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Climate anomalies and epidemics in South America at the end of the Colonial Period

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Abstract Climate is one of the most of influential natural factors on society and economy. One of the consequences of climate anomalies is the emergence of diseases and epidemics, especially in agrarian societies. The current concern with long-term climate change and its measurable consequences on health and disease gives new relevance to the question of how agrarian societies fared during sharp droughts and other climatic hardships, especially those subject to the disruptive processes of colonization. Not many studies have been done in Latin America that relate climate, epidemics and mortality from a historical perspective. This paper explores the association between climatic anomalies, epidemic events, and native demographic decline in the Alto Peru region in the highlands of Bolivia, in the late eighteenth and early nineteenth century. Studies of historic climatology indicate that adverse climate events became more frequent in the southern areas of South America during these centuries. There were extreme oscillations in precipitation, especially beginning in the 1750's which significantly impacted the largest group of people in late colonial Alto Peru: the indigenous population, whose vulnerability increased in face of local climatic anomalies and the resulting epidemiological risk. Both the quantitative and the qualitative analysis show associations between climatic and epidemic events.

Abbreviations

AGI Archivo General de Indias, Sevilla
AGN Archivo General de la Nación Argentina

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1 Introduction

Climate is one aspect of the natural environment that has had most influence on society and economy, in particular on agrarian societies. Generally, poorer regions and social sectors are more vulnerable to climatic variability, especially prolonged droughts and floods (Richardson et al. 2011). The incidence of climatic variability in colonial societies has been extensively studied for Mexico (Florescano 1980; Liverman 1990, 1999; Endfield et al. 2004; Acuña-Soto et al. 2005). The latter authors have shown that the native population collapse in 16th century Mexico was a demographic catastrophe with one of the highest death rates in history. The epidemiologic evidence has related to the reconstructed precipitation for north central Mexico through tree-ring. Both evidence indicating that the 1545 and 1576 epidemics of cocoliztli (Nahuatl for "pest") were indigenous hemorrhagic fevers transmitted by rodent hosts and aggravated by extreme drought conditions.

In past agrarian societies, one of the consequences of climate anomalies is the emergence of diseases and epidemics, along with their social and economic aftermath. In recent times, events such as the El Niño phenomenon and global climate change have suggested reevaluating the role of climate in human health (Epstein et al. 1995; Bouma and van der Kaay 1996; Lobitz et al. 2000; McMichael et al. 2001; Richardson et al. 2011; McMichael and Bertollini 2011).

According to the scenarios developed by climate scientists, an increase in temperature of a few degrees Celsius would produce, among other possible effects, a degradation of productive lands, an intensification of extreme climate events, a shift of climatic zones towards the poles, and droughts, due to climate imbalance in other areas. Overall, this would result in a large shift in agro-climatic regions worldwide. In terms of social and health effects, the impact of weather disasters is considerable and is unequally distributed (IPCC et al. 2007).

The current concern with long-term climate change and its associated consequences on health and disease gives new relevance to the question of how agrarian societies fared during intense droughts and other climatic hardships, especially those societies subject to the disruptive processes of colonization, such as in Mexico (Liverman 1999). While there are observable relationships between the occurrence of climatic hardships and the appearance of diseases, there is not a positive correlation in all cases. According to IPCC-Climate Change (2007), major storms and floods have occurred in the last two decades. Populations with poor sanitation infrastructure and high burdens of infectious disease often experience increased rates of respiratory and diarrheal diseases after floods. The effects of drought include death, malnutrition, and infectious and respiratory diseases (IPCC et al. 2007). Not many studies have been done in South America that relate climate conditions, epidemics, and mortality from a historical perspective. The most significant studies dealing with the colonial southern Andes are by E Tandeter (1991, 1995, 1998), C López Albornoz (1997), R Gil Montero and R Villalba (2005), and R Gil Montero et al. (2010). Colonial Andean societies have been very sensitive to climate anomalies, especially where agriculture is an important part of the economy. In the colonial chronicles, outstanding meteorological events are frequently mentioned, such as lengthy droughts, sometimes lasting several years. They are related to bad harvests, food shortage, famine, starvation, diseases, demographic drops, high mortality, social and economic crisis, and political conflict. Consequently, climate variations, principally recurrent droughts and floods, may have had a considerable impact on the living standards of colonial society, particularly among indigenous people.

Diseases and epidemics can be one of the immediate consequences of extreme climate events. Chroniclers and colonial officers are aware of the direct connection between floods or frosts and diseases, such as dysentery, catarrhal epidemics, and typhus (Prieto 2009).

More information has been found on epidemics suffered by natives than on those affecting Spaniards, especially smallpox and measles, which the colonial people related to droughts. In the colonial sources, diseases were commonly attributed to the predominant weather. In the year 1785 it was asserted that the drought "… and the rigors of the sun have caused some cases of dysentery and German measles [rubella] …" and that there was "a light epidemic similar to *tabardillo* [a form of typhus], due to the very severe frosts".[1] Again in 1789, a drought caused "many cases of *tabardillo*, diarrhea, and strong colds".[2]

The impacts of drought, flooding, or excessive rains were in especially strong on Andean communities in a subsistence economy. Their livestock and harvests were reduced or lost, resulting in malnutrition and weakened immune systems. This would facilitate the action of pathogens that are not always severe in normal conditions. Diseases (*pestis* or epidemics) and in many cases, massive death, were another highly destructive consequence for Andean communities, as they lost the capacity to produce the necessary food for the community.

Contemporary authors have found links between temperature and humidity and the spreading of certain diseases. For example, the virus that causes smallpox would be weakened by moisture, receding in the rainy season and advancing in the dry season. The activity of the flea that causes bubonic plague is higher with temperatures ranging between 20 °C and 32 °C, and lives four times longer when relative humidity is higher than 90 % (Lamb 1977:188, 244).

Poveda et al. (1992:184) found that there is a strong association between climatic conditions and malarial risk throughout Colombia. The authors have found that cases of malaria (P. vivax P. falciparum) peak during El Niño events, when precipitation diminishes and temperatures rise, which increases rates of mosquito reproduction and biting. Diminished rainfall can lead to the formation of ponds and stagnant pools, which may create more breeding sites. But the same authors consider also that in some tropical areas, excessive precipitation can increase breeding sites (Poveda et al. 1992:184).

