Revista de Climatología

Vol. 24 (2024): 01-08 ISSN 1578-8768

Recurrence of Intense winds and precipitation in the Rio Negro Hydrographic lower Basin (Argentina)

Grethel García Bu Bucogen[1]

[1] *Instituto Argentino de Oceanografía (CONICET-UNS). Bahía Blanca, 8000, Buenos Aires, ARGENTINA.*

Corresponding author: Grethel García Bu Bucogen, grethelgbb@gmail.com

(Recibido: 18-02-2024. Publicado: 21-06-2024.)

DOI: 10.59427/rcli/2024/v24.01-08

Abstract

The aim of the study is to analyze return periods and understand the occurrence of intense winds and precipitation in the Rio Negro hydrographic lower basin, in order to enhance the understanding of flood-related risks in the region. Precipitation and wind data were obtained from the NASA POWER project database and the Viedma Aero meteorological station of the National Meteorological Service. Return periods were calculated for both rainfall and intense winds using the Gumbel statistical distribution at a 95% confidence level. Results show predominant winds from the northwest, north, and north-northwest, with a more recurrent regime of moderate breeze. The analysis of Maximum Probable Precipitation (PMP) demonstrated that the highest rainfall occurs eastward of the basin, with a probability of daily precipitation exceeding 60 mm every two decades. Additionally, the occurrence of intense south winds is observed to potentially favor flood production approximately every 10 years. The findings of this research contribute to a better understanding of the risks associated with extreme rainfall and wind events, thereby facilitating the planning of mitigation and adaptation measures.

Keywords: *wind, precipitation, meteorological extreme event, flood, return period.*

Resumen

El objetivo del trabajo es analizar los períodos de retorno y comprender la producción de vientos y precipitaciones intensas en la cuenca hidrográfica inferior del río Negro, con el fin de mejorar la comprensión de los riesgos asociados a las inundaciones en la región. Se analizan datos de precipitación y viento obtenidos de la base de datos del proyecto POWER de la NASA y de la estación meteorológica Viedma Aero del Servicio Meteorológico Nacional. Se calculan los períodos de retorno tanto para lluvias como para vientos intensos a través de la distribución estadística de Gumbel al 95% de nivel de confianza. Los resultados muestran vientos predominantes del noroeste, norte y nornoroeste, con un régimen más recurrente de brisa moderada. El análisis de la Precipitación Máxima Probable (PMP) demostró que las mayores precipitaciones suceden hacia el este de la cuenca, con una probabilidad de precipitación diaria superior a 60 mm cada dos décadas. Además, se observa que la ocurrencia de vientos intensos del sur puede favorecer la producción de inundaciones aproximadamente cada 10 años. Los resultados de esta investigación contribuyen a una mejor comprensión de los riesgos asociados con eventos extremos de lluvia y viento, y facilitando la planificación de medidas de mitigación y adaptación.

Palabras claves: *viento, precipitación, evento meteorológico extremo, inundación, período de retorno.*

1 Introduction

Globally, a remarkable increase in the frequency of severe floods has been recorded, with climate variability being a determining factor in this phenomenon (IPCC, 2021; Falco et al., 2014). The close connection between seasonal rainfall patterns, snowmelt, and the thermal regime, which regulates evaporation, has been identified as crucial to understanding the occurrence of floods (Vich et al., 2014; Romero and González, 2016; Arguello Murillo et al., 2016). Research on precipitation, its variability, and trends is vital for assessing the probability of flood-related disasters, especially in a context of increasing frequency and intensity of global precipitation (Fenoglio, 2019).

Numerous studies worldwide have examined climate variability and its impact on the hydrological cycle, highlighting the importance of understanding these fluctuations (Trenberth et al., 2007; Guirado and López Bermúdez, 2011; Peña Rabadán, 2015; Sedano Cruz, 2017; Rabuffetti, 2018; Fenoglio, 2019; Kundzewicz and Pińskwar, 2022). The increase in precipitation frequency and intensity has triggered severe floods in various regions worldwide. In Europe, an increase in the probability of flash floods is anticipated due to the increasing intensity of precipitation (Dankers and Feyen, 2008). North America has experienced an increase in rainfall, tripling flood disasters in the last three decades (Kirchmeier Young and Zhang, 2020). In South America, 70% of flood events between 1951 and 2010 are attributed to the increase in rainfall patterns (Alifu et al., 2022).

