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SHORT COMMUNICATION

Drought periods during 18th century in central Chile (33°S): A historical reconstruction perspective revisiting Vicuña Mackenna's work

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Understanding past climate variability is important for obtaining better predictions of future changes. Documentary records are high temporal resolution proxies that can be used to reconstruct aspects of the climate, such as precipitation. Vicuña Mackenna developed a compilation of historical climatic events between the 16th and 19th centuries using chronicles from Spanish colonizers and town council records. The objective of this work was to classify dry and wet periods beginning in the 16th century using records from Vicuña Mackenna by generating a precipitation index based on events in the documentary evidence (e.g., epidemics, "pro pluvia" rogations, and infrastructural damage) into a simple annual precipitation index on an ordinal scale. The index used a three-term classification scale, with 0 representing normal years, 1 representing wet years, and −1 representing dry years. The documentary records were not substantial enough to identify wet/dry periods during the 16th and 17th centuries. However, it was possible to identify dry and wet years described by conquerors and settlers that first arrived in the study area. During the 18th century, two long periods of drought were identified: 1705 to 1718 and 1770 to 1797. During these droughts, people organized rogations to the *Virgen* and different saints in desperation due to the lack of water. Finally, during the 19th century, technological improvements in measuring precipitation made it possible to identify intermittent dry and wet periods with higher resolution and precision, and these events could be related to the El Niño–Southern Oscillation (ENSO).

KEYWORDS

Chile, climate, documentary records, drought, historical reconstruction, mid-latitudes, precipitation

1 | INTRODUCTION

Determining past climate variability is important for obtaining improved predictions of future climate changes (Neukom *et al*., 2014). Such records are especially relevant during the last millennia, which is the last period that was not affected by anthropogenic factors (Moy *et al*., 2008; Alvarez *et al*., 2015; Andres and Peltier, 2016). Among the different proxies that can be used to reconstruct past climate, documentary records are one of the most precise. These records can directly represent adverse climatic conditions that originate from problems and changes in the roles and organization of societies (Brázdil *et al*., 2005; Prieto and García Herrera, 2009). Documentary records are accurate and have high temporal resolutions, which allow them to distinguish between different climatic events, such as changes in precipitation and temperature (Brázdil *et al*., 2005). Several disadvantages are the lack of continuous time series and bias due to societal perception (Brázdil *et al*., 2005). Although there are disadvantages, documentary

records are an accurate and trusted source of climatic information (Brázdil *et al*., 2010).

Historically documented climate began in Chile with the Spanish settlers, specifically with the foundation of Santiago de Chile in 1541 (Prieto and García Herrera, 2009). Although indigenous people inhabited this territory before the arrival of Spanish conquerors, they did not maintain written records. The earliest climatic records in Chile are those from the Santiago area, which were first compiled by Mackenna (1877). Vicuña Mackenna used chronicles and town council (*Cabildo*) records to document climatic events (Ortlieb, 1994; Prieto and García Herrera, 2009). There are only two more recent historical compilations of climatic events, Taulis (1934) and Urrutia de Hazbún and Lanza Lazcano (1993), but it was not possible to verify this information due to the lack of references in their studies (Ortlieb, 1994; Prieto and García Herrera, 2009). Mackenna (1877) has been the only work in Chile which has compiled climatic events. Ortlieb (1994) analysed Vicuña Mackenna's work to reconstruct El Niño–Southern Oscillation (ENSO) years, focusing only in wet periods. Therefore, the compilation of Vicuña Mackenna is the only reliable source for inferring climatic events because its sources have been verified. Hence, the objective of this work is to classify dry and wet periods since the 16th century using the Mackenna (1877) records by generating a precipitation index based on ancient chronicles or other written records from people who lived in the Santiago region (Figure 1a).