In the case of dengue fever, there is evidence showing that the increased frequency of El Niño/La Niña phenomena in the last 100 years has contributed to the spreading of the disease, corresponding to increases in temperature and humidity (Senior 2008). High population density also appears to be a significant factor for increasing transmission rates (Barclay 2008), similar to what happened in the rural areas of Alto Peru in the *Queshua* zone. In the case of malaria, Shea K (2007) states that mosquitoes expand their habitat toward regions with higher temperatures and precipitation, where malaria becomes more contagious.

Beginning in the mid eighteenth century, reforms carried out by the recently installed Bourbon dynasty in Spain, and especially by Carlos III (1759–1788), had direct influence on the social, economic and demographic aspects of colonial society. However, the implementation of public health policies only reached the largest urban centers such as Mexico City, Lima, Buenos Aires, Bogotá or Santiago de Chile. There was a major difference in how these policies were implemented in population centers and in the countryside, especially among the indigenous peasants, who were much more vulnerable to famines and disease (Acevedo 1992; Tandeter 1995, 1998). This was not always the case. For example, smallpox started receding around 1797–98, mainly due to the expedition of Francisco de Balmis (1803–1808), which spread the vaccine throughout America, from north to south (Sánchez Albornoz 1973).

According to Tandeter (1995), lands available during this period to indigenous peasants, the great majority of the inhabitants in the study region, were reduced by the encroachment of Spanish farms. This author reports a marked increase in the peasant population from 1750

[1] AGI, Buenos Aires, file 73, December 1785
[2] AGI, Buenos Aires, file 109, December, 1789

to 1800, when less land was available to them. Tandeter (1995) concludes that in the long run, the imbalance of a higher population and fewer resources led to a decline in the quality of life for indigenous peoples.

The inhabitants of the Peruvian-Bolivian Altiplano were still enduring the effects of the massive general revolt led by Tupac Amaru in Cusco and Tupac Katari among the Aymara peoples in Alto Peru between 1780 and 1783. The rebellion impacted the peasant economy, an additional strain on already vulnerable conditions (Stern 1990). Besides the economic and social impacts, there were climatic impacts, including several particularly strong and frequent El Niño events from 1780 to 1804, some of which lasted two or even 3 years (García-Herrera et al. 2008). These events stalled the economic recovery of the peasants, heightening food shortages and reducing seeds necessary for the next agricultural cycle.

2 The study area and the Andean ecological zones

The study area comprises the subtropical southern Andes located in modern Bolivia. In the late eighteenth, this area belonged to the viceroyalty Río de la Plata, created in a 1776 by a mandate of the Spanish King Carlos III. With its capital in Buenos Aires, the new viceroyalty included territories in modern Argentina, Uruguay, Paraguay, Bolivia, and minor areas in Brazil and Chile. A 1782 royal order (*Real Ordenanza*) divided the viceroyalty in eight large administrative jurisdictions, or *intendencias*. The *intendencias* were divided into local districts, or *partidos*. The present study focuses on the Alto Peru region, which includes the *intendencias* of La Paz, Cochabamba, La Plata (Chuquisaca or Sucre), Potosi, and Puno.

In the Alto Peru region, the environment is divided into three ecological belts, defined by altitude: *Puna* (high plateau or altiplano), *Queshua* (valleys) and *Yungas* (cloud forest) (Fig. 2). The *Puna* is a very high altiplano region with two zones. High *Puna* (above 4000 masl) is characterized by extreme cold (350 annual days of frost), and only allows breeding llamas and alpacas. The low *Puna* (between 4000 and 3600 masl) is not as cold (100 annual days of frost) with more precipitation (between 200 and 700 mm), which and allows some agriculture, mostly potatoes. Below the *Puna* is the *Queshua* zone (between 3600 and 2400 masl), with moderate temperatures (on average 11–16 °C), mainly of valleys and steep ravines. Four fifths of the precipitation occurs between November and April, so corn and potato agriculture is possible. It is the zone with the highest density of peasants (Dollfus 1991). Next, the *Yungas* zone (between 2000 and 800 masl) has a warm climate (on average 18–21 °C) and more humidity (between 1500 and 5000 mm of annual precipitation). Agricultural crops are mostly in cotton and coca.

The relationships among climatic, geomorphologic and hydrological factors result in a landscape with marked temperature shifts at different altitudes. Moreover, there are shifts from extreme aridity to hyper-humidity, from steep slopes to flatlands, and from thick forest to bare soil, within relatively short distances (Troll and Brush 1987: 5). It was assumed that in each ecological belt, epidemics or diseases would emerge based on these basic characteristics, fundamentally in terms of aridity or humidity. Even though these zones' geographic limits and characteristics may have changed somewhat since the colonial period, these differences are thought to be minor in terms of the study's scale, especially in terms of internal variation within each zone (Morello 1983; Dollfus 1991).

This study may be able to establish relationships between these ecological zones (and their temperature and precipitation ranges) and information in the colonial chronicles, organized according to administrative entities. To spatially link these data we used a Geographic Information System to georeference colonial maps superimposed on modern maps (Figs. 1 and 2).

In this environment, highland ethnic groups developed strategies that stressed different resources in different ecological zones. John Murra (1975:59) describes this as "vertical control of a maximum of altitudinal zones". Ethnic groups' strategies toward climate hazards also took the region's morphological and altitudinal diversity into account. However, these strategies proved insufficient in the face of more severe or widespread drought, floods or frost (Prieto and Herrera 2002:71).