At the national level, research on climate variability and extreme hydrometeorological events is limited, particularly in the Argentine Patagonia (Paruelo et al., 1998; Garreaud et al., 2009; Bianchi, 2016; Romero and González, 2016). In the northern Argentine Patagonia, a positive trend in annual temperature has been observed in the last three decades, although the temporal evolution of precipitation series is disputed (Romero et al., 2014; Camilloni, 2018; Brendel et al., 2020; Pessacg et al., 2022). Due to the historical vulnerability of the lower sector of the Rio Negro (RN) hydrographic basin to river floods, attributed to low atmospheric pressures, strong winds obstructing drainage to the sea, and intense precipitation, this study proposes analyzing precipitation trends and calculating return periods for both rainfall and strong winds. This aims to enhance comprehension of the flood risks associated with high wind speeds in the region.

Study Area

The study area is the Rio Negro hydrographic lower basin (RNhlb) (Figure 1a). According to the delineation performed by Soldano (1947) and Atlas de Cuencas y Regiones Hídricas Superficiales de la República Argentina of the Subsecretaría de Recursos Hídricos (SSRH, 2010), the sector extends from the river mouth in the Atlantic Ocean to Segunda Angostura, between 40°-41° S and 63°-64° W, in the NE of Argentine Patagonia (Figure 1.1c). Its surface area covers approximately 3000 km^2 and its orientation is NW-SE.

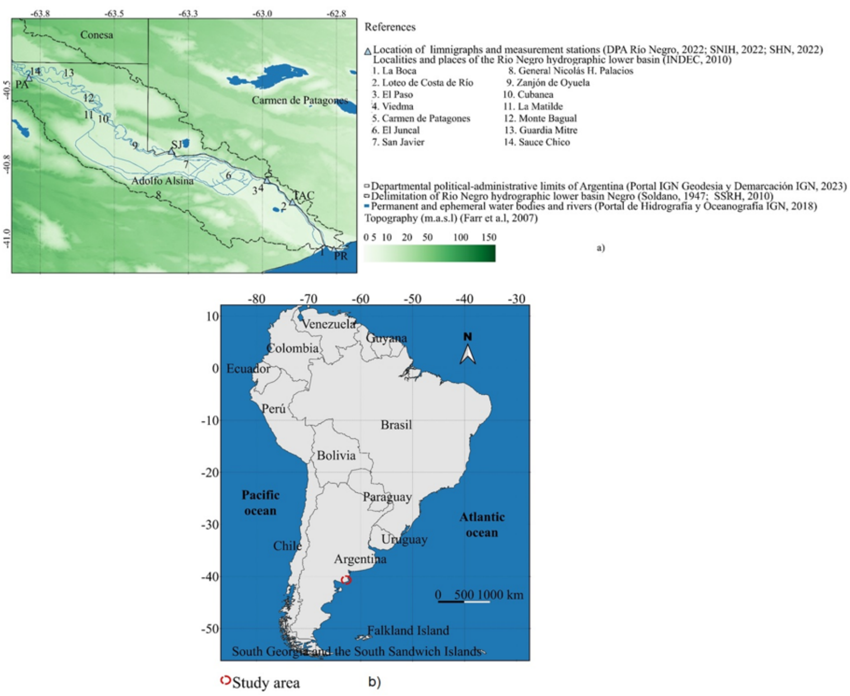


Figure 1: Study Area: a) Río Negro hydrographic lower basin of the, b) Relative location of the study area in the Republic of Argentina. Prepared based on data from Soldano (1947), Farr et al. (2007), SSRH (2010), INDEC (2010), and IGN (2018 and 2022).

The RN is located in the northern sector of its lower hydrographic basin (AIC, 2020) and features an allochthonous channel (AIC, 2020). The river's design in its lower stretch is meandering anastomosed, with abandoned channels, islands, and temporary lagoons (Luchsinger, 2006; Prates, 2008). The mean gauged flow of the river is 1020 m^3 s^{-1} and exhibits no significant seasonal variations (Gianola Otamendi, 2019). The channel width varies from 194 m at Primera Angostura to 300 m at the mouth during low-water periods (Prates et al., 2019).

