding with the duration of the El Niño-Southern Oscillation (ENSO) phenomenon. The wavelet plot for the valley station (Curicó) shows that the annual component shift occurs every 22 years. In the case of the yearly component shift, a more exhaustive analysis of the local conditions of the sector and the phenomena that originated it is necessary.

Regarding precipitation, differences were observed between the locations of the stations, with more significant variability in the stations located on the coast and in the foothills. The annual and interannual components were observed in the case of temperature still, a synoptic variation (<30 days) was added in the coastal and mountain range stations. As in the previous case, the lowest frequencies of the spectrum reflect phenomena with a typical duration of 3 to 7 years, coinciding with the duration of the El Niño-Southern Oscillation (ENSO) phenomenon. The Wavelet plot reinforces this aspect.

Climate variability within the Mataquito River basin exhibits notable variations across different temporal scales and geographical locations. The observed patterns can contribute significantly to planning activities, resources, infrastructure, and services within the Mataquito River basin. Understanding these variations is essential for informed decision-making regarding water

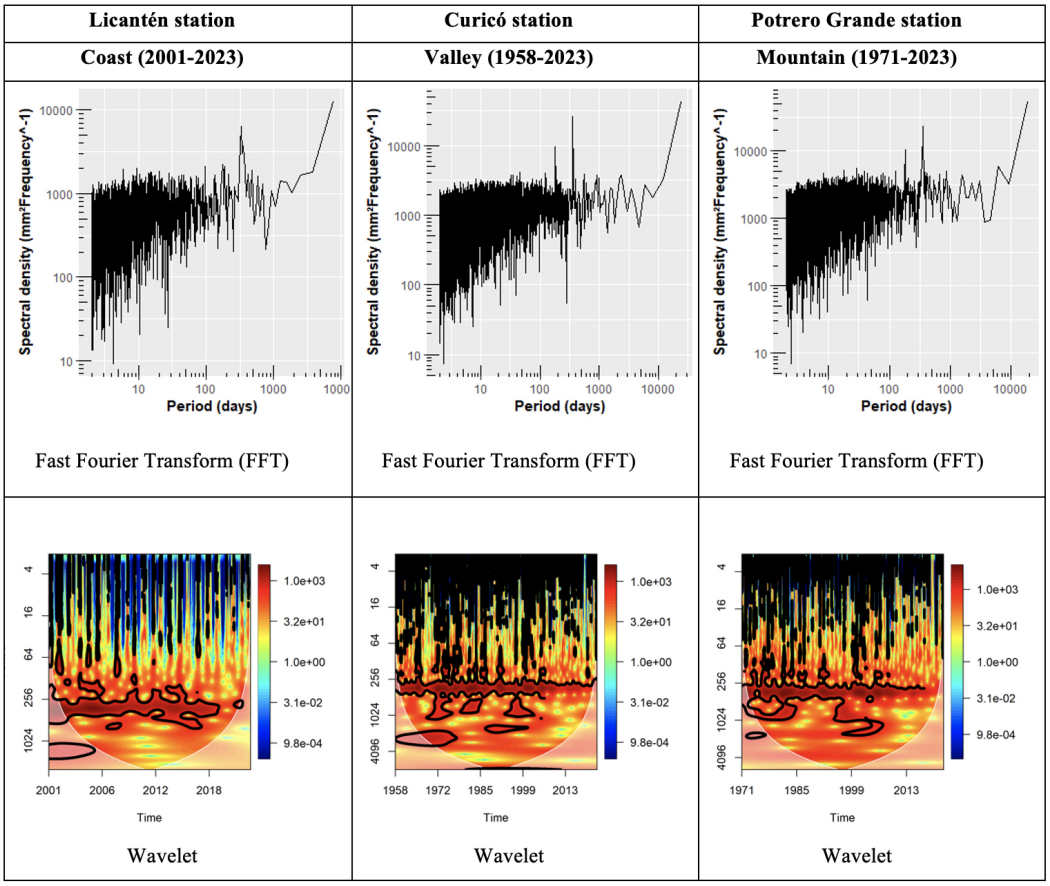

Figure 3. Spectral density of daily precipitation using the Fast Fourier Transform (FFT) and Wavelet. Licantén Station, Curicó Station, and Potrero Grande Station. Source: Own elaboration.

management, land use planning, and adaptation strategies to mitigate the impacts of climate change on the basin's ecosystems and communities. By recognizing and analyzing these patterns, stakeholders can develop more resilient and sustainable approaches to addressing the challenges posed by climate variability in the region.

For future studies, it is recommended to analyze the teleconnection with indicators of larger-scale climatic phenomena such as El Niño and the Pacific Decadal Oscillation, and the influences of topo climatic effects and local conditions. Furthermore, it would be desirable to have a more significant number of meteorological stations. Along these lines, further analysis should be carried out regarding orography, location, wind pattern analysis, and land use.

ACKNOWLEDGMENTS

This publication is part of the Project "Aplicación de Tecnologías de la información Geográfica al estudio integral y comparativo de problemáticas ambientales-Cod: 24/ZG14". CONICET, Argentina, and the Departamento de Ingeniería Geoespacial y Ambiental (DIGEA) and the Facultad de Ingeniería (FING) from Universidad de Santiago de Chile (USACH), Chile.

REFERENCES

Aguilera E (2019) ¿Minería en la Región del Maule? También es posible. *Revista Nueva Minería & Energía 119*: 43-44.

Araneda-Cabrera RC, Bermudez M, Puertas J (2021) Revealing the spatio-temporal characteristics of drought in Mozambique and their relationship with large-scale climate variability. *Journal of Hydrology: Regional Studies 38*: 2-16.

Beigt D, Piccolo MC (2009) Tendencia de la temperatura en una planicie de marea del estuario de Bahía Blanca (período 2000-2007). *Investigaciones geográficas 48*: 253-271.

Berman AL (2011) *Análisis de la variabilidad climática en la Patagonia Argentina*. Universidad de Buenos Aires, Argentina. 187 pp.

Biblioteca del Congreso Nacional de Chile (2020) I*nformación territorial, Región del Maule*. Biblioteca del Congreso Nacional de Chile, Chile. 17 pp.

Chapin S, Matson P, Vitousek P (2011) *Principles of Terrestrial Ecosystem Ecology*. Springer New York. Nueva York, EE. UU. 529 pp.

Ferrelli F, Luján ML, Piccolo MC (2017) Variabilidad climática temporal y sus efectos: aportes al ordenamiento territorial de la costa norte del estuario de Bahía Blanca (Argentina). *Revista Universitaria de Geografía 26*: 79-96.

Servicio Nacional de Geología y Minería (2010) *Peligro de inundación por tsunami e inundación por desborde de cauces. Área de Duao-Iloca*. Santiago, Chile. 30 pp.

Universidad de Chile (2006) *Estudio de la variabilidad climática en Chile para el siglo XXI*. Universidad de Chile. Santiago, Chile. 71 pp.

Wharton S, Flak M (2016) Climate indices strongly influence old-growth forest carbon exchange. *Environmental Research Letters 11*: 2-11.

Wilks D (2020) *Statistical Methods in the Atmospheric Sciences*. Springer New York. Nueva York, EE.UU. 818 pp.