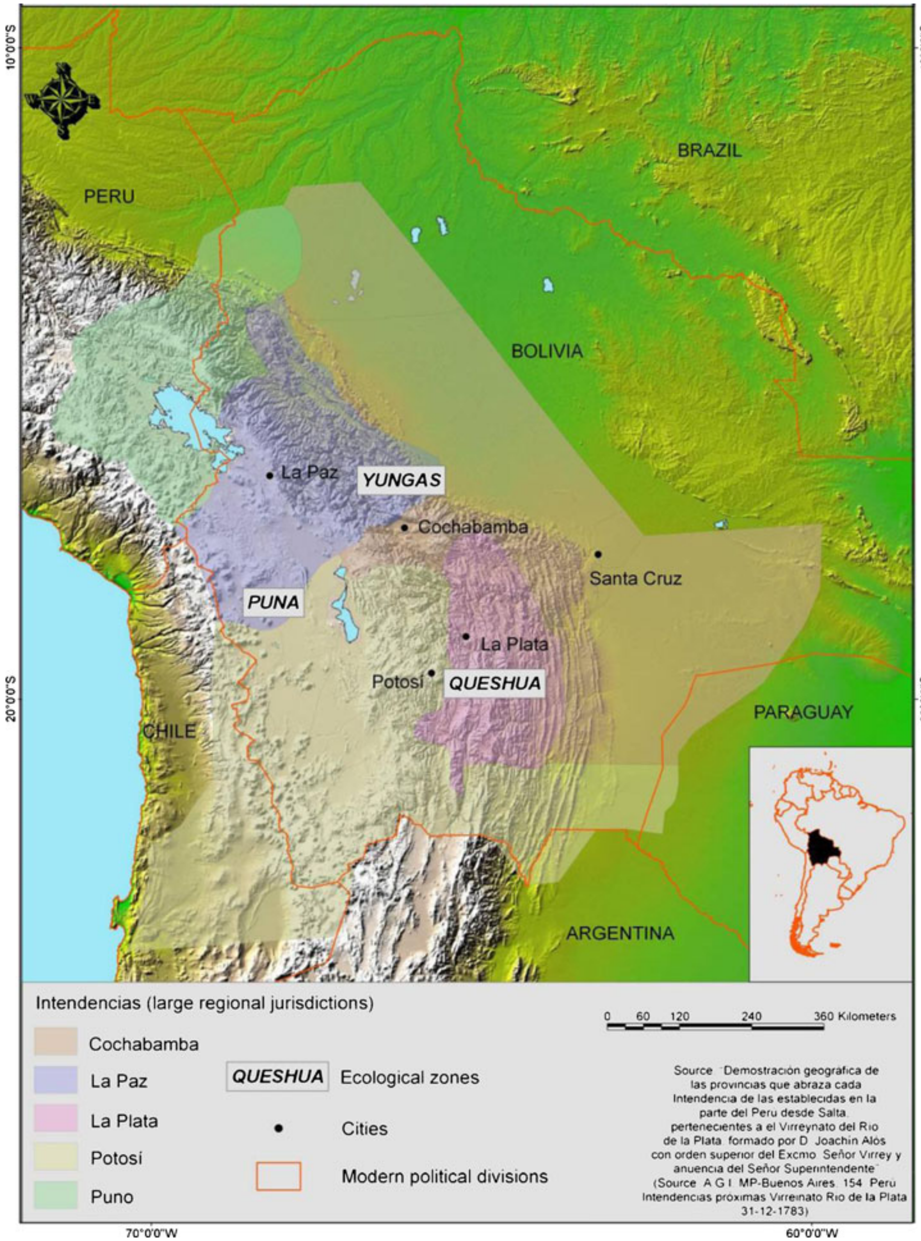

Fig. 1 Intendencias of Alto Peru in the late eighteenth century

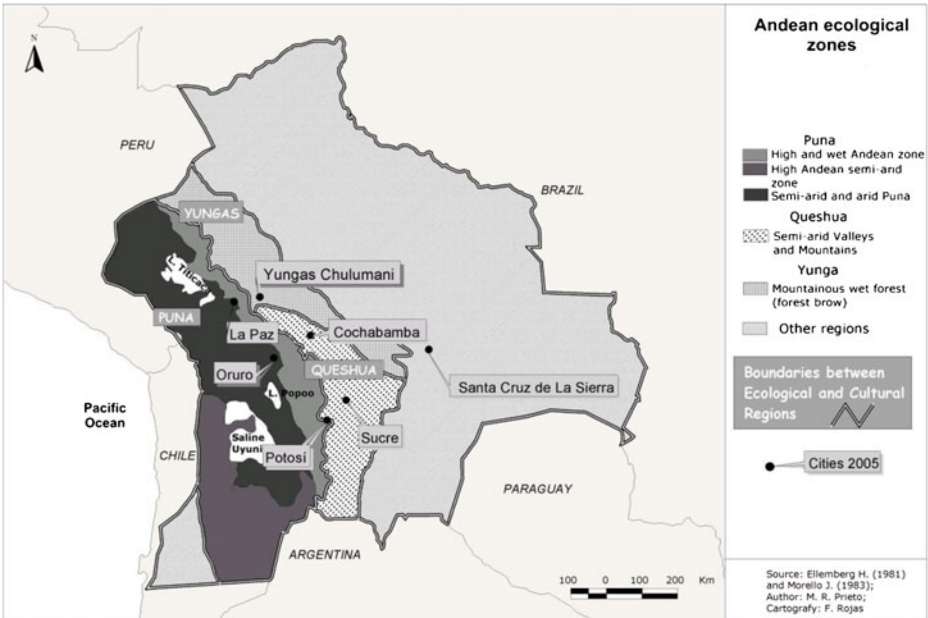

Fig. 2 Simplified map of ecological regions in modern Bolivia

At the turn of the eighteenth century, the circulation of resources between the *Puna*, *Queshua* and *Yungas* zones, as well as between haciendas, mines and cities, developed on two levels: (1) traditional vertical movements of ethnic groups between the zones, and (2) inter-regional commerce or exchange between natives or Spaniards. The *intendencias* and high altitude *partidos* of Alto Peru included at least two of the three ecological zones. This allowed complementing production with the exchange of agricultural products from each zone. In the case of local climate anomalies, food could be substituted by production from another zone (Prieto and Herrera 2002).

3 Sources and methodology

Unpublished archival sources were used to explore health vulnerability, climatic variability and extreme weather events in Alto Peru. The primary source for this study was "*Relaciones sextrimestrales de aguas*, *cosechas y demás particulares*" ("Bi-annual accounts of rains, harvests and other events", hereafter *Relaciones*). These reports were produced in response to a Spanish royal order on May 10th, 1784, which requested information on climate, agriculture, health and trade in each Hispanic-American town.[3]

Reports were sent to the Spanish Crown from 1785 to 1804 by the head officers of even the most remote villages of the Spanish dominion, including those in Río de la Plata viceroyalty. For this study, we have selected the reports sent by the delegates of the Alto Peru *intendencias* of Cochabamba, La Paz, La Plata (also named Chuquisaca or Sucre after 1776), Potosi, and Puno.