The soils in the study area belong to the Entisol and Aridisol orders, according to the Soil Taxonomy (2006), characterized by moderate to poor drainage (Pereyra, 2012). Topographical features, permeability, surface runoff, vegetation cover, and precipitation make the soils of the RNhlb prone to water and wind erosion, as well as degradation due to overgrazing (Panigatti, 2010). The northern region of the basin features cliffs and terraces in its relief, while the southern region exhibits flat landforms with slopes less than 3%, interspersed with plateaus and saline ridges sometimes exceeding 2 m above sea level (ECYT-AR, 2014). At the river mouth in the Atlantic Ocean, banks form, creating an open reflux delta (Piccolo and Perillo, 1999).

The climatology of the RNhlb is influenced by atmospheric circulation and topography, with the semi-permanent anticyclones of the South Atlantic and South Pacific and the subpolar low-pressure belt being the predominant synoptic systems (Coronato et al., 2017). The annual precipitation regime does not exceed 400 mm and is controlled by the seasonal migration of storm tracks (Bianchi, 2016). The wind regime is determined by the position of the South Atlantic anticyclone, which varies seasonally, with prevailing winds from the NE and E in summer and from the W in winter (Coronato et al., 2017). The combination of a high-pressure center and cyclones originating in north-central Argentina produces "Sudestadas," strong winds from the S and SE that occasionally cause floods (SMN, 1989; García, 2011). These climatic conditions confer arid and semi-arid characteristics to the RNhlb, classified as temperate semi-arid according to Köppen-Geiger, with the northern sector in the arid diagonal and the southern sector in the Monte plains and plateaus ecoregion (Morello et al., 2012; Gentile et al., 2020).

In the lower sector of RN are the administrative units of Adolfo Alsina and Conesa (Province of Río Negro), as well as Carmen de Patagones (Province of Buenos Aires). Loteo Costa de Río (665 inhabitants), El Juncal (83 inhabitants), San Javier (530 inhabitants), Guardia Mitre (856 inhabitants), and Viedma and Carmen de Patagones cities (73,322 inhabitants) are localized in the study area (Figure 1.1b). In total, the resident population according to the 2010 Census was 77,910 people (INDEC, 2010), with the region historically experiencing the highest population growth in the Viedma-Carmen de Patagones area (INDEC, 2001; 2010; 2022). The economic activity in the study area is characterized by the predominance of intensive agricultural activities under irrigation and livestock farming (Brailovsky, 2012).

2 Methodology

The precipitation data used in this study were acquired from the NASA POWER project reanalysis database (2021). García Bu Bucogen et al. (2022) validated this meteorological dataset for the study area. These data were obtained through the analysis of a 15-point grid with a spatial resolution of 0.5°, as illustrated in Figure 2. Information on the wind regime was extracted from the Viedma Aero station (40°52'00" S and 63°00'00" W) of the National Meteorological Service (SMN) for the period from 1981 to 2020, covering 40 years and using tri-hourly wind speed and direction data (SMN, 2021) (Figure 2).

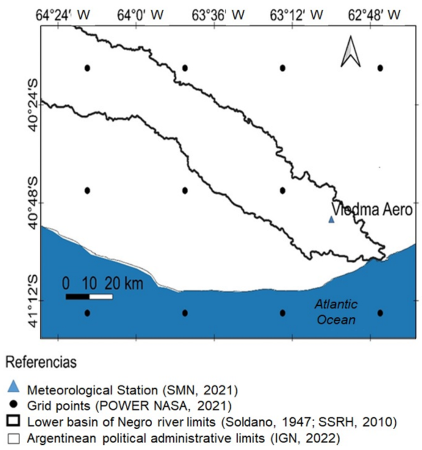


Figure 2: Location of the Viedma Aero measurement station and grid of data points from the NASA POWER Project reanalysis. Prepared based on data from SMN (2021) and the NASA POWER Project (2021).