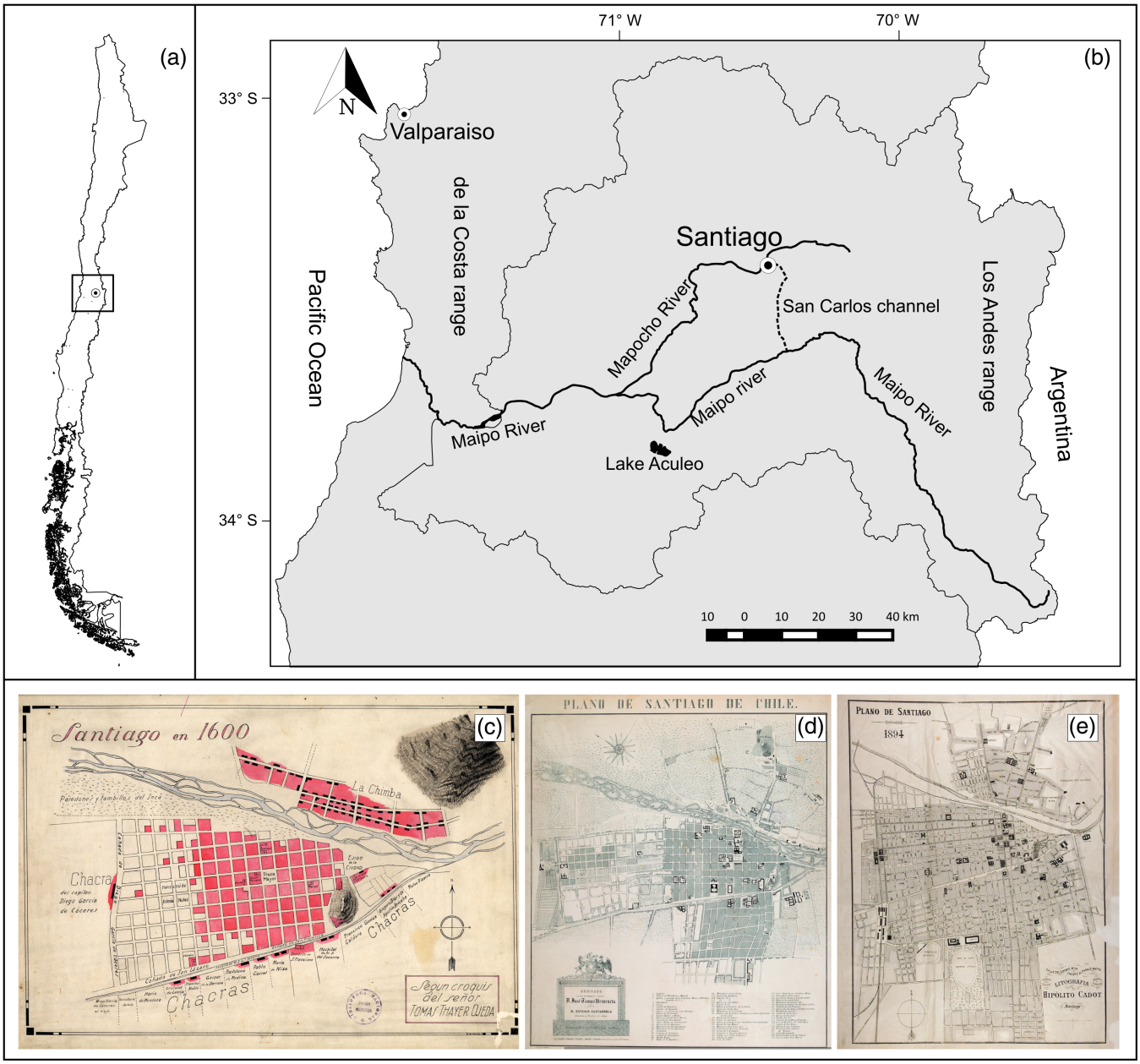

FIGURE 1 (a) Map of Chile showing the location of Santiago. (b) Map of the Metropolitan Region and its main features. (c) Map of Santiago in 1600 (from the Biblioteca Nacional de Chile, 2017a). (d) Map of Santiago during the 18th century (from the Memoria Chilena, 2017). (e) Map of Santiago in 1984 (from the Biblioteca Nacional de Chile, 2017b) [Colour figure can be viewed at wileyonlinelibrary.com]