[3] *AGI. Indiferente General*, *file. 661. Reales Cédulas*, *Decretos y Circulares. 1784*, *fol 1r. Doc. S/N. Circular a los virreyes*, *gobernadores e intendentes de América. Aranjuez*, *10 de mayo de 1784. (2 folios).*

These sources provide the most reliable information for reconstructing the past climate of this region. Weather appears to be a fundamental element for good harvests, as well as prices of crops. Information on the health and welfare of the population and labor force–mostly indigenous[4]—was indispensable for the development of the colonial economy. The *Relaciones* include eye-witness accounts from immediately after climatic events, as well as unusually catastrophic events. They provide more information for years with extreme events, than for less exceptional years. Rainfall indicators are more numerous and easier to determine, such as harvests. Indicators of temperature are not as clear, with the exception of the very low temperatures and frost.

As a source, the *Relaciones* has its limitations, but are a relatively consistent source, show continuity over time, and were written by officers of the Crown (García Herrera et al. 2003). The *Relaciones*, like most colonial sources, tend to describe anomalous or extreme climate events when they directly affected the population, especially in terms of harvests or epidemics: "… there is presently a shortage in [Potosi] because of the lack of rain, a circumstance which will reach a catastrophic degree if the drought continues".[5] This makes it difficult to evaluate observations during normal conditions. This also makes it difficult to estimate the normal disease burden, in quantity of people, but it seems that sources do not highlight periods of normal disease burden. Additionally, these records may be influenced by subjectivity or exaggeration, which influence the validity of the information used for reconstructing climatic chronologies. For instance, the impact of a storm may be exaggerated in a delegate's report in order to secure more funding from the Crown or Viceroy, or to avoid paying taxes. This uncertainty has to be recognized when analyzing the records.

Most of the *Relaciones* documents are currently located in the Archivo General de Indias of Seville (AGI).[6] Some 6-month periods can be found in the Colonial Section of the Archivo General de la Nación, Argentina (AGN). Finally, articles by Enrique Tandeter (1991, 1995, 1998) and B. Larson (1980) provide a few more observations on the first few years of the nineteenth century. The *Relaciones* from 1791 to 1795 and 1799 do not exist or are lost. The methodology used for identifying and evaluating rains, floods, and their relationship to the economy and epidemics in the Andean region was developed by the authors, as detailed elsewhere (e.g., Prieto et al. 2000).

Content analysis has been applied in different steps: produce a thematic guide for data extraction, identify the most significant indicators associated with each type of event, estimate precipitation and river levels, and verify the reliability of the information.

Two types of data have been obtained: *Direct data* (the larger amount of data) are from explicit references to meteorological and hydrological events, such as heavy rainfall, intense or prolonged droughts, and extraordinary events such as floods, snowfalls or frosts. *Indirect data* are from reports of effects produced by climatic events, such as damaged or lost harvests, famines, lack of food or livestock, prayers for rain (*rogativas*), cattle mortality or weight loss, increase in the price of agricultural products, deaths or epidemics.

An initial analysis identified the most significant indicators associated with each type of event in the *Relaciones*. The production of livestock can be treated as an indicator of

[4] Acevedo estimates that the native population reached 60 % to 70 % of the total, whereas the Spanish population–the majority living in cities–barely reached 20 %, of a total of nearly 800,000 inhabitants. Acevedo, "Las *Intendencias* Altoperuanas", 409–417. It is not known to which group belongs the 10 % of the remaining population, possibly they would be black people and of mixed race.

[5] "*…en la actualidad [Potosí] está con alguna escasez y carestía por falta de lluvia*, *cuia circunstancia tocará en grado de calamidad si continua la seca*". *AGI*, *Buenos Aires,file 587*, *February 1798*.

[6] AGI, Audiencia de Buenos Aires, files: 21, 73, 99, 107, 109, 383, 586, 587, 590; Indiferente General files 1559, 1528.

drought, since livestock breeding was the main source of income in the *Puna* (*llamas* and *alpacas*) and *Queshua* (European cattle) zones, and very sensitive to changes in pasture and water availability. Morello (1983), in his work on the great drought produced by El Niño in 1982–83 years in the Bolivian Altiplano, remarks on the lack of water suffered by the peasants, partial or total loss of livestock due to mortality, the effects of the drought on young animals, and miscarriages. These climate events reduced pasture and water (springs, wetlands, creeks) by at least 50 % (Gil Montero et al. 2010). Seed production was also used as an indicator, as it depended on the amount of rainfall during sowing, growth and maturation of the crops. Generally, dry years were associated with low production of crops, which caused natives to intensify traditional regional trade in order to satisfy food needs, as described for Lípez in 1787.[7] On the other hand, it must be taken into account that the existence of diverse microclimates means the impact of drought varied according to ecological conditions. Risks are not the same at the head of a valley than at the bottom, and they are not the same for crops adapted to more arid or more humid climates (Gil Montero et al. 2010). With respect to abundant precipitation, indirect data included the consequences of floods, heavy rains, hailstorms, and agricultural plagues, for example the destruction of crops, roads, bridges and public works.

To construct a range of precipitation intensity, two extreme situations were considered: a total lack of rain, or drought, between the planting and harvest season, and excessive precipitation leading to swelling of rivers or floods in the area. A five point qualitative scale was considered according to the available information: Very Abundant, Abundant, Normal, Scarce and Very Scarce. The normal years were considered when they are directly mentioned: "In this *partido* rains have been normal, so crops were regular",[8] and when there were no reports of the lack or excess of water, abundant crops or extreme events. In terms of temperature, we only considered two possibilities: very cold or frost, the most frequent categories mentioned in the *Relaciones*. Data were organized according to the political divisions of *intendencias* and *partidos*, described above.[9] These divisions were defined in a Geographic Information System, based on georeferenced colonial maps overlaid with current political and ecological maps (Figs. 1 and 2).

4 Climate anomalies during the 18th century in the central and southern Andes

In general, the climate presents variability in precipitation or temperature that can be seasonal or inter-annual. Climate anomalies hold a prominent position, when brief episodes of hours, days, or months brought disastrous consequences to economic activities (Nuñez 1987:3). These anomalies include catastrophic floods, long episodes of above average precipitation, prolonged drought, hail, early or late frosts and cold fronts.

Research in the central and southern Andes has shown that climatic conditions in the eighteenth century deteriorated, especially when compared to the seventeenth century. Gioda and Prieto (1999) developed a precipitation series, beginning in 1574, from Potosi (4000 masl) in the arid Puna. Water was used to power the silver mills in Potosí. For around 200 years, the importance of silver extraction to the Spanish economy led to the consistent recording of precipitation and droughts during the spring–summer season. Abundant precipitation was

[7] AGI, Indiferente General 1559, enero 1787.