To analyze the wind regime in the study area, the wind rose was examined, and the Beaufort scale classification was applied. The recurrence of intense winds, defined as wind speeds equal to or greater than 40 km/h (SMN, 2023), was determined using the Gumbel statistical distribution function. This statistical distribution is commonly used in probability and statistics to model maximum wind speeds and their return periods (Gumbel, 1941). The function was adjusted according to the methodology detailed by Mayo and Mitrani (2022) calculated at a 95% confidence level (Equation 1).

$$(x) = \exp\left[\exp\left[\frac{x-B}{A}\right]\right] \tag{1}$$

Where the coefficients are defined as follows: A = 0.779s and B = x - 0.45s. In this case, x represents the mean and s the standard deviation. The return period (Pr) is calculated according to the following expression (Mayo and Mitrani, 2022) (Equation 2):

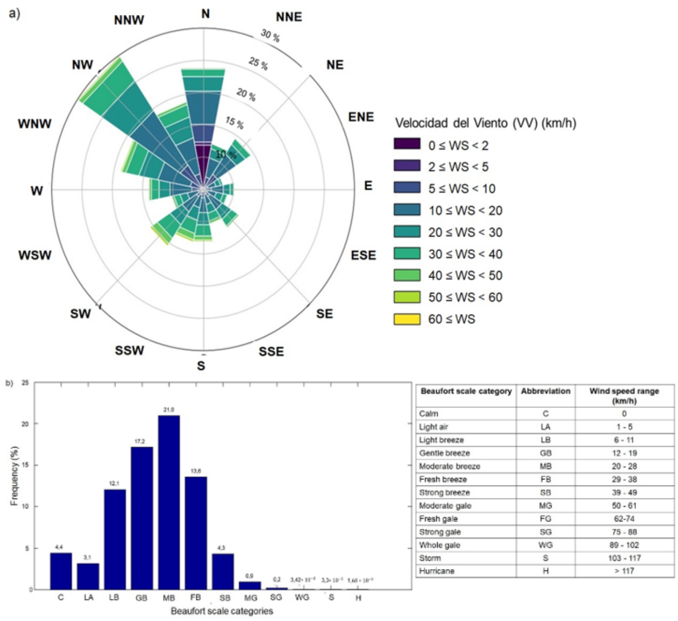
$$RP = \frac{1}{1-P_a} \tag{2}$$

Where RP and P_a are the return period in years and the cumulative probability.

A probable maximum precipitation (PMP) analysis was conducted using the series of maximum annual precipitation in 24 hours recorded at the grid points of the NASA POWER project (2021) (Figure 2). This analysis covered return periods ranging from 2 to 50 years. The quantification of extreme precipitation values was performed by applying the Gumbel statistical distribution using the method of moments. For this purpose, linear combinations of weighted probability moments were employed, following the methodology described by Lorente Casteló et al. (2013).

3 Results and discussion

The wind rose analysis for the period between 1981 and 2020 (SMN, 2021) revealed that the predominant winds recorded by the Viedma Aero weather station were from the northwest (NW), north (N), and north-northwest (NNW) directions (Figure 3a). According to the Beaufort scale, the most recurrent wind regime was classified as moderate breeze (MB), with speeds ranging from 12 to 19 km/h (Figure 3b). The results obtained are consistent with previous studies. The influence of air masses in the study area varies according to the seasons in Argentina (Bianchi and Cravero, 2010). The predominant winds at the Viedma Aero station, analyzed during the period 1981-2020, were from the northwest (NW), north (N), and north-northwest (NNW) directions (Figure 3a), consistent with studies by Coronato et al. (2017) and Gentile et al. (2020). These patterns are related to the position of the South Atlantic anticyclone, shifting southward in winter and northward in summer (Ramos and Campos, 2008).