Santiago is located in the central valley between the Andes and the coastal range in central Chile (Figure 1b). Central Chile has a Mediterranean climate; most precipitation occurs between May and October, with a maximum in July (Figure 2b). Inter-annual variability is driven by the ENSO and the Pacific Decadal Oscillation (PDO; Garreaud *et al*., 2009). Santiago is the most populated city in the country; the population in the metropolitan surrounding areas is approximately 7 million (Censo, 2017). Since its foundation, Santiago has obtained the majority of the country's population; however, during the 16th century, the population likely did not exceed 2,000 inhabitants (Mackenna, 1924) (Figure 1c). During the 17th century, but especially through the 18th century, a noticeable increase brought the estimated population to approximately 64,000 inhabitants (Archivo Nacional, 1953) (Figure 1d,e).

Population growth generates an increase in the resources needed for survival, which are provided by either governmental or religious services. Therefore, any climatological or environmental pressures on the lifestyles of the inhabitants are likely to be recorded, either by local writers or governmental or religious authorities (e.g., the number of precipitation-induced rogations registered by the Catholic church).

2 | METHODS

A precipitation index was developed according to Pfister (1999), where values based on documentary evidence were obtained by transforming basic documentary data into a simple annual precipitation index on an ordinal scale. The documentary evidence was obtained from Mackenna (1877): "Ensayo Histórico sobre el Clima de Chile." Mackenna (1877) registered climatic evidence from first-hand records of Spanish chronicles, administrative documents, manuscripts, and epistolary evidence during the Colonial period. For this study, climatic indicators related to droughts and high-precipitation events were analysed. The selected indicators for droughts were as follows: (a) variations in agricultural production, (b) epidemics (Brázdil *et al*., 2005) associated to lack of hygiene, due to no water available (Stanke *et al*., 2013), and (c) "pro pluvia" rogations, which are important in Catholic culture (Barriendos, 1997). Indicators of high-precipitation events were (a) floods, (b) infrastructural damages, (c) mouse plagues (Brázdil *et al*., 2005), and (d) "pro serenitate" rogations (Barriendos, 1997). Finally, the index used a three-term classification scale, with 0 representing normal years, 1 representing wet years, and −1 representing dry years.

3 | RESULTS AND DISCUSSION

A precipitation index was developed with the information from Mackenna (1877) using the classifications described in section 2. The climatic record used from Mackenna (1877) goes from 1541 until 1877, going through different politic-administrative periods of Chilean history. Starting with the Spanish colonization and domain, from middle of the 16th century until beginning of the 19th century, when the Independent starts. The final period is the consolidation of the republic during the decade of 1820. Overall, during the 16th and 17th centuries, there was limited information regarding climatic conditions; thus, it was not possible to identify important wet or dry periods. During the 18th century, two periods of droughts were identified: 1705 to 1718 and 1770 to 1797 (Figure 3a). Finally, there were intermittent wet and dry periods during the 19th century (Figure 3a), which could be related to ENSO (Ortlieb, 1994). In the following sections, a detailed description of the climatic conditions mentioned by Mackenna (1877) as shown in Table S1,