[8] *"En este partido han sido las aguas proporcionadas por cuya razón fueron las cosechas regulares*" AGI. Indiferente General, file 1559, July, 1787

[9] AGI MP-Buenos Aires, 154. Peru *Intendencias* Virreinato Río de la Plata (31-12-1783).

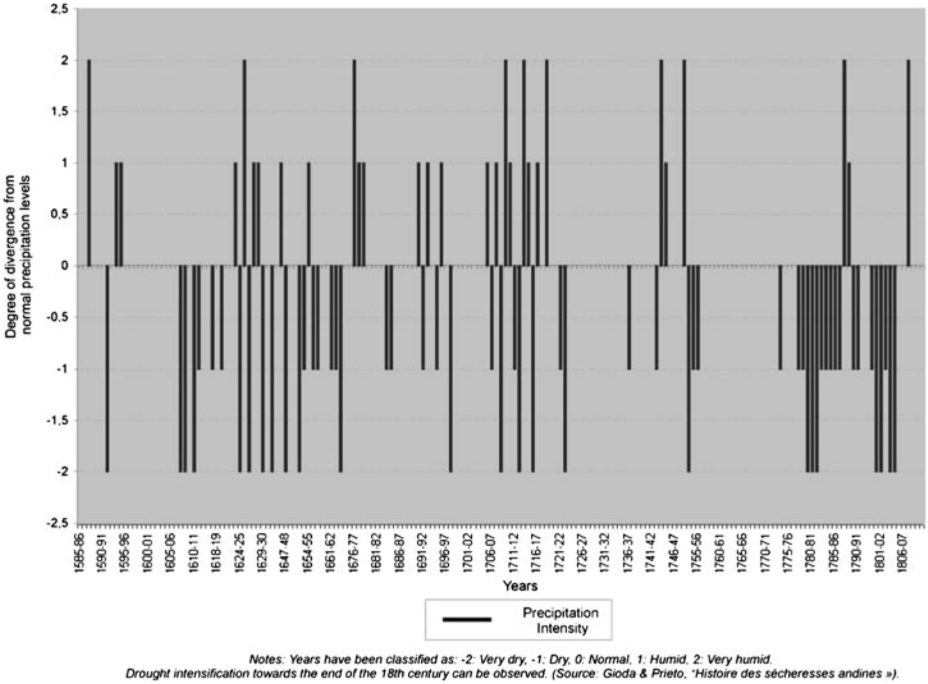

Fig. 3 Variation in precipitation in Potosi between 1585 and 1807

needed to fill the lakes that fed the river, which in turn drove the silver mills. Data from dry or humid years were compiled mainly from the Actas Capitulares of Potosí and from the Annals of Bartolomé Arzáns de Orzúa y Vela (1965, 1970). In Potosí, during 8 decades of the seventeenth century, there were only seven severe droughts. In contrast, during the eighteenth century, two cycles of drought and climatic anomalies occurred (Fig. 3). From 1709 to 1741, records report about 18 dry or wet years (more than 50 %). A relatively neutral period in the middle of the century gave way to another dry cycle from 1779 to 1805 with 14 years with intense droughts (around 50 %) (Gioda and Prieto 1999). For the last quarter of the eighteenth century in Alto Peru, it is important to highlight that droughts or floods were occurring simultaneously, as intense cold and frosts produced even more adverse consequences. Extreme climate events, primarily drought, showed a wide spatial distribution between 1785 and 1805, as indicated by the temporal and spatial data from the *Relaciones* (Prieto and Herrera 2002). Here, we review the most relevant adverse climate events over that period.

The 1780's were particularly dry in the area. The drought that had started in 1777–78 extended for several years, at least until 1782 (Gioda and Prieto 1999). For the agricultural year 1785−86, we rely on the *Relaciones*, which report a long episode of severe drought that had started in 1777, extended through 1785, 1786, and the 6-months of 1787.[10] In December of 1786 and January of the following year–usually months of higher than average precipitation–rainfall was scarce and even absent in large part of the territory. The drought was accompanied by a very cold autumn with early frosts, an exceptionally cold winter with "ice and winds" in 1787, and violent hail storms in some areas. This drought coincided with the beginning of the agricultural year for most Andean crops. It occurred with varying

[10] AGI, Buenos Aires, file 75, July 1787.

degrees of intensity in practically the whole study area except in the *Yungas* zone, where rainfall and temperature were moderate. The *Puna* zone suffered a more intense water shortage.

The agricultural year 1787–88, or the second half of 1787 and first half of 1788, showed a change in climatic conditions.[11] During the first 6-months of the agricultural year, all of Alto Peru experienced floods. In Yamparaes, in the province La Plata, rivers overflowed, and Potosi saw the "ruin of many buildings in the town, and especially in farmsteads of indians and *mitayos*".[12]

In Cochabamba, heavy rains had a direct effect on agricultural production and disrupted planting, where "many corn seeds rotted in the moist soil" (Larson 1980:196). The same happened in Porco and Chichas, where abundant rainfall caused "considerable damage to farms, vineyards, mills and lands that could not avoid the rapid impetuous and flooding of rivers".[13] The dry years of 1789–1790 were catastrophic only for Tarija, Bolivia. Friar Francisco de Tamajuncosa reports" a horrible famine in all the cordillera, particularly in the years of 1789 and 1790 because of the great shortage of rain… the cattle… died in the fields for lack of pastures…" (Tamajuncosa 1969: 112).[14]

Following a few years missing from the *Relaciones*, we reach the agricultural season of 1796–97. Although it showed some signs of drought, they were less widespread. In 1796 some months without rain were reported for Potosi, La Plata and particularly La Paz, where the lack of precipitation "delayed the coca harvest".[15] The scarce precipitation and poor harvests did not happen in all zones, so there was surely commerce between regions and ecological zones. Tandeter and Wachtel (1984) observed a relationship in Potosi between high prices, bad harvests, and a consequent increase in trade, as well as families consuming more of their own harvest. An increase in trade and local food stores could explain the absence of reports on diseases in 1796–1797, as the population maintained high immunological defenses because they did not suffer a lack of food. In contrast, rains were reported in the first half of 1797 in La Paz and Cochabamba: "…this year has been abundant in rains and therefore livestock births have increased, especially of cows and sheep".[16] In the first half of 1798 there was a shortage of water reported for La Paz and Potosí.[17]