Beaufort scale category	Abbreviation	Wind speed range (km/h)
Calm	C	0
Light air	LA	1 - 5
Light breeze	LB	6 - 11
Gentle breeze	GB	12 - 19
Moderate breeze	MB	20 - 28
Fresh breeze	FB	29 - 38
Strong breeze	SB	39 - 49
Moderate gale	MG	50 - 61
Fresh gale	FG	62-74
Strong gale	SG	75 - 88
Whole gale	WG	89 - 102
Storm	S	103 - 117
Hurricane	H	> 117

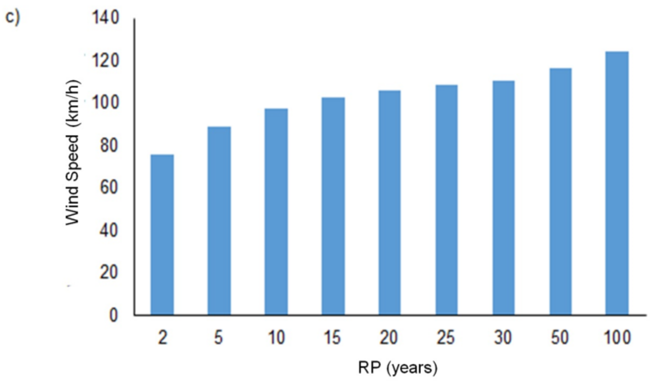


Figure 3: Wind rose and wind regimes at Viedma Aero (period 1981 - 2020): a) wind rose, b) frequent wind regimes according to the Beaufort scale, c) extreme wind speed values and their return periods through the calculation of the Gumbel distribution function. Prepared based on SMN data (2021).

The frequency of occurrence of south (S), southwest (SW), southeast (SE), and east (E) winds was 5%, 7%, 5%, and 3%, respectively (Figure 3a). It is worth noting that the recurrence of storms with winds exceeding 40 km/h was low, as only 5.5% of the records exceeded this threshold (Figure 3b). Estimates based on the Gumbel statistical distribution indicate that there is a probability of at least 10% every 10 years of recording wind speeds exceeding 95 km/h, while there is a probability of wind speeds exceeding 75 km/h every two years. It is estimated that in exceptional events that occur approximately once every 100 years, wind speeds could exceed 120 km/h (Figure 3c).

According to the analysis of the PMP based on daily data from the NASA POWER Project (2021), a longitudinal gradient in precipitation was observed, with precipitation likely to be more intense in the eastern sector and near the coast (Figure 4). This behavior was observed for all calculated return periods. The maps corresponding to the 2- and 5-year return periods did not show notable spatial differences (Figures 4a and b). PMP increased from 30 mm in the west to 60 mm in the east. For the 10-year return period (Figure 4c), a core of intense precipitation was visualized in the northeastern zone of the study area. This behavior persisted for return periods of 20 and 50 years (Figures 4d and e).

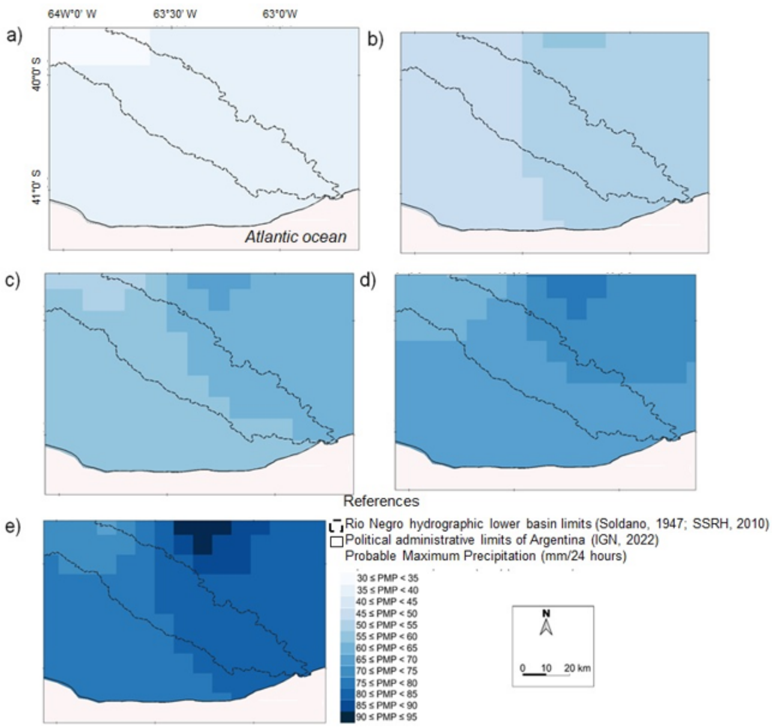


Figure 4: Spatial distribution of Probable Maximum Precipitation (mm/24 hours) according to different return periods: (a) 2 years, (b) 5 years, (c) 10 years, (d) 20 years, (e) 50 years. Prepared based on data from the NASA POWER Project (2021).