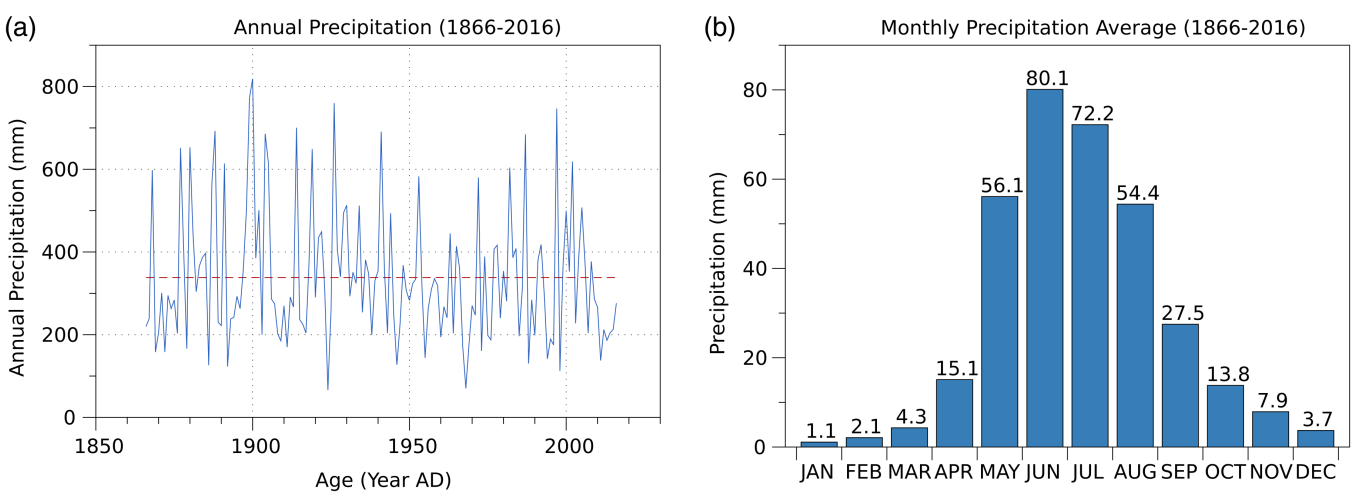

FIGURE 2 (a) Annual precipitation in Santiago (33°26′35″S; 70°38′40″W) between 1866 and 2016 (continuous line) and the average precipitation during this period (dotted line). (b) Monthly average precipitation from 1866 to 2016 (the data from 1866 to 1960 are from Ramirez, 1971; the data from 1961 until 2016 are from the Terraza Oficinas Centrales DGA meteorological station; 33°26′35″S; 70°38′40″W; Dirección General de Aguas, 2017) [Colour figure can be viewed at wileyonlinelibrary.com]