Droughts peaked again in the 1800–1801 agricultural cycle. As a consequence of the intense lack of water the wheat crop was destroyed in Cochabamba (Larson 1980: 197). The water deficit also threatened silver production in Potosi: "…because of the lack of rain in the last season, if there is not ample rainfall by next October, the silver grinding mills will have to be stopped."[18] This dry cycle culminated in the years 1803–1805, as a consequence of one of the most severe El Niño phenomena in the early nineteenth century. The most devastating effects were in the *intendencias* of Cochabamba, Potosi, and La Paz. In 1804–05 these effects reached the *intendencias* of Puno and La Plata (Tandeter 1991:11). In Cochabamba, two successive years of water shortages (1803–1804) caused a considerable reduction of all harvests (Larson 1980:197). In Potosi, the catastrophe was similar, because the droughts of 1804 and 1805 caused the silver-grinding mills to stop operating, crops were lost, prices

[11] AGI, Buenos Aires, file 99, January 1788
[12] AGI, Buenos Aires, file 107, July 1788.
[13] AGI, Buenos Aires, file 107, July 178.
[14] *"… un hambre horrible en toda la cordillera, particularmente en los años de 1789 y 1790 por la suma escasez de aguas… [El ganado]… se moría en el campo por falta de pastos*".
[15] AGI Buenos Aires file 590, January, 1796
[16] AGI, Buenos Aires file 21, Indiferente General file 1559, July 1797
[17] AGI, Buenos Aires file 589–587, July, 1801
[18] AGI, Buenos Aires, file 383, July 1801

increased and famine became generalized, according to data from Tandeter (1991:30) and the *Relaciones*.[19]

This stressful climate triggered the first great ecological crisis of the nineteenth century in the region. Its consequences were especially devastating because the crisis represented the culmination of a long dry cycle beginning in 1777, with short intervals in the 1780's and 1790's. The immediate consequence of these phenomena–droughts, frosts, floods–was food shortage, increased prices and, consequently, generalized famine. Tandeter and Wachtel (1984) show a relationship between food prices and climate variations in Potosi and Charcas during this period. Prices in 1805, as well as tithes, were at record highs, a clear indication of decreased agricultural production (Tandeter 1991:30).

The regional climatic cycle coincided with broader climatic trends, in particular with El Niño and La Niña events. Several studies have documented rainfall shortage or drought in the highland region of the central Andes during El Niño events (Aceituno et al. 2009). On the other hand, La Niña episodes provoke severe rains and floods. According to a recent chronology of El Niño events for northern Peru during 1550–1900, based on mainly primary sources from Trujillo, Peru, there were eight El Niño episodes from 1780 to 1804. Of these, four were strong or very strong: 1784–85, 1791–92 (very strong), 1799–1800, and 1803–04. The chronology also registers three events of moderate intensity in 1782–83, 1787, and 1796. These years roughly match with the worst droughts of the region (García-Herrera et al. 2008). Perhaps, 1788–89 was a La Niña year since the *Relaciones* report great rainfall and floods in almost all the region.

5 Climate events, diseases and epidemics between 1785 and 1805

The *Relaciones* allow to study the evolution of regional diseases and epidemics throughout the 20 years from 1785 to 1805. In all five *intendencias*, extreme weather was recorded from the second half of 1785 to the first half of 1787, subsiding only in the second half of 1787. In this period, there was scarce rainfall, extreme cold, and frosts. Only a few epidemics were recorded during the first three semesters: dysentery, rubella, and typhus, a disease that was also present in the following 3 years. Beginning in the first half of 1787, there is a proliferation of diseases such as typhus, yellow fever, measles, tertian fever, pleurisy and smallpox, in addition to common diseases like dysentery. Frosts and cold weather intensified the presence of hay fever (catarrhal) epidemics and pleurisy, fundamentally caused by growing numbers of the transmitting vector of typhus, the louse, which proliferates in low temperatures. In this period tertian fever was only recorded in the humid and warm areas of the *Yungas* ecological zone. In contrast, very abundant rains were reported in for the year 1788, mostly during the first half of the year, accompanied by rivers overflowing and flooding.

Nevertheless, the same diseases were reported in the first and second halves of the year. Diseases such as malaria and dysentery appeared as well, mostly in the *Yungas*, in response to the high humidity during that year.

For the two six-month periods of 1789, few diseases were reported, particularly those of an endemic nature like malaria, during a year with mild temperatures. But in 1790, when all five *intendencias* again underwent droughts and frosts, diseases and epidemics such as malaria, smallpox, typhus, pleurisy and dysentery became more prevalent.

[19] AGN, IX-18-7-2, November, 1804.

Throughout 1796, 1797 and 1798, there was an absence of climatic extremes and illnesses. The severe drought that would last for 5 years starts by 1800. However, there were no signs of epidemic diseases in the first 2 years. It must be remembered that the survival strategies used by Andean communities allowed them to endure drought years. In 1802 there were already signs of the presence of certain diseases like smallpox and dysentery, though in low proportions, similar to 1803, when scarlet fever emerges. But in 1804–05, the pressure of the prolonged drought, repeated failed harvests, rising prices and famine translated into a series of epidemics and diseases. Besides the most common diseases, like smallpox and typhus, other less frequent ones also appeared, such as erysipelas, angina and diphtheria.

Enrique Tandeter (1991) has studied the significant demographic drop produced by the ecological crisis of 1801–1805 in the area. One of the indicators of the drop was that cemeteries were full, mainly in the city of La Plata. He determined from parish records that there was a general increase in deaths in Sacaba and Acasio (Chayanta), by comparing normal years (1775−1779) and crisis years (1801–1805), with emphasis on the culmination of the crisis in the second half of 1805. He established that the birthrate remained high, but that mortality rates increased in 1803 and 1804, and dramatically in 1805.

This author (Tandeter 1991:24) attributed this mortality mainly to erysipelas, accompanied by angina and diphtheria. These diseases, and others described in the *Relaciones*, can safely be attributed to starvation, a result of the lost harvest during the drought.