The spatial distribution of PMP values in the study area (Figure 4) is consistent with the annual precipitation distribution reported by Bianchi and Cravero (2010). PMP values are higher in the eastern part of the study area. The results showed that, for return periods of 2, 5, 10, 20, and 50 years, PMP in 24 hours can exceed 30, 50, 60, 70, and 80 mm, respectively. The values found in the analysis exceed those reported by Desinventar (2021), where intense precipitation of 30 mm in 24 hours caused flooding on the Viedma waterfront in 1976.

4 Conclusions

Understanding the Probable Maximum Precipitation in 24-hour periods and its frequency is crucial for assessing flood risks. The analysis reveals higher PMP values towards the eastern part of the RNhlb. With a return period of every two decades, there is a likelihood of daily precipitation exceeding 60 mm. Moreover, with a return period of 50 years, these values would likely surpass 70 mm. Such intense rainfall events, especially exceeding 50 mm in 24 hours, pose a heightened risk of water saturation, particularly in areas with limited drainage capacity.

In addition to precipitation patterns, the presence of strong south winds emerges as a significant climatic factor influencing flood occurrences in the study area. While the recurrence of winds capable of triggering floods remains low, there exists a probability that intense winds could contribute to flood events approximately every 10 years.

5 References

Alifu H, Hirabayashi Y, Imada, Y, Shiogama, H (2022): Enhancement of river flooding due to global warming. Sci Rep, 12(1), 20687. doi: 10.1038/s41598-022-25182-6.

Arguello Murillo FP, González Santiago SM, Silva Rondón MM (2016): Variabilidad climática estacional e interanual de la precipitación y la temperatura de la cuenca del Río de Oro, área metropolitana de Bucaramanga, Santander. [Tesis de grado Ingeniería]. Unidades Tecnológicas De Santander.

Brailovsky AE (2012): Viedma, la capital inundable (primera parte).

Bianchi AR, Cravero SAC (2010): Atlas Climático Digital de la República Argentina. Ediciones Instituto Nacional de Tecnología Agropecuaria.

Bianchi E (2016): Dinámica espacio – temporal de la relación entre el clima y el funcionamiento de los ecosistemas de Patagonia Norte. [Tesis Doctoral]. Universidad Nacional de COMAHUE. Centro Regional Universitario Bariloche.

Brendel AS, del Barrio RA, Mora F, Orrego León EA, Rosales Flores J, Camoy JA (2020): Potencial agroclimático actual de la Patagonia moldeado por patrones térmicos e hídricos. Theoretical and Applied Climatology, 142, 855–868.

Camilloni I (2018): Argentina y el cambio climático. Ciencia e investigación, 68 (5).

Coronato A, Mazzoni E, Vazquez M, Coronato F (2017): Patagonia. Una síntesis de su Geografía Física. Río Gallegos: Ediciones Universidad Nacional de la Patagonia Austral. ISBN — 978-987-3714-40-5.

Dankers R, Feyen L (2008): Climate change impact on flood hazard in Europe: An assessment based on high resolution climate simulations. Journal of Geophysical Research, 113, D19105

DesInventar (2021): Inventario de desastres.

ECYT-AR (2014): Instituto de Desarrollo del Valle Inferior del Río Negro Comandante Luis Piedra Buena. La enciclopedia de ciencias y tecnologías en Argentina.

Falco M, Araujo P, Flombaum P, Carril AF (2014): Control de la precipitación en la variabilidad del ciclo del carbono en el noroeste de la Patagonia argentina. Congreso Argentino de Meteorología. Septiembre de 2018.