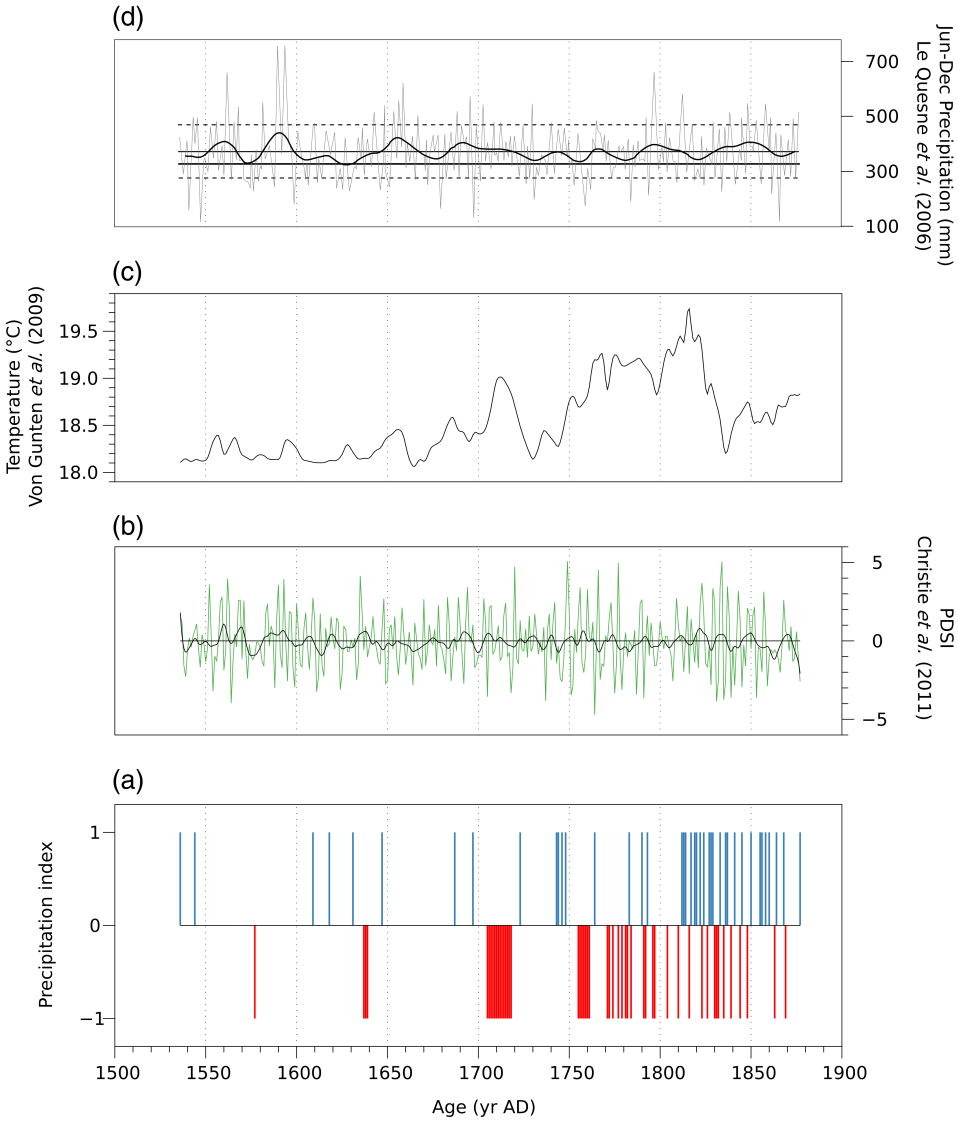

FIGURE 3 (a) Precipitation index developed from Mackenna (1877), where 1 represents wet years, 0 represents normal years, and −1 represents dry years. (b) Palmer severity drought index (PDSI) reconstruction from late spring to early summer using *Austrocedrus chilensis* tree rings in south-central Chile (Christie *et al*., 2011). (c) Austral summer temperature reconstruction in Lake Aculeo (33°S) using pigments from lake sediments (von Gunten *et al*., 2009). (d) June to December precipitation reconstruction using *A. chilensis* tree rings (Le Quesne *et al*., 2006; ©American Meteorological Society. Used with permission) [Colour figure can be viewed at wileyonlinelibrary.com]

Supporting Information is presented, and the dry and wet periods are presented in chronological order.

3.1 | Climate during the 16th and 17th centuries

The climate of central Chile was described by Mackenna (1877) as mild during the 16th and 17th centuries, although there were a few droughts and wet periods. The first individuals to record climatic conditions in Chile were Spanish colonizers, who documented climatic phenomena that caught their attention, and these records were later compiled by Mackenna (1877). The first year recorded was 1536 AD, when the Spanish colonizers experienced "deluges" that discouraged them from continuing exploration (p. 18). The winter of 1544 AD was described as outrageous due to the high amount of precipitation (p. 20), and Mackenna (1877) indicated in his book that the indigenous people had never experienced this type of event (p. 21). The first drought that was documented occurred in 1577 AD, when the Mapocho River water level diminished so severely that it generated problems in the water supply needed by Spanish settlers for irrigation (pp. 7–8). Another extreme "deluge" occurred in 1609 AD, which destroyed several crops and farms and generated a massive rat plague, which induced a religious rogation and procession (p. 28). Rat plagues are indicators of extreme rainfall events (Greenville *et al*., 2013) because rodents look for shelter in populated areas (Greenville *et al*., 2013). The year 1631 AD was also rainy, which provoked another rat plague. This rat plague was of such concern that the women of Santiago were invited to a procession (p. 141), despite their usual lack of participation in such events. The second drought occurred between 1637 and

1639 AD; this made inquisitional debt-collectors unable to charge taxes during this time due to the drought, which abruptly diminished harvests (p. 48). In 1647 AD, the winter was harsh, and there were 3 days of snowfall, which generated considerable livestock fatalities (p. 36). The year 1697 AD was also characterized by wet conditions due to a great flood in the area of Santiago, where several cattle and horses died (p. 38).