Emigration contributed to the spread of the epidemics. In the different districts of La Paz, in 1804, highland natives left areas with droughts and epidemics. A document from La Paz affirms that, “The lack of rainfall in the present and previous years has compelled *tributarios* [natives paying tribute] to leave with their entire families and say good bye to their native land because of the hunger they have experienced… The general plague had been advancing for months… Entire *ayllus* (extended families) had died … Those leaving pest and famine were counted by the hundreds… In Santiago de Machaca others had left in search for food, fleeing from the plague …because of the calamity of the previous years”.[20]

Even though we cannot determine exactly the exact geographic origins of emigration, we know that emigrating was one of the most widespread strategies of natives and peasants when epidemics appeared. This, together with commerce, could have been a vehicle for disease transmission. The phenomenon has been seen several times in the region more recently, suggesting possible expansion routes of epidemics. In 1878−1879, a severe drought caused by an El Niño event coincided with a malaria epidemic that started in Cochabamba and rapidly spread to La Paz and Oruro (Pentimalli and Rodriguez 1988).

5.1 A geographic analysis of epidemics and disease, 1785–1805

By means of the cartographic techniques previously mentioned, diseases and epidemics were located in the territory of Alto Peru, their frequency determined, and related to the occurrence of climate events.

We found a relationship between the above mentioned ecological zones, *Puna*, *Queshua* and *Yungas*, their distinct environmental characteristics of temperature and humidity, and predominance of certain diseases, at least when their first indications appeared. Spreading by direct or indirect contagions, they came to cover a large area that expanded beyond the original ecological zone where the diseases emerged. This could have been produced by the

[20] AGN, Colonial, IX-18-7, La Paz, June 11, 1804.

frequent and intense population movements in the region, high population densities in rural areas, and the short distance between ecological zones.

Nevertheless, some conclusions can be drawn, by analyzing Fig. 4. The highest number of epidemics over the period studied – between 4 and 7 – originated in the *Yungas* northern *Puna* zones, related to their environmental characteristics: higher humidity and temperature contributed to the proliferation of vectors, primarily mosquitoes. The *Queshua* zone presents lower number of epidemics across the period analyzed – between 2 and 3 – but the lowest frequency is observed in the south *Puna*, as a dry climate dominates the region.

In order to analyze the relationship between climate and disease in depth, three climate scenarios were selected that could have led to the emergence and spread of diseases, in the presence of an anomalous climate event. The information in the database was transferred onto a map for each scenario. Epidemics and vector-transmitted diseases (malaria, yellow fever and typhus) were separated from those transmitted by direct contagion.

Three main climate scenarios were determined:

- a- Droughts accompanied by low temperatures (1786-87).
- b- Abundant precipitation associated with flooding (1788).
- c- Prolonged drought (1797–1805).

In case a) the drought affected practically all of the Alto Peru *intendencias* and ecological zones. However, epidemics were focused in the north of the region, primarily in high and wetter *Puna* and *Yungas* zones. In the former, extreme cold and lack of rains accentuated diseases typical of the zone, such as pleurisy or catarrhal illnesses, as well as smallpox, rubella and measles. Some centers of yellow fever are also observed.

Diseases related to low temperatures, such as typhus and hay fever, predominated in the *Queshua* zone. On the contrary, in *Yungas* there was a predominance of vector-transmitted

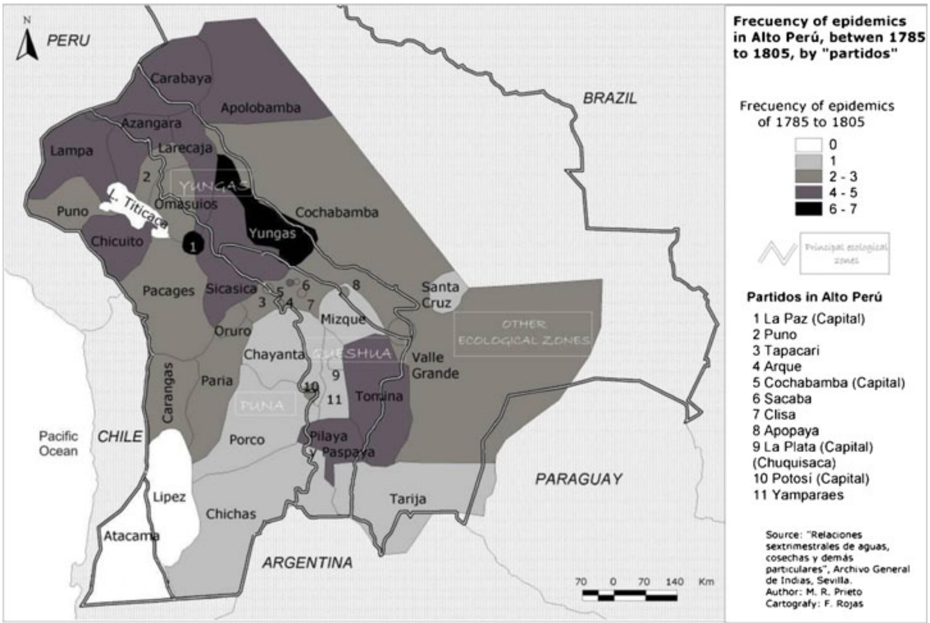

Fig. 4 Frequency of epidemics in Alto Peru, between 1785 to 1805, by *partido*

epidemics typical of that area, mostly malaria and yellow fever. The presence of intestinal infections is also verified. It is possible that the general decrease of precipitation during the period led to the development of ponds and stagnant pools, which generated more mosquito breeding sites.

In case b), the period was characterized by severe precipitations and flooding in all three ecological zones. Frequent smallpox cases are notable, concentrated in the valleys of the *Queshua* zone. In the *Yungas* zone, malaria and typhus are more frequent, whereas in the *Puna* zone, yellow fever is present, and to a lesser extent, typhus and dysentery.

As for case c), the long drought caused epidemics that evolved principally in the *Puna* zone. Erysipelas and angina stand out, and to a lesser extent diphtheria and typhus. The drought also caused cases of dysentery and a reappearance of smallpox and scarlet fever. In contrast, in the *Queshua* and *Yungas* zones, only isolated centers of erysipelas and angina are observed, and scarce cases of smallpox and scarlet fever. There are no data on malaria or yellow fever, which indicates that the drought reduced vector-transmitted diseases to a minimum, due to the disappearance of mosquito breeding sites.

The qualitative and geographic analysis of the *Relaciones* reveal associations between climatic, epidemic events and ecological zones.