Farr TG, Rosen PA, Caro E, Crippen R, Duren R, Hensley S, Kobrick M, Paller M, Rodríguez E, Roth L, Seal D, Shaffer S, Shimada J, Umland J, Werner M, Oskin M, Burbank D, Alsdorf D (2007): The Shuttle Radar Topography Mission. Rev. Geophys., 45 (2), 1-33.

Fenoglio EP (2019): Inundaciones urbanas y cambio climático : recomendaciones para la gestión - 1a ed mejorada. - Ciudad Autónoma de Buenos Aires : Secretaría de Ambiente y Desarrollo Sustentable de la Nación. ISBN 978-987-47402-6-7.

García M C (2011): Escenario de riesgo climático por sudestadas y tormentas en Mar del Plata y Necochea - Quequén, provincia de Buenos Aires, Argentina. Brazilian Geographical Journal: Geosciences and Humanities research medium, 2 (2), 286-304.

García Bu Bucogen G, Piccolo MC, Bohn VY (2022): Implementación de datos meteorológicos modelados en el norte patagónico argentino (1982-2017). Investigaciones Geográficas, (78), 67–87.

Garreaud RD, Vuille M, Compagnucci R, Marengo J (2009): Present-day South American climate. Palaeogeography, Palaeoclimatology and Palaeoecology, 281(3–4), 180– 195.

Gentile E, Martin P, Gatti I. (2020): Argentina físico-natural: Clima en Argentina. ANIDA. Atlas Nacional Interactivo de Argentina. Instituto Geográfico Nacional.

Gianola Otamendi A (2019): El Río Negro. Su uso como vía navegable. Boletín del Centro Naval, 851, 173 – 174. 851-GIANOLA-RIO-NEGRO.pdf (centronaval.org.ar)

Guirado SG, López Bermúdez F (2011): Tendencia de las precipitaciones y temperaturas en una pequeña cuenca fluvial del sureste peninsular semiárido. Boletín de la Asociación de Geógrafos Españoles, 56, 349 – 371.

Gumbel E (1941): The return period of flood flows. The annals of mathematical statistics, 12(2), 163-190.

INDEC (2010): Mapas temáticos Censo 2010 (GEOCENSO).

INDEC (2013): Definiciones de los indicadores del Censo Nacional de Población Hogares y Viviendas 2010. Base de Datos REDATAM.

INDEC (2022): Censo 2022: resultados provisorios. Instituto Nacional de Estadística y Censos (INDEC).

IPCC (2021): Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.Jiménez-Jiménez, S. I., Ojeda-Bustamante, W., InzunzaIbarra, M. A. y Marcial-Pablo, M. J. (2021). Analysis of the NASA-POWER system for estimating reference evapotranspiration in the Comarca Lagunera, Mexico. Ingeniería Agrícola y Biosistemas, 13(2), 201-226.

Kirchmeier Young MC, Zhang X (2020): Human influence has intensified extreme precipitation in North America. Earth, Atmospheric, And Planetary Sciences, 117 (24), 13308 – 13313.

Kundzewicz ZW, Pińskwar I (2022): Are Pluvial and Fluvial Floods on the Rise? Water, 14, 2612.

Lorente Casteló J, Casas Castillo MC, Rodríguez Solà R, Redaño A (2013): Intensidades extremas y precipitación máxima probable. In book: Fenómenos meteorológicos adversos en España (pp.142-155). Chapter: Intensidades extremas y precipitación máxima probable. Editors: AMV Ediciones.

Luchsinger H (2006): The late Quaternary landscape history of the middle rio Negro valley, Northern Patagonia, Argentina: Its impact on preservation of the archaeological record and influence on Late Holocene human settlement patterns. Tesis Doctoral, AyM Texas University, Texas. (Inédito)

Mayo AH, Mitrani Arenal I (2022): Período de retorno de las inundaciones costeras en el archipiélago cubano. Ingeniería Hidráulica y Ambiental, XLIII(1), 3-11.

Morello J, Matteucci, SD, Rodríguez AF, Silva M. (2012): Ecorregiones y complejos ecosistémicos Argentinos. Buenos Aires: Orientación Gráfica Editora S.R.L. ISBN: 978-9-871922-00-0.