Mackenna (1877) recorded several years of drought and floods during the 16th and 17th centuries, but there were not enough documentary records to develop a robust reconstruction. The lack of records during the 16th century could be because the Chilean territory was in a conquest process. Therefore Spanish settlers were in a war with the indigenous and did not documented prevailing climatic conditions during this time. Several authors (Le Quesne *et al*., 2009; Christie *et al*., 2011; Muñoz *et al*., 2016) have developed precipitation reconstructions from tree rings in south-central Chile. Christie *et al*. (2011) found a multi-decadal drought period that occurred at approximately 1585 AD (Figure 3b), and the first record of drought documented by Mackenna (1877) occurred in 1577 AD. Le Quesne *et al*. (2009) showed a drought between 1570 and 1635, and Muñoz *et al*. (2016) found that the driest year during the last four centuries in central Chile occurred in 1680 AD. Droughts in historical records are characterized by religious "pro pluvia" rogations in Catholic culture (Barriendos, 1997). These rogations occurred when the diminished harvest caused people to despair, which consequently meant there was a lack of food. At that time, the population surrounding Santiago's jurisdiction was small; as a consequence, the agricultural production would have been enough to feed the local population, and public rogations were not needed, which could explain why Mackenna (1877) did not fully record these periods.

3.2 | Climate during the 18th century

The 18th century started with a long period of drought between 1705 and 1718 AD (Figure 3a). The *Cabildo* of Santiago ordered a rogation due to the lack of rainfall on August 7, 1705 AD (p. 52; this event occurred during austral winter, which is important when considering that precipitation begins in May; Figure 2). Twelve years later, the situation did not change, and the *Cabildo* still instructed a rogation due to a long period of drought. The Mapocho River reached its lowest water level during the drought of 1717 AD (pp. 52–53), which caused the municipality to establish attentive laws to avoid water robbery. The vigilance towards water was expensive for the municipality, which inspired the idea to transfer water from Maipo to the Mapocho River (p. 59; Figure 1). The following year, Santiago had problems with the maintenance of ditch channels due to the lack of water, and, therefore, the *Cabildo* ordered a novena for the *Virgen del Socorro* in 1718 (p. 54). The decade starting in 1740 was characterized as wetter than the previous decades. In 1743 AD, the *Cabildo* requested a procession for the *Virgen del Socorro*, but this was not executed because it started to rain (pp. 65–67). 1746 AD was a rainy year, which caused the harvests to be more abundant than those in other years (pp. 68–69). Santiago was flooded in 1748 AD by a deluge, comparable with the deluge that occurred in 1609 AD, which destroyed the cutwater of the Mapocho River and the *Puente de los Siete Arcos* bridge (p. 69).

The second half of the 18th century was even drier than the first half; generally, after a period of drought, a rainy year occurred. According to Ortlieb (1994), the intermittent dry and wet periods described by Vicuña Mackenna were likely related with ENSO. The first drought documented during this period occurred under the government of Governor Manuel de Amat between 1755 and 1761 AD (pp. 72–73). This government was denoted as a time of *skinny cows* because the lack of water provoked an economic shortage; however, this period was followed by a flood in 1764 AD (p. 74). Mackenna (1877) established a 30-year period of drought between 1770 and 1797 AD, during which the following were the driest years: 1770, 1771, 1773, 1774, 1777, 1781, 1782, 1784, 1791, and 1797 AD (Figure 3a). The total amount of rainfall during 1770 was equivalent to five consecutive days of rain (p. 76). The following year, the *Cabildo* ordered a rogation to the *Virgen del Socorro* (p. 78), but it did not rain, and the fields were sterile (p. 79). As a consequence, another rogation was organized in September to the *Nuestra Madre Señora de las Mercedes* (pp. 80–81). By the year 1772 AD, the drought was so severe that there was a threat of famine (pp. 83–84). The following year, mules did not have enough food because of the drought, which delayed fish deliveries in Santiago during Lent (p. 84). Therefore, the mayor of Santiago asked for permission to eat meat 4 days a week during this period (p. 85). The year 1774 AD was the driest of the century, and it was mentioned that the following years were not more or less humid (p. 86). Farmers rejected the saints in 1777 AD because it had not rained during the last decade; therefore, they began to pray to *Señor de la Agonía* (pp. 86–87). The situation changed noticeably in 1779 AD, when several floods destroyed the bridge *de Cal y Canto*, which was under construction (p. 74, 90). The high-precipitation events during this year also generated a disease called *Malesito*, which symptoms were similar to Yellow Fever (p. 90) and it was mentioned that the floods and electrical storms seemed like atmospheric earthquakes. After the flood of 1779, drought continued between 1781 and 1782 AD (pp. 92–93; Figure 3a). As an example, Catholic mass could not be performed in Renca (near Santiago) because there was no water for the vinegar bottles (p. 94). The lack of water provoked a sanitary problem during the austral summer of 1784 AD because there was no water for people to clean their houses (p. 126). As a result, people began the rogations to the saints