In the more humid *Yungas* and northern *Puna* zones, a larger number of diseases were reported. Nevertheless, the emergence of epidemics in these zones varies independently from climatic variations, as diseases were present to greater or lesser degrees in dry and humid periods and wet or cold periods. These more frequent diseases are transmitted by vectors that, in spite of the increase in rainy periods, affect major population groups almost constantly, expanding to nearby areas when precipitation and temperature are conducive.

In the more arid southern *Puna*, the emergence of epidemics depended more on climatic variations. Diseases such as angina, pleurisy and chest colds considerably increased during dry periods.

In the *Queshua* zone we found fewer data on epidemics, which do not follow a clear pattern. The increase in smallpox during 1788 (the period of rains and floods) affected this region, but also affected other regions. Hence, it seems that disease depends less on specific climatic conditions. Something similar could have happened with dysentery, due to its relationship to poor hygienic conditions, which is found in different ecological zones, and in dry and humid periods.

5.2 Statistical analysis of climatic events and disease

A statistical analysis of the *Relaciones* data provides a different perspective on whether dry and wet periods are conducive to the emergence of disease. The *Relaciones* certainly constitute an imperfect dataset. The number of cases is limited, the units of analysis (the *intendencias*) have heterogeneous geographic coverage, and the measurement is certainly vague. Despite their limitations, however, they provide a consistent dataset with relatively fine-grained temporal coverage and simple yet standardized climatic information. As such, it is suitable for a simplified statistical analysis, to verify the effects of dry or wet conditions on the probabilities of the emergence of a disease. The ample ecological diversity within each intendancy makes the results tentative, so the working hypothesis is that there is no correlation between climate and disease.

The data from the *Relaciones* were structured as a cross-panel dataset. Rainfall and disease outbreaks were coded by 6-month period and *intendencia*. The information on rainfall was coded from 0 (normal year) to 2 (very scarce or very abundant). Information on cold conditions was not coded due to the suspicion of inconsistent reporting. All information on epidemics was aggregated for each *intendencia* and classified into types: pulmonary (including catarrh, cough and diphteria), mosquito-transmitted (yellow fever and malaria), human-transmitted virus (measles, rubella, smallpox), typhus, and dysentery. In total there are 72 cases in five *intendencies* and eighteen six-month periods, although some 6-month periods do not have information for some *intendencies*.

Cross-panel, random effects and a logit model were used to analyze the probability of rain scarcity or abundance that trigger different diseases. The use of a fixed effects model does not substantially change the results. The dependent variables (those to be explained) are the five groups of diseases (pulmonary, mosquito-transmitted, viral, typhus and dysentery), while the independent variables are "scarce" and "abundant" rainfall. The coding of dry and wet conditions in separate variables accounts for the fact that effects of rainfall is not linear; this allows modeling a scenario in which both scarce and abundant rainfall are conducive to the spread of disease. The logit model assesses how much scarce or abundant rains increase the probability of the incidence of a disease type. The effects are calculated as probabilities of disease outbreak as rainfall becomes scarcer or more abundant, relative to periods of normal rainfall.[21]

The results show that either scarce or abundant rainfall has a positive effect on the outbreak of disease of any kind, with the only (and statistically insignificant) exception of dysentery. The effects varied according to the specific epidemic. It was null in the case of dysentery. Dry conditions had a high and statistically significant effect on pulmonary diseases: the probability jumped to 56 % in 6-month periods with very scarce rainfall. The probability of typhus, a disease propagated by lice and fleas, increased 30 % in 6-month periods with very scarce rain, although the result is more uncertain. Humid conditions had the largest effect on viral diseases (37 %), mosquito-transmitted (19 %) and even pulmonary diseases (14 %).

In short, the statistical models support the hypothesis that abnormal climatic conditions were detrimental to health. An important result to point out is that very scarce and very abundant climatic conditions increased the probability of the outbreak of any disease by 59 and 53 %, respectively. The impacts of climatic events on late colonial populations in Alto Peru underlines the need to better understand vulnerability to disease related to climatic events, as well as the potential role of social adaptations and responses. The final section presents some preliminary suggestions in that direction.

6 Conclusions

Both the quantitative and the qualitative analysis based on the *Relaciones* show a degree of association between climatic and epidemic events. The probability of experiencing a disease in years with very scare or very abundant rains increased by more than 50 %. But the correlation is certainly not linear and does not exclude other explanatory factors. The literature typically emphasizes the association between drought and disease, in part because the environmental effects were likely exaggerated by a decline in food supply. Respiratory diseases significantly increased in these periods (the probability of respiratory diseases in a drought-stricken district was 55 % higher than in a district with normal conditions). The *Relaciones* also show that a long cycle of drought (e.g. 1800–1805) or the combination of drought and very cold temperatures was associated with a broader range of diseases as well.

[21] Stata 9.2 was used to estimate the logit models using the "xtlogit" routine; adjust was used to estimate the effects as probabilities.

Floods and abundant rains typically receive less attention but they were as harmful as drought conditions. Besides the association with vector-transmitted diseases such as malaria and yellow fever, the effects are moderate, but noticeable across a broader range of disease.

Direct and indirect causation contributes to the effect of climate on human disease. Climate events may directly foster the environmental conditions favorable to vectors of disease—e.g. rains and flooding are conducive to the spread malaria and yellow fever. But other causes are less direct and are mediated by social processes. Migration likely spread the localized impact of a drought or flood to a larger territory. Catastrophes such as drought and flood drove people to out of their home region in search for better conditions, who carried diseases elsewhere. Similarly, the effects of climate on food production may have had an impact on nutrition and disease resistance. This is perhaps the underlying explanation for why climatic anomalies raised the probability of disease incidence. Nevertheless, we have seen how certain diseases such as dysentery and smallpox are much less dependent on the climate than other respiratory diseases (especially in the *Puna* zone, during cold and dry periods) or those transmitted by vectors (especially during rainy periods in the *Yungas* zone). On the other hand, in the *Queshua* zone, the most demographically dense, we observed neither a more frequent epidemics nor a clear disease pattern in relation to climatic conditions.

Discussion must continue on social adaptations and levels of vulnerability to extreme climatic variations and to the appearance of epidemics. In this respect, there may other more important variables that could have influenced the spread and intensity of epidemics. For example, the differential demographic density in each *partido*, the intensity and trend of the population movements, commercial exchange, and the political, cultural and social logic that may have favored or slowed disease expansion.

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