Panigatti JL (2010): Argentina: 200 años, 200 suelos. Ediciones INTA. ISBN Nº 978-987-1623-85-3

Paruelo J, Beltrán AB., Jobbágy E, Sala OE, Golluscio R (1998): The climate of Patagonia: General patterns and controls on biotic processes. Ecologia Austral, 8. 85-101.

Peña Rabadán JC (2015): La reconstrucción de la dinámica fluvial y su conexión con la variabilidad climática a partir de fuentes documentales y registros instrumentales. Universidad de Barcelona.

Pereyra FX (2003): Ecoregiones de la Argentina. Anales 37. 208 p. y 1 mapa. Buenos Aires, Servicio Geológico Minero Argentino.

Pessacg N, Flaherty S, Solman S, Pascual M (2020): Climate change in northern Patagonia: critical decrease in water resources. Theorical and Applied Climatology, 140, 807–822.

Piccolo MC, Perillo GME (1999): Estuaries of Argentina: a review. En: Perillo, G.M.E., Piccolo, M.C. y Pino Quivira, M., (eds.) Estuaries of South America: their geomorphology and dynamics. Berlín: Environmental Science Series, Springer-Verlag. 101-132.

Portal Geodesia y demarcación IGN (2022): Geodesia y demarcación. Instituto Geográfico Nacional.

Portal Hábitat e infraestructura social IGN (2022): Hábitat e infraestructura social. Instituto Geográfico Nacional.

Portal Hidrografía y oceanografía IGN (2022): Hidrografía y oceanografía. Instituto Geográfico Nacional.

POWER NASA Project (2021): NASA Prediction Of Worldwide Energy Resource.

Prates L (2008): Los indígenas del río Negro: un enfoque arqueológico. Buenos Aires: Sociedad Argentina de Antropología. 321.

Prates LR, Martinez GA, Belardi JB (2019): Los ríos en la arqueología de Norpatagonia (Argentina). Revista del Museo de La Plata, 4(2), 633-656.

Rabuffetti AP (2018): Influencia de la variabilidad climática sobre la composición de la comunidad íctica en el tramo medio del Río Paraná. [Tesis Doctoral]. Universidad Nacional del Litoral.

Ramos MB, Campo AM (2008): Caracterización de estados de tiempo en el suroeste bonaerense, Argentina. Revista de Geografía Norte Grande, 40, 85 – 97.

Romero PE, Garbarini EM, González MH (2014): Características hídricas y climáticas del norte Patagónico. II Encuentro de investigadores en formación en Recursos Hídricos, 9–10 Octubre 2014. Ezeiza: INA, 95.

Romero PE, González MH (2016): Relación entre caudales y precipitación en algunas cuencas de la Patagonia norte. Revista de Geología Aplicada a la Ingeniería y al Ambiente, 36, 7 – 13. ISSN2422-5703 (En línea).

Sedano Cruz RK (2017): Influencia de la variabilidad climática en la modelación estadística de extremos hidrológicos en el Valle Alto del río Cauca, Colombia. Tesis Doctoral. Universidad Politécnica de Valencia. Valencia. España

SMN (1989b): Tormentas. Boletín Informativo 42. Buenos Aires

SMN (2021): Listado de Estaciones Meteorológicas del SMN. Ministerio de Defensa. Servicio Meteorológico Nacional.

SMN. (2023): ¿Qué son los vientos intensos?

Soldano FA (1947): Régimen de aprovechamiento de la red fluvial argentina. Módulo III: Región Patagónica. Editorial Cimera. 159 – 219.

SSRH (2010): Atlas de Cuencas y Regiones Hídricas Superficiales de la República Argentina. Subsecretaría de Recursos Hídricos.

Trenberth KE, Smith L, Qian T, Dai A, Fasullo J (2007): Estimates of the Global Water Budget and Its Annual Cycle Using Observational and Model Data. Journal of Hydrometeorology, 8(4), 758–69.

Vich AIJ, Norte FA, Lauro C (2014): Análisis regional de frecuencias de caudales de ríos pertenecientes a cuencas con nacientes en la cordillera de Los Andes. Meteorologica, 39(1), 3-26.