in 1791 AD because the soil was catastrophically infertile. That year, there were several reports of plague because there was not enough water to clean the sumps in the houses; there were also substantial livestock fatalities. Consequentially, the *Cabildo* request a rogation to the *Nuestra Señora del Rosario*, *la Grande* (pp. 128–129). As before, a rainy year followed the drought, and in 1793 AD, the water level of the Mapocho River was substantially higher (p. 140). Finally, 1797 AD was very dry, and precipitation events occurred after June 7th; as a consequence, the fields were sterile, and the livestock was extremely thin. Therefore, people organized a rogation to *San Isidro*, who is the saint patron of rain (p. 135).

Regarding other climatic records in the area, von Gunten *et al.* (2009) developed a temperature reconstruction (Figure 3c) from Lake Aculeo (Figure 1), where a cold period between the 16th and 18th centuries was identified, which was synchronous with the Little Ice Age (LIA). After this cold period, there was an increase in temperature between 1700 and 1720 AD (von Gunten *et al.*, 2009) (Figure 3c). The warm period described by von Gunten *et al.* (2009), coincided with the droughts between 1705 and 1718 AD, which were identified in this study as the longest drought during the second half of the 18th century. Furthermore, Martel-Cea *et al.* (2016) produced a precipitation reconstruction using pollen and diatoms as proxies in Lake Chepical (32°S), and they found a dry period during the 18th century. However, due to low resolutions, they could not identify the events with precision during those years. Le Quesne *et al.* (2006) used tree rings as a proxy and found a dry period between 1771 and 1785 AD (Figure 3d), which is the same period that Mackenna (1877) describes as "the driest year of the century." Currently, Garreaud *et al.* (2017) reconstruct precipitation during the last 1,000 years in central Chile using tree rings records. They found that the longest period of drought has been 2010–2015 AD and they did not describe the droughts of the 18th century. On the other hand, Bird *et al.* (2011) reconstructed annual precipitation associated with the South American summer monsoon (SASM) using $\delta^{18}O$ contain in calcite from lake Pumacocha (10°S) sediments. They found drier periods during LIA at the beginning and ending of the 18th century. Morales *et al.* (2012) also found a tendency to drought at the end of the 18th century in the *Altiplano* region (17°–22°S) in a reconstruction of SASM precipitation. The changes in SASM precipitation are modulated by ENSO, which caused latitudinal changes in the Intertropical Convergence Zone (ITCZ; Bird *et al.*, 2011; Morales *et al.*, 2015). A northern change of ITCZ would decrease precipitation related with SASM. Then, the dry period described by Mackenna (1877) could be associated with a northern change in the ITCZ provoked by ENSO phenomenon. The explanation of why the drought periods found in Mackenna (1877) records could be the perception of droughts by people. Consequently, the perception of drought and the demand of resources for sustenance were higher than those during the 17th century. Moreover, prolonged and moderate droughts (similar to those in the 18th century) could cause negative effects in water availability. Water supply decreased each year due to severe droughts (Barbeta *et al.*, 2015), which caused problems with agriculture.

3.3 | Climate during the 19th century

The 19th century was characterized by the implementation of technological improvements, which made quantitative measurements of precipitation possible. Therefore, a longer record of dry and wet years could be achieved (Figure 3a). The measurement of precipitation started in 1824 AD, when precipitation was only measured by the number of rain days annually. The first precipitation records began in 1850 AD, and the records were in millimetres per year. The lack of data before 1824 AD can be explained by the independence process, where the focus is the record of combats and political facts. Mackenna (1877) described the first half of the 19th century as wet. From 1827 to 1829 AD, several floods occurred, which destroyed multiple bridges in Santiago (pp. 214, 215, 340). In contrast, the period from 1830 to 1832 AD was very dry, and 1832 AD was the driest year from 1824 to 1850 AD (p. 287). From the same series, the wettest year was 1833 AD (p. 340), which was followed by another dry year in 1835 AD (p. 77). The years 1836 and 1837 AD were both wet, followed by a dry year in 1839 AD (p. 77). A 7-year wet period began in 1841 and ended in 1848, which disturbed the period of drought (p. 340, 299). Finally, 1850 AD was described as one of the roughest winters in Chile due to high precipitation events (p. 218). During the second half of the 19th century, precipitation began to be measured in millimetres, which made them comparable with current measurements. The years 1858 and 1860 AD were considered wet, with precipitation totals of 622 and 513 mm/year, respectively (p. 308), while 1863 AD was dry and calamitous due to a drought (only 114 mm/year; p. 326). The years 1864 and 1868 AD were very wet, with precipitation totals of 732 and 875 mm/year, respectively (p. 327, 328). Similar to past patterns, the following year (1869 AD) was very dry, and the precipitation total was only 149 mm/year (p. 260). Finally, 1877 AD was termed the year of Great Floods; these floods were comparable with those in 1856 and 1858 AD, p. 98, 272, 319). Unfortunately, this was when the book by Mackenna (1877) was written, so we do not have information regarding the amount of precipitation that fell.

Muñoz *et al.* (2016) observed an extreme drought between 1818 and 1822 AD in the Maule River, which is when Mackenna (1877) described a wet period. Nevertheless, Prieto and García Herrera (2009) described an increase of snowfall in the chilean-argentinian pass (32°S) between 1810 and 1830 by using historical records. Christie *et al.*

(2011) observed that 1849 AD was one of the most humid years during the 19th century (Figure 3b), and Mackenna (1877) described 1850 AD as the roughest winter in Chile. The aforementioned study also found that severe to moderate droughts occurred during 1860 (Christie *et al*., 2011) (Figure 3b), which matches with the description of calamitous drought by Mackenna (1877) at approximately 1863 AD. In general, the record during the 19th century was more complete than that during the previous centuries due to the technological advances in precipitation measurement that were implemented. For the same reason, this record was quantitative, especially after 1850 AD, when the measurements were recorded in millimetres.

4 | CONCLUSIONS

The historical data contained in the record of Vicuña Mackenna allowed for the identification of dry and wet periods since the 18th century with a high resolution. Although Vicuña Mackenna did not fully record the 16th and 17th centuries, he was able to identify several dry and wet years but with a very low resolution. The intense droughts identified during the 18th century were not fully documented by natural proxies; these different drought records could be attributed to perception and a more intensive use of land for agriculture. Finally, during the 19th century, the quantitative measurement of precipitation began. This study identified a pattern throughout the record in which, following a drought, a distinct period of intense rain occurred, which could be associated with ENSO. For future studies, it is necessary to complement the record of Vicuña Mackenna with other documental proxies, such as newspapers, and archives as the *Biblioteca Nacional de Chile* and the *Archivo General de Indias*, to improve the climatic reconstruction.

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CONFLICT OF INTERESTS

The authors declare no potential conflict of interests.

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SUPPORTING INFORMATION

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